Meeting Report

Workshop to discuss a potential European Regional Reanalysis project (EURRA)

ECMWF, 21-22 November 2005

1. Introduction

Following initial contacts between ECMWF and the European Environment Agency (EEA), the latter expressed a strong interest in commissioning, through Member-State interests and the needs of the European Commission to support the 6th Environment Action Plan, a high-resolution Europe-wide reanalysis describing the state of the atmosphere, coastal ocean, snow cover and land surfaces (including vegetation and soil moisture) over the last thirty years or more. Products would be widely distributed as part and following the data policy of the INSPIRE directive on spatial data information.

Such an ambitious project could be developed only over a multi-year time frame and would require the active involvement of the European Meteorological Infrastructure (EMI). Accordingly, the Director of ECMWF presented this opportunity to the EUMETNET Council, and was asked by the Council to organize an initial discussion. A Workshop to consider a potential European Regional Reanalysis project (EURRA) was held at ECMWF on 21 and 22 November 2005. Each of the National Meteorological Services (NMSs) of ECMWF's Member States was invited to be represented at the meeting.

The objectives of the Workshop were to capture:

- the extent of existing EMI expertise in the various facets of a high-resolution Europe-wide reanalysis;
- the extent of any synergy between EURRA and European plans for global reanalysis;
- views regarding the scope and organization of the project;
- expressions of interest in participating in the project from actors within the EMI.

In addition, the Workshop provided an opportunity to consider, in the context of EURRA, the EUROGRID project prepared by the Swedish Meteorological and Hydrological Institute in cooperation with members of the European Climate Support Network.

Representatives of twelve NMSs attended the Workshop. Dr Philippe Crouzet participated for most of the first day on behalf of the EEA, and Dr Fedor Mesinger (NCEP and the University of Maryland) attended as an invited expert with in-depth experience of the North American Regional Reanalysis project. Dr Mesinger also assisted ECMWF staff in the preparation of the workshop and the writing of this report.

Participants were welcomed to the meeting by the Director of ECMWF, Dominique Marbouty, who attended throughout the meeting as did the Heads of the Research and Operations Departments of ECMWF, the coordinator of the FP6 GEMS project on global environmental monitoring, and members of ECMWF's reanalysis project team.

Annex I contains a list of participants in the meeting. Annex II contains the agenda. Annex III provides a brief description of comprehensive reanalysis using four dimensional data assimilation, downscaling and specialized analysis of surface and near-surface fields.

2. Workshop presentations

The presentations made to the Workshop can be viewed at http://www.ecmwf.int/newsevents/meetings/workshops/. The summaries given below incorporate answers to questions and points made following the presentations.

2.1 The EEA's requirements for meteorological and climatological data

Philippe Crouzet presented the EEA's requirements for meteorological and climatological data. These requirements were further explored during a subsequent discussion session.

The EEA is an independent European Community body with membership broader than that of the EU itself and with responsibilities that extend to the southern shores of the Mediterranean. The EEA is a provider of information for environmental policy-making and assessment.

The interests of the EEA are mainly in data over land, related to primary water resources, water composition, ecosystems, air-quality and carbon-related issues. Ocean wave and current data are of interest for coastal erosion and sediment transport. Partner bodies have additional interests, such as those of the JRC in flood and crop forecasting. Meteorological and climatological datasets are not used alone, but in combination with many other datasets.

Variables of interest include some that are directly measured at a dense network of sites, temperature and rainfall in particular. Others, such as evapotranspiration and snow cover, must be estimated from a combination of observations and modelling. There is a need to construct datasets for associated time-varying surface characteristics.

The EEA does not have the capacity to collect observations and requires processed, gridded datasets. Most applications will aggregate data spatially, over catchment basins or ecosystems for example. The basic data grid could have a spacing of 10km or finer, provided the observations and modelling can support such a resolution. Precise requirements have yet to be elicited. Currently, the JRC has data on a 50km grid in its MARS (Monitoring Agriculture with Remote Sensing) database, but historic input to this database comes from the lower (~125km) resolution ERA-40 reanalysis.

Data are required at higher than daily frequency for some applications, air quality in particular. For many others, for example related to primary water resources, data will be aggregated in time to monthly or yearly averages. Coverage from the late 1940s onwards is desirable if data of sufficient accuracy can be provided. Data should go back at least until 1975/76. The period to be covered should be one part of the final discussions setting up the EURRA project. It is envisaged that the reanalysis system will be used also for near-real-time updating of the data record; the EEA's normal data collection is yearly.

In addition to retrospective analysed data, there is a need for forecast (hindcast) data covering at least the more recent past and key earlier events such as the Chernobyl accident or major fires. Prediction/scenario data for the future are also required, produced using models validated against the retrospective data.

The EEA is preparing a document specifying its data needs. It will include requirements from its partners in EIONET and from other EEA partners such as the JRC. It should be completed early in 2006. The EEA's requirements are viewed as quite urgent, so the next steps (outlined later in this report) should be taken as quickly as possible. Data access policy issues (also discussed later in this report) need in particular to be addressed.

2.2 Global reanalysis

Global reanalysis was introduced and reveiwed by Adrian Simmons, in a presentation prepared jointly with Sakari Uppala. Global reanalyses have, since early 1990s, become a major resource in meteorological research and development. The success of reanalysis has been significant. Not only climate, but also agriculture, weather, disaster, water, health, industry, ecosystems and biodiversity have been identified as subject areas that benefit from it. Reanalysis utilizes the data assimilation system developed primarily to provide initial conditions, "analyses", for daily numerical weather forecasting. In reanalysis a fixed data assimilation system is applied to multidecadal sets of global observations creating a sequence of “quasi-homogeneous” atmospheric and land/ocean/ice conditions every few hours. The gridded products are tailored to known user requirements. However the quality of reanalyses is affected by the quality of the assimilation system, the time-evolving characteristics of the observing system and the prescribed boundary conditions and specified atmospheric composition.

