# *Land-Atmosphere Interaction*

## *(and Cloud Formation)*

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# ***NOAA Center for Weather and Climate Prediction*** *(NCWCP), College Park, Maryland, USA*

# *Outline*

- Motivation
- Land-atmosphere interaction
- Near-surface interactions
- Land-PBL interactions
- Summary

# ***Motivation***

- **Land-atmosphere interaction** and coupling strength remain weak links in current land-surface and atmospheric prediction models.

- Coupling strength affects surface fluxes, so important for weather and climate.

- We need to understand the many land and atmospheric processes and interactions, with proper representation in weather and climate models.

- ***Coupling begins locally***.

# *Land-Atmosphere Interaction*

*Betts (1996)*

Diurnal timescales

Seasonal timescales

Century…

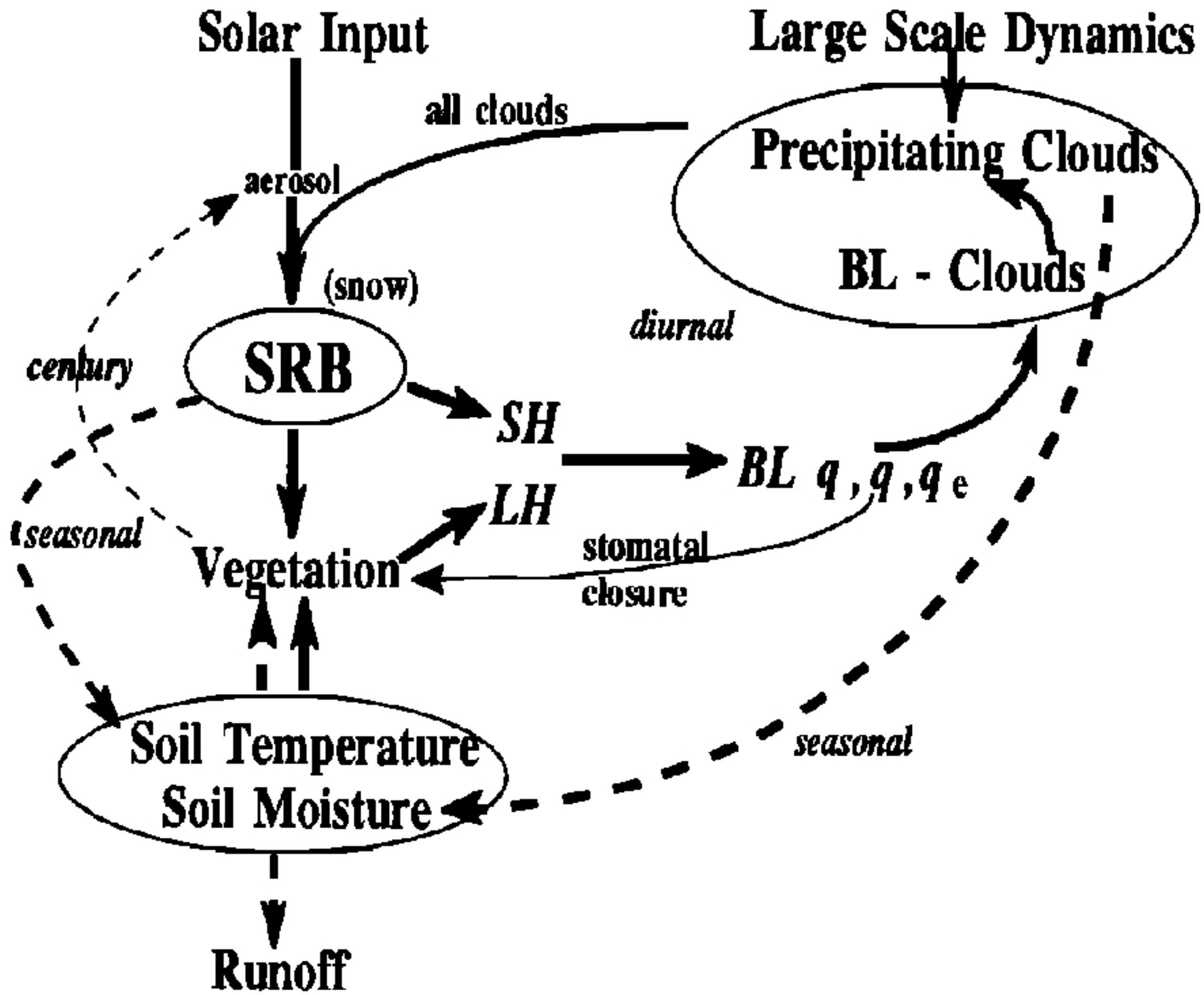



**Figure 1.** Schematic showing some important land surface-atmosphere interactions on different timescales.

# *Land-Atmosphere Interaction*

*Beljaars (2005)*

EC model/ TESSEL

"We discussed including this in a recent document, but dropped it because it was too confusing."

