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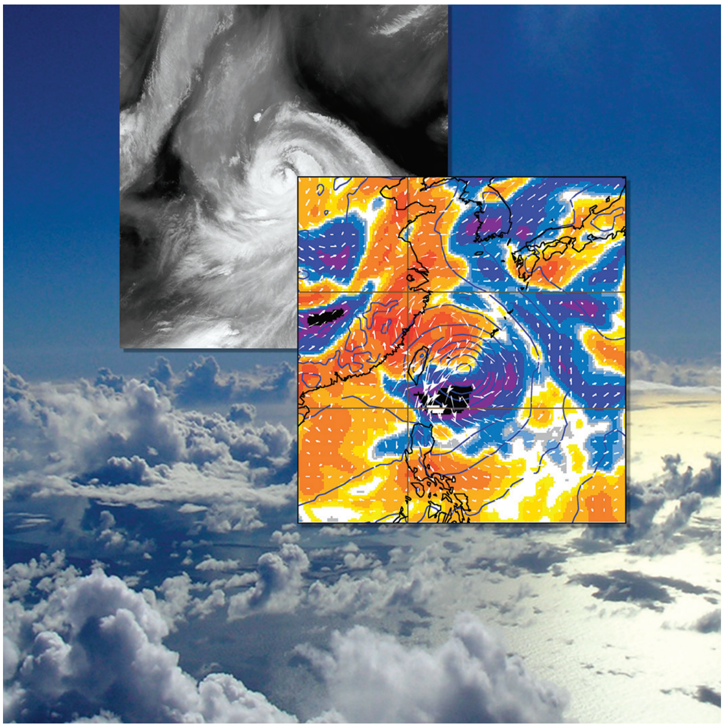
ERA-Interim: New ECMWF reanalysis products from 1989 onwards



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ERA-Interim: New ECMWF reanalysis products from 1989 onwards

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Over the past decade, reanalyses of multi-decadal series of past observations have become established as an important and widely utilized resource for the study of atmospheric and oceanic processes and predictability. Produced using fixed, modern versions of the data assimilation systems developed for numerical weather prediction, they also are being applied increasingly in many other fields that require a record of the state of either the atmosphere or its underlying land and ocean surfaces. Estimation of renewable energy resources, calculation of microwave telecommunication signal losses and study of bird migration are just three examples.

High-resolution operational forecasting systems provide good quality analyses for study of recent conditions. However, the pace of improvement of these systems is such that lower-resolution reanalyses produced using up-to-date assimilation systems provide products for all but the last few years that are generally superior to those available from the archives of past operational products. Reanalysis products are, by design, more suitable than their operational counterparts for use in studies of longer-term variability in climate, although they remain susceptible to changes in the observing system that can make accurate depiction of long-term trends problematic.

Two major ECMWF reanalyses have exploited the substantial advances made in the ECMWF forecasting system and technical infrastructure since operations began in 1979. The first project, ERA-15 (1979–1993), was launched in 1993 and the second “extended” reanalysis project, ERA-40 (1957–2002), in 1998; for details see *ECMWF Newsletters No. 73* and *No. 101.* The products of these reanalyses have been used extensively within the Member States and by the wider user community. They have also been used extensively within ECMWF in support of other activities, particularly for validating long-term model simulations, helping develop seasonal forecasting (enabling the DEMETER hindcasts, for example) and establishing the “climate” of EPS (Ensemble Prediction System) forecasts needed for construction of forecaster-aids such as the Extreme Forecast Index.

Reanalysis as an iterative and ongoing process

The recent ECMWF/GEO Workshop on Atmospheric Reanalysis (*ECMWF Newsletter No. 109*) emphasized that instead of being viewed as a series of largely independent “one-off” exercises, reanalysis has come to be seen more as an iterative process. In this process, developments in modelling, data-analysis techniques and computing power are allied with new data rescue efforts and data and experience from reanalyses carried out elsewhere, to produce a succession of reanalyses of increasing quality, accounting increasingly well for changes in the observing system.

Notwithstanding this, users often express a requirement for reanalyses to be extended in close to real time, in what is known as Climate Data Assimilation System (CDAS) mode. This has been adopted by the National Centers for Environmental Prediction (NCEP) for its two global reanalyses (NCEP/NCAR and NCEP/DOE) and more recently by the Japan Meteorological Agency in extending its JRA-25 (1979–2004) reanalysis. Whilst this approach provides users with up-to-date data in a conveniently familiar form, if continued too long it results in products of significantly lower quality than would be produced by a replacement reanalysis. In particular a fixed, older analysis system is unlikely to exploit well, if at all, new types of data from the evolving observing system.

The ERA-40 project was designed so that its production could be supported by funding of limited duration from the European Union’s Fifth Framework Programme. Production finished in April 2003, when the Fujitsu computer system on which it was running was decommissioned. With limited human resources available from then onwards, it was decided not to migrate the ERA-40 production system to the new IBM computers that had been installed. Instead, effort would be devoted to development of a new reanalysis system derived from the latest version of the operational ECMWF system. Tests had already indicated that several of the problems experienced in ERA-40 would be eliminated or significantly reduced: most notably a too-strong tropical oceanic precipitation that was marked from the early 1990s onwards and a too-strong Brewer-Dobson circulation in the stratosphere. This new reanalysis system would be used to produce an interim reanalysis that would be run for the data-rich 1990s and 2000s, and continued as an ECMWF Climate Data Assimilation System (ECDAS) until superseded by a new extended reanalysis - see Figure 1.

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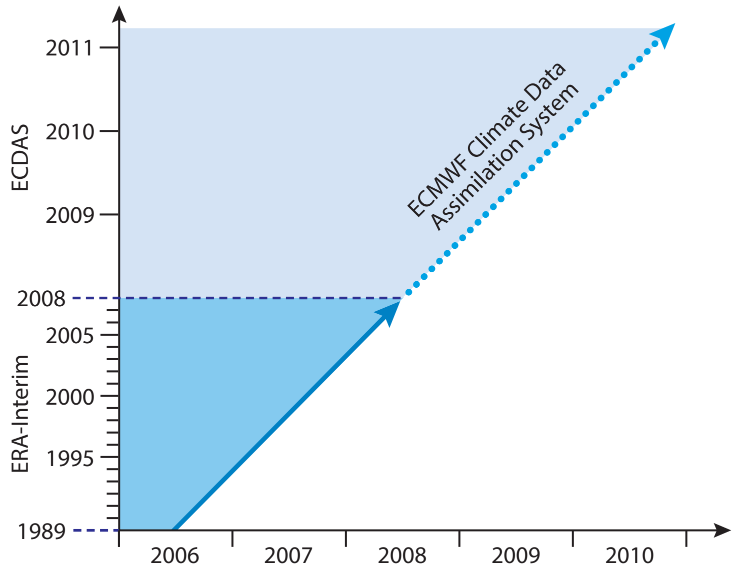

Figure 1 The schedule for ERA-Interim and its transition to ECMWF Climate Data Assimilation System (ECDAS). Note the change of scale beyond 2008 on the vertical axis.