Several global reanalyses have been performed: the US NCEP/NCAR 1948-present and NCEP/DOE 1979-present, the ECMWF ERA-15 1979-1993 and ERA-40 1957-2002, and the Japanese JRA-25 1979-2004. For the pre-1979 period the observations have been provided mostly by NCAR/NCEP and for the later years from multiple sources including NCEP, NCAR, ECMWF, NCDC and JMA.

It has been demonstrated that in ERA-40 the quality of forecasts, reflecting the quality of the analysis, is generally rather high in the Northern Hemisphere but nevertheless improving over time. Case studies of historical events such as the “Dutch Storm” in 1953 and the Windscale nuclear reactor fire in October 1957 show the capability of the data assimilation system to provide high-quality descriptions of these historic situations.

Despite the success of reanalyses the observational database is far from complete, especially over Europe. Since ERA-40, gaps have been identified in the surface data records. New data have already been found by NCAR to fill the main gaps, but snow data, for example, are still largely missing before 1976. Analysis quality is affected by these gaps, and applications of the near surface products have to take this into account. The agreement of the 2m temperature trend over Europe between ERA-40 and processed climate-station data has been shown to be excellent after 1979, but to deviate earlier due to the lack of sufficient near-surface data.

Reanalyses benefit from special efforts to reprocess geostationary satellite data by EUMETSAT and from ongoing work to homogenize upper-air temperature records and correct for radiation error in radiosonde temperatures and biases in surface pressure observations.

The global hydrological cycle in ERA-40 is not fully closed, but in local areas, such as over the Baltic catchment basin, comparison with observations shows good agreement, with only a small seasonal bias. The soil moisture over selected validation sites has been shown to have a realistic variability indicating the capability of the assimilation system to infer this quantity indirectly from other observations.

ECMWF’s plan is to start soon an “Interim” global reanalysis from 1989 onwards with an upgraded data-assimilation system using 12h 4D-Var. The experimental results show that the deficiencies identified in ERA-40 have to a large extent been addressed and the global hydrological balance has been improved. A positive signal has also been seen in the stratospheric analysis, the “age of air” now being older over the polar areas and in much better agreement with observations. The input data for the Interim Reanalysis will be largely as used for ERA-40, but will include newly reprocessed Meteosat winds from EUMETSAT, reprocessed altimeter height data for ocean waves and new GOME ozone profile retrievals from RAL. Radiosonde bias correction will be refined and bias correction will be introduced for surface-pressure data. Use of TOVS data will benefit from quality monitoring undertaken by JMA for JRA-25.

The next extended reanalysis ERA-65/75 (1938 or 1948 to 2012) is envisaged for production in the 2010-2012 timeframe. A major task for coming years will be to prepare the updated historical observational database as well as to understand the treatment of observation and model biases.

2.3 The North American Regional Reanalysis

In his presentation on the design and results of the North American Regional Reanalysis (NARR) Fedor Mesinger recalled the motivation for the effort. The idea was bought up in 1997, suggesting the exploration of the project “particularly if the RDAS [Regional Data Assimilation System] is significantly better than the global reanalysis at capturing the regional hydrological cycle, the diurnal cycle and other important features of weather and climate variability." The Eta Model and its data assimilation system (EDAS) were used, coupled to a state-of-the-art land-surface model (Noah), with the system driven by the lateral boundaries from the NCEP/DOE Global Reanalysis (GR2). Numerous datasets were used additional to or improved upon those used for the GR2, including a comprehensive precipitation analysis, bias corrected radiances, and various land surface input fields. Mesinger stressed the need for a domain considerably larger than the one of the area of interest. The project was funded by the NOAA Office of Global Programs (OGP) for over 6 years, with a total funding on the order of $4M; but with a considerable additional reliance on efforts of NCEP-funded personnel, and use of NCEP computer resources, including more than three months of use of all of the IBM SP supercomputer previously used for NCEP's operational production. 25 years of NARR were produced, 1979-2003, at a 32 km/45 layer resolution. Production is continued in near-real time as the Regional Climate Data Assimilation System (R-CDAS).

To assess the accuracy of the results, comparisons were made of fits to observations against those of the GR2. Just about all upper-air and near surface variables were shown to exhibit fits better than those of the GR2, either considerably, or somewhat. Improvements were generally greater in winter. Perhaps an unexpected result was that the upper air improvements were greatest in winds at jet stream levels. 2 m temperature fits were improved considerably both in winter and in summer. Winds at 10 m were improved considerably in winter, but only slightly in summer. Precipitation assimilation was one of the hallmarks of the project, with resulting precipitation fields extremely similar to those assimilated. Clearly, this bodes well for land surface hydrology over the areas where the precipitation analyses were reliable. One expectation of the project was an improved water budget closure compared to those of earlier reanalyses. This was shown to be realized, e.g., with the typical magnitude of the water budget residual over the Mississippi river basin, after removing the mean, of about half that of the GR2, and the mean of only about 1/5 that of the GR2. Considerable early use of the data is being made.

2.4 The EUROGRID project

Bengt Dahlström presented the concept of EUROGRID, and the proposal for a Showcase demonstration project.

EUROGRID was conceived as creating a database of gridded meteorological values of temperature, precipitation and other parameters covering Europe. In the first stage, the resolution would be at least of order 10km and there would be daily coverage for more than a decade. The system would subsequently be updated on a near real-time basis and extended further back in time to previous decades. A product-generation system would operate on the EUROGRID database and additional datasets. It would provide climatological, hydrological and environmental products covering the European area and sub-regions down to the local scale, both instant values and values integrated over months to decades. A system for dissemination of EUROGRID information to users, mainly web-based, was envisaged.

