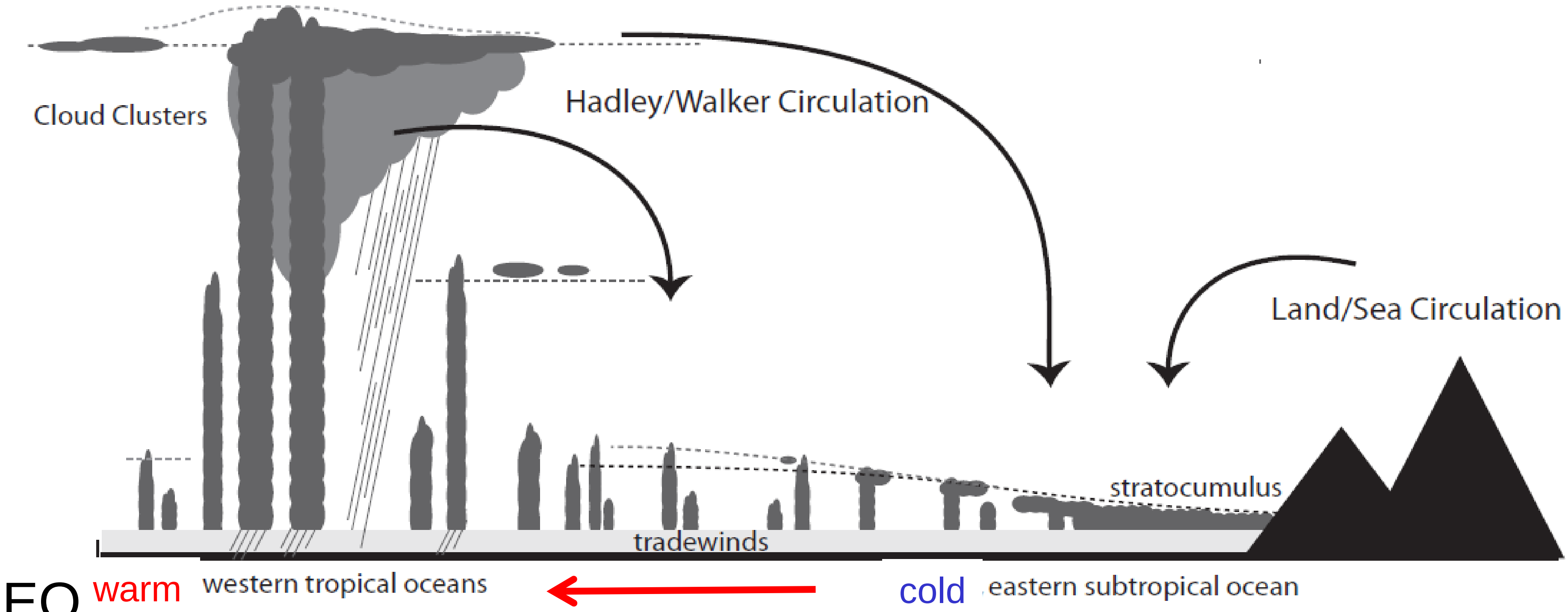
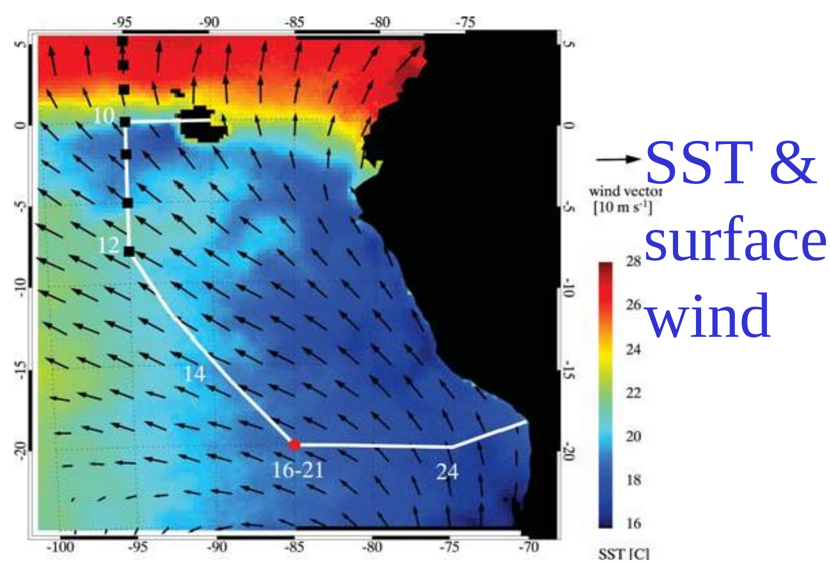
Stratocumulus – Theory and Model

Irina Sandu

- Introduction
- Characterisation
- Governing processes
- Parameterization
- Remaining Challenges
- Summary

Boundary layer clouds over oceans

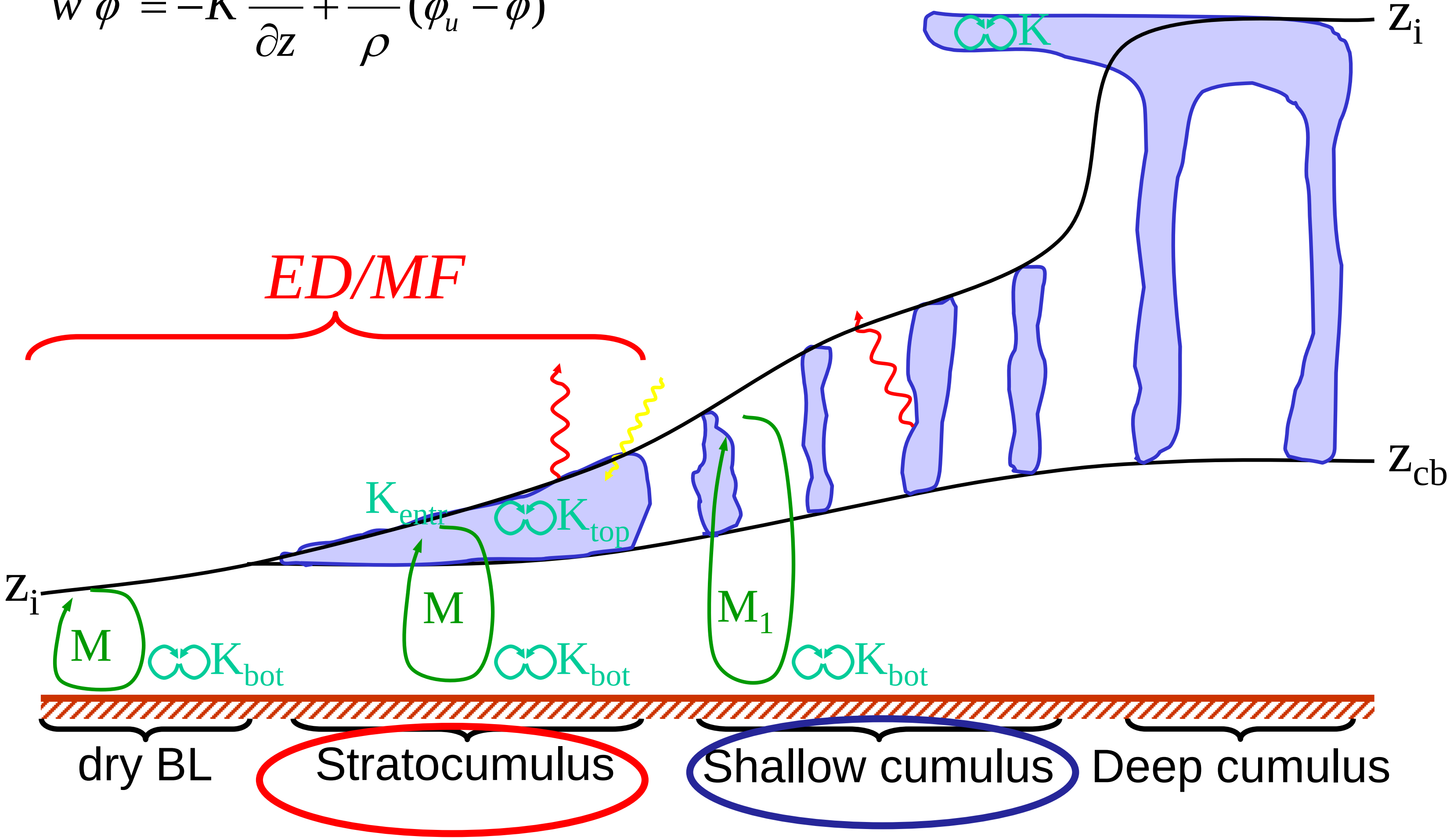




An ED/MF approach in IFS (2007)

Combined mass flux/diffusion:

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + \frac{M}{\rho}(\phi_u - \overline{\phi})$$



Boundary layer talks

Convection talks

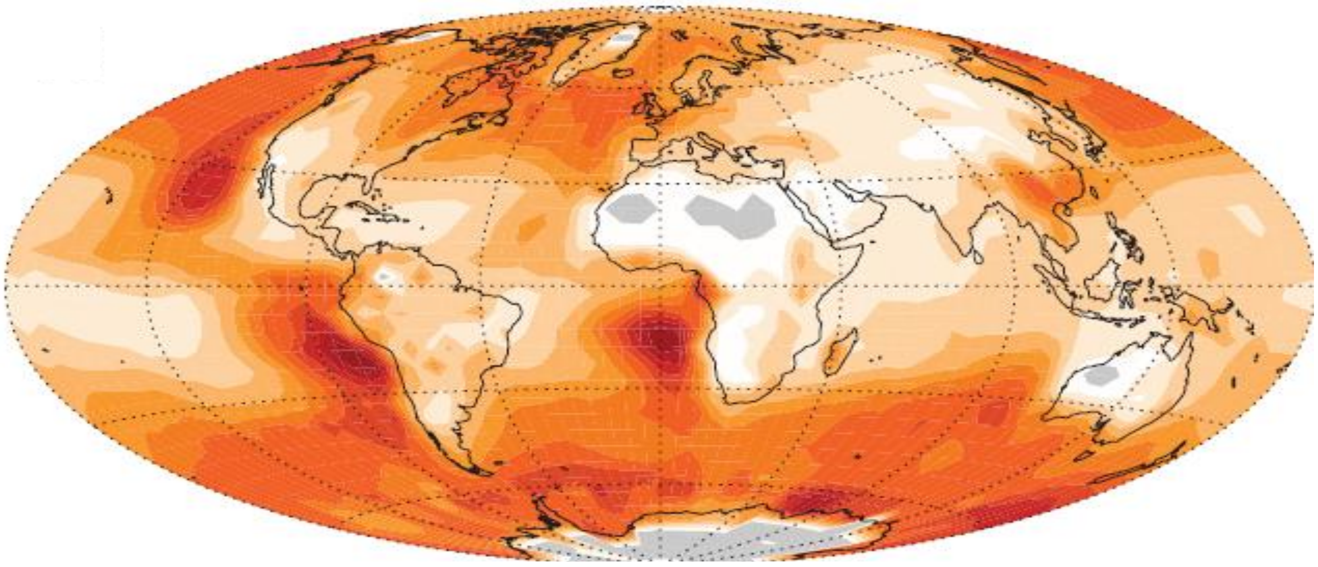
Stratocumulus – Why are they important?

☞ Cover in (annual) mean 29% of the planet (Klein and Hartmann, 1993)

☞ Cloud top albedo is 50-80% (in contrast to 7 % at ocean surface).

☞ A 4% increase in global stratocumulus extend would offset 2-3K global warming from CO_2 doubling (Randall et al. 1984).

☞ Coupled models have large biases in stratocumulus extent and SSTs.



