

# DirectionalStats.bib v1.15 (2020-11-06)

Arthur Pewsey and Eduardo García-Portugués

Find most updated version at <https://github.com/egarpor/DirectionalStatsBib>

## References

- Aakala, T., Shimatani, K., Abe, T., Kubota, Y., and Kuuluvainen, T. (2016). Crown asymmetry in high latitude forests: disentangling the directional effects of tree competition and solar radiation. *Oikos*, 125(7):1035–1043. doi:10.1111/oik.02858.
- Abe, T. (2010). *A Study of Families of Circular Distributions*. PhD thesis, Keio University.
- Abe, T., Kubota, Y., Shimatani, K., Aakala, T., and Kuuluvainen, T. (2012). Circular distributions of fallen logs as an indicator of forest disturbance regimes. *Ecological Indicators*, 18(1):559–566. doi:10.1016/j.ecolind.2012.01.010.
- Abe, T. and Ley, C. (2017). A tractable, parsimonious and flexible model for cylindrical data, with applications. *Econometrics and Statistics*, 4:91–104. doi:10.1016/j.ecosta.2016.04.001.
- Abe, T. and Pewsey, A. (2011a). Sine-skewed circular distributions. *Statistical Papers*, 52(3):683–707. doi:10.1007/s00362-009-0277-x.
- Abe, T. and Pewsey, A. (2011b). Symmetric circular models through duplication and cosine perturbation. *Computational Statistics & Data Analysis*, 55(12):3271–3282. doi:10.1016/j.csda.2011.06.009.
- Abe, T., Pewsey, A., and Shimizu, K. (2013). Extending circular distributions through transformation of argument. *Annals of the Institute of Statistical Mathematics*, 65(5):833–858. doi:10.1007/s10463-012-0394-5.
- Abe, T. and Shimatani, I. K. (2018). Cylindrical distributions and their applications to biological data. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 163–185. CRC Press, Boca Raton.
- Abe, T., Shimizu, K., and Pewsey, A. (2009). On Papakonstantinou’s extension of the cardioid distribution. *Statistics & Probability Letters*, 79(20):2138–2147. doi:10.1016/j.spl.2009.07.007.
- Abe, T., Shimizu, K., and Pewsey, A. (2010). Symmetric unimodal models for directional data motivated by inverse stereographic projection. *Journal of the Japan Statistical Society*, 40(1):45–61. doi:10.14490/jjss.40.045.
- Abeysasekara, S. and Collett, D. (1982). On the estimation of the parameters of the von Mises distribution. *Communications in Statistics – Theory and Methods*, 11(18):2083–2090. doi:10.1080/03610928208828371.
- Abraham, C., Molinari, N., and Servien, R. (2013). Unsupervised clustering of multivariate circular data. *Statistics in Medicine*, 32(8):1376–1382. doi:10.1002/sim.5589.
- Abraham, C., Servien, R., and Molinari, N. (2019). A clustering Bayesian approach for multivariate non-ordered circular data. *Statistical Modelling*, 19(6):595–616. doi:10.1177/1471082X18790420.
- Abrahamson, I. G. (1967). Exact Bahadur efficiencies for the Kolmogorov-Smirnov and Kuiper one- and two-sample statistics. *Annals of Mathematical Statistics*, 38(5):1475–1490. doi:10.1214/aoms/1177698702.
- Abramowitz, M. and Stegun, I. A. (1965). *Handbook of Mathematical Functions*. Dover, New York.
- Abrial, P., Moudén, Y., Starck, J.-L., Afeyan, B., Bobin, J., Fadili, J., and Nguyen, M. K. (2007). Morphological component analysis and inpainting on the sphere: application in physics and astrophysics. *The Journal of Fourier Analysis and Applications*, 13(6):729–748. doi:10.1007/s00041-006-6908-x.
- Abrial, P., Moudén, Y., Starck, J.-L., Fadili, J., Delabrouille, J., and Nguyen, M. K. (2008). Cmb data analysis and sparsity. *Statistical Methodology*, 5(4):289–298. doi:10.1016/j.stamet.2007.11.005.
- Abuzaid, A. H., Hussin, A. G., and Mohamed, I. B. (2013). Detection of outliers in simple circular regression models using the mean circular error statistic. *Journal of Statistical Computation and Simulation*, 83(2):269–277. doi:10.1080/00949655.2011.602679.
- Abuzaid, A. H., Hussin, A. G., Rambli, A., and Mohamed, I. (2012a). Statistics for a new test of discordance in circular data. *Communications in Statistics – Simulation and Computation*, 41(10):1882–1890. doi:10.1080/03610918.2011.624239.
- Abuzaid, A. H., Mohamed, I. B., and Hussin, A. G. (2009). A new test of discordancy in circular data. *Communications in Statistics – Simulation and Computation*, 38(4):682–691. doi:10.1080/03610910802627048.
- Abuzaid, A. H., Mohamed, I. B., and Hussin, A. G. (2012b). Boxplot for circular variables. *Computational Statistics*, 27(3):381–392. doi:10.1007/s00180-011-0261-5.

- Abuzaid, A. H., Mohamed, I. B., and Hussin, A. G. (2014). Procedures for outlier detection in circular time series models. *Environmental and Ecological Statistics*, 21(4):793–809. doi:10.1007/s10651-014-0281-8.
- Accardi, L., Cabrera, J., and Watson, G. S. (1987). Some stationary Markov processes in discrete time for unit vectors. *Metron*, 45(1-2):115–133.
- Ackermann, H. (1985). Distribution-free tolerance regions for circular data. *EDV in Medizin und Biologie*, 16(3):97–99.
- Ackermann, H. (1991). A Friedman-type test for circular data and arbitrary cell frequencies. *Biometrical Journal*, 33(6):643–654. doi:10.1002/bimj.4710330602.
- Adler, D., Murdoch, D., et al. (2020). *rgl: 3D Visualization Using OpenGL*. R package version 0.100.54. URL: <https://CRAN.R-project.org/package=rgl>.
- Agiomyrgiannakis, Y. and Stylianou, Y. (2009). Wrapped Gaussian mixture models for modeling and high-rate quantization of phase data of speech. *IEEE Transactions on Audio Speech and Language Processing*, 17(4):775–786. doi:10.1109/tasl.2008.2008229.
- Agostinelli, C. (2007). Robust estimation for circular data. *Computational Statistics & Data Analysis*, 51(12):5867–5875. doi:10.1016/j.csda.2006.11.002.
- Agostinelli, C. (2015). *R package wle: Weighted Likelihood Estimation*. R package version 0.9-91. URL: <https://CRAN.R-project.org/package=wle>.
- Agostinelli, C. and Lund, U. (2017). *R package circular: Circular Statistics*. R package version 0.4-93. URL: <https://CRAN.R-project.org/package=circular>.
- Agostinelli, C. and Romanazzi, M. (2013a). Nonparametric analysis of directional data based on data depth. *Environmental and Ecological Statistics*, 20(2):253–270. doi:10.1007/s10651-012-0218-z.
- Agostinelli, C. and Romanazzi, M. (2013b). *R package localdepth: Local Depth*. R package version 0.5-7. URL: <https://CRAN.R-project.org/package=localdepth>.
- Ahmad, I. A. and Dorea, C. C. Y. (2001). A note on goodness-of-fit statistics with asymptotically normal distributions. *Journal of Nonparametric Statistics*, 13(4):485–500. doi:10.1080/10485250108832862.
- Ailliot, P., Bessac, J., Monbet, V., and Pène, F. (2015). Non-homogeneous hidden Markov-switching models for wind time series. *Journal of Statistical Planning and Inference*, 160:75–88. doi:10.1016/j.jspi.2014.12.005.
- Ailliot, P. and Monbet, V. (2012). Markov-switching autoregressive models for wind time series. *Environmental Modelling and Software*, 30:92–101. doi:10.1016/j.envsoft.2011.10.011.
- Ainsleigh, P. (2017). A method for computing moments of quadratic forms involving wrapped random variables. *SIAM Journal on Matrix Analysis and Applications*, 38(2):554–573. doi:10.1137/16m1082019.
- Aitchison, J. (1986). *The Statistical Analysis of Compositional Data*, volume 25 of *Monographs on Statistics and Applied Probability*. Chapman & Hall, London. doi:10.1007/978-94-009-4109-0.
- Ajne, B. (1968). A simple test for uniformity of a circular distribution. *Biometrika*, 55(2):343–354. doi:10.1093/biomet/55.2.343.
- Alonso-Pena, M., Ameijeiras-Alonso, J., and Crujeiras, R. M. (2020). Nonparametric tests for circular regression. *Journal of Statistical Computation and Simulation*, to appear. doi:10.1080/00949655.2020.1818243.
- Altis, A., Nguyen, P. H., Hegger, R., and Stock, G. (2007). Dihedral angle principal component analysis of molecular dynamics simulations. *The Journal of Chemical Physics*, 126(24):244111. doi:10.1063/1.2746330.
- Altis, A., Otten, M., Nguyen, P. H., Hegger, R., and Stock, G. (2008). Construction of the free energy landscape of biomolecules via dihedral angle principal component analysis. *The Journal of Chemical Physics*, 128(24):245102. doi:10.1063/1.2945165.
- Alvo, M. (1998). On non-parametric measures of correlation for directional data. *Environmetrics*, 9(6):645–656. doi:10.1002/(sici)1099-095x(199811/12)9:6<645::aid-env328>3.0.co;2-b.
- Amaral, G. J. A., Dryden, I. L., and Wood, A. T. A. (2007). Pivotal bootstrap methods for  $k$ -sample problems in directional statistics and shape analysis. *Journal of the American Statistical Association*, 102(478):695–707. doi:10.1198/016214506000001400.
- Amayri, O. and Bouguila, N. (2011). Probabilistic clustering based on Langevin mixture. In *2011 10th International Conference on Machine Learning and Applications and Workshops*, volume 2, pp. 388–391, New York. IEEE. doi:10.1109/icmla.2011.6174513.
- Amayri, O. and Bouguila, N. (2012). Unsupervised feature selection for spherical data modeling: Application to image-based spam filtering. In Dziech, A. and Czyżewski, A. (Eds.), *Multimedia Communications, Services and Security*, volume 287 of *Communications in Computer and Information Science*, pp. 13–23, Berlin. Springer. doi:10.1007/978-3-642-30721-8\_2.
- Amayri, O. and Bouguila, N. (2013). On online high-dimensional spherical data clustering and feature selection. *Engineering Applications of Artificial Intelligence*, 26(4):1386–1398. doi:10.1016/j.engappai.2012.10.009.
- Amayri, O. and Bouguila, N. (2015). Beyond hybrid generative discriminative learning: spherical data classification. *Pattern Analysis and Applications*, 18(1):113–133. doi:10.1007/s10044-013-0323-0.
- Ameijeiras-Alonso, J. (2017). *Assessing Simplifying Hypotheses in Density Estimation*. PhD thesis, University of Santiago de Compostela.
- Ameijeiras-Alonso, J., Benali, A., Crujeiras, R. M., Rodríguez-Casal, A., and Pereira, J. M. (2019a). Fire seasonality

- identification with multimodality tests. *Annals of Applied Statistics*, 13(4):2120–2139. doi:10.1214/19-A0AS1273.
- Ameijeiras-Alonso, J., Crujeiras, R. M., and Rodríguez Casal, A. (2018). Directional statistics for wildfires. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 187–210. CRC Press, Boca Raton.
- Ameijeiras-Alonso, J., Lagona, F., Ranalli, M., and Crujeiras, R. M. (2019b). A circular nonhomogeneous hidden Markov field for the spatial segmentation of wildfire occurrences. *Environmetrics*, 30(2):e2501. doi:10.1002/env.2501.
- Ameijeiras-Alonso, J. and Ley, C. (2020). Sine-skewed toroidal distributions and their application in protein bioinformatics. *Biostatistics*, to appear. doi:10.1093/biostatistics/kxaa039.
- Ameijeiras-Alonso, J., Ley, C., Pewsey, A., and Verdebout, T. (2020). On optimal tests for circular reflective symmetry about an unknown central direction. *Statistical Papers*, to appear. doi:10.1007/s00362-019-01150-7.
- Amiri, A., Thiam, B., and Verdebout, T. (2017). On the estimation of the density of a directional data stream. *Scandinavian Journal of Statistics*, 44(1):249–267. doi:10.1111/sjos.12252.
- Amos, D. E. (1974). Computation of modified Bessel functions and their ratios. *Mathematics of Computation*, 28(125):235–251. doi:10.1090/s0025-5718-1974-0333287-7.
- Amson, E., Arnold, P., van Heteren, A. H., Canoville, A., and Nyakatura, J. A. (2017). Trabecular architecture in the forelimb epiphyses of extant xenarthrans (Mammalia). *Front. Zool.*, 14(1):52. doi:10.1186/s12983-017-0241-x.
- Andersen, E. S. (1954). On the fluctuations of sums of random variables. *Mathematica Scandinavica*, 1(2):263–285. doi:10.7146/math.scand.a-10407.
- Anderson, C. M. (1993). Graphical methods for circular and cylindrical data. Technical report, University of Waterloo.
- Anderson, C. M. (1994). *Location and Dispersion Analyses for Factorial Experiments with Directional Data*. PhD thesis, University of Waterloo.
- Anderson, C. M. and Wu, C. F. J. (1995). Measuring location effects from factorial-experiments with a directional response. *International Statistical Review*, 63(3):345–363. doi:10.2307/1403484.
- Anderson, C. M. and Wu, C. F. J. (1996). Dispersion measures and analysis for factorial directional data with replicates. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 45(1):47–61. doi:10.2307/2986222.
- Anderson, D. A. (1981). The circular structural model. *Journal of the Royal Statistical Society, Series B (Methodological)*, 43(2):131–141. doi:10.1111/j.2517-6161.1981.tb01162.x.
- Anderson, M. L. (2019). As the wind blows: the effects of long-term exposure to air pollution on mortality. *Journal of the European Economic Association*, 18(4):1886–1927. doi:10.1093/jeea/jvz051.
- Anderson, T. W. (1963). Asymptotic theory for principal component analysis. *Annals of Mathematical Statistics*, 34(1):122–148. doi:10.1214/aoms/1177704248.
- Anderson, T. W. and Stephens, M. A. (1972). Tests for randomness of directions against equatorial and bimodal alternatives. *Biometrika*, 59(325):613–621. doi:10.1093/biomet/59.3.613.
- Anderson-Cook, C. M. (1997). An extension to modeling cylindrical variables. *Statistics & Probability Letters*, 35(3):215–223. doi:10.1016/s0167-7152(97)00016-3.
- Andrews, D. F. (1974). A robust method for multiple linear regression. *Technometrics*, 16(4):523–531. doi:10.1080/00401706.1974.10489233.
- Aneshansley, D. J. and Larkin, T. S. (1981). V-test is not a statistical test of ‘homeward’ direction. *Nature*, 293(5829):239. doi:10.1038/293239a0.
- Arnaiz Tovar, G. and Ruiz-Rivas, C. (1986). Outliers in circular data: a Bayesian approach. *Quèstiió*, 10(1):1–6.
- Arnold, B. C. and SenGupta, A. (2006a). Probability distributions and statistical inference for axial data. *Environmental and Ecological Statistics*, 13(3):271–285. doi:10.1007/s10651-004-0011-8.
- Arnold, B. C. and SenGupta, A. (2006b). Recent advances in the analyses of directional data in ecological and environmental sciences. *Environmental and Ecological Statistics*, 13(3):253–256. doi:10.1007/s10651-006-0009-5.
- Arnold, B. C. and SenGupta, A. (2009). Flexible bivariate circular models. In SenGupta, A. (Ed.), *Advances in Multivariate Statistical Methods*, volume 4 of *Statistical Science and Interdisciplinary Research*, pp. 95–106. World Scientific, Hackensack. doi:10.1142/9789812838247\_0006.
- Arnold, K. J. (1941). *On Spherical Probability Distributions*. PhD thesis, Massachusetts Institute of Technology.
- Arnold, R. and Jupp, P. (2018). Orientations of symmetrical objects. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 25–44. CRC Press, Boca Raton.
- Arnold, R. and Jupp, P. E. (2013). Statistics of orthogonal axial frames. *Biometrika*, 100(3):571–586. doi:10.1093/biomet/ast017.
- Arnold, R., Jupp, P. E., and Schaebein, H. (2018). Statistics of ambiguous rotations. *Journal of Multivariate Analysis*, 165:73–85. doi:10.1016/j.jmva.2017.10.007.
- Arsham, H. (1988). Kuiper’s P-value as a measuring tool and decision procedure for the goodness-of-fit test. *Journal of Applied Statistics*, 15(2):131–135. doi:10.1080/02664768800000020.
- Artes, R. (2008). Hypothesis tests for covariance analysis models for circular data. *Communications in Statistics – Theory and Methods*, 37(8-10):1632–1640. doi:10.1080/03610920801893962.
- Artes, R., Paula, G. A., and Ranvaud, R. (2000). Analysis of circular longitudinal data based on generalized estimating

- equations. *Australian & New Zealand Journal of Statistics*, 42(3):347–358. doi:10.1111/1467-842x.00131.
- Artes, R. and Toloi, C. M. C. (2009). An autoregressive model for time series of circular data. *Communications in Statistics – Theory and Methods*, 39(1):186–194. doi:10.1080/03610920802650338.
- Asano, C. (1965). Runs test for a circular distribution and a table of probabilities. *Annals of the Institute of Statistical Mathematics*, 17(1):331–346. doi:10.1007/bf02868177.
- Ashby, M. P. J. and Bowers, K. J. (2013). A comparison of methods for temporal analysis of aoristic crime. *Crime Science*, 2(1):1. doi:10.1186/2193-7680-2-1.
- Audit, B. and Ouzounis, C. A. (2003). From genes to genomes: universal scale-invariant properties of microbial chromosome organisation. *Journal of Molecular Biology*, 332(3):617–633. doi:10.1016/S0022-2836(03)00811-8.
- Azzalini, A. (1985). A class of distributions which includes the normal ones. *Scandinavian Journal of Statistics*, 12(2):171–178.
- Azzalini, A. and Capitanio, A. (2014). *The Skew-Normal and Related Families*. Cambridge University Press, Cambridge. doi:10.1017/CB09781139248891.
- Baayen, C. and Klugkist, I. (2014). Evaluating order-constrained hypotheses for circular data from a between-within subjects design. *Psychological Methods*, 19(3):398–408. doi:10.1037/a0037414.
- Baayen, C., Klugkist, I., and Mechsner, F. (2012). A test of order-constrained hypotheses for circular data with applications to human movement science. *Journal of Motor Behavior*, 44(5):351–363. doi:10.1080/00222895.2012.709549.
- Baba, Y. (1981). Statistics of angular data. Wrapped normal distribution model. *Proceedings of the Institute of Statistical Mathematics*, 28(1):41–54.
- Babcock, H. W. (1961). The topology of the Sun’s magnetic field and the 22-year cycle. *Astrophysical Journal*, 133(2):572–587. doi:10.1086/147060.
- Bagchi, P. (1987). *Bayesian Analysis of Directional Data*. PhD thesis, University of Toronto.
- Bagchi, P. (1994). Empirical Bayes estimation in directional data. *Journal of Applied Statistics*, 21(4):317–326. doi:10.1080/757583874.
- Bagchi, P. and Guttman, I. (1988). Theoretical considerations of the multivariate von Mises-Fisher distribution. *Journal of Applied Statistics*, 15(2):149–169. doi:10.1080/02664768800000022.
- Bagchi, P. and Guttman, I. (1990). Spuriousity and outliers in directional data. *Journal of Applied Statistics*, 17(3):341–350. doi:10.1080/02664769000000006.
- Bagchi, P. and Kadane, J. B. (1991). Laplace approximations to posterior moments and marginal distributions on circles, spheres, and cylinders. *The Canadian Journal of Statistics*, 19(1):67–77. doi:10.2307/3315537.
- Bahlmann, C. (2006). Directional features in online handwriting recognition. *Pattern Recognition*, 39(1):115–125. doi:10.1016/j.patcog.2005.05.012.
- Bai, Z. D., Rao, C. R., and Zhao, L. C. (1988). Kernel estimators of density function of directional data. *Journal of Multivariate Analysis*, 27(1):24–39. doi:10.1016/0047-259X(88)90113-3.
- Bakshaev, A. (2010).  $N$ -distance tests of uniformity on the hypersphere. *Nonlinear Analysis: Modelling and Control*, 15(1):15–8. doi:10.15388/na.2010.15.1.14361.
- Baldi, P., Kerkycharian, G., Marinucci, D., and Picard, D. (2009a). Adaptive density estimation for directional data using needlets. *The Annals of Statistics*, 37(6A):3362–3395. doi:10.1214/09-aos682.
- Baldi, P., Kerkycharian, G., Marinucci, D., and Picard, D. (2009b). Asymptotics for spherical needlets. *The Annals of Statistics*, 37(3):1150–1171. doi:10.1214/08-AOS601.
- Ball, F. and Blackwell, P. (1992). A finite form for the wrapped Poisson distribution. *Advances in Applied Probability*, 24(1):221–222. doi:10.2307/1427738.
- Ball, F. G., Dryden, I. L., and Golalizadeh, M. (2008). Brownian motion and Ornstein–Uhlenbeck processes in planar shape space. *Methodology and Computing in Applied Probability*, 10(1):1–22. doi:10.1007/s11009-007-9042-6.
- Baltieri, D., Vezzani, R., and Cucchiara, R. (2012). People orientation recognition by mixtures of wrapped distributions on random trees. In Fitzgibbon, A., Lazebnik, S., Perona, P., Sato, Y., and Schmid, C. (Eds.), *Computer Vision – ECCV 2012*, volume 7576 of *Lecture Notes in Computer Science*, pp. 270–283, Berlin. Springer. doi:10.1007/978-3-642-33715-4\_20.
- Banerjee, A., Dhillon, I., Ghosh, J., and Sra, S. (2003). Generative model-based clustering of directional data. In *KDD ’03*, pp. 19–28, New York. Association for Computing Machinery. doi:10.1145/956750.956757.
- Banerjee, A., Dhillon, I. S., Ghosh, J., and Sra, S. (2005a). Clustering on the unit hypersphere using von Mises-Fisher distributions. *Journal of Machine Learning Research*, 6(Sep):1345–1382.
- Banerjee, A., Dhillon, I. S., Ghosh, J., and Sra, S. (2009). Text clustering with mixture of von Mises-Fisher distributions. In Srivastava, A. N. and Sahami, M. (Eds.), *Text Mining*, Chapman & Hall/CRC Data Mining and Knowledge Discovery Series, pp. 151–184. CRC Press, New York. doi:10.1201/9781420059458.
- Banerjee, A., Merugu, S., Dhillon, I. S., and Ghosh, J. (2005b). Clustering with Bregman divergences. *Journal of Machine Learning Research*, 6(Oct):1705–1749.
- Bangert, M., Hennig, P., and Oelfke, U. (2010). Using an infinite von Mises-Fisher mixture model to cluster treatment beam directions in external radiation therapy. In *ICMLA ’10*, pp. 746–751, Washington D. C. IEEE Computer Society. doi:10.1109/icmla.2010.114.
- Bao, L., Gneiting, T., Gritti, E. P., Guttorp, P., and Raftery, A. E. (2009). Bias correction and Bayesian model averaging for

- ensemble forecasts of surface wind direction. *Monthly Weather Review*, 138(5):1811–1821. doi:10.1175/2009mwr3138.1.
- Baragona, R. (2003). Further results on Lund’s statistic for identifying cluster in a circular data set with application to time series. *Communications in Statistics – Simulation and Computation*, 32(3):943–952. doi:10.1081/sac-120017869.
- Baranyi, T., Györi, L., and Ludmány, A. (2016). On-line tools for solar data compiled at the Debrecen observatory and their extensions with the Greenwich sunspot data. *Solar Physics*, 291(9):3081–3102. doi:10.1007/s11207-016-0930-1.
- Barbosa, S. M., Zafrir, H., Malik, U., and Piatibratova, O. (2010). Multiyear to daily radon variability from continuous monitoring at the Amram tunnel, southern Israel. *Geophysical Journal International*, 182(2):829–842. doi:10.1111/j.1365-246x.2010.04660.x.
- Baricz, A. (2014). Remarks on a parameter estimation for von Mises-Fisher distributions. *Computational Statistics*, 29(3-4):891–894. doi:10.1007/s00180-014-0493-2.
- Baringhaus, L. (1991). Testing for spherical symmetry of a multivariate distribution. *The Annals of Statistics*, 19(2):899–917. doi:10.1214/aos/1176348127.
- Barker, D., Huang, X.-Y., Liu, Z., Auligné, T., Zhang, X., Rugg, S., Ajjaji, R., Bourgeois, A., Bray, J., Chen, Y., Demirtas, M., Guo, Y.-R., Henderson, T., Huang, W., Lin, H. C., Michalakes, J., Rizvi, S., and Zhangs, X. (2012). The weather research and forecasting model’s community variational/ensemble data assimilation system: WRFDA. *Bulletin of the American Meteorological Society*, 93(6):831–843. doi:10.1175/bams-d-11-00167.1.
- Barndorff-Nielsen, O. E. (1978a). Hyperbolic distributions and distributions on hyperbolae. *Scandinavian Journal of Statistics*, 5(3):151–157.
- Barndorff-Nielsen, O. E. (1978b). *Information and Exponential Families*. Wiley Series in Probability and Mathematical Statistics. Wiley, Chichester. doi:10.1002/9781118857281.
- Barndorff-Nielsen, O. E., Blaesild, P., Jensen, J. L., and Jørgensen, B. (1982). Exponential transformation models. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 379(1776):41–65. doi:10.1098/rspa.1982.0004.
- Barndorff-Nielsen, O. E. and R., C. D. (1989). *Asymptotic Techniques for Use in Statistics*, volume 31 of *Monographs on Statistics and Applied Probability*. Chapman & Hall, London. doi:10.1007/978-1-4899-3424-6.
- Barnett, A. and Baker, P. (2020). *season: Analysing Seasonal Data R Functions*. R package version 0.3.12. URL: <https://CRAN.R-project.org/package=season>.
- Barnett, A. G. and Dobson, A. J. (2010). *Analysing Seasonal Health Data*. Statistics for Biology and Health. Springer, Heidelberg. doi:10.1007/978-3-642-10748-1.
- Barnett, V. and Lewis, T. (1994). *Outliers in Statistical Data*. Wiley Series in Probability and Statistics. Wiley, Chichester, third edition. doi:10.2307/2533352.
- Barr, D. R. and Shudde, R. H. (1973). A note on Kuiper’s  $V_n$  statistic. *Biometrika*, 60(3):663–664. doi:10.2307/2335018.
- Barragán, S., Fernández, M. A., Rueda, C., and Peddada, S. (2013a). isocir: an R package for constrained inference using isotonic regression for circular data, with an application to cell biology. *Journal of Statistical Software*, 54(4):1–17. doi:10.18637/jss.v054.i04.
- Barragán, S., Fernández, M. A., Rueda, C., and Peddada, S. D. (2013b). isocir: an R package for constrained inference using isotonic regression for circular data, with an application to cell biology. *Journal of Statistical Software*, 54(4):1–17. doi:10.18637/jss.v054.i04.
- Barragán, S., Rueda, C., and Fernández, M. A. (2017). Circular order aggregation and its application to cell-cycle genes expressions. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 14(4):819–829.
- Barragán, S., Rueda, C., Fernández, M. A., and Peddada, S. D. (2015). Determination of temporal order among the components of an oscillatory system. *PLOS One*, 10:e0124842. doi:10.1371/journal.pone.0124842.
- Barragán Andrés, S. (2014). *Procedimientos Estadísticos para Modelos Circulares con Restricciones de Orden Aplicados al Análisis de Expresiones de Genes*. PhD thesis, Universidad de Valladolid.
- Barros, A. M. G., Pereira, J., and Lund, U. J. (2012). Identifying geographical patterns of wildfire orientation: a watershed-based analysis. *Forest Ecology and Management*, 264:98–107. doi:10.1016/j.foreco.2011.09.027.
- Barros, C. M., Amaral, G. J. A., Nascimento, A. D. C., and Cysneiros, A. H. M. A. (2017). Detecting influential observations in Watson data. *Communications in Statistics – Simulation and Computation*, 46(14):6882–6898. doi:10.1080/03610926.2016.1139130.
- Bartels, R. (1984). Estimation in a bidirectional mixture of von Mises distributions. *Biometrics*, 40(3):777–784. doi:10.2307/2530921.
- Barton, D. E. and David, F. N. (1958). Runs in a ring. *Biometrika*, 45(3/4):572–578. doi:10.2307/2333207.
- Basu, A., Harris, I. R., Hjort, N. L., and Jones, M. C. (1998). Robust and efficient estimation by minimising a density power divergence. *Biometrika*, 85(3):549–559. doi:10.1093/biomet/85.3.549.
- Basu, S. and Jammalamadaka, S. R. (2002). Unimodality in circular data: a Bayes test. In Balakrishnan, N. (Ed.), *Advances on Methodological and Applied Aspects of Probability and Statistics*, pp. 141–158. Taylor & Francis, London. doi:10.1201/9780203493212-8.
- Batchelor, P. G. (2009). Tensors, polynomials and models for directional data. In Laidlaw, D. and Weickert, J. (Eds.), *Visualization and Processing of Tensor Fields*, Mathematics and Visualization, pp. 21–37. Springer, Berlin. doi:10.1007/

- Batschelet, E. (1965). *Statistical Methods for the Analysis of Problems in Animal Orientation and Certain Biological Rhythms*. American Institute of Biological Sciences, Washington D. C.
- Batschelet, E. (1971). Recent statistical methods for orientation data. In *Wallops Island 1970 Symposium on Animal Orientation*, pp. 61–91, Washington D. C. American Institute of Biological Sciences.
- Batschelet, E. (1981). *Circular Statistics in Biology*. Mathematics in Biology. Academic Press, London.
- Batschelet, E., Hillman, D., Smolensky, M., and Halberg, F. (1973). Angular-linear correlation coefficient for rhythmometry and circannually changing human birth rates at different geographic latitudes. *International Journal of Chronobiology*, 1(3):183–202.
- Batyrshin, I., Kubysheva, N., and Tarassov, V. (2020). Dissimilarity-based correlation of movements and events on circular scales of space and time. In Martínez-Villaseñor, L., Herrera-Alcántara, O., Ponce, H., and Castro-Espinoza, F. A. (Eds.), *Advances in Computational Intelligence*, volume 12469 of *Lecture Notes in Computer Science*, pp. 237–246, Cham. Springer. doi:10.1007/978-3-030-60887-3\_21.
- Beaudette, D. E., Roudier, P., and O’Geen, A. T. (2013). Algorithms for quantitative pedology: a toolkit for soil scientists. *Computers & Geosciences*, 52:258–268. doi:10.1016/j.cageo.2012.10.020.
- Beckman, R. J. and Cook, R. D. (1983). Outlier. .s. *Technometrics*, 25(2):119–163. doi:10.2307/1268541.
- Beckmann, P. (1959). The probability distribution of the vector sum of  $n$  unit vectors with arbitrary phase distributions. *Acta Technica*, 4(4):323–335.
- Bee, M., Benedetti, R., and Espa, G. (2017). Approximate maximum likelihood estimation of the Bingham distribution. *Computational Statistics & Data Analysis*, 108:84–96. doi:10.1016/j.csda.2016.11.004.
- Beh, J., Han, D. K., Durasiwami, R., and Ko, H. (2014). Hidden Markov model on a unit hypersphere space for gesture trajectory recognition. *Pattern Recognition Letters*, 36:144–153. doi:10.1016/j.patrec.2013.10.007.
- Bellman, R. A. (1961). *A Brief Introduction to Theta Functions*. Holt, Rinehart and Winston, New York.
- Belu, R. and Koracin, D. (2013). Statistical and spectral analysis of wind characteristics relevant to wind energy assessment using tower measurements in complex terrain. *Journal of Wind Energy*, 2013:1–12. doi:10.1155/2013/739162.
- Benali, A., Mota, B., Carvalhais, N., Oom, D., Miller, L. M., Campagnolo, M. L., and Pereira, J. (2017). Bimodal fire regimes unveil a global-scale anthropogenic fingerprint. *Global Ecology and Biogeography*, 26(7):799–811. doi:10.1111/geb.12586.
- Benford, F. (1938). The law of anomalous numbers. *Proc. Am. Philos. Soc.*, 78(4):551–572.
- Benjamin, J. B. M., Hussain, I., and Yang, M.-S. (2019). Possibilistic c-means clustering on directional data. In *2019 12th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)*, pp. 1–6, New York. IEEE. doi:10.1109/cisp-bmei48845.2019.8965703.
- Beran, J. (2004). *Statistics in Musicology*. Chapman & Hall/CRC Interdisciplinary Statistics Series. CRC Press, Boca Raton. doi:10.1201/9780203496947.
- Beran, J. and Ghosh, S. (2020). Estimating the mean direction of strongly dependent circular time series. *Journal of Time Series Analysis*, 41:210–228. doi:10.1111/jtsa.12500.
- Beran, R. (2016). Nonparametric estimation of trend in directional data. *Stochastic Processes and their Applications*, 126(12):3808–3827. doi:10.1016/j.spa.2016.04.018.
- Beran, R. J. (1968). Testing for uniformity on a compact homogeneous space. *Journal of Applied Probability*, 5(1):177–195. doi:10.1017/s002190020003237x.
- Beran, R. J. (1969a). Asymptotic theory of a class of tests for uniformity of a circular distribution. *Annals of Mathematical Statistics*, 40(4):1196–1206. doi:10.1214/aoms/1177697496.
- Beran, R. J. (1969b). The derivation of nonparametric two-sample tests from tests for uniformity of a circular distribution. *Biometrika*, 56(3):561–570. doi:10.1093/biomet/56.3.561.
- Beran, R. J. (1979). Exponential models for directional data. *The Annals of Statistics*, 7(6):1162–1178. doi:10.1214/aos/1176344838.
- Beran, R. J. and Fisher, N. I. (1998). Nonparametric comparison of mean directions or mean axes. *The Annals of Statistics*, 26(2):472–493. doi:10.1214/aos/1028144845.
- Berens, P. (2009). CircStat: a MATLAB toolbox for circular statistics. *Journal of Statistical Software*, 31(10):1–21. doi:10.18637/jss.v031.i10.
- Berman, M. (1983). Estimating the parameters of a circle when angular differences are known. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 32(1):1–6. doi:10.2307/2348036.
- Berman, M. and Culpin, D. (1986). The statistical behaviour of some least squares estimators of the centre and radius of a circle. *Journal of the Royal Statistical Society, Series B (Methodological)*, 48(2):183–196. doi:10.1111/j.2517-6161.1986.tb01401.x.
- Berman, M. and Griffiths, D. (1985). Incorporating angular information into models for stone circle data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 34(3):237–245. doi:10.2307/2347469.
- Bernoulli, D. (1735). Quelle est la cause physique de l’inclinaison des plans des orbites des planètes par rapport au plan de l’équateur de la révolution du soleil autour de son axe ; et d’où vient que les inclinaisons de ces orbites sont différentes en elles. In des Sciences, A. R. (Ed.), *Recueil des pièces qui ont remporté le prix de l’Académie Royale des Sciences*, volume 3,

- pp. 93–122. Académie Royale des Sciences, Paris.
- Bero, D. and Bingham, M. A. (2015). A permutation test for three-dimensional rotation data. *Involve*, 8(5):735–744. doi:10.2140/involve.2015.8.735.
- Bertotti, L. and Cavaleri, L. (2009). Wind and wave predictions in the Adriatic Sea. *Journal of Marine Systems*, 78, Supplement:S227–S234. doi:10.1016/j.jmarsys.2009.01.018.
- Bertrand-Retali, M. and Ait-Hennani, L. (1995). Uniform convergence of density estimators on spheres. *Applications Mathematicae*, 22(4):427–446. doi:10.4064/am-22-4-427-446.
- Best, D. and Fisher, N. (1979). Efficient simulation of the von Mises distribution. *Applied Statistics*, 28(2):152–157. doi:10.2307/2346732.
- Best, D. J. and Fisher, N. I. (1981). The bias of the maximum likelihood estimators of the von Mises-Fisher concentration parameters. *Communications in Statistics – Simulation and Computation*, 10(5):493–502. doi:10.1080/03610918108812225.
- Best, D. J. and Fisher, N. I. (1986). Goodness of fit and discordancy tests for samples from the Watson distribution on the sphere. *Australian Journal of Statistics*, 28(1):13–31. doi:10.1111/j.1467-842x.1986.tb00580.x.
- Bhattacharjee, S. (2020). *Tracking Space Debris Using Directional Statistics*. PhD thesis, University of Leeds.
- Bhattacharjee, S., Kent, J. T., Hussein, I. I., Faber, W. R., and Jah, M. K. (2017a). Application of directional statistics to problems in SSA. In *1st IAA Conference on Space Situational Awareness (ICSSA)*.
- Bhattacharjee, S., Kent, J. T., Hussein, I. I., and Jah, M. K. (2017b). Bayesian filtering using directional statistics for the space debris tracking problem. In *68th International Astronautical Congress 2017*, Paris. International Astronautical Federation.
- Bhattacharya, A. and Bhattacharya, R. (2012). *Nonparametric Inference on Manifolds*, volume 2 of *Institute of Mathematical Statistics Monographs*. Cambridge University Press, Cambridge. doi:10.1017/CB09781139094764.
- Bhattacharya, A. and Dunson, D. (2012). Nonparametric Bayes classification and hypothesis testing on manifolds. *Journal of Multivariate Analysis*, 111:1–19. doi:10.1016/j.jmva.2012.02.020.
- Bhattacharya, A. and Dunson, D. B. (2010). Nonparametric Bayesian density estimation on manifolds with applications to planar shapes. *Biometrika*, 97(4):851–865. doi:10.1093/biomet/asq044.
- Bhattacharya, R. and Patrangenaru, V. (2003). Large sample theory of intrinsic and extrinsic sample means on manifolds. *The Annals of Statistics*, 31(1):1–29. doi:10.1214/aos/1046294456.
- Bhattacharya, R. and Patrangenaru, V. (2005). Large sample theory of intrinsic and extrinsic sample means on manifolds–II. *The Annals of Statistics*, 33(3):1225–1259. doi:10.1214/009053605000000093.
- Bhattacharya, R. and Patrangenaru, V. (2014). Statistics on manifolds and landmarks based image analysis: a nonparametric theory with applications. *Journal of Statistical Planning and Inference*, 145:1–22. doi:10.1016/j.jspi.2013.08.001.
- Bhattacharya, S. and SenGupta, A. (2009a). Bayesian analysis of semiparametric linear-circular models. *Journal of Agricultural, Biological, and Environmental Statistics*, 14(1):33–65. doi:10.1198/jabes.2009.0003.
- Bhattacharya, S. and SenGupta, A. (2009b). Bayesian inference for circular distributions with unknown normalising constants. *Journal of Statistical Planning and Inference*, 139(12):4179–4192. doi:10.1016/j.jspi.2009.06.008.
- Bhattacharyya, G. K. and Johnson, R. A. (1969). On Hodges’s bivariate sign test and a test for uniformity of a circular distribution. *Biometrika*, 56(2):446–449. doi:10.1093/biomet/56.2.446.
- Bijral, A., Breitenbach, M., and Grudic, G. Z. (2007). Mixture of Watson distributions: a generative model for hyperspherical embeddings. In Meila, M. and Shen, X. (Eds.), *Proceedings of the Eleventh International Conference on Artificial Intelligence and Statistics*, Proceedings of Machine Learning Research, pp. 35–42, San Juan, Puerto Rico. PMLR.
- Bingham, C. (1964). *Distributions on the Sphere and on the Projective Plane*. PhD thesis, Yale University.
- Bingham, C. (1974). An antipodally symmetric distribution on the sphere. *The Annals of Statistics*, 2(6):1201–1225. doi:10.1214/aos/1176342874.
- Bingham, C. (1980). Distribution on the sphere. In Fienberg, S. E. and Hinkley, D. V. (Eds.), *R. A. Fisher: an Appreciation*, volume 1 of *Lecture Notes in Statistics*, pp. 171–181. Springer, New York. doi:10.1007/978-1-4612-6079-0\_17.
- Bingham, C. and Chang, T. (1988). The use of the Bingham distribution in spherical regression inference. Technical report, School of Statistics, University of Minnesota.
- Bingham, C., Chang, T., and Richards, D. (1992). Approximating the matrix Fisher and Bingham distributions: applications to spherical regression and procrustes analysis. *Journal of Multivariate Statistics*, 41:314–337. doi:10.1016/0047-259x(92)90072-n.
- Bingham, C. and Mardia, K. V. (1978). A small circle distribution on the sphere. *Biometrika*, 65(2):379–389. doi:10.1093/biomet/65.2.379.
- Bingham, M. A., Nordman, D. J., and Vardeman, S. B. (2009). Modeling and inference for measured crystal orientations and a tractable class of symmetric distributions for rotations in three dimensions. *Journal of the American Statistical Association*, 104(488):1385–1397. doi:10.1198/jasa.2009.ap08741.
- Bingham, M. A., Nordman, D. J., and Vardeman, S. B. (2012). Bayes inference for a tractable new class of non-symmetric distributions for 3-dimensional rotations. *Journal of Agricultural, Biological, and Environmental Statistics*, 17(4):527–543. doi:10.1007/s13253-012-0107-9.
- Bingham, M. A. and Scray, M. L. (2017). A permutation test for comparing rotational symmetry in three-dimensional rotation

- data sets. *Journal of Statistical Distributions and Applications*, 4(1):19. doi:10.1186/s40488-017-0075-2.
- Bingham, M. S. (1971). Stochastic processes with independent increments taking values in an Abelian group. *Proceedings of the London Mathematical Society*, s3-22(22):507–530. doi:10.1112/plms/s3-22.3.507.
- Bingham, M. S. (1975). Maximum likelihood characterization of the von Mises distribution. In Patil, G. P., Kotz, S., and Ord, J. K. (Eds.), *A Modern Course on Statistical Distributions in Scientific Work*, volume 17 of *NATO Science Series C: Mathematical and Physical Sciences*, pp. 387–398, Dordrecht. Springer. doi:10.1007/978-94-010-1848-7\_35.
- Bingham, M. S. (1978). A characterization of the uniform distribution on the circle in the analysis of directional data. *Journal of Applied Probability*, 15(4):852–857. doi:10.2307/3213441.
- Bishop, B. V. (1947). The frequency of thunderstorms at Kew observatory. *Meteorological Magazine*, 76:108–111.
- Blæsild, P. (1979). Conditioning with conic sections in the two-dimensional normal distribution. *The Annals of Statistics*, 7(3):659–670. doi:10.1214/aos/1176344686.
- Bloom, S. L. and Ésik, Z. (1989). Equational logic of circular data type specification. *Theoretical Computer Science*, 63(3):303–331. doi:10.1016/0304-3975(89)90012-1.
- Boente, G. and Fraiman, R. (1991). Nonparametric regression for directional data. *Trabajos de Matemática*, 176:1–13.
- Boente, G., Rodriguez, D., and González-Manteiga, W. (2014). Goodness-of-fit test for directional data. *Scandinavian Journal of Statistics*, 41(1):259–275. doi:10.1111/sjos.12020.
- Bogdan, M., Bogdan, K., and Futschik, A. (2002). A data driven smooth test for circular uniformity. *Annals of the Institute of Statistical Mathematics*, 54(1):29–44. doi:10.1023/A:1016109603897.
- van Bommel, L. and Johnson, C. N. (2014). Where do livestock guardian dogs go? movement patterns of free-ranging Maremma sheepdogs. *PLOS One*, 9(10):e111444. doi:10.1371/journal.pone.0111444.
- Boneva, L. I., Kendall, D. G., and Stefanov, I. (1971). Spline transformations: three new diagnostic aids for the statistical data-analyst. *Journal of the Royal Statistical Society, Series B (Methodological)*, 33(1):1–70. doi:10.1111/j.2517-6161.1971.tb00855.x.
- van den Boogaart, K. G. (2002). *Statistics for Individual Crystallographic Orientation Measurements*. Industriemathematik und Angewandte Mathematik. Shaker, Aachen.
- Boomsma, W., Mardia, K. V., Taylor, C. C., Ferkinghoff-Borg, J., Krogh, A., and Hamelryck, T. (2008). A generative, probabilistic model of local protein structure. *Proceedings of the National Academy of Sciences of the United States of America*, 105(26):8932–8937. doi:10.1073/pnas.0801715105.
- Boulerice, B. and Ducharme, G. R. (1994). Decentered directional data. *Annals of the Institute of Statistical Mathematics*, 46(3):573–586. doi:10.1007/BF00773518.
- Boulerice, B. and Ducharme, G. R. (1997). Smooth tests of goodness-of-fit for directional and axial data. *Journal of Multivariate Analysis*, 60(1):154–174. doi:10.1006/jmva.1996.1650.
- Bourguin, S., Durastanti, C., Marinucci, D., and Peccati, G. (2016). Gaussian approximation of nonlinear statistics on the sphere. *Journal of Mathematical Analysis and Applications*, 436(2):1121–1148. doi:10.1016/j.jmaa.2015.12.036.
- Bowers, J. A., Morton, I. D., and Mould, G. I. (2000). Directional statistics of the wind and waves. *Applied Ocean Research*, 22(1):13–30. doi:10.1016/S0141-1187(99)00025-5.
- Bowman, A. and Azzalini, A. (2018). *R package sm: Nonparametric Smoothing Methods*. R package version 2.2-5.6. URL: <https://CRAN.R-project.org/package=sm>.
- Bowman, A. W. (1992). Density based tests for goodness-of-fit. *Journal of Statistical Computation and Simulation*, 40(1-2):1–13. doi:10.1080/00949659208811361.
- Boyd, J. E. (2004). Synchronization of oscillations for machine perception of gaits. *Computer Vision and Image Understanding*, 96(1):35–59. doi:10.1016/j.cviu.2004.04.004.
- Breckling, J. (1989). *The Analysis of Directional Time Series: Applications to Wind Speed and Direction*, volume 61 of *Lecture Notes in Statistics*. Springer, London.
- Breitenberger, E. (1963). Analogues of the normal distribution on the circle and the sphere. *Biometrika*, 50(1/2):81–88. doi:10.2307/2333749.
- Brown, B. M. (1994). Grouping corrections for circular goodness-of-fit tests. *Journal of the Royal Statistical Society, Series B (Methodological)*, 56(1):275–283. doi:10.1111/j.2517-6161.1994.tb01977.x.
- Brunel, E. and Roche, A. (2015). Penalized contrast estimation in functional linear models with circular data. *Statistics*, 49(6):1298–1321. doi:10.1080/02331888.2014.993986.
- Brunhes, D. (1987). Une méthode de calcul de la fonction de répartition de la statistique de Kolmogorov-Kuiper d’ordre  $N$ . *Publications de l’Institut de Statistique de l’Université de Paris*, 32(1-2):3–17.
- Brunk, H. D. (1962). On the range of the difference between hypothetical distribution function and Pyke’s modified empirical distribution function. *Annals of Mathematical Statistics*, 33(2):525–532. doi:10.1214/aoms/1177704578.
- Brunner, L. J. and Lo, A. Y. (1994). Nonparametric Bayes methods for directional data. *The Canadian Journal of Statistics*, 22(3):401–412. doi:10.2307/3315601.
- Brunsdon, C. and Charlton, M. (2006). Local trend statistics for directional data - a moving window approach. *Computers, Environment and Urban Systems*, 30(2):130–142. doi:10.1016/j.compenvurbsys.2005.08.004.
- Brunsdon, C. and Corcoran, J. (2006). Using circular statistics to analyse time patterns in crime incidence. *Computers,*



- Environment and Urban Systems*, 30(3):300–319. doi:10.1016/j.compenvurbsys.2005.11.001.
- Bukal, M., Marković, I., and Petrović, I. (2017). Score matching based assumed density filtering with the von Mises-Fisher distribution. In *2017 20th International Conference on Information Fusion (FUSION)*, pp. 1–6, New York. IEEE. doi:10.23919/ICIF.2017.8009680.
- Bull, A. M. J. and Amis, A. A. (1998). Knee joint motion: description and measurement. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 212(5):357–372. doi:10.1243/0954411981534132.
- Bulla, J., Lagona, F., Maruotti, A., and Picone, M. (2012). A multivariate hidden Markov model for the identification of sea regimes from incomplete skewed and circular time series. *Journal of Agricultural, Biological, and Environmental Statistics*, 17(4):544–567. doi:10.1007/s13253-012-0110-1.
- Bulla, J., Lagona, F., Maruotti, A., and Picone, M. (2015). Environmental conditions in semi-enclosed basins: a dynamic latent class approach for mixed-type multivariate variables. *Journal de la Société Française de Statistique*, 156(1):114–137.
- Burke, M. D. (1979). On the asymptotic power of some  $k$ -sample statistics based on the multivariate empirical process. *Journal of Multivariate Analysis*, 9(2):183–205. doi:10.1016/0047-259X(79)90078-2.
- Burr, A. H. (1979). Analysis of phototaxis in nematodes using directional statistics. *Journal of Comparative Physiology*, 134(1):85–93. doi:10.1007/bf00610280.
- Burr, E. J. (1964). Small-sample distributions of the two-sample Cramér-von Mises  $W^2$  and Watson’s  $U^2$ . *Annals of Mathematical Statistics*, 35(3):1091–1098. doi:10.1214/aoms/1177703267.
- Buttarazzi, D. (2020). *bpDir: Boxplots for Directional Data*. R package version 0.1.1. URL: <https://CRAN.R-project.org/package=bpDir>.
- Buttarazzi, D., Pandolfo, G., and Porzio, G. C. (2018). A boxplot for circular data. *Biometrics*, 74(4):1492–1501. doi:10.1111/biom.12889.
- Butucea, C. (2007). Goodness-of-fit testing and quadratic functional estimation from indirect observations. *The Annals of Statistics*, 35(5):1907–1930. doi:10.1214/009053607000000118.
- Byrne, R. W., Noser, R., Bates, L. A., and Jupp, P. E. (2009). How did they get here from there? detecting changes of direction in terrestrial ranging. *Animal Behaviour*, 77(3):619–631. doi:10.1016/j.anbehav.2008.11.014.
- Byrne, S. and Girolami, M. (2013). Geodesic Monte Carlo on embedded manifolds. *Scandinavian Journal of Statistics*, 40(4):825–845. doi:10.1111/sjos.12036.
- Byth, K. (1982). On kernel methods of estimating marginal radial and angular probability density functions. *Biometrical Journal*, 24(1):49–58. doi:10.1002/bimj.4710240105.
- Cabeen, R. P. and Laidlaw, D. H. (2014). White matter supervoxel segmentation by axial DP-means clustering. In Menze, B., Langs, G., Montillo, A., Kelm, M., Müller, H., and Tu, Z. (Eds.), *Medical Computer Vision. Large Data in Medical Imaging. MCV 2013*, volume 8331 of *Lecture Notes in Computer Science*, pp. 95–104, Cham. Springer. doi:10.1007/978-3-319-05530-5\_10.
- Cabella, P. and Marinucci, D. (2009). Statistical challenges in the analysis of cosmic microwave background radiation. *The Annals of Applied Statistics*, 3(1):61–95. doi:10.1214/08-aos190.
- Cabrera, J., Schmidt-Koenig, K., and Watson, G. S. (1991). The statistical analysis of circular data. In Bateson, P. P. G. and Klopfer, P. H. (Eds.), *Perspectives in Ethology*, pp. 285–306. Springer, New York.
- Cabrera, J. and Watson, G. S. (1990). On a spherical median related distribution. *Communications in Statistics – Theory and Methods*, 19(6):1973–1986. doi:10.1080/03610929008830303.
- Cagnacci, F., Boitani, L., Powell, R. A., and Boyce, M. S. (2010). Animal ecology meets GPS-based radiotelemetry: a perfect storm of opportunities and challenges. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 365(1550):2157–2162. doi:10.1098/rstb.2010.0107.
- Cai, T., Fan, J., and Jiang, T. (2013). Distributions of angles in random packing on spheres. *Journal of Machine Learning Research*, 14(21):1837–1864.
- Cai, T. and Jiang, T. (2012). Phase transition in limiting distributions of coherence of high-dimensional random matrices. *Journal of Multivariate Analysis*, 107:24–39. doi:10.1016/j.jmva.2011.11.008.
- Caires, S. and Wyatt, L. R. (2003). A linear functional relationship model for circular data with an application to the assessment of ocean wave measurements. *Journal of Agricultural, Biological, and Environmental Statistics*, 8(2):153. doi:10.1198/1085711031571.
- Cairns, M. B. (1975). *A Structural Model for the Analysis of Directional Data*. PhD thesis, University of Toronto.
- Calderara, S., Prati, A., and Cucchiara, R. (2011). Mixtures of von Mises distributions for people trajectory shape analysis. *IEEE Transactions on Circuits and Systems for Video Technology*, 21(4):457–471. doi:10.1109/tcsvt.2011.2125550.
- Cammarota, V. and Marinucci, D. (2015). On the limiting behaviour of needlets polyspectra. *Annales de l’Institut Henri Poincaré Probabilités et Statistiques*, 51(3):1159–1189. doi:10.1214/14-AIHP609.
- Campos-Aranda, D. F. (2017). Definition of three flood seasons using directional statistics. *Tecnología y Ciencias del Agua*, 8(1):155–165. doi:10.24850/j-tyca-2017-01-11.
- Capaccioni, B., Valentini, L., Rocchi, M. B. L., Nappi, G., and Sarocchi, D. (1997). Image analysis and circular statistics for shape-fabric analysis: applications to lithified ignimbrites. *Bulletin of Volcanology*, 58(7):501–514. doi:10.1007/s004450050158.

