



## CONFERENCE REPORT

### **Report of the 4<sup>th</sup> World Climate Research Programme International Conference on Reanalyses**

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## **Report of the 4<sup>th</sup> World Climate Research Programme International Conference on Reanalyses**

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## FOREWORD

The **4th WCRP International Conference on Reanalyses** provided an opportunity for the international community to review and discuss the observational and modelling research, as well as process studies and uncertainties associated with reanalysis of the Earth System and its components. Characterizing the uncertainty and quality of reanalyses is a task that reaches far beyond the international community of producers, and into the interdisciplinary research community, especially those using reanalysis products in their research and applications. Reanalyses have progressed greatly even in the last 5 years, and newer ideas, projects and data are coming forward. While reanalysis has typically been carried out for the individual domains of atmosphere, ocean and land, it is now moving towards coupling using Earth system models. Observations are being reprocessed and they are providing improved quality for use in reanalysis. New applications are being investigated, and the need for climate reanalyses is as strong as ever. At the heart of it all, new investigators are exploring the possibilities for reanalysis, and developing new ideas in research and applications. Given the many centres creating reanalyses products (e.g. ocean, land and cryosphere research centres as well as NWP and atmospheric centers), and the development of new ideas (e.g. families of reanalyses), the total number of reanalyses is increasing greatly, with new and innovative diagnostics and output data. The need for reanalysis data is growing steadily, and likewise, the need for open discussion and comment on the data. The 4th Conference was convened to provide a forum for constructive discussion on the objectives, strengths and weaknesses of reanalyses, indicating potential development paths for the future. The overall success of this WCRP conference was demonstrated by the impressive attendance, with more than 270 participants from 42 countries. The Conference sponsorship from NASA, NOAA, NSF, DoE, ESA and EGU greatly contributed to the success and it is deeply acknowledged.

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## 1. Executive Summary

**Reanalyses have become an integral part of Earth system science research across many disciplines.** While originating in the atmospheric sciences and Numerical Weather Prediction (NWP), the essential methodology has been adopted in the fields of oceanography and terrestrial ecosystems and hydrology, with emerging research in atmospheric composition, cryosphere and carbon cycle disciplines. Major challenges lie ahead as the disparate nature of each discipline become joined in Earth system analyses. Clearly, substantial progress has been made since the last reanalysis conference (Jan 2008, Tokyo Japan). Newer atmospheric reanalyses (MERRA, CFSR and ERA-Interim) have been evaluated in depth, and many strengths and weaknesses identified. Early results from JRA-55 are becoming available. There is tremendous potential in the NOAA/ESRL 20CR surface data only reanalysis, and in the uncertainty provided from the ensemble. Ensembles of multiple reanalysis systems can provide valuable information. Although there are several reanalyses efforts worldwide at present, the community consensus is that the diversity among them will enable deeper understanding of the reanalyses systems, their strengths and weaknesses and their representation of the underlying earth system processes/phenomena. This is then reflected in the producers' plans (notably those of JMA and ECMWF) leaning toward "families" of reanalyses (each system producing various configurations of reanalysis). There is much to be learned about the observations, data assimilation, modelling, and coupling the Earth system but **new data systems, efficient computing and processing of the multitude of reanalyses products are urgently needed.** The integrating nature of reanalyses across components of the Earth system (land, ocean atmosphere) is a key benefit, but **to date very few reanalyses systems include all relevant data and assimilate all Earth system components.**

Observations are the fundamental resource for reanalysis. **The need for long-term records of continuous measurements cannot be overstated. Data recovery efforts for *in situ* and remotely sensed observations are essential to extend the records as far back in time as possible to support long historical reanalyses,** while concerted efforts to maintain and develop the observing system forward in time to ensure continuity for the future. Documenting the observations and their uses in past reanalyses can be beneficial both to use in future reanalyses and to understanding of the observations. Expertise for all the observations exists around the world, and so, international coordination of observations for reanalysis should be an imperative for international observations and research coordination programs such as GCOS, GEOSS, CEOS and WCRP. Confronting models with observations continues to be important but also confronting models (e.g. ocean and atmospheric models) and observations (e.g. discrepancies between micro-wave satellite records and radiosonde measurements) among themselves are equally important research tasks for the future. **Data assimilation methods continue to improve, but have more challenges ahead, such as the amelioration of shocks associated with changes to the observing system (also better characterizing and reducing model bias) and developing uncertainty estimates for reanalyses.** Reanalyses have recently been getting attention from the climate monitoring community, and so, their strengths, weaknesses and uncertainty are increasingly exposed.

Reanalysis users often ask which reanalysis is best for a given topic. As newer reanalyses come along, the answer may not be widely known, if at all. In this regard, the community of users and developers must collaborate, given the diversity of applications. The web site, *reanalysis.org*, has been promoted as an open media for conveying the latest understanding of reanalyses data. Additionally, NCAR's Climate Data Guide (<https://climatedataguide.ucar.edu/>)

is a very useful go-to **source for scientifically sound information and advice on the strengths, limitations and applications of climate data, including reanalyses.** While fundamental information is available primarily on atmosphere and ocean reanalyses, discussions on the latest research and understanding are progressing more slowly. Ultimately, it is incumbent on the researchers to assess the multitude of reanalyses objectively. **New data systems are required that allow for more efficient cross comparisons among the various reanalyses (such as those used for AMIP and CMIP studies and the Earth System Grid, ESG).**

The 4th WCRP International Conference on Reanalyses produced excellent discussions across all the important issues in reanalyses, but continuing the progress and improvements will require sustained efforts over the long term. While progress has been made across the major aspects of reanalyses, significant limitations persist. The conference has identified broad directions to continue the advancement of reanalysis:

- 1) **Quantitative Uncertainty** – Reanalyses are based on observations, and can include the errors of observations and the assimilating system. It is recommended to have reanalysis data available in a common framework so as to facilitate the analysis of their strengths and weaknesses. The notion of Families of reanalyses will likewise expose the impact of assimilating observations on the analyses. Ensemble methods can also provide quantitative uncertainty estimates. Lastly, passing observations and innovations into an easily accessible data format can promote deeper investigation of the use of observations in the reanalyses.
- 2) **Qualitative Uncertainty** – Often researchers inquire to the applicability of a reanalysis for a given phenomena, or even, which reanalysis is best. Often, this is not satisfactorily known, varies with application and requires significant time and research. Therefore, sharing reanalysis knowledge and research in a timely manner, among researchers and developers is a critical need to allow subsequent exploitation by the climate community. The *reanalysis.org* effort has provided an initial effort along these lines, but more participation is encouraged. In addition, <http://climatedataguide.ucar.edu> provides informed commentary on analysis and other datasets. Likely, even more lines of communications are required.
- 3) **Earth System Coupling** – The natural course of reanalysis development is toward, longer data sets with coupled Earth system components that will ultimately contribute to improved coupled predictions. The use of more varied observations (e.g. aerosols) will reinforce the physical representation of the Earth system processes in the reanalysis systems. There is a need to develop independent and innovative modeling, coupling and data assimilation methods to represent the Earth System throughout the time span of the observational record. More interdisciplinary collaborations in the system development and observational research will begin to address this need.
- 4) **Reanalyses, Observations and Stewardship** – While the observational records have been greatly improved since the first reanalyses through research, reprocessing and homogenizations, research and improvements continue their development. Reprocessing and intercalibrations of observed records are critical to improve the quality and consistency of reanalyses. *In situ* and satellite data need to be found, rescued and archived into suitable formats to extend the reanalysis record back in time. Reanalysis systems for the atmosphere, ocean, cryosphere, land, and coupled earth system are needed that maximize use of the observations as far back as each instrumental record will allow. It is important for the observational data and reanalysis developers to maintain communication, so the latest data are used in reanalyses, and also that output of reanalyses may contribute to the understanding of observations. Such an endeavor should be coordinated at an international level.

## 2. Background

The **4th WCRP International Conference on Reanalyses** (ICR4, held May 7-11 in Silver Spring MD) provided an opportunity for the international community to review and discuss the observational and modelling research, as well as process studies and uncertainties associated with reanalysis of the Earth System and its components. Characterizing the uncertainty and quality of reanalyses is a task that reaches far beyond the international community of producers, and into the interdisciplinary research community, especially those using the reanalysis products in their research and applications.

Atmospheric, oceanic and land reanalyses have become fundamental tools for weather, ocean, hydrology and climate research. They continue to evolve with improvements in data assimilation, numerical modeling, and observation recovery and quality control, and have become long-term climate and environmental records. Reanalyses are natural integrative tools, yet coupling the components of the Earth system in reanalyses remains a great challenge.

Observations are the key resource in producing reanalyses and improvements in algorithms and quality control are still advancing. Additional challenges remain to account for model bias as new data are assimilated and the observation record evolves (e.g., new instruments replace old ones). These issues are especially important for using reanalyses in climate research. Extending the reanalysis record back in time is a fundamental need of the weather and climate research community. Considering these challenges, the 4th WCRP International Conference on Reanalyses was convened with the following objectives:

1. Sharing understanding of the major challenges facing reanalyses: the changing observing system and Integrated Earth system.
2. Assessing the state of the disciplinary atmospheric, ocean, and land reanalyses, including the needs of the research community for weather, ocean, hydrology and climate reanalyses.
3. Reviewing the new developments in the reanalyses, models and observations for study of the Earth System.
4. Exploring international collaboration in reanalyses including its role in regional and global climate services.

Expected outcomes were:

- Fostering of communications between reanalysis development centres and the research community with a focus on an Earth System approach to reanalysis
- Enhanced collaboration of the international production centres
- Statement on the utility and need for reanalyses in weather, ocean, hydrology and climate studies for policy makers
- Identification of potential new areas for applications of reanalysis products
- Promotion of greater use of reanalysis and evaluation of strengths and weaknesses of reanalysis products
- Greater involvement of early career scientists and graduate students in reanalysis research and development

The Conference objectives were accomplished with strong support from the U.S. National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Department of Energy (DOE),

European Space Agency (ESA), the European Geophysical Union (EGU) and the WCRP, including the support for participation of 26 graduate students and early career scientists (less than 5 years since PhD). Overall, more than 79 registered participants were students (24) or early career scientists (55). Most presented research in posters and several in the oral sessions. An EGU Young Ambassador was invited to attend the meeting and give an oral presentation. The Earth System Sciences Interdisciplinary Center (UMd ESSIC) and Universities Space research Association (USRA) sponsored a career luncheon with the young scientist attendees, to discuss issues pertinent to building careers in the field of earth science modeling and data assimilation. The young scientists also participated as rapporteurs contributing to this final conference report.

The scientific sessions were organized to encourage interdisciplinary discussion and a broad definition of reanalyses. While atmospheric reanalyses have a long record of performance and research, owing to foundations in numerical weather prediction, ocean and land reanalyses have made significant progress in the recent past, especially since the 3<sup>rd</sup> WCRP reanalyses conference. Sessions covered the latest developments from atmospheric reanalysis centres, disciplinary research in atmospheric, oceanic and land modeling and reanalysis, as well as the critical components of observations and data assimilation. In addition sessions on integrated analyses and advancing reanalyses considered latest developments in new areas of research. Climate applications of reanalyses also produced interesting discussions on how reanalyses were being utilized. The conference was closed with a panel discussion with representatives national and international funding agencies and the major organizations that support development of reanalyses products to discuss their needs and expectations for the coming years in all aspects of reanalyses with active participation of conference attendees. This document provides a brief report on the conference and its daily sessions. For those interested in further details the slides and posters presented at the Conference are posted at <http://icr4.org>.

### 3. Sessions Overview

#### a. *Status and Plans*

The conference opened with a Keynote presentation (**Adrian Simmons, ECMWF**) covering the history and rationale of reanalyses, from its conception (suggested from the viewpoint of monitoring forecasting system development based a comment from Roger Daly at ECMWF and by others as well in the early 1980s) through the more recent time, and including some discussion about challenges that have presented themselves as systems have developed. Rather than providing a personal direction to the conference, Dr. Simmons presented a series of questions to the conference participants on the direction of future studies for discussion such as; 1) should we expect a single method to be optimal? How quickly and fully should various couplings be introduced?; 2) should global producers provide global downscaling?; 3) should balances be enforced or used as a diagnostic metric? He highlighted the importance of international coordination among developers, and the need to take on some overarching issues such as: coordination of analysis output (e.g. feedback files), coordination of input observations and their latest versions, linking to modelling activities (e.g. Earth System Grid), coordination on refreshing or terminating data streams. He concluded that the community of atmospheric reanalyses is realizing a third generation (CFSR, ERA Interim, JRA-55, MERRA, ASR) since the first projects in the mid-1990s (ERA15, NASA/DAO, NCEP/NCAR), and then the second wave (ERA40, JRA-25/JCDAS, NCEP/DOE, NARR).

Centres producing atmospheric reanalyses provided overviews of their current reanalysis efforts and a look forward into future developments. The **NASA Global Modeling and Assimilation Office (GMAO)** revisited the development of the Modern-Era Retrospective



analysis for Research and Applications (MERRA) project. In several examples, the current analyses demonstrate improvement in the representation of the large-scale circulation, compared with previous generations of reanalyses. However, significant deficiencies exist, and international collaboration is required to progress more efficiently. The Development of Integrated Earth System analysis (IESA) has progressed in many areas. Notably, weakly coupled aerosol reanalyses show promising results, and offline land and ocean reanalyses are providing a stepping-stone to coupled components. As observed data evolves with more advanced corrections and versions, international collaboration is needed to more efficiently share that knowledge. The input observations and forecast errors from the data assimilation are being made available. Future generations of re-analyses are required to improve the accuracy of the hydrological cycle, stratosphere, polar region, and uncertainty estimates, and reducing trend jump and analysis increments. GMAO strategy for IESA is stepwise, building on the GEOS-5 ADAS and assimilation for other components.

