Boundary layer structure and variability from 20°S VOCALS NOAA ship observations

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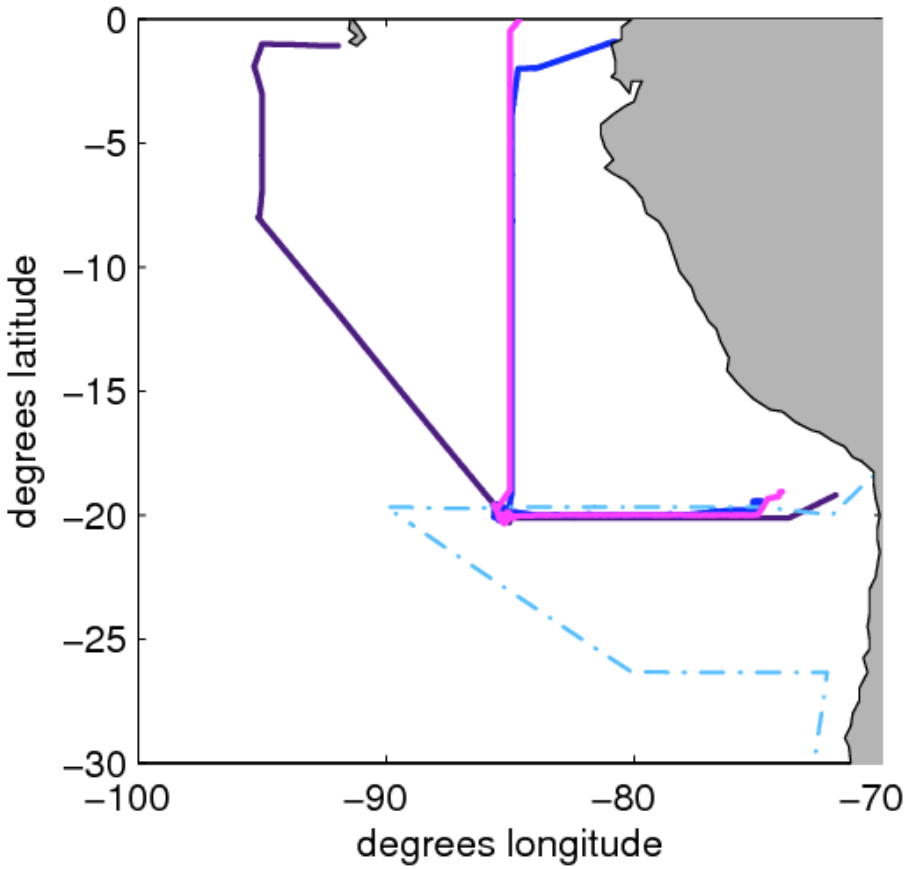
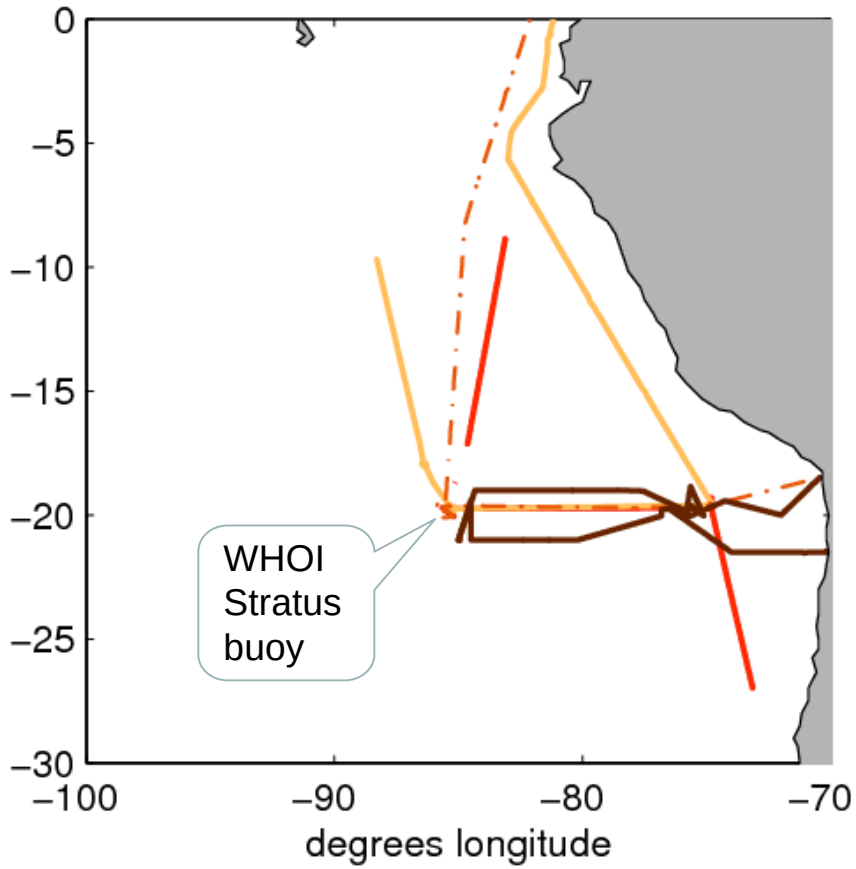
2nd VOCALS meeting
2009 July

