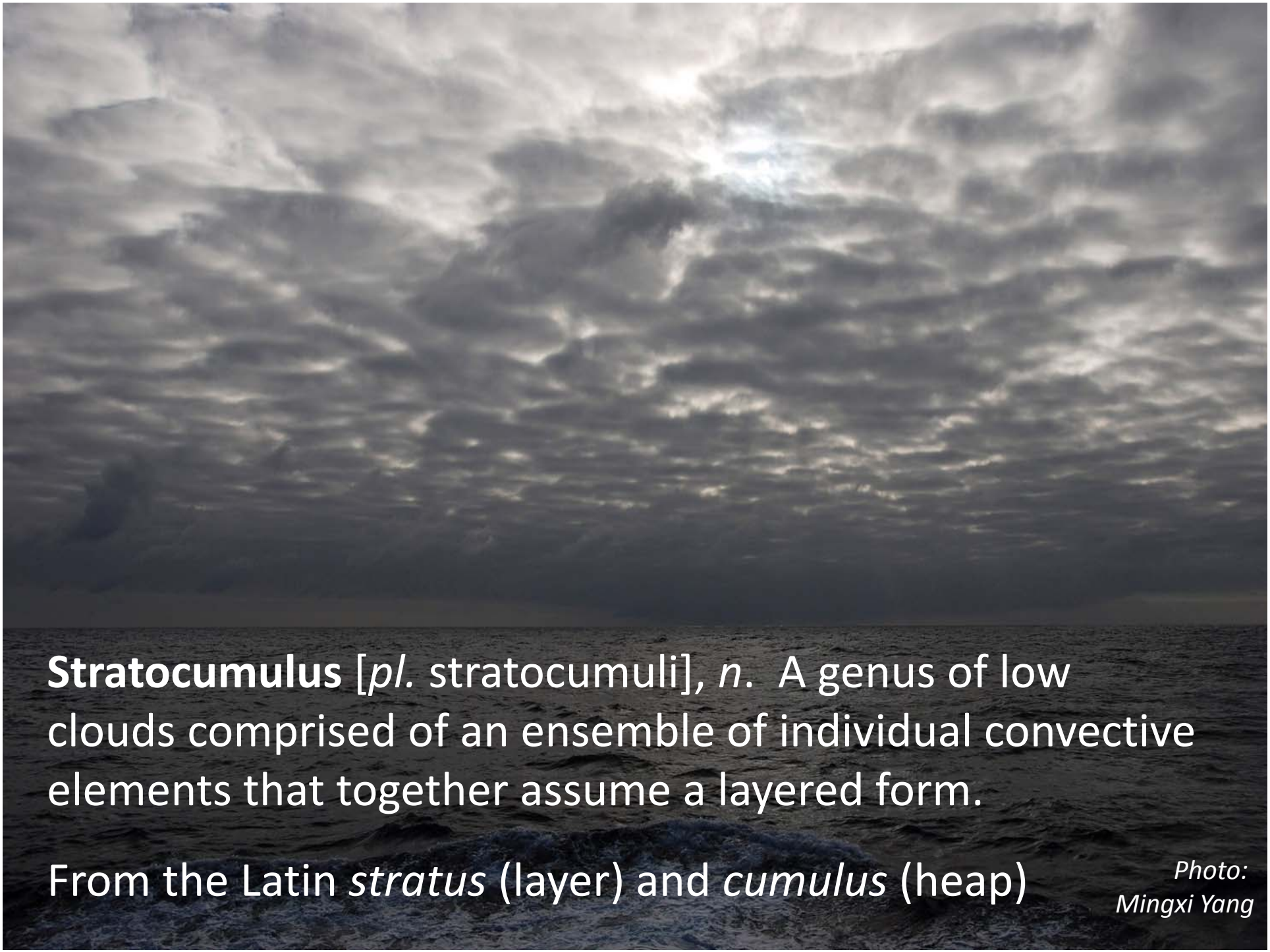
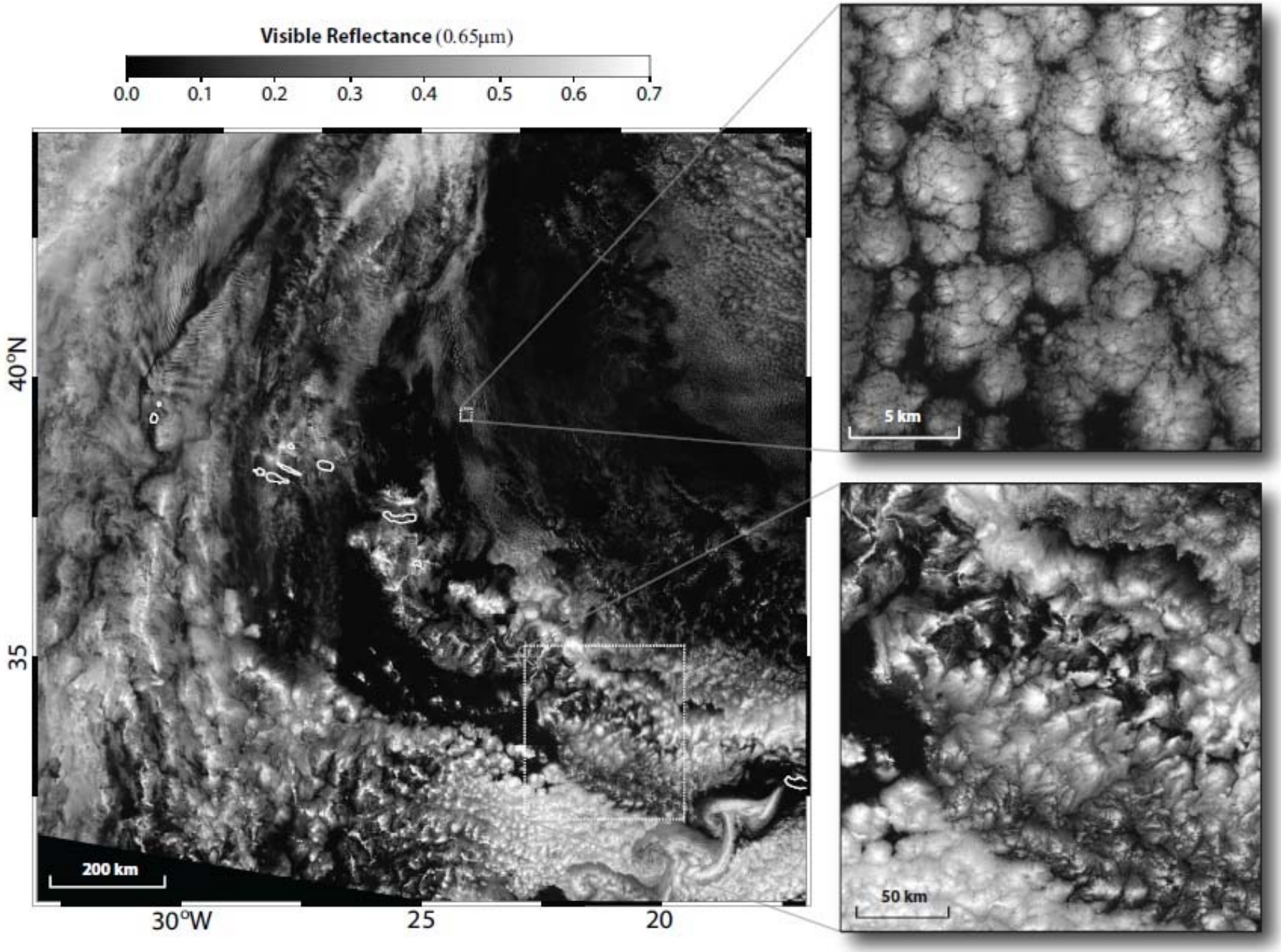

Stratocumulus



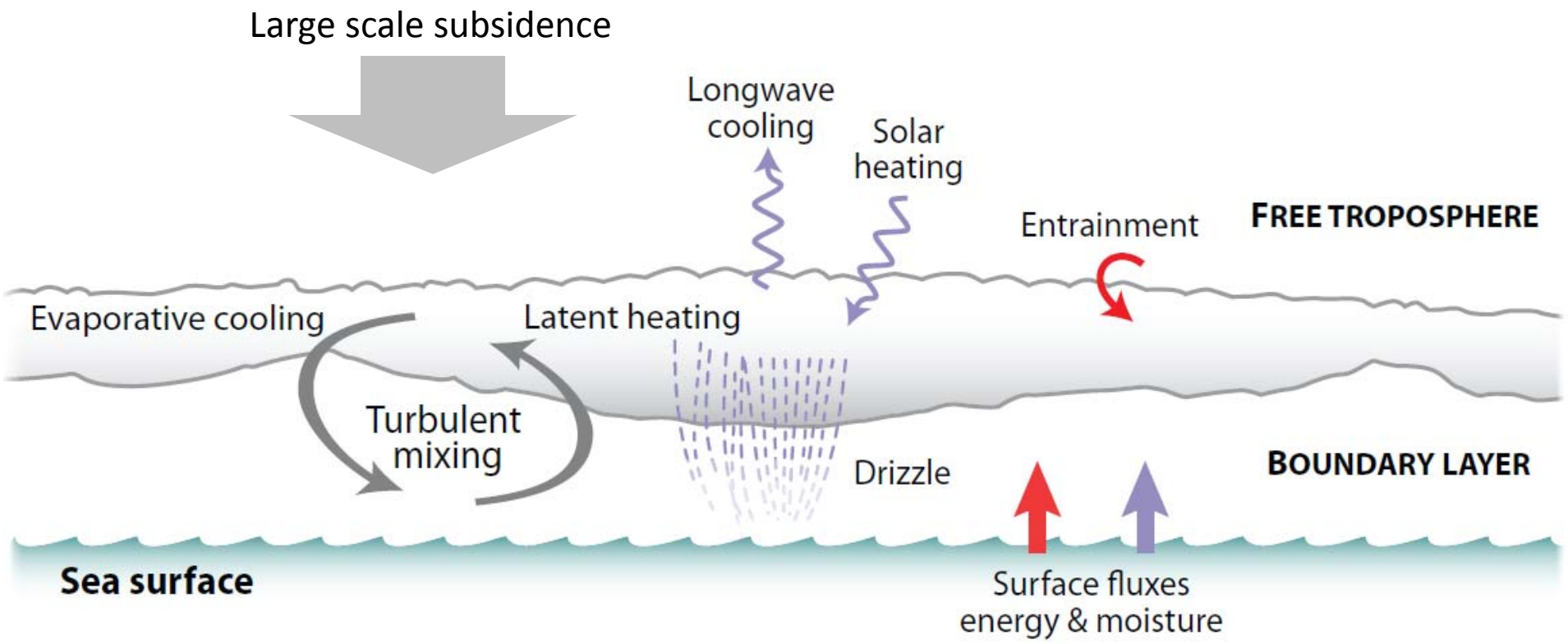
Stratocumulus [*pl.* stratocumuli], *n*. A genus of low clouds comprised of an ensemble of individual convective elements that together assume a layered form.

From the Latin *stratus* (layer) and *cumulus* (heap)

Photo: Mingxi Yang

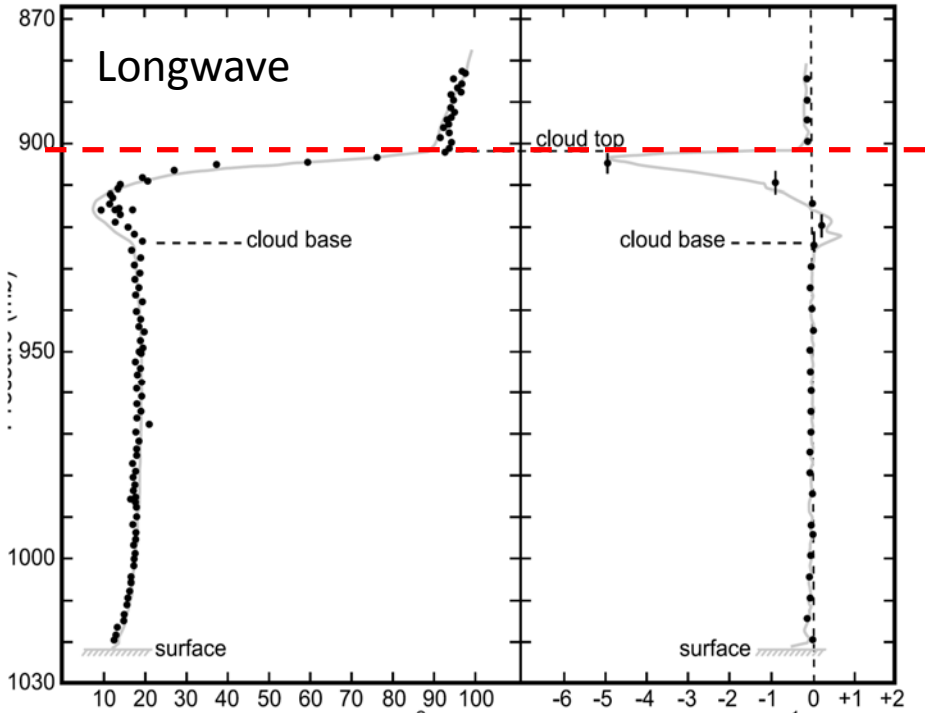

Visible Reflectance (0.65µm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
40°N
35
30°W
25
20
200 km
5 km
50 km

Key physical processes



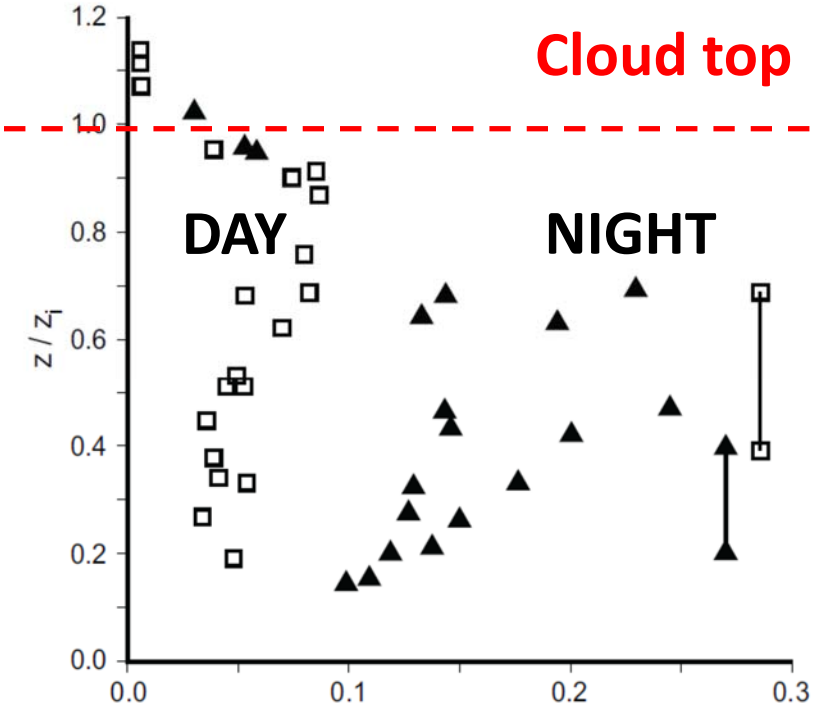
A convective cloud system

driven (primarily) from the top



Net upward flux [W m^{-2}] Heating rate [K hr^{-1}]

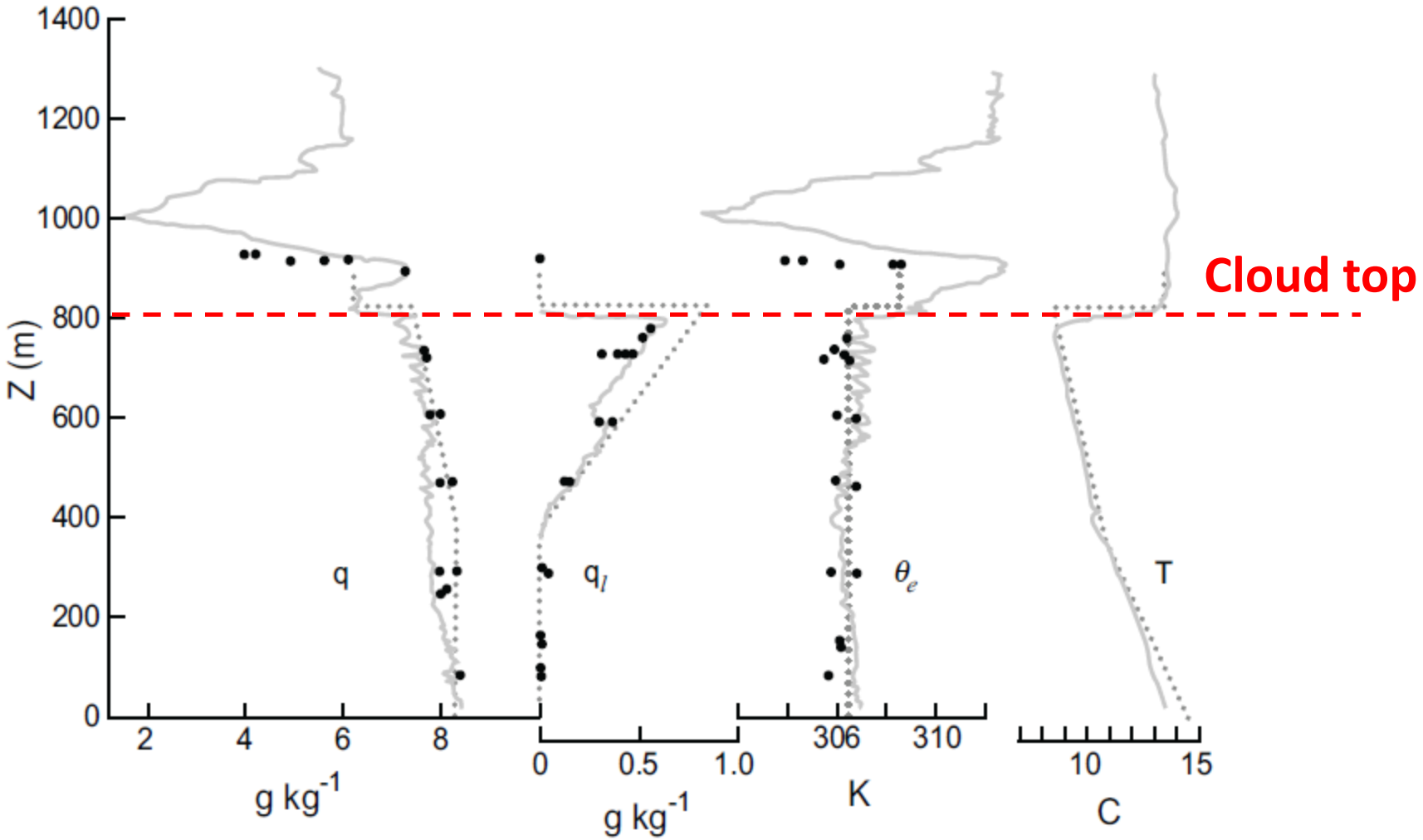
Slingo et al. (1982)



Vertical velocity variance [m^2 s^{-2}]

Hignett (1991)

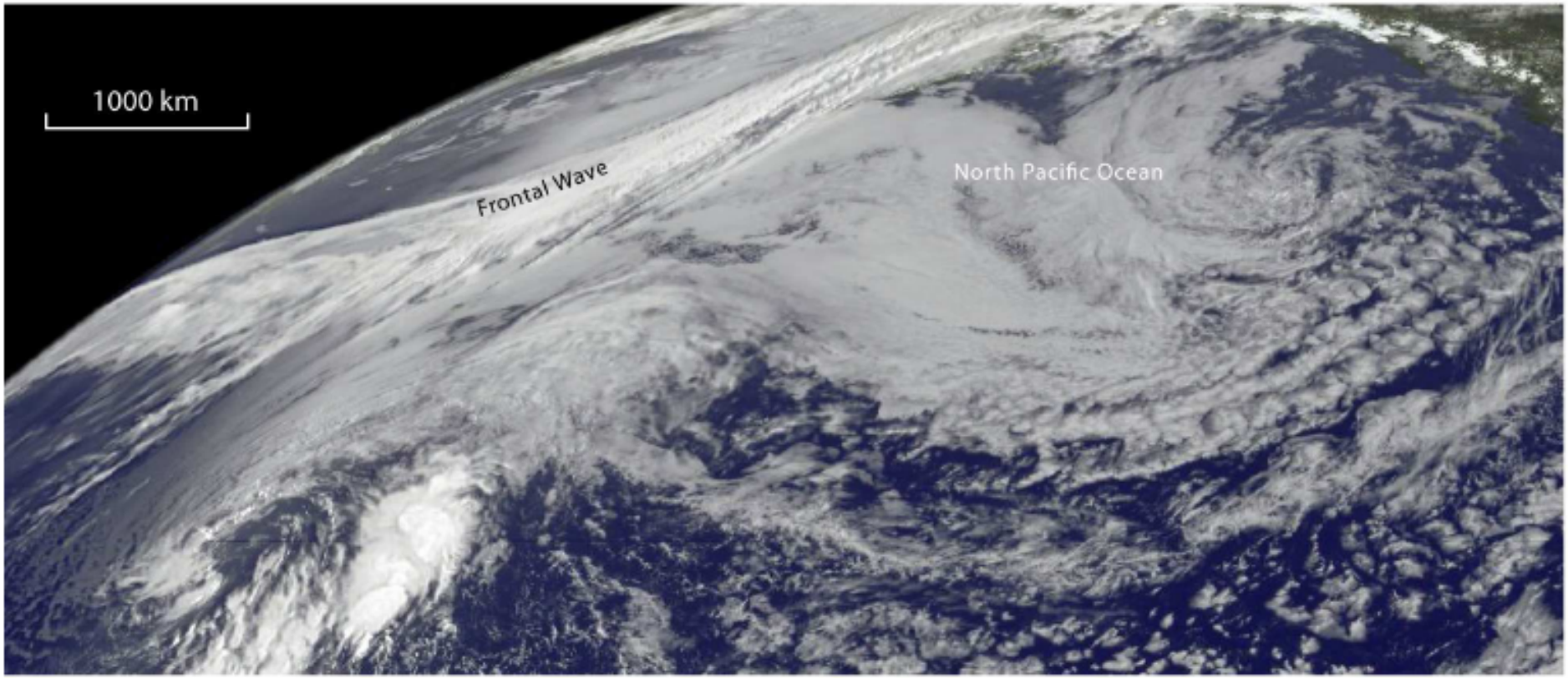
Stratocumulus-topped boundary layer (STBL): Well-mixed case



