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Enhanced Soundings for Local Coupling Studies: 2015 ARM Climate Research Facility Field Campaign

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November 2014

ARM
CLIMATE RESEARCH FACILITY

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Summary

Matching observed diurnal cycles is a fundamental yet extremely complex test for models. High temporal resolution measurements of surface turbulent heat fluxes and boundary layer properties are required to evaluate the daytime evolution of the boundary layer and its sensitivity to land-atmosphere coupling. To address this need, (12) one-day intensive observing periods (IOP) with enhanced radiosonding will be carried out at the ARM Southern Great Plains (SGP) Central Facility (CF) during summer 2015. Each IOP will comprise a single launch to correspond with the nighttime overpass of the A-Train of satellites (~0830 UTC) and hourly launches during daytime beginning from 1130 UTC and ending at 2130 UTC. At 3-hourly intervals (i.e., 1140 UTC, 1440 UTC, 1740 UTC, and 2040 UTC) a duplicate second radiosonde will be launched 10 minutes subsequent to launch of the on-hour radiosonde for the purpose of assessing horizontal atmospheric variability. In summary, each IOP will have a 14-sounding supplement to the 6-hourly operational sounding schedule at the ARM-SGP CF. The IOP days will be decided before sunset on the preceding day, according to the judgment of the PI's and taking into consideration daily weather forecasts and the operability of complimentary ARM-SGP CF instrumentation. An overarching goal of the project is to address how ARM could better observe land-atmosphere coupling to support the evaluation and refinement of coupled weather and climate models.

Acronyms and Abbreviations

AERI	Atmospheric emitted radiance interferometer
ARM	Atmospheric Radiation Measurement
CF	Central Facility
CTP	convective-triggering potential
DICE	Diurnal Cycle Experiment
EF	Extended facilities
GABLS	Global Atmospheric Boundary Layer Study
GEWEX	Global Energy and Water Cycle Experiment
GLACE	Global Land-Atmosphere Coupling Experiment
IOP	Intensive observing periods
PBL	Planetary boundary layer
PI	Principal Investigator
RL	Raman lidar
SGP	Southern Great Plains

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1.0 Introduction

The Global Energy and Water Cycle Experiment (GEWEX) and Global Land-Atmosphere Coupling Experiment (GLACE; Guo et al. 2006; Koster et al. 2006) demonstrated the strength of land-atmosphere coupling in affecting simulated climate predictability at the seasonal time scale, within a model. Using the multi-model mean coupling strength, GLACE identified three contiguous global regions where coupling exerts an especially strong influence. GLACE termed these regions coupling “hot spots”, one of which was the Southern Great Plains (SGP), which houses the Atmospheric Radiation Measurement (ARM) Climate Research Central Facility (CF), and is the most well-equipped of all the hot spots.

Two properties are satisfied at the SGP. First, evapotranspiration is controlled by soil moisture availability, and second, the evapotranspiration fluctuations (and conversely, sensible heating) are large enough to contribute significantly to cloud formation and rainfall. In the SGP, uniquely, convection may be supported during both wet and dry soil moisture extremes (i.e., Findell and Eltahir 2003; Ferguson and Wood 2011). However, the current ability to characterize this coupling (for both wet and dry cases) is poor. This gap in understanding is readily exposed by model misrepresentations of the daily surface heat flux cycles, planetary boundary layer (PBL) development, and convective precipitation triggering.

Despite the wealth of multi-process instrumentation at ARM-SGP CF, the general consensus from internationally-recognized land-atmosphere experts (Santanello et al. 2011b) is that the lack of high temporal resolution radio-soundings represent a prominent barrier to observing, and hence, modeling the daytime evolution of the PBL. Specifically, the current six hour operational radiosonde launch schedule and occasional three hour launch schedule (e.g., conducted over a few days during the International H2O Project 2002), are insufficient for capturing temporal variability of land-atmosphere interactions. High temporal resolution measurements of surface turbulent heat fluxes and lower boundary layer properties are required to evaluate the diurnal evolution of the boundary layer and its sensitivity to land-atmosphere coupling. This lack of sufficient co- located surface and atmospheric profile measurements has long been cited as a barrier to improving diagnoses and modeling of coupling mechanisms (e.g., Dirmeyer et al. 2006).

