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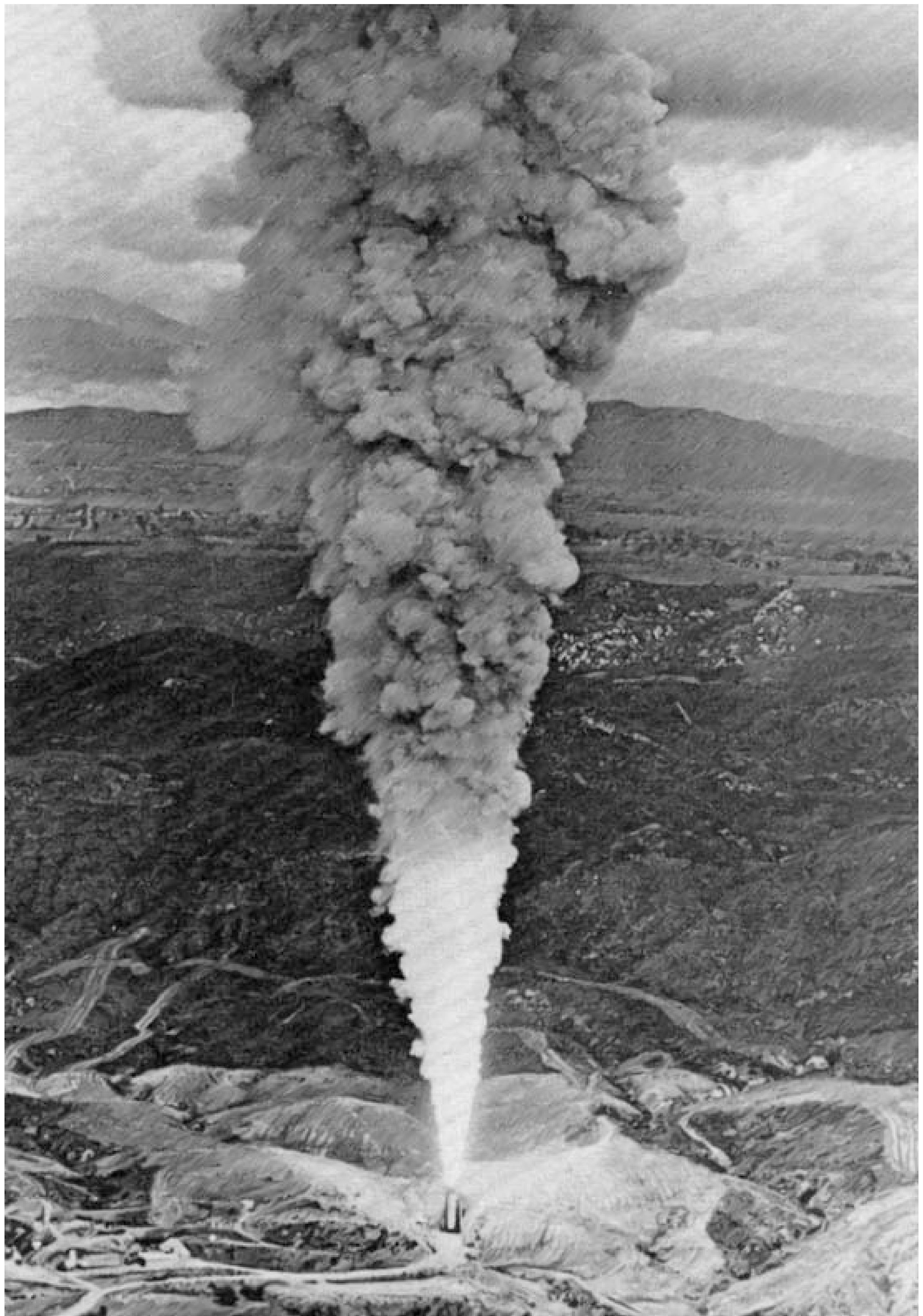
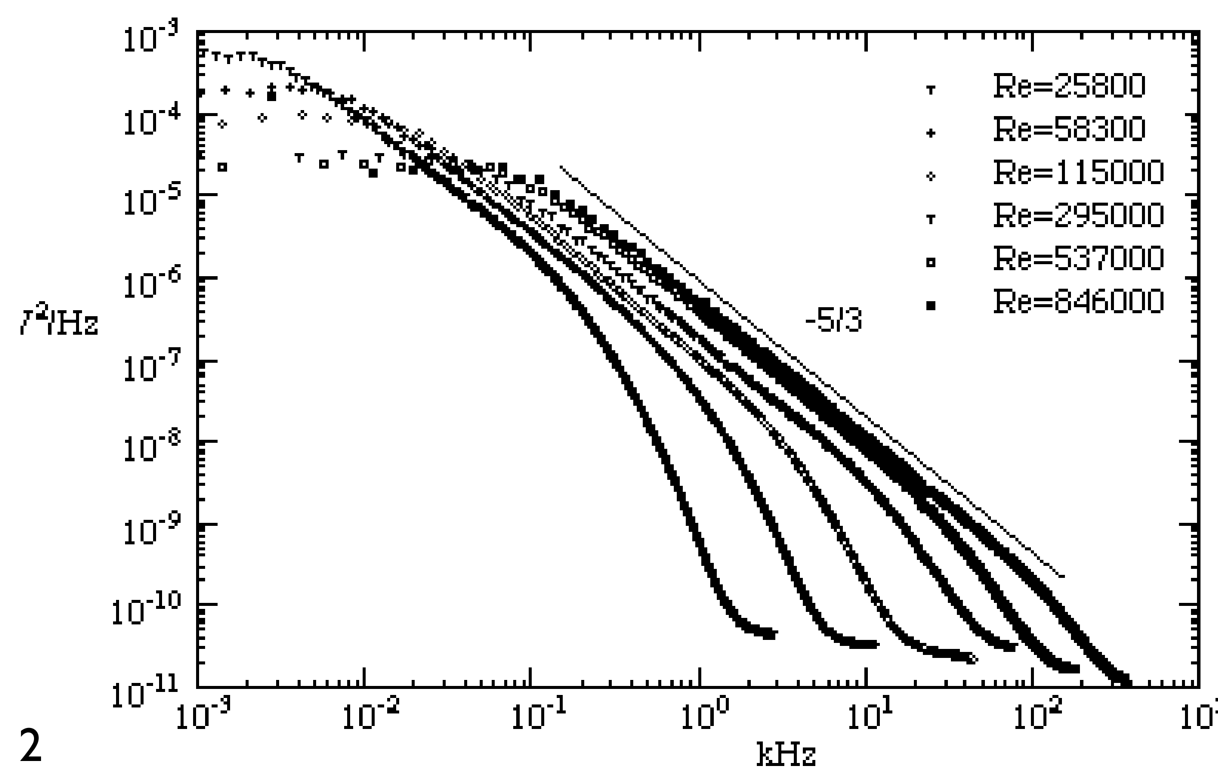
IMAGe-3 Nov 4 2005

Large Eddy Simulation: Estimation, Attribution, Exploration

what is large eddy simulation?



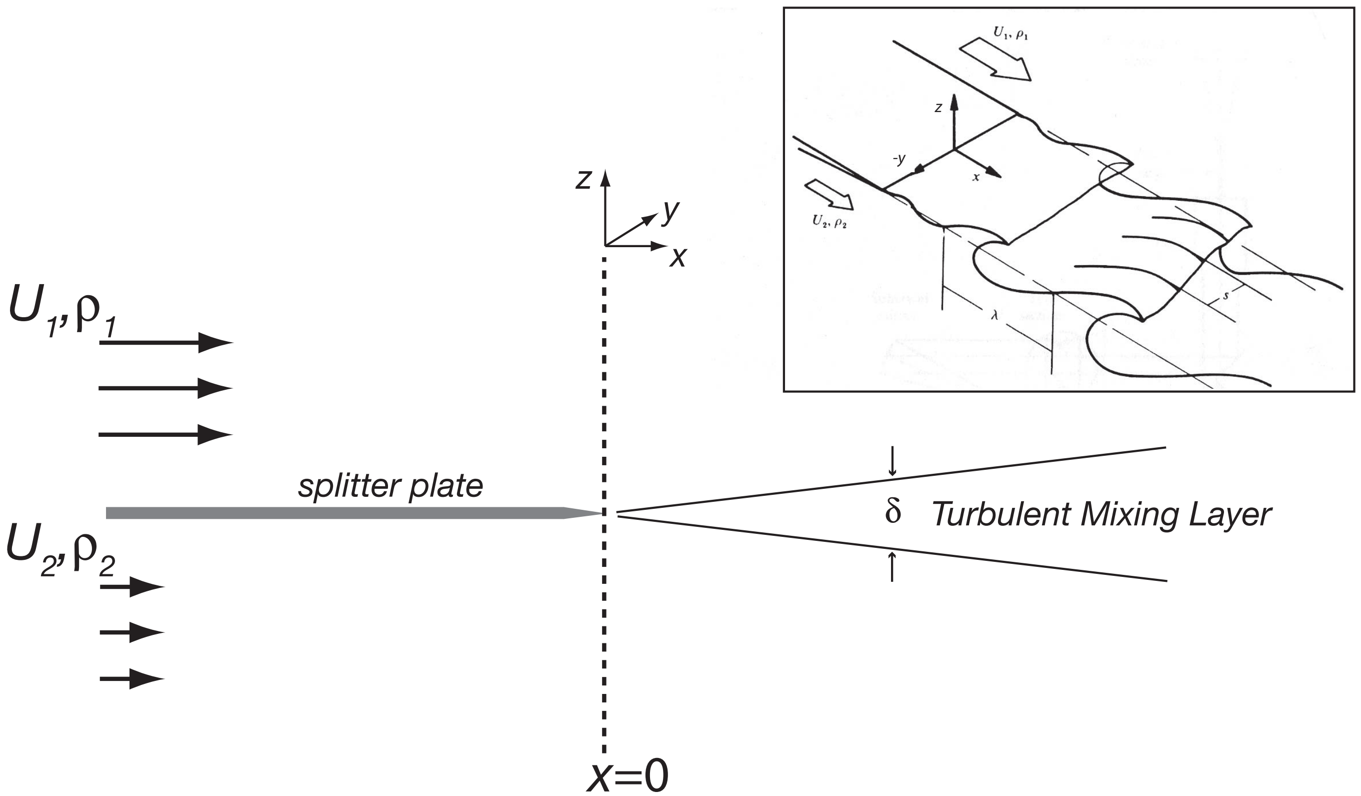
- A religion?
- Three-dimensional flows whose smallest cut-off/ filter scale is within a well developed inertial range of three dimensional turbulence.
- A flow realized in a manner which converges to Navier-Stokes (DNS) as the grid spacing of the solver that produces it goes to zero (auxillary condition)
- Compare to Eddy-Permitting simulations.



caveats?

