Capabilities of Ocean Mixed Layer Models

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ECMWF Workshop of Atmosphere-Ocean Interaction
"Near Surface Ocean Processes"

1) Introduction : The Oceanic Planetary Boundary Layer

2) **Hurricane Response**

3) **The Subtropical Gyre**

4) **The Equatorial Diurnal Cycle**

Mixing and Deepening Processes

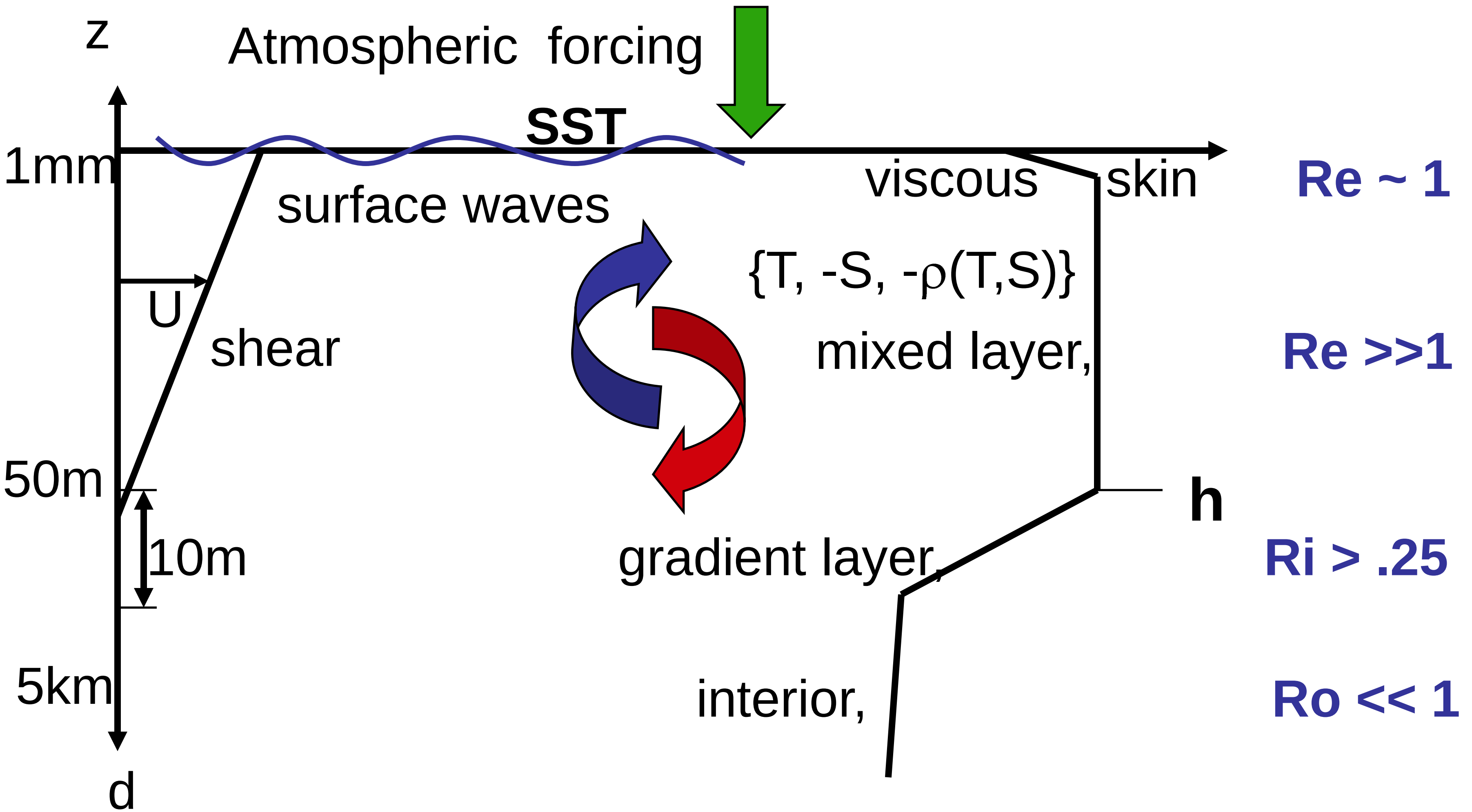
- Buoyancy Driven -- **Night-time convection**
  -- **Penetrative Convection**
  -- Winter deep convection
- Wind Driven -- **Inertial resonance**
- Wave Driven -- **Langmuir Circulation**
  -- **Breaking**
- Interior Driven -- **Current Shear**

Re-stratification and Shoaling Processes

- Surface -- **Diurnal**
- Instabilities -- **Mesoscale Eddies**
  -- **Sub-mesoscale Sub-mesoscale**

Hurricane **Subtropical Gyre** **Equatorial**

1) The Ocean Boundary Layer (OBL)



Layered structure is a consequence of the changing balance of terms with increasing distance, d.

Hurricane Response

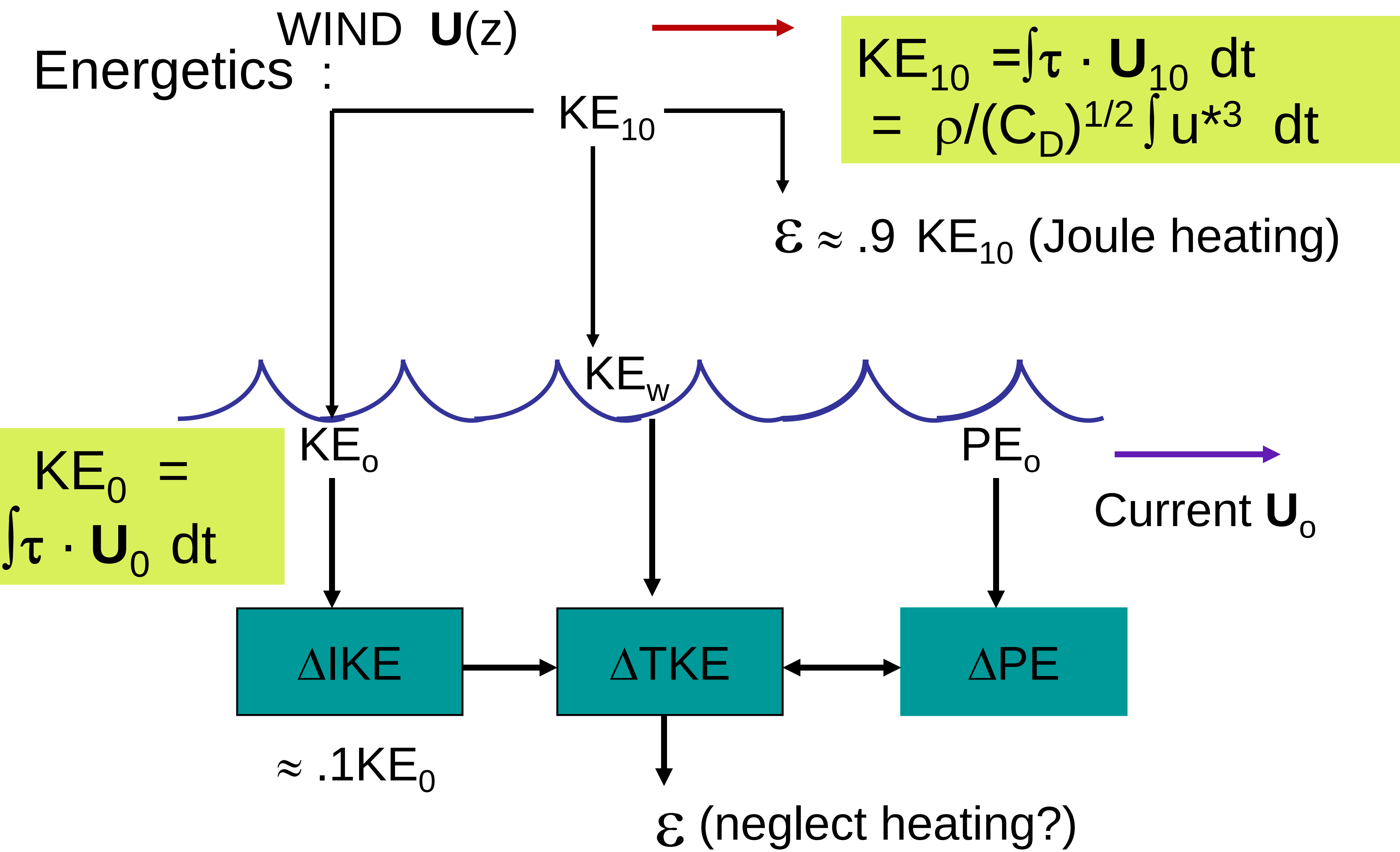
Mixing and Deepening Processes

- Wind Driven -- **Inertial resonance**
- Wave Driven -- **Breaking** (small)

