The ERA-40 Project Plan

Preface

The production and primary validation phase of the ERA-40 project is being funded for a three-year period from 1 April 2000 by the European Union under its Fifth Framework Programme in Energy, Environment and Sustainable Development, through contract EVK2-CT-1999-00027. This Project Plan is based closely on the technical annex of the contract, which follows a form prescribed by the European Commission. It was edited by Adrian Simmons and Rex Gibson of ECMWF, using input from other staff of ECMWF and from the partners in the project. In the planning phase the partners were represented by Klaus Arpe of the Max-Planck-Institut für Meteorologie, Tony Slingo of the Meteorological Office, Pascal Simon of Météo-France, Gerbrand Komen of Koninklijk Nederlands Meteorologisch Instituut, Roy Jenne and Kevin Trenberth of the National Center for Atmospheric Research, and Brian Hoskins and Julia Slingo of the University of Reading. ECMWF contributors included Tony Hollingsworth, Sakari Uppala, Per Kållberg and Keith Edwards. Rex Gibson was Project Manager for the preparatory phase of ERA-40 until his retirement from ECMWF at the end of August 1999. Sakari Uppala is the current ERA-40 Project Manager.

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1. SUMMARY

ERA-40 will use a variational data assimilation system to make a new synthesis of the *in-situ* and remotely-sensed measurements made over the period since mid-1957, when a major improvement was made to the atmospheric observing system in preparation for the International Geophysical Year, 1958. ERA-40 will produce analyses with six hourly frequency throughout the period, supplemented by intermediate three-hour forecasts. The products will be of high temporal and spatial resolution, with a grid-spacing close to 125km in the horizontal and with sixty levels in the vertical located between the surface and a height of about 65km. The basic analysed variables will include not only the conventional meteorological wind, temperature and humidity fields, but also stratospheric ozone and ocean-wave and soil conditions. Additional information will be produced concerning the quality of both the observations used and the analyses generated. A sophisticated archival/retrieval system will be used to store the results and make them widely available. Compact sub-sets of the data will be generated to reduce data retrieval costs. Extensive documentation will enable customers and users of the results to gain maximum benefit.

ERA-40 will adopt innovative analysis techniques, especially with respect to satellite data, and will use new types of observation and improved specifications of sea-surface temperatures and sea-ice distributions. It will build on experience gained earlier in carrying out re-analysis in Europe and the USA, and will deliver products that are unique in their combination of time-range, vertical extent, variety and accuracy.

For overlap periods of at least one year, ERA-40 will produce analyses with and without each significant addition to the observing system. This will enable assessment and quantification of the impact of these enhancements, and in particular will document the benefit of the development of the satellite observing system over the past three decades. The availability of ERA-40 analyses will also revitalize the use of data from past field experiments in the improvement of climate and weather forecasting models. ERA-40 products will be enhanced by short periods of higher resolution global assimilation. This will enable better exploitation of the observational data from experiments such as GATE (1974), ALPEX (1982) and TOGA-COARE (1992-93).

Validation and demonstration studies form an important component of ERA-40. A major aim of these is to provide checks on the quality of the analyses by comparison with independent measurements. This will be done either by direct verification of analysed or simply-derived values, or by verifying the output of different types of model that have been forced by the analysed values, for example an ocean circulation model and a snow model. This verification will be complemented by a selection of diagnostic, process and climatological studies based on the analyses which will not only provide examples to the general user of the ways in which the data can be applied, but also provide specific contributions towards meeting some of the broader targets of the European Union's Fifth Framework Work Programme in Energy, Environment and Sustainable Development. The studies will focus on trends in the observing system, the hydrological cycle, clear-sky radiation, Alpine snow simulation, upper-tropospheric and stratospheric ozone and water vapour, ocean waves, global mass, heat, energy and moisture budgets, and diagnosis of atmospheric circulation systems.

The ERA-40 analyses will, however, have a wider applicability than can be explored in the studies to be carried out under this project, and they will be used by a number of other projects under the Work Programme, ensuring effective application across a range of studies.

The need for a project with the objectives of ERA-40 was recognised by the Euroclivar concerted action funded under the Fourth Framework Work Programme. Euroclivar "strongly recommended that a new 40-year re-analysis be made in Europe in the next five years" (Bengtsson and Komen, 1997; Anderson et al., 1998). ERA-40 is thus expected to make a significant contribution to those objectives of the Fifth Framework Work Programme that match the objectives of the CLIVAR component of the World Climate Research Programme, either directly or by providing data in support of projects such as DEMETER, which will explore the potential for seasonal prediction, and PROMISE, which will make extensive use of ERA-40 analyses for validating climate and seasonal prediction models and for driving crop models for impact studies. Other research areas with strong potential for application of the ERA-40 analyses include ozone depletion and other aspects of atmospheric chemistry.

The partnership carrying out the project comprises the European Centre for Medium-Range Weather Forecasts (ECMWF), the national weather services of France (Météo-France), the Netherlands (Koninklijk Nederlands Meteorologisch Instituut, KNMI) and the United Kingdom (the Meteorological Office, UKMO), meteorological research institutes from Germany (Max-Planck-Institut für Meteorologie, MPIfM) and the USA (National Center for Atmospheric Research, NCAR), and the Meteorology Department of the University of Reading, UK (UREADMY). ECMWF has made extensive preparations for ERA-40, and will be the producer of the analyses and co-ordinator of the project. The other partners have been active in the planning and the preliminary studies for the project, and will carry out the bulk of the validation, diagnostic and exploitation studies. NCAR has also played an essential rôle in supplying ECMWF with observational data not previously held in the ECMWF archives.

Support for ERA-40 has been committed by a number of bodies in addition to the European Union:

- The partners in this project have supported the acquisition and preparation of the necessary observations, the trial production and validation of analyses, the assessment of user requirements and the general planning of the project.
- Institutions in China (IAP), Japan (JMA) and the USA (PCMDI) are funding the secondment of staff to work on the project.
- Several other institutions have provided specific holdings of past observational data.
- Fujitsu Ltd is providing substantial computing support for the project.
- EUMETSAT has committed to re-deriving winds from Meteosat-2 images for the period 1981-1988.
- The World Climate Research Programme and the Global Climate Observing System are providing funds in support of an External Advisory Group for the project. The Group has already met twice, in January 1998 and March 1999, to aid in the planning of the project, including the assessment of user requirements.

The capacity of the partners and these supporting institutions to provide ongoing manpower support for ERA-40 is limited. In particular, it is insufficient to meet the challenging objective of producing the re-analyses at a rate fast enough to satisfy the demand for ERA-40 products both from Fifth Framework research projects and from the wider scientific community. Re-analysis projects must proceed at sufficient speed for them not to be continually overtaken by developments in data-assimilation technique and large-scale computing. Accordingly, the funding from the EU under the Fifth Framework Programme will be used to enable the basic production of the re-analyses to be completed within a period of about two years, and to enable the necessary validation and demonstration studies to be undertaken.

The preparatory work for the project is now largely complete, enabling production of the ERA-40 analyses to commence close to the start of the EU-funded phase of the project, designated month 0. The subsequent principal milestones and direct results of the project are:

- Production rate rising to two analysed years per month by month 11.
- Analyses for 1987-1998 and 1957-1968 completed, monitored and archived by month 14.
- Interim validation and exploitation reports in month 17.
- Mid-project workshop to present project and interim results to users.
- Complete archive of analyses for 1957-2001 by month 31.
- Affordable data dissemination service by month 35.
- Full delivery of climate and statistical data by month 35.
- Final validation, exploitation and project reports in month 35.

2. SCIENTIFIC/TECHNICAL OBJECTIVES AND INNOVATION

2.1 Objectives

The primary objectives of ERA-40 are to:

- Produce and promote use of a comprehensive set of global analyses describing the state of the atmosphere and land and ocean-wave conditions from mid-1957 to 2001.
- Foster European and international research by making the observational archive, the analyses and the study reports widely available.

Enabling or secondary objectives are to:

- Create, maintain, and refine an archive of global meteorological and ocean-wave observations, both in-situ and remotely-sensed by satellite, to support re-analysis, forecast-model development, and climatological studies.
- Perform validation, diagnostic and exploitation studies to demonstrate the quality and applicability of the global analyses.
- Generate and make available statistical information (the “feedback statistics”) concerning the differences between observed values, analysis values and forecast values from which both analysis quality and observational quality may be diagnosed.
- Indicate the benefit of the major changes made to the observing system over the past forty years.

The specific tasks of ERA-40 include:

- acquisition, quality control, and generation of archives of observations for the period of the analysis;
- compilation of an extensive archive of metadata concerning the performance of each observation examined with respect to the data assimilation system;
- diagnosis of the archive of metadata to determine the impact of changes in the observing system over the period;

- documentation, in particular, of the impact of the introduction and subsequent enhancements of the satellite observing system over the past three decades;
- computation and archival of monthly, seasonal and climatological means, variances, and co-variances from the analysis products, including a climatology of ocean waves;
- validation of the analysis products with respect to hydrology, energy fluxes, ocean waves, clear-air radiation, stratospheric ozone and water vapour, general circulation diagnostics and medium-range weather forecasts;
- creation of an archive of products which will promote research into many areas, including the development of seasonal weather prediction and climate change studies;
- maintenance and refinement of data delivery and information dissemination services to ensure the widest possible availability of the results of the re-analysis.

Target dates for milestones and deliverables that indicate the progress of ERA-40 are provided within this document. Creation of an archive of observations and production of comprehensive sets of global analyses and feedback statistics are objectives which by their very nature are measurable in terms of data volumes generated and dates of general data availability. The validation reports to be produced by the project will provide verification of the quality of the analyses and observations. Further quantification of the success of the project will be provided by the statistics of requests for ERA-40 data from other EC-funded projects and from European and international researchers in general.

2.2 Data Assimilation

Atmospheric data assimilation comprises a sequence of analysis steps in which background information is combined with observations to produce an estimate of the state of the atmosphere (the “analysis”) at a particular time. The set of observations typically comprises several types of measurement, each with its own accuracy and distribution. The analysis is nevertheless complete in terms of the meteorological variables and domain of interest, to within a chosen spatial resolution. The background information essential to produce the complete representation comes from a short-range forecast initiated from the most-recent preceding analysis in the sequence. The observations and background forecast are combined using estimates of the statistics of their errors. In variational assimilation this combination is achieved by minimizing the sum of statistically-weighted measures of the deviations of analysed values from the observed and background values. The background forecast carries forward in time the information from the observations used in earlier assimilation cycles.

Data assimilation is used routinely to provide the initial conditions for operational weather forecast models. The resulting sequence of initial states provides as a by-product a comprehensive spatial and temporal record of the state of the atmosphere. It is based on a synthesis of the available observations and depends implicitly on the dynamics and physics represented in the numerical model used for the background forecast. The degree of dependence on the model varies with the density and relative accuracy of the observations (the error statistics), and in general differs from place to place and from one variable to another (from wind to humidity, for example).

The global analyses produced specifically for the Global Weather Experiment (GWE) in 1979 (Bengtsson et al., 1982) were utilized widely for research studies as reviewed in WMO (1985) and ECMWF (1985). Global operational forecasting systems became established at about the same time, and given the limitations of the one-year sampling period of the GWE, the operational analyses rapidly became a mainstay of atmospheric research. They were used, *inter alia*, for studies of atmospheric processes such as cyclogenesis (e.g. Bosart et al., 1992) and stratosphere-troposphere exchange (e.g.

Price and Vaughan, 1993), to aid the interpretation of satellite or other observational data not used in the assimilation (e.g. Appenzeller and Davies, 1992), to produce diagnostics of the general circulation of the atmosphere (e.g. Hoskins et al., 1989) or as a "truth" against which the performance of climate-simulation models could be judged (e.g. Mote et al., 1994).

Use of the operational products was not without its problems, however. Deficiencies in the analysis method or assimilating model could introduce significant biases in the resulting analyses, and could invalidate the conclusions drawn from them. Many of these deficiencies have been remedied over the course of the past two decades, but this has itself introduced long-term trends in the operational analysis products. This has inhibited the use of these products in the study of low-frequency climatic variability and climate change. These problems were compounded by difficulties experienced by many users of the analyses in knowing quite what was changed and when, what the impact was, and what also was the impact of changes in the observing system over the period of study.

2.3 Re-analysis as an improvement on operational data analyses

The above concerns led Bengtsson and Shukla (1988) and Trenberth and Olson (1988) to propose re-analysis of the record of past atmospheric observations using fixed, up-to-date data assimilation systems. Their proposals met with positive responses, and led to three major re-analysis projects:

- A fifteen-year analysis starting from 1979, ERA-15, produced by ECMWF (Gibson et al., 1997);
- A fifty-year analysis from 1948 produced by the National Centers for Environmental Prediction (NCEP), USA, in collaboration with NCAR (Kalnay et al., 1996);
- A fifteen-year analysis from March 1980 produced by the Data Assimilation Office (DAO) of the National Aeronautics and Space Administration (NASA), USA (Schubert et al., 1995).

Though largely successful, several quite significant problems have been detected in these re-analyses. For example, among the deficiencies identified in the ECMWF analyses (Kållberg, 1997) are:

- Generally too-cold surface temperatures in winter, and too-cold spring temperatures in boreal forests;
- Grossly erroneous Antarctic orography;
- Unrepresentative use of data from island stations influencing surface exchanges and precipitation;
- Severe drying of the western Amazonian land surface in the first half of the period;
- Shifts in temperature and humidity analyses in response to changes in satellite instruments.

2.4 ERA-40: a new re-analysis

ERA-40 will be a new European re-analysis which will improve considerably upon the earlier re-analyses. It will produce and disseminate analyses with higher horizontal resolution, a much more extensive and accurate description of the stratosphere, and finer resolution of the planetary boundary layer. It will provide a wider range of analysed fields, most notably ozone fields and ocean-wave fields from a coupled wave model. It will use an advanced but operationally-tested variational data assimilation system with a refined numerical model. This system does not exhibit, or exhibits to a much lower degree, the problems experienced in ERA-15. ERA-40 will provide an important second source of re-analysis data for the period 1957-1978 previously covered only by the NCEP/NCAR re-analysis.

ERA-40 will be innovative in its use of satellite data (Table 1). The radiance data from the HIRS/MSU/SSU instruments available since 1979 will be assimilated in raw rather than processed form, thus avoiding trends and variability due to the changes introduced in the processing over the past two decades. The earlier VTPR and recent AMSU data will also be assimilated in raw-radiance form. The fifteen-year ECMWF analysis provided evidence of a significant improvement in the quality of cloud-wind products from geostationary satellites throughout the 1980s (Uppala, 1997); ERA-40 will benefit from use of reprocessed winds from at least the Meteosat-2 satellite. ERA-40 will also be novel in its use for re-analysis of scatterometer winds, SSMI radiances (via a local retrieval of column water vapour and surface wind), ozone products and HIRS ozone-channel radiances.

Table 1: Satellite Data for ERA-40

Satellite and/or Instrument	Period	Type of Data
NOAA VTPR	1972 - 1978	Radiances
NIMBUS-7 TOMS	1978 - 1993	Ozone products
Meteosat, GOES and GMS	1979 -	Cloud-wind products
NOAA AVHRR/HIRS/MSU/ SSU/SBUV/AMSU	1979 -	Radiances; SST and ozone products
SMMR	1979 - 1987	Sea-ice products
SSM/I	1987 -	Radiances; sea-ice products
ERS Scatterometer and Altimeter	1991 -	Backscatter measurements and wave-height data

ERA-40 will use new externally-produced analyses of sea-surface temperature (SST) from the UKMO (pre-1981) and NCEP (post-1981). It will also adopt sea-ice distributions agreed externally by a WCRP-sponsored working group comprising representatives of UKMO, NCEP and the ACSYS community. UKMO and NCEP have ensured their SST analyses are consistent in the sea-ice margins.