Nicholls (*Quart. J. Roy. Meteorol. Soc.*, 1984)

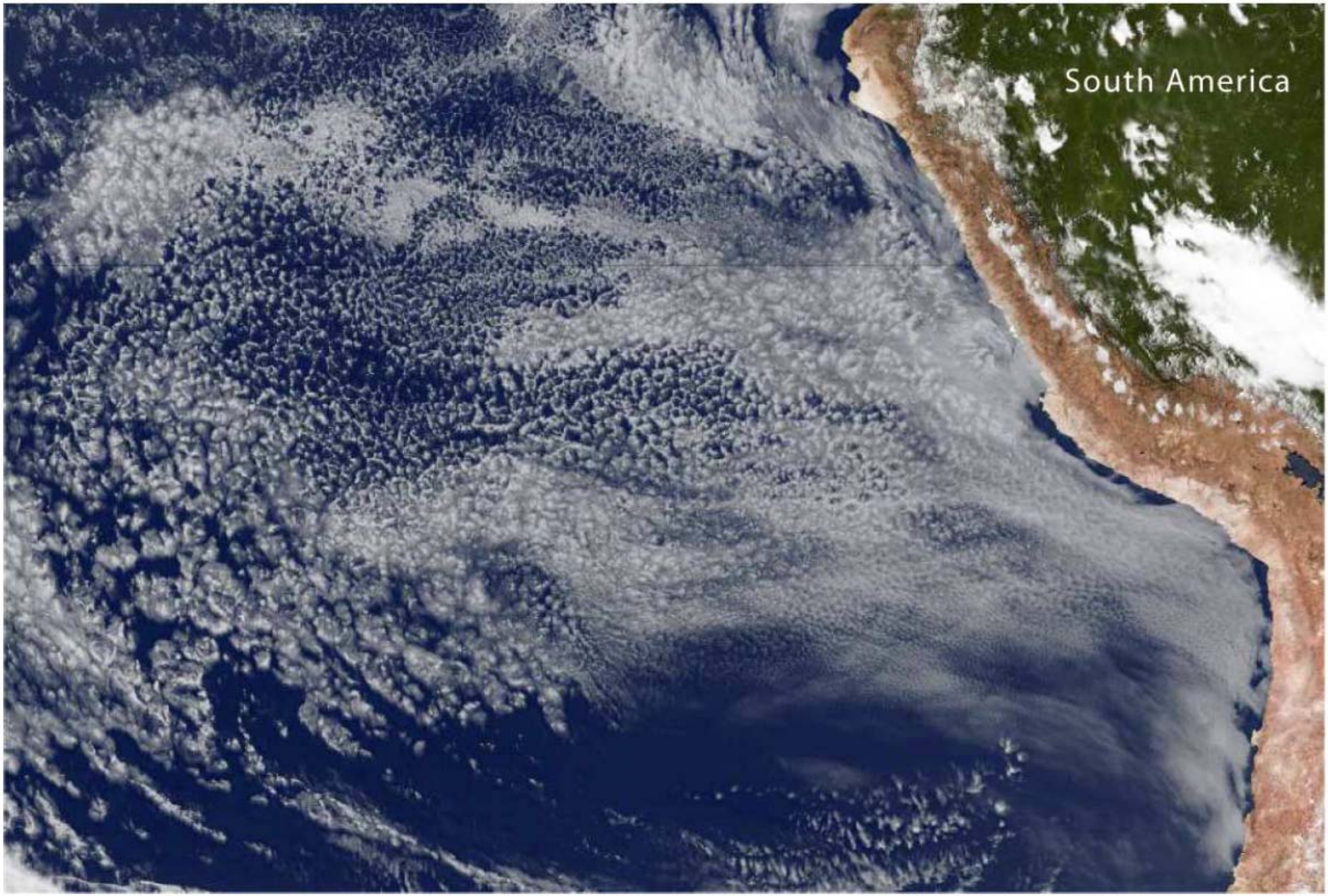
Midlatitude stratocumulus

31 August 2009 at 18:00 UTC

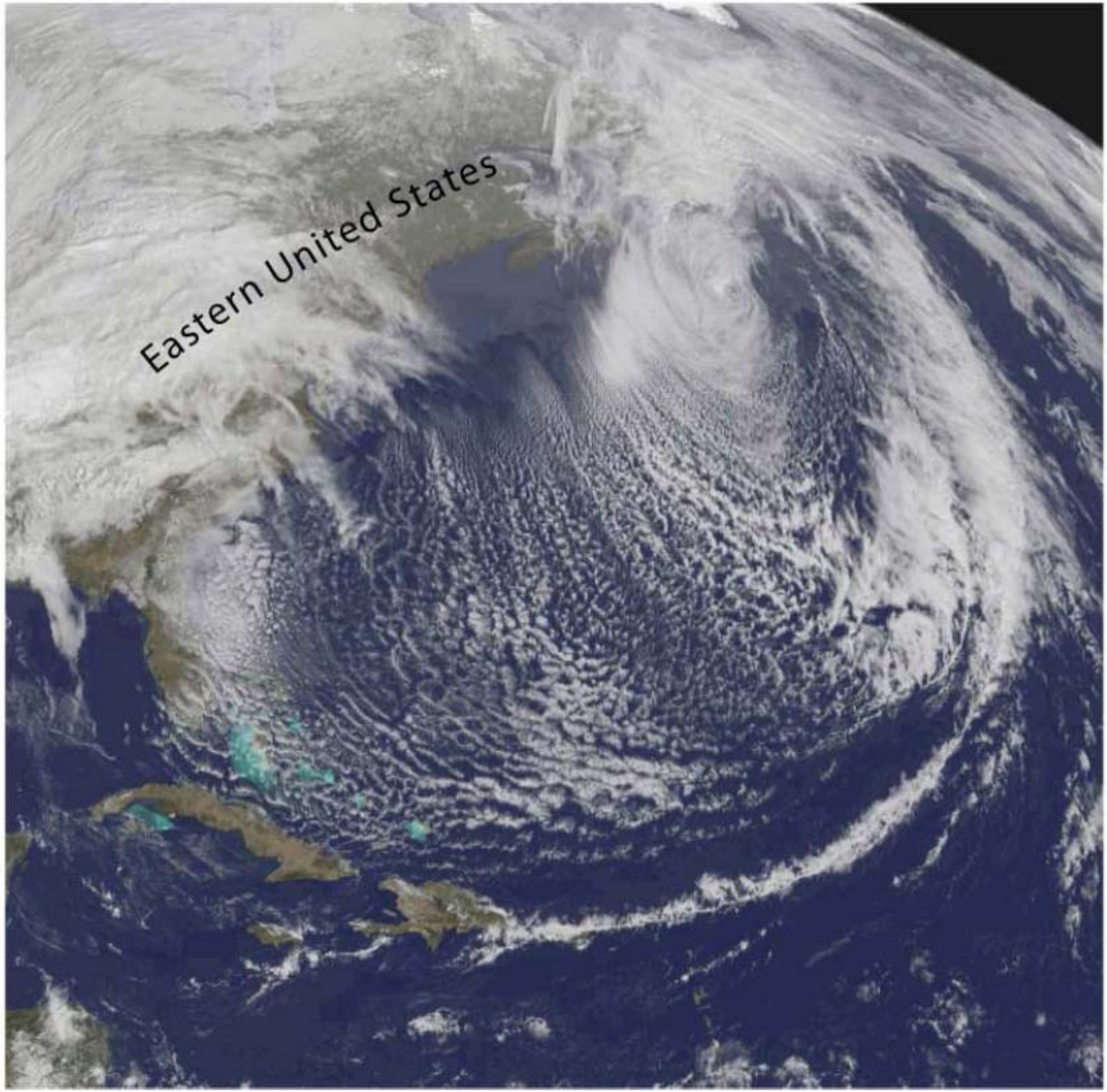


Subtropical stratocumulus

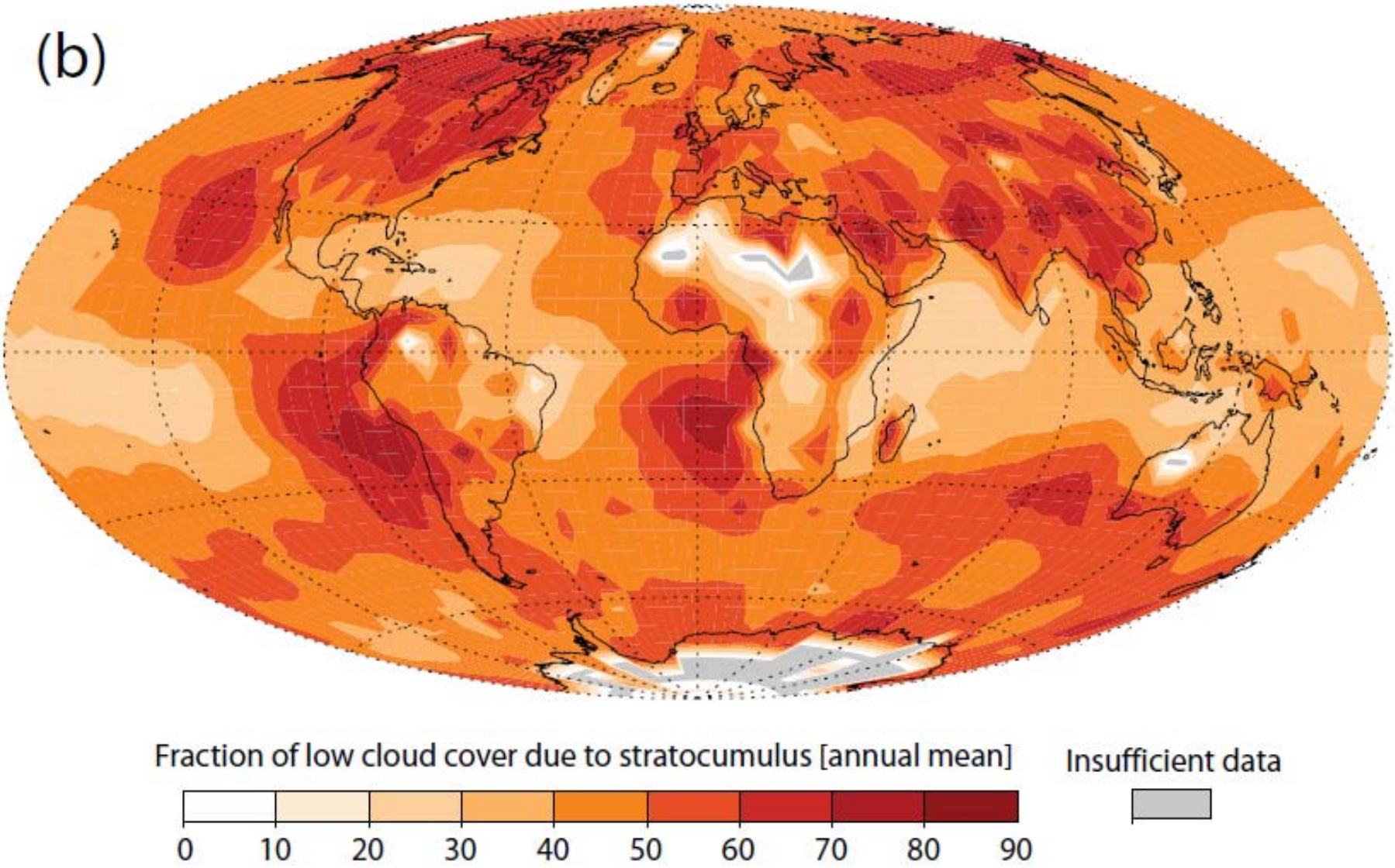
4 September 2009 at 20:45 UTC



Cold Air outbreak 18 March 2008 at 14:45 UTC



Stratocumulus cloud cover

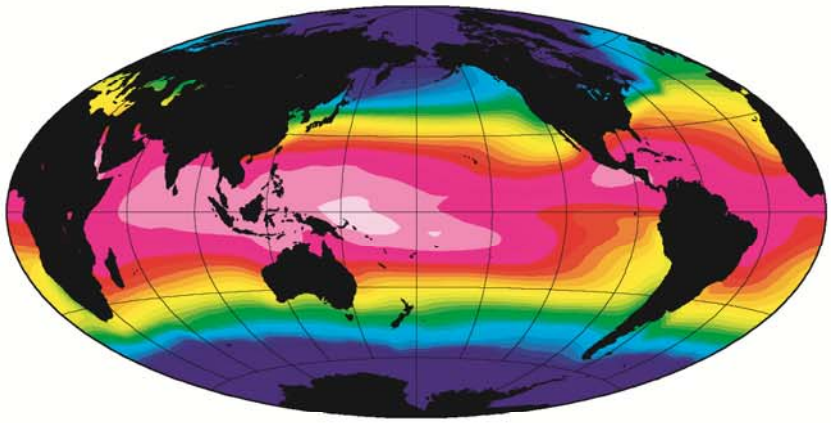


Sc coverage: **Land: 12%**; **Ocean: 23%**

80% of all stratocumulus cloud cover is marine

Cloud Atlas
Warren et al. (1986, 1988)

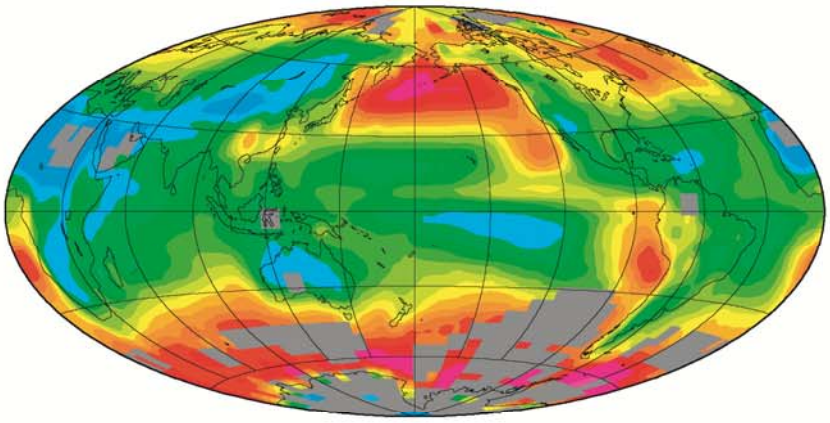
Sea Surface Temperature



NO DATA 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

deg C

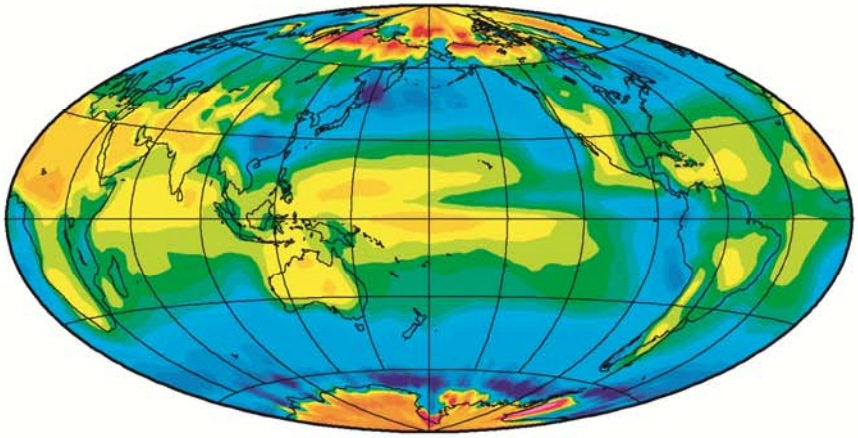
Annual Warren Stratus Cloud Amount



NO DATA 0 10 20 30 40 50 60 70 80

Percent

Net Radiative Cloud Forcing
1985-1986



NO DATA -140 -120 -100 -80 -60 -40 -20 0 20 40 60

W/m**2

Marc Michelsen
Dennis Hartmann

Lower tropospheric stability and low cloud cover

- **Greater stability**

$\Rightarrow$ stronger inversion

$\Rightarrow$ shallower PBL

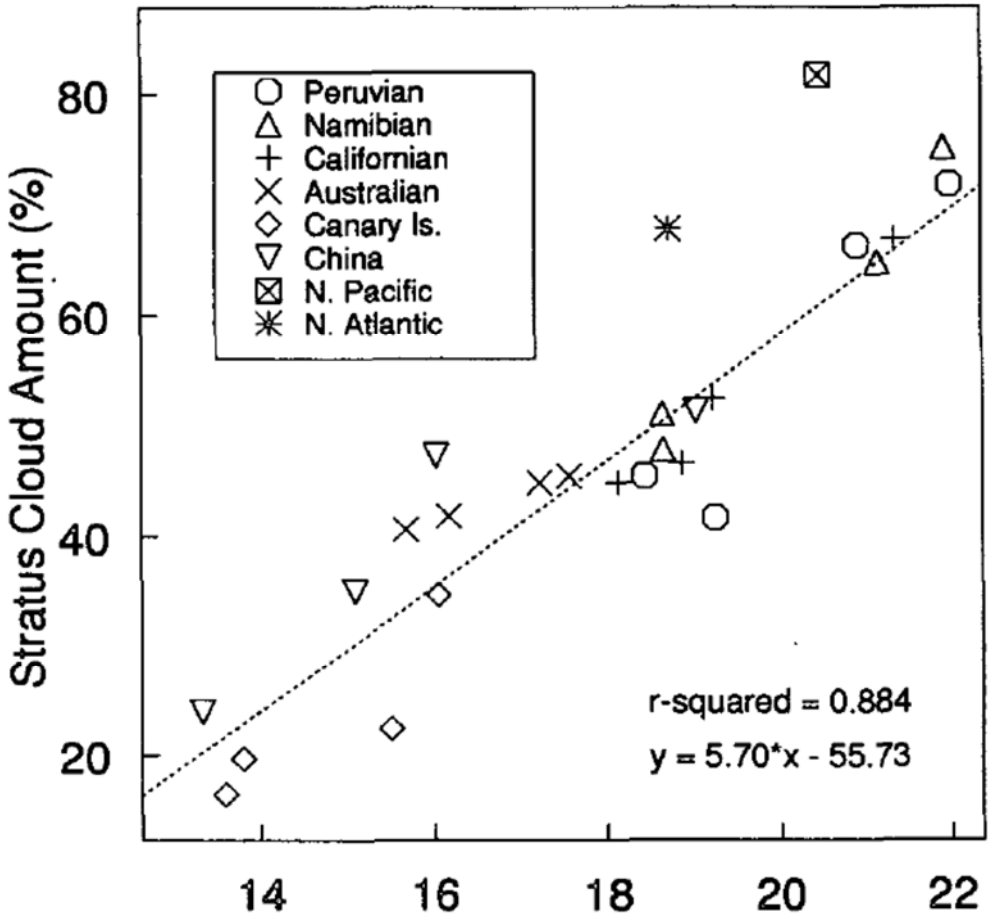
$\Rightarrow$ more well-mixed PBL

$\Rightarrow$ **more extensive Sc.**

- **Caveats**

Does not explain clouds under climate change

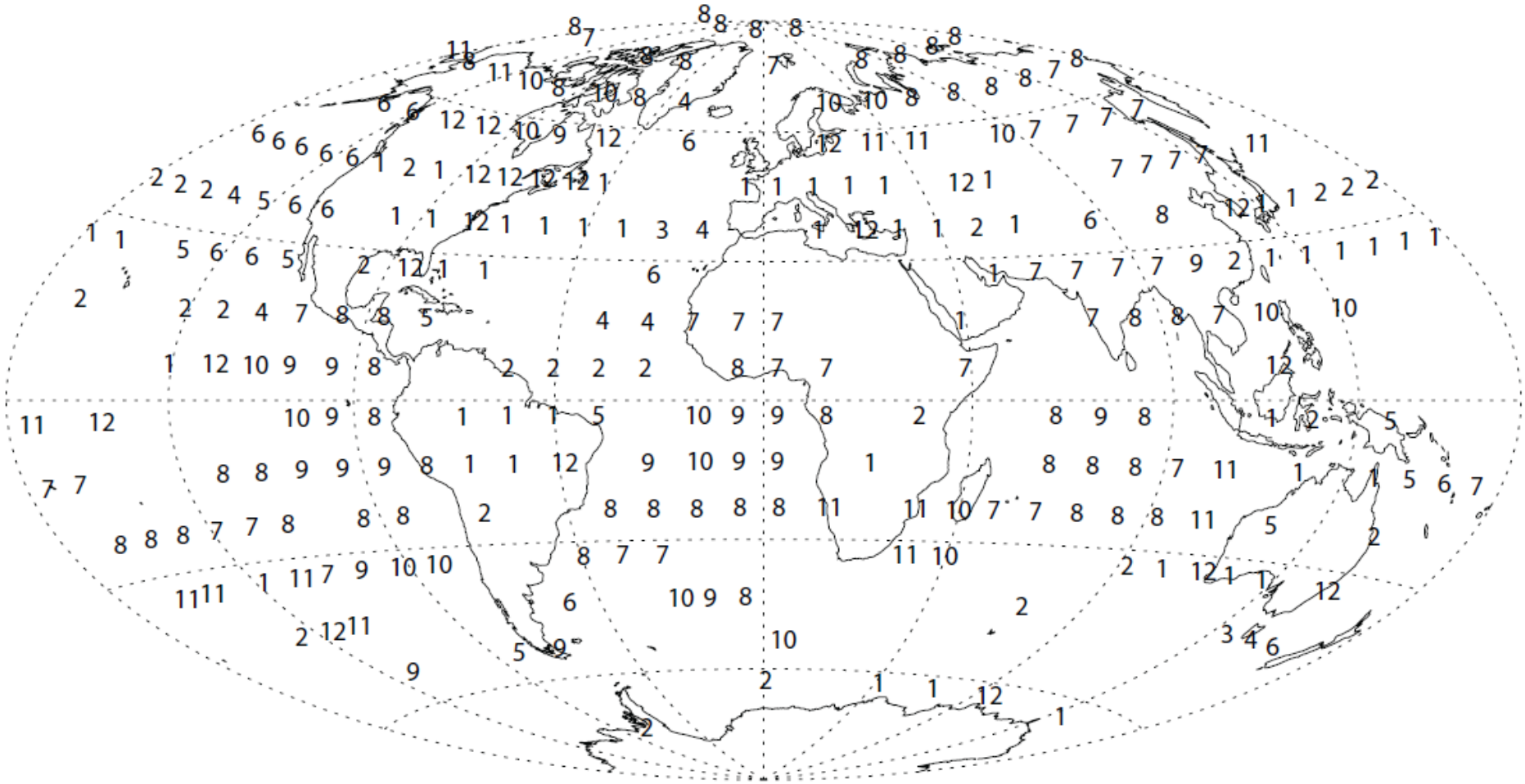
Does not explain midlatitude Sc coverage



