Land-Atmospheric Coupling Strength

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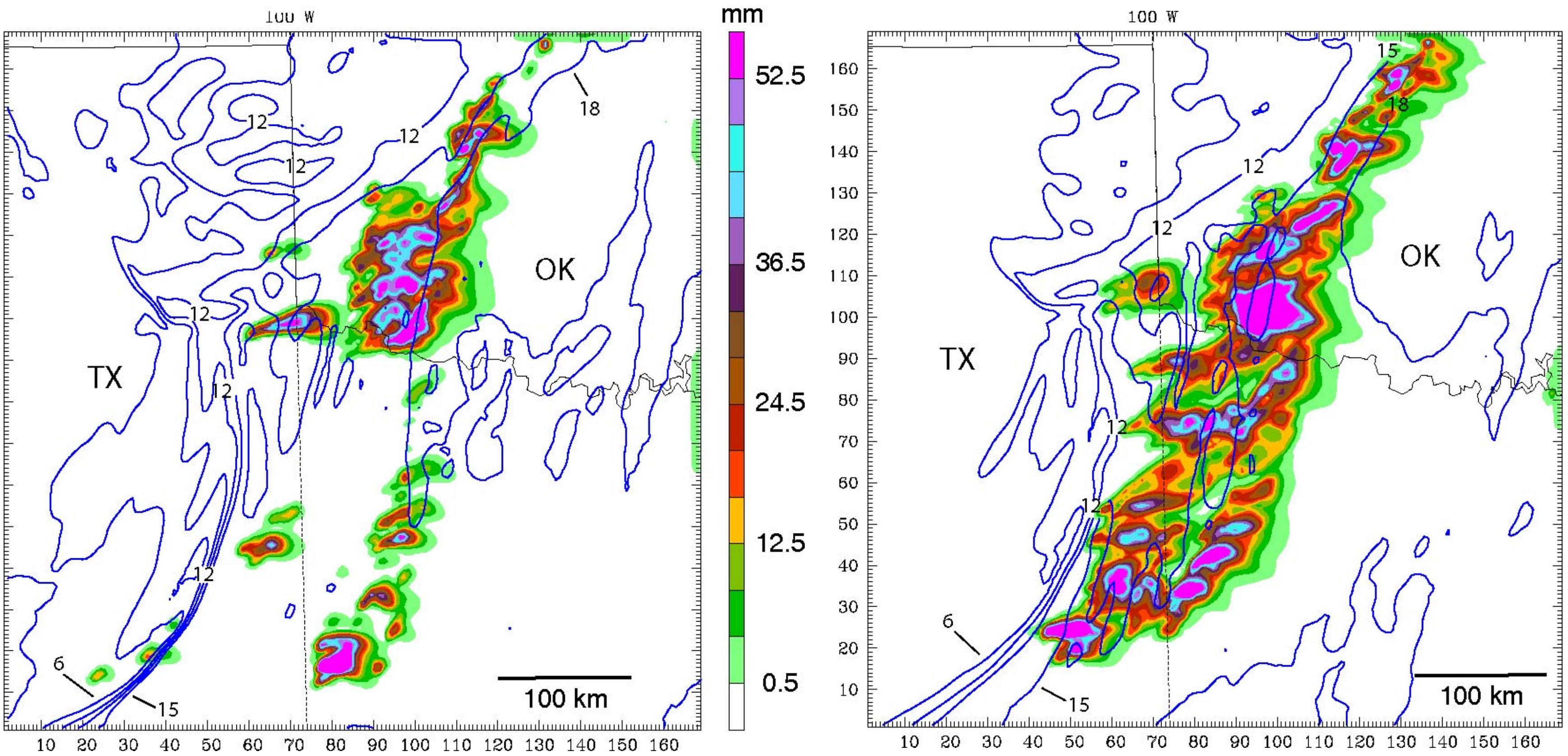
Land-Atmospheric Feedback May Hold the Key for Improving Weather and Climate Predictability

Regional weather and climate prediction: Beljaars et al., 1996; Paegle et al. 1996; Chen et al., 2001; Trier et al., 2004; Holt et al., 2006; Trier et al., 2008; etc.

