Prediction of the Eurasia/Siberian warm extreme events in 2020 in Version 2 of NASA's GEOS-S2S forecast system and the mechanism for their development and maintenance associated with Rossby-wave propagation

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Introduction

There were unprecedently frequent and strong warm extreme events across Eurasia/Siberia over the first half of 2020. Specifically, the NE Siberia experienced the record-breaking temperature that reached ~38°C in late June. This study examines the prediction of the extreme events in NASA's Global Earth Observing System Subseasonal to Seasonal (GEOS-S2S) forecast system to identify the extent to which the model can reasonably anticipate these extreme events. We focus on the forecasts at 10-15 day lead, which is beyond the weather forecast time scale. Following the examination of the GEOS-S2S model capability, dynamic mechanism that explains the cause/persistence of the extreme events is investigated. We perform the global stationary wave model to understand the role of Rossby wave propagation in driving the warm extremes.

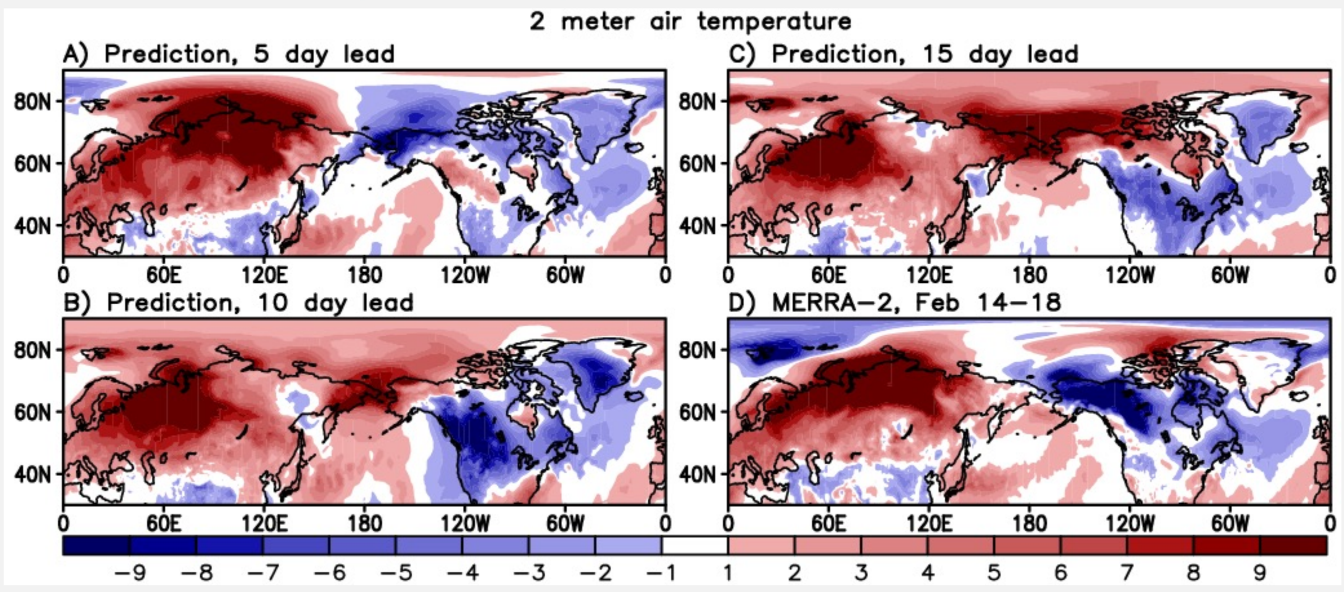
GEOS-S2S forecast model

- Fully coupled global model (atmosphere, land, ocean, sea ice, and chemistry)
- ~0.5 degree resolution for both atmosphere and ocean
- Initialized from a weakly coupled atmosphere-ocean data assimilation system
- For subseasonal prediction: Initialized every 5 days (=73 initial dates a year), 4 members at each initial date, up to 45-day lead prediction

