ECMWF ReAnalysis, 1957-2001, ERA-40

Sakari Uppala

ECMWF, Reading, U.K.,
Sakari.Uppala@ecmwf.int

1. Introduction

The new reanalysis project ERA-40, supported by the European Union and several other organizations, is progressing at ECMWF. It covers the period from mid-1957 to 2001 overlapping the earlier ECMWF reanalysis ERA-15 (1979-1993) and complementing the NCEP reanalysis, which runs from 1947. Reanalyses in general seek to achieve as great a time consistency as possible within the limitations of the data-assimilation scheme and the available observing systems. ERA-40 will use the historical ground-based WWW observations and observations from special experiments such as the 1974 Atlantic Tropical Experiment of the Global Atmospheric Research Program GATE, First GARP Global Experiment FGGE 1979, Alpine Experiment ALPEX 1982 and more recent 1992-1993 TOGA-COARE. The data have been made available to the project, mainly by NCAR/ NCEP, ECMWF, JMA and USNAVY. In addition, and to a much larger extent than in ERA-15, ERA-40 makes use of multichannel satellite radiances through a 3D-variational assimilation starting with data from the first VTPR sounding instrument in 1972 and continuing up to the present SSM/I, TOVS and ATOVS instruments. Analysis of ozone is also included. Cloud Motion Winds are used from 1979 onwards and EUMETSAT has undertaken to reprocess Meteosat winds for 1982-1988. The presentation will describe the pre-production phase of the project, its current status and the use of the observing systems through the period. Indications of the forecast quality will be given.

2. The use of observations in ERA-40

The first ECMWF reanalysis ERA-15 covered the period, 1979-1993, during which the observing system was relatively homogeneous. There were two sources of satellite data in ERA-15, data from the TOVS instruments in the form of Cloud Cleared Radiances (CCR) from NESDIS and the Cloud Motion Winds from geostationary satellites, both available throughout the period. The CCR data had gone through many preprocessing steps and 1d-retrievals were used in the Optimum Interpolation analysis (Gibson et al 1997). In ERA-40 the calibrated Level-1c radiances are used directly through 3D-Var (Andersson et al, 1998). Vertical Temperature Profiler Radiometer data, 1972-1979, are used for the first time in a data-assimilation as radiances. VTPR is a 8-channel infrared instrument. All earlier data-assimilations of VTPR data including the NCEP reanalysis have been based on the old operational temperature and humidity retrievals. The use of satellite radiances in ERA-40 allow for a more observation-driven stratospheric analysis during the second half of the reanalysis.

Data from Special Sensor Microwave/ Imager (SSM/I) data are used in ERA-40. The first satellite, F08, was launched in June 1987. The data, one satellite at any time before 1998, originate from F. Wentz (Wentz, 1991) in the form of navigated antenna temperatures, which are calibrated into brightness temperatures. In contrast to the use of TOVS and VTPR radiances the use of SSM/I radiances involves a one dimensional variational analysis of the total column water content and surface wind speed. ERS Scatterometer winds over the oceans are used in the wind analysis from 1994 onwards and altimeter wave height data from 1991 onwards in the wave analysis. Cloud Motion Wind processing techniques have been improved throughout the period, (Uppala, 1997), and EUMETSAT has initiated a task to reprocess the winds 1982-1988, (Leo van de Berg, in these proceedings).

The ozone observations to be used in the ERA-40 are TOMS total ozone and SBUV ozone layer measurements. All these observations are available from 1978 to the present time.

Conventional data for ERA-40 comes from a wide selection of sources. The ERA-40 period begins with the International Geophysical Year of 1958 when the foundation for the current conventional network was established. Most of these data have been collected by NCAR/ NCEP and will be used in ERA-40. Special datasets such as ECMWF observation archive, FGGE, ALPEX and PAOBs will also be included. A new updated Comprehensive Ocean-Atmosphere Data Set (COADS) has been provided by NCAR. Separate additional datasets have been received from JMA and US Navy archives. The conventional network has experienced large changes, e.g., disappearance of Ocean Weather Ships, and the general improvement of the observing system found in ERA-15.