Reanalyses at the **National Centers for Environmental Prediction (NCEP)**<sup>2</sup> have played a critical role in the refinement of the Climate Forecast System (version 2, CFSv2). The CFSR has achieved some significant improvements over previous reanalyses; for example, synoptic rainfall, MJO intraseasonal variability and provides improved NWP initial conditions, and fulfilled a primary goal: to create initial conditions for improved seasonal predictions. As in some current-generation reanalyses, CFSR experienced a spurious shift in the global water cycle as AMSU-A radiances begin to be assimilated. Experimentation with the CFSR system since, based some work at ECMWF with ERA-Interim, has also shown that these discontinuities can be mitigated by appropriate use of SSM/I and AMSU channels during the ATOVS transitions. The rather short spin-ups used to initialize the CFSR six processing streams created discontinuities at the boundaries, notably in ocean, and soil moisture fields. Several problems in the tropical reanalysis resulted from inappropriate bias correction of SSU channel 3 and overly narrow (21st century) structure functions applied during the 1980s. In order to address these issues, and to develop a replacement for the long running NCEP/NCAR Reanalysis-1 dataset, NCEP has developed a plan for a coarser resolution reanalysis to be run using no more than two streams. The plan includes adapting the operational Hybrid 3DVAR EnKF analysis to reanalyze the pre-TOVS period from 1948-1978, to be followed by or run alongside the years 1979-present. As much of the other new technology as possible will be installed in the proposed system, such as the possible utilization of cloudy radiances (in collaboration with NASA GMAO), and acquisition of newly created SNO re-calibrated TOVS and ATOVS radiances from NESDIS. The reanalysis programme across NOAA is in transition onto the new NOAA R&D computing environment, and NCEP is concurrently developing a climate reanalysis strategy to partner system development with ESRL.

The twentieth century reanalysis project is an international collaborative project led by **NOAA/ESRL and CIRES** to produce high-quality tropospheric reanalyses for the last 130+ years assimilating only surface pressure observations (with prescribed SST reconstructed data). The reanalysis provides the first-ever estimates of near-surface tropospheric 6-hourly fields extending back well into the 19th century, along with estimates of uncertainties. Data assimilation is executed using the ensemble filter algorithm (Whitaker and Hamill 2002). The International Surface Databank version 2 (ISPD), the major source of surface observations was assembled in partnership with GCOS/WCRP sponsored AOPC and OOPC working groups, and

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<sup>2</sup> Since the last reanalysis conference, the community has lost two members of the NCEP reanalysis program, Joseph Sela and Masao Kanamitsu, who made extensive contributions to the field throughout their careers.

ACRE. SIRCA (Sparse Input Reanalysis for Climate Application) is the next 2-10 years project of reanalysis spanning 19th-21th centuries. SIRCA (1850-2014) will be available in 2014.

The **Japan Meteorological Agency (JMA)** is conducting their second global atmospheric reanalysis JRA-55 (JRA Go! Go!). It covers 55 years, extending back to 1958. JRA-55 is the first reanalysis which covers more than 50 years with a 4D-Var data assimilation system. Reprocessed AMV and CSR of GMS and MTSAT and inflated background error for non-satellite era are also introduced for JRA-55. Early results of JRA-55 were presented and discussed, showing general improvements from JRA-25. Specifically, a large temperature bias in the lower stratosphere was significantly reduced by introduction of the new radiation scheme to the forecast model. The variational bias correction (VarBC) contributes to the diminution of unrealistic temperature variations found in the lower-stratospheric time series based on JRA-25. The dry land surface problem in the Amazon basin in JRA-25 was mitigated. While JRA-55 uses as many types and numbers of observational data as possible to give the best instantaneous field estimate, supplementary products are being provided without assimilating any satellite data (JRA-55C) and with no observational data (JRA-55AMIP). JRA-55C aims at retaining consistency for long years, even if its analysis quality may be inferior to JRA-55. JRA-55AMIP aims at confirming basic performance of the forecast model used in JRA-55. This set of reanalyses (the JRA-55 family) is expected to contribute to addressing some of the issues of current reanalyses such as impact of changing observing systems on representation of long-term climate trends and variability. Computations of JRA-55 for more than 35 years have been completed as of May 2012. The entire JRA-55 production will be completed in spring 2013.

The **European Centre for Medium-Range Weather Forecasts (ECMWF)** has extended the ERA-Interim reanalysis backward by a decade to 1979. Mainly as a result of the variational bias corrections of satellite radiances, the matchup with the beginning of the original production stream in 1989 is nearly seamless and the mean fit to radiosonde temperatures is well maintained throughout the 33-year period, from the lower troposphere up to the lower/middle stratosphere. However, fundamental limitations to the achievable temporal consistency in reanalysis will remain as long as models are imperfect and observations incomplete. Spurious shifts in ERA-Interim global mean precipitation have been caused by problems with the assimilation of rain-affected SSM/I radiance data; prospects for further improvement in this area are very good. ECMWF has also developed a new public data server that can be used to download global ERA-Interim fields at full resolution, with options for re-gridding and regional selection. Preparations for a new ECMWF reanalysis of the 20th century are now taking shape, under the umbrella of the EU-funded ERA-CLIM project.

In recent years, ocean reanalyses have thrived, providing data for climate variability studies and forecast initializations (**Detlef Stammer, U. Hamburg**). There are many ocean only and coupled-models development centers, and a substantial number of ocean reanalyses, using a variety of assimilation methods. The data has many applications such as climate variability of ocean heat content, the water cycle, salinity and convection, and sea level change. As in atmospheric reanalyses, the quantity and quality of ocean observations changes throughout the historical period, especially starting in the 2000s with the availability of more subsurface observations. Indeed, new observations will also begin to make a further impact on the ocean reanalyses, for example, GRACE bottom pressure and SMOS and Aquarius satellites ocean salinity observations. The number of reanalysis data sets has led to ensemble studies that are exposing the strengths and weaknesses of the data and its potential uses. This should contribute to the evolution of the methodology and quality of the reanalysis data.

## *b. Atmospheric Reanalyses*

The session on atmospheric reanalyses began with two invited talks about regional reanalysis efforts, and in particular about several international intercomparison projects using regional reanalyses. **Dale Barker (UKMO)** focused on the question of what there was to gain from a regional reanalysis at 12 km resolution, given the advent of global reanalyses at 25 km resolution. He stressed that the potential for benefit lies in the near surface weather, and is anticipated to come from the additional resolution, and the assimilation of radar and visibility observations. Early plans for the European regional reanalysis ensemble approach, with the acronym EURO4M, were presented, and some results from early simulations were presented as “proof of concept”. In answer to a question raised from the audience, Dr. Barker reported that the regional reanalysis fields did not exhibit any apparent issues related to the lateral boundaries in the early simulations.

**William Gutowski (Iowa State U.)** presented the model evaluation element of NARCCAP (North American Regional Climate Change Assessment Program), a regional model intercomparison focused on the continental United States, and the follow-on CORDEX (Coordinated Regional Climate Downscaling Experiment), examining regions covering most of the land areas on the globe. Results from the intercomparison revealed that the ensemble averaged fields match the verification more closely than any one model result, thus highlighting the importance of the use of ensembles of regional simulations. Some sensitivity to the reanalysis forcing is noted, causing systematic biases in the states and physics fields of the regional model.

The remaining talks in the session were focused on the use and evaluation of global reanalyses for different purposes, ranging from detecting climate change to assessing model bias. **Muthuel Chelliah (CPC/NCEP)** assessed the variability of CFSR, and compared against ERA-Interim and MERRA. The focus of the talk was on some aspects of variability in which the CFSR is an “outlier”. A spurious trend in global mean winds, humidity and temperature in the most recent few years of the CFSR period was shown, along with “outlier” behavior of ENSO indices, weaker vertical wind shear than the other reanalyses, and a weaker Walker circulation. For tropical climate studies, the CFSR may represent an improved reanalysis, because it is the first reanalysis now that is based on a coupled (partly) atmosphere-ocean-sea ice model and assimilation system.

In an invited talk, **Prashant Sardeshmukh (CIRES, NOAA ESRL)** provided an assessment of changing extremes in the 20CR. He clearly demonstrated the “non-Gaussianity” of some important indicators of climate change, that they are skewed and heavy-tailed, and made the case that these characteristics make detection and attribution difficult. He also cautioned that the newest generation of free-running simulations do not depict decadal variability well, and emphasized the need for long reanalysis records such as the 20CR surface pressure reanalysis record, or even longer. In order to represent the extremes, a model must adequately represent the first four moments of daily variability. Using this method, the 20CR does not show any substantial change in the NAO and Pacific Walker circulation from 1901 to the present.

**Mark Serreze (NSIDC CIRES)** examined the radiosonde and reanalysis records for the expected increasing trend in water vapor based on the increasing trend in temperature. He found that the reanalyses and the radiosondes all show a small increasing trend in water vapor, but that the radiosondes show the maximum trend in the fall and winter whereas the reanalyses all show a summertime trend. All of the reanalyses have a moist and warm bias at low levels. The reanalyses and radiosonde profiles are in general agreement in showing recent increases in tropospheric water vapor, which should be acting as a feedback to amplify warming.

The final two talks of the session were focused on the use of data assimilation for assessing and improving GCM error. **Dave Williamson (NCAR)** showed the results of a series of “Transpose-AMIP” experiments, which are short term forecasts initialized from reanalysis.

The model's climate error is mimicked in the 1-3 day difference from the (verifying) reanalysis, and the example of CAM5 precipitation error at high resolution was shown to analyze the character of the error. Some suggestions regarding the interactions between the reanalysis developers and user communities were discussed. For example, simple first order statements, such as, observations did affect the analysis in this area, or the analysis is very close to model first guess, would be useful to users. Also, reanalysis developers should make quality comparisons and advise potential users on where the analyses should and should not be used. Given the wide range of applications of reanalyses, this last suggestion needs to be addressed jointly with the user community.

**Andrea Molod (NASA GMAO)** described "Replay" experiments as a continuous simulation, constrained to follow the assimilation record with the addition of a 'data increment', computed as the difference between a short forecast and an assimilation field, calculated every 6 hours of the simulation. A series of parameter sensitivity experiments with replay were presented to assess the optimal parameter choice, based on precipitation and the size of the replay data increments. The replay result, developed from essentially modeling experiments, was confirmed with a set of data assimilation experiments.

The posters in the *Atmospheric Reanalysis* session were focused on studies which evaluated a wide variety of aspects of the different reanalyses. Several studies evaluated extreme precipitation events over the United States, in general finding that the short-term large extreme events are underestimated in all the reanalyses. Several studies were also presented examining the trends in the Arctic, finding general agreement among the reanalyses, but with some differences in details. Another group of studies examined tropical and extratropical storm behavior in the reanalyses. Again, in general, the reanalyses generally matched the observations well. One study examined the net radiation in the different reanalyses, and found that although the OLR is well captured, the reflected shortwave radiation is not and the result is a net imbalance at the top of the atmosphere of a few  $W/m^2$  in all three modern reanalyses. A series of posters was presented highlighting the improvements in the JRA-55 reanalysis relative to JRA-25. Two stratospheric studies focused on the impacts of the SSU/AMSU discontinuity in the observational record. Finally, two studies examined decadal variability from the reanalysis records, and showed robust signals by examining interannual precipitation anomalies in one, and by examining atmospheric angular momentum budgets in the other. Both of these studies found robust decadal signals despite the well known discontinuities in the observational record.

Overall, there appear strengths and weaknesses in the atmospheric reanalyses. These cannot be fully exposed by the developing centres themselves. It remains to be seen how best to convey this information to new users. The wiki based website, [reanalysis.org](http://reanalysis.org), is a grassroots attempt at such an enterprise. However, the conveyance of results there has not progressed.

### c. *Integrated Reanalysis*

**Arlindo da Silva (NASA GSFC)** provided an overview of the MERRA aerosol reanalysis toward an Integrated Earth System Analysis (IESA), reviewing various aerosol sources, their lifetime and major environmental impact through weather modification (precipitation patterns and temperature profiles), climate change (competition with greenhouse gas warming) and health hazards. Large uncertainties remain in the direct and indirect (cloud albedo) aerosol radiative forcing. IESA considers all land, atmosphere, ocean, carbon and aerosols (such as dust, sea salt, sulfate, black carbon and organic aerosol). The MERRAero version 1.1 is scheduled for public release in Summer 2012 and includes both 2D and 3D datasets. Daily fire emission data sets are based on MODIS fire radiative power tuned by inverse

calculation of aerosol optical depth (AOD) with prescribed diurnal cycle. Aerosol data assimilation focuses on NASA EOS instruments, MODIS for now, with 3D increments. AOD variables are being log-transformed and bias corrected. Empirical retrievals are achieved separately for the ocean and land using neural networks, the latter being more challenging due to the albedo. MERRAero clear-sky aerosol direct radiative effect compares well with previously published estimates over land and ocean. MERRAero provides time series of gridded aerosol products that are consistent with MODIS and in-situ AOD measurements. Analysis increments were demonstrated to be useful to diagnose errors in emission/removal processes. Inclusion of additional EOS aerosol sensors requires systematic homogenization of the observing system. Future efforts will include multi-channel 1D-Var approach for NASA EOS instruments and the assimilation of CALIPSO attenuated backscatter.

