Effects of Irrigation on surface energy balance using WRF/Noah LSM

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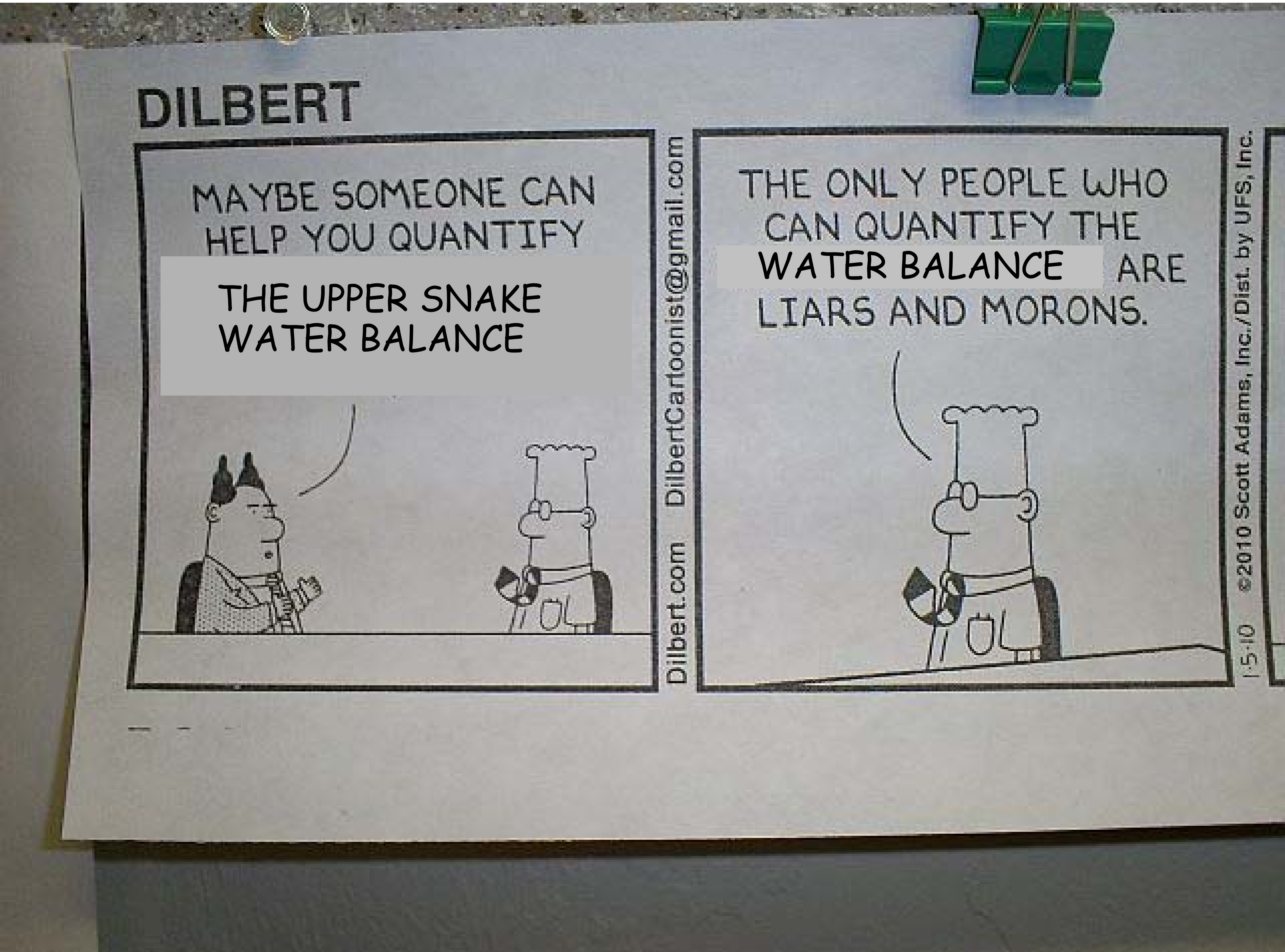
University of Arizona. Credit: John C. Palumbo

Overview

- Characteristics of Study Area
- Problem Description
- Model Modifications
- Results of Irrigation Additions
- Conclusions



DILBERT
MAYBE SOMEONE CAN HELP YOU QUANTIFY
THE UPPER SNAKE WATER BALANCE
THE ONLY PEOPLE WHO CAN QUANTIFY THE
WATER BALANCE
ARE LIARS AND MORONS.
Dilbert.com DilbertCartoonist@gmail.com
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Motivation

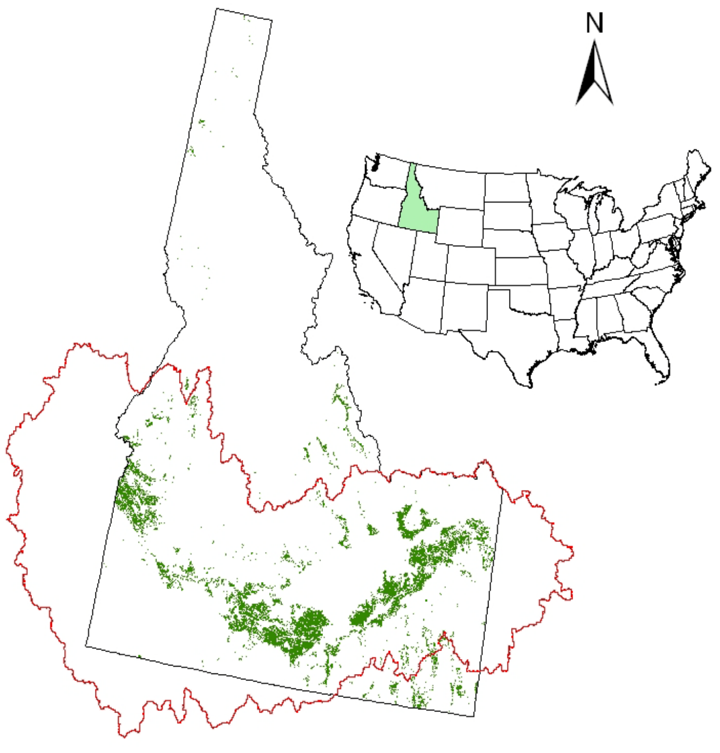
- Strong interactions between the land and atmosphere and the resulting feedbacks as altered by the anthropogenic changes
- Quantifying the surface fluxes and boundary layer properties as direct implications on the regional evolution of hydrometeorology
- Coupled mesoscale models can underestimate the actual evapotranspiration, primarily because either they misrepresent the amount of additional soil moisture added to the soil or due to the process formulation in the model

Background

Irrigation Effects from Previous studies

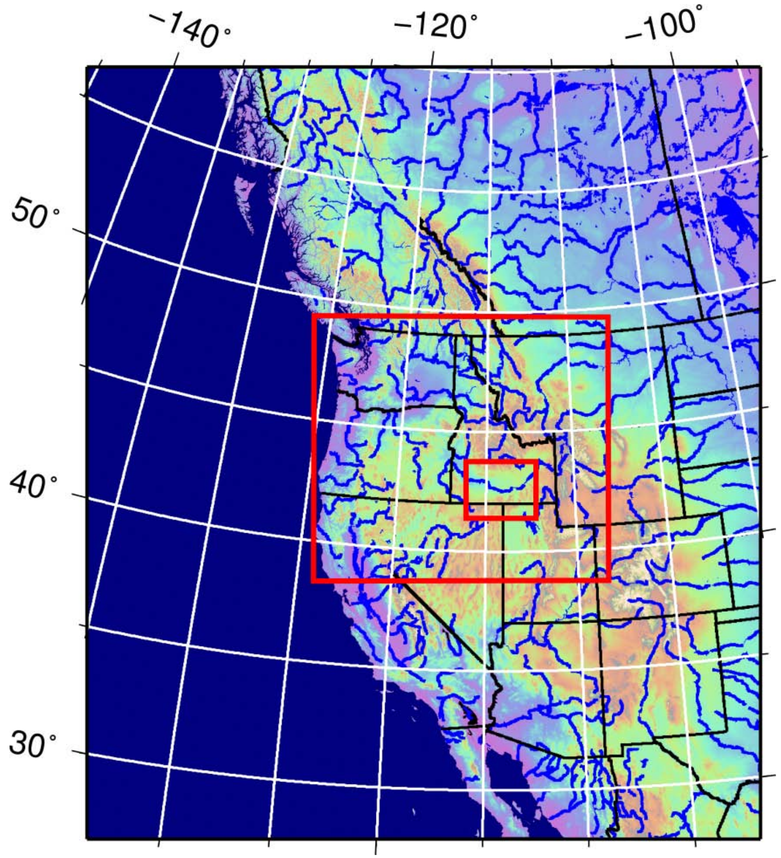
- Increased ET (Ozdogan et al., 2010; Adegoke et al., 2003)
- Change in Land Surface Fluxes (Ozdogan et al., 2010; Cook et al., 2010)
- Surface cooling (Cook et al., 2010)
- Taller cloud masses and early peak cloud formation over croplands (Adegoke et al., 2006)

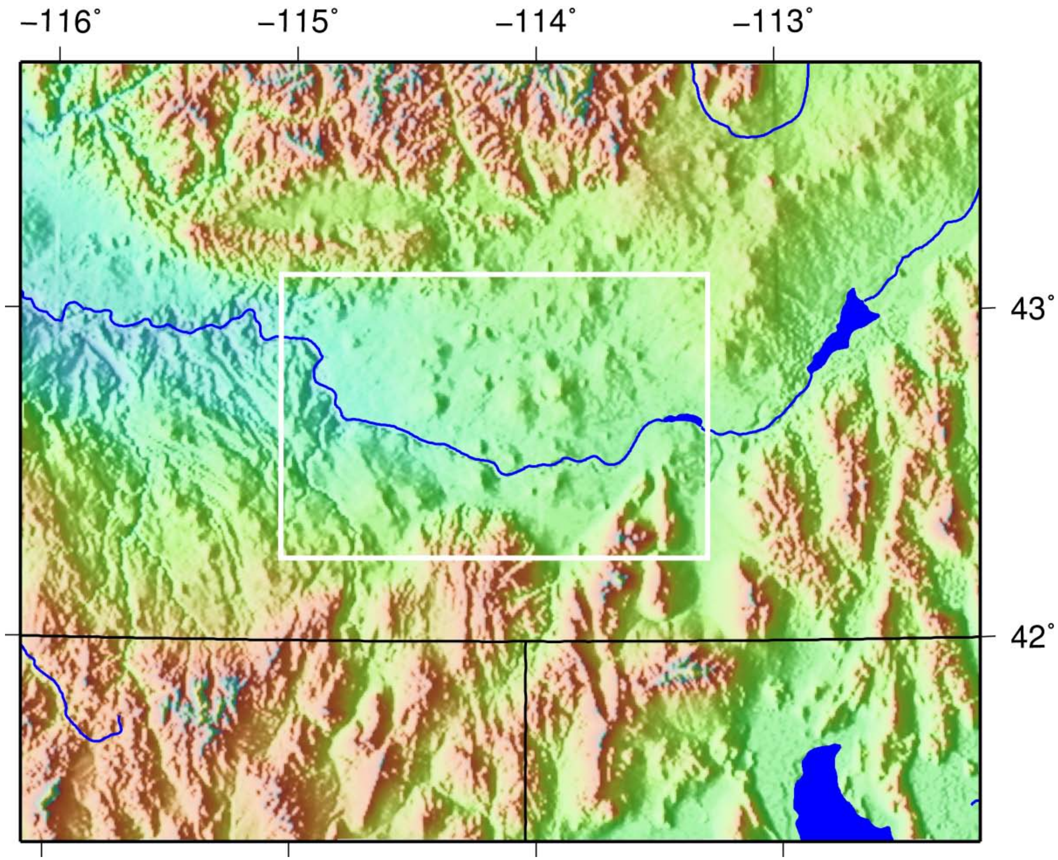
The Snake River Basin



- Idaho, with 3.3 million acres of irrigated land, ranked fifth in the nation for the state with the most irrigated crop land in 2007 (USDA, 2007).
- Both surface flooding and sprinkler irrigation is common in the study area.
- Surface flooding saturates the top layer of soil for an extended amount of time, roughly 12-24 hrs to provide adequate water throughout the root zone.
- Sprinkler irrigation is typically designed to provide as much water in a single pass as the top layer of soil can absorb without runoff.