2.5 Validation studies for ERA-40

Innovation in the validation and demonstration studies will come from the application of standard methods of diagnosis to an innovative set of analyses, from the validation of the analyses in comparison with new types of independent data, and from novel applications using independent models driven by the analyses. Studies of the long-term characteristics of the analyses will include:

- Calculation and verification of implied river discharges and changes in the level of inland seas;
- Verification of snow depth climatologies produced directly from the analyses and from a snow-model driven by the analyses;
- Verification of the performance of an ocean-circulation model driven by the ERA-40 surface fluxes;
- Assessment of trends and extreme events in the ocean wave fields.

Validation of the analyses for later years will include comparison of analysed upper tropospheric and stratospheric ozone and water-vapour fields with EU-funded MOZAIC aircraft data and UARS satellite data, comparison of precipitation fields with TRMM satellite data and comparison of radiation fields with CERES satellite data. Extensive comparisons will also be made with many of the field-experiment datasets over the period. Data from the EU-funded CLAUS project will be used to validate the characteristics of tropical convection in the analyses, and diagnostic methods developed under EU funding of the SHIVA and STOEC projects will also be applied. The medium-range forecasts to be produced regularly over the re-analysis period will provide a new source of information for the study of atmospheric predictability.

The validation studies will help to guard against the risk of major errors in the ERA-40 production system. They will also guard against the risk of misleading end-results by informing potential users of the limitations of analysis accuracy and applicability.

3. PROJECT WORKPLAN

3.1 Introduction

Work on the preparatory phase for ERA-40 has been carried out over more than two years, and will be largely completed by the start of the EU-funded phase of the project, designated to be the beginning of month 0. This preliminary work is delivering the archive of observations, the pre-production experimentation necessary to specify the production assimilation system, the monitoring tools and the production system software. Appendix A contains details of this work.

The major components of the workplan are co-ordination, preparation, production, validation/ exploitation, data dissemination and documentation. ECMWF will co-ordinate the project and provide much of the resources needed for production, which will run for 24 hours per day and seven days per week. It is vital that there is close liaison between all of the partners to ensure both a balanced contribution to the production, and efficiency and lack of overlap in the validation and exploitation studies. The management framework for the project has already been established, and is closely modelled on principles which led to the successful completion of ERA-15. The WCRP- and GCOS-funded External Advisory Group has met twice, and has assisted the partners in planning the project. Production has been split into sub-periods, and will be run in two parallel streams. Account has been taken of the planned re-computation of satellite cloud wind data, external to the project, to allow maximum time for these improved data to become available within the production schedule.

The validation teams distributed throughout the partnership will monitor the quality of the results as they are produced. Frequent feedback of information from these teams will enable a close watch to be kept on quality, and indicate the need for remedial action when problems are encountered. Validated results will become available to general users as soon as each year of production has been found to be satisfactory.

The primary deliverable of ERA-40 will be the analysis products. These include both the fields of basic analysed variables and derived products which have been identified as meeting specific user needs, based both on operational experience and on the views of the External Advisory Group and the partners in the project. Other major deliverables will be the feedback statistics and the final, integrated documentation of the production and of the validation and exploitation studies. The documentation will be freely available in printed form and on the World Wide Web; it will be of particular importance in enabling informed use to be made of the products and in stimulating new studies.

The amount of archived ERA-40 data will be very large. European meteorological institutions with access to the archival/retrieval system of ECMWF will be able to retrieve data directly at no additional cost. A data service will satisfy general requests from other customers, but customers could incur substantial data-retrieval costs. Affordable specialised datasets will be identified and made available for no more than media costs. Individual national arrangements may also be made for data supply, as for ERA-15.

The plans and preparations for ERA-40 were presented to the wider scientific community at the Second International Conference on Re-analyses held in August 1999. A workshop will be held mid-project to report on production progress, to assess validation progress, and to introduce potential customers to the emerging products data set. Project partners will participate in other external international meetings to report on progress and validation, and to publicise the products.

3.2 Project organization

The preparation phase of the project required the location, collection, acquisition, and organization of as full a set of global meteorological observations as possible for the period 1957 to the present. ECMWF had to extend its existing archive backwards in time and augment the archive with additional data for recent years. NCAR has, for many years, undertaken an extensive programme of data collection and rehabilitation. The results of this work have been made available to the project for exploitation. In addition, ECMWF has acquired the latest version of the Comprehensive Ocean Atmosphere Data Set (COADS), which contains weather reports from voluntary observing ships taken from log books, and which considerably augments the archive of reports received in real time. Its archive of satellite data has been augmented by the acquisition (from NCAR, NASA and LMD) of sets of raw-radiance data and satellite-based ozone products spanning the last three decades. Contact has also been made with the producers of satellite cloud motion and water vapour winds. These components of the observing system have improved significantly in quality over the years, and the producers have been actively encouraged to re-compute the early values from the data within their archives. Apart from these improved data, the acquisition of the observational data is now complete. Work to generate improved sets of sea-surface temperatures and sea-ice distribution data, constructed in such a manner that the data are consistent in the sea-ice margins, has also been stimulated.

The second stage of preparation has been the organization of a series of data assimilation experiments to check the various components of the proposed production system, particularly to ensure that the system is capable of performing well through all stages and states of the observing system. Given the innovative nature of many aspects of the proposed system and the extensive effort needed to produce a re-analysis of more than forty years, it is essential that this experimentation be carried out in a thorough manner, and that the eventual production system be thoroughly dependable and accurate. ECMWF and other interested parties have invested heavily in this programme of experimentation, which has already accelerated the testing of modified components that are directly benefiting operational numerical weather prediction and seasonal forecasting as well as the new re-analysis.

The work which is the subject of this Project Workplan comprises the re-analysis production, the production monitoring, an extensive programme of validation and exploitation, the setting up of the dissemination facilities and the provision of extensive documentation.

Production will be organised in two streams. Stream 1 will start with 1987 and run continuously through to the end of 2001, while stream 2 will run from 1957 onwards. Stream 1 will, initially, be given the higher priority. It will aim to deliver results which can be exploited by seasonal forecasting and other projects at an early stage. It will also provide much valuable information concerning the satellite data components of the modern observing system. The quantities of observational data required for stream 1 are much larger than those involved in stream 2, because of the more recent developments in satellite observations. Stream 2 will allow time for the re-processed satellite winds (for the period 1981 to 1988) to become available.

During production, the re-analysis results will be made available immediately to the validation partners. An extensive monitoring programme, run as part of the production suite, will provide quality-control information, detect any major errors, and provide feedback to the production concerning bias correction and poor-quality observations which need to be excluded from future production. This information, together with information provided to ECMWF by the validation partners, will enable correction and re-running of periods found to be seriously in error, and help generally to maintain the quality of the analyses.

Priority will be given to completing the production as quickly as possible. The process of data assimilation is designed to generate the best possible analyses from sets of heterogeneous data. Analyses of high quality and consistency can be produced provided there are sufficient high-quality observations. However, the observing system underwent many major changes throughout the period of ERA-40, and full use of the re-analysis results will require an understanding of the effect of these changes. The impact of the introduction of each major new observing sub-system will be assessed by running overlap analyses for one year with and without the new data. Candidate sub-systems include TOVS data, wind products from geostationary satellites, ERS scatterometer data and SSM/I data.

The validation and exploitation component will provide guidance to the production and generate added-value products. Its main aim is, however, to furnish potential users of the re-analyses with information and advice, particularly concerning the relative accuracy of the various constituents of the archive in various circumstances. Provisional information and results will be made available mid-project through the organization of a workshop, and by making available interim reports for each area of validation or exploitation. By the end of the project these interim reports will have been published in this project report series, fully documenting all aspects of the project.

The assimilation system for ERA-40 will be maintained and preserved long after the re-analysis is complete. It will be made available for further observing system experimentation, and will be used to update the set of re-analyses in near real time.

3.3 The partnership

ECMWF will be responsible for project co-ordination and the production of the analyses. The remaining partners are representative of the customer base for meteorological analyses. They have participated in the planning, and will validate the ERA-40 analyses and use them for a variety of applications. While not participating directly in the production, they will examine the emerging results of the re-analysis very soon after production. They will thus be able to supplement ECMWF's routine monitoring by drawing attention, at an early stage, to potential deficiencies and problems. This interaction between the production partner and the validation partners is essential to ensure that the final results of the re-analysis production are of the highest possible quality.

ECMWF is a European inter-governmental organisation active in data assimilation, atmospheric modelling and numerical weather prediction. It has successfully carried out previous projects involving numerical experimentation and state-of-the-art data assimilation, and combines high quality research expertise with a considerable depth of technical and operational experience. ECMWF itself has many applications and research programmes which will be used to validate and exploit the re-analysis products These include research into seasonal forecasting, studies of the impact of the component sub-systems of the global observing system, specific studies of the impact and quality of satellite observations, application to ocean-circulation models, and to the scientific and technical improvement of analysis and weather-forecast systems.

MPIfM is a leading German institute for climate modelling and research and a major customer for analysis data. It has extensive experience in the validation of analyses and climate simulations, with special expertise in the validation of the hydrological cycle.

Météo-France, KNMI and UKMO are the national meteorological services of France, the Netherlands and the United Kingdom. They have a broad range of operational and research responsibilities, and a broad customer base from the public, governmental and commercial sectors. In their R&D rôles they are themselves customers for synthesized analysis data.

UKMO has a research group with particular experience in the exploitation and validation of analysis data through the modelling of clear-sky radiation; this group will apply its expertise to the ERA-40 analyses. UKMO also has an on-going programme of research into seasonal forecasting, and will exploit the re-analysis products to this end. Its expertise in stratospheric assimilation and modelling will also be of value to the project.

Météo-France has collaborated closely with ECMWF in the development of atmospheric models and variational data assimilation, and in particular provided the parametrization of ozone sources and sinks to be used in the assimilating model for the re-analysis. Météo-France will validate and exploit the re-analysis products with respect to stratospheric ozone and ocean surface fluxes. It will also use products as input to a model to diagnose and simulate Alpine snow cover, and input to a chemistry-transport model.

KNMI has extensive experience and interests in studies of the modelling, prediction and climatology of ocean waves. It will work on the validation and exploitation of the ocean-wave products. KNMI also has a substantial research effort in stratospheric ozone, and will contribute to studies of the re-analyses in this area.

NCAR is a US institute for atmospheric research that is participating in the project on a self-funding basis. NCAR has invested many man-years of effort into the preparation of the historic observational data essential to the project, has actively supported the dissemination of previous re-analysis products to North American customers, and has contributed to the exploitation and validation of previous re-analyses. NCAR will provide support in all of these areas for ERA-40.

UREADMY is a British university department of meteorology with interests in global atmospheric modelling and studies of the general circulation and climate. It has long experience in the use of past operational analyses and re-analyses from a number of sources. UREADMY will bring unique expertise with respect to the assessment of those aspect of the global circulation, such as the North Atlantic Oscillation, which have a particular bearing on European Climate, and will, in addition, provide expertise for the assessment of aspects such as ENSO, the Asian Summer Monsoon, tropical convection, and storm track behaviour. It will also contribute to the validation of upper tropospheric and stratospheric humidity and ozone.

Further information on the partner institutions is given in section 8.

3.4 Project time table

The project time-table is illustrated in the form of a Gantt chart in figure 1. Linkage is difficult to show, as most of the validation work packages (WP4100 to WP 4800) and those of the production (WP3100) and monitoring (WP3200) interact almost continuously with each other. The deliverables of the project (see section 3.8) are illustrated by milestone symbols which highlight the time at which they are expected to be provided. Deliverables D07, D08 and D09 are not shown as they are produced almost continuously by the monitoring work package (WP3200). Deliverables D03, the quarterly reports to the EC, are similarly not shown. Also not shown is the time of initial availability of data to users external to the

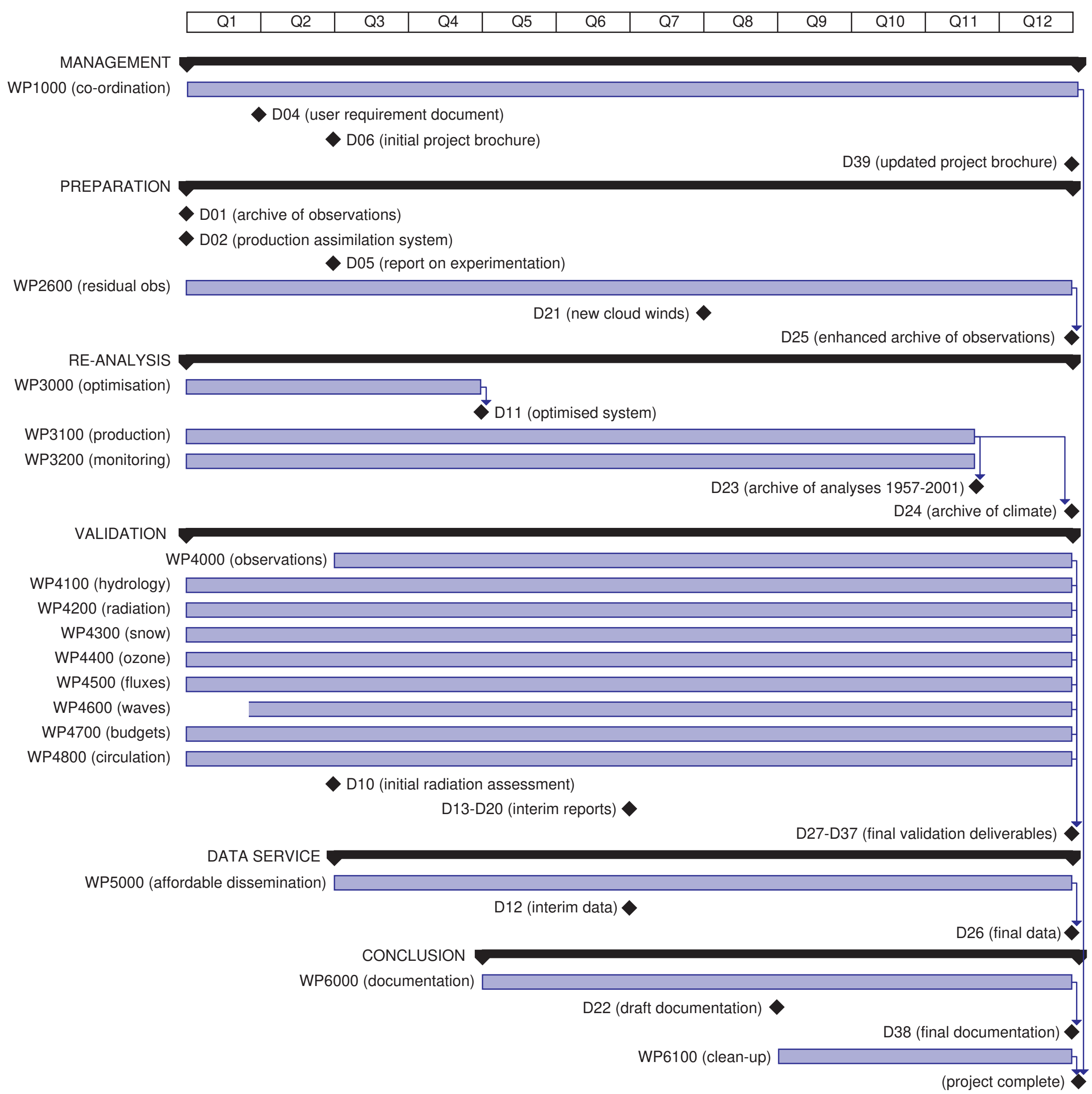

Figure 1 Gantt chart showing time table of work packages and deliverables. The time axis is marked in units of Figure quarters, Q1 denoting the first three months of the production phase of the project (months 0, 1 and 2).

project. Data will be made available once sufficient validation has been performed on each completed year of re-analysis. In most cases, this will be within three months of the completion of the production for that year.