**Kei Yoshimura (U. Tokyo)** presented a 20th century isotope reanalysis based on time series in corals, tree-rings and tropical ice cores and offering a cost-effective way to dynamically downscale an ensemble mean field and make a first comparison with historical isotopic proxy data. Stable isotopes provide a “time capsule of climate” covering a much longer record than man-made observations. Through a forward proxy modeling approach with a GCM/RCM and offline modules, the impact from each environmental factor is explicitly quantifiable. Data assimilation is achieved via spectral nudging but it is questionable whether the ensemble mean fields are appropriate lateral boundary conditions because the transient component of moisture divergence is smoothed out in the ensemble mean field. A systematic downscaling for each member would be too expensive; instead, a method using ensemble mean increments modifying single members is developed and clearly improves skill, almost as good as when 3 members are used directly.

**Rongqian Yang (EMC/NCEP/NWS/NOAA)** analyzed surface water and energy budgets over the northern hemisphere in three data assimilation systems, which are impacted by the land model physics and the way and efficiency by which observations (precipitation and snow) are assimilated in the system. Whilst the OSU LSM (GR2) uses direct observed precipitation and snow cover, CFSR has an implicit approach to the same variables. CFSR precipitation is lower than GR2 in summer, both being higher than GLDAS. CFSR evaporation is much lower than GR2 both in summer and winter and lower than GLDAS in winter. CFSR runoff is much lower than GR2 both in summer and winter and they are both lower than GLDAS. GR2 soil moisture is closer to GLDAS. The water CFSR and GR2 anomaly fields are comparable, GR2 having the largest interannual variability. CFSR has slightly lower net shortwave and high net longwave in summer than GR2, both being close to GLDAS. CFSR latent heat flux is lower than GR2 in summer, both being higher than GLDAS. CFSR sensible heat flux is higher than GR2 in both seasons and closer to GLDAS. CFSR, GR2 and GLDAS surface temperature are all in good agreement. The CFSR and GR2 energy anomaly field are comparable, with GR2 having the largest interannual variability. The new NCEP CFSR has many improvements, especially on summer high bias in precipitation in the GR2 via the new Noah LSM as well as recent advances in atmospheric model physics.

The budget terms in CFSR are in closer agreement with the offline GLDAS using the same land model, implying that land atmosphere interaction is well represented in the CFSR. Surface water budgets are mainly impacted by precipitation, which is determined by background model bias and efficiency of the assimilation technique. The direct removal of soil water in GR2 is not efficient as the background model has a high bias. The adjustment made to soil moisture in the CFSR via the semi-coupled GLDAS approach does improve soil moisture in the CFS, which is very important to summer-season predictions. Surface energy budgets are in better agreement

with each other and with the satellite retrievals. The inter-annual variability in both surface water and energy terms are close to each other.

**David Bromwich (Ohio State U.)** presented the plans for the very high resolution (10 km, 3 hrs) Arctic System Reanalysis (ASR) covering 2000-2011 which has adopted a system-oriented approach and will provide a convenient synthesis of Arctic field programs. The ASR includes an optimized version of WRF, the WRF variational data assimilation and a high resolution land data assimilation (HRLDAS). The model implements a fractional sea ice description in the Noah LSM as well as a variable ice thickness and snow cover. It also improves treatment of heat transfer for ice sheets and a revised surface energy balance calculation in the Noah-LSM. Model evaluations have been performed over Greenland, the Arctic Ocean (SHEBA site), Alaska, and Antarctica. ASR-Interim (30 km) uses atmospheric sea ice and land observations for comparison. ASR-Interim shows superior skill to ERA-Interim on wind speed, 2m temperature, 2m dew point and surface pressure and more realistic circulation patterns. The results from the ASR-Interim data assimilations are hence very encouraging. The Polar WRF, WRF-3DVar and Noah Land Data Assimilation will be updated to correct the bias in Q2m, T2m, and precipitation, and to improve ASR performance for the final run at 10 km scheduled for completion in September 2012. ASR data are distributed by NCAR's Research Data Archive and NOAA Earth System Research Laboratory (ESRL).

#### *d. Ocean Reanalysis*

ECMWF and NCEP have done reanalyses that are primarily in support of operational seasonal to interannual forecasting. **Magdalena Balmaseda (ECMWF)** presented a discussion of the new ECMWF Ocean Reanalysis System (ORAS4). The system uses the NEMO ocean model at 1° resolution and the 3DVar version of NEMOVAR. It assimilates subsurface temperature and salinity, SST and sea surface height from satellite altimetry, and is forced by surface fluxes from ERA-40 and ERA-Interim. The ORAS4 displays some interesting climate signals: decadal variation in the Atlantic Meridional Overturning Circulation (AMOC) including a slowdown in the most recent decade, a vertical redistribution of heat content, and changes in the Pacific equatorial thermocline associated with changes in the wind-stress. Uncertainty with respect to these signals will remain until the sensitivity of the reanalysis to such things as the distribution of the observations, bias correction and SST variations can be evaluated.

With the Climate Forecast System Reanalysis (CFSR), NCEP has taken the pioneering step of constructing a quasi-coupled reanalysis where the separate atmosphere and ocean components take their first guess from the coupled model forecast. R. Kistler discussed the CFSR in some detail in Status and Plans; here, **Caihong Wen (NOAA NCEP CPC)** presented a study of Pacific tropical instability waves (TIWs) in the CFSR. The reanalysis produces coherent patterns associated with the TIWs both in ocean and atmosphere, which vary seasonally with the oceanic cold tongue. The pressure-driven winds are in phase with the SST. The surface wind convergence produces a vertical circulation cell, which in turn, causes large variations in water vapor and low-level cloud cover. The variation in net heat flux produced by the variations in winds, water vapor and low clouds result in a negative feedback on the SST of about  $40 \text{ Wm}^{-2}\text{K}^{-1}$ . Compared with *in situ* and satellite observations the TIW variability is well reproduced in the CFSR, although the strength of the variability of SST and wind is too weak by about 25%.

The goal of the MyOcean project is to deliver operational products based on ocean state estimation that are designed to assist those responsible for environmental and civil security policy making, assessment and implementation. There were three presentations based on reanalyses associated with MyOcean. **Andrea Storto (Centro Euro-Mediterraneo per i**

**Cambiamenti Climatici**) described the CMCC eddy-permitting global reanalysis, comprised from the NEMO 3.2 ocean model (at  $\frac{1}{4}^\circ$  resolution) and the C-GLORS 3D-Var assimilation. The UK MetOffice EN3 temperature and salinity profile data, NOAA SST and all available altimetry and a mean dynamic topography from AVISO are all assimilated. Otherwise, ERA-Interim provides surface atmospheric forcing. To reduce model bias, particular care is taken to first correct the precipitation flux and the radiative fluxes through intercomparisons with satellite based data products. Another important factor in the skill of the reanalysis is the use in the analysis of non-homogeneous, seasonally dependent background error correlation length-scale and covariance. Further work will be done to improve the vertical temperature – salinity covariance and to improve the initialization and spin-up of the reanalysis.

**Laurent Parent (Mercator Océan)** presented the Global Ocean Reanalysis and Simulation (GLORYS), a cooperative effort of the French CNRS, Mercator-Océan and CORIOLIS. This system is also based on the NEMO3 ocean model at  $\frac{1}{4}^\circ$  resolution with 75 vertical layers. The assimilation system is a reduced order Kalman filter (SEEK). A 3D-Var scheme is used to correct model temperature and salinity bias prior to applying the SEEK filter. The assimilated data are temperature and salinity from the CORIOLIS data centre and altimetric data from AVISO. GLORYS is forced with a combination of Large-Yeager CORE surface fluxes and ERA-Interim turbulent fluxes and surface radiation. GLORYS correlates well with 3-day average time-series from the global array of tide gauges. Meridional Atlantic transports in GLORYS correlate well with estimates from the RAPID array at  $26.5^\circ$  N, although the vertical distribution of the transport is not well resolved in GLORYS. **Bernard Barnier (LEGI-CNRS, Université de Grenoble)** offered a particularly interesting example of the potential benefit of eddy permitting ocean models. This was the demonstration that in the GLORYS at  $\frac{1}{4}^\circ$  resolution, the analysis increments in the Labrador Sea mimic the effect of otherwise unresolved eddies in re-stratifying deep convective columns. While this may be a local effect particular to the Labrador Sea, it could have beneficial consequences for monitoring the Atlantic meridional overturning circulation.

Two presentations were given regarding historical ocean reanalysis reaching back to the 19th century. **Benjamin Geise (Texas A&M U)** discussed an ensemble of ocean reanalyses for the period 1871-2008, forced by momentum fluxes from the 20th century atmospheric reanalysis (20CRv2) and bulk formulae derived from its atmosphere. The Simple Ocean Data Assimilation (SODA) built on the POP ocean model was used for the reanalysis and only SST data from ICOADS 2.5 were assimilated. The SST data are sparse in the early stages of the reanalysis, but they begin to have a sufficient impact early in the 20th century for the reanalysis to capture the basic structure of El Niño events. The results show strong El Niños at either end of the 20th century and variability in the location of the events, but no trend in either of these features. **James Carton (U. Maryland)** described experiments with SODA for the period 1995-1998 where a Nature Run was subsampled for synthetic observations of the type and distribution available during different time periods of the 20th century. Experiments forced with monthly climatological surface fluxes showed that not until 1960s were there sufficient surface and subsurface observations for the analysis to reproduce both phases of ENSO and shifts in the Indian dipole in the absence of information from surface forcing. Conversely, experiments forced by 20CRv2 were able to reproduce the same climate anomalies with only the observations that would have been available in the 1920s. In other words, there was enough information in 20CRv2 to achieve this result in the absence of extensive ocean observations and, thus lend some credence to long historical reanalyses.

**Shaoqing Zhang (NOAA GFDL)** described progress with the Ensemble Coupled Data Assimilation (ECDA) system. The ECDA v3.1 couples the CM2.1 atmosphere and the MOM4.1

ocean, and is used to reanalyze the second half of the 20th century. While biases remain (e.g. too strong trades and too weak westerlies), the reanalysis successfully captures important climate signals. The ECDA currently assimilates synthetic atmospheric observations from the NCEP/NCAR reanalysis raising the issue of a “double bias” in the analysis which will be addressed by assimilating real observations directly. A number of ambitious projects are anticipated for the next several years: a high-resolution CM2.5 ECDA v4.0 for seamless weather through climate studies, an extended variability estimation and decadal prediction study with CM2.1 ECDA v4.0, the impact of sea-ice observations on decadal variability, and an earth system project assimilating altimetric and land data.

**E. Joseph Metzger (Naval Research Laboratory)** described an eddy resolving  $1/12^\circ$  global reanalysis that uses the Hybrid Coordinate Ocean Model (HYCOM) and the Navy Coupled Ocean Data Assimilation (NCODA) scheme and spans the period 1993-2010. The analysis uses atmospheric forcing from NCEP’s CSFR with the wind-stress derived from the 10m winds, bias-corrected relative to QuickScat satellite observation. The project is unique in resolving the mesoscale ocean eddies in a full global analysis. Its purpose will be to provide the U. S. Navy with a tool for training and planning activities that require information on the variability of the ocean climate at a resolution necessary for Navy operations.

**Jieshun Zhu (COLA/IGES)** discussed the variability of upper ocean heat content in the tropical Atlantic as represented in a six-member ensemble of ocean reanalyses. The signal is relatively weak and a conventional EOF analysis of each member showed large variability across the members in the leading modes. An EOF analysis of the ensemble average validated well against altimetry sea level, suggesting that using an ensemble average rather than a single analysis might be a better way to study climate variability in regions where the signal to ratio is weak. Additional studies of multiple reanalysis products were presented as posters. **Nicole Colasacco-Thumm (U. of Wisconsin-Madison)** evaluated surface heat fluxes associated with the ENSO in five atmospheric reanalyses, while **Masahisa Kubota (Tokai U.)** studied Northern Hemisphere high-latitude heat fluxes in eight atmospheric reanalyses. Furthermore, **Arun Kumar (NOAA NCEP CPC)** looked at the ocean-atmosphere feedbacks associated with ENSO and found that while there was overall agreement among the analyses, there were significant differences in the details and concluded that the ensemble average was better than individual members for this purpose.

A poster by **Johnson Zachariah (Cochin U.)** presented a study that used NCEP’s GODAS reanalysis to construct a more complex description of the Lakshadweep Low than what was previously accepted in terms of its variability and propagation along the Indian Equatorial wave guide. Two studies, described in posters, used ocean-data synthesis to correct atmospheric forcing variables thus producing consistent less biased ocean model experiments. **Armin Koehl (U. Hamburg)** examined changes in heat and fresh water content in the 1948-2009 GECCO2 adjoint analysis where the atmospheric variables, surface temperature, humidity, precipitation and 10m winds, were included in the control vector. In another poster, **Marion Meinville (LEGI-CNRS Grenoble)** presented an experiment that corrected the same atmospheric variables (and downward radiation) from ERA-Interim by a somewhat different method. The idea was to take advantage of the relative accuracy of satellite SST observations. With the atmospheric variables again included in the control vector, SST was assimilated into an ocean model using the SEEK filter. The atmospheric variables are corrected in accord with observed SST and ocean dynamics (e.g. removing a negative trend in the net heat flux that would otherwise cool the ocean).

