What can the equilibria of bulk models tell us about the world?

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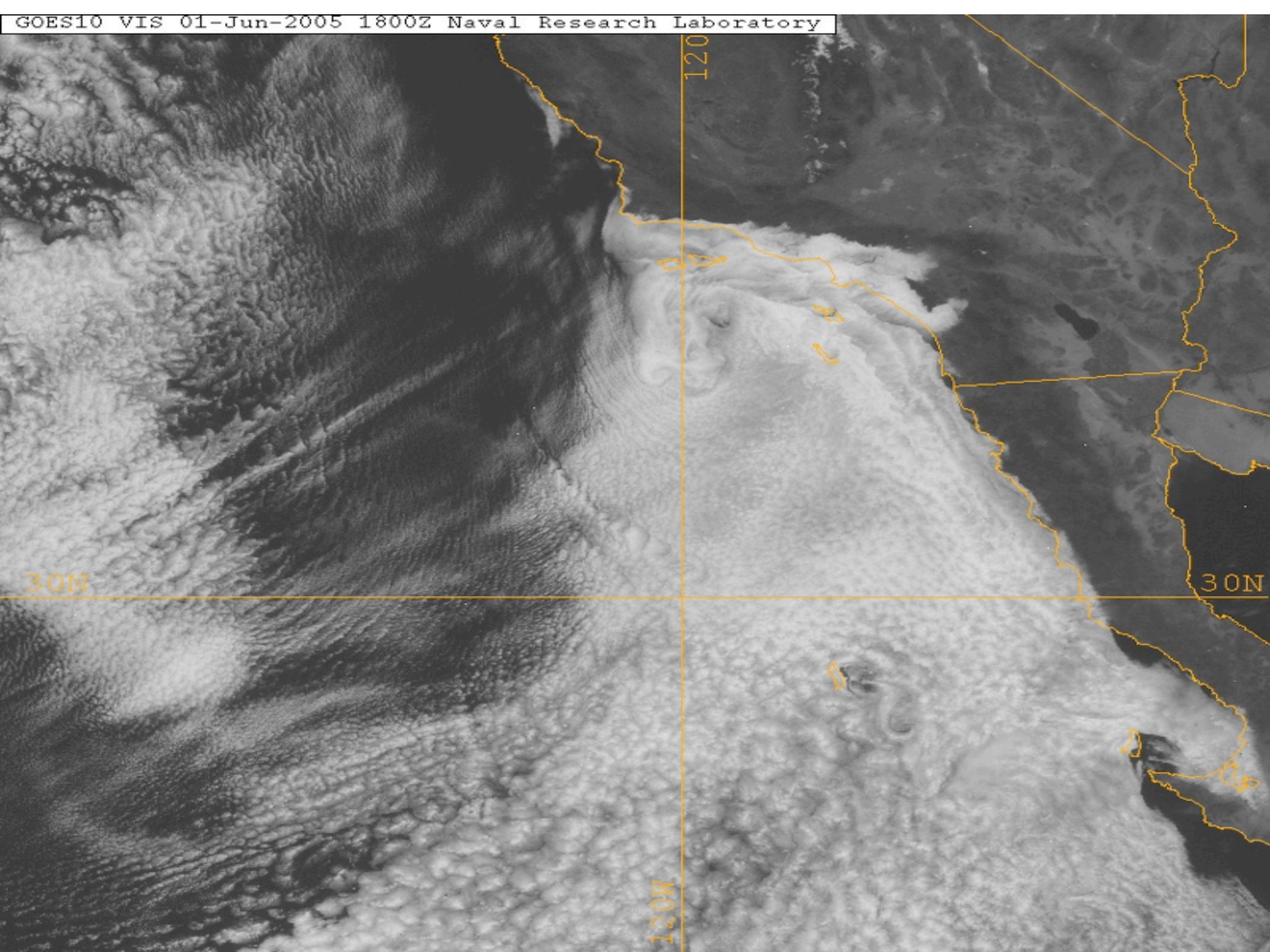
UCLA


GOES10 VIS 01-Jun-2005 1800Z Naval Research Laboratory
120W
30N
30N
120W

Observations

- Data explosion places demands on theory.
- Social crisis means that the framework for systematically and quantitatively exploring ideas is often not available.
- Weather prediction is less amenable to geography.

Our Bulk Model

$$\frac{\partial h}{\partial t} = E - Dh + u\frac{\partial h}{\partial x}$$

$$h\frac{\partial \langle s_l \rangle}{\partial t} = V(s_{l,0} - \langle s_l \rangle) + E(s_{l,+} - \langle s_l \rangle) - \frac{\triangle F_R}{\rho} + u\frac{\partial \langle s_l \rangle}{\partial x}$$

$$h\frac{\partial \langle q_t \rangle}{\partial t} = V(q_{t,0} - \langle q_t \rangle) + E(q_{t,+} - \langle q_t \rangle) + u\frac{\partial \langle q_t \rangle}{\partial x}$$

$$\text{where} \quad \langle \mathcal{X} \rangle = \frac{1}{h}\int_0^h \mathcal{X} dz, \quad \mathcal{X} \in (s_l, q_t)$$

$$\text{and} \quad V = C_D \|U\|$$

0-0

Equations for mass (as measured by PBL depth, *h*), dry enthalpy (s_l) and moisture (q_t) integrated over the PBL. *V* indicates surface exchange, *E* the entrainment measures the diabatic growth rate (i.e., mixing with free troposphere) and like V is parameterizaed, *Dh* is the vertical motion, i.e., the adiabatic growth rate.

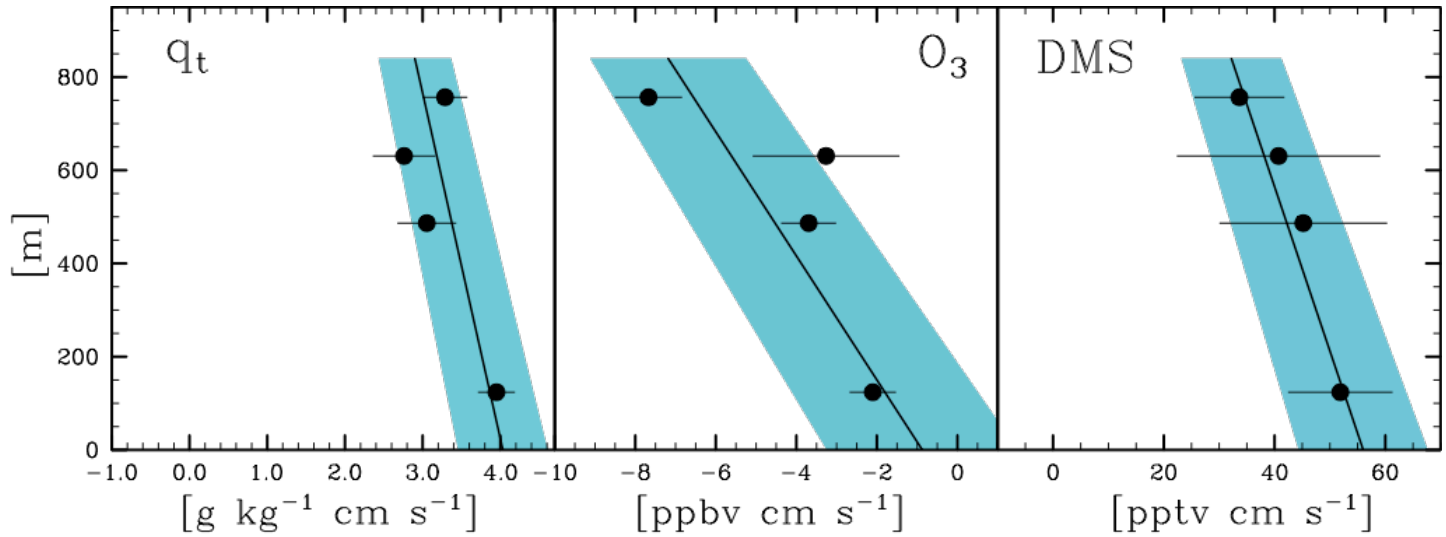
Entrainment Closures

$$\mathcal{B} = f(z, E, \triangle F_R, s_{l,0}, q_{t,0})$$

$$\eta = \frac{\int_0^h (\mathcal{B}_{NE} - \mathcal{B}) dz}{\int_0^h \mathcal{B}_{NE} dz} \qquad \mathcal{B}_{min} = -\frac{2k}{1-k}\langle \mathcal{B} \rangle$$

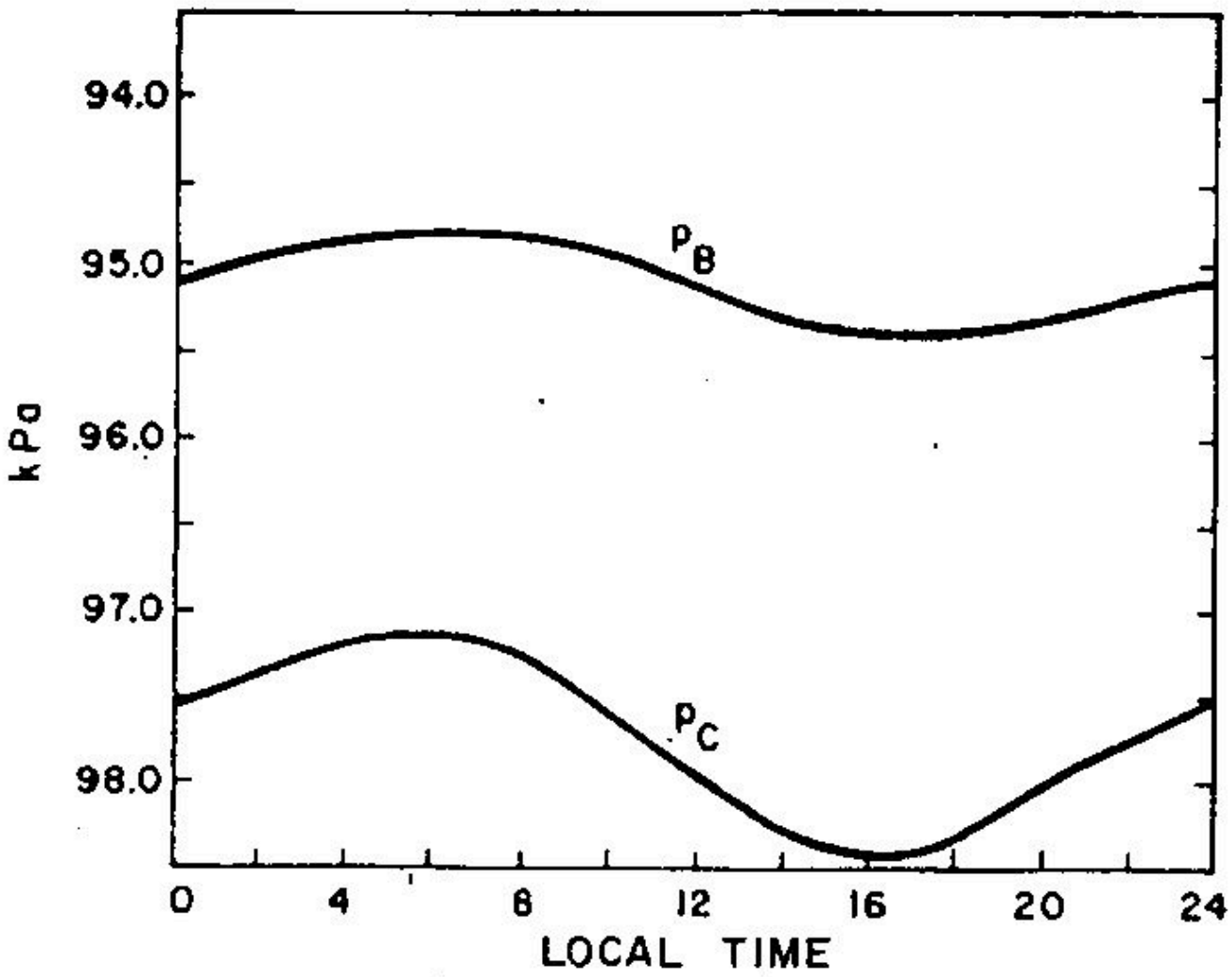
although for analytical work

$$E = \alpha \frac{\triangle F_R}{\triangle s_l}$$



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	$E_{\Delta s_l=11}$	$E_{\Delta F=0}$	$E_{q_{l+}=5.0}$	$E_{SST=290.4}$
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