The ERA-Interim reanalysis system

With increased computer power available, the use of 4D-Var, tried-and-tested in operations since 1997, became feasible for ERA-Interim. Preparatory experiments were thus carried out to evaluate 4D-Var, with 6- and 12-hourly cycling, in comparison with 6-hour 3D-Var as used for ERA-40. The tests employed the T159L60 model resolution used for ERA-40, but a newer version of the forecasting system, IFS Cy29r1. Also tested was a new variational bias correction scheme (VarBC) for radiance data.

Experimental assimilations were carried out mainly for two periods: August 1999 to December 2000, and January to December 1989, the starting year for ERA-Interim. The benefit of using 4D-Var was seen in systematically better forecast performance, especially in the southern hemisphere. 12-hour 4D-Var was more resilient than 6-hour 3D-Var over a period during which data was lost from one of the two polar-orbiting satellites operating at the time. Important improvements were seen in the hydrological cycle, with 12-hour 4D-Var having the smallest model spin-up/down. Precipitation-minus-evaporation was much closer globally to zero than in ERA-40. The new reanalyses also were tested by Beatriz Monge-Sanz (University of Leeds) for application in chemical transport modelling; they gave a larger, more realistic “age-of-air” in the stratosphere than seen using either ERA-40 or operational analyses for the year 2000.

The quality of analyses was also validated by other means: fit of background forecasts to the observations used, fit of surface winds to independent buoy winds, agreement with independent tropical-cyclone track data, and comparison of precipitation with independent estimates from the Global Precipitation Climatology Project (GPCP). All pointed to a small but systematic edge in favour of 12-hour 4D-Var with VarBC.

Production of ERA-Interim, from 1989 onwards, began in summer 2006. Enhanced computer power enabled horizontal resolution to be increased to T255, but vertical resolution was kept at the 60 levels used for ERA-40. The latest cycle of the model (IFS Cy31r1/2) was adopted, as introduced operationally in September and chosen for the next version of the ECMWF seasonal forecasting system. In summary, the main advances of the ERA-Interim data assimilation over the ERA-40 system, including the changes in the use of observations, are given in Box A.

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Differences in data assimilation and use of observations between ERA-40 and ERA-Interim

A

Data assimilation

The main advances in the ERA-Interim data assimilation compared to ERA-40 are:

- 12 hour 4D-Var.
- T255 horizontal resolution.
- Better formulation of background error constraint.
- New humidity analysis.
- Improved model physics.
- Data quality control that draws on experience from ERA-40 and JRA-25.
- Variational bias correction of satellite radiance data, and other improvements in bias handling.
- More extensive use of radiances, and improved fast radiative transfer model.

Observations

ERA-Interim uses mostly the sets of observations acquired for ERA-40, supplemented by data for later years from ECMWF's operational archive. There are, however, a few noteworthy exceptions:

- ***Altimeter wave-heights.*** A new ERS altimeter wave-height dataset has been acquired from ESA, providing data of more uniform quality than the Fast Delivery Dataset used from August 1991 onwards in ERA-40
- ***Winds and clear-sky radiances.*** EUMETSAT provided reprocessed winds and clear-sky radiances from Meteosat-2 (1982-1988) for ERA-40 and are currently reprocessing later Meteosat data for ERA-Interim.
- ***Ozone profiles.*** Reprocessed GOME data from the Rutherford Appleton Laboratory will provide ozone profile information from 1995 onwards.
- ***Radio occultation measurements.*** CHAMP GPS radio occultation measurements, processed and archived at UCAR, have been obtained to cover the period from mid 2001 to mid 2006. Subsequent occultation data, from the constellation of CHAMP, GRACE and COSMIC receivers, has been received operationally.

Boundary forcing fields

Boundary forcing fields are taken from ERA-40 until 2001, and from ECMWF operations for later dates.

Handling of biases

Observations of the atmosphere are prone to biases, and it is important to adjust data to remove these biases if an assimilation system is to make optimal use of a wide variety of observations. Biases tend to change over time due to often-undocumented changes in instrumentation and in the processing carried out by data providers. Consequently bias correction is particularly important and challenging in a reanalysis that is to be used to study climatic trends and low frequency variability. The use of a comprehensive forecast model to generate background estimates for the data assimilation system provides a powerful tool to aid this bias correction.

ERA-40 used a scheme for correcting systematic errors in radiosonde temperatures due to short-wave radiation and other effects. Stations were separated into groups representing different countries or areas where it was assumed that similar types of sonde were used at any one time. Mean differences between background forecasts and observations were accumulated for each station group over at least twelve months for different classes of solar elevation. It was then decided manually for each group whether to apply a correction and if so whether to adjust for the complete bias or (more commonly) only for the component dependent on solar elevation. The corrections were reassessed from time to time and revised if necessary. The scheme was applied only from 1980 onwards.

Using statistics archived from ERA-40 and subsequent operational data assimilation, observation-minus-background time series for individual radiosonde stations have been used to derive a homogenization scheme, in which discontinuities in the mean temperature record due to equipment or data-processing changes are identified and removed. This work was started by Leopold Haimberger at ECMWF, and has been continued by him at the University of Vienna. The resulting homogenized radiosonde temperatures are being used in ERA-Interim. The homogenisation does not account for seasonal variations in solar heating, which are dealt with by applying a revised version of the ERA-40 bias correction scheme to the homogenised data.

Biases in satellite radiances in ERA-Interim are estimated and corrected using the variational bias correction (VarBC) scheme described in *ECMWF Newsletter No. 107.* Regression parameters describing the biases for each radiance channel are estimated during the data assimilation by treating them as additional degrees of freedom in the 4D-Var minimisation. This radiance bias correction scheme is adaptive and self-contained, in that it does not require any external information about satellite biases. It performed well in the preparatory experiments for ERA-Interim, and has been used in operations since September 2006. It solves most of the

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technical problems experienced with manual bias tuning, smoothly corrects bias drifts, handles data gaps, and can quickly develop bias corrections for new sensors. Variational bias correction of all radiance data simultaneously with the adjustment of the model state appears to remove many of the detrimental side effects of sub-optimal and/or conflicting bias corrections seen in ERA-40. As a result, the fit to conventional data improves, and the system is able to assimilate larger numbers of observations overall.

