# Observational and Modeling Analysis of Land-Atmosphere Interactions over Adjacent Irrigated and Rainfed Cropland During the GRAINEX Field Campaign

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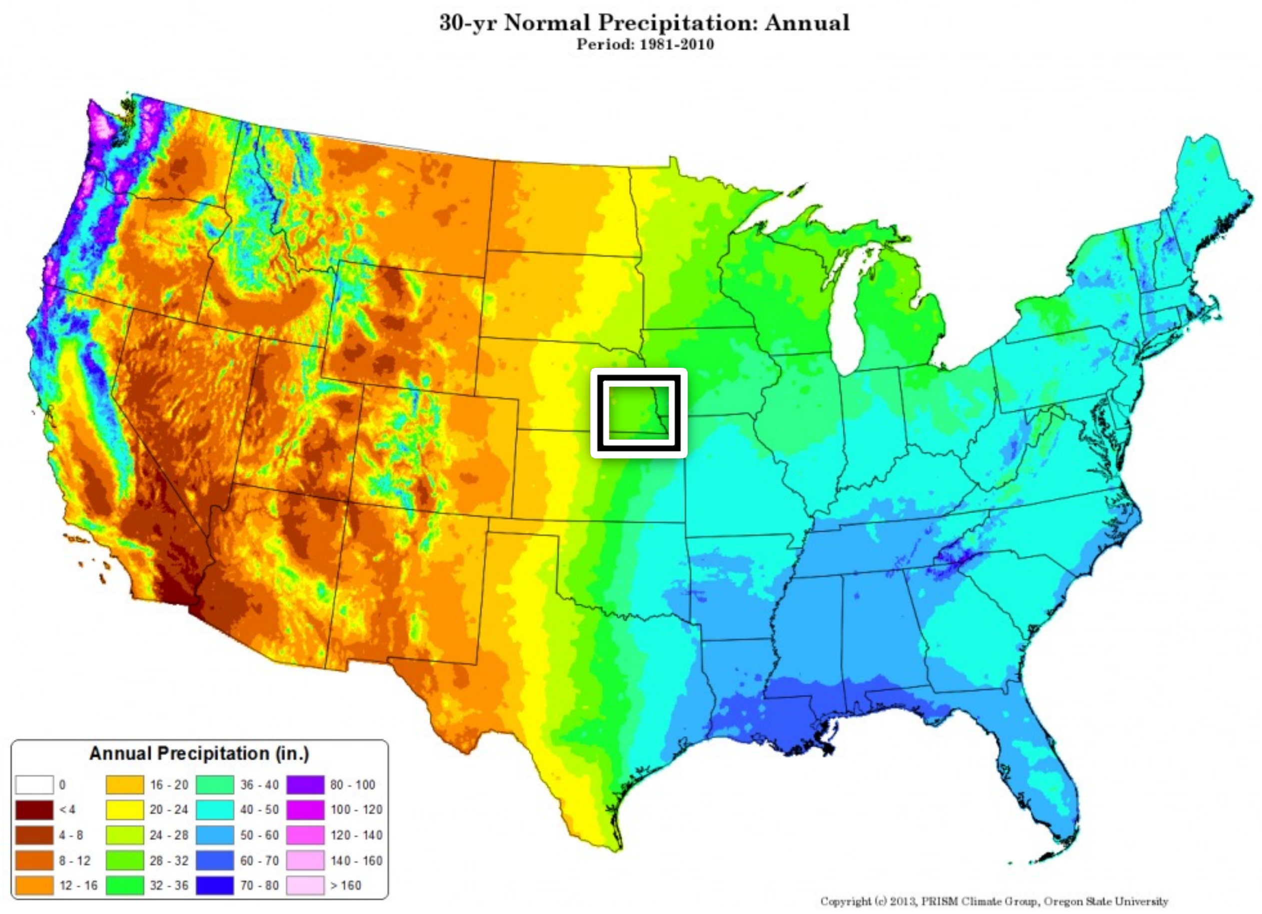
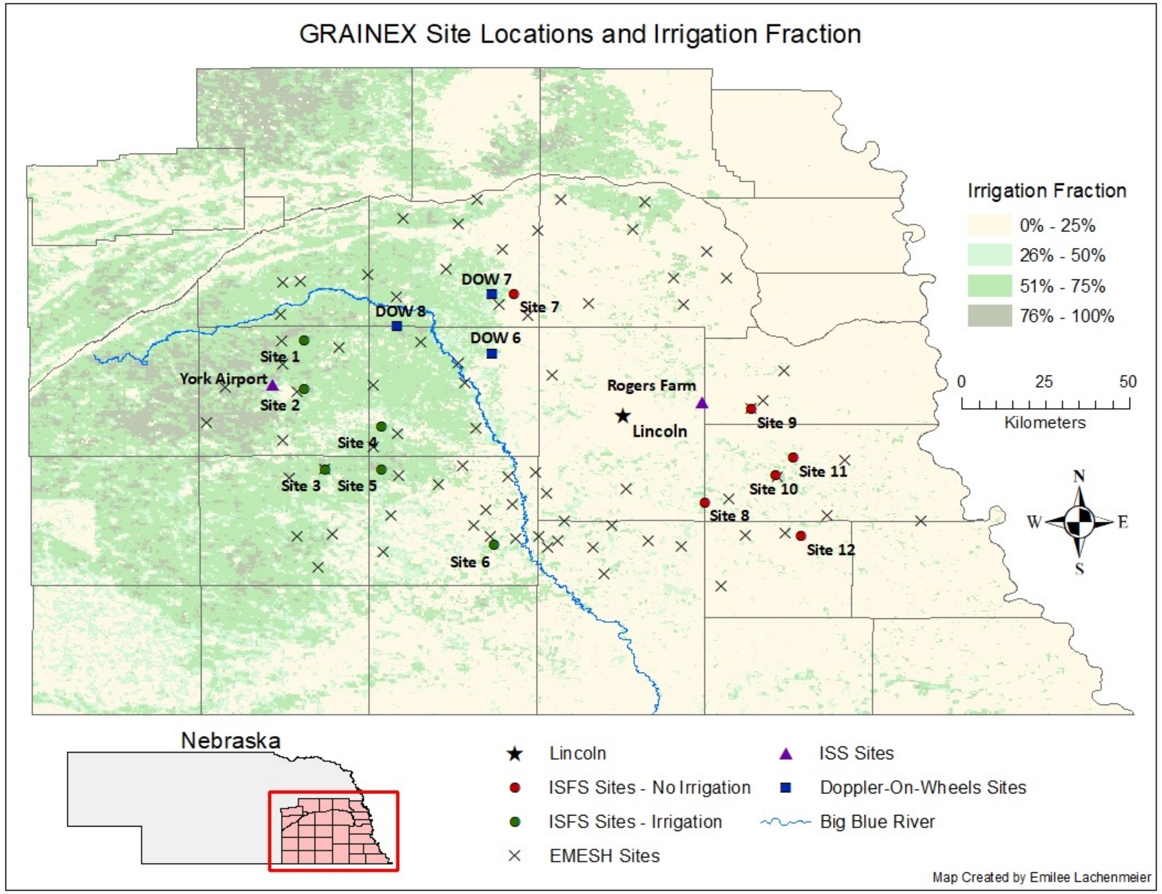
# GRAINEX