It may be noted that the preparation extends throughout the project. This is because the refinement of the observations archive will continue through WP2600, delivering an archive of observations which benefits from data investigation instigated by quality problems encountered during the production.

The figure covers only the three-year phase of the project for which funding is provided by the EU. The work packages for the preparation phase specified in Appendix A are not shown, but the deliverables of these work packages (D01, D02 and D05) are included.

3.5 Milestones

The following milestones (Table 2) have been defined.In addition, there will be regular reports to the European Commission.

Table 2: Milestones list

Milestone No.	Milestone title	Target month
M01	Initial assessment - clear sky radiation	5
M02	Optimised production system	11
M03	Production 1987-1998	14
M04	Production 1957-1968	14
M05	Affordable dissemination - interim data	17
M06-13	Interim validation reports	17
M14	Re-processed cloud motion winds	20
M15	Draft project documentation	23
M16	Production 1999-2001 & overlap experiments	31
M17	Production 1969-1986 & overlap experiments	31
M18	Archive of analyses 1957-2001	31
M19	Archive of monthly and climate data	35
M29	Enhanced observations archive	35
M21	Affordable dissemination - final data sets	35
M22	Alpine snow climatology	35
M23	Climatology of ocean waves	35
M24-32	Final validation reports	35
M33	Project report series	35
M34	End of project	35

3.6 Graphical presentation of the project's components

The relationships between the major components of ERA-40 are illustrated in figure 2.

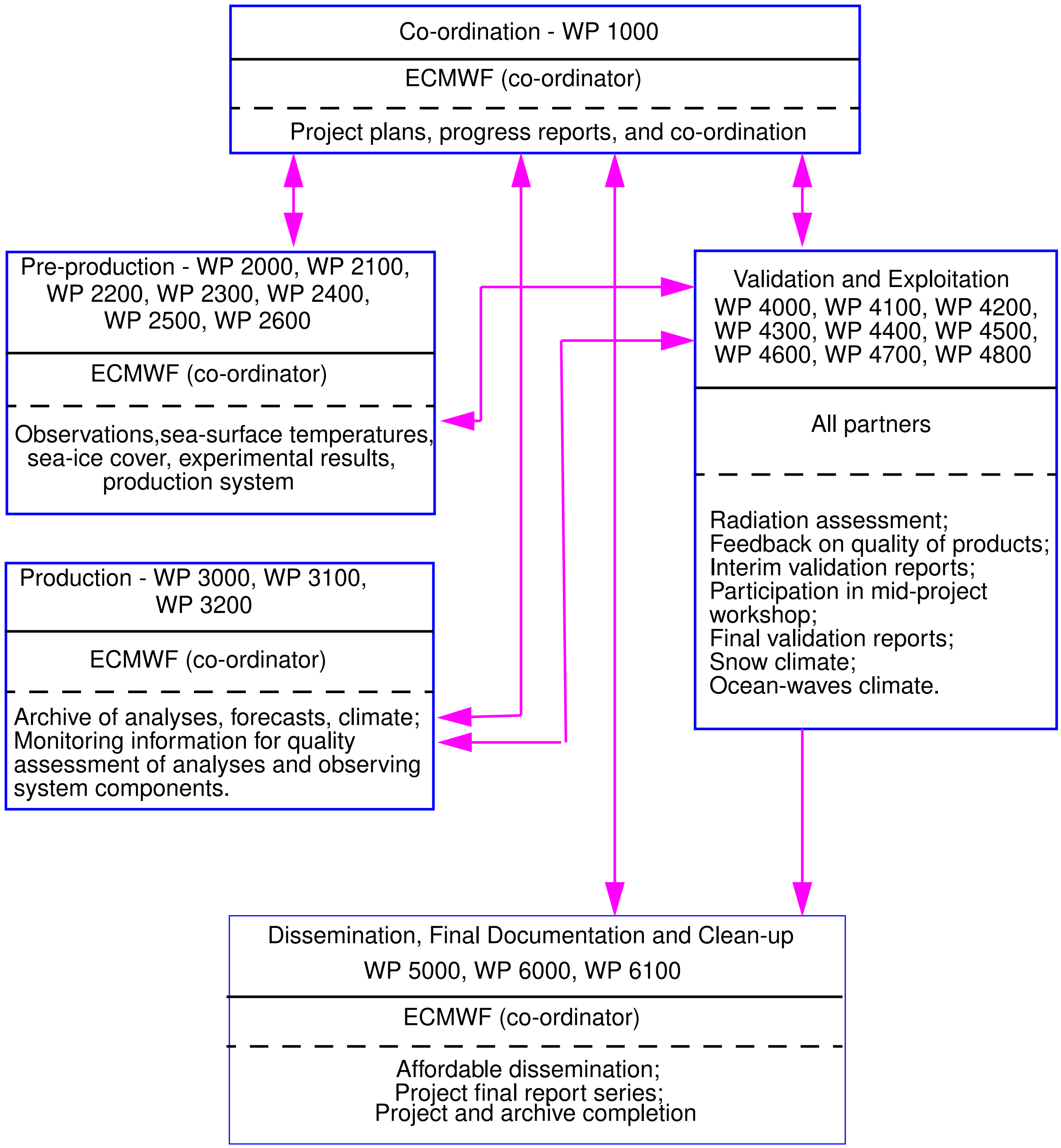

Figure 2 Components of ERA-40

3.7 Workpackage list

Workpackage No.	Workpackage title	Lead partners	Start month	End month	Deliverable No.
WP1000	Co-ordination	ECMWF	0	35	D03, D04 D06, D39
WP2600	Residual observation preparation	ECMWF	0	35	D21, D25
WP3000	System optimisation	ECMWF	0	11	D11
WP3100	Production	ECMWF	0	31	D23, D24
WP3200	Production monitoring	ECMWF	0	31	D07 to D09
WP4000	Validation with respect to observations	ECMWF	6	35	D13, D29
WP4100	Validation with respect to hydrology	MPIfM	0	35	D14, D30
WP4200	Validation of clear sky radiation simulation	UKMO	0	35	D10, D31
WP4300	Validation of alpine-snow simulation	Météo-France	0	35	D15, D27, D32
WP4400	Validation of upper-tropospheric and stratospheric ozone and water vapour	Météo-France UREADMY	0	35	D16, D34
WP4500	Validation of ocean surface fluxes	Météo-France	0	35	D17, D33
WP4600	Ocean wave product validation and analysis	KNMI	3	35	D18, D28, D35
WP4700	Validation of global mass, heat, energy, and moisture budgets	NCAR	0	35	D19, D36
WP4800	Diagnosis of atmospheric circulation systems	UREADMY Météo-France	0	35	D20, D37
WP5000	Affordable dissemination	ECMWF	6	35	D12, D26
WP6000	Final documentation	ECMWF	12	35	D22, D38
WP6100	Clean-up	ECMWF	24	35	

3.8 Deliverables list

Deliverable No.	Deliverable title	Delivery date	Nature	Dissemination level
D01	Observations archive and forcing fields	Month 0	Data	Restricted
D02	Production system	Month 0	Other	Restricted
D03	Quarterly reports to the EC	Months 2,5,...35	Report	Restricted
D04	User requirement document	Month 2	Report	Public
D05	Report on experimentation	Month 5	Report	Public
D06	Initial project brochure	Month 6	Report	Public
D07	Identified systematic and gross errors of different observing systems; bias corrections	Continuous	Data	Restricted
D08	Statistics on the impact of observations on the products	Continuous	Data	Restricted
D09	Metadata for users	Continuous	Data	Public
D10	Initial assessment - clear sky radiation	Month 5	Report	Public
D11	Optimised production throughput	Month 11	Other	Restricted
D12	Affordable dissemination - interim data	Month 17	Data	Public
D13-D20	Interim validation reports	Month 17	Report	Public
D21	Pre-processed new cloud motion winds	Month 20	Data	Restricted
D22	Draft of project documentation	Month 23	Report	Public
D23	Archive of analyses and forecasts 1957-2001	Month 31	Data	Public
D24	Archive of monthly and climate means	Month 35	Data	Public
D25	Enhanced observations archive	Month 35	Data	Restricted
D26	Affordable dissemination - final data sets	Month 35	Data	Public
D27	Alpine snow climatology	Month 35	Data	Restricted
D28	Climatology of ocean waves	Month 35	Report	Public
D29-D37	Final validation reports	Month 35	Report	Public
D38	Project report series	Month 35	Report	Public
D39	Updated project brochure	Month 35	Report	Public

Deliverables D01, D02 and D05 are from workpackages outside of the scope of the EU-funded phase of the project, described in Appendix A. Deliverables D02 and D11, ascribed a nature of “Other”, are the initial production and optimised versions of the complex data assimilation system being developed for ERA-40. The “Public” dissemination level as applied to data is interpreted as meaning that data may be distributed to any individual or organization, but that restrictions may be applied to the onward distribution by the recipient to third parties, subject to the rules of data distribution imposed by the Council of ECMWF. The archives of observations have a “Restricted” dissemination level because some observational datasets were supplied to ECMWF for use in ERA-40 but with restrictions on their onward distribution.

3.9 Workpackage descriptions

The following workpackage descriptions exclude the workpackages expected to be complete by start of the EU-funded stage of the project, the beginning of month 0. Details of the preparatory workpackages are contained in Appendix A.

Workpackage number:	**WP1000 Co-ordination**
Start date:	**Month 0**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Scientific and technical co-ordination, liaison, planning, management and review to ensure successful completion of the project. Input: Formal and informal information from all participants; advice from the External Advisory and Steering Groups; interactive update on progress.

Description of work

Detailed planning, co-ordination, and integration are essential if the stated objectives are to be achieved. While each partner will be responsible for its individual workpackages, ECMWF will assume responsibility for overall co-ordination and planning, under the guidance of a Steering Group comprising representatives of each of the partners.

This task includes the setting up of meetings of the External Advisory Group and the Steering Group, liaison with other partners on a day-to-day basis, formulating the overall work programmes and plans for ECMWF, integrating these with the work to be performed by the remaining partners, and supervising the remaining workpackages of ECMWF.

The definition of the users' requirements, and the participation of the users in the planning and direction of the project is mainly achieved through the External Advisory Group. This group comprises the Steering Group, augmented by representatives of the major customers and recognised scientific experts in the production and application of global analyses. WCRP and GCOS are supporting ERA-40 through funding the attendance of experts at meetings of the External Advisory Group.

An important function of this workpackage will be to co-ordinate the production, monitoring, and validation, and the archival and documentation of the results. Rapid access to status, progress and results will be provided through direct links and Internet features. Further activities are organization of mid-project workshop, and participation in international seminars to inform customers of progress, quality, and availability of results.

Specific deliverables of this workpackage are quarterly status reports to the EC, the user requirement document, and the project brochure to be produced initially in the early stages of the project and updated at the end of the project. Formats for these documents will be as agreed with the EC.

Deliverables

D03: Quarterly reports to the EC (months 2,5,...35).
D04: User requirement document (month 2).
D06: Initial project brochure (month 6).
D39: Updated project brochure (month 35).

Milestones and expected results

Achievement of all project milestones and successful completion of project.

Workpackage number:	**WP2600 Residual observation preparation**
Start date:	**Month 0**
Lead partner:	**ECMWF**

Objectives and input to workpackage

To acquire and pre-process additional data which become available after month 0 (especially re-processed cloud motion and water vapour winds); to improve the observations archive. Input: Data from various sources.

Description of work

Progress to date indicates that, by the start of month 0, the system development (WP2300), the development of monitoring tools (WP2400), and the experimentation (WP2500) will be complete (see Appendix A). The acquisition and pre-processing of the observations and forcing fields (WP2000 and WP2100) will also be complete for many of the years of the re-analysis period.

There are plans, external to this project, for Eumetsat to compute new cloud-motion and water-vapour winds from Meteosat-2 images, and re-processed winds may also be available from GOES satellites. The production schedule has been planned so as to enable these data, if made available to the expected time table, to be exploited. This workpackage allows for the acquisition and pre-processing of these data. Additionally, it allows for a continuation of WP2200 (problem chasing), with the aim of making available to the re-analysis production (WP3100) the best set of observations possible within the production time-frame. Improvements to the archive of observations which miss the deadlines for production will also be attempted, but with lower priority. Such further enhancements would be of value to the monitoring and validation, and would provide added value to this unique data depository.

Deliverables

D21: Pre-processed new cloud-motion and water-vapour winds (month 20).
D25: Enhancements to the observations archive (continuous throughout project).

Milestones and expected results

M14: Preparation of re-processed cloud motion and water vapour winds (month 20).

Workpackage number: **WP3000 System optimisation**
Start date: **Month 0**
Lead partner: **ECMWF**

Objectives and input to workpackage
To configure and optimise the assimilation system to achieve a sustained production rate of the order of one month of data assimilation each day. Input: The initial production system delivered by WP2300 (Appendix A).

Description of work
In the preparation of the initial production system priority has been given to ensuring robustness and scientific correctness. While efficiency has also been given a high priority, production experience will provide opportunity for further optimisation.

The production goal is to complete production over a two year period. This requires a sustained production rate of about one month per production day, allowing for periods where errors are detected and production needs to be re-run. Current experience with the pre-production system indicates that although this rate may not be quite achieved by the initial production system, it will be possible to carry out the required optimisation over the first year of production and achieve the production targets. Optimization of the system will thus continue after the start of production, using experience gained during the experimentation and early production. Bottlenecks will be identified, tackled and removed.

Deliverables
D11: Gradually enhanced throughput of the production system during the first year of production.

Milestones and expected results
M02: An optimised production system able to achieve the objectives by month 11.

Workpackage number: **WP3100 Production**
Start date: **Month 0**
Lead partner: **ECMWF**

Objectives and input to workpackage
Re-analysis of the global atmosphere, land-surface and ocean waves from mid-1957 to 2001. Input: Acquired and pre-processed observations, sea-surface temperature and sea-ice data (WP2000, 2100, 2200 - see Appendix A); enhanced observations (WP2600); bias corrections (WP3200); monitoring and validation feedback (WP3200, 4000, 4100, 4200, 4300, 4400, 4500, 4600, 4700, 4800).

Description of work
Production will include comprehensive pre-analysis observation handling including the necessary bias corrections, the data assimilation, the post-processing and archiving of the results, and the preparation of immediate monitoring material. Regular forecasts will be run from the resulting analyses; verification of these against subsequent analyses will provide an additional measure of the analysis quality. Observing system experiments will be run with and without major new observational sub-systems. Metadata, including statistics for each observed element, quality-control information returned from the analyses, and other information concerning how each element was used within the system, will be preserved. Deliverables will be made available to Partners as produced, and to other customers when each whole year has been reasonably validated.