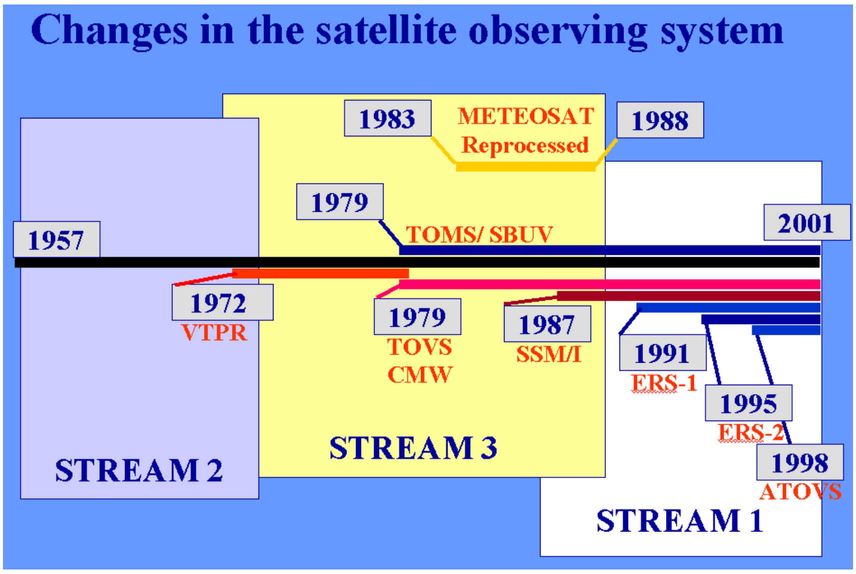

Figure 1 Use of observing systems in the three Streams

There are several periods with similarities in observations and in their distribution. The periods for the temperature, moisture and humidity analysis are:

- no satellite data mid-1957-1972
- VTPR 1973-1978
- TOVS and Cloud Motion Winds 1979->
- TOVS and Cloud Motion Winds and SSM/I mid-1987->
- TOVS and Cloud Motion Winds and SSM/I and ERS 1991->
- TOVS and Cloud Motion Winds and SSM/I and ERS and ATOVS mid-1998->

and for ozone analysis:

- mid 1957-1978 only ozone parameterization
- use of TOMS and SBUV data 1979 onwards

After selecting a unique 6 hourly set of conventional observations and Cloud Motion Winds from the PREODB (S. Saarinen, in these proceedings) the data enter the 3D-Var FGAT together with the six hour set of satellite radiances from VTPR, TOVS and SSM/I. Observations with suspect quality are handled by a special time dependent “blacklist”. It defines the active observations and the observations entering the analysis in passive mode. Departures will be calculated for all observations, but passive observations will not effect the minimization. The decisions to control the use of observations are based on the monitoring results using the statistical information collected over the previous analysis times as shown for example on the ERA-40 web-pages. This includes the observation departure statistics as well as the statistics on the structure and magnitude of the analysis increments.

Handling of biases of the satellite radiance data and the radiosonde temperatures is an important part of the system. In contrast to ERA-15 where radiances were corrected at the end of each month, the ERA-40 bias tuning is more stable and the same corrections can be used until real drift or failure in the instrument happens. ERA-40 also makes use of the Stratospheric Sounding Unit (SSU) and since radiances are the dominating datasource in the stratosphere attention is paid to quarantee analysis continuity, (G. Kelly, in these proceedings). A radiosonde temperature bias correction scheme was developed (N. Sokka, in these proceedings) and is used in from l980 onwards.

Inside the analysis all observations, conventional and satellite, are compared with the background. Estimates of the forecast error in radiance space are used in the quality control of radiances, which is consistent with the treatment of conventional data.

Equalling the improvements seen in the global observing system during ERA-15, it is hoped that after the ERA-40 project, the scientific community will be able to measure the beneficial impact of each observing system on the analysis even more objectively. This can be done directly from the analyses, from the statistical information collected during the data-assimilation and from the quality of regular short range forecasts. Additional observing system experiments will be carried out on the major observing system changes to help in the overall quality assessment.

3. Design of the analysis system for ERA-40

The starting point for the design was the operational data-assimilation system with all the developments since ERA-15, discussed by A. Simmons the following presentation. Altogether 25 years of data-assimilation in about 150 experiments was carried out for 1986-1989 and 1999, as shown schematically in Fig 2.