The stability of the adaptive scheme depends on the amount of information about the biases available from other observations. To test and illustrate this, a simple experiment was performed in which all observations were withheld from one of two otherwise identical assimilations during a period of two weeks, causing the two systems to drift apart considerably. Figure 2 shows the divergence of the global mean analysed temperatures in the two systems, due to model bias, followed by a re-convergence after the reintroduction of observations. Re-convergence in the uppermost levels is relatively slow, consistent with the lack of observations at those levels. Further discussion of the performance of VarBC at these levels is given in the following section.

An automatic, adaptive scheme to correct various systematic errors in surface-pressure data has also been developed and implemented in operations, as described in *ECMWF Newsletter No. 108*. The scheme is especially important for reanalysis, which makes use of several historical data sources with varying characteristics and poorer metadata than available today. The reported surface pressure observations (SYNOP, SHIP, DRIBU) are corrected if a systematic deviation from the background forecast is detected that is not supported by neighbouring observations. The error can be due to incorrect station-elevation data or a buoy-sensor that reports biased values. In current ECMWF operations the number of corrected stations can exceed 1,000 and in ERA-Interim even more. The Vostok station in Antarctica provides a good illustration of the scheme's performance. For ERA-15, David Bromwich and colleagues (Ohio State University) found that moisture transport over the eastern Antarctic was unrealistic. By investigating the geopotential increments, analysis-minus-background, a systematic difference was found to stem from an error of about 60 m in the height of the station. In ERA-40 the elevation was corrected before the data entered analysis. In ERA-Interim the bias has been identified and corrected automatically by the scheme, as illustrated in Figure 3.

The altimeter wave height data from the European Remote Sensing satellites ERS-1 and ERS-2 have been compared with buoy measurements and bias corrections have been calculated for use in ERA-Interim. ERS scatterometer data have also been re-calibrated, based on triple collocation with buoy measurements and ERA-40 background 10-metre wind speeds. The study also showed ERA-40 winds to be 0.25–0.40 m s^{-1} weaker than the buoy winds. Figure 4 shows time series comparing the ERS scatterometer data with bias-corrected ERA-40 winds.

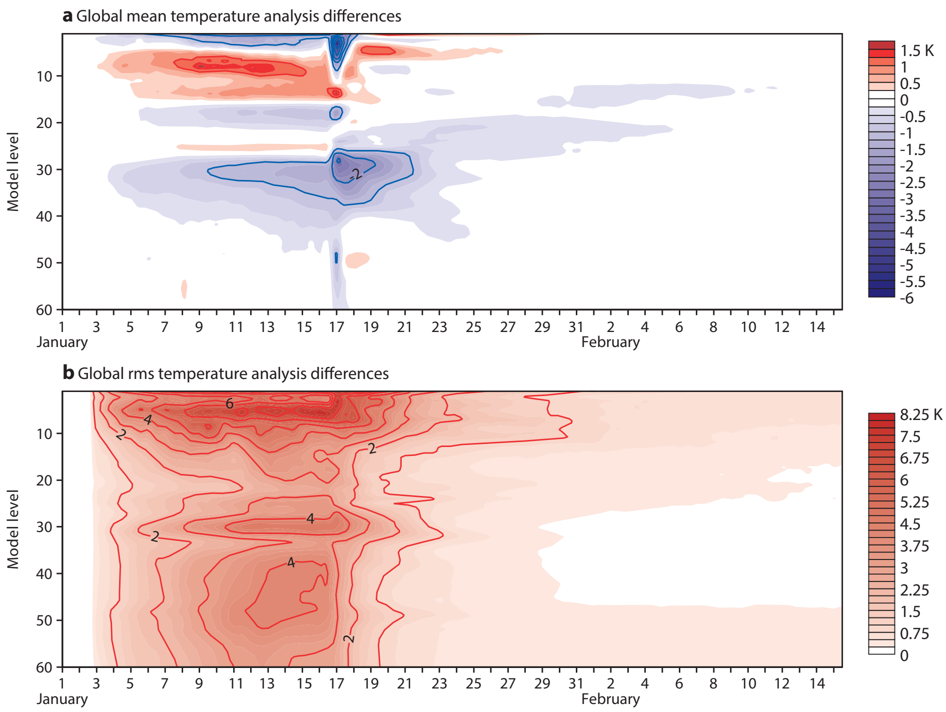

Figure 2 Evolution of (a) global mean and (b) root-mean-square temperature differences between a control assimilation (using all available observations and variational bias correction on all radiance data) and an experimental assimilation in which all observations were withheld from 3–17 January. The divergence in global mean temperature is due to model bias.

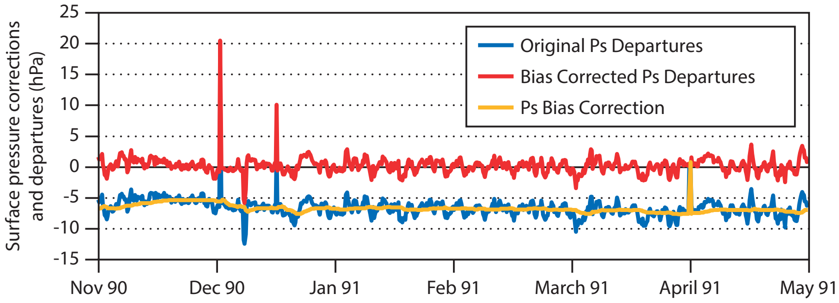

Figure 3 Correction of surface pressure for the Vostok station (78° 27'S, 106° 52'E) in Antarctica, which has a wrong station height in the historical data records. The blue line shows the original departures (i.e. the observed pressure minus the pressure interpolated from the background forecast to the incorrect station altitude). The yellow line shows the applied bias corrections and the red line shows the departures after the bias correction. The bias correction scheme retains the high-frequency signal from the observations.

