Role of Land-Atmospheric Coupling Strength in the Modeled Diurnal Cycle of Summer Precipitation

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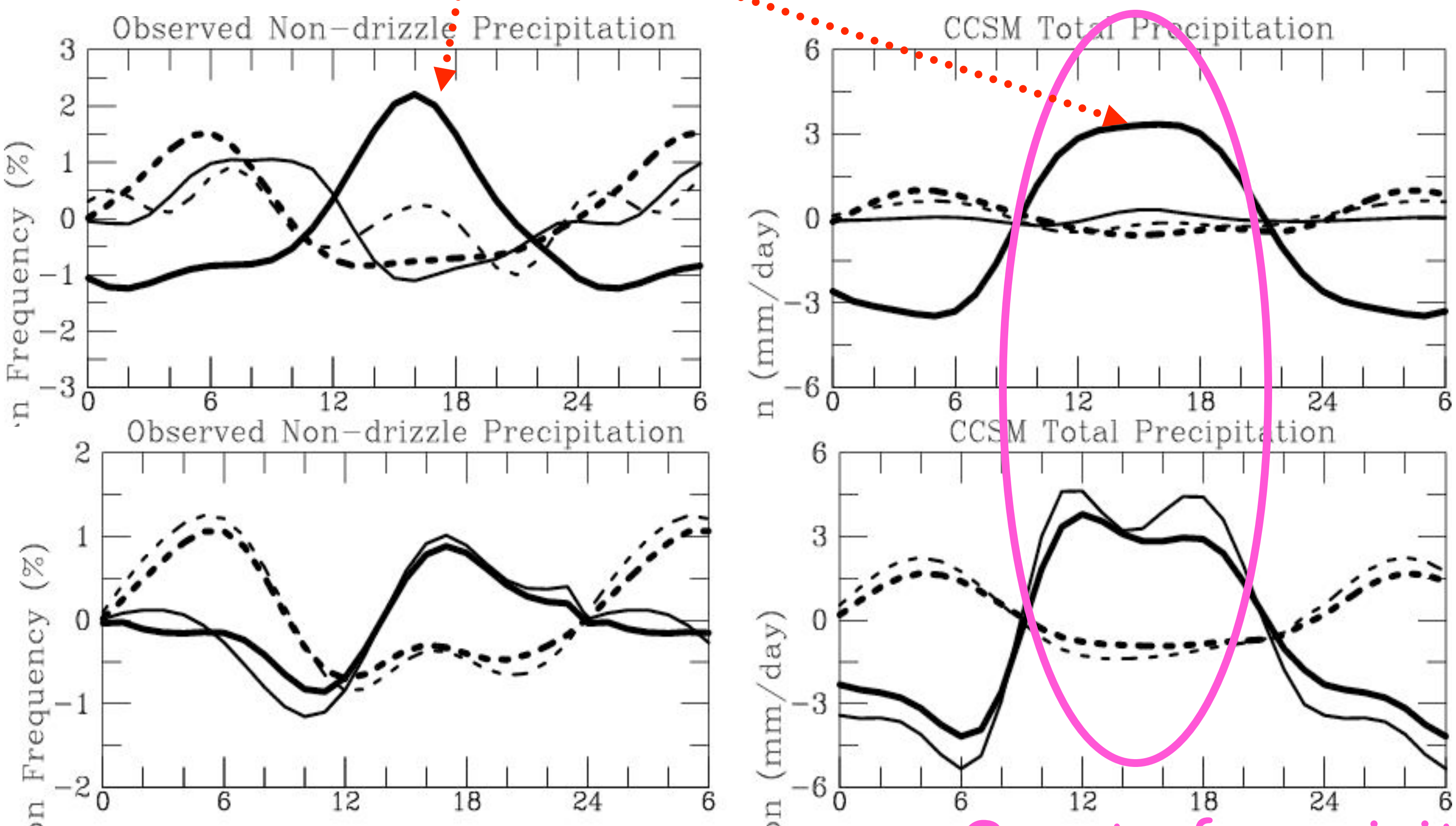
Mean Precip. Diurnal Cycle, Land (solid) vs. Ocean (dashed)

Obs.

CCSM2



25°N–70°N

25°N–25°S

thick line=JJA, thin line = DJF

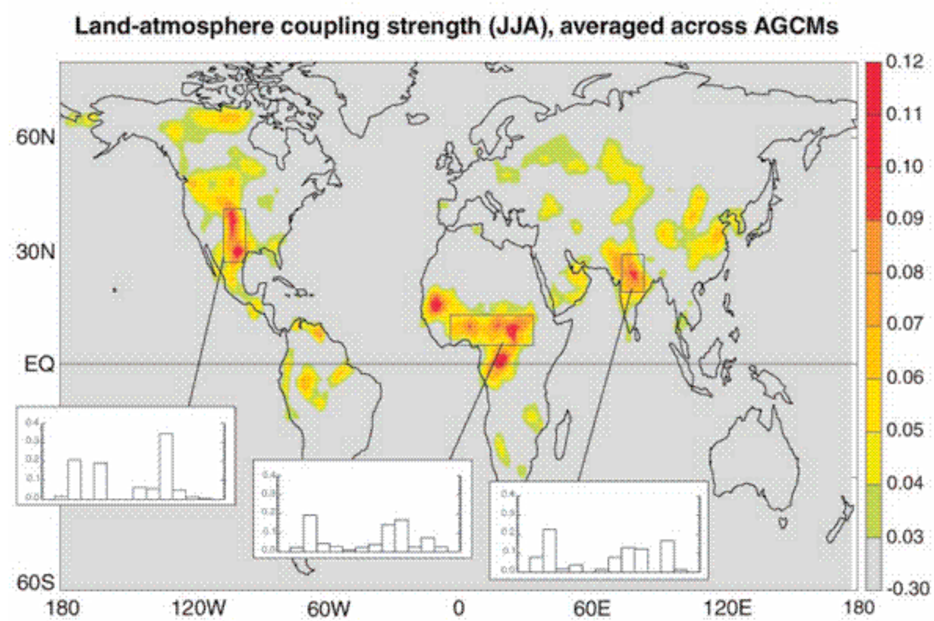
Dai and Trenberth 2004

Onset of precipitation too soon, and duration too long
Intensity too low

Land-Atmospheric Feedback May Hold the Key for Improving Weather and Climate Predictability

Regional weather and climate prediction: Beljaars et al., 1996; Paegle et al. 1996; Chen et al., 2001; Trier et al., 2004; Kim and Hong, 2007, Trier et al., 2008; etc.

Global climate: Precipitation-soil moisture coupling "hot spots"
Koster et al., 2004
Zhang et al., 2008



Koster et al., 2004, Science

Contrasting view: land-surface models may represent a too strong coupling in climate models, leading to too-much evaporation and wrong soil moisture-precipitation feedback (Ruiz-Barradas and Nigam; 2005, JC)

Scientific Questions

- Should we trust the pervious model-based analysis?
- What is the right land-atmospheric coupling strength? How does the Noah land model represent such coupling?
- What is impact of coupling strength on summer precipitation ?

Various Coupling Strength Indexes

How to 'measure' land-atmosphere feedback?