$$LTS = \theta_{700} - \theta_0 \quad [\mathrm{K}]$$

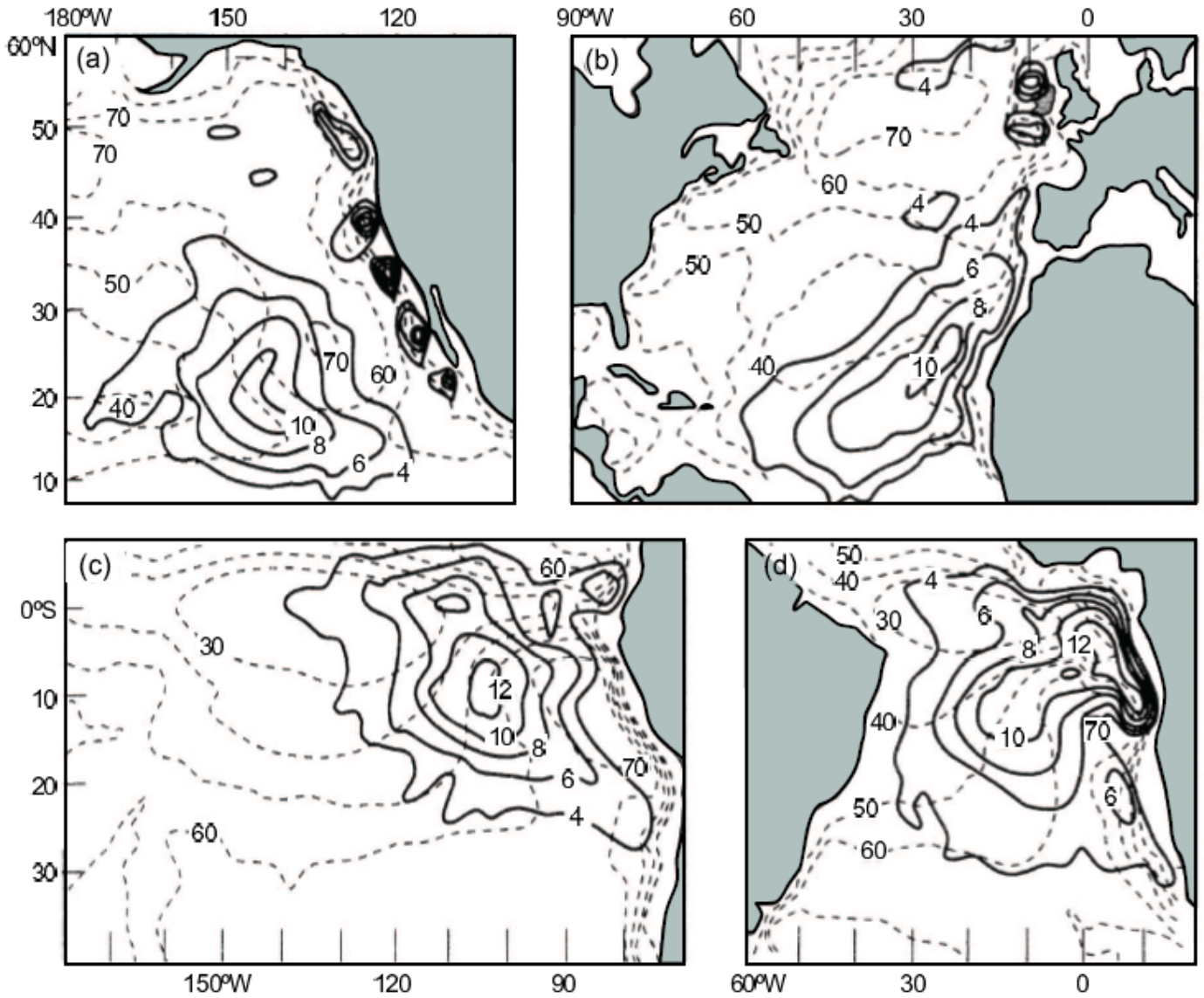
Klein and Hartmann (1993)

Seasonality of Sc cloud cover

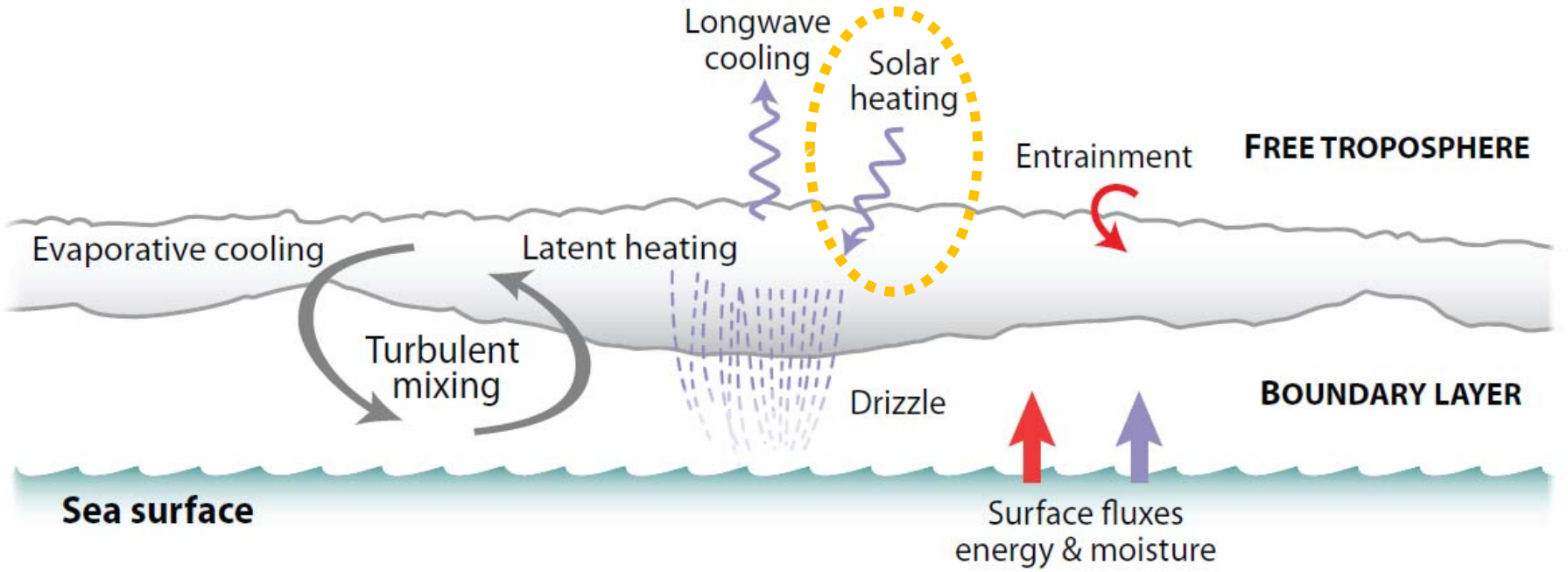


(b) Month of maximum stratocumulus cover

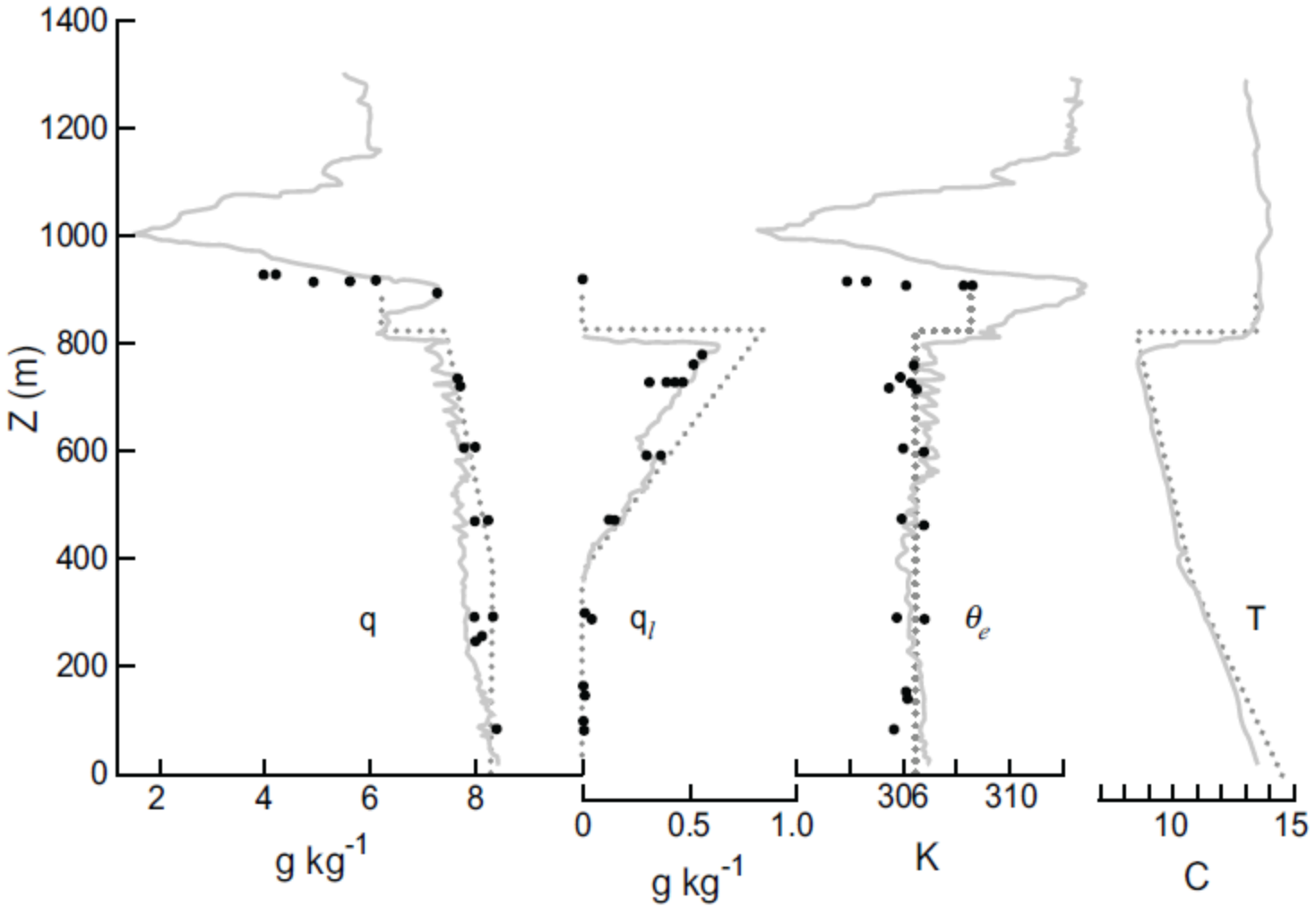
Diurnal amplitude



Rozendaal, Leovy, Klein (*J. Climate*, 1995)

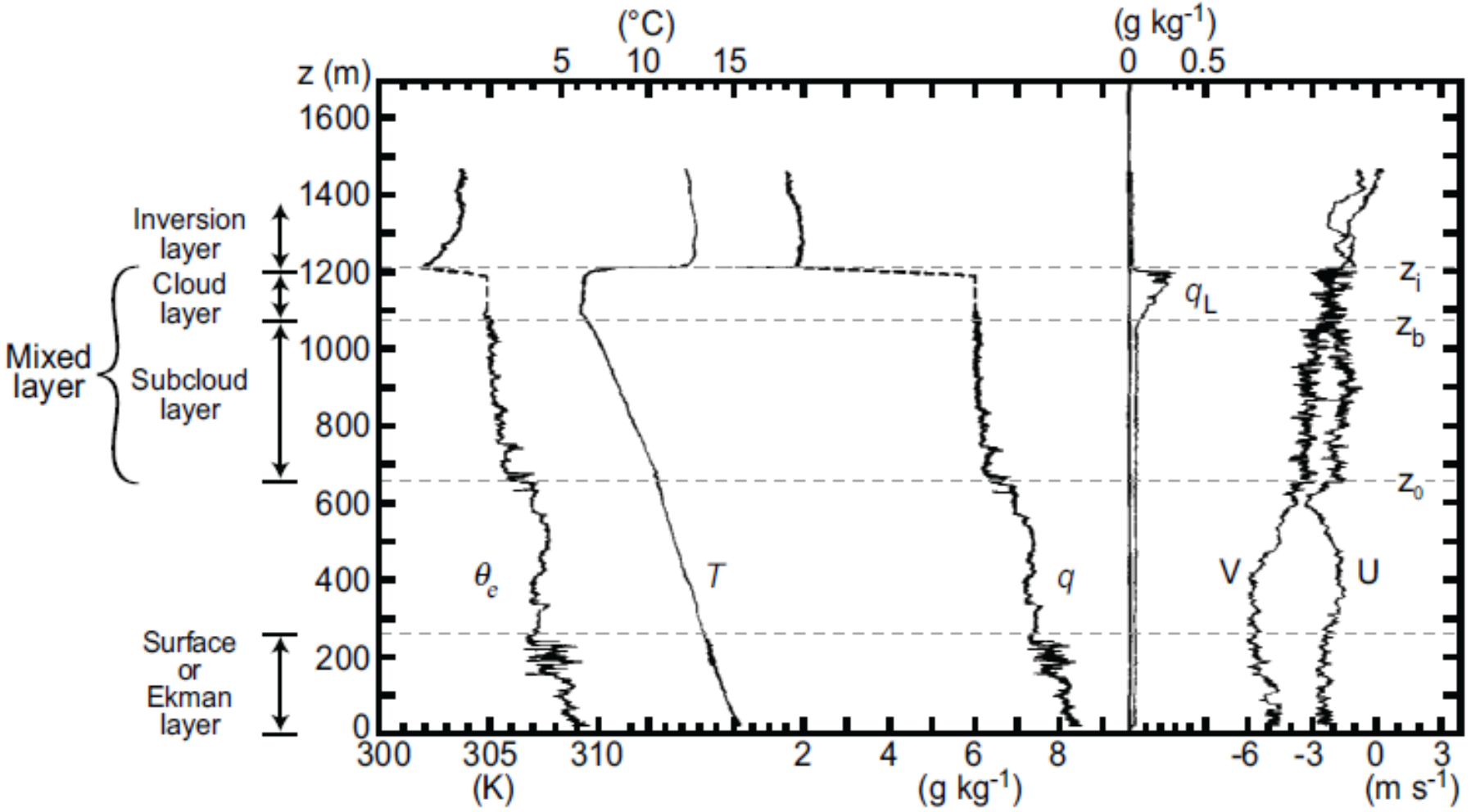

Longwave
cooling
Solar
heating
Entrainment
FREE TROPOSPHERE
Evaporative cooling
Latent heating
Turbulent
mixing
Drizzle
BOUNDARY LAYER
Sea surface
Surface fluxes
energy & moisture

Stratocumulus-topped boundary layer (STBL): Well-mixed case



Nicholls (*Quart. J. Roy. Meteorol. Soc.*, 1984)

Stratocumulus-topped boundary layer (STBL): Decoupled case



Nicholls and Leighton (*Quart. J. Roy. Meteorol. Soc.*, 1986)

"Schubert" circuit diagrams

from Bretherton (1997)

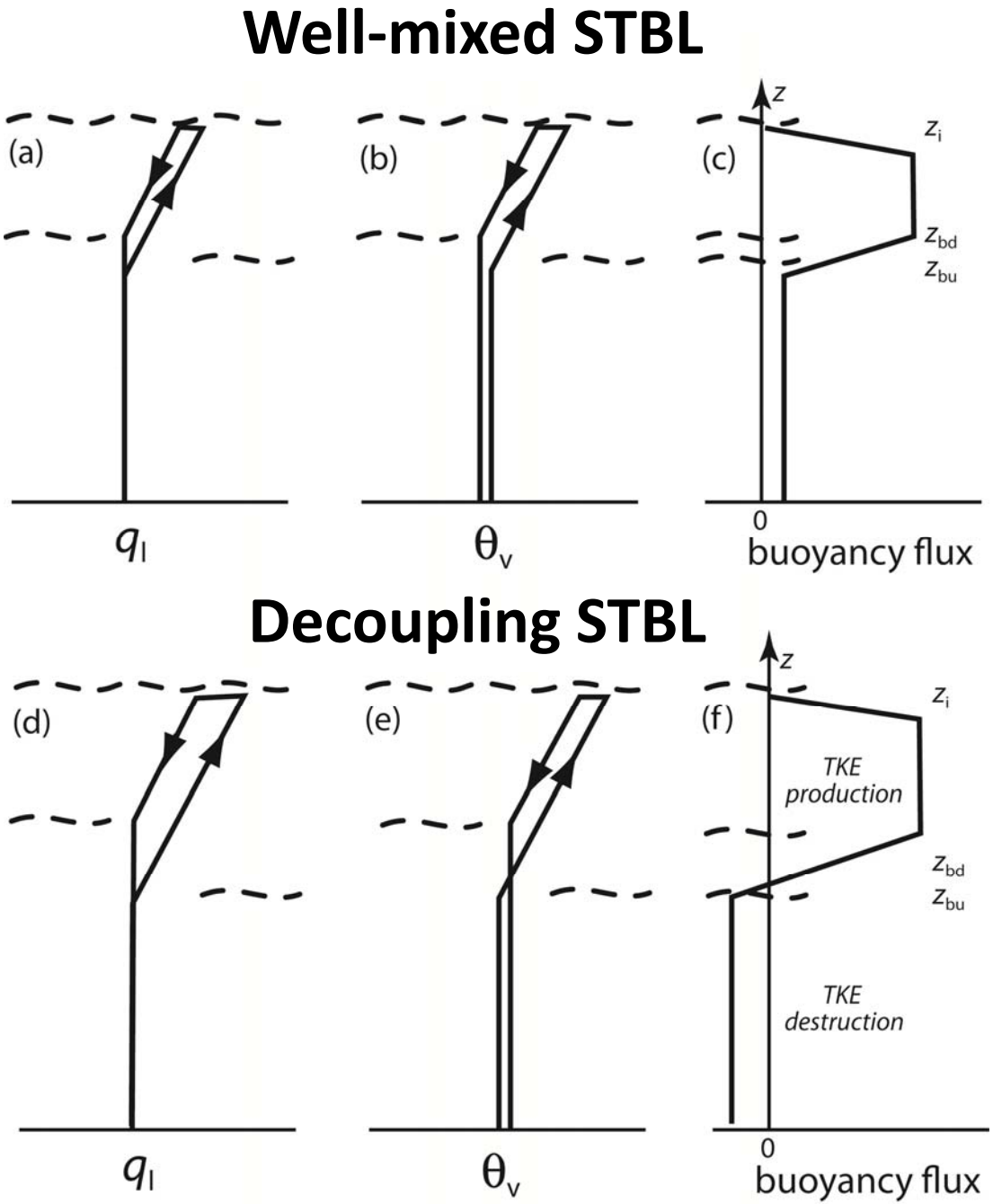
Thicker cloud generates more in-cloud TKE through stronger latent heating

