Entrainment Processes – Aircraft Measurements

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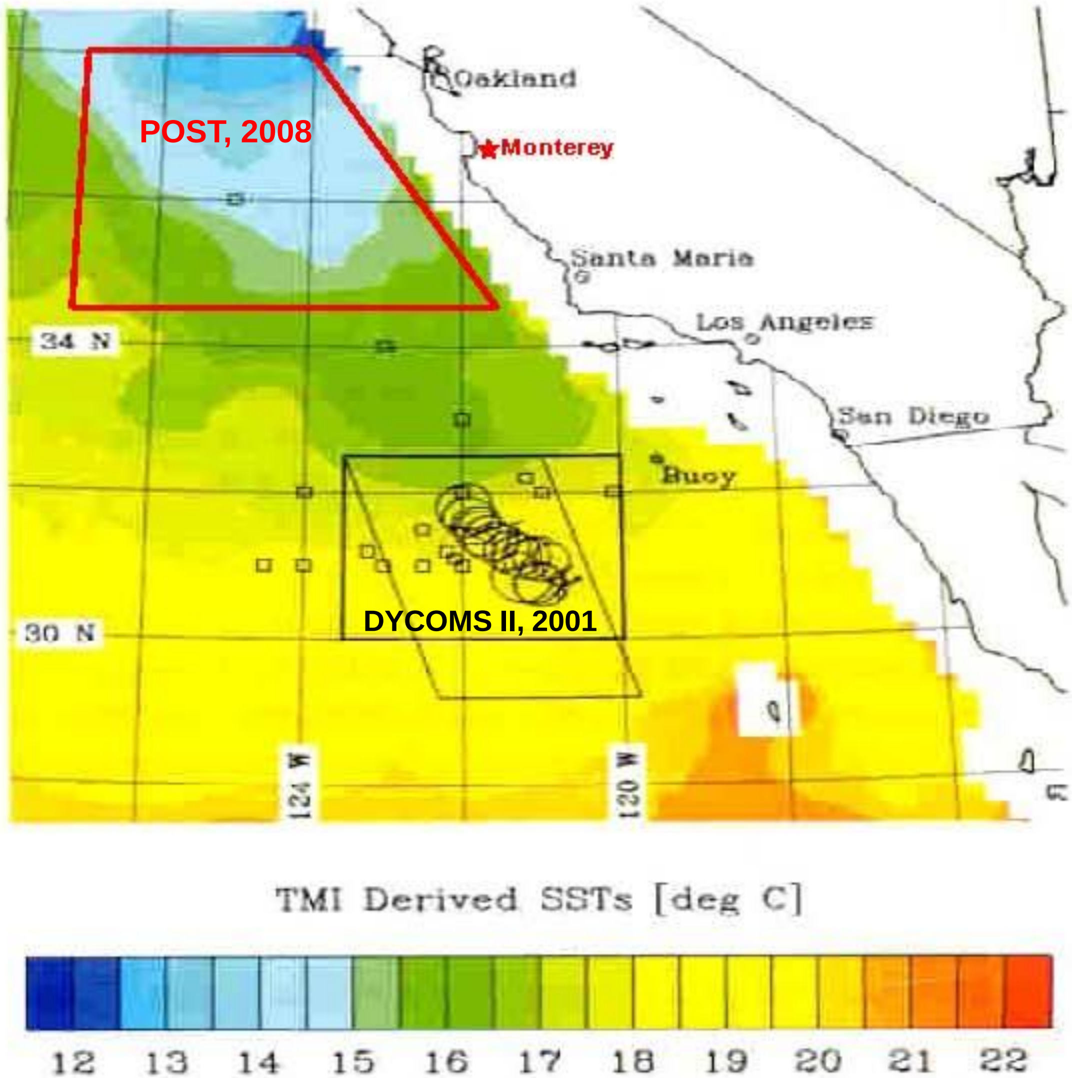
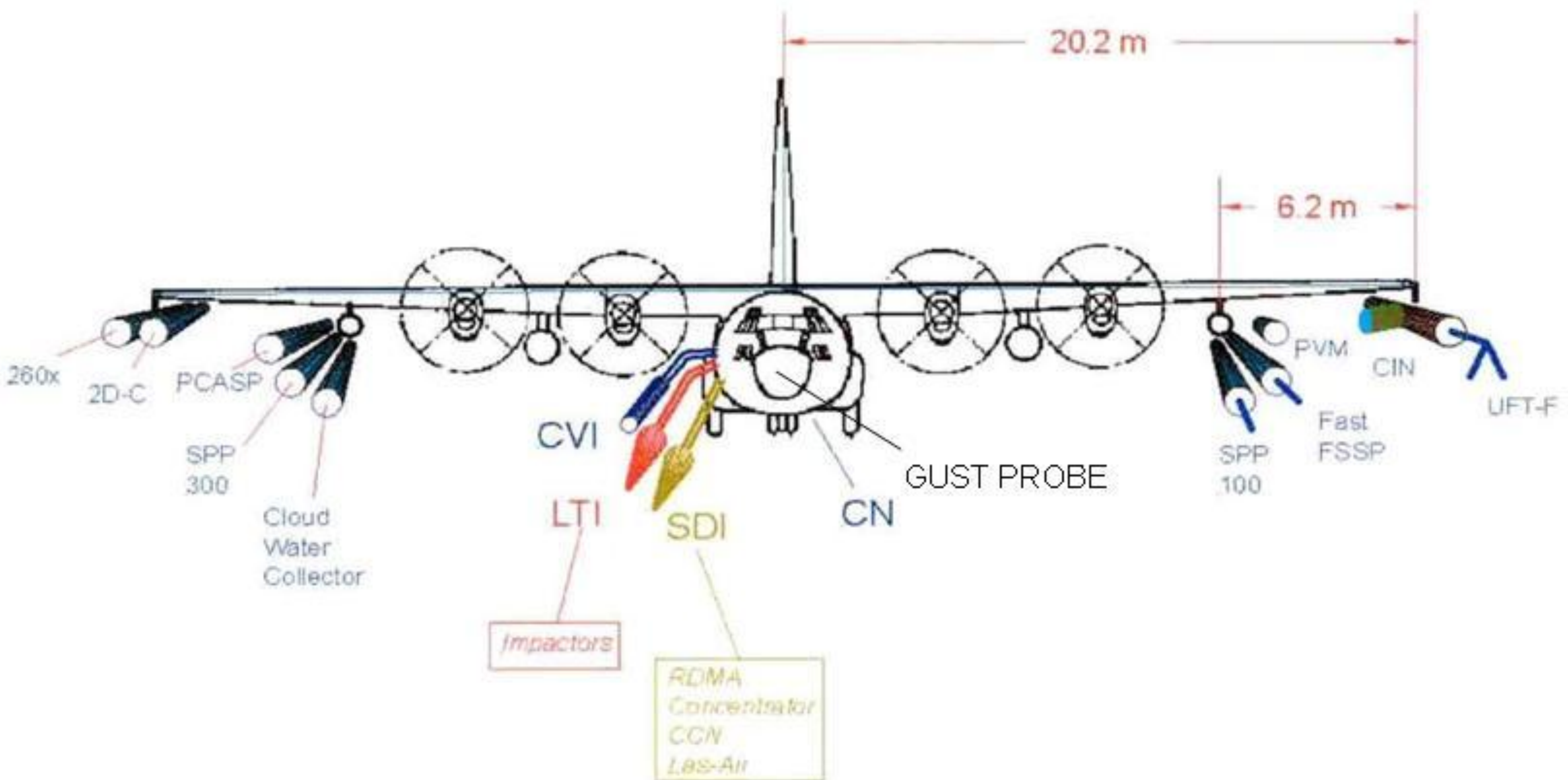
BNL, July 8, 2011

(Photo by Djamal Khelif)

DYCOMS II (Stevens et al., *B.A.M.S.*, 2003, **38**)



