An Assessment of Contemporary Global Reanalyses in the Polar Regions

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1. Introduction

The global atmospheric reanalyses (ERA-40, NCEP1 and NCEP2, and JRA-25) are powerful tools for climate analysis in the polar regions, mainly due to the low density of observations. The reliability of the reanalyses in the Arctic is far greater than that in the Antarctic, especially prior to the modern satellite era (post 1978). Bromwich and Fogt (2004) provide an extensive review of the performance of ERA-40 and NCEP1 in the middle and high latitudes of the Southern Hemisphere (SH). They find that ERA-40 demonstrates a strong dependence on satellite data in these regions, and that prior to 1979 correlations between ERA-40 2-m temperature, mean sea level pressure (MSLP), and 500 hPa geopotential height and observations during winter are low and even negative at times. For NCEP1, a marked erroneous trend exists in the winter MSLP fields, particularly in East Antarctica, that exists until the mid-1990s. This positive bias was first reported by Hines et al. (2000) and Marshall and Harangozo (2000). Bromwich and Fogt (2004) conclude that the reanalyses are not reliable in the *non-summer* months prior to 1979 in the middle and high latitudes of the SH; before this period they are likely more a reflection of their own model climatology than reality.

In comparison, a study by Bromwich and Wang (2005) find good agreement between the reanalyses and two independent rawinsonde data sets at the Arctic Ocean periphery for the late 1980s into the early 1990s. Their study finds that the reanalyses not only capture the circulation indicated by the high skill in the geopotential height, wind speed, and wind direction, but also the moisture variability. Bromwich and Wang (2005) compare the precipitable water vapor and specific humidity from the reanalyses and the rawinsonde archives, and demonstrate that the reanalyses have only small biases with a good representation of the overall observed moisture variability.

This paper presents a current examination of recent findings in the reanalyses' skill in the high latitudes. It stems largely from an April 2006 SCAR-funded workshop on the high latitude reanalyses held at the British Antarctic Survey. Due to space constraints, only certain deficiencies are highlighted. Interested parties are referred to Bromwich and Fogt (manuscript in preparation), which provides a more in-depth look at the reanalyses in the polar regions.

2. Pre-satellite era (1958-1978) vs. modern satellite era (1979-2001) comparisons

The adjustment to vast quantities of satellite data entering ERA-40 at the start of the modern satellite era creates a discontinuity in the area-weighted snow accumulation over Antarctica (Fig. 1), as first seen by van den Berg et al. (2005). Figure 1 shows that the jump is largest over the high interior (triangles, >3000m elevation), and represents changes of over 50% in these regions. The large quantity of satellite data entering ERA-40 at 1979 adjusts it to the Rossby longwave pattern over the Southern Ocean. In turn, this creates enhanced regions of poleward moisture flux after 1979, leading to the jump in Antarctic accumulation.

Cyclonic variability is also markedly different between the reanalyses before and during the modern satellite era in the SH. Using the cyclone tracking algorithm of Hoskins and Hodges (2002), Fig. 2 (provided by Kevin Hodges, University of Reading) presents the intensity and number of matched winter systems between