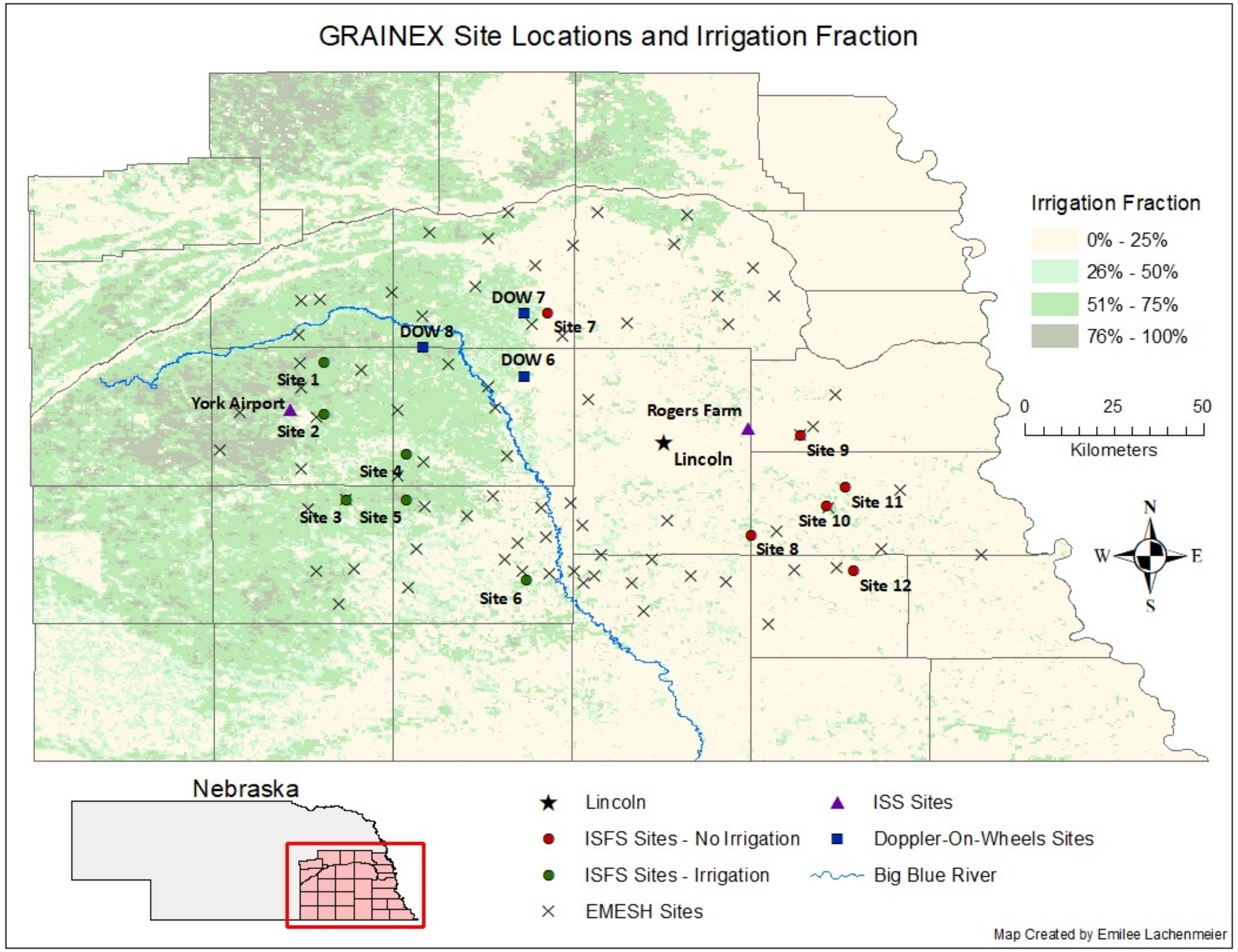



**PRISM 30-year normal precipitation climatology. Credit: http://www.prism.oregonstate.edu/normals**

The Great Plains Irrigation Experiment (GRAINEX) is a field experiment for monitoring land-atmosphere interactions over adjacent irrigated and non-irrigated areas, west and east of the Big Blue river in SE Nebraska.

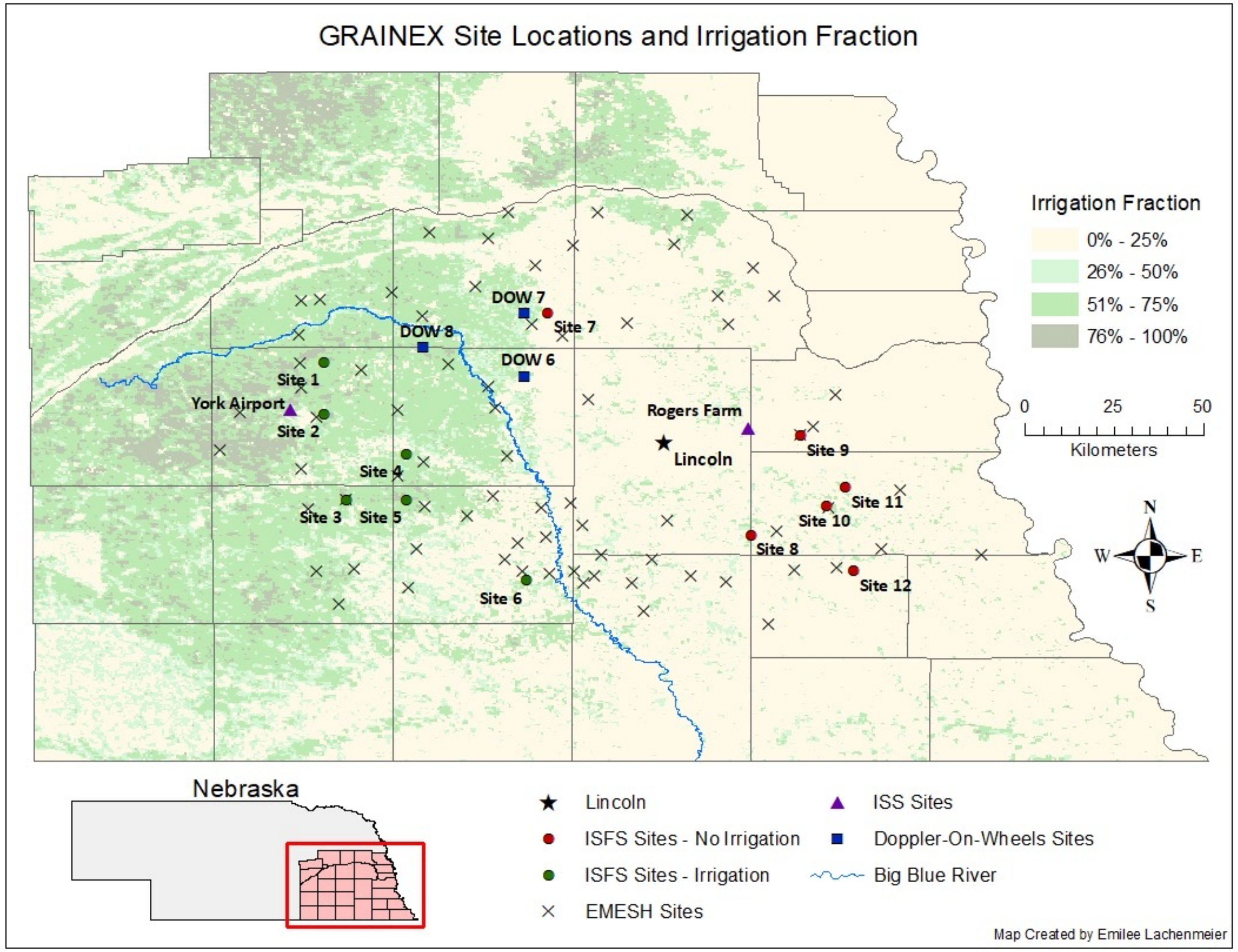


# Motivation




- How does boundary layer development differ between irrigated and non-irrigated regions?
- Is irrigation the dominant contributor for observed differences (e.g. isolate role of irrigation forcing compared to large scale advective tendencies?)
- Do these differences in land-atmosphere coupling in the presence of heterogenous land surface properties impact isolated convection
- Does baroclinicity caused by irrigation induce mesoscale circulations and enhance convective development?
- What proportion of irrigation is recycled as local rainfall?
- Is there observational/modeling evidence of the downwind growth of convection leading to enhanced precipitation in non-irrigated regions.
- Development of an extensive data set to examine land-atmosphere coupling processes associated with irrigation.

