From ERA-15 to ERA-40 and ERA-Interim

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1. Introduction

Over the past decade, reanalyses have become established as an important and widely utilised resource for the study of atmospheric and oceanic processes and predictability, and for use in a wide range of applications that require a record of the state of either the atmosphere or its underlying land and ocean surfaces. Whilst high-resolution operational forecasting systems continue to provide what currently are the best possible analyses of recent conditions, the rapid pace of improvements in data assimilation and increases in computer power enables an up-to-date reanalysis system to provide products for all but the last few years that are superior to those available from the archives of past operational products. Moreover, the reanalysis products, unlike their operational counterparts, do not suffer from inhomogeneities due to changes in the data assimilation system, and thus are in principle more suited to use in studies of low frequency variability and trends in climate that complement studies of climate change based on individual instrumental records and climate-model simulations.

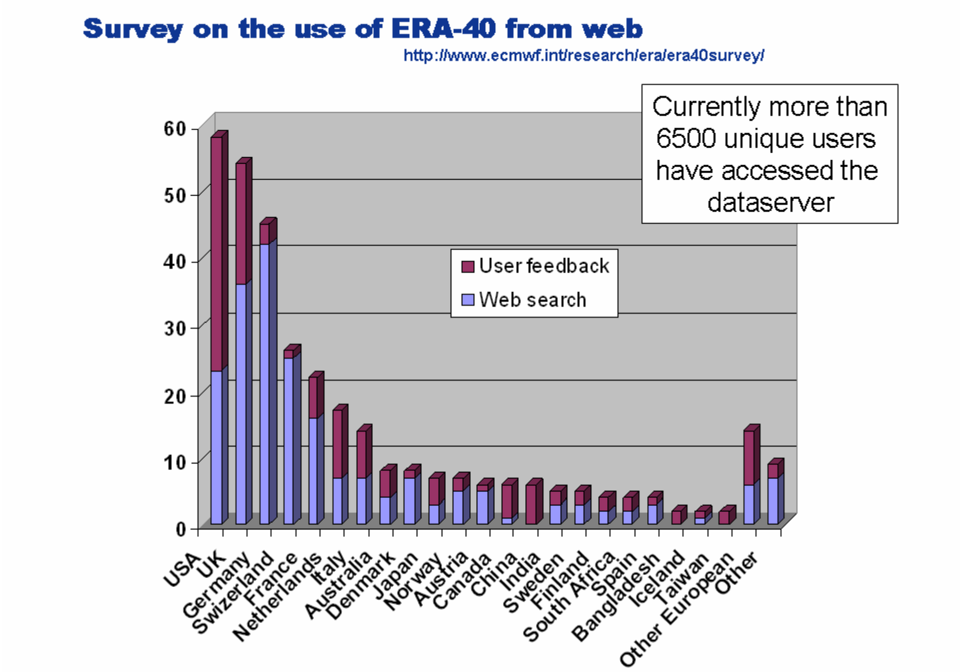

Figure 1 ERA-40 user survey carried out in 2005. The survey is summarized in ECMWF Newsletter 104.

Two recent 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 (Gibson et al (1997)) was launched in 1993 and the second “extended” reanalysis project ERA-40 (Uppala et al (2005)) in 1998.

2. From ERA-15 to ERA-40

- Period ERA-15 (1979-1993) → ERA-40 (1957-2002)
- Improved data assimilation
    - Higher resolution assimilating model T106L31 → T159L60
    - Variational analysis method; Optimum Interpolation → 3D-Var FGAT
    - Analysis of ozone
- Much more extended use of satellite data; VTPR and SSU radiances were assimilated for the first time
- ERA-15 experience → ERA-40 blacklist and bias handling
- More comprehensive use of conventional observations
- A more stable static bias correction scheme for radiance data was used in ERA-40
- Use of Meteosat reprocessed winds, CSR monitored in passive mode
- Improved SST & ICE dataset
- Ocean wave height analysis

The ERA-40 product quality can be seen as a clear improvement to ERA-15. The funding and support for these projects was shared by the Member and Cooperating States of ECMWF, EU framework programmes and several institutes notably in the USA, Japan and China. Pending resources sufficient to support the next extended reanalysis, ECMWF has recently begun

3. ERA-Interim

With increased computer power available, the use of 4D-Var, in operations since 1997, became feasible for the use in reanalysis. It was decided to initiate a new reanalysis activity, ERA-Interim, that would be run for the data-rich 1990s and 2000s, and continued in CDAS mode until superseded by a new extended reanalysis.