94.0
95.0
96.0
97.0
98.0
kPa
p_B
p_C
0
4
8
12
16
20
24
LOCAL TIME

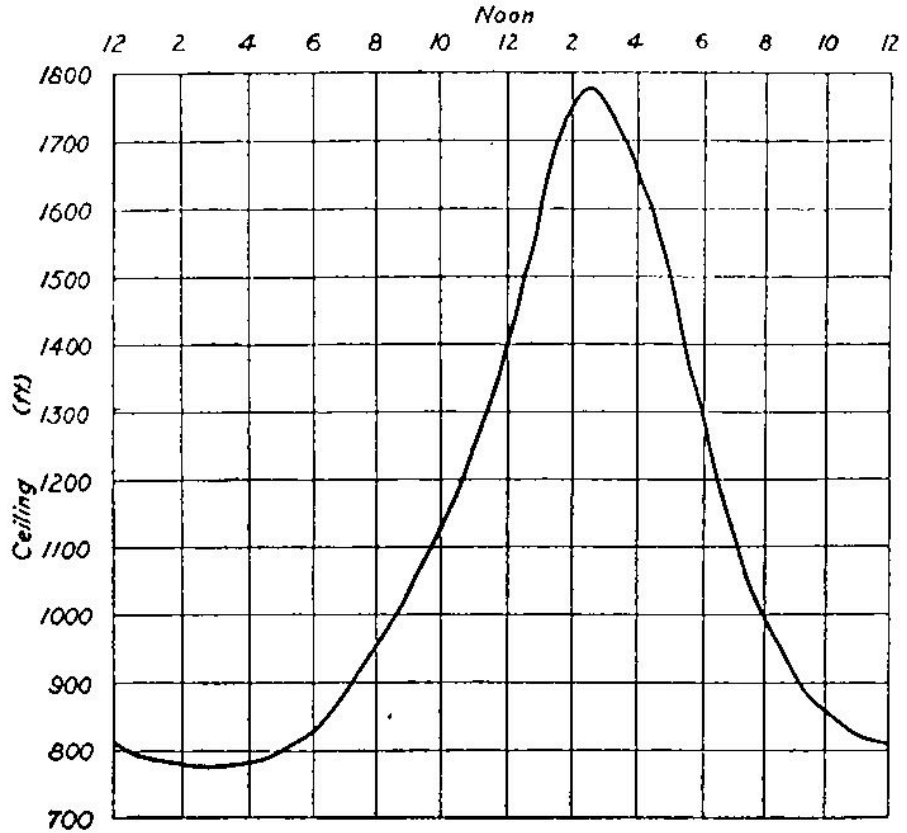


FIGURE 1.—Average hourly ceiling height at Oakland, Calif., during prevalence of stratus cloudiness.

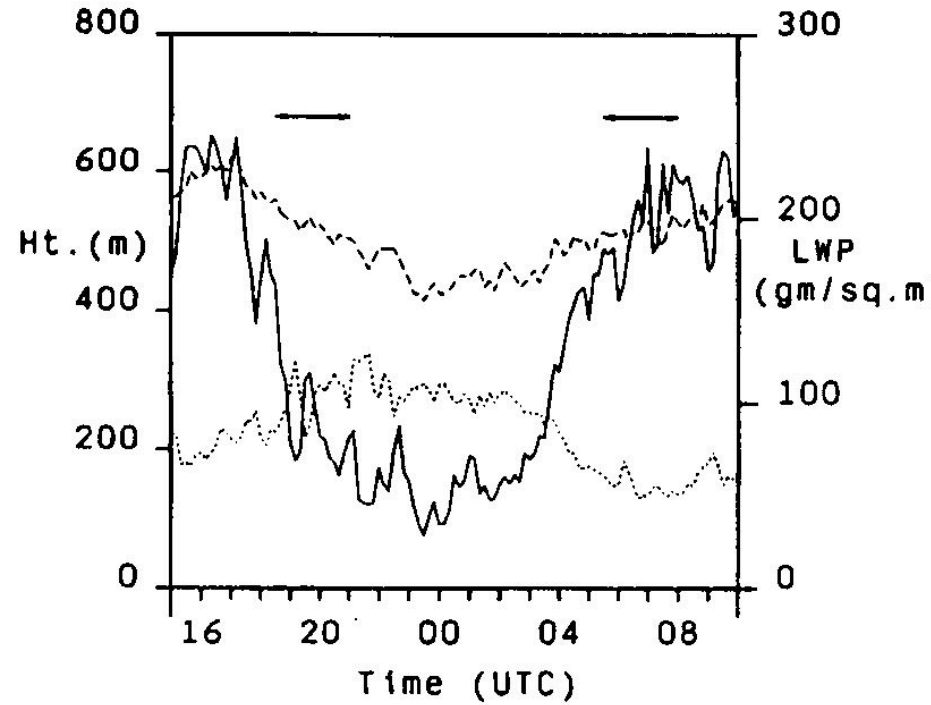
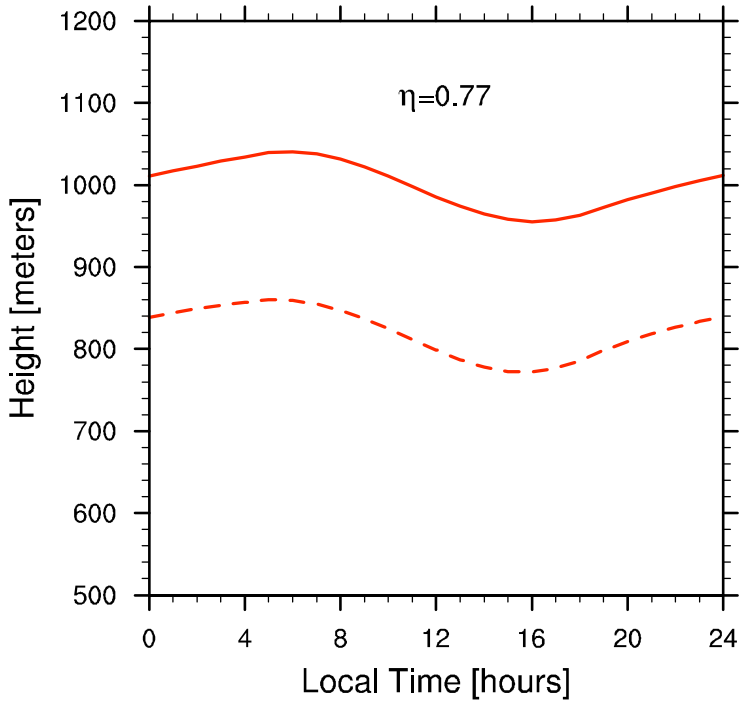
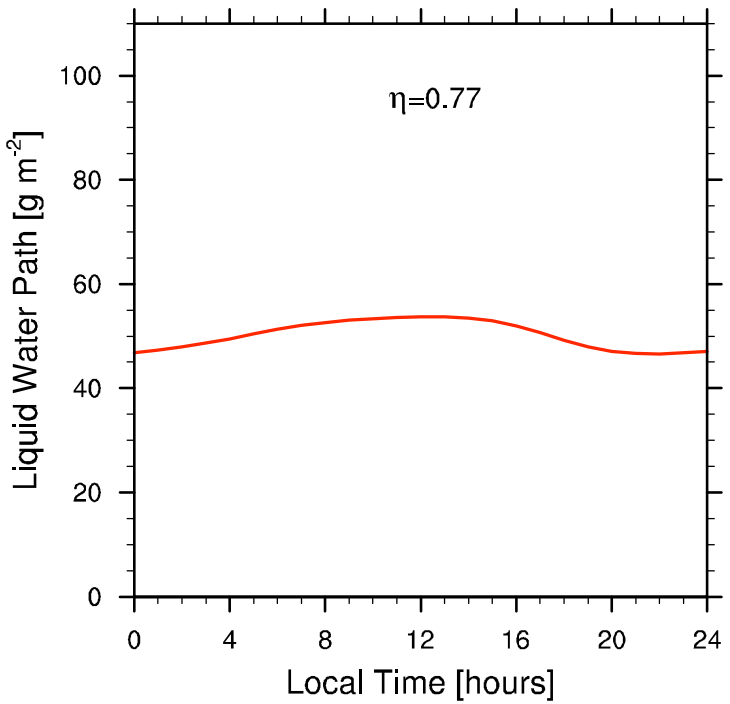
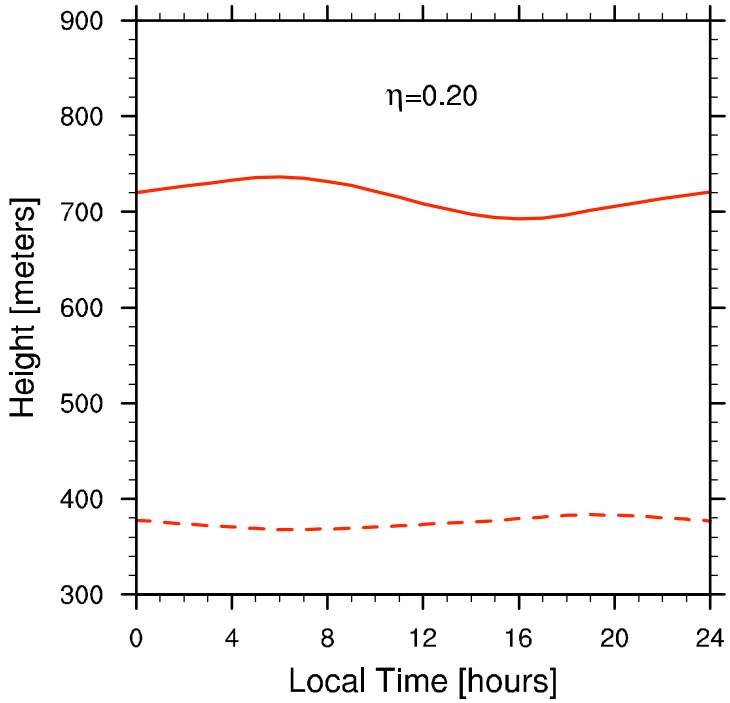
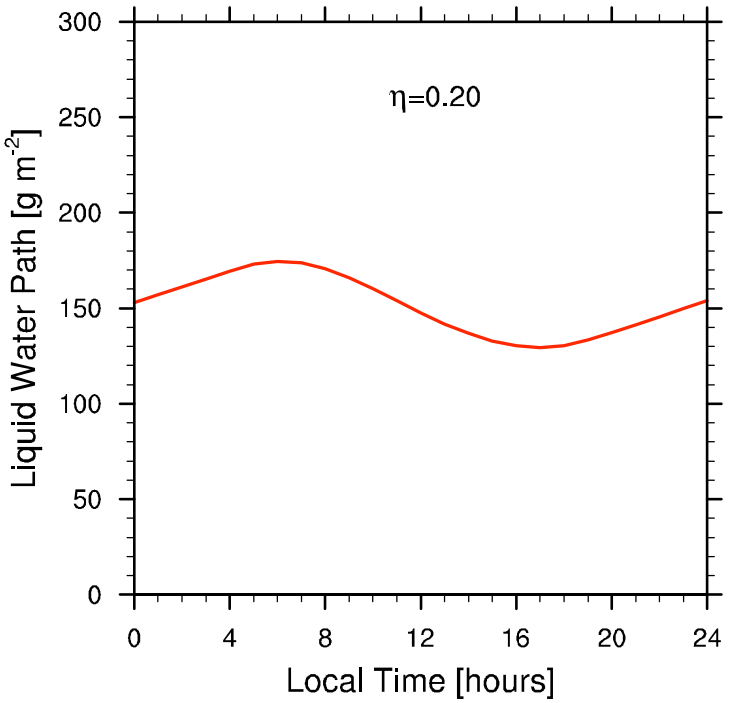


FIG. 1. Liquid water path, LWP, (full line) and height of cloud top (dashed line) and cloud base (dotted line) against time from 1500 UTC 14 July to 1000 UTC 15 July. The arrows denote the periods selected for direct comparison. Local noon occurred at 2004.


