

Sen Zhao, PhD

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RESEARCH INTERESTS

Climate variability, dynamics, and predictability; Climate impacts and change; multi-scale interactions of the Earth system; El Niño-Southern Oscillation; Climate modeling; Seasonal forecast; Wave dynamics and atmospheric teleconnections; Paleoclimate

EDUCATION

Ph.D. Meteorology 2011– 2016

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Dissertation: “*Theory of Cross-Equatorial Propagation of Planetary Wave in Horizontally Non-Uniform Basic Flow and Its Applications in Atmospheric Teleconnections*”.

B.S. Atmospheric Sciences 2007– 2011

College of Atmospheric Sciences, and School of Mathematics and Statistics, Lanzhou University, China

Thesis: “*Evaluation of WRF microphysics and cumulus schemes in simulating Hurricane Katrina*”

PROFESSIONAL APPOINTMENTS

SOEST Assistant Researcher 2021.11 – Present

School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i at Mānoa, USA

Project: Tropical climate dynamics & predictability and sea level science

Postdoctoral Fellow 2016.10 – 2021.10

Department of Atmospheric Sciences, University of Hawai'i at Mānoa, USA. Mentor: Fei-Fei Jin

Project: Dynamic diagnosis and modeling of ENSO variability and inter-basin interactions

Research Assistant 2012.09 – 2016.09

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, China. Advisor: Jianping Li

Project: Interhemispheric Rossby wave propagation theory and atmospheric teleconnections

GRANTS AND SCHOLARSHIPS

- **NSF grant** (2024-2027), *Dynamics and predictability of coastal El Nino events, and implications for ENSO diversity*, C. Karamperidou (lead PI) and **S. Zhao (co-PI)**, budget \$644,460.
- **DOE grant** (pending), *Quantifying and Understanding Ocean Biogeochemistry-ENSO/TIW Interactions & Feedbacks in Earth System Models*, F.-F. Jin (lead PI), M. Stuecker, F. M. Hoffman, A. Wittenberg, **S. Zhao (Co-I)**.
- **NSF grant** (pending), *Collaborative Research: South America continent, a land bridge for inter-hemispheric teleconnections*, R. Fu (lead PI), F.-F. Jin, **S. Zhao (Co-I)**, and S.Y. Zhao.
- **NOAA MAPP grant** (2023–2026), *Developing Dynamically Constrained Projections of ENSO Activity and Associated Coastal Hazards – An Application to the Hawaiian and US-Affiliated Pacific Islands*. F.-F. Jin (lead PI), M. Stuecker, N. Li, A. Wittenberg, **S. Zhao (co-I)**, J. Boucharel., Z. Yang
- **National Scholarship** (2013), Ministry of Education of China, No. 50257
- **China National Encouragement Scholarship** (2010)
- **First Class Scholarship of Lanzhou University** (2009)
- **China National Encouragement Scholarship** (2008)

PUBLICATIONS

ORCID: [0000-0002-5597-1109](https://orcid.org/0000-0002-5597-1109) [Google Scholar](https://scholar.google.com/citations?user=...) (citations ~1700, H-index 20 by May 2024)