- From budget analysis: feedback numbers (p, β)

$$\beta = \frac{E}{E + Q_{in}}$$

- From statistical analysis: Diagnosis of coupling coefficient Ω from ensemble model experiments
  - Take variance of precipitation across ensemble, σ_P^2
  - Compare σ_P^2 from ensemble W (normal) with ensemble S (prescribed soil moisture)

$$\Omega = \frac{\sigma_P^2(W) - \sigma_P^2(S)}{\sigma_P^2(W)}$$

  - If $\sigma_P^2(W) \approx \sigma_P^2(S) \rightarrow \Omega \approx 0$, low coupling
  - If $\sigma_P^2(S)$ disappears $\rightarrow \Omega \approx 1$, strong coupling

Our approach for assessing land-atmospheric coupling strength

- Use long-term (at least two years) AmeriFlux data to reconstitute surface exchange coefficients C_h across difference land-cover types and climate regimes

$$SH = \rho C_p C_h |U_a| (\theta_s - \theta_a) \qquad LE = \rho\, C_h |U_a| (q_s - q_a)$$

$$C_h = \frac{H}{\rho c_p |u_a| (\theta_s - \theta_a)}$$

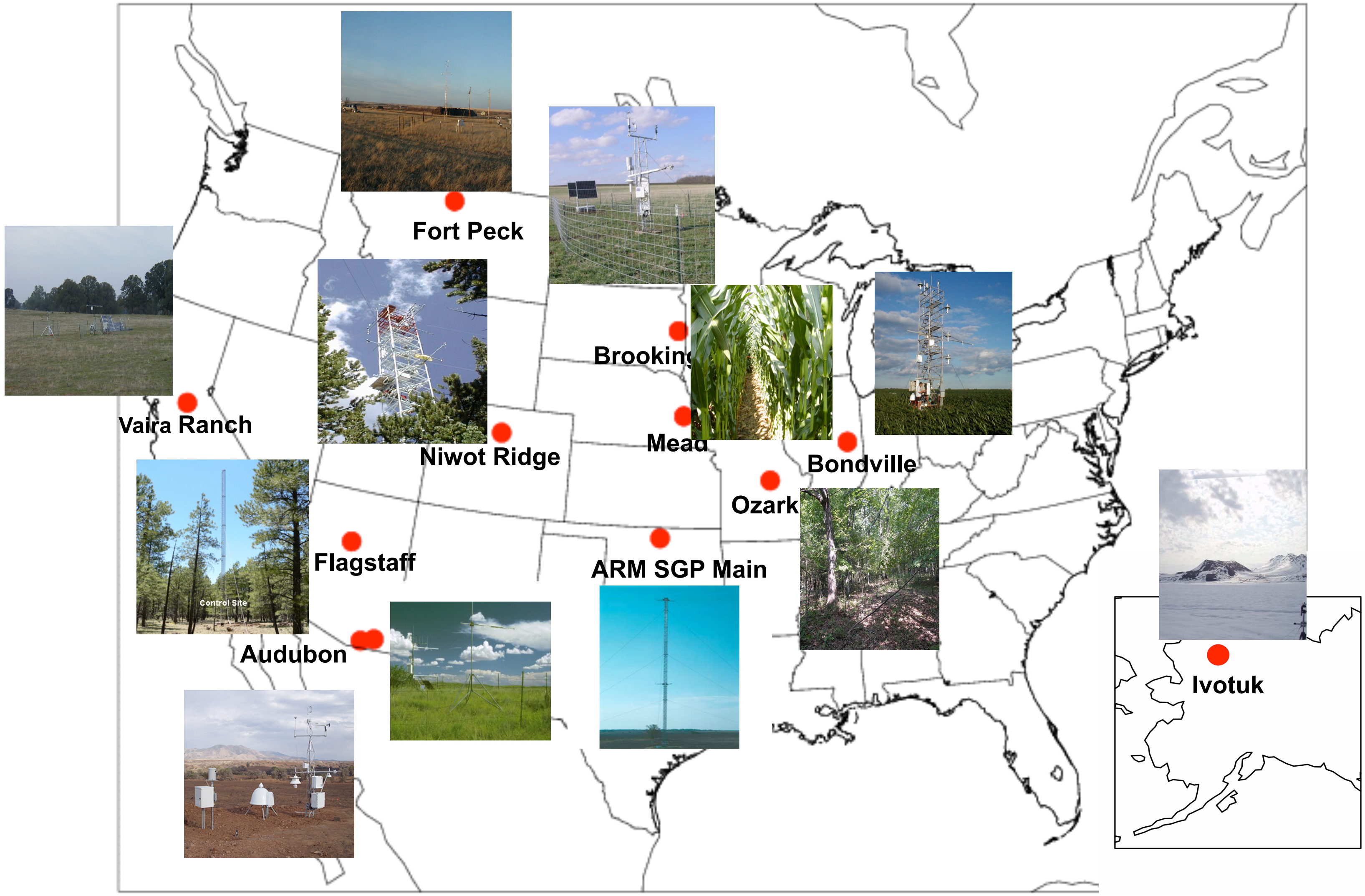
C_h is calculated at 30-min intervals, averaged for midday (1000-1500 LST), and then averaged for spring and summer (growing season).

Chen and Zhang, 2009, *Geophysical Research Letter*.

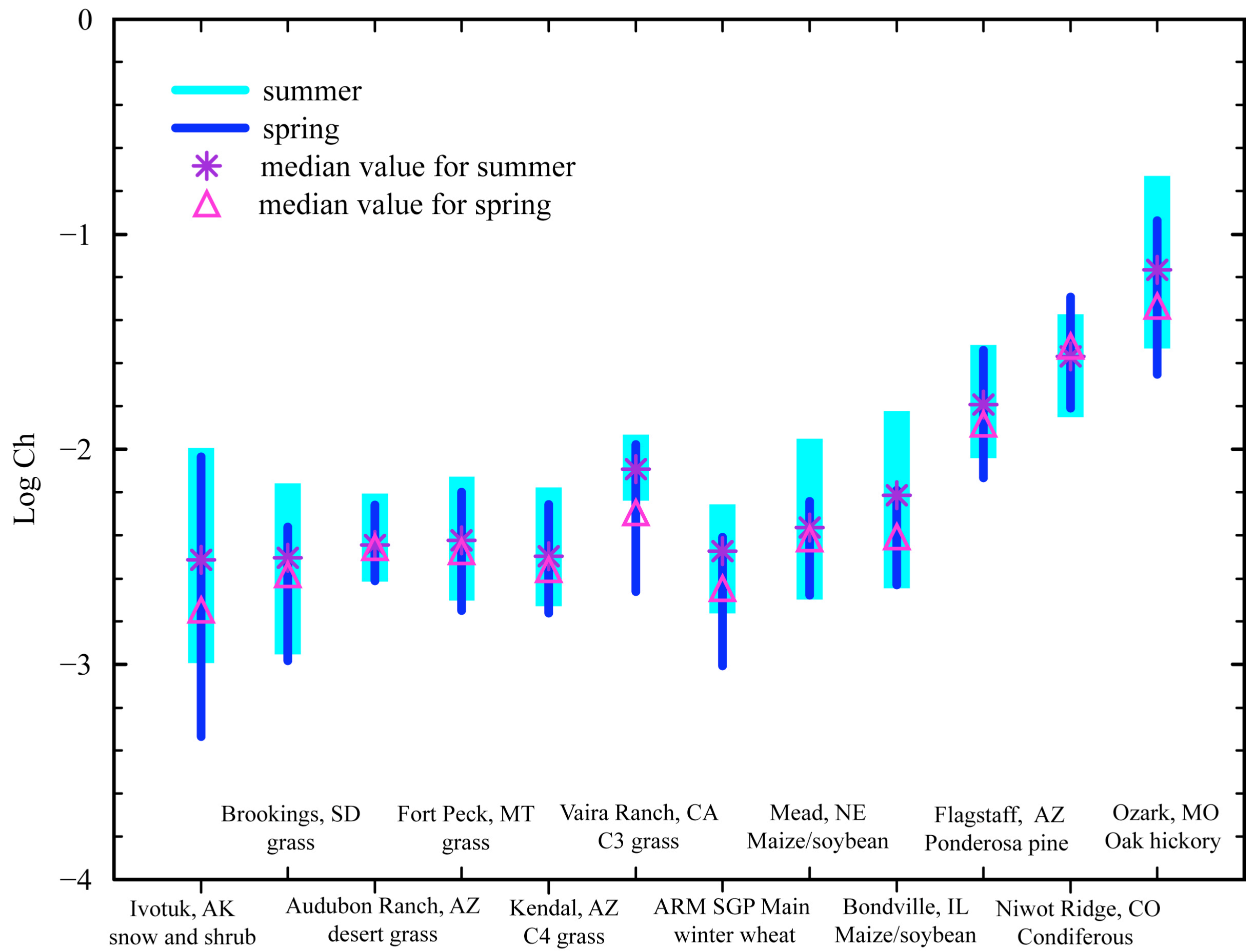
Keep in mind

- Soil moisture, vegetation controls the partition of total incoming energy at surface into latent and sensible heat fluxes.
- The coupling (Ch) controls the total amount of heat and moisture feedback to the atmosphere.
  - larger Ch, larger SH and LE, more coupling.
  - smaller Ch, smaller SH and LE, less coupling.

