ECMWF/GEO Workshop on Atmospheric Reanalysis
19 - 22 June 2006

Workshop Report

1. Introduction

A workshop on Atmospheric Reanalysis was held at ECMWF from 19 to 22 June 2006. Funding was provided by ECMWF and GEO, and the programme for the meeting was developed in liaison with the WCRP Observation and Assimilation Panel (WOAP) and the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC). The workshop considered the status of and plans for global reanalysis in Europe, Japan, and North America, and discussed the work needed to prepare for the new generation of multi-decadal global reanalyses to succeed ERA-40, JRA-25 and the NCEP reanalyses. Conclusions of recent workshops were reviewed, including the 2005 NASA/NOAA/NSF Workshop on the Development of Improved Observational Data Sets for Reanalysis[1], the 2005 ECMWF/NWP-SAF Workshop on Bias Estimation and Correction in Data Assimilation[2], the 2005 ECMWF Workshop on a potential European Regional Reanalysis project (EURRA)2 and the 2006 SCAR/CliC/ICPM Workshop on High Latitude Reanalysis[3]. Specific consideration was given to complementary aspects of data-assimilation development and to key user requirements. The scope for coordination of international reanalysis activities was discussed.

Section 2 of this report contains brief summaries of the workshop presentations. All presentations may be viewed in their entirety at http://www.ecmwf.int/newsevents/meetings/workshops/. Section 3 describes the conclusions and recommendations derived from plenary workshop discussions.

2. Workshop presentations

Participants were welcomed by the Head of the Research Department of the ECMWF, Philippe Bougeault, who emphasised the importance of obtaining long-term funding of reanalysis activities at the ECMWF, particularly to ensure the transfer of knowledge acquired during the planning and production of ERA-40.

2.1. Experience and plans of reanalysis centres

Sakari Uppala (ECMWF) presented an overview of progress made from ERA-15 to ERA-40, and described current activities and developments at the ECMWF in preparation of the next global reanalysis. Particular emphasis was placed on the requirements for observation handling and system monitoring, which differ from operational NWP in many respects. ECMWF will soon start production of an Interim Reanalysis to cover the modern satellite era beginning in 1989. The ERA-Interim reanalysis will serve as a bridge to the next major reanalysis, and will provide a test bed for new developments in monitoring and data assimilation. Recovery, organization, and homogenization of observations, and the availability of improved SST and sea-ice datasets will be critical to the success of the next global reanalysis.

Kazutoshi Onogi (JMA) announced the successful completion of JRA-25 in March 2006, which was conducted as a joint research project of JMA and CRIEPI (Central Research Institute of Electric Power Industry) in Japan, and covers the period 1979-2004. From 2005, JRA-25 is transitioned to JMA-CDAS and

[1] http://polar.gsfc.nasa.gov/pubs/conf/index.php

[2] http://www.ecmwf.int/newsevents/meetings/workshops/

[3] http://ipo.npolar.no/reports/archive/reanalWS_apr2006.pdf

is being updated in real-time. Special features of the input data and several aspects of the performance were discussed in detail; an article on JRA-25 has been submitted to the Journal of Meteorological Society of Japan. The workshop audience was encouraged to use the JRA-25 products, which are freely available for research purposes on the internet. Onogi took the opportunity to announce the Third WCRP Reanalysis Conference, which is to take place in Tokyo in January 2008.

Michele Rienecker (GMAO) presented an overview of atmospheric reanalyses previously produced in the United States, and outlined current plans and potential reanalysis activities in the U.S.. Rienecker pointed out that there is currently no national coordination or oversight in this area, nor is there a coherent NOAA program for reanalysis activities. The conclusions of the 2003 Workshop on Ongoing Analysis of the Climate System, held in Boulder, Colorado, were presented, and a CCSP Implementation Plan currently being developed as a CCSP deliverable was briefly described. NASA's Modern Era Reanalysis for Research and Applications (MERRA), production of which is about to begin, was described in some detail.

2.2. Status and needs for reanalysis: user views

Kevin Trenberth (NCAR), who chairs WOAP and is coordinating lead author of the IPCC chapter on observations of the atmosphere and the surface, stressed the need for (and lack of) long-term continuity of the input data for atmospheric reanalyses. Problems have been identified with all components of the existing observing system, including radiosondes, due to changes in the instrumentation and processing methods. Trenberth expressed high expectations for the use of GPS radio-occultation measurements combined with a reference radiosonde network as a baseline set of measurements for future reanalyses. He also stressed the importance of reprocessing past observations, and strongly endorsed the need for repeated comprehensive reanalyses of all observations.

Simon Tett (Met Office) explored various issues related to the validation of climate models, with examples drawn from both global and regional climate modelling. The difficulties in assessing low-frequency variability and climate change were discussed, and it was stressed that the uncertainties involved are complex. There is a need for methods, possibly based on ensemble techniques, which can provide error estimates that are useful for climate analysis.

Brian Hoskins (Reading University) presented a number of impressive examples of dynamical-process studies based on reanalysis data. Reanalyses have become one of the pillars of this type of research, on synoptic as well as planetary scales. Innovative diagnostics related to storm-tracking statistics, cyclone genesis, blocking frequency and synoptic activity, and the hydrological cycle were shown. A few examples from the ERA-40 atlas, now available at http://www.ecmwf.int/research/era/ERA-40_Atlas/docs/index.html, were also included.

Beatriz Monge-Sanz (Leeds University) reviewed past and present experience with reanalysis products, as well as requirements for future reanalyses, from the point of view of chemical transport modelling (CTM) applications. Part of this presentation was based on solicited views from other members of the CTM community. Weaknesses identified in ERA-40 related to stratospheric transport include inaccurate polar temperatures, a too strong Brewer-Dobson circulation, and not enough tropical isolation. It was recommended that the quality of long-term stratospheric transport in the reanalysis (e.g., in terms of age of air) be checked prior to production, and it was pointed that CTMs provide efficient tools for performing the necessary tests. For trend studies it would be desirable if future reanalyses were updated in real-time.

Christoph Schär (ETH) discussed the role of terrestrial water storage in interannual climate variability, and how to exploit reanalysis data such as ERA-40 for surface hydrology studies. Sensitivity studies with global and regional models have shown that soil-moisture temperature feedbacks played a central role in the extreme summer temperatures experienced in Europe in 2003. With regard to ERA-40 quality it was found

that estimates of water-vapour convergence are reasonably reliable, but soil moisture content is not. Since precipitation variability is a prime source of terrestrial water storage, precipitation observations should be included in the reanalysis. Generally, a more realistic representation of the land surface is needed and some form of land-surface data assimilation must be implemented to improve the interannual climate variability in future reanalysis products.

David Bromwich (BPRC) presented a detailed assessment of global reanalyses for Polar regions, reflecting the findings of the Workshop on High Latitude Reanalyses held at Cambridge, 10-12 April 2006. It was found that there is a sharp change in skill in the reanalyses from 1958-1978 to 1979-2001 in the Southern Ocean and Antarctica, particularly in ERA-40. The skill for the Arctic region is much better than that for the Antarctic throughout the whole period. In the Southern Hemisphere prior to the modern satellite era each reanalysis apparently reflects its own model climatology. The use of all available data, including early satellite soundings, is needed to improve this. To make better use of sparse observations requires at least retuning of the existing data assimilation schemes, and possibly the use of an altogether different assimilation method for the early period.