- Carnicero, J. A., Ausín, M. C., and Wiper, M. P. (2013). Non-parametric copulas for circular-linear and circular-circular data: an application to wind directions. *Stochastic Environmental Research and Risk Assessment*, 27(8):1991–2002. doi:10.1007/s00477-013-0733-y.
- Carnicero, J. A., Wiper, M. P., and Ausín, M. C. (2018). Density estimation of circular data with Bernstein polynomials. *Hacetatepe Journal of Mathematics and Statistics*, 47(2):273–286. doi:10.15672/hjms.2014437525.
- Carnicero Carreño, J. A. (2011). *Semi-parametric and Non-parametric Methods for Directional Data*. PhD thesis, Universidad Carlos III de Madrid.
- Carta, J. A., Ramirez, P., and Bueno, C. (2008). A joint probability density function of wind speed and direction for wind energy analysis. *Energy Conversion and Management*, 49(6):1309–1320. doi:10.1016/j.enconman.2008.01.010.
- Cartwright, D. E. (1963). The use of directional spectra in studying the output of a wave recorder on a moving ship. In *Ocean Wave Spectra*, pp. 203–218, Englewood Cliffs. Prentice-Hall.
- Cecil, T., Osher, S., and Vese, L. (2004). Numerical methods for minimization problems constrained to  $S^1$  and  $S^2$ . *Journal of Computational Physics*, 198(2):567–579. doi:10.1016/j.jcp.2004.01.020.
- Cetingul, H. E. and Vidal, R. (2009). Intrinsic mean shift for clustering on Stiefel and Grassmann manifolds. In *2009 IEEE Conference on Computer Vision and Pattern Recognition*, pp. 1896–1902, New York. IEEE. doi:10.1109/cvpr.2009.5206806.
- Chakraborty, S. and Wong, S. W. K. (2019). *BAMBI: Bivariate Angular Mixture Models*. R package version 2.3.0. URL: <https://CRAN.R-project.org/package=BAMBI>.
- Chan, Y. M. and He, X. (1993). On median-type estimators of direction for the von Mises-Fisher distribution. *Biometrika*, 80(4):869–875. doi:10.2307/2336878.
- Chandrasekhar, S. (1943). Stochastic problems in physics and astronomy. *Reviews of Modern Physics*, 15(1):1–89. doi:10.1103/revmodphys.15.1.
- Chang, H. (1993a). *The Analysis of Directional Data: Performance Comparisons of Randomization and Parametric Methods*. PhD thesis, University of Illinois at Urbana-Champaign.
- Chang, H.-J. (1991). *Some Optimal Tests in Directional Data*. PhD thesis, University of California at Santa Barbara.
- Chang, T. (1986). Spherical regression. *The Annals of Statistics*, 14(3):907–924. doi:10.1002/0471667196.ess0734.
- Chang, T. (1987). On the statistical properties of estimated rotations. *Journal of Geophysical Research: Solid Earth*, 92(B7):6319–6329. doi:10.1029/jb092ib07p06319.
- Chang, T. (1988). Estimating the relative rotation of two tectonic plates from boundary crossings. *Journal of the American Statistical Association*, 83(404):1178–1183. doi:10.1080/01621459.1988.10478717.
- Chang, T. (1989). Spherical regression with errors in variables. *The Annals of Statistics*, 17(1):293–306. doi:10.1214/aos/1176347017.
- Chang, T. (1993b). Spherical regression and the statistics of tectonic plate reconstructions. *International Statistical Review*, 61(2):299–316. doi:10.2307/1403630.
- Chang, T. (2004). Spatial statistics. *Statistical Science*, 19(4):624–635. doi:10.1214/088342304000000567.
- Chang, T. and Ko, D. (1995).  $M$ -estimates of rigid body motion on the sphere and in Euclidean space. *The Annals of Statistics*, 23(5):1823–1847. doi:10.1214/aos/1176324325.
- Chang, T. and Rivest, L.-P. (2001).  $M$ -estimation for location and regression parameters in group models: a case study using Stiefel manifolds. *The Annals of Statistics*, 29(3):784–814. doi:10.1214/aos/1009210690.
- Chang, T. and Tsai, M.-T. (2003). Asymptotic relative Pitman efficiency in group models. *Journal of Multivariate Analysis*, 85(2):395–415. doi:10.1016/S0047-259X(02)00062-3.
- Chang-Chien, S.-J., Hung, W.-L., and Yang, M.-S. (2012). On mean shift-based clustering for circular data. *Soft Computing*, 16(6):1043–1060. doi:10.1007/s00500-012-0802-z.
- Chang-Chien, S.-J., Yang, M.-S., and Hung, W.-L. (2010). Mean shift-based clustering for directional data. In *Third International Workshop on Advanced Computational Intelligence*, pp. 367–372, New York. IEEE. doi:10.1109/IWACI.2010.5585203.
- Chaubey, Y. P. (2018). Smooth kernel estimation of a circular density function: a connection to orthogonal polynomials on the unit circle. *Journal of Probability and Statistics*, 2018:1–4. doi:10.1155/2018/5372803.
- Chaudhuri, P. and Marron, J. S. (1999). SiZer for exploration of structures in curves. *Journal of the American Statistical Association*, 94(447):807–823. doi:10.1080/01621459.1999.10474186.
- Chave, A. D. (2015). A note about Gaussian statistics on a sphere. *Geophysical Journal International*, 203(2):893–895. doi:10.1093/gji/ggv324.
- Chen, L., Singh, V. P., Guo, S., Fang, B., and Liu, P. (2013). A new method for identification of flood seasons using directional statistics. *Hydrological Sciences Journal*, 58(1):28–40. doi:10.1080/02626667.2012.743661.
- Chen, W.-J. (1983). *Directional Data and Some Tests of Hypothesis*. PhD thesis, University of Florida.
- Cheng, D., Cammarota, V., Fantaye, Y., Marinucci, D., and Schwartzman, A. (2020). Multiple testing of local maxima for detection of peaks on the (celestial) sphere. *Bernoulli*, 26(1):31–60. doi:10.3150/18-bej1068.
- Cheng, M.-Y. and Wu, H.-T. (2013). Local linear regression on manifolds and its geometric interpretation. *Journal of the American Statistical Association*, 108(504):1421–1434. doi:10.1080/01621459.2013.827984.

- Chernov, N. (2011). *Circular and Linear Regression*, volume 117 of *Monographs on Statistics and Applied Probability*. CRC Press, Boca Raton. doi:10.1201/EBK1439835906.
- Chikuse, Y. (1990a). Distributions of orientations on Stiefel manifolds. *Journal of Multivariate Analysis*, 33:247–264. doi:10.1016/0047-259x(90)90049-n.
- Chikuse, Y. (1990b). High dimensional limit theorems and matrix decompositions on the Stiefel manifold. *Journal of Multivariate Analysis*, 34:145–162. doi:10.1016/0047-259x(91)90054-6.
- Chikuse, Y. (1990c). The matrix angular central Gaussian distribution. *Journal of Multivariate Analysis*, 33:265–274. doi:10.1016/0047-259x(90)90050-r.
- Chikuse, Y. (1991). Asymptotic expansions for distributions of the large-sample matrix resultant and related statistics on the Stiefel manifold. *Journal of Multivariate Analysis*, 39:270–283. doi:10.1016/0047-259x(91)90101-7.
- Chikuse, Y. (1993a). Asymptotic theory for the concentrated Langevin distributions on the Grassmann manifold. In Matsusita, K., Puri, M. L., and Hayakawa, T. (Eds.), *Statistical Science and Data Analysis*, pp. 237–245, Utrecht. VSP.
- Chikuse, Y. (1993b). High dimensional asymptotic expansions for the matrix langevin distributions on the Stiefel manifold. *Journal of Multivariate Analysis*, 44:82–101. doi:10.1006/jmva.1993.1005.
- Chikuse, Y. (1994). Invariant measures on Stiefel manifolds with applications to multivariate analysis. In Anderson, T. W., Fang, K. T., and Olkin, I. (Eds.), *Multivariate Analysis and its Applications*, volume 24 of *Lecture Notes-Monograph*, pp. 177–193. Institute of Mathematical Statistics, Hayward. doi:10.1214/lnms/1215463795.
- Chikuse, Y. (1998). Density estimation on the Stiefel manifold. *Journal of Multivariate Analysis*, 66(2):188–206. doi:10.1006/jmva.1998.1747.
- Chikuse, Y. (2003). *Statistics on Special Manifolds*, volume 174 of *Lecture Notes in Statistics*. Springer, Heidelberg. doi:10.1007/978-0-387-21540-2.
- Chikuse, Y. and Watson, G. S. (1995). Large sample asymptotic theory of the test for uniformity on the Grassmann manifold. *Journal of Multivariate Analysis*, 53:18–31. doi:10.1006/jmva.1995.1043.
- Chinnathambi, V., Sankaralingam, E., Thangaraj, V., and Padma, S. (2019). Despeckling of ultrasound images using directionally decimated wavelet packets with adaptive clustering. *IET Image Processing*, 13(1):206–215. doi:10.1049/iet-ipr.2018.5011.
- Chirikjian, G. S. and Kyatkin, A. (2001). *Engineering Applications of Noncommutative Harmonic Analysis*. CRC Press, Boca Raton. doi:10.1115/1.1421108.
- Chiuso, A. and Picci, G. (1998). Visual tracking of points as estimation on the unit sphere. In Kriegman, D. J., Hager, G. D., and Morse, A. S. (Eds.), *The Confluence of Vision and Control*, volume 237 of *Lecture Notes in Control and Information Sciences*, pp. 90–105, London. Springer. doi:10.1007/BFb0109665.
- Choi, E. and Hall, P. (1999). Data sharpening as a prelude to density estimation. *Biometrika*, 86(4):941–947. doi:10.1093/biomet/86.4.941.
- Chou, R. J. (1986). Small sample theory of the Langevin distribution. *Australian Journal of Statistics*, 28(3):335–344. doi:10.1111/j.1467-842x.1986.tb00706.x.
- Chou, R. J. (1990). Unbiasedness of some tests in the Langevin distribution. *Sankhyā, Series B*, 52(3):256–260.
- Chou, R.-J. and Hwang, T.-C. (1985). Correlation between unit vectors. *Chinese Journal of Mathematics*, 13(2):137–152.
- Choulakian, V., Lockhart, R. A., and Stephens, M. A. (1994). Cramér-von Mises statistics for discrete distributions. *The Canadian Journal of Statistics*, 22(1):125–137. doi:10.2307/3315828.
- Christie, D. (2015). Efficient von Mises-Fisher concentration parameter estimation using Taylor series. *Journal of Statistical Computation and Simulation*, 85(16):3259–3265. doi:10.1080/00949655.2014.965169.
- Ciucci, P., Reggioni, W., Maiorano, L., and Boitani, L. (2009). Long-distance dispersal of a rescued wolf from the northern apennines to the western alps. *The Journal of Wildlife Management*, 73(8):1300–1306. doi:10.2193/2008-510.
- Clark, R. M. (1983). Estimation of parameters in the marginal Fisher distribution. *Australian Journal of Statistics*, 25(2):227–237. doi:10.1111/j.1467-842x.1983.tb00375.x.
- Clark, R. M. (1985). A FORTRAN program for constrained sequence-slotting based on minimum combined path length. *Computers & Geosciences*, 11(5):605–617. doi:10.1016/0098-3004(85)90089-5.
- Clark, R. M. (1988). An evaluation by simulation of alternative estimators for the marginal Fisher distribution. *Journal of Applied Statistics*, 15(2):235–246. doi:10.1080/02664768800000028.
- Clark, R. M. and Morrison, B. J. (1983). A normal approximation to the Fisher distribution. *Geophysical Journal International*, 73(1):271–273. doi:10.1111/j.1467-842x.1983.tb01201.x.
- Codling, E. A. and Hill, N. A. (2005). Calculating spatial statistics for velocity jump processes with experimentally observed reorientation parameters. *Journal of Mathematical Biology*, 51(5):527–556. doi:10.1007/s00285-005-0317-7.
- Codling, E. A., Plank, M. J., and Benhamou, S. (2008). Random walk models in biology. *Journal of the Royal Society Interface*, 5(25):813–834. doi:10.1098/rsif.2008.0014.
- Cohen, T. S., Geiger, M., Köhler, J., and Welling, M. (2018). Spherical CNNs. In *Proceedings of the 6th International Conference on Learning Representations (ICLR 2018)*, pp. 1903–1910. OpenReview.net.
- Coles, S. (1998). Inference for circular distributions and processes. *Statistics and Computing*, 8(2):105–113. doi:10.1023/A:1008930032595.

- Coles, S. G. and Walshaw, D. (1994). Directional modeling of extreme wind speeds. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 43(1):139–157. doi:10.2307/2986118.
- Collett, D. (1980). Outliers in circular data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 29(1):50–57. doi:10.2307/2346410.
- Collett, D. and Lewis, T. (1981). Discriminating between the von Mises and wrapped normal distributions. *Australian Journal of Statistics*, 23(1):73–79. doi:10.1111/j.1467-842x.1981.tb00763.x.
- Comte, F. and Taupin, M. L. (2003). Adaptive density deconvolution for circular data. Technical Report MAP5 2003-10, Université Paris Descartes.
- Cordeiro, G. M. and Ferrari, S. (1991). A modified score test statistic having chi-squared distribution to order  $n^{-1}$ . *Biometrika*, 78(3):573–582. doi:10.1093/biomet/78.3.573.
- Cordeiro, G. M., Paula, G. A., and Botter, D. A. (1994). Improved likelihood ratio tests for dispersion models. *International Statistical Review*, 62(2):257–274. doi:10.2307/1403512.
- Cornea, E., Zhu, H., Kim, P., and Ibrahim, J. G. (2017). Regression models on Riemannian symmetric spaces. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 79(2):463–482. doi:10.1111/rssb.12169.
- Costa, M., Koivunen, V., and Poor, H. V. (2014). Estimating directional statistics using wavefield modeling and mixtures of von-Mises distributions. *IEEE Signal Processing Letters*, 21(12):1496–1500. doi:10.1109/lsp.2014.2341651.
- Couzin, I. D., Krause, J., Franks, N. R., and Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. *Nature*, 433(7025):513–516. doi:10.1038/nature03236.
- Cox, D. R. (1975). Discussion of “Statistics of directional data”. *Journal of the Royal Statistical Society, Series B (Methodological)*, 37(3):380–381. doi:10.1111/j.2517-6161.1975.tb01550.x.
- Cox, D. R. and Hinkley, D. V. (1979). *Theoretical Statistics*. Chapman & Hall, London. doi:10.1201/b14832.
- Cox, N. J. (1990). A note on Playfair John and the statistics of directional data. *Mathematical Geology*, 22(2):211–212. doi:10.1007/BF00891824.
- Cox, N. J. (2004). *CIRCSTAT: Stata Modules to Calculate Circular Statistics*. Durham University, Durham.
- Cox, T. F. and Cox, M. A. A. (1991). Multidimensional scaling on a sphere. *Communications in Statistics – Theory and Methods*, 20(9):2943–2953. doi:10.1080/03610929108830679.
- Craig, P. S. (1988). *Time Series Analysis for Directional Data*. PhD thesis, Trinity College Dublin.
- Creer, K. M. (1962). The dispersion of the geomagnetic field due to secular variation and its determination for remote times from paleomagnetic data. *Journal of Geophysical Research*, 67(9):3461–3476. doi:10.1029/jz067i009p03461.
- Creer, K. M., Irving, E., and Nairn, A. E. M. (1959). Palaeomagnetism of the Great Whin sill. *Geophysical Journal International*, 2(4):306–323. doi:10.1111/j.1365-246x.1959.tb05802.x.
- Cremers, J. (2020). *bpnreg: Bayesian Projected Normal Regression Models for Circular Data*. R package version 1.0.3. URL: <https://CRAN.R-project.org/package=bpnreg>.
- Cremers, J., Mainhard, T., and Klugkist, I. (2018a). Assessing a Bayesian embedding approach to circular regression models. *Methodology*, 14:69–81. doi:10.1027/1614-2241/a000147.
- Cremers, J., Mulder, K. T., and Klugkist, I. (2018b). Circular interpretation of regression coefficients. *British Journal of Mathematical and Statistical Psychology*, 71(1):75–95. doi:10.1111/bmsp.12108.
- Cremers, J., Pennings, H. J. M., and Ley, C. (2020). Regression models for cylindrical data in psychology. *Multivariate Behavioral Research*, to appear. doi:10.1080/00273171.2019.1693332.
- Cressie, N. (1977a). Clustering on the circle. *Bulletin of the International Statistical Institute*, 47(4):124–127.
- Cressie, N. (1977b). On some properties of the scan statistic on the circle and the line. *Journal of Applied Probability*, 14(2):272–283. doi:10.1017/s0021900200104954.
- Cruz-Orive, L. M., Hoppeler, H., Mathieu, O., and Weibel, E. R. (1985). Stereological analysis of anisotropic structures using directional statistics. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 34(1):14–32. doi:10.2307/2347881.
- Csörgő, S. and Faraway, J. J. (1996). The exact and asymptotic distributions of Cramér-von Mises statistics. *Journal of the Royal Statistical Society, Series B (Methodological)*, 58(1):221–234. doi:10.1111/j.2517-6161.1996.tb02077.x.
- Cuesta-Albertos, J. A., Cuevas, A., and Fraiman, R. (2009). On projection-based tests for directional and compositional data. *Statistics and Computing*, 19(4):367–380. doi:10.1007/s11222-008-9098-3.
- Cuevas, A., González-Manteiga, W., and Rodríguez-Casal, A. (2006). Plug-in estimation of general level sets. *Australian & New Zealand Journal of Statistics*, 48(1):7–19. doi:10.1111/j.1467-842X.2006.00421.x.
- Curry, J. R. (1956). The analysis of two-dimensional orientation data. *The Journal of Geology*, 64(2):117–131. doi:10.1086/626329.
- Curry, C., Marsland, S., and McLachlan, R. I. (2019). Principal symmetric space analysis. *Journal of Computational Dynamics*, 6(2):251–276. doi:10.3934/jcd.2019013.
- Cutland, N. and Ng, S.-A. (1993). The Wiener sphere and Wiener measure. *The Annals of Probability*, 21(1):1–13. doi:10.1214/aop/1176989390.
- Cutting, C., Paindaveine, D., and Verdebout, T. (2017a). Testing uniformity on high-dimensional spheres against monotone rotationally symmetric alternatives. *The Annals of Statistics*, 45(3):1024–1058. doi:10.1214/16-aos1473.

- Cutting, C., Paindaveine, D., and Verdebout, T. (2017b). Tests of concentration for low-dimensional and high-dimensional directional data. In Ahmed, S. E. (Ed.), *Big and Complex Data Analysis*, Contributions to Statistics. Springer, New York. doi:10.1007/978-3-319-41573-4\_11.
- Cutting, C., Paindaveine, D., and Verdebout, T. (2020). On the power of axial tests of uniformity on spheres. *Electronic Journal of Statistics*, 14(1):2123–2154. doi:10.1214/20-EJS1716.
- D’Agostino, R. B. and Stephens, M. A. (Eds.) (1986). *Goodness-of-Fit Techniques*, volume 68 of *Statistics: Textbooks and Monographs*. Marcel Dekker, New York.
- Dagpunar, J. (1990). Sampling from the von Mises distribution via a comparison of random numbers. *Statistics*, 17(1):165–168. doi:10.1080/757582656.
- Dai, F. and Xu, Y. (2013). *Approximation Theory and Harmonic Analysis on Spheres and Balls*. Springer Monographs in Mathematics. Springer, New York. doi:10.1007/978-1-4614-6660-4.
- Dai, X. and Müller, H.-G. (2018). Principal component analysis for functional data on Riemannian manifolds and spheres. *The Annals of Statistics*, 46(6B):3334–3361. doi:10.1214/17-aos1660.
- Damien, P. and Walker, S. (1999). A full Bayesian analysis of circular data using the von Mises distribution. *The Canadian Journal of Statistics*, 27(2):291–298. doi:10.2307/3315639.
- Damon, J. and Marron, J. S. (2014). Backwards principal component analysis and principal nested relations. *Journal of Mathematical Imaging and Vision*, 50(1):107–114. doi:10.1007/s10851-013-0463-2.
- Daniels, H. E. (1954). A distribution-free test for regression parameters. *Annals of Mathematical Statistics*, 25(3):499–513. doi:10.1214/aoms/1177728718.
- Darling, D. A. (1953). On a class of problems related to the random division of an interval. *Annals of Mathematical Statistics*, 24(2):239–253. doi:10.1214/aoms/1177729030.
- Darling, D. A. (1983). On the asymptotic distribution of Watson’s statistic. *The Annals of Statistics*, 11(4):1263–1266. doi:10.1214/aos/1176346340.
- Darling, J. E. (2016). *Bayesian Inference for Dynamic Pose Estimation Using Directional Statistics*. PhD thesis, Missouri University of Science and Technology.
- Daubechies, I., Lu, J., and Wu, H.-T. (2011). Synchrosqueezed wavelet transforms: an empirical mode decomposition-like tool. *Applied and Computational Harmonic Analysis*, 30(2):243–261. doi:10.1016/j.acha.2010.08.002.
- Daubenspeck, J. A. and Ogden, R. D. (1978). Estimation of response slopes in respiratory control using directional statistics. *Journal of Applied Physiology*, 45(5):823–829. doi:10.1152/jappl.1978.45.5.823.
- David, F. N. and Barton, D. E. (1962). *Combinatorial Chance*. Griffin, London.
- David, F. N., Kendall, M. G., and Barton, D. E. (1966). *Symmetric Functions and Allied Tables*. Cambridge University Press, Cambridge.
- David, H. A. (1970). *Order Statistics*. Wiley, New York. doi:10.1002/0471722162.
- David, H. A. and Newell, D. J. (1965). The identification of annual peak periods for a disease. *Biometrics*, 21(3):645–650. doi:10.2307/2528547.
- Degerine, S. (1977). Tests on the dispersion parameter in von Mises distributions. In Barra, J.-R., Brodeau, F., Romier, G., and Van Cutsem, B. (Eds.), *Recent Developments in Statistics*, pp. 403–408, Amsterdam. North-Holland.
- Degerine, S. (1978). Sur la complétion des structures de von Mises. *Comptes Rendus de l’Académie des Sciences, Série A*, 287:29–31.
- Degerine, S. (1979a). Lois de von Mises et lois liées. *Annales de l’Institut Henri Poincaré. Nouvelle Série. Section B. Calcul des Probabilités et Statistique*, 15(1):63–77.
- Degerine, S. (1979b). Tests optimaux sur les paramètres des lois de von Mises. *Annales de l’Institut Henri Poincaré. Nouvelle Série. Section B. Calcul des Probabilités et Statistique*, 15(4):375–392.
- Delechelle, E., Peron, M.-C., and Guyot, S. (2007). Circular statistics of fractional fields. *IEEE Signal Processing Letters*, 14(4):275–278. doi:10.1109/lsp.2006.885288.
- D’Elia, A. (2001). A statistical model for orientation mechanism. *Statistical Methods and Applications*, 10(1-3):157–174. doi:10.1007/BF02511646.
- Demni, H., Messaoud, A., and Porzio, G. C. (2019). The cosine depth distribution classifier for directional data. In Bauer, N., Ickstadt, K., Lübke, K., Szepannek, G., Trautmann, H., and Vichi, M. (Eds.), *Applications in Statistical Computing*, Studies in Classification, Data Analysis, and Knowledge Organization, pp. 49–60. Springer, Cham. doi:10.1007/978-3-030-25147-5\_4.
- Deschepper, E., Thas, O., and Otttoy, J.-P. (2008). Tests and diagnostic plots for detecting lack-of-fit for circular-linear regression models. *Biometrics*, 64(3):912–920. doi:10.1111/j.1541-0420.2007.00950.x.
- Dette, H., Konstantinou, M., Schorning, K., and Gösmann, J. (2019). Optimal designs for regression with spherical data. *Electronic Journal of Statistics*, 13(1):361–390. doi:10.1214/18-ejs1524.
- Dette, H. and Melas, V. B. (2003). Optimal designs for estimating individual coefficients in Fourier regression models. *The Annals of Statistics*, 31(5):1669–1692. doi:10.1214/aos/1065705122.
- Dette, H., Melas, V. B., and Pepelyshev, A. (2005). Optimal designs for three-dimensional shape analysis with spherical harmonic descriptors. *The Annals of Statistics*, 33(6):2758–2788. doi:10.1214/009053605000000552.

- Detle, H. and Wiens, D. P. (2009). Robust designs for 3D shape analysis with spherical harmonic descriptors. *Statistica Sinica*, 19(1):83–102.
- Dhillon, I. and Sra, S. (2003). Modeling data using directional distributions. Technical Report TR-03-06, Department of Computer Sciences, University of Texas at Austin.
- Dhillon, I. S., Marcotte, E. M., and Roshan, U. (2003). Diametrical clustering for identifying anti-correlated gene clusters. *Bioinformatics*, 19(13):1612–1619. doi:10.1093/bioinformatics/btg209.
- Dhillon, I. S. and Modha, D. S. (2001). Concept decompositions for large sparse text data using clustering. *Machine Learning*, 42(1):143–175. doi:10.1023/A:1007612920971.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2014a). Local likelihood estimation for multivariate directional data. In *Proceedings of COMPSTAT 2014*, pp. 553–560, The Hague. International Statistical Institute.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2016a). A note on nonparametric estimation of circular conditional densities. *Journal of Statistical Computation and Simulation*, 86(13):2573–2582. doi:10.1080/00949655.2016.1146279.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2016b). Practical performance of local likelihood for circular density estimation. *Journal of Statistical Computation and Simulation*, 86(13):2560–2572. doi:10.1080/00949655.2016.1149588.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2017). Nonparametric estimating equations for circular probability density functions and their derivatives. *Electronic Journal of Statistics*, 11(2):4323–4346. doi:10.1214/17-EJS1318.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2018a). Circular local likelihood. *TEST*, 27(4):921–945. doi:10.1007/s11749-017-0576-9.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2018b). Nonparametric classification for circular data. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 241–257. CRC Press, Boca Raton.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2019a). Kernel density classification for spherical data. *Statistics & Probability Letters*, 144:23–29. doi:10.1016/j.spl.2018.07.018.
- Di Marzio, M., Fensore, S., Panzera, A., and Taylor, C. C. (2019b). Local binary regression with spherical predictors. *Statistics & Probability Letters*, 144:30–36. doi:10.1016/j.spl.2018.07.019.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2009). Local polynomial regression for circular predictors. *Statistics & Probability Letters*, 79(19):2066–2075. doi:10.1016/j.spl.2009.06.014.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2011). Kernel density estimation on the torus. *Journal of Statistical Planning and Inference*, 141(6):2156–2173. doi:10.1016/j.jspi.2011.01.002.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2012a). Non-parametric smoothing and prediction for nonlinear circular time series. *Journal of Time Series Analysis*, 33(4):620–630. doi:10.1111/j.1467-9892.2012.00794.x.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2012b). Smooth estimation of circular cumulative distribution functions and quantiles. *Journal of Nonparametric Statistics*, 24(4):935–949. doi:10.1080/10485252.2012.721517.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2013). Non-parametric regression for circular responses. *Scandinavian Journal of Statistics*, 40(2):238–255. doi:10.1111/j.1467-9469.2012.00809.x.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2014b). Nonparametric regression for spherical data. *Journal of the American Statistical Association*, 109(506):748–763. doi:10.1080/01621459.2013.866567.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2016c). Nonparametric circular quantile regression. *Journal of Statistical Planning and Inference*, 170:1–14. doi:10.1016/j.jspi.2015.08.004.
- Di Marzio, M., Panzera, A., and Taylor, C. C. (2019c). Nonparametric rotations for sphere-sphere regression. *Journal of the American Statistical Association*, 114(525):466–476. doi:10.1080/01621459.2017.1421542.
- Diaconis, P. (1988). *Group Representations in Probability and Statistics*, volume 11 of *Lecture Notes–Monograph Series*. Institute of Mathematical Statistics, Hayward.
- Diggle, P. J. and Fisher, N. I. (1985). SPHERE: a contouring program for spherical data. *Computers & Geosciences*, 11(6):725–766. doi:10.1016/0098-3004(85)90015-9.
- Diggle, P. J. and Fisher, N. I. (1989). Reply to comments on “SPHERE: a contouring program for spherical data”. *Computers & Geosciences*, 15(6):1031–1032. doi:10.1016/0098-3004(89)90018-6.
- Diggle, P. J., Fisher, N. I., and Lee, A. J. (1985). A comparison of tests of uniformity for spherical data. *Australian Journal of Statistics*, 27(1):53–59. doi:10.1111/j.1467-842x.1985.tb00547.x.
- Dimroth, E. (1962). Untersuchungen zum Mechanismus von Blastesis und syntexis in Phylliten und Hornfelsen des süd-westlichen Fichtelgebirges I. Die statistische Auswertung einfacher Gürteldiagramme. *Tschermaks Mineralogische und Petrographische Mitteilungen*, 8(2):248–274. doi:10.1007/bf01131328.
- Dimroth, E. (1963). Fortschritte der Gefügestatistik. *Neues Jahrbuch für Mineralogie*, 13:186–192.
- DLMF (2020). *NIST Digital Library of Mathematical Functions*. <http://dlmf.nist.gov/>, Release 1.0.27 of 2020-06-15. F. W. J. Olver, A. B. Olde Daalhuis, D. W. Lozier, B. I. Schneider, R. F. Boisvert, C. W. Clark, B. R. Miller and B. V. Saunders, eds. URL: <http://dlmf.nist.gov/>.
- Dobson, A. J. (1978). Simple approximations to the von Mises concentration statistic. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 27(3):345–346. doi:10.2307/2347172.
- Dokmanic, I. and Petrinovic, D. (2010). Convolution on the  $n$ -sphere with application to pdf modeling. *IEEE Transactions*

- on *Signal Processing*, 58(3):1157–1170. doi:10.1109/TSP.2009.2033329.
- Donnelly, A., Misstear, B., and Broderick, B. (2011). Application of nonparametric regression methods to study the relationship between NO<sub>2</sub> concentrations and local wind direction and speed at background sites. *Science of the Total Environment*, 409(6):1134–1144. doi:10.1016/j.scitotenv.2010.12.001.
- Dortet-Bernadet, J.-L. and Wicker, N. (2008). Model-based clustering on the unit sphere with an illustration using gene expression profiles. *Biostatistics*, 9(1):66–80. doi:10.1093/biostatistics/kxm012.
- Dovretzky, A. and Wolfowitz, J. (1951). Sums of random integers reduced modulo  $m$ . *Duke Mathematical Journal*, 18(2):501–507. doi:10.1215/s0012-7094-51-01840-6.
- Downs, T. D. (1966). Some relationships among the von Mises distributions of different dimensions. *Biometrika*, 53(1/2):269–272. doi:10.2307/2334080.
- Downs, T. D. (1972). Orientation statistics. *Biometrika*, 59(3):665–676. doi:10.1093/biomet/59.3.665.
- Downs, T. D. (1974). Rotational angular correlation. In Ferin, M., Halberg, F., and van der Wiele, L. (Eds.), *Biorhythms and Human Reproduction*, pp. 97–104. Wiley, New York.
- Downs, T. D. (2003). Spherical regression. *Biometrika*, 90(3):655–668. doi:10.1093/biomet/90.3.655.
- Downs, T. D. and Gould, A. L. (1967). Some relationships between the normal and von Mises distributions. *Biometrika*, 54(3-4):684–687. doi:10.2307/2335068.
- Downs, T. D. and Liebman, J. (1969). Statistical methods for vectorcardiographic directions. *IEEE Transactions on Biomedical Engineering*, BME-16(1):87–94. doi:10.1109/TBME.1969.4502609.
- Downs, T. D. and Mardia, K. V. (2002). Circular regression. *Biometrika*, 89(3):683–697. doi:10.1093/biomet/89.3.683.
- Dryden, I. L. (2005). Statistical analysis on high-dimensional spheres and shape spaces. *The Annals of Statistics*, 33(4):1643–1665. doi:10.1214/009053605000000264.
- Dryden, I. L. (2019). *shapes: Statistical Shape Analysis*. R package version 1.2.5. URL: <https://CRAN.R-project.org/package=shapes>.
- Dryden, I. L. and Kent, J. T. (Eds.) (2015). *Geometry Driven Statistics*. Wiley Series in Probability and Statistics. Wiley, Chichester. doi:10.1002/9781118866641.
- Dryden, I. L. and Mardia, K. V. (1991). Theoretical and distributional aspects of shape analysis. In *Probability Measures on Groups X*, pp. 95–116, Boston. Springer. doi:10.1007/978-1-4899-2364-6\_7.
- Dryden, I. L. and Mardia, K. V. (1998). *Statistical Shape Analysis*. Wiley Series in Probability and Statistics. Wiley, Chichester.
- Dryden, I. L. and Mardia, K. V. (2016). *Statistical Shape Analysis with Applications in R*. Wiley Series in Probability and Statistics. Wiley, Chichester, second edition. doi:10.1002/9781119072492.
- Ducharme, G. R., Jhun, M., Romano, J., and Truong, K. N. (1985). Bootstrap confidence cones for directional data. *Biometrika*, 72(3):637–645. doi:10.1093/biomet/72.3.637.
- Ducharme, G. R. and Milasevic, P. (1987a). Some asymptotic properties of the circular median. *Communications in Statistics – Theory and Methods*, 16(3):659–664. doi:10.1080/03610928708829394.
- Ducharme, G. R. and Milasevic, P. (1987b). Spatial median and directional data. *Biometrika*, 74(1):212–215. doi:10.1093/biomet/74.1.212.
- Ducharme, G. R. and Milasevic, P. (1990). Estimating the concentration of the Langevin distribution. *The Canadian Journal of Statistics*, 18(2):163–169. doi:10.2307/3315565.
- Ducharme, G. R., Vincent, C., and Aliaume, C. (2012). A statistical test to detect vortices in the current fields of bodies of water. *Environmental and Ecological Statistics*, 19(3):345–367. doi:10.1007/s10651-012-0190-7.
- Dudley, R. M., Perkins, P. C., and Giné, M. E. (1975). Statistical tests for preferred orientation. *The Journal of Geology*, 83(6):685–705. doi:10.1086/628162.
- Duerinckx, M. and Ley, C. (2012). Maximum likelihood characterization of rotationally symmetric distributions on the sphere. *Sankhyā, Series A*, 74(2):249–262. doi:10.1007/s13171-012-0004-x.
- Dufour, J. M. and Roy, R. (1976). On spectral estimation for a homogeneous random process on the circle. *Stochastic Processes and their Applications*, 4(2):107–120. doi:10.1016/0304-4149(76)90029-6.
- Durand, D. and Greenwood, J. A. (1957). Random unit vectors II: usefulness of Gram-Charlier and related series in approximating distributions. *Annals of Mathematical Statistics*, 28(4):978–985. doi:10.1214/aoms/1177706798.
- Durand, D. and Greenwood, J. A. (1958). Modifications of the Rayleigh test for uniformity in analysis of two-dimensional orientation data. *The Journal of Geology*, 66(3):229–238. doi:10.1086/626501.
- Dyck, H. D. and Mattice, W. A. (1941). A study of excessive rainfalls. *Monthly Weather Review*, 69(10):293–302. doi:10.1175/1520-0493(1941)069<0293:asoer>2.0.co;2.
- Eben, K. (1983). Classification into two von Mises distributions with unknown mean directions. *Aplikace Matematiky*, 28(3):230–237.
- Ebner, B., Henze, N., and Yukich, J. E. (2018). Multivariate goodness-of-fit on flat and curved spaces via nearest neighbor distances. *Journal of Multivariate Analysis*, 165:231–242. doi:10.1016/j.jmva.2017.12.009.
- Eckert, S. A., Moore, J. E., Dunn, D. C., van Buiten, R. S., Eckert, K. L., and Halpin, P. N. (2008). Modeling loggerhead turtle movement in the mediterranean: importance of body size and oceanography. *Ecological Applications*, 18(2):290–308.

