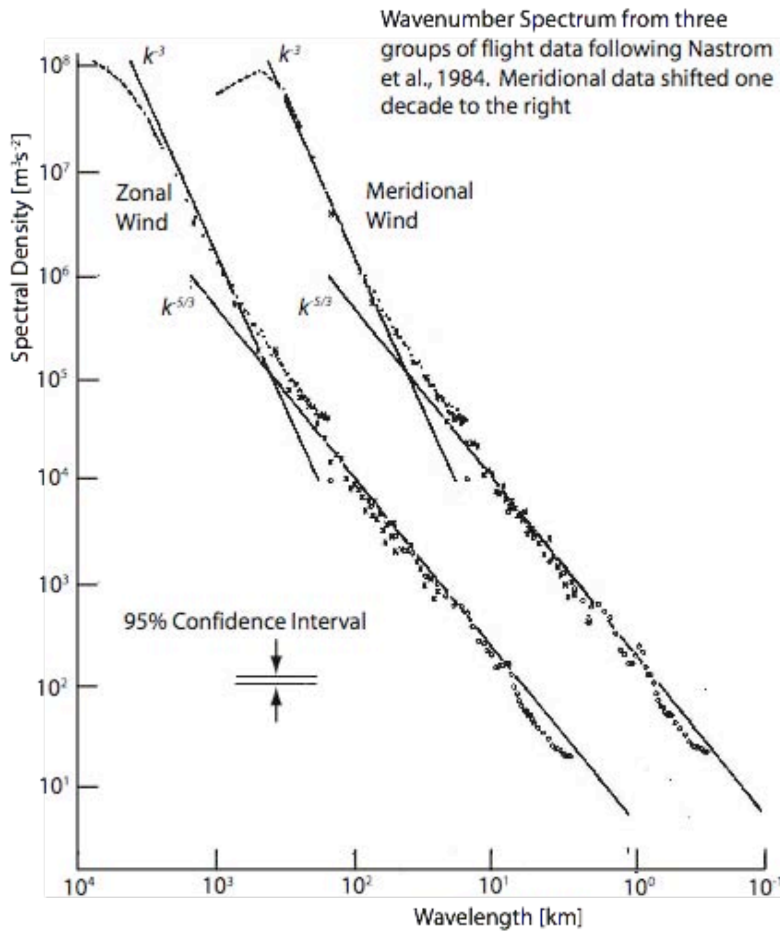
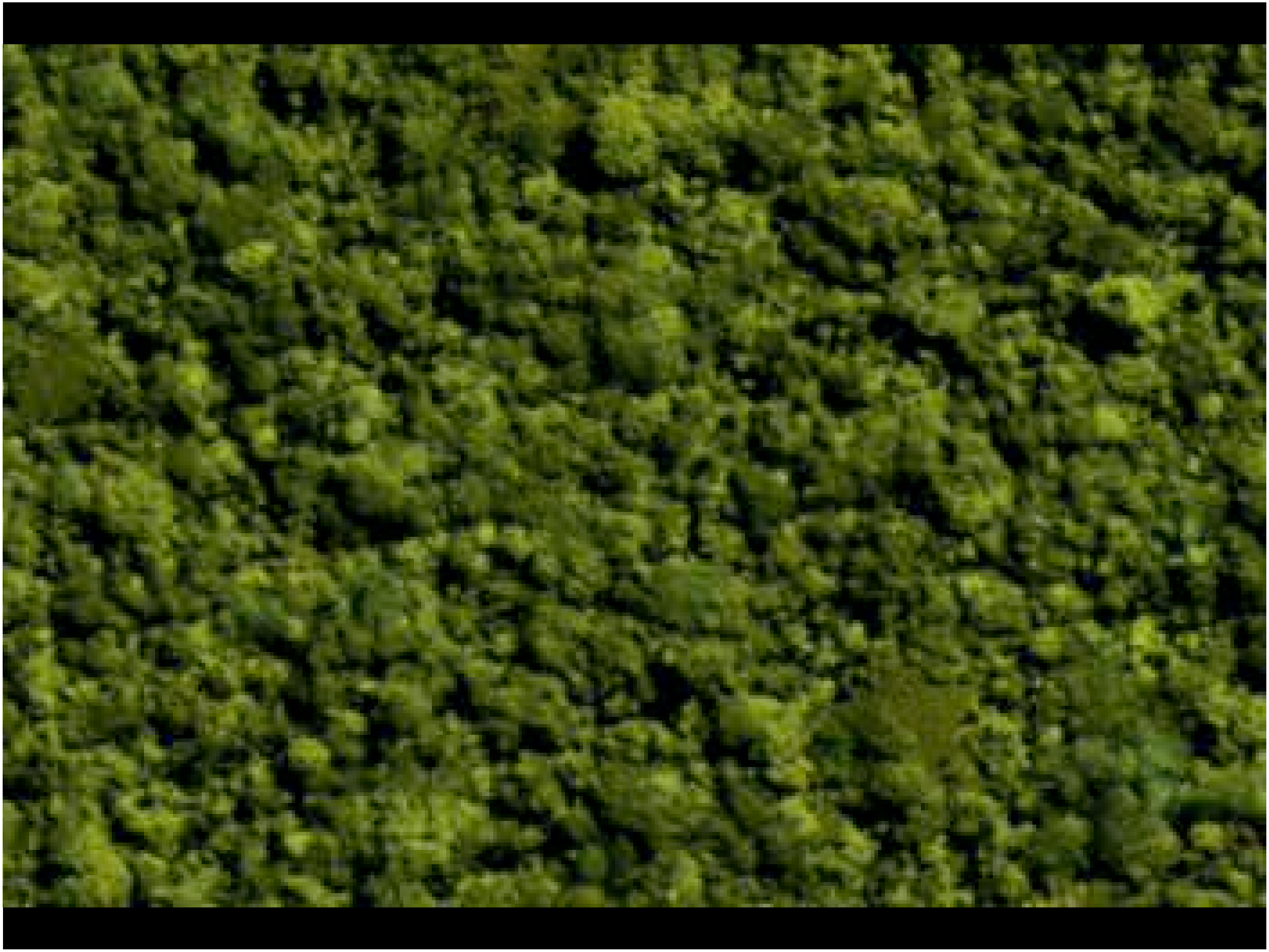
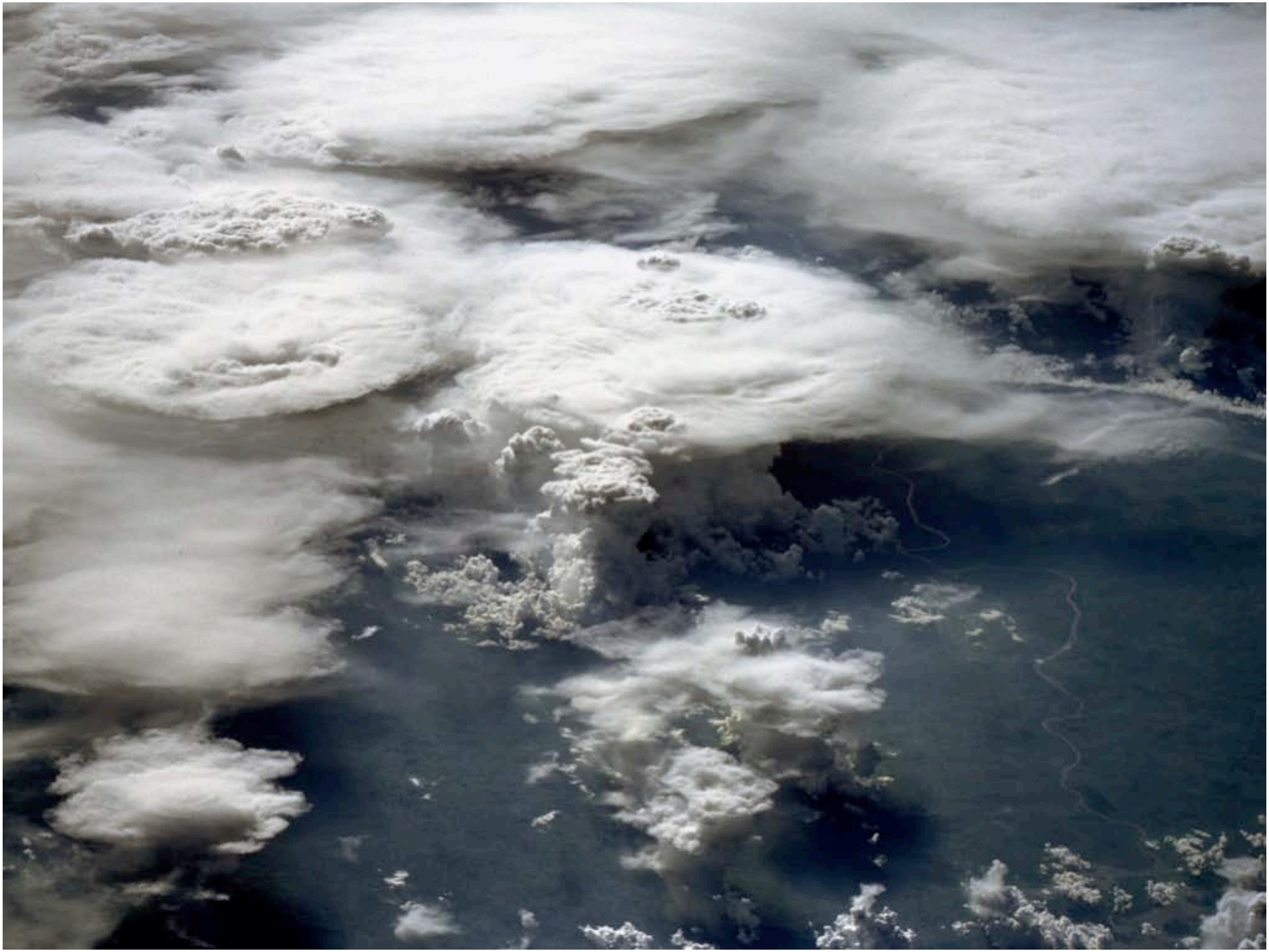
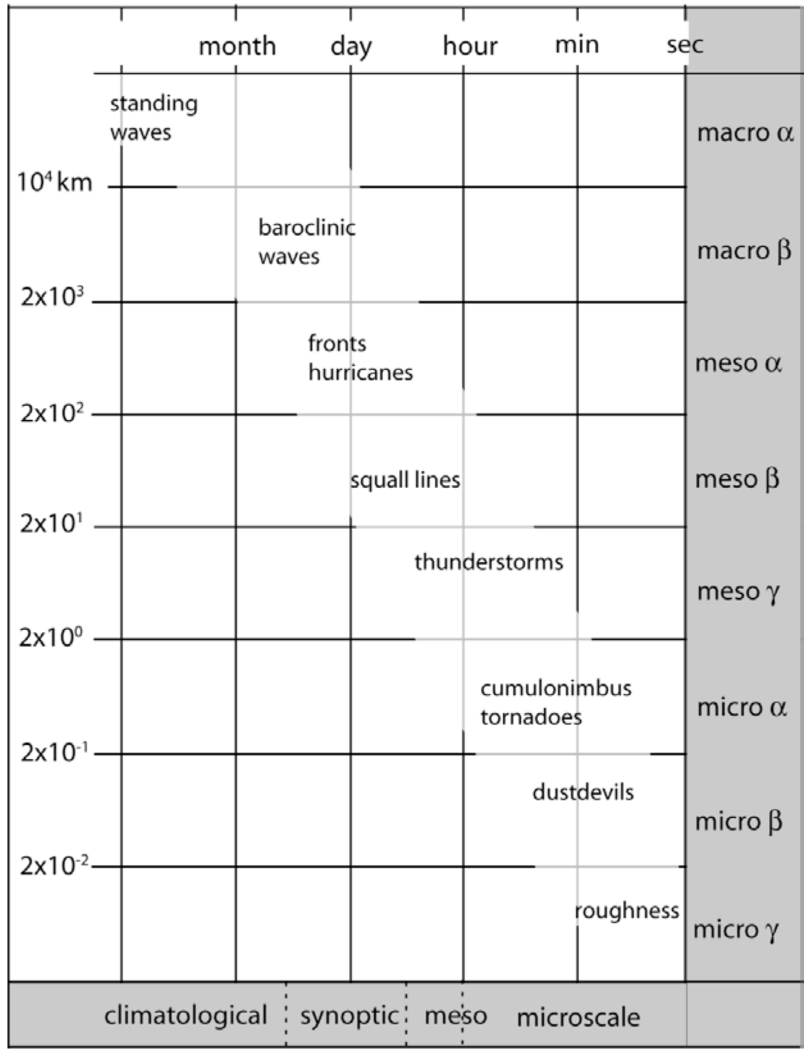
[redacted]


