The NCEP–NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation

Robert Kistler,[*] Eugenia Kalnay,[+] William Collins,[*] Suranjana Saha,[*] Glenn White,[*] John Woollen,[*] Muthuvel Chelliah,[#] Wesley Ebisuzaki,[#] Masao Kanamitsu,[#] Vernon Kousky,[#] Huug van den Dool,[#] Roy Jenne,[@] and Michael Fiorino[&]

Editor's note: This article is accompanied by a CD-ROM that contains the complete documentation of the NCEP–NCAR Reanalysis and all of the data analyses and forecasts. It is provided to members through the sponsorship of SAIC and GSC.

1. Introduction

The National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) have cooperated in a project (denoted "reanalysis") to produce a retroactive record of more than 50 years of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities. This effort involved the recovery of land surface, ship, rawinsonde, pibal, aircraft, satellite, and other data. These data were then quality controlled and assimilated with a data assimilation system kept unchanged over the reanalysis period. This eliminated perceived climate jumps associated with changes in the operational (real time) data assimilation system, although the reanalysis is still affected by changes in the observing systems. During the earliest decade (1948–57), there were fewer upper-air data observations and they were made 3 h later than the current main synoptic times (e.g., 0300 UTC), and primarily in the Northern Hemisphere, so that the reanalysis is less reliable than for the later 40 years. The reanalysis data assimilation system continues to be used with current data in real time (Climate Data Assimilation System or CDAS), so that its products are available from 1948 to the present. The products include, in addition to the gridded reanalysis fields, 8-day forecasts every 5 days, and the binary universal format representation (BUFR) archive of the atmospheric observations. The products can be obtained from NCAR, NCEP, and from the National Oceanic and Atmospheric Administration/Climate Diagnostics Center (NOAA/CDC). (Their Web page addresses can be linked to from the Web page of the NCEP–NCAR reanalysis at http://wesley.wwb.noaa.gov/Reanalysis.html.)

This issue of the *Bulletin* includes a CD-ROM with a documentation of the NCEP–NCAR reanalysis (Kistler et al. 1999). In this paper we present a brief summary and some highlights of the documentation (also available on the Web at http://atmos.umd.edu/~ekalnay/). The CD-ROM, similar to the one issued with the March 1996 issue of the *Bulletin,* contains 41 yr (1958–97) of monthly means of many reanalysis variables and estimates of precipitation derived from satellite and in situ observations (see the appen-

*Environmental Modeling Center, National Centers for Environmental Prediction, Washington, D.C.
+Department of Meteorology, University of Maryland, College Park, Maryland.
#Climate Prediction Center, National Centers for Environmental Prediction, Washington, D.C.
#National Center for Atmospheric Research, Boulder, Colorado.
&Lawrence Livermore National Laboratory, Livermore, California, and European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom.
Corresponding author address: Dr. Eugenia Kalnay, Dept. of Meteorology, University of Maryland, 2213 Computer and Space Science Building, College Park, MD 20742-2425.
E-mail: ekalnay@atmos.umd.edu
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dix for an introduction to the CD-ROM). It also contains selected monthly fields for the earlier decade (1948–57). The full CD-ROM contents and the reanalysis for 1999 and later years as well as additional detailed documentation and links are also available at the NCEP–NCAR reanalysis Web site (see also the appendix).

2. Brief description of the reanalysis system

The reanalysis data assimilation system, described in more detail in Kalnay et al. (1996), includes the NCEP global spectral model operational in 1995, with 28 "sigma" vertical levels and a triangular truncation of 62 waves, equivalent to about 210-km horizontal resolution. The analysis scheme is a three-dimensional variational (3DVAR) scheme cast in spectral space denoted spectral statistical interpolation (Parrish and Derber 1992). The assimilated observations are upper-air rawinsonde observations of temperature, horizontal wind, and specific humidity; operational Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS) vertical temperature soundings from NOAA polar orbiters over ocean, with microwave retrievals excluded between 20°N and 20°S due to rain contamination; TOVS temperature soundings over land only above 100 hPa; cloud-tracked winds from geostationary satellites; aircraft observations of wind and temperature; land surface reports of surface pressure; and oceanic reports of surface pressure, temperature, horizontal wind, and specific humidity.

Gridded variables, the most widely used product of the reanalysis, have been classified into three classes (Kalnay et al. 1996): *type A variables,* including upper-air temperatures, rotational wind, and geopotential height, are generally strongly influenced by the available observations and are therefore the most reliable product of the reanalysis. *Type B variables,* including moisture variables, divergent wind, and surface parameters, are influenced both by the observations and by the model, and are therefore less reliable. *Type C variables,* such as surface fluxes, heating rates, and precipitation, are completely determined by the model (subject to the constraint of the assimilation of other observations). They should be used with caution and whenever possible compared with model-independent estimates. It is frequently noted that even when the model estimates are biased, the interannual variability tends to be correlated with independent observations.

Although the reanalysis data assimilation system is maintained constant, the observing system has evolved substantially. We can separate the evolution of the global observing system into three major phases: the "early" period from the 1940s to the International Geophysical Year in 1957, when the first upper-air observations were established; the "modern rawinsonde network" from 1958 to 1978; and the "modern satellite" era from 1979 to the present. In order to facilitate the assessment of data coverage, the CD-ROM includes an observation data count program and a data file that allows the user to determine how many and what type of observations were available within each 2.5° to 2.5° grid box at any given time. An example of this application is Fig. 1, created using the CD-ROM data, and showing the zonal mean number of *all* types of observations available to the reanalysis from 1946 to 1998. It is recommended that the user consult this database as a complement to the analysis grids in order to assess their observational content.

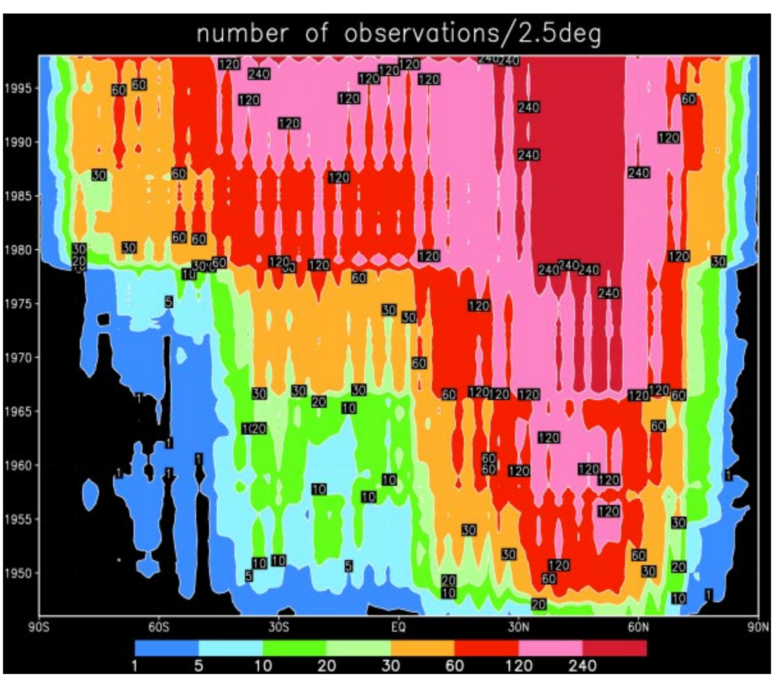

FIG. 1. Zonal mean number of all types of observations per 2.5° lat–long box per month from 1946 to 1998. A 12-month running mean has been applied.

Until 1 June 1957, upper-air observation times were done 3 h earlier than the current synoptic times 0000, 0600, 1200, and 1800 UTC. For this reason the reanalysis for the first decade (1948–57) is performed at the observing times (0300, 0900, 1500, and 2100 UTC). To facilitate comparisons with later periods, however, the 3-h forecasts and model diagnostic fields are also made available in the reanalysis at the current main synoptic times. It should be noted that the forecast error covariance, tuned to the present observing system, was kept constant throughout the reanalysis. This implies less than optimal information extraction during the presatellite era.

The documentation in the CD-ROM describes the many different sources of observations put together for this project, giving an inventory for each data source as a function of time. The BUFR observational data archive includes "events" or metadata pertaining to the observation, such as information about quality control and the departure of the observation from both the background and the analysis (Woollen and Zhu 1997). We note that in the process of performing the reanalysis and constructing the BUFR archive, we discovered a major (and still unresolved) mystery in the operational Global Telecommunication System (GTS). For 27 months in the early 1990s geographically different and complementary rawinsonde data were transmitted in real time to NCEP and to the European Centre for Medium-Range Weather Forecasts (ECMWF) so that each center had only about half of these data.

Quality control (QC) and monitoring of rawinsondes were an important component of the reanalysis, which included two QC systems: optimal interpolation QC (Woollen et al. 1994) for all observations, and the complex quality control for heights and temperatures program (CQCHT; Collins 1999). The CQCHT was used to assess the quality of radiosonde heights and temperatures and to actually *correct many errors based on hydrostatic consistency.* The errors found, their origin, and the type of corrections made are discussed in the documentation, and a record kept in the events file. The total number of rawinsondes is shown in Fig. 2 and the number of error corrections in Fig. 3. It is particularly interesting that when the "NMC Office Note 29"[1] encoding scheme was introduced in 1973, the number of errors detected in the reanalysis increased substantially, presumably because of coding errors (Fig. 3), and the operational forecast skill, in turn, suffered a considerable deterioration at that time (Kalnay et al. 1998). Unlike the operational forecasts, the reanalysis benefited from the advanced quality control and error correction, and showed an impressive improvement in the forecast skill in 1974, presumably due to the use of this modern format that included more precision in the data storage (Fig. 7).

[1]Available from NCEP, 5200 Auth Rd., Washington, DC 20233.

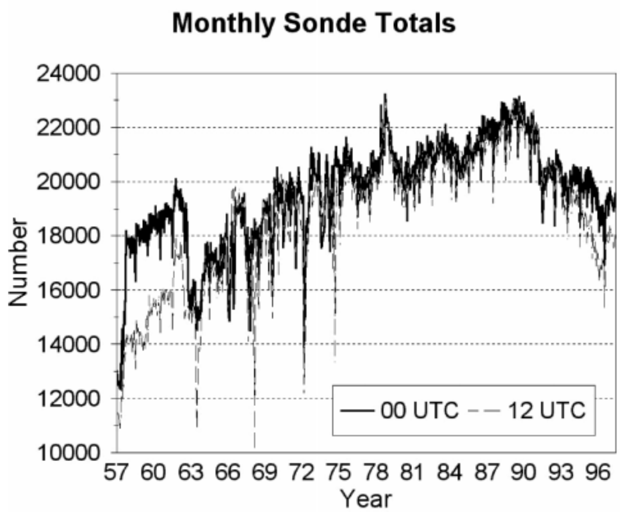

FIG. 2. Total number of radiosondes used by the reanalysis at the main observation times.

3. Changes in the observing systems and their impact on the reanalysis

The impact of the major changes in the observing systems on the reanalysis is very complex. In this section it is assessed using several measures.

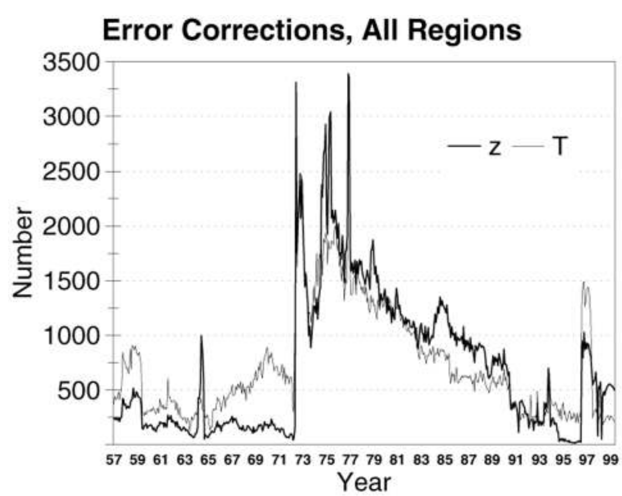

FIG. 3. Time variation in the number of type 1 and 2 hydrostatic errors.