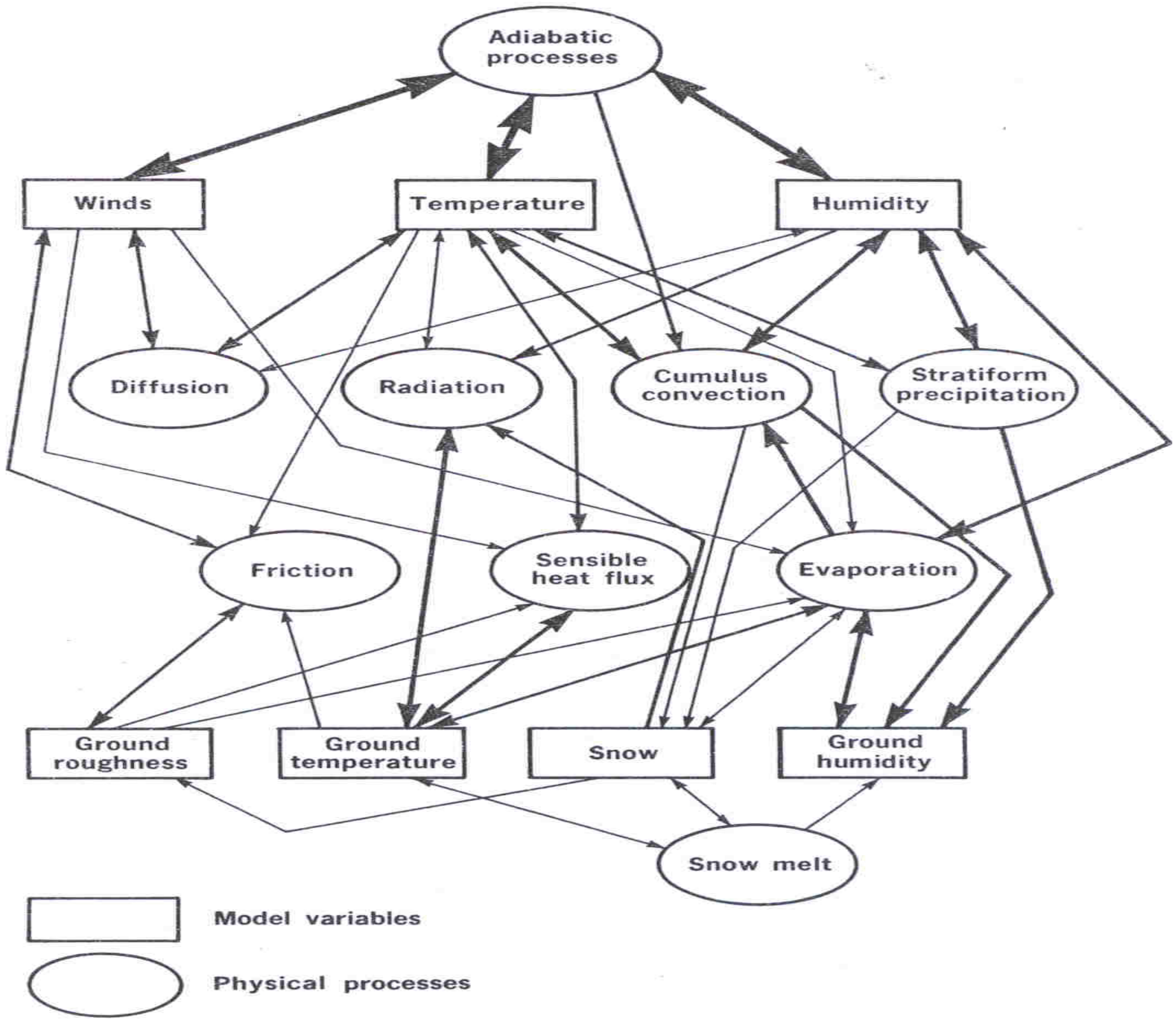
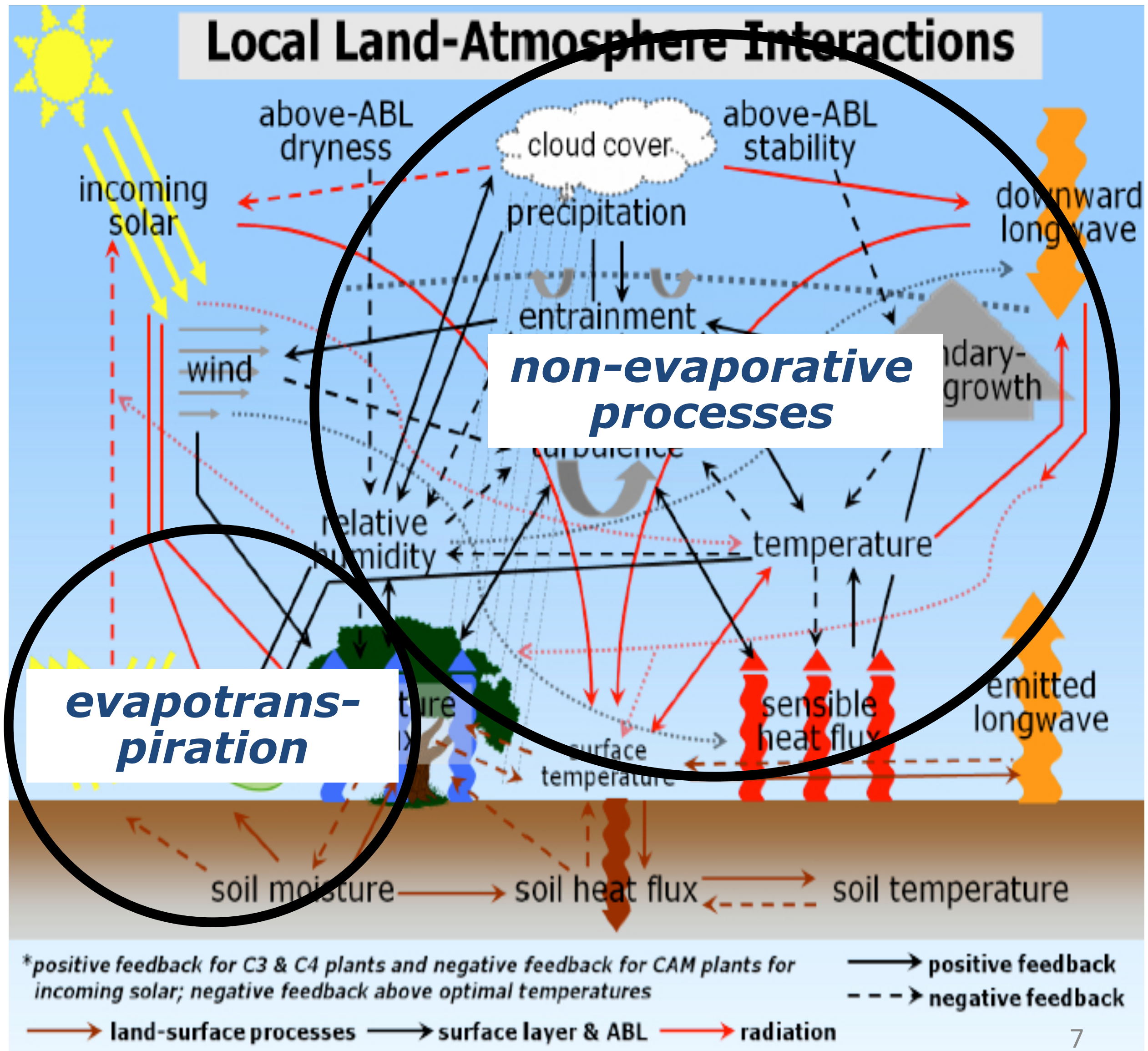



Fig. 1.1 Schematic representation of the processes included in the ECMWF model.

# *Land-Atmosphere Interaction*

Adapted from *Ek & Holtslag (2004)*

Characterized many land and atmospheric processes and feedbacks for typical daytime with focus on soil moisture vs other processes.




*"GEWEX Imperatives: Plans for 2013 and Beyond"* (gewex.org)

# *Land-Atmosphere Interaction*

*van Heerwaarden et al (2009)*

Negative feedback mechanisms and the relationships among variables that regulate evaporation.

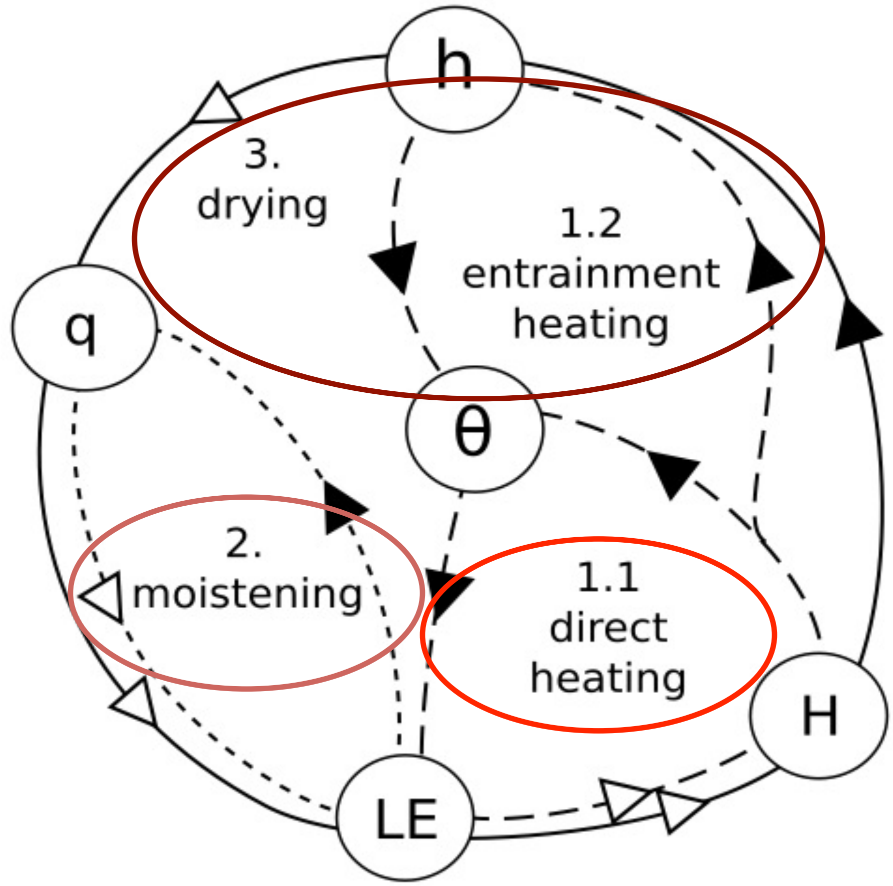
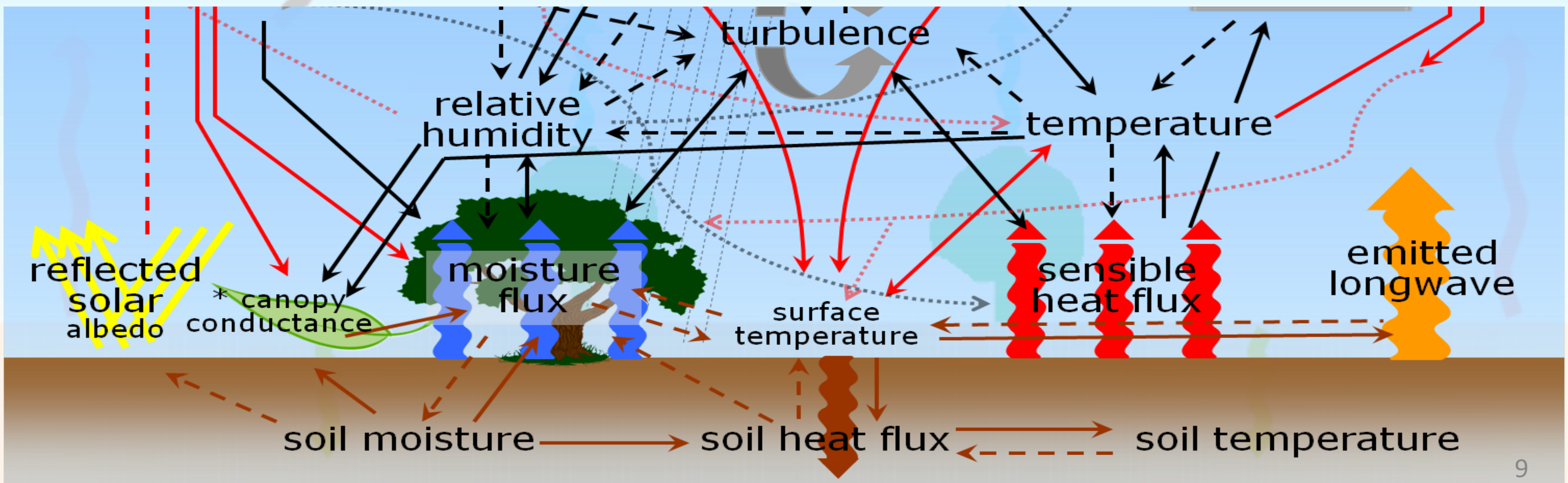