Locations of 12 selected AmeriFlux sites



Observational Evidence

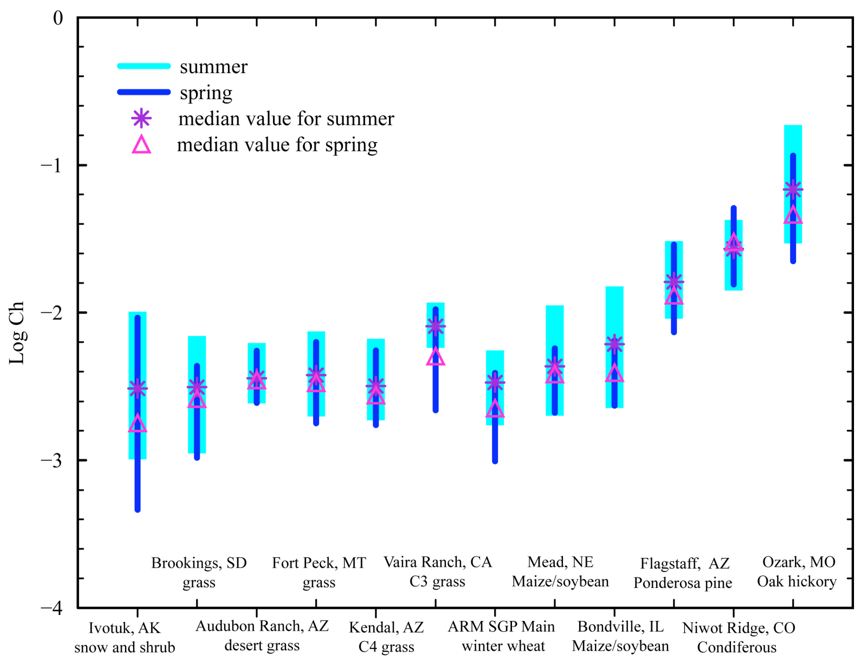


Higher C_h (strong coupling) for tall vegetation (forests)

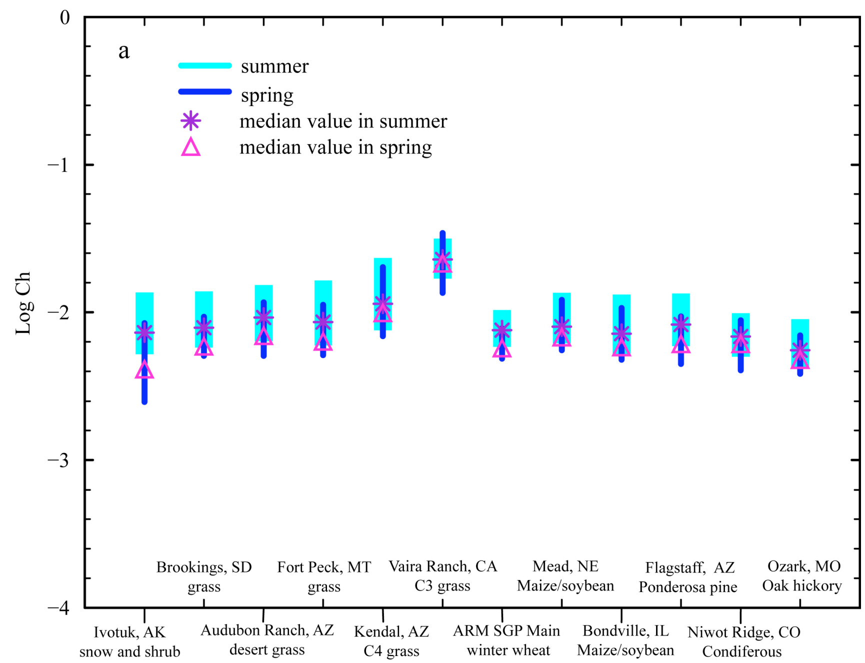
Summer C_h is slightly higher than spring values

How Noah is doing?

C_h observations



C_h calculated by Noah



Problems

- modeled C_h has less variability for different land cover
- Noah overestimate (underestimate) C_h for short vegetation (tall vegetation). Agree with Ruiz-Barradas and Nigam (2005).

Chen and Zhang, 2009, GRL.

C_h formulation in Noah

Based on Monin-Obukhov similarity theory

$$C_h = \frac{k^2 / R}{\left[\ln(\frac{z}{z_{om}}) - \Psi_m(\frac{z}{L}) + \Psi_m(\frac{z_{om}}{L})\right]\left[\ln(\frac{z}{z_{ot}}) - \Psi_h(\frac{z}{L}) + \Psi_h(\frac{z_{ot}}{L})\right]}$$

Using Zilitinkevich scheme to calculate

$$Z_{ot} = Z_{om}\exp(-kC\sqrt{R_e^*})$$

Surface fluxes are more sensitive to treatment of roughness length for heat/moisture than to M-O based surface layer schemes themselves. C (or Czil) =0.1 (Chen et al. 1997, Boundary Layer Meteorol.).

