Ocean Mixed Layers

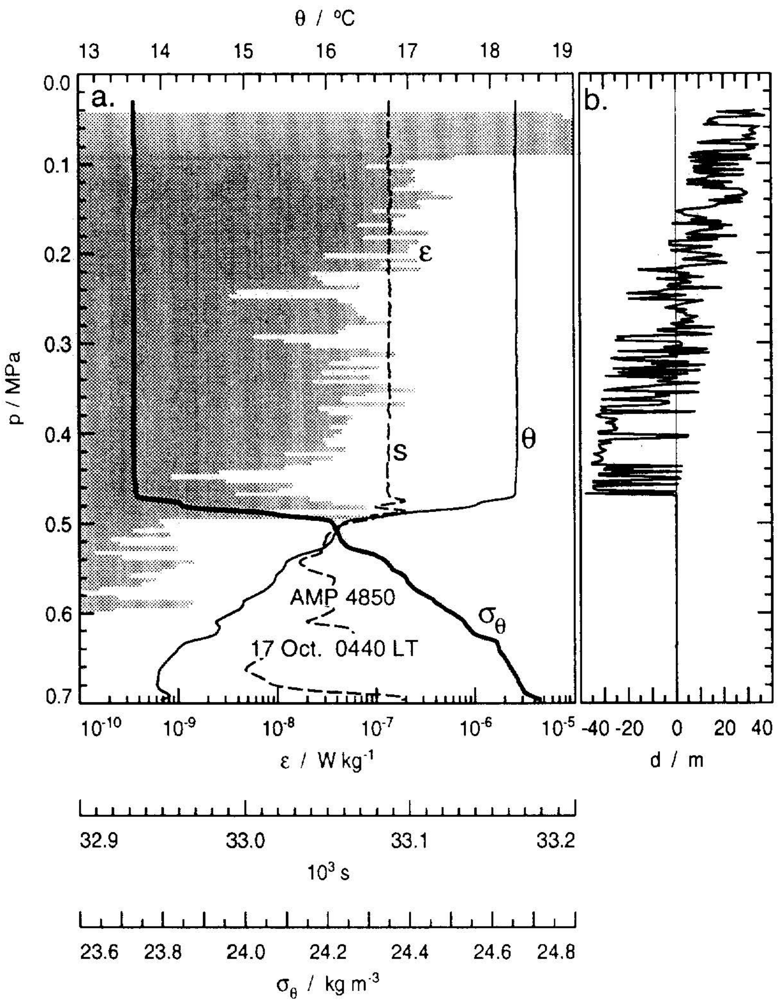


Fig. 2. Profile taken during convective equilibrium on PATCHEX; later in the same night as shown in Fig. 1. Panel a. Profiles of ε, θ, salinity and σ_θ. The shading is ε, estimated in 0.5 m bins: θ and σ_θ have been processed with a 0.8 m triangular filter. Panel b. Thorpe displacements; the instability extending to 0.48 MPa shows active convection reaching the seasonal thermocline.

