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A Preliminary Examination of a Conventional EnKF Atmospheric Reanalysis

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1. Introduction

Atmospheric reanalyses can be optimized to produce the most accurate reanalysis by assimilating all observations including satellite observations. However, this type of reanalysis often shows discontinuities in various time series with the introduction of new satellite systems (*ex.*, Zhang *et al*. 2012). Another approach was taken by the 20th Century Reanalysis (Compo *et al*. 2011), the time series were made more homogeneous by only assimilating surface pressure observations. However, the cost of homogeneity is a less accurate reanalysis because much fewer observations were assimilated. The Climate Prediction Center (CPC) wanted a NCEP/NCAR Reanalysis (R1) replacement that would be between these two extremes. The replacement reanalysis had to have accuracy of R1, eliminate the gross artifacts from the introduction of various satellites and span from the 1950's to the present.

There is a hierarchy of reanalyses (few to more observations, potentially few to more artifacts caused by changes in the observational systems):

0) Observed SST is used to force an atmospheric model, *ex.* AMIP
1) Surface observations are assimilated, *ex.* 20th Century Reanalysis (surface pressure), ERA-20C (surface pressure and surface winds)
2) Conventional observations (non-satellite) observations are assimilated, *ex.* JRA-55C
3) Conventional and satellite observations are assimilated, ex. R1, ERA-interim, MERRA2, JRA-55
4) Conventional, satellite and marine observations are used in a coupled atmospheric-ocean assimilation system, *ex.* CFSR

Can we replace R1 with a conventional-observation based reanalysis and satisfy the accuracy requirements? To answer this question, we ran several decades with a newly developed analysis system, CORe.

2. Details of CORe (Conventional Observation Reanalysis)

The CORe system is an ensemble-Kalman-filter atmospheric data assimilation system (Jeff Whitaker *et al.*, CDWP 2016). The system uses an 80-member ensemble using a recent version of the T254 L64 semi-Lagrangian GFS model (NCEP's Global Forecast System). The CORe was run from 1950 to mid-2010 in 6 streams using a 1 year overlap between the streams. CORe assimilated conventional observations, cloud track winds, and GPS-RO (COSMIC) data. The last two items use satellite data but they are relatively insensitive to the biases in the satellite sensors. (GPS-RO is based on timing information and should not suffer from biases in the radiance measurements. The cloud track winds use radiance for the height assignment but a 0.5 degree Celsius error will only give a 51 m height error assuming an adiabatic lapse rate.)

3. Evaluation of CORe in the mid-latitudes

A common method of evaluating the performance of a data-assimilation system is to find the skill of a forecast run from the analyses. Figure 1 shows the anomaly correlation of the 5-day 500 mb height forecast

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in the Northern Hemisphere. The red line shows that the R1 anomaly correlation starts at 0.5 and reaches 0.72 at the end of the time series. The multicolored line shows the skill of the various streams of CORe which starts at 0.62 and ends at 0.82. For the period, the forecasts using the CORe model from the CORe analyses as initial conditions were superior the R1 forecasts using the R1 analyses.

Figure 2 is similar to Fig. 1 except it is for the Southern hemisphere. The Southern hemisphere is expected to be more difficult for CORe because there are fewer conventional observations and R1 assimilates satellite data. R1 has much higher forecast skill in the first 6 years and roughly the same skill in the last decade. We speculate that the R1's skill in the first 6 years is artificial, caused by a lack of Southern hemisphere observations in the early period. Assuming the skill is artificial, CORe was similar or better than R1 in this case. The behavior in the last 7 years is examined in more detail in the section, "Unusual Behavior".

The forecast skill scores are suggestive but not proof that CORe analyses are better than the R1 analyses. The CORe forecasts were done using a much better model. For example, the CORe model had 4x the horizontal resolution (T254 *vs.* T62) and 2.3x the vertical resolution (64 levels *vs.* 28 levels). In addition, the CORe model is based on a 20-year newer version of the NCEP global model. So some of the improved skill is undoubtedly from the improved CORe model.

Another approach is to assume that a modern reanalysis that assimilates conventional and satellite data is the "truth". For "truth", we will be using the well-regarded ERA-interim. The red line in Fig. 3 shows the anomaly correlation of the monthly mean 500 mb height of CORe and ERA-interim for 30°-60°N. The green line is similar to the red line except it shows the anomaly correlation of R1 and ERA-interim. Most of the time, the red line is higher than the green line showing that CORe more resembles ERA-interim than R1. The difference between the red and green lines is shown by the difference between the blue and horizontal black lines.