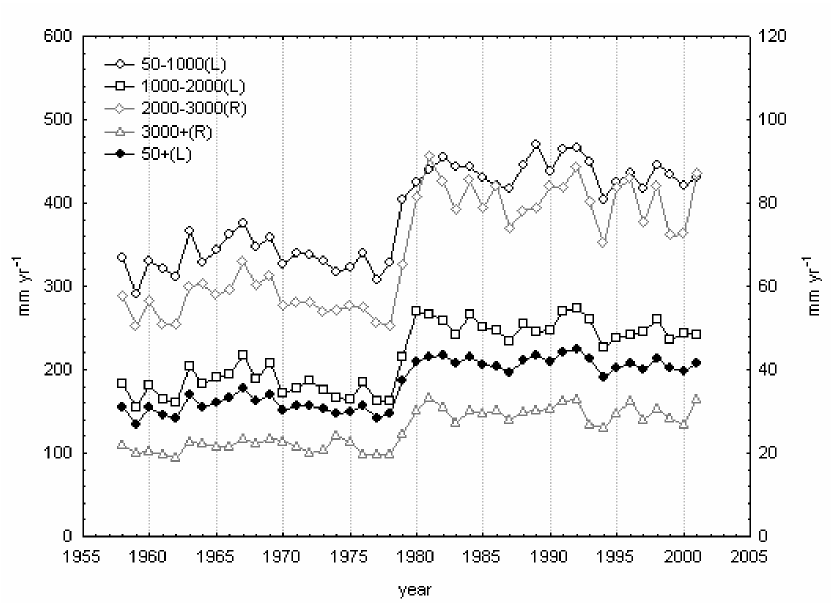

Figure 1. Annual mean area-weighted ERA-40 accumulation (precipitation minus evaporation) for various regions of Antarctica based on elevation. Key gives elevation band along with the vertical axis (L or R) that applies.

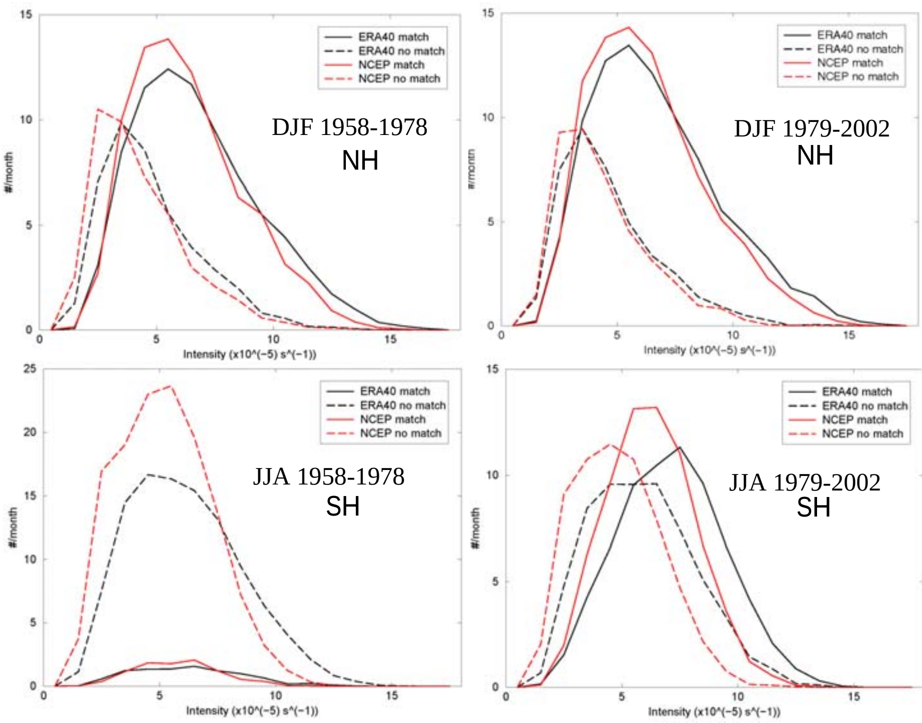

Figure 2. Mean winter cyclone intensity for 1958-1978 (left column) and 1979-2002 (right column) based on the number of matched systems between the reanalyses. Plots for the NH DJF are in the first row; plots for the SH JJA are in the second row. Black lines are for ERA-40, red are for NCEP1. Matched cyclones are indicated by solid lines and unmatched by dashed lines.

ERA-40 and NCEP1 before and after 1979. In the NH, only the weaker systems do not match and the reanalyses are in good agreement throughout all of 1958-2002. In the SH, however, few cyclones match before 1979. Even after 1979, the number and intensity of matched and unmatched systems is similar. The lack of matching prior to 1979 in the SH suggests that the tracked cyclones are functions of the model climatologies in the reanalyses.