Eric Martin (Météo-France) discussed validation of ERA-40 products in mountainous areas, using synoptic station data complemented by information from a regional analysis system (SAFRAN) and snow model (CROCUS). Given the relatively crude model topography it was found that ERA-40 temperatures were surprisingly accurate. Monthly variability of precipitation was reasonably well captured, but the fine scale patterns in the region were clearly not reproduced and snowfall was underestimated. Snow cover estimates are difficult to validate due to representativity issues. For future reanalyses, a higher spatial resolution may help improve representation of the small scales, but the general increase in orographic height with increasing resolution may make validation against observations made in Alpine valleys more complicated. It was pointed out that the objectives for the treatment of the land-surface in mountain regions will have to be clearly defined.

Michele Rienecker (GMAO) discussed requirements for atmospheric reanalyses from the point of view ocean modelling. Ocean models and assimilation systems are particularly sensitive to prescribed surface forcing fields. Several existing surface flux products were described and compared with ERA-40. Findings of the Surface Flux Panel at the 2003 Boulder Workshop on Ongoing Analysis of the Climate System were reviewed, noting the conclusion that current reanalysis surface flux products are inadequate for climate analyses or for forcing ocean and land surface models. Accurate surface fields, rather than flux estimates, are preferred in order that ocean modellers can calculate their own surface fluxes. A key Panel recommendation was to accelerate the development of coupled atmosphere-ocean assimilation systems.

2.3. Developments in data assimilation for reanalysis

Lennart Bengtsson (ESSC) discussed data assimilation requirements for climate reanalysis and described some of his work on observing system experiments (OSEs). Several key climate analysis questions for which reanalysis data would be most useful were stated, and potential limitations in currently available reanalyses were listed. Many of these stem from changes in the observing system, which have resulted in spurious and/or wrongly estimated trends in global mean parameters such as precipitation, tropospheric temperatures, column water vapour, and total kinetic energy. Necessary improvements in data assimilation systems include the identification of model and observation biases, reduction in systematic model errors to improve the representation of the land-surface and hydrological cycle, increased horizontal and vertical resolution, and the use of a long assimilation window to improve dynamical consistency. More active involvement by the climate community in the development of future reanalyses should be encouraged, for example, by providing access to experimental reanalysis systems for the purpose of performing OSEs and other sensitivity experiments.

Mike Fisher (ECMWF) presented ideas for optimizing data assimilation systems for reanalysis purposes. Unlike analysis systems tailored for weather prediction, a reanalysis (or retrospective analysis) system can be designed to make use of future as well as past observations. Propagation of past information in the data assimilation system can be improved by lengthening the assimilation time window in a weak-constraint 4D-Var system. This would reduce the dependence of the analysis on accurate background error statistics. An indication of the ideal window length can be obtained from OSEs performed with the ECMWF system, complemented by Kalman filter experiments performed with a simplified system. Both types of experiment indicate that the memory of the initial dynamical state in a global atmospheric data assimilation system is in the range 7-10 days.

Yannick Trémolet (ECMWF) described recent progress in the development of a weak-constraint 4D-Var system at the ECMWF. A weak-constraint system allows for additional degrees of freedom to account for model errors. The system can support several different formulations, corresponding to (1) 4D-Var with model forcing terms, (2) 4D-Var with a model bias term, and (3) estimation of a 4D model state. Experimentation is currently being performed with the first and second formulations, and some promising early results were shown. A scheme for cycling a long-window weak-constraint analysis was outlined. Future work will concentrate on designing and implementing appropriate constraints for the model error terms, and studying the interactions between model and observation biases.

Dick Dee (ECMWF) presented an adaptive bias correction scheme for satellite radiances to be used in the ERA-Interim reanalysis. The scheme estimates the bias parameters associated with each radiance channel by adding additional degrees of freedom to the 4D-Var minimisation. The automated system has been shown to perform well in many preliminary experiments. It solves many technical problems associated with manual bias tuning, smoothly corrects bias drifts, handles data gaps, and can quickly develop bias corrections for new instruments. There are strong indications that the variational bias correction of radiance data improves the fit to conventional data as well. However, the scheme can wrongly correct observations where the model is biased and no other unbiased observations exist.

Per Kållberg (ECMWF/SMHI) presented diagnostics of the hydrological cycle obtained from recent experiments for 1989-1990 and 1999-2000, performed in preparation of ERA-Interim. Compared to ERA-40, it was shown that precipitation in the new system is more realistic (relative to GPCP) both in the tropics and at mid-latitudes. There is no longer a temporal shift between the two periods in total column water vapour and precipitation. Precipitation spin-up has been reduced, and global P-E is in good balance. The new system produces less cirrus cloud, especially in the tropics, and more stratus over upwelling regions in the subtropical oceans. Revisions in the humidity analysis formulation and the cloud/radiation parametrizations have lead to substantial changes in the energy balances at the top and bottom of the atmosphere. Top-of-atmosphere energy exchange has improved with respect to ERA-40, but the surface energy exchange has deteriorated somewhat. The Saharan soil is drier and warmer in the recent experiments.

Anton Beljaars (ECMWF) reviewed the developments in model physics at ECMWF since ERA-40, and described some of the highlights in detail. Substantial progress has been made in, for example, the moist boundary-layer scheme, ice microphysics, and convection. Synoptic variability in ERA-40 tends to be very good, but results may not be bias free. Spin-up has been reduced since ERA-40, and while it is difficult to make a precise link between model changes and impact on spin-up, it is clear that this is due to a combination of improvements in model physics and data assimilation. It was pointed out that model development benefits from reanalysis.

Pedro Viterbo (IM Portugal) discussed issues in land-surface data assimilation (LDAS), needed to control drifts in slow components of the land state. Since there are no routine direct observations of primary state variables (root zone moisture, snow mass, and above-ground biomass), data assimilation must rely on

complex observation operators to extract information indirectly from the observables (e.g., screen-level temperature and humidity, precipitation, snow cover, microwave radiance data, and remote sensing products such as leaf-area index (LAI) products derived from Normalized Difference Vegetation Index (NDVI) data). Strengths and weaknesses of the ERA-40 land surface scheme were discussed, and some specific proposals were made for improvements that can be implemented in time for the next global reanalysis. These involve running an off-line LDAS in parallel with the reanalysis, using 2m temperature and humidity observations as well as 24-48h precipitation forecasts to drive the root-zone soil moisture state, and using the resulting soil water estimates as a weak constraint to the soil water analysis component of the reanalysis system.

Jean Bidlot (ECMWF) spoke on ocean wave analysis and the use of surface wind observations over the oceans. The ECMWF system features two-way coupling between the wave model and the atmospheric model, with benefits to both wave model (via high temporal wind-field resolution) and atmospheric model (via wave-dependent surface roughness). Some of the known problems with the ERS-1 and ERS-2 data used in ERA-40 for the wave analysis have been corrected in the reprocessed data obtained from ESA. ENVISAT and Jason data can be used for more recent years. Surface wind data in ERA-40 were not always used with the correct anemometer height, and some valuable data from moored buoys should be recovered for the next reanalysis.