EUROGRID would be able to make direct use of the analyses produced by the proposed EURRA project.

The EUROGRID Showcase would provide a demonstration of the potential of a full-scale EUROGRID, enabling the concept of EUROGRID to be developed accordingly. The deliverables would be:

- high quality resolution gridded precipitation and temperature datasets for 1999, and additional lower quality data fields for the years 1991-2005;
- a demonstration package with documentation, for the creation of climatological products and other material from the gridded database and additional datasets;
- a plan for an objective validation and rating of present estimation methods for temperature, precipitation, wind and humidity;
- a report containing views and experiences from the Showcase together with an outline of how to proceed with the next step.

A proposal for the Showcase was submitted to the EUMETNET Council in October 2005, who deferred a decision pending exploration of the potential for EURRA and consideration of the synergy between the two projects and possible associated cost savings. SMHI will present a modified proposal, which takes account of synergies with EURRA, to the EUMETNET Council in April 2006.

2.5 NMSs' expertise, achievements and first expressions of interest in EURRA

Representatives of each of the NMSs made short presentations of their service's expertise, achievements and interest in participating in EURRA.

Austrian Meteorological and Geodynamical Institute (ZAMG) Helfried Scheifinger stressed Austria's excellent data coverage from a variety of surface stations, including many over complex Alpine topography. He identified several special data sets produced for a variety of projects. Station coverage is particularly extensive during the last two decades or so. He also pointed out the expertise available in a number of relevant activities, such as analysis and validation over complex topography.

Danish Meteorological Institute (DMI) Leif Laursen emphasized operational characteristics of the DMI-HIRLAM model and its 3D-Var and 4D-Var data assimilation systems. He showed examples of results, of the progress in model skill, and of the value added due to the use of a limited area model (LAM). The model and systems, as well as the expertise available, make DMI an ideal candidate to be a EURRA production partner. A phased approach for EURRA was suggested, starting with downscaling using ERA-40, followed by data assimilation at increasingly higher resolution. The need for R&D on many aspects of high resolution data assimilation was stressed. Obtaining high quality surface parameters, 2m temperature, 10m wind and precipitation, should be the emphasis.

Finnish Meteorological Institute (FMI) Sylvain Joffre emphasized FMI's experience in running a high resolution version of the HIRLAM model, and in particular in data assimilation systems. Comprehensive activities in dispersion modelling and atmospheric chemistry, involving a variety of projects including hosting the Ozone SAF, were stressed. FMI was interested in reprocessing ERA-40 observations using the HIRLAM reference system, in analyzing atmospheric pollutant concentrations using its specialized regional models SILAM and MATCH, and in validation of tropospheric trace gas columns.

Météo-France François Bouttier expressed the desirability of including a data-driven 2D reanalysis of several crucial fields, in particular of precipitation, cloudiness and the surface state/hydrology, given that these are not likely to be done better in full 3D reanalyses. He pointed out the availability at Météo-France of the so-called SIM (SAFRAN-ISBA-MODCOU) hydrological suite, operational in France and documented in the literature. SIM computes all terms of the energy and water budgets, including surface runoff, soil water and water drainage to water tables. The SAFRAN surface analysis tool accounts for sub-grid elevation and slope in handling precipitation and other hydrological elements, and is used for interpolating all parameters representing the atmospheric forcing, at the Aladin space resolution. The so-called ANTILOPE precipitation analysis system is nearing an operational phase and could be adapted to Europe-wide data as part of EURRA. The ALADIN/AROME system is ready now for use in 10- and 2-km downscaling. 10-km assimilation with ALADIN is operational and experimental 2.5-km assimilation using AROME will begin in the near future. Air quality aspects were proposed to be addressed using the MOCAGE system; historical emission maps were a requirement for this. Finally, a multi-model EURRA was proposed, managed by a coordination of the European NWP consortia.

German Weather Service (DWD) Jörg Schulz outlined the expertise available at DWD, in particular as used for the design of the DWD Lokalmodell (LM). A configuration of the model with a grid length of 2.8 km and about 50 layers in vertical is planned for operational implementation at the end of 2006. Assimilation of radar data was demonstrated. Schultz reported on numerous high quality in-situ and ground-based remote sensing observational systems active at DWD's Lindenberg observatory: the so-called Lindenberg Column. The Lindenberg data would be highly suitable for validation of reanalysis products to be produced by EURRA. Also relevant to EURRA was the work of the Climate Monitoring SAF, hosted by DWD. This SAF provides 2- and 3-D atmospheric fields such as several cloud parameters and water vapour and some surface fields such as albedo. Where complementary to EUMETSAT efforts, for example for passive microwave radiances, the planned work in this context included inter-satellite calibration activities. DWD's potential contributions to EURRA thus include those in the fields of model development, validation, and the development, validation and possibly provision of homogenous satellite data. The desirability of producing an ensemble of reanalyses was stressed.

Royal Netherlands Meteorological Institute (KNMI) Jeanette Onvlee emphasized the need to define beforehand the scope of the effort, what models are to be used, to what extent downscaling is used in the early phase and whether the project includes a forecasting component. The importance of a preparation phase including work on model biases, the selection of systems and the selection and collection of observations, was emphasized. KNMI can contribute in soil data assimilation schemes, based especially on its experience with the ELDAS project, and in coupling of atmospheric with chemical transport models, where participation in the RETRO project had resulted in estimates of the chemical state of the atmosphere based on the meteorological reanalyses from ERA-40. Further contributions could be made in downscaling to obtain near-surface wind profiles, and in the collection of high resolution meteorological data and the provision of satellite data on atmospheric composition.

