Trends from Reanalyses: Progress over the last 10 years

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ABSTRACT

1. Introduction

The current global atmospheric reanalyses of 2022 from European Centre for Medium-Range Weather Forecasts (ECMWF), Japan Meteorological Agency (JMA), NASA, and the National Centers for Environmental Prediction (NCEP) are compared with reanalyses from systems that were available in 2012. We found that three of the modern reanalyses demonstrated similar trends in many of the large-scale averages. The consistency of the 2012 reanalyses was weaker, and could not resolve the expected anthropogenic forcing.

2. Data and Methods

The monthly means were analyzed from:

- CFSR (Climate Forecast System Reanalysis): Saha et al (2010)
- CORe (Conventional Observation Reanalysis): Ebisuzaki et al (2021)
- ERA-5 (ECMWF Reanalysis version 5): Hersbach et al (2020)
- ERA-interim (ECMWF Reanalysis Interim): Dee et al (2011)
- JRA-25 (Japanese 25-year Reanalysis): Kazutoshi et al (2007)
- JRA-55 (Japanese 55-year Reanalysis): Kobayashi et al (2015)
- MERRA (Modern-Era Retrospective Analysis for Research and Applications): Rienecker et al (2011)
- MERRA2 (Modern-Era Retrospective Analysis for Research and Applications Version 2): Galero et al (2017)

NOAA's Conventional Observational Reanalysis (CORe) (Ebisuzaki, et al, 2021), has completed processing data for the years 1950-2020, and we are working towards making it an operational product. During the evaluation of CORe, we found significant improvements in how the reanalyses systems from 2022 compared with reanalysis systems that were current in 2012.

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Table 1: The leading global reanalyses for the 1979-2012 period, as of 2012.

Reanalysis System	Period of Record	Model Members
CFSR	1979-ongoing	NCEP, CFSv2 for 2010+
ERA-interim	1979-2019	ECMWF, replaced by ERA-5
JRA-25	1979-2014	JMA and CRIEPI, replaced by JRA-55
MERRA	1979-2016	NASA, replaced by MERRA-2

Table 2: The leading global reanalyses for the 1980-2021 period, as of 2022.

Reanalysis System	Period of Record	Model Members
CORe	1950-ongoing	NCEP, working to make it operational
ERA-5	1950-ongoing	ECMWF, 1950-1957 is preliminary
JRA-55	1958-ongoing	JMA, JMA is in production of a replacement
CFSR	1979-ongoing	NCEP, CFSv2 for 2010+
MERRA2	1980-ongoing	NASA

A researcher from 2012 could have produced Figure 1 using data available in 2012. The top plot shows the 500 hectopascal global temperature anomaly (degrees Celsius) for CFSR (red), ERA-interim (black), JRA-25 (green) and MERRA (blue) removing the 1981-2020 climatology. The bottom plot of figure 1 shows the same except it shows the difference from ERA-interim. Assuming the anthropogenic forcing is O (0. Order(0.1C) degrees Celsius per decade), then you can expect an anthropogenic forcing of O (0.3/33years) over the period covered by the plot. Since the reanalyses (bottom plot, fig. 1) show differences greater than 0.3, the individual reanalyses are not resolving the trend well.