Stratocumulus cloud cover (annual mean)

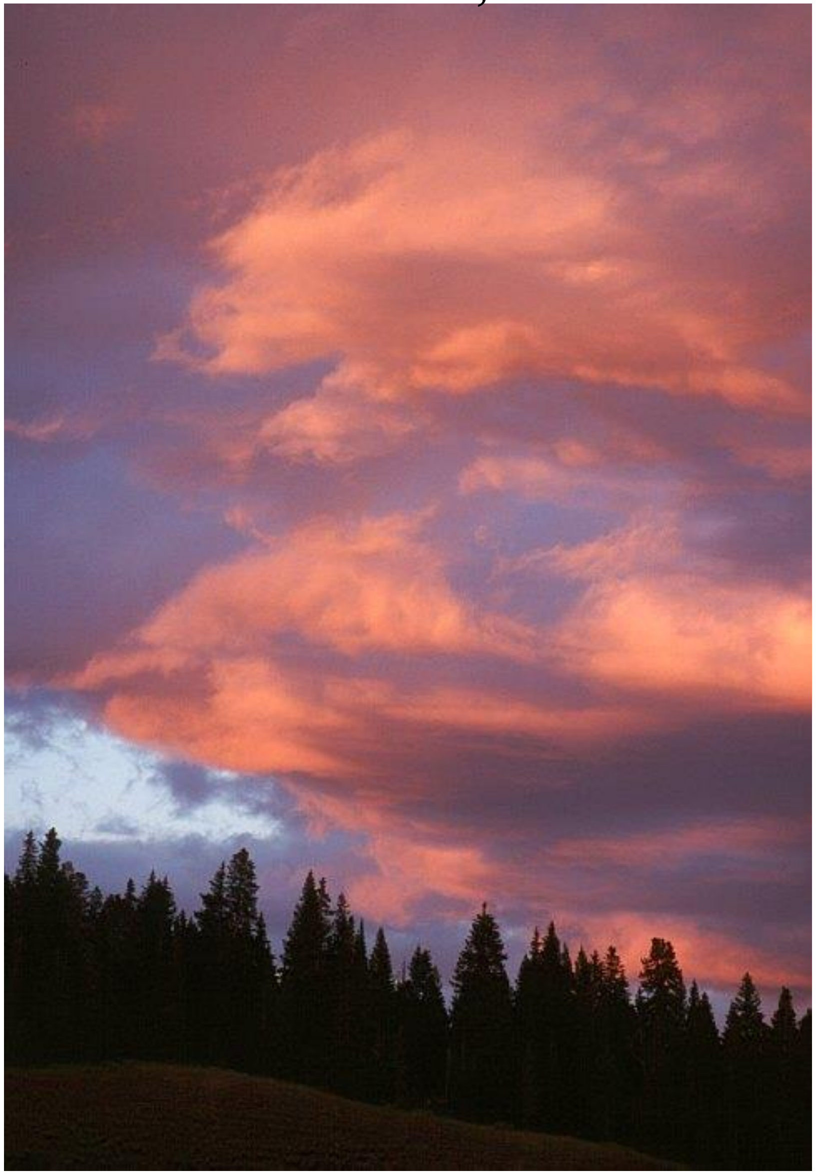
Wood, 2012,based on Han and Waren, 2007

Stratocumulus … over Land

Germany

Stratocumulus stratiformis translucidus

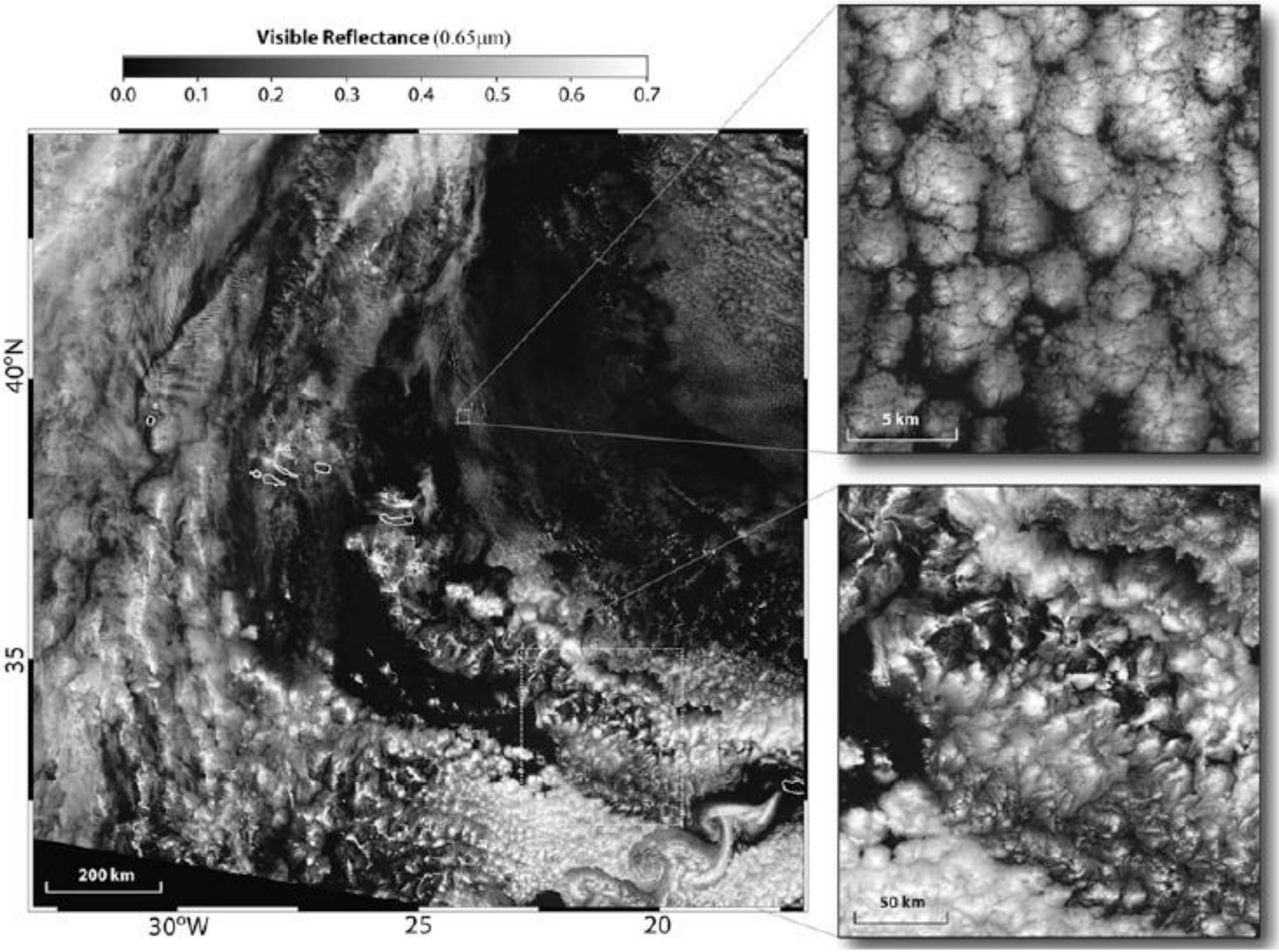
Yellowstone,USA



Stratocumulus stratiformis opacus cumulogenitus

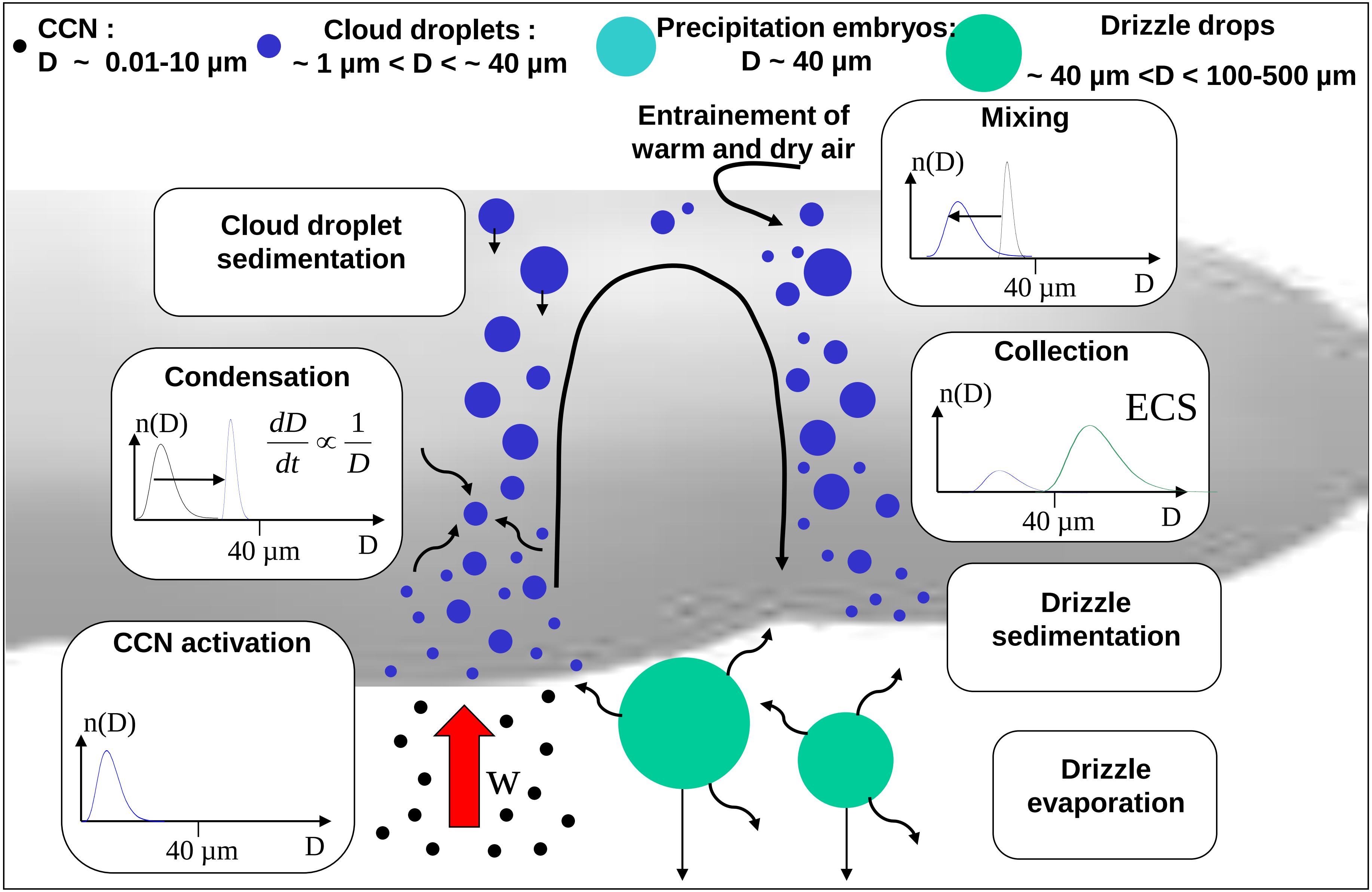
Bernhard Mühr, *www.wolkenatlas.de*

Stratocumulus …Macroscales

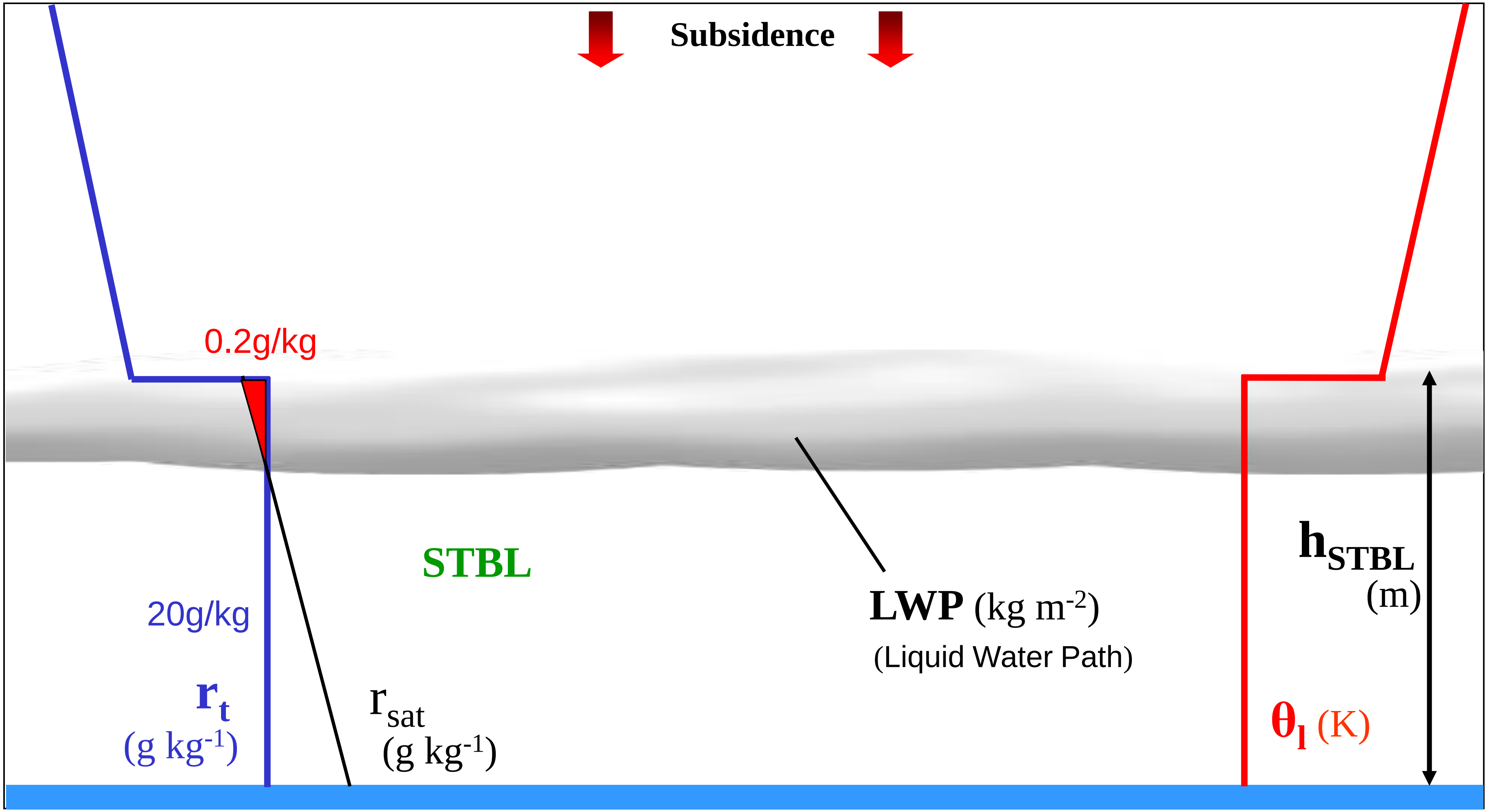


