Exploiting Satellite Observations of the PBL for Land-Atmosphere Interaction Studies

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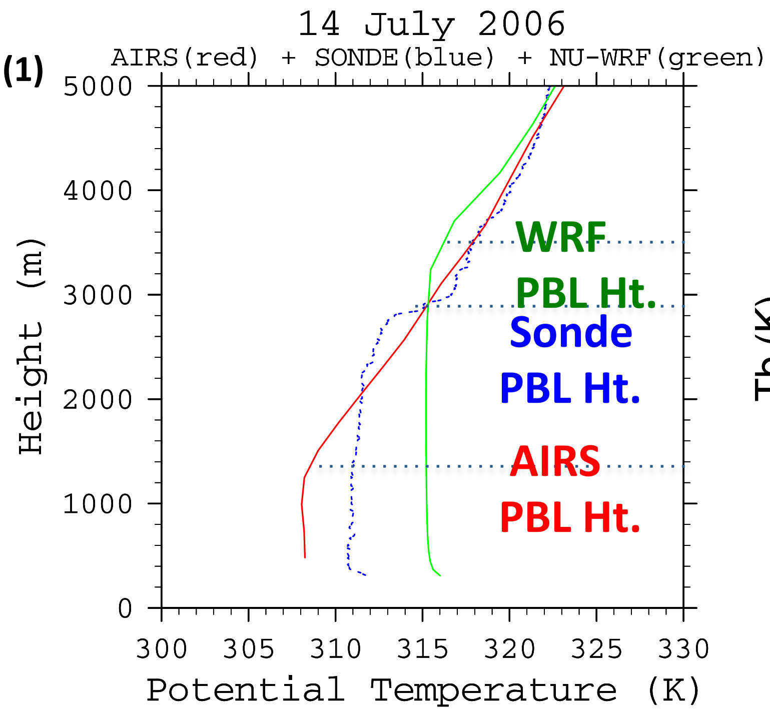

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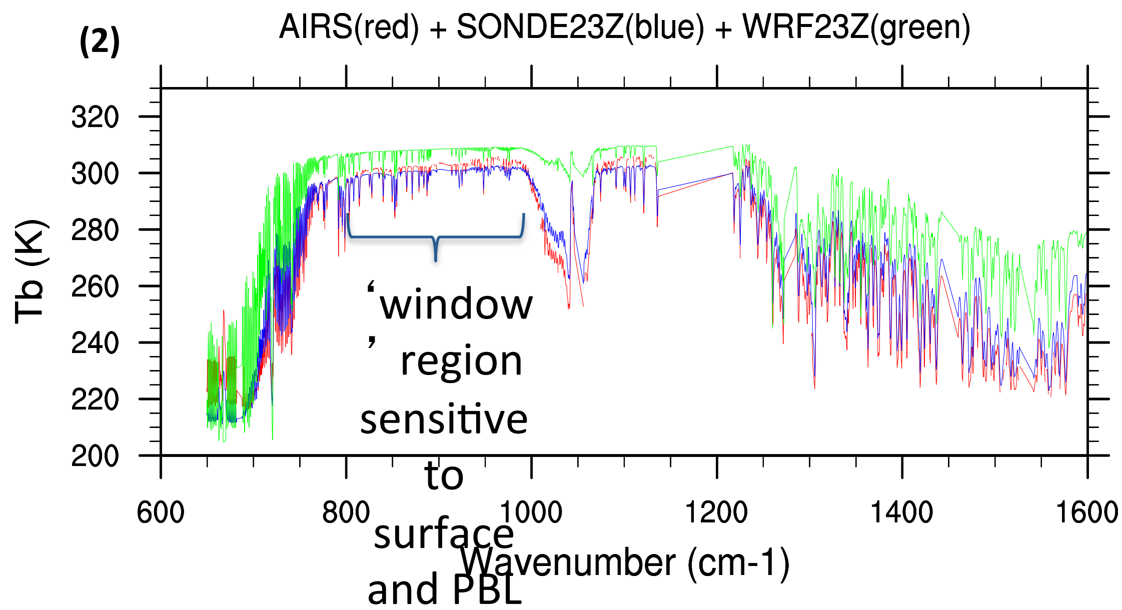