Figure 1. Feedbacks in the coupled land–atmosphere system. Closed arrows represent positive relationships, and open arrows negative relationships. Each of the three feedbacks has a distinct line style. *LE* is the latent heat flux, *H* is the sensible heat flux, $\theta$ is the bulk potential temperature of the CBL, $q$ is the bulk specific humidity of the CBL and $h$ is the CBL height.

# *Near-Surface Interactions*

- What is nature of ***near-surface*** land-atmosphere coupling? For strong (weak) coupling, a given soil moisture change yields large (small) ET change.
- What is relationship between soil moisture and ET (or *ef*) in terms of near-surface turbulence, atmospheric variables, vegetation and soil processes.
- Expand work of Jacobs et al (2008), Jarvis (1985) et al, and others.



# *Near-Surface Interactions:*

## Soil moisture – transpiration relationship

**Evaporative fraction for transpiration:**

$$ef_t = \frac{s + \frac{\rho c_p g_a \delta e}{R_n - G}}{s + \gamma\left(1 + \frac{g_a}{g_c}\right)},$$

*Penman-Monteith*

**Evap. fraction change with soil moisture change:**

$$\frac{\partial \ln ef_t}{\partial \Theta} = \frac{1}{\delta\Theta_{rz}}\left\{\left[\left(\frac{s+\gamma}{\gamma}\right)\frac{g_c}{g_a} + 1\right]^{-1} + \left[\frac{s(R_n - G)}{\rho c_p g_a \delta e} + 1\right]^{-1} \frac{\delta\Theta_{rz}}{\Theta_{ns}} \frac{b\beta G}{(R_n - G)}\right\}$$

| | ga/gc-term: stomatal control vs sfc-layer turbulence, range: 0-1 (J08, J85) | vG-term: soil heat flux contribution, 0 to O(1) |
|---|---|---|
| **Stronger Coupling:** | ***Strong stomatal control, strong turbulence, e.g. forest with dry soil*** | ***Strong turbulence, dry air, large G, small Rn, large soil heat flux, wet soil*** |
| **Weaker Coupling:** | ***Weak stomatal control, weak turbulence, e.g. grassland with wet soil*** | ***Weak turbulence, moist air, small G, large Rn, small soil heat flux, dry soil*** |

# *Near-surface Interactions:*

## Vegetated

**Stronger Coupling**

***"ωv" coupling parameter***
***= ga/gc + vG terms***

*Additional factors:*

- T ↑ RH ↓ Rn ↓ → ωv ↑
- forest > grass
- sand > clay
- *ga/gc term >> vG term (generally)*

***Fluxnet Data Sets with good soil moisture measurements***

**Weaker Coupling**

strong

TURBULENCE

weak

dry

**SOIL MOISTURE**

wet

# *Near-Surface Interactions:*
## Evaporative Fraction vs Soil Moisture

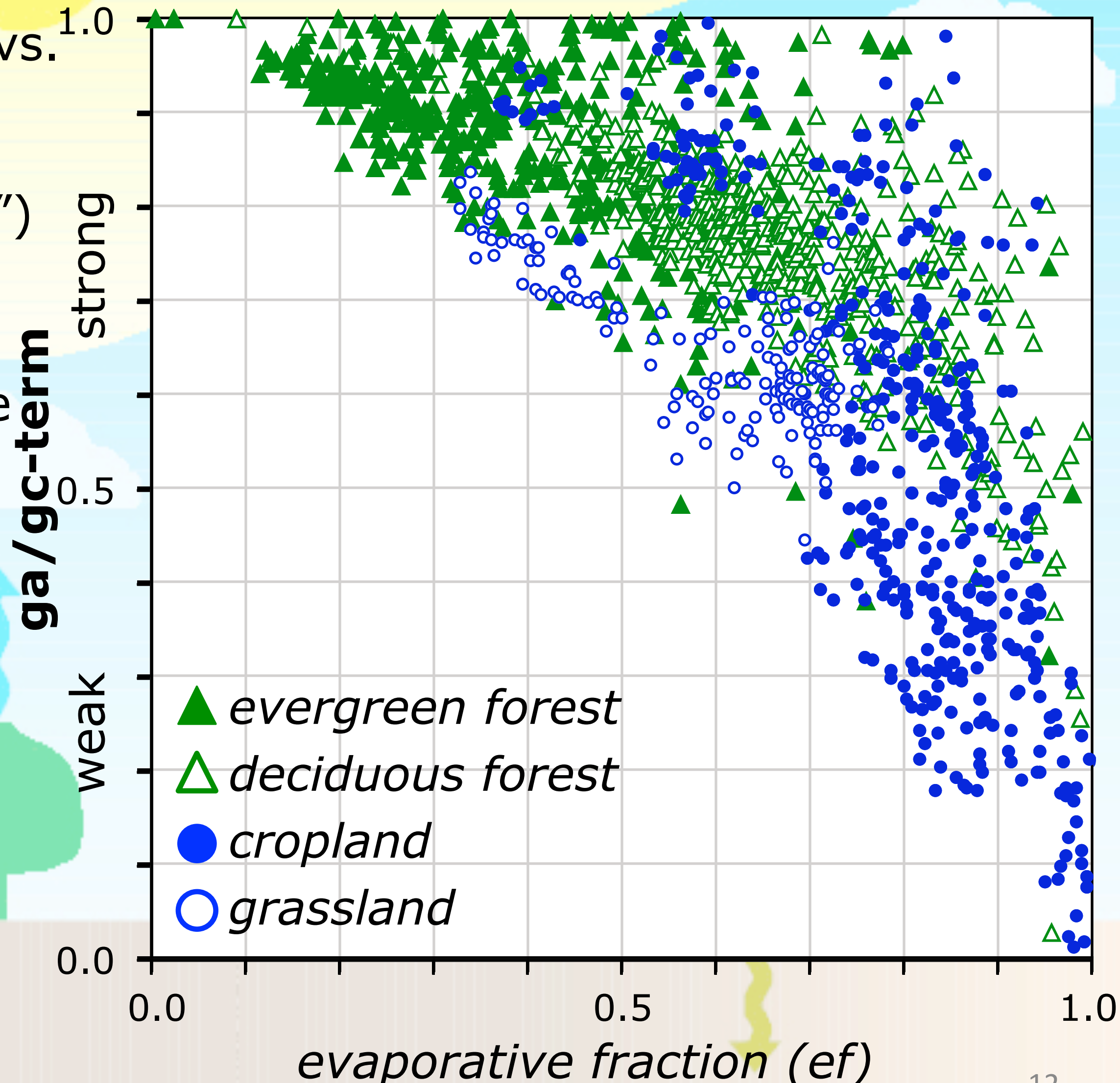
- evaporative fraction (ef) vs. **ga/gc-term** (coupling strength) from surface flux site observations ("Fluxnet")

- higher ef:

- stronger land-atmosphere coupling for forests.

