Objective 2.1.4: 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.

NASA has continued progress toward improving its description of the water and energy cycle, including the size and movement between its stores. Coincident use of multiple satellite and model data sources have led to improvement both in the quantification of the water and energy cycle and the uncertainty estimates of its terms, with both groundwater and total storage two newly provided variables provided by the GRACE satellite. GRACE data has been used to provide large area estimates of the change in total water storage, with estimates of groundwater over-abstraction in the Middle-East and California. . The state of the Refinement of the global water and energy balance has been derived from NASA satellite data 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. Progress is being made to observe water quality over oceans, lakes and rivers as highlighted at a NASA water quality workshop and in the creation of a new NASA water quality remote sensing science team.

The NASA Energy and Water cycle Study (NEWS) has compiled a 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 and helping to improve climate model predictions using advanced diagnostics. 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. NEWS has initiated a new science team with inovative integration projects focused on the role of clouds in the climate system, the origins and dynamics of the 2012 midwestern drought, and the ~2002 global climate shift.

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

Special Highlights

1) **The International Satellite Cloud climatology Project (ISCCP) celebrated its 30 year anniversary in April 2013.** ISCCP, the first project of the World Climate Research Program, organized by NASA, evolved as a multi-national, multi-agency cooperative effort to operate a multi-satellite global observing system and to perform a multi-data analysis to produce systematic and comprehensive cloud products. Over the course of its lifetime, ISCCP went beyond production of just cloud statistics to characterizing the associated properties of the atmosphere and surface that affect cloud processes and, together with cloud properties, affect Earth's radiation budget. Research achievements employing ISCCP and other satellite data products contributed to (1) the capability to determine the surface and in-atmosphere radiation budgets as well as the cloud effects on radiative fluxes at the surface, in atmosphere and at the top of atmosphere, (2) the beginning of the quantification of the relationships of cloud properties and precipitation, (3) the beginning of the characterization of different weather states from cloud property patterns and their associated radiative and latent heating amounts and atmospheric properties and dynamics, and (4) setting upper limits on the magnitude of the interannual variability of clouds. The conclusion of a major international cloud product assessment effort emphasized the generally good quantitative agreement among a dozen products concerning the basic cloud properties – amount, top temperature/pressure, optical thickness and particle size – and their latitudinal and seasonal variations. http://www1.cuny.edu/mu/forum/2013/04/09/anniversary-conference-celebrates-30-years-of-cloud-research/

Improved Changes in Groundwater

2) **NASA Satellites Find Fresh Water Loses in the Middle East**
A new study using data from a pair of gravity-measuring NASA satellites finds that large parts of the arid Middle East region lost freshwater reserves rapidly during the past decade. In this study, observations from the Gravity Recovery and Climate Experiment (GRACE) satellite mission were used to evaluate freshwater storage trends in the north-central Middle East, including portions of the Tigris and Euphrates River Basins and western Iran, from January 2003 to December 2009. GRACE data show an alarming rate of decrease in total water storage of approximately -27.2 ± 0.6 mm yr^{-1} equivalent water height, equal to a volume of 143.6 km^3 during the course of the study period. Additional remote-sensing information and output from land surface models were used to identify that groundwater losses are the major source of this trend. The approach used in this study provides an example of "best current capabilities" in regions like the Middle East, where data access can be severely limited. Results indicate that the region lost 17.3 ± 2.1 mm yr^{-1} equivalent water height of groundwater during the study period, or 91.3 ± 10.9 km^3 in volume. Furthermore, results raise important issues regarding water use in trans-boundary river basins and aquifers, including the necessity of international water use treaties and resolving discrepancies in international water law, while amplifying the need for increased monitoring for core components of the water budget. (Feb 2013) Scientists found during a seven-year period beginning in 2003 that parts of Turkey, Syria, Iraq and Iran along the Tigris and Euphrates river basins **lost 117 million acre feet (144 cubic kilometers) of total stored freshwater. That is almost the amount of water in the Dead Sea.** The researchers attribute about 60 percent of the loss to pumping of groundwater from underground reservoirs.

The findings are the result of one of the first comprehensive hydrological assessments of the entire Tigris-Euphrates-Western Iran region. Because obtaining ground-based data in the area is difficult, satellite data, such as those from NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites, are essential. GRACE is providing a global picture of water storage trends and is invaluable when hydrologic observations are not routinely collected or shared beyond political boundaries. (Feb 2013)

Reference: Voss, K. A., J. S. Famiglietti, M. Lo, C. de Linage, M. Rodell, *and* S. C. Swenson (2013), Groundwater depletion in the Middle East from GRACE with implications for trans-boundary water management in the Tigris-Euphrates-Western Iran region, Water Resour. Res., 49, *doi:*10.1002/wrcr.20078.
Website: http://science.gsfc.nasa.gov/earth/hydrology/

3) **Water in the Balance**
Using GRACE data, researchers were able to identify several water 'hotspots' in the United States, including its key food producing regions in 1) California's Central Valley, and 2) the southern High Plains aquifer; a broad swath of the southeastern U. S. that has been plagued by persistent drought, including 3) Houston, Texas, 4) Alabama, and 5) the Mid-Atlantic region; and 6) the flood-prone upper Missouri River basin. They also noted that since 2003, the wetter, northern half of the U.S. has become wetter, while the drier, southern half has become drier.

According to Famiglietti and Rodell, without coordinated and proactive management, the aquifers supplying the Central Valley and the southern High Plains with water for irrigation will deplete their groundwater reserves, perhaps within decades, putting the nation's food supply at considerable risk. Meanwhile, if sufficient measures are not taken, the upper Missouri River basin will experience extensive flood damage. The authors state that using GRACE, groundwater supplies can now be better managed, while the lead-time for flood and drought predictions could be substantially increased, potentially saving hundreds of millions of dollars and countless lives in the process.

Reference: J. S. Famiglietti, M. Rodell. Water in the Balance. *Science*, 2013; 340 (6138): 1300 DOI: 10.1126/science.1236460

4) **Atmospheric Rivers**
Narrow bands of strong atmospheric water vapor transport, referred to as "atmospheric rivers" (ARs), are responsible for the majority of wintertime extreme precipitation/flood events in the west coast of North America, with important contributions to the seasonal water balance. A series of studies have been conducted to understand the impacts of ARs on various components of the water cycle, and the connection between AR activity and large-scale conditions of the climate system.

Importance of ARs to California Water Resources

Guan et al. (2010): Analysis of assimilated and in situ data for water years (WYs) 2004–2010 indicates that on average 6 to 7 AR events per winter contributed 40% of total seasonal snow accumulation in California's Sierra Nevada, with the contribution dominated by just 1–2 extreme events in some years. In situ and remotely sensed observations show that snow accumulation associated with ARs are sensitive to small changes in surface air temperatures (on the order of a few degrees), highlighting the vulnerability of the Sierra Nevada snowpack under projected regional climate warming.

Kim et al. (2013): Effects of AR landfalls in California on the cold-season precipitation are examined for the cold seasons of WY2001–2010 using observed data and regional modeling. The CPC/NCEP gridded daily precipitation analysis shows that 10–30% of the cold-season precipitation totals in California have occurred during AR landfalls. While AR-landfall days in the California coast are almost evenly split between the northern and southern coasts across 37.5°N, there exists a strong north-to-south gradient in terms of AR precipitation intensity and percentage contribution to total precipitation, suggesting localized impacts of ARs. It is found that AR landfalls are closely related with the occurrence of heavy precipitation events. The freezing-level altitudes are systematically higher for AR wet days than non-AR wet days, consistent with ARs' sensitivity to temperature in terms of snow accumulation. Cold season simulations for WY2001–2010 show that the WRF model can reasonably simulate important features in both the seasonal and AR precipitation totals, an important capability for assessing the impact of global climate variations and change on future hydrology in California.

These results, along with ongoing analysis on the impact of ARs on groundwater levels in California, reveal the previously unexplored significance of ARs with regard to water resources in California.

References:

Guan, B., N. P. Molotch, D. E. Waliser, E. J. Fetzer, and P. J. Neiman (2010), Extreme snowfall events linked to atmospheric rivers and surface air temperature via satellite measurements, Geophys. Res. Lett., 37, L20401, doi:10.1029/2010GL044696.

Kim J., D. E. Waliser, P. J. Neiman, B. Guan, J.-M. Ryoo, and G. A. Wick (2013), Effects of atmospheric river landfalls on the cold season precipitation in California, Clim. Dyn., doi: 10.1007/s00382-012-1322-3.

ARs and Large-scale Conditions: Potential Predictability?

Guan et al. (2012): The relationships between the Madden–Julian oscillation (MJO), activities of ARs, and the resulting snowpack accumulation in the California Sierra Nevada, are analyzed based on 13 yr of observations for WY1998–2010 inclusive. The AR activity, as measured by the number of high-impact ARs, mean per event snow water equivalent (SWE) changes, and the cumulative SWE changes, is shown to be significantly augmented when MJO convection is active over the far western tropical Pacific.

Guan et al. (2013): The anomalously snowy winter season of 2010/11 in the Sierra Nevada is analyzed in terms of snow water equivalent (SWE) anomalies and the role of ARs. Mean April 1 SWE was 56% above normal averaged over 100 snow sensors. Twenty AR dates occurred during the season, which is double the mean seasonal occurrence. Fifteen out of the 20 AR dates were associated with the negative phases of the Arctic Oscillation (AO) and the Pacific-North American (PNA) teleconnection pattern. The analysis suggests the massive Sierra Nevada snowpack during the 2010/11 winter season is primarily related to anomalously high frequency of ARs favored by the joint phasing of negative AO and negative PNA.

Such connections between AR activity and modes of large-scale variability have implications for potential predictability of ARs on subseasonal/seasonal time scales of importance to water resource management.

References:

Guan, B., D. E. Waliser, N. P. Molotch, E. J. Fetzer, and P. J. Neiman (2012), Does the Madden–Julian Oscillation influence wintertime atmospheric rivers and snowpack in the Sierra Nevada? Mon. Wea. Rev., 140, 325–342, doi:10.1175/MWR-D-11-00087.1.

Guan, B., N. P. Molotch, D. E. Waliser, E. J. Fetzer, and P. J. Neiman: The 2010/11 snow season in California's Sierra Nevada: Role of atmospheric rivers and modes of large-scale variability, Water Resour. Res., in revision.

Reference: J. S. Famiglietti, M. Rodell. Water in the Balance. *Science*, 2013; 340 (6138): 1300 DOI: 10.1126/science.1236460

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	

Additional Highlights:

- **2013 Artic Sea Ice Maximum is 5th Lowest on Record**

A NASA analysis led by Joey Comiso determined that the annual maximum Arctic sea ice extent was reached on Feb. 28 and it was the fifth lowest sea ice winter extent in the past 35 years. The new maximum —5.82 million square miles (15.09 million square kilometers) is in line with a continuing trend in declining winter Arctic sea ice extent: nine of the ten smallest recorded maximums have occurred during the last decade. The 2013 winter extent is 144,402 square miles (374,000 square kilometers) below the average annual maximum extent for the last three decades.

Reference: http://www.nasa.gov/topics/earth/features/arctic-seaicemax-2013.html.
Website: http://neptune.gsfc.nasa.gov/csb/

- **NASA takes to the air to measure the world's water.**

The AirSWOT program will help to map fresh water resources and explore how the oceans impact climate change. NASA knows that access to fresh water and the impacts of climate change will be two of this century's biggest challenges. The ongoing AirSWOT mission, a partnership with the French and Canadian space agencies, will help to improve our understanding in both of those areas.

Leading researchers in remote sensing of river discharge recently met in Chapel Hill, NC at a NASA-funded workshop to discuss new approaches for incorporation of SWOT's unprecedented observations into discharge estimation algorithms. Workshop participants discussed the current state of SWOT discharge algorithms, identified major sources of error and algorithmic uncertainty, and recommended future courses of research
Reference: http://www.mnn.com/earth-matters/wilderness-resources/stories/nasa-takes-to-the-air-to-measure-the-worlds-water

- **NASA Data Pinpoints Glaciers' Role in Sea Level Rise**

A new study of glaciers worldwide using observations from two NASA satellites has helped resolve differences in estimates of how fast glaciers are disappearing and contributing to sea level rise.

The new research found glaciers outside of the Greenland and Antarctic ice sheets, repositories of 1 percent of all land ice, lost an average of 571 trillion pounds (259 trillion kilograms) of mass every year during the six-year study period, making the oceans rise 0.03 inches (0.7 mm) per year. This is equal to about 30 percent of the total observed global sea level rise during the same period and matches the combined contribution to sea level from the Greenland and Antarctica ice sheets. The study compares traditional ground measurements to satellite data from NASA's Ice, Cloud, and Land Elevation Satellite (ICESat) and Gravity Recovery and Climate Experiment (GRACE) missions to estimate ice loss for glaciers in all regions of the planet. The study period spans 2003 to 2009, the years when the two missions overlapped. "For the first time, we have been able to very precisely constrain how much these glaciers as a whole are contributing to sea level rise," said Alex Gardner, Earth scientist at Clark University in Worcester, Mass., and lead author of the study. "These smaller ice bodies are currently losing about as much mass as the ice sheets." Glaciers distinct from the Greenland and Antarctic Ice Sheets are losing large amounts of water to the world's oceans. However, estimates of their contribution to sea level rise disagree. We provide a consensus estimate by standardizing existing, and creating new, mass-budget estimates from satellite gravimetry and altimetry and from local glaciological records. In many regions, local measurements are more negative than satellite-based estimates. All regions lost mass during 2003–2009, with the largest losses from Arctic Canada, Alaska, coastal Greenland, the southern Andes, and high-mountain Asia, but there was little loss from glaciers in Antarctica. Over this period, the global mass budget was –259 ± 28 gigatons per year, equivalent to the combined loss from both ice sheets and accounting for 29 ± 13% of the observed sea level rise.

Reference: Alex S. Gardner, Geir Moholdt, J. Graham Cogley, Bert Wouters, Anthony A. Arendt, John Wahr, Etienne Berthier, Regine Hock, W. Tad Pfeffer, Georg Kaser,

Stefan R. M. Ligtenberg, Tobias Bolch, Martin J. Sharp, Jon Ove Hagen, Michiel R. van den Broeke, and Frank Paul, A Reconciled Estimate of Glacier Contributions to Sea Level Rise*: 2003 to 2009, Science* 17 May 2013: 852-857.
Website: http://www.nasa.gov/topics/earth/features/glacier-sea-rise.html

- **GPM Takes Rain Measurements Global**

The Global Precipitation Measurement, or GPM, mission will set a new standard for precipitation measurements from space and it's doing so by joining forces with countries around the world, keeping not just one satellite's weather eye on the horizon, but nine.

An upcoming satellite mission from NASA and the Japanese Space Agency aims to fill in those gaps both in coverage and in scientists' understanding of precipitation.
"We need virtually continuous observation everywhere to construct a complete picture of precipitation around the globe, and that requires a lot of resources," says Arthur Hou, GPM project scientist at NASA's Goddard Space Flight Center in Greenbelt, Md.

For the GPM mission, NASA and the Japan Aerospace and Exploration Agency (JAXA) are joining forces with the space agencies of France and India, as well as the operators of meteorological satellites in Europe and the United States. The eight partner satellites on the mission are called the GPM constellation.

- **Pole-to-Pole Coverage**

The GPM Core Observatory is being built and tested at Goddard Space Flight Center. Expanding coverage also means expanding the types of precipitation that GPM will measure, most notably light rain and snowfall. They account for about half of the precipitation in temperate mid-latitudes and cold high latitudes and are major contributors to freshwater resources in places like the United Kingdom and northern Europe, the southern Appalachian Mountains and the snow packs of the Rocky Mountains and the Sierra Nevada.

The new data on light rain and snow, like all the measurements GPM will make, won't just affect the weather forecast. They will also improve what climate modelers can say about the distribution of rainfall in the coming years.

Reference: Ellen Gray, NASA Goddard Space Flight Center, April 12, 2013
Website: http://pmm.nasa.gov/node/778

Appendix 4: Supporting Material for Objective 2.1.4 cont.

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

- **Lo, M.-H., and J. S. Famiglietti, Irrigation in California's Central Valley strengthens the southwestern U.S. water cycle, *Geophys. Res. Lett.,* 40, 301–306, doi:10.1002/grl.50108**

Characterizing climatological and hydrological responses to agricultural irrigation continues to be an important challenge to understanding the full impact of water management on the Earth's environment and hydrological cycle. In this study, we use a global climate model, combined with realistic estimates of regional agricultural water use, to simulate the local and remote impacts of irrigation in California's Central Valley. We **demonstrate a clear mechanism that the resulting increase in evapotranspiration and water vapor export significantly impacts the atmospheric circulation in the southwestern United States, including strengthening the regional hydrological cycle**. We also identify that irrigation in the Central Valley initiates a previously unknown, anthropogenic loop in the regional hydrological cycle, in which summer precipitation is increased by 15%, causing a corresponding increase in Colorado River streamflow of ~30%. Ultimately, some of this additional streamflow is returned to California via managed diversions through the Colorado River aqueduct and the All-American Canal. (Jan 2013

- **Houborg, R., M. Rodell, B. Li, R.Reichle, and B. F. Zaitchik (2012), Drought indicators based on model-assimilated Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage observations, Water Resour. Res., 48, W07525, doi:10.1029/2011WR011291)**

The Gravity Recovery and Climate Experiment (GRACE) twin satellites observe time variations in Earth's gravity field, which yield valuable information about changes in terrestrial water storage (TWS). Previous drought monitors lacked objective information on deep soil moisture and groundwater conditions, which are useful indicators of drought. Extensive data sets of groundwater storage from U.S. Geological Survey monitoring wells and soil moisture from the Soil Climate Analysis Network were used to assess improvements in the hydrological modeling skill resulting from the assimilation of GRACE TWS data. The results point toward modest, but statistically significant, improvements in the hydrological modeling skill across major parts of the United States, highlighting the potential value of a GRACE-assimilated water storage field for improving drought detection. (July 2012)

- **Wang, S.-Y., J.-H. Yoon, R. R. Gillies, and C. Cho, 2013: What caused the winter drought in western Nepal during recent years? *Journal of Climate*, doi: 10.1175/JCLI-D-12-00800.1** (2013)

Western Nepal has experienced consecutive and worsened winter drought conditions since 2000 culminating in a severe drought episode during 2008-2009. In this study, the meteorological conditions and a historical perspective of the winter droughts in western Nepal were analyzed using respectively instrumental records, satellite observations and climate model simulations. Meteorological diagnosis using atmospheric reanalysis revealed that (1) winter drought in western Nepal is linked to the Arctic Oscillation and

its decadal variability, which initiates a tropospheric short-wave train across Eurasia and South Asia, and that (2) the persistent warming of the Indian Ocean likely contributes to the suppression of rainfall through enhanced local Hadley circulation. Simulations from the CMIP5 sets of historical single-forcing experiments indicated that increased loading of anthropogenic aerosols is also a compounding factor in the precipitation decline during the later decades. It is therefore conceivable that the recent spells of decadal drought in Nepal drought are symptomatic of both natural variability and anthropogenic influences. Given the observations that winter precipitation has declined to near zero while groundwater has hardly been replenished, appropriate management of western Nepal’s water resources is both critical and necessary.