(a) MM5 initialized with EDAS soil fields **(b) MM5 initialized with HRLDAS soil fields**

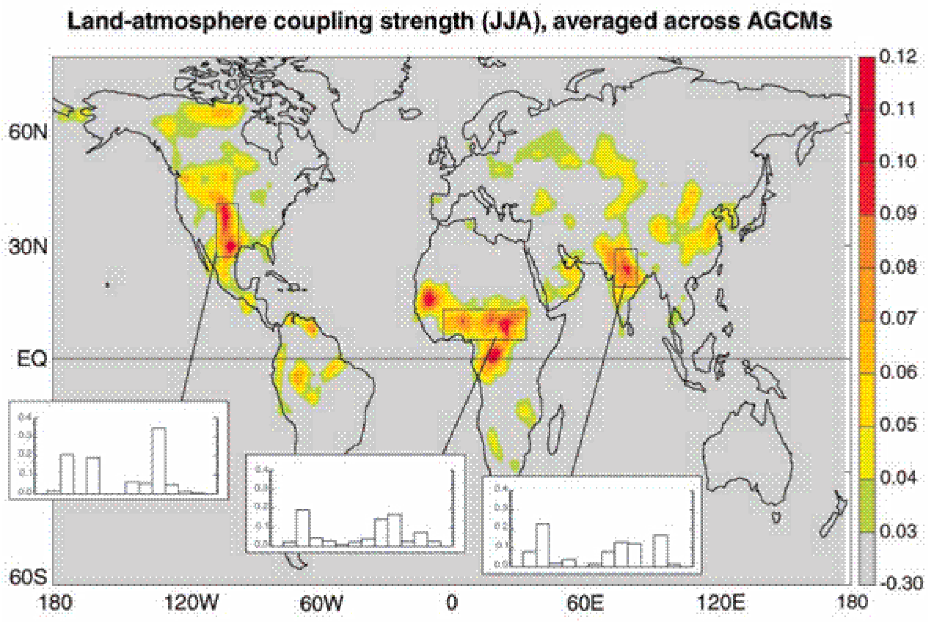


Simulation with EDAS soil fields put TX convection in wrong area (Trier, Chen, and Mannng, 2004, MWR)

- Findell and Eltahir (2003) analyzed soil moisture – precipitation feedback, using atmospheric sounding of 6:00 am and a simple land-PBL model
- Negative feedback: dry soils favoring convection
  - Drive PBL to reach LCL
- Positive feedback: wet soil favoring convection
  - Build up of MSE to trigger convection

Global Scale

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?
- How does the Noah land model represent such coupling?

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

Approach

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

$$SH = \rho C_p C_h |U_a| (\theta_s - \theta_a) \quad LE = \rho C_p C_h |U_a| (q_q - q_a)$$