Production will be split into two parallel streams. Initially one stream will process data from 1987 onwards, for which there is a particularly urgent demand to support seasonal forecasting work, while the other will be devoted to the earlier and potentially more problematic data. The second stream will overlap the first, enabling the full period from 1981 to 1988, for which there will be externally re-processed satellite wind information, to be processed last.

Extensive information on production and archive status will be made available on-line to partners. Partners, and many principal customers, will be able to access data immediately on production using a high speed network. Information for other customers will be provided via the Internet, and will give details of validated products as they become available.

The archives generated will include:
- 6-hourly analyses;
- short-range forecasts to provide supplementary information;
- ten-day forecasts, at regular intervals;
- feedback statistics relating the background and analysis values to the observed values;
- monthly means of the analyses and short-range forecasts;
- climate means based on the full re-analysis period.

The archives will be made widely available according to the ECMWF Council's standard rules concerning distribution of non-real-time products. In particular, they will be provided on request to governmental bodies, universities, research institutes and other non-profit seeking organizations worldwide at cost of reproduction. Subsets of the products will be defined in liaison with the External Advisory Group to enable reproduction of these subsets at reduced cost. Arrangements may be made for sub-archives to be available within a nation from a national source.

Deliverables
D23: archive of analyses and forecasts. D24: archive of monthly and climate means.

Milestones and expected results
Stream 1: M03: 1987 to 1998 by month 14. M16: 1999 to 2001 plus some overlap OSE's by month 31.
Stream 2: M04: 1957 to 1971 by month 14. M17: 1972 to 1986 plus remaining OSE's by month 31.

Workpackage number:	**WP3200 Production monitoring**
Start date:	**Month 0**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Quality assurance of production; generation of bias correction for satellite radiances and radiosonde data; generation of information on suspect stations; provision of information important to users of the re-analysis products. Input: Re-analysis results (WP3100)

Description of work

The production will be highly automated, and will be run for 24 hours per day for seven days per week. The throughput rate will be high and a wide variety of output will be produced. Very close scrutiny of production will be needed so that manual intervention, and corrective action where necessary, can be effectively administered. Monitoring tools will be used continuously to assess the quality of the analysis and forecast products with respect to the observations. This will enable interception of problems at an early stage.

The use of observational data by the assimilation system will be monitored to identify and exclude observations of persistently poor quality. The excluded observations will be monitored passively and re-introduced when improvements are detected. As observation quality changes, the monitoring will deliver revised bias corrections for use in future production.

An additional function of the monitoring will be the detection of unexpected changes in the response to the various components of the observing system. The analyses and short-range forecasts will also be assessed by comparing their climate characteristics with existing knowledge. The overall response of the analysis to observations will be monitored by monthly statistics (means, standard deviations, etc.) of the analysis increments over different geographical regions. A representative sample of analyses will be used as initial conditions for extended forecasts, the results of which will be verified throughout the production as a measure of the analysis quality.

Deliverables

D07: Identified systematic and gross errors of different observing systems; bias corrections.
D08: Statistics of the impact of observations on the products.
D09: Metadata concerning re-analysis quality and critical events for users of the products.

Milestones and expected results

Sufficient information for input into the next production month at the end of each production month. Completion of the remaining deliverables as soon after each production milestone as possible.

Workpackage number:	**WP4000 Validation with respect to observations**
Start date:	**Month 6**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Quantitative assessment of the differences between analysed and observed values; assessment of performance of the assimilation system, and the components of the observing system. Input: Re-analysis results and monitoring statistics (WP3100 and WP3200)

Description of work

The statistics produced by the production monitoring will enable valuable quantitative assessments to be made of the differences between the analysed and observed values. Since the data assimilation process is a synthesis of all available observations, by performing such analyses on each of the individual sub-systems of the global observing system over long time periods it is possible to generate information concerning the accuracy of the analyses, and also of the various types of observations.

Monitoring statistics will thus be used to measure the performance of the data assimilation relative to each major component of the observing system. Information will be generated concerning analysis accuracy, and the performance of individual observing systems over time.

At the end of the re-analysis these results will be published in graphical form. This will provide a valuable assessment for future users of both the re-analysis products and the observations.

Deliverables

D13: Interim report (month 17).
D26: Final report (month 35).

Milestones and expected results

M06: Interim report (month 17).
M24: Final report (month 35).

Workpackage number:	**WP4100 Validation with respect to hydrology**
Start date:	**Month 0**
Lead partner:	**MPIfM**

Objectives and input to workpackage

Establishment of confidence in ERA-40 results relating to the hydrological cycle. Guidance to users concerning product selection and reliability. Input: Re-analysis results (WP3100)

Description of work

The analysis data produced by ECMWF will be copied continuously to the data bank of MPIfM. Checks will be made that values are reasonable. Long-term means of precipitation and latent heat fluxes will be compared with available climatological estimates. The diurnal cycle and precipitation statistics will be investigated for reasonableness. Time series of precipitation and latent heat flux will be searched for unreasonable variations using both subjective judgement and comparisons with observational data where available. Precipitation and snow depth data will be compared with observational data where available. Differences between precipitation and evaporation will be used to calculate river discharges and these will be compared with corresponding observations. The resulting sea-level changes for closed basins like the Volga/Caspian Sea and the Great Salt Lake will be compared with observations.

The re-analysis data from NCEP will be used for comparison, and further evaluations will focus on areas or periods of discrepancies.

Also, guidance will be given as to which of the ERA-40 results are likely to be the more reliable. For example, it has been shown for ERA-15 that it is more advantageous to use precipitation values from 12-24 hour forecasts as estimates of the truth rather than those from the shorter range forecasts. Biases in the precipitation amounts are to be expected at least in some areas and it would be valuable if a statement could be made that the variabilities are nevertheless reasonable.

Results from TRMM will be available for the last few years of the re-analysis; these will provide some insight into the vertical profiles of droplets, giving a new dimension to model validation.

Deliverables

D14: Interim report (month 17).
D30: Final report (month 35).

Milestones and expected results

M07: Interim report (month 17).
M25: Final reports (month 35)

Workpackage number:	**WP4200 Validation of clear sky radiation simulation**
Start date:	**Month 0**
Lead partner:	**UKMO**

Objectives and input to workpackage

Comparisons of the fluxes at the top of the atmosphere with satellite radiation budget measurements, enabling quality assessment of the analysed surface temperatures and upper tropospheric humidities. Input: Re-analysis results, including simulations of the clear-sky fluxes and heating rates on the ERA-40 vertical grid (WP3100).

Description of work

This package will build on the successful validation of ERA-15 performed by UKMO. UKMO will access the re-analyses created by ECMWF through the existing dedicated link between the institutions and will perform the assessments. This does not necessarily need to be done in near-real time, although this could be valuable to help spot problems as early as possible and report them to ECMWF.

All the required diagnostics will be archived at ECMWF, so this work package will mainly be concerned with comparisons with data from ERBE, ScaRaB and CERES. Supporting data such as surface temperature and atmospheric temperature and humidities will be extracted from the ERA-40 archives. Most comparisons will use monthly mean data, but consideration will also be given to comparisons at higher frequency to study the contribution from sampling biases in the satellite data. The comparisons will enable an independent assessment of the ERA-40 products, in particular the surface temperatures and atmospheric humidities. Results from parallel runs of the assimilation system in which selected measurements are withheld may be used to assess the extent to which the humidity analysis is controlled by the data, as opposed to the model. Where appropriate, additional simulations will be performed at UKMO to conduct sensitivity and other studies. If time and resources allow, the comparisons will be extended to include all-sky conditions for both shortwave and longwave fluxes, to enable an assessment of the full radiation budget of ERA-40.

Deliverables

D10: Initial assessment (month 5).
D31: Final report (month 35).

Milestones and expected results

M01: Initial assessment based on trial period (month 5).
M26: Final report at end of project (month 35).

Workpackage number:	**WP4300 Validation of Alpine snow simulation**
Start date:	**Month 0**
Lead partner:	**Météo-France**

Objectives and input to workpackage

Comparison of ERA-40 surface fields and snow cover with Alpine observations; production of a comprehensive snow climatology of the French Alps. Input: Re-analysis results (WP3100)

Description of work

The ERA-40 outputs over the French Alps will be checked by various methods. The precipitation, temperature, and snow cover will be compared with observations. The surface meteorological variables will be used to force a snow model and the corresponding snow cover will be compared with both observations and ERA-40 snow cover. All these results will also be compared to ERA-15 results in order to evaluate the influence of the meteorological model and analysis system on the results.

A snow depth climatology will be produced by using the SAFRAN (meteorological analysis in mountainous regions) and CROCUS (a precise snow model) systems developed by Météo-France. The meteorological input will be obtained from Météo-France's climatological data base. A few long term series of snow depth will be used for the validation. This snow climatology can be used for further climate variability studies.

Deliverables

D15: Interim report (month 17).
D27: Alpine snow climatology (month 35).
D32: Final report (month 35).

Milestones and expected results

M08: Interim report (month 17).
M22: Snow climatology (month 35).
M27: Final reports (month 35).

Workpackage number:	**WP4400 Validation of upper-tropospheric and stratospheric ozone and water vapour**
Start date:	**Month 0**
Lead partners:	**Météo-France, UREADMY**

Objectives and input to workpackage

Assessment of the quality of ERA-40 upper-tropospheric and stratospheric ozone and water-vapour products. Input: Re-analysis results (WP3100); in-situ data from MOZAIC, EASOE, SESAME, ozone sondes, etc.

Description of work

Météo-France:

Using the assimilated 3D ozone fields produced by ECMWF, Météo-France will create a data bank containing daily total (i.e. vertically integrated) ozone fields and zonally averaged ozone fields. Vertical profiles of ozone will also be reconstructed from ERA-40 fields for a number of selected stations of the ozone observing network and stored by Météo-France in this databank.

First, a comparison of the total ozone fields with those from TOMS data will be made; strictly speaking, this is not an independent validation of ERA-40 products, since TOMS measurements will be assimilated during the project, but this will be a simple check of ERA-40 ozone fields. A second check on total ozone will be made using total ozone fields computed with an algorithm developed by Météo-France and operating on TOVS data. In addition to this, measurements from recent field campaigns (EASOE, SESAME), during which many different instruments were used, and in-situ ozone measurements from the MOZAIC experiment (commercial instrumented aircraft) will be used for a truly independent validation of the ozone fields. For this purpose, a procedure interpolating the model's 3D ozone fields to the aircraft trajectories will be developed. Such a validation, however, will only be possible for the last years of the ERA-40 period.

For a validation of the ozone field in the earlier period, in particular the pre-satellite years during which no ozone data will be used in the assimilation, a set of stations where the most reliable and longest time series of ground-based measurements of ozone are available will be chosen and compared with the ozone fields produced by the assimilation.

UREADMY:

Satellite measurements will be used for validation in collaboration with the UTLS programme of the UK Natural Environment Research Council. Also, MOZAIC data will be used to validate the ozone and water vapour fields, with particular reference to the isentropic transport across the tropopause associated with transient, small scale features. UREADMY has already used MOZAIC data to verify the transport of water vapour between the upper troposphere and lower stratosphere seen in recent operational analyses, and collaborated with Météo-France in the MOZAIC-3 bid to the Fifth Framework Programme. The area of stratospheric/tropospheric exchange is one in which UREADMY has considerable expertise. It will be important to assess how well the ERA-40 analyses represent stratospheric/tropospheric exchange processes, such as tropopause folding; this will be achieved by the application of sophisticated tracer methods.

Deliverables

D16: Interim report (month 17).
D33: Final report (month 35).

Milestones and expected results

M09: Interim report (month 17).
M28: Final report (month 35).

Workpackage number:	**WP4500 Validation of ocean surface fluxes**
Start date:	**Month 0**
Lead partner:	**Météo-France**

Objectives and input to workpackage

Evaluation of the quality of the ERA-40 ocean surface fluxes. Input: Re-analysis results (WP3100)

Description of work

Firstly, the radiative and turbulent ocean surface fluxes derived from ERA-40 will be compared with an earlier re-analysis. The two data sets will also be compared with fluxes derived from COADS (Da Silva et al, 1994) and with satellite-derived surface radiative fluxes.

Secondly, oceanic surface fluxes from ERA-40 will be compared with in situ observations collected during dedicated experiments. These experiments, conducted in different ocean areas, include TOGA-COARE (Western Pacific, 1992-1993), SEMAPHORE (Azores, 1993), CATCH (North Atlantic, 1997) and FETCH (Mediterranean sea, 1998). During these experiments, special measurements were made to calibrate new flux parametrizations. These parametrizations will be used first to calculate bulk fluxes from oceanic and atmospheric ERA-40 outputs and, secondly, to compare with those calculated by the ERA-40 system.

With an hypothesis of energy budget equilibrium over a multi-year period, the meridional oceanic heat transport in each oceanic basin can be derived from the net surface heat flux. These transports will be compared against other estimates including direct calculations from temperature and current measurements as published in the literature, and recent WOCE estimates.

ERA-40 ocean fluxes will also be validated indirectly by using them to constrain a primitive equation oceanic model; a similar comparison has previously been completed over the Tropical Atlantic with fluxes from an earlier re-analysis. An updated version of this model is being developed and will be used if available. The validation of the model will be performed by comparing the oceanic model outputs with in-situ measurements provided by Voluntary Ships of Opportunity and the PIRATA mooring network, with the Levitus 94 climatology, and, if available, with an updated Levitus climatology including WOCE data.

Deliverables

D17: Interim report (month 17).
D34: Final report (month 35).

Milestones and expected results

M10: Interim report (month 17).
M29: Final report (month 35).

Workpackage number:	**WP4600 Ocean wave product validation and analysis**
Start date:	**Month 3**
Lead partner:	**KNMI**

Objectives and input to workpackage

Assessment of the quality of the ERA-40 surface winds over the ocean; generation of a 40-year ocean wave climatology. Input: Re-analysis results (WP3100)

Description of work

KNMI will collect all relevant wave observations and compare these with the predictions of ERA-40. This will provide an assessment of the quality of the near surface winds. The resulting wave data set will be used to study the climatology of ocean waves, with a special interest in patterns of interannual and decadal variability.

To validate the quality of the re-analysis, the ocean wave predictions will be compared with observations. In addition, a thorough statistical analysis will be made of the 40-year surface wind and wave climate. Work comprises five parts. The first half year will be used to develop methods for the analysis of the wave results. Also, wave aspects of the pre-production experimentation will be checked. In the second part of the work the database of wave observations already available to partner 5 will be extended. This database will comprise visual observations and buoy observations in addition to satellite observations. The historic data set analysed by Bouws et al.(1996) will also be used. In the third part ERA-40 near-surface winds and waves will be studied and the waves will be compared with observations. This comparison will include time series and probability distribution functions for a given location as well as monthly mean global wave height charts. In the fourth part the relation between wind speed and the momentum flux in ERA-40 will be compared with proposed parametrizations and published experimental studies. In the final part of the work, the wave climatology will be studied. Monthly mean values will be generated, but in addition, extreme events and the high frequency behaviour (90% percentiles) of wind and waves will be studied. The traditional search for trends will be replaced with a method in which the variability of the dominant EOFs is studied.

Deliverables

D18: Interim report (month 17).
D28: Climatology of ocean waves (month 35).
D35: Final report (month 35).

Milestones and expected results

M11: Interim reports (month 17).
M23: Climatological analysis (month 35).
M30: Final report (month 35).