Predictions (2m air T) of the extreme events selected

14-18 February

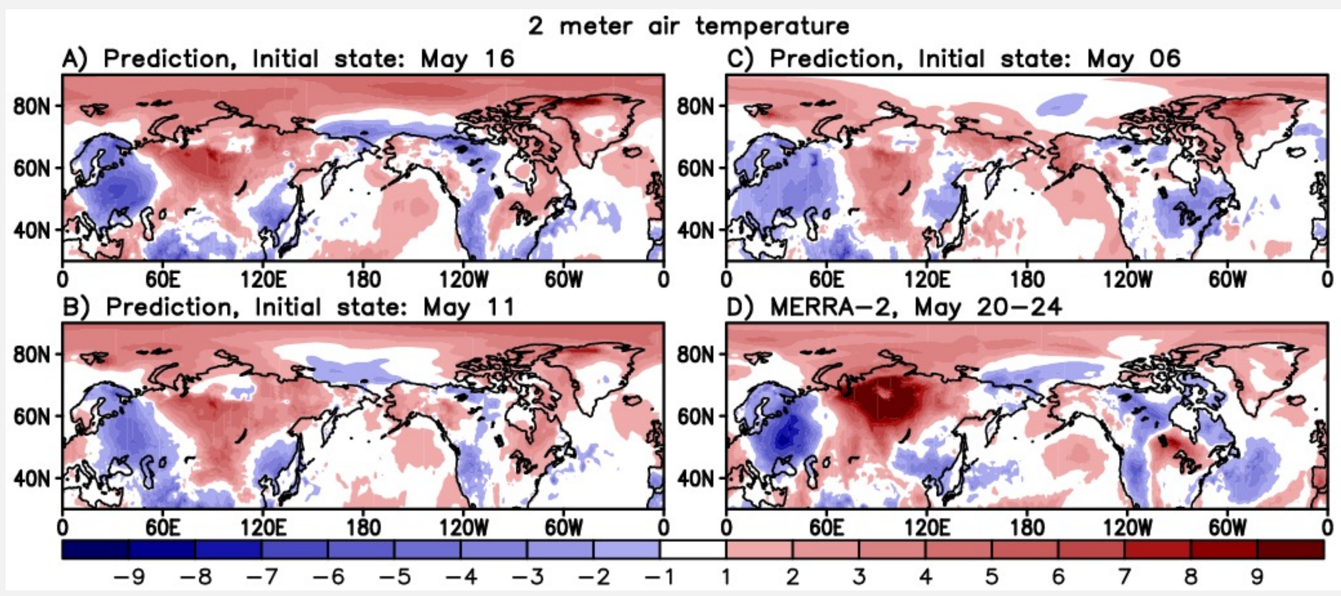
5-day | 15-day | 10-day | MERRA-2



Location and amplitude of warm extreme is captured well at 5 day lead. The location of the predicted warm extreme at 10 day lead is shifted to the west (compared to obs.).