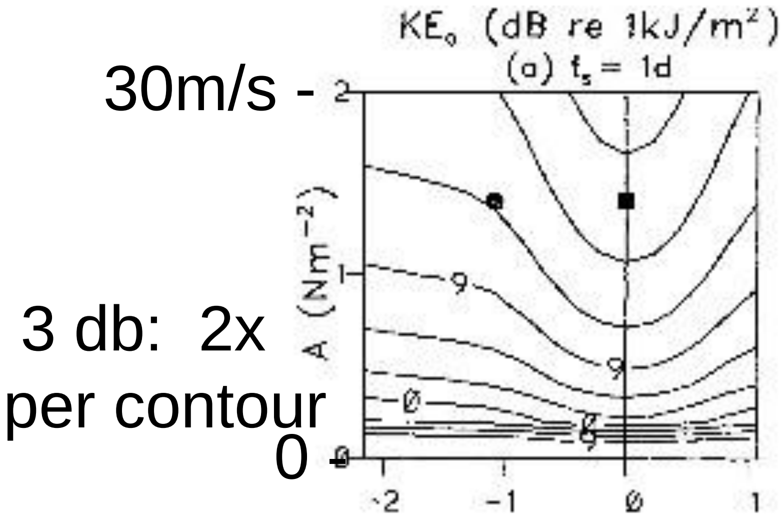
Re-stratification and Shoaling Processes

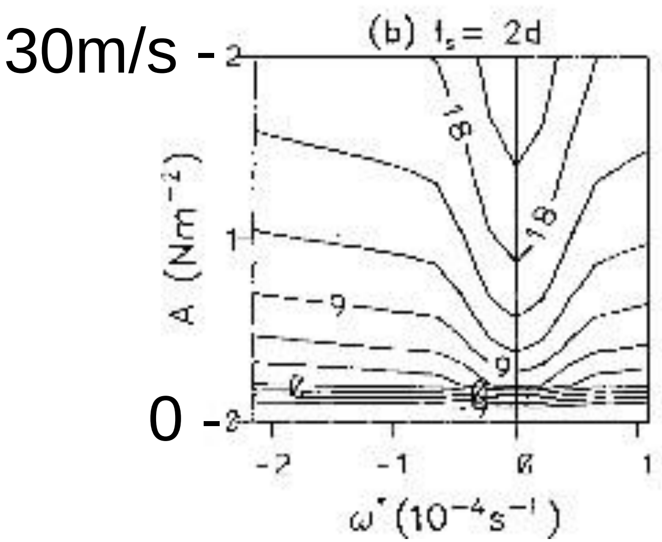
- Instabilities -- **Sub-mesoscale**

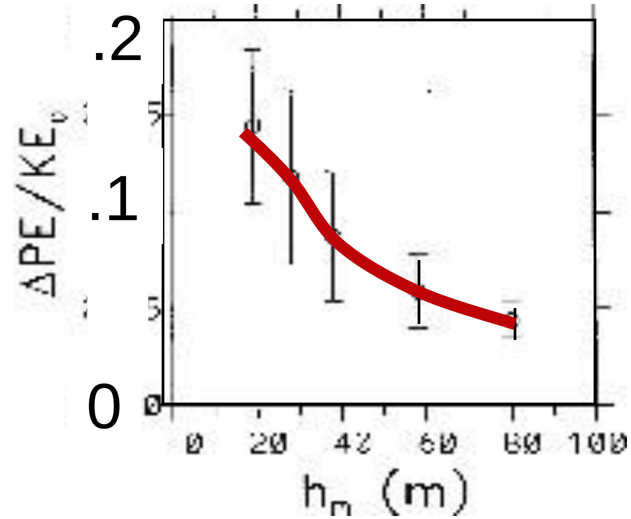
Hurricane Response

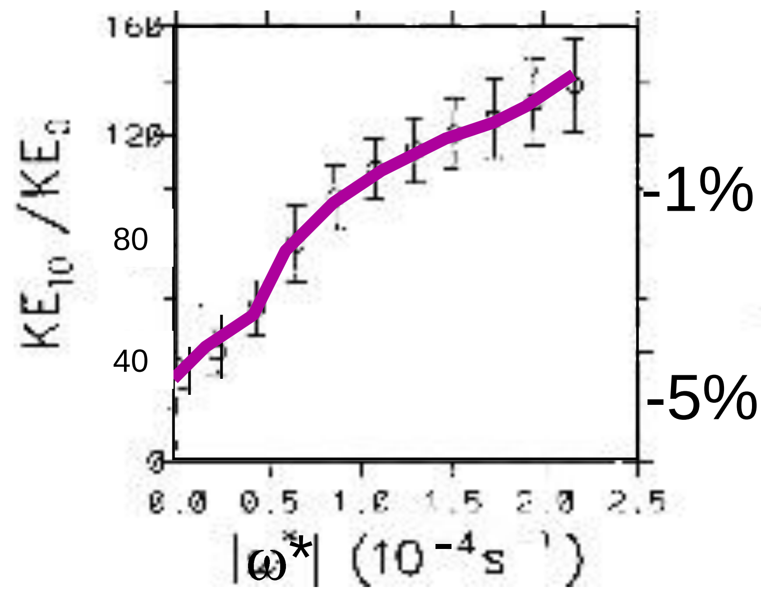


Inertial Resonance , KE_o : $\omega^* = (\omega - f)$
$\tau = A \sin^n(\pi t/\Delta t) \quad \exp\{ -j (\omega^*+f) t /\Delta t\}$

