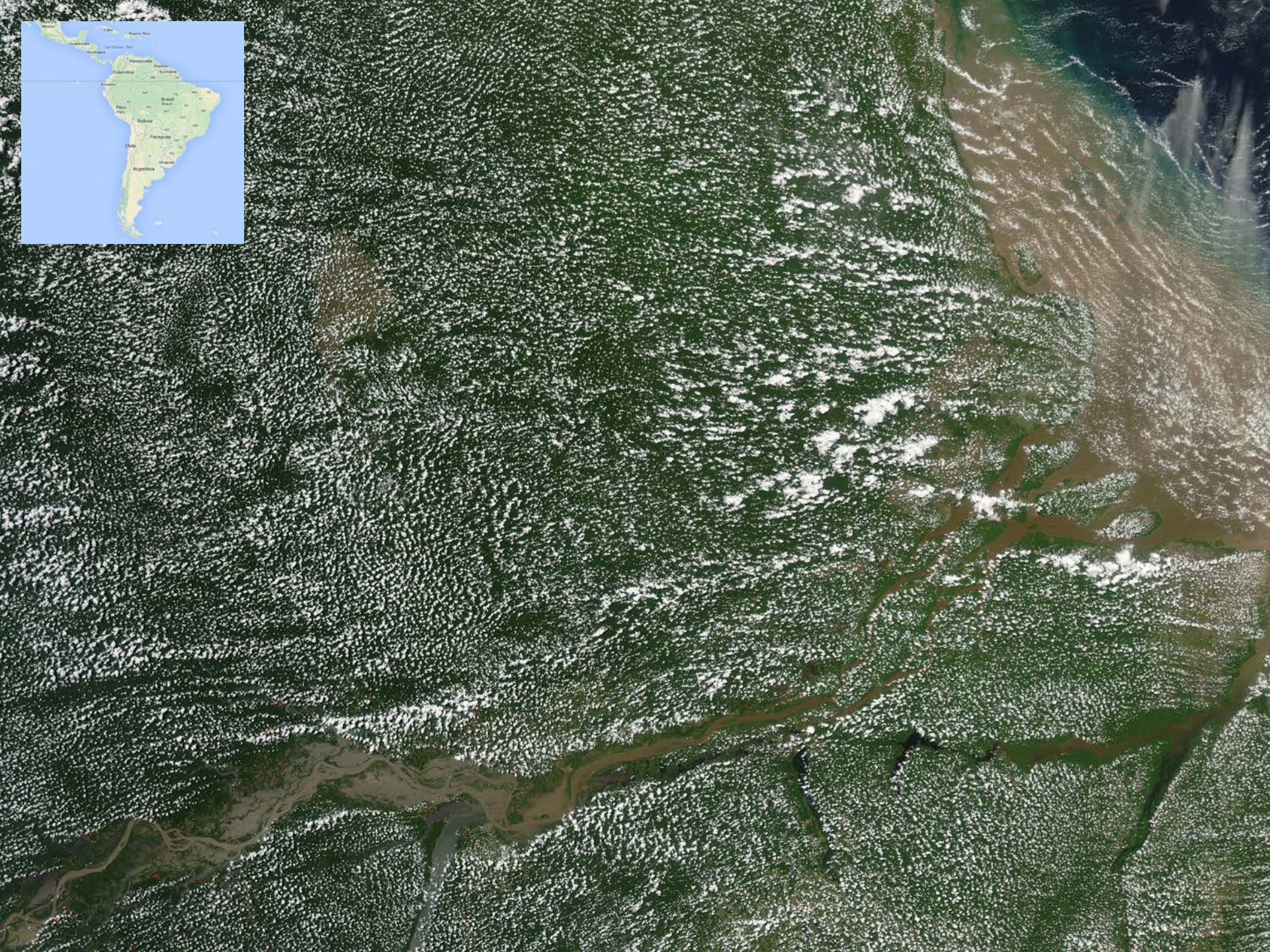
# LAND-ATMOSPHERE INTERACTIONS: INTERESTS AND CHALLENGES

Pierre Gentine – Columbia U., Betts AK, D'Andrea F – ENS, Malte Rieck, MPI, Hohenegger C – MPI, Nicolas Rochetin - Meteo France, Ben Lintner - Rutgers, Kirsten Findell, GFDL….


Venezuela
Colombia
Brasil
Peru
Bolivia
Paraguay
Chile
Argentina

# Land-atmosphere interactions



- Nice review by Joe earlier.
- Why does it matter?

- **Subdiurnal/diurnal:**
  modification of boundary layer and coupling with cloud layer

- **Short to medium time scales:**
  improved weather predictions
  (especially precipitation variability, extremes)

- **Long-term:**
  coupling between the surface energy, water and $CO_2$ cycle:
  what is the fate of most ecosystems?

# Land-atmosphere interactions



- Why is it complicated?

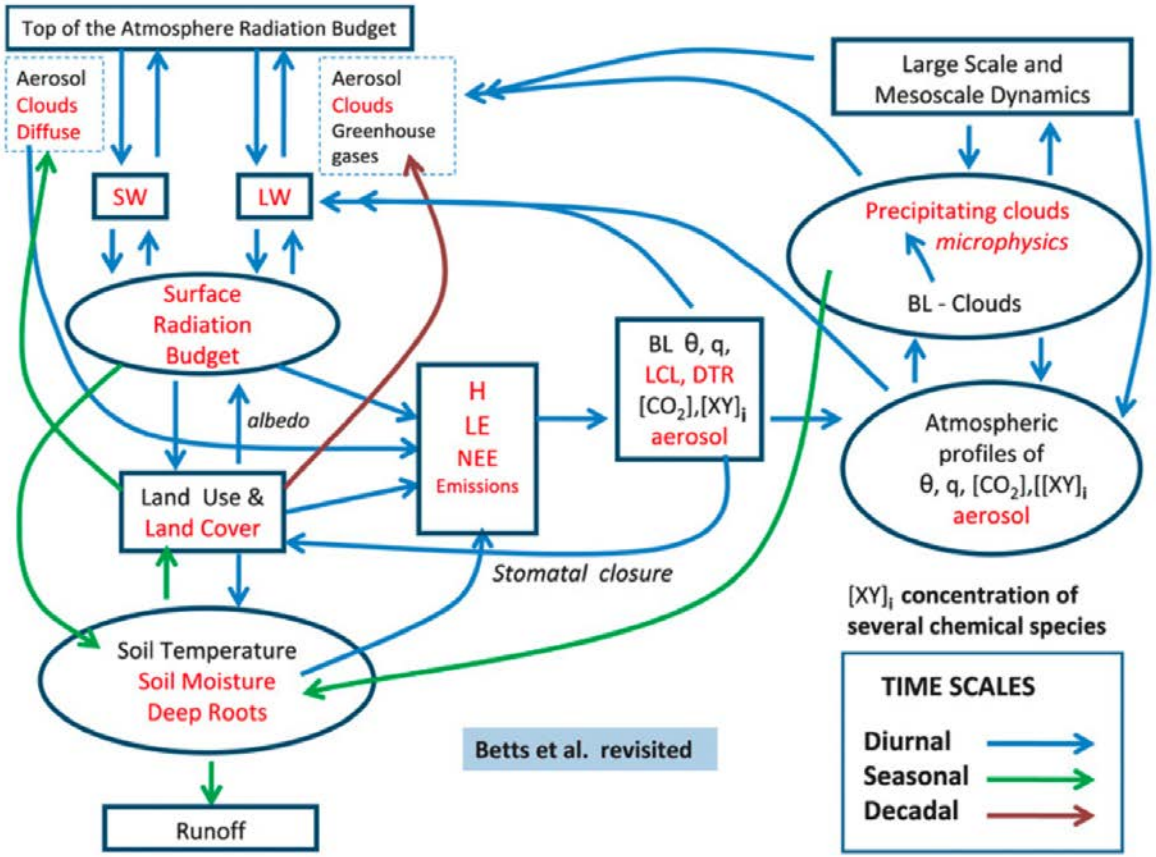



**Figure 1**: Schematic overview of land-atmosphere interactions from *Betts and Silva Dias* [2010].

# LA-interactions: why do they matter?



- Boundary layer dynamics
- Convection triggering/characteristics
- Radiation budget
- Cold pool dynamics
- Aerosols/VOCs – deep convection
- Coupling with radiation/larger-scale circulations
- Coupling with $CO_2$