Workpackage number:	**WP4700 Evaluation of global mass, heat, energy and moisture budgets**
Start date:	**Month 0**
Lead partner:	**NCAR**

Objectives and input to workpackage

Commentary on and measures of confidence for the physical consistency of various fields for use in diagnostic studies; suggestions for possible improvements in the analysis system, including data treatment, analysis, and assimilating model. Input: Re-analysis results (WP3100)

Description of work

NCAR will conduct consistency checks on (i) the budget of the mass of dry air, (ii) the moisture budget, (iii) the heat and energy budgets with an emphasis on influences on temperatures. Comparisons will be made with results from NCEP re-analysis for the same times.

Balancing the dry air mass budget is a basic consistency check as there are no sources and sinks, and adjustments must be made to the method of analysis to ensure that a mass balance is achieved or it distorts all other results. From the analysed tendency and convergence of moisture, the surface fresh water flux, which corresponds to the difference between surface evaporation and precipitation (E-P), will be computed as a residual and compared with values from the model. Both of these feed into the energy budget and are essential first steps. Similarly, the energy and/or heat budgets can and will be computed from the analysed changes in energy storage in the atmosphere and transports of energy (the dynamics), and compared with model-generated physical quantities such as diabatic heating. Satellite data can and will be used to determine parts of the diabatic heating, such as the radiation at the top of the atmosphere; the moisture budget can give latent heating, ocean data can be used to determine changes in ocean heat storage (where sufficient data are available), and surface fluxes can be estimated in some cases as residuals and compared with model estimates; all these aspects will be exploited. The main quantities that will exist throughout the record will be atmospheric heat fluxes, and these will be tracked along with how they relate to temperature changes. A more comprehensive view of the physical consistency of the analysis quantities will result.

Deliverables

D19: Interim report (month 17).
D36: Final report (month 35).

Milestones and expected results

M12: Interim report (month 17).
M31: Final reports (month 35).

Workpackage number:	**WP4800 Diagnosis of atmospheric circulation systems**
Start date:	**Month 0**
Lead partners:	**UREADMY, Météo-France**

Objectives and input to workpackage

Validation of the re-analyses through diagnosis of various atmospheric circulation systems and use of transport models. Input: Re-analysis results (WP3100), expertise and data from CLAUS, SHIVA, STOEC and earlier re-analyses, and pre-existing transport models.

Description of work

Validation of the temporal and spatial characteristics of tropical convection

This will use the global high resolution brightness temperature dataset developed by the EU-funded Cloud Archive User Service (CLAUS), as well as the objective tracking method to study the behaviour of tropical cyclones and mesoscale systems. This technique has already been used successfully to study African easterly wave behaviour in the earlier 15-year European re-analysis in comparison with Meteosat observations and radiosonde data. The CLAUS data have been used very effectively to show systematic errors in the simulation of the diurnal cycle in tropical land and ocean based convection in a range of climate models. UREADMY also has considerable expertise in diagnosing the MJO and its interannual variability. The behaviour of the MJO in ERA-40 will be analysed, building on experience with the NCEP 50-year re-analysis.

Assessment of the global circulation and its interannual variability, e.g. NAO, ENSO

This will build on UREADMY's long term programme in general circulation diagnostics using operational data. This Partner has an active programme on the seasonal to interannual variability of the North Atlantic and European sector, with a particular focus on the rôle of ocean-atmosphere interaction and the impact of ENSO.

Assessment of the representation of the Asian Summer Monsoon

UREADMY will apply expertise developed in this area through the EU-funded SHIVA project and through a detailed earlier comparison between re-analyses and observations. ERA-40 data will also be used to drive crop models relevant to India and Africa, with the aim of developing a combined seasonal weather and crop productivity forecasting system.

Assessment of storm track behaviour

UREADMY has extensive expertise in this area which is being developed further through the EU-funded STOEC project. The representation of storm tracks in ERA-40 will be assessed using diagnostics of the transient fluxes as well as application of an objective tracking method which provides a new view of storm track behaviour.

Lagrangian view of the general circulation

UREADMY and Météo-France have used operational data for trajectory calculations designed to exhibit the Lagrangian behaviour of the atmosphere. UREADMY will pursue its studies further with an assessment of the interannual variability of the air reaching N.W. Europe, and an investigation of the history of the dry air in subtropical regions. The inclusion of convective fluxes in these calculations will be an important new aspect that will be made possible by ERA-40.

Météo-France will carry out related studies for the stratosphere, using a transport model with passive tracers (such as the age of the air) or long-lived tracers with simplified chemistry (such as CH_4) that can be compared with independent observations. These studies will thus provide an indirect validation of the mean residual circulation (or diabatic circulation) produced by ERA-40. Such a validation is fundamental in view of the potential widespread application of the ERA-40 fields to force stratospheric chemical-transport models.

Deliverables

D20: Interim report (month 17). D37: Final report (month 35).

Milestones and expected results

M13: Interim report (month 17). M32: Final report (month 35).

Workpackage number:	**WP5000 Affordable dissemination**
Start date:	**Month 6**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Generation and dissemination of affordable data. Input: re-analysis archive (WP3100)

Description of work

The re-analysis archive will be extremely large (of order several tens of terabytes). Very few customers will be able or willing to accommodate such a large volume of data in its entirety. Data dissemination will be supported, tailored to individual needs, by means of selective access to the archives made possible by an advanced, state of the art archive/retrieval system. Even so, access to and delivery of large amounts of data by this means will incur substantial costs for those customers who are not connected to the archive/retrieval system. While many of these customers have demonstrated by past orders their willingness to accept such costs, there remain many more for whom such costs are prohibitive.

To address this problem a number of “affordable data sets”, comprising user oriented sub-sets of the full archive, will be defined. Some will be made available at low cost as a CD-ROM and/or DVD series. Some sub-sets of data may also be made available via the Internet.

Deliverables

D12: Affordable interim dissemination data (month 17).
D26: Affordable final dissemination data (month 35).

Milestones and expected results

M05: Interim affordable data (month 17).
M21: Final data sets (month 35).

Workpackage number:	**WP6000 Final documentation**
Start date:	**Month 12**
Lead partner:	**ECMWF**

Objectives and input to workpackage

A comprehensive set of project documentation, of particular relevance to the users of the re-analysis products. Input: Re-analysis production and monitoring results (WP3100, WP3200); validation results (WP4000 to WP4800 inclusive)

Description of work

The production of the re-analyses, any problems encountered, and the results of the monitoring and validation will be fully documented in this project report series. This documentation will enhance the value of the products, enabling users to obtain maximum benefit from them.

This workpackage relates only to the integration, editing and publication of the final project documentation; documentation will be produced by all partners throughout the project as subtasks of all workpackages.

Interim and final documentation will be made available both as paper reports and as electronic documents.

Deliverables

D22: Project draft documentation (month 17).
D38: Project report series (month 35).

Milestones and expected results

M15: Draft documentation (month 23).
M33: Final project documentation (month 35).

Workpackage number:	**WP6100 Clean-up**
Start date:	**Month 24**
Lead partner:	**ECMWF**

Objectives and input to workpackage
Late production and post-production clean-up. Completion of outstanding tasks.

Description of work
This task allows for the completion of data management. In particular, attention will be given to the completion of the archive process, and the provision of an archive containing all identified useful supplementary data.

Some aspects of the data organization (generation of climate, etc.) can only be begun when the production has reached an advanced stage. However, every attempt will be made to complete as much of the data organization and clean-up as possible during the production, leaving only a small amount of work to be undertaken post-production.

Deliverables
As listed under all other workpackages.

Milestones and expected results
M34: End of project (month 35).

4. CONTRIBUTION TO OBJECTIVES OF THE EU WORK PROGRAMME

4.1 Better exploitation of existing data and adaptation of existing observing systems (Research and Technological Development Priority 2.4.1)

ERA-40 is aimed explicitly at better exploitation of the observational data sets amassed globally over more than forty years. It will integrate consistently measurements of varying accuracy from a wide variety of in situ and remotely-sensing instruments to produce the comprehensive global sets of analyses needed by the general researcher. It will also provide feedback on estimated trends and variability in the performance of individual observing systems, of potential value to those working more closely with the data record from each individual system. Information will also be provided on the impact of the development of the observing system on the quality of the analyses.

4.2 Climate change prediction and scenarios (Research and Technological Development Priority 2.1.3)

ERA-40 products will provide a primary basis for assessment of seasonal predictability and the development of improved seasonal forecasting systems. They will provide more extensive and significantly improved data sets for use in studies such as DEMETER that extend those undertaken in the EU-funded PROVOST project, which utilized ERA-15 analyses.

ERA-40 analyses are likely to be widely used for the validation of global climate-simulation models. They will also be useful for the validation of the high-resolution regional models that have been developed to study local impacts of climate change. By driving such models with a long sequence of high-quality boundary values from ERA-40 analyses, the ability of these models to simulate local features can be determined by comparing model values of parameters such as low-level temperature or precipitation with detailed station records.

ERA-40 products should also prove invaluable in the emerging field of searching for the fingerprint of global change in the climate record. Climate models predict characteristic changes in the vertical temperature profile which depend on latitude and season. These fingerprints are currently being sought in the radiosonde record, but it will also be possible to use the ERA-40 data as a source for such comparisons. Previous re-analyses have in particular achieved some success in the depiction of the cooling trend in the lower stratosphere, and the longer record and accompanying ozone fields from ERA-40 should help in the elucidation of the mechanisms involved. The re-analysis fields will also find important applications in studies of low-frequency variability, particularly the marked changes that have occurred over the North Atlantic over the past forty years, leading, for example, to a substantial increase in mean wave height at a number of locations.

4.3 Stratospheric ozone depletion (Research and Technological Development Priority 2.1.2)

ERA-40 will build on past investment of the EU in the SODA project, which has facilitated the development of a European capability for the assimilation of ozone data. The ozone analyses for the past twenty years will reflect trends inherent in TOVS radiance data and in TOMS and SBUV data products. They will cover the period for which the NIMBUS-7 TOMS data recorded the appearance of the ozone hole over Antarctica, and the periods of intensive measurement campaigns such as EASOE and SESAME which received significant EU funding under earlier programmes. The ERA-40 data will provide a background for development of improved data assimilation systems for ozone and for more detailed studies of its sources, transport and sinks, using chemistry-transport models (CTMs) for example. They will also support studies to prepare for the exploitation of data from ENVISAT and the EOS series of satellites.

4.4 Atmospheric composition change (Research and Technological Development Priority 2.1.1)

ERA-40 will provide a comprehensive 40-year record of the temperature and wind fields necessary for driving the CTMs used to study the distribution of the chemical species which influence surface UV-levels, air quality and climate. It will use a data assimilation system that will produce additional information such as convective mass-fluxes, precipitation rates and vertical diffusion for which chemistry-transport modellers have clear requirements.

4.5 Contributions to other objectives

ERA-40 data will facilitate studies of the mechanisms and predictability of the major episodes of drought over the past four decades, and studies of the flooding of large river basins such as the Mississippi and the Rhine. Their potential use as boundary values for higher-resolution regional models could be particularly useful in this context. As such, they will contribute towards Research and Technological Development Priority **1.5.2 (Improved flood and drought forecasting)** and the Generic Activity **I.1.2 (Floods and hydrological risks)**.

ERA-40 will generate a forty-year global climatology of ocean waves, which will contribute towards Research and Technological Development Priority **3.4 (Operational forecasting of environmental constraints of offshore activities)**.

5. COMMUNITY ADDED VALUE AND CONTRIBUTION TO EU POLICIES

There is a major and essential European dimension to ERA-40. The project builds upon a substantial European and worldwide investment in operational and research measurements of the atmosphere and in research into methods for their analysis. It builds also upon a substantial additional European investment in the infrastructure for data processing, archiving and dissemination. ERA-40 will supply basic data sets and supplementary information that are a fundamental requirement of research to address environmental problems of global concern, in which Europe in particular has a keen interest and a capability for world leadership in achieving solutions.

ERA-40 is a demanding project that can be achieved on the time scale and with the resources identified in this document only by virtue of its execution at a European level. Indeed, ECMWF was itself founded in recognition of the need for European integration to ensure effective progress and Europe-wide delivery of benefits in the processing of global meteorological observations and the production of global weather forecasts. Only a limited number of national European institutions have a capability for global weather analysis, and ECMWF is unique within Europe in its experience of re-analysis, in the quality and range of its products, in its technical facilities for the processing, archival, retrieval and dissemination of data, in its holdings of the necessary observational data and in its preparation for a new re-analysis.

Although ECMWF has a central rôle in the project, very considerable added value is provided to ERA-40 by the other members of the consortium. NCAR has already provided its unique holdings of past observations to enable the period of ERA-40 to be extended back to 1957. More generally, the other partners bring to the project a combined expertise in validation and applications far broader than that possessed by ECMWF alone, as detailed elsewhere in this Plan. This expertise has already been exploited in the detailed planning of the project, and will be utilized in broadening the monitoring of the ERA-40 analyses and in carrying out validation and representative application studies. This will help ensure the basic quality of the analyses and will promote informed use of them by providing evidence of their strengths and weaknesses and of their suitability for a range of further studies, many of which will be in support of the specific aims of the Fifth Framework Work Programme.

The observations to be used as input to ERA-40 were made as a result of a considerable sustained financial investment by many countries of the world over several decades. There has also been a substantial European investment to build up the infrastructure for operational global data assimilation and forecasting at ECMWF. A significant investment has been made by NCAR in the collection, processing and supply of the historical observational data, and by ECMWF, the supporting institutions and other partners in this project in preparing the observations and data assimilation system for the production phase. The primary output data of ERA-40, together with the additional data relating to the observations used, will represent substantial added value produced at a relatively small additional cost. ERA-40 will in particular add value to the field-experiment data whose interpretation and exploitation will benefit and in many cases be revitalized by the availability of ERA-40 products. Collection of these data has in many instances been supported by European funding.

The contribution of ERA-40 towards meeting a number of Research and Technological Development priorities of the Fifth Framework Work Programme in Energy, Environment and Sustainable Development has been summarised in the preceding section. Relevance was indicated in particular to the topics of stratospheric ozone depletion, climate change predictions and scenarios, and atmospheric composition change. As such, ERA-40 will provide a key resource and promote studies which will lead to better-informed EU policies in support of the Montreal and Kyoto Protocols, and will add to the science base which will be essential for the adoption of new Protocols as risks and consequences in these areas become clearer. It will also provide a resource for research in support of the UN Convention to Combat Desertification. ERA-40 will strengthen the contribution that Europe can make to the World Climate Research Programme, its CLIVAR, GEWEX and SPARC projects in particular, and the International Geosphere-Biosphere Programme, particularly its BAHC project. ERA-40 will contribute towards meeting Europe's need for climate prediction and scenarios. ERA-40 data will also find important applications in chemical-transport modelling and may thereby support the development of protocols under the Convention on Long Range Transboundary Air Pollution.

More generally, there are few aspects of life that are unaffected by weather or climate. Sound long-term EU policies for agriculture, fisheries, energy, transport and health, as well as environment, must take account of the potential for changes in air-quality, weather and climate. The primary test of any physically-based system for predicting future changes must be its ability to reproduce and help understand past changes. ERA-40 will define better the state of the atmosphere and ocean over a period which, for example, has seen a pronounced change in atmospheric circulation characteristics over the North Atlantic and in the associated ocean waves and ocean circulation, with consequent implications for fishery, shipping and off-shore energy activities. Related changes in the distributions of wind, temperature and precipitation over Europe have implications for agriculture and air quality. The period of ERA-40 also encompasses two extreme and several other instances of the El Niño phenomenon, with its major social and economic implications, particularly in the tropics. ERA-40 will provide a major database for the development of seasonal forecasting systems, enabling in due course a better preparedness in the development and implementation of shorter-term foreign-aid policies.

