A Modeling Study of Irrigation Effects on Surface Fluxes and Land–Atmosphere–Cloud Interactions (LACI) in the Southern Great Plains

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The National Agricultural Statistics Service (NASS) provides timely, accurate, and useful statistics in service to U.S. agriculture.

Irrigation change in SGP (Data source: NASS)

Irrigation accounts for about 70% of the global freshwater withdrawals and 90% of consumptive water uses (Siebert et al. 2010).
Objectives

- To improve the representations of irrigation and the interaction with land and air in a regional modeling framework.
- To evaluate the WRF performance in simulating the surface water and energy budgets and land-atmosphere-cloud interactions (LACI) over the SGP region and whether the use of a more realistic irrigation scheme will improve the simulation.
- To investigate the impact of irrigation on land surface fluxes, boundary layer structure, initiation of convective clouds and local climate.
- To better understand the role of soil moisture changes induced by human activities (e.g. irrigation) in affecting cumulus clouds, land-atmosphere interaction and water recycling.
Model

Configuration

Version: WRF 3.2
Microphysics: Morrison
Radiation: RRTMG Scheme
PBL: Mellor-Yamada-Janjic
Land-Surface: NOAH
Cumulus: Kain-Fritsch
Horizontal Resolution: 12 km
Simulation periods:
May 1 – Oct 1, 2006 (dry)
May 1 – Oct 1, 2007 (wet)

Simulations:
Control (2006, 2007)
Irrigation (2006, 2007)
Observations

**ARM:**
- **EC:** Eddy Correlation
- **EBBR:** Energy Balance Bowen Ratio (LH, SH)

**SWATS:** Soil Water and Temperature System (SM, T)

**SMOS:** Surface Meteorological Observation System

**Others:**
- **OKM:** Oklahoma Mesonet
- **ABRFC:** Arkansas–Red Basin River Center
- **NLDAS2:** North American Land Data Assimilation System
Evaluation of Precipitation (left) and Surface Flux (right)

WRF (12km)  

UW 1/8 degree

NLDAS2  

ABRFC (4km)

JJA 2006  

Dry

JJA, 2006

Dry

JJA, 2007  

Wet

Wet
Incorporated an irrigation scheme into the Noah land surface model as part of WRF.

Integrated the satellite-measured potentially irrigation area data into our model.

Irrigation is triggered when root-zone soil moisture availability (MA) is below a specific threshold (e.g. 50%) over croplands or pastures during the growing season (Apr – Oct).

$$MA = \frac{SM - SM_{WP}}{SM_{FC} - SM_{WP}}$$

where SM is current root-zone soil moisture, SM_{WP} and SM_{FC} are soil wilting point and field capacity, respectively.
Irrigation-induced changes (JJA 2006)
Vertical Profiles (1300-1500LST)

- a) Potential temperature (K) vs. Height above Surface (m)
- b) Specific Humidity (g kg⁻¹) vs. Height above Surface (m)
- c) Moist Static Energy (10³ J kg⁻¹) vs. Height above Surface (m)
- d) Relative humidity (%) vs. Height above Surface (m)
Decrease in both Lifting Condensation Level (LCL) and Planetary Boundary Layer Height (PBLH)

Clouds form if LCL < PBLH, so positive of values of $|dLCL| - |dPBLH|$ indicate a more likely cloud formation.
5-day mean Lifting Condensation Level LCL and surface fluxes

- **PBLH**: PBL Height (m)
- **SH**: Sensible Heat (W/m²)
- **LH**: Latent Heat (W/m²)
- **LCL**
- **(LH/SH+LH)**

**Con-irr, 2006, 2007**

- **r = 0.84**
- **r = 0.85**
- **r = -0.12**
- **r = -0.73**
5-day mean soil moisture and surface fluxes

- **PBLH**
  - Sensible Heat (W/m²)
  - Soil Moisture (g/g)
  - Correlation: $r = -0.80$

- **LH**
  - Latent Heat (W/m²)
  - Soil Moisture (g/g)
  - Correlation: $r = 0.37$

- **SH**
  - Soil Heat (W/m²)
  - Soil Moisture (g/g)
  - Correlation: $r = -0.85$

- **LCL**
  - Latent Cooling (W/m²)
  - Soil Moisture (g/g)
  - Correlation: $r = -0.90$
An operational-like irrigation scheme is incorporated into the Noah-WRF model to enable the investigation of the irrigation effects on cumulus cloud and land-air interactions. Including irrigation reduces the model bias in LH, SH and soil moisture in a dry summer.

Irrigation adds additional water to the surface, leading to the increase in soil moisture (SM) and evapotranspiration (EV). The near surface air is cooled because of the decreased SH, which is compensated with the increased LH.

Irrigation-induced decrease in lifting condensation level is larger than the decrease in mixed layer depth, suggesting an increasing probability of shallow cloud formation, which is linked closely to the partitioning of the surface fluxes and soil moisture.

The land-atmosphere interactions behave differently under wet and dry conditions. In the dry year, the land-atmosphere interactions likely play a more important role in the regional water cycle. In the wet year when the EV is not constrained by the SM, however, we find weaker correlations between SM and surface fluxes.
Irrigation-induced changes

Monthly Change

Changes in SH & LH

Diurnal cycle

Changes in LH & SH

Changes in T, Q & Precip
### Table 1 Correlation Coefficients between soil moisture (LCL) and surface flux as a function of Average time. LCL=Lifting Condensation Level.

<table>
<thead>
<tr>
<th></th>
<th>PBL</th>
<th>SH</th>
<th>LH</th>
<th>LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5-day</strong></td>
<td>-0.80</td>
<td>-0.86</td>
<td>0.37</td>
<td>-0.90</td>
</tr>
<tr>
<td><strong>Soil Moisture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10-day</strong></td>
<td>-0.85</td>
<td>-0.88</td>
<td>0.41</td>
<td>-0.93</td>
</tr>
<tr>
<td><strong>30-day</strong></td>
<td>-0.90</td>
<td>-0.90</td>
<td>0.66</td>
<td>-0.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>PBL</th>
<th>SH</th>
<th>LH</th>
<th>LH/(SH+LH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5-day</strong></td>
<td>0.84</td>
<td>0.85</td>
<td>-0.12</td>
<td>-0.73</td>
</tr>
<tr>
<td><strong>LCL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10-day</strong></td>
<td>0.87</td>
<td>0.88</td>
<td>-0.19</td>
<td>-0.81</td>
</tr>
<tr>
<td><strong>30-day</strong></td>
<td>0.92</td>
<td>0.94</td>
<td>-0.58</td>
<td>-0.94</td>
</tr>
</tbody>
</table>
Soil moisture change

- The irrigation-induced soil memory and resulted wetter and cooler surface from the previous period can last for a few weeks to months, implying a lagging effect of irrigation at the scale potentially from intraseasonal to seasonal.
(a) Summer (JJA), 2006

(b) Summer (JJA), 2007