<u>Objective 2.1.4</u>: Progress in quantifying the key reservoirs and fluxes in the global water cycle and assessing water cycle change and water quality.

The cycling of energy and water has obvious and significant implications for the health and prosperity of society. The availability and quantity of water is vital to life on earth and helps to tie together the Earth's lands, oceans and atmosphere into an integrated physical system.

Over the past year, NASA has continued progress toward improving its description of the water cycle, including the size and movement between its stores. Coincident use of multiple satellite data sources (e.g. AMSR-E, TRMM, MODIS, etc.), especially those of different but linked variables have led to improvement both in the quantification of the water cycle and the uncertainty estimates of its terms, with both groundwater and total storage two newly provided variables. Furthermore GRACE data has been used to provide large area estimates of the change in total water storage of the land that by definition has to equal the sum of precipitation, evaporation, and run-off. Refinement of the global water balance has been made globally and regionally, and on annual and monthly time scales. Shorter term remote sensing data sets (EOS era~10 years) have been combined with longer term satellite records (e.g. snow covered area) and land surface model simulations to provide assessment capability to determine if, where, and how the water cycle might be changing. Open ocean remote sensing capabilities to assess water properties are being tested against collected coastal and in-land water body samples to determine the feasibility and capability of remote sensing observations to determine water quality.

The NASA Energy and Water cycle Study (NEWS) has compiled the first-ever satellite-based energy and water cycle climatology, including monthly, continental and oceanic averages of the Earth's radiation balance, as well as precipitation, evaporation and water vapor. The accompanying uncertainty evaluation adds a believability measure for application of this data and is helping to guide future satellite technology decisions. This new integrated global water and energy assessment is being used in conjunction with NASA's Modern Era Retrospective-Analysis for Research and Applications (MERRA) reanalysis, to study and improve predictions of weather and climate variability. These integrated water and energy satellite studies have also provided insights to the mechanisms and severity of mid-western U.S. floods and droughts, which will help mitigate future damage caused by these extremes.

Other examples of scientific progress outlined in the appended list of references for Objective 2.1.4 include:

• **Global river basin analysis – satellite data and modeling depict runoff sensitivity in 194 major river basins around the world (Tang and Lettenmaier, 2012).** The study demonstrated for the first time 21st century runoff sensitivity of 194 major global river basins using global mean temperature change as an index of anthropogenic climate changes in temperature and precipitation. Results show that the runoff sensitivity implied by the IPCC experiments is relatively stable across emissions scenarios and global mean temperature increments, but varies substantially across models with the exception of the high-latitudes and currently arid or semi-arid areas. River runoff is a key index of renewable water resources that affect almost all human and natural systems. Any substantial change in runoff will therefore have serious social, environmental, and ecological consequences. Estimated runoff response to global mean temperature change implied by the climate change experiments were generated in response to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). In contrast to previous studies, it is estimated that the runoff sensitivity using global mean temperature change can be used as an index of anthropogenic climate changes in temperature and precipitation, with the rationale that this removes the dependence on emissions scenarios.

• **SMAP prospects and preliminary studies speaking for the added-value of soil moisture in advancing our predictive understanding of water cycle dynamics. (Mastropieto et al, 2011).** As one of the four first-tier missions recommended by the National Research Council's Committee on Earth Science and Applications from Space, SMAP will provide comprehensive global mapping measurements of soil moisture and freeze/thaw state in order to enhance understanding of the processes that link the water, energy, and carbon cycles. The primary objectives of SMAP are to improve worldwide weather and flood forecasting, enhance climate prediction, and refine drought and agriculture monitoring during its 3 year mission.

• **Land-ocean coupling studies via GRACE – value added to water cycle dynamics. (Bailing et al, 2012)** A land surface model's ability to simulate states (e.g., soil moisture) and fluxes (e.g., runoff) is limited by uncertainties in meteorological forcing and parameter inputs as well as inadequacies in model physics. In this study, anomalies of terrestrial water storage (TWS) observed by the Gravity Recovery and Climate Experiment (GRACE) satellite mission were assimilated into the NASA Catchment land surface model in western and central Europe for a 7-year period, using a previously developed ensemble Kalman smoother. GRACE data assimilation led to improved runoff estimates (in temporal correlation and root mean square error) in 17 out of 18 hydrological basins, even in basins smaller than the effective resolution of GRACE. In addition to improving temporal correlations, GRACE data assimilation also reduced increasing trends in simulated monthly TWS and runoff associated with increasing rates of precipitation.

• **Snowstorms in Baltimore/Washington region in Feb 2010 (Foster et al.).** The snowfall in the Baltimore/Washington metropolitan area during the winter of 2009/2010 was unprecedented and caused serious snow-related disruptions. One of the biggest contributing factors to the unusually severe winter weather in 2009/2010, throughout much of the middle latitudes, was the Arctic Oscillation. A concerted effort was made to link remotely sensed falling snow observations to remotely sensed snow cover and snowpack observations in the Baltimore/Washington area. This work shows that falling snow intensity and/or the presence of liquid water clouds impacts the ability to reliably detect snow water equivalent. Moreover, changes in the condition of the snowpack, especially in the surface features, negatively affect retrieval performance.

• **GRACE use in drought monitoring in west and central Europe (Bailey et al., 2012).** Anomalies of terrestrial water storage (TWS) observed by the Gravity Recovery and Climate Experiment (GRACE) satellite mission were assimilated into the NASA Catchment land surface model in western and central Europe for a 7-year period, using a previously developed ensemble Kalman smoother. GRACE data assimilation led to improved runoff estimates (in temporal correlation and root mean square error) in 17 out of 18 hydrological basins, even in basins smaller than the effective resolution of GRACE. Improvements in root zone soil moisture were less conclusive, partly due to the shortness of the in situ data record. GRACE data assimilation also had significant impacts in groundwater estimates including trend and seasonality. In addition to improving temporal correlations, GRACE data assimilation also reduced increasing trends in simulated monthly TWS and runoff associated with increasing rates of precipitation.

• **Tropical Pacific SST and effect on Arctic precipitation (Hegyi and Deng, 2011).** The temporal and spatial characteristics of decadal-scale variability in the Northern Hemisphere (NH) cool-season (October–March) Arctic precipitation are identified from both the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) and the Global Precipitation Climatology Project (GPCP) precipitation data sets. This decadal variability is shown to be partly connected to the decadal-scale variations in tropical central Pacific sea surface temperatures (SSTs) that are primarily associated with a decadal modulation of the El Niño–Southern Oscillation (ENSO), i.e., transitions between periods favoring typical eastern Pacific warming (EPW) events and periods favoring central Pacific warming (CPW) events.

FY 2011 Annual Performance Goal	FY 09	FY10	FY11	FY12
2.1.4.1: ES-11-9: Demonstrate planned progress in quantifying the key reservoirs and fluxes in the global water cycle and assessing water cycle change and water quality. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.	Green	Green	Green	

Appendix 4: Supporting Material for Objective 2.1.4

Progress in quantifying the key reservoirs and fluxes in the global water cycle and in assessing water cycle change and water quality.

Major activities / accomplishments

1) **An analysis of seasonal trends in the first ever global maps of microwave emission depth index showed that changes in emission depth might be tied to changes in land surface moisture and vegetation conditions**. Emission depth was derived from multisensor satellite data time series including data from NASA's Advanced Microwave Scanning Radiometer-EOS (AMSR-E) and Moderate Resolution Imaging Spectroradiometer (MODIS). This work may improve our ability to assess drought impacts and surface fluxes of water globally through the estimation of surface moisture availability and drought-induced vegetation stress and dieback. The work promises to also lead to improved measurements of land surface temperature from microwave sensor data, which provide the only means for sensing surface temperature from space in both clear and cloudy conditions.

Reference: Galantowicz, J. F., J.-L. Moncet, P. Liang, A. E. Lipton, G. Uymin, C. Prigent, and C. Grassotti, 2011: Subsurface emission effects in AMSR E measurements: Implications for land surface microwave emissivity retrieval. *J. Geophys. Res.,* 116, D17105, doi:10.1029/2010JD015431.(Sept 2011)

Website:
http://www.aer.com/science-research/atmosphere/remote-sensing/environmental-monitoring/microwave-surface-emissivity-dat

2) In evaluating the regional water cycle over the United States, we identified a range of quality in MERRA (and all reanalyses) summer precipitation and interannual variability related to extremes. Specifically, the Northwest US summertime interannual variability is very well reproduced, owing to lagged forcing from the previous springtime ENSO. The quality of reanalyses degrades eastward to the Midwest region, as the observed ENSO forcing weakens, but reanalyses continue to be influenced by ENSO. We continue to investigate the quality of land-atmosphere interaction in reanalyses as well as their ability to generate precipitation form mesoscale convective complexes**. NEWS has provided the scientific motivation, but we also provide an interpretation of these results for the National Climate Assessment (NCA) and utilizing reanalyses in climate monitoring.**

Reference: Cullather, R. I., M. G. Bosilovich, 2012: The Moisture Budget of the Polar Atmosphere in MERRA. *J. Climate*, **25**, 5–24. (Jan 2012)
Note: For NEWS this will be written up for publication, and will also make a contribution to a new USCLIVAR Working Group on Large-scale Influence on Extremes

Websites:
http://gmao.gsfc.nasa.gov/projects/NCA/ with a detailed report for NCA at http://gmao.gsfc.nasa.gov/projects/NCA/MERRA_US_Climate_v3.pdf
doi: http://dx.doi.org/10.1175/2011JCLI4138.1

3) Evapotranspiration (ET) is the transfer of liquid water from Earth's surface to the atmosphere, including both evaporation and plant transpiration. ET links the water and energy cycles, it is a process essential to the movement of water and energy around the Earth, and understanding

and properly simulating ET is essential for weather forecasting and climate prediction. However, ET is difficult to measure, and different estimation techniques don't always produce the same results. ET was estimated by closing a water budget with observation based (including TRMM) precipitation data, gauged runoff data, and terrestrial water storage changes from GRACE. **The study demonstrated for the first time that while uncertainty in water budget based estimates of ET is often too large for those estimates to be useful, uncertainty in the mean annual cycle is small enough that it is practical for evaluation of other ET products, weather and climate prediction systems, and satellite based ET retrievals**. Further, the water budget based ET time series in two tropical river basins, one in Brazil and the other in central Africa, exhibited a weak annual cycle, helping to resolve debate about the strength of the annual cycle of ET in such regions and how ET is constrained throughout the year.

Reference: Rodell, M., E. B. McWilliams, J. S. Famiglietti, H. K. Beaudoing, and J. Nigro , 2011: Estimating evapotranspiration using an observation based terrestrial water budget, *Hydrological Processes*, DOI: 10.1002/hyp.8369 (Dec 2011)

Website:
https://sites.google.com/site/newccip/?pli=1

4) The lack of observational data for use in evaluating the realism of model-based land–atmosphere feedback signal and strength has been deemed a major obstacle to future improvements to seasonal weather prediction by the Global Land–Atmosphere Coupling Experiment (GLACE). **This study provides the first observationally based guidance for future spatially and temporally focused studies of land–atmosphere interactions**

Reference: Ferguson, Craig R., E. F. Wood, 2011: Observed Land–Atmosphere Coupling from Satellite Remote Sensing and Reanalysis. *J. Hydrometeor*, **12**, 1221–1254.
Website:
doi: http://dx.doi.org/10.1175/2011JHM1380.1 (Dec 2011)

5) While the Arctic region has been warming strongly in recent decades, anomalously large snowfall in recent winters has affected large parts of North America, Europe, and East Asia. **A study combining satellite data sets of sea ice extent and snow cover with climate model simulations demonstrates that the recent decrease in Arctic sea ice area is linked to**

changes in the winter Northern Hemisphere atmospheric circulation. The circulation changes result in more frequent episodes of atmospheric blocking patterns, which lead to increased cold surges and snow over large parts of the northern continents. These findings are being used to improve seasonal forecasting of snow and temperature anomalies across northern continents.

Reference: Liu, J., J. Curry, H. Wang, and M. Song, 2012: Impact of Declining Arctic Sea Ice on Winter Snowfall, *Proc Natl Acad Sci.*, 109(11):4074-4079., (*PNAS, Mar 12*)

Website:
http://www.pnas.org/content/early/2012/02/17/1114910109.short
http://curryja.files.wordpress.com/2012/03/pnas.pdf

Press releases:
http://www.gatech.edu/newsroom/release.html?nid=112691
http://www.sciencedaily.com/releases/2012/02/120227111052.htm

6) The study demonstrated for the first time 21st century runoff sensitivity of 194 major global river basins using global mean temperature change as an index of anthropogenic climate changes in temperature and precipitation. Results show that the runoff sensitivity implied by the IPCC experiments is relatively stable across emissions scenarios and global mean temperature increments, but varies substantially across models with the exception of the high-latitudes and currently arid or semi-arid areas.

River runoff is a key index of renewable water resources which affect almost all human and natural systems. Any substantial change in runoff will therefore have serious social, environmental, and ecological consequences. Estimated runoff response to global mean temperature change implied by the climate change experiments were generated in response to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). In contrast to previous studies, is estimated that the runoff sensitivity using global mean temperature change as an index of anthropogenic climate changes in temperature and precipitation, with the rationale that this removes the dependence on emissions scenarios. The runoff sensitivities are slightly higher at 0.5°C warming than for larger amounts of warming. The estimated ratio of runoff change to (local) precipitation change (runoff elasticity) ranges from about one to three, and the runoff temperature sensitivity (change in runoff per degree C of local temperature increase) ranges from decreases of about 2 to 6% over most basins in North America and the middle and high latitudes of Eurasia.

Reference: Tang, Q., and D. P. Lettenmaier, 2012: 21st Century Runoff Sensitivities of Major Global River Basins, *Geophys. Res. Lett.*, 39, L06403. (Mar 2012)

Website:
http://dx.doi.org/10.1029/2011GL050834

7) GCPEx: What We Don't Know About Snow

Droughts and climate change are making the snow pack a shrinking water resource, and managers have a greater need than ever to know exactly how much water is locked in snow. But to know that, scientists first have to know just how much water snow carries as it falls to the ground. As part of an effort to improve snow measurements by satellites, NASA's Global Precipitation Measurement (GPM) mission and their partners, Environment Canada ran a large experiment in Southern Ontario in January and February 2012, called the GPM Cold-season Precipitation Experiment (GCPEx).

GCPEx used instrumented aircraft (NASA DC-8, NASA-funded University of North Dakota Cessna Citation, and Canadian National Research Council Convair 580) for flights over and through falling snow events with additional measurements from heavily-instrumented ground sites located in and around the Environment Centre for Atmospheric Research Experiments (CARE) located in Egbert, Ontario. The DC-8 aircraft carried active radar and a passive radiometer instruments similar to those to be flown on the GPM Core satellite. They collected data from 17 snow events that will be used to improve understanding of snow dynamics inside clouds, including size, distribution, and water content of snowflakes. The data collected is currently being analyzed and will be used for algorithm development of snow detection from space using GPM.