- **Wang, S.-Y., B. Buckley, J.-H. Yoon and B. Fosu. 2013: Intensification of pre-monsoon tropical cyclones in the Bay of Bengal and its impacts on Myanmar. *J. Geophysical Research*, doi: 10.1002/lrd.50396.**

Multiple global reanalysis and precipitation datasets were analyzed in order to explain the dynamic mechanisms that lead to an observed intensification of the monsoon trough and associated tropical cyclone activity over the Bay of Bengal (BOB) during the pre-monsoon month of May. We find that post-1979 increases in both pre-monsoon precipitation and tropical cyclone intensity are a result of enhanced large-scale monsoon circulation, characterized by lower-level cyclonic and upper-level anti-cyclonic anomalies. Such circulation anomalies are manifest of the tropospheric expansion that is caused by regional warming. The deepened monsoon trough in the BOB not only affects tropical cyclone frequency and timing, but also acts to direct more cyclones towards Myanmar. We propose that increasing sea surface temperature in the BOB has contributed to an increase in cyclone intensity. Our analyses of the Community Earth System Model single-forcing experiments suggest that tropospheric warming and a deepening of the monsoon trough can be explained by two discreet anthropogenic causes an increase in absorption due to aerosol loading, and an increase in the land-ocean thermal contrast that results from increased greenhouse gases. The ensuing circulation changes provide favorable conditions for tropical cyclones to grow and to track eastward towards Myanmar.(April 2013)

- **Wang, S.-Y., R. R. Gillies, and H. van den Dool, 2013: On the yearly phase delay of winter intraseasonal mode in the western United States. *Climate Dynamics*, DOI: 10.1007/s00382-013-1784-y**

In the western United States, persistent and recurrent flow patterns not only modulate precipitation events but also result in prolonged surface inversion episodes. In this region, the frequency of persistent ridge/trough events ranges between 20 and 40 days, well within the intraseasonal timescale. Based on NCEP reanalysis data starting at 1949, with a focus on the interior West, we observed that episodes of prolonged ridge/trough events appear to occur about a week later every year and resets every 5–7 years—a previously undocumented phenomenon examined herein. Diagnostic analyses indicate that the interplay between regional intraseasonal flow patterns and the North Atlantic Oscillation (NAO) alternates the preferred timeframe for the persistent ridge/trough events to occur. This may result from different phases of the NAO shifting the winter mean ridge and such shifts modulate the occurrence and timing of persistent ridge/trough events. When the timing changes evolve around the quasi-6 years cycle of the NAO, the resultant evolution forms what appears to be a steady phase delay in the ridge/trough events year after year. These results are a further step in disclosing the multiple-scale interaction between intraseasonal and interannual modes and its regional climate/weather impact.(May 2013)

- **Gu, G., R.F. Adler, 2012: Interdecadal variability/long-term changes in global precipitation patterns during the past three decades: global warming and/or pacific decadal variability? *Clim. Dyn*.**

This study explores how global precipitation and tropospheric water vapor content vary on the interdecadal/long-term time scale during past three decades (1988–2010 for water vapor), in particular to what extent the spatial structures of their variations relate to changes in surface temperature. EOF analyses of satellite-based products indicate that the first two modes of global precipitation and columnar water vapor content anomalies are in general related to the El Niño-Southern oscillation. The spatial patterns of their third modes resemble the corresponding linear fits/trends estimated at each grid point, which roughly represent the interdecadal/long-term changes happening during the same time period. Global mean sea surface temperature (SST) and land surface temperature have increased during the past three decades. However, the water vapor and precipitation patterns of change do not reflect the pattern of warming, in particular in the tropical Pacific basin. Therefore, other mechanisms in addition to global warming likely exist to account for the spatial structures of global precipitation changes during this time period.

An EOF analysis of longer-record (1949–2010) SST anomalies within the Pacific basin (60oN–60oS) indicates the existence of a strong climate regime shift around 1998/1999, which might be associated with the Pacific decadal variability (PDV) as suggested in past studies. Analyses indicate that the observed linear changes/trends in both precipitation and tropospheric water vapor during 1988–2010 seem to result from a combined impact of global mean surface warming and the PDV shift. In particular, in the tropical central-eastern Pacific, a band of increases along the equator in both precipitation and water vapor sandwiched by strong decreases south and north of it are likely caused by the opposite effects from global-mean surface warming and PDV-related, La Niña-like cooling in the tropical central-eastern Pacific. **This narrow band of precipitation increase could also be considered an evidence for the influence of global mean surface warming.**

Brown, M. E., V. Escobar, S. Moran , D. Entekhabi , P. E. O'Neill , E. G. Njoku , B. Doorn , and J. K. Entin (2013) NASA's Soil Moisture Active Passive (SMAP) Mission and Opportunities For Applications Users, *Bulletin of American Meteorological Society* 10.1175/BAMS-D-11-00049

Water in the soil, both its amount (soil moisture) and its state (freeze/thaw) plays a key role in water and energy cycles, in weather and climate, and in the carbon cycle. Additionally, soil moisture touches upon human lives in a number of ways from the ravages of flooding to the needs for monitoring agricultural and hydrologic droughts. Because of their relevance to weather, climate, science, and society, accurate and timely measurements of soil moisture and freeze/thaw state with global coverage are critically important.

The SMAP Applications program is ground-breaking and serves as an example for other NASA missions to expand their focus to include user communities' needs in the early phases of mission development. Through a team that includes an

applications lead on the Science Definition Team (SDT), leadership from the mission, and an applications coordinator, the applications program works to characterize the community of mission data users through workshops and applied research. We have also initiated a program of Early Adopters to promote application research in the pre-launch stages of the mission, in order to provide a better understanding of how SMAP data products can be scaled and integrated onto organizations' policy, business, and management activities. These efforts will expand the use of the data after launch, and increase the societal benefit of the mission.

Su, H., J.H. Jiang, C. Zhai, V. Perun, J.T. Shen, A.D. Del Genio, L.S. Nazarenko, L.J. Donner, L.W. Horowitz, C.J. Seman, C.J. Morcrette, J. Petch, M.A. Ringer, J. Cole, M. dos Santos Mesquita, T. Iversen, J.E. Kristjansson, A. Gettelman, L.D. Rotstayn, S.J. Jeffrey, J.-L. Dufresne, M. Watanabe, H. Kawai, T. Koshiro, T. Wu, E.M. Volodin, T. L'Ecuyer, J. Teixeira, and G.L. Stephens, 2013: Diagnosis of regime-dependent cloud simulation errors in CMIP5 models using "A-Train" satellite observations and reanalysis data. *J. Geophys. Res*., 118, 2762-2780, doi:10.1029/2012JD018575.

The vertical distributions of cloud water content (CWC) and cloud fraction (CF) over the tropical oceans, produced by 13 coupled atmosphere-ocean models submitted to the Phase 5 of Coupled Model Intercomparison Project (CMIP5), are evaluated against CloudSat/CALIPSO observations as a function of large-scale parameters. Available CALIPSO simulator CF outputs are also examined. A diagnostic framework is developed to decompose the cloud simulation errors into large-scale errors, cloud parameterization errors and covariation errors. We find that the cloud parameterization errors contribute predominantly to the total errors for all models. The errors associated with large-scale temperature and moisture structures are relatively greater than those associated with large-scale midtropospheric vertical velocity and lower-level divergence. All models capture the separation of deep and shallow clouds in distinct large-scale regimes; however, the vertical structures of high/low clouds and their variations with large-scale parameters differ significantly from the observations. The CWCs associated with deep convective clouds simulated in most models do not reach as high in altitude as observed, and their magnitudes are generally weaker than CloudSat total CWC, which includes the contribution of precipitating condensates, but are close to CloudSat nonprecipitating CWC. All models reproduce maximum CF associated with convective detrainment, but CALIPSO simulator CFs generally agree better with CloudSat/CALIPSO combined retrieval than the model CFs, especially in the midtroposphere. Model simulated low clouds tend to have little variation with large-scale parameters except lower-troposphere stability, while the observed low cloud CWC, CF, and cloud top height vary consistently in all large-scale regimes. (April 2013)

Young, A. H., J. J. Bates, and J. A. Curry (2013), Application of cloud vertical structure from CloudSat to investigate MODIS-derived cloud properties of cirriform, anvil, and deep convective clouds, J. Geophys. Res. Atmos., 118, 4689–4699, doi:10.1002/jgrd.50306.

CloudSat cloud vertical structure is combined with the CALIPSO Lidar and Collection-5 Level 2 cloud data from Aqua's Moderate Resolution Imaging Spectroradiometer (MODIS) to investigate the mean properties of high/cirriform, anvil, and deep convective (DC) clouds. Cloud properties are sampled over 30°S–30°N for 1 year and compared to existing results of Collection-4 Aqua MODIS high-level cloud observations where cloud types were categorized using the International Satellite Cloud Climatology Project (ISCCP) cloud classification scheme. Results show high/cirriform sampled in this study have high biases in cloud top pressure and temperature due to CloudSat's sensitivity to thin high clouds. Mean cloud properties of DC show reasonable agreement with existing DC results notwithstanding mean cloud optical thickness which is ~23% higher due to the exclusion of thick cirrus and anvil clouds. Anvil cloud properties are a mix between high/cirriform and DC according to ISCCP cloud optical thickness thresholds whereby ~80% are associated with high/cirriform and the other 20% are associated with DC. The variability of cloud effective particle radii was also evaluated using DC with ≥5 dBZ echoes at and above 10 km. No evidence of larger cloud effective particle radii are given despite considering higher reaching echoes. Using ISCCP cloud optical thickness thresholds, ~25% of DC would be classified as cirrostratus clouds. These results provide a basis to evaluate the uncertainty of the ISCCP cloud classification scheme and MODIS-derived cloud properties using active satellite observations. (May 2013)

Rapp, Anita, Matthew Lebsock and Tristan L'Ecuyer, 2013: Low cloud precipitation climatology in the southeastern Pacific marine stratocumulus region using CloudSat, Environ. Res. Lett. 8 014027 doi:10.1088/1748-9326/8/1/014027.

A climatology of low cloud surface precipitation occurrence and intensity from the new CloudSat 2C-RAIN-PROFILE algorithm is presented from June 2006 through December 2010 for the southeastern Pacific region of marine stratocumulus. Results show that over 70% of low cloud precipitation falls as drizzle. Application of an empirical evaporation model suggests that 50–80% of the precipitation evaporates before it reaches the surface. Segregation of the CloudSat ascending and descending overpasses shows that the majority of precipitation occurs at night. Examination of the seasonal cycle shows that the precipitation is most frequent during the austral winter and spring; however there is considerable regional variability. Conditional rain rates increase from east to west with a maximum occurring in the region influenced by the South Pacific Convergence Zone. Area average rain rates are highest in the region where precipitation rates are moderate, but most frequent. The area average surface rain rate for low cloud precipitation for this region is ~0.22 mm d^{-1}, in good agreement with *in situ* estimates, and is greatly improved over earlier CloudSat precipitation products. These results provide a much-needed quantification of surface precipitation in a region that is currently underestimated in existing satellite-based precipitation climatologies.

Haynes, J. M., T. H. Vonder Haar, T. L'Ecuyer, and D. Henderson (2013), Radiative heating characteristics of Earth's cloudy atmosphere from vertically resolved active sensors, Geophys. Res. Lett., 40, 624–630, doi:10.1002/grl.50145.

High vertical resolution CloudSat radar measurements, supplemented with cloud boundaries and aerosol information from the CALIPSO lidar, are used to examine radiative heating features in the atmosphere that have not previously been characterized by passive sensors. The monthly and annual mean radiative heating/cooling structure for a 4 year period between 2006 and 2010 is derived. The mean atmospheric radiative cooling rate from CloudSat/CALIPSO is 0.98 K d^{1} (1.34 K d^{1} between 150 and 950 hPa) and is largely a reflection of the Earth's mean water vapor distribution, with sharp vertical gradients introduced by clouds. It is found that there is a minimum in cooling in the tropical lower to middle troposphere, a cooling maximum in the upper-boundary layer of the Southern Hemisphere poleward of 10 latitude, and a minimum in cooling in the lower boundary layer in the middle to high latitudes of both hemispheres. Clouds tops tend to strongly cool the upper- boundary layer all year in the midlatitudes to high latitudes of the Southern Hemisphere (where peak seasonal mean winter cooling is 3.4Kd^{1}), but this cooling is largely absent in the corresponding parts of the Northern Hemisphere during boreal winter, resulting in a hemispheric asymmetry in cloud radiative cooling.

- **Harrison, K. W., S. V.Kumar, C. D.Peters-Lidard, and J. A.Santanello (2012), Quantifying the change in soil moisture modeling uncertainty from remote sensing**

observations using Bayesian inference techniques, *Water Resour. Res*., 48, W11514, doi:10.1029/2012WR012337.

Operational land surface models (LSMs) compute hydrologic states such as soil moisture that are needed for a range of important applications (e.g., drought, flood, and weather prediction). The uncertainty in LSM parameters is sufficiently great that several researchers have proposed conducting parameter estimation using globally available remote sensing data to identify best fit local parameter sets. However, even with in situ data at fine modeling scales, there can be significant remaining uncertainty in LSM parameters and outputs. Here, using a new uncertainty estimation subsystem of the NASA Land Information System (LIS) (described herein), a Markov chain Monte Carlo (MCMC) technique is applied to conduct Bayesian analysis for the accounting of parameter uncertainties. The Differential Evolution Markov Chain (DE-MC) MCMC algorithm was applied, for which a new parallel implementation was developed. A case study is examined that builds on previous work in which the Noah LSM was calibrated to passive (L-band) microwave remote sensing estimates of soil moisture for the Walnut Gulch Experimental Watershed. In keeping with prior related studies, the parameters subjected to the analysis were restricted to the soil hydraulic properties (SHPs). The main goal is to estimate SHPs and soil moisture simulation uncertainty before and after consideration of the remote sensing data. The prior SHP uncertainty is based on the original source of the standard SHP lookup tables for the Noah LSM. Conclusions are drawn regarding the value and viability of Bayesian analysis over alternative approaches (e.g., parameter estimation, lookup tables) and further research needs are identified. (Nov 2012)

Zhu, Z.; Bi, J.; Pan, Y.; Ganguly, S.; Anav, A.; Xu, L.; Samanta, A.; Piao, S.; Nemani, R.R.; Myneni, R.B. 2013: Global Data Sets of Vegetation Leaf Area Index (LAI)3g and Fraction of Photosynthetically Active Radiation (FPAR)3g Derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) for the Period 1981 to 2011.." *Remote Sens.* 5, no. 2: 927-948.

Long-term global data sets of vegetation Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR) are critical to monitoring global vegetation dynamics and for modeling exchanges of energy, mass and momentum between the land surface and planetary boundary layer. LAI and FPAR are also state variables in hydrological, ecological, biogeochemical and crop-yield models. The generation, evaluation and an example case study documenting the utility of 30-year long data sets of LAI and FPAR are described in this article. A neural network algorithm was first developed between the new improved third generation Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) and best-quality Terra Moderate Resolution Imaging Spectroradiometer

(MODIS) LAI and FPAR products for the overlapping period 2000–2009. The trained neural network algorithm was then used to generate corresponding LAI3g and FPAR3g data sets with the following attributes: 15-day temporal frequency, 1/12 degree spatial resolution and temporal span of July 1981 to December 2011. The quality of these data sets for scientific research in other disciplines was assessed through (a) comparisons with field measurements scaled to the spatial resolution of the data products, (b) comparisons with broadly-used existing alternate satellite data-based products, (c) comparisons to plant growth limiting climatic variables in the northern latitudes and tropical regions, and (d) correlations of dominant modes of interannual variability with large-scale circulation anomalies such as the EI Niño-Southern Oscillation and Arctic Oscillation. These assessment efforts yielded results that attested to the suitability of these data sets for research use in other disciplines. The utility of these data sets is documented by comparing the seasonal profiles of LAI3g with profiles from 18 state-of-the-art Earth System Models: the models consistently overestimated the satellite-based estimates of leaf area and simulated delayed peak seasonal values in the northern latitudes, a result that is consistent with previous evaluations of similar models with ground-based data. The LAI3g and FPAR3g data sets can be obtained freely from the NASA Earth Exchange (NEX) website. (Feb 2013)

Stephens, G L., J. Li, M. Wild, C. A. Clayson, N. Loeb, S. Kato, T. L'Ecuyer, P. W. Stackhouse Jr, M. Lebsock and T. Andrews, (2012) An update on Earth's energy balance in light of the latest global observations. *Nature Geoscience* Progress Article.

