A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales

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Land-atmosphere (L-A) interactions and coupling remain weak links in current observational and modeling approaches to understanding and predicting the Earth-Atmosphere system. The degree to which the land impacts the atmosphere (and vice-versa) is difficult to quantify given the disparate resolutions and complexities of land surface and atmospheric models and lack of comprehensive observations at the process level [1, 2, 3].

However, the convective planetary boundary layer (PBL) serves as a short-term memory of land surface processes (through the integration of regional surface fluxes on diurnal scales), and therefore is diagnostic of the surface energy balance [4, 5, 6,7]. Further, the equilibrium established between land surface and mixed layer fluxes and states in a growing PBL is a function of the degree of coupling and the impact of feedbacks within the L-A system [8]. As such, knowledge of temperature and moisture evolution in the PBL can be instrumental in estimating surface fluxes and properties across regional scales as well as quantifying and improving L-A representations in coupled models.

While recent progress has been made in identifying modeled hotspots of large-scale and seasonal L-A coupling [9], a comprehensive approach to diagnosing the full nature of *local land-atmosphere coupling* (hereafter referred to as 'LoCo') at the process-level has yet to be developed. The degree of LoCo is a critical component of prediction models and impacts the simulation of sensible weather, turbulence, convective initiation, and precipitation across a range of scales.

In order for a robust methodology to diagnose coupling to be effective and useful to the community, it must be comprehensive and integrative of L-A processes and feedbacks; while at the same time able to be implemented using easily observed and understood properties of the system. The need for a framework that can be applied to models and evaluated against observations will only become more critical to ensure that advances in measurement technologies such as satellite remote sensing of the land surface and PBL are properly incorporated into L-A studies and models (e.g. data assimilation).

A relatively straightforward but untested approach that may satisfy these requirements for local and diurnal time scales is the concept of vector representation of PBL heat and moisture (energy) budgets, as introduced by Betts [10] in the form of 'mixing diagrams'. This conservative variable approach relates the diurnal evolution of specific humidity (q) and potential temperature (θ) to the land surface and mixed layer energy balance and, in effect, the diurnal equilibrium established by L-A interactions. The daytime variability of θ and q is sensitive to and integrative of the dominant processes involved in LoCo, the calculation of which requires only the diurnal evolution of θ and q, mean surface sensible heat flux (H_{sfc}), and mean PBL height (*PBLH*), all which are routinely measured and output from coupled models.

To serve as an experimental testbed for LoCo diagnostics, the community-supported Weather Research and Forecasting (WRF) model has been coupled to the Land Information System (LIS) developed by the National Aeronautics and Space Administration (NASA) [11]. LIS-WRF combines a suite of atmospheric turbulence (i.e. PBL) schemes with a flexible, high-resolution representation and initialization of land surface physics and states using multiple land surface model (LSM) options, and therefore can be used to evaluate the behavior of different L-A couplings against each other using readily available observations.

We have tested the LIS-WRF model and mixing diagram approach on a number of field experiments encompassing a range of surface/atmospheric conditions [12]. Figure 1 shows the near-surface soil moisture conditions during a June 2002 campaign in the U.S. Southern Great Plains (SGP) as spun-up for 2.5 years by LIS using the Noah land surface model. The soil temperature and moisture states generated by this simulation are then used as input to the coupled LIS-WRF simulation over the identical domain. The high-resolution of LIS and its datasets produce improved initial conditions over the default WRF model reproducing the significant spatial heterogeneity of soil and vegetation conditions in the SGP.

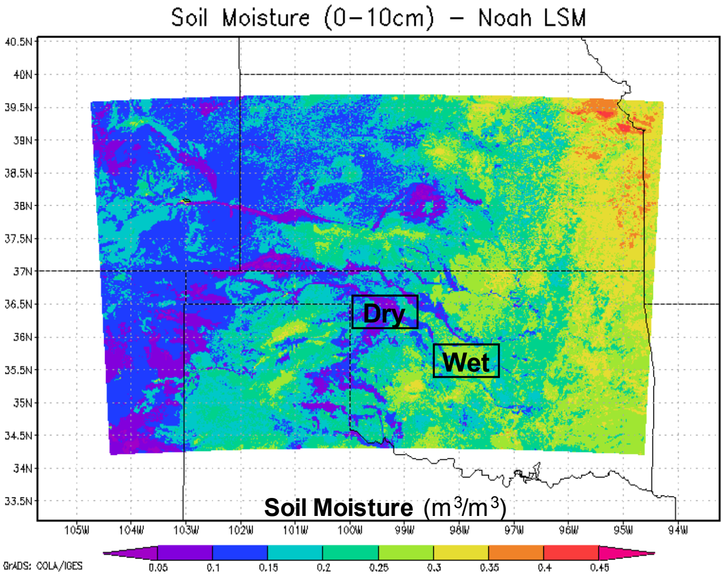

Figure 1: Near-surface soil moisture (0-10cm) valid at 7am on 12 June 2002 as simulated from a 2.5 year spinup of the Noah land surface model (using LIS) over a 1-km horizontal resolution domain in the SGP.

