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Near Surface Hydrometeorology for Sustainable Water Management

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Abstract

Due to strong interactions between the land and atmosphere and the resulting feedbacks as altered by the anthropogenic changes, it is critical to quantify the surface fluxes and boundary layer properties that has direct implications on the regional evolution of hydrometeorology. This study evaluates the impact of irrigation using the Weather Research and Forecasting (WRF) numerical weather prediction (NWP) model in the Snake River Basin in Idaho. Our simulation extends for the period in the growing season and compares the control and irrigation runs to assess the irrigation induced cooling on the surface energy balance. Understanding this near surface cooling is directly useful for sustainable water management under changing climate conditions in the future. We present simulated latent and sensible heat fluxes as well as air temperature, relative humidity and the depth of the planetary boundary layer (PBL) over the region.

Introduction

South Central Idaho is a semiarid region characterized by low annual precipitation. Average annual precipitation ranges from 200 to 250 mm and the mean annual air temperature range is between 5 °C- 10.9 °C, July being the warmest month with the highest evaporation (Kjelstrom, 1995). Extensive agricultural activities between April and September, which heavily depend on irrigation supplied from both surface and groundwater resources due to the inadequacy of precipitation in the plain. The Snake River is the main source of surface water supply for irrigation. The addition of water to the system through irrigation changes the land-atmospheric interactions by affecting the energy and water budgets, by partitioning most of the energy into latent heat, and reducing sensible heat, thus increasing evapotranspiration (ET). Due to the cooling effects induced by irrigation over the irrigated lands and the advection in the surrounding areas, the dynamic nature of the exchanges between the land and atmosphere needs a thorough investigation. Quantifying the amount of water applied to the field by considering the feedbacks will provide a sound basis for sustainable water management.

Many modeling and observational studies have shown the effects of irrigation not only on latent heat flux, but also on other boundary layer properties. Observational studies have shown an increase in latent heat flux with irrigation (Lei and Yang, 2010; Suyker and Verma, 2009). Some observational

studies have shown the effects of irrigation on lower atmospheric properties and cloud formation (Adegoke et al., 2007). Irrigation has been incorporated with many modeling studies and the results show the effects on water and energy balance (Evans and Zaitchik, 2008; Ozdogan et al., 2010; Adegoke et al., 2003; Haddeland et al., 2006), and irrigation-induced surface cooling (Cook et al., 2010). The objective of this study is to identify the impact of irrigation on surface fluxes using the Weather Research and Forecasting model (WRF). This study will highlight its effects on the boundary layer properties such as air temperature, relative humidity and planetary boundary layer depth (PBL)

Irrigation Method

Since the choice of irrigation method (flood or surface irrigation), frequency of irrigation, and the amount of water applied in one irrigation event depends on the irrigation practice of each farmer, a common method was applied for all the fields in the area considering only the water need of the soil instead of applying water at the same frequency. Only the cells classified as irrigated cropland in the land use categories were subjected for irrigation in the model. There are three adjustable parameters: 1) minimum percentage of soil moisture (MinPCT), which serves as an irrigation trigger, 2) the start date of the irrigation season, and 3) the end date. The available soil moisture of the second soil layer (10 – 40 cm) was used to trigger irrigation. The second layer's soil moisture was compared with minimum soil moisture (MSM) to determine if irrigation is required. This is because the thin first soil layer of 10 cm is generally subjected to direct evaporation and will be dried soon. MSM is defined by

$$MSM = (\theta_{ref} - \theta_{wilt}) \times MinPCT + \theta_{wilt}$$

where θ_{ref} and θ_{wilt} are reference and wilting soil moisture. The period was from April 1st through October 31st.

