Representation of Arctic Precipitation in ERA-40

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1. Introduction

It is increasingly recognized that the hydro-climatology of the Arctic plays an important role in the climate system. The freshwater budget of the Arctic Ocean is strongly influenced by river runoff and precipitation less evapotranspiration (P-ET) over the ocean itself. These freshwater sources influence salinity and sea ice conditions, which can impact on freshwater fluxes through the Fram Strait into the North Atlantic. The degree of surface freshening in the northern North Atlantic is thought to influence the production of deepwater and the thermohaline circulation. Changes in the terrestrial hydrologic cycle may alter soil moisture, impacting on plant communities. Arctic soils and wetlands are potentially significant sources of global carbon dioxide and methane. Fluxes appear to respond sensitively to altered soil moisture and temperature.

The Arctic research community has expressed continued interest in reanalysis depictions of the Arctic hydrologic budget. In large part, this stems from recognition of reanalysis as a potential tool that circumvents shortcomings of in situ data networks. Records of river discharge are fairly comprehensive. By contrast, the network of high-latitude precipitation (P) monitoring stations is sparse and time series contain biases due to under-catch of solid precipitation and other problems. Different gauge and shield combinations used by different northern countries introduce variations in catch efficiency that are especially large for high wind speeds [Goodison et al., 1998; Yang et al., 2001]. Timely updates of station precipitation data are difficult to obtain. The monitoring network is also degrading due to closure of many sites in Russia and Canada. Canada is also seeing a trend toward the use of automated stations. Reliable information on evapotranspiration (ET) is particularly sparse, especially in a spatially distributed sense.

Serreze and Hurst [2000] found good agreement between depictions of mean annual and monthly Arctic precipitation from ERA-15 and gauge-corrected, gridded station records. Aerological estimates of P-ET calculated from wind and humidity profiles in the NCEP and ERA-15 reanalyses appear to be of generally good quality [Cullather et al., 2000; Serreze et al., 2001a; Genthon, 1998]. There are considerable biases in precipitation forecasts from the NCEP reanalysis, but interannual variability is generally well represented. Through re-scaling NCEP forecasts to eliminate systematic biases and application of statistical downscaling techniques, one can take advantage of the rapid posting of reanalysis updates to monitor Arctic precipitation [Serreze et al., 2001b]. Other studies using reanalysis data in hydrologic applications include Bromwich et al. [1998], Bowling et al. [2000] and Walsh et al. [1998].

The Arctic community has eagerly awaited the new ERA-40 reanalysis. Here, we perform an initial assessment of monthly precipitation in ERA-40, using the 2.5^{o} x 2.5^{o} fields over the years 1989-1992. Comparisons are made with results from ERA-15. Validation relies on bias-corrected station data over land areas and the central Arctic Ocean. ET fields are also briefly examined.

2. Precipitation Data Sets

2.1. Arctic Ocean

The Russian Arctic and Antarctic Research Institute (AARI) conducted meteorological studies on drifting ice stations over the central Arctic Ocean during 1950-1991. A total of 30 "North Pole" (or NP) ice stations were manned during this period (NP-2 through NP-31; NP-1, the first ice station, operated during 1937-1938). The average duration of each station was 2.4 years. Yang [1999] performed daily bias corrections to the NP precipitation records. We use data from NP-30 and NP-31 for the years 1989 and 1990. Each station provides complete records (24 months each) for this period. Position is reported as the average station location for each month.

2.2. Land Areas

Records from several different data sets were merged. The first is an updated version of the Groisman et al. [1991] archive which contains monthly time series for 622 land stations in the former Soviet Union. Records are available through the early 1990s for most stations and through the late 1990s for a smaller subset. Values are adjusted for biases associated with winds and wetting losses. The wetting loss is the portion of precipitation that sticks to the walls of the gauge after it is emptied. The second archive is identified as National Climatic Data Center (NCDC) data set TD-9816 "Canadian Monthly Precipitation". The most recent records extend through 1990. Bias corrections are detailed by Groisman [1998].

These two data sets provide coverage for all Arctic land areas except for Alaska, Greenland and northern Europe. For these areas, data from the Global Historical Climatological Network (GHCN) archive are used [Vose et al., 1992]. We retained only those stations with no duplicates in the two archives just discussed. Bias adjustments are based on local interpolation of the Legates and Willmott [1990] correction factors to the station locations. Coverage for Eurasia was further improved with an additional 105 stations for the years 1966-1990 within the Ob, Yenisey and Lena basins obtained through collaboration with V. Vuglinsky (State Hydrometeorological Institute, St. Petersburg, Russia). These data were also adjusted using the Legates and Willmott corrections.

3. Precipitation Validation

3.1. Central Arctic Ocean

Figure 1 summarizes the mean annual cycles in observed precipitation along with those from ERA-40 (6-hour and 24-hour forecasts) and ERA-15 (24-hour forecasts). The observed annual cycle combines the NP-30 and NP-31 records. The reanalysis values are based on the grid point closest to each drifting station location.

Both reanalyses capture the observed seasonal cycle, which is characterized by a late summer maximum and winter-half minimum. Surprisingly, the observations match closest with ERA-15. The ERA-40 totals from both the 6-hour and 24-hour forecasts are too high from spring through early autumn while both reanalyses are somewhat too low during winter. Winter is when the bias corrections in the NP data are largest.

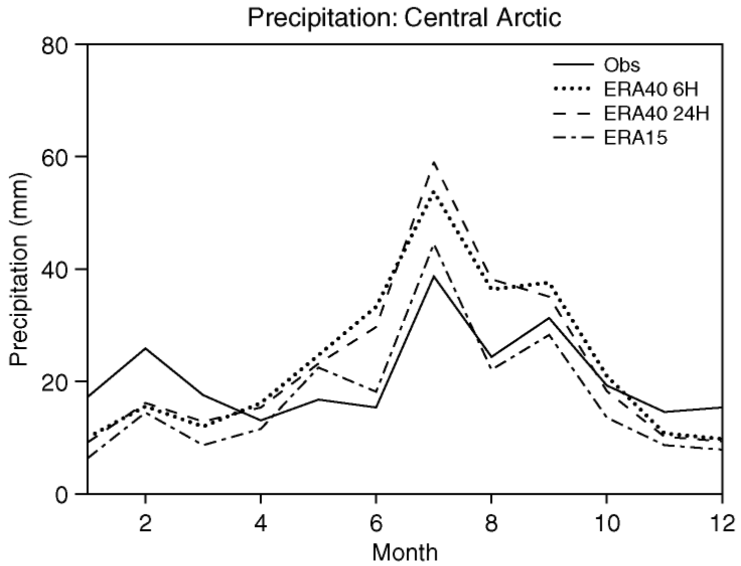

Figure 1 Mean seasonal cycles of precipitation (mm) over the central Arctic Ocean based on North Pole (NP) data for 1989-1990, with corresponding forecasts from ERA-40 and ERA-15. Each monthly mean is based on four cases.