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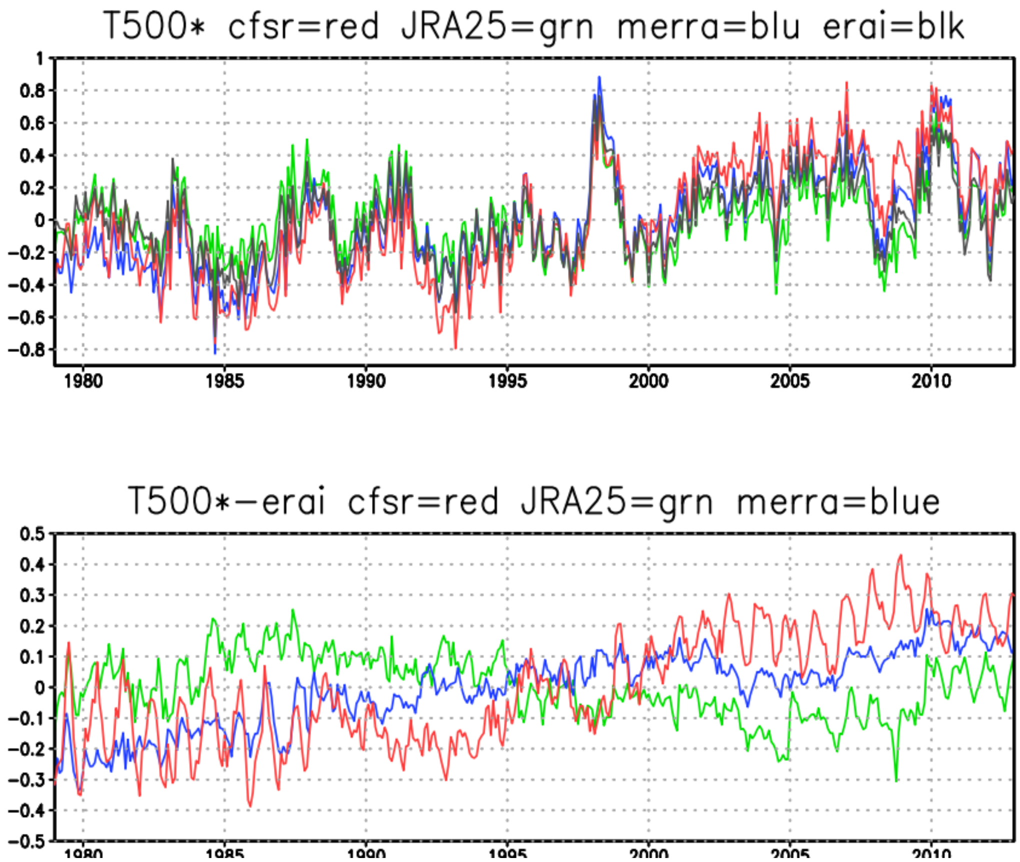

Figure 1: Top: Global mean 500 hectopascal temperature anomaly (degrees Kelvin) for CFSR (red), JRA-25 (green), MERRA (blue) and ERA-interim (black) using 1981-2010 climatologies. Bottom: similar to top except the time series are the deviations from ERA-interim anomalies.

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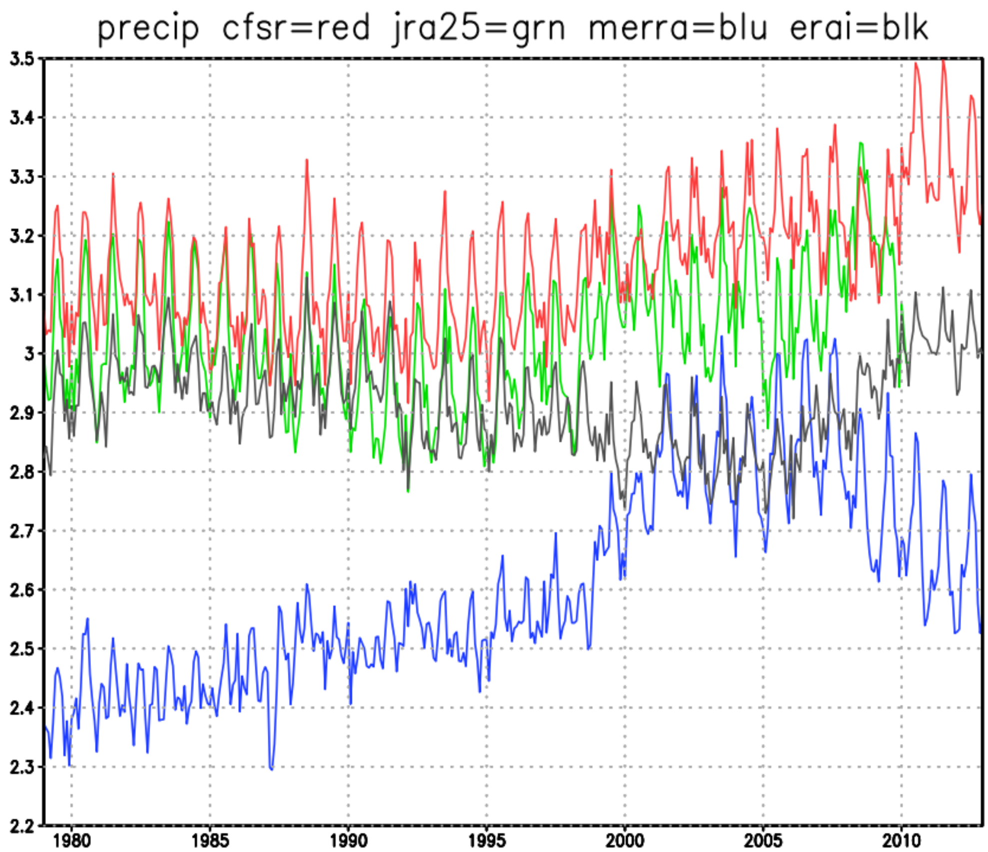