Adrian Simmons (ECMWF) discussed trends and low-frequency variations in reanalyses, which can be affected by biases in models and observations, by changes in observational coverage over time, and by the data assimilation scheme. The recent US CCSP report on temperature trends essentially rejects the use of reanalyses for the purpose of trend assessment. Simmons examined the quality of ERA-40 trends in surface, tropospheric, and stratospheric fields, comparing with other data products used for climate analysis. Despite known problems and limitations, ERA-40 does have a role to play in the study of recent climate trends and represents a clear step forward from earlier reanalyses for the depiction of trends. There is considerable room for improvement still, and a number of specific items were identified that could be addressed in future reanalyses.

Gil Compo (CIRES) presented results of a feasibility study for a 100-year reanalysis project that would use surface pressure observations only. An ensemble Kalman filter was used to assimilate 2001 surface pressure data at densities typical of 1895, 1905, 1915, and 1935. The results suggest that a reanalysis of the lower-tropospheric circulation of the entire 20th century is feasible in the Northern Hemisphere using just the available surface observations. It was shown that the quality of the data assimilation scheme is important for extrapolating surface information to the upper troposphere. Additional marine observations will further increase the fidelity of the reanalysis and give errors comparable to modern 2-3 day forecasts. Preliminary results using actual 1944 and 1947 surface pressure observations suggest that these feasibility conclusions are realistic.

Jean-Noël Thépaut (ECMWF) showed results of 3D-Var and 4D-Var assimilation experiments that used surface pressure observations only. These and other OSEs with the ECMWF assimilation system were performed to investigate the impact of surface pressure observations in a system overwhelmed by satellite data. It was shown that 4D-Var in particular is capable of providing realistic atmospheric analyses based on surface data only, but that the background error statistics used in the analysis are important and should be adapted to the state of the observing system.

2.4. Observations and boundary forcing fields

Sakari Uppala (ECMWF) discussed observational requirements for future reanalyses, and presented conclusions and recommendations from the September 2005 workshop on the development of improved observational data sets for reanalysis, which was sponsored by NASA, NOAA, and NSF, and held in College

Park, Maryland, USA. The key programmatic recommendation of the workshop was directed at WOAP, which was urged to appoint a working group of experts, charged with developing a plan for "The On-going Development of Improved Observational Data Sets for Reanalysis" that describes the necessary resources, infrastructure, institutional commitments, and coordination on technical issues needed in this area.

Leo van de Berg (EUMETSAT) described past, current, and planned reprocessing activities at EUMETSAT. For ERA-40 and JRA-25, Meteosat-2/3 image data were recalibrated, and atmospheric motion vector (AMV) products were produced at improved spatial and temporal resolutions. Current reprocessing activities in support of future reanalysis include the retrieval of clear-sky radiance products and derivation of AMV from high-resolution VIS image data. Lessons learned have led to improvements in systems design and various algorithm upgrades.

Philip Brohan (Met Office) discussed the development of SST and sea-ice datasets at the Hadley Centre. These products incorporate available data from ships, buoys, ATSR, AVHRR, SSMI, and ice charts. Generation of the blended product involves quality control, bias adjustments, and spatial interpolation for areas with no observations. The Hadley Centre provides error estimates along with the product, which attempt to account for station, sampling, coverage, and bias uncertainties. Depending on customer requirements, the product can be provided at different spatial and temporal resolutions.

Leopold Haimberger (University of Vienna) discussed his work on the homogenisation of radiosonde station data based on ERA-40 background departures. An automated system was developed for detecting and correcting breaks in individual station series, based on statistical homogeneity tests. The main assumption in the procedure is that the background temperature information from the reanalysis is independent and sufficiently homogeneous for this purpose. The procedure involves adjustments to the mean background temperatures that account for spurious signals known to be caused by problems in the reanalysis (e.g., erroneous bias corrections of satellite radiances), and this introduces an uncertainty in the trends obtained from the corrected radiosonde data. The homogenised radiosonde data set and extensive documentation is available at http://www.univie.ac.at/theoret-met/research/RAOBCORE/

Mark McCarthy (Met Office) discussed plans for work on the reprocessing and homogenisation of infra-red sounder (HIRS and VTPR) data archives, to be undertaken at the Hadley Centre. Changes in spectral response of individual instruments along with orbit drift and other factors have introduced time-dependent systematic biases into the historical record. Where possible known biases will be determined analytically (e.g. spectral response change and orbit drift) and as a function of the atmospheric state, and viewing geometry. Unknown biases (e.g. poorly defined spectral response functions) will be determined separately through empirically based methods utilizing the periods of satellite overlap.

2.5. Other aspects

Jörg Schulz (DWD) described the achievements and future plans of the Satellite Application Facility on Climate Monitoring (CMSAF), which is a component of the EUMETSAT Distributed Application Ground Segment. A variety of water vapour, cloud, and radiation products are available at different temporal and spatial resolutions that could be used for validating global and regional reanalyses, for improving model cloud parameterization schemes, and for verifying radiation budget components. Plans for reprocessing and generating long homogeneous thematic climate data records, and for the addition of new products to facilitate an improved understanding of the energy and water cycle were discussed.

Adrian Simmons (ECMWF) presented results from the workshop that took place at the ECMWF in November 2005 concerning a potential European Regional Reanalysis project (EURRA) commissioned by the European Environment Agency (EEA). The main interest for the EEA is to obtain high-resolution gridded data over land to support assessment of primary water resources, water composition, status and

potential of ecosystems, air quality and climate-change issues. The regional reanalysis project could involve several production phases using approaches with different levels of complexity, and was likely to be carried out primarily by the European national weather services, with ECMWF serving as liaison to the EEA, at least in the initial developmental phase. A major component of such a project would be the development of a database of observations, with obvious benefits for the next global reanalysis.

3. Conclusions of the plenary discussion

3.1. User aspects

3.1.1. The user base

The number of users of reanalysis products is considerable. Counts of users accessing ECMWF's public data server for ERA-40 products (see Uppala's first presentation at this workshop), or citing Kalnay et al.'s paper on the NCEP/NCAR reanalysis, run into the thousands. Users from ECMWF and its Member States typically retrieve some 3 million fields per week from the Centre's MARS archive of ERA-40 data, and users may also be served the data by national centres. Given the widespread use and potential of reanalysis data, there is concern that their limitations are not always realized, emphasizing the need for good documentation and ongoing user support, and interchange of user experience, as discussed in 3.1.3.

The user base for atmospheric reanalysis is broad, and extends well beyond the scientific research community. There is a need for reanalysis data for use in application models, as demonstrated for example by the many EC-funded projects (such as CANDIDOZ, DEMETER, ENACT, ENSEMBLES and RETRO) that exploited ERA-40 data. Demand was made clear also during the workshop exploring the potential for EURRA (Simmons' second presentation). Education is a further application area, where use is beginning to be made of the web version of the ERA-40 Atlas, for example.