Wavenumber Spectrum from three groups of flight data following Nastrom et al., 1984. Meridional data shifted one decade to the right
Spectral Density [m³s⁻²]
Wavelength [km]
Zonal Wind
Meridional Wind
k⁻³
k⁻³
k⁻⁵/³
k⁻⁵/³
95% Confidence Interval
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁴
10³
10²
10¹
10⁰
10⁻¹

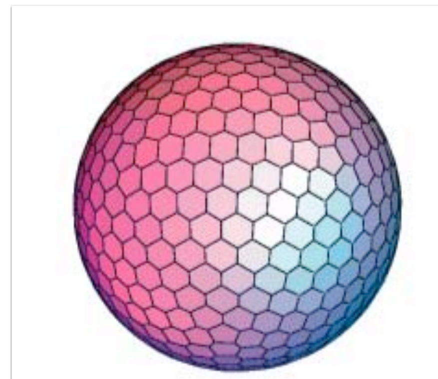


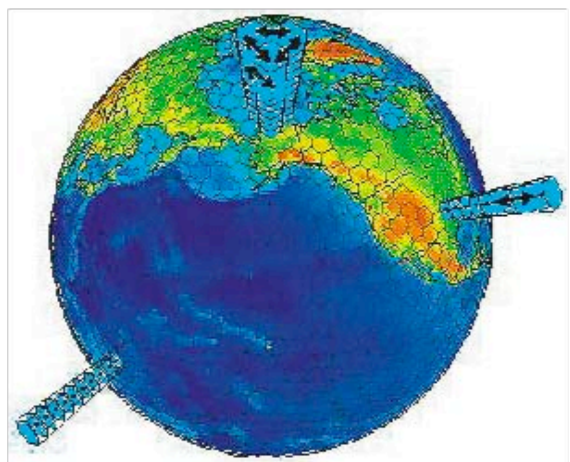


From Orlanski (1975) *A Rational Subdivision of Scales for Atmospheric Processes*

