SMAP: For Modeling and Analysis

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University of Nebraska-Lincoln
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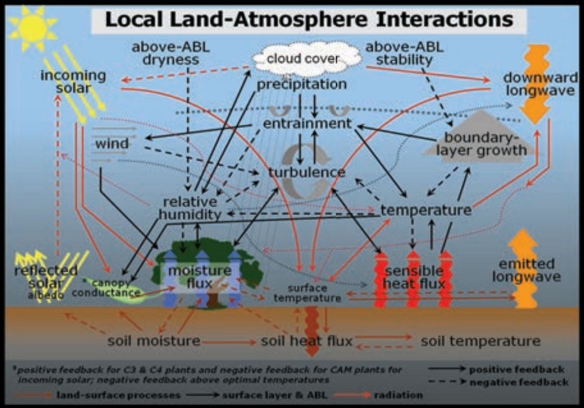
Outline

- Part 1: Impact of soil moisture initial conditions derived from models and observations on short-term weather prediction
    - Led by Joe Santanello
    - Modeling study

- Part 2: Irrigation signals detected from SMAP soil moisture retrievals
    - *Lawston et al. 2017, Geophysical Research Letters*
    - Observational study

Motivation

- The complexity of land-atmosphere (L-A) interactions can be synthesized into simple process chain on Local L-A Coupling ('LoCo')



Δ SM ⟶ Δ EF_{sm} ⟶ Δ PBL ⟶ Δ ENT ⟶ Δ EF_{atm} ⟶ Δ P/Clouds

- **Overarching Goal:** Better understand the how/why of soil moisture impacts on NWP via understanding links in the LoCo process-chain.

- **Approach:** Intercompare suite of soil moisture initial conditions (including SMAP) for coupled WRF simulations

Santanello, J. A., et al. (2018): **Land-Atmosphere Interactions: The LoCo Perspective**. *Bulletin of the American Meteorological Society*, June 2018 (in press).

LAND–ATMOSPHERE INTERACTIONS

The LoCo Perspective

Joseph A. Santanello Jr., Paul A. Dirmeyer, Craig R. Ferguson, Kirsten L. Findell, Ahmed B. Tawfik, Alexis Berg, Michael Ek, Pierre Gentine, Benoit P. Guillod, Chiel van Heerwaarden, Joshua Roundy, and Volker Wulfmeyer

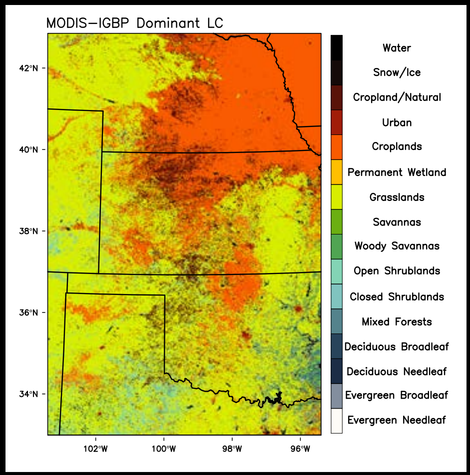
Metrics derived by the LoCo working group have matured and begun to enter the mainstream, signaling the success of the GEWEX approach to foster grassroots participation.

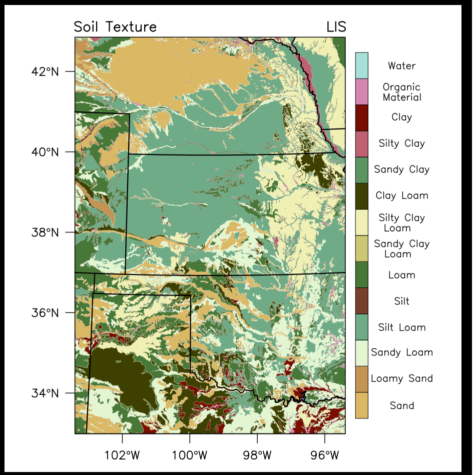
Compare LSM v. SMAP v. in-situ

- Understand the behavior and variability of SMAP soil moisture retrievals and their relationship to LSM output and in-situ data

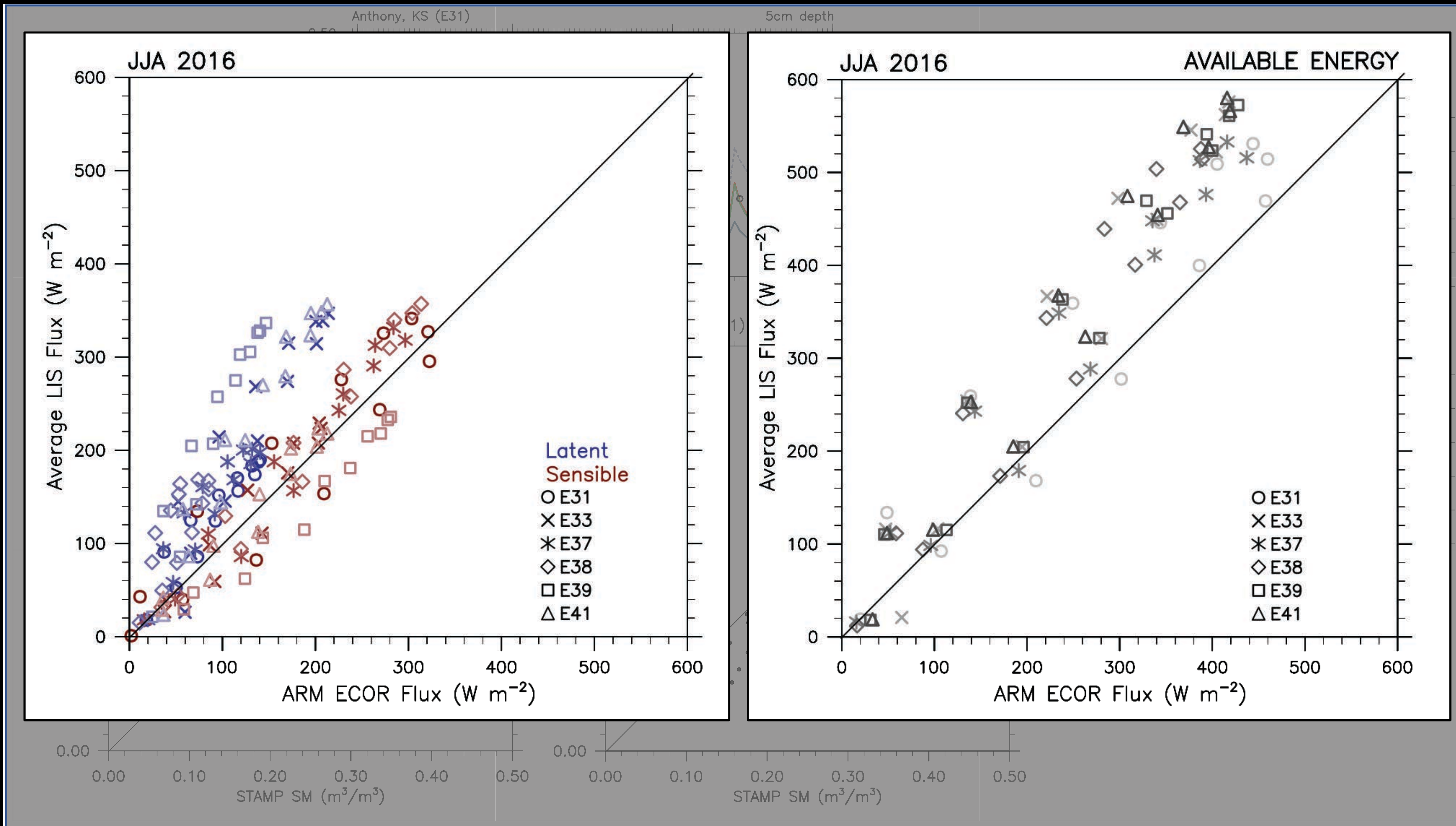
- Experimental design:
  - US Southern Great Plains
  - NASA's Land information System (LIS) with Noah LSM
  - Domain: 1100x750 @ 1 km resolution
  - LIS spinup: 1 Jan 2011 – 31 Dec 2016
    - Control Run:
      - NLDAS-2 forcing
      - Climatological greenness (GVF)
    - Permutations:
      - Forcing (NLDAS-2 v. GDAS)
      - GVF (Climatological v. VIIRS)
      - Soil Layer (0-10cm, 0-5cm, 0-2 cm)

- Datasets:
  - SMAP L3 Enhanced product
  - ARM-SGP data
    - EBBR/ECOR flux towers
    - EBBR, SWATS soil moisture (pre-2016)
    - STAMP soil moisture (2016-on)





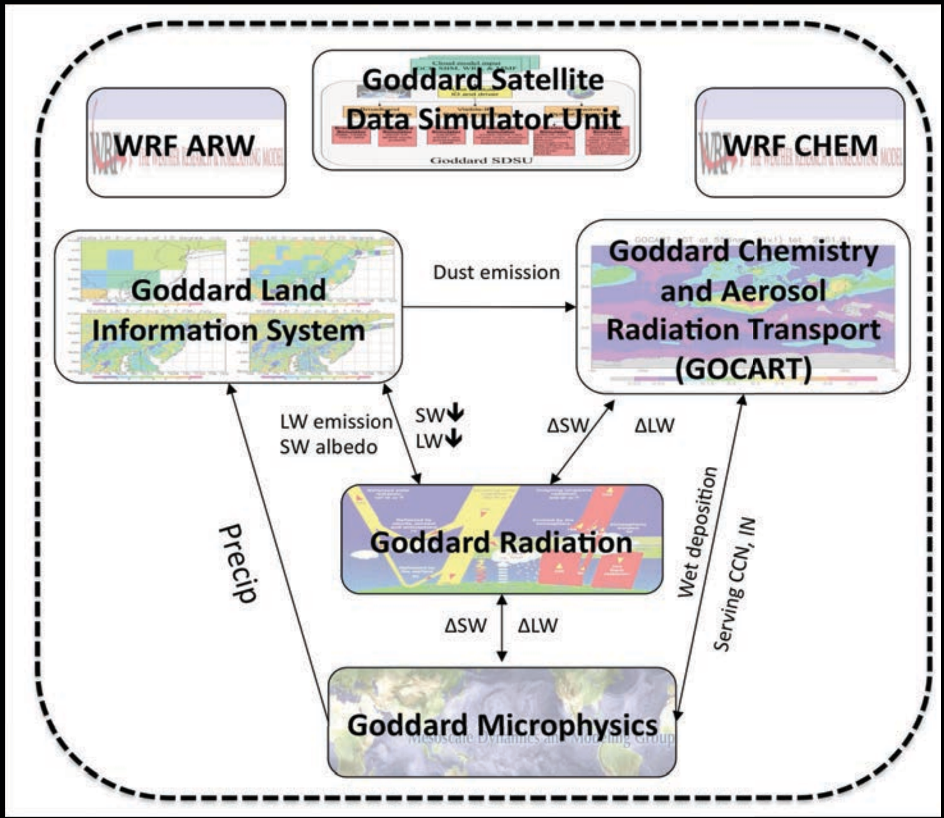
Compare LSM v. SMAP v. in-situ



Modeling tools and experimental design

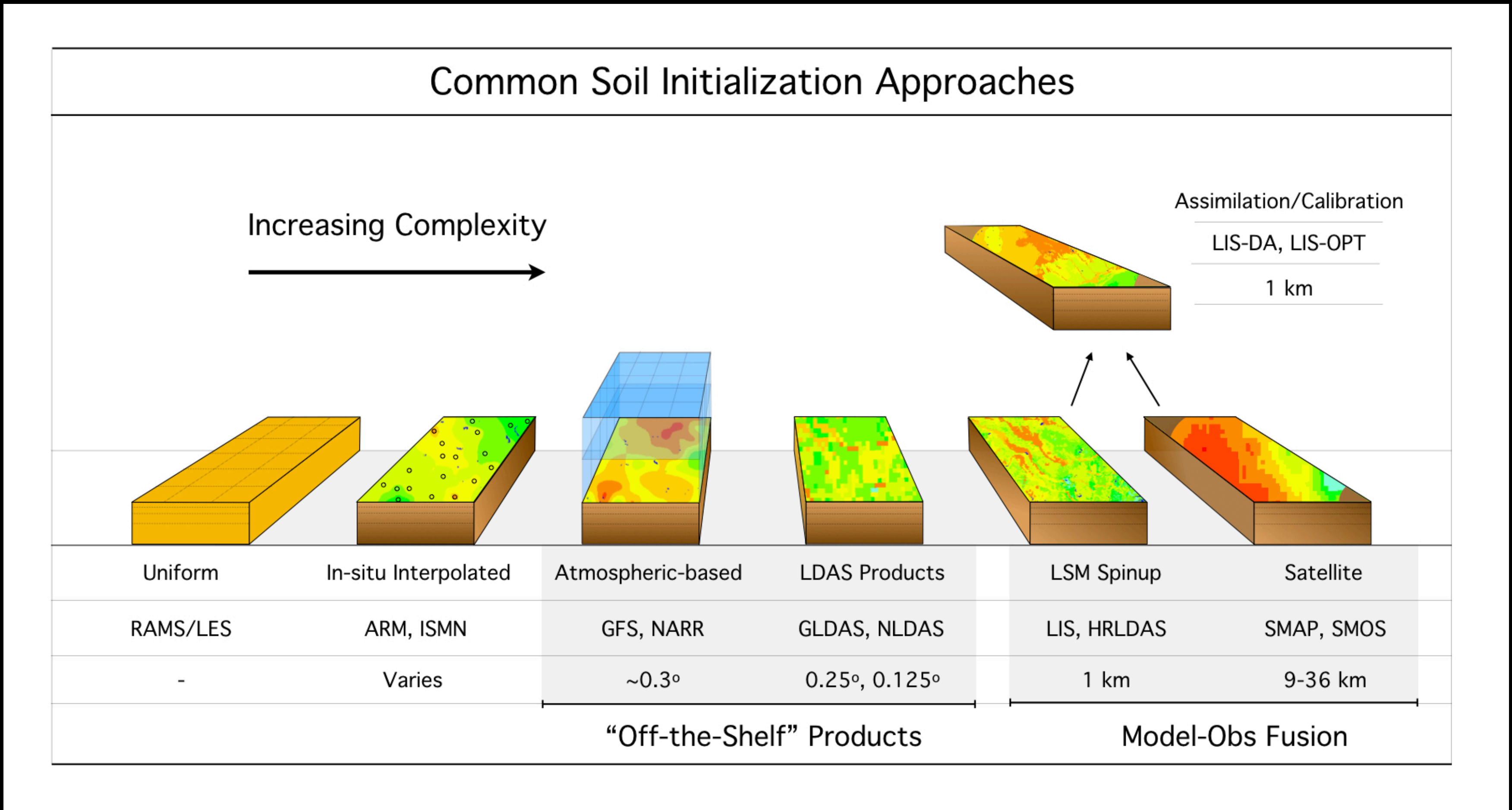
NASA Unified WRF (NU-WRF)

