**NOAA Climate Reanalysis Task Force Workshop**

**Meeting Report**

NCWCP Conference Center

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1. **Background**

The goal of retrospective data assimilation or “reanalysis” is to combine disparate observations into physically consistent estimates of the past state of the Earth system and its components, e.g., ocean, atmosphere, waves, land, cryosphere, and ionosphere, with quantified uncertainties. Reanalyses spanning the instrumental record of each component are an important requirement for climate monitoring and for advancing predictive understanding, whether for determining the effects of changing boundary conditions and composition, or for providing initial conditions for retrospective forecasts. For almost 40 years, the availability of reanalyses has led to advances in understanding and predicting weather and climate variability, from extreme events to centennial trends. NOAA has been and continues to be an important contributor in the progress towards this goal.

Recent developments across NOAA, in partnership with universities and international agencies, are accelerating improvements to achieve this goal. The NOAA Climate Reanalysis Task Force (NCRTF)[[1]](#footnote-1) is charged with coordinating relevant research activities funded by the NOAA Climate Program Office and is focused on advancing reanalysis towards monitoring and understanding of climate variability. Additionally, NOAA advances in prediction from minutes to decades require reanalyses spanning many years to serve as initial conditions and as verifications for reforecasts that help quantify predictability and improve forecast skill.

As part of the weather and climate prediction enterprise, research improving models, data assimilation systems, and historical observational databases leads to improved reanalysis datasets generated regularly with increasing fidelity for all of the Earth System components. The NCRTF workshop was convened with the intent to highlight advancements in these areas across NOAA, university and international efforts; identify gaps; and improve coordination of future activities to meet the requirements of the diverse array of users of reanalyses. A series of presentations and vigorous discussion of NCRTF activities, related developments in NCEP and other US weather and climate forecasting systems, and international efforts in these areas was organized to strengthen NOAA’s and partner organizations’ development and utilization of these important datasets.

Specific workshop objectives were to:

1. Report on NCRTF progress
2. Exchange reanalysis approaches, algorithms, and techniques currently in use and under development
3. Discuss techniques for addressing outstanding issues in the reanalysis efforts
4. Identify the various requirements for reanalysis products
5. Determine strategies and overlaps for national and international reanalysis efforts based on scientific drivers for climate and weather research.

The NCRTF Workshop was held May 4–5 2015 at the National Center for Weather and Climate Prediction in College Park, Maryland. The workshop was attended by over 40 participants representing the national and international reanalysis community. Agencies represented included NOAA, NASA, NCAR, and ECMWF.

After welcoming remarks by an NCEP representative, the workshop began with an introduction to the NCRTF and the workshop, as well as background on the purpose of reanalysis. This was followed by five sessions, each to address a specific objective or objectives, as described below:

* *National and International Reanalysis Efforts* (Day 1)

Objective: Determine strategies and overlaps for national and international reanalysis efforts based on scientific drivers for climate and weather research

* *Developments in the Stratosphere* (Day 1)

Objective: Discuss techniques for addressing outstanding issues in the reanalysis efforts

* *Assimilation Development and Experiments: Atmosphere* (Day 1)

Objective: Exchange reanalysis approaches, algorithms, and techniques currently in use and under development. Discuss techniques for addressing outstanding issues in the reanalysis efforts

* *Assimilation Development and Experiments: Ocean and Sea Ice* (Day 2)

Objective: Exchange reanalysis approaches, algorithms, and techniques currently in use and under development. Discuss techniques for addressing outstanding issues in the reanalysis efforts

* *Reanalysis Evaluation* and intercomparison (Day 2)

Objective: Identify the various requirements for reanalysis products. Discuss the use of independent observations to evaluate the long-term fidelity of reanalysis products and the associated applications of reanalysis products for climate studies.

Each session contained between four and eight 20-minute presentations, and was capped by a 20–30-minute discussion period led by a moderator furnished in advance with questions from attendees related to the session topic and objective. A rapporteur was assigned to each session. At the conclusion of the last session on Day 2, the rapporteurs provided 5-minute summaries of their session to spur a final round of discussion to close the workshop.

In the remainder of the report, the key workshops outcomes and recommendations will be described (sections 2 and 3, respectively). Next steps and opportunities will be discussed (section 4), along with information about how to obtain further information on the workshop and NOAA reanalysis (section 5), and acknowledgements will be provided (section 6).