Finally, while most work presented used global reanalyses, two poster presentations were concerned with regional analyses. **Maria G. Escobar (Escuela Superior Politécnica del**



**Litoral**), examined the potential of a reanalysis based on the Regional Ocean Modeling System (ROMS) in the part of the eastern Pacific between the Galapagos Islands and the coast of Ecuador. **Ye Liu (Swedish Meteorological and Hydrological Institute)** presented experiments in the Baltic Sea using the Rossby Center Ocean (RCO) model and an ensemble OI assimilation system. Ultimately, accurate operational analyses in both regions would have important societal benefits.

**Bernard Barnier (LEGI-CNRS)** provided some insights from the European Project MyOcean, which is developing and operating an Ocean Monitoring Service including GLORYS, a global ocean reanalyses. He discussed global ocean (including sea-ice) reanalyses covering the altimeter era at eddy-permitting resolution, much higher than used in atmospheric reanalysis. Whilst the ocean observing system has continuously improved, especially with the Argo profiling network and satellite altimetry which provide access to ocean currents and constrain model dynamics, the situation has actually worsened below 2000m depth. The DRAKKAR model uses a SEEK filter with background error covariances calculated from an ensemble of 3D anomalies, adaptive error covariances consistent with the innovation, a bias correction for temperature and salinity and an incremental analysis update. The benefit of assimilating Argo data starting around 2003 is very apparent in global error statistics. The examination of innovation data allows the detection of erroneous observations. The intercomparison with other coordinated MyOcean reanalyses and with independent estimate suggests skills for sea level changes and upper ocean heat content. Air-sea fluxes and meridional circulation remain challenging quantities to be estimated. Recommendations include the continuation of altimetry missions and the Argo fleet, the rescue of more historical data, and the move towards eddy-resolving reanalyses.

*e. Land Reanalysis*

The foremost limitation of land reanalyses is the accuracy of their precipitation forcing, and to a lesser degree, the accuracy and consistency of all atmospheric (e.g., precipitation, radiation, surface pressure, wind, and air temperature, humidity, carbon dioxide) forcing. Atmospheric forcings are particularly uncertain for the pre-satellite era (i.e., pre-1970s). Land reanalyses such as MERRA-Land explicitly demonstrate the impact of direct insertion of observed precipitation on the land surface hydrology of the reanalysis. Likewise, CFSR demonstrates improvements via a semi-coupled land analysis, forced with a blended gauge-satellite precipitation product, every 00Z. However, the fact that CFSR is outperformed by NLDAS Noah over CONUS underscores the need to correct not only precipitation, but other atmospheric forcings as well. Improvements in the land reanalysis can also derive from the land itself.

**Rolf Reichle (NASA GMAO)** discussed the MERRA-Land team efforts toward the implementation of direct input and/or assimilation of satellite retrieved parameters (e.g., soil, vegetation, albedo) and land states (e.g., soil moisture, snow, and terrestrial water storage) to avoid the use of look-up tables (e.g., time-invariant constants and fixed seasonal cycles). In an off-line post-analysis framework, he demonstrated significant improvements of the MERRA-Land surface and root zone soil moisture through assimilation of remotely-sensed surface soil moisture (AMSR-E). The development path is toward multivariate assimilation (e.g., of soil moisture, land surface temperature, and snow cover) in a coupled land-atmosphere system. The land component of the carbon cycle, including data assimilation, is under development.

Land surface evapo-transpiration is a key component of both the water and energy cycles, as well as integral to land-atmosphere interactions. **Brigitte Mueller (ETH Zurich)** evaluated

the evapo-transpiration from reanalyses, model sources, observed records and the IPCC climate simulations. Reanalyses tend to have higher precipitation and evaporation over land compared with models and available observed data. Most data sources show declining trends of evapotranspiration in the southern extratropical regions during 1998-2005, however, models and reanalyses are more varied and uncertain in the equatorial tropics. The land temperature records of reanalyses appear robust, at least for efforts looking at land atmosphere interactions. The coupling of the land in reanalyses encompasses more land area than has been diagnosed in previous modeling studies.

There is strong interest within the user community to apply reanalyses to investigate hydrometeorological extremes (i.e., flood, drought, and heat waves), and long-term trends, as well as their relation to CMIP5 historical and 21st century projections. An open question is how accurate are reanalyses' screen-level variable fields (i.e. temperature, humidity, pressure, and wind)? While temperature is generally a robust quantity over land, regional biases in any given reanalysis can occur. **Xubin Zeng (U. Arizona)** developed a bias corrected reanalysis temperature data set from the MERRA 1-hourly surface collection. This high frequency data allows testing of the definitions of minimum, maximum and mean daily air temperature, in order to perform inter-comparison with observed records (Tmin, Tmax). In their example, the CRU (Tmax minus Tmin) in winter decreases with time from 1979-2009 much faster than the adjusted MERRA data. The results show that the 24-hourly mean to represent daily and monthly mean T are more accurate than the historical method (i.e. (Tmax+Tmin)/2). Zeng's recommendation is for the adoption of a new paradigm for national climate data records. In the future, reanalyses should provide 1-hourly frequency for surface and diurnally varying quantities.

For more timely completion of modern high-resolution reanalyses several production streams have been used (i.e., six for CFSR, three for MERRA). **Jesse Meng (NCEP)** evaluated the land processes of the NCEP CFSR. Despite a year or more of spin-up (or stream overlap), some examples show that the total soil moisture column carries the shock of the initialization forward. Naturally, this raises a concern for step shifts in the time series, which could affect and/or effect trends, as well as the accuracy and uncertainty of the data. Dependent on the application, issues of spin-up and stream discontinuity will be of more or less of an issue. NCEP has planned a single stream land reanalysis to reduce the spin-up issues related to new data streams, thereby improving data support for applications such as the Global Drought Monitor.

Land forcings and coupling (interactions) are crucial for regional climate and applications, underscoring the need for corresponding and well-coordinated validation programs. Reanalysis centres do not have the resources to evaluate every potential use of the data and must rely on the feedback of independent investigators. International projects, such as GLASS and GHP are significant contributors to such activities, and should be encouraged to maintain communications with the reanalysis development centres.

#### *f. Data Assimilation*

As noted by **Dick Dee (ECMWF)** assimilation of atmospheric observations continues to progress in complexity as well as spatial and temporal resolution. Within the ERA-CLIM project, development of a hybrid ensemble variational data assimilation system advances the suite of tools at ECMWF; the ensemble approach may provide a means of populating the background error covariance matrix with time-variant information, heretofore an unresolved issue in variational assimilation. The initial demonstration of assimilating surface pressure observations now offers some promises for a hybrid data assimilation system. The longer assimilation windows reduce background errors which are smaller in the interior of the window.

This is easier to exploit in reanalysis than in forecasting. Overlapping windows suggest improved forecasts against contiguous windows. Weak-constraint 4D-Var can be used to estimate persistent model errors, for recent periods, for example, which can then be applied in the past to poorly observed periods. The need for coupling with the ocean was illustrated on MJO representation in seasonal forecasting.

**Toshiyuki Ishibashi (JMA)** discussed linear and nonlinear observation impact approaches, whilst recognizing they provide different quantities and cannot be compared to each other. The tangent linear model based approach sheds light on the spatio-temporal evolution of the impact of each dataset, which can be compared with integrated background errors. Covariance optimization including a linear observation impact estimation based on expectation or sensitivity measures were presented. The latter allowed diagnosis of a too large observational error covariance and too small background covariance in the JMA GDAS system. An extended 4D-Var data assimilation with reference analysis information is helpful in analyzing errors of a data assimilation system and to design future observational systems. With the variational assimilation systems presented, the accurate, time-varying estimation of error covariance matrices represented the main challenge to move forward.

**Christian Keppenne (NASA GMAO)** discussed the potential benefit of ensemble data assimilation schemes deriving background-error covariances in time and especially space from a single model run compared to traditional EnKF and EnOI. Adaptive error covariance inflation to aim for preset target value, logistic transformation of the ice field in the Arctic, and flow adaptive localization were some of the technical details presented. The method provides multivariate updates of unobserved variables. The space-derived covariances seem most effective.

According to **Zhiquan Liu (NCAR)** both the 3D-Var assimilation of Arctic observations in the Arctic System Reanalysis (ASR) and the effort to correct radiosonde measurements of temperature and wind profiles have revealed the importance of correcting for biases in the retrieved values before assimilation can be profitable. The seasonal variation of model forecast errors in the stratosphere forms the basis for background error covariance statistics. Discontinuities caused by background error covariances suggest the need to use nudging near the top of the grid. Efforts to employ variational bias correction (VarBC), an approach employed by ECMWF, will be pursued in both ASR and ERA-CLIM data assimilation efforts.

**Jack Woollen (NOAA)** presented a study of four problems identified in diagnostic reviews of the CFSRR reanalysis, and discussed the adjustments required and the experiments made to demonstrate resolution of the issues. The VarBC was turned off for SSU channel 3 which resolved the model warm bias feedback introduced by applying the bias correction in the otherwise data void region near the model top, and resulted in large jumps at the stream boundaries. Jumps in radiosonde radiation bias corrections caused by changes in operational tables created discontinuities in mean fits to radiosonde temperatures and a potentially bad interaction with the variational satellite bias corrections, which was addressed by installing a continuous adaptive procedure based on evolving monthly statistics. The tropical tropospheric cold bias against radiosondes (and other reanalyses) during the 1980's was corrected by increasing the forecast variance at all levels in the data sparse tropical region. The QBO wind reversal was not well captured in the CFSRR system, which was also largely due to overly narrow tropical forecast error covariance structure function pre-1998. The corrections will be carried into the next round of NCEP reanalyses as important lessons learned.

**Marco Milan (University of Wien)** presented variational bias correction methods for radiosonde data (temperature and wind) and discussed various bias models, assuming the model itself is unbiased. The wind bias is normally constant over the whole profile whilst for

temperature a more physical approach is warranted, taking into account various groups of radiosondes.

**Saroja Polavarapu (Environment Canada)** analyzed some of the unique challenges of middle atmosphere data assimilation which are related to the dynamics of this region such as the Brewer-Dobson stratospheric wave-driven circulation. It was noted that model lids have been raised to 80 km at operational centres in the past 10 years, stressing the importance of better assimilating satellite radiances with sensitivities to 0.1 hPa. Assimilating data below the mesosphere improves large scales in the mesosphere. It is also recommended not to bias correct observations at model top and rather anchor analyses at top using uncorrected data. Gravity waves propagate the information vertically. They may be a nuisance in the troposphere but they are prevalent in the mesosphere and are part of the signal. Gravity Wave Drag schemes can be helpful by parameterizing the effect of subgrid scale waves on the mean flow using assumptions about sources in the troposphere, vertical propagation and breaking. These issues are being addressed within the Stratospheric Processes and their Role in Climate (SPARC) reanalysis intercomparison project.

*g. Applied Climate Uses of Reanalyses*

The vertical heating profiles in reanalyses are crucial to understanding the background modeling and physics of the processes as noted by **Chidong Zhang (RSMAS U. Miami)**. Differences exist across the various atmospheric reanalyses, generally related to their cumulus parameterizations, and these differences can significantly affect results. Tropical convection shows bimodal and trimodal heating peaks, depending on reanalyses, and in the tropics, the variations among reanalyses are substantial. However, current observations are insufficient to verify the reanalyses. Field campaigns have the observations in certain locations, but are costly, yet, more are needed.

Reanalyses provide the data to force many other models and diagnostics. **Paul Dirmeyer (GMU/COLA)** used MERRA to force quasi-isentropic back trajectories of water mass in the atmosphere, to better explain global and regional water cycles. The new tool presented here is the Relative Entropy (also called Kullback-Leibler Divergence or Information Divergence) which measures the difference between two probability distributions. In this study, one distribution is the climatological evaporative source for rainfall over a given area, and the other distribution is the source conditioned on extremes in precipitation (“drought” and “flood” deciles). The results show that droughts are more driven by circulation changes while flood events are more driven by local sources of water. The budget closure in the reanalysis data can have an effect on methods like these, and improved closure would reduce the uncertainty.

Initial conditions for seasonal forecasts have importance, especially in the soil moisture. Using the CFSR initial conditions for seasonal predictions, **Kingtse Mo (NOAA CPC)** evaluated soil moisture seasonal forecasts from the CFSv2 model. Spin up of the background forecast over the first 6 hours led to initial condition errors and ultimately significant degradation of the seasonal prediction. The spin up problem prevents the coupled land analysis from reaching its full potential in seasonal predictions.

The NCEP CFSR tropical cyclone relocator has allowed for improved representations of tropical cyclones in the reanalysis fields. **Ben Schenkel (FSU)** has evaluated tropical cyclones in CFSR, focusing on their impact on the large-scale environment. Tropical cyclones in the Pacific seem to have systematic effects on the tropical easterly jet and the polar jet, traceable to the heating and moistening anomalies the TCs generate. There is some difference among reanalyses, but the large scale pressure anomalies are generally consistent.

