## DirectionalStats

June 25, 2020

## 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., Moudden, 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., Moudden, 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 0.100.50. 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. (2019). Nonparametric tests for circular regression. arXiv:1910.07825.
- 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. (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., 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. (2019). 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. (2019). Sine-skewed toroidal distributions and their application in protein bioinformatics. arXiv:1910.13293.
- 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.
- 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, 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. Qüestiió, 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 Schaeben, 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.
- 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.
- 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). Spuriosity and outliers in directional data. *Journal of Applied Statistics*, 17(3):341–350. doi:10.1080/0266476900000006.
- 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., Kerkyacharian, 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., Kerkyacharian, 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*, 6:1345–1382.
- 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*, 6:1705–1749.
- 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., Grimit, 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.
- 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 0.3.10. 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:10.1007/978-3-540-88378-4\_2.
- 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.
- 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.
- 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. *Applicationes 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.
- 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:10.1214/00905360500000093.
- 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. *Jornal 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. 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. Industriemathematick 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.
- 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<sup>2</sup> and Watson's U<sup>2</sup>. 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-aoas190.
- 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(1):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.
- 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.
- 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. Hacettepe Journal of Mathematics and Statistics, 47(2):273–286. doi:10.15672/hjms.2014437525.
- Carnicero Carrreño, 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 2.2.0. 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. 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. (2012). 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 wrappped normal distributions. *Australian Journal of Statistics*, 23(1):73–79. doi:10.1111/j.1467-842x.1981.tb00763.x.
- 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. (2019). Regression models for cylindrical data in psychology. *Multivariate Behavioral Research*, to appear. doi:10.1080/00273171.2019.1693332.
- Cressie, N. (1977). 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.
- Csörgö, 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.

- Curray, 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. (2019). On the power of axial tests of uniformity on spheres. arXiv:1910.09391.
- 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 Ottoy, 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.
- Dette, 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.
- 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 Phylitten und Hornfelsen des südwestlichen 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.

- 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 NO2 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. Spinger. 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-AOAS1115.
- 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.
- Eğecioğlu, 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.
- 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.
- Faÿ, G., Delabrouille, J., Kerkyacharian, 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-aoas619.
- Fejér, L. (1916). Über trigonometrische Polynome. Journal für die reine und angewandte Mathematik, 146:53-82. doi: 10.1515/crll.1916.146.53.
- Felicísimo, 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.
- 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., Ekbom, 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., Guttmann, 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.
- Freeden, W. and Maier, T. (2002). On multiscale denoising of spherical functions: basic theory and numerical aspects. Electronic Transactions on Numerical Analysis, 14:56–78.
- Freeden, 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.
- 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.
- 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.
- 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. (2018). sdetorus: Statistical Tools for Toroidal Diffusions. URL: https://github.com/egarpor/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. 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. *Unpublished*.
- 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 1.0.7. 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. (2020a). A review of uniformity tests on the hypersphere. arXiv:1804.00286.
- García-Portugués, E. and Verdebout, T. (2020b). 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.  $Sankhy\bar{a}$ , 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., Julier, S. J., and Hanebeck, U. D. (2016). 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.
- 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, Bejing. 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.
- 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.
- 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.
- 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.
- 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., 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*, 8:1583–1623.
- 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.

- 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-aoas803.
- 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.
- 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, 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.
- 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-Stumpfhauser, 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-Stumpfhauser, 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.
- 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.
- Holzmann, H., Munk, A., and Stratmann, B. (2004). Identifiability of finite mixtures with applications to circular distributions.  $Sankhy\bar{a}$ , 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.
- 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.
- 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 indépendent de la loi. Comptes Rendus de l'Académie des Sciences, Série A, 283:387–390.
- 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.
- 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 Crnkić, 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 Goria, 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*, to appear.
- 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 sistribution 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 sudy: 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.
- 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-aoas576.
- 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*, to appear. 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 circulas: 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.

- 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-aoas370.
- 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/qjmam/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 Computation Spherical 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*, to appear.
- 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., 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. (2018). 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.
- 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.
- Kerkyacharian, 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.
- 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.
- 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.
- 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 3.3.0. 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 and 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., 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. (2014). 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.
- 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., 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/jphystap: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 Rudolp, 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.
- de Leeuw, J., Hornik, K., and Mair, P. (2009). Isotone optimization in R: pool-adjacent-violators a lgorithm (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., Kastanauskaite, 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.
- 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-AOAS296.
- 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. (2019). 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, 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 S0(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. (2017a). Nonparametric CUSUM charts for angular data with applications in health science and astrophysics. *REVSTAT*, to appear.
- Lombard, F., Hawkins, D. M., and Potgieter, C. J. (2017b). 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*, 9:2579–2605.
- 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 bicompact groups (in Russian). *Theoria Verojatna*, 12(2):307–321.
- Maling, D. H. (1992). Coordinate Systems and Map Projections. Pergamon Press, Oxford. doi:10.1016/C2009-0-11149-2. Mammasis, 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. 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 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., Kerkyacharian, 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.
- 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., Mathe, J., Donnat, C., Jorda, M., and Pennec, X. (2018). geomstats: a Python package for Riemannian geometry in machine learning. arXiv:1805.08308.
- 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.probengmech.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. 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. (2020). 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.
- 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., Frellsen, 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.  $Journal\ of\ Applied\ Statistics,\ 42(9):1962-1972.\ doi:10.1080/02664763.2015.1014892.$
- 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. 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.
- 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). Appplications 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 Statistic, pp. 501–532. Wiley, Hoboken. doi:10.1002/9781118147634.ch15.
- Oualkacha, 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.
- Oualkacha, 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*, to appear.
- 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.
- 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.
- 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 covariation 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.
- Pertsemlidis, 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, Milton Keynes.
- 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.
- 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.
- 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.
- Pokorny, 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 probabilitiés. 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. doi:10.1002/wics.1512.
- 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.
- Pukkila, 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.  $Sankhy\bar{a}$ , 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.
- 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, Calcutta.
- 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.ijrmms.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, L. (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, L. (1905). The problem of the random walk. Nature, 72(1866):318. doi:10.1038/072318a0.
- Rayleigh, L. (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 3×3 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.
- Rodriguez-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., Baruque, 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.
- Rodriguez-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. 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. (1972). 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.
- 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 Girija, 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.
- 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 Strokorb, 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. and Embleton, B. J. J. (1985). Prefolding and overprint magnetic signatures in Precambrian (~2.9-2.7Ga) 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.
- 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, South Africa.

- 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.
- 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 prepivoting. *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 a plication 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, University 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.
- 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, 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 Moitoza, 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.
- 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 1.0.0. 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.
- Titterington, 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<sup>14</sup> eV to 10<sup>17</sup> 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 4.3. 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 Miese 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.
- 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., Holmstrom, 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.
- Watamori, 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.
- Watamori, Y. (1996). Statistical inference of Langevin distribution for directional data. *Hiroshima Mathematical Journal*, 26(1):25-74. doi:10.32917/hmj/1206127487.
- Watamori, 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.
- Watamori, 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.
- Watamori, 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.
- 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 as 183: 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., Pękalska, 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, 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 Compututer Scence*, 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.
- 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.
- 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.
- Zernkie, 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.
- Zhang, L., Li, Q., Guo, Y., Yang, Z., and Zhang, L. (2018). 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, 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.