Peer-reviewed journal articles

46. Zhao, S., F.-F. Jin, M. F. Stuecker, P. R. Thompson, J.-S. Kug, M. J. McPhaden, M.A. Cane, A. T. Wittenberg, and W. Cai (2024). [Explainable El Niño Predictability from Climate Mode Interactions](#). *Nature*. in press.
45. Tang, X., J. Li, Y. Zhang, Y. Li, and S. Zhao (2023). [Synergistic Effect of El Niño and Negative Phase of North Atlantic Oscillation on Winter Precipitation in the Southeastern United States](#). *J. Climate*, 36(6), 1767–1791.
44. Shi, F., H. Goose, J. Li, Q. Yin, F. Ljungqvist, T. Lian, C. Sun, L. Wang, Z. Wu, J. Li, S. Zhao, C. Xu, W. Liu, T. Liu, T. Nakatsuka, and Z. Guo (2022): [Interdecadal to multidecadal variability of East Asian summer monsoon over the past half millennium](#). *J. Geophys. Res.: Atmos.*, 127 (30), e2022JD037260.
43. Shi, F., C. Sun, A. Guion, Q. Yin, S. Zhao, T. Liu, and Z. Guo (2022): [Roman Warm Period and Late Antique Little Ice Age in an Earth System Model Large Ensemble](#). *J. Geophys. Res.: Atmos.*, 127(16), e2021JD035832.
42. Zhao, S., and C. Karamperidou (2022): [Competing Effects of Eastern and Central-Western Pacific Winds in the Evolution of the 2017 Extreme Coastal El Niño](#). *Geophys. Res. Lett.*, 49(15), e2022GL098859.
41. Li, X., Z.-H. Hu, S. Zhao, R. Ding, and B. Zhang (2022): [On the asymmetry of the tropical Pacific thermocline fluctuation associated with ENSO recharge and discharge](#). *Geophys. Res. Lett.*, 49(11), e2022GL099242.
40. Tang X., J. Li, H. Zhang, and S. Zhao (2022): [Representation of Rossby wave propagation and its effect on the teleconnection between the Indian summer monsoon and extratropical rainfall in the Met Office Unified Model](#). *Climate Dyn.*, 58 (3), 907-924
39. Zhao, S., F.-F. Jin, and M. F. Stuecker (2021): [Understanding Lead Times of Warm-Water-Volumes to ENSO Sea Surface Temperature Anomalies](#). *Geophys. Res. Lett.*, 48(19), e2021GL094366.
38. Chen H.-C., F.-F. Jin, S. Zhao, A. T. Wittenberg, and S. Xie (2021): [ENSO Dynamics in the E3SM-1-0, CESM2, and GFDL-CM4 Climate Models](#). *J. Climate*, 34 (23), 9365-9384.
37. Zhao, S., F.-F. Jin, X. Long, and M. Cane (2021): [On the Breakdown of ENSO's Relationship with Thermocline Depth in the Central-Equatorial Pacific](#). *Geophys. Res. Lett.*, 48(9), e2020GL092335.
36. Zhou, X., Q. Chen, Z. Wang, M. Xu, S. Zhao, Z. Cheng, and F. Feng (2020): [Longer duration of the weak stratospheric vortex during extreme El Niño events linked to spring Eurasian coldness](#). *J. Geophys. Res.: Atmos.*, 125(16), e2019JD032331.
35. Liu, T., J. Li, Q. Wang, S. Zhao (2020): [Influence of the Autumn SST in the Southern Pacific Ocean on Winter Precipitation in the North American Monsoon Region](#). *Atmosphere*, 11(8), 844.
34. Tseng, Y., R. Ding, S. Zhao, Y. Kuo, and Y. Liang (2020): [Could the North Pacific Oscillation Be Modified by the Initiation of East Asian Winter Monsoon?](#) *J. Climate*, 33, 2389–2406.
33. Xue, A., F.-F. Jin, W. Zhang, J. Boucharel, S. Zhao, and X. Yuan (2020): [Delineating the Seasonally Modulated Nonlinear Feedback onto ENSO from Tropical Instability Waves](#). *Geophys. Res. Lett.*, 47(7), e2019GL085863.
32. Zhao, S., M. F. Stuecker, F.-F. Jin, J. Feng, H. Ren, W. Zhang, and J. Li (2020): [Improved Predictability of the Indian Ocean Dipole using a Stochastic-Dynamical Model compared to the North American Multi-model Ensemble Forecast](#). *Wea. Forecasting*, 35(2), 379–399.
31. Zhang Y., J. Li, S. Zhao, F. Zheng, J. Feng, Y. Li, Y. Xu (2020): [Indian Ocean tripole mode and its associated atmospheric and oceanic processes](#). *Climate Dyn.*, 55(5), 1367-1383.
30. Feng, J., J. Li, F.-F. Jin, Z. Liu, and S. Zhao (2019): [Effect of El Niño on the Response Ratio of Hadley Circulation to Different SST Meridional Structures](#). *Climate Dyn.*, 53, 3877–3891.
29. Zhao, S., F.-F. Jin, and M. F. Stuecker (2019): [Improved Predictability of the Indian Ocean Dipole Using Seasonally Modulated ENSO Forcing Forecasts](#). *Geophys. Res. Lett.*, 46(16), 9980–9990.