Figure 2: The global mean precipitation anomaly (millimeters/day) from CFSR (red), ERA-interim (black), JRA-25 (green) and MERRA (blue), removing 1981-2010 climatologies. The reanalyses from 2012 showed no consistency.

In 2022, the situation looks different. Figure 3 shows the difference in the 500 hectopascal temperature anomalies of CORe and ERA-5 (top plot, red), JRA-55 and ERA-5 (top plot, green), CFSR and ERA-5 (bottom plot, black) and MERRA-2 and ERA-5 (bottom plot, purple). As seen in the top plot of Figure 3, CORe and JRA-55 are within 0.1 degree Celsius of ERA-5. From the bottom plot of Figure 3, CFSR is within 0.5 degrees Celsius of ERA-5, and MERRA2 is within 0.3 degrees Celsius of ERA-5. The top plot shows that CORe, ERA-5 and JRA-55 are very consistent with each other. The bottom plot shows that older CFSR and MERRA-2 show more differences from the CORe/ERA-5/JRA-55 set of reanalyses as measured by the root mean square differences.

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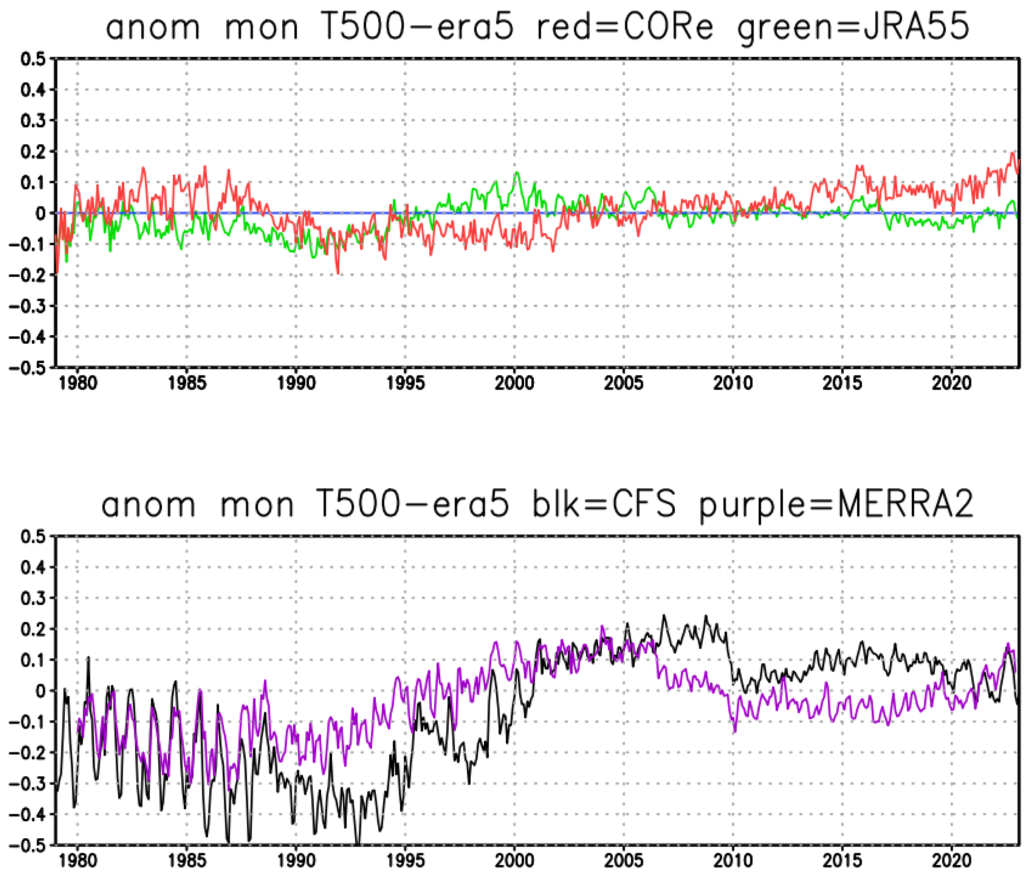