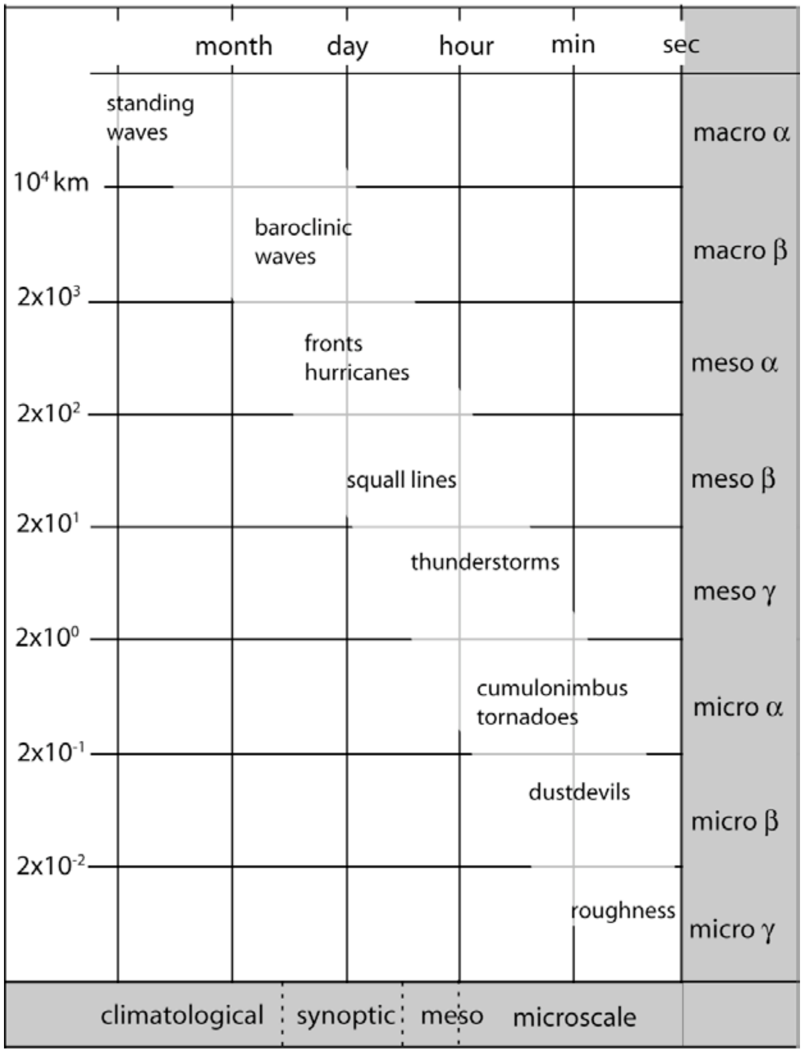


Building a General Circulation Model (GCM)

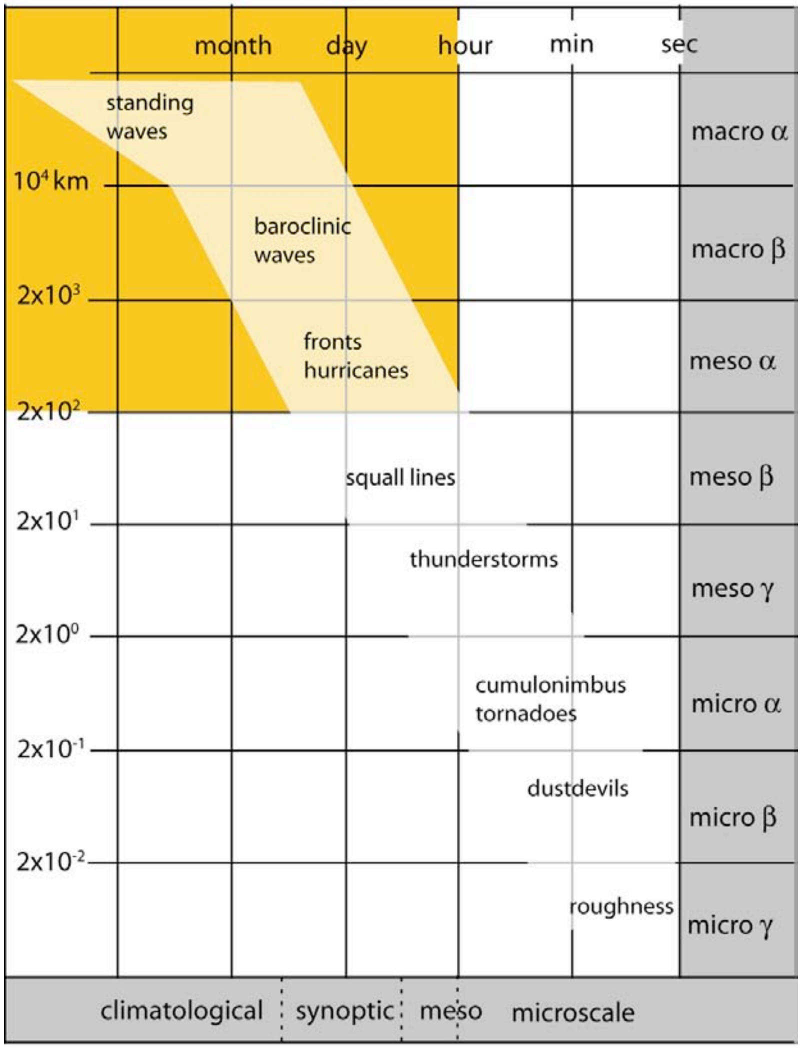




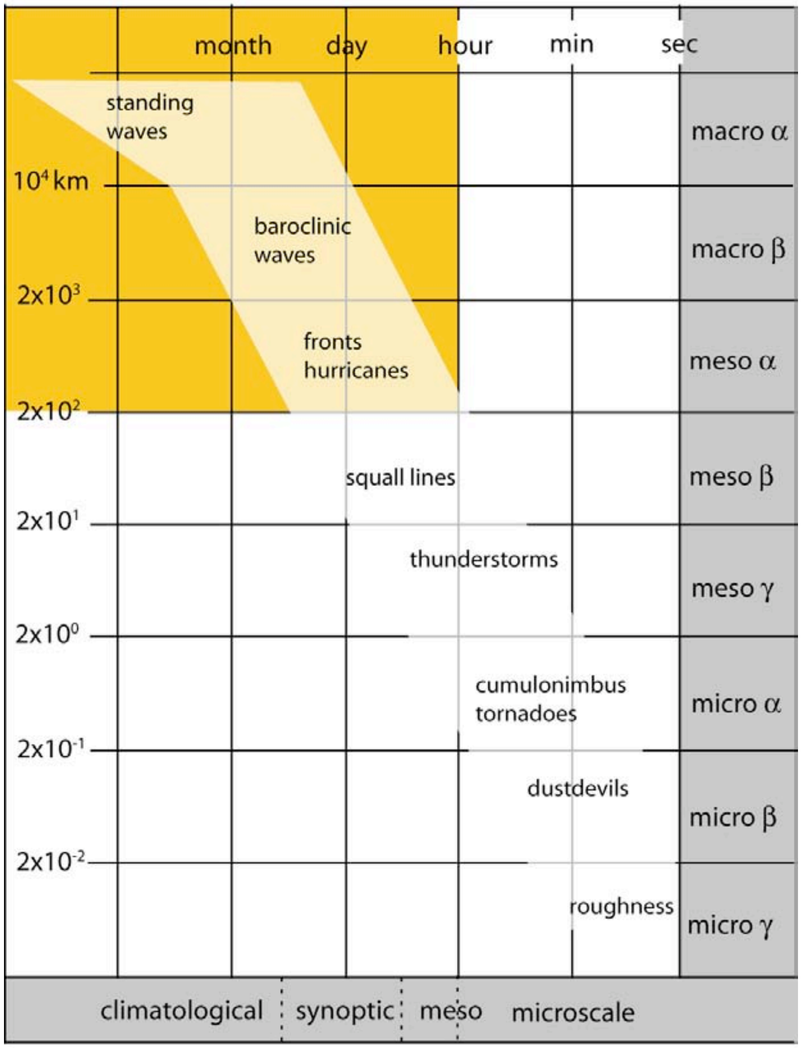
From Orlanski (1975) *A Rational Subdivision of Scales for Atmospheric Processes*



From Orlanski (1975) *A Rational Subdivision of Scales for Atmospheric Processes*



From Orlanski (1975) *A Rational Subdivision of Scales for Atmospheric Processes*



Consider

$$\frac{\partial \theta}{\partial t} + \frac{\partial u_i \theta}{\partial x_i} = 0. \quad (1)$$

If

$$u_i = \overline{u}_i + u_i', \quad \text{and} \quad \theta = \overline{\theta}_i + \theta',$$

then

$$\frac{\partial \overline{\theta}}{\partial t} + \frac{\partial \overline{u}_i \overline{\theta}}{\partial x_i} = -\frac{\partial \overline{u_i' \theta'}}{\partial x_i}. \quad (2)$$

