MERRA and US Reanalysis Plans and Activities

Michele Rienecker[1], Phil Arkin[2], Max Suarez[1], Ricardo Todling[1]
Ron Gelaro[1], Julio Bacmeister[1]
Siegfried Schubert[1], Michael Bosilovich[1]

[1] Global Modeling and Assimilation Office, NASA/GSFC, Greenbelt, MD 20771
[2] Earth System Science Interdisciplinary Center, U. Maryland, College Park, MD 20742

1. Abstract

This presentation summarizes atmospheric reanalyses that have been conducted in the U.S., as well as the preparation for and status of the atmospheric reanalysis to be undertaken in the Global Modeling and Assimilation Office (GMAO) at NASA/Goddard Space Flight Center. This reanalysis, termed MERRA: Modern Era Reanalysis for Research and Applications, will focus on the consistency of the analyses from the perspective of the atmospheric branch of the hydrological cycle.

2. Reanalysis Efforts in the U.S.

Atmospheric reanalyses within the U.S. began with the GEOS-1 reanalysis for the period from 1980 to 1995 from the NASA/Data Assimilation Office. This was quickly superseded by the NCEP/NCAR Reanalysis-1, covering the period from 1948 to the present (see Kalnay et al., 1996 and http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html). The reanalysis uses a frozen global data assimilation system and a data base as complete as possible. The data assimilation system (3D-Var) and the global spectral model are identical to the NCEP operational system on January 1995, but with a horizontal resolution of T62 (about 210 km) and 28 vertical levels. Several problems associated with data errors were corrected in the NCEP/DOE Reanalysis-2 (1979-1993); at the same time the physics parameterizations were updated (see Kanamitsu et al., 2002 and http://www.cpc.ncep.noaa.gov/products/wesley/reanalysis2/index.html). The Reanalysis-1 product is kept current through the Climate Data Assimilation System (CDAS, see Kistler et al., 2001).

NCEP's North American Regional Reanalysis (NARR) project (see Mesinger et al., 2006 and http://wwwt.emc.ncep.noaa.gov/mmb/rreanl/) for the North American domain was conducted with the NCEP Eta Model and its Data Assimilation System coupled to the Noah land surface model. It uses data sets additional to or improved upon those of the global reanalyses. The NARR initially covered the 25-year period 1979-2003 at 32 km resolution with 45 layers and with 3-hourly output. Precipitation observations have been assimilated into the atmospheric analysis so that the forcing to the land surface model is more accurate than in previous reanalyses. Consequently, NARR provides a much improved analysis of land hydrology and land-atmosphere interaction. The NARR is being continued in near-real time as the Regional Climate Data Assimilation System, R-CDAS.

All of these analyses have been extremely valuable and widely used. However, there has been no coherent national program with coordination and/or oversight. Workshops and planning for a national program for continual reanalysis have been undertaken on several occasions. The latest report, from a workshop on the

Ongoing Analysis of the Climate System, in August 2003, is available at http://www.joss.ucar.edu/joss_psg/meetings/climatesystem/. The workshop recommended periodic reanalyses covering three distinct observational regimes:

- **R1979** – post 1979, the satellite era – with the goal of a continuous climate record and an improved hydrological cycle,
- **R1950** – post 1950, the era of upper air observations, with a substantial but changing upper air network – with the emphasis on continuity and the low-frequency signal, especially interannual-to-decadal variability, and
- **R1850** – post 1850, the historical era, with availability of a minimal set of surface observations – with the goal of the best and longest consistent analysis, focused on the surface Northern Hemisphere as well as climate change time scales.

The workshop also recommended a continental-scale regional reanalysis at very high spatial resolution.

One of the outcomes of the proposed US ongoing analysis of the climate system has been a vision for an Integrated Earth System Analysis (IESA) Project, incorporating physical, chemical and biological processes. The IESA would have two components: Ongoing Earth System Analyses that would provide the national foundation for assessing the current state of the global Earth system in near real-time and on an ongoing basis; and Earth System Reanalyses that define a baseline "Earth System Analysis of Record" to serve as the nation's best assessment of how the Earth system has varied over the recent historical period. The IESA Project is still in the early stages of discussion, but is recognized as the ultimate goal for future reanalysis efforts.

3. Modern Era Reanalysis for Research and Applications (MERRA)

MERRA (see Bosilovich et al., 2006 and http://gmao.gsfc.nasa.gov/research/merra/) will be undertaken with the GMAO's new data assimilation system, GEOS-5, which integrates the GEOS-5 atmospheric model with the Gridpoint Statistical Interpolation (GSI) analysis system being developed jointly by NCEP and GMAO. The GSI analysis solver was developed at NCEP to support inhomogeneous and anisotropic 3D background error covariances (e.g., Wu et al., 2002; Derber et al. 2003; Purser et al. 2003).

The GEOS-5 atmospheric model is a weather-and-climate capable model using the finite-volume dynamical core (Lin, 2004). In developing GEOS-5, attention has focused on the representation of moist processes (see http://gmao.gsfc.nasa.gov/systems/geos5/). The tropical precipitation morphology has been analyzed in Bacmeister et al. (2006). Developments of GEOS-5 were guided by a realistic representation of tracer transports and stratospheric dynamics. The ozone analysis of the DAS is input to the radiation package along with an aerosol climatology. GEOS-5 is coupled to a catchment-based hydrologic model (Koster et al., 2000) and a sophisticated multi-layer snow model (Stieglitz et al., 2001).