Climate change is governed by changes to the global energy balance. At the top of the atmosphere, this balance is monitored globally by satellite sensors that provide measurements of energy flowing to and from Earth. By contrast, observations at the surface are limited mostly to land areas. As a result, the global balance of energy fluxes within the atmosphere or at Earth's surface cannot be derived directly from measured fluxes, and is therefore uncertain. This lack of precise knowledge of surface energy fluxes profoundly affects our ability to understand how Earth's climate responds to increasing concentrations of greenhouse gases. In light of compilations of up-to-date surface and satellite data, the surface energy balance needs to be revised. Specifically, the longwave radiation received at the surface is estimated to be significantly larger, by between 10 and 17 Wm^{-2}, than earlier model-based estimates. Moreover, the latest satellite observations of global precipitation indicate that more precipitation is generated than previously thought. This additional precipitation is sustained by more energy leaving the surface by evaporation — that is, in the form of latent heat flux — and thereby offsets much of the increase in longwave flux to the surface. (Sept.2013)

Kato, Seiji, Norman G. Loeb, Fred G. Rose, David R. Doelling, David A. Rutan, Thomas E. Caldwell, Lisan Yu, Robert A. Weller, 2013: Surface Irradiances Consistent with CERES-Derived Top-of-Atmosphere Shortwave and Longwave Irradiances. *J. Climate*, 26, 2719–2740.
doi:

The estimate of surface irradiance on a global scale is possible through radiative transfer calculations using satellite-retrieved surface, cloud, and aerosol properties as input. Computed top-of-atmosphere (TOA) irra- diances, however, do not necessarily agree with observation-based values, for example, from the Clouds and the Earth's Radiant Energy System (CERES). This paper presents a method to determine surface irradiances using observational constraints of TOA irradiance from CERES. A Lagrange multiplier

procedure is used to objectively adjust inputs based on their uncertainties such that the computed TOA irradiance is consistent with CERES-derived irradiance to within the uncertainty. These input adjustments are then used to determine surface irradiance adjustments. Observations by the Atmospheric Infrared Sounder (AIRS), Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), CloudSat, and Moderate Resolution Imaging Spectroradiometer (MODIS) that are a part of the NASA A-Train constellation provide the uncertainty es- timates. A comparison with surface observations from a number of sites shows that the bias [root-mean-square (RMS) difference] between computed and observed monthly mean irradiances calculated with 10 years of data is 4.7 (13.3) W m^{-2} for downward shortwave and 22.5 (7.1) W m^{-2} for downward longwave irradiances over ocean and 21.7 (7.8) W m^{-2} for downward shortwave and 21.0 (7.6) W m^{-2} for downward longwave irradi- ances over land. The bias and RMS error for the downward longwave and shortwave irradiances over ocean are decreased from those without constraint. Similarly, the bias and RMS error for downward longwave over land improves, although the constraint does not improve downward shortwave over land. This study demonstrates how synergetic use of multiple instruments (CERES, MODIS, CALIPSO, CloudSat, AIRS, and geostationary satellites) improves the accuracy of surface irradiance computations. (May 2013

Ferguson, Craig R., Eric F. Wood, 2011: Observed Land–Atmosphere Coupling from Satellite Remote Sensing and Reanalysis. J. Hydrometeor, 12, 1221254.doi:http://dx.doi.org/10.1175/2011JHM1380.1

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. (Dec.2012)

Lahoz, W. A., G. J. M. De Lannoy, 2013. Closing the gaps in our knowledge of the hydrological cycle of the Earth system: Conceptual problems. *Surv. Geophys.*, . 10.1007/s10712-013-9221-7.

This paper reviews the conceptual problems limiting our current knowledge of the hydrological cycle over land. We start from the premise that to understand the hydrological cycle we need to make observations and develop dynamic models that encapsulate our understanding. Yet, neither the observations nor the models could give a complete picture of the hydrological cycle. Data assimilation combines observational and model information and adds value to both the model and the observations, yielding increasingly consistent and complete estimates of hydrological components. In this review paper we provide a historical perspective of conceptual problems and discuss state-of-the-art hydrological observing, modelling and data assimilation systems. (March 2013)

Getirana, A. C. V. and Peters-Lidard, C.: Estimating water discharge from large radar altimetry datasets, *Hydrol. Earth Syst. Sci*., 17, 923-933, doi:10.5194/hess-17-923-2013, 2013

The objective of this study is to evaluate the potential of large altimetry datasets as a complementary gauging network capable of providing water discharge in ungauged regions. A rating curve-based methodology is adopted to derive water discharge from altimetric data provided by the Envisat satellite at 475 virtual stations (VS) within the Amazon basin. From a global-scale perspective, the stage–discharge relations at VS are built based on radar altimetry and outputs from a modeling system composed of a land surface model and a global river routing scheme. In order to quantify the impact of model uncertainties on rating-curve based discharges, a second experiment is performed using outputs from a simulation where daily observed discharges at 135 gauging stations are introduced in the modeling system. Discharge estimates at 90 VS are evaluated against observations during the curve fitting calibration (2002–2005) and evaluation (2006–2008) periods, resulting in mean normalized RMS errors as high as 39 and 15% for experiments without and with direct insertion of data, respectively. Without direct insertion, uncertainty of discharge estimates can be mostly attributed to forcing errors at smaller scales, generating a positive correlation between performance and drainage area. Mean relative streamflow volume errors (RE) of altimetry-based discharges varied from 15 to 84% for large and small drainage areas, respectively. Rating curves produced a mean RE of 51% versus 68% from model outputs. Inserting discharge data into the modeling system decreases the mean RE from 51 to 18%, and mean NRMSE from 24 to 9%. These results demonstrate the feasibility of applying the proposed methodology to the continental or global scales. (2013)

Mohr, K.I, W.-K. Tao, J.-D. Chern, S.V. Kumar, C.D. Peters-Lidard, 2013. The NASA-Goddard Multi-scale Modeling Framework-Land Information System: Global land/atmosphere interaction with resolved convection, *Environmental Modeling and Software*, 39, pp 103--115, doi:10.1016/j.envsoft.2012.02.023

The present generation of general circulation models (GCM) use parameterized cumulus schemes and run at hydrostatic grid resolutions. To improve the representation of cloud-scale moist processes and land–atmosphere interactions, a global, Multi-scale Modeling Framework (MMF) coupled to the Land Information System (LIS) has been developed at NASA-Goddard Space Flight Center. The MMF–LIS has three components, a finite-volume (fv) GCM (Goddard Earth Observing System Ver. 4, GEOS-4), a 2D cloud-resolving model (Goddard Cumulus Ensemble, GCE), and the LIS, representing the large-scale atmospheric circulation, cloud processes, and land surface processes, respectively. The non-hydrostatic GCE model replaces the single-column cumulus parameterization of fvGCM. The model grid is composed of an array of fvGCM gridcells each with a series of embedded GCE models. A horizontal coupling strategy, GCE ↔ fvGCM ↔ Coupler ↔ LIS, offered significant computational efficiency, with the scalability and I/O capabilities of LIS permitting land–atmosphere interactions at cloud-scale. Global simulations of 2007–2008 and comparisons to observations and reanalysis products were conducted. Using two different versions of the same land surface model but the same initial conditions, divergence in regional, synoptic-scale surface pressure patterns emerged within two weeks. The sensitivity of large-scale circulations to land surface model physics revealed significant functional value to using a scalable, multi-model land surface modeling system in global weather and climate prediction. (Jan 2013)

Guan, B., D. E. Waliser, J.-L. F. Li, and A. da Silva, 2013. Evaluating the impact of orbital sampling on satellite—climate model comparisons. *J. Geophys. Res.*, 118, 355-369. doi:10.1029/2012JD018590.

The effect of orbital sampling is one of the chief uncertainties in satellite–climate model comparisons. In the context of an ongoing activity to make satellite data more accessible for model evaluation (i.e., obs4MIPs), six variables (temperature, specific humidity, ozone, cloud water, cloud cover, and ocean surface wind) associated with six satellite instruments are evaluated for the orbital sampling effect. Comparisons are made between reanalysis and simulated satellite-sampled data in terms of bias and pattern similarity. It is found that the bias introduced by orbital sampling for long-term annual means, monthly climatologies, and monthly means is largely negligible, which is within ~3% of the standard deviation of the three quantities for most fields. The bias for 2-hPa temperature and specific humidity, while relatively large (9–10%), is within the estimated observational uncertainty. In terms of pattern similarity, cloud water and upper level specific humidity are the most sensitive to orbital sampling among the variables considered, with the magnitude of the sampling effect dependent on the spatial resolution—insignificant at 1.25°×1.25° resolution for both. For all variables considered, orbital sampling effects are not an important consideration for model evaluation at 1.25°×1.25° resolution. At 0.5°×0.5°, orbital sampling is potentially important for cloud water and upper level specific humidity when evaluating model long-term annual means and monthly climatologies, and for cloud water when evaluating monthly means, all in terms of pattern similarities. Orbital sampling is not an important factor for evaluating zonal means in call cases considered. (Jan 2013)

Maggioni, Viviana, Rolf H. Reichle, Emmanouil N. Anagnostou, 2013: The Efficiency of Assimilating Satellite Soil Moisture Retrievals in a Land Data Assimilation System Using Different Rainfall Error Models. *J. Hydrometeor*, 14, 368–374. doi: http://dx.doi.org/10.1175/JHM-D-12-0105.1

The efficiency of assimilating near-surface soil moisture retrievals from Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) observations in a Land Data Assimilation System (LDAS) is assessed using satellite rainfall forcing and two different satellite rainfall error models: a complex, multidimensional satellite rainfall error model (SREM2D) and the simpler (control) model (CTRL) used in the NASA Goddard Earth Observing System Model, version 5 LDAS. For the study domain of Oklahoma, LDAS soil moisture estimates improve over the satellite retrievals and the open-loop (no assimilation) land surface model estimates, exhibiting higher daily anomaly correlation coefficients (e.g., 0.36 in the open loop, 0.38 in the AMSR-E, and 0.50 in LDAS for surface soil moisture). The LDAS soil moisture estimates also match the performance of a benchmark model simulation forced with high-quality radar precipitation. Compared to using the CTRL rainfall error model in LDAS, using the more complex SREM2D exhibits only slight improvements in soil moisture estimates.(Feb 2013)

Zaitchik, Benjamin F., Joseph A. Santanello, Sujay V. Kumar, Christa D. Peters-Lidard, 2013: Representation of Soil Moisture Feedbacks during Drought in NASA Unified WRF (NU-WRF). ***J. Hydrometeor*****, 14, 360–367.**
doi: http://dx.doi.org/10.1175/JHM-D-12-069.1

Positive soil moisture–precipitation feedbacks can intensify heat and prolong drought under conditions of precipitation deficit. Adequate representation of these processes in regional climate models is, therefore, important for extended weather forecasts, seasonal drought analysis, and downscaled climate change projections. This paper presents the first application of the NASA Unified Weather Research and Forecasting Model (NU-WRF) to simulation of seasonal drought. Simulations of the 2006 southern Great Plains drought performed with and without soil moisture memory indicate that local soil moisture feedbacks had the potential to concentrate precipitation in wet areas relative to dry areas in summer drought months. Introduction of a simple dynamic surface albedo scheme that models albedo as a function of soil moisture intensified the simulated feedback pattern at local scale—dry, brighter areas received even less precipitation while wet, whereas darker areas received more—but did not significantly change the total amount of precipitation simulated across the drought-affected region. This soil-moisture-mediated albedo land–atmosphere coupling pathway is structurally excluded from standard versions of WRF(Feb 2013)

Randles, C. A., Kinne, S., Myhre, G., Schulz, M., Stier, P., Fischer, J., Doppler, L., Highwood, E., Ryder, C., Harris, B., Huttunen, J., Ma, Y., Pinker, R. T., Mayer, B., Neubauer, D., Hitzenberger, R., Oreopoulos, L., Lee, D., Pitari, G., Di Genova, G., Quaas, J., Rose, F. G., Kato, S., Rumbold, S. T., Vardavas, I., Hatzianastassiou, N., Matsoukas, C., Yu, H., Zhang, F., Zhang, H., and Lu, P.: Intercomparison of shortwave radiative transfer schemes in global aerosol modeling: results from the AeroCom Radiative Transfer Experiment, Atmos. Chem. Phys., 13, 2347-2379, doi:10.5194/acp-13-2347-2013, 2013.

In this study we examine the performance of 31 global model radiative transfer schemes in cloud-free conditions with prescribed gaseous absorbers and no aerosols (Rayleigh atmosphere), with prescribed scattering-only aerosols, and with more absorbing aerosols. Results are compared to benchmark results from high-resolution, multi-angular line-by-line radiation models. For purely scattering aerosols, model bias relative to the line-by-line models in the top-of-the atmosphere aerosol radiative forcing ranges from roughly −10 to 20%, with over- and underestimates of radiative cooling at lower and higher solar zenith angle, respectively. Inter-model diversity (relative standard deviation) increases from ~10 to 15% as solar zenith angle decreases. Inter-model diversity in atmospheric and surface forcing decreases with increased aerosol absorption, indicating that the treatment of multiple-scattering is more variable than aerosol absorption in the models considered. Aerosol radiative forcing results from multi-stream models are generally in better agreement with the line-by-line results than the simpler two-stream schemes. Considering radiative fluxes, model performance is generally the same or slightly better than results from previous radiation scheme intercomparisons. However, the inter-model diversity in aerosol radiative forcing remains large, primarily as a result of the treatment of multiple-scattering. Results indicate that global models that estimate aerosol radiative forcing with two-stream radiation schemes may be subject to persistent biases introduced by these schemes, particularly for regional aerosol forcing. (March 2013)

Tian, Y., G. J. Huffman, R. F. Adler, L. Tang, M. Sapiano, V. Maggioni, and H. Wu (2013). Modeling Errors in Daily Precipitation Measurements: Additive or Multiplicative? *Geophysical Research Letters*, 6.10.1002/grl.50320

The definition and quantification of uncertainty depend on the error model used. For uncertainties in precipitation measurements, two types of error models have been widely adopted: the additive error model and the multiplicative error model. This leads to incompatible specifications of uncertainties and impedes intercomparison and application. In this letter, we assess the suitability of both models for satellite-based daily precipitation measurements in an effort to clarify the uncertainty representation. Three criteria were employed to evaluate the applicability of either model: (1) better separation of the systematic and random errors; (2) applicability to the large range of variability in daily precipitation; and (3) better predictive skills. It is found that the multiplicative error model is a much better choice under all three criteria. It extracted the systematic errors more cleanly, was more consistent with the large variability of precipitation measurements, and produced superior predictions of the error characteristics. The additive error model had several weaknesses, such as nonconstant variance resulting from systematic errors leaking into random errors, and the lack of prediction capability. Therefore, the multiplicative error model is a better choice. (May 2013)

Reichle, R. H., G. J. M. De Lannoy, B. A. Forman, C. S. Draper, and Q. Liu 2013: Connecting Satellite Observations with Water Cycle Variables through Land Data Assimilation: Examples Using the NASA GEOS-5 LDAS, *Surveys in Geophysics*, in press, doi:10.1007/s10712-013-9220-8, 2013.

A land data assimilation system (LDAS) can merge satellite observations (or retrievals) of land surface hydrological conditions, including soil moisture, snow, and terrestrial water storage (TWS), into a numerical model of land surface processes. In theory, the output from such a system is superior to estimates based on the observations or the model alone, thereby enhancing our ability to understand, monitor, and predict key elements of the terrestrial water cycle. In practice, however, satellite observations do not correspond directly to the water cycle variables of interest. The present paper addresses various aspects of this seeming mismatch using examples drawn from recent research with the ensemble-based NASA GEOS-5 LDAS. These aspects include (1) the assimilation of coarse-scale observations into higher-resolution land surface models, (2) the partitioning of satellite observations (such as TWS retrievals) into their constituent water cycle components, (3) the forward modeling of microwave brightness temperatures over land for radiance-based soil moisture and snow assimilation, and (4) the selection of the most relevant types of observations for the analysis of a specific water cycle variable that is not observed (such as root zone soil moisture). The solution to these challenges involves the careful construction of an observation operator that maps from the land surface model variables of interest to the space of the assimilated observations. (2013)

Wong, J., Barth, M. C., and Noone, D.: Evaluating a lightning parameterization based on cloud-top height for mesoscale numerical model simulations, Geosci. Model Dev., 6, 429-443, doi:10.5194/gmd-6-429-2013, 2013

The Price and Rind lightning parameterization based on cloud-top height is a commonly used method for predicting flash rate in global chemistry models. As mesoscale simulations begin to implement flash rate predictions at resolutions that partially resolve convection, it is necessary to validate and understand the behavior of this method within such a regime. In this study, we tested the flash rate parameterization, intra-cloud/cloud-to-ground (IC:CG) partitioning parameterization, and the associated resolution dependency "calibration factor" by Price and Rind using the Weather Research and Forecasting (WRF) model running at 36 km, 12 km, and 4 km grid spacings within the continental United States. Our results show that while the integrated flash count is consistent with observations when model biases in convection are taken into account, an erroneous frequency distribution is simulated. When the spectral characteristics of lightning flash rate are a concern, we recommend the use of prescribed IC:CG values. In addition, using cloud-top from convective parameterization, the "calibration factor" is also shown to be insufficient in reconciling the resolution dependency at the tested grid spacing used in this study. We recommend scaling by areal ratio relative to a base-case grid spacing determined by convective core density. (2013)

Noone, D., Risi, C., Bailey, A., Berkelhammer, M., Brown, D. P., Buenning, N., Gregory, S., Nusbaumer, J., Schneider, D., Sykes, J., Vanderwende, B., Wong, J., Meillier, Y., and Wolfe, D.: Determining water sources in the boundary layer from tall tower profiles of water vapor and surface water isotope ratios after a snowstorm in Colorado, Atmos. Chem. Phys., 13, 1607-1623, doi:10.5194/acp-13-1607-2013, 2013.

