Offering capabilities in global modelling is putting the European Centre for Medium-Range Weather Forecasts at the forefront of climate reanalyses. **Dr Dick Dee**, Head of the Reanalysis Section, discusses some of the research challenges they are facing

The forefront of **climate monitoring**

Can you tell us what the role of the European Centre for Medium-Range Weather Forecasts (ECMWF) is in the European Reanalysis of Global Climate Observations (ERA-CLIM) project?

The ECMWF provides experience in global modelling and data assimilation and has made its high-performance computing and state-of-the-art archiving facilities available to the ERA-CLIM project. In return, this particular project provides ECMWF with financial support for several scientists to maintain and improve its reanalysis capability. ECMWF has a long tradition of producing climate reanalyses; originally in support of its own research and development, but increasingly to serve the wider scientific community. Recent ECMWF reanalysis products such as ERA-40 and ERA-Interim have numerous users worldwide and are essential to the research and development the Centre undertakes in support of forecasting.

What systems do you use in order to produce state-of-the-art representations of the atmosphere from previously collected data?

Reanalysis uses modern forecasting and data assimilation systems to reprocess – or reanalyse – past observations. The ERA-CLIM reanalyses make use of the state-of-the-art systems and facilities developed at the ECMWF, which are the result of 35 years of European investment in global numerical weather prediction. ECMWF reanalysis products are among the most used datasets in geosciences today.

How have you dealt with obstacles to ensure you can produce meaningful datasets in the ERA-CLIM project?

A major challenge for this particular project is to collect and organise the vast numbers of available input observations needed for reanalysis. Roughly half of the project's resources are dedicated to data rescue, digitisation and quality control. The term 'data rescue' refers to the painstaking process of digging through old archives around the world in order to locate reports of weather observations that are potentially valuable for climate studies. The data must be located, imaged, digitised and carefully screened for quality control. ERA-CLIM partners in Portugal, France, Switzerland, Russia and Chile are engaged in these efforts to prepare millions of new observations from remote and sparsely observed locations that have never before been used for reanalysis. Nothing is more important than to preserve these unique and valuable climate observations for posterity and there is a great deal more work to be done in this area. Unfortunately, data rescue activities around the world tend to be severely underfunded.

In addition, we are dealing with the fact that uncertainties in reanalysis are fundamentally the result of incomplete or inaccurate observations and changes in the observing system over time. Prior to the satellite era, for example, most measurements of sea-surface temperature were made with buckets. During the 20th Century the type of bucket used gradually changed from wood to canvas to rubber. Each material has different properties leading to different biases in the measurement data. Since it is usually not known which type of bucket was used for a given measurement, this introduces a fundamental uncertainty in the dataset. One of the methods we use for exposing and quantifying this type of uncertainty is to generate multiple reanalyses, each produced with slightly different, but equally plausible, estimates of historic sea-surface temperatures.

Can you describe what ECMWF's plans are for the coming two years of the ERA-CLIM project?

This three-year project started in 2011 and much has been accomplished during the first year. The data rescue and digitisation efforts so far have produced large inventories of available sources, which have been prioritised based on their expected impact on climate reanalyses. For example, early upper-air observations of temperature, wind and humidity in the tropics and at high latitudes – critical regions for climate – are at the top of the list, as are data from stations with long records. Improved estimates of global sea-surface temperatures and sea-ice concentrations have been created that are necessary as input for the ERA-CLIM reanalyses. Much useful work has been undertaken on the identification of early satellite instruments that are potentially useful for reanalysis, and a start has been made on the reprocessing and recalibration of some of the more recent satellite data records. The work at ECMWF during the first year has concentrated on building the tools and systems needed for the very ambitious programme of reanalysis production in the coming years.

Looking back to predict the future

The collaborative **European Reanalysis of Global Climate Observations** project is delving into a long history of weather data, in the hope that a clearer picture of future climate change will emerge

CLIMATE REANALYSIS IS increasingly seen as critical for understanding the processes associated with climate change and informing future climate change scenarios. Reanalysis combines information from past meteorological observations with modern forecast models, using data assimilation techniques originally developed for numerical weather prediction. This helps improve the forecast models and also enables scientists to build robust climate models that accurately represent the evolution of the atmosphere during the past century, as described by vast numbers of observations available from numerous sources. One of the most important requirements for a successful reanalysis is to collect and prepare those observations to ensure that they are up to the standards required by today's sophisticated data assimilation systems. A collaborative project called the European Reanalysis of Global Climate Observations (ERA-CLIM) is attempting to deliver precisely this.

Funded by the European Union under the Seventh Framework Programme (FP7), ERA-CLIM is now in its second of a three-year action plan. Some of the key priorities for this collaboration are to improve the available observational record for the early 20th Century, to undertake pilot reanalyses and to evaluate and minimise any uncertainties in the data – with the ultimate aim of delivering the climate reanalyses that can support the establishment of climate change services by the European Commission. Such complex work is most definitely a long-term commitment, as Project Coordinator Dr Dick Dee explains: "Preparing and conducting a new reanalysis is a major undertaking that can take between five to 10 years to complete".

A climate reanalysis must be continuously updated with new observations in order to monitor key atmospheric parameters that are responsive to climate change. In addition, the entire dataset needs to span at least a few decades because natural variations found in the climate records can hide some of the longer-term movements and trends. "Changes in atmospheric circulation that are of particular concern to society – such as regional aspects of warming or enduring changes in rainfall patterns – can only be reliably detected in time series that are sufficiently long," Dee points out.