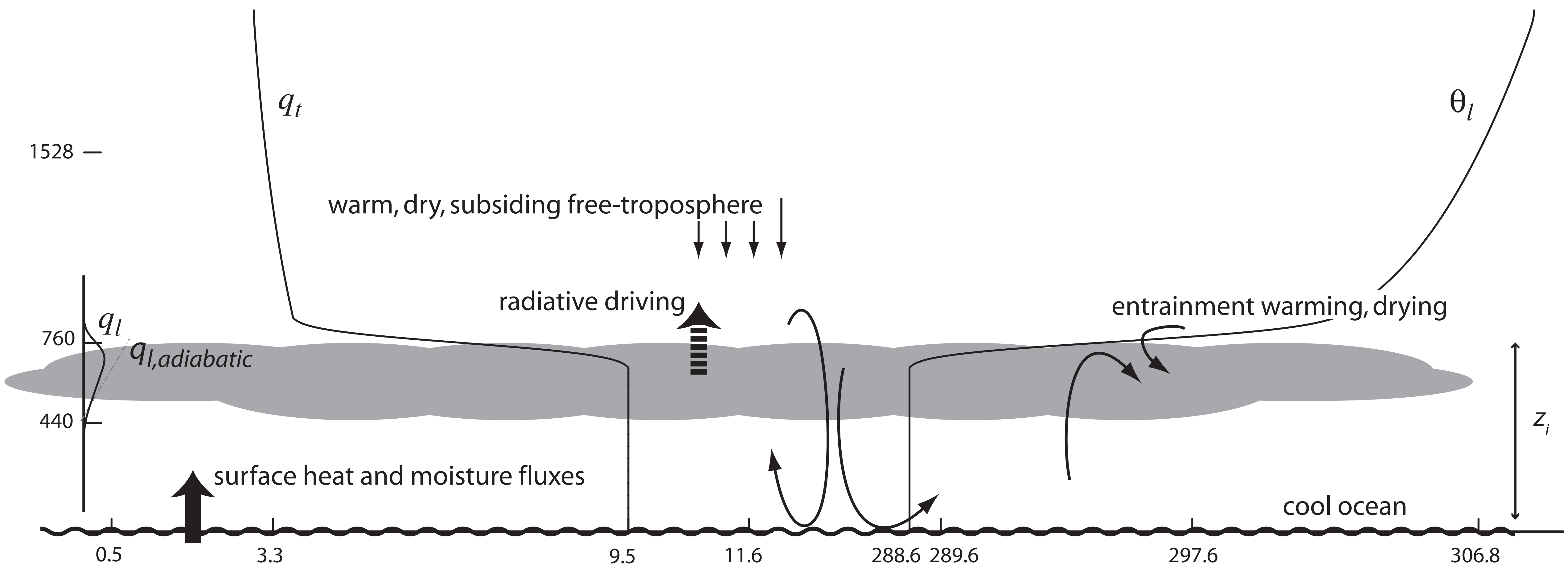
- Notwithstanding the phenomenological theories, closures that properly mediate the cascade have proven elusive.
- Most flows of interest are bounded, and interact with their boundaries in interesting, and important ways... and calculations are always under-resolved at boundaries.
- Stratification.
- Tests on flows of interest are almost always impossible.

what is it good for?
(i) parameter estimation



- Pseudoempiricism...
- The spreading angle of the mixing layer.
- Partitioning of energy among velocity components.
- Similarity profile of downstream velocity.

*my pet problem**



*(not nearly so important as deep convection ...)

Recall from last time, the bulk equation may be written as

$$h\frac{D\widehat{\phi}}{Dt} - \Delta_+\phi\left[\frac{Dh}{Dt} + \mathcal{D}h\right] = -\Delta\overline{w'\phi'} - \Delta F_\phi \quad (1)$$

Defining,

$$V \equiv -\frac{\overline{w'\phi'}_0}{\Delta_0\phi}, \quad M \equiv -\frac{\overline{w'\phi'}_+}{\Delta_+\phi} \quad \text{and} \quad E \equiv \frac{Dh}{Dt} + \mathcal{D}h + M \quad (2)$$

yields

$$\frac{Dh}{Dt} = E - \mathcal{D}h - M \quad (3)$$

$$\frac{D\widehat{s}}{Dt} = \frac{E(q_+ - \widehat{q}) - V(\widehat{q} - q_0) - \Delta F_s}{h} \quad (4)$$

$$\frac{D\widehat{q}}{Dt} = \frac{E(q_+ - \widehat{q}) - V(\widehat{q} - q_0) - -\Delta F_q}{h} \quad (5)$$

Given the large-scale flow $(\mathcal{D}, s_+, q_+)$, surface properties, s_0, q_0 and F_s, F_q, as a function of the state, closure requires a specification of M, V, E.