MERRA will use a ½ degree resolution model and analysis, with 72 levels to 0.01 hPa. A 2-degree resolution version of the MERRA system (called Sweeper) is being run to progress quickly through the input data to help identify problems. MERRA production will be accomplished through three streams (Figure 1). The streams will be initialized by the Sweeper run, and then spun up one more year to address the downscaling of the coarse grid data. When one stream catches another, there will be some overlap in the processed data. We intend to continue some of this overlap to evaluate the uncertainty and sensitivity of the analysis system to initial conditions.

In 1987, SSM/I becomes available and will strongly affect the water cycle. Subsequent advanced data products from EOS-era satellites, such as AIRS, TMI and QuikSCAT, likewise contribute to the analysis

data and impact the climate record. To help assess the effect of new data on the reanalysis, an additional analysis will continue with the Reduced Observing System Baseline (ROSB) data stream. The ROSB will use only the non-satellite conventional data and the TOVS data for the entire period. With the ROSB we will assess the impact of the modern observing system on forecasts and analyses (e.g. water and energy budgets) and begin to understand how to incorporate new instruments and data into the long term climate time series.

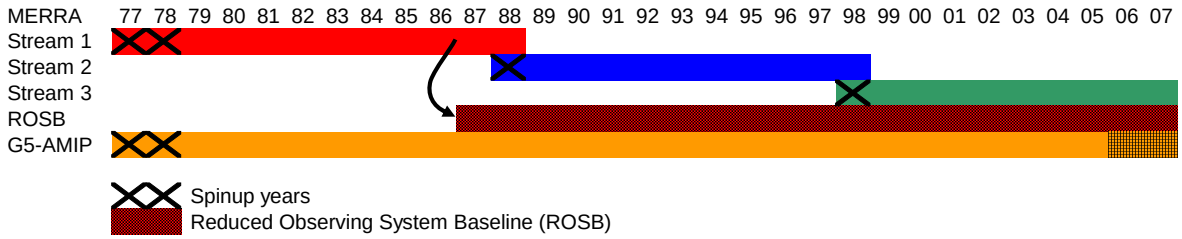

Figure 1 Configuration of MERRA production computing streams. The highest priority streams (1-3) include the full resolution output and complete input data. The Reduced Observing System Baseline (ROSB) will continue from Stream 1 but withhold new and advanced observing systems. G5-AMIP is a model-only integration to define the model's climate.

4. References

Bacmeister, J.T., M.J. Suarez, and F.R. Robertson: Rain re-evaporation, boundary-layer/convection interactions and Pacific rainfall patterns in an AGCM, (accepted *J. Atmos. Sci*.), 2006.

Bosilovich M., and coauthors: NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA), *U.S. CLIVAR Variations*, June 2006.

Derber, J. C., R. J. Purser, W.-S. Wu, R. Treadon, M. Pondeca, D. Parrish, and D. Kleist: Flow-dependent Jb in a global grid-point 3D-Var. *Proc. ECMWF annual seminar on recent developments in data assimilation for atmosphere and ocean.* Reading, UK, 8-12 Sept. 2003.

Kalnay, E., and coauthors: The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, **77**, 437–471, 1996.

Kanamitsu, M., W. Ebisuzaki, J. Woollen, S-K Yang, J.J. Hnilo, M. Fiorino, and G. L. Potter: NCEP-DOE AMIP-II Reanalysis (R-2), *Bull. of the Amer. Met. Soc.*, **83**, 1631-1643, 2002.

Kistler, R., and coauthors: The NCEP/NCAR 50-year reanalysis project, *Bull. Amer. Meteor. Soc.*, **82**, 247–267, 2001.

Koster, R. D., M. J. Suárez, A. Ducharne, M. Stieglitz, and P. Kumar: A catchment-based approach to modeling land surface processes in a GCM, Part 1, Model Structure. *J. Geophys. Res.*, **105**, 24809-24822, 2000.

Lin, S.-J.: A vertically Lagrangian Finite-Volume Dynamical Core for Global Models. *Mon. Wea. Rev.*, **132**, 2293-2307, 2000.

Mesinger, F., and coauthors: North American Regional Reanalysis, *Bull. Amer. Meteor. Soc.*, **87**, 343–360, 2006.

Purser, R. J., W.-S. Wu, D. F. Parrish, and N. M. Roberts, 2003: Numerical aspects of the application of recursive filters to variational statistical analysis. Part I: Spatially homogeneous and isotropic Gaussian covariances. *Mon. Wea. Rev*., **131**, 1524-1535, 2003.

Stieglitz, M., A. Ducharne, R. D. Koster, and M. J. Suarez, 2001: The Impact of Detailed Snow Physics on the Simulation of Snow Cover and Subsurface Thermodynamics at Continental Scales. *J. Hydromet.*, 2, 228-242, 2001.

Wu, W.-S., R.J. Purser and D.F. Parrish, 2002: Three-dimensional variational analysis with spatially inhomogeneous covariances. *Mon. Wea. Rev*., **130**, 2905-2916.