Norwegian Meteorological Institute (met.no) Øyvind Saetra reported on the design and performance of the ocean and sea ice analysis system run by met.no under the auspices of the Ocean and Sea Ice (OSI) SAF. The system is being used for a sea-ice reanalysis from 1987 onwards in partnership with DMI and the Met office. An SST analysis based on OSI SAF products has also been implemented. Met.no has an historical archive of sea-ice extent back to the 1800s, although quality is questionable prior to 1960. Saetra noted that there was a considerable potential interest from the off-shore energy industry in ocean products of the type that EURRA could provide. Met.no is a member of the HIRLAM consortium, but also runs the UK mesoscale model at 4km resolution. It will contribute to mesoscale assimilation of cloudy-radiance, radar-wind and precipitation data under the HIRLAM-Aladin/AROME cooperation. Other data-assimilation interests include use of scatterometer ocean-wind data and use of AMSU data over Arctic sea ice. Met.no produces daily 1km-resolution analyses of temperature and precipitation over Norway, and as such has developed expertise in producing such analyses over rugged terrain. Work is being done on downscaling for ocean wave analysis.

Portugese Institute of Meteorology (IM) Pedro Viterbo summarized relevant activities at IM, and in particular emphasized IM's interests sparked by the recent severe drought of 2005, the worst in the last 60 years. IM runs the ALADIN model at 10km, thereby resolving the Portuguese topography better than the global ECMWF forecasts, with improved accuracy in near-surface wind and 2m temperature forecasts. IM also runs a 3rd generation wave model, a transport model for oil spills and a storm surge model. It is the host institute of the Land SAF. IM is well positioned for an active role in EURRA, through data mining and observation quality control (taking ERA-40 data coverage and feedback as a starting point), through checking of ancillary input fields and early production results over Portugal, through provision of precipitation observations and analysis and through validation of ocean products against offshore buoys. Viterbo stressed that EURRA needs a dedicated land-surface workpackage for which IM could be a focal centre. The workpackage would cover assembly of observations, execution of an ensemble of off-line surface models forced where possible by observations (a multi-model EURRA-LDAS), and evaluation of how best to use the results in subsequent core high-resolution EURRA assimilations.

Spanish National Institute of Meteorology (INM) Jana Sánchez Arriola reported on INM's participation in a number of European projects. Among other contributions, this included INM's development of the existing HIRLAM surface analysis and a new surface parameterization package. Numerous other modelling activities within the HIRLAM consortium were and are being made by INM in data assimilation and model physics components. The operational suite at INM, running on a CRAY X1 E supercomputer, uses a

17km/40-level configuration, for an area including all of Europe and major parts of North Africa and the Atlantic. A nested run using a 5km horizontal resolution is in an experimental phase. Potential data activities in support of EURRA were recovery of Spanish surface synoptic and radiosonde observations missing from ERA-40 and provision of rain-gauge data from INM's network of climate stations. Supply of radar data was a further possibility. INM shares the view of IM as to the importance of a land-surface workpackage, and could act jointly as a focal centre for this activity.

Swedish Meteorological and Hydrological Institute (SMHI) Per Kållberg and Anna Jansson summarized features of the HIRLAM 4D-Var data assimilation system. They went on to describe the "Baltic Bridge" reanalysis carried out for 1999-2000 in collaboration with FMI. This focussed on the Baltic Sea runoff area; precipitation fields from the assimilation verified well. Potential SMHI contributions to a EURRA data assimilation based on a 3D/4D-Var HIRLAM/ALADIN configuration included 4D-Var error covariance modelling, a coupled ocean model including ice-drift, a model for lake temperature and ice, assimilation of radar winds and GPS humidity, and a chemistry model. SMHI could also offer expertise in snow-cover physics. A mesoscale analysis scheme MESAN based on optimal interpolation and a HIRLAM first guess has been operational at SMHI since 1997. It has been run at resolutions of 22, 11 and 4km, and used to provide input to specialised radiation, atmospheric chemistry, fire-risk and hydrological models. It has also been run for the period from 1990 onwards using ERA-40 data for the first guess and observations from the SMHI archive, producing analyses at a resolution of 11km every six hours. Fits to Scandinavian climate data for temperature and precipitation were improved over ERA-40.

MeteoSwiss Mark Liniger emphasized the expertise of Meteo-Swiss in mountain data analysis. The homogenisation of long-term records and the availability of Alpine snow and precipitation datasets were discussed. Frei and Schär's collection of rain gauge observations in the whole Alpine region included 5,800 stations. MeteoSwiss is participating in a workpackage of the ENSEMBLES project that will produce a high-resolution gridded observational dataset for Europe and supports the proposed EUROGRID project. Work with MeteoSwiss's LM-based forecasting system relevant to EURRA included assimilation of radar data and downscaling from ERA-40 to produce high-resolution wind fields for more than 100 European winter storms. Results of dynamical downscaling at ETH were shown, with a number of regional climate models replicating observations much better than a driving global climate model. The well-developed Swiss infrastructure for dissemination and use of reanalysis data from ERA-40 was presented. MeteoSwiss is interested in participating in EURRA, and proposes to focus on Alpine-specific validation and climate-risk analysis. Liniger stressed the desirability of near-real-time updates of EURRA products.