In response to this perceived need, DOE ARM is supporting an enhanced radiosonde launch campaign at the ARM-SGP CF, to be conducted 15 June to 31 August 2015. This campaign constitutes a fourteen-sounding supplement to the six hour operational sounding schedule at the ARM-SGP CF, as illustrated in Figure 1, on each of twelve (or more) Intensive Operational Period (IOP) days. Each of the soundings constitutes a distinct added value to the total record, incrementally increasing its usefulness. For example, the nighttime sounding correspondent with the overpass of the Earth observing satellites A-Train (0830 UTC) will provide an additional measurement of the residual layer, which has previously been identified as a primary control on daytime convective PBL evolution over land (Medeiros et al. 2005; Santanello et al. 2007). It will also enable evaluation of the representativeness of the 1200 UTC (local sunrise) profile traditionally used to parameterize the residual layer at ARM-SGP CF. The impact of variability between soundings on derived coupling diagnostics (i.e., those of Ferguson and Wood, 2011; Roundy et al. 2013) can also be quantified. The daytime hourly soundings will constitute, to our knowledge, the highest temporal resolution, multi-day record of the daytime PBL evolution ever collected. The new record of enhanced soundings should contribute substantially to improved process-level understanding and modeling of land- atmosphere couplings.

With the approaching 2016 SGP CF reconfiguration, intended to provide improved high-resolution modeling, it is crucial to first address how ARM can more efficiently observe land-atmosphere coupling and support the evaluation and refinement of coupled models. Augmenting the ARM-SGP CF operational suite of instruments with hourly daytime soundings will enable the campaign to sufficiently evaluate observed land-atmosphere couplings, as well as ARM's current capabilities to make such observations The campaign was specifically designed using a cost-effective approach, to achieve a measurable impact on current scientific understanding and serve as a benchmark for, or against, future intensive sounding campaigns, either at ARM-SGP CF (i.e., as an extension of this campaign's twelve-day record) or as part of a larger, regional-scale hydro-climatology experiment (i.e., North American Water Program: http://www.nawaterprogram.org/tracemtg.html).

