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Editorial: Recent advances in climate reanalysis

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Editorial on the Research Topic
Recent advances in climate reanalysis

Climate reanalysis is a dynamically consistent dataset produced by the combination of observations and a dynamical model through a mathematical method called data assimilation (DA, Kalnay et al., 1996; Carrassi et al., 2018). The reanalysis is highly important for the climate research community. It can be used for the evaluation of historical model simulations, the understanding of climate change and its impact, the study of climate variability and teleconnections, and the initialisation and validation of climate predictions.

As of today, most climate reanalyzes are either atmospheric reanalyzes (e.g., ERA5, Hersbach et al., 2020) or oceanic reanalyzes (e.g., ORAS5, Zuo et al., 2019), and are produced with models without atmosphere-ocean coupling. Such reanalyzes can achieve a high degree of accuracy, but only in their respective domain of the climate system. Coupled reanalyzes [e.g., CERA-20C (Laloyaux et al., 2018) and the NCEP Climate Forecast System Reanalysis (Saha et al., 2010)] are produced by models with atmosphere-ocean coupling and so account for coupled dynamics of the climate.

This special issue is to explore recent advances in climate reanalyzes. It collects six research articles consisting of new DA techniques (Shen et al.; Wang et al.) and novel observations for the reanalyzes (Brönnimann), new model system (Fujii et al.), reanalysis comparisons (Dunn et al.) and applications (Boer et al.).

Parameter estimation for the general circulation model (GCM) is typically performed jointly with state estimation and uses ensemble-based DA methods. Since the model parameters are often globally-uniform values, assimilating an enormous number of observations causes the accumulation of sampling errors and yields suboptimal parameter estimation. Shen et al. proposed a new parameter estimation method to handle this issue. In the new method, they assimilated all observations to estimate the states but a subset of observations that result in maximum total variance reduction to update the parameters. They tested the method in Lorenz-96 models and showed that it effectively estimates the model parameters and provides more accurate analyzes. The new method has the potential to be used in GCMs to efficiently improve model parameters and produce more accurate climate reanalyzes.

Sea surface temperature (SST) data is critical for climate reanalysis, e.g., from 1850 to the present. However, when using ensemble-based DA methods, the assimilation of SST data can degrade the reanalysis performance below the ocean mixed layer (Counillon et al., 2016). Wang et al. introduced vertical localization to assimilate SST data in an isopycnal coordinate ocean model. They empirically formulated three tapering functions from a long pre-industrial simulation. The tapering functions vary with the calendar month and the space and were tested in an identical framework within the Norwegian Climate Prediction Model (NorCPM, Bethke et al., 2021) over the period 1980–2010. Wang et al. found that vertical localization significantly mitigates the degradation and thus improves the reanalysis accuracy, e.g., in the North Atlantic and the North Pacific. Among the three tapering functions, a step function that updates until the last isopycnal layer for which a significant correlation between temperature and SST leads to the best performance.

Data rescue efforts (Brönnimann et al., 2018) are critical to improve the reanalysis and extend it backwards in time. Brönnimann used an off-line DA approach and assimilated additional observations (e.g., surface pressure, temperature, upper-air data and column ozone) into the Twentieth Century Reanalysis Version 3 (20CRv3, Slivinski et al., 2019) for three historical case studies (i.e., Europe in 1807, Sub-Saharan Africa in 1877/1878 and Europe in 1926/1927). They demonstrated that the additional observations led to a substantial improvement for 20CRv3. They also addressed the question of what time reanalyses can be extended back. They found that land-based information would be useful to extend a reanalysis back to 1781, although very little ship-based information is available over that period.

Since February 2022, a new global ocean DA system has been used by Japan Meteorological Agency (JMA) for operational seasonal predictions. The new system is composed of lower-resolution (non-eddy-permitting) and higher-resolution (eddy-permitting) subsystems and has been described in Fujii et al.. It employs the four-dimensional variational (4DVAR) method to update the temperature and salinity fields in the lower-resolution subsystem and downscales the update into the higher-resolution subsystem. Fujii et al. compared also 4DVAR to the three-dimensional variational (3DVAR) method in producing reanalyzes with the new system. They found that 4DVAR outperforms 3DVAR in reducing the bias and error of temperature along the thermocline and near the surface in the equatorial vertical section.

Climate reanalysis and observations are often used to study climate extremes. Dunn et al. provided comparisons between observation-based indices of temperature and precipitation extremes (HadEX3, Dunn et al., 2020) and extreme indices computed from six climate reanalyzes. They showed both HadEX3 and reanalyzes are useful to investigate the behavior of the extremes indices. For the extreme indices of temperature, all datasets agree well in most regions, even though issues are identified in some of the modern reanalyses. The advantage of reanalyses is the complete global coverage. However, HadEX3 is more closely linked to observations and has a longer temporal record. The datasets agree less in the extreme indices of precipitation. For the indices in assessing longer accumulation periods or more moderate extremes, the datasets agree better.

Boer et al. conducted an investigation on the differences between eleven reanalysis and station-based products of near-surface air temperature and then used these products for the assessment of the prediction skill of the Canadian Centre for Climate Modeling and Analysis forecasting system. They found considerable differences between products, which had impacts on the verification of the prediction, including the ensemble mean. Their analysis made the model developers and assessors aware of the differences that can arise when using different products for verification. This study motivated efforts to ensure a common dataset being used, for example, in decadal prediction projects. The implication is that one should use some consistent datasets when verifying decadal forecasting results.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

XW was employed by Axiom at NOAA/NWS/NCEP/EMC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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