GPM is an international satellite mission that will unify and set new standards for precipitation measurements from space, providing the next-generation observations of rain and snow worldwide every three hours. The Core satellite, provided by NASA and the Japan Space Exploration Agency (JAXA), is being built at Goddard Space Flight Center and is scheduled to launch in 2014.

http://pmm.nasa.gov/featured-articles/gcpex-what-we-dont-know-about-snow

8) SMAP

AIAA ICES 2011 - Mastropietro, A. J., E. Kwack, R. Mikhaylov, M.

Spencer, P. Hoffman, D. Dawson, J. Piepmeier, D. Hudson, J. Medeiros 2011: Preliminary Evaluation of Passive Thermal Control for the Soil Moisture Active Passive (SMAP) Radiometer (GSFC)

http://smap.jpl.nasa.gov/publications/index.cfm

NASA's Earth observing Soil Moisture Active & Passive (SMAP) Mission is scheduled to launch in November 2014 into a 685 km near-polar, sun synchronous orbit. As one of the four first-tier missions recommended by the National Research Council's Committee on Earth Science and Applications from Space, SMAP will provide comprehensive global mapping measurements of soil moisture and freeze/thaw state in order to enhance understanding of the processes that link the water, energy, and carbon cycles. The primary objectives of SMAP are to improve worldwide weather and flood forecasting, enhance climate prediction, and refine drought and agriculture monitoring during its 3 year mission. The SMAP instrument architecture incorporates an L-band radar and an L-band radiometer which share a common feed horn and parabolic mesh reflector. The instrument rotates about the nadir axis at approximately 14 rpm, thereby providing a conically scanning wide swath antenna beam that is capable of achieving global coverage within 3 days. In order to make the necessary precise surface emission measurements from space, the electronics and hardware associated with the radiometer in particular must meet very tight short term (instantaneous and orbital) and long term (monthly and mission) thermal stabilities. Short term orbital stabilities, for example, must not exceed 0.6oC/orbit, while longer term mission drift must not exceed 15oC. Maintaining these tight thermal stabilities is quite challenging because the sensitive electronics are located on a fast spinning platform that can either be in full sunlight or eclipse, thus exposing them to a highly transient environment. In the interest of providing a low cost solution to proper thermal management of the instrument, a passive design approach was first implemented early in the design cycle. A Thermal Desktop model was created in order to help evaluate the passive design and assist the project with deciding if a more advanced active control scheme would be required in order to meet the tight stabilities with sufficient margin. This paper will discuss the preliminary thermal model predictions and summarize what thermal stabilities can be realistically achieved through passive means on a fast spinning platform exposed to both direct sunlight and eclipse in low Earth orbit.

Major scientific findings or discoveries

<u>Extremes</u>

Jiang, T. and Y. Deng (2011), Downstream modulation of North Pacific atmospheric river activity by East Asian cold surges, *Geophys. Res. Lett.*, 38, L20807, doi:10.1029/2011GL049462. (Oct 2011)

http://www.agu.org/pubs/crossref/2011/2011GL049462.shtml

An East Asian cold surge (EACS) is characterized by rapid advancement of a polar airmass toward the east coast of the Eurasian continent in boreal winter. Over the east coast of Asia, extratropical cyclogenesis and the amplitudes of atmospheric disturbances ranging from synoptic to subseasonal timescales are immediately enhanced as the cold air approaches. This study investigates for the first time the impact of these EACS-excited disturbances on the activity of atmospheric rivers (ARs) over the North Pacific. Applying a new AR detection algorithm to the NASA MERRA dataset, we show that the daily occurrence probability of ARs over the eastern North Pacific near the west coast of U.S. is effectively modulated by EACS. In particular, this downstream dynamical modulation goes through two distinct stages: during the period Day 0–3, where Day 0 corresponds to the time of the peak intensity of an EACS event, high-frequency (HF, <6-day) baroclinic disturbances developed over the western North Pacific and Gulf of Alaska lead to significant poleward moisture transport over these two regions, and during the period Day 4–6, intermediate-low frequency (IF-LF, >12-day) barotropic disturbances developed from the merging of high-frequency troughs increase the daily occurrence probability of ARs near the west coast of the U.S. by 50%, relative to the climatological value. The results reported here demonstrate the critical role of IF and LF disturbances in establishing the link between the predictability of EACS and that of the AR-related extreme precipitation events in the western U.S. in boreal winter.

Liu, Jiping, J. Curry, H. Want, and M. Song, 2012: Impact of Declining Arctic Sea Ice on Winter Snowfall, submitted to Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029 China, (*PNAS, March 2012*)

http://www.pnas.org/content/early/2012/02/17/1114910109.short

Arctic sea ice has declined 6.44% per decade since 1979, and now a study finds this decrease may be a key driver in recent northern continental cold and snowy winters. Liu and colleagues examined impacts of extensive retreat of sea ice in summer and its slow recovery in autumn on northern hemisphere winter climate by analyzing observational data and model simulations for the period 1979 to 2010. The authors demonstrated that the pronounced ice loss could alter atmospheric circulation patterns, weakening the westerly winds blowing across the North Atlantic from Canada to Europe. The weakened westerlies tend to enhance blocking circulations, which favor more frequent incursions of cold air masses from the Arctic into northern continents. At the same time, retreat of sea ice in summer and its slow recovery in autumn greatly enhance moisture flux from the ocean to the atmosphere. Together, these changes can lead to increased heavy snowfall in Europe and the Northeastern and Midwestern United States during winter. The authors believe the determined climate relationships may be useful in seasonal forecasting of snow and temperature anomalies over northern continents.

Bailing Li , M. Rodell, B. F. Zaitchik, R. H. Reichle, R. D. Koster, T. M. van Dam 2012: Assimilation of GRACE Terrestrial Water Storage into a Land Surface Model: Evaluation and Potential Value for Drought Monitoring in Western and Central Europe. *j.hydrol*.2012.04.035 (April 2012)

http://www.sciencedirect.com/science/article/pii/S0022169412003228

A land surface model's ability to simulate states (e.g., soil moisture) and fluxes (e.g., runoff) is limited by uncertainties in meteorological forcing and parameter inputs as well as inadequacies in model physics. In this study, anomalies of terrestrial water storage (TWS) observed by the Gravity Recovery and Climate Experiment (GRACE) satellite mission were assimilated into the NASA Catchment land surface model in western and central Europe for a 7-year period, using a previously developed ensemble Kalman smoother. GRACE data assimilation led to improved runoff estimates (in temporal correlation and root mean square error) in 17 out of 18 hydrological basins, even in basins smaller than the effective resolution of GRACE. Improvements in root zone soil moisture were less conclusive, partly due to the shortness of the in situ data record. GRACE data assimilation also had significant impacts in groundwater estimates including trend and seasonality. In addition to improving temporal correlations, GRACE data assimilation also reduced increasing trends in simulated monthly TWS and runoff associated with increasing rates of precipitation. The assimilation downscaled (in space and time) and disaggregated GRACE data into finer scale components of TWS which exhibited significant changes in their dryness rankings relative to those without data assimilation, suggesting that GRACE data assimilation could have a substantial impact on droughtmonitoring. Signals of drought in GRACE TWS correlated well with MODIS Normalized Difference Vegetation Index (NDVI) data in most areas. Although they detected the same droughts during warm seasons, drought signatures in GRACE derived TWS exhibited greater persistence than those in NDVI throughout all seasons, in part due to limitations associated with the seasonality of vegetation. Mass imbalances associated with GRACE data assimilation and challenges of using GRACE data for droughtmonitoring are discussed.

Foster, J. L., Skofronick-Jackson, G., Meng, H., Wang, J. R., Riggs, G., Kocin, P. J. Johnson, B. T., Cohen, J. Hall, D. K. and S. V. Nghiem, (2012), Passive microwave remote sensing of the historic February 2010 snowstorms in the Middle Atlantic region of the USA. *Hydrol. Process*.. doi: 10.1002/hyp.8418 (Jan 2012)

http://onlinelibrary.wiley.com/doi/10.1002/hyp.8418/abstract

The snowfall in the Baltimore/Washington metropolitan area during the winter of 2009/2010 was unprecedented and caused serious snow-related disruptions. In February 2010, snowfall totals approached 2 m, and because maximum temperatures were consistently below normal, snow remained on the ground the entire month. One of the biggest contributing factors to the unusually severe winter weather in 2009/2010, throughout much of the middle latitudes, was the Arctic Oscillation. Unusually high pressure at high latitudes and low pressure at middle latitudes forced a persistent exchange of mass from north to south. In this investigation, a concerted effort was made to link remotely sensed falling snow observations to remotely sensed snow cover and snowpack observations in the Baltimore/Washington area. Specifically, the Advanced Microwave Scanning Radiometer onboard the Aqua satellite was used to assess snow water equivalent, and the Advanced Microwave Sounding Unit-B and Microwave Humidity Sounder were employed to detect falling snow. Advanced Microwave Scanning Radiometer passive microwave signatures in this study are related to both snow on the ground and surface ice layers. In regard to falling snow, signatures indicative of snowfall can be observed in high frequency brightness temperatures of Advanced Microwave Sounding Unit-B and Microwave Humidity Sounder. Indeed, retrievals show an increase in snow water equivalent after the detection of falling snow. Yet, this work also shows that falling snow intensity and/or the presence of liquid water clouds impacts the ability to reliably detect snow water equivalent. Moreover, changes in the condition of the snowpack, especially in the surface features, negatively affect retrieval performance.

Dominguez, F., E. Rivera, D. P. Lettenmaier, and C. L. Castro 2012: Changes in winter precipitation extremes for the western United States under a warmer climate as simulated by regional climate models, *GeophysRes Lett,39, L05803 (March 2012)*

http://www.agu.org/pubs/crossref/2012/2011GL050762.shtml

We find a consistent and statistically significant increase in the intensity of future extreme winter precipitation events over the western United States, as simulated by an ensemble of regional climate models (RCMs) driven by IPCC AR4 global climate models (GCMs). All eight simulations analyzed in this work consistently show an increase in the intensity of extreme winter precipitation with the multi-model mean projecting an area-averaged 12.6% increase in 20-year return period and 14.4% increase in 50-year return period daily precipitation. In contrast with extreme precipitation, the multi-model ensemble shows a decrease in mean winter precipitation of approximately 7.5% in the southwestern US, while the interior west shows less statistically robust increases.

Mishra, V., F. Dominguez, and D. P. Lettenmaier, 2012: Urban precipitation extremes: how reliable are regional climate models?, *Geophysical Research Letters*, 39, L03907 (Feb 2012)
http://www.agu.org/pubs/crossref/2012/2011GL050658.shtml

We evaluate the ability of regional climate models (RCMs) that participated in the North American Regional Climate Change Assessment Program (NARCCAP) to reproduce the historical season of occurrence, mean, and variability of 3 and 24-hour precipitation extremes for 100 urban areas across the United States. We show that RCMs with both reanalysis and global climate model (GCM) boundary conditions behave similarly and underestimate 3-hour precipitation maxima across almost the entire U.S. RCMs with both boundary conditions broadly capture the season of occurrence of precipitation maxima except in the interior of the western U.S. and the southeastern U.S. On the other hand, the RCMs do much better in identifying the season of 24-hour precipitation maxima. For mean annual precipitation maxima, regardless of the boundary condition, RCMs consistently show high (low) bias for locations in the western (eastern) U.S. Our results indicate that RCM-simulated 3-hour precipitation maxima at 100-year return period could be considered acceptable for stormwater infrastructure design at less than 12% of the 100 urban areas (regardless of boundary conditions). RCM performance for 24-hour precipitation maxima was slightly better, with performance acceptable for stormwater infrastructure design judged adequate at about 25% of the urban areas.

Modeling (including contributions from the MERRA special collection)

Bosilovich, M. G., F. R. Robertson, J. Chen, 2011: Global Energy and Water Budgets in MERRA. *J. Climate*, 24, 5721–5739. (Nov 2011)
(http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4175.1

Reanalyses, retrospectively analyzing observations over climatological time scales, represent a merger between satellite observations and models to provide globally continuous data and have improved over several generations. Balancing the earth's global water and energy budgets has been a focus of research for more than two decades. Models tend to their own climate while remotely sensed observations have had varying degrees of uncertainty. This study evaluates the latest NASA reanalysis, the Modern Era Retrospective-Analysis for Research and Applications (MERRA), from a global water and energy cycles perspective, to place it in context of previous work and demonstrate the strengths and weaknesses.

MERRA was configured to provide complete budgets in its output diagnostics, including the incremental analysis update (IAU), the term that represents the observations influence on the analyzed states, alongside the physical flux terms. Precipitation in reanalyses is typically sensitive to the observational analysis. For MERRA, the global mean precipitation bias and spatial variability are more comparable to merged satellite observations [the Global Precipitation and Climatology Project (GPCP) and Climate Prediction Center Merged Analysis of Precipitation (CMAP)] than previous generations of reanalyses. MERRA ocean evaporation also has a much lower value, which is comparable to independently derived estimate datasets. The global energy budget shows that MERRA cloud effects may be generally weak, leading to excess shortwave radiation reaching the ocean surface.

Evaluating the MERRA time series of budget terms, a significant change occurs that does not appear to be represented in observations. In 1999, the global analysis increments of water vapor changes sign from negative to positive and primarily lead to more oceanic precipitation. This change is coincident with the beginning of Advanced Microwave Sounding Unit (AMSU) radiance assimilation. Previous and current reanalyses all exhibit some sensitivity to perturbations in the observation record, and this remains a significant research topic for reanalysis development. The effect of the changing observing system is evaluated for MERRA water and energy budget terms.

Cullather, R. I., M. G. Bosilovich, 2012: The Moisture Budget of the Polar Atmosphere in MERRA. *J. Climate*, 25, 5–24. (Jan 2012)
doi: http://dx.doi.org/10.1175/2011JCLI4138.1

Components of the atmospheric energy budget from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) are evaluated in polar regions for the period 1979–2005 and compared with previous estimates, in situ observations, and contemporary reanalyses. Closure of the budget is reflected by the analysis increments term, which indicates an energy surplus of 11 W m^{-2} over the North Polar cap (70°–90°N) and 22 W m^{-2} over the South Polar cap (70°–90°S). Total atmospheric energy convergence from MERRA compares favorably with previous studies for northern high latitudes but exceeds the available previous estimate for the South Polar cap by 46%. Discrepancies with the Southern Hemisphere energy transport are largest in autumn and may be related to differences in topography with earlier reanalyses. For the Arctic, differences between MERRA and other sources in top of atmosphere (TOA) and surface radiative fluxes are largest in May. These differences are concurrent with the largest discrepancies between MERRA parameterized and observed surface albedo. For May, in situ observations of the upwelling shortwave flux in the Arctic are 80 W m^{-2} larger than MERRA, while the MERRA downwelling longwave flux is underestimated by 12 W m^{-2} throughout the year. Over grounded ice sheets, the annual mean net surface energy flux in MERRA is erroneously nonzero. Contemporary reanalyses from the Climate Forecast Center (CFSR) and the Interim Re-Analyses of the European Centre for Medium-Range Weather Forecasts (ERA-I) are found to have better surface parameterizations; however, these reanalyses also disagree with observed surface and TOA energy fluxes. Discrepancies among available reanalyses underscore the challenge of reproducing credible estimates of the atmospheric energy budget in polar regions.