3.1.2. Specific user requirements

The full range of user activities could not be represented at the workshop, but several specific topics were covered in discussions.

Data from reanalyses have become one of the pillars of research into dynamical processes on synoptic to planetary scales (Hoskins' presentation). Here the main requirement is for improvements in the handling of lower frequencies and the representation of moist processes and surface fluxes, to enable more trust to be placed in heating fields and studies of the linkages between tropics and extratropics to be placed on a firmer footing.

Reanalyses have become the major source of information for understanding physical processes and their change in the data-sparse Polar regions, as discussed at the recent Workshop on High Latitude Reanalysis. Nevertheless, the differences in some aspects of the quality of reanalyses for the southern hemisphere between the satellite era and the pre-satellite era are larger for ERA-40 than for the earlier NCEP/NCAR reanalysis (Bromwich's presentation). Assimilations using only surface-pressure data suggest that better performance in the pre-satellite era can be obtained by use of 4D- rather than 3D-Var and by use of revised background-error covariances (Thépaut's presentation; see also section 3.3.1). The Ensemble Kalman Filter offers a viable alternative approach for analysing periods with sparse data coverage (Compo's presentation).

User requirements were clearly expressed by the CTM community prior to ERA-40, and have been updated by Monge-Sanz' presentation. CTM users require a good representation of the Brewer-Dobson circulation and polar stratospheric temperatures in winter and springtime. These are areas where ERA-40 was deficient, and for which improvement is expected from ERA-Interim.

The issue of long-term continuity and how to determine and convey to users information on uncertainty and problems is paramount for the climate-change community (Trenberth's presentation). A further requirement is for well-balanced budgets, although whether these should be imposed as a constraint on reanalyses or be used as a measure of reanalysis quality is an open question.

Requirements for increased horizontal resolution were expressed for ocean waves, air-sea fluxes and Antarctic sea-ice modelling. Specific additional post-processed products identified were time-averaged vertical velocity, and 50hPa resolution for pressure-level fields.

Precipitation is a key product of interest to users. It is, for example, the product for which most queries have been received by the ERA-40 project team, related both to the accuracy of products and the most appropriate forecast range to use. For this product, the improvements in tropical precipitation realised in JRA-25 (Onogi's presentation) and expected from ERA-Interim (Kållberg's presentation) should be noted, as should the use of high-latitude ERA-40 data in the construction of a new global precipitation climatology proposed by Arkin at the Workshop on High Latitude Reanalysis.

Many of the other queries received by the ERA-40 project team have related to surface fields.

3.1.3. General user requirements

Good communication of information on the strengths and weaknesses of reanalyses is a general user requirement. Documentation of results by the producers of reanalyses in web pages, project reports and journal articles is clearly of key importance. This does not obviate the need for reanalysis teams to respond to individual user enquiries or studies, but in such circumstances the existence of good documentation makes responding a much easier and more satisfactory process. Documentation should cover important experimentation carried out in preparation for the reanalysis, any supporting observing system experiments (OSEs) carried out to assess the impact of substantial changes to the observing system, and any other relevant experimentation, such as AMIP-style simulations (model runs for the reanalysis period forced by the boundary and composition values prescribed in the reanalysis).

Notwithstanding the above, it has to be recognised that reanalysis teams are small, and cannot mirror the full range of expertise within the user community. Much of the appreciation of the strengths and weaknesses of the reanalyses thus has to come from the users themselves. Some of this can occur during production if selected user groups in major application areas provide monitoring and early validation, as happened in ERA-40, but more will come through assessment of products by the user community at large. Feedback of information to reanalysis producers and exchange of information among users are needed. An internet-based mechanism such as offered by Google Groups could help achieve this.

Many users want measures of expected accuracy or uncertainty (as expressed, for example in Tett's presentation). For primary analysed variables this can be provided in part by the departure statistics from the data assimilation. Here there is a need for such analysis feedback information to be made readily available in user-friendly form, such as developed by NCAR as part of the ERA-40 data services it provides for North American users. Ensembles of data assimilations using perturbations to observations, model and boundary values can in principle provide further measures of uncertainty, not only of the primary analysed variables but also of important derived variables such as precipitation and surface fluxes. Although ensemble techniques may not be sufficiently mature or affordable for extensive use in the next generation of comprehensive reanalyses, they may nevertheless be run for subsets of the reanalysis periods to provide some estimates of uncertainty.

Statistical correction of ERA-40 products was developed by for KNMI for significant wave height (Bidlot's presentation) and by ECMWF for the precipitation fields to be used for ocean-model forcing. Development

and supply of further such products from either existing or future reanalyses is considered to be worthwhile pursuing.

The NCAR and JRA reanalyses, but not ERA-40, are being continued in CDAS (close to real-time) mode. A clear user requirement exists for this, although the approach is not without its difficulties. Changes made in operational NWP systems to adjust to changes in the observing system may not be as directly applicable or as optimal in performance in the older versions of the data assimilation systems used for the CDAS. Moreover, additional technical effort may be needed to migrate the CDAS system as well as the newer operational system to new computer hardware. As an alternative, the requirements of some users may be met by using recent operational products to extend the reanalysis time series, using adjustments based on results from parallel runs to ensure a degree of homogeneity of products across changes in model resolution and parametrizations.

Understanding of some aspects of ERA-40 was enhanced by remote access to the data assimilation system to perform OSEs and other sensitivity experiments (Bengtsson's presentation). It is likely to be practical to provide such facilities only to a limited number of collaborating groups for future reanalyses, but this is considered highly desirable.

Involvement of User Advisory Groups in future reanalyses is particularly important. Views of the panels and working groups of WCRP and GCOS also help set the requirements for future activities (Trenberth's presentation). ECMWF also receives comments on its plans for reanalysis from its Advisory Committees, and has received feedback from a survey of users who have downloaded ERA-40 data from its public data server. A more systematic survey of the requirements for reanalysis among its Member-State users might also be undertaken.

3.1.4. Period for future reanalysis

Various options exist for the period of future reanalyses. For many users, sufficient data will be provided by new reanalyses of the satellite era for which products will generally be most reliable. It is important that there be ongoing effort to improve reanalyses for this era, in particular as regards the use of satellite data from the beginning of the TOVS period, which proved to be problematic in ERA-40 (Simmons' first presentation), and as regards the analysis of the upper stratosphere, which suffered from discontinuities throughout (presentations by Onogi and Simmons). For this, the results from various homogenization projects for the relevant satellite and radiosonde data should be utilized as fully as possible.

There is, nevertheless, a requirement from users for analyses further back in time, if they can be provided of sufficient quality. The EEA, for example, expressed an interest in regional data as far back as 1947 at the EURRA workshop, and there is climatological interest in earlier events such as the El Niño of 1940/41 and the warmth of Greenland in the preceding decade. Data from 1948 onwards (following establishment of the network of Atlantic and Pacific Ocean weather ships) have already been assimilated in the NCEP/NCAR reanalysis, and 4D-Var offers capability for improved assimilation of the data from radiosondes that were launched at times away from the main synoptic hours in the early years. There is potential also for assimilation for a decade or so earlier for which upper air data are available from a smaller number of radiosonde ascents and more numerous pilot balloons. A preliminary analysis would be beneficial for radiosonde homogenization for the pre-1957 period (Haimberger's presentation). Study of this period could be a project in its own right involving data recovery and exploratory reanalysis, and the project could serve as preparation for a subsequent complete reanalysis up to the present day.

