Real-time forecasts over the Arctic region during 2017/2018 Arctic expedition of the KOPRI IBRV Araon

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Abstract

Starting in 2017, the Korea Polar Research Institute (KOPRI) has performed real-time weather forecasts over the Arctic region during the Arctic cruise period of the IBRV Araon to support scientific activities of the Araon. 6-hourly radiosonde observations from the Araon are assimilated using the 3D-Var data assimilation method in a cycling mode, and 5-day forecasts are made using the polar-optimized Weather Research and Forecasting (Polar WRF) model. Effects of assimilating additional radiosonde observations on weather forecasts over the Arctic region are investigated using reanalysis data and independent observations.

Key words: real-time forecasts, radiosonde observations, 3D-Var, Polar WRF

1. Introduction

Predictability of numerical weather prediction (NWP) is limited because of uncertainties in initial conditions and model dynamical/physical processes. Initial conditions of numerical models can be improved by the process called data assimilation (DA). DA combines observations and model forecasts (usually, called background) in a statistically optimal way. Effects of DA can be maximized by the use of more sophisticated DA methods and more qualified observations.

Conventional observations over the Arctic region are very sparse compared to those in mid-latitude regions. Starting from 2015, radiosonde observations have been conducted during the Arctic expedition of the Ice-Breaking Research Vessel (IBRV), Araon of the KOPRI. In 2018, radiosonde observations were taken during the Special Observing Period (SOP-2) of the Year of Polar Prediction (YOPP).

In order to support scientific activities during the Arctic cruise of the Araon, near-real-time forecasts over the Arctic region have been performed since 2017, using the weather component of the Korea Polar Prediction System (KPOPS-weather). Forecasts results such as sea-level pressure (SLP), 2-m temperature, 2-m relative humidity, 10-m wind, and precipitation were transmitted to the Araon on every Monday, Wednesday, and Friday. In this study, effects of assimilating additional radiosonde observations from the Araon are evaluated by analyzing real-time forecast results during 2017/2018 Arctic cruise of the Araon.

2. Numerical experiment

2.1 Numerical models

The KPOPS-weather consists of two parts: forecast model and DA system. A forecast model is based on the Polar WRF Model (Hines and Bromwich, 2008). Compared to the WRF model (Skamarock and others, 2008), some physical processes, such as Noah land surface model (Tewari and others, 2004), are modified for use in the Polar Regions in the Polar WRF. A DA system is based on the three-dimensional variational (3D-Var) method within the WRF Data Assimilation (WRFDA) system (Barker and others, 2012).

2.2 Experimental design

Background error covariance is calculated using the National Meteorological Center (NMC) method (Parrish and Derber, 1992) where background error statistics are computed based on the differences between 24-h and 12-h forecasts starting at 00 UTC and 12 UTC on every day of August 2016. Radiosonde observations from the Araon are quality-controlled, and observational errors are assigned based on instrument and representativeness errors. Geographical locations of radiosonde observations from the Araon are shown in Fig. 1.

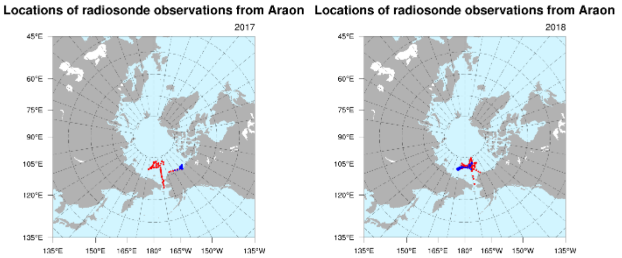

Fig. 1 Geographical locations of radiosonde observations from the Araon for 2017 (left) and 2018 (right).

Experimental periods for 2017 and 2018 are August 7 - September 13 2017 and August 6 - September 17 2018, respectively. During the experimental period, on each day, 6-hourly DA cycles are conducted four times (i.e. 1-day cycling) and 5-day forecasts are made using the analysis of the final cycle. Background for each day's first cycle is from 6-hour forecast starting from National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) analysis, and lateral boundary conditions come from NCEP GFS forecasts. Two experiments are performed in parallel: one without DA (CTL experiment) and the other with assimilating radiosonde observations from the Araon (DA experiment) to assess effects of the assimilation of additional observations on forecasts over the Arctic region.

3. Results and discussion

3.1 Evaluation of analyses

In order to check whether radiosonde observations are assimilated successfully, O-B (observation minus background) and O-A (observation minus analysis) statistics from all DA cycles are investigated. Root mean square (RMS) of O-A is always smaller than RMS of O-B for all variables (i.e. zonal/meridional wind, temperature, and water vapor) and cycles, which implies radiosonde observations are properly assimilated using the 3D-Var method (Fig. 2).