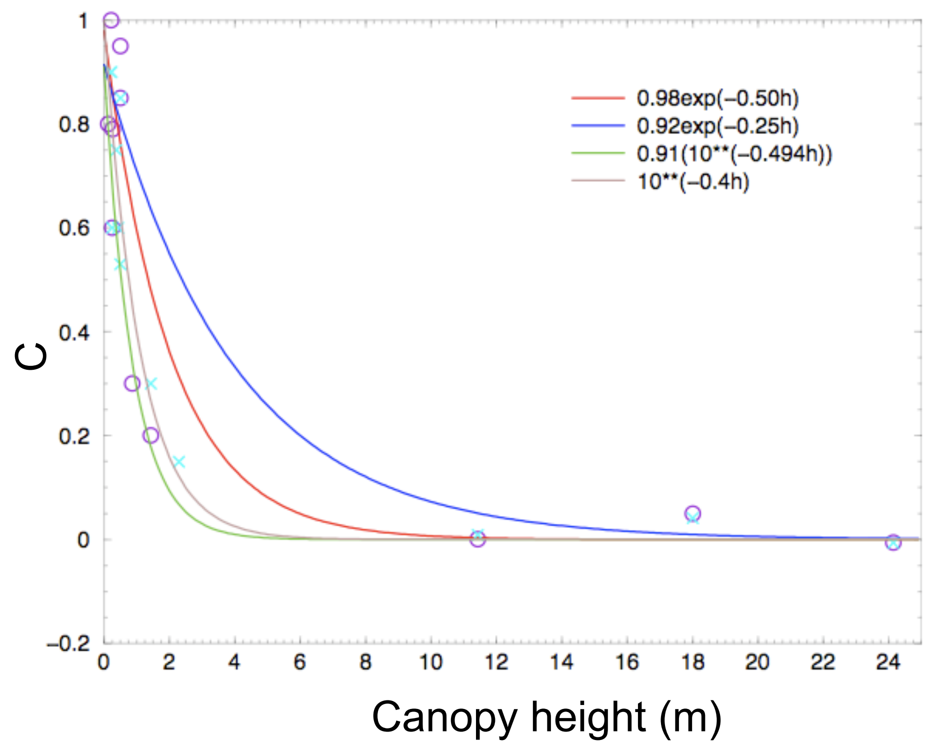
Alternative Approach

1) Zilitinkevich scheme

$$Z_{ot} = Z_{om} \exp(-kC\sqrt{R_e^*})$$

Here $C = 10^{(-0.4h)}$

h is the canopy height in meter, based on calibration with AmeriFlux data



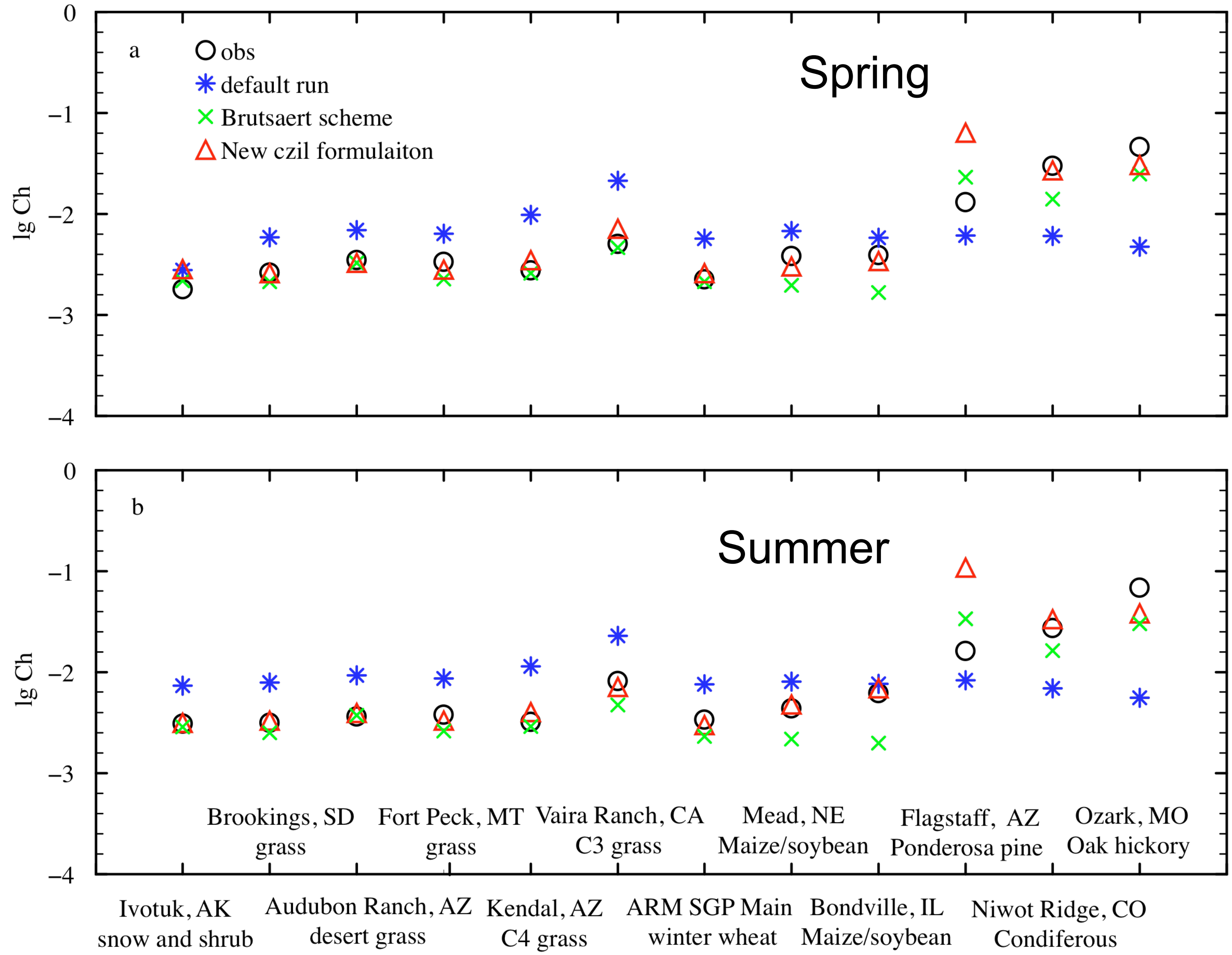
2) *Brutsaert Scheme*

Smoth surface: $Z_{ot} = 0.395\nu / u_*$

Bluff-rough surface: $Z_{ot} = 7.4 Z_{om} \exp(-2.46 (R_e^*)^{1/4})$

Tall trees: $Z_{ot} = \beta Z_{om}$

Ch calculated with alternative formulations



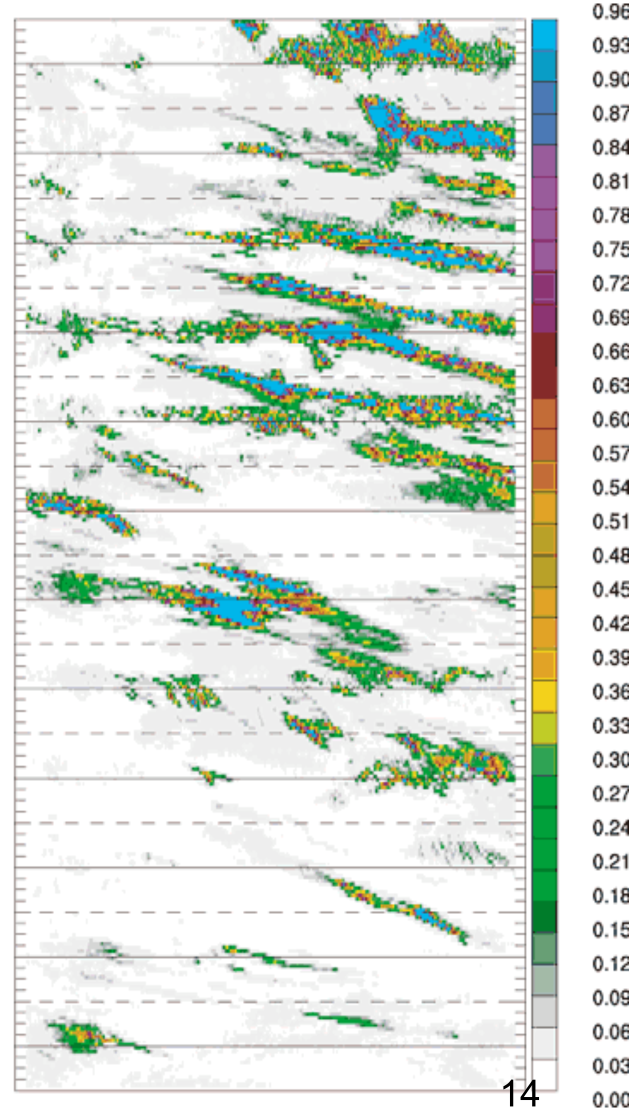
Observations; Noah results with the default C=0.1

Brutsaert (1982); New Czil formulation based on AmeriFlux data

How does the treatment of Ch impact precipitation?