- **The Planetary Boundary Layer** (PBL; <4km above the surface) is a critical reservoir and integrator of land surface process, water and energy cycling, and land-atmosphere (L-A) interactions.
- **Observations of PBL height, temperature, and humidity** are therefore necessary for evaluation and development of L-A coupling in weather and climate models.
- Current **satellite-based *indirect* estimates of PBL structure** (such as from AIRS; **Fig. 1**) are limited by biases in the PBL and/or insufficient spatial, vertical, or temporal coverage.
- By **converting profiles into radiances** (brightness temperature; Tb) measured by the satellite (**Fig. 2**), models and in-situ observations can be ***directly*** compared against the full spectrum of instrument channels sensitive to the land surface and PBL.

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References:

•**Matsui, T., J. Santanello, J. J. Shi, W.-K. Tao, D. Wu, C. Peters-Lidard, E. Kemp, M. Chin, D. Starr, M. Sekiguchi, and F. Aires, 2014:** Introducing Multi-Sensor Satellite Radiance-based Evaluation for Regional Earth System Modeling, *Journal of Geophysical Research,* (accepted).

•**Santanello, J. A., M. A. Friedl, J. Susskind, S. Palm, and B. Zavodsky, 2010**: The Synergistic Use of NASA Satellites to Characterize the PBL and its Role in Land-Atmosphere Interactions. *15th International Symposium for the Advancement of Boundary Layer Remote Sensing (ISARS),* 28-30 June.

•**Peters-Lidard, C.D., E. M. Kemp, T. Matsui, J. A. Santanello, Jr., S. V., Kumar, J. Jacob, T. Clune, W.-K. Tao, M. Chin, A. Hou, J. L. Case,, D. Kim, K.-M. Kim, W. Lau, Y. Liu, J.-J. Shi, D. Starr, Q. Tan,, Z. Tao, B. Zaitchik, B. Zavodsky, S. Zhang, M. Zupanski, 2014:** Integrated Modeling of Aerosol, Cloud, Precipitation and Land Processes at Satellite-Resolved Scales with the NASA Unified-Weather Research and Forecasting Model, *Environmental Modelling & Software,* (submitted).

Data Sources:

•**AIRS** measures L1B cloud-cleared radiances across the NIR spectrum, and from this retrieves L2 vertical profiles of temperature and humidity through the troposphere. AIRS (aboard Aqua) is a high resolution sounding instrument that employs 2378 spectral channels with a footprint at nadir of 13km. One profile retrieval is generated for each 3x3 array of AIRS footprints, giving a spatial resolution of 45km and 100 vertical levels and a target accuracy of 1°K/1km for temperature and 15%/2km for humidity.

•Corresponding model output for the same site and time period is from the **NASA Unified WRF (NU-WRF)** model, which is coupled to **NASA's Land Information System (LIS)** to allow for investigations of land-atmosphere coupling and land surface model spinup and calibration. NU-WRF has been run over a large 1km domain over the SGP for this study.

•In-situ observations are from **radiosonde** launches at the **DOE-ARM** facility in Lamont, OK.

•Modeled and observed radiances (Tb) are then generated from the **GSFC Satellite Data Simulator Unit (G-SDSU)** with the addition of the new **Stand Alone Radiative Transfer Algorithm (SARTA)** that exactly replicates the Tb channel resolution of AIRS.

Technical Description of Figures:

Figure 1: Intercomparison of vertical temperature profiles in the lower troposphere from AIRS (red), radiosonde (blue), and NU-WRF (green) on 14 July 2006 over the U.S. SGP region. Limitations of AIRS vertical resolution and accuracy are apparent (PBL height too low; profiles too cold) and limit the ability of AIRS profile retrievals to be used as observations or benchmarks for models.

Figure 2: Brightness temperature spectra for AIRS, sonde, and NU-WRF valid at the same time and location as Fig. 1. By converting the model and sonde profiles into Tb radiance space using G-SDSU/SARTA, direct comparison over 2378 channels can be performed to see where differences, sensitivities, and accuracies lie across the spectrum. The window and PBL-sensitive channels are of primary interest for L-A interaction studies.

