Land-Atmosphere Coupling in Observations and Models

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(Credit: Anton Beljaars for ERA40 runs)

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Land-Atmosphere Interactions

Valsavarenche, Valle d'Aosta, Italy

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RACC

Research on Adaptation to Climate Change

Timeline

• *Liquid potential temperature, enthalpy transport, ML model*	• Betts, 1970, 73, 75
• **VIMHEX, GATE**	
• *Conserved thermodynamics*	• Betts **1982**,83,**1984**,85,86
• *Saturation point*	
• *Convective parameterization*	• *Betts and Miller 1986*
• *Tropical BL equilibrium; radiative coupling across timescale*	• Betts and Ridgway 1988,89
• **FIFE, BOREAS**	• Betts and Ball 1995, 98…
• *Vector diagrams for BL*	• Betts 1992
• *Soil moisture-precip. feedback*	• Beljaars et al 1996
• **GEWEX, ERA40**	• Betts et al. 1998, 99…
• **LBA** *Radiative-convective equil.*	• Betts and Jakob 2002b
• *Equilibrium BL over land*	• Betts 2000, Betts et al 2004
• *LW Radiative coupling: NBL & DTR*	• Betts 2006
• ***Understanding hydrometeorology***	• **Betts 2004 (AMS Horton lecture)**
• ***Land-surface-atmos. coupling in observations and models***	• **Betts 2009**
• ***Canadian Prairies***	• **Betts et al. 2013,14,15**

Review my understanding..

- *Betts, A. K., J.H. Ball, A.C.M. Beljaars, M.J. Miller and P. Viterbo, 1996: The land-surface-atmosphere interaction: a review based on observational and global modeling perspectives. J. Geophys. Res.* ***101****, 7209-7225.*
- ***Betts, A. K. (2004): Understanding Hydrometeorology using global models. Bull. Amer. Meteorol. Soc., 85, 1673-1688. (AMS Robert E. Horton Lecture)***
  - *Capsule summary:* A new framework is proposed for understanding the land-surface coupling in global models between soil moisture, cloud base and cloud cover, the radiation fields, the surface energy partition, evaporation and precipitation.
- ***Betts, A. K. (2009): Land-surface-atmosphere coupling in observations and models. J. Adv. Model Earth Syst., Vol. 1, Art. #4, 18 pp., doi: 10.3894/JAMES.2009.1.4***
  - The diurnal cycle and the daily mean at the land-surface result from the coupling of many physical processes. The framework of this review is largely conceptual; looking for relationships and information in the coupling of processes in models and observations.

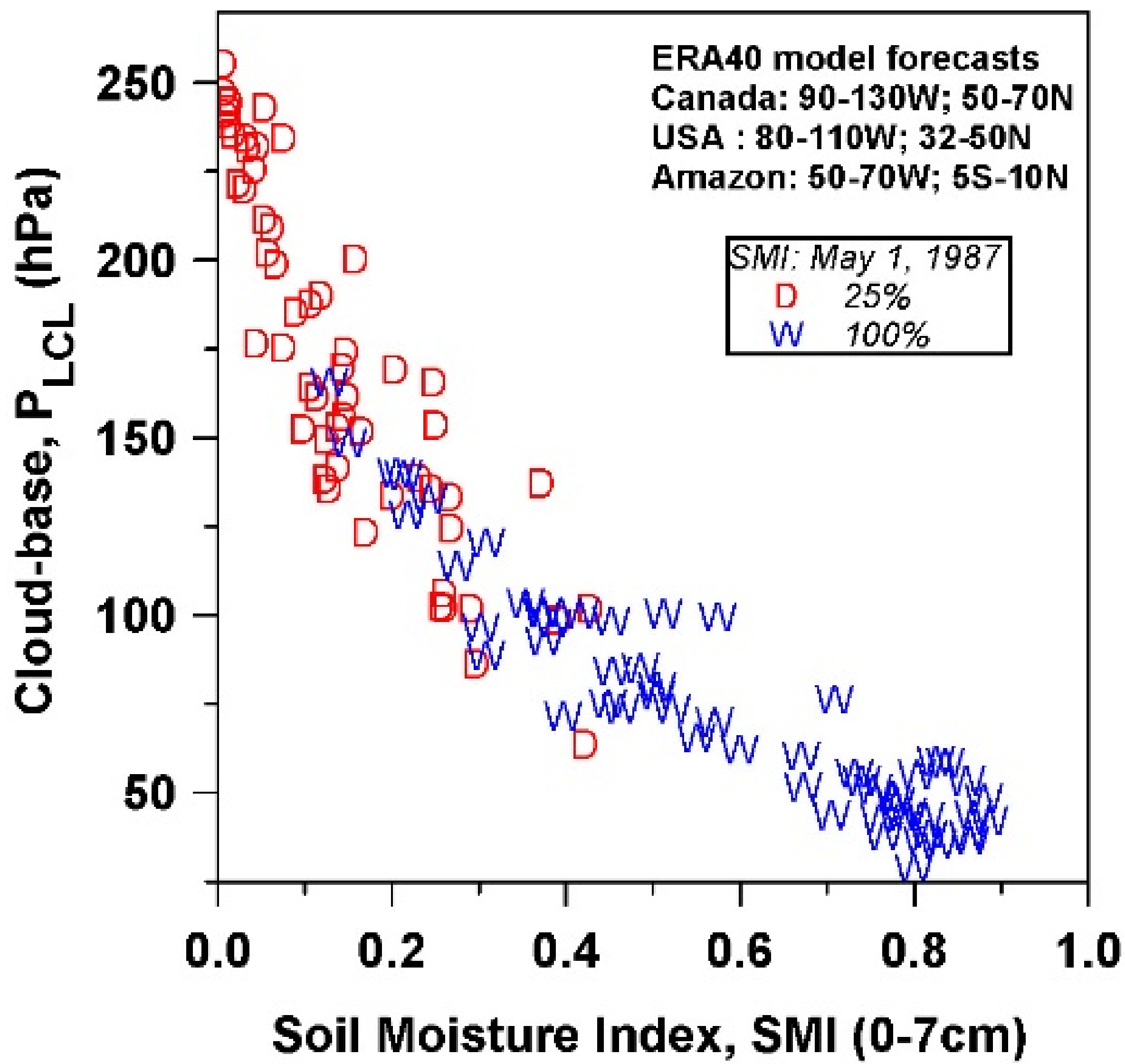
Understanding Hydrometeorology using global models *(Betts 2004)*

“The title of this paper is meant to be a paradox. Usually we rely on simple models to gain understanding, but hydrometeorology is too complex for that, and too important for us to be satisfied with rough approximations. The <u>climate interactions of water (vapor, liquid and ice, and its phase changes and radiation interactions)</u> are everywhere, and they are central to and closely coupled to life, and to understanding climate change….”

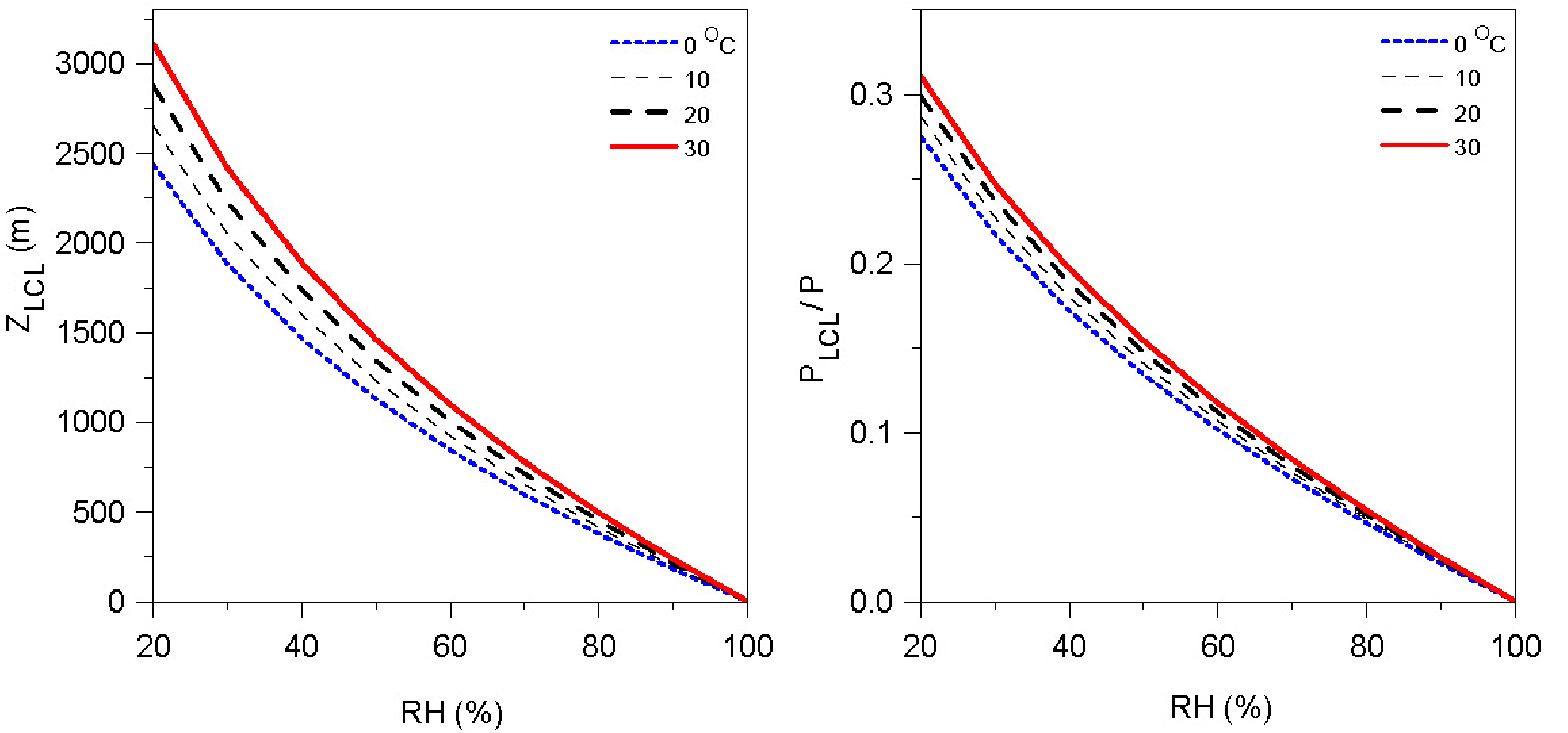
- ***Maps the coupling of processes using ERA40 data***