1. **Key overall outcomes of the workshop** 
   1. Improved coordination of NCRTF with ongoing reanalysis efforts at NCEP.
   2. Enhanced awareness of complementary reanalysis efforts among national and international agencies.
   3. Identified challenges and possible solutions to the competing uses of reanalysis dataset, including needs for instantaneous accuracy and long-term consistency.
   4. Recommend that reanalysis centers disseminate datasets about the analysis process, such as observation feedback information.
2. **Session summaries**

After a welcome by Arun Kumar and an introduction to the NCRTF and the workshop goals by Gil Compo, Huug van den Dool presented the keynote question of the workshop, “What is Reanalysis for”? With more than 20,000 citations to the main papers describing reanalysis datasets, there are many answers to this question, but a few overarching goals were articulated. One important reason for reanalysis is to provide initial conditions for reforecasts, another is to demonstrate improvements in a forecasting and analysis system by generating better forecasts with a new system compared to an older system using historical observations. Another key reason is to obtain a description of the general circulation, its statistics, and its variability in a consistent manner for as long as possible. Challenges to meeting this goal include the variations of the observing system imposing unphysical inhomogeneities (“jumps”) on the reanalysis representation of those statistics. Interannual to decadal variability and trends can be of the same magnitude as these unphysical jumps. These challenges present difficulties in simultaneously meeting other goals of reanalysis: generating the best short-term and best long-term climate diagnostics and monitoring, making maximal use of all observations ever taken, making use of observations never analyzed before, studying and understanding historically important events which are often extremes. It is an open question whether accuracy and homogeneity can be balanced in a single reanalysis dataset.

* 1. **National and International Reanalysis Efforts**

Suru Saha presented that reanalysis priorities at NCEP’s Environmental Modeling Center (EMC) are focused on coupled data assimilation and forecasting. EMC priorities are predictions from subseasonal to the 6-week range, and from seasonal to the 6-month range. An outstanding issue is how improve upon the previous computing and storage systems, perhaps by utilizing cloud computing and storage. Plans for EMC’s next reanalysis include an upgrade in data assimilation to hybrid 4DEnVar and inclusion of aerosols, sea ice, land, waves, and ocean components. High priorities in terms of development in the “physics” are scale-aware PDF-based subgrid scale turbulence and cloudiness schemes, aerosols with consistent microphysics, improved convection-cloudiness-radiation interactions, non-orographic gravity wave drag, Hybrid gain 3DVar/Local Ensemble Transform Kalman Filter in the Global Ocean Data Assimilation (GODAS), and use of Near Sea Surface Temperature (NSST) assimilation development.

Arun Kumar described how NCEP’s issues and requirements for climate reanalysis concern two major areas: forecasting and monitoring. Reanalyses for monitoring are needed both for attribution and for many societal applications. In terms of forecasts, reanalyses are needed to initialize, provide base climatologies for bias correction, and to verify and re-calibrate models. A key challenge is dealing with discontinuities in reanalysis data sets arising from interactions between model bias and observational platform changes. Another challenge is balancing requirements for reforecasts versus climate monitoring, climate studies, and attribution. One way to meet this challenge is with different reanalysis datasets using a common assimilation framework and model, such as in the developing NOAA next generation climate reanalysis system. This will use a hierarchical approach with systems of increasing complexity from models driven only by SST (i.e., an AMIP simulation), to assimilation of only surface observations (e.g., 20th Century Reanalysis), to assimilation of only conventional upper-air observations, to assimilation of the modern observing system including satellite radiances, radars, and GPS signals.

Dick Dee described work at ECMWF, ERA5 (T639L137, 10-member EDA, all-sky radiances, varBC for everything) will succeed ERA-interim and will be available for 1979-present. The ERACLIM project to generate reanalyses spanning the 20th century will transition to ERACLIM2, which will feature coupled land-atmosphere-ocean-sea ice-biogeochemical components and extend back to 1901. The project includes considerable data rescue, both of conventional observations and historical satellite observations from the 1960s and 1970s. Additionally, it was reported that another project, the new Copernicus climate change services, will include operational support for reanalysis.

Zhiquan Liu presented Chinese Meteorological Agency reanalysis plans are for a satellite era (1979-present), near-real-time 30-km resolution, atmospheric reanalysis and a concurrent land-surface reanalysis. It will be created from an previous version of IFS (T639), using GSI 3DEnVar (T213 ensemble). DART will be used for land surface data assimilation.

Ron Gelaro introduced NASA’s new MERRA2, designed to addresses the limitations of MERRA1, using the recent version of GEOS5 (0.5 degree, L72, 3Dvar). MERRA2, which was made publically available in July 2015, uses new satellite types, reduces spurious trends and imbalances in water and energy cycles, and tests new coupling methodologies. The MERRA2 spans 1980–2015 and is updated in real time with 2-3 week latency. Hourly surface and 2d fields are provided; 20% of total dataset is related to aerosols. MERRA2-driven chemistry, ocean and land analyses will follow. The next version of MERRA will included coupling between atmosphere, ocean, sea ice, and land components. It will have a 0.25 deg atmosphere and 25 km ocean, with hybrid 4DEnVar used for atmosphere data assimilation, EnKF for land, and EnOI for ocean.