Reanalysis further back in time based on analysis of surface-pressure data is feasible (Compo's presentation; see also that of Thépaut), and extension to include marine wind data and other types of synoptic data over land is possible. Such reanalysis would complement alternative approaches to the analysis of historic daily

weather records such as undertaken for the North Atlantic and Europe from 1850 onwards within the EC-funded EMULATE project. The proposal of Compo and collaborators to carry out a 20th Century Reanalysis Project using the available surface-pressure observations was endorsed by the workshop. If the proposal is funded, the case for one or more other groups becoming involved in reanalysis spanning this time range should be reassessed in the light of the results obtained.

3.2. Observations and boundary and forcing fields

3.2.1. Observations for assimilation in reanalyses

The key programmatic recommendation of the 2005 Workshop on the Development of Improved Observational Data Sets for Reanalysis was "for the WCRP Observations and Assimilation Panel (WOAP) to appoint a working group of experts charged with developing a plan for 'The On-going Development of Improved Observational Data Sets for Reanalysis', that describes the necessary resources, infrastructure, institutional commitments, and coordination on technical issues outlined in this report" (Uppala's second presentation). This recommendation is endorsed by the present workshop, with the proviso that there be liaison between WCRP and GCOS to ascertain whether the working group would more appropriately be set up with the involvement of the GCOS AOPC (in liaison with the oceanic and terrestrial panels as needed) as well as (or instead of) WOAP. This work should have high priority not only because all reanalysis projects need improved input data but also because each day brings new data and the task of setting up the databases becomes ever larger and more complex.

It is envisaged that different centres or agencies would take responsibility for particular types of conventional data or the datasets from particular series of satellite instruments, but that a central catalogue would be maintained showing what data are available. Reanalysis centres themselves need to be involved in the process to ensure that all types of data they need are covered and that their other requirements are met as fully as possible.

Archiving of observational data should have the purpose of re-processing/reanalysis in mind. An important requirement is for application of common standards in areas such as

- version control, with older versions used in previous reanalyses supported for user access;
- metadata, which should include feedback data from previous reanalyses;
- data formats.

Reanalysis centres can cope with a few self-descriptive, well-designed and documented data formats such as structured ASCII, netCDF and BUFR, so the specification of data formats need not be too restrictive

A merged dataset is required for each type of conventional observation, including flagging of suspected duplicates and retention of information on the archival source of each observation. This is particularly important for radiosonde data where many different input datasets are available and data need different types of conversion to bring them to a common format, a process that proved problematic in ERA-40.

Responsibilities for satellite datasets for use in reanalysis are generally viewed as remaining with the satellite agencies' responsible for the original measurements. A particular reanalysis system will typically assimilate a mix of Level-1b (or higher) radiances or level-2 products, and higher-level products, such as derived by the EUMETSAT SAFs (Schulz' presentation), may be used for validation. Reprocessing of radiance data and new derivations of products is an important requirement for improved reanalysis, and has been responded to by the reprocessing of Meteosat/ADC data by EUMETSAT (van de Berg's presentation) and GMS data by JMA (Onogi's presentation), and other activities such as those for VTPR and HIRS data (McCarthy's presentation). There is much more that could and should be done, however (Trenberth's presentation).

Comprehensive requirements for both reprocessed and new satellite-based products for climate, including reanalysis, have recently been set out in a supplement to the GCOS Implementation Plan.

The recovery of older routine observations and their supply to international data centres or reanalysis centres is a need that is being met to only a limited extent. For example, ERA-40 suffered from absence or very small numbers of SYNOP data from many countries (including several ECMWF Member States) prior to 1967 (Simmons' first presentation). It is likely that most of the missing data exist in at least the archives of the national weather services, although digitisation may be required.

Data from field experiments or reference observation sites may be used in reanalysis either as additional data for assimilation or as independent data for validation (which may entail passing the data passively through the assimilation system to generate feedback statistics). Reanalysis centres need to accumulate holdings of such data, ideally in near-real-time (especially for use in CDAS) if data can be supplied in this way.

3.2.2. Homogenisation of radiosonde data

Adaptive methods built into the data assimilation system provide an effective way of correcting the biases in several of the types of observation used in reanalysis, especially radiances (Dee's presentation). However, at least one major observation type should remain out of such an adaptive approach to prevent the analysis system from producing long-term trends that simply mirror imperfect trends inherent in the assimilating model. The approach currently used at ECMWF is to use a separate scheme for homogenisation of the times series of radiosonde temperature data with a supplemental correction for seasonal variation of the radiation error (Haimberger's presentation). The homogenisation utilizes time series of differences between radiosonde and background (currently ERA-40) data, and there remains an open question as to the extent to which the homogenisation should entail adjustment due to differences between overall background and radiosonde trends. Treatments of the humidity and wind biases in radiosonde data need to be developed.

3.2.3. Sea-surface temperature and sea-ice distributions

The distributions of sea-surface temperature (SST) and sea ice specified in atmospheric reanalyses force trends and low-frequency variability in the assimilating atmospheric model, and may be especially influential on reanalysis products in earlier periods when there is limited coverage of observations with which to constrain the analysis. Improvements in the analysis of SST and sea-ice will come from better databases of historic observations, better satellite data for recent years and from better bias adjustments and interpolation methods (Brohan's presentation). There is evidence of the importance of fine spatial resolution of SST and ice margins for accurate representation of surface fluxes, and at least weekly temporal resolution is desirable to capture key transitions. There is also, however, a trade-off between the spatial and temporal resolution of the analyses and their reliability, and quite what is the best compromise for reanalysis for any particular epoch is not clear.

One question that arises is how much should be done by reanalysis centres themselves rather than those centres that produce the SST and sea-ice analyses (if different, as is the case for current European effort). Provision of the analyses at relatively high resolution but with information on observation density and other quality indicators would give reanalysis centres the option of making informed decisions on how to use the data in aggregation and redistribution onto the model grid, typically with daily resolution, and uncertainty information could be exploited in ensemble approaches to data assimilation. AMIP-style runs could be used by either producers of the analyses or the reanalysis centres to assess candidate resolutions and quantify impacts of uncertainties.

3.2.4. Vegetation

Soil moisture is a key parameter for summer climate, and one which is not in general handled reliably by current data assimilation systems (presentations by Schär and Viterbo). A better treatment of vegetation is an important requirement for progress, and future systems are expected to include analysis of biomass, using input data from remote sensing such as retrievals of Leaf Area Index, for which the observational record extends back to 1982.

This is a fast-moving field and several choices will have to be made for future data assimilation systems. The situation should be assessed later as part of detailed preparations for the next series of major reanalyses.

3.2.5. Snow cover

Snow-depth observations analysed in ERA-40 were limited to Canada for the early years the reanalysis period. Data covering the former Soviet Union were used from 1966 onwards, but data from other countries could be used only from 1976 onwards. JRA-25 benefited from digitized Chinese snow-depth data and snow cover from SSMI (Onogi's presentation). Since ERA-40 was completed, the ECMWF snow analysis has been extended to include assimilation of the daily snow-cover product of NOAA/NESDIS.