the stratocumulus question

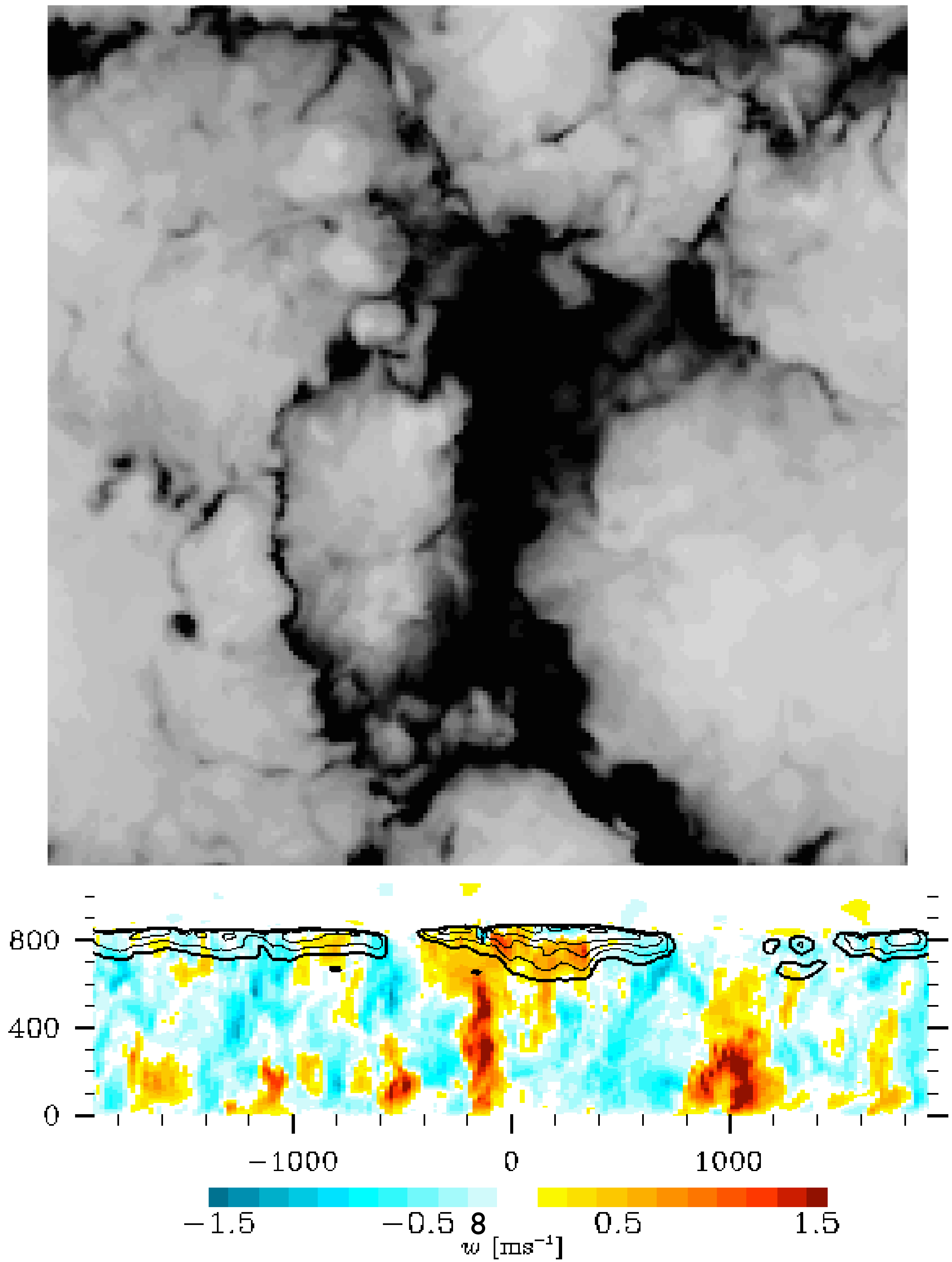
If

$$M = 0 \quad \text{and} \quad V = C_d \|\mathbf{v}\|$$

and

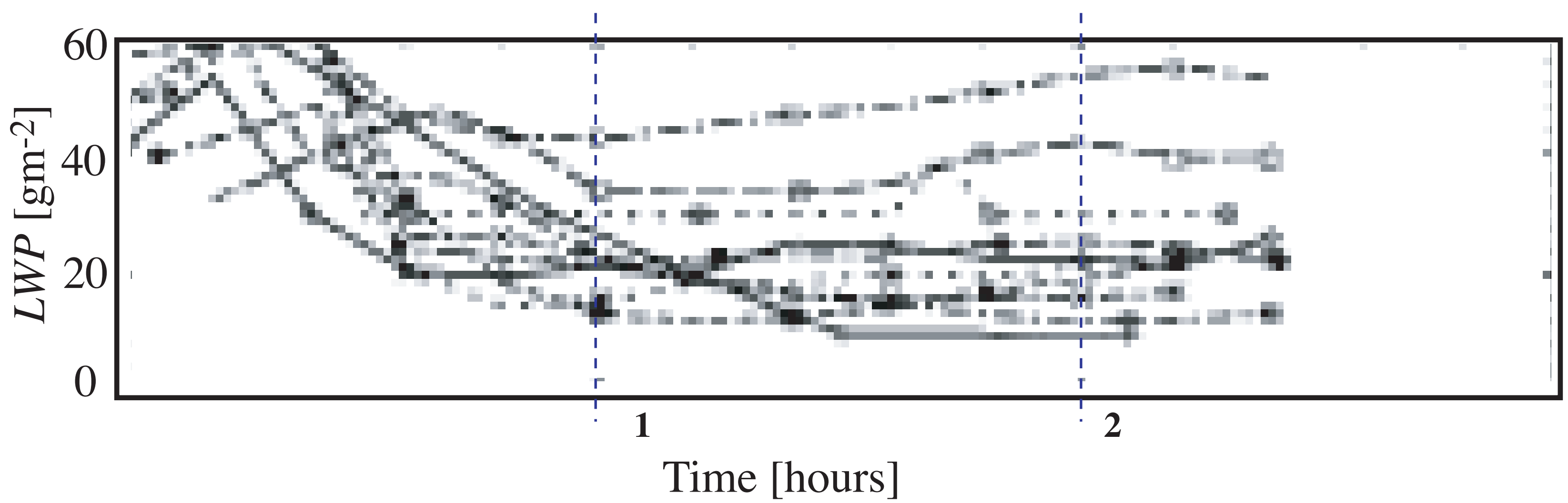
$$E = \alpha \frac{\Delta F_s}{s_+ - \widehat{s}}$$

what is alpha?

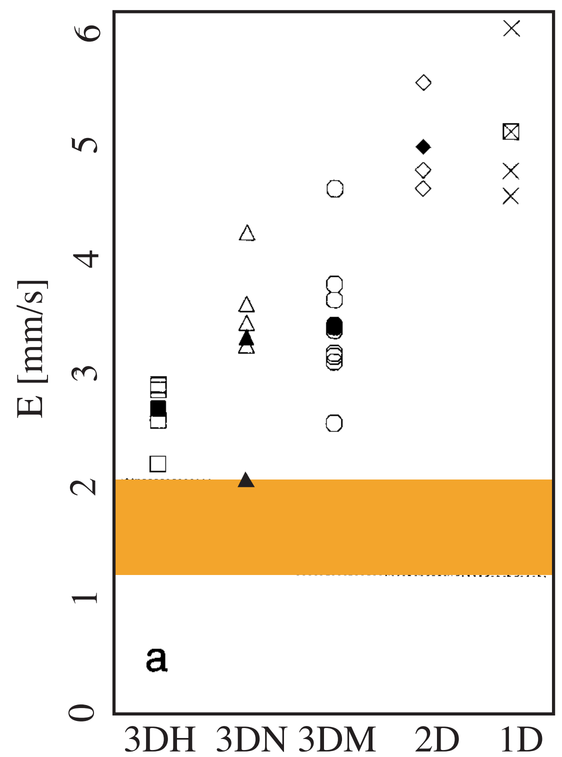

800
400
0
−1000
0
1000
−1.5
−0.5
0.5
1.5
w [ms⁻¹]

woops...

Table 4. The averaged growth rate of the cloud-top height during the second hour of simulation	
Group	*E*
KNMI	1.68
UOK	1.32
UMIST	0.94
NCAR	0.91
UKMO	0.86
CSU	0.67
UW	0.51
MPI	0.44
WVU	0.28
ARAP	0.24



Moeng *et al., Bull. Amer. Meteorol. Soc.* (1996)



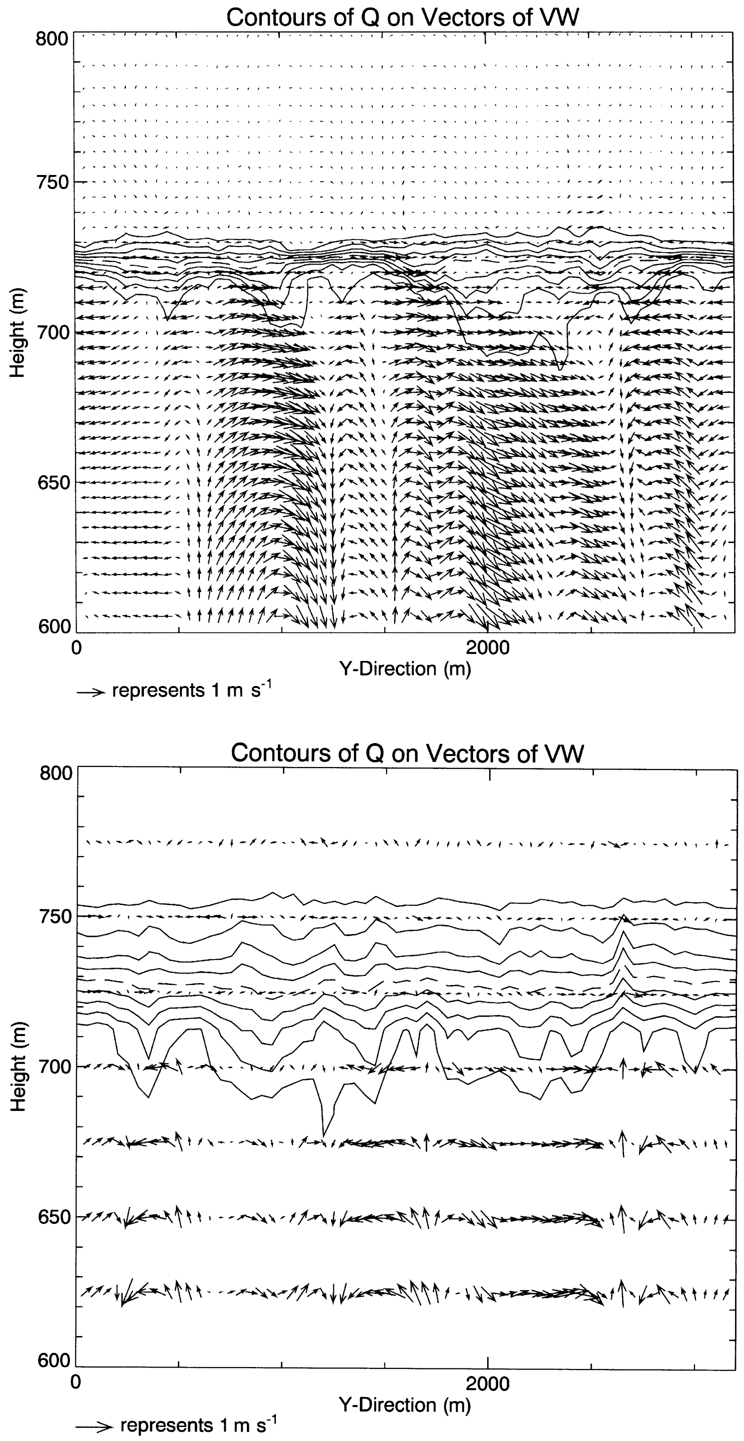
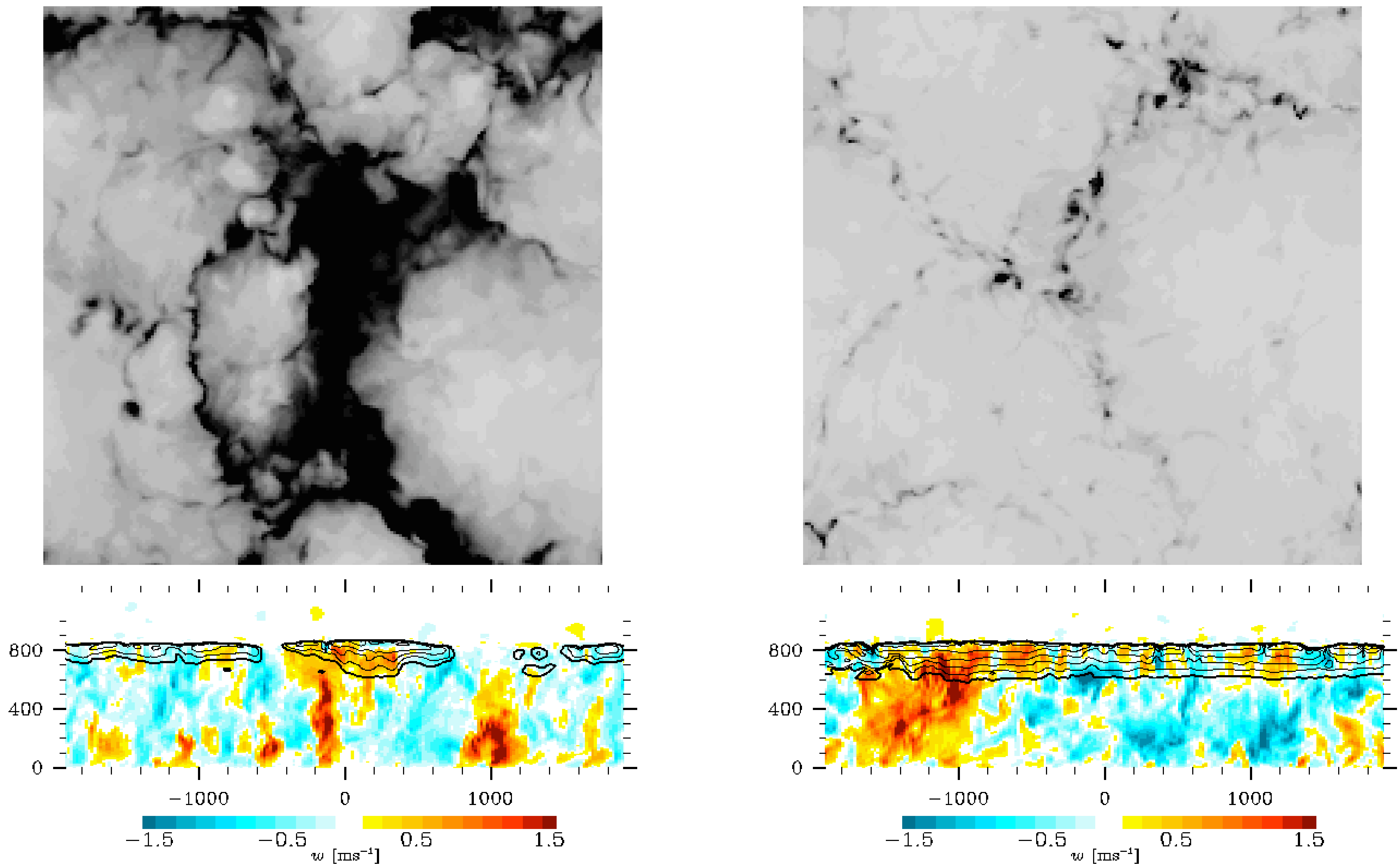