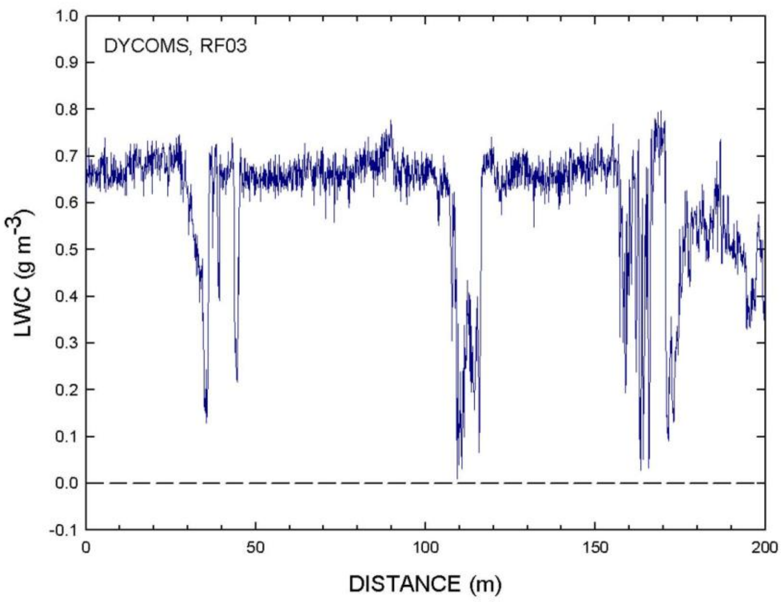
DYCOMS-II Probe Locations



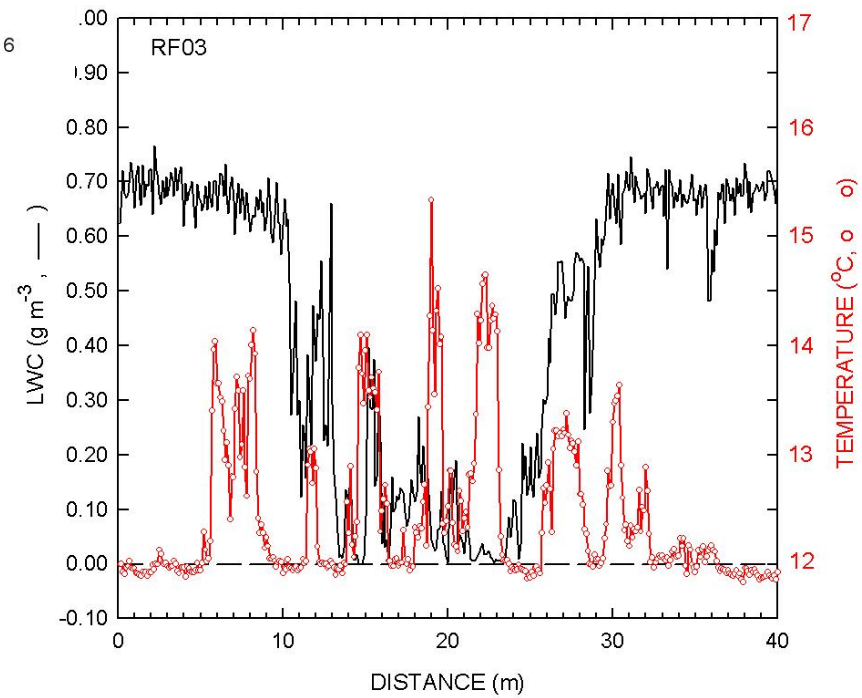
plus aerosol sampling with instruments inside aircraft

UFT - temperature, **1000 Hz**
FFSSP - droplet no. and size, **100 Hz**
PVM - LWC and effective radius, **1000 Hz**

CLOUD HOLES



CO-LOCATION



ACCURACY

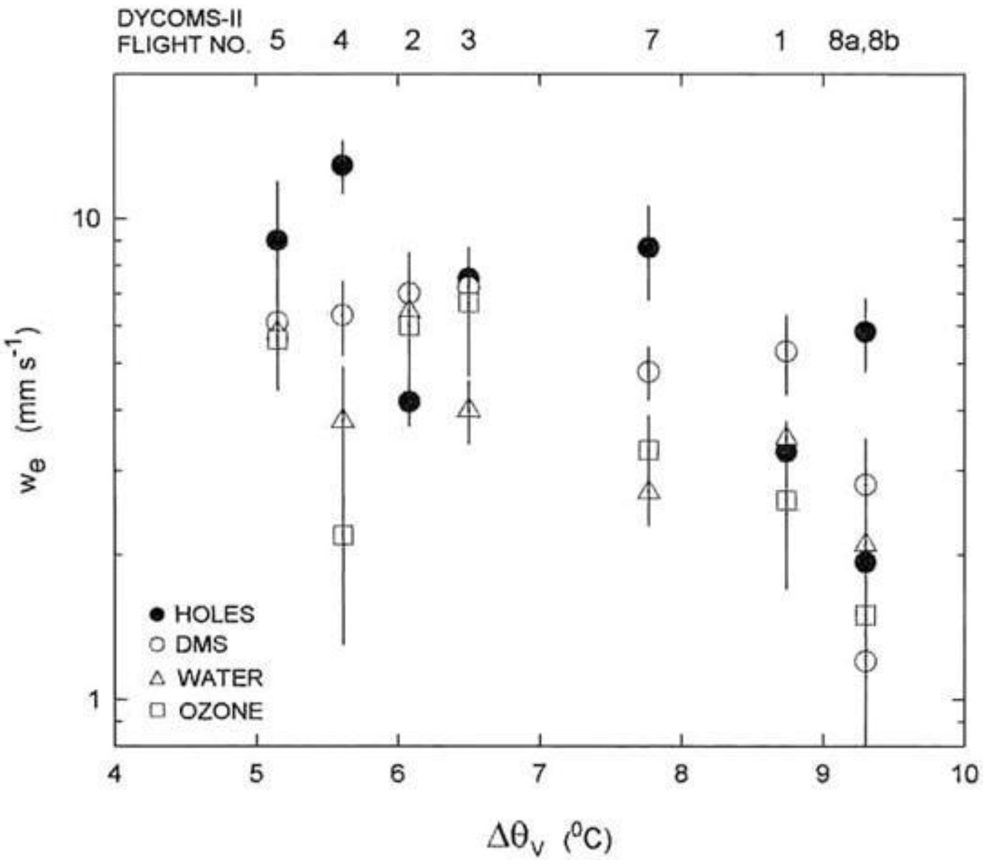
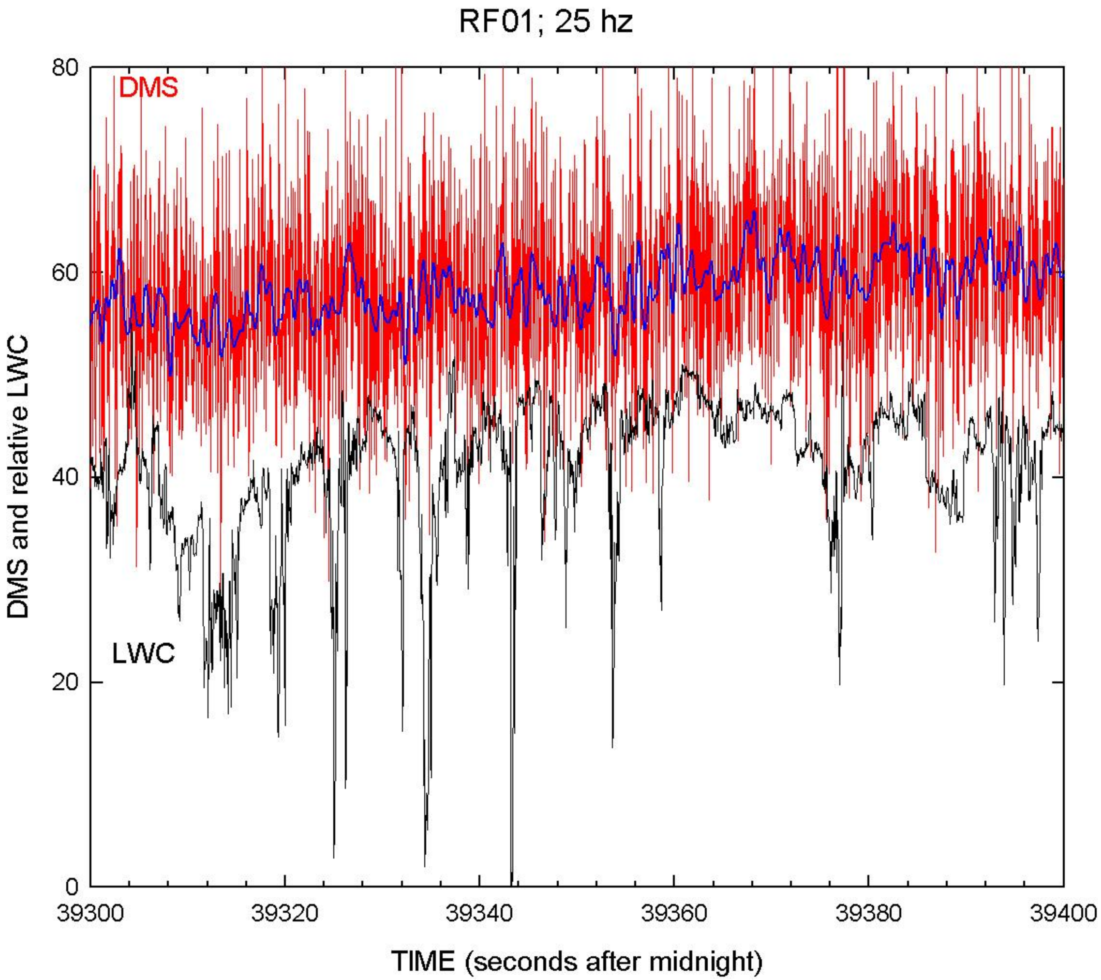
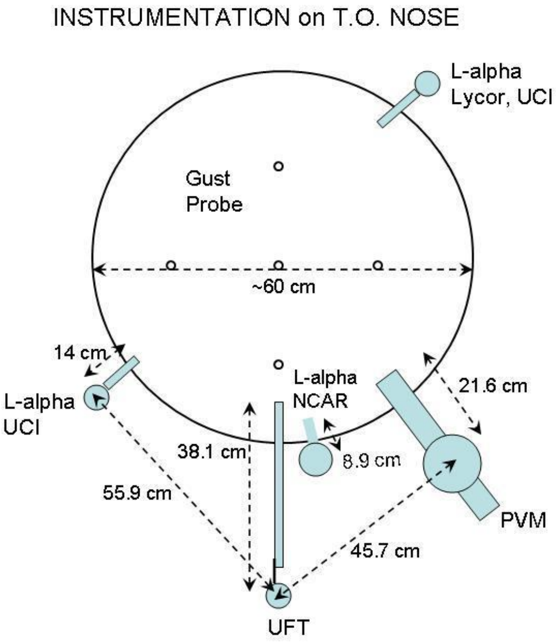


Fig. 1 - Comparison of entrainment velocity (w_e) into Sc measured by four independent measurements on the NCAR C-130 aircraft during DYCOMS-II as a function of the buoyancy jump ($\Delta\theta_v$) at cloud top. The solid data are for conditional sampling of cloud "holes" (Gerber et al., 2005; J.A.S.), and the hollow data are for the the flux-jump method using "DMS", total "water", and "ozone" scalars (Faloona et al., 2005; J.A.S.) The vertical lines through each data are +1/-1 standard deviation.