Validation of CMIP5 present day climate is important, but generally limited to the more data rich areas and regions. **Chunxue Yang (Texas A&M U.)** used the SODA ocean analyses to compare with presently available CMIP5 present day simulations, especially focusing on the characteristics of ENSO. The SODA ocean analysis is an ensemble, driven by the 20CR atmospheric ensemble, which permits the extension of data back in time to the 1870s. The results indicate that 1) the CMIP5 models produce a reasonable ENSO in strength and location, 2) ENSO does not change much over the century (in either SODA or CMIP5 simulations) and 3) most models do not capture the asymmetry between El Niño and La Niña.

With scarcity of observed data in many regions, reanalyses can be useful tools for applied interests. For example, **Gil Lizcano (Vortex R&D)** presented an overview of the use of reanalyses in the wind energy industry. In many regions, installing an observing site can be prohibitively expensive. Reanalyses may be able to help with optimizing site location, in conjunction with regional model downscaling, and multiple sources of data (for uncertainty estimates). While some systematic biases are evident, reanalyses are proving useful to the industry.

In discussing global energy and water budgets, **Kevin Trenberth (NCAR)** evaluated all of the most recent reanalyses, especially looking at the ocean-land transport and using TOA radiation, GRACE and runoff data. Many differences among reanalysis transport occur, possibly related to resolution (coastlines), topography, sea ice and lakes, noisy fields (e.g. divergence) and significant differences in the P and E fields. Ultimately, P and E are generally too large in reanalyses, and so water residence time is too short. The atmospheric moisture budget provides better estimates of the divergence (P-E) field than does P and E. Substantial variations in the constant definitions of reanalyses exist (e.g. topography and land/sea masks). While there are notable improvements over the previous generations of reanalyses, there is room for significant advancement and reduction of uncertainty.

#### *h. Observations: In-Situ*

**Leopold Haimberger (U. Wien)** presented recent work on the bias adjustment for the upper air temperature and wind data. Spatio-temporal consistency has improved and now provides uncertainty estimates. The comparison with neighborhood data is useful in this context. An amplification of surface trends was noted in the tropics. Homogenization of pre-1958 data using 20CR appears feasible. The sampling bias in early wind speed data is currently being explored using a variational approach. It is recommended to exploit GSICS efforts for remote sensing temperature bias adjustments for the satellite era. The provision of breakpoint information in the method can assist the variational bias correction.

**Imke Durre (NOAA NCDC)** presented the Integrated Global Radiosonde Archive (IGRA) which consists of radiosonde and pilot balloon observations from stations worldwide. The reanalysis community is encouraged to contribute its radiosonde data to the IGRA initiative, which in turn will make it available to a global community of researchers, policy makers, educators, and others. IGRA version 2 is currently in development and will have substantial improvements in coverage over its predecessor, both in space and time. IGRA is freely available from NOAA's National Climatic Data Center. Ultimately a future version of IGRA will contain radiosonde and pibal data digitized for ERA-CLIM.

**Yanjun Guo (National Climate Center, CMA)** presented an intercomparison of three techniques for detecting historical changes in the Chinese radiosonde network. Changes were particularly prominent in 1966 and 2000 due to changes in observation practice at the national scale. Although results showed limited consistency in the temporal and spatial distribution of

identified break points in the context of metadata events, significant uncertainties still existed in their identification, adjustment and impact on trend. The adjustment deduced from the reanalysis ranged widely and were larger than those from the nighttime series and impacted temperature trend.

**Steven Worley (NCAR)** reviewed the archive, project and activities of the International Comprehensive Ocean-Atmosphere Data Set. ICOADS 2.5 was released in 2009 and is updated monthly using GTS reports. The new release includes a dozen new data sources that also improve coverage in the early part of the record and another dozen is awaiting inclusion in ICOADS. The data set is freely available from NOAA and NCAR. NOAA/ESRL will terminate involvement in ICOADS in June 2012, which will significantly impact delayed-mode activities (e.g., retrospective development that focuses on integration of historical collections) and the Value-Added Database. Notably, all reanalyses to this point have used ICOADS, so all future reanalyses are likely to be impacted by this change in production plans for ICOADS.

**Dian Seidel (NOAA)** discussed the adequacy of past upper-air observations, analyses and reanalyses for climate research. Uncertainties have been exposed but not resolved. One “climate data record” from one type of observation is not sufficient. Redundant, independent approaches are needed to better constrain structural uncertainties. The Global Reference Upper Air Network (GRUAN) is meant to address these problems. As a reference network, GRUAN is designed to have traceable standards at every step, have known error sources removed, and have uncertainties quantified for every datum. GRUAN will provide long-term, high-quality upper-air climate records at a small number of locations as well as constrain and calibrate data from more spatially comprehensive global observing systems. Feedback on the utility of GRUAN to the reanalysis community is most welcome, particularly with respect to the location of future GRUAN stations. For example, as the network expands, it would be beneficial from a satellite perspective to have GRUAN stations on remote islands in the tropics and the Arctic.

*i. Observations: Remotely Sensed*

Satellite products used in reanalyses are broadly organized by application (land, ocean, or atmosphere) and by level of processing (level-1, -2, or -3). These three levels correspond, respectively, to 1) instrument measurements, 2) geolocated geophysical retrievals, and 3) gridded products. Some products are related to either the boundaries between Earth system components (e.g. sea-surface temperature, at the interface between ocean and atmosphere) or the transport from one component to another (e.g. precipitation, liquid and solid water flowing from atmosphere to the land and ocean); they can be applied to several types of reanalyses, although with different methods (assimilation instead of validation, for example).

To date, satellite instruments measured components of the electromagnetic radiation; for that reason, owing to the weak penetration of radiation into ocean and land, only the surface or very-near surface of ocean and land can be remotely sensed. Consequently, only the atmosphere has enjoyed regular sensing of its vertical structure by satellite. However, as presented at this conference, there now starts to be a 'long' record (>10 years) of accurate measurements of the gravity field, possibly allowing the reconstruction of variations of the mass field in the ocean and land domains.

For the atmospheric component, the list of satellite products used in reanalysis is diverse and extensive, due to the history of using these data in numerical weather prediction. This list, only summarized here, includes: (level-1) infrared and microwave radiances, bending angles at radio frequencies from radio occultation, (level-2 or -3) retrievals of upper-air wind, of near-surface wind above oceans, of tropospheric and stratospheric ozone, of tropospheric (or

vertically integrated) water vapor, of aerosol optical depth, of greenhouse gases (e.g., methane), and of reactive gases (e.g., nitrogen oxide). For the land component, the list of products used or considered for use is growing rapidly, thanks to developments in observation technology and better understanding of surface processes (models) and data assimilation methods in the last ten years. The products used for assimilation and model validation include, typically at level 2 (or 3), surface soil moisture, precipitation estimates, snow cover fraction and snow water equivalent, water surface elevation, terrestrial water storage, and vegetation- or carbon-related products. For the ocean component, the satellite products include estimates of sea-surface state (temperature, ice cover fraction, height), ocean salinity, and ocean bottom pressure.

A major innovation discussed at this conference is the recent (now ~10 years) availability of precise measurements of the gravity field, from the GRACE mission. With complex inversion methods, these measurements can be used to retrieve mass fluctuations in the various fluid components of the Earth system, namely ice-sheet mass, terrestrial ground-water storage and ocean bottom pressure. These new measurements of the gravity field could help realize fully coupled Earth system data assimilation and models, where the mass distributions in each domain are constrained to match the overall gravity field measurements.

**Paul Poli, ECMWF**, discussed the challenges associated with assimilating remotely sensed data into reanalyses, their amount, their use and their overall impact on different reanalyses. Satellite data are typically used for assimilation (level 1 to 3), nudging (level 2 and 3) and boundary conditions and initial conditions (level 3) and involve either inverse techniques to derive more elaborate products (i.e. from level 1 to level 2) or direct techniques to go back to basic geophysical measurements (ie. from level 2 to 1). Reanalysis is about reconstructing past weather in a forward integration. Critical to this process is the observation operator which simulates observations given the atmospheric state. The timeline of observations in ERA-Interim emphasizes the golden age of remote sensing in the last decade. The use of only a single microwave instrument such as NOAA-14 MSU can greatly improve forecast skill. However there are many breaks in the reanalyses' time series, due to changes in the satellite input (e.g. TOVS for ATOVS in CFSR and MERRA and SSM/I in JRA and ERA-Interim). The way microwave imager data are used may impact on the mean state with significant differences in global average total daily precipitation. Bias correction of the MSU channel 3 leads to significant error reduction in ERA. Accounting for passband filter frequency shift of the order of 10-80 MHz, for AMSU-A channels, improves microwave sounder usage significantly. By using the CO<sub>2</sub> profile as a predictor, new spectroscopy and better characterization of the pressure cell, the assimilation of the measurements from the Stratospheric Sounding Unit also improved. It was noted that millions of images are still waiting to be assimilated and are currently unexploited. Continuing with the current trend to directly use satellite measurements, one may expect in the future a growing use of the original satellite measurements in place of gridded retrieved products.

**Joerg Schulz, EUMETSAT**, provided an overview of satellite data records for reanalysis by presenting the space segment history and evolution and synergies with other space agencies. Reprocessing of the Meteosat Atmospheric Motion Vectors is an important contribution to reanalyses at NWP Centres through a substantially improved coverage and impact of re-processed winds from Meteosat satellites. The EUMETSAT Convention in 2000 which gave a commitment to support Climate Monitoring and Climate Change Detection has triggered a subsequent Council resolution (2009) and an implementation plan (2010) with involvement of EUMETSAT in many related climate activities such as GSICS, CEOS, ESA CCI, GCOS, SCOPE-CM and WCRP. About a dozen climate data records will be released over the period 2012-2013, some being already available. The reprocessing of some missions, such as

GOME-2, is necessary owing to the degradation of sensors over time. Regarding radio occultation, there is an excellent agreement between centres on bending angles in the lower stratosphere, large differences are found below and above due to different processing approaches. The ASCAT L1b data record is now calibrated dynamically since Sept 2009. The international community has embarked on the creation of Fundamental Climate Data Records (FCDRs) for archived satellite data (EUMETSAT, NOAA-CDR program and similar programs);

Space agencies work in GSICS and SCOPE-CM frameworks to achieve intercalibration of satellite data records and deliver products respectively. The quantification of uncertainties presents a number of serious challenges owing to the number and diversity of information sources. A “zipper model” with delta corrections defined in channel space is used to transfer references for intercalibration which requires estimation of both transfer uncertainty and drift in reference standard. EUMETSAT offers long term continuity of space observations, key for Climate Data Records (CDR) and reanalysis inputs. The ERA-CLIM project has helped to speed up activities at EUMETSAT, which has committed more work on CDRs.

**Isaac Moradi, University of Maryland** presented the new CDRs from microwave AMSU-A and AMSU-B/MHS instruments. Products will include rain rate, ice water path, total precipitable water, cloud liquid water, snow cover and snow water equivalent FCDR and TCDR for 2000-2010 for all satellites. Source data include the NOAA-15, 16, 17, 18, 19 and Metop-A L1b data. AMSU/MHS bias sources were discussed and the talk focused on geolocation error caused by human errors, satellite clock and attitude offset, sensor pointing error, and poor spacecraft ephemeris. The correction method, which quantifies geolocation error by analysing coastlines and their along and cross track offsets, takes care of all these error sources but is applicable only to the microwave window channel. Scan bias is characterized by comparing Tb with same atmospheric condition for each beam position.

**Shinya Kobayashi** introduced satellite meteorological products for climate monitoring at **JMA**, covering Atmospheric Motion Vector (AMV) and Clear Sky Radiance (CSR) as a contribution to the Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM). These products are provided to JRA-55. The re-processed AMVs from GMS, GOES-9 and MTSAT-1R have been using the latest algorithms as of Sept. 2009. Reprocessed Clear Sky Radiances (CSR) from GMS-5, GOES-9 and MTSAT-1R provide area averages for cloud free pixels, from 1995 onward, offering information not only on the upper-tropospheric humidity but also on the upper-tropospheric wind field. The original spectral response function (SRF) measurements of the GMS-5 water vapor channel were contaminated by atmospheric water vapor absorption. Use of the corrected SRF and the latest spectroscopy in the radiative transfer model has improved the assimilation of the radiances. Observing System Experiments (OSEs) using the JRA-55 data assimilation system for reprocessed AMVs and CSRs have demonstrated the expected improvement on reanalysis products.

**Hans Hersbach, ECMWF** discussed observations and forcing data for the ERA-CLIM project, whose objective is to integrate and improve the 20th century instrumental record, in preparation for the next comprehensive ERA reanalysis through a series of reanalysis experiments. A proper long-term evolution of forcing fields is important for all pilot reanalyses. Sea surface temperature and sea-ice cover are taken from the Hadley Centre HadISST2. CMIP5 forcing is used for radiation and surface parameterization (solar forcing, greenhouse gases, ozone, tropospheric aerosols and stratospheric volcanic aerosols, albedo, vegetation type and cover and leaf area index). AMIP runs have examined the impact of these CMIP5 parameters which is usually modest except for volcanic sulphate. The International Surface Pressure Databank (ISPD) contains 1.4 billion observations covering 1768-2008 and the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) R2.5 350 million reports from 1662-



2011. ISPD contains feedback from 20CR whilst ICOADS does not. There remain some challenges in terms of data QC for these data bases such as formatting, station information and identifier (for bias correction). The translation into a uniform Observation Feedback Archive (OFA) is non-trivial. ERA-CLIM will develop a significant effort in data recovery and digitization for the pre-1957 period in sensitive regions.