The generally better performance of ERA-15 is further evident in monthly time series of observed precipitation and the forecasts at the closest grid point (Figure 2 and 3). For example, the July 1989 precipitation peak at NP-31 (observation #7) is captured very well by ERA-15 while it is overestimated by ERA-40. However, for both reanalyses there are periods when the correspondence with observations is poor. The squared correlations between the 48 station months of NP data and the 6-hour and 24-hour ERA-40 totals are 0.52 and 0.53, respectively. That between the observations and ERA-15 is slightly higher (0.56).

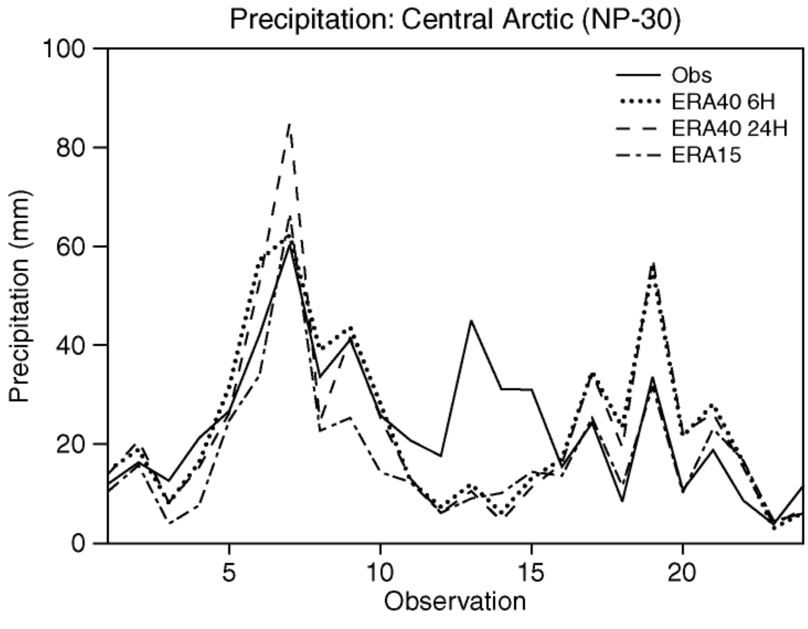

Figure 2 Monthly time series of precipitation (mm) from North Pole station NP-30 with corresponding forecasts from ERA-40 and ERA-15 (24-hour). There are 24 monthly values, starting January 1989 and ending December 1990.

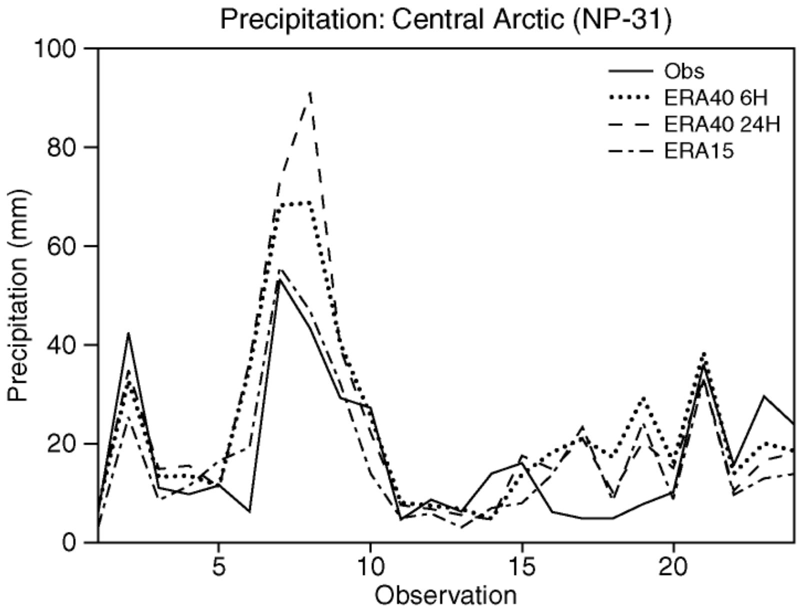

Figure 3 Same as Figure 2, but for North Pole station NP-31.

3.2. Terrestrial Regions

The more extensive land data allows for more detailed comparisons. For each year and month from 1989-1992, an estimate of observed precipitation was obtained at each reanalysis grid point via a Cressman [1959] interpolation using a 250-km sphere of influence. If there were fewer than two land stations within the 250 km radius, the interpolated value was treated as missing. The Arctic land area north of 60^{o}N was then divided into sectors of 30^{o} longitude. Scatter plots were prepared for each sector illustrating the relationships between modeled and observed precipitation. Analyses were performed separately for the 6-hour and 24-hour ERA-40 forecasts and the 24-hour ERA-15 forecasts. Regression lines were computed, along with the squared correlations between the observed and modeled values. To increase the number of cases, the scatter plots are based on paired monthly values falling into each of the four standard calendar seasons. Interpolating the station data acts to “scale up” the observations to be more comparable to the fairly coarse-resolution ERA data available to us.

Results based on the ERA-40 24-hour forecasts (winter and summer) are provided in Figures 4 and 5. The performance of ERA-40 for winter could be best be described as mixed. Squared correlations in the different sectors range from a low of 0.28 (120-150^{o}E) to a high of 0.80 (90-120^{o}E). It must be stressed that the strength of the correlations that can be obtained depends on the quality of the observations. Even with the Cressman interpolations, scatter can be introduced because of local variations in station exposure (e.g., windward vs. lee slopes). This problem is more severe where the density of stations is low, as is the case for northern Canada, eastern Eurasia and the northern North Atlantic. Furthermore, in areas with complex topography, stations tend to be biased toward sheltered valley sites. Correlations also tend to be lower in areas with meager precipitation for the reason that even small measurement errors (or inappropriate bias corrections) can contaminate the reported totals.