Brainerd and Gregg, 1995

0.5 Mpa ≈ 50m depth

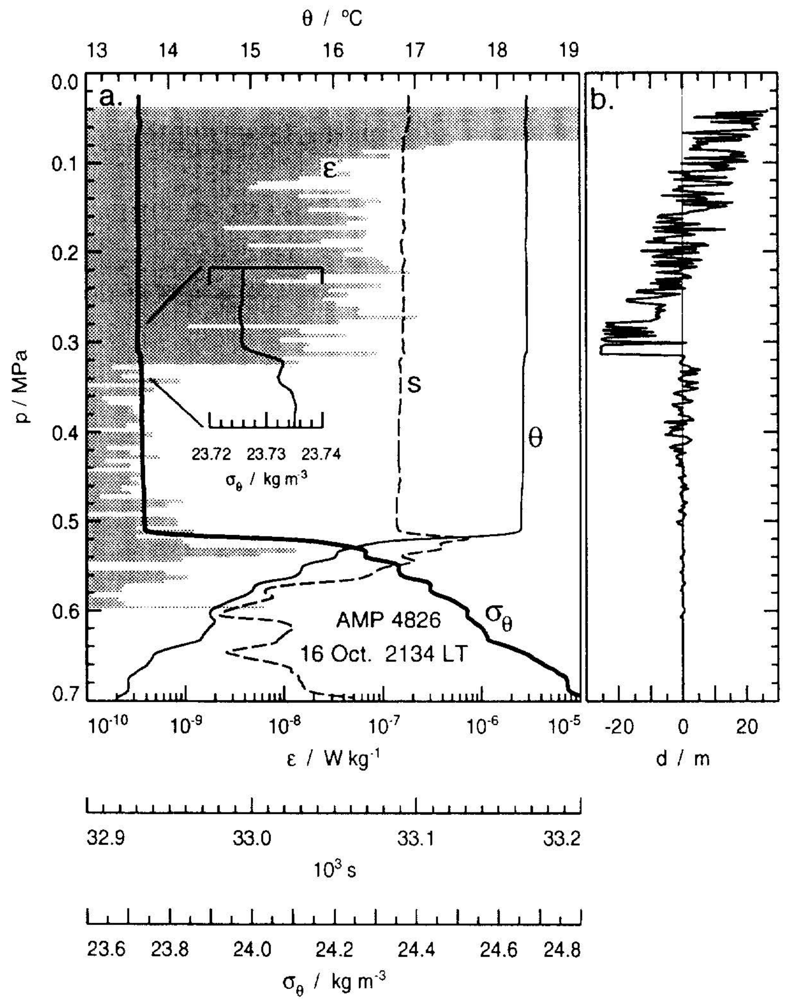
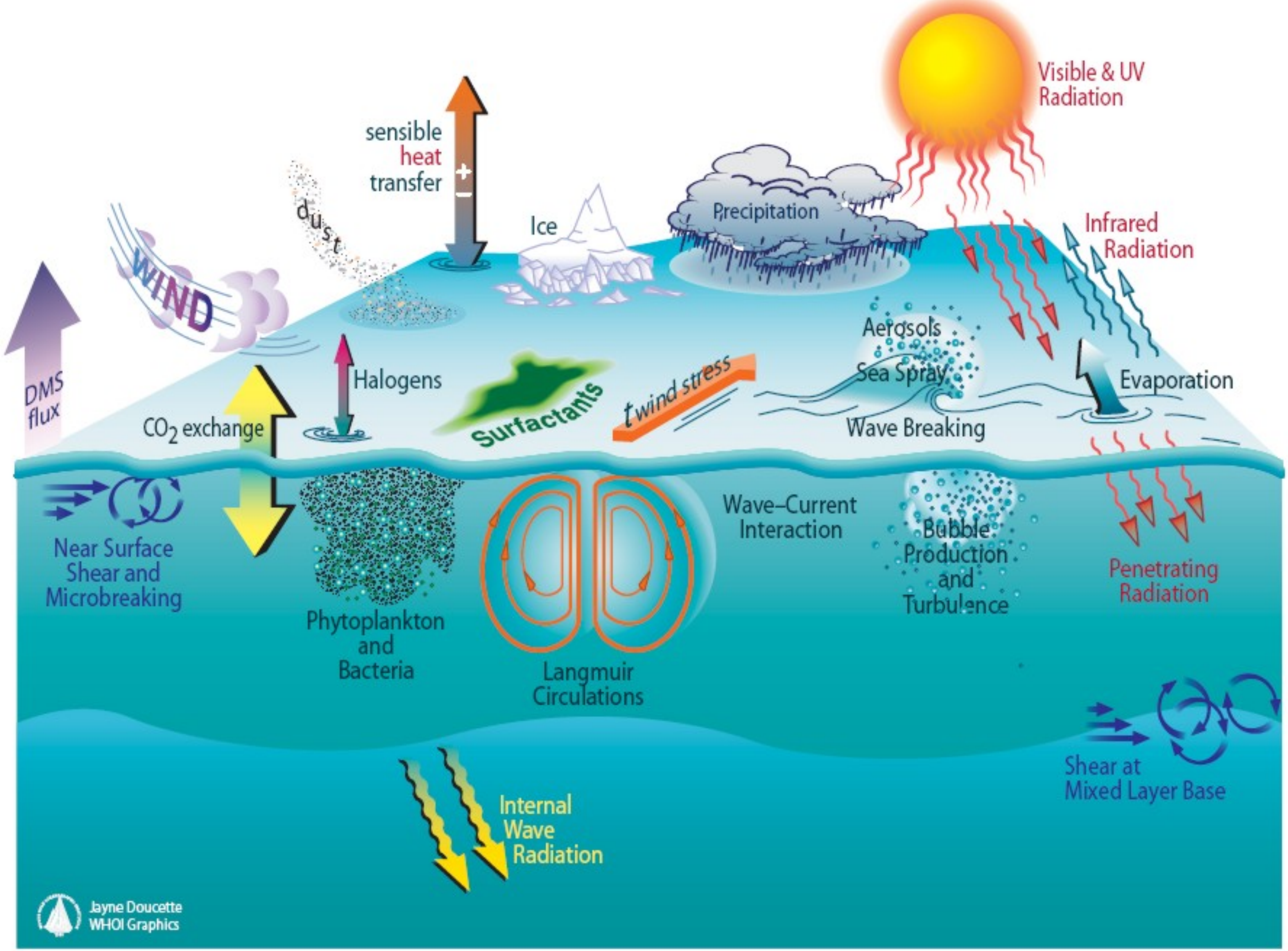