- weaker land-atmosphere coupling for cropland and grassland.

- lower ef: strong coupling regardless of vegetation type: due to stronger surface heating and turbulence (larger ga, smaller gc).




***Need to include vG-term***

# *Near-Surface Interactions:*

## Soil moisture – “bare” soil evap relationship

**Evap. frac. for bare soil evaporation:**
**(can’t use Ed=f(Θ)Ep)**

$$ef_d = \frac{\rho_w L_v}{R_n - G}\left[\frac{\delta\Theta_{ns}}{\delta z} D_\Theta + K_\Theta\right]$$

*Mahrt & Pan (1983)*

**Evap. fraction change with soil moisture change:**

$$\frac{\partial \ln ef_d}{\partial \Theta} = \frac{1}{\Theta_{ns}}\left\{\frac{[\Theta_{ns} + (\beta+2)\delta\Theta_{ns}]\, s_\Theta + (2\beta+3)}{1 + \delta\Theta_{ns}\, s_\Theta} + \frac{b\beta G}{R_n - G}\right\}$$

**Θ-term: soil hydraulic properties contribution**

**bG-term: soil heat flux contribution**

**Stronger Coupling:** ***Wet soil*** — ***Large soil heat flux, small Rn, wet soil***

**Weaker Coupling:** ***Dry soil*** — ***Large Rn, small soil heat flux, dry soil***

# *Near-surface Interactions:*

"Bare" soil

***"ωb" coupling parameter=***

***Θ + bG terms***

***Stronger Coupling***

*Additional factors:*

- T ↓ Rn ↓ RH ↓ → *ωb* ↑
- forest > grass (roughness/partial veg cover)
- sand > clay
- Θ term >> bG term (generally)

**strong** ↑ **TURBULENCE** weak

***Weaker coupling***

***Fluxnet Data Sets?***

**dry** → **SOIL MOISTURE** → **wet**

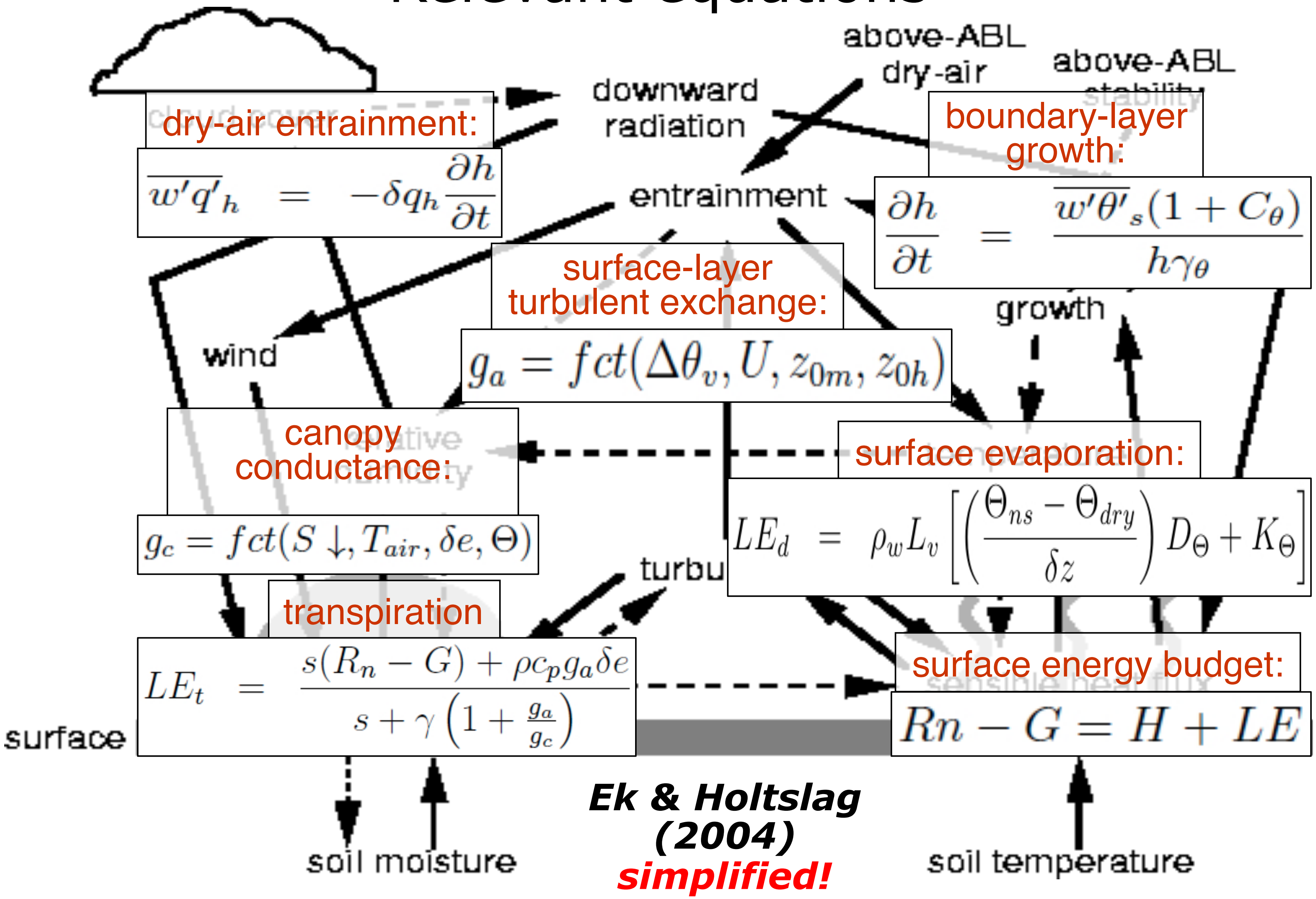
# ***Land-PBL Interaction:*** Cloud Formation

- How does land surface impact onset of Cumulus?
- What is the role of soil moisture and atmospheric processes?
- How to quantify?
- Relative humidity evolution (RH tendency) at the Atmospheric Boundary Layer (ABL) top is expected to control cloud initiation:

$RH = q/q_s$ — *q=specific humidity (g/kg)*; *$q_s$=saturation specific humidity (g/kg)*