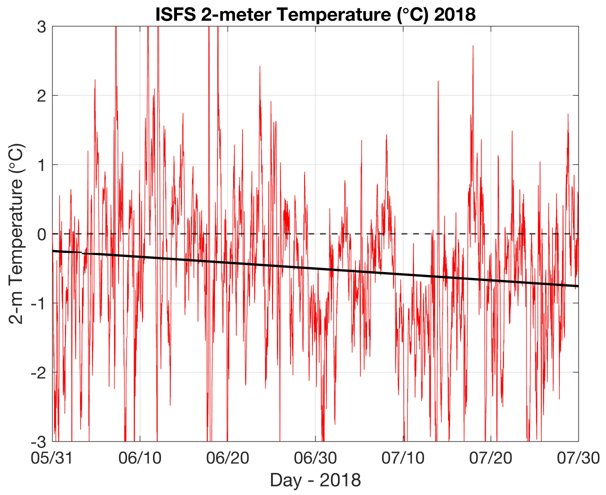
# IOPs / Observation Platforms

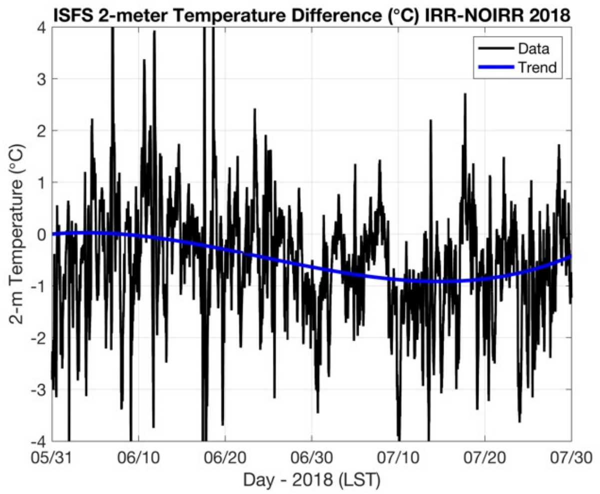


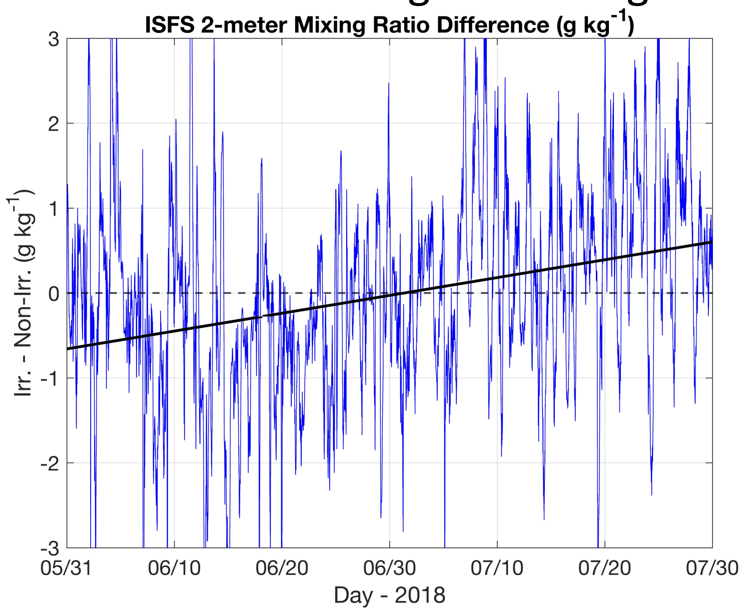

- Two phases (IOP1/2):
  - 1: Commencement of irrigation “Binary switch” – Rapid change in moisture availability in growing season. (May 30 - June 13, 2018)
  - 2: Intensive irrigation (July 16 - 30, 2018).
- Observation Platforms
  - **ISFS** – Integrated Surface Flux System (6 – Irrigated, 6 – Non-Irrigated)
  - **ISS** – Integrated Sounding System (Mass, Momentum, Moisture Profilers; 1 irrigated and 1 non-irrigated)
  - **DOW**s – Doppler on Wheels along irrigation gradient;
  - **EMESH** – 75 University of Alabama in Huntsville Environmental Monitoring, Economical Sensor Hubs (EMESH) stations –Surface meteorology, soil moisture and soil temperature (2 levels)
  - **Radiosondes**: Balloons launched from the ISS and DOW sites (8 times a day from sunrise to sunset)
  - **Land Surface State / Surface Meteorology**: All locations except DOWs

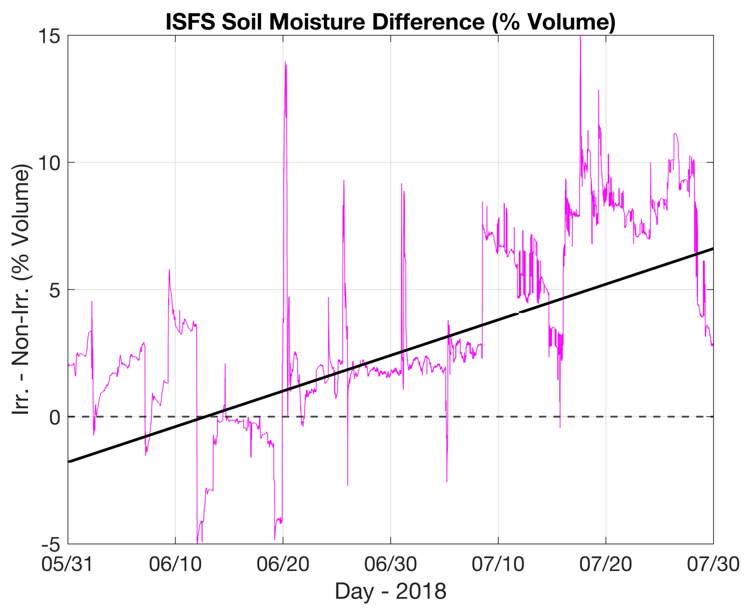
# Seasonal – Obs.

- Statistically significant trends in 2-meter temperature, mixing ratio, and 5 cm soil moisture difference between ISFS irrigated and non-irrigated sites.
- 5-minute time interval from 30 May 2018 to 30 July 2018.
- Linear and polynomial trend in temperature follows is consistent with depressed temperatures over irrigation while polynomial fit shows the strongest impact of irrigation on temperature around ~ 01 July 2018
- Linear fit is 2-m mixing ratio shows a similar impact with the difference field turning positive around ~ 01 July 2018
- Soil moisture difference at 5 cm shows a steady increase in trend during the season with synoptic-scale systems driving the values between wet and dry in the first half of the season with irrigation being a driver in the second half.