*General Discussion:*

*The discussion from this section centered around how technology and/or resources could be shared among various groups for a common benefit. The workshop participants first discussed whether a centralized database is useful for reanalysis observations and observation feedback. There was more than one opinion about the format of such a database. It was pointed out that a decentralized approach using conversion software is more practical, at least for the time being. This is what has in fact developed over the three decades of collaborative reanalysis activities internationally. It is likely in the future that databases of common and open scientific interest will feature multi-lingual access and storage of information without worrying about such a thing as common formats*

*The question was raised of whether it is possible to scale the observational database as new satellite instruments are introduced. It was suggested that the most important issue is adopting unified standards for metadata in order to bridge the gap between hindcasts and monitoring.*

*It was noted that the NCEP/NCAR Reanalysis 1 (R1) is still widely used for monitoring because of its near real-time aspect, and because it is relatively stable for a long term time series. Although it is generally felt that some unification in reanalysis systems for hindcasts and climate monitoring is possible, as well as a worthwhile strategy, the point was made in several discussions, and forums, and in fact is general practice among reanalysis centers, that a family of reanalysis systems and products, using shared technology, is the most appropriate way to resolve conflicting requirements for different reanalysis purposes, without having necessarily separate project boundaries.*

*Another issue discussed was what advances in ocean coupling are appropriate now, and how to best spin up oceans. It was noted that using ‘streams’ is a problem for ocean reanalysis. It was reported that ECMWF is looking at the sensitivity of deep oceans as the ocean spins up, and that it is only possible to constrain the first few hundred meters of the ocean, not the deep oceans. On the other hand, layers operating on decadal and shorter time scales can be tracked to some extent using the observational network of the last 30 years.*

*Finally, the question was raised as to how, if a reanalysis dataset is not uniformly better in each new iteration, this should be communicated, or justified. Of course the definition of uniformly better is an important factor in considering this question.*

* 1. **Developments in the Stratosphere**

The status of NCEP’s improvements of the stratosphere in reanalysis was presented by Craig Long. Problems were noted with the representation of oscillations. Difficulties with necessary satellite bias corrections were discussed. Observation transitions between satellite observing systems have led to jumps. Multiple tests with CFSR have been performed, in which SSU Ch3 and AMSU Ch14 were compared. CFSR and a 3-year test run are found to match well for the seasonal cycle. A conclusion was that while there is an understanding of why problems exist in the representation of the stratosphere, it is not known how to solve them.

John McCormack from NRL discussed water vapor in the stratosphere, photochemical production and loss, and its latitude, seasonal, and altitude dependence. The knowledge is helpful for parameterizations. Analysis of specific humidity was presented with and without photochemistry. Some of the large differences in the upper levels that were shown are potentially due to the inclusion of spurious data. It was noted that accurate prognostic humidity in the upper-troposphere and lower stratosphere region can reduce model bias. The quality of the available upper-level data, both historically and currently, was discussed.

Sarah Lu gave an overview of aerosol modeling and described the need for including aerosols in climate reanalysis. It was noted that aerosols are critical for capturing cloud-radiation interactions, to improve data assimilation, and to assess air quality. Including aerosols affects operational models, with operational benefits seen for medium-range forecasting. Operational climate models also benefit from capturing aerosol-chemistry-climate interactions. It is also desirable to have prognostic aerosol capabilities, and to do trajectory analysis related to volcanic eruptions.

Arlindo DaSilva presented the NASA Goddard aerosol reanalysis, which is underway. It was noted that aerosols are underdetermined in general. Observing systems include Lidar, a ground-based network (aeronet), and satellite retrievals. MERRAero, which spans 2002 – present, was described. It was found to compare well with aeronet and was also evaluated with OMI. The radiative effects of different species and the regional climatology of PM2.5 over the continental U.S. was discussed, with particular focus on differences in PM2.5 in winter months in the Northwest and Southwest, and uncertainties in observing PM2.5. A new model will resolve mass and number concentration. MERRA2 was noted as the first to integrate aerosols into reanalysis.

*General Discussion:*

*C: We need better modeling and more observations in the stratosphere.*

*Q: What are the advantages of having the model top at 0.01 hPa compared to 0.2 hPa?*

*Q: Why are there differences in PM2.5 in winter months in the Northwest and Southwest?*

*A: Weak nitrate signal due to the dropoff of agriculture and biamass burning in winter.*

* 1. **Assimilation Development and Experiments: Atmosphere**

Developments of 20CR using the Ensemble Kalman filter were presented by Jeff Whitaker. It was shown that 20CR surface pressure only analysis is a useful testbed for new ideas. For this case without many observations, quality control (QC) is very important. Assuming a non-Gaussian distribution for errors in the QC system and using varying localization length scales are novel aspects of the new development. It is believed that the QC technique, together with a higher resolution model, should produce an analysis that is ~25% better than 20CRv2. It was noted that the QC technique is similar to Fuqing Zhang’s adaptive covariance relaxation method but that it adds perturbation to the ensemble. The technique retains the rotation of the structure but changes the amplitude.

*Q: What is the difference from Fuqing’s (adaptive covariance relaxation?) method?*

*A: Similar but adding perturbation to the ensemble. Retain the rotation of the*

*structure but change the amplitude.*

Jack Woollen presented a comparison of two ensemble based reanalysis systems, the NCEP dual-res (T254/126 Hybrid 3D-VAR/EnKF, and ERSL single-resolution (NOSAT) pure EnKF, for three 1-year periods and their comparison with ERA/ERAInt and GR1. It was concluded that the EN system shows good potential to rerun GR1 (i.e., NCEP-NCAR reanalysis) very efficiently, The EN results are good in the Northern hemisphere even without satellite observations, but direct radiance assimilation is nominally necessary for a full GR1 replacement. The NOSAT could be used for reanalyzing 1948-1975 in any case.