The subsequent integration of the LIS-WRF model generates the coupled evolution of L-A states that can be diagnosed using mixing diagrams, as shown in Fig. 2. Here, the 12-hour change in 2-meter Lq and $C_p\theta$ as simulated by LIS-WRF during 12 June 2002 is shown for the dry and wet soil moisture sites from Fig. 1. Results show how the sensitivity of the L-A equilibrium to the specific choice of PBL scheme and LSM varies across surface moisture regimes and can be quantified and evaluated against observations. There are noticeably different signatures exhibited at each site, with significant warming and drying occurring at the dry site as a result of strong surface heating leading to vigorous and deep PBL growth (and dry air entrainment). The converse is evident at the wet site, with a moistening signature dominant as a result of strong evaporation and limited PBL growth.

More importantly, the evolution of θ and q is fully described by vector components that represent the fluxes of heat and moisture from the land surface and the top of the PBL (entrainment). Therefore, the L-A equilibrium established on this day can be quantified by the derived fluxes that make up the complete heat and moisture budget of the PBL. Also note that the model range depicts the spread due to different PBL-LSM combinations in LIS-WRF, and when evaluated against observations can be used to pinpoint the weaknesses in either the land and/or atmospheric component of the model.

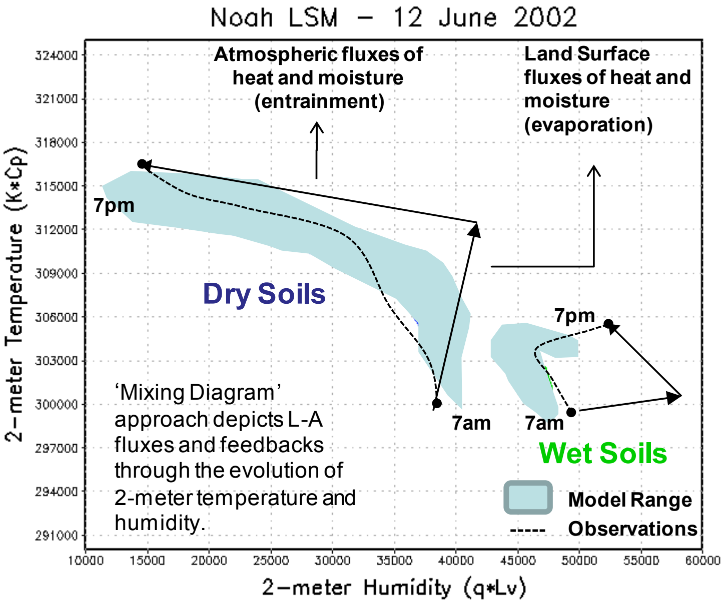

Figure 2: Diurnal co-evolution of 2m-specific humidity and 2m-potential temperature as simulated by LIS-WRF for the dry and wet soil moisture locations in Fig. 1 using the Noah LSM coupled to the three different PBL schemes. The shaded regions for each indicate the model range for each of the PBL-LSM couplings (red, green, and blue lines). Also shown are the vectors (black arrows) that represent the fluxes of heat and moisture from the land surface versus those from the atmosphere due to entrainment.

Overall, this methodology provides a potential pathway to study factors controlling LoCo using the LIS-WRF system. This work, funded by the NASA Energy and Water Cycle Study (NEWS) and supported by the NASA Modeling and Prediction (MAP) and Air Force Weather Forecasting Agency (AWFA) programs, serves as the backbone for an international effort supported by the GEWEX Global Land/Atmosphere System Study (GLASS) to evaluate LoCo in models and observations across the globe. Also, these studies combine models with observations to evaluate the significance and accuracy of these interactions and can be applied to any model and location of interest.

Finally, from a remote sensing perspective the diurnal evolution of temperature and humidity near the surface (e.g. Moderate Resolution Imaging Spectroradiometer, MODIS; Atmospheric Infrared Sounder, AIRS), in combination with surface flux estimates based on soil moisture estimation (e.g. Soil Moisture Active Passive, SMAP; Soil Moisture and Ocean Salinity, SMOS) and remote sounding of the lower troposphere (e.g. AIRS; Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, CALIPSO) will all be measurable from space within the next decade. Therefore, a simple yet robust technique such as this will enable satellite remote sensing to be used to evaluate land-atmosphere coupling continuously across the globe.

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