… (not exhaustive)

# Boundary-layer (PBL) dynamics



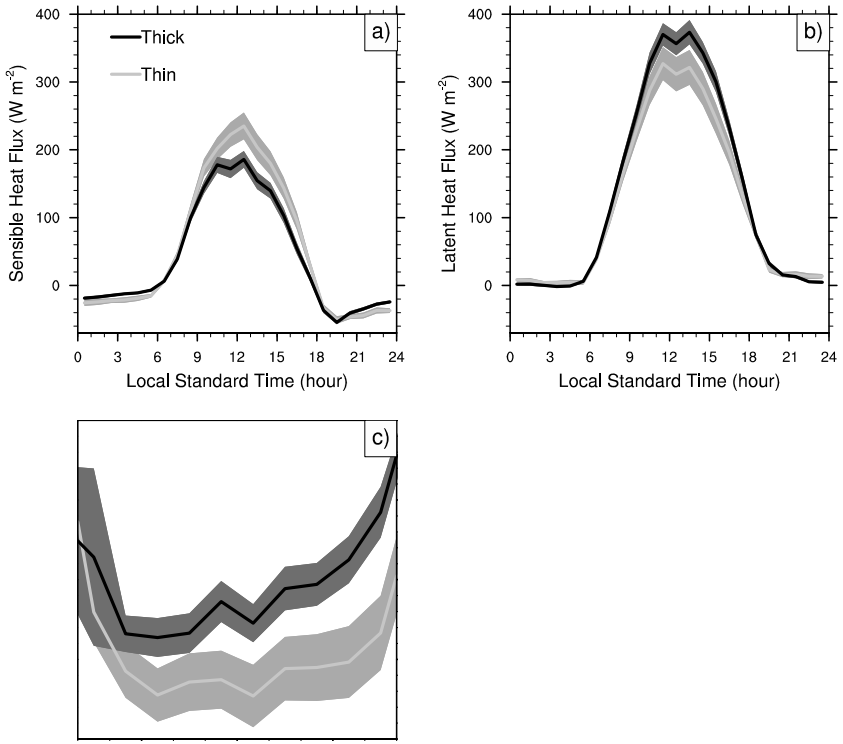
- Joe talked about it:
- Changes in surface energy partitioning (Bowen ratio)
- Change in PBL entrainment rate
- Change statistics distribution of conserved variables

Gentine et al.. (2013). A Probabilistic Bulk Model of Coupled Mixed Layer and Convection. Part II: Shallow Convection Case. *JAS*, *70*(6), 1557–1576.