Monthly snow-cover data are available back to 1966, and the daily snow-analysis systems used for reanalysis should be adapted to use them. Hand-analysed maps provide potentially useful information for earlier periods.

Snow analysis is particularly challenging in mountainous regions, but here there is much that can be learnt from validation of reanalysis products in well-observed regions such as the Alps (Martin's presentation). Global reanalyses may also be used to drive regional or local models to produce improved analyses or climatologies, as discussed in the context of the potential for EURRA.

3.2.6. Precipitation

Assimilating information on precipitation over land is of significant potential impact to reanalysis itself (especially through its effect on soil moisture and latent hear fluxes) and to end users, for whom it is a key parameter (section 3.1.2). A feature of the North American Regional Reanalysis reported by Mesinger at the EURRA workshop (Simmons' second presentation) was its successful assimilation of information provided in the form of gridded precipitation analyses. Promising results have also been obtained from a first attempt at such assimilation in the framework developed for the assimilation of rain-affected microwave radiances over sea that is now used in ECMWF operations and ERA-Interim.

Analysis of gauge, and for recent years radar, data over land is an active and challenging area of research, whether it be done stand-alone for general use (including as an input data source for reanalysis) or directly within a comprehensive data assimilation system. Problems of scale and representativity, and data availability, have to be addressed.

3.2.7. Composition

Atmospheric models used in reanalysis systems need to allow for long-term temporal variations in the main radiatively active constituents of the atmosphere if assimilation of temperature and other data that exhibit consequent trends and low-frequency variability is to be optimal. Trends of greenhouse gases were specified in ERA-40, but the distribution of aerosols was fixed.

Specification of aerosols using distributions as adopted by climate models in their simulations of 20th century climate (as illustrated in Tett's presentation) could be used in future reanalyses. Capability for direct analysis of aerosols (and greenhouse and chemically reactive gases) through assimilation of satellite data is being developed for the ECMWF system within the EC-funded GEMS project. This will enable more

comprehensive treatment of atmospheric composition in reanalyses for the current decade, with some possibilities to go a decade or two further back in time, for example assimilating data on aerosol over the ocean from AVHRR.

Ozone was an analysed and prognostic model variable in ERA-40, but a climatological distribution was specified for the calculation of radiative tendencies. This followed the practice adopted for the operational ECMWF forecasting system. Use of the analysed and modelled ozone distribution in the calculation of radiative tendencies will soon be reassessed for operational use, and should be well established before next major ECMWF reanalysis. A trend in chlorine loading was used in the parametrization of ozone loss due to heterogeneous chemistry, but the upper-stratospheric source of water vapour was not changed over time due to a trend in methane. These areas also require some attention prior to the next reanalysis.

3.3. Data assimilation

3.3.1. Assimilation window and error estimation

Reanalysis has typically used data assimilation systems developed primarily for operational weather prediction. The level of investment that is made in the improvement of such systems (including the assimilating models, as illustrated in Beljaars' presentation) means that it is likely that future reanalysis systems will continue in most cases to be based on such operational analysis systems. However, there is potential for these reanalysis systems to benefit from using configurations that differ from their operational counterparts by more than at present. Exploiting this will require effort to be devoted to reanalysis-specific experimentation and system development beyond that needed for NWP application.

In particular, success in the development of longer-window weak-constraint 4D-Var could enable effective use to be made of observations made several days later than the analysis time to reduce analysis error below what is achievable in NWP, improve balance, and reduce the dependence of the analysis on the specification of background error covariances (presentations by Fisher and Trémolet). Meanwhile, as long as the background error specification continues to exert a strong influence on the analysis in data sparse regions (notably the southern hemisphere in the pre-satellite era, section 3.1.2), there is a need to utilize adaptive estimation of the change in error statistics over time. This is already the case for the Ensemble Kalman Filter as used to investigate extended reanalysis using only surface-pressure observations (Compo's presentation). Within the 3D- and 4D-Var approaches otherwise used for reanalysis, an adaptive approach based on accumulated statistics of observation-background differences should be investigated. An alternative, more expensive approach, using the spread of a small ensemble to estimate variances, is already under development because of its promise for flow-dependent error estimation in NWP application. This approach would also provide estimates of uncertainty required by users (see 3.1.3).

3.3.2. Handling of biases

Handling of biases in both observations and model within the data assimilation system has been a focus of recent research, and such research should continue. Variational bias correction of radiance data (Dee's presentation) will be assessed through its performance in ERA-Interim, although its benefit for future longer reanalyses may come especially from better treatment of the biases in earlier satellite data, which proved problematic for some evaluations of trends for the satellite era from ERA-40 (Simmons' first presentation). Trends computed for longer periods are prone to suffer from the effects of model biases that are less well constrained by observations earlier than later in the period. Ongoing improvement of the models themselves is a basic requirement, but approaches to estimation and correction for model bias in weak-constraint 4D-Var are showing promising results (Trémolet's presentation). There remains, nevertheless, a question over the interpretation of the model bias terms derived from weak constraint 4D-Var, as Trémolet showed that observation rather than model bias may be picked up by his approach. Addressing this is important if model-

bias terms derived from recent well-observed periods are to be applied in reanalysis for earlier data-sparse periods.

3.3.3. Monitoring

Techniques and tools for monitoring long-running data assimilations have improved since ERA-40 was carried out, but more needs to be done. An expert system that would detect apparent problems and ring alarm bells would be particularly beneficial, and in this regard reanalysis may benefit from developments carried out for NWP, where such a system is needed to cope with the increasing types and volumes of satellite data being processed with little or no routine manual intervention. Information on data usage and quality from reanalysis monitoring and other sources should be exchanged among reanalysis centres, as has occurred, for example between ECMWF and JMA, with information flowing from ERA-40 to JRA-25 and back to ERA-Interim. Elements of operational data monitoring are being developed within the NWP SAF in Europe, and tools developed as part of this common effort should be readily applicable by other centres.

3.3.4. Coupled assimilation

The assimilating atmospheric model for ERA-40 was coupled to an ocean-wave model that had its own analysis system. Improved ocean-wave (and marine surface wind) analyses are expected from ERA-Interim, which is using the higher quality reprocessed ESA/ OPR (Ocean Product) altimeter data, from the beginning August 1991 until present day, instead of the ESA/ NRT (Near Real Time Product) used in ERA-40. Also ERA-Interim ocean-wave analyses benefit from the higher horizontal resolution of the assimilating model. There is scope for further improvement from improvement in the database of surface wind observations (Bidlot's presentation).

Improved treatment of land-surface conditions is an important requirement for future reanalyses. Here the possibility of a coupling between the atmospheric data assimilation and a separate Land Surface Data Assimilation System is outlined in Viterbo's presentation. Related discussion is also given in sections 3.2.4, 3.2.5 and 3.2.6.