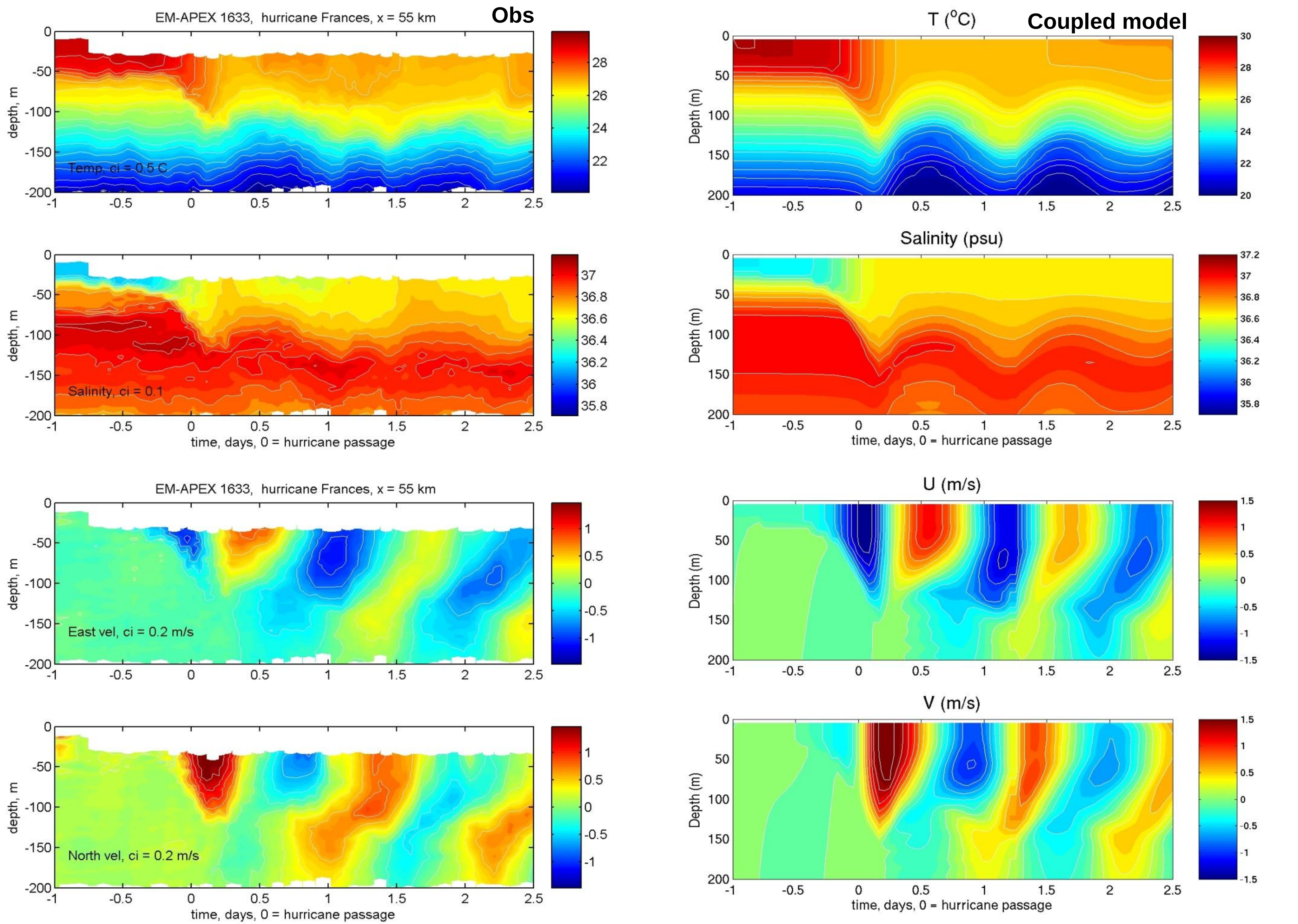








QuickTime™ and a
BMP decompressor
are needed to see this picture.


Obs
Coupled model
EM-APEX 1633, hurricane Frances, x = 55 km
Temp, ci = 0.5 C
Salinity, ci = 0.1
East vel, ci = 0.2 m/s
North vel, ci = 0.2 m/s
depth, m
time, days, 0 = hurricane passage
T (°C)
Salinity (psu)
U (m/s)
V (m/s)
Depth (m)

Subtropical Gyre

Mixing and Deepening Processes

- Buoyancy Driven -- **Penetrative Convection**
- Wave Driven -- **Langmuir Circulation**

Re-stratification and Shoaling Processes

- Instabilities -- **Sub-mesoscale**

SUBMESOSCALE EDDY PARAMETERIZATION
(Fox-Kemper, Ferrari, and Hallberg 2008)

The associated streamfunction is given by

$$\Psi = C_e \mu(z) \frac{H^2 \left|\overline{\nabla \mathbf{b}}\right| \times \mathbf{z}}{\sqrt{f^2 + 1/t^2}} \max\left[\left(\frac{\min(\Delta x, 1^\circ)}{L}\right), 1\right]$$