3. Reanalyses comparisons during the modern satellite ERA, 1979-2002

3.1. The Antarctic

Although there is a large jump in the ERA-40 Antarctic accumulation at 1979, there are also significant differences between the precipitation trends in the reanalyses during the modern satellite era. Because of bias correction schemes that were still adjusting to the large quantity of satellite data, precipitation estimates from ERA-40 aren't reliable until 1985 (Adrian Simmons, personal communication 2006). Table 1 presents Antarctic precipitation minus evaporation (P-E) trends (with 95% confidence intervals) from ERA-40, NCEP2, and JRA-25 as seen in Monaghan et al. (2006); P-E closely resembles snow accumulation in Antarctica. Notably, all three trends are not statistically significant. However, they differ in sign, with only NCEP2 producing a positive trend. Monaghan et al. (2006) compared accumulation values from the reanalyses with Antarctic ice core data and find that ERA-40 best captures the magnitude and variability of accumulation over the continent. This comparison with ice core data also shows that JRA-25 produces excessive precipitation in the high interior of Antarctica.

Table 1 Antarctic P-E trends, 1985-2001, from the various reanalyses. Trends are calculated over the grounded ice sheet only. From Monaghan et al.(2006)

Reanalysis	Trend (mm yr^{-2})
ERA-40	-0.29 ± 0.62
JRA-25	-0.47 ± 0.88
NCEP2	-0.58 ± 0.74

3.2. The Arctic

Precipitation is also a challenging field for reanalyses to capture in the Arctic. Serreze et al. (2005) show that NCEP1 produces excessive summer precipitation over the Arctic landmasses (Fig. 3) compared to results from a blended gauge network. ERA-40 and the Global Precipitation Climatology Project (GPCP) biases are much smaller, with consistent performance throughout all months.

The reanalyses also handle clouds and their associated shortwave radiation passing through them quite differently in the Arctic. John Walsh, from the University of Alaska-Fairbanks, has examined the cloud and radiation variaibility in ERA-40 and NCEP1 compared with those measured at the Atmospheric Radiation Measurement (ARM) site at Barrow, Alaska (71^{o}N, 156^{o}W) for June 2001. The cloud fraction and downwelling shortwave radiation are presented in Fig. 4 for ERA-40 (Fig. 4a) and NCEP1 (Fig. 4b). Clearly ERA-40 does a much better job of predicting cloud variability,indicated by the good agreement between observed and the reanalysis value of cloud fraction. Notably, NCEP1 produces deficient cloud cover at this location, which leads to a large positive bias in the downwelling shortwave radiation. ERA-40 also has a marked positive bias in the downwelling shortwave radiation. However, this bias is related to the physical properties of clouds in ERA-40 (not shown). John Walsh has determined that ERA-40 simply allows too much shortwave radiation to pass through the modeled clouds unless at near-overcast conditions, thus creating the strong positive bias.

4. Summary and conclusions

The reanalyses perform much better in the Arctic than the Antarctic, and are reliable back until 1958. In the SH, they are only reliable during the summer prior to 1979; before this period they are likely more a reflection of their model climatology than reality. During the modern satellite era, differences still exist between the reanalyses, including cyclone characteristics and circulation differences in the Southern Ocean