*Q: In a "pure" Ensemble Kalman Filter system, is the ensemble mean ” meaningful” event even though it is not balanced?*

*A: It was suggested that if there is any imbalance, it should show up in precipitation. For initial assessment, ensemble mean is the natural first thing to look at.*

*C: Both anomaly correlations and fits to observation should be examined, as well as precip measures in order to fully evaluate these results.*

*Q: You showed a wind divergence in 1981. Could it be caused by volcanic aerosol?*

*A: (belated) It was at the wrong time for Chichon, if I’m not mistaken.*

*Q: Does GR1 replacement really need satellite data?(rhetorical)*

*Q: Do you have southern hemisphere applications to show the need of observations?*

*C: 1975 ensemble without radiance works better or even improved.*

Daryl Kleist presented progress on the 4D hybrid EnVar and other DA development for the NCEP GFS. Experiments were performed with real observations using hybrid 3D-Var and hybrid 4D-VAR, bias correction for radiance and conventional observations, and assimilation of cloud/precipitation. It was suggested in the presentation that a suite of future work to be conducted at NCEP and UMD, including scale-dependent scaling, synergy between ENVAR and ENKF, etc.

*Q: Does the Hydrid 4DVAR work as well as 4DVAR?*

*Q: Have you done any head-to-head comparison?*

*A: With the right configuration, experiments showed hybrid 4DVAR is not 100% 4DVAR*

*but is close.*

Eugenia Kalnay showed new applications of data assimilation to reanalysis, algorithms for correcting model bias and reanalysis jumps. Estimation and correcting model bias was done by focusing on the analysis increments. Additionally, model errors in the diurnal cycle were found using EOFs from reanalysis. It was shown that the state dependent errors could be found using coupled SVD’s. A correction scheme was proposed based on new and old analysis increments to correct potential bias introduced by new observations.

*Q: How important is diurnal cycle error?*

*A: the correction will reduce the bias.*

*Q: How does the correction work?*

*A: There are two parts in the correction. First, correction for jump , and Second,*

*correction for model bias.*

Gil Compo presented a reanalysis effort for Tambora 1815 in which it was shown that 20CR surface pressure-only system can represent the 1815 event with good skill. It was shown that the atmospheric circulation change may be driven by volcanic aerosols based on the better forecast skill from a set of assimilations including the volcanic aerosols and a set without. Of note was that the climate variability in the reanalysis seems to be larger than the signals derived from tree rings.

*C: When you go back to that far, there are many rainfall observations that could be*

*useful.*

*Q: Are differences in forecast skill meaningful?*

*A: The time series of the reanalysis forecast show that the aerosol improvement is*

*statistically significance.*

*General Discussion:*

*New research approaches are required to understand reasons for jumps in climate reanalysis as new observational platforms are introduced. It was asked how it can be known where the jumps come from, where the model bias is, and how it can be diagnosed. It was noted that there are model drifts in addition to jumps, and that jumps technically can be corrected, while drifts are usually not easily identifiable. Drifts may be a confluence of model biases and jumps, with no automatic ways to identify them. To address this issue of drift, feedback data are needed, as well as gridded versions of intercomparisons.*

* 1. **Assimilation Development and Experiments: Ocean and Sea Ice**

This session consisted of eight talks, six describing ocean analysis activities and one each looking at the land and sea ice systems.

The session began with a presentation by Guilliame Vernieres of NASA/GMAO describing some of the activities being carried out by the GMAO oceans group, called IODAS. The IODAS project has a 1/12th-deg eddy resolving effort led by Keppenne, but the main effort is directed towards a ½-deg MOM4p1 ocean (currently), likely transitioning to a ¼-deg MOM5 in the coming months (the final decision has not been made). The analysis period mirrors the analysis period for the GMAO atmospheric product, MERRA. The current assimilation methodology is an ensemble method known as ENOI. Thhe data being assimilated includes historical hydrographic data, SST data (currently a gridded product), sea surface salinity (SSS) from the Aquarius satellite, and altimeter sea level. Much effort has been expended to develop a skin-SST model to allow coupling to the GEOS atmosphere. The system also includes a wave model, while work is underway to include ocean color information.

The second and third presentations in this session, by Drs. Xue and Penny, introduced the corresponding NOAA NCEP analysis system GODAS. The first presentation by Dr. Xue compared a number of products such as ocean heat content from various operational centers, highlighting some of the strengths and weaknesses of the current GODAS. It included the results of some data sensitivity experiments. This presentation was followed up by Dr. Penny’s presentation on new developments in GODAS. A highlight was his presentation of tests of the new HYBRID-GODAS, which builds on the current 3DVAR with the ensemble transform Kalman Filter LETKF. The control experiment uses the current GODAS for the period 1991-2011. The second experiment uses the hybrid-GODAS with 56 ensemble members. Surface forcing is provided by 20CR. In brief, the new analysis represents considerable improvement over the current model. For example, Dr. Penny shows that the RMS and mean of observation minus forecast differences of variables such as temperature and salinity are significantly reduced. Finally he pointed to the use of his system at ECMWF in a series of comparison studies.