# ***Land-PBL Interaction:***

## Relevant equations



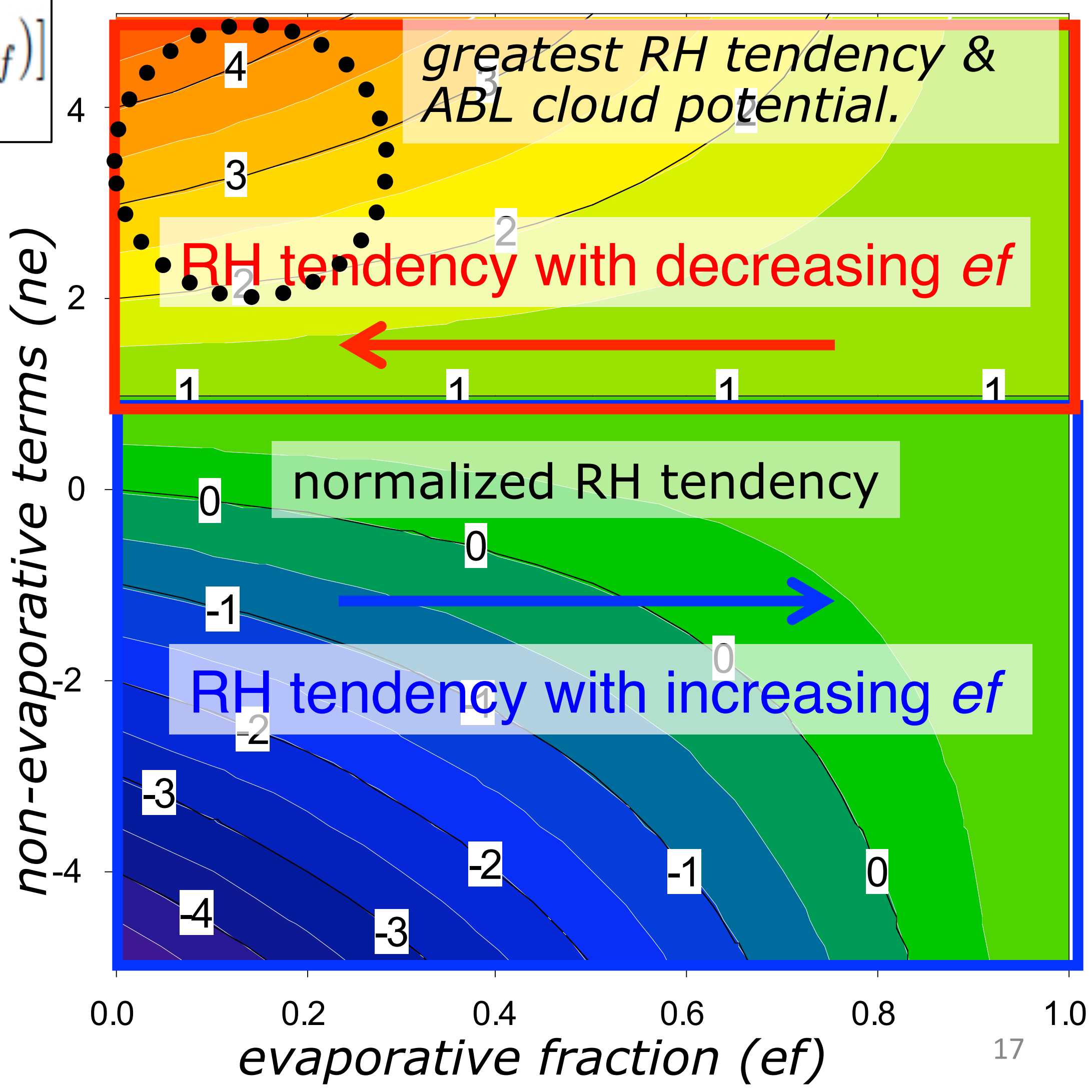
# *Land-PBL Interaction:*
## RH tendency at PBL top

$$\frac{\partial RH}{\partial t} = \left(\frac{R_n - G}{\rho L_v h q_s}\right)\left[e_f + ne(1 - e_f)\right]$$

$$ne = L_v / c_p (1 + C_\theta)\left[\frac{\Delta q}{h\gamma_\theta} + RH\left(\frac{c_2}{\gamma_\theta} - c_1\right)\right]$$

- ABL-growth regime (weaker above-PBL stability & $\Delta$q small)

- surface moistening regime (stronger above-PBL stability and/or $\Delta$q large)