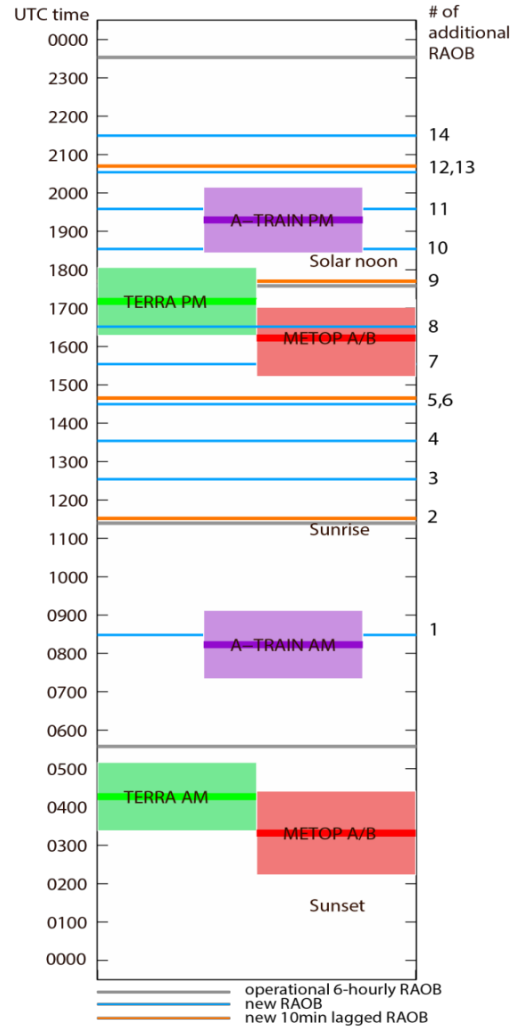

Figure 1. Projected July 2015 overpass times at ARM- SGP for several platforms superimposed on the campaign launch schedule (in UTC: 0530, 0830, 1130,1140, 1230, 1330, 1430, 1440, 1530, 1630, 1730, 1740,1830, 1930, 2030, 2040, 2130, and 2330). The A-Train consists of GCOM-W1, Aqua, Cloudsat, CALIPSO, PARASOL, and Aura. Aqua carries AIRS, CERES, and AMSR-E; Terra carries CERES and MODIS; and MetOp-A/B both carry IASI.

2.0 Science Objectives

The first overarching goal of the enhanced observational period was to improve current understanding, observation, and modeling of the PBL diurnal evolution; particularly through enhanced understanding of the contributing role of land surface to this process. The second goal was to identify the optimal time(s), measurement(s), and sampling frequency for characterizing daily land-atmosphere couplings over the Southern Great Plains.

To accomplish these objectives, a series of analyses will be conducted using the twelve-day campaign dataset. First, the suitability of conducting three and six hour soundings for computing land- atmosphere mixing diagrams will be assessed (Figure 2; Betts 1992, Santanello et al., 2009). This approach allows components of the land-PBL coupled system to be evaluated simultaneously, including; mixed-layer temperature and humidity, surface and PBL heat, and moisture fluxes and PBL height. Specifically, the three and six hour profile sampling errors will be quantified, relative to both hourly and ten minute soundings. The resulting error rate will then be transferred to the diagnostic space. Uncertainty estimates of approximate PBL height measurements will also be calculated using the ARM PBLHTSONDE product (if available), which includes Heffter, Bulk Richardson, and Liu and Liang estimates. The ten minute soundings (at 1140, 1440, 1740, and 2040 UTC) will provide bulk estimates of the horizontal variability in temperature and moisture for the lowest 300 hPa above ground layer, at a spatial resolution of approximately four km. Conducting frequent soundings can reveal whether a given radiosonde was launched within a roll updraft or not (Weckwerth et al. 1996; Bennett et al. 2010).

We propose ten minutes (4km) constitutes a reasonable time frame for producing resolutions which accurately monitor PBL evolution for land signals. This campaign will use the forty-eight (four pairs x twelve days) pairs of ten-minute spaced-apart soundings to define a minimum unbiased measurement error profile. Next, the error profile will be utilized to prescribe detection limits in the model space of coupling diagnostics (for a list, see Santanello et al., 2011b) and coupled regional climate models. No similar estimates of inherent natural variability exist, to our knowledge. Correspondingly, the enhanced temporal sounding record will enable assessments regarding the impact of observation time on the convective-triggering potential low-level humidity index (CTP-HI) framework; which describes atmospheric controls on soil moisture-rainfall feedbacks (Findell and Eltahir, 2003; Figure 3: Roundy et al. 2013). This assessment first requires the quantification of diurnal-scale variability of both CTP and HI, which are both currently poorly understood.