7 years of 20°S Stratus/VOCALS ship tracks





2001 Oct 22 — Oct 24

2003 Nov 21 — Nov 23

2004 Dec 10 — Dec 07

2005 Oct 18 — Oct 20

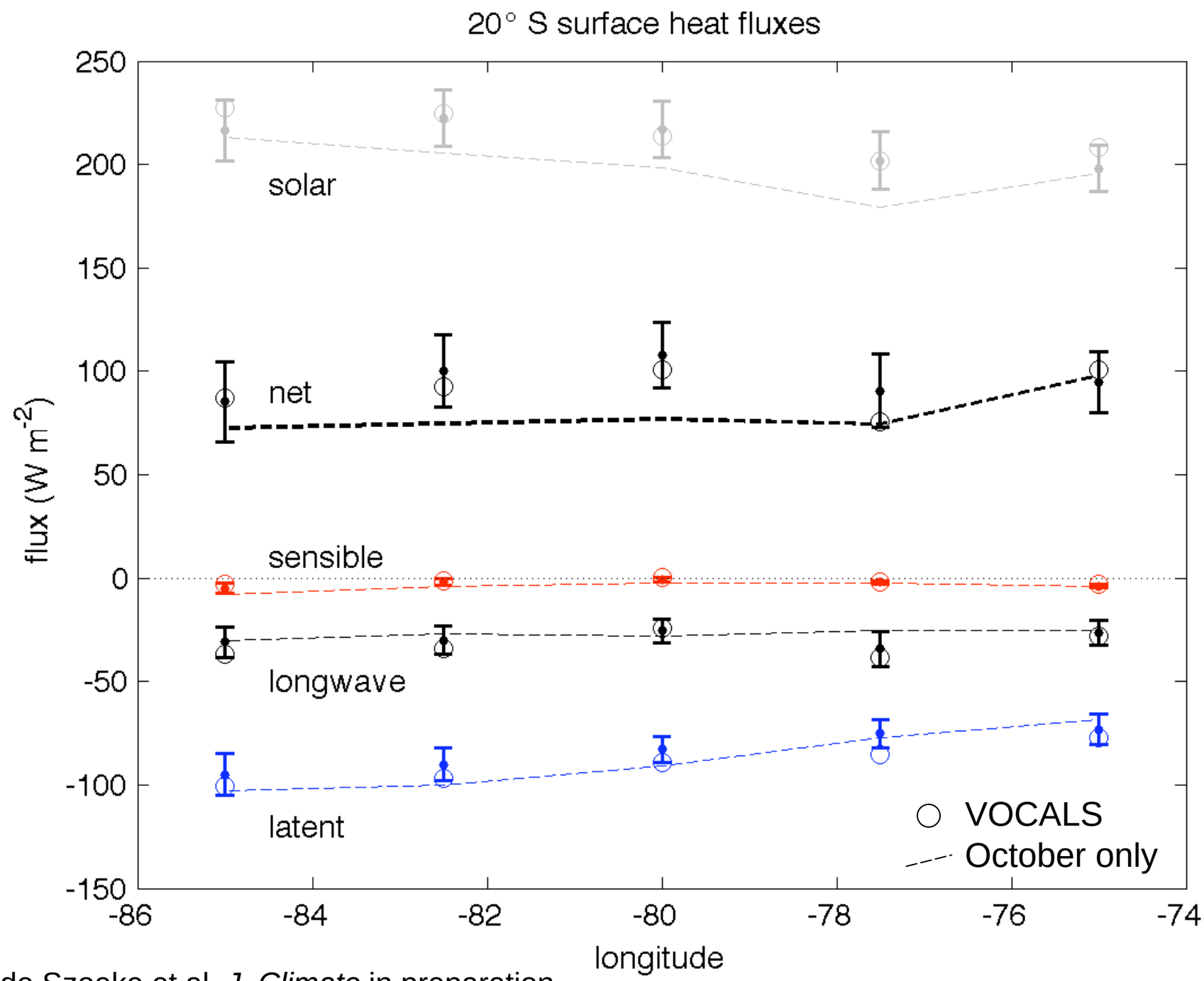
2006 Oct 20 — Oct 22

2007 Oct 26 — Oct 24

2008 Oct 27 — Oct 30

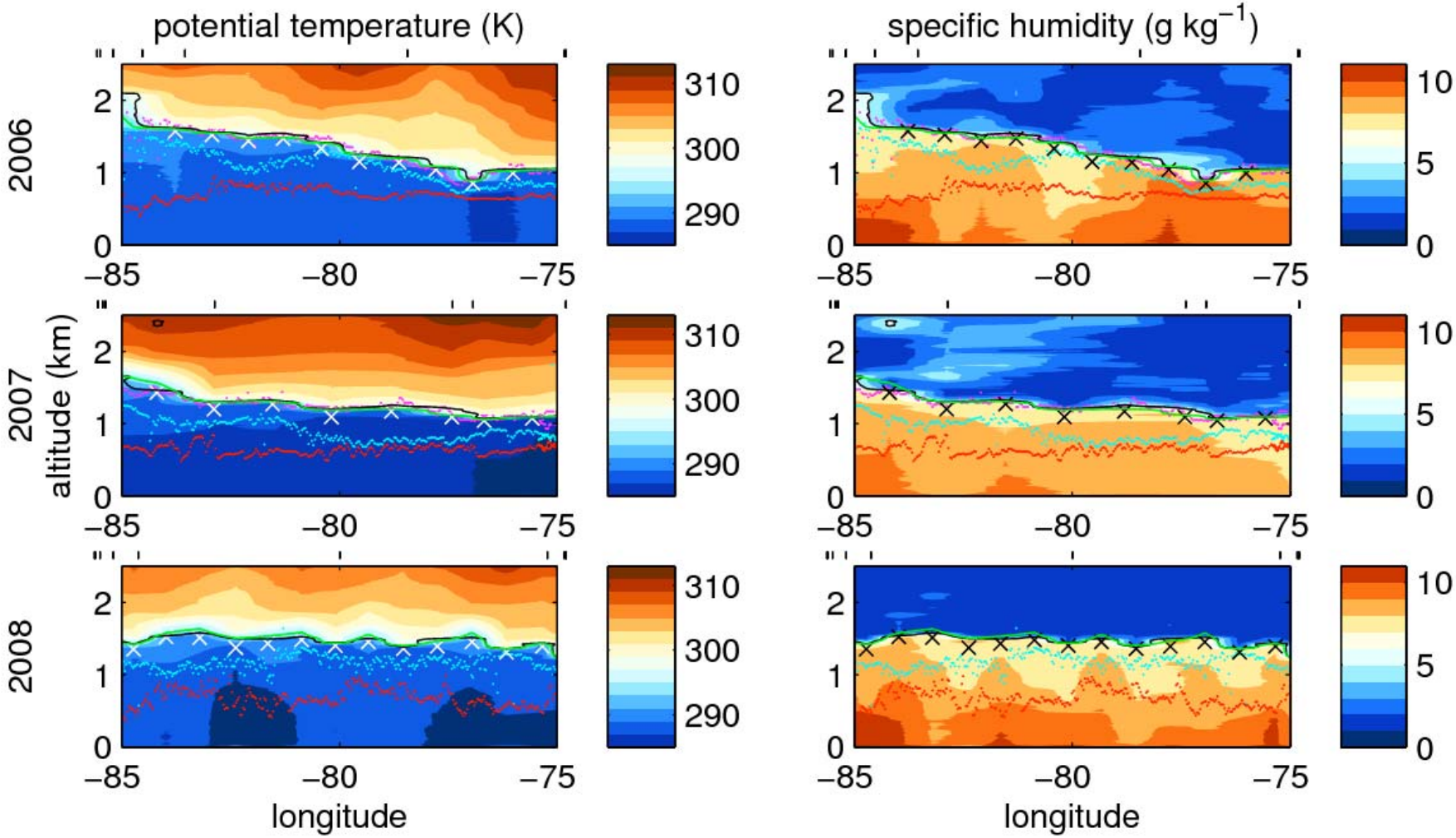
2008 Nov 20 — Nov 11, Nov 28

VOCALS



de Szoeke et al. *J. Climate* in preparation

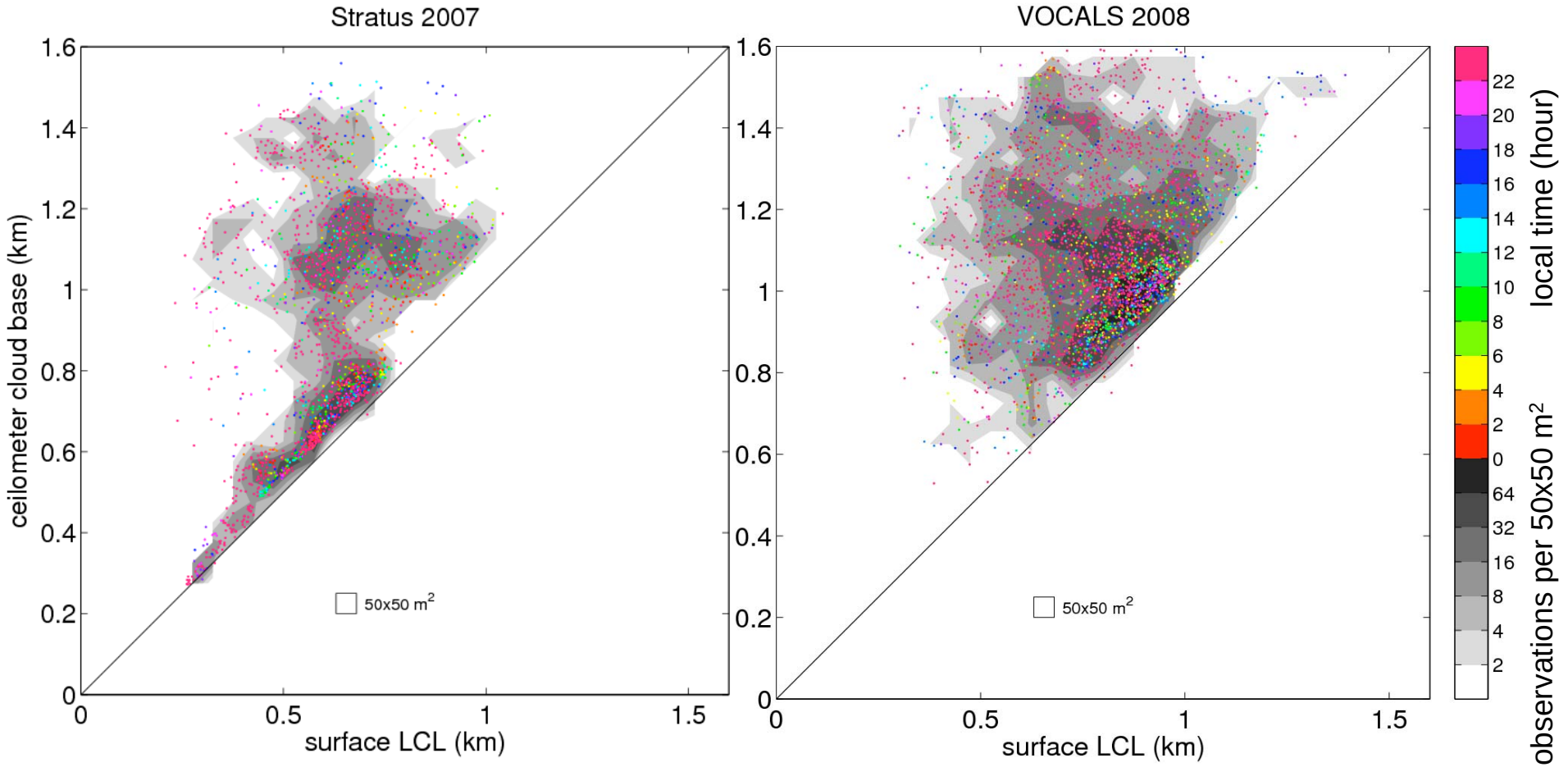
Radiosonde profiles along 20˚S



PBL height tilted west in 2001, 2005, 2006, 2007, 2008 (leg 2);
no tilt in 2003, 2004, 2008 (leg 1).

C-130 85˚ W sections provide snapshots.