# Convection triggering



- **Land-surface affects surface Bowen ratio, PBL and convective initiation**

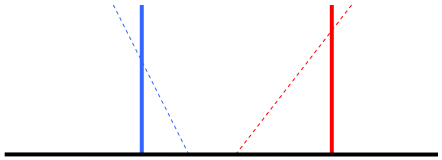


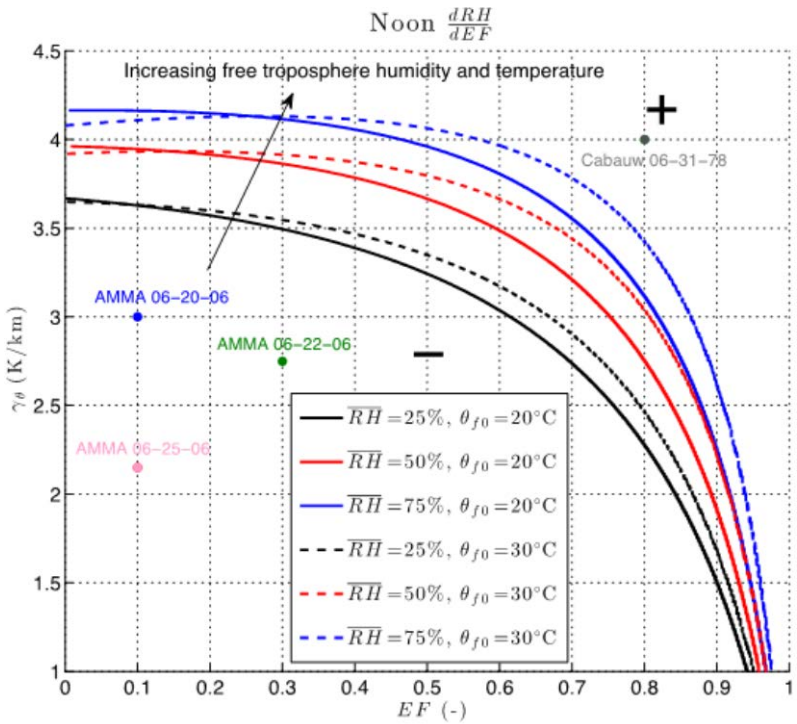

Zhang and Klein
2013, JGR-Atmo

# Convection triggering



- **Land-surface affects surface Bowen ratio, PBL and convective initiation**





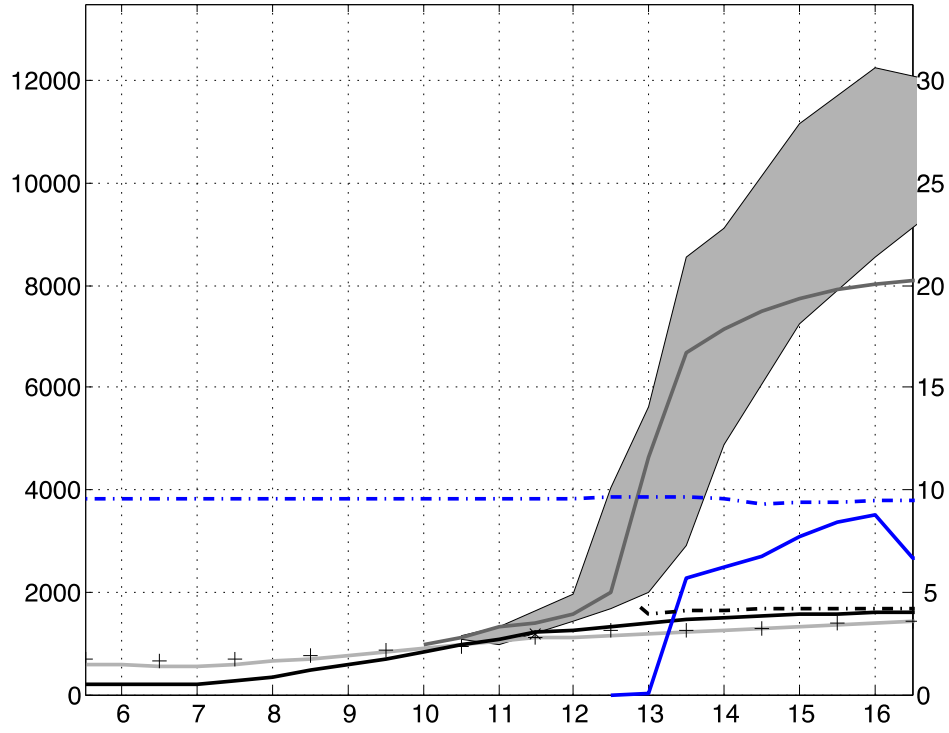

Betts et al.
2006, JGR-Atmo

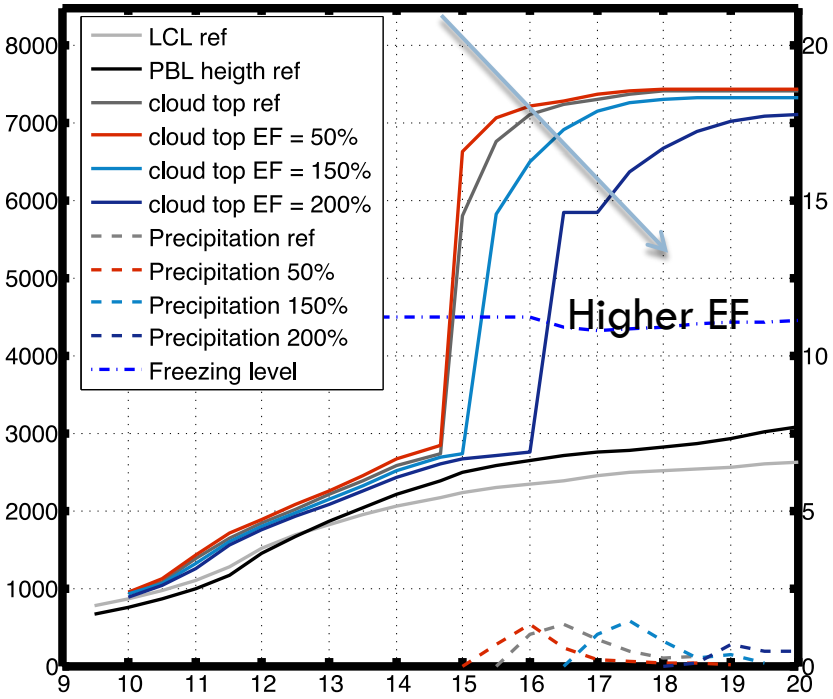
Gentine et al.
2013, JHM

# Convection triggering



- **Land-surface affects surface Bowen ratio, PBL and convective initiation**



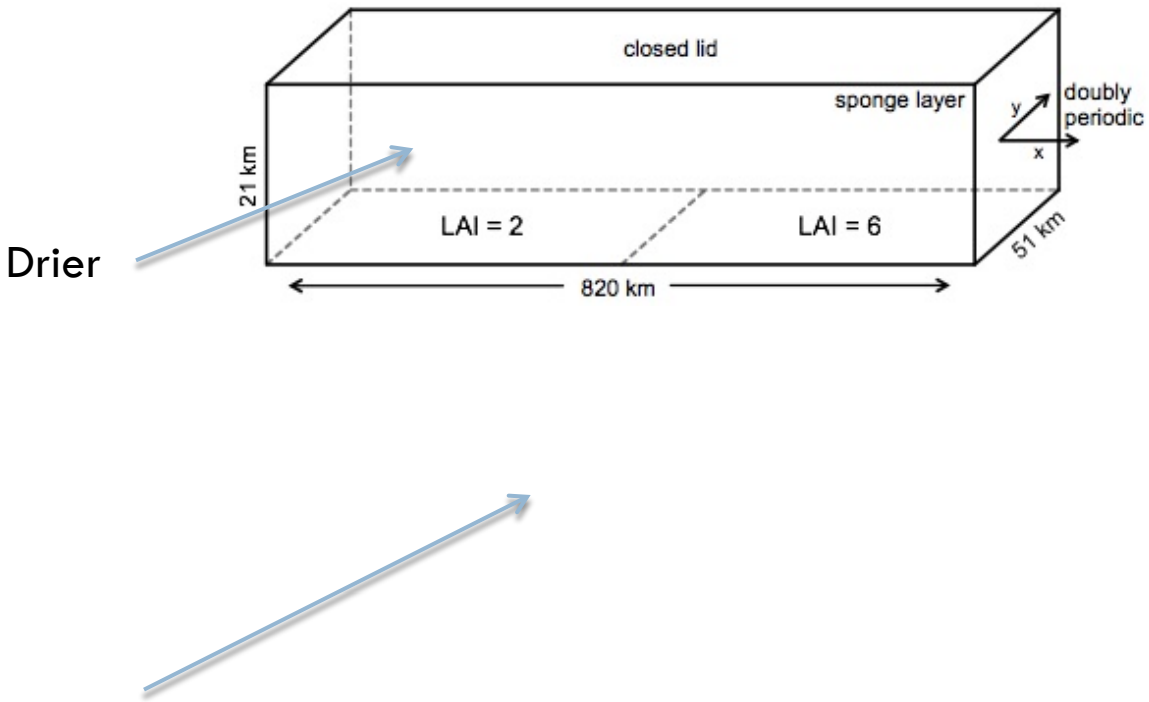




D'Andrea, Gentine, Betts, Lintner, 2014 JAS

# Convection triggering



- **Land-surface heterogeneity induces mesoscale circulation, which can trigger convection**

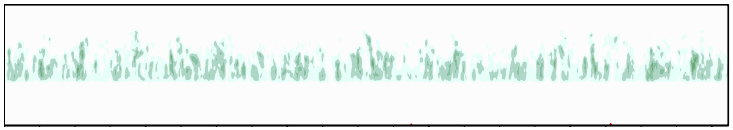


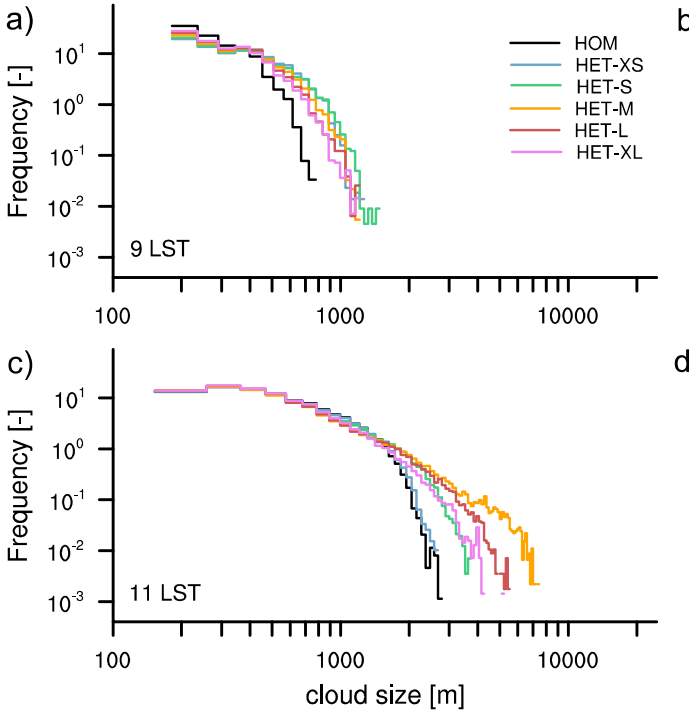

LES simulations
Rieck, Gentine and Hohenegger (2014) QJRMS Submitted

# Convection triggering



- **Land-surface heterogeneity induces mesoscale circulation, which can trigger convection**