Figure 3: Top: global mean 500 hectopascal temperature anomaly for CORe (red) and JRA-55 (green) minus the corresponding ERA-55 values using 1991-2020 climatologies. Bottom: Similar to top except for CFSR (black) and MERRA2 (purple).

Figure 4 is similar to Figure 3 except it shows the global precipitation anomaly (millimeters per day). CORe (red), ERA-55 (blue) and JRA-55 (green) agree to 0.1 millimeters per day and show similar time series (top plot, Figure 4). The bottom plot shows that precipitation from CFSR (black) and MERRA2 (purple) are not as consistent as the newer reanalyses. For the rest of the figures, we will only consider CORe, ERA-5 and JRA-55.

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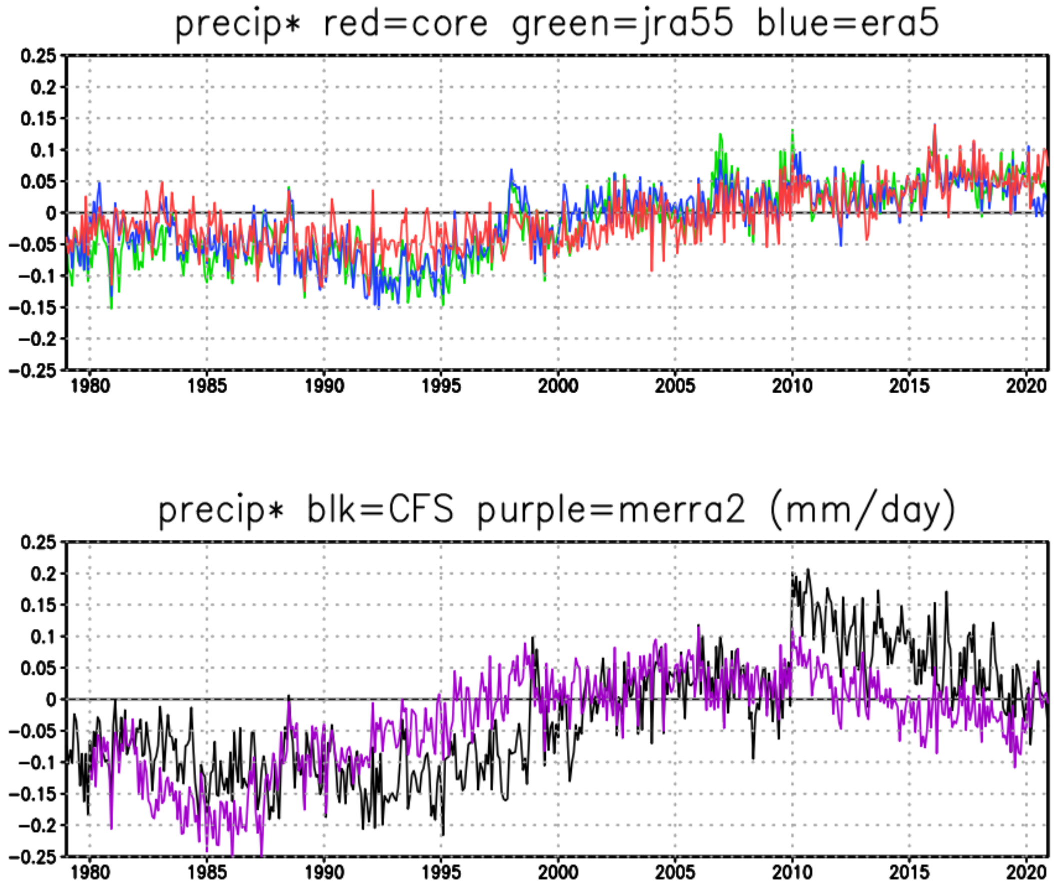

Figure 4: Top: global-mean precipitation anomaly for CORe (red), JRA-55 (green) and ERA-5 (blue) using 1991-2020 climatologies. Bottom: same as top except for CFSR (black), and MERRA2 (purple).

