Final Report

Evaluation of Reanalysis Products in the Arctic

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Results and Accomplishments

How well can we estimate the state of the atmosphere in the polar regions in retrospective reanalyses? In the data sparse Arctic, atmospheric reanalyses are poorly constrained by observations and are strongly influenced by model parameterizations. There are currently seven different sets of global reanalysis products that are current or near current in temporal coverage: NCEP-1, NCEP-2, CFSR, 20CR, MERRA, ERA-Interim, and JRA-25.

Retrospective analyses have been a critical tool in studying weather and climate variability. Reanalyses blend the continuity and breadth of output data from a numerical model with the constraint of vast quantities of surface, radiosonde, aircraft, and satellite observational data. The result is a long-term continuous and spatially complete data record. Reanalysis products are used in many different applications including evaluation of atmospheric circulation patterns and processes, change detection, the forcing of ice–ocean models, regional atmospheric models, land models, or air chemistry models, and for establishing the initial conditions for forecast models. Better understanding the strengths and weaknesses of these products will improve our ability to evaluate the long-term trends in the rapidly changing Arctic environment and may also improve our ability to make seasonal projections of sea ice and weather conditions in the Arctic.

In this focused study we compare the monthly mean estimates of the surface and tropospheric air temperature, the surface pressure and winds, the total precipitation, and the surface and top-of-the-atmosphere radiative fluxes in a three-tiered set of analyses. The first-order comparisons are made to independent point observations from a selected set of land stations and drifting ice stations. The second-order comparisons are made of the seasonal means of the fields from each of the reanalyses. Finally, the third-order comparisons are made of the 30-year trends in the fields of each of the reanalyses.

The ultimate goal is to better understand the strengths and weaknesses of these products in a data-sparse region where the reanalysis models may differ the most and to determine which product is best suited for forcing a coupled ice-ocean model in reproducing the observed ice thickness.

We presented preliminary results as a poster at the 4th WCRP International Reanalysis Conference in Washington D.C., planned for May 7-11, 2012 and at the American Meteorological Society Conference on Polar Meteorology and Oceanography.

A paper was written and submitted to the Journal of Climate in December 2013. It is still under review after revisions. The abstract reads as follows:

> Atmospheric reanalyses depend on a mix of observations and model forecasts. In data-sparse regions such as the Arctic, the reanalysis solution is more dependent on the model structure, assumptions, and data assimilation methods than in data-rich regions. Seven reanalysis datasets for the Arctic region are compared over the 30-year period 1981–2010: NCEP-R1, NCEP-R2, CFSR, 20CR, MERRA, ERA-Interim, and JRA-25. Emphasis is placed on variables not observed directly including surface fluxes and precipitation and their trends. The monthly averaged surface temperatures, radiative fluxes, precipitation, and wind speed are compared to observed values to assess how well the reanalysis data solutions capture the seasonal cycles. Three models stand out as being more consistent with independent observations: CFSR, MERRA, and ERA-Interim. A coupled ice–ocean model is forced with four of the datasets to determine how estimates of the ice thickness compare to observed values for each forcing and how the total ice volume differs among the simulations. Significant differences in the correlation of the simulated ice thickness with submarine measurements were found, with the MERRA products giving the best correlation (R=0.82). The trend in the total ice volume in September is greatest with MERRA (–0.41 10^3 km^3 yr^{-1}) and least with CFSR (–0.27 10^3 km^3 yr^{-1}).

The results are highlighted here with four figures. Figure 1 shows the comparison of 10-m wind speeds measured at drifting ice stations to the estimates from each of the products. The smallest bias is for the NCEP-R1 product and the best correlation is for the ERA-Interim product. Figure 2 shows a comparison of the 2-m air temperature in winter for all seven of the different products to their median. There are significant regional variations in the different products. NCEP-R1 is colder and 20CR substantially warmer than the consensus. Figure 3 shows the trend in the annual-average 2-m air temperature. While all of the models show warming, there are significant differences in the magnitude and spatial patterns of the trends. Finally Figure 4 shows the total ice volume in March and September from the PIOMAS ice-ocean model forced with four of the products. The mean bias of each simulation compared to submarine measurements of ice draft has been removed by model adjustments. While there is broad agreement in the simulations we find that the MERRA products produce a simulation with the highest correlation with the sporadic submarine ice-draft measurements made from 1980 through 2005. Following model tuning, the correlation between the model ice draft and the measured ice draft for the four models is R = 0.76, 0.79, 0.80, and 0.82 for ERA-I, CFSR, NCEP-R1, and

MERRA, respectively. These correlations are for 50-km ice draft measurements taken within the data release area for the submarines from different months, but primarily in the spring and fall. Thus MERRA does better in simulating the ice draft variability than the other products and the difference in the correlation from the next best, NCEP-R1, is significant at a p-value of 0.98.