A closely related data assimilation activity is being carried out at University of Maryland and described in the 4th presentation by Dr. Carton. The ¼ deg MOM5 ocean model is similar to that being examined at GMAO and similar to one likely to be adopted at NCEP. The focus of this presentation was on the impact of different wind products on the assimilation system (e.g. comparing MERRA2 with ERA-Int). The sixth presentation by Dr. Giese presented examination of a reduced version of the SODA system in a series of experiments with the Whitaker/Compo 20th century reanalysis effort in which the ocean is forced by 20CRv2 fluxes, then the modified SSTs resulting from the ocean reanalysis are reintroduced into the atmospheric reanalysis system, etc. (20CRv2 → SODAsi.2 → 20CRv2c → SODAsi.3). The presentation described two large ENSO events: one in 1916-1920 when observations were sparse, and the 1997/98 El Nino with dense observations. It was found that prescribing SST to the atmosphere reduces uncertainties in surface forcings and reduces spread.

The fifth presentation by Dr. Xu Li presented NOAA’s effort in developing a skin-SST algorithm. The need for a skin SST algorithm had previously been introduced in Dr. Verniere’s talk. It arises partly because passive remote sensing of SST uses either infrared/visible frequencies or at microwave frequencies. The former which provide a more accurate measurement with uncertainties less than 0.5C, reflect the temperature of the upper microns of the water column, well within the near surface laminar sublayer. The latter, while less accurate are insensitive to cloud cover, and may reflect the temperature of the upper few mm of the water column. The distinction is important because solar stratification and evaporative cooling can leave a subtropical ocean under low wind conditions with a complex temperature structure that may vary by as much as 3C in the upper 3m of the water column. The final data set are the in situ observations reflecting temperature one or more meters below the surface. Many of these are ship intake measurements, but some are from fixed buoys and some are from surface drifters. Of these the latter are most accurate, with an individual uncertainty of perhaps 0.5C. Dr. Li reviewed this complex problem as presented the result of their effort to parameterize the effects of these unresolved processes.

The final two talks addressed two other key systems: the land surface and sea ice. The land surface assimilation system was presented by Dr.s Ek and Meng. For the GLDAS, there is an upgraded Noah Land model with new land data, an improved land data assimilation scheme, CPC daily precipitation, stream flow, and a GLDAS2 single stream replay compared to CFSR. The land surface spin up is more critical in dry land. The second talk by Xingren discussed some of the ongoing sea ice prediction activities within NOAA EMC. These include by a very simple empirical sea ice prediction system and some preliminary planning for a full sea ice prediction system within the upcoming CFSv3.

*General Discussion:*

*This session prompted considerable discussion about the details of the ocean analysis systems and the one coupled system. Among the topics discussed was the source of the data, for example, for sea ice cover, the constraints on the temperature and salinity of water in the deep ocean, and the impact of observations from the TOGA/TAO array. The lack of sea ice thickness information was discussed. In a related discussion, it was pointed out that there is a need to resolve diurnal processes within the oceanic mixed layer (a component of NSST) as a necessary component to improving the assimilation of satellite data.*

*Another topic discussed was the appearance in the reanalyses to a greater or lesser extent of jumps due to the introduction of new observations and whether or not this is a result of an observing system bias or a model bias. Climate reforecasts require continuous climate reanalysis without artificial jumps for calibrating model climatology and model hindcast skill. It was noted that changes in observations also lead to changes in surface fluxes, leading to changes in background covariance and jumps in ocean reanalysis. Indeed, concern about those jumps led to efforts such as the 20th century reanalysis which deliberately excludes satellite and upper air data. The alternative view was put forward that perhaps jumps in variability due to changes in the observing system is an inherent aspect of the inconsistent historical sampling and that we should not try to lessen their impact but allow users to see the variations.*

*Another topic which came up in this session was the need to carry out reanalysis productions in a set of overlapping streams for computational efficiency. The question then arises, how much overlap is needed in order to stitch together the individual streams (an issue that arose in the CFSR reanalysis)? In terms of data assimilation streams, the ocean, land, and stratosphere it was suggested that there was a need for a spin-up overlap of 2-5 years. It was suggested that running a low resolution version of the coupled data assimilation system could provide initial conditions from which different streams can be initialized.*

*The session included recommendations regarding the types of reanalysis performance statistics that should be kept for each system. Among those considered vital are the forecast minus observation and forecast minus analysis statistics. The issue of how much horizontal resolution is needed for the ocean was raised in this session but remains unresolved.*