Wood, 2012

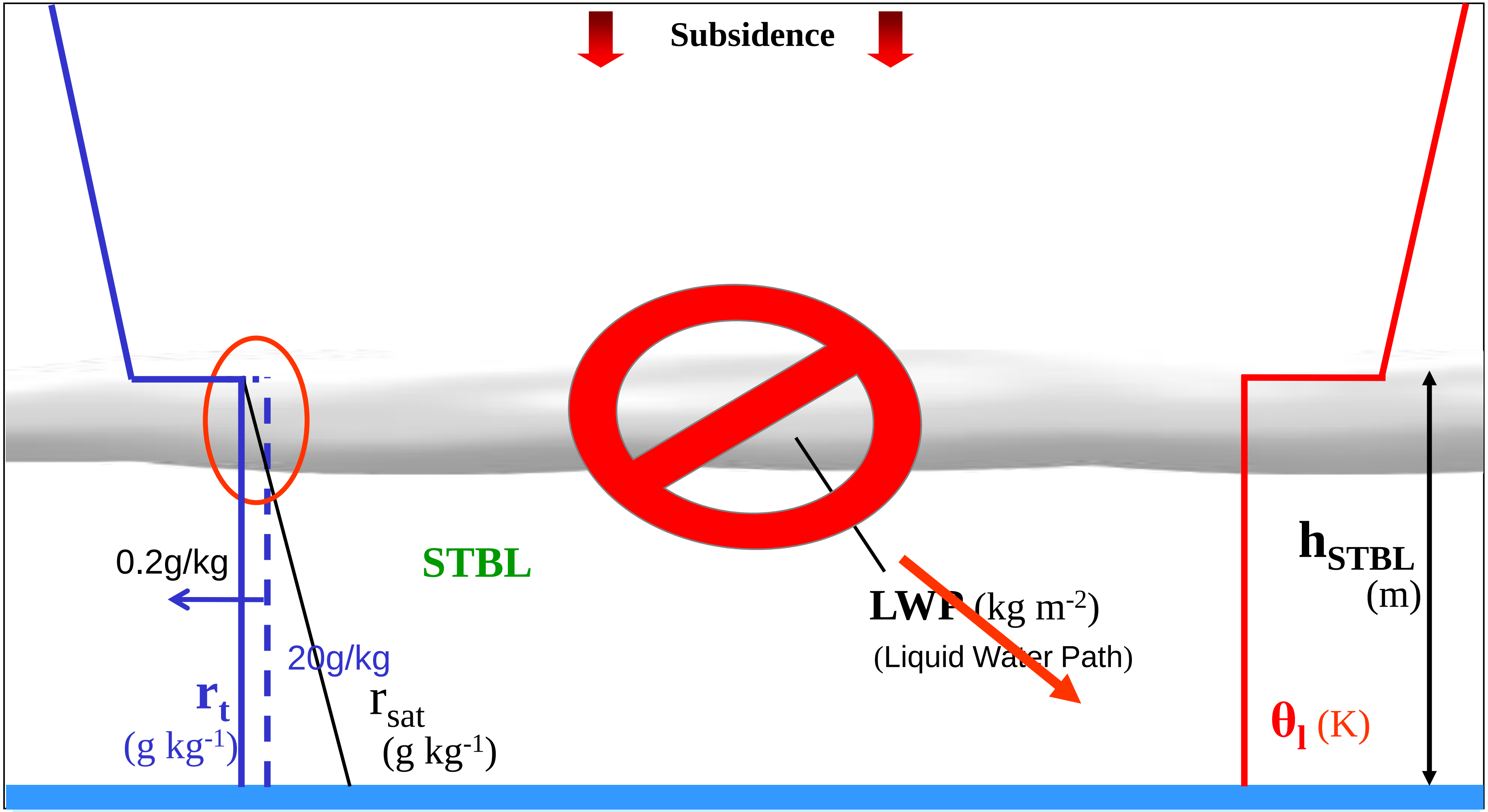
Stratocumulus ….Microscales or Cloud microphysics



Characterisation of a STBL

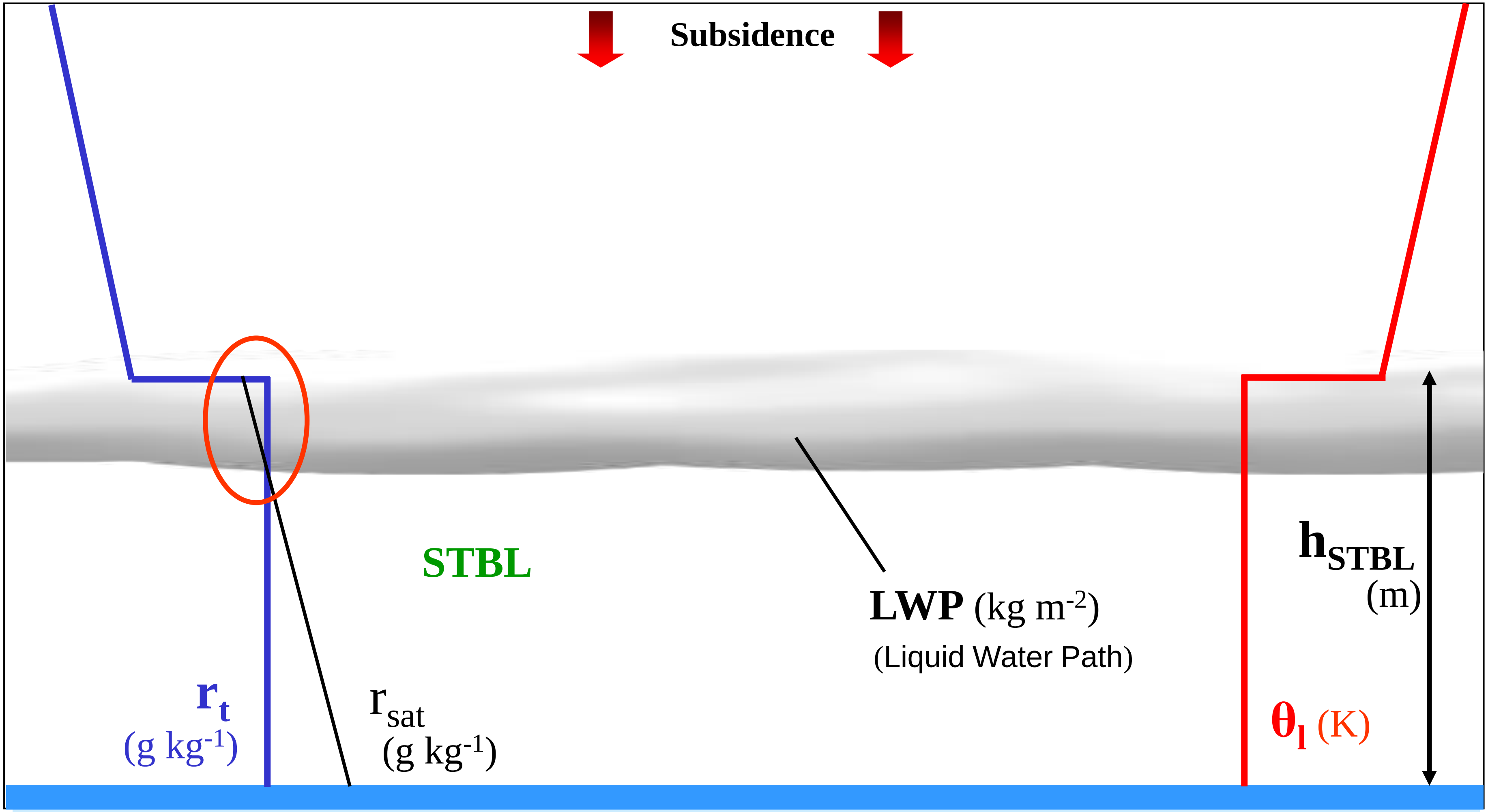


Characterisation of a STBL



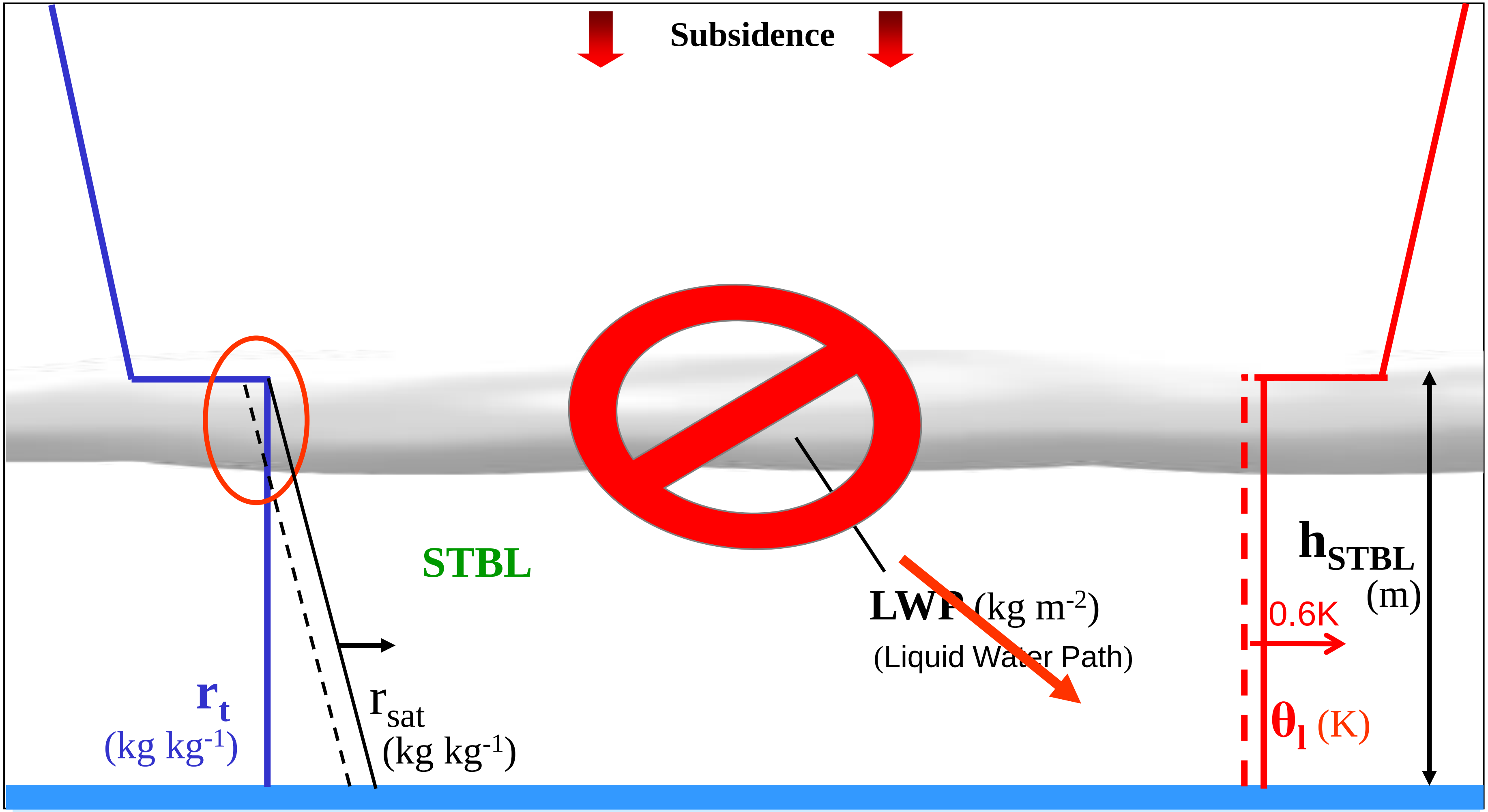
Such a cloudy system is extremely sensitive to thermodynamical conditions

Characterisation of a STBL



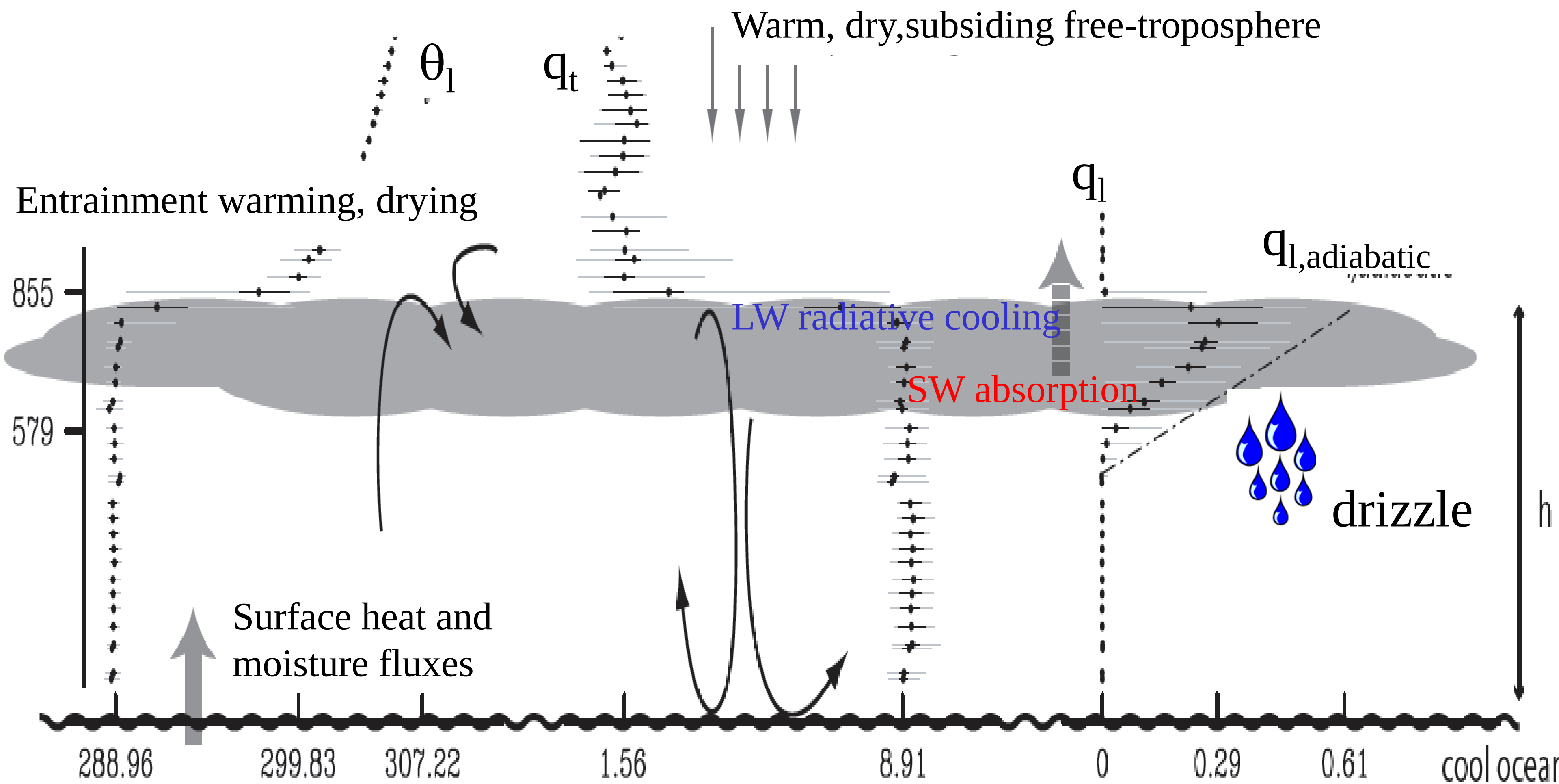
Such a cloudy system is extremely sensitive to thermodynamical conditions