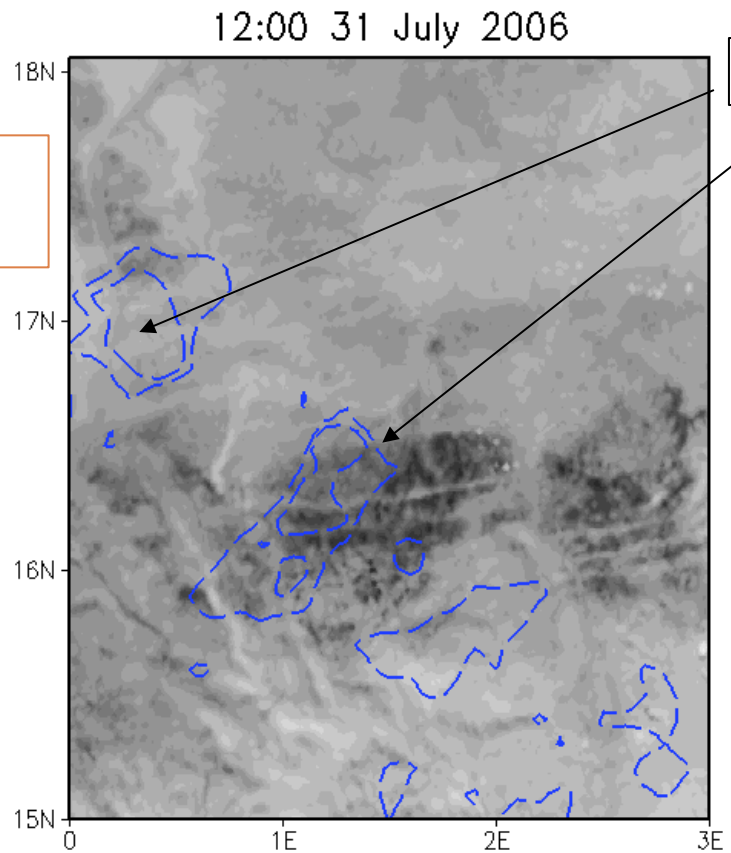



Rieck et al. 2014 WRR

# Convection triggering



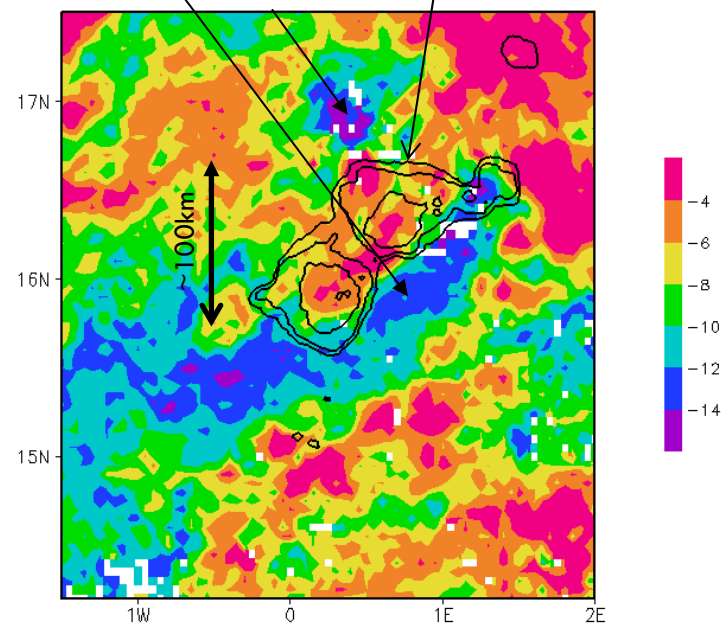
Blue contours: Land Surface Temperature anomalies (LSTA)




Visible Imagery from Meteosat

Cloud-top temperatures (-40,-50,-60C)

Cold (wet) features




Map wet/dry areas with Land Surface Temperature (LST) at ~3km (MSG/LandSAF)

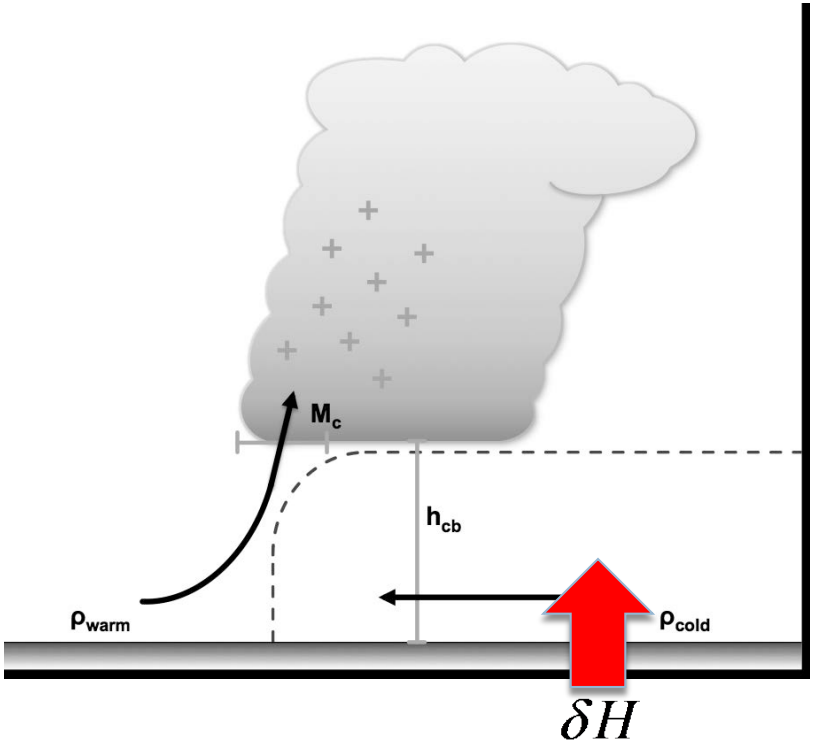
**Convective initiation along edge of wet-dry edge**

- Taylor et al, QJRMS 2010 Also Birch et al QJ 2012, Klupfel et al QJ 2012, Gantner and Kalthoff QJ 2010

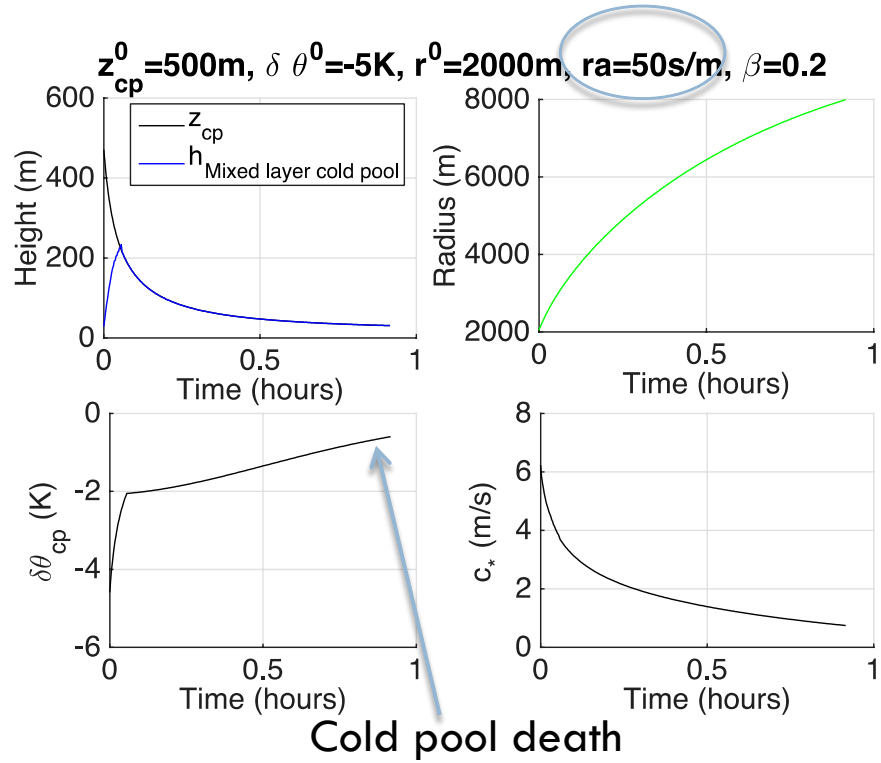
# Cold pool dynamics



- **Differential heating below cold pool relates to surface characteristics (roughness, temperature)**
- **Controls cold pool life cycle**