Coupling: Soil Moisture to LCL

- ERA40 model
  - May 1 1987
  - 120-day FX
  - Dry-down
  - 5-day means
- SMI linked to
  - saturation drop across leaf
  - RH and LCL
  - *(Precip coupled)*

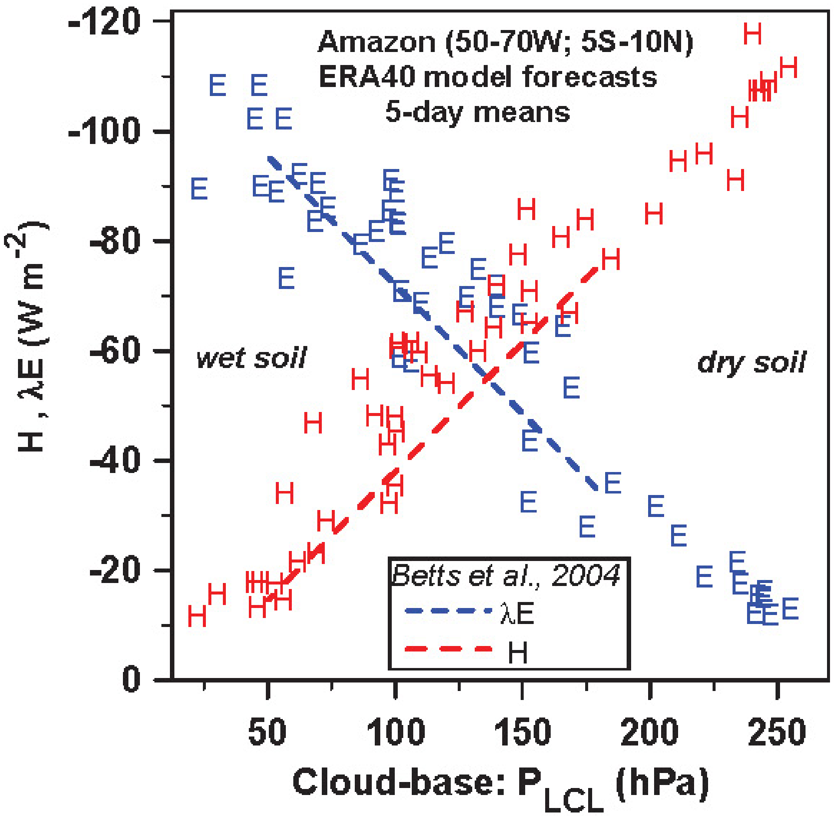


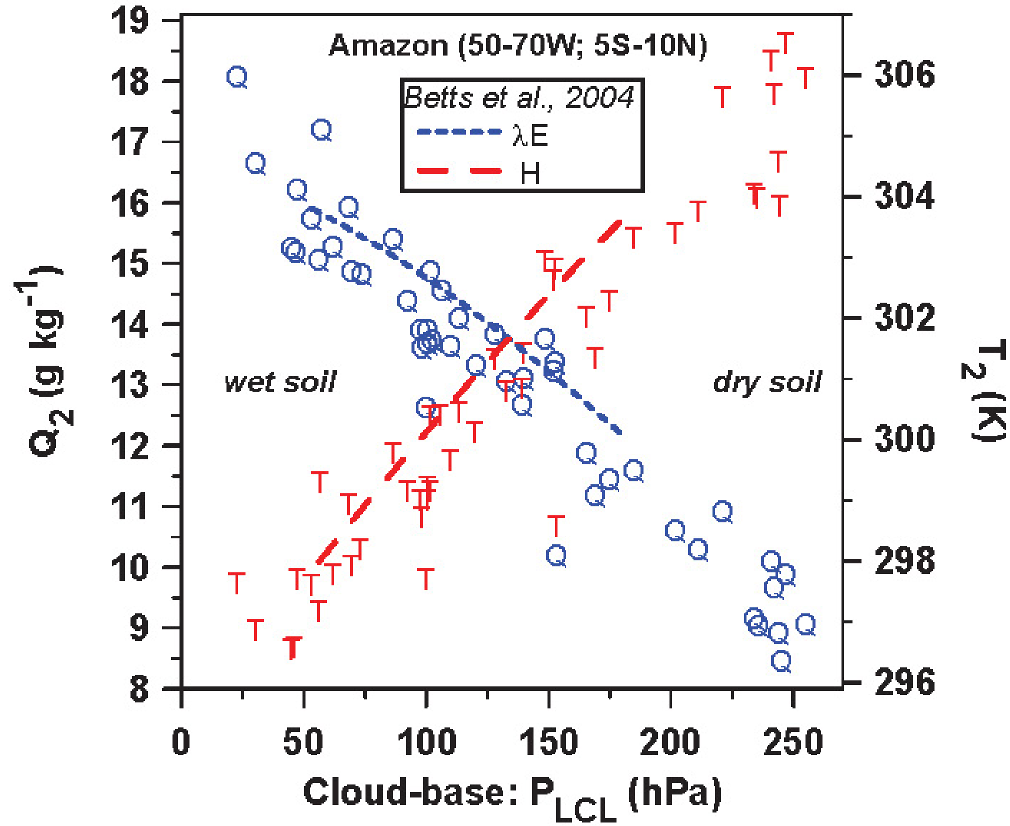
RH to LCL



- **RH and LCL are closely related**

Coupling: LCL, fluxes, T_2, Q_2



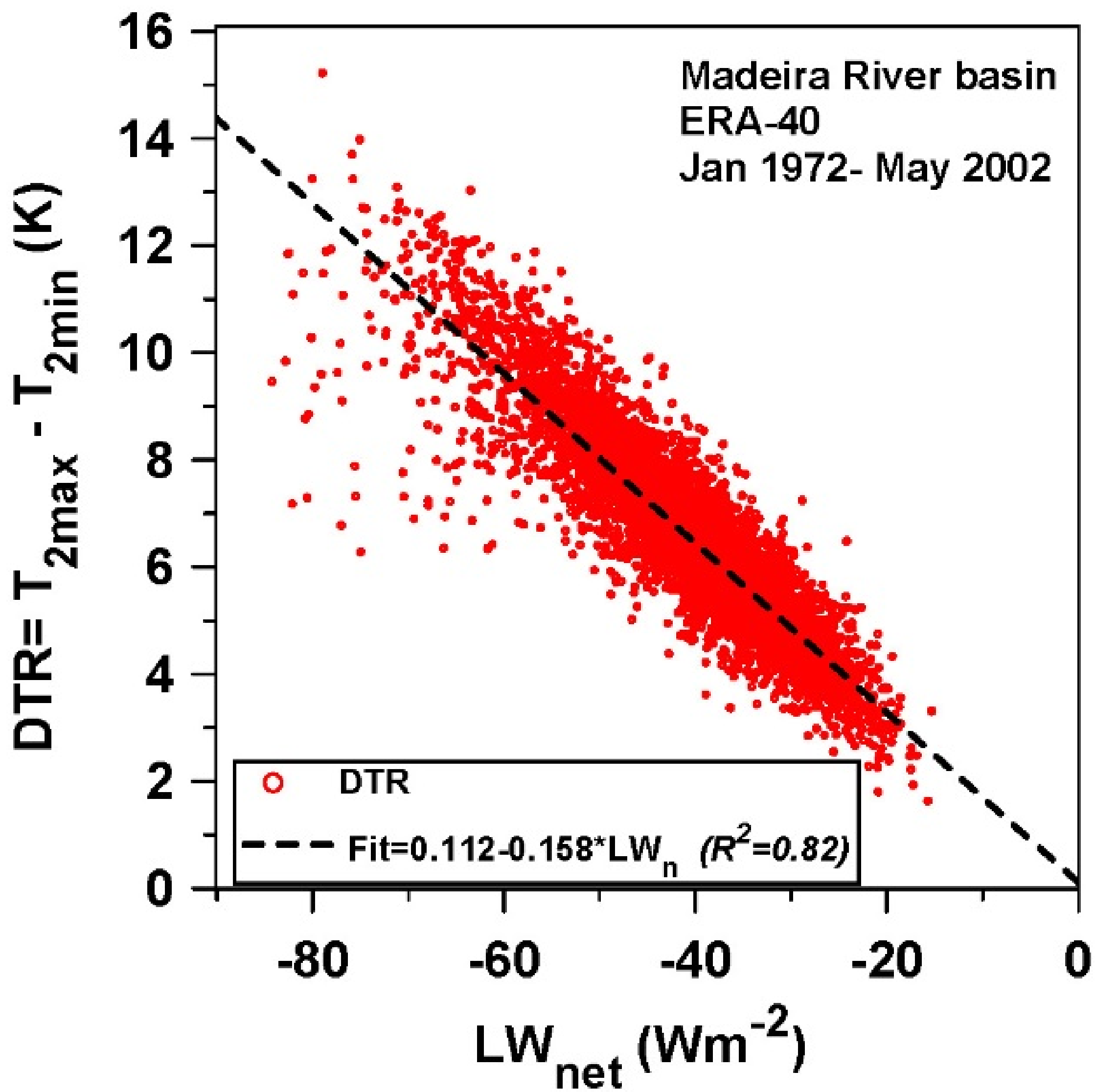


- **LCL linked to surface fluxes, equilibrium T and Q**
- **ERA40 5-day means are consistent with idealized mixed layer model *(Betts et al. 2004)***

Coupling: DTR to LW_{net}

- **ERA40 reanalysis**
  - **Madeira basin daily means**
  - **30 years**
- **R^2= 0.82**
- **LW_{net} is tight constraint on DTR**

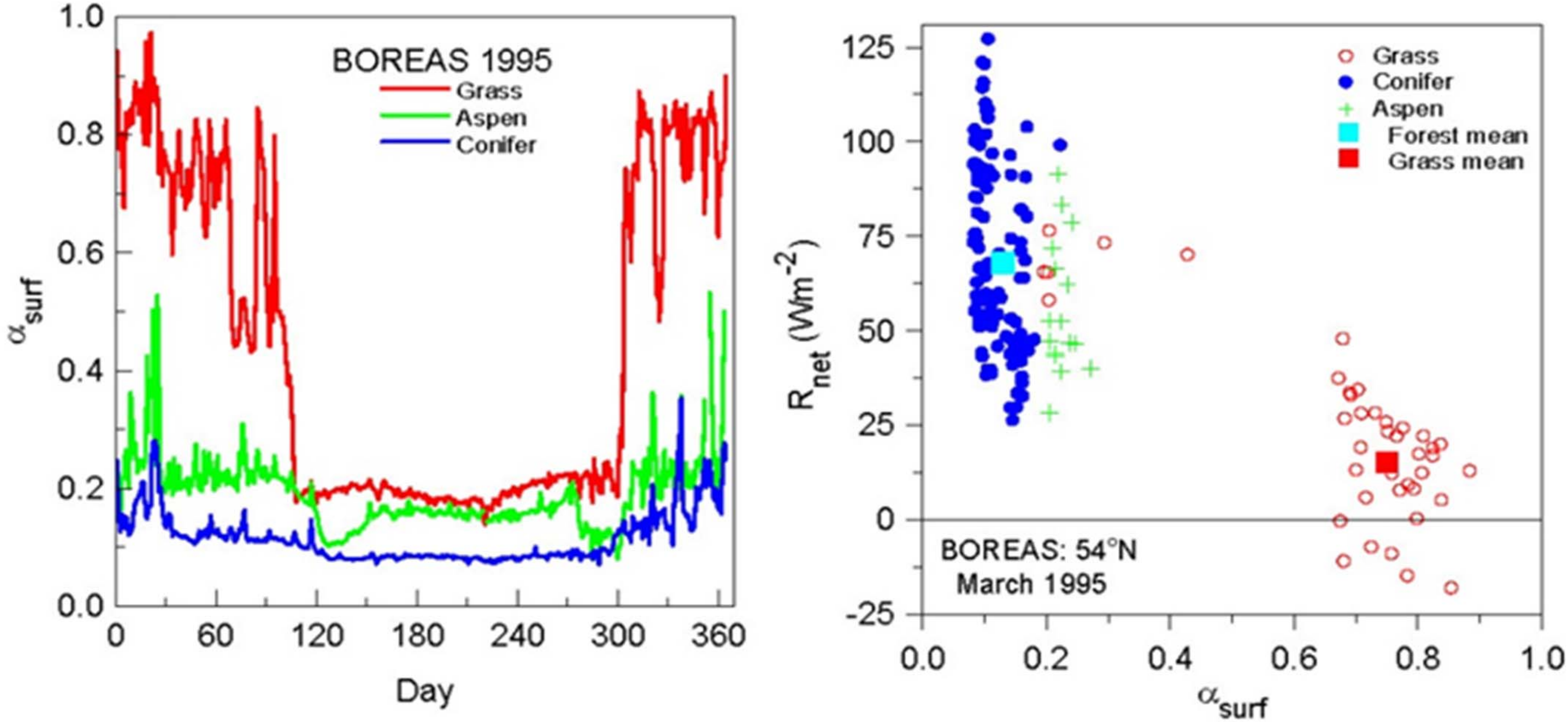
Betts (2004, 2006)



Betts, A. K. (2009), Land-surface-atmosphere coupling in observations and models (JAMES)

- “The diurnal cycle and the daily mean at the land-surface result from the coupling of many physical processes”
  - Surface albedo and cloud albedo to SW (and LW)
  - LW coupling to RH and clouds
  - Soilwater availability, surface fluxes T, RH and LCL
  - Vector methods for understanding mixed layer evolution
  - Surface, LCL and precipitation coupling
  - Compare shortwave cloud forcing and diabatic precipitation forcing in ERA-40 with observations.