Coupling of atmosphere/ocean-wave assimilation systems with ocean-circulation assimilation systems (touched on in Rienecker's second presentation) offers the prospect of improved estimates of surface fluxes, and better balanced initial conditions for seasonal-to-interannual prediction. The latter requires reanalyses to enable retrospective forecasts to be carried out for calibration and validation of prediction systems. Development of effective capability for fully coupled atmosphere/ocean reanalysis poses substantial challenges in addition to those faced in improving atmospheric reanalysis, but an incremental approach is possible, beginning with a loosely coupled system analysing flux corrections, for example.

Coupling of ECMWF's atmospheric model with CTMs is being developed as part of the GEMS project, and will be used in short-term reanalyses for recent years which will extend the product set to include distributions of chemically reactive gases.

3.4. International coordination

Under the WCRP and GCOS, the international monitoring, promotion and coordination of work related to atmospheric reanalysis is a joint responsibility of WOAP and AOPC. The activities of these panels are needed to ensure that the particular requirements of climate monitoring and research are taken as fully as possible into account by the reanalysis centres, and to help these centres carry out their activities in a way that maximizes benefit to the community of users of reanalysis products. As noted in a paper developed by WOAP at its first session[4], international coordination of the work of reanalysis centres desirably includes

[4] http://copes.ipsl.jussieu.fr/Organization/COPESStructure/Reports/Reanalysis1.html

staggering the production of reanalyses and exchange of observational databases and of information on observation and product quality, so that each new reanalysis can build optimally on those that precede it. Coordination and collaboration also needs to be developed further between those centres carrying out reanalysis and other centres and researchers undertaking recovery, reprocessing and general stewardship of observational data, as discussed in section 3.2.1 of this report. The WOAP paper also calls for the establishment of national or regional focal points as a minimum first step to ensure that that coordination of their reanalysis efforts can proceed satisfactorily.

Such formal coordination is, however, difficult in current circumstances. The absence of U.S. national coordination and oversight and of a coherent NOAA programme, notwithstanding the continuing NCEP CDASs and new activities such as NASA's MERRA, (Rienecker's first presentation) makes wider coordination and even the identification of a U.S. focal point difficult. The present limited level of long-term funding (discussed further in section 3.5) means that the timing of Europe's next comprehensive reanalysis, to succeed ERA-40, may be determined primarily by the time at which short-term funding becomes available rather than by considerations of coordination with North America and Asia.

There is, nevertheless, already a healthy level of collaboration between reanalysis teams at the working level. ERA-40 benefited from NCEP's pre-processing of observational datasets supplied by NCAR, as well as NCEP's supply of its own holdings of observational data. In turn, observational datasets used in ERA-40 were made available to JMA for use in JRA-25, and some of the additional observations used in JRA-25 are now available to ECMWF. Information on data monitoring and data usage has also been exchanged, and a tradition of mutually beneficial secondment of staff from the USA, Japan and elsewhere to ECMWF that started in 1979 for the original reanalysis of the FGGE year continues to this day.

At the regional level, collaborative and coordinated involvement of the European national meteorological services will be essential if the EURRA project is to proceed. There would be an evident synergy between EURRA and the global ECMWF reanalysis activity that would most likely provide EURRA with its required boundary values, and global reanalysis in general should benefit from observational data recovery instigated by EURRA. EURRA must not, however, drain the limited resources that are currently devoted to global reanalysis in Europe.

Data policy issues were not discussed widely at the workshop, but it is evident that the execution and exploitation of reanalysis will be enhanced by widespread adoption of the data-sharing principles outlined in the ten-year implementation plan for GEOSS, namely:

- There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation.
- All shared data, metadata, and products will be made available with minimum time delay and at minimum cost.
- All shared data, metadata, and products free of charge or no more than cost of reproduction will be encouraged for research and education.

Whilst most observational datasets used by reanalysis are provided without restriction, some datasets that are vitally important to the quality of products have been provided without authority for the data to be made available to third parties. Analysis-feedback metadata for these datasets cannot be supplied to the users of reanalysis products, inhibiting fully-informed exploitation of the products. Relaxing the additional restrictions on international supply placed on national data centres would enable users worldwide to benefit from particular services (such as NCAR's provision of feedback metadata) that are currently offered nationally by these centres.

3.5. Need for continuity of funding for producers of reanalyses

A specific and substantial concern is the absence of sufficient long-term institutional funding for carrying out reanalysis. The timescale of preparation, production and post-production tasks related to a major reanalysis is close to a decade, and although specific external short-term research funding can be sought to cover periods of peak activity or well-contained sub-projects, long-term funding of a core reanalysis team is needed to ensure effective and efficient progress. Formal collaboration among reanalysis producers or with observational data providers, for example to stagger production or link it in with the availability of new observational databases, is made difficult if the timing of a new reanalysis is determined by when short-term funding becomes available rather than by scientific or technical considerations. Lack of long-term funding commitment also inhibits the build-up and transfer of expertise within institutions, the continuation of reanalyses in CDAS mode, and ongoing product development, data services and user support following completion of a major reanalysis. It may also inhibit the data recovery and reanalysis-specific developments in data assimilation needed to improve future reanalyses.

Ongoing advocacy for reanalysis from the committees, panels and working groups of GEO, GCOS and WCRP is needed to support efforts to secure the necessary funding.

Annex 1: List of participants

Lecturers

Name	Affiliation
Anton Beljaars	ECMWF Shinfield Park Reading Berks RG2 9AX anton.beljaars@ecmwf.int
Lennart Bengtsson	Environmental Systems Science Centre (ESSC) Harry Pitt Building 3 Earley Gate, Whiteknights, Reading RG6 6AL olb@mail.nerc-essc.ac.uk
Leo van de Berg	EUMETSAT Am Kavalleriesand 31 D-64205 Darmstadt, Germany berg@eumetsat.de
Jean Bidlot	ECMWF Shinfield Park Reading Berks RG2 9AX jean.bidlot@ecmwf.int
Philip Brohan	Met Office FitzRoy Road Exeter EX1 3PB philip.brohan@metoffice.gov.uk
David Bromwich	Byrd Polar Research Center Scott Hall Room 108, 1090 Carmack Road The Ohio State University, Columbus, Ohio 43210-1002, USA bromwich.1@osu.edu
Gil Compo	NOAA/CIRES/Climate Diagnostics Center University of Colorado, 216 UCB Boulder, CO 80309-0216 USA gilbert.p.compo@noaa.gov
Dick Dee	ECMWF Shinfield Park Reading Berks RG2 9AX dick.dee@ecmwf.int
Mike Fisher	ECMWF Shinfield Park Reading Berks RG2 9AX mike.fisher@ecmwf.int
Leopold Haimberger	Institut für Meteorologie und Geophysik, Universität Wien Althanstraße 14 A - 1090 Wien Austria leopold.haimberger@univie.ac.at