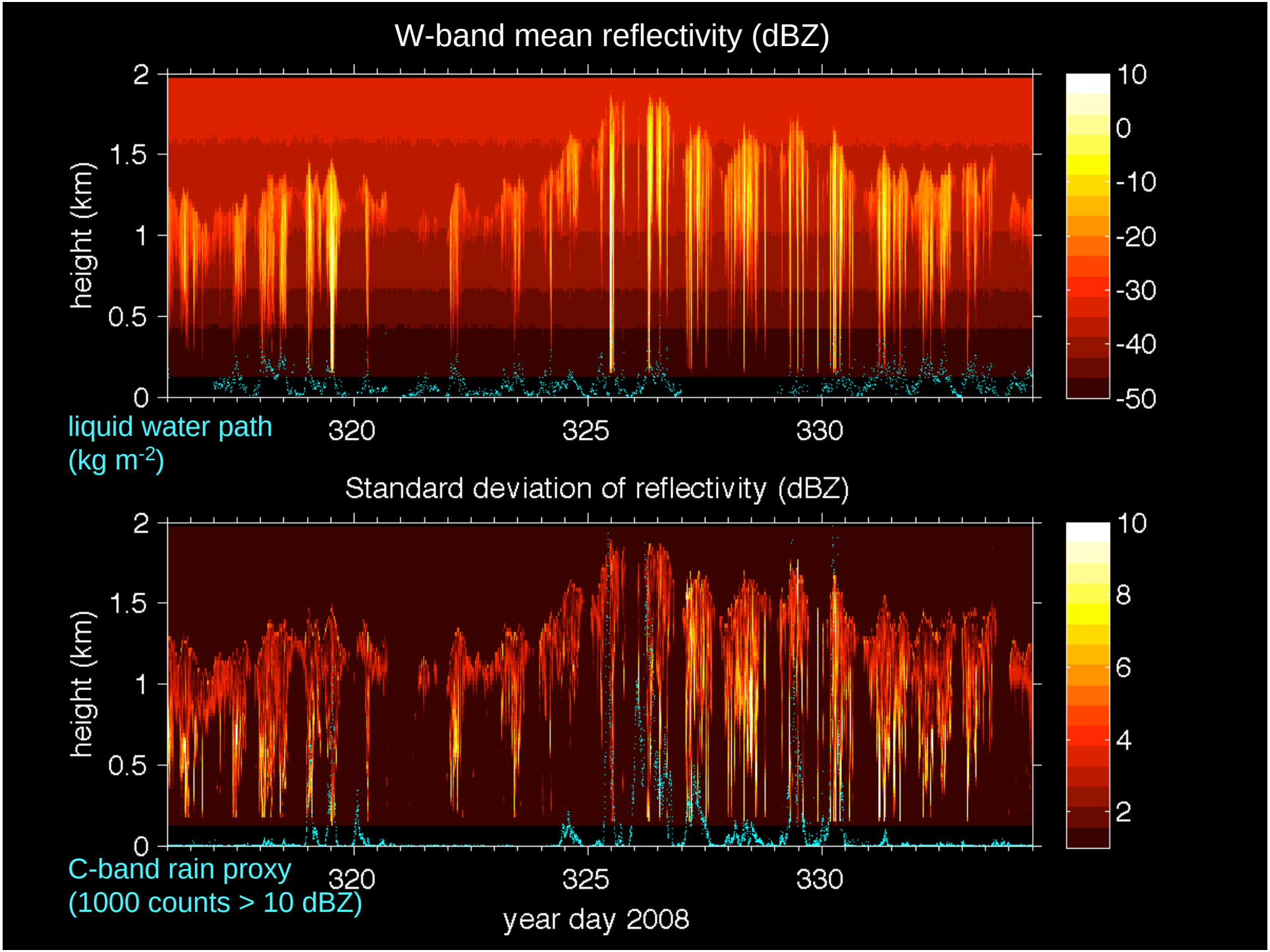
Decoupling observed from the ship

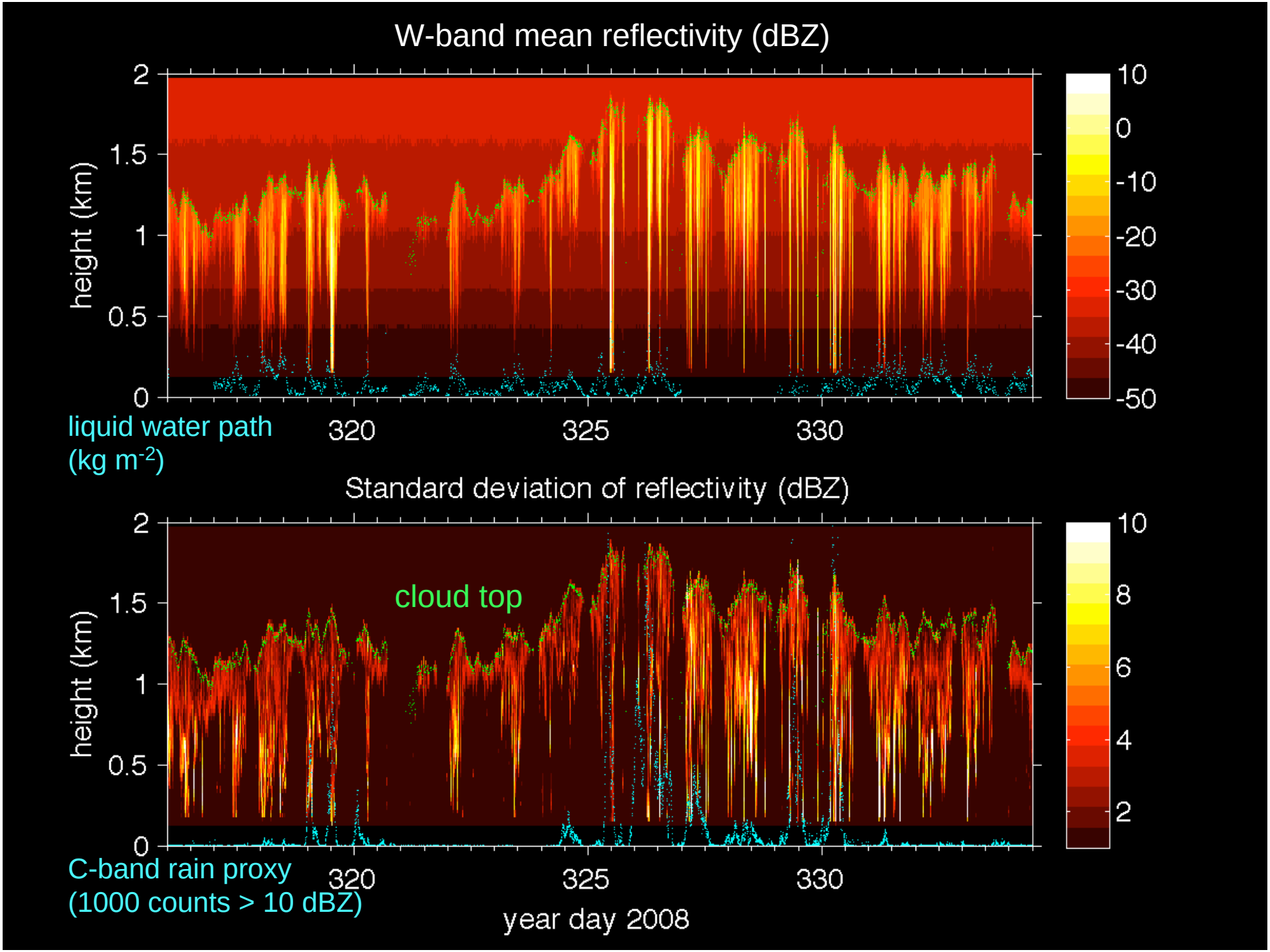


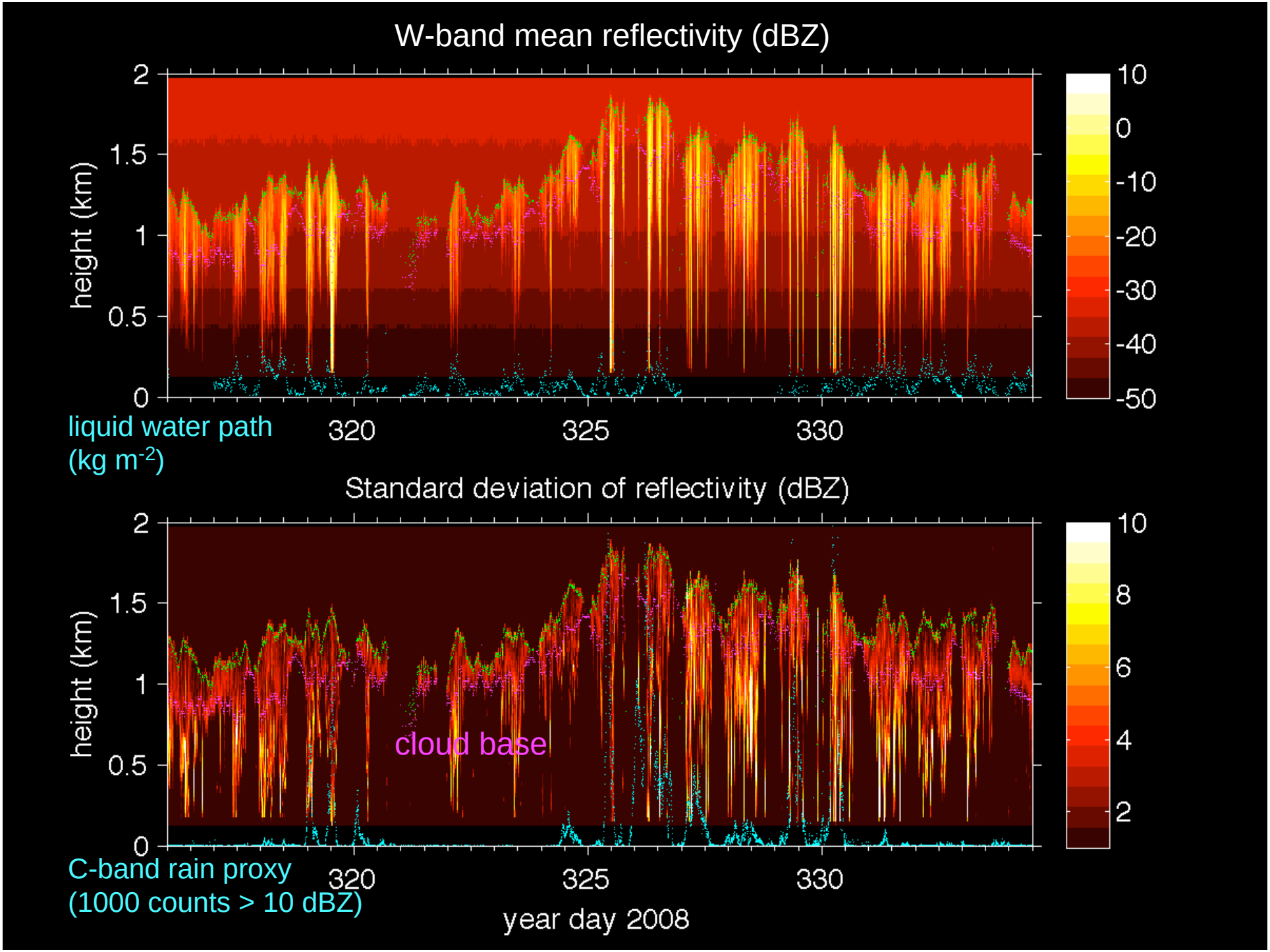
- Lowest cloud base is 10% higher than lifting condensation level (LCL).
- Cloud base above 900 m decouples from surface layer.
- VOCALS cloud bases are higher and show more continuous spectrum of decoupling.

W-band Doppler cloud radar

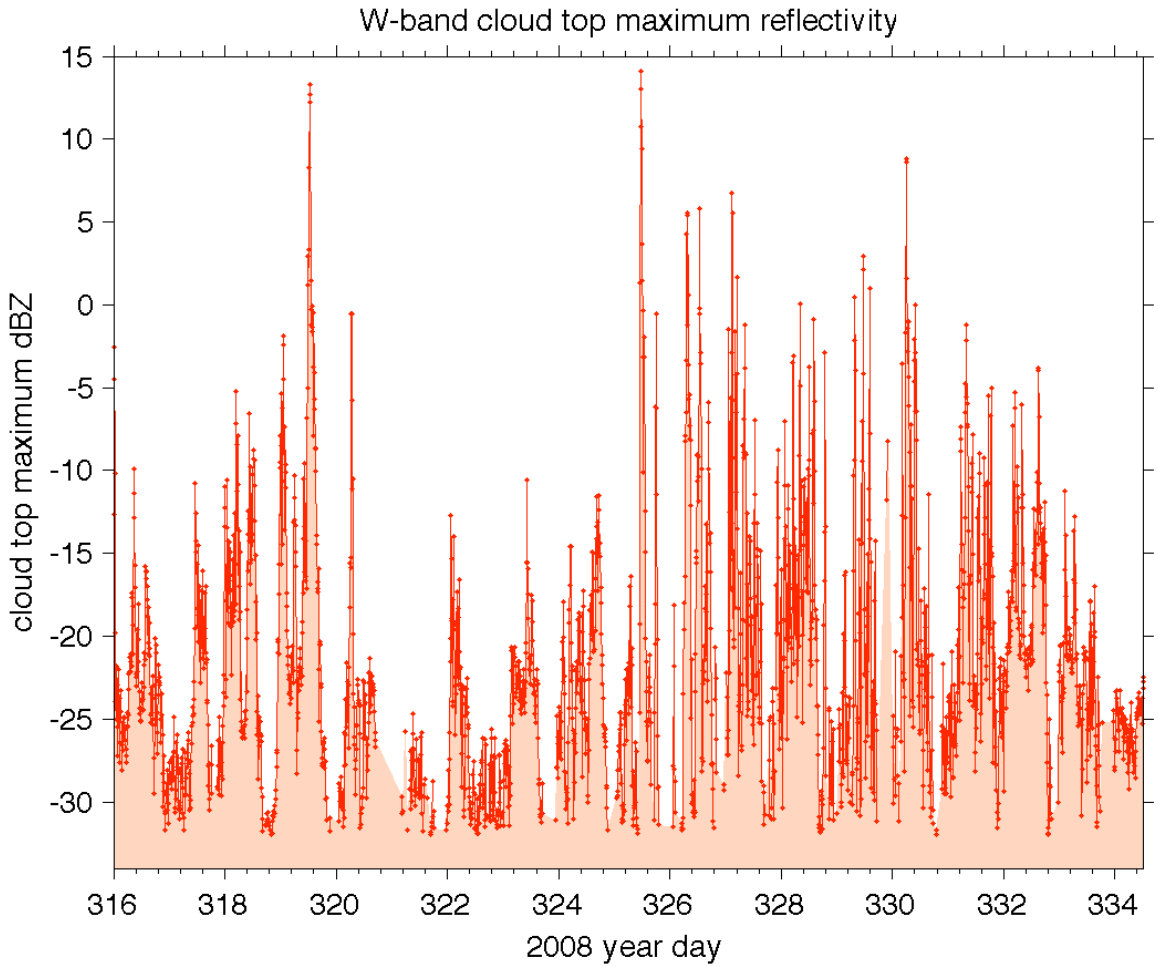
- 3.17 mm wavelength, 94.56 GHz
- 3.5 Hz sampling
- Vertically staring
- 02 deck of the *Ronald H. Brown*


W-band mean reflectivity (dBZ)
height (km)
2
1.5
1
0.5
0
10
0
-10
-20
-30
-40
-50
liquid water path
(kg m-2)
320
325
330
Standard deviation of reflectivity (dBZ)
height (km)
2
1.5
1
0.5
0
10
8
6
4
2
C-band rain proxy
(1000 counts > 10 dBZ)
320
325
330
year day 2008


W-band mean reflectivity (dBZ)
height (km)
2
1.5
1
0.5
0
10
0
-10
-20
-30
-40
-50
liquid water path
(kg m-2)
320
325
330
Standard deviation of reflectivity (dBZ)
cloud top
10
8
6
4
2
C-band rain proxy
(1000 counts > 10 dBZ)
year day 2008


W-band mean reflectivity (dBZ)
height (km)
2
1.5
1
0.5
0
10
0
-10
-20
-30
-40
-50
liquid water path
(kg m-2)
320
325
330
Standard deviation of reflectivity (dBZ)
height (km)
2
1.5
1
0.5
0
10
8
6
4
2
cloud base
C-band rain proxy
(1000 counts > 10 dBZ)
320
325
330
year day 2008

- Select maximum W-band reflectivity near cloud top.