Surface Albedo with Snow

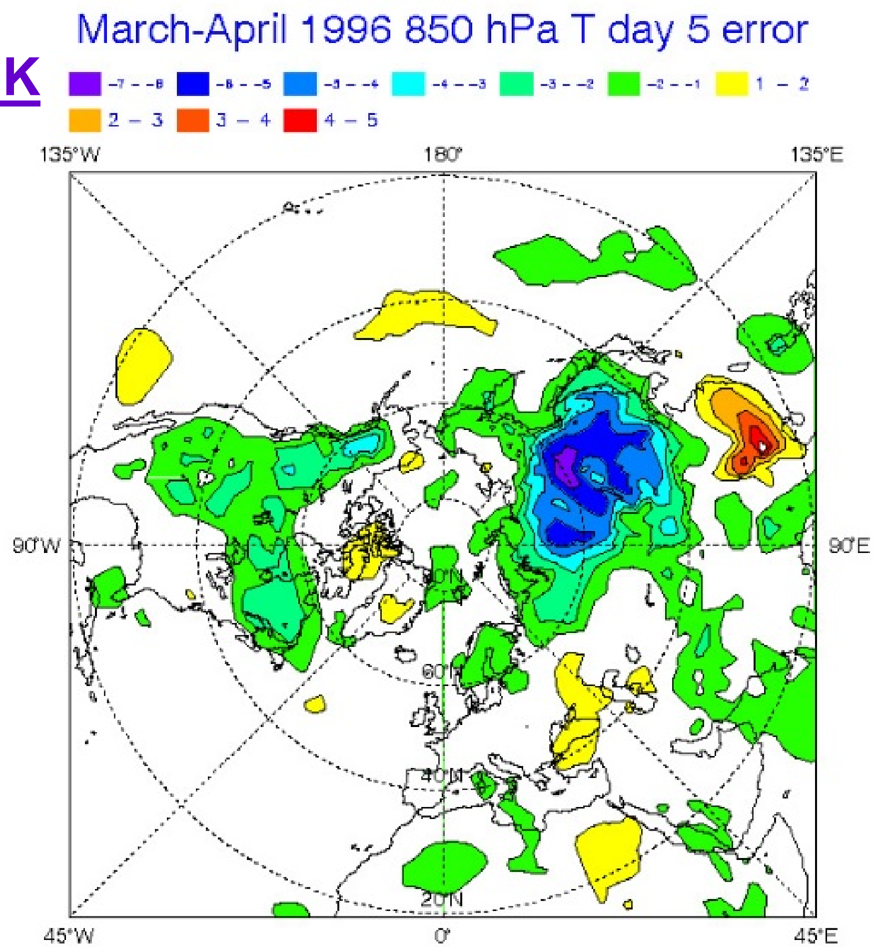


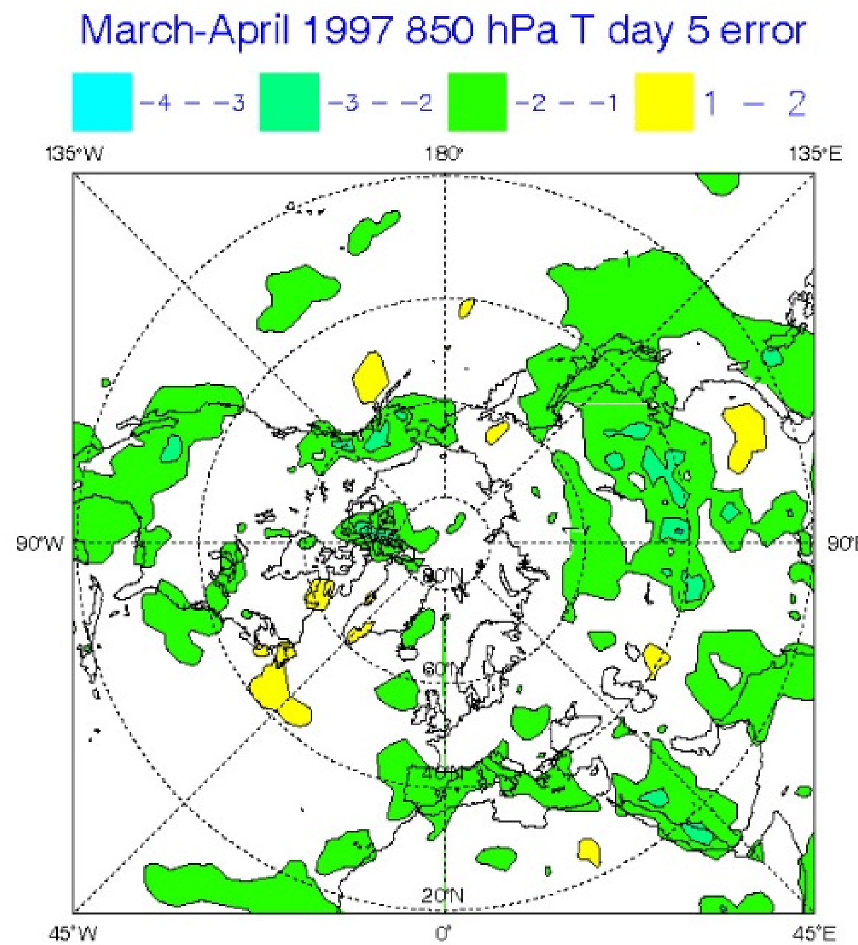
- **Range of albedo with vegetation**
  - **Much larger in winter**
  - **Large impact on R_{net} in spring**