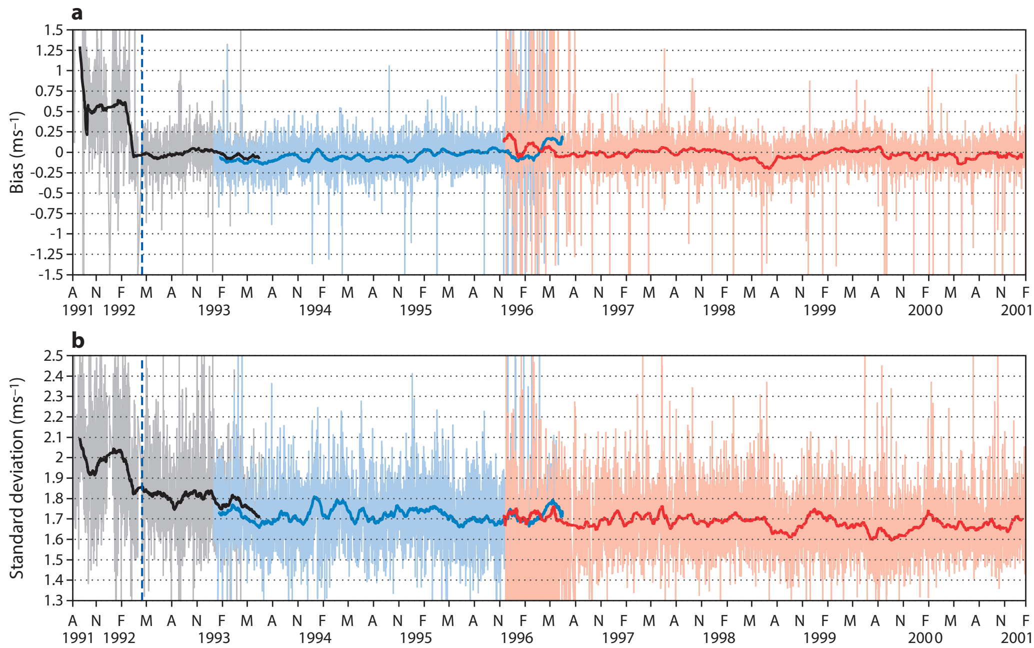

Figure 4 Time series of (a) mean and (b) standard deviation of the differences between recalibrated ERS scatterometer wind speeds and the bias-corrected ERA-40 background winds. In blue and red are ERS-1 and ERS-2 data as used in ERA40; in black are ERS-1 data that were not assimilated in ERA-40. Also shown are the 30-day moving averages. The blue vertical dashed line indicates how far back in time the assimilation of ERS-1 data could start using the re-calibrated data.

Performance of the data assimilation

Monitoring the performance of the data assimilation is an essential part of reanalysis production and there are several complementary ways to do this. Under normal circumstances, 10–15 days of analyses are produced every actual day. Statistics are needed over quite long periods, and have to be examined regularly. Based on experience with ERA-15 and ERA-40, comprehensive monitoring diagnostics with routine web-based display have been further developed for ERA-Interim. They include:

- Time series and monthly-means (maps and cross-sections), for quantities such as basic analysed and forecast variables, and their differences from ERA-40.
- Means and standard deviations of the analysis-minus-background increments and the observation-minus-background and observation-minus-analysis departures for all assimilated observations.
- Number of used, blacklisted and rejected conventional data.
- Radiosonde bias correction statistics.
- Predictors and corrections from the VarBC scheme for radiances.

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The monthly-mean meridional cross-sections of zonal-mean temperature show some marked differences between ERA-Interim and ERA-40 in the stratosphere, particularly at the higher levels where only radiance data are available for assimilation. Figure 5 presents an example, for August 1990. ERA-40 was prone to the occurrence of a spurious oscillatory structure in the vertical profile of temperature in polar regions, which was most marked over Antarctica in late winter and spring. In ERA-Interim, this oscillatory structure is much reduced in amplitude, as illustrated in Figure 5. This is because VarBC, in the absence of other "anchoring" data (mainly radiosonde temperatures), absorbs most of the model bias into the radiance adjustments and reduces the analysis increments dramatically in the upper stratosphere. The source of the oscillatory structure in ERA-40 was the large temperature increments made to reduce differences between model and observed radiances originating from quite deep layers centred in the upper stratosphere.

In addition, ERA-Interim is generally much warmer than ERA-40 in the upper stratosphere, by some 7 to 11 K at around 3 hPa. Away from the poles, the difference shown in Figure 5 is similar to that seen in the annual mean for 1990. An assessment of uncertainties in climatologies of wind and temperature in the stratosphere and mesosphere by the SPARC (Stratospheric Processes and their Role in Climate) project has shown that the ERA-40 analyses for the early 1990s have an upper stratospheric cold bias of up to 5 K compared with the consensus of other climatologies. The warmer mean upper-stratospheric temperatures in ERA-Interim indicate that the bias has shifted from cold to warm for these years, but not changed much in magnitude. The upper stratospheric temperature bias in ERA-Interim is in fact similar to the bias seen in ERA-40 for the years prior to the availability of satellite radiance data. This is because VarBC adjusts the measured radiances towards the preferred warm state of the background model in the absence of other types of observation. Recent experimental results suggest that the upper stratospheric model bias is better controlled by not applying bias correction to SSU channel-3 radiances, which have maximum sensitivity to temperatures at 1.5 hPa.

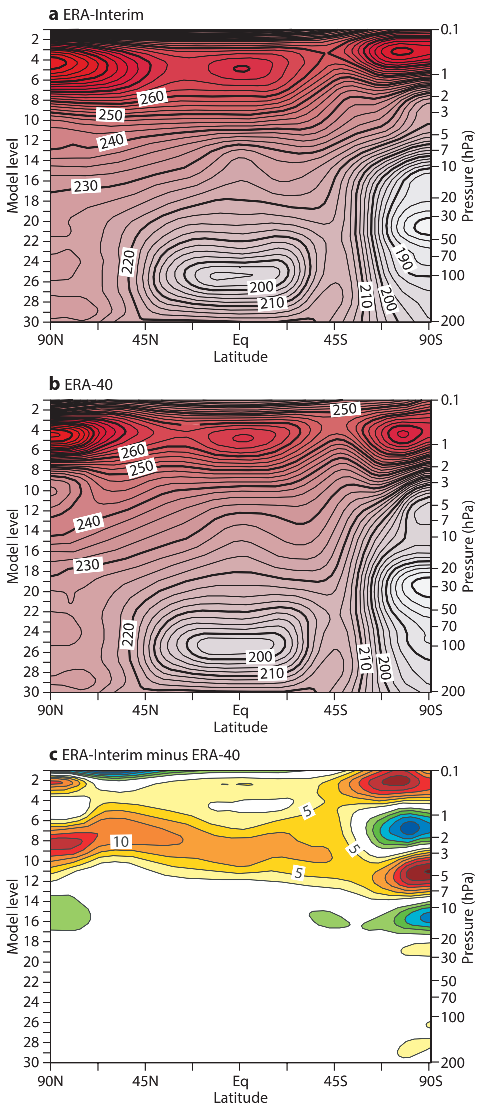

Figure 5 Meridional cross-sections showing the zonal-mean temperature analysis averaged for the month of August 1990 from (a) ERA-Interim and (b) ERA-40. (c) Difference between (a) and (b). The contour interval is 2.5 K. For the difference plot, the zero contour is suppressed, and negative values are denoted by green and blue shading.