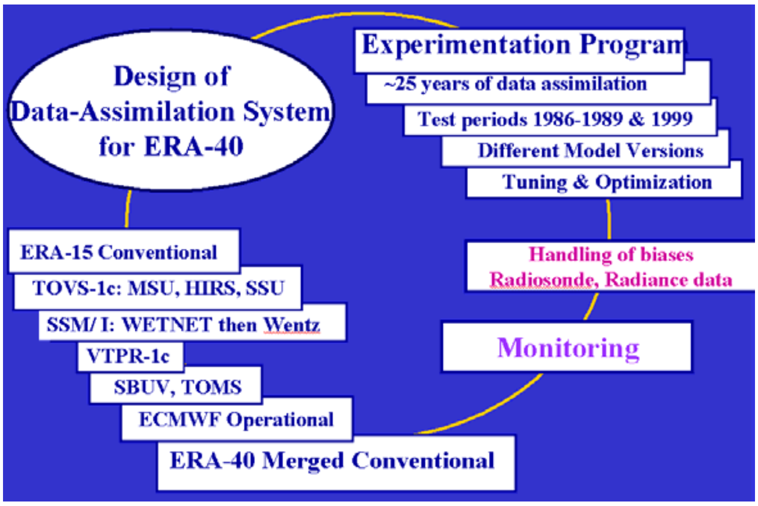

Figure 2 Testing towards ERA-40 data-assimilation system

- Firstly the new surface parametrization scheme, P. Viterbo in these proceedings, was tested using the ERA-15 conventional observations only. The assimilation had to be long to pick up any possible drifts in the surface parameters.

- Since TOVS is the dominant sounding instrument in ERA-40 several tests were carried out with MSU, HIRS and SSU introducing them one by one. The radiance tuning was done in a few data-assimilation iterations. 1999 gave an important opportunity to tune the radiances between TOVS (MSU/HIRS/SSU) and ATOVS(AMSU-A) to guarantee consistency in particular between SSU and AMSU-A. A special long assimilation with all TOVS instruments included passively was carried out in order to monitor possible problems in the 1C-radiances. If the computer resources would have permitted such a “probing” assimilation through the full 1c-dataset would have provided very useful information for understanding the inconsistencies between instruments and for the construction of the blacklist. In parallel to the TOVS experimentation extensive work was carried out to create a “clean” 1c-dataset for the full period and at the same time updating the list of incorrect and/or suspect channels, A. Hernandez in these proceedings.

- Based on the TOVS assimilation the SSM/ I data were first used from the WETNET data in 1987 and later the same tests were repeated using the data from F. Wentz, which were obtained for the production.

- Extensive work was carried out to understand the old VTPR dataset. Maximum amount of information was extracted into the new 1c-dataset. When the preliminary version of the PREODB was available the VTPR radiances were tested using 1976 data. Quality control limits to eliminate cloud contaminated VTPR data were defined. Similar work was done for the HIRS radiances. The bias tuning for VTPR turned out to be especially difficult since each satellite had two instruments and frequent decisions were made during the VTPR operational time to change from one to the other.

- The ERS1 scatterometer data were monitored during the production and after the necessary tuning the data were introduced actively into the assimilation, L. Isaksen in these proceedings.

- The ozone analysis was tested during the production assimilation and it was introduced actively in January 1991 in Stream 1, see A. Dethof & E. Holm, in these proceedings.

- The SST and SEAICE datasets from NCEP & Hadley Center, N. Rayner in these proceedings, were also tested in separate assimilations. Interpolation to daily values values was carried out by M. Fiorino.

- Tests were also carried out (M. Fiorino) on possible bogusing of Tropical Cyclone data by creating wind profiles during the assimilation. The consensus was not to bogus, partly due to the short experimentation period, and to use the best track data for independent validation.

- A radiosonde temperature bias correction scheme was developed and is used from 1980 onwards after enough of statistics was collected. Due to the inconsistencies in the old radiosonde data concerning the station characteristics, the system required extensive work and includes unavoidable simplifications Niko Sokka and K. Onogi in these proceedings.

- The online observation database, PREODB, was developed, S. Saarinen in these proceedings. It contains all conventional observation sources, which are merged into a unique dataset during the production. Predefined rules are applied to extract the best observation from duplicate sources.