Figure 5 shows a smoothed global 500 hectopascal temperature anomaly from 1950-2020. For smoothing, a one year running mean was used. Note that the preliminary ERA-5 was used for 1950-1957. CORe (red), ERA-5 (black) and JRA-55 (green) agree very well in the later period. CORe and ERA-5 have difference up to 0.1 degrees Celsius, which occurred in the 1950's, so the three reanalyses have a consistent 500 hectopascal global temperature trend with differences that are much smaller than the expected anthropogenic forcing.

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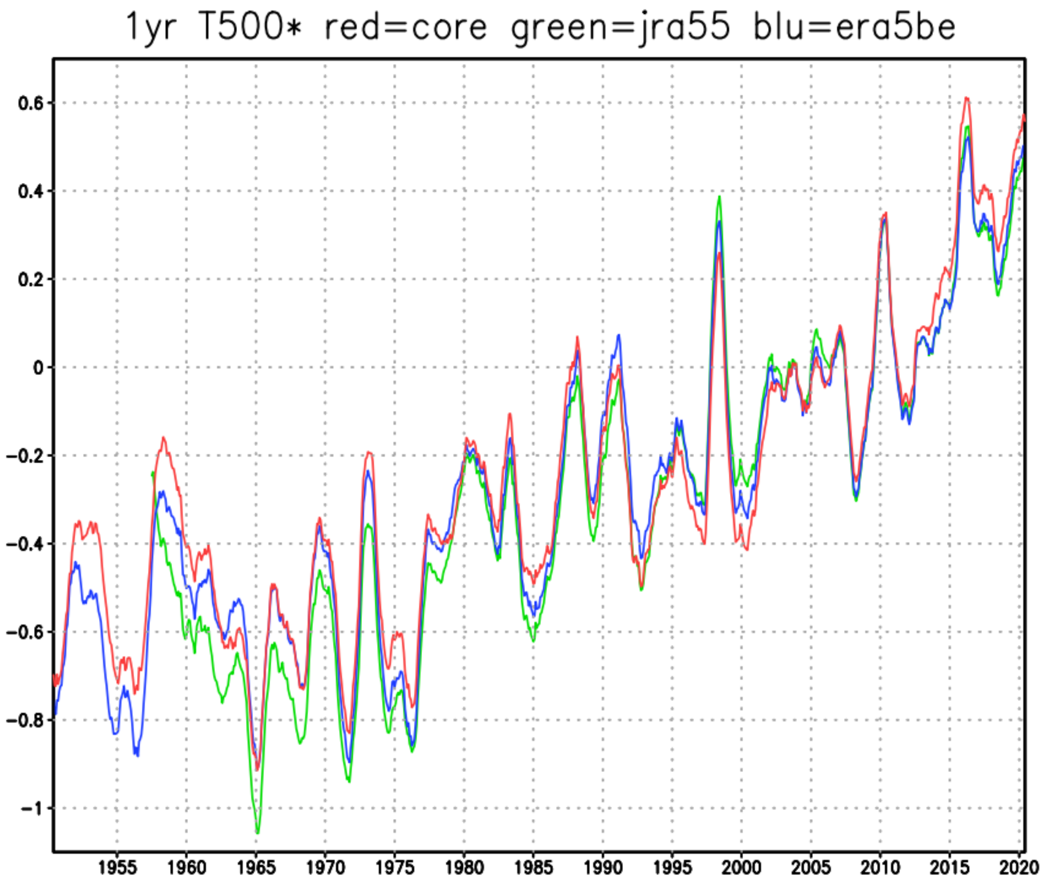

Figure 5: Global-mean 500 hectopascal temperature anomaly with a 1-year running mean smoothing for CORe (red), JRA-55 (green) and ERA-5 (blue). Used 1991-2020 climatologies, and ERA-5 used 1950-1957 preliminary analyses.