ERA-40 will also provide information to assist the formulation of future European policies for maintenance and development of the observing systems needed to monitor climate and to provide the starting point for predictions of climate change. It will provide evidence of the evolution of the quality of individual components of the past and present global observing system through the feedback statistics produced during the data assimilation process. Furthermore, the overlap experiments will quantify the impact of major changes to the observing system on the global analyses, particularly the impact of the satellite-based components that have been progressively introduced during the past three decades. It will also be possible to quantify the impact of the fixed Ocean Weather Ships that provided important coverage of the North Atlantic in the period before data from commercial aircraft and satellites became available. ERA-40 will provide comprehensive atmospheric data sets which will be invaluable in assessing the likely utility of proposed future instruments. An understanding of the importance of the various existing components of the observing system and of the likely benefits of new components, especially satellite-borne components, is vital for the sound economic planning of the future integrated observing system. ERA-40 will help to enhance the rôle that Europe can play within world agencies such as the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS).

There is a specific need for documentation and dissemination of the importance of microwave remote sensing in particular. There is substantial commercial pressure for widening the spectral bands that are allocated to the rapidly expanding telecommunications industry, encroaching on the frequencies used to sense the atmosphere and surface conditions. Observing system experiments such as planned for ERA-40 have an important application in providing information to help formulate and support the submissions of governments and other bodies to the World Radio Conference, the international forum for world agreement on the use of radio frequencies.

6. CONTRIBUTION TO COMMUNITY SOCIAL OBJECTIVES

6.1 Quality of life, health and safety of the citizens

ERA-40 will help to improve the quality of life and health and safety for the European (and world) citizen at home and abroad. The overall quality of life will benefit in general from the significant rôle ERA-40 has to play in the preservation of the environment against detrimental change, discussed further below. There are serious health concerns over the depletion of the stratospheric ozone that provides a shield from the harmful effects of ultra-violet radiation and over directly damaging effects of breathing air of poor quality. Past re-analysis data has been utilized for studies of the meteorological and chemical processes involved. The increased range, variety and accuracy of products from ERA-40 will significantly enhance the benefit that can be gained from such studies.

The incidence of disease has a dependence on weather and climate, and here too there is benefit to be gained from the application of ERA-40 data. For example, studies of the incidence of diseases such as malaria and meningitis in the tropics have relied on use of inadequate climatologies from individual land-based observing stations. Adaptation of such studies to use re-analysis data to study past fluctuations in disease rates would be a prelude to exploiting data from seasonal forecasting systems to target preventative measures on those most at risk. Improved crop forecasts may similarly be derived from the application of re-analysis data in the development of crop-yield models and from the subsequent use of data of similar format from seasonal forecasting systems. Application studies in these areas are planned as part of the DEMETER seasonal-forecasting project funded by the Fifth Framework Programme. This is in addition to the crop-model application included in WP4800 of this plan.

It has been noted earlier in this plan that ERA-40 data have a rôle to play in the study of floods, droughts and longer term hydrological changes, all of which have consequences for the quality of life, health and safety. More generally, the many lessons to be learnt from production of the ERA-40 analyses, from the observing system experiments, from the improved exploitation of field-experiment data, and from the seasonal forecasting experiments that will exploit ERA-40 data, will contribute towards an improvement in weather forecasting on a range of temporal and spatial scales, with consequent social and economic benefits to the users of the forecasts.

The ERA-40 analyses will lead to improved understanding of the nature and predictability of fluctuations in the atmospheric circulation over the decadal time scale, and of related fluctuations in ocean-wave and ocean-circulation characteristics. This will be of relevance for improved long-term management of fish stocks and agricultural development. Better and more readily applicable climatological knowledge of atmospheric conditions and sea-state should yield further social benefits, through improvements in areas such as rain-sensitive mobile telecommunications reception and transport safety regulations. Indeed, despite its known deficiencies the precipitation and water-vapour climatology from the earlier European re-analysis, ERA-15, has been adopted by the International Telecommunications Union as its recommended basis for the calculation of atmospheric losses in microwave telecommunication signals, replacing a standard based on general climatological classifications. Demand for an improved standard such as can be supplied by ERA-40 is high.

6.2 Environment and natural resources

ERA-40 will assist in the preservation of the environment. It will provide the most accurate and comprehensive synthesis of the observational database that can currently be constructed to record the present state of the global environment and the changes that have occurred over the past four or more decades. It will serve as a baseline or climate norm for future assessment of change to the large-scale environment. ERA-40 will provide improved data for validation of the atmospheric general circulation models that are used to simulate and understand recent climate fluctuations and trends, and to predict future large-scale environmental change. Environmental benefit may derive from applying ERA-40 data in studies to improve the use of weather-sensitive renewable energy resources and as input data for environmental impact studies at global, regional and national scale. ERA-40 will be a vital next step towards a much expanded capability for environmental monitoring, with the potential use of multiple future satellite sensors and more advanced data assimilation systems to provide estimates of the evolving global distributions of greenhouse gases and pollutants.

Another type of application of ERA-40 data will bring further understanding of environmental change, and contribute to environmental preservation or enhancement. ERA-40 will provide the basic long time-series of reliable atmospheric data needed to drive specialised models of the processes involved in the evolution of environmental components on annual and decadal time scales. It will thus facilitate many detailed studies of components such as stratospheric ozone, chemical transport in the troposphere, soil-vegetation-atmosphere dynamics, catchment-basin hydrology, glacial extent, and snow and sea-ice cover. Provision of the atmospheric forcing of detailed ocean models, for example to study the atmosphere-ocean exchange of carbon dioxide, is another important application. Establishing the capability of process models to reproduce variations over the past forty years is vital for assessing the confidence that can be placed in the predictions of such models when forced by putative future atmospheric conditions derived from general circulation models. Comparison of analysis-driven process-model output with independent observations is included in the validation and exploitation component of ERA-40.

6.3 Employment, education, training and working conditions

ERA-40 will make the heterogeneous and expensively accumulated observational database available in a synthesized, globally gridded form that can be utilized by the many members of the scientific community who cannot make easy use of the raw instrumental data from the many observing platforms. In particular, the re-analysis data will be readily usable by research students and graduate trainees. It will also provide a rich source of general educational material.

ERA-40 will contribute towards the development of skills and employment in Europe. The comprehensive gridded analyses covering both troposphere and stratosphere over a period of more than forty years will broaden the applicability of climatological data in many areas of activity, and lead to a work force in research and development with enhanced skills in the utilization and exploitation of such data.

Apart from the general development of skills, ERA-40 will provide opportunities for enhanced provision of climatological services in the global marketplace. A particular example concerns the climatology of ocean waves, sound knowledge of which, especially of the probability for extreme sea-states, is of vital importance for marine engineering. The multi-decadal climatology of ocean waves resulting from ERA-40 should find numerous applications in ship design, ship routing, coastal protection, harbour design and oil exploration. The benefits will be largest for the poorly-observed (but increasingly exploited) regions for which the ERA-40 results will be the most complete source of information available.

Improved knowledge of past fluctuations and trends in weather and climate, and consequent improvements in prediction, will enable industry to improve its planning for the supply of the many products for which demand is weather-sensitive. A more efficient use of natural resources will be a further consequence. Refinement of estimates of future climate change may allow industry and employment to avoid suffering from unnecessarily cautious and restrictive policies developed in response to “worst-case” scenarios.

7. ECONOMIC DEVELOPMENT AND SCIENTIFIC AND TECHNICAL PROSPECTS

There will be substantial exploitation of the results of ERA-40 by the partners in this proposal beyond the specific studies that will be undertaken under the validation workpackages. The central rôles that the partners play within their national communities and the wider scientific community will help further to promote the application of the data.

ECMWF will exploit widely the results of ERA-40 and the experience gained in the production of the analyses. Its principal direct use of the products of ERA-40 will be in its programme of seasonal forecasting. Planned work in this area includes studies covered by the DEMETER project supported under the Fifth Framework Work Programme. The UK Meteorological Office and Météo-France are also partners in DEMETER.

ECMWF will make special use of the ERA-40 products at the times of the field campaigns that are most useful for the development of its forecast model. This will include the production of new, higher-resolution analyses for the periods of interest. ECMWF will use the ERA-40 analyses to validate the extended integrations it performs to assess the realism of the climate of its forecast model. It will exploit the information gained as to the rôle of specific components of the observing system in planning its programme of research and in the feedback it provides to data producers, the meteorological satellite organizations in particular. In addition, ECMWF will address any weaknesses in the performance of its data analysis and assimilating model revealed by ERA-40, to the benefit of the accuracy of the operational medium-range forecasts it issues to its European Member States.

The ERA-40 products will be used at MPIfM for a wide range of purposes concerning the validation of climate models and for diagnostic studies. MPIfM works in co-operation with the German Climate Computing Centre (DKRZ), which is the focal point for climate research for many institutes in Germany and neighbouring countries. By making the ERA-40 data available to their partners, investigations will be initiated which have not previously been addressable because climate research needs time series data that are largely unbiased and that cover a period of several decades. It will be a prime task of MPIfM to examine the ERA-40 data and to detect possible biases. There is a growing need to investigate the impact of climate variability on society, and hydrological data will be especially important, for example the availability of fresh water for human consumption, climate in relation to flooding, etc.. Forty years of re-analysis data, which will for the first time be sufficiently comprehensive, will enable such studies to be undertaken.

The UK Meteorological Office will use the ERA-40 products in work on clear-sky radiation and seasonal forecasting, as discussed above. In addition, a wide range of variables from the re-analysis will be used in detailed evaluations of the performance of the Unified Forecast/Climate Model. Results from ERA-15 are already used extensively for this purpose.

Météo-France will continue to exploit ERA-40 data with respect to snow-related studies, ozone chemistry, air-sea interaction, predictability, marine forecasting, and seasonal forecasting.

KNMI will exploit the results from the wave model in the course of its climate-change studies. During the EC-funded WASA project KNMI looked at changes of North Atlantic wave heights that might result from increased atmospheric levels of greenhouse gases. One of the problems in that study was the poorly-known natural variability. With the availability of a forty-year climatology of ocean waves a better estimate of that variability can be obtained. Furthermore, the study can be extended to the global scale. The wave data from ERA-40 will be used as a high-quality reference in the framework of an INTAS-funded collaboration with SOC (Southampton) and IORAS (Moscow) to assess the quality of different sources of wave-height estimates.

NCAR will provide ERA-40 data to academic customers within the USA, and will continue to exploit the data within the Climate Analysis Section in their efforts to increase understanding of atmospheric and climate variability and climate change.

Exploitation of results at UREADMY will be through reports, published papers and presentations at conferences and workshops. ERA-40 analyses will be used for the validation of climate models, particularly the UKMO Unified Model. UREADMY is actively involved in AMIP II and will exploit the results in the various AMIP II Diagnostic Sub-projects in which it plays a leading rôle (e.g. Tropical Variability, Monsoons). UREADMY is coordinating a monsoon project called “Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change (PROMISE)” which also is funded under the Fifth Framework Programme. The project will make extensive use of ERA-40 for validating climate and seasonal prediction models and for driving crop models for the impact studies. Wider use by members of UGAMP is expected to follow the pattern of use of ERA-15 by UK Universities and Research Institutes, discussed below.

EUMETSAT, ESA and other satellite operators will have the opportunity to exploit the feedback produced with respect to the quality of their data. They will also be able to use ERA-40 products for the development of improved products, and for the re-computation of historic products to improve their quality.

The customer potential and interest in ERA-40 products may be gauged by the scale of the current demand for the ERA-15 data. These data can be accessed directly by ECMWF and its Member States through an on-line archive. In the 11-month period ending 31 March 1999, the retrieval system satisfied request for ERA data at an average rate of almost 25,000 per month. 86% of these requests were from the Member States. The Member States exploit the data within their own country, and are responsible for meeting the needs of their national governments and customers. In addition, the ERA-15 data have been made available to meet national needs through the British Atmospheric Data Centre (BADC), MPIfM, and NCAR. The ECMWF Data Services support non-European customers, and have completed in excess of 180 large orders for ERA-15 data. A reference data set of selected upper-air and surface fields at standard resolution has been made available on CD-ROMs, 1200 of which have been distributed worldwide. The data dissemination strategy for ERA-40 will build on this success, with the production of a wider range of specialist data sets, which can be provided on new media such as DVD and through a web-based data service.

As an example of the extent of national use of re-analyses, a total of 99 research projects in the UK had been supported by the provision of ERA-15 analyses by the BADC within a year or so of production being completed. These projects covered a wide range of applications, many of them identified earlier in this document as benefiting from the availability of re-analyses. They comprised diagnosis of the atmospheric general circulation, regional circulations and weather systems, validation of general circulation models, chemical transport-modelling and data assimilation, ocean circulation modelling, interpretation of independent satellite measurements, and studies of sea-ice, atmospheric composition, hydrology, radio refractivity and local air quality. The greater time-range, vertical extent, variety and accuracy of the products of ERA-40 are expected to lead both to an even more intensive use of re-analysis data in areas of previous application, and to innovative applications which widen the range of utility of the data, leading to the policy-support and social and economic benefits discussed earlier.

All the national meteorological services of the Member States of ECMWF will have direct networked access to the complete set of ERA-40 data. They act as agents for their National Governments, who are major customers for weather and climate information, and through their Membership of WMO and their participation in WCRP, GCOS and GOOS, act as agents for these customers also. These European meteorological services will be well-positioned to exploit the full set of products in meeting the needs of these major national and international customers. Experience with respect to the exploitation of the ERA-15 analyses provides assurance that these and other customers will extract a very substantial benefit from ERA-40.

8. THE PARTNERS

8.1 European Centre for Medium-Range Weather Forecasts (ECMWF)

ECMWF is an international organization supported by eighteen European states, and with co-operation agreements with several other European states, EUMETSAT and WMO. It is responsible for producing operational global data analyses and medium-range forecasts for its Member States, and undertakes a comprehensive programme of research to ensure the continued development and improvement of its products. ECMWF has active groups of researchers working on the development of atmospheric models and on data assimilation methods, with a special emphasis on the variational assimilation of satellite data. ECMWF also has a research programme aimed at the development of seasonal forecasting techniques.

In September 1996 ECMWF successfully completed a fifteen-year re-analysis (ERA-15), from 1979 to 1993, using a one-dimensional variational analysis system for satellite radiances coupled to an Optimal Interpolation analysis system. This project demonstrated clearly the benefit of the assimilation of satellite radiance data, and was able to illustrate that a two-satellite system could produce better analyses than a one-satellite system. ERA-15 also provided clear evidence of the improvement in quality of the cloud-motion winds produced by the operators of the geostationary meteorological satellites over the re-analysis period, and identified scope for further improvement. The ERA-15 analyses have found widespread application, as discussed further in section 7. The Project Manager designated for ERA-40 was a senior member of the ERA-15 production and diagnostic team, and much of the expertise he gained from ERA-15 will be carried forward into management of the ERA-40 project.

ECMWF is equipped with the most advanced supercomputers, fast telecommunications links, powerful workstation servers, and unique facilities for data handling and archives. Fujitsu Ltd, the current supplier of supercomputer services to ECMWF, has made available additional computer resources, free of charge, especially for re-analysis and related activities.

