Cloud and land surface interactions

Cathy Hohenegger[1] and Christoph Schär[2]

[1] Max Planck Institute for Meteorology, Hamburg, Germany
[2] ETH Zurich, Zurich, Switzerland

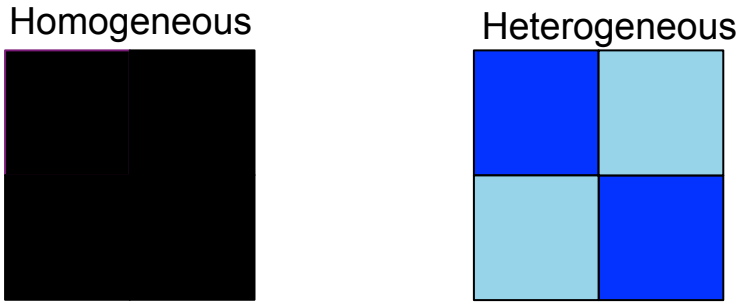
Outline

1. **Basic concepts and processes**

2. **Feedbacks**
    1. Static heterogeneity
    2. Homogeneous surface conditions
    3. Dynamic heterogeneity

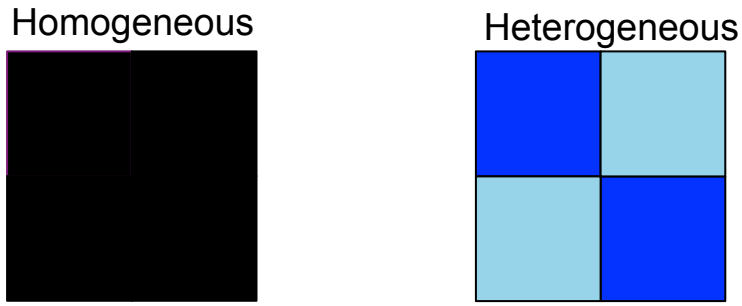
3. **Extremes**

Static heterogeneity



Surface conditions are spatially heterogeneous and vary on a much longer timescale than cloud/precipitation process

Static heterogeneity



Surface conditions are spatially heterogeneous and vary on a much longer timescale than cloud/precipitation process

1. Basic principle
2. Effects on clouds and precipitation
3. Examples
4. Open issues

Static heterogeneity induces a mesoscale circulation:

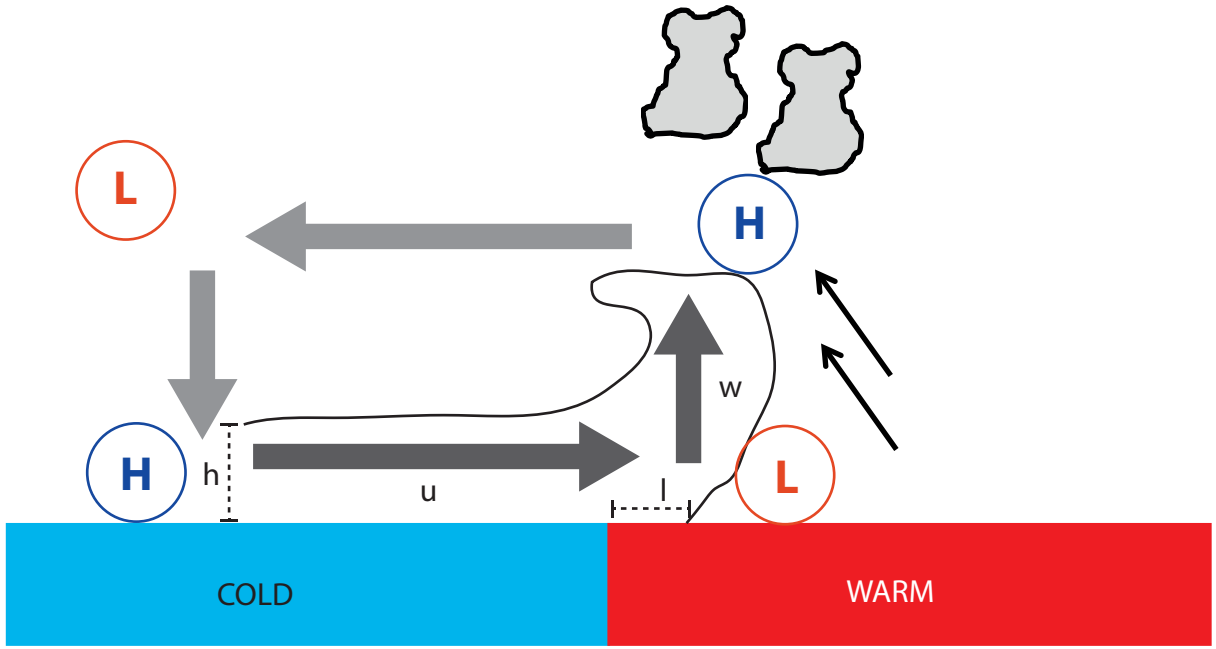
▪ Mountain-valley wind	Height differences
▪ Land-sea breeze	Sea <-> Land
▪ Lake breeze	Lake <-> Land
▪ River breeze	River <-> Land
▪ Vegetation breeze	Different plant cover types

- **Halley 1686**: An historical account of the trade winds, and monsoons, observable in the seas between and near the tropicks, with an attempt to assign physical cause of said winds
- **Buchan 1860**: Handy book of meteorology
- **Davis et al. 1889**: An investigation of the sea-breeze
- **Schmidt F.H. 1947**: An elementary theory of the land- and sea breeze circulation
- **Haurwitz, B 1947**: Comments on the sea-breeze circulation

The cause of the land and sea breeze is that the land is “heated to a much greater degree than the sea during the day, by which the air resting on it being also heated, ascends, and the cooler air of the sea breeze flows in to supply its place. But during the night the temperature of the land and the air above it falls below that of the sea, and the air thus becoming heavier and denser flows over the sea as a land breeze” quoted from Buchan (1860)

Basic principle

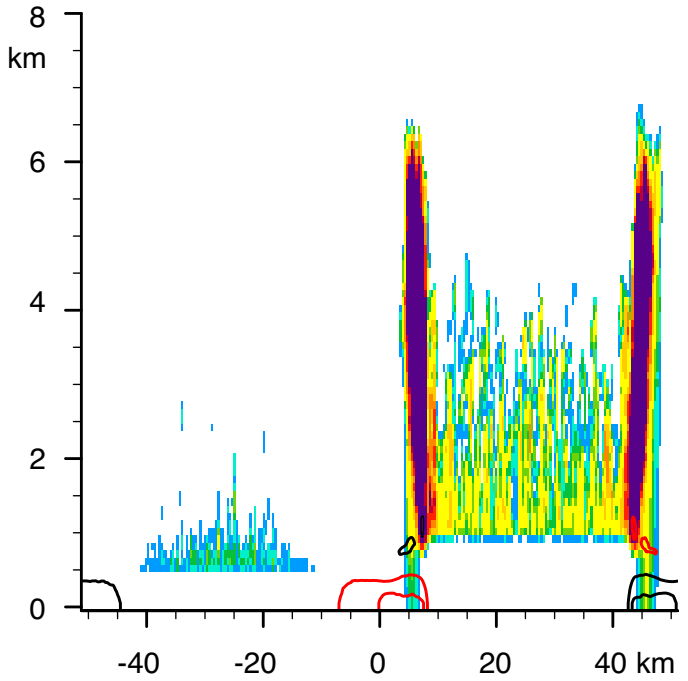
Static heterogeneity



- Crosman and Horel (2010)
- Antonelli and Rotunno (2007)

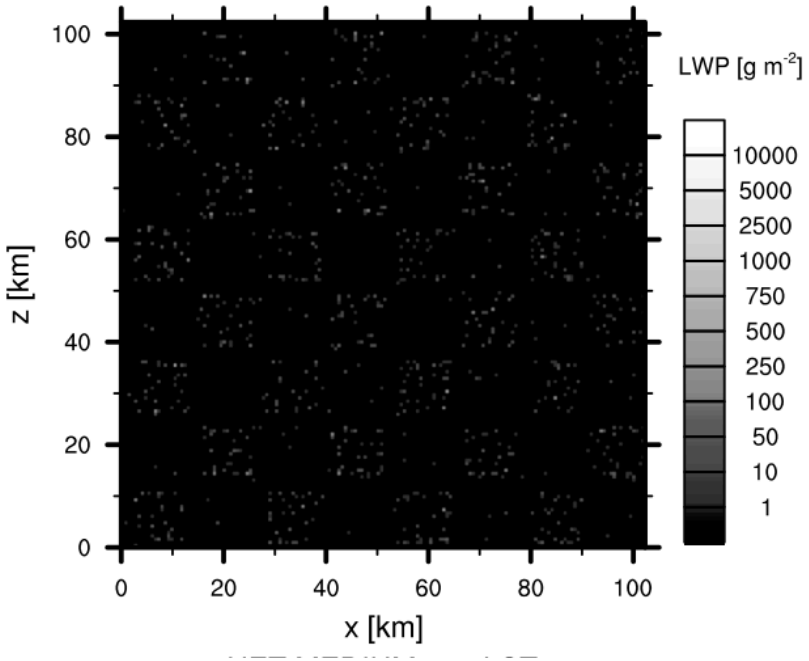
On a heterogeneous surface:

- Clouds favored at the breeze front
  - Zone of upward motion
  - Lower CIN (Garcia-Carreras et al. 2011)
  - Higher relative humidity (van Heerwaarden, C. C. and J. Vilà - Guerau de Arellano, 2008)

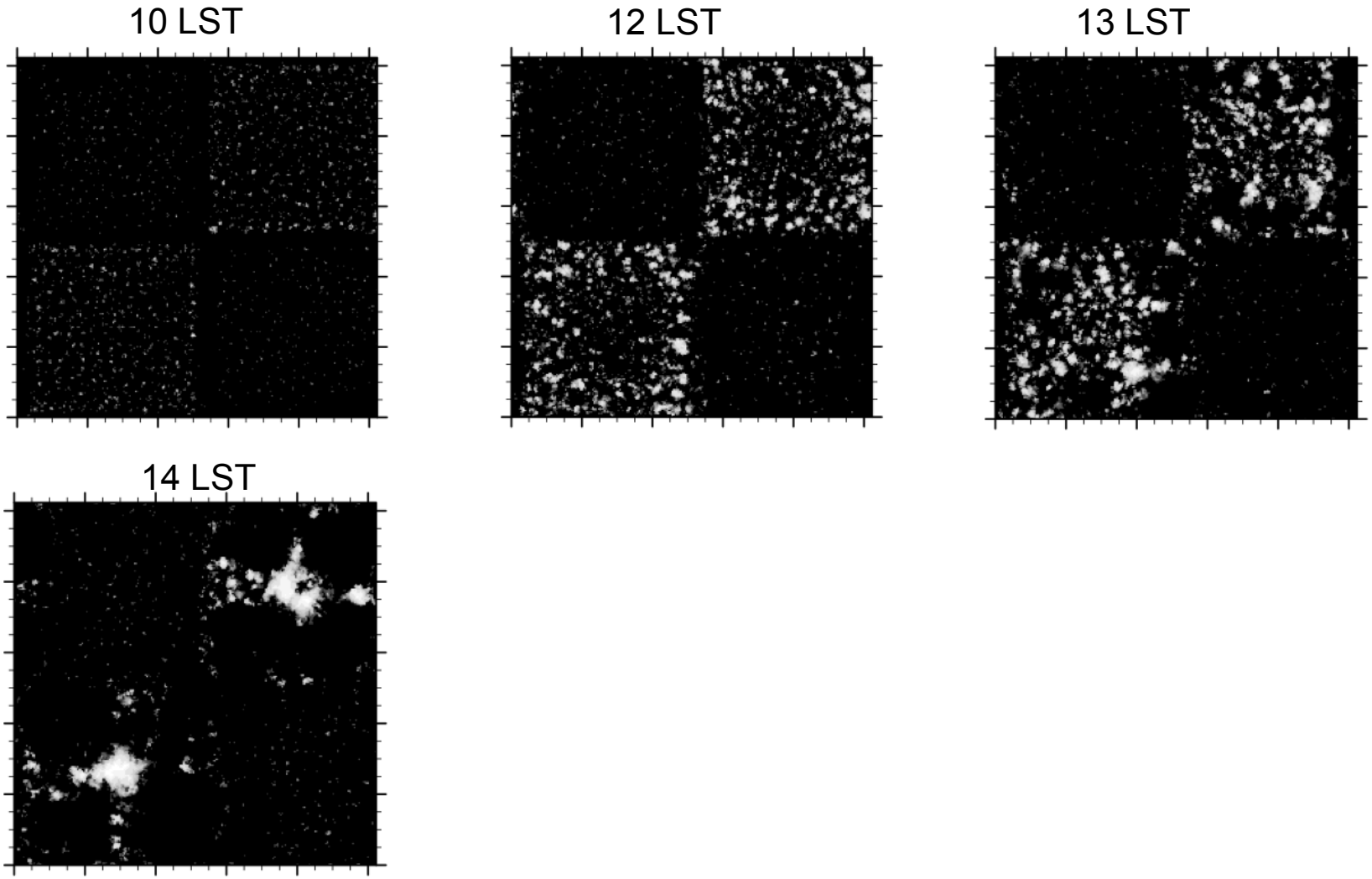


On a heterogeneous surface:

- Clouds favored at the breeze front
- Earlier clouds/precipitation on the dry patch (Kang and Bryan 2011)

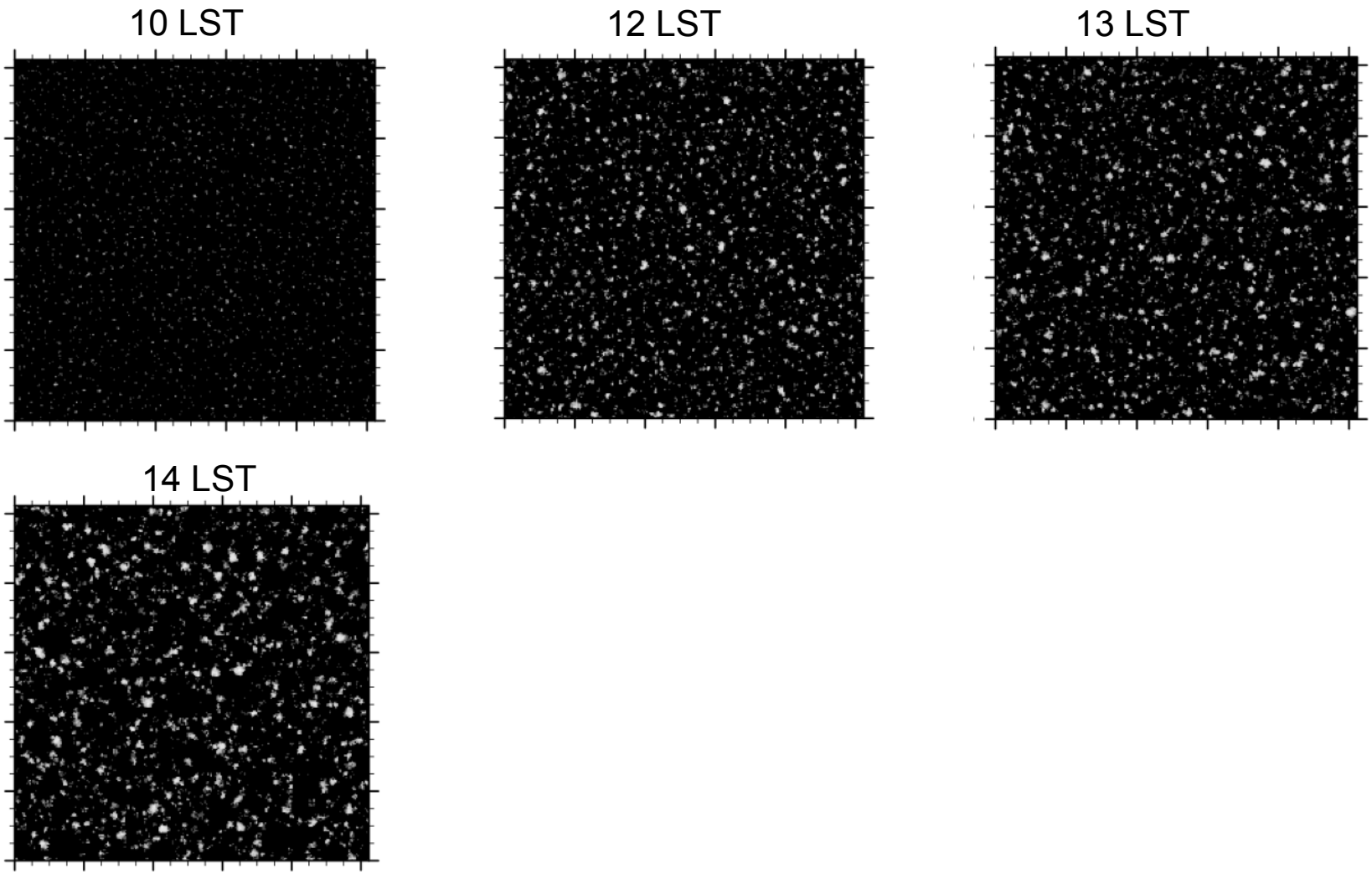


Effects on clouds/precipitation — Static heterogeneity



(Malte Rieck)

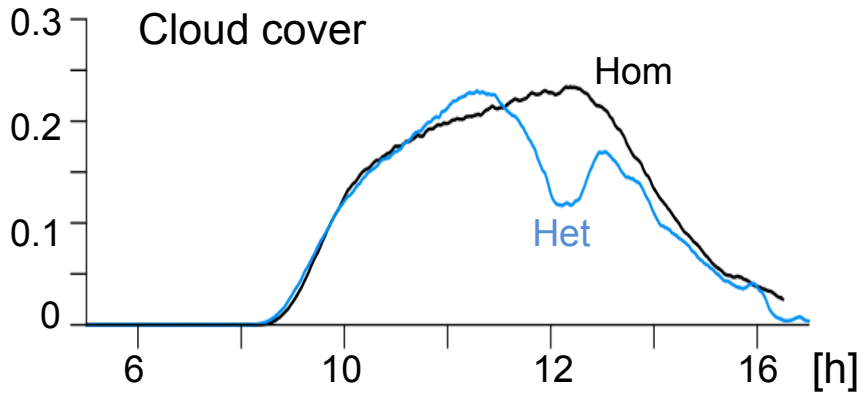
Effects on clouds/precipitation — Static heterogeneity



(Malte Rieck)

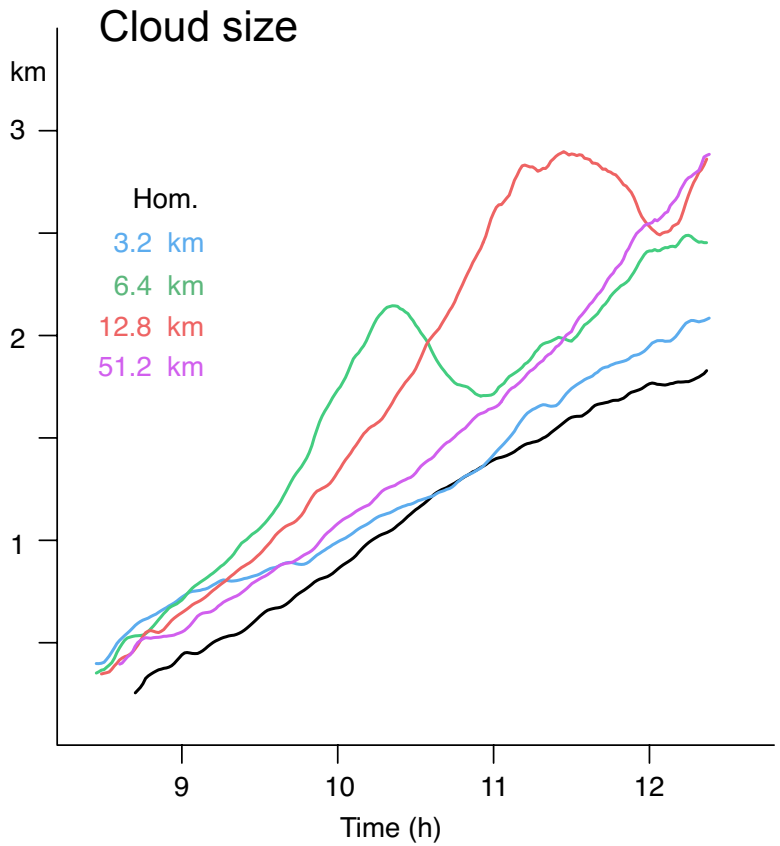
Heterogeneous <-> Homogeneous

- Changes in cloud cover related to changes in precipitation



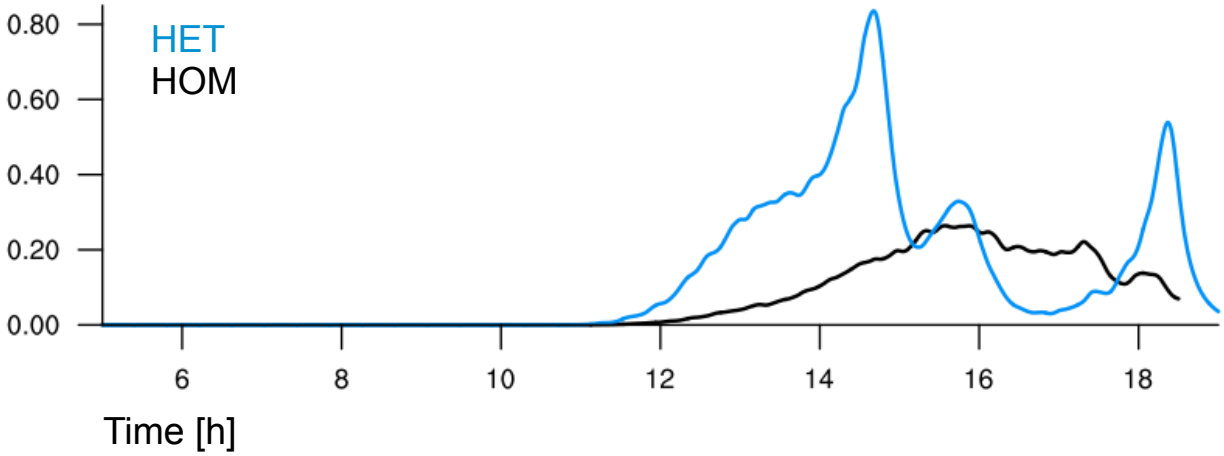
Heterogeneous <-> Homogeneous

- Changes in cloud cover related to changes in precipitation
- Influence of heterogeneity on cloud size