Figure 5. As Fig. 4, but using standard (25 m) vertical resolution.

Bretherton *et al., Quart. J. Roy. Meteorol. Soc.* (1998)


800
400
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1.5
w [ms⁻¹]
800
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0
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1000
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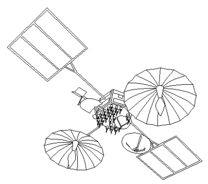
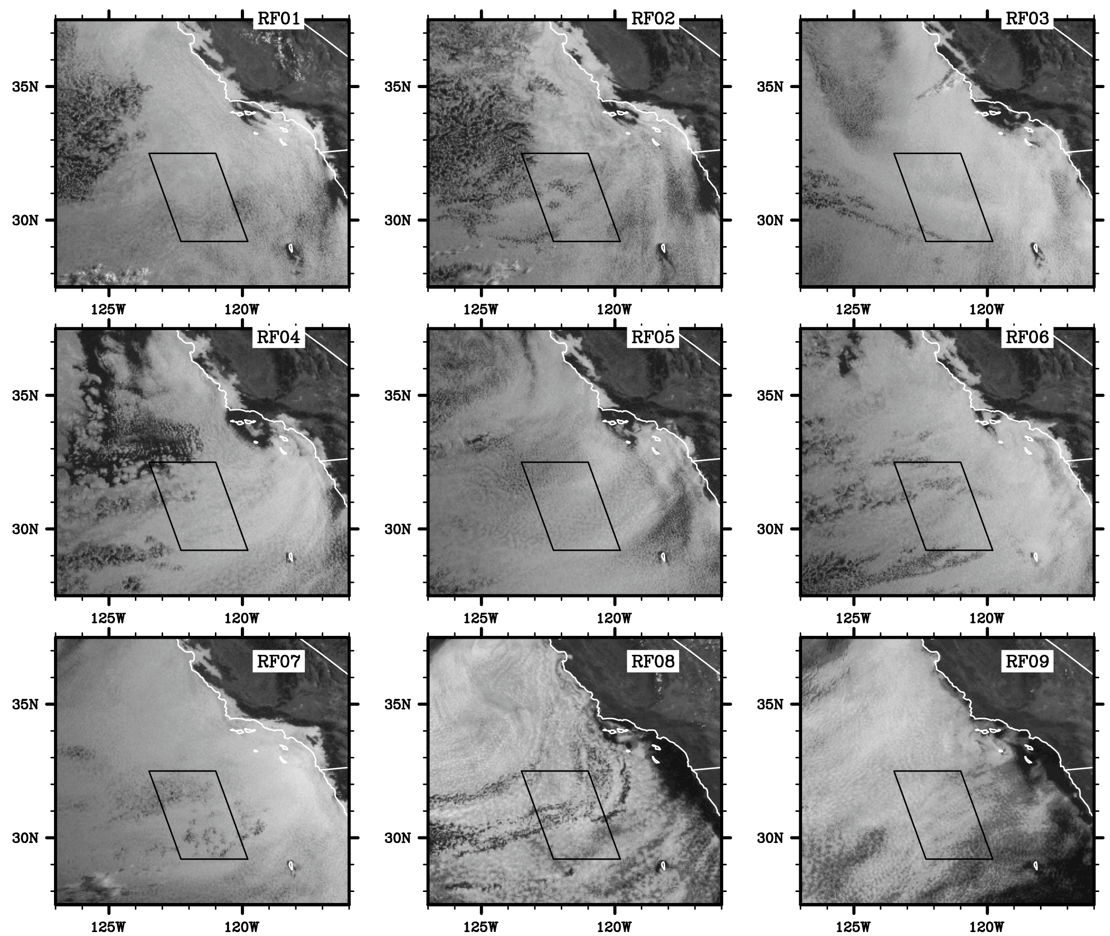
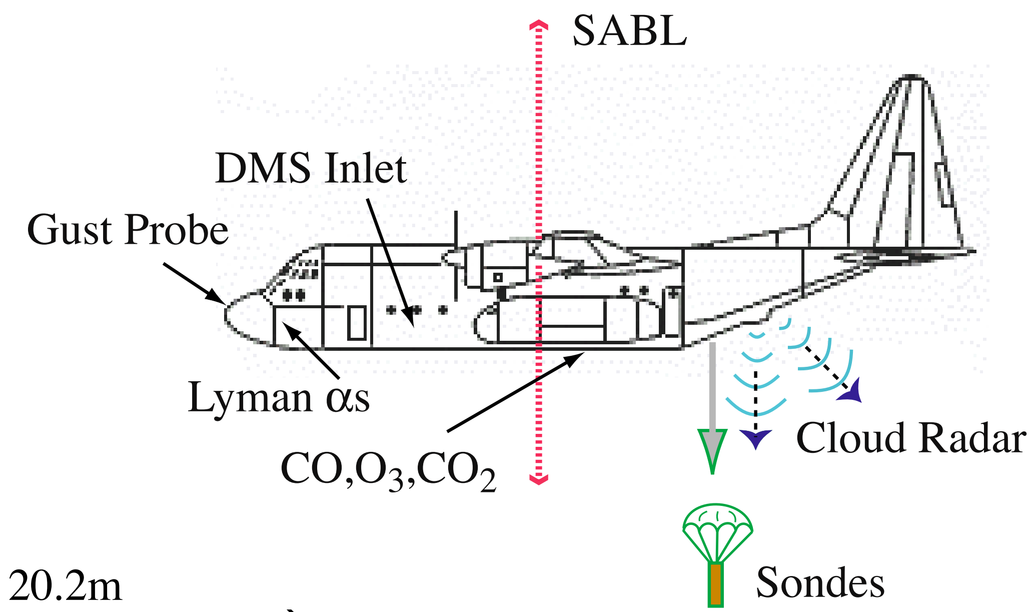
0.5
1.5
w [ms⁻¹]

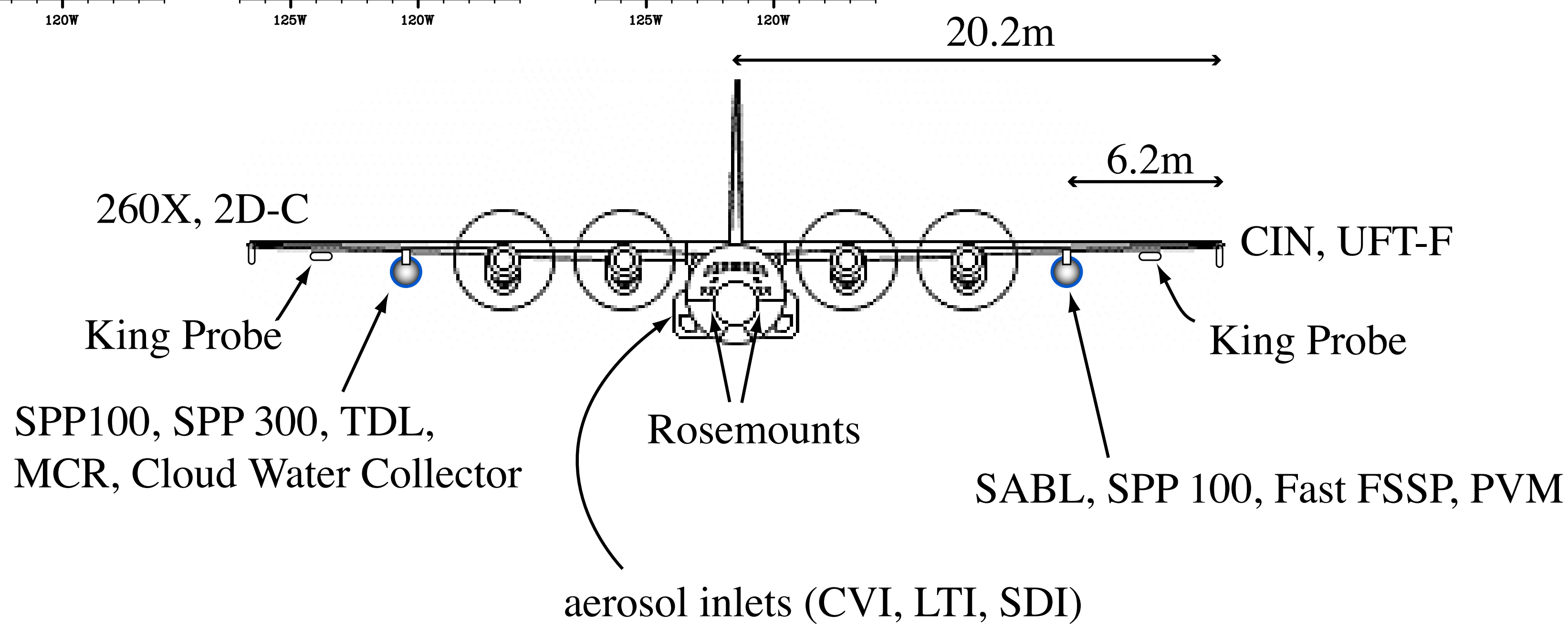
DYCOMS-II (July 2001): observing platforms