- doi:10.1890/06-2107.1.
- Eckrote, M. D. and Bingham, M. A. (2017). A permutation test for the spread of three-dimensional rotation data. *Journal of Nonparametric Statistics*, 29(3):553–560. doi:10.1080/10485252.2017.1339304.
- Edwards, J. H. (1961). The recognition and estimation of cyclic trends. *Annals of Human Genetics*, 25(1):83–87. doi:10.1111/j.1469-1809.1961.tb01501.x.
- Efromovich, S. (1997). Density estimation for the case of supersmooth measurement error. *Journal of the American Statistical Association*, 92(438):526–535. doi:10.2307/2965701.
- Efron, B. (1979). Bootstrap methods: another look at the jackknife. *The Annals of Statistics*, 7(1):1–26. doi:10.1214/aos/1176344552.
- Ehler, M. (2012). Random tight frames. *The Journal of Fourier Analysis and Applications*, 18(1):1–20. doi:10.1007/s00041-011-9182-5.
- Ehler, M. and Galanis, J. (2011). Frame theory in directional statistics. *Statistics & Probability Letters*, 81(8):1046–1051. doi:10.1016/j.spl.2011.02.027.
- Eisen, M. B., Spellman, P. T., Brown, P. O., and Botstein, D. (1998). Cluster analysis and display of genome-wide expression patterns. *Proceedings of the National Academy of Sciences of the United States of America*, 95(25):14863–14868. doi:10.1073/pnas.95.25.14863.
- El Khattabi, S. and Streit, F. (1996). Identification analysis in directional statistics. *Computational Statistics & Data Analysis*, 23(1):45–63. doi:10.1016/s0167-9473(96)00020-5.
- Elad, A., Keller, Y., and Kimmel, R. (2005). Texture mapping via spherical multi-dimensional scaling. In Kimmel, R., Sochen, N. A., and Weickert, J. (Eds.), *Scale Space and PDE Methods in Computer Vision*, volume 3459 of *Lecture Notes in Computer Science*, pp. 443–455, Berlin. Springer. doi:10.1007/11408031\_38.
- Ellis, S. P. (1991). Topological aspects of the location problem for directional and axial data. *International Statistical Review*, 59(3):389–394. doi:10.2307/1403694.
- Elmore, R. T., Hettmansperger, T. P., and Xuan, F. (2006). Spherical data depth and a multivariate median. In Liu, R. Y., Serfling, R., and Souvaine, D. L. (Eds.), *Data depth: Robust Multivariate Analysis, Computational Geometry and Applications*, volume 72 of *DIMACS Series in Discrete Mathematics and Theoretical Computer Science*, pp. 87–101. American Mathematical Society, Providence.
- Eltzner, B. and Huckemann, S. (2017). Applying backward nested subspace inference to tori and polyspheres. In Nielsen, F. and Barbaresco, F. (Eds.), *Geometric Science of Information*, volume 10589 of *Lecture Notes in Computer Science*, pp. 587–594, Cham. Springer. doi:10.1007/978-3-319-68445-1\_68.
- Eltzner, B., Huckemann, S., and Mardia, K. V. (2018). Torus principal component analysis with applications to RNA structure. *The Annals of Applied Statistics*, 12(2):1332–1359. doi:10.1214/17-A0AS1115.
- Eltzner, B. and Huckemann, S. F. (2019). A smeary central limit theorem for manifolds with application to high-dimensional spheres. *The Annals of Statistics*, 47(6):3360–3381. doi:10.1214/18-AOS1781.
- Eltzner, B., Jung, S., and Huckemann, S. (2015). Dimension reduction on polyspheres with application to skeletal representations. In Nielsen, F. and Barbaresco, F. (Eds.), *Geometric Science of Information*, volume 9389 of *Lecture Notes in Computer Science*, pp. 22–29, Cham. Springer. doi:10.1007/978-3-319-25040-3\_3.
- Émery, M. (1989). *Stochastic Calculus in Manifolds*. Universitext. Springer, Berlin. doi:10.1007/978-3-642-75051-9.
- Endo, H. (1995). Correspondence analysis of an artificial binary cylinder data. *Statistics & Probability Letters*, 25(3):231–240. doi:10.1016/0167-7152(94)00226-X.
- Engel, C. and Ebert, E. (2007). Performance of hourly operational consensus forecasts (OCFs) in the Australian region. *Weather and Forecasting*, 22(6):1345–1359. doi:10.1175/2007waf2006104.1.
- Eplett, W. J. R. (1979). The small sample distribution of a Mann-Whitney type statistic for circular data. *The Annals of Statistics*, 7(2):446–453. doi:10.1214/aos/1176344626.
- Eplett, W. J. R. (1982). Two Mann-Whitney type rank tests. *Journal of the Royal Statistical Society, Series B (Methodological)*, 44(2):270–286. doi:10.1111/j.2517-6161.1982.tb01208.x.
- Epp, R. J., Tukey, J. W., and Watson, G. S. (1971). Testing unit vectors for correlation. *Journal of Geophysical Research*, 76(35):8480–8483. doi:10.1029/jb076i035p08480.
- Erdem, E. and Shi, J. (2011). Comparison of bivariate distribution construction approaches for analysing wind speed and direction data. *Wind Energy*, 14(1):27–41. doi:10.1002/we.400.
- Esteves, C., Allen-Blanchette, C., Makadia, A., and Daniilidis, K. (2020). Learning SO(3) equivariant representations with spherical CNNs. *International Journal of Computer Vision*, 128:588–600. doi:10.1007/s11263-019-01220-1.
- Eğecioglu, O. and Srinivasan, A. (2000). Efficient nonparametric density estimation on the sphere with applications in fluid mechanics. *SIAM Journal on Scientific Computing*, 22(1):152–176. doi:10.1137/S1064827595290462.
- Faber, W. R., Hussein, I. I., Kent, J. T., Bhattacharjee, S., and Jah, M. (2018). Optical data processing using directional statistics in a multiple hypothesis framework with maneuvering objects. In *2018 Space Flight Mechanics Meeting*, Reston. American Institute of Aeronautics and Astronautics. doi:10.2514/6.2018-1971.
- Faber, W. R., Hussein, I. I., Kent, J. T., Bhattacharjee, S., and Jah, M. K. (2017). FBK optical data association in a multi-hypothesis framework with maneuvers. In Ryan, S. (Ed.), *Proceedings of the Advanced Maui Optical and Space Surveillance*



- (AMOS) Technologies Conference, Maui. The Maui Economic Development Board.
- Fallaize, C. J. and Kypraios, T. (2016). Exact Bayesian inference for the Bingham distribution. *Statistics and Computing*, 26(1-2):349–360. doi:10.1007/s11222-014-9508-7.
- Farebrother, R. W. (1995). Simple methods for fitting circles or points to spherical data. In Tiit, E. M., Kollo, T., and Niemi, H. (Eds.), *Multivariate Statistics and Matrices in Statistics*, volume 3 of *New Trends in Probability and Statistics*, pp. 135–139, Utrecht. VSP.
- Fay, G., Delabrouille, J., Kerkycharian, G., and Picard, D. (2013). Testing the isotropy of high energy cosmic rays using spherical needlets. *The Annals of Applied Statistics*, 7(2):1040–1073. doi:10.1214/12-aos619.
- Fejér, L. (1916). Über trigonometrische Polynome. *Journal für die reine und angewandte Mathematik*, 146:53–82. doi:10.1515/crll.1916.146.53.
- Felcísimo, A., Ruíz Cuetos, J. C., Polo García, M. E., Cuartero, A., and García Rodríguez, J. C. (2014). *VecStatGraphs3D: Vector Analysis Using Graphical and Analytical Methods in 3D*. R package version 1.6. URL: <https://CRAN.R-project.org/package=VecStatGraphs3D>.
- Feller, W. A. (1966). *An Introduction to Probability Theory and its Applications*. Wiley, New York.
- Feltz, C. J. and Goldin, G. A. (1992). Generalization of the Kolmogorov-Smirnov goodness-of-fit test, using group invariance. *Journal of Nonparametric Statistics*, 1(4):357–370. doi:10.1080/10485259208832535.
- Feltz, C. J. and Goldin, G. A. (2001). Partition-based goodness-of-fit tests on the line and the circle. *Australian & New Zealand Journal of Statistics*, 43(2):207–220. doi:10.1111/1467-842X.00166.
- Fernandes, K. and Cardoso, J. S. (2016). Discriminative directional classifiers. *Neurocomputing*, 207:141–149. doi:10.1016/j.neucom.2016.03.076.
- Fernández, M. A., Rueda, C., and Peddada, S. D. (2012). Identification of a core set of signature cell cycle genes whose relative order of time to peak expression is conserved across species. *Nucleic Acids Research*, 40(7):2823–2832. doi:10.1093/nar/gkr1077.
- Fernández-Durán, J. J. (2004). Circular distributions based on nonnegative trigonometric sums. *Biometrics*, 60(2):499–503. doi:10.1111/j.0006-341x.2004.00195.x.
- Fernández-Durán, J. J. (2007). Models for circular-linear and circular-circular data constructed from circular distributions based on nonnegative trigonometric sums. *Biometrics*, 63(2):579–585. doi:10.1111/j.1541-0420.2006.00716.x.
- Fernández-Durán, J. J. and Gregorio-Domínguez, M. M. (2010). Maximum likelihood estimation of nonnegative trigonometric sum models using a Newton-like algorithm on manifolds. *Electronic Journal of Statistics*, 4:1402–1410. doi:10.1214/10-EJS587.
- Fernández-Durán, J. J. and Gregorio-Domínguez, M. M. (2014a). Distributions for spherical data based on nonnegative trigonometric sums. *Statistical Papers*, 55(4):983–1000. doi:10.1007/s00362-013-0547-5.
- Fernández-Durán, J. J. and Gregorio-Domínguez, M. M. (2014b). Modeling angles in proteins and circular genomes using multivariate angular distributions based on multiple nonnegative trigonometric sums. *Statistical Applications in Genetics and Molecular Biology*, 13(1):1–18. doi:10.1515/sagmb-2012-0012.
- Fernández-Durán, J. J. and Gregorio-Domínguez, M. M. (2016). CircNNTSR: an R package for the statistical analysis of circular, multivariate circular, and spherical data using nonnegative trigonometric sums. *Journal of Statistical Software*, 70(6):1–19. doi:10.18637/jss.v070.i06.
- Fernández-González, P., Benavides-Piccione, R., Leguey, I., Bielza, C., Larrañaga, P., and De Felipe, J. (2017a). Dendritic branching angles of pyramidal neurons of the human cerebral cortex. *Brain Structure and Function*, 222(4):1847–1859.
- Fernández-González, P., Bielza, C., and Larrañaga, P. (2017b). Univariate and bivariate truncated von Mises distributions. *Progress in Artificial Intelligence*, 6(2):171–180. doi:10.1007/s13748-016-0109-x.
- Ferrari, C. (2009). *The Wrapping Approach for Circular Data Bayesian Modeling*. PhD thesis, Univeristy of Bologna.
- Ferreira, J. T. A. S., Juárez, M. A., and Steel, M. F. J. (2008). Directional log-spline distributions. *Bayesian Analysis*, 3(2):297–316. doi:10.1214/08-ba311.
- Figueiredo, A. (2007). Comparison of tests of uniformity defined on the hypersphere. *Statistics & Probability Letters*, 77(3):329–334. doi:10.1016/j.spl.2006.07.012.
- Figueiredo, A. (2009). Discriminant analysis for the von Mises-Fisher distribution. *Communications in Statistics – Simulation and Computation*, 38(9):1991–2003. doi:10.1080/03610910903200281.
- Figueiredo, A. (2017). Bootstrap and permutation tests in ANOVA for directional data. *Computational Statistics*, 32(4):1213–1240. doi:10.1007/s00180-017-0739-x.
- Figueiredo, A. and Gomes, P. (2003). Power of tests of uniformity defined on the hypersphere. *Communications in Statistics – Simulation and Computation*, 32(1):87–94. doi:10.1081/sac-120013113.
- Figueiredo, A. and Gomes, P. (2005). Discordancy test for the bipolar Watson distribution defined on the hypersphere. *Communications in Statistics – Simulation and Computation*, 34(1):145–153. doi:10.1081/sac-200047092.
- Figueiredo, A. and Gomes, P. (2006). Discriminant analysis based on the Watson distribution defined on the hypersphere. *Statistics*, 40(5):435–445. doi:10.1080/02331880600766662.
- Findlater, J., Harrower, T. N. S., Howkins, G. A., and Wright, H. L. (1966). Surface and 900 mb wind relationships. Technical Report 23, Meteorological Office, London.

- Firle, S., Bommarco, R., Ekblom, B., and Natiello, M. (1998). The influence of movement and resting behavior on the range of three carabid beetles. *Ecology*, 79(6):2113–2122. doi:10.1890/0012-9658(1998)079[2113:tiomar]2.0.co;2.
- Fisher, N. I. (1982a). Goodness-of-fit and outlier detection procedures for samples from Fisher’s distribution on the sphere. *Contemporary Mathematics*, 9:377–380. doi:10.1090/conm/009/655998.
- Fisher, N. I. (1982b). Robust estimation of the concentration parameter of Fisher’s distribution on the sphere. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 31(2):152–154. doi:10.2307/2347979.
- Fisher, N. I. (1985). Spherical medians. *Journal of the Royal Statistical Society, Series B (Methodological)*, 47(2):342–348. doi:10.1111/j.2517-6161.1985.tb01362.x.
- Fisher, N. I. (1986a). Correction to: “Robust comparison of dispersions for samples of directional data”. *The Australian Journal of Statistics*, 28(3):424. doi:10.1111/j.1467-842X.1986.tb00715.x.
- Fisher, N. I. (1986b). Robust comparison of dispersion for samples of directional data. *Australian Journal of Statistics*, 28(2):213–219. doi:10.1111/j.1467-842X.1986.tb00601.x.
- Fisher, N. I. (1986c). Robust tests for comparing the dispersions of several Fisher or Watson distributions on the sphere. *Geophysical Journal International*, 85(3):563–572. doi:10.1111/j.1365-246X.1986.tb04532.x.
- Fisher, N. I. (1987). Problems with the current definitions of the standard deviation of wind direction. *Journal of Climate and Applied Meteorology*, 26(11):1522–1529. doi:10.1175/1520-0450(1987)026<1522:pwtcdo>2.0.co;2.
- Fisher, N. I. (1989). Smoothing a sample of circular data. *Journal of Structural Geology*, 11(6):775–778. doi:10.1016/0191-8141(89)90012-6.
- Fisher, N. I. (1993). *Statistical Analysis of Circular Data*. Cambridge University Press, Cambridge. doi:10.1017/cbo9780511564345.
- Fisher, N. I. and Best, D. (1984). Goodness-of-fit tests for Fisher’s distribution on the sphere. *Australian Journal of Statistics*, 26(2):142–150. doi:10.1111/j.1467-842X.1984.tb01228.x.
- Fisher, N. I. and Hall, P. (1989). Bootstrap confidence regions for directional data. *Journal of the American Statistical Association*, 84(408):996–1002. doi:10.1080/01621459.1989.10478864.
- Fisher, N. I. and Hall, P. (1990a). Correction: “Bootstrap confidence regions for directional data”. *Journal of the American Statistical Association*, 85(410):608. doi:10.2307/2289832.
- Fisher, N. I. and Hall, P. (1990b). New statistical methods for directional data I: bootstrap comparison of mean directions and the fold test in palaeomagnetism. *Geophysical Journal International*, 101(2):305–313. doi:10.1111/j.1365-246X.1990.tb06570.x.
- Fisher, N. I. and Hall, P. (1991a). Bootstrap algorithms for small samples. *Journal of Statistical Planning and Inference*, 27(2):157–169. doi:10.1016/0378-3758(91)90013-5.
- Fisher, N. I. and Hall, P. (1991b). A general statistical test for the effect of folding. *Geophysical Journal International*, 105(2):419–427. doi:10.1111/j.1365-246X.1991.tb06723.x.
- Fisher, N. I. and Hall, P. (1992). Bootstrap methods for directional data. In Mardia, K. V. (Ed.), *The Art of Statistical Science*, Wiley Series in Probability and Mathematical Statistics, pp. 47–63. Wiley, Chichester.
- Fisher, N. I., Hall, P., Jing, B.-Y., and Wood, A. T. A. (1996). Improved pivotal methods for constructing confidence regions with directional data. *Journal of the American Statistical Association*, 91(435):1062–1070. doi:10.1080/01621459.1996.10476976.
- Fisher, N. I., Huntington, J. F., Jackett, D. R., Willcox, M. E., and Creasey, J. W. (1985). Spatial analysis of two-dimensional orientation data. *Journal of the International Association for Mathematical Geology*, 17(2):177–194. doi:10.1007/bf01033153.
- Fisher, N. I. and Lee, A. J. (1981). Nonparametric measures of angular-linear association. *Biometrika*, 68(3):629–636. doi:10.1093/biomet/68.3.629.
- Fisher, N. I. and Lee, A. J. (1982). Non-parametric measures of angular-angular association. *Biometrika*, 69(2):315–321. doi:10.2307/2335405.
- Fisher, N. I. and Lee, A. J. (1983). A correlation coefficient for circular data. *Biometrika*, 70(2):327–332. doi:10.1093/biomet/70.2.327.
- Fisher, N. I. and Lee, A. J. (1986). Correlation coefficients for random variables on a unit sphere or hypersphere. *Biometrika*, 73(1):159–164. doi:10.1093/biomet/73.1.159.
- Fisher, N. I. and Lee, A. J. (1992). Regression models for an angular response. *Biometrics*, 48(3):665–677. doi:10.2307/2532334.
- Fisher, N. I. and Lee, A. J. (1994). Time series analysis of circular data. *Journal of the Royal Statistical Society, Series B (Methodological)*, 56(2):327–339. doi:10.1111/j.2517-6161.1994.tb01981.x.
- Fisher, N. I. and Lewis, T. (1983). Estimating the common mean direction of several circular or spherical distributions with differing dispersions. *Biometrika*, 70(2):333–341. doi:10.1093/biomet/71.3.655.
- Fisher, N. I. and Lewis, T. (1985). A note on spherical splines. *Journal of the Royal Statistical Society, Series B (Methodological)*, 47(3):482–488. doi:10.1111/j.2517-6161.1985.tb01378.x.
- Fisher, N. I., Lewis, T., and Embleton, B. J. (1987). *Statistical Analysis of Spherical Data*. Cambridge University Press, Cambridge. doi:10.1017/cbo9780511623059.

- Fisher, N. I., Lewis, T., and Willcox, M. E. (1981). Tests of discordancy for samples from Fisher’s distribution on the sphere. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 30(3):230–237. doi:10.2307/2346346.
- Fisher, N. I., Lunn, A. D., and Davies, S. J. (1993). Spherical median axes. *Journal of the Royal Statistical Society, Series B (Methodological)*, 55(1):117–124. doi:10.1111/j.2517-6161.1993.tb01471.x.
- Fisher, N. I. and Marron, J. S. (2001). Mode testing via the excess mass estimate. *Biometrika*, 88(2):499–517. doi:10.1093/biomet/88.2.499.
- Fisher, N. I. and Powell, C. M. (1989). Statistical analysis of two-dimensional palaeocurrent data: methods and examples. *Australian Journal of Earth Sciences*, 36(1):91–107. doi:10.1080/14400958908527953.
- Fisher, N. I. and Willcox, M. E. (1978). A useful decomposition of the resultant length for samples from the von Mises-Fisher distributions. *Communications in Statistics – Simulation and Computation*, 7(3):257–267. doi:10.1080/03610917808812075.
- Fisher, R. A. (1929). Tests of significance in harmonic analysis. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, 125(796):54–59. doi:10.1098/rspa.1929.0151.
- Fisher, R. A. (1953). Dispersion on a sphere. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 217(1130):295–305. doi:10.1098/rspa.1953.0064.
- Fisher, R. A. (1959). *Statistical Methods and Scientific Inference*. Oliver and Boyd, Edinburgh, second edition.
- Fitak, R. R., Caves, E. M., and Johnsen, S. (2018). Orientation in pill bugs: an interdisciplinary activity to engage students in concepts of biology, physics and circular statistics. *The American Biology Teacher*, 80(8):608–618. doi:10.1525/abt.2018.80.8.608.
- Fitak, R. R. and Johnsen, S. (2017). Bringing the analysis of animal orientation data full circle: model-based approaches with maximum likelihood. *Journal of Experimental Biology*, 220(21):3878–3882. doi:10.1242/jeb.167056.
- Fletcher, P. T., Lu, C., Pizer, S. M., and Joshi, S. (2004). Principal geodesic analysis for the study of nonlinear statistics of shape. *IEEE Transactions on Medical Imaging*, 23(8):995–1005. doi:10.1109/tmi.2004.831793.
- Forbes, P. G. M. and Mardia, K. V. (2015). A fast algorithm for sampling from the posterior of a von Mises distribution. *Journal of Statistical Computation and Simulation*, 85(13):2693–2701. doi:10.1080/00949655.2014.928711.
- Franaszek, M., Shah, M., Cheok, G. S., and Saidi, K. S. (2015). The axes of random infinitesimal rotations and the propagation of orientation uncertainty. *Measurement*, 72:68–76. doi:10.1016/j.measurement.2015.04.020.
- Franke, A., Caelli, T., Kuzyk, G., and Hudson, R. J. (2006). Prediction of wolf (*Canis lupus*) kill-sites using hidden Markov models. *Ecological Modelling*, 197(1-2):237–246. doi:10.1016/j.ecolmodel.2006.02.043.
- Franke, J., Redenbach, C., and Zhang, N. (2016). On a mixture model for directional data on the sphere. *Scandinavian Journal of Statistics*, 43(1):139–155. doi:10.1111/sjos.12169.
- Fraser, D. and Massam, H. (1988). Location inference on spheres and cylinders. *Journal of Statistical Planning and Inference*, 18(2):195–201. doi:10.1016/0378-3758(88)90005-5.
- Fraser, D. A. S. (1968). *The Structure of Inference*. Wiley, New York.
- Fraser, D. A. S. (1979). *Inference and Linear Models*. McGraw-Hill, New York.
- Fraser, D. A. S., Guttman, I., and Styan, G. P. H. (1976). Serial correlation and distributions on the sphere. *Communications in Statistics – Theory and Methods*, 1(2):97–118. doi:10.1080/03610927608827336.
- Fraser, M. D., Hsu, Y.-S., and Walker, J. J. (1981). Identifiability of finite mixtures of von Mises distributions. *The Annals of Statistics*, 9(5):1130–1131. doi:10.1214/aos/1176345595.
- Freedman, W. and Maier, T. (2002). On multiscale denoising of spherical functions: basic theory and numerical aspects. *Electronic Transactions on Numerical Analysis*, 14:56–78.
- Freedman, W., Schreiner, M., and Franke, R. (1997). A survey on spherical spline approximation. *Surveys Math. Indust*, 7:29–85.
- Freedman, L. S. (1979). The use of a Kolmogorov-Smirnov type statistic in testing hypotheses about seasonal variation. *Journal of Epidemiology and Community Health*, 33(3):223–228. doi:10.1136/jech.33.3.223.
- Freedman, L. S. (1981). Watson’s  $U_N^2$  statistic for a discrete distribution. *Biometrika*, 68(3):708–711. doi:10.2307/2335458.
- Frellsen, J., Mardia, K. V., Borg, M., Ferkinghoff-Borg, J., and Hamelryck, T. (2012). Towards a general probabilistic model of protein structure: the reference ratio method. In Hamelryck, T., Mardia, K., and Ferkinghoff-Borg, J. (Eds.), *Bayesian Methods in Structural Bioinformatics*, Statistics for Biology and Health, pp. 125–134. Springer, Berlin. doi:10.1007/978-3-642-27225-7\_4.
- Frellsen, J., Moltke, I., Thiim, M., Mardia, K. V., Ferkinghoff-Borg, J., and Hamelryck, T. (2009). A probabilistic model of RNA conformational space. *PLOS Computational Biology*, 5(6):e1000406. doi:10.1371/journal.pcbi.1000406.
- Frisch, D., Li, K., and Hanebeck, U. D. (2020). Optimal reduction of Dirac mixture densities on the 2-sphere. In *Proceedings of the 1st Virtual IFAC World Congress (IFAC-V 2020)*.
- Fryer, D., Olenko, A., Li, M., and Wang, Y. (2020). *rcosmo: Cosmic Microwave Background Data Analysis*. R package version 1.1.2. URL: <https://CRAN.R-project.org/package=rcosmo>.
- Fu, Y., Chen, J., and Li, P. (2008). Modified likelihood ratio test for homogeneity in a mixture of von Mises distributions. *Journal of Statistical Planning and Inference*, 138(3):667–681. doi:10.1016/j.jspi.2007.01.003.
- Fujikoshi, Y. and Watamori, Y. (1992). Tests for the mean direction of the Langevin distribution with large concentration

- parameter. *Journal of Multivariate Analysis*, 42(2):210–225. doi:10.1016/0047-259x(92)90044-g.
- Futschik, A. and Hudec, M. (1998). Rotation invariant tests for discrete uniformity against peak shaped alternatives. *Communications in Statistics – Simulation and Computation*, 27(2):431–457. doi:10.1080/03610919808813488.
- Gadsden, R. J. and Kanji, G. P. (1981). Sequential analysis for angular data. *Journal of the Royal Statistical Society, Series D (The Statistician)*, 30(2):119–129. doi:10.2307/2987564.
- Gadsen, R. J. and Kanji, G. K. (1983). Sequential analysis applied to circular data. *Communications in Statistics, Part C (Sequential Analysis)*, 1(4):305–314. doi:10.1080/07474948308836020.
- Gagliardo, A., Ioalè, P., Savini, M., and Wild, M. (2008). Navigational abilities of homing pigeons deprived of olfactory or trigeminally mediated magnetic information when young. *Journal of Experimental Biology*, 211(13):2046–2051. doi:10.1242/jeb.017608.
- Gamage, S. S. and Lasenby, J. (2002). New least squares solutions for estimating the average centre of rotation and the axis of rotation. *Journal of Biomechanics*, 35(1):87–93. doi:10.1016/s0021-9290(01)00160-9.
- Gao, F. Q. and Li, L. N. (2010). Large deviations and moderate deviations for kernel density estimators of directional data. *Acta Mathematica Sinica, English Series*, 26(5):937–950. doi:10.1007/s10114-010-7205-9.
- García-Portugués, E. (2013). Exact risk improvement of bandwidth selectors for kernel density estimation with directional data. *Electronic Journal of Statistics*, 7:1655–1685. doi:10.1214/13-ejs821.
- García-Portugués, E. (2014). *Nonparametric Inference with Directional and Linear Data*. PhD thesis, University of Santiago de Compostela.
- García-Portugués, E. (2020a). *DirStats: Nonparametric Methods for Directional Data*. R package version 0.1.6. URL: <https://CRAN.R-project.org/package=DirStats>.
- García-Portugués, E. (2020b). *sdetorus: Statistical Tools for Toroidal Diffusions*. R package version 0.1.7. URL: <https://CRAN.R-project.org/package=sdetorus>.
- García-Portugués, E., Barros, A. M. G., Crujeiras, R. M., González-Manteiga, W., and Pereira, J. (2014). A test for directional-linear independence, with applications to wildfire orientation and size. *Stochastic Environmental Research and Risk Assessment*, 28(5):1261–1275. doi:10.1007/s00477-013-0819-6.
- García-Portugués, E., Crujeiras, R. M., and González-Manteiga, W. (2013a). Exploring wind direction and SO<sub>2</sub> concentration by circular-linear density estimation. *Stochastic Environmental Research and Risk Assessment*, 27(5):1055–1067. doi:10.1007/s00477-012-0642-5.
- García-Portugués, E., Crujeiras, R. M., and González-Manteiga, W. (2013b). Kernel density estimation for directional-linear data. *Journal of Multivariate Analysis*, 121:152–175. doi:10.1016/j.jmva.2013.06.009.
- García-Portugués, E., Crujeiras, R. M., and González-Manteiga, W. (2015). Central limit theorems for directional and linear random variables with applications. *Statistica Sinica*, 25(3):1207–1229. doi:10.5705/ss.2014.153.
- García-Portugués, E., Crujeiras, R. M., and González-Manteiga, W. (2018a). Smoothing-based tests with directional random variables. In Gil, E., Gil, E., Gil, J., and Gil, M. A. (Eds.), *The Mathematics of the Uncertain*, volume 142 of *Studies in Systems, Decision and Control*, pp. 175–184. Springer, Cham. doi:10.1007/978-3-319-73848-2\_17.
- García-Portugués, E., Golden, M., Sørensen, M., Mardia, K. V., Hamelryck, T., and Hein, J. (2018b). Toroidal diffusions and protein structure evolution. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 61–93. CRC Press, Boca Raton.
- García-Portugués, E., Navarro-Esteban, P., and Cuesta-Albertos, J. A. (2020a). On a projection-based class of uniformity tests on the hypersphere. *arXiv:2008.09897*.
- García-Portugués, E., Paindaveine, D., and Verdebout, T. (2020b). On optimal tests for rotational symmetry against new classes of hyperspherical distributions. *Journal of the American Statistical Association*, to appear. doi:10.1080/01621459.2019.1665527.
- García-Portugués, E., Paindaveine, D., and Verdebout, T. (2020c). *rotasym: Tests for Rotational Symmetry on the Hypersphere*. R package version 1.0.9. URL: <https://CRAN.R-project.org/package=rotasym>.
- García-Portugués, E., Sørensen, M., Mardia, K. V., and Hamelryck, T. (2019). Langevin diffusions on the torus: estimation and applications. *Statistics and Computing*, 29(1):1–22. doi:10.1007/s11222-017-9790-2.
- García-Portugués, E., Van Keilegom, I., Crujeiras, R. M., and González-Manteiga, W. (2016). Testing parametric models in linear-directional regression. *Scandinavian Journal of Statistics*, 43(4):1178–1191. doi:10.1111/sjos.12236.
- García-Portugués, E. and Verdebout, T. (2018). A review of uniformity tests on the hypersphere. *arXiv:1804.00286*.
- García-Portugués, E. and Verdebout, T. (2020). *sphunif: Uniformity Tests on the Circle, Sphere, and Hypersphere*. URL: <https://github.com/egarpor/sphunif>.
- Garner, J. B. (1968). Analysis of the distribution of directions in two dimensions. Technical Report 48, Department of Probability and Statistics, Sheffield University.
- Gates, D. J. and Westcott, M. (1980). Further bounds for the distribution of minimum interpoint distance on a sphere. *Biometrika*, 67(2):466–469. doi:10.1093/biomet/67.2.466.
- Gatto, R. (2000). Multivariate saddlepoint test for the wrapped normal model. *Journal of Statistical Computation and Simulation*, 65(1-4):271–285. doi:10.1080/00949650008812002.
- Gatto, R. (2006). A bootstrap test for circular data. *Communications in Statistics – Theory and Methods*, 35(1-3):281–292.

- doi:10.1080/03610920500440057.
- Gatto, R. (2008). Some computational aspects of the generalized von Mises distribution. *Statistics and Computing*, 18(3):321–331. doi:10.1007/s11222-008-9060-4.
- Gatto, R. (2009). Information theoretic results for circular distributions. *Statistics*, 43(4):409–421. doi:10.1080/09603100802395947.
- Gatto, R. (2017). Multivariate saddlepoint tests on the mean direction of the von Mises-Fisher distribution. *Metrika*, 80(6-8):733–747. doi:10.1007/s00184-017-0625-0.
- Gatto, R. and Jammalamadaka, S. R. (2003). Inference for wrapped symmetric  $\alpha$ -stable circular models. *Sankhyā*, 65(2):333–355.
- Gatto, R. and Jammalamadaka, S. R. (2007). The generalized von Mises distribution. *Statistical Methodology*, 4(3):341–353. doi:10.1016/j.stamet.2006.11.003.
- Gatto, R. and Jammalamadaka, S. R. (2015). On two-sample tests for circular data based on spacing-frequencies. In Dryden, I. L. and Kent, J. T. (Eds.), *Geometry Driven Statistics*, Wiley Series in Probability and Statistics, pp. 129–145. Wiley, Chichester. doi:10.1002/9781118866641.
- Gatto, R. and Mayer, M. (2005). Saddlepoint approximations for some models of circular data. *Statistical Methodology*, 2(4):233–248. doi:10.1016/j.stamet.2005.04.002.
- Gauss, C. F. (1809). *Theoria Motus Corporum Coelestium in Sectionibus Conicis Solem Ambientium*. Cambridge University Press, Cambridge. Reprint of the 1809 original. doi:10.1017/cbo9780511841705.
- Geary, R. C. (1936). The distribution of “Student’s” ratio for non-normal samples. *Supplement to the Journal of the Royal Statistical Society*, 3(2):178–184. doi:10.2307/2983669.
- Gelfand, A. E. and Schliep, E. M. (2016). Spatial statistics and Gaussian processes: a beautiful marriage. *Spatial Statistics*, 18(part A):86–104. doi:10.1016/j.spasta.2016.03.006.
- Genest, M., Masse, J.-C., and Plante, J.-F. (2019). *depth: Nonparametric Depth Functions for Multivariate Analysis*. R package version 2.1-1.1. URL: <https://CRAN.R-project.org/package=depth>.
- Genton, M. G. and Hall, P. (2007). Statistical inference for evolving periodic functions. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 69(4):643–657. doi:10.1111/j.1467-9868.2007.00604.x.
- George, B. J. (2005). *Bayesian Regression for Circular Data*. PhD thesis, George Washington University.
- George, B. J. and Ghosh, K. (2006). A semiparametric Bayesian model for circular-linear regression. *Communications in Statistics – Simulation and Computation*, 35(4):911–923. doi:10.1080/03610910600880302.
- Ghazanfarihesari, A. and Sarmad, M. (2016). *CircOutlier: Detection of Outliers in Circular-Circular Regression*. R package version 3.2.3. URL: <https://CRAN.R-project.org/package=CircOutlier>.
- Ghosh, K., Jammalamadaka, S. R., and Tiwari, R. (2003). Semiparametric Bayesian techniques for problems in circular data. *Journal of Applied Statistics*, 30(2):145–161. doi:10.1080/0266476022000023712.
- Ghosh, K., Jammalamadaka, S. R., and Vasudaven, M. (1999). Change-point problems for the von Mises distribution. *Journal of Applied Statistics*, 26(4):423–434. doi:10.1080/02664769922313.
- Ghosh, M., Zhong, X., SenGupta, A., and Zhang, R. (2019). Non-subjective priors for wrapped Cauchy distributions. *Statistics & Probability Letters*, 153:90–97. doi:10.1016/j.spl.2019.05.016.
- Gidskehaug, A. (1976). Statistics on a sphere. *Geophysical Journal International*, 45(3):657–676. doi:10.1111/j.1365-246x.1976.tb06916.x.
- Giles, D. E. (2013). Exact asymptotic goodness-of-fit testing for discrete circular data with applications. *Chilean Journal of Statistics*, 4(1):19–34.
- Gilitschenski, I., Kurz, G., and Hanebeck, U. D. (2013). Bearings-only sensor scheduling using circular statistics. In *Proceedings of the 16th International Conference on Information Fusion*, pp. 515–521, New York. IEEE.
- Gilitschenski, I., Kurz, G., and Hanebeck, U. D. (2015). Non-identity measurement models for orientation estimation based on directional statistics. In *2015 18th International Conference on Information Fusion (Fusion)*, pp. 727–733, New York. IEEE.
- Gilitschenski, I., Kurz, G., Hanebeck, U. D., and Siegwart, R. (2016a). Optimal quantization of circular distributions. In *2016 19th International Conference on Information Fusion (FUSION)*, pp. 1813–1820, New York. IEEE.
- Gilitschenski, I., Kurz, G., Julier, S. J., and Hanebeck, U. D. (2014). Efficient Bingham filtering based on saddlepoint approximations. In *2014 International Conference on Multisensor Fusion and Information Integration for Intelligent Systems (MFI)*, pp. 1–7, New York. IEEE. doi:10.1109/MFI.2014.6997734.
- Gilitschenski, I., Kurz, G., Julier, S. J., and Hanebeck, U. D. (2016b). Unscented orientation estimation based on the Bingham distribution. *IEEE Transactions on Automatic Control*, 61(1):172–177. doi:10.1109/tac.2015.2423831.
- Gill, J. and Hangartner, D. (2010). Circular data in political science and how to handle it. *Political Analysis*, 18(3):316–336. doi:10.1093/pan/mpq009.
- Giné, E. (1975). Invariant tests for uniformity on compact Riemannian manifolds based on Sobolev norms. *The Annals of Statistics*, 3(6):1243–1266. doi:10.1214/aos/1176343283.
- Giummolè, F., Mameli, V., Ruli, E., and Ventura, L. (2019). Objective Bayesian inference with proper scoring rules. *TEST*, 28(3):728–755. doi:10.1007/s11749-018-0597-z.

- Giunchi, D. and Baldaccini, N. E. (2004). Orientation of juvenile barn swallows (*Hirundo rustica*) tested in Emlen funnels during autumn migration. *Behavioral Ecology and Sociobiology*, 56(2):124–131. doi:10.1007/s00265-004-0769-6.
- Gneiting, T. (1998). Simple tests for the validity of correlation function models on the circle. *Statistics & Probability Letters*, 39(2):119–122. doi:10.1016/s0167-7152(98)00042-x.
- Gneiting, T. (2013). Strictly and non-strictly positive definite functions on spheres. *Bernoulli*, 19(4):1327–1349. doi:10.3150/12-bejsp06.
- Gneiting, T., Larson, K., Westrick, K., Genton, M. G., and Aldrich, E. (2006). Calibrated probabilistic forecasting at the stateline wind energy center: the regime-switching space-time method. *Journal of the American Statistical Association*, 101(475):968–979. doi:10.1198/016214506000000456.
- Godtliebsen, F., Marron, J. S., and Chaudhuri, P. (2002). Significance in scale space for bivariate density estimation. *Journal of Computational and Graphical Statistics*, 11(1):1–21. doi:10.1198/106186002317375596.
- Goh, G. and Dey, D. K. (2014). Bayesian model diagnostics using functional Bregman divergence. *Journal of Multivariate Analysis*, 124:371–383. doi:10.1016/j.jmva.2013.11.008.
- Golden, M., García-Portugués, E., Sørensen, M., Mardia, K. V., Hamelryck, T., and Hein, J. (2017). A generative angular model of protein structure evolution. *Molecular Biology and Evolution*, 34(8):2085–2100. doi:10.1093/molbev/msx137.
- Gopal, S. and Yang, Y. (2014). Von Mises-Fisher clustering models. In Xing, E. P. and Jebara, T. (Eds.), *Proceedings of the 31st International Conference Machine Learning*, volume 32 of *Proceedings of Machine Learning Research*, pp. 154–162, Beijing. PMLR.
- Gordon, A. D., Jupp, P. E., and Byrne, R. W. (1989). The construction and assessment of mental maps. *British Journal of Mathematical and Statistical Psychology*, 42(2):169–182. doi:10.1111/j.2044-8317.1989.tb00906.x.
- Gordon, L. and Hudson, M. (1977). A characterization of the von Mises distribution. *The Annals of Statistics*, 5(4):813–814. doi:10.1214/aos/1176343906.
- Goto, Y., Yoda, K., and Sato, K. (2017). Asymmetry hidden in birds’ tracks reveals wind, heading, and orientation ability over the ocean. *Science Advances*, 3(9):e1700097. doi:10.1126/sciadv.1700097.
- Gould, A. L. (1969). A regression technique for angular variates. *Biometrics*, 25(4):683–700. doi:10.2307/2528567.
- Gower, J. C. (1975). Generalized Procrustes analysis. *Psychometrika*, 40:33–51. doi:10.1007/BF02291478.
- Gradshteyn, I. S. and Ryzhik, I. M. (2014). *Table of Integrals, Series, and Products*. Academic Press, Amsterdam, eighth edition. doi:10.1016/C2013-0-10754-4.
- Graham, J. W. (1949). The stability and significance of magnetism in sedimentary rocks. *Journal of Geophysical Research*, 54(2):131–167. doi:10.1029/jz054i002p00131.
- Grancher, D., Bar-Hen, A., Paris, R., Lavigne, F., and Brunstein, D. (2012). Spatial interpolation of circular data: application to Tsunami of December 2004. *Advances and Applications in Statistics*, 30(1):19–29.
- Graul, C. and Poppinga, C. (2018). *bReeze: Functions for Wind Resource Assessment*. R package version 0.4-3. URL: <https://CRAN.R-project.org/package=bReeze>.
- Gray, H. L. and Odell, P. L. (1966). On sums and products of rectangular variates. *Biometrika*, 53(3-4):615–619. doi:10.2307/2333673.
- Green, P. J. and Mardia, K. V. (2006). Bayesian alignment using hierarchical models, with applications in protein bioinformatics. *Biometrika*, 93(2):235–254. doi:10.1093/biomet/93.2.235.
- Greenwood, J. A. (1959a). Corrections to trigonometric moments for grouping. Technical Report 1, Statistical Laboratory, Iowa State College.
- Greenwood, J. A. (1959b). *Distribution Theory of Some Angular Variates*. PhD thesis, Harvard University.
- Greenwood, J. A. and Durand, D. (1955). The distribution of length and components of the sum of  $n$  random unit vectors. *Annals of Mathematical Statistics*, 26:233–246. doi:10.1214/aoms/1177728540.
- Greenwood, M. (1946). The statistical study of infectious diseases. *Journal of the Royal Statistical Society*, 109(2):85–110. doi:10.2307/2981176.
- Grimit, E. P., Gneiting, T., Berrocal, V. J., and Johnson, N. A. (2006). The continuous ranked probability score for circular variables and its application to mesoscale forecast ensemble verification. *Quarterly Journal of the Royal Meteorological Society*, 132(621C):2925–2942. doi:10.21236/ada454859.
- Grimshaw, S. D., Whiting, D. G., and Morris, T. H. (2001). Likelihood ratio tests for a mixture of two von Mises distributions. *Biometrics*, 57(1):260–265. doi:10.1111/j.0006-341x.2001.00260.x.
- Grohs, P. (2011). Continuous shearlet tight frames. *The Journal of Fourier Analysis and Applications*, 17(3):506–518. doi:10.1007/s00041-010-9149-y.
- Gruet, J.-C. (2000). A note on hyperbolic von Mises distributions. *Bernoulli*, 6(6):1007–1020.
- Gu, X., Mulder, J., Deković, M., and Hoijtink, H. (2014). Bayesian evaluation of inequality constrained hypotheses. *Psychological Methods*, 19(4):511–527. doi:10.1037/met0000017.
- Gu, X., Wang, Y., Chan, T. F., Thompson, P. M., and Yau, S.-T. (2004). Genus zero surface conformal mapping and its application to brain surface mapping. *IEEE Transactions on Medical Imaging*, 23(8):949–958.
- Gual-Arnau, X. and Cruz-Orive, L. M. (2000). Systematic sampling on the circle and on the sphere. *Advances in Applied Probability*, 32(3):628–647.

- Guardiola, J. H. (2020). The spherical-Dirichlet distribution. *Journal of Statistical Distributions and Applications*, 7(1):6. doi:10.1186/s40488-020-00106-9.
- Guella, J. C., Menegatto, V. A., and Porcu, E. (2018). Strictly positive definite multivariate covariance functions on spheres. *Journal of Multivariate Analysis*, 166:150–159. doi:10.1016/j.jmva.2018.03.001.
- Gumbel, E. J. (1954). Applications of the circular normal distribution. *Journal of the American Statistical Association*, 49(266):267–297. doi:10.1080/01621459.1954.10483505.
- Gumbel, E. J., Greenwood, J. A., and Durand, D. (1953). The circular normal distribution: theory and tables. *Journal of American Statistical Association*, 48(261):131–152. doi:10.1080/01621459.1953.10483462.
- Gupta, D. (1976). Some mixtures of von Mises distributions. *South African Statistical Journal*, 10(1):69–76.
- Gupta, D. (1977). Some mixtures of the Von Mises distribution, II. *South African Statistical Journal*, 11(2):181–186.
- Gurarie, E., Andrews, R. D., and Laidre, K. L. (2009). A novel method for identifying behavioural changes in animal movement data. *Ecology Letters*, 12(5):395–408. doi:10.1111/j.1461-0248.2009.01293.x.
- Guttorp, P. and Lockhart, R. A. (1988). Finding the location of a signal: a Bayesian analysis. *Journal of the American Statistical Association*, 83(402):322–330. doi:10.1080/01621459.1988.10478601.
- Györi, L., Baranyi, T., and Ludámy, A. (2016). Comparative analysis of Debrecen sunspot catalogues. *Monthly Notices of the Royal Astronomical Society*, 465(2):1259–1273. doi:10.1093/mnras/stw2667.
- de Haas-Lorentz, G. L. (1913). *Die Brownsche Bewegung und einige verwandte Erscheinungen*. Frieder, Vieweg und Sohn, Brunswick. doi:10.1007/978-3-322-99070-9.
- Haldane, J. B. S. (1960). The addition of random vectors. *Sankhyā*, 22(3):213–220.
- Hall, P. (1984). Random, nonuniform distribution of line segments on a circle. *Stochastic Processes and their Applications*, 18(2):239–261. doi:10.1016/0304-4149(84)90298-9.
- Hall, P., Reimann, J., and Rice, J. (2000). Nonparametric estimation of a periodic function. *Biometrika*, 87(3):545–557. doi:10.1093/biomet/87.3.545.
- Hall, P., Watson, G. S., and Cabrera, J. (1987). Kernel density estimation with spherical data. *Biometrika*, 74(4):751–762. doi:10.1093/biomet/74.4.751.
- Hall, P. and Yin, J. (2003). Nonparametric methods for deconvolving multiperiodic functions. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 65(4):869–886. doi:10.1046/j.1369-7412.2003.00420.x.
- Halvorsen, K., Lesser, M., and Lundberg, A. (1999). A new method for estimating the axis of rotation and the center of rotation. *Journal of Biomechanics*, 32:1221–1227. doi:10.1016/s0021-9290(99)00120-7.
- Hamelryck, T., Mardia, K., and Ferkinghoff-Borg, J. (Eds.) (2012). *Bayesian Methods in Structural Bioinformatics*. Statistics for Biology and Health. Springer, Heidelberg. doi:10.1007/978-3-642-27225-7.
- Hamsici, O. C. and Martinez, A. M. (2007). Spherical-homoscedastic distributions: the equivalency of spherical and normal distributions in classification. *Journal of Machine Learning Research*, 8(Jul):1583–1623.
- Hanbury, A. G. and Serra, J. (2001). Morphological operators on the unit circle. *IEEE Transactions on Image Processing*, 10(12):1842–1850. doi:10.1109/83.974569.
- Hanebeck, U. D. and Lindquist, A. (2014). Moment-based Dirac mixture approximation of circular densities. *IFAC Proceedings Volumes*, 47(3):5040–5048. doi:10.3182/20140824-6-ZA-1003.02486.
- Hanks, E. M., Hooten, M. B., and Alldredge, M. W. (2015). Continuous-time discrete-space models for animal movement. *The Annals of Applied Statistics*, 9(1):145–165. doi:10.1214/14-aos803.
- Hansen, K. M. and Mount, V. S. (1990). Smoothing and extrapolation of crustal stress orientation measurements. *Journal of Geophysical Research: Solid Earth*, 95(B2):1155–1165. doi:10.1029/jb095ib02p01155.
- Hanson, B., Klink, K., Matsuura, K., Robeson, S. M., and Willmott, C. J. (1992). Vector correlation: review, exposition, and geographic application. *Annals of the Association of American Geographers*, 82(1):103–116. doi:10.1111/j.1467-8306.1992.tb01900.x.
- Hara, K., Nishino, K., and Ikeuchi, K. (2008). Mixture of spherical distributions for single-view relighting. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 30(1):25–35. doi:10.1109/tpami.2007.1164.
- Harder, T., Boomsma, W., Paluszewski, M., Frellsen, J., Johansson, K. E., and Hamelryck, T. (2010). Beyond rotamers: a generative, probabilistic model of side chains in proteins. *BMC Bioinformatics*, 11(1):306. doi:10.1186/1471-2105-11-306.
- Harrison, D. and Kanji, G. K. (1988). The development of analysis of variance for circular data. *Journal of Applied Statistics*, 15(2):197–224. doi:10.1080/02664768800000026.
- Harrison, D., Kanji, G. K., and Gadsden, R. J. (1986). Analysis of variance for circular data. *Journal of Applied Statistics*, 13(2):123–138. doi:10.1080/02664768600000021.
- Hart, T., Mann, R., Coulson, T., Pettorelli, N., and Trathan, P. (2010). Behavioural switching in a central place forager: patterns of diving behaviour in the macaroni penguin (*Eudyptes chrysolophus*). *Marine Biology*, 157(7):1543–1553. doi:10.1007/s00227-010-1428-2.
- Hartman, P. and Watson, G. S. (1974). “normal” distribution functions on spheres and the modified Bessel functions. *The Annals of Probability*, 2(4):593–607. doi:10.1214/aop/1176996606.
- Harvey, P. K. and Ferguson, C. C. (1976). On testing orientation data for goodness-of-fit to a von Mises distribution. *Computers & Geosciences*, 2(2):261–268. doi:10.1016/0098-3004(76)90111-4.