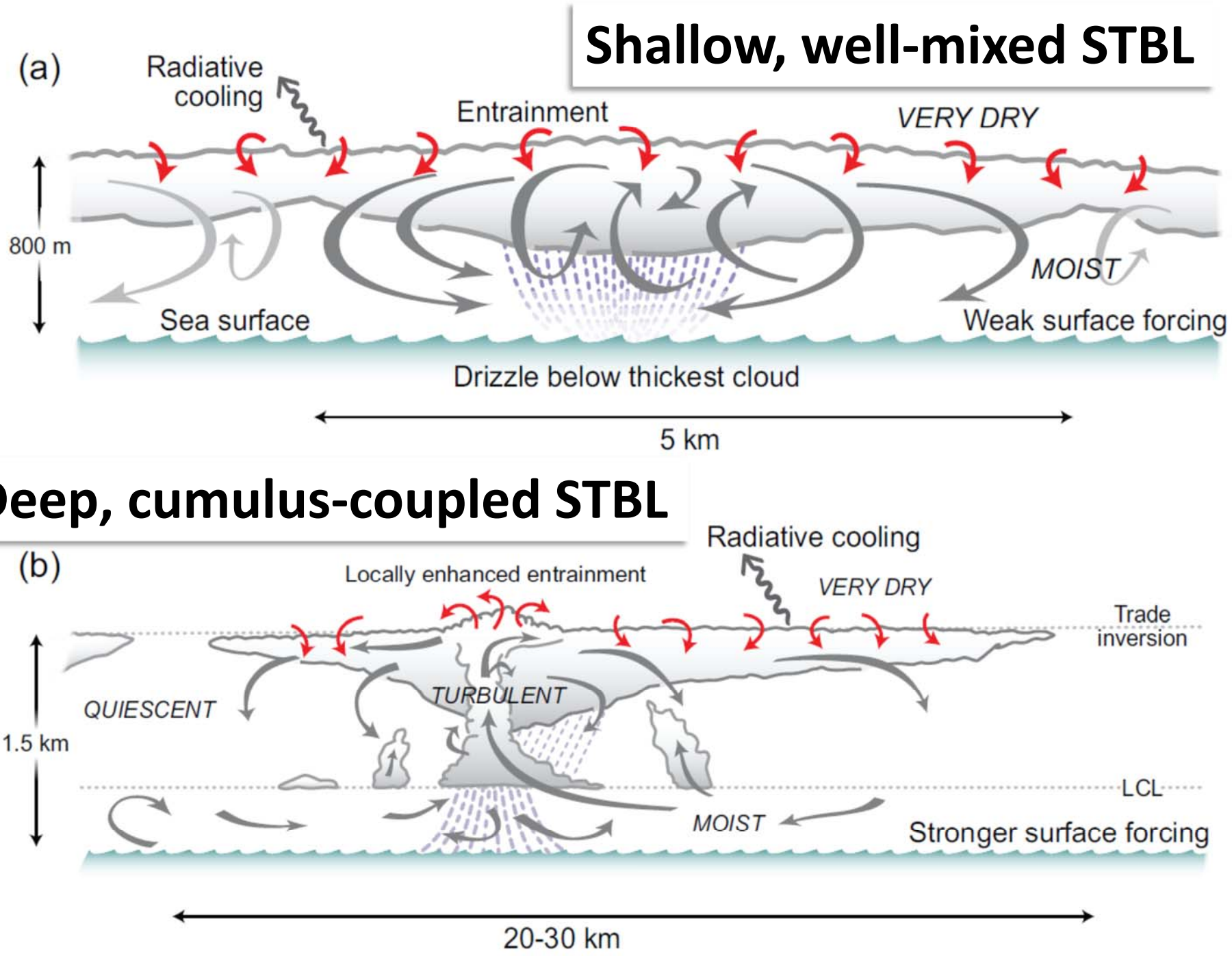
⇒ more entrainment

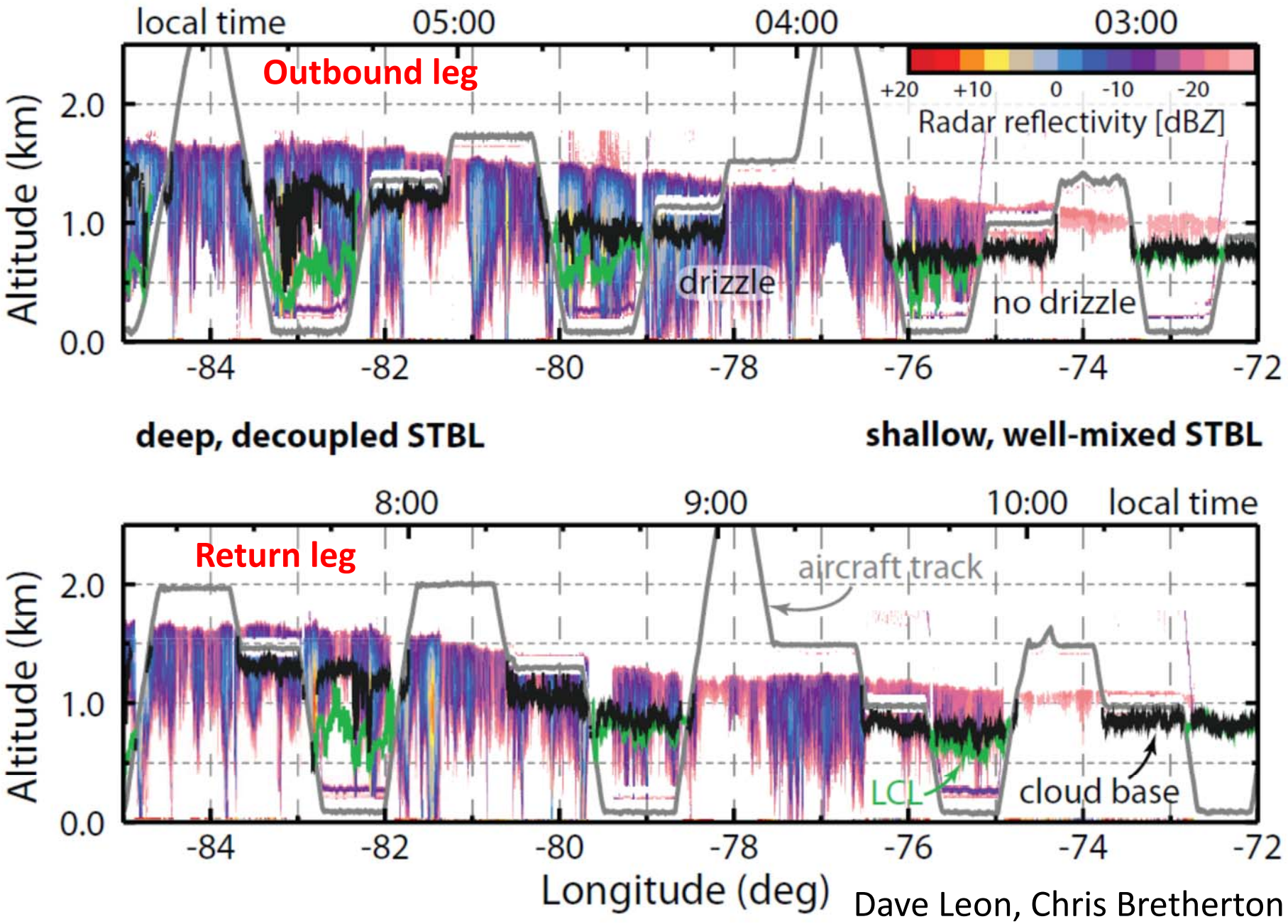
⇒ relatively drier downward moving parcel with elevated cloud base

⇒ creation of negative buoyancy flux

⇒ TKE destruction below cloud

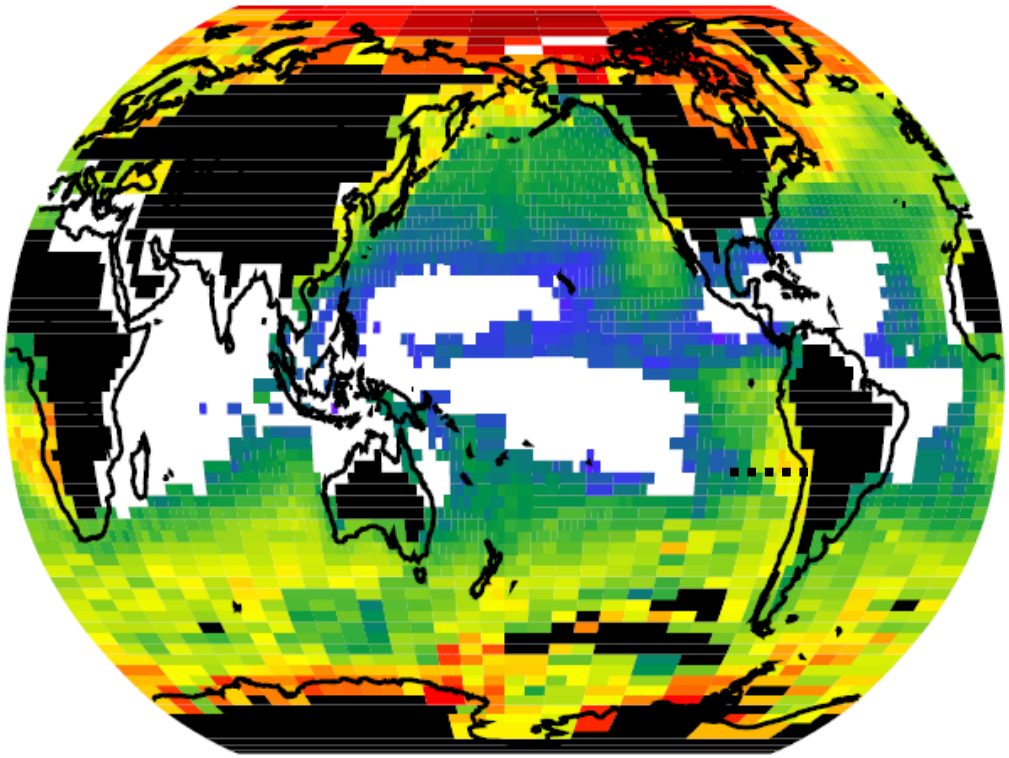



Shallow, well-mixed STBL
(a)
Radiative cooling
Entrainment
VERY DRY
800 m
MOIST
Sea surface
Weak surface forcing
Drizzle below thickest cloud
5 km
Deep, cumulus-coupled STBL
(b)
Radiative cooling
Locally enhanced entrainment
VERY DRY
Trade inversion
QUIESCENT
TURBULENT
1.5 km
LCL
MOIST
Stronger surface forcing
20-30 km

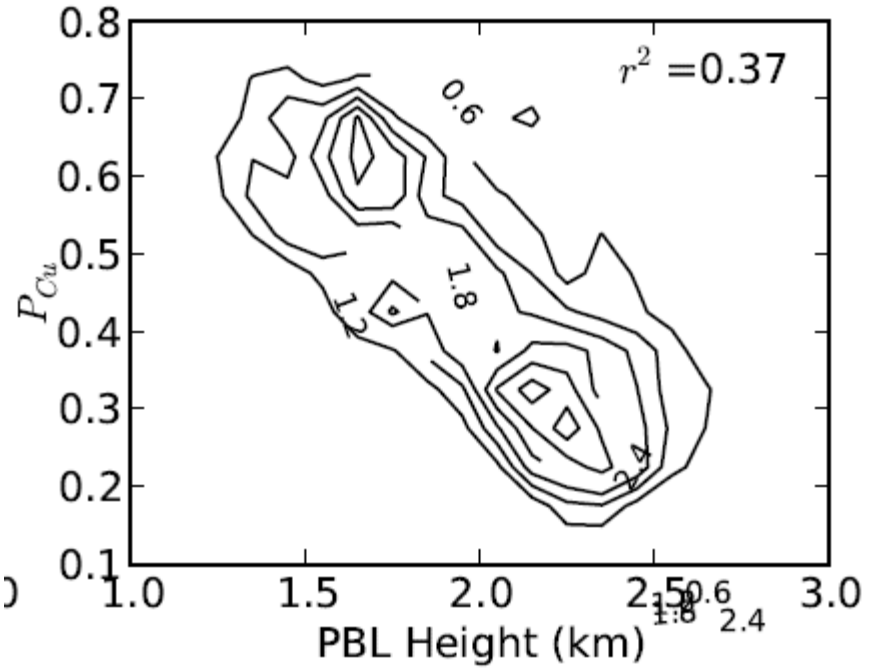


Dave Leon, Chris Bretherton

Where are STBLs decoupled?



PBL height from GPS Radio Occultation

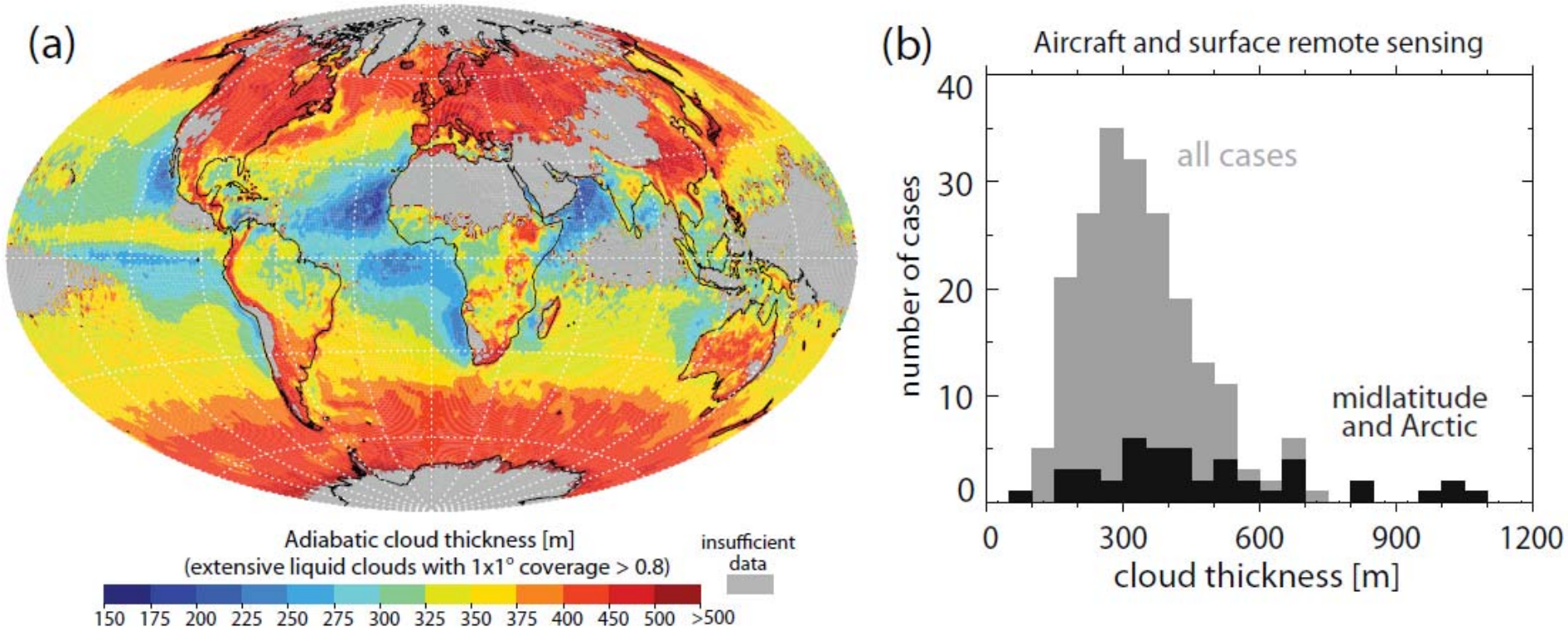


Fraction coupled

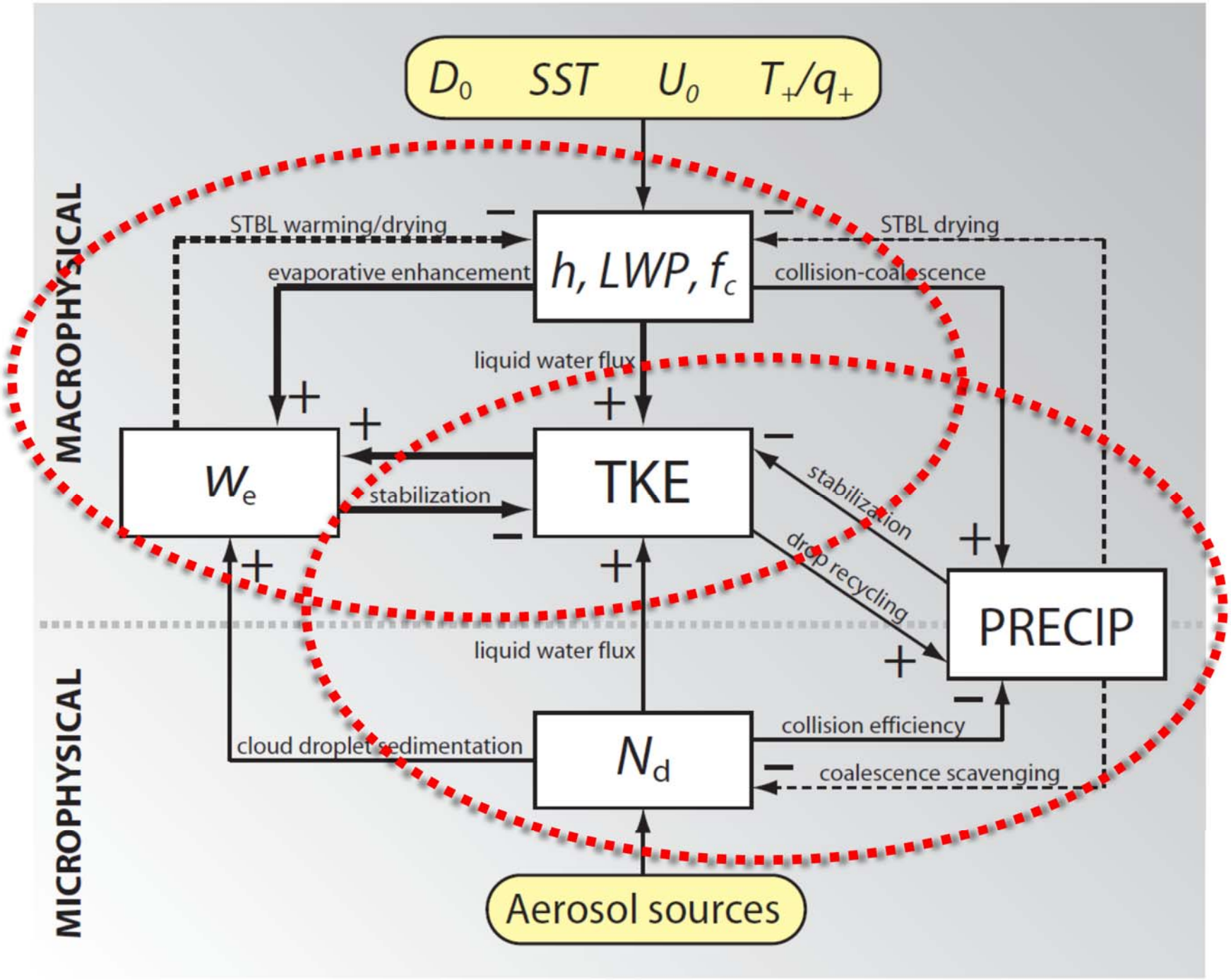
0.25 0.0.5 0.75 1

Caldwell et al. (2012)