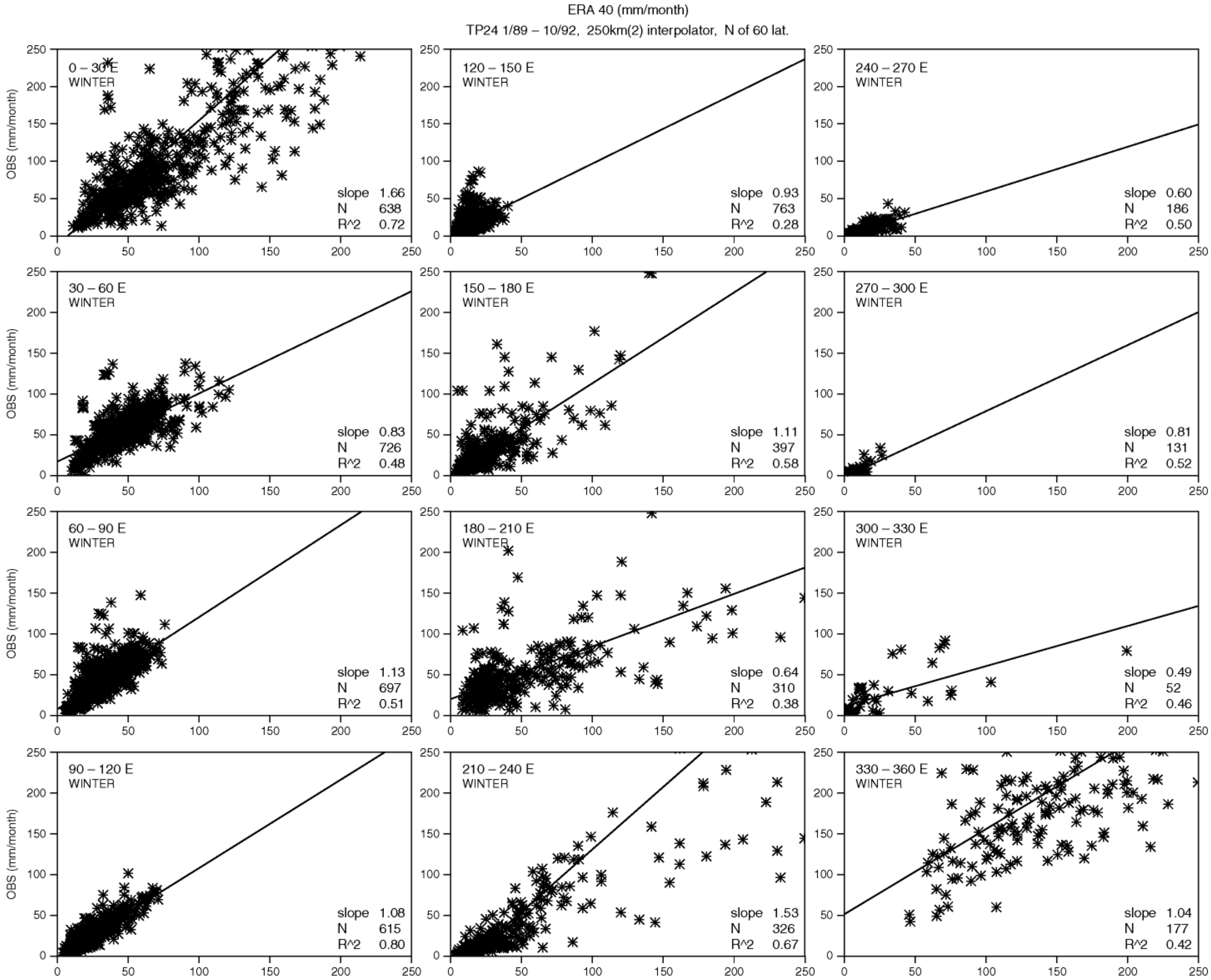

Figure 4 Scatter plots of observed precipitation (mm) from land station versus ERA-40 forecasts (24-hour) for winter. The scatter plots are for sectors of 30o longitude extending down to 60oN. The station data were interpolated to the model grid points in each sector using a Cressman routine with a 250 km sphere of influence. Also shown is the linear regression best fit, the number of cases and the squared correlation between observed and modeled precipitation.

Put differently, the "true" correlations are likely higher than indicated in Figure 4. The sector with the lowest squared correlation (120°-150°E) is dry (due to dominance of the Siberian High) and topographically complex with a low station density [Serreze et al., 2001b] (since the number of years of available data from each station varies by sector, this is not well reflected in N). By comparison, the sector 90°-120°E, where ERA-40 performs very well, is characterized by somewhat higher precipitation and where the station density is greater.

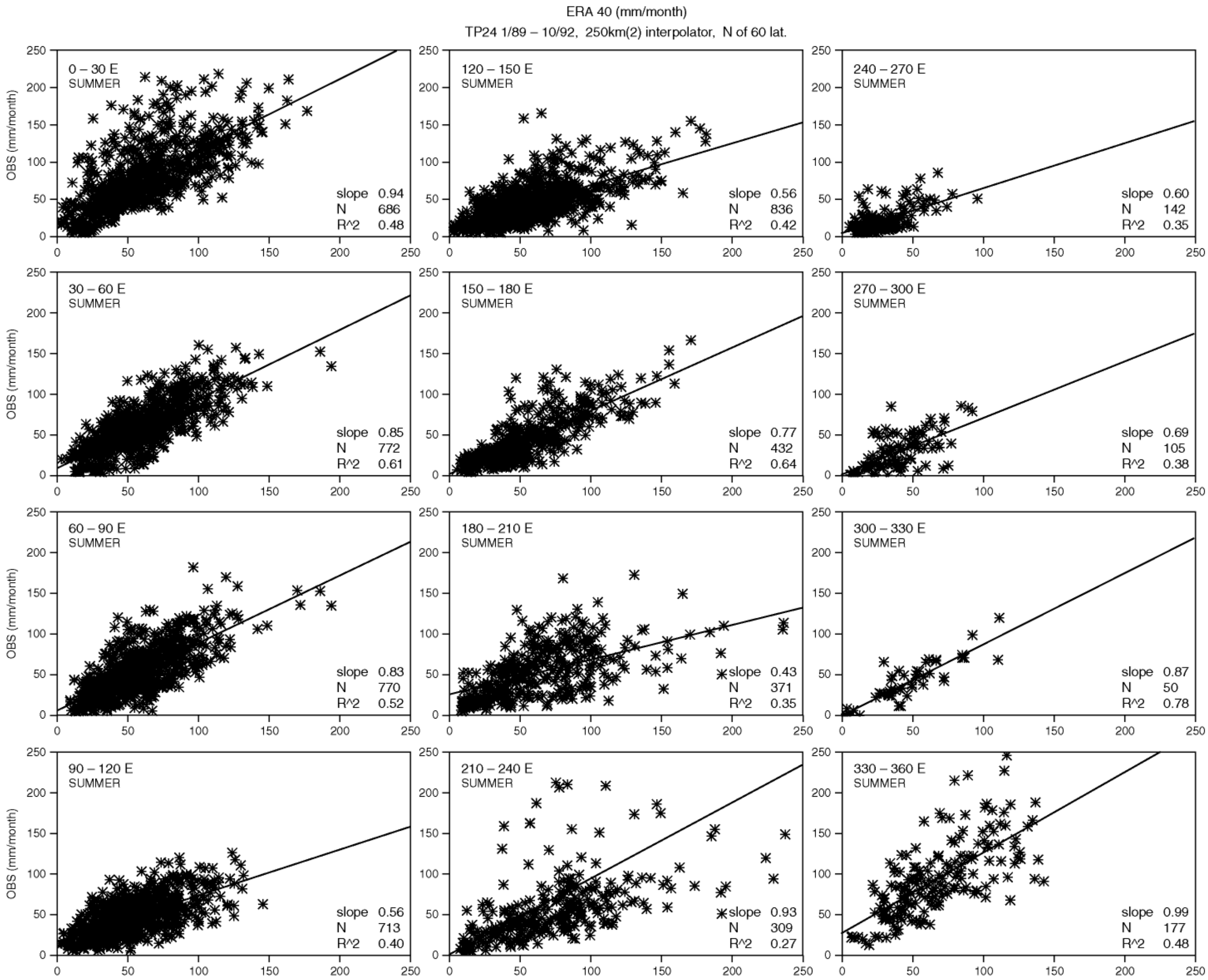

Figure 5 Same as Figure 4, but for summer.