DMS ACCURACY



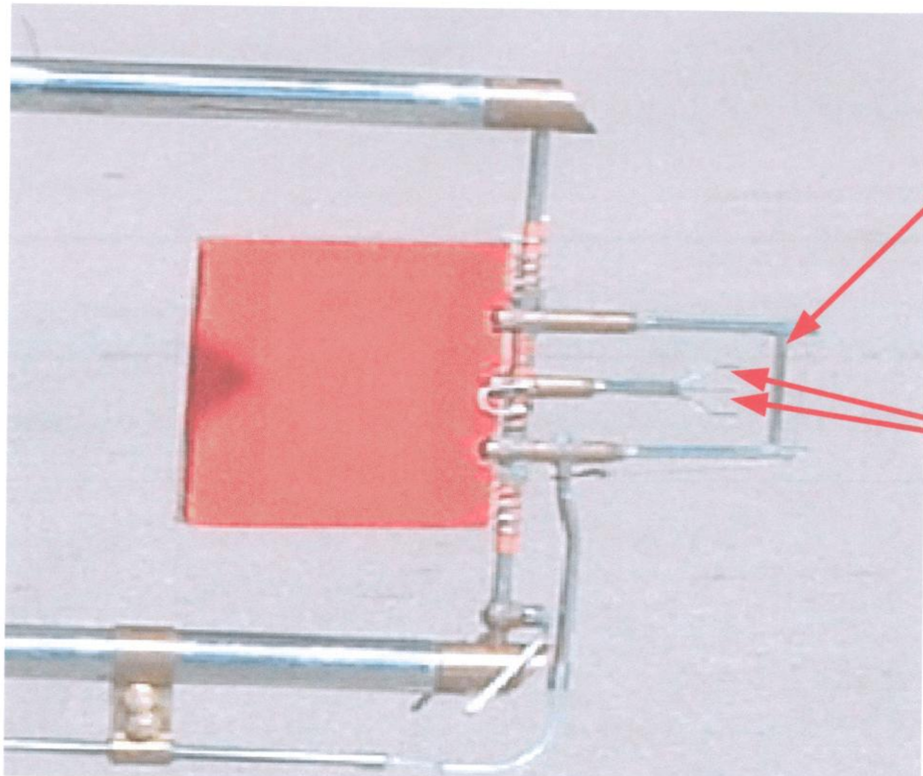
POST Probe Locations



http://www.eol.ucar.edu/projects/post/

Variables/Probes for Aircraft Entrainment Measurements

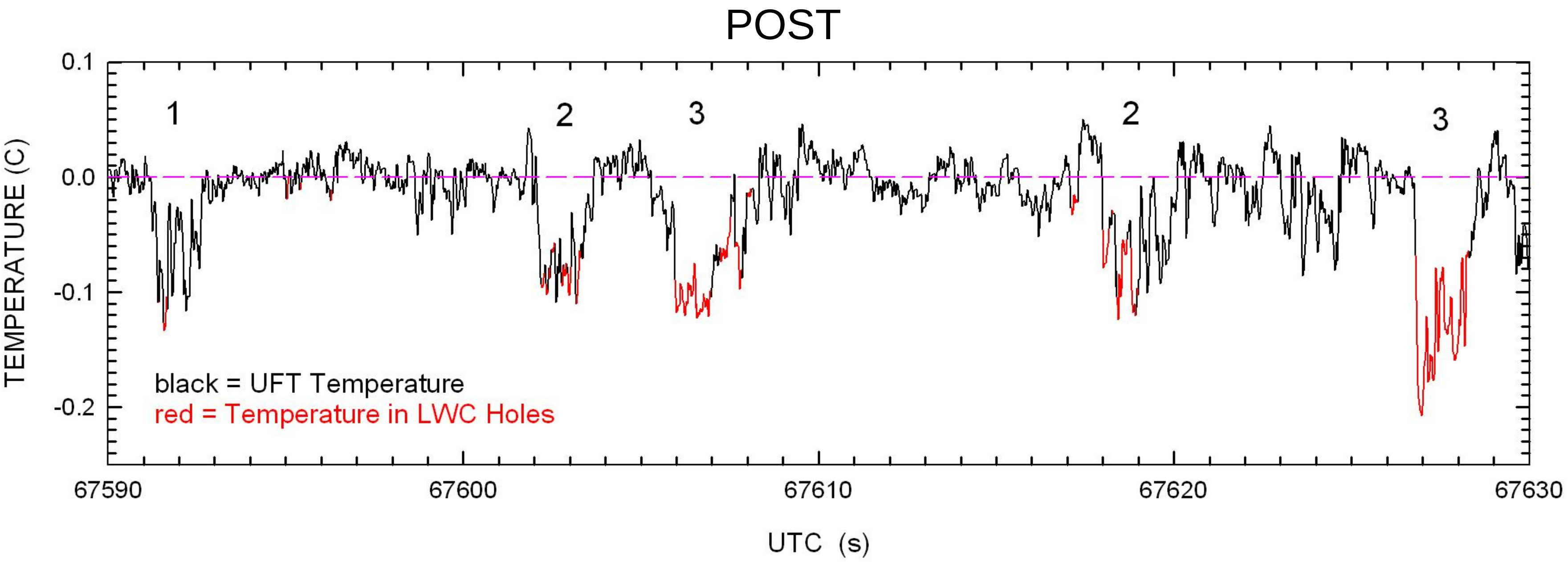
variable	probe
T	**UFT** - University of Warsaw, Poland (1000hz)
q_v	**Lyman-alpha** – NCAR (100hz);UCI (3hz)
LWC, r	**PVM** - Gerber Scientific (1000hz)
u, v, w	**gust probe** - CIRPAS Twin Otter (40hz)
rad.	**i.r. and visible radiometers** – NRL (10hz)



protective rod

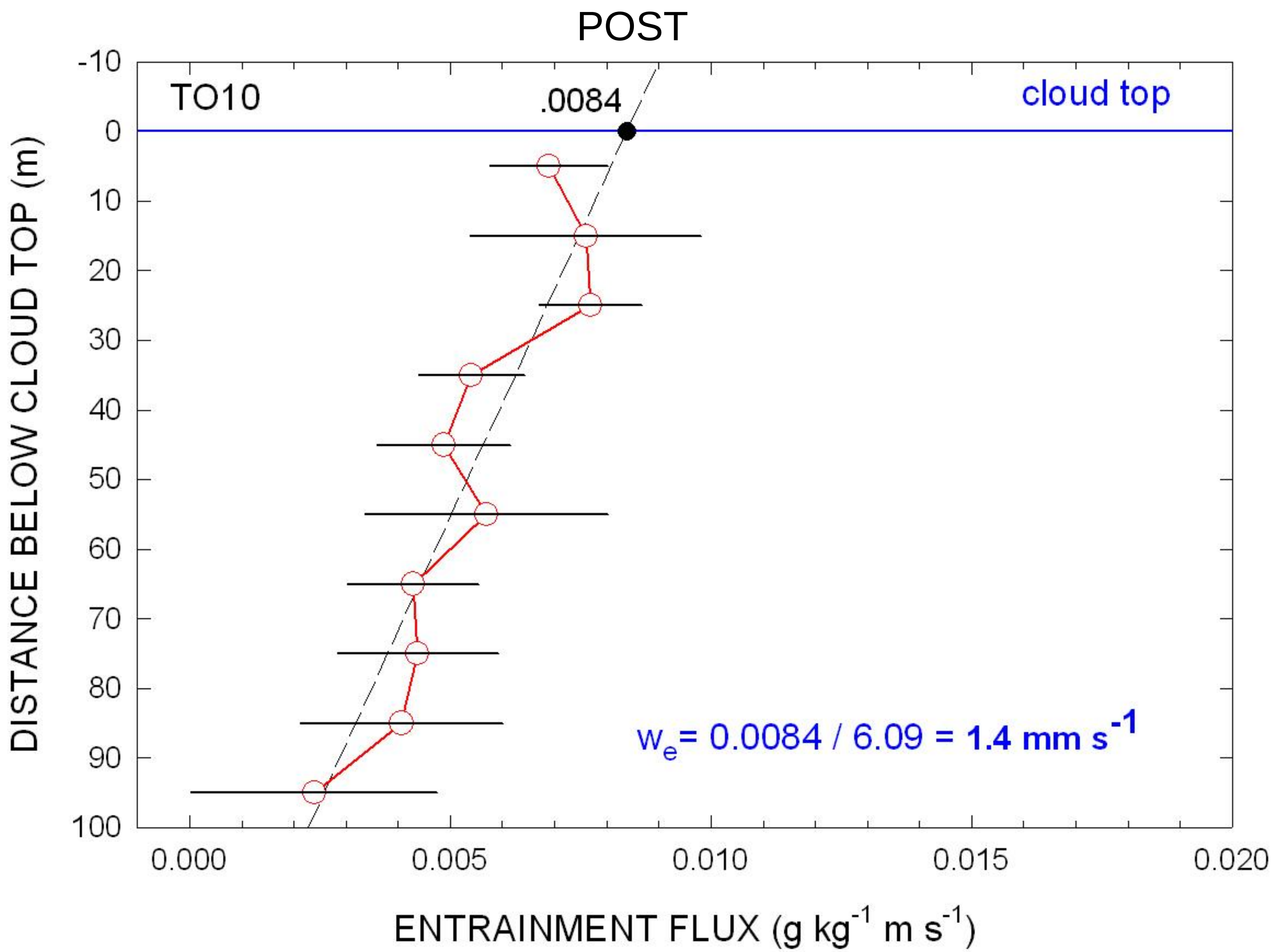
sensing wires

UFT Temperature and LWC Holes



ENTRAINMENT VELOCITY, w_e

Method	Eqn.	Definitions
Difference	$$w_e = \frac{dz_i}{dt} - W$$	dz_i/dt = change of cloud top height W = mean subsidence velocity
Flux-Jump	$$w_e = \frac{\overline{w'\phi'}}{\Delta\phi}$$	$w'\phi'$ = flux of scalar at inversion base $\Delta\phi$ = jump of scalar across inversion
Conditional-Sampling	$$w_e = \frac{A_h}{A_t}\frac{\overline{w' \times (\phi_f - \phi_h)}}{\Delta\phi}$$	A_h = cloud top area with holes A_t = total cloud top area ϕ_f = scalar in unaffected cloud ϕ_h = scalar in cloud hole