A TRULY GLOBAL COLLABORATION

The ERA-CLIM project is a major consortium that stretches across the globe to link up with national meteorological services, climate research institutes and satellite data providers. The European Centre for Medium-Range Weather Forecasts (ECMWF), where Dee heads up the Reanalysis Section, is coordinating the pan-European project with partners based in the UK, Austria, Switzerland, Russia, Portugal, Germany and France, as well as further afield in Chile. They also keenly maintain links with data providers and reanalysis producers in the US and Japan, with other relevant EU-funded research projects (including EURO4M, CARBONES, and MONARCH-A) and some of the other past and present data rescue activities taking place under the umbrella of the Atmospheric Circulation Reconstructions over the Earth (ACRE) initiative.

Essentially, ERA-CLIM offers to deliver a comprehensive history of the changes in the Earth's atmosphere over the last century by rescuing early weather observations and making them available for use in today's climate models, to support climate change monitoring and prediction services. The project will generate nearly one petabyte of gridded climate data, all of which will be easily accessible through the Internet. The collaboration has recently reported some impressive progress, particularly in the field of data rescue. For example, the project partners have been able to expose considerable amounts of early weather data that have not been previously available, including some of the early 20th Century upper air data from the tropical and high latitude regions. They have also identified a number of new sources of data that do not yet exist in digital archives – including annual climate reports. Whilst the process for uncovering this type of data is time consuming, it has wide-reaching application once the data become freely available in the form of a reanalysis. The ERA-CLIM project is also tasked with rescuing some of the pre-1979 satellite data that are held on inherently temporary media and must be archived in a way that allows it to be easily incorporated into the latest climate models before it is lost forever.

SUPPORTING THE END-USER

To mark the successful completion of the first year of ERA-CLIM, the first General Assembly

The collaboration has recently reported some impressive progress, particularly in the field of data rescue

was held in Portugal in December 2011. This meeting presented a chance for the project partners to get together and share the progress that has been made. Partners were able to discuss some of the challenges they have faced and talk to the Advisory Board about the work. It was at this first General Assembly that ERA-CLIM's Advisory Board recommended an open and transparent data policy and rapid and efficient access for the end-users in government agencies, the wider scientific research community and commercial services – such as in the reinsurance industry and the renewable energy sector. According to Dee, the most effective way to achieve transparency is for ERA-CLIM to make use of the data archiving and dissemination services available at ECMWF, thus providing access to all of the climate datasets produced by the project: "Beyond this, we have taken a radical step towards full transparency by making every single one of the billions of observations used in ERA-CLIM climate reanalyses traceable to source and accessible to end-users," he explains.

One of the ways this will be accomplished in practice is through the ERA-CLIM Observation Feedback Archive (OFA) that has recently been developed and is due for release later in 2012. The objective of the OFA is to be a web-based archive where end-users can access a wide range of raw data that has been previously collected by the ERA-CLIM reanalyses, combine it with other technical information (such as methods of observation and quality indicators) and then produce their own analysis. From Dee's perspective this type of system has every potential to become a powerful tool for exposing the information content of reanalysis data and for helping to assess uncertainties: "We are very excited that the OFA is a ground-breaking development in ERA-CLIM, which we believe will make a lasting contribution to climate science".

It is the hope of the ERA-CLIM collaboration that the reanalyses they produce will become a 'major backbone' of Europe's future climate monitoring and prediction services, and similar initiatives elsewhere in the world. The true value of the reanalysis is realised in the ability of end-users to readily access high-quality data that they can then use to gain insight into the global climate and how it is changing, based on the best available historical climate observations. The global reanalysis information they are producing is valuable for many different applications in Europe, and Dee offers a long list of examples, including the production of specialised high-resolution regional climate indicators, planning and optimising renewable energy provision, developing new building codes and setting up road maintenance schemes that are appropriate for a changing climate. Perhaps one of the most important outcomes of the ERA-CLIM project is that the reanalyses will provide robust, science-based data that policy makers can rely on when planning and deciding upon adaptation and mitigation measures.

ERA-CLIM

EUROPEAN REANALYSIS OF GLOBAL CLIMATE OBSERVATIONS

OBJECTIVES

To prepare input data and assimilation systems for a new global atmospheric reanalysis of the 20th Century. This involves recovery and digitisation of early meteorological observations, reprocessing and recalibration of radiance measurements from satellites, and preparation of climate-quality atmospheric forcing data and boundary conditions.

PARTNERS

European Centre for Medium-Range Weather Forecasts, UK • **The Met Office**, UK • **Institut für Meteorologie und Geophysik**, University of Vienna, Austria • **Oeschger Centre for Climate Change Research**, University of Bern, Switzerland • **Russian Research Institute for Hydrological Information**, Hydrometeorological Centre of Russia, Russia • **Fundação da Faculdade de Ciências**, Portugal • **European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)**, Germany • **Météo-France**, France • **Universidad del Pacífico**, Chile

FUNDING

EU Seventh Framework Programme (FP7) – contract no. 265229

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DR DICK DEE obtained his degree in Applied Mathematics from New York University in1983. He first joined PUC-Rio in Brazil as a mathematics professor, and then worked for six years as a research scientist at Delft Hydraulics in The Netherlands. This was followed by 10 years at NASA's Goddard Space Flight Center in the US before eventually joining ECMWF. His primary area of expertise is data assimilation, with special interest in the treatment of biases in models and observations.