η=0.77
Height [meters]
Local Time [hours]
1200
1100
1000
900
800
700
600
500
0
4
8
12
16
20
24


η=0.77
Liquid Water Path [g m-2]
Local Time [hours]
100
80
60
40
20
0
0
4
8
12
16
20
24

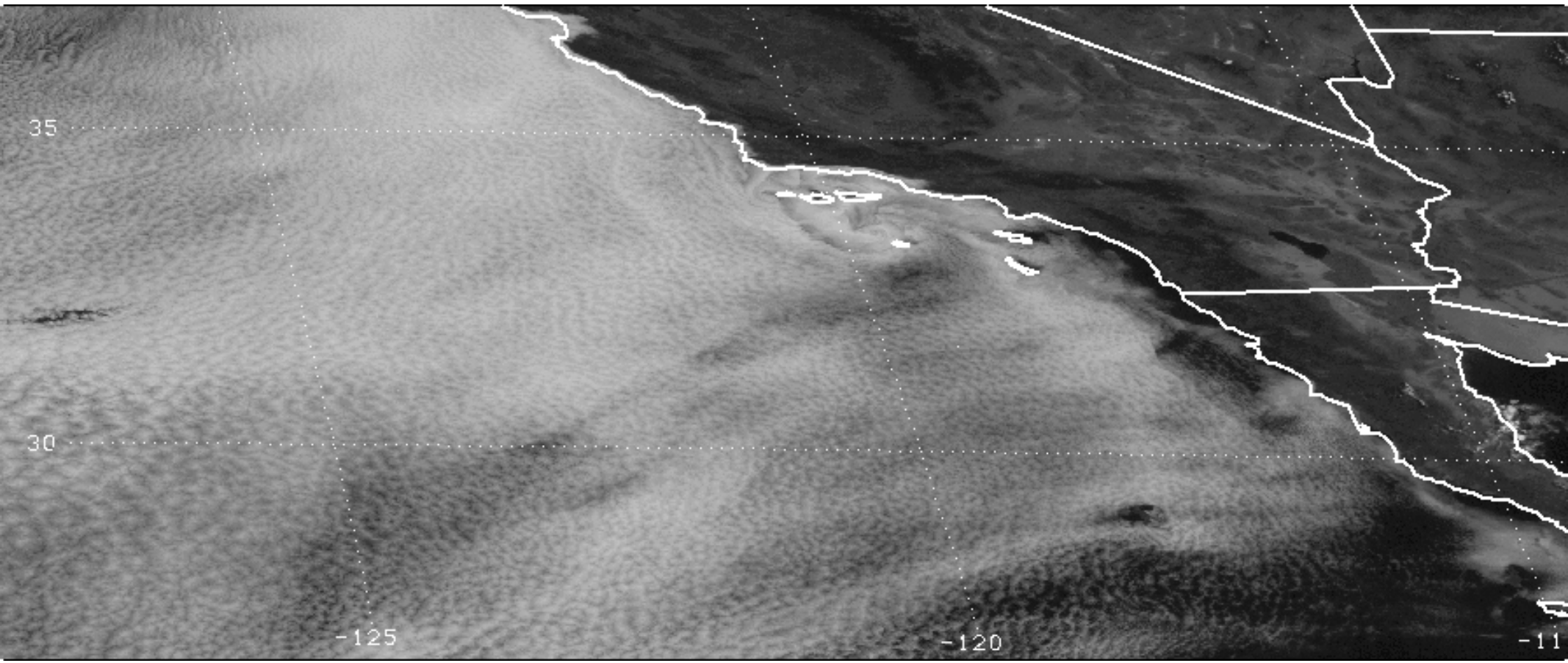

η=0.20
Height [meters]
Local Time [hours]
900
800
700
600
500
400
300
0
4
8
12
16
20
24


η=0.20
Liquid Water Path [g m-2]
Local Time [hours]
300
250
200
150
100
50
0
0
4
8
12
16
20
24

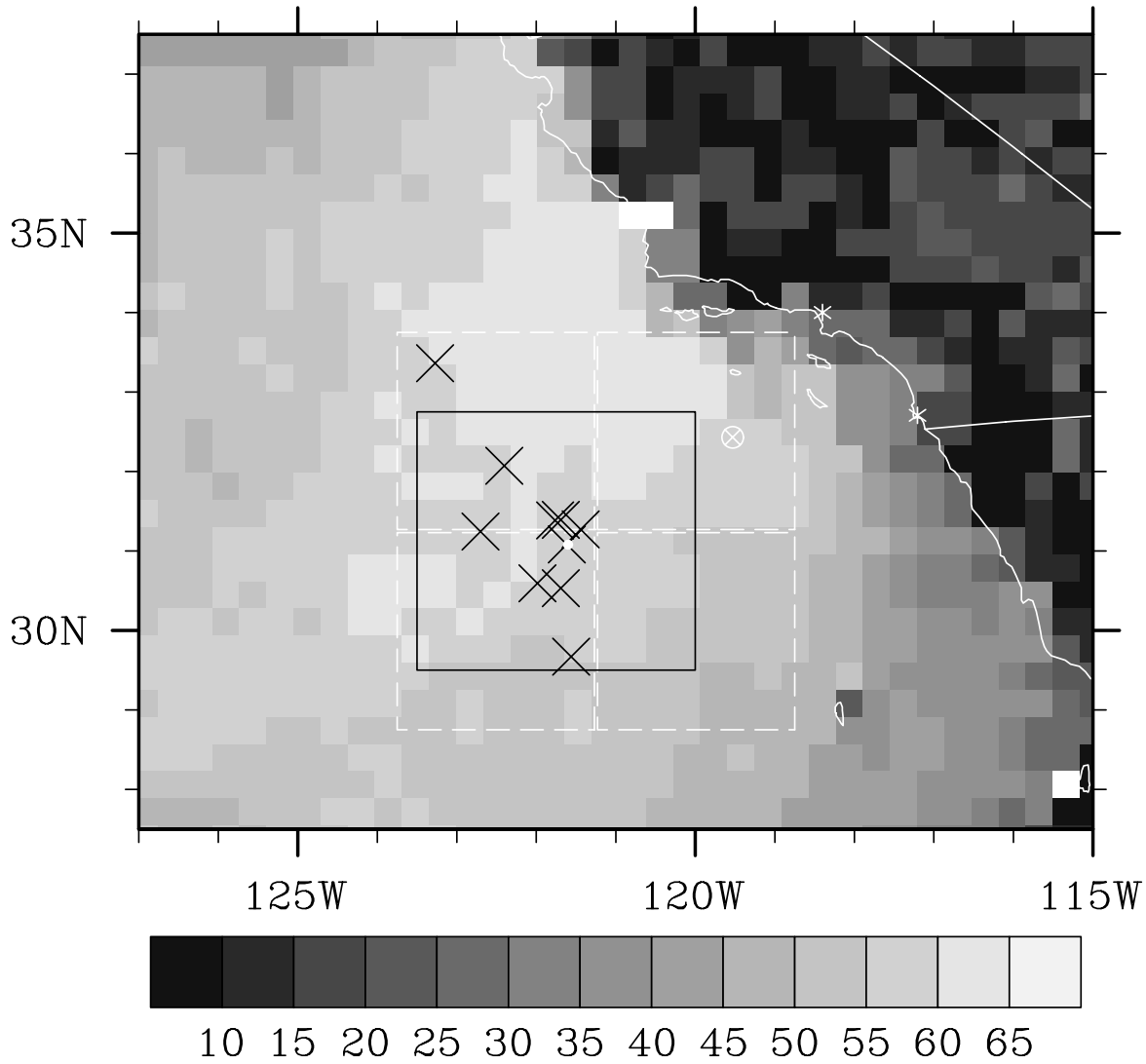
Remarks

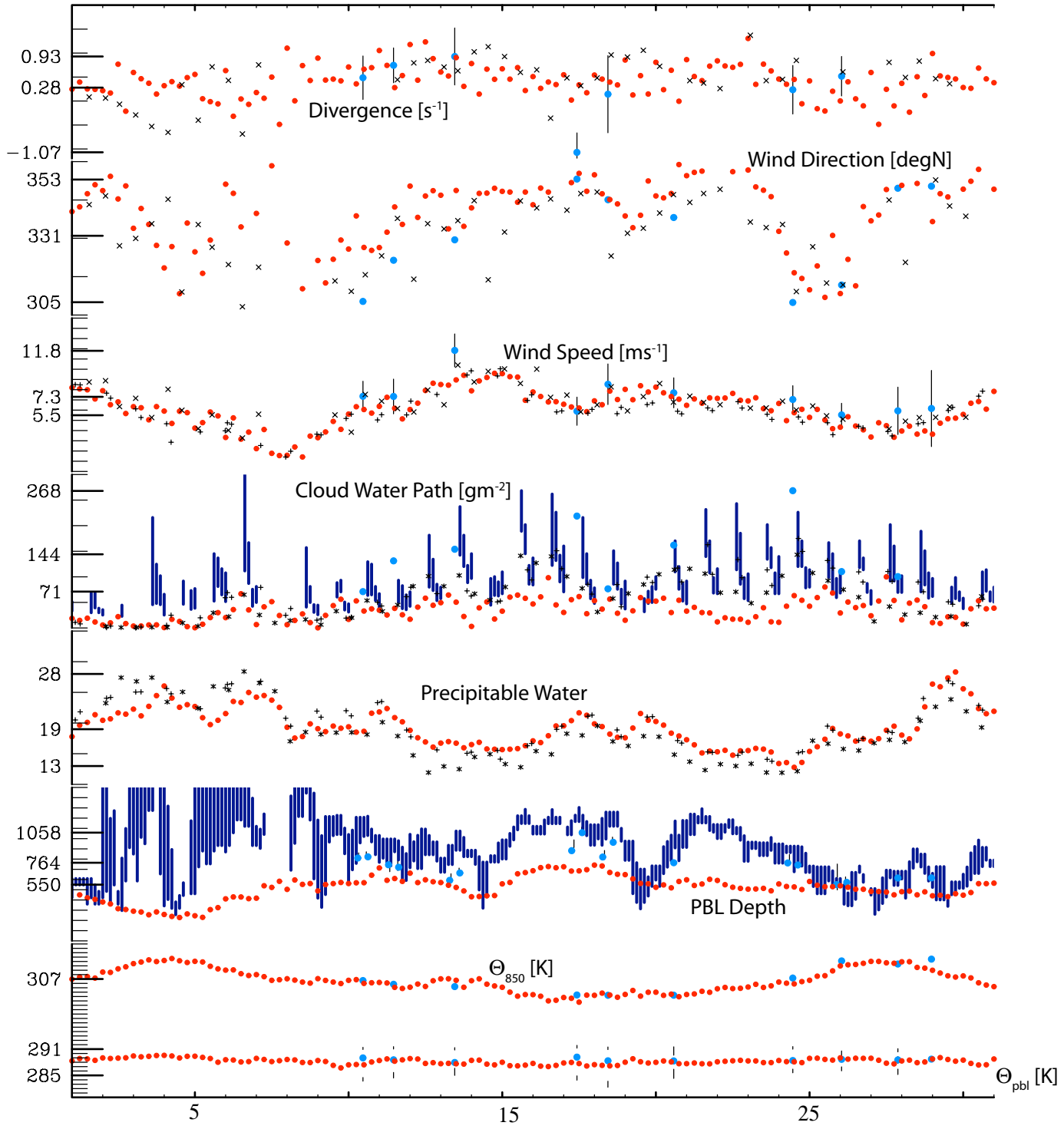
- Simple model, plausible closure, decent diurnal cycle.
- Progress on the closures, challenges to implementation (Adrian Lock).
- Mixed layer models are only well mixed at first order (Sungsu Park).
- How can we evaluate the framework more critically.

