Validation of Atmospheric Reanalyses Against Tethersonde Data from the Central Arctic Ocean in Spring and Summer 2007

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The structure and processes in the atmospheric boundary layer (ABL) over the ice-covered Arctic Ocean is quantitatively not well known. Detailed observations have been made only during ship and aircraft campaigns and ice stations. At the drifting ice station TARA, from 25 April to 31 August 2007, total of 95 tethersonde soundings during 39 sounding days were made. A Vaisala DigiCORA Tethersonde System was used to measure the vertical profiles of the air temperature, relative humidity, wind speed, and wind direction up to the height of 2 km. The average top height of the soundings was 1240 m. For this study, 29 profiles up to 890 m were selected.

Tara tethersonde sounding data were not sent to the GTS network of the WMO. The data therefore provides a rare possibility for validation of atmospheric model reanalyses against an independent data set. The following reanalyses were validated against TARA sounding data:

* ERA-Interim;
* JCDAS JMA;
* NCEP-DOE;
* NCEP-CFSR;
* NASA-MERRA.

The reanalysis products were horizontally linearly interpolated to TARA sounding sites. In the vertical, the reanalysis results were linearly extrapolated from the model levels (from 2 levels of NCEP-DOE to 9 levels of ERA-Interim) to the sounding levels. In addition, the reanalysis products for 2 m temperature and humidity and 10 m wind speed were validated. For all variables, the bias (model value minus observation), root mean square error (RMSE) and correlation coefficient R against observations were calculated.

Measurement period average temperature was at 10 m level –4 °C. A temperature inversion was based at 70 m with the temperature increasing from –4.2 °C to –2.8 °C by the height of 890 m. The shape of temperature profile was best captured by the ERA-Interim; only in the lowermost 300 m a warm bias of up to 2 °C appeared. The NCEP-CFSR was very good below 200 m, but had a cold bias in higher altitudes, up to 2 °C, supposedly caused by problems in capturing temperature inversions. MERRA average temperature profile had warm bias below 400 m up to 2 °C similarly to ERA-Interim and cold bias less than 0.5 °C above. JCDAS gave a linear temperature gradient –5 °C /1000 m that disagree with the measured profile. Correlations between models and observed temperature were high, with average in ERA-Interim and NCEP-DOE even R = 0.95. Single profiles of JCDAS and NCEP-DOE models differ from the measured profiles even more than 10 °C. Higher positive errors occurred in spring with measured ground level temperatures about –15 °C. Higher negative errors occurred in summer during strong temperature inversions. Extreme errors in temperature concurred with higher wind speeds.

The average specific humidity was from 2.7 g/kg to 2.9 g/kg in the whole profile. Average relative humidity decreased from 90 %RH at ground level to 75 %RH at 900 m. The specific humidity profile was best captured by NCEP-CFSR, with mostly dry bias of up to 0.3 g/kg. As there was wet bias in whole NCEP-CFSR relative humidity profile, up to 8 %RH, specific humidity dry bias is clear result of the cold bias in the NCEP-CFSR model. ERA-Interim followed very well the shape of the observed specific humidity profile, but with a wet bias of 0.3 – 0.5 g/kg. ERA-Interim relative humidity had wet bias in the whole profile, up to 9 %RH. MERRA specific humidity had small wet bias at 10 m but at higher levels the bias turned dry and increased to 0.5 g/kg. MERRA relative humidity had dry bias about 6 %RH in the whole profile. JCDAS and NCEP-DOE average humidity profiles were tilted with a wet bias 0.6 g/kg at models first level to dry bias 0.2 g/kg at the sounding top level. Correlations between models and observed specific humidity were high, between 0.7 and 0.95 with best results by NCEP-CFSR and ERA-Interim with average R = 0.9. The high correlation is mostly produced by generally low humidity in April and May, compared to summer months. Correlations between models and observed relative humidity were smaller, averagely R = 0.3. Higher positive errors in the single specific humidity profiles, even more than 3 g/kg, occurred with ERA-Interim. Higher negative errors in specific humidity, less than –2 g/kg, occurred with NCEP models that can be explained with strong, 8 °C, temperature inversions that were not captured by the models.

The average wind speed was at ground level 3.2 m/s and increased rapidly to 5.6 m/s at 130 m. Above this altitude the wind speed was steadily varying between 5.6 m/s to 6.2 m/s. At 10 m, most models showed too high average wind speed, but above 100 m, models average wind speed was too low in all models. Wind speed profile was best captured by ERA-Interim and JCDAS with mostly negative bias smaller than 0.6 m/s. NCEP-DOE underestimated wind speed by 1 m/s and NCEP-CFSR by 1.7 m/s at all models levels above ground level. MERRA average wind speed was close to the measured one below 200 m, but underestimated it at higher levels by up to 1.2 m/s. Correlation between models and observed wind speed was highest in ERA-Interim (averagely $R = 0.7$) and worst in MERRA ($R < 0.5$ below 500 m and even $R < 0.2$ above). Maximal errors of single profiles exceeded even 5 m/s in NCEP-CFSR and MERRA models. Larger positive errors concurred with calm weather, larger negative errors usually with stronger temperature inversions.

In conclusion – there is no model that performs best in all variables and layers. All models had problems in some parameters, supposedly due to lack of in situ measurement data and inappropriate description of the boundary layer physics. This validation against independent dataset brought out strengths and weaknesses of major atmospheric reanalyses. According to this validation, NCEP-CFSR outperformed other models at ground level in all parameters and in specific humidity in the whole profile. ERA-Interim worked best at higher levels in temperature and wind speed. Also, ERA-Interim had highest correlations with observations in all variables.

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