Characterisation of a STBL



Such a cloudy system is extremely sensitive to thermodynamical conditions

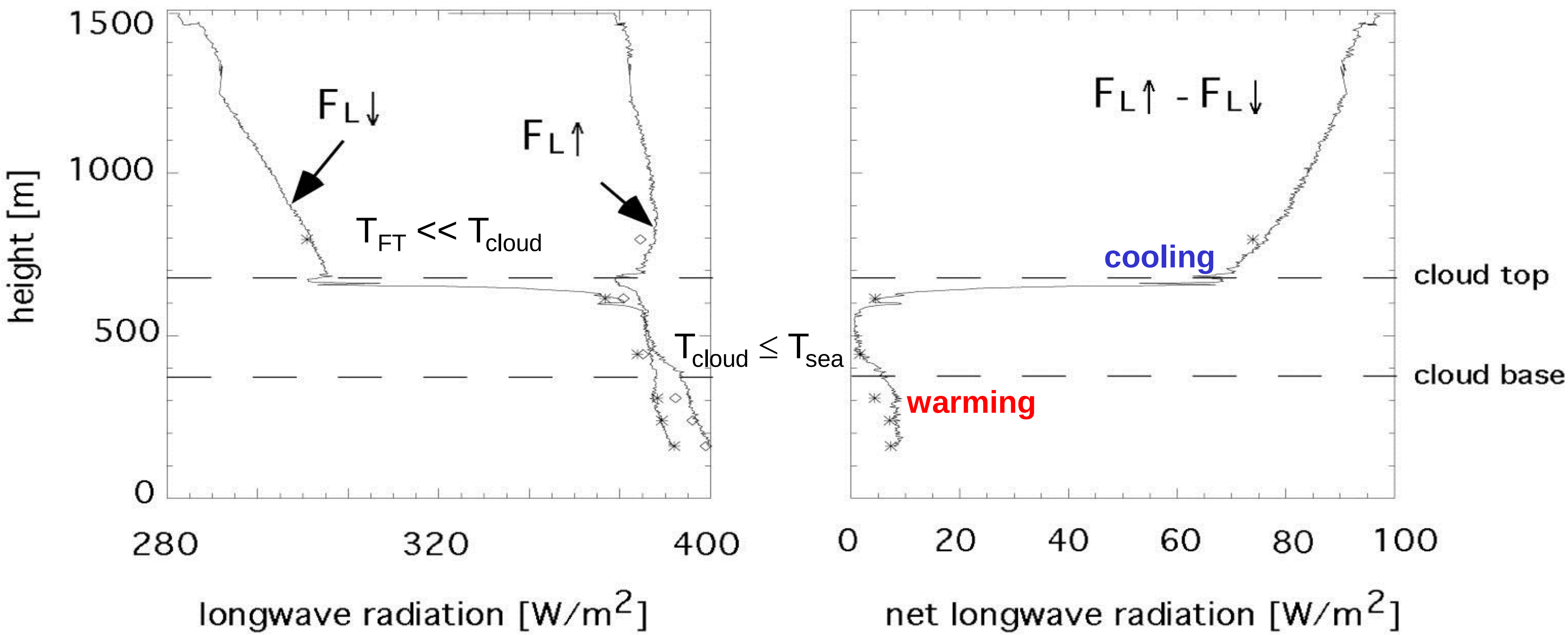
Processing controlling cloud evolution



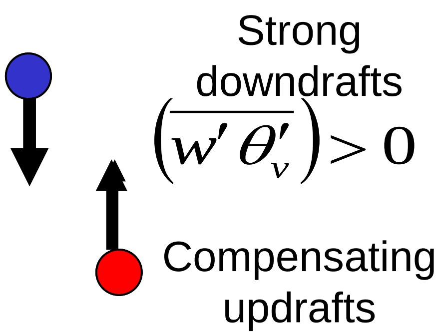
Courtesy of Bjorn Stevens (data from DYCOMS-II)

Radiative transfer

Longwave radiation

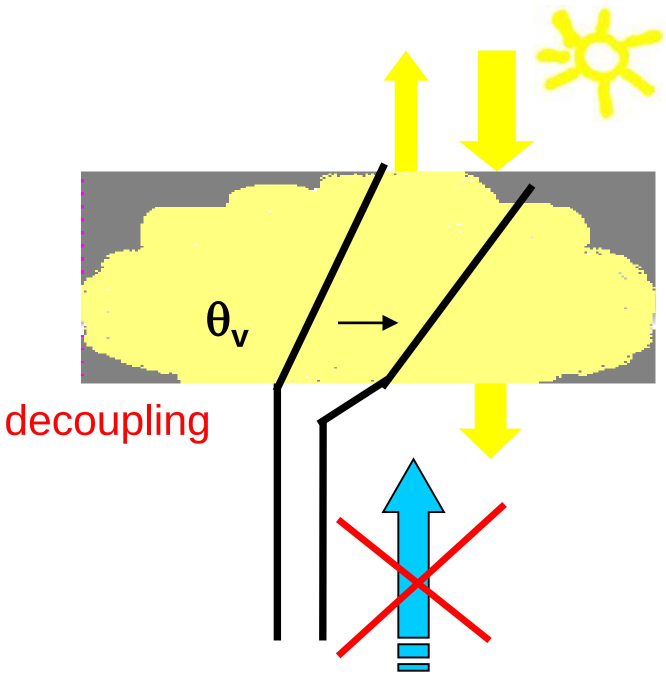


At cloud top $\frac{\partial\bar{\theta}}{\partial t} \approx 8K/hour$



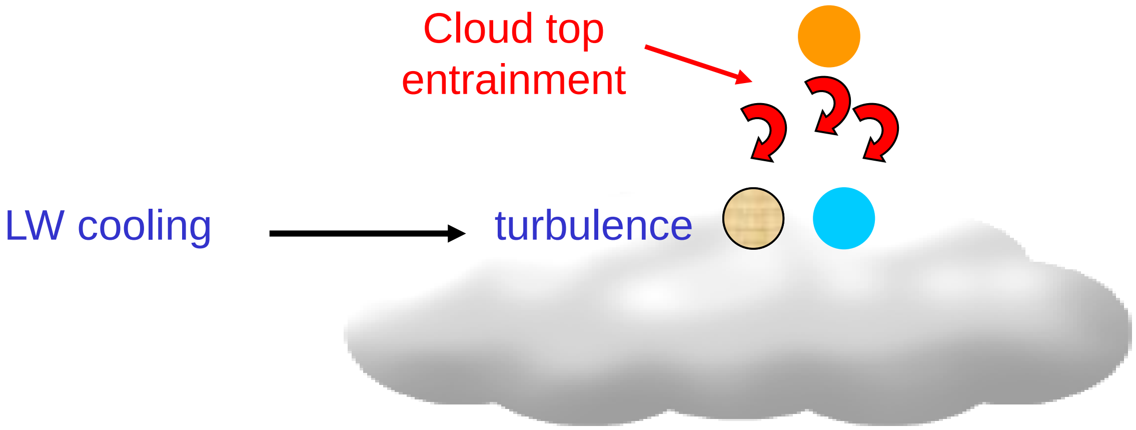
$\left(\overline{w'\theta_v'}\right) > 0$

Shortwave radiation



- ☞ partially compensates LW cooling
- ☞ Stabilises the cloud layer
- ☞ Slight inversion at the cloud base
- ☞ The cloud water content diminishes

Cloud top entrainment



☞ Entrained air cools

☞ Cloudy air warms, a part of liquid water evaporates

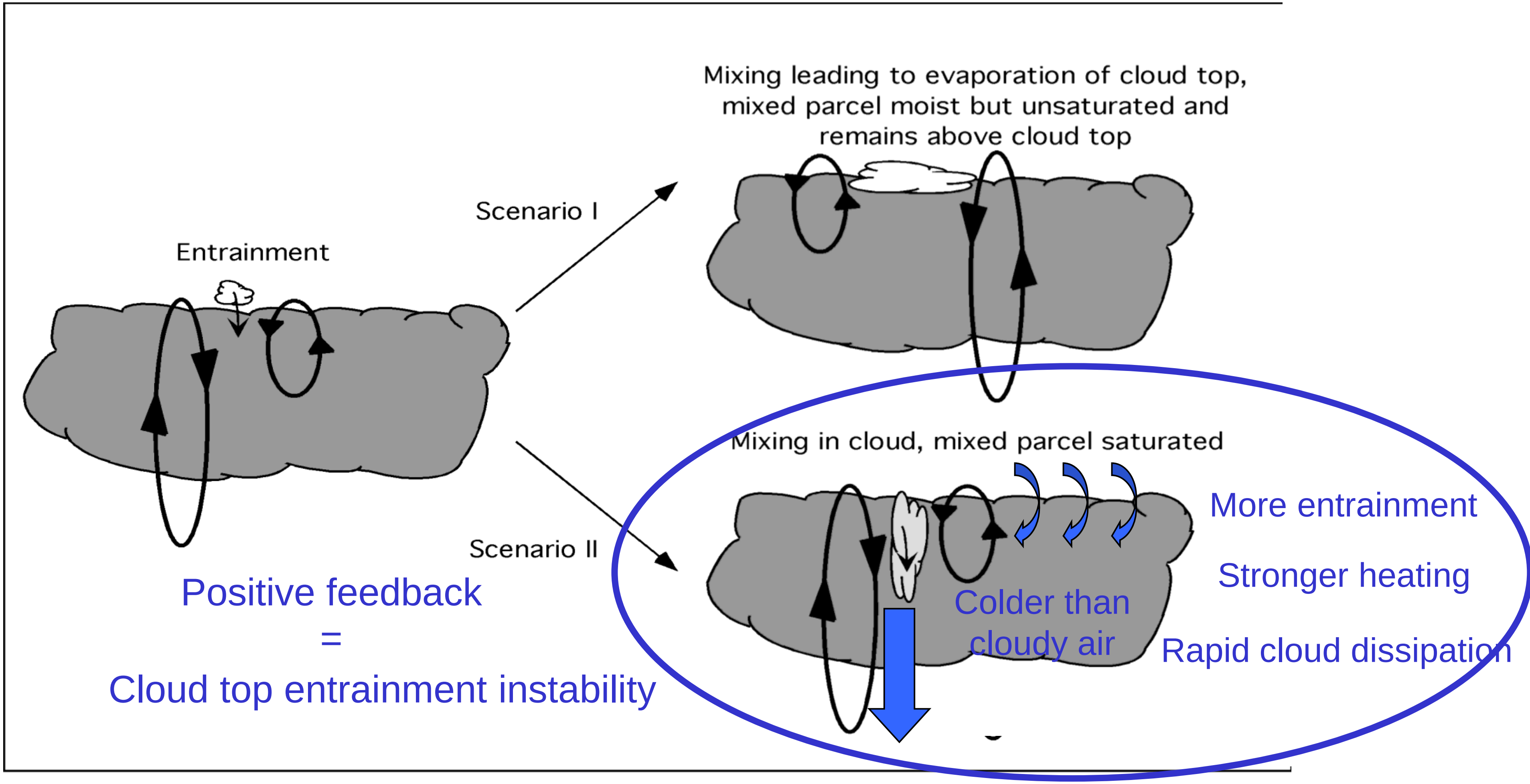
☞ LWC at cloud top inferior to adiabatic case

☞ Growth of the STBL

☞ Warming and drying of the STBL

Cloud top entrainment

☞ growth of the STBL, warming and heating, partially compensates the radiative cooling, modifies cloud droplet distribution.