The D/H isotope ratio is used to attribute boundary layer humidity changes to the set of contributing fluxes for a case following a snowstorm in which a snow pack of about 10 cm vanished. Profiles of H_2O and CO_2 mixing ratio, D/H isotope ratio, and several thermodynamic properties were measured from the surface to 300 m every 15 min during four winter days near Boulder, Colorado. Coeval analysis of the D/H ratios and CO_2 concentrations find these two variables to be complementary with the former being sensitive to daytime surface fluxes and the latter particularly indicative of nocturnal surface sources. Together they capture evidence for strong vertical mixing during the day, weaker mixing by turbulent bursts and low level jets within the nocturnal stable boundary layer during the night, and frost formation in the morning. The profiles are generally not well described with a gradient mixing line analysis because D/H ratios of the end members (i.e., surface fluxes and the free troposphere) evolve throughout the day which leads to large uncertainties in the estimate of the D/H ratio of surface water flux. A mass balance model is constructed for the snow pack, and constrained with observations to provide an optimal estimate of the partitioning of the surface water flux into contributions from sublimation, evaporation of melt water in the snow and evaporation from ponds. Results show that while vapor measurements are important in constraining surface fluxes, measurements of the source reservoirs (soil water, snow pack and standing liquid) offer stronger constraint on the surface water balance. Measurements of surface water are therefore essential in developing observational programs that seek to use isotopic data for flux attribution. (Feb 2013)

Kim, Ji-Eun, M. Joan Alexander, 2013: Tropical Precipitation Variability and Convectively Coupled Equatorial Waves on Submonthly Time Scales in Reanalyses and TRMM. *J. Climate*, 26, 3013–3030.doi: http://dx.doi.org/10.1175/JCLI-D-12-00353.1

Tropical precipitation characteristics are investigated using the Tropical Rainfall Measuring Mission (TRMM) 3-hourly estimates, and the result is compared with five reanalyses including the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Re-Analysis (ERA-Interim), Modern Era Retrospective Analysis for Research and Applications (MERRA), National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) reanalysis (NCEP1), NCEP–U.S. Department of Energy (DOE) reanalysis (NCEP2), and NCEP–Climate Forecast System Reanalysis (CFSR). Precipitation characteristics are evaluated in terms of the mean, convectively coupled equatorial wave activity, frequency characteristics, diurnal cycle, and seasonality of regional precipitation variability associated with submonthly scale waves. Generally the latest reanalyses such as ERA-Interim, MERRA, and CFSR show better performances than NCEP1 and NCEP2. However, all the reanalyses are still different from observations. Besides the positive mean bias in the reanalyses, a spectral analysis revealed that the reanalyses have overreddened spectra with persistent rainfall. MERRA has the most persistent rainfall, and CFSR appears to have the most realistic variability. The diurnal cycle in NCEP1 is extremely exaggerated relative to TRMM. The low-frequency waves with the period longer than 3 days are

relatively well represented in ERA-Interim, MERRA, and CFSR, but all the reanalyses have significant deficiencies in representing convectively coupled equatorial waves and variability in the high-frequency range. (May 2013)

David, C. H., Z.-L. Yang, and J. S. Famiglietti (2013), Quantification of the upstream-to-downstream influence in the Muskingum method and implications for

speedup in parallel computations of river flow, Water Resour. Res., 49, 2783–2800, doi:10.1002/wrcr.20250.

The mathematical formulation of the Muskingum method, like that of many numerical schemes used for river routing, requires that all upstream river reaches be updated prior to updating the flow rate of any given reach. Due to this topological constraint, such numerical schemes have traditionally been solved in an upstream to downstream manner which imposes inherent limitations on the speedup that can be achieved in a parallel computing environment because each computing core has to wait for completion of all cores addressing upstream sub-basins prior to starting its own sub-basin. The research presented in this paper quantifies the exact influence among river reaches during the update step of the Muskingum method and shows that the influence decreases with increasing distance between two reaches until it becomes too small to be accounted for by floating-point arithmetic. A formal definition of the minimal distance from which the relative influence becomes numerically inexistent – the radius of influence – is presented. Based on this distance, expressed as a number of river reaches, a new estimate of the maximum theoretical speedup that can be achieved by the Muskingum method or by similar numerical schemes is presented and implies large potential gains in computing time when domains are much larger than the radius of influence. An application to the approximately 180,000 river reaches of the Upper Mississippi River Basin at a 15-minute time step over 2004 shows a radius of influence on the order of 150 river reaches. The speedup obtained for this application is much higher than previously thought possible, but also much lower than could be attained, suggesting that further investigations are necessary. (May 2013)

Guan, B., D. E. Waliser, J.-L. F. Li, and A. da Silva, 2013. Evaluating the impact of orbital sampling on satellite—climate model comparisons. *J. Geophys. Res.*, 118, 355-369. doi:10.1029/2012JD018590.

The effect of orbital sampling is one of the chief uncertainties in satellite–climate model comparisons. In the context of an ongoing activity to make satellite data more accessible for model evaluation (i.e., obs4MIPs), six variables (temperature, specific humidity, ozone, cloud water, cloud cover, and ocean surface wind) associated with six satellite instruments are evaluated for the orbital sampling effect. Comparisons are made between reanalysis and simulated satellite-sampled data in terms of bias and pattern similarity. It is found that the bias introduced by orbital sampling for long-term annual means, monthly climatologies, and monthly means is largely negligible, which is within ~3% of the standard deviation of the three quantities for most fields. The bias for 2-hPa temperature and specific humidity, while relatively large (9–10%), is within the estimated observational uncertainty. In terms of pattern similarity, cloud water and upper level specific humidity are the most sensitive to orbital sampling among the variables considered, with the magnitude of the sampling effect dependent on the spatial resolution—insignificant at 1.25° × 1.25° resolution for both. For all variables considered, orbital sampling effects are not an important consideration for model evaluation at 1.25° × 1.25° resolution. At 0.5° × 0.5°, orbital sampling is potentially

important for cloud water and upper level specific humidity when evaluating model long-term annual means and monthly climatologies, and for cloud water when evaluating monthly means, all in terms of pattern similarities. Orbital sampling is not an important factor for evaluating zonal means in call cases considered. (Jan 2013)

Sud, Y. C., Lee, D., Oreopoulos, L., Barahona, D., Nenes, A., and Suarez, M. J.: Performance of McRAS-AC in the GEOS-5 AGCM: aerosol-cloud-microphysics, precipitation, cloud radiative effects, and circulation, Geosci. Model Dev., 6, 57-79, doi:10.5194/gmd-6-57- 2013.

A revised version of the Microphysics of clouds with Relaxed Arakawa-Schubert and Aerosol-Cloud interaction scheme (McRAS-AC) including, among others, a new ice nucleation parameterization, is implemented in the GEOS-5 AGCM. Various fields from a 10-yr-long integration of the AGCM with McRAS-AC are compared with their counterparts from an integration of the baseline GEOS-5 AGCM, as well as satellite observations. Generally McRAS-AC simulations have smaller biases in cloud fields and cloud radiative effects over most of the regions of the Earth than the baseline GEOS-5 AGCM. Two systematic biases are identified in the McRAS-AC runs: one is underestimation of cloud particle numbers around 40° S–60° S, and one is overestimate of cloud water path during the Northern Hemisphere summer over the Gulf Stream and North Pacific. Sensitivity tests show that these biases potentially originate from biases in the aerosol input. The first bias is largely eliminated in a test run using 50% smaller radius of sea-salt aerosol particles, while the second bias is substantially reduced when interactive aerosol chemistry is turned on. The main weakness of McRAS-AC is the dearth of low-level marine stratus clouds, a probable outcome of lack of explicit dry-convection in the cloud scheme. Nevertheless, McRAS-AC largely simulates realistic clouds and their optical properties that can be improved further with better aerosol input. An assessment using the COSP simulator in a 1-yr integration provides additional perspectives for understanding cloud optical property differences between the baseline and McRAS-AC simulations and biases against satellite data. Overall, McRAS-AC physically couples aerosols, the microphysics and macrophysics of clouds, and their radiative effects and thereby has better potential to be a valuable tool for climate modeling research. (Jan. 2013)

Sahoo, A. K., G. J. M. De Lannoy, R. H. Reichle, and P. R. Houser, 2013, Assimilation and Downscaling of Satellite Observed Soil Moisture over the Little River Experimental Watershed in Georgia, USA., *Advances in Water Resources*, vol. 52, pages 19-33.

A three dimensional Ensemble Kalman filter (3-D EnKF) and a one dimensional EnKF (1-D EnKF) are used in this study to assimilate Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) coarse grid (25 km) soil moisture retrievals into the Noah land surface model for fine-scale (1 km) surface soil moisture estimation over the Little River Experimental Watershed (LREW), Georgia, USA. For the 1-D EnKF integration, the satellite observations are a priori partitioned to the model fine scale resolution, whereas in the 3-D EnKF integration, the original coarse grid satellite observations are directly used and downscaling is accomplished within the 3-D EnKF update step. In both cases, a first order a priori forecast bias correction is applied. Validation against in situ observations shows that both EnKF algorithms improve the soil moisture estimates, but the 3-D EnKF algorithm better preserves the spatial coherence. It is illustrated how surface soil moisture assimilation affects the deeper layer soil moisture

and other water budget variables. Through sensitivity experiments, it is shown that data assimilation accelerates the moisture redistribution compared to the model integrations without assimilation, as surface soil moisture updates are effectively propagated over the entire profile. In the absence of data assimilation, the atmospheric conditions (especially the ratio of evapotranspiration to precipitation) control the model state balancing. (Feb 2013)

Wang, A. and X. Zeng (2013), Development of global hourly 0.5-degree land surface air temperature datasets, *Journal of Climate*, doi:10.1175/JCLI-D-12-00682.1

Land surface air temperature (SAT) is one of the most important variables in weather and climate studies, and its diurnal cycle and day-to-day variation are also needed for a variety of applications. Global long-term hourly SAT observational data, however, do not exist. While such hourly products could be obtained from global reanalyses, they are strongly affected by model parameterizations and hence are found to be unrealistic in representing the SAT diurnal cycle (even after the monthly mean bias correction).

Global hourly 0.5-degree SAT datasets are developed here based on four reanalysis products [MERRA (1979-2009), ERA-40 (1958-2001), ERA-Interim (1979-2009), and NCEP/NCAR (1948-2009)] and the CRU TS3.10 data for 1948-2009. Our three-step adjustments include the spatial downscaling to 0.5-degree grid cells, the temporal interpolation from 6-hourly (in ERA-40 and NCEP/NCAR) to hourly using the MERRA hourly SAT climatology for each day (and the linear interpolation from 3-hourly in ERA-Interim to hourly), and the mean bias correction in both monthly mean maximum and minimum SAT using the CRU data.

The final products have exactly the same monthly maximum and minimum SAT as the CRU data, and perform well in comparison with in situ hourly measurements over six sites and with a regional daily SAT dataset over Europe. They agree with each other much better than the original reanalyses, and the spurious SAT jumps of reanalyses over some regions are also substantially eliminated. One of the uncertainties in our final products can be quantified by their differences in the true monthly mean (using 24 hourly values) and the monthly averaged diurnal cycle. (2013)

Wang, K. and R. E. Dickinson (2013), Global atmospheric downward longwave radiation at the surface from ground-based observations, satellite retrievals, and reanalyses, *Rev. Geophys.*, 51, doi:10.1002/rog.20009

Atmospheric downward longwave radiation at the surface (L_d) varies with increasing CO_2 and other greenhouse gases. This study quantifies the uncertainties of current estimates of global L_d at monthly to decadal timescales and its global climatology and trends during the past decades by a synthesis of the existing observations, reanalyses, and satellite products. We find that current L_d observations have a standard deviation error of ~3.5 W m^{-2} on a monthly scale. Observations of L_d by different pyrgeometers may differ substantially for lack of a standard reference. The calibration of a pyrgeometer significantly affects its quantification of annual variability. Compared with observations collected at 169 global land sites from 1992 to 2010, the L_d derived from state-of-the-art satellite cloud observations and reanalysis temperature and humidity profiles at a grid scale of ~1° has a bias of ±9 W m^{-2} and a standard deviation of 7 W m^{-2}, with a nearly zero overall bias. The standard deviations are reduced to 4 W m^{-2} over tropical oceans

when compared to L_d observations collected by 24 buoy sites from 2002 to 2011. The −4 W m^{-2} bias of satellite L_d retrievals over tropical oceans is likely because of the overestimation of L_d observations resulting from solar heating of the pyrgeometer. Our best estimate of global means L_d from 2003 to 2010 are 342 ± 3 W m^{-2} (global), 307 ± 3

W m^{-2} (land), and 356 ± 3 W m^{-2} (ocean). Estimates of L_d trends are seriously compromised by the changes in satellite sensors giving changes of water vapor profiles. (May 2013)

Lorenz, Christof, Harald Kunstmann, 2012: The Hydrological Cycle in Three State-of-the-Art Reanalyses: Intercomparison and Performance Analysis. *J. Hydrometeor*, 13, 1397–1420. doi: http://dx.doi.org/10.1175/JHM-D-11-088.1

The three state-of-the-art global atmospheric reanalysis models—namely, ECMWF Interim Re-Analysis (ERA-Interim), Modern-Era Retrospective Analysis for Research and Applications (MERRA; NASA), and Climate Forecast System Reanalysis (CFSR; NCEP)—are analyzed and compared with independent observations in the period between 1989 and 2006. Comparison of precipitation and temperature estimates from the three models with gridded observations reveals large differences between the reanalyses and also of the observation datasets. A major source of uncertainty in the observations is the spatial distribution and change of the number of gauges over time. In South America, active measuring stations were reduced from 4267 to 390. The quality of precipitation estimates from the reanalyses strongly depends on the geographic location, as there are significant differences especially in tropical regions. The closure of the water cycle in the three reanalyses is analyzed by estimating long-term mean values for precipitation, evapotranspiration, surface runoff, and moisture flux divergence. Major shortcomings in the moisture budgets of the datasets are mainly due to inconsistencies of the net precipitation minus evaporation and evapotranspiration, respectively, ($P - E$) estimates over the oceans and landmasses. This imbalance largely originates from the assimilation of radiance sounding data from the *NOAA-15* satellite, which results in an unrealistic increase of oceanic $P - E$ in the MERRA and CFSR budgets. Overall, ERA-Interim shows both a comparatively reasonable closure of the terrestrial and atmospheric water balance and a reasonable agreement with the observation datasets. The limited performance of the three state-of-the-art reanalyses in reproducing the hydrological cycle, however, puts the use of these models for climate trend analyses and long-term water budget studies into question. (Oct.2012

Liu, Peters-Lidard C, Kumar S, Foster J , Shaw M, Y. Tian, and F.G. Hall (2013). Assimilating satellite-based snow depth and snow cover products for improving snow predictions in Alaska *Advances in Water Resources*, *54*, 208–227 10.1016/j.advwatres.2013.02.005

Several satellite-based snow products are assimilated, both separately and jointly, into the Noah land surface model for improving snow prediction in Alaska. These include the standard and interpreted versions of snow cover fraction (SCF) data from the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the snow depth (SD) estimates from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E). The satellite-based SD estimates are adjusted against in situ observations via statistical interpolation to reduce the potentially large biases, prior to being assimilated using an ensemble Kalman filter. A customized, rule-based direct insertion approach is developed to assimilate the two SCF datasets. Our results indicate that considerable overall improvement on snow prediction can be achieved via assimilating the bias-adjusted satellite SD estimates; however, the improvement does not always translate into improvements in streamflow prediction. Assimilating the standard MODIS SCF is found to have little impact on snow and streamflow predictions, while assimilating the interpreted SCF estimates, which have reduced cloud coverage and improved snow mapping accuracy, has resulted in the most consistent improvements on snow and streamflow predictions across the study domain. (April 2013)

Ouellette, K. J., C. de Linage, and J. S. Famiglietti (2013), Estimating snow water equivalent from GPS vertical site-position observations in the western United States, *Water Resour. Res*., 49, 2508–2518, doi:10.1002/wrcr.20173.

Accurate estimation of the characteristics of the winter snowpack is crucial for prediction of available water supply, flooding, and climate feedbacks. Remote sensing of snow has been most successful for quantifying the spatial extent of the snowpack, although satellite estimation of snow water equivalent, fractional snow covered area, and snow depth is improving. Here we show that GPS observations of vertical land surface loading reveal seasonal responses of the land surface to the total weight of snow, providing information about the stored snow water equivalent. We demonstrate that the seasonal signal in SOPAC GPS vertical land surface position time series at six locations in the western United States is driven by elastic loading of the crust by the snowpack. GPS observations of land surface deformation are then used to predict the water load as a function of time at each location of interest and compared for validation to nearby SNOTEL observations of snow water equivalent. Estimates of soil moisture are included in the analysis and result in considerable improvement in the prediction of snow water equivalent. (May 2013)

Li, B., and M. Rodell (2013). Spatial variability and its scale dependency of observed and modeled soil moisture over different climate regions *Hydrol. Earth Syst. Sci*, *17*, 1177-1188 10.5194/hess-17-1177-2013

Past studies on soil moisture spatial variability have been mainly conducted at catchment scales where soil moisture is often sampled over a short time period; as a result, the observed soil moisture often exhibited smaller dynamic ranges, which prevented the complete revelation of soil moisture spatial variability as a function of mean soil moisture. In this study, spatial statistics (mean, spatial variability and skewness) of in situ soil moisture, modeled and satellite-retrieved soil moisture obtained in a warm season (198 days) were examined over three large climate regions in the US. The study found that spatial moments of in situ measurements strongly depend on climates, with distinct mean, spatial variability and skewness observed in each climate zone. In addition, an upward convex shape, which was revealed in several smaller scale studies, was observed for the relationship between spatial variability of in situ soil moisture and its spatial mean when statistics from dry, intermediate, and wet climates were combined. This upward convex shape was vaguely or partially observable in modeled and satellite-retrieved soil moisture estimates due to their smaller dynamic ranges. Despite different environmental controls on large-scale soil moisture spatial variability, the correlation between spatial variability and mean soil moisture remained similar to that observed at small scales, which is attributed to the boundedness of soil moisture. From the smaller support (effective area or volume represented by a measurement or estimate) to larger ones, soil moisture spatial variability decreased in each climate region. The scale dependency of spatial variability all followed the power law, but data with large supports showed stronger scale dependency than those with smaller supports. The scale dependency of soil moisture variability also varied with climates, which may be linked to the scale dependency of precipitation spatial variability. Influences of environmental controls on soil moisture spatial variability at large scales are discussed. The results of this study should be useful for diagnosing large scale soil moisture estimates and for improving the estimation of land surface processes. (March 2013)

Kurum, M. (2013). Quantifying scattering albedo in microwave emission of vegetated terrain *Remote Sensing of Environment*, *129*, 66-74 10.1016/j.rse.2012.10.021.