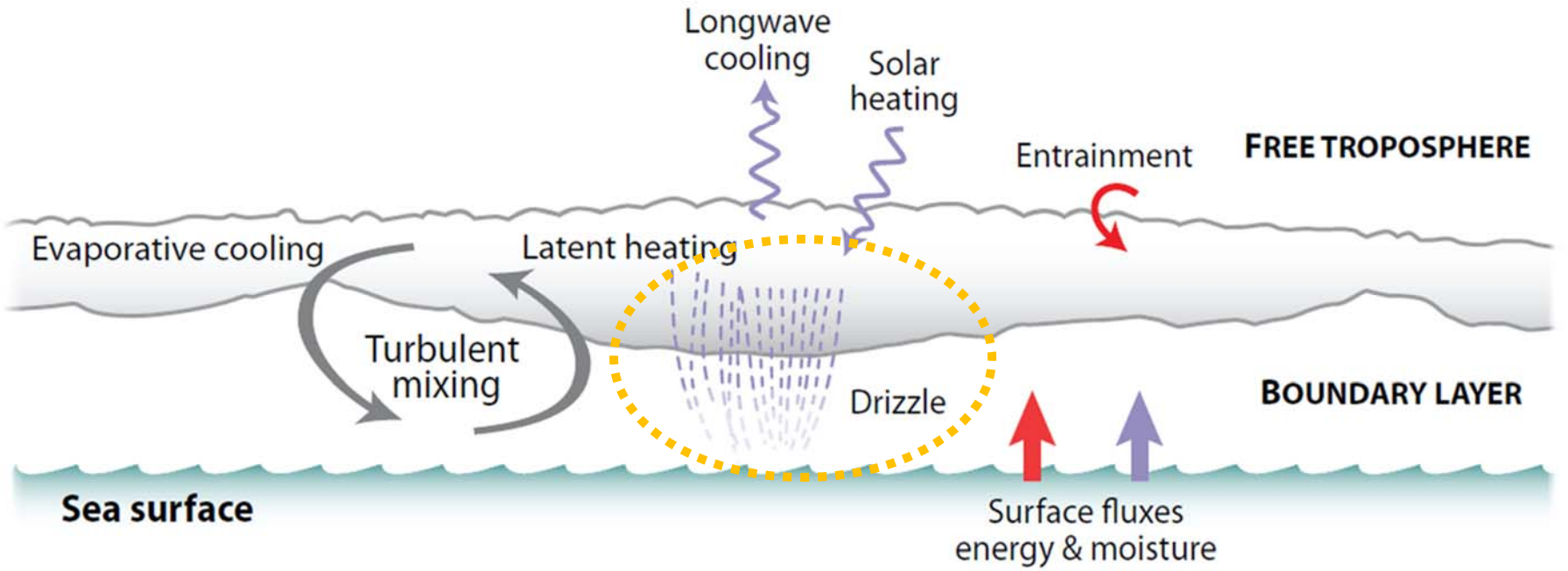
Stratocumulus cloud thickness



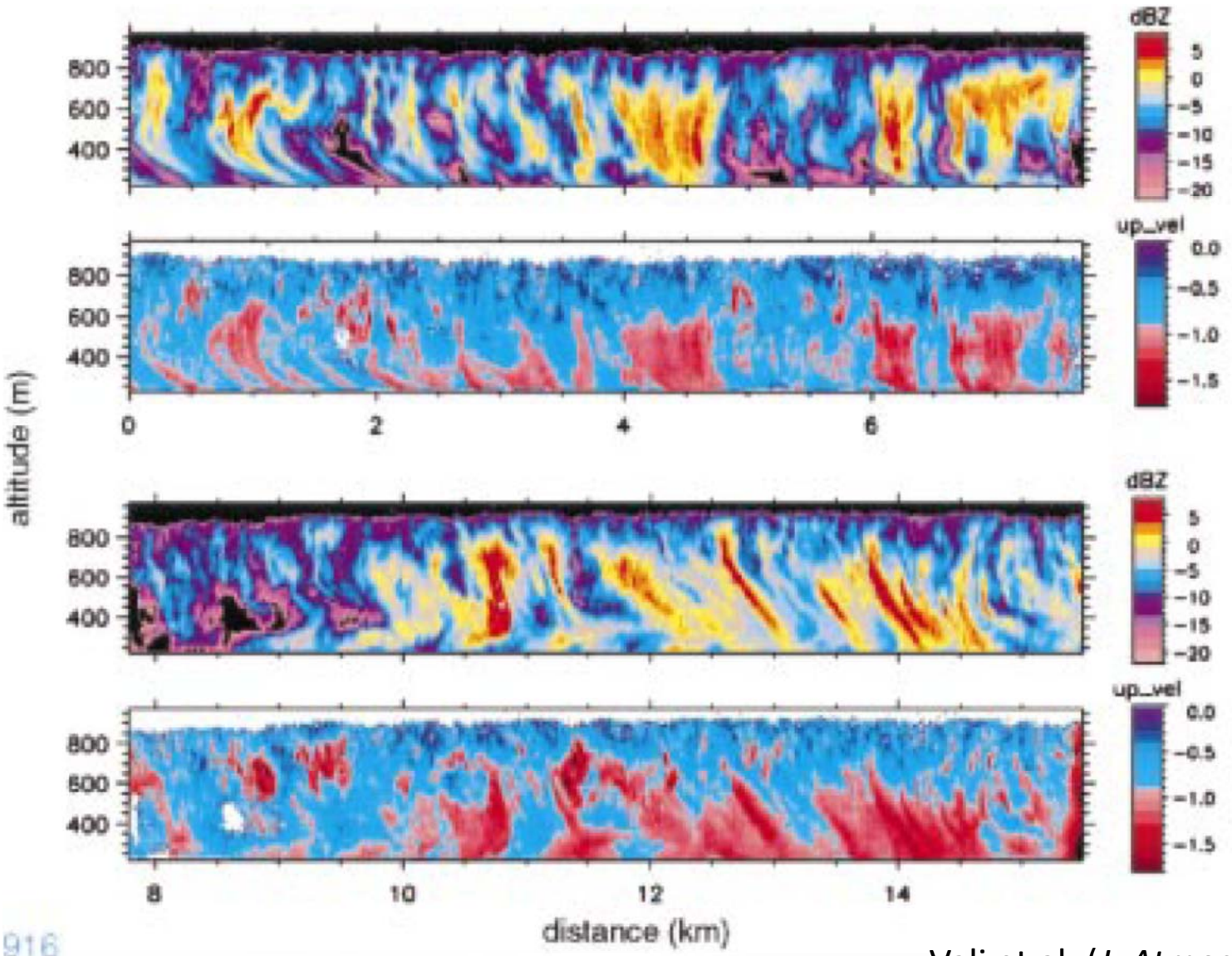
Data are from the published literature and available datasets from recent stratocumulus field campaigns (Nicholls and Leighton 1986; Boers and Krummel 1998; Miles et al. 2000; Pawlowska and Brenguier 2003; Comstock et al. 2004; vanZanten et al. 2005; Wood 2005a; Lu et al. 2007; McFarquhar et al. 2007; Lu et al. 2009; Wood and coauthors 2011)


D_0 SST U_0 T_+/q_+
MACROPHYSICAL
MICROPHYSICAL
STBL warming/drying
STBL drying
evaporative enhancement
collision-coalescence
h, LWP, f_c
liquid water flux
w_e
TKE
stabilization
stabilization
drop recycling
PRECIP
liquid water flux
collision efficiency
cloud droplet sedimentation
N_d
coalescence scavenging
Aerosol sources

Precipitation



‘Early’ radar measurements of drizzle

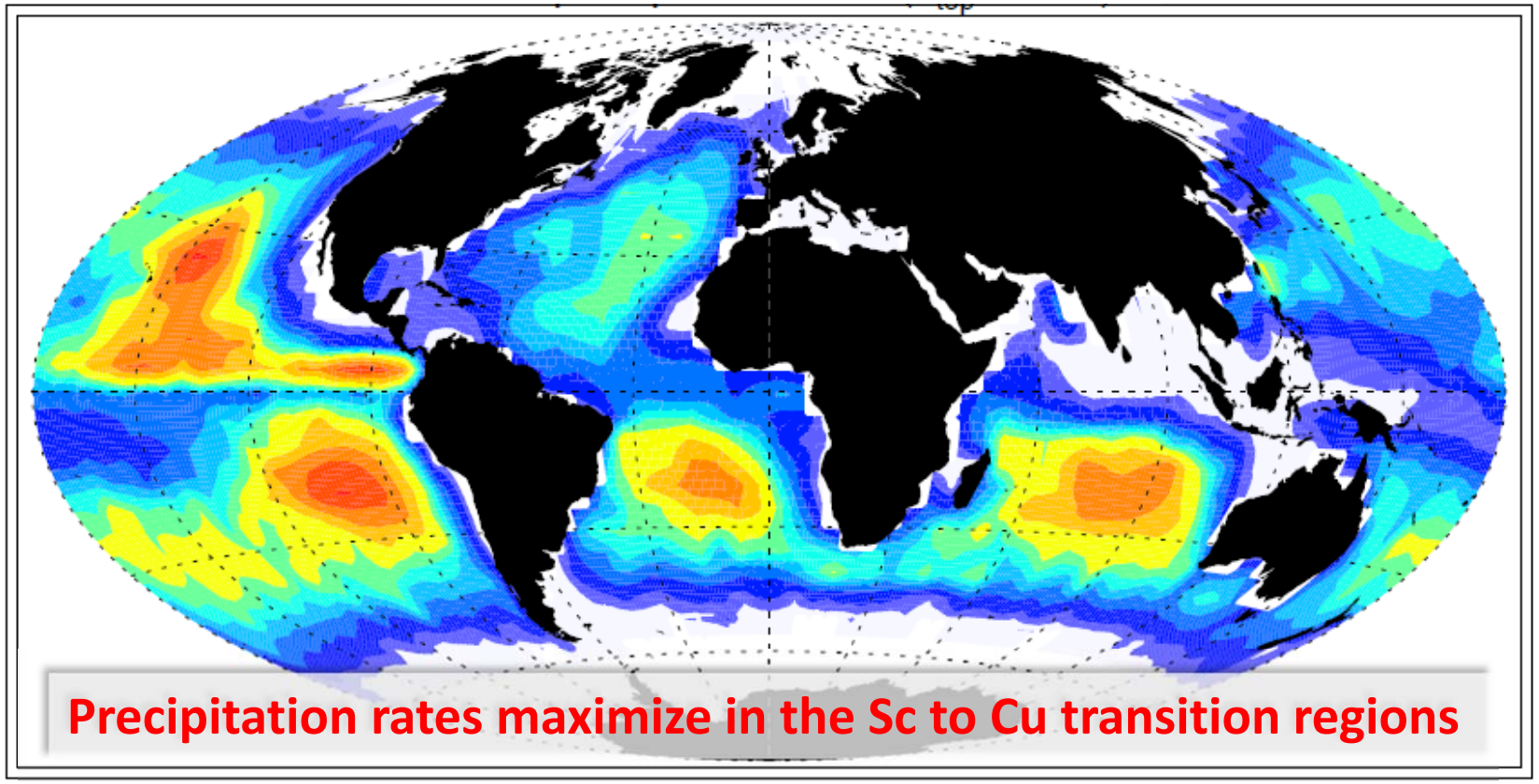


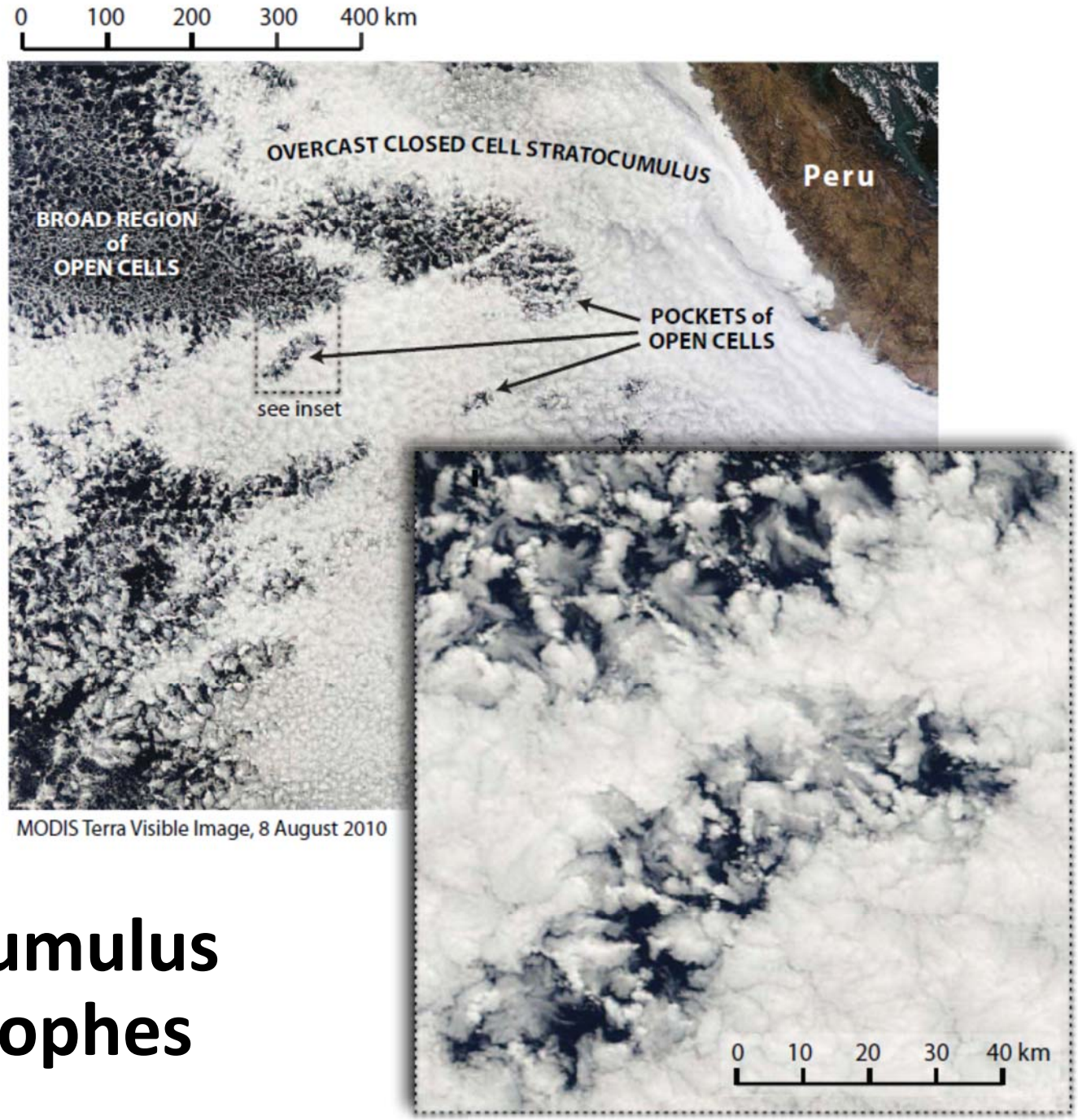
Vali et al. (*J. Atmos. Sci.*, 1998)

Precipitation from low clouds

(end of the noughties)