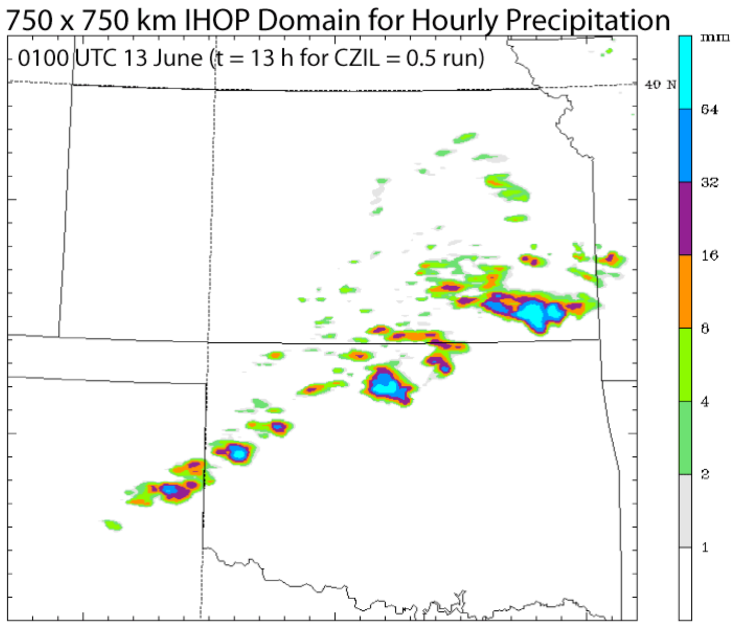
- Focus on10-16 June 2002 summer convective precipitation episodes using WRF with 3-km grid spacing.
- Investigate
  - The degree to which accurate vegetation and soil conditions can improve1-12 h QPF.
  - – The degree to which the land atmospheric coupling affect the convection initiation and development.

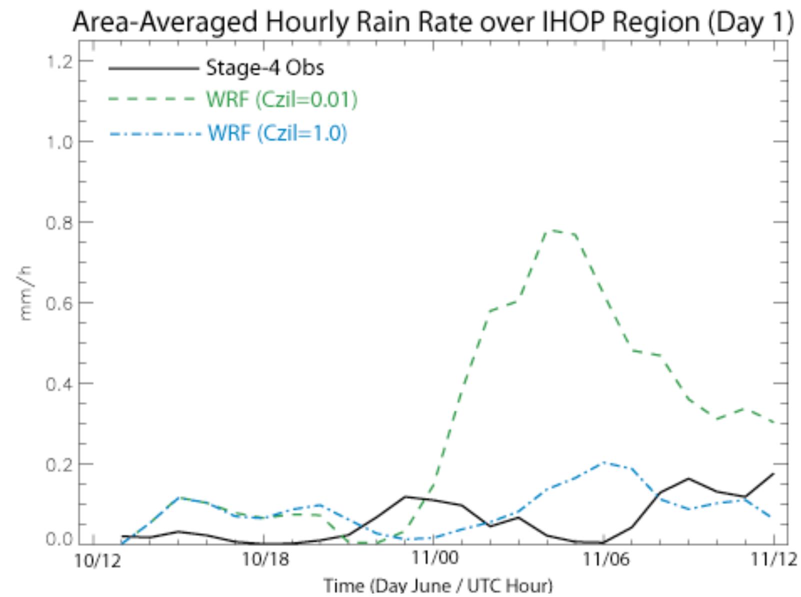
Hovmoller diagrams of rain

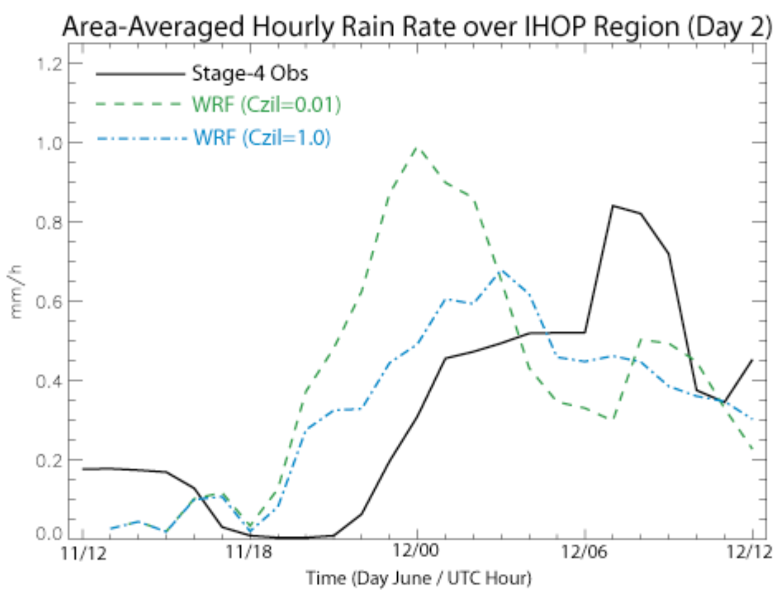


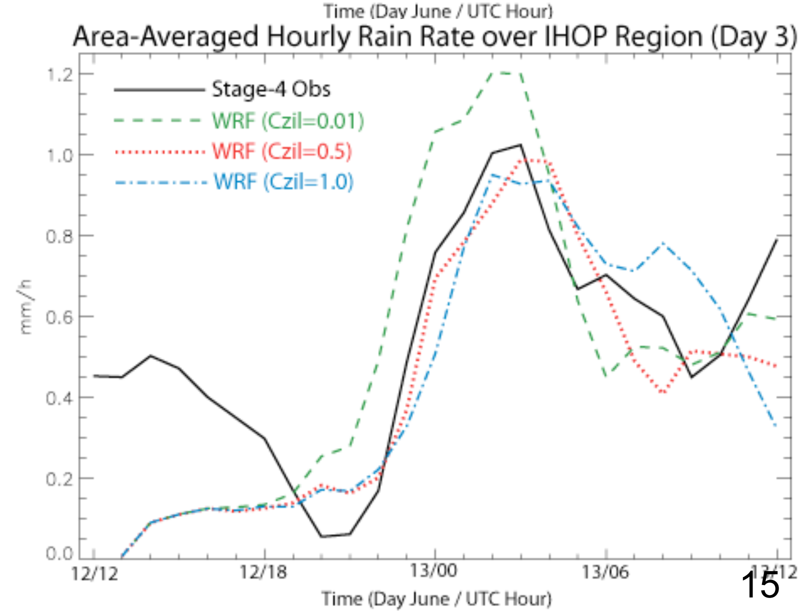
Black: Obs; Green: more coupling

Red: less coupling; Blue: least coupling



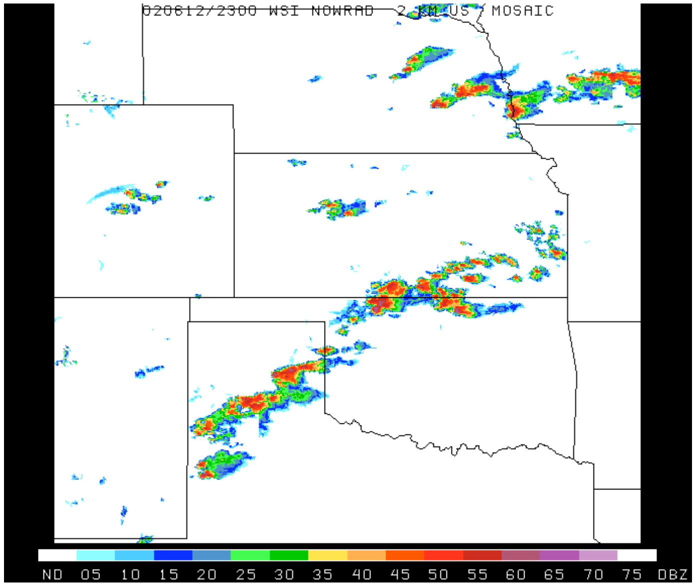




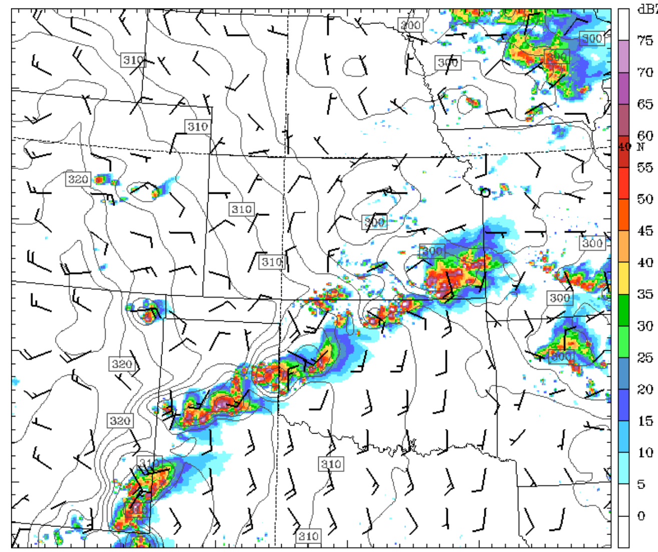


Day Three Case Study at 2300 UTC 12 June (t = 9 h)