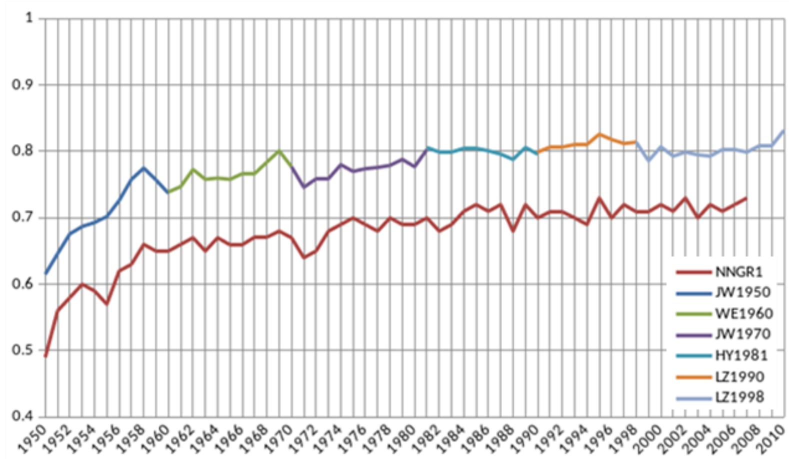

Fig. 1 Anomaly Correlation of Northern Hemisphere 500 mb height 5-day forecast (see text for details).

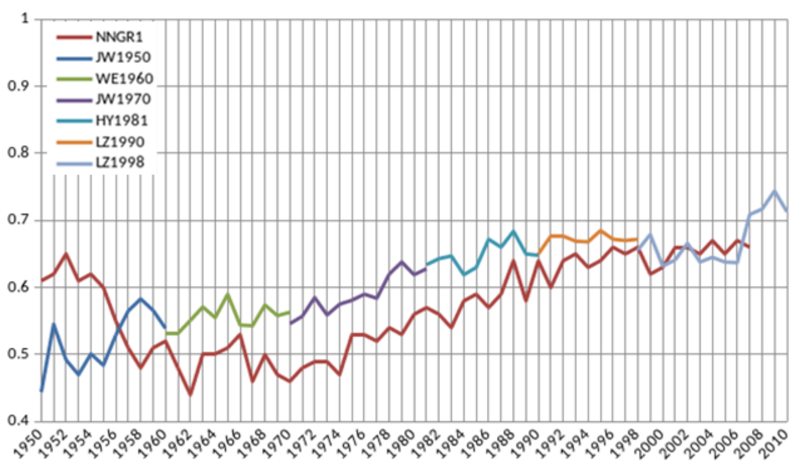

Fig. 2 Same as Fig. 1 but for Southern Hemisphere.

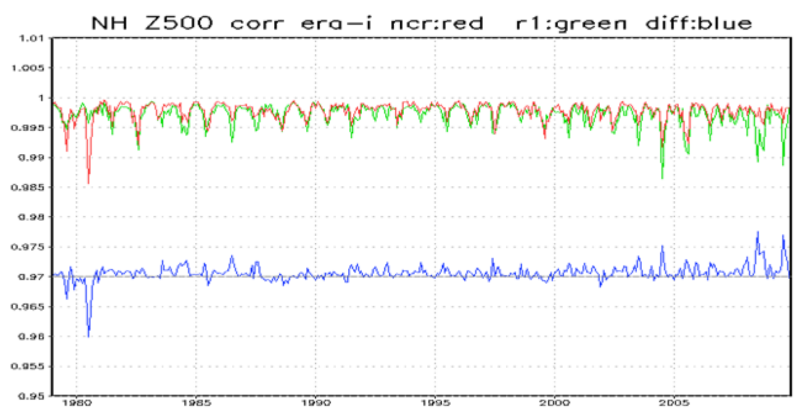

Fig. 3 Northern Hemisphere monthly mean 500 mb height anomaly correlation of CORe and ERA-interim vs. R1 and ERA-interim (see text for details).

There is an unusual dip in the CORe skill in the early 1980's. In this period, the various analyses shows some uncertainty. For example, if you correlate CORe and the MERRA1 reanalyses, you do not get the dip and CORe more resembles MERRA1 than R1 resembles the MERRA1 for period of the dip.

Figure 4 is similar to Fig. 3 except it for the Southern Hemisphere (60°-30°S). Both R1 and CORe have high correlations but not as high as in the Northern hemisphere. More often than not, CORe is closer to ERA-interim than R1 is to ERA-interim. The 2000-2007 period is an exception.