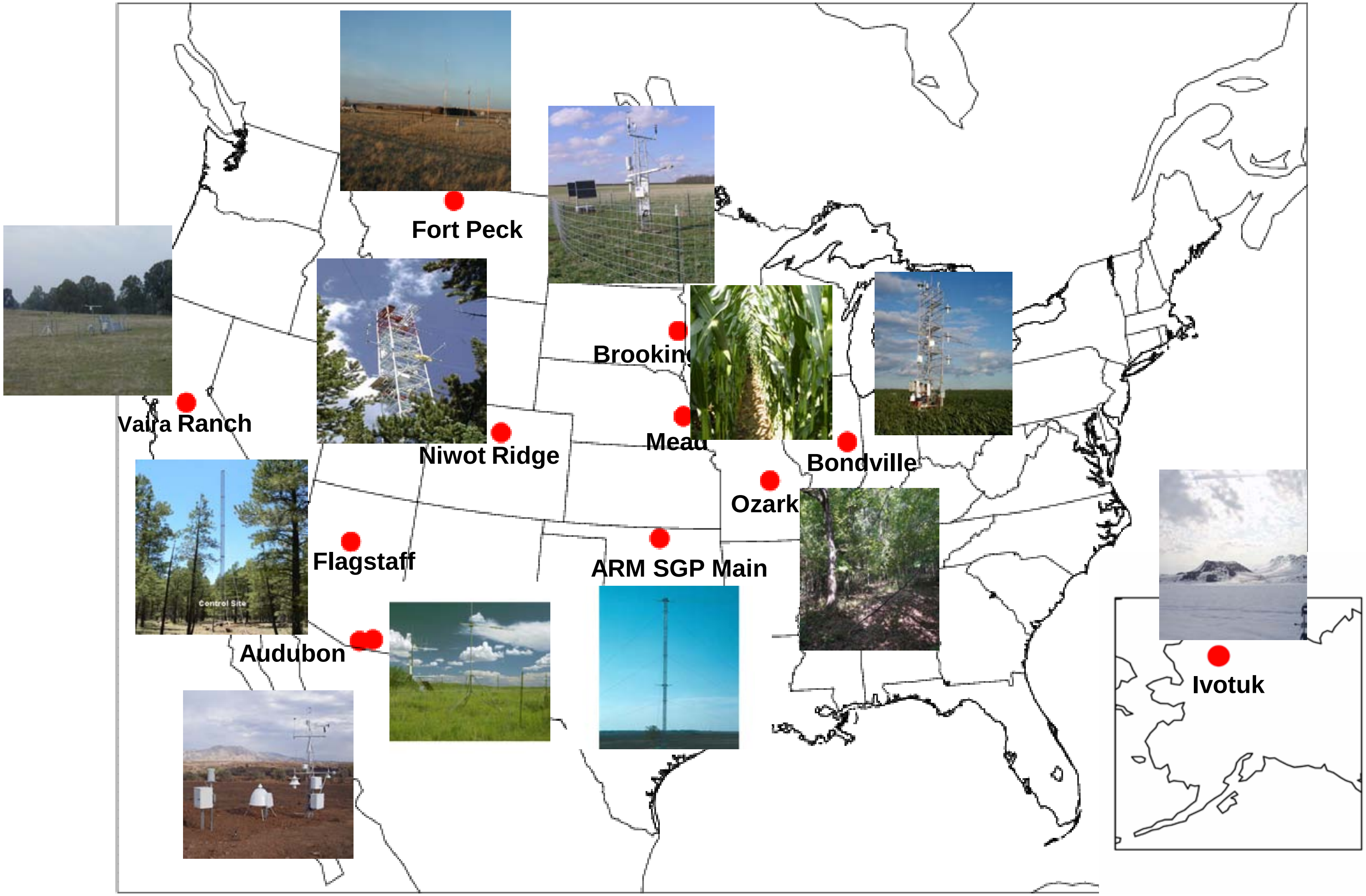
$$C_h = \frac{H}{\rho c_p |u_a| (\theta_s - \theta_a)}$$