# ***Land-PBL Interaction:***
# Land & PBL processes and RH tendency

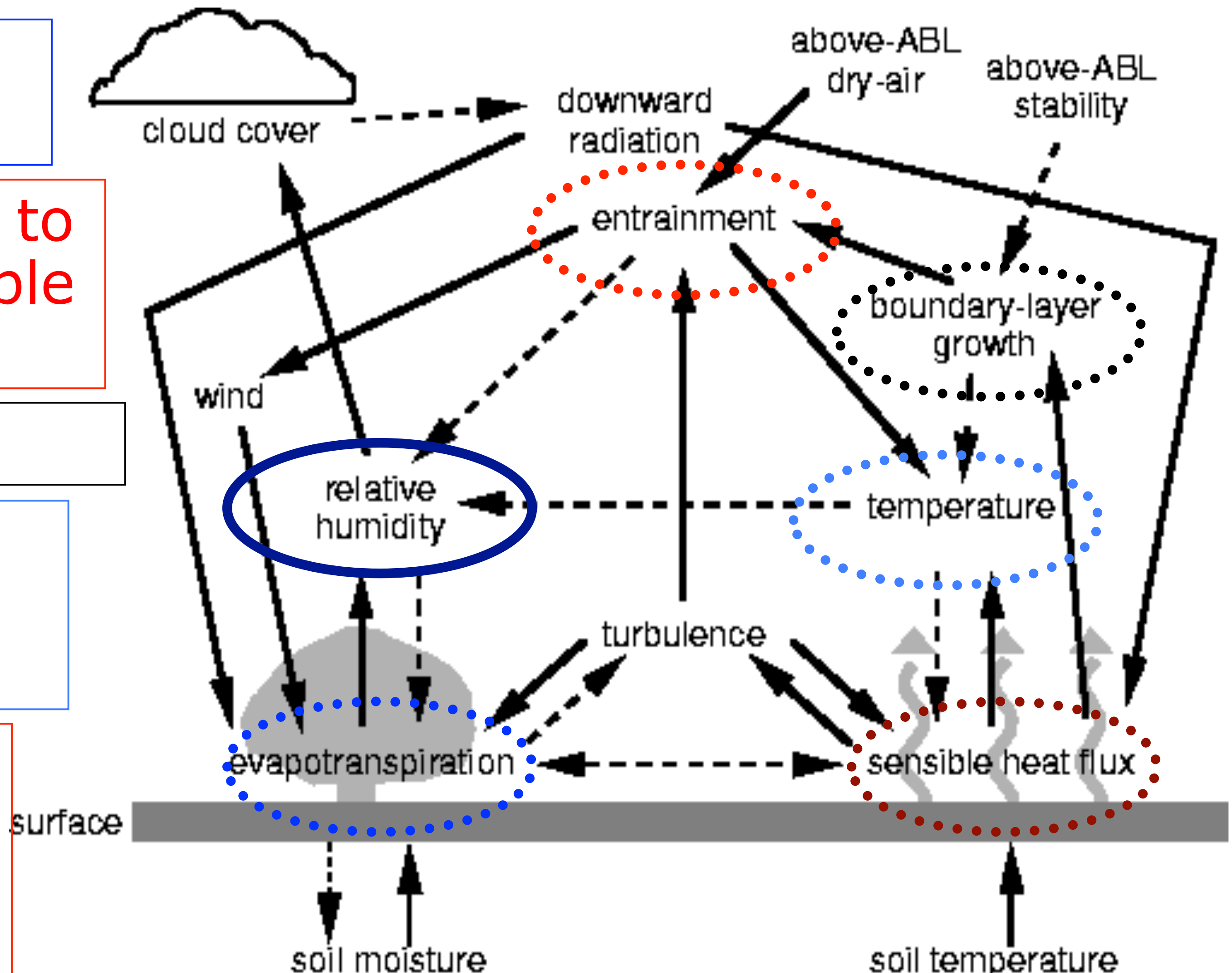
Surface evaporation

Warming due to surface sensible heat flux

ABL growth…

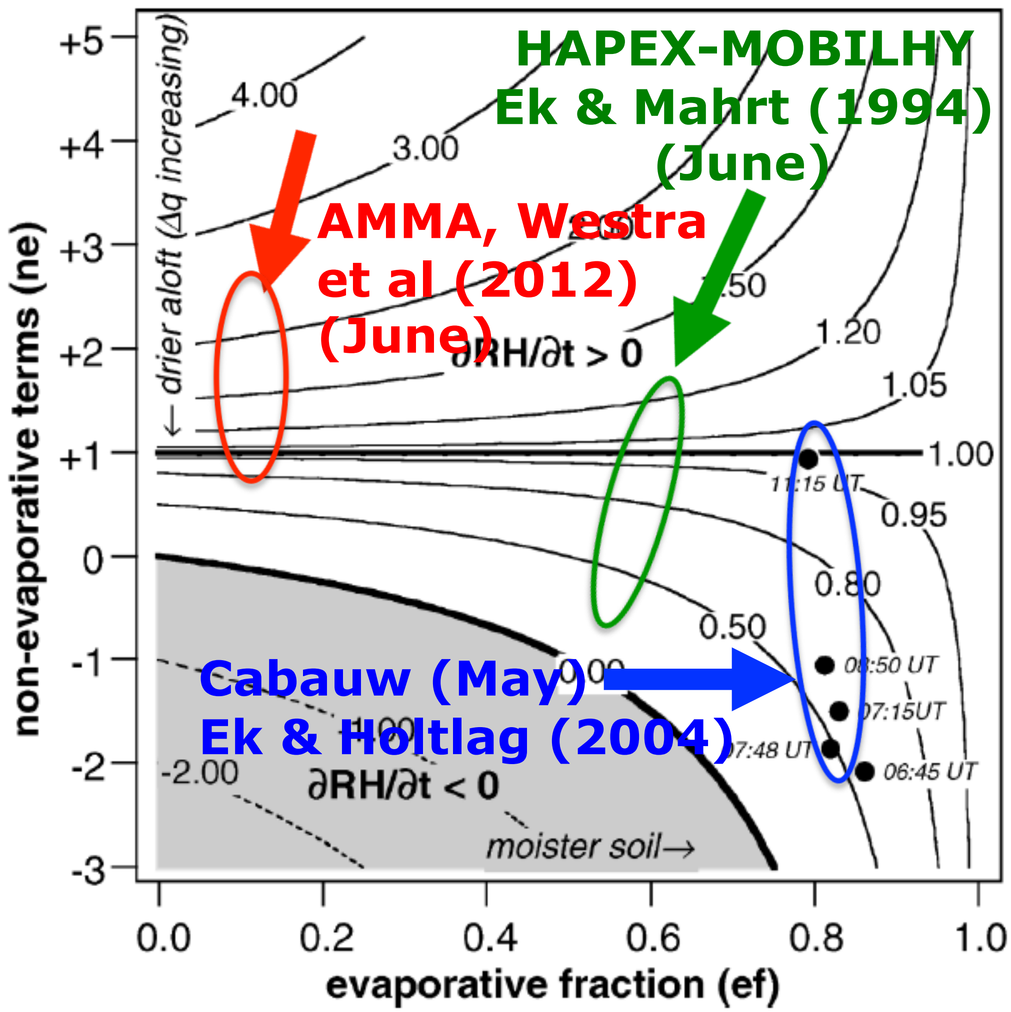
…ABL-top temperature decrease

…ABL-top dry-air & warm-air entrainment



# *Land-PBL Interaction:*
## Observations

- Evaporative fraction ~constant, *ne* increases during day. How general?
- Observed mid-afternoon ABL cloud formation (<20% cover)
- Need to evaluate data sets from more field programs.



# ***Land-PBL Interaction:***

## Sensitivity tests for coupled land-PBL model and cumulus initiation

**weaker inversion**

**stronger inversion**

**dry air**

**moist air**

- Examine role of soil moisture: vary soil moisture from dry to wet,
- Vary inversion strength from weak to strong,
- Vary dry air above dry air above the boundary layer from dry to moist,
- Other tests: different vegetation and soil types, background advection, different regions & seasons.