Support for the validation of the ERA-15 analyses was provided by the EU. Other EU-funded environmental projects in which ECMWF has been involved are CLAUS, CLOREVAL, DUACS, EUCREM, EUROTRMM, PROVOST and SODA.

The Head of Research of ECMWF will act as ERA-40 Project Co-ordinator. The Head of the Data Division in the Research Department will act as Contact Point, and provide overall supervision and guidance. The ERA-40 Project Manager will be a highly experienced consultant funded directly by ECMWF.

8.2 Max-Planck-Institut für Meteorologie (MPIfM)

The Max-Planck-Institute for Meteorology in Hamburg (MPIfM, or MPG.IMET) is one of the leading institutes for climate research in Germany and has a long experience in developing and applying climate models. MPIfM atmospheric, oceanic and coupled models are run in climate and forecast mode in different combinations and are applied in studies of interannual to decadal climate variability and predictability. Model results are diagnosed and used for further processing at many research institutes around the world. MPIfM has participated successfully in many EU-projects. MPIfM has considerable general experience in diagnosis of the hydrological cycle, and has particular experience of comparing the representations of the hydrological cycle provided by existing re-analyses. MPIfM cooperates closely with the German Climate Computer Centre (DKRZ).

A senior scientist from MPIfM will be directly responsible for this project, under the Director of the Department for Model Development at MPIfM. He will be assisted by a scientist from MPIfM, with support provided by a member of DKRZ.

8.3 The Meteorological Office (UKMO)

The Meteorological Office is the national meteorological service of the United Kingdom, providing an extensive range of weather forecasts and other services for the public, the armed services, other government departments, civil aviation and a wide range of other customers. Advice to the government on climate change is provided by the Hadley Centre for Climate Prediction and Research. A Unified

Forecast/Climate model is used to support both meteorological and climate prediction activities, backed by about 250 research staff. The work is supported by an extensive computing system including a massively parallel supercomputer and a large number of workstations.

The Head of Unified Model Parametrizations will lead the validation of ERA-40 products with respect to clear-sky radiative fluxes. One other member of staff will perform the simulations and the comparisons between clear-sky longwave fluxes and data from ERBE, ScaRaB and CERES.

8.4 Météo-France

Within Météo-France, the National Centre for Meteorological Research (CNRM) is the department responsible for conducting the largest part of the meteorological research activities, and for coordinating research/development undertakings conducted within other departments. Primarily oriented towards the needs of public utility in the domain of meteorology, the research actions encompass the atmosphere, extending to, and including, closely related fields and boundaries, such as stratospheric ozone chemistry, upper ocean, physics and dynamics of the snow cover, surface hydrology, etc.. To carry out its missions, CNRM hosts approximately 225 permanent positions (one-third being research scientists), and 45 students and visitors, working in specialized divisions. Two of these divisions will be directly involved in the ERA-40 project. The first is the snow centre CEN (study of snow mantle, techniques and methodologies associated with the forecasting of avalanches), situated in Grenoble. The second is the climate group GMGEC (physical processes for climate, ozone, long-range forecasting, climate evolution, development and management of the atmospheric part of the French community climate model, etc.), through its Middle Atmosphere Research Team (ERAM) and Air-Sea Exchange Team (MEMO), located in Toulouse.

The main areas investigated in the past by the CEN team include physical and mechanical properties of snow, snow cover modelling, and interaction between snow and the atmosphere. Investigative tools available include the physically based snow model CROCUS and the meteorological analysis system adapted to the mountainous environment SAFRAN. CEN also manages the French snow database; in addition they have coupled the snow model CROCUS with the Météo-France ARPEGE GCM and participated in the validation of the ERA-15 re-analyses.

The ERAM team of the CNRM has a long experience of stratospheric modelling, with dynamical (ARPEGE GCM) as well as chemistry-transport (REPROBUS) models. It developed the parametrization for the computation of ozone photochemical sources and sinks that will be used by ECMWF in its data assimilation system for ERA-40. Recently, the team has been involved in European campaigns (EASOE, SESAME,...) studying the ozone chemistry in the arctic regions. It has also been involved in several European projects concerning various aspects of stratospheric modelling: TOPOZ, SODA, EuroGRIPS, AEROCHEM.

In addition to this modelling aspect, the ERAM team is also active in the field of ozone measurements, being in charge of the constitution and maintenance of the data bank for the EU's MOZAIC project and producing daily global total ozone maps from TOVS data.

The MEMO team at CNRM specializes in air-sea interaction studies and has experience in oceanic and atmospheric modelling at the mesoscale applied to ocean field-experiment data sets. PREVI/MAR, the marine forecast team of SCEM (Service Central D'Exploitation de la Météorologie), is in charge of the AVISO service and the MERCATOR project (operational oceanography).

The head of the snow physics and snow modelling team at CNRM, will be responsible for the validation concerning the snow cover in the Alps.

An experienced scientist will be in charge of the analysis and validation of the ozone fields produced during the ERA-40 project, with assistance for the data handling of the ozone products provided by a second staff member.

The head of the MEMO team and the deputy director of PREVI/MAR will be jointly responsible for the validation of oceanic surface fluxes.

The head of the climate division will contribute to the validation of oceanic fluxes and coordinate the whole activity of Météo-France for the project.

8.5 Royal Netherlands Meteorological Institute (KNMI)

KNMI is the national meteorological service of the Netherlands, and has a long tradition of research into the atmosphere and the ocean.

Research on ocean waves started in the 1950s and 1960s when Groen and Dorrestein developed manual wave forecasting methods. These methods were used for ship routing applications until 1988. KNMI also participated in Jonswap, the first major international wave measurement campaign. In the 1970s Sanders developed GONO (Golven Noordzee), one of the first second generation numerical wave prediction models. This model was used operationally to forecast wind sea and swell at the North Sea. Later it was also implemented for the South China Sea. In the early 1980s GONO was compared with other models in the SWAMP (Sea Wave modelling project) study. As a result of this intercomparison the WAM group (founded on the initiative of Klaus Hasselmann and chaired by Gerbrand Komen) started to develop a so-called third generation wave prediction model. This model, the WAM model has now been successfully implemented in many operational and research centres. The model is described in detail in “Dynamics and Modelling of Ocean Waves” (Komen, et al. 1996). At KNMI the WAM model is used to predict waves in the North Sea, up to 36 hours ahead. ECMWF couples the model with its atmospheric model to produce operational 10-day wave forecasts, and will use this coupled system for ERA-40. Recently KNMI has been active in studies concerning the rôle of waves in air/sea interaction; assimilation of wave observations in wave models; inverse wave modelling; decadal wave climate variability; and the possible effect of CO_2 doubling on the wave climate of the North Atlantic.

KNMI also has an extensive programme of research into ozone. It has a global tracer transport model which includes an advection and a chemistry module and is coupled to the analysed fields from ECMWF. It also has a two-dimensional global ozone transport model, which is being used to produce global analyses of total ozone.

The Head of the Oceanography Group of KNMI will coordinate KNMI's contribution to ERA-40, assisted by two staff members providing scientific and technical support. The wave analysis work will be carried out by a scientist supported by the EU funding. The Head of the Atmospheric Composition Research Division and the working group leader of Atmospheric Composition Modelling will contribute to the ozone validation.

8.6 National Center for Atmospheric Research (NCAR)

The National Center for Atmospheric Research (NCAR) is a leading institute for research on the atmosphere, climate system, and ocean in the USA. It undertakes research in many areas. Two sections within NCAR will contribute to ERA-40 - the Data Support Section, which is already assisting in the preparation and provision of the observations, and which will subsequently assist with the delivery of data to customers, and the Climate Analysis Section, which will provide validation support, and subsequently evaluate and exploit the ERA-40 products.

Many observational datasets have been gathered and prepared by the Data Support Section. The datasets of surface and upper-air data have been put into fewer formats and many consistency checks have been made. The data have been combined with location and elevation data so that global analyses can be made. These data have been used in the NCEP/NCAR project to re-analyse the global atmosphere for the 50-year period 1948-1997. As time goes on, it becomes possible to include some data that were not available in digital form at an earlier time. The datasets of observed data have been sent from NCAR to ECMWF under this plan. This group at NCAR will also handle the output from ERA-40 so that the US research community can obtain access.

The goal of the Climate Analysis Section of NCAR is to increase understanding of atmospheric and climate variability and climate change through parallel development and analysis of observational, assimilated and model-generated datasets, and by using the datasets for empirical studies, diagnostic analyses and model evaluation to document comprehensively the variability, the processes involved and its causes.

The comprehensive evaluation of datasets is an integral part of this work and the global analyses from ECMWF and NCEP have been used extensively in NCAR’s work. A listing of datasets can be seen on the web at www.cgd.ucar.edu/cas/catalog.

The Head of the Data Support Section leads the team responsible for the supply of observations and the provision of re-analysis products to customers within the US research community. The Deputy Head provides overall supervision and guidance. Seven staff members are involved in various aspects of the work.

The Head of the Climate Analysis Section at NCAR will be the principal investigator with respect to validation and exploitation, with technical support and scientific backup provided by three members of the Section.

8.7 Department of Meteorology, University of Reading (UREADMY)

The Department of Meteorology at The University of Reading was founded in 1965. It is the major university atmospheric sciences department in the UK. In the most recent Government assessments of both teaching and research, the Department received the highest grades, excellent and 5* respectively.

The Department currently has 16 members of academic staff, 50 research grant funded staff and 11 support staff. About 50 undergraduate students are currently registered for BSc degrees involving meteorology and a further 60 postgraduate students are registered for research and MSc degrees.

The Department has recently moved to a new purpose-built building with facilities that include laboratories and a library. It is situated about 3km from ECMWF and 15km from the UK Meteorological Office, and has very strong links with both institutions.

The Department has research in most areas of meteorology, in atmospheric physics and chemistry, and in dynamical oceanography. The research ethos is one of interaction between all areas of research and all researchers in the Department. However, the research is sometimes viewed under the headings of Regional Weather Systems (RWS) and Global Circulation and Climate (GCC)

Under the RWS there is research in dynamics of weather systems, radar meteorology, convection, tropical weather systems, data analysis, satellite estimation of rainfall, micro-meteorology, boundary layer dynamics and tropospheric chemistry. Associated with RWS is the Joint Centre for Mesoscale Meteorology which includes a UKMO group situated in the Department. The Department also leads the Universities Weather Research Network.

In GCC there is research on planetary fluid dynamics, computational fluid dynamics, dynamical processes, palaeoclimate modelling, statistical methods, and radiation and climate processes. Associated with GCC is the Centre for Global Atmospheric Modelling, CGAM, the major coordinating centre for the UK Universities Atmospheric Modelling Programme (UGAMP). UGAMP is an inter-university programme funded by the Natural Environment Research Council (NERC).

UGAMP's scientific research is driven by the need for a better understanding of the atmosphere and other components of the climate system in order to reduce uncertainties in climate forecasting. To achieve this end, it is essential to know what the real atmosphere is like and to develop numerical models that can accurately reproduce, and predict, its behaviour. UGAMP research therefore relies heavily on the use of diverse observational data sets and on experimentation with and development of numerical models.

A major focus of research at CGAM targets understanding the mechanisms and predictability of fluctuations climate. CGAM scientists have made major contributions to understanding the tropical Madden-Julian Oscillation, variations in the Asian summer Monsoon, and the rôle of the Atlantic Ocean in the climate system. Increasingly, this research programme relies on experimentation with coupled ocean-atmosphere models as well as atmosphere-only models. CGAM is playing a leading rôle in research to establish the extent to which climate fluctuations on seasonal and longer timescales are predictable. As a key part of this activity CGAM is developing collaborative relationships with a diverse range of potential user groups, for example in agriculture and public health.

The holder of the Established Chair in Meteorology in the University of Reading will be the lead investigator for ERA-40.The Director and Deputy Director of CGAM will supervise particular aspects of the work.

9. PROJECT MANAGEMENT

ERA-40 can be divided into a number of branches of activity:

1. Co-ordination (WP 1000)
2. Preparation (WP 2000, 2100, 2200, 2300, 2400, 2500, 2600)
3. Production (WP 3000, 3100, 3200)
4. Validation and exploitation (WP 4000, 4100, 4200, 4300, 4400, 4500, 4600, 4700, 4800)
5. Dissemination, documentation and clean-up (WP 5000, 6000, 6100)

Tables showing the milestones and the scheduling of the workpackages have been presented in section 3.

The first three and last branches of activity will be the prime responsibility of ECMWF. The validation and exploitation workpackages in the fourth branch of activity will be primarily the responsibility of the other partners in this project. A summary of the rôles of these partners in the project has been given in section 3.

ECMWF will provide the Project Co-ordinator and the Project Manager. The Project Manager will be responsible for the day-to-day management of the project. This will include co-ordinating the workpackages within branches 1, 2, 3 and 5, and liaising with the workpackage leaders associated with branch 4 to ensure effective progress of the project as a whole. The Project Manager will report to senior management of ECMWF and will work (with their assistance as required) on the detailed planning and monitoring of the project, and on any problem-solving that is needed.

Work on the preparatory phase of ERA-40 has reached a very advanced stage. The progress has been made possible by external support from the Japan Meteorological Agency (JMA), the Institute of Atmospheric Physics (IAP), Beijing, the University of California Program for Climate Model Diagnosis and Intercomparison (PCMDI), and Fujitsu Ltd., obtained as a result of direct contacts from ECMWF. Two project management groups have been convened, an External Advisory Group and a Steering Group. Both of these bodies are chaired by the Project Co-ordinator, the Head of Research of ECMWF.

The management structure is illustrated in Figure 3.

The External Advisory Group represents a broad cross-section of customers for re-analysis products. It comprises scientists from each partner together with selected scientists who represent principal user-groups such as WMO, WCRP, GCOS, UCAR, CLIVAR, and others. The Scientific Advisory Committee of ECMWF also nominates a member of this Group. Two meetings of this group have taken place to date. It has provided direction in drawing up the detailed project plan, including advice on the details of the production system and on the archive of re-analysis products. It will advise on any changes deemed necessary to the plan, and will contribute to the assessment of the preliminary results of the validation and exploitation tasks.

The Steering Group is chaired by the Project Co-ordinator. It comprises additionally the Head of Operations, the Division Heads and Project Manager from ECMWF, and a representative of each of the remaining partners. Appropriate advisors may accompany Steering Group representatives. Much of the work of this group is conducted informally, by e-mail and correspondence, with meetings where necessary. Its task is to review the planning, the preparation of the observational data and of the assimilation system, the pre-production experimentation, the production and archiving of results, the progress with the validation and exploitation tasks and the project documentation.

A major strength of the partnership is that all partners are thoroughly experienced in working together. Most are inter-connected electronically through a dedicated, high bandwidth network, facilitating the rapid exchange of information and data, and direct access to the sophisticated archival/retrieval system to which the ERA-40 results will be written. All partners have high speed Internet connections. Special arrangements are already in place for sharing ERA-40 information between partners through a dedicated Internet web site, and for sharing larger files of information and data through a dedicated Internet ftp site. Each partner has well defined contact points, and liaison through e-mail and meetings when necessary is well established between the contact points, the Project Co-ordinator and the Project Manager.