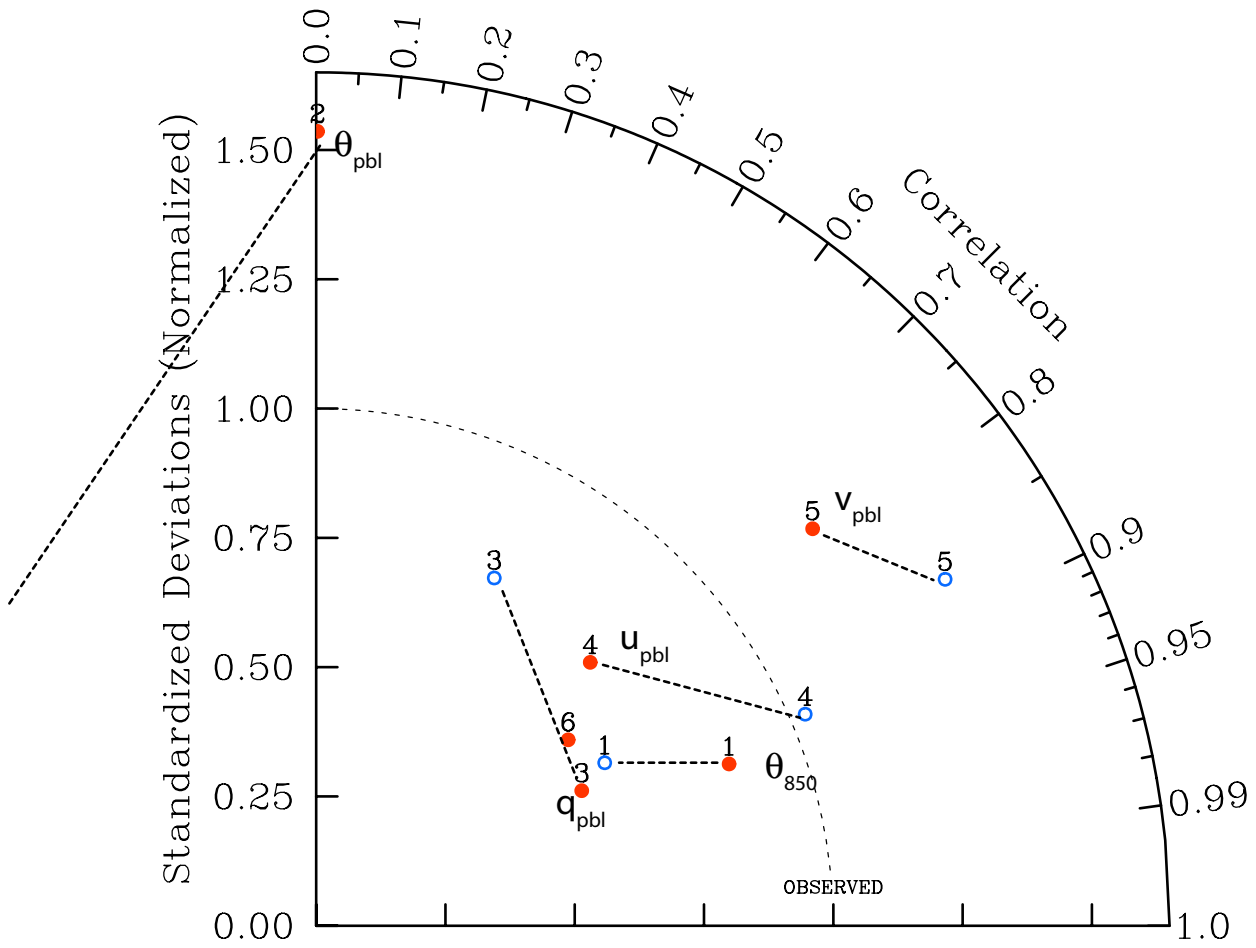
July 27, 2001



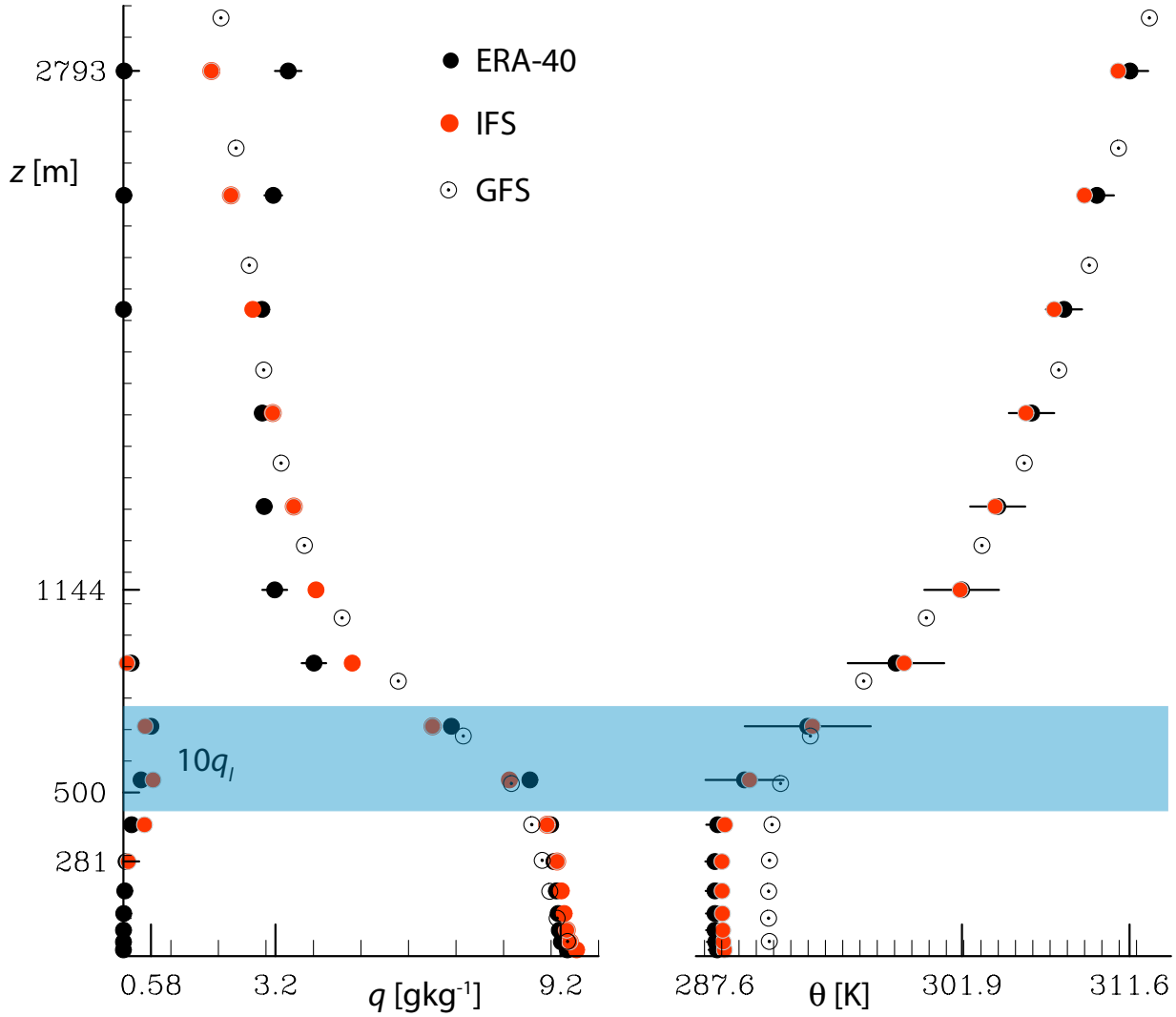
DYCOMS-II:




0.93
0.28
Divergence [s-1]
−1.07
353
Wind Direction [degN]
331
305
11.8
Wind Speed [ms-1]
7.3
5.5
268
Cloud Water Path [gm-2]
144
71
28
Precipitable Water
19
13
1058
764
550
PBL Depth
Θ850 [K]
307
291
285
Θpbl [K]
5
15
25