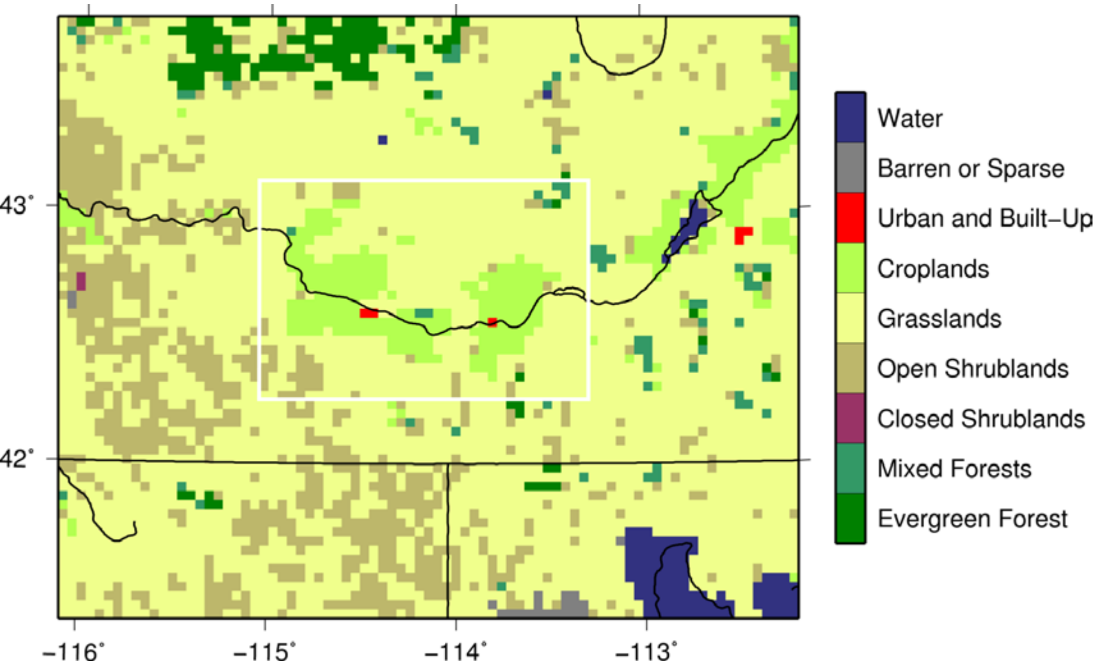
Domains and Topography





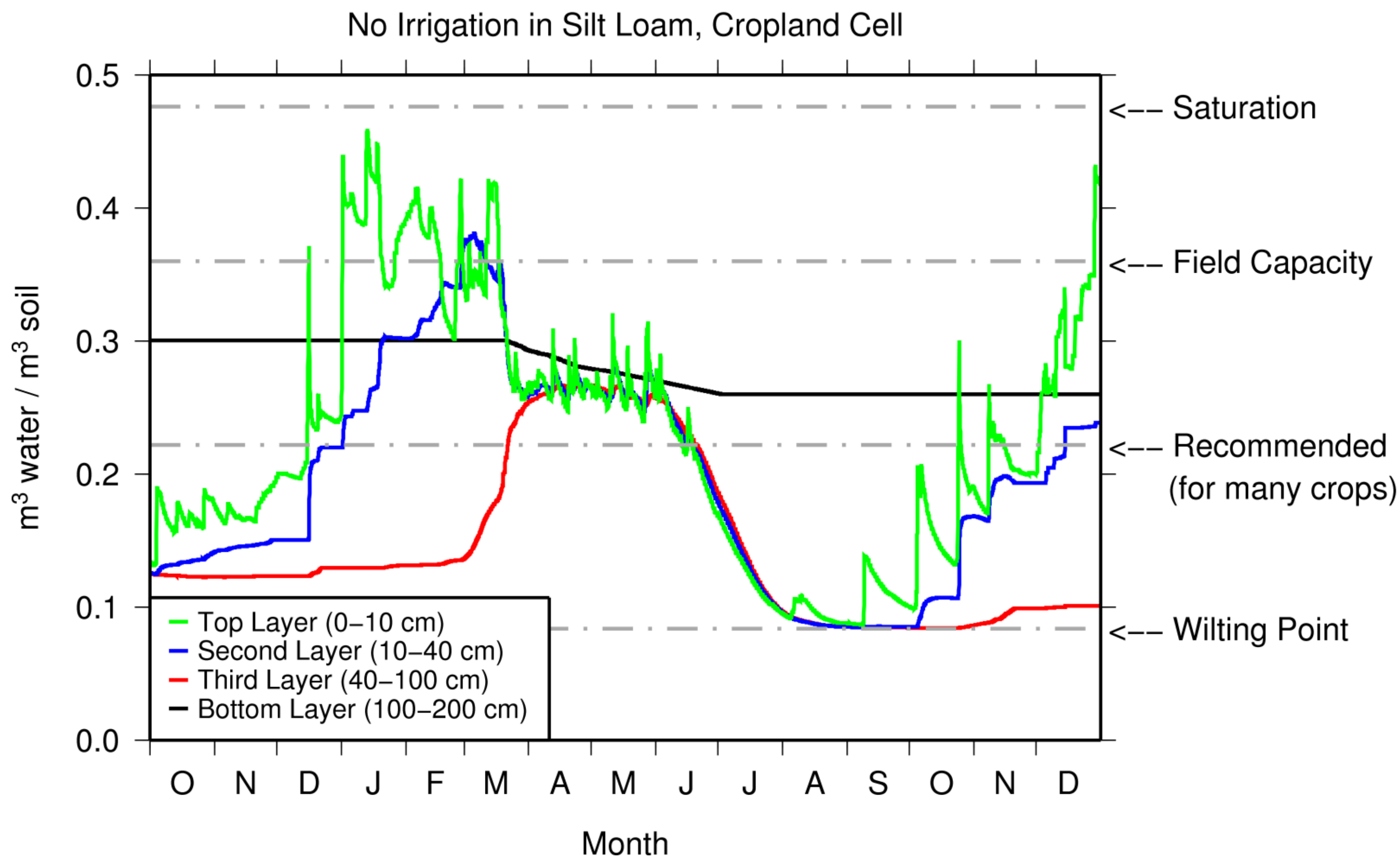
Three domains on left with middle and inner domains outlined in red.
Inner domain on right with an area of interest (AOI) outlined in white.
AOI is arid due to mountain rain shadows and foehn winds.

Snake River Plains: Inner Domain Landuse



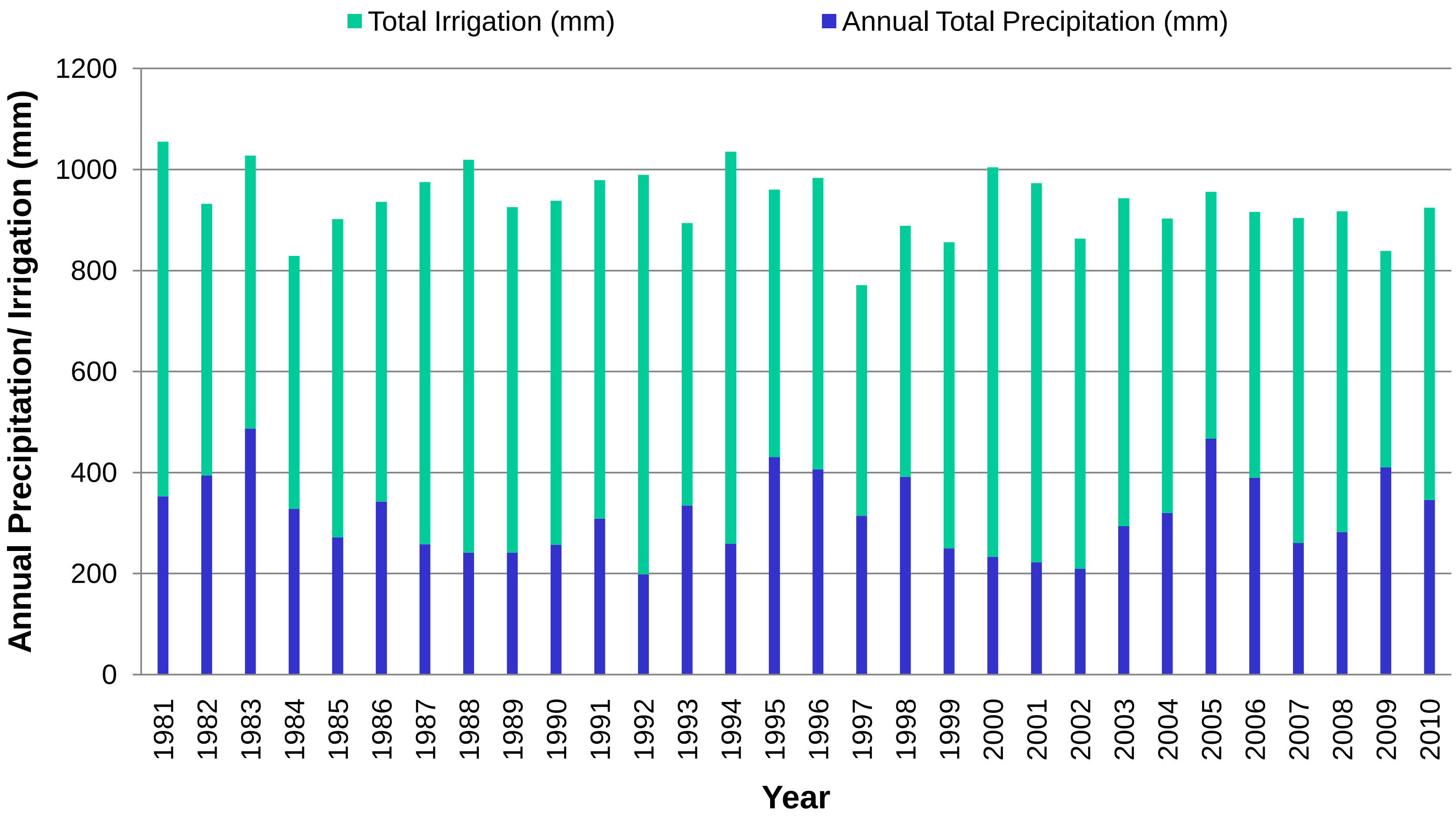
- MODIS 30 arc-second data using modified IGBP landuse categories
- All of croplands in this area are irrigated
- All light green cropland cells become model irrigated.
- White outline indicates area of interest (AOI) for statistics and most spatial plots.