Scientific significance, societal relevance, and relationships to future missions: Land-atmosphere interactions remain weak links in our current quantification of the water and energy cycle. This work combines unique NASA satellite and model products to evaluate the ability of current sensors (namely AIRS) to retrieve variability in land-PBL properties and in turn used as a global benchmark to which evaluate models against. To date, profile retrievals from AIRS in lower troposphere over land have shown limited accuracy, but empirical studies suggest that radiances themselves are in fact sensitive to land and PBL variability. Thus, transforming model output profiles into radiance space enables direct comparison across satellite, models, and in-situ observations.

****Improvement in profile retrieval in the lower troposphere should be stressed as a priority for next-generation satellite missions, but is still largely ignored as PBL monitoring at daily and regional scales remains a significant gap in our suite of global observations.***

LIS-based NLDAS Transitioned to Operations at NOAA/NCEP

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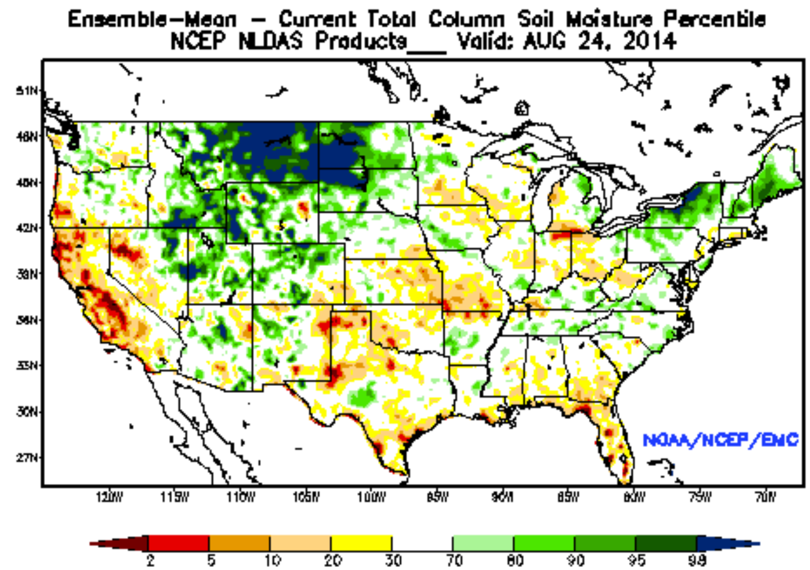
Highlight:

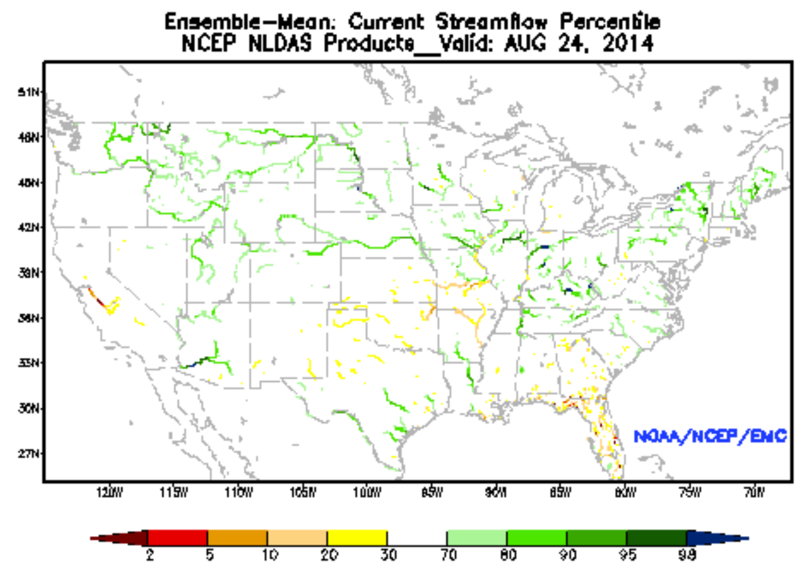
NLDAS – the North American Land Data Assimilation System – became part of NOAA's National Centers for Environmental Prediction (NCEP) Central Operations on 5 August 2014. It is a collaborative project between NOAA/NCEP Environmental Modeling Center, NASA/GSFC, Princeton Univ., the Univ. of Washington, NOAA's Office of Hydrologic Development, and NOAA's Climate Prediction Center.

