Report: **Scientific achievements in 2018**

Project: **1059**

Project title: **H2020 Blue-Action: Arctic Impact on Weather and Climate**

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Initialized decadal predictions of the rapid warming of the North Pacific around 1990 and associated atmospheric impacts in the persistent warm period thereafter

Around 1990, the North Pacific Ocean (40°-50°N, 160°-200°E) underwent a rapid warming, with sea surface temperatures (SSTs) increasing by 2C from 1988 to 1991, and then underwent a persistent warm period from 1991 to 1997. Corresponding to the changes in SST patterns, reanalysis data revealed that during the 1990s, there was a "Sudden Stratospheric Warming (SSW) minimum" period. To be specific, no major SSWs were observed during the nine consecutive winters from 1989/1990 to 1997/1998. Moreover, a previous modelling study suggested that the enhanced North Pacific sea surface temperatures are unfavourable for the occurrence of the major SSWs. In particular, enhanced North Pacific SSTs lead to the formation of the negative western Pacific atmospheric teleconnection pattern - specifically, a positive anomaly of the Aleutian low, which inhibits planetary wave propagation into the stratosphere.

Here, the extent to which a climate prediction system initialized using observations of the ocean and atmosphere states is able to capture the observed changes in North Pacific SSTs in 1990s and other atmospheric variables is investigated (Dai et al., in prep. for Journal of Climate). The decadal climate prediction system based on the stratosphere resolving atmosphere-ocean coupled Max-Planck-Institute Earth System Model (MPI-ESM) is used in this study, in the low-resolution (LR T63L47/GR15L40), mixed-resolution (MR T63L95/TP04L40) and high-resolution (HR T127L95/TP04L40) configurations.

The results show that, for all of the three versions of the Earth System Model, the ensemble hindcasts initialized at the end of 1987 capture the rapid rise in North Pacific SST around 1990 and the follow-up persistent warm period over 1991-1997 (Figure 1, right panels), which are not captured by the uninitialized hindcasts (Figure 4.1, left panels). Furthermore, the ensemble-mean hindcasts initialized in 1987 are able to reproduce the observed features in atmospheric circulation related to the North Pacific warming, including the weakening of the Aleutian low in the troposphere (especially in HR configuration, Figure 2h), and the strengthening of the stratospheric polar vortex (especially in LR configuration, Figure 2b). These results show that, despite the generally low predictive skill in North Pacific Ocean, the decadal climate prediction system shows considerable skill at least in specific cases.

The onset of major SSWs has significant follow-on effects on surface weather and climate in the northern Hemisphere extratropical regions. As the anomalous circulation of a major SSW propagate downwards into the troposphere over a period of several weeks, a negative phase of the Arctic Oscillation forms near the surface, which leads to a strong anomalous warm Arctic and cold Eurasia. Thus, successfully predicting North Pacific SSTs is likely important to predict stratospheric climate and surface climate over Arctic and Eurasia.

