A comparison of Polar Weather Research and Forecasting Model output and data from the Norwegian Young Sea Ice Field Experiment

Sarah Y. Murphy

1. Introduction

The global climate is heavily influenced by processes that occur in the Arctic. A lack of observation has led to difficulty understanding atmospheric processes in polar regions. Regardless of the fact that this is such an important location, observations can be limited both spatially and temporally. This scarcity of observations stems from the harsh conditions and difficulty in deploying ground-based instruments. Observations are key to improving models, which are necessary for understanding processes occurring in the polar regions. Evidence has shown that Arctic cloud and precipitation processes, as key elements of the climate system, are changing with amplified Arctic warming (Zhang et al., 2019). Models in the polar regions have the largest uncertainties relative to other parts of the world, particularly in the simulations of the clouds and radiation budget.

The Polar Weather Research and Forecasting model (Polar WRF) has parameterizations developed specifically for the polar regions, including mechanisms to handle variations in sea ice thickness, fraction and snow depth. Polar WRF has been used for weather forecasting in Antarctica and has been tested over ice and land in the Arctic (Bromwich et al. 2009). However, testing over thin, young sea ice has not been conducted. Phase partitioning in mixed-phase clouds is a topic of particular interest, because the Polar WRF microphysics schemes handle these clouds differently. In fact, most of the microphysical parameters used in Polar WRF have been validated using data from the mid-latitudes rather than the polar regions.

2. The Norwegian Young Sea Ice Experiment

The Norwegian Young Sea Ice Experiment (N-ICE2015) is a 6-month Arctic field experiment in which atmospheric measurements were taken on and around a Norwegian icebreaker frozen into sea ice. The icebreaker, the *R/V Lance*, moved with the sea ice north of Svalbard, Norway during the transition period from January through July 2021 (Granskog et al. 2016). This field experiment is of particular interest from a modeling perspective due to the magnitude of the temperature and pressure change during and after winter storm periods. This experiment is the first to take measurements of the clouds and atmosphere since the Surface Heat Budget of the Arctic (SHEBA) field experiment in 1997 and 1998. However, the storms observed during the N-ICE2015 observational period showed temperature increases significantly larger than those seen at SHEBA (Cohen et al. 2017). Additionally, throughout much of the field experiment, strong temperature inversions were observed over the surface, similar to what was seen at SHEBA (Kayser et al. 2017). While these strong inversions are not unique to N-ICE2015, they are often underrepresented in Polar WRF simulations (Hines et al. 2015). A variety of instruments were deployed on the N-ICE expedition, and not limited to those listed here. In this project, radiosondes, the MicroPulse Lidar (MPL), a meteorological tower, an Eddy

Covariance system, and radiometers were used (Granskog et al. 2016; Walden et al. 2017).

3. Research Goals

This project sets out to explore the N-ICE atmospheric dataset to answer the following questions:

- What are the important factors that influence the surface energy budget over young, thin sea ice? In particular, what are the contributions from longwave and shortwave radiation, and sensible and latent heat flux?
- How do the different boundary-layer and cloud-microphysics schemes in Polar WRF perform under the conditions observed during the N-ICE field campaign? What are the key variables in these schemes that control simulated cloud properties and surface energy budget?

4. Modeling Methods

The WRF model version 4.1.4 was run with polar optimizations created by The Ohio State University using the following settings. These optimizations include improvements of heat transfer over ice and updating sea ice fraction (Hines and Bromwich 2008). These improvements have been tested over Arctic land and have had analysis done using SHEBA data, but have not yet been tested over first-year sea ice. The unique and large storms seen during N-ICE, along with the persistent surface temperature inversions present during the winter, make this dataset particularly interesting to use for Polar WRF validation.

A wide range of settings for both the microphysics and boundary layer parameters were selected primarily based on frequency of use in published studies. A range of boundary-layer parameters were selected to observe which most accurately represented the strong near-surface inversions in the Arctic and the radiative influence this can have on the surface. Alternatively, clouds also have strong radiative importance in the Arctic; cloud microphysics settings were selected for study here to determine which parameterization most accurately simulate these clouds, which are likely to be mixed phase or have supercooled water present.

- Land Surface Model: Unified Noah Land Surface Model (Noah LSM)
- Microphysics Schemes:
  - Goddard
  - Predicted Particle Properties (P3)
  - WRF Single-Moment 5-Class
  - Morrison Bulk Two-Moment
- Boundary Layer Schemes:
  - Yonsei University
  - Mellor-Yamada-Janjic (MYJ)
  - Mellor-Yamada-Nakanishi-Niino (MYNN)
- Surface Layer:
  - Revised MM5 (all runs except those using the MYJ boundary layer scheme)
  - ETA Similarity (only runs using MYJ)

- Input Datasets:
  - Boundary and Initial Conditions: ECMWF ERA-Interim Reanalysis
  - Snow depth and ice thickness: PIOMAS
  - Ice extent: SSMI

A 3-nested domain setup was used and can be seen in figure 1. The highest resolution domain is 3km by 3km, located just north of Svalbard and encompassing the entire N-ICE field experiment domain.