Assuming no systematic biases in the model or the observations, the regression slopes ought to have a value of one. No systematic pattern emerges for winter. Some of the computed slopes are greater than one (modeled precipitation is too low) and some are less than one (modeled precipitation is too high).

Overall, the squared correlations between observed and modeled precipitation are somewhat lower for summer (Figure 5). This is not surprising. At least for sub-Arctic lands, much of the summer precipitation is of convective origin, meaning that the correlation length scale for precipitation is smaller. For some sectors, the squared correlations are higher than for winter. Most of the regression slopes are substantially less than one, indicating a tendency for ERA-40 to over-estimate summer precipitation.

No large systematic differences are found between the winter 24-hour and 6-hour ERA-40 forecasts with respect to either the squared correlations or the regression slopes. By comparison, for summer, the slopes from the 6-hour forecasts are a bit larger for most sectors. We will return to this issue shortly when comparisons are made between spatial fields of precipitation.

As a general statement, for both summer and winter, the 24-hour ERA-15 forecasts are just as good as those from ERA-40. For some sectors, ERA-40 performs slightly better while for others, ERA-15 is superior. As outlined earlier, over the central Arctic Ocean, ERA-15 looks better.

4. Spatial Fields: Precipitation and ET

4.1. Seasonal Precipitation

As a further assessment we assembled fields of the difference in seasonal mean precipitation (1989-1992) between ERA-40 and ERA-15 based on the 24-hour forecasts (Figure 6). For large areas, the totals are within +/- 20 mm of each other. Perhaps the most obvious difference (see also Figure 1), is that summer precipitation in ERA-40 is substantially higher (> 40 mm) over the Arctic Ocean. From comparisons with the NP-30 and NP-31 data, the ERA-15 results appear to be more correct. ERA-40 is also higher along the northern end of the North Atlantic storm track and the Gulf of Alaska. Note especially the much higher ERA-40 totals along the southeast coast of Greenland for winter and the southeast Alaskan coast for winter and spring, which appear related to orography.

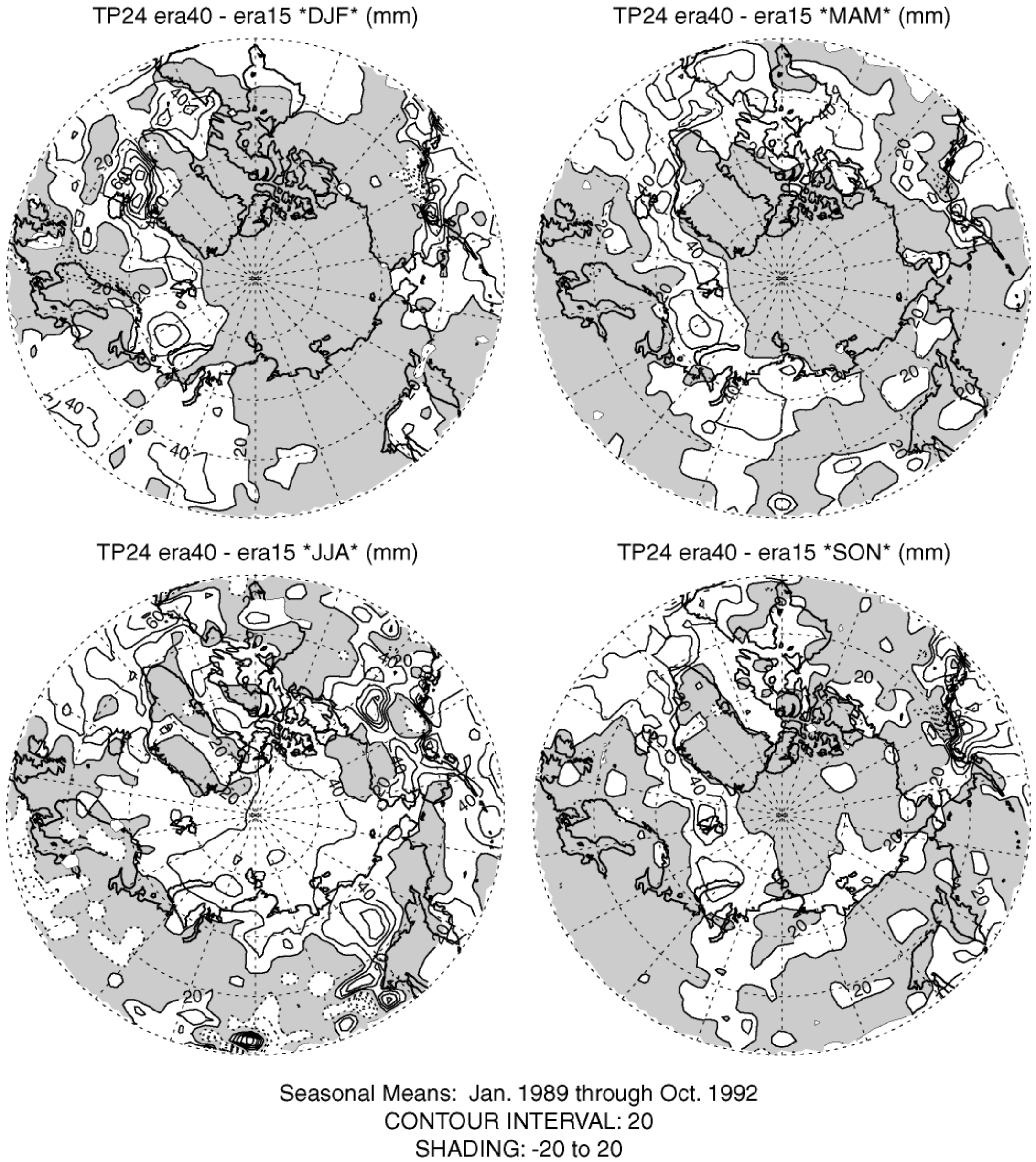

Figure 6 ERA-40 minus ERA-15 precipitation (24-hour) for the four seasons based on 1989-1992 means (mm).

Building on previous discussion, there are substantial differences between the seasonal mean 6-hour 24-hour ERA-40 forecasts that are largest in summer. For this season, totals from the 6-hour forecasts are lower by 30-90 mm over much of northern Eurasia and North America (Figure 7). This is due to lower 6-hour totals in both the stratiform and convective components of precipitation (Figures 8 and 9).