Rieck et al. 2014 QJRMS submitted




Cold pool prototype with Zhiming Kuang

# VOC effect on deep convection



- **Big part of GoAmazon project**
- **Example pollen:**

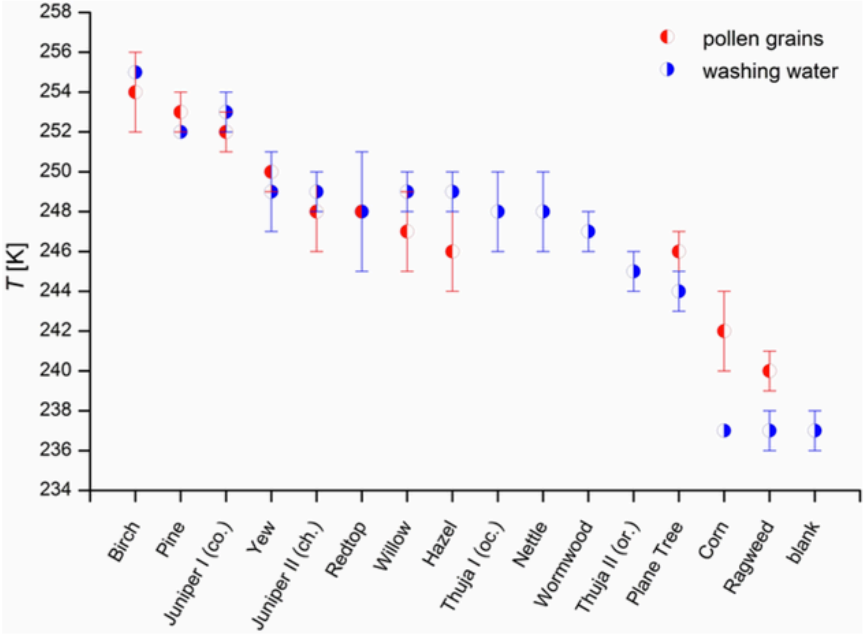


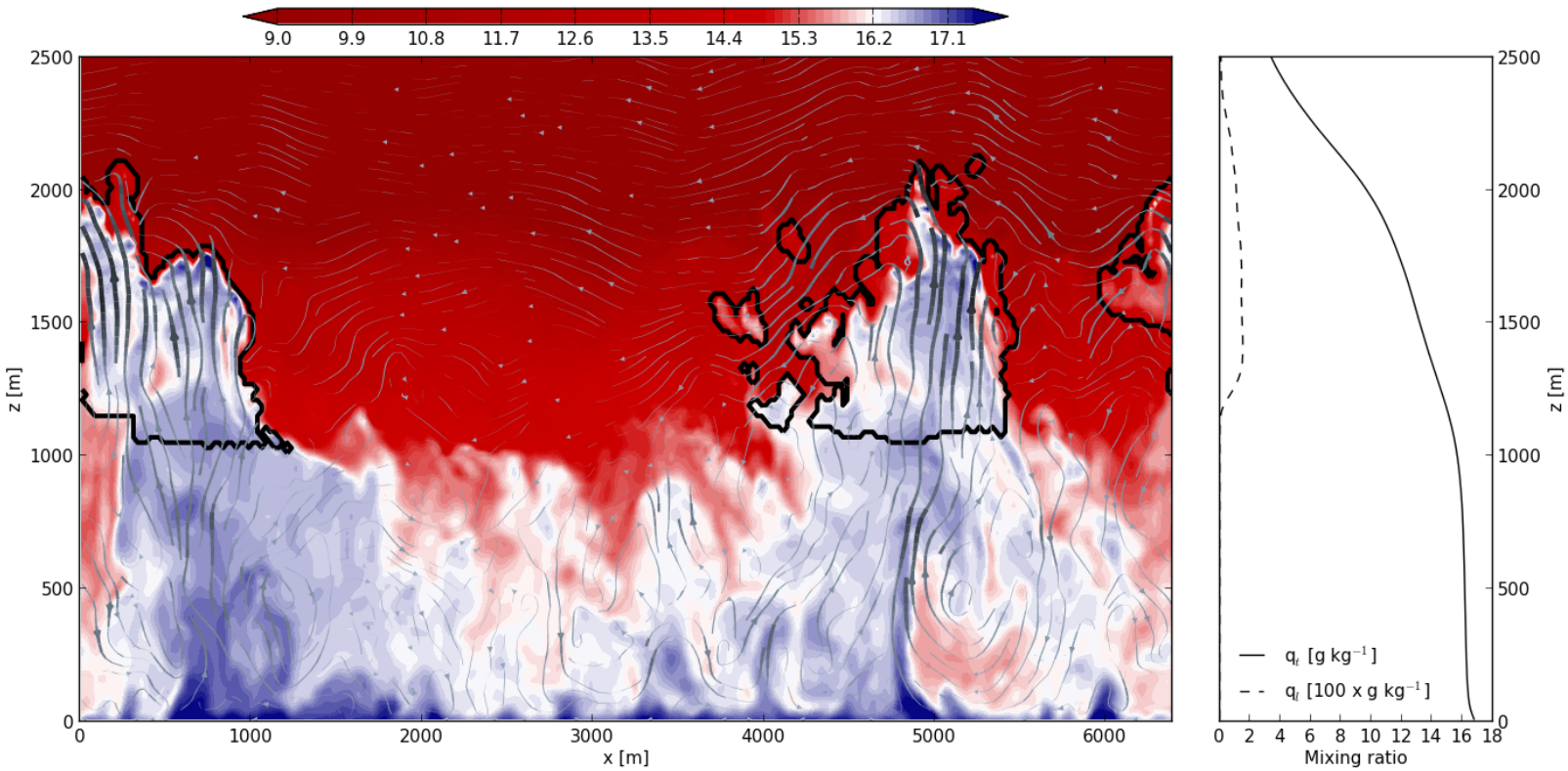

**Fig. 1.** Median freezing temperatures of different pollen samples: whole pollen grains and washing waters. The error bars mark the standard deviation rounded to integer numbers in Kelvin. If the calculated error is smaller than 0.5 K, no error bars are given.

Pummer et al. (2012) ACP

# $CO_2$ coupling



- **Photosynthesis-ET coupling through stomata: Impact on clouds (clouds roots in photosynthesis), plants like diffuse liaht**



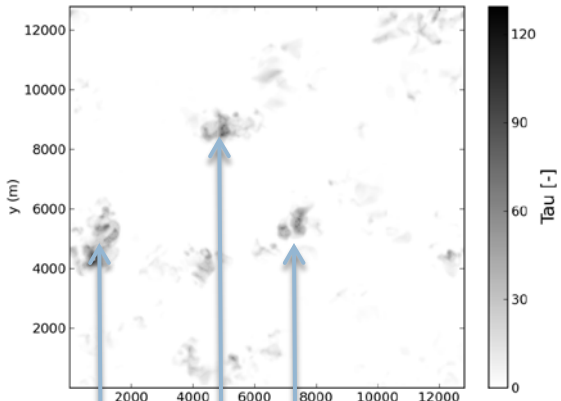

Vilà-Guerau de Arellano et al. (2013) GRL

# $CO_2$ coupling

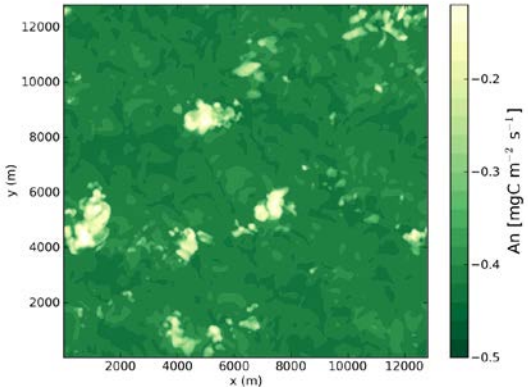


- **Photosynthesis-ET coupling through stomata: Impact on clouds (clouds roots in photosynthesis), plants like diffuse light**