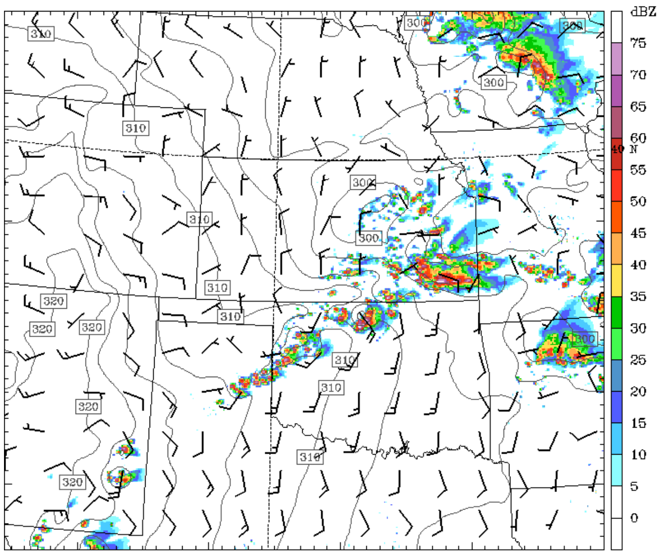
NOWRAD Observations



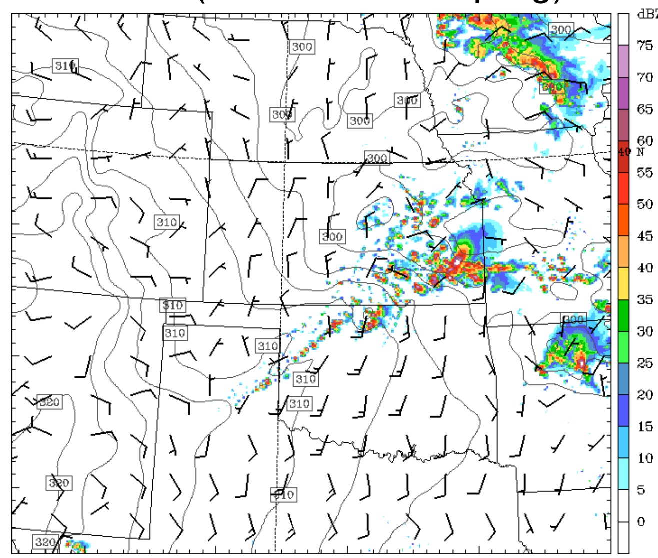
CZIL = 0.01 (Strong Land Coupling)



CZIL = 0.5 default WRF/Noah

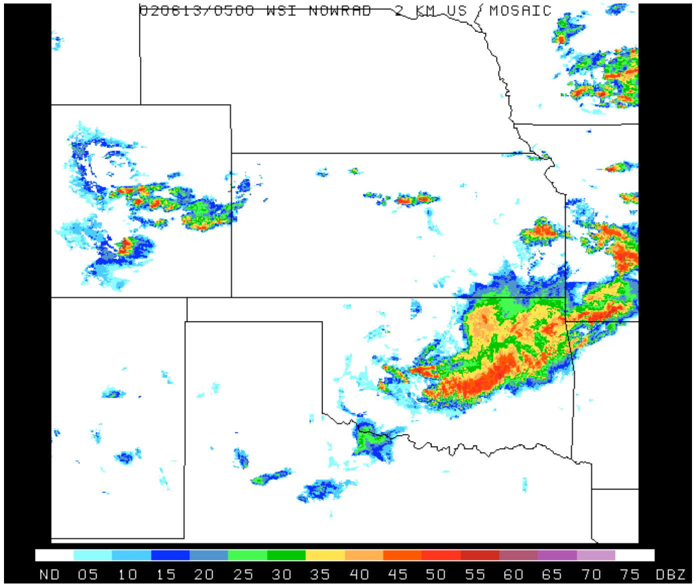


CZIL = 1.0 (Weak Land Coupling)

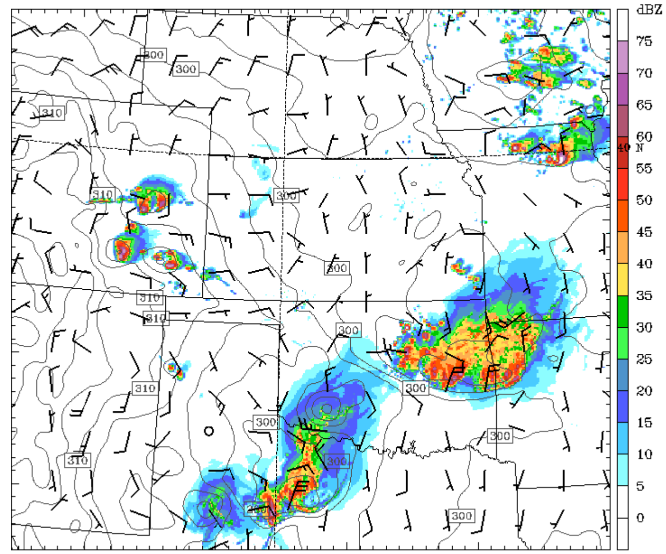


Day Three Case Study at 0500 UTC 13 June (t = 17 h)

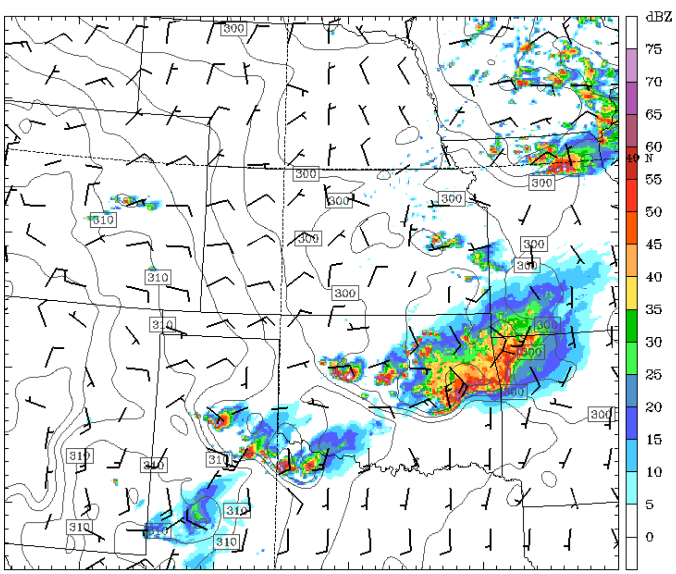
NOWRAD Observations



CZIL = 0.01 (Strong Land Coupling)