GOES, AVHRR, TRMM, QuickScat



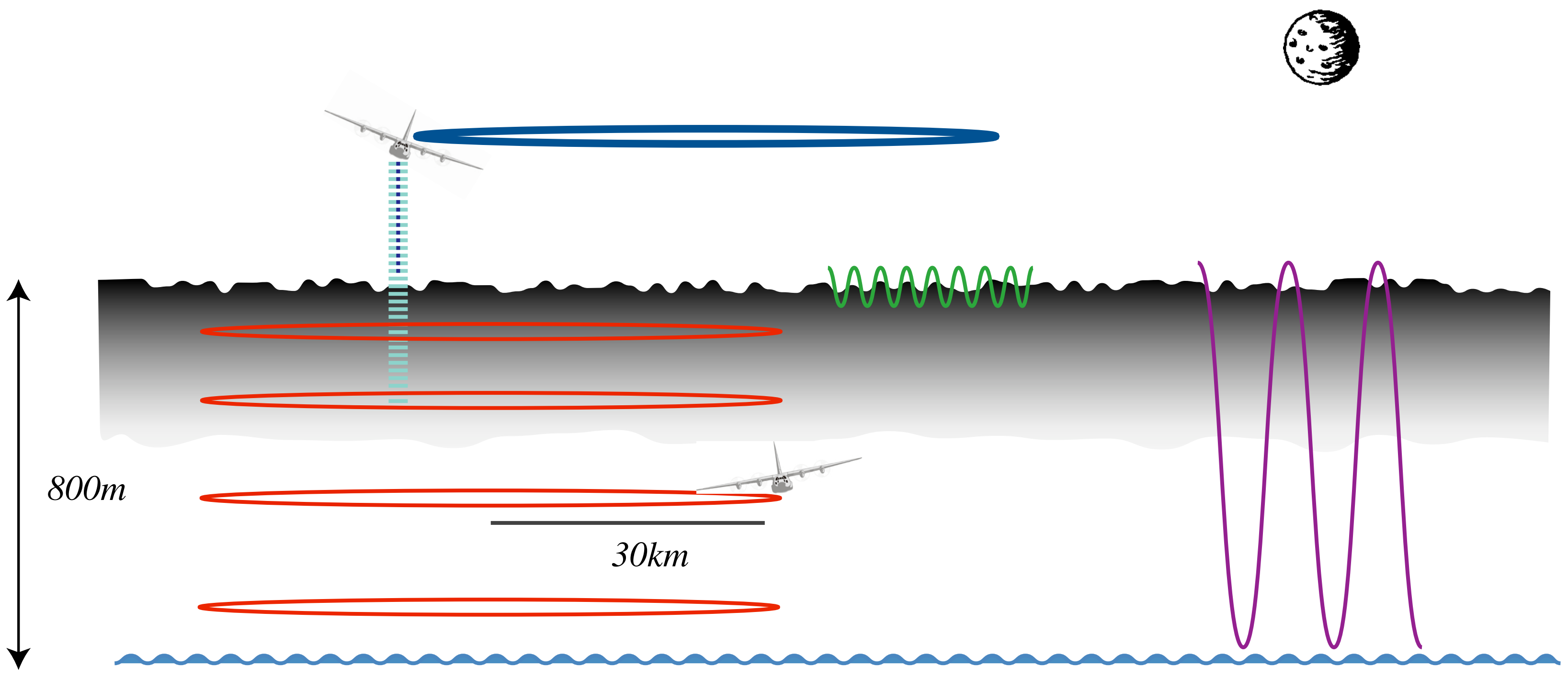


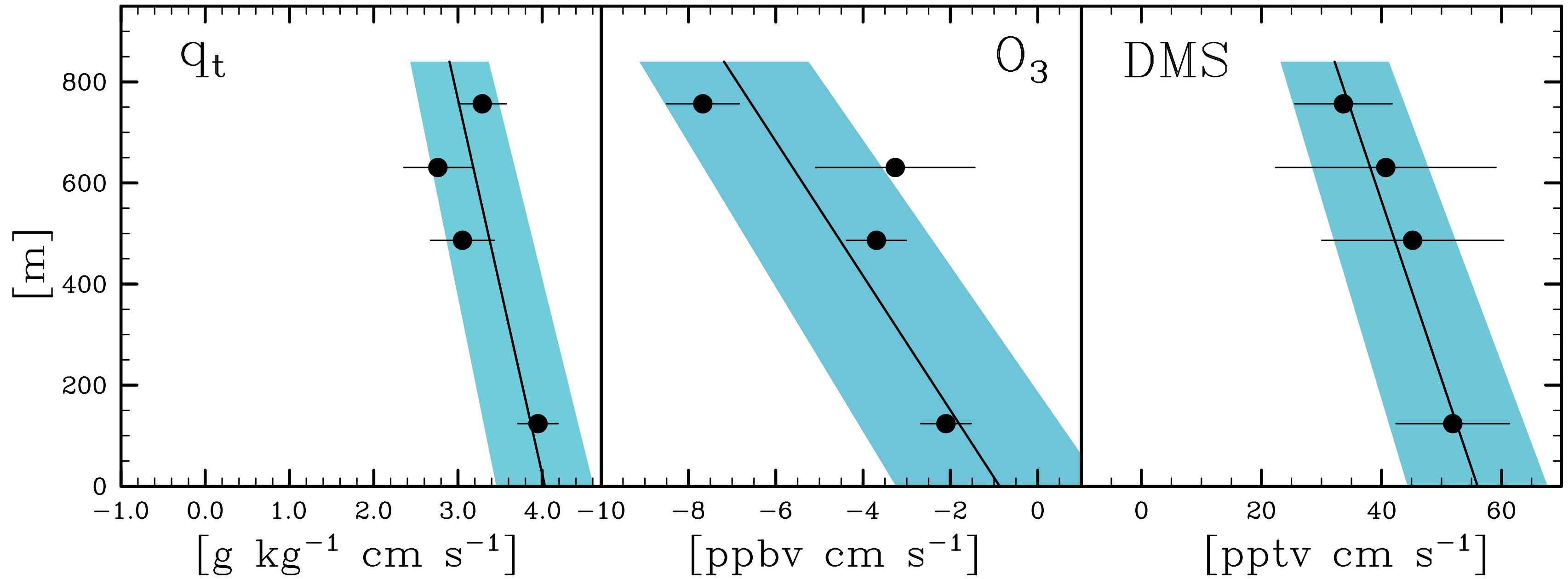




adapted from Stevens et al., (2003)