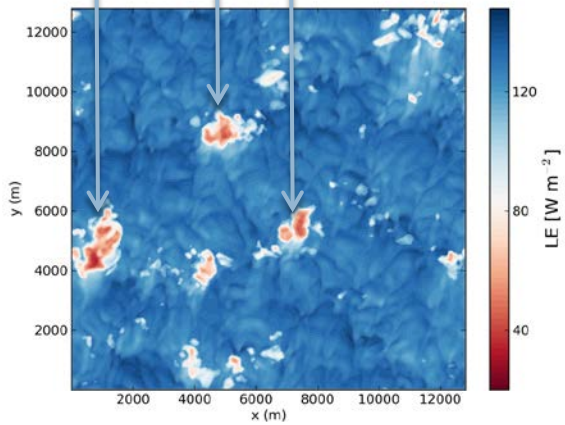
Cloud optical depth



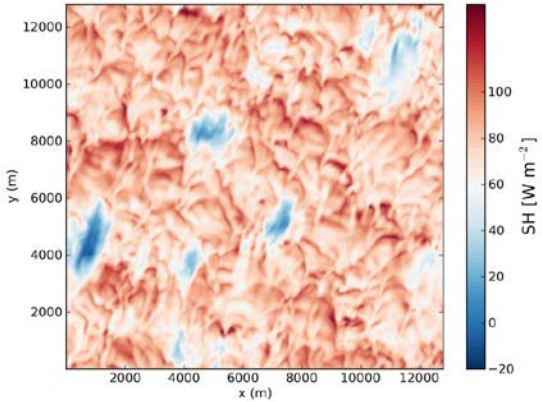

C3 grass photosynthesis



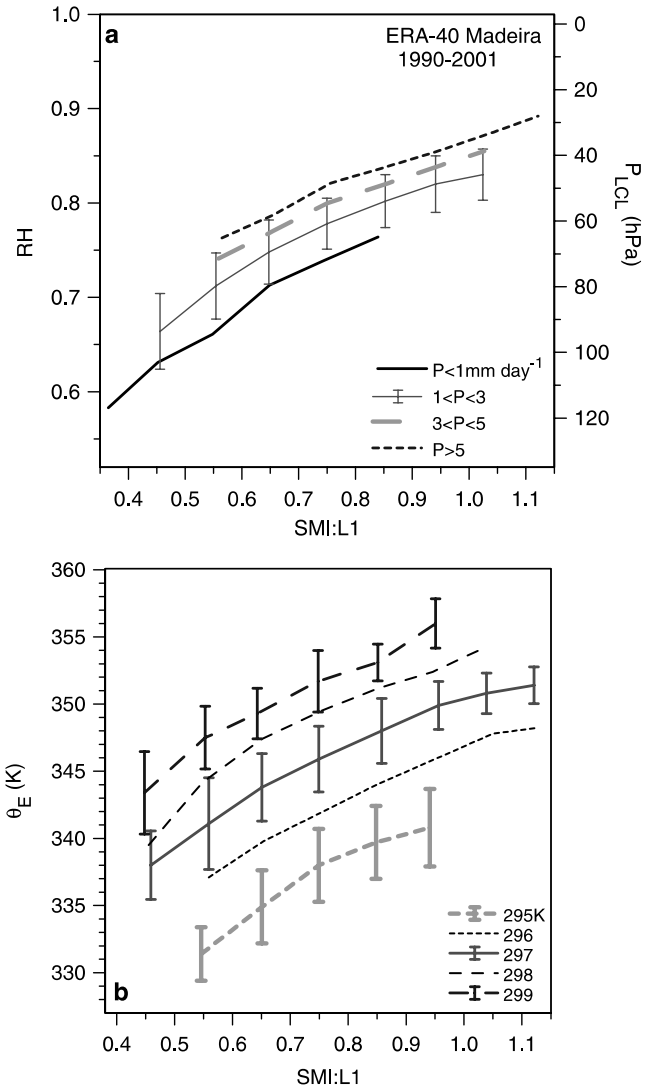

Latent heat




Sensible heat




Vilà-Guerau de Arellano et al. (2013


a
ERA-40 Madeira
1990-2001
RH
$P_{LCL}$ (hPa)
SMI:L1
P<1mm day$^{-1}$
1<P<3
3<P<5
P>5
b
$\theta_E$ (K)
SMI:L1
295K
296
297
298
299

# Challenges: assessing the feedback



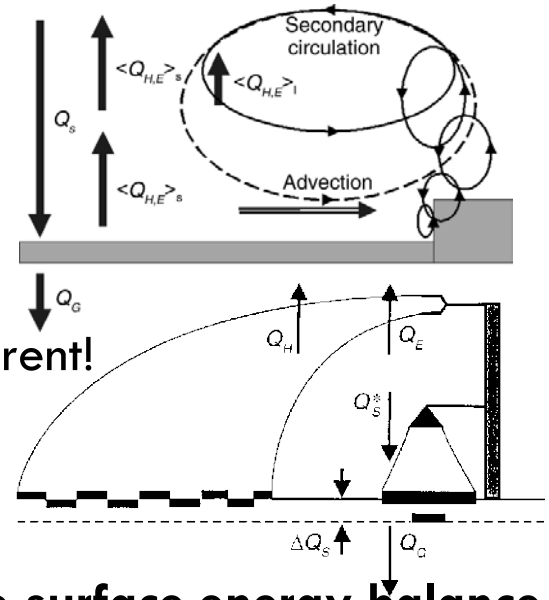
- **We have several options:**

  - **Observations**
  - **Numerical simulations**
  - **Theory**

# What are our strategies?



- **Observations limitations:**
- We do not close the **surface energy budget** (~20% error)
- 1) Large eddies (coherent structures) not "seen" by eddy-covariance system (short-time average miss large eddies)
- 2) Surface heterogeneity induce circulation not integrated by eddy-covariance system



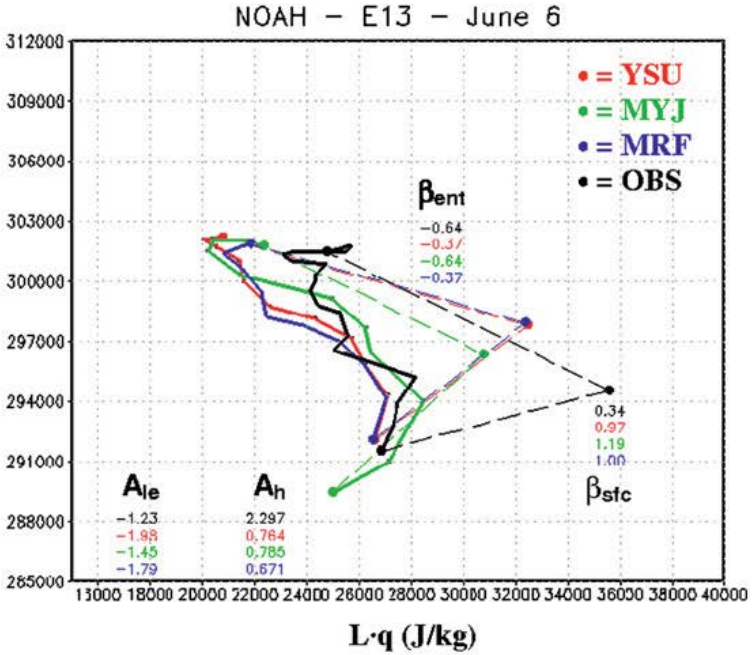

- 3) Footprints are just different!
- Need for **new large-scale surface energy balance measurements**

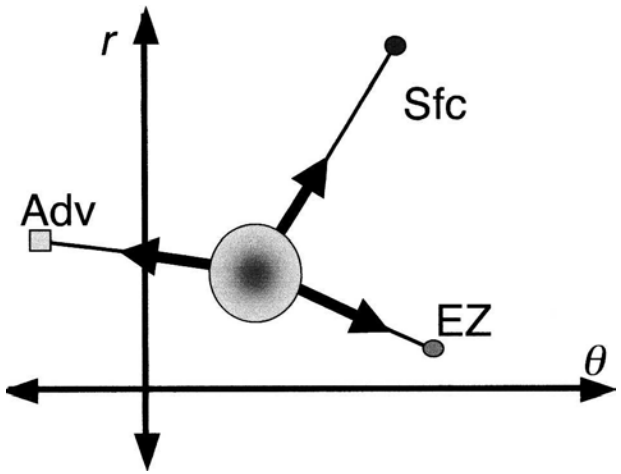
# What are our strategies?



- **Observations:**

  define metrics to isolate feedback (locally)




Santanello, J. A., Jr., et al. (2009). A Modeling and Observational Framework for Diagnosing Local Land–Atmosphere Coupling on Diurnal Time Scales. *Journal of Hydrometeorology*, *10*(3), 577–599. doi:10.1175/2009JHM1066.1

Berg, L. K., & Stull, R. B. (2005). A simple parameterization coupling the convective daytime boundary layer and fair-weather cumuli. *Journal of the Atmospheric Sciences*, *62*(6), 1976–1988.

# What are our strategies?



- **Observations:**

  define metrics to isolate feedback (apply similar methodology – continental size)

$$TFS = \sigma_{EF} \frac{\partial \text{freq(Rain)}}{\partial EF}$$

$$AFS = \sigma_{EF} \frac{\partial \text{Intensity(Rain)}}{\partial EF}$$

Findell, K. L., P. Gentine, B. R. Lintner, and C. Kerr (2011), Probability of afternoon precipitation in eastern United States and Mexico enhanced by high evaporation, *Nat Geosci*, *4*(7), 434–439, doi:10.1038/NGEO1174.