28. Wang, Q., J. Li, Y. Li, J. Xue, **S. Zhao**, Y. Xu, Y. Wang, Y. Zhang, D. Dong, and J. Zhang (2019): [Modulation of tropical cyclone tracks over the western North Pacific by intra-seasonal Indo-western Pacific convection oscillation during the boreal extended summer](#). *Climate Dyn.*, 52(1-2), 913–927.
27. **Zhao, S.**, J. Li, Y. Li, F.-F. Jin, and J. Zheng (2019): [Interhemispheric Influence of Indo-Pacific Convection Oscillation on Southern Hemisphere Rainfall through Southward Propagation of Rossby Waves](#). *Climate Dyn.*, 52(5), 3203–3221.
26. Shi, F., H. Goosse, F. Klein, **S. Zhao**, T. Liu, and Z. Guo (2019): [Monopole mode of precipitation in East Asia modulated by the South China Sea over the last four centuries](#). *Geophys. Res. Lett.*, 46(24), 14713–14722.
25. Li, Y., J. Feng, J. Li, and **S. Zhao** (2018): [The Circle Diagram in the Group Velocity Domain for Rossby Wave under the Horizontally Non-Uniform Flow](#). *SOLA*, 14, 121–125.
24. Li, Y., J. Li, F. Kucharski, J. Feng, **S. Zhao**, and J. Zheng (2018): [Two Leading Modes of the Interannual Variability in South American Surface Air Temperature during Austral Winter](#). *Climate Dyn.*, 51(5-6), 2141–2156.
23. Liu, T., J. Li, Y. Li, **S. Zhao**, F. Zheng, J. Zheng, and Z. Yao (2018): [Influence of the May Southern Annular Mode on the South China Sea Summer Monsoon](#). *Climate Dyn.*, 51(11-12), 4095–4107.
22. Feng, J., J. Li, F.-F. Jin, **S. Zhao**, and J. Zhu (2018): [Relationship between the Hadley circulation and different tropical meridional SST structures during boreal summer](#). *J. Climate*, 31(16), 6575–6590.
21. Stuecker, M. F., C. M. Bitz, K. C. Armour, C. Proistosescu, S. M. Kang, S.-P. Xie, D. Kim, S. McGregor, W. Zhang, **S. Zhao**, W. Cai, Y. Dong, and F.-F. Jin (2018): [Polar Amplification Dominated by Local Forcing and Feedbacks](#). *Nature Climate Change*, 8(12), 1076–1081. ([News & Views](#))
20. Xue, J., J. Li, C. Sun, **S. Zhao**, J. Mao, D. Dong, Y. Li, and J. Feng (2018): [Decadal-Scale Teleconnection between South Atlantic SST and Southeast Australia Surface Air Temperature in Austral Summer](#). *Climate Dyn.*, 50(7-8), 2687–2703.
19. Zhou, X., J. Li, F. Xie, R. Ding, Y. Li, **S. Zhao**, J. Zhang, and Y. Li (2018): [The Effects of the Indo-Pacific Warm Pool on the Stratosphere](#). *Climate Dyn.*, 51(11-12), 4043–4064.
18. Huyan, L., J. Li, **S. Zhao**, C. Sun, D. Dong, T. Liu, and Y. Zhao (2017): [The Impact of Layer Perturbation Potential Energy on the East Asian Summer Monsoon](#). *J. Climate*, 30(17), 7087–7103.
17. Tian, W., Y. Li, F. Xie, J. Zhang, M. P. Chipperfield, W. Feng, Y. Hu, **S. Zhao**, X. Zhou, Y. Yang, and X. Ma (2017): [The relationship between lower-stratospheric ozone at southern high latitudes and sea surface temperature in the East Asian marginal seas in austral spring](#). *Atmos. Chem. Phys.*, 17(11), 6705–6722.
16. Xie, F., J. Li, J. Zhang, W. Tian, Y. Hu, **S. Zhao**, C. Sun, R. Ding, J. Feng, and Y. Yang (2017): [Variations in North Pacific Sea Surface Temperature Caused by Arctic Stratospheric Ozone Anomalies](#). *Environ. Res. Lett.*, 12(11), 114023.
15. Shi, F., **S. Zhao**, Z. Guo, H. Goosse, and Q. Yin (2017): [Multi-proxy reconstructions of May–September precipitation field in China over the past 500 years](#). *Clim. Past*, 13(12), 1919–1938.
14. Stuecker, M. F., A. Timmermann, F.-F. Jin, Y. Chikamoto, W. Zhang, A. T. Wittenberg, E. Widiasih, and **S. Zhao** (2017): [Revisiting ENSO/Indian Ocean Dipole Phase Relationships](#). *Geophys. Res. Lett.*, 44(5), 2481–2492. (**AGU Editor’s Highlight**)
13. Feng, J., J. Li, F.-F. Jin, **S. Zhao**, and F. Xie (2017): [The responses of the Hadley circulation to different meridional SST structures in the seasonal cycle](#). *J. Geophys. Res.: Atmos.*, 122(15), 7785–7799.
12. Qin, J., R. Ding, Z. Wu, J. Li, and **S. Zhao** (2017): [Relationships between the extratropical ENSO precursor and leading modes of atmospheric variability in the Southern Hemisphere](#). *Adv. Atmos. Sci.*, 34(3), 360–370.
11. Ding, R., J. Li, Y.-h. Tseng, K.-J. Ha, **S. Zhao**, and J.-Y. Lee (2016): [Interdecadal change in the lagged relationship between the Pacific–South American pattern and ENSO](#). *Climate Dyn.*, 47(9-10), 2867–2884.
10. Yang, F., N. Wang, F. Shi, F. C. Ljungqvist, **S. Zhao**, and T. Liu (2016): [The spatial distribution of precipitation over the West Qinling region, China, AD 1470–2000](#). *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 443, 278–285.