Example of the Problem



- Unrealistically low soil moisture content for actively cultivated cropland during the growing season.
- Lack of soil moisture prevents model from generating adequate evapotranspiration

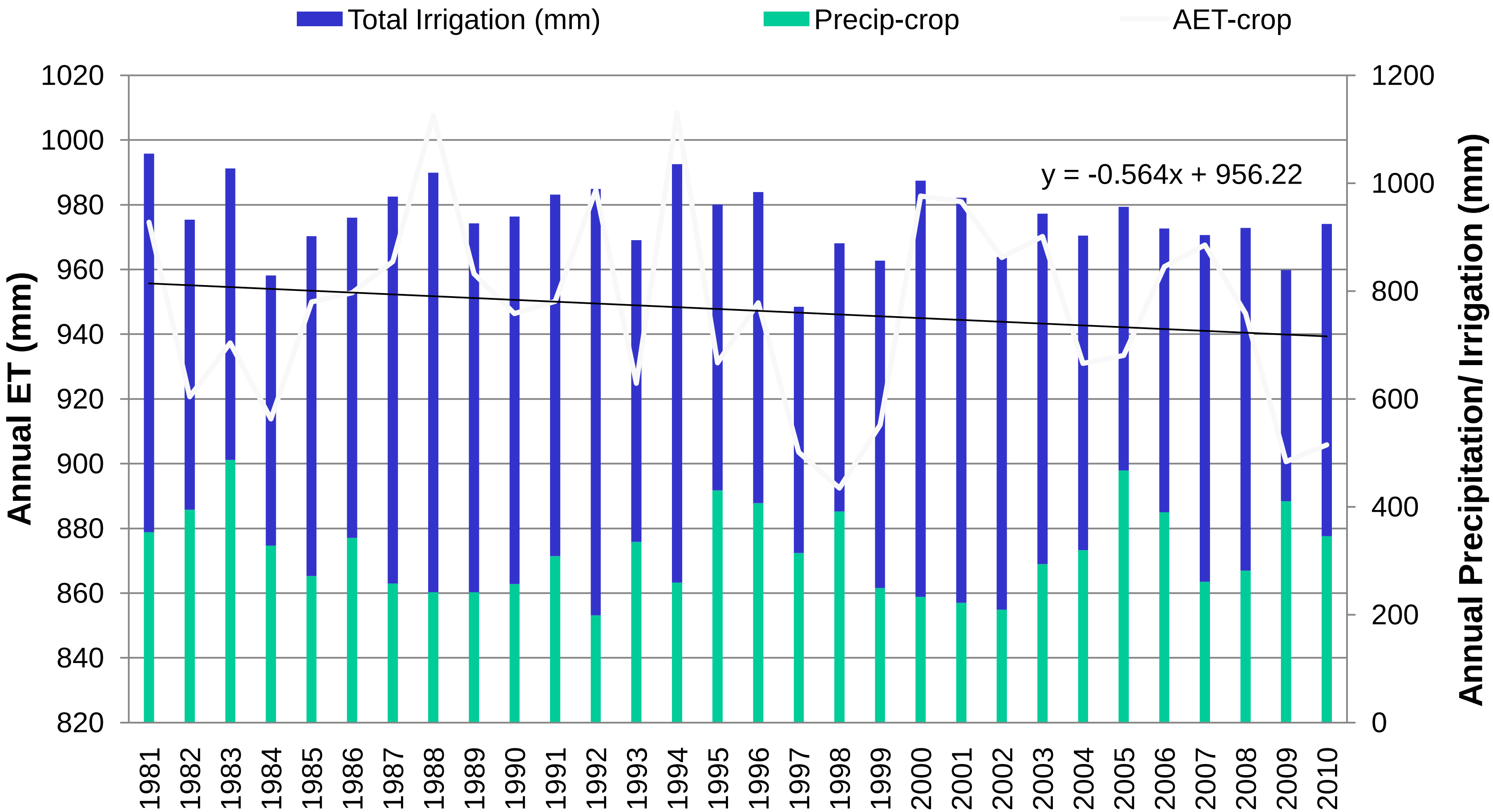
Precipitation plus Irrigation in the Model



Average Irrigation amount 620 mm for past 30 years (1981- 2010)

Long Term Climatology

Long Term Trends of ET in Croplands Decreasing?



Variables in simulating irrigation

- Identify crop lands that receive irrigation (IGBP=12).
- Select Irrigation method to use (4 methods)
- Length of irrigation season (start and end dates).
- Soil moisture level that triggers irrigation event.
- *Length of time (hours) for each irrigation event.
- *Target soil moisture at which to stop irrigation event.
- *Amount of water applied per irrigation event.
- *Parameters controlling efficiency of water application.

* only used for some methods.

Ideal Method

- When soil moisture in any of the 3 root zone layers for cropland are below specified minimum (iw_min = 0.50), set soil moisture in all root layers to specified target level (iw_target = 1.0).
- Used field capacity as specified target (iw_target = 1.0).
- Used 24 hours as minimum time between irrigation events (iw_cycle = 24).

Furrow Irrigation (Timed Flood Method)

- Meant to imitate flooding furrows between rows of crops for a fixed amount of time.
- When soil moisture in any root zone layer drops below minimum (iw_min = 0.50), at each timestep during specified number of hours (iw_cycle = 12), set top layer to saturation level.
- Additional water can be added to surface runoff variable as an “application inefficiency” but was not used for these runs (iw_loss = 0.0). Depending on equipment, 30%-75% is range mentioned in agricultural extension brochures.

Sprinkler Method

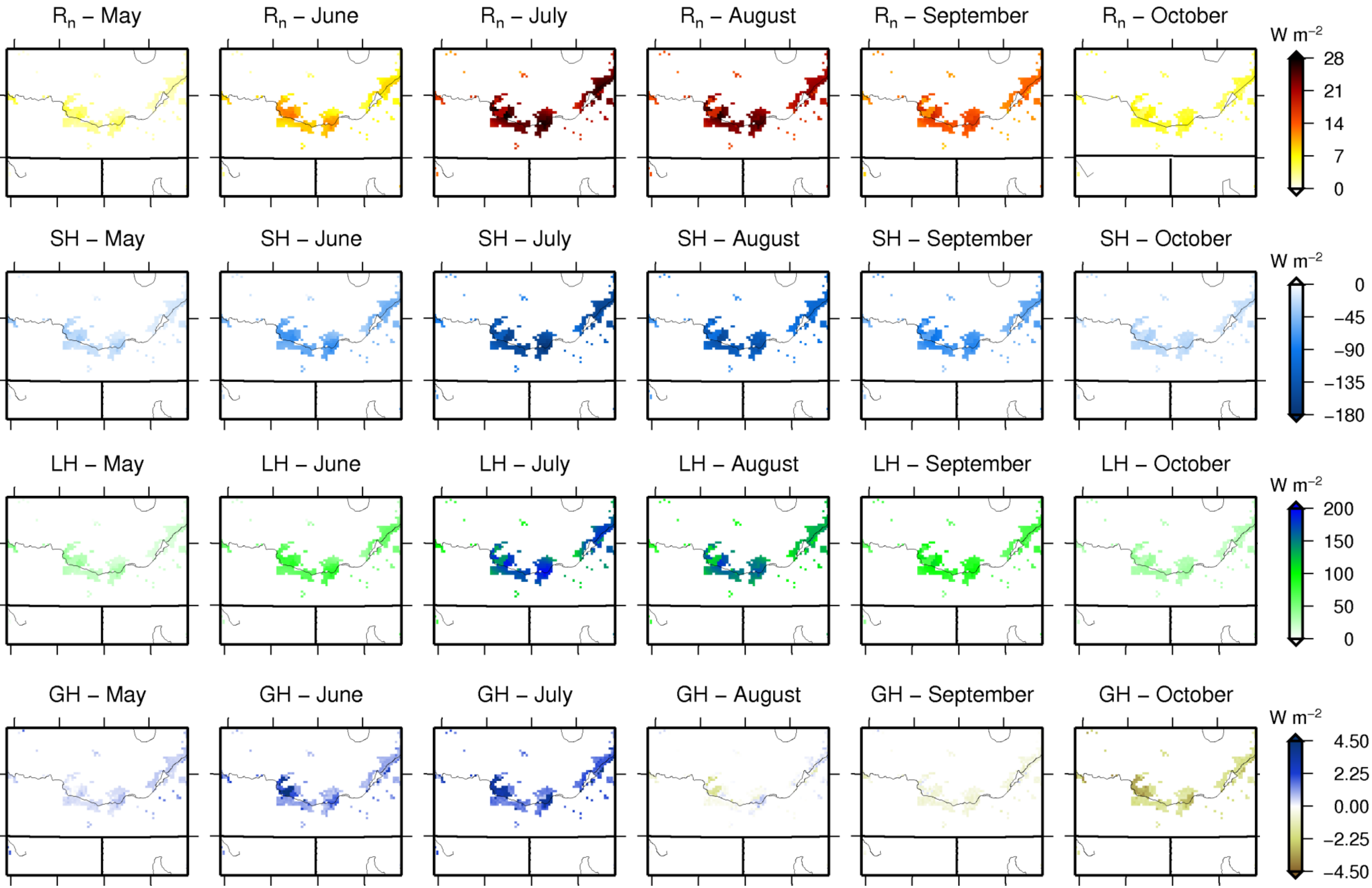
- Imitates slow application of water with large moving sprinklers, e.g. center pivot or lateral line.
- If root zone layer drops below the minimum, add the specified amount (iw_max_amt = 22.9 mm) to the top soil layer divided over the specified time range (iw_cycle = 60 hrs).
- Divert part of amount to canopy interception
- Divert part of amount (iw_loss = 0.0392, 3.92%) directly to evaporation. Divert additional amount (iw_factor = 0.0251) * wind speed to ET. These represent wind drift and evaporation losses (WDEL).

Combined Method

- Simple method meant to saturate top layer only once, like sprinklers, but without canopy interception and WDEL.
- If second soil layer drops below minimum soil moisture (iw_min = 0.50), set top layer to saturation level.
- Minimum time between irrigation events can be controlled, if desired (iw_cycle = 1 hr).
- Allows some additional drying of top layer via direct evaporation.