"Observational increments," that is, differences between the 6-h forecast and the observations are an excellent measure of the quality of the 6-h forecast, but unfortunately they are not easily computed a posteriori for a large database like the reanalysis. "Analysis increments," that is, differences between the 6-h forecast and the analysis, can be used as a proxy for the observational increments over data-rich regions, and since they are a measure of the 6-h forecast error started from the previous analysis, they provide a quantitative assessment of the quality of the analysis. In regions without observations, the analyses are essentially identical to the first guess, so that near-zero analysis increments are indicative of a *lack of observations,* rather than of a perfect forecast. Figures 4a and 4b show the geographical distribution of the rms of the analysis increments (analysis minus 6-h forecast) at 500-hPa heights for 1958 and 1996. In 1996, in the satellite era, these averaged analysis increments are rather small and uniform and depend mostly on latitude. In the Tropics they are about 5 m, in the Northern Hemisphere (NH) extratropics generally between 5 and 10 m, and in the Southern Hemisphere (SH) between 10 and 18 m. This suggests that the quality of the analysis is also rather uniform. In 1958, by contrast, the increments were almost zero over the South Pacific and south Indian Oceans, indicating lack of observations to update the first guess in these regions. At the same time, the increments were large in regions with rawinsondes, downstream of data-sparse regions, indicating large forecast errors. The contrast is particularly clear in the SH extratropics, where rms increments over land were generally 10–15 m in 1996, and up to 35 m over high-latitude rawinsonde stations in 1958.

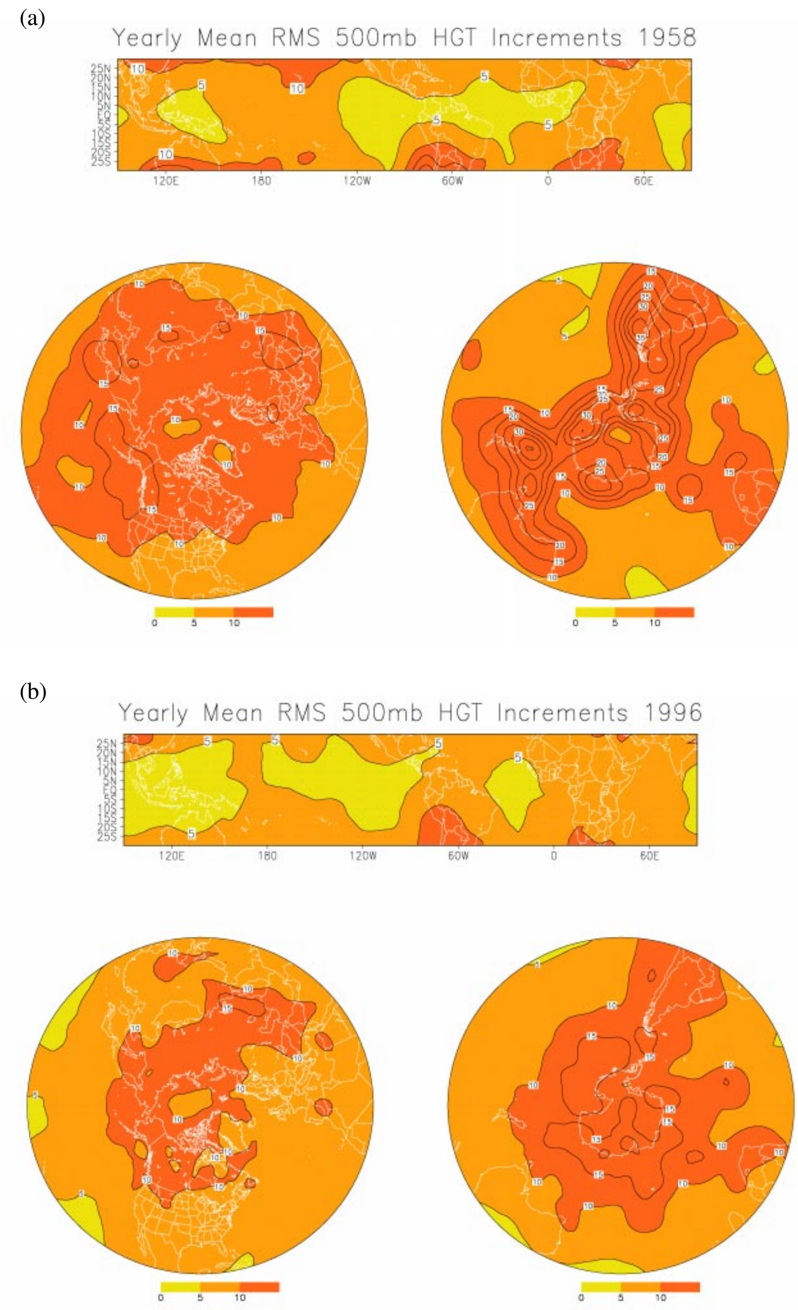

FIG. 4. Geographical distribution of the 6-h forecast rms increment (analysis minus first guess) of 500-hPa heights for (a) 1958 and (b) 1996.

The impact of the introduction of the satellite observing system on the forecast skill (an important measure of the quality of the reanalysis) is shown by comparing "SAT" versus "NOSAT" experiments carried out for the year 1979. The SAT experiment is the regular reanalysis based on the assimilation of all available data. In the NOSAT experiment satellite observations were not used. The forecasts were verified against both satellite and no-satellite analyses but only the more accurate SAT verifications are shown. The forecast impact is small in the NH and much larger in the SH (Figs. 5a and 5b). Despite the lower skill of the daily forecasts, monthly mean anomalies are still quite well captured (e.g., Fig. 6). The impact of changes in the observing systems over time is sum-

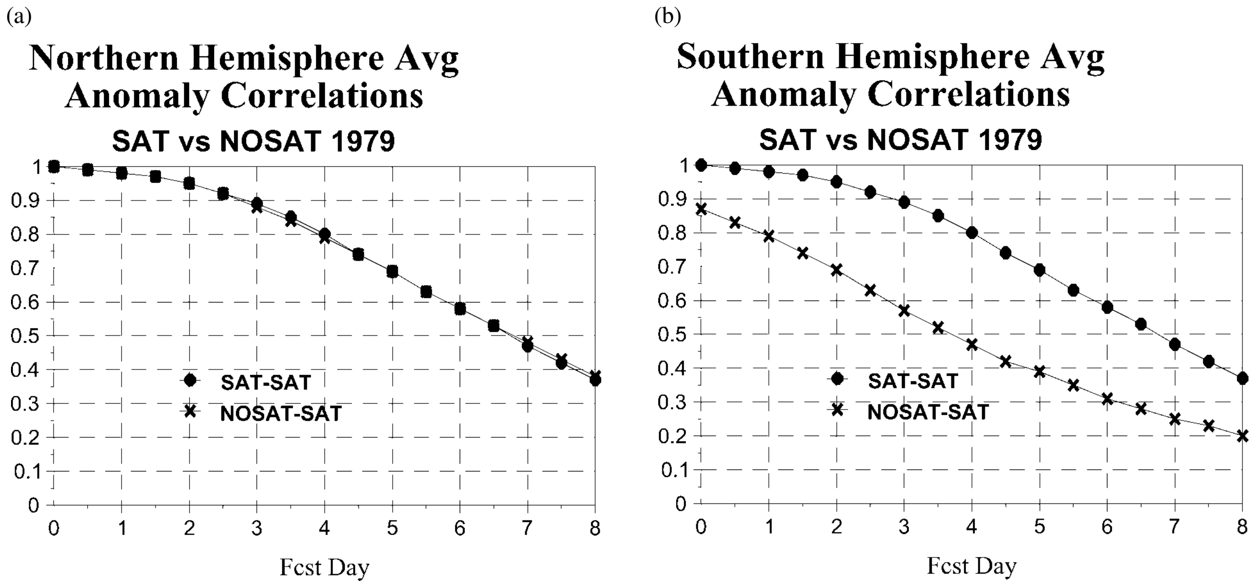

FIG. 5. Anomaly correlation decay for the (a) Northern Hemisphere and the (b) Southern Hemisphere with time averaged over 73 predictions (one every 5 days) in 1979 with initial conditions from the analysis using all observations (SAT) and without using satellite data (NOSAT). They are both verified with the SAT analysis.

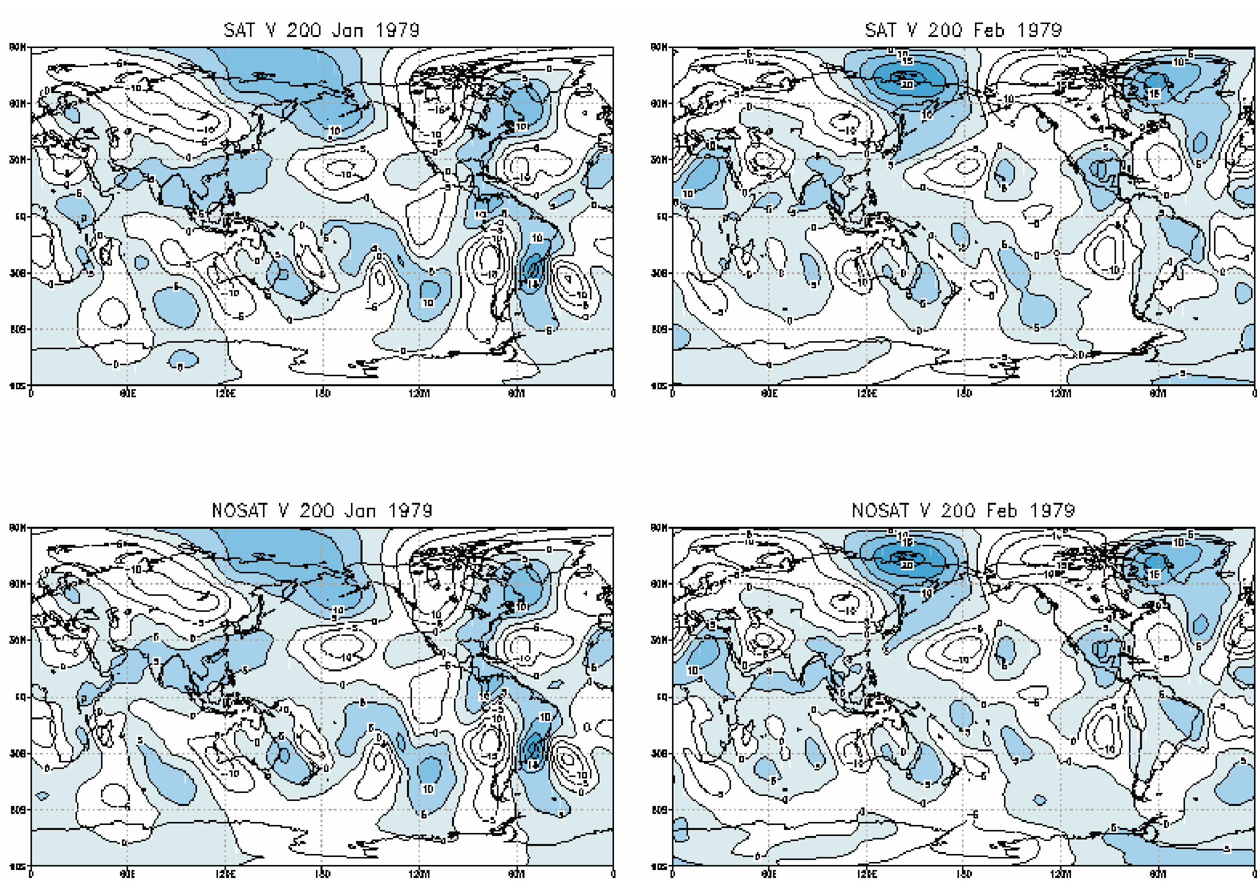

FIG. 6. Monthly average 200-hPa meridional wind for Jan and Feb 1979 from the analysis using satellite data (SAT) and for a NOSAT reanalysis.