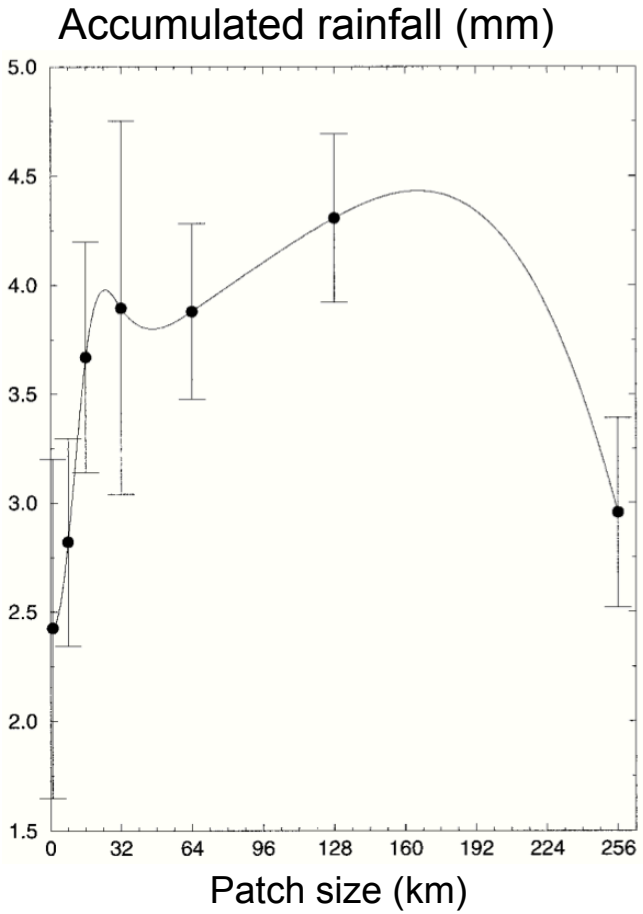
Heterogeneous <-> Homogeneous

- Changes in cloud cover related to changes in precipitation
- Influence of heterogeneity on cloud size
- Changes in precipitation timing and amount

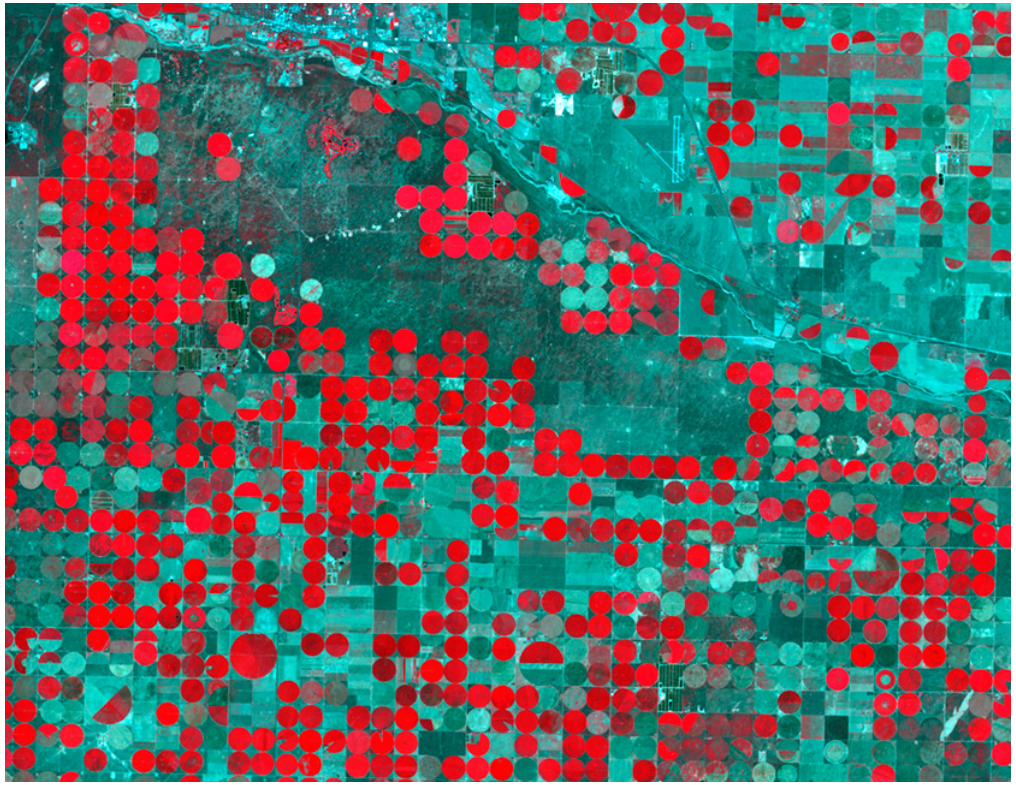


Heterogeneous <-> Homogeneous

- Changes in cloud cover related to changes in precipitation
- Influence of heterogeneity on cloud size
- Changes in precipitation timing and amount
- Precipitation maximized at the Rossby radius of deformation (Lynn et al. 1997)

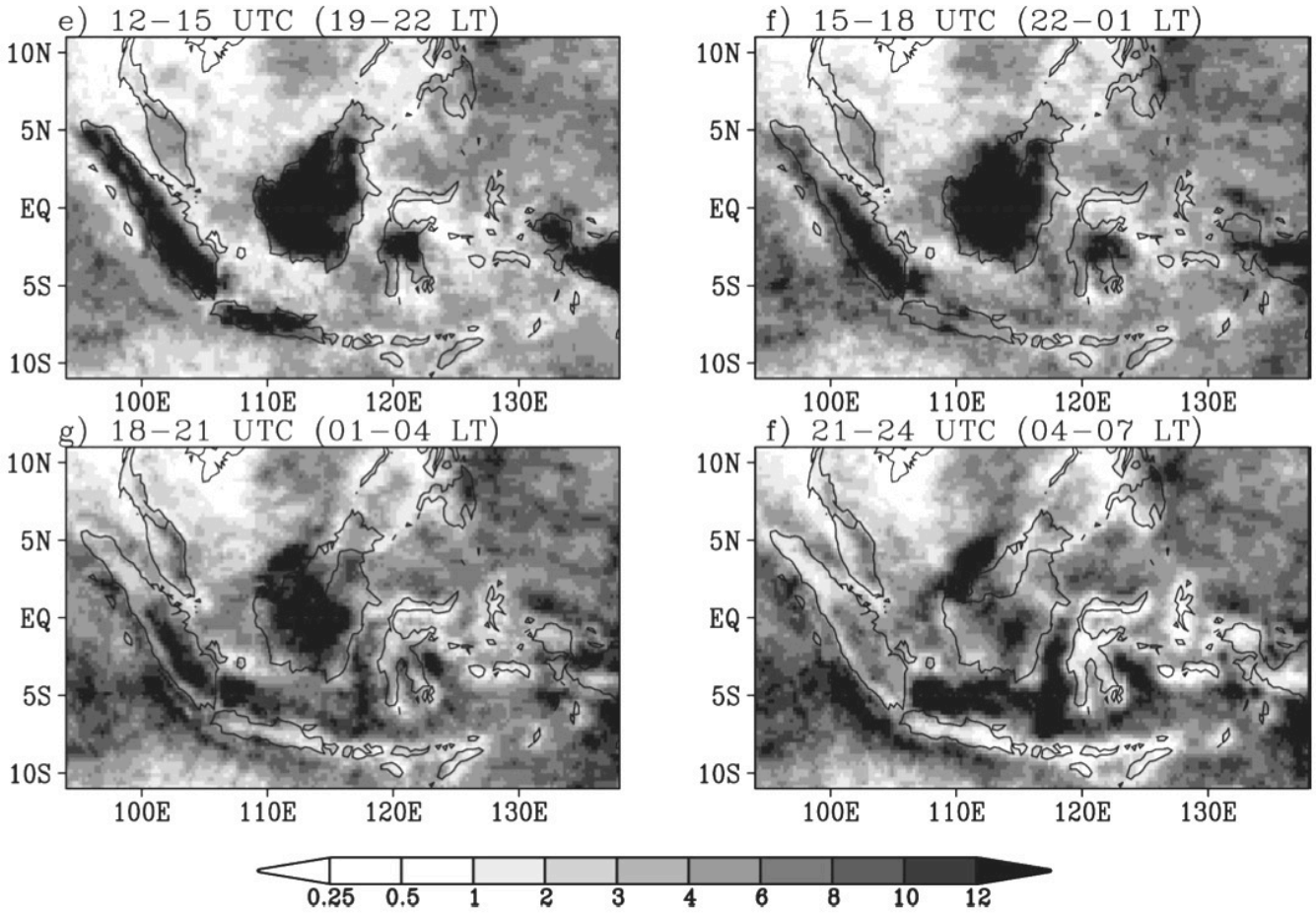


- Largest effect to be expected for heterogeneities of scale O(100 km)
- Atmosphere acting as a filter



(Landsat)

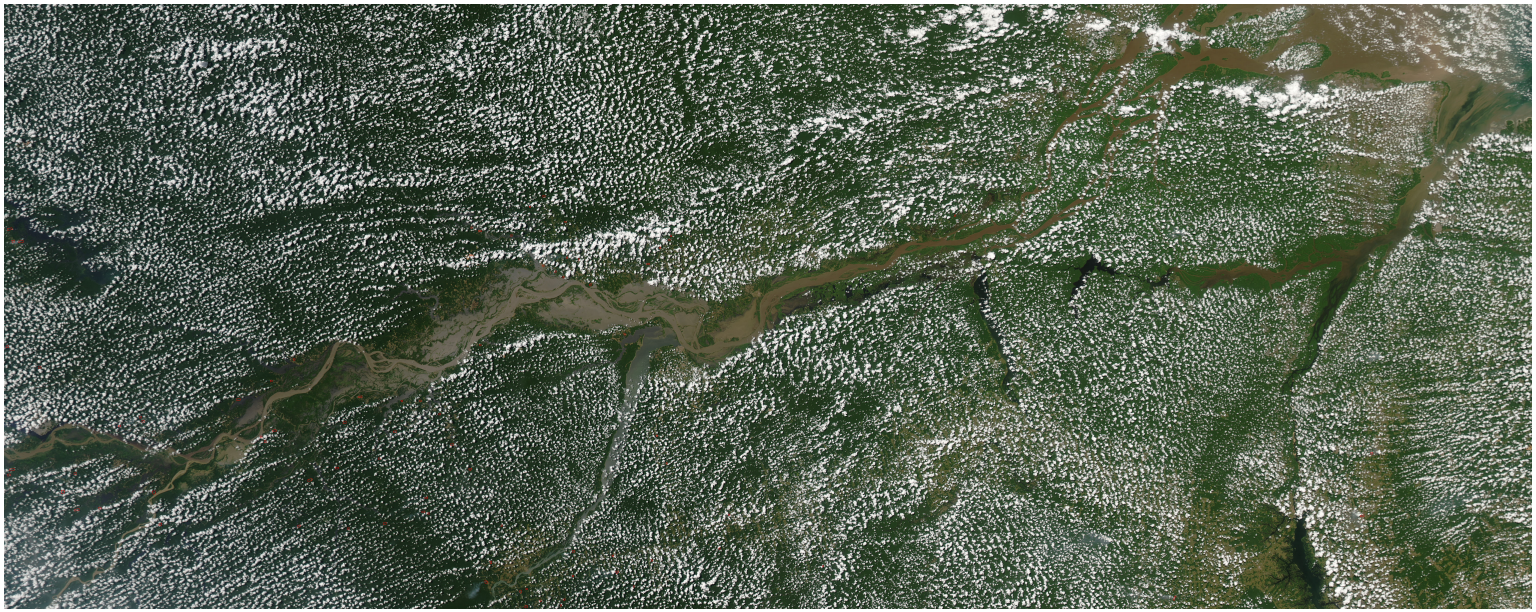
- Land-sea breeze and mountain-valley wind, Maritime continent