POST
TO10
.0084
cloud top
w_e= 0.0084 / 6.09 = **1.4 mm s^{-1}**
DISTANCE BELOW CLOUD TOP (m)
-10
0
10
20
30
40
50
60
70
80
90
100
0.000
0.005
0.010
0.015
0.020
ENTRAINMENT FLUX (g kg^{-1} m s^{-1})

JUMP-METHOD ASSUMPTIONS

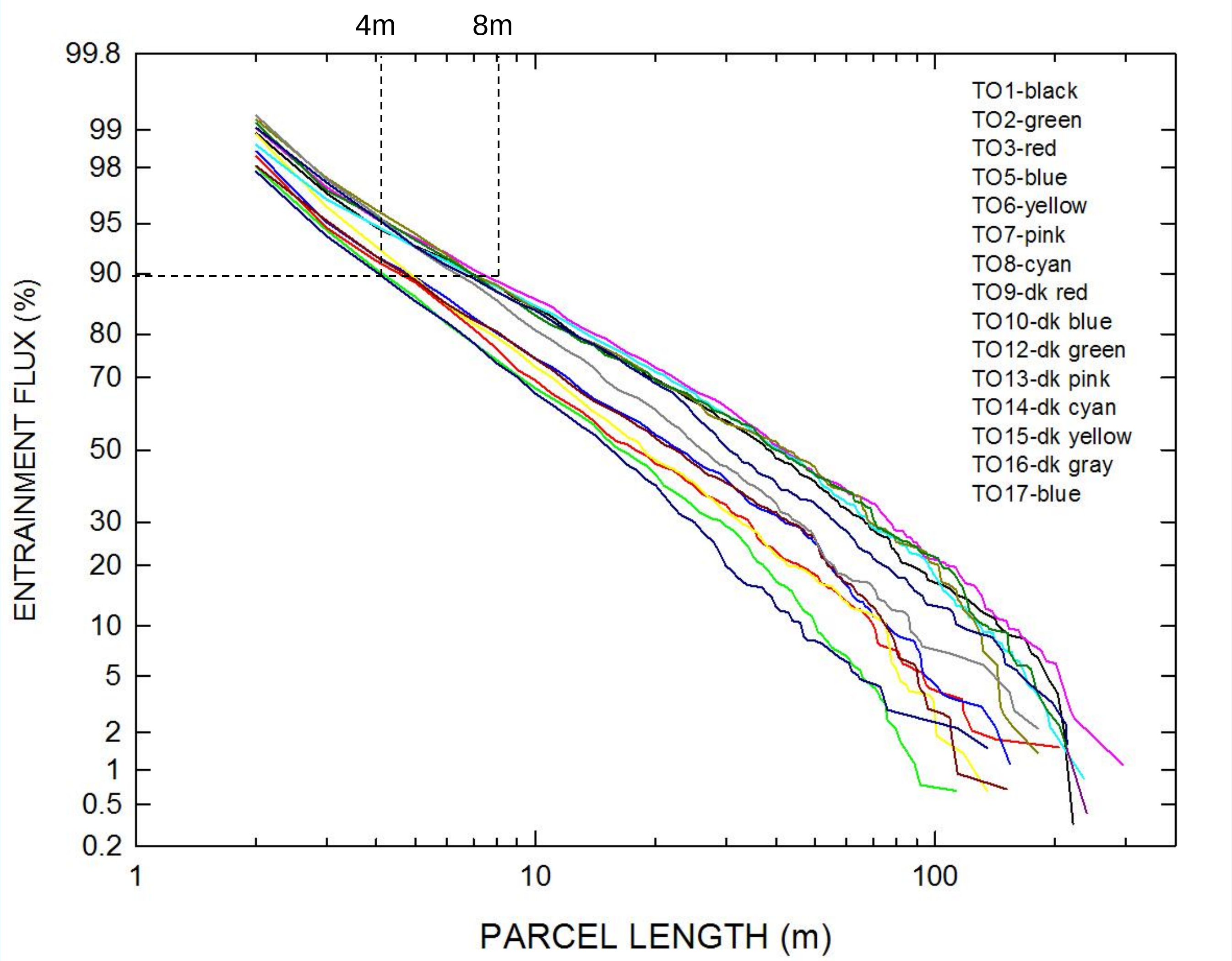
#1 Entrainment air descends

#2 Entrainment fluxes are linear with height

#3 Jump thickness above cloud top is small

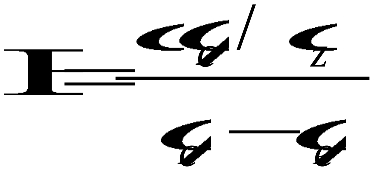
LOG - PROBABILITY FLUX vs HOLE LENGTH

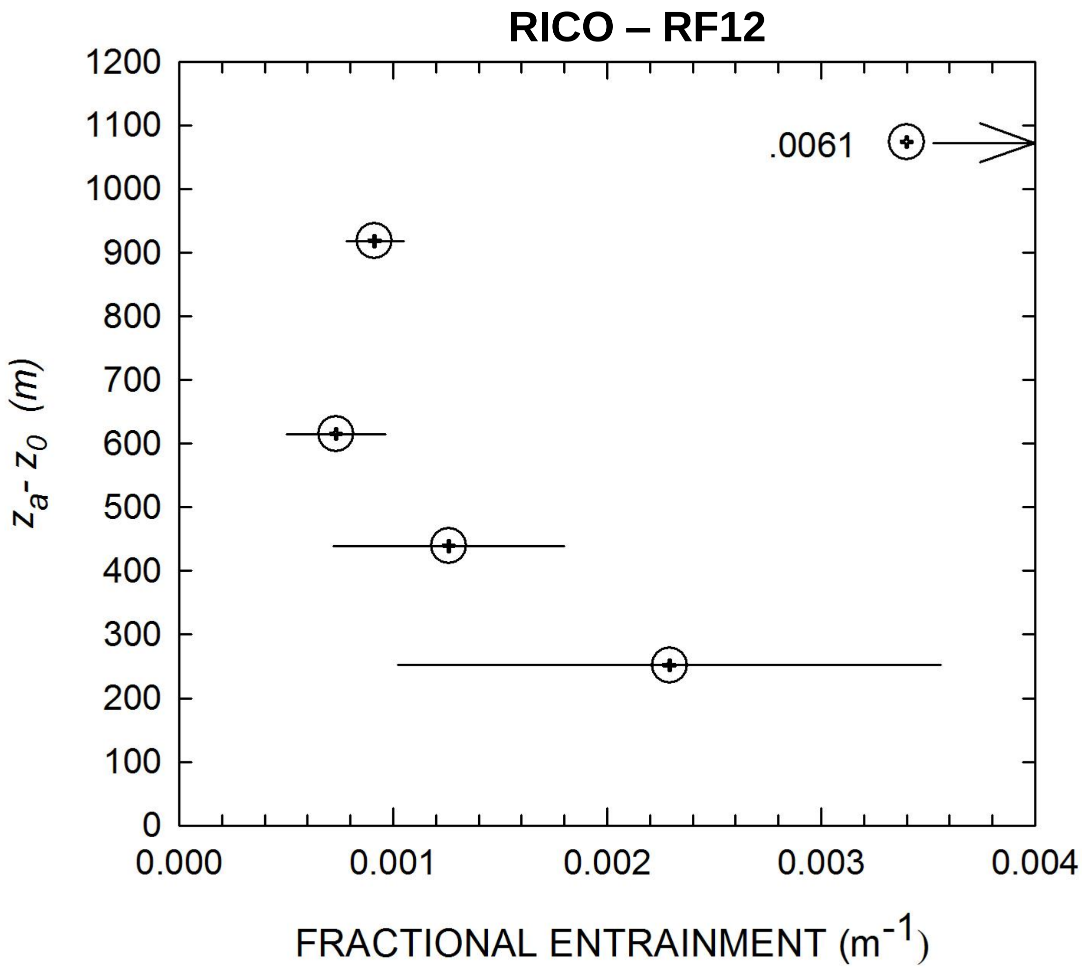
POST



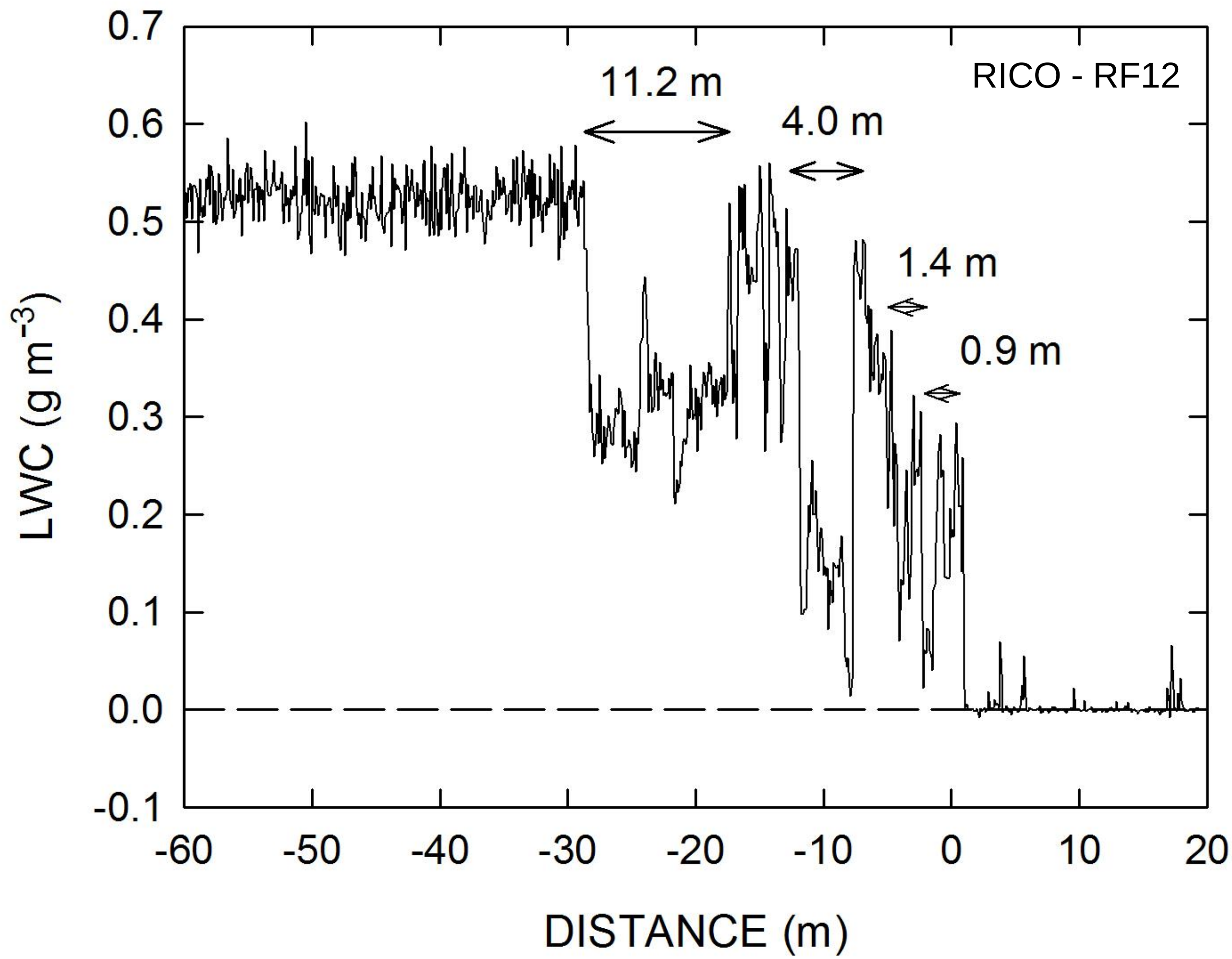
RICO (Rain in Cumulus Over the Ocean)