Met Office (UK) Richard Jones reported on the Hadley Centre's regional climate modelling, done presently at 25 km horizontal resolution, with 19 levels. The system incorporates anthropogenic forcings and can be forced by ERA-40 data. It in turn is used to drive catchment-based and grid-based river models, 2D storm-surge models and 3D shelf-seas models. Jones stressed the role that such regional climate models, driven by global reanalysis data, could play in providing the initial products from EURRA. The data from subsidiary models offered additional products and opportunities for integrated validation. The Hadley Centre's expertise in SST analysis (used in ERA-40) and accumulation of other climate datasets were also relevant to EURRA. It expected by 2007 to offer an SST data set from 1850 to present at user-defined resolution. Andrew Lorenc reported on the Met Office's data assimilation activities and potential to contribute to EURRA. Its 4D-Var system was shown to perform clearly better than its 3D-Var system. UK LAM forecasts were demonstrated to be as good as any in Europe as verified against UK radar data. The Met Office wants to help define and develop the EURRA proposal. In particular, it is well placed to contribute early in the project to downscaling using regional climate modelling, regional atmospheric data assimilation, SST analysis, and studies of climate change and multi-decadal variability. Later in the project, it can contribute to radar-data assimilation and coastal ocean assimilation.

3. Possible project outline

Adrian Simmons presented an outline of the components of a possible EURRA project. This was based on ECMWF's experience with global reanalysis and its perception of what was feasible for regional reanalysis, and on input received from participants in advance of the meeting. The proposal was accepted by the meeting as a sound basis for the way forward. The outline below incorporates revisions based on comments made during and immediately following the presentation. Further views of the participants on the project are recorded in section 4 below.

3.1 Design and organisation

General organisational aspects associated with the setting up of the project were discussed later in the Workshop (see Section 5).

The possible scope and timetable of the project were considered. Questions that need to be addressed include:

- What balance should be struck between 3D/4D data assimilation activities as in a conventional global reanalysis and specialised 2-D analysis/downscaling activities, several examples of which were shown in the earlier presentations from the Meteorological Services?
- Should the project include or depend on the proposed ERA-65/75 global reanalysis, which itself was dependent on securing funding?
- What are possible production phases?
- For each phase, what range of products will be provided, and over what domain?

A possible set of production phases for the project is set out in the following table. It maps out the stages for a project of around ten years duration that would culminate in a European mesoscale reanalysis produced using a 2km-resolution data assimilation system. Extension of existing national capabilities as presented to the meeting could result in analyses of a small number of key variables at a resolution well below 10km already within the early phases of the project, in addition to the more comprehensive set of ~10km-resolution products produced by downscaling and data assimilation using regional NWP and climate models.

Phase	Resolution and Period	Name and nature	Production period
1	10km regional 1957-2008	EURRA-1 Downscaled from ERA-40 and ERA-Interim	2007-2008
2	10km regional 1989-2009	EURRA-2 Reanalysis using ERA-Interim lateral BCs	2008-2009
3a	10km regional 1938/48-2012	EURRA-3 Reanalysis using ERA-65/75 lateral BCs	2010-2012
3b	2km regional 1938/48-2012	EURRA-4 Downscaled from EURRA-3	2010-2012
4	2km regional 1989-2012	EURRA-5 Reanalysis using lateral BCs from ERA-65/75 and/or EURRA3	2013-2014

Decisions as to whether to proceed with later phases, and subsequent detailed planning for these phases, could be deferred pending progress with earlier phases.

User requirements need to be kept to the fore in the planning stage, and the various phases of the project will require recasting in terms of products supplied rather than analysis methodology. Representative key users should be involved in the planning and production/validation phases of the project.

3.2 Development of a database of observations

Development of a database of observations is essential for any subsequent EURRA analysis. This activity should build on the datasets already accumulated by global reanalysis projects such as ERA-40 and JRA-25, and by major climate data centres such as NCAR and NCDC. It should exploit the results of European initiatives such as those of the ECSN, of EU projects such as Ensembles and of the EUMETSAT SAFs.

EURRA will require access to national high-resolution observational datasets. National efforts may be needed to prepare additional datasets and fill gaps in existing datasets.

Development and production of a regional data analysis or assimilation for EURRA requires:

- Gathering data from various sources
- Creating optimal merged input datasets
- Pre-production formatting and quality control

The database of observations will be an internal deliverable of EURRA in its own right. A subset may be supported for external delivery, the extent of which will depend on the restrictions placed on component datasets by their original suppliers.

Much of the work done in EURRA on this topic will be applicable for global as well as regional reanalysis.

3.3 Provision of 2D-analyses and input data fields for data assimilation

EURRA will need to produce a number of high-resolution analyses by methods other than use of comprehensive regional data assimilation. Many of the requirements of the EEA and end-users for surface fields may best be met in this way, in the first instance at least. Moreover, the comprehensive regional numerical models to be used in EURRA will themselves require certain fields to be specified using the results of specialized analyses.

National expertise in producing direct analyses of surface temperature and rainfall directly from high-resolution national observations was demonstrated in several of the NMS presentations, and other relevant products were also demonstrated, such as surface incoming solar energy over Germany derived by the EUMETSAT Climate Monitoring SAF. Use of high-resolution atmospheric models to derive a wider variety of fields downscaled from lower resolution global analyses, ERA-40 in particular, was also demonstrated. Off-line land-surface models forced by a blend of observational data and atmospheric-model data provide a further way of deriving some of the required fields. As with the building of the observational archive, EURRA activities in the production of such analyses should be complementary to related activities such as those of the ECSN, of EU projects such as Ensembles and of the EUMETSAT SAFs.