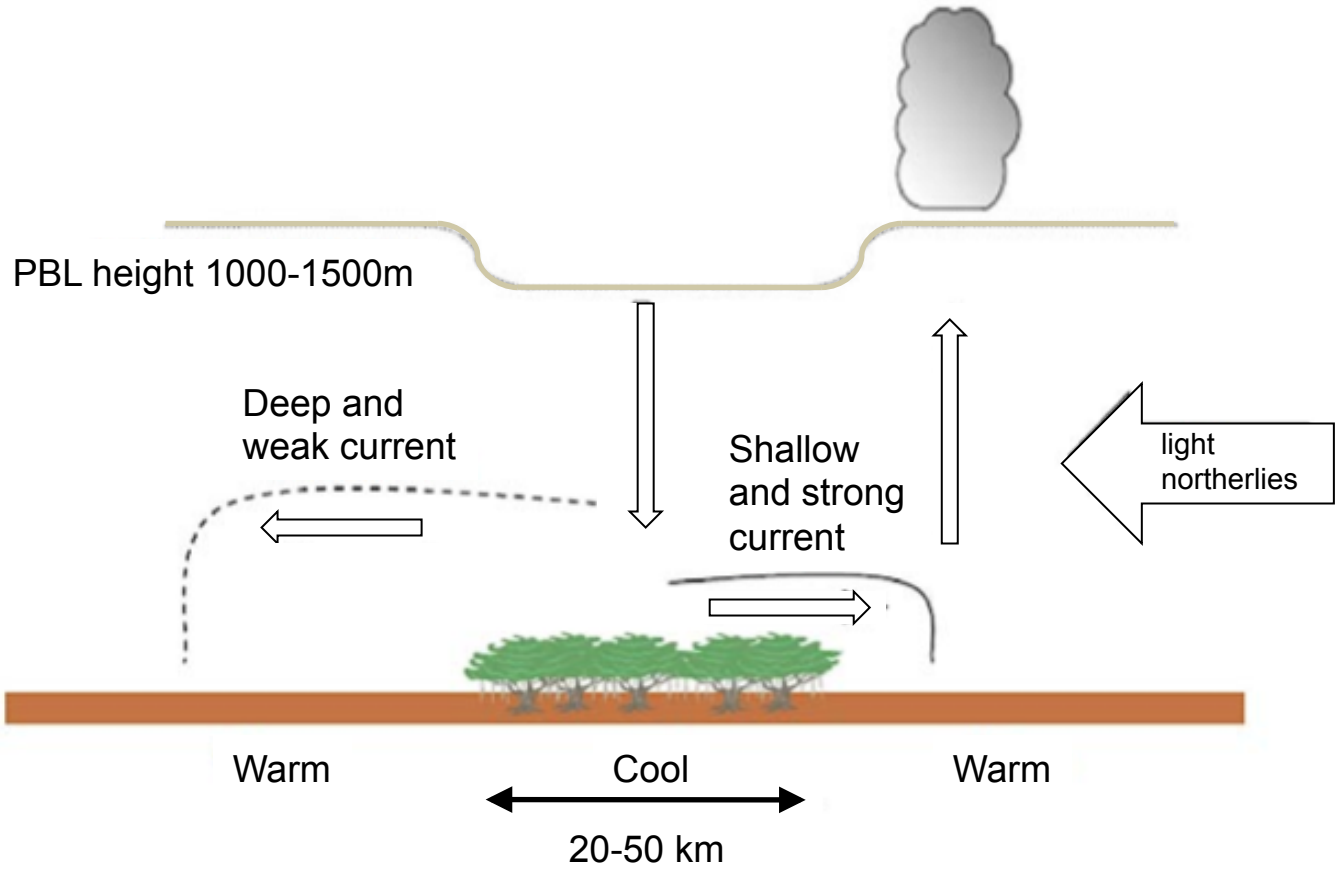
(Qian 2008)

- Lake Breeze, lake Eire

- River Breeze, Amazon

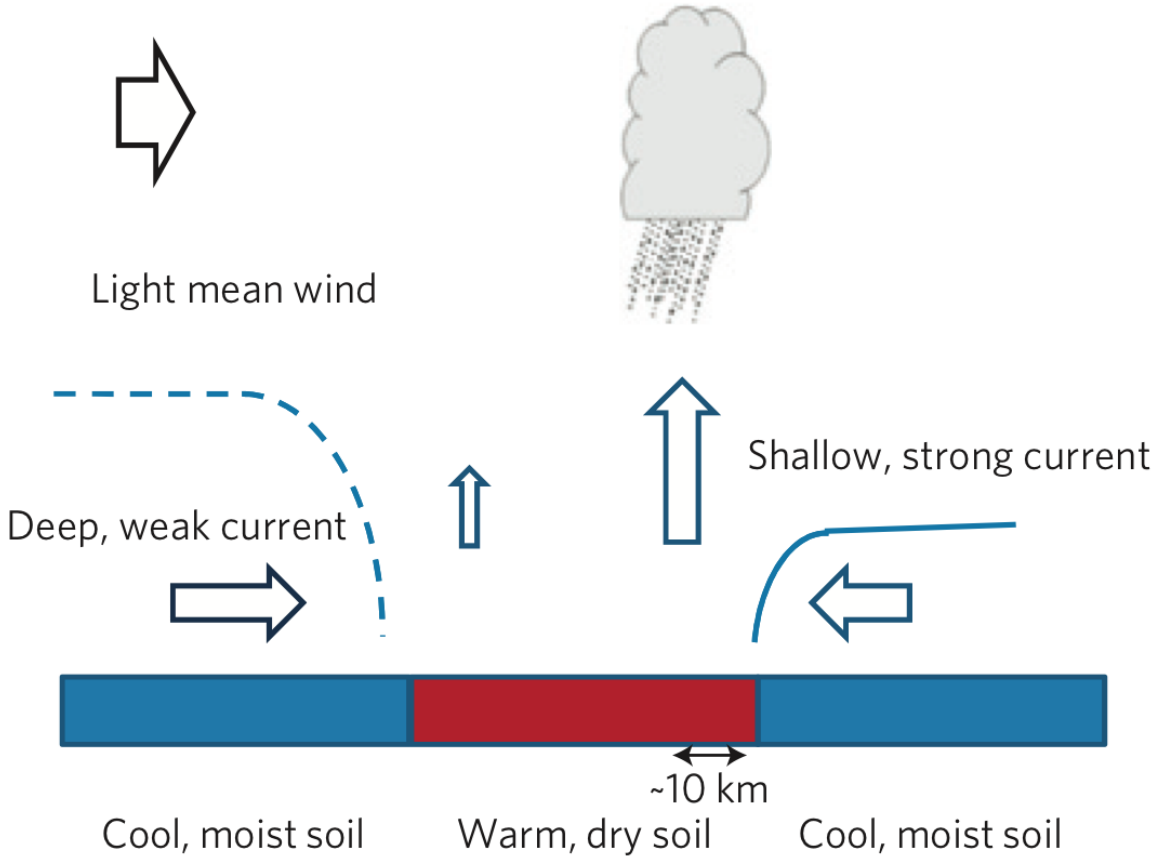


- Vegetation breeze, tropics, Benin



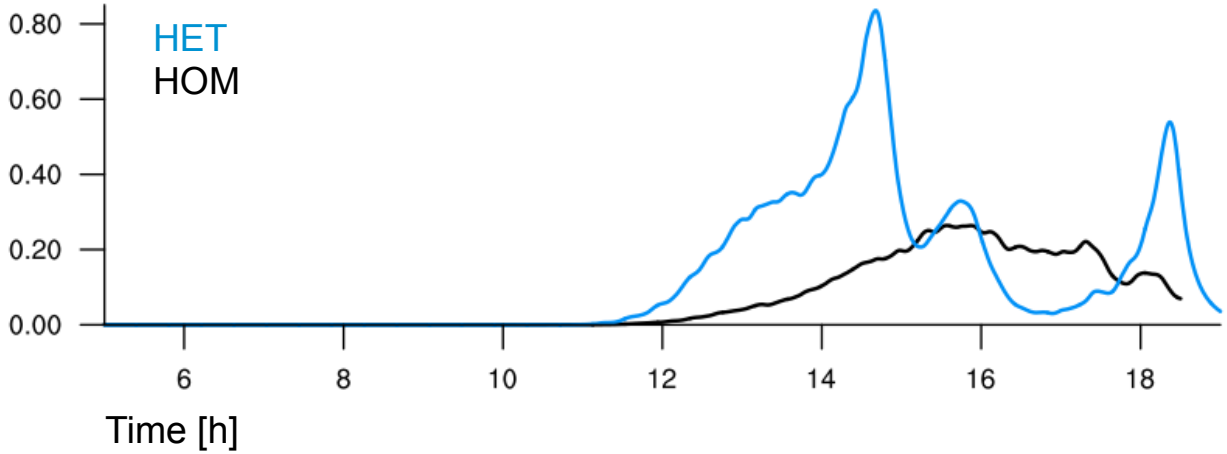
(Garcias-Carreras et al. 2010)

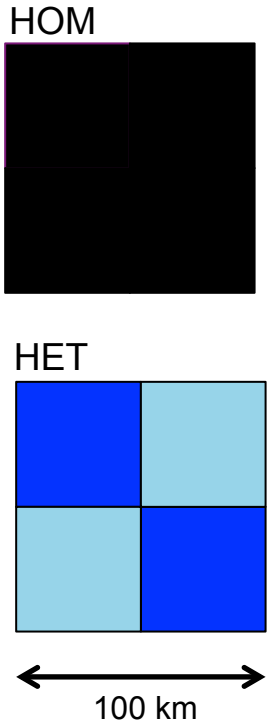
- Soil breeze, semi-arid, Sahel



(Taylor et al. 2011)

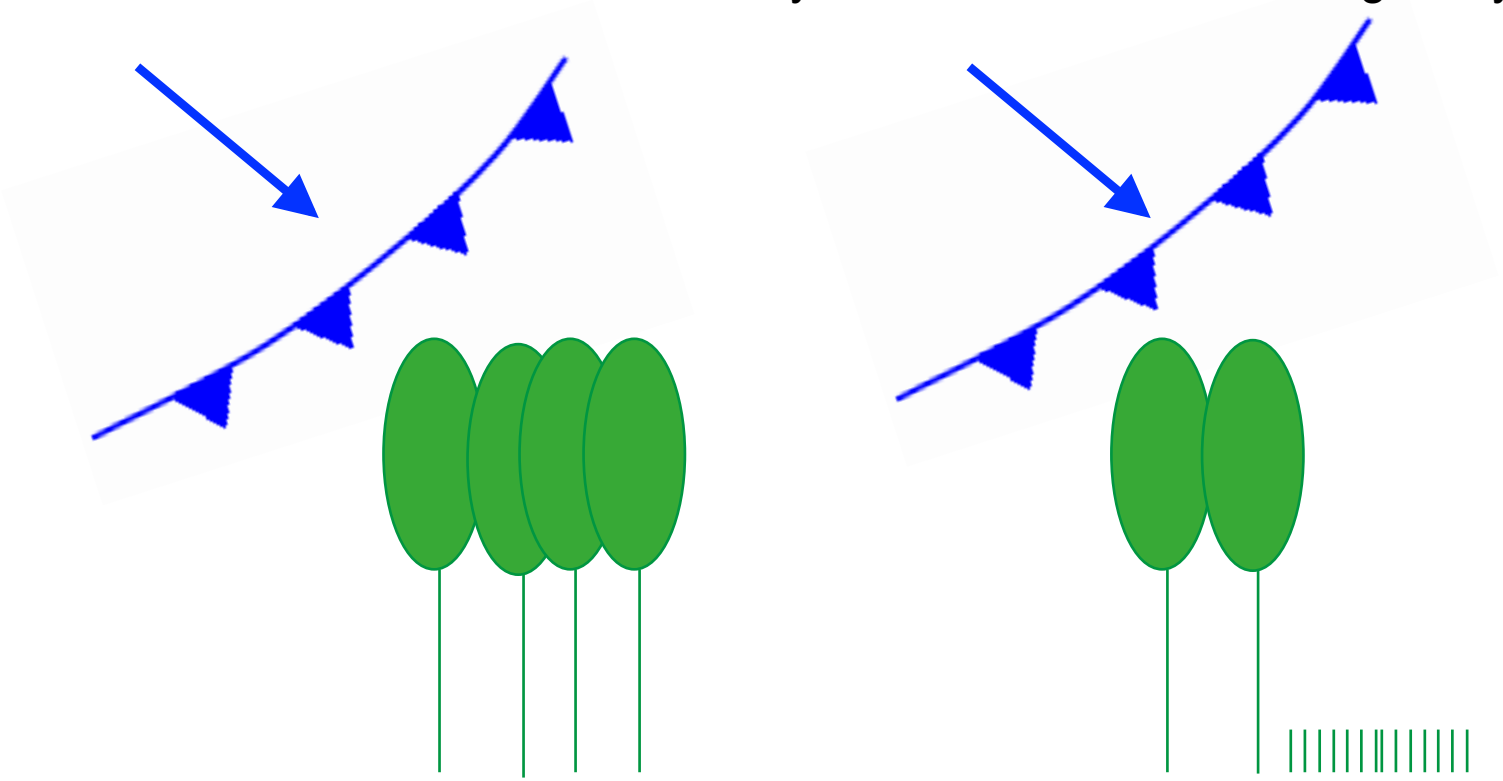
- Representation in GCM





(Malte Rieck)