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

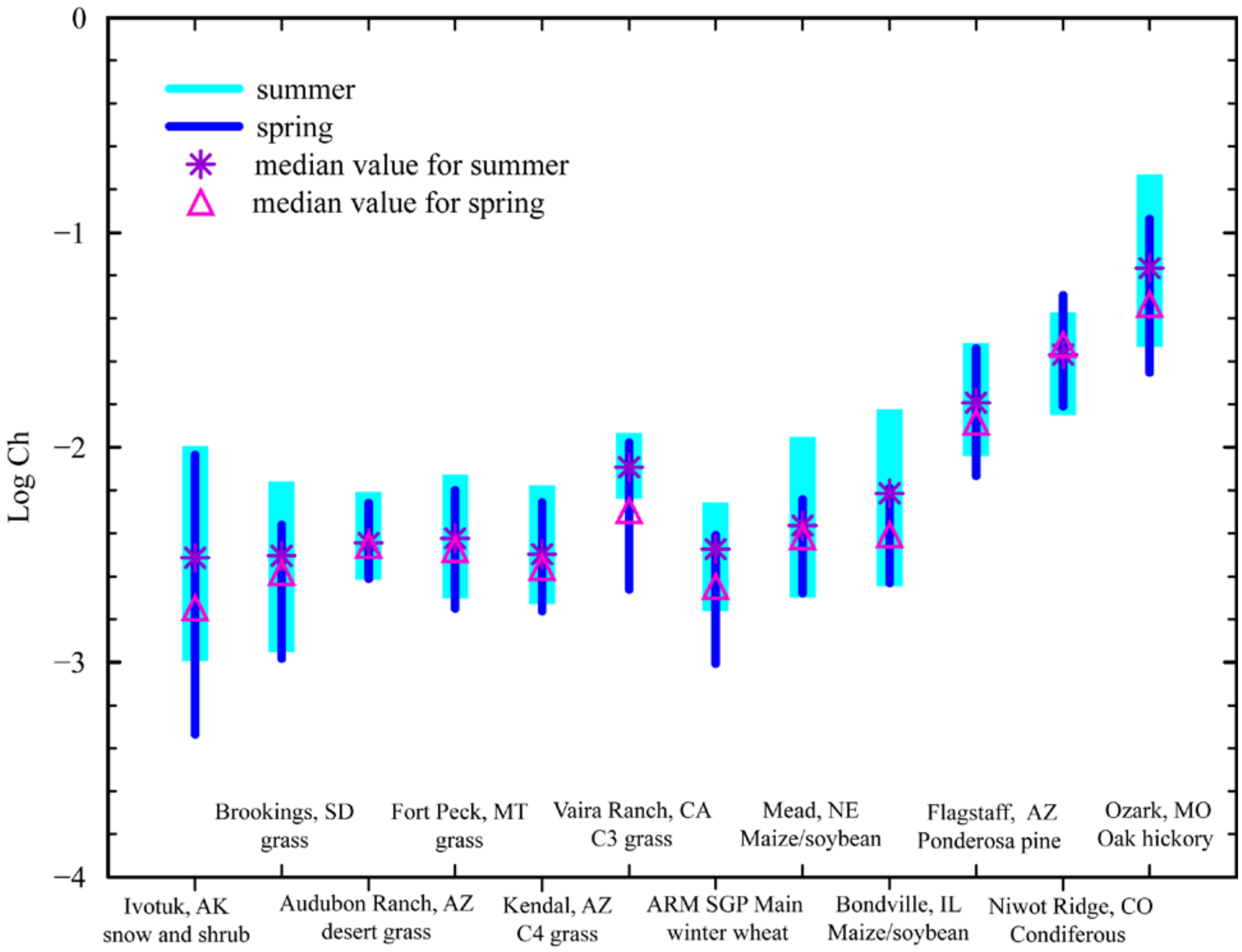
Keep in mind

- 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

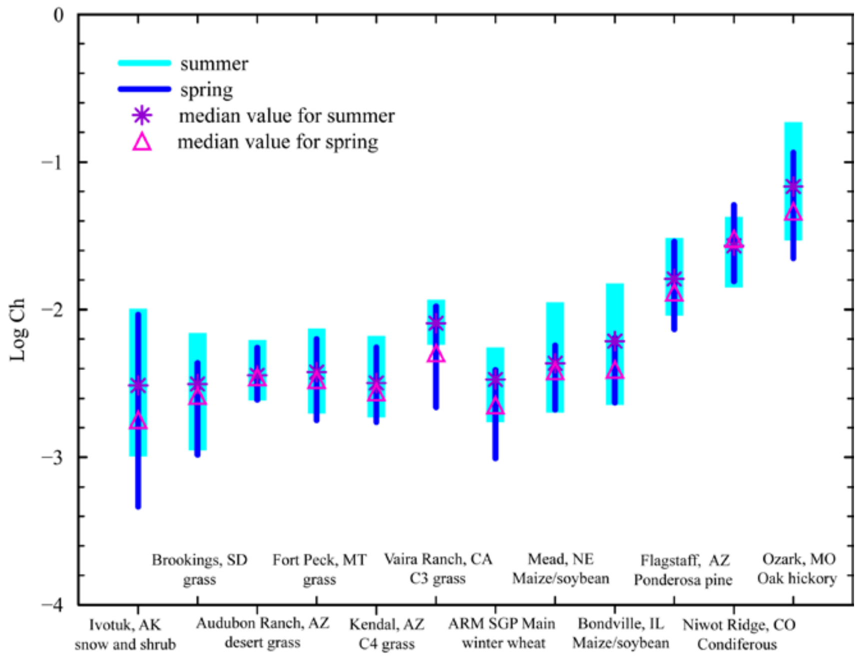


Higher C_h (strong coupling) for tall vegetation (forests)