- Many monitoring tools have been developed during the production in order to diagnose possible problems. However with three active streams it still is difficult to identify the problem, when it happens. A special monthly “suite” is running after every month, calculating radiosonde biases, monthly mean statistics and it also creates plots of mean increments, cross-sections, mean fields, time-series of the previous and numbers of active/ rejected data. Results are displayed on the project website.

In general the experimentation program was aimed particatarly at responding to the findings and critisism concerning aspects of ERA-15 analyses, for example (Kållberg, 1997). At the same time the recent developments in the data-assimilation system were incorporated for the use in the reanalysis.

4. Project Schedule

The ERA-40 production is organized in three streams covering different stages in the evolution of the observing system. Stream 1 covers the most recent period, with analyses running from the beginning of January 1989 onwards. Stream 2 runs from September 1957 onwards and Stream 3 from January 1973 onwards.

For Stream 1 the "warming up" of the analysis started from September 1986:

September 1986 - October 1988:	Experiment 0012
November 1988 - December 1988:	Experiment 0017
January 1989 onwards:	Experiment 0018

While the Stream-1 had started tests were carried out on the use of observations from pre-1979 periods.

September 1957 - December 1957	Experiment: 0272
January 1958 onwards:	Experiment: 0020
January 1973 onwards:	Experiment: 0030

On the ERA-40 web pages http://www.ecmwf.int/research/era, the progress of the project can be followed with various monitoring diagnostics. The example in Figure 4 shows the status information.