Fig. 1. Profile taken during convective deepening on PATCHEX: 2134 LT (local time, UTC—8 h). Panel a. Profiles of ε, θ, salinity and σ_θ. The shading is ε, estimated in 0.5 m bins; θ and σ_θ have been processed with a 0.8 m triangular filter. The small density step at 0.32 MPa (inset) is the bottom of the mixing layer. Panel b. Thorpe displacements; the large instability extending down to 0.31 MPa fills the active mixing layer.

Brainerd and Gregg, 1995


Visible & UV Radiation
sensible heat transfer
+
−
dust
WIND
Ice
Precipitation
Infrared Radiation
DMS flux
Halogens
Surfactants
τ wind stress
Aerosols
Sea Spray
Evaporation
CO_2 exchange
Wave Breaking
Near Surface Shear and Microbreaking
Phytoplankton and Bacteria
Langmuir Circulations
Wave–Current Interaction
Bubble Production and Turbulence
Penetrating Radiation
Internal Wave Radiation
Shear at Mixed Layer Base
Jayne Doucette WHOI Graphics

- Properties close to the surface of the ocean tend to be well mixed and relatively uniform with depth.
- Depth of mixed layer depends on surface forcing (wind and buoyancy) and entrainment from below and can vary from O(1 meter) to in excess of 1000m.
- Strong warming or freshwater input leads to a shallow layer
- Strong cooling leads to a deep layer
- Properties exchanged with the atmosphere (heat, freshwater, gases) are quickly mixed throughout the layer of active mixing (a few minutes to a few hours)
- Entrainment at base of mixed layer brings nutrients into the surface layer.
- Light received by phytoplankton depends on the depth of the layer and level of turbulence.

Mixed Layer Depth, h

Definition based on change from surface:

$$\Delta\sigma(z) = \sigma(z)-\sigma(z=0)$$

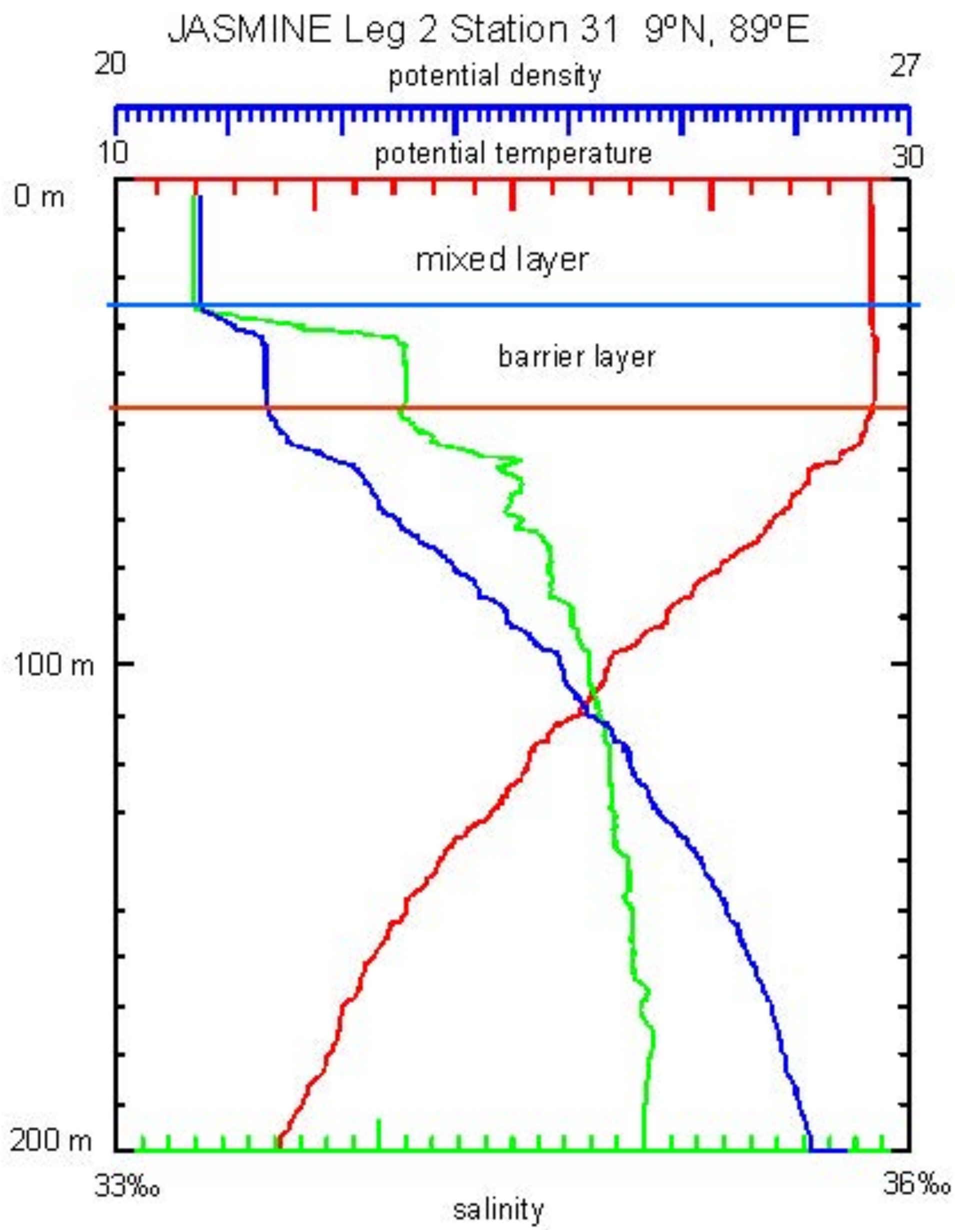
h_σ depth when $\Delta\sigma$ crosses some threshold (say 0.03kgm-3; needs to be refined depending on situation)