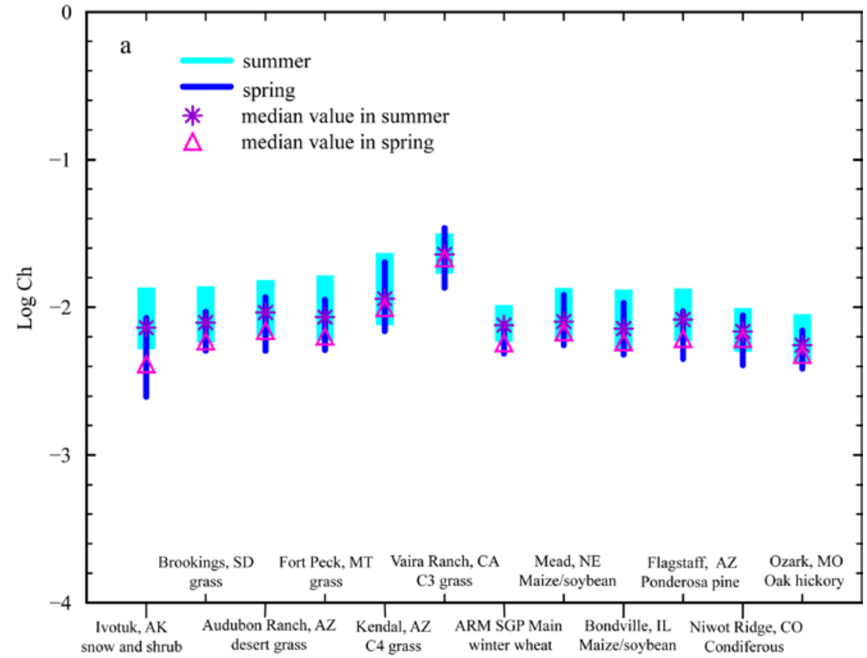
Summer C_h is slightly higher than spring values

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).

C_h formulation in Noah

Based on Monin-Obukhov similarity theory

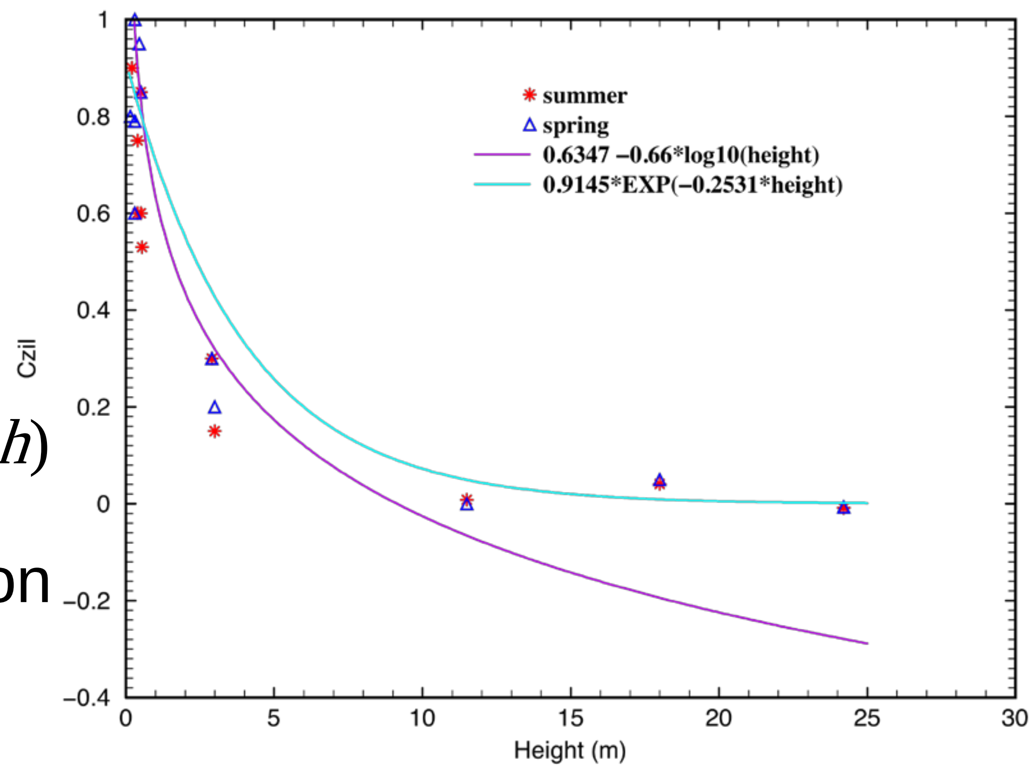
$$C_h = \frac{k^2 / R}{\left[\ln\left(\frac{z}{Z_{om}}\right) - \Psi_m\left(\frac{z}{L}\right) + \Psi_m\left(\frac{Z_{om}}{L}\right)\right]\left[\ln\left(\frac{z}{Z_{ot}}\right) - \Psi_h\left(\frac{z}{L}\right) + \Psi_h\left(\frac{Z_{ot}}{L}\right)\right]}$$

Using Zilitinkevich scheme to calculate

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

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).