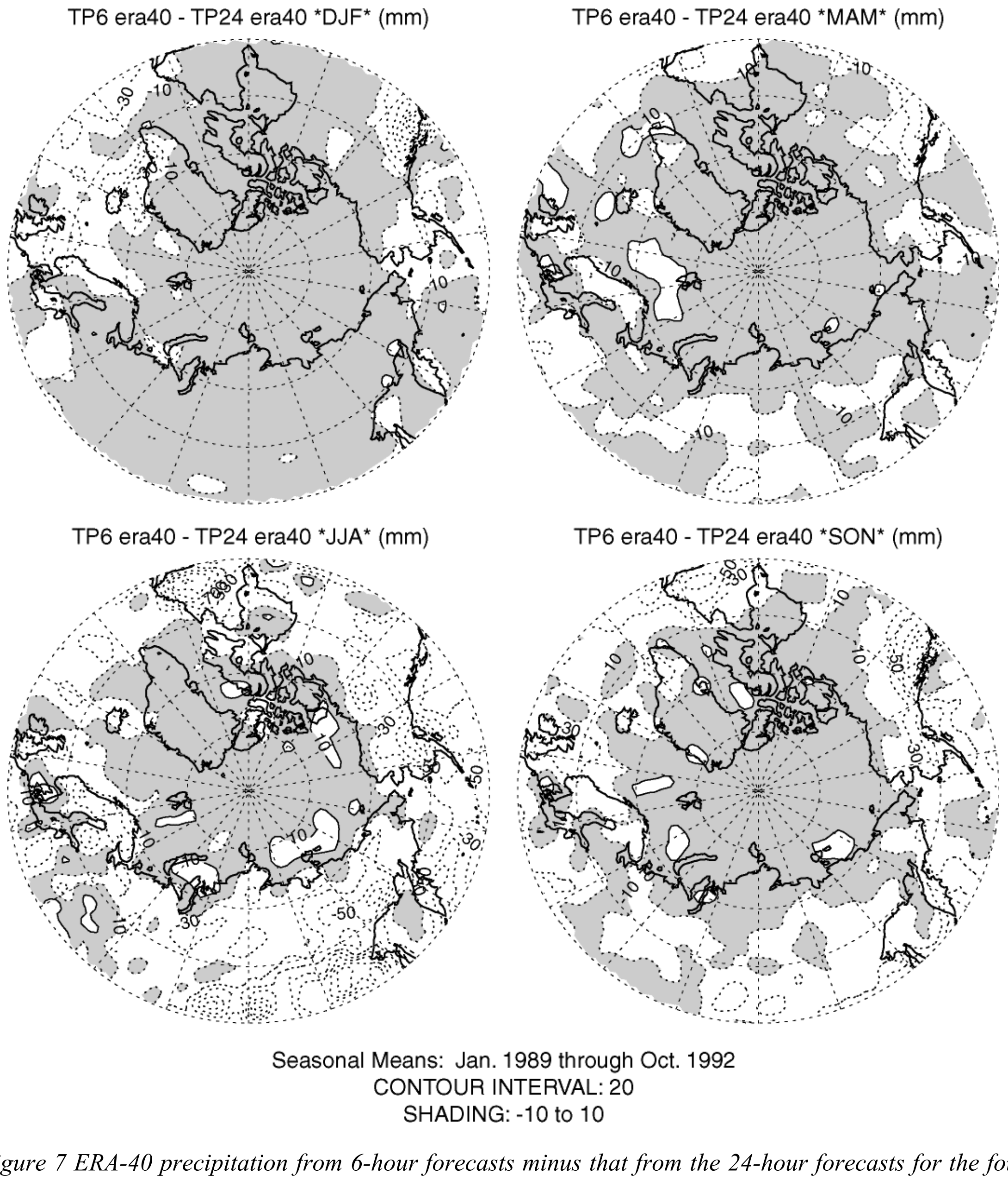

Figure 7 ERA-40 precipitation from 6-hour forecasts minus that from the 24-hour forecasts for the four seasons based on 1989-1992 means (mm).

We have no data for which to validate the two components of precipitation separately. Mean seasonal fields of convective precipitation from ERA-40 (24-hour) are provided in Figure 10. All that can be said is that the they appear reasonable in a qualitative sense. As expected, winter convective precipitation is absent over land areas and the Arctic Ocean, but is significant over the northern North Atlantic. Summer convective precipitation over land has local peaks of well over 100 mm.