- Provides an observation-driven, integrated modeling system that represents aerosol, cloud, precipitation and land processes at satellite resolved scales (1-4km)
- Integrates unique NASA observation and modeling assets under one roof:
  - Satellite data
  - Model Physics
  - Expertise/Software
- One day simulations (11-12 July 2015)
  - 1 km resolution
  - Same domain as LIS simulations



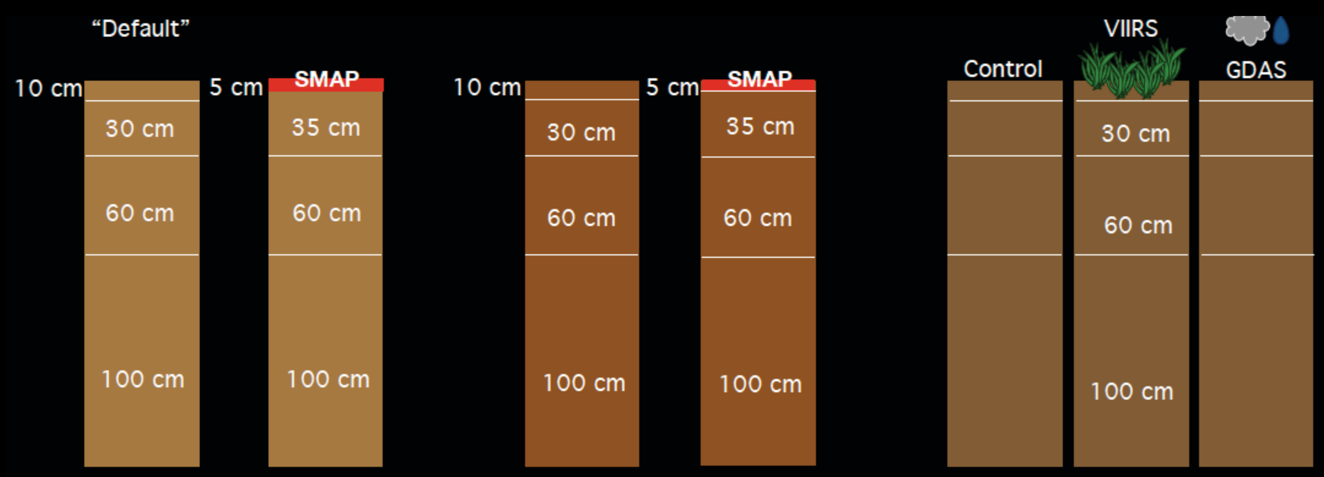
Impacts of soil moisture ICs on NWP

- Intercompare a suite of land surface (including SMAP-infused) initialization approaches in WRF and their resultant downstream impacts on coupled prediction



Impacts of soil moisture ICs on NWP

Initialization Source	Forcing	GVF
LIS (Control)	NLDAS-2	Climatology
LIS (GDAS)	GDAS	VIIRS
LIS (VIIRS)	NLDAS-2	VIIRS
NLDAS	NLDAS-2	Climatology
NARR	NARR	Climatology
GFS	GFS	Climatology
SMAP & NARR	NARR	-
SMAP & NLDAS-2	NLDAS-2	-

