**NOAA Climate Reanalysis Task Force Workshop**

**Meeting Report**

NCWCP Conference Center

5830 University Research Court

College Park, Maryland

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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 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 seasons require reanalyses spanning many years to serve as initial conditions and 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 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 weather and climate forecasting systems, and international efforts in these areas was proposed 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, 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* (Day 2)

Objective: Identify the various requirements for reanalysis products.

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 CRTF with ongoing reanalysis efforts at NCEP
	2. Enhanced awareness of complementary reanalysis efforts among national and international agencies
2. **Session summaries**
	1. **National and International Reanalysis Efforts**
		1. **Summary of presentations**

Reanalysis priorities at NCEP’s Environmental Modeling Center (EMC) are focused on coupled data assimilation and forecasting, with priorities of predictions at subseasonal to the 6-week range, and from seasonal to the 6-month range. An outstanding issue is how to utilize cloud computing and storage. An upgrade in data assimilation to hybrid 4DEnVar and inclusion of aerosols, sea ice, land and ocean components is planned. High priorities in terms of physics are scale-aware PDF-based subgrid scale turbulence and cloudiness schemes, aerosols with consistent microphysics, convection-cloudiness-radiation interactions, non-orographic GWD, Hybrid gain 3DVar/LETKF GODAS, and NSST development. NCEP’s issues and requirements for climate reanalysis concern monitoring, attribution, and societal applications. In terms of forecasts, reanalysis is needed to initialize, and provide base climatology for bias correction, and to verify and re-calibrate models. Key challenges are dealing with discontinuities in reanalysis data sets arising from interaction with model bias and observational platform changes, connecting different reanalysis efforts, and balancing requirements for reforecasts versus climate monitoring, analysis, and attribution.

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 will transition to ERACLIM2 which will feature coupled land-atmosphere-ocean-sea ice-biogeochemical components. The new Copernicus climate change services will include operational support for reanalysis.

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

NASA’s new MERRA2 addresses the limitations of MERRA1, using the recent version of GEOS5 (0.5 degree, L72, 3Dvar). MERRA2, which was released in July 2015, uses new satellite types, reduces spurious trends and imbalances in water and energy cycles, and tests 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 is aerosols. MERRA2 driven chem, ocean and land analyses will follow. The next version of MERRA will be atmosphere-ocean-ice-land coupled, and 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.

* + 1. **Discussion of outstanding issues**

The workshop participants first discussed whether a centralized database is needed for reanalysis observations/innovation stats. In response, it was posited that a decentralized database would be better and more practical, with communications software such that different databases can talk to each other. The question of whether it is possible to scale with new satellite instruments was raised. It was suggested that the most important issue is adopted 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 because of its near real-time aspect, and because it is most stable for long-term time series. Although it was felt that a unified reanalysis for both hindcasts and monitoring should be an NCEP goal, for now there is a desire to keep these two reanalysis systems separate at NCEP.

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. 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. The concept of using a slab ocean was considered problematic, with some layers operating on such long times scales that they can’t be tracked. On the other hand, layers operating on decadal and shorter time scales can be tracked.

Finally, the question was posed as to how, if a reanalysis dataset is not uniformly better in each new iteration, this should be communicated.

* 1. **Developments in the Stratosphere**
		1. **Summary of presentations**

The status of NCEP’s improvements of the stratosphere in reanalysis was presented. Problems were noted with the representation of oscillations, and satellite bias corrections are needed(?) Observation transitions 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.

An overview of aerosol modeling and the need for including aerosols in climate reanalysis was described. It was noted that aerosols are critical for capturing cloud-radiation interactions, to improve data assimilation, and to assess air quality. Including aerosols impacts operational models, with operational benefits seen for medium-range forecasting, and capturing aerosol-chemistry-climate interactions. It is also desirable to have prognostic aerosol capabilities, and to do trajectory analysis related to volcanic eruption. At NASA Goddard, aerosol reanalysis 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.

In terms of water vapor in the stratosphere. photochemical P-L, and latitude, seasonal, altitude dependence, was discussed. The knowledge is helpful for parameterizations. Analysis of specific humidity is done with and without photochemistry. Large differences in the upper levels are potentially due to the inclusion of spurious data. It was noted that accurate prognostic humidity in the UTLS can reduce model bias. The quality of the upper-level data was discussed.

* + 1. **Discussion of outstanding issues**

The question was posed as to whether better modeling or better observations are needed in the stratosphere. Advantages of having the model top at 0.01 hPa compared to 0.2 hPa were discussed.

* 1. **Assimilation Development and Experiments: Atmosphere**
		1. **Summary of presentations**

Developments of 20CR using the Ensemble Kalman filter were presented. It was shown that 20CR surface pressure only analysis is a useful testbed for new ideas. For this case without many observations, QC is very important. Non-Gaussian QC and varying localization length scales are novel aspects of the new development. It is believed that the QC technique, together with high-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.

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, was presented for three 1-year periodsa and their comparison with ERA/ERAInt and GR1. It was concluded that the EN system shows good potential to rerun GR1 very efficiently. The EN results are good in the Northern hemisphere even without satellite observations, but direct radiance assimilation is necessary for a full GR1 replacement. The faster NOSAT could be used for reanalyzing 1948-1975.

A presentation was provided of 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.

New applications of data assimilation to reanalysis, basically on correcting on model bias and reanalysis jumps, were shown. Estimate and correct model bias was done by focusing on the analysis increments, and diurnal cycle model errors 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 AI to correct potential bias introduced by new observations.