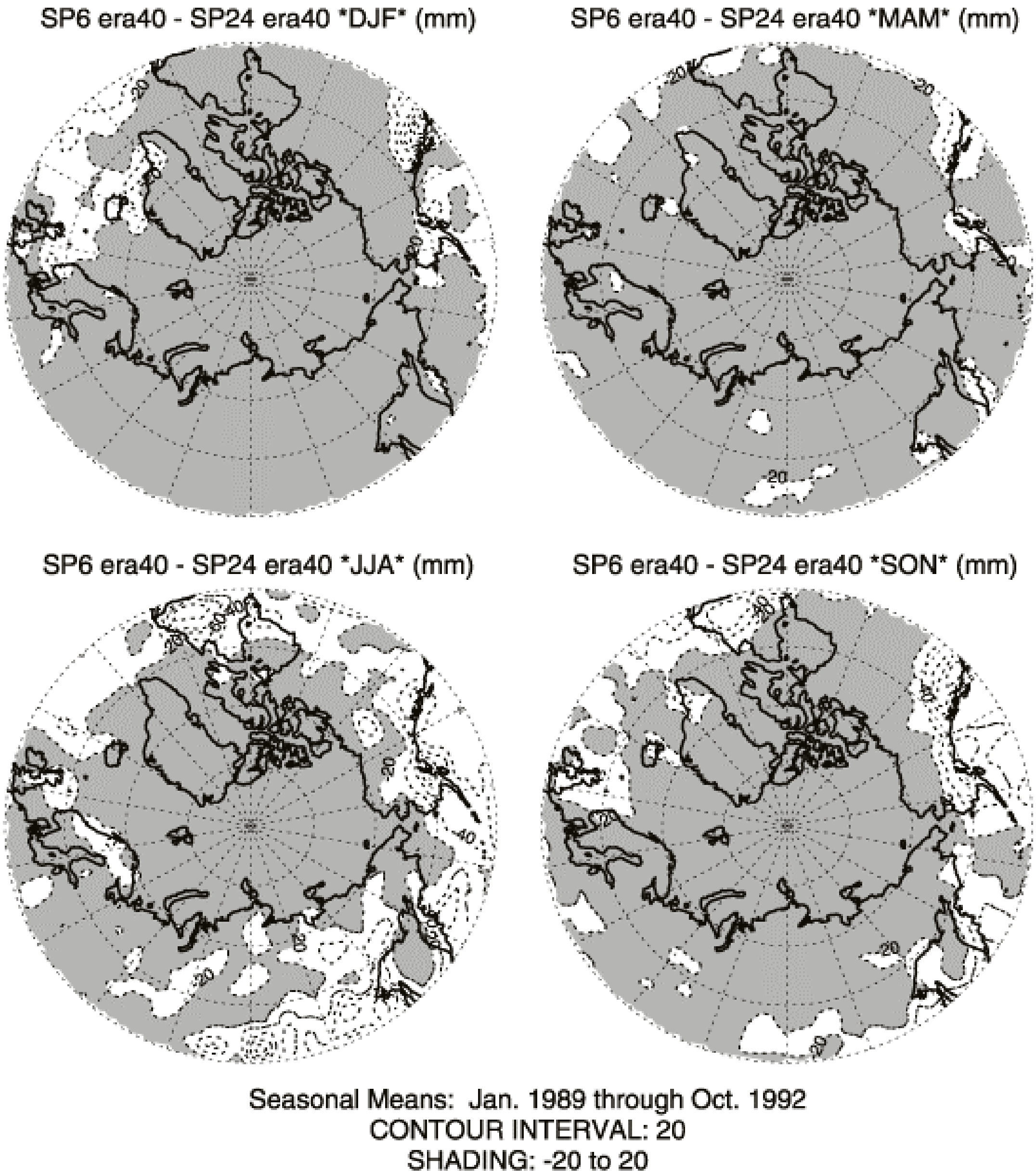

Figure 8 ERA-40 stratiform precipitation from 6-hour forecasts minus that from the 24-hour forecasts for the four seasons based on 1989-1992 means (mm).

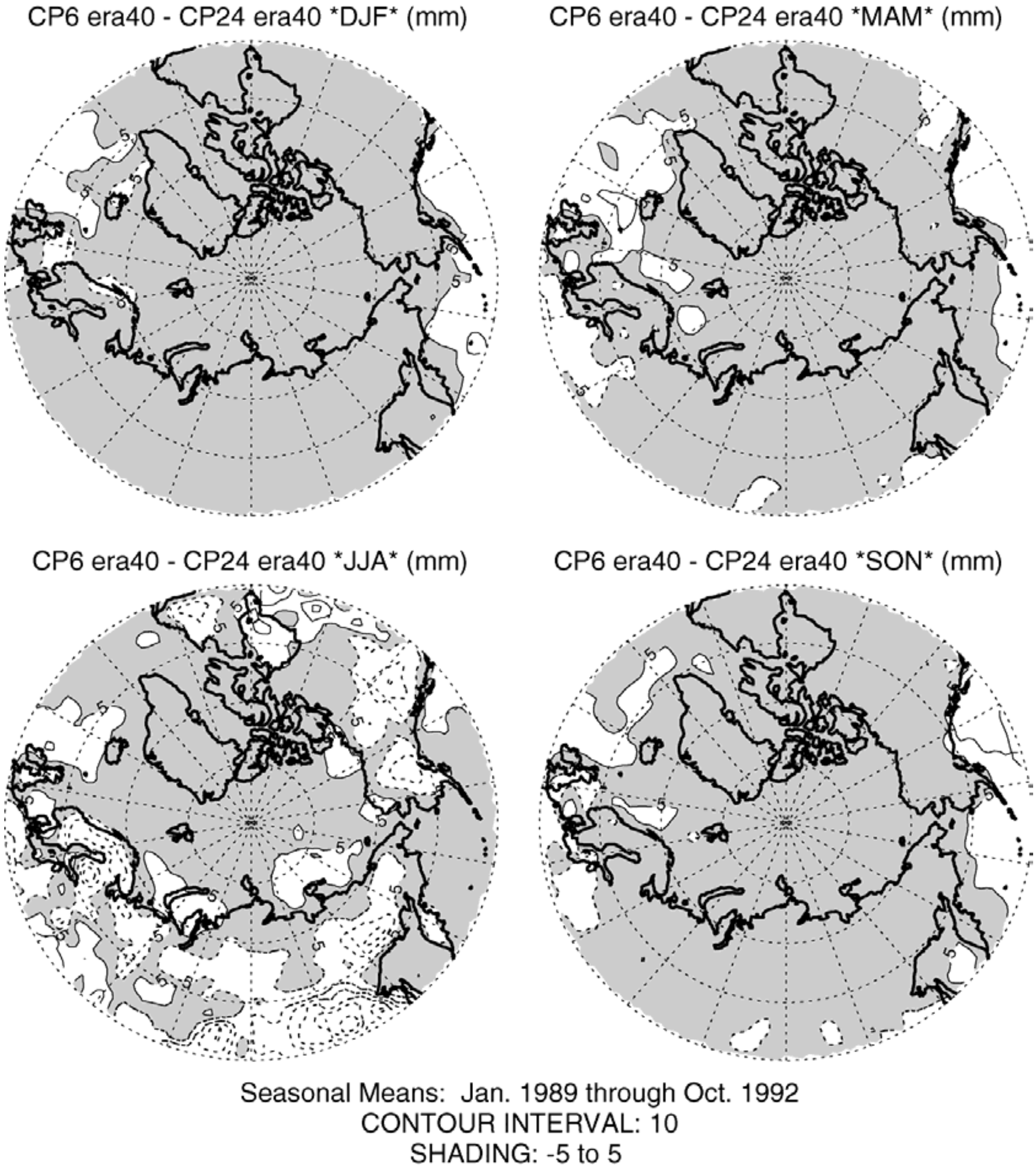

Figure 9 ERA-40 convective precipitation from 6-hour forecasts minus that from the 24-hour forecasts for the four seasons based on 1989-1992 means (mm).