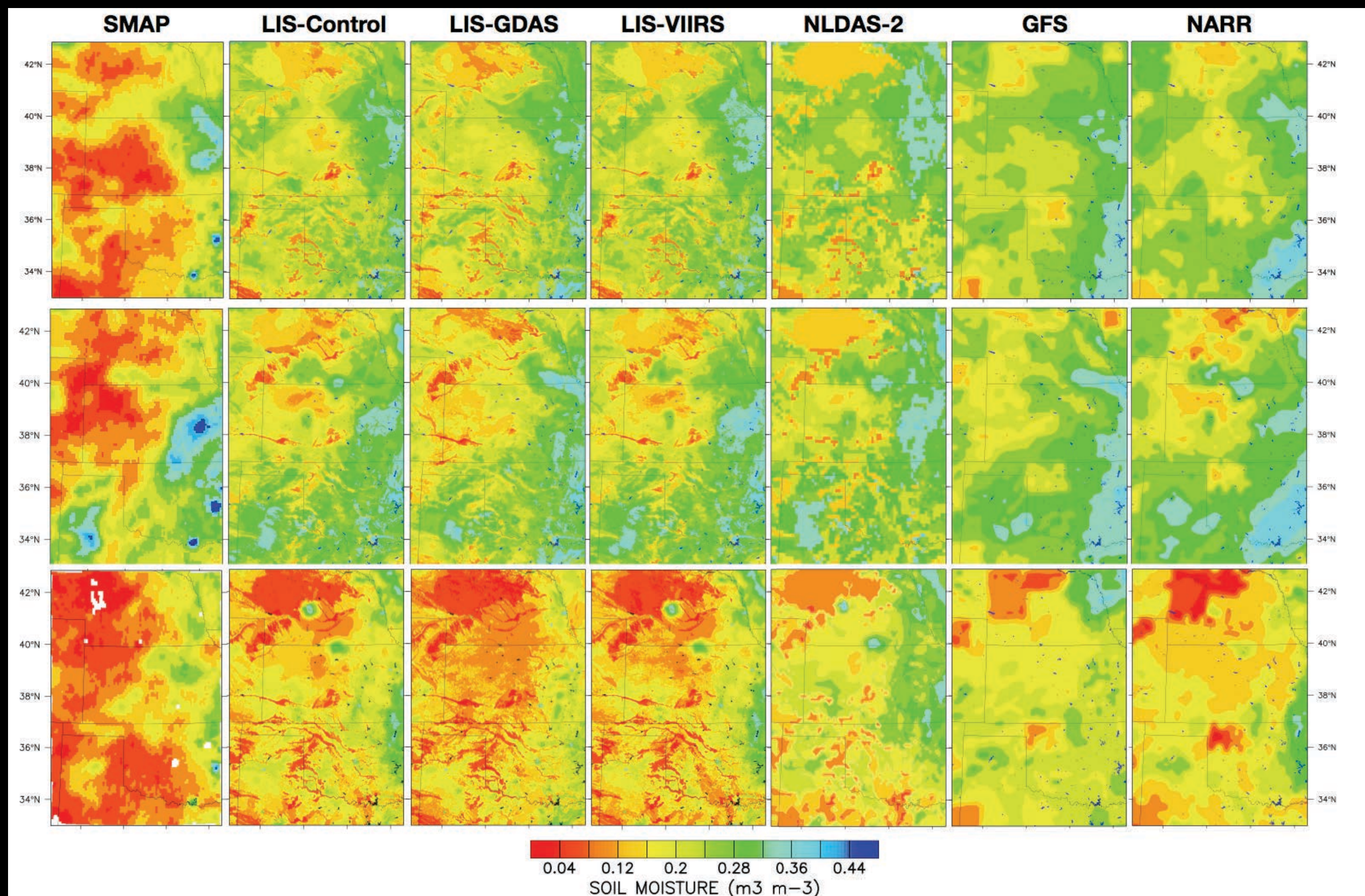


Soil Moisture Initialization

9 Jun 2015

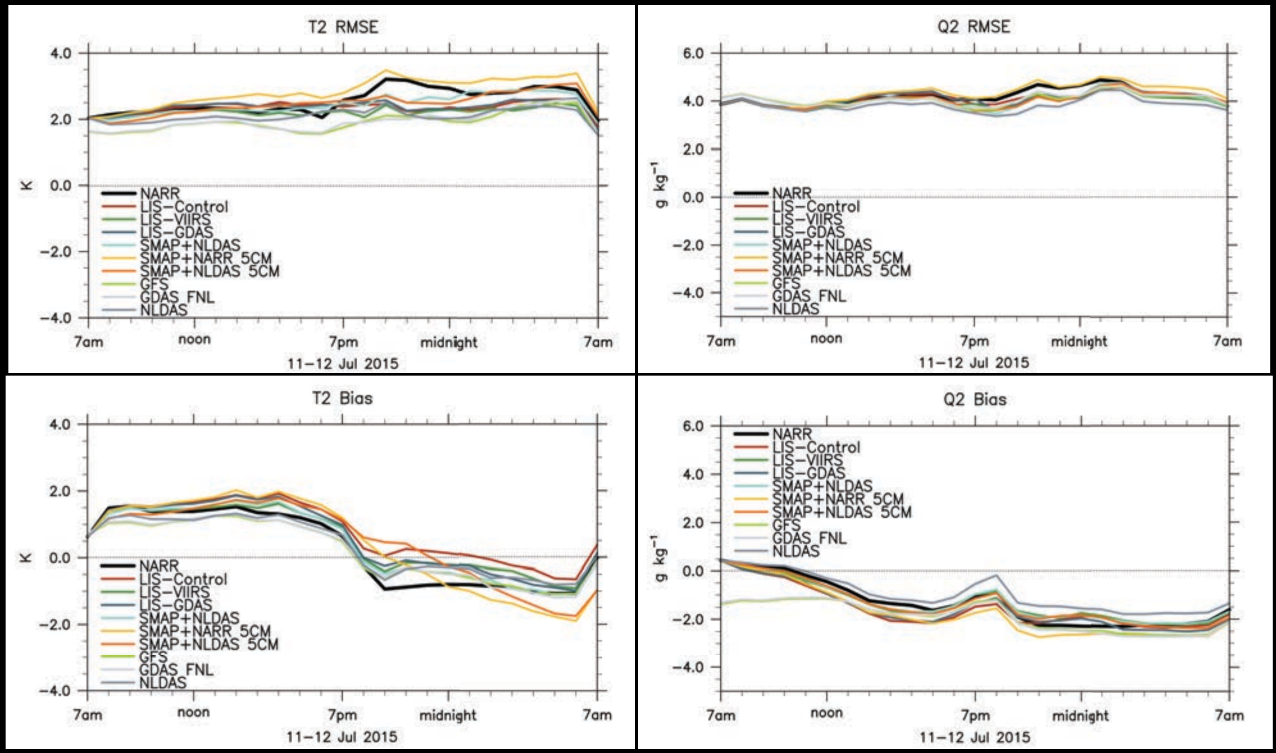
11 Jul 2015

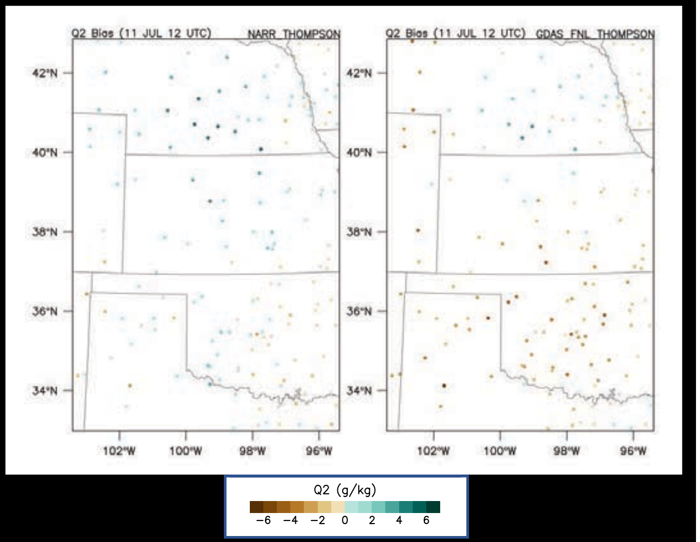
28 Aug 2015



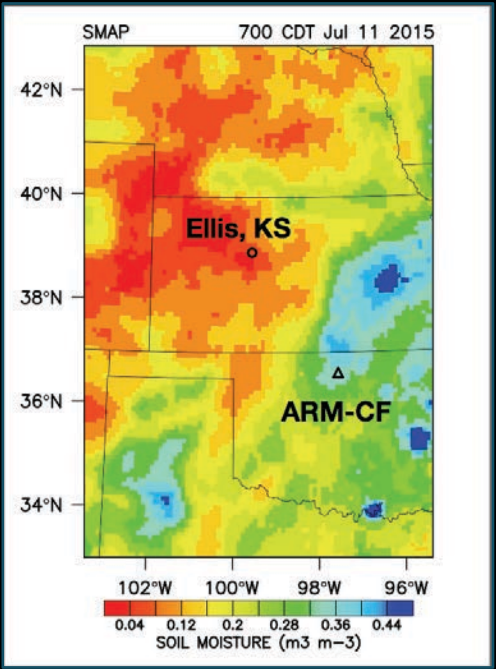
33km 1km 1km 1km 12km 25km 32km

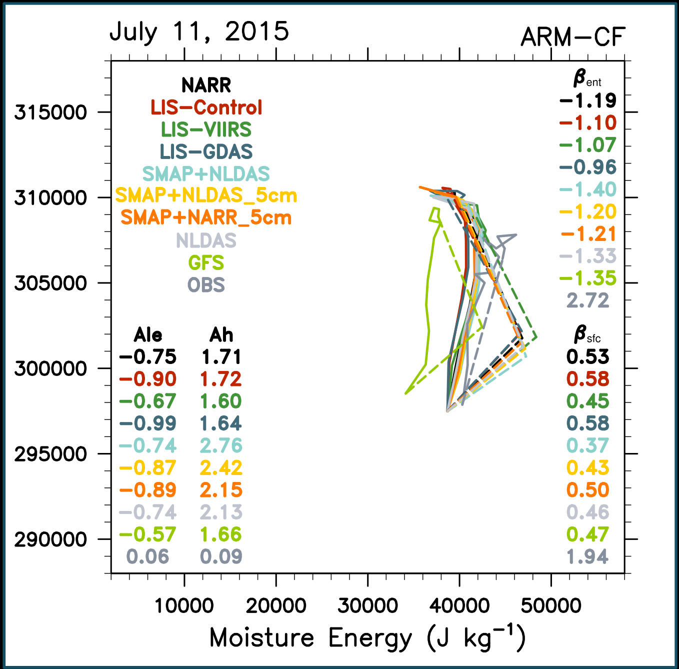
Impacts on Ambient Weather

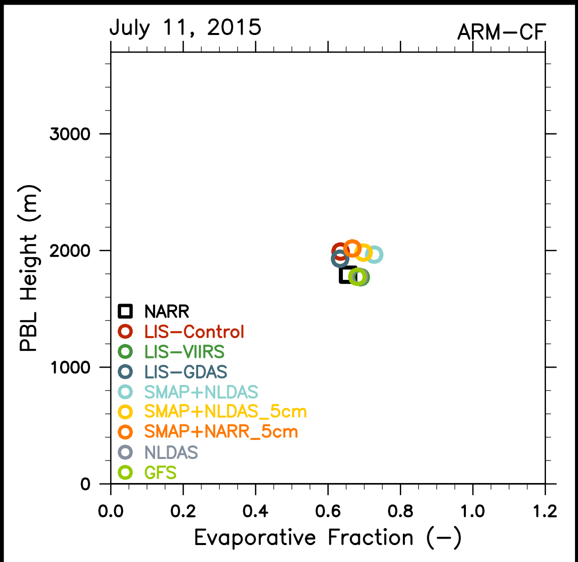




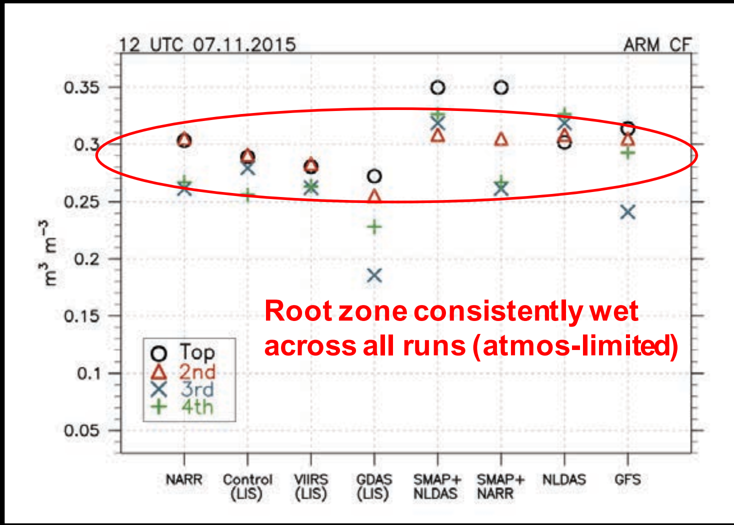
Part 1 Phase 2: Impacts on LoCo Process Chain







ARM-Central Facility



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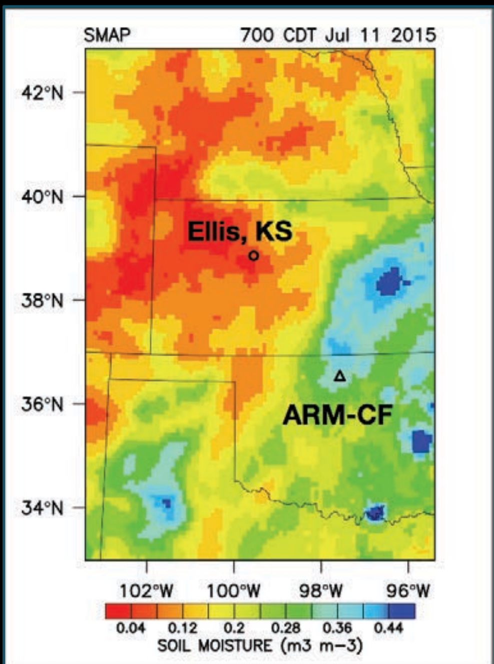
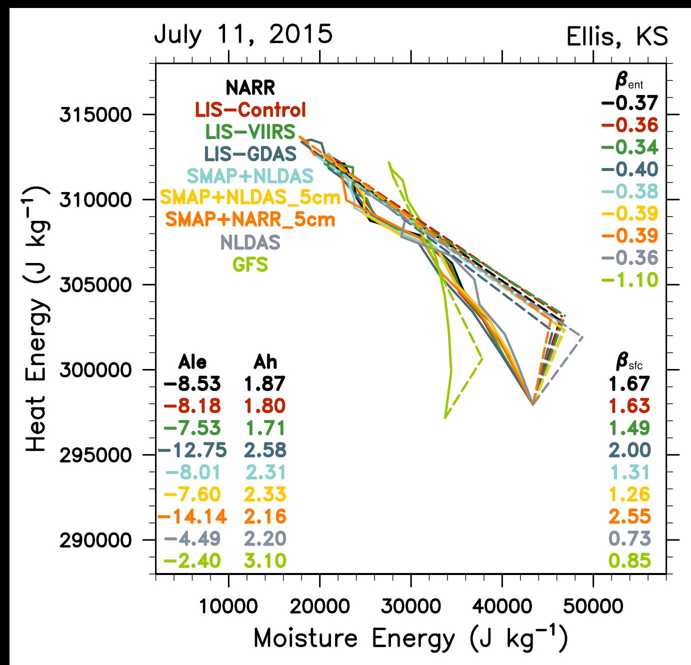
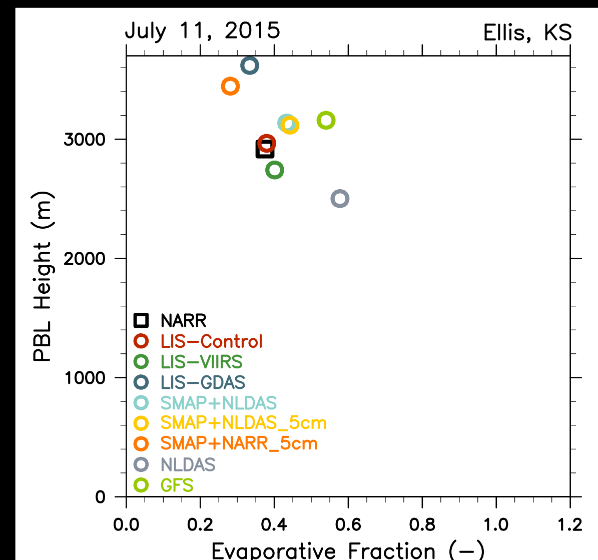
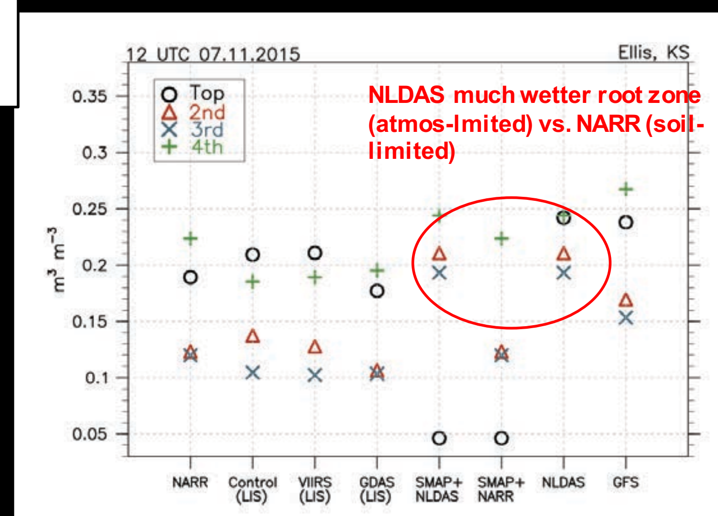