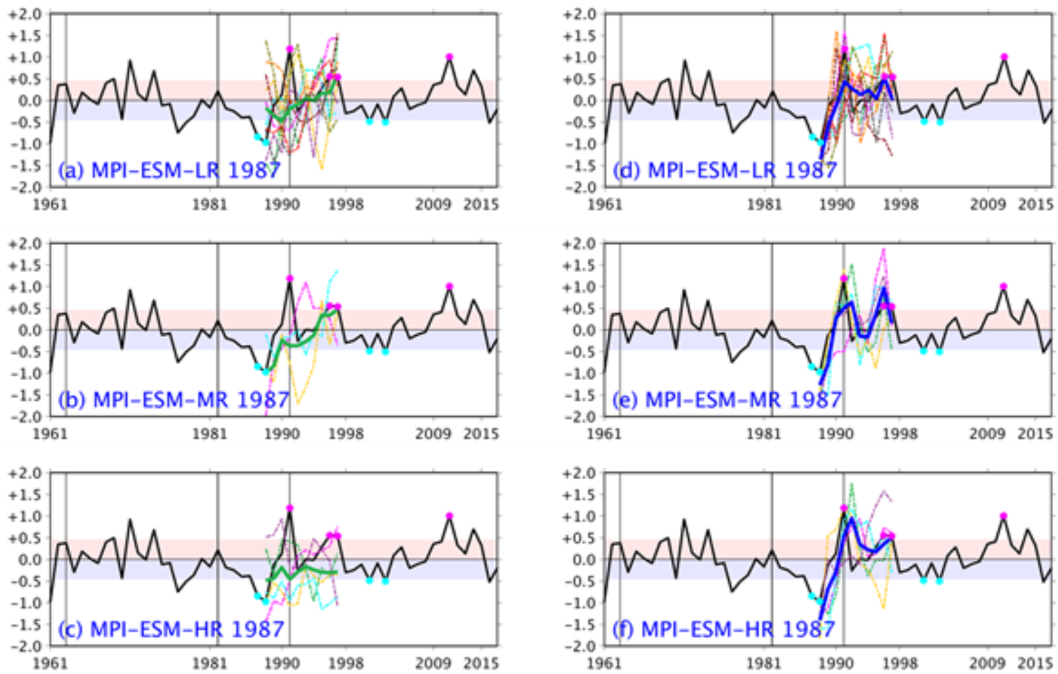

Figure 1. SST anomalies (in ℃) for the North Pacific (40°-50°N, 160°-200°E) during winter season [calculated by taking a January-February (JF) average] from 1961 to 2017. Shown is the HadISST1 observations (solid black), the ensemble mean of MPI-ESM (left panels) uninitialized hindcasts (thick solid green); and (right panels) initialized hindcasts (initialized in 1987, thick solid blue), in the (top) LR; (middle) MR; and (bottom) HR configurations. The thin coloured curves show each realization of simulations. The black vertical lines indicate volcanic eruptions: Mount Agung (March 1963), El Chichón (April 1982) and Mt. Pinatubo (June 1991). *From Dai et al., 2018 (in preparation)*