- Representation in GCM
- Interaction of fronts/convective systems with surface heterogeneity



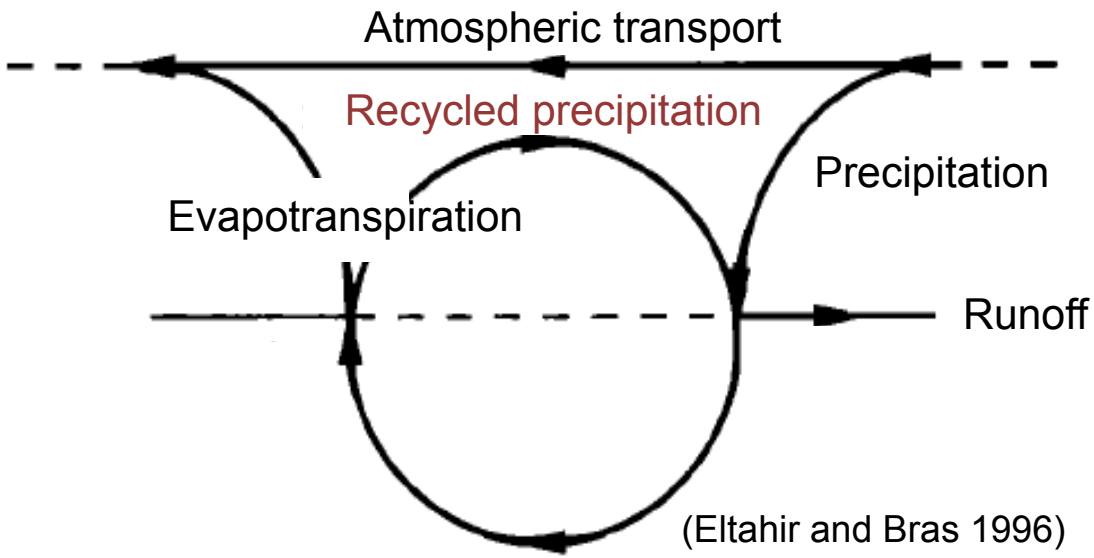
Outline

1. **Basic concepts and processes**

2. **Feedbacks**
    1. Static heterogeneity
    2. Homogeneous surface conditions
    3. Dynamic heterogeneity

3. **Extremes**

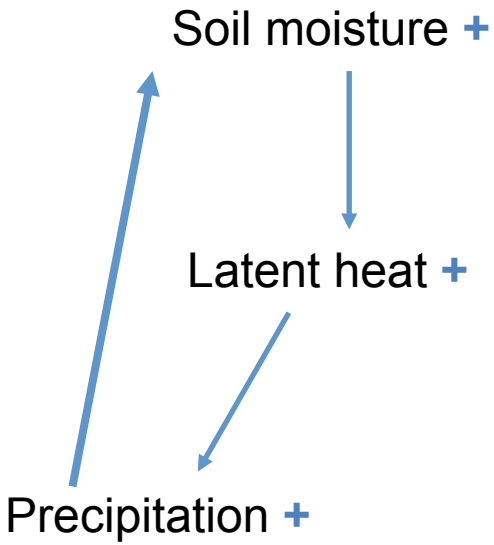
Homogeneous surface conditions

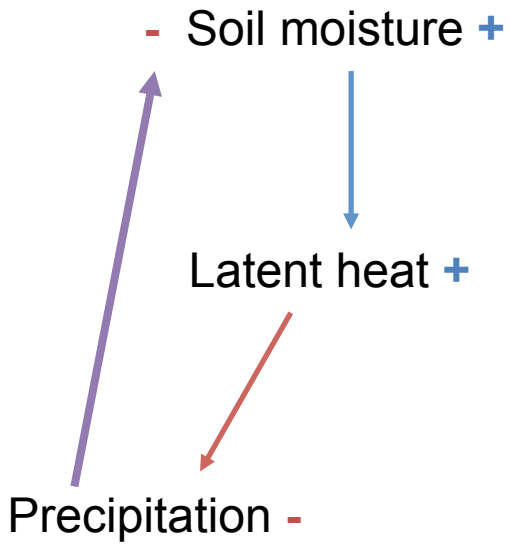


- How does evapotranspiration and precipitation couple?
- Does an increase in soil moisture increase precipitation?

Feedbacks

Homogeneous surface conditions

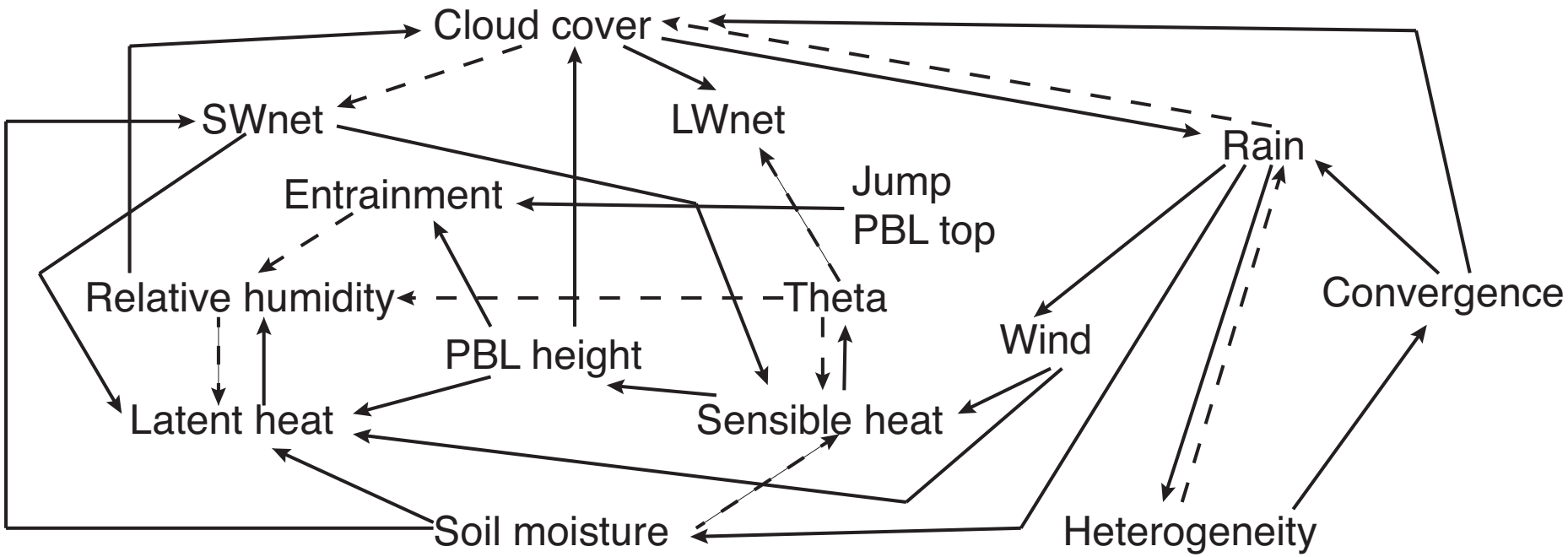




- Positive feedback
- Long soil moisture memory
- Key for seasonal predictions

- Negative feedback

A mess….


Cloud cover
SWnet
LWnet
Rain
Entrainment
Jump
PBL top
Relative humidity
Theta
Convergence
Wind
PBL height
Latent heat
Sensible heat
Soil moisture
Heterogeneity

Homogeneous surface conditions

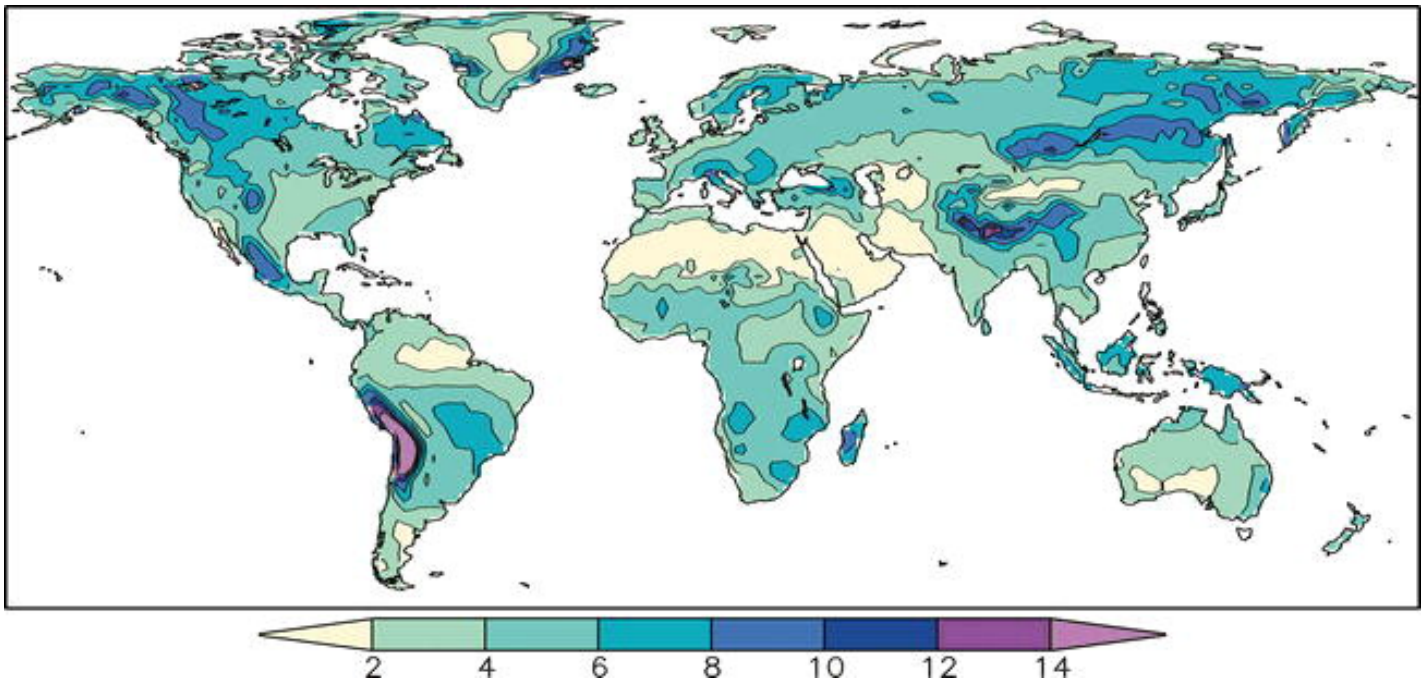
Soil moisture-precipitation feedback

1. Process analysis, based on model results
    1. Direct SMP feedback (Direct coupling)
    2. Circulation
    3. First indirect SMP feedback (Local coupling)
    4. Second indirect SMP feedback (Local coupling)
2. Geographical distribution of SMP feedback
3. Open issues