Preparatory experiments have been 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 cycle 29r1. 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 1989, the starting year for ERA-Interim. The benefit of using 4D-Var can be seen in systematically better forecast performance, especially in the southern hemisphere. Important improvements can be seen in the hydrological cycle, with 12-hour 4D-Var having the smallest model spin-up/down. Precipitation-minus-evaporation is much closer globally to zero than in ERA-40. The new reanalyses also give 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 has also been 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 GPCP. All points to a small but systematic edge in favour of 12-hour 4D-Var with VarBC.

In summary the main characteristics of the ERA-Interim data assimilation system are:

- Period 1989 onwards and will continue in close to real time in so-called “Climate Data Assimilation System (CDAS)” mode
- Will serve as an intermediate reanalysis between ERA-40 and the next extended reanalysis, and complement CDAS activities in Japan and the USA
- 12-hour 4D-Var with improved humidity analysis and upgraded model physics
- Assimilating model T255L60, a possible rerun using T255L91 model to be decided in early 2008
- Observations and boundary fields from ERA-40 and operations
- Improved use of Level-1c radiances; improved fast radiative transfer model, assimilation of clear-sky radiances from geostationary satellites and 1d-retrievals of rain-affected SSM/ I radiances
- Handling of biases
  - Adaptive bias correction of radiances, Dick Dee (in these proceedings)
  - Radiosondes temperatures
    - Updated tables for the solar angle dependent biases, Ulf Andrae (2004)
    - Homogenization, Leopold Haimberger (2005)
  - Correction of SHIP/ SYNOP surface pressure biases
- Use of reprocessed Meteosat winds, Leo Van de Berg (in these proceedings)
- New improved set of Altimeter wave height data from 1991 onwards Jean Bidlot (in these proceedings)
- Use of re-calibrated ERS scatterometer winds.

Instead of being viewed as a one-off effort, reanalysis has come to be seen as an iterative process, where developments in modelling, data-assimilation techniques, data-rescue efforts and computing power, and data and experience from other centres who have completed reanalyses, are utilized to produce successive reanalyses of increasing quality, that in particular account increasingly well for changes in observing systems. To illustrate the evolving data assimilation and modelling capability at ECMWF, the verification of tropical wind forecasts for 1989 and 1990 are shown in Figure 2 for the original operations, ERA-15, ERA-40 and a preliminary version of the ERA-Interim assimilation. The increase in vertical resolution of the assimilating model is shown in Figure 3 for the three reanalyses.

