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

Energetics:

\[ KE_{10} = \int \tau \cdot U_{10} \, dt \]
\[ = \frac{\rho}{(C_D)^{1/2}} \int u^3 \, dt \]
\[ \varepsilon \approx 0.9 \, KE_{10} \text{ (Joule heating)} \]

\[ KE_0 = \int \tau \cdot U_0 \, dt \approx 0.1 \, KE_0 \]

\[ \Delta I KE \quad \Delta T KE \quad \Delta P E \]

\[ \varepsilon \text{ (neglect heating?)} \]
Inertial Resonance, $\mathbf{KE}_0$:

$\omega^* = (\omega - f)$

$\tau = A \sin^n (\pi t/\Delta t) \exp\{-j (\omega^* + f) t /\Delta t\}$

30 m/s -

3 dB: 2x per contour
QuickTime™ and a BMP decompressor are needed to see this picture.
Subtropical Gyre

Mixing and Deepening Processes
  • Buoyancy Driven  --  Penetrative Convection
  • Wave Driven  --  Langmuir Circulation

Re-stratification and Shoaling Processes
  • Instabilities  --  Sub-mesoscale
The associated streamfunction is given by

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

where

- \( C_e \): efficiency factor (0.06-0.08),
- \( \mu \): quartic shape function,
- \( H \): mixed layer depth,
- \( b \): buoyancy vertically averaged over \( H \),
- \( f \): Coriolis parameter,
- \( t \): time scale (1 day - 1 week),
- \( \Delta x \): model grid resolution,
- \( L \): length scale.

\[
L = \max \left( \frac{|\nabla b| H}{f^2 \left| \frac{NH}{f} \right|}, L_{\text{min}} \right) \quad \text{with } L_{\text{min}} = 1-10 \text{ km}
\]
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

Heat

Cool

\[ \frac{\langle w\Theta \rangle}{Q_0} \]
Langmuir uptake of CFCs

\[ \frac{L_a}{u^*} \]
CFC-11 along 170W in Feb 1994

Zonal Wind Case
Fall penetrative convection

Assume:

1. Surface buoyancy flux $A_\alpha$
2. Buoyancy entrainment $A_\gamma = A_\beta = 0.2A_\alpha$
3. Vigorous boundary layer mixing ($h_2 = 2h_1$)

1. pre-convection (thick)
2. post-convection (thin)
Convective Spice Injection

1. pre-convection (thick)
   \( Tu = 71.6^\circ \)

2. post-convection (thin)

Assume:

a) Surface buoyancy flux \( A_\alpha \)

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 \( A_\alpha \) due entirely to winter surface heat loss
Convective Spice Injection

1. pre-convection (thick)
   \( Tu = 71.6^\circ \)
2. post-convection (thin)
   \( Tu = 76^\circ \)

Assume:

a) Surface buoyancy flux \( A_\alpha \)
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

g) Surface buoyancy flux \( A_\alpha \) due entirely to winter surface heat loss

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

Tu_b
SH Winter
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

CCSM3

u (cm s^{-1})

Pacific

C1D

u (cm s^{-1})

Depth (m)

0

50

100

\theta (\degree C)

0

25.4

25.0

24.6

24.2

23.8

23.4

23.0

22.6

22.2

21.8

21.4

21.0

Depth (m)

0

50

100

days

1

2

3

4

5
Pacific Equator:

- $-w'u'$ (cm$^2$ s$^{-2}$)
- $-w'\theta'$ ($\times 10^{-3}$ cm °C s$^{-1}$)
- Depth (m)
- Day
FINIS