- NLDAS provides near real-time updates of land-surface conditions, including precipitation, temperature, soil moisture, snow, surface fluxes, and streamflow, over the continental United States.
- NLDAS is also used to initialize land-surface conditions for short-term weather predictions.

Relevance:

- NLDAS is used as an input to the U.S. Drought Monitor, which provides weekly drought assessments in the United States. These assessments are used by policymakers in allocating drought relief.
- NLDAS uses the NASA-developed Land Information System (LIS) software framework. Future versions of NLDAS using LIS will include new and upgraded land-surface models as well as data assimilation of remotely-sensed land-surface states.





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Project Summary: The goal of the North American Land Data Assimilation System (NLDAS) is to construct quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available observations and model output to support modeling and drought monitoring activities. A major accomplishment occurred on 5 Aug 2014 at NOAA/NCEP/EMC with the implementation of NLDAS into NCEP Operations.

Scientific Heritage: This research was made possible by the long heritage of collaboration between the NLDAS partners on the development of observation products, land-surface models, software frameworks (including the NASA-developed Land Information system – LIS), and hydrologic applications. Significant references for the development of NLDAS include Mitchell et al. (2004) and Xia et al. (2012); for the development of LIS, please see Kumar et al. (2006) and Peters-Lidard et al. (2007).

Earth Science Data Products: NLDAS uses a near real-time atmospheric analysis product from NCEP, together with a gridded analysis of precipitation gauge observations, to drive the land-surface models. The research version of NLDAS has included data assimilation of products from AMSR-E, AMSR2, MODIS, ASCAT, and GRACE, and will be transitioned into NCEP operations in the next 1-2 years, including data from SMAP following its launch.

Technical Description of Figures:
Figure 1: NLDAS Drought Monitor image from 24 Aug 2014 for the ensemble mean total column soil moisture percentile. The color bar corresponds to U.S. Drought Monitor severity categories, with darker red indicating exceptional drought. The percentiles are calculated against the long-term NLDAS climatology from Jan 1979, and indicate where in that climatology the conditions on the given date are present.

Figure 2: Same as Figure 1, but for streamflow.

Application to ESDAS: NLDAS products are used as one of the inputs to the U.S. Drought Monitor, which provides weekly drought assessments that are used by policymakers in allocating drought relief. NLDAS is also used for water management, crop damage assessments, water quality applications, and initial conditions for weather forecasts. Numerous studies have shown improved outputs for these applications from the use of NLDAS data products.

References:
Kumar, S.V., C.D. Peters-Lidard, et al., 2006: Land Information System - An Interoperable Framework for High Resolution Land Surface Modeling. *Environmental Modelling & Software*, **21**, 1402-1415. DOI:10.1016/j.envsoft.2005.07.004