Irrigation Effects

Effects on Surface Fluxes



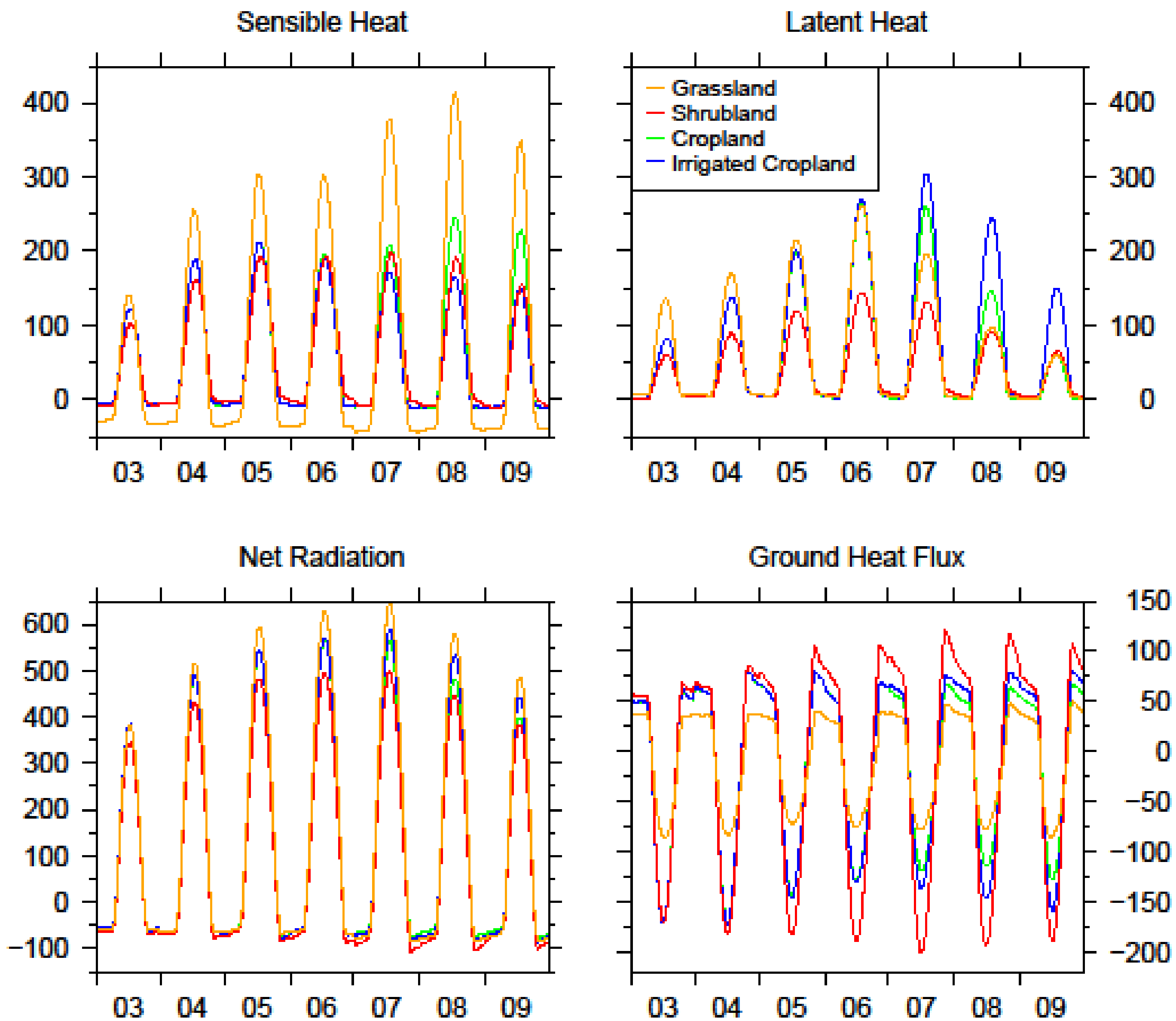
11 W m^{-2} ↑

62 W m^{-2} ↓

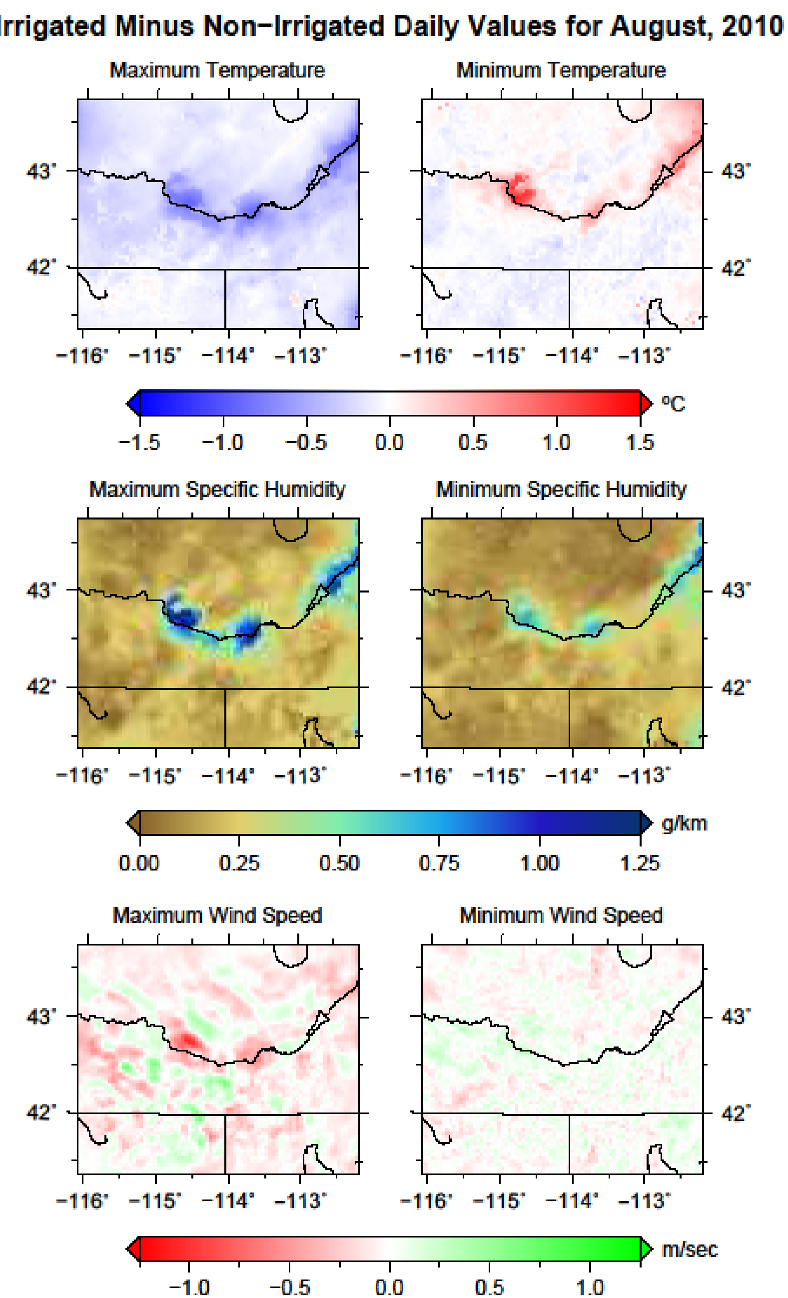
72 W m^{-2} ↑

0.3 W m^{-2} ↑

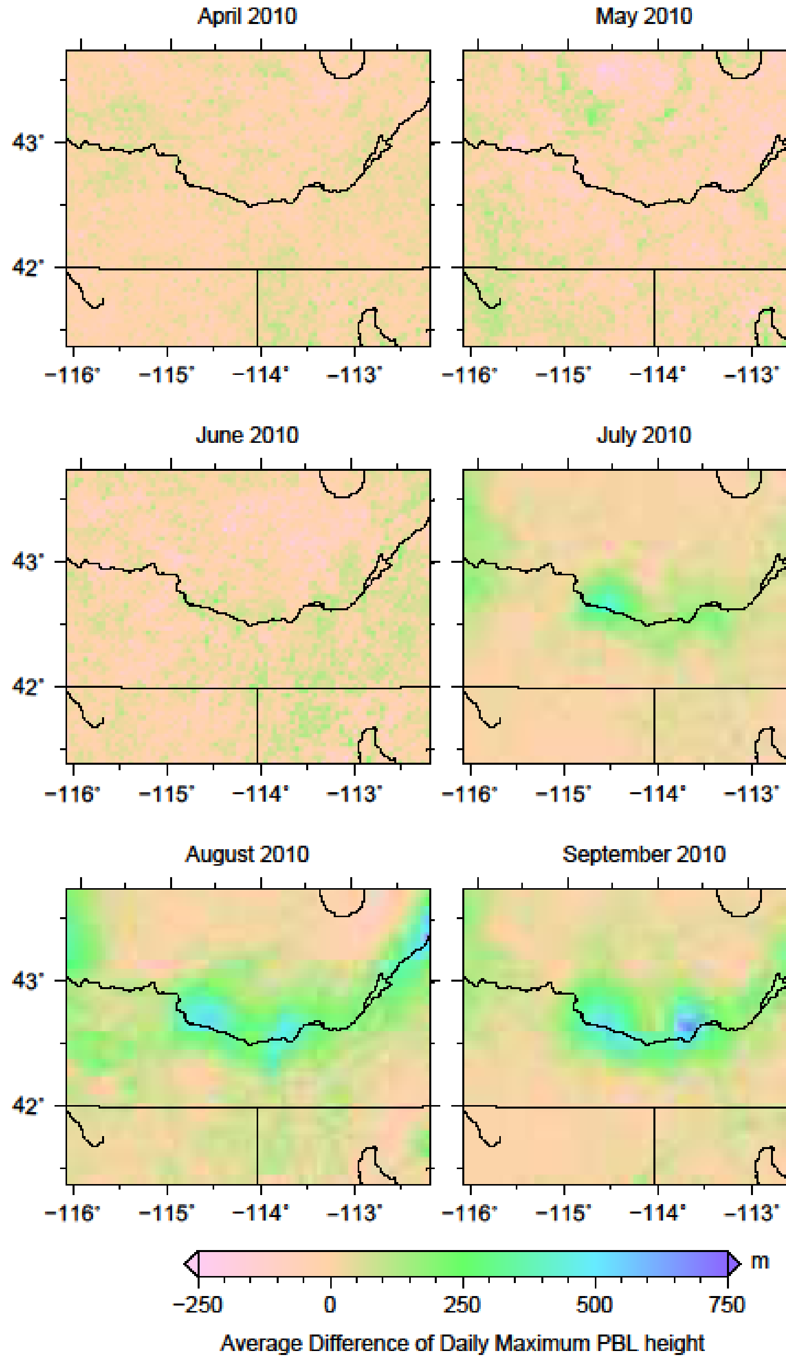
Energy Balance



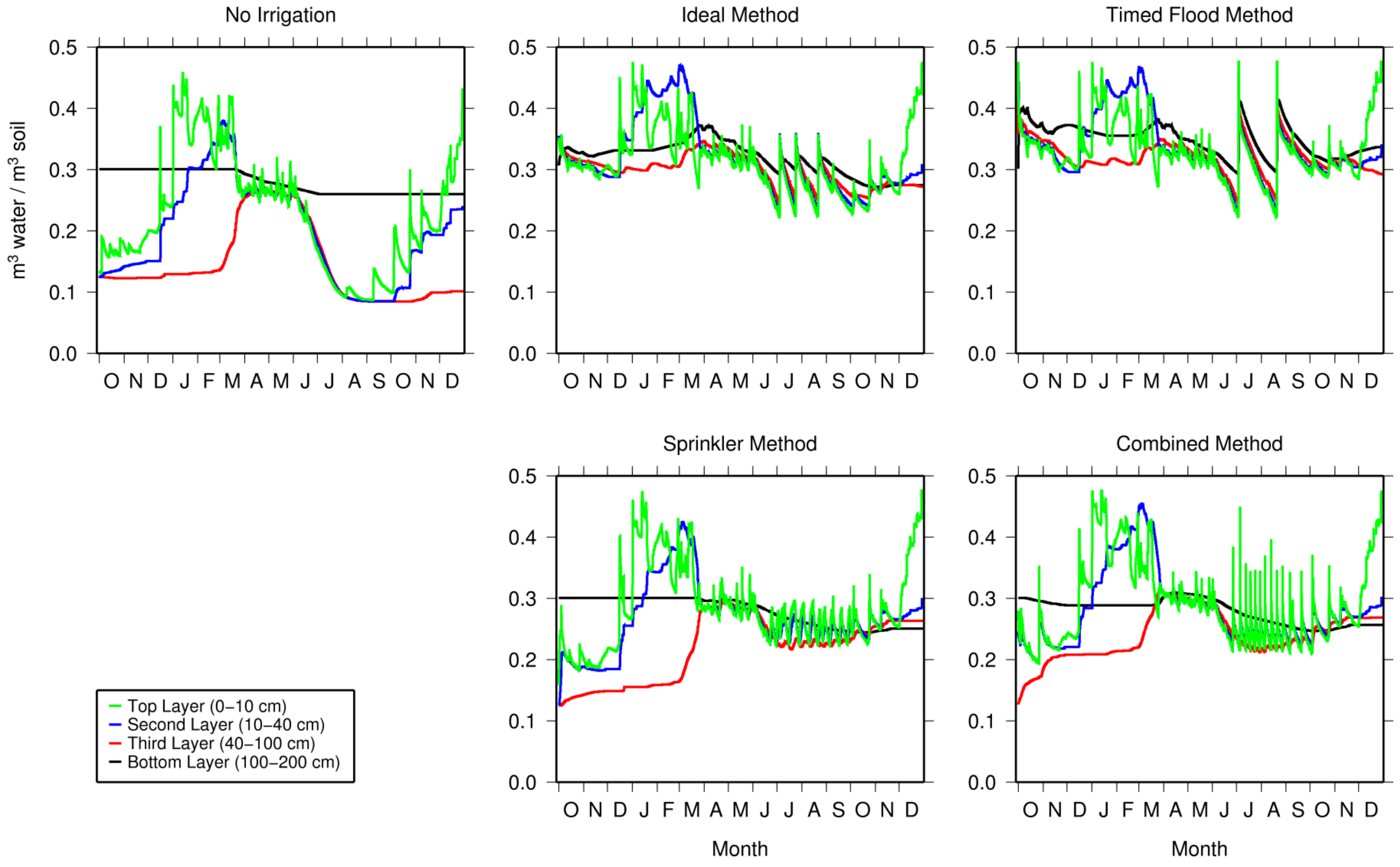
Near surface Temperature, Specific Humidity and Wind Speed