Differences are much smaller at lower levels, but still exceed 1 K at the tropical tropopause, with ERA-Interim colder than ERA-40. They can exceed 0.5 K lower in the troposphere. Because of these mean differences, unadjusted ERA-Interim and ERA-40 products should not be mixed in time-series analysis of trends and low-frequency variability.

Figure 6 shows root-mean-square and mean differences between radiosonde temperature measurements and the background and analysed values from ERA-40 and ERA-Interim. The root-mean-square differences between the observations and background are generally smaller in ERA-Interim. The 12-hour 4D-Var analysis used for ERA-Interim does not fit the data quite as closely as ERA-40's 6-hour 3D-Var, but the improved fit of the background forecasts (which are at 9-hour range for ERA-Interim compared with 6-hour range for ERA-40) is indicative of a generally better analysis. The bias in ERA-Interim is mostly smaller and less oscillatory in structure than in ERA-40, although it is larger and of opposite sign (warm for ERA-Interim and cold for ERA-40) for the small numbers of observations at the 5 hPa level. ERA-Interim accepts slightly fewer data at most levels, though more are used near the surface and tropopause.

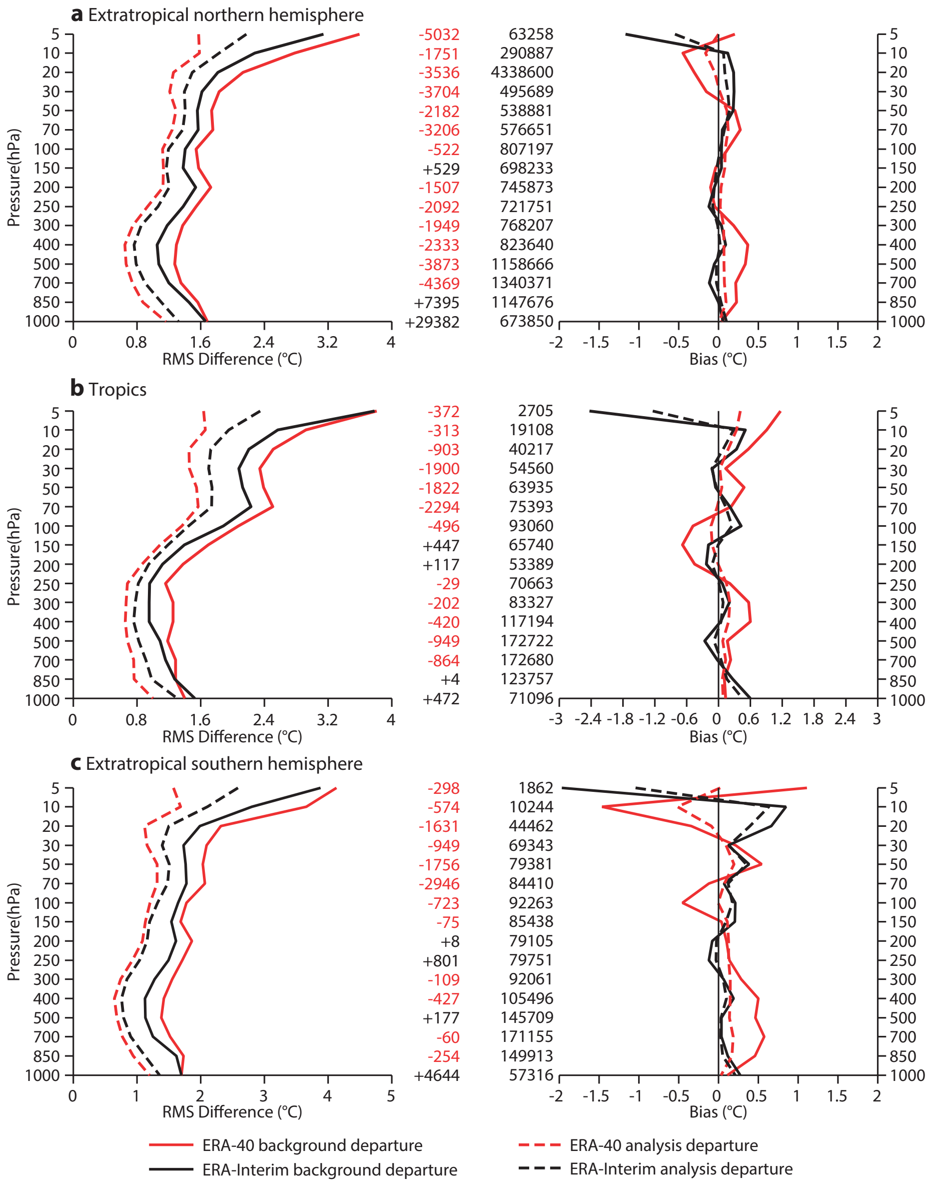

Figure 6 The root-mean-square difference and bias between radiosonde temperature measurements and the background (solid lines) and analysed values (dotted lines) from ERA-40 (red) and ERA-Interim (black) for (a) extratropical northern hemisphere, (b) tropics and (c) extratropical southern hemisphere for all 12 UTC soundings made in 1990. The two columns of numbers indicate the difference in number of data used (left; ERA-Interim minus ERA-40) and the number of data used by ERA-Interim (right).

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The hydrological cycle

In ERA-40, historical HIRS, MSU and SSU radiance data were assimilated directly for the first time and SSM/I radiance data were used in a 1D-Var retrieval of total-column water vapour (TCWV) that was used to supply input data for the analysis. These data had a profound impact on the humidity analysis and related products derived from the hydrological cycle of the background model. These products thus have different characteristics during the ERA-40 period depending on whether or which radiance data were assimilated. The ERA-40 assimilation system used the radiance data to correct a too-dry background model state in non-precipitating regions over the tropical oceans. The analysis system in use at the time spread much of this moistening also into precipitating regions, where the assimilating model rejected almost all the moisture added by the analysis. This resulted in excessive precipitation over the tropical oceans, excessive associated latent heating and a feedback process that enhanced the moistening further. Problems were exacerbated following the eruption of Mount Pinatubo in June 1991, when the effect of volcanic aerosols on HIRS radiances was misinterpreted as a moisture signal, and were locked in by subsequent bias corrections and the feedback process.