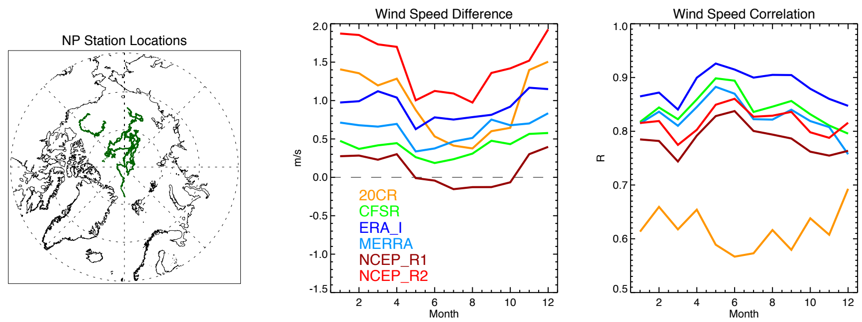

Fig. 1. Comparison of the daily average 10-m wind speed from the North Pole drifting ice stations of the former Soviet Union with model estimates. Thirteen station-years are included between the years of 1981 and 1990. Right: Map of the station locations; Middle: monthly wind speed bias of each model (model – observed; mean annual wind speed is 4.1 m s^{-1}; Left: correlation of the daily wind speeds by month. The observational data are from the Arctic and Antarctic Research Institute in Leningrad and are archived at the National Snow and Ice Data Center.

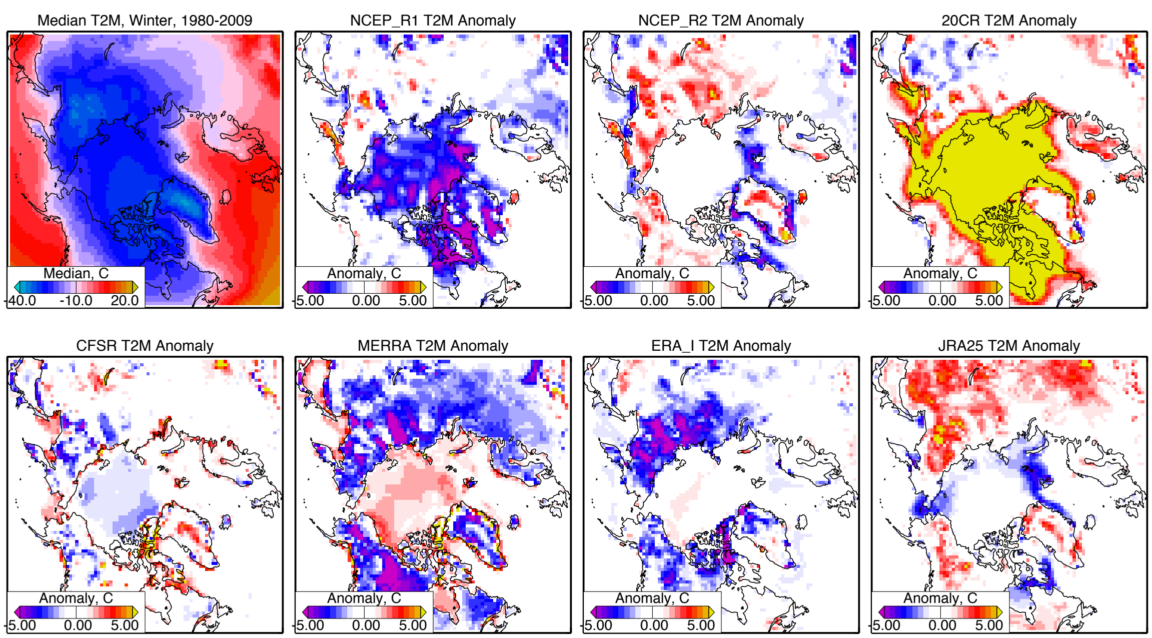

Fig. 2. 2-m air temperature in winter (DJF). The median of the seasonal means for the seven models is in the upper left and the deviations from the median for each of the models are in the subsequent maps.