CZIL = 0.5 default WRF/Noah



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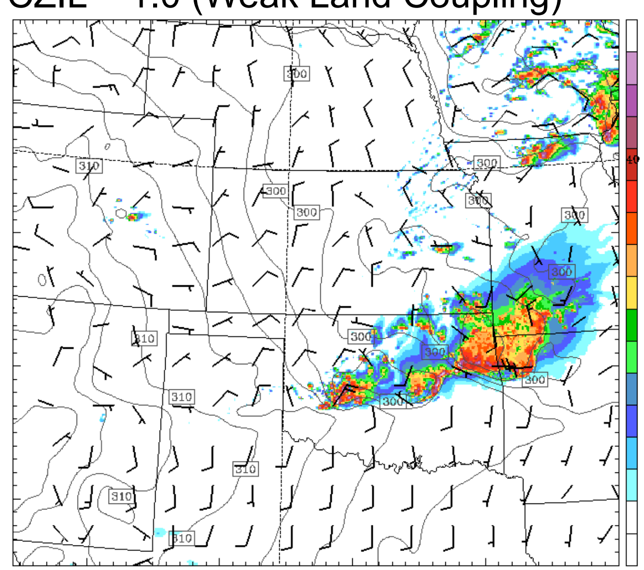
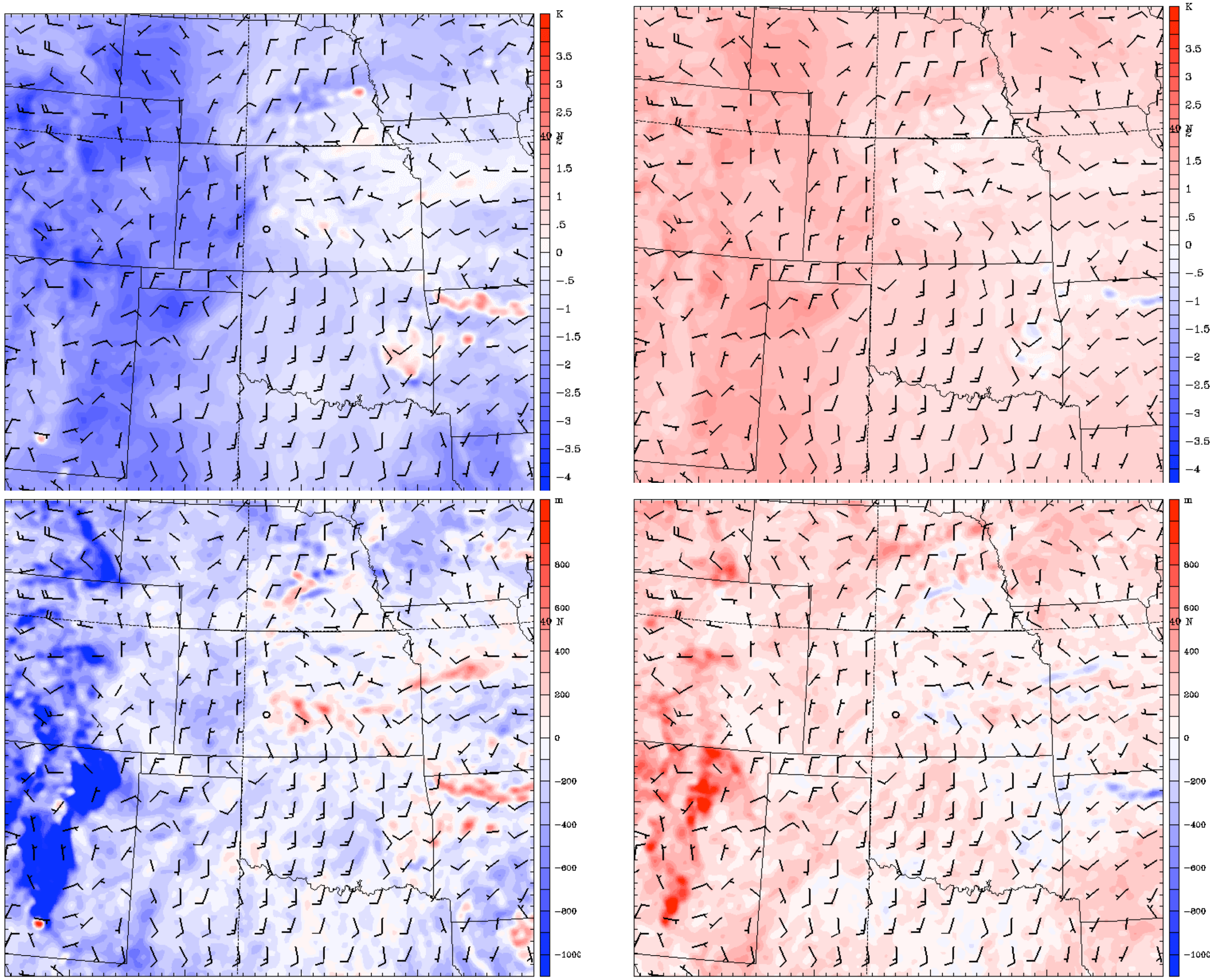


Day Three Case Study at 1800 UTC 12 June (t = 6 h)