ERA-Interim benefits from several subsequent developments of the ECMWF forecasting system, some of them a direct response to the problems experienced in ERA-40. These include:

- The new humidity analysis and improved model physics.
- Direct assimilation of SSM/I radiances and more selective use of HIRS radiances.
- Variational bias correction and use of 4D-Var.

All of these influence precipitation over the tropical oceans in the background forecasts.

It is interesting to compare the annual-mean precipitation rates from ERA-Interim and ERA-40 with the observation-based estimates of the Global Precipitation Climatology Project (GPCP). The left-hand panels of Figure 7 present differences between ERA-Interim and GPCP, ERA-40 and GPCP, and ERA-Interim and ERA-40 for 1990. The right-hand panels show the corresponding differences in TCWV based on the version-6 SSM/I retrievals over oceans produced by Remote Sensing Systems (RSS). Precipitation is higher in both ERA-Interim and ERA-40 than in GPCP over the tropical oceans. ERA-Interim is the closer to GPCP, but ERA-40 and ERA-Interim are nevertheless in closer agreement with each other than either is to the GPCP estimate. At higher latitudes, ERA-Interim is in closer agreement with GPCP than ERA-40. TCWV from ERA-Interim is significantly lower than from ERA-40, and closer to RSS.

Figure 8 shows corresponding time series from 1989 to 1992 of monthly-mean TCWV and precipitation rate averaged over the tropical oceans, including results from the recently completed JRA-25 reanalysis as well as those from the older ERA-40 reanalysis and the newer ERA-Interim reanalysis. Precipitation estimates from the RSS retrievals are included as well as the GPCP estimates. Neither JRA-25 nor ERA-Interim shows the increase in TCWV and precipitation following the eruption of Pinatubo in June 1991 seen for ERA-40. TCWV from JRA-25 is close to the RSS retrievals, but tends to be a little lower. ERA-Interim is in very good agreement with the RSS retrievals. In this regard, it should be noted that the ERA reanalyses use SSM/I radiances calibrated by RSS, whereas JRA-25 obtained SSM/I radiances from the National Climatic Data Center (NCDC). Precipitation from JRA-25 is somewhat higher than from ERA-Interim, and both are quite substantially higher than the GPCP and RSS estimates.

A further indication of improvement of the hydrological cycle in ERA-Interim comes from diagnosis of the global balance of precipitation and evaporation. The excess of precipitation over evaporation seen in ERA-40 is much reduced in ERA-Interim. Precipitation remains higher than evaporation, however, consistent with the indications from Figures 7 and 8 that rainfall over the tropical oceans is still somewhat too high, notwithstanding uncertainties in the accuracy of the observation-based estimates.

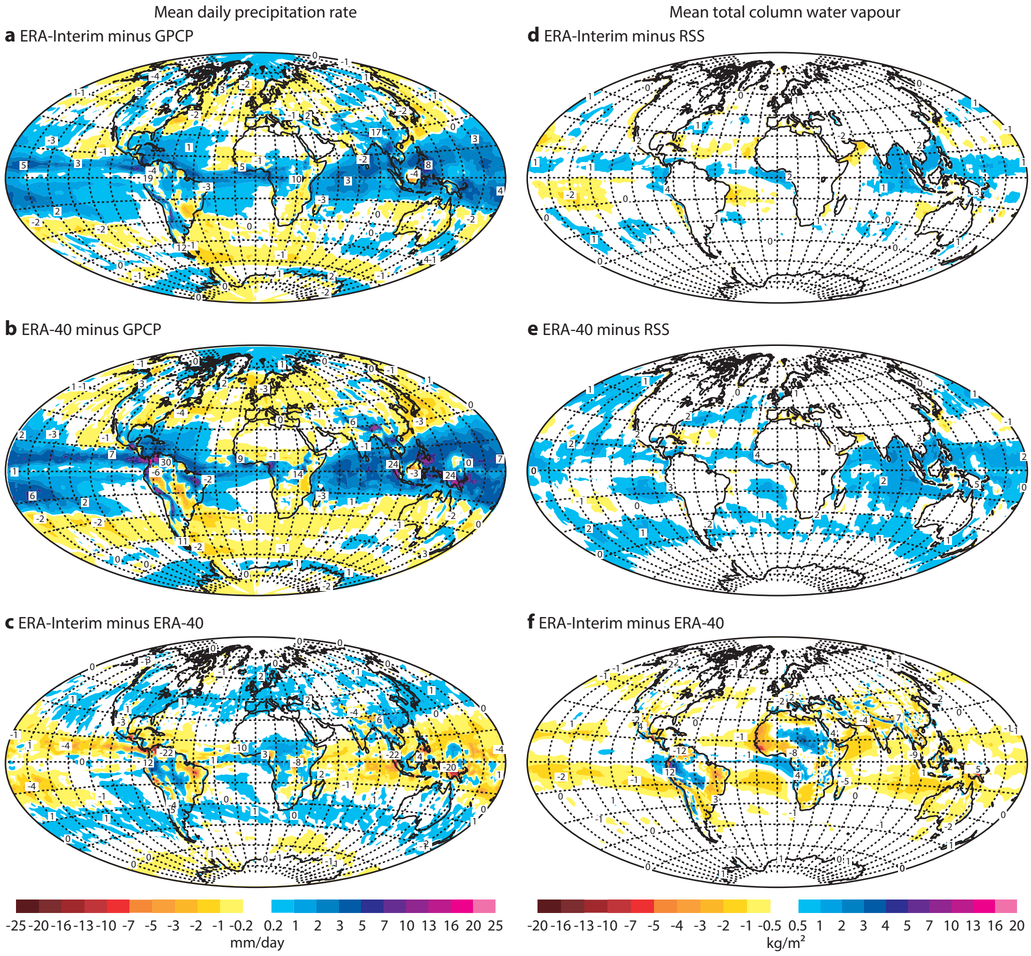

Figure 7 Left: the difference in the mean daily precipitation rate for 1990 (mm/day) for (a) ERA-Interim minus GPCP, (b) ERA-40 minus GPCP and (c) ERA-Interim minus ERA-40 (bottom). Right: the difference in mean total column water vapour for 1990 (kg m^{-2}) for (d) ERA-Interim minus RSS, (e) ERA-40 minus RSS and (f) ERA-Interim minus ERA-40. RSS denotes the version-6 retrievals from SSM/I produced by Remote Sensing Systems.