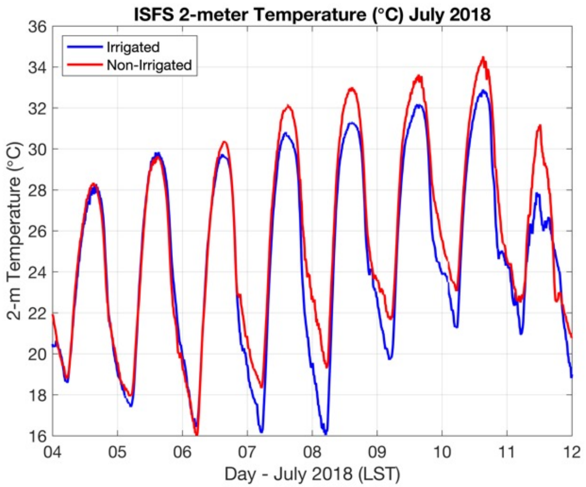



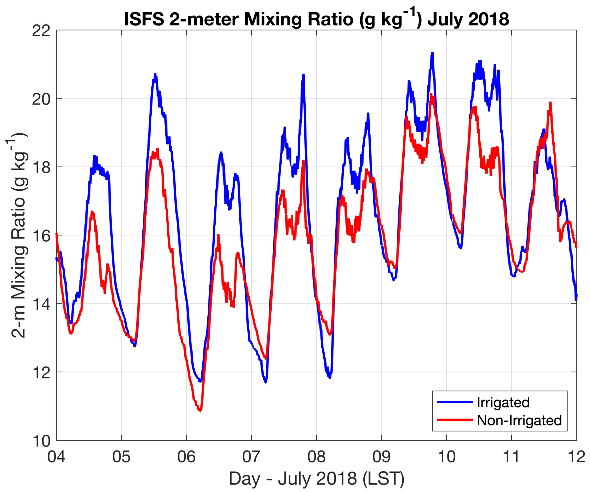



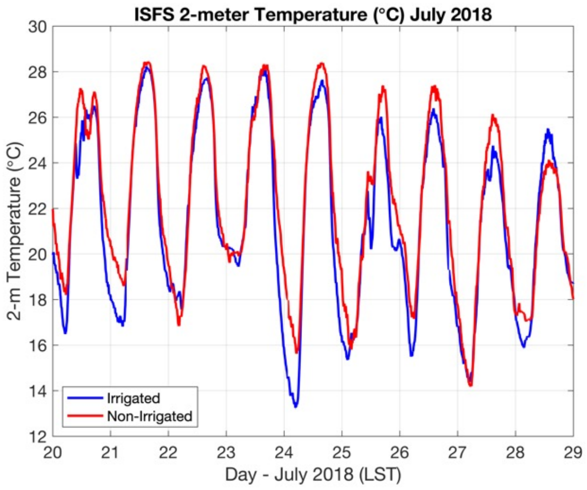
# Biweekly – IOP timescale Obs.