9. Zheng, F., J. Li, Y. Li, **S. Zhao**, and D. Deng (2016): [Influence of the Summer NAO on the Spring-NAO-Based Predictability of the East Asian Summer Monsoon](#). *J. Appl. Meteor. Climatol.*, 55(7), 1459–1476.
8. Zheng, J., Q. Wu, Y. Guo, and **S. Zhao** (2016): [The Impact of Summertime North Indian Ocean SST on Tropical Cyclone Genesis over the Western North Pacific](#). *SOLA*, 12, 242–246.
7. Kazmi, D. H., J. Li, C. Ruan, **S. Zhao**, and Y. Li (2016): [A Statistical Downscaling Model for Summer Rainfall over Pakistan](#). *Climate Dyn.*, 47(7–8), 2653–2666.
6. **Zhao, S.**, J. Li, and C. Sun (2016): [Decadal Variability in the Occurrence of Wintertime Haze in Central Eastern China Tied to the Pacific Decadal Oscillation](#). *Sci. Rep.*, 6, 27424. (**Top 100 read Scientific Reports articles in 2016**)
5. Shi, F., Q. Ge, B. Yang, J. Li, F. Yang, F. C. Ljungqvist, O. Solomina, T. Nakatsuka, N. Wang, **S. Zhao**, C. Xu, K. Fang, M. Sano, G. Chu, Z. Fan, N. P. Gaire, and M. U. Zafar (2015): [A Multi-Proxy Reconstruction of Spatial and Temporal Variations in Asian Summer Temperatures over the Last Millennium](#). *Climatic Change*, 131(4), 663–676.
4. Zhu, G., W. Lin, **S. Zhao**, and Y. Cao (2015): [Spatial and temporal variation characteristics of ocean waves in the South China Sea during the boreal winter](#). *Acta Oceanol. Sin.*, 34(1), 23–28.
3. Sun, C., J. Li, and **S. Zhao** (2015): [Remote Influence of Atlantic Multidecadal Variability on Siberian Warm Season Precipitation](#). *Sci. Rep.*, 5, 16853.
2. Li, Y., J. Li, F.-F. Jin, and **S. Zhao** (2015): [Interhemispheric Propagation of Stationary Rossby Waves in a Horizontally Nonuniform Background Flow](#). *J. Atmos. Sci.*, 72(8), 3233–3256.
1. **Zhao, S.**, J. Li, and Y. Li (2015): [Dynamics of an Interhemispheric Teleconnection across the Critical Latitude through a Southerly Duct during Boreal Winter](#). *J. Climate*, 28(19), 7437–7456.