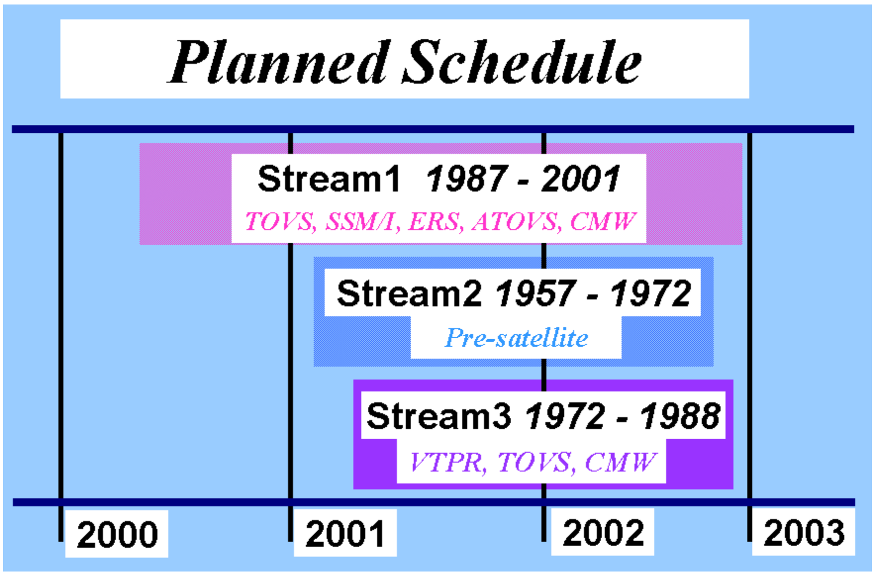

Figure 3 Original production plan

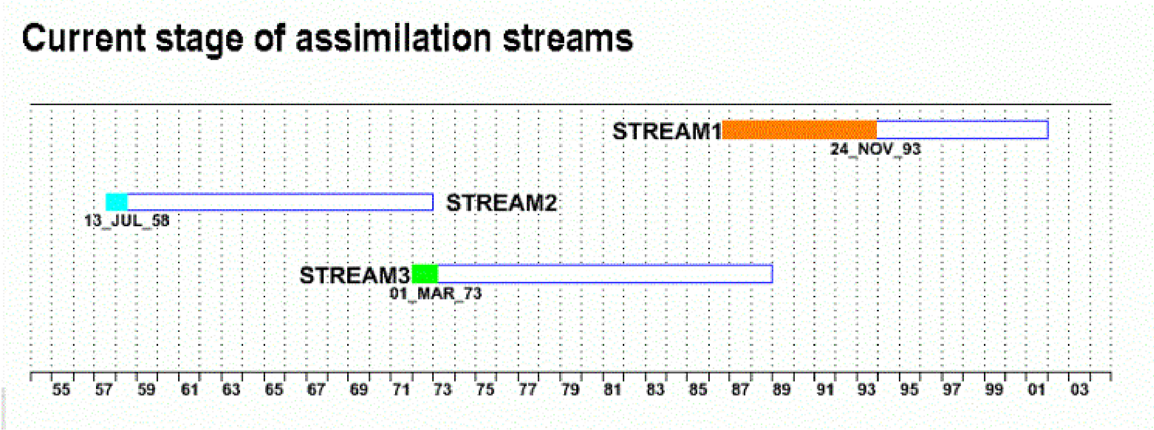

Figure 4 Status of different Streams at the time of the Workshop

The system has been optimized, but work is still needed to speedup processes in order to complete the project before the end of March 2003. Stream 3 will be complemented by the introduction the METEOSAT reprocessed winds and a fairly complex set of NOAA satellites, some which operated only for a short period.

5. Analysis characteristics

The following gives a few examples to illustrate the analysis and first guess quality.

- Figure 5 and 6 show the standard deviation (STD) of 500 hPa height increments in May 1958 and May 1993 respectively. The STD is in general much smoother in 1993 than in 1958. In the Southern Hemisphere, the lack of satellite data is reflected as poorer first guess fields downstream of data void ocean areas. Much larger random errors in the first guess in South America, around Australia and Antarctica can be found in 1958 than in 1993. The analysis increment in the Tropics is small in 1958 due to the lack of data.