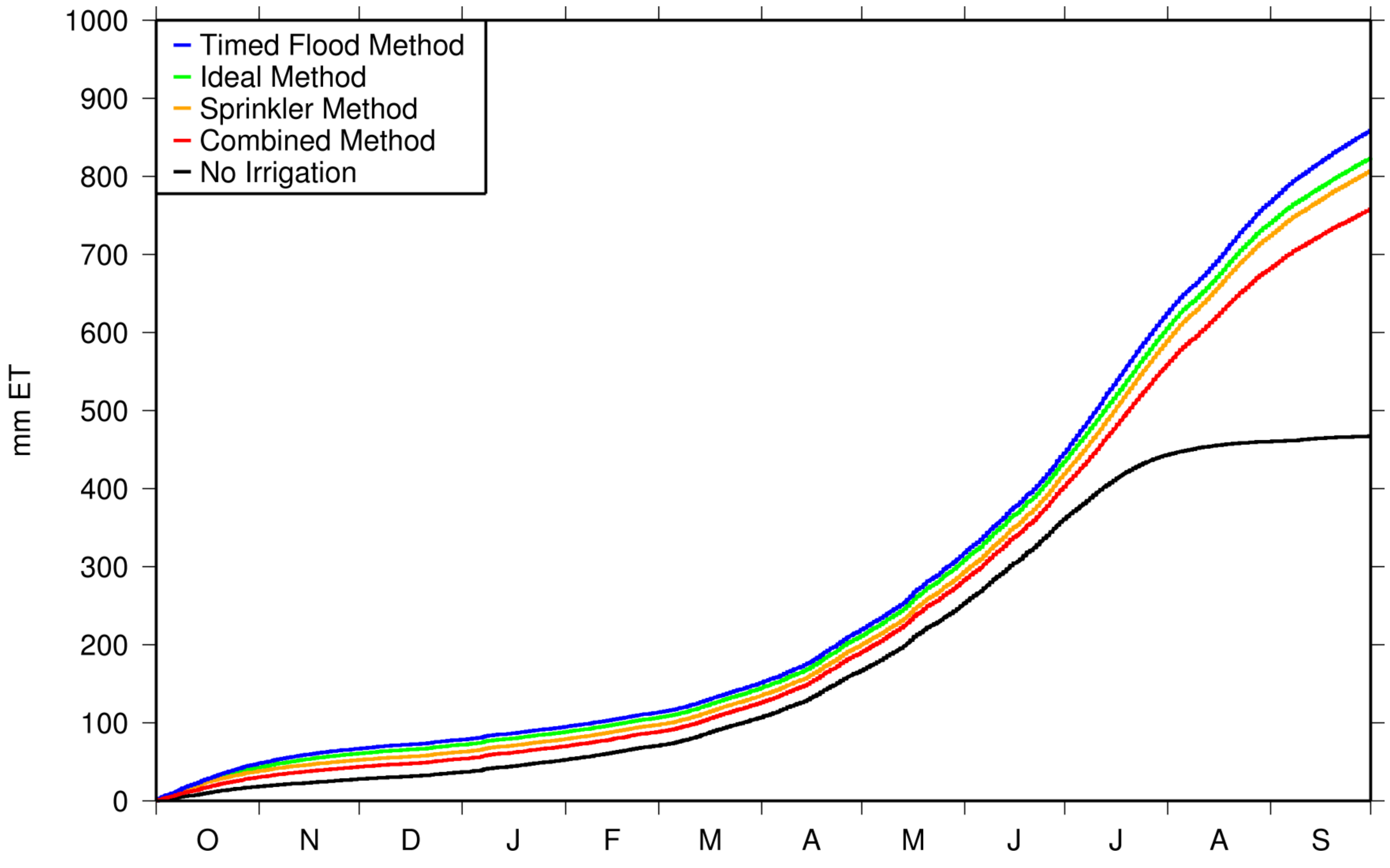
Average Difference of Daily Maximum PBL Height



Effects on Soil Moisture



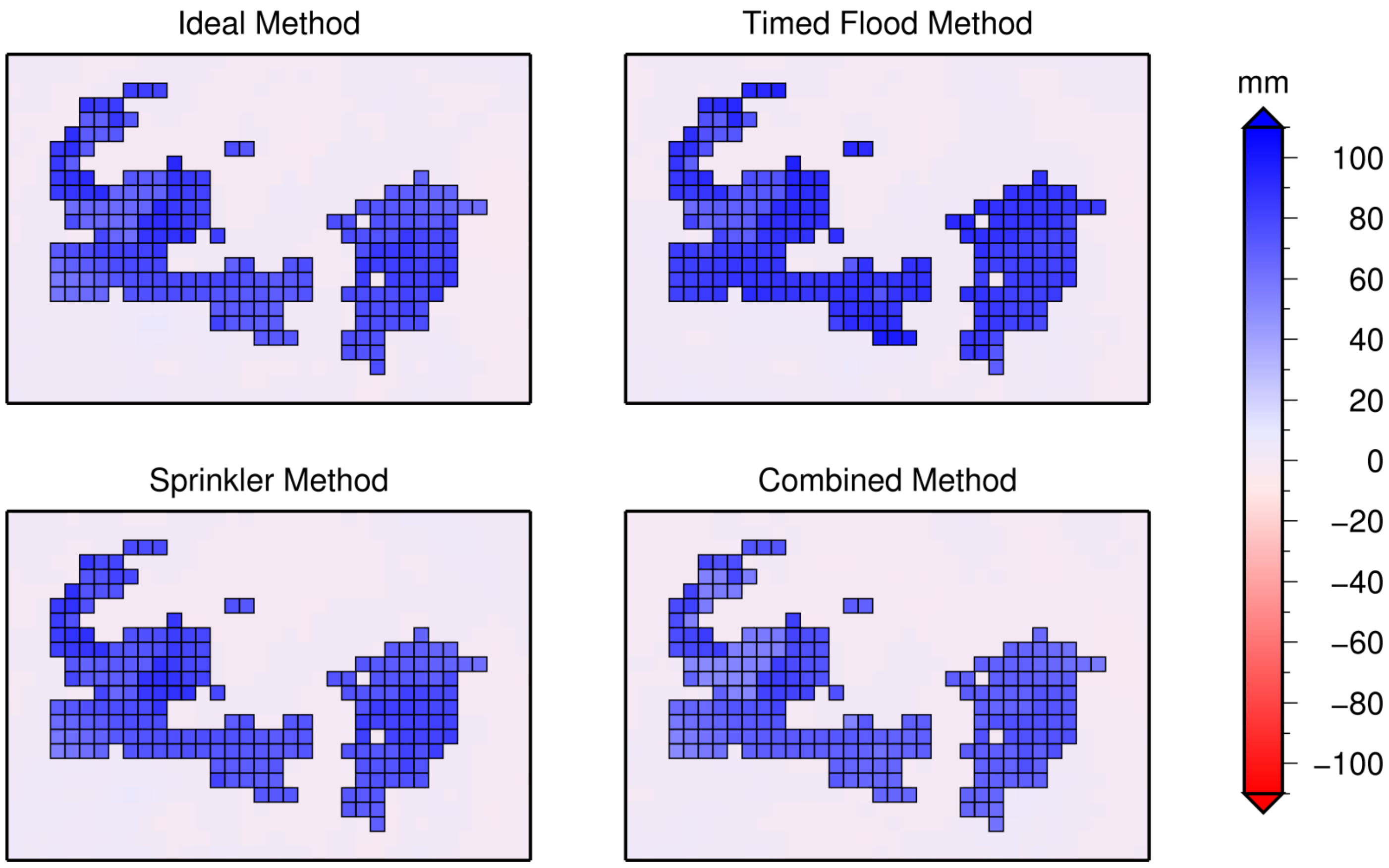
Accumulated ET by Irrigation Method for 2010 Water Year



Comparison of Irrigation Methods
Water Year Oct 2009 through Sep 2010

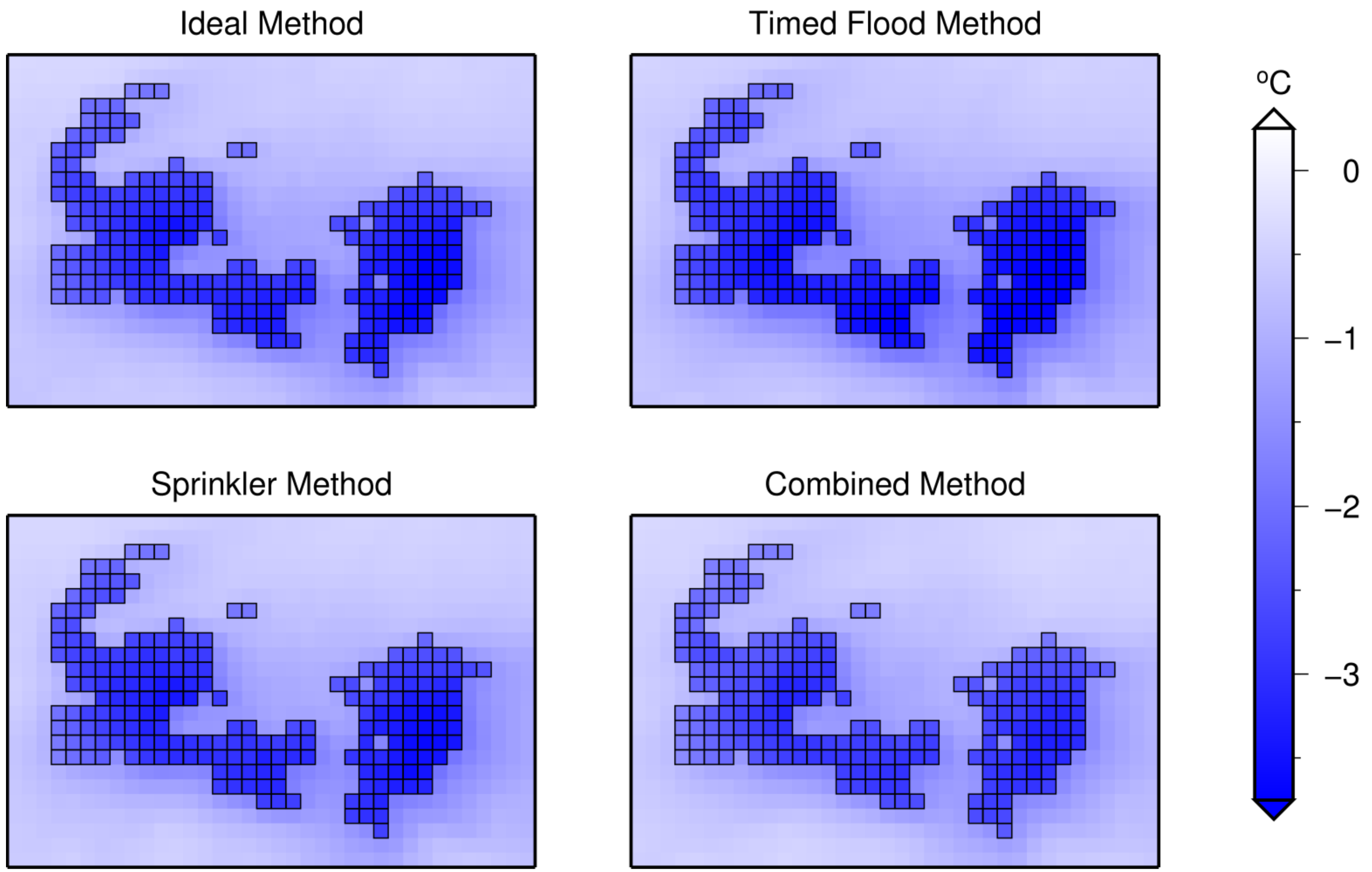
Method	Irrigation Events	Water Applied	ET	Surface Runoff	Subsurface flow	Precipitation
No Irrigation	-	-	467.1 mm	12.3 mm	43.6 mm	390.2 mm
Ideal	5.6	624.7 mm	823.4 mm	22.9 mm	240.3 mm	403.5 mm
Timed Flood	4.1	944.2 mm	857.9 mm	22.6 mm	596.2 mm	405.9 mm
Sprinkler	21.6	515.3 mm	806.5 mm	19.0 mm	62.2 mm	402.5 mm
Combined	15.9	394.9 mm	757.5 mm	16.8 mm	53.9 mm	400.9 mm

Monthly ET Difference, August 2010



Similar spatial distribution with all four irrigation methods. Quantity of ET seems dependent on effectiveness of method in keeping soil moisture available to modeled vegetation.