CloudSat max column precipitation rate for clouds with tops < 3 km

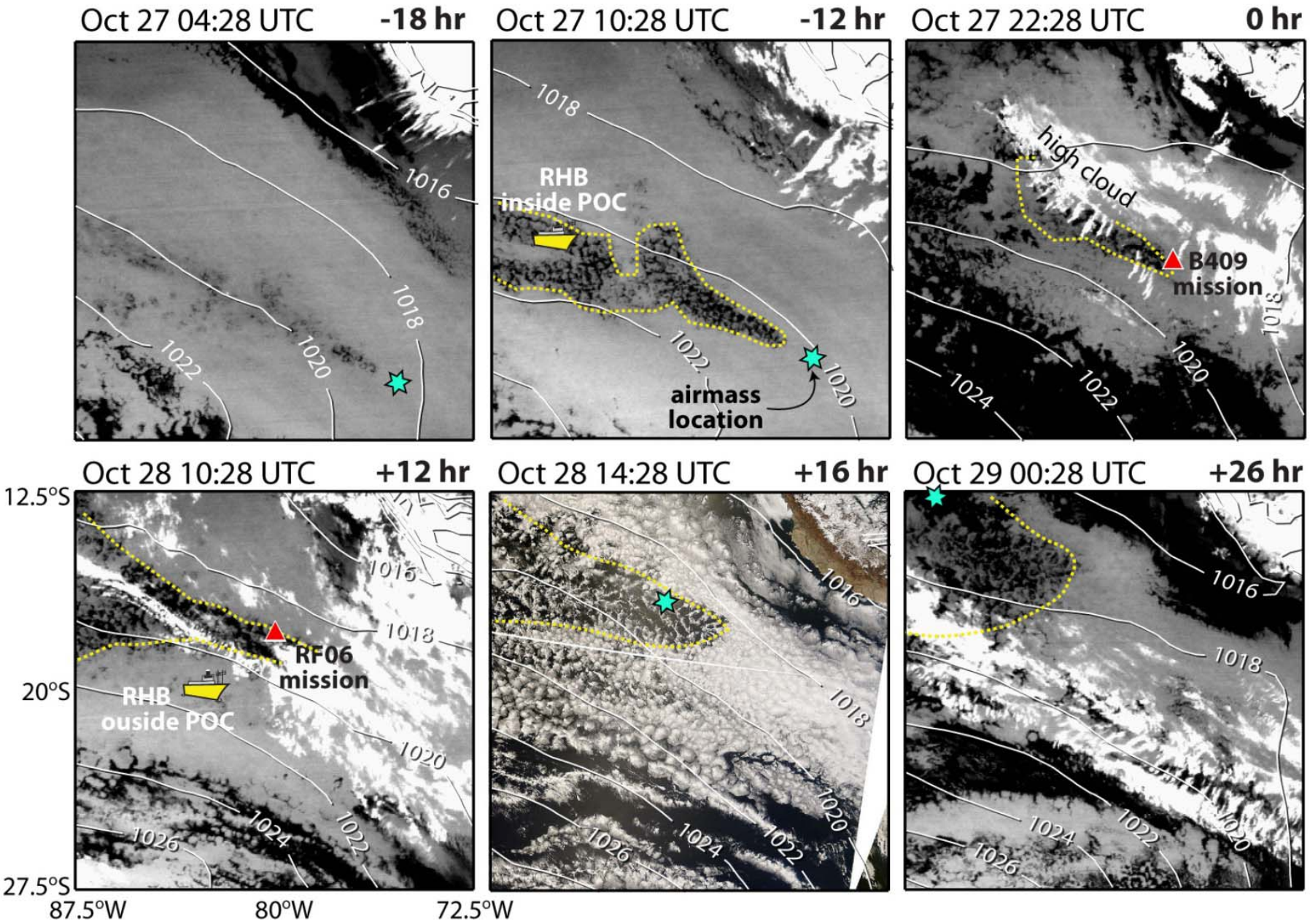


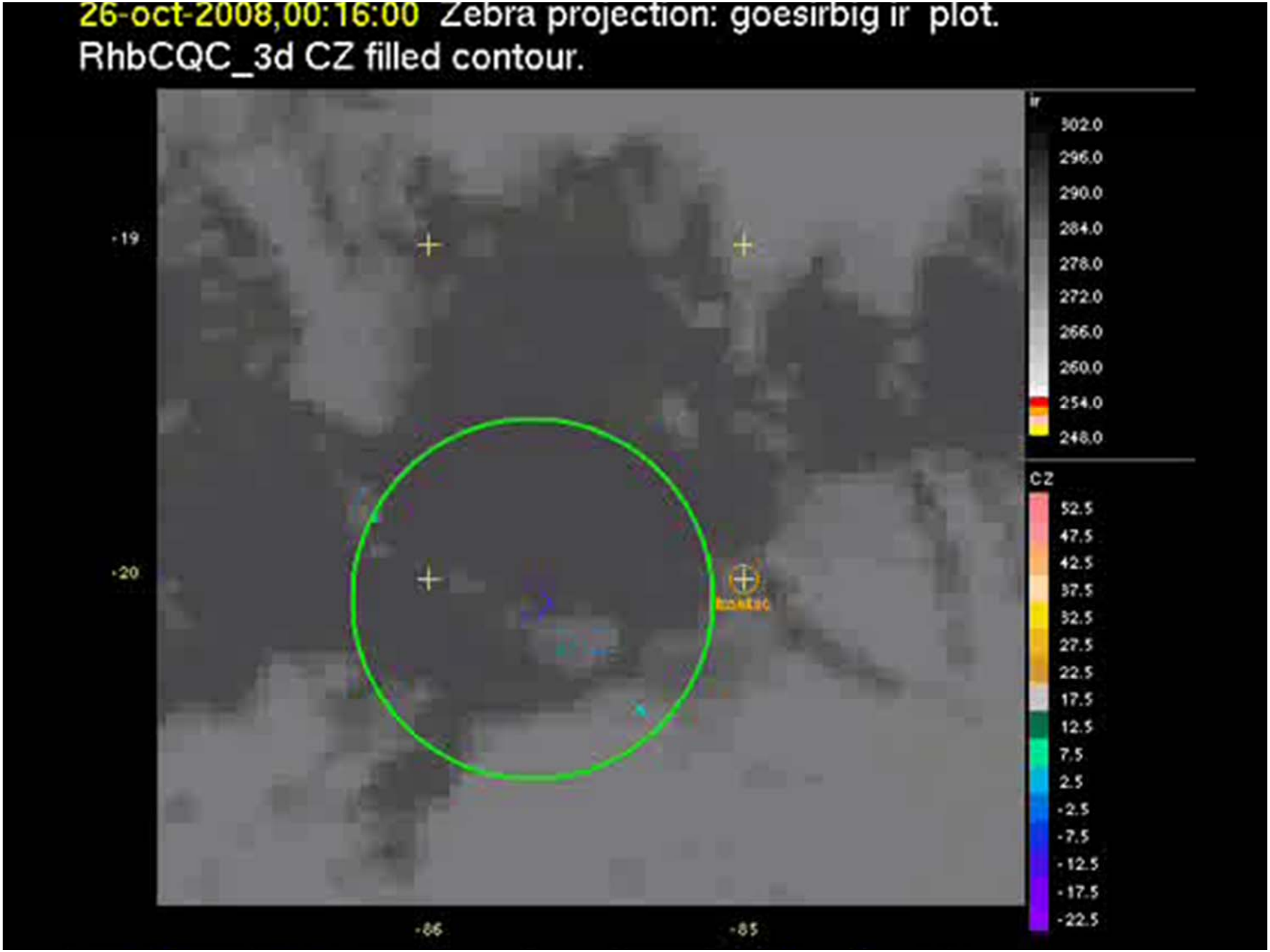


MODIS Terra Visible Image, 8 August 2010

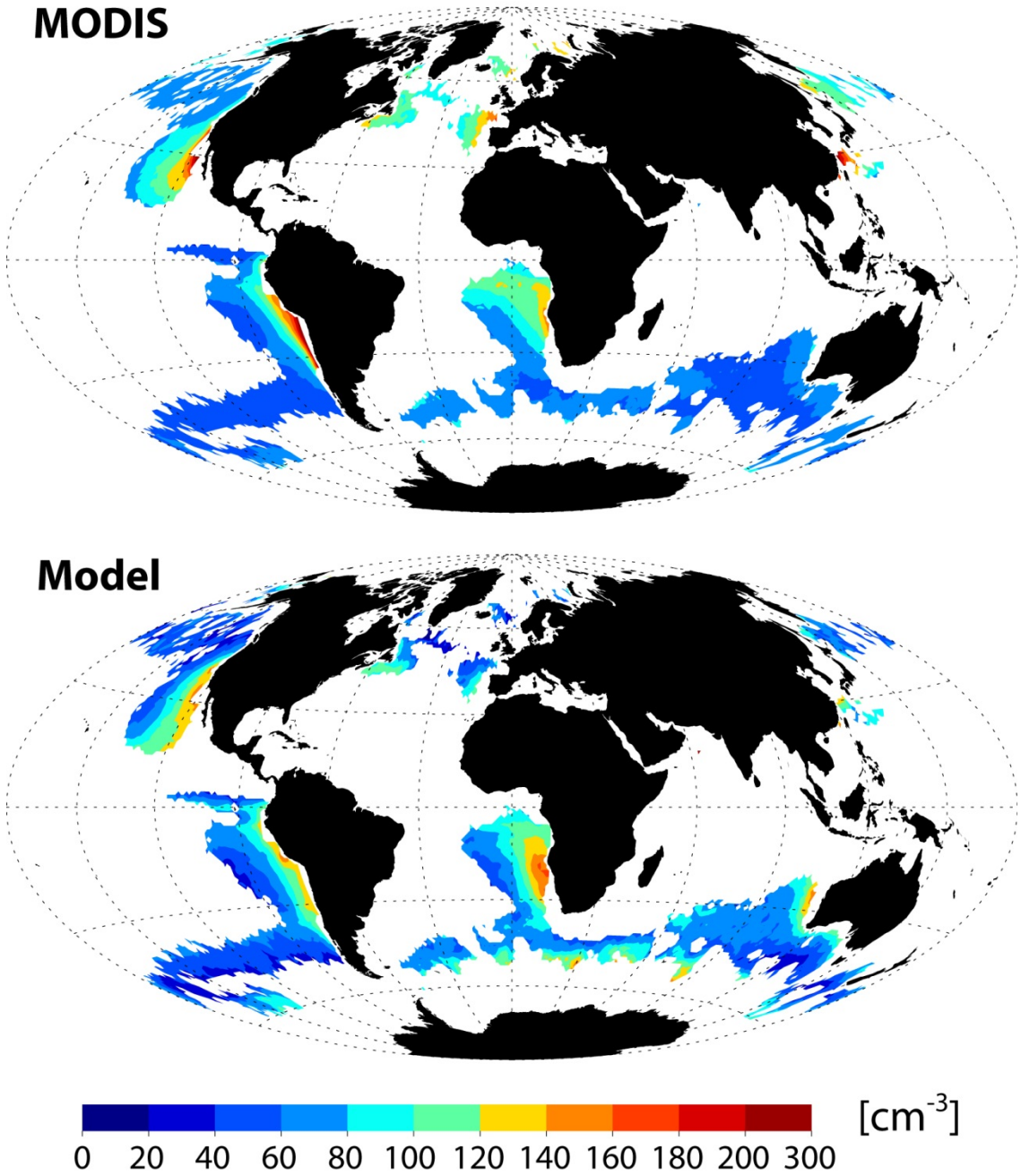
Stratocumulus catastrophes

Pocket of Open Cells, case 27/28 Oct 2007




26-oct-2008,00:16:00 Zebra projection: goesirbig ir plot.
RhbCQC_3d CZ filled contour.
ir
302.0
296.0
290.0
284.0
278.0
272.0
266.0
260.0
254.0
248.0
CZ
52.5
47.5
42.5
37.5
32.5
27.5
22.5
17.5
12.5
7.5
2.5
-2.5
-7.5
-12.5
-17.5
-22.5
-19
-20
-86
-85

Much of the stratocumulus cloud droplet concentration variability can be explained by precipitation scavenging

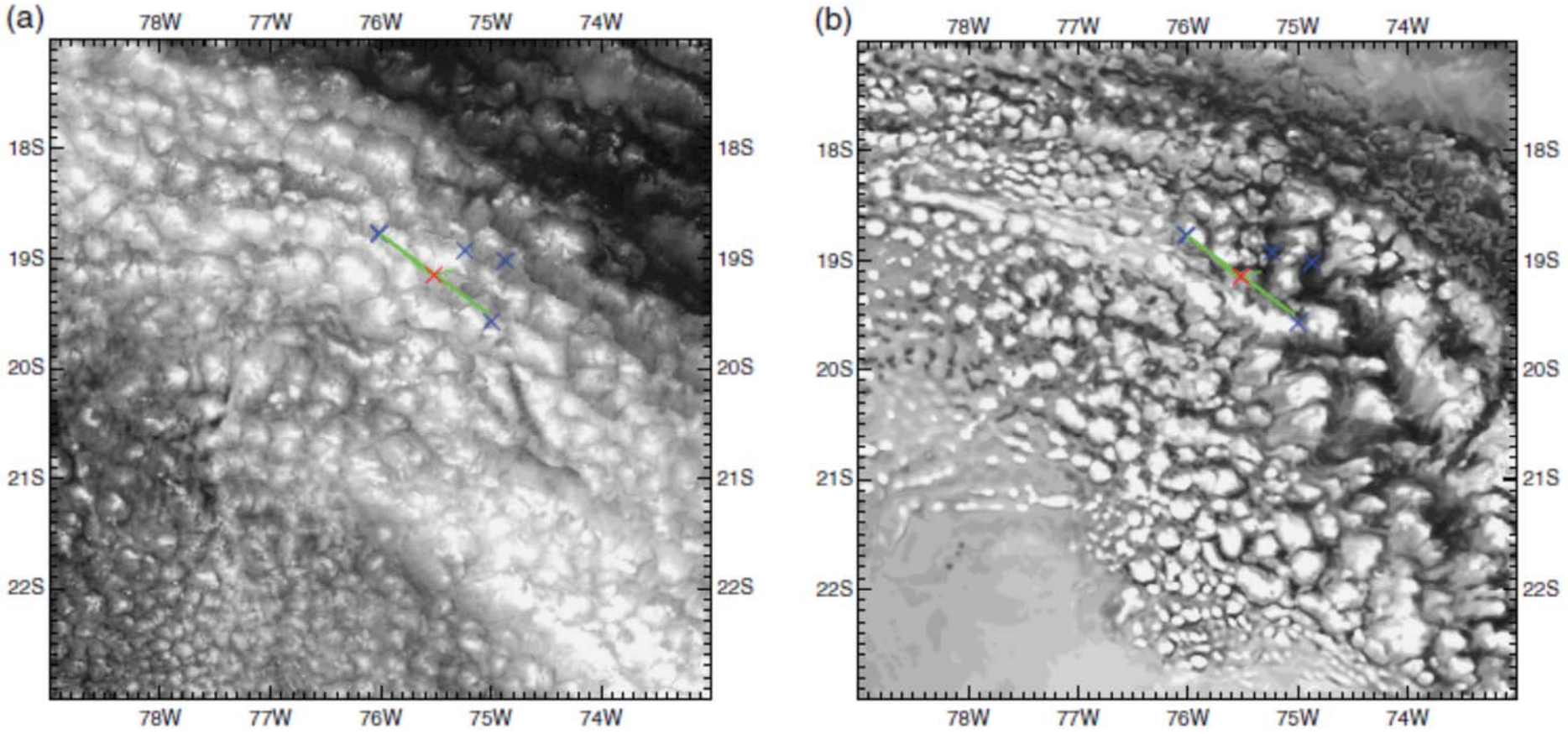


What remains to be done?

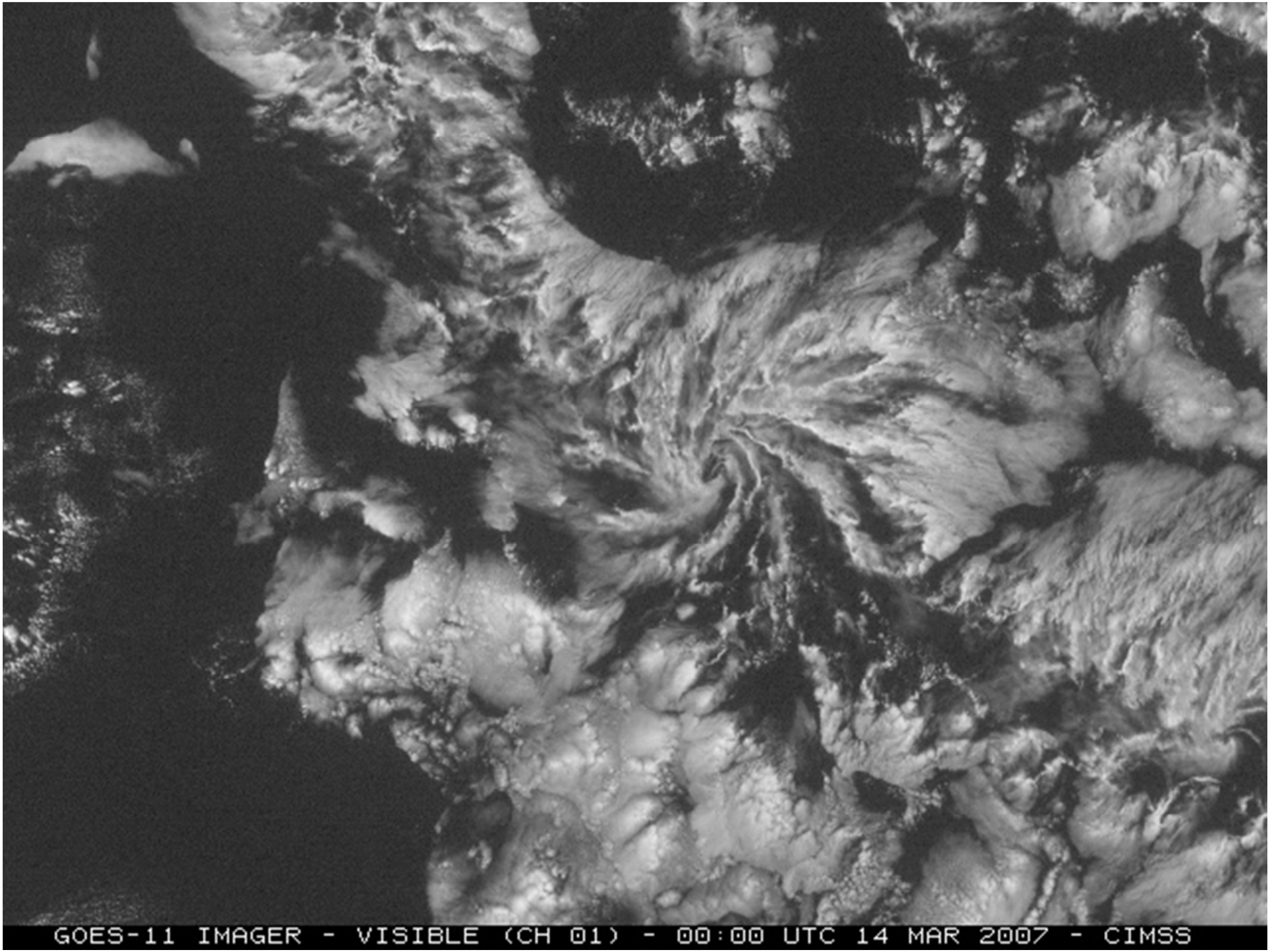
- Understanding of entrainment and key processes affecting it remains poor
  - New measurement techniques required
  - Large eddy models do not yet explicitly model entrainment
- Large scale model treatments of low clouds are improving but low cloud feedback not narrowing significantly. Why?
- Aerosol impacts on Sc and (perhaps as importantly) Sc impacts on aerosols are not well known

Satellite

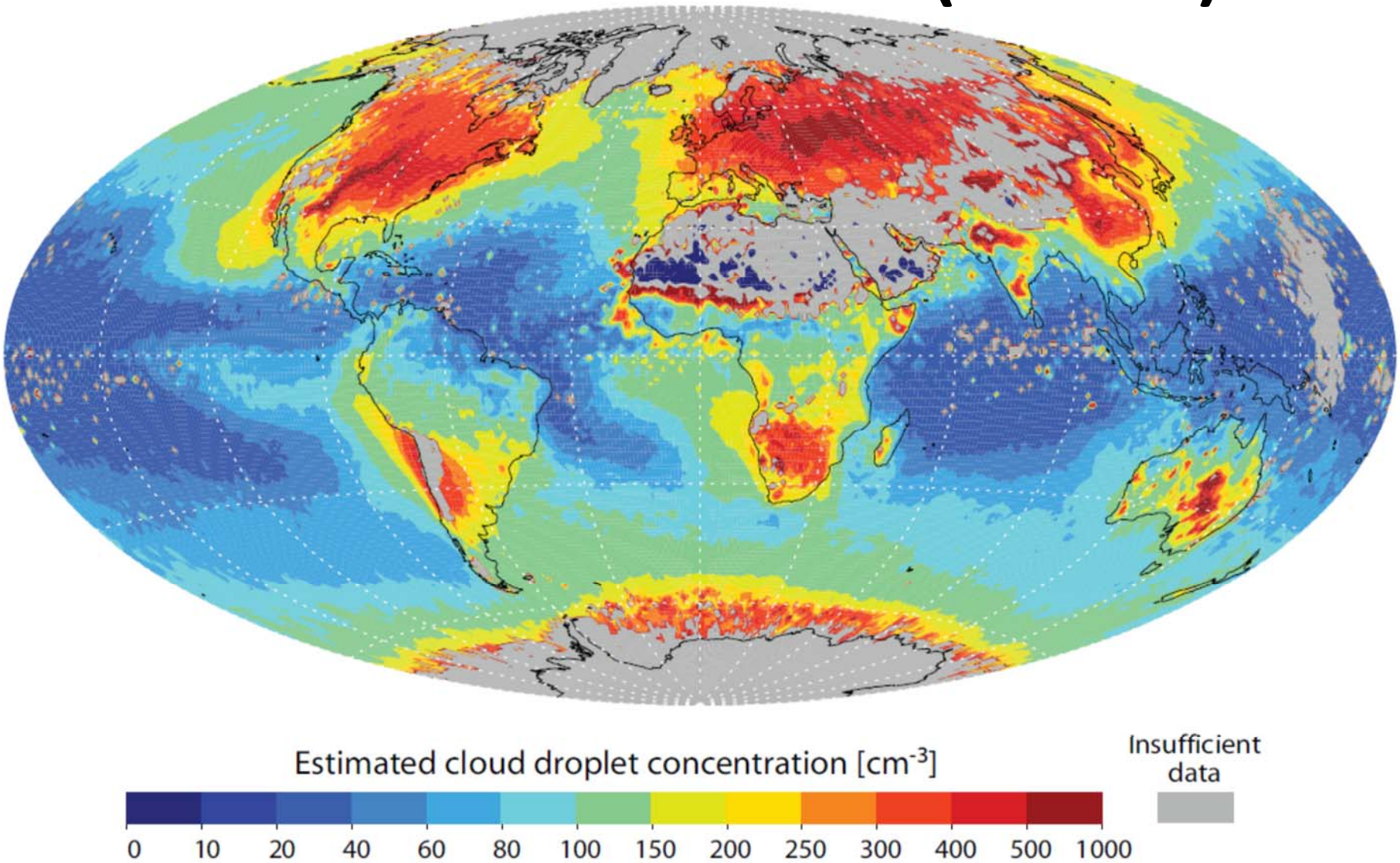
Model (UKMO)

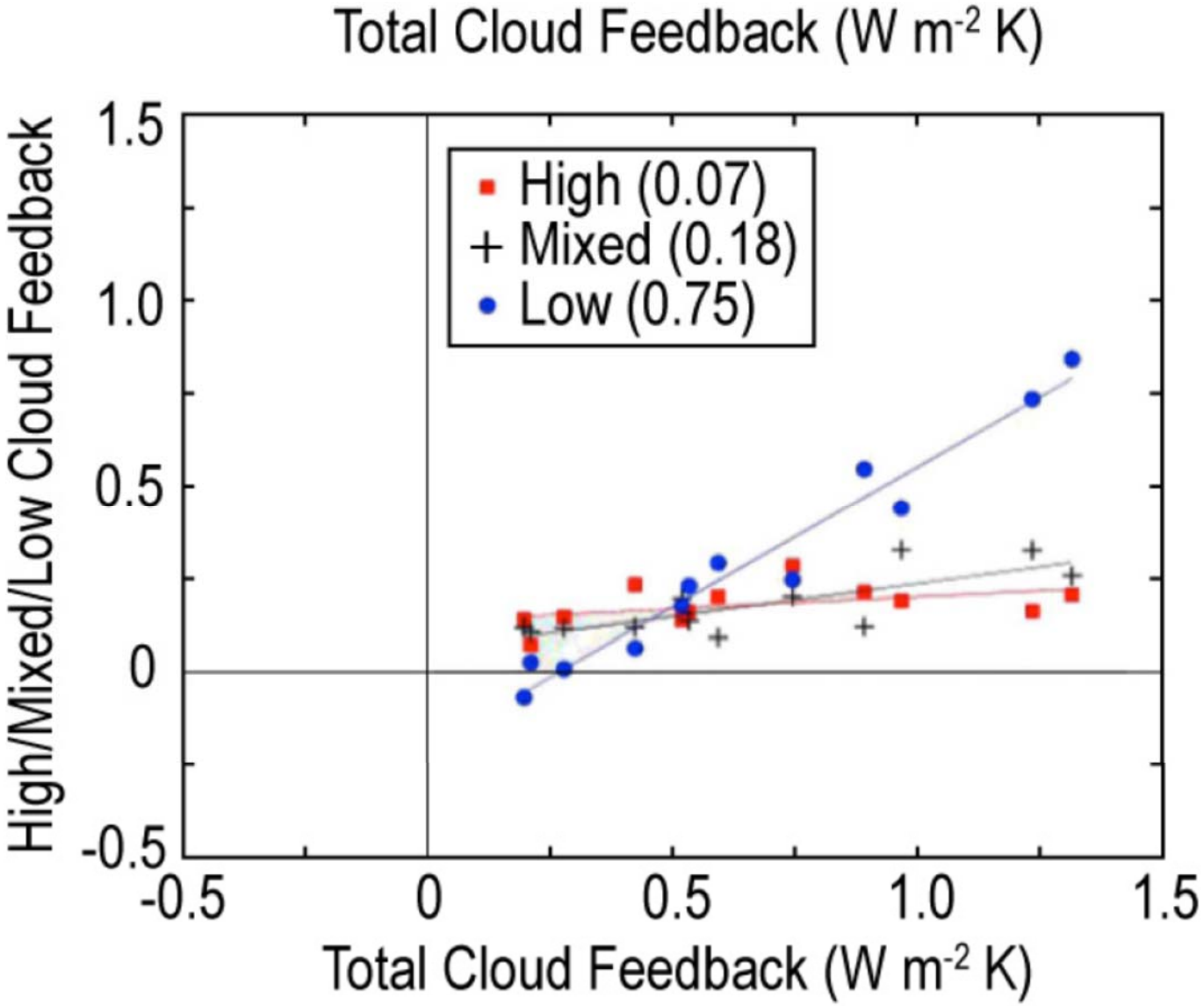


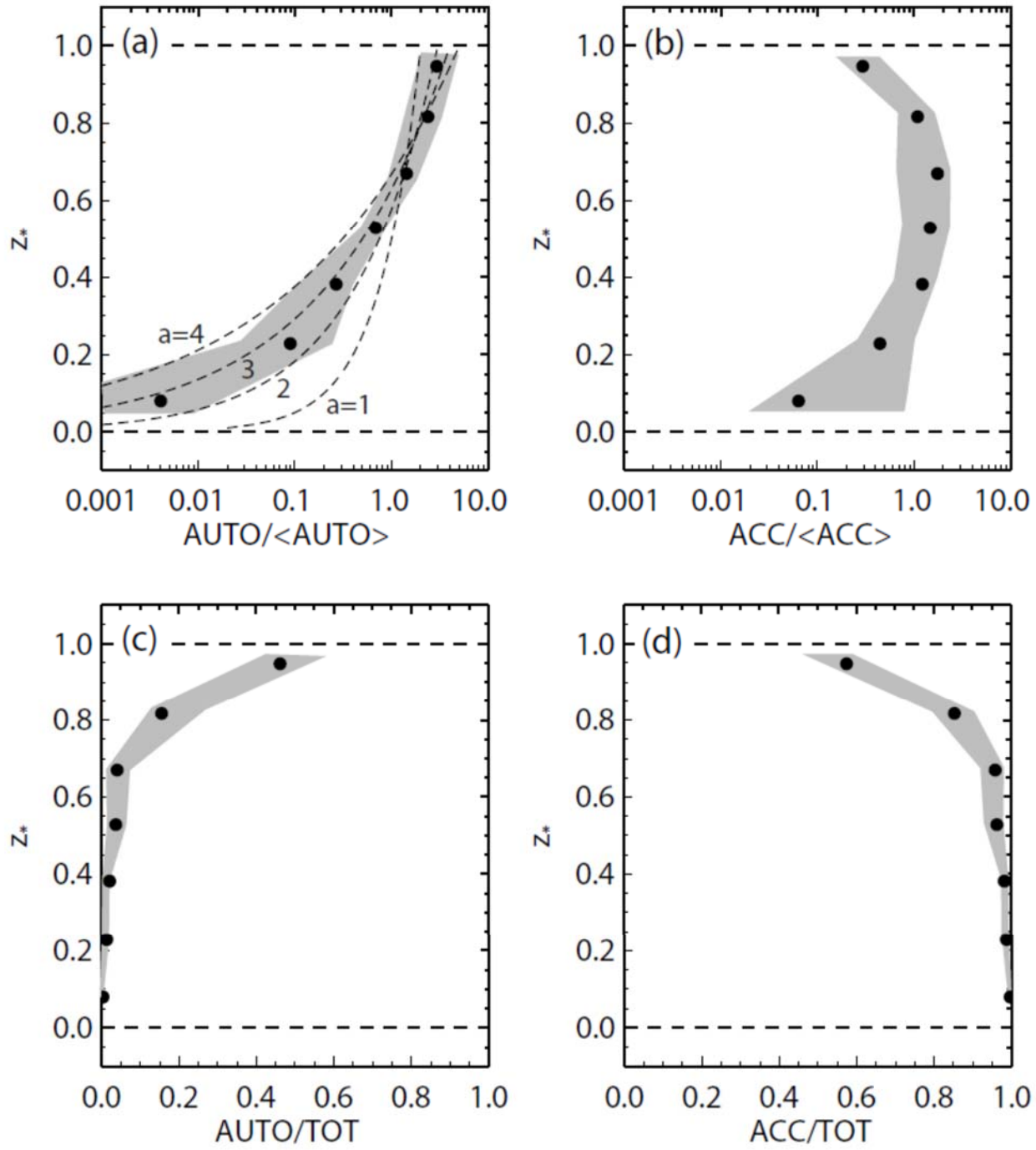
Boutle and Abel (2012)