EURRA will need to produce the high-resolution fields to be specified in the regional downscaling model(s) and data assimilation system(s) to be used in the project. The precise requirement will vary from model to model, and depend on whether certain surface fields are derived as part of the data assimilation process or specified from off-line specialised analyses. Fields, many of which will be time-varying, may include:

- Sea-surface temperature and ice distributions
- Lake temperatures and ice state
- Land-surface and soil characteristics
- Precipitation and snow analyses
- Atmospheric composition

3.4 Development of data assimilation for regional reanalysis

Application of regional data assimilation systems developed for numerical weather prediction to regional reanalysis should not require new fundamental research in the first instance, but will require some development activities. Areas that will need addressing include:

- Specification of background and observation error covariances, which may need adaptation for earlier states of the observing system
- Treatment of biases (model as well as observational)
- Use of early satellite data
- Extension of use of certain data from local to regional scale, radar data in particular
- Choice of domain
- Development of monitoring tools and quality measures
- Implementation of run-time diagnostics in the assimilating model

Broadening the scope of EURRA may require more basic research and development, for example in the field of coastal ocean data assimilation.

3.5 Production of reanalyses

Finalisation of a production data assimilation system for EURRA will require a period of pre-operational testing to confirm its meteorological performance and check the utilization of specific observational datasets. Technical optimisation may be required to ensure the complete suite of tasks executes in a way that ensures both rapid throughput and efficient use of computer resources.

Monitoring of the production data assimilation will be a key activity. Pre-production data screening and adaptive bias-correction systems can be adopted to limit the requirement for on-the-fly data-use and bias-correction decisions, which can be demanding of manpower.

Post-production data processing will include formation of additional datasets such as monthly means, climatologies and subsets suitable for specific types of user. It will also entail revision of archive streams, for example constructing time series for individual analysed variables, analysis feedback files for individual types of observation and datasets on standard output grids.

3.6 Validation

A programme of validation of the products of EURRA will be needed. Validation will guide users as to the suitability of the products for their application and provide developers with information needed for future improvement of regional reanalysis systems.

Validation can also help directly to avoid problems in the quality of products. The validation programme should be developed at an early stage of the project so that components can be activated to check the results of pre-production testing. Validation should be continued as a "near-real-time" activity as production proceeds, forming an important element of production monitoring.

Validation should be linked to primary user requirements. It should be a distributed task, with some done by the team primary responsible for the production phase and the remainder carried out by other stakeholders in the project.

3.7 Dissemination

A range of dissemination activities will also need to be developed:

- Data services
- Documentation
- User support
- Workshops
- Training

4. NMSs' views on the project and their possible data provision

Tony Hollingsworth conducted a "tour-de-table" to sound out the views of the Member-State participants as to what were considered to be the key elements of a EURRA project, what were considered to be the most important elements to ensure a quick and successful first phase of the project, and what were the data sets that each NMS was likely to be able to provide to the project. The outcome is summarised in the Table below.

	Key elements of the EURRA project	Key elements for a fast start	Contributions of digitised observations for assimilation/validation
Austria	• As in draft project outline	• 2D analyses • Development of observational data base	• As in presentation
Denmark	• R&D in 4D-Var for high-resolution data assimilation • Collect 2D input data fields	• Start downscaling exercises, using more than one modelling system; could include spectral nudging of large scales • Produce off-line 2D analyses of some surface variables • Investigate model climate drifts when forced by only lateral boundary conditions	• All available data
Finland	• As Denmark • Coordination within HIRLAM consortium • Include chemical state of the atmosphere	• Downscaling • Begin data collection activities	• All available data, including radar and various satellite data • For validation: Sodankylä mast data; Helsinki Testbed network
France	• Evolution of physiographical conditions • Air quality (requires history of emissions) • Encompass user requirements	• Start data collection, including (cloudy) satellite and radar data • Focus on 2D analysis products	• Will provide what is appropriate given the EURRA user requirements
Germany	• EEA user requirements: 2D surface fields, especially precipitation • Validation of downscaled products using Lindenberg Observatory data	• Use of 2D SAF operational products, after survey	• GPCP data • Lindenberg validation data • Can provide specialised satellite data sets if funded
Netherlands	• Precipitation, surface properties, air quality • Physiography requires special attention	• Downscaling and validation using several models • Exploit existing data collection initiatives • Get users involved quickly	• Radar and ground-based remote sensing data • Cabauw validation data • Atmospheric composition data

	Key elements of the EURRA project	Key elements for a fast start	Contributions of digitised observations for assimilation/validation
Norway	• Observational data base • Choice of model system • Validation aspects • Educating users on potential of the products	• Get organised quickly • Downscaling techniques	• Historical sea ice data from mid 19th century - weekly since 1960's • Gridded 1km resolution temperature + precipitation + snow water equivalent over Norway • International Polar Year will provide new observations
Portugal	• Observation collection • Long period (>30 years) • Updates within 2 weeks of real time • Surface energy and water balance sufficiently accurate to allow anomaly identification • Accurate wind speed climatology • Validation and dissemination	• Dynamical downscaling OK only if conserving dynamic energy balance	• Data rescue at IM will be focussed on EURRA • Additional precipitation data • Off-shore Navy buoys
Spain	• Collection of all available observations • Continuous update with time-lag to allow inclusion of data not exchanged in real time • Good physiographic data • Workpackage with specific focus on continental land surface • Overall domain to be sufficient for study of meso-cyclones over sea, e.g. W and SW of Canary Islands	• Provide NMSs with information on gaps in ERA-40 observational coverage over their territory	• All available GTS and climatological-network data • Pluviometric information is already in digitised form, but early radiosonde, pilot and synop data need digitisation
Sweden	• Availability and QC of observational data • 3D data assimilation • 2D analysis of parameters sensitive to geographically varying structure functions • Support for tropospheric air chemistry (pollution dispersion) models, e.g. MATCH	• Sort out the data policies • Find out how best to downscale ERA-40 to 10km resolution • Adapt 2D scheme to fit into 3D environment.	• All available data in 'BÅK'-archive of QCed conventional data – 'synoptic' and 'climate' • Cooperation between Baltic states: Sea-ice thickness and SST digitised 6-10 yrs back. Historical 5-daily sea-ice analysis exists on paper. • River runoff into Baltic • Radial winds from radar • GPS data for total water vapour • Mast data from taiga forest