where

C_e: efficiency factor (0.06-0.08),

μ: quartic shape function,

H: mixed layer depth,

b: buoyancy vertically averaged over H,

f: Coriolis parameter,

t: time scale (1 day – 1 week),

Δx: model grid resolution,

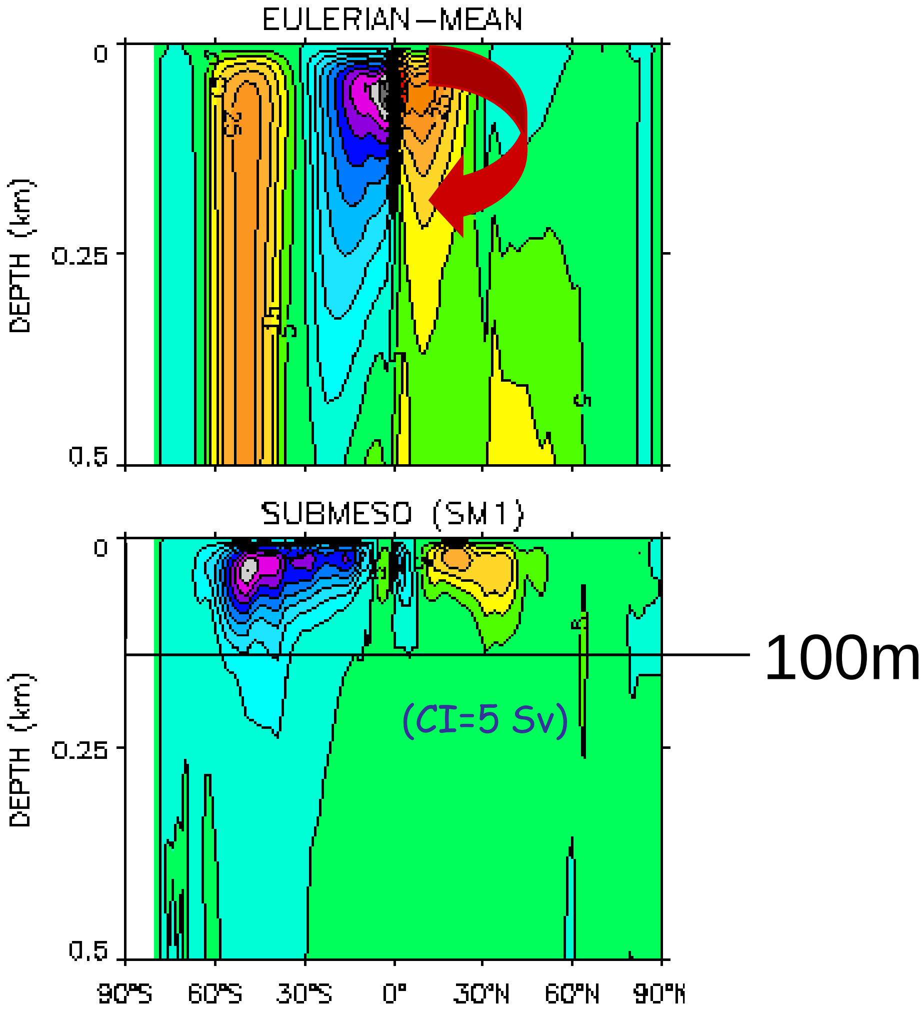
L: length scale

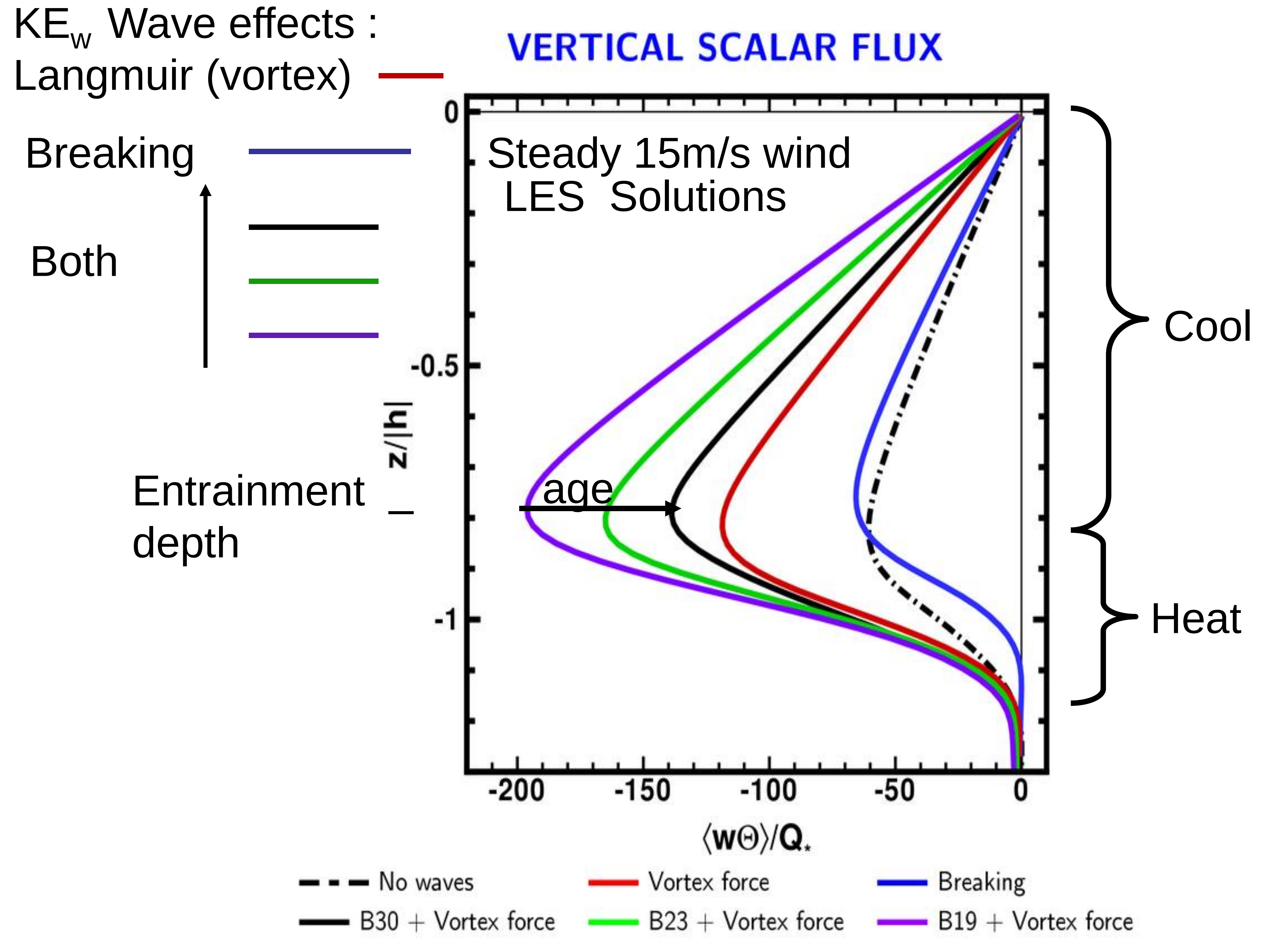
$$L = \max\left(\frac{\left|\overline{\nabla \mathbf{b}}\right| H}{f^2}, \frac{NH}{|f|}, L_{\min}\right)$$

with L_{min} = 1-10 km

Sub-mesoscale restratification

MERIDIONAL OVERTURNING STREAMFUNCTIONS (GLOBAL)



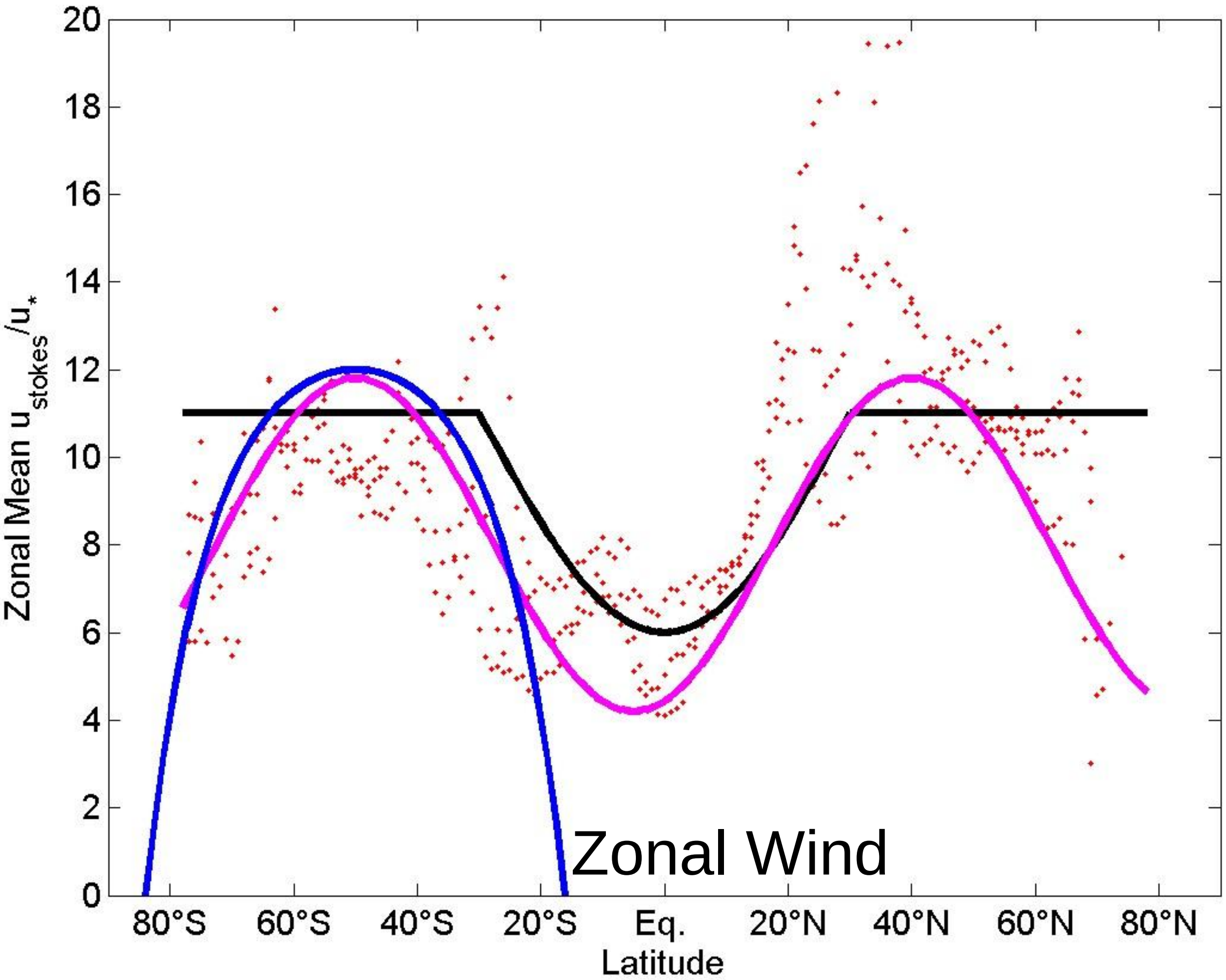


KE$_w$ Wave effects :
Langmuir (vortex)
Breaking
Both
Entrainment depth
VERTICAL SCALAR FLUX
Steady 15m/s wind
LES Solutions
age
Cool
Heat
0
-0.5
-1
z/|h|
-200
-150
-100
-50
0
⟨wΘ⟩/Q*
No waves
Vortex force
Breaking
B30 + Vortex force
B23 + Vortex force
B19 + Vortex force