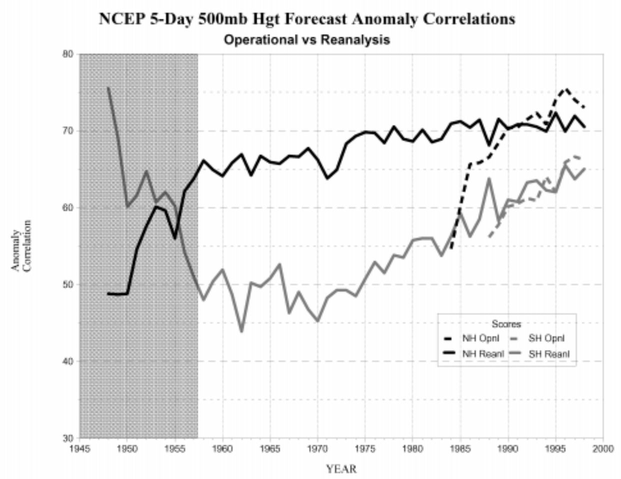

FIG. 7. Annually averaged 5-day anomaly correlation for the 50 yr of reanalysis forecasts (full lines), as well as the operational scores (dashed lines), which are available only for the last decade. The first decade (shaded) has almost no data in the Southern Hemisphere, so that the high anomaly correlations simply represent agreement of the model with itself.

marized by Fig. 7, which compares the skill of the operational forecasts (affected also by changes in the model and data assimilation methods) with the reanalysis forecast skill. The pre-1958 era is shaded to indicate that this is the least reliable period, especially for the SH, where high correlations between analysis and forecasts in 1948 are simply the result of a lack of observations, that is, the "reanalysis" is mostly a model forecast. However, this is clearly not the case in the NH even before 1958. Indeed, Fig. 7 shows that with a modern four-dimensional data assimilation system even the early upper-air observing system can produce fairly skillful initial conditions in the NH.

The ability to produce fairly accurate initial conditions in the NH extratropics even before 1958 is confirmed by two forecasts of major events in the earliest period. The first is a forecast of the famous Thanksgiving storm of 1950, which had a profound influence in the development of numerical weather prediction (Phillips 1958; Smith 1950). Figures 8a and 8b present the impressive 96-h prediction and verifying reanalysis for the storm of 26 November 1950. The hemispheric anomaly correlation for this case is 0.76, indicating a remarkable degree of accuracy, suggesting that this historic storm was actually quite predictable. The rather high predictability of this historic storm is confirmed by the fact that all forecasts with lead times from 4.5 days to 1 day verifying on the same day show good agreement in its prediction. The second storm is the equally famous North Sea gale of 31 January–2 February 1953 that broke dikes in Holland and caused thousands of deaths throughout northern Europe. The forecasts from the reanalysis initial conditions (Fig. 9) indicate that a current data assimilation system would have been able to provide gale warnings up to 4 days in advance.

4. Use of reanalysis in climate studies and the impact of the observing systems

Thousands of scientists from all over the world have already made extensive use of data from the NCEP–NCAR and other reanalysis projects. Many studies compare reanalysis output data with various types of real-world estimates and with other reanalysis projects. In this section we present several climate applications, with emphasis on the impact of changes in the observing system on the climatology of the reanalysis. Figure 10a shows the bias in the temperature anomalies defined for a climatology corresponding to 1979–97, and Fig. 10b the geographical distribution of this bias at 200 hPa, where it is maximum. This should caution users interested in long-term studies to take into account the possible introduction of artificial jumps and trends into the reanalysis by changes in observing systems (Trenberth et al. 2001). For this reason, we recommend that anomalies for periods before 1979 be computed with respect to a presatellite climatology (e.g., 1958–78).

Figure 11 shows the monthly zonal mean of the zonal wind at the equator for the 50 yr of reanalysis. The quasi-biennial oscillation (QBO) is very apparent throughout the reanalysis, although in the first decade the available rawinsonde observations were not abundant enough to determine its strength in the reanalysis. Because of the sparsity of equatorial rawinsondes, the amplitudes are somewhat underestimated even in later years, but the reanalysis provides for the first time a long-term global indication of the timing and 3D structure of the QBO.

While the NCEP analysis system efficiently assimilates upper-air observations, it is only marginally influenced by surface observations because the model orography differs from reality, and because surface observations do not affect significantly the upper-air potential vorticity. Furthermore, the 2-m temperature analysis is strongly influenced by the model parameterization of energy fluxes at the surface, and for these reasons is classified as a B variable. We compared monthly mean 2-m temperature produced by the NCEP–NCAR reanalysis with the surface analysis based purely on land and marine 2-m surface temperature observations compiled by Jones (1994). Despite the problems mentioned above, Fig. 12 shows a fairly good correspondence between the time series, including the "climate shift in the mid-to-late 1970s" noted recently in the literature (Trenberth and Hurrell 1994). Figure 13 compares surface temperature anomalies from the Shanghai Observatory with the reanalysis estimated at the closest grid at 2.5° by 2.5° resolution, which happens to be an "ocean," not a "land" point in the reanalysis. Despite the distance to the exact location and the lack of effective use of the surface data in the reanalysis, there is good correspondence between the two estimations of annual anomalies. It is interesting to note that after 1980 the two series remain parallel, but the Shanghai observations are higher by about 0.5 K or more. This shift could be due to a change in the surface station or to increasing "urban heat island" effect. This suggests that similar comparisons with other stations may provide a useful tool in assessing the impact of urbanization effects on surface temperature and help separate them from climate trends.

Figure 14 shows the imbalances in the global mean energy budgets at the surface, at the top of the atmosphere, as a 12-month running mean over the 50 yr of reanalysis. The atmosphere (in the reanalysis) lost energy throughout the 50 yr, consistent with a cold bias in the

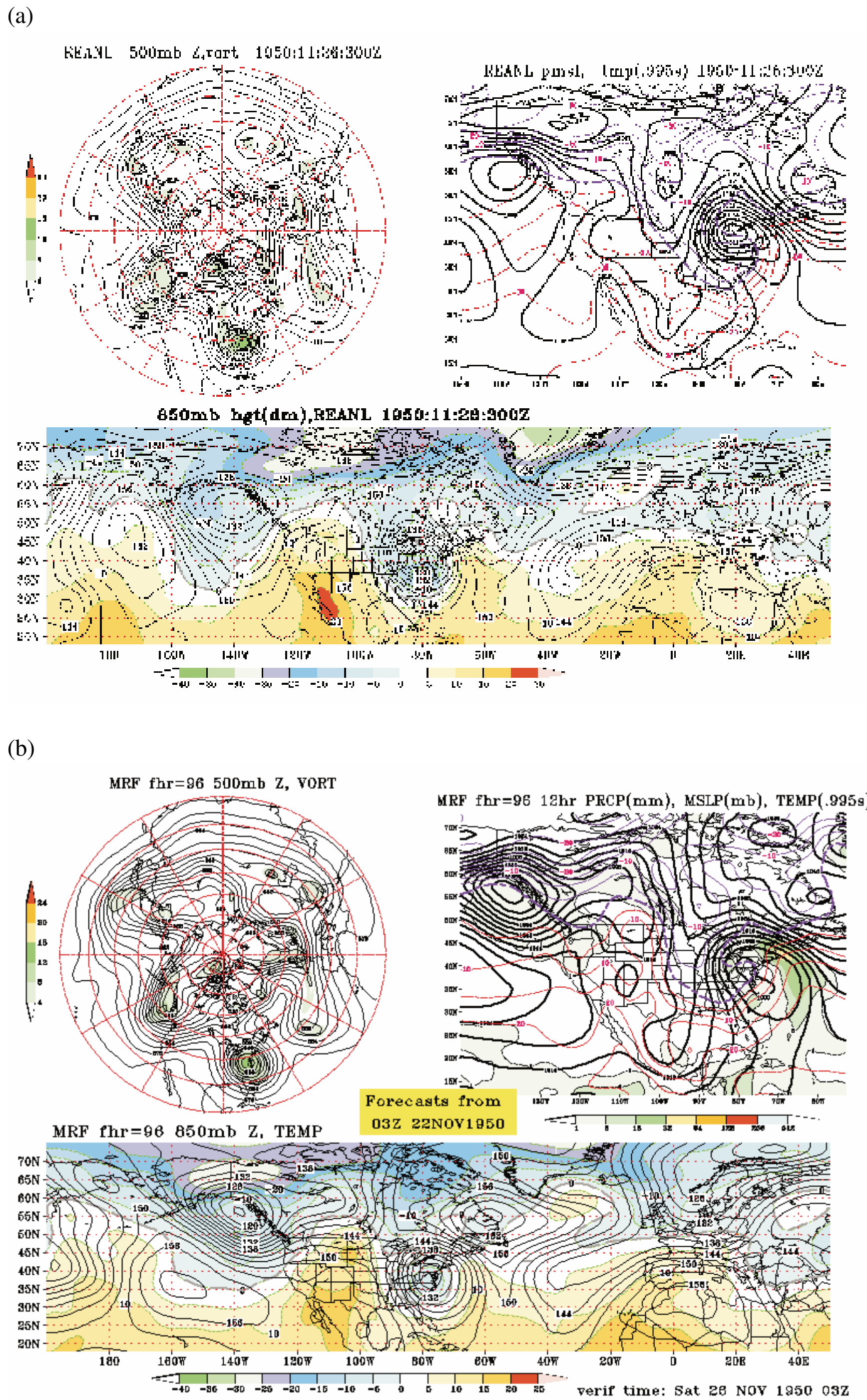

Fig. 8. (a) Analysis valid at 0300 UTC 26 Nov 1950: (upper-left panel) hemispheric 500-hPa heights and absolute vorticity, (upper-right panel) mean SLP (MSLP) (hPa) in black, lowest model level temperature (°C), with temperatures above freezing in dashed red, below freezing in dashed blue, 0°C in bold dashed blue, and (lower panel) 850-hPa-height contours (dm) and shaded temperature (°C). (b) The 96-h prediction from the reanalysis valid at 0300 UTC 26 Nov 1950. Panels are the same as in Fig. (a) except that the upper-right panel includes 12-h accumulated precipitation in green-shaded contours.