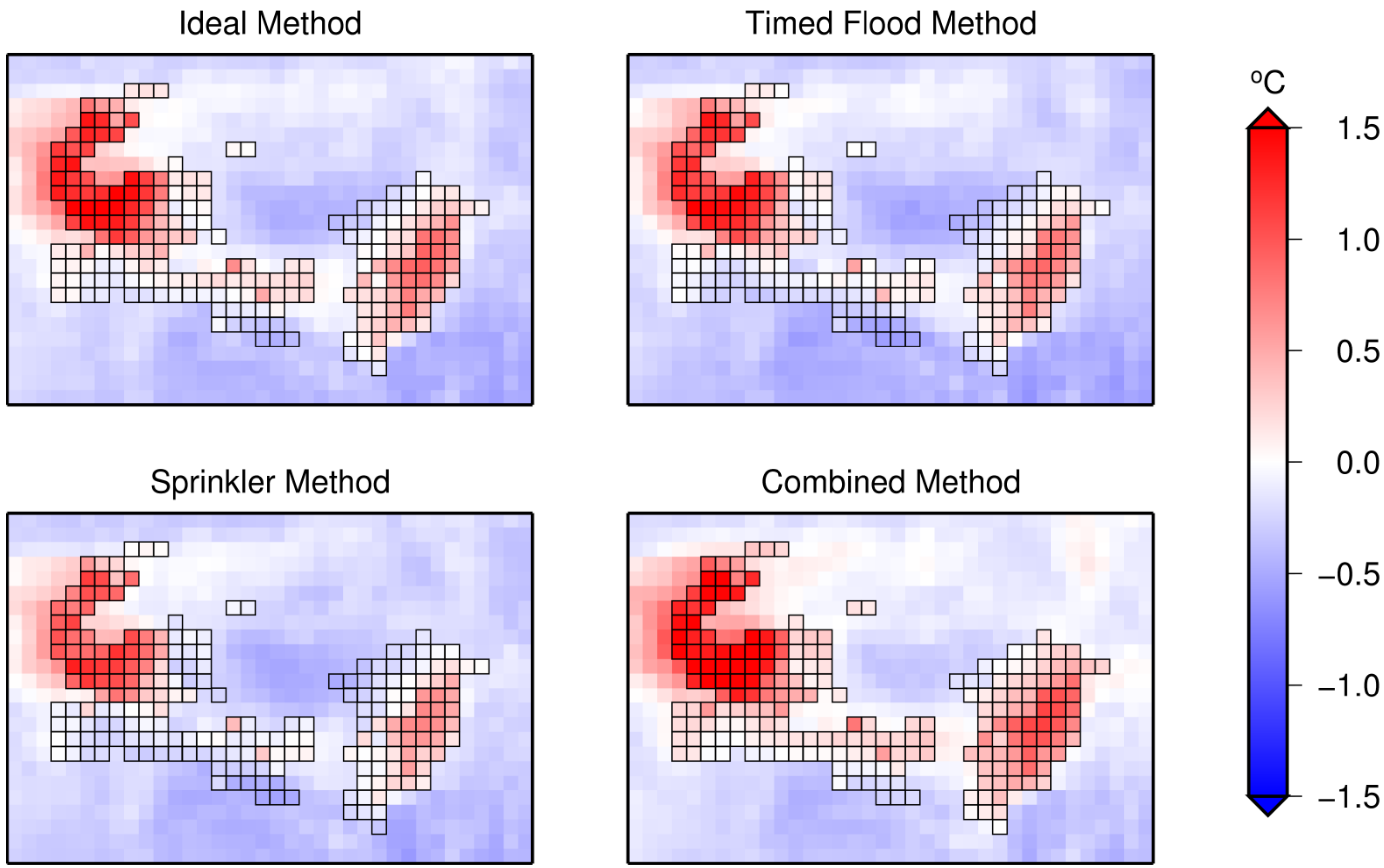
Daily High 2m Temperature Difference



Daily high for each method minus daily high for "No Irrigation," averaged for August, 2010.

Dramatic difference for cropland cells, outlined in black, some advective influence, especially to east of croplands.

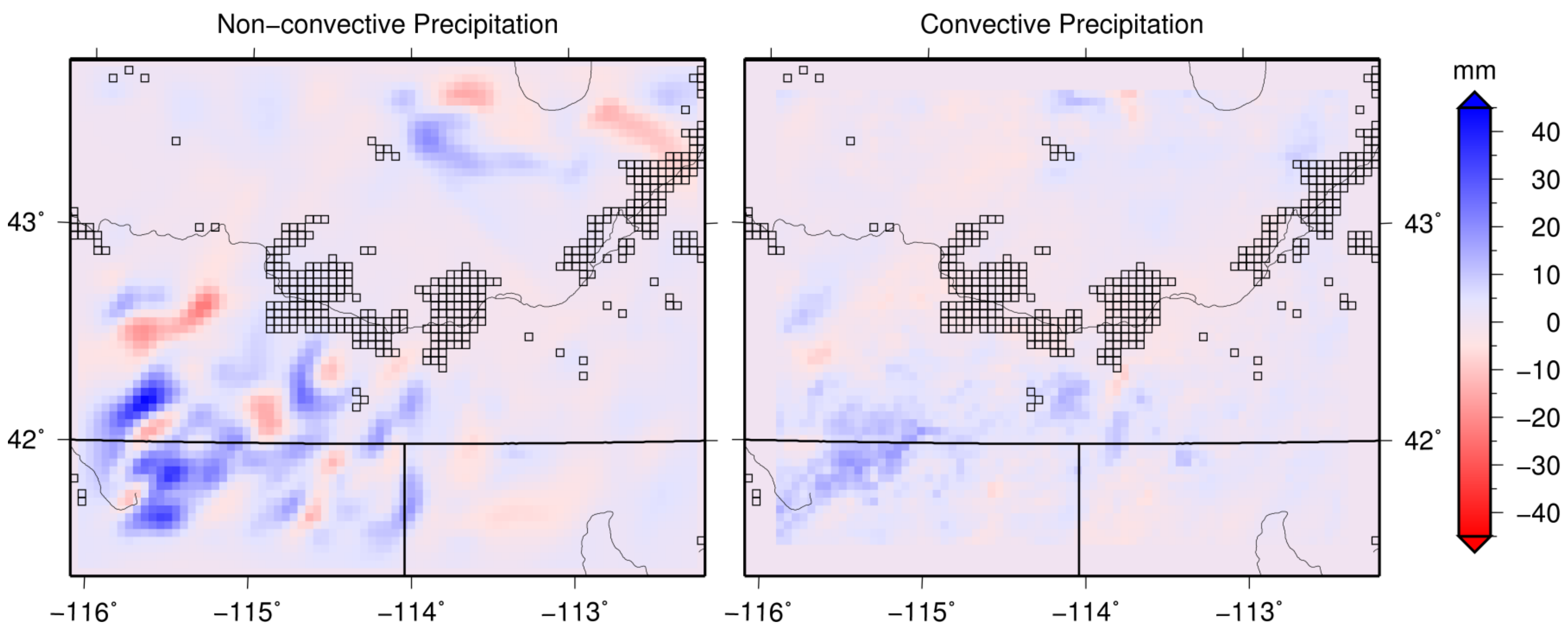
Daily Low 2m Temperature Difference



Daily low for each method minus daily low for "No Irrigation," averaged for August, 2010.

Lows for non-cropland cells reduced at night too. Low speed, locally influenced winds give mixed results for cropland cells.

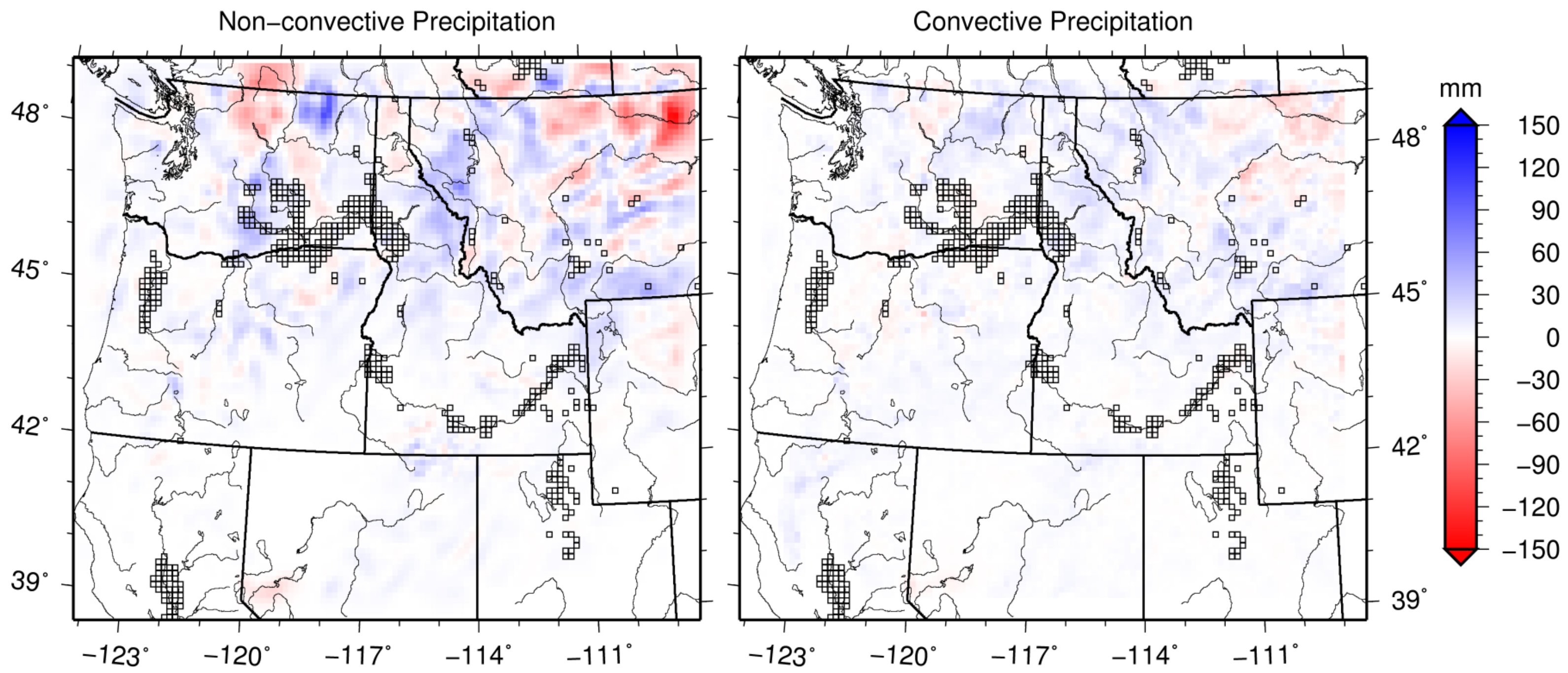
Irrigation Induced Precipitation Difference for Entire Inner Domain



Accumulated precipitation difference between "Sprinkler Method" and "No Irrigation" for July, August, and September, 2010.

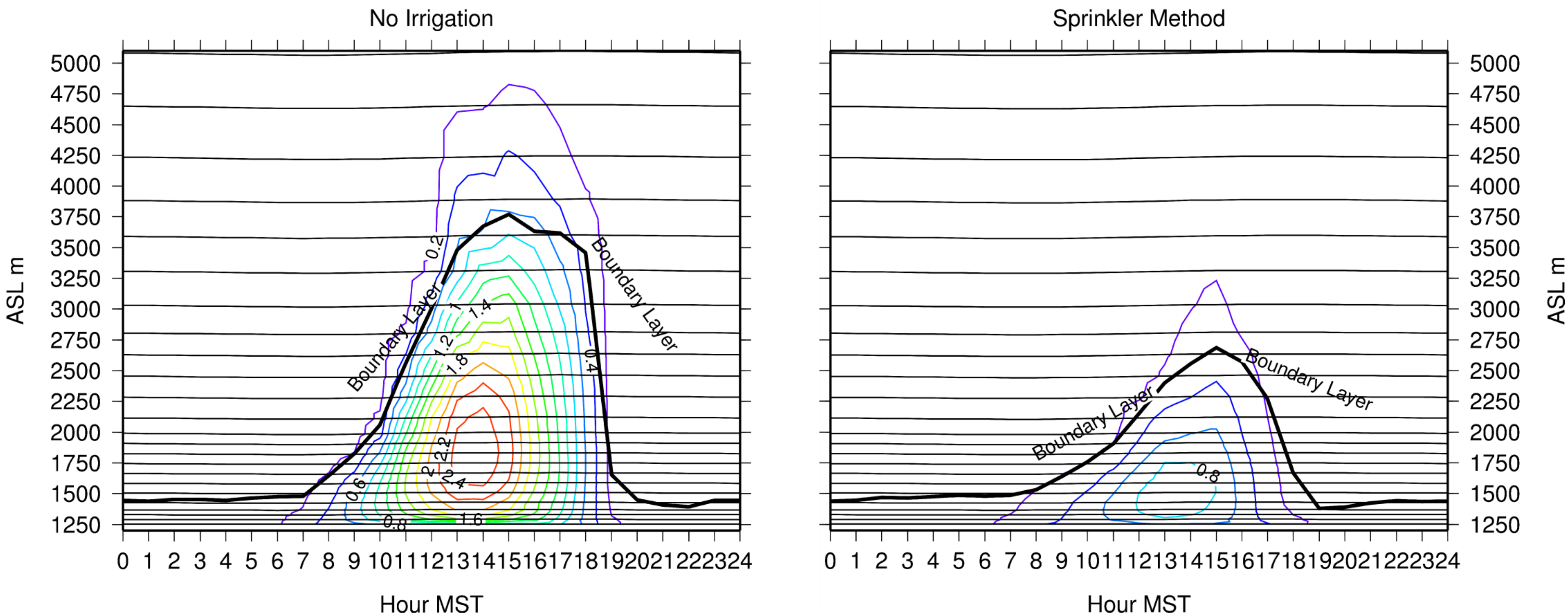
Both non-convective and convective show some increases, mostly over surrounding mountains. Source of moisture may be from irrigated middle domain or from inner domain causing decreased lifting condensation level (LCL).