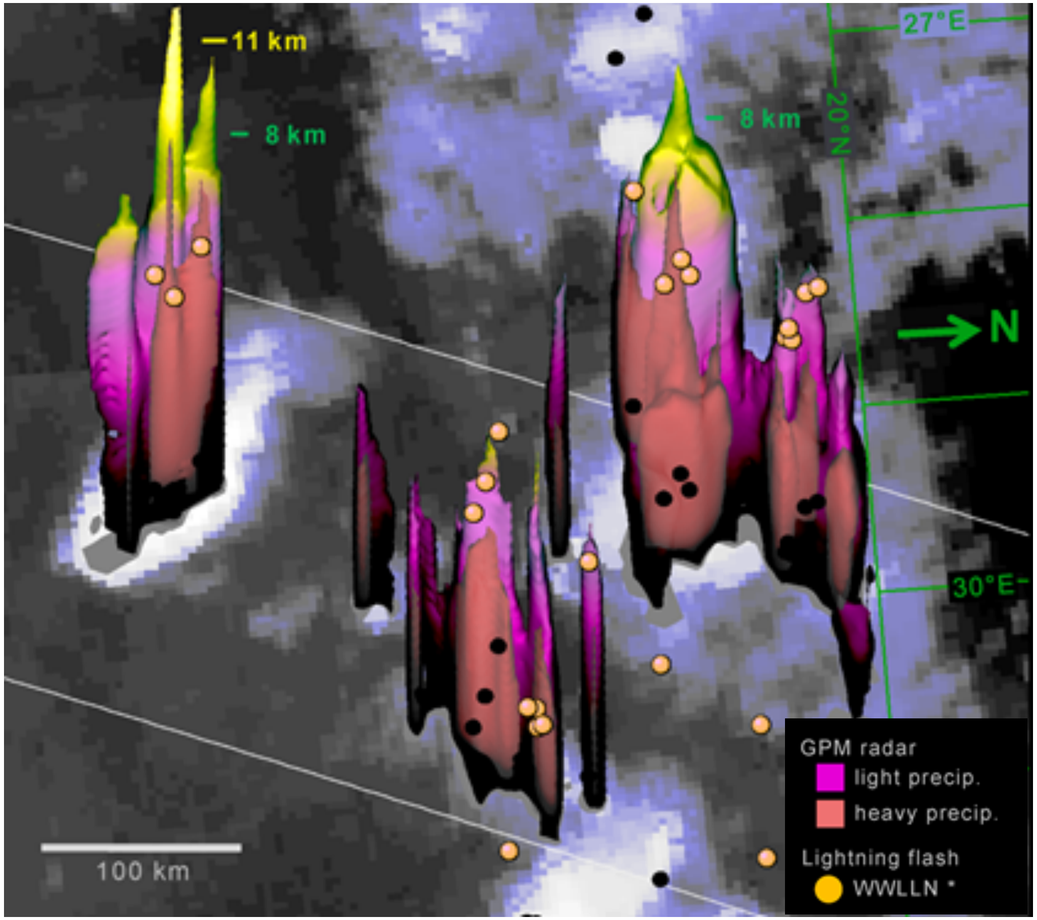
Mitchell, K.E., et al., 2004: The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. *Journal of Geophysical Research*, **109**, D07S90, DOI:10.1029/2003JD003823.

Peters-Lidard, C.D., P.R. Houser, Y. Tian, S.V. Kumar, et al., 2007: High-performance Earth system modeling with NASA/GSFC's Land Information System. *Innovations in Systems and Software Engineering*. **3**(3), 157-165. DOI:10.1007/s11334-007-0028-x

Xia, Y., et al., 2012: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System project phase 2 (NLDAS-2): 1. Intercomparison and application of model products, *Journal of Geophysical Research*, **117**, D03109, DOI:10.1029/2011JD016048

TRMM and GPM observe a rare Sahara Desert storm

GPM Team, NASA/GSFC



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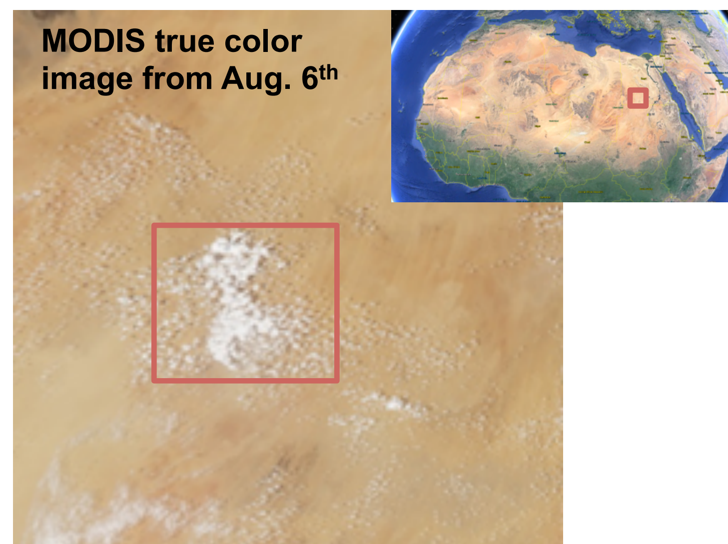

On August 6, 2014, the TRMM and GPM satellites saw a swarm of thunderstorms over a portion of the Sahara Desert where rain is particularly rare. Both the TRMM and GPM satellites carry a Ku-band radar capable of revealing the three-dimensional structure of precipitation.