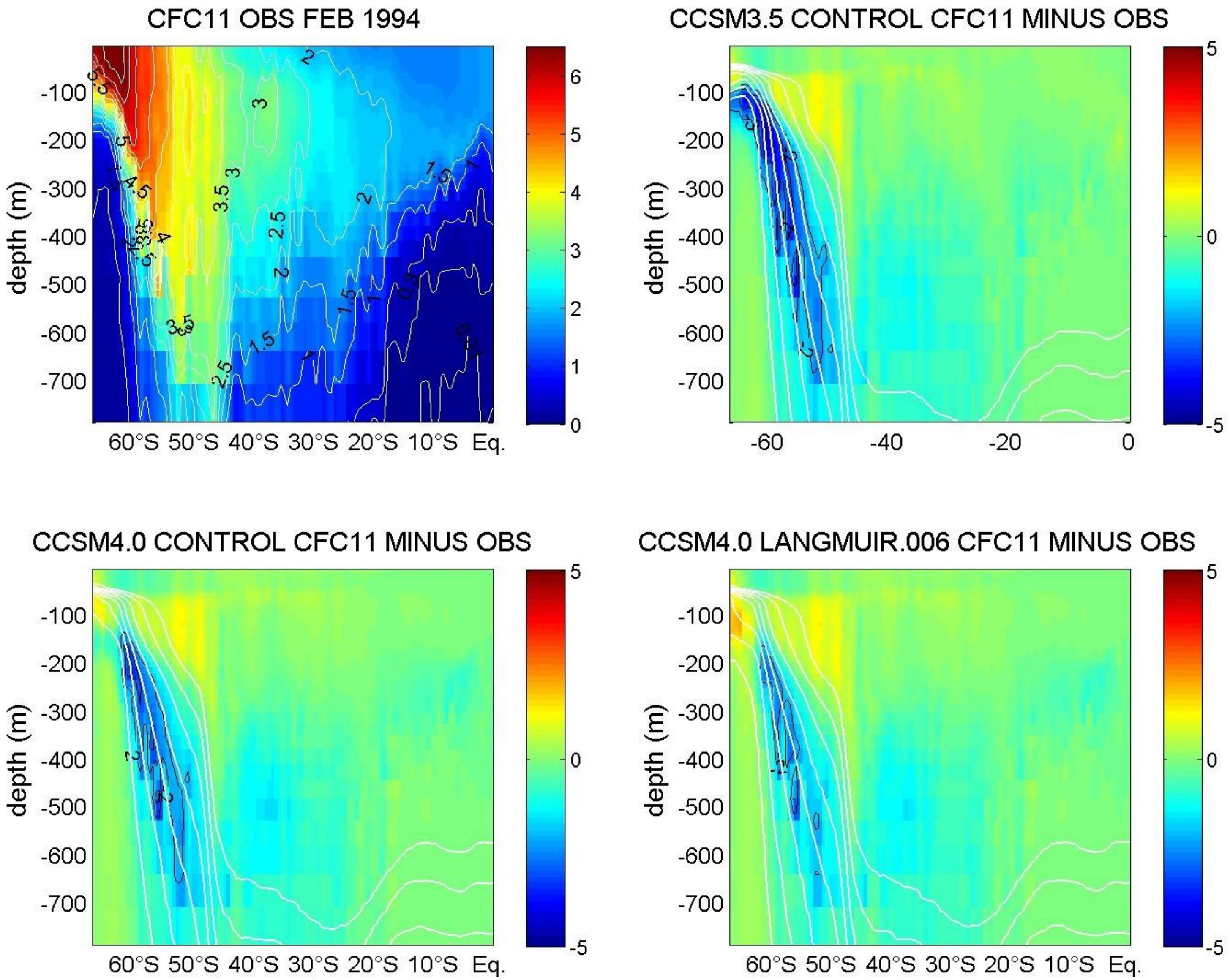
Langmuir uptake of CFCs

L_a^{-2}

$\frac{Ustokes}{u^*}$

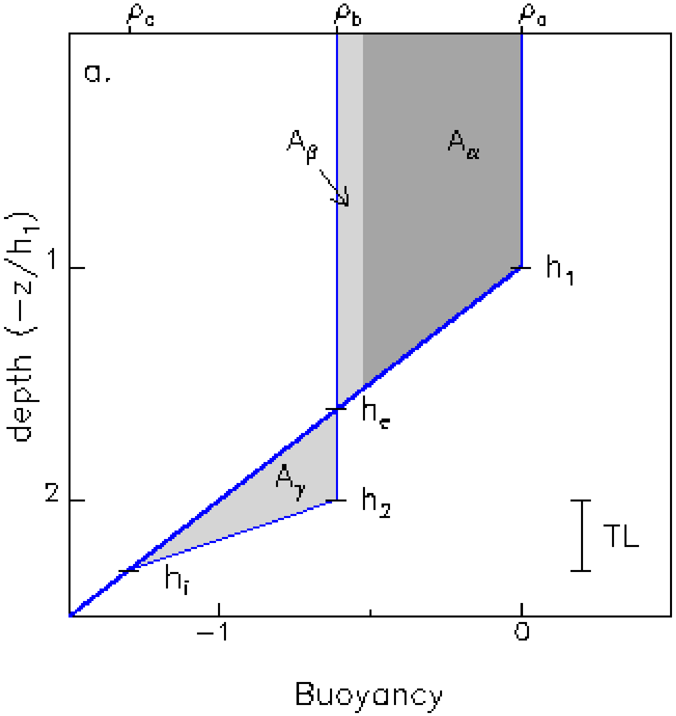


CFC-11 along 170W in Feb 1994



Zonal Wind Case

Fall penetrative convection



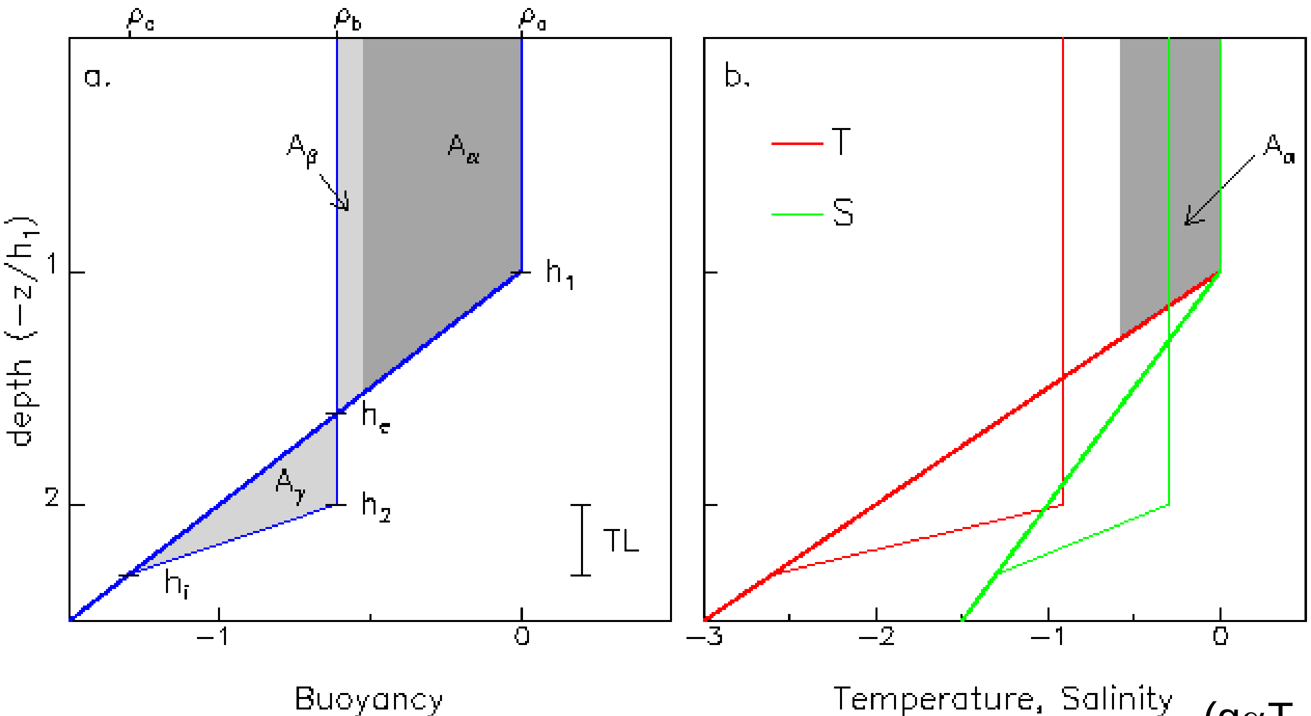
1. pre-convection (thick)

2. post-convection (thin)

Assume:

a) Surface buoyancy flux A_α
b) buoyancy entrainment $A_\gamma = A_\beta = 0.2A_\alpha$
c) Vigorous boundary layer mixing ($h_2 = 2h_1$)

Convective Spice Injection



(gαT, gβS)

1. pre-convection (thick)

   Tu = 71.6°

2. post-convection (thin)