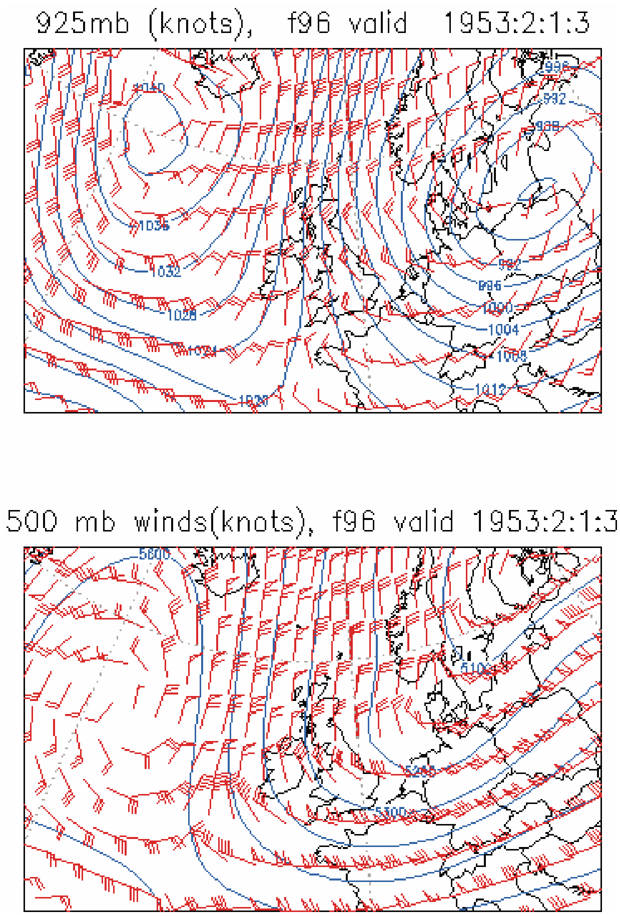

FIG. 9. The 96-h forecast valid at 0300 UTC 1 Feb, indicating the North Sea gale that caused thousands of deaths in northern Europe.

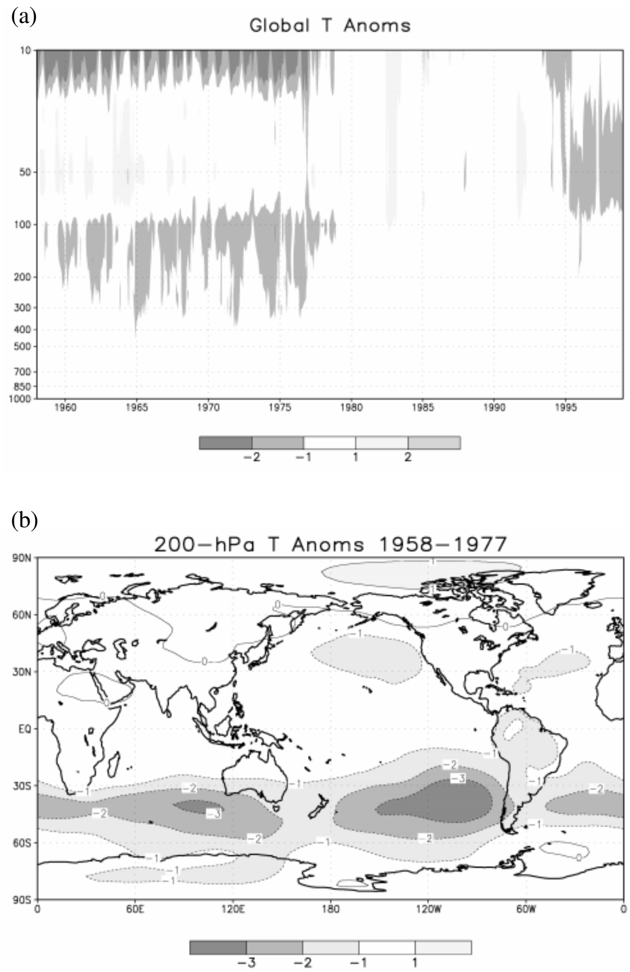

FIG. 10. (a) Cross section of globally averaged temperature anomalies showing the impact of the satellite observing system introduced in 1979. (b) Geographical distribution of the bias of the temperature at 200 hPa defined for 1958–77 and compared with the climatology defined for the years 1979–97.

atmospheric model used in the data assimilation system. At the top of the atmosphere, the reanalysis reflected too much shortwave radiation to space. The deficit to space increased over the years in the reanalysis, reflecting an increase in outgoing longwave radiation that was particularly strong in the late 1970s when satellite temperature soundings were introduced. Changes in the surface energy budget reflect primarily changes in the latent heat flux. The surface net heat flux imbalance has a very similar pattern to global mean precipitation with a correlation of –0.90. The CD-ROM documentation also shows that the variable moisture loading in the atmosphere, which peaks in July when the global mean temperature is highest, causes an annual variation in global mean surface pressure.

Isentropic Potential Vorticity (IPV) has become widely used in diagnostic studies because it is individually conserved under adiabatic, frictionless motion. The NCEP–NCAR reanalysis includes four-times daily IPV at 11 levels of potential temperature, computed directly from the model variables. This allows higher accuracy than a posteriori computations. For example the reanalysis IPV has been used to show that the decrease in total ozone in the NH midlatitudes during the last decade is due to a poleward shift in the upper-level subtropical polar fronts, rather than to changes in the chemical reactions (R. Hudson 2000, personal communication).

5. Problems and known errors in the reanalysis

In this section we briefly review some of the *uncorrected* problems that have been uncovered in the reanalysis. These problems, and many other errors that *were corrected in time* within the reanalysis, were discovered both by internal NCEP monitoring and by outside users who had access to early results. Some of the problems were inevitable, such as those due to changes in the observing systems or to model deficiencies whose improvement is a long-term project. Some were mistakes corrected once they were discovered, but when they affected periods longer than a few months, it was not possible to rerun the reanalysis with the corrected version. We have tried to make the users aware of these problems, and detailed information is available at the reanalysis Web site (http://wesley.wwb.noaa.gov/Reanalysis.html). Not surprisingly, many problems were also discovered in the observations themselves, and both corrected and uncorrected problems were reported back to NCAR, so that future reanalyses will benefit from the a priori knowledge. The "metadata" included in the BUFR archive, such as differences between observations and the 6-h forecast, and other quality control information, can also be very useful in this respect.

Three human errors made in the assimilation were discovered too late to repeat the period of reanalysis affected by the error. Their impact is discussed here and in further detail on the reanalysis Web page.

(1) During 1974–94, snow cover corresponding to 1973 was used every year by mistake. This error has its largest impact near the surface over regions where the correct mask is snow free and the 1973 mask is snow covered, or vice versa. An examination of the various snow masks suggests that North America has the most impact in transition seasons (October in particular), less in winter, and least in the summer (see the Web site above for more details). An important but inevitable variant of this problem occurs for the years when observed snow cover was simply not available, prior to 1967 in the NH, and throughout the reanalysis in the SH. In the reanalysis we used climatological snow cover in the SH, and we used climatologically constrained, model-predicted snow cover in the NH for 1948–67.

(2) PAOBs are estimates of the sea level pressure produced by Australian analysts using satellite data, conventional data, and time continuity for the data-poor Southern Ocean. PAOBs are used in the current NCEP operational analyses but with weights four times lower than other observations (the observation errors for PAOBs are assumed to be 2 hPa compared to 1 hPa for stations), and they are not used at all at ECMWF. Unfortunately, in the NCEP–NCAR reanalysis the use of a different convention for longitude led to a shift of 180° in the use of the data for 1979–92.

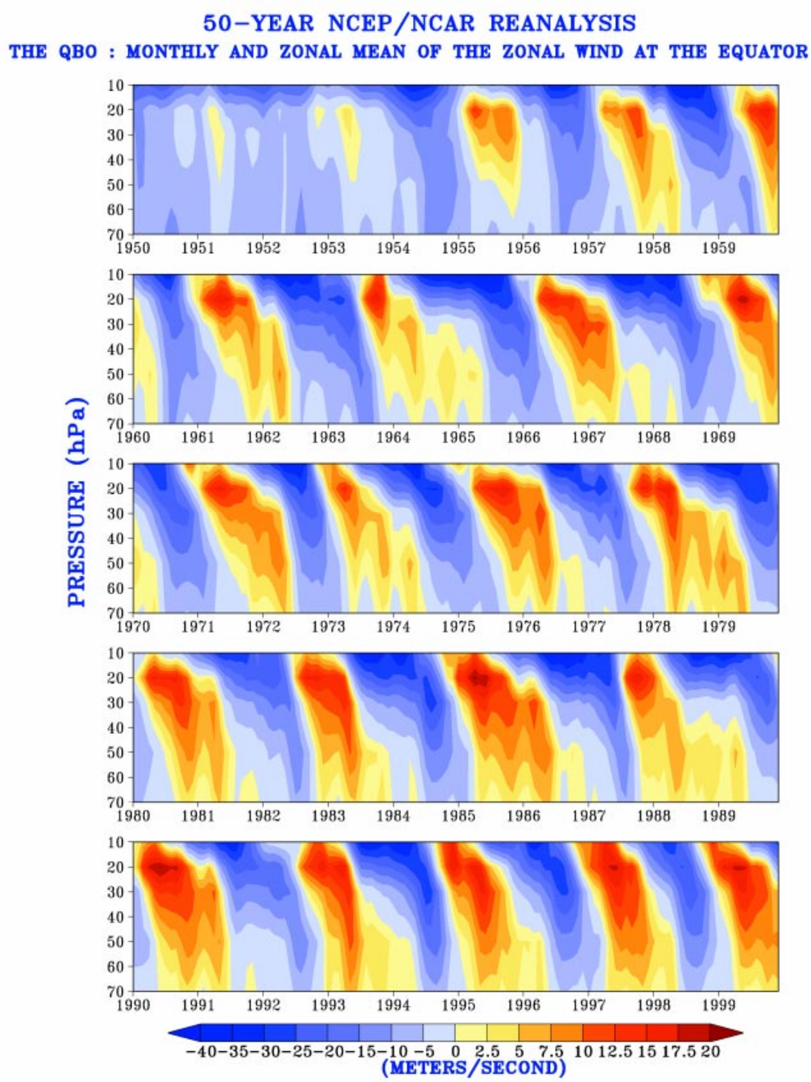

Fig. 11. Monthly zonal mean of the zonal wind at the equator for 50 yr of reanalysis above 100 hPa.

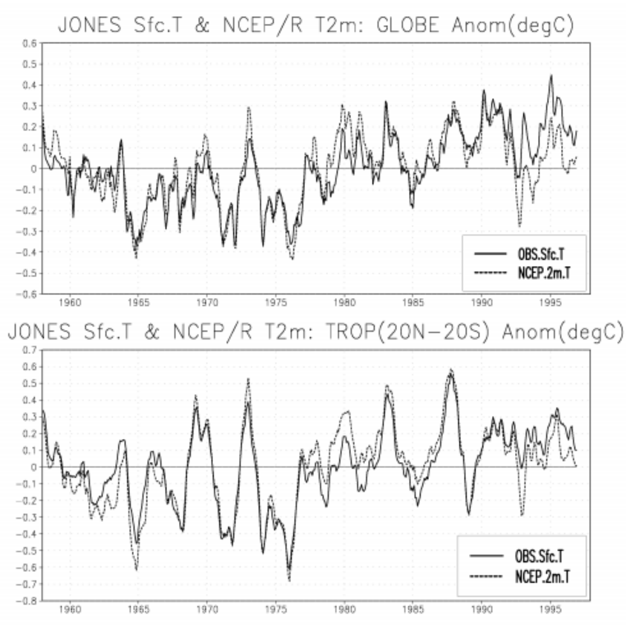

FIG. 12. Time series of global and tropical mean surface monthly temperature anomalies from NCEP–NCAR and from Jones (1994).