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References:
Kelley, Owen A. (2014). Where the least rainfall occurs in the Sahara Desert, the TRMM radar reveals a different pattern of rainfall each season. Journal of Climate, doi: http://dx.doi.org/10.1175/JCLI-D-14-00145.1.

Data Sources: GPM Dual-frequency Precipitation Radar (DPR) and GPM Microwave Imager (GMI) data. World Wide Lightning Location Network (WWLLN) , data courtesy of Robert Holzworth (University of Washington). MODIS True Color image of the area observed. Google Earth © image of the region for context.

Technical Description of Figures:
Graphic 1: The GPM satellite flew over the eastern side of the thunderstorm cluster in the early evening (7 PM local time) and saw three wide, rain features producing lightning. Each of these three features were 50-80 km across, suggesting they each contained multiple rain-cells. Such multi-cells features can persist for hours, much longer than typical single-cell thunderstorms. The World Wide Lightning Location Network (WWLLN) saw a somewhat higher flash rate in the evening storms observed by GPM compared to the WWLLN flash rate for the single-cell storms seen a few hours earlier by TRMM.

Almost half of the lightning that the TRMM LIS instrument has observed all year in this very dry portion of the Sahara Desert occurred in connection with the August 6 thunderstorm cluster. Other data available in near-realtime can help us begin to piece together why these thunder storms occurred over such an unlikely place on August 6. The NCEP reanalysis suggests two things were different on August 6 compared with the previous 5 days at least. The tropical low-level moisture that often fuels intense thunderstorms to the south had moved several hundred kilometers northward toward the central Sahara on August 6. The large-scale upward motion that typically occurs over the hot, barren, central Sahara in the summer had moved somewhat southward on August 6 so that it lined up with the extra moisture that was coming northward. This "bomb" went off in the afternoon once the sun-baked desert surface became warm enough to trigger convection. The cloud-top temperatures available every 30 minutes from geosynchronous satellites shows that whereas only low clouds had formed in the late afternoon of August 5, the northern edge of the moisture intrusion was peppered with thunderstorms along an east-west line from the Rea Sea westward for approximately
1500 kilometers into the east-central Sahara Desert.

Scientific significance, societal relevance, and relationships to future missions: The TRMM satellite has been in orbit almost 17 years, and this long record enables us to appreciate the unusualness of the August 6, 2014, thunderstorm cluster. This cluster formed along the southern boundary of the part of the Sahara Desert that receives the least rainfall of any continental region on Earth within 35 degrees of the Equator. This region of the Sahara is bounded by 20-27N 22-32E according to a paper recently accepted by the Journal of Climate that was written by NASA Goddard researcher Owen Kelley.

This region of the central Sahara receives only 1-5 millimeters (≤ 0.2 inches) of rain a year on average according to the TRMM radar, and this region is as large as the entire southeast United States. In comparison, more rain falls over both the U.S. mid-Atlantic states (1 meter or ~40 inches) and even most of the rest of the Sahara Desert (10-100 mm or 0.4-4 inches). In the August 6, 2014 thunderstorm cluster, TRMM and GPM estimated that rain was falling at a rate of 2 to 20 millimeters an hour under about half of thunderstorm cells which is modest for a typical United States East Coast thunderstorm but rain at this rate could have delivered much of a year's worth of rain over this very arid region if it were sustained for a significant fraction of an hour.

The rare thunderstorms that contribute significantly to the annual rainfall accumulation in the east-central Sahara Desert can only be studied from space because this part of the Sahara lacks a network of ground radars and only a handful of location in this large region contribute rain-gauge observations to public data archives.