Investigation of the Effects of Mesoscale Ocean Eddies on the Midlatitude Storm Tracks and Their Predictability

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Problem Statement

Our goal was to investigate the possibility that *ocean mesoscale variability* from the ocean was a process responsible for systematic errors in the prediction of the slowly varying large-scale component of the atmospheric flow.

The project contributed to addressing the following key questions listed in the NOAA Subseasonal-to-Seasonal (S2S) Prediction Task Force summary document:

- What are the dominant physical sources of S2S predictability, and how well are those sources simulated and predicted?
- How well do models represent interactions between the tropics and extratropics, troposphere and stratosphere, ocean and atmosphere, land and atmosphere, and between S2S and other timescales?
- What are the main sources of model systematic errors on S2S timescales?

The project investigated the physical processes by which ocean mesoscale variability can affect midlatitude atmospheric variability in the North Pacific at the S2S timescales.

Methodology

Two ensembles of numerical simulations were generated with a high-resolution atmospheric global circulation model coupled to a slab ocean model. The two ensembles differed only in the treatment of the SST data used for the specification of the SST initial conditions and the estimation of the oceanic heat transport: one ensemble (control ensemble) was generated by retaining, while the other (filtered ensemble) by filtering the mesoscale variability of the SST data. The effect of mesoscale SST variability on the atmospheric processes was assessed by comparing the terms of the atmospheric eddy kinetic energy balance equation for the two ensembles. (Jia et al. (2019) provides a detailed description of the design of the simulation experiments.)

Key Findings

The atmospheric feedback to the ocean, in response to the ocean mesoscale variability, leads to large-scale changes of the SST. This large-scale SST response has a major direct impact on the slowly varying component of the atmospheric flow (Fig. 1). In addition, in the Kuroshio Extension, the mesoscale SST variability enhances the upper tropospheric transfer of kinetic energy from the core of the North-Pacific Jet Stream to the synoptic scale waves (Fig.2). The weakening of the jet reduces the vertical wind shear, which weakens the baroclinic instability of the atmospheric flow (Fig. 3). The weakened baroclinic instability leads to a reduced production of eddy kinetic energy by baroclinic instability. This reduced production of eddy kinetic energy leads to a reduced transfer of kinetic energy from the synoptic-scale waves to the jet downstream, shortening the jet (Fig. 2). In summary, the results suggest that ocean mesoscale variability has a major effect on midlatitude atmospheric processes that play important roles in the atmospheric variability at the S2S timescales. (Szunyogh et al. 2020 provides a detailed discussion of the diagnostic results.)

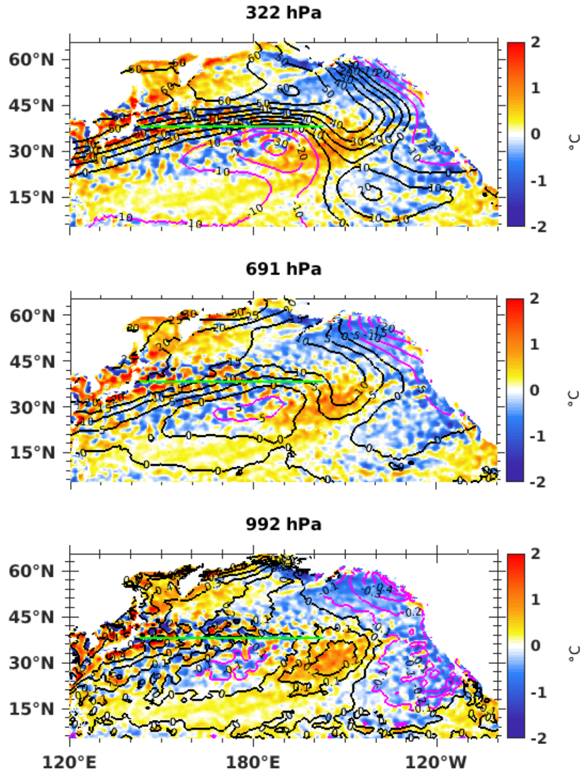

Figure 1. Illustration of the relationship between the feedback from the atmosphere to the ocean and the slowly varying component of the atmospheric flow. Shown are (color shades) the mean SST differences between the two experiments and (contours) the mean geopotential height difference at three different atmospheric pressure levels. The contour intervals (black indicating positive and magenta indicating negative values) are 0.2 gpm, 5 gpm, and 10 gpm at 992 hPa, 691 hPa, and 322 hPa, respectively. The green line segment indicates the position of the vertical cross section of Figs. 2 and 3. (From Szunyogh et al. 2020).