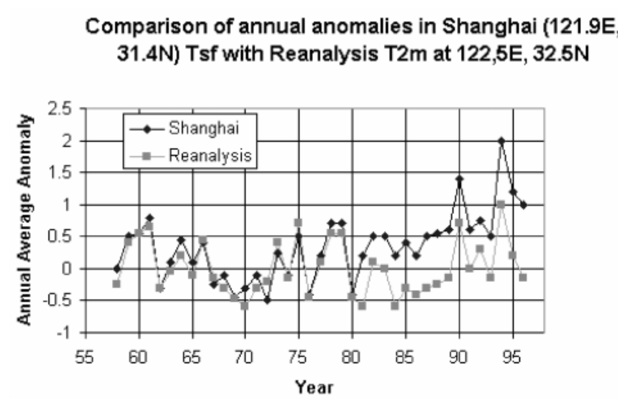

FIG. 13. Comparison of annually averaged surface temperature anomalies measured at the Shanghai Observatory (31.4° lat, 121.9° long) with the reanalysis estimated at the closest grid at 2.5° by 2.5° resolution, which is an "ocean" point.

To assess the impact of this error, the original reanalysis was repeated for 1979 with correctly located PAOBs. This impact turned out to be relatively small for three separate reasons: i) As indicated above, the weights given to the PAOBs are small compared to other surface pressure observations. ii) Due to geostrophic adjustment, the assimilation system does not "retain" surface pressure observations, especially in the Tropics. The sea level pressure is changed in the analysis to become closer to the PAOBs, but this change quickly disappears during the 6-h forecast. iii) The PAOBs with large differences with the first guess were eliminated by the optimal interpolation–based quality control.

The comparison for 1979 with the corrected analysis led to the following conclusions: (a) The NH was not affected at all. (b) The SH was significantly affected only poleward of 40°S. (c) The largest differences were close to the surface and decreased rapidly with height. (d) Day-to-day differences were small on a planetary scale but significant on a synoptic scale. (e) Differences decreased rapidly as the timescale went from synoptic to monthly (because of 3, above). (f) The impact on monthly means of quadratic quantities used for budgets, transports, etc. is negligible for all cross products except for the squares of the geopotential anomalies $\overline{\phi'\phi'}$, where the instantaneous errors are squared before the geostrophic adjustment minimizes their effect. In other words, the effect of the PAOBs error on monthly mean transports of momentum, geopotential, or temperatures such as $\overline{u'v'}$, $\overline{v'\phi'}$, or $\overline{u'T'}$ is negligibly small. (g) The rms differences in the 500-hPa heights with and without the error were of similar magnitude as the difference between the NCEP and ECMWF operational analyses south of 40°S (a measure of uncertainty in the analysis). (h) The rms difference in the 850-hPa temperature was smaller than the rms difference between the NCEP and ECMWF operational analyses. In summary, SH studies using monthly mean data should not be adversely af-

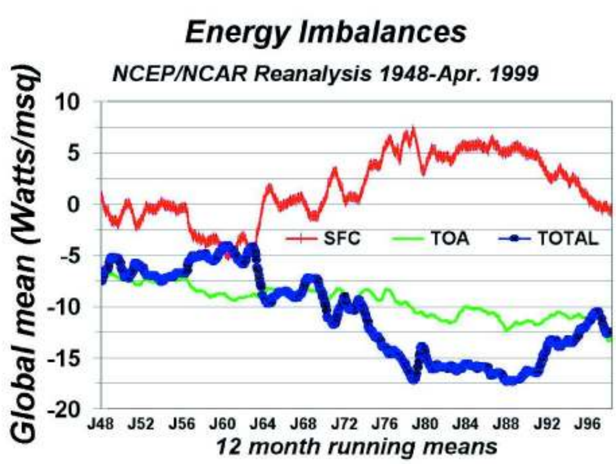

FIG. 14. Monthly mean globally averaged net energy flux from the atmosphere to the earth's surface (SFC), at the TOA, and the total energy gained by the atmosphere each month (TOTAL) (the sum of SFC and TOA). Positive fluxes in SFC and TOA are downward; negative values of TOTAL indicate a loss of energy by the atmosphere. A 12-month running mean has been applied.

fected [except for quadratic perturbations of the sea level pressure (SLP) or geopotential height]. Studies of synoptic-scale features south of 40°S are affected by the addition of an error that has a magnitude comparable to the basic uncertainty of the analyses. This unfortunate error, which affects the reanalysis from 1980 to 1992, was corrected in the NCEP–Department of Energy (DOE) reanalysis (section 8).

(3) Throughout the reanalysis, the forecast model had a formulation of the horizontal moisture diffusion, which unfortunately caused moisture convergence leading to unreasonable snowfall over high-latitude valleys in the winter ("spectral snow"; see Fig. 18 near Siberia). This problem has been corrected in the NCEP operational model as well as in the second stage of the reanalysis (Reanalysis 2) and is discussed in more detail on the reanalysis Web site. The effects are present in the "PRATE" field, but has been corrected a posteriori in the "XPRATE" model precipitation (which is the one included in the CD-ROM). However, moisture fluxes cannot be corrected a posteriori. Another minor model problem occurred in the sensible heat flux parameterization, which allowed surface sensible heat flux to go to zero if the surface wind vanished. As a result, the surface temperature could occasionally have unrealistically high values. This parameterization was corrected early during the course of the reanalysis.

6. Comparisons of fluxes estimated by the NCEP–NCAR, NASA/DAO, and ECMWF reanalyses

This section compares fluxes and precipitation from the NCEP–NCAR reanalysis discussed in this paper, the ECMWF 15-yr reanalysis (ERA-15), and the National Aeronautics and Space Administration (NASA) Data Assimilation Office (DAO) 17-yr reanalysis. Recall that these fields are of type C, that is, produced by the model while it is "nudged" toward the atmosphere during the data assimilation. It is important to have available several reanalyses to make an estimate of the reliability of their results, especially for quantities and trends that cannot be accurately estimated from direct measurements. In this section we compare reanalyses' surface and top-of-the-atmosphere (TOA) fluxes with independent estimates from observations. Section 7 assesses the importance of differences in upper-air variables and trends by comparing them with interannual variability.

A large number of studies of precipitation and surface and top of the atmosphere fluxes in the reanalyses were presented at the First and Second World Climate Research Programme (WCRP) International Conferences on Reanalyses held in 1997 and 1999 (WCRP 1998, 2000). A review of several studies of air–sea fluxes from reanalyses and a comprehensive comparison of air–sea fluxes from four global reanalyses (including the NCEP–DOE reanalysis) with independent estimates over the period 1981–92 can be found in section 11.4 of the final report of the Joint WCRP–Scientific Committee on Oceanic Research (SCOR) Working Group on Air–Sea Fluxes (Taylor 2000). Stendahl and Arpe (1997) presented a comprehensive evaluation of the hydrological cycle in the reanalyses; an updated evaluation can be found in Arpe et al. (2000).

a. *Surface energy and momentum fluxes*

There is no "ground truth" for most of these fluxes, since they are not directly measured and have to be estimated indirectly from observations and sometimes significantly tuned to ensure net energy balance. Satellites, however, directly measure TOA radiative fluxes. In this section we compare monthly mean surface fluxes and precipitation as well as TOA radiative fluxes from the three reanalyses to each other and to independent estimates.

Table 1 shows global mean components of the ocean surface energy balance for the three reanalyses for 1981–92. It also shows the da Silva et al. (1994) original air–sea fluxes averaged over 1981–92 [based on the Comprehensive Ocean–Atmosphere Data Set (COADS)] and satellite-based estimates of surface net shortwave radiation (NSW) by Darnell et al. (1992) and net longwave radiation by Gupta et al. (1992) averaged over July 1983–June 1991. It shows the level of uncertainty from observational estimates and from the reanalyses for different components of the surface fluxes.

A comparison of ocean surface fluxes from the reanalyses with da Silva et al. (1994) reveals similar patterns in long-term means and in annual cycles. Temporal correlations of monthly mean evaporation from da Silva et al. (1994) with the NCEP–NCAR reanalysis for 1981–92 (Fig. 15) are highest where the COADS observations are most abundant. Operational forecasts display nearly as much skill in the Southern Hemisphere as in the Northern Hemisphere (Kalnay et al. 1998), indicating that modern data assimilation

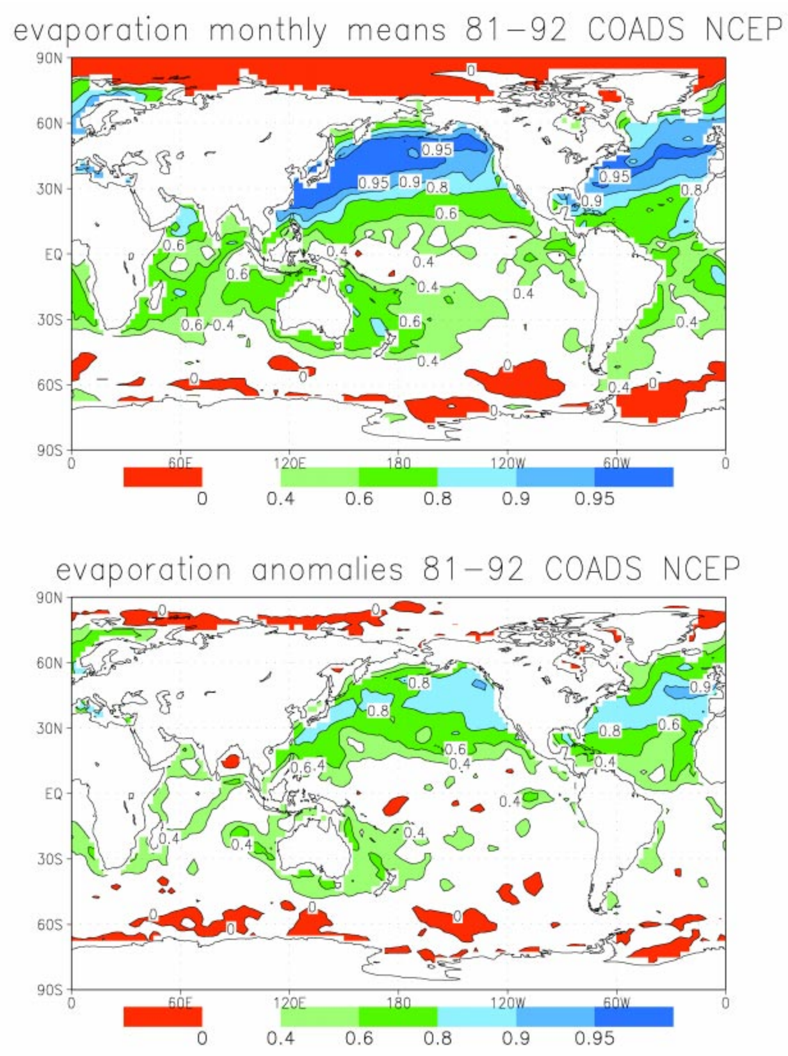

FIG. 15. Time correlation of evaporation from da Silva et al. (1992) and from the NCEP–NCAR reanalysis for 1981–92 for (top) monthly means and (bottom) monthly mean anomalies from the annual cycles. Contours are 0.0, 0.4, 0.6, 0.8, 0.9, 0.95.

Similar patterns of high temporal correlation with da Silva et al. (1994) over regions of high COADS observational density and low correlation in COADS data-sparse regions are observed for evaporation, surface stress, and net heat flux for all three reanalyses (not shown). Correlations for net heat flux and surface stress are summarized in Tables 1 and 2 in appendix B of the documentation in the CD-ROM. Anomalies in these fields from the three reanalyses correlate well with each other over the oceans except near the poles and the equator; evaporation anomalies from the three reanalyses do not agree with each other over land.