20-24 May

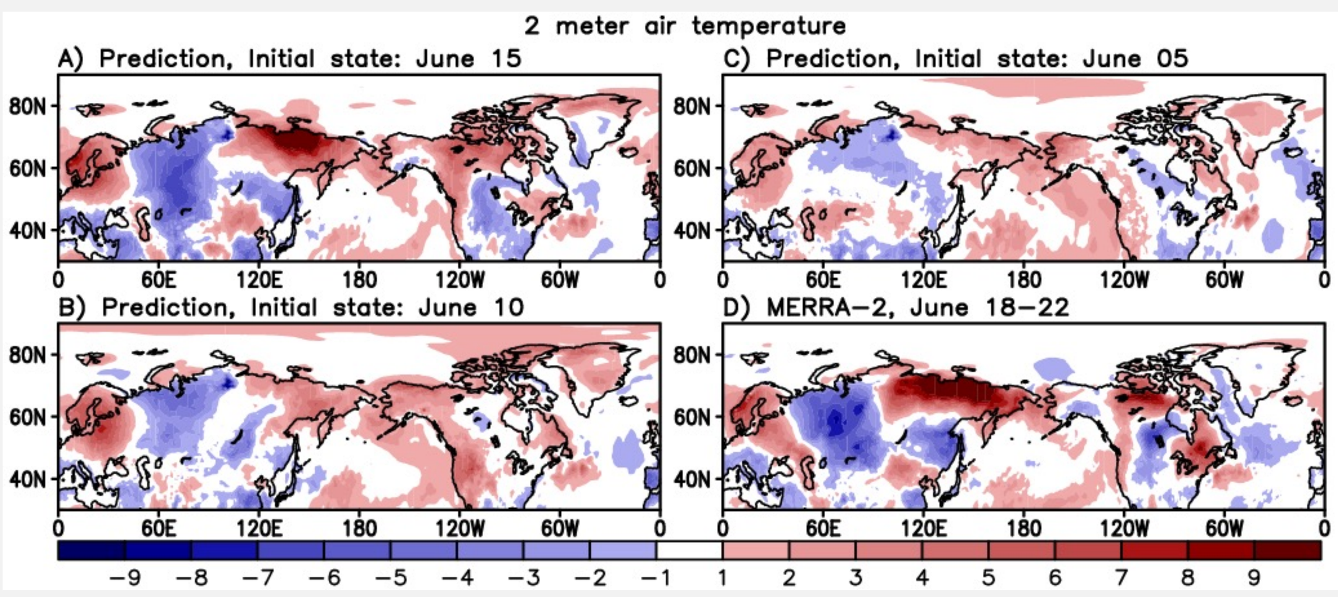
5-day | 15-day | 10-day | MERRA-2



Location of the warm and cold anomalies are captured well at 5, 10, and 15 day forecast leads, but with smaller amplitude than the observed.