Alternatives



1) Zilitinkevich scheme

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

Here $C = 0.92 \exp(-0.25h)$

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

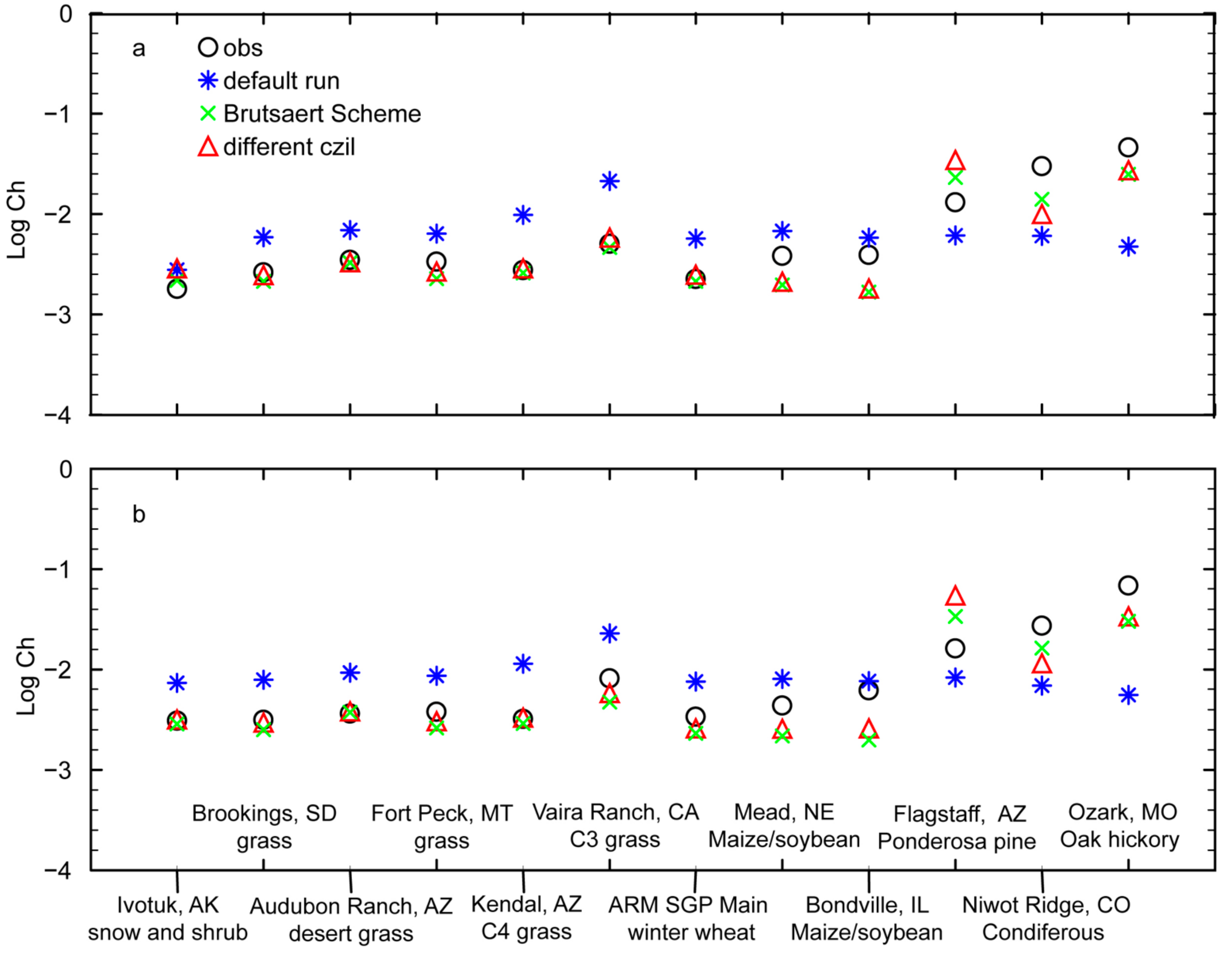
2) *Brutsaert Scheme*

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

Alternatives



Observations; Noah results with the default C=0.1

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

Summary

- Observations show larger Ch and thus stronger coupling for tall vegetation than that for short vegetation.
- LSM problems: overestimate (underestimate) Ch for short (tall) vegetation. Imply that they may overestimate evaporation for US Great Plains.
- These may lead wrong land-atmospheric feedback in coupled weather and climate models.
- But they can be improved by modest changes in the treatment of roughness length for heat.