Can define in terms of temperature

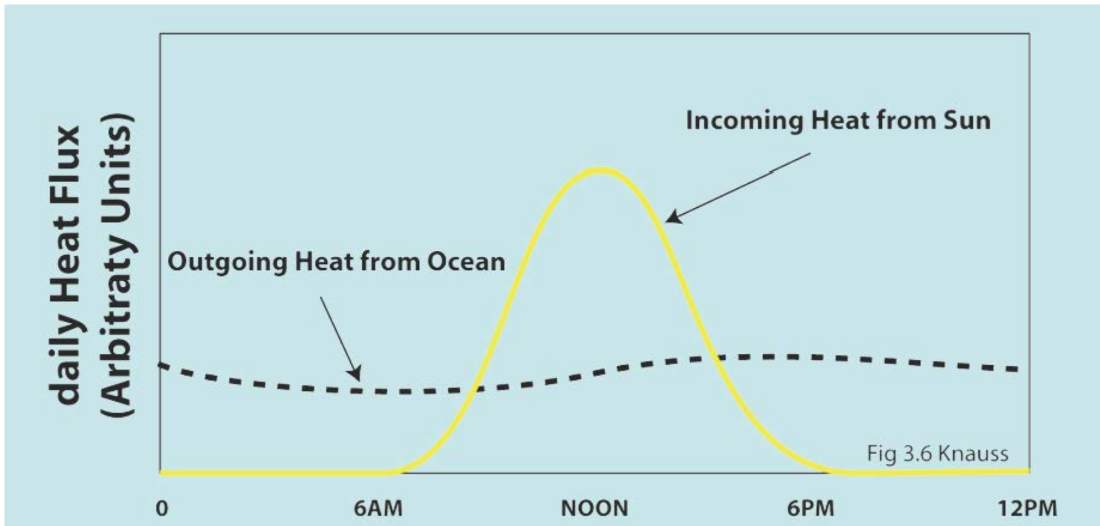
$$\Delta T=T(z=0)-T(z)$$

h_T depth when ΔT crosses some threshold (say 0.2^0C)

NOTE: h_σ not always the same as h_T



Barrier layer:
Lindstrom et al 1987


daily Heat Flux
(Arbitraty Units)
Incoming Heat from Sun
Outgoing Heat from Ocean
Fig 3.6 Knauss
0
6AM
NOON
6PM
12PM