- Hasnat, M. A., Alata, O., and Trémeau, A. (2014). Unsupervised clustering of depth images using Watson mixture model. In *2014 22nd International Conference on Pattern Recognition*, pp. 214–219, New York. IEEE. doi:10.1109/icpr.2014.46.
- Hassanzadeh, F. and Kalaylioglu, Z. (2018). A new multimodal and asymmetric bivariate circular distribution. *Environmental and Ecological Statistics*, 25(3):363–385. doi:10.1007/s10651-018-0409-3.
- Hauberg, S. (2018). Directional statistics with the spherical normal distribution. In *2018 21st International Conference on Information Fusion (FUSION)*, pp. 704–711, New York. IEEE. doi:10.23919/ICIF.2018.8455242.
- Hawkins, D. M. and Lombard, F. (2015). Segmentation of circular data. *Journal of Applied Statistics*, 42(1):88–97. doi:10.1080/02664763.2014.934665.
- Hawkins, D. M. and Lombard, F. (2017). Cusum control for data following the von Mises distribution. *Journal of Applied Statistics*, 44(8):1319–1332.
- Hayakawa, T. (1990). On tests for the mean direction of the Langevin distribution. *Annals of the Institute of Statistical Mathematics*, 42(2):359–373. doi:10.1007/bf00050842.
- Hayakawa, T. and Puri, M. L. (1985). Asymptotic expansions of the distributions of some test statistics. *Annals of the Institute of Statistical Mathematics*, 37(1):95–108. doi:10.1007/bf02481083.
- He, L. and Yue, R.-X. (2020). R-optimal designs for trigonometric regression models. *Statistical Papers*, 61(5):1997–2013. doi:10.1007/s00362-018-1017-x.
- He, X. (1992). Robust statistics of directional data: a survey. In Saleh, A. K. M. E. (Ed.), *Nonparametric Statistics and Related Topics*, pp. 87–96, New York. North-Holland.
- He, X. and Simpson, D. G. (1992). Robust direction estimation. *The Annals of Statistics*, 20(1):351–369. doi:10.1214/aos/1176348526.
- Healy, D. M. and Kim, P. T. (1996). An empirical Bayes approach to directional data and efficient computation on the sphere. *The Annals of Statistics*, 24(1):232–254. doi:10.1214/aos/1033066208.
- Healy, D. M. J., Hendriks, H., and Kim, P. T. (1998). Spherical deconvolution. *Journal of Multivariate Analysis*, 67(1):1–22. doi:10.1006/jmva.1998.1757.
- Heard, N. A., Holmes, C. C., and Stephens, D. A. (2006). A quantitative study of gene regulation involved in the immune response of Anopheline mosquitoes: an application of Bayesian hierarchical clustering of curves. *Journal of the American Statistical Association*, 101(473):18–29. doi:10.1198/016214505000000187.
- Hendriks, H. (1990). Non-parametric estimation of a probability density on a Riemannian manifold using Fourier expansions. *The Annals of Statistics*, 18(2):832–849. doi:10.1214/aos/1176347628.
- Hendriks, H. (1991). A Cramér-Rao type lower bound for estimators with values in a manifold. *Journal of Multivariate Analysis*, 38(2):245–261. doi:10.1016/0047-259x(91)90044-3.
- Hendriks, H. (1992). The admissibility of the empirical mean location for the matrix von Mises-Fisher family. Technical report, Department of Mathematics, Catholic University of Nijmegen.
- Hendriks, H., Janssen, J. H. M., and Ruymgaart, F. H. (1993). Strong uniform convergence of density estimators on compact Euclidean manifolds. *Statistics & Probability Letters*, 16(4):301–305. doi:10.1016/0167-7152(93)90135-6.
- Hendriks, H. and Landsman, Z. (1996a). Asymptotic behavior of sample mean location for manifolds. *Statistics & Probability Letters*, 26(2):169–178. doi:10.1016/0167-7152(95)00007-0.
- Hendriks, H. and Landsman, Z. (1996b). Asymptotic tests for mean location on manifolds. *Comptes Rendus de l'Académie des Sciences, Série I (Mathématique)*, 322(8):773–778.
- Hendriks, H. and Landsman, Z. (1998). Mean location and sample mean location on manifolds: asymptotics, tests, confidence regions. *Journal of Multivariate Analysis*, 67(2):227–243. doi:10.1006/jmva.1998.1776.
- Hendriks, H., Landsman, Z., and Ruymgaart, F. (1996). Asymptotic behavior of sample mean direction for spheres. *Journal of Multivariate Analysis*, 59(2):141–152. doi:10.1006/jmva.1996.0057.
- Henry, G. and Rodriguez, D. (2009a). Kernel density estimation on Riemannian manifolds: asymptotic results. *Journal of Mathematical Imaging and Vision*, 34(3):235–239. doi:10.1007/s10851-009-0145-2.
- Henry, G. and Rodriguez, D. (2009b). Robust nonparametric regression on Riemannian manifolds. *Journal of Nonparametric Statistics*, 21(5):611–628. doi:10.1080/10485250902846439.
- Henze, N. (2018). On the consistency of the spacings test for multivariate uniformity, including on manifolds. *Journal of Applied Probability*, 55(2):659–665. doi:10.1017/jpr.2018.41.
- Herbert-Acero, J. F., Probst, O., Réthoré, P.-E., Larsen, G. C., and Castillo-Villar, K. K. (2014). A review of methodological approaches for the design and optimization of wind farms. *Energies*, 7(11):6930–7016. doi:10.3390/en7116930.
- Herglotz, G. (1911). Über Potenzreihen mit positivem, reellen Teil im Einheitskreis. *Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig, Mathematisch-Physikalische Klasse*, 63:501–511. doi:10.1007/978-3-322-90926-8\_1.
- Hermans, M. and Rasson, J. P. (1985). A new Sobolev test for uniformity on the circle. *Biometrika*, 72(3):698–702. doi:10.1093/biomet/72.3.698.
- Hernandez-Stumpfhäuser, D., Breidt, F. J., and Opsomer, J. D. (2016). Hierarchical Bayesian small area estimation for circular data. *The Canadian Journal of Statistics*, 44(4):416–430. doi:10.1002/cjs.11303.
- Hernandez-Stumpfhäuser, D., Breidt, F. J., and van der Woerd, M. J. (2017). The general projected normal distribution of



- arbitrary dimension: modeling and Bayesian inference. *Bayesian Analysis*, 12(1):113–133. doi:10.1214/15-ba989.
- Herz, C. S. (1955). Bessel functions of matrix argument. *Annals of Mathematics*, 61(3):474–523. doi:10.2307/1969810.
- Hetherington, T. J. (1981). *Analysis of Directional Data by Exponential Models*. PhD thesis, University of California at Berkeley.
- Hill, B. M. (1960). A relationship between Hodges’ bivariate sign test and a nonparametric test of Daniels. *Annals of Mathematical Statistics*, 31(4):1190–1192. doi:10.1214/aoms/1177705689.
- Hill, G. W. (1976). New approximations to the von Mises distribution. *Biometrika*, 63(3):673–676. doi:10.2307/2335751.
- Hill, G. W. (1977). Algorithm 518: incomplete Bessel function  $I_0(x)$ ; the von Mises distribution. *ACM Transactions on Mathematical Software*, 3(3):279–284.
- Hill, G. W. (1981). Evaluation and inversion of the ratios of modified Bessel functions  $I_1(x)/I_0(x)$  and  $I_{1.5}(x)/I_{0.5}(x)$ . *ACM Transactions on Mathematical Software*, 7(2):199–208.
- Hill, N. A. and Häder, D.-P. (1997). A biased random walk model for the trajectories of swimming micro-organisms. *Journal of Theoretical Biology*, 186(4):503–526. doi:10.1006/jtbi.1997.0421.
- Hill, T. P. (1995). A statistical derivation of the significant-digit law. *Statistical Science*, 10(4):354–363. doi:10.1214/ss/1177009869.
- Hinkelmann, K. (Ed.) (2012). *Design and Analysis of Experiments. Volume 3*. Wiley Series in Probability and Statistics. John Wiley & Sons, Hoboken. doi:10.1002/9781118147634.
- Hinkle, J., Fletcher, P. T., and Joshi, S. (2014). Intrinsic polynomials for regression on Riemannian manifolds. *Journal of Mathematical Imaging and Vision*, 50(1):32–52. doi:10.1007/s10851-013-0489-5.
- Hinkley, D. V. and Cox, D. R. (1974). *Theoretical Statistics*. Chapman & Hall, London. doi:10.1007/978-1-4899-2887-0.
- Hinton, G. E. and Roweis, S. T. (2003). Stochastic neighbor embedding. In Becker, S., Thrun, S., and Obermayer, K. (Eds.), *Advances in Neural Information Processing Systems 15 (NIPS 2002)*, pp. 857–864, Cambridge, Massachusetts. MIT Press.
- Hirata, N. (2016). Differential impact cratering of Saturn’s satellites by heliocentric impactors. *Journal of Geophysical Research: Planets*, 121(2):111–117. doi:10.1002/2015JE004940.
- Hjort, N. L. and Jones, M. C. (1996). Locally parametric nonparametric density estimation. *The Annals of Statistics*, 24(4):1619–1647. doi:10.1214/aos/1032298288.
- Ho, S. C. (1984). *Small Sample Inference for the Bingham Distribution*. PhD thesis, University of Minnesota.
- Hodges, J. L. (1955). A bivariate sign test. *Annals of Mathematical Statistics*, 26(3):523–527. doi:10.1214/aoms/1177728498.
- Hoff, P. D. (2009). Simulation of the matrix Bingham-von Mises-Fisher distribution, with applications to multivariate and relational data. *Journal of Computational and Graphical Statistics*, 18(2):438–456. doi:10.1198/jcgs.2009.07177.
- Hogg, R. V. and Craig, A. T. (1965). *Introduction to Mathematical Statistics*. Macmillan, New York, second edition.
- Hokimoto, T. and Shimizu, K. (2008). An angular-linear time series model for waveheight prediction. *Annals of the Institute of Statistical Mathematics*, 60(4):781–800. doi:10.1007/s10463-008-0207-z.
- Hokimoto, T. and Shimizu, K. (2014). A non-homogeneous hidden Markov model for predicting the distribution of sea surface elevation. *Journal of Applied Statistics*, 41(2):294–319.
- Holguin, J. (1980). The application of directional methods in  $p$  dimensions. Master’s thesis, Department of Mathematics, Simon Fraser University.
- Hollman, J. H., Deusinger, R. H., Van Dillen, L. R., and Matava, M. J. (2002). Knee joint movements in subjects without knee pathology and subjects with injured anterior cruciate ligaments. *Physical Therapy*, 82(10):960–972. doi:10.1093/ptj/82.10.960.
- Holmquist, B. (1985). Correlation measures for circular data. In Lanke, J. and Lindgren, G. (Eds.), *Contributions to Probability and Statistics in Honour of Gunnar Blom*, pp. 157–168. Department of Mathematical Statistics, Lund University.
- Holmquist, B. (1991). Estimating and testing the common mean direction of several von Mises-Fisher populations with known concentration. *Statistics*, 22(3):369–378. doi:10.1080/02331889108802318.
- Holmquist, B. and Gustafsson, P. (2017). A two-level directional model for dependence in circular data. *The Canadian Journal of Statistics*, 45(4):461–478. doi:10.1002/cjs.11345.
- Holst, L. (1981). On convergence of the coverage by random arcs on a circle and the largest spacing. *The Annals of Probability*, 9(4):648–655. doi:10.1214/aop/1176994370.
- Holzmann, H., Munk, A., and Stratmann, B. (2004). Identifiability of finite mixtures - with applications to circular distributions. *Sankhyā*, 66(3):440–449.
- Holzmann, H., Munk, A., Suster, M., and Zucchini, W. (2006). Hidden Markov models for circular and linear-circular time series. *Environmental and Ecological Statistics*, 13(3):325–347. doi:10.1007/s10651-006-0015-7.
- Hooten, M. B., Johnson, D. S., Hanks, E. M., and Lowry, J. H. (2010). Agent-based inference for animal movement and selection. *Journal of Agricultural, Biological, and Environmental Statistics*, 15(4):523–538. doi:10.1007/s13253-010-0038-2.
- Horne, J. S., Garton, E. O., Krone, S. M., and Lewis, J. S. (2007). Analyzing animal movements using Brownian bridges. *Ecology*, 88(9):2354–2363. doi:10.1890/06-0957.1.
- Hornik, K., Feinerer, I., Kober, M., and Buchta, C. (2012). Spherical  $k$ -means clustering. *Journal of Statistical Software*, 50(10):1–22. doi:10.18637/jss.v050.i10.
- Hornik, K. and Grün, B. (2011). topicmodels: an R package for fitting topic models. *Journal of Statistical Software*,

- 40(13):1–30. doi:10.18637/jss.v040.i13.
- Hornik, K. and Grün, B. (2013). On conjugate families and Jeffreys priors for von Mises-Fisher distributions. *Journal of Statistical Planning and Inference*, 143(5):992–999. doi:10.1016/j.jspi.2012.11.003.
- Hornik, K. and Grün, B. (2014a). movMF: an R package for fitting mixtures of von Mises-Fisher distributions. *Journal of Statistical Software*, 58(10):1–31. doi:10.18637/jss.v058.i10.
- Hornik, K. and Grün, B. (2014b). On maximum likelihood estimation of the concentration parameter of von Mises-Fisher distributions. *Computational Statistics*, 29(5):945–957.
- Horwood, J. T. and Poore, A. B. (2014). Gauss von Mises distribution for improved uncertainty realism in space situational awareness. *SIAM/ASA Journal on Uncertainty Quantification*, 2(1):276–304. doi:10.1137/130917296.
- Hospers, J. (1955). Rock magnetism and polar wandering. *The Journal of Geology*, 63(1):59–74. doi:10.1086/626226.
- Hotz, T. (2013). Extrinsic vs intrinsic means on the circle. In Nielsen, F. and Barbaresco, F. (Eds.), *Geometric Science of Information*, volume 8085 of *Lecture Notes in Computer Science*, pp. 433–440, Berlin. Springer. doi:10.1007/978-3-642-40020-9\_7.
- Hotz, T. and Huckemann, S. (2015). Intrinsic means on the circle: uniqueness, locus and asymptotics. *Annals of the Institute of Statistical Mathematics*, 67(1):177–193.
- Hoyt, R. S. (1947). Probability functions for the modulus and angle of the normal complex variable. *Bell System Technical Journal*, 26(2):318–359. doi:10.1002/j.1538-7305.1947.tb01318.x.
- Hsu, E. P. (2002). *Stochastic Analysis on Manifolds*, volume 38 of *Graduate Studies in Mathematics*. American Mathematical Society, Providence. doi:10.1090/gsm/038.
- Hu, Y., Yan, C., Hsu, C.-H., Chen, Q.-R., Niu, K., Komatsoulis, G. A., and Meerzaman, D. (2014). OmicCircos: a simple-to-use R package for the circular visualization of multidimensional omics data. *Cancer Informatics*, 13:20. doi:10.4137/cin.s13495.
- Huber, P. (1964). Robust estimation of a location parameter. *Annals of Mathematical Statistics*, 35(1):73–101. doi:10.1007/978-1-4612-4380-9\_35.
- Hubert, L., Arabie, P., and Meulman, J. (1997). Linear and circular unidimensional scaling for symmetric proximity matrices. *British Journal of Mathematical and Statistical Psychology*, 50(2):253–284. doi:10.1111/j.2044-8317.1997.tb01145.x.
- Huckemann, S. and Hotz, T. (2009). Principal component geodesics for planar shape spaces. *Journal of Multivariate Analysis*, 100(4):699–714. doi:10.1016/j.jmva.2008.08.008.
- Huckemann, S., Hotz, T., and Munk, A. (2010a). Intrinsic shape analysis: geodesic PCA for Riemannian manifolds modulo isometric Lie group actions. *Statistica Sinica*, 20(1):1–58.
- Huckemann, S., Kim, K.-R., Munk, A., Rehfeldt, F., Sommerfeld, M., Weickert, J., and Wollnik, C. (2016). The circular SiZer, inferred persistence of shape parameters and application to early stem cell differentiation. *Bernoulli*, 22(4):2113–2142. doi:10.3150/15-BEJ722.
- Huckemann, S. and Ziezold, H. (2006). Principal component analysis for Riemannian manifolds, with an application to triangular shape spaces. *Advances in Applied Probability*, 38(2):299–319. doi:10.1239/aap/1151337073.
- Huckemann, S. F. and Eltzner, B. (2018). Backward nested descriptors asymptotics with inference on stem cell differentiation. *The Annals of Statistics*, 46(5):1994–2019. doi:10.1214/17-AOS1609.
- Huckemann, S. F., Kim, P. T., Koo, J.-Y., and Munk, A. (2010b). Möbius deconvolution on the hyperbolic plane with application to impedance density estimation. *The Annals of Statistics*, 38(4):2465–2498. doi:10.1214/09-aos783.
- Huffer, F. W. (1988). Some results concerning random arcs on the circle. *Journal of Applied Probability*, 25(4):833–838. doi:10.1017/s0021900200041644.
- Huffer, F. W. (1990). Ordering distributions on the circle with respect to uniformity. *Journal of Multivariate Analysis*, 33(2):310–327. doi:10.1016/0047-259x(90)90054-1.
- Hughes, G. (2007). *Multivariate and Time Series Models for Circular Data with Applications to Protein Conformational Angles*. PhD thesis, University of Leeds.
- Humphreys, R. K. and Ruxton, G. D. (2017). Consequences of grouped data for testing for departure from circular uniformity. *Behavioral Ecology and Sociobiology*, 71(11):167. doi:10.1007/s00265-017-2393-2.
- Hundrieser, S., Eltzner, B., and Huckemann, S. F. (2020). Finite sample smeariness of Fréchet means and application to climate. *arXiv:2005.02321*.
- Hung, W.-L., Chang-Chien, S.-J., and Yang, M.-S. (2012). Self-updating clustering algorithm for estimating the parameters in mixtures of von Mises distributions. *Journal of Applied Statistics*, 39(10):2259–2274. doi:10.1080/02664763.2012.706268.
- Hung, W.-L., Chang-Chien, S.-J., and Yang, M.-S. (2015). An intuitive clustering algorithm for spherical data with application to extrasolar planets. *Journal of Applied Statistics*, 42(10):2220–2232. doi:10.1080/02664763.2015.1023271.
- Hurwitz, A. (1903). Über die Fourierschen Konstanten integrierbarer Funktionen. *Mathematische Annalen*, 57(4):425–446. doi:10.1007/978-3-0348-4161-0\_33.
- Hüsler, J. (1982). Random coverage of the circle and asymptotic distributions. *Journal of Applied Probability*, 19(3):578–587. doi:10.2307/3213515.
- Hussain, I., Ali, S. M., Khan, B., Ullah, Z., Mehmood, C. A., Jawad, M., Farid, U., and Haider, A. (2019). Stochastic wind energy management model within smart grid framework: a joint bi-directional service level agreement (SLA) between smart

- grid and wind energy district prosumers. *Renewable Energy*, 134:1017–1033. doi:10.1016/j.renene.2018.11.085.
- Hyvärinen, A. (2005). Estimation of non-normalized statistical models by score matching. *Journal of Machine Learning Research*, 6(Apr):695–709.
- Ibero, M. (1975). Déviation de la loi empirique d’une variable bidimensionnelle. *Comptes Rendus de l’Académie des Sciences, Série A*, 281:1059–1062.
- Ibero, M. (1976). Un test d’ajustement bidimensionnel indépendant de la loi. *Comptes Rendus de l’Académie des Sciences, Série A*, 283:387–390.
- Idé, T., Phan, D. T., and Kalagnanam, J. (2016). Change detection using directional statistics. In Kambhampati, S. (Ed.), *Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence (IJCAI-16)*, pp. 1613—1619, Palo Alto. AAAI Press.
- Illes, M. and Boue, M. (2013). Robust estimation for area of origin in bloodstain pattern analysis via directional analysis. *Forensic Science International*, 226(1-3):223–229. doi:10.1016/j.forsciint.2013.01.030.
- Imoto, T., Shimizu, K., and Abe, T. (2019). A cylindrical distribution with heavy-tailed linear part. *Japanese Journal of Statistics and Data Science*, 2(1):129–154. doi:10.1007/s42081-019-00031-5.
- Irving, E. (1964). *Paleomagnetism and its Applications to Geological and Geophysical Problems*. Wiley, New York.
- Irving, E. and Ward, M. A. (1964). A statistical model of the geomagnetic field. *Pure and Applied Geophysics*, 57(1):47–52. doi:10.1007/bf00879707.
- Irwin, M. E., Cressie, N., and Johannesson, G. (2002). Spatial-temporal nonlinear filtering based on hierarchical statistical models. *TEST*, 11(2):249–302. doi:10.1007/BF02595708.
- Isham, V. (1977). A Markov construction for a multidimensional point process. *Journal of Applied Probability*, 14(3):507–515. doi:10.2307/3213453.
- Jacimovic, V. and Crnkic, A. (2017). Collective motions of globally coupled oscillators and some probability distributions on circle. *Physics Letters A*, 381(24):1989–1994. doi:10.1016/j.physleta.2017.04.024.
- Jacob, S. and Jayakumar, K. (2013). Wrapped geometric distribution: a new probability model for circular data. *Journal of Statistical Theory and Applications*, 12(4):348–355. doi:10.2991/jsta.2013.12.4.3.
- Jaffé, L. (1956). Effect of polarized light on polarity of fucus. *Science*, 123(3207):1081–1082. doi:10.1126/science.123.3207.1081.
- Jammalamadaka, S. R. and Gorla, M. N. (2004). A test of goodness-of-fit based on Gini’s index of spacings. *Statistics & Probability Letters*, 68(2):177–187. doi:10.1016/j.spl.2004.02.009.
- Jammalamadaka, S. R. and Kozubowski, T. J. (2003). A new family of circular models: the wrapped Laplace distributions. *Advances in Applied Statistics*, 3(1):77–103.
- Jammalamadaka, S. R. and Kozubowski, T. J. (2004). New families of wrapped distributions for modeling skew circular data. *Communications in Statistics – Theory and Methods*, 33(9):2059–2074. doi:10.1081/sta-200026570.
- Jammalamadaka, S. R. and Lund, U. J. (2006). The effect of wind direction on ozone levels: a case study. *Environmental and Ecological Statistics*, 13(3):287–298. doi:10.1007/s10651-004-0012-7.
- Jammalamadaka, S. R. and Mangalam, V. (2009). A general censoring scheme for circular data. *Statistical Methodology*, 6(3):280–289. doi:10.1016/j.stamet.2008.10.002.
- Jammalamadaka, S. R., Meintanis, S., and Verdebout, T. (2020). On new Sobolev tests of uniformity on the circle with extension to the sphere. *Bernoulli*, 26(3):2226–2252. doi:10.3150/19-BEJ1191.
- Jammalamadaka, S. R. and Sarma, Y. (1988). A correlation coefficient for angular variables. In Matusita, K. (Ed.), *Statistical Theory and Data Analysis II*, pp. 349–364, Amsterdam. North-Holland.
- Jammalamadaka, S. R. and SenGupta, A. (1998). Predictive inference for directional data. *Statistics & Probability Letters*, 40(3):247–257. doi:10.1016/S0167-7152(98)00101-1.
- Jammalamadaka, S. R. and SenGupta, A. (2001). *Topics in Circular Statistics*, volume 5 of *Series on Multivariate Analysis*. World Scientific, Singapore. doi:10.1142/4031.
- Jammalamadaka, S. R. and Terdik, G. H. (2019). Harmonic analysis and distribution-free inference for spherical distributions. *Journal of Multivariate Analysis*, 171:436–451. doi:10.1016/j.jmva.2019.01.012.
- Jander, R. (1957). Die optische Richtungsorientierung der Roten Waldameise (*Formica Rufa* L.). *Zeitschrift für Vergleichende Physiologie*, 40(2):162–238. doi:10.1007/bf00297947.
- Jayakumar, K. and Jacob, S. (2012). Wrapped skew Laplace distribution on integers: a new probability model for circular data. *Open Journal of Statistics*, 2:106–114. doi:10.4236/ojs.2012.21011.
- Jaynes, E. T. (1957). Information theory and statistical mechanics. *Physical Review A*, 106(4):620–630. doi:10.1103/physrev.108.171.
- Jeffreys, H. (1948). *Theory of Probability*. Oxford University Press, Oxford, second edition.
- Jensen, H. (1959). Daily determinations of the microseismic direction in Copenhagen during the IGY 1958. Technical Report 38, Meddelelser fra Dansk Geologisk Forening.
- Jensen, J. L. (1981). On the hyperboloid distribution. *Scandinavian Journal of Statistics*, 8(4):193–206.
- Jensen, J. L. (1995). *Saddlepoint Approximations*. Oxford Statistical Science Series. Oxford University Press, Oxford.
- Jensen, M. H., Mallasto, A., and Sommer, S. (2019). Simulation of conditioned diffusions on the flat torus. In Nielsen, F. and

- Barbaresco, F. (Eds.), *Geometric Science of Information*, volume 11712 of *Lecture Notes in Computer Science*, pp. 685–694, Cham. Springer. doi:10.1007/978-3-030-26980-7\_71.
- Jeong, J., Jun, M., and Genton, M. G. (2017). Spherical process models for global spatial statistics. *Statistical Science*, 32(4):501–513. doi:10.1214/17-STS620.
- Jha, J. and Biswas, A. (2018). Distribution and time-series modelling of ordinal circular data. *Environmetrics*, 29(2):e2490. doi:10.1002/env.2490.
- Jin, K.-R. and Ji, Z.-G. (2004). Case study: modeling of sediment transport and wind-wave impact in Lake Okeechobee. *Journal of Hydraulic Engineering*, 130:1055–1067. doi:10.1061/(asce)0733-9429(2004)130:11(1055).
- Jirina, M. (1978). A biased roulette. *Annales de l'Institut Henri Poincaré. Nouvelle Série. Section B. Calcul des Probabilités et Statistique*, 14(1):1–23.
- Joffe, A. and Klotz, J. (1962). Null distribution and Bahadur efficiency of the Hodges bivariate sign test. *Annals of Mathematical Statistics*, 33(2):803–807. doi:10.1214/aoms/1177704600.
- Johannes, J. and Schwarz, M. (2013). Adaptive circular deconvolution by model selection under unknown error distribution. *Bernoulli*, 19(5A):1576–1611. doi:10.3150/12-BEJ422.
- Johnson, N. L. (1966). Paths and chains of random straight-line segments. *Technometrics*, 8(2):303–317. doi:10.1080/00401706.1966.10490349.
- Johnson, R. A. and Shieh, G. S. (2002). On tests of independence for spherical data-invariance and centering. *Statistics & Probability Letters*, 57(4):327–335. doi:10.1016/S0167-7152(02)00083-4.
- Johnson, R. A. and Wehrly, T. E. (1977). Measures and models for angular correlation and angular-linear correlation. *Journal of the Royal Statistical Society, Series B (Methodological)*, 39(2):222–229. doi:10.1111/j.2517-6161.1977.tb01619.x.
- Johnson, R. A. and Wehrly, T. E. (1978). Some angular-linear distributions and related regression models. *Journal of the American Statistical Association*, 73(363):602–606. doi:10.1080/01621459.1978.10480062.
- Jolliffe, I. T. (2002). *Principal Component Analysis*. Springer Series in Statistics. Springer, New York, second edition. doi:10.1007/b98835.
- Jona-Lasinio, G., Gelfand, A., and Jona-Lasinio, M. (2012). Spatial analysis of wave direction data using wrapped Gaussian processes. *The Annals of Applied Statistics*, 6(4):1478–1498. doi:10.1214/12-aos576.
- Jona-Lasinio, G., Gelfand, A. E., and Mastrantonio, G. (2018). Spatial and spatio-temporal circular processes with application to wave directions. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 129–162. CRC Press, Boca Raton.
- Jona Lasinio, G., Mastrantonio, G., and Santoro, M. (2019). *CircSpaceTime: Spatial and Spatio-Temporal Bayesian Model for Circular Data*. R package version 0.9.0. URL: <https://CRAN.R-project.org/package=CircSpaceTime>.
- Jona Lasinio, G., Santoro, M., and Mastrantonio, G. (2020). CircSpaceTime: an R package for spatial and spatio-temporal modelling of circular data. *Journal of Statistical Computation and Simulation*, 90(7):1315–1345. doi:10.1080/00949655.2020.1725008.
- Jones, C. L. (1983). A note on the use of directional statistics in weighted Euclidean distances multidimensional-scaling models. *Psychometrika*, 48(3):473–476. doi:10.1007/bf02293688.
- Jones, M. C. (2014). Generating distributions by transformation of scale. *Statistica Sinica*, 24(2):749–772. doi:10.5705/ss.2011.304.
- Jones, M. C. (2015). On families of distributions with shape parameters. *International Statistical Review*, 83(2):175–192.
- Jones, M. C. and Pewsey, A. (2005). A family of symmetric distributions on the circle. *Journal of the American Statistical Association*, 100(472):1422–1428. doi:10.1198/016214505000000286.
- Jones, M. C. and Pewsey, A. (2012). Inverse Batschelet distributions for circular data. *Biometrics*, 68(1):183–193. doi:10.1111/j.1541-0420.2011.01651.x.
- Jones, M. C., Pewsey, A., and Kato, S. (2015). On a class of circulars: copulas for circular distributions. *Annals of the Institute of Statistical Mathematics*, 67(5):843–862.
- Jones, T. A. (2006a). MATLAB functions to analyze directional (azimuthal) data – I: single-sample inference. *Computers & Geosciences*, 32(2):166–175. doi:10.1016/j.cageo.2005.06.009.
- Jones, T. A. (2006b). MATLAB functions to analyze directional (azimuthal) data — II: correlation. *Computers & Geosciences*, 32(2):176–183. doi:10.1016/j.cageo.2005.06.021.
- Jones, T. A. (2010). MATLAB functions to analyze directional (azimuthal) data – III: q-sample inference. *Computers & Geosciences*, 36(4):520–525. doi:10.1016/j.cageo.2009.07.011.
- Jones, T. A. and James, W. R. (1969). Analysis of bimodal orientation data. *Mathematical Geosciences*, 1(2):129–135. doi:10.1007/bf02048557.
- Jonsen, I. D., Mills Flemming, J., and Myers, R. A. (2005). Robust state-space modeling of animal movement data. *Ecology*, 86(11):2874–2880. doi:10.1890/04-1852.
- Jonsen, I. D., Myers, R. A., and James, M. C. (2006). Robust hierarchical state-space models reveal diel variation in travel rates of migrating leatherback turtles. *Journal of Animal Ecology*, 75(5):1046–1057. doi:10.1111/j.1365-2656.2006.01129.x.
- Jonsen, I. D., Myers, R. A., and James, M. C. (2007). Identifying leatherback turtle foraging behaviour from satellite telemetry using a switching state-space model. *Marine Ecology Progress Series*, 337:255–264. doi:10.3354/meps337255.

- Jørgensen, B. (1987). Small dispersion asymptotics. *Brazilian Journal of Probability and Statistics*, 1(1):59–90.
- Jung, S., Dryden, I. L., and Marron, J. S. (2012). Analysis of principal nested spheres. *Biometrika*, 99(3):551–568. doi:10.1093/biomet/ass022.
- Jung, S., Foskey, M., and Marron, J. S. (2011). Principal arc analysis on direct product manifolds. *The Annals of Applied Statistics*, 5(1):578–603. doi:10.1214/10-aos370.
- Jung, S., Liu, X., Marron, J. S., and Pizer, S. M. (2010). Generalized PCA via the backward stepwise approach in image analysis. In Angeles, J., Boulet, B., Clark, J. J., Kövecses, J., and Siddiqi, K. (Eds.), *Brain, Body and Machine*, volume 83 of *Advances in Intelligent and Soft Computing*, pp. 111–123, Berlin. Springer. doi:10.1007/978-3-642-16259-6\_9.
- Jupp, P. E. (1984). A Poincaré limit theorem for wrapped probability distributions on compact symmetric spaces. *Mathematical Proceedings of the Cambridge Philosophical Society*, 95(2):329–334. doi:10.1017/s0305004100061600.
- Jupp, P. E. (1987). A non-parametric correlation coefficient and a two-sample test for random vectors or directions. *Biometrika*, 74(4):887–890. doi:10.1093/biomet/74.4.887.
- Jupp, P. E. (1988). Residuals for directional data. *Journal of Applied Statistics*, 15(2):137–147. doi:10.1080/02664768800000021.
- Jupp, P. E. (1995). Some applications of directional statistics to astronomy. In Tiit, M., Kollo, T., and Niemi, H. (Eds.), *New Trends in Probability and Statistics*, volume 3, pp. 123–133. VSR, Utrecht.
- Jupp, P. E. (2001). Modifications of the Rayleigh and Bingham tests for uniformity of directions. *Journal of Multivariate Analysis*, 77(1):1–20. doi:10.1006/jmva.2000.1922.
- Jupp, P. E. (2005). Sobolev tests of goodness of fit of distributions on compact Riemannian manifolds. *The Annals of Statistics*, 33(6):2957–2966. doi:10.1214/009053605000000697.
- Jupp, P. E. (2008). Data-driven Sobolev tests of uniformity on compact Riemannian manifolds. *The Annals of Statistics*, 36(3):1246–1260. doi:10.1214/009053607000000541.
- Jupp, P. E. (2009). Data-driven tests of uniformity on product manifolds. *Journal of Statistical Planning and Inference*, 139(11):3820–3829. doi:10.1016/j.jspi.2009.05.019.
- Jupp, P. E. (2015). Copulae on products of compact Riemannian manifolds. *Journal of Multivariate Analysis*, 140:92–98. doi:10.1016/j.jmva.2015.04.008.
- Jupp, P. E. and Kent, J. T. (1987). Fitting smooth paths to spherical data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 36(1):34–46. doi:10.2307/2347843.
- Jupp, P. E., Kim, P. T., Koo, J.-Y., and Wiegert, P. (2003). The intrinsic distribution and selection bias of long-period cometary orbits. *Journal of the American Statistical Association*, 98(463):515–521. doi:10.1198/016214503000000305.
- Jupp, P. E. and Kume, A. (2020). Measures of goodness of fit obtained by almost-canonical transformations on Riemannian manifolds. *Journal of Multivariate Analysis*, 176:104579. doi:10.1016/j.jmva.2019.104579.
- Jupp, P. E. and Mardia, K. V. (1979). Maximum likelihood estimators for the matrix von Mises-Fisher and Bingham distributions. *The Annals of Statistics*, 7(3):599–606. doi:10.1214/aos/1176344681.
- Jupp, P. E. and Mardia, K. V. (1980). A general correlation coefficient for directional data and related regression problems. *Biometrika*, 67(1):163–173. doi:10.1093/biomet/67.1.163.
- Jupp, P. E. and Mardia, K. V. (1981). Amendments and corrections: “A general correlation coefficient for directional data and related regression problems” [*Biometrika* **67** (1980), no. 1, 163–173; MR 82b:62068]. *Biometrika*, 68(3):738. doi:10.2307/2335467.
- Jupp, P. E. and Mardia, K. V. (1989). A unified view of the theory of directional statistics. *International Statistical Review*, 57(3):261–294.
- Jupp, P. E., Regoli, G., and Azzalini, A. (2016). A general setting for symmetric distributions and their relationship to general distributions. *Journal of Multivariate Analysis*, 148:107–119. doi:10.1016/j.jmva.2016.02.011.
- Jupp, P. E. and Spurr, B. D. (1983). Sobolev tests for symmetry of directional data. *The Annals of Statistics*, 11(4):1225–1231. doi:10.1214/aos/1176346335.
- Jupp, P. E. and Spurr, B. D. (1985). Sobolev tests for independence of directions. *The Annals of Statistics*, 13(3):1140–1155. doi:10.1214/aos/1176349661.
- Jupp, P. E. and Spurr, B. D. (1989). Statistical estimation of a shock centre: slate islands astrobleme. *Mathematical Geology*, 21(2):191–198. doi:10.1007/bf00893214.
- Jupp, P. E., Spurr, B. D., Nichols, G. J., and Hirst, J. P. P. (1987). Statistical estimation of the apex of a sedimentary distributary system. *Mathematical Geology*, 19(4):319–333.
- Kac, M. and Van Kampen, E. R. (1939). Circular equidistributions and statistical independence. *American Journal of Mathematics*, 61(3):677–682. doi:10.2307/2371322.
- Kadum, H. F., Knowles, D., and Cal, R. B. (2019). Quantification of preferential contribution of Reynolds shear stresses and flux of mean kinetic energy via conditional sampling in a wind turbine array. *Journal of Fluids Engineering*, 141(2):021201.
- Kagan, A. M., Rao, C. R., and Linnik, Y. V. (1973). *Characterization Problems in Mathematical Statistics*. Wiley Series in Probability and Mathematical Statistics. Wiley, New York.
- Kaiser, R. (2006). On the geomagnetic direction problem: a nonexistence result. In Monaco, R., Mulone, G., Rionero, S., and Ruggeri, T. (Eds.), *Proceedings “WASCOM 2005” 13th Conference on Waves and Stability in Continuous Media*, pp.

- 292–297, Singapore. World Scientific. doi:10.1142/9789812773616\_0039.
- Kaiser, R. (2012). Uniqueness and non-uniqueness in the non-axisymmetric direction problem. *The Quarterly Journal of Mechanics and Applied Mathematics*, 65(3):357–360. doi:10.1093/qjmath/hbs005.
- Kakarala, R. and Watson, G. S. (1997). Lower bounds for the divergence of directional and axial estimators. *Australian Journal of Statistics*, 39(3):253–260. doi:10.1111/j.1467-842x.1997.tb00690.x.
- Kanatani, K. (1984). Distribution of directional data and fabric tensors. *International Journal of Engineering Science*, 22(2):149–164. doi:10.1016/0020-7225(84)90090-9.
- Kanika, Kumar, S., and SenGupta, A. (2015). A unified approach to decision-theoretic properties of the MLEs for the mean directions of several Langevin distributions. *Journal of Multivariate Analysis*, 133:160–172. doi:10.1016/j.jmva.2014.09.002.
- Kanzawa, Y. (2015). On possibilistic clustering methods based on Shannon/Tsallis-entropy for spherical data and categorical multivariate data. In Torra, V. and Narukawa, Y. (Eds.), *Modeling Decisions for Artificial Intelligence*, volume 9321 of *Lecture Notes in Computer Science*, pp. 115–128, Cham. Springer. doi:10.1007/978-3-319-23240-9\_10.
- Kanzawa, Y. (2016). On Bezdek-type possibilistic clustering for spherical data, its kernelization, and spectral clustering approach. In Torra, V., Narukawa, Y., Navarro-Arribas, G., and Yañez, C. (Eds.), *Modeling Decisions for Artificial Intelligence*, volume 9880 of *Lecture Notes in Computer Science*, pp. 178–190, Cham. Springer. doi:10.1007/978-3-319-45656-0\_15.
- Karmaker, S. C. (2016). *On Some Circular Distributions Induced by Inverse Stereographic Projection*. PhD thesis, Concordia University.
- Karney, C. F. F. (2013). Algorithms for geodesics. *Journal of Geodesy*, 87(1):43–55.
- Kasarapu, P. and Allison, L. (2015). Minimum message length estimation of mixtures of multivariate Gaussian and von Mises-Fisher distributions. *Machine Learning*, 100(2-3):333–378. doi:10.1007/s10994-015-5493-0.
- Kato, S. (2007). *Statistical Models for Data Which Include Angular Observations*. PhD thesis, Keio University.
- Kato, S. (2009). A distribution for a pair of unit vectors generated by Brownian motion. *Bernoulli*, 15(3):898–921. doi:10.3150/08-bej178.
- Kato, S. (2010). A Markov process for circular data. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 72(5):655–672. doi:10.1111/j.1467-9868.2010.00748.x.
- Kato, S. and Eguchi, S. (2016). Robust estimation of location and concentration parameters for the von Mises-Fisher distribution. *Statistical Papers*, 57(1):205–234.
- Kato, S. and Jones, M. C. (2010). A family of distributions on the circle with links to, and applications arising from, Möbius transformation. *Journal of the American Statistical Association*, 105(489):249–262. doi:10.1198/jasa.2009.tm08313.
- Kato, S. and Jones, M. C. (2013). An extended family of circular distributions related to wrapped Cauchy distributions via Brownian motion. *Bernoulli*, 19(1):154–171. doi:10.3150/11-bej397.
- Kato, S. and Jones, M. C. (2015). A tractable and interpretable four-parameter family of unimodal distributions on the circle. *Biometrika*, 102(1):181–190. doi:10.1093/biomet/asu059.
- Kato, S. and McCullagh, P. (2020). Some properties of a Cauchy family on the sphere derived from the Möbius transformations. *Bernoulli*, 26(4):3224–3248. doi:10.3150/20-BEJ1222.
- Kato, S. and Pewsey, A. (2015). A Möbius transformation-induced distribution on the torus. *Biometrika*, 102(2):359–370. doi:10.1093/biomet/asv003.
- Kato, S., Pewsey, A., and Jones, M. C. (2018). Circulas from Fourier series. Technical Report 7, School of Mathematics and Statistics, Open University.
- Kato, S. and Shimizu, K. (2008). Dependent models for observations which include angular ones. *Journal of Statistical Planning and Inference*, 138(11):3538–3549. doi:10.1016/j.jspi.2006.12.009.
- Kato, S., Shimizu, K., and Shieh, G. S. (2008). A circular-circular regression model. *Statistica Sinica*, 18(2):633–645.
- Kaufman, C. G., Ventura, V., and Kass, R. E. (2005). Spline-based non-parametric regression for periodic functions and its application to directional tuning of neurons. *Statistics in Medicine*, 24(14):2255–2265. doi:10.1002/sim.2104.
- Keilson, J., Petrondas, D., Sumita, U., and Wellner, J. (1983). Significance points for some tests of uniformity on the sphere. *Journal of Statistical Computation and Simulation*, 17(3):195–218. doi:10.1080/00949658308810656.
- Kelker, D. G. and Langenberg, C. W. (1987). A mathematical model for orientation data from macroscopic elliptical conical folds. *Mathematical Geology*, 19(8):729–743. doi:10.1007/bf00893011.
- Kendall, D. G. (1974a). Hunting quanta. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 276(1257):231–266.
- Kendall, D. G. (1974b). Pole-seeking Brownian motion and bird navigation. *Journal of the Royal Statistical Society, Series B (Methodological)*, 36(3):365–417. doi:10.1111/j.2517-6161.1974.tb01013.x.
- Kendall, D. G. (1984). Shape manifolds, Procrustean metrics, and complex projective space. *Bulletin of the London Mathematical Society*, 16(2):81–121. doi:10.1112/blms/16.2.81.
- Kendall, D. G. (1985). Exact distributions for shapes of random triangles in convex sets. *Advances in Applied Probability*, 17(2):308–329. doi:10.2307/1427143.
- Kendall, D. G., Barden, D., Carne, T. K., and Le, H. (1999). *Shape and Shape Theory*. Wiley Series in Probability and Statistics. Wiley, Chichester. doi:10.1002/9780470317006.

- Kendall, D. G. and Young, G. A. (1984). Indirectional statistics and the significance of an asymmetry discovered by Birch. *Monthly Notices of the Royal Astronomical Society*, 207(3):637–647. doi:10.1093/mnras/207.3.637.
- Kendall, M. G. (1957). *A Course in Multivariate Analysis*. Griffin, London.
- Kendall, M. G. and Stuart, A. (1969). *The Advanced Theory of Statistics*. Hafner Publishing Company, New York, third edition.
- Kent, J. (1978a). Time-reversible diffusions. *Advances in Applied Probability*, 10(4):819–835. doi:10.2307/1426661.
- Kent, J. T. (1975). Discussion of “Statistics of directional data”. *Journal of the Royal Statistical Society, Series B (Methodological)*, 37(3):377–378. doi:10.1111/j.2517-6161.1975.tb01550.x.
- Kent, J. T. (1977). The infinite divisibility of the von Mises-Fisher distribution for all values of the parameter in all dimensions. *Proceedings of the London Mathematical Society*, s3-35(2):359–384. doi:10.1112/plms/s3-35.2.359.
- Kent, J. T. (1978b). Limiting behaviour of the von Mises-Fisher distribution. *Mathematical Proceedings of the Cambridge Philosophical Society*, 84(3):531–536. doi:10.1017/s030500410005533x.
- Kent, J. T. (1978c). Some probabilistic properties of Bessel functions. *The Annals of Probability*, 6(5):760–770. doi:10.1214/aop/1176995427.
- Kent, J. T. (1982). The Fisher-Bingham distribution on the sphere. *Journal of the Royal Statistical Society, Series B (Methodological)*, 44(1):71–80. doi:10.1111/j.2517-6161.1982.tb01189.x.
- Kent, J. T. (1983a). Identifiability of finite mixtures for directional data. *The Annals of Statistics*, 11(3):954–988. doi:10.1214/aos/1176346264.
- Kent, J. T. (1983b). Information gain and a general measure of correlation. *Biometrika*, 70(1):163–173. doi:10.1093/biomet/70.1.163.
- Kent, J. T. (1987). Asymptotic expansions for the Bingham distribution. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 36(2):139–144. doi:10.2307/2347545.
- Kent, J. T., Bhattacharjee, S., Faber, W. R., and Hussein, I. I. (2020). A unified approach to the orbital tracking problem. In *2020 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 82–87, New York. IEEE. doi:10.1109/MFI49285.2020.9235258.
- Kent, J. T., Bhattacharjee, S., Hussein, I., and Jah, M. K. (2017a). Geometric restructurization of the space object tracking problem for improved uncertainty representation. In Flohrer, T. and Schmitz, F. (Eds.), *Proceedings 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017*. ESA Space Debris Office.
- Kent, J. T., Bhattacharjee, S., Hussein, I. I., Faber, W. R., and Jah, M. (2018a). Fisher-Bingham-Kent mixture models for angles-only observation processing. In *2018 Space Flight Mechanics Meeting*, Reston. American Institute of Aeronautics and Astronautics. doi:10.2514/6.2018-1972.
- Kent, J. T., Bhattacharjee, S., Hussein, I. I., and Jah, M. (2018b). Nonlinear filtering using directional statistics for the orbital tracking problem with perturbation effects. In *2018 Space Flight Mechanics Meeting*, Reston. American Institute of Aeronautics and Astronautics. doi:10.2514/6.2018-0474.
- Kent, J. T., Bhattacharjee, S., Hussein, I. I., and Jah, M. K. (2017b). Angles-only data association using directional discrimination analysis. In McMahon, J. W., Leve, F. W., Guo, Y., and Sims, J. A. (Eds.), *Spaceflight Mechanics 2017*, volume 160 of *Advances in the Astronautical Sciences Series*, pp. 1287–1293, San Diego. Univelt.
- Kent, J. T., Bhattacharjee, S., Hussein, I. I., and Jah, M. K. (2017c). Orbital error propagation analysis using directional statistics for space objects. In McMahon, J. W., Leve, F. W., Guo, Y., and Sims, J. A. (Eds.), *Spaceflight Mechanics 2017*, volume 160 of *Advances in the Astronautical Sciences Series*, pp. 1277–1286, San Diego. Univelt.
- Kent, J. T., Bhattacharjee, S., Hussein, I. I., and Jah, M. K. (2018c). The performance of a direction-based Bayesian filter in the orbital tracking problem. In Parker, J. S., Seago, J. H., Strange, N. J., and Scheeres, D. J. (Eds.), *Astrodynamics 2017*, volume 162 of *Advances in the Astronautical Sciences Series*, pp. 1287–1293, San Diego. Univelt.
- Kent, J. T., Briden, J. C., and Mardia, K. V. (1983). Linear and planar structure in ordered multivariate data as applied to progressive demagnetization of palaeomagnetic remanence. *Geophysical Journal International*, 75(3):593–621. doi:10.1111/j.1365-246x.1983.tb05001.x.
- Kent, J. T., Ganeiber, A. M., and Mardia, K. V. (2018d). A new unified approach for the simulation of a wide class of directional distributions. *Journal of Computational and Graphical Statistics*, 27(2):291–301. doi:10.1080/10618600.2017.1390468.
- Kent, J. T., I. Hussein, I., and Jah, M. K. (2016). Directional distributions in tracking of space debris. In *2016 19th International Conference on Information Fusion (FUSION)*, pp. 2081–2086, New York. IEEE.
- Kent, J. T. and Mardia, K. V. (1997). Consistency of Procrustes estimators. *Journal of the Royal Statistical Society, Series B (Methodological)*, 59(1):281–290. doi:10.1111/1467-9868.00069.
- Kent, J. T. and Mardia, K. V. (2009). Principal component analysis for the wrapped normal torus model. In Gusnanto, A., Mardia, K. V., and Fallaize, C. J. (Eds.), *LASR 2009 – Statistical Tools for Challenges in Bioinformatics*, pp. 39–41, Leeds. Department of Statistics, University of Leeds.
- Kent, J. T. and Mardia, K. V. (2015). The winding number for circular data. In Mardia, K. V., Gusnanto, A., Nooney, C., and Voss, J. (Eds.), *LASR 2015 – Geometry-Driven Statistics and its Cutting Edge Applications: Celebrating Four Decades of Leeds Statistics Workshops*, pp. 47–50, Leeds. Department of Statistics, University of Leeds.