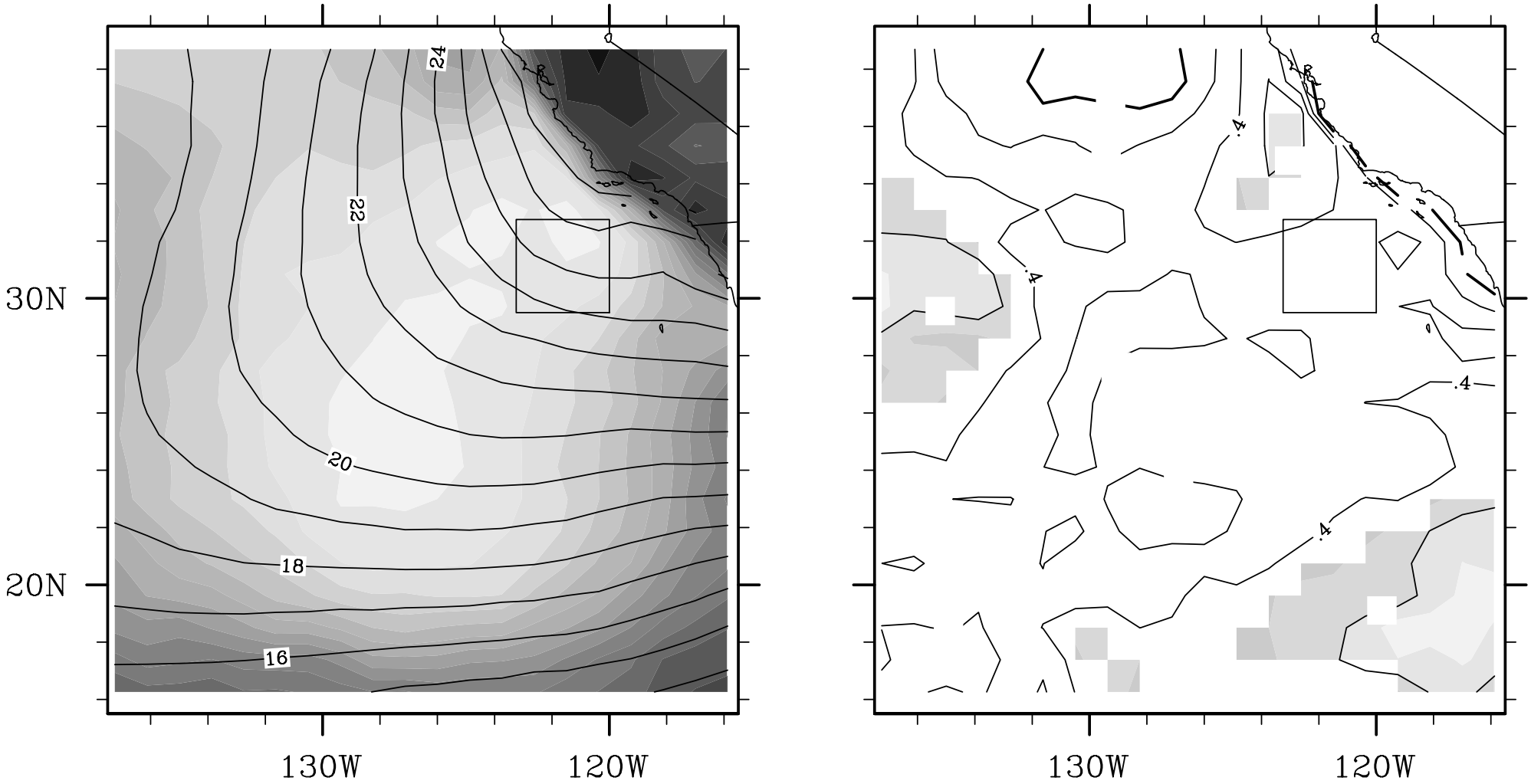


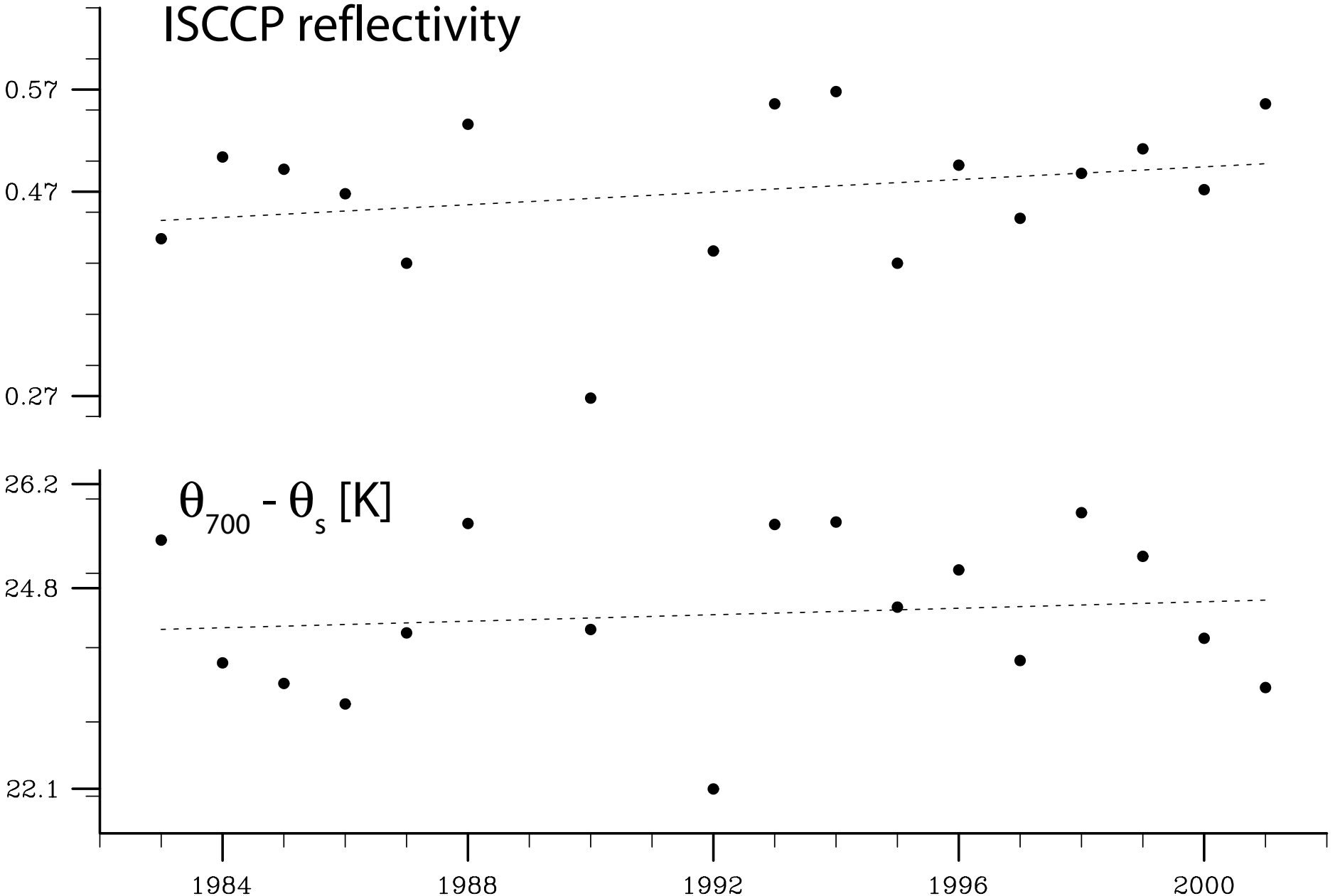
(6) denotes PBL depth. Not available from NCEP

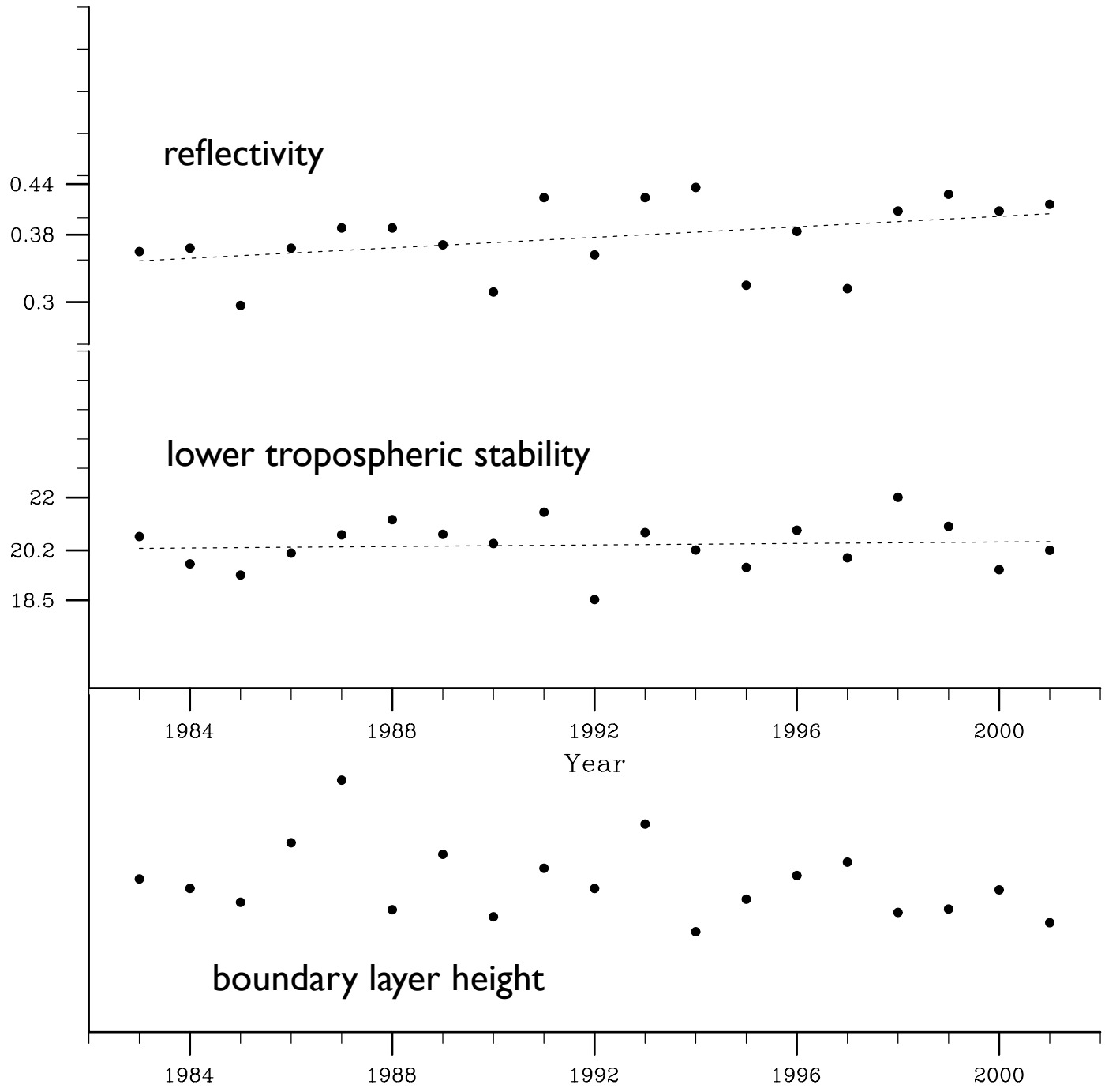

ERA-40
IFS
GFS
2793
1144
500
281
z [m]
10q_l
0.58
3.2
q [gkg-1]
9.2
287.6
θ [K]
301.9
311.6

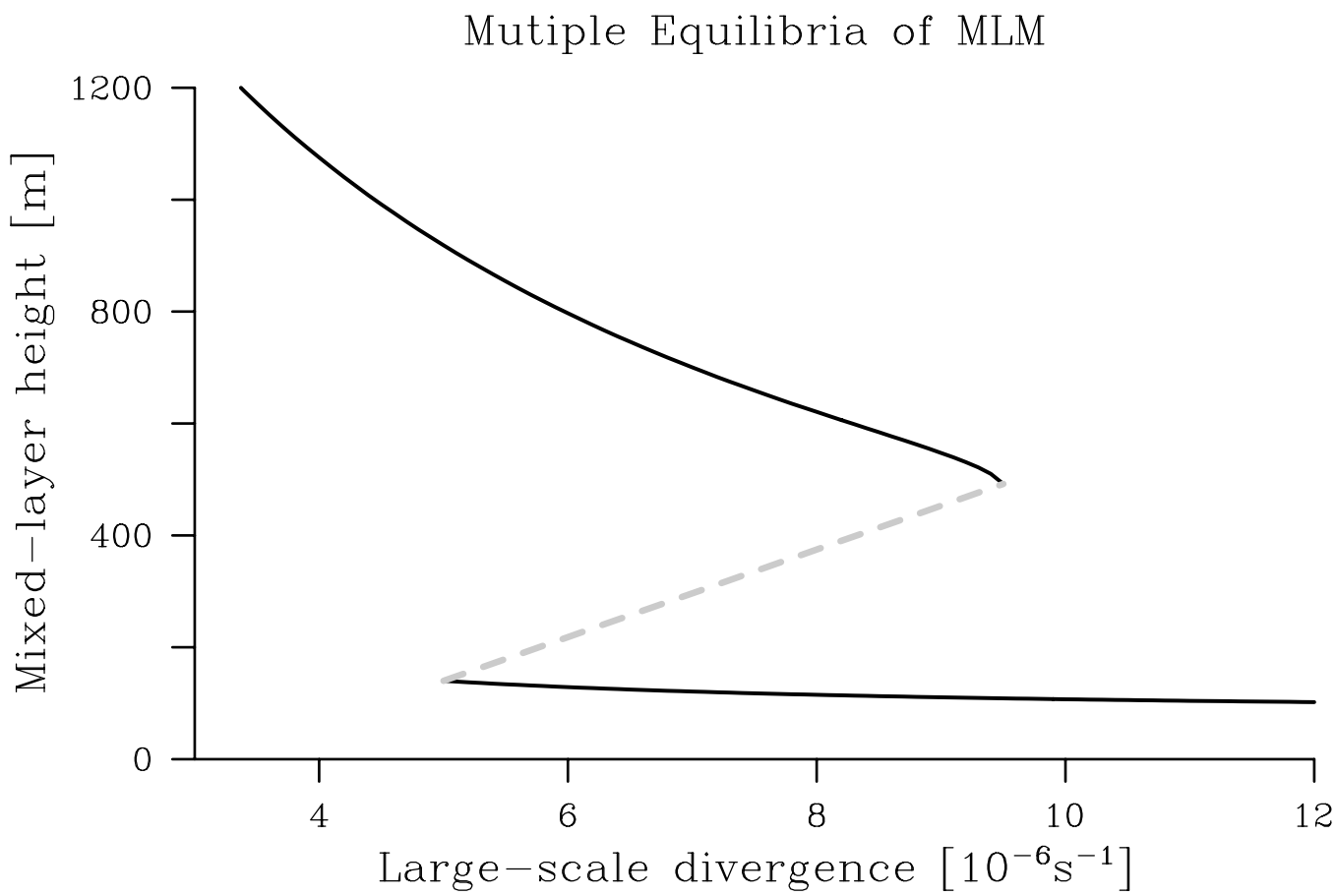
Remarks

- Boundary layer too shallow, and cloud too thin. Both are well documented shortcomings of forecast, global, and mesoscale models, and of the reanalyses (just ask CsB).
- Boundary forcings well represented, i.e., theta at 850 hPa, SSTs, divergence, windspeeds.
- ISCCP Record now as long as the OWS record (see data explosion comment at outset).