Assume:

a) Surface buoyancy flux A_α

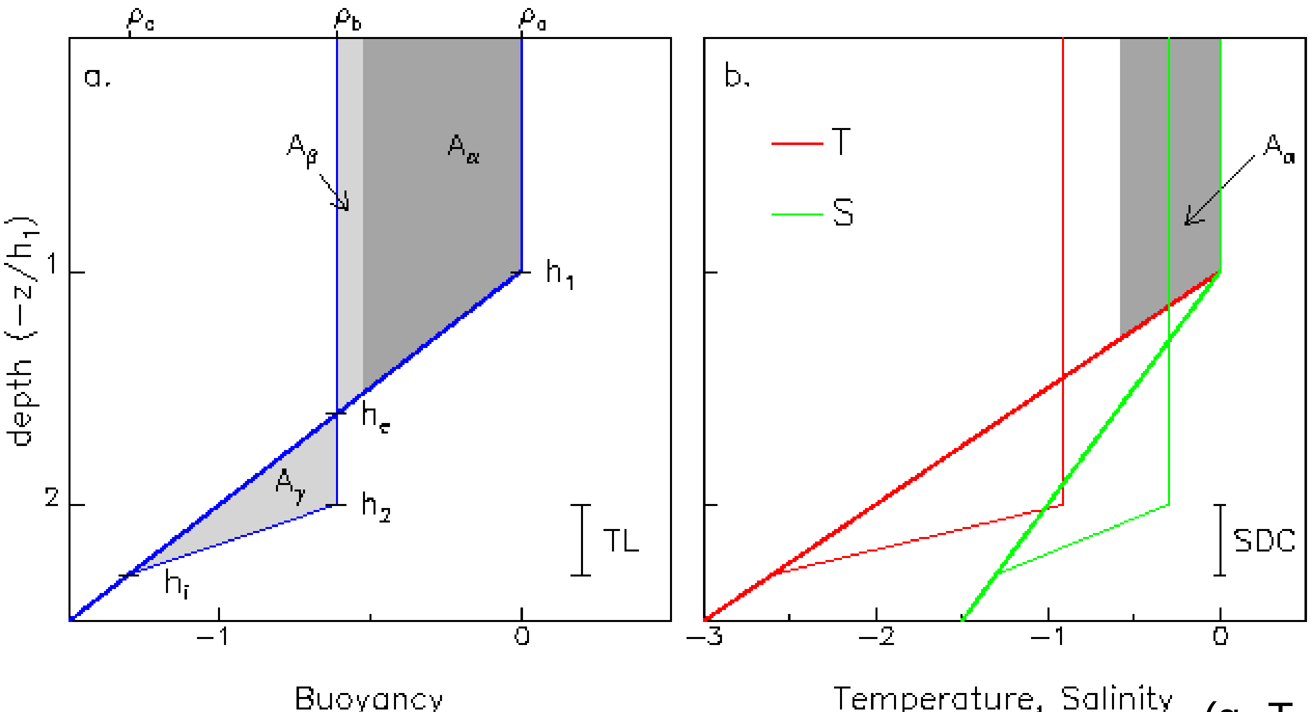
b) buoyancy entrainment $A_\beta = A_\gamma = 0.2A_\alpha$

c) Vigorous boundary layer mixing ($h_2 = 2h_1$)

d) Partially density compensated initial profile

e) Surface buoyancy flux A_α due entirely to winter surface heat loss

Convective Spice Injection



(gαT, gβS)

1. pre-convection (thick)

   Tu = 71.6°

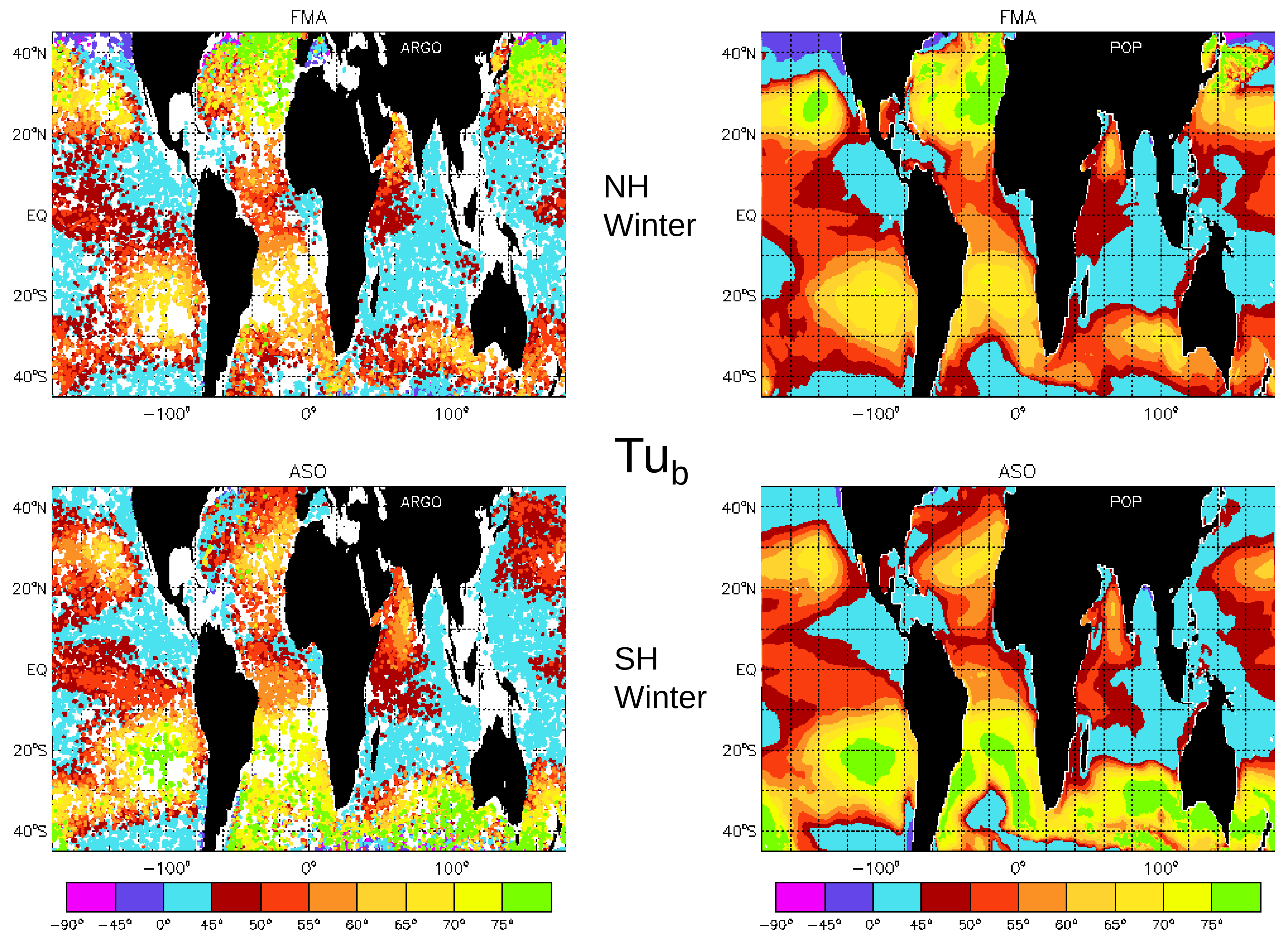
2. post-convection (thin)

   Tu = 76°

Assume:

a) Surface buoyancy flux A_α
b) buoyancy entrainment $A_\beta = A_\gamma = 0.2A_\alpha$
c) Vigorous boundary layer mixing ($h_2 = 2h_1$)
d) Partially density compensated initial profile
e) Surface buoyancy flux A_α due entirely to winter surface heat loss

⇒ Penetrative convection generates a strongly density compensated layer below the well-mixed layer


FMA
ARGO
FMA
POP
NH
Winter
Tu_b
ASO
ARGO
ASO
POP
SH
Winter
40°N
20°N
EQ
20°S
40°S
−100°
0°
100°
−90° −45° 0° 45° 50° 55° 60° 65° 70° 75°