- Kent, J. T., Mardia, K. V., and McDonnell, P. (2006). The complex Bingham quartic distribution and shape analysis. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 68(5):747–765. doi:10.1111/j.1467-9868.2006.00565.x.
- Kent, J. T., Mardia, K. V., and Rao, J. S. (1979). A characterization of the uniform distribution on the circle. *The Annals of Statistics*, 7(4):882–889. doi:10.1214/aos/1176344737.
- Kent, J. T., Mardia, K. V., and Taylor, C. C. (2008). Modelling strategies for bivariate circular data. In Barber, S., Baxter, P. D., Gusnanto, A., and Mardia, K. V. (Eds.), *LASR 2008 – The Art & Science of Statistical Bioinformatics*, pp. 70–73, Leeds. Department of Statistics, University of Leeds.
- Kent, J. T. and Tyler, D. E. (1988). Maximum likelihood estimation for the wrapped Cauchy distribution. *Journal of Applied Statistics*, 15(2):247–254. doi:10.1080/02664768800000029.
- Kerkycharian, G., Pham Ngoc, T. M., and Picard, D. (2011). Localized spherical deconvolution. *The Annals of Statistics*, 39(2):1042–1068. doi:10.1214/10-aos858.
- Kesemen, O., Tezel, Ö., and Özkul, E. (2016). Fuzzy  $c$ -means clustering algorithm for directional data (FCM4DD). *Expert systems with applications*, 58:76–82. doi:10.1016/j.eswa.2016.03.034.
- Kesemen, O., Tezel, Ö., Özkul, E., and Tiryaki, B. K. (2020). Fuzzy  $c$ -means directional clustering (fcmde) algorithm using trigonometric approximation. *Turkish Journal of Electrical Engineering & Computer Sciences*, 28:140–152. doi:10.3906/elk-1903-118.
- Khan, A. H. and Yaqub, M. (1980). Distribution of a distance function. *Annals of the Institute of Statistical Mathematics*, 32(1):247–253. doi:10.1007/bf02480329.
- Khang, T. F., Soo, O. Y. M., Tan, W. B., and Lim, L. H. S. (2016). Monogenean anchor morphometry: systematic value, phylogenetic signal, and evolution. *PeerJ*, 4:e1668. doi:10.7717/peerj.1668.
- Khatri, C. G. and Mardia, K. V. (1977). The von Mises-Fisher matrix distribution in orientation statistics. *Journal of the Royal Statistical Society, Series B (Methodological)*, 39(1):95–106. doi:10.1111/j.2517-6161.1977.tb01610.x.
- Kikuchi, D. A. (1982). Directional data abstracts: 1972-1981. Technical Report 265, Department of Statistics, Ohio State University.
- Kim, B., Huckemann, S., Schulz, J., and Jung, S. (2019). Small-sphere distributions for directional data with application to medical imaging. *Scandinavian Journal of Statistics*, 46(4):1047–1071. doi:10.1111/sjos.12381.
- Kim, N. C. and So, H. J. (2018). Directional statistical Gabor features for texture classification. *Pattern Recognition Letters*, 112:18–26. doi:10.1016/j.patrec.2018.05.010.
- Kim, P. T. (1991). Decision theoretic analysis of spherical regression. *Journal of Multivariate Analysis*, 38(2):233–240. doi:10.1016/0047-259x(91)90042-z.
- Kim, P. T. (1998). Deconvolution density estimation on  $SO(N)$ . *The Annals of Statistics*, 26(3):1083–1102. doi:10.1214/aos/1024691089.
- Kim, P. T. and Koo, J.-Y. (2002). Optimal spherical deconvolution. *Journal of Multivariate Analysis*, 80(1):21–42. doi:10.1006/jmva.2000.1968.
- Kim, P. T., Koo, J. Y., and Park, H. J. (2004). Sharp minimaxity and spherical deconvolution for super-smooth error distributions. *Journal of Multivariate Analysis*, 90(2):384–392. doi:10.1016/j.jmva.2003.08.004.
- Kim, P. T., Koo, J.-Y., and Pham Ngoc, T. M. (2016). Supersmooth testing on the sphere over analytic classes. *Journal of Nonparametric Statistics*, 28(1):84–115. doi:10.1080/10485252.2015.1113284.
- Kimball, B. F. (1950). On the asymptotic distribution of the sum of powers of unit frequency differences. *Annals of Mathematical Statistics*, 21(2):263–271. doi:10.1214/aoms/1177729843.
- Kimber, A. C. (1985). A note on the detection and accommodation of outliers relative to Fisher’s distribution on the sphere. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 34(2):169–172. doi:10.2307/2347369.
- Klemelä, J. (1999). Asymptotic minimax risk for the white noise model on the sphere. *Scandinavian Journal of Statistics*, 26(3):465–473. doi:10.1111/1467-9469.00160.
- Klemelä, J. (2000). Estimation of densities and derivatives of densities with directional data. *Journal of Multivariate Analysis*, 73(1):18–40. doi:10.1006/jmva.1999.1861.
- Klemelä, J. (2003). Lower bounds for the asymptotic minimax risk with spherical data. *Journal of Statistical Planning and Inference*, 113(1):113–136. doi:10.1016/S0378-3758(01)00303-2.
- Klemelä, J. S. (1997). *Estimation of Densities and Functionals of Densities with Spherical Data*. PhD thesis, Helsingin Yliopisto.
- Klotz, J. (1959). Null distribution of the Hodges bivariate sign test. *Annals of Mathematical Statistics*, 30(4):1029–1033. doi:10.1214/aoms/1177706086.
- Klotz, J. (1964). Small sample power of the bivariate sign tests of Blumen and Hodges. *Annals of Mathematical Statistics*, 35(4):1576–1582. doi:10.1214/aoms/1177700382.
- Klugkist, I., Bullens, J., and Postma, A. (2012). Evaluating order-constrained hypotheses for circular data using permutation tests. *British Journal of Mathematical and Statistical Psychology*, 65(2):222–236. doi:10.1111/j.2044-8317.2011.02018.x.
- Klugkist, I., Cremers, J., and Mulder, K. (2018). Bayesian analysis of circular data in social and behavioral sciences. In Ley,



- C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 211–240. CRC Press, Boca Raton.
- Kluyver, J. C. (1906). A local probability theorem. *Koninklijke Nederlandse Akademie Van Wetenschappen. Proceedings Series A: Mathematical Sciences*, pp. 341–350.
- Ko, D. (1985). *Robust Statistics on Compact Metric Spaces*. PhD thesis, University of Washington.
- Ko, D. (1992). Robust estimation of the concentration parameter of the von Mises-Fisher distribution. *The Annals of Statistics*, 20(2):917–928. doi:10.1214/aos/1176348663.
- Ko, D. and Chang, T. (1993). Robust  $M$ -estimators on spheres. *Journal of Multivariate Analysis*, 45(1):104–136. doi:10.1006/jmva.1993.1029.
- Ko, D. and Guttorp, P. (1988). Robustness of estimators for directional data. *The Annals of Statistics*, 16(2):609–618. doi:10.1214/aos/1176350822.
- Kokic, P. N. (1987). On tests of uniformity for randomly distributed arcs on a circle. *Australian & New Zealand Journal of Statistics*, 29(2):179–187. doi:10.1111/j.1467-842x.1987.tb00733.x.
- Koyama, T. (2013). A holonomic ideal which annihilates the Fisher-Bingham integral. *Funkcialaj Ekvacioj*, 56(1):51–61. doi:10.1619/fesi.56.51.
- Koyama, T., Nakayama, H., Nishiyama, K., and Takayama, N. (2014). Holonomic gradient descent for the Fisher-Bingham distribution on the  $d$ -dimensional sphere. *Computational Statistics*, 29(3):661–683. doi:10.1007/s00180-013-0456-z.
- Kozanek, M., Hosseini, A., Liu, F., Van de Velde, S. K., Gill, T. J., Rubash, H. E., and Li, G. (2009). Tibiofemoral kinematics and condylar motion during the stance phase of gait. *Journal of Biomechanics*, 42(12):1877–1884. doi:10.1016/j.jbiomech.2009.05.003.
- Kranstauber, B., Kays, R., LaPoint, S. D., Wikelski, M., and Safi, K. (2012). A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. *Journal of Animal Ecology*, 81(4):738–746. doi:10.1111/j.1365-2656.2012.01955.x.
- Kranstauber, B., Smolla, M., and Scharf, A. K. (2020). *move: Visualizing and Analyzing Animal Track Data*. R package version 4.0.4. URL: <https://CRAN.R-project.org/package=move>.
- Kreiss, J. P. (1987). On adaptive estimation in stationary ARMA processes. *The Annals of Statistics*, 15(1):112–133. doi:10.1214/aos/1176350256.
- Krumbein, W. C. (1939). Preferred orientation of pebbles in sedimentary deposits. *The Journal of Geology*, 47(7):673–706. doi:10.1086/624827.
- Kubiak, T. and Jonas, C. (2007). Applying circular statistics to the analysis of monitoring data - patterns of social interactions and mood. *European Journal of Psychological Assessment*, 23(4):227–237.
- Kucwaj, J.-C., Reboul, S., Stienne, G., Choquel, J.-B., and Benjelloun, M. (2017). Circular regression applied to GNSS-R phase altimetry. *Remote Sensing*, 9(7):651. doi:10.3390/rs9070651.
- Kueh, A. (2012). Locally adaptive density estimation on the unit sphere using needlets. *Constructive Approximation*, 36(3):433–458. doi:10.1007/s00365-012-9170-2.
- Kuhn, W. and Grün, F. (1942). Beziehungen zwischen elastischen Konstanten und Dehnungsdoppelbrechung hochelastischer Stoffe. *Kolloid-Zeitschrift*, 101(3):248–271. doi:10.1007/bf01793684.
- Kuiper, N. H. (1960). Tests concerning random points on the circle. *Koninklijke Nederlandse Akademie Van Wetenschappen. Proceedings Series A: Mathematical Sciences*, 63:38–47. doi:10.1016/s1385-7258(60)50006-0.
- Kume, A., Preston, S. P., and Wood, A. T. A. (2013). Saddlepoint approximations for the normalizing constant of Fisher-Bingham distributions on products of spheres and Stiefel manifolds. *Biometrika*, 100(4):971–984. doi:10.1093/biomet/ast021.
- Kume, A. and Sei, T. (2018). On the exact maximum likelihood inference of Fisher-Bingham distributions using an adjusted holonomic gradient method. *Statistics and Computing*, 28(4):835–847.
- Kume, A. and Walker, S. G. (2006). Sampling from compositional and directional distributions. *Statistics and Computing*, 16(3):261–265. doi:10.1007/s11222-006-8077-9.
- Kume, A. and Walker, S. G. (2009). On the Fisher-Bingham distribution. *Statistics and Computing*, 19(2):167–172.
- Kume, A. and Wood, A. T. A. (2005). Saddlepoint approximations for the Bingham and Fisher-Bingham normalising constants. *Biometrika*, 92(2):465–476. doi:10.1093/biomet/92.2.465.
- Kume, A. and Wood, A. T. A. (2007). On the derivatives of the normalising constant of the Bingham distribution. *Statistics & Probability Letters*, 77(8):832–837. doi:10.1016/j.spl.2006.12.003.
- Kurz, G. (2015). *Directional Estimation for Robotic Beating Heart Surgery*. PhD thesis, Karlsruhe Institute of Technology.
- Kurz, G., Dolgov, M., and Hanebeck, U. D. (2015). Nonlinear stochastic model predictive control in the circular domain. In *2015 American Control Conference (ACC)*, pp. 1623–1628, New York. IEEE. doi:10.1109/ACC.2015.7170965.
- Kurz, G., Faion, F., and Hanebeck, U. D. (2013). Constrained object tracking on compact one-dimensional manifolds based on directional statistics. In *International Conference on Indoor Positioning and Indoor Navigation*, pp. 1–9, New York. IEEE. doi:10.1109/IPIN.2013.6817860.
- Kurz, G., Gilitschenski, I., Dolgov, M., and Hanebeck, U. D. (2014a). Bivariate angular estimation under consideration of dependencies using directional statistics. In *53rd IEEE Conference on Decision and Control*, pp. 2615–2621, New York.

- IEEE. doi:10.1109/CDC.2014.7039789.
- Kurz, G., Gilitschenski, I., and Hanebeck, U. D. (2014b). Deterministic approximation of circular densities with symmetric Dirac mixtures based on two circular moments. In *17th International Conference on Information Fusion (FUSION)*, pp. 1–8, New York. IEEE.
- Kurz, G., Gilitschenski, I., and Hanebeck, U. D. (2014c). Nonlinear measurement update for estimation of angular systems based on circular distributions. In *2014 American Control Conference*, pp. 5694–5699, New York. IEEE. doi:10.1109/ACC.2014.6858982.
- Kurz, G., Gilitschenski, I., and Hanebeck, U. D. (2016a). Recursive Bayesian filtering in circular state spaces. *IEEE Aerospace and Electronic Systems Magazine*, 31(3, 2):70–87. doi:10.1109/maes.2016.150083.
- Kurz, G., Gilitschenski, I., and Hanebeck, U. D. (2016b). Unscented von Mises-Fisher filtering. *IEEE Signal Processing Letters*, 23(4):463–467. doi:10.1109/lsp.2016.2529854.
- Kurz, G., Gilitschenski, I., Julier, S. J., and Hanebeck, U. D. (2014d). Recursive Bingham filter for directional estimation involving 180 degree symmetry. *Journal of Advances in Information Fusion*, 9(2):90–105.
- Kurz, G., Gilitschenski, I., Pfaff, F., Drude, L., Hanebeck, U. D., Haeb-Umbach, R., and Siegwart, R. Y. (2019). Directional statistics and filtering using libDirectional. *Journal of Statistical Software*, 89(4):1–31. doi:10.18637/jss.v089.i04.
- Kurz, G., Gilitschenski, I., Siegwart, R. Y., and Hanebeck, U. D. (2016c). Methods for deterministic approximation of circular densities. *Journal of Advances in Information Fusion*, 11(2):138–156.
- Kurz, G. and Hanebeck, U. D. (2015a). Heart phase estimation using directional statistics for robotic beating heart surgery. In *2015 18th International Conference on Information Fusion (Fusion)*, pp. 703–710, New York. IEEE.
- Kurz, G. and Hanebeck, U. D. (2015b). Stochastic sampling of the hyperspherical von mises–fisher distribution without rejection methods. In *2015 Sensor Data Fusion: Trends, Solutions, Applications (SDF)*, pp. 1–6, New York. IEEE. doi:10.1109/SDF.2015.7347705.
- Kurz, G. and Hanebeck, U. D. (2015c). Toroidal information fusion based on the bivariate von Mises distribution. In *2015 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 309–315, New York. IEEE. doi:10.1109/MFI.2015.7295826.
- Kurz, G. and Hanebeck, U. D. (2017). Deterministic sampling on the torus for bivariate circular estimation. *IEEE Transactions on Aerospace and Electronic Systems*, 53(1):530–534. doi:10.1109/TAES.2017.2650079.
- Kurz, G., Pfaff, F., and Hanebeck, U. D. (2016d). Discrete recursive Bayesian filtering on intervals and the unit circle. In *2016 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 442–448, New York. IEEE. doi:10.1109/MFI.2016.7849528.
- Kurz, G., Pfaff, F., and Hanebeck, U. D. (2016e). Kullback–Leibler divergence and moment matching for hyperspherical probability distributions. In *2016 19th International Conference on Information Fusion (FUSION)*, pp. 2087–2094, New York. IEEE.
- Kurz, G., Pfaff, F., and Hanebeck, U. D. (2017). Nonlinear toroidal filtering based on bivariate wrapped normal distributions. In *2017 20th International Conference on Information Fusion (FUSION)*, pp. 1–8, New York. IEEE. doi:10.23919/ICIF.2017.8009831.
- Kutil, R. (2012). Biased and unbiased estimation of the circular mean resultant length and its variance. *Statistics*, 46(4):549–561.
- Lacour, C. and Pham Ngoc, T. M. (2014). Goodness-of-fit test for noisy directional data. *Bernoulli*, 20(4):2131–2168. doi:10.3150/13-bej553.
- Lagona, F. (2016). Regression analysis of correlated circular data based on the multivariate von Mises distribution. *Environmental and Ecological Statistics*, 23(1):89–113. doi:10.1007/s10651-015-0330-y.
- Lagona, F. (2018). Correlated cylindrical data. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 45–59. CRC Press, Boca Raton.
- Lagona, F., Jdanov, D., and Shkolnikova, M. (2014). Latent time-varying factors in longitudinal analysis: a linear mixed hidden Markov model for heart rates. *Statistics in Medicine*, 33(23):4116–4134. doi:10.1002/sim.6220.
- Lagona, F. and Picone, M. (2011). A latent-class model for clustering incomplete linear and circular data in marine studies. *Journal of Data Science*, 9(4):585–605.
- Lagona, F. and Picone, M. (2012). Model-based clustering of multivariate skew data with circular components and missing values. *Journal of Applied Statistics*, 39(5):927–945. doi:10.1080/02664763.2011.626850.
- Lagona, F. and Picone, M. (2013a). Classification of multivariate linear-circular data with nonignorable missing values. In Grigoletto, M., Lisi, F., and Petrone, S. (Eds.), *Complex Models and Computational Methods in Statistics*, Contributions to Statistics, pp. 161–173. Springer, Milan. doi:10.1007/978-88-470-2871-5\_13.
- Lagona, F. and Picone, M. (2013b). Maximum likelihood estimation of bivariate circular hidden Markov models from incomplete data. *Journal of Statistical Computation and Simulation*, 83(7):1223–1237. doi:10.1080/00949655.2012.656642.
- Lagona, F. and Picone, M. (2016). Model-based segmentation of spatial cylindrical data. *Journal of Statistical Computation and Simulation*, 86(13):2598–2610.
- Lagona, F., Picone, M., and Maruotti, A. (2015a). A hidden Markov model for the analysis of cylindrical time series.

- Environmetrics*, 26(8):534–544. doi:10.1002/env.2355.
- Lagona, F., Picone, M., Maruotti, A., and Cosoli, S. (2015b). A hidden Markov approach to the analysis of space-time environmental data with linear and circular components. *Stochastic Environmental Research and Risk Assessment*, 29(2):397–409.
- Laha, A. K. and Mahesh, K. C. (2012). SB-robust estimator for the concentration parameter of circular normal distribution. *Statistical Papers*, 53(2):457–467.
- Laha, A. K. and Mahesh, K. C. (2015). Robustness of tests for directional mean. *Statistics*, 49(3):522–536.
- Laha, A. K. and Putatunda, S. (2018). Real time location prediction with taxi-GPS data streams. *Transportation Research Part C: Emerging Technologies*, 92:298–322. doi:10.1016/j.trc.2018.05.005.
- Laha, A. K., Raja, A. C. P., and Mahesh, K. C. (2019). SB-robust estimation of mean direction for some new circular distributions. *Statistical Papers*, 60(3):527–552. doi:10.1007/s00362-016-0853-9.
- Landler, L., Ruxton, G. D., and Malkemper, E. P. (2018). Circular data in biology: advice for effectively implementing statistical procedures. *Behavioral Ecology and Sociobiology*, 72(8):128. doi:10.1007/s00265-018-2538-y.
- Landler, L., Ruxton, G. D., and Malkemper, E. P. (2019a). Circular statistics meets practical limitations: a simulation-based Rao’s spacing test for non-continuous data. *Movement Ecology*, 7(1):15. doi:10.1186/s40462-019-0160-x.
- Landler, L., Ruxton, G. D., and Malkemper, E. P. (2019b). The Hermans–Rasson test as a powerful alternative to the Rayleigh test for circular statistics in biology. *BMC Ecology*, 19:30. doi:10.1186/s12898-019-0246-8.
- Langevin, P. (1905a). Magnétisme et théorie des électrons. *Annales de Chimie et de Physique*, 5:70–127.
- Langevin, P. (1905b). Sur la théorie du magnétisme. *Journal de Physique Théorique et Appliquée*, 4(1):678–693. doi:10.1051/jphysap:019050040067800.
- Langrock, R., King, R., Matthiopoulos, J., Thomas, L., Fortin, D., and Morales, J. M. (2012). Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions. *Ecology*, 93(11):2336–2342. doi:10.1890/11-2241.1.
- Lark, R. M., Clifford, D., and Waters, C. N. (2013). Modelling complex geological angular data with the projected normal distribution and mixtures of von Mises distributions. *Solid Earth Discussions*, 5(2):2181–2202. doi:10.5194/se-5-631-2014.
- Larriba, Y., Rueda, C., Fernández, M. A., and Peddada, S. D. (2020). Order restricted inference in chronobiology. *Statistics in Medicine*, 39(3):265–278. doi:10.1002/sim.8397.
- Larsen, P. V., Blaesild, P., and Sørensen, M. K. (2002). Improved likelihood ratio tests on the von Mises-Fisher distribution. *Biometrika*, 89(4):947–951. doi:10.1093/biomet/89.4.947.
- Laubscherand, N. F. and Rudolph, G. J. (1968). A distribution arising from random points on the circumference of a circle. Technical Report 268, Council for Scientific and Industrial Research, Pretoria.
- Lawson, A. (1988a). Fitting the von Mises distribution using GLIM. *Journal of Applied Statistics*, 15(2):255–260. doi:10.1080/02664768800000030.
- Lawson, A. (1988b). On tests for spatial trend in a non-homogeneous Poisson process. *Journal of Applied Statistics*, 15(2):225–234. doi:10.1080/02664768800000027.
- Lawson, A. B. (1992). GLIM and normalising constant models in spatial and directional data analysis. *Computational Statistics & Data Analysis*, 13(3):331–348. doi:10.1016/0167-9473(92)90140-b.
- Laycock, P. J. (1975). Optimal design: regression models for directions. *Biometrika*, 62(2):305–311. doi:10.1093/biomet/62.2.305.
- Le Bihan, N., Chatelain, F., and Manton, J. H. (2016). Isotropic multiple scattering processes on hyperspheres. *IEEE Transactions on Information Theory*, 62(10):5740–5752. doi:10.1109/TIT.2015.2508932.
- Le Cam, L. (1960). Locally asymptotically normal families of distributions. *University of California Publications in Statistics*, 3:27–98.
- Le Cam, L. (1986). *Asymptotic Methods in Statistical Decision Theory*. Springer Series in Statistics. Springer, New York. doi:10.1007/978-1-4612-4946-7.
- Le Cam, L. and Yang, G. (2000). *Asymptotics in Statistics*. Springer Series in Statistics. Springer, New York, second edition. doi:10.1007/978-1-4612-1166-2.
- Lee, A. (2010). Circular data. *Wiley Interdisciplinary Reviews: Computational Statistics*, 2(4):477–486. doi:10.1002/wics.98.
- Lee, D. and Plataniotis, K. N. (2015). Towards a full-reference quality assessment for color images using directional statistics. *IEEE Transactions on Image Processing*, 24(11):3950–3965. doi:10.1109/tip.2015.2456419.
- Lee, G., Ding, Y., Genton, M. G., and Xie, L. (2015). Power curve estimation with multivariate environmental factors for inland and offshore wind farms. *Journal of the American Statistical Association*, 110(509):56–67. doi:10.1080/01621459.2014.977385.
- Lee, J. C. (1980). A circular sign test for uniformity. In Matusita, K. (Ed.), *Recent Developments in Statistical Inference and Data Analysis*, pp. 191–195, New York. North-Holland.
- Lee, J. M. and Ruymgaart, F. H. (1996). Nonparametric curve estimation on Stiefel manifolds. *Journal of Nonparametric Statistics*, 6(1):57–68. doi:10.1080/10485259608832663.
- Lee, J.-R. and Ho, H.-S. (2008). Circular statistics in musicology. *Communications of the Korean Statistical Society*, 15(2):273–282. doi:10.5351/ckss.2008.15.2.273.
- Lee, Y. and Kim, W. C. (2014). Concise formulas for the surface area of the intersection of two hyperspherical caps. Technical

- report, Korea Advanced Institute of Science and Technology.
- de Leeuw, J., Hornik, K., and Mair, P. (2009). Isotone optimization in R: pool-adjacent-violators algorithm (PAVA) and active set methods. *Journal of Statistical Software*, 32(5):1–24. doi:10.18637/jss.v032.i05.
- Leguey, I., Bielza, C., and Larrañaga, P. (2019a). Circular Bayesian classifiers using wrapped Cauchy distributions. *Data & Knowledge Engineering*, 122:101–115. doi:10.1016/j.datak.2019.05.005.
- Leguey, I., Bielza, C., Larrañaga, P., Kastanauskaitė, A., Rojo, C., Benavides-Piccione, R., and De Felipe, J. (2016). Dendritic branching angles of pyramidal cells across layers of the juvenile rat somatosensory cortex. *Journal of Comparative Neurology*, 524(13):2567–2576. doi:10.1002/cne.23977.
- Leguey, I., Larrañaga, P., Bielza, C., and Kato, S. (2019b). A circular-linear dependence measure under Johnson-Wehrly distributions and its application in Bayesian networks. *Information Sciences*, 486:240–253. doi:10.1016/j.ins.2019.01.080.
- Leguey Vitoriano, I. (2018). *Directional-Linear Bayesian Networks and Applications in Neuroscience*. PhD thesis, Universidad Politécnica de Madrid.
- Lehmacher, W. and Lienert, G. A. (1980). Note on a binomial test against sectoral preference of circular observations. *Biometrical Journal*, 22(3):249–252. doi:10.1002/bimj.4710220306.
- Lehmann, E. L. (1959). *Testing Statistical Hypotheses*. Wiley, New York.
- Lehmann, E. L. and Romano, J. P. (2005). *Testing Statistical Hypotheses*. Springer Texts in Statistics. Springer, New York, third edition. doi:10.1007/0-387-27605-X.
- Leng, K. and Yang, Q. (2012). Fabric tensor characterization of tensor-valued directional data: solution, accuracy, and symmetrization. *Journal of Applied Mathematics*, pp. 516060. doi:10.1155/2012/516060.
- Lennox, K. P., Dahl, D. B., Vannucci, M., Day, R., and Tsai, J. W. (2010). A Dirichlet process mixture of hidden Markov models for protein structure prediction. *The Annals of Applied Statistics*, 4(2):916–942. doi:10.1214/09-A0AS296.
- Lennox, K. P., Dahl, D. B., Vannucci, M., and Tsai, J. W. (2009). Density estimation for protein conformation angles using a bivariate von Mises distribution and Bayesian nonparametrics. *Journal of the American Statistical Association*, 104(486):586–596. doi:10.1198/jasa.2009.0024.
- Lenth, R. V. (1981a). On finding the source of a signal. *Technometrics*, 23(2):149–154. doi:10.1080/00401706.1981.10486257.
- Lenth, R. V. (1981b). Robust measures of location for directional data. *Technometrics*, 23(1):77–81. doi:10.2307/1267979.
- León, C. A., Massé, J.-C., and Rivest, L.-P. (2006). A statistical model for random rotations. *Journal of Multivariate Analysis*, 97(2):412–430. doi:10.1016/j.jmva.2005.03.009.
- Leonenko, N. N. and Ruiz-Medina, M. D. (2018). Increasing domain asymptotics for the first Minkowski functional of spherical random fields. *Theory of Probability and Mathematical Statistics*, 97:127–149. doi:10.1090/tpms/1053.
- Leong, P. and Carlile, S. (1998). Methods for spherical data analysis and visualization. *Journal of Neuroscience Methods*, 80(2):191–200. doi:10.1016/S0165-0270(97)00201-X.
- Lesosky, M., Kim, P. T., and Kribs, D. W. (2008). Regularized deconvolution on the 2D-Euclidean motion group. *Inverse Problems*, 24(5):055017. doi:10.1088/0266-5611/24/5/055017.
- Lévy, P. (1939). L’addition des variables aléatoires définies sur une circonférence. *Bulletin de la Société Mathématique de France*, 67:1–41.
- Lewis, T. (1975). Probability functions which are proportional to characteristic functions and the infinite divisibility of the von Mises distribution. *Journal of Applied Probability*, 12(S1):19–28. doi:10.1017/S0021900200047525.
- Lewis, T. (1976). On the infinite divisibility of the von Mises distribution. *Journal of the Australian Mathematical Society*, 22(3):332–342. doi:10.1017/S1446788700014786.
- Lewis, T. and Fisher, N. I. (1982). Graphical methods for investigating the fit of a Fisher distribution to spherical data. *Geophysical Journal International*, 69(1):1–13. doi:10.1111/j.1365-246X.1982.tb04931.X.
- Lewis, T. and Fisher, N. I. (1995). Estimating the angle between the mean directions of two spherical distributions. *Australian Journal of Statistics*, 37(2):179–191. doi:10.1111/j.1467-842X.1995.tb00652.X.
- Ley, C., Paindaveine, D., and Verdebout, T. (2015). High-dimensional tests for spherical location and spiked covariance. *Journal of Multivariate Analysis*, 139:79–91. doi:10.1016/j.jmva.2015.02.019.
- Ley, C., Sabbah, C., and Verdebout, T. (2014). A new concept of quantiles for directional data and the angular Mahalanobis depth. *Electronic Journal of Statistics*, 8(1):795–816. doi:10.1214/14-ejs904.
- Ley, C., Swan, Y., Thiam, B., and Verdebout, T. (2013). Optimal R-estimation of a spherical location. *Statistica Sinica*, 23(1):305–332. doi:10.5705/ss.2011.206.
- Ley, C., Swan, Y., and Verdebout, T. (2017). Efficient ANOVA for directional data. *Annals of the Institute of Statistical Mathematics*, 69(1):39–62. doi:10.1007/s10463-015-0533-X.
- Ley, C. and Verdebout, T. (2014a). Local powers of one- and multi-sample tests for the concentration of Fisher-von Mises-Langevin distributions. *International Statistical Review*, 82(3):440–456.
- Ley, C. and Verdebout, T. (2014b). Simple optimal tests for circular reflective symmetry about a specified median direction. *Statistica Sinica*, 24(3):1319–1339. doi:10.5705/ss.2013.083.
- Ley, C. and Verdebout, T. (2017a). *Modern Directional Statistics*. Chapman & Hall/CRC Interdisciplinary Statistics Series.

- CRC Press, Boca Raton. doi:10.1201/9781315119472.
- Ley, C. and Verdebout, T. (2017b). Skew-rotationally-symmetric distributions and related efficient inferential procedures. *Journal of Multivariate Analysis*, 159:67–81. doi:10.1016/j.jmva.2017.02.010.
- Ley, C. and Verdebout, T. (Eds.) (2018). *Applied Directional Statistics*. Chapman & Hall/CRC Interdisciplinary Statistics Series. CRC Press, Boca Raton. doi:10.1201/9781315228570.
- Li, C., Ma, J., Yang, P., and Li, Z. (2019a). Detection of cloud cover using dynamic thresholds and radiative transfer models from the polarization satellite image. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 222:196–214. doi:10.1016/j.jqsrt.2018.10.026.
- Li, K., Frisch, D., Noack, B., and Hanebeck, U. D. (2019b). Geometry-driven deterministic sampling for nonlinear Bingham filtering. In *2019 18th European Control Conference (ECC)*, pp. 381–387, New York. IEEE. doi:10.23919/ECC.2019.8796102.
- Li, K., Frisch, D., Radtke, S., Noack, B., and Hanebeck, U. D. (2018a). Wavefront orientation estimation based on progressive Bingham filtering. In *2018 Sensor Data Fusion: Trends, Solutions, Applications (SDF)*, pp. 1–6, New York. IEEE. doi:10.1109/SDF.2018.8547094.
- Li, K., Kurz, G., Bernreiter, L., and Hanebeck, U. D. (2018b). Nonlinear progressive filtering for SE(2) estimation. In *2018 21st International Conference on Information Fusion (FUSION)*, pp. 712–719, New York. IEEE. doi:10.23919/ICIF.2018.8455231.
- Li, K., Pfaff, F., and Hanebeck, U. D. (2019c). Hyperspherical deterministic sampling based on Riemannian geometry for improved nonlinear Bingham filtering. In *2019 22th International Conference on Information Fusion (FUSION)*, pp. 1–8, New York. IEEE.
- Li, K., Pfaff, F., and Hanebeck, U. D. (2020a). Hyperspherical unscented particle filter for nonlinear orientation estimation. In *Proceedings of the 1st Virtual IFAC World Congress (IFAC-V 2020)*.
- Li, K., Pfaff, F., and Hanebeck, U. D. (2020b). Nonlinear von Mises–Fisher filtering based on isotropic deterministic sampling. In *2020 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 108–113, New York. IEEE. doi:10.1109/MFI49285.2020.9235260.
- Li, K., Pfaff, F., and Hanebeck, U. D. (2021). Unscented dual quaternion particle filter for SE(3) estimation. *IEEE Control Systems Letters*, 5(2):647–652. doi:10.1109/LCSYS.2020.3005066.
- Li, L. (2014). Moderate deviations results for a symmetry testing statistic based on the kernel density estimator for directional data. *Communications in Statistics – Theory and Methods*, 43(14):3007–3018. doi:10.1080/03610926.2012.694545.
- Li, L. N. and Gao, F. Q. (2009). Rates of strong uniform consistency for kernel density estimators of directional data. *Acta Mathematica Scientia. Series A. Chinese Edition*, 29(3):707–715.
- Li, T.-H. (1999). Multiscale representation and analysis of spherical data by spherical wavelets. *SIAM Journal on Scientific Computing*, 21(3):924–953. doi:10.1137/S1064827598341463.
- Liao, S., Gavves, E., and Snoek, C. G. M. (2019). Spherical regression: learning viewpoints, surface normals and 3D rotations on  $n$ -spheres. In *Proceedings of the 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, New York. IEEE. doi:10.1109/CVPR.2019.00999.
- Liddell, I. G. and Ord, J. K. (1978). Linear-circular correlation coefficients: some further results. *Biometrika*, 65(2):448–450. doi:10.1093/biomet/65.2.448.
- Lin, L., Rao, V., and Dunson, D. (2017a). Bayesian nonparametric inference on the Stiefel manifold. *Statistica Sinica*, 27(2):535–553. doi:10.5705/ss.202016.0017.
- Lin, L., St. Thomas, B., Zhu, H., and Dunson, D. B. (2017b). Extrinsic local regression on manifold-valued data. *Journal of the American Statistical Association*, 112(519):1261–1273. doi:10.1080/01621459.2016.1208615.
- Lin, S.-B. (2019). Nonparametric regression using needlet kernels for spherical data. *Journal of Complexity*, 50:66–83. doi:10.1016/j.jco.2018.09.003.
- Lindman, H. and Caelli, T. (1978). Constant curvature Riemannian scaling. *Journal of Mathematical Psychology*, 17:89–109. doi:10.1016/0022-2496(78)90025-1.
- Liu, D., Peddada, S. D., Li, L., and Weinberg, C. R. (2006). Phase analysis of circadian-related genes in two tissues. *BMC Bioinformatics*, 7(1):87.
- Liu, D., Umbach, D. M., Peddada, S. D., Li, L., Crockett, P. W., and Weinberg, C. R. (2004). A random-periods model for expression of cell-cycle genes. *Proceedings of the National Academy of Sciences of the United States of America*, 101(19):7240–7245. doi:10.1073/pnas.0402285101.
- Liu, P., Heinson, W. R., Sumlin, B. J., Shen, K.-Y., and Chakrabarty, R. K. (2018a). Establishing the kinetics of ballistic-to-diffusive transition using directional statistics. *Physical Review E*, 97(4):042102. doi:10.1103/physreve.97.042102.
- Liu, R. Y., Parelius, J. M., and Singh, K. (1999). Multivariate analysis by data depth: descriptive statistics, graphics and inference. *The Annals of Statistics*, 27(3):783–858.
- Liu, R. Y. and Singh, K. (1992). Ordering directional data: concepts of data depth on circles and spheres. *The Annals of Statistics*, 20(3):1468–1484. doi:10.1214/aos/1176348779.
- Liu, X., Yue, R.-X., and Wong, W. K. (2018b).  $D$ -optimal design for the heteroscedastic Berman model on an arc. *Journal of Multivariate Analysis*, 168:131–141. doi:10.1016/j.jmva.2018.07.003.

- Lo, A. and Cabrera, J. (1987). Bayes procedures for rotationally symmetric models on the sphere. *The Annals of Statistics*, 15(3):1257–1268. doi:10.1214/aos/1176350504.
- Lo, J. T.-H. (1977). Exponential Fourier densities and optimal estimation and detection on the circle. *IEEE Transactions on Information Theory*, 23(1):110–116. doi:10.1109/tit.1977.1055662.
- Lo, J. T.-H. and Eshleman, L. R. (1977). Exponential Fourier densities on  $S^2$  and optimal estimation and detection for directional processes. *IEEE Transactions on Information Theory*, 23(3):321–336. doi:10.1109/tit.1977.1055713.
- Lo, J. T.-H. and Eshleman, L. R. (1979a). Exponential Fourier densities and optimal estimation for axial processes. *IEEE Transactions on Information Theory*, 25(4):463–470. doi:10.1109/tit.1979.1056058.
- Lo, J. T.-H. and Eshleman, L. R. (1979b). Exponential Fourier densities on  $S^0(3)$  and optimal estimation and detection for rotational processes. *SIAM Journal of Applied Mathematics*, 36(1):73–82.
- Loader, C. R. (1996). Local likelihood density estimation. *The Annals of Statistics*, 24(4):1602–1618. doi:10.1214/aos/1032298287.
- Lockhart, R. A. and Stephens, M. A. (1985). Tests of fit for the von Mises distribution. *Biometrika*, 72(3):647–652. doi:10.1093/biomet/72.3.647.
- Lombard, F. (1988). The change-point problem for angular data: a non-parametric approach. *Technometrics*, 28(4):391–397.
- Lombard, F., Hawkins, D. M., and Potgieter, C. (2020). Nonparametric CUSUM charts for angular data with applications in health science and astrophysics. *REVSTAT*, 18(4):461–481.
- Lombard, F., Hawkins, D. M., and Potgieter, C. J. (2017). Sequential rank CUSUM charts for angular data. *Computational Statistics & Data Analysis*, 105:268–279. doi:10.1016/j.csda.2016.08.001.
- Lombard, F. and Maxwell, R. K. (2012). A cusum procedure to detect deviations from uniformity in angular data. *Journal of Applied Statistics*, 39(9):1871–1880. doi:10.1080/02664763.2012.683857.
- López, M. D., Rodrigo, J., and Lantarón, S. (2018). Searching for optimal positions through directional data in a political competition model. *International Journal of Operational Research*, 33(1):127–138. doi:10.1504/IJOR.2018.094234.
- López-Cruz, P. L., Bielza, C., and Larrañaga, P. (2015). Directional naive Bayes classifiers. *Pattern Analysis and Applications*, 18(2):225–246. doi:10.1007/s10044-013-0340-z.
- Lopez-Moreno, I., Ramos, D., Gonzalez-Dominguez, J., and Gonzalez-Rodriguez, J. (2011). von Mises-Fisher models in the total variability subspace for language recognition. *IEEE Signal Processing Letters*, 18(12):705–708. doi:10.1109/lsp.2011.2170566.
- Lord, R. D. (1948). A problem on random vectors. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 39(288):66–71.
- Lord, R. D. (1954). The use of the Hankel transform in statistics: I. general theory and examples. *Biometrika*, 41(1/2):44–55. doi:10.2307/2333004.
- Loudon, T. V. (1964). Computer analysis of orientation data in structural geology. Technical Report 13, Northwestern University.
- Lu, L., Anderson-Cook, C. M., Otieno, B. S., and Hamada, M. S. (2011). Metrics, design and analysis of simulation studies for evaluating directional data methods. *Journal of Statistical Theory and Applications*, 10(2):115–142.
- Lu, Y., Corander, J., and Yang, Z. (2019). Doubly stochastic neighbor embedding on spheres. *Pattern Recognition Letters*, 128:100–106. doi:10.1016/j.patrec.2019.08.026.
- Lukacs, E. (1970). *Characteristic Functions*. Hafner Publishing Company, New York, second edition.
- Lund, U. (1999a). Cluster analysis for directional data. *Communications in Statistics – Simulation and Computation*, 28(4):1001–1009. doi:10.1080/03610919908813589.
- Lund, U. (1999b). Least circular distance regression for directional data. *Journal of Applied Statistics*, 26(6):723–733. doi:10.1080/02664769922160.
- Lund, U. (2002). Tree-based regression for a circular response. *Communications in Statistics – Theory and Methods*, 31(9):1549–1560. doi:10.1081/sta-120013011.
- Lund, U. and Jammalamadaka, S. R. (2000). An entropy-based test for goodness of fit of the von Mises distribution. *Journal of Statistical Computation and Simulation*, 67(4):319–332. doi:10.1080/00949650008812048.
- Lund, U. J. (1998). *Regression and Goodness of Fit for Directional Data*. PhD thesis, University of California at Santa Barbara.
- Lunga, D. and Ersoy, O. (2013). Spherical stochastic neighbor embedding of hyperspectral data. *IEEE Transactions on Geoscience and Remote Sensing*, 51(2):857–871. doi:10.1109/tgrs.2012.2205004.
- Lwin, T. (1975). On von Mises directions. *Annals of the Institute of Statistical Mathematics*, 27(1):79–85. doi:10.1007/bf02504626.
- Maag, U. R. (1966). A  $k$ -sample analogue of Watson’s  $U^2$  statistic. *Biometrika*, 53(3-4):579–583. doi:10.1093/biomet/53.3-4.579.
- Maag, U. R. and Dicaire, G. (1971). On Kolmogorov-Smirnov type one-sample statistics. *Biometrika*, 58(3):653–656. doi:10.1093/biomet/58.3.653.
- van der Maaten, L. J. P. and Hinton, G. E. (2008). Visualizing high-dimensional data using t-SNE. *Journal of Machine Learning Research*, 9(Nov):2579–2605.

- Mackenzie, J. K. (1957). The estimation of an orientation relationship. *Acta Crystallographica*, 10(1):61–62. doi:10.1107/s0365110x57000146.
- Mahmood, E. A., Rana, S., Hussin, A. G., and Midi, H. (2017a). Adjusting outliers in univariate circular data. *Pertanika Journal of Science and Technology*, 25(4):1147–1158.
- Mahmood, E. A., Rana, S., Midi, H., and Hussin, A. G. (2017b). Detection of outliers in univariate circular data using robust circular distance. *Journal of Modern Applied Statistical Methods*, 16(2):22. doi:10.22237/jmasm/1509495720.
- Maitra, R. and Ramler, I. P. (2010). A  $k$ -mean-directions algorithm for fast clustering of data on the sphere. *Journal of Computational and Graphical Statistics*, 19(2):377–396. doi:10.1198/jcgs.2009.08155.
- Maksimov, V. M. (1967). Necessary and sufficient statistics for the family of shifts of probability distributions on continuous bicomact groups (in Russian). *Theoria Veroyatna*, 12(2):307–321.
- Maling, D. H. (1992). *Coordinate Systems and Map Projections*. Pergamon Press, Oxford. doi:10.1016/C2009-0-11149-2.
- Mammassis, K., Stewart, R. W., and Thompson, J. S. (2009). Spatial fading correlation model using mixtures of von Mises-Fisher distributions. *IEEE Transactions on Wireless Communications*, 8(4):2046–2055. doi:10.1109/twc.2009.080505.
- Manly, B. F. J. (2007). *Randomisation, Bootstrap and Monte Carlo Methods in Biology*. Chapman & Hall/CRC Texts in Statistical Science Series. Chapman & Hall, Boca Raton, third edition. doi:10.1201/9781315273075.
- Mann, K. A., Gupta, S., Race, A., Miller, M. A., and Cleary, R. J. (2003). Application of circular statistics in the study of crack distribution around cemented femoral components. *Journal of Biomechanics*, 36(8):1231–1234. doi:10.1016/s0021-9290(03)00091-5.
- Marchetti, G. M. and Scapini, F. (2003). Use of multiple regression models in the study of sandhopper orientation under natural conditions. *Estuarine, Coastal and Shelf Science*, 58(S):207–215. doi:10.1016/s0272-7714(03)00047-7.
- Mardia, K. (2018). A new estimation methodology for standard directional distributions. In *2018 21st International Conference on Information Fusion (FUSION)*, pp. 724–729, New York. IEEE.
- Mardia, K. V. (1967). A non-parametric test for the bivariate two-sample location problem. *Journal of the Royal Statistical Society, Series B (Methodological)*, 29(2):320–342. doi:10.1111/j.2517-6161.1967.tb00699.x.
- Mardia, K. V. (1968). Small sample power of a non-parametric test for the bivariate two-sample location problem in the normal case. *Journal of the Royal Statistical Society, Series B (Methodological)*, 30(1):83–92. doi:10.1111/j.2517-6161.1968.tb01508.x.
- Mardia, K. V. (1969a). On the null distribution of a non-parametric test for the bivariate two-sample problem. *Journal of the Royal Statistical Society, Series B (Methodological)*, 31(1):98–102. doi:10.1111/j.2517-6161.1969.tb00769.x.
- Mardia, K. V. (1969b). On Wheeler and Watson’s two-sample test on a circle. *Sankhyā*, A31(2):177–190.
- Mardia, K. V. (1970). A bivariate non-parametric  $c$ -sample test. *Journal of the Royal Statistical Society, Series B (Methodological)*, 32(1):74–87. doi:10.1111/j.2517-6161.1970.tb00817.x.
- Mardia, K. V. (1972a). A multi-sample uniform scores test on a circle and its parametric competitor. *Journal of the Royal Statistical Society, Series B (Methodological)*, 34(1):102–113. doi:10.1111/j.2517-6161.1972.tb00891.x.
- Mardia, K. V. (1972b). *Statistics of Directional Data*. Probability and Mathematical Statistics. Academic Press, London.
- Mardia, K. V. (1975a). Characterizations of directional distributions. In Patil, G. P., Kotz, S., and Ord, J. K. (Eds.), *A Modern Course on Statistical Distributions in Scientific Work*, volume 17 of *NATO Science Series C: Mathematical and Physical Sciences*, pp. 365–385, Dordrecht. Springer. doi:10.1007/978-94-010-1848-7\_34.
- Mardia, K. V. (1975b). Distribution theory for the von Mises-Fisher distribution and its application. In Patil, G. P., Kotz, S., and Ord, J. K. (Eds.), *A Modern Course on Statistical Distributions in Scientific Work*, volume 17 of *NATO Advanced Study Institutes Series C - Mathematical and Physical Sciences*, pp. 113–130. Springer, Dordrecht. doi:10.1007/978-94-010-1842-5\_10.
- Mardia, K. V. (1975c). Statistics of directional data. *Journal of the Royal Statistical Society, Series B (Methodological)*, 37(3):349–393. doi:10.1111/j.2517-6161.1975.tb01550.x.
- Mardia, K. V. (1976). Linear-circular correlation coefficients and rhythmometry. *Biometrika*, 63(2):403–405. doi:10.2307/2335637.
- Mardia, K. V. (1977). Distributions on Stiefel and Grassmann manifolds, and their applications. *Advances in Applied Probability*, 9(3):435–436. doi:10.2307/1426097.
- Mardia, K. V. (1979). Discussion of “Conditional independence in statistical theory”. *Journal of the Royal Statistical Society, Series B (Methodological)*, 41(1):1–31. doi:10.1111/j.2517-6161.1979.tb01052.x.
- Mardia, K. V. (1980). Discussion of “Simulating the ley hunter”. *Journal of the Royal Statistical Society, Series A (General)*, 143(2):109–140. doi:10.2307/2981985.
- Mardia, K. V. (1981a). Directional statistics in geosciences. *Communications in Statistics – Theory and Methods*, 10(15):1523–1543. doi:10.1080/03610928108828131.
- Mardia, K. V. (1981b). The evolution of directional models in geosciences since Fisher. In Merriam, D. F. (Ed.), *Down-to-Earth Statistics*, pp. 39–46. Syracuse University, Syracuse.
- Mardia, K. V. (1981c). Recent directional distributions with applications. In Taillie, C., Patil, G. P., and Baldessari, B. A. (Eds.), *Statistical Distributions in Scientific Work*, volume 79 of *Nato Science Series C*, pp. 1–19, Heidelberg. Springer.
- Mardia, K. V. (1988a). Directional data analysis: an overview. *Journal of Applied Statistics*, 15(2):115–122. doi:10.1080/

02664768800000018.