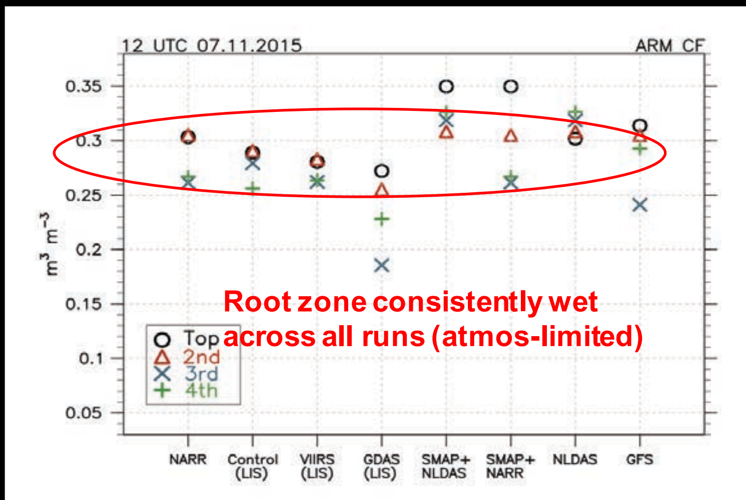


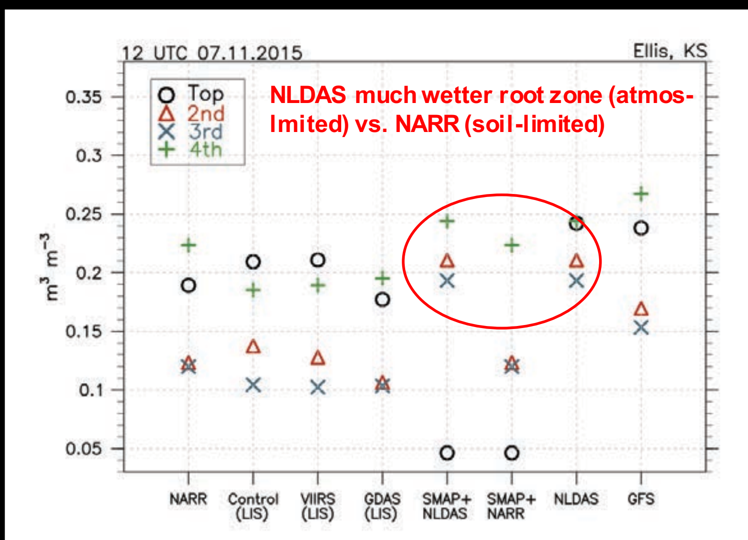


ARM-Central Facility

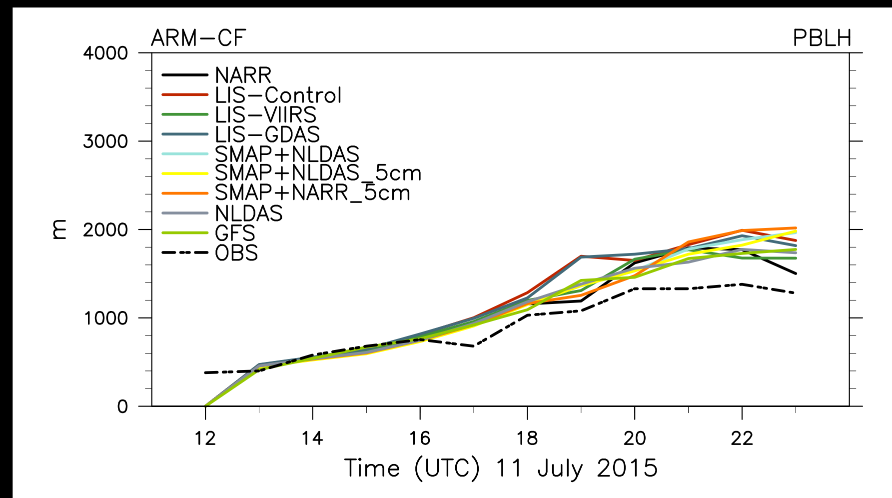
PBL Impacts

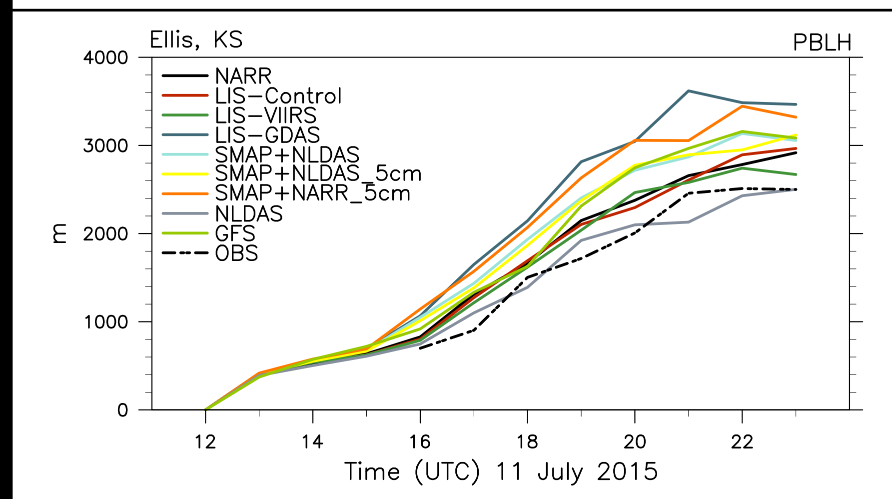
SM by layer and case



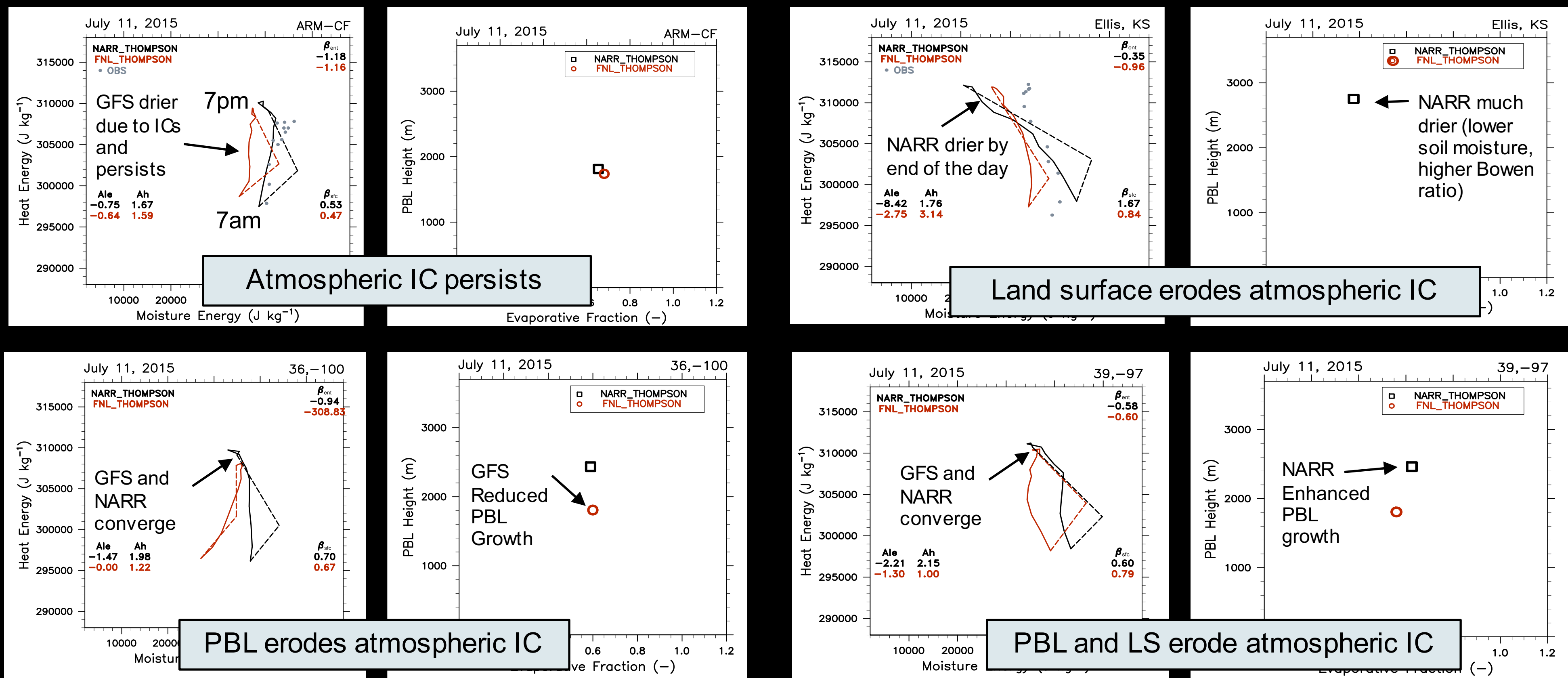


PBL Height Evolution

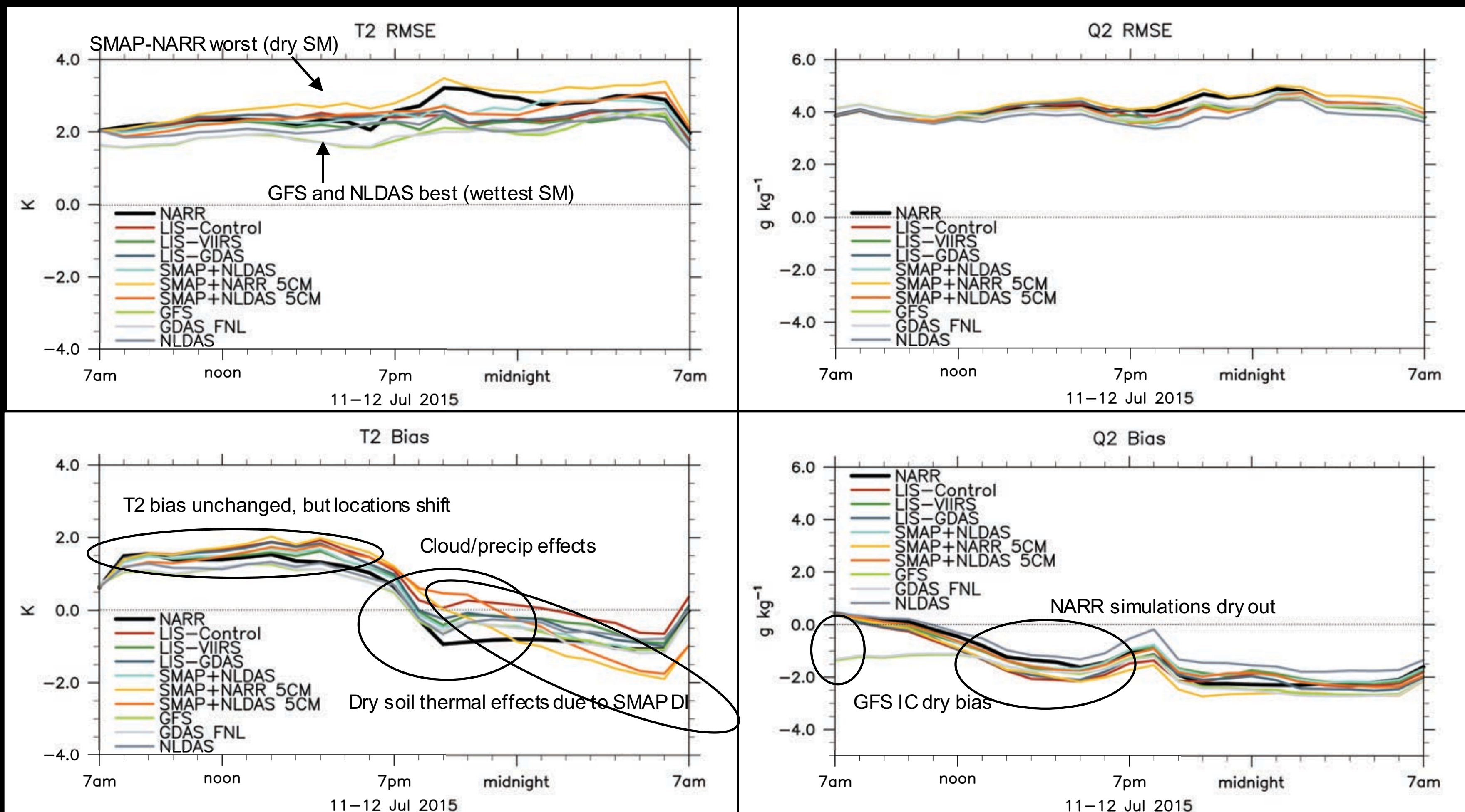




Impact of Atmospheric v. Land Surface ICs



Coupling Impacts on Ambient Weather



Part 1: Discussion

- SMAP products look good overall compared to LSMs, in-situ, and for irrigation detection
  - Captures the overall heterogeneity and dynamics of soil moisture in the region
  - 9 km enhanced product is useful; supports use for DA and calibration runs
  - There remains an 'observability' issue between LSM and observed soil moisture

- Impact of soil moisture initialization can be understood via process-level analysis (LoCo)
  - Bulk impacts on Fx statistics are not always straightforward or systematic, involve complex L-A feedbacks
    - Any improvement in prediction (T, RH, Precip) can be the right answer for the wrong (or unknown) reasons
  - Positive impacts of soil moisture or other land/LSM developments may be diminished due to atmospheric ICs and inherent biases of the coupled system
    - Any degradation in prediction can be the wrong answer for the right reasons (e.g. improved land surface)
  - Understanding the coupling therefore becomes critically important to identifying the how/why of forecast impacts

Part 2: Irrigation Signals Detected from SMAP Soil Moisture Retrievals

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL075733

Irrigation Signals Detected From SMAP Soil Moisture Retrievals

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Key Points:
- To date, irrigation detection from passive microwave satellites has proven difficult even over well-known, expansive regions of agriculture
- The new enhanced soil moisture product from the Soil Moisture Active Passive satellite can detect irrigation signals in three regions
- Satellite detection of irrigation increases our ability to understand, monitor, and predict human impacts on the water cycle

Supporting Information:
- Supporting Information S1

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Abstract Irrigation can influence weather and climate, but the magnitude, timing, and spatial extent of irrigation are poorly represented in models, as are the resulting impacts of irrigation on the coupled land-atmosphere system. One way to improve irrigation representation in models is to assimilate soil moisture observations that reflect an irrigation signal to improve model states. Satellite remote sensing is a promising avenue for obtaining these needed observations on a routine basis, but to date, irrigation detection in passive microwave satellites has proven difficult. In this study, results show that the new enhanced soil moisture product from the Soil Moisture Active Passive satellite is able to capture irrigation signals over three semiarid regions in the western United States. This marks an advancement in Earth-observing satellite skill and the ability to monitor human impacts on the water cycle.

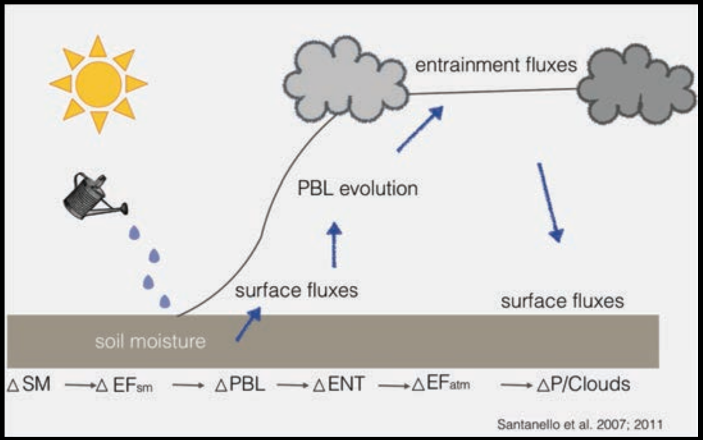
Plain Language Summary When farmers use irrigation over large areas, it can make the air cooler and more humid, sometimes even changing how clouds form and where rain falls. For this reason, it is important to know where and when irrigation is used, how wet the soil becomes, and how long it stays artificially wet. This information is critical for improving weather models, and therefore forecasts, in the food baskets of the world. However, until now it has been difficult to find accurate and consistent irrigation practice information over time and for large areas. In this paper, we show that a NASA satellite that measures soil moisture routinely across the globe is able to detect wet soil resulting from irrigation in naturally dry environments. This marks an advancement in Earth-observing satellite skill and improves our ability to monitor and predict human impacts on the water cycle.