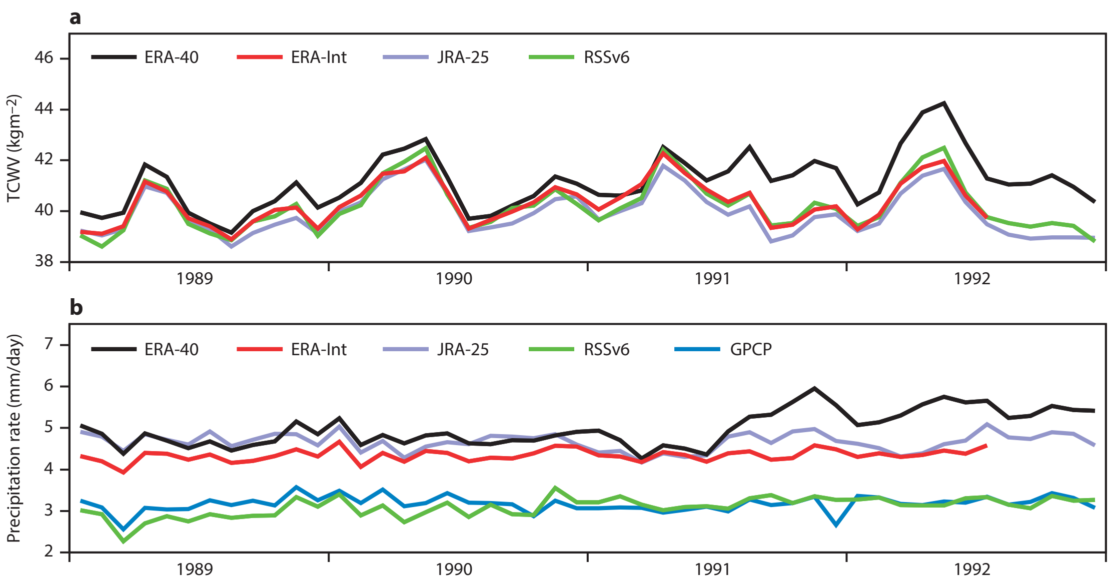

Figure 8 Time series of (a) monthly-mean total column water vapour (kg m^{-2}) and (b) precipitation rate (mm day^{-1}) averaged over tropical oceans, from the ERA-40, ERA-Interim and JRA-25 reanalyses, from version-6 SSM/I retrievals produced by Remote Sensing Systems and (for precipitation only) from GPCP.

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Stratospheric transport

The studies of "age of air" in the preparatory assimilations indicate that ERA-Interim will provide much better datasets than ERA-40 for driving models of stratospheric chemical transport and stratosphere/troposphere exchange. Further evidence for this is provided by examination of the representation of stratospheric humidity in ERA-Interim. As in ERA-40, no change to the stratospheric humidity is made by the ERA-Interim analysis other than removal of any supersaturation. This means that the distribution of humidity is determined primarily in the sequence of 12-hour background forecasts, by tropospheric exchange, by the upper-level moistening due to parametrized methane oxidation and by advection, with some loss due to precipitation in the cold polar night.

In the tropical stratosphere, relatively dry air introduced at the tropical tropopause in boreal winter, and relatively moist air introduced in boreal summer, are transported slowly upwards. This transport was much too strong in ERA-40, with successive layers of moist and dry air reaching above 10 hPa in well under a year, as illustrated in Figure 9(a). In ERA-Interim, the upward transport is slower, as indicated by the shallower slope of contours in the lower stratosphere in Figure 9(b). The stratosphere is also generally moister in ERA-Interim. This is because of a revised treatment of clouds that allows significant near-tropopause supersaturation (countering a drying effect due to colder tropical-tropopause temperatures) and a stronger near-stratopause source from methane oxidation. The changes bring the ERA-Interim analyses of stratospheric moisture into closer agreement with the picture gained from occultation and limb-sounding data from a number of satellite missions.

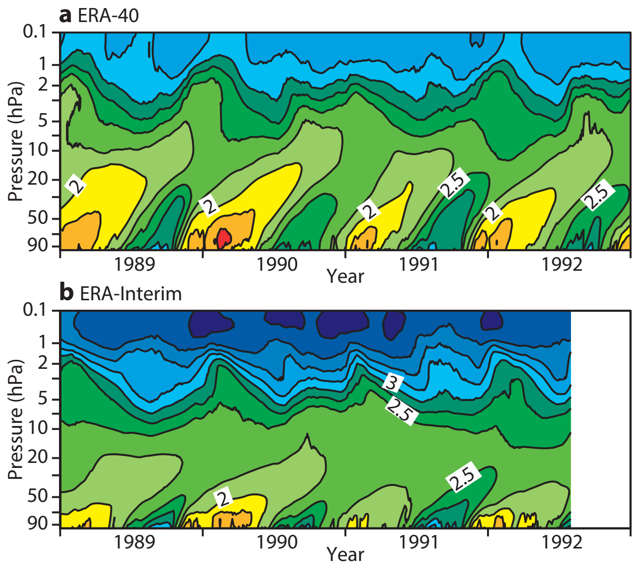

Figure 9 Pressure/time cross-sections showing specific humidity averaged from 10°N to 10°S from (a) ERA-40 and (b) ERA-Interim. The contour interval is 0.25 mg/kg.

Improved forecasts

Ten-day forecasts were run 12-hourly from the ERA-40 analyses, and the same is being done for ERA-Interim. Comparison of the accuracy of these forecasts with those from operations provides further evidence of the improvement of forecasting systems over the years. Figure 10 presents anomaly correlations of 500 hPa height forecasts for the extratropical northern and southern hemispheres averaged from January 1989 to December 1990 for the ERA-40 and ERA-Interim versions of the forecasting system, and for the original operations. Also shown are the corresponding operational results for the two-year period from January 2005 to December 2006. A related plot for 850 hPa tropical winds was included in the workshop report published in *ECMWF Newsletter No. 109.*

Figure 10 shows a substantial improvement in forecast skill of ERA-40 over ECMWF operations for 1989/90. ERA-Interim in turn improves substantially on ERA-40, especially in the southern hemisphere. The use of 4D-Var in ERA-Interim is likely to be a key factor behind the larger improvement in the southern hemisphere, where using a more sophisticated assimilation technique compensates for the much poorer in-situ data coverage.