Closure requires

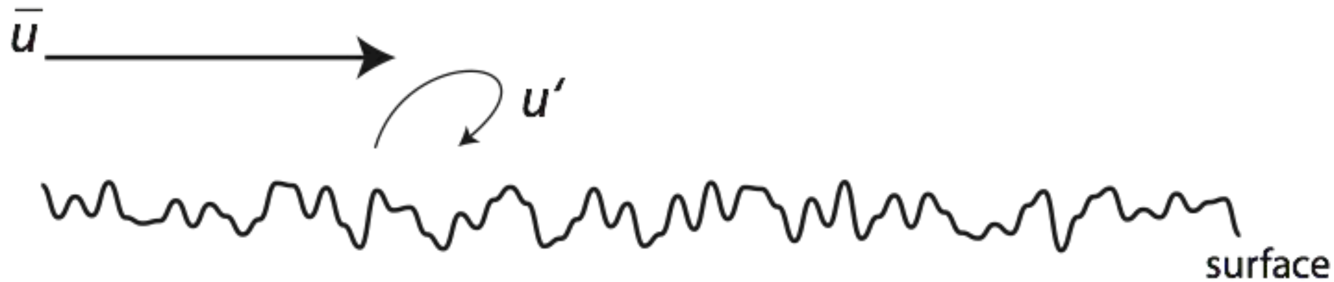
$$\overline{u_i' \theta'} = f(\overline{\theta}, \overline{u}_i) \quad (3)$$

or what in the jargon in our field is called a *parameterization.*

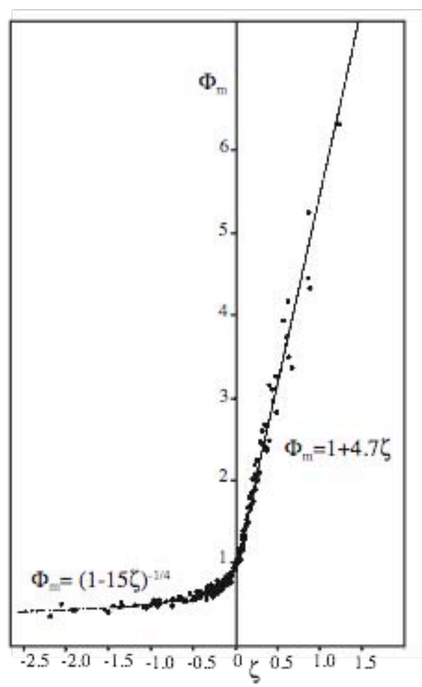
What are the Atoms?

(representing small scale processes in large scale simulations of the climate system)

Parameterizing Surface Exchange:



$\overline{u'w'} = -u_*^2 = f(\bar{u},\nu,z,\omega,r,h,d,T,\ldots)$ *perhaps* $u_* = \alpha z(d\bar{u}/dz)$



which can be written as

$$(d\bar{u}/dz)(z/u_*) = \Phi$$

where Φ is universal. Alternatively, if other parameters come into play, one might conjecture that

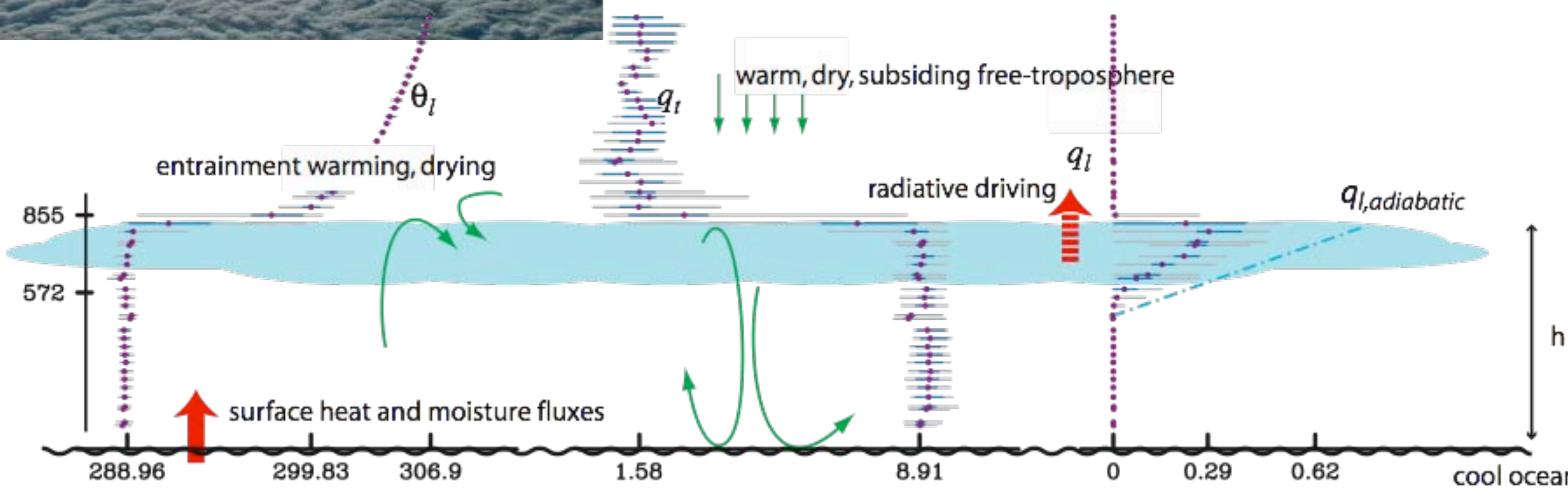
$$(d\bar{u}/dz)(z/u_*) = \Phi(\zeta).$$

where ζ measures that other parameter.

A Three Step Process

1. Insight
2. Dimensional Analysis
3. Empiricism

Stratocumulus Topped Boundary Layer



$$\frac{D}{Dt}\langle s\rangle = \overline{w's'}_0 - \overline{w's'}_h - (F_{h_-} - F_0)$$

$$\frac{D}{Dt}\langle q\rangle = \overline{w'q'}_0 - \overline{w'q'}_h$$

$$\frac{Dh}{Dt} = W + E$$

Parameterize:

$$\overline{w's'}_h = -E(s_+ - s) + F_{h_+} - F_{i-}$$

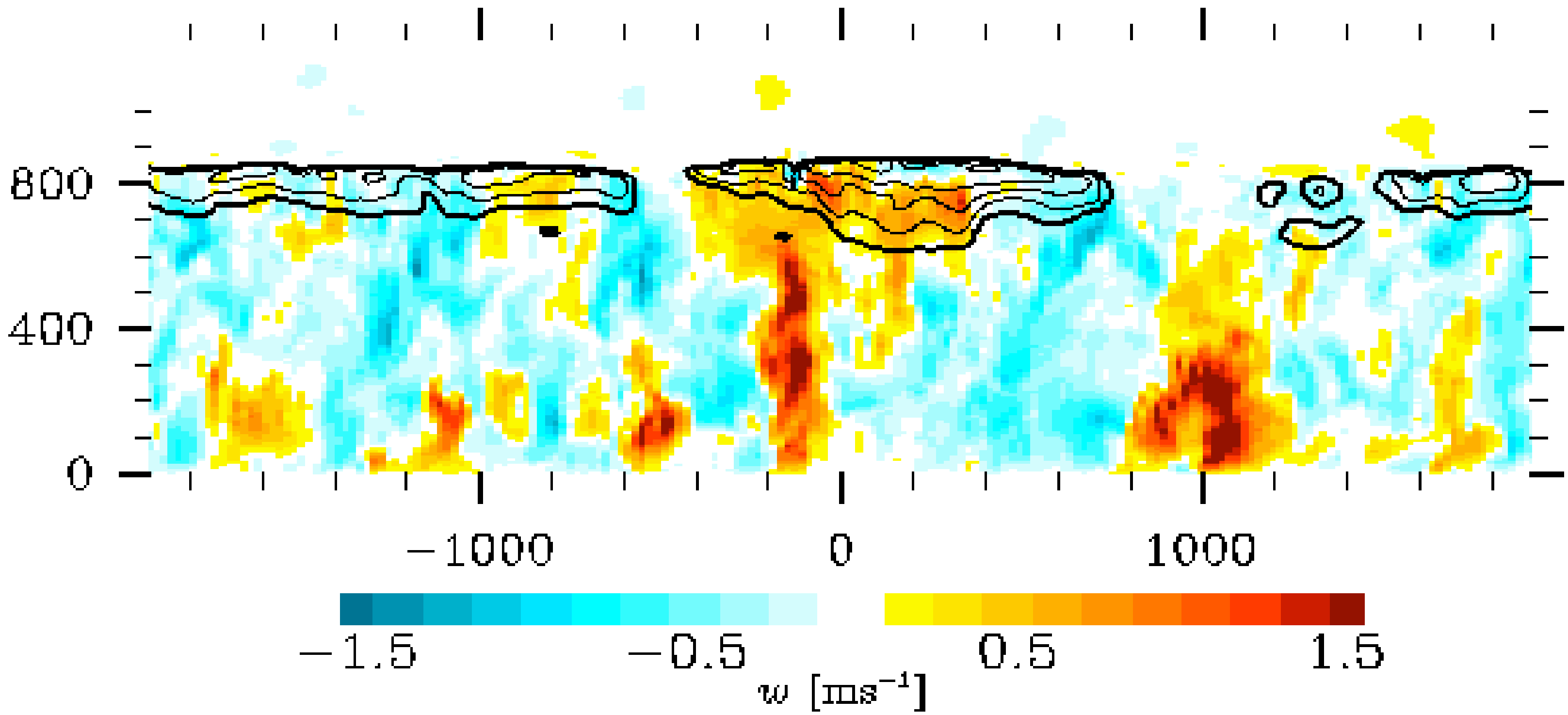
$$\overline{w's'}_0 = -V(s - s_0)$$

$$\overline{w'q'}_h = -E(q_+ - q)$$

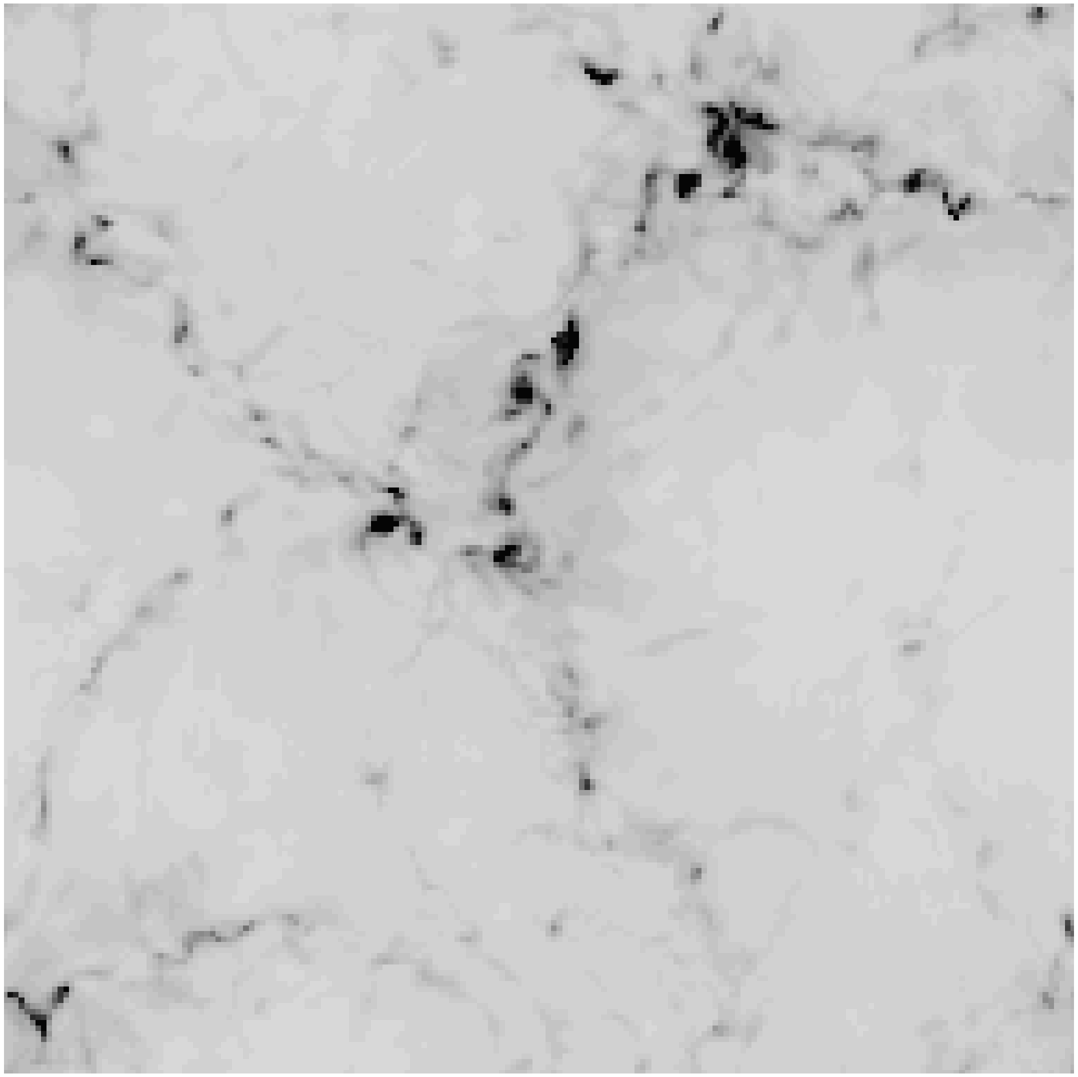