- Mardia, K. V. (1988b). Multi-dimensional multivariate Gaussian Markov random fields. *Journal of Multivariate Analysis*, 24(2):265–284.
- Mardia, K. V. (Ed.) (1992). *The Art of Statistical Science*. Wiley Series in Probability and Mathematical Statistics. Wiley, Chichester.
- Mardia, K. V. (1999). Directional statistics and shape analysis. *Journal of Applied Statistics*, 26(8):949–957. doi:10.1080/02664769921954.
- Mardia, K. V. (2010). Bayesian analysis for bivariate von Mises distributions. *Journal of Applied Statistics*, 37(3):515–528. doi:10.1080/02664760903551267.
- Mardia, K. V. (2013a). Some aspects of geometry driven statistical models. In Mardia, K. V., Gusnanto, A., Riley, A. D., and Voss, J. (Eds.), *LASR 2013 – Statistical Models and Methods for non-Euclidean Data with Current Scientific Applications*, pp. 7–15, Leeds. Department of Statistics, University of Leeds.
- Mardia, K. V. (2013b). Statistical approaches to three key challenges in protein structural bioinformatics. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 62(3):487–514. doi:10.1111/rssc.12003.
- Mardia, K. V., Bogle, S., and Edwards, R. (1983). The statistics of response slope. *Journal of Applied Physiology*, 54(1):309–313.
- Mardia, K. V. and Edwards, R. (1982). Weighted distributions and rotating caps. *Biometrika*, 69(2):323–330. doi:10.1093/biomet/69.2.323.
- Mardia, K. V., Edwards, R., and Puri, M. L. (1977). Analysis of central place theory. *Bulletin of the International Statistical Institute*, 47(1):93–110. doi:10.21236/ada051861.
- Mardia, K. V. and El-Atoum, S. A. M. (1976). Bayesian inference for the von Mises-Fisher distribution. *Biometrika*, 63(1):203–206. doi:10.1093/biomet/63.1.203.
- Mardia, K. V., Foldager, J. I., and Frellsen, J. (2018). Directional statistics in protein bioinformatics. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 1–23. CRC Press, Boca Raton.
- Mardia, K. V. and Frellsen, J. (2012). Statistics of bivariate von Mises distributions. In Hamelryck, T., Mardia, K., and Ferkinghoff-Borg, J. (Eds.), *Bayesian Methods in Structural Bioinformatics*, Statistics for Biology and Health, pp. 159–178. Springer, Berlin. doi:10.1007/978-3-642-27225-7\_6.
- Mardia, K. V. and Gadsden, R. J. (1977). A circle of best fit for spherical data and areas of vulcanism. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 26(3):238–245.
- Mardia, K. V. and Holmes, D. (1980). A statistical analysis of megalithic data under elliptic pattern. *Journal of the Royal Statistical Society, Series A (General)*, 143(3):293–302. doi:10.2307/2982130.
- Mardia, K. V., Holmes, D., and Kent, J. T. (1984). A goodness-of-fit test for the von Mises-Fisher distribution. *Journal of the Royal Statistical Society, Series B (Methodological)*, 46(1):72–78. doi:10.1111/j.2517-6161.1984.tb01278.x.
- Mardia, K. V., Hughes, G., Taylor, C. C., and Singh, H. (2008). A multivariate von Mises distribution with applications to bioinformatics. *The Canadian Journal of Statistics*, 36(1):99–109. doi:10.1002/cjs.5550360110.
- Mardia, K. V. and Jupp, P. E. (1999). *Directional Statistics*. Wiley Series in Probability and Statistics. Wiley, Chichester. doi:10.1002/0471667196.ess7086.
- Mardia, K. V., Kent, J. T., and Bibby, J. M. (1979). *Multivariate Analysis*. Probability and Mathematical Statistics. Academic Press, London.
- Mardia, K. V., Kent, J. T., and Laha, A. K. (2016). Score matching estimators for directional distributions. *arXiv:1604.08470*.
- Mardia, K. V., Kent, J. T., Zhang, Z., and Taylor, C. C. (2011). Exploratory data analysis with applications to bioinformatics. Technical Report STAT11-04, Department of Statistics, University of Leeds.
- Mardia, K. V., Kent, J. T., Zhang, Z., Taylor, C. C., and Hamelryck, T. (2012). Mixtures of concentrated multivariate sine distributions with applications to bioinformatics. *Journal of Applied Statistics*, 39(11):2475–2492. doi:10.1080/02664763.2012.719221.
- Mardia, K. V. and Khatri, C. G. (1977). Uniform distribution on a Stiefel manifold. *Journal of Multivariate Analysis*, 7(3):468–473. doi:10.1016/0047-259x(77)90087-2.
- Mardia, K. V. and Patrangenaru, V. (2005). Directions and projective shapes. *The Annals of Statistics*, 33(4):1666–1699. doi:10.1214/009053605000000273.
- Mardia, K. V. and Puri, M. L. (1978). A spherical correlation coefficient robust against scale. *Biometrika*, 65(2):391–395. doi:10.1093/biomet/65.2.391.
- Mardia, K. V., Southworth, H. R., and Taylor, C. C. (1999). On bias in maximum likelihood estimators. *Journal of Statistical Planning and Inference*, 76(1-2):31–39. doi:10.1016/s0378-3758(98)00176-1.
- Mardia, K. V. and Spurr, B. D. (1973). Multisample tests for multimodal and axial circular populations. *Journal of the Royal Statistical Society, Series B (Methodological)*, 35(3):422–436. doi:10.1111/j.2517-6161.1973.tb00970.x.
- Mardia, K. V. and Sriram, K. (2020). Families of discrete circular distributions with some novel applications. *arXiv:2009.05437*.
- Mardia, K. V. and Sutton, T. W. (1975). On the modes of a mixture of two von Mises distributions. *Biometrika*, 62(3):699–701.



- doi:10.1093/biomet/62.3.699.
- Mardia, K. V. and Sutton, T. W. (1978). A model for cylindrical variables with applications. *Journal of the Royal Statistical Society, Series B (Methodological)*, 40(2):229–233. doi:10.1111/j.2517-6161.1978.tb01668.x.
- Mardia, K. V., Taylor, C. C., and Subramaniam, G. K. (2007). Protein bioinformatics and mixtures of bivariate von Mises distributions for angular data. *Biometrics*, 63(2):505–512. doi:10.1111/j.1541-0420.2006.00682.x.
- Mardia, K. V. and Voss, J. (2014). Some fundamental properties of a multivariate von Mises distribution. *Communications in Statistics – Theory and Methods*, 43(6):1132–1144. doi:10.1080/03610926.2012.670353.
- Mardia, K. V. and Walder, A. N. (1988). On Kendall’s spherical blackboard. Technical report, Department of Statistics, University of Leeds.
- Mardia, K. V. and Zemroch, P. J. (1975a). Algorithm as 80: Spherical statistics. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 24(1):144–146. doi:10.2307/2346720.
- Mardia, K. V. and Zemroch, P. J. (1975b). Algorithm AS 81: circular statistics. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 24(1):147–150. doi:10.2307/2346721.
- Mardia, K. V. and Zemroch, P. J. (1975c). Algorithm as 86: The von Mises distribution function. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 24(2):268–272. doi:10.2307/2346578.
- Mardia, K. V. and Zemroch, P. J. (1977). Table of maximum likelihood estimates for the Bingham distribution. *Journal of Statistical Computation and Simulation*, 6(1):29–34. doi:10.1080/00949657708810165.
- Marinucci, D. and Peccati, G. (2011). *Random Fields on the Sphere*. London Mathematical Society Lecture Note Series. Cambridge University Press, Cambridge.
- Marinucci, D., Pietrobon, D., Balbi, A., Baldi, P., Cabella, P., Kerkycharian, G., Natoli, P., Picard, D., and Vittorio, N. (2008). Spherical needlets for cosmic microwave background data analysis. *Monthly Notices of the Royal Astronomical Society*, 383(2):539–545. doi:10.1111/j.1365-2966.2007.12550.x.
- Markov, A. A. (1912). *Wahrscheinlichkeitsrechnung*. Taubner, Leipzig.
- Markovic, I., Cesic, J., and Petrovic, I. (2015). Von Mises mixture PHD filter. *IEEE Signal Processing Letters*, 22(12):2229–2233. doi:10.1109/lsp.2015.2472962.
- Marrero, O. (1982). The performance of several statistical tests for seasonality in monthly data. *Journal of Statistical Computation and Simulation*, 17(4):275–296. doi:10.1080/00949658308810666.
- Marriott, F. H. C. (1969). Associated directions. *Biometrics*, 25(4):775–776.
- Marron, J. S. and Alonso, A. M. (2014). Overview of object oriented data analysis. *Biometrical Journal*, 56(5):732–753. doi:10.1002/bimj.201300072.
- Marsaglia, G. (1972). Choosing a point from the surface of a sphere. *Annals of Mathematical Statistics*, 43(2):645–646. doi:10.1214/aoms/1177692644.
- Marshall, A. W. and Olkin, I. (1961). Game theoretic proof that Chebyshev inequalities are sharp. *Pacific Journal of Mathematics*, 11(4):1421–1429. doi:10.2140/pjm.1961.11.1421.
- Martin, M., Cremades, L. V., and Santabarbara, J. M. (1999). Analysis and modelling of time series of surface wind speed and direction. *International Journal of Climatology*, 19(2):197–209. doi:10.1002/(sici)1097-0088(199902)19:2<197::aid-joc360>3.0.co;2-h.
- Maruotti, A. (2016). Analyzing longitudinal circular data by projected normal models: a semi-parametric approach based on finite mixture models. *Environmental and Ecological Statistics*, 23(2):257–277. doi:10.1007/s10651-015-0338-3.
- Maruotti, A., Punzo, A., Mastrantonio, G., and Lagona, F. (2016). A time-dependent extension of the projected normal regression model for longitudinal circular data based on a hidden Markov heterogeneity structure. *Stochastic Environmental Research and Risk Assessment*, 30(6):1725–1740. doi:10.1007/s00477-015-1183-5.
- Mash’al, M. and Hosseini, R. (2015). K-means++ for mixtures of von Mises-Fisher distributions. In *2015 7th Conference on Information and Knowledge Technology (IKT)*, pp. 1–6, New York. IEEE. doi:10.1109/ikt.2015.7288786.
- Mastrantonio, G. (2018). The joint projected normal and skew-normal: a distribution for poly-cylindrical data. *Journal of Multivariate Analysis*, 165:14–26. doi:10.1016/j.jmva.2017.11.006.
- Mastrantonio, G. and Calise, G. (2016). Hidden Markov model for discrete circular-linear wind data time series. *Journal of Statistical Computation and Simulation*, 86(13):2611–2624. doi:10.1080/00949655.2016.1142544.
- Mastrantonio, G., Gelfand, A. E., and Jona Lasinio, G. (2016a). The wrapped skew Gaussian process for analyzing spatio-temporal data. *Stochastic Environmental Research and Risk Assessment*, 30(8):2231–2242. doi:10.1007/s00477-015-1163-9.
- Mastrantonio, G., Jona Lasinio, G., and Gelfand, A. E. (2016b). Spatio-temporal circular models with non-separable covariance structure. *TEST*, 25(2):331–350. doi:10.1007/s11749-015-0458-y.
- Mastrantonio, G., Jona Lasinio, G., Maruotti, A., and Calise, G. (2015a). On initial direction, orientation and discreteness in the analysis of circular variables. *arXiv:1509.08638v1*.
- Mastrantonio, G., Jona Lasinio, G., Maruotti, A., and Calise, G. (2019). Invariance properties and statistical inference for circular data. *Statistica Sinica*, 29(1):67–80. doi:10.5705/ss.202016.0067.
- Mastrantonio, G., Maruotti, A., and Jona Lasinio, G. (2015b). Bayesian hidden Markov modelling using circular-linear general projected normal distribution. *Environmetrics*, 26(2):145–158. doi:10.1002/env.2326.

- Matthews, G. V. T. (1961). “nonsense” orientation in mallard *Ans Platyrhynchos* and its relation to experiments on bird navigation. *Ibis*, 103a:211–230. doi:10.1111/j.1474-919X.1961.tb02435.x.
- Mazumder, S. and Bhattacharya, S. (2016). Bayesian nonparametric dynamic state space modeling with circular latent states. *Journal of Statistical Theory and Practice*, 10(1):154–178. doi:10.1080/15598608.2015.1100562.
- Mazumder, S. and Bhattacharya, S. (2017). Nonparametric dynamic state space modeling of observed circular time series with circular latent states: a Bayesian perspective. *Journal of Statistical Theory and Practice*, 11(4):693–718. doi:10.1080/15598608.2017.1305922.
- McClintock, B. T., King, R., Thomas, L., Matthiopoulos, J., McConnell, B. J., and Morales, J. M. (2012). A general discrete-time modeling framework for animal movement using multistate random walks. *Ecological Monographs*, 82(3):335–349. doi:10.1890/11-0326.1.
- McCullagh, P. (1996). Möbius transformation and Cauchy parameter estimation. *The Annals of Statistics*, 24(2):787–808. doi:10.1214/aos/1032894465.
- McFadden, P. L. (1980a). The best estimate of Fisher’s precision parameter  $k$ . *Geophysical Journal International*, 60(3):397–407. doi:10.1111/j.1365-246x.1980.tb04816.x.
- McFadden, P. L. (1980b). Determination of the angle in a Fisher distribution which will be exceeded with a given probability. *Geophysical Journal International*, 60(3):391–396. doi:10.1111/j.1365-246x.1980.tb04815.x.
- McFadden, P. L. (1980c). Simple graphical methods for estimating the confidence region about the orientation of the intersection of two planes: discussion. *Canadian Journal of Earth Sciences*, 17(8):1111–1113. doi:10.1139/e80-113.
- McFadden, P. L. and Lowes, F. J. (1981). The discrimination of mean directions drawn from Fisher distributions. *Geophysical Journal International*, 67(1):19–33. doi:10.1111/j.1365-246x.1981.tb02729.x.
- McGraw, T., Vemuri, B. C., Yezierski, B., and Mareci, T. (2006). Von Mises-Fisher mixture model of the diffusion ODF. In *3rd IEEE International Symposium on Biomedical Imaging: Nano to Macro, 2006*, pp. 65–68, New York. IEEE. doi:10.1109/isbi.2006.1624853.
- McKellar, A. E., Langrock, R., Walters, J. R., and Kesler, D. C. (2015). Using mixed hidden Markov models to examine behavioral states in a cooperatively breeding bird. *Behavioral Ecology*, 26(1):148–157. doi:10.1093/beheco/aru171.
- McLachlan, G. and Peel, D. (2000). *Finite Mixture Models*. Wiley Series in Probability and Statistics. Wiley, New York. doi:10.1002/0471721182.
- McLellan, C. R., Worton, B. J., Deasy, W., and Birch, A. N. E. (2015). Modelling larval movement data from individual bioassays. *Biometrical Journal*, 57(3):485–501. doi:10.1002/bimj.201400035.
- McMillan, G. P., Hanson, T. E., Saunders, G., and Gallun, F. J. (2013). A two-component circular regression model for repeated measures auditory localization data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 62(4):515–534. doi:10.1111/rssc.12004.
- McNeill, L. (1993). Interpolation and smoothing of mapped circular data. *South African Statistical Journal*, 27(1):23–49.
- McVinish, R. and Mengersen, K. (2008). Semiparametric Bayesian circular statistics. *Computational Statistics & Data Analysis*, 52(10):4722–4730. doi:10.1016/j.csda.2008.03.016.
- Meilán-Vila, A., Francisco-Fernández, M., and Crujeiras, R. M. (2020a). Goodness-of-fit tests for parametric regression models with circular response. *arXiv:2008.13473*.
- Meilán-Vila, A., Francisco-Fernández, M., Crujeiras, R. M., and Panzera, A. (2019). Nonparametric regression estimation for circular data. *Proceedings*, 21(1):27. doi:10.3390/proceedings2019021027.
- Meilán-Vila, A., Francisco-Fernández, M., Crujeiras, R. M., and Panzera, A. (2020b). Nonparametric multiple regression estimation for circular responses. *TEST*, to appear. doi:10.1007/s11749-020-00736-w.
- Meintanis, S. and Verdebout, T. (2019). Le Cam maximin tests for symmetry of circular data based on the characteristic function. *Statistica Sinica*, 29(3):1301–1320. doi:10.5705/ss.202016.0016.
- Mendoza, C. E. (1984). *Smoothing Directional Data*. PhD thesis, Princeton University.
- Mendoza, C. E. (1986). Smoothing unit vector fields. *Mathematical Geology*, 18(3):307–322. doi:10.1007/bf00898034.
- Meng, Y., Huang, J., Wang, G., Zhang, C., Zhuang, H., Kaplan, L., and Han, J. (2019). Spherical text embedding. In Wallach, H., Larochelle, H., Beygelzimer, A., d’Alché Buc, F., Fox, E., and Garnett, R. (Eds.), *Advances in Neural Information Processing Systems 32 (NIPS 2019)*, pp. 8208–8217. Curran Associates.
- Merrifield, A., Myerscough, M. R., and Weber, N. (2006). Statistical tests for analysing directed movement of self-organising animal groups. *Mathematical Biosciences*, 203(1):64–78. doi:10.1016/j.mbs.2006.03.022.
- Mettes, P., van der Pol, E., and Snoek, C. (2019). Hyperspherical prototype networks. In Wallach, H., Larochelle, H., Beygelzimer, A., d’Alché Buc, F., Fox, E., and Garnett, R. (Eds.), *Advances in Neural Information Processing Systems 32 (NIPS 2019)*, pp. 1487–1497. Curran Associates.
- Miao, B. Q. and Zhao, L. C. (1988). Detection of change points using rank methods. *Communications in Statistics – Theory and Methods*, 17(9):3207–3217. doi:10.1080/03610928808829799.
- Michelot, T., Langrock, R., Patterson, T., and McClintock, B. (2016a). moveHMM: an R package for the statistical modelling of animal movement data using hidden Markov models. *Methods in Ecology and Evolution*, 7(11):1308–1315. doi:10.1111/2041-210X.12578.
- Michelot, T., Langrock, R., and Patterson, T. A. (2016b). moveHMM: an R package for the statistical modelling

- of animal movement data using hidden Markov models. *Methods in Ecology and Evolution*, 7(11):1308–1315. doi:10.1111/2041-210X.12578.
- Milne-Thomson, L. M. (1933). *The Calculus of Finite Differences*. Macmillan, London.
- Miolane, N., Le Brigant, A., Mathe, J., Hou, B., Guigui, N., Thanwerdas, Y., Heyder, S., Peltre, O., Koep, N., Zaatiti, H., Hajri, H., Cabanes, Y., Gerald, T., Chauchat, P., Shewmake, C., Kainz, B., Donnat, C., Holmes, S., and Pennec, X. (2020). geomstats: A Python package for Riemannian geometry in machine learning. *arXiv:2004.04667*.
- Mirvaliev, M. (1979). Rejection of outlying results of angular measurements. *Theory of Probability and its Applications*, 23(4):814–819. doi:10.1137/1123100.
- von Mises, R. (1918). Über die “Ganzzahligkeit” der Atomgewichte und verwandte Fragen. *Physikalische Zeitschrift*, 19:490–500.
- Miyata, Y., Shiohama, T., and Abe, T. (2019). Estimation of finite mixture models of skew-symmetric circular distributions. *Metrika*. doi:10.1007/s00184-019-00756-z.
- Modlin, D., Fuentes, M., and Reich, B. (2012). Circular conditional autoregressive modeling of vector fields. *Environmetrics*, 23(1):46–53. doi:10.1002/env.1133.
- Moghimbeygi, M. and Golalizadeh, M. (2019). A longitudinal model for shapes through triangulation. *ASTA. Advances in Statistical Analysis*, 103(1):99–121. doi:10.1007/s10182-018-0324-9.
- Moghimbeygi, M. and Golalizadeh, M. (2020). Spherical logistic distribution. *Communications in Mathematics and Statistics*, 8(2):151–166. doi:10.1007/s40304-018-00171-2.
- Mohamed, I. B., Rambli, A., Khaliddin, N., and Ibrahim, A. I. N. (2016). A new discordancy test in circular data using spacings theory. *Communications in Statistics – Simulation and Computation*, 45(8):2904–2916. doi:10.1080/03610918.2014.932799.
- Mokhtar, N. A., Zubairi, Y. Z., and Hussin, A. G. (2018). A clustering approach to detect multiple outliers in linear functional relationship model for circular data. *Journal of Applied Statistics*, 45(6):1041–1051. doi:10.1080/02664763.2017.1342779.
- Monbet, V. (2020). *NHMSAR: Non-Homogeneous Markov Switching Autoregressive Models*. R package version 1.17. URL: <https://CRAN.R-project.org/package=NHMSAR>.
- Monbet, V., Ailliot, P., and Prevosto, M. (2007). Survey of stochastic models for wind and sea state time series. *Probabilistic Engineering Mechanics*, 22(2):113–126. doi:10.1016/j.pro bengmech.2006.08.003.
- Monnier, J.-B. (2011). Non-parametric regression on the hypersphere with uniform design. *TEST*, 20(2):412–446. doi:10.1007/s11749-011-0233-7.
- Montanari, A. and Calò, D. G. (2013). Model-based clustering of probability density functions. *Advances in Data Analysis and Classification*, 7(3):301–319. doi:10.1007/s11634-013-0140-8.
- Mooney, J. A., Helms, P. J., and Jolliffe, I. T. (2003). Fitting mixtures of von Mises distributions: a case study involving sudden infant death syndrome. *Computational Statistics & Data Analysis*, 41(3-4):505–513. doi:10.1016/s0167-9473(02)00181-0.
- Moore, B. R. (1980). A modification of the Rayleigh test for vector data. *Biometrika*, 67(1):175–180. doi:10.1093/biomet/67.1.175.
- Morales, J. M. and Ellner, S. P. (2002). Scaling up animal movements in heterogeneous landscapes: the importance of behavior. *Ecology*, 83(8):2240–2247. doi:10.1890/0012-9658(2002)083[2240:suamih]2.0.co;2.
- Morales, J. M., Haydon, D. T., Frair, J., Holsinger, K. E., and Fryxell, J. M. (2004). Extracting more out of relocation data: building movement models as mixtures of random walks. *Ecology*, 85(9):2436–2445. doi:10.1890/03-0269.
- Morales, J. M., Moorcroft, P. R., Matthiopoulos, J., Frair, J. L., Kie, J. G., Powell, R. A., Merrill, E. H., and Haydon, D. T. (2010). Building the bridge between animal movement and population dynamics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1550):2289–2301. doi:10.1098/rstb.2010.0082.
- Moran, P. A. P. (1975). Quaternions, Haar measure and the estimation of a palaeomagnetic rotation. *Journal of Applied Probability*, 12(S1):295–301. doi:10.1017/s0021900200047720.
- Moran, P. A. P. (1979). The closest pair of  $n$  random points on a sphere. *Biometrika*, 66(1):158–162. doi:10.2307/2335257.
- Morellato, L. P. C., Alberti, L. F., and Hudson, I. L. (2010). Application of circular statistics in plant phenology: a case studies approach. In Hudson, I. L. and Keatley, M. R. (Eds.), *Phenological Research*, pp. 339–359. Springer, Dordrecht. doi:10.1007/978-90-481-3335-2\_16.
- Moreno Chavez, G., Castillo Rivera, F., Sarocchi, D., Borselli, L., and Rodriguez-Sedano, L. A. (2018). FabricS: a user-friendly, complete and robust software for particle shape-fabric analysis. *Computers & Geosciences*, 115:20–30. doi:10.1016/j.cageo.2018.02.005.
- Morphet, W. J. (2009). *Simulation, Kriging, and Visualization of Circular-Spatial Data*. PhD thesis, Utah State University.
- Morphet, W. J. and Symanzik, J. (2010). The circular dataimage, a graph for high-resolution circular-spatial data. *International Journal of Digital Earth*, 3(1):47–71. doi:10.1080/17538940903277657.
- Morris, J. and Laycock, P. J. (1974). Discriminant analysis of directional data. *Biometrika*, 61(1):335–341. doi:10.1093/biomet/61.2.335.
- Mu, Y., Nguyen, P. H., and Stock, G. (2005). Energy landscape of a small peptide revealed by dihedral angle principal component analysis. *Proteins: Structure, Function, and Bioinformatics*, 58(1):45–52. doi:10.1002/prot.20310.

- Muirhead, R. J. (1982). *Aspects of Multivariate Statistical Theory*. Wiley Series in Probability and Statistics. Wiley, New York.
- Mukhopadhyay, N. (2002). A conversation with Kanti Mardia. *Statistical Science*, 17(1):113–148. doi:10.1214/ss/1023799001.
- Mulder, K., Jongsmas, P., and Klugkist, I. (2020a). Bayesian inference for mixtures of von Mises distributions using reversible jump MCMC sampler. *Journal of Statistical Computation and Simulation*, 90(9):1539–1556. doi:10.1080/00949655.2020.1740997.
- Mulder, K. and Klugkist, I. (2017). Bayesian estimation and hypothesis tests for a circular generalized linear model. *Journal of Mathematical Psychology*, 80:4–14. doi:10.1016/j.jmp.2017.07.001.
- Mulder, K., Klugkist, I., van Renswoude, D., and Visser, I. (2020b). Mixtures of peaked power Batschelet distributions for circular data with application to saccade directions. *Journal of Mathematical Psychology*, 95:102309. doi:10.1016/j.jmp.2019.102309.
- Mulder, K. T. (2019). *Bayesian Circular Statistics: von Mises Solutions for Practical Problems*. PhD thesis, University of Utrecht.
- Mulder, K. T. and Klugkist, I. (2021). Bayesian tests for circular uniformity. *Journal of Statistical Planning and Inference*, 211:315–325. doi:10.1016/j.jspi.2020.06.002.
- Munk, A. (1998). Tchebycheff-experiments. *Statistics*, 31(4):289–324. doi:10.1080/02331889808802642.
- Munro, M. A. and Blenkinsop, T. G. (2012). MARD—A moving average rose diagram application for the geosciences. *Computers & Geosciences*, 49:112–120. doi:10.1016/j.cageo.2012.07.012.
- Mushkudiani, N. A. (2002). Small nonparametric tolerance regions for directional data. *Journal of Statistical Planning and Inference*, 100(1):67–80. doi:10.1016/S0378-3758(01)00093-3.
- Nakayama, H., Nishiyama, K., Noro, M., Ohara, K., Sei, T., Takayama, N., and Takemura, A. (2011). Holonomic gradient descent and its application to the Fisher-Bingham integral. *Advances in Applied Mathematics*, 47(3):639–658. doi:10.1016/j.aam.2011.03.001.
- Narcowich, F., Petrushev, P., and Ward, J. (2006a). Decomposition of Besov and Triebel-Lizorkin spaces on the sphere. *Journal of Functional Analysis*, 238(2):530–564. doi:10.1016/j.jfa.2006.02.011.
- Narcowich, F. J., Petrushev, P., and Ward, J. D. (2006b). Localized tight frames on spheres. *SIAM Journal on Mathematical Analysis*, 38(2):574–594. doi:10.1137/040614359.
- Natanegara, F. (2003). *Bayesian Models for Circular Data*. PhD thesis, Baylor University.
- Navarro, A. K. W., Frelsen, J., and Turner, R. E. (2017). The multivariate generalised von Mises distribution: inference and applications. In *Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence (AAAI-17)*, pp. 2394–2400, San Francisco. Association for the Advancement of Artificial Intelligence.
- Neeman, T. and Chang, T. (2001). Rank score statistics for spherical data. In Viana, M. A. G. and Richards, D. S. P. (Eds.), *Algebraic Methods in Statistics and Probability*, volume 287 of *Contemporary Mathematics*, pp. 241–254. American Mathematical Society, Providence. doi:10.1090/conm/287/04789.
- Neeman, T. M. (1995). *Rank Statistics for Spherical Data*. PhD thesis, University of Virginia.
- Newcomb, S. (1881). Note on the frequency of use of the different digits in natural numbers. *American Journal of Mathematics*, 4(1):39–40. doi:10.2307/2369148.
- Ngoc, T. M. P. (2018). Noisy directional data. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 95–110. CRC Press, Boca Raton.
- Nicosia, A., Duchesne, T., Rivest, L.-P., and Fortin, D. (2017). A general hidden state random walk model for animal movement. *Computational Statistics & Data Analysis*, 105:76–95. doi:10.1016/j.csda.2016.07.009.
- Nikulin, V. N. (1989). Stability of a characterization of the von Mises distribution. *Journal of Mathematical Sciences*, 47(1):2336–2345. doi:10.1007/bf01104823.
- Nodehi, A., Golalizadeh, M., and Heydari, A. (2015). Dihedral angles principal geodesic analysis using nonlinear statistics. *Journal of Applied Statistics*, 42(9):1962–1972. doi:10.1080/02664763.2015.1014892.
- Nodehi, A., Golalizadeh, M., Maadooliat, M., and Agostinelli, C. (2020). Estimation of parameters in multivariate wrapped models for data on a  $p$ -torus. *Computational Statistics*, to appear. doi:10.1007/s00180-020-01006-x.
- North, H. C., Pairman, D., and Belliss, S. E. (2019). Boundary delineation of agricultural fields in multitemporal satellite imagery. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 12(1, SI):237–251. doi:10.1109/jstars.2018.2884513.
- Núñez-Antonio, G. and Geneyro, E. (2020). A multivariate projected gamma model for directional data. *Communications in Statistics: Case Studies, Data Analysis and Applications*, to appear. doi:10.1080/03610918.2019.1612910.
- Núñez-Antonio, G. and Gutiérrez-Peña, E. (2005a). A Bayesian analysis of directional data using the projected normal distribution. *Journal of Applied Statistics*, 32(10):995–1001. doi:10.1080/02664760500164886.
- Núñez-Antonio, G. and Gutiérrez-Peña, E. (2005b). A Bayesian analysis of directional data using the von Mises-Fisher distribution. *Communications in Statistics – Simulation and Computation*, 34(4):989–999. doi:10.1080/03610910500308495.
- Núñez-Antonio, G. and Gutiérrez-Peña, E. (2014). A Bayesian model for longitudinal circular data based on the projected normal distribution. *Computational Statistics & Data Analysis*, 71:506–519. doi:10.1016/j.csda.2012.07.025.

- Núñez-Antonio, G., Gutiérrez-Peña, E., and Escarela, G. (2011). A Bayesian regression model for circular data based on the projected normal distribution. *Statistical Modelling*, 11(3):185–201. doi:10.1177/1471082x1001100301.
- Núñez-Antonio, G., Mendoza, M., Contreras-Cristán, A., Gutiérrez-Peña, E., and Mendoza, E. (2018). Bayesian nonparametric inference for the overlap of daily animal activity patterns. *Environmental and Ecological Statistics*, 25(4):471–494. doi:10.1007/s10651-018-0414-6.
- Oba, S., Kato, K., and Ishii, S. (2005). Multi-scale clustering for gene expression profiling data. In *Fifth IEEE Symposium on Bioinformatics and Bioengineering (BIBE '05)*, pp. 210–217, New York. IEEE. doi:10.1109/BIBE.2005.41.
- Oden, N. L. (1993). Assessing directional effects in spatial data. *Statistics in Medicine*, 12(19-20):1795–1805. doi:10.1002/sim.4780121907.
- Okubo, A. and Levin, S. A. (2013). *Diffusion and Ecological Problems*, volume 14 of *Interdisciplinary Applied Mathematics*. Springer, New York, second edition. doi:10.1007/978-1-4757-4978-6.
- Okumura, H. (1997). Cardinal  $B$  splines and circular data. In Elaydi, S., Györ, I., and Ladas, G. (Eds.), *Advances in Difference Equations*, pp. 473–480, Amsterdam. Gordon and Breach.
- Oliveira, M. (2013). *Nonparametric Circular Methods for Density and Regression*. PhD thesis, University of Santiago de Compostela.
- Oliveira, M., Crujeiras, R. M., and Rodríguez-Casal, A. (2012). A plug-in rule for bandwidth selection in circular density estimation. *Computational Statistics & Data Analysis*, 56(12):3898–3908. doi:10.1016/j.csda.2012.05.021.
- Oliveira, M., Crujeiras, R. M., and Rodríguez-Casal, A. (2013). Nonparametric circular methods for exploring environmental data. *Environmental and Ecological Statistics*, 20(1):1–17. doi:10.1007/s10651-012-0203-6.
- Oliveira, M., Crujeiras, R. M., and Rodríguez-Casal, A. (2014a). CircSiZer: an exploratory tool for circular data. *Environmental and Ecological Statistics*, 21(1):143–159. doi:10.1007/s10651-013-0249-0.
- Oliveira, M., Crujeiras, R. M., and Rodríguez-Casal, A. (2014b). NPCirc: an R package for nonparametric circular methods. *Journal of Statistical Software*, 61(9):1–26. doi:10.18637/jss.v061.i09.
- Oliveira, M., Crujeiras, R. M., and Rodríguez-Casal, A. (2014c). NPCirc: an R package for nonparametric circular methods. *Journal of Statistical Software*, 61(9):1–26. doi:10.18637/jss.v061.i09.
- Oliveira-Santos, L. G. R., Zucco, C. A., and Agostinelli, C. (2013). Using conditional circular kernel density functions to test hypotheses on animal circadian activity. *Animal Behaviour*, 85(1):269–280. doi:10.1016/j.anbehav.2012.09.033.
- Oller, J. M. and Corcuera, J. M. (1995). Intrinsic analysis of statistical estimation. *The Annals of Statistics*, 23(5):1562–1581. doi:10.1214/aos/1176324312.
- Olver, F. W. J., Lozier, D. W., Boisvert, R. F., and Clark, C. W. (Eds.) (2010). *NIST Handbook of Mathematical Functions*. Cambridge University Press, Cambridge.
- Ong, S. H. and SenGupta, A. (2012). Bivariate and multivariate circular distributions by mixtures. *Journal of Indian Statistical Association*, 50:193–204.
- Onstott, T. C. (1980). Applications of the Bingham distribution function in palaeomagnetic studies. *Journal of Geophysical Research: Solid Earth*, 85(B3):1500–1510. doi:10.1029/jb085ib03p01500.
- Otieno, B. S. (2002). *An Alternative Estimate of Preferred Direction for Circular Data*. PhD thesis, Virginia Polytechnic Institute and State University.
- Otieno, B. S. and Anderson-Cook, C. M. (2006). Measures of preferred direction for environmental and ecological circular data. *Environmental and Ecological Statistics*, 13(3):311–324. doi:10.1007/s10651-004-0014-5.
- Otieno, S. B. and Anderson-Cook, C. M. (2012). Design and analysis of experiments for directional data. In Hinkelmann, K. (Ed.), *Design and Analysis of Experiments*, Wiley Series in Probability and Statistics, pp. 501–532. Wiley, Hoboken. doi:10.1002/9781118147634.ch15.
- Ouakacha, K. and Rivest, L.-P. (2009). A new statistical model for random unit vectors. *Journal of Multivariate Analysis*, 100(1):70–80. doi:10.1016/j.jmva.2008.03.004.
- Ouakacha, K. and Rivest, L.-P. (2012). On the estimation of an average rigid body motion. *Biometrika*, 99(3):585–598. doi:10.1093/biomet/ass020.
- Pabst, B. and Vicentini, H. (1978). Dislocation experiments in the migrating sea star *Astropecten jonstoni*. *Marine Biology*, 48(3):271–278. doi:10.1007/BF00397154.
- Paindaveine, D. and Verdebout, T. (2015). Optimal rank-based tests for the location parameter of a rotationally symmetric distribution on the hypersphere. In Hallin, M., Mason, D., Pfeifer, D., and Steinebach, J. (Eds.), *Mathematical Statistics and Limit Theorems*, pp. 249–269. Springer, Cham. doi:10.1007/978-3-319-12442-1\_14.
- Paindaveine, D. and Verdebout, T. (2016). On high-dimensional sign tests. *Bernoulli*, 22(3):1745–1769. doi:10.3150/15-bej710.
- Paindaveine, D. and Verdebout, T. (2017). Inference on the mode of weak directional signals: a Le Cam perspective on hypothesis testing near singularities. *The Annals of Statistics*, 45(2):800–832. doi:10.1214/16-aos1468.
- Paindaveine, D. and Verdebout, T. (2020). Inference for spherical location under high concentration. *The Annals of Statistics*, 48(5):2982–2998. doi:10.1214/19-AOS1918.
- Paine, P. J., Preston, S. P., Tsagris, M., and Wood, A. T. A. (2018). An elliptically symmetric angular Gaussian distribution. *Statistics and Computing*, 28(3):689–697. doi:10.1007/s11222-017-9756-4.

- Paine, P. J., Preston, S. P., Tsagris, M., and Wood, A. T. A. (2020). Spherical regression models with general covariates and anisotropic errors. *Statistics and Computing*, 30(1):153–165. doi:10.1007/s11222-019-09872-2.
- Paluszewski, M. and Hamelryck, T. (2010). Mocapy++ - a toolkit for inference and learning in dynamic Bayesian networks. *BMC Bioinformatics*, 11(126):1–6. doi:10.1186/1471-2105-11-126.
- Panaretos, V. M., Pham, T., and Yao, Z. (2014). Principal flows. *Journal of the American Statistical Association*, 109(505):424–436. doi:10.1080/01621459.2013.849199.
- Pandolfo, G., D’Ambrosio, A., and Porzio, G. C. (2018a). A note on depth-based classification of circular data. *Electronic Journal of Applied Statistical Analysis*, 11(2):447–462. doi:10.1285/i20705948v11n2p447.
- Pandolfo, G., Paindaveine, D., and Porzio, G. C. (2018b). Distance-based depths for directional data. *The Canadian Journal of Statistics*, 46(4):593–609. doi:10.1002/cjs.11479.
- Papakonstantinou, V. (1979). *Beiträge zur Zirkulären Statistik*. PhD thesis, University of Zurich.
- Papakonstantinou, V. (1984). The distribution of the length of  $n$  random unit vectors for a von Mises population. *Statistics & Probability Letters*, 2(2):111–115. doi:10.1016/0167-7152(84)90059-2.
- Pardo, A., Real, E., Krishnaswamy, V., López-Higuera, J. M., Pogue, B. W., and Conde, O. M. (2017). Directional kernel density estimation for classification of breast tissue spectra. *IEEE Transactions on Medical Imaging*, 36(1):64–73. doi:10.1109/tmi.2016.2593948.
- Park, H. S. (2012). Asymptotic behavior of the kernel density estimator from a geometric viewpoint. *Communications in Statistics – Simulation and Computation*, 41(19):3479–3496. doi:10.1080/03610926.2011.585009.
- Park, H. S. (2013). Comparison of relative efficiency of kernel density estimator with the exponential map. *Journal of the Korean Statistical Society*, 42(2):267–275. doi:10.1016/j.jkss.2012.08.007.
- Parthasarathy, K. R. (1967). *Probability Measures on Metric Spaces*. Probability and Mathematical Statistics. Academic Press, New York. doi:10.1016/b978-1-4832-0022-4.50006-5.
- Pataky, T. C. and Challis, J. H. (2020). Using directional statistics to test hypotheses regarding rigid body attitude: comparison to univariate and multivariate Cardan angle tests. *Journal of Biomechanics*, 111:109976. doi:10.1016/j.jbiomech.2020.109976.
- Patlak, C. S. (1953). A mathematical contribution to the study of orientation of organisms. *The Bulletin of Mathematical Biophysics*, 15(4):431–476. doi:10.1007/bf02476435.
- Patterson, T. A., Basson, M., Bravington, M. V., and Gunn, J. S. (2009). Classifying movement behaviour in relation to environmental conditions using hidden Markov models. *Journal of Animal Ecology*, 78(6):1113–1123. doi:10.1111/j.1365-2656.2009.01583.x.
- Paula, G. A. (1996). Influence diagnostics in proper dispersion models. *The Australian Journal of Statistics*, 38(3):307–316. doi:10.1111/j.1467-842x.1996.tb00685.x.
- Pearson, E. S. (1963). Comparison of tests for randomness of points on a line. *Biometrika*, 50(3/4):315–323. doi:10.2307/2333902.
- Pearson, E. S. and Stephens, M. A. (1962). The goodness-of-fit tests based on  $W_N^2$  and  $U_N^2$ . *Biometrika*, 49(3/4):397–402. doi:10.2307/2333974.
- Pearson, K. (1905). The problem of the random walk. *Nature*, 72(1867):294–342. doi:10.1038/072294b0.
- Pearson, K. (1906). Mathematical contributions to the theory of evolution – XV A mathematical theory of random migration. *Draper’s Company Research Memoirs, Biometric Series*, 3:1–60. doi:10.5962/bhl.title.57440.
- Peck, S. L. (1999). Quantitative analysis of movement: measuring and modeling population redistribution in animals and plants. *Ecology*, 80(4):1451–1453. doi:10.1086/393125.
- Peel, D., Whiten, W. J., and McLachlan, G. J. (2001). Fitting mixtures of Kent distributions to aid in joint set identification. *Journal of the American Statistical Association*, 96(453):56–63. doi:10.1198/016214501750332974.
- Peker, K. O. and Bacanlı, S. (2015). A group sequential test of circular data using the von Mises distribution. *Hacettepe Journal of Mathematics and Statistics*, 44(6):1569–1578. doi:10.15672/HJMS.2014388077.
- Pelé, J., Moreau, M., Abdi, H., Rodien, P., Castel, H., and Chabbert, M. (2014). Comparative analysis of sequence co-variation methods to mine evolutionary hubs: examples from selected GPCR families. *Proteins: Structure, Function, and Bioinformatics*, 82(9):2141–2156. doi:10.1002/prot.24570.
- Pelletier, B. (2005). Kernel density estimation on Riemannian manifolds. *Statistics & Probability Letters*, 73(3):297–304. doi:10.1016/j.spl.2005.04.004.
- Pelletier, B. (2006). Non-parametric regression estimation on closed Riemannian manifolds. *Journal of Nonparametric Statistics*, 18(1):57–67. doi:10.1080/10485250500504828.
- Pelz, W. and Good, I. J. (1976). Approximating the lower tail-areas of the Kolmogorov-Smirnov one-sample statistic. *Journal of the Royal Statistical Society, Series B (Methodological)*, 38(2):152–156. doi:10.1111/j.2517-6161.1976.tb01579.x.
- Pennec, X. (2018). Barycentric subspace analysis on manifolds. *The Annals of Statistics*, 46(6A):2711–2746. doi:10.1214/17-aos1636.
- Pérez, I. A., Sánchez, M. L., García, M. A., and Pardo, N. (2012). Analysis of CO<sub>2</sub> daily cycle in the low atmosphere at a rural site. *Science of the Total Environment*, 431:286–292. doi:10.1016/j.scitotenv.2012.05.067.
- Perraudin, N., Defferrard, M., Kacprzak, T., and Sgier, R. (2019). DeepSphere: efficient spherical convolutional neural

- network with HEALPix sampling for cosmological applications. *Astronomy and Computing*, 27:130–146. doi:10.1016/j.ascom.2019.03.004.
- Perrin, F. (1928). Étude mathématique du mouvement brownien de rotation. *Annales Scientifiques de l'École Normale Supérieure*, 45(3):1–51. doi:10.24033/asens.782.
- Perry, J. (1992). *Gait Analysis*. SLACK Incorporated, Thorofare.
- Persson, T. (1979). A new way to obtain Watson's  $U^2$ . *Scandinavian Journal of Statistics*, 6(3):119–122.
- Pertselmidis, A., Zelinka, J., Fondon, J. W., Henderson, R. K., and Otwinowski, Z. (2005). Bayesian statistical studies of the Ramachandran distribution. *Statistical Applications in Genetics and Molecular Biology*, 4(1). doi:10.2202/1544-6115.1165.
- Pewsey, A. (2000). The wrapped skew-normal distribution on the circle. *Communications in Statistics – Theory and Methods*, 29(11):2459–2472. doi:10.1080/03610920008832616.
- Pewsey, A. (2002a). *Contributions to the Analysis of Skew Data on the Line and Circle*. PhD thesis, Open University.
- Pewsey, A. (2002b). Testing circular symmetry. *The Canadian Journal of Statistics*, 30(4):591–600. doi:10.2307/3316098.
- Pewsey, A. (2004a). The large-sample joint distribution of key circular statistics. *Metrika*, 60(1):25–32. doi:10.1007/s001840300294.
- Pewsey, A. (2004b). Testing for circular reflective symmetry about a known median axis. *Journal of Applied Statistics*, 31(5):575–585. doi:10.1080/02664760410001681828.
- Pewsey, A. (2006). Modelling asymmetrically distributed circular data using the wrapped skew-normal distribution. *Environmental and Ecological Statistics*, 13(3):257–269. doi:10.1007/s10651-005-0010-4.
- Pewsey, A. (2008). The wrapped stable family of distributions as a flexible model for circular data. *Computational Statistics & Data Analysis*, 52(3):1516–1523. doi:10.1016/j.csda.2007.04.017.
- Pewsey, A. (2018a). Applied directional statistics with R: an overview. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 277–290. CRC Press, Boca Raton.
- Pewsey, A. (2018b). Circular data models. *Wiley StatsRef: Statistics Reference Online*, pp. 1–10. doi:10.1002/9781118445112.stat05741.pub2.
- Pewsey, A. and García-Portugués, E. (2020). Recent advances in directional statistics. *arXiv:2005.06889*.
- Pewsey, A. and Jones, M. C. (2005). Discrimination between the von Mises and wrapped normal distributions: just how big does the sample size have to be? *Statistics*, 39(2):81–89. doi:10.1080/02331880500031597.
- Pewsey, A. and Kato, S. (2016). Parametric bootstrap goodness-of-fit testing for Wehrly-Johnson bivariate circular distributions. *Statistics and Computing*, 26(6):1307–1317. doi:10.1007/s11222-015-9605-2.
- Pewsey, A., Lewis, T., and Jones, M. C. (2007). The wrapped  $t$  family of circular distributions. *Australian & New Zealand Journal of Statistics*, 49(1):79–91. doi:10.1111/j.1467-842x.2006.00465.x.
- Pewsey, A., Neuhäuser, M., and Ruxton, G. D. (2013). *Circular Statistics in R*. Oxford University Press, Oxford.
- Pewsey, A., Shimizu, K., and de la Cruz, R. (2011). On an extension of the von Mises distribution due to Batschelet. *Journal of Applied Statistics*, 38(5):1073–1085. doi:10.1080/02664761003759024.
- Pewsey, A. R. (2003). The characteristic functions of the skew-normal and wrapped skew-normal distributions. In *27 Congreso Nacional de Estadística e Investigación Operativa: Lleida, del 8 al 11 de abril de 2003*, pp. 4383–4386. University of Lleida, Spain.
- Pfaff, F. (2019). *Multitarget Tracking Using Orientation Estimation for Optical Belt Sorting*. PhD thesis, Karlsruhe Institute of Technology.
- Pfaff, F., Kurz, G., and Hanebeck, U. D. (2015). Multimodal circular filtering using Fourier series. In *2015 18th International Conference on Information Fusion (Fusion)*, pp. 711–718, New York. IEEE.
- Pfaff, F., Kurz, G., and Hanebeck, U. D. (2016a). Multivariate angular filtering using Fourier series. *Journal of Advances in Information Fusion*, 11(2):206–226.
- Pfaff, F., Kurz, G., and Hanebeck, U. D. (2016b). Nonlinear prediction for circular filtering using Fourier series. In *2016 19th International Conference on Information Fusion (FUSION)*, pp. 1821–1828, New York. IEEE.
- Pfaff, F., Kurz, G., and Hanebeck, U. D. (2017a). Filtering on the unit sphere using spherical harmonics. In *2017 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 124–130, New York. IEEE. doi:10.1109/MFI.2017.8170417.
- Pfaff, F., Kurz, G., Pieper, C., Maier, G., Noack, B., Kruggel-Emden, H., Gruna, R., Hanebeck, U. D., Wirtz, S., Scherer, V., Längle, T., and Beyerer, J. (2017b). Improving multitarget tracking using orientation estimates for sorting bulk materials. In *2017 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 553–558, New York. IEEE. doi:10.1109/MFI.2017.8170379.
- Pfaff, F., Li, K., and Hanebeck, U. D. (2019a). Association likelihoods for directional estimation. In *2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS)*, pp. 211–217, New York. IEEE. doi:10.1109/ICPHYS.2019.8780240.
- Pfaff, F., Li, K., and Hanebeck, U. D. (2019b). Fourier filters, grid filters, and the Fourier-interpreted grid filter. In *2019 22th International Conference on Information Fusion (FUSION)*, pp. 1–8, New York. IEEE.
- Pfaff, F., Li, K., and Hanebeck, U. D. (2020a). Estimating correlated angles using the hypertoroidal grid filter. In *2020 IEEE*

- International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, pp. 101–107, New York. IEEE. doi:10.1109/MFI49285.2020.9235220.
- Pfaff, F., Li, K., and Hanebeck, U. D. (2020b). A hyperhemispherical grid filter for orientation estimation. In *2020 IEEE 23rd International Conference on Information Fusion (FUSION)*, pp. 1–8, New York. IEEE. doi:10.23919/FUSION45008.2020.9190611.
- Pfaff, F., Li, K., and Hanebeck, U. D. (2020c). The spherical grid filter for nonlinear estimation on the unit sphere. In *Proceedings of the 1st Virtual IFAC World Congress (IFAC-V 2020)*.
- Pham Ngoc, T. M. (2019). Adaptive optimal kernel density estimation for directional data. *Journal of Multivariate Analysis*, 173:248–267. doi:10.1016/j.jmva.2019.02.009.
- Pincus, H. J. (1953). The analysis of aggregates of orientation data in the earth sciences. *The Journal of Geology*, 61(6):482–509. doi:10.1086/626124.
- Pinkham, R. S. (1961). On the distribution of first significant digits. *Annals of Mathematical Statistics*, 32(4):1223–1230. doi:10.1214/aoms/1177704862.
- Pitt, M. K. and Shephard, N. (1999). Filtering via simulation: auxiliary particle filters. *Journal of the American Statistical Association*, 94(446):590–599. doi:10.2307/2670179.
- Pizer, S. M., Jung, S., Goswami, D., Vicory, J., Zhao, X., Chaudhuri, R., Damon, J. N., Huckemann, S., and Marron, J. S. (2013). Nested sphere statistics of skeletal models. In Breuß, M., Bruckstein, A., and Maragos, P. (Eds.), *Innovations for Shape Analysis, Mathematics and Visualization*, pp. 93–115. Springer, Berlin. doi:10.1007/978-3-642-34141-0\_5.
- Poincaré, H. (1912). Chance. *Monist*, 22(1):31–52. doi:10.5840/monist19122211.
- Pokorný, D. and Kurth, R. A. (2005). Validation of an interpersonal circumplex model by means of directional statistics: perspectives of experts, laymen and patients. *Diagnostica*, 51(3):113–123. doi:10.1026/0012-1924.51.3.113.
- Polsen, O. and Taylor, C. C. (2015). Parametric circular-circular regression and diagnostic analysis. In Dryden, I. L. and Kent, J. T. (Eds.), *Geometry Driven Statistics*, Wiley Series in Probability and Statistics, pp. 115–128. Wiley, Chichester. doi:10.1002/9781118866641.ch5.
- Pólya, G. (1919). Zur Statistik der sphärischen Verteilung der Fixsterne. *Astronomische Nachrichten*, 208(12):175–180. doi:10.1002/asna.19182081205.
- Pólya, G. (1930). Sur quelques points de la théorie des probabilités. *Annales de l'institut Henri Poincaré*, 1(2):117–161.
- Porcu, E., Bevilacqua, M., and Genton, M. G. (2016). Spatio-temporal covariance and cross-covariance functions of the great circle distance on a sphere. *Journal of the American Statistical Association*, 111(514):888–898. doi:10.1080/01621459.2015.1072541.
- Porcu, E., Furrer, R., and Nychka, D. (2020). 30 years of space-time covariance functions. *WIREs Computational Statistics*, to appear:e1512. doi:10.1002/wics.1512.
- Potgieter, C. J. (2019). Sequential monitoring of circular processes related to the von Mises distribution. In Lio, Y., Ng, H. K. T., Tsai, T.-R., and Chen, D.-G. (Eds.), *Statistical Quality Technologies*, ICSA Book Series in Statistics, pp. 127–150. Springer, Cham. doi:10.1007/978-3-030-20709-0\_6.
- Pramesti, G. (2016). Exponential circular distribution motivated by inverse stereographic projection. *International Journal of Applied Mathematics and Statistics*, 54(2):114–122.
- Prentice, M. J. (1978). On invariant tests of uniformity for directions and orientations. *The Annals of Statistics*, 6(1):169–176. doi:10.1214/aos/1176344075.
- Prentice, M. J. (1982). Antipodally symmetric distributions for orientation statistics. *Journal of Statistical Planning and Inference*, 6(3):205–214. doi:10.1016/0378-3758(82)90025-8.
- Prentice, M. J. (1984). A distribution-free method of interval estimation for unsigned directional data. *Biometrika*, 71(1):147–154. doi:10.1093/biomet/71.1.147.
- Prentice, M. J. (1986). Orientation statistics without parametric assumptions. *Journal of the Royal Statistical Society, Series B (Methodological)*, 48(2):214–222. doi:10.1111/j.2517-6161.1986.tb01404.x.
- Prentice, M. J. (1987). Fitting smooth paths to rotation data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 36(3):325–331. doi:10.2307/2347791.
- Prentice, M. J. (1988). Using sample principal axes to estimate small circles and ellipses on the sphere. *Journal of Applied Statistics*, 15(2):171–177. doi:10.1080/02664768800000023.
- Prentice, M. J. (1989). Spherical regression on matched pairs of orientation statistics. *Journal of the Royal Statistical Society, Series B (Methodological)*, 51(2):241–248. doi:10.1111/j.2517-6161.1989.tb01761.x.
- Presnell, B., Morrison, S. P., and Littell, R. C. (1998). Projected multivariate linear models for directional data. *Journal of the American Statistical Association*, 93(443):1068–1077. doi:10.2307/2669850.
- Presnell, B. and Rumcheva, P. (2008). The mean resultant length of the spherically projected normal distribution. *Statistics & Probability Letters*, 78(5):557–563. doi:10.1016/j.spl.2007.09.007.
- Pukhila, T. M. and Rao, C. R. (1988). Pattern recognition based on scale invariant discriminant functions. *Information Sciences*, 45(3):379–389. doi:10.1016/0020-0255(88)90012-6.
- Puri, M. L. and Rao, J. S. (1977). Problems of association for bivariate circular data and a new test of independence. In Krishnaiah, P. R. (Ed.), *Multivariate Analysis IV*, pp. 513–522, Amsterdam. North-Holland.