- Also maximum liquid water mixing ratio $Q_{c,top}$
- Not sensitive to large precipitating drops

Cloud diurnal cycle

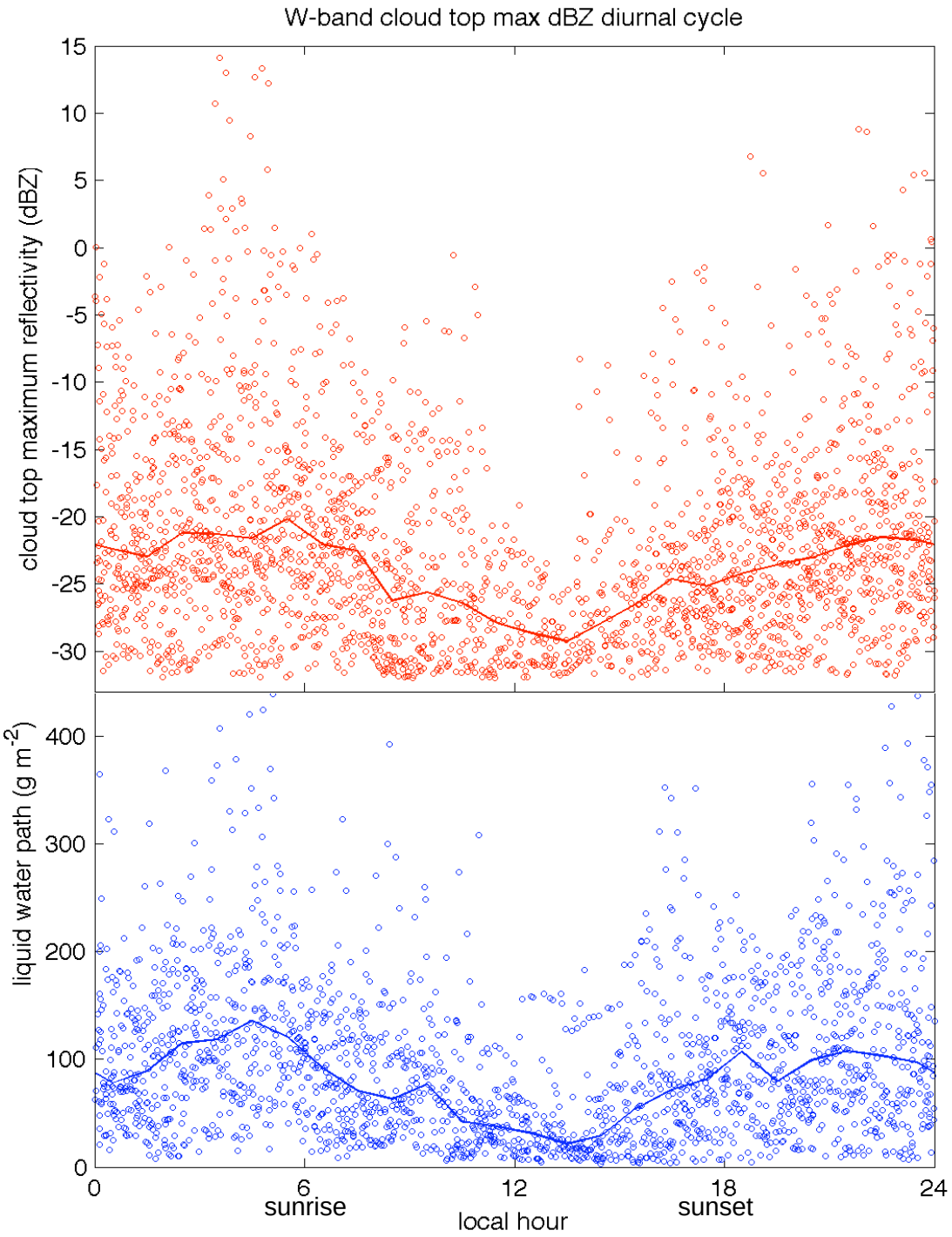
- Ship samples round-the-clock.
- Diurnal composites:
  - reflectivity
  - liquid water path
  - cloud geometry
- Hourly median

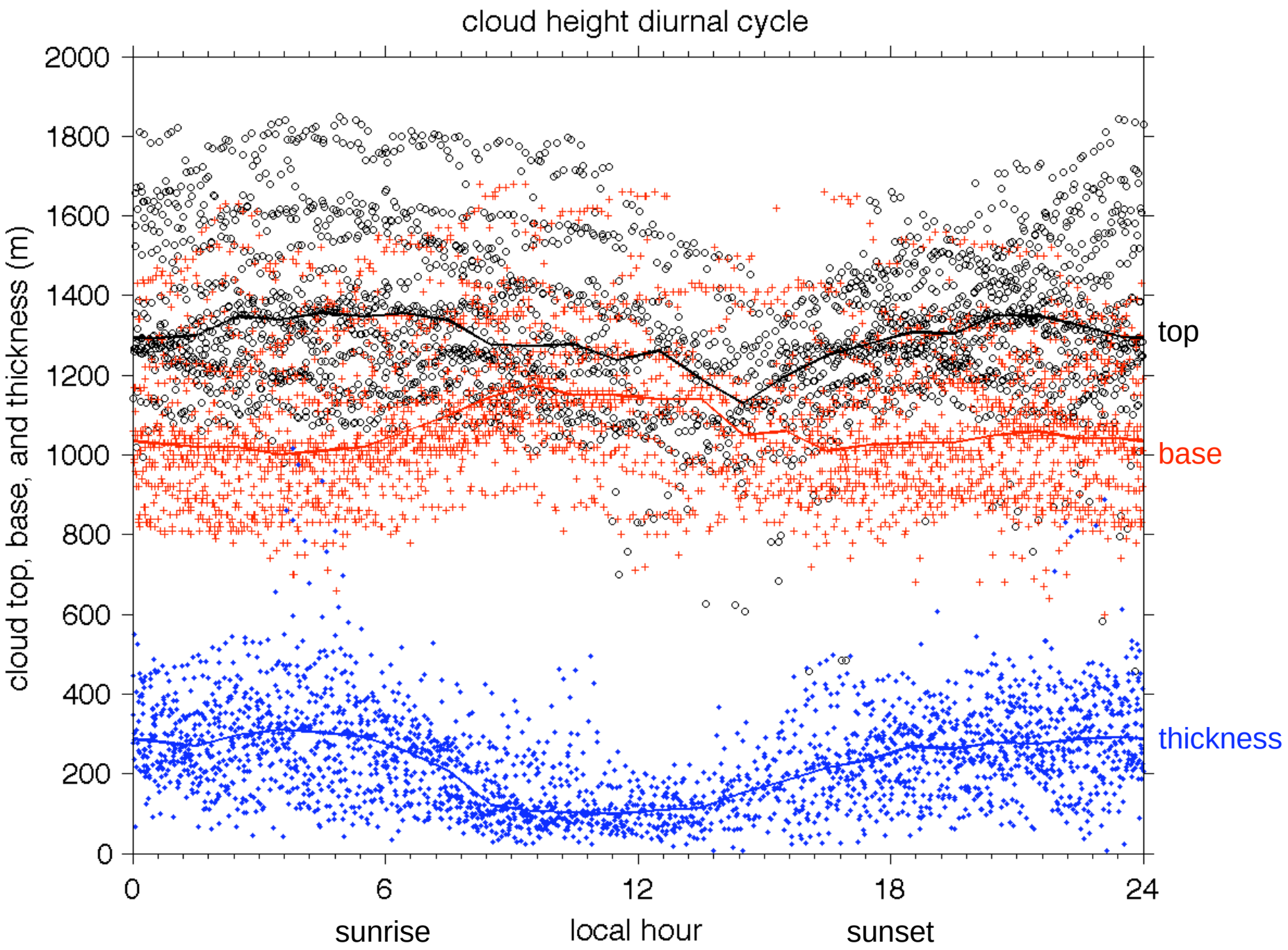
Diurnal cycle

Cloud top reflectivity

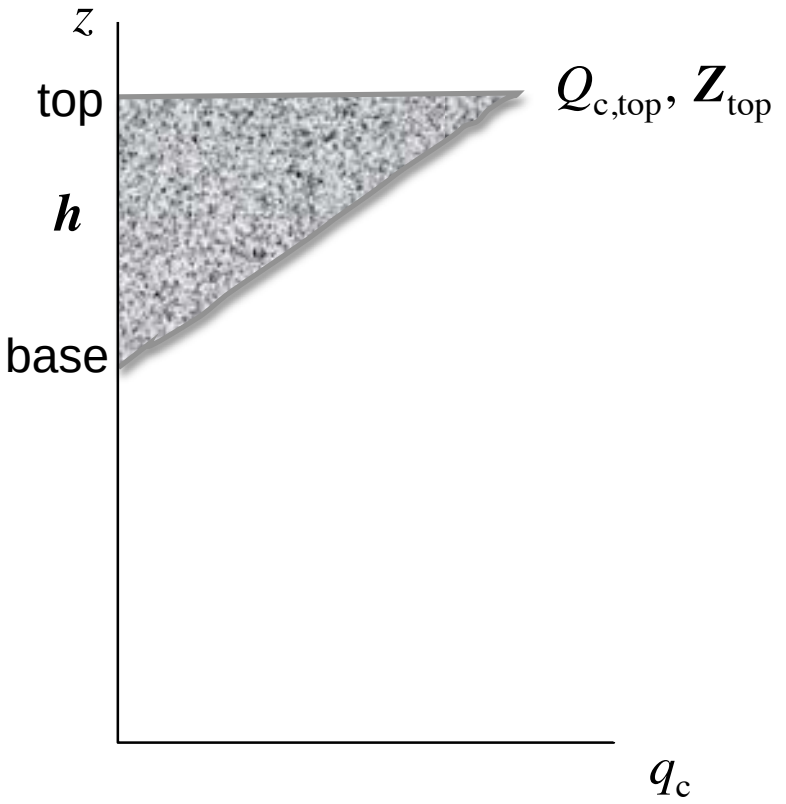
Liquid water path

physical retrieval
(Zuidema, *GRL* 2005)