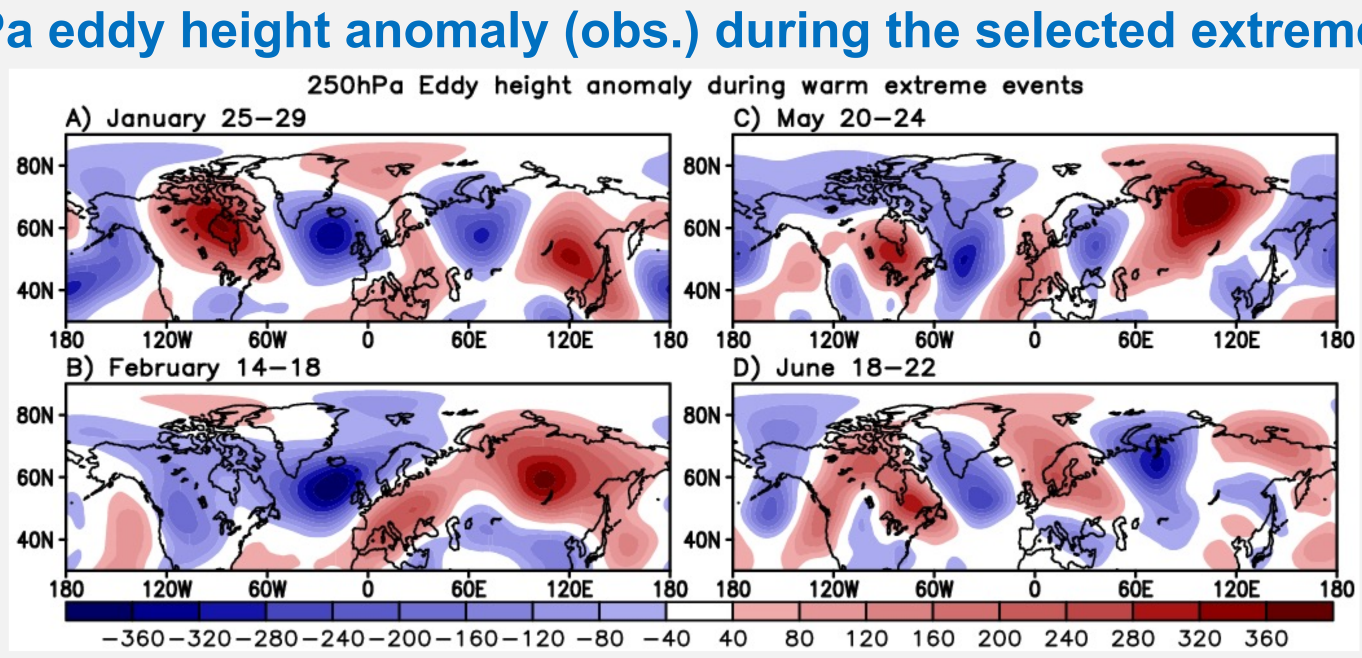
18-22 June

5-day | 15-day | 10-day | MERRA-2



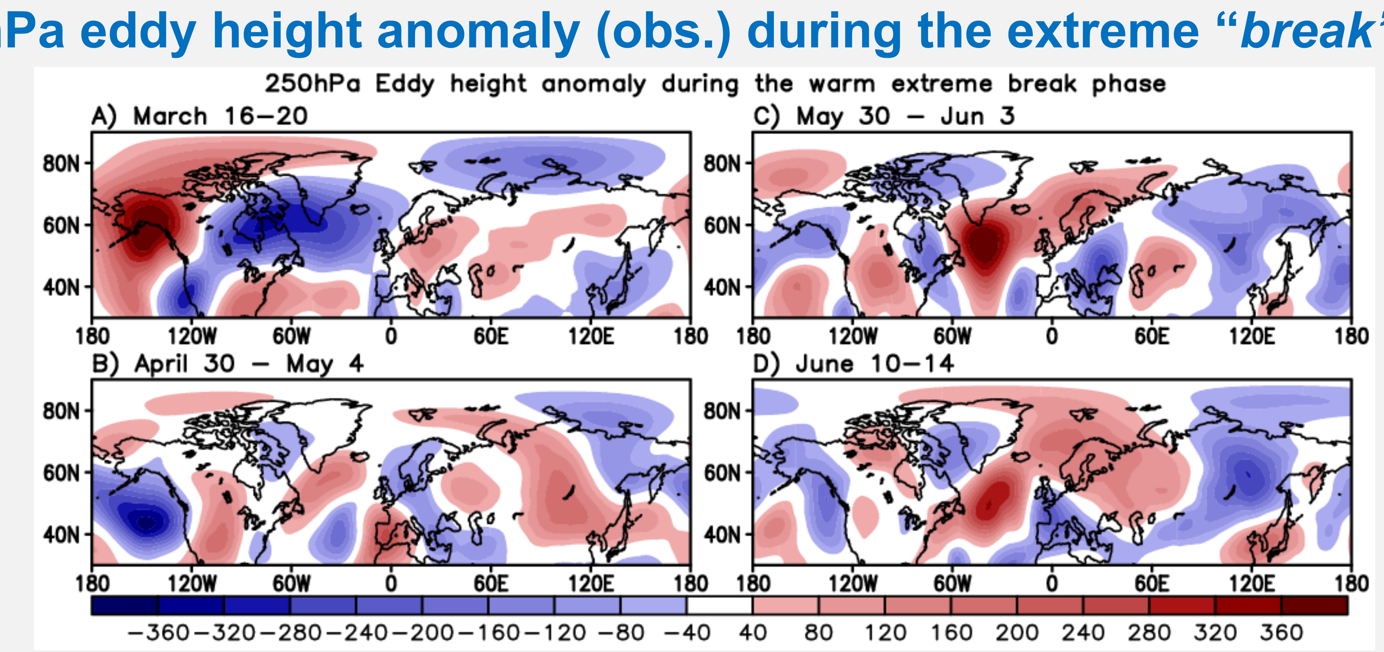
Location of the warm and cold anomalies are predicted well at 5, 10, and 15 day forecast leads. Anomaly over NE Siberia is predicted well with similar amplitude at 5 day lead.