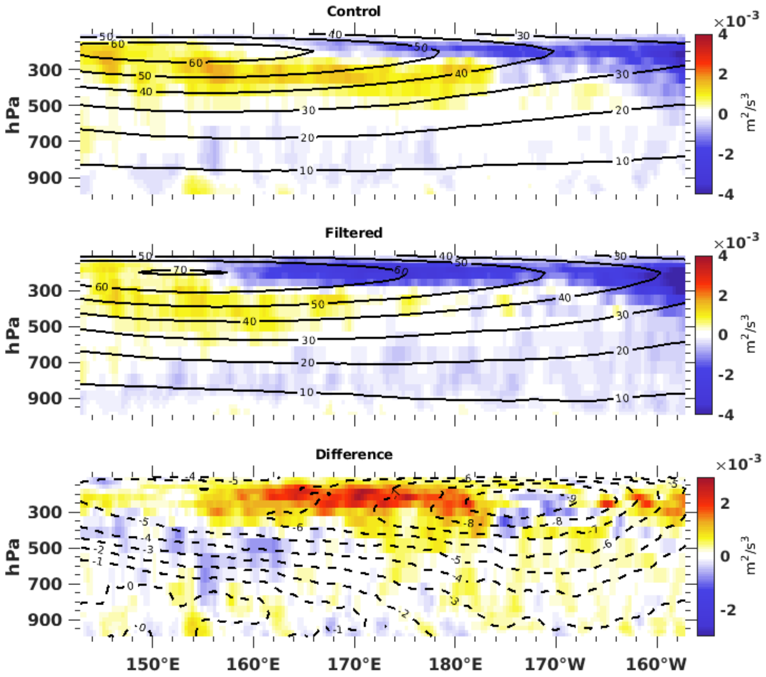
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Figure 2. The effect of mesoscale SST variability on the barotropic energy conversion along the Kuroshio Extension. Shown are the vertical cross sections of (color shades) the energy conversion and (contours) mean zonal wind speed for (top) the control experiment and (middle) the filtered experiment. Also shown are (bottom) the differences between the top two panels. (From Szunyogh et al. 2020.)

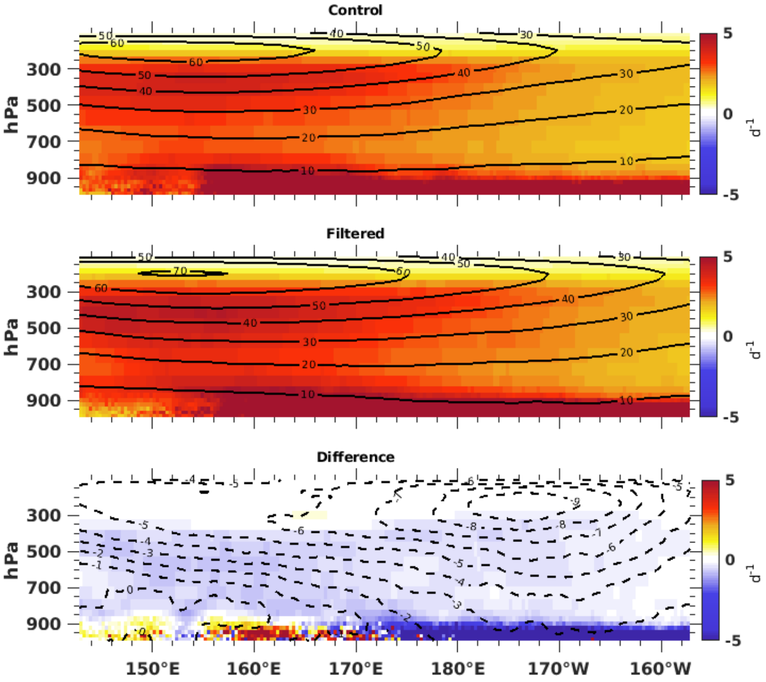
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Figure 3. The effect of ocean mesoscale variability on the baroclinic instability along the Kuroshio Extension. Shown are the vertical cross sections of (color shades) the mean Eady index of baroclinic instability and (contours) mean zonal wind speed for the (top) control experiment and (middle) filtered experiment. Also shown are (bottom) the differences between the top two panels. (From Szunyogh et al. 2020.)