# What are our strategies?



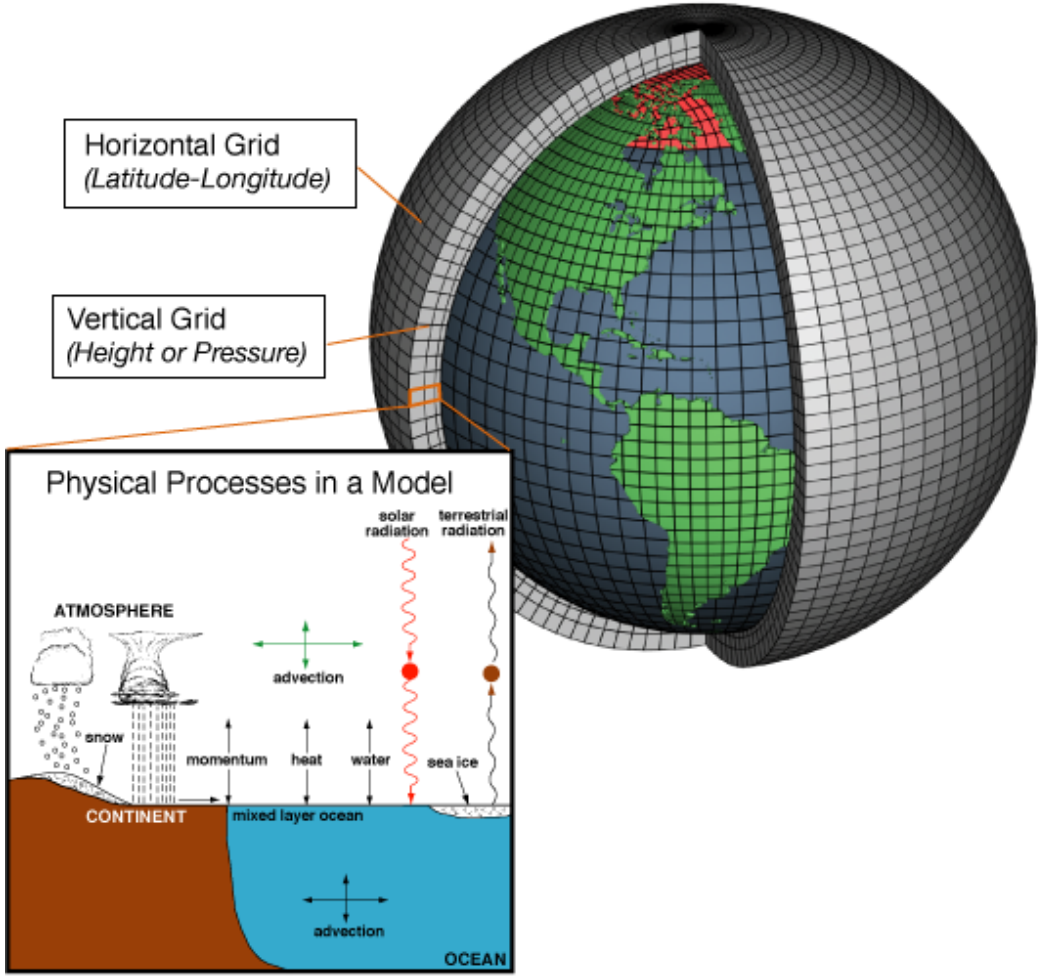
- **Observations limitations:**
- Many variables are **not observed** (e.g. soil moisture, evapotranspiration…)
- Only statistical link: **no causality**

Sugihara, G., R. May, H. Ye, C. H. Hsieh, E. Deyle, M. Fogarty, and S. Munch (2012), Detecting causality in complex ecosystems, *Science*, 338(6106), 496–500, doi:10.1126/science.1227079.

# What are our strategies?



- **Climate models:**



# What are our strategies?



- **Climate models:**

  define an experiment to isolate feedback (e.g. GLACE: impose soil moisture)

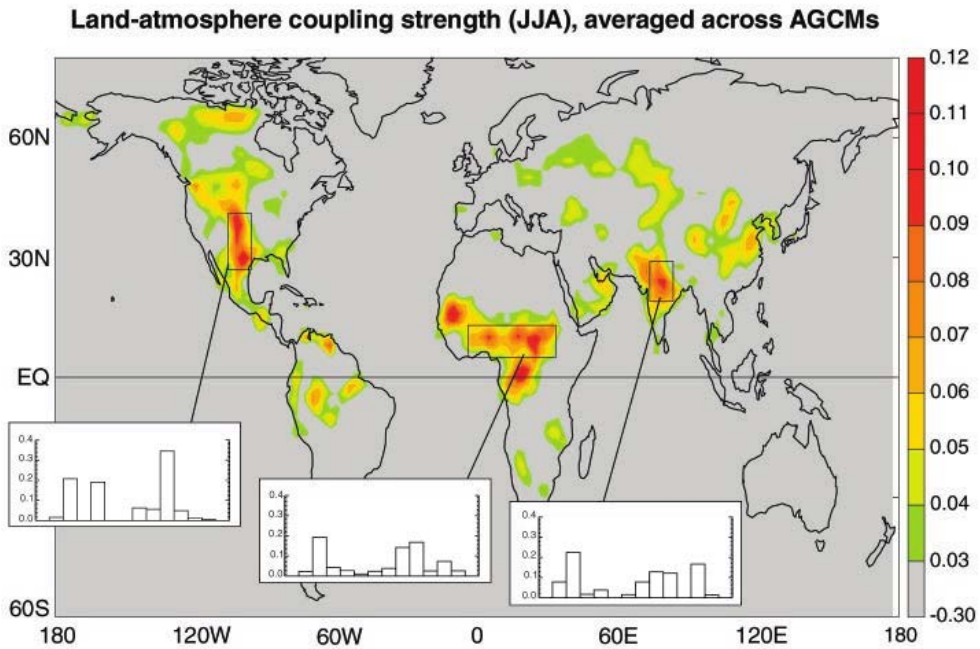



**Fig. 1.** The land-atmosphere coupling strength diagnostic for boreal summer (the Ω difference, dimensionless, describing the impact of soil moisture on precipitation), averaged across the 12 models participating in GLACE. (**Insets**) Areally averaged coupling strengths for the 12 individual models over the outlined, representative hotspot regions. No signal appears in southern South America or at the southern tip of Africa.

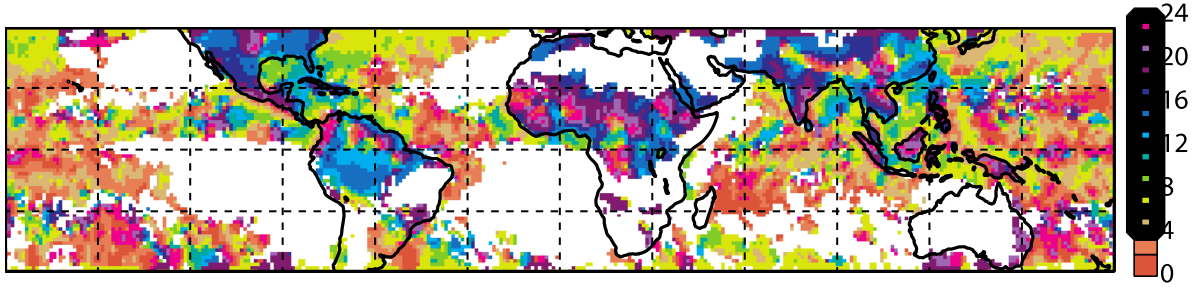
Koster, R. D. et al. (2004), Regions of strong coupling between soil moisture and precipitation, *Science*, *305*(5687), 1138–1140.