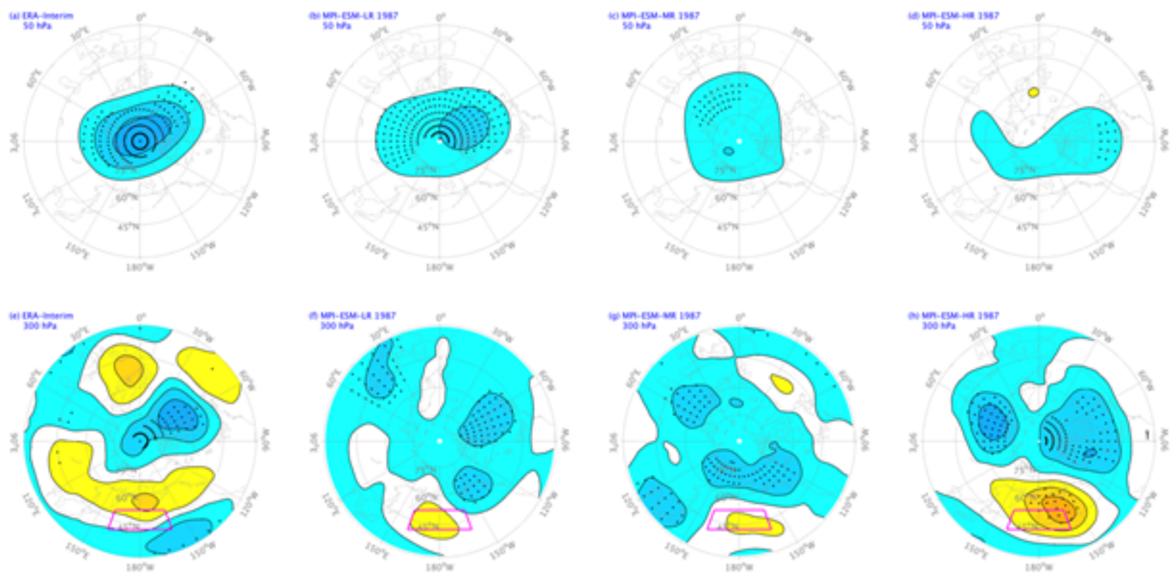

Figure 2. Geopotential height anomalies averaged over 1991-1997 at (top panels) 50 hPa and (bottom panels) 300 hPa. Shown is (a,e) the ERA-interim reanalysis, followed by the ensemble mean of MPI-ESM initialized hindcasts (initialized in 1987) in the (b,f) LR; (c,g) MR; and (d,h) HR configurations. Contours start from ±10 m with an interval of 20 m for 300 hPa; contours start from ±35 m with an interval of 70 m for 50 hPa. Stippling denotes anomalies that are statistically significant at the $p < 0.10$ level as determined with a two-tailed Monte-Carlo test. It is noteworthy that, for a better graphical display, the values of geopotential height anomalies from initialized hindcasts have been multiplied by a factor of 2. *From Dai et al., 2018 (in preparation)*

Arctic warming impacts by atmospheric pathway

The aim of our research is to quatify the role of Arctic Amplification on Eurasian winter. Previous studies have found that Arctic Amplification is related to cold winters over Eurasia. This relation is suggested to be linked with Arctic sea ice (SIC) melting with global warming. However, there are also evidences of colder winter and warm Arctic being related to the atmospheric internal variability. There are also studies that suggest a link of decadal scale variability in sea surface temperature (SST) like AMV or PDV with Arctic and mid-latitude climate. We try to distinguish the role of these boundary forcing from SST and SIC from the internal atmospheric variability through our four set of AMIP-type experiments, where 1) daily varying SIC and SST, 2) climatological SIC over Arctic with daily varying SST, 3) daily varying SIC and SST with PDV signal removed and 4) daily varying SIC and SST with AMV signal removed forcings are applied.

The Barents Sea temperature variability shows a close relation with Arctic sea ice change. Therefore, we investigate the temperature variability over the Eurasian region with respect to the Barents Sea surface air temperature (SAT). We do that by performing regression of the SAT elsewhere with the Barents Sea averaged SAT (Fig3a). To understand the same connection without the effect of Arctic amplification, a same regression analysis is performed with de-trended SAT (Fig3b). A difference of these two regressions will show the effect of the trend or the Arctic Amplification on the temperature variability over the Eurasian region (Fig 3c).

Our results show a dipole structure in SAT, where a warmer Arctic is connected to colder central to eastern Eurasia in ERA interim (Fig3a) (Ghosh et al, in preparation). This relation is reproduced best in the model with climatological SIC condition, indicating that this dipole structure is not related to the Arctic Amplification. The other experimental setups also bring mild cooling effect over the eastern Eurasia, which is stronger when the AMV is removed. When the trend is removed from SAT, all the experiments seem to reproduce the dipole temperature structure reasonably better (Fig3b). This result strongly suggests that the dipole pattern is related to the atmospheric internal variability and can occur without the Arctic amplification. Whereas, the Arctic amplification related variability has tendency to bring warmer SAT over Eurasia. Interestingly, that is not the case in observations. Changes in the SAT variation with respect to Arctic Amplification shows a cooling over the central Eurasia in the ERA interim (Fig3c). This cooling effect, which is apart from the internal variability, is missing in the model simulations, where we find a general warming effect. Therefore, our results suggest that internal variability plays a major role in connecting Arctic temperature to Eurasian SAT. However, apart from internal variability, there is a cooling effect over central Eurasia from the Arctic Amplification in the observation, which the model is unable to capture. This is a new finding and could be a valuable addition in the field of Arctic research.

We further plan to investigate the robustness of the results by increasing the number of ensembles and also we try to understand the exact reasons of the similar and differing responses in the model and in ERA interim. To identify the ocean's role in bringing warmer condition over the Eurasia, we plan to run another set of experiment with climatological SST.

