

# CURRENT STATUS OF THE ECMWF RE-ANALYSIS (ERA) PROJECT

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## 1. INTRODUCTION

The European Centre for Medium-range Weather Forecasts (ECMWF) has provided data from its archive for Meteorological Research for many years. The ECMWF Re-Analysis (ERA) project was devised in response to the wishes expressed by many users of these data. It is funded by the ECMWF Council, the European Union (EU), the Program for Climate Model Diagnosis and Intercomparison (PCMDI, University of California), the World Meteorological Organisation (WMO), the Centre for Ocean-Land-Atmosphere Studies (COLA), the Japan Meteorological Agency (JMA), and Cray Research Incorporated. In addition contributions in terms of data and assistance have been forthcoming from many quarters, including ECMWF Member States, the National Center for Environmental Prediction (NCEP) Washington, the National Center for Atmospheric Research (NCAR), and the Australian Bureau of Meteorology.

### 1.1 Objectives

The goal is to produce a validated and documented 15-year (1979-1993) global atmospheric data set of assimilated data at high horizontal and vertical resolution. This data set, generated using a consistent assimilation system, provides three dimensional descriptions of the velocity, temperature, geopotential and humidity fields for the atmosphere. In addition, analyses of surface parameters (temperature, pressure, soil moisture, etc.), surface fluxes of heat, moisture, radiation and other diagnosed quantities are included.

## 2. ORGANISATION

The project began in February 1993 and will end in 1996. A team of 3 people are assigned for the duration of the project, with an additional 3 people each for 2 years; this includes two EU fellowship students, and a staff contribution from JMA.

An internal steering group together with the ECMWF Director reviews the project management. An external advisory group provides advice.

### 2.1 Data Sources

The real time ECMWF data collection (which has a 3 day cut-off) are augmented by the following additional data:

- NOAA satellite radiance data for the 15 year period;
- The COADS ship data set;
- FGGE and ALPEX final IIb data sets;
- Additional GMS cloud winds, AIREP and TEMP data supplied by JMA;
- Australian PAOB data;
- NOAA Climate Analysis Centre and UK Meteorological Office GISST delayed mode sea surface temperature (SST) analyses;
- SMMR and SSM/I data for sea ice cover.

## 2.2 The Data Assimilation System

The development of a reliable and robust assimilation system suitable for the fast rate required to generate the analyses within the project's time-scale required an intense period of experimentation to select the appropriate version of the forecasting model and the spatial analysis procedure employed in the assimilation system, coupled with major software and data handling development to establish the technical support.

The ERA data assimilation system is a special version of the ECMWF operational data assimilation system which includes:

- intermittent statistical (Optimum Interpolation) analysis with 6 hour cycling;
- one dimensional variational (1D-VAR) physical retrieval of TOVS cloud cleared radiance (CCR) data;
- Diabatic, non-linear normal mode initialisation (five vertical modes);
- a T106 forecast model with 31 hybrid vertical levels, and a fully 3 dimensional semi-Lagrangian advection scheme;

- a physical parametrization package which includes mean orography with a compatible gravity wave drag formulation, a 4 layer prognostic soil scheme with no external forcing (Viterbo and Beljaars, 1995), and full model prediction of cloud water content and cloud cover.

In addition, the following external forcing is used:

- UK Meteorological Office GISST 1 degree monthly sea surface temperature analyses (1978 to October 1981), NMC 1 degree weekly (November 1981 to 1993);
- ice limits derived by ERA from SMMR and SSM/I data (Nomura, 1995);

### 2.3 The Production System

The production system is designed to organise the generation of one month of re-analysis; it is then used repeatedly for continuous production. Production tasks are co-ordinated using the ECMWF Supervisor Monitor Scheduler (SMS), which also controls ECMWF's daily operations and research experiments. This enables tasks to be initiated on various computer platforms, and supports complex scheduling criteria.

Analyses and forecasts are run on a Cray C90; two Silicon Graphics file servers are used for the on-line data bases and pre- and post-processing. A Cray YMP-EL is used for monitoring and monthly and seasonal product generation.

An Empress data base system is used for handling observations, analysis feed-back statistics, and fields of results. Observational data are pre-fetched from archives, one month at a time, organised in data base form, and checked before use. Suitable results (fields and feedback) from each forecast/analysis cycle are entered into data bases prior to the generation of monthly statistics and addition to the archive.

Three months of observational data and feed-back, and two months of results are retained on-line within the file systems of the SGI servers. This enables end of month processing and validation to be performed with on-line data, and the archive to be constructed in the form of monthly files. The ECMWF Meteorological Archive and Retrieval System (MARS) has been extended to interface to these data bases, providing a single interface for access to either on-line or archive data.

#### 2.4 **Validation**

The validation exercise provides rapid, critical evaluation of the data-sets as they are produced, enabling defects to be detected as they arise. This is being done through diagnostic studies of the analyses as they become available, and performed with the assistance of a number of external validation partners (for further details see Gibson et al., 1994). Results from these studies will also provide an essential component of the final scientific documentation.

#### 2.5 **Archives and Data Services**

The additional observational data, and a comprehensive set of re-analysis results will be added to the ECMWF archive.

Four main validated and documented data sets are being produced, forming the basis for data services:

ERA Basic Analysis Data Set

ERA Advanced Analysis Data Set

ERA Supplementary Fields Data Set

ERA Climate and Statistics Data Set

The Basic Data Set provides selected variables in compact form at 2.5 degree resolution and will be particularly useful for users with limited data processing resources. It contains geopotential, temperature, vertical velocity, two components of wind, and relative humidity at 15 standard pressure levels, together with a number of surface and diagnostic parameters. The volume of one year of such data is about 4.5 Gigabytes.