ERA-Interim for 1989/90 cannot match ECMWF's operational performance for the past two years, as measured by most scores. This is due partly to the lower resolution of the ERA-Interim data assimilation system and partly to improvements in the observing system over the past one and a half decades. These differences tend to predominate over the advantage ERA-Interim has of using the very latest version of the model and data assimilation system. Only for specific regions and variables for which forecasts have been markedly improved very recently, most notably temperature in the tropical troposphere, does the benefit of using the latest version of the forecasting system outweigh the other effects.

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The 60% value for the 1989/90 mean of the anomaly correlations of 500 hPa height for operations is reached at about 6½ days range for the northern hemisphere and 5½ days for the southern hemisphere. For 2005/6, the corresponding value is 8 days for both hemispheres. In operations, the southern hemisphere especially has benefited from improvements in technique such as 4D-Var and the direct assimilation of radiances, and from improvements in the satellite component of the observing system. ERA-40 provided evidence for the latter for the period up to 2001, and ERA-Interim in due course will determine the extent to which this continues beyond 2001.

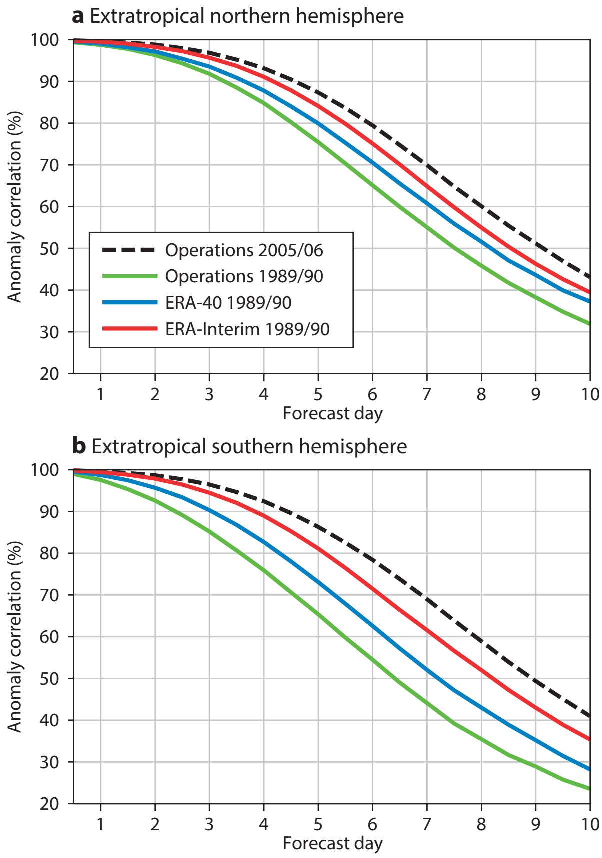

Figure 10 Anomaly correlation (%) of 500 hPa height forecasts averaged over all daily forecasts from 12 UTC for the period from January 1989 to December 1990 for (a) extratropical northern hemisphere and (b) extratropical southern hemisphere for Operations 2005/06, Operations 1989/90, ERA-40 1989/90 and ERA-Interim 1989/90.

Outlook

ERA-Interim represents a substantial step forward over ERA-40 in several respects. Its products, however, have yet to be scrutinized to the extent that was possible in the more fully funded ERA-40 project. Feedback from users based on their experience with the first release of data will be important in assessing the requirements for further work. Current activites at ECMWF include ongoing model improvement, with some emphasis on biases at the uppermost levels, and refinement of the 91-level version of the assimilation system introduced into operations in February 2006. Work to limit the effect of remaining model biases through weak-constraint 4D-Var is giving encouraging results, and re-evaluation and adjustment of the variational radiance bias-correction scheme will be undertaken based on its long-term performance in ERA-Interim.

The current production run of ERA-Interim is likely to catch up with real time in the first half of 2008. Around that time a decision will be made whether simply to continue with this run or to carry out a second complete run for the same period using an upgraded, 91-level version of the assimilation system. In the former case, a rerun of the first three or so years of production to correct the minor problems encountered to date may be undertaken. Decisions will depend on the level of funding secured for core reanalysis activities, of which ERA-Interim is a part, and the prospects for the extra, shorter-term funding needed to carry out a comprehensive, extended reanalysis to replace fully ERA-40. The latter will require development work to:

- Improve handling of the early satellite radiance data.
- Specify more appropriate background error statistics for the pre-satellite period.
- Acquire and utilize additional or replacement data from a variety of sources of past observations.

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Availability of the ERA-Interim products

The first formal release of ERA-Interim products, for 1989, 1990 and 1991, will be made soon. Member-State users with MARS access will be able to obtain these data by specifying EXPVER=5 and class=EI. Other users will be able to obtain the data from ECMWF's Data Services. The first products for these years should be regarded as provisional, since the re-processed Meteosat winds have yet to be used and several small problems were detected and corrected on-the-fly in the assimilation for these first years. Data from subsequent years will be released once production for each year is completed and validated.

A second release, of updated products, will be considered once the outlook for reanalysis activities at ECMWF has become clearer.

Public access to a selection of products on the external ECMWF Data Server will be provided after ERA-Interim has reached August 2002, the end of ERA-40. Data for subsequent years will be added periodically. Since ERA-Interim is being undertaken with limited funding as part of ECMWF's general programme of research and development, the extent and timing of the public service will depend on the availability of resources.

For additional information on the progress of ERA-Interim and on the availability of data, users are advised to consult the ECMWF re-analysis web pages www.ecmwf.int/ research/era and the web pages of ECMWF Data Services www.ecmwf.int/products/data.

Final remarks

The successful launch of ERA-Interim has been due to the willingness of institutions to provide data and the high level of cooperation and commitment shown by colleagues involved in the project. We are appreciative of the substantial effort by EUMETSAT to reprocess the historical Meteosat data, ESA for providing the ERS altimeter wave-height dataset, Rutherford Appleton Laboratory for providing the ozone profile data and UCAR for providing the radio occultation measurements. In addition we would like to acknowledge the contributions made by Ulf Andrae, Peter Bauer, Jean Bidlot, Claire Delsol, Hans Hersbach, Lars Isaksen, Per Kållberg, Ioannis Mallas and Carole Peubey from ECMWF, Byoung-Kwon Park on secondment from Korean Meteorological Institute, and many others from ECMWF and the Member States who have supported the development of ERA-Interim. The Japanese Meteorological Agency has engaged in ongoing cooperation with ECMWF on reanalysis, and this has included supporting the secondment of Shinya Kobayashi to ECMWF.

The development of ERA-Interim has demonstrated what can be achieved when many people work effectively together to a common purpose. There is no doubt that all this effort will be of great benefit to the meteorological and climate community.

Further Reading

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