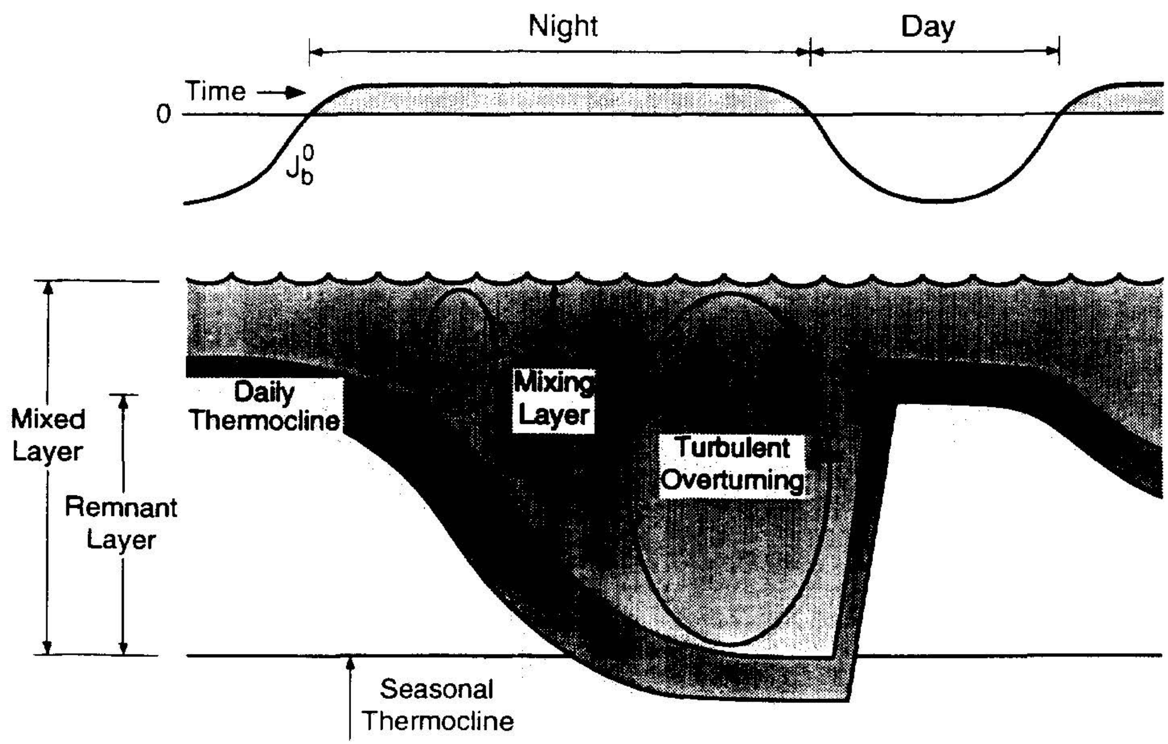
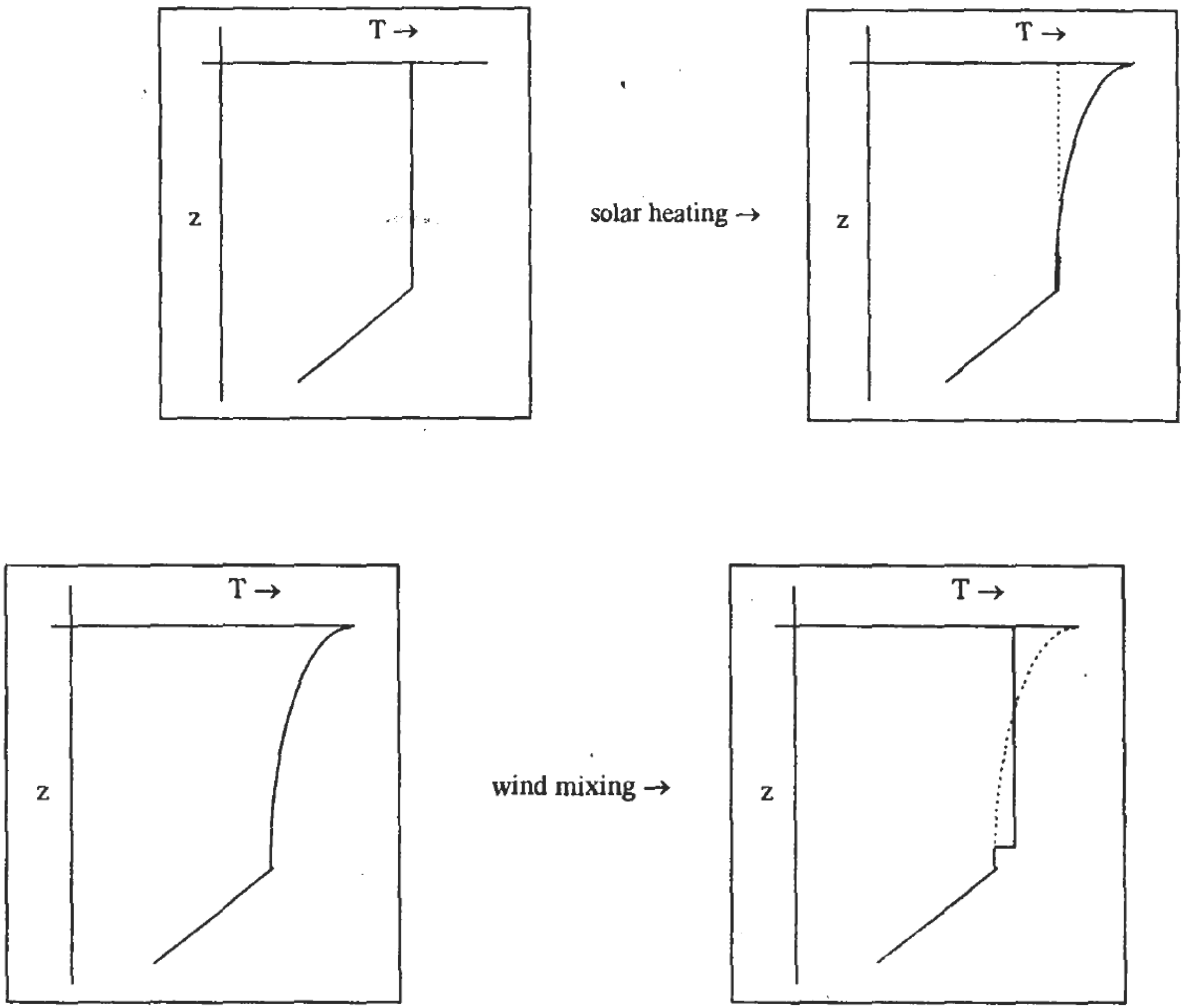


Fig. 5. Diagram showing depth zones in a typical diurnal mixed layer cycle.