Robertson, F. R., M. G. Bosilovich, J. Chen, T. L. Miller, 2011: The Effect of Satellite Observing System Changes on MERRA Water and Energy Fluxes. *J. Climate*, 24, 5197–5217. (Oct 2011)
http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4227.1

Like all reanalysis efforts, the Modern Era Retrospective-Analysis for Research and Applications (MERRA) must contend with an inhomogeneous observing network. Here the effects of the two most obvious observing system epoch changes, the Advanced Microwave Sounding Unit-A (AMSU-A) series in late 1998 and, to a lesser extent, the earlier advent of the Special Sensor Microwave Imager (SSM/I) in late 1987 are examined. These sensor changes affect model moisture and enthalpy increments and thus water and energy fluxes, since the latter result from model physics processes that respond sensitively to state variable forcing. Inclusion of the analysis increments in the MERRA dataset is a unique feature among reanalyses that facilitates understanding the relationships between analysis forcing and flux response.

In stepwise fashion in time, the vertically integrated global-mean moisture increments change sign from drying to moistening and heating increments drop nearly 15 W m^{-2} over the 30 plus years of the assimilated products. Regression of flux quantities on an El Niño–Southern Oscillation sea surface temperature (SST) index analysis reveals that this mode of climate variability dominates interannual signals and its leading expression is minimally affected by satellite observing system changes. Conversely, precipitation patterns and other fluxes influenced by SST changes associated with Pacific decadal variability (PDV) are significantly distorted. Observing system changes also induce a nonstationary component to the annual cycle signals.

Principal component regression is found useful for identifying artifacts produced by changes of satellite sensors and defining appropriate adjustments. After the adjustments are applied, the spurious flux trend components are greatly diminished. Time series of the adjusted precipitation and the Global Precipitation Climatology Project (GPCP) data compare favorably on a global basis. The adjustments also provide a much better depiction of precipitation spatial trends associated with PDV-like forcing. The utility as well as associated drawbacks of this statistical adjustment and the prospects for future improvements of the methodology are discussed.

Santanello, J. A., C. D. Peters-Lidard, S. V. Kumar, 2011: Diagnosing the Sensitivity of Local Land–Atmosphere Coupling via the Soil Moisture–Boundary Layer Interaction. *J. Hydrometeor*, **12**, 766–786. (Oct 2011)

http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-10-05014.1?journalCode=hydr

The inherent coupled nature of earth's energy and water cycles places significant importance on the proper representation and diagnosis of land–atmosphere (LA) interactions in hydrometeorological prediction models. However, the precise nature of the soil moisture–precipitation relationship at the local scale is largely determined by a series of nonlinear processes and feedbacks that are difficult to quantify. To quantify the strength of the local LA coupling (LoCo), this process chain must be considered both in full and as individual components through their relationships and sensitivities. To address this, recent modeling and diagnostic studies have been extended to 1) quantify the processes governing LoCo utilizing the thermodynamic properties of mixing diagrams, and 2) diagnose the sensitivity of coupled systems, including clouds and moist processes, to perturbations in soil moisture. This work employs NASA's Land Information System (LIS) coupled to the Weather Research and Forecasting (WRF) mesoscale model and simulations performed over the U.S. Southern Great Plains. The behavior of different planetary boundary layers (PBL) and land surface scheme couplings in LIS–WRF are examined in the context of the evolution of thermodynamic quantities that link the surface soil moisture condition to the PBL regime, clouds, and precipitation. Specifically, the tendency toward saturation in the PBL is quantified by the lifting condensation level (LCL) deficit and addressed as a function of time and space. The sensitivity of the LCL deficit to the soil moisture condition is indicative of the strength of LoCo, where both positive and negative feedbacks can be identified. Overall, this methodology can be applied to any model or observations and is a crucial step toward improved evaluation and quantification of LoCo within models, particularly given the advent of next-generation satellite measurements of PBL and land surface properties along with advances in data assimilation schemes.

Brunke, M. A., Z. Wang, X. Zeng, M. Bosilovich, and C.-L. Shie, 2011: An Assessment of the Uncertainties in Ocean Surface Turbulent Fluxes in 11 Reanalysis, Satellite-Derived, and Combined Global Datasets. *J. Climate*, 24, 5469–5493.doi: http://dx.doi.org/10.1175/2011JCLI4223.1 (Nov 2011)

Ocean surface turbulent fluxes play an important role in the energy and water cycles of the atmosphere–ocean coupled system, and several flux products have become available in recent years. Here, turbulent fluxes from 6 widely used reanalyses, 4 satellite-derived flux products, and 2 combined product are evaluated by comparison with direct covariance latent heat (LH) and sensible heat (SH) fluxes and inertial-dissipation wind stresses measured from 12 cruises over the tropics and mid- and high latitudes. The biases range from −3.0 to 20.2 W m^{-2} for LH flux, from −1.4 to 6.0 W m^{-2} for SH flux, and from −7.6 to 7.9 × 10^{-3} N m^{-2} for wind stress. These biases are small for moderate wind speeds but diverge for strong wind speeds (>10 m s^{-1}). The total flux biases are then further evaluated by dividing them into uncertainties due to errors in the bulk variables and the residual uncertainty. The bulk-variable-caused uncertainty dominates many products' SH flux and wind stress biases. The biases in the bulk variables that contribute to this uncertainty can be quite high depending on the cruise and the variable. On the basis of a ranking of each product's flux, it is found that the Modern-Era Retrospective Analysis for Research and Applications (MERRA) is among the "best performing" for all three fluxes. Also, the European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis (ERA-Interim) and the National Centers for Environmental Prediction–Department of Energy (NCEP–DOE) reanalysis are among the best performing for two of the three fluxes. Of the satellite-derived products, version 2b of the Goddard Satellite-Based Surface Turbulent Fluxes (GSSTF2b) is among the best performing for two of the three fluxes. Also among the best performing for only one of the fluxes are the 40-yr ERA (ERA-40) and the combined product objectively analyzed air–sea fluxes (OAFlux). Direction for the future development of ocean surface flux datasets is also suggested.

Wong, S., E. J. Fetzer, B. H. Kahn, B. Tian, B. H. Lambrigtsen, H. Ye, 2011: Closing the Global Water Vapor Budget with AIRS Water Vapor, MERRA Reanalysis, TRMM and GPCP Precipitation, and GSSTF Surface Evaporation. *J. Climate*, 24, 6307–6321.doi: http://dx.doi.org/10.1175/2011JCLI4154.1 (Dec 2011)

The possibility of using remote sensing retrievals to estimate apparent water vapor sinks and heat sources is explored. The apparent water vapor sinks and heat sources are estimated from a combination of remote sensing, specific humidity, and temperature from the Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit (AIRS) and wind fields from the National Aeronautics and Space Administration (NASA)'s Goddard Space Flight Center (GSFC)'s Modern Era Retrospective-Analysis for Research and Applications (MERRA). The intraseasonal oscillation (ISO) of the Indian summer monsoon is used as a test bed to evaluate the apparent water vapor sink and heat source. The ISO-related northward movement of the column-integrated apparent water vapor sink matches that of precipitation observed by the Tropical Rainfall Measuring Mission (TRMM) minus the MERRA surface evaporation, although the amplitude of the variation is underestimated by 50%. The diagnosed water vapor and heat budgets associated with convective events during various phases of the ISO agree with the moisture–convection feedback mechanism. The apparent heat source moves northward coherently with the apparent water vapor sink associated with the deep convective activity, which is consistent with the northward migration of the precipitation anomaly. The horizontal advection of water vapor and dynamical warming are strong north of the convective area, causing the northward movement of the convection by the destabilization of the atmosphere. The spatial distribution of the apparent heat source anomalies associated with different phases of the ISO is consistent with that of the diabatic heating anomalies from the trained heating (TRAIN Q1) dataset. Further diagnostics of the TRAIN Q1 heating anomalies indicate that the ISO in the apparent heat source is dominated by a variation in latent heating associated with the precipitation.

Cullather, R. I., M. Bosilovich, 2012: The Energy Budget of the Polar Atmosphere in MERRA. *J. Climate*.(Jan 2012)
http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4138.1?journalCode=clim
Components of the atmospheric energy budget from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) are evaluated in polar regions for the period 1979–2005 and compared with previous estimates, in situ observations, and contemporary reanalyses. Closure of the budget is reflected by the analysis increments term, which indicates an energy surplus of 11 W m^{-2} over the North Polar cap (70°–90°N) and 22 W m^{-2} over the South Polar cap (70°–90°S). Total atmospheric energy convergence from MERRA compares favorably with previous studies for northern high latitudes but exceeds the available previous estimate for the South Polar cap by 46%. Discrepancies with the Southern Hemisphere energy transport are largest in autumn and may be related to differences in topography with earlier reanalyses. For the Arctic, differences between MERRA and other sources in top of atmosphere (TOA) and surface radiative fluxes are largest in May. These differences are concurrent with the largest discrepancies between MERRA parameterized and observed surface albedo. For May, in situ observations of the upwelling shortwave flux in the Arctic are 80 W m^{-2} larger than MERRA, while the MERRA downwelling longwave flux is underestimated by 12 W m^{-2} throughout the year. Over grounded ice sheets, the annual mean net surface energy flux in MERRA is erroneously nonzero. Contemporary reanalyses from the Climate Forecast Center (CFSR) and the Interim Re-Analyses of the European Centre for Medium-Range Weather Forecasts (ERA-I) are found to have better surface parameterizations; however, these reanalyses also disagree with observed surface and TOA energy fluxes. Discrepancies among available reanalyses underscore the challenge of reproducing credible estimates of the atmospheric energy budget in polar regions.

Harnik, N., J. Perlwitz, and T. Shaw, 2011: Observed decadal changes in downward wave coupling between the stratosphere and troposphere in the

Southern Hemisphere. *J. Climate*, 24, 2558-4569. (Sept 2011)
http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4118.1

Downward wave coupling dominates the intraseasonal dynamical coupling between the stratosphere and troposphere in the Southern Hemisphere. The coupling occurs during late winter and spring when the stratospheric basic state forms a well-defined meridional waveguide, which is bounded above by a reflecting surface. This basic-state configuration is favorable for planetary wave reflection and guides the reflected waves back down to the troposphere, where they impact wave structures. In this study decadal changes in downward wave coupling are analyzed using the Modern Era Retrospective-Analysis for Research and Applications (MERRA) dataset.

A cross-spectral correlation analysis, applied to geopotential height fields, and a wave geometry diagnostic, applied to zonal-mean zonal wind and temperature data, are used to understand decadal changes in planetary wave propagation. It is found that downward wave 1 coupling from September to December has increased over the last three decades, owing to significant increases at the beginning and end of this 4-month period. The increased downward wave coupling is caused by both an earlier onset of the vertically bounded meridional waveguide configuration and a persistence of this configuration into December. The latter is associated with the observed delay in vortex breakup. The results point to an additional dynamical mechanism whereby the stratosphere has influenced the tropospheric climate in the Southern Hemisphere.

Kennedy, A. D., X. Dong, B. Xi, S. Xie, Y. Zhang, and J. Chen, 2011: A Comparison of MERRA and NARR Reanalysis Datasets with the DOE ARM SGP Continuous Forcing data. *J. Climate*, 24, 4541-4557. (Sept 2011)
http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI3978.1

Atmospheric states from the Modern-Era Retrospective analysis for Research and Applications (MERRA) and the North American Regional Reanalysis (NARR) are compared with data from the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site, including the ARM continuous forcing product and Cloud Modeling Best Estimate (CMBE) soundings, during the period 1999–2001 to understand their validity for single-column model (SCM) and cloud-resolving model (CRM) forcing datasets. Cloud fraction, precipitation, and radiation information are also compared to determine what errors exist within these reanalyses. For the atmospheric state, ARM continuous forcing and the reanalyses have good agreement with the CMBE sounding information, with biases generally within 0.5 K for temperature, 0.5 m s^{-1} for wind, and 5% for relative humidity. Larger disagreements occur in the upper troposphere ($p < 300$ hPa) for temperature, humidity, and zonal wind, and in the boundary layer ($p > 800$ hPa) for meridional wind and humidity. In these regions, larger errors may exist in derived forcing products. Significant differences exist for vertical pressure velocity, with the largest biases occurring during the spring upwelling and summer downwelling periods. Although NARR and MERRA share many resemblances to each other, ARM outperforms these reanalyses in terms of correlation with cloud fraction. Because the ARM forcing is constrained by observed precipitation that gives the adequate mass, heat, and moisture budgets, much of the precipitation (specifically during the late spring/early summer) is caused by smaller-scale forcing that is not captured by the reanalyses. While reanalysis-based forcing appears to be feasible for the majority of the year at this location, it may have limited usage during the late spring and early summer, when convection is common at the ARM SGP site. Both NARR and MERRA capture the seasonal variation of cloud fractions (CFs) observed by ARM radar–lidar and Geostationary Operational Environmental Satellite (GOES) with high correlations (0.92–0.78) but with negative biases of 14% and 3%, respectively. Compared to the ARM observations, MERRA shows better agreement for both shortwave (SW) and longwave (LW) fluxes except for LW-down (due to a negative bias in water vapor): NARR has significant positive bias for SW-down and negative bias for LW-down under clear-sky and all-sky conditions. The NARR biases result from a combination of too few clouds and a lack of sufficient extinction by aerosols and water vapor in the atmospheric column. The results presented here represent only one location for a limited period, and more comparisons at different locations and longer periods are needed.

Reichle, R. H., R. D. Koster, G. J. M. De Lannoy, B. A. Forman, Q. Liu, S. Mahanama, and A. Toure. 2011: Assessment and Enhancement of MERRA Land Surface Hydrology Estimates. *J. Climate*, 24, 6322-6338, doi: (Dec 2011)
http://dx.doi.org/10.1175/JCLI-D-10-05033.1.

The Modern-Era Retrospective Analysis for Research and Applications (MERRA) is a state-of-the-art reanalysis that provides, in addition to atmospheric fields, global estimates of soil moisture, latent heat flux, snow, and runoff for 1979–present. This study introduces a supplemental and improved set of land surface hydrological fields ("MERRA-Land") generated by rerunning a revised version of the land component of the MERRA system. Specifically, the MERRA-Land estimates benefit from corrections to the precipitation forcing with the Global Precipitation Climatology Project pentad product (version 2.1) and from revised parameter values in the rainfall interception model, changes that effectively correct for known limitations in the MERRA surface meteorological forcings. The skill (defined as the correlation coefficient of the anomaly time series) in land surface hydrological fields from MERRA and MERRA-Land is assessed here against observations and compared to the skill of the state-of-the-art ECMWF Re-Analysis-Interim (ERA-I). MERRA-Land and ERA-I root zone soil moisture skills (against in situ observations at 85 U.S. stations) are comparable and significantly greater than that of MERRA. Throughout the Northern Hemisphere, MERRA and MERRA-Land agree reasonably well with in situ snow depth measurements (from 583 stations) and with snow water equivalent from an independent analysis. Runoff skill (against naturalized stream flow observations from 18 U.S. basins) of MERRA and MERRA-Land is typically higher than that of ERA-I. With a few exceptions, the MERRA-Land data appear more accurate than the original MERRA estimates and are thus recommended for those interested in using MERRA output for land surface hydrological studies.