	Key elements of the EURRA project	Key elements for a fast start	Contributions of digitised observations for assimilation/validation
Switzerland	• Spatial resolution must represent Alpine region • Long period (>30 years) • Near real-time updates • 3D physical consistency • Validation • Multi-model downscaling • Links to EUROGRID and ECSN • Domain to include entire Mediterranean • Accurate winds • Support flood prediction	• Downscaling of ERA-40	• Potentially many types of data (e.g. homogenised surface data) • Snow analysis over Switzerland • Ground-based ozone data and Alpine precipitation
United Kingdom	• Support drought and flood prediction • Precipitation assimilation leading to improved prediction • User requirements • At least 40 years • Full set of forcings (aerosols, atmospheric composition) • Input data fields • Extra diagnostics for validation, such as satellite observation operators	• Build on systems that work now • Combine 2D analyses with regional climate models forced by ERA-40 • Get user feedback as quickly as possible • Use of ENSEMBLES deliverables	• No clash between Met Office data policy and use for EURRA project • Hadley centre research datasets for validation • Radar data only for recent years - earlier data very difficult to recover • Hope to make available 5km UK temperature and precipitation dataset

5. Organization

Philippe Bougeault outlined and led a discussion on the organizational issues to be considered in the setting up and running of EURRA.

5.1 Data policy issues

Data policy issues will need to be resolved both for the high-resolution climate observations supplied for the EURRA project and for the data fields and other feedback information generated by the project.

For observations, it has to be established whether the datasets supplied can be used:

- only for current phases of EURRA,
- for future re-analysis projects, carried out within or outside Europe,
- for future research projects, or
- without restriction.

Datasets held within the EURRA observational database and any related analysis feedback data would have to be marked accordingly. Dataset enhancement due to any recovery efforts funded as part of EURRA, and the additional quality-control information provided by the feedback from the use of the data in EURRA production, would have to be considered.

The data policy for the deliverables of the EURRA project raised additional issues. At least a subset of primary variables would be made freely available at a particular resolution, but with increasing resolution the datasets would generally fit with increasing accuracy the observations on which the analyses were based, which may have been supplied for restricted use in EURRA and similar projects. Extending the EURRA analyses in near-real-time could introduce new issues. Other questions could arise if there is joint funding of EURRA rather than complete funding coordinated by a body such as the EEA.

The meeting was not the forum to pursue these issues further. Eventually it was likely that decisions would have to be taken at the level of the Directors of the NMSs through EUMETNET, in liaison with EURRA's external funding agencies and any other organisations that supply significant data to the project.

5.2 Preparation of the project

It was proposed that a Coordinator be appointed at ECMWF, with EEA funding, to develop a detailed plan for the project and be a point of contact with the EEA to ensure that the plan is consistent with their requirements and funding possibilities. The Coordinator would work in collaboration with representatives of each of the four main European regional NWP consortia in a Coordinating Group to formulate the plan, keeping the NMSs of ECMWF's Member States and Cooperating States informed of progress and seeking their feedback. The main work in EURRA would not be done by ECMWF, although ECMWF could, for example, host the database and contribute a new background global analysis for later phases of the project. ECMWF was best placed to deal with the EEA in the preparatory phase, but the Coordinator for later phases could come from elsewhere, from the consortium responsible for the chosen regional data assimilation system in particular. The final decision on the method of developing the plan and coordinating the project would, however, lie with the EEA, Member States and the European Commission.

The final formulation of workpackages and deliverables would need to be agreed by the EEA and Coordinating Group, possibly also with external scientific and end-user advice.

The attribution of workpackages to individual organisations could be done by consensus or by an informal tendering process with a decision by the Coordinating Group, or by a formal open competitive tendering process. In the latter case the decision-making could be either through the governing policies and structures of the EEA, or by EUMETNET if the process is delegated to the meteorological community by the EEA. The Coordinator, and possibly other bodies, could act as advisers in the formal review process. Offers of partners could be evaluated based on:

- Existing expertise of the partner
- Relevance and quality of proposed system
- Funding requested
- Capacity to deliver on time

Ideally, more than one partner might produce specific product sets, thereby providing some measure of uncertainty to be attached to the product values. Such an ensemble approach to the full data-assimilation components of the project would, however, be expensive, and funding more than one data assimilation for a particular phase might be difficult.

Deliverables will need to be defined very precisely and be compatible with global funding available, and each workpackage should be formulated with a maximum possible funding.

Finalizing the description of workpackages and deliverables will be a demanding task. The fastest realistic timetable would be for this to be completed within the third quarter of 2006, with assignment of tasks around the end of 2006 for initial workpackages to be carried out in 2007 and 2008. Funding of these initial workpackages would need to be confirmed through discussions within the EEA membership and the European Commission. Funding for the later phases could come partly through the EEA and partly from other sources.

6. Conclusion

Dominique Marbouty noted that there was general agreement on the proposed overall framework for the project and the approach to getting the project started. Many participants had stressed the crucial importance of creating the observational database for the project, and the use of downscaling was seen by many to be a key element for a quick start and early provision of products. As to the immediate next steps, ECMWF would prepare the meeting report by January 2006, and the EEA requirements document was expected at about the same time. These would form the basis for further discussions between ECMWF and the EEA with a view to setting up the Coordinating Group to prepare a detailed project plan. This plan would be product oriented and would allow for an incremental implementation of the project. As Director of ECMWF he would report verbally the outcome of this meeting to the ECMWF Council at its December 2005 session and he would present the meeting report and progress of subsequent discussions to the next session of the EUMETNET Council.