Direct SMP feedback **Positive**

- An increase in soil moisture yields an increase in precipitation within the same region because more water can be evaporated

Mean recycling ratio, area 10^5 km^2

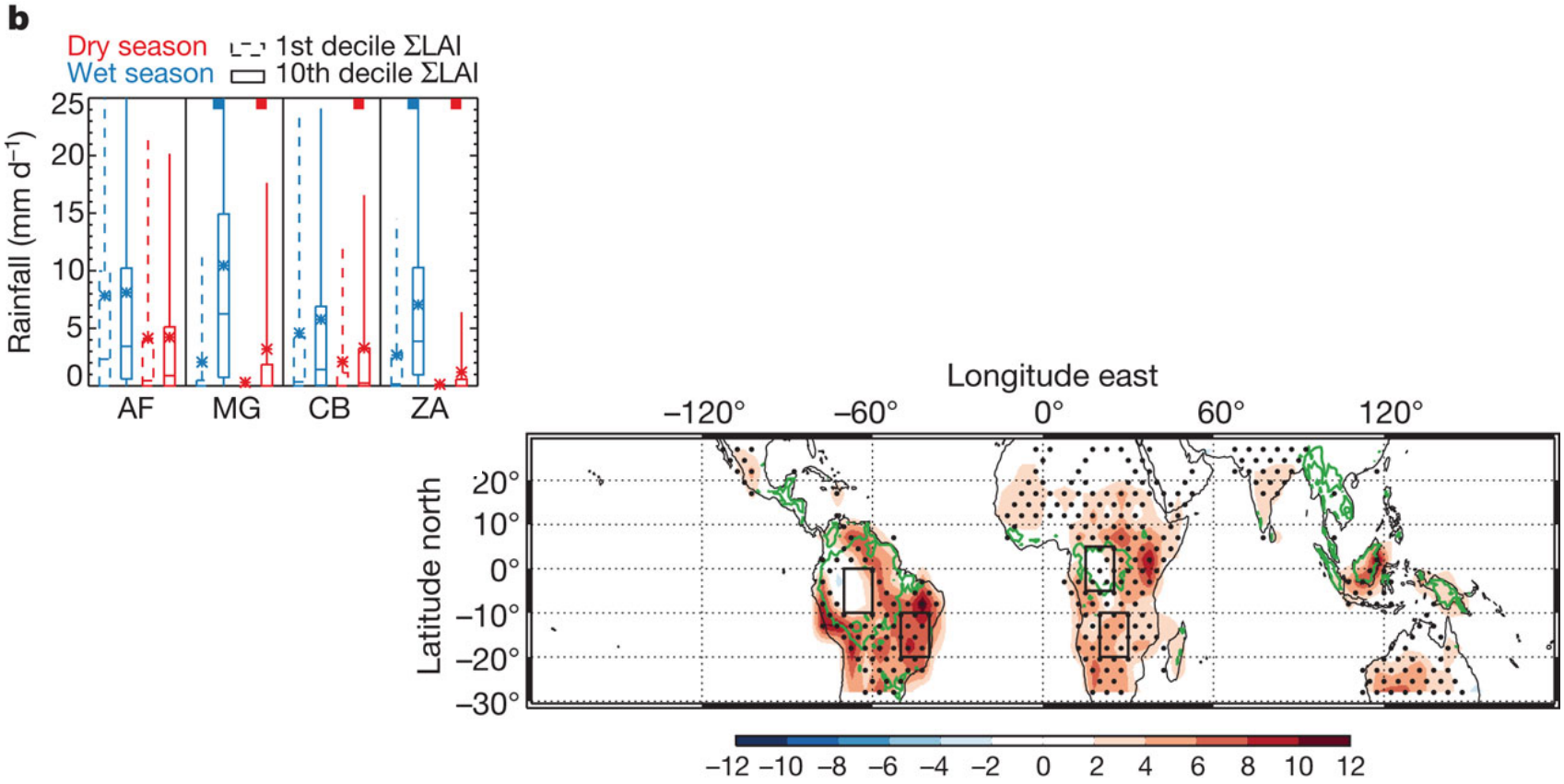


(Dirmeyer and Burbarker 2007)

Direct SMP feedback

Positive

- Unlikely but can be important for downstream region

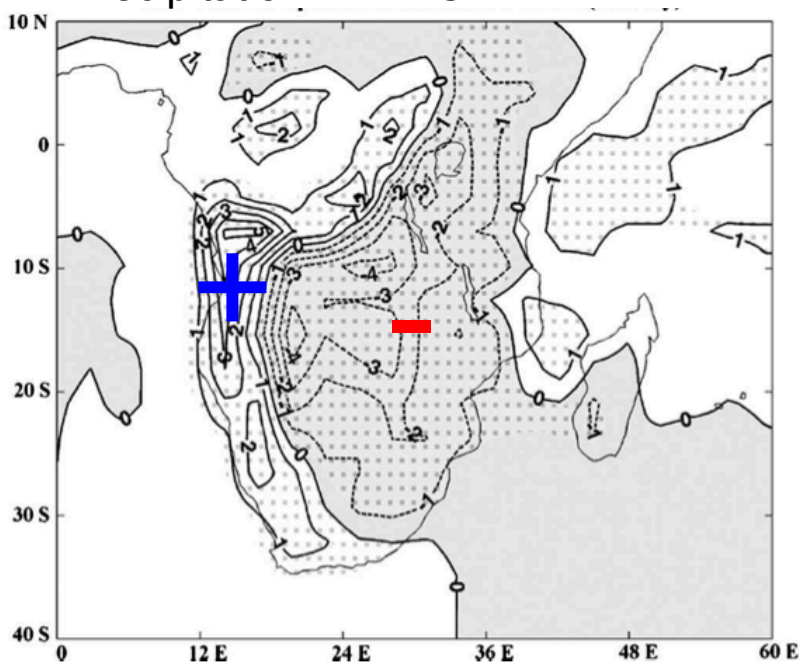


(Spracklen et al. 2012)

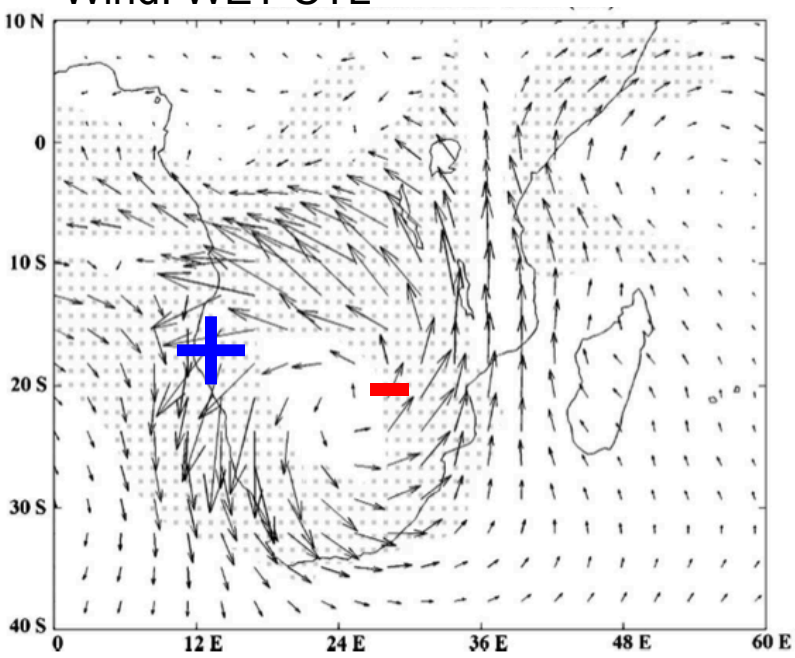
Large-scale patterns Positive/Negative

- A drying of the soil changes the large-scale pattern (e.g. Pal and Eltahir 2003, Cook et al. 2006)

Precipitation: WET-CTL



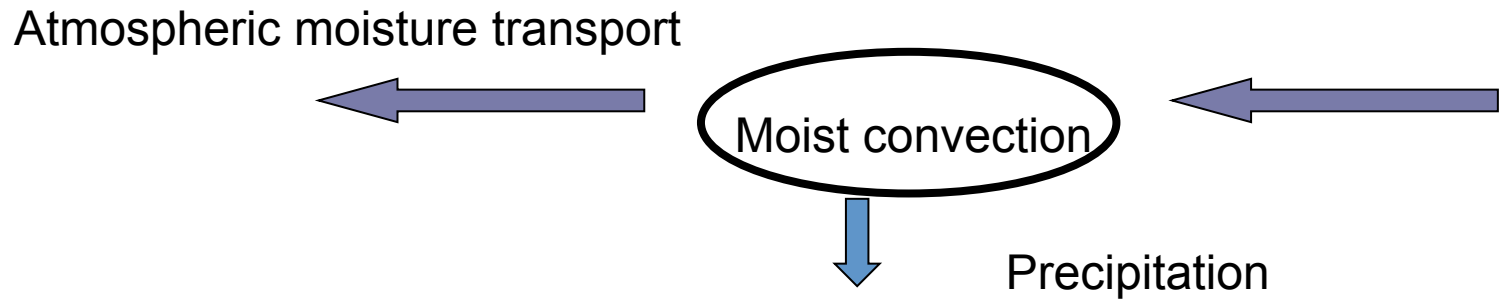
Wind: WET-CTL



(Cook et al. 2006)

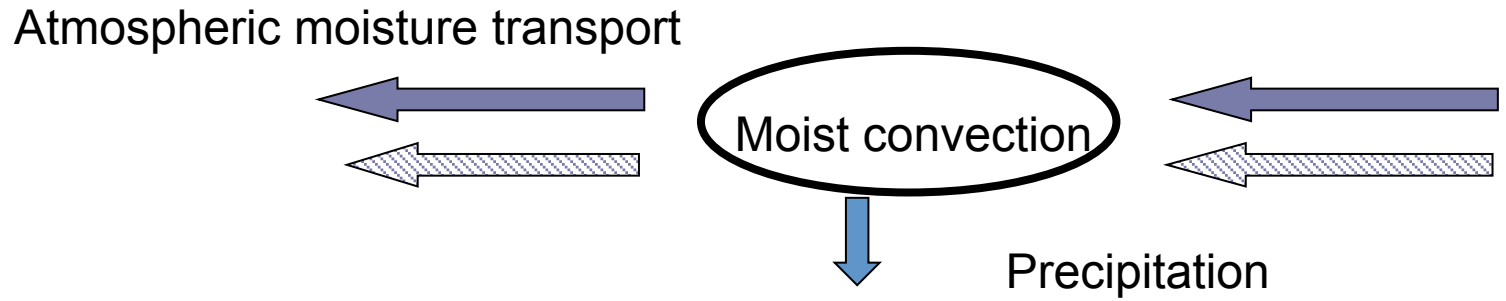
First indirect SMP **Positive**

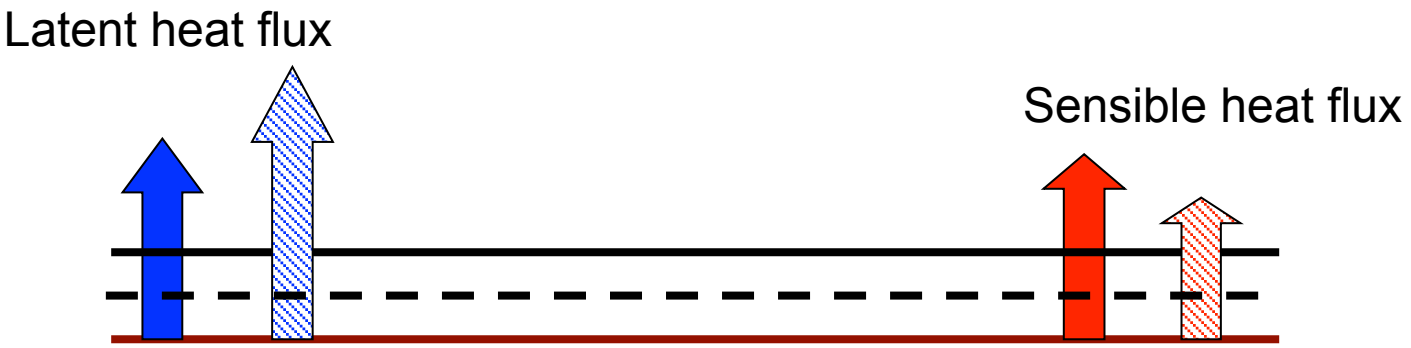
- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Betts et al 1996, Schär et al. 1999)