Annex 1: List of participants

Name	Affiliation
Brian Hoskins	Department of Meteorology, University of Reading, PO Box 243, Reading RG6 6BB b.j.hoskins@reading.ac.uk
Per Kållberg	ECMWF Shinfield Park Reading Berks RG2 9AX per.kallberg@ecmwf.int
Eric Martin	Météo-France, CNRM/GMME 42 avenue Coriolis 31057 Toulouse, France eric.martin@meteo.fr
Mark McCarthy	Climate Variability Met Office Hadley Centre Fitzroy road Exeter Devon EX1 3PB UK mark.mccarthy@metoffice.gov.uk
Beatriz Monge-Sanz	University of Leeds, Institute for Atmospheric Science (IAS) School of Earth and Environment Leeds LS2 9JT beatriz@env.leeds.ac.uk
Kazutoshi Onogi	Japan Meteorological Agency, Climate Prediction Division 1-3-4 Ote-machi Chiyoda-ku, 100-8122 Tokyo, Japan konogi@naps.kishou.go.jp
Michele Rienecker	Global Modeling and Assimilation Office Code 610.1, Goddard Space Flight Center Greenbelt, MD 20771, USA michele.m.rienecker@nasa.gov
Christoph Schär	Institut f. Atmosphäre und Klima Universitätstrasse 16, ETH-Zentrum, CHN L 12.1 CH-8092 Zürich, Switzerland christoph.schaer@env.ethz.ch
Jörg Schulz	Deutscher Wetterdienst (DWD) Postfach 10 04 65 D-63004 Offenbach, Germany joerg.schulz@dwd.de
Adrian Simmons	ECMWF Shinfield Park Reading Berks RG2 9AX adrian.simmons@ecmwf.int
Simon Tett	Hadley Centre for Climate Prediction and Research Met Office FitzRoy Road, Exeter EX1 3PB simon.tett@metoffice.gov.uk

Annex 1: List of participants

Name	Affiliation
Jean-Noël Thépaut	ECMWF Shinfield Park Reading Berks RG2 9AX jean-noel.thepaut@ecmwf.int
Yannick Trémolet	ECMWF Shinfield Park Reading Berks RG2 9AX yannick.tremolet@ecmwf.int
Kevin Trenberth	NCAR / Climate and Global Dynamics Division P.O. Box 3000 Boulder, CO 80307 USA trenbert@ucar.edu
Sakari Uppala	ECMWF Shinfield Park Reading Berks RG2 9AX sakari.uppala@ecmwf.int
Pedro Viterbo	Instituto de Meteorologia Rua C ao Aeroporto 1700-077 Lisboa, Portugal pedro.viterbo@meteo.pt

Observers

Randy Dole	NOAA/CIRES/Climate Diagnostics Center University of Colorado, 216 UCB Boulder, CO 80309-0216, USA randall.m.dole@noaa.gov
Elizabeth Kent	James Rennell Division (254/26) National Oceanography Centre, Southampton European Way, Southampton, SO14 3ZH, UK eck@noc.soton.ac.uk
Andrew Lorenc	Met Office FitzRoy Road Exeter EX1 3PB andrew.lorenc@metoffice.gov.uk
Bruce Macpherson	Met Office FitzRoy Road Exeter EX1 3PB bruce.macpherson@metoffice.gov.uk

Annex II: Programme
ECMWF/GEO Workshop on Atmospheric Reanalysis, 19-22 June 2006

Monday 19 June 2006

11.00-11.10 Philippe Bougeault .....Welcome

Experience and plans of reanalysis centres

11.10-11.50 Sakari Uppala (ECMWF).....From ERA-15 to ERA-40 and ERA-Interim

11.50-12.30 Kazutoshi Onogi (JMA).....JRA-25 and plans

12.30-13.45 *Lunch*

13.45-14.25 Michele Rienecker (GMAO).....MERRA and activities for atmospheric reanalyses in the US

Status and needs for reanalysis: user views

14.25-15.00 Kevin Trenberth (NCAR).....Observations and their analysis for WCRP/COPES

15.00-15.35 Simon Tett (Met Office).....Validation of climate models

15.35-16.00 *Coffee*

16.00-16.35 Brian Hoskins (Univ Reading).....Dynamical-process studies

16.35-17.10 Beatriz Monge-Sanz (Univ Leeds).Chemical transport modelling

17.10-17.45 Christoph Schär (ETH).....Land surface processes

17.45 *Cocktail Party*

Tuesday 20 June 2006

09.00-09.35 David Bromwich (BPRC).....An assessment of comtemporary global reanalyses in the polar regions

09.35-10.10 Eric Martin (Météo-France) .....Applications in mountain areas

10.10-10.45 Michele Rienecker (GMAO).....Ocean-model needs from re-analyses

10.45-11.10 *Coffee*

Developments in data assimilation for reanalysis

11.10-11.45 Lennart Bengtsson (ESSC).....Data assimilation requirements for climate reanalysis

11.45-12.20 Mike Fisher (ECMWF) .....Optimizing data assimilation for reanalysis

12.20-12.55 Yannick Trémolet (ECMWF).....Accounting for model biases in data assimilation

12.55-14.05 *Lunch*

14.05-14.40 Dick Dee (ECMWF) .....Adaptive bias correction of radiances

14.40-15.15 Per Kållberg (ECMWF/SMHI) .....The hydrological cycle

15.15-15.50 Anton Beljaars (ECMWF).....Surface and boundary layer schemes

15.50-16.15 *Coffee*

16.15-16.50 Pedro Viterbo (IM, Portugal).....Land-surface data assimilation systems

16.50-17.25 Jean Bidlot (ECMWF).....Ocean wave analysis

17.25-18.00 Adrian Simmons (ECMWF).....Capturing trends and low-frequency variations

Annex II: Programme
ECMWF/GEO Workshop on Atmospheric Reanalysis, 19-22 June 2006

Wednesday 21 June 2006

09.00-09.35 Gil Compo (CDC).....Ensemble Kalman Filter analysis, and its application to reanalysis using only surface-pressure observations

09.35-10.10 Jean-Noël Thépaut (ECMWF).....Assimilating only surface-pressure observations in 3- and 4D-Var, and other observing-system impact studies

Observations and boundary forcing fields

10.10-10.45 Sakari Uppala (ECMWF).....Observational requirements for future reanalyses

10.45-11.10 *Coffee*

11.10-11.45 Leo van de Berg (EUMETSAT)....Reprocessed satellite data products for assimilation and validation

11.45-12.20 Philip Brohan (Met Office).....Development of SST and sea-ice datasets

12.20-12.55 Leopold Haimberger (U Vienna)...Homogenization of radiosonde data

12.55-14.05 *Lunch*

14.05-14.40 Mark McCarthy (Met Office) .....Homogenization of HIRS/SSU/VTPR radiances

Other aspects

14.40-15.15 Jörg Schulz (DWD).....The Climate Monitoring SAF

15.15-15.50 Adrian Simmons (ECMWF).....The potential for EURRA, a European Regional Reanalysis

15.50-16.15 *Coffee*

16.15-18.00 **Discussion session:**

- User needs for reanalysis
- Observation datasets and boundary forcing fields
- Homogenization of data
- Requirements for the data assimilation system

18.00 *Informal buffet in the ECMWF Restaurant*

Thursday 22 June 2006

09.15-10.30 **Discussion session** (continued)

10.30-10.55 *Coffee*

10:55-12.15 **Discussion session** (continued)

12.15-13.45 *Lunch*

13:45-15:30 **Concluding discussion: Summary of user needs and recommendations for future reanalysis activities**