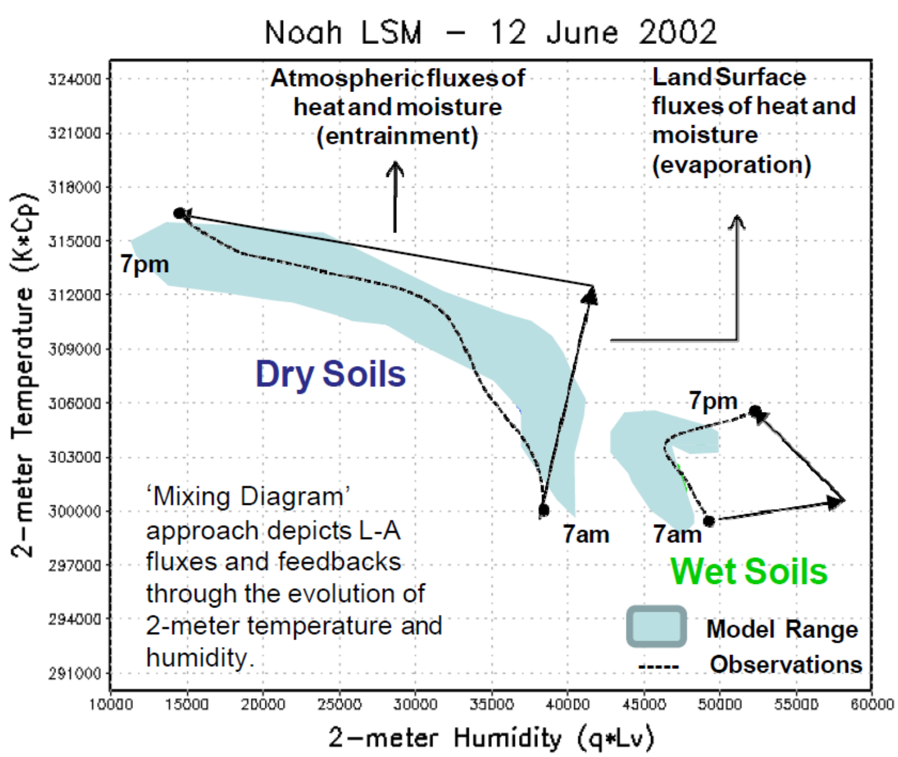

Figure 2. Mixing diagram showing the diurnal co-evolution (7am-7pm) of 2m-specific humidity and 2m-potential temperature on 12 June 2002 at a dry and wet soil location, as simulated by a coupled mesoscale model (derived from Figs. 2-5 in Santanello et al. 2009). Shaded regions indicate the model range for different LSM-PBL scheme couplings (red, green, and blue) compared to actual observations (dashed black). Also shown for the dry site, are vectors that represent heat and moisture fluxes from the land surface, compared with those from the atmosphere.

The enhanced sounding record is anticipated to support advanced understanding in several areas, including: the role of surface soil moisture in the development of clouds (i.e., Ek et al. 2004; Westra et al. 2012; Santanello et al. 2009, 2011a), the temporal variability of the coupling signal (i.e., Roundy et al. 2013), land-PBL model physics (e.g., Santanello et al. 2013) and coupling diagnostic inter-comparison and refinement; a goal of GEWEX LoCo (Santanello et al. 2011b).

The GEWEX Global Atmospheric Boundary Layer Study (GABLS) working group recently completed a single-column model Diurnal Cycle Experiment (DICE), in which the impacts of model parameterization interactions on land-atmosphere coupling (http://appconv.metoffice.com/dice/dice.html) were evaluated. The experiment focused on three days of the CASES-99 field experiment in Kansas. However, its methodology could easily be transferred to the SGP for observing periods during the field campaign. All of DICE's data requirements will be available for twelve days, rather than three. The benefit of enhanced temporal resolution soundings is the potential to enable GABLS to diagnose at precisely which time(s) during the course of the diurnal cycle the model skill is most sensitive to coupling. This new information presents the opportunity to potentially examine process-level studies of models and thus, either achieve model improvements or recommend very specific and focused field campaigns.