The Advanced Data Set gives access to the results of the re-analysis at the horizontal and temporal resolutions of the generating system. Users may obtain these data either on the grids used by the generating system (T106 spherical harmonics for upper air data, N80 Gaussian grid for surface and diagnostic parameters), or interpolated to a regular latitude/longitude grid of their choice. The parameters supported are similar to those described for the basic data set above. In addition to the 15 standard pressure levels, data are available on the 31 level hybrid vertical co-ordinate system used by the generating models. The volume of one year of such data is about 7.5 Gigabytes for 15 pressure levels, or 13 Gigabytes if the 31 model levels are specified.

The Supplementary Fields Data Set is generated from the first guess forecasts, and provides parameters such as surface flux of sensible and latent heat, surface and top of the atmosphere radiation fluxes, and rainfall. These are retained at model resolution; interpolation to other resolutions will be supported. First guess forecasts based on 00 UTC and 12 UTC are run to 24 hours, enabling these parameters to be obtained from the 12 to 24 hour forecast periods. The volume of one year of such data is about 1.5 Gigabytes.

The Climate and Statistics Data Set contains monthly and seasonal means data together with a number of statistics generated at the end of each production month. These data enable access to many of the climatological aspects of the results without recourse to the full daily data. Considerable discussion has taken place with eminent atmospheric scientists and potential users to determine the contents of this data set. The volume of one year of such data is about 0.75 Gigabytes.

All ERA results are archived in either WMO GRIB or BUFR representation.

### 3. STATUS

Currently (August 1995) ERA production has reached April 1985. By the end of 1995 it is expected that the first 10 years will be complete, and that all 15 years will have been processed by the end of the second quarter of 1996.

#### 3.1 Data acquisition

The sea surface temperature data produced by NMC Washington, and by the UK Meteorological Office have been acquired. These have been subjected to comparisons, and examined in detail for various events including El Niño periods. Attention has been given to the representation of sea ice within the SST data. Comparisons with ice coverage obtained directly from SMMR and SSM/I data resulted in the decision to derive ice coverage separately (Nomura, 1995).

NMC Washington have made available the COADS ship data-set as part of the co-operation established between the ECMWF and NMC re-analysis groups.

NOAA satellite cloud cleared radiance data have been purchased and obtained jointly with NCAR. There are, unfortunately, gaps in these data (about 8 months are missing in total); NESDIS level 1 data, where available, have been obtained for these periods.

FGGE, Alpex Level II-B, and the other observational data listed in 2.2 above have been translated into the representation forms used within the Centre's archive.

### 3.2 Establishment of the Data Assimilation System

A programme of experimentation, planned jointly with ECMWF's Research Department, has been undertaken to determine to what extent the data assimilation system to be used should differ from that of the Centre's daily operations. This was necessary because the system, once established, should remain fixed for the full re-analysis production.

Even after formal ERA production had begun experiments aimed at fully refining the system continued. Although this caused some delay for the ERA production, it has led to improved assimilation systems for both ERA and the Centre's operations. It also demonstrated the effectiveness of an efficient re-analysis system for enhancing the productivity of a research programme.

The end product has been the establishment of a data assimilation system for ERA production identical to that introduced into ECMWF's daily operations in early 1995, except for differences in resolution.

### 3.3 The Production System

The system has proved relatively robust, and is capable of performing one year of re-analysis per month.

### 3.4 Validation

The feed-back provided by a number of external validators was especially useful during the experimentation and early production periods. Coupled with the internal validation effort, it enabled experimental results to be assessed quickly in an unbiased and well reasoned manner.

Results of the various validation projects are by no means complete. Interesting aspects noted to date include:

- the ERA 1982-83 El Niño - Southern Oscillation is more intense compared to the ECMWF operations archive;
- various aspects concerning the evolution of the observing system - especially the improvement in the quality of radiosonde data;
- Simulated clear-sky outgoing longwave radiation at the top of the atmosphere, and surface fluxes and atmospheric cooling rate profiles are being obtained using the SAMPSON model with ERA data (Slingo, Pamment and Webb - Hadley Centre);

- a critical appraisal of the global hydrological cycle is being undertaken (Arpe, Bengtsson and Stendel - Max Plank)
- preparations are being made to use ERA data to simulate the Alpine snow mantle (Cariolle - Météo France)

### 3.5 Archive and Data Services

Data are available to ECMWF Member States via the Centre's Meteorological Archive and Retrieval System (MARS).

Data Services, which include, where appropriate, extraction and interpolation facilities, enable access to the data sets for meteorological research workers. A charge is made to cover the costs of extraction and to enable the support of the Data Services unit to meet the demands of users.

## 4. CONCLUDING REMARKS

Close co-operation with the Research and Operations Departments has resulted in a good assimilation system for both ERA and Operations. The usefulness of the ERA system as a tool for Research purposes has been demonstrated both during the experimentation which lead to the choice of system, and subsequently, when some further test runs were carried out with the ERA system. ERA production has provided feedback on performance and quality; it has also generated an archive of considerable potential usefulness.

Accelerated research has lead to operational implementation of some of the changes which contributed to the ERA system in a timely manner. Co-operation with the Operations Department has lead to improvements in the archives and archive support, improved monitoring tools, and the identification of system optimisation techniques which can be applied generally.

The archive of re-analysis results has been eagerly investigated by the validation team, and is in considerable demand elsewhere. It can contribute to assessments of the performance of the observing system, and may be considered more consistent with climate than any previously obtained through data assimilation. Results are being used to drive an ocean model, and for research into seasonal forecasting.

## 5. REFERENCES

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