Ref - More coupling | Ref - Less coupling

Sfc Theta

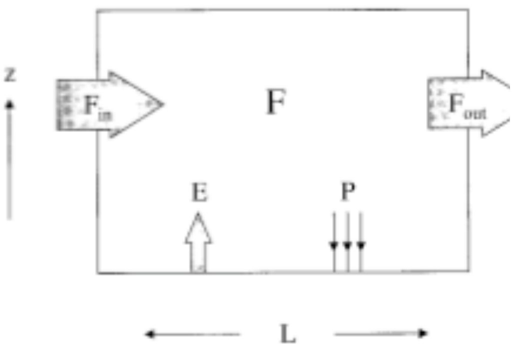
PBL Height

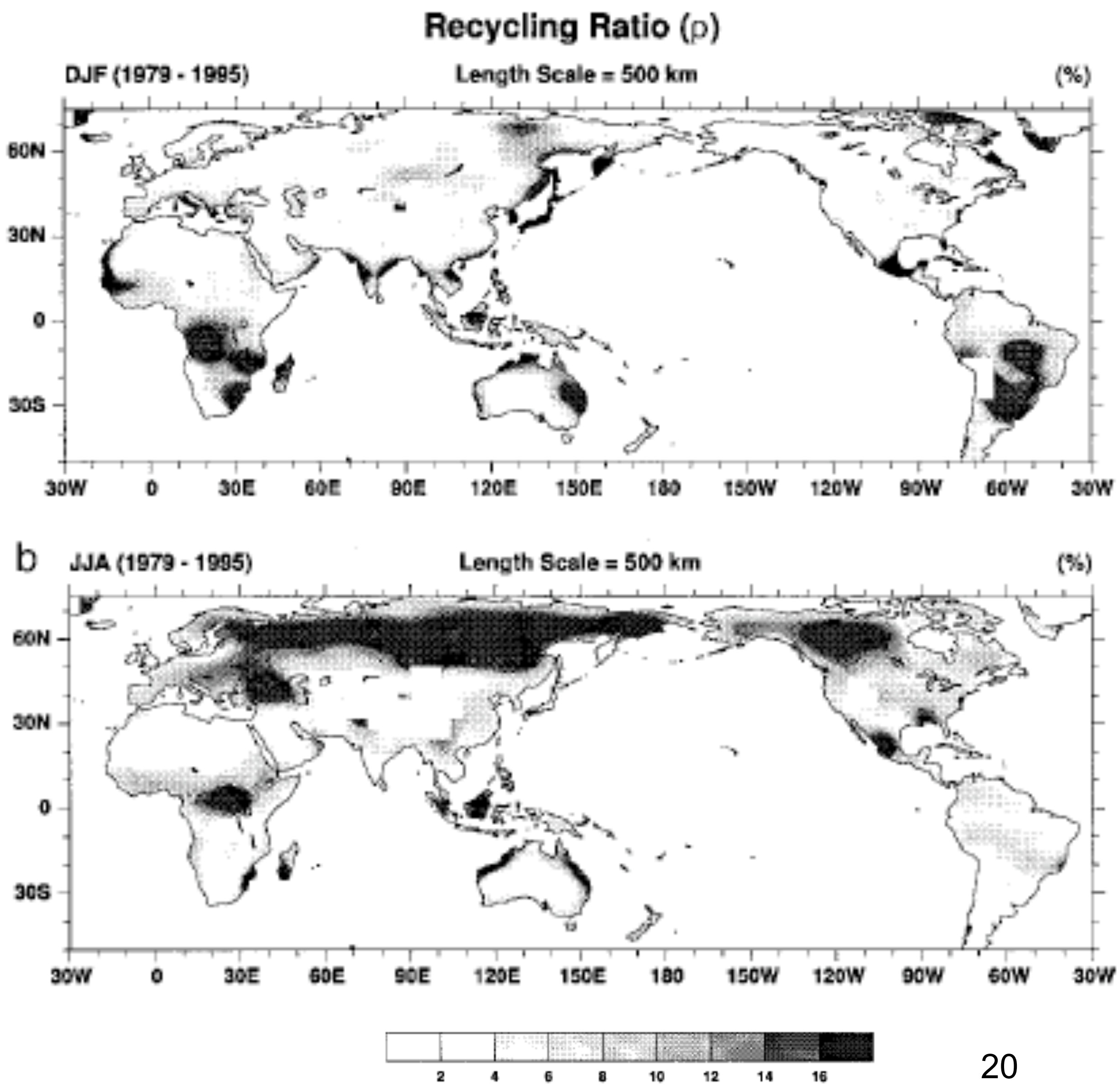


Summary

- LSM problems: overestimate (underestimate) Ch for short (tall) vegetation. These may lead wrong land-atmospheric feedback in coupled weather and climate models.
- The diurnal cycle and amount of a 6-day summer precipitation is sensitive to the treatment of land-atmospheric coupling.
- Strong coupling resulted in deeper PBL depth, early triggering, and somewhat-too-long duration.
- However, less coupling does not provide sufficient PBL development to trigger convection in high plains.
- It's impact on climate model precipitation needs to be investigated.

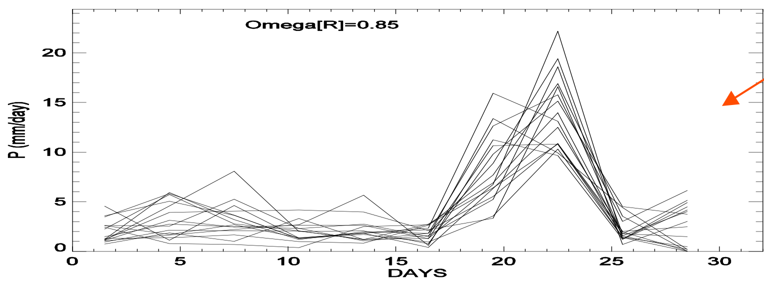
Global recycle ratio





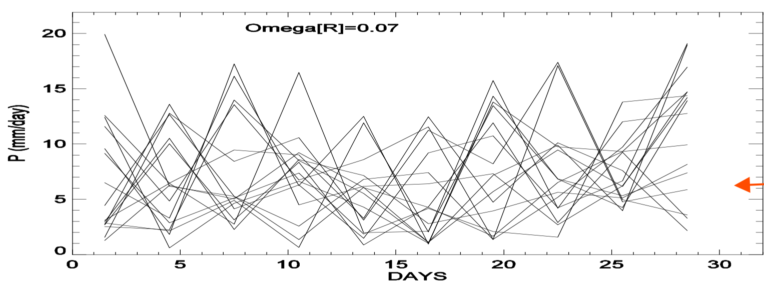
Trenberth, J.Climate, 1999

Soil-Precipitation Coupling Strength



All simulations in ensemble respond to the land surface boundary condition in the same way

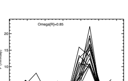
→ strong coupling



Simulations in ensemble have no coherent response to the land surface boundary condition

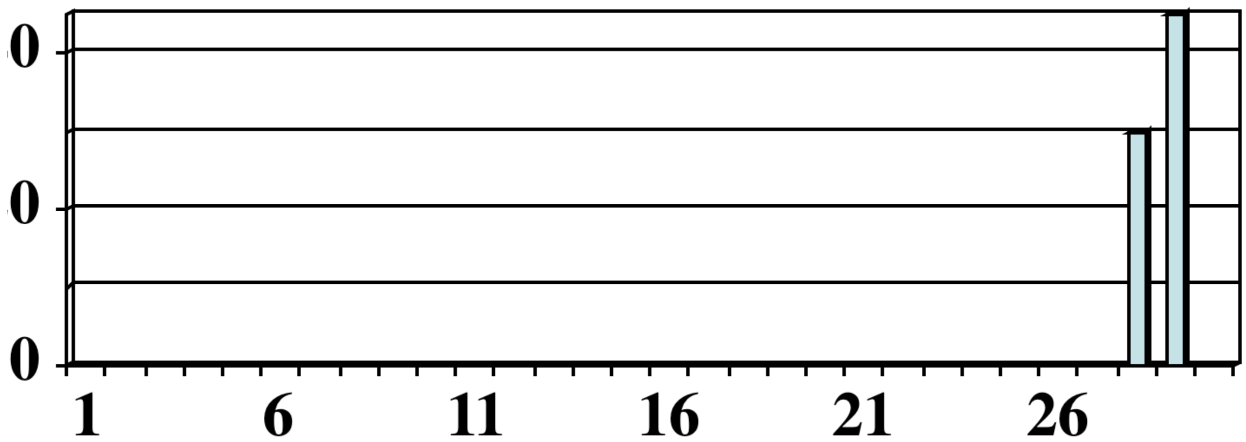
→ weak coupling

Koster et al, 2004, Science



Daily Precipitation at 2 stations: both having 75 mm total

A



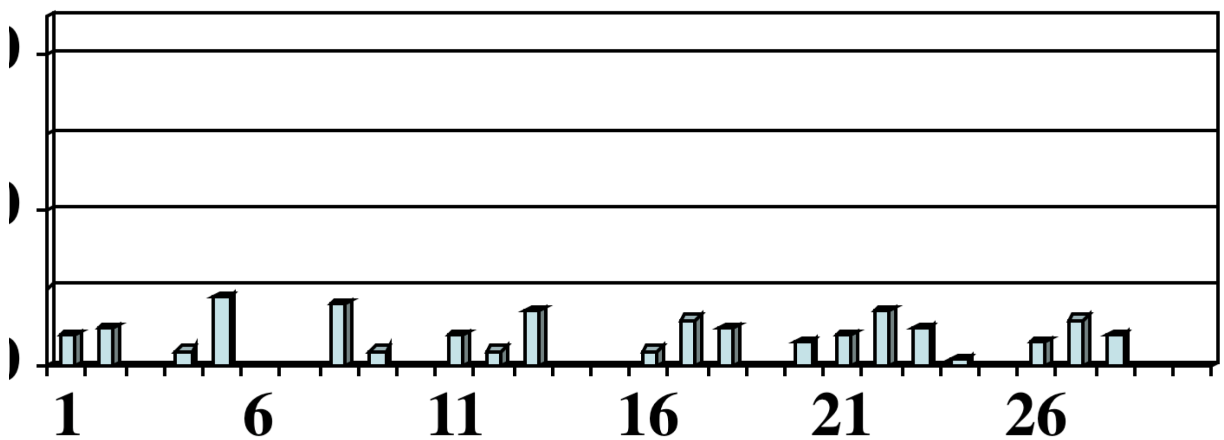
Frequency 6.7%
Intensity 37.5 mm

drought
wilting plants

wild fires

local
floods

B



Frequency 67%
Intensity 3.75 mm

soil moisture replenished
virtually no runoff