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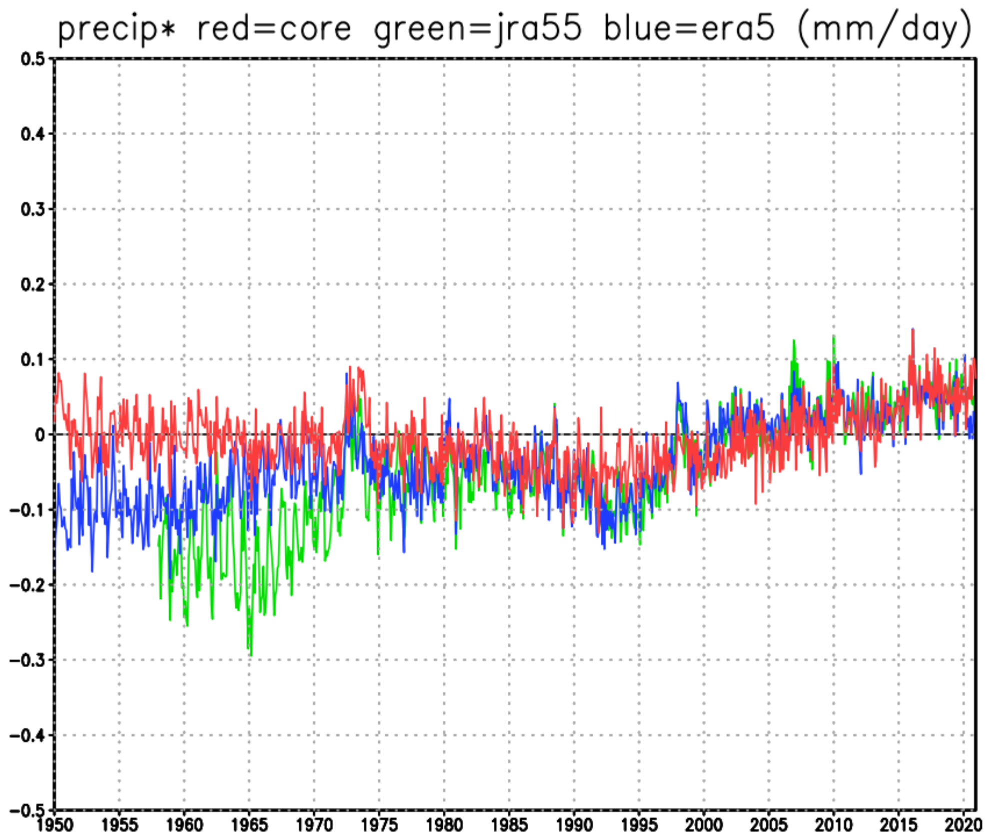

Figure 6: Global-mean precipitation anomaly for CORe (red), JRA-55 (green) and ERA-5 (blue) using 1991-2020 climatologies.

Figure 6 shows the global precipitation anomaly from 1950-2020 for CORe (red), ERA-5 (blue) and JRA-55 (green). From 1973 onwards, the three reanalyses show good consistency, with a slight increase in precipitation with time.

Figure 7 shows the globally averaged anomalous temperature as a function of time and pressure. There is much agreement in the troposphere. CORe is warmer in the early stratosphere; however, much of the warmth is coming from the poorly observed southern hemisphere.