Firstly, it was decided if a simulation date was within the irrigation season and if the grid was classified as an irrigated cropland. Then, the available soil moisture was compared with MSM to decide if the irrigation was required at this time step. If the available soil moisture was below MSM, the soil moisture of the first soil layer was saturated at this time step as done by Adegoke et al. (2003) and Evans and Zaitchik (2008) although these two methods differed slightly. The minimum percentage (MinPCT) used in this study was 50%, which is a recommended threshold limit for many crops as the depletion level at which to start irrigation. Saturating the top layer would allow water to flow to the soil layers

below. The water loss from runoff and losses during irrigation were not accounted here and it was assumed that enough water was available for fulfilling the irrigation requirement in the model.

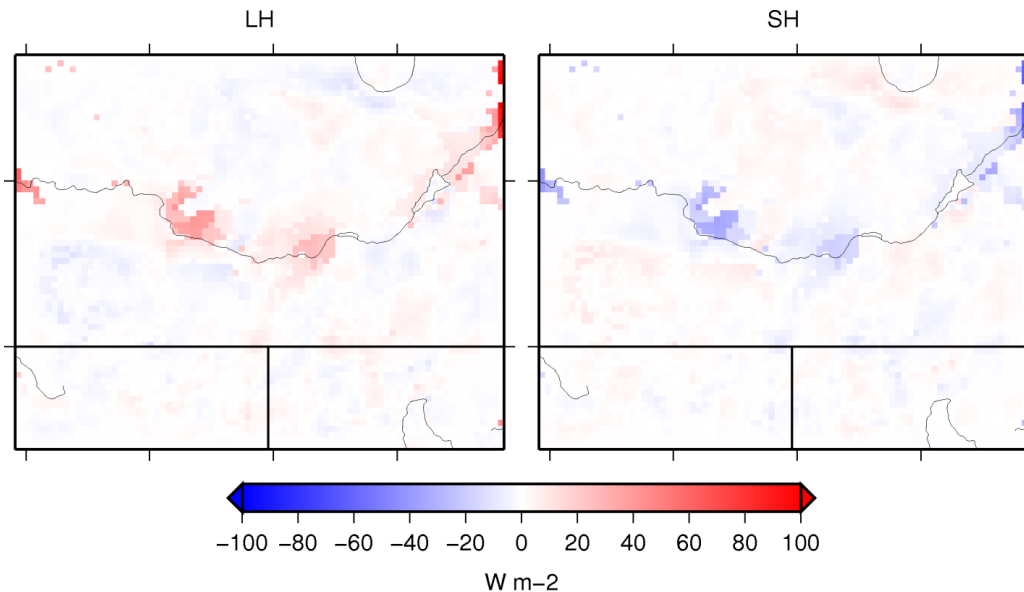


Figure 1. Differences in latent and sensible heat fluxes for July 2010 between irrigated and non-irrigated simulation.

Results and Discussion

Irrigation in the Model

Being identified as a critical process during the growing season over agricultural lands, irrigation water was added to replenish soil moisture periodically to the first soil layer (0 - 10cm). This was done throughout the growing season from April to October. On average, the total irrigation amount of water applied over croplands was approximately 620 mm in 2010.

Effects of Irrigation

Effects on the Surface Fluxes

The surface energy balance is typically affected by irrigation through diurnal fluctuations in soil moisture. Increased soil moisture by irrigation changes the energy partitioning between latent and sensible heat flux. Figure 1 illustrates the differences in latent and sensible heat fluxes with and without irrigation. These simulated surface fluxes were the mean hourly values for the month of July. The effects appeared to be limited in spatial extent only to the irrigated areas since the irrigation induced changes

happened only over croplands. The addition of irrigation water increased the latent heat flux over agricultural areas, which led to an increase in ET. Conversely, simulated sensible heat flux decreased over the same area. As an example, in July, simulated latent heat flux increased by 11 W m^{-2} and sensible heat flux decreased by 10 W m^{-2} averaged for the region. The effects were high during the peak