LATERAL FRACTIONAL ENTRAINMENT

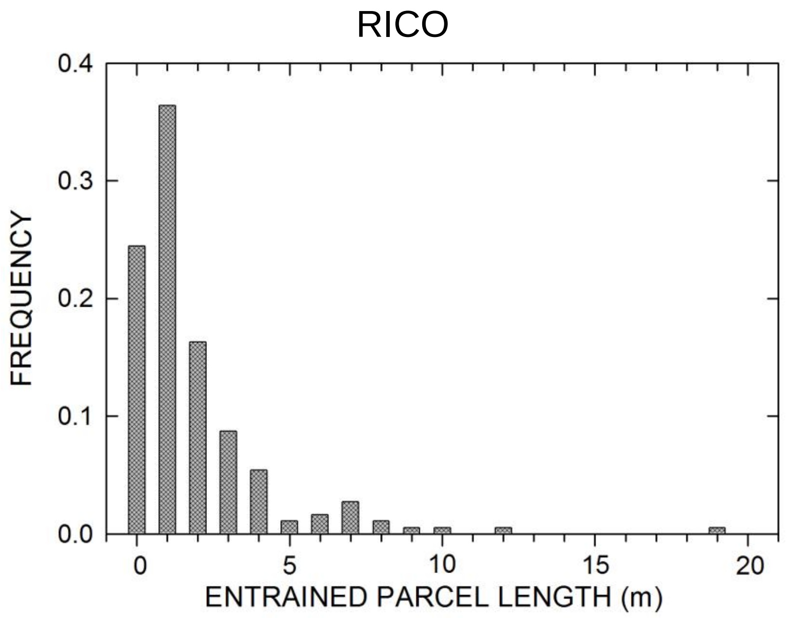


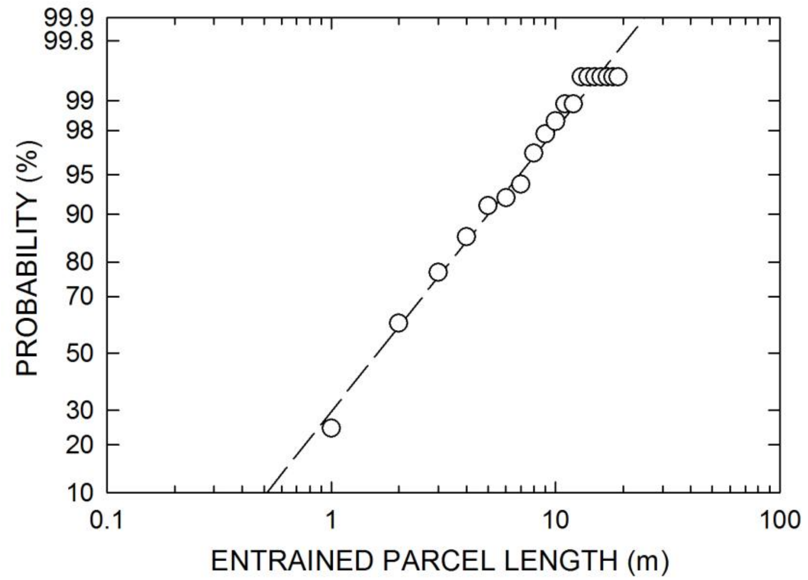


ENTRAINMENT SCALES



ENTRAINMENT SCALES



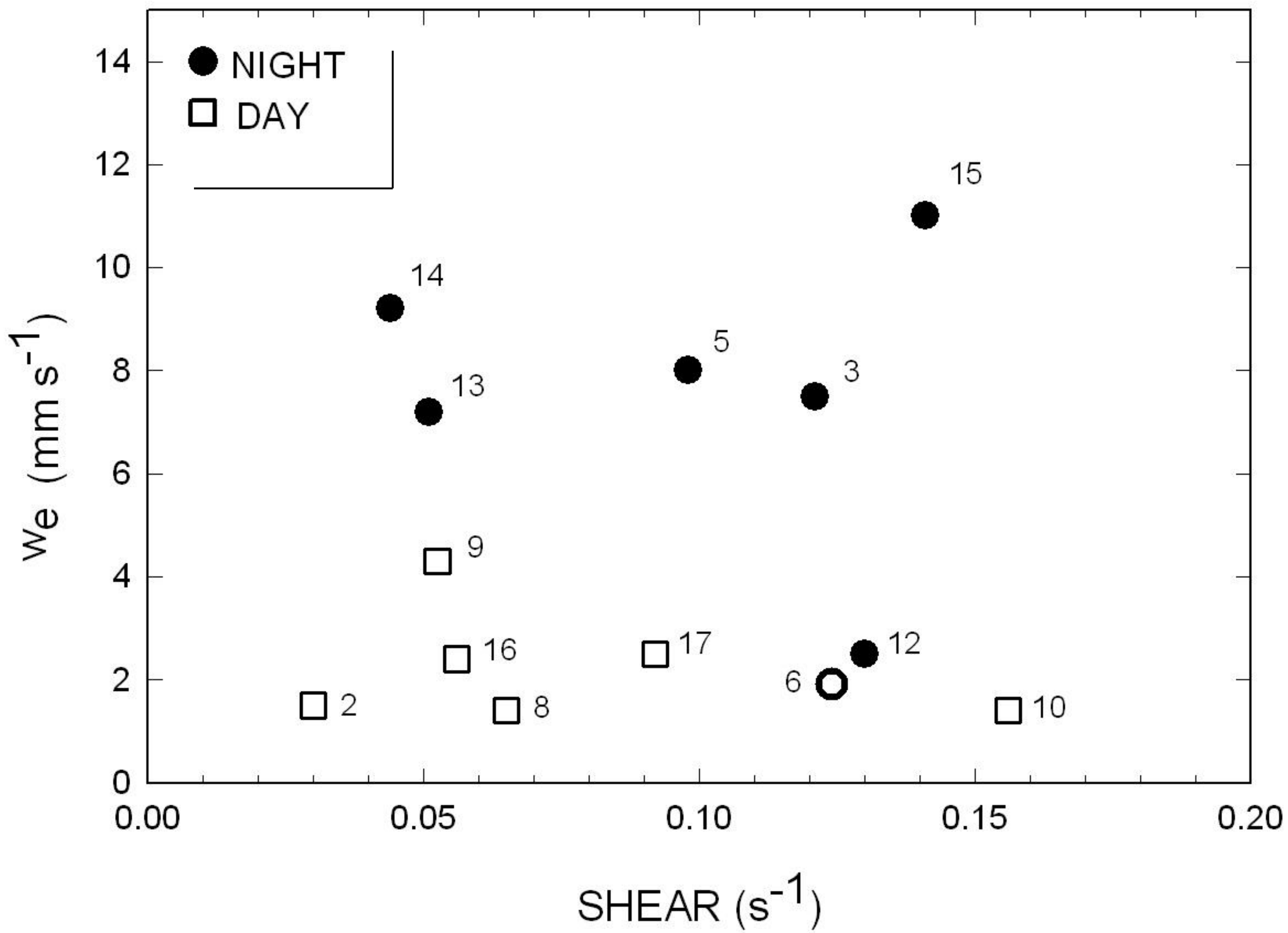


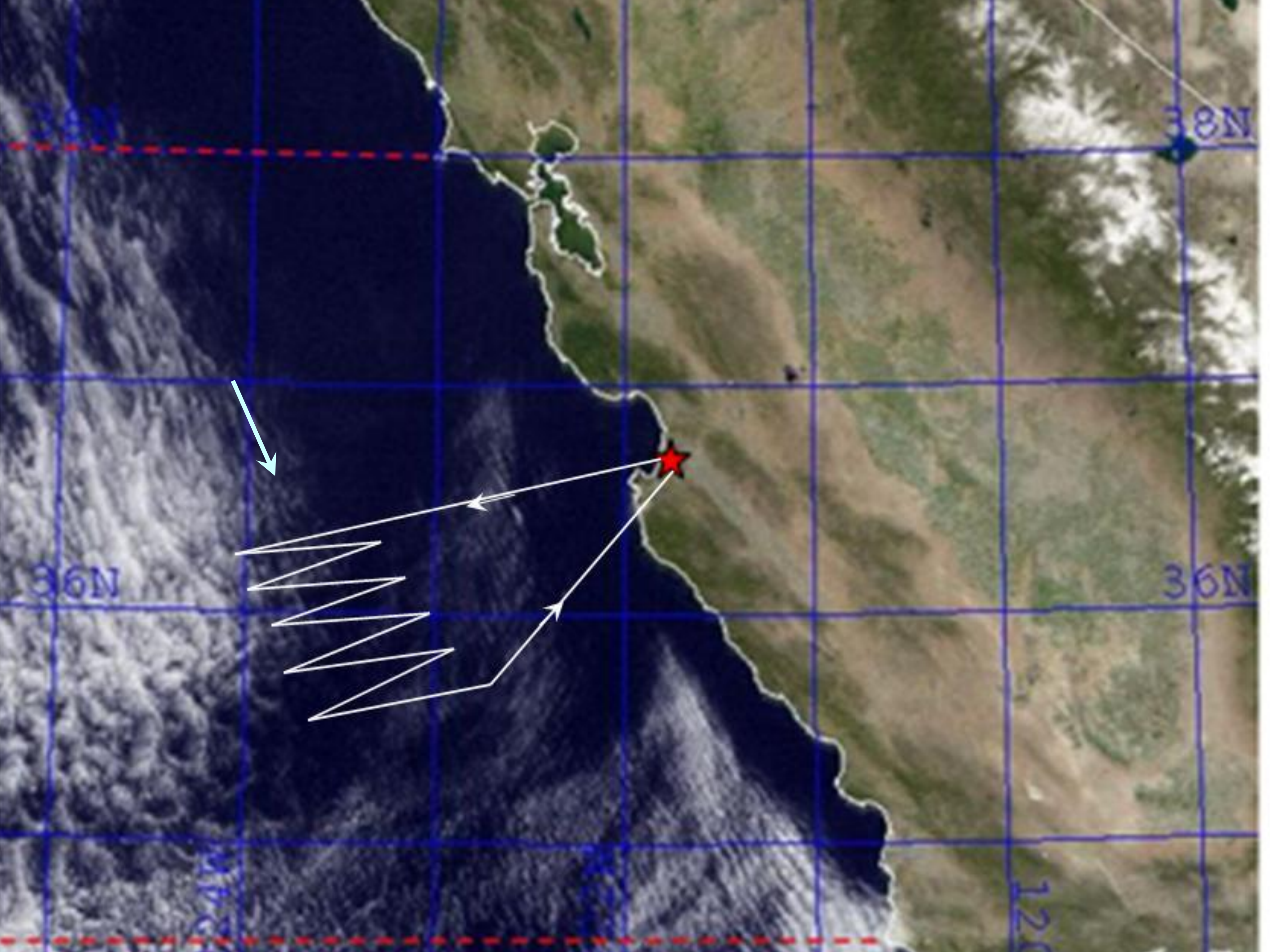
TO MAKE ENTRAINMENT PROGRESS:

- Understand Physical Processes
- Parameterize Fine Scale Processes
- Compare LES With Observations
- Conduct Additional Aircraft Campaigns

(http://www.gerberscience.com/writings.html)

Extras follow


NIGHT
DAY
15
14
5
3
13
9
16
17
12
6
2
8
10
14
12
10
8
6
4
2
0
0.00
0.05
0.10
0.15
0.20
We (mm s-1)
SHEAR (s-1)