Irrigation Induced Precipitation Difference for Middle Domain



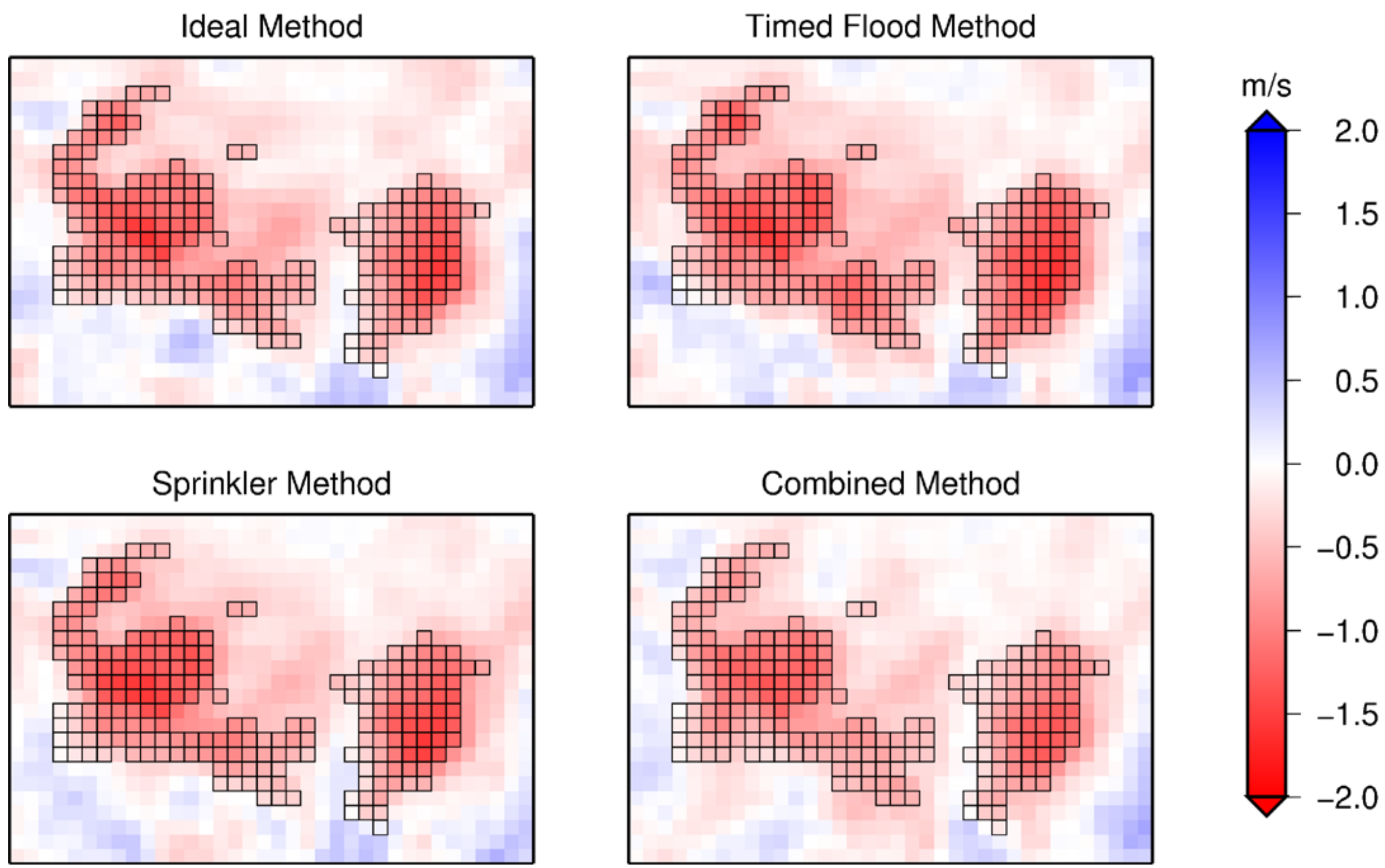
Middle domain, also for July, August, and September, 2010. Majority of change is redistribution rather than local to irrigated areas. Only a small amount is from convective scheme.

Effects on TKE and BPL Height



Graphs of TKE are for a single cropland cell but for a composite day averaged from all days in August, 2010. Without irrigation, more energy is converted to sensible heat, rather than latent heat, resulting in more convective turbulence and higher PBL heights, as calculated by MYJ PBL scheme. Horizontal lines are grid cell mass heights.

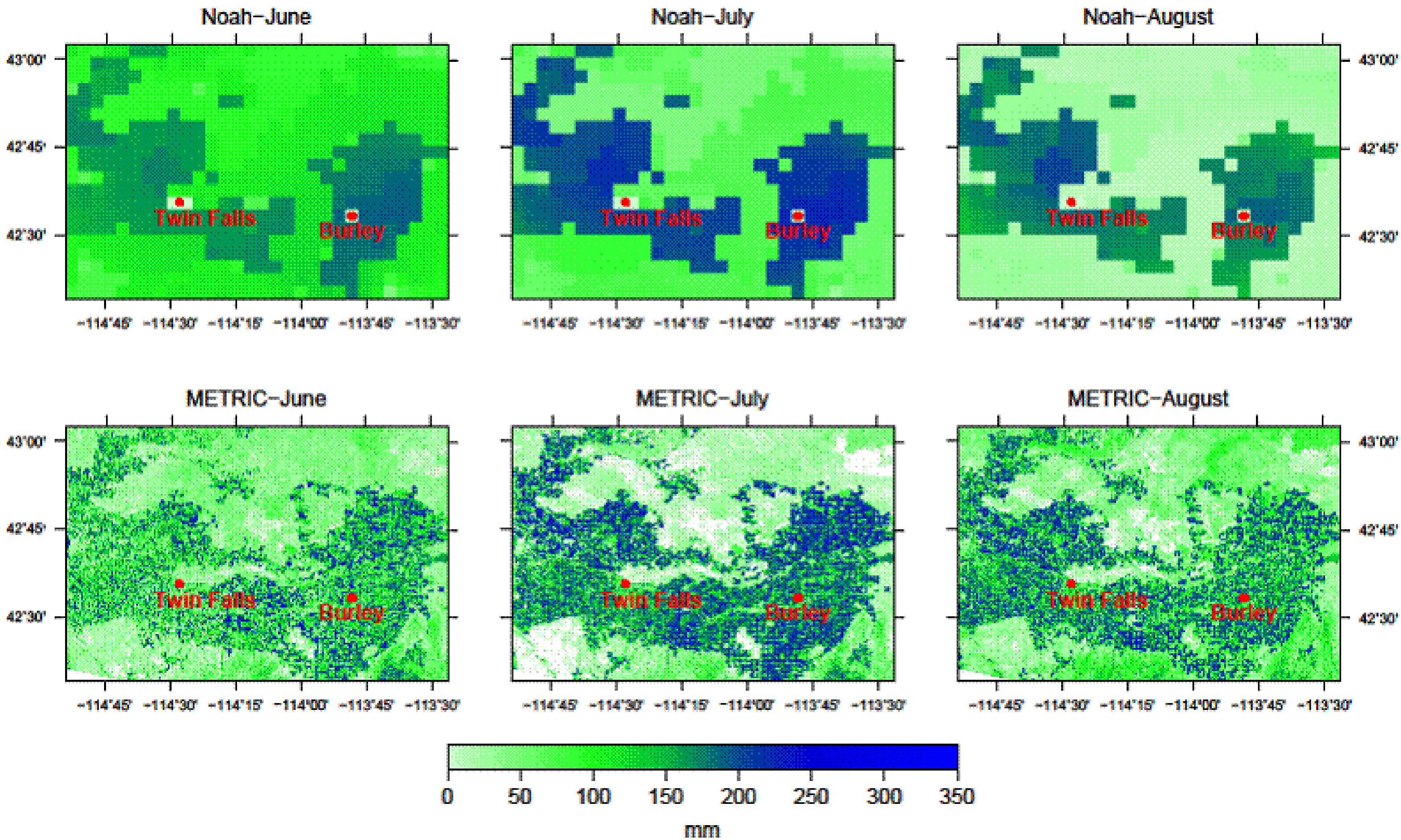
Effects on 10m Wind Speeds



Daily highest speed for each method minus daily highest speed for "No Irrigation," averaged for August, 2010.

Entire area is influenced, but the reduced turbulence seems To entrain less high speed winds over cropland cells.

Goal for High Resolution ET modeling



Conclusions

- Partitioning of surface energy balance components, primarily sensible and latent heat fluxes appears appropriate.
- Irrigation causes observable difference in near surface temperatures, humidity, PBL heights and ET.
- Identifying the crop water consumption (by specific irrigation methods) provides a valuable decision making tool for sustainable water resources management

Acknowledgements

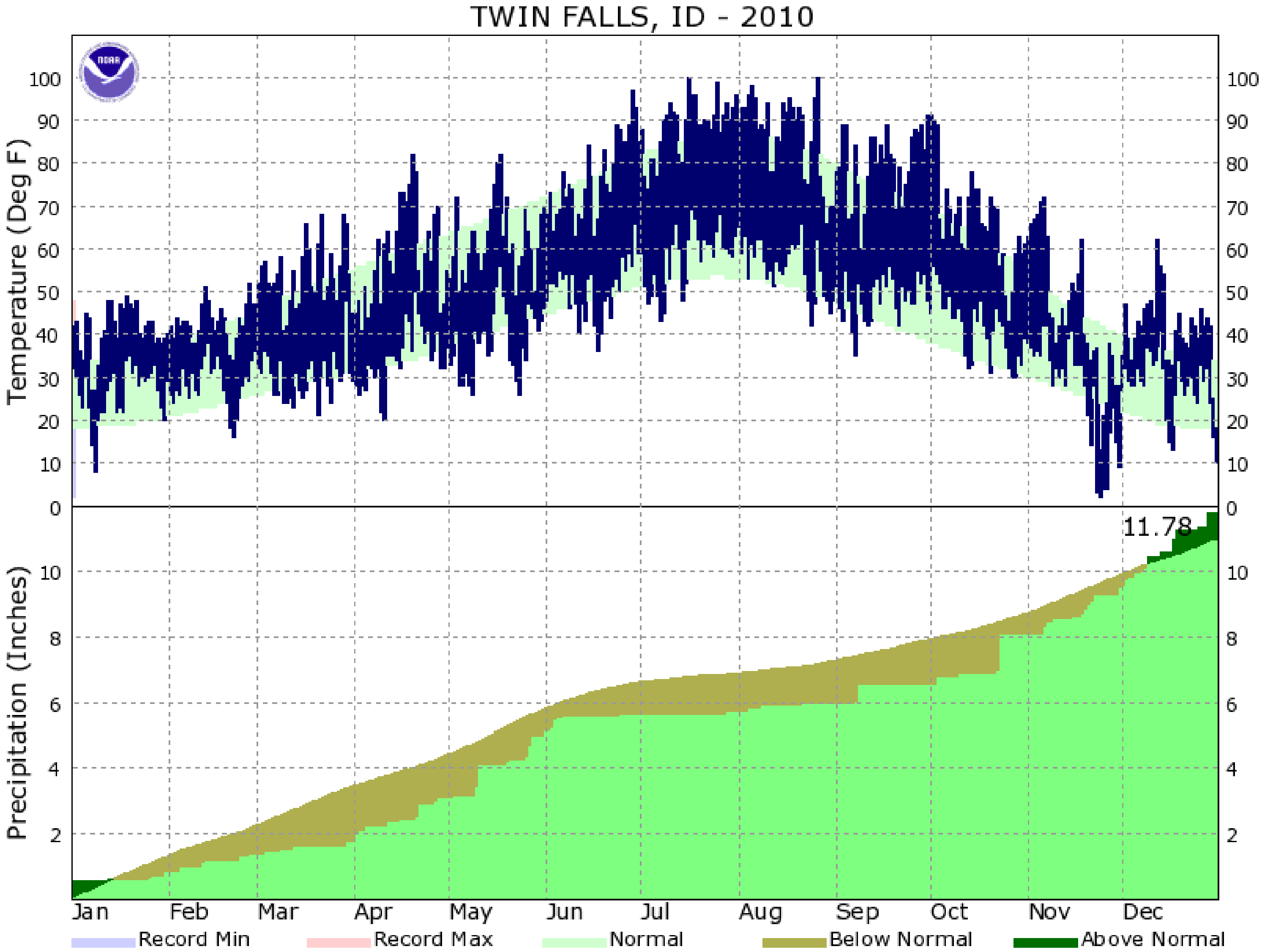
Research was funded by EPSCoR
and the National Science Foundation