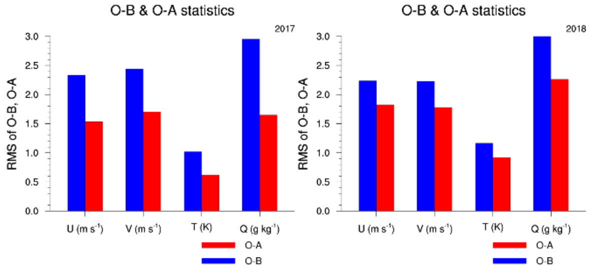

Fig. 2 RMS of O-B (blue) and O-A (red) averaged over all DA cycles for zonal wind (m s^{-1}), meridional wind (m s^{-1}), temperature (K), and water vapor mixing ratio (g kg^{-1}). Water vapor mixing ratio is multiplied by a factor of 10 for plotting with the other variables. O-B and O-A statistics for 2017 (left) and 2018 (right) are shown.

3.2 Verification of forecasts against reanalysis data

5-day forecasts from all fourth cycles are verified against European Centre for Medium-range Weather Forecasts (ECMWF) ERA Interim reanalysis data. Although there can be some errors over the Arctic region in ERA Interim reanalysis, ERA Interim reanalysis can be considered to be close to truth because all available observations are assimilated with sophisticated DA method. The following variables are verified: SLP, 2-m temperature, 10-m wind, and temperature/geopotential height/wind at 850/500/200 hPa. Errors are computed for regions north of 70°N.

Root-mean-square-errors (RMSEs) of SLP for CTL and DA experiments and differences between the two experiments as a function of forecast length are shown in Fig. 3. Errors increase with increasing forecast length in both experiments. Although the difference in SLP error between CTL and DA experiments is not large (i.e. statistically insignificant), RMSEs of DA experiment are smaller than those of CTL experiment and this feature lasts for about 72 (120) hours for 2017 (2018) cases. The same characteristics are observed for the other variables, except for 2-m temperature and 850-hPa temperature. Variation of temperature error shows a diurnal cycle, and it seems that errors of temperature variable are dominated by deficiencies of physical processes, rather than uncertainties of initial conditions.

3.3 Verification of forecasts against Araon ship observations

In addition to radiosonde observations, atmospheric variables such as temperature, relative humidity, wind, and radiative fluxes are also observed on the Araon. Because these observations are not assimilated, they can be used for verification as independent observations. Forecasts are verified against observations taken from instruments on board the Araon. Errors of SLP, 2-m temperature, 2-m relative humidity, and 10-m wind are calculated (Fig. 4).

Forecast improvements (i.e. differences in error between the two experiments) when verified against Araon observations are larger than those when verified against reanalysis, especially for 2017 cases.

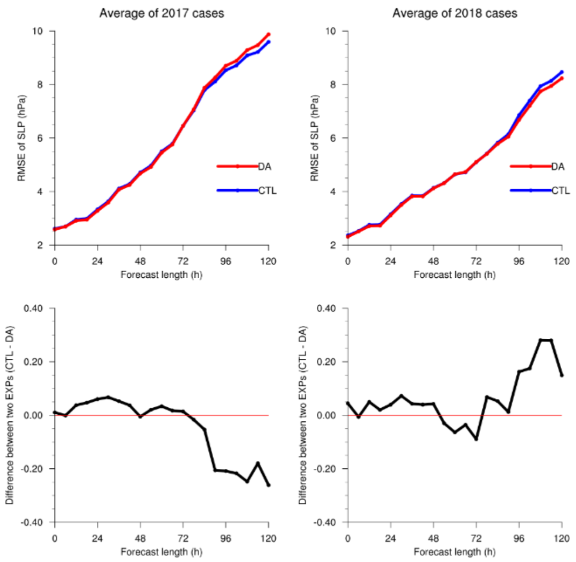

Fig. 3 RMSEs of SLP for CTL (blue) and DA (red) experiments and differences (black) between the two experiments as a function of forecast length. Results for 2017 (left) and 2018 (right) are shown.

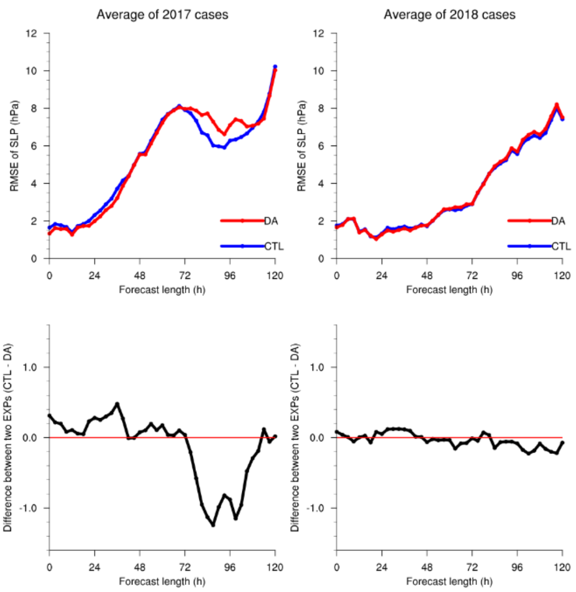

Fig. 4 Same as Fig. 3 except for verified against Araon observations.