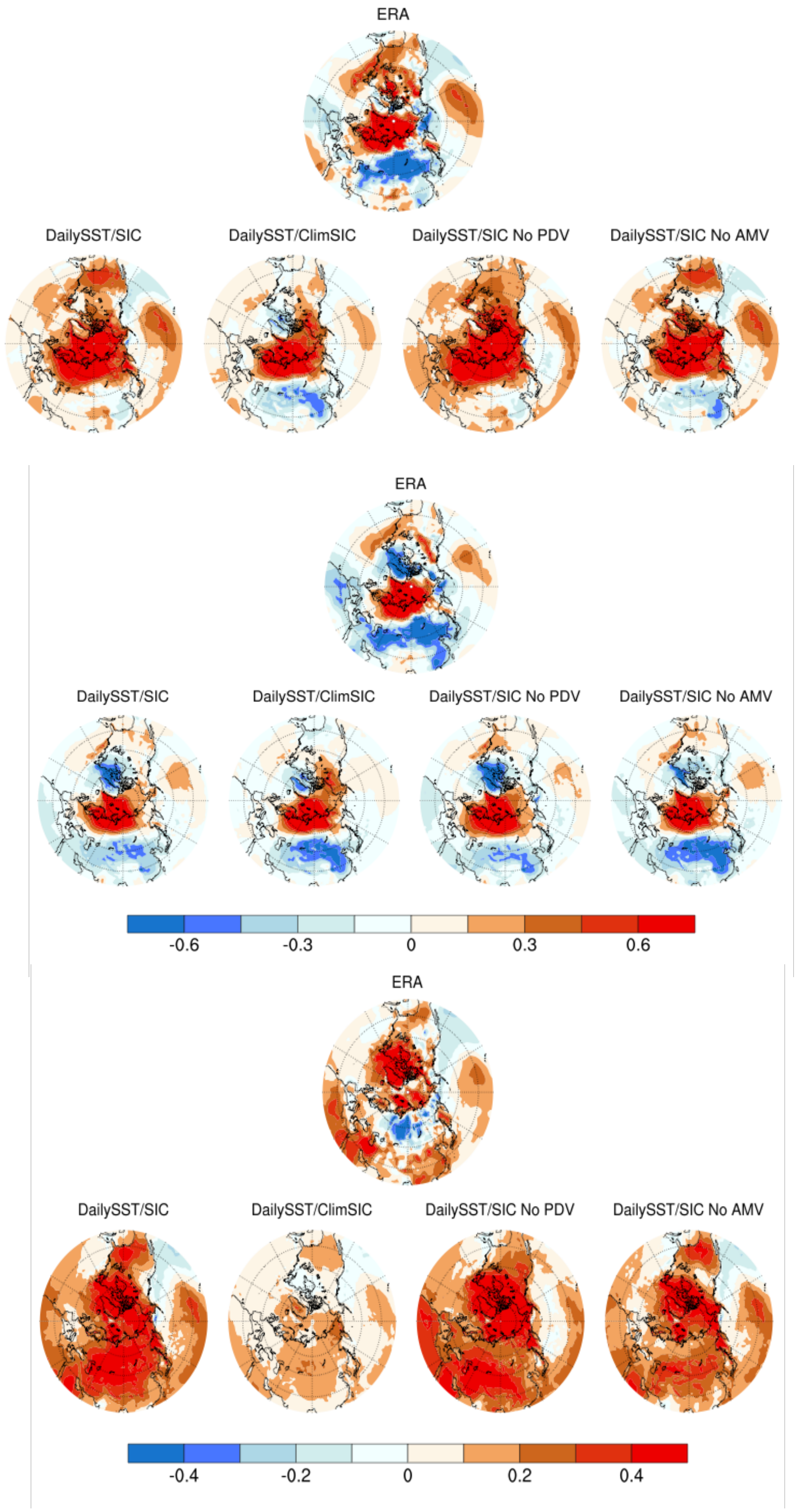

Fig 3: a) Regression NH SAT anomaly on Barents Sea averaged SAT anomaly in ERA interim and for ensemble mean (8 members) of 4 set of experiments with daily SST and SIC, daily SST climatology SIC, daily SST and SIC with PDV signal removed, daily SST and SIC with AMV signal removed . b) The same as in **a** but with de-trended SAT anomalies. c) the difference of regression fields in a from b. *From Ghosh et al, 2018(in preparation).*