White and da Silva (1998) show many other characteristics of reanalyses fluxes: (a) In the equatorial Pacific, ERA-15 evaporation is significantly lower after 1987 than before, a change not seen in the other two reanalyses. Evidence of a similar abrupt change has been found in other fields from the ERA-15 reanalysis (Stendel and Arpe 1997; see also Fig. 20). (b) In the equatorial Pacific, zonal surface stress from ERA-15 is somewhat stronger than da Silva et al. (1994), while zonal surface stress from the NCEP reanalysis is too weak (White 1996b). (c) The time mean surface NSW from ERA-15 and the Goddard Earth Observing System (GEOS) shows little evidence of the influence of low-level systems produce accurate daily analyses of the Southern Hemisphere. The differences in correlations between COADS data-rich and data-poor regions are not nearly so evident in correlations of reanalyses with each other or with independent estimates of fluxes and precipitation based on satellite data. This suggests that the large variation in correlation in Fig. 15 is due to the relative lack of ship observations outside 20°–60°N and that the usefulness of COADS in defining interannual variability may be largely limited to the Northern Hemisphere midlatitudes and a few other regions.

TABLE 1. Global mean ocean surface energy balance (W m^{-2}) estimated from COADS data by da Silva et al. (1994), from the three reanalyses, and from satellite-based estimates.

	COADS (original)	ERA-15	GEOS	NCEP	Satellite
Sensible heat	−10	−9.8	−10.6	−10.9	
Latent heat	−88	−103	−80	−93	
Net shortwave	+170	+160	+198	+166	+173
Net longwave	−49	−50.6	−67.9	−56.4	−41.9
Net heat flux	+23	−3.4	+39.8	+5.6	

oceanic stratus clouds, while NCEP's NSW shows more evidence of the influence of low-level stratus cloud.

It has been suggested that satellite estimates of surface NSW may be more reliable than other global estimates of surface NSW, although satellite estimates of surface NSW can differ markedly from surface measurements (White 1996a). Temporal correlations of reanalysis estimates of surface NSW with satellite estimates of surface NSW by Darnell et al. (1992) are given in Table 3 in appendix B of the documentation in the CD-ROM. ECMWF has more variability in monthly anomalies of surface NSW in the Tropics than does the satellite estimate; NCEP has less than the satellite estimate.

b. Top of the atmosphere

At the TOA, Earth Radiation Balance Experiment (ERBE) observations of both short- and longwave radiation can be compared with the reanalyses. Temporal correlations are given in Tables 4 and 5 in appendix B of the documentation in the CD-ROM. The reanalyses all have less TOA NSW than ERBE over the tropical oceans, while GEOS has more TOA NSW than ERBE outside the Tropics. The NCEP time mean TOA outgoing longwave radiation (OLR) for 1985–89 is closest to ERBE, while the ERA-15 estimate is too high and GEOS too low in the Tropics and too high outside the Tropics. ERA-15 and GEOS display too much variability in monthly anomalies of TOA OLR in the Tropics; NCEP has too much variability in midlatitudes and too little over the tropical oceans.

c. Precipitation

Figure 16a compares zonal mean precipitation over land (top) and ocean (bottom) from the three reanalyses with two independent estimates by Xie and Arkin (1996, 1998, hereafter XA) and by the Global Precipitation Climatology Project (GPCP; WCRP 1990) for 1988–92. Figure 16b compares the standard deviation of monthly mean rainfall anomalies from the three reanalyses and from XA over land (top) and ocean (bottom) for 1988–92. The results suggest that NCEP and GEOS underestimate variability over the tropical oceans and the ERA-15 reanalysis substantially overestimates it. All three reanalyses and GPCP have more variability in oceanic precipitation at higher latitudes than XA (it should be noted that infrared satellite estimates in extratropical latitudes are less reliable). Rms differences from the monthly means of XA are shown in Table 2. Of the three reanalyses, ERA has the lowest rms difference over the Northern Hemisphere continents and the extratropical oceans, but the largest rms difference over the Tropics, especially over land. NCEP has the lowest rms differences in the Tropics and the largest in the Northern Hemisphere. Table 6 in appendix B in the CD-ROM documentation presents temporal correlations of precipitation from the reanalyses and GPCP with the XA estimates.

7. Comparisons of reanalyses estimates of variables of types A, B, and C

a. Examples of variables of types A, B, *and* C

As indicated in the introduction, we should expect the reanalyses to agree fairly well with each other for fields based on type A variables that are strongly influenced by observations. An example of such a field is the zonally averaged u component of the wind, which is primarily nondivergent (Fig. 17) except in the Tropics where the model influence is larger and makes it a B variable. The zonally averaged meridional velocity, not shown, corresponds to divergent flow and is therefore a B variable. The NCEP–NCAR and ERA-15 reanalyses are qualitatively very similar for the u

TABLE 2. Rms differences in monthly means (mm day^{-1}) over (a) land and (b) ocean in precipitation between the reanalyses and Xie and Arkin (XA) averaged over different regions for 1981–92. Also shown are rms differences in monthly means between GPCP and Xie and Arkin for 1988–94.

	ERA15-XA	GEOS-XA	NCEP-XA	GPCP-XA
a) Land monthly means				
Global	1.59	1.41	1.48	0.39
20°–80°N	0.81	0.96	1.10	0.25
20°S–20°N	3.34	2.51	2.38	0.67
20°–80°S	1.28	1.11	1.29	0.35
b) Ocean monthly means				
Global	1.81	1.92	1.91	1.21
20°–80°N	1.25	1.48	1.51	0.99
20°S–20°N	2.84	2.80	2.77	1.89
20°–80°S	1.15	1.32	1.31	0.63

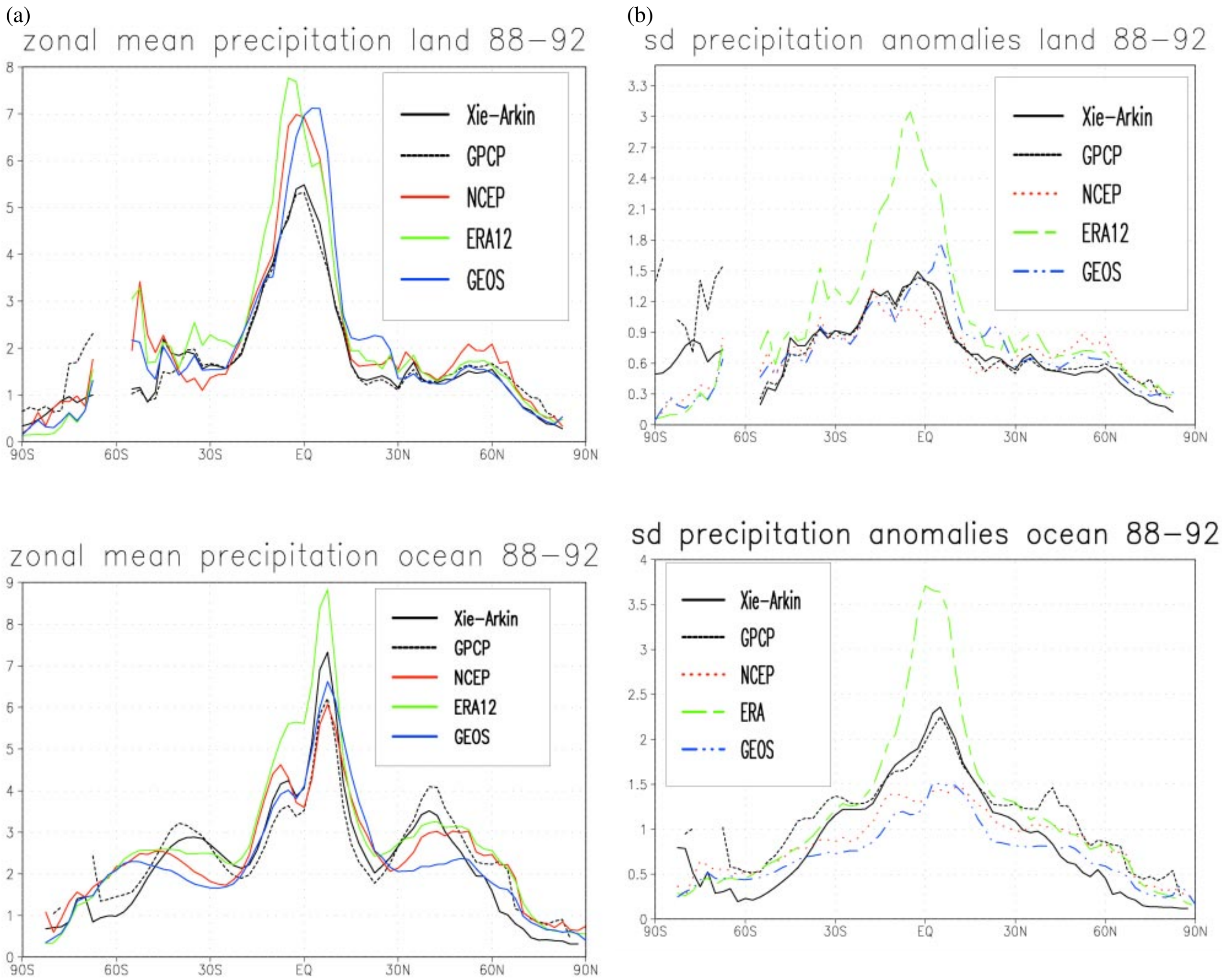

FIG. 16. (a) Zonal mean precipitation over (top) land and (bottom) ocean averaged over 1988–92. The black solid curve indicates the Xie–Arkin estimate; the dashed black curve, the GPCP estimate; the green curve, the ERA estimate; the red curve, NCEP; and the blue curve, GEOS. (b) Same as in (a) but for the standard deviation of the precipitation anomalies.

field but with significant differences in the Tropics, especially when scaled with the interannual variability. Precipitation (from the model) is an example of a C variable and Fig. 18 compares the reanalyses with Xie and Arkin's (1998) estimation of precipitation from observations also known as CPC Merged Analysis of Precipitation (CMAP). Except for the spectral valley snow problem in the NCEP precipitation discussed in section 5, apparent in high latitudes over Asia and North America, both systems produced fairly realistic precipitation. Differences are smaller than the range of the field (~2 mm day^{-1} compared to a range of 0–17 mm day^{-1}) and close to the temporal variation (not shown). Recall that the field showed in this figure for the NCEP reanalysis is PRATE, but that the spectral valley snow problem has been corrected a posteriori in the XPRATE field included in the CD-ROM.

b. Interannual variability

The December–January–February (DJF) interannual variability (IAV) of the 850-hPa temperature with respect to the 15-yr mean is shown in Fig. 19. The bottom two panels show the ratio of IAV to total temporal variance. High values imply that the interannual variability is significant compared to the climatological seasonal cycle. The areas of high values in the Tropics show that about half of the total variance comes from IAV and that the annual cycle is rather weak. This is also the region where SST anomalies have the most profound effect on the circulation and, hence, where ENSO predictions are most successful. The two reanalyses agree remarkably well in the ratio of interannual to total variability except over Brazil. Scaling of the differences by total temporal variance allows intervariable comparisons and gives the user a sense of their reliability when applying the data to physical problems.

c. Trends

Reanalyses allows an easy calculation of long-term trends in high-interest variables such as free-atmosphere air temperature. However changes in the observing systems within the reanalyses may obscure climate changes. These spurious climate perturbations need to be assessed and perhaps corrected before unbiased climate assessments can be made. Agreement between two reanalyses in the climate trend is an important necessary but not sufficient condition for confidence in climate trends. As an example, we present in Fig. 20 the linear trend of the zonally averaged temperature anomaly. There are several features in the trend where there is reasonably good agreement, leading to some confidence in the results, but the pattern in the Tropics is profoundly different. ERA-15 indicates a very large positive warming in the lower tropical troposphere, which is not present in the NCEP reanalysis. A comparison of temperature anomalies at 850 hPa with the NASA/DAO reanalysis (not shown) showed very good agreement with the NCEP anomalies. As shown by Fiorino et al. (1999) the ERA-15 apparent warming resulted from an interaction between the model and the use of TOVS radiances that locked in a positive bias during a sudden and large change in the microwave sounding unit channels in November 1986 (see also Trenberth et al. 2001).