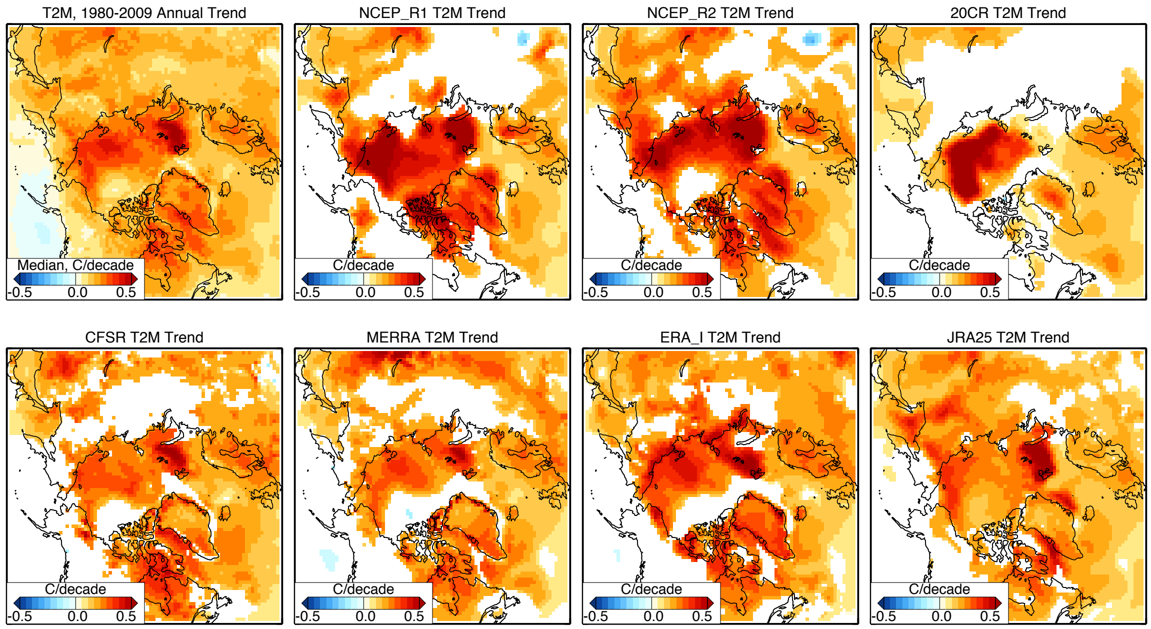

Fig. 3. Comparisons of annual 2-m air temperature trends. The upper left map is the median and the individual model trends in the other maps are actual, not anomalies. The trend is plotted only for regions exceeding 95% confidence that the trend is non-zero.

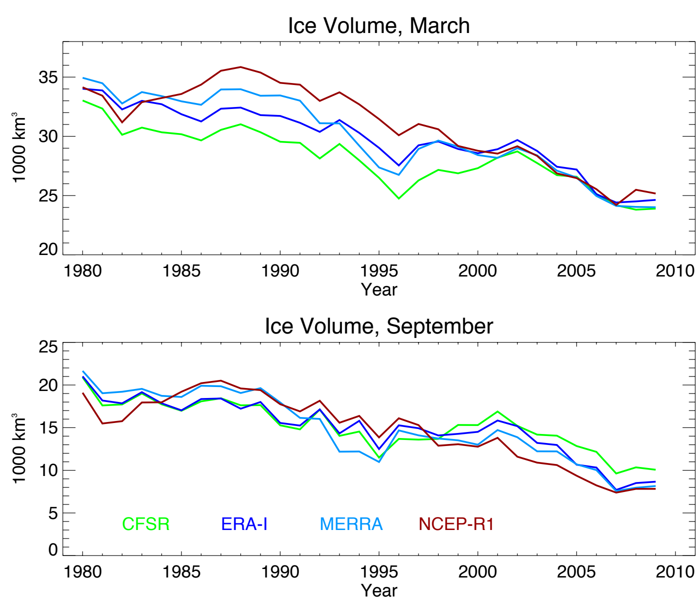

Fig. 4. Total Arctic sea ice volume computed by the PIOMAS coupled ice-ocean model for March and September using forcing data from four different reanalysis datasets.

Highlights

- There is a large range in the fidelity of the different products when compared to unassimilated in situ observations of air temperature, downwelling radiative fluxes, and precipitation. In general three products stand out as being the best: CFSR, MERRA, and ERA-Interim. The 20CR product is very poor in the Arctic due to a mistake in sea ice coverage. The NCEP-R1 and R2 radiative flux fields are also very poor.
- Individual fields have a large range of variability across the different models depending on the variable considered. Variables tightly controlled by observations have variability of the seasonal means across models less than that seen in the interannual variability while variables not tightly controlled by observations have variability 2 to 5 times the interannual variability.
- All four of the products tested (NCEP-R1, CFSR, ERA-Interim and MERRA) did a good job at recreating the ice draft measurements from submarines and all simulations resulted in similar downward trends in sea ice volume. MERRA does better in simulating the ice draft variability than the other products as measured by the correlation of the submarine ice drafts with the PIOMAS simulations.

Publications

Lindsay, R., M. Wensnahan, A. Schweiger, and J. Zhang, 2013: Evaluation of seven different atmospheric reanalysis products in the Arctic, *J. Clim*., submitted.

Posters

Lindsay, R., M. Wensnahan, 2013: Evaluation of seven different atmospheric reanalysis products in the Arctic. *AMS Polar Meteorology and Oceanography Conference*, Seattle WA. April 30, 2013.

Lindsay, R., M. Wensnahan, 2012: Evaluation of seven different atmospheric reanalysis products in the Arctic. *WCRP Reanalysis Conference*, Silver Spring MD. May 7-11, 2012.

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