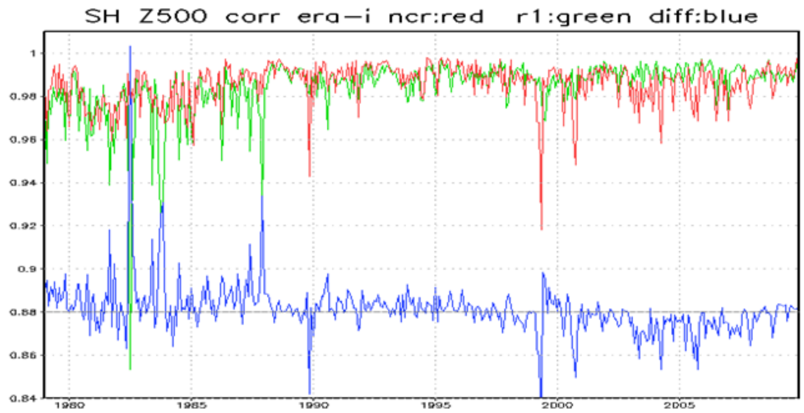

Fig. 4 Same as Fig. 3 but for Southern Hemisphere (60°-30°S).

4. Evaluation of CORe in the tropics

Figure 5 is like Fig. 3 except it shows the anomaly correlation for the 500 mb temperature in the 20°S-20°N band. The improvement by CORE is about 0.1 (blue line – black line) even though R1 assimilated satellite temperature retrievals. CORe's improved skill may be from a better model: higher resolution, modeled vs diagnostic clouds and better moist parameterizations.

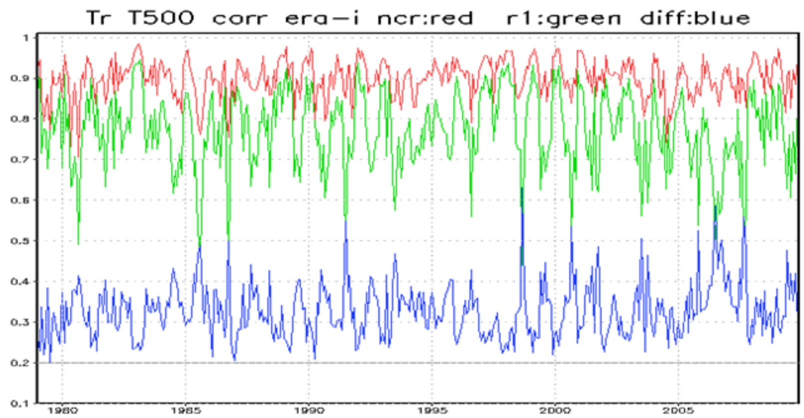

Fig. 5 Same as Fig. 3 but for 500 mb temperature in the tropics.

Figure 6 is like Fig. 5 except it is for the 200 mb zonal wind. Generally CORe did better than R1. The skill scores of CORe showed a smaller drop in the early period than R1. This suggests that CORe is better at handling low observation densities.

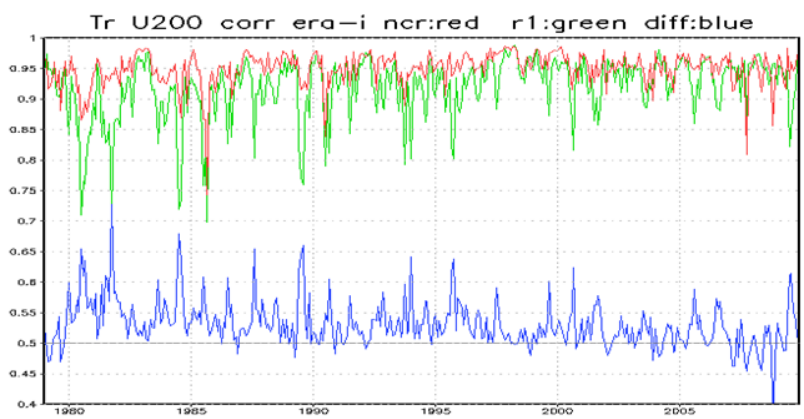

Fig. 6 Same as Fig. 5 but for 200 mb zonal wind.

5. Evaluation of CORe in the stratosphere

Modern stratosphere analyses are heavily influenced by the satellite observations because aircraft and many sondes don't go higher than the lower stratosphere. However, the stratospheric fields tend to smoother than their tropospheric counterparts, so an advanced system may not need as many observations to make a good analysis. Figure 7 is like Fig. 6 except for the tropical 50 mb zonal wind. CORe's anomaly correlation is about 0.15 better than R1 (blue line – black line). CORe's hybrid pressure-sigma vertical coordinates and ensemble Kalman filtering system may be the major factors for the improvement of CORe.

Figure 8 is like Fig. 7 except for the 60°-30°S band. Even though there are few sonde stations in the 60°-30°S band, CORe was usually more skillful than R1.