$$\overline{w'q'}_0 = -V(q - q_0)$$

with

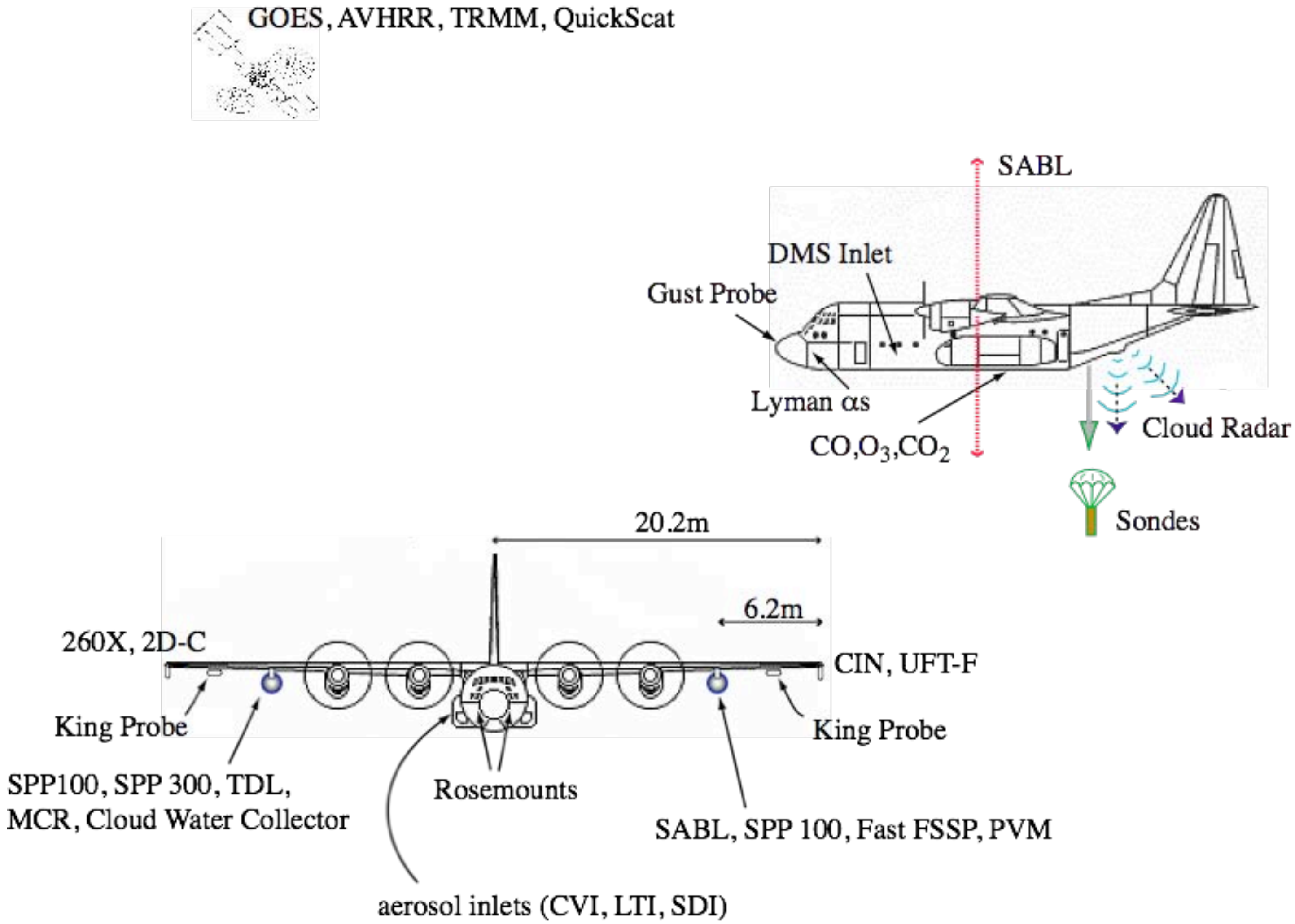
$$E = \alpha\frac{F_{h_+} - F_0}{s_+ - s}.$$



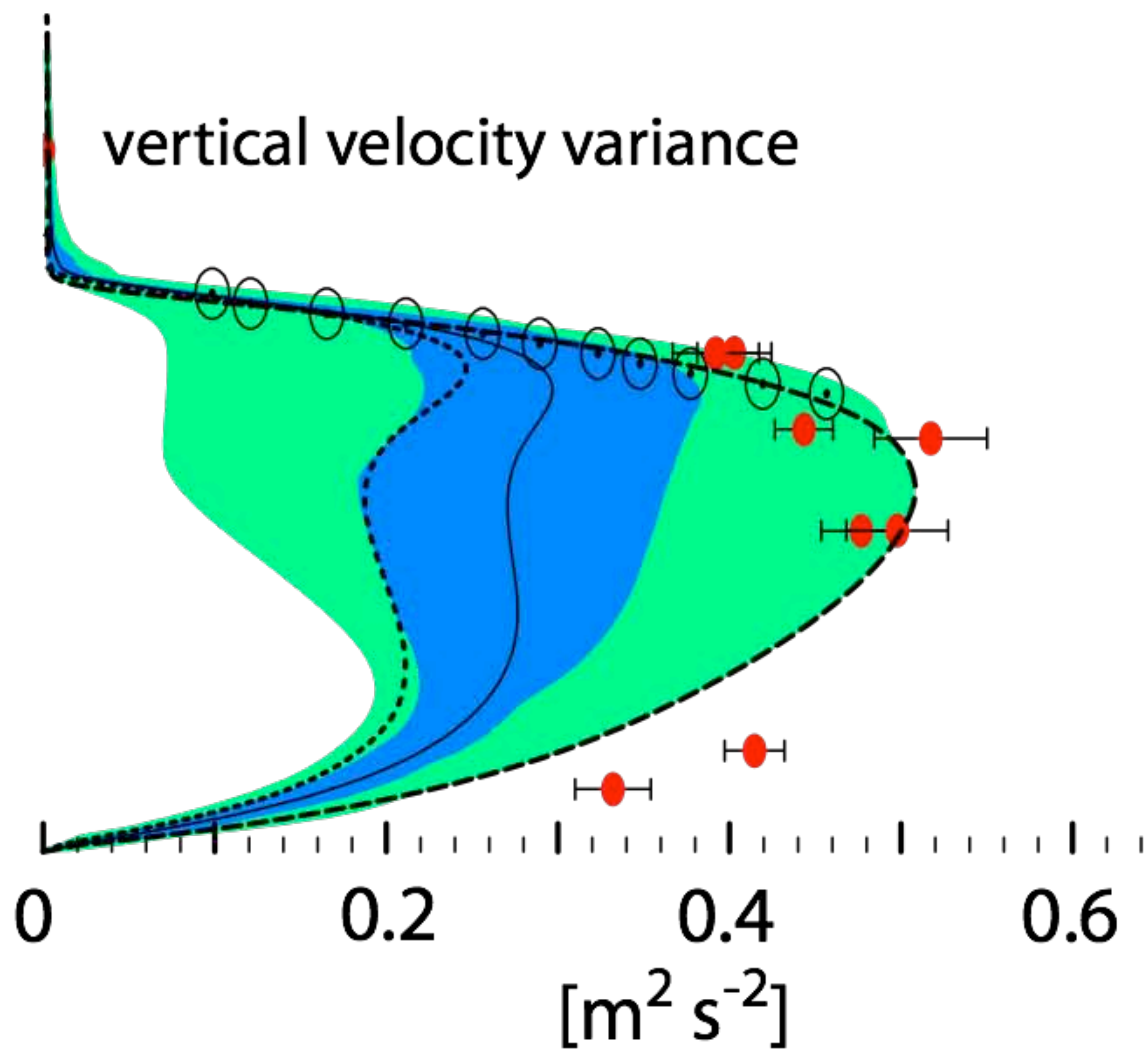
800
400
0
−1000
0
1000
−1.5
−0.5
0.5
1.5
w [ms⁻¹]