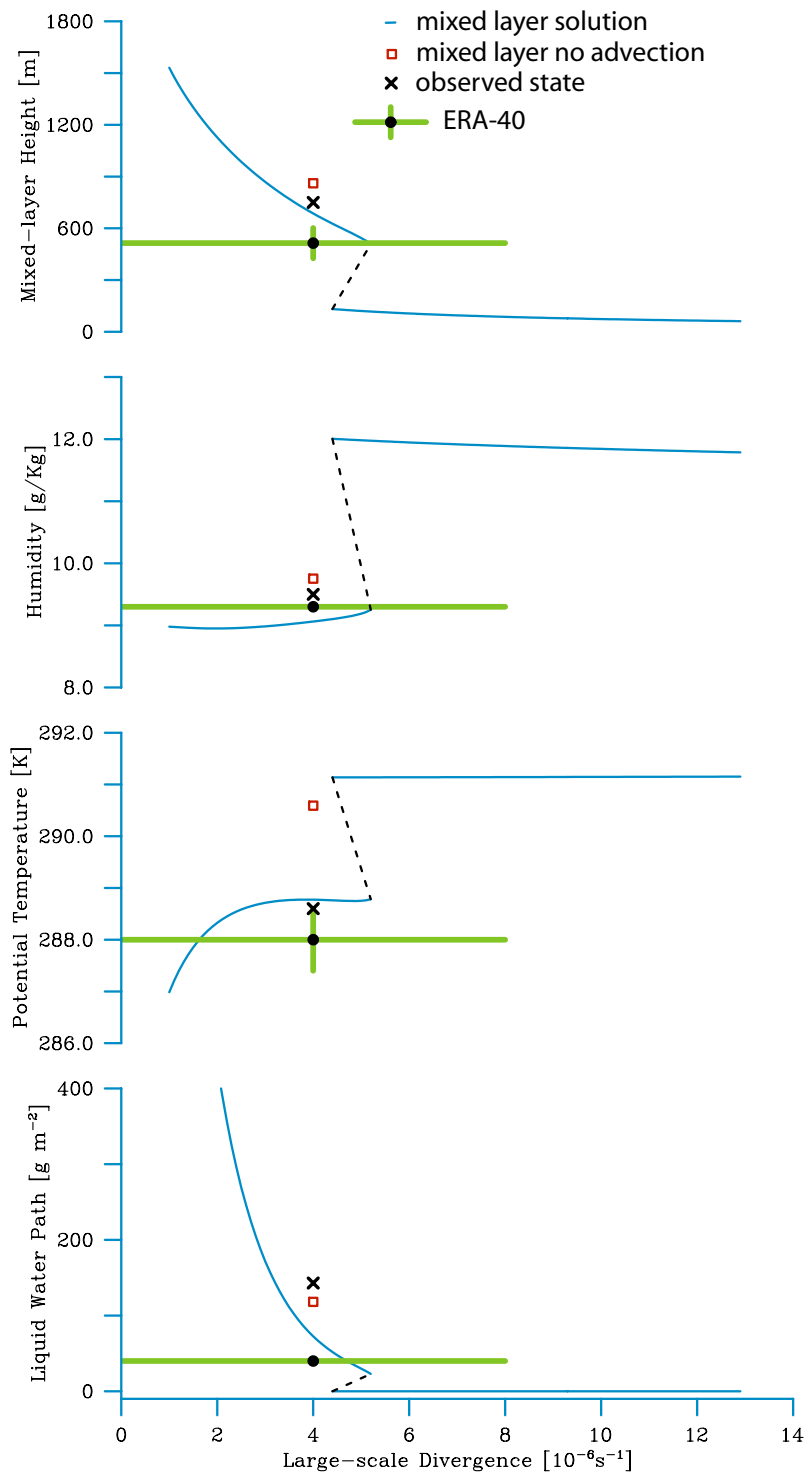

24
22
20
18
16
30N
20N
130W
120W
.4
.4
.4
.4
130W
120W


ISCCP reflectivity
0.57
0.47
0.27
θ700 - θs [K]
26.2
24.8
22.1
1984
1988
1992
1996
2000

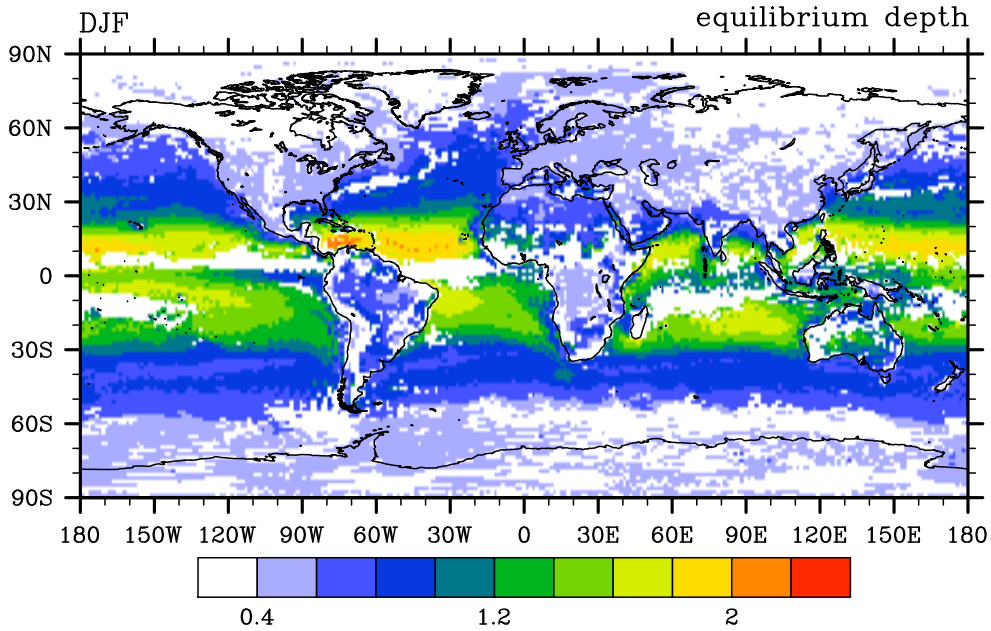

reflectivity
0.44
0.38
0.3
lower tropospheric stability
22
20.2
18.5
1984
1988
1992
1996
2000
Year
boundary layer height
1984
1988
1992
1996
2000

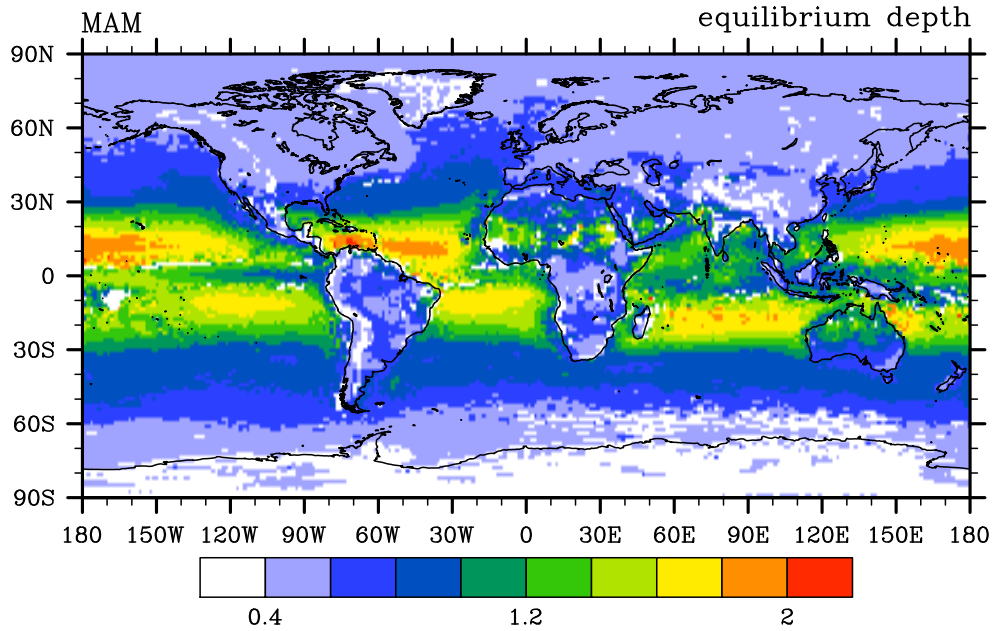


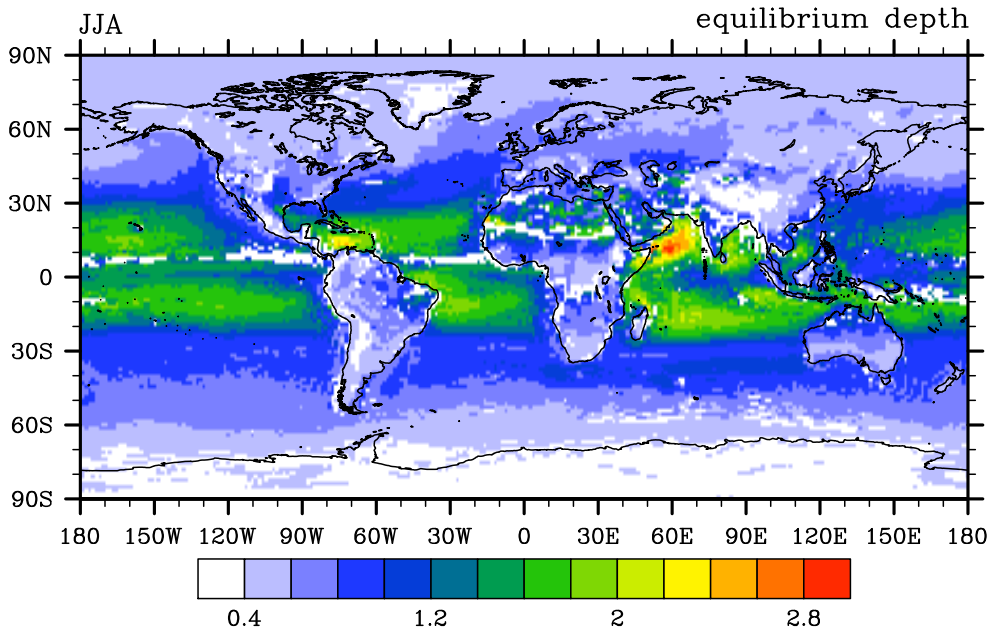
Steady state solutions without advection, showing multiple equilibrium. A dry shallow PBL inwhich weak entrainment is maintained by shear defines the lower branch, a cloud topped layer driven by buoyancy associated with cloud top radiative cooling defines the upper branch (e.g., Randall and Suarez, 1984). Multiple equilibrium regime depends on state.