250hPa eddy height anomaly (obs.) during the selected extreme events



Wavetrain-like anomaly distributions → role of the Rossby wave propagations?

250hPa eddy height anomaly (obs.) during the extreme "*break*" phase



Wavetrain-like pattern is less well organized, and the amplitude of anomalies is smaller.

Can the Siberian heatwave patterns be reproduced by the model (stationary wave model) forced by Rossby wave source (RWS)?

Global stationary wave model (SWM)

The dry dynamical core of an Atmospheric General Circulation Model with 14 un-evenly spaced vertical levels on sigma coordinates.

The SWM is forced by an estimate of the vorticity transient (as a mid-latitude RWS) or diabatic heating/cooling.

The atmospheric basic state in the SWM is the 3-D climatology taken from MERRA-2 reanalysis.

Rossby wave source (RWS) (from quasi-geostrophic vorticity equation)

Linearized form of RWS (e.g., Sardeshmukh and Hoskins 1988)

$$RWS = -V'_\chi \cdot \nabla(\bar{\zeta} + f) - (\bar{\zeta} + f)\nabla \cdot V'_\chi - \zeta'\nabla \cdot \bar{V}_\chi - \bar{V}_\chi \cdot \nabla\zeta'$$

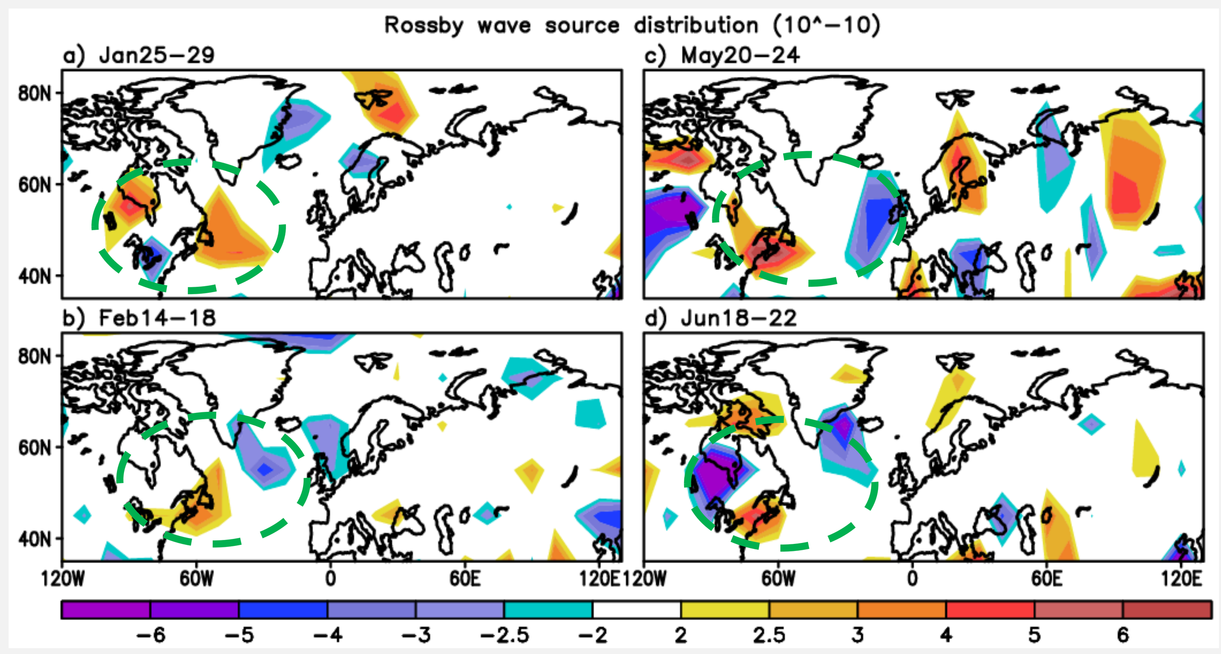
V_χ : divergent component of the wind, ζ: relative vorticity, f: planetary vorticity