First indirect SMP **Positive**

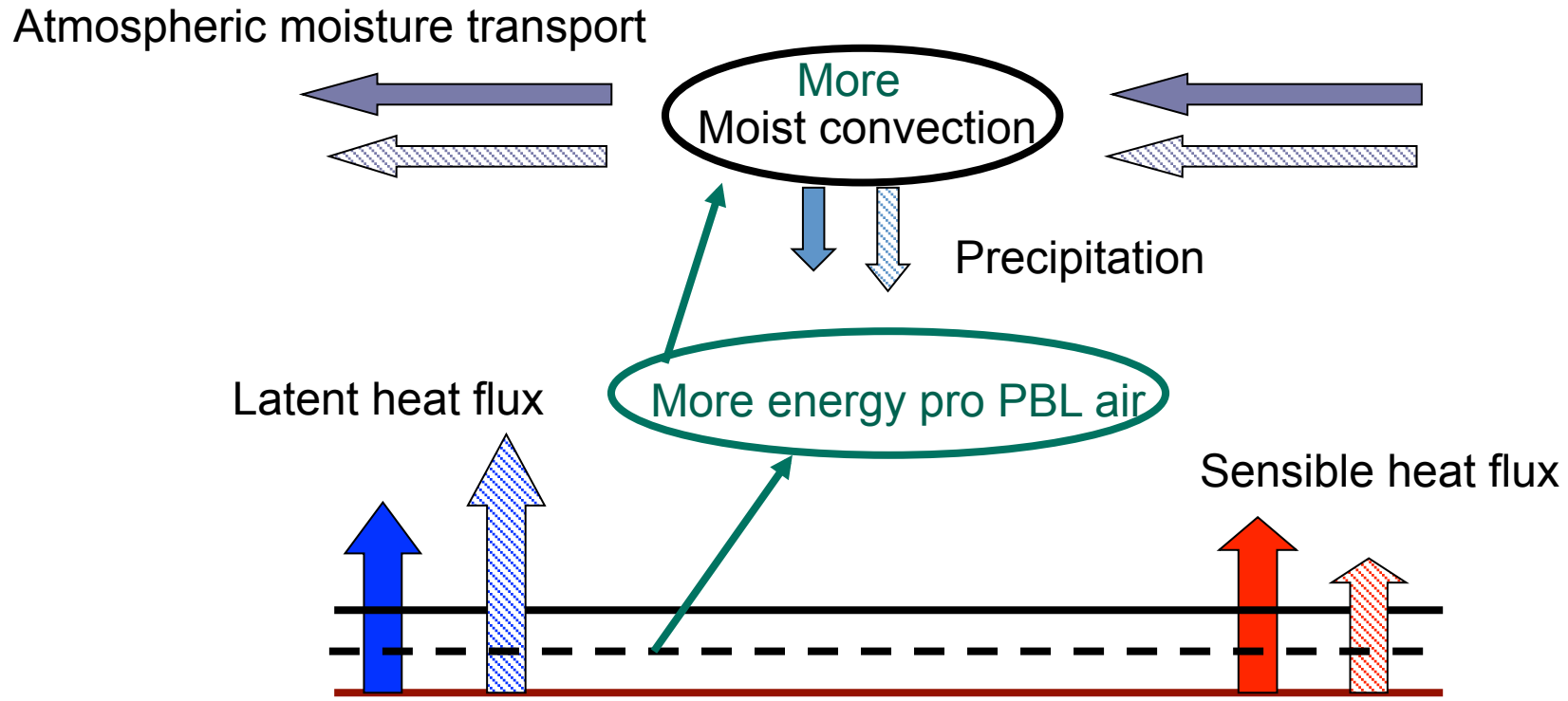
- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Betts et al 1996, Schär et al. 1999)





First indirect SMP **Positive**

- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Betts et al 1996, Schär et al. 1999)



First indirect SMP **Positive**

- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Betts et al 1996, Schär et al. 1999)

What about radiation ?

- Generated convective clouds impact shortwave radiation

$$\text{Soil moisture} \uparrow \text{Evapotranspiration} \uparrow \text{Convection} \uparrow$$
$$\text{Convection} \uparrow \text{Cloud} \uparrow \text{Shortwave radiation} \downarrow$$
$$\text{Shortwave radiation} \downarrow \text{Evapotranspiration} \downarrow \text{Convection} \downarrow$$

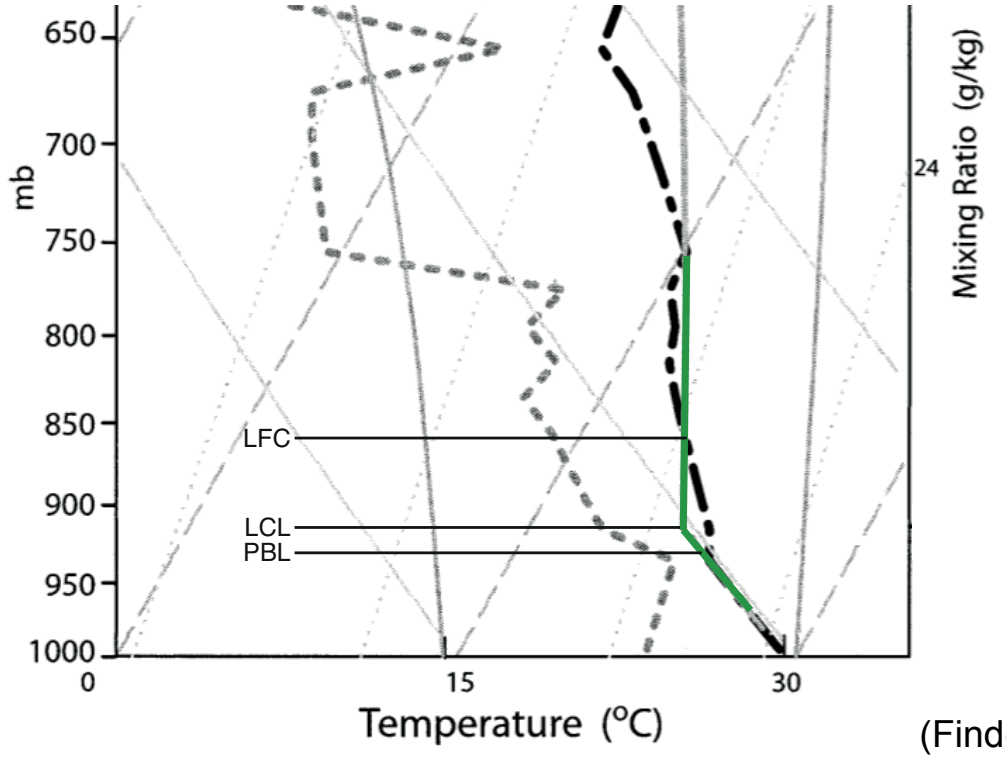
- But they also impact longwave radiation

$$\text{Convection} \uparrow \text{Cloud} \uparrow \text{Surface temperature} \downarrow \text{Longwave radiation} \uparrow$$

- Longwave tends to win

First indirect SMP (alternate explanation) **Positive**

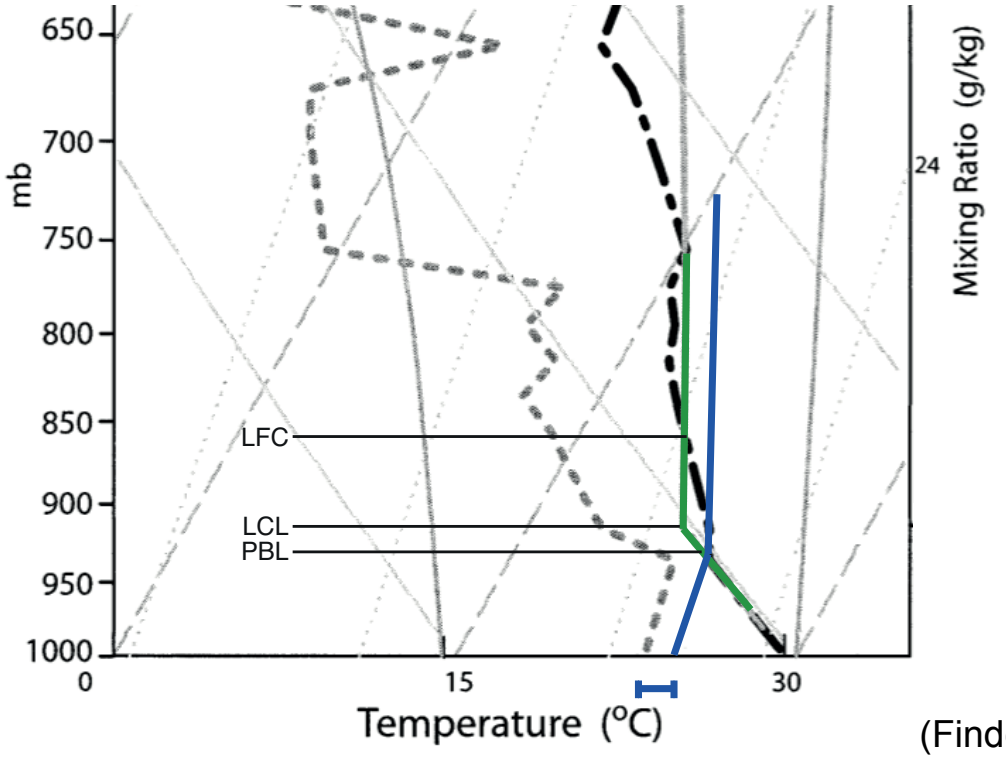
- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Findell and Eltahir 2003)



(Findell and Eltahir 2003, adapted)

First indirect SMP (alternate explanation) **Positive**

- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes more efficient at converting water vapor into precipitation (e.g. Findell and Eltahir 2003)