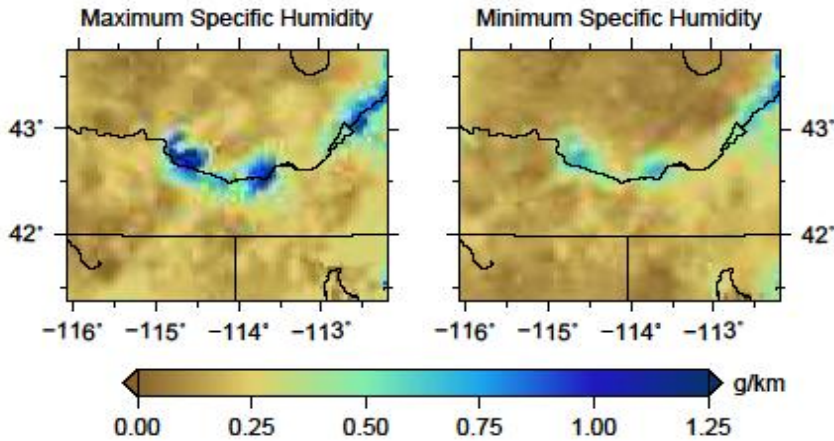


Figure 2. Maximum and minimum specific humidity averaged over August 2010 as a difference between irrigated and non-irrigated simulation runs.

growing months in this area, like in July and August, when intensive irrigation took place. Ozdogan et al. (2010) also showed the effects were significant mostly during July and August when considering the entire United States using the uncoupled model runs. Results showed that the number of irrigation events was high during July or August.

Effects on Specific Humidity

Figure 2 shows how the maximum and minimum daily values of specific humidity are affected by implementing irrigation. For the minimum and maximum daily values, the difference of irrigated minus non-irrigated results were averaged over August, 2010. August was used because the soil moisture in the two model runs had diverged greatly, yet there was still enough solar radiation to cause maximum differences. The affected area was more diffuse with maximum temperatures because daytime winds were stronger and advecting the effects to neighboring non-cropland cells. Some effects away from any cropland cells were most likely caused by irrigation creating small differences in cloud and rain distribution or perhaps by differences in runtime initialization of the shallow convection scheme. The generally dry air in the region allowed quick dilution of ET which could explain why specific humidity

effects remained fairly local to the cropland cells. Also, the maximum wind speed reduced over irrigated cropland cells. It could be partly explained by the fact that reduced sensible heat caused less convection which in turn either drew in less surrounding air to replace the upward movement or the reduced convection entrained less of the higher speed, upper winds.

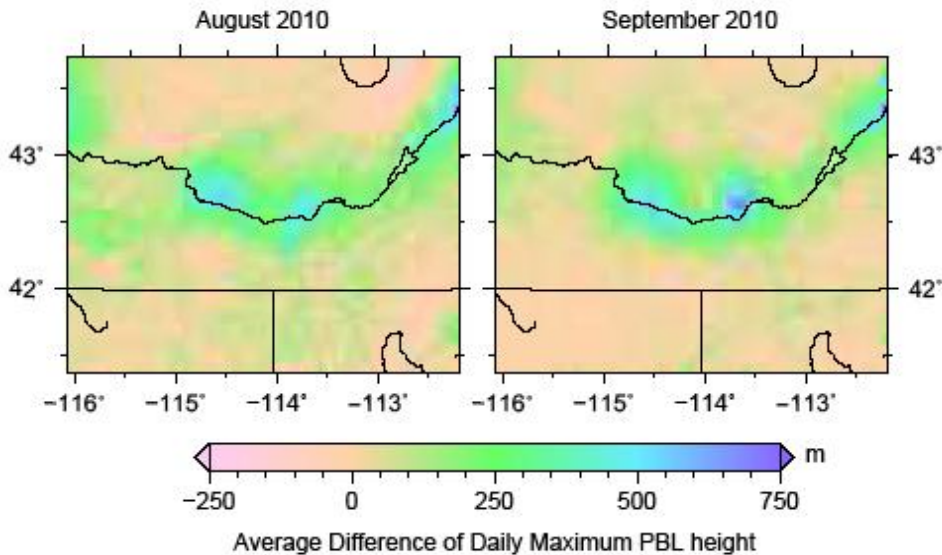


Figure 3. Differences in daily maximum planetary boundary layer heights between irrigated and non-irrigated simulation runs averaged over August and September, 2010.