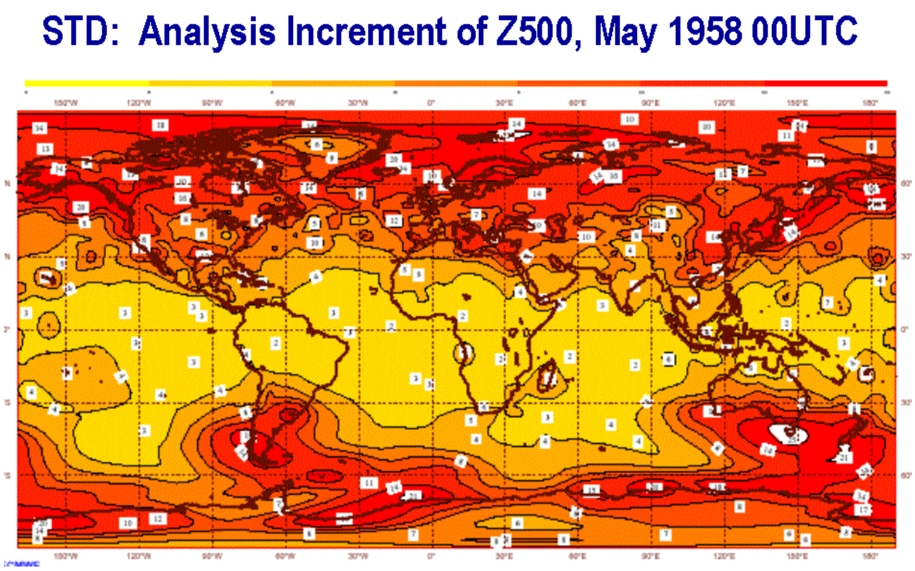

Figure 5 Standard Deviation of 500 hPa height increment: May 1958

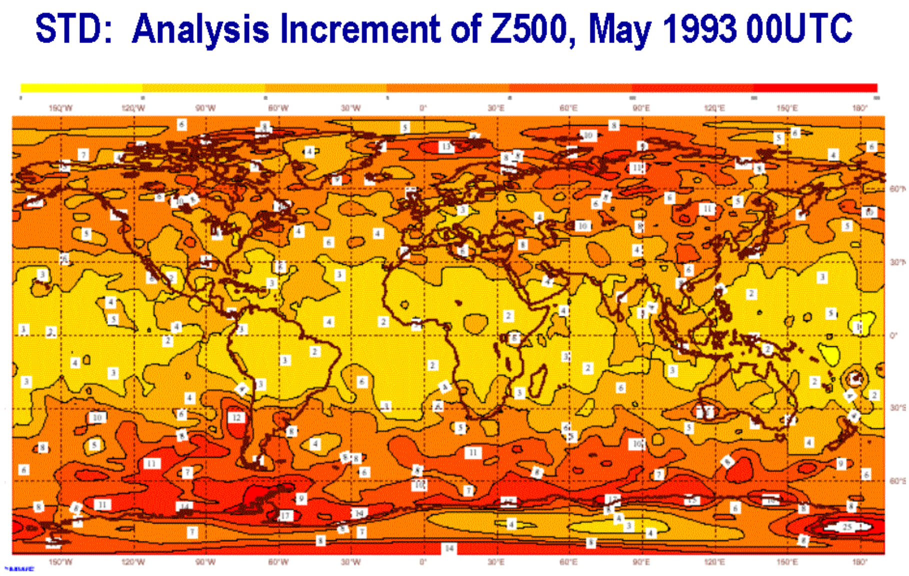

Figure 6 Standard Deviation of 500 hPa height increment: May 1993

- Figure 7 shows the difference between the monthly mean temperature analysis and monthly mean first guess temperature as a cross-section for May 1958 and 1993. In 1993 there are satellite data, which are correcting the first guess temperature. Especially above 10hpa the effect of SSU can be seen. 1958 gives the impression of a good quality assimilation, since the analysis is correcting the first guess less than in 1993, but this is due to too few data.

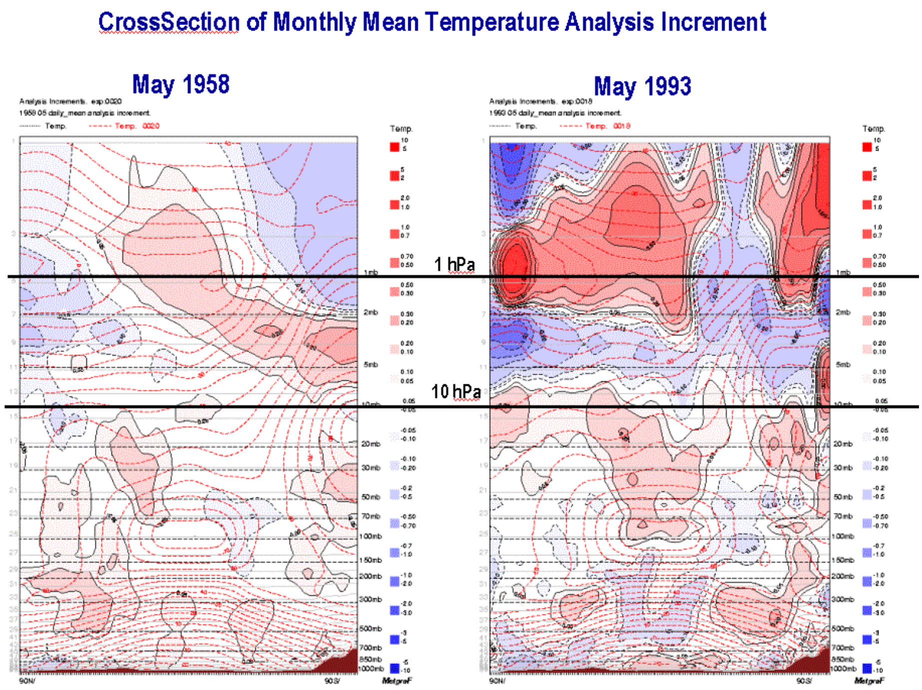

Figure 7 Monthly Mean Temperature Analysis Increment in May 1958 and 1993.

- Figure 8 illustrates the impact from the introduction of VTPR instrument on the 12th of December 1972 on the 30hPa geopotential. The geopotential is increased and the STD of the increment is clearly larger after the introduction of VTPR. This a clean example of a discontinuity introduced by a new observing system.