This study provides a theoretical/physical framework to quantify the vegetation scattering effects on radiometric microwave measurements of soil moisture. The model development and analysis is presented to assess the limitations of the existing $\tau - \omega$ (tau-omega) model with respect to vegetated landscapes and thus to extend the usefulness of the $\tau - \omega$ model to a wider range of vegetation conditions. An explicit expression is driven for an effective albedo of vegetated terrain from the zero- and multiple-order radiative transfer solutions. The formulation establishes a direct physical link between the effective vegetation parameterization and the theoretical description of absorption and scattering within the canopy. Evaluation of the derived albedo for corn canopies (stem-dominated vegetation) with data taken during the Huntsville 1998 field experiment (Hsv98) are shown and discussed. The simulation results are in good agreement with the data and show that the effective albedo values are significantly smaller than the single-scattering albedo values and increase monotonically as soil moisture increases. The model is also used to simulate effective albedo from a soybean canopy (leaf dominated vegetation) at L-band. Both results illustrate that the fitted albedo values, which are found in the literature, represent effective albedo values rather than the single-scattering albedo values.(Feb 2013)

Yatheendradas, S., et al. (2012), Distributed assimilation of satellite-based snow extent for improving simulated streamflow in mountainous, dense forests: An example over the DMIP2 western basins, *Water Resour. Res.*, 48, W09557, doi:10.1029/2011WR011347.

Snow cover area affects snowmelt, soil moisture, evapotranspiration, and ultimately streamflow. For the Distributed Model Intercomparison Project – Phase 2 Western basins, we assimilate satellite-based fractional snow cover area (fSCA) from the Moderate Resolution Imaging Spectroradiometer, or MODIS, into the National Weather Service (NWS) SNOW-17 model. This model is coupled with the NWS Sacramento Heat Transfer (SAC-HT) model inside the National Aeronautics and Space Administration's (NASA) Land Information System. SNOW-17 computes fSCA from snow water equivalent (SWE) values using an areal depletion curve. Using a direct insertion, we assimilate fSCAs in two fully distributed ways: (1) we update the curve by attempting SWE preservation, and (2) we reconstruct SWEs using the curve. The preceding are refinements of an existing simple, conceptually guided NWS algorithm. Satellite fSCA over dense forests inadequately accounts for below-canopy snow, degrading simulated streamflow upon assimilation during snowmelt. Accordingly, we implement a below-canopy allowance during assimilation. This simplistic allowance and direct insertion are found to be inadequate for improving calibrated results, still degrading them as mentioned above. However, for streamflow volume for the uncalibrated runs, we obtain: (1) substantial to major improvements (64–81%) as a percentage of the control run residuals (or distance from observations), and (2) minor improvements (16–22%) as a percentage of observed values. We highlight the need for detailed representations of canopy-snow optical radiative transfer processes in mountainous, dense forest regions if assimilation-based improvements are to be seen in calibrated runs over these areas. (Sept 2012)

Demaria, E. M. C., E. P. Maurer, J. Sheffield, E. Bustos, D. Poblete, S. Vicuña, F. Meza, 2013: Using a Gridded Global Dataset to Characterize Regional Hydroclimate in Central Chile. *J. Hydrometeor*, 14, 251–265. doi: http://dx.doi.org/10.1175/JHM-D-12-047.1

Central Chile is facing dramatic projections of climate change, with a consensus for declining precipitation, negatively affecting hydropower generation and irrigated agriculture. Rising from sea level to 6000 m within a distance of 200 km, precipitation characterization is difficult because of a lack of long-term observations, especially at higher elevations. For understanding current mean and extreme conditions and recent hydroclimatological change, as well as to provide a baseline for downscaling climate model projections, a temporally and spatially complete dataset of daily meteorology is essential. The authors use a gridded global daily meteorological dataset at 0.25° resolution for the period 1948–2008, adjusted by monthly precipitation observations interpolated to the same grid using a cokriging method with elevation as a covariate. For validation, daily statistics of the adjusted gridded precipitation are compared to station observations. For further validation, a hydrology model is driven with the gridded 0.25° meteorology and streamflow statistics are compared with observed flow. The high elevation precipitation is validated by comparing the simulated snow extent to Moderate Resolution Imaging Spectroradiometer (MODIS) images. Results show that the daily meteorology with the adjusted precipitation can accurately capture the statistical properties of extreme events as well as the sequence of wet and dry events, with hydrological model results displaying reasonable agreement with observed streamflow and snow extent. This demonstrates the successful use of a global gridded data product in a relatively data-sparse region to capture hydroclimatological characteristics and extremes. (Feb 2013)

Zhu, Z.; Bi, J.; Pan, Y.; Ganguly, S.; Anav, A.; Xu, L.; Samanta, A.; Piao, S.; Nemani, R.R.; Myneni, R.B. Global Data Sets of Vegetation Leaf Area Index (LAI)3g and Fraction of Photosynthetically Active Radiation (FPAR)3g Derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) for the Period 1981 to 2011. *Remote Sens.* 2013, *5*, 927-948

Long-term global data sets of vegetation Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR) are critical to monitoring global vegetation dynamics and for modeling exchanges of energy, mass and momentum between the land surface and planetary boundary layer. LAI and FPAR are also state variables in hydrological, ecological, biogeochemical and crop-yield models. The generation, evaluation and an example case study documenting the utility of 30-year long data sets of LAI and FPAR are described in this article. A neural network algorithm was first developed between the new improved third generation Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) and best-quality Terra Moderate Resolution Imaging Spectroradiometer (MODIS) LAI and FPAR products for the overlapping period 2000–2009. The trained neural network algorithm was then used to generate corresponding LAI3g and FPAR3g data sets with the following attributes: 15-day temporal frequency, 1/12 degree spatial resolution and temporal span of July 1981 to December 2011. The quality of these data sets for scientific research in other disciplines was assessed through (a) comparisons with field measurements scaled to the spatial resolution of the data products, (b) comparisons with broadly-used existing alternate satellite data-based products, (c) comparisons to plant growth limiting climatic variables in the northern latitudes and tropical regions, and (d) correlations of dominant modes of interannual variability with large-scale circulation anomalies such as the EI Niño-Southern Oscillation and Arctic Oscillation. These assessment efforts yielded results that attested to the suitability of these data sets for research use in other disciplines. The utility of these data sets is documented by comparing the seasonal profiles of LAI3g with profiles from 18 state-of-the-art Earth System Models: the models consistently overestimated the satellite-based estimates of leaf area and simulated delayed peak seasonal values in the northern latitudes, a result that is consistent with previous evaluations of similar models with ground-based data. The LAI3g and FPAR3g data sets can be obtained freely from the NASA Earth Exchange (NEX) website.**(Feb 2013)**

Kam, Jonghun, Justin Sheffield, Xing Yuan, Eric F. Wood, 2013: The Influence of Atlantic Tropical Cyclones on Drought over the Eastern United States (1980–2007). *J. Climate*, 26, 3067–3086.doi: http://dx.doi.org/10.1175/JCLI-D-12-00244.1

To assess the influence of Atlantic tropical cyclones (TCs) on the eastern U.S. drought regime, the Variable Infiltration Capacity (VIC) land surface hydrologic model was run over the eastern United States forced by the North American Land Data Assimilation System phase 2 (NLDAS-2) analysis with and without TC-related precipitation for the period 1980–2007. A drought was defined in terms of soil moisture as a prolonged period below a percentile threshold. Different duration droughts were analyzed—short term (longer than 30 days) and long term (longer than 90 days)—as well as different drought severities corresponding to the 10th, 15th, and 20th percentiles of soil moisture depth. With TCs, droughts are shorter in duration and of a lesser spatial extent. Tropical cyclones variously impact soil moisture droughts via late drought initiation, weakened drought intensity, and early drought recovery. At regional scales, TCs decreased the average duration of moderately severe short-term and long-term droughts by less than 4 (10% of average drought duration per year) and more than 5 (15%) days yr^{-1}, respectively. Also, they removed at least two short-term and one long-term drought events over 50% of the study region. Despite the damage inflicted directly by TCs, they play a crucial role in the alleviation and removal of drought for some years and seasons, with important implications for water resources and agriculture. (May 2013)

Xia, Y., M. EK, J. Sheffield, B. Livneh, M. Hunag, H. Wei, S. Feng, L. Luo, J. Meng, and E. Wood, 2013: Validation of Noah-simulated Soil temperature in the North America Land Data Assimilation System Phase 2. *J. Applied Meteorology and Climatology*, 52, 455-471, doi:10.1175/JAMC-D-12-033.1.

Soil temperature can exhibit considerable memory from weather and climate signals and is among the most important initial conditions in numerical weather and climate models. Consequently, a more accurate long-term land surface soil temperature dataset is needed to improve weather and climate simulation and prediction, and is also important for the simulation of agricultural crop yield and ecological processes. The North American Land

Data Assimilation phase 2 (NLDAS-2) has generated 31 years (1979–2009) of simulated hourly soil temperature data with a spatial resolution of ⅛°. This dataset has not been comprehensivly evaluated to date. Thus, the purpose of this paper is to assess Noah-simulated soil temperature for different soil depths and time scales. The authors used long-term (1979–2001) observed monthly mean soil temperatures from 137 cooperative stations over the United States to evaluate simulated soil temperature for three soil layers (0–10, 10–40, and 40–100 cm) for annual and monthly time scales. Short-term (1997–99) observed soil temperatures from 72 Oklahoma Mesonet stations were used to validate simulated soil temperatures for three soil layers and for daily and hourly time scales. The results showed that the Noah land surface model generally matches observed soil temperature well for different soil layers and time scales. At greater depths, the simulation skill (anomaly correlation) decreased for all time scales. The monthly mean diurnal cycle difference between simulated and observed soil temperature revealed large midnight biases in the cold season that are due to small downward longwave radiation and issues related to model parameters. (Feb 2013)

Roundy, J.K., Ferguson,C.R., and Wood, E.F. (2013). Temporal Variability of Land-Atmosphere Coupling and Its Implications for Drought over the Southeast United States. *Journal of Hydrometeorology*, 14(2), 622-635, doi:10.1175/JHM-D-12-090.1.

Droughts represent a significant source of social and economic damage in the southeast United States. Having sufficient warning of these extreme events enables managers to prepare for and potentially mitigate the severity of their impacts. A seasonal hydrologic forecast system can provide such warning, but current forecast skill is low during the convective season when precipitation is affected by regionally varying land surface heat flux contributions. Previous studies have classified regions into coupling regimes based on the tendency of surface soil moisture anomalies to trigger convective rainfall. Until now, these classifications have been aimed at assessing the long-term dominant feedback signal. Sufficient focus has not been placed on the temporal variability that underlies this signal. To better understand this aspect of coupling, a new classification methodology suitable at daily time scales is developed. The methodology is based on the joint probability space of surface soil moisture, convective triggering potential, and the low-level humidity index. The methodology is demonstrated over the U.S. Southeast using satellite remote sensing, reanalysis, and hydrological model data. The results show strong persistence in coupling events that is linked to the land surface state. A coupling-based drought index shows good agreement with the temporal and spatial variability of drought and highlights the role of coupling in drought recovery. The implications of the findings for drought and forecasting are discussed. (April 2013)

Román, M.O., Gatebe, C.K., Shuai, Y., Wang, Z., Gao, F., J. Masek, He, T., Liang, S., and Schaaf, C.B. (2013). Use of in situ and airborne multiangle data to assess MODIS- and Landsat-based estimates of directional reflectance and surface albedo *IEEE Transactions on Geoscience and Remote Sensing* 10.1109/TGRS.2013.2243457

Droughts represent a significant source of social and economic damage in the southeast United States. Having sufficient warning of these extreme events enables managers to prepare for and potentially mitigate the severity of their impacts. A seasonal hydrologic forecast system can provide such warning, but current forecast skill is low during the convective season when precipitation is affected by regionally varying land surface heat flux contributions. Previous studies have classified regions into coupling regimes based on the tendency of surface soil moisture anomalies to trigger convective rainfall. Until now, these classifications have been aimed at assessing the long-term dominant feedback signal. Sufficient focus has not been placed on the temporal variability that underlies this signal. To better understand this aspect of coupling, a new classification methodology suitable at daily time scales is developed. The methodology is based on the joint probability space of surface soil moisture, convective triggering potential, and the low-level humidity index. The methodology is demonstrated over the U.S. Southeast using satellite remote sensing, reanalysis, and hydrological model data. The results show strong persistence in coupling events that is linked to the land surface state. A coupling-based drought index shows good agreement with the temporal and spatial variability of drought and highlights the role of coupling in drought recovery. The implications of the findings for drought and forecasting are discussed.

The quantification of uncertainty in satellite-derived global surface albedo products is a critical aspect in producing complete, physically consistent, and decadal land property data records for studying ecosystem change. A challenge in validating albedo measurements acquired from space is the ability to over- come the spatial scaling errors that can produce disagreements between satellite and field-measured values. Here, we present the results from an accuracy assessment of MODIS and Landsat-TM albedo retrievals, based on collocated comparisons with tower and airborne Cloud Absorption Radiometer (CAR) measurements collected during the 2007 Cloud and Land Surface Interaction Campaign (CLASIC). The initial focus was on evaluating inter- sensor consistency through comparisons of intrinsic bidirectional reflectance estimates. Local and regional assessments were then performed to obtain estimates of the resulting scaling uncer- tainties, and to establish the accuracy of albedo reconstructions during extended periods of precipitation. In general, the satellite- derived estimates met the accuracy requirements established for the high-quality MODIS operational albedos at 500 m (the greater of 0.02 units or ±10% of surface measured values). However, results reveal a high degree of variability in the root-mean-square error (RMSE) and bias of MODIS visible (0.3–0.7 μm) an Landsat-TM shortwave (0.3–5.0 μm) albedos; where, in some cases, retrieval uncertainties were found to be in excess of 15%. Results suggest that an overall improvement in MODIS shortwave albedo retrieval accuracy of 7.8%, based on comparisons between MODIS and CAR albedos, resulted from the removal of sub-grid scale mismatch errors when directly scaling-up the tower mea- surements to the MODIS satellite footprint. (March 2013)

Wernberg, T., D. A. Smale, F. Tuya, M. S. Thomsen, T. J. Langlois, T. de Bettignies, S. Bennett, and C. S. Rousseaux, 2013. An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. *Nature Climate Change*, 3, 78-82. doi:10.1038/nclimate1627

Extreme climatic events, such as heat waves, are predicted to increase in frequency and magnitude as a consequence of global warming but their ecological effects are poorly understood, particularly in marine ecosystems1, 2, 3. In early 2011, the marine ecosystems along the west coast of Australia—a global hotspot of biodiversity and endemism4, 5—experienced the highest-magnitude warming event on record. Sea temperatures soared to unprecedented levels and warming anomalies of 2–4 °C persisted for more than ten weeks along >2,000 km of coastline. We show that biodiversity patterns of temperate seaweeds, sessile invertebrates and demersal fish were significantly different after the warming event, which led to a reduction in the abundance of habitat-forming seaweeds and a subsequent shift in community structure towards a depauperate

state and a tropicalization of fish communities. We conclude that extreme climatic events are key drivers of biodiversity patterns and that the frequency and intensity of such episodes have major implications for predictive models of species distribution and ecosystem structure, which are largely based on gradual warming trends

W. T. Crow, S. V. Kumar, and J. D. Bolten·On the utility of land surface models for agricultural drought monitoring, 2012. *Hydrol. Earth Syst. Sci. 16,3451-3460*

The lagged rank cross-correlation between model- derived root-zone soil moisture estimates and remotely sensed vegetation indices (VI) is examined between Jan- uary 2000 and December 2010 to quantify the skill of var- ious soil moisture models for agricultural drought monitor- ing. Examined modeling strategies range from a simple an- tecedent precipitation index to the application of modern land surface models (LSMs) based on complex water and energy balance formulations. A quasi-global evaluation of lagged VI/soil moisture cross-correlation suggests, when globally averaged across the entire annual cycle, soil moisture esti- mates obtained from complex LSMs provide little added skill (< 5 % in relative terms) in anticipating variations in veg- etation condition relative to a simplified water accounting procedure based solely on observed precipitation. However, larger amounts of added skill (5–15 % in relative terms) can be identified when focusing exclusively on the extra-tropical growing season and/or utilizing soil moisture values acquired by averaging across a multi-model ensemble. (Sept 2012)

Bindschadler, R., S. Nowicki, A. Abe-Ouchi, A. Ashwanden, H. Choi, J. Fastook, G. Granzow, R. Greve, G. Gutowski, U. Herzfeld, C. Jackson, J. Johnson, C. Khroulev, A. Levermann, W. H. Lipscomb, M. A. Martin, M. Morlighem, B. R. Parizek, D. Pollard, S. F. Price, D. Ren, F. Saito, T. Sato, H. Seddik, H. Seroussi, K. Takahashi, R. Walker, and W. L. Wang. (2013). Ice-sheet model sensitivities to environmental forcing and their use in projecting future sea level (the SeaRISE project) *Journal of Glaciology*, *59*(214) 10.3189/2013JoG12J125