A reanalysis effort for Tambora 1815 was presented in which it was shown that 20CR surface pressure-only reanalysis can represent the 1815 event with good skill. It was shown that the atomspheric circulation change may be driven by volcanic aerosol. Of note was that the climate variability in the reanalysis seems to be larger than the signals derived from tree rings.

* + 1. **Discussion of outstanding issues**

What research approaches are required to understand reasons for jumps in climate reanalysis with new observational platforms was discussed. 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 seen. 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 is needed, supported by some gridded versions of intercomparisons. It is necessary to get these grids into the community and go to a common format.

Whether in a "pure" Ensemble Kalman Filter, the ensemble mean is meaningful even though it is not balanced was also discussed. It was suggested that if there is any imbalance, it should show up in precipitation. For initial assessment, ensemble mean is the first thing to look at and easy to access, but it was noted that the ensemble mean doesn’t mean anything.

* 1. **Assimilation Development and Experiments: Ocean and Sea Ice**
		1. **Summary of presentations**

The MERROcean was discussed. It is produced for 1978-present with the following specifications: MOM4p1, at ½ degree, EnOI, Covariance from joint EOFs of coupled model, Altimetry infers 3-D temperature, O-F. Development includes Skin SST, a wave model, at ¼ degree, MOM5, Aquarius SSS. In terms of the GODAS OSE, TAO/TRITON is important for constraining equatorial temperature, and Argo is important for constraining off-equatorial temperature, overall quality of salinity, SSH and surface currents. The drawbacks of GODAS are that there is too strong a fit to data, and there is damped salinity variability. For the HYBRID-GODAS, 3DVAR combines with LETKF. The reanalysis is for 1991-2011, with 56 ensemble members forced by 20CR. The RMS and mean of O-F is reduced with time. For SODA, it is produced with MOMv5.1, at ¼ degree, for 1979-present. (ERA-Interim, bias correction, Hybrid, O-F, A-F, challenges in sea ice analysis?).

The near sea surface temperature (NSST) model for diurnal thermocline layer warming and thermal skin layer cooling is in GFS, to be implemented in CFS. In terms of ENSO in SODAs, (20CRv2 → SODAsi.2 → 20CRv2c → SODAsi.3), two large ENSO events were looked at: 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.

For the GLDAS, there is upgraded Noah Land, 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. Sea ice (?) and an eddy resolving model were discussed [details missing..].

* + 1. **Discussion of outstanding issues**

Jumps are due to the introduction of new observations. A question was posed whether efforts should be made to reduce jumps, which may represent a better analysis and show model biases. 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. The analysis of sea ice extent

And sea ice thickness before satellite era was questioned. It was noted that NSST is used to integrate satellite data and resolve diurnal mixed layer. This improves salinity, mixed layer depth, and deep ocean analysis.

In terms of data assimilation streams, the ocean, land, and stratosphere need spin up of 2-5 years. Climate forecasts require continuous climate reanalysis without artificial jumps for calibrating model climatology and model hindcast skill. Running a low resolution of coupled data assimilation system could provide initial conditions from which different streams can be initialized.

Recommendations were made to examine F-O and F-A and evaluate impacts of observations and data assimilation scheme on ocean reanalysis, and to perform ensemble data assimilation, and coupled data assimilation (?). The question was raised as to whether an eddy resolving model is needed.

* 1. **Reanalysis Evaluation**
		1. **Summary of presentations**

An approach to conserve dry mass and water consistency in reanalyses at NASA GMAO was presented. Three modifications were made to the model, analysis, and increments. An analysis of energy and freshwater budgets over the global ocean in atmospheric reanalyses based on surface fluxes from many reanalysis products with validation to in situ buoys was also presented. It was found that most uncertainty is concentrated in the tropics, and the spread in heat fluxes are primarily seen in the SW fluxes.

In terms of the impact of NCEP Reanalysis R2 and CFSR fluxes on MOM4 simulations, various surface fluxes from the R2 were replaced with surface fluxes from the CFSR to identify which surface uncertainties had the largest impact on the ocean uncertainty. It was found that heat flux drives SST, that wind stress drives D20, and that E-P drives SSS (??).

An evaluation and intercomparison of clouds, precipitation, and radiation budgets in recent reanalyses using satellite-surface observations was presented, which included a comparison of cloud fraction (CF), precipitation rate (PR), and net cloud radiative effect (CRE) from 5 different reanalyses. It was found that in some cases, large biases in CF, PR and CRE are present in the reanalyses, but that the fields are physically consistent.

In an investigation of two extreme summer Arctic sea-ice extent anomalies in 2007 and 1996, a comparison was presented of three different historical periods experiencing extreme conditions vs. historical average (1996, 2007, 2012), and their dynamical features. It was concluded that extremes triggered by anomalous synoptic patterns. An increase in clouds led to increase in net LW down into the ocean. The LW effect is dominant due to the high angle of incidence of SW and the persistent presence of the downward LW.

A presentation on a reanalysis evaluation in polar regions showed updates on reanalysis of sea-ice and land-ice ice in the polar regions, including comparison between regional and global models for reanalysis over polar ice sheets. It was found that sea and land ice data assimilation are still in early phases, and that climatological forcings are difficult to improve upon but reanalysis may be informed by higher resolution regional model reanalysis studies.

* + 1. **Discussion of outstanding issues**

Notes missing?

1. **Next steps and future coordination**
2. **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

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