Brainerd and Gregg, 1995

Basics: warming



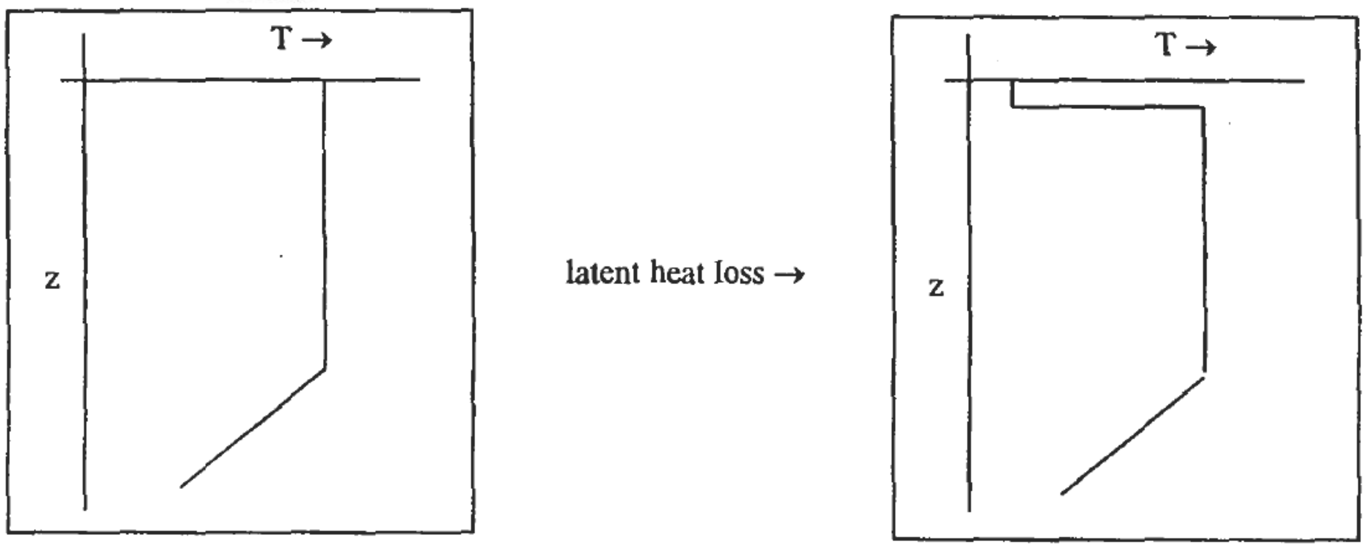
PE ⬇

Requires TKE to mix heat down. PE ⬆

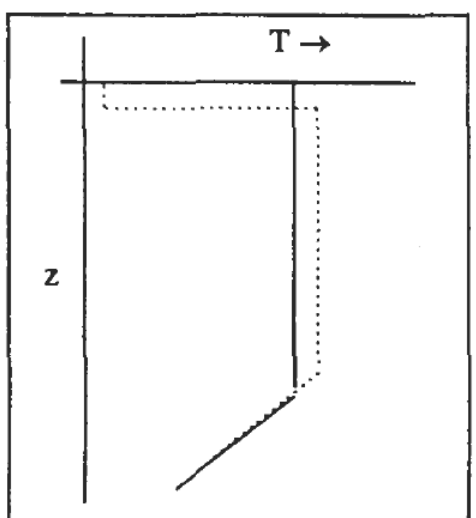
Change in SST dependent on mixing within the layer and entrainment from below.