Impact of boreal forest albedo error

Large Cold Biases

-7K

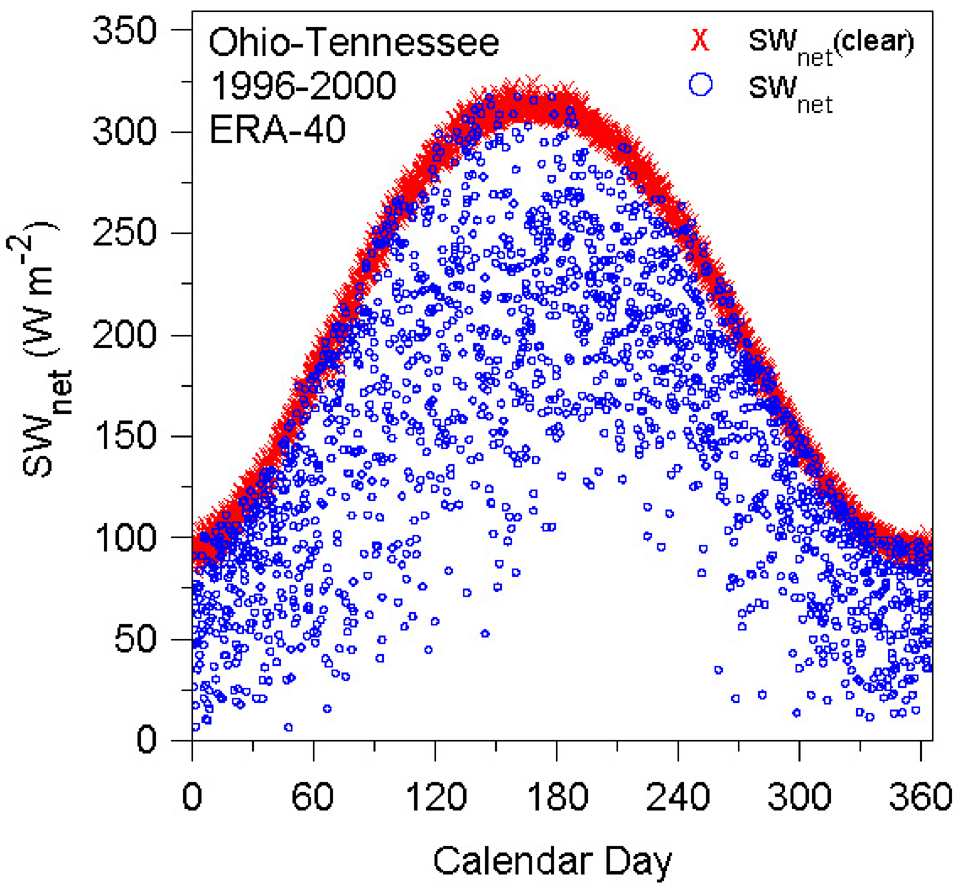


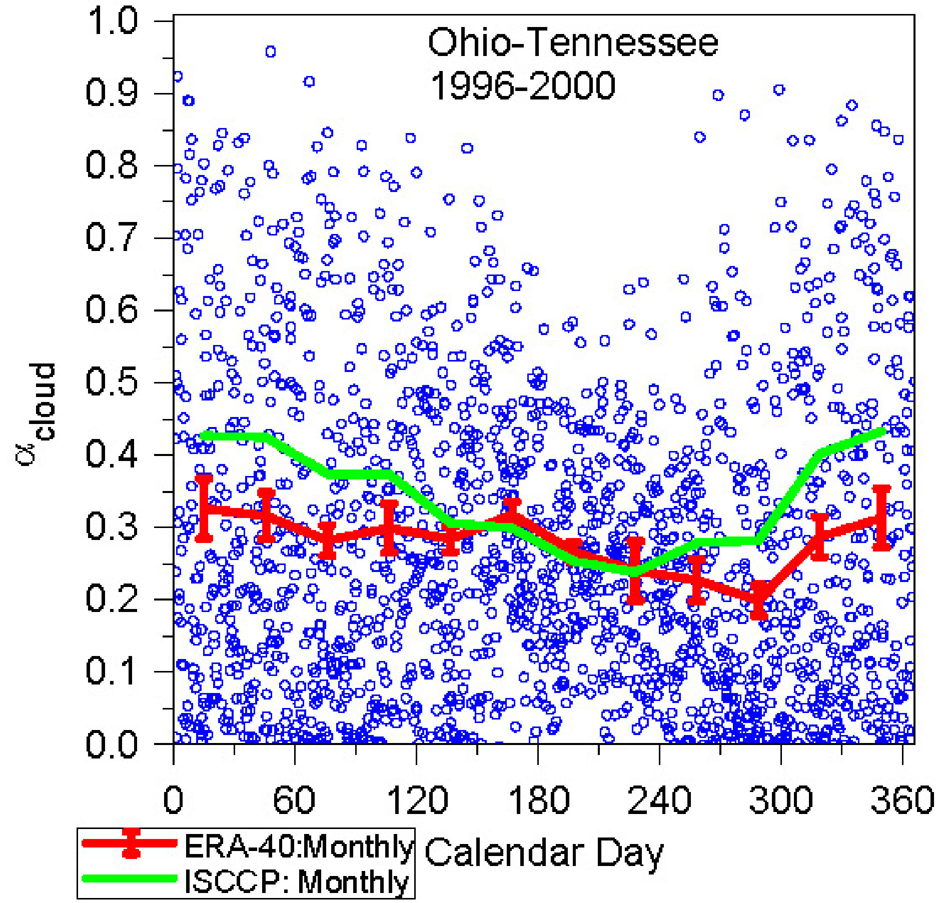


- **Boreal forest**

$\alpha_{surf} \approx 0.8$ **$\alpha_{surf} \approx 0.2$**

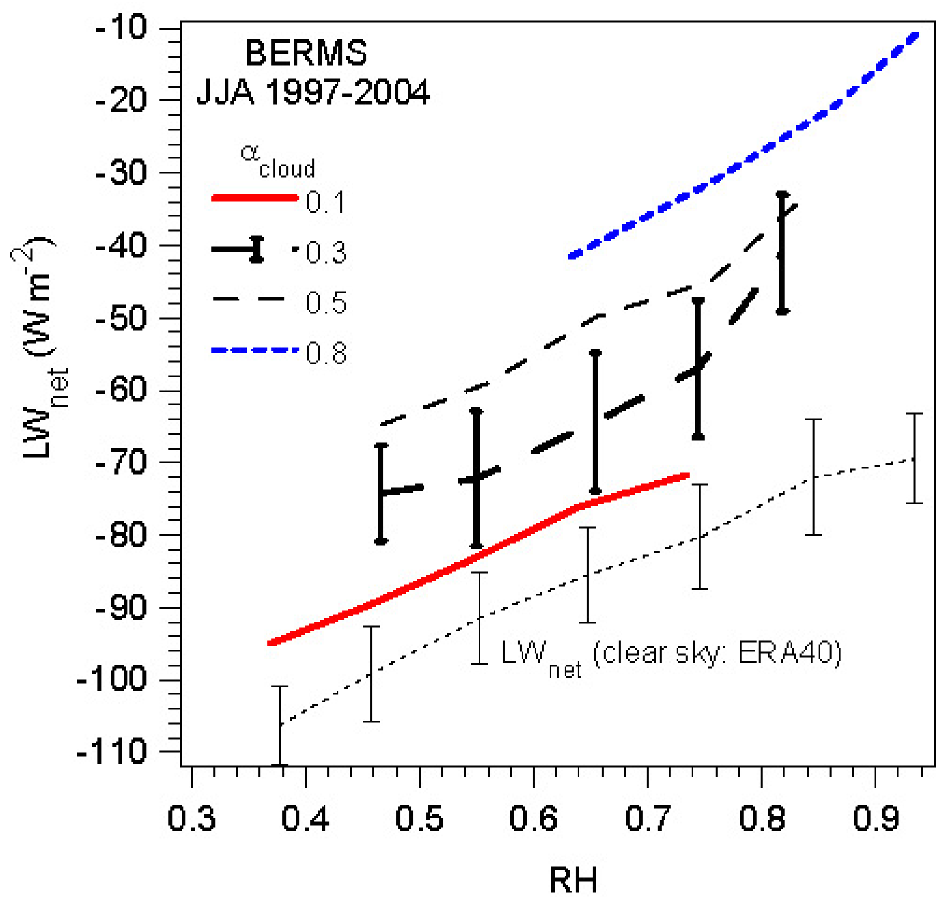
Effective Cloud Albedo

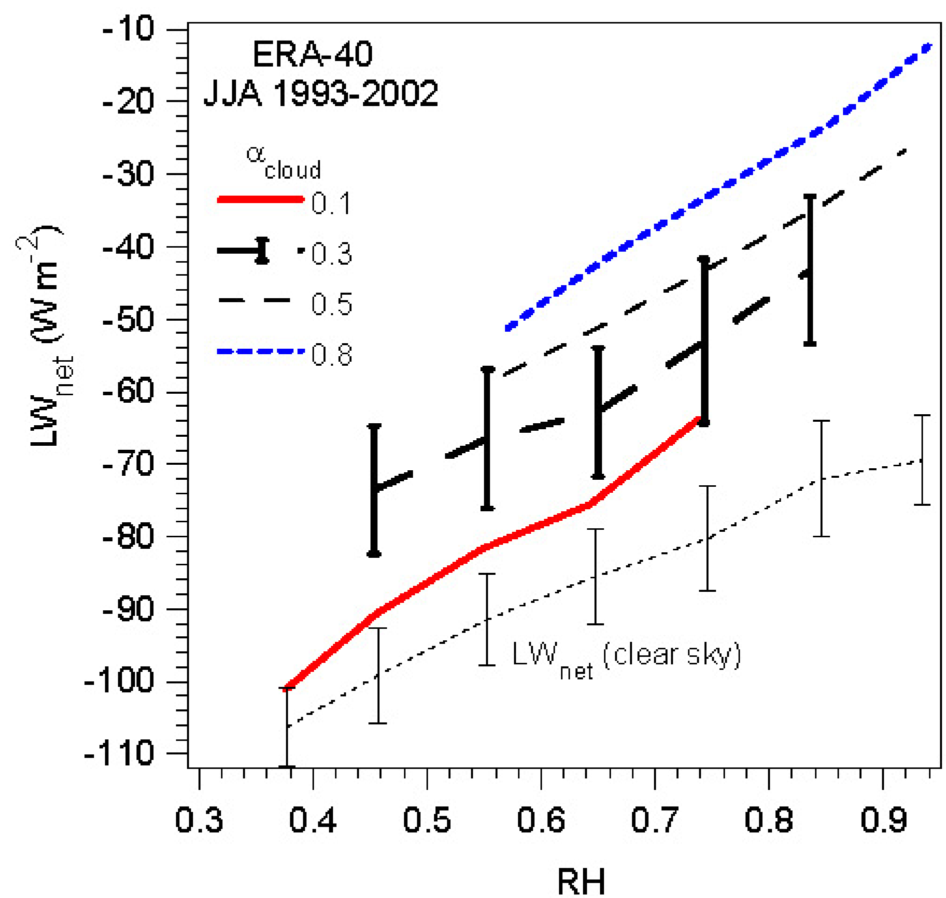




- **$SWCF = SW_{net} - SW_{net}(clear)$**
- **ECA (α_{cloud}) $= - SWCF/SW_{net}(clear)$**