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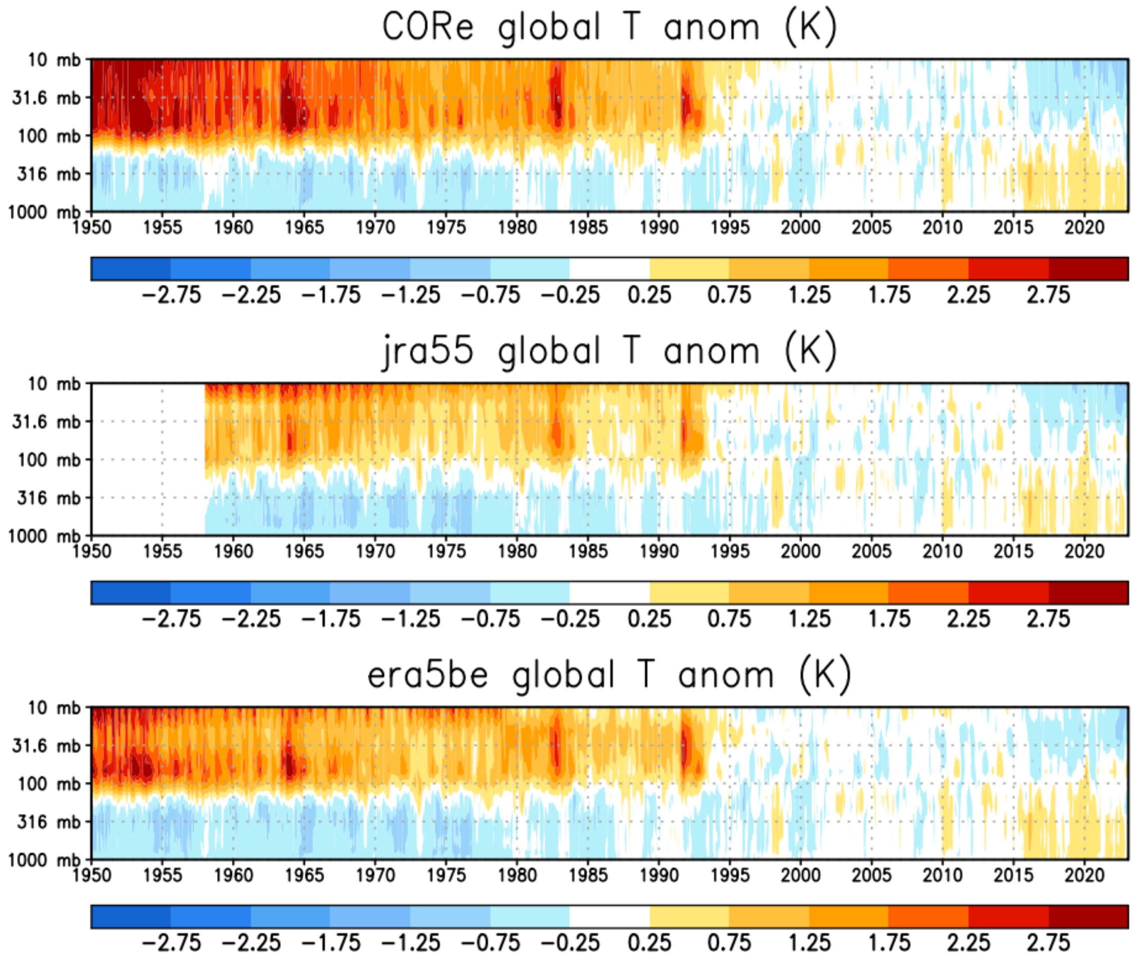

Figure 7: Global-mean temperature anomaly as function of pressure and time for CORe (top), JRA-55 (middle) and ERA-5 (bottom). Used 1991-2020 climatologies and ERA-5 1950-1957 preliminary analyses.

Figure 8 is similar to figure 7 but for 30 degrees North-60 degrees North, and from 20-2 hectopascals. 30 degrees North-60 degrees North was chosen because of there are more radiosondes in that latitude band. This plot shows that these reanalyses have some notable differences. For example, JRA-55 shows a warmth in the 2-4 hectopascal region in the late pre-satellite period. ERA-5 shows a cold anomaly in the 6-2 hectopascal region from 1967-1973 that is not seen in the other reanalyses. In the 10-20 hectopascal levels, the reanalyses have smaller root mean square differences.

