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Title: Evaluation of NASA’s Global Water Cycle Data: Interannual Variability, Inter-decadal Changes and Trends

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MERRA Analysis and Diagnostics

The progress of MERRA has gone well, and by the end of July 2009, the period of 1979 through 2005 will be available online. We are engaged in the development of several papers on the MERRA energy and water cycles. In evaluating the global energy budget, we first compare MERRA with the consensus budget analysis developed by Trenberth et al (2009) in Figure 1. This consensus was built on the evaluation of many different observation and model products and processes. In Reanalyses, however, the influence of observations on the results must also be accounted (numbers labeled with “ana” names are from the analysis of observations). While it is interesting to note that the imbalance of energy at the surface relates to the influence of the observations in the atmosphere. However, the path that energy takes to balance this budget will be developed over the course of this work. For example, we can also see that the MERRA clouds are either too few or too thin, compared to the consensus analysis. In addition, this is for a limited period during the EOS observing period, but we see a low frequency trend over the long time series of MERRA data.

Figure 1 Global Energy budget terms from MERRA (in Red) and Trenberth et al (2009).

We can also track the progression of the biases in time. The MERRA precipitation has an increasing trend, but GPCP is generally neutral. The OLR is generally biased high but the bias decreases in time, related more to the ocean than the land which is biased low. The land also has a slight decreasing trend, while ocean has an increasing trend. EBAF OLR is a more recent EOS based data product. It shows that there may be some bias in the SRB data. However, to a first approximation, the error and uncertainty of the reanalyses is much greater than that of the observations. In evaluating MERRA, we may need to consider the 80s separately from the rest of the period, given that the net imbalance as the surface is larger and the biases tend to be larger in that period.

Figure 2 Annual mean time series of Global, ocean and land averages of OLR, Precipitation and ocean evaporation. (for JRA OLR, the right axis is used)

Figure 3 Surface Ocean Flux Anomalies over the ocean from MERRA

Figure 3 shows how the oceanic surface fluxes change in time. Not shown is the clouds and analysis increments, both of which change accordingly (increments increase from negative to positive in time). These changes are more than what is observed in the satellite of observational records, and related to changes in the observing system and how observations constrain the model background. The MERRA trends are less related to the real global warming signal, than to the model biases against the changing observing system. The main advantage of the MERRA data set is the complete water and energy budget, which we, and other researchers, can use to characterize the Earth system, and ultimately, how to improve the model.

Along those lines, we have already begun to evaluate the impact of observations on the reanalysis system. Chen et al (2009) has presented experiments where we remove the increments of water vapor from the systems budget, keeping all the other observations that are included in the analysis. The feedback is interesting, in that, it is not merely a local influence on the precipitation. The circulation is greatly modified, such that the ITCZ is not necessarily weakened, but rather made more broad or diffuse. With the water vapor increments, the ITCZ is more narrow (more in agreement with observed precipitation), as in Figure 4.

With this work we have characterized the broad effect of the water vapor analysis in MERRA. Over convective regions, less water vapor in the lower troposphere causes less convective precipitation in no-vapor run, even though more water vapor in middle troposphere and no significant change of high cloud. Although the global mean precipitation has little difference, the difference in the distribution of precipitation is significant between control run and no-vapor run. The omega field is closely related with the precipitation field in the tropics. So the difference in water vapor field ultimately causes differences in general circulation. The root of the difference between no-vapor run and control run is the bias of the model and the tendency of the system to approach the model climatology when less constrained by the "observation" data.

Figure 4 Mean precipitation for the GEOS5 analysis and differences from the control of the experiment to remove water vapor increments in the analysis, while keeping other terms. The changes in Precipitation are the result of both the change in mass of water in the atmosphere and the dynamic circulation.

As part of the MERRA hydroclimatolical evaluation, we are examining ocean turbulent flux fields and their variations. This is proceeding along two paths. First, in an effort to validate the ability of MERRA to reproduce measured surface turbulent processes over the ocean, an in-situ set of surface measurements has been gathered for point to point comparisons. This dataset consists of two data sources of ocean surface measurements. The first source is the National Oceanographic Data Center (NODC) which archives the National Data Buoy Center (NDBC) moored buoy data. The second source of surface data is the TAO/PIRATA/RAMA moored buoy array supplied by the Pacific Marine Environmental Laboratory (PMEL). For this study, NDBC buoys cover the time period 1979-2008 while the PMEL set consists of measurements over the period 1988-2008. Standardization of measurements to a 10m height and calculation of fluxes are done using the COARE 3.0 flux algorithm. Warm-layer/Cool-skin effects are taken into account as well. The use of the COARE 3.0 algorithm demands surface radiative flux components as well. As most buoys do not have these observations, this measurement is taken from the nearest GEWEX-SRB 3.0(SW)/2.5(LW) data gridpoint when necessary.