overbar: climatological average, prime: anomaly

Terms (1) and (4) on the right hand side: vorticity advection

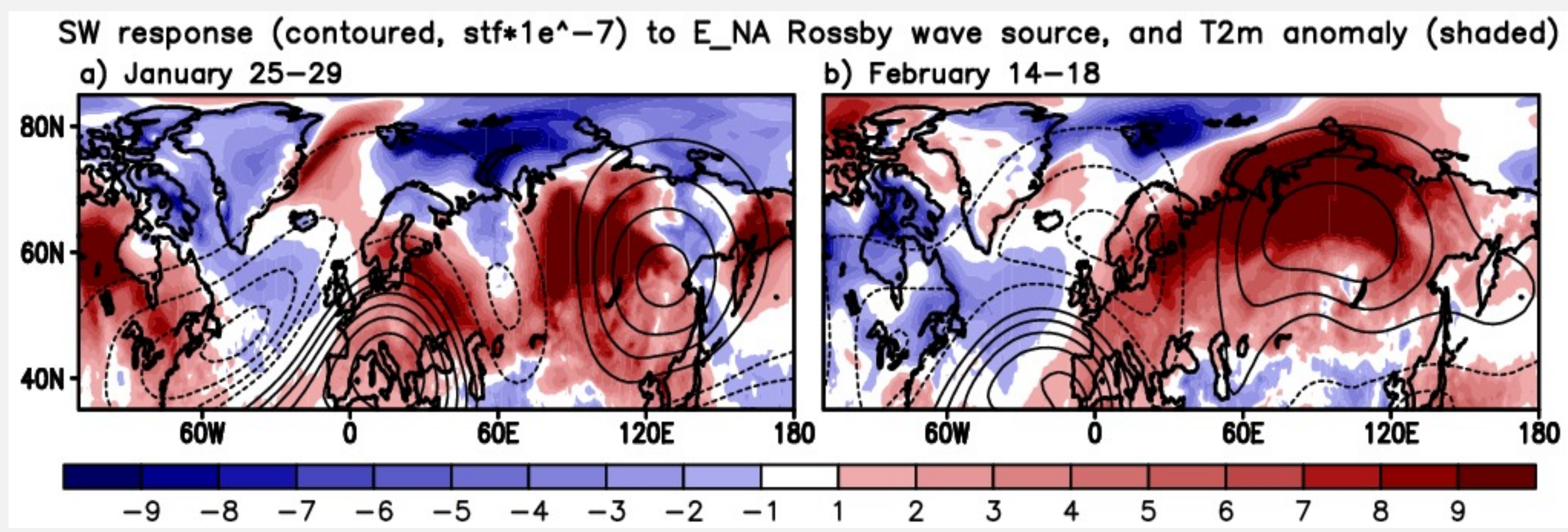
Terms (2) and (3): generation of wave vorticity by the divergence of the divergent wind