Roberts, J. B., F. R. Robertson, C. A. Clayson, and M. G. Bosilovich, 2011: Characterization of turbulent latent and sensible heat flux exchange between the atmosphere and ocean in MERRA. *J. Climate*. (Feb 2012)
http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00029.1?journalCode=clim

Turbulent fluxes of heat and moisture across the atmosphere–ocean interface are fundamental components of the earth's energy and water balance. Characterizing both the spatiotemporal variability and the fidelity of these exchanges of heat and moisture is critical to understanding the global water and energy cycle variations, quantifying atmosphere–ocean feedbacks, and improving model predictability. This study examines the veracity of the recently completed NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA) product in terms of its turbulent surface fluxes. This assessment employs a large dataset of directly measured turbulent fluxes as well as other turbulent surface flux datasets. The spatial and temporal variability of the surface fluxes are examined in terms of their annual-mean climatologies, their seasonal covariability of near-surface bulk parameters, and their representation of extremes. The impact of data assimilation on the near-surface parameters is assessed through evaluation of the incremental analysis update tendencies. It is found that MERRA turbulent surface fluxes are relatively accurate for typical conditions but have systematically weak vertical gradients in moisture and temperature and a weaker covariability between the near-surface gradients and wind speed than found in observations. This results in an underestimate of the surface latent and sensible heat fluxes over the western boundary current and storm-track regions. The assimilation of observations generally acts to bring MERRA closer to observational products by increasing moisture and temperature near the surface and decreasing the near-surface wind speeds.

Schenkel, B. and R. Hart, 2012: An Examination of Tropical Cyclone Position and Intensity Differences within Atmospheric Reanalysis Datasets. *J. Climate*. (May 2012)

http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4208.1

The following study examines the position and intensity differences of tropical cyclones (TCs) among the Best-Track and five atmospheric reanalysis datasets to evaluate the degree to which reanalyses are appropriate for studying TCs. While significant differences are found in both reanalysis TC intensity and position, the representation of TC intensity within reanalyses is found to be most problematic owing to its underestimation beyond what can be attributed solely to the coarse grid resolution. Moreover, the mean life cycle of normalized TC intensity within reanalyses reveals an underestimation of both prepeak intensification rates as well as a delay in peak intensity relative to the Best-Track. These discrepancies between Best-Track and reanalysis TC intensity and position can further be described through correlations with such parameters as Best-Track TC age, Best-Track TC intensity, Best-Track TC location, and the extended Best-Track TC size. Specifically, TC position differences within the 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40), ECMWF Interim Re-Analysis (ERA-I), and Modern Era Retrospective-Analysis for Research and Applications (MERRA) exhibit statistically significant correlations ($0.27 \leq R \leq 0.38$) with the proximity of TCs to observation dense areas in the North Atlantic (NATL) and western North Pacific (WPAC). Reanalysis TC intensity is found to be most strongly correlated with Best-Track TC size ($0.53 \leq R \leq 0.70$ for maximum 10-m wind speed; $-0.71 \leq R \leq -0.53$ for minimum mean sea level pressure) while exhibiting smaller, yet significant, correlations with Best-Track TC age, Best-Track TC intensity, and Best-Track TC latitude. Of the three basins examined, the eastern North Pacific (EPAC) has the largest reanalysis TC position differences and weakest intensities possibly due to a relative dearth of observations, the strong nearby terrain gradient, and the movement of TCs away from the most observation dense portion of the basin over time. The smaller mean Best-Track size and shorter mean lifespan of Best-Track EPAC TCs may also yield weaker reanalysis TC intensities. Of the five reanalyses, the smaller position differences and stronger intensities found in the Climate Forecast System Reanalysis (CFSR) and Japanese 25-year Reanalysis (JRA-25) are attributed to the use of vortex relocation and TC wind profile retrievals, respectively. The discrepancies in TC position between the Best-Track and reanalyses combined with the muted magnitude of TC intensity and its partially nonphysical life cycle within reanalyses suggests that caution should be exercised when utilizing these datasets for studies that rely either on TC intensity (raw or normalized) or track. Finally, several cases of nonphysical TC structure also argue that further work is needed to improve TC representation while implying that studies focusing solely on TC intensity and track do not necessarily extend to other aspects of TC representation.

Mapes, B. J., J. T. Bacmeister, 2012: Diagnosis of tropical biases and the MJO from patterns in MERRA's analysis tendency fields. *Journal of Climate* (Apr.2012)

http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00424.1

The Modern Era Reanalysis for Research and Applications (MERRA) is realistic, including its Madden-Julian Oscillation (MJO) which the underlying model (GEOS-5) lacks. In MERRA's budgets, analysis tendencies (ATs) make evolution realistic despite model shortcomings. ATs are the negative of physical process errors, if dynamical tendencies are accurate. Pattern resemblance between ATs and physical tendencies suggest which processes are erroneous. We examined patterns of tropical ATs in 4 dimensions and found several noteworthy features.

Temperature AT profiles show that moist physics has erroneous sharp cooling at 700 hPa, a signature of misplaced melting and perhaps excessive precipitation evaporation. This excites a distinctive (fingerprint) erroneous short vertical wavelength temperature structure, perhaps a cause of GEOS-5's too-slow convectively coupled waves. The globe's largest AT of 200hPa wind stems from overactive heating over the Intra-Americas Seas region in summer, with the same moist physics fingerprint. The erroneous heating produces a baroclinic vortex that is countered by ATs opposing its temperature and momentum fields in a thermal wind balanced sense. Lack of restraint in the deep convection scheme is also indicated in MJO composites, where the water vapor AT is anomalously positive on the leading edge indicating a premature vapor sink. Since GEOS-5 lacks an MJO, this diagnosis suggests that the transition from shallow to deep convection (moistening to drying) is crucial in the real-world MJO. This is not news, but its diagnosis by ATs provides an objective, repeatable way to measure the effect that could be a useful guide in model development.

Decker, M., M. A. Brunke, Z. Wang, K. Sakaguchi, X. Zeng, M. G. Bosilovich, 2012: Evaluation of the Reanalysis Products from GSFC, NCEP, and ECMWF Using Flux Tower Observations. *Journal of Climate*, Vol. 25, Iss. 6, pp. 1916–1944. (Mar 2012)

http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00004.1

Reanalysis products produced at the various centers around the globe are utilized for many different scientific endeavors, including forcing land surface models and creating surface flux estimates. Here, flux tower observations of temperature, wind speed, precipitation, downward shortwave radiation, net surface radiation, and latent and sensible heat fluxes are used to evaluate the performance of various reanalysis products [NCEP–NCAR reanalysis and Climate Forecast System Reanalysis (CFSR) from NCEP; 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) and ECMWF Interim Re-Analysis (ERA-Interim) from ECMWF; and Modern-Era Retrospective Analysis for Research and

Applications (MERRA) and Global Land Data Assimilation System (GLDAS) from the Goddard Space Flight Center (GSFC)]. To combine the biases and standard deviation of errors from the separate stations, a ranking system is utilized. It is found that ERA-Interim has the lowest overall bias in 6-hourly air temperature, followed closely by MERRA and GLDAS. The variability in 6-hourly air temperature is again most accurate in ERA-Interim. ERA-40 is found to have the lowest overall bias in latent heat flux, followed closely by CFSR, while ERA-40 also has the lowest 6-hourly sensible heat bias. MERRA has the second lowest and is close to ERA-40. The variability in 6-hourly precipitation is best captured by GLDAS and ERA-Interim, and ERA-40 has the lowest precipitation bias. It is also found that at monthly time scales, the bias term in the reanalysis products are the dominant cause of the mean square errors, while at 6-hourly and daily time scales the dominant contributor to the mean square errors is the correlation term. Also, it is found that the hourly CFSR data have discontinuities present due to the assimilation cycle, while the hourly MERRA data do not contain these jumps.

Wu, **M-L C.,** O. Reale, S. D. Schubert, M. J. Suarez, C. D. Thorncroft 2012: African Easterly Jet: Barotropic Instability, Waves and Cyclogenesis**.** *Journal of Climate*, (Mar 2012)

http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4241.1?journalCode=clim

This study investigates the structure of the African easterly jet, focusing on instability processes on a seasonal and subseasonal scale, with the goal of identifying features that could provide increased predictability of Atlantic tropical cyclogenesis. The Modern-Era Retrospective Analysis for Research and Applications (MERRA) is used as the main investigating tool. MERRA is compared with other reanalyses datasets from major operational centers around the world and was found to describe very effectively the circulation over the African monsoon region. In particular, a comparison with precipitation datasets from the Global Precipitation Climatology Project shows that MERRA realistically reproduces seasonal precipitation over that region. The verification of the generalized Kuo barotropic instability condition computed from seasonal means is found to have the interesting property of defining well the location where observed tropical storms are detected. This property does not appear to be an artifact of MERRA and is present also in the other adopted reanalysis datasets. Therefore, the fact that the areas where the mean flow is unstable seems to provide a more favorable environment for wave intensification, could be another factor to include—in addition to sea surface temperature, vertical shear, precipitation, the role of Saharan air, and others—among large-scale forcings affecting development and tropical cyclone frequency. In addition, two prominent modes of variability are found based on a spectral analysis that uses the Hilbert–

Huang transform: a 2.5–6-day mode that corresponds well to the African easterly waves and also a 6–9-day mode that seems to be associated with tropical–extratropical interaction.

Zib, B. J. **,** X. Dong, B. Xi, and A. Kennedy, 2012: Evaluation and Intercomparison of Cloud Fraction and Radiative Fluxes in Recent Reanalyses over the Arctic using BSRN Surface Observations. *J. Climate*, Vol. 25, Iss. 7, pp. 2291–2305. (Apr 2012)

http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00147.1?journalCode=clim

With continual advancements in data assimilation systems, new observing systems, and improvements in model parameterizations, several new atmospheric reanalysis datasets have recently become available. Before using these new reanalyses it is important to assess the strengths and underlying biases contained in each dataset. A study has been performed to evaluate and compare cloud fractions (CFs) and surface radiative fluxes in several of these latest reanalyses over the Arctic using 15 years (1994–2008) of high-quality Baseline Surface Radiation Network (BSRN) observations from Barrow (BAR) and Ny-Alesund (NYA) surface stations. The five reanalyses being evaluated in this study are (i) NASA's Modern-Era Retrospective analysis for Research and Applications (MERRA), (ii) NCEP's Climate Forecast System Reanalysis (CFSR), (iii) NOAA's Twentieth Century Reanalysis Project (20CR), (iv) ECMWF's Interim Reanalysis (ERA-I), and (v) NCEP–Department of Energy (DOE)'s Reanalysis II (R2). All of the reanalyses show considerable bias in reanalyzed CF during the year, especially in winter. The large CF biases have been reflected in the surface radiation fields, as monthly biases in shortwave (SW) and longwave (LW) fluxes are more than 90 (June) and 60 W m^{-2} (March), respectively, in some reanalyses. ERA-I and CFSR performed the best in reanalyzing surface downwelling fluxes with annual mean biases less than 4.7 (SW) and 3.4 W m^{-2} (LW) over both Arctic sites. Even when producing the observed CF, radiation flux errors were found to exist in the reanalyses suggesting that they may not always be dependent on CF errors but rather on variations of more complex cloud properties, water vapor content, or aerosol loading within the reanalyses.

.

Schubert, S. H. Wang, M. Suarez, 2011: Warm Season Subseasonal Variability and Climate Extremes in the Northern Hemisphere: The Role of Stationary Rossby Waves. *Journal of Climate*, Vol. 24, Iss. 18, pp. 4773–4792. (Sept 2011)

http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-10-05035.1

This study examines the nature of boreal summer subseasonal atmospheric variability based on the new NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA) for the period 1979–

2010. An analysis of the June, July, and August subseasonal 250-hPa meridional v-wind anomalies shows distinct Rossby wave–like structures that appear to be guided by the mean jets. On monthly subseasonal time scales, the leading waves [the first 10 rotated empirical orthogonal functions (REOFs) of the 250-hPa v wind] explain about 50% of the Northern Hemisphere v-wind variability and account for more than 30% (60%) of the precipitation (surface temperature) variability over a number of regions of the northern middle and high latitudes, including the U.S. northern Great Plains, parts of Canada, Europe, and Russia. The first REOF in particular consists of a Rossby wave that extends across northern Eurasia where it is a dominant contributor to monthly surface temperature and precipitation variability and played an important role in the 2003 European and 2010 Russian heat waves. While primarily subseasonal in nature, the Rossby waves can at times have a substantial seasonal mean component. This is exemplified by REOF 4, which played a major role in the development of the most intense anomalies of the U.S. 1988 drought (during June) and the 1993 flooding (during July), though differed in the latter event by also making an important contribution to the seasonal mean anomalies. A stationary wave model (SWM) is used to reproduce some of the basic features of the observed waves and provide insight into the nature of the forcing. In particular, the responses to a set of idealized forcing functions are used to map the optimal forcing patterns of the leading waves. Also, experiments to reproduce the observed waves with the SWM using MERRA-based estimates of the forcing indicate that the wave forcing is dominated by submonthly vorticity transients.

Mahanama, S. P., B. Livneh, R. D. Koster, D. P. Lettenmaier, and R. H. Reichle, 2012: Soil Moisture, Snow, and Seasonal Streamflow Forecasts in the United States, *J. Hydrometeorol*.,13, 189-203. (Feb 2012)

http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-11-046.1?journalCode=hydr

Land surface model experiments are used to quantify, for a number of U.S. river basins, the contributions (isolated and combined) of soil moisture and snowpack initialization to the skill of seasonal streamflow forecasts at multiple leads and for different start dates. Snow initialization has a major impact on skill during the spring melting season. Soil moisture initialization has a smaller but still statistically significant impact during this season, and in other seasons, its contribution to skill dominates. Realistic soil moisture initialization can contribute to skill at long leads (over 6 months) for certain basins and seasons. Skill levels in all seasons are found to be related to the ratio of initial total water storage (soil water plus snow) variance to the forecast period precipitation variance, allowing estimates of the potential for skill in areas outside the verification basins.

Kennedy, **A. D.** X. Dong, B. Xi, S. Xie, Y. Zhang, and J. Chen, 2011: A Comparison of MERRA and NARR Reanalyses with the DOE ARM SGP data. *J. Climate*, Vol. 24, Iss. 17, pp. 4541–4557. (Sept 2011)
http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI3978.1

Atmospheric states from the Modern-Era Retrospective analysis for Research and Applications (MERRA) and the North American Regional Reanalysis (NARR) are compared with data from the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site, including the ARM continuous forcing product and Cloud Modeling Best Estimate (CMBE) soundings, during the period 1999–2001 to understand their validity for single-column model (SCM) and cloud-resolving model (CRM) forcing datasets. Cloud fraction, precipitation, and radiation information are also compared to determine what errors exist within these reanalyses. For the atmospheric state, ARM continuous forcing and the reanalyses have good agreement with the CMBE sounding information, with biases generally within 0.5 K for temperature, 0.5 m s^{-1} for wind, and 5% for relative humidity. Larger disagreements occur in the upper troposphere ($p < 300$ hPa) for temperature, humidity, and zonal wind, and in the boundary layer ($p > 800$ hPa) for meridional wind and humidity. In these regions, larger errors may exist in derived forcing products. Significant differences exist for vertical pressure velocity, with the largest biases occurring during the spring upwelling and summer downwelling periods. Although NARR and MERRA share many resemblances to each other, ARM outperforms these reanalyses in terms of correlation with cloud fraction. Because the ARM forcing is constrained by observed precipitation that gives the adequate mass, heat, and moisture budgets, much of the precipitation (specifically during the late spring/early summer) is caused by smaller-scale forcing that is not captured by the reanalyses. While reanalysis-based forcing appears to be feasible for the majority of the year at this location, it may have limited usage during the late spring and early summer, when convection is common at the ARM SGP site. Both NARR and MERRA capture the seasonal variation of cloud fractions (CFs) observed by ARM radar–lidar and Geostationary Operational Environmental Satellite (GOES) with high correlations (0.92–0.78) but with negative biases of 14% and 3%, respectively. Compared to the ARM observations, MERRA shows better agreement for both shortwave (SW) and longwave (LW) fluxes except for LW-down (due to a negative bias in water vapor): NARR has significant positive bias for SW-down and negative bias for LW-down under clear-sky and all-sky conditions. The NARR biases result from a combination of too few clouds and a lack of sufficient extinction by aerosols and water vapor in the atmospheric column. The results presented here represent only one location for a limited period, and more comparisons at different locations and longer periods are needed.