Equatorial Diurnal Cycle

Mixing and Deepening Processes

- Buoyancy Driven -- **Night-time convection**

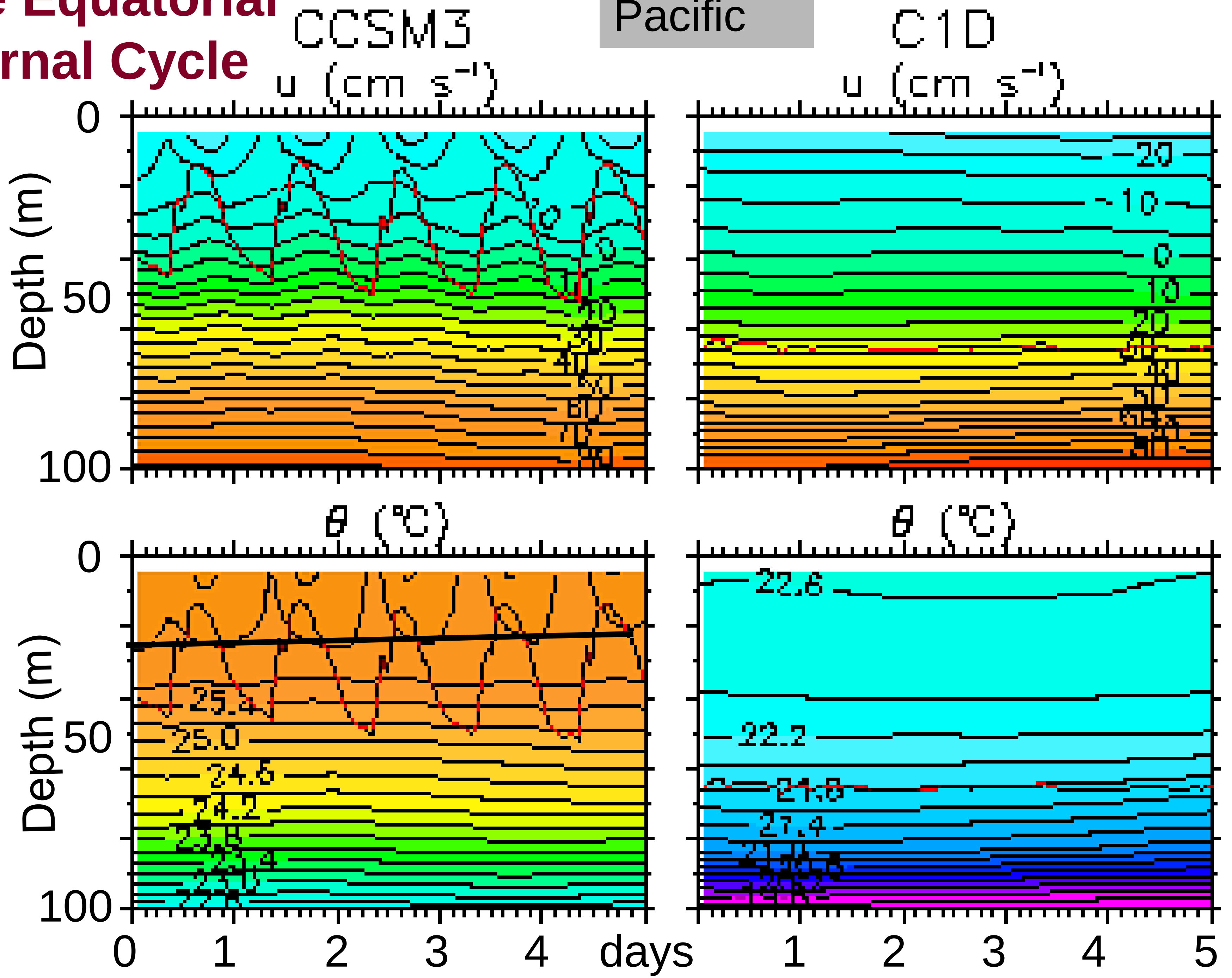
- Interior Driven -- **Current Shear**

Re-stratification and Shoaling Processes

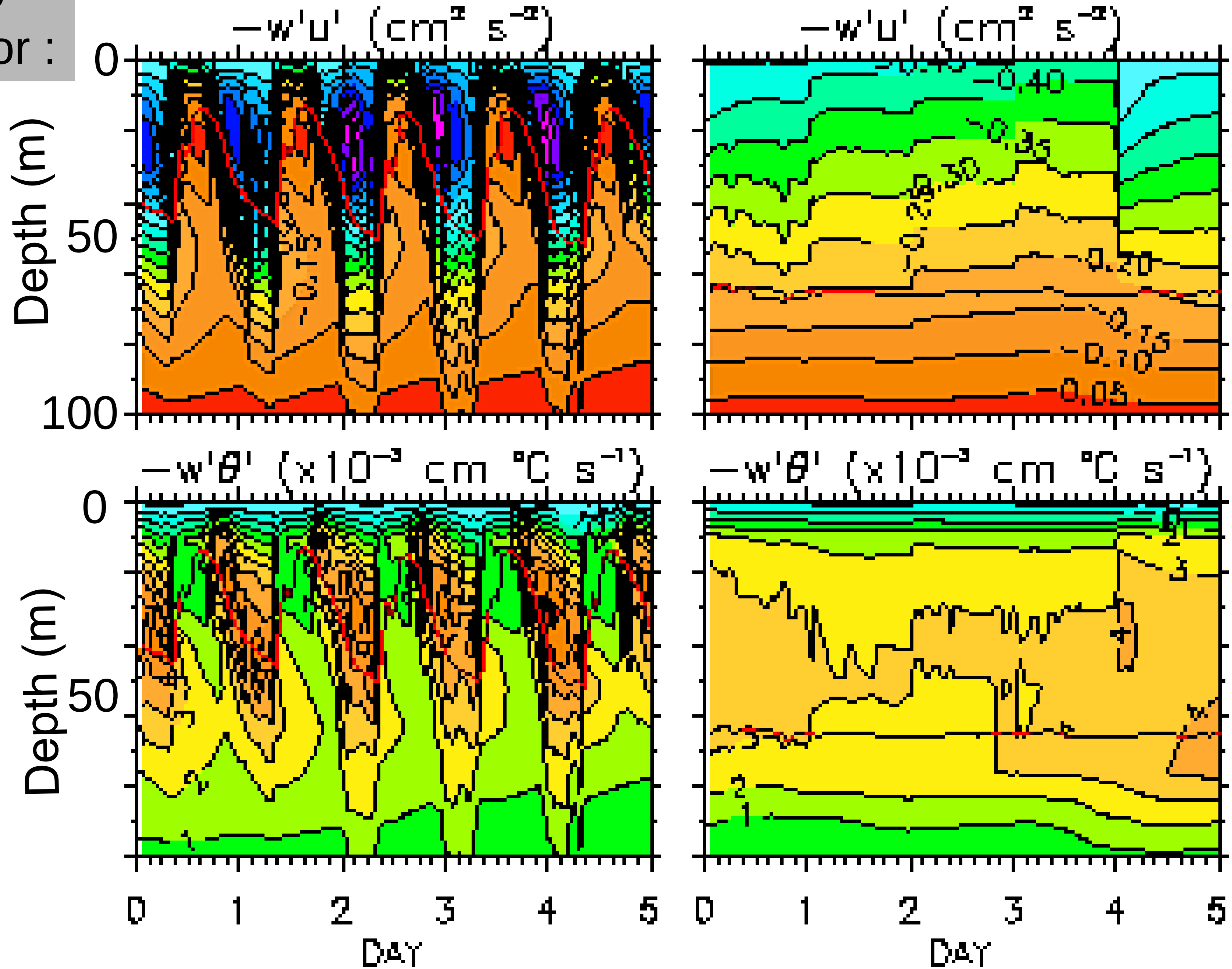
- Surface -- **Diurnal**

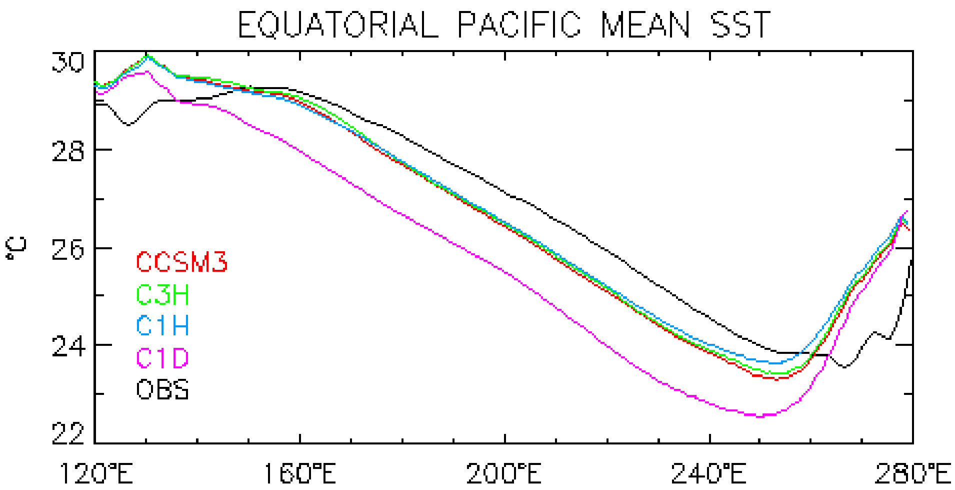
The Equatorial Diurnal Cycle

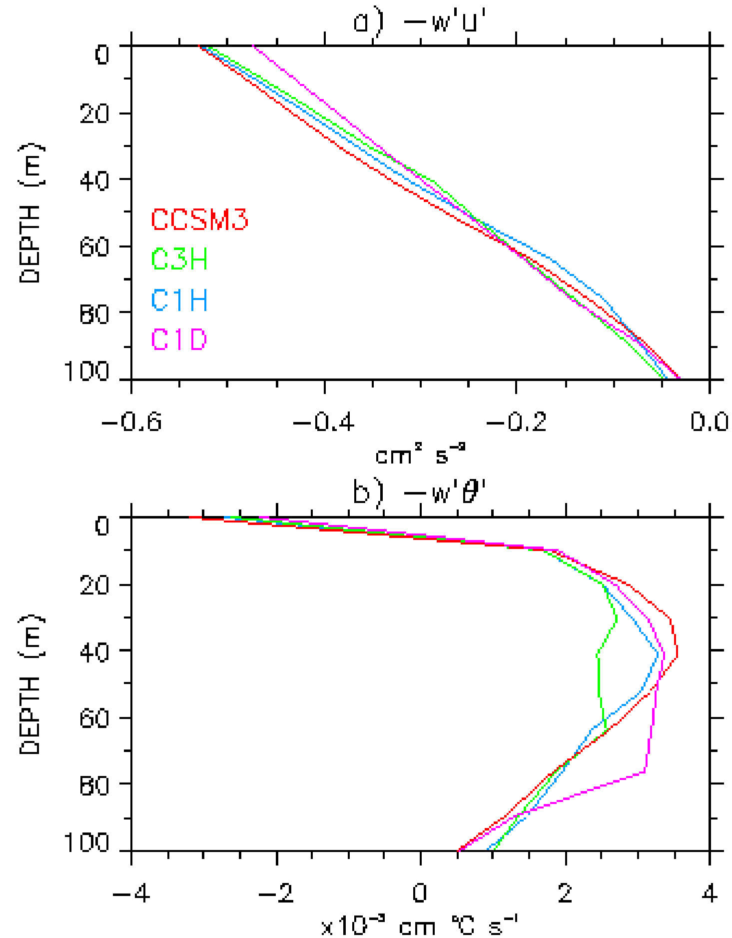