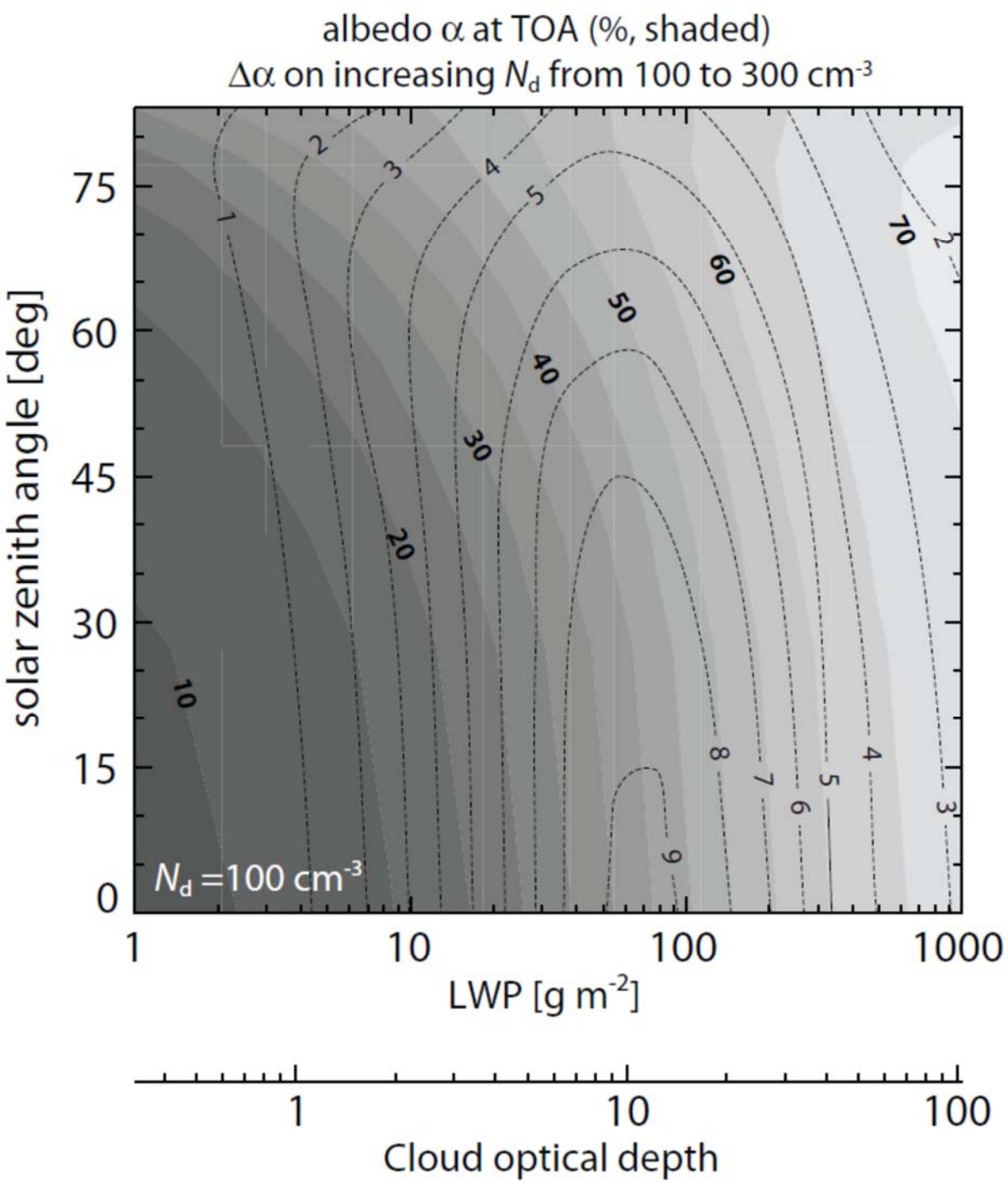

GOES-11 IMAGER - VISIBLE (CH 01) - 00:00 UTC 14 MAR 2007 - CIMSS

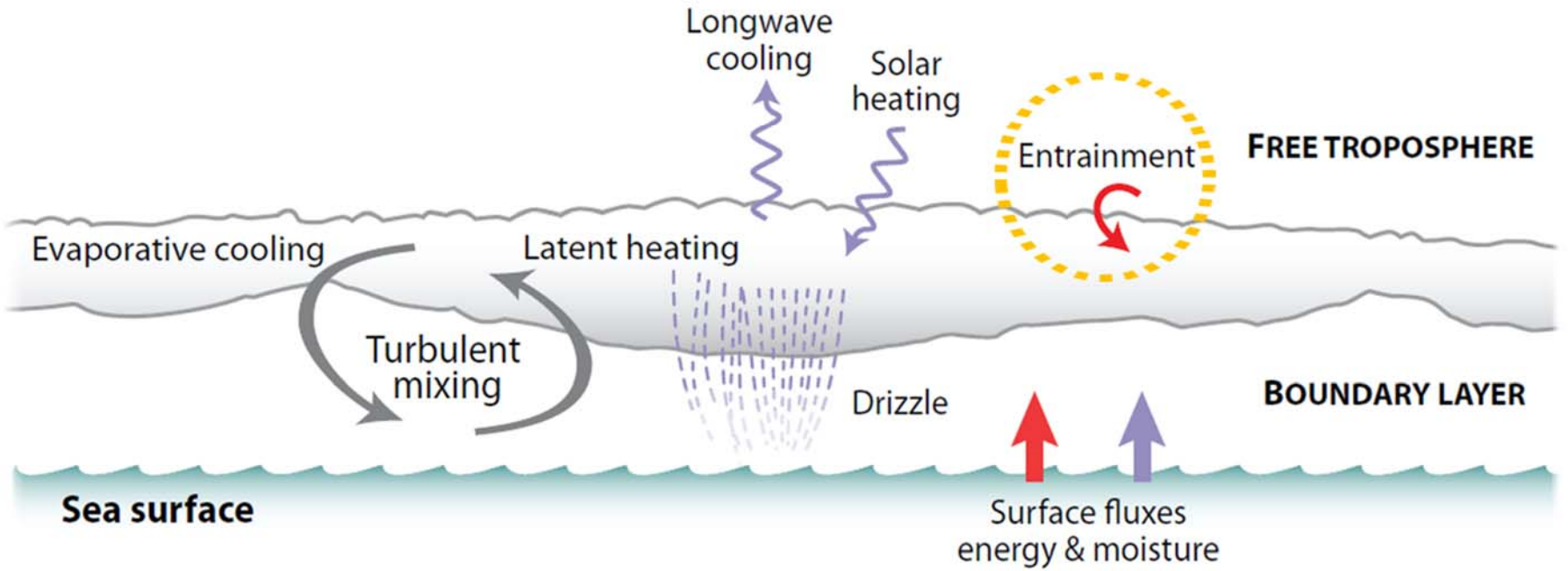
Cloud droplet concentration for stratiform low clouds (MODIS)

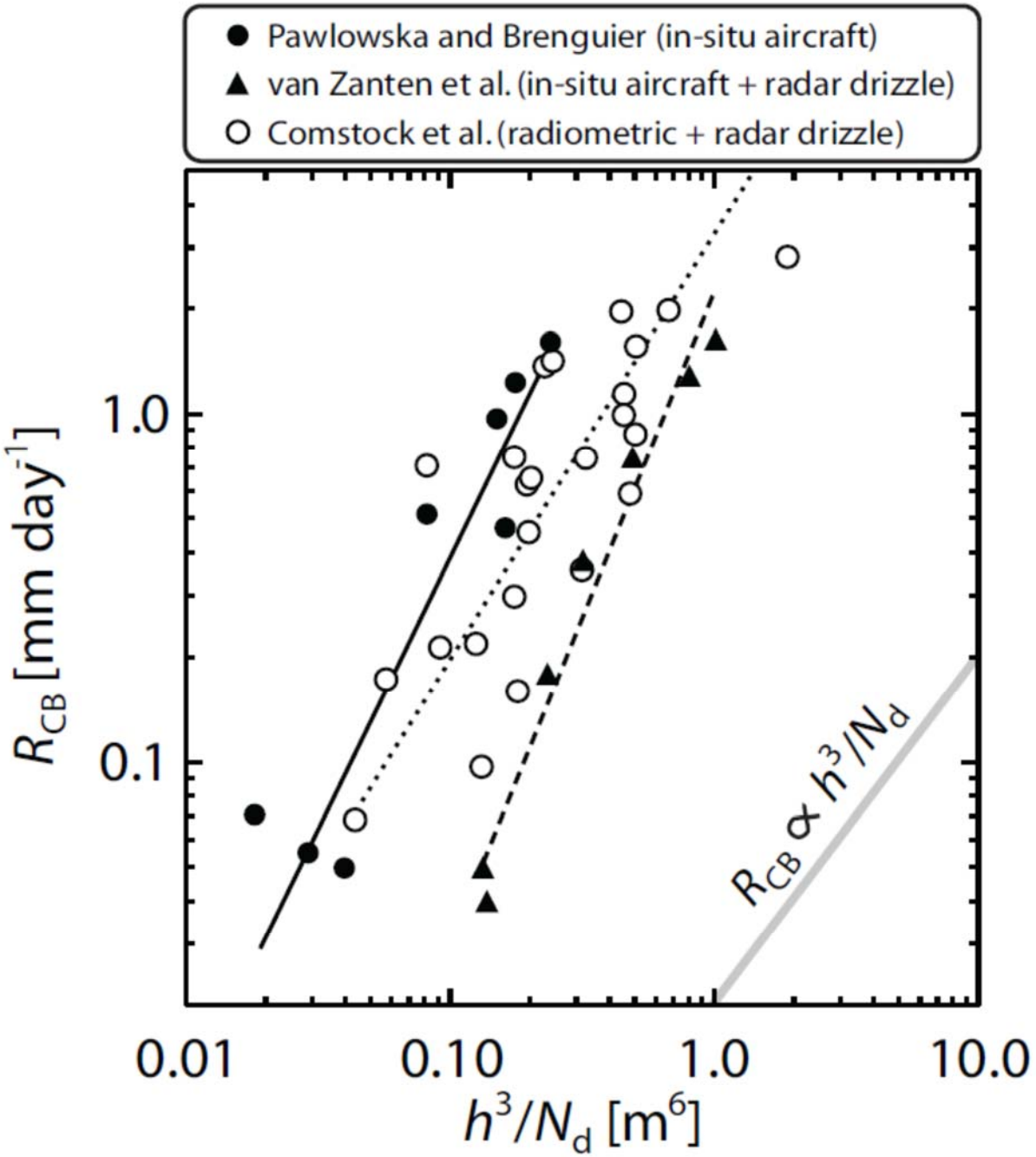



Total Cloud Feedback (W m-2 K)
High/Mixed/Low Cloud Feedback
High (0.07)
Mixed (0.18)
Low (0.75)
1.5
1.0
0.5
0
-0.5
-0.5
0
0.5
1.0
1.5
Total Cloud Feedback (W m-2 K)


(a)
(b)
(c)
(d)
z*
AUTO/<AUTO>
ACC/<ACC>
AUTO/TOT
ACC/TOT
a=4
3
2
a=1
0.001
0.01
0.1
1.0
10.0
0.0
0.2
0.4
0.6
0.8
1.0


albedo α at TOA (%, shaded)
Δα on increasing N_d from 100 to 300 cm^{-3}
solar zenith angle [deg]
0
15
30
45
60
75
N_d =100 cm^{-3}
1
10
100
1000
LWP [g m^{-2}]
1
10
100
Cloud optical depth


Longwave cooling
Solar heating
Entrainment
FREE TROPOSPHERE
Evaporative cooling
Latent heating
Turbulent mixing
Drizzle
BOUNDARY LAYER
Sea surface
Surface fluxes energy & moisture


Pawlowska and Brenguier (in-situ aircraft)
van Zanten et al. (in-situ aircraft + radar drizzle)
Comstock et al. (radiometric + radar drizzle)
R_{CB} [mm day^{-1}]
1.0
0.1
0.01
0.10
1.0
10.0
h^3/N_d [m^6]
$R_{CB} \propto h^3/N_d$

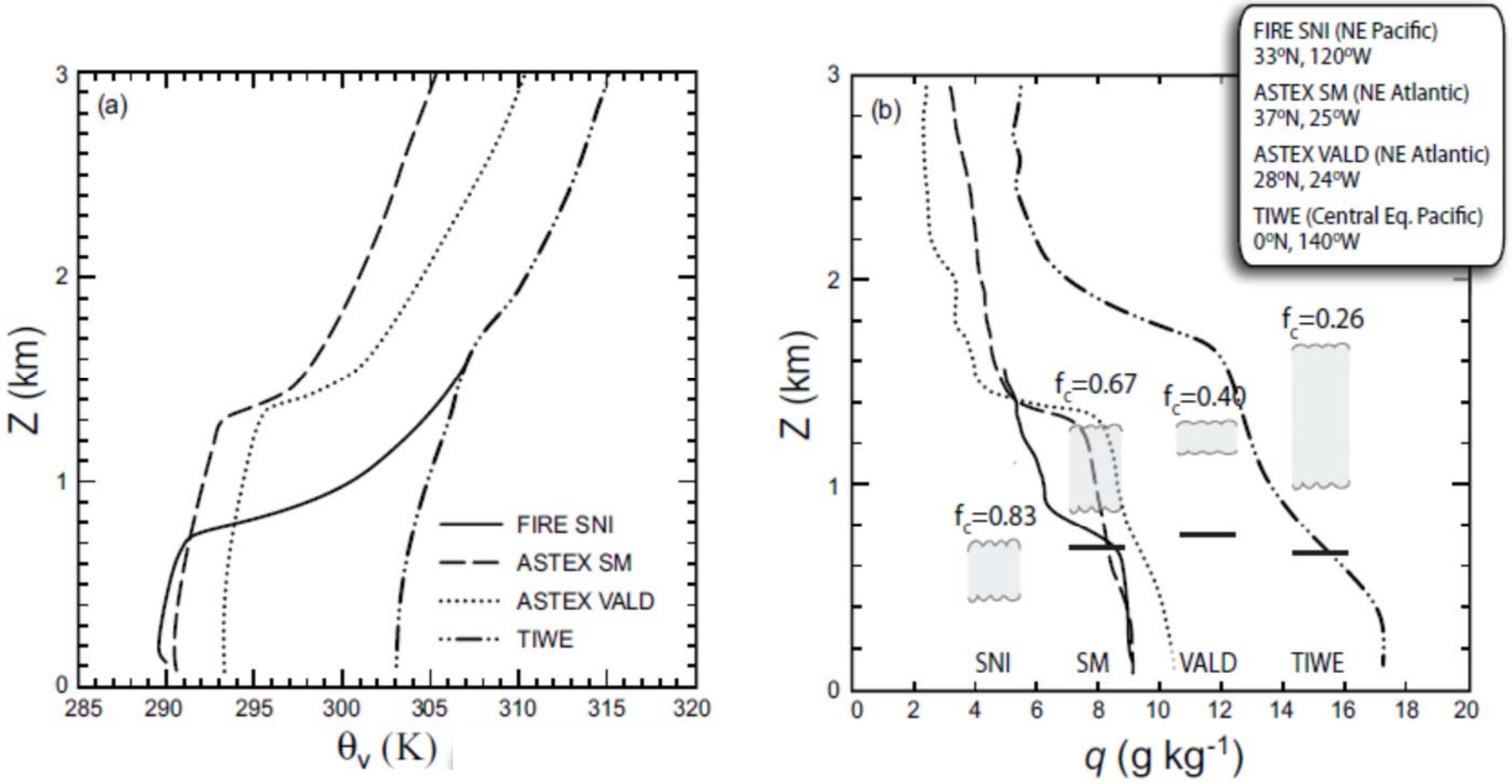
Well-mixed summertime Sc off the Californian coast

Photo: Gabor Vali

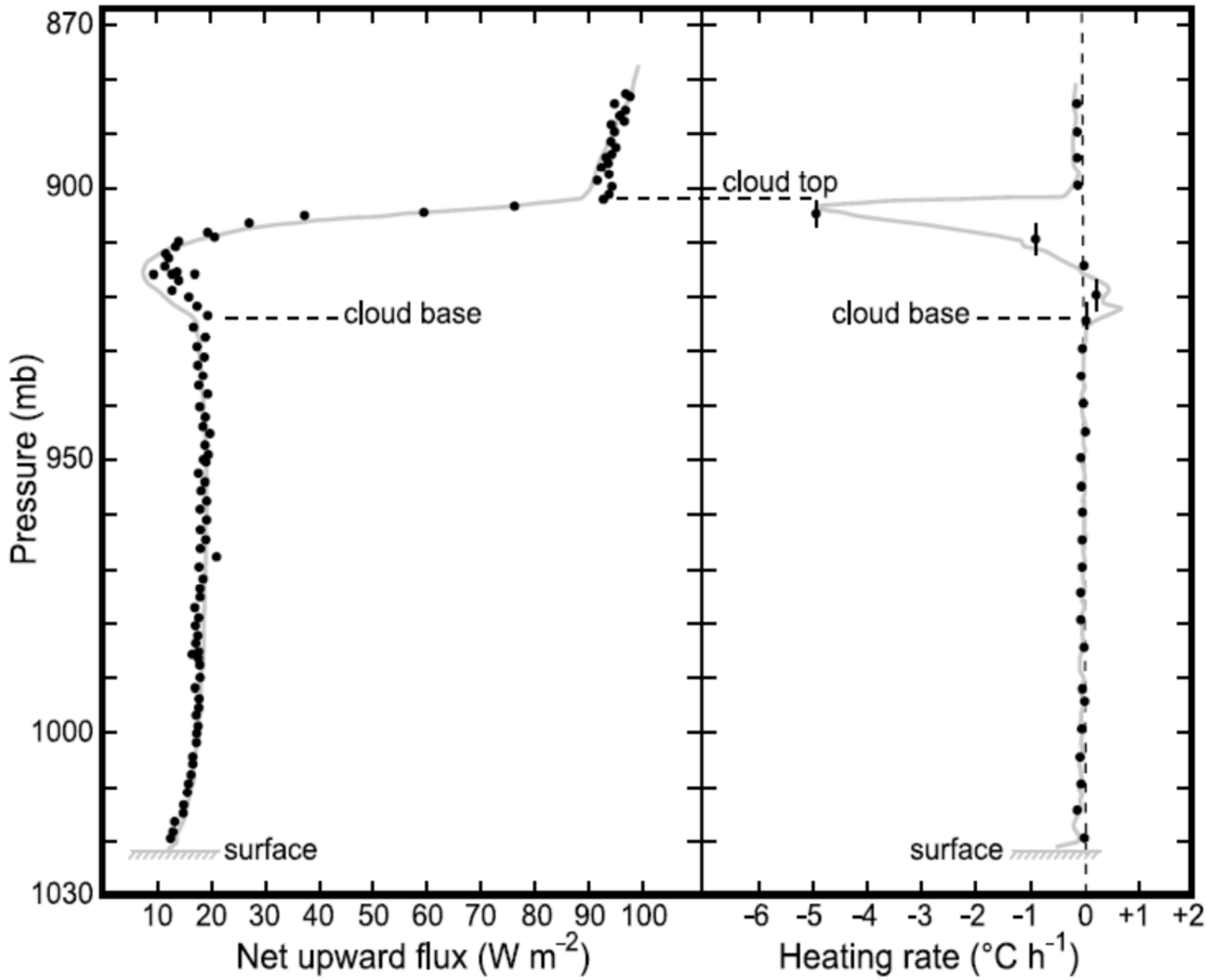
Decoupled marine Sc over the remote southeastern Pacific Ocean