# What are our strategies?



- **Climate models: problem:**
  - Difficult to understand all feedbacks (advection, local effects)
  - Precipitation over continents is not good

    Diurnal bias/drizzle
    (convective parameterization problem)

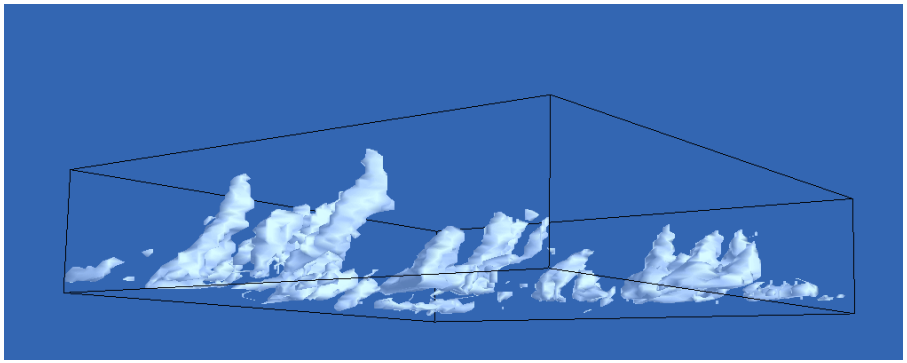


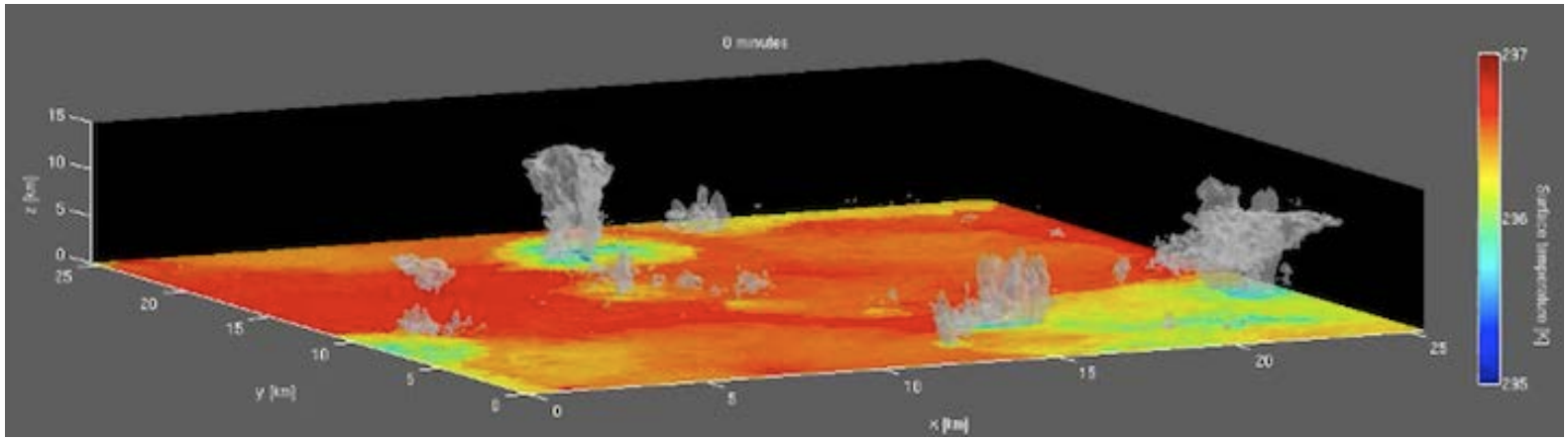

Bechtold, P., N. Semane, P. Lopez, J.-P. Chaboureau, A. Beljaars, and N. Bormann (2013), Representing equilibrium and non-equilibrium convection in large-scale models, *J Atmos Sci*, 130919100122007, doi:10.1175/JAS-D-13-0163.1.

# What are our strategies?



- **Cloud resolving models (CRM):**
  - Higher resolution, can resolve convection






Courtesy Caroline Muller, Ladhyx, France

# What are our strategies?



- **Cloud resolving models (CRM):**
  - Feedback between soil moisture and precipitation even **changes sign**, at 2km: **explicit convection** is a **game changer**
    - Good news but we specify the large-scale! Too strong constraint…

Hohenegger, C., P. Brockhaus, C. S. Bretherton, and C. Schaer (2009), The Soil Moisture-Precipitation Feedback in Simulations with Explicit and Parameterized Convection, *J Climate*, *22*(19), 5003–5020, doi:10.1175/2009JCLI2604.1.

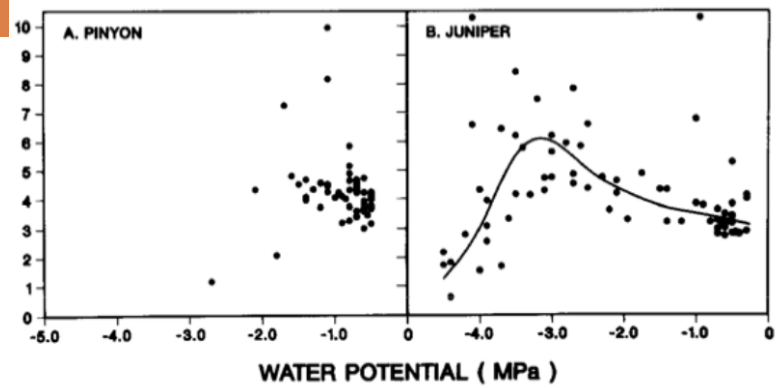
downgraded onto the 25-km grid.

# LA interactions summer school 2015



- Alpine Summer School
- Valsavarenche, Valle d'Aosta (Italy), **22 June - 1 July, 2015**
- Directors of the Course:
  Pierre Gentine - Columbia University, NY, USA
  Albert A. M. Holtslag - Wageningen University, The Netherlands
- Lecturers:
  Joe Santanello - NASA, USA
  Alan Betts - Atmospheric Research, USA
  Anton Beljaars - ECMWF, UK Kirsten Findell - NOAA/GFDL, USA
  Gabriel Katul - Duke Univ., NC, USA
  Dara Entekabi - MIT, MA, USA
  Dennis Baldocchi - UC Berkeley, CA, USA
  Sonia Seneviratne - ETH, Switzerland
  Cathy Hohenegger - MPI, Germany
  Chiel van Heerwaarden - MPI, Germany
  Jordi Vila-Guerrau - Wageningen Univ., The Netherlands
  Gert-Jan Steeneveld - Wageningen Univ., The Netherlands
  John Finningan - CSIRO, Australia
  Chris Taylor - CEH Wallingford, UK
  Benjamin Lintner - Rutgers Univ., NJ, USA
  Guido Salvucci - Boston Univ., MA, USA
- Program:
  Ecophysiology, surface hydrology, soil-plant-atmosphere continuum, turbulence, surface fluxes, boundary layer, shallow and deep convection, coupling to large scale, data assimilation
- Website: http://www.to.isac.cnr.it/aosta/

# How is this related to $CO_2$?

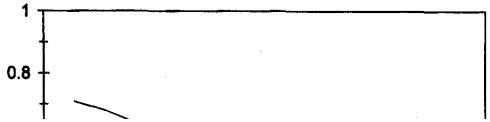


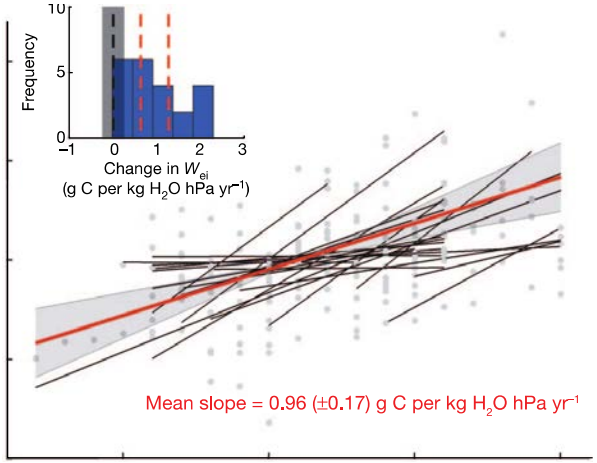

ure 2. Instantaneous water use efficiency versus predawn xylem pressure potential for (A) phytotror
wn pinyon pine, (B) phytotron-grown juniper.

$$wue(\psi_s)$$

$EF_d$ and the midday evaporative fraction $EF_m$ have been determined. $EF_m$ is calculated as the ratio between the midday evaporation and the midday available energy and $EF_d$ as the ratio between the mean evaporation ($\lambda E_d$) and the mean available energy ($A_d$) during the daytime. The daytime, $d$, is taken as the period when the sensible heat flux is positive ($H > 0$), i.e. when the coupling between the surface and the mixed-layer occurs. It corresponds approximately to the time of day when $A = R_n - G > 0$. The duration of $d$ depends upon the amount of solar radiation, but it is always shorter than the day length $\delta$, defined as the duration between sunrise and sunset. However, most of the evaporation process occurs during $d$.

$$EF(\psi_s)$$




$$GPP = wue\ EF\ R_n$$

How will this change with increased CO2: most likely increased wue (based on FluxNet data)