cloud height diurnal cycle
cloud top, base, and thickness (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
6
12
18
24
sunrise
local hour
sunset
top
base
thickness

cloud microphysics retrieval

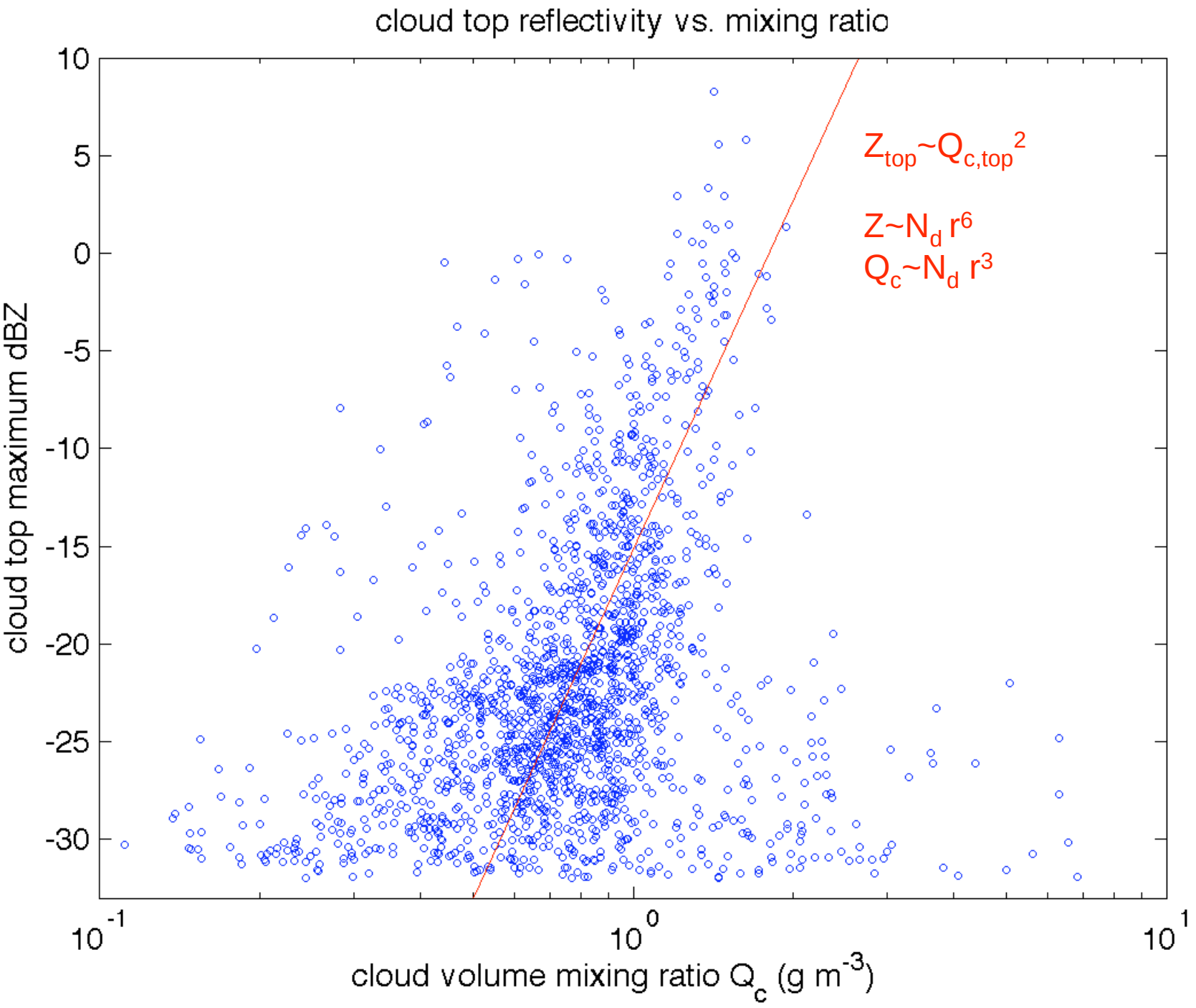


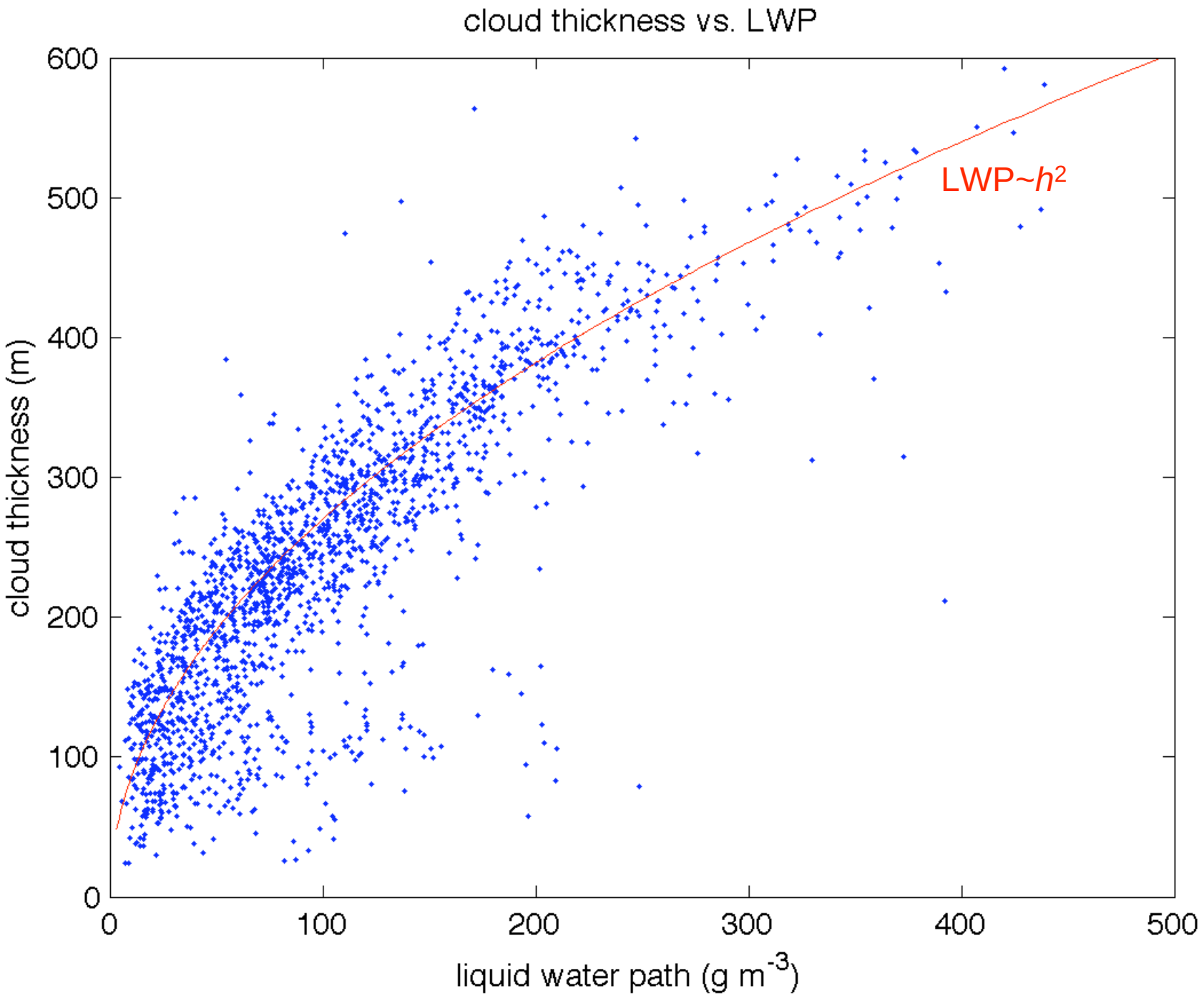
$$\begin{cases} Q_c = \rho_L \, 4\pi/3 \, r_{3eff}^{\,3} \, N_d \\ Z = 2^6 \, r_{6eff}^{\,6} \, N_d \end{cases}$$

$$\mathbf{LWP} = h/2 \; Q_{c,top}$$

Compute empirical relations of Z_{top}, h, and LWP.