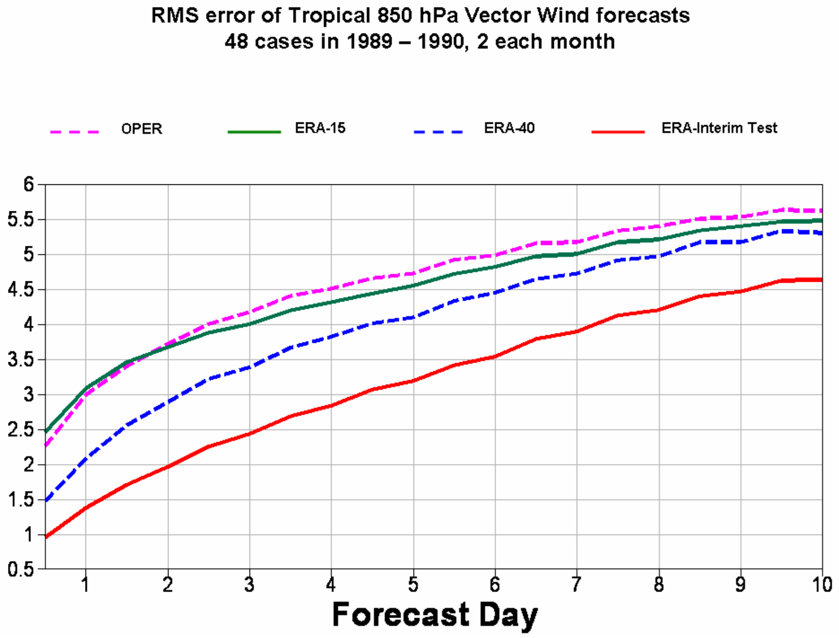

Figure 2: RMS of the Tropical vector wind forecasts error at 850 hPa for the old operations, ERA-15, ERA-40 and Preliminary ERA-Interim verified against their own analysis. There is a gradual improvement from operations to ERA-15 and ERA-40 and a dramatic improvement to ERA-Interim.

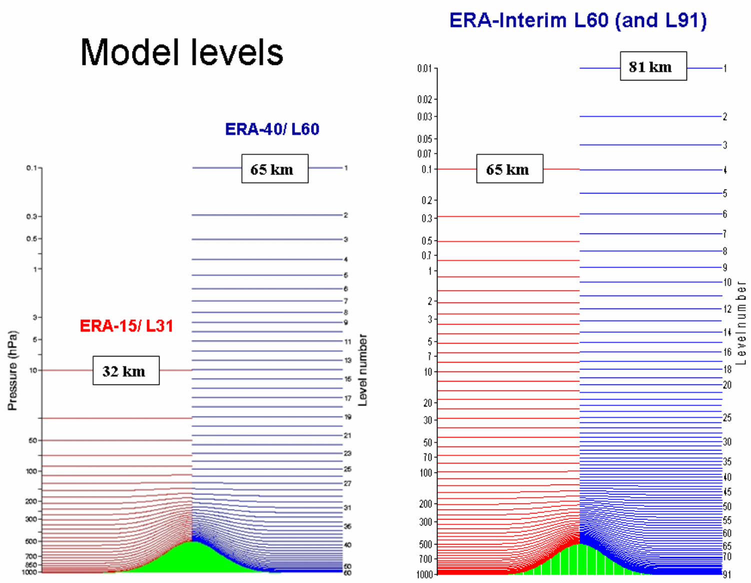

Figure 3: Evolution of the vertical resolution of the assimilating model from ERA-15 to ERA-40 and ERA-Interim. The direct assimilation of radiances has been one deciding factor for the extra levels in the stratosphere.

4. From ERA-Interim to ERA-Extended

- Could start ~2010
- Period ~1940 onwards
- New recovered observations and advanced homogenization methods to be used
- Use of improved SST & ICE dataset

- New generations of extended “climate reanalyses” are likely to exploit possibilities not open to daily operational weather prediction. A reanalysis system can make use of observations taken over a period after the analysis time as well as before.
- Utilization of the available observational information may be improved by lengthening the time window of the data assimilation in a weak-constraint 4D-Var system.
- New approaches for handling observational and model biases also show promise for use in reanalysis

Despite being able to exploit the scientific and technical infrastructure developed for weather forecasting, reanalyses remain large and demanding undertakings. They require multi-institutional collaboration to acquire not only the many types of daily data to be ingested but also the necessary boundary forcing fields and specifications of atmospheric composition. Product continuity has to be maximized, involving the homogenization of input observations in addition to the bias handling built into the assimilation system itself. The production phase of a reanalysis commonly runs to a tight timetable dictated by funding constraints or availability of computing resources, and requires intensive monitoring to ensure satisfactory scientific and technical performance, and documentation, data services and user support are needed long after production is complete. Because of the complexity of these tasks, the potential for improved reanalysis cannot be realized without proper long-term organization, funding and international collaboration.

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