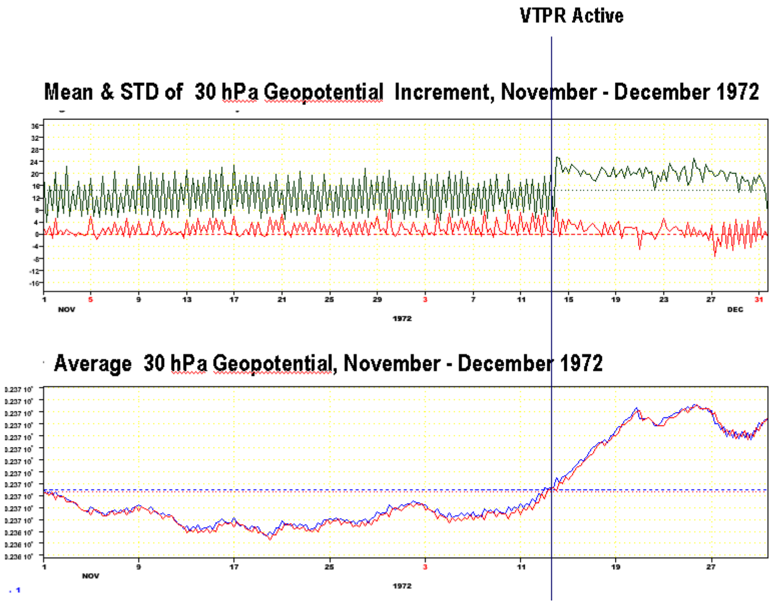

Figure 8 The change in the analysis and first guess (lower panel) and in the mean analysis increment of 30hPa geopotential after the introduction of VTPR in Stream 3.

- Figure 9 gives an indication of the quality of the tropical circulation in different streams and in comparison with ERA-15. The RMS of observation-minus-first guess of the meridional wind component shows that the model circulation is closest to the radiosonde observations in 1993 and better in 1973 than in 1958. The three years of ERA-15 would indicate that the quality of circulation in 1973 of ERA-40 is equivalent to that of 1991-1993 in ERA-15 and year 1993 in ERA-40 is clearly superior to ERA-15.

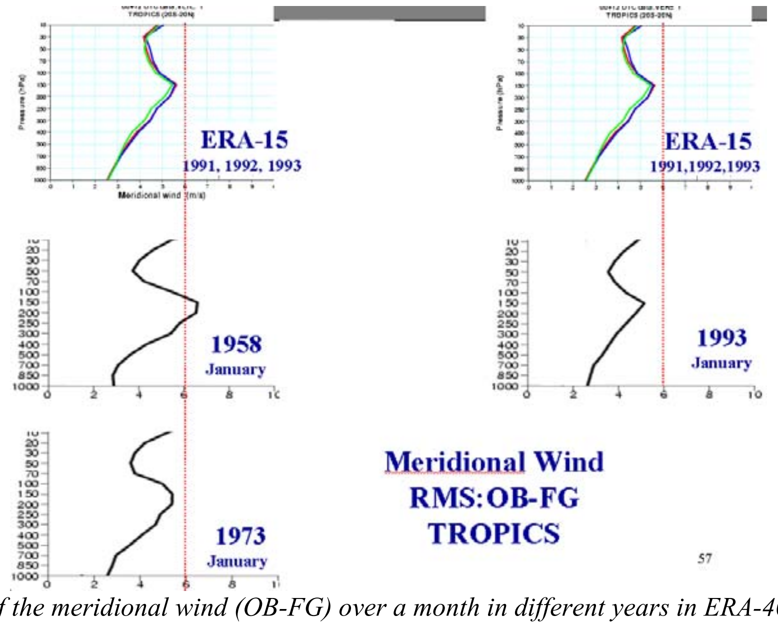

Figure 9 RMS of the meridional wind (OB-FG) over a month in different years in ERA-40 in the Tropics. ERA-15 given as a reference.

6. Indications of forecast quality

A preliminary comparison of the forecast quality between ERA-40, ERA-15 and the old operational ECMWF forecasts for 24 cases distributed evenly over 1989 shows that the ERA-40 forecast skill of 500 hPa height is better than in ERA-15 and much better than in operations for both hemispheres (Fig 10). Forecasts have been run using the same model as was used in the assimilation. Even more clear improvement can be seen in the quality of tropical wind forecasts, especially at higher levels, (Fig 11).