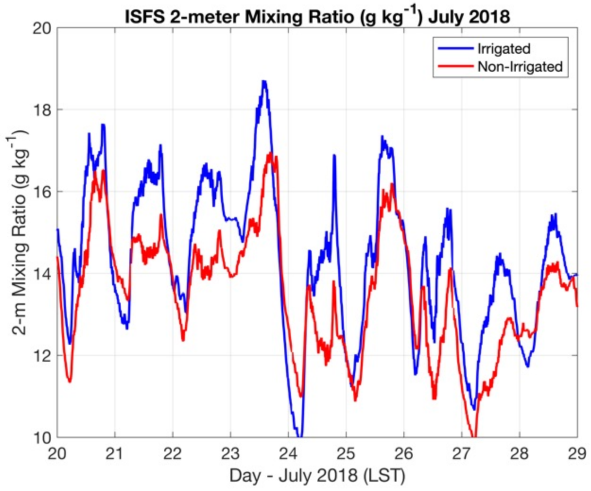
Pre-IOP2



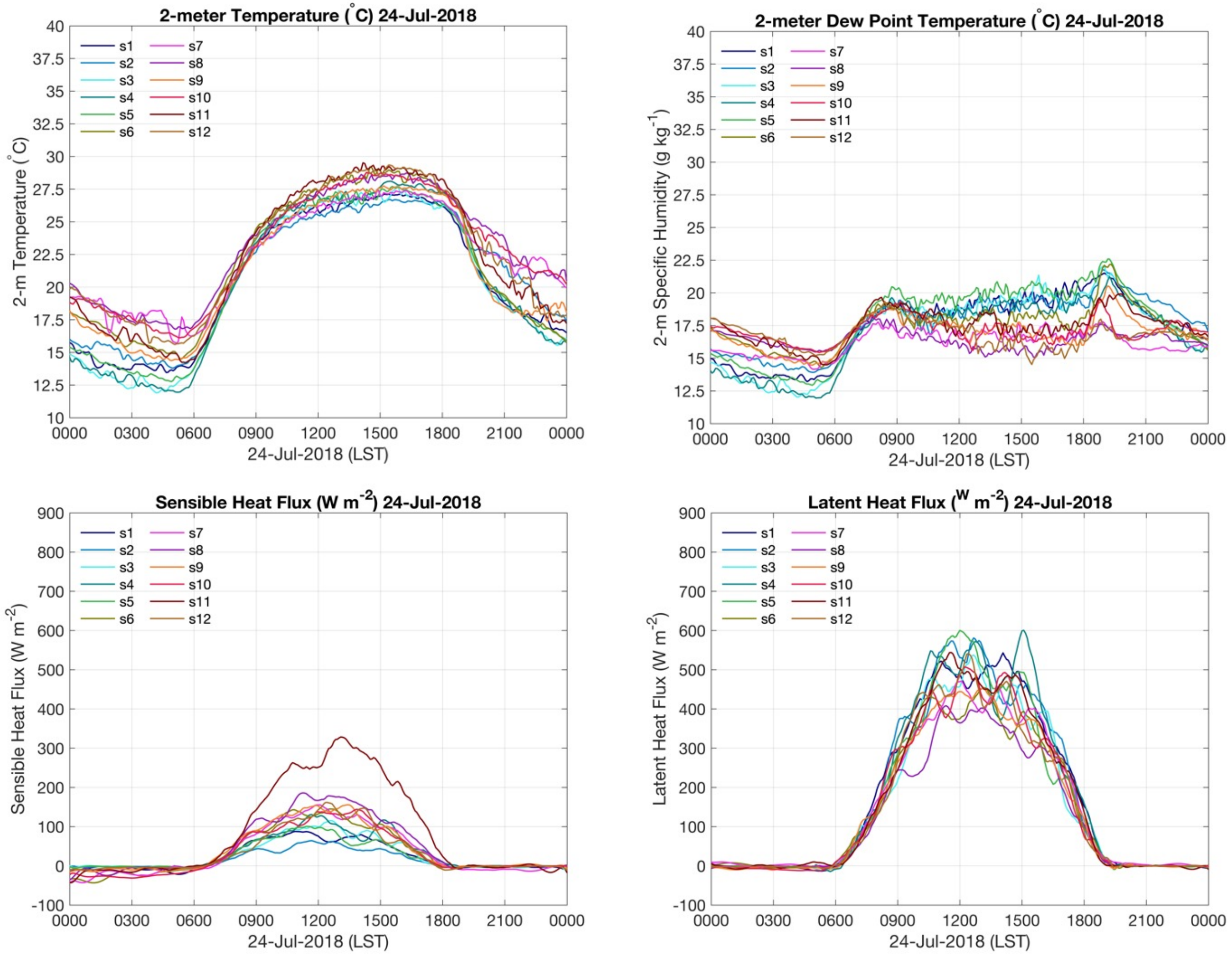

IOP2



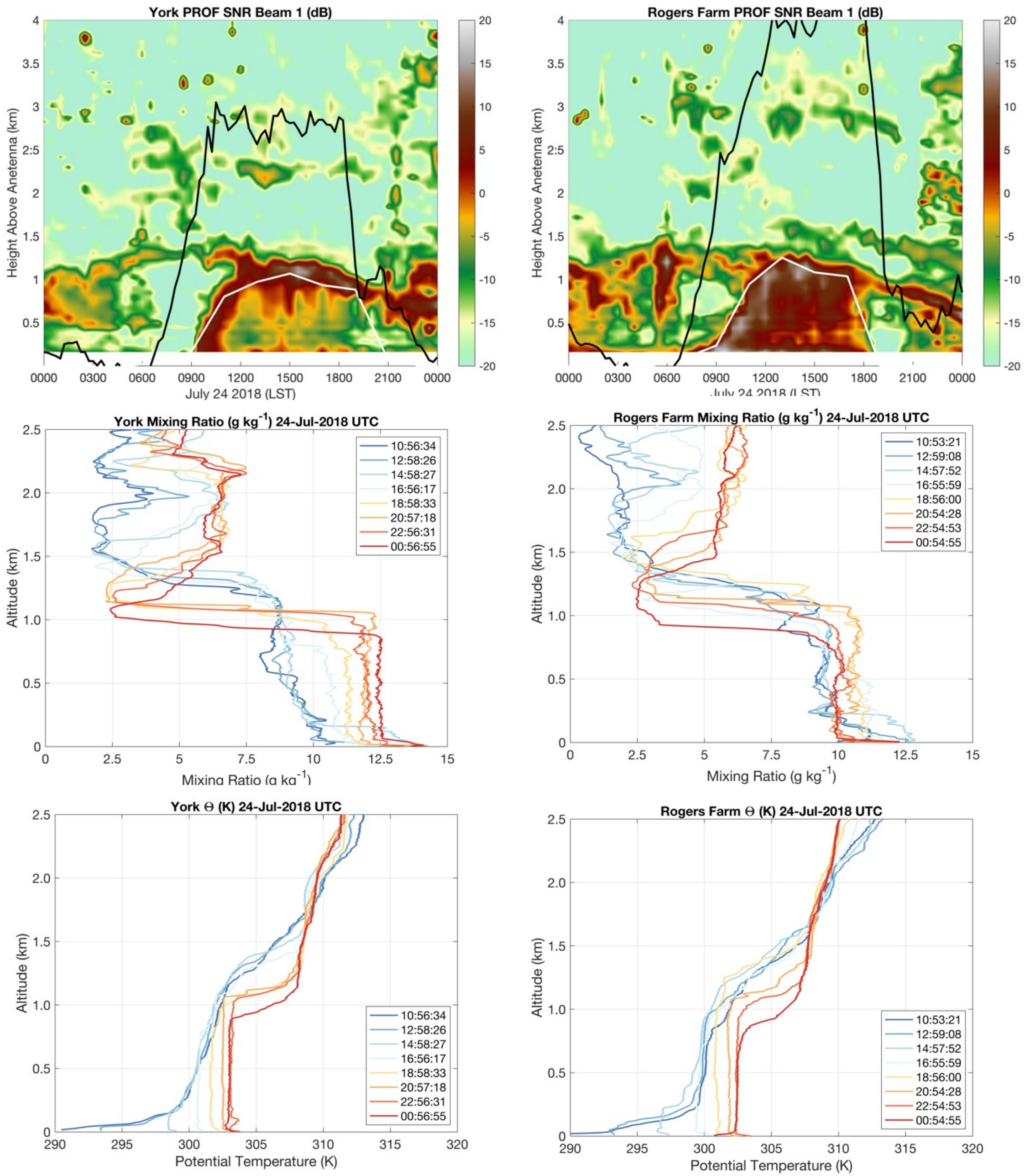

- As the irrigation “binary switch” occurred later than expected (~01 July 2018), IOP1 is not discussed here, but will be examined in future work.
- Early July (Pre-IOP2) was marked by broad high pressure across much of the USA leading to strong land-atmosphere interactions over the GRAINEX domain
  - Successive days of increasing temperature as land-atmosphere coupling was strong under persistent sunny skies.
  - Actual ET leading to increasing mixing ratios atmospheric thirst goes up with increasing temperature.
  - Well observed dual spikes in moisture, one associated with the early maximum that sets in prior to PBL entrainment drying, the other associated with moisture flux convergence during the afternoon-evening transition.
- IOP2 was characterized by periods of both precipitation and irrigation. 24 July 2018 will be further investigated here while 22-24 July 2018 is highlighted in an upcoming Bulletin of the American Meteorological Society article.

# Diurnal Obs. I – Surface Evolution



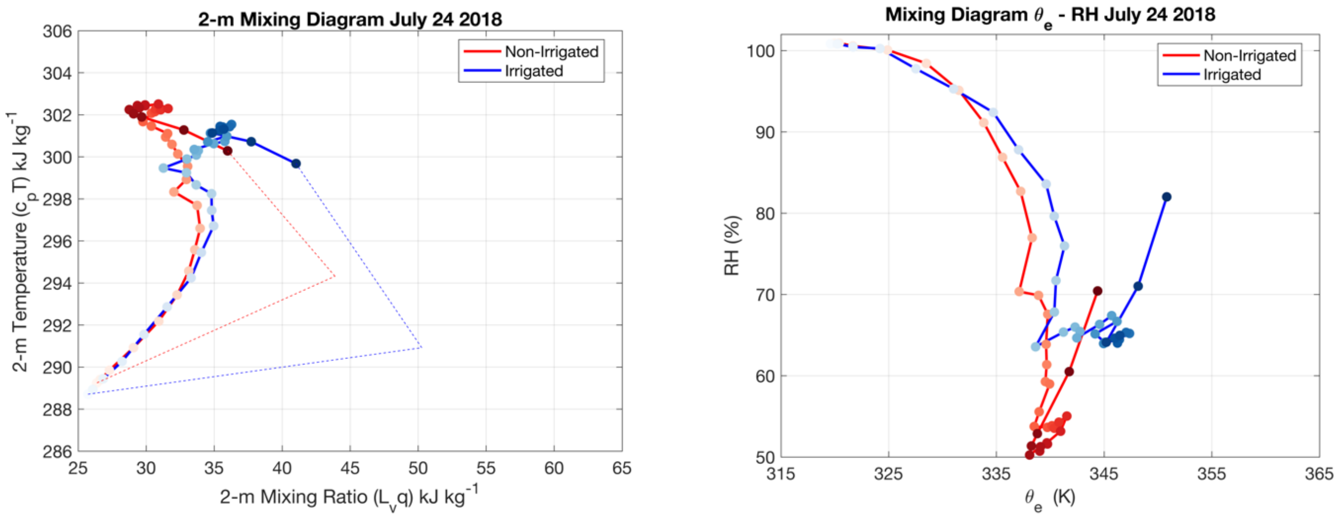

- Warm Colors: ISFS non-irrigated (NI) sites.
- Cool Colors: ISFS irrigated (I) sites.
- Larger Sensible Heat Fluxes over NI leads to significantly larger warmer 2-m temperatures compared to I sites, aided by stronger PBL entrainment.
- After sunrise, the latent heat flux increases rapidly, peaking first in the mid afternoon with a larger magnitude over I sites.
- Dew point temperature peaks first in the mid to late morning prior to the onset of PBL entrainment.
- Strong PBL entrainment coupled with a lower Bowen ratio over NI leads to a gradual decrease in dew point through the afternoon.
- Conversely, weaker PBL entrainment and a larger latent heat flux over irrigated sites leads to a gradual increase in dew point temperature through the afternoon.
- Both I and NI sites display a second mixing ratio peak from moisture flux convergence during the transition from a convective to a stable surface layer.