Wu, M.-L. C., O. Reale, S. Schubert, M. Suarez, and C. Thorncroft, 2011: African Easterly Jet: Barotropic Instability, Waves and Cyclogenesis. *J. Climate*. (Mar 2012)

http://journals.ametsoc.org/doi/abs/10.1175/2011JCLI4241.1?journalCode=clim

This study investigates the structure of the African easterly jet, focusing on instability processes on a seasonal and subseasonal scale, with the goal of identifying features that could provide increased predictability of Atlantic tropical cyclogenesis. The Modern-Era Retrospective Analysis for Research and Applications (MERRA) is used as the main investigating tool. MERRA is compared with other reanalyses datasets from major operational centers around the world and was found to describe very effectively the circulation over the African monsoon region. In particular, a comparison with precipitation datasets from the Global Precipitation Climatology Project shows that MERRA realistically reproduces seasonal precipitation over that region. The verification of the generalized Kuo barotropic instability condition computed from seasonal means is found to have the interesting property of defining well the location where observed tropical storms are detected. This property does not appear to be an artifact of MERRA and is present also in the other adopted reanalysis datasets. Therefore, the fact that the areas where the mean flow is unstable seems to provide a more favorable environment for wave intensification, could be another factor to include—in addition to sea surface temperature, vertical shear, precipitation, the role of Saharan air, and others—among large-scale forcings affecting development and tropical cyclone frequency. In addition, two prominent modes of variability are found based on a spectral analysis that uses the Hilbert–Huang transform: a 2.5–6-day mode that corresponds well to the African easterly waves and also a 6–9-day mode that seems to be associated with tropical–extratropical interaction.

Yearsley, J., 2012: A grid based approach for simulating streamflow temperature, *Water Resour. Res*.,48, W03506, doi:10.1029/2011WR011515 (Mar 2012)

http://www.agu.org/pubs/crossref/2012/2011WR011515.shtml

Applications of grid-based systems are widespread in many areas of environmental analysis. In this study, the concept is adapted to the modeling of water temperature by integrating a macroscale hydrologic model, variable infiltration capacity (VIC), with a computationally efficient and accurate water temperature model. The hydrologic model has been applied to many river basins at scales from 0.0625° to 1.0°. The water temperature model, which uses a semi-Lagrangian numerical scheme to solve the one-dimensional, time-dependent equations for thermal energy balance in advective river systems, has been applied and tested on segmented river systems in the Pacific Northwest. The state-space structure of the water temperature model described in previous work is extended to include propagation of uncertainty. Model results focus on proof of concept by comparing statistics from a study of a test basin with results from other studies that have used either process models or statistical models to estimate water temperature. The results from this study compared favorably with those of selected case studies using data-driven statistical models. The results for deterministic process models of water temperature were generally better than the grid-based method, particularly for those models developed from site-specific, data-intensive studies. Biases in the results from the grid-based system are attributed to heterogeneity in hydraulic characteristics and the method of estimating headwater temperatures.

Xia, Y., K. Mitchell, M. Ek, J. Sheffield, B. Cosgrove, E. F. Wood, L. Luo, C. Alonge, H. Wei, J. Meng, B. Livneh, D. Lettenmaier, V. Koren, Q. Duan, K. Mo, Y. Fan, D. Mocko, 2012: Continental-Scale Water and Energy Flux Analysis and Validation for the North American Land Data Assimilation System Project Phase 2 (NLDAS-2): 1. Intercomparison and Application of Model Products, *J. Geophys. Res.*, **117**, D03109, doi:10.1029/2011JD016048. (Feb 2012)
http://www.agu.org/pubs/crossref/2012/2011JD016051.shtml

Results are presented from the second phase of the multiinstitution North American Land Data Assimilation System (NLDAS-2) research partnership. In NLDAS, the Noah, Variable Infiltration Capacity, Sacramento Soil Moisture Accounting, and Mosaic land surface models (LSMs) are executed over the conterminous U.S. (CONUS) in realtime and retrospective modes. These runs support the drought analysis, monitoring and forecasting activities of the National Integrated Drought Information System, as well as efforts to monitor large-scale floods. NLDAS-2 builds upon the framework of the first phase of NLDAS (NLDAS-1) by increasing the accuracy and consistency of the surface forcing data, upgrading the land surface model code and parameters, and extending the study from a 3-year (1997–1999) to a 30-year (1979–2008) time window. As the first of two parts, this paper details the configuration of NLDAS-2, describes the upgrades to the forcing, parameters, and code of the four LSMs, and explores overall model-to-model comparisons of land surface water and energy flux and state variables over the CONUS. Focusing on model output rather than on observations, this study seeks to highlight the similarities and differences between models, and to assess changes in output from that seen in NLDAS-1. The second part of the two-part article focuses on the validation of model-simulated streamflow and evaporation against observations. The results depict a higher level of agreement among the four models over much of the CONUS than was found in the first phase of NLDAS. This is due, in part, to recent improvements in the parameters, code, and forcing of the NLDAS-2 LSMs that were initiated following NLDAS-1. However, large inter-model differences still exist in the northeast, Lake Superior, and western mountainous regions of the CONUS, which are associated with cold season processes. In addition, variations in the representation of sub-surface hydrology in the four LSMs lead to large differences in modeled evaporation and subsurface runoff. These issues are important targets for future research by the land surface modeling community. Finally, improvement from NLDAS-1 to NLDAS-2 is summarized by comparing the streamflow measured from U.S. Geological Survey stream gauges with that simulated by four NLDAS models over 961 small basins.

Vinukollu, R. K., J. Sheffield, E. F. Wood, M. Bosilovich, and D. Mocko, 2012: Multimodel analysis of Energy and Water Fluxes: Intercomparisons between Operational Analyses, a Land Surface Model and Remote Sensing, *Journal of Hydromet.*, **13**(1), 3-26, doi:10.1175/2011JHM1372.1. (Feb 2012)
http://journals.ametsoc.org/doi/abs/10.1175/2011JHM1372.1

Evapotranspiration (ET) is the key water cycle variable that links the water, energy and carbon cycles. Obtaining a global perspective of its mean value and variability is hampered by sparse and inaccurate (lack of budget closure) in-situ observations. A long-term (1984-2008), daily multi-algorithm retrievals have been developed and analyzed that provides important new insights into the spatial and temporal variability of ET.

Using data from seven global model operational analyses (OA), one land surface model, and various remote sensing retrievals, the energy and water fluxes over global land areas are intercompared for 2003/04. Remote sensing estimates of evapotranspiration (ET) are obtained from three process-based models that use input forcings from multisensor satellites. An ensemble mean (linear average) of the seven operational (mean-OA) models is used primarily to intercompare the fluxes with comparisons performed at both global and basin scales. At the global scale, it is found that all components of the energy budget represented by the ensemble mean of the OA models have a significant bias. Net radiation estimates had a positive bias (global mean) of 234 MJ m^{-2} yr^{-1} (7.4 W m^{-2}) as compared to the remote sensing estimates, with the latent and sensible heat fluxes biased by 470 MJ m^{-2} yr^{-1} (13.3 W m^{-2}) and −367 MJ m^{-2} yr^{-1} (11.7 W m^{-2}), respectively. The bias in the latent heat flux is affected by the bias in the net radiation, which is primarily due to the biases in the incoming shortwave and outgoing longwave radiation and to the nudging process of the operational models. The OA models also suffer from improper partitioning of the surface heat fluxes. Comparison of precipitation (*P*) analyses from the various OA models, gauge analysis, and remote sensing retrievals showed better agreement than the energy fluxes. Basin-scale comparisons were consistent with the global-scale results, with the results for the Amazon in particular showing disparities between OA and remote sensing estimates of energy fluxes. The biases in the fluxes are attributable to a combination of errors in the forcing from the OA atmospheric models and the flux calculation methods in their land surface schemes. The atmospheric forcing errors are mainly attributable to high shortwave radiation likely due to the underestimation of clouds, but also precipitation errors, especially in water-limited regions.

Yilmaz, M. Tugrul, Timothy DelSole, Paul R. Houser, 2011: Improving Land Data Assimilation Performance with a Water Budget Constraint. *J. Hydrometeor*, **12**, 1040–1055. (Oct 2011) doi: http://dx.doi.org/10.1175/2011JHM1346.1

A weak constraint is introduced in ensemble Kalman filters to reduce the water budget imbalance that occurs in land data assimilation. Two versions of the weakly constrained filter, called the weakly constrained ensemble Kalman filter (WCEnKF) and the weakly constrained ensemble transform Kalman filter (WCETKF), are proposed. The strength of the weak constraint is adaptive in the sense that it depends on the statistical characteristics of the forecast ensemble. The resulting filters are applied to assimilate synthetic observations generated by the Noah land surface model over the Red Arkansas River basin. The data assimilation experiments demonstrate that, for all tested scenarios, the constrained filters produce analyses with nearly the same accuracy as unconstrained filters, but with much smaller water balance residuals than unconstrained filters.

Shrestha, R., P. R. Houser, and V. G. Anantharaj (2011), An optimal merging technique for high-resolution precipitation products, *J. Adv. Model. Earth Syst.*, 3, M12003, doi:10.1029/2011MS000062 (Dec 2011)

http://www.agu.org/pubs/crossref/2011/2011MS000062.shtml

Precipitation products are currently available from various sources at higher spatial and temporal resolution than any time in the past. Each of the precipitation products has its strengths and weaknesses in availability, accuracy, resolution, retrieval techniques and quality control. By merging the precipitation data obtained from multiple sources, one can improve its information content by minimizing these issues. However, precipitation data merging poses challenges of scale-mismatch, and accurate error and bias assessment. In this paper we present Optimal Merging of Precipitation (OMP), a new method to merge precipitation data from multiple sources that are of different spatial and temporal resolutions and accuracies. This method is a combination of scale conversion and merging weight optimization, involving performance-tracing based on Bayesian statistics and trend-analysis, which yields merging weights for each precipitation data source. The weights are optimized at multiple scales to facilitate multiscale merging and better precipitation downscaling. Precipitation data used in the experiment include products from the 12-km resolution North American Land Data Assimilation (NLDAS) system, the 8-km resolution CMORPH and the 4-km resolution National Stage-IV QPE. The test cases demonstrate that the OMP method is capable of identifying a better data source and allocating a higher priority for them in the merging procedure, dynamically over the region and time period. This method is also effective in filtering out poor quality data introduced into the merging process.

Yilmaz, M. Tugrul, Timothy DelSole, Paul R. Houser, 2012: Reducing Water Imbalance in Land Data Assimilation: Ensemble Filtering without Perturbed Observations. *J. Hydrometeor*, **13**, 413–420. (Feb 2012)
http://dx.doi.org/10.1175/JHM-D-11-010.1 (Feb 2012)

It is well known that the ensemble Kalman filter (EnKF) requires updating each ensemble member with perturbed observations in order to produce the proper analysis-error covariances. While increased accuracy in a mean square sense may be preferable in many applications, less accuracy might be preferable in other applications, especially if the variables being assimilated obey certain conservation laws. In land data assimilation, for instance, the update in soil moisture often produces a water balance residual, in the sense that the input water is not equal to output water. This study shows that suppressing the perturbation of observations in the EnKF and in the weakly constrained ensemble Kalman filter significantly improves the water balance residuals without significantly increasing the state errors.

Climatology

Rodell, M., D. P. Chambers, and J. S. Famiglietti, [Global Climate: Hydrological Cycle] Groundwater and Terrestrial Water Storage. In "State of the Climate in 2010", Blunden, J., D. S. Arndt, and M. O. Baringer, Eds. *Bull. Amer. Meteor. Soc*., 92 (6), S49-S52, 2011 (June 2011)
http://biotech.law.lsu.edu/climate/noaa/climate-2010/bams-sotc-2010-references-hi-rez.pdf

The NASA/German Gravity Recovery and Climate Experiment (GRACE) was launched in March 2002. Rather than looking downward, GRACE continuously monitors the locations of and precise distance between twin satellites that orbit in tandem about 200 m apart. Variations in mass near Earth's surface cause heterogeneities in its gravity field, which in turn affect the orbits of satellites. Thus, scientists can use GRACE data to map Earth's gravity field with enough accuracy to discern month-to month changes caused by ocean circulation and redistribution of water stored on and in the land (Tapley et al, 2004; Wahr et al. 2004). Sources of uncertainty include the inherent limitations of the measurement technique and instruments, issues associated with spatial resolution and mathematical representation of the gravity field, and inaccuracy in removing other gravitational influences, such as atmospheric circulation, post-glacial rebound, and solid earth movements, which are either independently modeled and removed or are assumed to be negligible on a monthly to sub-decadal timescales.

Rodell, M., J. S. Famiglietti, D. P. Chambers, and J. Wahr, Sidebar 2.2: Contributions of GRACE to climate monitoring. In "State of the Climate in 2010", Blunden, J., D. S. Arndt, and M. O. Baringer, Eds. *Bull. Amer. Meteor. Soc*., 92 (6), S50-S51, 2011. (June 2011)
http://journals.ametsoc.org/doi/abs/10.1175/1520-0477-92.6.S1

Several large-scale climate patterns influenced climate conditions and weather patterns across the globe during 2010. The transition from a warm El Niño phase at the beginning of the year to a cool La Niña phase by July contributed to many notable events, ranging from record wetness across much of Australia to historically low Eastern Pacific basin and near-record high North Atlantic basin hurricane activity. The remaining five main hurricane basins experienced below- to well-below-normal tropical cyclone activity. The negative phase of the Arctic Oscillation was a major driver of Northern Hemisphere temperature patterns during 2009/10 winter and again in late 2010. It contributed to record snowfall and unusually low temperatures over much of northern Eurasia and parts of the United States, while bringing above-normal temperatures to the high northern latitudes. The February Arctic Oscillation Index value was the most negative since records began in 1950.