Surface fluxes

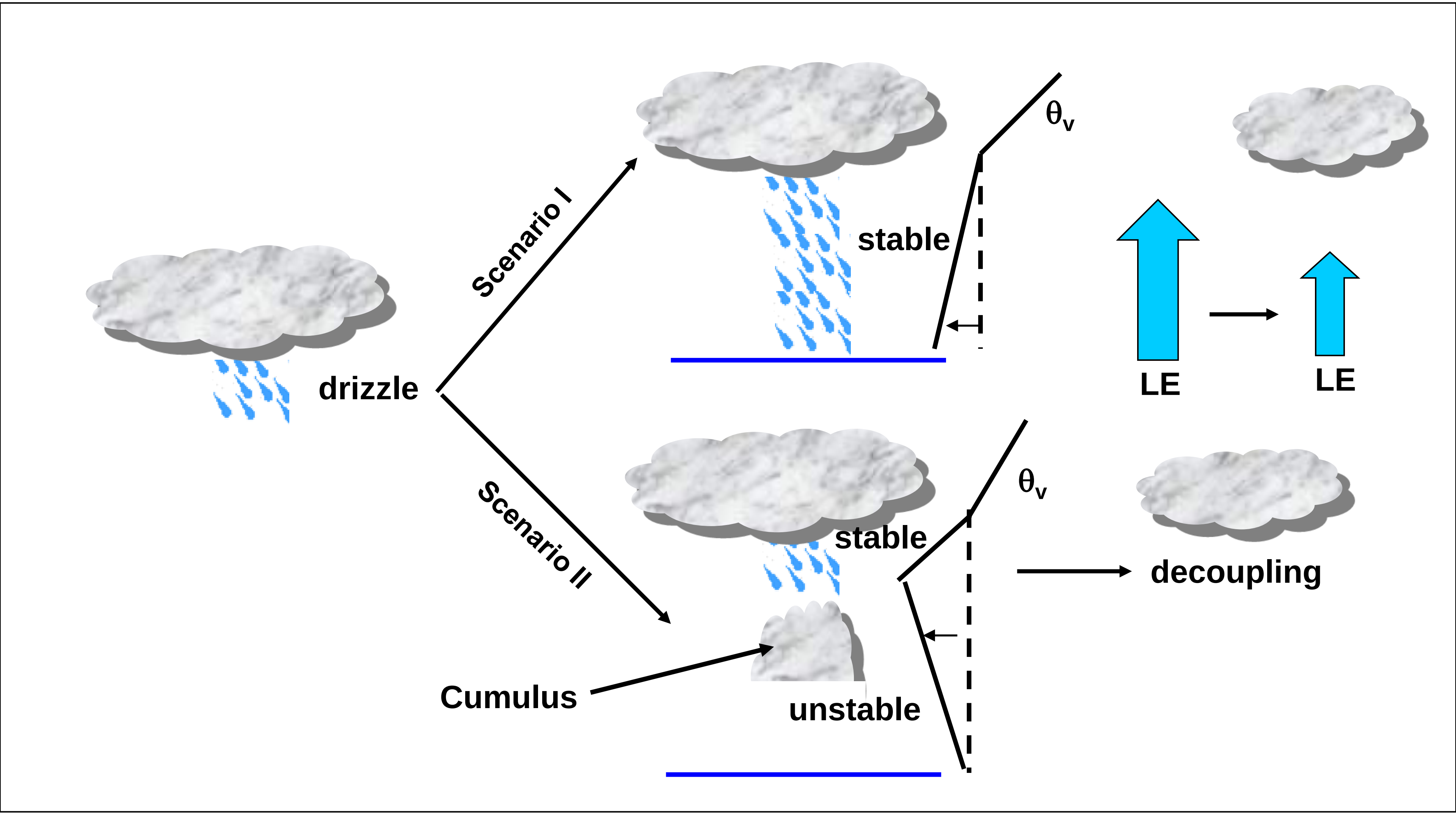
- ☞ Sensible heat flux (H)
  - Important for maintaining turbulence in the under cloud layer
- ☞ Latent heat flux
  - Vapour supply for the cloud layer
  - Role in the cloud break up (transition to shallow cumulus)

Precipitation flux

- Even if weak (1mm/day) important for STBL dynamics and energetics
- Precipitation flux ~ 30 W/m2 (same as latent flux!)
- Latent heat released during drizzle formation acts to weaken the vertical movements

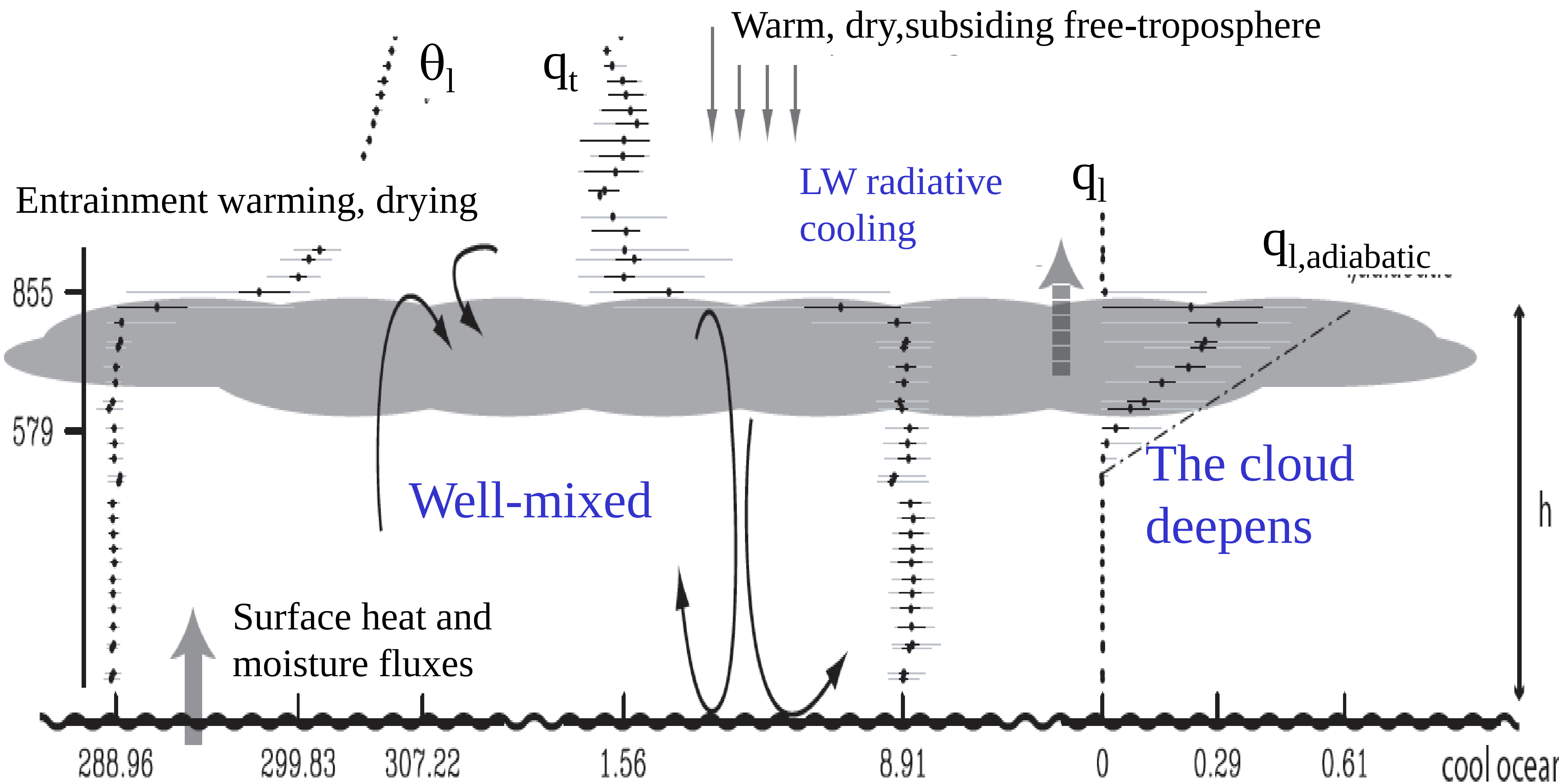
Precipitation flux

☞ Under cloud evaporation affects the dynamics of the boundary layer



The diurnal cycle of a non-precipitating stratocumulus

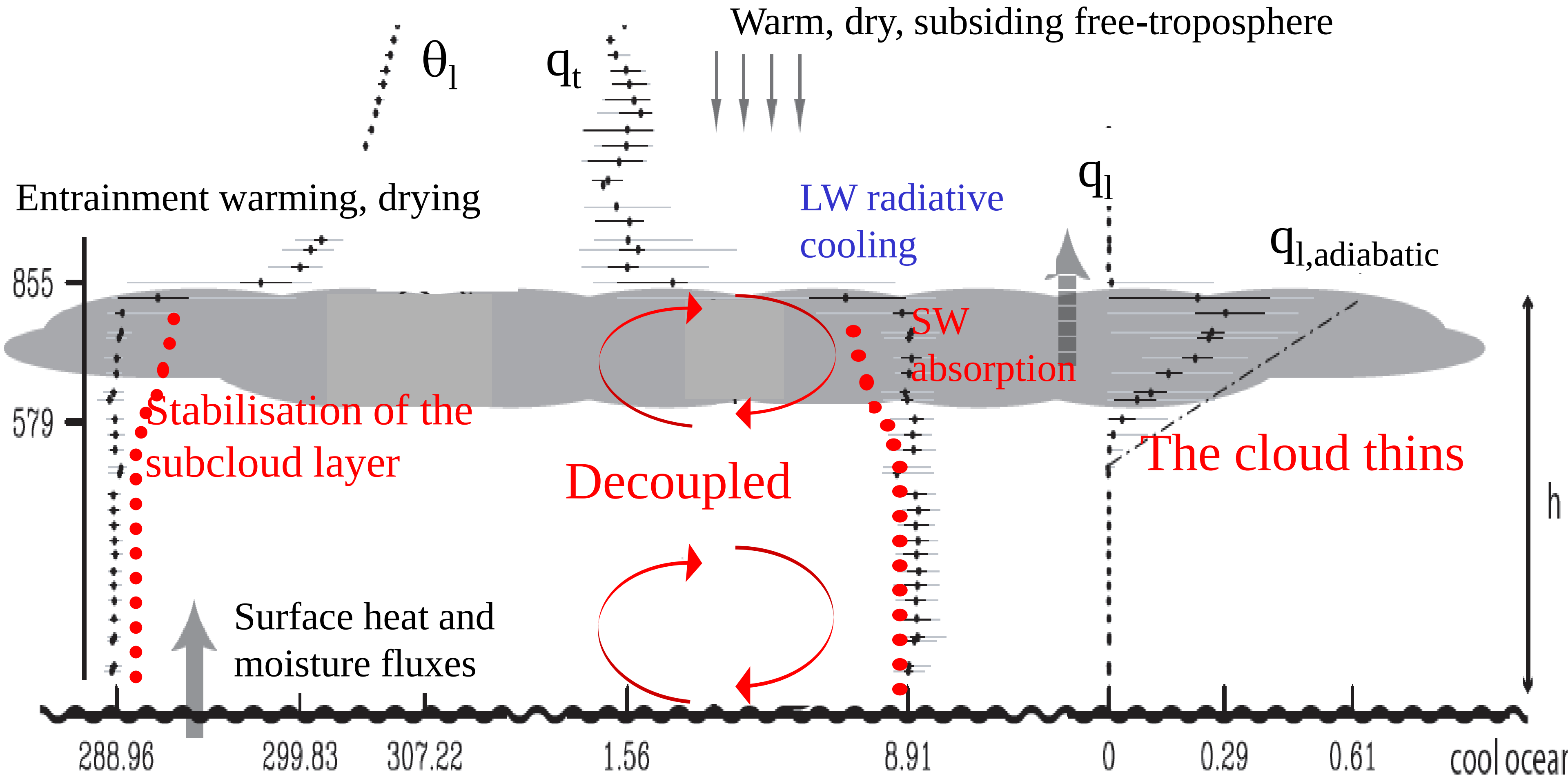
Night-time



Courtesy of Bjorn Stevens (data from DYCOMS-II)

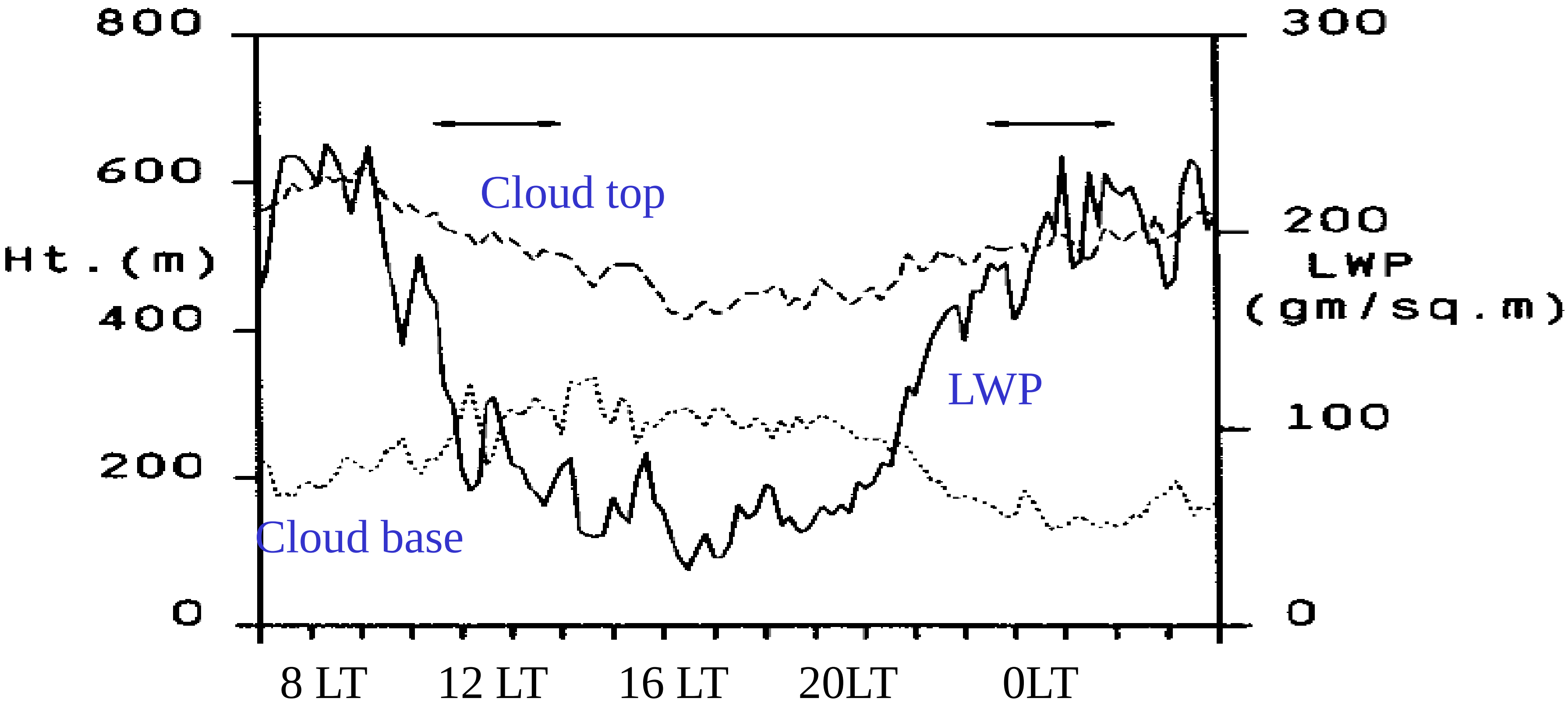
The diurnal cycle of a non-precipitating stratocumulus