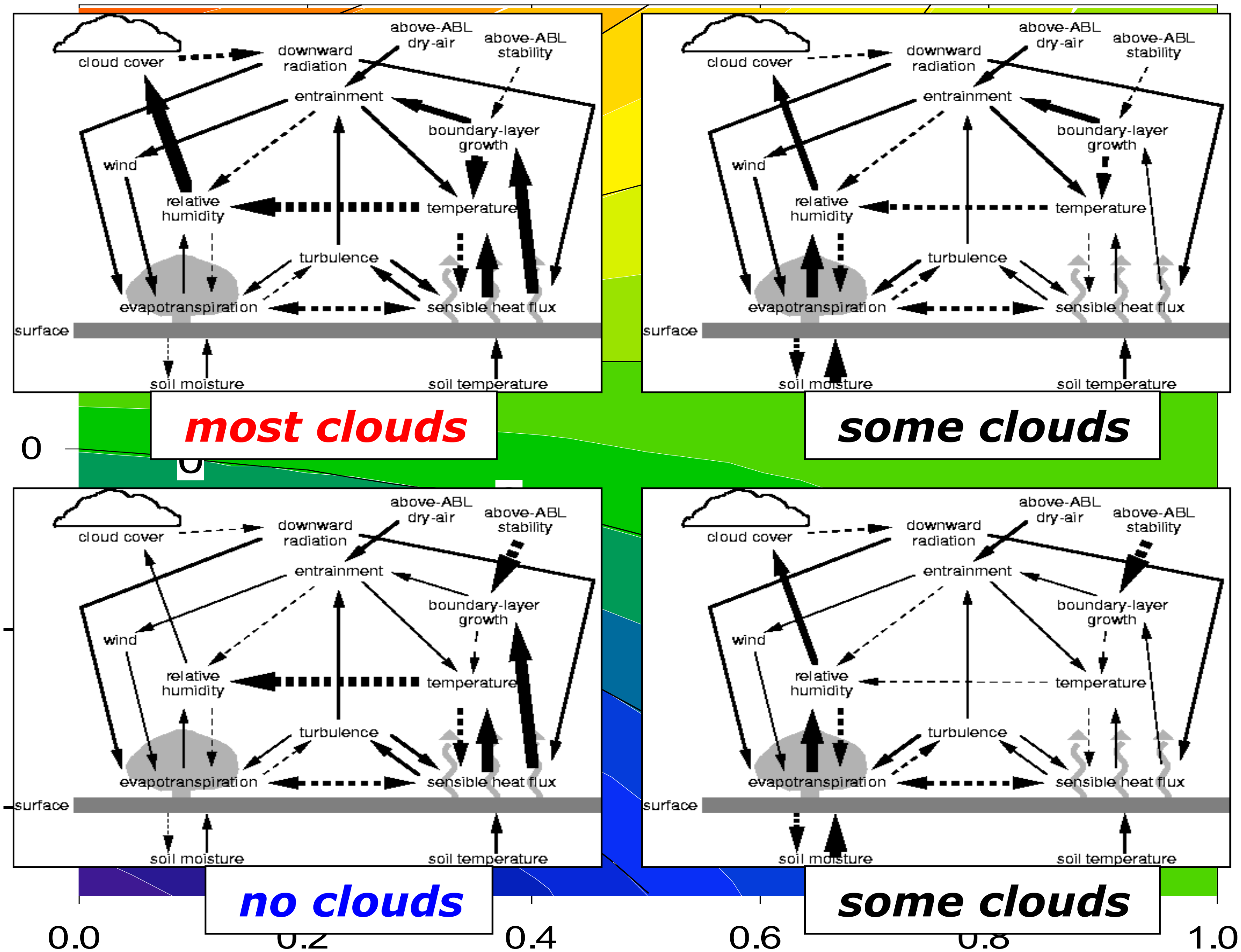
**dry soil**

**wet soil**

# *Land-PBL Interaction:*
## Model sensitivity tests and RH tendency

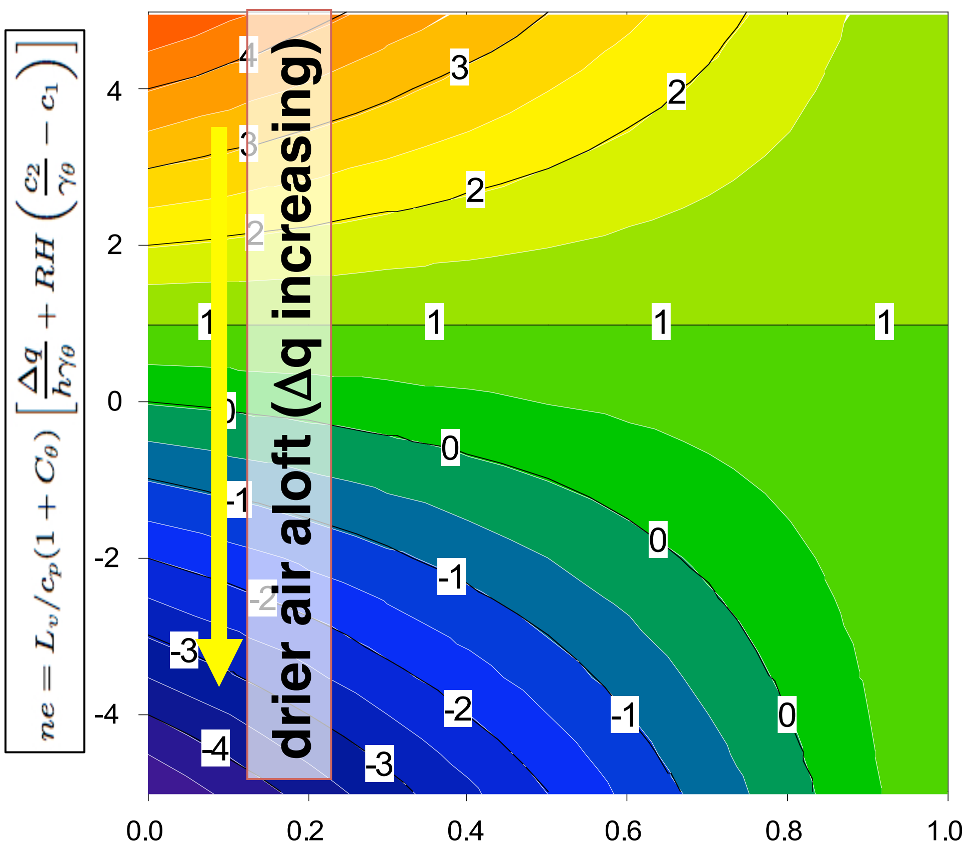
**WEAK ABOVE-ABL STABILITY**

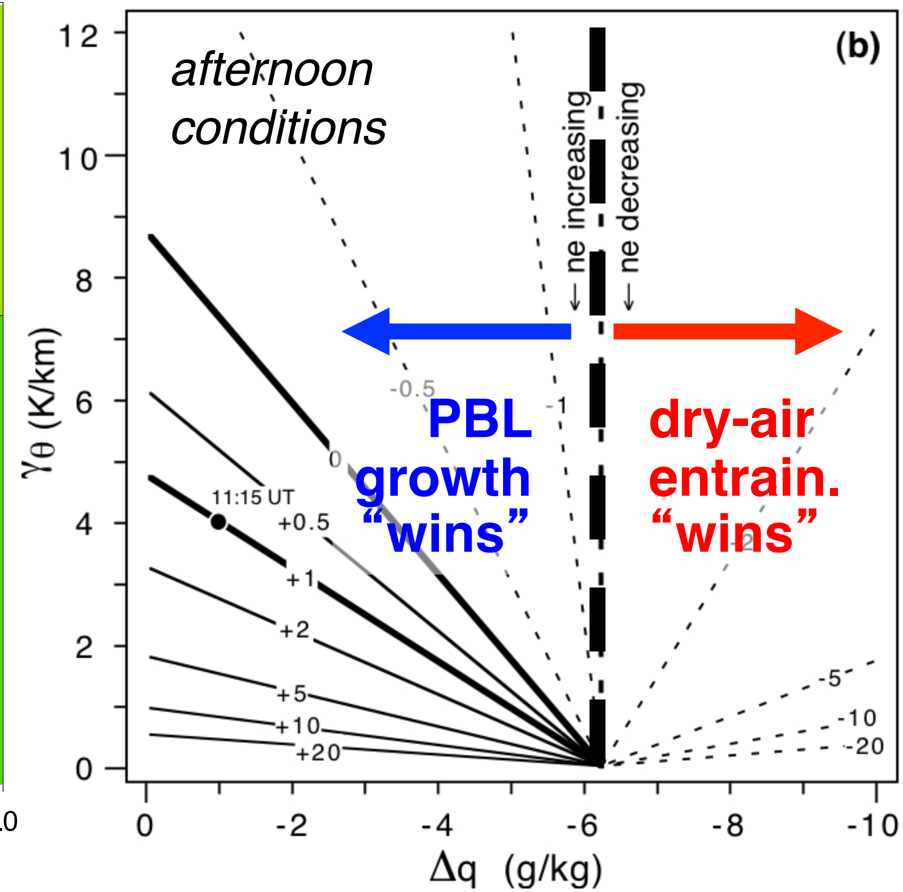
**STRONG ABOVE-ABL STABILITY**




**DRY SOIL** ⟷ **MOIST SOIL**

# *Land-PBL Interaction:*
## Boundary-layer growth vs dry air entrainment




- if $\Delta q$ > critical value (more negative/drier, =fct(h,RH)), then ***ne*** decreases with decreasing above-ABL stability, so dry-air entrainment "wins" over BL growth.