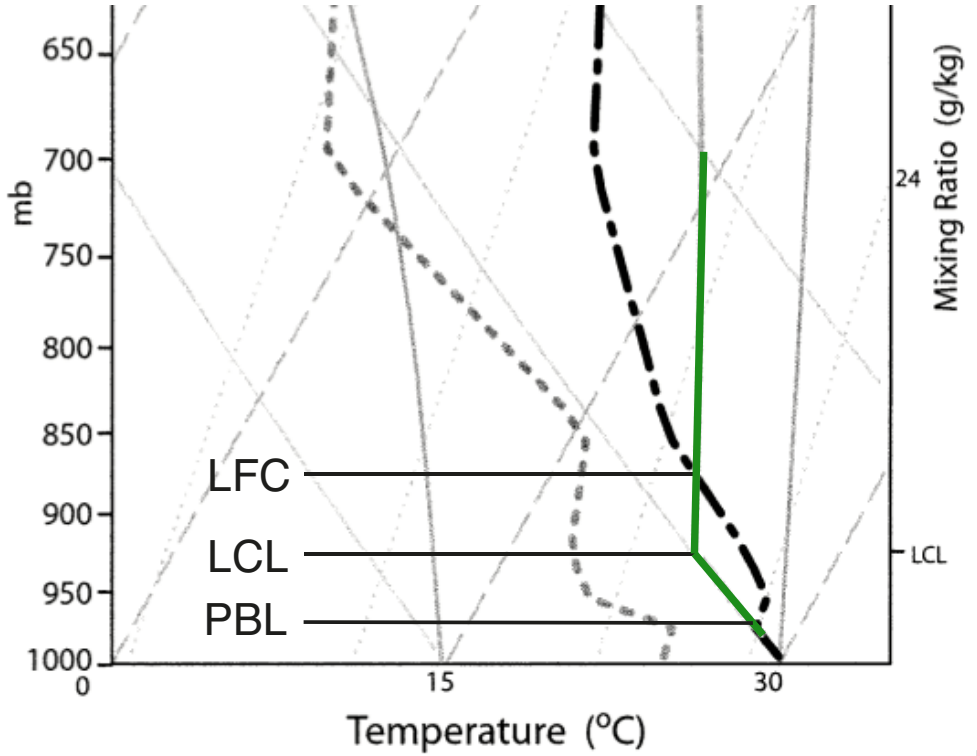


(Findell and Eltahir 2003, adapted)

Second indirect SMP

Negative

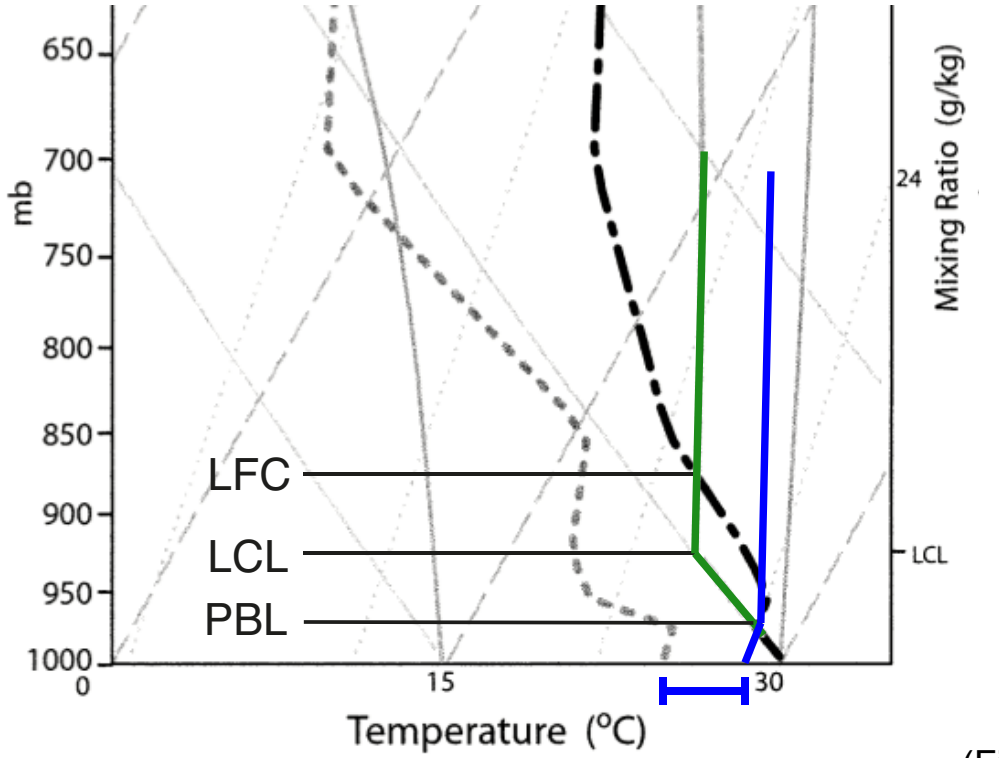
- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes less efficient at converting water vapor into precipitation (e.g. Findell and Eltahir 2003)



(Findell and Eltahir 2003, adapted)

Second indirect SMP **Negative**

- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes less efficient at converting water vapor into precipitation (e.g. Findell and Eltahir 2003)

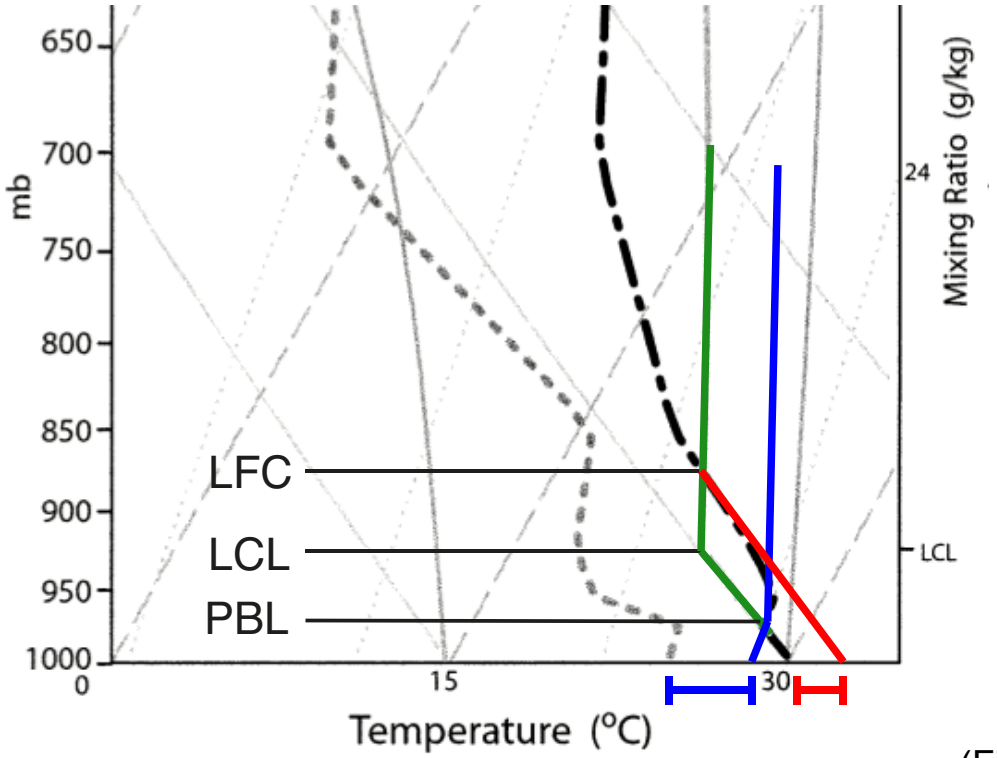


(Findell and Eltahir 2003, adapted)

Second indirect SMP

Negative

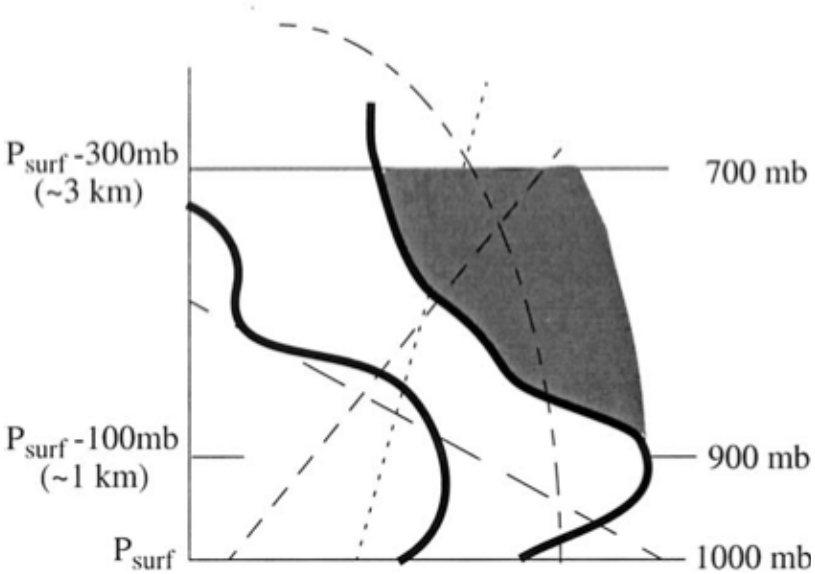
- Through changes in the thermodynamic structure of the PBL, the atmosphere becomes less efficient at converting water vapor into precipitation (e.g. Findell and Eltahir 2003)

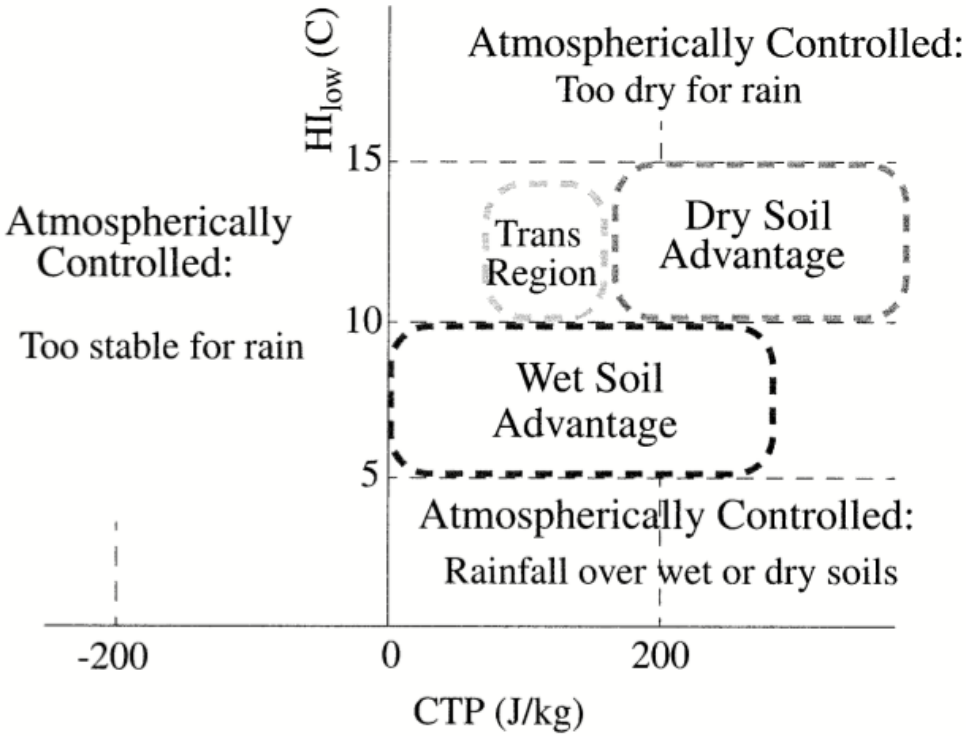


(Findell and Eltahir 2003, adapted)

The CTP-HI_{low} framework (Findell and Eltahir 2003)

$$HI_{low=}=T_{950}-T_{d950}+T_{850}-T_{d850}$$





Homogeneous surface conditions

Soil moisture-precipitation feedback

1. Process analysis, based on model results
    1. Direct SMP feedback (Direct coupling) +
    2. Circulation +/-
    3. First indirect SMP feedback (Local coupling) +
    4. Second indirect SMP feedback (Local coupling) -
2. Geographical distribution of SMP feedback
3. Open issues