The 2010 average global land and ocean surface temperature was among the two warmest years on record. The Arctic continued to warm at about twice the rate of lower latitudes. The eastern and tropical Pacific Ocean cooled about 1°C from 2009 to 2010, reflecting the transition from the 2009/10 El Niño to the 2010/11 La Niña. Ocean heat fluxes contributed to warm sea surface temperature anomalies in the North Atlantic and the tropical Indian and western Pacific Oceans. Global integrals of upper ocean heat content for the past several years have reached values consistently higher than for all prior times in the record, demonstrating the dominant role of the ocean in the Earth's energy budget. Deep and abyssal waters of Antarctic origin have also trended warmer on average since the early 1990s. Lower tropospheric temperatures typically lag ENSO surface fluctuations by two to four months, thus the 2010 temperature was dominated by the warm phase El Niño conditions that occurred during the latter half of 2009 and early 2010 and was second warmest on record. The stratosphere continued to be anomalously cool.

Annual global precipitation over land areas was about five percent above normal. Precipitation over the ocean was drier than normal after a wet year in 2009. Overall, saltier (higher evaporation) regions of the ocean surface continue to be anomalously salty, and fresher (higher precipitation) regions continue to be anomalously fresh. This salinity pattern, which has held since at least 2004, suggests an increase in the hydrological cycle.

Sea ice conditions in the Arctic were significantly different than those in the Antarctic during the year. The annual minimum ice extent in the Arctic—reached in September—was the third lowest on record since 1979. In the Antarctic, zonally averaged sea ice extent reached an all-time record maximum from mid-June through late August and again from mid-November through early December. Corresponding record positive Southern Hemisphere Annular Mode Indices influenced the Antarctic sea ice extents.

Greenland glaciers lost more mass than any other year in the decade-long record. The Greenland Ice Sheet lost a record amount of mass, as the melt rate was the highest since at least 1958, and the area and duration of the melting was greater than any year since at least 1978. High summer air temperatures and a longer melt season also caused a continued increase in the rate of ice mass loss from small glaciers and ice caps in the Canadian Arctic. Coastal sites in Alaska show continuous permafrost warming and sites in Alaska, Canada, and Russia indicate more significant warming in relatively cold permafrost than in warm permafrost in the same geographical area. With regional differences, permafrost temperatures are now up to 2°C warmer than they were 20 to 30 years ago. Preliminary data indicate there is a high probability that 2010 will be the 20th consecutive year that alpine glaciers have lost mass.

Atmospheric greenhouse gas concentrations continued to rise and ozone depleting substances continued to decrease. Carbon dioxide increased by 2.60 ppm in 2010, a rate above both the 2009 and the 1980–2010 average rates. The global ocean carbon dioxide uptake for the 2009 transition period from La Niña to El Niño conditions, the most recent period for which analyzed data are available, is estimated to be similar to the long-term average. The 2010 Antarctic ozone hole was among the lowest 20% compared with other years since 1990, a result of warmer-than-average temperatures in the Antarctic stratosphere during austral winter between mid-July and early September

Editors note: For easy download the posted pdf of the State of the Climate for 2009 is a low-resolution file. A high-resolution copy of the report is available by clicking here. Please be patient as it may take a few minutes for the high-resolution file to download.

Stephens, G. L., M. Wild, P. W. Stackhouse, T. L'Ecuyer, S. Kato, D. S.

Henderson, 2012: The Global Character of the Flux of Downward Longwave Radiation. *J. Climate*, **25**, 2329–2340.doi:(Apr. 2012)
http://dx.doi.org/10.1175/JCLI-D-11-00262.1

Four different types of estimates of the surface downwelling longwave radiative flux (DLR) are reviewed. One group of estimates synthesizes global cloud, aerosol, and other information in a radiation model that is used to calculate fluxes. Because these synthesis fluxes have been assessed against observations, the global-mean values of these fluxes are deemed to be the most credible of the four different categories reviewed. The global, annual mean DLR lies between approximately 344 and 350 W m^{-2} with an error of approximately ±10 W m^{-2} that arises mostly from the uncertainty in atmospheric state that governs the estimation of the clear-sky emission. The authors conclude that the DLR derived from global climate models are biased low by approximately 10 W m^{-2} and even larger differences are found with respect to reanalysis climate data. The DLR inferred from a surface energy balance closure is also substantially smaller that the range found from synthesis products suggesting that current depictions of surface energy balance also require revision. The effect of clouds on the DLR, largely facilitated by the new cloud base information from the *CloudSat* radar, is estimated to lie in the range from 24 to 34 W m^{-2} for the global cloud radiative effect (all-sky minus clear-sky DLR). This effect is strongly modulated by the underlying water vapor that gives rise to a maximum sensitivity of the DLR to cloud occurring in the colder drier regions of the planet. The bottom of atmosphere (BOA) cloud effect directly contrast the effect of clouds on the top of atmosphere (TOA) fluxes that is maximum in regions of deepest and coldest clouds in the moist tropics.

Lebsock, M. D., and T. S. L'Ecuyer, 2011: The retrieval of warm rain from CloudSat, *J. Geophys. Res*., 116, D20209 (Oct 2011)
http://www.agu.org/pubs/crossref/2011/2011JD016076.shtml

An algorithm for the retrieval of warm rain over oceans for CloudSat that uses
ancillary information from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is presented. The method builds upon the architecture of the standard CloudSat 2C-RAIN-PROFILE product. Several general enhancements of that architecture have been made, including the implementation of a fast two-stream multiple-scattering radar model and a detailed error characterization. The algorithm has also been modified to specifically target the retrieval of warm rain by using ancillary MODIS visible optical depth observations to construct a parameterization of the cloud water path, implementing a model of the evaporation of rain below cloud base, and introducing a realistic representation of warm raindrop size distributions. With these important algorithm modifications, the CloudSat 2C-RAIN-PROFILE product is ideally suited to examine the distribution and

magnitude of light rain over oceans

Su Z, Roebeling RA, Schulz J, Holleman I, Levizzani V, Timmermans WJ, Rott H, Mognard-Campbell N, de Jeu R, Wagner W, Rodell M, Salama MS, Parodi GN and Wang L. 2011.Observation of Hydrological Processes Using Remote Sensing. In: Peter Wilderer (ed.) Treatise on *Water Science*, vol. 2, pp. 351-399 Oxford: Academic Press. ****see attached doc**

Kato, S. et al., 2011: Improvements of top-of-atmosphere and surface irradiance computations with CALIPSO-, CloudSat-, and MODIS-derived cloud and aerosol properties, *J. Geophys. Res*., 116, D19209, doi:10.1029/2011JD016050. (Oct 2011)
http://www.agu.org/pubs/crossref/2011/2011JD016050.shtml

One year of instantaneous top-of-atmosphere (TOA) and surface shortwave and longwave irradiances are computed using cloud and aerosol properties derived from instruments on the A-Train Constellation: the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite, the CloudSat Cloud Profiling Radar (CPR), and the Aqua Moderate Resolution Imaging Spectrometer (MODIS). When modeled irradiances are compared with those computed with cloud properties derived from MODIS radiances by a Clouds and the Earth's Radiant Energy System (CERES) cloud algorithm, the global and annual mean of modeled instantaneous TOA irradiances decreases by 12.5 W m−2 (5.0%) for reflected shortwave and 2.5 W m−2 (1.1%) for longwave irradiances. As a result, the global annual mean of instantaneous TOA irradiances agrees better with CERES-derived irradiances to within 0.5W m−2 (out of 237.8 W m−2) for reflected shortwave and 2.6W m−2 (out of 240.1 W m−2) for longwave irradiances. In addition, the global annual mean of instantaneous surface downward longwave irradiances increases by 3.6 W m−2 (1.0%) when CALIOP- and CPR-derived cloud properties are used. The global annual mean of instantaneous surface downward shortwave irradiances also increases by 8.6 W m−2 (1.6%), indicating that the net surface irradiance increases when CALIOP- and CPR-derived cloud properties are used. Increasing the surface downward longwave irradiance is caused by larger cloud fractions (the global annual mean by 0.11, 0.04 excluding clouds with optical thickness less than 0.3) and lower cloud base heights (the global annual mean by 1.6 km). The increase of the surface downward longwave irradiance in the Arctic exceeds 10 W m−2 (~4%) in winter because CALIOP and CPR detect more clouds in comparison with the cloud detection by the CERES cloud algorithm during polar night. The global annual mean surface downward longwave irradiance of 345.4 W m−2 is estimated by combining the modeled instantaneous surface longwave irradiance computed with CALIOP and CPR cloud profiles with the global annual mean longwave irradiance from the CERES product (AVG), which includes the diurnal variation of the irradiance. The estimated bias error is −1.5 W m−2 and the uncertainty is 6.9 W m−2. The uncertainty is predominately caused by the near-surface temperature and column water vapor amount uncertainties.

Hegyi, B. M., and Y. Deng, 2011: A dynamical fingerprint of tropical Pacific sea surface temperatures on the decadal‐scale variability of cool‐season Arctic precipitation, *J. Geophys. Res*., 116, D20121, doi:10.1029/2011JD016001 (Oct 2011)

http://www.agu.org/pubs/crossref/2011/2011JD016001.shtml

The temporal and spatial characteristics of decadal-scale variability in the Northern Hemisphere (NH) cool-season (October–March) Arctic precipitation are identified from both the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) and the Global Precipitation Climatology Project (GPCP) precipitation data sets. This decadal variability is shown to be partly connected to the decadal-scale variations in tropical central Pacific sea surface temperatures (SSTs) that are primarily associated with a decadal modulation of the El Niño–Southern Oscillation (ENSO), i.e., transitions between periods favoring typical eastern Pacific warming (EPW) events and periods favoring central Pacific warming (CPW) events. Regression and composite analyses reveal that increases of central Pacific SSTs drive a stationary Rossby wave train that destructively interferes with the wave number-1 component of the extratropical planetary wave. This destructive interference is opposite to the mean effect of typical EPW on the extratropical planetary wave. It leads to suppressed upward propagation of wave energy into the polar stratosphere, a stronger stratospheric polar vortex, and a tendency toward a positive phase of the Arctic Oscillation (AO). The positive AO tendency is synchronized on the decadal scale with a poleward shift of the NH storm tracks, particularly in the North Atlantic. Storm track variations further induce changes in the amount of moisture transported into the Arctic by synoptic eddies. The fluctuations in the eddy moisture transport ultimately contribute to the observed decadal-scale variations in the total Arctic precipitation in the NH cool season.

Feng, Z., X. Dong, B. Xi, C. Schumacher, P. Minnis, and M. Khaiyer, 2011: Top-of-atmosphere radiation budget of convective core/stratiform rain and anvil clouds from deep convective systems, *J. Geophys. Res*., 116, D23202, doi:10.1029/ 2011JD016451. (Dec 2011)

http://www.agu.org/pubs/crossref/2011/2011JD016451.shtml

A new hybrid classification algorithm to objectively identify Deep Convective Systems (DCSs) in radar and satellite observations has been developed. This algorithm can classify the convective cores (CC), stratiform rain (SR) area and nonprecipitating anvil cloud (AC) from the identified

DCSs through an integrative analysis of ground-based scanning radar and geostationary satellite data over the Southern Great Plains. In developing the algorithm, AC is delineated into transitional, thick, and thin components. While there are distinct physical/dynamical differences among these subcategories, their top-of-atmosphere (TOA) radiative fluxes are not significantly different. Therefore, these anvil subcategories are grouped as total anvil, and the radiative impact of each DCS component on the TOA radiation budget is quantitatively estimated. We found that more DCSs occurred during late afternoon, producing peak AC fraction right after sunset. AC covers 3 times the area of SR and almost an order of magnitude larger than CC. The average outgoing longwave (LW) irradiances are almost identical for CC and SR, while slightly higher for AC. Compared to the clear-sky average, the reflected shortwave (SW) fluxes for the three DCS components are greater by a factor of 2–3 and create a strong cooling effect at TOA. The calculated SW and LW cloud radiative forcing (CRF) of AC contribute up to 31% of total NET CRF, while CC and SR contribute only 4 and 11%, respectively. The hybrid classification further lays the groundwork for studying the life cycle of DCS and improvements in geostationary satellite IR-based precipitation retrievals.

Hall, D. K., J. L. Foster, N. E. DiGirolamo, and G. A. Riggs, 2012: Snow cover, snowmelt timing and stream power in the Wind River Range, Wyoming. *Geomorphology*, v. 137, no. 1, pp. 87-93, doi: 10.1016/j.geomorph.2010.11.011.

(Mar 2012)

Earlier onset of springtime weather, including earlier snowmelt, has been documented in the western United States over at least the last 50 years. Because the majority (> 70%) of the water supply in the western U.S. comes from snowmelt, analysis of the declining spring snowpack (and shrinking glaciers) has important implications for the management of streamflow. The amount of water in a snowpack influences stream discharge which can also influence erosion and sediment transport by changing stream power, or the rate at which a stream can do work, such as move sediment and erode the stream bed. The focus of this work is the Wind River Range (WRR) in west-central Wyoming. Ten years of Moderate-Resolution Imaging Spectroradiometer (MODIS) snow-cover, cloud-gap-filled (CGF) map products and 30 years of discharge and meteorological station data are studied. Streamflow data from streams in WRR drainage basins show lower annual discharge and earlier snowmelt in the decade of the 2000s than in the previous three decades, though no trend of either lower streamflow or earlier snowmelt was observed *within* the decade of the 2000s. Results show a statistically-significant trend at the 95% confidence level (or higher) of increasing weekly maximum air temperature (for three out of the five meteorological stations studied) in the decade of the 1970s, and also for the

40-year study period as a whole. The extent of snow-cover (percent of basin covered) derived from the lowest elevation zone (2500–3000 m) of the WRR, using MODIS CGF snow-cover maps, is strongly correlated with maximum monthly discharge on 30 April, where Spearman's Rank correlation, r_s = 0.89 for the decade of the 2000s. We also investigated stream power for Bull Lake Creek above Bull Lake; and found a trend (significant at the 90% confidence level) toward reduced stream power from 1970 to 2009. Observed changes in streamflow and stream power may be related to increasing weekly maximum air temperature measured during the 40-year study period, possibly contributing to a reduction in snow cover. In addition, the strong relationship between percent of basin that was snow covered, and maximum monthly streamflow indicates that MODIS snow-cover maps are useful for predicting streamflow, and can be used to improve management of water resources in the drought-prone western United States.

Hall, D., J. L. Foster, S. Kumar, J. Y. L. Chien, and G.A. Riggs, 2012: Improving the accuracy of the AFWA-NASA (ANSA) blended snow-cover product over the Lower Great Lakes region *Hydrol. Earth Syst. Sci. Discuss.*, *9*, 1141-1161 10.5194/hessd-9-1141-2012 (Jan 2012)
http://www.hydrol-earth-syst-sci-discuss.net/9/1141/2012/hessd-9-1141-2012.html

The Air Force Weather Agency (AFWA) – NASA blended snow-cover product, called ANSA, utilizes Ear th Obser ving System standard snow products from the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) to map daily snow cover and snow-water equivalent (SWE) globally. We have compared ANSA-derived SWE with SWE values calculated from snow depths repor ted at ~1500 National Climatic Data Center (NCDC) co-op stations in the Lower Great Lakes Basin. Compared to station data, the ANSA significantly underestimates SWE in densely-forested areas. We use two methods to remove some of the bias obser ved in forested areas to reduce the root-mean-square error (RMSE) between the ANSA- and station-derived SWE. First, we calculated a 5-yr mean ANSA-derived SWE for the winters of 2005–2006 through 2009–2010, and developed a 5-yr mean bias-corrected SWE map for each month. For most of the months studied during the 5-yr period, the 5-yr bias correction improved the agreement between the ANSA-derived and station-derived SWE. However, anomalous months such as when there was ver y little snow on the ground compared to the 5-yr mean, or months in which the snow was much greater than the 5-yr mean, showed poorer results (as expected). We also used a 7-day running mean (7DRM) bias correction method using days just prior to the day in question to correct the ANSA data. This method was more effective in reducing the RMSE between the ANSA- and co-op-derived SWE values, 20 and in capturing the effects of anomalous snow conditions.