Figure 5. Monthly Latent and Sensible heat flux comparisons between ensemble buoys and MERRA.

Preliminary comparisons suggest a LHF over-prediction (bias) of approximately 11.6 Wm^{-2} at buoy locations and an rms difference of order 30 Wm^{-2} (Figure 5). Agreement is better for sensible heat fluxes in an absolute sense, though this quantity is much smaller so relative errors are larger than for latent heat flux. These are preliminary numbers and the analysis of these comparisons will be a major focus over the next few months.

A second component of this work will consist of comparisons of the emerging SEAFLUX turbulent heat flux products using a new neural net algorithm. This will facilitate maximum leverage of SSM/I data with the COARE 3.0 algorithm to examine regional patterns and interannual variability. Details regarding progress on this data set are presented below.

Tropical Water / Energy Cycle Variability

We are also continuing efforts in Integration of NEWS / GEWEX Data for Intraseasonal Diagnostics. One major mode of short-term climate variability concerns intraseasonal scale tropospheric temperature / precipitation variations centered in the tropical band. Climate models are notoriously poor at replicating this scale of variability. It is important to know to what degree the feedback processes at work on intraseasonal scales might also be compromised in climate simulations and what physical processes in the models. One of our tasks this year was to revisit and expand an analysis performed by Spencer et al., (2007), hereafter S07, in which we brought in improved data sets of precipitation TRMM 3B42, NOAA AMSU-B ice water path (IWP), OAFLUX turbulent energy fluxes.

Our compositing procedure identified nearly 40 events of elevated tropical atmospheric temperature in AMSU-B channel 5 temperature, T5, during the 2000-2006 period. Working with tropically-averaged values, we built composites of various quantities referenced to the intraseasonal temperature events. This allowed us to ask the following questions: (i) How is tropospheric temperature related to tropical deep convection and the associated ice cloud fractional amount (ICF) and ice water path (IWP)? (ii) What is the source of moisture sustaining the convection and what role does deep convection play in mediating the PBL – free atmospheric temperature equilibration? (iii) What affect do convectively generated upper-tropospheric clouds have on the TOA radiation budget?

Figure 6 Composite moisture budget referenced to the largest composite AMSU-A Ch 5 temperature maximum at day 0. Note that OAFLUX ocean LHF (green) cannot support 3B42 precipitation (blue) and SSMI-estimated vapor storage (red). The residual (black) is the inferred moisture flux convergence. Precipitation anomaly leads maximum tropical atmospheric intraseasonal temperature anomaly by nearly 10 days.

Our results can be summarized as follows:

(1) As in S07 we find a clear maximum in precipitation that precedes the development of the tropospheric mean temperature maximum. However in the present analysis we find the largest precipitation anomaly at day -9 or -8, well before the day -3 maximum noted in S07. AMSU-B ICF and IWP, largely a signal of precipitation-size ice, also maximize near day -9 giving confidence in this estimate of the precipitation / T5 phase relationship.

(2) MODIS ICF actually maximizes one to two days earlier than MODIS IWP and the AMSU-B quantities. Nevertheless, the reasonably tight phasing between AMSU-B and MODIS IWP time series in relationship to precipitation underscores the strong control that penetrating deep convective systems exert on evolving upper-tropospheric cloud extent and ice water content.

(3) A rise in near-surface moist entropy leads that of atmospheric temperature, peaking four days prior to T5. Apart from the phase difference, the lack of symmetry between the two time series argues against strict quasi-equilibrium in PBL / free atmospheric moist static stability but does support a quasi-equilibrium relationship between an evolving convective cloud population and large scale forcing.