38N
36N
36N

ENTRAINMENT: JUMP-METHOD ASSUMPTIONS

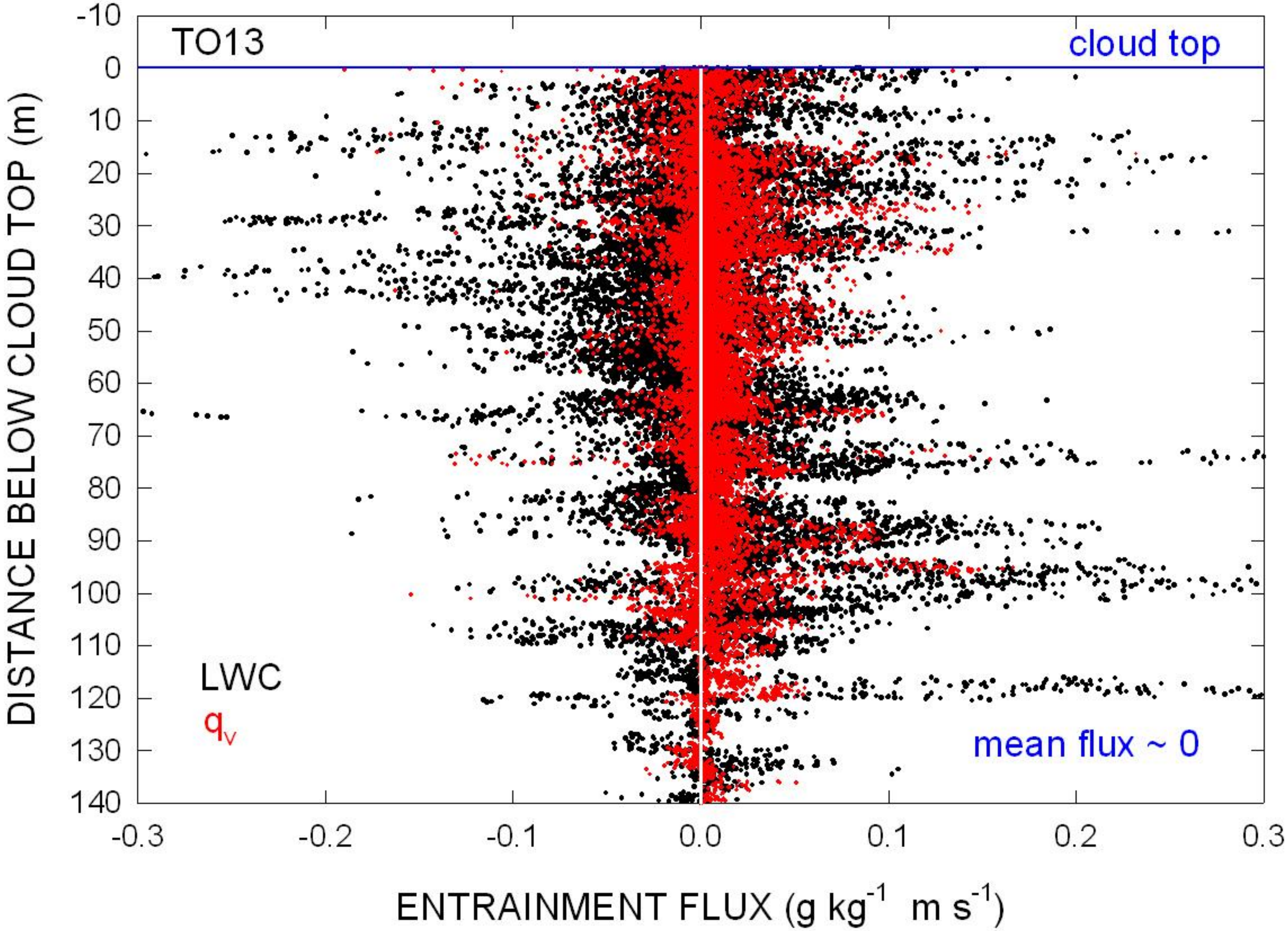
#1 Entrainment air descends

#2 Entrainment fluxes are linear with height

#3 Jump thickness above cloud top is small

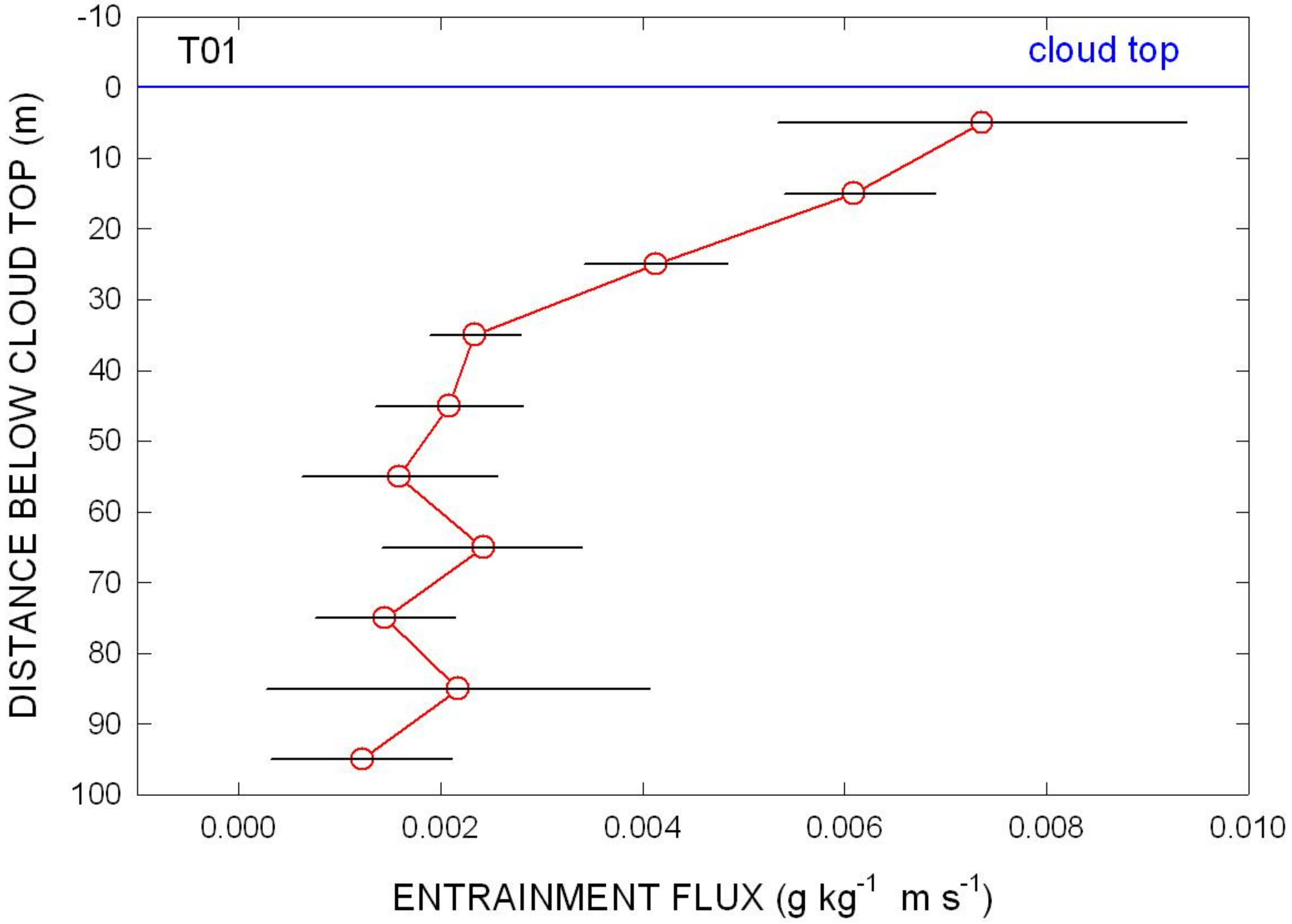
#1

Mean Flux ~ 0



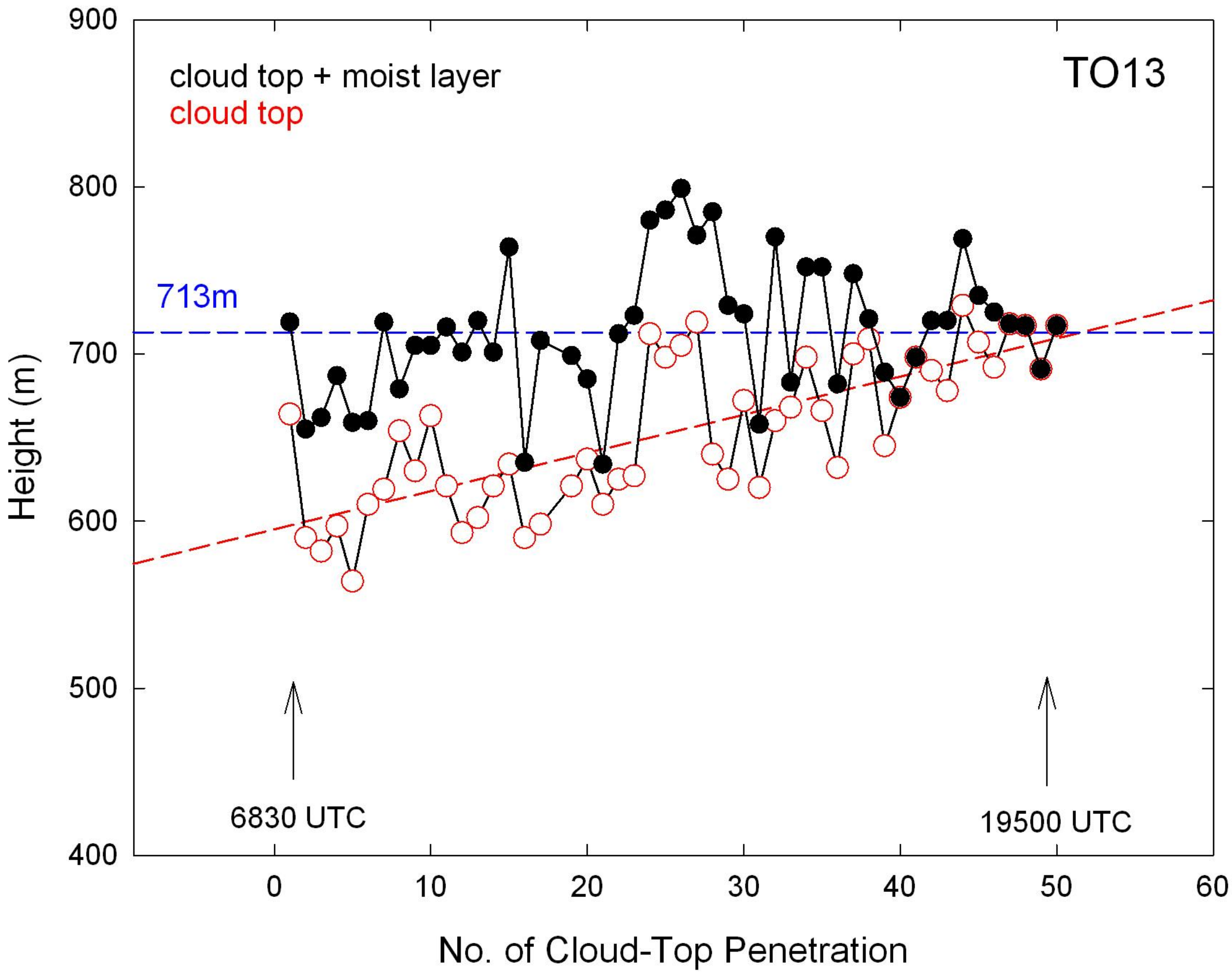
TO13
cloud top
LWC
q_v
mean flux ~ 0
DISTANCE BELOW CLOUD TOP (m)
ENTRAINMENT FLUX (g kg^{-1} m s^{-1})