6. Unusual behavior

This is the first long-term test of the CORe system, so it expected that some problems would be found. Zhang (CDPW 2016) shows some problems. We also found that some of the tropical radiative fluxes were off, suggesting that the forecast model needed to be retuned for the T254 resolution. Some of the skill scores shows some artifacts. Figure 9 is like Fig. 4 (SH 500 mb height) except for using 00Z daily analyses and using JRA-55 instead of ERA-interim. The plot shows that the CORe skill rapidly declines (7/2000) and recovers (8/2007). Perhaps some erroneous data slipped through the QC.

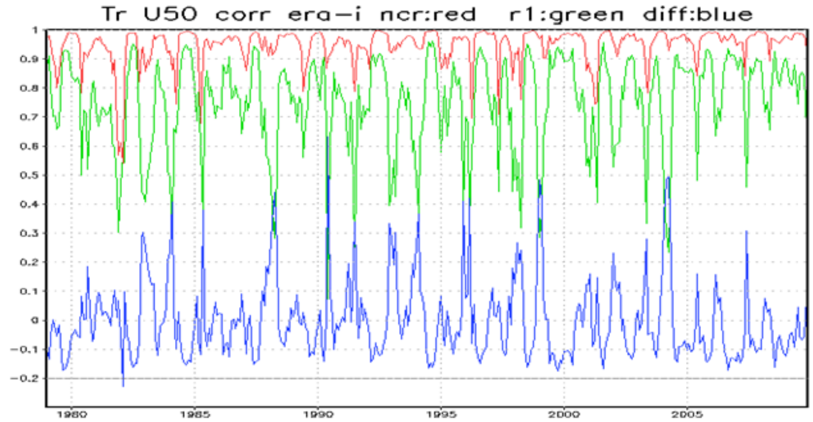

Fig. 7 Same as Fig. 6 but for tropical 50 mb zonal wind.

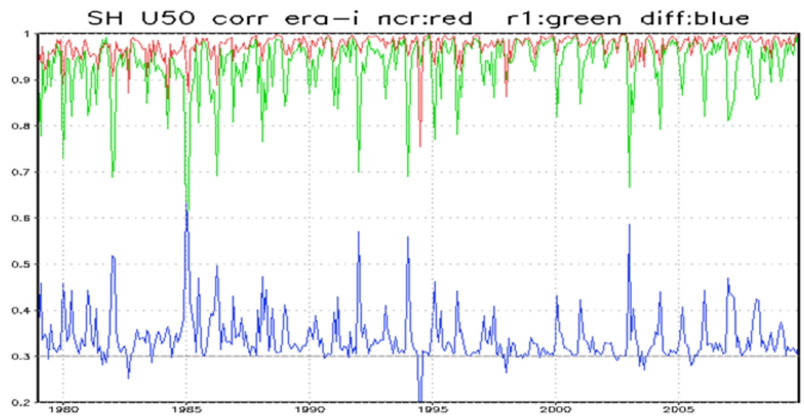

Fig. 8 Same as Fig. 7 but for Southern Hemisphere 60°-30°S band.

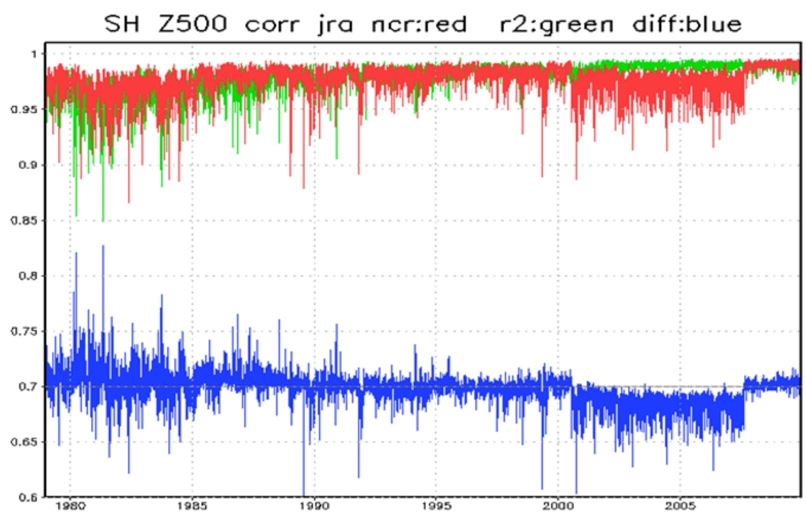

Fig. 9 Same as Fig. 4 but for using 00Z daily analyses and using JRA-55 instead of ERA-interim.

7. Summary

A mostly conventional observation based reanalysis is attractive because it eliminates the "climate shifts" caused by new satellites. CORe demonstrates that such an analysis can have similar or better skill than R1. The "unusual behavior" is probably caused by something in the assimilated observations. These observations need to be identified and removed if erroneous.

References

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