Dominique Marbouty concluded the meeting by thanking all participants for their informative and constructive contributions to the meeting.

Annex I: List of Participants

European Environment Agency:

Philippe Crouzet

ECMWF Members States:

Austria	Helfried Scheifinger
Denmark	Eigil Kaas, Leif Laursen
Finland	Carl Fortelius, Sylvain Joffre
France	Pierre Bessemoulin, François Bouttier
Germany	Franz Berger, Jörg Schulz
Netherlands	Jeanette Onvlee
Norway	Øyvind Saetra, Ole Einar Tveito
Portugal	Pedro Viterbo
Spain	Jana Sánchez Arriola
Sweden	Bengt Dahlström, Anna Jansson, Per Kållberg
Switzerland	Walter Kirchhofer, Mark Liniger
UK	Richard Jones, Andrew Lorenc

Invited Expert:

Fedor Mesinger

ECMWF:

Dominique Marbouty
Philippe Bougeault
Walter Zwieflhofer
Dick Dee
Anthony Hollingsworth
Adrian Simmons
Sakari Uppala

Annex II: Workshop agenda

Discussion of a potential European Regional Reanalysis (EURRA) project

ECMWF, 21-22 November 2005

Monday 21 November

0930-0945	Welcome	Dominique Marbouty
0945-1030	The European Environment Agency's requirements for reanalysed meteorological fields	Philippe Crouzet
1030-1100	Coffee	
1100-1145	Global reanalysis: Lessons learned and current plans	Adrian Simmons Sakari Uppala
1145-1245	The North American Regional Reanalysis: Results obtained and lessons learned	Fedor Mesinger
1245-1400	Lunch	
1400-1420	The Showcase EUROGRID proposal	Bengt Dahlström
1420-1540	Questions and discussion of the EEA's requirements	Chair: Adrian Simmons
1540-1610	Coffee	
1610-1810	Presentations by Member States of their expertise, achievements and first expressions of interest in participation in a European Regional Reanalysis project: 1610-1630 Austria 1630-1650 Denmark 1650-1710 Finland 1710-1730 France 1730-1750 Germany 1750-1810 Netherlands	Chair: Adrian Simmons

Tuesday 22 November

0900-1100	Continuation of presentations by Member States of their expertise, achievements and first expressions of interest in participation in a European Regional Reanalysis project: 0900-0920 Norway 0920-0940 Portugal 0940-1000 Spain 1000-1020 Sweden 1020-1040 Switzerland 1040-1100 United Kingdom	Chair: Adrian Simmons
1100-1115	Coffee	
1115-1300	Discussion session: Scope, time-frame and resources for a European Regional Reanalysis project. Further expressions of interest from participants regarding the work-packages and data they can offer	Chair: Tony Hollingsworth
1300-1400	Lunch	
1330-1500	Discussion session: Organisation of project, including data policy issues	Chair: Philippe Bougeault
1500-1530	Coffee	
1530-1630	Summary, conclusions and next steps	Chair: Dominique Marbouty

Annex III: Data assimilation, downscaling, and specialized analysis of surface and near-surface fields

In meteorology, the term *reanalysis* is often used to refer to the production of comprehensive, integrated datasets describing the evolution of the atmosphere and related surface conditions over recent decades, using the process of data assimilation. This process comprises a sequence of analysis steps in which background information for a short period, typically of six- or twelve-hour hour duration, is combined with information from observations for the period to produce an estimate of the state of the atmosphere (the “analysis”) at a particular time. The background information comes from a short-range forecast initiated from a preceding analysis in the sequence. The blending of background and observational information is done in a way consistent with appropriate statistical and physical constraints. The background forecast carries forward in time and spreads in space the information from the observations used in earlier assimilation cycles. In reanalysis, a fixed, modern data assimilation system is used to process the observations taken over several decades, most of which were previously analysed soon after they were taken for the purpose of weather forecasting, using less advanced techniques than are available today. The quality of reanalysis products depends on the realism of the assimilating model, on the accuracy and density of the available historical observations and on the way model states and observations are merged. Quality may thus vary from one variable to another to another, from one region to another and between periods with different observational coverage.

Reanalysis is a well-established activity for production of global datasets with a horizontal resolution of the order of 100km or coarser, as discussed in Section 2.2. Regional data assimilation systems, taking boundary values from global reanalyses, can also be used to provide higher-resolution products for continental domains. The first such effort, for North America, is discussed in Section 2.3.

Other approaches may be used to provide regional products with higher resolution than those provided by the global systems. Comprehensive sets of products can be derived by a process of dynamical *downscaling*, in which the higher resolution data are provided by a regional atmospheric model forced by larger-scale data from a global reanalysis. *Specialized analyses* may also be produced for surface or near-surface fields for which comprehensive fine-resolution measurements are available; precipitation and temperature at two-metre height over land are the prime examples. These analyses may be based solely on observational input, or may include some degree of modelling, for example to allow for orographic variations. They may use background information from global reanalyses, directly or via downscaling. Land-surface products may also be produced using assimilation into a land-surface model, with atmospheric forcing provided by observations where available, and by atmospheric reanalyses otherwise. Examples of the various approaches can be found in the NMSs’ presentations to the Workshop. In practice, the most appropriate approach for any particular product will depend on the nature of the product, the domain over which it is required, the availability of observations and the evolving capability to model the variables concerned and to assimilate the relevant observations.