Daytime



Courtesy of Bjorn Stevens (data from DYCOMS-II)

Diurnal cycle during observed during FIRE-I experiment



Hignett, 1991 (data from FIRE-I)

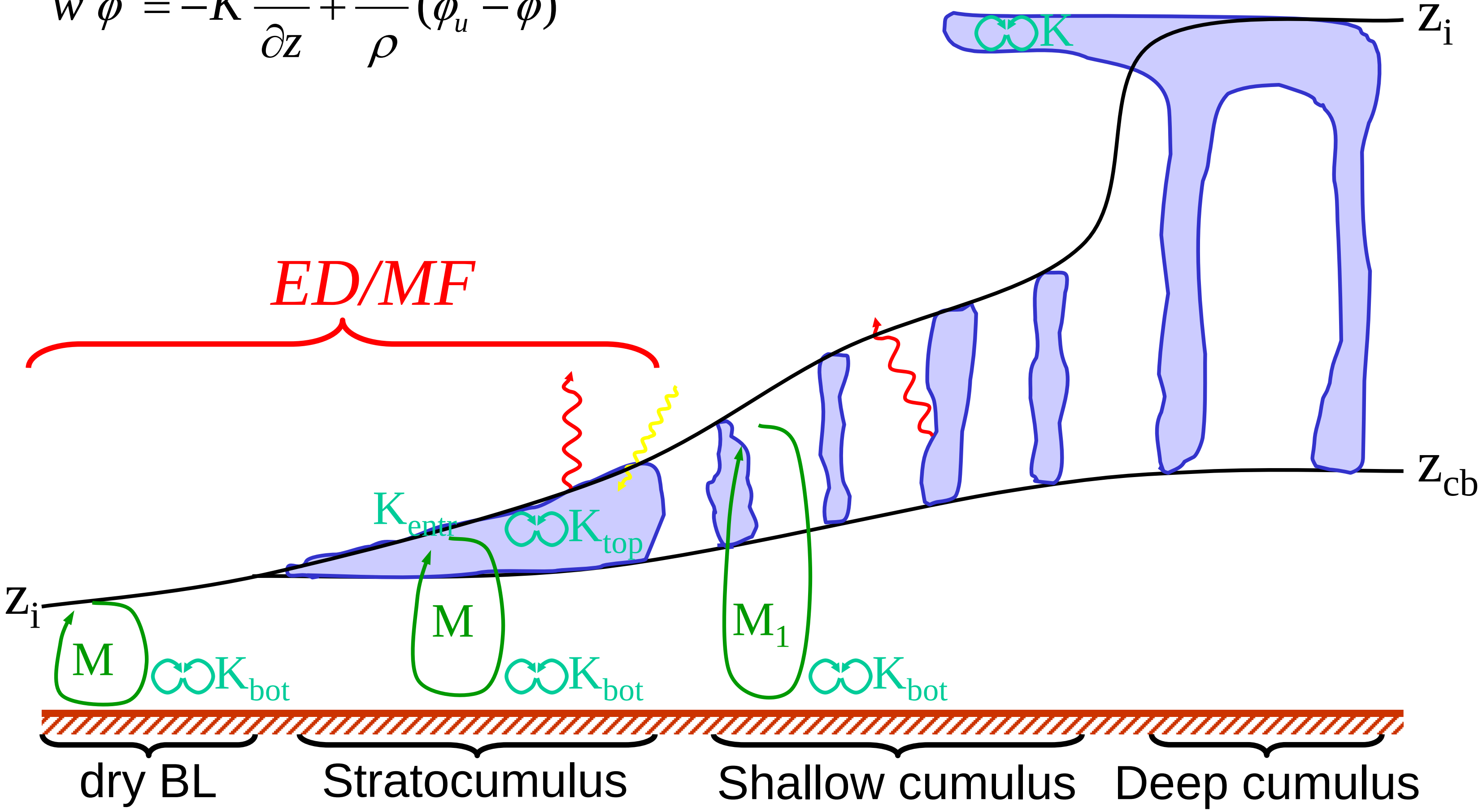
Stratocumulus parameterization - Ingredients

- Strong mixing
  - Cloud top driven
  - Surface driven
- Cloud top entrainment
  - function of cloud top radiative cooling and surface flux
- Radiation interaction
- Drizzle
- Transition to trade cumulus
  - high/low cloud fraction

An ED/MF approach in IFS (2007)

Combined mass flux/diffusion:

$$\overline{w'\phi'} = -K\frac{\partial\bar{\phi}}{\partial z} + \frac{M}{\rho}(\phi_u - \bar{\phi})$$



parameterization choices

Mass-flux

☞ updraft model:

- entrainment: $\varepsilon = \frac{a}{z} + b$
- detrainment: $3 \cdot 10^{-4}\ m^{-1}$ in cloud
- parcel determines PBL depth ($w_{up} = 0$)

☞ mass flux: $\frac{\partial M}{\partial z} = (\varepsilon - \delta) M$

K-diffusion

☞ diffusion:

- K-profile to represent the surface driven diffusion
- Ktop ~ ΔF_{LW} to represent the cloud top driven diffusion

☞ cloud top entrainment:

$$\overline{w's'_v}^{entr} = -0.2 \cdot \left(\overline{w's'_v}^{sfc} + c_p \Delta F_{LW} \right)$$

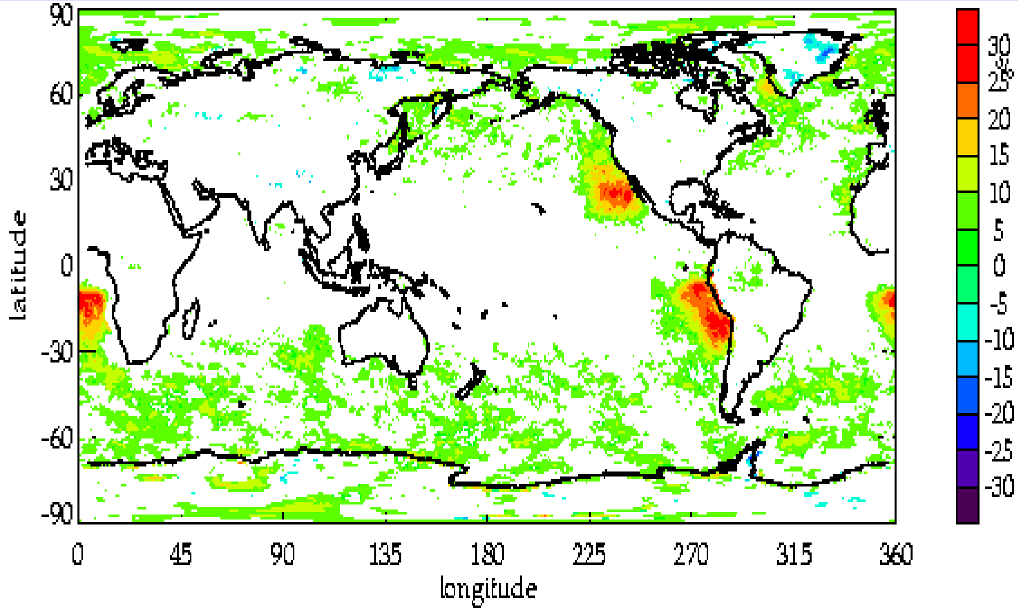
cloud variability

☞ cloud cover:

- total water variance equation

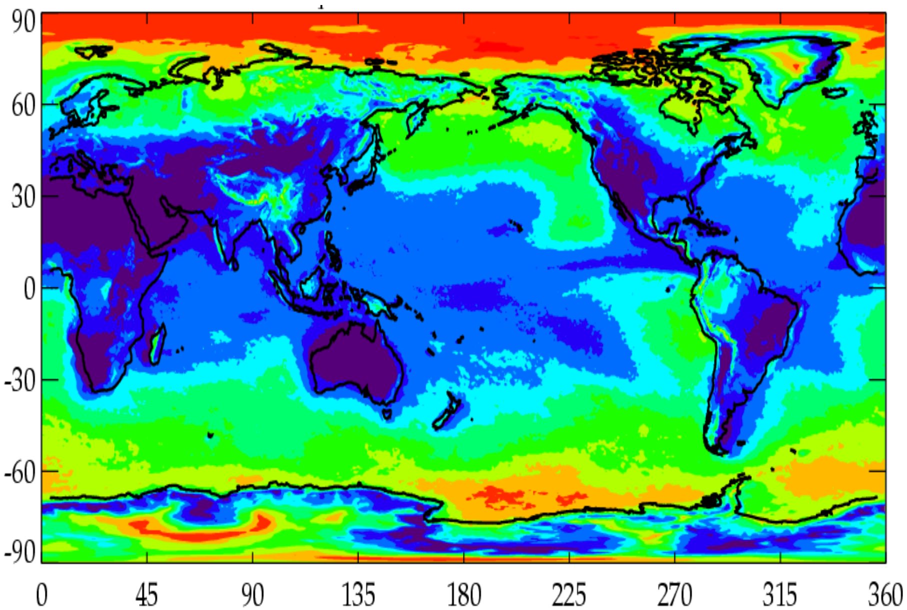
$$\frac{\partial \sigma_{qt}^2}{\partial t} = -2\overline{w'q'_t}\frac{\partial q_t}{\partial z} - \frac{\overline{w_u}^z \sigma_{qt}^2}{h_{PBL}}$$

Results: Low cloud cover (EDMF-old)