* 1. **Reanalysis Evaluation**

Ricardo Todling described a recent work on the dry mass and water conservation in the NASA GMAO MERRA system, the former following on from work by Trenberth and Smith (J. Climate, 18, 864–875, 2005). Three modifications were made to the model, analysis, and increments to improve these conservations. Questions were raised as to why *changing integrated dry mass to be constant makes precipitation better and what is the effect on bias in mass and water conservation scheme.*  Todling *responded that because the dynamics conserve mass, so that only thing that should change or control the water is the physics, but if you allow the assimilation to adjust it then it can get out of balance. The increments are just scaled by a single number (e.g. 0.9999 or 0.0001). The details behind these experiments use the same same model and are described in another document. [can we get the document reference?].* Todling also pointed out that by doing so, *the model becomes less biased than before.*

Lisan Yu presented an evaluation of ocean surface energy and freshwater budgets in early and recent atmospheric reanalyses, satellite-based products, and an ocean state estimation. Independent buoy time series measurements and satellite salinity observations were used to identify and understand the source of uncertainty. She showed that most uncertainties are concentrated in the tropical oceans, and that the spread in ocean energy budget is due primarily to the shortwave components and the spread in the freshwater budget is to the precipitation associated with the ITCZ/SPCZ. The large uncertainties present a major challenge for using reanalysis records in detection and attribution of long-term climate trends and variability Question was raised on the use of buoy measurements. Specifically, *buoy measurements of SW are made at different heights. How the height differences can be accounted in the evaluation Yu responded that SW measurements made by buoys at sea are sensitive to the change of incident angle (due to waves) and not to the change of height.* Question was also focused on the CFSR data processing. *CFSR has hourly output, each hour is a cumulative measure up to*

*the forecast hour, and hourly output should not be averaged to get daily data. Yu responded that the data processing followed the instructions specified in the CFSR technical documentations and the identified uncertainty in the CFSR clouds is not due to data processing but a “real” problem in the model.*

Caihong Wen focused on presenting the oceanic response, simulated using GFDL MOM4 numerics, to NCEP Reanalysis 2 (R2) and CFSR surface fluxes. The experiments examined both variations in the depth of the thermocline as represented by the depth of the 20C isotherm (mainly reflecting surface winds), SST (generally controlled by net surface heat flux except in upwelling regions), and SSS (generally controlled by net surface freshwater flux). The work aimed to explore the ways in which surface flux uncertainties impact the ocean uncertainty in ocean properties.

Erica Dolinar presented an evaluation and intercomparison of clouds, precipitation, and radiation budgets in 5 different recent reanalyses and satellite-surface observations. She included a comparison of cloud fraction (CF), precipitation rate (PR), and net cloud radiative effect (CRE). She found that in some cases, large biases in CF, PR and CRE are present in the reanalyses, but that the fields are physically consistent. There are still issues parameterizing convective and MBL clouds as well as their impact on radiation budget. Advancement in convective­type cloud parameterization slow.

Xiquan Dong compared two extreme summer Arctic sea-ice extent anomalies in the summers of 2007/2012 and 1996. The summers of 2007 and 2012 were striking for the low level of Arctic sea ice, the lowest that had been seen in the observational record to that point, while 1996 was a summer with similarly anomalously high sea ice concentration. A synoptic analysis of these extreme events highlighted the importance of particular extreme synoptic events in leading to unusual retention or loss of sea ice, such as the August storm that played a critical role in the 2012 sea ice minimum and an intensification of the Beaufort sea level high in the sea ice maximum in 1996. Dr. Dong also pointed to a radiative flux mechanism in which an increase in clouds led to increase in net long wave radiation down into the ocean. The long wave radiation effect is dominant due to the high angle of incidence of SW and the persistent presence of the downward long wave radiation. Refarding whether we should *be skeptical about the ‘correlation implies causation’ argument in (p.14) analysis, Dong responded that Increase in clouds led to increase in net LW down into the ocean. LW effect is dominant due to the high angle of incidence of SW and the persistent presence of the downward LW.*

*C: There was also discussion of the changes occurring in particular marginal seas.*

Richard Cullather provided an introduction to the results of recent atmospheric reanalyses of high latitude fluxes. His presentation included comparison between regional and global models for reanalysis over polar ice sheets. The results suggested that the reanalyses are still struggling to do better than climatology in these regions, but progress may be helped by examination of higher resolution regional model reanalysis studies such as the Greenland regional models MAR and RACM02. *The polar talks raised a number of issues, perhaps more than could be resolved. Among these was a follow-up question about the role of cloud-radiation feedback processes in the reanalyses and nature. Several other questions addressed the uncertainties in comparison data sets. For example, Cullather pointed to the uncertainty associated with the use of passive microwave remote sensing of sea ice cover in summer due to the complex surface properties of the sea ice. He pointed out that when you change sea ice cover you need to change the ocean to be compatible with this cover. Also, thinking about the couple system, he pointed out that there is still considerable uncertainty in sea ice volume (Cevallier et al., Climate Dynam., 2015)*