Ten ice-sheet models are used to study sensitivity of the Greenland and Antarctic ice sheets to prescribed changes of surface mass balance, sub-ice-shelf melting and basal sliding. Results exhibit a large range in projected contributions to sea-level change. In most cases, the ice volume above flotation lost is linearly dependent on the strength of the forcing. Combinations of forcings can be closely approximated by linearly summing the contributions from single forcing experiments, suggesting that nonlinear feedbacks are modest. Our models indicate that Greenland is more sensitive than Antarctica to likely atmospheric changes in temperature and precipitation, while Antarctica is more sensitive to increased ice-shelf basal melting. An experiment approximating the Intergovernmental Panel on Climate Change's RCP8.5 scenario produces additional first-century contributions to sea level of 22.3 and 8.1 cm from Greenland and Antarctica, respectively, with a range among models of 62 and 14 cm, respectively. By 200 years, projections increase to 53.2 and 26.7cm, respectively, with ranges of 79 and 43cm. Linear interpolation of the sensitivity results closely approximates these projections, revealinthe relative contributions of the individual forcings on the combined volume change and suggesting that total ice-sheet response to complicated forcings over 200 years can be linearized. (2013)

Gary Toller ; Xiaoxiong Xiong ; Junqiang Sun ; Brian N. Wenny ; Xu Geng, et al. Terra and Aqua moderate-resolution imaging spectroradiometer collection 6 level

1B algorithm, *J. Appl. Remote Sens*. 7(1), 073557 (May 22, 2013). ; http://dx.doi.org/10.1117/1.JRS.7.073557

The moderate-resolution imaging spectroradiometer (MODIS) was launched on the Terra spacecraft on Dec.18, 1999 and on Aquaon May 4, 2002. The data acquired by these instruments have contributed to the long-term climate data record for more than a decade and represent a key component of NASA's Earth observing system. Each MODIS instrument observes nearly the whole Earth each day, enabling the scientific characterization of the land, ocean, and atmosphere. The MODIS Level 1B (L1B) algorithms input uncalibrated geo-located observations and convert instrument response into calibrated reflectance and radiance, which are used to generate science data products. The instrument characterization needed to run the L1B code is currently implemented using time-dependent lookup tables. The MODIS characterization support team, working closely with the MODIS Science Team, has improved the product quality with each data reprocessing. We provide an overview of the new L1B algorithm release, designated collection 6. Recent improvements made as a consequence of on-orbit calibration, on-orbit analyses, and operational considerations are described. Instrument performance and the expected impact of L1B changes on the collection 6 L1B products are discussed. (May2013)

- **Indrani Das, E., Ted A. Scambos, Michael Wolovick, Timothy T. Creyts, M. Studinger, Nicholas Frearson, Julien P. Nicolas, Jan T. M. Lenaerts, and Michiel R. van den Broeke (2013). Influence of persistent wind scour on the surface mass balance of Antarctica *Nature Geoscience* 10.1038/ngeo1766**

Accurate quantification of surface snow accumulation over Antarctica is a key constraint for estimates of the Antarctic mass balance, as well as climatic interpretations of ice-core records[1, 2]. Over Antarctica, near-surface winds accelerate down relatively steep surface slopes, eroding and sublimating the snow. This wind scour results in numerous localized regions (≤200 km^2) with reduced surface accumulation[3, 4, 5, 6, 7]. Estimates of Antarctic surface mass balance rely on sparse point measurements or coarse atmospheric models that do not capture these local processes, and overestimate the net mass input in wind-scour zones[3]. Here we combine airborne radar observations of unconformable stratigraphic layers with lidar-derived surface roughness measurements to identify extensive wind-scour zones over Dome A, in the interior of East Antarctica. The scour zones are persistent because they are controlled by bedrock topography. On the basis of our Dome A observations, we develop an empirical model to predict wind-scour zones across the Antarctic continent and find that these zones are predominantly located in East Antarctica. We estimate that ~ 2.7–6.6% of the surface area of Antarctica has persistent negative net accumulation due to wind scour, which suggests that, across the continent, the snow mass input is overestimated by 11–36.5 Gt yr^{-1} in present surface-mass-balance calculations. (March 2013)

- **Parkinson, C., and J. C. Comiso. (2013). On the 2012 record low Arctic sea ice cover: Combined impact of preconditioning and an August storm *Geophysical Research Letters,*, *40*, 1-6 10.1002/grl.50349**

A new record low Arctic sea ice extent for the satellite era, 3.4×10^6 km^2, was reached on 13 September 2012; and a new record low sea ice area, 3.0×10^6 km^2, was reached

on the same date. Preconditioning through decades of overall ice reductions made the ice pack more vulnerable to a strong storm that entered the central Arctic in early

August 2012. The storm caused the separation of an expanse of 0.4×10^6 km^2 of ice that melted in total, while its removal left the main pack more exposed to wind and waves, facilitating the main pack's further decay. Future summer storms could lead to a further acceleration of the decline in the Arctic sea ice cover and should be carefully monitored.
(April 2013)

- **Frei A, Tedesco M, Lee S, Foster J, Hall D, Kelly R, Robinson D. A review of global satellite-derived snow products. Advances in Space Research. 2012;50 (8):1007-1029.**

Snow cover over the Northern Hemisphere plays a crucial role in the Earth's hydrology and surface energy balance, and modulates feedbacks that control variations of global climate. While many of these variations are associated with exchanges of energy and mass between the land surface and the atmosphere, other expected changes are likely to propagate downstream and affect oceanic processes in coastal zones. For example, a large component of the freshwater flux into the Arctic Ocean comes from snow melt. The timing and magnitude of this flux affects biological and thermodynamic processes in the Arctic Ocean, and potentially across the globe through their impact on North Atlantic Deep Water formation.Several recent global remotely sensed products provide information at unprecedented temporal, spatial, and spectral resolutions. In this article we review the theoretical underpinnings and characteristics of three key products. We also demonstrate the seasonal and spatial patterns of agreement and disagreement amongst them, and discuss current and future directions in their application and development. Though there is general agreement amongst these products, there can be disagreement over certain geographic regions and under conditions of ephemeral, patchy and melting snow. (Oct 2012)

- **Paul, F., N. Barrand, E. Berthier, T. Bolch, K. Casey, H. Frey, S.P. Joshi, V. Konovalov, R. Le Bris, N. Moelg, G. Nosenko, C. Nuth, A. Pope, A. Racoviteanu, P. Rastner, B. Raup, K. Scharrer, S. Steffen, and S. Winsvold (2013). On the accuracy of glacier outlines derived from remote sensing data *Annals of Glaciology*, *54*(63), 171-182 10.3189/2013AoG63A296**

Deriving glacier outlines from satellite data has become increasingly popular in the past decade. In particular when glacier outlines are used as a base for change assessment, it is important to know how accurate they are. Calculating the accuracy correctly is challenging, as appropriate reference data (e.g. from higher-resolution sensors) seldom available. Moreover, after the required manual correction of the raw outlines (e.g. for debris cover), such a comparison would only reveal the accuracy of the analyst rather than of the algorithm applied. Here we compare outlines for clean and debris- covered glaciers, as derived from single and multiple digitizing by different or the same analysts on very high- (1m) and medium-resolution (30m) remote-sensing data, against each other and to glacier outlines derived from automated classification of Landsat Thematic Mapper data. Results show a high variability in the interpretation of debris-covered glacier parts, largely independent of the spatial resolution (area differences were up to 30%), and an overall good agreement for clean ice with sufficient contrast to the surrounding terrain (differences $5%). The differences of the automatically derived outlines from a reference value are as small as the standard deviation of the manual

digitizations from several analysts. Based on these results, we conclude that automated mapping of clean ice is preferable to manual digitization and recommend using the latter method only for required corrections of incorrectly mapped glacier parts (e.g. debris cover, shadow). (2013)

• **Rennermalm, A., S. Moustafa, J. Mioduszewski, V. Chu, R. Forster, B. Hagedorn, J. Harper, T. Mote, D. Robinson, C. Shuman, L. Smith, and M. Tedesco. (2013). Understanding Greenland ice sheet hydrology using an integrated multi-scale approach *Environmental Research Letters*, *8*(1), 015017 10.1088/1748-9326/8/1/015017**

• Improved understanding of Greenland ice sheet hydrology is critically important for assessing its impact on current and future ice sheet dynamics and global sea level rise. This has motivated the collection and integration of *in situ* observations, model development, and remote sensing efforts to quantify meltwater production, as well as its phase changes, transport, and export. Particularly urgent is a better understanding of albedo feedbacks leading to enhanced surface melt, potential positive feedbacks between ice sheet hydrology and dynamics, and meltwater retention in firn. These processes are not isolated, but must be understood as part of a continuum of processes within an integrated system. This letter describes a systems approach to the study of Greenland ice sheet hydrology, emphasizing component interconnections and feedbacks, and highlighting research and observational needs. (Feb. 2013)

• **Shi, Xiaogang, Stephen J. Déry, Pavel Ya. Groisman, Dennis P. Lettenmaier, 2013: Relationships between Recent Pan-Arctic Snow Cover and Hydroclimate Trends. *J. Climate*, 26, 2048–2064.**
doi: http://dx.doi.org/10.1175/JCLI-D-12-00044.1

Using the Variable Infiltration Capacity (VIC) land surface model forced with gridded climatic observations, the authors reproduce spatial and temporal variations of snow cover extent (SCE) reported by the National Oceanic and Atmospheric Administration (NOAA) Northern Hemisphere weekly satellite SCE data. Both observed and modeled North American and Eurasian snow cover in the pan-Arctic have statistically significant negative trends from April through June over the period 1972–2006. To diagnose the causes of the pan-Arctic SCE recession, the authors identify the role of surface energy fluxes generated in VIC and assess the relationships between 15 hydroclimatic indicators and NOAA SCE observations over each snow-covered sensitivity zone (SCSZ) for both North America and Eurasia. The authors find that surface net radiation (SNR) provides the primary energy source and sensible heat (SH) plays a secondary role in observed changes of SCE. As compared with SNR and SH, latent heat has only a minor influence on snow cover changes. In addition, these changes in surface energy fluxes resulting in the pan-Arctic snow cover recession are mainly driven by statistically significant decreases in snow surface albedo and increased air temperatures (surface air temperature, daily maximum temperature, and daily minimum temperature), as well as statistically significant increased atmospheric water vapor pressure. Contributions of other hydroclimate variables that the authors analyzed (downward shortwave radiation, precipitation, diurnal temperature range, wind speed, and cloud cover) are not significant for observed SCE changes in either the North American or Eurasian SCSZs. (Mar 2013)

• **Douville, H., A. Ribes, B. Decharme, R. Alkama, and J. Sheffield, 2013: Anthropogenic influence on multi-decadal changes in reconstructed global evapotranspiration, *Nature Climate Change*, 3, 59-62, doi:10.1038/nclimate1632.**

Global warming is expected to intensify the global hydrological cycle with an increase of both evapotranspiration (EVT) and precipitation. Yet the magnitude and spatial distribution of this global and annual mean response remains highly uncertain. Better constraining land EVT in twenty-first-century climate scenarios is critical for predicting changes in surface climate, including heatwaves, and droughts evaluating impacts on ecosystems and water resources, and designing adaptation policies. Continental scale EVT changes may already be underway but have never been attributed to anthropogenic emissions of greenhouse gases and sulphate aerosols. Here we provide global gridded estimates of annual EVT and demonstrate that the latitudinal and decadal differentiation of recent EVT variations cannot be understood without invoking the anthropogenic radiative forcings. In the mid-latitudes, the emerging picture of enhanced EVT confirms the end of the dimming decades8 and highlights the possible threat posed by increasing drought frequency to managing water resources and achieving food security in a changing climate.

• **Sheffield, J., E. F. Wood, and M. L. Roderick, 2012: Little change in global drought over the past 60 years. *Nature*, 491, 435-438. doi:10.1038/nature11575.**

Drought is expected to increase in frequency and severity in the future as a result of climate change, mainly as a consequence of decreases in regional precipitation but also because of increasing evaporation driven by global warming. Previous assessments of historic changes in drought over the late twentieth and early twenty-first centuries indicate that this may already be happening globally. In particular, calculations of the Palmer Drought Severity Index (PDSI) show a decrease in moisture globally since the 1970s with a commensurate increase in the area in drought that is attributed, in part, to global warming. The simplicity of the PDSI, which is calculated from a simple water-balance model forced by monthly precipitation and temperature data, makes it an attractive tool in large-scale drought assessments, but may give biased results in the context of climate change6. Here we show that the previously reported increase in global drought is overestimated because the PDSI uses a simplified model of potential evaporation that responds only to changes in temperature and thus responds incorrectly to global warming in recent decades. More realistic calculations, based on the underlying physical principles8 that take into account changes in available energy, humidity and wind speed, suggest that there has been little change in drought over the past 60 years. The results have implications for how we interpret the impact of global warming on the hydrological cycle and its extremes, and may help to explain why palaeoclimate drought reconstructions based on tree-ring data diverge from the PDSI-based drought record in recent years9, 10. (Sept 2012)

• **Sheffield, Justin, Ben Livneh, Eric F. Wood, 2012: Representation of Terrestrial Hydrology and Large-Scale Drought of the Continental United States from the North American Regional Reanalysis. *J. Hydrometeor*, 13, 856–876.**
doi: http://dx.doi.org/10.1175/JHM-D-11-065.1

The North American Regional Reanalysis (NARR) is a state-of-the-art land–atmosphere reanalysis product that provides improved representation of the terrestrial hydrologic cycle compared to previous global reanalyses, having the potential to provide an enhanced picture of hydrologic extremes such as floods and droughts and their driving mechanisms. This is partly because of the novel assimilation of observed precipitation, state-of-the-art land surface scheme, and higher spatial resolution. NARR is evaluated in terms of the terrestrial water budget and its depiction of drought at monthly to annual time scales against two offline land surface model [Noah v2.7.1 and Variable Infiltration Capacity (VIC)] simulations and observation-based runoff estimates over the continental United States for 1979–2003. An earlier version of the Noah model forms the land component of NARR and so the offline simulation provides an opportunity to diagnose NARR land surface variables independently of atmospheric feedbacks. The VIC model has been calibrated against measured streamflow and so provides a reasonable estimate of large-scale evapotranspiration. Despite similar precipitation, there are large differences in the partitioning of precipitation into evapotranspiration and runoff. Relative to VIC,NARR and Noah annual evapotranspiration is biased high by 28% and 24%, respectively, and the runoff ratios are 50% and 40% lower. This is confirmed by comparison with observation-based runoff estimates from 1130 small, relatively unmanaged basins across the continental United States. The overestimation of evapotranspiration by NARR is largely attributed to the evapotranspiration component of the Noah model, whereas other factors such as atmospheric forcings or biases induced by precipitation assimilation into NARR play only a minor role. A combination of differences in the parameterization of evapotranspiration and in particular low stomatal resistance values in NARR, the seasonality of vegetation characteristics, the near-surface radiation and meteorology, and the representation of soil moisture dynamics, including high infiltration rates and the relative coupling of soil moisture with baseflow in NARR, are responsible for the differences in the water budgets. Large-scale drought as quantified by soil moisture percentiles covaries closely over the continental United States between the three datasets, despite large differences in the seasonal water budgets. However, there are large regional differences, especially in the eastern United States where the VIC model shows higher variability in drought dynamics. This is mostly due to increased frequency of completely dry conditions in NARR that result from differences in soil depth, higher evapotranspiration, early snowmelt, and early peak runoff. In the western United States, differences in the precipitation forcing contribute to large discrepancies between NARR and Noah/VIC simulations in the representation of the early 2000s drought. (June 2012)

Livneh, B., and D. P. Lettenmaier (2013), Regional parameter estimation for the unified land model, *Water Resour. Res*., 49, 10.1029/2012WR012220.