DYCOMS-II (July 2001): flight strategy



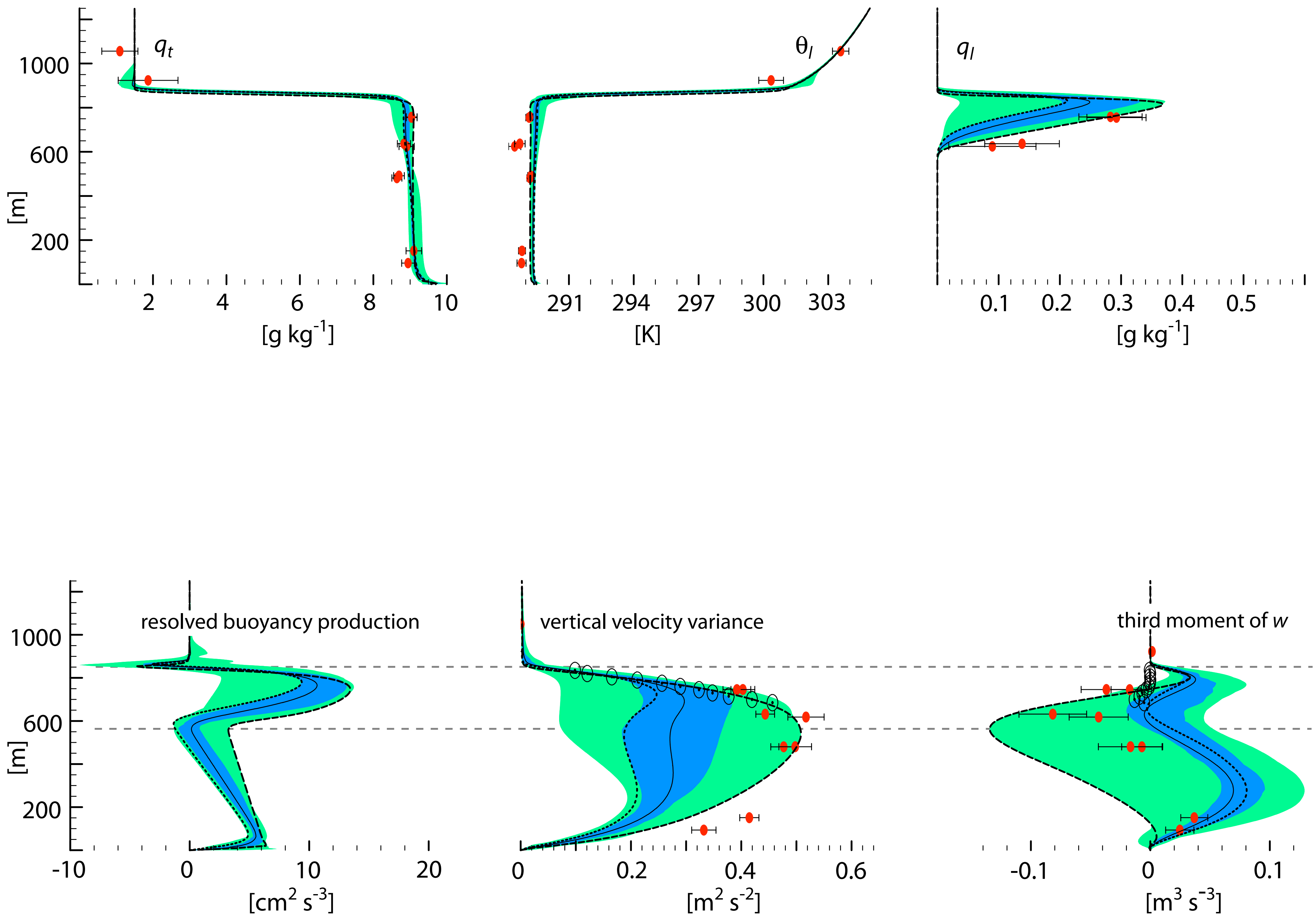


Method	Estimate [cm s^{-1}]
q_t budget	0.31 ± 0.08
s_l budget	0.47 ± 0.08
q_t cloud-top flux	0.39 ± 0.06
O_3 cloud-top flux	0.31 ± 0.09
DMS cloud-top flux	0.53 ± 0.08
Weighted Average	0.40 ± 0.03

	Base Case		Test Cases		
Model	E	$E_{\Delta s_l=11}$	$E_{\Delta F=0}$	$E_{q_{t+}=5.0}$	$E_{SST=290.4}$
AL	0.23	0.20	0.08	0.21	0.16
CM	0.45	0.41	0.03	0.45	0.41
DL	0.56	0.46	0.18	0.40	0.43
NT ($a_2 = 60$)	0.81	0.65	0.36	0.59	0.54
NT ($a_2 = 30$)	0.57	0.46	0.25	0.43	0.38
LL $\eta = 0.25$	0.46	0.37	0.20	0.28	0.31

Stevens *et al.*, 2003, QJRMS.

LES evaluation using DYCOMS-II data

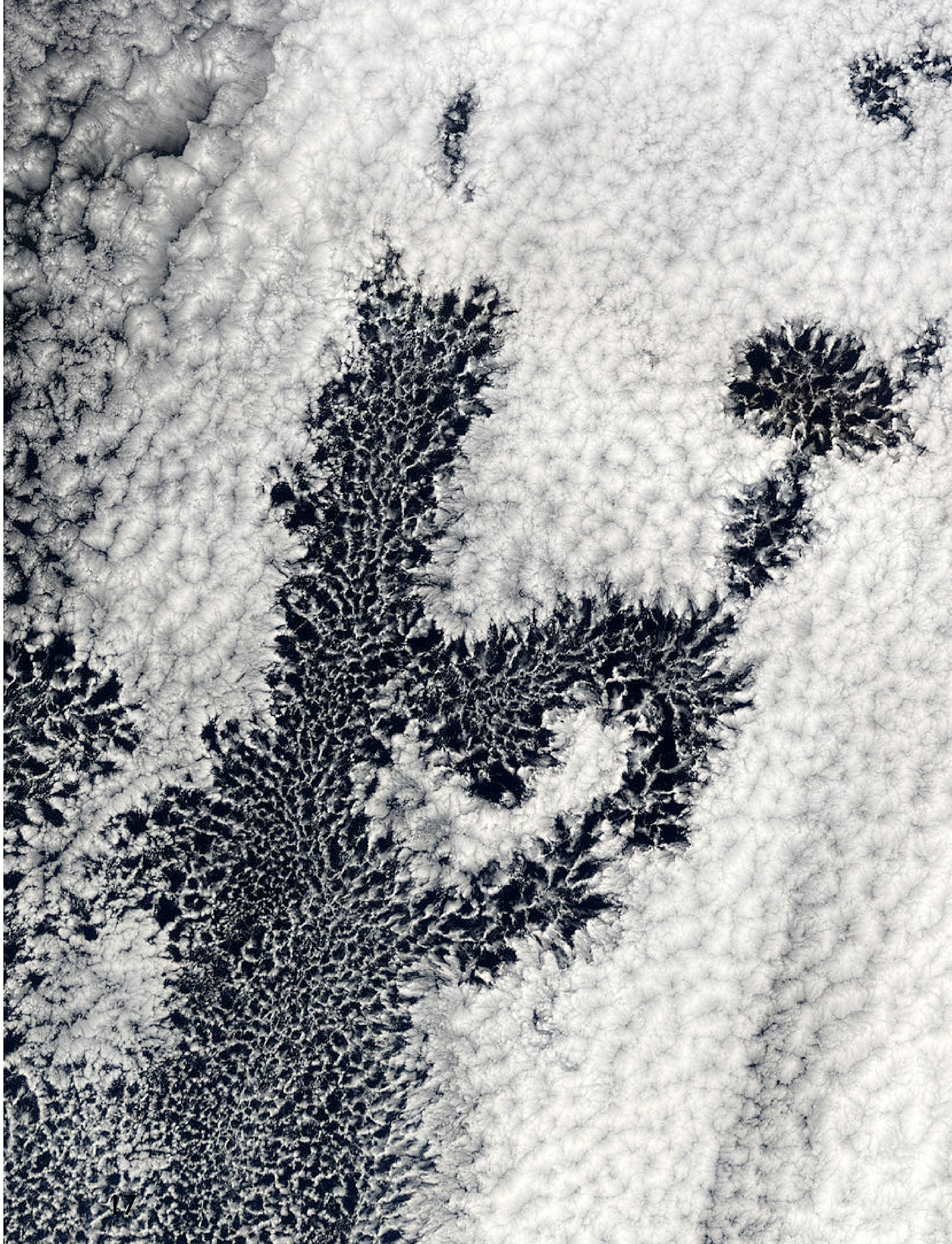


(stevens *et al.*, 2005, MWR)

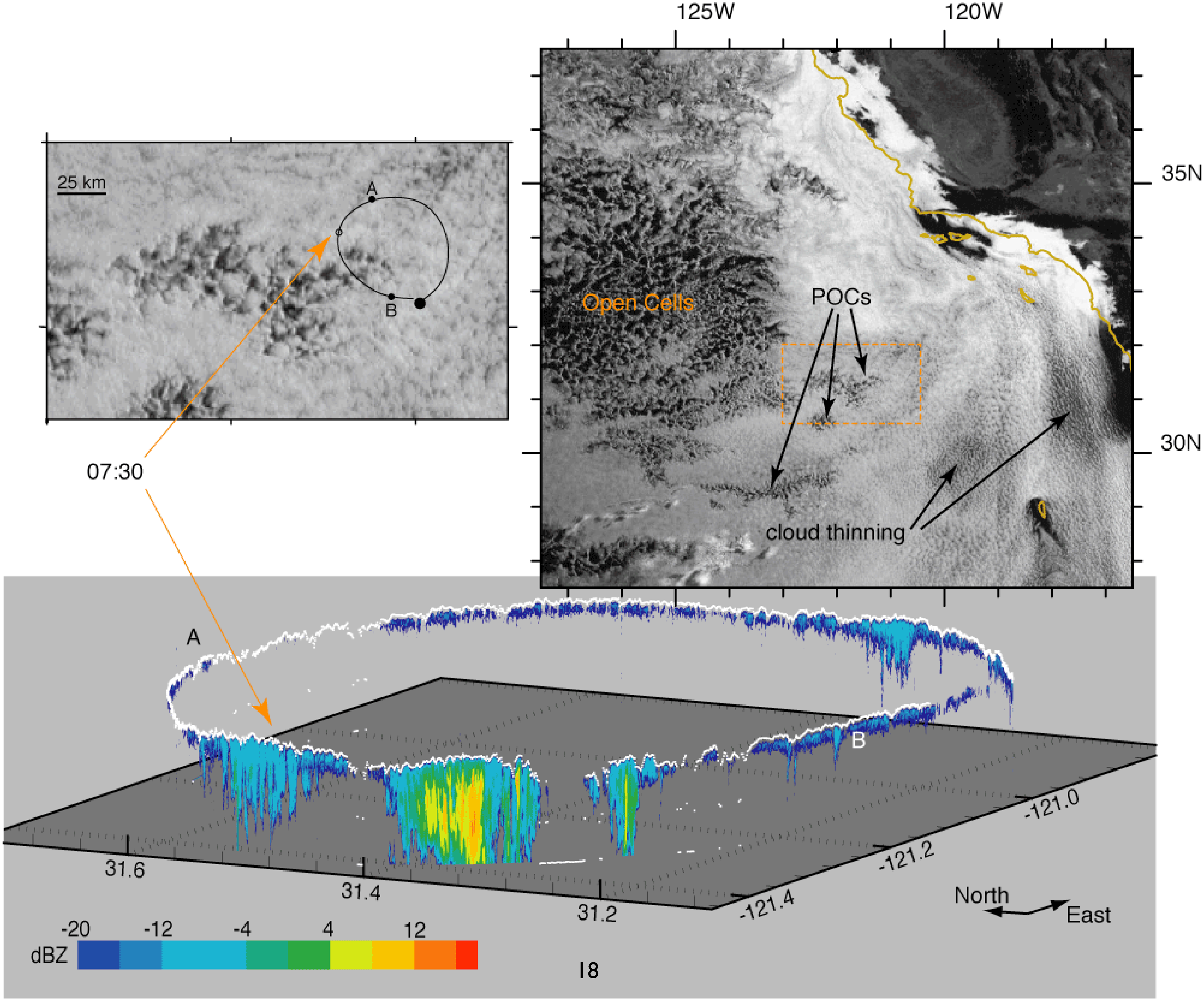
remarks

- efforts to reduce mixing made most models perform better in almost every respect.
- groups whose simulations better represented the cloud layer tried to take credit ...
- data does seem to bound entrainment, which usefully guides parameterization (tuesday's talk).