As indicated before, an important recommendation for the estimation of trends, in addition to the intercomparison of the reanalyses, is to compute trends separately for the periods before and after 1979, and to compare NH and SH trends. Agreement among these different estimates should increase the confidence in the results.

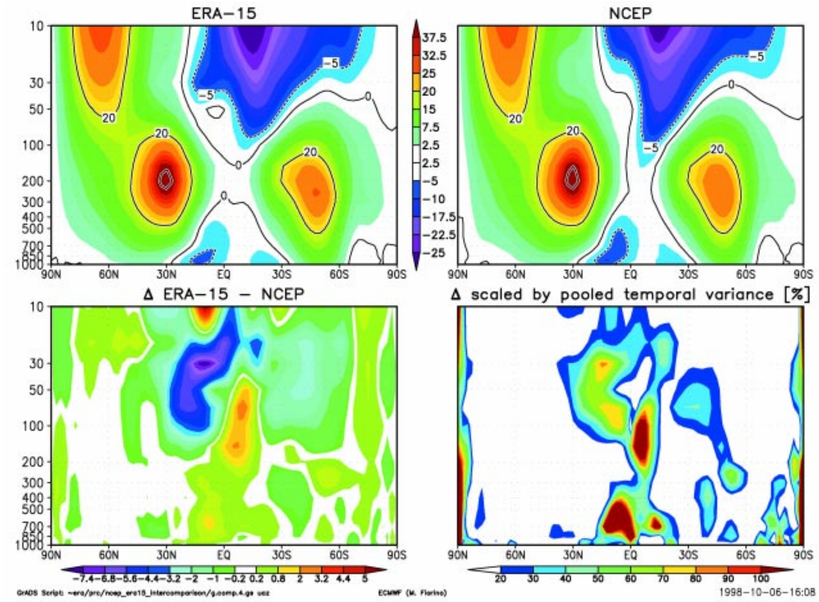

Fig. 17. Intercomparison of the mean DJF zonally averaged zonal wind during the ERA-15 period Jan 1979–Feb 1994 for the ERA-15 and NCEP Reanalyses. The NCEP – ERA-15 difference, and the difference scaled by the total temporal variability (in %), are displayed in the bottom two panels.

8. Summary and future work

We have emphasized that although the NCEP–NCAR reanalysis system was essentially unchanged during the more than 50 years processed, there were two major changes in the observing system. The first took place during 1948–57, when the upper-air net-

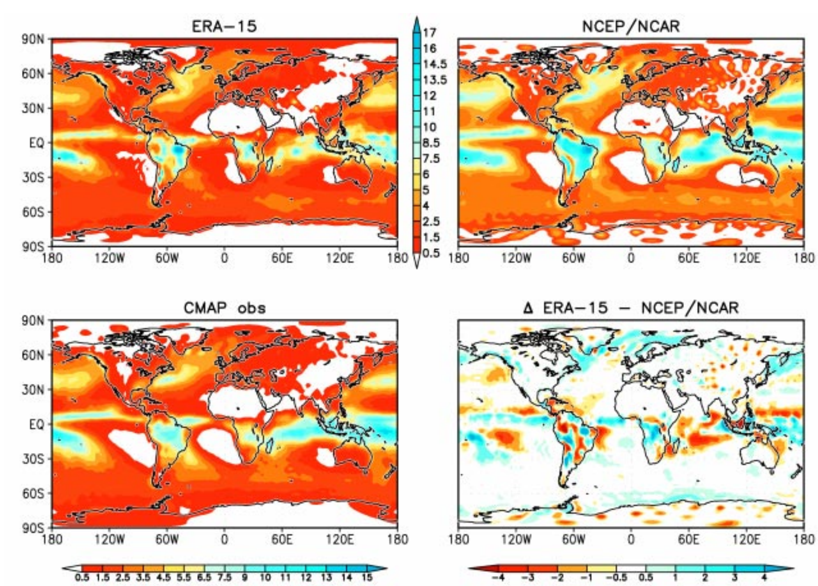

Fig. 18. Intercomparison of the mean DJF precipitation (top panels) against an analysis of observations and the difference during ERA-15 period Jan 1979–Feb 1994.

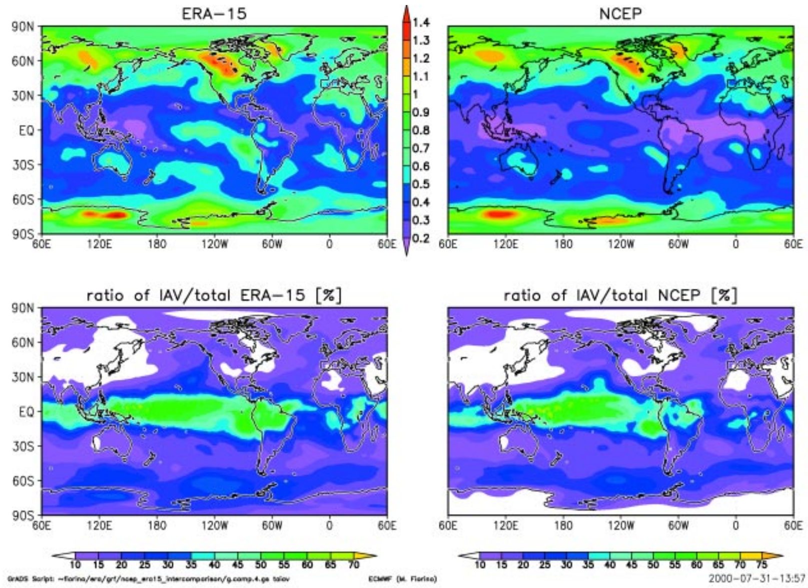

FIG. 19. As in Fig. 1 except for 850-hPa interannual variance of temperature. The ratio of the interannual variance to the total variance is shown in the bottom panels.

work was being established, and the second in 1979 when the global operational use of satellite soundings was introduced. The introduction of satellite data in 1979 resulted in a significant change in the climatology, especially above 200 hPa and south of 50°S, suggesting that the climatology based on the years 1979–present day is most reliable. The 8-day "reforecasts" indicate that the first decade is much less reliable than the last four. Nevertheless, in the NH it was possible to skillfully reforecast 4 days in advance the first "storm of the century" of November 1950 and the North Sea gale of February 1953 that cost thousands of lives in Europe.

Reanalysis can be used for daily to seasonal and interannual timescales. However, because of the changes in the observing system, estimation of trends with the reanalysis is not recommended. If it is attempted, several checks should be also performed to test the reliability of the results, including the following: (a) Check the observational coverage that was available to the reanalysis (available on the CD-ROM). It should be remembered that rawinsonde observations are much more important than surface observations for the reanalysis: in the absence of rawinsondes, the reanalysis results are not reliable even if there are plenty of surface observations. (b) Compute trends for the periods before and after 1979 separately. The climatology before 1979 is more dominated by the model climatology in data-sparse areas, leading to the generation of spurious trends. (c) Compare trends for the SH with those of the NH. Agreement among the trends could increase confidence in the results. (d) Compute the trends for more than one reanalysis. Again, agreement among the trends derived for reanalyses increases their reliability, although it is not sufficient to ensure it.

In addition to the inevitable problems associated with changes in the observing system and model deficiencies whose corrections is a long-term project, human errors were also detected in the course of the project. Many errors were detected and corrected in time to repeat short reanalysis periods. However, some errors were not detected until long periods were already processed and could not be repeated. We reviewed these errors and their consequences, and posted detailed discussions online. They have all been corrected in a reanalysis being performed by NCEP in collaboration with the DOE for the period 1979–98 (Reanalysis 2).

The NCEP–DOE Reanalysis 2 is a follow-on to the NCEP–NCAR Reanalysis Project. Its purpose is to correct known problems in the NCEP–NCAR Reanalysis 1 and to serve as a basic verification dataset for the Second Atmospheric Model Intercomparison Project. In this follow-on project, global analyses are made using an updated forecast model (the one used in the NCEP–NCAR Reanalysis 1 was developed in 1994), updated data assimilation system, improved diagnostic outputs, and corrections of the known processing problems. Preliminary results from NCEP–DOE Reanalysis 2 have been encouraging. The corrections to the human processing errors have resulted in changes to some of the fields, and the changes to the system itself, some of which have also become operational at NCEP, have led to other significant improvements. The shortwave fluxes are improved by the introduction of a new shortwave parameterization (based on Chou 1992). Changes in convective parameterization, boundary layer physics, and moisture diffusion have improved the precipitation especially in the summer over the southeastern United States and over the polar regions in winter. Use of observed pentad precipitation in the soil wetness assimilation resulted in much more realistic interannual variability and better fit to observation. At the time of writing, the NCEP–DOE reanalyses for 1979–95 have been completed. The entire project will be finished by late 2000. The up-to-date monthly averaged and selected daily fields are available online at http://wesley.wwb.noaa.gov/Reanalysis2/. It is planned that the full dataset will be sent to NCAR for formal distribution.

The NCEP–DOE Reanalysis 2 should be considered as an updated NCEP–NCAR reanalysis and not a next-generation reanalysis. It is also not a replacement since it will not go back to the 1950s. Although NCEP–DOE reanalysis has some significant improvements, a next-generation reanalysis would have much higher resolution, assimilation of rainfall and radiances, further improvements in the forecast model, and use advanced data assimilation techniques such as 4D-VAR assimilation, improvements already under development or operational at NCEP.

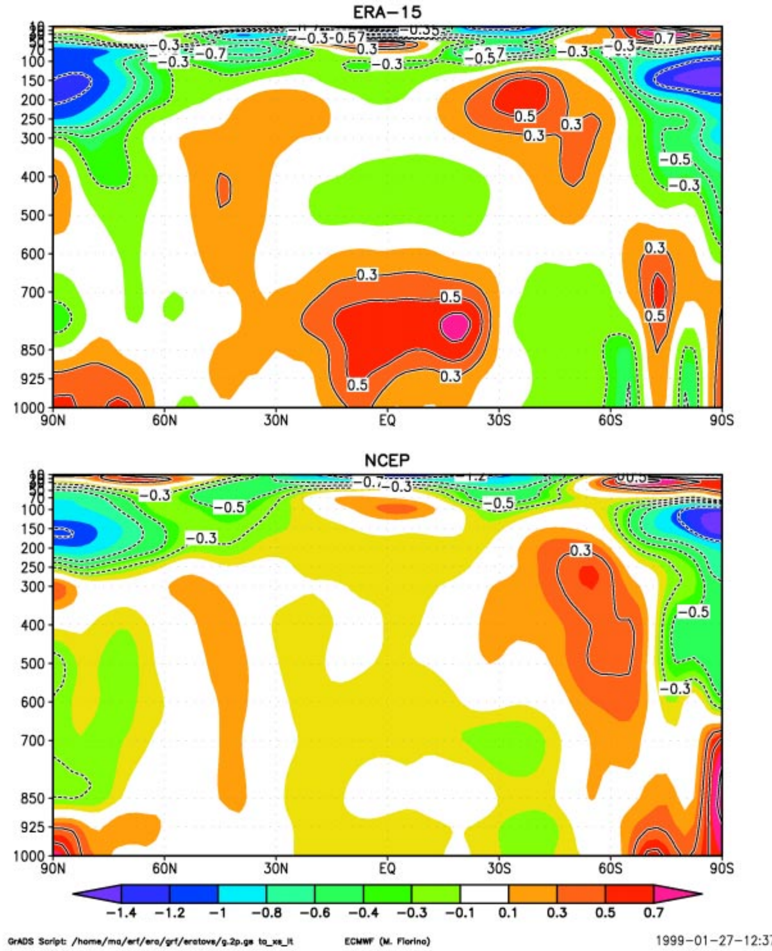

FIG. 20. Intercomparison of the decadal linear trend [°C (10 yr)$^{-1}$] in zonal average temperature anomaly during ERA-15 period Jan 1979–Feb 1994.