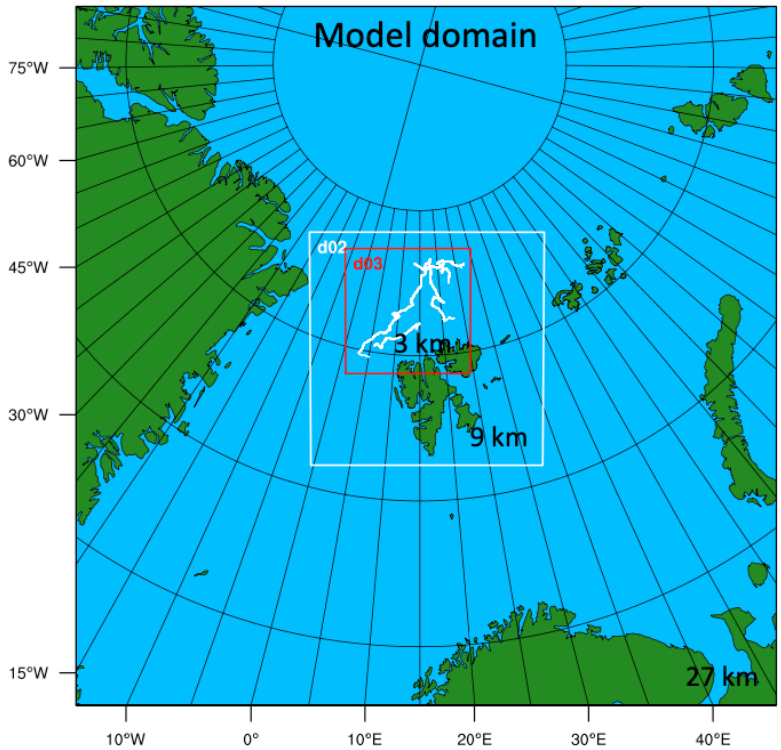

Figure 1. Model domain used when running the Polar Weather Research and Forecasting model. Each domain's grid spacing resolution is listed in the bottom right corner of each domain and the domain label is in the top left corner for the two nested domains. The white lines in the third domain (d03) indicate the ship location throughout the experiment.

5. Discussion

A brief analysis of the entire experiment and how closely the input data and model data replicate the conditions seen during the N-ICE field experiment. A case study was selected for further analysis for the purpose of keeping this report brief. A more thorough study has been done over both the entire experiment period extending to additional case study periods, with the goal of modifying the schemes and improving model performance.

To determine where the model is going wrong, we must first determine if the input data is accurate. Basic meteorological variables such as the temperature, relative humidity, and pressure.

On average, the ERA-Interim values and N-ICE values for sea level pressure matched remarkably well. Overall, there is a slight positive bias of approximately 1 hPa in ERA-Interim when compared to the N-ICE measurements. Temperature, on the other hand, did not have as strong of agreement, and the ERA-Interim data had a stronger positive bias of a few degrees, seen primarily during the colder season, with a decreasing bias as the temperature warms to the freezing point. It is important to note that Graham et al., 2019 did a detailed analysis of reanalysis datasets compared to the conditions seen at N-ICE. They found that, while there is a warm bias in temperatures in ERA-Interim, that it was still more accurate at representing the storm periods than other reanalysis datasets, including ERA-Interim’s successor, ERA-5 (Graham et al., 2019).

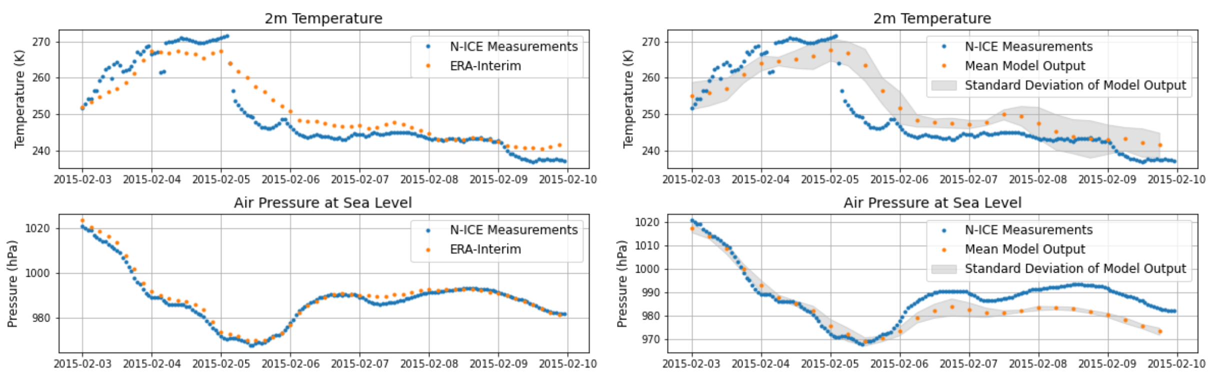

Figure 2. Measurements from the N-ICE experiment (blue markers, all plots) for 2 m air temperature (top plots) and sea level pressure (bottom plots). ERA-Interim data is plotted with the measurement data (orange, left) and the mean model output data (orange, right) with +/- 1 standard deviation spreads (gray shading, left plots).