The session provided some useful conclusions, summarized below. It is important to keep in mind that most satellite products are indirect observations (they only observe the imprint of nature onto the electromagnetic or the gravity field), and hence the understanding of underlying physics is necessary to interpret results. These physical parameters and the related uncertainties need to be better understood, which will improve, provided the observations are safeguarded appropriately, and kept along with all necessary ancillary information to understand the instruments' inherent characteristics. This point is very important: no raw satellite products should ever be discarded, even if the product is deemed to have 'little value' at the time it is collected. One cannot predict, at the time of measurement, the future value of these satellite observations when better understanding of the physics or more powerful processing tools (e.g. 4D-Var) become available.

Reanalysis users need to be better informed about the satellite products employed in reanalysis production, for example in the form of a synthesized and standardized set of information (what/how/when satellite data are used). Exchanges between reanalysis teams about experience with the impacts of and methods to use satellite products should be promoted. As the various global and regional reanalyses compute their own estimates of satellite biases, efforts should be made to compare these estimates, between each other, but also with other estimates obtained from satellite instrument inter-calibration.

Satellite data reprocessing should remain a priority, as errors sometimes as basic as incorrect geolocation are still not systematically addressed (most efforts focus on the calibration of the level-1 or level-2 products), although new generic algorithms have been developed to correct for these errors due to satellite and sensor attitude errors.

Information on early satellites and instruments needs to be shared to promote coordination of international satellite data recovery. An impetus for this action are twofold: the impending retirement of a generation of physicists who have worked with these satellite data and have unique knowledge, and the aging of digital media used to store the raw observations, sometimes in proprietary databases with no documentation and support. Examples of satellite data loss, mentioned at the conference, should be alarming enough to trigger action now.

Most space agencies with geostationary orbiting satellites have reprocessed their data, or have plans to do so with the exception of the GOES meteorological satellites. Planning for new instrument capabilities (e.g. 183 GHz channel in geostationary orbit, sea-ice thickness, soil moisture) is generally done outside the reanalysis community, but this community should voice its needs for a continuous satellite record. The question of "which satellite record" can be partially answered by realizing what missions bring unique information, sufficient to determine the start of the "satellite era" for each atmospheric/land/ocean reanalysis community.

#### *j. Advancing Reanalyses*

Within the last decade the applications and coincident development of reanalyses has evolved in new and exciting ways. This session was intended to cover some of those applications and developing research activities.

Monitoring Atmospheric Composition and Climate (MACC) (**Adrian Simmons, ECMWF**) is a broad EC project that uses reanalyses in a substantial way. There are 48 partner institutions co-funded by the European Union as part of Europe's GMES initiative. The reanalysis carries carbon dioxide, methane, aerosols and reactive gases, observed by AIRS, SCIAMACHY, MODIS (AOD), among others. Emissions from fires are also included (using MODIS and SEVIRI data). The data products include forecasts, delayed analysis and reanalysis. A degree of success of the reanalysis was demonstrated using results from a number of validation activities. MACC-II is continuing the project but will likely reprocess only limited periods. Long-term funding commitment is needed, including to the observing systems; there is in particular no plan for long-term provision of data from limb sounding.

Operational ocean reanalyses have been evaluated to better understand the uncertainties across models, data assimilation and observations (**Yan Xue, NOAA NCEP**). Ten operational analyses show increasing consistency with time and number of observations particularly in the tropical Pacific, the tropical Indian Ocean and extra-tropical southern oceans, due to constraints from tropical mooring arrays and Argo floats. Heat content anomalies at 300m are highly correlated among the operational reanalyses around ENSO variations; however, significant uncertainty occurs with the representation of the Atlantic variability. The ensemble shows promise as a tool to monitor signals and uncertainties in upper ocean heat content in real time.

A review of archaeological satellite data has shown a number of promising datasets worth investigating (**Roger Saunders, Met Office**). Of course, several challenges must be overcome, such as, finding the data on readable media with sufficient metadata. There are several international agencies supporting the recovery and reprocessing of satellite data (e.g. NASA, ESA, EUMETSAT and NOAA). Simultaneous nadir overpasses have provided quality checking for some types of available instruments but use of the reanalysis fields themselves to simulate the observations is a powerful method of checking the consistency and uncertainties of past datasets. The future continuity of a number of atmospheric and ocean essential climate variables is in jeopardy as current systems age and are not replaced.

Climate monitoring is a developing area where reanalyses can make more progress, and surface air temperature is generally a robust reanalysis variable (**Russell Vose, NCDC**). Reanalyses can serve as a counterpart to pure instrumental records and a link to other Earth system variables. A key to this work is utilizing the multitude of reanalyses to overcome issues of uncertainty in any one reanalysis, such as the influence of background model bias. There are variations from reanalysis to reanalysis in temperature trends, and there is a distribution in the range of trends. The reanalyses and HCN agree that there is widespread warming across the United States in 1979-2008.

Using the recent Russian heat wave as an example, the requirements for using reanalyses in attribution studies were examined by **Siegfried Schubert, NASA GMAO**. The suggested requirements are as listed: exploratory, dynamical framework analysis and prognostic. Exploratory activities require consistency across space and time scales of interest, as well as adequate representation of phenomena of interest. Some bias may be tolerable for the assessment, but shifts and jumps would adversely affect it. The dynamical framework analysis requires dynamical consistency for the diagnosis of processes of interest. For example, balanced budgets would be most desirable (i.e. the long term contribution of analysis increments should be minimal). Model experimentation (prognostic analysis) requires consistency between background model and reanalysis (initial conditions, boundary and other forcing). Model simulated and observed fields should be in some sense dynamically indistinguishable. Since present reanalyses do not yet meet these requirements fully, this provides a standard the next reanalyses would be compared against.

k. *Agency Panel and Discussion*

**Michael Bosilovich**, chair of the conference, presented a summary of the week, thanking the reporting teams and highlighting the density of the sessions and material presented and reported. He noted the progress on modelling and data assimilation techniques and the strong presence of the ocean reanalysis community during the meeting. How quickly full coupling between domains will be achieved and how often we should refresh reanalyses were some of the important questions raised during the conference. He noted the rather small number of regional reanalyses, whose uncertainties should be better quantified, the need to further improve models with greater cooperation with the NWP community and the need to better define data policies. It was also suggested to exploit the reanalysis.org web resource as a tool for the community.

Representatives from the DOE, NCEO, EC, ECMWF, ESA, JMA, NASA, and NOAA discuss the following topics:

- Current and future plans, programs and priorities for developing and/or fostering the use of reanalysis products
- Agency perspectives on associated opportunities and challenges so as to develop a common understanding
- Requirements of agencies/entities and the scientific community to fulfill their respective mission
- How the agencies can sustain each other in this process in a collaborative way.

Ghassem Asrar on behalf of **Alan O'Neil from the National Centre for Earth Observation (NCEO, UK)** discussed challenges and opportunities in reanalysis activities some possible ideas for greater progress in the future. NCEO understands the importance of the reanalysis activities and presently it is increasingly engaged in atmospheric and ocean reanalysis projects through collaboration with ECMWF and UK Meteorological Office. Despite its importance, the existence of the reanalysis activities becomes very difficult at least in Europe because it mostly operates at the margin of operational centres and because of lack of funding. Therefore, a securely funded, internationally coordinated programme of re-analysis for the Earth System needs to be undertaken as an ongoing strategic programme, and that in Europe the Commission needs to take this fully on board in working with the main delivery centres. A lot of works still needs to be done on the reliability of the reanalysis products for trend detection and attribution and also their use in products where quantities are derived from model analysis.

**Renu Joseph, from Climate and Environmental Science (CES) Division of Department of Environment (DOE)** discussed different activities, plans and opportunities regarding the use of reanalysis products in their Climate and Earth System Models (CESMs). DOE seeks to understand the effect greenhouse-gas emissions have on the Earth's climate and the biosphere and to provide unique, world-leading capabilities in cloud and aerosol observations, modelling and process research and to build foundational science to support effective energy and environmental decision making. The goal of CES is to advance fundamental understanding of climate variability and climate change by developing CESMs at different temporal and spatial scales in order to understand climate and energy impacts on the environment. The organization is currently giving priorities for fostering the use of reanalysis products in the climate model analysis. Therefore, the focus is to develop user friendly software tools which are capable of managing large data volume and providing analysis and diagnostic tools, to validate and verify models, and to develop new components of the Earth System

models. Besides these, there is considerable interest in high resolution models that require high resolution reanalysis products. So, the opportunities and challenges are there to validate and verify these model results along with the other components of the ESMs. In conclusion, Dr. Joseph proposed some interagency activities such as USGCRP, US CLIVAR, ESPC and interagency solicitations (EaSM, NMME, etc.) so that the DOE and the scientific community can sustain each other in this process in a collaborative way.

**Kazutoshi Onogi from Japan Meteorological Agency (JMA)** discussed many aspects of the Japanese Reanalysis (JRA) project such as problems regarding re-analysis in general, JMA contributions and future plans. He reviewed the history of the Japanese reanalysis and noted that the usefulness of reanalysis had not been recognized easily before the reanalysis products became available. He mentioned that the first JRA project (JRA-25) was completed in 2006 and the 2nd JRA project (JRA-55) is currently ongoing and planned to be completed in 2013. The JRA products are currently being used in the climate monitoring and seasonal forecasting activities of JMA in order to provide quality services to the communities. These products have to fill a certain quality level to reproduce various meteorological phenomena. Therefore, the main policy of JRA is the use of an operationally quality proven data assimilation and forecasting system. Although, the details of the next JRA production have not yet been discussed, priority would be given in the reduction of the systematic biases that still exist in JRA-55, improvement of the physical processes (tropical precipitation, land surface processes etc.), enhancement of horizontal and vertical resolution and the use of upper air observations. Besides these, some of the practical problems regarding the difficulty to maintain Climate Data Assimilation systems (CDAS) for many years need to be taken care of. As the Data Assimilation (DA) of CDAS is getting old with time, new satellite data (e.g. radiances) cannot be assimilated easily in the old DA system, as the development for the latest operational NWP model has higher priority than the development for CDAS. JMA has a plan to introduce a new version of JMA Climate Data Assimilation System (JCDAS). He announced that after the completion of JRA-55, the JRA-25 based JCDAS will be replaced with an improved JRA-55 based version.

**Don Anderson from NOAA** discussed different aspects of the NOAA reanalysis project, its goal, overall achievements and future strategies. NOAA pioneered many areas of reanalysis, such as the ocean-atmosphere coupling and currently dedicates a significant portion of its budget to reanalysis. The goals include climate monitoring, climate model evaluation, forecasts initialization and verification. At the beginning, he discussed NOAA's overall achievements at different stages such as R1 reanalysis, first attempts at atmosphere/ocean coupled reanalysis with CFSR, first attempts at 20<sup>th</sup> century reanalysis using only surface air pressure and SSTs, ensemble coupled data assimilation approaches developed at GFDL where they made significant contributions. He then focused on NOAA's future strategies include fostering internal (NOAA wide) and external collaborations with NASA, WCRP and other international communities in order to develop next generation climate reanalysis with data assimilation/model infrastructures common to reanalysis for the whole of the 20th century. He also stressed the need for training and education of the next generation of model developers who are needed to replenish the expertise at or near retirement.

**Dick Dee** explained that the main driver of reanalysis at **ECMWF** has been to improve numerical weather prediction through model development aspects. Nowadays, the scope of reanalyses has expanded as a general service to the community as well and provides a close link to the European Commission but also other agencies such as ESA and EUMETSAT, for both research and applications. ERA-CLIM for example offers a lot of opportunities for collaboration but resources are somewhat precarious and there is a general lack of long-term financial commitment. As a community, all players are after the best estimate gridded climate data set and

there is no unique way to achieve this, because of the diversity of end-users with their different requirements. Regional reanalyses, coupling and longer reanalyses back in time are some important objectives for the immediate future.

**Claus Bruning (European Commission)** discussed their R&D initiatives for high-quality, homogeneous and consistent climate data sets and ERA-40 was a major effort in this regard. The current FP7 programme includes a number of actions involving reanalysis efforts such as ERA-CLIM, EURO4M with further development efforts mainly under GMES. The upcoming call in 2012 will include coordination actions of EO data for climate, the construction of ECV datasets, focusing on quality and user applications. Some R&D priorities will shift from detection to adaptation. Calls will include a focus on climate services and will cover coupling methods, an ensemble of regional systems so as to prepare the building blocks for regionally targeted climate information meeting requirements for data on ECVs. In 2014, the new Horizon 2020 framework program will cover the various aspects of the emerging Global Framework for Climate Services.

**David Considine representing NASA**, emphasized that analyses and reanalyses are part of NASA's mission to supply observations and related data to the community. Modeling activities at NASA are to add value to observations. NASA will continue to support reanalyses because they serve its own mission. MERRA is a high priority and the plan is to make it available on the ESG. ECCO's major aim is to understand ocean heat transport. The reasonable timeline is to plan for one new major effort every decade, such as a comprehensive ESM reanalysis. Efficient collaboration through interoperable numerical and analysis code and through sharing observational data sets may sometimes compensate somewhat the impact of unsecured resources such as CPU time and R&D manpower, but not a complex satellite observing system.