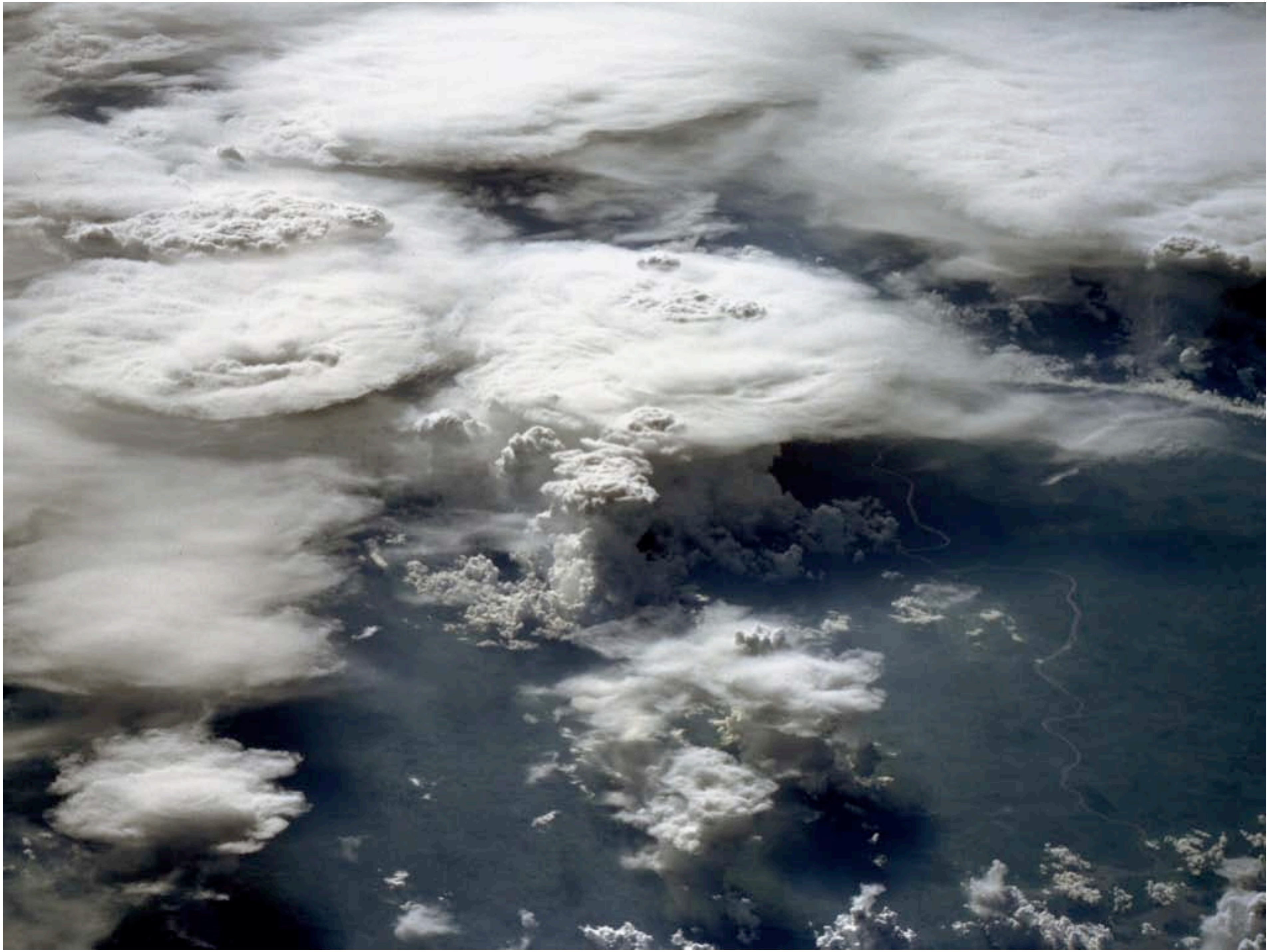


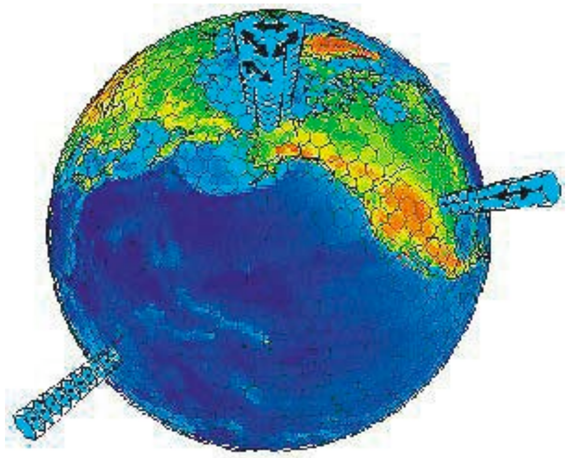
DYCOMS-II (July 2001): observing platforms

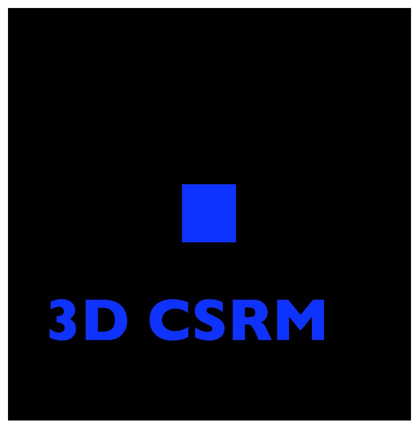


adapted from Stevens et al., *BAMS*, **84** (2003)


vertical velocity variance
0
0.2
0.4
0.6
[m^2 s^{-2}]







64 columns
64 wide

64 columns
8 wide

8 columns
8 wide

(Following Grabowski, Khairoutdinov and Randall)