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3

#2



T01
cloud top
-10
0
10
20
30
40
50
60
70
80
90
100
DISTANCE BELOW CLOUD TOP (m)
0.000
0.002
0.004
0.006
0.008
0.010
ENTRAINMENT FLUX (g kg-1 m s-1)

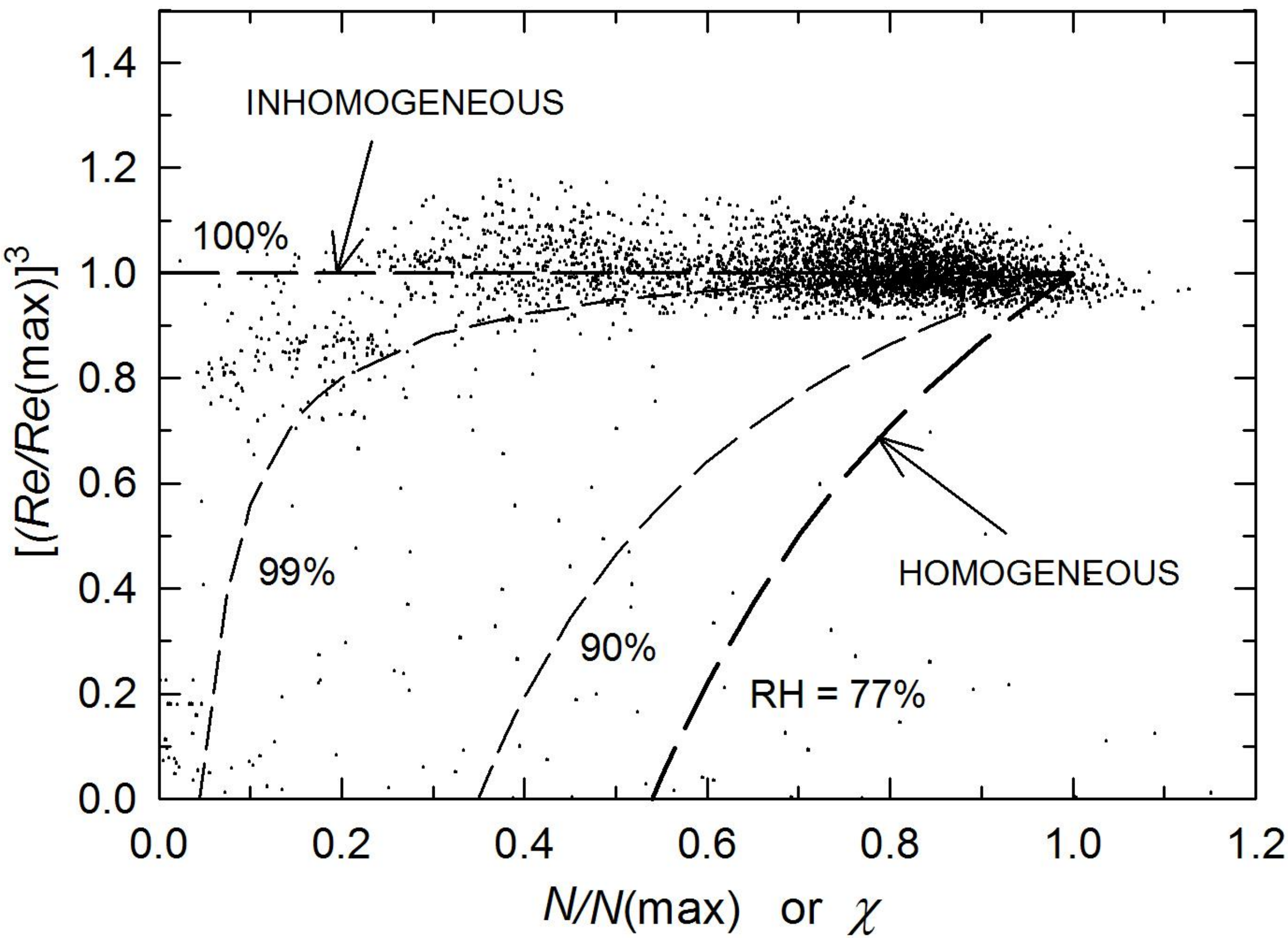
#3



cloud top + moist layer
cloud top
TO13
713m
Height (m)
900
800
700
600
500
400
0
10
20
30
40
50
60
6830 UTC
19500 UTC
No. of Cloud-Top Penetration