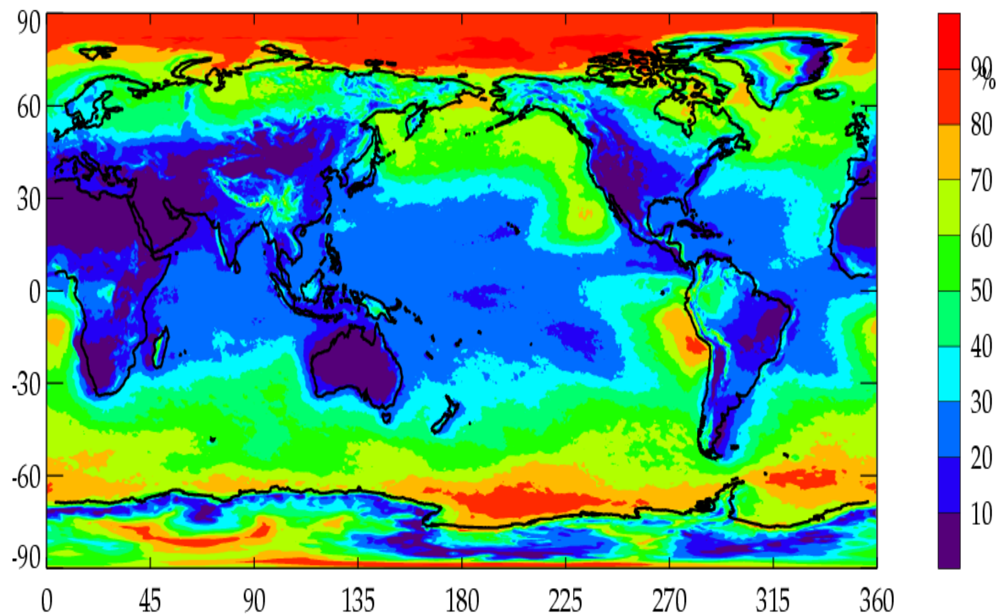


T511
time=10d
n=140
2001 & 2004

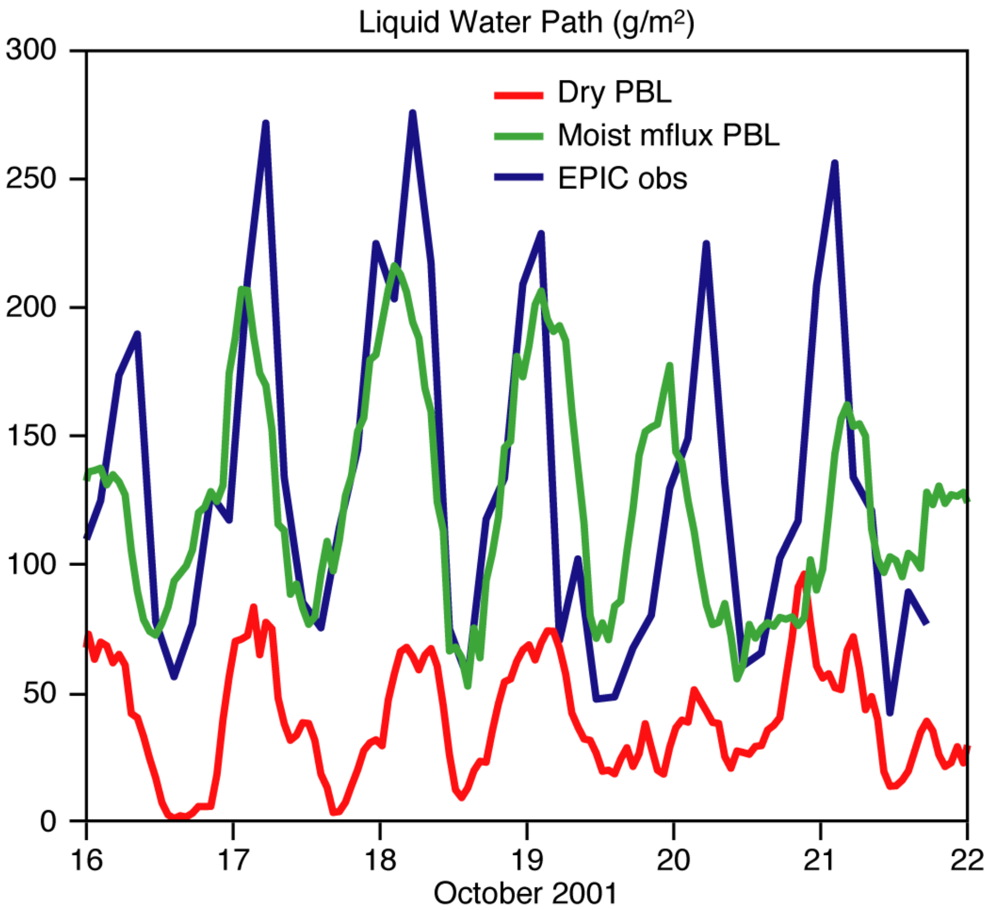
old: CY28R4

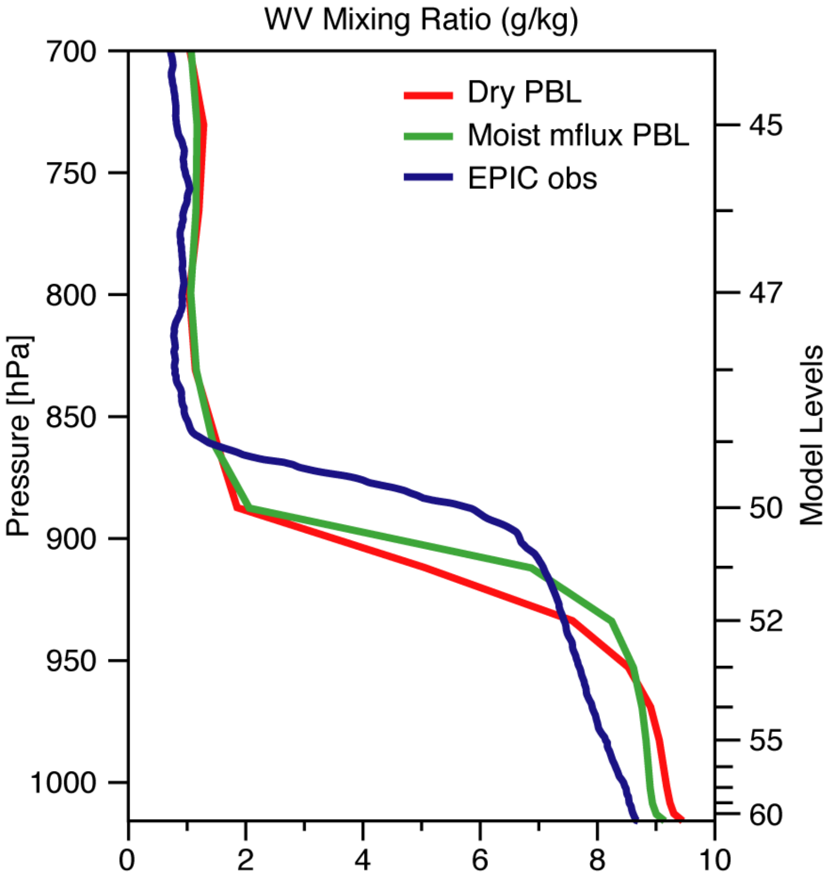


EDMF PBL



Results: EPIC column extracted from 3D forecasts



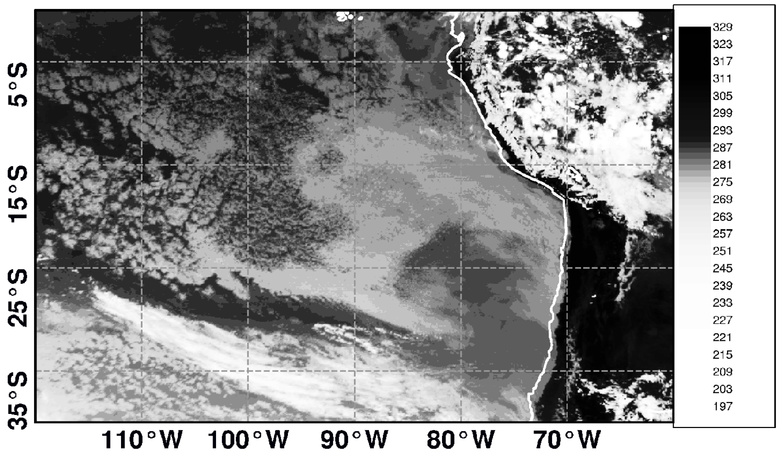


VOCALS field experiment off Chile

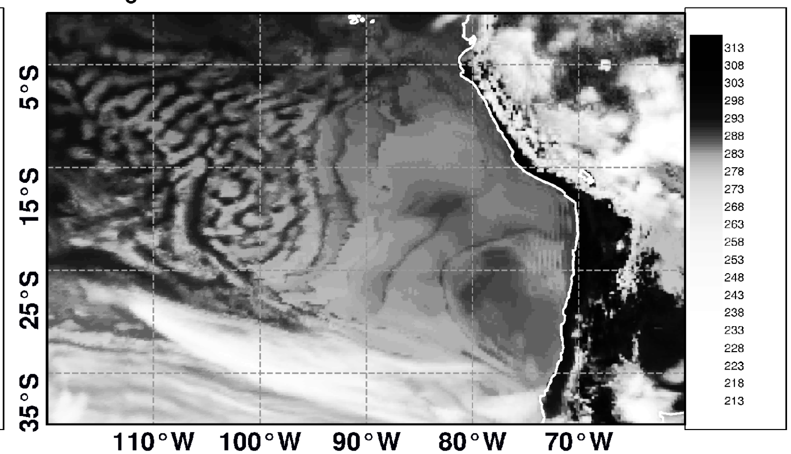
GOES12 10.8µm

ECMWF 10.8µm

GOES12IR10.8 20081018 18 UTC

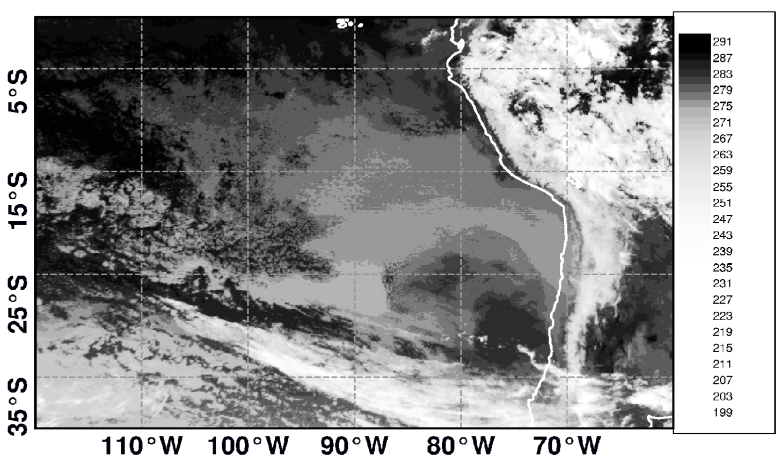


RTTOV gen. GOES12IR10.8 ECMWF Fc 20081018 00 UTC+18h:

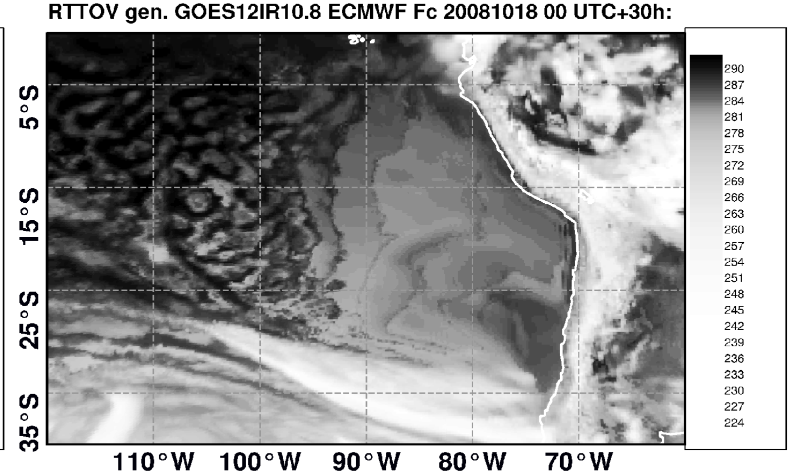


12LT

GOES12IR10.8 20081019 6 UTC



RTTOV gen. GOES12IR10.8 ECMWF Fc 20081018 00 UTC+30h:

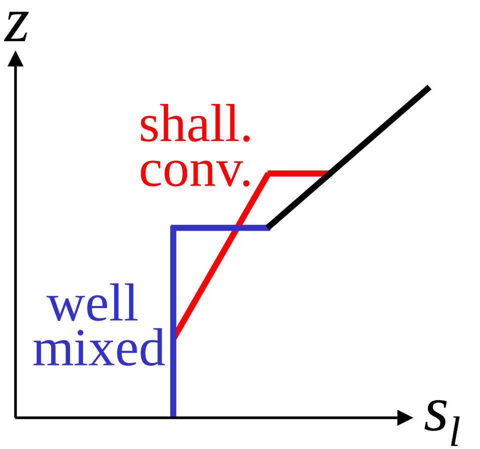


0LT

Stratocumulus Parameterization Challenges

- cloud top entrainment
- numerics
- the scheme is active only if the boundary layer is unstable

- drizzle
  - amount/evaporation

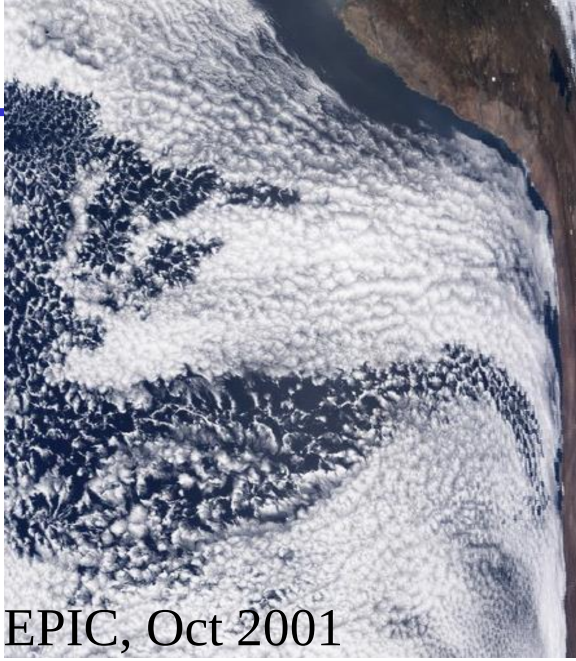


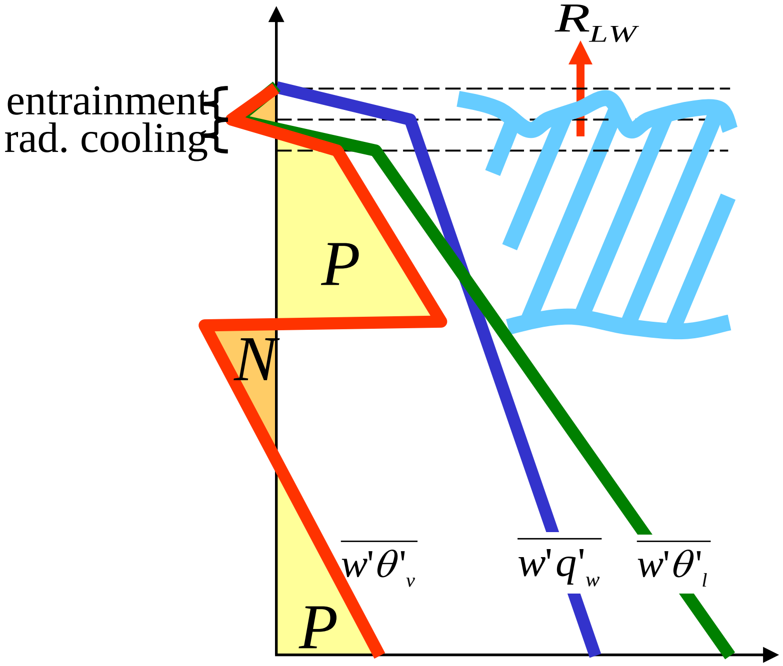
- cloud regime (stratocumulus/trade cumulus)
  - open/closed cells
  - decoupling
  - interaction between solar warming and drizzle evaporative cooling