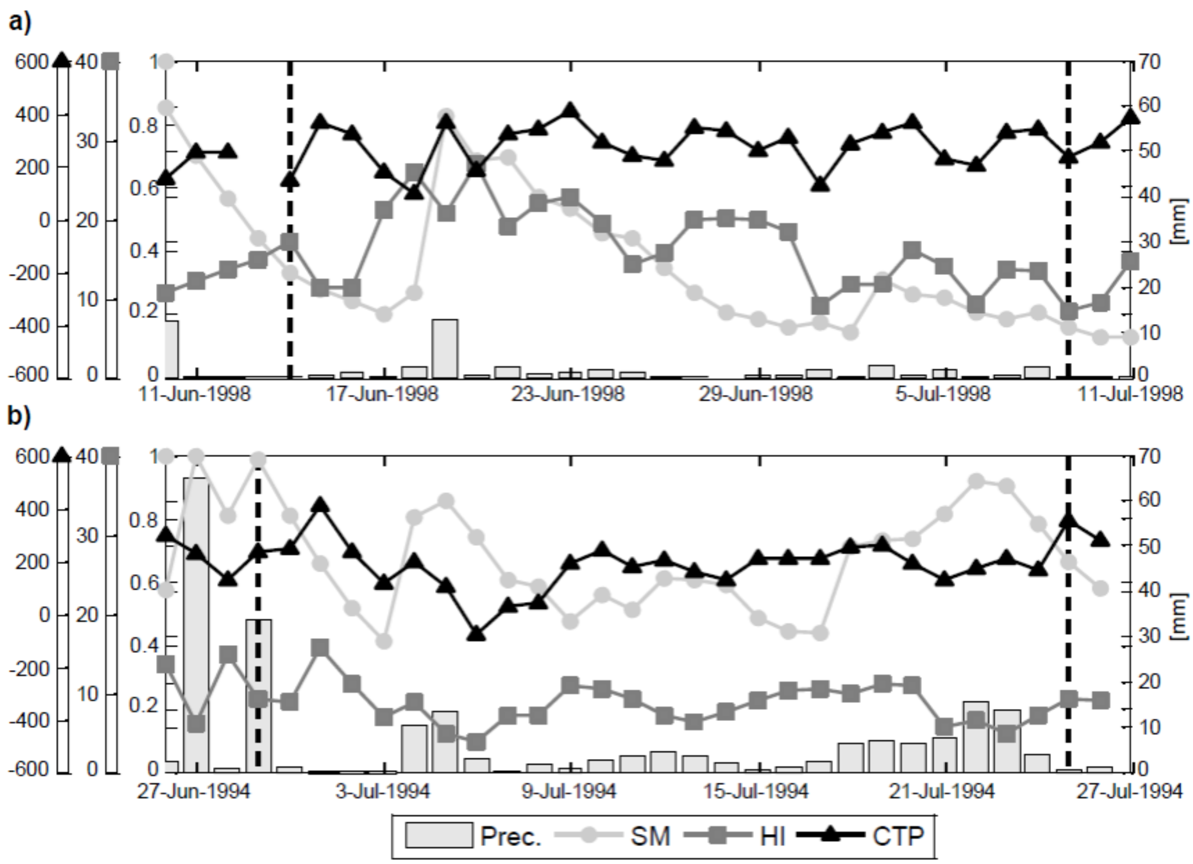

Figure 3. Examples of (a) dry and (b) wet coupling events for an arbitrary grid cell (34.375^{0}N, 81.875^{0}W) in the Southeast U.S., classified using MERRA CTP and HI and VIC SM. The precipitation estimates are taken from the NLDAS-2 daily product. Vertical dotted lines indicate the start and end of each event. Values of CTP < -600 J kg-1 are removed for clarity. (Roundy et al., 2013).

3.0 Assets and IOP Day's Schedule

The campaign requires a minimum of 168 additional radiosonde launches at the ARM-SGP CF on twelve or more IOP days between 15 June and 31 August 2015. On each IOP day, in addition to the four daily operational ARM soundings, fourteen campaign radiosondes will be launched according to the schedule on Figure 1 (above). Specifically, the daily schedule will comprise a single launch corresponding with the nighttime overpass of the A-Train of satellites, (~0830 UTC) and hourly launches during daytime, conducted from 1130 UTC to 2130 UTC. At three hour intervals (i.e., 1140 UTC, 1440 UTC, 1740 UTC, and 2040 UTC), a duplicate radiosonde will be launched ten minutes subsequent to the launch of the on-hour radiosonde, for the purpose of assessing horizontal atmospheric variability (i.e., the effects of advection and local circulation)(Weckwerth et al. 1996; Bennett et al. 2010). On average, a radiosonde will ascend to 700 hPa, at a point 4 km downwind from its launch site, within ten minutes of launch. The ground receiver(s) will record all retrievable radiosonde transmissions (i.e., from the surface to twenty hPa or higher).