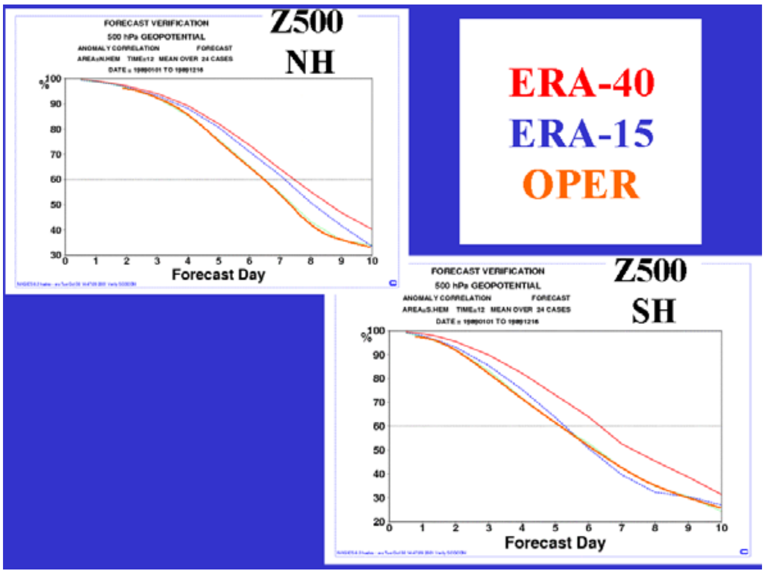

Figure 10 Hemispheric Anomaly Correlations of 500 hPa height for 24 matching cases in 1989: ERA-40 model, ERA-15 model and the old operational model from their own analyses.

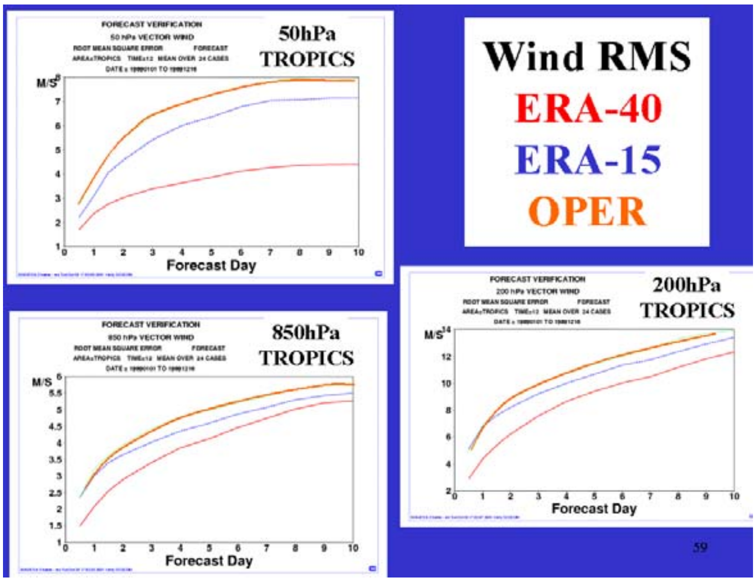

Figure 11 Tropical wind RMS for 24 matching cases in 1989: ERA-40 model, ERA-15 model and the old operational model from their own analyses.

7. Conclusions

Initial assessment of the ERA-40 system performance, which has mainly been based on the period 1989 onwards, shows that the analysis quality is good in comparison with ERA-15 and ECMWF's operations at the time. Satellite radiances are used extensively and the analysis is responding well to the signals in the data. This also means that possible problems in the data are easily absorbed into the analysis unless noticed in the monitoring. Compared to ERA-15, in ERA-40 the satellite bias corrections are valid for longer periods helping to achieve better time consistency. Concerns have been raised about high precipitation rates over the Tropics and the imbalance of P-E, (Kållberg, Hagemann in these proceedings) and. Investigations are underway to understand the possible causes. The tropical wind observations fit the first guess better in later years indicating improving quality of the wind analysis. Also the initial medium range forecasts indicate a good performance in ERA-40 especially for the tropical wind forecasts.

The interaction between the Project Partners and the ERA-Group has been good, resulting in several important discoveries. The timetable shows that the completion of the project according to the plan is very tight considering the still unknown problems. More optimization is needed possibly including setting up an extra Stream. The products have been available for the Partners immediately after the archiving. Active use of the data has also been made by the ECMWF Member States. The purpose of this mid-term workshop is to indicate the strengths and weaknesses of the ERA-40 production and to find ways for corrective actions.

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