  - **$SW_{net} = (1-\alpha_{surf})(1-\alpha_{cloud})\ SW_{dn}(clear)$**

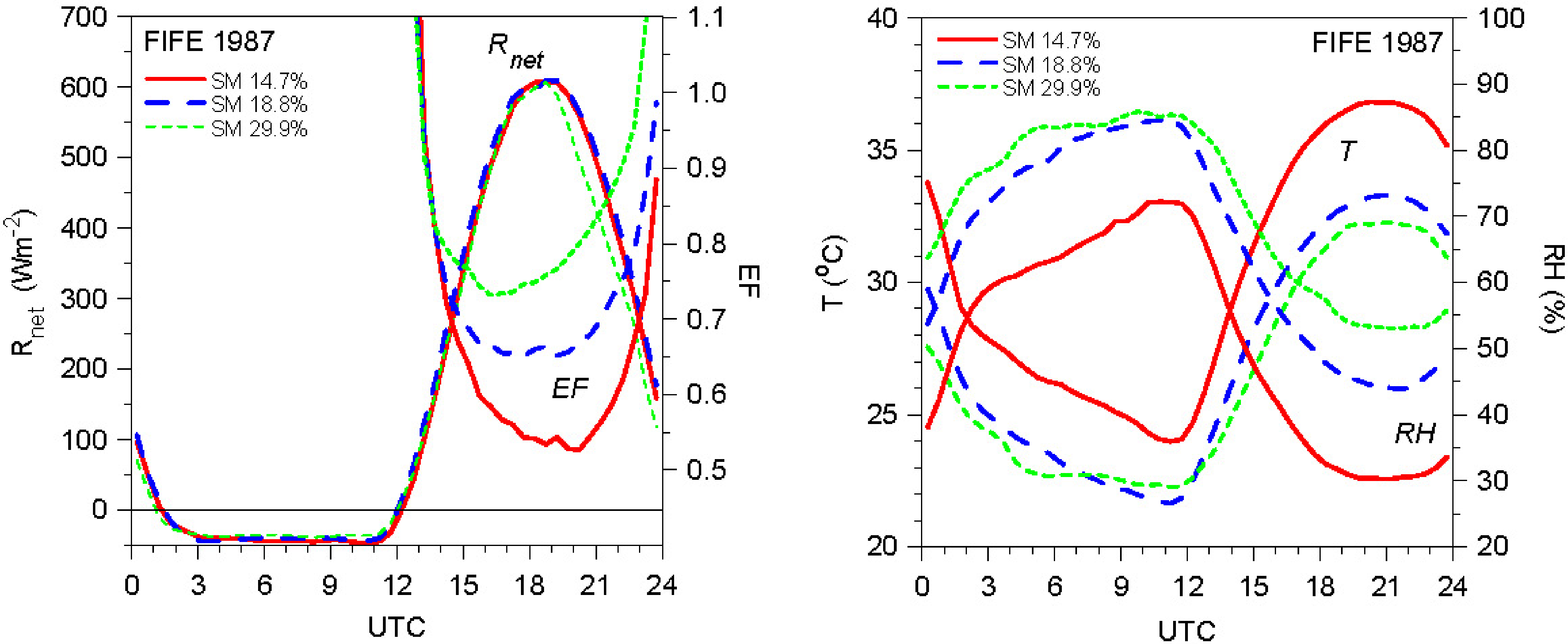
LW_{net}, RH and Clouds





- **Observations versus ERA40**
  - **LWCF and water vapor greenhouse**
  - **(LW_{net} to DTR)**

Soil Moisture - Surface Energy Budget



- Summer diurnal cycle of FIFE grassland
- <u>Clear days</u> stratified by soil moisture
- EF and RH increase; T falls with SM