1. Introduction

Irrigation is required to meet the world's food demands, but also drastically alters the water cycle. By increasing soil moisture (SM), irrigation repartitions the surface energy balance, increasing evaporation and decreasing sensible heat flux and temperature (Bonfils & Lobell, 2007; Kanamaru & Kanamitsu, 2008). The altered energy balance can be significant enough to influence clouds and precipitation through land-atmosphere

Motivation

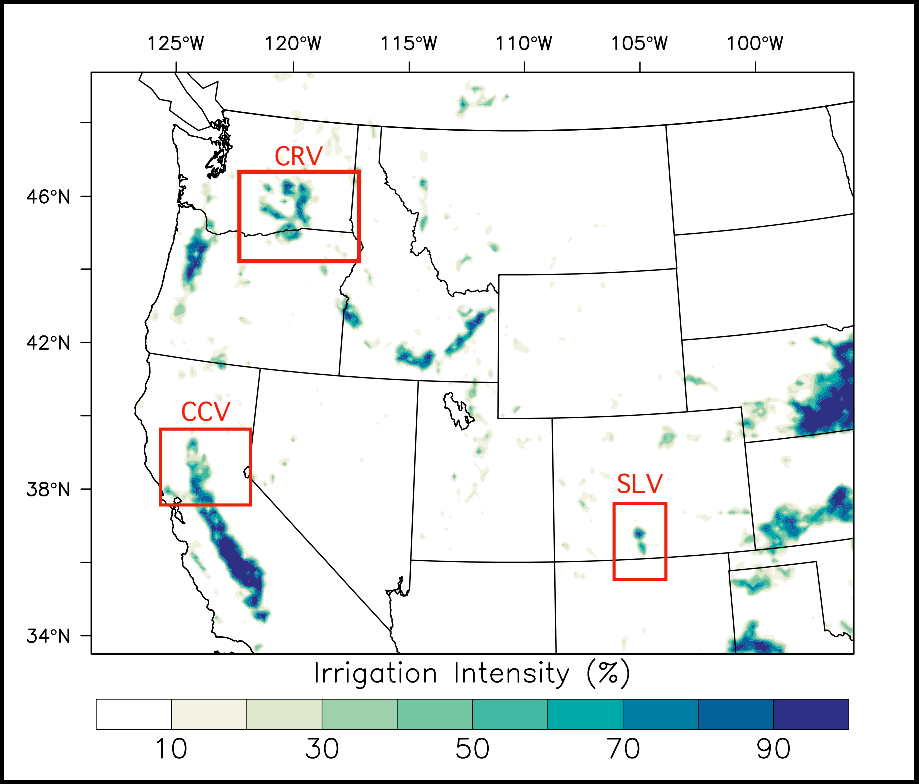
- Irrigation can influence weather and climate, but impacts of irrigation are poorly represented in models, if included at all.
- Satellite-based irrigation detection via soil moisture can help but has been limited to date (SMOS, AMSRE, ASCAT, etc.)
- This study explores the utility of the NASA's new Soil Moisture Active Passive (SMAP) satellite for identify irrigated regions and timing.



Santanello et al. 2011

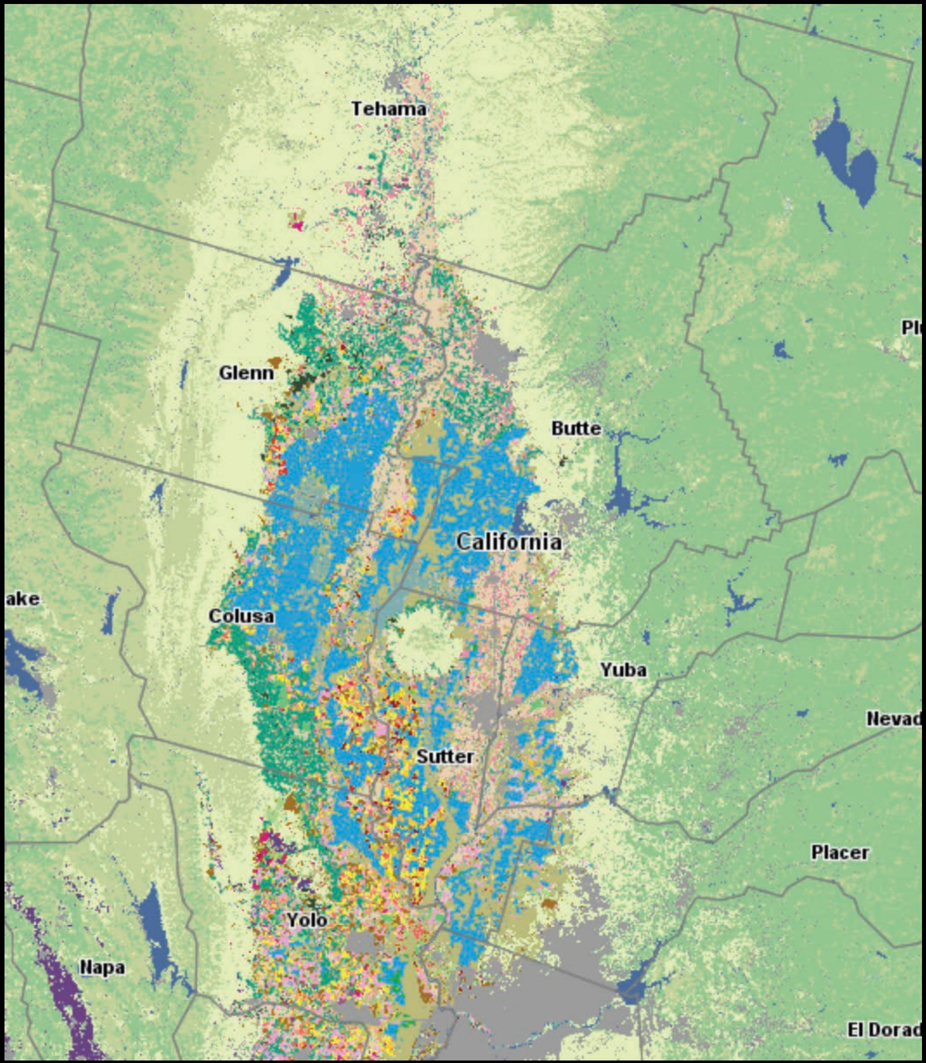
Data & Methods

- Three case study regions:
  1. Sacramento Valley, California (CCV)
  2. San Luis Valley, Colorado (SLV)
  3. Columbia River Valley (CRV)
- Datasets:
  1. SMAP Enhanced soil moisture
  2. NCEP Stage IV daily precipitation
  3. MODIS Terra true color reflectance
  4. US Dept of Ag crop bulletins
- Analyzed in three ways:
  1. Spatially in/out of growing season
  2. Temporally at irrigated/non-irrigated points
  3. Time integrated & normalized precip/soil moisture metric



From Salmon et al. (2013)

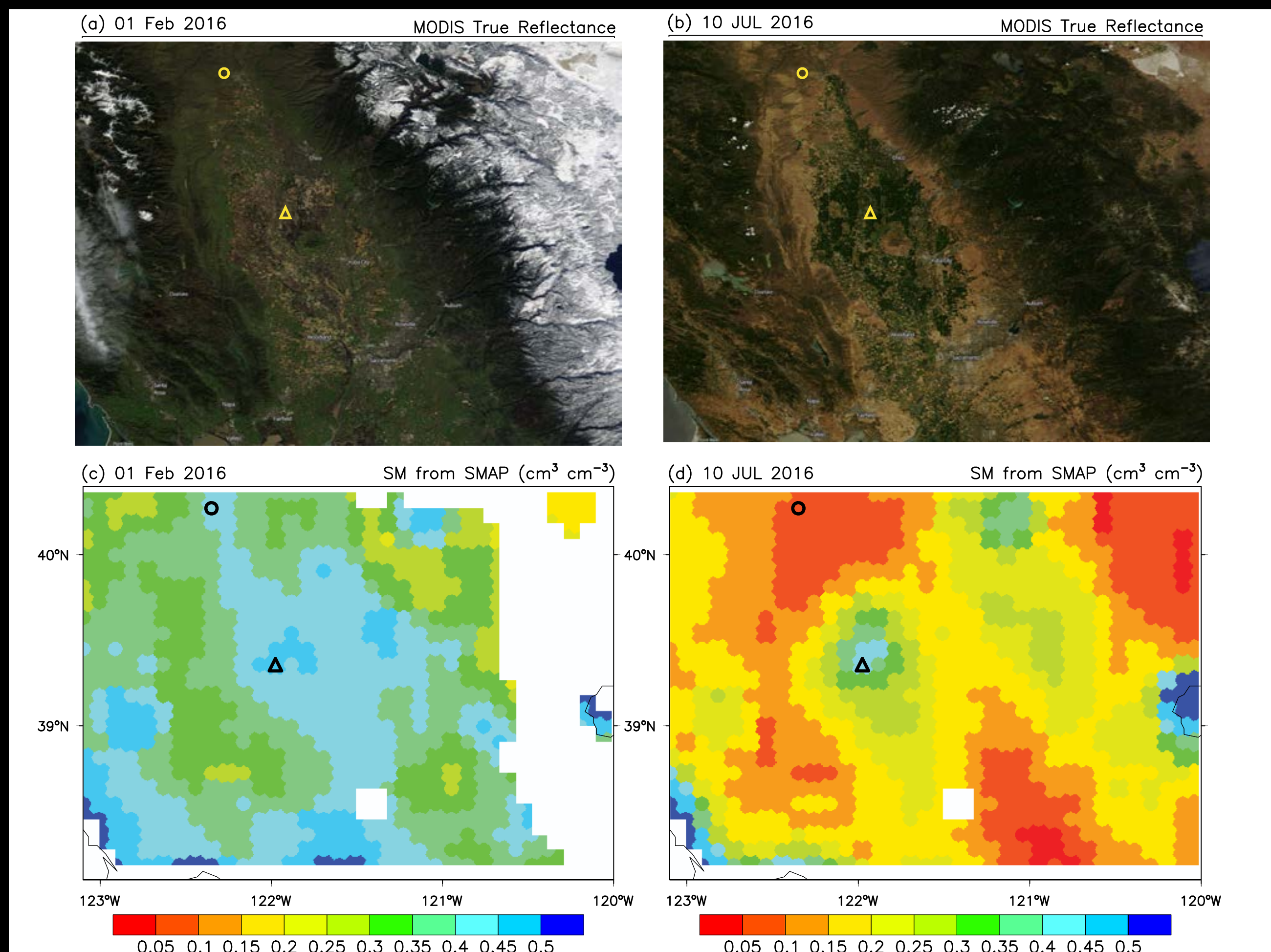
Case Study 1: Sacramento Valley



Credit: CropScape (USDA NASS)

Credit: Cal Rice News

Results: Sacramento Valley



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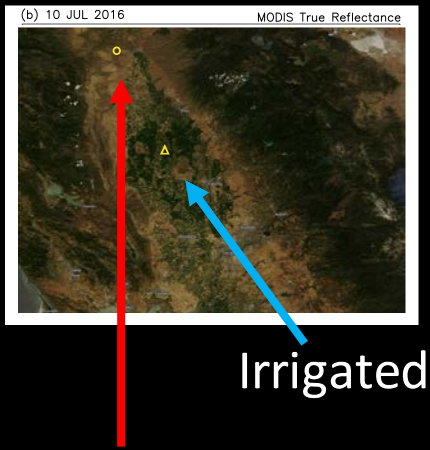
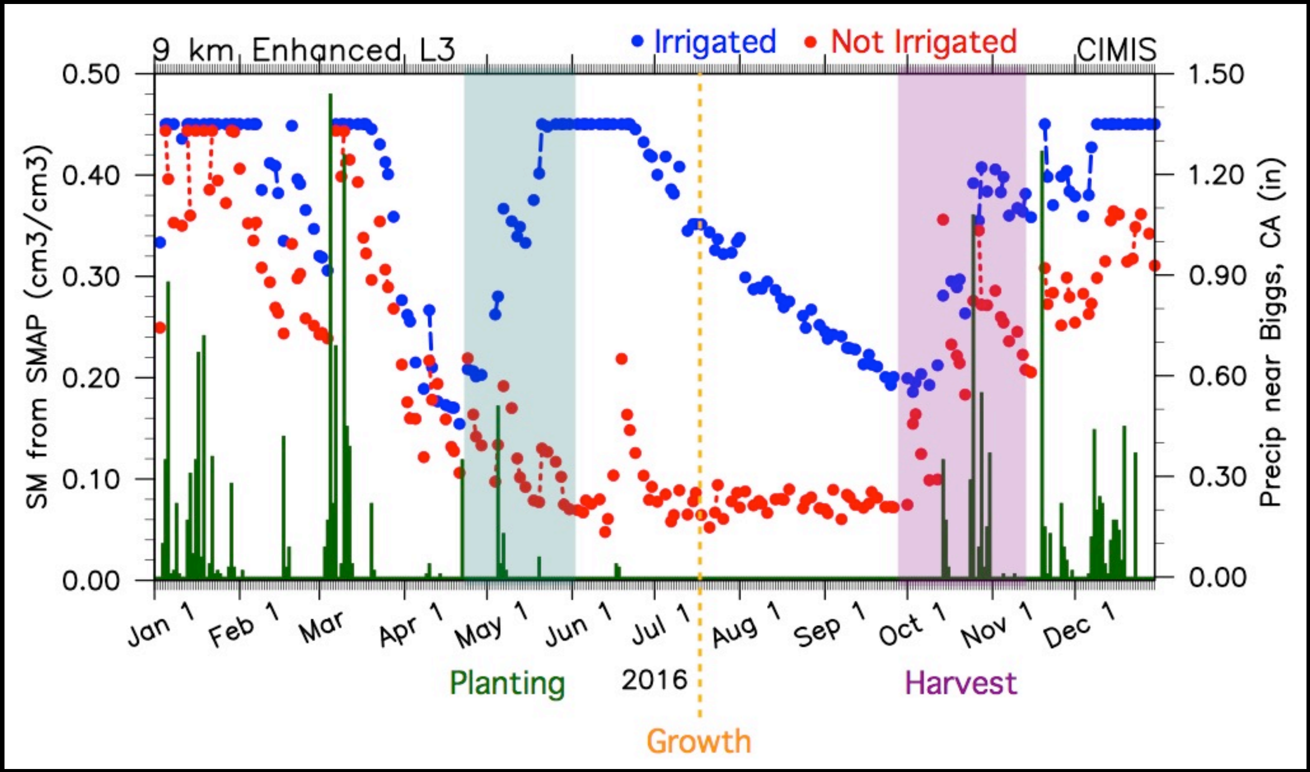
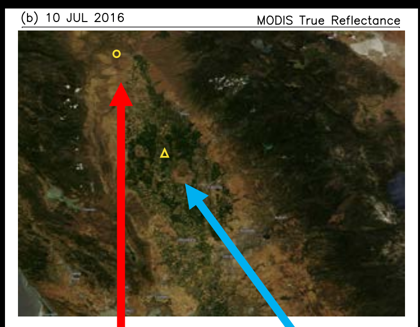