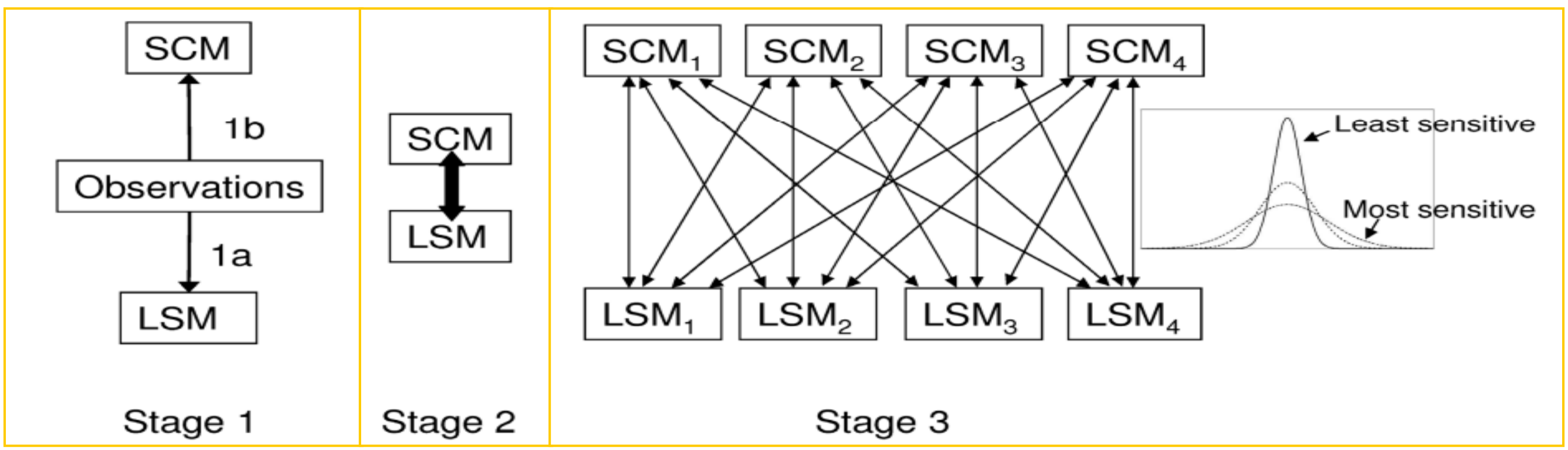
# *Land-PBL Interaction:*

## Diurnal land-atmos. coupling experiment (DICE)

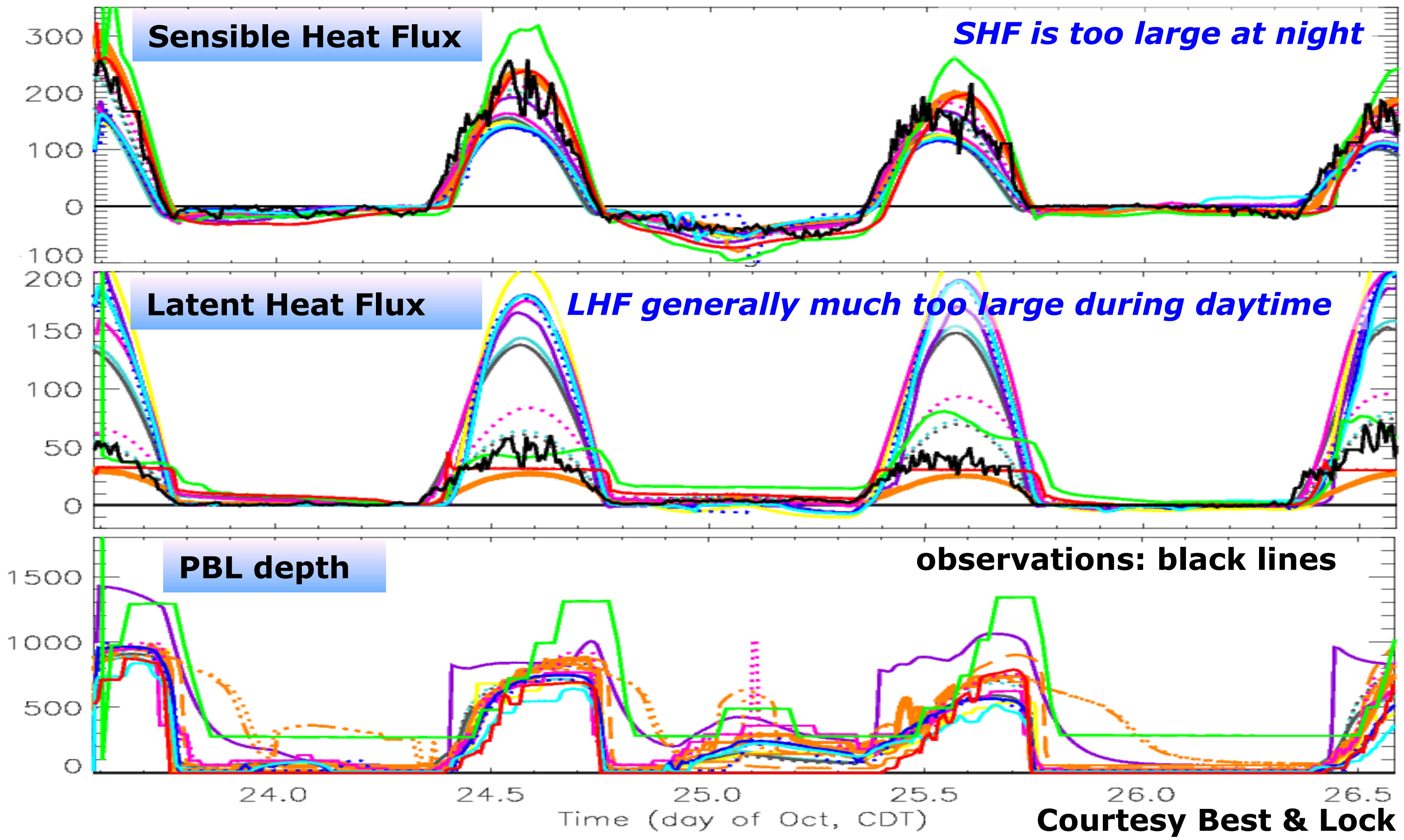
***Objective:*** Assess impact of land-atmosphere feedbacks.
Stage 1: stand alone land, and stand alone single column model (SCM).
Stage 2: Coupled land-SCM.
Stage 3: Sensitivity of different LSM and SCM to variations in forcing.

***Data Set:*** CASES-99 field experiment in Kansas, using 3 days: 23-26 Oct 1999, 19UTC-19UTC.

***Joint GEWEX GLASS-GASS project*** –outgrowth of GABLS2 where land-atmosphere coupling was identified as a important mechanism. Lead by Martin Best and Adrian Lock (UKMO).



# ***Land-PBL Interaction:***
## Initial DICE phase 2 (coupled) results




**Courtesy Best & Lock**

*First DICE workshop at UKMO, Exeter, UK, 14-16 Oct 2013.*

# ***Summary***

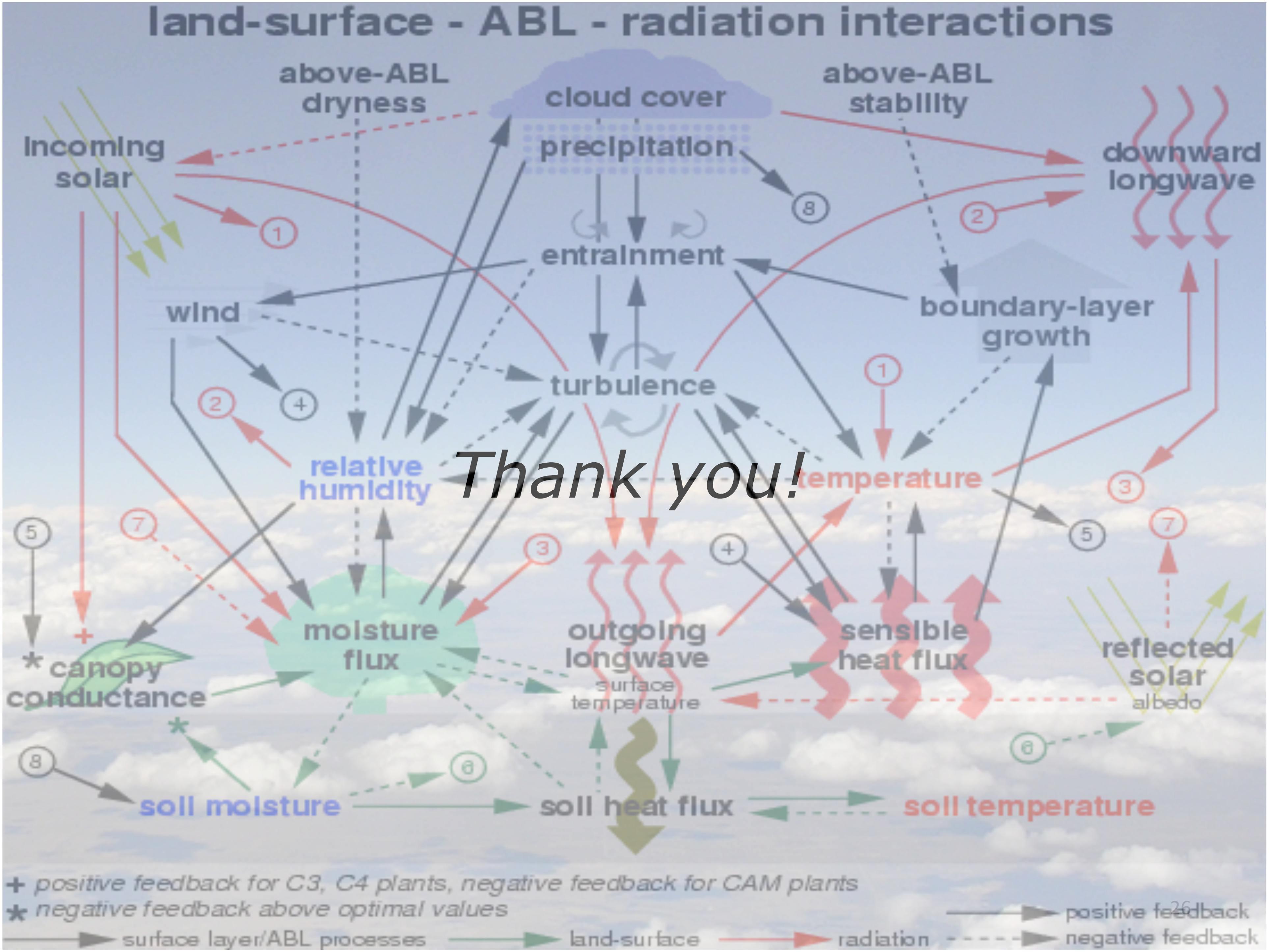
- *Process level* understanding is required to properly represent land-atmosphere interaction (e.g. near-surface, land-PBL) in weather and climate models to get the *"Right answers for the right reasons."*

- Data wish list: Extensively "mine" **Fluxnet** land data sets and **PBL field programs** for many different regions/seasons (including diurnal cycle); good soil moisture measurements & bare soil sites needed.

- Collaborative efforts from GEWEX GLASS PLUMBER/ PALS, LoCo, GLASS-GASS DICE, GABLS, and other programs/projects → use such testing procedures in our model development. *"Step-wise", "Pyramid"*

- Important consideration: scale-dependencies and single-site representativeness vs model grid scale.

# Thank you!


land-surface - ABL - radiation interactions
above-ABL dryness
cloud cover
above-ABL stability
incoming solar
precipitation
downward longwave
entrainment
wind
boundary-layer growth
turbulence
relative humidity
temperature
moisture flux
outgoing longwave
sensible heat flux
reflected solar
canopy conductance
surface temperature
albedo
soil moisture
soil heat flux
soil temperature
+ positive feedback for C3, C4 plants, negative feedback for CAM plants
* negative feedback above optimal values
surface layer/ABL processes
land-surface
radiation
positive feedback
negative feedback