# Diurnal Obs. II – PBL Evolution

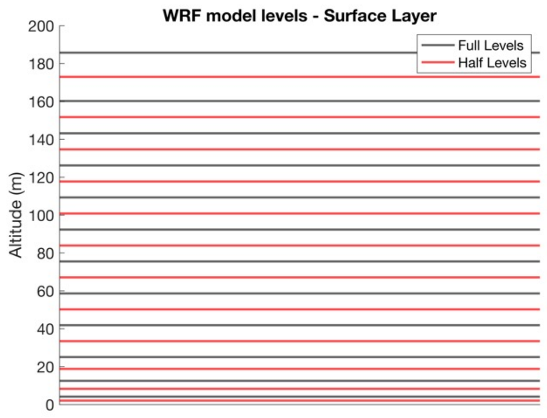


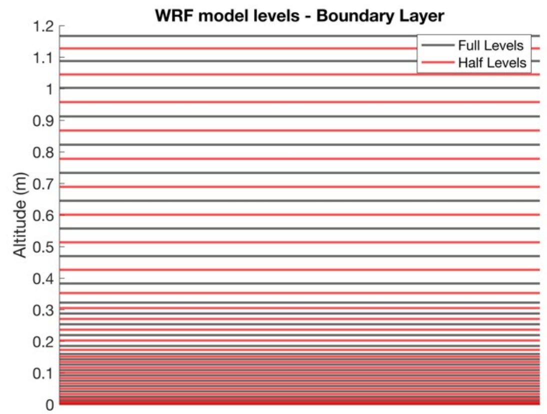

- Signal-to-Noise Ratio wind profiler PBL height (colorfill) matches up well with Bulk Richardson Number defined PBL height (white contour) from radiosonde launched (top row).
- Lower PBL heights are observed at the irrigated (I) ISS site (left column) compared to the non-irrigated (NI) ISS site (right column).
- Unsurprisingly, with a lower mean PBL moist static energy over irrigation, the lifting condensation level is substantially lower over irrigation relative to non-irrigation.
- Balloon launch observed mixing ratio (middle row) and potential temperature (bottom row) are displayed every 2 hours from just before sunrise to just after sunset.
- The strong drop off in mixing ratio and increase in mixing ratio between the PBL and the free troposphere is indicative of entrainment.
- The systematic increase in mixing ratio with time is clearly observed over irrigation whereas above the surface layer over non-irrigated cropland, the mixing ratio increases rapidly in the morning, more slowly in the early afternoon, and decreases in the late afternoon and evening.
- The above bullet can be explained with the aid of the potential temperature profiles:
  - Above the strong surface layer inversion at both I and NI ISS sites, a residual layer is observed at the NI site while the early morning soundings are slightly stable at the I site.
  - As a result, early morning PBL growth over NI cropland is more explosive relative to that over irrigated cropland. The smaller growth in specific humidity and its decline in the afternoon is hinted at by the continuous lowering of the entrainment layer with time.

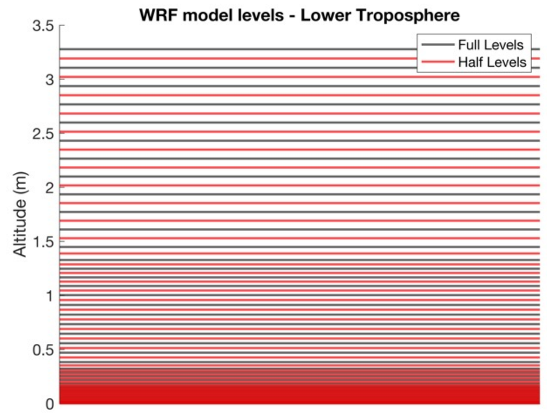
# Diurnal Obs. II – Mixing Diagrams




- Mixing Diagrams (left; Betts 1992, Santanello et al. 2009) representative a column integrated moist static energy budget with surface fluxes input through the  bottom boundary (lower dashed line) and entrainment fluxes through the top boundary (upper dashed line). Advective fluxes through the lateral boundaries are considered small due to the fair weather conditions and the difficulty in advection calculations from observations.
- On the left is the near surface moist static energy phase space while on the right is a similar figure but with relative humidity along the y-axis and equivalent potential temperature along the x-axis. Note the individual dots represent time segments of 20 minutes from sunrise to sunset.
- Rapid increases in both temperature and mixing ratio (and RH and $\theta_e$) in the early to mid morning hours leads to near constant moist static energy ($\theta_e$) while undergoing a rapid drop in RH.
- There is a reversal in the slope of both figures in the late morning as entrainment occurs at similar strength over both ISS sites
- In the afternoon, there is an aggregation of points representing a rough balance between surface radiative forcing and PBL top entrainment.
- While the entrainment moisture fluxes display a similar magnitude over both irrigated and non-irrigated cropland, the lower PBL height over irrigation and the larger surface latent heat flux leads to a larger mean moist static energy. Conversely, the larger sensible heat fluxes over non-irrigated cropland
- During the afternoon-evening transition there is a sharp increase in both RH and $\theta_e$ as moisture flux increases the mixing ratio as the temperature falls.



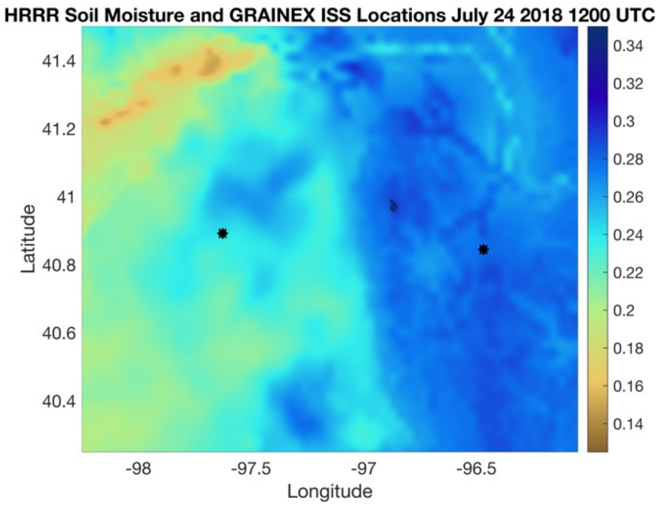



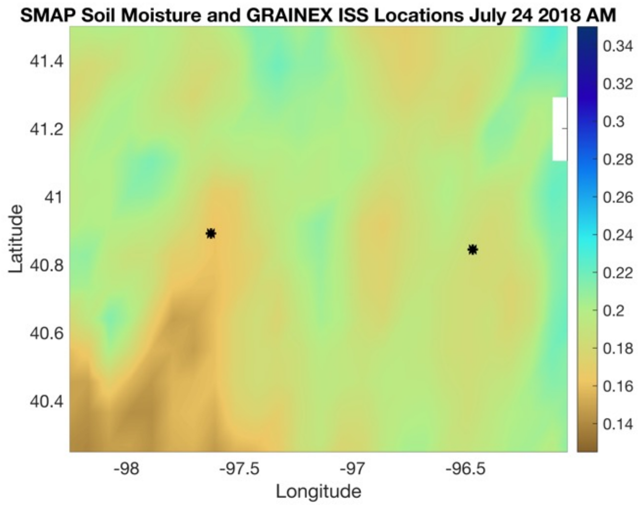



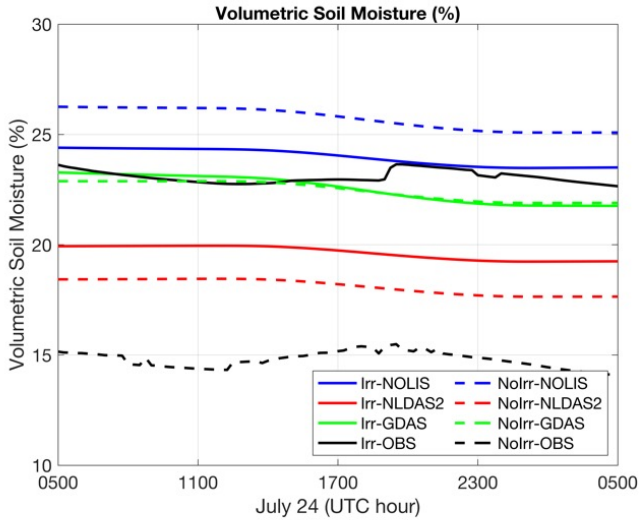

# Diurnal Modeling I - Setup

- Weather and Research Forecasting Model v4.2
- Simulation from 23 July 2018 2100 UTC to 25 July 2018 0600 UTC
- 1 km horizontal grid spacing
- 97 vertical levels (distributed as seen on left through lower troposphere)
- High Resolution Rapid Refresh Analyses (3 km grid spacing) used for initial / boundary conditions
- Model physics identical to HRRR model except for the land surface model (LSM), which was changed to be consistent with offline spinup of land surface state.
- Land surface spinup:
  - NASA Land Information System (LIS)
  - Noah LSM
  - North American Land Data Assimilation System (NLDAS2) and Global Data Assimilation System (GDAS) employed for meteorological forcing.
  - 12-member Soil Moisture Active/Passive (SMAP) data assimilation from May 2015 through August 2018.