- Puri, M. L., Rao, J. S., and Yoon, Y. (1979). A simple test for goodness-of-fit based on spacings with some efficiency comparisons. In Jurečková, J. (Ed.), *Contributions to Statistics*, pp. 197–209. Reidel, Dordrecht.
- Purkayastha, S. (1991). A rotationally symmetric directional distribution obtained through maximum likelihood characterization. *Sankhyā, Series A*, 53(1):70–83.
- Purkayastha, S. (1992). Maximum likelihood characterization of the von Mises-Fisher matrix distribution. *Sankhyā, Series A*, 54(1):123–127.
- Purkayastha, S. (1995). An almost sure representation of sample circular median. *Journal of Statistical Planning and Inference*, 46(1):77–91. doi:10.1016/0378-3758(94)00092-a.
- Pycke, J.-R. (2007a). A decomposition for invariant tests of uniformity on the sphere. *Proceedings of the American Mathematical Society*, 135(9):2983–2993. doi:10.1090/s0002-9939-07-08804-1.
- Pycke, J.-R. (2007b). U-statistics based on the Green’s function of the Laplacian on the circle and the sphere. *Statistics & Probability Letters*, 77(9):863–872. doi:10.1016/j.spl.2006.11.009.
- Pycke, J.-R. (2010). Some tests for uniformity of circular distributions powerful against multimodal alternatives. *The Canadian Journal of Statistics*, 38(1):80–96. doi:10.1002/cjs.10048.
- Pyke, R. (1965). Spacings. *Journal of the Royal Statistical Society, Series B (Methodological)*, 27(3):395–449. doi:10.1111/j.2517-6161.1965.tb00602.x.
- Qin, X., Zhang, J.-S., and Yan, X.-D. (2011). A nonparametric circular-linear multivariate regression model with a rule-of-thumb bandwidth selector. *Computers and Mathematics with Applications*, 62(8):3048–3055. doi:10.1016/j.camwa.2011.08.016.
- Qiu, X., Wu, S., and Wu, H. (2015). A new information criterion based on Langevin mixture distribution for clustering circular data with application to time course genomic data. *Statistica Sinica*, 25(4):1459–1476. doi:10.5705/ss.2013.030.
- Quenouille, M. H. (1947). On the problem of random flights. *Mathematical Proceedings of the Cambridge Philosophical Society*, 43(4):581–582. doi:10.1017/s0305004100023835.
- Quill, R. E. (2017). *Statistical Characteristics of Wind Fields Over Complex Terrain with Applications in Bushfire Modelling*. PhD thesis, University of New South Wales.
- R Core Team (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. URL: <https://www.R-project.org/>.
- Rabbani, A., Mostaghimi, P., and Armstrong, R. T. (2019). Pore network extraction using geometrical domain decomposition. *Advances in Water Resources*, 123:70–83. doi:10.1016/j.advwatres.2018.11.003.
- Rakhimberdiev, E., Saveliev, A., Piersma, T., and Karagicheva, J. (2017). FLIGHTR: an R package for reconstructing animal paths from solar geolocation loggers. *Methods in Ecology and Evolution*, 8(11):1482–1487. doi:10.1111/2041-210X.12765.
- Ramachandran, G. N., Ramakrishnan, C., and Sasisekharan, V. (1963). Stereochemistry of polypeptide chain configurations. *Journal of Molecular Biology*, 7:95–99. doi:10.1016/s0022-2836(63)80023-6.
- Ramler, I. P. (2008). *Improved Statistical Methods for k-means Clustering of Noisy and Directional data*. PhD thesis, Iowa State University.
- Ranalli, M., Lagona, F., Picone, M., and Zambianchi, E. (2018). Segmentation of sea current fields by cylindrical hidden Markov models: a composite likelihood approach. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 67(3):575–598. doi:10.1111/rssc.12240.
- Rancourt, D., Rivest, L.-P., and Asselin, J. (2000). Using orientation statistics to investigate variations in human kinematics. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 49(1):81–94. doi:10.1111/1467-9876.00180.
- Randles, R. H., Fligner, M. A., Policello, G. E., and Wolfe, D. A. (1980). An asymptotically distribution-free test for symmetry versus asymmetry. *Journal of the American Statistical Association*, 75(369):168–172. doi:10.1080/01621459.1980.10477448.
- Rao, C. R. (1965). *Linear Statistical Inference and its Applications*. Wiley, New York.
- Rao, J. S. (1969). *Some Contributions to the Analysis of Circular Data*. PhD thesis, Indian Statistical Institute.
- Rao, J. S. (1972a). Bahadur efficiencies of some tests for uniformity on the circle. *Annals of Mathematical Statistics*, 43(2):468–479. doi:10.1214/aoms/1177692627.
- Rao, J. S. (1972b). Some variants of chi-square for testing uniformity on the circle. *Zeitschrift für Wahrscheinlichkeitstheorie und Verwandte Gebiete*, 22(1):33–44. doi:10.1007/bf00538904.
- Rao, J. S. (1976). Some tests based on arc-lengths for the circle. *Sankhyā, Series B*, 38(4):329–338.
- Rao, J. S. (1984). Nonparametric methods in directional data analysis. In Krishnaiah, P. R. and Sen, P. K. (Eds.), *Handbook of Statistics 4*, pp. 755–770. Elsevier, Amsterdam. doi:10.1016/s0169-7161(84)04033-5.
- Rao, J. S. and Mardia, K. V. (1980). Pitman efficiencies of some two-sample nonparametric tests. In Matusita, K. (Ed.), *Recent Developments in Statistical Inference and Data Analysis*, pp. 248–254, New York. North-Holland.
- Rao, J. S. and SenGupta, S. (1970). An optimum hierarchical sampling procedure for cross-bedding data. *The Journal of Geology*, 78(5):533–544. doi:10.1086/627551.
- Rao, J. S. and Yoon, Y. (1983). Comparison of the limiting efficiencies of two chi-square type tests for the circle. *Journal of the Indian Statistical Association*, 21(1):19–26.
- Rasouli, V. and Harrison, J. P. (2010). Assessment of rock fracture surface roughness using Riemannian statistics of linear

- profiles. *International Journal of Rock Mechanics and Mining Sciences*, 47(6):940–948. doi:10.1016/j.ijrmmms.2010.05.013.
- Ratanaruamkarn, S., Niewiadomska-Bugaj, M., and Wang, J.-C. (2009). A new estimator of a circular median. *Communications in Statistics – Simulation and Computation*, 38(6):1269–1291. doi:10.1080/03610910902899950.
- Ravindran, P. (2002). *Bayesian Analysis of Circular Data Using Wrapped Distributions*. PhD thesis, North Carolina State University.
- Ravindran, P. and Ghosh, S. K. (2011). Bayesian analysis of circular data using wrapped distributions. *Journal of Statistical Theory and Practice*, 5(4):547–561. doi:10.1080/15598608.2011.10483731.
- Rayleigh, Lord. (1880). On the resultant of a large number of vibrations of the same pitch and of arbitrary phase. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 10(60):73–78. doi:10.1080/14786448008626893.
- Rayleigh, Lord. (1905). The problem of the random walk. *Nature*, 72(1866):318. doi:10.1038/072318a0.
- Rayleigh, Lord. (1919). On the problem of random vibrations, and of random flights in one, two, or three dimensions. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 37(220):321–347. doi:10.1080/14786440408635894.
- Reed, W. J. and Pewsey, A. (2009). Two nested families of skew-symmetric circular distributions. *TEST*, 18(3):516–528. doi:10.1007/s11749-008-0111-0.
- Reginato, M. (2016). monographaR: an R package to facilitate the production of plant taxonomic monographs. *Brittonia*, 68(2):212–216. doi:10.1007/s12228-015-9407-z.
- Reisinger, J., Waters, A., Silverthorn, B., and Mooney, R. J. (2010). Spherical topic models. In *ICML '10*, pp. 903–910, Madison. Omnipress. doi:10.5555/3104322.
- Riccardi, L., Nguyen, P. H., and Stock, G. (2009). Free-energy landscape of RNA hairpins constructed via dihedral angle principal component analysis. *The Journal of Physical Chemistry B*, 113(52):16660–16668. doi:10.1021/jp9076036.
- Richards, D. S. P. (1995). Exact asymptotics for some probability distributions on compact manifolds. *The Annals of Statistics*, 23(5):1582–1586. doi:10.1214/aos/1176324313.
- Richardus, P. and Adler, R. K. (1972). *Map Projections for Geodesists, Cartographers and Geographers*. North-Holland, London.
- Rivest, L.-P. (1982). Some statistical methods for bivariate circular data. *Journal of the Royal Statistical Society, Series B (Methodological)*, 44(1):81–90. doi:10.1111/j.2517-6161.1982.tb01190.x.
- Rivest, L.-P. (1984a). On the information matrix for symmetric distributions of the hypersphere. *The Annals of Statistics*, 12(3):1085–1089. doi:10.1214/aos/1176346724.
- Rivest, L.-P. (1984b). Symmetric distributions for dependent unit vectors. *The Annals of Statistics*, 12(3):1050–1057. doi:10.1214/aos/1176346720.
- Rivest, L.-P. (1986). Modified Kent’s statistics for testing the goodness-of-fit of the Fisher distribution in small concentrated samples. *Statistics & Probability Letters*, 4(1):1–4. doi:10.1016/0167-7152(86)90028-3.
- Rivest, L.-P. (1988). A distribution for dependent unit vectors. *Communications in Statistics – Theory and Methods*, 17(2):461–483. doi:10.1080/03610928808829634.
- Rivest, L.-P. (1989). Spherical regression for concentrated Fisher-von Mises distributions. *The Annals of Statistics*, 17(1):307–317. doi:10.1214/aos/1176347018.
- Rivest, L.-P. (1995). Comment: some local linear models for the assessment of geometric integrity. *Statistica Sinica*, 5(1):204–210.
- Rivest, L.-P. (1997). A decentred predictor for circular-circular regression. *Biometrika*, 84(3):717–726. doi:10.1093/biomet/84.3.717.
- Rivest, L.-P. (1999). Some linear model techniques for analyzing small circle spherical data. *The Canadian Journal of Statistics*, 27(3):623–638. doi:10.2307/3316117.
- Rivest, L.-P. (2001). A directional model for the statistical analysis of movement in three dimensions. *Biometrika*, 88(3):779–791. doi:10.1093/biomet/88.3.779.
- Rivest, L.-P., Baillargeon, S., and Pierrynowski, M. (2008). A directional model for the estimation of the rotation axes of the ankle joint. *Journal of the American Statistical Association*, 103(483):1060–1069. doi:10.1198/016214508000000643.
- Rivest, L.-P. and Chang, T. (2006). Regression and correlation for  $3 \times 3$  rotation matrices. *The Canadian Journal of Statistics*, 34(2):187–202. doi:10.1002/cjs.5550340201.
- Rivest, L.-P., Duchesne, T., Nicosia, A., and Fortin, D. (2016). A general angular regression model for the analysis of data on animal movement in ecology. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 65(3):445–463. doi:10.1111/rssc.12124.
- Rivest, L.-P. and Kato, S. (2019). A random-effects model for clustered circular data. *The Canadian Journal of Statistics*, 47(4):712–728. doi:10.1002/cjs.11520.
- Rivest, L.-P. and Oualkacha, K. (2018). On modeling of SE(3) objects. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 111–127. CRC Press, Boca Raton.
- Roberts, P. H. and Ursell, H. D. (1960). Random walk on a sphere and on a Riemannian manifold. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 252(1012):317–356. doi:10.1098/rsta.

- 1960.0008.
- Roberts, P. H. and Winch, D. E. (1984). On random rotations. *Advances in Applied Probability*, 16(3):638–655. doi:10.2307/1427291.
- Robotham, A. (2013). *sphereplot: Spherical Plotting*. R package version 1.5. URL: <https://CRAN.R-project.org/package=sphereplot>.
- Rocchi, M. B. L. and Perlini, C. (2002). Is the time of suicide a random choice? A new statistical perspective. *Crisis*, 23(4):161–166. doi:10.1027//0227-5910.23.4.161.
- Rodgers, J. L., Beasley, W. H., and Schuelke, M. (2014). Graphical data analysis on the circle: wrap-around time series plots for (interrupted) time series designs. *Multivariate Behavioral Research*, 49(6):571–580. doi:10.1080/00273171.2014.946589.
- Rodríguez, C. E., Núñez-Antonio, G., and Escarela, G. (2020). A Bayesian mixture model for clustering circular data. *Computational Statistics & Data Analysis*, 143:106842. doi:10.1016/j.csda.2019.106842.
- Rodríguez-Lujan, L., Bielza, C., and Larrañaga, P. (2015). Regularized multivariate von mises distribution. In Puerta, J. M., Gámez, J. A., Dorronsoro, B., Barrenechea, E., Troncoso, A., Baruke, B., and Galar, M. (Eds.), *Advances in Artificial Intelligence*, volume 9422 of *Lecture Notes in Computer Science*, pp. 25–35, Cham. Springer. doi:10.1007/978-3-319-24598-0\_3.
- Rodríguez-Lujan, L., Bielza, C., and Larrañaga, P. (2017). Frobenius norm regularization for the multivariate von Mises distribution. *International Journal of Intelligent Systems*, 32(2):153–176. doi:10.1002/int.21834.
- Ronchetti, E. (1992). Optimal robust estimators for the concentration parameter of a von Mises-Fisher distribution. In Mardia, K. V. (Ed.), *The Art of Statistical Science*, Wiley Series in Probability and Mathematical Statistics, pp. 65–74. Wiley, Chichester.
- Rosenthal, M., Wu, W., Klassen, E., and Srivastava, A. (2014). Spherical regression models using projective linear transformations. *Journal of the American Statistical Association*, 109(508):1615–1624. doi:10.1080/01621459.2014.892881.
- Ross, H. E., Crickmar, S. D., Sills, N. V., and Owen, E. P. (1969). Orientation to the vertical in free divers. *Aerospace Medicine*, 40(7):728–732.
- Rothman, E. (1969). *Properties and Applications of Test Statistics Invariant Under Rotation of a Circle*. PhD thesis, The Johns Hopkins University.
- Rothman, E. (1972a). A test for uniformity of a circular distribution based on a density estimator. In Tracy, D. S. (Ed.), *Symmetric Functions in Statistics*, pp. 197–202, Windsor. University of Windsor.
- Rothman, E. D. (1971). Tests of coordinate independence for a bivariate sample on a torus. *Annals of Mathematical Statistics*, 42(6):1962–1969. doi:10.1214/aoms/1177693064.
- Rothman, E. D. (1972b). Tests for uniformity of a circular distribution. *Sankhyā, Series A*, 34(1):23–32.
- Rouvinen, S. and Kuuluvainen, T. (1997). Structure and asymmetry of tree crowns in relation to local competition in a natural mature Scots pine forest. *Canadian Journal of Forest Research*, 27(6):890–902. doi:10.1139/x97-012.
- Roy, A., Pal, A., and Garain, U. (2017). JCLMM: A finite mixture model for clustering of circular-linear data and its application to psoriatic plaque segmentation. *Pattern Recognition*, 66:160–173. doi:10.1016/j.patcog.2016.12.016.
- Roy, R. (1972). Spectral analysis for a random process on the circle. *Journal of Applied Probability*, 9(4):745–757. doi:10.1017/s0021900200036123.
- Roy, R. (1973). Estimation of the covariance function of a homogeneous process on the sphere. *The Annals of Statistics*, 1(4):780–785. doi:10.1214/aos/1176342475.
- Roy, R. (1976). Spectral analysis for a random process on the sphere. *Annals of the Institute of Statistical Mathematics*, 28(1):91–97. doi:10.1007/bf02504732.
- Rudin, W. (1987). *Real and Complex Analysis*. McGraw-Hill, New York, third edition.
- Rueda, C., Fernández, M. A., Barragán, S., Mardia, K. V., and Peddada, S. D. (2016). Circular piecewise regression with applications to cell-cycle data. *Biometrics*, 72(4):1266–1274. doi:10.1111/biom.12512.
- Rueda, C., Fernández, M. A., Barragán, S., and Peddada, S. D. (2015). Some advances in constrained inference for ordered circular parameters in oscillatory systems. In Dryden, I. L. and Kent, J. T. (Eds.), *Geometry Driven Statistics*, Wiley Series in Probability and Statistics, pp. 97–114. Wiley, Chichester. doi:10.1002/9781118866641.ch4.
- Rueda, C., Fernández, M. A., and Peddada, S. D. (2009). Estimation of parameters subject to order restrictions on a circle with application to estimation of phase angles of cell cycle genes. *Journal of the American Statistical Association*, 104(485):338–347. doi:10.1198/jasa.2009.0120.
- Ruhkin, A. L. (1972). Some statistical decisions about distributions on a circle for large samples. *Sankhyā, Series A*, 34:243–250.
- Rumcheva, P. (2005). *Projected Multivariate Linear Models for Directional Data*. PhD thesis, University of Florida.
- Rumcheva, P. and Presnell, B. (2017). An improved test of equality of mean directions for the Langevin-von Mises-Fisher distribution. *Australian & New Zealand Journal of Statistics*, 59(1):119–135. doi:10.1111/anzs.12183.
- Russell, G. S. and Levitin, D. J. (1996). An expanded table of probability values for Rao’s spacing test. *Communications in Statistics – Simulation and Computation*, 24(4):879–888. doi:10.1080/03610919508813281.
- Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, 39(6):1161–1178. doi:

10.1037/h0077714.

- Rutkowska, A., Kohnová, S., and Banasik, K. (2018). Probabilistic properties of the date of maximum river flow, an approach based on circular statistics in lowland, highland and mountainous catchment. *Acta Geophysica*, 66(4):755–768. doi:10.1007/s11600-018-0139-9.
- Ruymgaart, F. H. (1989). Strong uniform convergence of density estimators on spheres. *Journal of Statistical Planning and Inference*, 23(1):45–52. doi:10.1016/0378-3758(89)90038-4.
- Ryali, S., Chen, T., Supekar, K., and Menon, V. (2013). A parcellation scheme based on von Mises-Fisher distributions and Markov random fields for segmenting brain regions using resting-state fMRI. *NeuroImage*, 65:83–96. doi:10.1016/j.neuroimage.2012.09.067.
- Sadikon, N. H., Ibrahim, A. I. N., Mohamed, I., and Shimizu, K. (2019). A new test of discordancy in cylindrical data. *Communications in Statistics – Simulation and Computation*, 48(8):2512–2522. doi:10.1080/03610918.2018.1458131.
- Sadys, M., Kennedy, R., and Skjoth, C. A. (2015). An analysis of local wind and air mass directions and their impact on Cladosporium distribution using HYSPLIT and circular statistics. *Fungal Ecology*, 18:56–66. doi:10.1016/j.funeco.2015.09.006.
- Sahoo, I., Guinness, J., and Reich, B. J. (2019). A test for isotropy on a sphere using spherical harmonic functions. *Statistica Sinica*, 29(3):1253–1276. doi:10.5705/ss.202017.0475.
- Said, S., Bombrun, L., and Berthoumieu, Y. (2019). Warped Riemannian metrics for location-scale models. In *Geometric Structures of Information, Signals Communication Technology*, pp. 251–296. Springer, Cham. doi:10.1007/978-3-030-02520-5\_10.
- Salah, A. and Nadif, M. (2017). Social regularized von Mises-Fisher mixture model for item recommendation. *Data Mining and Knowledge Discovery*, 31(5, SI):1218–1241. doi:10.1007/s10618-017-0499-9.
- Salah, A. and Nadif, M. (2019). Directional co-clustering. *Advances in Data Analysis and Classification*, 13(3):591–620. doi:10.1007/s11634-018-0323-4.
- Sánchez, E. H. and Scarpa, B. (2012). A wrapped flexible generalized skew-normal model for a bimodal circular distribution of wind direction. *Chilean Journal of Statistics*, 3(2):129–141.
- Sapiro, G. (2001a). *Geometric Partial Differential Equations and Image Analysis*. Cambridge University Press, Cambridge. doi:10.1017/CB09780511626319.
- Sapiro, G. (2001b). Harmonic map flows and image processing. In Devore, R. A., Iserles, A., and Süli, E. (Eds.), *Foundations of Computational Mathematics*, volume 284 of *London Mathematical Society Lecture Note Series*, pp. 299–322. Cambridge University Press, Cambridge. doi:10.1017/CB09781107360198.011.
- Sargsyan, K., Hua, Y. H., and Lim, C. (2015). Clustangles: an open library for clustering angular data. *Journal of Chemical Information and Modeling*, 55(8):1517–1520. doi:10.1021/acs.jcim.5b00316.
- Sargsyan, K., Wright, J., and Lim, C. (2012). GeoPCA: a new tool for multivariate analysis of dihedral angles based on principal component geodesics. *Nucleic Acids Research*, 40(3):e25–e25. doi:10.1093/nar/gkv1000.
- Sarkar, I. C., Mudholkar, G. S., and Raubertas, R. F. (1995). An approximation to the distribution of the resultant from a Fisher distribution. *Communications in Statistics – Simulation and Computation*, 24(1):227–241. doi:10.1080/03610919508813239.
- Sarma, R., Rao, A. V. D., and Giriya, S. V. S. (2011). On characteristic functions of the wrapped lognormal and the wrapped Weibull distributions. *Journal of Statistical Computation and Simulation*, 81(5):579–589. doi:10.1080/00949650903436547.
- Sarma, Y. R. and Jammalamadaka, S. R. (1993). Circular regression. In Matsusita, K., Puri, M. L., and Hayakawa, T. (Eds.), *Statistical Science and Data Analysis*, pp. 109–128, Utrecht. VSP.
- Sau, M. F. and Rodriguez, D. (2018). Minimum distance method for directional data and outlier detection. *Advances in Data Analysis and Classification*, 12(3):587–603. doi:10.1007/s11634-017-0287-9.
- Saw, J. G. (1978). A family of distributions on the  $m$ -sphere and some hypothesis tests. *Biometrika*, 65(1):69–73. doi:10.2307/2335278.
- Saw, J. G. (1983). Dependent unit vectors. *Biometrika*, 70(3):665–671. doi:10.1093/biomet/70.3.665.
- Saw, J. G. (1984). Ultraspherical polynomials and statistics on the  $m$ -sphere. *Journal of Multivariate Analysis*, 14(1):105–113. doi:10.1016/0047-259x(84)90051-4.
- Scapini, F., Aloia, A., Bouslama, M. F., Chelazzi, L., Colombini, I., ElGtari, M., Fallaci, M., and Marchetti, G. M. (2002). Multiple regression analysis of the sources of variation in orientation of two sympatric sandhoppers, *Talitrus saltator* and *Talorchestia brito*, from an exposed Mediterranean beach. *Behavioral Ecology and Sociobiology*, 51(5):403–414. doi:10.1007/s00265-002-0451-9.
- Scealy, J. L. and Welsh, A. H. (2011). Regression for compositional data by using distributions defined on the hypersphere. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 73(3):351–375. doi:10.1111/j.1467-9868.2010.00766.x.
- Scealy, J. L. and Welsh, A. H. (2014a). Colours and cocktails: compositional data analysis: 2013 Lancaster lecture. *Australian & New Zealand Journal of Statistics*, 56(2):145–169. doi:10.1111/anzs.12073.
- Scealy, J. L. and Welsh, A. H. (2014b). Fitting Kent models to compositional data with small concentration. *Statistics and*

- Computing*, 24(2):165–179. doi:10.1007/s11222-012-9361-5.
- Scealy, J. L. and Welsh, A. H. (2017). A directional mixed effects model for compositional expenditure data. *Journal of the American Statistical Association*, 112(517):24–36. doi:10.1080/01621459.2016.1189336.
- Scealy, J. L. and Wood, A. T. A. (2019). Scaled von Mises–Fisher distributions and regression models for paleomagnetic directional data. *Journal of the American Statistical Association*, 114(528):1547–1560. doi:10.1080/01621459.2019.1585249.
- Schach, S. (1967). Nonparametric tests of location for circular distributions. Technical Report 95, Department of Statistics, Minnesota University.
- Schach, S. (1969a). Nonparametric symmetry tests for circular distributions. *Biometrika*, 56(3):571–577. doi:10.1093/biomet/56.3.571.
- Schach, S. (1969b). On a class of nonparametric two-sample tests for circular distributions. *Annals of Mathematical Statistics*, 40(5):1791–1800. doi:10.1214/aoms/1177697392.
- Schaeben, H. (1986). Comment on “SPHERE: a contouring program for spherical data”. *Computers & Geosciences*, 12(5):729. doi:10.1016/0098-3004(86)90050-6.
- Schaeben, H. (1993). Towards statistics of crystal orientations in quantitative texture analysis. *Journal of Applied Crystallography*, 26(1):112–121. doi:10.1107/s0021889892009270.
- Schaeben, H. (1999). The de la Vallée Poussin standard orientation density function. *Textures and Microstructures*, 33:365–373. doi:10.1155/tsm.33.365.
- Schatte, P. (1983). On sums modulo  $2\pi$  of independent random variables. *Mathematische Nachrichten*, 110(1):243–262. doi:10.1002/mana.19831100118.
- Schlather, M., Malinowski, A., Menck, P. J., Oesting, M., and Storkorb, K. (2015). Analysis, simulation and prediction of multivariate random fields with package RandomFields. *Journal of Statistical Software*, 63(8):1–25. doi:10.18637/jss.v063.i08.
- Schmidt, P. W. (1976). The non-uniqueness of the Australian Mesozoic palaeomagnetic pole position. *Geophysical Journal International*, 47(2):285–300. doi:10.1111/j.1365-246X.1976.tb01274.x.
- Schmidt, P. W. and Embleton, B. J. J. (1985). Prefolding and overprint magnetic signatures in Precambrian ( $\sim 2.9$ – $2.7$  Ga) igneous rocks from the Pilbara Craton and Hamersley Basin, NW Australia. *Journal of Geophysical Research*, 90(B4):2967–2984. doi:10.1029/JB090iB04p02967.
- Schmidt-Koenig, K. (1958). Experimentelle Einflussnahme auf die 24-Stunden-Periodik bei Brieftauben und deren Auswirkungen unter besonderer Berücksichtigung des Heimfindevermögens. *Zeitschrift für Tierpsychologie*, 15(3):301–331. doi:10.1111/j.1439-0310.1958.tb00568.x.
- Schmidt-Koenig, K. (1963). On the role of the loft, the distance and the site of release in pigeon homing (the “cross-loft experiment”). *Biological Bulletin*, 125(1):154–164. doi:10.2307/1539298.
- Schmidt-Koenig, K. (1965). Current problems in bird orientation. In Lehrman, D. S., Hinde, R. A., and Shaw, E. (Eds.), *Advances in the Study of Behaviour*, volume 1, pp. 217–278. Academic Press, New York. doi:10.1016/s0065-3454(08)60059-5.
- Schnute, J. T. and Groot, K. (1992). Statistical analysis of animal orientation data. *Animal Behaviour*, 43(1):15–33. doi:10.1016/s0003-3472(05)80068-5.
- Schoenberg, I. J. (1942). Positive definite functions on spheres. *Duke Mathematical Journal*, 9(1):96–108. doi:10.1215/S0012-7094-42-00908-6.
- Schou, G. (1978). Estimation of the concentration parameter in von Mises-Fisher distributions. *Biometrika*, 65(2):369–377. doi:10.2307/2335217.
- Schuler, M. and Gebelin, H. (1955). *Five Place Tables of Elliptical Functions based on Jacobi’s Parameter  $q$* . Springer, Berlin.
- Schulz, J., Jung, S., Huckemann, S., Pierrynowski, M., Marron, J. S., and Pizer, S. M. (2015). Analysis of rotational deformations from directional data. *Journal of Computational and Graphical Statistics*, 24(2):539–560. doi:10.1080/10618600.2014.914947.
- Schutte, W. D. (2014). *Nonparametric Estimation of the Off-Pulse Interval(s) of a Pulsar Light Curve*. PhD thesis, North-West University.
- Scott, J. G. (2011). Bayesian estimation of intensity surfaces on the sphere via needlet shrinkage and selection. *Bayesian Analysis*, 6(2):307–327. doi:10.1214/11-BA611.
- Seal, B. and SenGupta, A. (2012). On the foundations of dependency models and parameters for random variables on cylinder  $R^3$ . *Calcutta Statistical Association Bulletin*, 64(255-256):151–165. doi:10.1177/0008068320120301.
- Sei, T. (2013). A Jacobian inequality for gradient maps on the sphere and its application to directional statistics. *Communications in Statistics – Theory and Methods*, 42(14):2525–2542. doi:10.1080/03610926.2011.563017.
- Sei, T. and Kume, A. (2015). Calculating the normalising constant of the Bingham distribution on the sphere using the holonomic gradient method. *Statistics and Computing*, 25(2):321–332. doi:10.1007/s11222-013-9434-0.
- Sei, T., Shibata, H., Takemura, A., Ohara, K., and Takayama, N. (2013). Properties and applications of Fisher distribution on the rotation group. *Journal of Multivariate Analysis*, 116:440–455. doi:10.1016/j.jmva.2013.01.010.
- Seifert, L., Coeurjolly, J.-F., Hérault, R., Wattebled, L., and Davids, K. (2013). Temporal dynamics of inter-limb coordination

- in ice climbing revealed through change-point analysis of the geodesic mean of circular data. *Journal of Applied Statistics*, 40(11):2317–2331. doi:10.1080/02664763.2013.810194.
- Selby, B. (1964). Girdle distributions on a sphere. *Biometrika*, 51(3-4):381–392. doi:10.2307/2334144.
- Self, S. G. and Liang, K.-Y. (1987). Asymptotic properties of maximum likelihood estimators and likelihood ratio tests under nonstandard conditions. *Journal of the American Statistical Association*, 82(398):605–610. doi:10.1080/01621459.1987.10478472.
- Selkirk, K. (1982). Statistics on a circle. *Teaching Statistics*, 4(3):87–92. doi:10.1111/j.1467-9639.1982.tb00475.x.
- SenGupta, A. (2004). On the constructions of probability distributions for directional data. *Bulletin of the Calcutta Mathematical Society*, 96(2):139–154.
- SenGupta, A. and Bhattacharya, S. (2015). Finite mixture-based Bayesian analysis of linear-circular models. *Environmental and Ecological Statistics*, 22(4):667–679. doi:10.1007/s10651-015-0325-8.
- SenGupta, A., Kim, S., and Arnold, B. C. (2013). Inverse circular-circular regression. *Journal of Multivariate Analysis*, 119:200–208. doi:10.1016/j.jmva.2013.04.011.
- SenGupta, A. and Laha, A. K. (2008a). A Bayesian analysis of the change-point problem for directional data. *Journal of Applied Statistics*, 35(5-6):693–700. doi:10.1080/02664760801924004.
- SenGupta, A. and Laha, A. K. (2008b). A likelihood integrated method for exploratory graphical analysis of change point problem with directional data. *Communications in Statistics – Theory and Methods*, 37(11-12):1783–1791. doi:10.1080/03610920701826401.
- SenGupta, A. and Ong, S. H. (2014). A unified approach for construction of probability models for bivariate linear and directional data. *Communications in Statistics – Theory and Methods*, 43(10-12):2563–2569. doi:10.1080/03610926.2013.800883.
- SenGupta, A. and Pal, C. (2001). On optimal tests for isotropy against the symmetric wrapped stable-circular uniform mixture family. *Journal of Applied Statistics*, 28(1):129–143. doi:10.1080/02664760120011653.
- SenGupta, A. and Rao, J. S. (1991). On locally optimal tests for the mean direction of the Langevin distribution. *Statistics & Probability Letters*, 12(6):537–544. doi:10.1016/0167-7152(91)90009-g.
- SenGupta, A. and Roy, R. (2011). Testing homogeneity of mean directions for circular dispersion models. *Calcutta Statistical Association Bulletin*, 63(249-252):141–155. doi:10.1177/0008068320110107.
- SenGupta, A. and Roy, S. (2005). A simple classification rule for directional data. In Balakrishnan, N., Nagaraja, H. N., and Kannan, N. (Eds.), *Advances in Ranking and Selection, Multiple Comparisons, and Reliability*, Statistics for Industry and Technology, pp. 81–90. Birkhäuser, Boston. doi:10.1007/0-8176-4422-9\_5.
- SenGupta, A. and Ugwuowo, F. I. (2011). A classification method for directional data with application to the human skull. *Communications in Statistics – Theory and Methods*, 40(3):457–466. doi:10.1080/03610920903377807.
- SenGupta, S. and Rao, J. S. (1966). Statistical analysis of crossbedding azimuths from the Kamthi formation around Bheemaram, Pranhita-Godavari valley. *Sankhyā, Series B*, 28(1):165–174.
- Sepehri, A. (2019). New tests of uniformity on the compact classical groups as diagnostics for weak-\* mixing of Markov chains. *Bernoulli*, 25(2):1536–1567. doi:10.3150/18-BEJ1029.
- Serfling, R. J. (1980). *Approximation Theorems of Mathematical Statistics*. Wiley Series in Probability and Statistics. Wiley, New York. doi:10.1002/9780470316481.
- Shao, Y. and Hahn, M. G. (1996). On a distribution-free test of fit for continuous distribution functions. *Scandinavian Journal of Statistics*, 23(1):63–73.
- Sharples, J. J. (2008). Review of formal methodologies for wind-slope correction of wildfire rate of spread. *International Journal of Wildland Fire*, 17(2):179–193. doi:10.1071/wf06156.
- Sharples, J. J., McRae, R. H. D., and Weber, R. O. (2010). Wind characteristics over complex terrain with implications for bushfire risk management. *Environmental Modelling and Software*, 25(10):1099–1120. doi:10.1016/j.envsoft.2010.03.016.
- Shepherd, J. and Rao, J. S. (1970). Pitman efficiencies of tests based on spacings. In Puri, M. L. (Ed.), *Nonparametric Techniques in Statistical Inference*, pp. 405–415. Cambridge University Press, Cambridge.
- Sherman, B. (1950). A random variable related to the spacing of sample values. *Annals of Mathematical Statistics*, 21(3):339–361. doi:10.1214/aoms/1177729794.
- Shieh, G. S. and Johnson, R. A. (2005). Inference based on a bivariate distribution with von Mises marginals. *Annals of the Institute of Statistical Mathematics*, 57(4):789–802. doi:10.1007/bf02915439.
- Shieh, G. S., Johnson, R. A., and Frees, E. W. (1994). Testing independence of bivariate circular data and weighted degenerate  $U$ -statistics. *Statistica Sinica*, 4(2):729–747.
- Shieh, G. S., Zheng, S., Johnson, R. A., Chang, Y.-F., Shimizu, K., Wang, C.-C., and Tang, S.-L. (2011). Modeling and comparing the organization of circular genomes. *Bioinformatics*, 27(7):912–918. doi:10.1093/bioinformatics/btr049.
- Shimatani, I. K., Yoda, K., Katsumata, N., and Sato, K. (2012). Toward the quantification of a conceptual framework for movement ecology using circular statistical modeling. *PLOS One*, 7(11):e50309. doi:10.1371/journal.pone.0050309.
- Shimizu, K. (2008). Recent developments in directional statistics: distributional aspects. *Bulletin of the Computational Statistics of Japan*, 19(2):127–150. doi:10.20551/jscswabun.19.2\_127.