*General discussion:*

*The main themes of this session included (i) evaluating and understanding the various dimensions of uncertainty in reanalyses, (ii) articulating and prioritizing critical uncertainties and their impacts on applications of the reanalysis products, and (iii) promoting focused research endeavors that improve the reanalysis models and reduce the uncertainties.*

*The leading issue in the presentations was the identification of the source, degree, and nature of uncertainty in reanalyses. Biases in surface fluxes in the open oceans and at high latitudes were focused. The lack of sufficient in situ observations to identify and quantify the global biases in flux components was acknowledged. It was noted that some biases are the artifacts of the changes in observation platforms, such as the injection of the ATOVS data in around 1998 that causes an abrupt change in precipitation and/or humidity time series, and some biases might be due to the parameterization schemes, such as cloud, that remain a challenge for model development.*

*The session raised questions about the potential applicability of the reanalyses to studies of climate change detection and attribution. The biases in reanalysis products often promote a skeptical point of view on the statistical significance of the decadal and longer-term variability exhibited in the reanalysis time series. It was noted that the global ocean-surface energy and freshwater budgets are not conserved in recent reanalyses, and reanalyses still try to struggle in the polar regions with many issues, such as the parameterization ofclouds, longwave radiation, cloud-aerosol interaction, etc.*

*The session also engaged with the issue of improving the assimilation systems, and using diagnosed observation and forecast differences to improve the physical representation of the model. This kind of endeavor was deemed welcome and necessary.*

*Recommendations for this session included prioritizing the dissemination of critical uncertainties in reanalyses and the critical areas of improvement.*

1. **Next steps and future coordination**

The brief reports by the rapporteurs from the individual sessions were accompanied by a series of audience questions that highlighted some of the uncertainties and the need for follow-up projects. For session 2 one question asked what was needed to improve historical analysis of the properties of the stratosphere – more observations or better models? For session 3 there were several questions, leading to discussion, about how to initialize the ocean for coupled predictions. For example, most observations today only extend through the upper 2 km of the ocean, and the question was asked whether it could be possible to use CMIP-type models to initialize the lower 2 km of the ocean. There was also some discussion about the usefulness of eddy permitting (e.g. ¼-deg) or eddy resolving (1/12th-deg) resolution for the ocean. Finally there was a brief statement by Dr. Saha regarding a key step being taken by NOAA EMC to develop CFSv3. It was recognized that this meeting was a bit premature to map out the details of CFSv3 though. The subject of coordination of activities was a theme throughout the meeting.

1. **Further information**

NCRTF workshop website

Climate Program Office news item on workshop

Reanalysis.org

1. **Acknowledgements**

MAPP program

NCEP for hosting

Appendix I – table of participants

Appendix II – final agenda

**NOAA Climate Reanalysis Task Force Technical Workshop**

***NOAA Center for Weather and Climate Prediction***

***College Park, MD***

**4 - 5 May 2015**

**Organizers:** Jim Carton, Gilbert Compo, Arun Kumar, Suru Saha, Heather Archambault

**Workshop Objectives:**

Report on NOAA Climate Reanalysis Task Force progress

Exchange reanalysis approaches, algorithms, and techniques currently in use

and under development.

Discuss techniques for addressing outstanding issues in the reanalysis efforts,

e.g., presence of spurious discontinuities and trends, coupling of Earth System

components, inclusion of new areas such as aerosols.

Identify the various requirements for reanalysis products.

Determine strategies and overlaps for national and international reanalysis efforts

based on scientific drivers for climate and weather research.

Each presentation slot is 80% for oral presentation and 20% for questions.

**Monday 4 May**

8:00–9:00 a.m. Registration

9:00 a.m. *Welcome*

Arun Kumar, NCEP/CPC

9:05 a.m. *Introduction to the Climate Reanalysis Task Force and Workshop*

Gil Compo, U. of Colorado/CIRES & NOAA/ESRL/PSD

9:20 a.m. *What is Reanalysis for?*

Huug van den Dool, NCEP/CPC

**1. National and International Reanalysis Efforts**

**Objective:** Determine strategies and overlaps for national and international reanalysis

efforts based on scientific drivers for climate and weather research.

**Session Chair:** Gil Compo, U. of Colorado/CIRES & NOAA/ESRL/PSD

**Rapporteur:** Jeff Whitaker, NOAA/ESRL/PSD

9:40 a.m. *Plans for Reanalysis at NCEP’s Environmental Modeling Center*

Suru Saha, NCEP/EMC

10:00 a.m. *Issues, Requirements, and Research towards NOAA’s Next Generation of*