NCEP's future reanalysis plans, if supported, call for an updated global reanalysis using a state-of-the-art system every 10 years or so, and a maintenance of a CDAS allowing analysis of current climate anomalies. Within this timescale major improvements in the operational global system should take place, making the previous reanalysis further away from the state of the art, and justifying such major effort. Future reanalyses will be greatly facilitated by the quality-controlled, comprehensive observational database created by the present reanalysis, so that the development and execution of new global reanalyses should be completed in four to five years. In the meantime, it has been suggested that a regional reanalysis over North America would be particularly useful. Following a workshop on regional reanalysis that took place in Norman, Oklahoma, during March 1998, a plan was developed for regional reanalysis. It uses the operational mesoscale Eta Model given by global reanalysis boundary conditions, at about 30-km resolution, more resolution than would be currently possible with a global system, and much higher than the 210 km used in the first global reanalysis. One major addition of the regional reanalysis is the 3D-VAR assimilation of radiances as well as the assimilation of "observed" precipitation. The latter should have the effect of forcing a very realistic hydrologic cycle during the reanalysis. If the regional reanalysis system currently under development is successful, an execution phase will start in 2001. A new global reanalysis could then follow around 2005. The benefits derived from reanalysis to the research and operational communities have been so important that it seems justifiable to support such a continued project as part of the operational mission of the NWS.

Acknowledgments. We are very grateful to the current and former directors of NCEP, Louis Uccellini, Ron McPherson, and Bill Bonner, for their continued support of this project. Without the generous help provided by Jordan Alpert, Alan Basist, Ken Campana, John Derber, Mike Halpert, Don Garrett, Robert Grumbine, John Janowiak, Bert Katz, Dennis Keyser, Kingtse C. Mo, David Parrish, Hua-lu Pan, Richard Reynolds, Chester Ropelewski, Tom Smith, Diane Stokes, and Yuejian Zhu, from NCEP, and from Dennis Joseph, Steve Worley, Chi-Fan Shih, Wilbur Spangler, Bob Dattore, Joey Comeaux, Gregg Walters, and Roy Barnes from NCAR, this project could not have been carried out. The NCEP Central Operations personnel support and the consultation with Cray Research analysts have also been essential.

The UKMO provided the sea surface temperature analysis pre-1982. ECMWF and NASA/GLA have provided us with observations to fill data gaps. Several large datasets for early years were prepared by either the USAF or NCDC sections at Asheville and have been very valuable. Richard Davis was the liaison to this project from NCDC. Ernest Kung (University of Missouri) provided the MIT rawinsonde dataset. John Lanzante from GFDL did the initial stage of processing of the TD54 rawinsonde dataset.

A number of countries directly provided data that helped reanalysis. The tables in the CD-ROM list these sources, and more detailed lists are available. People in many countries and laboratories also deserve credit for data preparation. Key participants are the observers around the world who work day and night to take the observations that make these analyses possible. Their contributions are gratefully acknowledged.

The project has been supported since its inception by the NOAA Office for Global Programs, by the National Weather Service, and by the National Science Foundation (NCAR). Without their enthusiastic support we would not have been able to develop this project. We are particularly grateful to Mark Eakin, Rick Lawford, Mike Coughlan, and Ken Mooney for their encouragement and guidance.

The Advisory Committee, chaired by Julia Nogués-Paegle from 1989 to 1993, by Abraham Oort from 1993 to 1997, and by Randy Dole from 1998 to 1999, has been a continuous source of advice and comfort when problems arose. Mark Cane, Julia Nogués-Paegle, and Milt Halem originally suggested performing a very long reanalysis, and J. Shukla spearheaded such a project throughout the research community. We are grateful to them and to other members of the panel, including Maurice Blackmon, Donald Johnson, Per Kallberg, David Salstein, Siegfried Schubert, John Lanzante, Yochanan Kushnir, John Michael Wallace, and James Hurrell.

Appendix: Introduction to the 51-Yr NCEP–NCAR Reanalysis Monthly Mean CD-ROM

This CD-ROM contains 41 (1958–98) years of selected monthly mean fields from the NCEP–NCAR reanalysis project. Several levels of monthly mean heights, temperatures, winds, specific humidity, and vertical velocity are included, together with precipitation, surface and top of the atmosphere fluxes, and near-surface fields. A monthly climatology of these fields averaged over 1979–98 is included.

For several fields [500- and 700-hPa heights, 700-hPa temperatures, 200- and 850-hPa winds, sea level pressure, and surface temperatures (SST)] we have included 51 yr (1948–98). Independent estimates of precipitation and OLR globally (1979–98) and precipitation and surface air temperature over the United States (1948–98) are included, as are grids of the number of different types of observation by month (1946–98). A comprehensive interactive menu is provided to plot the fields on the CD-ROM.

Additional monthly mean and daily fields can be found on annual CD-ROMs for each year of the NCEP–NCAR reanalysis. As of December 2000, they are available for 1953–99 and can be obtained from the Data Support Services of the National Center for Atmospheric Research. Monthly mean fields after December 1998, including the most recent month processed, can also be found online at http://wesley.wwb.noaa.gov/ncep_data/index_sgi51_png.html.

Problems and questions should be directed to Dr. Glenn H. White, Environmental Modeling Center, W/NP23, WWB, Rm. 207, National Centers for Environmental Prediction, 5200 Auth Rd., Camp Springs, MD 20746; E-mail: Glenn.White@Noaa.Gov; telephone, 301-763-8000 ext. 7238.

To run the demo from Windows95, enter E:\DEMO.BAT at the RUN option from the START menu, assuming the CD-ROM is device E:

To run the demo from MS-DOS or the MS-DOS prompt, enter

E:
DEMO

To run the demo from Windows98,

a) Click on "MyComputer",
b) Click on your CDROM drive,
c) Click on "demo.bat"

To run grads directly

a) Click on "MyComputer",
b) click on your cdrom drive,
c) click on "start.bat",
d) click on "Programs" directory,
e) click on "PCGRADS" directory,
f) click on "grads.exe",
g) press the enter key (to select landscape format),
h) type in the control file you wish to open. "open/data/monthly/hgt.ctl" will open the file containing monthly mean heights. Names and locations of the ctl files are in WHEREIS.IT. It is possible to run the demo on some workstations. See the end of README.UNX. G. White successfully ran it on his LINUX box which had GrADS already on it. To run GrADS from MS-DOS, enter E:START E:, assuming the cdrom is device E:, or simply type in start and follow directions.

Data Fields on the NCEP/NCAR Reanalysis Monthly Mean CD-ROM

The first name of the control file (which are all of the form *.CTL) is given in parentheses followed by the variable name if different from the name of the control file. The directories below also contain alternative control files (*.CTU and *.CTS) for certain types of computers, as well as the index files and grib files for each of the quantities listed.

The following code indicates the type of value or average provided for each variable:

O = analysis
6 = 6 hour forecast
o = observed
A = 0–6 hour average/accumulation of forecast starting from the analysis
MO = monthly average of analyses (4 times per day)
Ma = monthly average of averages/accumulations (4 times per day)
Mg = monthly average of first guess (4 times per day)
Mo = monthly average of observations
L = 2.5° × 2.5° lat–long grid (144 × 73)
LU = 2.5° × 2.5° lat–long grid for United States (27×13) 230°–295°E, 22.5°–52.5°N

List of fields available:

Directory DATA

surface	o L model's land–sea mask (LAND25;land)
surface	o L model's orography (HGT25;hgt)

Directory DATA/MONTHLY

surface	Ma L latent heat flux (LHTFL)
surface	Ma L net long wave radiation (NLWRS)
surface	Ma L net solar radiation (NSWRS)
surface	Ma L precipitation (XPRATE;prate) units kg/m^2/sec
	Multiply by 86400 to get mm/day
surface	Ma L sensible heat flux (SHTFL)
surface	Mg L surface pressure (PRSSFC)
surface	Ma L surface stress (WINSTR;ustrs,vstrs)
surface	Mg L temperature (TMPSFC)
2 meter	Mg L q (Q2M), T (TMP2M)
10 meter	Mg L winds (WIN10M;u10m,v10m)
mean sea level	MO L mean sea level pressure (PRMSL)
1000 hPa	MO L Z (HGT)
925 mb	MO L Z (HGT), T (TMP), U/V (Wind;u,v), q (Q)
850 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
700 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
500 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
300 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
250 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v)
200 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), omega (VVEL)
100 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v)
70 hPa	MO L Z (HGT)
50 hPa	MO L Z (HGT), U/V (WIND;u,v)
30 hPa	MO L Z (HGT)
20 hPa	MO L Z (HGT), U/V (WIND;u,v)
top of atmosphere	Ma L upward longwave radiation (OLR)
top of atmosphere	Ma L net solar radiation (NSWRT)
atmospheric column	MO L precipitable water (PWAT)

Directory DATA/CLIM/C7998

surface	Ma L latent heat flux (LHTFL)
surface	Ma L net long wave radiation (NLWRS)
surface	Ma L net solar radiation (NSWRS)
surface	Ma L precip corrected for valley snow problem (XPRATE;prate)
	units kg/m^2/sec; Multiply by 86400 to get mm/day
surface	Ma L sensible heat flux (SHTFL)
surface	Mg L surface pressure (PRSSFC)
surface	Ma L surface stress (WINSTR;ustrs,vstrs)
surface	Mg L temperature (TMPSFC)
2 meter	Mg L q (Q2M), T (TMP2M)
10 meter	Mg L winds (WIN10M;u10m,v10m)
mean sea level	MO L mean sea level pressure (PRMSL)
1000 hPa	MO L Z (HGT)
925 mb	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q)
850 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
700 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
500 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
300 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), q (Q), omega (VVEL)
250 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v)
200 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v), omega (VVEL)
100 hPa	MO L Z (HGT), T (TMP), U/V (WIND;u,v)
70 hPa	MO L Z (HGT)
50 hPa	MO l Z (HGT), U/V (WIND;u,v)
30 hPa	MO L Z (HGT)
20 hPa	MO L Z (HGT), U/V (WIND;u,v)
top of atmosphere	Ma L upward longwave radiation (OLR)
top of atmosphere	Ma L net solar radiation (NSWRT)
atmospheric column	MO L precipitable water (PWAT)

Directory DATA/OBS

surface	Mo L precipitation estimate from Xie–Arkin (PRATE), mm/day
top of atmosphere	Mo L upward longwave radiation from satellite (OLR)

Directory DATA/OBS/CDIV

surface	Mo LU precipitation estimate from raingauges (PRATE)
	units kg/m^2/sec; Multiply by 86400 to get mm/day
2 meter	Mo LU T from climate division observations (TMP2M)
	DATA/DATA
surface	Mo L land stations (DEN;adpsfc)
surface	Mo L Australian manual sea level pressure bogus (DEN;sfcbog)
surface	Mo L ship reports (DEN;sfcshp)
1000–700, 300–100 hPa	Mo L satellite winds (DEN;satwnd)
300–100 hPa	Mo L aircraft reports (DEN;aircft)
atmospheric column	Mo L radiosondes (DEN-adpupa)
atmospheric column	Mo L satellite temperature soundings (DEN;satemp)

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