stratocumulus to *trade cumulus*

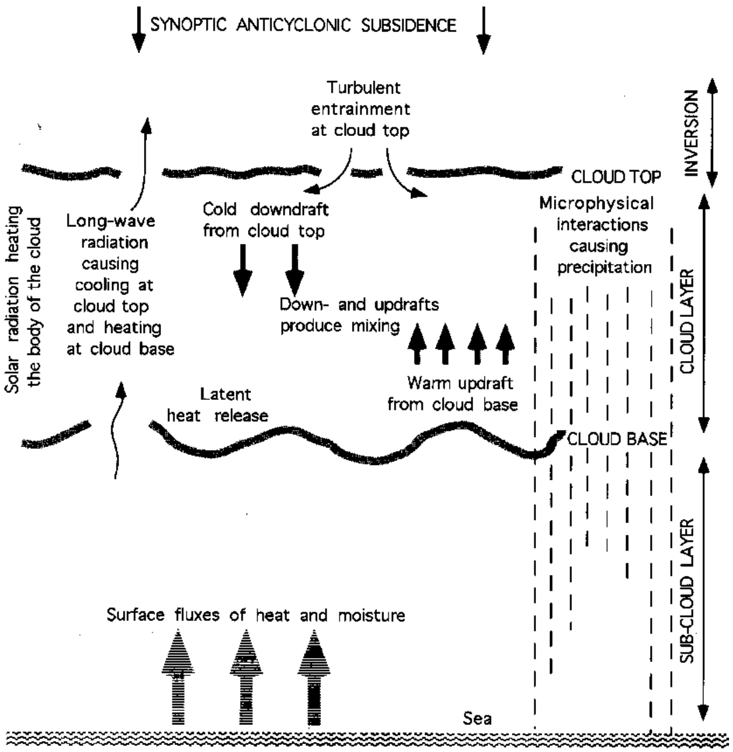
transition criteria

- ☞ EIS (Wood and Bretherton, 2006)
- ☞ static stability: $\theta_{700hPa} - \theta_{sfc} < 14K$
- ☞ buoyancy flux integral ratio: $N/P > 0.1$


EPIC, Oct 2001

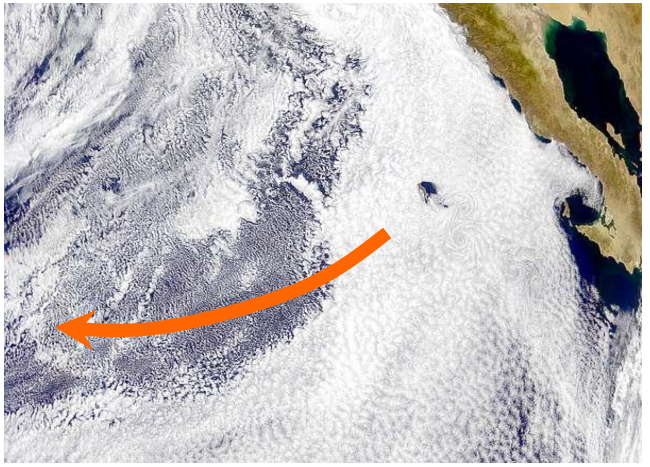


Summary

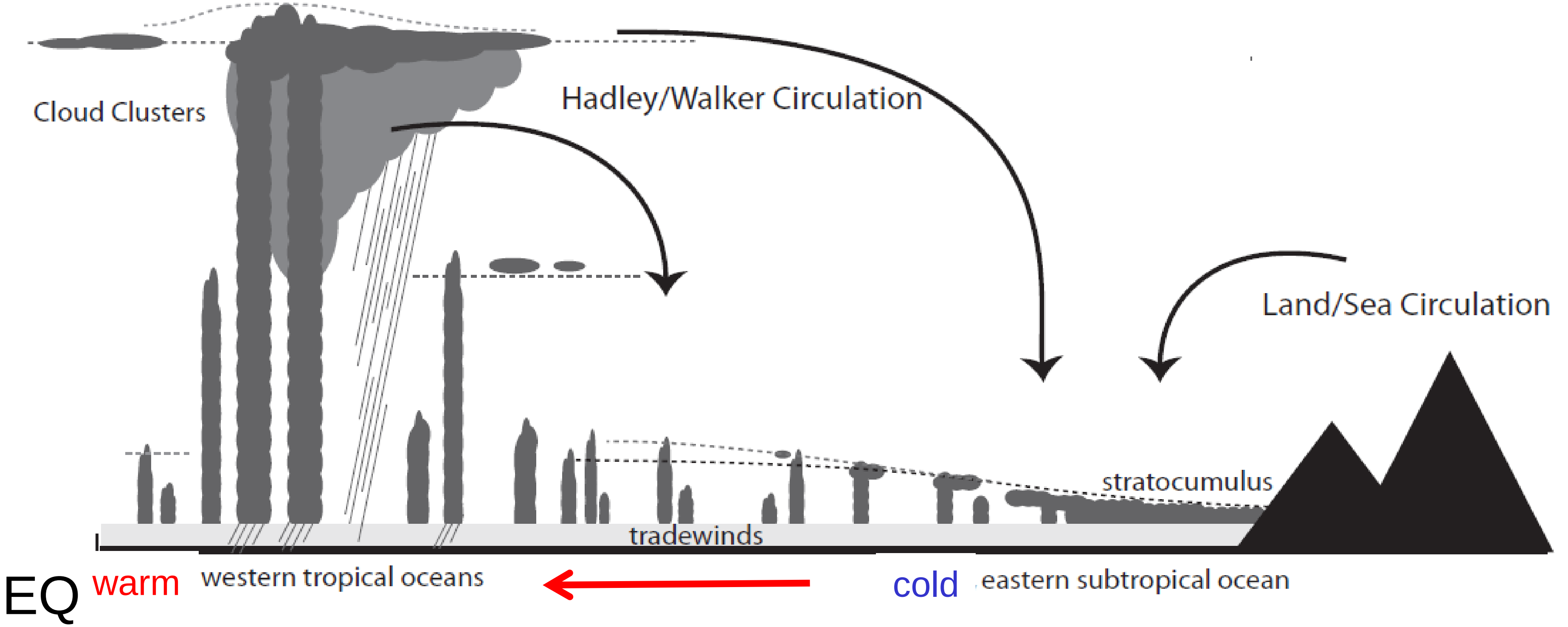


- Stratocumulus: *important*
  - climate
  - land temperature
- Stratocumulus: *simple at a first sight*
  - horizontally uniform
    (cloud fraction ~100%)
  - vertically uniform
    (well-mixed)
- Stratocumulus: *difficult to parameterize*
  - multiple processes
  - multiple scales

The stratocumulus to cumulus transition



NE Pacific



Simple conceptual model of the transition

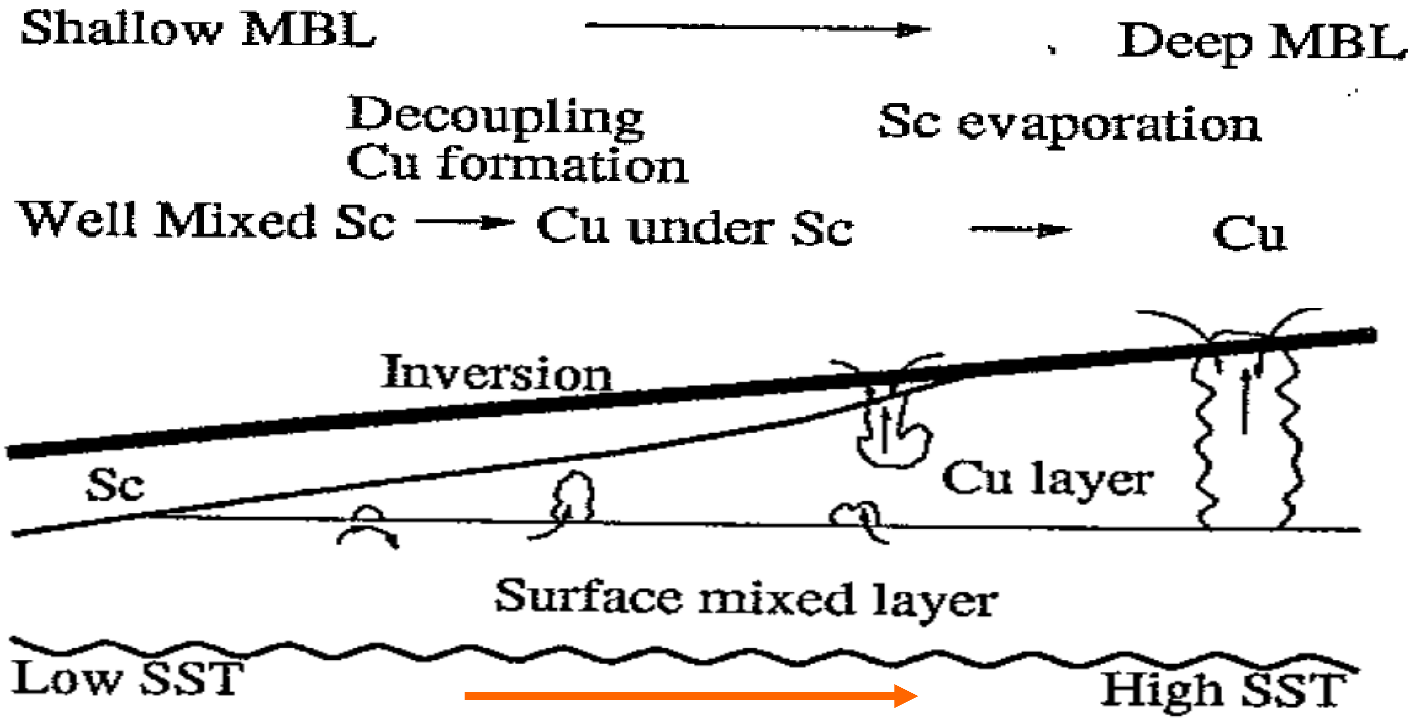


Figure 1. A conceptual diagram of the STT.

(Bretherton et al., 1992)

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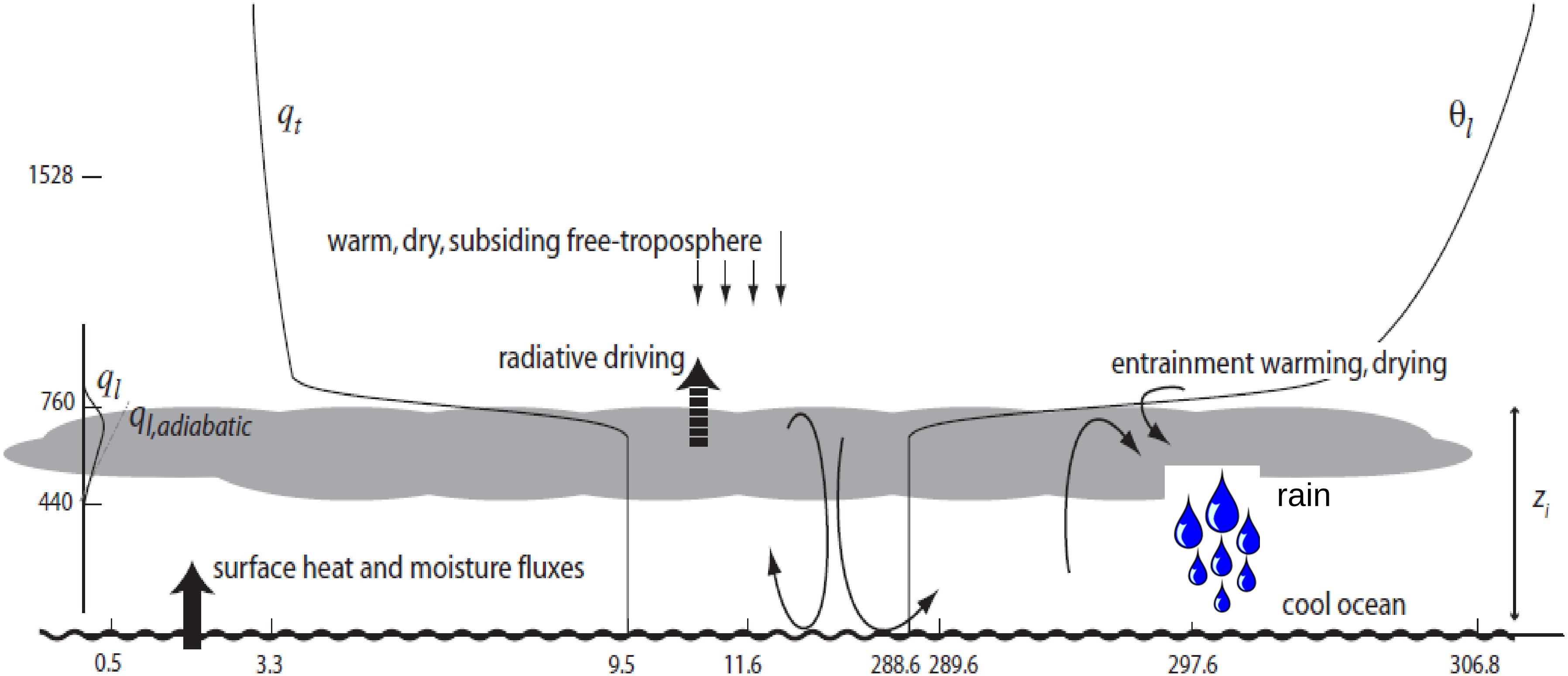
Sandu, Stevens, Pincus, ACP, 2010

Sandu and Stevens, JAS, 2012

Main processes controlling the cloud evolution



- Inversion strength
- Large-scale subsidence
- Rain formation
- Rain evaporation