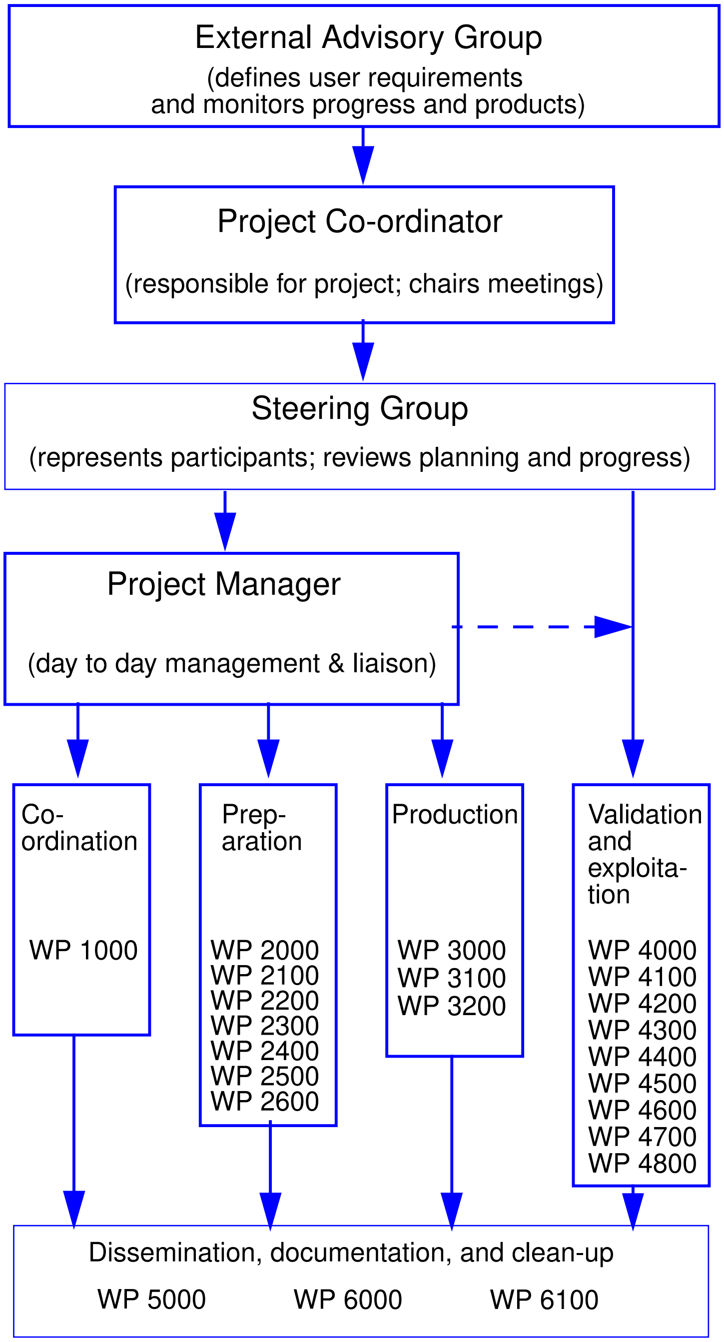

Figure 3 ERA-40 management structure

10. RELATED EU-FUNDED PROJECTS

ERA-40 will build on the success of many earlier EU-funded projects. Special references to CLAUS, EASOE, ERA-15, MOSAIC, PROVOST, SESAME, SHIVA, SODA, STOEC and WASA have been made earlier in this document.

ERA-40 analyses will be a major input to the DEMETER and PROMISE projects being funded under the EU's Fifth Framework Work Programme in Environment and Sustainable Development.

Progress in the related projects MAIA and HIPOCAS will be monitored and appropriate links will be established as necessary. Links with relevant WCRP, GOOS and GCOS activities will be developed, building on those established in the preparation phase of ERA-40.

Appendix A: Workpackages of the Preparatory Phase

Workpackage number:	**WP2000 Data acquisition**
Start date:	**Month 0 - 24**
Lead partners:	**NCAR, ECMWF**

Objectives and input to workpackage
The acquisition of as many meteorological observations covering the period since 1957 as possible.
Input: Historical observational data from many sources.

Description of work
NCAR has gathered and prepared many data sets of the surface and upper air observations that are necessary for re-analysis; these data, and software to assist in the reading of these data, have been made available to ECMWF. Many person-years have been invested in a programme of remedial work with respect to these historic data. NCAR is continuing to develop and extend this work, providing appropriate results, libraries of station histories, and additional observations to ECMWF. These data include global radiosonde and radar winds, aircraft data, early satellite data from 1969 onwards, surface, and marine data. They also include extensive associated library information, giving metadata and historical details of observing stations included within the data sets.

Software has been checked that it is usable on ECMWF's computer systems and modifications made where necessary. Since much of the delivered software was specific to Cray computers, alterations to the read and write sections of the codes have been made. Data are being converted from Cray-specific file form to a file form which can be read by the modified software.

Files of data are being generated which can be stored on archive media, and subsequently used by the pre-processing.

The sources listed by Lystad (1995) relating to radiosonde metadata are being used to generate comprehensive histories for radiosonde stations. Other references, such as Gaffen (1993) and material resulting from radiosonde intercomparisons, are also being followed up. Some of this information will be used in bias correction and blacklist compilation. Improvements will be made where possible to the station information for the post-1979 period currently incorporated in an archive generated from the WMO station lists.

Snow-depth data have been augmented by the data recently made available from the former Soviet Union. Other sources of long-term snow-depth data are being investigated.

Analysis of sea-surface temperature (SST) is a specialized activity, and ECMWF will use external sources in ERA-40. The best available SST analyses are considered to be the latest version of GISST (Rayner et al., 1994) for the early years, and those from Reynolds (1994) for the period from November 1981 onwards. However, there are known inconsistencies, especially relating to sea ice cover, which it would be desirable to overcome before using these data as forcing fields for ERA-40. The authors of these data are known to be collaborating and working to provide enhanced products, including resolution of these inconsistencies. It is planned to use the results of this collaboration for ERA-40.

Deliverables
Files of stored meteorological observations, checked for readability and completeness, for the period since 1957 ordered by source and type. These data are input to WP2100.

Milestones and expected results
Input data for WP2100 (delivered).

Workpackage number: **WP2100 Pre-processing**
Start date: **Month 0 - 24**
Lead partner: **ECMWF**

Objectives and input to workpackage
Objective: An archive of decoded, checked, and re-formatted observations for the period since 1957. Input: Observations acquired under WP2000.

Description of work
Observational data needs to be decoded and subjected to an initial quality-control procedure. This procedure differs according to the type of observation, but generally involves checking each individual element for reasonable values, and, where possible, computing inter-element checks. The checked observations will then be re-formatted into the input form expected by the data assimilation system (WMO FM94 BUFR). Finally, sets of observations need to be written to archive media for input to the data assimilation system when required.

Deliverables
Sufficient coded observations and forcing fields for experimentation (WP2500) (Delivered).
D01 (part): Observations archive - Sufficient coded observations and forcing fields for production (WP3000).

Milestones and expected results
Sufficient coded observations and forcing fields for experimentation (WP2500) (Delivered).
Sufficient coded observations and forcing fields for production (WP3000) to begin and be sustained at the planned rate (month 0).

Workpackage number:	**WP2200 Problem chasing**
Start date:	**Month 0 - 24**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Error corrections to the archive of observations.

Description of work

During the data acquisition (WP 2000) and pre-processing (WP 2100) some problem data are being encountered. Investigative work is being undertaken to try to resolve such problems. If problems cannot be resolved within a reasonable allocation of resources the problem data will be omitted from the production through the application of a blacklist of undesirable data.

Deliverables

D01 (part): Observations archive - Enhancements to the observations.
D02 (part): Production system - Initial blacklist

Milestones and expected results

Residual work will be carried over to WP2600 at month 0.

Workpackage number: **WP2300 Systems development**
Start date: **Month 0 - 18**
Lead partner: **ECMWF**

Objectives and input to workpackage
Generation of a robust, reliable re-analysis production system. Input: An extensive existing data assimilation system, together with many of the additional required applications.

Description of work
The re-analysis production system will need to perform re-analysis reliably and quickly. It will need to be sufficiently general that, where necessary, a number of copies of the system can run in parallel.

Overall control of the system will be achieved using an automated scheduler which has been developed and used in an operational environment for some time. The individual sub-systems of the production system will pre-fetch the observations for a one month period, perform one month of data assimilation, perform various monitoring tasks using the tools developed under WP 2400, archive the results, and generate end-of-the-month statistics, such as monthly means, variance and co-variance. A large number of ten-day forecasts will also be run from the analysis products while they are still on-line.

Scheduling of the production will be carried out to reach a high degree of parallelism of tasks. Data will be pre-fetched well ahead of their use. A specially developed data base will be used for the organization of the observations. Use will be made of powerful supercomputing resources for assimilation and modelling, combined with workstation servers for the bulk on-line storage of data, and sophisticated data handling facilities and software for archives.

The system will be modified as necessary to handle the older data, especially for the early forms of satellite radiance data. The adjustments required for VTPR data, and for handling and correcting the biases of old radiosonde data, will be developed.

A correctly functioning system has been produced at an early stage to perform the necessary experimentation (WP2500 below). This preliminary system will be generalised, so that more than one version can run in parallel, and optimised, so that the planned rate of production can be achieved with a minimum of computational resources.

Deliverables
A functioning prototype system to support experimentation (WP 2500).
D02 (part): Production system - an initial system to enable WP3000 (production) to begin.

Milestones and expected results
Prototype system (month 0 - 15) (Delivered).
Production system (month 0).

Workpackage number:	**WP2400 Development of monitoring tools**
Start date:	**Month 0 - 12**
Lead partner:	**ECMWF**

Objectives and input to workpackage
Development of an enhanced set of bias-correction and monitoring tools. Input: A selection of existing tools.

Description of work
Production problems must be detected quickly, their cause diagnosed, and remedial action taken. The development of a sufficiently comprehensive set of monitoring and diagnostic tools is essential to maximise both the rate of production and the confidence in the product. A number of powerful tools are already available to monitor re-analysis production and quantify bias. These are being enhanced to ensure problems are detected and addressed quickly. Systems are being developed to address the radiation bias of some radiosonde data; bias-correction tools are also being developed for the effective use of satellite radiance data. It is also important to pre-determine likely data-related and processing-related errors, and to provide appropriate detection tools in advance.

Deliverables
D02 (part): Production system - bias-correction schemes to be used in production (WP3100).
D02 (part): Production system - enhanced monitoring tools to be used in production (WP3100 and WP3200).

Milestones and expected results
The production bias-correction schemes (month 0).
Monitoring tools for use with WP3100 and WP3200 (month 0).

Workpackage number:	**WP2500 Experimentation**
Start date:	**Month 0 - 15**
Lead partner:	**ECMWF**

Objectives and input to workpackage

Scientific check-out and experimentation to enable the specification of the composition of the production system. Input: Pre-production assimilation systems from WP2300.

Description of work

The exact configuration of the production system will be decided after completing a programme of experimentation. The available options are being tested against sample data reflecting the observing system at several crucial transitional periods. The External Advisory Group has reviewed the results to date, and advised on the exact components of the production system, which will be checked out and frozen.

One recent year of analysis has been run with and without satellite radiance data using the pre-production system. Besides giving useful information on the impact of these data, this will be part of a set of experiments to provide evidence of the likely accuracy of the re-analysis for periods before 1972. Further observing system experiments are being run to check the use of data from the various components of the observing system employed at some time over the past four decades.

The pre-production system is being modified as necessary and used for the experimentation. The experimentation with the pilot system is being used to check thoroughly the behaviour of the assimilating model and analysis system, in particular newly-developed modifications which are candidates for use in the production system.

Deliverables

D02 (part): Production system - specification of the production system (WP2300 and WP3100).
D05: Report on experimentation, quantifying expected confidence in production quality (month 5).

Milestones and expected results

Specifications to WP2300 to enable the production system to be made ready for WP3100.
Report on the experimentation giving advice to users on expected confidence in production quality.

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Appendix C: List of Acronyms

AEROCHEM	Project to study effect of aircraft emissions on ozone
ALPEX	Alpine Experiment
AMIP	Atmospheric Model Intercomparison Project
AMSU	Advanced Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
BADC	British Atmospheric Data Centre
BAHC	Biospheric Aspects of the Hydrological Cycle
CATCH	An ocean experiment, North Atlantic, 1997
CD-ROM	Compact Digital Read Only Memory
CERES	Clouds and the Earth’s Radiant Energy System
CLIVAR	WCRP Study of Climate Variability and Predictability
COADS	Comprehensive Ocean Atmosphere Data Set
COARE	Coupled Ocean-Atmosphere Response Experiment
CTM	Chemistry-Transport Model
DAO	Data Assimilation Office
DEMETER	Development of a European Multi-model Ensemble System for Seasonal to Interannual Prediction
DKRZ	Deutsches Klimarechenzentrum
DUACS	Developing Use of Altimetry for Climate Studies
DVD	Digital Video Disk or Digital Versatile Disk
EASOE	European Arctic Stratospheric Ozone Experiment
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ENVISAT	Environmental Satellite of ESA
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
ERA-40	A Forty-Year European Re-Analysis
ERBE	Earth Radiation Budget Experiment
ERS	Earth Resource Satellite
ESA	European Space Agency
EU	European Union
EUCREM	European Cloud-Resolving Modelling Programme
EUMETSAT	European organization for the Exploitation of Meteorological Satellites
FETCH	An ocean experiment, Mediterranean Sea, 1998
FGGE	First GARP Global Experiment
GARP	Global Atmosphere Research Programme
GATE	GARP Atlantic Tropical Experiment
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water cycle Experiment
GISST	Global sea-Ice and Sea Surface Temperature data set

GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOOS	Global Ocean Observing System
GWE	Global Weather Experiment
HIPOCAS	Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe
HIRS	High-resolution Infrared Spectrometer
INTAS	International Association for the Promotion of Co-operation with Scientists from the new Independent States of the Former Soviet Union
IORAS	P. P. Shirshov Institute of Oceanology of the Russian Academy of Sciences
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LMD	Laboratoire de Météorologie Dynamique
MAIA	Monitoring Atlantic Inflow to the Arctic
MOZAIC	Measurement of Ozone by Airbus in-Service Aircraft
MPIfM	Max-Planck-Institut für Meteorologie
MSU	Microwave Sounding Unit
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
OSE	Observing System Experiment
PIRATA	Pilot Research Moored Array in the Tropical Atlantic
PROVOST	Prediction Of Climate Variations on Seasonal to Interannual Timsecales
R&D	Research and Development
ScaRaB	Scanner for Radiation Budget
SEMAPHORE	An ocean experiment, Azores, 1993
SESAME	Second European Stratospheric Arctic and Mid-latitude Experiment
SHIVA	Studies of the Hydrology, Influence and Variability of the Asian Summer Monsoon
SMMR	Scanning Multichannel Microwave Radiometer
SOC	Southampton Oceanography Centre
SODA	Studies of Ozone Distributions based on Assimilated Satellite Measurements
SPARC	Stratospheric Processes and their Rôle in Climate
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit
STOEC	Storm-Track Upper Ocean Interactions and the impact on European Climate
TIROS	Television Infra-Red Observation Satellite
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPOZ	Towards the Prediction of Stratospheric Ozone
TRMM	Tropical Rainfall Measuring Mission

TOVS	TIROS operational vertical sounder
UARS	Upper Atmosphere Research Satellite
UKMO	United Kingdom Meteorological Office
UREADMY	Department of Meteorology, University of Reading
USA	United States of America
UV	Ultra-Violet
VTPR	Vertical Temperature Profile Radiometer
WAM	Wave Model
WASA	Waves and Storms in the North Atlantic
WCRP	World Climate Research Programme
WMO	World Meteorological organization
WOCE	World Ocean Climate Experiment
WP	WorkPackage