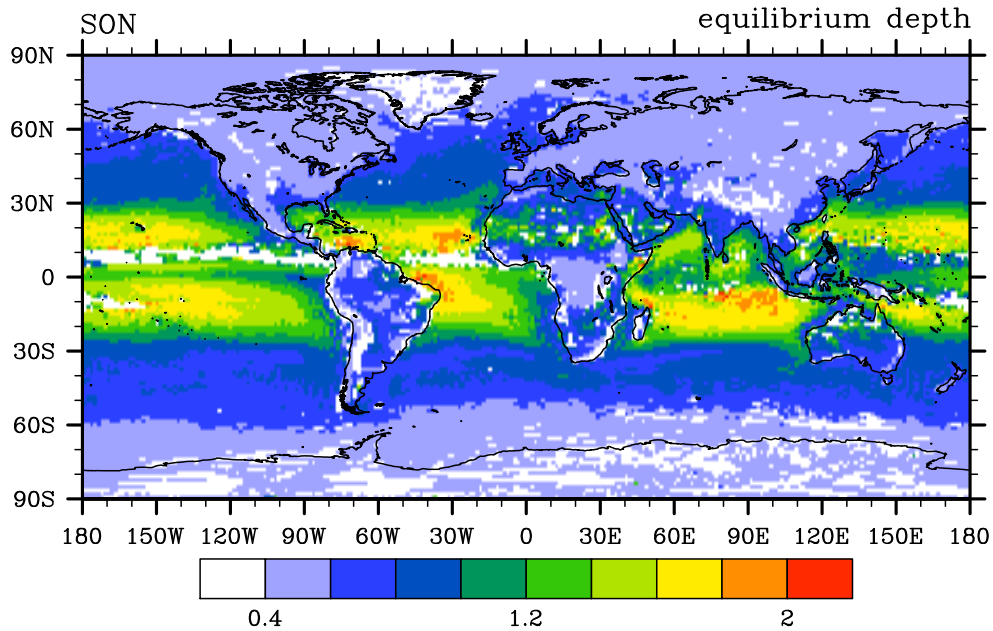

mixed layer solution
mixed layer no advection
observed state
ERA-40
Mixed−layer Height [m]
1800
1200
600
0
Humidity [g/Kg]
12.0
10.0
8.0
Potential Temperature [K]
292.0
290.0
288.0
286.0
Liquid Water Path [g m⁻²]
400
200
0
0
2
4
6
8
10
12
14
Large−scale Divergence [10⁻⁶s⁻¹]

Planetary Alpha (entrainment efficiency)