**Anjali Bamzai** outlined NSF's approach to science, which is hypothesis driven and which has supported many projects in the field of climate research and related reanalyses (ECCO, Arctic reanalysis, etc), covering e.g. physical oceanography, tropical storms studies. Twenty recent awards involving reanalyses were focused on CMIP5 itself. R&D on data assimilation also includes radio-occultation. It was also noted that reanalyses are often used as "observations" to examine the quality of short-term forecast. NSF scientists hence need reanalyses and their derived quantities and have to deal with biases. NSF will continue to support R&D on reanalysis and its application for societal use in partnership with other agencies.

**Michael Rast** introduced the ESA Earth Observation (EO) missions, comprising meteorological satellites, GMES Sentinel missions and Earth Explorer missions (GOCE, SMOS, Cryosat, Swarm, ADM AEOLUS, Earth Care), hoping to be able to continue this "golden age" of EO in the near future despite the recent loss of ENVISAT. He stressed the importance and success of mission synergies within the ESA programme and with external agencies. Submitted Earth Explorer 7 missions are currently in competition and one of BIOMASS, CoReH2O/Snow and PREMIER will be selected. The ESA Climate Change Initiative work of the science communities for 11 selected ECVs has started. The Climate Change Summits in Copenhagen and Cancun have underlined the importance of this activity. He concluded by noting inherent synergies between EO and reanalysis. Global EO data play a key role in reanalysis. Reanalysis supports data quality assessment and consistency check (e.g. from Level 1 to higher level products like CCI data sets). He also observed that long-term continuity of essential data is important beyond sensor life.

**The discussion with the audience** pursued further some of the topics identified by the panelists in more detail. It was noted that whilst reanalyses are fundamental for climate research, funding is not sustained in a dedicated manner. Quite often, the calls for re-analyses proposals

are embedded in other solicited research tasks which make it very difficult to address the reanalyses research challenges in a holistic manner. For example, reanalyses can benefit from the expertise and synergies that may exist in observations, modeling, assimilation, and reanalysis, fields that can help to improve each other. In Europe, GMES has been identified as a vehicle to support reanalysis research for various domains such as the ocean and the atmosphere. The European Commission stated that the calls for reanalyses research will be identified in its future solicitations that will cover global and regional reanalyses, as well as data quality. ECMWF has been successful so far in developing reanalyses because of a rather clearly defined focus, but the approach is more 'project-oriented' and still lacking a long-term sustained funding. In the US, it was recognized NOAA has played a key role in "setting the course" and NSF has been helpful in providing necessary resources to move forward. Sustaining such efforts into the future is key to progress in the exciting field of reanalyses.

One participant recalled that reanalyses are "by far the most used and valuable data source in climate research". Data reprocessing represents a critical step for reanalyses to meet the standards of the science community and to provide the expected service. Reanalyses are being used to examine major climate processes and teleconnections, to provide recommendations for updates on the observing system such as new satellite missions (e.g. through decadal surveys at NASA and science user communities at ESA). NOAA's Climate Change Science Program now pushes for integrated Earth System reanalyses.

Observations remain the most critical component of reanalyses as compared to numerical and assimilation techniques and resources. Satellite remote sensing in particular has a very long lead time. Participants were "encouraged to bring this point home" so as to help sustaining and developing observing networks. Equally, the recovery, rescue and archive of older datasets are also important to go back in time and fill major gaps as much as possible. Much rescued data is available from NCAR/NCDC and major national meteorological agencies. The Obs4MIPs NASA effort is also a major contribution, especially for seasonal and decadal predictions numerical experiments.

The audience also stressed the role of WCRP in setting priorities and making a case for reanalysis as being central to its mission, especially in view of the still large uncertainties on the hydrological cycle, and precipitation extremes that are being addressed by several agencies (such as NASA, NSF) through their respective specific programmes. The importance of training and capacity development, especially with a focus on validation of reanalyses was also highlighted as a major opportunity in the way forward.

Dr. Ghassem Asrar and Dr. Michael Bosilovich thanked everyone, the participants, sponsors and organizers for attending the conference, contributing to high quality presentations and discussions, and equally important in supporting the implementation of the recommendations and priorities resulting from the conference. They highlighted the need for follow through in between the international reanalyses conferences to ensure greater progress. They closed and the conference at noon on Friday.

#### **4. Conference Conclusions**

Reanalyses have become an integral part of Earth system science research across many disciplines. While originating in the atmospheric sciences and Numerical Weather Prediction (NWP), the essential methodology has been adopted in the fields of oceanography and terrestrial ecosystems and hydrology, with emerging research in atmospheric composition, cryosphere and carbon cycle disciplines. Major challenges lie ahead as the disparate nature of each become joined in Earth system analyses. Clearly, substantial progress has been made since the last

reanalysis conference (Jan 2008, Tokyo Japan). MERRA, CFSR and ERA-Interim have been evaluated in depth, and many strengths and weaknesses identified. First results are available from JRA-55. Likewise, we see that there is much to be learned from the ESRL 20CR surface pressure reanalysis. Ocean reanalyses are demonstrating that ensembles of multiple reanalysis systems can provide valuable information. While there are a number of reanalyses at present, the community consensus is that there is much to be exploited from the set of different reanalyses. These results are reflected in the developing centres plans (notably JMA and ECMWF) leaning toward “families” of reanalyses (each system producing various configurations of reanalysis). Yet, there is much to be learned about the observations, data assimilation, modeling, and coupling the whole Earth system.

The importance of observing systems cannot be overstated, especially in the stratosphere and deep ocean to anchor the reanalyses. Assessing robust observational and model error covariances, preferably varying over time is complex and expensive. Whilst many producing and research centres have developed and investigated bias correction methods, it should be stressed that both models and data contain biases. Preliminary results indicate the potential benefit of coupling the ocean and atmosphere domains for improved forecasts and reanalyses. Data assimilation is also helpful in designing observing systems and in identifying erroneous data but should be consistent with the processes it aims to resolve and requires appropriate model development for that purpose. Air-sea fluxes and deep-sea circulation remain challenging quantities to be estimated. Given the discontinuous nature of the observational record, data assimilation techniques will be the primary way to develop more temporally continuous reanalysis output data.

*In situ* observations are fundamental to reanalyses in many aspects and vice-versa. They complement the remote sensing network and provide reference data sets for calibration, validation and bias correction purposes. Reanalyses would benefit from a greater range of high quality monitoring products for validation purposes. New high resolution data products such as GPCP and HadISD may provide valuable ‘high quality’ input data. Data archives such as ICOADS and IGRA are being continuously populated by newly rescued data. Efforts such as ACRE and IEDRO are crucial to rescuing and archiving historical data and the ISTI has the potential to become a valuable land data source in the future. Reanalyses are used to identify and correct particular data sets such as those from radiosondes. The identification of breakpoints in data time series is critical to the success of adjustment methods and subsequent derivation of climate trends. Some observing systems are facing budget cuts and struggle to maintain a critical mass of resources.

Remote sensing provides useful input data for reanalyses, mostly for the last three decades but older imagery might be exploited as well with ad-hoc processing. Yet, satellite data present some unique challenges. They require inter-calibration and regular re-processing. Spectral response functions may require corrections as well. Climate Data Records are now becoming available to the scientific community. A proper long-term evolution of forcing fields is important for all pilot reanalyses.

Integrating the components of the Earth system in a reanalysis framework exposes the complexity of an observing and modelling system approach. For example, direct and indirect (cloud albedo) aerosol negative radiative forcing will provide feedback on the other analyzed components. Empirical optical depth retrieval and variable transformation are some of the techniques being used to that effect. Forward proxy modelling approaches using ensemble mean increments modifying single members are able to decrease the computational burden of reanalyses and improves overall skill. Land atmosphere interaction is well represented in the

CFSR. The high resolution (30km) Arctic System Reanalysis (ASR)-Interim shows superior skill to ERA-Interim on many parameters and a new release at 10 km is expected in Sept 2012.

There is a move towards using reanalyses for monitoring some aspects of the climate (e.g. BAMS State of the Climate temperature, land surface humidity, aerosols etc.), and the potential value of reanalyses in this respect is large. However, there are still some considerable limitations regarding long-term monitoring that do need to be addressed. These are mainly temporal homogeneity across the entry and drop out of various observing systems (e.g., ATOVS entry in 1997), and balancing the water budget especially over the oceans. Used with caution, reanalyses are still highly valuable as long-term records and it was recognized that some level of review may be useful to provide context for future use as monitoring products.

Reanalyses will most likely increase in number and complexity in the coming years. Incorporating reanalyses in improved data systems, such as the Earth System Grid (ESG) designed to facilitate IPCC assessments would facilitate the comparisons among reanalyses and independent observations and would shed more light on the quality and variability among reanalyses. International coordination across the disciplines and centres is needed to improve communications across the community of users and developers. Likewise, input observations are improving and increasing (through data rescue efforts), and reanalyses projects need clear guidance on the latest developments in the observations community. The need for reanalyses is as clear now, as it was when the concept was first put forward more than two decades ago.. Progress has been made, yet significant challenges remain, such as the impact of observing system changes. Continuing research and development will improve the most serious deficiencies, but communications across the communities will facilitate that research. Sustained and focused support for reanalyses research by the funding agencies will ensure greater progress in this budding field that has great potential in demonstrating the complimentary power of observations and models to offer science-based information for decision makers in addressing the challenges and opportunities associated with weather, climate and ultimately environmental services.



## 5. Appendix: Acronyms

20CR Twentieth Century Reanalysis  
3DVAR 3 Dimensional Variational Assimilation  
ACRE Atmospheric Circulation Reconstructions over the Earth  
AIRS Atmospheric Infrared Sounder  
AMIP Atmospheric Model Intercomparison Project  
AMSU Advanced Microwave Sounding Unit  
AMOC Atlantic Meridional Overturning Circulation  
AMV Atmospheric Motion Vectors  
AOD Aerosol Optical Depth  
ARS Arctic System Reanalysis  
CDR Climate Data Records  
CERES Cloud's and the Earth's Radiant Energy System  
CFSR Climate Forecasting System Reanalysis  
CIRES Cooperative Institute for Research in Environmental Sciences  
CMAP NOAA Climate Prediction Center (CPC) Merged Analysis of Precipitation  
CMIP Coupled Model Intercomparison Project  
CORDEX Coordinated Regional Downscaling Experiment  
CPC Climate Prediction Center  
ECMWF European Centre for Medium Range Weather Forecasts  
EGU European Geophysical Union  
EnKF Ensemble Kalman Filter  
ENSO El Niño Southern Oscillation  
EO Earth Observations  
ERA ECMWF Reanalysis (40 year or Interim)  
ESA European Space Agency  
ESRL Earth System Research Laboratory  
EUMETSAT European Organisation for the Exploitation of Meteorological Satellites  
FCDR Fundamental Climate Data Records  
GCM General Circulation Model  
GCOS Global CLimate Observing System  
GEOS-5 Goddard Earth Observing System (Version 5)  
GFCS Global Framework for Climate Services  
GLDAS Global Land Data Assimilation System  
GLORYS Global Ocean Reanalysis and Simulation  
GMAO Global Modeling and Assimilation Office  
GPCC Global Precipitation Climatology Centre  
GPCP Global Precipitation Climatology Project  
GRACE Gravity Recovery and Climate Experiment  
GRUAN GCOS Reference Upper Air Network  
GSI Gridpoint Statistical Interpolation  
GSICS Global Space-based Intercalibration System  
HadISD Hadley Centre high resolution climate dataset over land  
HOAPS Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data  
HYCOM Hybrid Coordinate Ocean Model

IAS Inter-America Seas  
IAU Incremental Analysis Update  
IEDRO International Environmental Data Rescue Organization  
IGRA International Global Radiosonde Archive  
ICOADS International Comprehensive Ocean-Atmosphere Data Set  
IESA Integrated Earth System Analysis  
ISCCP International Satellite Cloud Climatology Project  
ISTI International Surface Temperature Initiative  
ITCZ Intertropical Convergence Zone  
JMA Japan Meteorological Agency  
JRA-25 Japanese 25 year reanalysis  
JRA-55 Japanese 55 year reanalysis  
LW Longwave  
MERRA Modern Era Retrospective-analysis for Research and Applications  
NASA National Aeronautics and Space Administration  
NCAR National Centers for Atmospheric Research  
NCEP National Center for Environmental Prediction  
NOAA National Oceanic and Atmospheric Administration  
NR1 NCEP–NCAR reanalysis  
NR2 NCEP Department of Energy reanalysis  
NSF National Science Foundation  
NSIDC National Snow and Ice Data Center  
NWP Numerical Weather Prediction  
OAFUX Objectively Analyzed air-sea Fluxes  
OI Optimal Interpolation  
OLR Outgoing longwave radiation  
ORAS Ocean Reanalysis System  
OSE Observing System Experiments  
PW Petawatt  
RCM Regional Climate Model  
SMOS Soil Moisture Ocean Salinity  
SPCZ South Pacific Convergence Zone  
SRB Surface Radiation Budget  
SSM/I Special Sensor Microwave Imager  
SST Sea Surface Temperature  
SSU Stratospheric Sounding Unit  
TIROS Television Infrared Observation Satellite  
TOA Top of atmosphere  
TOVS TIROS Operational Vertical Sounder  
WCRP World Climate Research Program  
WHOI Woods Hole Oceanographic Institution