We describe a regional parameter estimation scheme for the unified land model developed using a set of 220 river basins (102–104 km2) distributed across the conterminous United States. We evaluate predictive relationships between geographically varying catchment features and the model's soil parameters using principal components analysis. In addition to commonly used catchment descriptors (meteorological, geomorphic, and land-cover characteristics), we used satellite remote-sensing products and the United States Geologic Survey Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) database. In a series of regionalization experiments, we contrast the more conventional procedure of using locally optimized parameters as predictands, with an approach that searches for zonally representative parameter values, using limited additional simulations. Parameters were evaluated through hydrologic model simulations in which daily flows were compared with observations over a 20 year period. We show that the penalty in streamflow prediction skill for using zonal parameters at a given basin (i.e., locally) is comparatively smaller

than the penalty for using local parameters zonally. Regionalizations using zonal parameters and local catchment descriptors had the best model performance for both training and validation periods. Finally, we investigate the potential for transferring parameters globally by repeating the regionalization using only catchment attributes derived from globally available data and show that for the United States, model performance is only slightly worse than when U.S.-specific data area used.
(Jan 2013)

- **Werdell, P., B.A. Franz, S.W. Bailey, G. Feldman, Emmanuel Boss, Vittorio E. Brando, Mark Dowell, Takafumi Hirata, Samantha J. Lavender, ZhongPing Lee, Hubert Loisel, Fréderic Mélin, Timothy S. Moore, Timothy J. Smyth, David Antoine, Emmanuel Devred, Odile Hembise Fanton d'Andon, and Antoine Mangin (2013). Generalized ocean color inversion model for retrieving marine inherent optical properties *APPLIED OPTICS*, *52*(10)**

Ocean color measured from satellites provides daily, global estimates of marine inherent optical properties (IOPs). Semi-analytical algorithms (SAAs) provide one mechanism for inverting the color of the water observed by the satellite into IOPs. While numerous SAAs exist, most are similarly constructed and few are appropriately parameterized for all water masses for all seasons. To initiate community-wide discussion of these limitations, NASA organized two workshops that deconstructed SAAs to identify similarities and uniqueness and to progress toward consensus on a unified SAA. This effort resulted in the development of the generalized IOP (GIOP) model software that allows for the construction of different SAAs at runtime by selection from an assortment of model parameterizations. As such, GIOP permits isolation and evaluation of specific modeling assumptions, construction of SAAs, development of regionally tuned SAAs, and execution of ensemble inversion modeling. Working groups associated with the workshops proposed a preliminary default configuration for GIOP (GIOP-DC), with alternative model parameterizations and features defined for subsequent evaluation. In this paper, we: (1) describe the theoretical basis of GIOP; (2) present GIOP-DC and verify its comparable performance to other popular SAAs using both *in situ* and synthetic data sets; and, (3) quantify the sensitivities of their output to their parameterization. We use the latter to develop a hierarchical sensitivity of SAAs to various model parameterizations, to identify components of SAAs that merit focus in future research, and to provide material for discussion on algorithm uncertainties and future emsemble applications. (2013)

- **Ham, Y.-G., J.-S. Kug, and J.-Y. Park, 2013. Sea surface temperature in the north tropical Atlantic as a trigger for El-Niño — Southern oscillation events. *Nat. Geosci.*, 6, 112-116. doi:10.1038/NGEO1686.**

El Niño events, the warm phase of the El Niño/Southern Oscillation (ENSO), are known to affect other tropical ocean basins through teleconnections. Conversely, mounting evidence suggests that temperature variability in the Atlantic Ocean may also influence ENSO variability[1, 2, 3, 4, 5]. Here we use reanalysis data and general circulation models to show that sea surface temperature anomalies in the north tropical Atlantic during the boreal spring can serve as a trigger for ENSO events. We identify a subtropical teleconnection in which spring warming in the north tropical Atlantic can induce a low-level cyclonic atmospheric flow over the eastern Pacific Ocean that in turn produces a low-level anticyclonic flow over the western Pacific during the following months. This flow generates easterly winds over the western equatorial Pacific that cool the equatorial Pacific and may trigger a La Niña event the following winter. In addition, El Niño events led by cold anomalies in the north tropical Atlantic tend to be warm-pool El Niño events, with a centre of action located in the central Pacific6, 7, rather than canonical El Niño events. We suggest that the identification of temperature anomalies in the north tropical Atlantic could help to forecast the development of different types of El Niño event. (Jan 2013)

• **D. P. Chambers, J. L. Chen, R. S. Nerem, and B. D. Tapley 2012; Interannual Sea Level Change and the Earth's Water Mass Budget, *Geophys. Res. Ltrs, 27*, 3073-3076, 2000**

The relationship between interannual global mean sea level change and the Earth's water mass budget is examined between 1993 and 1998 by removing the steric (thermal) component from mean sea level computed with TOPEX/Poseidon (T/P) Mby expendable bathythermographs and interpolated to a global grid by empirical orthogonal function (EOF) reconstruction. Results indicate that from late-1995 to early-1998, the thermal expansion of sea level was significantly higher than the total sea level change measured by T/P, suggesting that fresh water mass was lost from the ocean. The size of the maximum water mass lost is equivalent to about 18 mm of sea level. An error analysis indicates that this value is significant at the 95% confidence level. Results from numerical models show similar magnitudes of water mass change in the ocean at interannual periods, but at different phases. (Dec.2012)

• **Evan, A. T., and J. R. Norris, 2012: On global changes in effective cloud height. *Geophys. Res. Lett.*, 39, L19710, doi:10.1029/2012GL053171.**

Clouds represent a major source of uncertainty in models of the Earth's climate response to man-made global warming. As the world warms, changes in cloud cover and cloud properties could, in principle, either counter or amplify the warming from growing concentrations of atmospheric CO_2 One way in which clouds alter the global energy budget is through the emission of longwave radia- tion to space, which is a function of the cloud emissivity and cloud top temperature. Assuming a constant tempera- ture profile in the atmosphere, as cloud heights increase the amount of longwave radiation leaving the planet goes down and, assuming radiative balance at the top of the atmo- sphere, planetary temperatures will over time respond by increasing. Therefore, there may exist a positive or negative longwave "cloud height feedback" if global warming causes a systematic change in cloud heights, although the total cloud feedback is dependent on additional aspects of chan- ges in cloud properties, like cloud emissivity and cloud fraction. (Oct.2012)

• **Storelvmo, T., J. Kristjannsson, H. Muri, M. Pfeffer, D. Barahona, and A. Nenes, 2013. Cirrus cloud seeding has potential to cool climate. *Geophys. Res. Lett.*, 40, 178-182. 10.1029/2012GL054201**.

Cirrus clouds, thin ice clouds in the upper troposphere, have a net warming effect on Earth's climate. Consequently, a reduction in cirrus cloud amount or optical thickness would cool the climate. Recent research indicates that by seeding cirrus clouds with particles that promote ice nucleation, their lifetimes and coverage could be reduced. We have tested this hypothesis in a global climate model with a state-of-the-art representation of cirrus clouds and find that cirrus cloud seeding has the potential to cancel the entire warming caused by human activity from pre-industrial times to present day. However, the desired effect is only obtained for seeding particle concentrations that lie within an optimal range. With lower than optimal particle concentrations, a seeding exercise would have no effect. Moreover, a higher than optimal concentration results in an over-seeding that could have the deleterious effect of prolonging cirrus lifetime and contributing to global warming. (Jan 2013)

- **Su, Hui, Jonathan H. Jiang, 2013: Tropical Clouds and Circulation Changes during the 2006/07 and 2009/10 El Niños. *J. Climate*, 26, 399–413. doi: http://dx.doi.org/10.1175/JCLI-D-12-00152.1**

Changes in tropical cloud vertical structure, cloud radiative forcing (CRF), and circulation exhibit distinctly different characteristics during the 2006/07 and 2009/10 El Niños, revealed by *CloudSat* and *Cloud–Aerosol Lidar and Infrared Pathfinder Satellite* (*CALIPSO*) observations and reanalysis data. On the tropical average, the 2009/10 has a decrease of clouds from 2 to 14 km, an increase of clouds in the boundary layer, and an increase of cirrus clouds above 14 km. The tropical-mean cloud anomalies in the middle to upper troposphere (6–14 km) for the 2006/07 El Niño are nearly opposite to those in 2009/10 El Niño. The tropical averaged net CRF anomaly at the top of the atmosphere (TOA) is 0.6–0.7 W m^{-2} *cooling* (0.02–0.5 W m^{-2} *warming*) for the 2009/10 (2006/07) El Niño. The 2009/10 El Niño is associated with a strengthening of tropical circulation, increased high (low) clouds in extremely strong ascending (descending) regimes, and decreased clouds in the middle and high altitudes in a broad range of moderate circulation regimes. The strengthening of tropical circulation is primarily caused by the enhancement of the Hadley circulation. The 2006/07 El Niño is associated with a weakening of the tropical circulation, primarily caused by the reduction of the Walker circulation. The cloud anomalies in each circulation regime are approximately opposite for these two El Niños. The analysis herein suggests that both the magnitude and pattern of sea surface temperature anomalies in the two events contribute to the differences in clouds and circulation anomalies, with magnitude playing a dominant role. The contrasting behaviors of the two El Niños highlight the nonlinear response of tropical clouds and circulation to El Niño SST forcing. (Jan 2013)

- **Jiang, X., et al., 2013: Influence of El Nino on Mid-tropospheric CO2 from Atmospheric Infrared Sounder and Model. *J.Atmos. Sci.*, 223-230.**

The authors investigated the influence of El Niño on midtropospheric CO_2 from the Atmosphere Infrared Sounder (AIRS) and the model for Ozone and Related Chemical Tracers, version 2.(MOZART-2). AIRS midtropospheric CO_2 data are used to study the temporal and spatial variability of CO_2 in response to El Niño. CO_2 differences between the central and western Pacific Ocean correlate well with the Southern Oscillation index. To reveal the temporal and spatial variability of the El Niño signal in the AIRS mid- tropospheric CO_2, a multiple regression method is applied to the CO_2 to data from September 2002 to February 2011. There is more or (less) midtropospheric CO_2 in the central Pacific and less or more big tropospheric CO_2 in the Western Pacific during El Niño or La Niña events. Similar results are seen in the Mozart-2 convoved tropospheric $C0_2$, although the El Niño signal in the Mozart-2 is weaker than that in the AIRS data. (Jan 2013)

- **Jiang, X., et al., 2013: Influence of Stratospheric Sudden Warming on AIRS Mid-tropospheric CO2. *J.Atmos. Sci.*, doi:10.1175/JAS-D-13-064.1.**

Mid-tropospheric CO_2 retrievals from the Atmospheric Infrared Sounder (AIRS) were used to explore the influence of stratospheric sudden warming (SSW) on CO_2 in the mid to upper-troposphere. To choose the SSW events that had strong coupling between the stratosphere and troposphere, we applied a principal component analysis to the NCEP2 geopotential heights data at 17 pressure levels. Two events (April 2003 and March 2005), which have strong couplings between the stratosphere and troposphere, were chosen to investigate the influence of SSW on AIRS mid-tropospheric CO_2. We investigated the temporal and spatial variations of AIRS mid-tropospheric CO_2 before and after the SSW events, and found that the mid-tropospheric CO_2 concentrations increased by 2-3 ppm within a few days after the SSW events. Our results can be used to better understand how the chemical tracers respond to the large-scale dynamics in the high latitudes. (2013

- **Santanello, Joseph A., Christa D. Peters-Lidard, Aaron Kennedy, Sujay V. Kumar, 2013: Diagnosing the Nature of Land–Atmosphere Coupling: A Case Study of Dry/Wet Extremes in the U.S. Southern Great Plains. *J. Hydrometeor*, 14, 3–24. doi: http://dx.doi.org/10.1175/JHM-D-12-023.1**

Land–atmosphere (L–A) interactions play a critical role in determining the diurnal evolution of land surface and planetary boundary layer (PBL) temperature and moisture states and fluxes. In turn, these interactions regulate the strength of the connection between surface moisture and precipitation in a coupled system. To address model deficiencies, recent studies have focused on development of diagnostics to quantify the strength and accuracy of the land–PBL coupling at the process level. In this paper, a diagnosis of the nature and impacts of local land–atmosphere coupling (LoCo) during dry and wet extreme conditions is presented using a combination of models and observations during the summers of 2006 and 2007 in the U.S. southern Great Plains. A range of diagnostics exploring the links and feedbacks between soil moisture and precipitation is applied to the dry/wet regimes exhibited in this region, and in the process, a thorough evaluation of nine different land–PBL scheme couplings is conducted under the umbrella of a high-resolution regional modeling test bed. Results show that the sign and magnitude of errors in land surface energy balance components are sensitive to the choice of land surface model, regime type, and running mode. In addition, LoCo diagnostics show that the sensitivity of L–A coupling is stronger toward the land during dry conditions, while the PBL scheme coupling becomes more important during the wet regime. Results also demonstrate how LoCo diagnostics can be applied to any modeling system (e.g., reanalysis products) in the context of their integrated impacts on the process chain connecting the land surface to the PBL and in support of hydrological anomalies. (Feb 2013)

- **Tao, Z., Santanello, J. A., Chin, M., Zhou, S., Tan, Q., Kemp, E. M., and Peters-Lidard, C. D.: Effect of land cover on atmospheric processes and air quality over the continental United States – a NASA unified WRF (NU-WRF) model study, Atmos. Chem. Phys. Discuss., 13, 5429-5475, doi:10.5194/acpd-13-5429-2013, 2013.**

The land surface plays a crucial role in regulating water and energy fluxes at the land–atmosphere (L–A) interface and controls many processes and feedbacks in the climate system. Land cover and vegetation type remains one key determinant of soil moisture content that impacts air temperature, planetary boundary layer (PBL) evolution, and precipitation through soil moisture–evapotranspiration coupling. In turn it will affect atmospheric chemistry and air quality. This paper presents the results of a modeling study of the effect of land cover on some key L–A processes with a focus on air quality. The newly developed NASA Unified Weather Research and Forecast (NU-WRF) modeling system couples NASA's Land Information System (LIS) with the community WRF model and allows users to explore the L–A processes and feedbacks. Three commonly used satellite-derived land cover datasets, i.e. from the US Geological Survey (USGS) and University of Maryland (UMD) that are based on the Advanced Very High Resolution Radiometer (AVHRR) and from the Moderate Resolution Imaging Spectroradiometer (MODIS), bear large differences in agriculture, forest, grassland, and urban spatial distributions in the continental United States, and thus provide an excellent case to investigate how land cover change would impact atmospheric processes and air quality. The weeklong simulations demonstrate the noticeable differences in soil moisture/temperature, latent/sensible heat flux, PBL height, wind, NO_2/ozone, and $PM_{2.5}$ air quality. These discrepancies can be traced to associate with the land cover properties, e.g. stomatal resistance, albedo and emissivity, and roughness characteristics. It also implies that the rapid urban growth may have complex air quality implications with reductions in peak ozone but more frequent high ozone events.

- **Bracegirdle, Thomas J., Gareth J. Marshall, 2012: The Reliability of Antarctic Tropospheric Pressure and Temperature in the Latest Global Reanalyses. *J. Climate*, 25, 7138–7146.**

In this study, surface and radiosonde data from staffed Antarctic observation stations are compared to output from five reanalyses [Climate Forecast System Reanalysis (CFSR), 40-yr ECMWF Re-Analysis (ERA-40), ECMWF Interim Re-Analysis (ERA-Interim), Japanese 25-year Reanalysis (JRA-25), and Modern Era Retrospective-Analysis for Research and Applications (MERRA)] over three decades spanning 1979–2008. Bias and year-to-year correlation between the reanalyses and observations are assessed for four variables: mean sea level pressure (MSLP), near-surface air temperature (T_s), 500-hPa geopotential height (H_{500}), and 500-hPa temperature (T_{500}).

It was found that CFSR and MERRA are of a sufficiently high resolution for the height of the orography to be accurately reproduced at coastal observation stations. Progressively larger negative T_s biases at these coastal stations are apparent for reanalyses in order of decreasing resolution. However, orography height bias cannot explain large winter warm biases in CFSR, JRA-25, and MERRA (11.1°, 10.2°, and 7.9°C, respectively) at Amundsen–Scott and Vostok, which have been linked to problems with representing the surface energy balance.

Linear trends in the annual-mean T_{500} and H_{500} averaged over Antarctica as a whole were found to be most reliable in CFSR, ERA-Interim, and MERRA, none of which show significant trends over the period 1979–2008. In contrast JRA-25 shows significant negative trends over 1979–2008 and ERA-40 gives significant positive trends during the 1980s (evident in both T_{500} and H_{500}). Comparison to observations indicates that the positive trend in ERA-40 is spurious. At the smaller spatial scale of individual stations all five reanalyses have some spurious trends. However, ERA-Interim was found to be the most reliable for MSLP and H_{500} trends at station locations. (Oct. 2012)

• **Bosilovich, M., 2013. Regional climate and variability of NASA MERRA and recent reanalyses: US summertime precipitation and temperature.** ***J. Appl. Meteorol. Clim.*****. doi:10.1175/BAMS-D-12-00191.**

Reanalyses have increasingly improved resolution and physical representation of regional climate, and so may provide useful data in many regional applications. However, these data are not observations and their limitations and uncertainties need to be closely investigated. We assess reanalyses ability to reproduce the seasonal variations of precipitation and temperature over the United States during summer, when model forecasts have characteristically weak forecast skill. Precipitation variations are reproduced well over much of the United States, especially in the Northwest, where ENSO contributes to the large-scale circulation. Some significant biases in the seasonal mean do exist. The weakest regions are Midwest and Southeast where land atmosphere interactions strongly affect the physical parameterizations in the forecast model. In particular, MERRA's variance is too low (extreme seasonal averages are weak), while • ERA-Interim's variability is affected by spurious low frequency trends. Surface temperature is generally robust among the reanalyses examined, though; reanalyses that • assimilate near-surface observations have distinct advantages. Observations and forecast error from MERRA are used to assess the reanalysis uncertainty across U.S. regions. These data help show where the reanalysis is realistically replicating physical processes, and provide guidance on the quality of the data, and needs for further development.(Jan 2013)

• **Tharammal, T., A. Paul, U. Merkel, and D. Noone, 2013: Influence of LGM boundary conditions on the global water isotope distribution in an atmospheric general circulation model,** ***Clim. Past*****, 9, 789.809, doi:10.5194/cp-9-789-2013**.