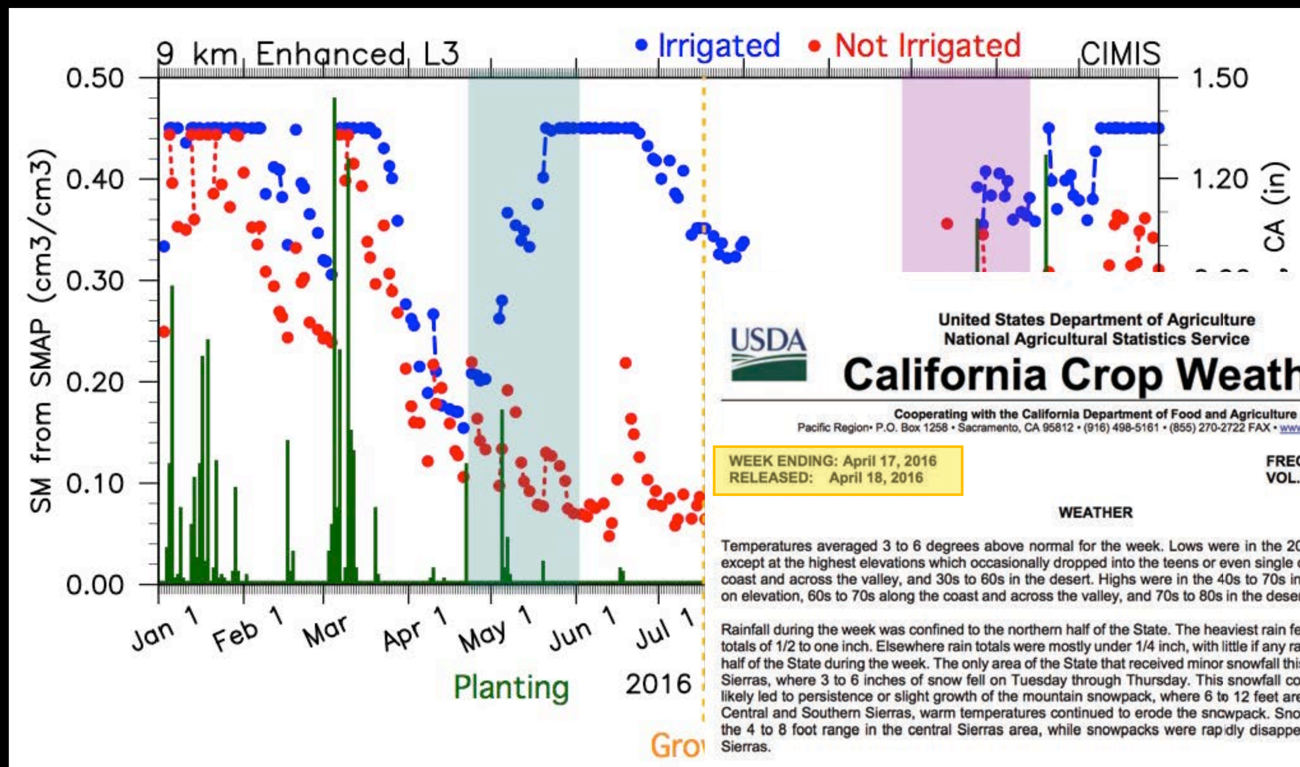
SMAP detects the onset of flood irrigation in May and sustained, elevated soil moisture in the flooded rice paddy in summer.

Results: Sacramento Valley



Irrigated

Not irrigated



United States Department of Agriculture
National Agricultural Statistics Service

California Crop Weather

Cooperating with the California Department of Food and Agriculture
Pacific Region• P.O. Box 1258 • Sacramento, CA 95812 • (916) 498-5161 • (855) 270-2722 FAX • www.nass.usda.gov/ca

WEEK ENDING: April 17, 2016
RELEASED: April 18, 2016

FREQUENCY: Weekly
VOL. 36 NO. 41

WEATHER

Temperatures averaged 3 to 6 degrees above normal for the week. Lows were in the 20s to 40s in the mountains except at the highest elevations which occasionally dropped into the teens or even single digits, 30s to 50s along the coast and across the valley, and 30s to 60s in the desert. Highs were in the 40s to 70s in the mountains depending on elevation, 60s to 70s along the coast and across the valley, and 70s to 80s in the desert.

Rainfall during the week was confined to the northern half of the State. The heaviest rain fell across the far north, with totals of 1/2 to one inch. Elsewhere rain totals were mostly under 1/4 inch, with little if any rain falling over the southern half of the State during the week. The only area of the State that received minor snowfall this week was in the Northern Sierras, where 3 to 6 inches of snow fell on Tuesday through Thursday. This snowfall combined with temperatures likely led to persistence or slight growth of the mountain snowpack, where 6 to 12 feet are still commonplace. In the Central and Southern Sierras, warm temperatures continued to erode the snowpack. Snowpacks continued to be in the 4 to 8 foot range in the central Sierras area, while snowpacks were rapidly disappearing across the southern Sierras.

FIELD CROPS

Alfalfa, oats, barley, and winter forage were cut, baled, and trucked from fields. **Winter wheat** continued to mature and was rated as 85 percent good to excellent. **Corn** continued to grow and some new fields were planted. Rice fields were beginning to be watered and seeded. **Cotton** was 40 percent planted in locations around the State but needed warmer temperatures to facilitate emergence. Pasture and rangeland condition was 65 percent good to excellent.

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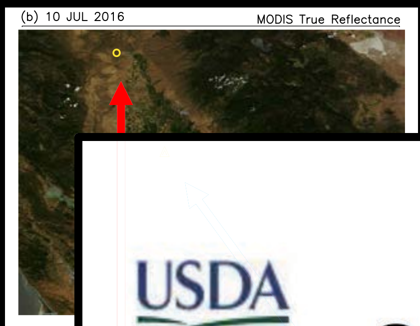
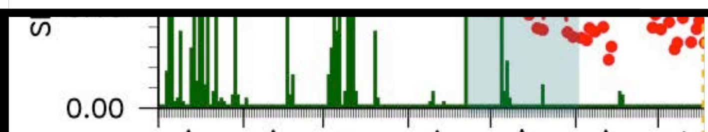
Results: Sacramento Valley





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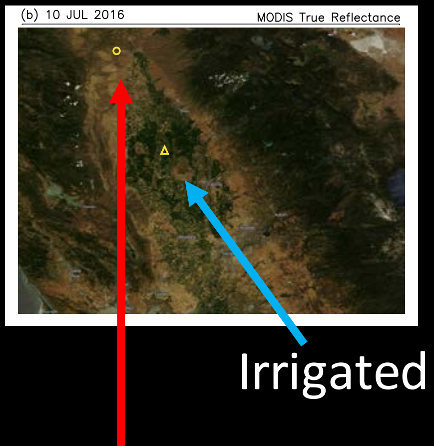
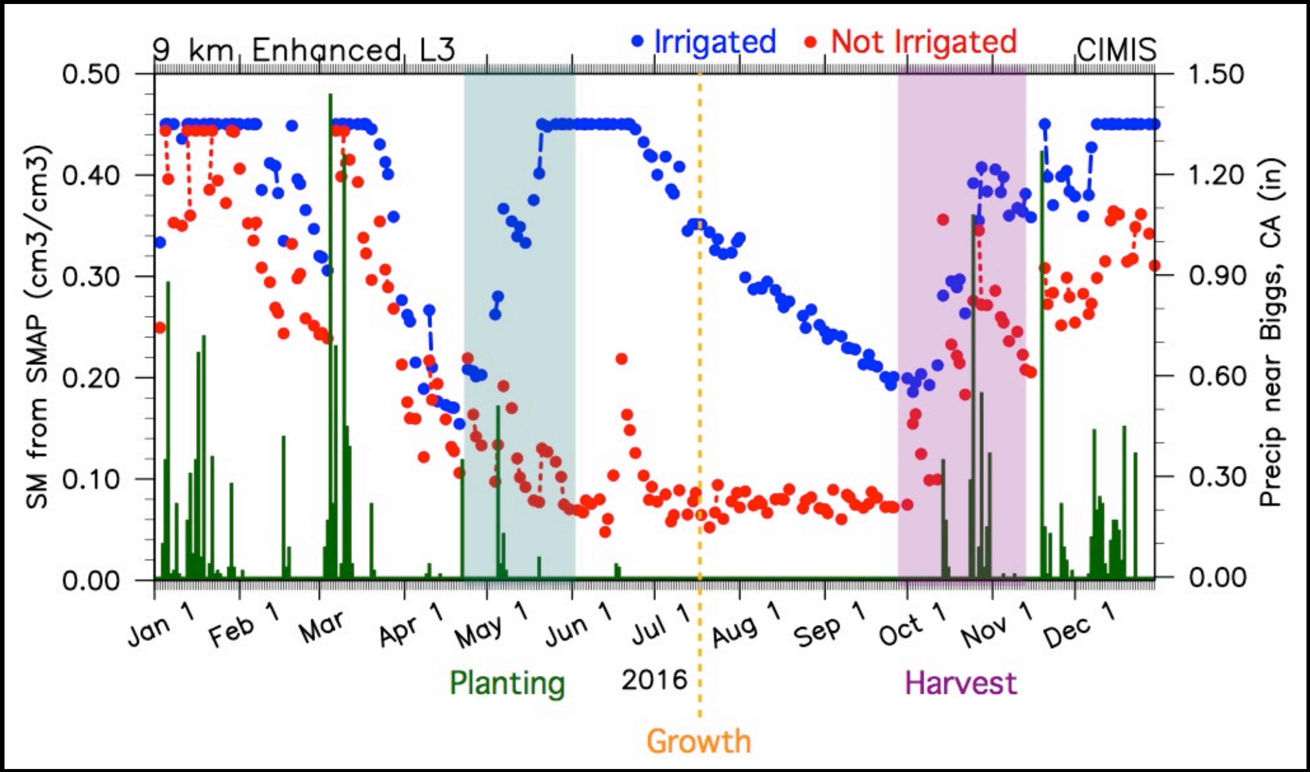




SMAP detects the onset of flood irrigation in May and sustained, elevated soil moisture in the flooded rice paddy in summer.

Soil Moisture/Rainfall Metric

- Concept: High soil moisture co-located with low precipitation may indicate irrigation
  - ➢ Analyze soil moisture and precipitation
- Method: For precip and SM in each study area

1) Accumulate values over time (June & July 2016):

$$\beta_{ji} = \sum_{t=0}^{n} x_{ji}(t)$$

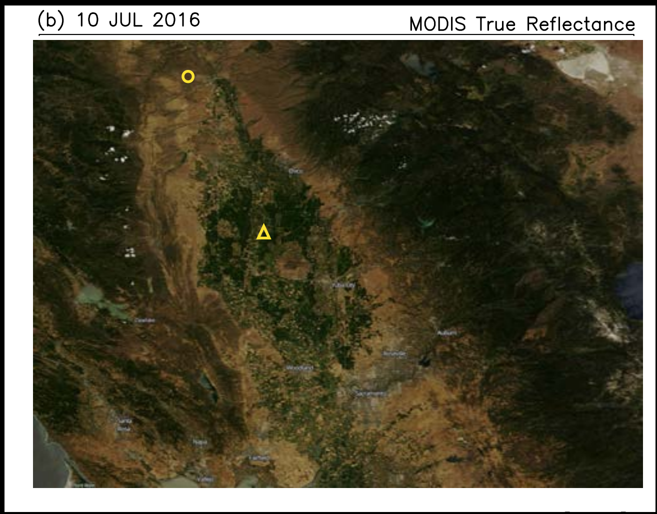
2) Normalize:

$$N_{ji} = \frac{\beta_{ji} - \min(\beta)}{\max(\beta) - \min(\beta)}$$

- Result: Relative (to each region and time period) measure of wettest/driest (SMAP) and rainiest/least rainy (precip) areas.