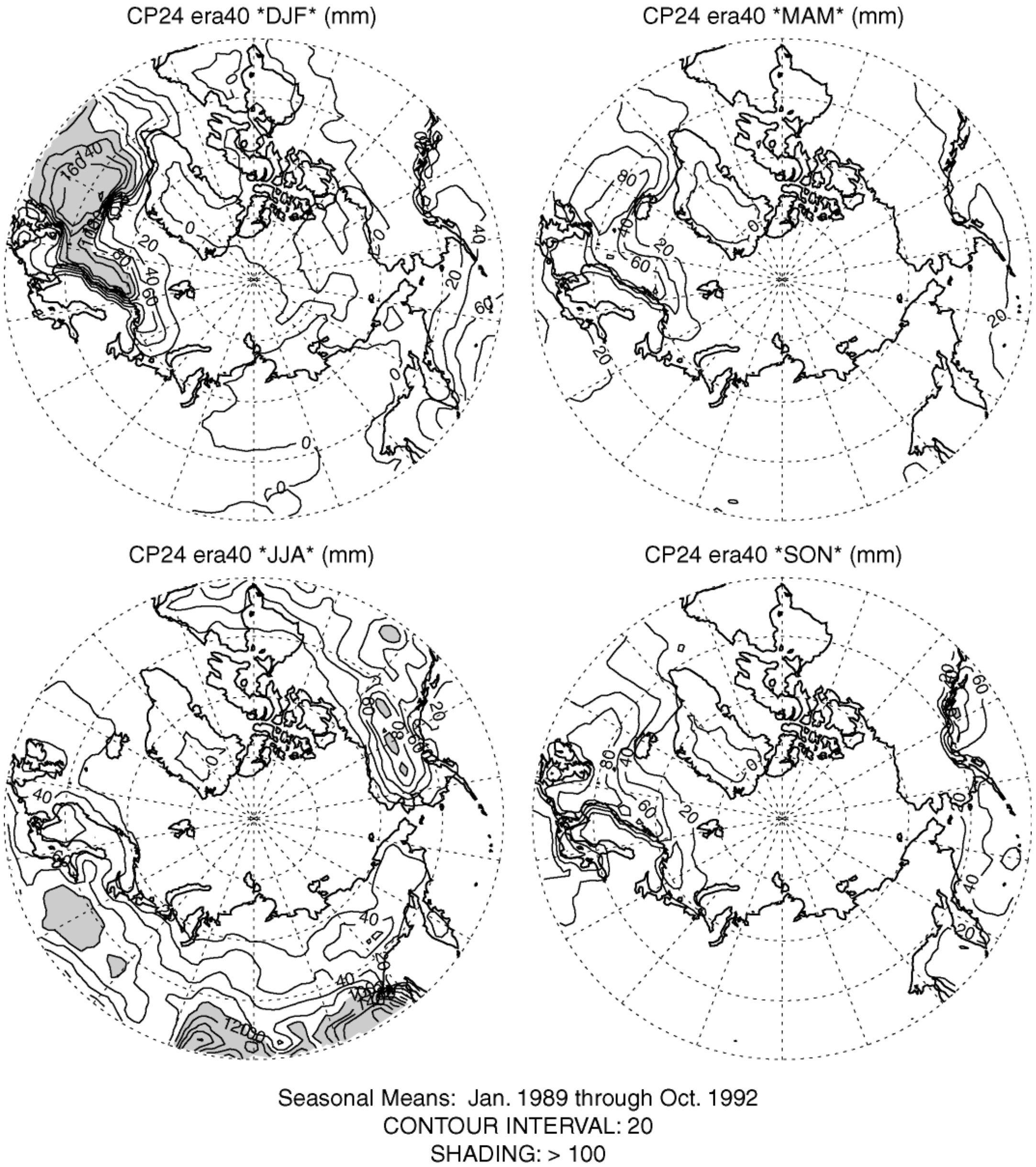

Figure 10 ERA-40 convective precipitation (24-hour) for the four seasons based on 1989-1992 means (mm).

4.2. Evapotranspiration (ET)

Winter ET totals from the 24-hour forecasts over land and the Arctic Ocean are very small, while over the northern North Atlantic, they locally exceed 350 mm. Peak summer values over land areas are from 200-250 mm, with Arctic Ocean values of about 50 mm (Figure 11). There is little difference between the 6-hour and 24-hour forecasts (not shown).

It is instructive to contrast seasonal mean ET from ERA-40 and ERA-15 (Figure 12). For much of the Arctic, the two estimates are with +/- 10 mm of each other. The most notable differences for winter, spring and autumn are the higher ERA-40 values over parts of the north Atlantic and Arctic peripheral seas. ET from ERA-40 is also higher in summer over the central Arctic ocean. The higher ET rates correspond to higher precipitation totals relative to ERA-15 (see Figure 6), indicative of a more vigorous hydrologic cycle.

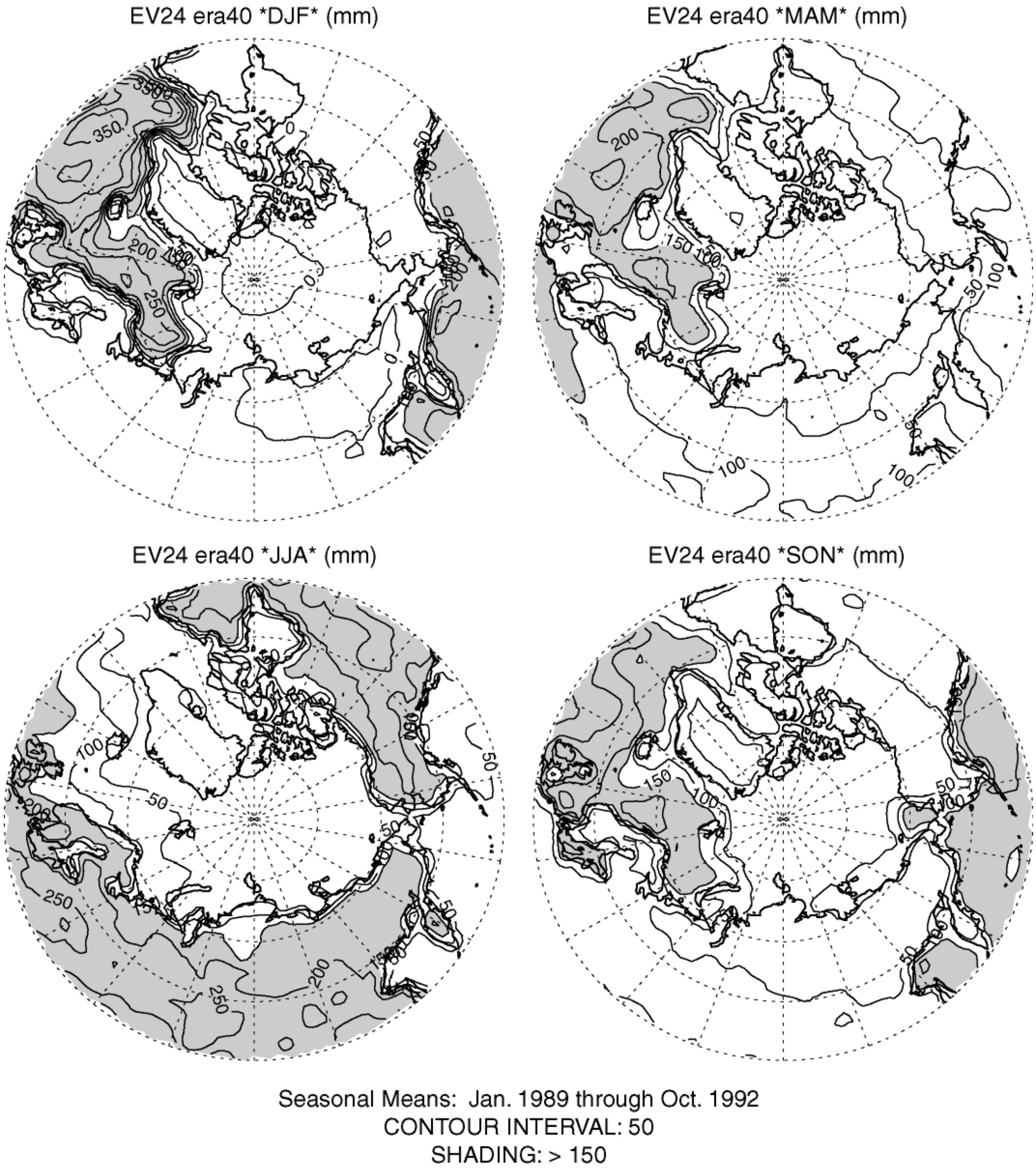

Figure 11 ERA-40 evapotranspiration (24-hour) for the four seasons based on 1989-1992 means (mm).