# Diurnal Modeling II – Soil Moisture Initialization



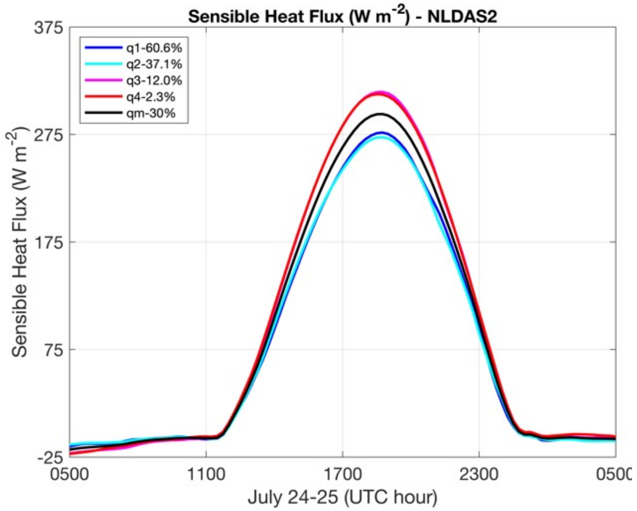



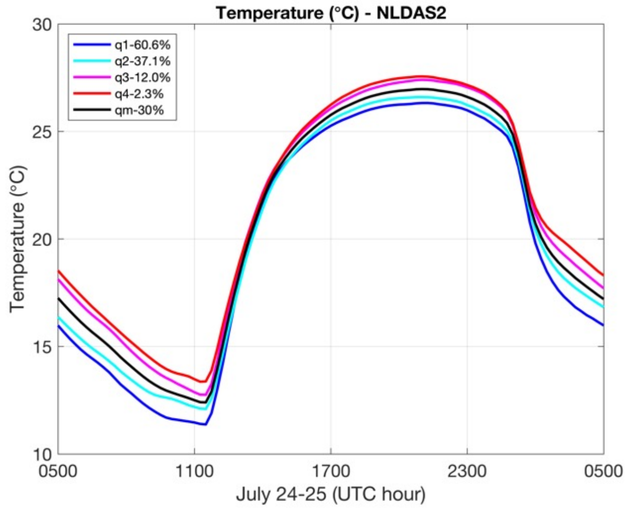



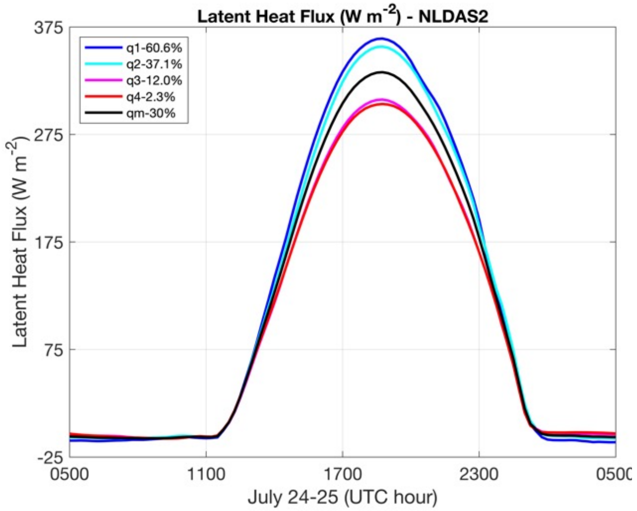

- Land surface states, particularly soil moisture, are taking on great significance in numerical modeling at all spatiotemporal scales.
- HRRR soil moisture (left) reflects the climatological precipitation distribution, humid continental transitioning to semi-arid. HRRR does not account for irrigation.
- SMAP Level 3 data (center) provides more detail and temporal validity, but in this case, does not well represent the spatial distribution of irrigation.
- Averaging over irrigated (solid) and non-irrigated (dashed) locations (right), the HRRR analyses (blue) reflect the opposite soil moisture distribution as observed during GRAINEX (black).
- GDAS (green) shows virtually no difference between irrigated and non-irrigated cropland while NLDAS2 (red) does show a realistic distribution, but with a much smaller difference between irrigated and non-irrigated sites as is observed.

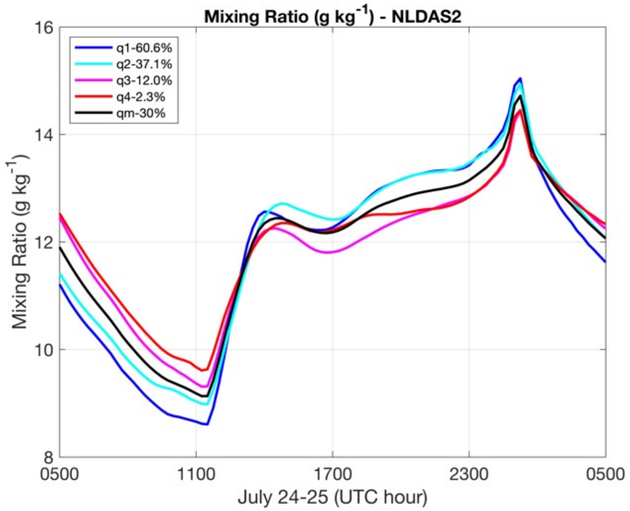
# Diurnal Modeling III – Modeled Quartiles

Quartiles sorted by irrigation fraction (%) with mean values of 2.3% (red), 12% (magenta), 37.1% (cyan), and 60.6% (blue), and an overall mean of 30% (black)