Peer-reviewed book chapter

1. Jin F.-F., H.-C. Chen, **S. Zhao**, M. Hayashi, C. Karamperidou, M. F. Stuecker, R. Xie, and L. Geng (2020): [Simple ENSO Models](#). In: Santoso A, Cai W, McPhaden MJ (eds) *El Niño Southern Oscillation in a Changing Climate*, 119–151.

Submitted

- Zhao, S.**, N. Li, F.-F. Jin, K. F. Cheung, Z. Yang (2024). Strong El Niño Influence on Island-scale Wave Climate in Hawaii. *Communications Earth & Environment*, under review.
- Gunnarson J. L., M. F. Stuecker, and **S. Zhao** (2024). [Drivers of Future Extratropical Sea Surface Temperature Variability Changes in the North Pacific](#). *npj Climate and Atmospheric Science*. in revision.

In preparation

- Zhao, S.**, P. R. Thompson, F.-F. Jin. Influence of ENSO on the compounding effect of sea level and ocean waves.
- Zhao, S.**, F.-F. Jin: A Robust Assessment of the Bjerknes-Wyrtki-Jin Indices for ENSO Linear Stability and Periodicity.
- Vialard, J., et al.: The ENSO recharge oscillator conceptual model: Past achievements, future prospects. In preparation for *Reviews of Geophysics*.
- Kim, S.-K., et al.: The Community Recharge Oscillator Model. In preparation for *Geoscientific Model Development*.

PRESENTATIONS

Talks

- Competing Effects of Eastern and Central-Western Pacific Winds in the Evolution of the 2017 Extreme Coastal El Niño and Implication for El Niño Diversity, *IRCC-KIST-IPRC Joint Workshop on Climate Change and Prediction*, East West Center, Honolulu, 01/2023
- Advances in Understanding of ENSO's Relationship with Equatorial Pacific Thermocline, *Climate Dynamics Group Seminar, visual*, 05/2022
- Understanding Lead Times of Warm-Water-Volumes to ENSO Sea Surface Temperature Anomalies, *SIO-UH Oahu Workshop on Ocean-Atmosphere Interactions and Climate Predictability*, Honolulu, 03/2022
- Dynamics and Implications for ENSO's Subsurface Ocean Temperature Vertical Dipole Anomalies in the Central Equatorial Pacific, *Ocean Science Meeting 2022*, Honolulu, 02/2022
- Advancing Understanding of ENSO's Relationship with Equatorial Pacific Thermocline, *Atmospheric Sciences Seminar, University of Hawai'i at Mānoa*, Honolulu, 09/2021
- Improved Predictability of the Indian Ocean Dipole Using Seasonally Modulated ENSO Forcing, *AOGS 15th Annual Meeting*, Honolulu, June 03–08, 2018
- Decadal Variability in the Occurrence of Wintertime Haze in Central Eastern China Tied to the Pacific Decadal Oscillation, *AOGS 15th Annual Meeting*, Honolulu, June 03–08, 2018

Posters

- A robust assessment of the Bjerknes-Wyrtki-Jin indices for ENSO growth rate and periodicity, *AGU Fall Meeting 2019*, San Francisco, USA, December 9–13, 2019
- Interhemispheric influence of the Indo-Pacific convection oscillation on Southern Hemisphere rainfall, *AOGS 13th Annual Meeting*, Beijing, China, July 31–August 5, 2016
- Interhemispheric influence of the Indo-Pacific convection oscillation on Southern Hemisphere rainfall, *The 13th General Circulation Model Simulations of the East Asian Climate (EAC) workshop*, Beijing, China, March 24–25, 2016
- The Hemispheric Propagation of Stationary waves in Atmosphere, *EGU General Assembly 2013*, Vienna, Austria, April 7–12, 2013
- The Hemispheric Propagation of Stationary waves in Atmosphere, *ICDM Workshop 2012*, Kunming, China, August 6–9, 2012