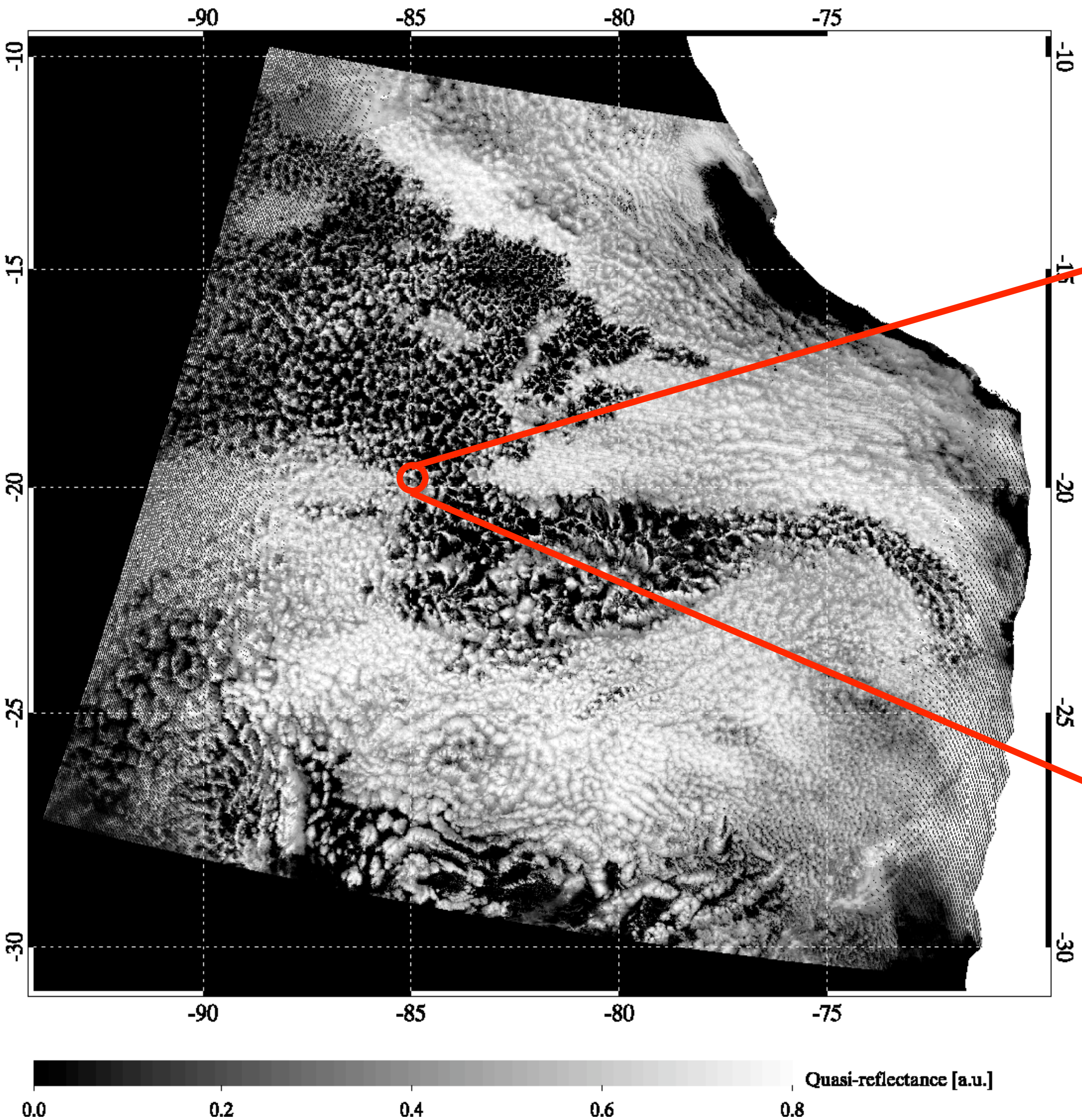
what is it good for?
(ii) attribution

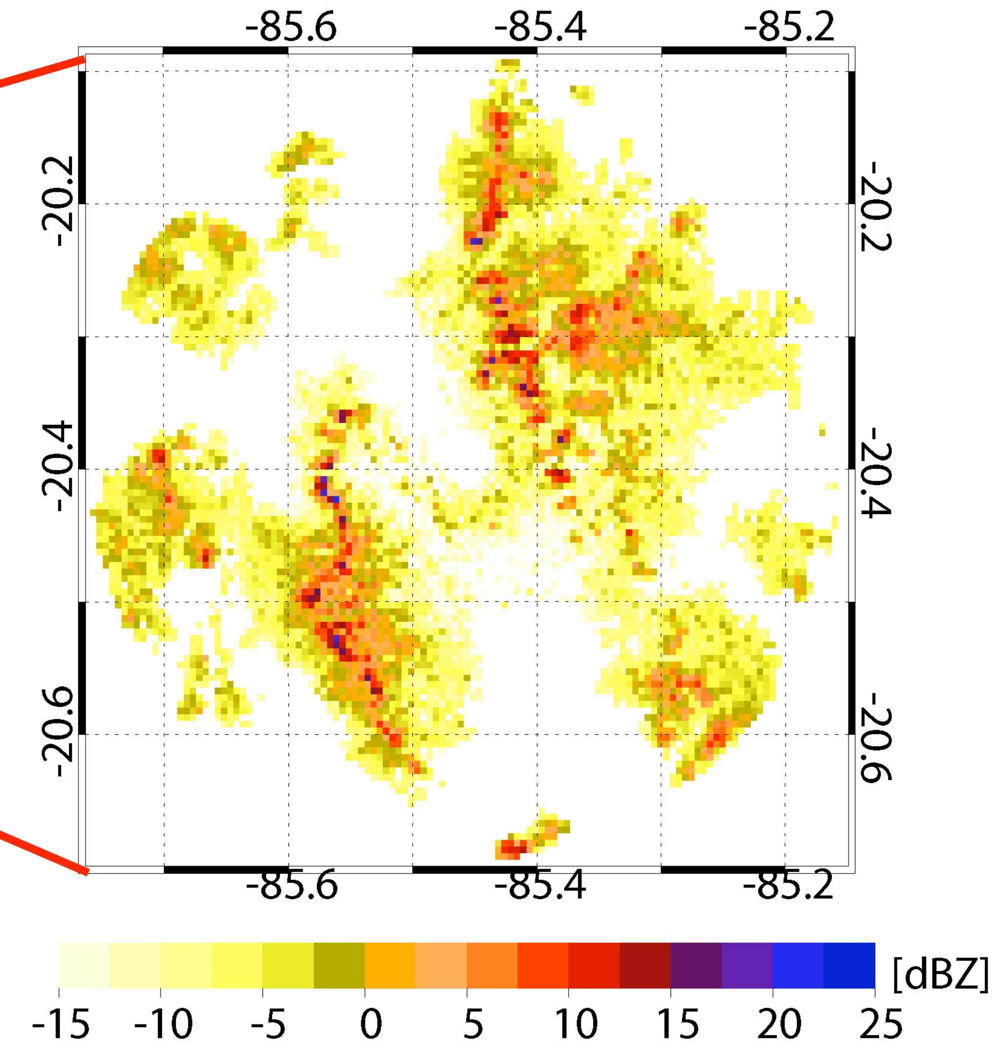


Pockets of Open Cells during DYCOMS



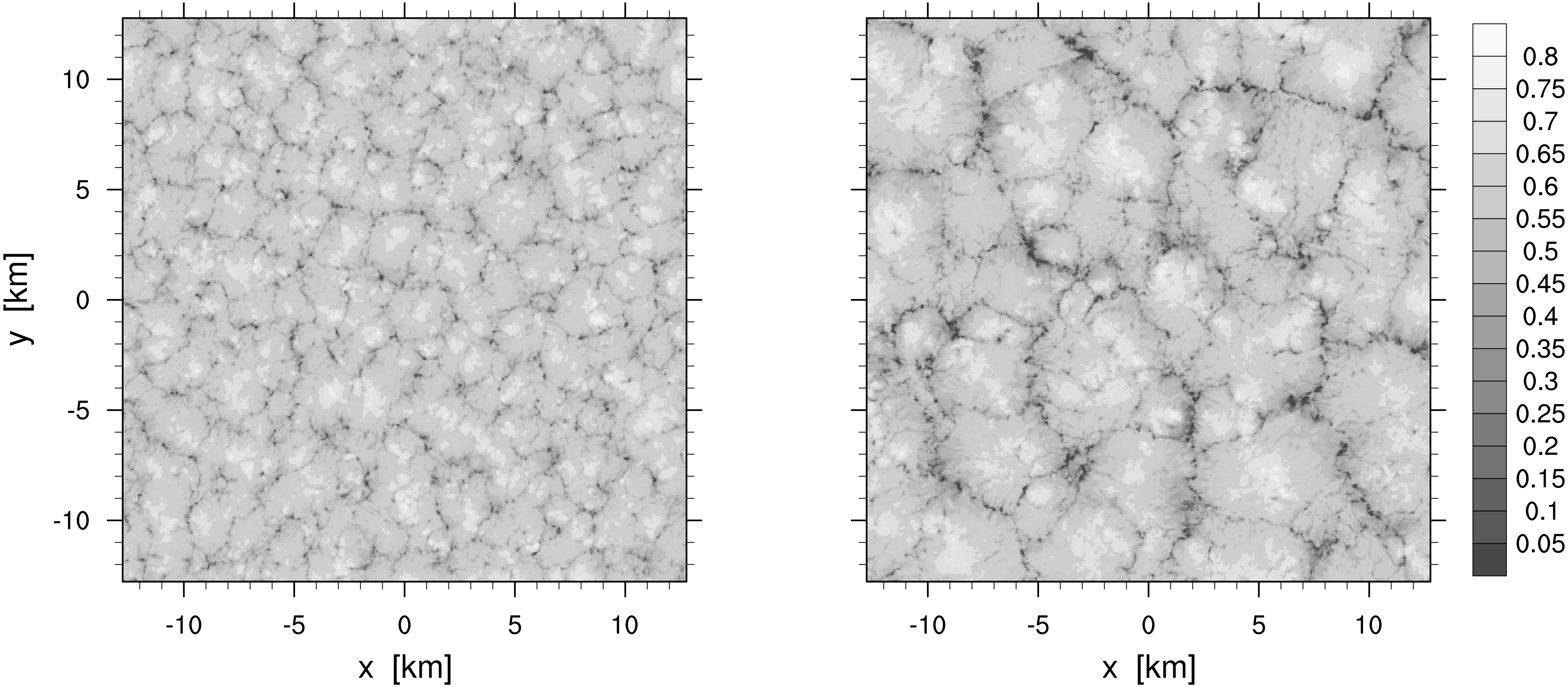
... and EPIC





Comstock, Yuter, Wood, Bretherton

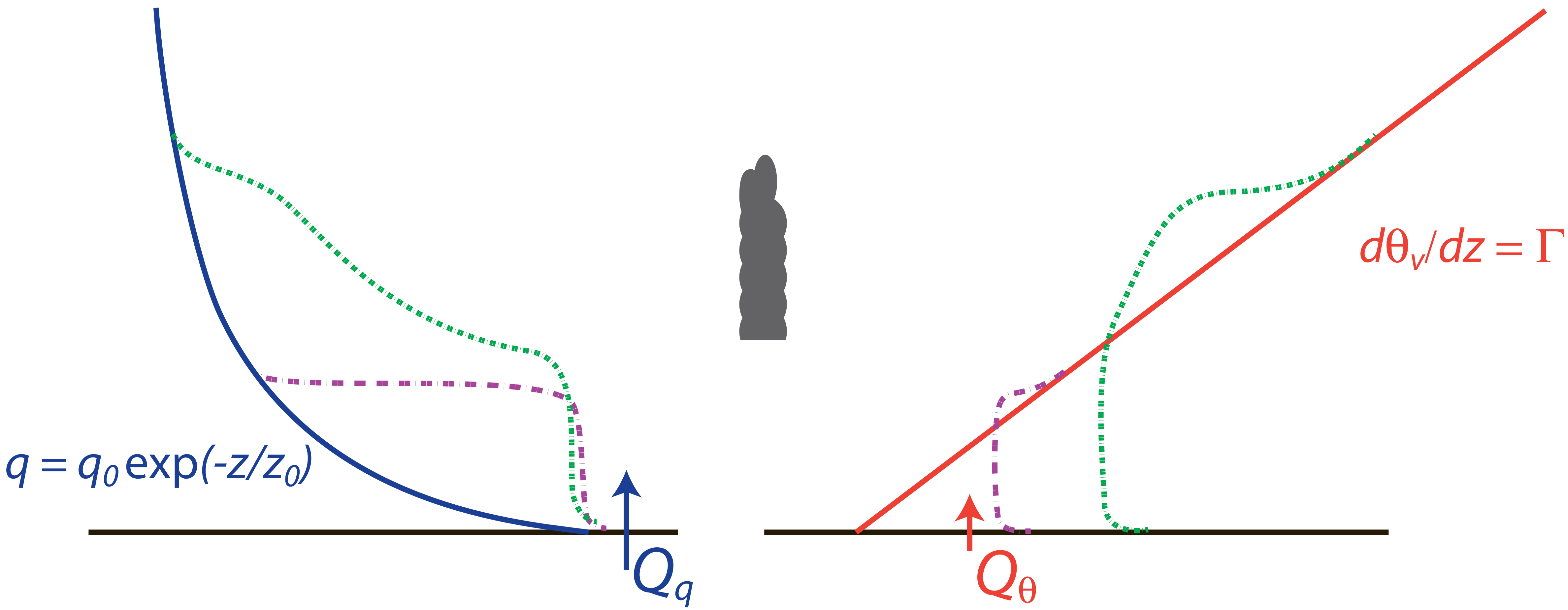
(LES) Pseudo Albedo at 5400 and 17100s



thanks to v. savic-jovcic

what is it good for?
(ii) exploration

Trade wind analog to dry convection



- what determines growth rate of layer?
- cloud fraction?
- mass flux at cloud base?
- velocity scales?

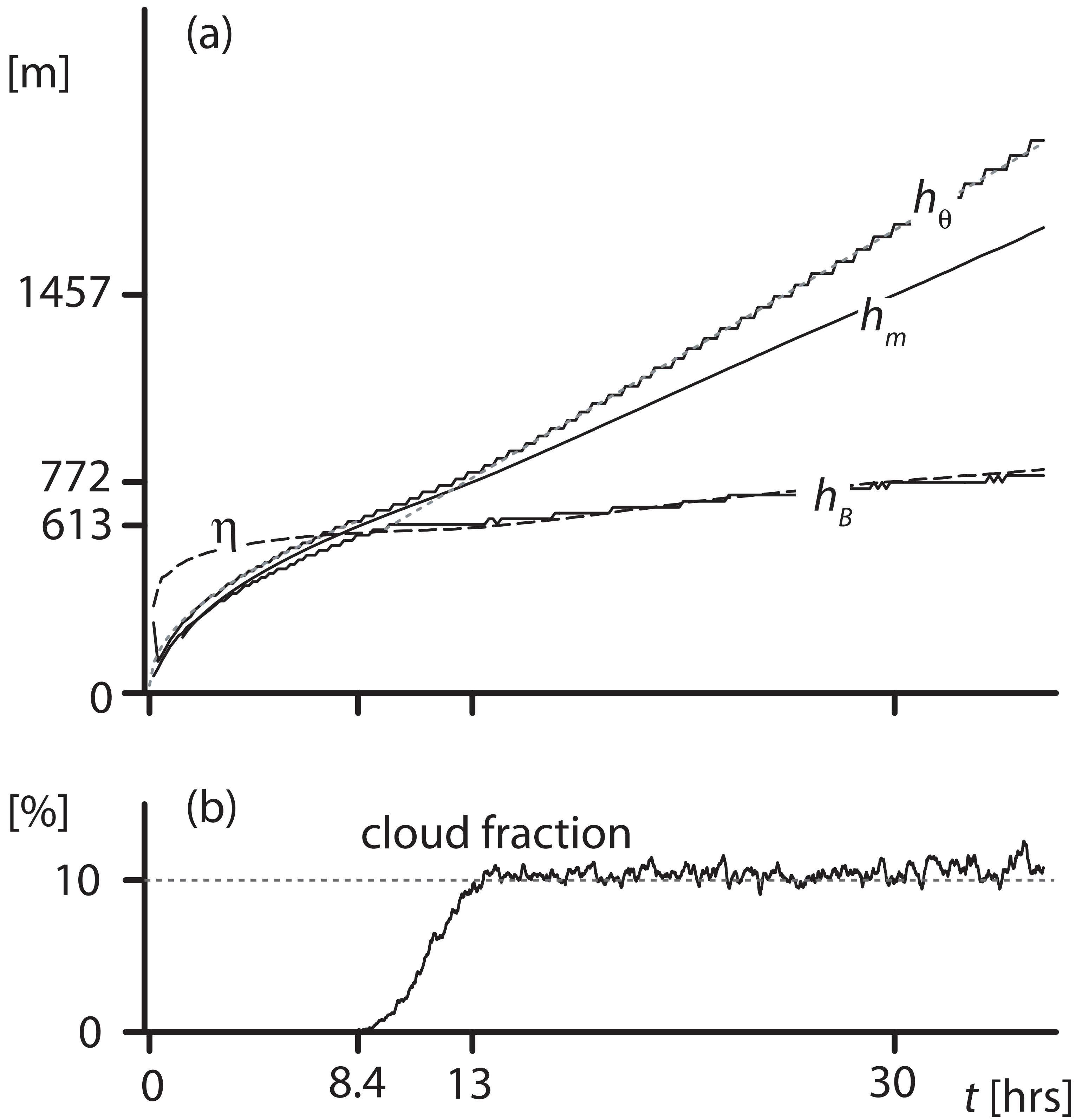
Visualizations (from three vantage points) of large-eddy simulations of non-precipitating shallow convection: nz=131, nx=ny=128, dz~dx=dy=37.5m

Side view

45 deg view (soon)

top view (eventually)

Temporal evolution of distinguished layers:



remarks

- layer grows as t ... growth is mostly through injection, as opposed to mechanical mixing.
- mass flux scaling determined by subcloud layer scale velocity scales.
- more on shallow convection* in Zhiming's talk

*(not nearly so important as deep convection ...)

concluding remarks

- large-eddy simulation is a popular and effective way to generate information about turbulent flows.
- because most flows of interest depend critically on the interaction of a flow with either the surface or the bounding fluid there is no guarantee that the information will be useful.
- these statements apply equally to other flow solving strategies (CRM).
- our persistent use of the methodology is also a statement about the alternatives.