RWS distribution during the selected warm extreme events

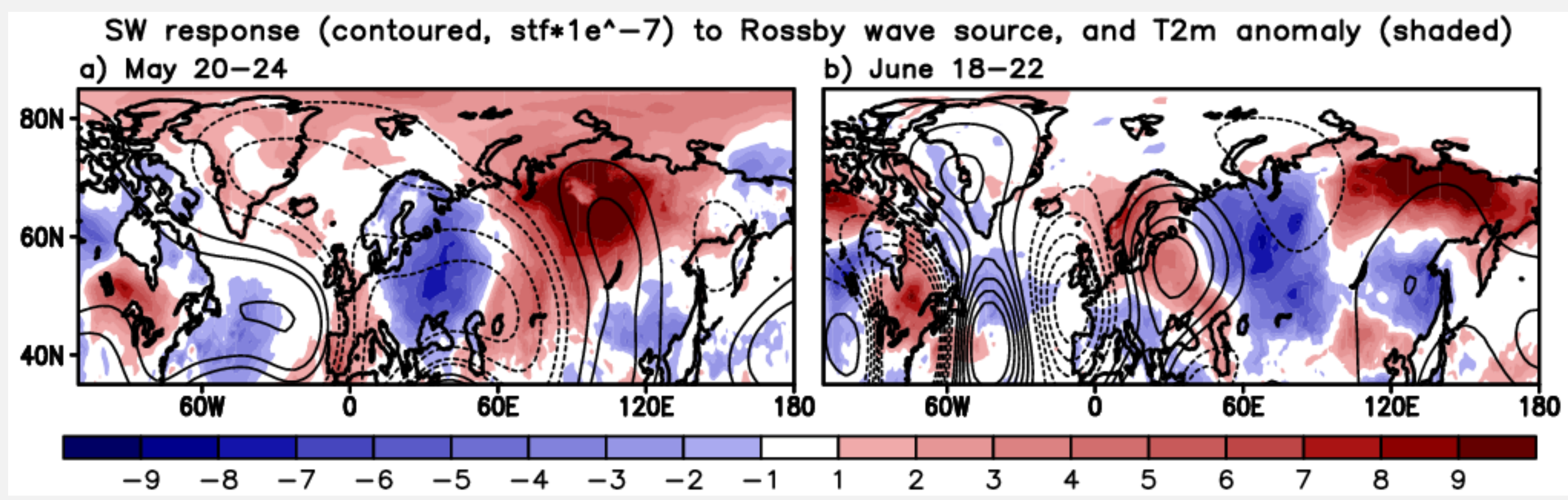


Larger amplitude of RWS tends to be found over the eastern North America (near the storm track) and the mid-latitude Atlantic.

Stationary wave response to RWS during the selected warm extreme events (cold season) (contour: eddy streamfunction (stf), shading: obs. T2m)



Stationary wave response to RWS during the selected warm extreme events (warm season)



The model produces the stf pattern that may cause the warm extreme events over Siberia. The pattern is similar to the observed 250hPa eddy height anomaly distribution over Siberia shown on the lower-left of this poster.

Conclusions

- Location and amplitude of the strong temperature anomalies during the warm extreme events is predicted well at 5 day lead.
- Predictions at ~10 and ~15 day leads show a wide range of skill. Either very good in terms of location/amplitude, accurate prediction of the location with underestimated amplitude, or predicted extreme events zonally shifted (compared to observed)
- Wavetrain-like patterns in terms of eddy height anomalies tend to be clearer across the Atlantic and Eurasian mid-latitudes during the warm extreme events.
- The SWM experiment results demonstrate that the occurrence of Siberian heatwaves and their geographical locations is significantly controlled by the Rossby wave propagation originating from the E. North America or Atlantic.

Our publications on the Siberian warm extremes in 2020

Schubert, S. D., Y. Chang, A. M. DeAngelis, R. Koster, Y.-K. Lim, and H. Wang, 2022: Exceptional warmth in the Northern Hemisphere during January through March of 2020: The roles of unforced and forced modes of atmospheric variability. *J. Climate*, **35**, 2565-2584, doi:10.1175/JCLI-D-21-0291.1.

Collow, A. B. M., N. P. Thomas, M. G. Bosilovich, Y.-K. Lim, S. D. Schubert, and R. D. Koster, 2022: Seasonal variability in the mechanisms behind the 2020 Siberian heatwaves. *J. Climate*, **35**, 3075-3090, doi:10.1175/JCLI-D-21-0432.1.

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