4.0 Operational Consideration

Properly trained ARM-SGP CF staff technicians must be on-site to launch the radiosondes. The IOP days will be decided upon no later than sunset of the preceding day, according to the Principal Investigator's (PI's) judgment, and with consideration to daily weather forecasts and current operability of associated ARM-SGP CF instrumentation (see Section 5). At least three IOP days, conducted during times of exceptional interest to the research community, will run during the period of overlap with the ARM Support for the Plains Elevated Convection at Night (AS-PECAN) campaign (PI: David Turner). The AS-PECAN campaign runs from 1 June to 15 July 2015. Among other resources, AS-PECAN calls for daily supplemental radiosondes at 0230, 0830, and 2030 UTC at the CF. Therefore, on IOP days shared with AS-PECAN, single 0830 and 2030 UTC radiosondes will serve both campaigns.

Operational time decisions will be made by PI-Ferguson (crferguson@albany.edu), in consultation with Co-PI's Santanello and Gentine and AS-PECAN PI-Turner, as applicable. PI-Ferguson should have access to the CF on all IOP days.

5.0 Additional Measurement Priorities

It is essential to conduct representative samples of the full land-atmosphere continuum twenty-four hours a day to sufficiently parameterize the environment in support of single-column model experiments and coupled model evaluations/refinements. Screen-level temperature, humidity and pressure; 10m wind; soil moisture and temperature, incident shortwave and longwave radiation, and precipitation are primary determinants of the land's hydro-meteorological condition. The land surface state (namely, soil wetness) must be known to interpret surface energy flux partitioning (i.e., latent-, sensible-, and ground heat flux); which is then measured by eddy correlation surface flux stations and estimated using energy balance Bowen ratio systems. Doppler lidars and radar profilers provide important characterizations of the sub-synoptic scale environment (i.e., the Gulf of Mexico low-level jet). Remote sensing profilers, including the atmospheric emitted radiance interferometer (AERI) and Raman lidar (RL), provide high temporal resolution profiles of temperature and humidity. The enhanced soundings present an opportunity to evaluate suitability for use in land-atmosphere coupling studies. Microwave radiometer retrievals of total column precipitation water vapor/ice enable bias correction of the radiosonde humidity profiles to occur. Finally, ceilometers enable cloud base height and boundary layer height measurement estimations to be made. At a minimum, all measurement requirements for the hourly ARMBE-LAND, ARMBE-STNS, and ARMBE-2DGRID products should be met.

A summary of critical measurements at the CF and extended facilities (EFs) is provided below.

1. Central Facility:
   a. Surface meteorology: surface meteorology systems (MET)
   b. Surface state and turbulent heat fluxes:
      - Energy balance Bowen ratio (EBBR)
      - Eddy correlation surface flux station (ECOR)
      - Surface energy balance system (SEBS)
      - Soil water and temperature system (SWATS)
   c. Atmospheric temperature, moisture, and wind profiles:
      - Microwave radiometer (MWR)
      - Doppler lidar (DL)
      - 915 MHz radar wind profiler (RWP)
      - Atmospheric emitted radiance interferometer (AERI)
      - Raman lidar (RL)
      - Ceilometer (CEIL and VCEIL)
2. Extended facilities:
   a. Surface meteorology: surface meteorology systems (MET)
   b. Surface state and turbulent heat fluxes:
      - Energy balance Bowen ratio (EBBR)
      - Eddy correlation surface flux station (ECOR)
      - Surface energy balance system (SEBS)
      - Soil water and temperature system (SWATS)

6.0 Quality Control and Dissemination

Supplemental radiosondes are expected to be integrated into the ARM data archive following the same established quality control and dissemination protocol applied to all operational six hour radiosondes at the CF. Thus, the supplemental radiosondes will be included in products such as: LSSONDE, MERGESONDE, PBLHT/PBLHTSONDE, and ARMBE-ATM. They will be made publicly available within six months of the experiment's conclusion. Additionally, all sounding data should be made available at the native temporal frequency of the GPS radiosonde. The above procedures are intended to ensure the broadest possible applications and greatest short-term impact of the data.