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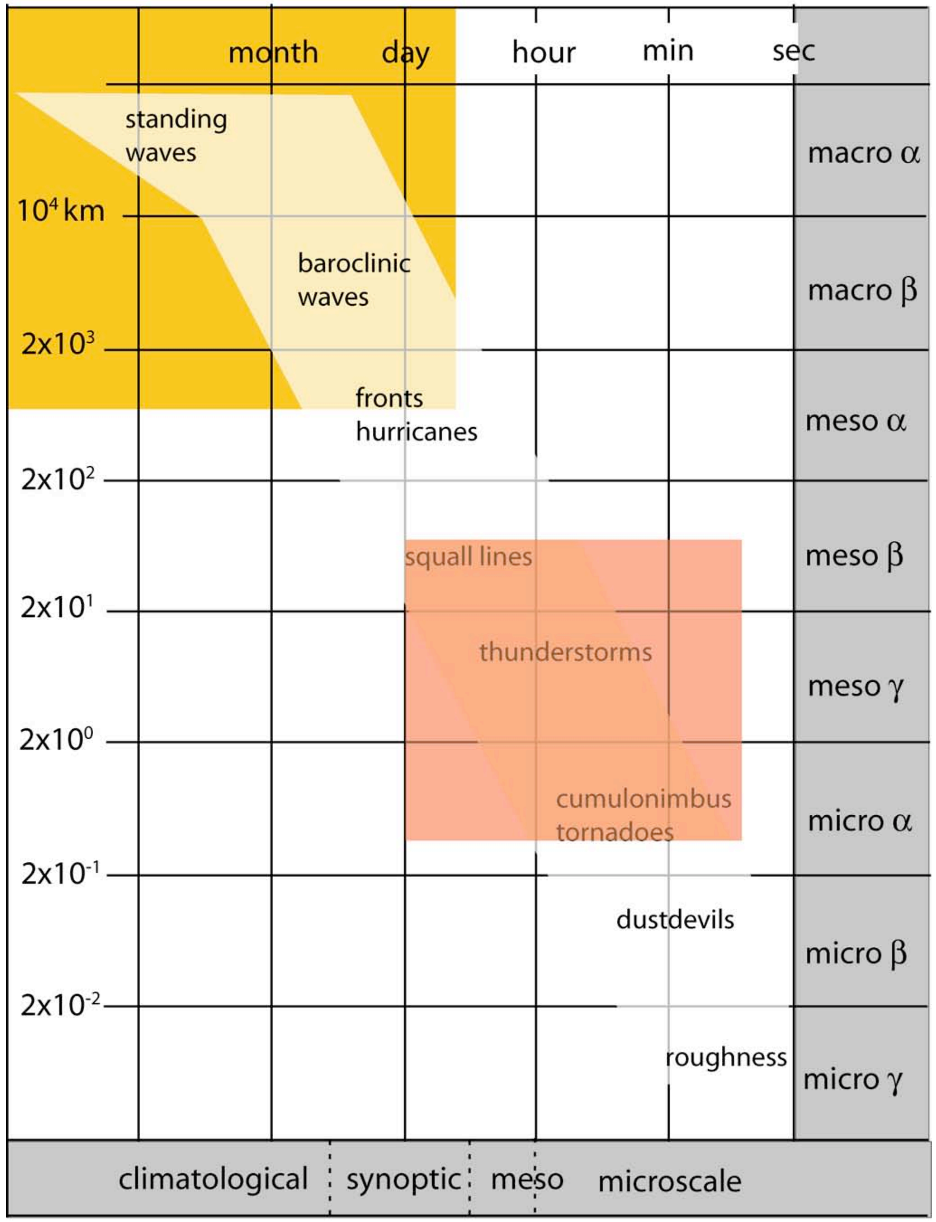
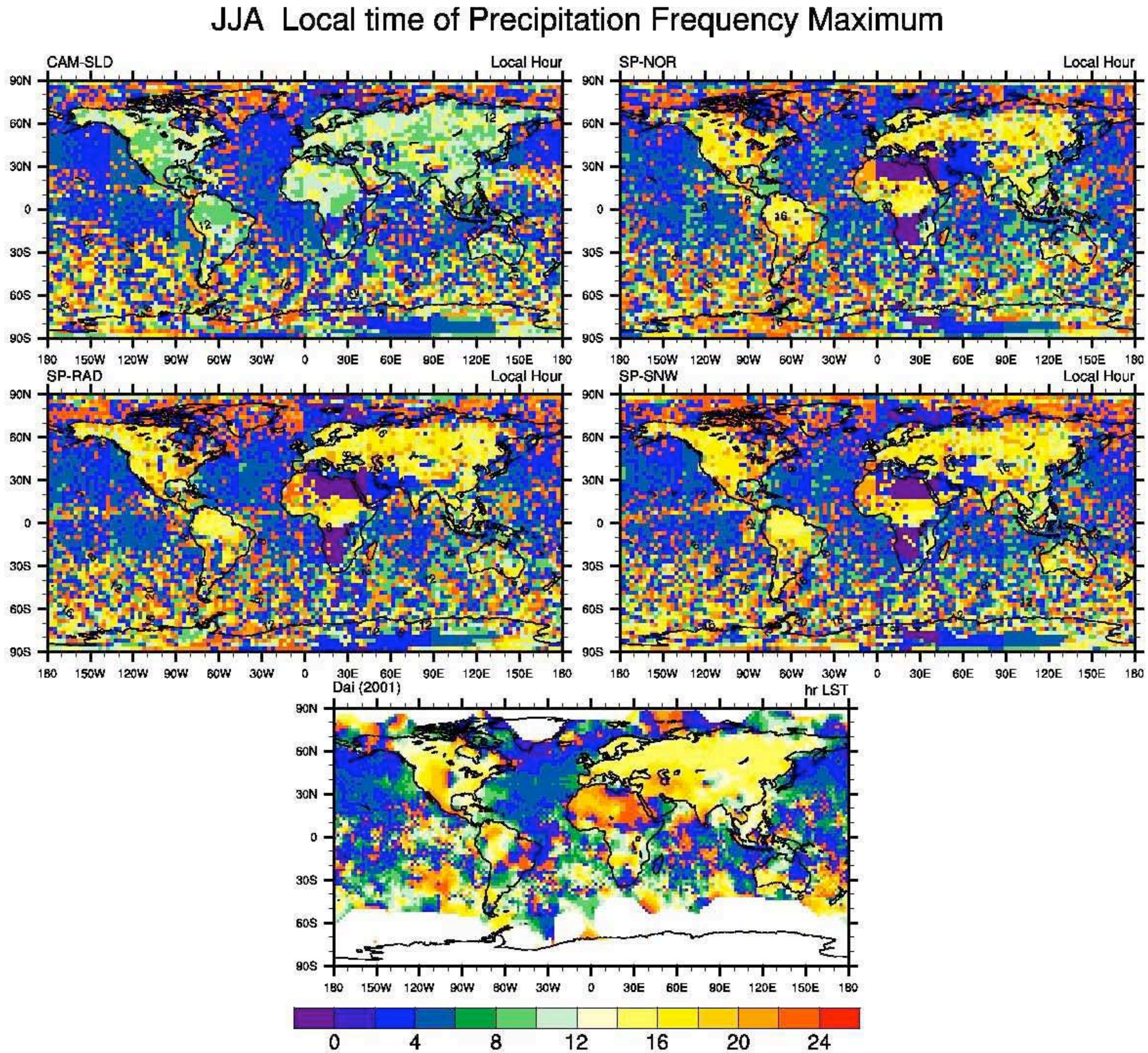
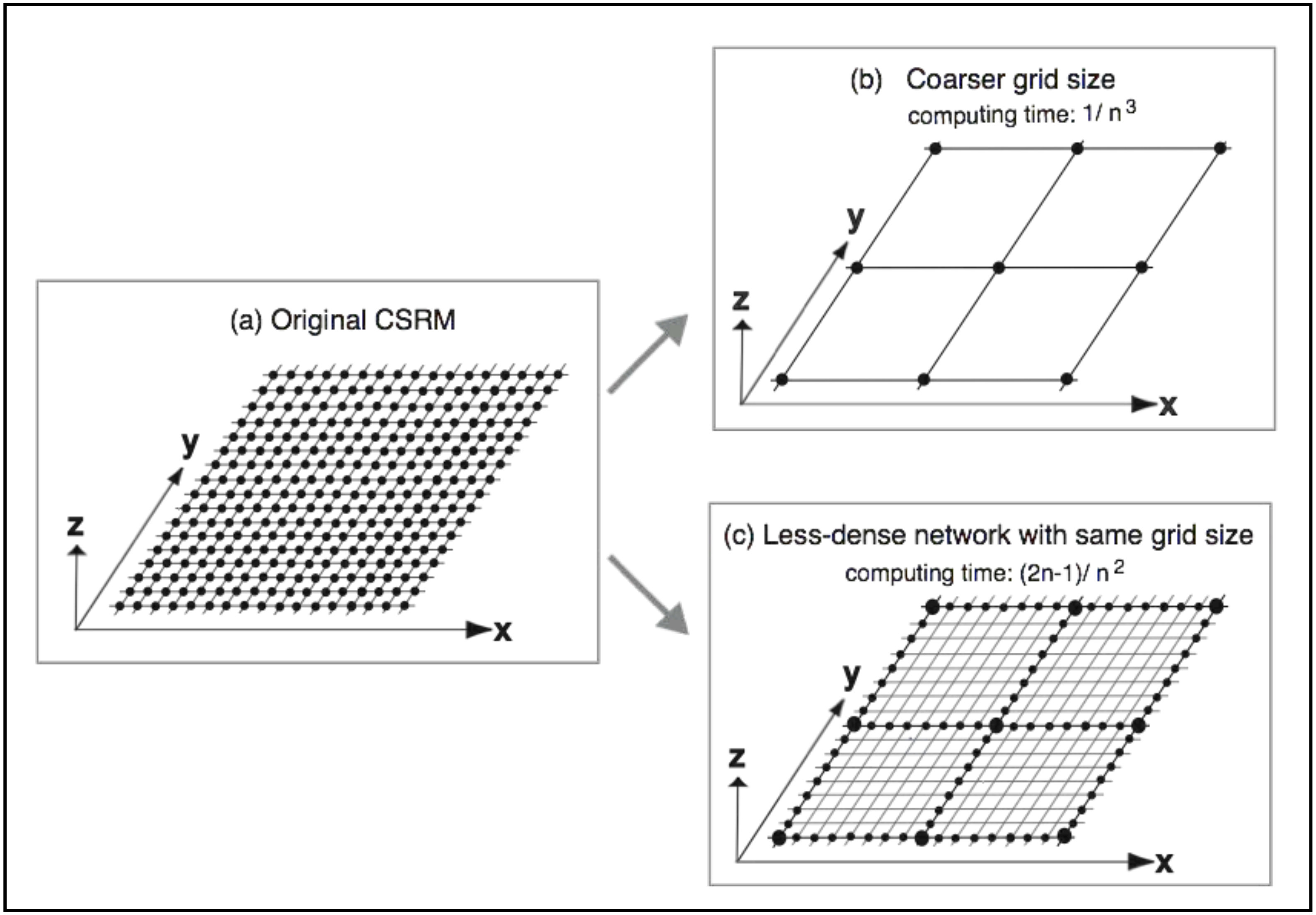




(graphic courtesy of D. Randall, Colorado State)



Following Arakawa (graphic courtesy of D. Randall, Colorado State)

Summary

1. The system is heterogeneous with myriad scales.

2. The intractability of the equations (turbulence) demands empiricism.

3. Some progress can be made by assuming local homogeneity and interpolating among idealizations.

4. The empirical step is non-trivial.

5. New, truly multiscale approaches which exploit massive computational capacity are promising, and only just beginning to be exploited.

Special thanks to David A. Randall for sharing his work on “super-parameterization” with me.