$$(\pi\rho_L/12)^2 \, (r_{3eff}/r_{6eff})^6 \, N_d \, Z_{top} \, h^2 = \mathrm{LWP}^2$$


cloud top reflectivity vs. mixing ratio
cloud top maximum dBZ
cloud volume mixing ratio Q_c (g m^-3)
10
5
0
-5
-10
-15
-20
-25
-30
10^-1
10^0
10^1
Z_top~Q_c,top^2
Z~N_d r^6
Q_c~N_d r^3


cloud thickness vs. LWP
LWP~h^2
cloud thickness (m)
liquid water path (g m^{-3})
0
100
200
300
400
500
600

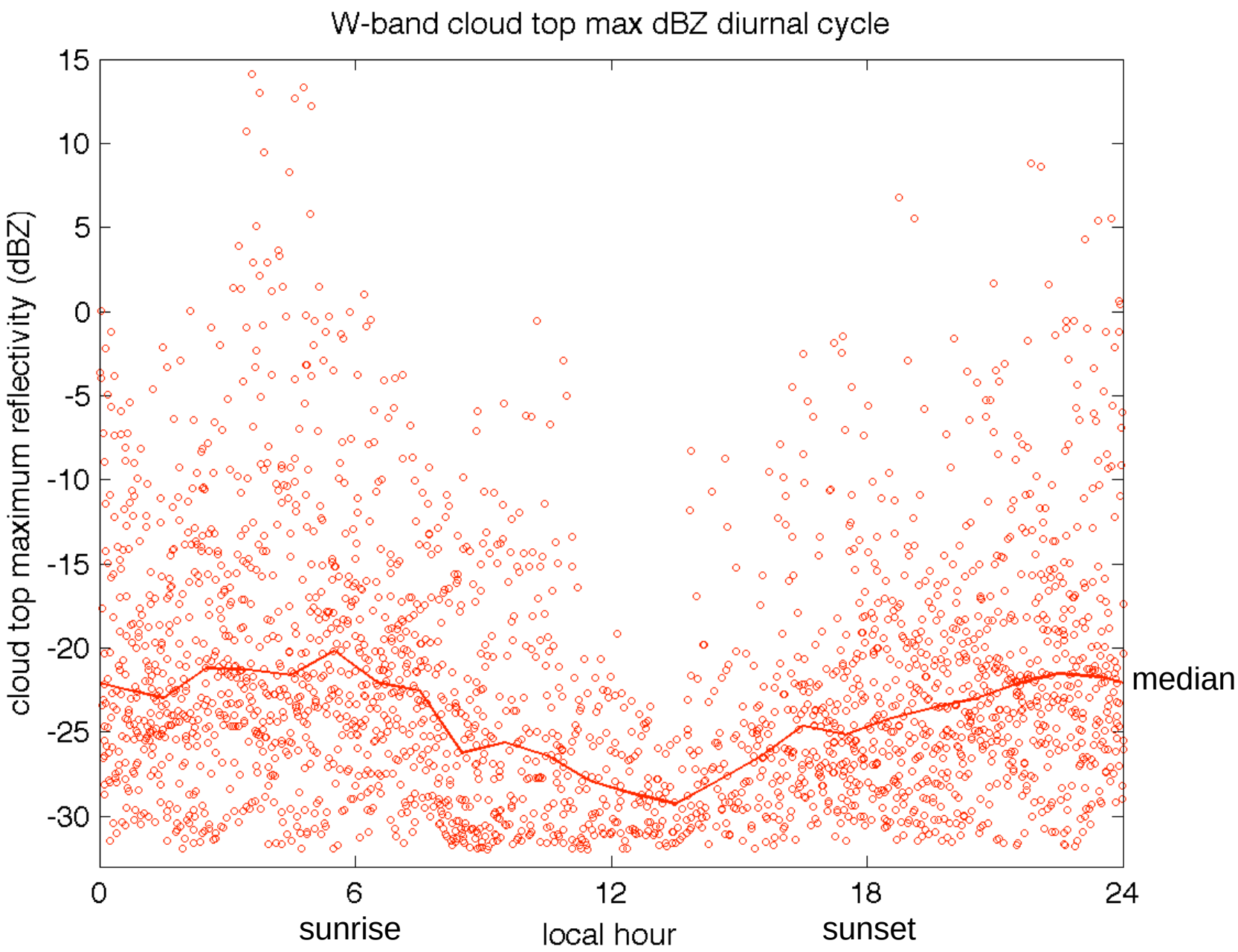
Suggestions

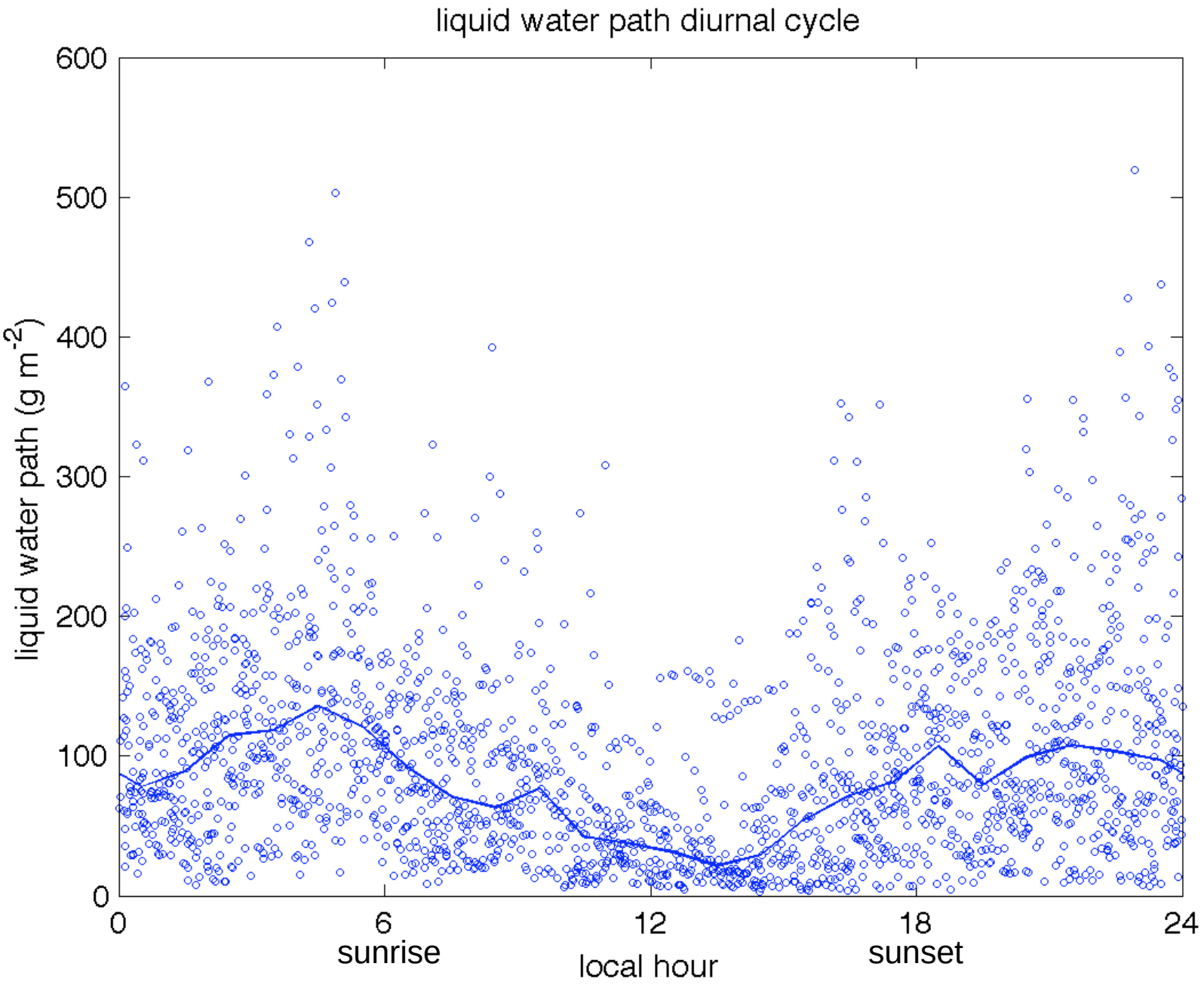
- Cloud macrophysical relations of LWP, maximum reflectivity, cloud thickness.
- Retrieve microphysical information, e.g. cloud droplet number concentration?

$$N_d = \mathrm{LWP}^2 h^{-2} (\pi \rho_L / 12)^{-2} Z_{top}^{-1} (r_{3eff}/r_{6eff})^{-6}$$

More Suggestions

- Diurnal cycle is more consistent for cloud geometry than cloud composition or precipitation.
  - Other factors affect rain besides radiation and subsidence.
  - sampling infrequent non-normal rain distribution.
- Are CCN variations more effective during daylight when clouds are thinner?
  - thin clouds sensitive but thick nocturnal clouds swamp CCN effect.