## 6. Appendix: Conference Agenda

Monday, 7 May 2012		
0730 - 0830	Registration and Continental Breakfast	
0830 - 0845	Welcome and Practical Information	Michael Bosilovich, NASA/GMAO
0845 - 0900	Welcome Address	Ghassem Asrar, WCRP
	<b>Status and Plans</b>	Chair: Katsumoto Onogi, JMA
0900 - 0945	<b>Keynote Address:</b>	
	Challenges of Reanalysis: Past, Present, and Future	Adrian Simmons, ECMWF
0945 - 1015	MERRA and Beyond - Towards the Development of Integrated Earth System Analysis at the NASA Global Modeling and Assimilation Office	Michael Bosilovich, NASA/GMAO
1015 - 1045	Break	
	Status and Plans (continued)	Chair: Michael Bosilovich, NASA/GMAO
1045 - 1115	Reanalysis at the NOAA National Centers for Environmental Prediction	Robert Kistler, NOAA/NCEP
1115 - 1145	Developing the Sparse Input Reanalysis for Climate Applications (SIRCA), 1850-2013	Gil Compo, CIRES/CDC and NOAA ESRL/PSD
1145 - 1215	The Japanese 55-Year Reanalysis (JRA-55): Progress and Status	Katsumoto Onogi, JMA
1215 - 1330	Lunch	
	Status and Plans (continued)	Chair: Suru Saha, NOAA/NCEP
1330 - 1400	ECMWF Status and Plans	Dick Dee, ECMWF
1400 - 1430	Ocean Reanalyses	Detlef Stammer, University of Hamburg
	<b>Atmospheric Reanalyses</b>	Chairs: Gil Compo, CIRES/CDC and NOAA ESRL/PSD; Ana Nunes, Federal University of Rio de Janeiro
1430 - 1500	Regional Reanalyses: Why Bother?	Invited Talk: Dale Barker, UK Met Office
1500 - 1530	CORDEX and NARCCAP: Foundation in Reanalyses	Invited Talk: William Gutowski, Iowa State University
1530 - 1600	Break and Poster Display	
1600 - 1615	Evaluating the Tropospheric Variability in NCEP's Climate Forecast System Reanalysis	Muthuvel Chelliah, CPC/NCEP/NWS
1615 - 1645	Assessing Changes in Climate Extremes over the 20th and 21st Century	Invited Talk: Prashant SardesmuKh, CIRES, NOAA/ESRL
1645 - 1700	Recent Changes in Tropospheric Water Vapor Over the Arctic as Assessed from Radiosondes and Atmospheric Reanalyses	Mark Serreze, NSIDC/CIRES

1700 - 1715	Use of Reanalyses to Examine Climate Model Errors in Short Forecasts	Dave Williamson, NCAR
1715 - 1730	Using "Replay" to MERRA for AGCM Model Development	Andrea Molod, NASA/GMAO
1730	Adjourn	
1800	Reception and Poster Viewing	
Tuesday, 8 May 2012		
0730 - 0830	Registration and Continental Breakfast	
	<b>Integrated Earth System Analysis</b>	Chair: Michael Bosilovich, NASA/GMAO
0830 - 0900	MERRAero: The MERRA Aerosol Reanalysis	Invited Talk: Arlindo da Silva, NASA GSFC
0900 - 0920	20th Century Isotope Reanalysis	Kei Yoshimura, University of Tokyo
0920 - 0940	Surface Water and Energy Budgets over the Northern Hemisphere in Three Data Assimilation Systems	
	Rongqian Yang, EMC/NCEP/NWS/NOAA	
0940 - 1000	Very High Resolution Arctic System Reanalysis for 2000-2011	David Bromwich, Ohio State University
1000 - 1030	Break	
1030 - 1200	Poster Session	
1200 - 1330	Early Career Scientists/Students Luncheon	
	Bill Corso, USRA	Antonio J. Busalacchi, ESSIC
	Aschok Kaveeshwar, STC	Michele Rienecker, NASA
	<b>Ocean and Sea Ice Reanalyses</b>	Chair: Detlef Stammer, University of Hamburg
1330 - 1400	Assessing the Robustness of Climate Signals in the New ECMWF Ocean Reanalysis System 4 (ORAS4)	Invited Talk: Magdalena Balmaseda, ECMWF
1400 - 1415	Reanalyzed Ocean-Atmosphere Characteristics of Tropical Instability Waves Simulated in the NCEP Climate Forecast System Reanalysis	Caihong Wen, NOAA NCEP/Wyle IS/CPC
1415 - 1430	Reanalyzed Oceanic Variability from GFDL Ensemble Coupled Data Assimilation	Shaoqing Zhang, GFDL/NOAA
1430 - 1445	An Eddy-Resolving Ocean Reanalysis Using the 1/12° Global HYbrid Coordinate Ocean Model and the Navy Coupled Ocean Data Assimilation Scheme	E. Joseph Metzger, NRL
1445 - 1500	An Ensemble Estimation of the Variability of Upper-ocean Heat Content over the Tropical Atlantic Ocean with Multi-Ocean Reanalysis Products	Jieshun Zhu, COLA/IGES
1500 - 1515	Historical Ocean Ensemble Reanalyses	Benjamin Giese, Texas A&M University
1515 - 1530	Detecting Historical Ocean Climate Variability	James Carton, University of

		Maryland
1530 - 1600	Break and Poster Display	
1600 - 1630	What Data Assimilation Increments of an Eddy-Permitting Global Ocean Reanalysis Tell Us about Deep Convection in the Labrador Sea	Bernard Barnier, CNRS
1630 - 1645	The CMCC Eddy-Permitting Global Ocean Reanalysis (1991-2010)	Andrea Storto, CMCC
1645 - 1700	Heat and Freshwater Budgets Estimated from Global Eddy-Permitting Reanalyses over 1989-2010	Bernard Barnier, CNRS
1700 - 1715	GLORYS ¼° Global Ocean Reanalysis and Simulations of the Period 1992-Present	Laurent Parent, Mercator Océan
1715 - 1730	Discussion	
1730	Adjourn	
Wednesday, 9 May 2012		
0730 - 0830	Registration and Continental Breakfast	
	<b>Land Reanalysis</b>	Chair: Michael Ek, NOAA/NCEP
0830 - 0900	Land Surface Analysis and Reanalysis at the NASA Global Modeling and Assimilation Office	Invited Talk: Rolf Reichle, NASA/GSFC
0900 - 0920	Land Evapotranspiration in Reanalyses: Comparisons to Observations-Based Data Sets, Land-Surface Models, and IPCC AR4 Simulations	EGU Young Ambassador: Brigitte Mueller, ETH Zurich
0920 - 0940	Development of Global 0.5-Degree Hourly Land Surface Air Temperature Data from 1948-2009 Based on the CRU In Situ Data as well as MERRA, ERA-40, ERA-Interim, and NCEP Reanalysis Data	Xubin Zeng, University of Arizona
0940 - 1000	Land Surface Climatology in the NCEP Climate Forecast System Reanalysis	Jesse Meng, NOAA/NCEP/EMC
1000 - 1030	Break	
1030 - 1200	Poster Session	
1200 - 1330	Lunch	
	<b>Data Assimilation</b>	Chairs: Dick Dee, ECMWF; Robert Kistler, NOAA/NCEP
1330 - 1400	Data Assimilation for Reanalysis	Invited Talk: Dick Dee, ECMWF
1400 - 1420	Diagnosis of Data Assimilation Systems: Observation Impact Estimation, Error Covariance Matrix Optimization, and Analysis Error Estimation	Toshiyuki Ishibashi, JMA MRI
1420 - 1440	A Fast Flow Adaptive Error Covariance Estimation Technique and Application	Christian Keppenne, NASA/GSFC
1440 - 1500	WRF Atmospheric Data Assimilation: Lessons Learned from Arctic System Reanalysis	Zhiquan Liu, NCAR
1500 - 1520	Problems Found in CFSR and Solutions Tested for CFSRL	Jack Woollen, IMSG/NOAA/NCEP
1520 - 1550	Break and Poster Display	
1550 - 1610	Variational Bias Correction for Radiosonde Data	Marco Milan, University of

		Vienna
1610 - 1640	The Unique Challenges of Middle Atmosphere Data Assimilation	Invited Talk: Saroja Polavarapu, Environment Canada
1640 - 1725	Keynote Address: Global Ocean Reanalyses at Eddy-Permitting Resolution: Insights from the European Project MyOcean	Bernard Barnier, CNRS
1725	Adjourn	
Thursday, 10 May 2012		
0730 - 0830	Registration and Continental Breakfast	
	<b>User Applications</b>	Chair: Siegfried Schubert, NASA GSFC
0830 - 0845	Diabatic Heating Profiles in GFSR, MERRA, and ERA-Interim	Chidong Zhang, University of Miami
0845 - 0900	A Water Cycle Perspective on the Connection Between Precipitation Extremes and Circulation Anomaly	Paul Dirmeyer, George Mason University and COLA/IGES
0900 - 0915	Drought Monitoring and Prediction Based on the Climate Forecast System Reanalysis and Reforecasts	Kingste Mo, NOAA/NWS/CPC
0915 - 0930	An Evaluation and Application of Tropical Cyclones within Reanalysis Data Sets	Ben Schenkel, Florida State University
0930 - 0945	Using Ocean Reanalysis to Validate CMIP5 Historical Experiments in the Tropical Pacific Ocean	Chunxue Yang, Texas A&M University
0945 - 1000	How Reanalysis Can Reduce Wind Resource Long-Term Assessment Uncertainty	Gil Lizcano, Vortex
1000 - 1030	Break	
1030 - 1200	Poster Session	
1200 - 1330	Lunch	
1330 - 1400	An Evaluation of Reanalysis Energy Transports between Ocean and Land	Invited Talk: Kevin Trenberth, NCAR
	<b>In Situ Observations</b>	Chair: Russell Vose, NOAA/NCDC
1400 - 1430	Bias Corrections for the Global In Situ Upper Air Temperature and Wind Data Set	Invited Talk: Leopold Haimberger, University of Vienna
1430 - 1445	Enhanced Data Coverage in Version 2 of the Integrated Global Radiosonde Archive	Imke Durre, NOAA NCDC
1445 - 1500	Uncertainty in Radiosonde Temperatures Trend in China Relating to Homogenization Using Reanalysis as Reference and Comparison with Satellite Data	Yanjun Guo, CMA National Climate Center
1500 - 1515	The Marine Surface Reference Data Set ICOADS: Status, Future, and IVAD	Steve Worley, NCAR
1515 - 1530	What Is the GCOS Reference Upper Air Network (GRUAN) and How Can It Be Useful to Reanalysis Efforts?	Dian Seidel, NOAA R/ARL

1530 - 1600	Break and Poster Display	
	<b>Remotely Sensed Observations</b>	Chair: Roger Saunders, Met Office
1600 - 1630	Assimilation of Satellite Observations in Global Reanalysis: A Double-Edged Sword	Invited Talk: Paul Poli, ECMWF
1630 - 1645	EUMETSAT Satellite Data Records for Reanalysis	Joerg Schulz, EUMETSAT
1645 - 1700	Climate Data Records from Microwave Satellite Data: A New High Quality Data Source for Reanalyses	Isaac Moradi, University of Maryland
1700 - 1715	Use of the Reprocessed GMS/MTSAT Data in JRA-55	Shinya Kobayashi, JMA
1715 - 1730	Observations and Forcing Data for the ERA-CLIM Project	Hans Hersbach, ECMWF
1730	Adjourn	
Friday, 11 May 2012		
0730 - 0830	Continental Breakfast	
	<b>Advancing Reanalyses</b>	Chair: Michael Bosilovich, NASA/GMAO
0830 - 0850	The MACC Reanalysis: An 8-Year Data Set on Atmospheric Composition	Adrian Simmons, ECMWF
0850 - 0910	A Comparative Analysis of Upper Ocean Heat Content Variability from an Ensemble of Operational Ocean Reanalyses	Yan Xue, NOAA/NCEP/CPC
0910 - 0930	Extending the Use of Satellite Data for Reanalyses	Roger Saunders, Met Office
0930 - 0950	An Intercomparison of Temperature Trends in the U.S. Historical Climatology Network and Recent Atmospheric Reanalyses	Russell Vose, NOAA/NCDC
0950 - 1010	The Role of Reanalysis in Model Validation and Attribution Studies	Siegfried Schubert, NASA/GSFC
1010 - 1040	Break	
1040 - 1340	<b>Agency Priorities: An Open Panel Discussion with Conference Participants</b>	Chair: Ghassem Asrar, Director of WCRP
	Representatives from the DOE, EC, ECMWF, ESA, JMA, NASA, and NOAA (others TBA) discuss the following topics:	
	Current and future plans, programs and priorities for developing and/or fostering the use of reanalysis products	
	Agency perspectives on associated opportunities and challenges so as to develop a common understanding	
	Requirements of agencies/entities and the scientific community to fulfill their respective mission	

	How the agencies can sustain each other in this process in a collaborative way	
	DOE: Joseph Renu	
	EC: Claus Bruning (by teleconference)	
	ECMWF: Dick Dee	
	ESA: Michael Rast	
	JMA: Kazutoshi Onogi	
	NASA: David Considine	
	NOAA: Don Anderson	
	NSF: Anjuli Bamzai	