Saturation Point: Moist Thermodynamics & Conserved variables

Saturation Point Analysis of Moist Convective Overturning

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(Manuscript received 26 May 1981, in final form 25 January 1982)

(Betts 1982)

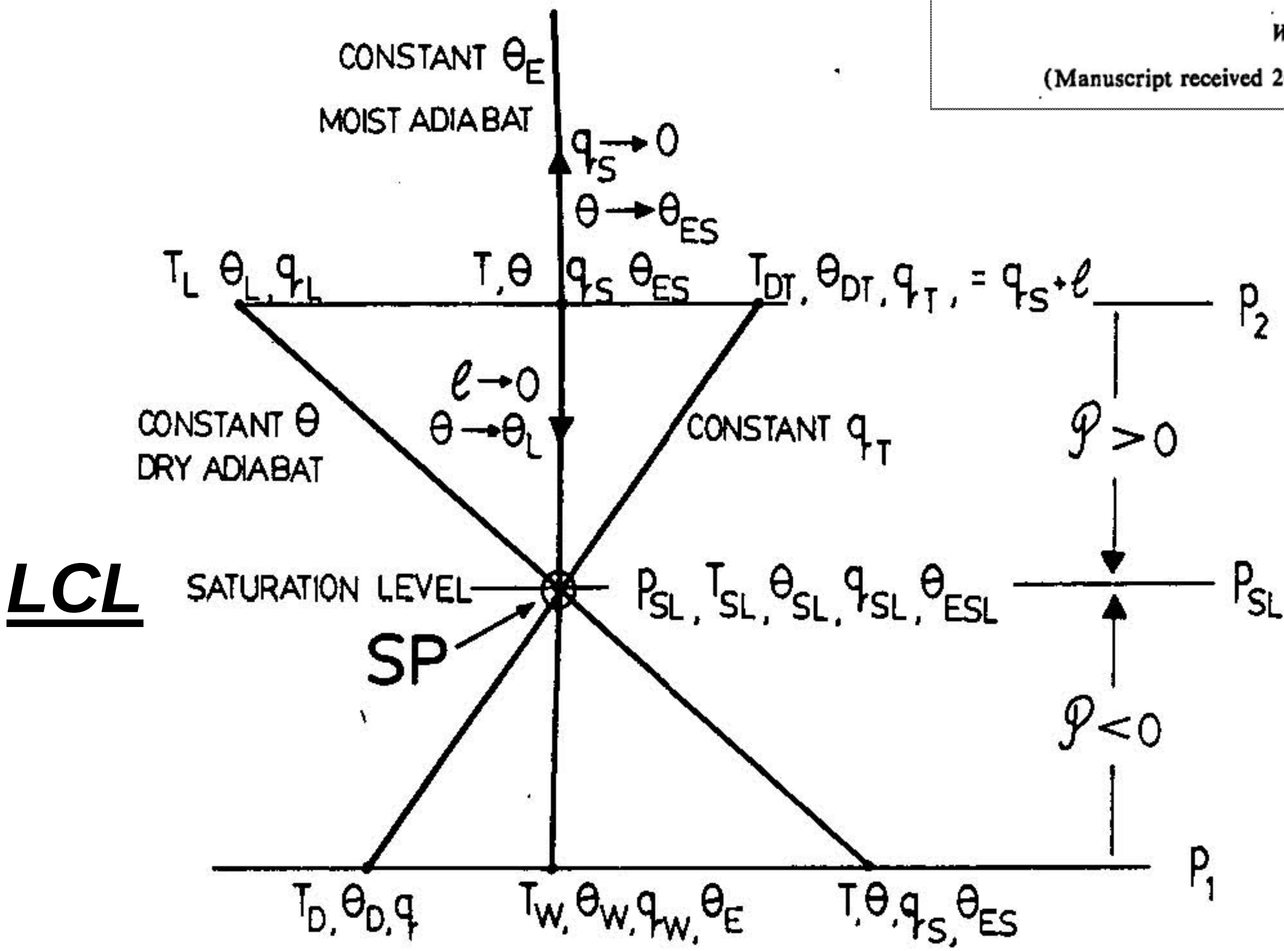


FIG. 1. Sketch thermodynamic diagram (tephigram), showing the relationship of Saturation Point SP (T_{SL}, p_{SL}) to the conserved parcel properties (θ_{SL}, θ_{ESL}, q_{SL}) which are independent of parcel pressure, and to the parcel properties at other pressure levels, such as (T, T_W, T_D) at p_1, for unsaturated air (for which $\mathcal{P} < 0$). The

Diabatic processes change saturation point

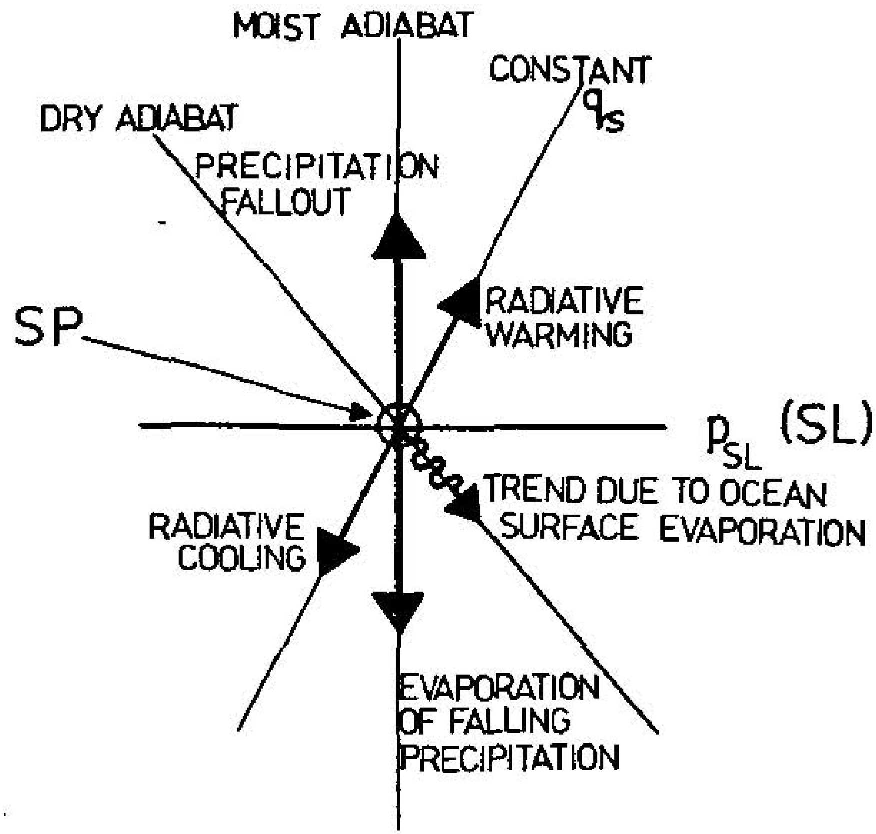
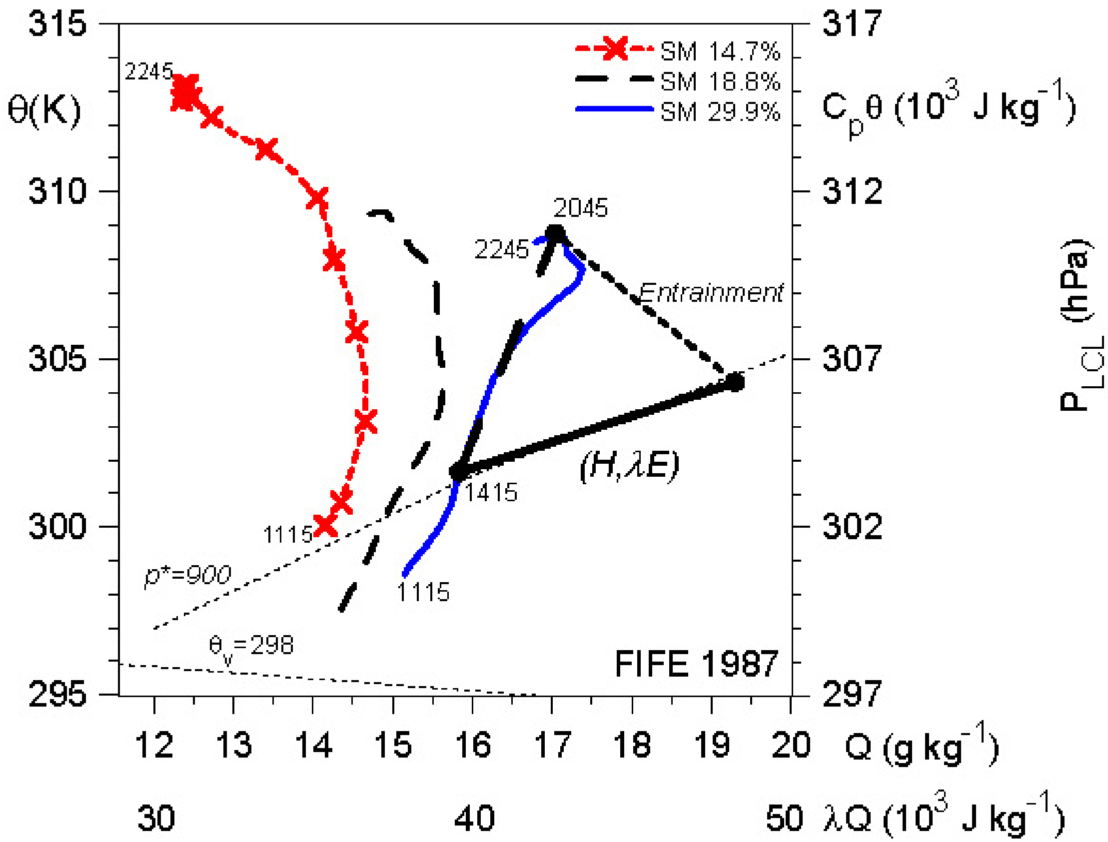
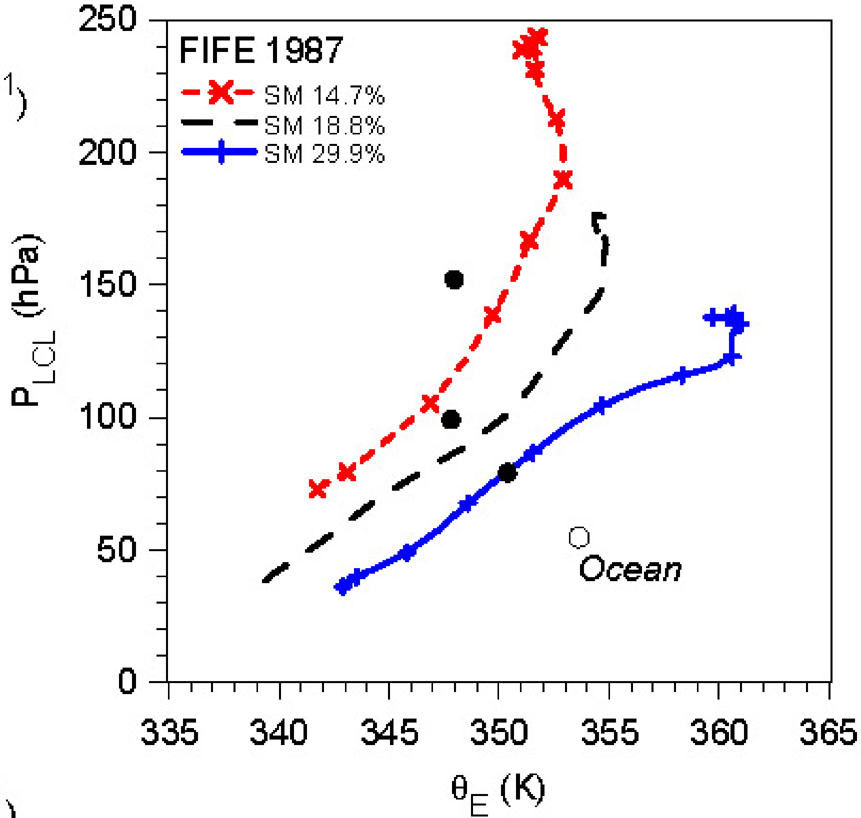