W-band cloud top max dBZ diurnal cycle
cloud top maximum reflectivity (dBZ)
15
10
5
0
-5
-10
-15
-20
-25
-30
0
6
12
18
24
sunrise
local hour
sunset
median

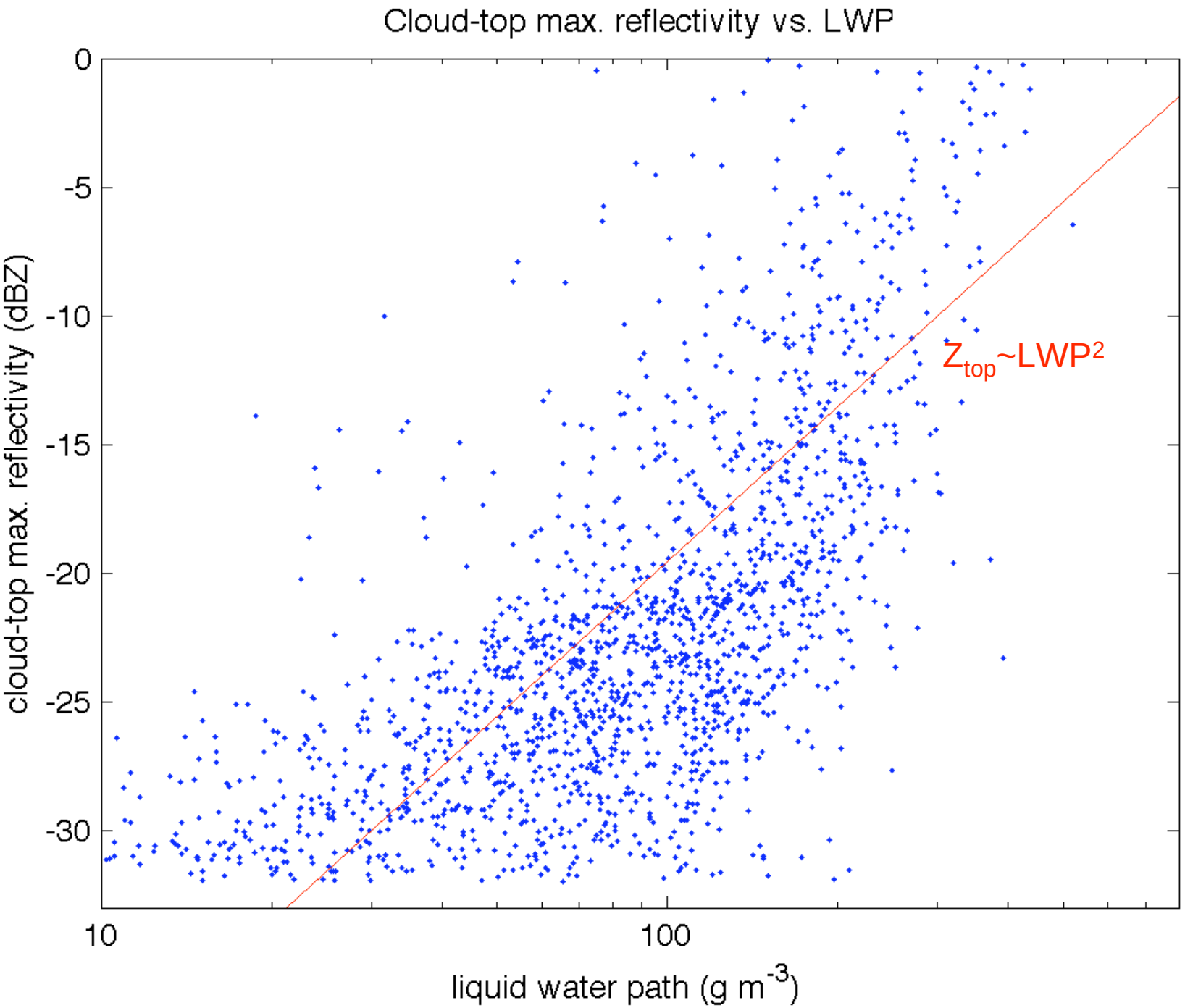


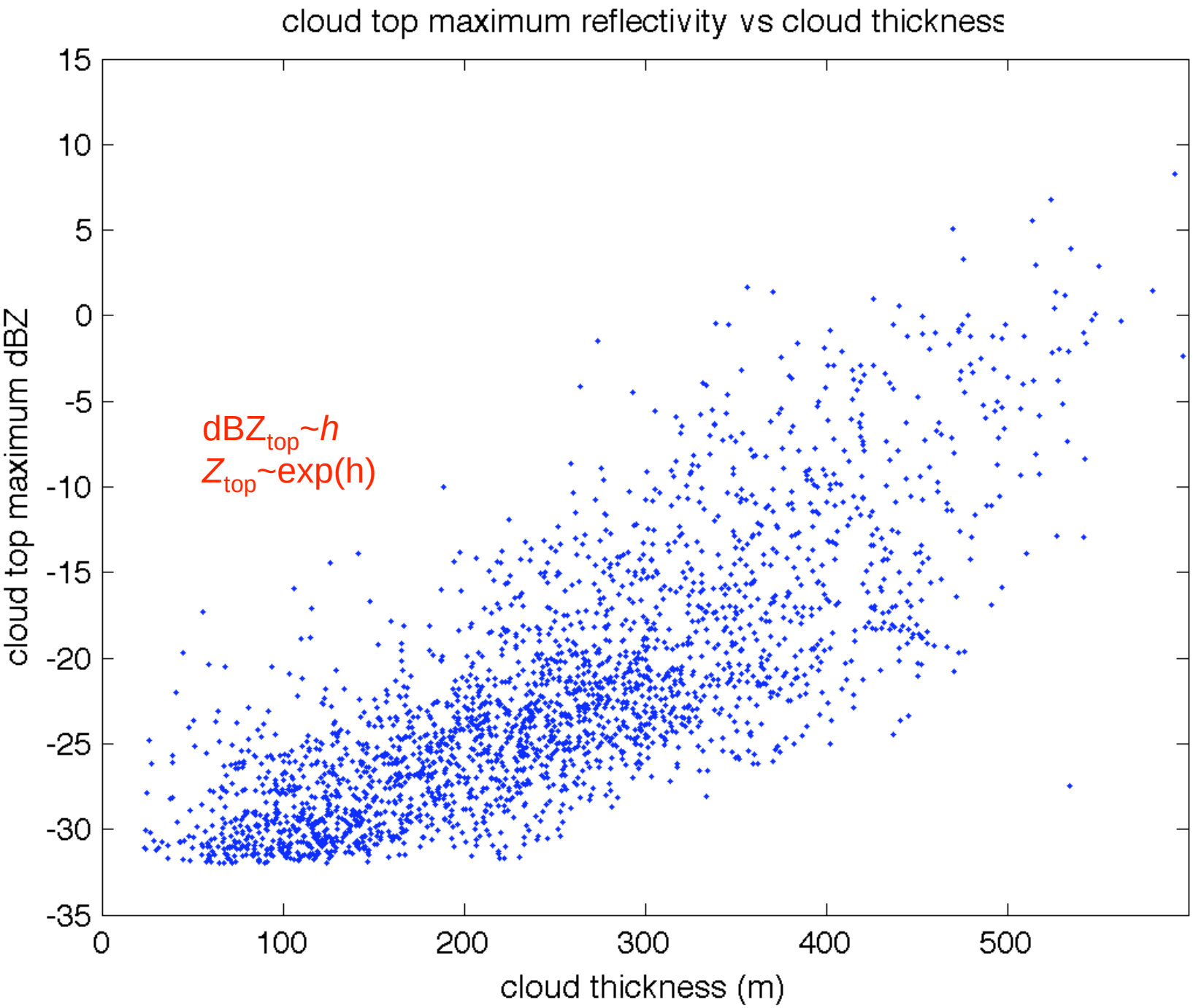
physical retrieval (Zuidema, *GRL* 2005)

Microphysical retrieval

$$(\pi\rho_L/12)^2\,(r_{3\mathrm{eff}}/r_{6\mathrm{eff}})^6\,N_d\,\max_z(Z)\,h^2 = \mathrm{LWP}^2$$

$r_{3\mathrm{eff}}/r_{6\mathrm{eff}}$	ratio of 3 to 6 moment of N(r) at cloud top
max(Z)	reflectivity at cloud top
h	cloud thickness
N_d	cloud drop number
LWP	liquid water path


Cloud-top max. reflectivity vs. LWP
0
-5
-10
-15
-20
-25
-30
cloud-top max. reflectivity (dBZ)
10
100
liquid water path (g m-3)
Ztop~LWP2


cloud top maximum reflectivity vs cloud thickness
cloud top maximum dBZ
cloud thickness (m)
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
0
100
200
300
400
500
dBZtop~h
Ztop~exp(h)