Tang, Q., and D. P. Lettenmaier, 2012: 21st century runoff sensitivities of major global river basins, *Geophys. Res. Lett.*, 39, L06403. (Mar 2012)
http://www.agu.org/pubs/crossref/2012/2011GL050834.shtml

River runoff is a key index of renewable water resources which affect almost all human and natural systems. Any substantial change in runoff will therefore have serious social, environmental, and ecological consequences. We estimate the runoff response to global mean temperature change implied by the climate change experiments generated for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). In contrast to previous studies, we estimate the runoff sensitivity using global mean temperature change as an index of anthropogenic climate changes in temperature and precipitation, with the rationale that this removes the dependence on emissions scenarios. Our results show that the runoff sensitivity implied by the IPCC experiments is relatively stable across emissions scenarios and global mean temperature increments, but varies substantially across models with the exception of the high-latitudes and currently arid or semi-arid areas. The runoff sensitivities are slightly higher at 0.5°C warming than for larger amounts of warming. The estimated ratio of runoff change to (local) precipitation change (runoff elasticity) ranges from about one to three, and the runoff temperature sensitivity (change in runoff per degree C of local temperature increase) ranges from decreases of about 2 to 6% over most basins in North America and the middle and high latitudes of Eurasia.

Evaporation and Latent Heating

Moncet, J.-L., P. Liang, A. E. Lipton, J. F. Galantowicz, and C. Prigent, 2011: Discrepancies between MODIS and ISCCP land surface temperature products analyzed with microwave measurements. *J. Geophys. Res.*, 116, D21105. (Nov 2011)
http://www.agu.org/pubs/crossref/2011/2010JD015432.shtml

This paper compares land surface temperature (LST) products from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the International Satellite Cloud Climatology Project (ISCCP). With both sources, the LST data are derived from infrared measurements. For ISCCP, LST is a secondary product in support of the primary cloud analyses, but the LST data have been used for several other purposes. The MODIS measurements from the Aqua spacecraft are taken at about 01:30 and 13:30 local time, and the ISCCP three-hourly data, based on several geostationary and polar orbiting satellites, were interpolated to the MODIS measurement times. For July 2003 monthly averages over all clear-sky locations, the ISCCP-MODIS differences were +5.0 K and +2.5 K for day and night, respectively, and there were areas with differences as large as 25 K. The day–night differences were as much as ~10 K higher for ISCCP than for MODIS. The MODIS measurements were more consistent with independent microwave measurements from AMSR-E, by several measures, with respect to day–night differences and day-to-day variations.

Galantowicz, J. F., J.-L. Moncet, P. Liang, A. E. Lipton, G. Uymin, C. Prigent, and C. Grassotti, 2011: Subsurface emission effects in AMSR E measurements: Implications for land surface microwave emissivity retrieval. *J. Geophys. Res.,* 116, D17105, doi:10.1029/2010JD015431.(Sept 2011)

http://www.agu.org/pubs/crossref/2011/2010JD015431.shtml

An analysis of land surface microwave emission time series shows that the characteristic diurnal signatures associated with subsurface emission in sandy deserts carry over to arid and semiarid regions worldwide. Prior work found that diurnal variation of Special Sensor Microwave/Imager (SSM/I) brightness temperatures in deserts was small relative to International Satellite Cloud Climatology Project land surface temperature (LST) variation and that the difference varied with surface type and was largest in sand sea regions. Here we find more widespread subsurface emission effects in Advanced Microwave Scanning Radiometer-EOS (AMSR-E) measurements. The AMSR-E orbit has equator crossing times near 01:30 and 13:30 local time, resulting in sampling when near-surface temperature gradients are likely to be large and amplifying the influence of emission depth on effective emitting temperature relative to other factors. AMSR-E measurements are also temporally coincident with Moderate Resolution Imaging Spectroradiometer (MODIS) LST measurements, eliminating time lag as a source of LST uncertainty and reducing LST errors due to undetected clouds. This paper presents monthly global emissivity and emission depth index retrievals for 2003 at 11, 19, 37, and 89 GHz from AMSR-E, MODIS, and SSM/I time series data. Retrieval model fit error, stability, self-consistency, and land surface modeling results provide evidence for the validity of the subsurface emission hypothesis and the retrieval approach. An analysis of emission depth index, emissivity, precipitation, and vegetation index seasonal trends in northern and southern Africa suggests that changes in the emission depth index may be tied to changes in land surface moisture and vegetation conditions.

Rodell, M., E. B. McWilliams, J. S. Famiglietti, H. K. Beaudoing,and J. Nigro , 2011: Estimating evapotranspiration using an observation based terrestrial water budget, *Hydrological Processes*, DOI: 10.1002/hyp.8369 (Dec 2011)

http://onlinelibrary.wiley.com/doi/10.1002/hyp.8369/full

Evapotranspiration (ET) is difficult to measure at the scales of climate models and climate variability. While satellite retrieval algorithms do exist, their accuracy is limited by the sparseness of *in situ* observations available for calibration and validation, which themselves may be unrepresentative of 500 m and larger scale satellite footprints and grid pixels. Here, we use a combination of satellite and ground-based observations to close the water budgets of seven continental scale river basins (Mackenzie, Fraser, Nelson, Mississippi, Tocantins, Danube, and Ubangi), estimating mean ET as a residual. For any river basin, ET must equal total precipitation minus net runoff minus the change in total terrestrial water storage (TWS), in order for mass to be conserved. We make use of precipitation from two global observation-based products, archived runoff data, and TWS changes from the Gravity Recovery and Climate Experiment (GRACE) satellite mission. We demonstrate that while uncertainty in the water budget-based estimates of monthly ET is often too large for those estimates to be useful, the uncertainty in the mean annual cycle is small enough that it is practical for evaluating other ET products**.** Here, we evaluate five land surface model simulations, two operational atmospheric analyses, and a recent global reanalysis product based on our results. An important outcome is that the water budget-based ET time series in two tropical river basins, one in Brazil and the other in central Africa, exhibit a weak annual cycle, which may help to resolve debate about the strength of the annual cycle of ET in such regions and how ET is constrained throughout the year. The methods described will be useful for water and energy budget studies, weather and climate model assessments, and satellite-based ET retrieval optimization

Vinukollu, R. K., R. Meynadier, J. Sheffield, E. F. Wood, 2011:Multi-model, multi-sensor estimates of global evapotranspiration: climatology, uncertainties and trends, *Hydrol. Process.* 25, 3993–4010 (Dec 2011)
http://onlinelibrary.wiley.com/doi/10.1002/hyp.8393/abstract

Estimating evapotranspiration (ET) at continental to global scales is central to understanding the partitioning of energy and water at the earth's surface and the feedbacks with the atmosphere and biosphere, especially in the context of climate change. Recent evaluations of global estimates from remote sensing, upscaled observations, land surface models and atmospheric reanalyses indicate large uncertainty across the datasets of the order of 50% of the global annual mean value. In this paper, we explore the uncertainties in global land ET estimates using three process-based ET models and a set of remote sensing and observational based radiation and meteorological forcing datasets. Input forcings were obtained from International Satellite Cloud Climatology Project (ISCCP) and Surface Radiation Budget (SRB). The three process-based ET models are: a surface energy balance method (SEBS), a revised Penman–Monteith (PM) model, and a modified Priestley–Taylor model. Evaluations of the radiation products from ISCCP and SRB show large differences in the components of surface radiation, and temporal inconsistencies that relate to changes in satellite sensors and retrieval algorithms. In particular, step changes in the ISCCP surface temperature and humidity data lead to spurious increases in downward and upward longwave radiation that contributes to a step change in net radiation, and the ISCCP data are not used further. An ensemble of global estimates of land surface ET are generated at daily time scale and 0.5 degree spatial resolution for 1984–2007 using two SRB radiation products (SRB and SRBqc) and the three models. Uncertainty in ET from the models is much larger than the uncertainty from the radiation data. The largest uncertainties relative to the mean annual ET are in transition zones between dry and humid regions and monsoon regions. Comparisons with previous studies and an inferred estimate of ET from long-term inferred ET indicate that the ensemble mean value is reasonable, but generally biased high globally. Long-term changes over 1984–2007 indicate a slight increase over 1984–1998 and decline thereafter, although uncertainties in the forcing radiation data and lack of direct linkage with soil moisture limitations in the models prevents attribution of these changes.

Ferguson, Craig R., E. F. Wood, 2011: Observed Land–Atmosphere Coupling from Satellite Remote Sensing and Reanalysis. *J. Hydrometeor*, **12**, 1221–1254.
doi: http://dx.doi.org/10.1175/2011JHM1380.1 (Dec 2011)

The lack of observational data for use in evaluating the realism of model-based land–atmosphere feedback signal and strength has been deemed a major obstacle to future improvements to seasonal weather prediction by the Global Land–Atmosphere Coupling Experiment (GLACE). To address this need, a 7-yr (2002–09) satellite remote sensing data record is exploited to produce for the first time global maps of predominant coupling signals. Specifically, a previously implemented convective triggering potential (CTP)–humidity index (HI) framework for describing atmospheric controls on soil moisture–rainfall feedbacks is revisited and generalized for global application using CTP and HI from the Atmospheric Infrared Sounder (AIRS), soil moisture from the Advanced Microwave Scanning Radiometer for Earth Observing System (EOS) (AMSR-E), and the U.S. Climate Prediction Center (CPC) merged satellite rainfall product (CMORPH). Based on observations taken during an AMSR-E-derived convective rainfall season, the global land area is categorized into four convective regimes: 1) those with atmospheric conditions favoring deep convection over wet soils, 2) those with atmospheric conditions favoring deep convection over dry soils, 3) those with atmospheric conditions that suppress convection over any land surface, and 4) those with atmospheric conditions that support convection over any land surface. Classification maps are produced using both the original and modified frameworks, and later contrasted with similarly derived maps using inputs from the National Aeronautics and Space Administration (NASA) Modern Era Retrospective Analysis for Research and Applications (MERRA). Both AIRS and MERRA datasets of

CTP and HI are validated using radiosonde observations. The combinations of methods and data sources employed in this study enable evaluation of not only the sensitivity of the classification schemes themselves to their inputs, but also the uncertainty in the resultant classification maps. The findings are summarized for 20 climatic regions and three GLACE coupling hot spots, as well as zonally and globally. Globally, of the four-class scheme, regions for which convection is favored over wet and dry soils accounted for the greatest and least extent, respectively. Despite vast differences among the maps, many geographically large regions of concurrence exist. Through its ability to compensate for the latitudinally varying CTP–HI–rainfall tendency characteristics observed in this study, the revised classification framework overcomes limitations of the original framework. By identifying regions where coupling persists using satellite remote sensing this study provides the first observationally based guidance for future spatially and temporally focused studies of land–atmosphere interactions. Joint distributions of CTP and HI and soil moisture, rainfall occurrence, and depth demonstrate the relevance of CTP and HI in coupling studies and their potential value in future model evaluation, rainfall forecast, and/or hydrologic consistency applications.

Azarderakhsh, M., W. B. Rossow, F. Papa, H. Norouzi, and R. Khanbilvardi, 2011: Diagnosing water variations within the Amazon basin using satellite data, *J. Geophys. Res*., 116, D24107, doi:10.1029/2011JD015997.(Dec 2011)

http://www.agu.org/pubs/crossref/2011/2011JD015997.shtml

The components of the Amazon water budget and their spatiotemporal variability are diagnosed using monthly averaged remote sensing-based data products for the period September 2002-December 2006. The large Amazon basin is divided into 14 smaller watersheds, and for each of these sub-basins, fresh water discharge is estimated from the water balance equation using satellite data products. The purpose of this study is to learn how to apply satellite data with global coverage over the large tropical regions; therefore several combinations of remote sensing estimates including total water storage changes, precipitation and evapotranspiration. The results are compared to gauge-based measurements and the best spatiotemporal agreement between estimated and observed runoff is within 1 mm/d for the combination of precipitation from the GPCP and the Montana evapotranspiration product. Mean annual precipitation, evapotranspiration and runoff for the whole basin are estimated to be 6.3, 2.27 and 3.02 mm/d respectively but also show large spatial and temporal variations at sub-basin scale. Using the most consistent data combination, the seasonal dynamics of the water budget within the Amazon system are examined. Agreement between satellite based and in situ runoff is improved when lag-times between sub-basins are included (RMSE from 0.98 to 0.61 mm/d). We estimate these lag times based on satellite-inferred inundation extents. The results reveal not only variations of the basin forcing but also the complex response of the inter-connected sub-basin (SB) water budgets. Inter-annual and inter-SB variation of the water components are investigated and show large anomalies in northwestern and eastern downstream SBs; aggregate behavior of the whole Amazon is more complex than can be represented by a simple integral of the forcing over the whole river system.

Norouzi, **H. ,** M. Temimi, W. B. Rossow, C. Pearl, M. Azarderakhsh, and R. Khanbilvardi, 2011: The sensitivity of land emissivity estimates from AMSR-E at C and X bands to surface properties, *Hydrol. Earth Syst. Sci*., 15, 3577–3589 (Nov 2011)

http://www.hydrol-earth-syst-sci.net/15/3577/2011/hess-15-3577-2011.html

Microwave observations at low frequencies exhibit more sensitivity to surface and subsurface properties with little interference from the atmosphere. The objective of this study is to develop a global land emissivity product using passive microwave observations from the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) and to investigate its sensitivity to land surface properties. The developed product complements existing land emissivity products from SSM/I and AMSU by adding land emissivity estimates at two lower frequencies, 6.9 and 10.65 GHz (C- and X-band, respectively). Observations at these low frequencies penetrate deeper into the soil layer. Ancillary data used in the analysis, such as surface skin temperature and cloud mask, are obtained from International Satellite Cloud Climatology Project (ISCCP). Atmospheric properties are obtained from the TIROS

Operational Vertical Sounder (TOVS) observations to determine the small upwelling and downwelling atmospheric emissions as well as the atmospheric transmission. A sensitivity test confirms the small effect of the atmosphere but shows that skin temperature accuracy can significantly affect emissivity estimates. Retrieved emissivities at C- and X-bands and their polarization differences exhibit similar patterns of variation with changes in land cover type, soil moisture, and vegetation density as seen at SSM/I-like frequencies (Ka and Ku bands). The emissivity maps from AMSR-E at these higher frequencies agree reasonably well with the existing SSM/I-based product. The inherent discrepancy introduced by the difference between SSM/I and AMSR-E frequencies, incidence angles, and calibration has been assessed significantly greater standard deviation of estimated emissivity compared to SSM/I land emissivity product was found over desert regions. Large differences between emissivity estimates from ascending and descending overpasses were found at lower frequencies due to the inconsistency between thermal IR skin temperatures and passive microwave brightness temperatures which can originate from below the surface. The mismatch between day and night AMSR-E emissivity is greater than ascending and descending differences of SSM/I emissivity. This is because of unique orbit time of AMSR-E (01:30 a.m./p.m. LT) while other microwave sensors have orbit time of 06:00 to 09:00 (a.m./p.m.). This highlights the importance of considering the penetration depth of the microwave signal and diurnal variability of the temperature in emissivity retrieval. The effect of these factors is greater for AMSR-E observations than SSM/I observations, as AMSR-E observations exhibit a greater difference between day and night measures. This issue must be addressed in future studies to improve the accuracy of the emissivity estimates especially at AMSR-E lower frequencies.