*Climate Reanalyses*

Arun Kumar, NCEP/CPC

10:20 a.m. Coffee Break

10:40 a.m. *Reanalysis at ECMWF*

Dick Dee, ECMWF

11:00 a.m. *CMA 40-year GSI based reanalysis: plans and progress*

Zhiquan Liu, NCAR

11:20 a.m. *MERRA-2, GMAO reanalysis efforts/plans*

Ron Gelaro, NASA/GMAO

11:40 a.m. Discussion

Moderator: Heather Archambault, NOAA/CPO

12:10 p.m. Lunch

**2. Developments in the Stratosphere**

**Objective:** Discuss techniques for addressing outstanding issues in the reanalysis

efforts

**Session Chair:** Ron Gelaro, NASA/GMAO

**Rapporteur:** Erica Dolinar, U. of North Dakota

1:30 p.m. *Status at NCEP to improve the stratosphere in reanalysis*

Craig Long, NCEP/CPC

1:50 p.m. *Aerosol modeling*

Sarah Lu, SUNY-Albany

2:10 p.m. *Water vapor in the stratosphere*

John McCormack, Naval Research Laboratory

2:30 p.m. *Aerosol Reanalysis at NASA Goddard Space Flight Center*

Arlindo da Silva, NASA/GMAO

2:50 p.m. Discussion

Moderator: Dan Barrie, NOAA/CPO

3:10 p.m. Coffee Break

**3. Assimilation Development and Experiments: Atmosphere**

**Objectives:** Exchange reanalysis approaches, algorithms, and techniques currently in

use and under development. Discuss techniques for addressing outstanding issues in

the reanalysis efforts

**Session Chair:** Arun Kumar, NCEP/CPC

**Rapporteur:** Lisan Yu, WHOI

3:30 p.m. *Developments in the Ensemble Kalman Filter*

Jeff Whitaker, NOAA/ESRL/PSD

3:50 p.m. *Forecast results and QBO response from NCEP conventional data only*

*T254 EnKF only cycling semi-Lagrangian Reanalysis in 1970, 1981*

Jack Woollen, IMSG & NCEP/EMC

4:10 p.m. *Hybrid Data Assimilation at NCEP*

Daryl Kleist, U. of Maryland

4:30 p.m. *New applications of Data Assimilation to Reanalysis*

Eugenia Kalnay, U. of Maryland

4:50 p.m. *Reanalysis for Tambora 1815*

Gil Compo, U. of Colorado/CIRES & NOAA/ESRL Physical Sciences

Division

5:10 p.m. Discussion

Moderator: Gil Compo

5:30 p.m. Close for day

6:30 p.m. Informal dinner at Franklin’s

**Tuesday 5 May**

**4. Assimilation Development and Experiments: Ocean and Sea ice**

**Objectives:** Exchange reanalysis approaches, algorithms, and techniques currently in

use and under development. Discuss techniques for addressing outstanding issues in

the reanalysis efforts

**Session Chair:** Suru Saha, NCEP/EMC

**Rapporteur:** Yan Xue, NCEP/CPC

8:30 a.m. *NASA ocean data assimilation*

Guilliame Vernieres, NASA/GMAO SSAI

9:00 a.m. *Impacts of ocean observations on NCEP GODAS analysis*, Yan Xue,

NCEP/CPC

9:15 a.m. *Advancing Ocean Data Assimilation and Reanalysis*

Steve Penny*,* U. of Maryland & NCEP

9:30 a.m. *UMD SODA -- problems and progress*

Jim Carton, U. of Maryland

9:45 a.m. *The development of NSST within the NCEP GFS/CFS*

Xu Li, NCEP/EMC

10:00 a.m. Coffee Break

10:30 a.m. *ENSO in a large ensemble of historical reanalyses*

Ben Giese, Texas A&M University

10:45 a.m. *Land data assimilation at NCEP/EMC*

Mike Ek and Jesse Meng, NCEP/EMC

11:00 a.m. *Sea ice development at NCEP/EMC*

Xingren Wu, NCEP/EMC

11:15 a.m. Discussion

Moderator: Jim Carton, U. of Maryland

12:10 p.m. Lunch

**5. Reanalysis Evaluation**

**Objective:** Identify the various requirements for reanalysis products.

**Session Chair:** Jim Carton**,** U. of Maryland

**Rapporteur:** Steve Penny, U. of Maryland

1:30 p.m. *Dry-mass conservation and water consistency in reanalysis*

Ricardo Todling, NASA/GMAO

1:50 p.m. *Air-sea heat and freshwater fluxes in Atmospheric Reanalyses*

Lisan Yu, Woods Hole Oceanographic Institute

2:10 p.m. *Impacts of NCEP Reanalysis R2 and CFSR fluxes on MOM4 simulations*

Caihong Wen, NCEP/CPC

2:30 p.m. *Evaluation and intercomparison of clouds, precipitation, and radiation*

*budgets in recent reanalyses using satellite-surface observations*

Erica Dolinar, U. of North Dakota

2:50 p.m. Coffee Break

3:10 p.m. *Investigation of two extreme summer Arctic sea-ice extent anomalies in*

*2007 and 1996*

Xiquan Dong*,* U. of North Dakota

3:30 p.m. *Reanalysis evaluation in polar regions*

Richard Cullather, NASA/GMAO

3:50 p.m. Rapporteurs give 5 minute summary of their session

4:15 p.m. Discussion and writing assignments

Moderator: Gil Compo

5:00 p.m. Close of Workshop

1. http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/ClimateReanalysisTaskForce.aspx [↑](#footnote-ref-1)