Effects on Planetary Boundary Layer

The impacts of irrigation on the boundary layer height due to the difference in soil moisture in the root zone was evident for irrigated versus non irrigated cropland as the difference in maximum daily PBL height averaged over the month is shown in Figure 3. Some minor differences apparently resulted from fluctuations in model runs caused by initializations of random factors in the shallow convection scheme. The added irrigation cooled the surface and reduced the PBL height. The reduction in peak PBL height over croplands was maximum in August and September. This reduction was higher than that of July because without irrigation, September was very dry for all vegetation. In July, even without irrigation, PBL height over croplands was lower than other natural vegetation because of the high green vegetation fraction in the growing season, which resulted in a cooler surface over the croplands than for natural vegetation. Therefore, the reduction in height compared to non-irrigated conditions was less for July.

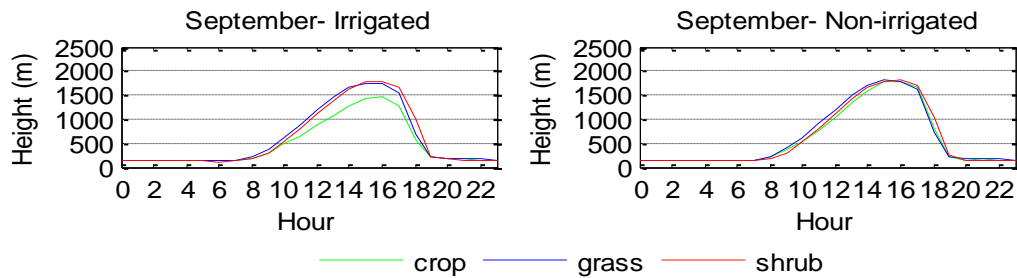


Figure 4. Diurnal evolution of planetary boundary layer for the month of September for the irrigated and non-irrigated conditions.

Figure 4 shows the development of the planetary boundary layer during the day with and without the application of irrigation. Only monthly averages of May, July, and September are shown here. PBL height was maximum during the daytime when the earth surface was warmer than the air above. During the night time, the height ranged approximately 100 – 200 m from the ground. During May, irrigation had not affected the development of the PBL, and the PBL height ranged from 1.6 km – 1.8 km for the three vegetation types. In July (peak growing month), irrigation had brought down the peak PBL height for croplands by approximately 150 m. For natural vegetations, the peak height was around 2.2 km and 2.3 km.

Conclusions

The availability of water in the Snake River Plain is paramount to agricultural operations. In order to estimate how much water need to be applied, quantifying evapotranspiration to meet the crop water demand is critical. We have shown in this research how important it is to include anthropogenic – induced changes to the landscape that will have direct impact on using our scarce water resources sustainably. During the growing season, irrigation has a significant effect in semiarid agricultural regions. It affects both energy and water budget components. In order to incorporate this fact in WRF, an irrigation scheme was added, which supplied enough moisture source to the crops. Average irrigation water added during the whole growing in 2010 was 620 mm. This changed the surface energy budget mainly by increasing latent heat flux and decreasing sensible heat flux. As a result, the added water has cooled the atmosphere by reducing the air temperature. Also, it has added moisture to the atmosphere increasing the specific humidity. Resulting from the cooled atmosphere, a reduction in the height of the PBL was evident. Further investigation into a few specific formulations of soil moisture addition to root zone column and long-term simulation will be required to fully understand the impact of anthropogenic land use changes on the regional and local climate.

Acknowledgements

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