FIG. 3. Schematic showing change in saturation point produced by the irreversible diabatic processes of precipitation fallout or evaporation; radiative cooling or heating; and the tendency caused by ocean surface evaporation.

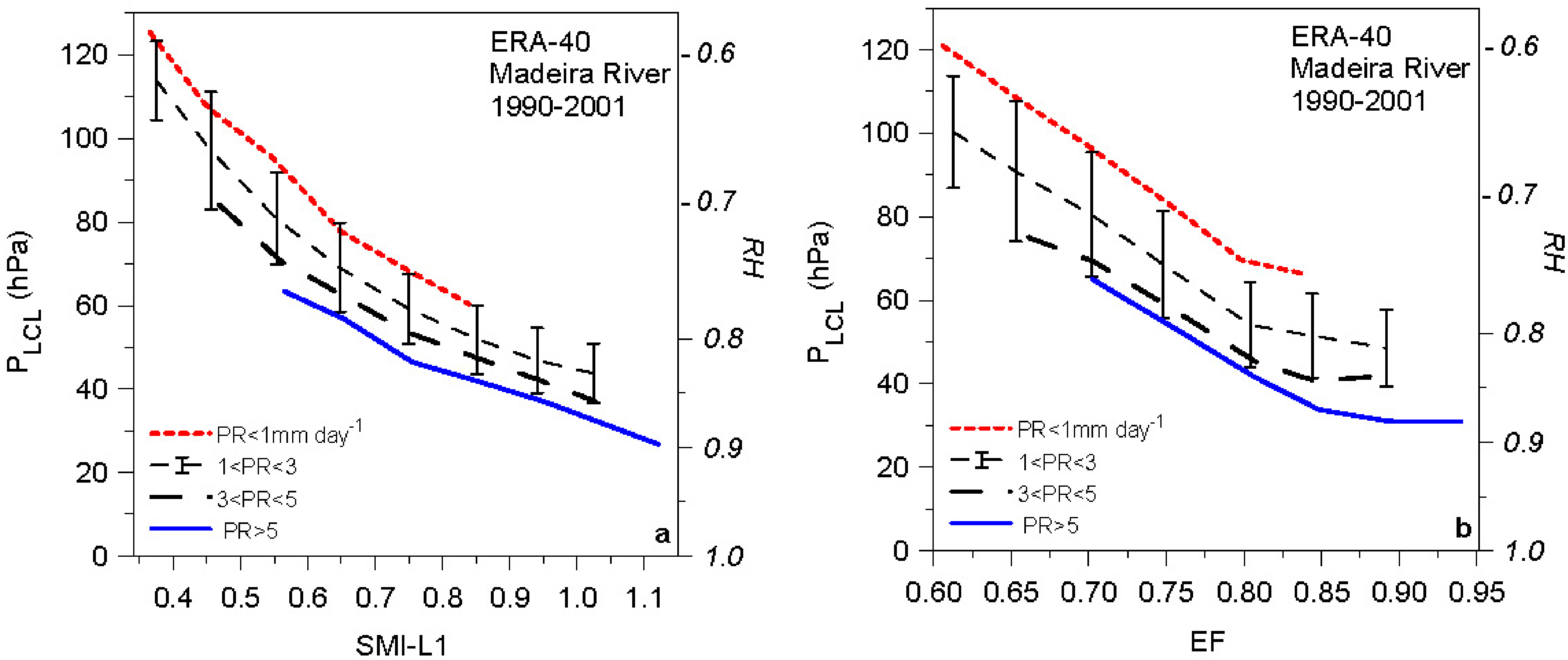
2-D Vector Schematics





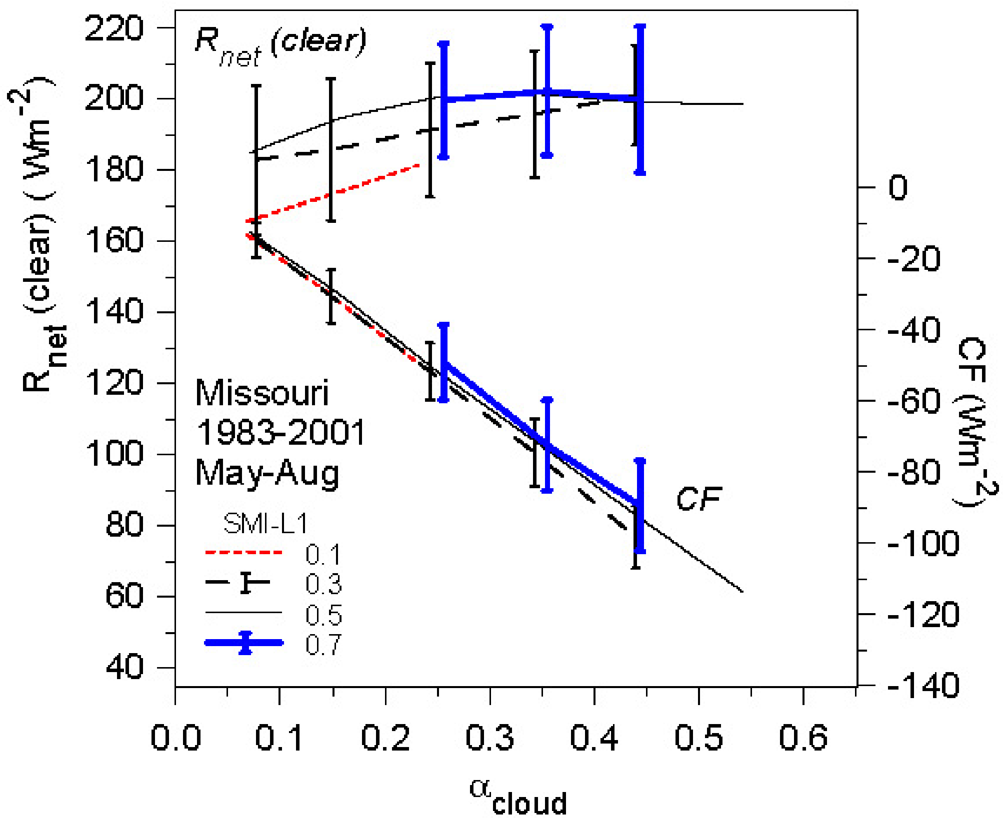
- $\Delta\boldsymbol{\xi}_{\mathbf{m}}/\Delta t = (\mathbf{F}_s - \mathbf{F}_i)/\ \rho\Delta Z_i$
- *See text for details*