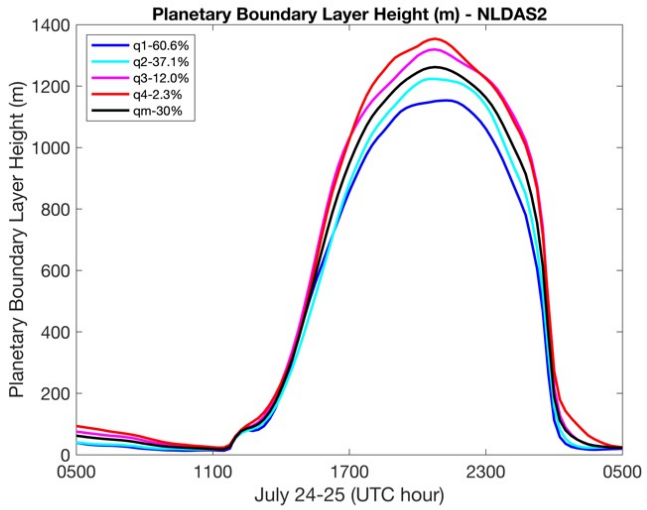


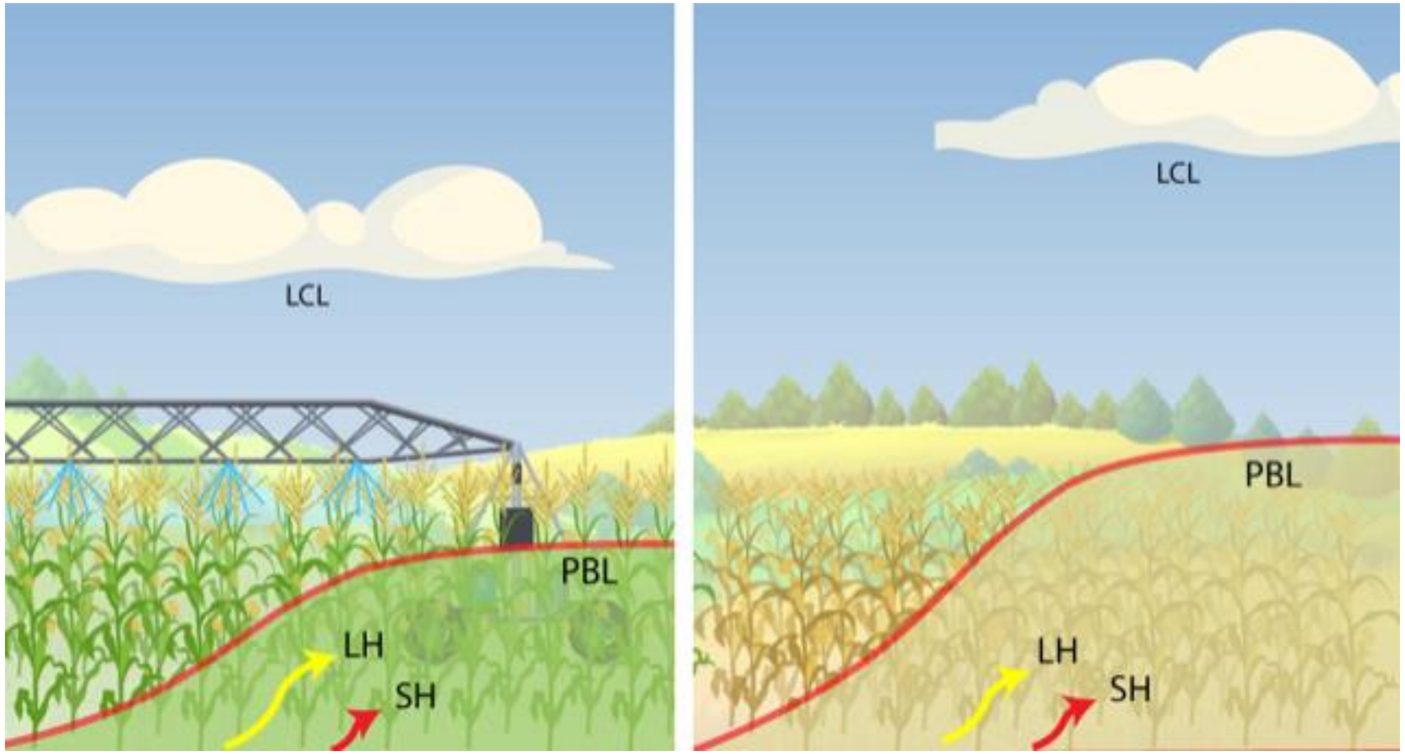




- Modeled PBL diurnal evolution (NLDAS2 presented) does well at simulating observed behavior except for the magnitudes.
- Modeled sensible heat fluxes are overestimated while latent heat fluxes are underestimated (left column).
- Temperatures are underestimated despite the overestimate of sensible heat fluxes.
- Mixing ratio values are also underestimated, consistent with the underestimation of latent heat fluxes. However, the persistent increase over lower irrigation fraction through the afternoon is not consistent with observations.
- The above two bullets point to the difficulty of PBL physics to properly account for entrainment.
- PBL heights are accurately represented in the simulation.



# Conclusions



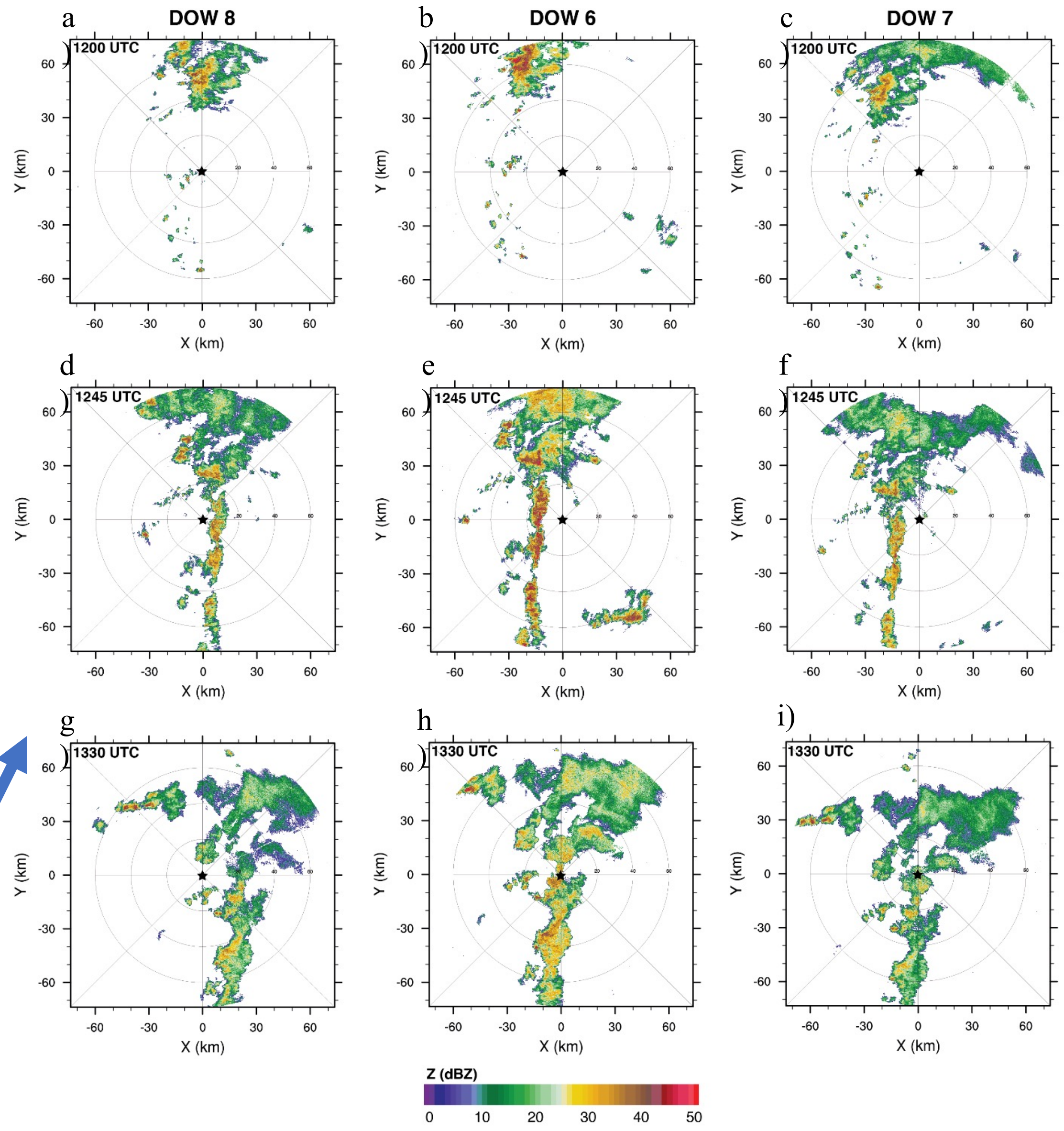

- In the ~150x150 km$^2$ GRAINEX domain, a region of adjacent cropland that is rainfed (east) and intensely irrigated (west) was examined in a 2018 field experiment
- A clear irrigation signal is observed despite the soil moisture gradient from irrigation opposing the soil moisture gradient associated the transition from a humid continental to semi-arid climate.
- The irrigated (non-irrigated) cropland is characterized by larger (smaller) latent heat fluxes and near surface specific humidity, smaller (larger) sensible heat fluxes and near surface temperature, and smaller (larger) PBL heights and lifting condensation levels.

# Future Work

- Hybrid Mesoscale-Microscale Simulation
  - Nested 200m grid across GRAINEX domain
  - Nested 40m grids over Irrigated and Non-Irrigated ISS sites near York and Lincoln

- Terrain induced slope flow and impacts on the Low-Level Jet (LLJ)

- Biweekly simulations with data assimilation and data assimilation denial (DOWs) for the IOPs to investigate outflow boundaries, LLJ structure and local and regional precipitation patterns




Precipitation forming preferentially over irrigation and dissipating over non-irrigated cropland on 23 July 2018