3.4 Verification of forecasts against buoy observations

Observational data collected by the International Arctic Buoy Program (IABP) can provide pressure and temperature information over the Arctic Ocean, and they can be used as independent observations for verification. Geographical locations of IABP buoys available in 2017 and 2018 are shown in Fig. 5. Note that only observations from buoys north of 70°N are used for verification.

Figure 6 shows Mean Absolute Errors (MAEs) of surface pressure for CTL and DA experiments and their differences as a function of forecast length. Through the assimilation of additional radiosonde observations from the Araon, errors of DA experiment are less than those of CTL experiment up to approximately 24 hours for both years, and for 2018 cases, positive effects of DA last for at least 120 hours. Forecast improvements in DA experiment when verified against buoy observations are greater than those when verified against ERA Interim reanalysis, and this implies effects of DA are larger over areas where conventional observations are relatively sparse (i.e. continent vs. ocean).

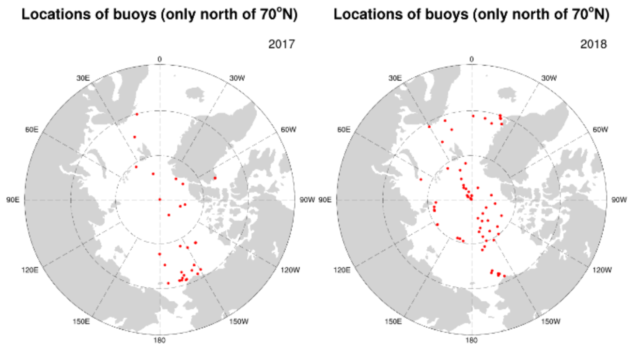

Fig. 5 Geographical locations of IABP buoys for 2017 (left) and 2018 (right).

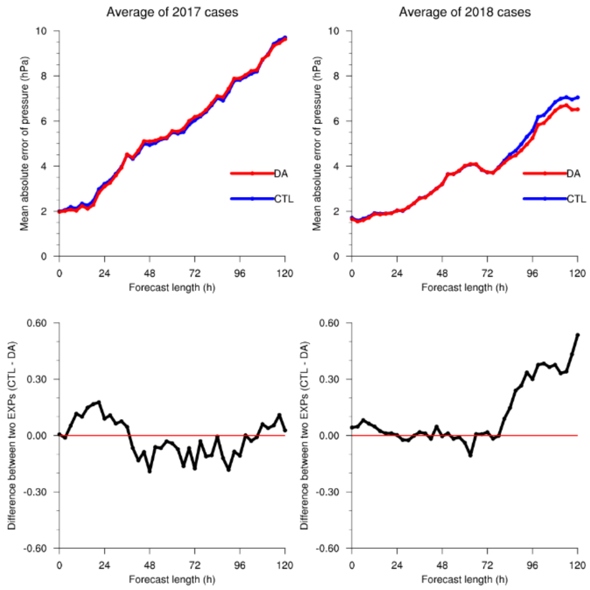

Fig. 6 Mean absolute errors (MAEs) of surface pressure for CTL (blue) and DA (red) experiments and their differences (black) as a function of forecast length. Results for 2017 (left) and 2018 (right) are shown.

4. Summary and conclusions

Radiosonde observations from the Araon are assimilated using the 3D-Var method in DA experiment, and analyses/forecasts of the DA experiment are compared to those of the CTL experiment (without DA) to investigate the impact of the assimilation of additional observations on analyses/forecasts over the Arctic region. From O-B and O-A statistics, it is concluded that radiosonde observations are successfully assimilated at all DA cycles.

Forecasts from all fourth DA cycles are verified against ERA Interim reanalysis, Araon ship observations, and IABP buoy observations. Overall, the assimilation of additional radiosonde observations leads to improved analyses, and these improved analyses result in reduced forecast errors although the magnitude of improvements is not large (i.e. statistically insignificant). Positive effects of DA last for approximately 72 hours for 2017 cases, and in 2018, forecast improvements are observed even for 120-h forecasts. Reduction in forecast errors is more significant over areas where conventional observations are relatively sparse.

In order to make use of additional, but limited observations efficiently, more sophisticated DA methods such as ensemble Kalman filter (EnKF) and hybrid methods will be tested. In those methods, flow-dependent background error covariance can spread observed information more appropriately both in horizontal and vertical directions. In addition, balloon drift information (i.e. horizontal location and elapsed time) will be utilized through the use of 4D-Var method. Finally, sensitivity experiments of physical schemes will be done to assess errors of thermodynamic variables, which may be related to diurnal cycle, energy budget, and so on.

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