The summer plot also reveals significant differences (both positive and negative) between the two reanalyses over land areas.

Serreze and Hurst [2000] compared mean annual ET totals from ERA-15 for seven locations along 65^{o}N with corresponding values from a number of poorly documented published maps. The range between estimates for the same location exceeds 100 mm! The ERA-15 estimates could only be stated as lying within the range of estimates. This is also the case for ERA-40. Table 1 lists what we think are the two best estimates summarized by Serreze and Hurst [2000] along with the four-year mean reanalysis totals.

We recently acquired time series of monthly ET for a number of sites in Russia based on lysimeters. Most of the records begin in the early 1970s and extend through 1985. Records are most abundant for summer. Comparisons with these data suggest that summer ET rates are too high in both ERA-40 and ERA-15. Mean July totals for the 12 sites north of 60^{o}N (with at least five years of data) range from 33 to 79 mm. The mean

July values from ERA-40 (24-hour forecasts) are higher at all but one station by amounts ranging from 5-50 mm. Comparisons with ERA-15 are similar.

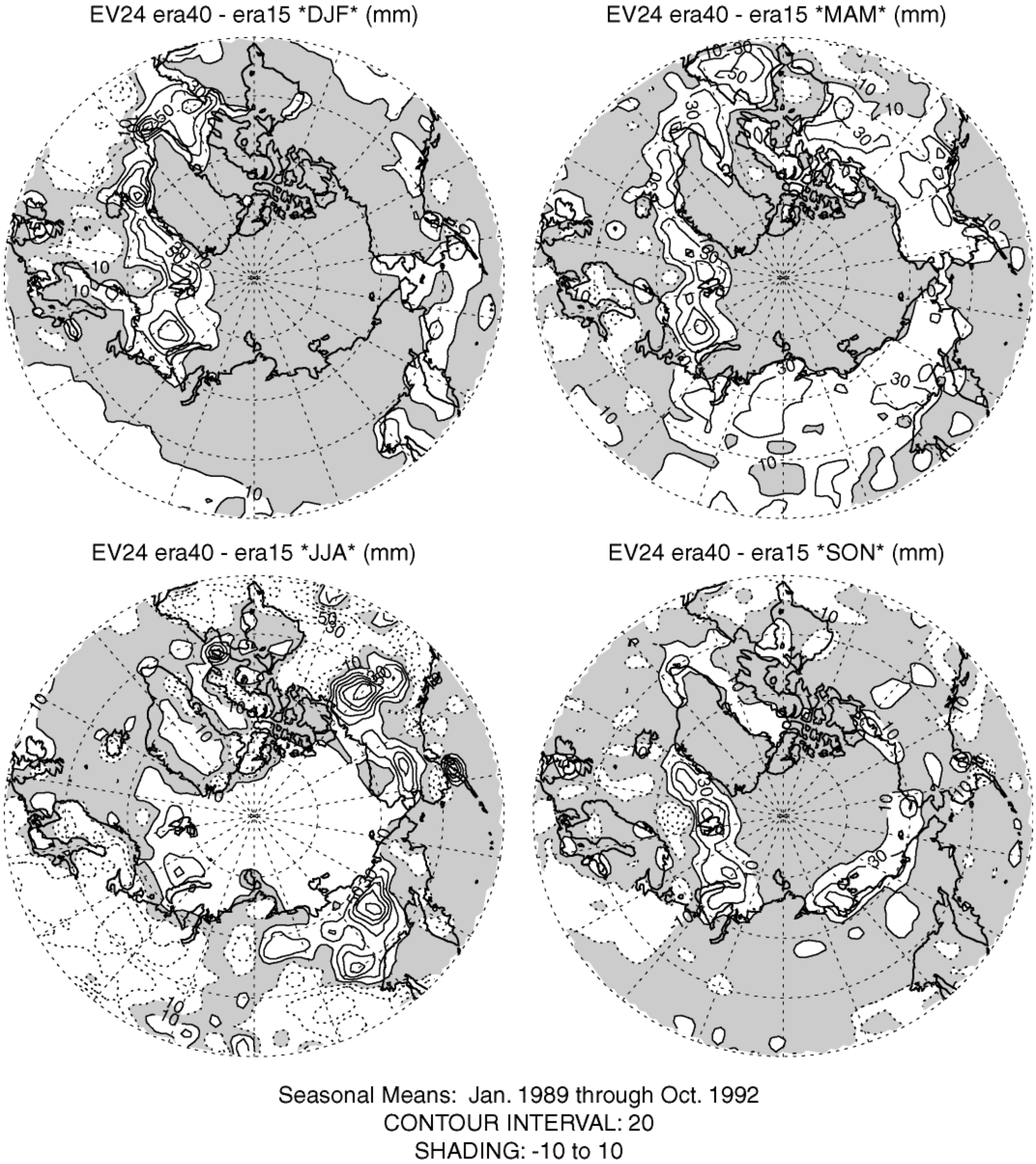

Figure 12 ERA-40 minus ERA-15 evapotranspiration (24-hour) for the four seasons based on 1989-1992 means (mm).

Long.	ERA-15	ERA-40	OBS1	OBS2
45°	396	317	350	400
75°	343	338	375	---
105°	241	247	300	---
135°	205	267	275	220
165°	243	268	225	250
225°	281	338	---	255
255°	239	244	---	200

OBS1: From Lydolph [1977]

OBS2: From Korzun [1976]

Table 1 Annual mean ET (mm) along 65°N from ERA-15, ERA-40 and observations (OBS)

5. Summary

Serreze and Hurst [2000] concluded that with respect to mean Arctic precipitation, the performance of ERA-15 was very encouraging. The present study, while based on only a few years of data, indicates that anticipated improvements in the ERA-40 precipitation forecasts have not yet been realized. Indeed, in some respects, such as precipitation over the central Arctic Ocean, ERA-15 seems to perform better. Although somewhat different results might be expected from evaluation of ERA-40 at full resolution (and with additional years of data), we are hopeful that the solution lies with problems in this initial run of ERA-40 identified by other investigators. Of particular concern is the cold bias in lower tropospheric temperatures centered over the Arctic Ocean (see the paper in this volume by D. Bromwich).

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