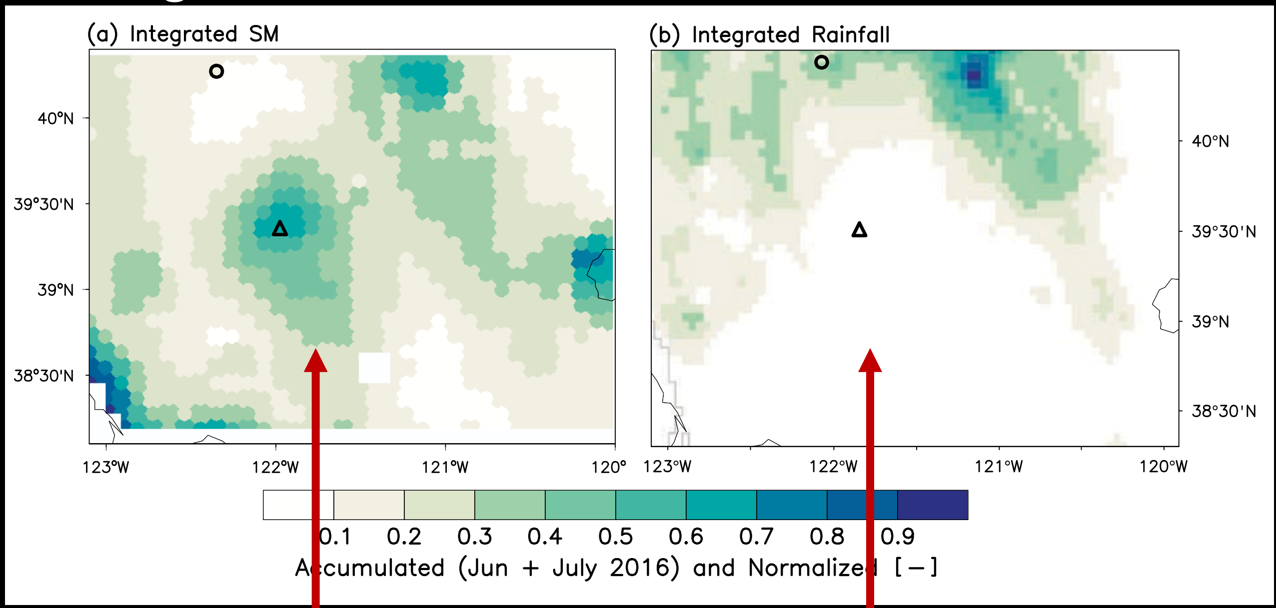
Results: Sacramento Valley

MODIS True color reflectance



Integrated soil moisture

Integrated rainfall



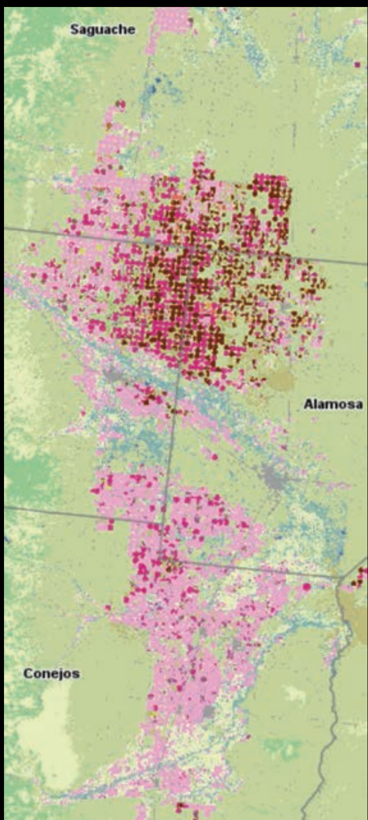
Relatively high soil moisture…

But local minimum in precipitation

Conclusions

- In three semi-arid regions, SMAP is able to detect the bulk seasonal timing and spatial signal of irrigation via elevated soil moisture relative to adjacent non-irrigated regions
- Flood irrigation is easiest to detect
- Limitations apply
- Future work will apply these approaches globally and will use SMAP-Sentinel downscaled 1 km soil moisture

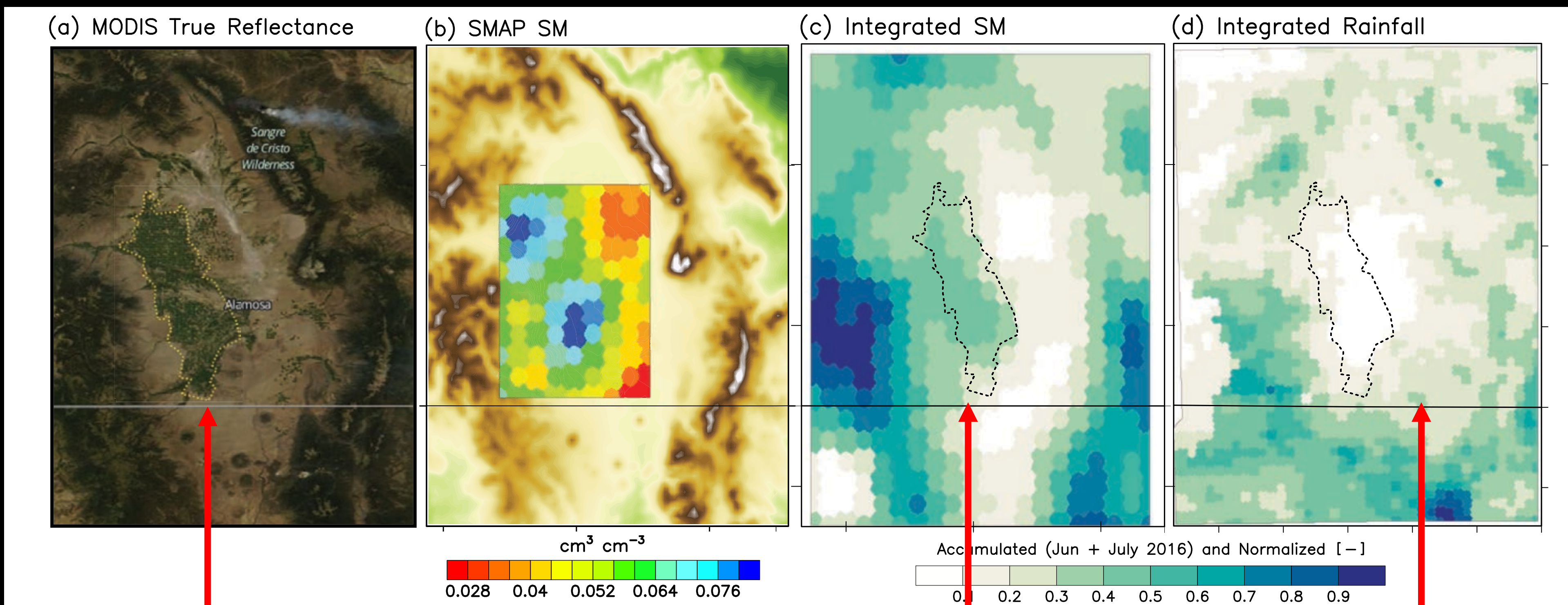
Case Study 2: San Luis Valley



Credit: Alamosa.org

Credit: USDA NASS

Results: San Luis Valley



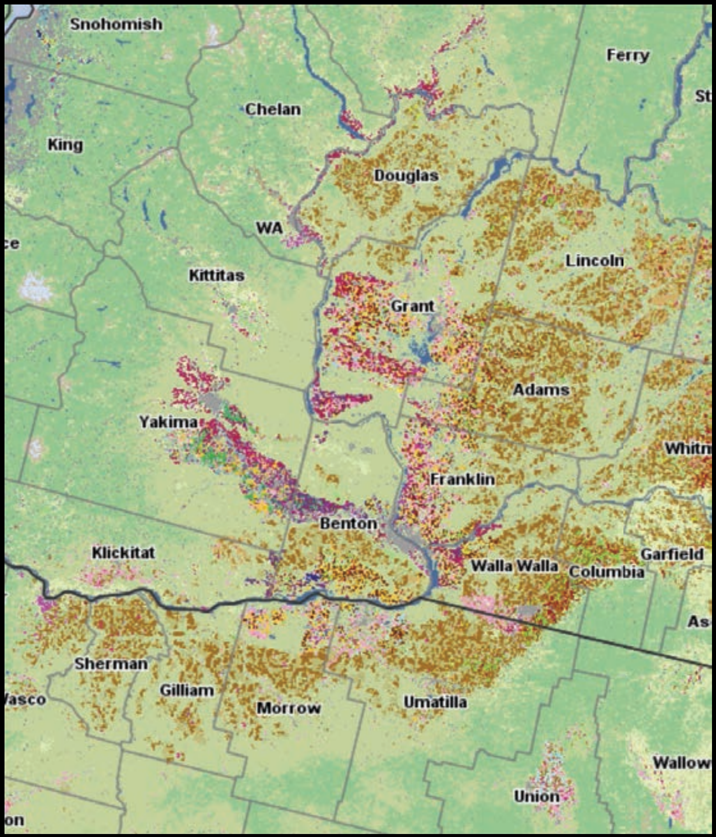
Irrigation in the valley

Relatively high soil moisture…

But local minimum in precipitation

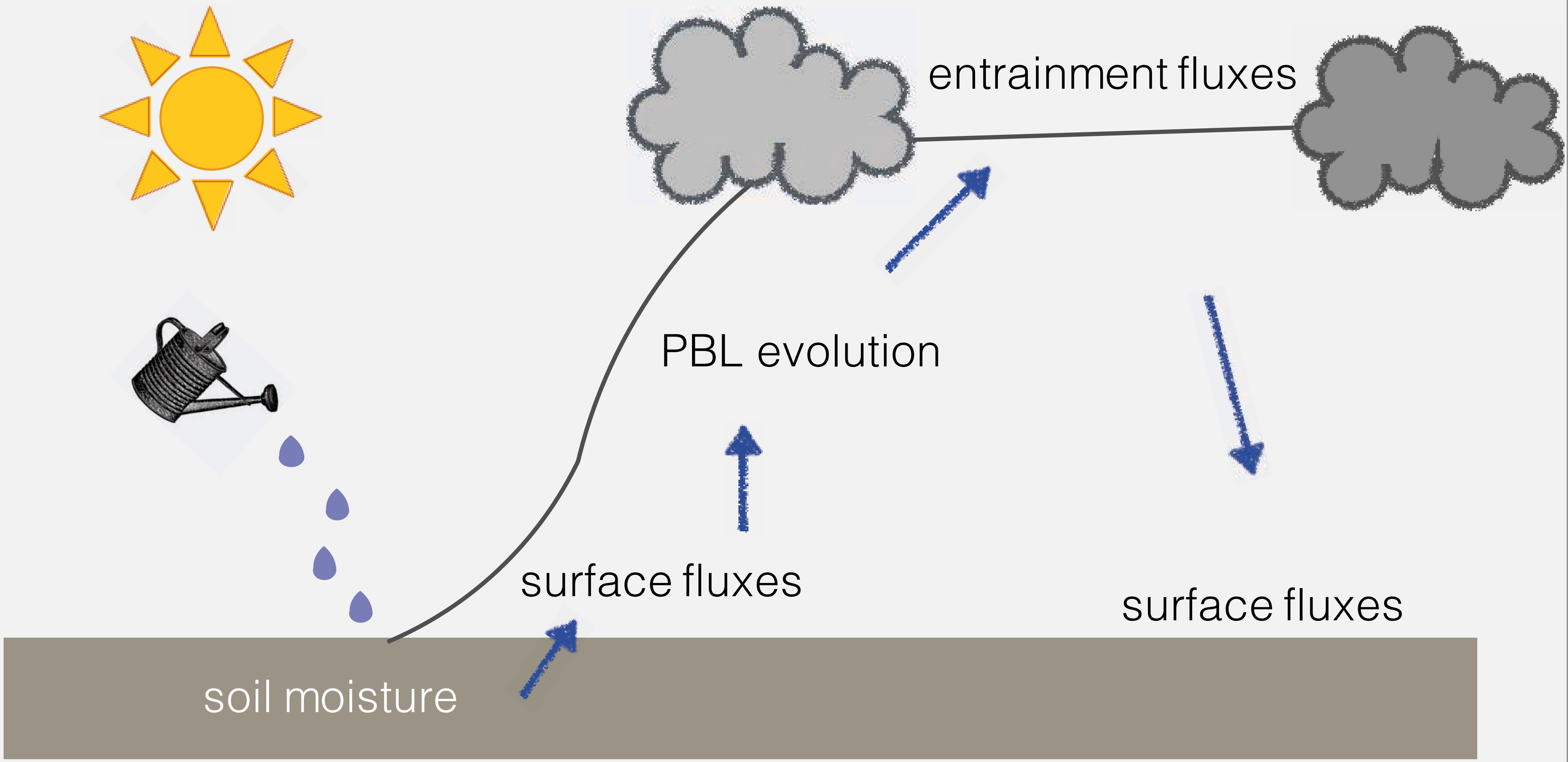
Case Study 3: Columbia River Valley

Credit: John Clement



Credit: CropScape (USDA NASS)