- Shimizu, K. (2018). Probability distributions in directional statistics: a review. *Journal of the Japan Statistical Society. Japanese Issue*, 47(2):103–140. doi:10.11329/jjssj.47.103.
- Shimizu, K. and Iida, K. (2002). Pearson type VII distributions on spheres. *Communications in Statistics – Theory and Methods*, 31(4):513–526. doi:10.1081/sta-120003131.
- Shimizu, K. and Wang, M.-Z. (2013). Use of directional statistics in environmental science. *Proceedings of the Institute of Statistical Mathematics*, 61(2):289–305.
- Shin, Y.-K. (1995). Double bootstrap confidence cones for spherical data based on pre pivoting. *Journal of the Korean Statistical Society*, 24(1):183–195.
- Sibuya, M. (1962). A method for generating uniformly distributed points on  $n$ -dimensional spheres. *Annals of the Institute of Statistical Mathematics*, 14(1):81–85. doi:10.1007/bf02868626.
- Siegel, S. (1956). *Nonparametric Statistics for the Behavioural Sciences*. McGraw-Hill, New York.
- Siew, H. Y. (2007). *Directional Models with Applications to Environmental Data*. PhD thesis, Graduate University for Advanced Studies.
- Siew, H.-Y., Kato, S., and Shimizu, K. (2008). The generalized  $t$ -distribution on the circle. *Japan Journal of Applied Statistics*, 37(1):1–16. doi:10.5023/jappstat.37.1.
- Siew, H.-Y. and Shimizu, K. (2008). The generalized symmetric Laplace distribution on the sphere. *Statistical Methodology*, 5(6):487–501. doi:10.1016/j.stamet.2007.11.004.
- Signorini, D. F. and Jones, M. C. (2004). Kernel estimators for univariate binary regression. *Journal of the American Statistical Association*, 99:119–126. doi:10.1198/016214504000000115.
- Sikaroudi, A. E., Welch, D. A., Woehl, T. J., Faller, R. E., J. E., Browning, N. D., and Park, C. (2018). Directional statistics of preferential orientations of two shapes in their aggregate and its application to nanoparticle aggregation. *Technometrics*, 60(3):332–344. doi:10.1080/00401706.2017.1366949.
- Silverman, B. (1978). Distances on circles, toruses and spheres. *Journal of Applied Probability*, 15(1):136–143. doi:10.1017/S0021900200105650.
- Singh, H., Hnizdo, V., and Demchuk, E. (2002). Probabilistic model for two dependent circular variables. *Biometrika*, 89(3):719–723. doi:10.1093/biomet/89.3.719.
- Sinz, F., Berens, B., Kuemmerer, M., and Wallis, T. (2018). *PyCircStat: Circular Statistics with Python*. URL: <https://github.com/circstat/pycircstat>.
- Sittel, F., Filk, T., and Stock, G. (2017). Principal component analysis on a torus: theory and application to protein dynamics. *The Journal of Chemical Physics*, 147(24):244101. doi:10.1063/1.4998259.
- Sklar, M. (1959). Fonctions de répartition à  $n$  dimensions et leurs marges. *Publications de l’Institut de Statistique de l’Université de Paris*, 8:229–231.
- Small, C. G. (1987). Measures of centrality for multivariate and directional distributions. *The Canadian Journal of Statistics*, 15(1):31–39. doi:10.2307/3314859.
- Small, C. G. (1996). *The Statistical Theory of Shape*. Springer Series in Statistics. Springer, New York. doi:10.1007/978-1-4612-4032-7.
- Smith, P. N., Refshauge, K. M., and Scarvell, J. M. (2003). Development of the concepts of the knee kinematics. *Archives of Physical Medicine and Rehabilitation*, 84:1895–1902. doi:10.1016/s0003-9993(03)00281-8.
- Soderkvist, I. and Wedin, P. (1993). Determining the movements of the skeleton using well-configured markers. *Journal of Biomechanics*, 26:1473–1477. doi:10.1016/0021-9290(93)90098-y.
- Soetaert, K. (2019). *plot3D: Plotting Multi-Dimensional Data*. R package version 1.3. URL: <https://CRAN.R-project.org/package=plot3D>.
- Solari, S. and Angel Losada, M. (2016). Simulation of non-stationary wind speed and direction time series. *Journal of Wind Engineering and Industrial Aerodynamics*, 149:48–58. doi:10.1016/j.jweia.2015.11.011.
- Somerville, M. C., Mukerjee, S., and Fox, D. L. (1996). Estimating the wind direction of maximum air pollutant concentration. *Environmetrics*, 7(2):231–243. doi:10.1002/(sici)1099-095x(199603)7:2<231::aid-env207>3.0.co;2-i.
- Sommer, S. (2013). Horizontal dimensionality reduction and iterated frame bundle development. In Nielsen, F. and Barbaresco, F. (Eds.), *Geometric Science of Information*, volume 8085 of *Lecture Notes in Computer Science*, pp. 76–83, Berlin. Springer. doi:10.1007/978-3-642-40020-9\_7.
- Sommer, S. (2019). An infinitesimal probabilistic model for principal component analysis of manifold valued data. *Sankhyā, Series A*, 81(1):37–62. doi:10.1007/s13171-018-0139-5.
- Sommer, S., Lauze, F., and Nielsen, M. (2014). Optimization over geodesics for exact principal geodesic analysis. *Advances in Computational Mathematics*, 40(2):283–313. doi:10.1007/s10444-013-9308-1.
- Song, H., Liu, J., and Wang, G. (2012). High-order parameter approximation for von Mises-Fisher distributions. *Applied Mathematics and Computation*, 218(24):11880–11890. doi:10.1016/j.amc.2012.05.050.
- Soubeyrand, S., Enjalbert, J., and Sache, I. (2008). Accounting for roughness of circular processes: using Gaussian random processes to model the anisotropic spread of airborne plant disease. *Theoretical Population Biology*, 73(1):92–103. doi:10.1016/j.tpb.2007.09.005.
- Souden, M., Kinoshita, K., and Nakatani, T. (2013). An integration of source location cues for speech clustering in distributed

- microphone arrays. In *2013 IEEE International Conference on Acoustics, Speech and Signal Processing*, pp. 111–115, New York. IEEE. doi:10.1109/icassp.2013.6637619.
- Soukissian, T. H. (2014). Probabilistic modeling of directional and linear characteristics of wind and sea states. *Ocean Engineering*, 91:91–110. doi:10.1016/j.oceaneng.2014.08.018.
- Soukissian, T. H. and Karathanasi, F. E. (2017). On the selection of bivariate parametric models for wind data. *Applied Energy*, 188:280–304. doi:10.1016/j.apenergy.2016.11.097.
- Spain, A. V., Okello-Oloya, T., and John, R. D. (1983). Orientation of the termitaria of two species of *Amitermes* (*Isoptera: Termitinae*) from Northern Queensland. *Australian Journal of Zoology*, 31(2):167–177. doi:10.1071/Z09830167.
- Spurr, B. D. (1981). On estimating the parameters in mixtures of circular normal distributions. *Mathematical Geology*, 13(2):163–173. doi:10.1007/bf01031392.
- Spurr, B. D. and Koutbeiy, M. A. (1991). A comparison of various methods for estimating the parameters in mixtures of von Mises distributions. *Communications in Statistics – Simulation and Computation*, 20(2-3):725–741. doi:10.1080/03610919108812980.
- Sra, S. (2007). *Matrix Nearness Problems in Data Mining*. PhD thesis, University of Texas at Austin.
- Sra, S. (2012). A short note on parameter approximation for von Mises-Fisher distributions: and a fast implementation of  $I_s(x)$ . *Computational Statistics*, 27(1):177–190. doi:10.1007/s00180-011-0232-x.
- Sra, S. (2018). Directional statistics in machine learning: a brief review. In Ley, C. and Verdebout, T. (Eds.), *Applied Directional Statistics*, Chapman & Hall/CRC Interdisciplinary Statistics Series, pp. 259–276. CRC Press, Boca Raton.
- Sra, S., Jain, P., and Dhillon, I. (2007). Modeling data using directional distributions: Part ii. Technical Report TR-07-05, Max Planck Institute for Biological Cybernetics.
- Sra, S. and Karp, D. (2013). The multivariate Watson distribution: maximum-likelihood estimation and other aspects. *Journal of Multivariate Analysis*, 114:256–269. doi:10.1016/j.jmva.2012.08.010.
- Srivastava, M. S. and Khatri, C. G. (1979). *An Introduction to Multivariate Statistics*. North-Holland, New York.
- Stam, A. J. (1982). Limit theorems for uniform distributions on spheres in high dimensional Euclidean spaces. *Journal of Applied Probability*, 19(1):221–229. doi:10.2307/3213932.
- Stanfill, B., Genschel, U., and Hofmann, H. (2013). Point estimation of the central orientation of random rotations. *Technometrics*, 55(4):524–535. doi:10.1080/00401706.2013.826145.
- Stanfill, B., Genschel, U., Hofmann, H., and Nordman, D. (2015). Nonparametric confidence regions for the central orientation of random rotations. *Journal of Multivariate Analysis*, 135:106–116. doi:10.1016/j.jmva.2014.12.003.
- Stanfill, B., Hofmann, H., and Genschel, U. (2014). rotations: an R package for SO(3) data. *The R Journal*, 6:68–78. doi:10.32614/rj-2014-007.
- Steck, G. P. (1969). The Smirnov two-sample tests as rank tests. *Annals of Mathematical Statistics*, 40(4):1449–1466. doi:10.1214/aoms/1177697516.
- Stein, M. (1991). The analysis of directional time series: applications to wind speed and direction. *Technometrics*, 33(4):485–486. doi:10.1080/00401706.1991.10484887.
- Stephens, M. A. (1962a). Exact and approximate tests for directions. I. *Biometrika*, 49(3):463–477. doi:10.2307/2333980.
- Stephens, M. A. (1962b). Exact and approximate tests for directions. II. *Biometrika*, 49(3/4):547–552. doi:10.1093/biomet/49.3-4.547.
- Stephens, M. A. (1962c). *The Statistics of Directions: the von Mises and Fisher Distributions*. PhD thesis, Univeristy of Toronto.
- Stephens, M. A. (1963a). The distribution of the goodness-of-fit statistic  $U_n^2$ . I. *Biometrika*, 50(3/4):303–313. doi:10.2307/2333901.
- Stephens, M. A. (1963b). Random walk on a circle. *Biometrika*, 50(3/4):385–390. doi:10.2307/2333907.
- Stephens, M. A. (1964a). The distribution of the goodness-of-fit statistic  $U_N^2$ . II. *Biometrika*, 51(3/4):393–397. doi:10.2307/2334145.
- Stephens, M. A. (1964b). The testing of unit vectors for randomness. *Journal of the American Statistical Association*, 59(305):160–167. doi:10.1080/01621459.1964.10480709.
- Stephens, M. A. (1965a). Appendix to “Equatorial distributions on a sphere” by G. S. Watson. *Biometrika*, 52(1/2):200–201.
- Stephens, M. A. (1965b). The goodness-of-fit statistic  $V_n$ : distribution and significance points. *Biometrika*, 52(3/4):309–321. doi:10.1093/biomet/52.3-4.309.
- Stephens, M. A. (1965c). Significance points for the two-sample statistic  $U_{M,N}^2$ . *Biometrika*, 52(3/4):661–663. doi:10.2307/2333724.
- Stephens, M. A. (1967). Tests for the dispersion and the modal vector of a distribution on a sphere. *Biometrika*, 54(1/2):211–223. doi:10.2307/2333864.
- Stephens, M. A. (1969a). A goodness-of-fit statistic for the circle, with some comparisons. *Biometrika*, 56(1):161–168. doi:10.1093/biomet/56.1.161.
- Stephens, M. A. (1969b). Multi-sample tests for the Fisher distribution for directions. *Biometrika*, 56(1):169–181. doi:10.1093/biomet/56.1.169.
- Stephens, M. A. (1969c). Results from the relation between two statistics of the Kolmogorov-Smirnov type. *Annals of*



- Mathematical Statistics*, 40(5):1833–1837. doi:10.1214/aoms/1177697396.
- Stephens, M. A. (1969d). Techniques for directional data. Technical report, Department of Statistics, Stanford University.
- Stephens, M. A. (1969e). Tests for randomness of directions against two circular alternatives. *Journal of the American Statistical Association*, 64(325):280–289. doi:10.1080/01621459.1969.10500971.
- Stephens, M. A. (1969f). Tests for the von Mises distribution. *Biometrika*, 56(1):149–160. doi:10.1093/biomet/56.1.149.
- Stephens, M. A. (1970). Use of the Kolmogorov-Smirnov, Cramér-von Mises and related statistics without extensive tables. *Journal of the Royal Statistical Society, Series B (Methodological)*, 32(1):115–122. doi:10.1111/j.2517-6161.1970.tb00821.x.
- Stephens, M. A. (1972). Multisample tests for the von Mises distribution. *Journal of the American Statistical Association*, 67(338):456–461. doi:10.1080/01621459.1972.10482410.
- Stephens, M. A. (1974). EDF statistics for goodness of fit and some comparisons. *Journal of the American Statistical Association*, 69(347):730–737. doi:10.1080/01621459.1974.10480196.
- Stephens, M. A. (1975a). Axial and bimodal data on a sphere. In Gupta, R. P. (Ed.), *Proceedings of Conference at Dalhousie University, Halifax, Nova Scotia*, pp. 311–323, Amsterdam. North-Holland.
- Stephens, M. A. (1975b). A new test for the modal vector of the Fisher distribution. *Biometrika*, 62(1):171–174. doi:10.1093/biomet/62.1.171.
- Stephens, M. A. (1977). Whitworth runs on a circle. *Annals of the Institute of Statistical Mathematics*, 29(1):287–294. doi:10.1007/bf02532790.
- Stephens, M. A. (1979). Vector correlation. *Biometrika*, 66(1):41–48. doi:10.1093/biomet/66.1.41.
- Stephens, M. A. (1982). Use of the von Mises distribution to analyse continuous proportions. *Biometrika*, 69(1):197–203. doi:10.1093/biomet/69.1.197.
- Stephens, M. A. (1992). On Watson’s ANOVA for directions. In Mardia, K. V. (Ed.), *The Art of Statistical Science*, Wiley Series in Probability and Mathematical Statistics, pp. 75–85. Wiley, Chichester. doi:10.21236/ada253576.
- Stevens, W. L. (1939). Solution to a geometrical problem in probability. *Annals of Eugenics*, 9(4):315–320. doi:10.1111/j.1469-1809.1939.tb02216.x.
- Straub, J., Chang, J., Freifeld, O., and Fisher, J. W. I. (2015). A Dirichlet process mixture model for spherical data. In Lebanon, G. and Vishwanathan, S. V. N. (Eds.), *Proceedings of the Eighteenth International Conference on Artificial Intelligence and Statistics*, volume 38 of *Proceedings of Machine Learning Research*, San Diego. PMLR.
- Stroock, D. W. (2000). *An Introduction to the Analysis of Paths on a Riemannian manifold*, volume 74 of *Mathematical Surveys and Monographs*. American Mathematical Society, Providence. doi:10.1090/surv/074.
- Su, J., Kurtek, S., Klassen, E., and Srivastava, A. (2014). Statistical analysis of trajectories on Riemannian manifolds: bird migration, hurricane tracking and video surveillance. *Annals of Applied Statistics*, 8(1):530–552. doi:10.1214/13-AOAS701.
- Su, Y. and Wu, X.-K. (2011). Smooth test for uniformity on the surface of a unit sphere. In *2011 International Conference on Machine Learning and Cybernetics*, pp. 867–872, New York. IEEE. doi:10.1109/icmlc.2011.6016757.
- Sun, S. Z. and Lockhart, R. A. (2019). Bayesian optimality for Beran’s class of tests of uniformity around the circle. *Journal of Statistical Planning and Inference*, 198:79–90. doi:10.1016/j.jspi.2018.03.006.
- Sungur, E. A. and Orth, J. M. (2014). Understanding directional dependence through angular correlation. *Communications in Statistics – Theory and Methods*, 43(19):4143–4155. doi:10.1080/03610926.2012.707735.
- Sutherland, D. H., Kaufman, K. R., and Moitza, J. R. (1994). Kinematics of normal human walking. In Rose, J. and Gamble, J. G. (Eds.), *Human Walking*, pp. 23–44. Williams and Wilkins, Baltimore.
- Taghia, J., Ma, Z., and Leijon, A. (2014). Bayesian estimation of the von-Mises Fisher mixture model with variational inference. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 36(9):1701–1715. doi:10.1109/tpami.2014.2306426.
- Taijeron, H. J., Gibson, A. G., and Chandler, C. (1994). Spline interpolation and smoothing on hyperspheres. *SIAM Journal on Scientific Computing*, 15(5):1111–1125. doi:10.1137/0915068.
- Takács, L. (1996). On a test for uniformity of a circular distribution. *Mathematical Methods of Statistics*, 5(1):77–98.
- Takasu, Y., Yano, K., and Komaki, F. (2018). Scoring rules for statistical models on spheres. *Statistics & Probability Letters*, 138:111–115. doi:10.1016/j.spl.2018.02.054.
- Tanabe, A., Fukumizu, K., Oba, S., Takenouchi, T., and Ishii, S. (2007). Parameter estimation for von Mises-Fisher distributions. *Computational Statistics*, 22(1):145–157. doi:10.1007/s00180-007-0030-7.
- Tanasi, C. (1982). A problem of random anisotropic walk for a new circular model. *Atti della Accademia di scienze, lettere e arti di Palermo*, 3(1):59–92.
- Tang, H., Chu, S. M., and Huang, T. S. (2009). Generative model-based speaker clustering via mixture of von Mises-Fisher distributions. In *2009 IEEE International Conference on Acoustics, Speech and Signal Processing*, pp. 4101–4104, New York. IEEE. doi:10.1109/icassp.2009.4960530.
- Tango, T. (1984). The detection of disease clustering in time. *Biometrics*, 40(1):15–26. doi:10.2307/2530740.
- Taniguchi, M., Kato, S., Ogata, H., and Pewsey, A. (2020). Models for circular data from time series spectra. *Journal of Time Series Analysis*, to appear. doi:10.1111/jtsa.12549.
- Tasdan, F. and Cetin, M. (2014). A simulation study on the influence of ties on uniform scores test for circular data. *Journal*

- of *Applied Statistics*, 41(5):1137–1146. doi:10.1080/02664763.2013.862224.
- Tasdan, F. and Yeniay, O. (2014). Power study of circular ANOVA test against nonparametric alternatives. *Hacettepe Journal of Mathematics and Statistics*, 43(1):97–115.
- Tasdan, F. and Yeniay, O. (2018). A comparative simulation of multiple testing procedures in circular data problems. *Journal of Applied Statistics*, 45(2):255–269. doi:10.1080/02664763.2016.1273886.
- Tashiro, Y. (1962). On methods for generating uniform random points on the surface of a sphere. *Annals of the Institute of Statistical Mathematics*, 29(1):295–300. doi:10.1007/bf02532791.
- Taylor, C. C. (2008). Automatic bandwidth selection for circular density estimation. *Computational Statistics & Data Analysis*, 52(7):3493–3500. doi:10.1016/j.csda.2007.11.003.
- Taylor, C. C., Lafratta, G., and Fensore, S. (2018). *nprotreg: Nonparametric Rotations for Sphere-Sphere Regression*. R package version 1.0.1. URL: <https://CRAN.R-project.org/package=nprotreg>.
- Taylor, C. C., Mardia, K. V., Di Marzio, M., and Panzera, A. (2012). Validating protein structure using kernel density estimates. *Journal of Applied Statistics*, 39(11):2379–2388. doi:10.1080/02664763.2012.710898.
- Theobald, C. M. (1975). An inequality for the trace of the product of two symmetric matrices. *Mathematical Proceedings of the Cambridge Philosophical Society*, 77(2):265–267. doi:10.1017/s0305004100051070.
- Tiku, M. L. (1965). Chi-square approximations for the distributions of goodness-of-fit statistics  $U_n^2$  and  $W_n^2$ . *Biometrika*, 52(3/4):630–633. doi:10.1093/biomet/52.3-4.630.
- Tipping, M. E. and Bishop, C. M. (1999). Probabilistic principal component analysis. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 61(3):611–622. doi:10.1111/1467-9868.00196.
- Titchmarsh, E. C. (1958). *The Theory of Functions*. Oxford University Press, Oxford.
- Titterton, D. M., Smith, A. F. M., and Makov, U. E. (1985). *Statistical Analysis of Finite Mixture Distributions*, volume 198 of *Wiley Series in Probability and Statistics*. Wiley, Chichester.
- Toyoda, Y., Suga, K., Murakami, K., Hasegawa, H., Shibata, S., Domingo, V., Escobar, I., Kamata, K., Bradt, H., Clark, G., and La Pointe, M. (1966). Studies of primary cosmic rays in the energy region  $10^{14}$  eV to  $10^{17}$  eV (Bolivian Air Shower Joint Experiment). In *Proceedings of the Ninth International Conference on Cosmic Rays, London, September 1965*, volume 2, pp. 708–711, London. The Institute of Physics and the Physical Society.
- Traa, J. and Smaragdis, P. (2013). A wrapped Kalman filter for azimuthal speaker tracking. *IEEE Signal Processing Letters*, 20(12):1257–1260. doi:10.1109/lsp.2013.2287125.
- Tracey, J. A., Zhu, J., and Crooks, K. (2005). A set of nonlinear regression models for animal movement in response to a single landscape feature. *Journal of Agricultural, Biological, and Environmental Statistics*, 10(1):1–18. doi:10.1198/108571105x29056.
- Tran, N. H. (2007). Fracture orientation characterization: minimizing statistical modelling errors. *Computational Statistics & Data Analysis*, 51(6):3187–3196. doi:10.1016/j.csda.2006.10.024.
- Tsagris, M. and Alenazi, A. (2019). Comparison of discriminant analysis methods on the sphere. *Communications in Statistics: Case Studies, Data Analysis and Applications*, 5(4):467–491. doi:10.1080/23737484.2019.1684854.
- Tsagris, M., Athineou, G., Sajib, A., Amson, E., and Waldstein, M. J. (2020). *Directional: Directional Statistics*. R package version 4.4. URL: <https://CRAN.R-project.org/package=Directional>.
- Tsai, M.-T. (2009). Asymptotically efficient two-sample rank tests for modal directions on spheres. *Journal of Multivariate Analysis*, 100:445–458. doi:10.1016/j.jmva.2008.05.009.
- Tsai, M.-T. and Sen, P. K. (2007). Locally best rotation-invariant rank tests for modal location. *Journal of Multivariate Analysis*, 98:1160–1179. doi:10.1016/j.jmva.2007.01.007.
- Tsuruta, Y. and Sagae, M. (2017a). Asymptotic property of wrapped Cauchy kernel density estimation on the circle. *Bulletin of Informatics and Cybernetics*, 49:1–10. doi:10.5109/2232318.
- Tsuruta, Y. and Sagae, M. (2017b). Higher order kernel density estimation on the circle. *Statistics & Probability Letters*, 131:46–50. doi:10.1016/j.spl.2017.08.003.
- Tsuruta, Y. and Sagae, M. (2018). Properties for circular nonparametric regressions by von Mises and wrapped Cauchy kernels. *Bulletin of Informatics and Cybernetics*, 50:1–13.
- Tsuruta, Y. and Sagae, M. (2020). Theoretical properties of bandwidth selectors for kernel density estimation on the circle. *Annals of the Institute of Statistical Mathematics*, 72(2):511–530. doi:10.1007/s10463-018-0701-x.
- Tung, D. D. and Jammalamadaka, S. R. (2013). On the Gini mean difference test for circular data. *Communications in Statistics – Theory and Methods*, 42(11):1998–2008. doi:10.1080/03610926.2011.601947.
- Tyler, D. E. (1987). Statistical analysis for the angular central Gaussian distribution on the sphere. *Biometrika*, 74(3):579–589. doi:10.1093/biomet/74.3.579.
- Uesu, K., Shimizu, K., and SenGupta, A. (2015). A possibly asymmetric multivariate generalization of the Möbius distribution for directional data. *Journal of Multivariate Analysis*, 134:146–162. doi:10.1016/j.jmva.2014.11.004.
- Ulrich, G. (1984). Computer generation of distributions on the  $m$ -sphere. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 33(2):158–163. doi:10.2307/2347441.
- Umbach, D. and Jammalamadaka, S. R. (2009). Building asymmetry into circular distributions. *Statistics & Probability Letters*, 79(5):659–663. doi:10.1016/j.spl.2008.10.022.

- Umbach, D. and Jammalamadaka, S. R. (2012). On introducing asymmetry into circular distributions. *Pakistan Journal of Statistics and Operation Research*, 8(3):531–535. doi:10.18187/pjsor.v8i3.524.
- Upton, G. J. G. (1970). *Significance Tests for Directional Data*. PhD thesis, Birmingham University.
- Upton, G. J. G. (1973). Single-sample tests for the von Mises distribution. *Biometrika*, 60(1):87–99. doi:10.1093/biomet/60.1.87.
- Upton, G. J. G. (1974). New approximations to the distribution of certain angular statistics. *Biometrika*, 61(2):369–373. doi:10.1093/biomet/61.2.369.
- Upton, G. J. G. (1976). More multisample tests for the von Mises distribution. *Journal of the American Statistical Association*, 71(355):675–678. doi:10.1080/01621459.1976.10481545.
- Upton, G. J. G. (1986). Approximate confidence intervals for the mean direction of a von Mises distribution. *Biometrika*, 73(2):525–527. doi:10.1093/biomet/73.2.525.
- Upton, G. J. G. and Fingleton, B. (1989). *Spatial Data Analysis by Example*. Wiley Series in Probability and Mathematical Statistics. Wiley, Chichester.
- van der Vaart, A. W. (2000). *Asymptotic Statistics*. Cambridge Series in Statistical and Probabilistic Mathematics. Cambridge University Press, Cambridge. doi:10.1017/CB09780511802256.
- Vanni, L., Baldaccini, N. E., and Giunchi, D. (2017). Cue-conflict experiments between magnetic and visual cues in dunlin *Calidris alpina* and curlew sandpiper *Calidris ferruginea*. *Behavioral Ecology and Sociobiology*, 71(4):61. doi:10.1007/s00265-017-2290-8.
- Veeraraghavan, A., Srivastava, A., Roy-Chowdhury, A. K., and Chellappa, R. (2009). Rate-invariant recognition of humans and their activities. *IEEE Transactions on Image Processing*, 18(6):1326–1339. doi:10.1109/TIP.2009.2017143.
- Venkatraman, D. and Khong, A. W. H. (2018). Directional statistics approach based on instantaneous rotational parameters of tri-axial trajectories for footstep detection. *Circuits Systems and Signal Processing*, 37(5):1958–1987. doi:10.1007/s00034-017-0647-x.
- Verdebout, T. (2015). On some validity-robust tests for the homogeneity of concentrations on spheres. *Journal of Nonparametric Statistics*, 27(3):372–383. doi:10.1080/10485252.2015.1041945.
- Verdebout, T. (2017). On the efficiency of some rank-based test for the homogeneity of concentrations. *Journal of Statistical Planning and Inference*, 191:101–109. doi:10.1016/j.jspi.2017.05.009.
- Villacorta, A. and Jammalamadaka, S. R. (2009). Optimal text space representation of student essays using latent semantic analysis. In SenGupta, A. (Ed.), *Advances in Multivariate Statistical Methods*, volume 4 of *Statistical Science and Interdisciplinary Research*, pp. 107–129. World Scientific, Hackensack. doi:10.1142/9789812838247\_0007.
- Vincez, S. A. and Bruckshaw, J. M. (1960). Note on the probability distribution of a small number of vectors. *Mathematical Proceedings of the Cambridge Philosophical Society*, 56(1):21–26. doi:10.1017/s0305004100034253.
- Vistelius, A. B. (1966). *Structural Diagrams*. Pergamon, London.
- Vuollo, V. and Holmstrom, L. (2018). A scale space approach for exploring structure in spherical data. *Computational Statistics & Data Analysis*, 125:57–69. doi:10.1016/j.csda.2018.03.014.
- Vuollo, V., Holmström, L., Aarnivala, H., Harila, V., Heikkinen, T., Pirttiniemi, P., and Valkama, A. M. (2016). Analyzing infant head flatness and asymmetry using kernel density estimation of directional surface data from a craniofacial 3D model. *Statistics in Medicine*, 35(26):4891–4904. doi:10.1002/sim.7032.
- de Waal, D. J. (1979). On the normalizing constant for the Bingham-von Mises-Fisher matrix distribution. *South African Statistical Journal*, 13(2):103–112.
- Wahba, G. (1966). A least squares estimate of satellite attitude, Problem 65.1. *SIAM Review*, 8:385–386.
- Wahba, G. (1975). Smoothing noisy data with spline functions. *Numerische Mathematik*, 24(5):383–393. doi:10.1007/BF01437407.
- Wahba, G. (1981). Spline interpolation and smoothing on the sphere. *SIAM Journal on Scientific and Statistical Computing*, 2(1):5–16. doi:10.1137/0902002.
- Wainwright, B. D. (2019). *Contributions to Directional Statistics Based Clustering Methods*. PhD thesis, University of California at Santa Barbara.
- Wallraff, H. G. (1979). Goal-orientated and compass-oriented movements of displayed homing pigeons after confinement in differentially shielded aviaries. *Behavioral Ecology and Sociobiology*, 5(2):201–225. doi:10.1007/bf00293306.
- Wang, F. (2013). *Space and Space-Time Modeling of Directional Data*. PhD thesis, Duke University.
- Wang, F. and Gelfand, A. E. (2013). Directional data analysis under the general projected normal distribution. *Statistical Methodology*, 10(1):113–127. doi:10.1016/j.stamet.2012.07.005.
- Wang, F. and Gelfand, A. E. (2014). Modeling space and space-time directional data using projected Gaussian processes. *Journal of the American Statistical Association*, 109(508):1565–1580. doi:10.1080/01621459.2014.934454.
- Wang, F., Gelfand, A. E., and Jona-Lasinio, G. (2015). Joint spatio-temporal analysis of a linear and a directional variable: space-time modeling of wave heights and wave directions in the Adriatic Sea. *Statistica Sinica*, 25(1):25–39.
- Wang, J., Boyer, J., and Genton, M. G. (2004). A skew-symmetric representation of multivariate distributions. *Statistica Sinica*, 14(4):1259–1270.
- Wang, M. and Shimizu, K. (2012). On applying Möbius transformation to cardioid random variables. *Statistical Methodology*,

- 9(6):604–614. doi:10.1016/j.stamet.2012.04.001.
- Wang, M. and Wang, D. (2016). VMF-SNE: embedding for spherical data. In *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 2344–2348, New York. IEEE. doi:10.1109/icassp.2016.7472096.
- Wang, X. and Zhao, L. (2001). Laws of the iterated logarithm for kernel estimator of density function of spherical data. *Journal of Systems Science and Mathematical Sciences*, 21(3):264–273.
- Wang, X., Zhao, L., and Wu, Y. (2000). Distribution free laws of the iterated logarithm for kernel estimator of regression function based on directional data. *Chinese Annals of Mathematics. Series B*, 21(4):489–498. doi:10.1142/S0252959900000480.
- Wang, X. M. (2002). Exponential bounds of mean error for the kernel regression estimates with directional data. *Chinese Annals of Mathematics. Series A*, 23(1):55–62.
- Wang, X. M. and Ma, L. (2000). Nearest neighbor estimator for density function of directional data. *Journal of Biomathematics*, 15(3):332–338.
- Wang, X. M. and Zhao, L. C. (2003). A law of logarithm for kernel density estimators with directional data. *Acta Mathematica Sinica, Chinese Series*, 46(5):865–874.
- Wang, Z. and Song, J. (2016). Cross-entropy-based adaptive importance sampling using von Mises-Fisher mixture for high dimensional reliability analysis. *Structural Safety*, 59:42–52. doi:10.1016/j.strusafe.2015.11.002.
- Watanabe, Y. (1992). Tests for a given linear structure of the mean direction of the Langevin distribution. *Annals of the Institute of Statistical Mathematics*, 44(1):147–156. doi:10.1007/bf00048677.
- Watanabe, Y. (1996). Statistical inference of Langevin distribution for directional data. *Hiroshima Mathematical Journal*, 26(1):25–74. doi:10.32917/hmj/1206127487.
- Watanabe, Y. and Fujioka, T. (2005). Confidence regions for the mean direction of the von Mises-Fisher distribution. *Communications in Statistics – Theory and Methods*, 34(3):671–678. doi:10.1081/sta-200052132.
- Watanabe, Y. and Jupp, P. E. (2005). Improved likelihood ratio and score tests on concentration parameters of von Mises-Fisher distributions. *Statistics & Probability Letters*, 72(2):93–102. doi:10.1016/j.spl.2004.10.017.
- Watanabe, Y. and Kakimizu, O. (1996). On a geometric approach to distributions on a circle. *Hiroshima Mathematical Journal*, 26(1):91–101. doi:10.32917/hmj/1206127490.
- Waterman, T. H. (1963). The analysis of spatial orientation. In Autrum, H., Bünning, E., Frisch, K. V., Hadorn, E., Kühn, A., Mayr, E., Pirson, A., Straub, J., Stubbe, H., and Weidel, W. (Eds.), *Orientierung der Tiere / Animal Orientation*, volume 26 of *Ergebnisse der Biologie / Advances in Biology*, pp. 98–117. Springer, Berlin. doi:10.1007/978-3-642-99872-0\_11.
- Watson, G. N. (1948). *A Treatise on the Theory of Bessel Functions*. Cambridge University Press, Cambridge, second edition.
- Watson, G. S. (1956a). Analysis of dispersion on a sphere. *Geophysical Supplements to the Monthly Notices of the Royal Astronomical Society*, 7(4):153–159. doi:10.1111/j.1365-246x.1956.tb05560.x.
- Watson, G. S. (1956b). A test for randomness of directions. *Geophysical Supplements to the Monthly Notices of the Royal Astronomical Society*, 7:160–161. doi:10.1111/j.1365-246x.1956.tb05561.x.
- Watson, G. S. (1960). More significance tests on the sphere. *Biometrika*, 47:87–91. doi:10.2307/2332961.
- Watson, G. S. (1961). Goodness-of-fit tests on a circle. *Biometrika*, 48(1/2):109–114. doi:10.2307/2333135.
- Watson, G. S. (1962). Goodness-of-fit tests on a circle. II. *Biometrika*, 49(1/2):57–63. doi:10.2307/2333467.
- Watson, G. S. (1965). Equatorial distributions on a sphere. *Biometrika*, 52(1/2):193–201. doi:10.2307/2333824.
- Watson, G. S. (1966). The statistics of orientation data. *The Journal of Geology*, 74(5, Part 2):786–797. doi:10.1086/627211.
- Watson, G. S. (1967). Another test for the uniformity of a circular distribution. *Biometrika*, 54(3/4):675–677. doi:10.2307/2335064.
- Watson, G. S. (1969). Some problems in the statistics of directions. *Bulletin of the International Statistical Institute*, 42:374–385.
- Watson, G. S. (1970). Orientation statistics in the earth sciences. *Bulletin of the Geological Institute of the University of Uppsala*, 2(1):73–89.
- Watson, G. S. (1971). *Selected Topics in Statistical Theory*. Mathematical Association of America, Washington D. C. Notes on lectures given at the 1971 MAA Summer Seminar, Williams College, Williamstown, Massachusetts.
- Watson, G. S. (1976). Optimal invariant tests for uniformity. In Williams, E. J. (Ed.), *Studies in Probability and Statistics*, pp. 121–127. North-Holland, Amsterdam.
- Watson, G. S. (1981). Three aspects of the statistics of directions. In Lidl, R. (Ed.), *Papers in Algebra, Analysis and Statistics*, volume 9 of *Contemporary Mathematics*, pp. 187–205. American Mathematical Society, Providence.
- Watson, G. S. (1982a). Distributions on the circle and sphere. *Journal of Applied Probability*, 19(A):265–280. doi:10.2307/3213566.
- Watson, G. S. (1982b). The estimation of palaeomagnetic pole position. In Kallianpur, G., Krishnaiah, P. R., and Ghosh, J. K. (Eds.), *Stochastics and Probability*, pp. 703–712. North-Holland, Amsterdam.
- Watson, G. S. (1983a). Large sample theory for distributions on the hypersphere with rotational symmetries. *Annals of the Institute of Statistical Mathematics*, 35(1):303–319. doi:10.1007/bf02480985.
- Watson, G. S. (1983b). Large sample theory of the Langevin distribution. *Journal of Statistical Planning and Inference*, 8(3):245–256. doi:10.1016/0378-3758(83)90043-5.
- Watson, G. S. (1983c). Limit theorems on high dimensional spheres and Stiefel manifolds. In Karlin, S., Amemiya, T., and

- Goodman, L. A. (Eds.), *Studies in Econometrics, Time Series and Multivariate Statistics*, pp. 559–570. Academic Press, New York. doi:10.1016/B978-0-12-398750-1.50034-6.
- Watson, G. S. (1983d). Optimal and robust estimation on the sphere. *Bulletin of the International Statistical Institute*, 2:816–818.
- Watson, G. S. (1983e). *Statistics on Spheres*. University of Arkansas Lecture Notes in the Mathematical Sciences. Wiley, New York.
- Watson, G. S. (1984a). The calculation of confidence regions for eigenvectors. *Australian Journal of Statistics*, 26(3):272–276. doi:10.1111/j.1467-842x.1984.tb00450.x.
- Watson, G. S. (1984b). The theory of concentrated Langevin distributions. *Journal of Multivariate Analysis*, 14(1):74–82. doi:10.1016/0047-259x(84)90047-2.
- Watson, G. S. (1985). Interpolation and smoothing of directed and undirected line data. In Krishnaiah, P. R. (Ed.), *Multivariate Analysis VI*, pp. 613–625, Amsterdam. North-Holland.
- Watson, G. S. (1986a). The shapes of a random sequence of triangles. *Advances in Applied Probability*, 18(1):156–169. doi:10.1017/s0001867800015615.
- Watson, G. S. (1986b). Some estimation theory on the sphere. *Annals of the Institute of Statistical Mathematics*, 38(1):263–275. doi:10.1007/bf02482515.
- Watson, G. S. (1988a). The computer simulation treatment of directional data. *Recent Researches in Geology, Geological Survey of Canada*, 12(1):19–23.
- Watson, G. S. (1988b). The Langevin distribution on high dimensional spheres. *Journal of Applied Statistics*, 15(2):123–130. doi:10.1080/02664768800000019.
- Watson, G. S. (1989). Statistics of rotations. In Heyer, H. (Ed.), *Probability Measures on Groups IX*, volume 1379 of *Lecture Notes in Mathematics*, pp. 398–413, Berlin. Springer. doi:10.1007/bfb0087866.
- Watson, G. S. (1990). Permutation tests for the independence of a scalar and a unit vector. *Journal of Applied Statistics*, 17(2):277–281. doi:10.1080/757582840.
- Watson, G. S. (1995a). Distribution of angles between unit vectors and the multiple comparison problem for unit vectors. *Journal of Applied Statistics*, 21(4):327–333.
- Watson, G. S. (1995b).  $U_n^2$  test for uniformity of discrete distributions. *Journal of Applied Statistics*, 22(2):273–276. doi:10.1080/757584621.
- Watson, G. S. and Beran, R. J. (1967). Testing a sequence of unit vectors for serial correlation. *Journal of Geophysical Research*, 72(22):5655–5659. doi:10.1029/jz072i022p05655.
- Watson, G. S. and Debiche, M. G. (1992). Testing whether two Fisher distributions have the same center. *Geophysical Journal International*, 109(1):225–232. doi:10.1111/j.1365-246x.1992.tb00092.x.
- Watson, G. S. and Irving, E. (1957). Statistical methods in rock magnetism. *Geophysical Journal International*, 7(6):289–300. doi:10.1111/j.1365-246x.1957.tb02882.x.
- Watson, G. S. and Williams, E. J. (1956). On the construction of significance tests on the circle and on the sphere. *Biometrika*, 43(3/4):344–352. doi:10.2307/2332913.
- Watson, R. E. (1987). *Two Educational Comparisons of Linear and Circular Statistics*. PhD thesis, Loyola University of Chicago.
- Webb, C. O., Ackerly, D. D., and Kembel, S. W. (2008). Phylocom: software for the analysis of phylogenetic community structure and trait evolution. *Bioinformatics*, 24(18):2098–2100. doi:10.1093/bioinformatics/btn358.
- Wehner, R. and Müller, M. (1985). Does interocular transfer occur in visual navigation by ants? *Nature*, 315(6016):228–229. doi:10.1038/315228a0.
- Wehrly, T. E. (1976). *Models for Bivariate Directional Data and Angular-Linear Data with Applications to Statistical Inference*. PhD thesis, University of Wisconsin.
- Wehrly, T. E. and Johnson, R. A. (1980). Bivariate models for dependence of angular observations and a related Markov process. *Biometrika*, 67(1):255–256. doi:10.1093/biomet/67.1.255.
- Wehrly, T. E. and Shine, E. P. (1981). Influence curves of estimators for directional data. *Biometrika*, 68(1):334–335. doi:10.1093/biomet/68.1.334.
- Wei, Y., Nadler, W., and Hansmann, U. H. E. (2008). Backbone and side-chain ordering in a small protein. *The Journal of Chemical Physics*, 128(2):025105. doi:10.1063/1.2819679.
- Weiss, G. H. and Kiefer, J. E. (1983). The Pearson random walk with unequal step sizes. *Journal of Physics A: Mathematical and General*, 16(3):489–495. doi:10.1088/0305-4470/16/3/009.
- Weller, Z. D. (2018). spTest: an R package implementing nonparametric tests of isotropy. *Journal of Statistical Software*, 83(4):1–24. doi:10.18637/jss.v083.i04.
- Wellner, J. A. (1979). Permutation tests for directional data. *The Annals of Statistics*, 7(5):929–943. doi:10.1214/aos/1176344779.
- Wells, M. T. and SenGupta, A. (Eds.) (2011). *Advances in Directional and Linear Statistics*. Springer, Heidelberg. doi:10.1007/978-3-7908-2628-9.
- Wheeler, S. and Watson, G. S. (1964). A distribution-free two-sample test on the circle. *Biometrika*, 51(1/2):256–257.

doi:10.2307/2334214.

- Wichmann, B. A. and Hill, I. D. (1982). Algorithm as183: an efficient and portable pseudo-random number generator. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 31(2):188–190. doi:10.2307/2347988.
- Wilkie, D. (1983). Rayleigh test for randomness of circular data. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 32(3):311–312. doi:10.2307/2347954.
- Wilson, R. C. and Hancock, E. R. (2010). Spherical embedding and classification. In Hancock, E. R., Wilson, R. C., Windeatt, T., Ulusoy, I., and Escolano, F. (Eds.), *Structural, Syntactic, and Statistical Pattern Recognition*, volume 6218 of *Lecture Notes in Computer Science*, pp. 589–599, Berlin. Springer. doi:10.1007/978-3-642-14980-1\_58.
- Wilson, R. C., Hancock, E. R., Pekalska, E., and Duin, R. P. W. (2014). Spherical and hyperbolic embeddings of data. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 36(11):2255–2269. doi:10.1109/tpami.2014.2316836.
- Wilson, R. C., Hancock, E. R., Pekalska, E., and Duin, R. P. W. (2010). Spherical embeddings for non-Euclidean dissimilarities. In *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, pp. 1903–1910, New York. IEEE. doi:10.1109/cvpr.2010.5539863.
- Winter, A. (1933). On the stable distribution laws. *American Journal of Mathematics*, 55(1):335–339.
- Winter, A. (1947). On the shape of the angular case of Cauchy’s distribution curves. *Annals of Mathematical Statistics*, 18(4):589–593.
- Wood, A. T. A. (1982). A bimodal distribution for the sphere. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, 31(1):52–58. doi:10.2307/2347074.
- Wood, A. T. A. (1985). *Some Topics in the Analysis of Spherical Data*. PhD thesis, Open University.
- Wood, A. T. A. (1987). The simulation of spherical distributions in the Fisher-Bingham family. *Communications in Statistics – Simulation and Computation*, 16(3):885–898. doi:10.1080/03610918708812624.
- Wood, A. T. A. (1988). Some notes on the Fisher-Bingham family on the sphere. *Communications in Statistics – Theory and Methods*, 17(11):3881–3897. doi:10.1080/03610928808829843.
- Wood, A. T. A. (1993). Quadratic exponential distributions for categorical and directional data. *Computational Statistics*, 8(2):141–159.
- Wood, A. T. A. (1994). Simulation of the von Mises-Fisher distribution. *Communications in Statistics – Simulation and Computation*, 23(1):157–164. doi:10.1080/03610919408813161.
- Wood, A. T. A. (1995). When is a truncated covariance function on the line a covariance function on the circle? *Statistics & Probability Letters*, 24(2):157–164. doi:10.1016/0167-7152(94)00162-2.
- Wood, S. N. (2003). Thin plate regression splines. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 65(1):95–114. doi:10.1111/1467-9868.00374.
- Wood, S. N. (2017). *Generalized Additive Models*. Chapman & Hall/CRC Texts in Statistical Science Series. CRC Press, Boca Raton, second edition. doi:10.1201/9781315370279.
- Wouters, H., Thas, O., and Ottoy, J.-P. (2009). Data-driven smooth tests and a diagnostic tool for lack-of-fit for circular data. *Australian & New Zealand Journal of Statistics*, 51(4):461–480. doi:10.1111/j.1467-842X.2009.00558.x.
- Wu, C. and Deng, W. (1996). Edgeworth expansion for circular distribution. *Applied Mathematics. A Journal of Chinese Universities. Ser. B*, 11(3):295–306. doi:10.1007/BF02664798.
- Xie, X. (2013). *sspline: Smoothing Splines on the Sphere*. R package version 0.1-6. URL: <https://CRAN.R-project.org/package=sspline>.
- Xu, D. and Wang, Y. (2019). *cplots: Plots for Circular Data*. R package version 0.4-0. URL: <https://CRAN.R-project.org/package=cplots>.
- Xu, D. and Wang, Y. (2020). Area-proportional visualization for circular data. *Journal of Computational and Graphical Statistics*, 29(2):351–357. doi:10.1080/10618600.2019.1654881.
- Xu, H., Nichols, K., and Schoenberg, F. P. (2011). Kernel regression of directional data with application to wind and wildfire data in Los Angeles County, California. *Forest Science*, 57(4):343–352. doi:10.1093/forestscience/57.4.343.
- Xu, P. L. (2002). Isotropic probabilistic models for directions, planes and referential systems. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 458(2024):2017–2038. doi:10.1098/rspa.2002.0966.
- Xu, Z. (2016). An alternative circular smoothing method to nonparametric estimation of periodic functions. *Journal of Applied Statistics*, 43(9):1649–1672. doi:10.1080/02664763.2015.1117590.
- Yamaji, A. and Sato, K. (2011). Clustering of fracture orientations using a mixed Bingham distribution and its application to paleostress analysis from dike or vein orientations. *Journal of Structural Geology*, 33(7):1148–1157. doi:10.1016/j.jsg.2011.05.006.
- Yamamoto, E. and Yanagimoto, T. (1995). A modified likelihood ratio test for the mean direction in the von Mises distribution. *Communications in Statistics – Theory and Methods*, 24(10):2659–2678. doi:10.1080/03610929508831640.
- Yang, M.-S., Chang-Chien, S.-J., and Hung, W.-L. (2016). An unsupervised clustering algorithm for data on the unit hypersphere. *Applied Soft Computing*, 42:290–313. doi:10.1016/j.asoc.2015.12.037.
- Yang, M.-S., Chang-Chien, S.-J., and Kuo, H.-C. (2014). On mean shift clustering for directional data on a hypersphere. In Rutkowski, L., Korytkowski, M., Scherer, R., Tadeusiewicz, R., Zadeh, L. A., and Zurada, J. M. (Eds.), *Artificial Intelligence and Soft Computing*, volume 8468 of *Lecture Notes in Computer Science*, pp. 809–818, Cham. Springer.

- doi:10.1007/978-3-319-07176-3\_70.
- Yang, M.-S. and Pan, J.-A. (1997). On fuzzy clustering of directional data. *Fuzzy Sets and Systems*, 91(3):319–326. doi:10.1016/s0165-0114(96)00157-1.
- Yaqub, M. and Khan, A. H. (1980). On the distribution of a distance function on the sphere. *Metrika*, 27(1):145–151. doi:10.1007/bf01893591.
- Yeh, S.-Y., Harris, K. D. M., and Jupp, P. E. (2013). A drifting Markov process on the circle, with physical applications. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 469(2156):20130092. doi:10.1098/rspa.2013.0092.
- Yfantis, E. A. and Borgman, L. E. (1982). An extension of the von Mises distribution. *Communications in Statistics – Theory and Methods*, 11(15):1695–1706. doi:10.1080/03610928208828342.
- Yoshimura, I. (1978). On a test of homogeneity hypothesis for directional data. *Sankhyā, Series A*, 40(3):310–312.
- You, K. (2020). *RiemBase: Functions and C++ Header Files for Computation on Manifolds*. R package version 0.2.4. URL: <https://CRAN.R-project.org/package=RiemBase>.
- Yu, J. Y. and Zhang, W. (2013). A sampling approach for protein backbone fragment conformations. *International Journal of Data Mining and Bioinformatics*, 7(2):180–195. doi:10.1504/ijdmb.2013.053191.
- Yuan, T. (2020). The 8-parameter Fisher–Bingham distribution on the sphere. *Computational Statistics*, to appear. doi:10.1007/s00180-020-01023-w.
- Zar, J. H. (1976). Two-sample and multi-sample testing of circular data. *Behavior Research Methods and Instrumentation*, 8(3):329–330. doi:10.3758/bf03201734.
- Zar, J. H. (2010). *Biostatistical Analysis*. Prentice Hall, New York, fifth edition.
- Zatsiorsky, V. M. (1998). *Kinematics of Human Motion*. Human Kinematics, Champaign.
- Zempléni, A. (2019). Estimating high quantiles based on dependent circular data. *Journal of Mathematical Sciences*, 237(6):865–874. doi:10.1007/s10958-019-04213-0.
- Zernike, F. (1928). Wahrscheinlichkeitsrechnung und mathematische Statistik. In Duschek, A., Lense, J., Mader, K., Radakovic, T., Zernike, F., and Thirring, H. (Eds.), *Mathematische Hilfsmittel in der Physik*, volume 3 of *Handbuch der Physik*, pp. 171–181. Springer, Berlin. doi:10.1007/978-3-642-90784-5\_12.
- Zhan, X., Ma, T., Liu, S., and Shimizu, K. (2019). On circular correlation for data on the torus. *Statistical Papers*, 60(6):1827–1847. doi:10.1007/s00362-017-0897-5.
- Zhang, L., Li, Q., Guo, Y., Yang, Z., and Zhang, L. (2018a). An investigation of wind direction and speed in a featured wind farm using joint probability distribution methods. *Sustainability*, 10(12):4338. doi:10.3390/su10124338.
- Zhang, M. and Fletcher, T. (2013). Probabilistic principal geodesic analysis. In Burges, C. J. C., Bottou, L., Welling, M., Ghahramani, Z., and Weinberger, K. Q. (Eds.), *Advances in Neural Information Processing Systems 26*, pp. 1178–1186, Red Hook. Curran Associates.
- Zhang, Y. and Chen, Y.-C. (2020). Kernel smoothing, mean shift, and their learning theory with directional data. *arXiv:2010.13523*.
- Zhang, Z., Klassen, E., and Srivastava, A. (2018b). Phase-amplitude separation and modeling of spherical trajectories. *Journal of Computational and Graphical Statistics*, 27(1):85–97. doi:10.1080/10618600.2017.1340892.
- Zhang, Z., Klassen, E., and Srivastava, A. (2019). Robust comparison of kernel densities on spherical domains. *Sankhyā, Series A*, 81(1):144–171. doi:10.1007/s13171-018-0131-0.
- Zhao, L. and Wu, C. (2001). Central limit theorem for integrated squared error of kernel estimators of spherical density. *Science in China Series A: Mathematics*, 44(4):474–483. doi:10.1007/bf02881884.
- Zhao, Y. and Konishi, S. (1997). Limit distributions of multivariate kurtosis and moments under Watson rotationally symmetric distributions. *Statistics & Probability Letters*, 32(3):291–299. doi:10.1016/s0167-7152(96)00086-7.
- Zhao, Y. and Yang, Z. H. (2005). Kernel stereographic projection density estimator and its pointwise convergence rate. *Chinese Annals of Mathematics. Series A*, 26(1):19–30.
- Zou, G., Hua, J., and Muzik, O. (2007). Non-rigid surface registration using spherical thin-plate splines. In Ayache, N., Ourselin, S., and Maeder, A. (Eds.), *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2007*, pp. 367–374, Berlin. Springer. doi:10.1007/978-3-540-75757-3\_45.
- Zucchini, W., MacDonald, I. L., and Langrock, R. (2016). *Hidden Markov Models for Time Series*, volume 150 of *Monographs on Statistics and Applied Probability*. CRC Press, Boca Raton, second edition. doi:10.1201/b20790.
- Zuo, Y. and Serfling, R. (2000). General notions of statistical depth function. *The Annals of Statistics*, 28(2):461–482. doi:10.1214/aos/1016218226.
- Zygmund, A. (1959). *Trigonometric Series*. Cambridge University Press, Cambridge. doi:10.1017/cbo9781316036587.