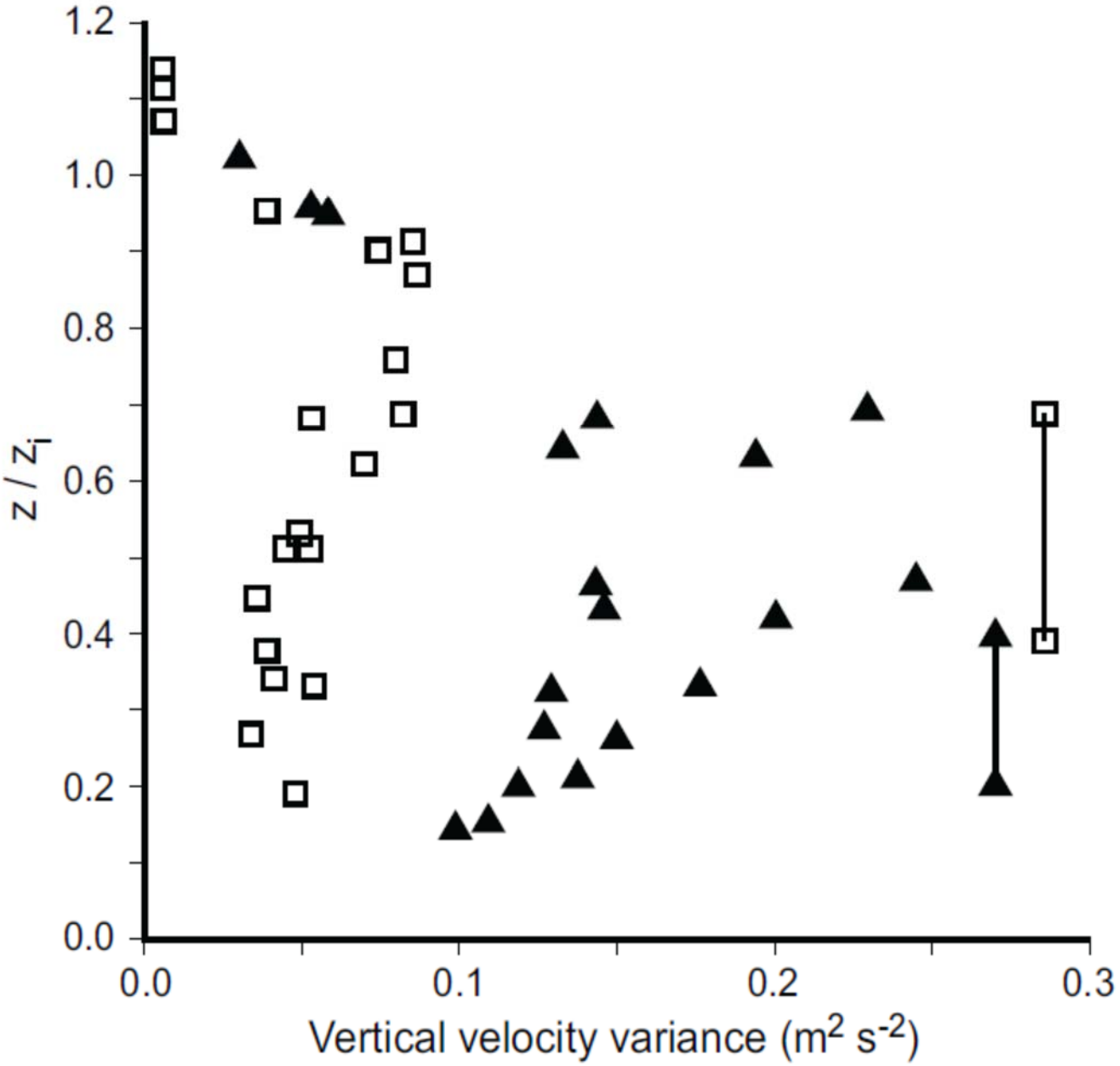
Photo: Sandy Yuter

Canonical profiles

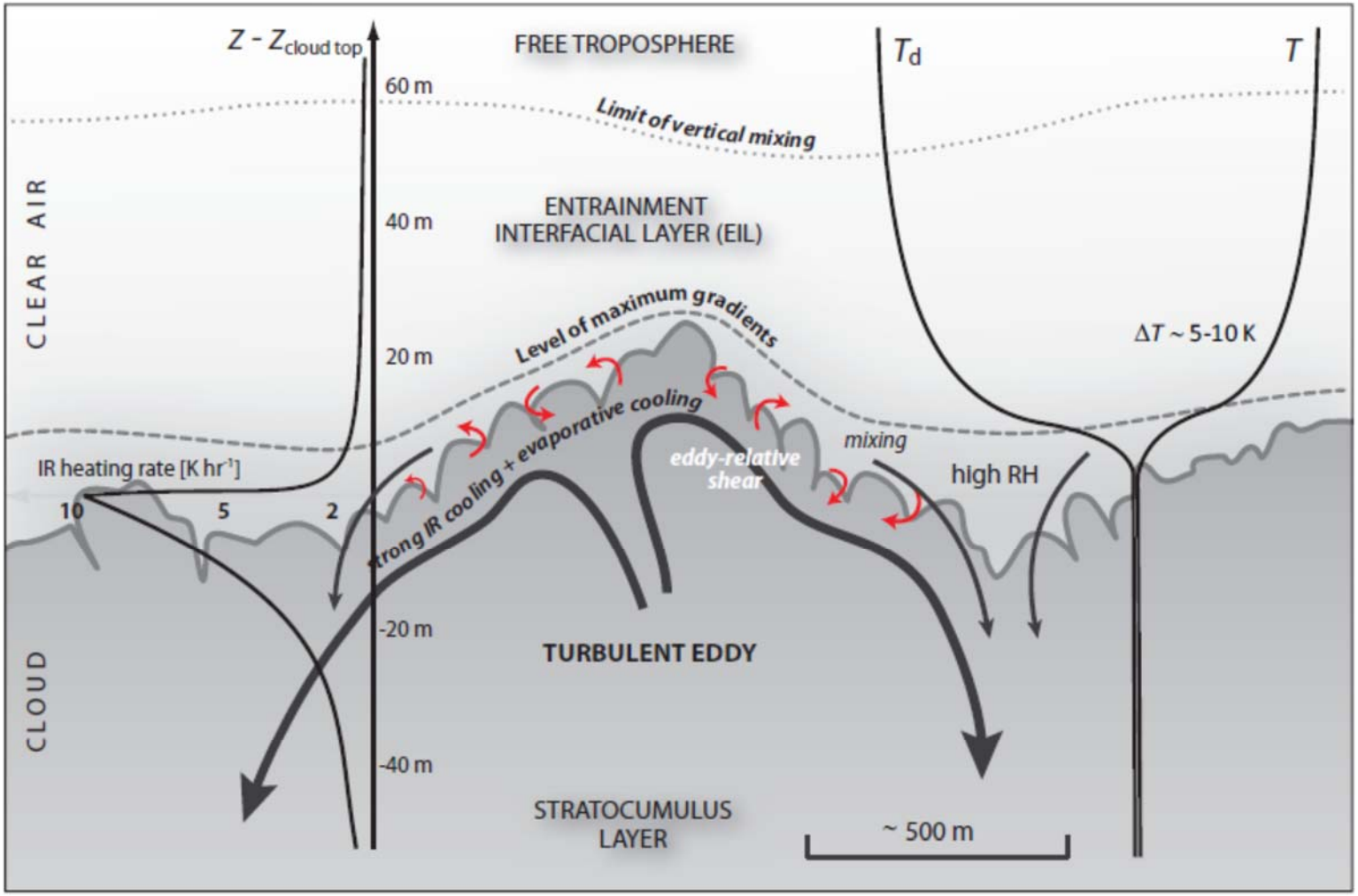


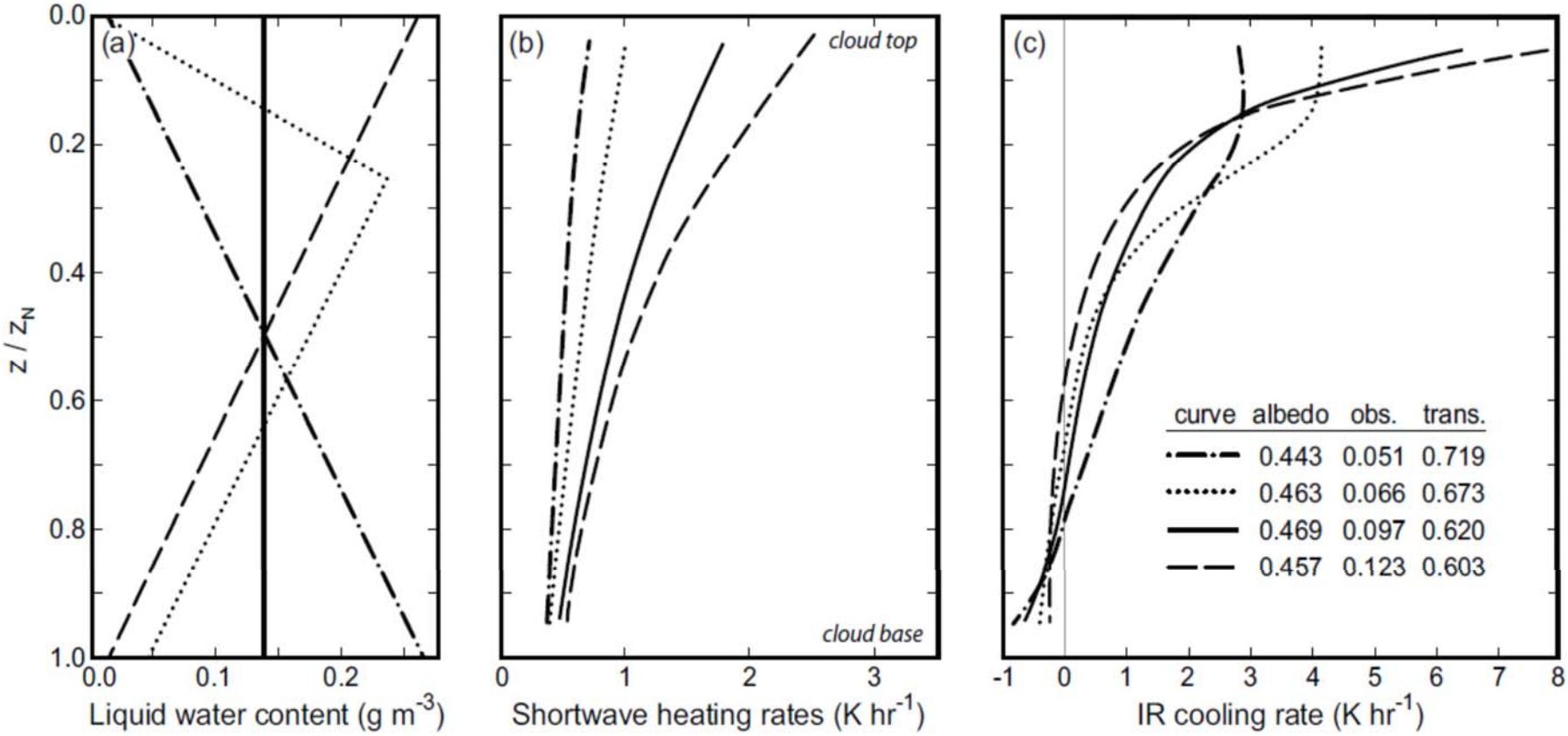
Albrecht et al. (J. Geophys. Res., 1995)

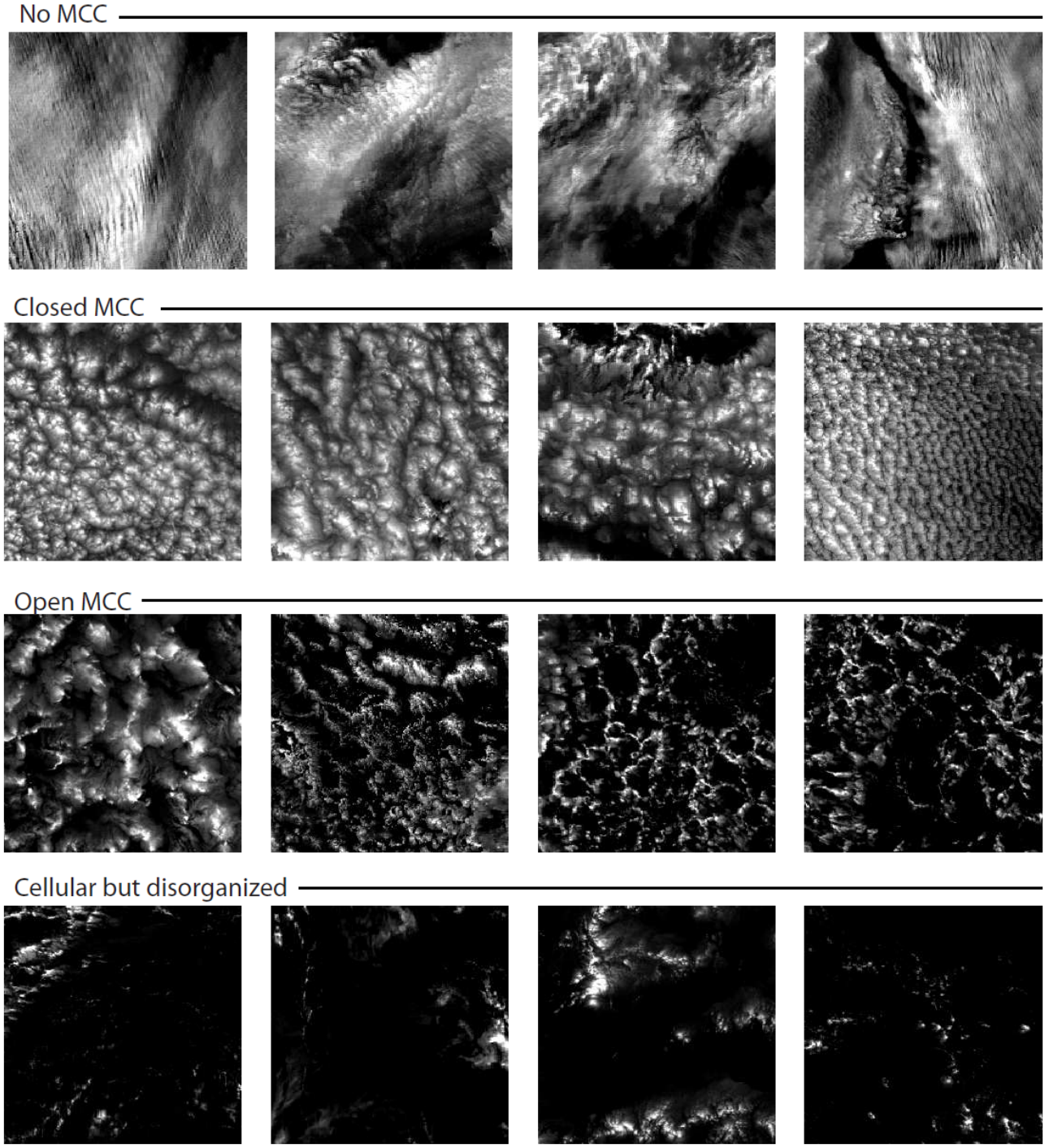

870
900
950
1000
1030
Pressure (mb)
cloud base
surface
cloud top
cloud base
surface
10 20 30 40 50 60 70 80 90 100
Net upward flux (W m-2)
-6 -5 -4 -3 -2 -1 0 +1 +2
Heating rate (°C h-1)


1.2
1.0
0.8
0.6
0.4
0.2
0.0
z / z_i
0.0
0.1
0.2
0.3
Vertical velocity variance (m^2 s^-2)

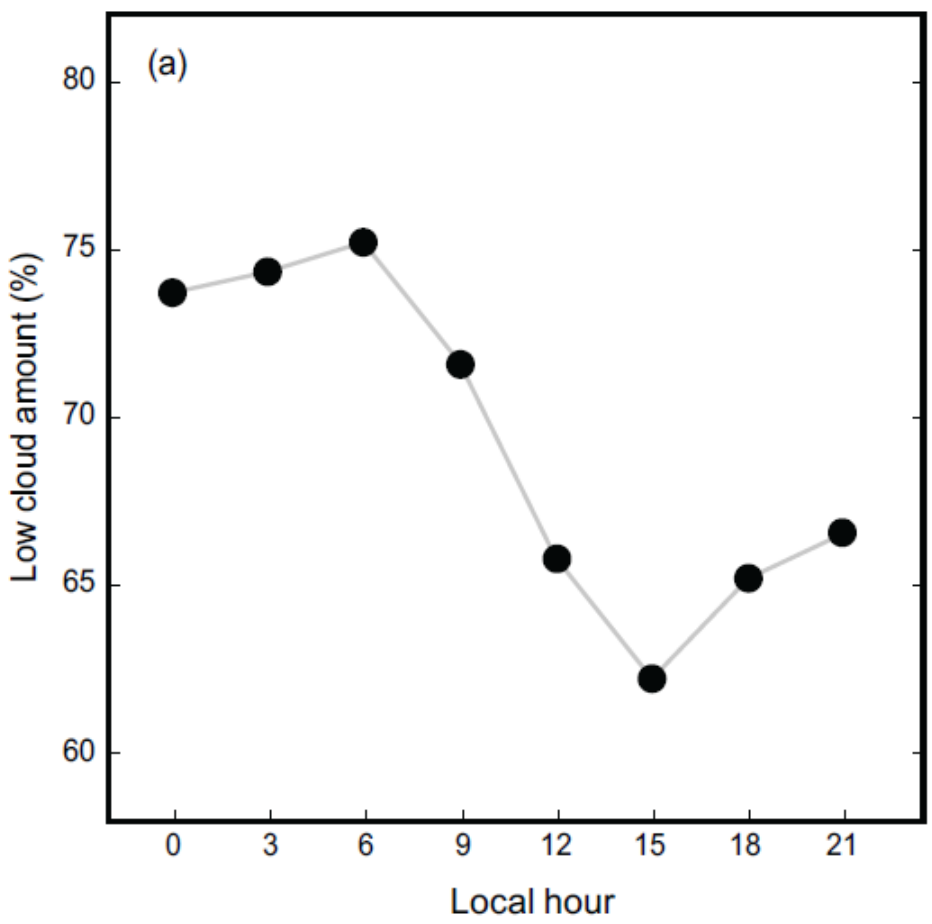
Entrainment interfacial layer

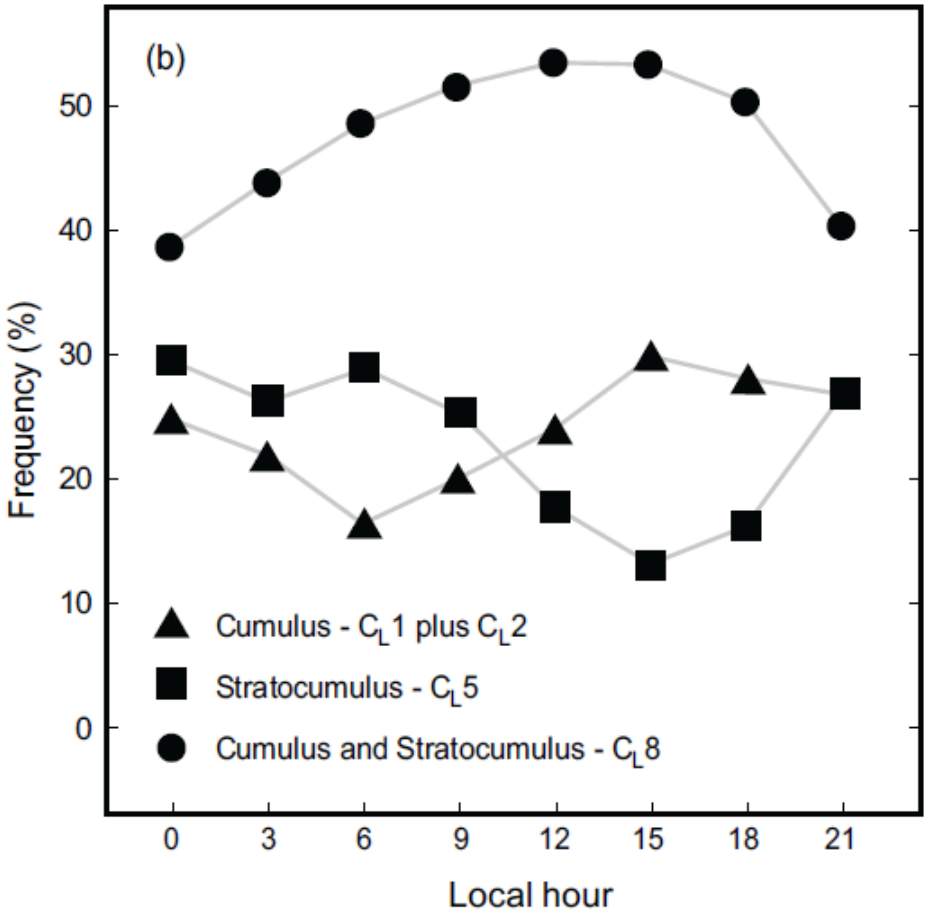



(a)
(b)
(c)
cloud top
cloud base
z / z_N
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.1
0.2
Liquid water content (g m-3)
0
1
2
3
Shortwave heating rates (K hr-1)
-1
0
1
2
3
4
5
6
7
8
IR cooling rate (K hr-1)
curve albedo obs. trans.
0.443 0.051 0.719
0.463 0.066 0.673
0.469 0.097 0.620
0.457 0.123 0.603


No MCC
Closed MCC
Open MCC
Cellular but disorganized

Diurnal cycle (140°W, 30°N)





Klein, Hartmann, Norris (*J. Climate*, 1995)