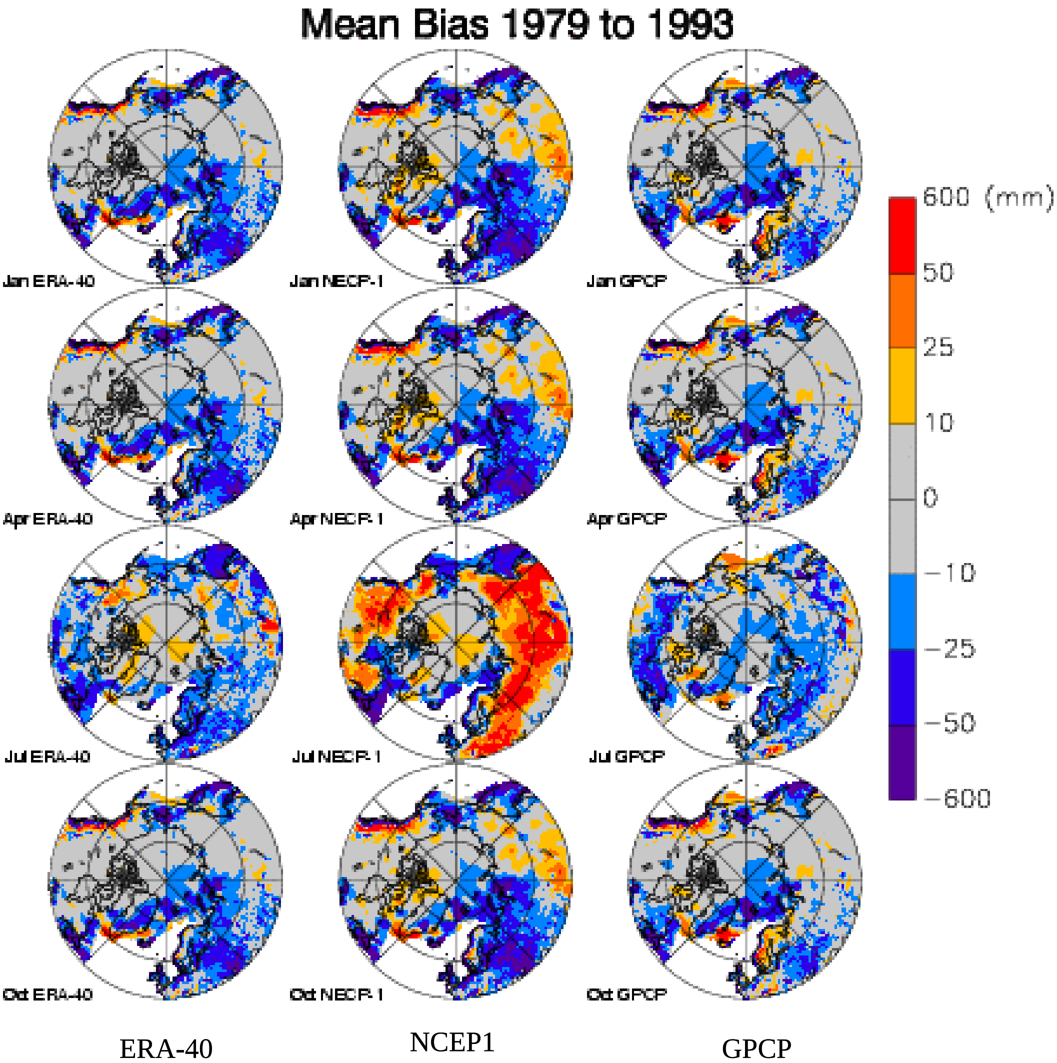

Figure 3 Mean bias (1979-1993) of accumulated precipitation (in mm) for January (first row), April (second row), July (third row), and October (last row) for ERA-40, NCEP1, and GPCP. Adapted from Serreze et al. (2005).

and Antarctica, differing precipitation trends and / or magnitudes in both hemispheres, and cloud variability and its associated impacts on the radiation in the Arctic.

Clearly, improvements need to be made to conduct reanalyses in the SH prior to 1979. Larger quantities of data need to be assimilated in the data sparse regions of the Southern Ocean and the interior of Antarctica to help guide the reanalysis. Roy Jenne, from the National Center for Atmospheric Research (NCAR), has suggested a few data sources to help in the SH:

- Data from pilot baloons, which have coverage over southern South America and the Antarctic Peninsula region back until 1949, and coastal Antarctic at the IGY
- Early satellite sounding data (SIRS, SRC), available from as early as 1969

- The use of "bogus" MSLP and 500 hPa height (like PAOBS) observations, 1950-1969, generated from analyses

Different assimilation schemes, one tuned to the modern satellite era, and another tuned to work in data sparse regions prior to 1979, might also be necessary to produce a reliable reanalysis product in these challenging areas. However, the benefits will be greatly worth the effort, as reanalysis products have been and will continue to be a valuable tool in these data sparse regions.