The storm period selected for analysis here takes place from February 3rd to 12, 2015. This storm period was determined using pressure and wind change thresholds described in Cohen et al. (2016). This period was chosen as the ERA-Interim input data closely represented the measurements during this time. Figure 2 shows the N-ICE measurements and the ERA-Interim values on the same plot. Here, we can see that pressure is fairly accurately represented in ERA-Interim but there are some issues with temperature, particularly during the sharp temperature drop that took place on February 5th. The ERA-Interim values appear to have a more gradual onset of the cooler, drier air than the N-ICE measurements recorded.

The right side of figure 2 shows the mean model output value for 2 meter temperature (top) and the sea level pressure (bottom). The orange points here represent the mean of all model output in the innermost domain. The gray shading behind representations +/- 1 standard deviation of the mean. The similarities in the input data and measurements data, as well as the interesting and unique temperature drop during this period, are why this was the selected study period.

Agreement between the model, the input data, and the measurements agreed relatively well until the start of the day on the 5th, when the wind shifted from coming from the south to out of the north, bringing cool, dry air in (Walden et al., 2017, Cohen et al., 2017). Model vertical profiles show that the cool, dry air near the surface was not only delayed in its time of onset but did not cause as rapid of a cooling of both the surface and the entire atmospheric column. While some scheme combinations replicated the measurements better than others, some even improving upon the input data, all values were too warm at both the surface and at 3 meters during the time of cooling on the 5th.

6. Conclusion

The goal of this project is to analyze how the Polar optimized version of WRF performs when compared to measurements taken over first-year sea ice. In this paper, one case study from February 2nd through 9th is briefly analyzed to summarize how the model performs during a period in which the site was experiencing storm conditions. This storm period was characterized by a shift in the wind direction, which resulted in a change in both humidity and temperature. This drastic change in temperature was not well captured in the model output, as the cold air at the surface came in at a delayed rate.

Further work on this project includes analysis of the entire experiment period, including variables such as the cloud properties, surface radiative and turbulent fluxes, and more details about the moisture profiles. Additionally, multiple study periods have been selected for further analysis. Future steps include model experiments and modification with the goal of improving model output.

Works Cited

Cohen, L., S. R. Hudson, V. P. Walden, R. M. Graham, and M. A. Granskog, 2017: Meteorological conditions in a thinner Arctic sea ice regime from winter to summer during the Norwegian Young Sea Ice expedition (N-ICE2015). Journal of Geophysical Research: Atmospheres, 122, 7235–7259, https://doi.org/10.1002/2016jd026034.

Graham, R. M., and Coauthors, 2017: A comparison of the two Arctic atmospheric winter states observed during N-ICE2015 and SHEBA. Journal of Geophysical Research: Atmospheres, 122, 5716–5737, https://doi.org/10.1002/2016jd025475.

Granskog, M. A., P. Assmy, S. Gerland, G. Spreen, H. Steen, and L. Smedsrud, 2016: Arctic Research on Thin Ice: Consequences of Arctic Sea Ice Loss. Eos, 97, 1–6, https://doi.org/10.1029/2016eo044097.

Hines, K. M., and D. H. Bromwich, 2008: Development and Testing of Polar Weather Research and Forecasting (WRF) Model. Part I: Greenland Ice Sheet Meteorology*. Monthly Weather Review, 136, 1971–1989, https://doi.org/10.1175/2007mwr2112.1.

——, ——, L. S. Bai, M. Barlage, and A. G. Slater, 2011: Development and Testing of Polar WRF. Part III: Arctic Land*. Journal of Climate, 24, 26–48, https://doi.org/10.1175/2010jcli3460.1.

——, ——, ——, C. M. Bitz, J. G. Powers, and K. W. Manning, 2015: Sea Ice Enhancements to Polar WRF*. Monthly Weather Review, 143, 2363–2385, https://doi.org/10.1175/mwr-d-14-00344.1.

Kayser, M., and Coauthors, 2017: Vertical thermodynamic structure of the troposphere during the Norwegian young sea ICE expedition (N-ICE2015). Journal of Geophysical Research: Atmospheres, 122, 10,855-10,872, https://doi.org/10.1002/2016jd026089.

Walden, V. P., S. R. Hudson, L. Cohen, S. Y. Murphy, and M. A. Granskog, 2017: Atmospheric components of the surface energy budget over young sea ice: Results from the N-ICE2015 campaign. Journal of Geophysical Research: Atmospheres, 122, 8427–8446, https://doi.org/10.1002/2016jd026091.

Zhang, R., H. Wang, Q. Fu, P. Rasch, and X. Wang, 2019: Unraveling driving forces explaining significant reduction in satellite-inferred Arctic surface albedo since the 1980s. Proc. Natl. Acad. Sci. U.S.A., doi:10.1073/pnas.1915258116.