To understand the validity of $\delta^{18}O$ proxy records as indicators of past temperature change, a series of experiments was conducted using an atmospheric general circulation model fitted with water isotope tracers (Community Atmosphere Model version 3.0, IsoCAM). A pre-industrial simulation was performed as the control experiment, as well as a simulation with all the boundary conditions set to Last Glacial Maximum (LGM) values. Results from the pre-industrial and LGM simulations were compared to experiments in which the influence of individual boundary conditions (greenhouse gases, ice sheet albedo and topography, sea surface temperature (SST), and orbital parameters) were changed each at a time to assess their individual impact. The experiments were designed in order to analyze the spatial variations of the oxygen isotopic composition of precipitation ($\delta^{18}O_{precip}$) in response to individual climate factors. The change in topography (due to the change in land ice cover) played a significant role in reducing the surface temperature and $\delta^{18}O_{precip}$ over North America. Exposed shelf areas and the ice sheet albedo reduced the Northern Hemisphere surface temperature and $\delta^{18}O_{precip}$ further. A global mean cooling of 4.1 °C was simulated with combined LGM boundary conditions compared to the control simulation, which was in agreement with previous experiments using the fully coupled Community Climate System Model (CCSM3). Large reductions in $\delta^{18}O_{precip}$ over the LGM ice sheets were strongly linked to the temperature decrease over them. The SST and ice sheet topography changes were responsible for most of the changes in the climate and hence the $\delta^{18}O_{precip}$ distribution among the simulations. (April 2013)

• **Lewis, S.C., A.N. LeGrande, M. Kelley, and G.A. Schmidt, 2013: Modeling insights into deuterium excess as an indicator of water vapor source conditions. *J. Geophys. Res.*, 118, 243-262, doi:10.1029/2012JD017804.**

Deuterium excess (d) is interpreted in conventional paleoclimate reconstructions as a tracer of oceanic source region conditions, such as temperature, where precipitation originates. Previous studies have adopted coisotopic approaches (using both $\delta^{18}O$ and d) to estimate past changes in both site and oceanic source temperatures for ice core sites using empirical relationships derived from conceptual distillation models, particularly Mixed Cloud Isotopic Models (MCIMs). However, the relationship between d and oceanic surface conditions remains unclear in past contexts. We investigate this climate-isotope relationship for sites in Greenland and Antarctica using multiple simulations of the water isotope-enabled Goddard Institute for Space Studies ModelE-R general circulation model and apply a novel suite of model vapor source distribution (VSD) tracers to assess d as a proxy for source temperature variability under a range of climatic conditions. Simulated average source temperatures determined by the VSDs are compared to synthetic source temperature estimates calculated using MCIM equations linking d to source region conditions. We show that although deuterium excess is generally a faithful tracer of source temperatures as estimated by the MCIM approach, large discrepancies in the isotope-climate relationship occur around Greenland during the Last Glacial Maximum simulation, when precipitation seasonality and moisture source regions were notably different from the present. This identified sensitivity in d as a source temperature proxy suggests that quantitative climate reconstructions from deuterium excess should be treated with caution for some sites when boundary conditions are significantly different from the present day. Also, the exclusion of the influence of humidity and other evaporative source changes in MCIM regressions may be a limitation of quantifying source temperature fluctuations from deuterium excess in some instances. (Jan 2013)

• **Morrill, C., LeGrande, A. N., Renssen, H., Bakker, P., and Otto-Bliesner, B. L.: Model sensitivity to North Atlantic freshwater forcing at 8.2 ka, *Clim. Past*, 9, 955-968, doi:10.5194/cp-9-955-2013, 2013.**

We compared four simulations of the 8.2 ka event to assess climate model sensitivity and skill in responding to North Atlantic freshwater perturbations. All of the simulations used the same freshwater forcing, 2.5 Sv for one year, applied to either the Hudson Bay (northeastern Canada) or Labrador Sea (between Canada's Labrador coast and Greenland). This freshwater pulse induced a decadal-mean slowdown of 10–25% in the Atlantic Meridional Overturning Circulation (AMOC) of the models and caused a large scale pattern of climate anomalies that matched proxy evidence for cooling in the Northern Hemisphere and a southward shift of the Intertropical Convergence Zone. The multi-model ensemble generated temperature anomalies that were just half as large as those from quantitative proxy reconstructions, however. Also, the duration of AMOC and climate anomalies in three of the simulations was only several decades, significantly shorter than the duration of ~150 yr in the paleoclimate record. Possible reasons for these discrepancies include incorrect representation of the early Holocene climate and ocean state in the North Atlantic and uncertainties in the freshwater forcing estimates. (2013)

• van Vliet,M. T.H., H.P.W.Franssen, Yearsley, J. R. Fulco Ludwig, Ingjerd Haddeland, Dennis P. Lettenmaier, Pavel Kabat, 2013: Global river discharge and water temperature under climate change, *Global Environ. Change*, Issue 2, 450-464

Climate change will affect hydrologic and thermal regimes of rivers, having a direct impact on freshwater ecosystems and human water use. Here we assess the impact of climate change on global river flows and river water temperatures, and identify regions that might become more critical for freshwater ecosystems and water use sectors. We used a global physically based hydrological-water temperature modelling framework forced with an ensemble of bias-corrected general circulation model (GCM) output for both the SRES A2 and B1 emissions scenario. This resulted in global projections of daily river discharge and water temperature under future climate. Our results show an increase in the seasonality of river discharge (both increase in high flow and decrease in low flow) for about one-third of the global land surface area for 2071–2100 relative to 1971–2000. Global mean and high (95th percentile) river water temperatures are projected to increase on average by 0.8–1.6 (1.0–2.2) °C for the SRES B1–A2 scenario for 2071–2100 relative to 1971–2000. The largest water temperature increases are projected for the United States, Europe, eastern China, and parts of southern Africa and Australia. In these regions, the sensitivities are exacerbated by projected decreases in low flows (resulting in a reduced thermal capacity). For strongly seasonal rivers with highest water temperatures during the low flow period, up to 26% of the increases in high (95th percentile) water temperature can be attributed indirectly to low flow changes, and the largest fraction is attributable directly to increased atmospheric energy input. A combination of large increases in river temperature and decreases in low flows are projected for the southeastern United States, Europe, eastern China, southern Africa and southern Australia. These regions could potentially be affected by increased deterioration of water quality and freshwater habitats, and reduced water available for human uses such as thermoelectric power and drinking water production. (April 2013)

• Gu, G., R.F. Adler, 2012: Interdecadal variability/long-term changes in global precipitation patterns during the past three decades: global warming and/or pacific decadal variability? *Clim. Dyn*.

This study explores how global precipitation and tropospheric water vapor content vary on the interdecadal/long-term time scale during past three decades (1988–2010 for water vapor), in particular to what extent the spatial structures of their variations relate to changes in surface temperature. EOF analyses indicate that the observed linear changes/trends in both precipitation and tropospheric water vapor during 1988–2010 seem to result from a combined impact of global mean surface warming and the PDV shift. In particular, in the tropical central-eastern Pacific, a band of increases along the equator in both precipitation and water vapor sandwiched by strong decreases south and north of it are likely caused by the opposite effects from global-mean surface warming and PDV-related, La Niña-like cooling in the tropical central-eastern Pacific. This narrow band of precipitation increase could also be considered an evidence for the influence of global mean surface warming.

• **Mersel, M. K., L. C. Smith, K. M. Andreadis, and M. T. Durand (2013), Estimation of river depth from remotely sensed hydraulic relationships, Water Resour. Res., 49, doi:10.1002/wrcr.20176.**

The Surface Water and Ocean Topography (SWOT) radar interferometer satellite mission will provide unprecedented global measurements of water surface elevation (*h*) for inland water bodies. However, like most remote sensing technologies SWOT will not observe river channel bathymetry below the lowest observed water surface, thus limiting its value for estimating river depth and/or discharge. This study explores if remotely sensed observations of river inundation width and *h* alone, when accumulated over time, may be used to estimate this unmeasurable flow depth. To test this possibility, synthetic values of *h* and either cross-sectional flow width (*w*) or effective width (W_e, inundation area divided by reach length) are extracted from 1495 previously surveyed channel cross-sections for the Upper Mississippi, Illinois, Rio Grande, and Ganges-Brahmaputra river systems, and from 62 km of continuously acquired sonar data for the Upper Mississippi. Two proposed methods (called "Linear" and "Slope-Break") are tested that seek to identify a small subset of geomorphically "optimal" locations where *w* or W_e covary strongly with *h*, such that they may be usefully extrapolated to estimate mean cross-sectional flow depth (*d*). While the simplest Linear Method is found to have considerable uncertainty, the Slope-Break Method, identifying locations where two distinct hydraulic relationships are identified (one for moderate to high flows and one for low flows), holds promise. Useful slope breaks were discovered in all four river systems, ranging from 6 (0.04%) to 242 (16%) of the 1495 studied cross-sections, assuming channel bathymetric exposures ranging from 20% to 95% of bankfull conditions, respectively. For all four rivers, the derived depth estimates from the Slope-Break Method have root mean squared errors (RMSEs) of <20% (relative to bankfull mean depth) assuming at least one channel bathymetry exposure of ~25% or greater. Based on historic discharge records and HEC-RAS hydraulic modeling, the Upper Mississippi and Rio Grande rivers experience adequate channel exposures at least ~60% and ~42% of the time, respectively. For the Upper Mississippi, so-called "reach-averaging" (spatial averaging along some predetermined river length) of native-resolution *h* and W_e values reduces both RMSE and longitudinal variability in the derived depth estimates, especially at reach-averaging lengths of ~1000–2000 m. These findings have positive implications for SWOT and other sensors attempting to estimate river flow depth and/or discharge solely from incomplete, remotely sensed hydraulic variables, and suggest that useful depth retrievals can be obtained within the spatial and temporal constraints of satellite observations.

• **Gao, H., C. Birkett, and D.P. Lettenmaier, 2012. Global monitoring of large reservoir storage from satellite remote sensing, *Water Resources Research* 48, W09504, doi: 10.1029/2012WR012063.**

We studied 34 global reservoirs for which good quality surface elevation data could be obtained from a combination of five satellite altimeters for the period from 1992 to 2010. For each of these reservoirs, we used an unsupervised classification approach using the Moderate Resolution Imaging Spectroradiometer (MODIS) 16-day 250 m vegetation product to estimate the surface water areas over the MODIS period of record (2000 to 2010). We then derived elevation-area relationships for each of the reservoirs by combining the MODIS-based estimates with satellite altimeter-based estimates of reservoir water elevations. Through a combination of direct observations of elevation and surface area along with documented reservoir configurations at capacity, we estimated storage time histories for each reservoir from 1992 to 2010. We evaluated these satellite-based data products in comparison with gauge observations for the five largest reservoirs in the United States (Lakes Mead, Powell, Sakakawea, Oahe, and Fort Peck Reservoir). The storage estimates were highly correlated with observations (R = 0.92 to 0.99), with values for the normalized root mean square error (NRMSE) ranging from 3% to 15%.

The storage mean absolute error (expressed as a percentage of reservoir capacity) for the reservoirs in this study was 4%. The multidecadal reconstructed reservoir storage variations are in accordance with known droughts and high flow periods on each of the five continents represented in the data set. (Sept 2012)

Major activities / accomplishments:

- **GCPEx Wraps Up Cold Season Field Campaign**

For six weeks in Ontario, Canada, scientists and engineers lead a field campaign to study the science and mechanics of falling snow. The datasets retrieved will be used to generate algorithms which translate what the GPM Core satellite "sees" into precipitation rates, including that of falling snow. Field campaigns are critical in improving satellite and precipitation measurements. Now a phenomenal effort actually goes into quality controlling all of the data we collected.
http://pmm.nasa.gov/node/591

- **Iowa Flood Studies** The Iowa Flood Studies (IFloodS) are a ground measurement campaign that took place in eastern Iowa from May 1 to June 15, 2013. Ground data now being collected in northeastern Iowa by the Iowa Flood Studies experiment will evaluate how well NASA's Global Precipitation Measurement (GPM) mission satellite rainfall data can be used for flood forecasting. The overarching objective of integrated hydrologic ground validation activities supporting the Global Precipitation Measurement Mission (GPM) is to provide better understanding of the strengths and limitations of the satellite products, in the context of hydrologic applications.

Specific science objectives and related goals are: 1. Quantify the physical characteristics and space/time variability of rain (rates, DSD, process/"regime") and map to satellite rainfall retrieval uncertainty. 2. Assess satellite rainfall retrieval uncertainties at instantaneous to daily time scales and evaluate propagation/ impact of uncertainty in flood-prediction. 3. Assess hydrologic predictive skill as a function of space/time scales, basin morphology, and land use/cover. 4. Discern the relative roles of rainfall quantities such as rate and accumulation as compared to other factors (e.g. transport of water in the drainage network) in flood genesis. 5. Refine approaches to "integrated hydrologic GV" concept based on IFloodS experiences and apply to future GPM Integrated GV field efforts.

Collectively the observational assets will provide a means to create high quality (time and space sampling) ground "reference" rainfall and stream flow datasets. The ground reference radar and rainfall datasets will provide a means to assess uncertainties in both satellite algorithms (physics) and products. Subsequently, the impact of uncertainties in the satellite products can be evaluated in coupled weather, land-surface and distributed hydrologic modeling frameworks as related to flood prediction.
http://pmm.nasa.gov/**node/784**

- **NASA's IceBridge Finishing Up Successful Arctic Campaign, Filling in Gaps**

Terminus of Wordie Glacier in northeast Greenland with small terminal moraine. Wordie Glacier is a land-terminating glacier that is not in contact with water in the fjord. Scientists and engineers with NASA's Operation IceBridge continued their work to gather vital information on Arctic ice with flights into areas not extensively covered in previous campaigns. With one sea ice flight and one ice sheet survey in the books, researchers headed toward the end of the campaign and the last of the mission's high priority flights.

This mission also involved coordinating with a satellite that provides data for the Global Fiducials Library (GFL) at the U.S. Geological Survey. GFL is a collaborative effort between various academic institutions and U.S. government agencies that maintains a long-term record of high-resolution imagery of Arctic sea ice The objective of this collaboration was to see how feasible coordinating observations from multiple sources is and to find out what benefits there are in combining such measurements of Arctic sea ice cover.The Apr. 23 flight was a new mission designed to fill in a gap in surface elevation and ice thickness coverage in north Greenland.

SMAP

- **SMAP Validation Experiment 2012 (SMAPVEX12)**

SMAPVEX12 is the primary pre-launch field campaign for SMAP established to provide data for algorithm evaluation and testing and applications development. Several agencies in the U.S. and Canada are cooperating in the SMAPVEX12 data acquisition, processing and analysis.

The ground and airborne data acquisition phase of SMAPVEX12 took place over a period of approximately six weeks from June 6 to July 19, 2012 in an agricultural region south of Winnipeg, Manitoba (Canada). The campaign was organized jointly with the Canadian SMAP Science Team who were responsible for coordinating the site logistics and ground data sampling.

- **Highlights and Meetings**

SMAP is now eight months into Phase C since successful CDR in July 2012

  Algorithm Theoretical Basis Documents have matured and released.
  Project's major prelaunch field campaign (SMAPVEX12) successfully completed
  Excellent progress following Delta II selection

Since CDR instrument, antenna and spacecraft subsystems manufactured

System integration an test phase has matured for the systems integration review (SIR: April 8-10, 2013.

SMAP Satellite Soil Moisture Validation and Application Workshop

The objective of the workshop was to discuss and reconcile recent methodological advances in the validation and application of global satellite soil moisture data. The workshop focused on soil moisture products derived from current and future active and passive microwave sensors operating in the low frequency range from 1 to 10 GHz, including but not limited to ASCAT, SMOS, AMSR-E, ASAR, SMAP, Sentinel-1 and any combination thereof.

The end goal for the workshop was to collect material for a white paper on "Best practice guidelines for the validation of satellite soil moisture data using in situ data hosted by the International Soil Moisture Network (ISMN)" which is foreseen as a contribution to GEWEX, CEOS, TOPC, and WMO. (July 2013)

Joint SMAP/GPM Teacher Workshop; a hit!

The SMAP and GPM Mission Education teams held a groundbreaking multi-mission teacher workshop on Wednesday, June 26, 2013 at the NASA Goddard Space Flight

Center. This workshop, the SMAP-GPM Joint Mission Teacher Workshop, was attended by 15 middle school teachers from the Goddard region. Teachers were from Maryland, Delaware, Virginia, and Pennsylvania.

This workshop was designed to showcase how NASA studies soil moisture and global precipitation from space. We connected how soil moisture and precipitation directly relates to the global water cycle and the teachers performed some engaging, hands-on activities and experiments that can be used in their classrooms.

SMAP/ICESat-2 Joint Mission Tutorial Workshop, Fairbanks, AK
Alaska Satellite Facility (ASF), September 18-20, 2012
The goals for the workshop were 1). to address value-added data products and science returns from combined SMAP/ICESat-2 data, 2). identify challenges and needs for cryosphere, northern forests, land and ocean science applications, 3).Identify new users

for SMAP mapping radar and ICESat-2 altimetry data, e.g. vegetation mapping, sea-ice mapping, etc 4). 5). motivate joint mission efforts and innovative applications with prelaunch hydrosphere and cryosphere applications using other mission products from existing missions (Sept 2012)

Additional SMAP meetings and workshop include:

- **Canadian SMAP Science Workshop #3, Ottawa, Canada**
  3rd Canadian SMAP Science Workshop, March 20-21, 2013
- **SMAP Science Definition Team (SDT) Meeting #10, Pasadena, CA**
  10th meeting of the SMAP Science Definition Team, March 5-7, 2013
- **SMAP Cal/Val Workshop #3, Oxnard, CA**
  3rd SMAP Cal/Val Workshop, November 14-16, 2012
- **SMAP/GPM/GRACE-FO/SWOT Joint Mission Tutorial Workshop, Reston, VA**
  USGS National Center. **October 17, 2012**
- **SMAP Science Definition Team (SDT) Meeting #9, Pasadena, CA**
  9th meeting of the SMAP Science Definition Team, October 3-4, 2012

* **(SMAP slides attached)**

Other Meetings:

- A **GRACE workshop** was held at JPL, July 15-17, 2013 on the use of GRACE data to monitor, simulate and understan d ongoing changes in the Earth's hydrosphere and water cycle. Since 2002, the GRACE mission has been measuring Earth's gravity field variations and continues to do so in unprecedented detail, revealing key insights into Earth's water storage and transport processes over land, ice and oceans.

2013 NASA Water Resources workshops

- **Nile Basin Remote Sensing and Modeling Demonstration Meeting 2013 May 7; NASA Headquarters, Washington DC, USA**
- **NASA Satellites for Moroccan Water Resources 2013 April 4; NASA Goddard, Greenbelt, Maryland, USA**
- **Practical Use of Satellites for Improved Water & Environmental Management 2013 Mar. 7; World Bank offices, Washington DC, USA**

- The **2013 NEWS** (NASA Energy and Water cycle Study) **Science Team Meeting**, held May 1-2, 2013, has been structured to embrace the 18 new NEWS science investigations selected by NASA as a result of the ROSES-2011 solicitation. Current working groups are charged with coordinating and integrating NEWS PI science investigations; liaise with relevant flight missions and NASA R&A Programs; implement annual assessment of progress in meeting NEWS scientific requirements; and contribute to periodic Implementation Plan (IP) updates. A principal goal of the working groups is to promote the development of scientific papers. Current NEWS working groups include **Extremes, Climate Shift, Evaporation and Latent Heating and Clouds and Radiation**.

- **Workshop: Water Cycle Missions for the Next Decade**

Building on the first Earth Science Decadal Survey, NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space, and the 2012 Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, a workshop on Water Cycle Missions for the Next Decade took place in April 2013 to gather wisdom and determine how to prepare for the next generation of water cycle missions, in support of the second Earth Science Decadal Survey. The workshop discussed the intersection between science questions, technology readiness and satellite design optimization in a series of breakout group discussions designed to lead to a set of water cycle mission formulation groups. The workshop will hopefully lead to formulating next-generation water cycle mission working groups and white papers, designed to identify capacity gaps and inform NASA. Approximately 129 people registered for this workshop.