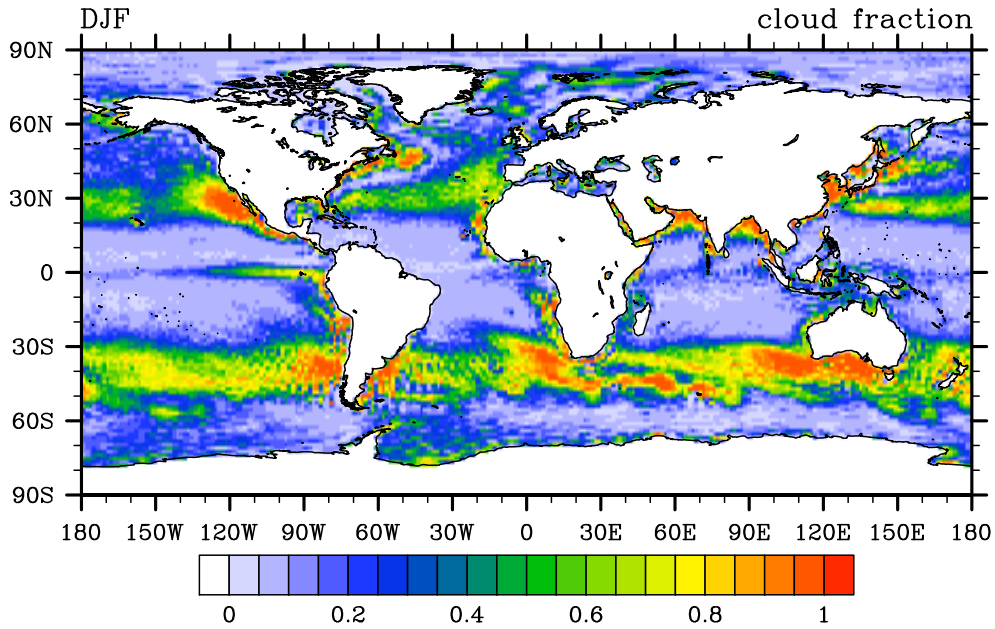


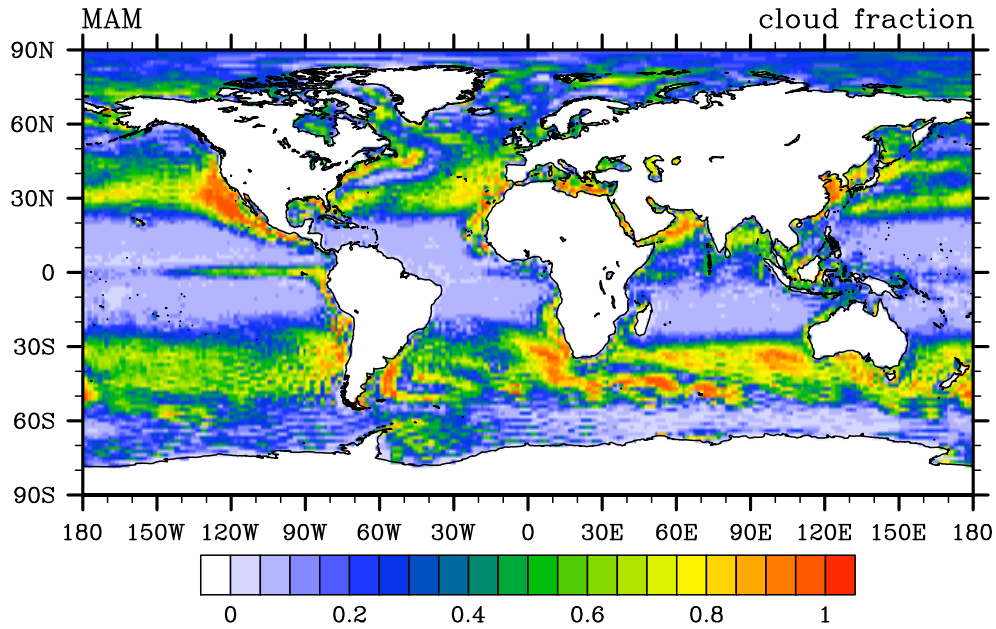


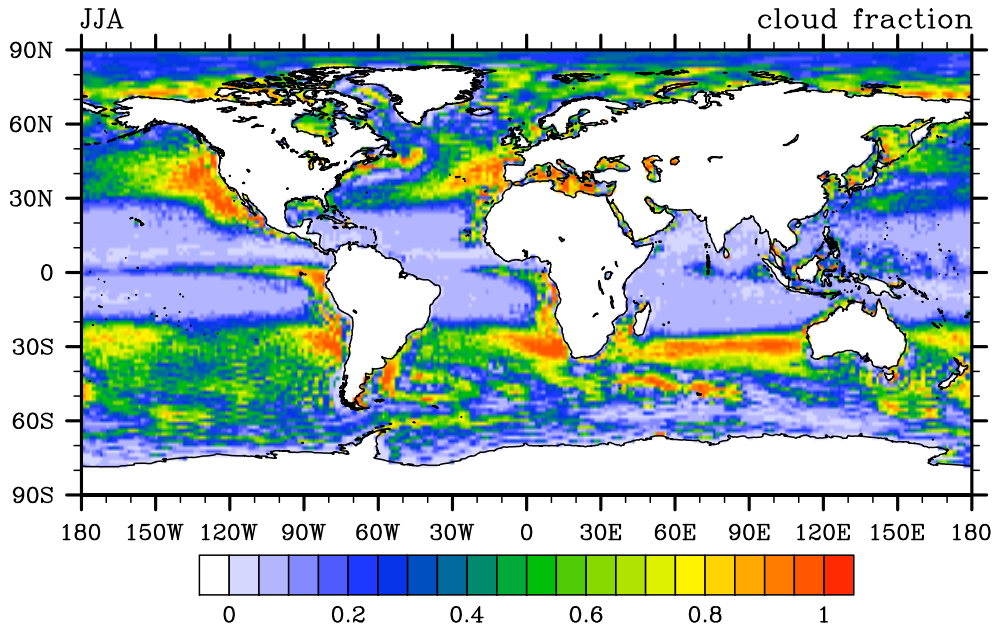


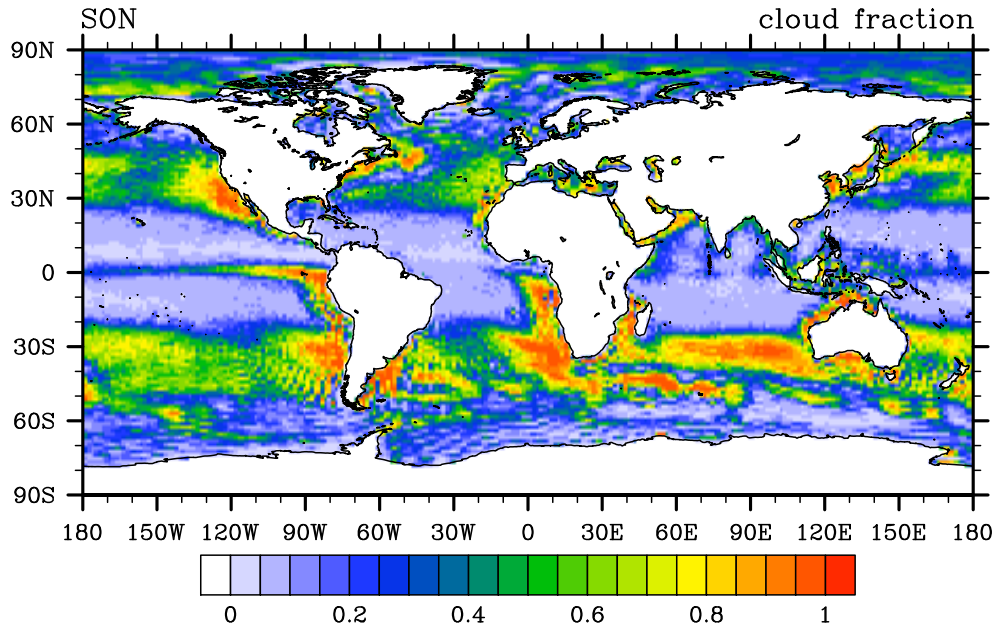


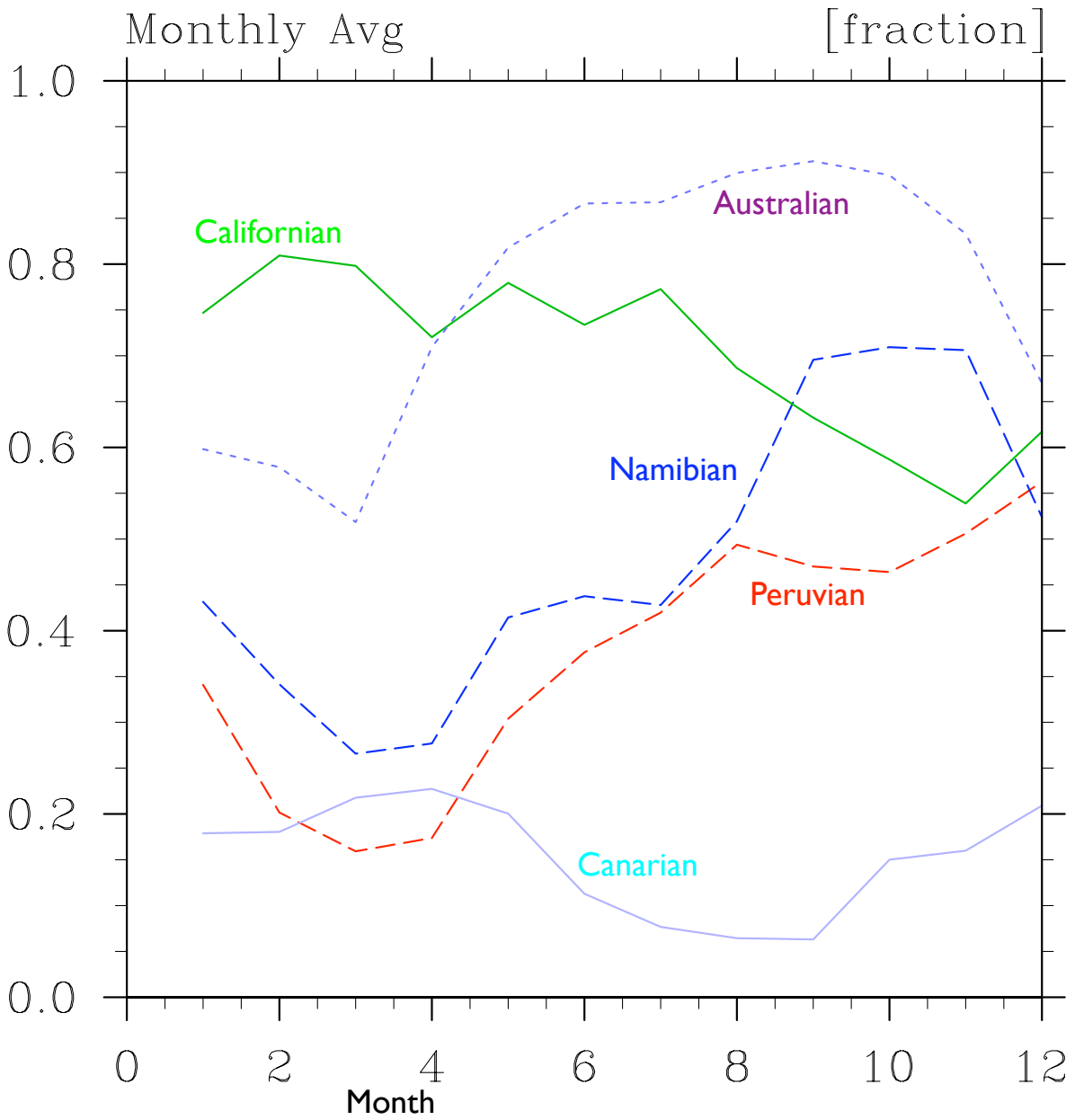
Cloud Fraction

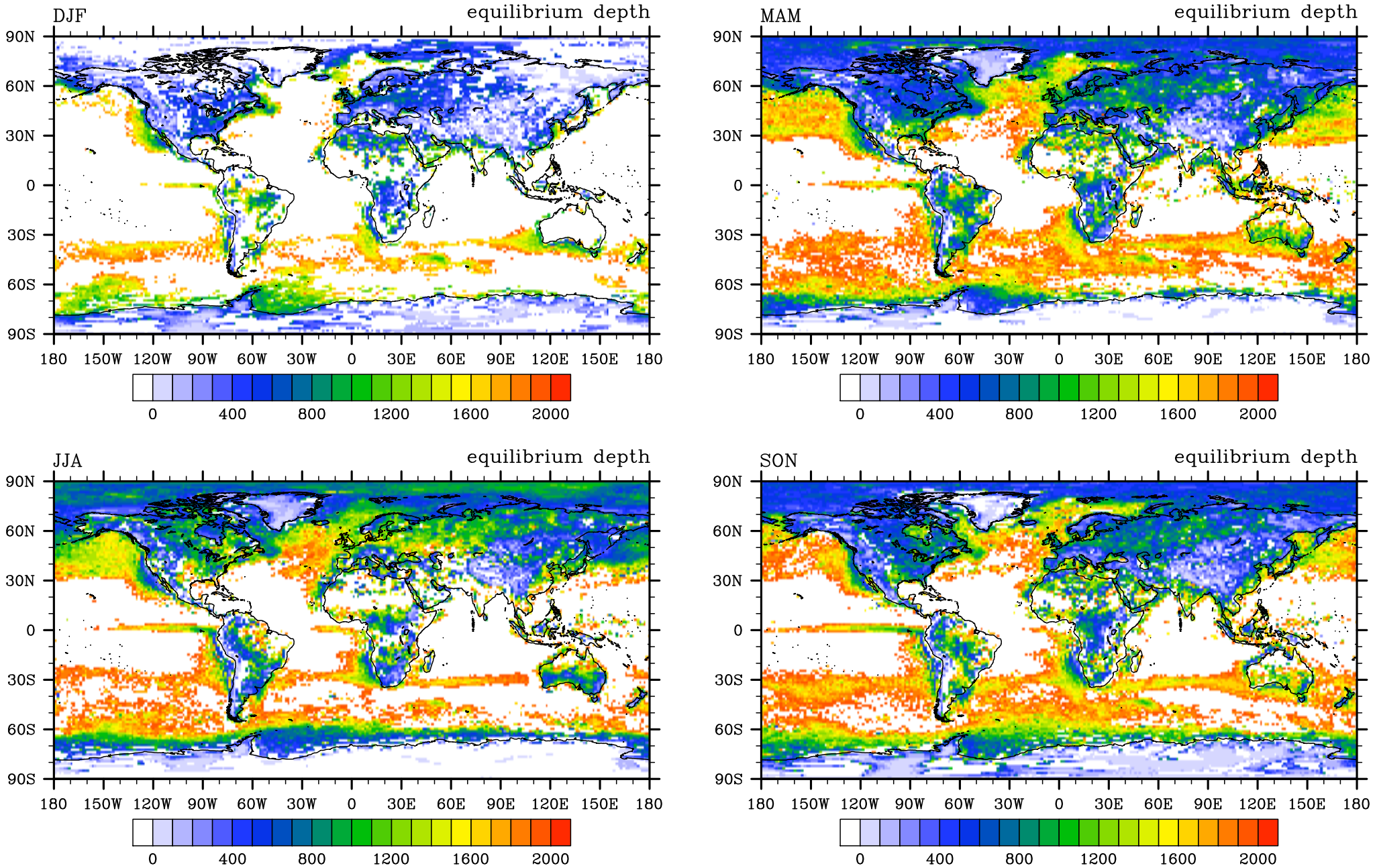






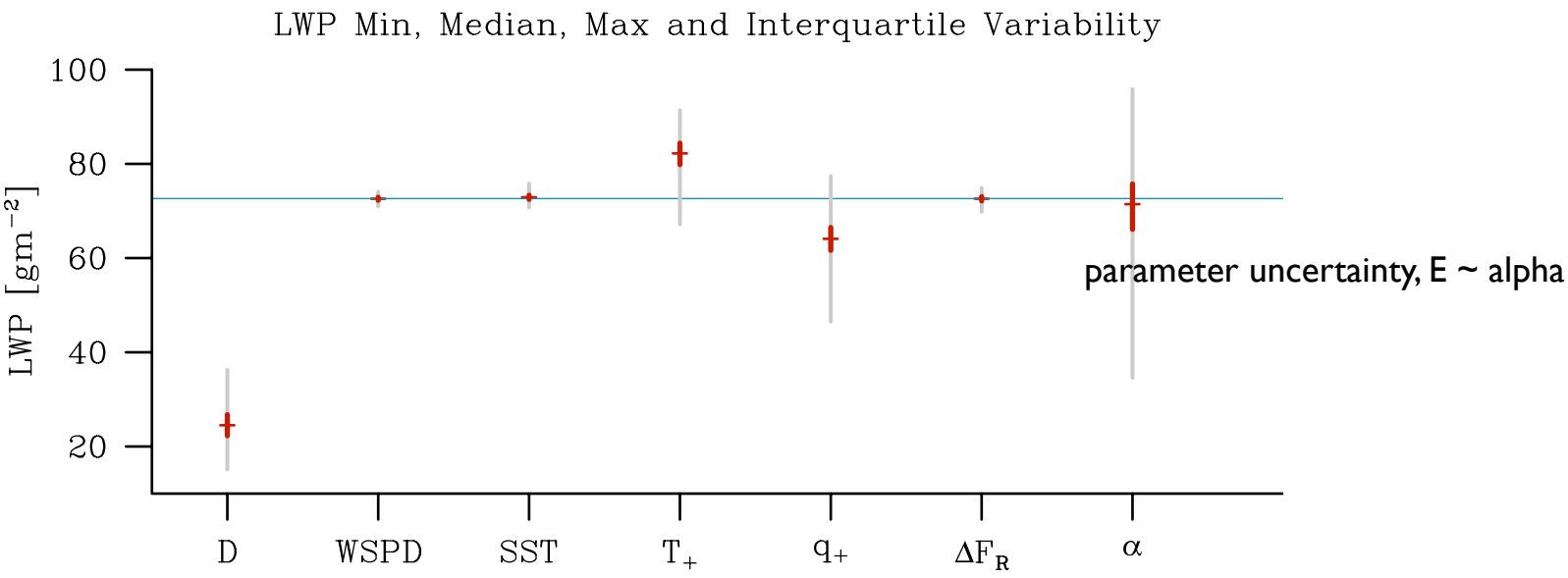



Monthly Avg
[fraction]
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
Month
Californian
Australian
Namibian
Peruvian
Canarian


DJF
equilibrium depth
MAM
equilibrium depth
JJA
equilibrium depth
SON
equilibrium depth
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 400 800 1200 1600 2000

Remarks

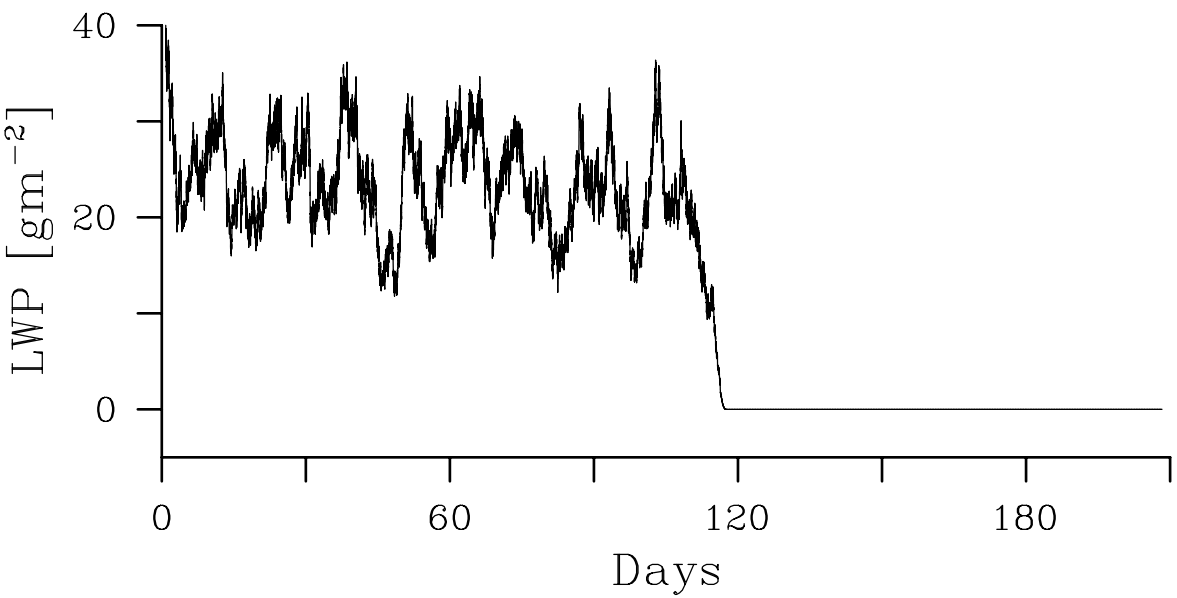
- NCEP selecting clear equilibrium solution?
- Some reasonable aspects to climatology
- Radiative entrainment fraction might be a useful basis for regime selection, and cloud fraction.
- Needs more systematic exploration ... weather noise?



model solutions with variability of large-scale state, or parameters (i.e., E~alpha) added as (white) noise

model solutions effectively linear in most forcings or parameters, except for large-scale divergence where we see the expression of the models multiple equilibria driving it to a relatively uncloudy state.

Catastrophe:



Summary

- Data explosion places demands on theory.
- Integral quantities seem like a reasonable starting point.
- Multiple equilibria pose challenges to this approach.
- Some remarkably useful data sources (ERA for boundary fluxes, ISCCP for cloud and boundary layer depth), which are already yielding surprises.