Pacific

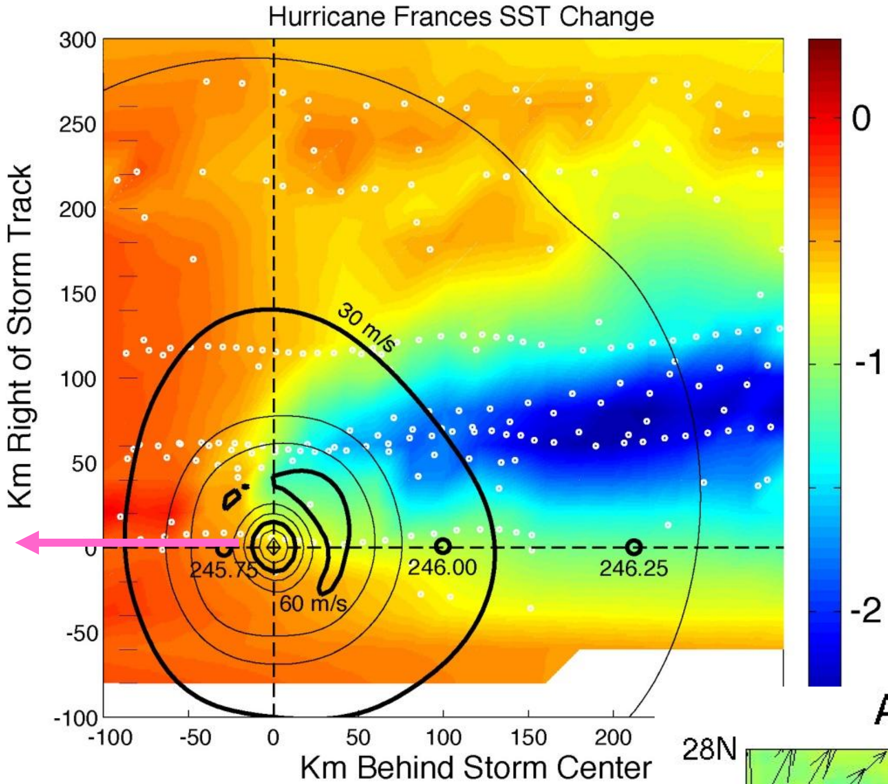


Pacific
Equator :



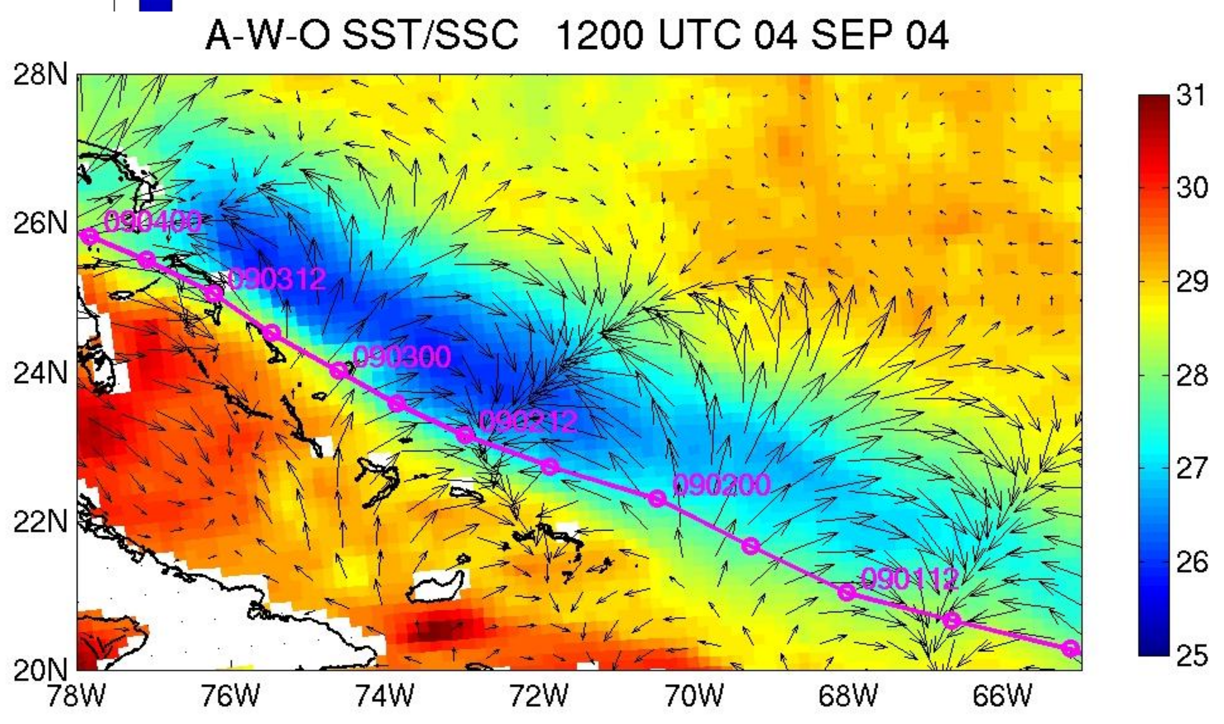

EQUATORIAL PACIFIC MEAN SST
°C
CCSM3
C3H
C1H
C1D
OBS
120°E
160°E
200°E
240°E
280°E


a) −w'u'
DEPTH (m)
CCSM3
C3H
C1H
C1D
cm² s⁻²
b) −w'θ'
DEPTH (m)
x10⁻³ cm °C s⁻¹



CBLAST observed SST

Coupled model SST



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