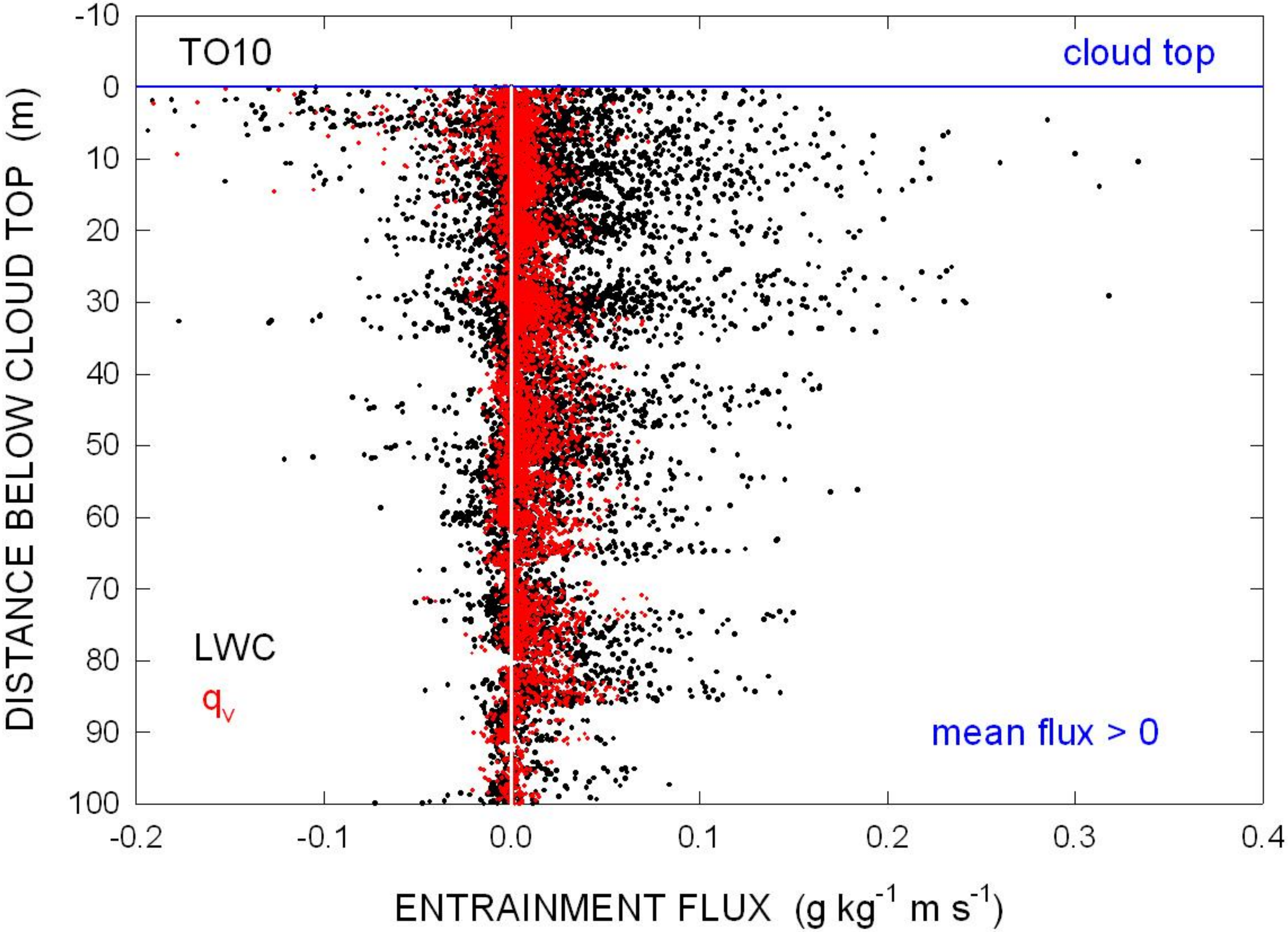
$$w_e = \frac{A_1}{A_1 + A_2}\frac{< w' \times q_T' >}{\Delta q_T} = \overset{\mathbf{A}}{A_r}\,\frac{< w' \times [(\overset{\mathbf{B}}{LWC'}/\rho) + \overset{\mathbf{C}}{q_v'}] >}{\underset{\mathbf{D}}{\Delta q_T}}$$

(Nicholls, S., 1989: *Q.J.R.M.S*., **115**, 487-511)

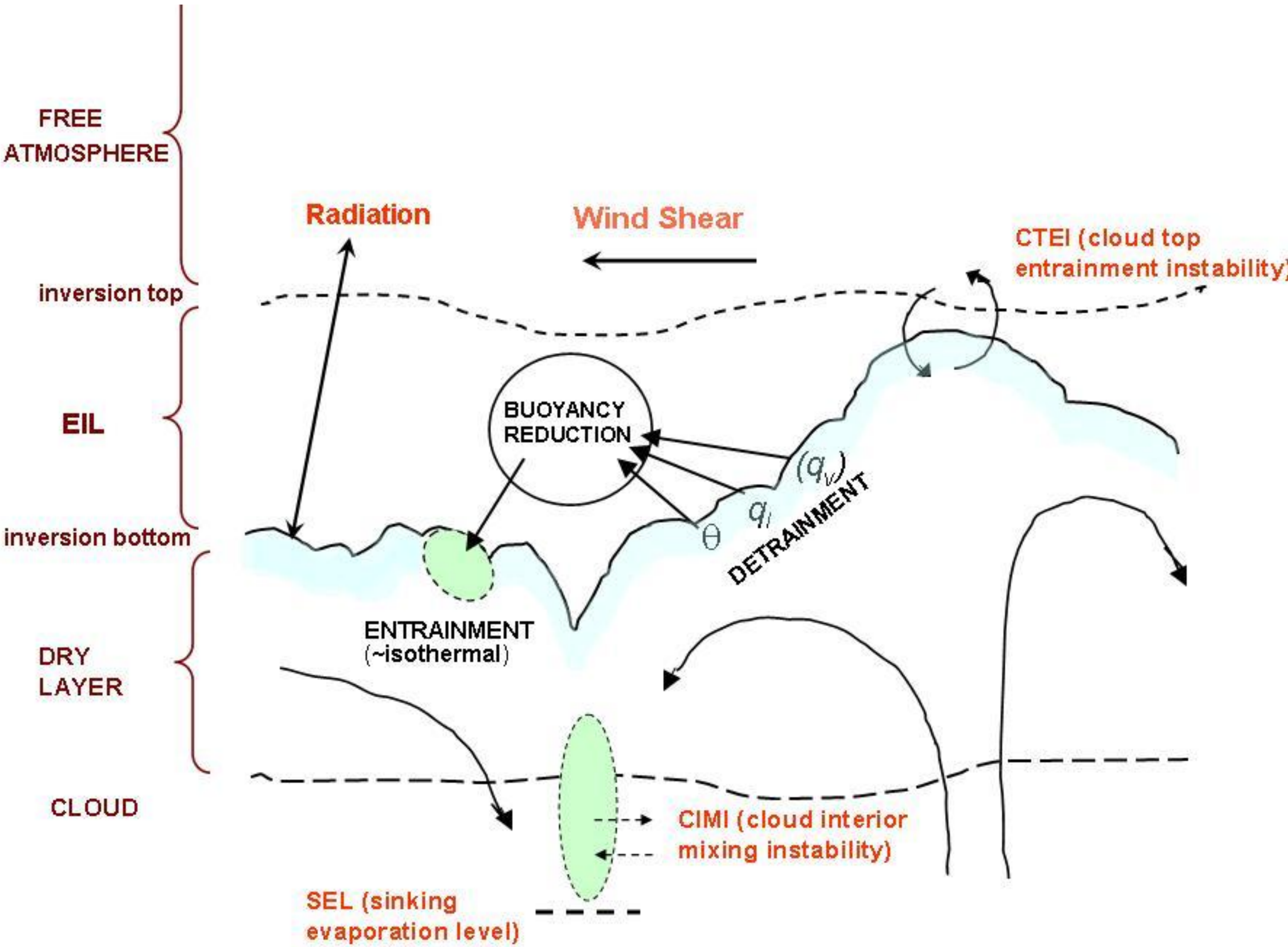


INHOMOGENEOUS
100%
99%
90%
RH = 77%
HOMOGENEOUS
[(Re/Re(max)]^3
N/N(max) or χ
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Mean Flux > 0



TO10
cloud top
mean flux > 0
LWC
q_v
DISTANCE BELOW CLOUD TOP (m)
ENTRAINMENT FLUX (g kg^{-1} m s^{-1})
-10
0
10
20
30
40
50
60
70
80
90
100
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4



Krueger, 1993: J.Atmos. Sci., 50, 3078-3090.
Wang and Albrecht, 1994: J.Atmos. Sci., 51,1530-1547.