7.0 References

Bennett, LJ, TM Weckwerth, AM Blyth, B Geerts, MA Qun, and YP Richardson. 2010. "Observations of the evolution of the nocturnal and convective boundary layers and the structure of open-celled convection on 14 June 2002." *Monthly Weather Review* 138(7): 2589-2607.

Betts, AK. 1992. "FIFE atmospheric boundary layer budget methods." *Journal of Geophysical Research* 97D: 523-532.

Dirmeyer, PA, RD Koster, and ZC Guo. 2006. "Do global models properly represent the feedback between land and atmosphere?" *Journal of Hydrometeorology* 7(6): 1177-1198.

Ek, MB, and AAM Holtslag. 2004. "Influence of soil moisture on boundary layer cloud development." *Journal of Hydrometeorology* 5(1): 86-99.

Ferguson, CR., and EF Wood. 2011. "Observed land-atmosphere coupling from satellite remote sensing and re-analysis." *Journal of Hydrometeorology* 12(6): 1221-1254.

Findell, KL, and EAB Eltahir. 2003. "Atmospheric controls on soil moisture-boundary layer interactions. Part II: Feedbacks within the continental United States." *Journal of Hydrometeorology* 4(3): 570-583.

Guo, ZC, et al. 2006. "GLACE: The global land-atmosphere coupling experiment. Part II: Analysis." *Journal of Hydrometeorology* 7(4): 611-625.

Koster, RD, et al. 2006. "GLACE: The Global Land-Atmosphere Coupling Experiment. Part I: Overview." *Journal of Hydrometeorology* 7(4): 590-610.

Medeiros, B, A Hall, and B Stevens. 2005. "What controls the mean depth of the PBL?" *Journal of Climate* 18: 3157-3172.

Roundy, JK, CR Ferguson, and EF Wood. 2013. "Temporal variability of land-atmosphere coupling and its implications to drought over the southeast United States" *Journal of Hydrometeorology* 14(2): 622-635.

Santanello, JA, MA Friedl, and MB Ek. 2007. "Convective planetary boundary layer interactions with the land surface at diurnal time scales: diagnostics and feedbacks". *Journal of Hydrometeorology* 8: 1082-1097.

Santanello, JA, CD Peters-Lidard, SV Kumar, C Alonge, and WK Tao. 2009. "A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales." *Journal of Hydrometeorology* 10(3): 577-599.

Santanello, JA, CD Peters-Lidard, and SV Kumar. 2011. "Diagnosing the sensitivity of local land-atmosphere coupling via the soil moisture-boundary layer interaction." *Journal of Hydrometeorology*, 12(5): 766-786.

Santanello, JA, CR Ferguson, M Ek, P Dirmeyer, O Tuinenburg, C Jacobs, C Van Heerwaarden, KL Findell, P Gentine, and B Lintner. 2011. "Local land-atmosphere coupling (LoCo) research: status and results." *GEWEX newsletter* 21(4): 7-9.

Santanello, J. A., C. Peters-Lidard, A. Kennedy, and S Kumar. 2013. "Diagnosing the nature of land-atmosphere coupling: A case study of dry/wet extremes in the U.S. southern Great Plains." *Journal of Hydrometeorology* 14(1): 3-24.

Weckwerth, TM, JW Wilson, and RM Wakimoto. 1996. "Thermodynamic variability within the convective boundary layer due to horizontal convective rolls." *Monthly Weather Review* 124(5): 769-784.

Westra, D, GJ Steeneveld, and AAM Holtslag. 2012. "Some observational evidence for dry soils supporting enhanced relative humidity at the convective boundary layer top." *Journal of Hydrometeorology* 13(4): 1347-1358.

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