TEACHING AND MENTORING

- **Guest Lecturer**, “Applied Atmospheric Dynamics” (ATMO 402), Instructor: Fei-Fei Jin, UH Mānoa spring semester 2020.
- **Co-Instructor**, “Dynamics of El Niño–Southern Oscillation Phenomenon” (ATMO 752), Instructor: Fei-Fei Jin, UH Mānoa spring semester 2019
- **Guest Lecturer**, “Applied Atmospheric Dynamics” (ATMO 402), Instructor: Fei-Fei Jin, UH Mānoa spring semester 2019

OTHER PROFESSIONAL SERVICES AND EXPERIENCE

CLIVAR working group member: ENSO conceptual models (2022 – Present)

Reviewer for international journals

Proceedings of the National Academy of Sciences of the United States of America (*PNAS*), *Geophysical Research Letters*, *Journal of Climate*, *Climate Dynamics*, *npj Climate and Atmospheric Science*, *Atmospheric Chemistry and Physics*, *Environmental Research Letters*, *Journal of Geophysical Research-Atmosphere*, *Journal of Geophysical Research-Oceans*, *Journal of the Atmospheric Sciences*, *Scientific Reports*, *Deep-Sea Research Part I*, *Atmosphere*,

Theoretical and Applied Climatology, Progress in Oceanography, Agronomy Journal, Earth and Space Science, Frontiers of Earth Science

Scientific Societies

American Geophysical Union (AGU), Asia Oceania Geosciences Society (AOGS), European Geosciences Union (EGU)

OTHER SELECTED HONORS AND AWARDS

- **Contemporary Undergraduate Mathematical Contest in Modeling Award**, National Second Prize and Special Prize of Gansu Province, CSIAM, 2009
- **Outstanding Student Leader**, University of the Chinese Academy of Sciences, 2012, 2013, 2014
- **Outstanding Student**, University of the Chinese Academy of Sciences, 2012, 2013, 2014, 2015
- **Outstanding Graduate**, Lanzhou University, 2011

DEVELOPED TOOLKITS AND MODELS

- **An extended nonlinear recharge oscillator model (XRO)**. The XRO exhibits skillful ENSO forecasts better than global climate models and comparable to the most skillful AI ENSO models.
- **A simple stochastic-dynamical IOD prediction system**. The system exhibits generally higher skill and longer lead times for predicting IOD events than current operational forecast systems.
- **An intermediate tropical ocean model (iTOM)**. This is a linear continuously stratified ocean model extended to all tropical oceans with a more realistic coastline and a space dependent background stratification, show improved performance than Zebiak-Cane type ocean model.
- **Rossby wave ray and phase tracing**. A software package for investigating the Rossby wave propagation and its phase evolution in a horizontally non-uniform basic flow.

SKILLS

- **Modeling using General Circulation Models (NCAR CESM and GFDL models):**
 - CESM1/2 OGCM POP2 momentum and buoyancy fluxes forced experiments.
 - CESM1/2 Fully coupled and slab-ocean experiments.
 - CESM AGCM SST/SIC sensitivity experiments and aqua-planet experiments.
 - GFDL CM2.1/CESM pacemaker experiments.
- **Modeling using Intermediate and Simple Models:**
 - Linear Baroclinic Models
 - Isca
 - Intermediate tropical ocean model
 - Zebiak-Cane ENSO Model
 - SPEEDY
 - Gill-Matsuno Model
 - Shallow Water Model for Global Ocean
 - Barotropic Model
 - Recharge Oscillator Model
- **Mathematical reasoning**
- **Coding:** Python, Fortran, Matlab, CDO, NCO, NCL, Ferret, Gnuplot, R, Linux Shells, LATEX, C++
- **Languages:** Mandarin (native) and English (fluent)

Last updated: May 24, 2024