(4) Ocean evaporation by itself is unable to account for the variations in precipitation and the much smaller storage of water vapor. The implied necessity for vertically-integrated moisture convergence into the convecting regions of the tropical ocean domain is also consistent with the small signal in SST relative to T5 and suggesting dynamical circulations and energy transports connecting precipitating regions to adjacent poleward non-convective regions. (see Figure 5)

(5) Energy loss from increased SW reflection tracks precipitation strongly but remains elevated after the precipitation maximum. In contrast LW planetary warming anomalies weaken and reverse sign in conjunction with the decline of convective precipitation anomalies and warming of those precipitating cloud tops. The combined effect is the development of a net radiative loss to the planet with peaks of near 1.25 W m-2 from day -6 to day 6.

In summary, our analysis shows that intraseasonal events have a coherent signal when integrated over the tropical oceans. This amounts to an intraseasonal spin-up / spin-down of the circulation and, we speculate, energy transport. In the process moisture is brought in to the convecting tropics to support invigorated deep convection. An associated net loss of energy at the top-of-atmosphere results. Our next step in this analysis will be to determine to what degree this mode of variability is present in the MERRA analysis and in the GEOS-5 model used as the assimilating model.

NEWS / SEAFLUX Turbulent Heat Flux Product

Finally, there has been significant progress in finalizing an improved methodology to derive turbulent fluxes from SSM/I passive microwave data. This work represents a collaborative effort between this investigation (MSFC) and that of Dr. Carol Anne Clayson at Florida State University (FSU). Brent Roberts, a FSU student under the auspices of the NASA Graduate Student Researchers Program, has developed and implemented a neural network based approach that provides superior error characteristics compared to existing algorithms studied under the SEAFLUX project. Using a model that involves 8 input and 10 hidden neurons, significant error reduction is seen in the five outputs needed to drive flux algorithms: specific humidity (Qa), air temperature (Ta), wind speed (U), sea surface temperature (SST), and precipitable water (PW).

Qa (g/kg)			Ta (deg C)			U (m/s)			SST (deg C)		
Algorithm	RMSE	BIAS	Algorithm	RMSE	BIAS	Algorithm	RMSE	BIAS	Algorithm	RMSE	Bias
NNET	1.32	0.16	NNET	1.32	-0.03	NNET	1.58	-0.16	NNET	0.59	-0.01
Bentamy	1.83	0.29	RHTA	2.27	-0.54	GS	2.07	-0.11	OISST	0.66	0.22
Jackson	2.07	0.85	MLR	1.60	-0.16	GSW	2.40	1.03			
Schluessel	2.00	0.55									
Schulz	2.14	0.28									
Singh	1.70	-0.29									

Table 1. NNET: Neural net RHTA: Assuming constant RH in retrieval MLR: Mult Linear Reg
GS: Goodberlet and Swift, (1992) GSW: Goodberlet, Swift, and Wilkerson, (1989)

This neural net algorithm will feed flux calculations using the COARE 3.0 flux algorithm with inputs from the SSMI historical archive and will be available to the NEWS community. Over the next few months we will be using these diagnostics to evaluate the MERRA fields and variability on a variety of scales.

Presentations:

“Reanalyses and the climate change trend”, Chen J., ESSIC seminar, College Park, MD, June 16, 2008.

“The impact of water vapor observations in global data assimilation”, Bosilovich M.G., J. Chen, F. R. Robertson, Y. Chang, AGU Chapman Conference on Atmospheric Water Vapor and Its Role in Climate, Kailua-Kona, HI, October 20-24, 2008.

“MERRA’s global/regional energy and water cycles”, Bosilovich M.G., J. Chen, F. R. Robertson, 4th Annual NEWS PI Meeting, Baltimore, MD, November 3-5, 2008.

“The interrelationships among water and energy parameters in reanalyses”, Chen J., M. Bosilovich, the 23rd Conference on Hydrology and the 21st Conference on Climate Variability and Change, Phoenix, AZ, January 11-15, 2009.

"TOA radiation fluxes and precipitation in reanalyses", Chen J., M. G. Bosilovich, Gordon Research Conferences on Radiation & Climate, New London, NH, July 5-10, 2009.

Papers:

Bosilovich, M. G., J. Chen and F. R. Robertson, MERRA Global Water and Energy Budgets. To be submitted.

Roberts, B., C. A. Clayson, F. R. Robertson, and D. Jackson, Predicting near-surface characteristics from SSM/I using neural networks with a first guess approach. *To be submitted to JGR.*

Ramey, H. S. and F. R. Robertson, Tropical Intraseasonal Variability: Coherent temperature, cloud-radiative and precipitation signals on a global scale. *To be submitted to JGR*.