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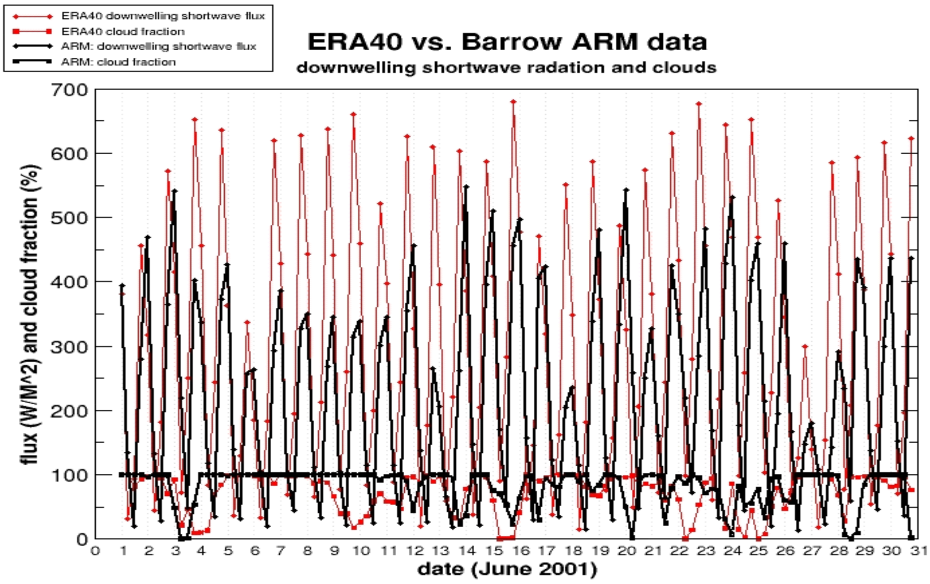

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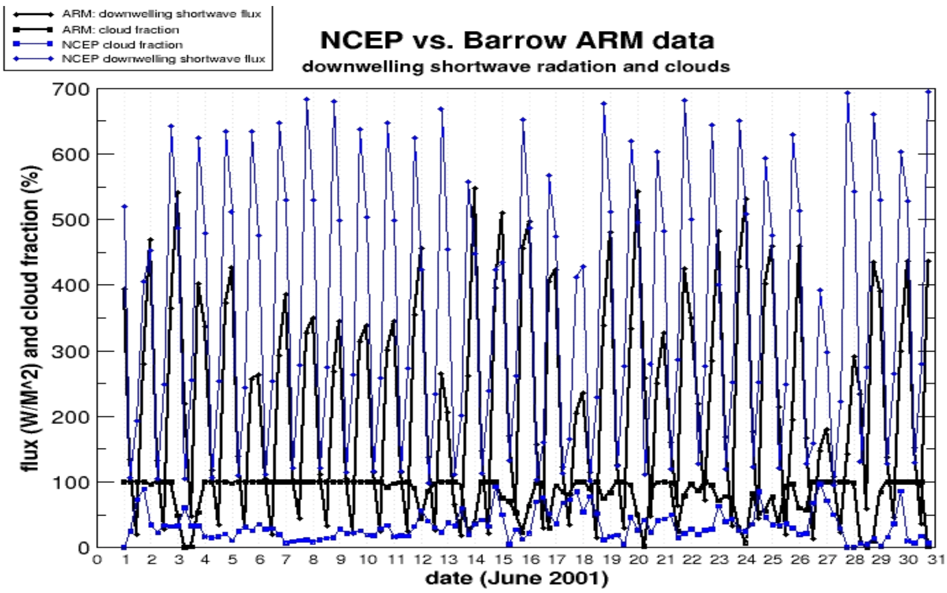

Figure 4 Observed downwelling shortwave radiation and cloud fraction data for Barrow ARM site during June 2001 compared with equivalent data from a) ERA-40 and b) NCEP1. Observed values are in black and reanalyses values are in color

Acknowledgments

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