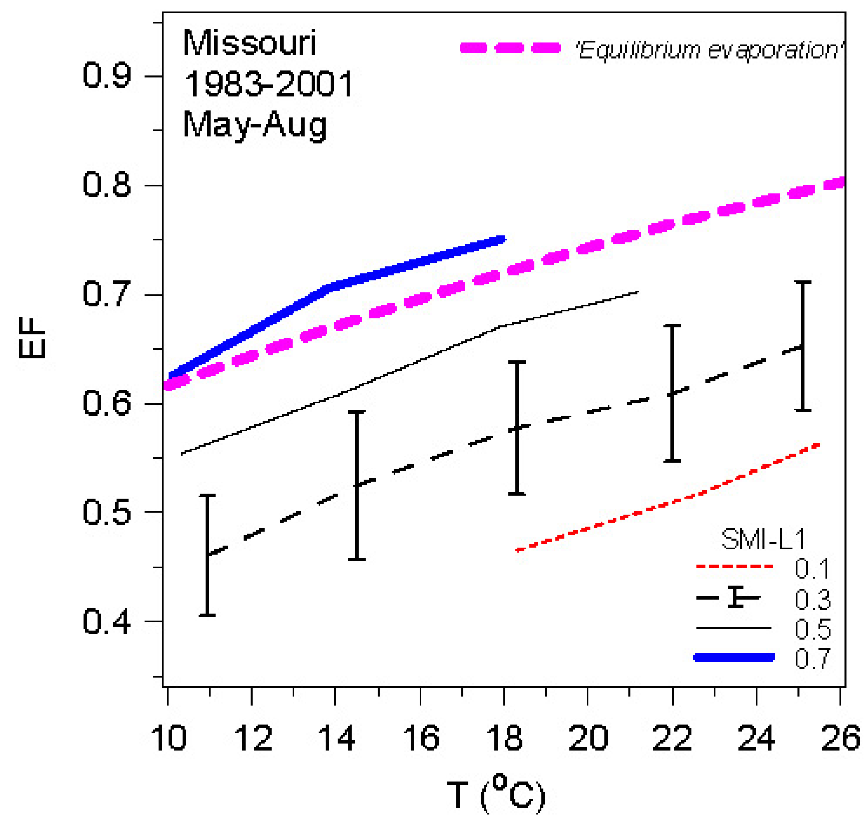
Land-BL coupling



- **Joint dependence of P_{LCL} on**
  - **SMI-L1 and precipitation rate**
  - **EF and precipitation rate**

Separating Cloud and Surface Processes

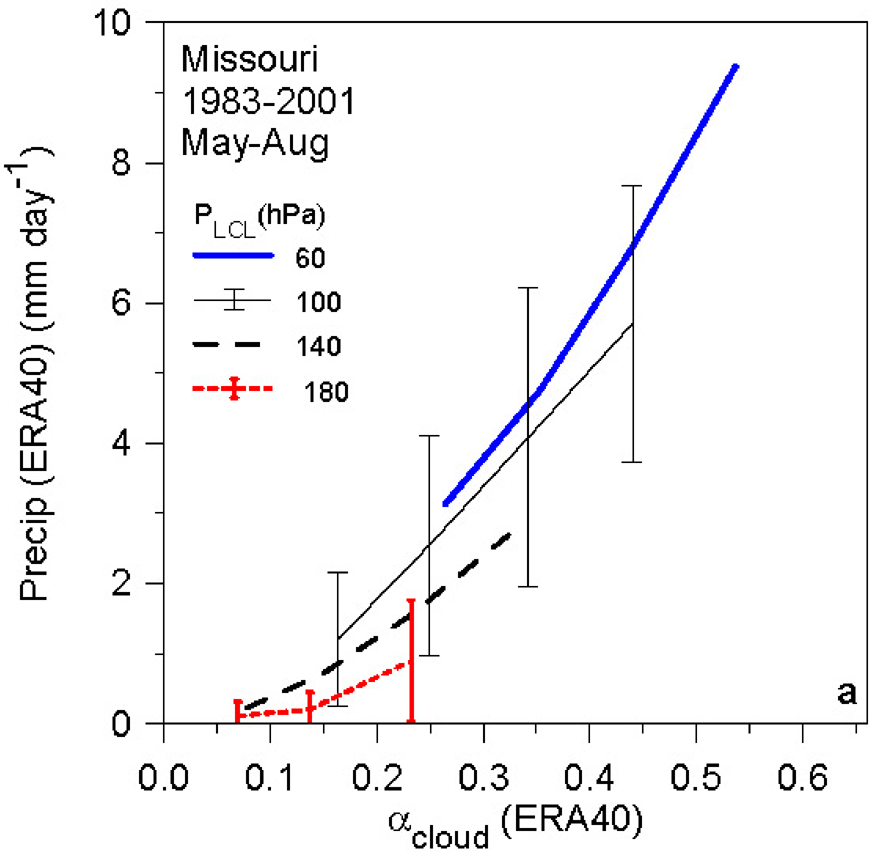


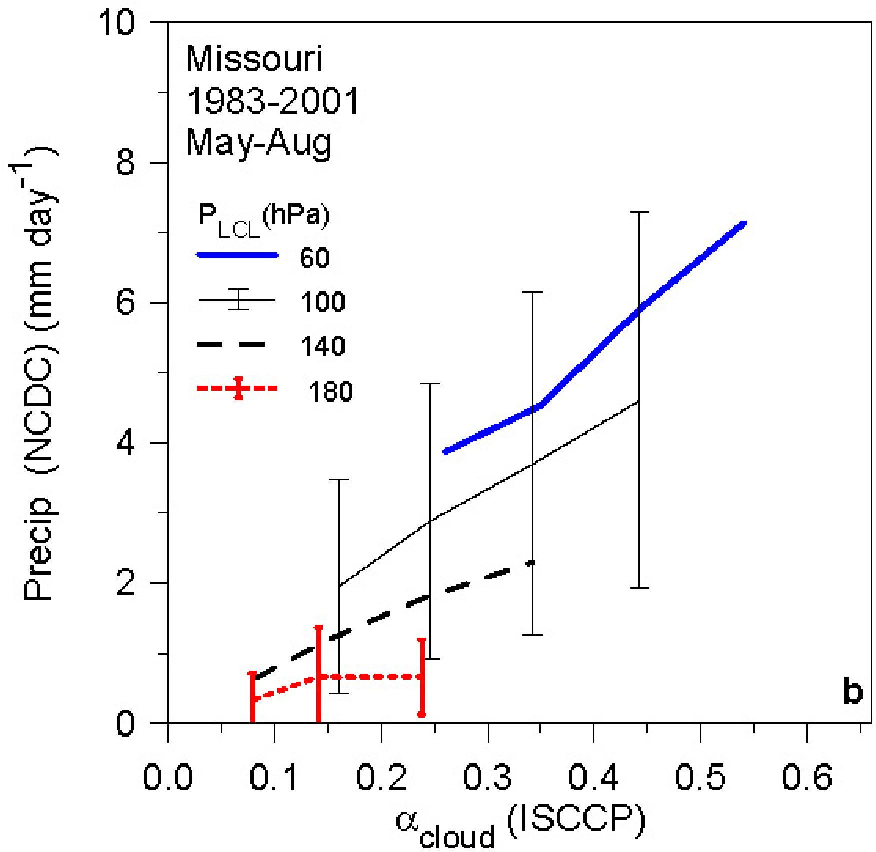


- R_{net} = F(CF)

EF = F(T, SMI)

SWCF to precipitation forcing





- **Ratio of key diabatic forcings**
  - **Precipitation warms atmosphere**
  - **SWCF cools surface: too small in ERA40**

Betts (2004, 2009) Reviews

- **Daily mean ERA40 data** ***(Reanalysis/forecast)***
  - **LW_{net} to DTR**
  - **LW_{net} to RH and cloud**
  - **SMI to LCL and RH**
  - **SWCF and precipitation forcing**
- **Snow albedo and forecast skill**
- **FIFE diurnal cycle**
  - **SM dependence of T and RH (clear sky)**
  - **2D vector figures**
- **<u>Fully coupled system</u>**