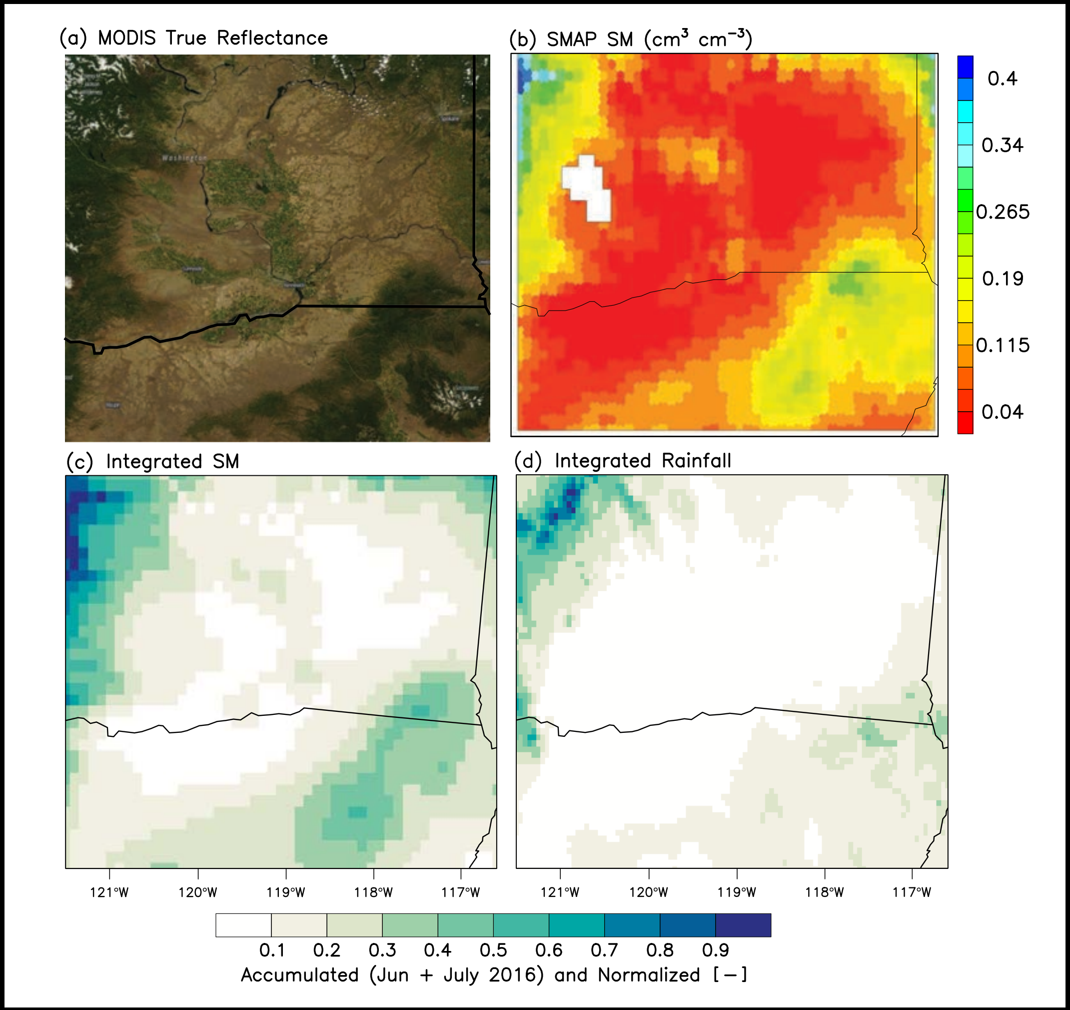
Science Motivation



Δ SM ⟶ Δ EF_{sm} ⟶ ΔPBL ⟶ ΔENT ⟶ $\Delta$$EF_{atm}$ ⟶ ΔP/Clouds

Santanello et al. 2007; 2011

Results: Columbia River Valley



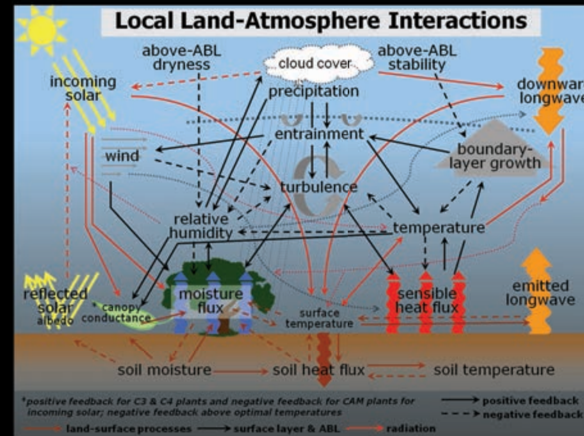
A complicating factor in this region is the proximity to rivers and lakes which could contaminate the SMAP signal.

Part 1: Motivation

- The complexity of land-atmosphere (L-A) interactions can be synthesized into simple process chain on Local L-A Coupling ('LoCo')

- Overarching Goal: Better understand the how/why of soil moisture impacts on NWP via understanding links in the LoCo process-chain.

- Two Phases:
  - Phase 1: Explore SMAP soil moisture products
  - Phase 2: Intercompare suite of soil moisture initial conditions for coupled WRF simulations



LAND–ATMOSPHERE INTERACTIONS

The LoCo Perspective

Joseph A. Santanello Jr., Paul A. Dirmeyer, Craig R. Ferguson, Kirsten L. Findell, Ahmed B. Tawfik, Alexis Berg, Michael Ek, Pierre Gentine, Benoit P. Guillod, Chiel van Heerwaarden, Joshua Roundy, and Volker Wulfmeyer

Metrics derived by the LoCo working group have matured and begun to enter the mainstream, signaling the success of the GEWEX approach to foster grassroots participation.

The role of land–atmosphere (L-A) interactions in weather and climate prediction has emerged over the last two decades as important but inherently challenging and complex. One reason is that L-A interaction research has proceeded "in reverse" compared to most science. Typically in Earth system sciences, observations inform theory, which then leads to the development and gradual refinement of conceptual and numerical models based on elucidated physical processes. The benchmark for such models' success, and the progress of the underlying science, is when they begin to consistently outperform purely statistical approaches inherently not based in the representation of physical processes (Best et al. 2015).

Conversely, coupled L-A (i.e., weather and climate) models arose well before the theoretical basis for

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The abstract for this article can be found in this issue, following the table of contents.

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Santanello, J. A., et al. (2018): **Land-Atmosphere Interactions: The LoCo Perspective**. *Bulletin of the American Meteorological Society*, June 2018 (in press).

Can SMAP detect irrigation?

Concept:

- In these known irrigated areas, low precipitation consistently co-located with high soil moisture may indicate irrigation

  → Compare precipitation (Stage IV analysis) and SMAP soil moisture

Method:

For precip and SM in each study area:

1) Accumulate values over time (June & July 2016):

$$\beta_{ji} = \sum_{t=0}^{n} x_{ji}(t)$$

2) Normalize:

$$N_{ji} = \frac{\beta_{ji} - \min(\beta)}{\max(\beta) - \min(\beta)}$$

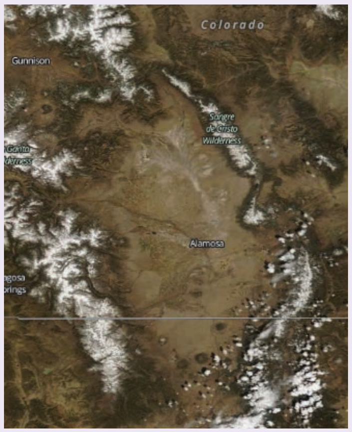
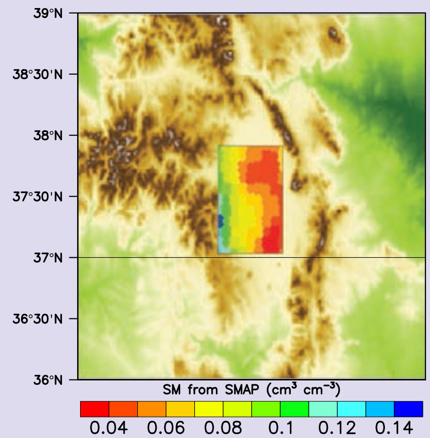
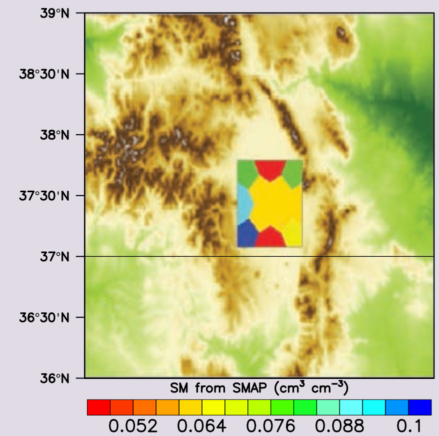
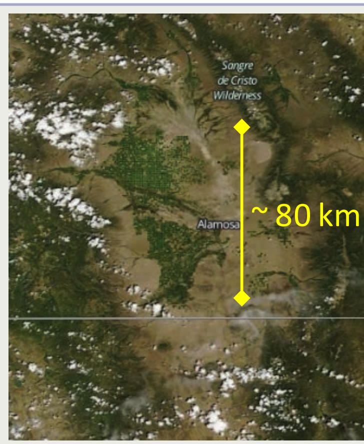
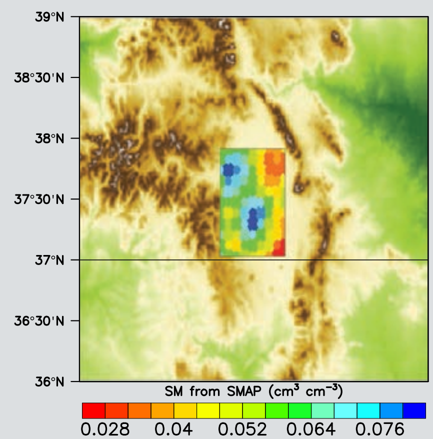
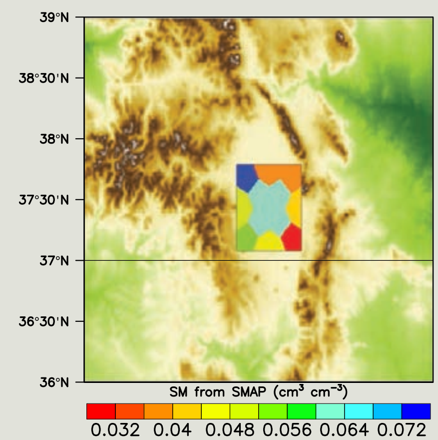
Result:

Relative (to each region and time period) measure of wettest/driest (SMAP) and rainiest/least rainy (precip) areas.

Motivation

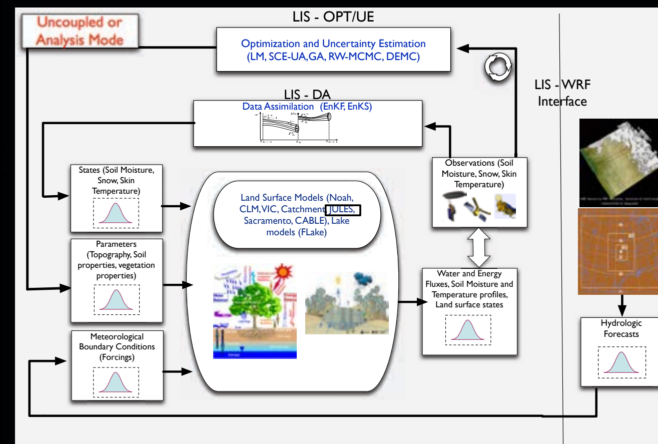
- Irrigation can influence weather and climate, but impacts of irrigation are poorly represented in models, if included at all.
- Satellite-based irrigation detection via soil moisture can help but has been limited to date (SMOS, AMSRE, ASCAT, etc.)
- This study explores the utility of the NASA's new Soil Moisture Active Passive (SMAP) satellite for identify irrigated regions and timing.

Results: San Luis Valley

		Enhanced (9km)	36 km
Before Irrigation (April)			
During Irrigation (July)			

Modeling tools and experimental design

- NASA's Land Information System
  - Provides a suite of LSMs under a consistent, high performance computing and software framework that allows for:
    - Land DA, Calibration
    - Flexible forcing, parameters, physics, ensembles
    - Coupling to WRF



- NASA Unified WRF (NU-WRF)
  - Provides an observation-driven, integrated modeling system that represents aerosol, cloud, precipitation and land processes at satellite resolved scales (1-4km)
  - Integrates unique NASA observation and modeling assets under one roof:
    - Satellite data
    - Model Physics
    - Expertise/Software