Issues for Further Investigation

The present project was a pilot study whose findings call for further investigations with a more refined experiment design. First, while coupled experiments with a slab ocean model have the advantage over fully coupled experiments that the SST biases are smaller, the SST of a slab ocean is primarily driven by the estimates of the oceanic heat fluxes. Because large-scale SST differences play a central role in driving the slowly varying component of the atmospheric flow, the simulation experiments would benefit from a more refined estimation of the oceanic heat fluxes. Also, while the results are based on ensemble and time averages, the time averages are only for a two-week period of a single year. Repeating the experiments for longer time periods of multiple years would be highly desirable. Finally, it will be important to carry out forecast rather than simulation experiments to examine whether or not the effects of ocean mesoscale variability on the slowly varying, large-scale atmospheric flow translate into statistically significant forecast improvements at the S2S timescales.

Publications from the project

1. Szunyogh, I., E. Forinash, G. Gyarmati, Y. Jia, P. Chang, and R. Saravanan, 2020: A study of the effect of SST mesoscale variability on the North Pacific Jet Stream and Storm Track. Manuscript (to be submitted to *JAMES*)*,* 24 pages.
2. Jia, Y., P. Chang, I. Szunyogh, R. Saravanan, J. T. Bacmeister, 2019: A modeling strategy for the investigation of the effect of ocean mesoscale SST variability on atmospheric dynamics. *Geophysical Research Letters,* **46,** 3982-3989.
3. Han, F., I. Szunyogh, 2018: A technique for the verification of precipitation forecasts and its application to a problem of predictability. *Mon. Wea. Rev.*, 1303-1318.
4. Han, F., I. Szunyogh, 2018: How well can an ensemble predict the uncertainty in the location of winter storm precipitation? *Tellus A,* **70,** 1440870.

Oral presentations on the project

1. Saravanan, R., I. Szunyogh, E. Forinash, G. Gyarmati, Y. Jia, and P. Chang, 2020: *An investigation of the effect of ocean mesoscale variability on the dynamics of the North Pacific Jet Stream and Storm Track.* Ocean Sciences Meeting, San Diego, CA, February 16-21.
2. Szunyogh, I., E. Forinash, G. Gyarmati, Y. Jia, P. Chang, and R. Saravanan, 2020: *An Investigation of the effect of ocean mesoscale variability on the dynamics of the North Pacific Jet Stream and Storm Track.* AMS Annual Meeting 2020, Boston, MA, January 13-16, 2020.
3. Szunyogh, I., and N. Zagar, 2020: *Operational forecast-based estimates of the practical predictability of weather.* AMS Annual Meeting 2020, Boston, MA, January 13-16, 2020.

4. Szunyogh, I., and F. Han, 2019: *Verification of the location of winter storm precipitation events in ensemble forecasts.* 27th IUGG General Assembly, Montreal, Canada, July 8-18, 2019.
5. Jia, Y., P. Chang, I. Szunyogh, R. Saravanan, J. T. Bacmeister, E. Forinash, 2019: A modeling strategy for the investigation of the effect of ocean mesoscale variability on atmospheric dynamics. 27th IUGG General Assembly, Montreal, Canada, July 8-18, 2019.
6. Szunyogh, I., 2019: *The effects of ocean mesoscale variability on the energetics of the atmosphere in the midlatitudes*. S2S Prediction Task Force Monthly Meeting, June 19, 2019.
7. Saravanan, R., X. Ma, X. Liu, J. Steinweg-Woods, J. Kurian, R. Montuoro, P. Chang, and I. Szunyogh, 2018: The role of the midlatitude ocean in sub-seasonal prediction. International Conference on Subseasonal to Decadal Prediction, NCAR, Boulder, CO, September 17-21, 2018.
8. Szunyogh, I., 2018: *On the Predictability of Winter Storm Precipitation.* S2S Prediction Task Force Monthly Meeting, March 21, 2018.
9. Szunyogh, I., 2018: *How well can the NCEP Global Ensemble Forecast System capture the uncertainty in the analyses and forecasts of winter storm precipitation?* 8th EnKF Workshop, Mont Gabriel, Quebec, Canada, May 7-11, 2018.

Graduate Students Supported

1. Eric Forinash, Atmospheric Sciences, M.Sc., Texas A&M University, degree was awarded in December 2019. Placement: NOAA Federal, Meteorologist, National Weather Service, Corpus Christi, TX
2. Fan Han, Atmospheric Sciences, Ph.D., Texas A&M University, degree was awarded in December 2017. Placement: Research Associate, School of Meteorology, The University of Oklahona, Norman, OK.

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