Tang, Q., E. R. Vivoni, F. Munoz-Arriola, and D. P. Lettenmaier, 2012: Predictability of evapotranspiration patterns using remotely-sensed vegetation dynamics during the North American monsoon, *J. Hydrometeorol*., 13, 103-121. (Feb 2012)
http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-11-032.1

The links between vegetation, evapotranspiration (ET), and soil moisture (SM) are prominent in western Mexico—a region characterized by an abrupt increase in rainfall and ecosystem greenup during the North American monsoon (NAM). Most regional-scale land surface models use climatological vegetation and are therefore unable to capture fully the spatiotemporal changes in these linkages. Interannually varying and climatological leaf area index (LAI) were prescribed, both inferred from the space-borne Moderate Resolution Imaging Spectroradiometer (MODIS), as the source of vegetation parameter inputs to the Variable Infiltration Capacity (VIC) model applied over the NAM region for 2001–08. Results at two eddy covariance tower sites for three summer periods were compared and evaluated. Results show that both vegetation greening onset and dormancy dates vary substantially from year to year with a range of more than half a month. The model using climatological LAI tends to predict lower (higher) ET than the model using observed LAI when vegetation greening occurs earlier (later) than the mean greening date. These discrepancies were especially large during approximately two weeks at the beginning of the monsoon. The effect of LAI on ET estimates was about 10% in the Sierra Madre Occidental and 30% in the continental interior. VIC-estimated ET based on interannually varying LAI had high interannual variability at the greening onset and dormancy periods corresponding to the vegetation dynamics. The greening onset date was highly related to ET early in the monsoon season, indicating the potential usefulness of LAI anomalies for predicting early season ET.

Liu, J., J. A. Curry, C. A. Clayson, M. A. Bourassa, 2011: High-Resolution Satellite Surface Latent Heat Fluxes in North Atlantic

Hurricanes. *Mon. Wea. Rev.*, **139**, 2735–2747.doi: http://dx.doi.org/10.1175/2011MWR3548.1 (Sept 2011)

This study presents a new high-resolution satellite-derived ocean surface flux product, XSeaFlux, which is evaluated for its potential use in hurricane studies. The XSeaFlux employs new satellite datasets using improved retrieval methods, and uses a new bulk flux algorithm formulated for high wind conditions. The XSeaFlux latent heat flux (LHF) performs much better than the existing numerical weather prediction reanalysis and satellite-derived flux products in a comparison with measurements from the Coupled Boundary Layer Air–Sea Transfer (CBLAST) field experiment. Also, the XSeaFlux shows well-organized LHF structure and large LHF values in response to hurricane conditions relative to the other flux products. The XSeaFlux dataset is used to interpret details of the ocean surface LHF for selected North Atlantic hurricanes. Analysis of the XSeaFlux dataset suggests that ocean waves, sea spray, and cold wake have substantial impacts on LHF associated with the hurricanes.

NASA Water Resources

Rodell, M., 2011: Satellite Gravimetry Applied to Drought Monitoring", chapter in Remote Sensing of Drought: Innovative Monitoring Approaches, B. Wardlow, M. Anderson, and J. Verdin, Eds., CRC Press/Taylor and Francis, in press, 2011.

Houser, P. R. Gabriëlle J. M. De Lannoy and J. P. Walker, 2012: Hydrologic Data Assimilation, Approaches to Managing Disaster – Assessing Hazards, Emergencies and Disaster Impacts, Prof. John Tiefenbacher (Ed.), ISBN: 978-953-51-0294-6, *InTech* (Mar 2012) http://www.intechopen.com/books/approaches-to-managing-disaster-assessing-hazards-emergencies-and-disaster-impacts

Approaches to Managing Disaster - Assessing Hazards, Emergencies and Disaster Impacts demonstrates the array of information that is critical for improving disaster management. The book reflects major management components of the disaster continuum (the nature of risk, hazard, vulnerability, planning, response and adaptation) in the context of threats that derive from both nature and technology. The chapters include a selection of original research reports by an array of international scholars focused either on specific locations or on specific events. The chapters are ordered according to the phases of emergencies and disasters. The text reflects the disciplinary diversity found within disaster management and the challenges presented by the co-mingling of science and social science in their collective efforts to promote improvements in the techniques, approaches, and decision-making by emergency-response practitioners and the public. This text demonstrates the growing complexity of disasters and their management, as well as the tests societies face every day.

De Lannoy, G. J. M., R. H. Reichle, K. R. Arsenault, P. R. Houser, S. Kumar, N. E. C. Verhoest, and V. R. N. Pauwels (2012), Multiscale assimilation of Advanced Microwave Scanning Radiometer–EOS snow water equivalent and Moderate Resolution Imaging Spectroradiometer snow cover fraction observations in northern Colorado, W*ater Resour. Res.,* 48, W01522, doi:10.1029/ 2011WR010588. (Jan 2012)

http://www.agu.org/pubs/crossref/2012/2011WR010588.shtml

Eight years (2002–2010) of Advanced Microwave Scanning Radiometer–EOS
(AMSR-E) snow water equivalent (SWE) retrievals and Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover fraction (SCF) observations are assimilated separately or jointly into the Noah land surface model over a domain in Northern Colorado. A multiscale ensemble Kalman filter (EnKF) is used, supplemented with a rule-based update. The satellite data are either left unscaled or are scaled for anomaly assimilation. The results are validated against in situ observations at 14 high-elevation Snowpack Telemetry (SNOTEL) sites with typically deep snow and at 4 lower-elevation Cooperative Observer Program (COOP) sites. Assimilation of coarse-scale AMSR-E SWE and fine-scale MODIS SCF observations both result in realistic spatial SWE patterns. At COOP sites with shallow snowpacks, AMSR-E SWE and MODIS SCF data assimilation are beneficial separately, and joint SWE and SCF assimilation yields significantly improved root-mean-square error and correlation values for scaled and unscaled data assimilation. In areas of deep snow where the SNOTEL sites are located, however, AMSR-E retrievals are typically biased low and assimilation without prior scaling leads to degraded SWE estimates. Anomaly SWE assimilation could not improve the interannual SWE variations in the assimilation results because the AMSR-E retrievals lack realistic interannual variability in deep snowpacks. SCF assimilation has only a marginal impact at the SNOTEL locations because these sites experience extended periods of near-complete snow cover. Across all sites, SCF assimilation improves the timing of the onset of the snow season but without a net improvement of SWE amounts.

THP

Arora, B., B. P. Mohanty, and J. T. McGuire, 2012:Uncertainty in dual permeability model parameters for structured soils, *Water Resour. Res*., 48, W01524, doi:10.1029/2011WR010500. (Jan 2012)

Successful application of dual permeability models (DPM) to predict contaminant
transport is contingent upon measured or inversely estimated soil hydraulic

and solute
transport parameters. The difficulty in unique identification of parameters for the additional macropore- and matrix-macropore interface regions, and knowledge about requisite experimental data for DPM has not been resolved to date. Therefore, this study quantifies uncertainty in dual permeability model parameters of experimental soil columns with different macropore distributions (single macropore, and low- and high-density multiple macropores). Uncertainty evaluation is conducted using adaptive Markov chain Monte Carlo (AMCMC) and conventional Metropolis-Hastings (MH) algorithms while assuming 10 out of 17 parameters to be uncertain or random. Results indicate that AMCMC resolves parameter correlations and exhibits fast convergence for all DPM parameters while MH displays large posterior correlations for various parameters. This study demonstrates that the choice of parameter sampling algorithms is paramount in obtaining unique DPM parameters when information on covariance structure is lacking, or else additional information on parameter correlations must be supplied to resolve the problem of equifinality of DPM parameters. This study also highlights the placement and significance of matrix-macropore interface in flow experiments of soil columns with different macropore densities. Histograms for certain soil hydraulic parameters display tri-modal characteristics implying that macropores are drained first followed by the interface region and then by pores of the matrix domain in drainage experiments. Results indicate that hydraulic properties and behavior of the matrix-macropore interface is not only a function of saturated hydraulic conductivity of the macroporematrix interface (*Ksa*) and macropore tortuosity (*lf*) but also of other parameters of the matrix and macropore domains.

Jana, R. B., and B. P. Mohanty, 2012: On topographic controls of soil hydraulic parameter scaling at hillslope scales, *Water Resour. Res*., 48, W02518, doi:10.1029/2011WR011204. (Feb 2012)

http://www.agu.org/pubs/crossref/2012/2011WR011204.shtml

Most upscaling efforts for soil hydraulic parameters developed thus far have opted to
ignore the effect of topography in their derivation of effective parameter values. This
approach, which considers a flat terrain with no lateral flows, is reasonable as long as the
coarser support dimensions are of the order of a few hundred meters. In such a scenario, the upscaled characteristics of the parameters are governed predominantly by the texture and structure of the soil in the domain. However, when upscaling fine-scale hydraulic parameter data to much larger extents (hillslope scales and beyond), topography plays a bigger role and can no longer be ignored. Efforts to model hydrologic processes and phenomena,

with particular emphasis on those occurring in the unsaturated zone, are conducted at various scales. We present here a study to isolate the influence of topographic variations on the effective, upscaled soil hydraulic parameters under different hillslope configurations. The power-averaging operator algorithm was used to aggregate fine-scale soil hydraulic parameters to coarser resolutions. Hydrologic scenarios were simulated using HYDRUS-3D for four different topographic configurations under different conditions to test the validity of the upscaled soil hydraulic parameters. The outputs from the simulations (fluxes and soil moisture states) were compared across multiple scales for validating the effectiveness of the upscaled soil hydraulic parameters. It was found that the power-averaging algorithm produced reasonably good estimates of effective soil hydraulic parameters at coarse scales. Further, a probable threshold dimension beyond which the topography dominates the soil hydraulic property variation was analyzed. On the basis of only the topography, the scaling algorithm was able to capture much of the variation in soil hydraulic parameters required to generate equivalent flows and soil moisture states in a coarsened domain.

Jana, R. B., and B. P. Mohanty, 2012: A topography-based scaling algorithm for soil hydraulic parameters at hillslope scales: Field testing, *Water Resour. Res.*, 48, W02519, doi:10.1029/2011WR011205. (Feb 2012)
http://www.agu.org/pubs/crossref/2012/2011WR011205.shtml

Soil hydraulic parameters were upscaled from a 30 m resolution to a 1 km resolution
using a new aggregation scheme (described in the companion paper) where the scale
parameter was based on the topography. When soil hydraulic parameter aggregation or
upscaling schemes ignore the effect of topography, their application becomes limited at
hillslope scales and beyond, where topography plays a dominant role in soil deposition and formation. Hence the new upscaling algorithm was tested at the hillslope scale (1 km) across two locations : (1) the Little Washita watershed in Oklahoma, and (2) the Walnut Creek watershed in Iowa. The watersheds were divided into pixels of 1 km resolution and the effective soil hydraulic parameters obtained for each pixel. Each pixel/domain was then simulated using the physically based HYDRUS-3-D modeling platform. In order to account for the surface (runoff/on) and subsurface fluxes between pixels, an algorithm to route infiltration-excess runoff onto downstream pixels at daily time steps and to update the soil moisture states of the downstream pixels was applied. Simulated soil moisture states were compared across scales, and the coarse scale values compared against the airborne soil moisture data products obtained during the hydrology

experiment field campaign periods (SGP97 and SMEX02) for selected pixels with different topographic complexities, soil distributions, and land cover. Results from these comparisons show good correlations between simulated and observed soil moisture states across time, topographic variations, location, elevation, and land cover. Stream discharge comparisons made at two gauging stations in the Little Washita watershed also provide reasonably good results as to the suitability of the upscaling algorithm used. Based only on the topography of the domain, the new upscaling algorithm was able to provide coarse resolution values for soil hydraulic parameters which effectively captured the variations in soil moisture across the watershed domains.

Jana, R. B., and B. P. Mohanty (2012), A comparative study of multiple approaches to soil hydraulic parameter scaling applied at the hillslope scale, *Water Resour. Res*., 48, W02520, doi:10.1029/2010WR010185. (Feb 2012)
http://www.agu.org/pubs/crossref/2012/2010WR010185.shtml

Soil hydraulic parameters were upscaled from a 30 m resolution to a 1 km resolution
using four different aggregation schemes across the Little Washita watershed in Oklahoma. A topography-based aggregation scheme, a simple homogenization method, a Markov chain Monte Carlo (MCMC)-based stochastic technique, and a Bayesian neural network (BNN) approach to the upscaling problem were analyzed in this study. The equivalence of the upscaled parameters was tested by simulating water flow for the watershed pixels in HYDRUS-3-D, and comparing the resultant soil moisture states with data from the electronically scanned thin array radiometer (ESTAR) airborne sensor during the SGP97 hydrology experiment. The watershed was divided into pixels of 1 km resolution and the effective soil hydraulic parameters obtained for each pixel. The domains were then simulated using the physics-based HYDRUS-3-D platform. Simulated soil moisture states were compared across scales, and the coarse scale values compared against the ESTAR soil moisture data products during the SGP97 hydrology experiment period. Results show considerable correlations between simulated and observed soil moisture states across time, topographic variations, location, elevation, and land cover for techniques that incorporate topographic information in their routines. Results show that the inclusion of topography in the hydraulic parameter scaling algorithm accounts for much of the variability. The topography-based scaling algorithm, followed by the BNN technique, were able to capture much of the variation in soil hydraulic parameters required to generate equivalent soil moisture states in a coarsened domain. The homogenization and MCMC methods, which did not account for topographic variations, performed poorly in providing effective soil hydraulic parameters at the coarse scale.

Xu, Y.,Z-L Yang, 2012: Climatic Change, A method to study the impact of climate change on variability of river flow: an example from the Guadalupe River in Texas, Climatic Change, DOI: 10.1007/s10584-011-0366-4 (Mar 2012)

http://www.springerlink.com/content/15031kg511100031/

This work introduced a method to study river flow variability in response to climate change by using remote sensing precipitation data, downscaled climate model outputs with bias corrections, and a land surface model. A meteorological forcing dataset representing future climate was constructed via the delta change method in which the modeled change was added to the present-day conditions. The delta change was conducted at a fine spatial and temporal scale to contain the signals of weather events, which exhibit substantial responses to climate change. An empirical transformation technique was further applied to the constructed forcing to ensure a realistic range. The meteorological forcing was then used to drive the land surface model to simulate the future river flow. The results show that preserving fine-scale processes in response to climate change is a necessity to assess climatic impacts on the variability of river flow events.