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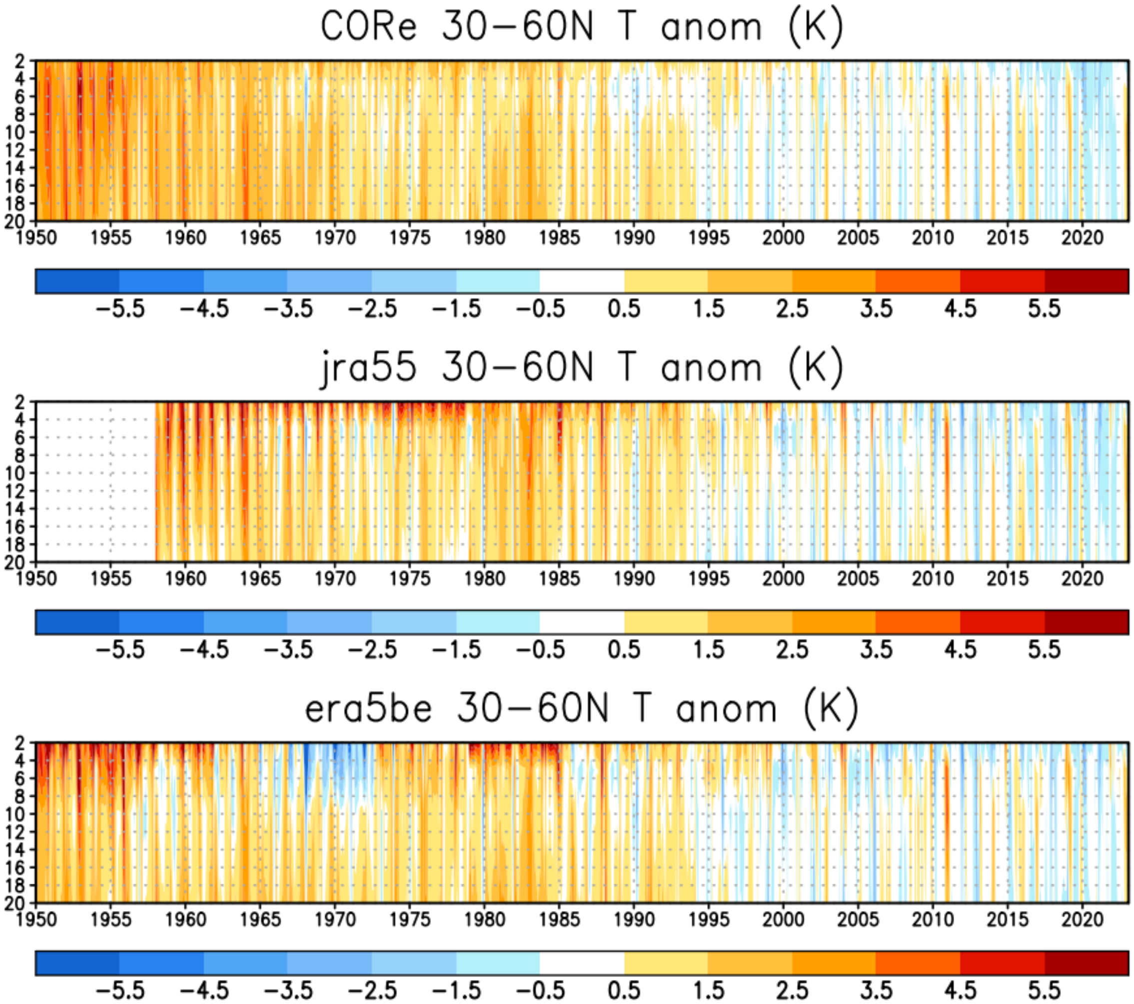

Figure 8: Similar to Figure 7, except for 30 degrees North-60 degrees North means, and 20-1 hectopascal levels.

3. Conclusion

Three out of 5 modern reanalyses (CORe, ERA-5, JRA-55) have a consistent trend of large-regional averages for many variables. They have different data assimilation systems (CORe: Ensemble Kalman Filter, ERA-5: hybrid 4D-var, JRA-55: 4D-var) and different treatment of satellite data (CORe: only AMV (Atmospheric Motion Vectors), ERA-5: all sky+AMV, JRA-55: clear sky+AMV). The three systems have different models, and quality control (QC) procedures. So, these newer reanalysis systems are quite varied. This suggests that the reanalyses have improved and are converging to a common trend. This improves the utility of the newer reanalyses to examine trends.

4. Data availability

CORe is in the public domain and data availability is being arranged. CFSR is in the public domain and is available from National Centers for Environmental Information (NCEI). ERA-interim and ERA-5 are available from the European Center from Medium Range Weather Forecasting (ECMWF) through Copernicus for ERA-5. JRA-25 and JRA-55 are available from the Japan Meteorological Agency

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(JMA). MERRA and MERRA-2 are available from the National Aeronautics and Space Administration, Goddard Space Flight Center (NASA/GSFC) by https://gmao.gsfc.nasa.gov/reanalysis/MERRA, and https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2.

5. References

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