Thank you

- Questions
- Comments
- Suggestions

Additional slides follow this one.
If interested in viewing additional data, download this presentation from the conference website.

2010 Meteorological Data and Averages for KTWF, a Station Within the Area of Interest



WRF Namelist: Domains

```
&time_control
start_*          = 2009-10-01 00:00
end_*            = 2011-01-01 09:00

&domains
time_step        = 72
e_we             = 90,115,82
e_sn             = 99,103,67
e_vert           = 39,39,39
eta_levels       = ...
p_top            = 10000.00
dx,dy            = 36000,12000,4000
i_parent_start = 1,31,60
j_parent_start = 1,33,25
feedback         = 1
smooth_option    = 2
smooth_cg_topo = .true.
```

- 15 month runs for calendar year data and LSM spin up
- Eta levels from UW forecast
- Extra smoothing
- 2 way nest feedback
- Short time step and smoothing to help reduce persistent CFL errors in innermost domain

WRF Namelist: Dynamics

```
&dynamics
w_damping                  = 1
diff_opt                   = 1
km_opt                     = 4
diff_6th_opt               = 2,2,2
damp_opt                   = 3
dampcoef                   = 0.2,0.2,0.2
gwd_opt                    = 1
epssm                      = 0.3,0.3,0.3
moist_adv_opt              = 1,1,1
scalar_adv_opt             = 1,1,1
chem_adv_opt               = 1,1,1
tke_adv_opt                = 1,1,1
```

- Upper damping
- Simple diffusion
- 2D deformation
- Gravity wave drag
- Positive-definite advection options
- Time off centering (epssm) changed for persistent CFL errors

WRF Namelist: Physics

```
&physics
mp_physics                 = 8,8,8
ra_lw_physics              = 4,4,4
ra_sw_physics              = 4,4,4
radt                       = 5,5,5
sf_sfclay_physics          = 2,2,2
bl_pbl_physics             = 2,2,2
sf_surface_physics         = 2,2,2
cu_physics                 = 5,5,5
cudt                       = 5,5,5
ishallow                   = 0
cugd_avedx                 = 3
isfflx                     = 1
sst_update                 = 1
sst_skin                   = 1
tmn_update                 = 1
usemonalb                  = .false.
```

- Thompson microphysics
- RRTMG long and short wave radiation
- MYJ PBL with Janjic ETA surface layer
- Noah LSM with MODIS
- Grell 3D cumulus (no ishallow), to capture local precipitation and cloud fraction changes
- Update of vegetation fraction (sst_update) which updates albedo, LAI, emissivity, & z_0

Registry Additions: state Variables

```
integer IW_EVENTS ij misc  1 - rh6 "IW_EVENTS" "COUNT OF EVENTS"    ""
real    IW_ACCUM  ij misc  1 - rh6 "IW_ACCUM"  "ACCUMULATED WATER" "mm"
real    IW_REMAIN ij misc  1 - r   "IW_REMAIN" "REMAINING TIME"    "sec"
```

- “IW_EVENTS” Used for tracking number of times each grid cell was irrigated
- “IW_ACCUM” is the amount of irrigation water added to each cell
- “IW_REMAIN” indicates amount of time in current irrigation cycle remaining for irrigation methods that are timed.

Registry Additions: rconfig Variables

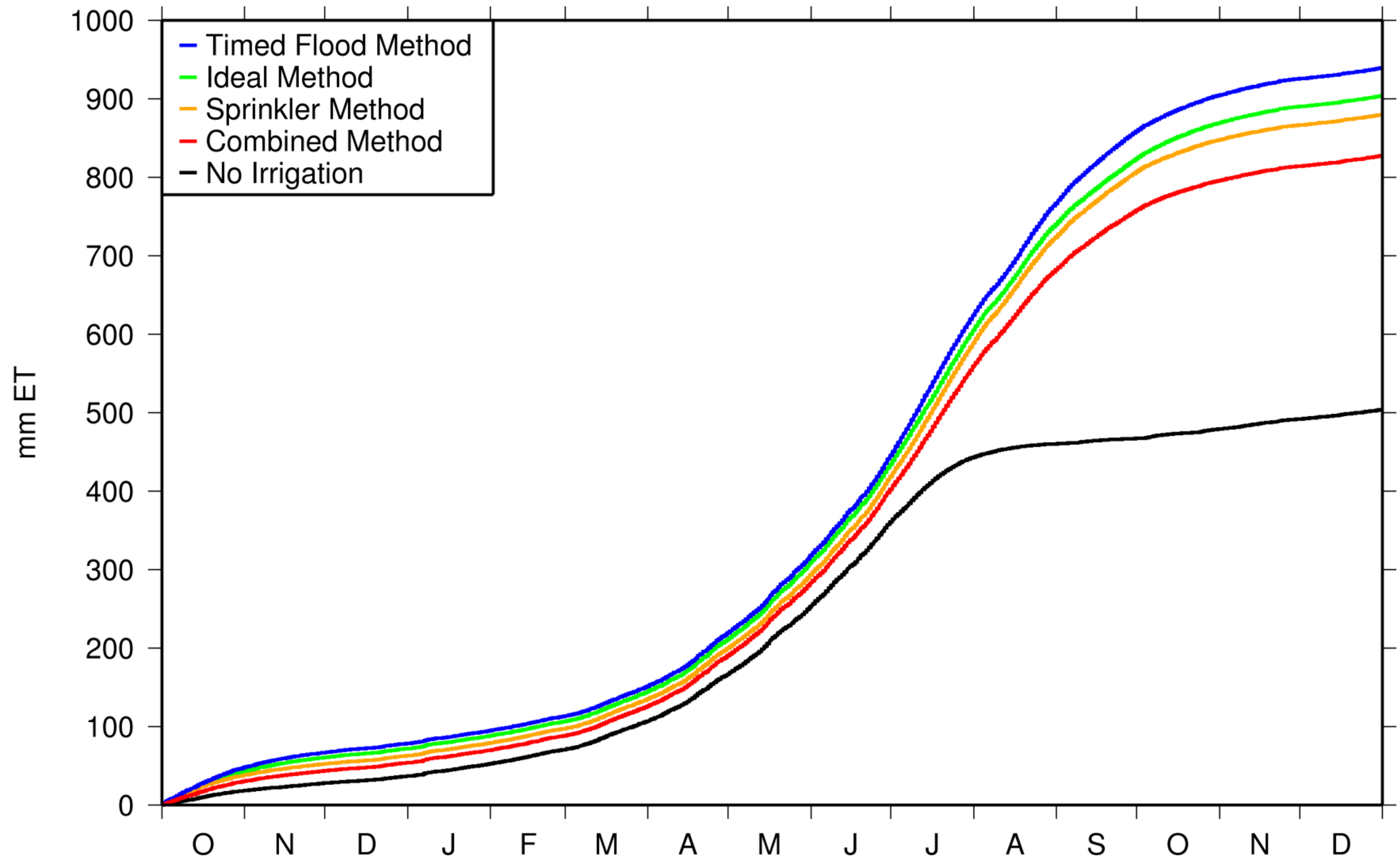
```
integer iw_lu        namelist,physics 50 0 rh "iw_lu"
  "list of landuse categories that get irrigation"                ""
integer iw_method    namelist,physics 50 0 rh "iw_method"
  "method used to apply irrigation water"                         ""
integer iw_first_day namelist,physics 50 0 rh "iw_first_day"
  "julian day irrigation can begin for each cat in iw_lu"         ""
integer iw_last_day  namelist,physics 50 0 rh "iw_last_day"
  "julian day irrigation must stop for each cat in iw_lu"         ""
real    iw_min       namelist,physics 50 0 rh "iw_min"
  "min pct of avail water triggering irrig for each cat in iw_lu" ""
real    iw_target    namelist,physics 50 0 rh "iw_target"
  "target pct of avail water for each category in iw_lu"          ""
real     iw_cycle     namelist,physics 50 0 rh "iw_cycle"
  "min time needed to perform irrigation"                      "hours"
real    iw_max_amt   namelist,physics 50 0 rh "iw_max_amt"
  "max amount of water that can be applied per cycle"             "mm"
real    iw_loss      namelist,physics 50 0 rh "iw_loss"
  "ampplication inefficiency"                                "percent"
real    iw_factor    namelist,physics 50 0 rh "iw_factor"
  "wind speed factor used in sprinkler method for loss"   "% m-1 sec"
```

10 Configuration variables added for controlling irrigation schemes.

Ideal Flood Method
(Added and tested but not in results shown)

- An intermediate approach between “Ideal” and “Timed Flood” without deep percolation.
- When any root zone layer drops below minimum (iw_min = 0.50), at each timestep, set top soil layer to saturation level until enough added to reach target moisture in all root zone layers (iw_target = 1.0).
- Additional water can be added to surface runoff variable as an “application inefficiency” but was not used for these runs (iw_loss = 0.0).

Accumulated ET by Irrigation Method for 15 Month Simulation



Abstract

Considering the land surface characteristics in modeling weather and climate is critical as the net radiation is partitioned into latent, sensible and ground heat fluxes. Conversion of available energy into latent or sensible heat is controlled by soil moisture. The extensive agricultural area in arid southern Idaho relies on the supply of about 60 cm of water through irrigation for crop production. Irrigation in Idaho is quite varied and complex. Recently, an algorithm was included in the WRF model to represent irrigation wherein additional water to the soil column altered the energy and water budget estimation. This study adds four grid-cell level irrigation schemes, namely ideal replenishment, surface flooding, surface sprinkling, and a combination to the Noah LSM in WRF, each having strong and weak points in capturing the complexities of sprinkler or furrow irrigation in agriculture practices. The ideal replenishment simply increases soil moisture when a lower limit is reached. The surface flooding saturates the top soil layer for a specified amount of time. The surface sprinkling adds a specified amount of water, minus evaporative loss, over a specified time. The combination scheme saturates the top soil layer for one time step. Results of each scheme are evaluated for local effects of additional latent heat and reduced sensible heat. Expectedly, the results show cooler, more humid local conditions as well as lower TKE, shallower PBL heights, and mildly weaker winds. Local precipitation and cloud fraction changes are minimal, consisting of minor redistribution.

Values Used For All Four Examples

- Irrigated MODIS IGBP category of “croplands” (iw_lu = 12).
- Used April 1st as start of irrigation season (iw_first_day = 91).
- Used October 31st as end of season (iw_last_day = 304).
- Used common recommendation of 50% of range between wilting point and field capacity as specified minimum (iw_min=0.50).