Figure courtesy: S. R. Shetye

Basics: cooling

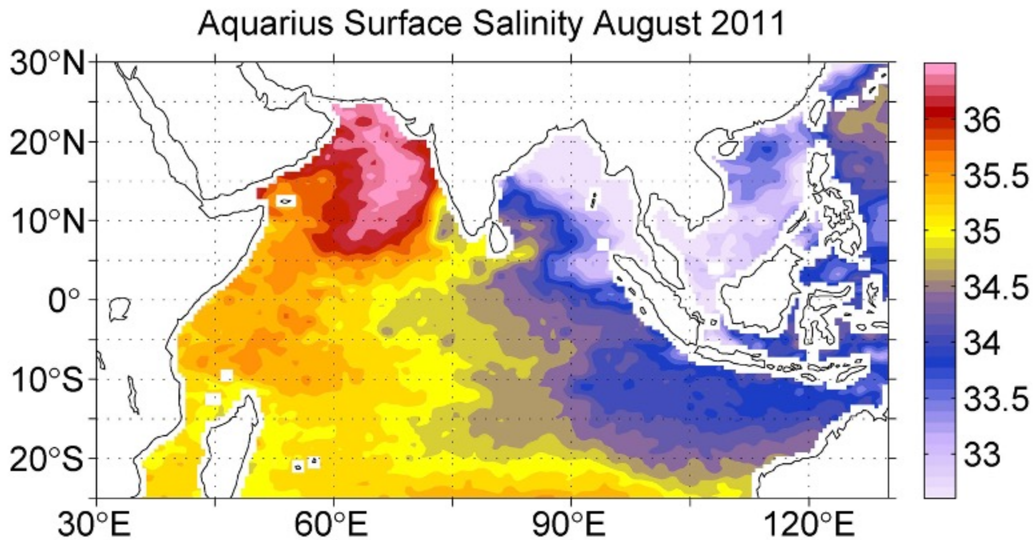


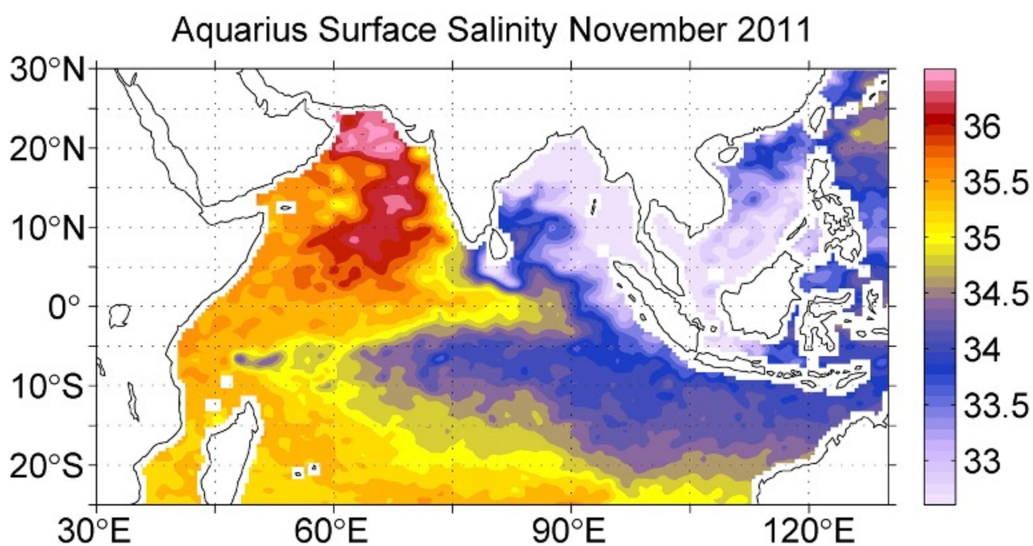
PE ⬆



PE converted to TKE (convection) which mixes cooler water down. PE ⬇

Figure courtesy: S. R. Shetye


Aquarius Surface Salinity August 2011
30°N
20°N
10°N
0°
10°S
20°S
30°E
60°E
90°E
120°E
36
35.5
35
34.5
34
33.5
33


Aquarius Surface Salinity November 2011
30°N
20°N
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0°
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20°S
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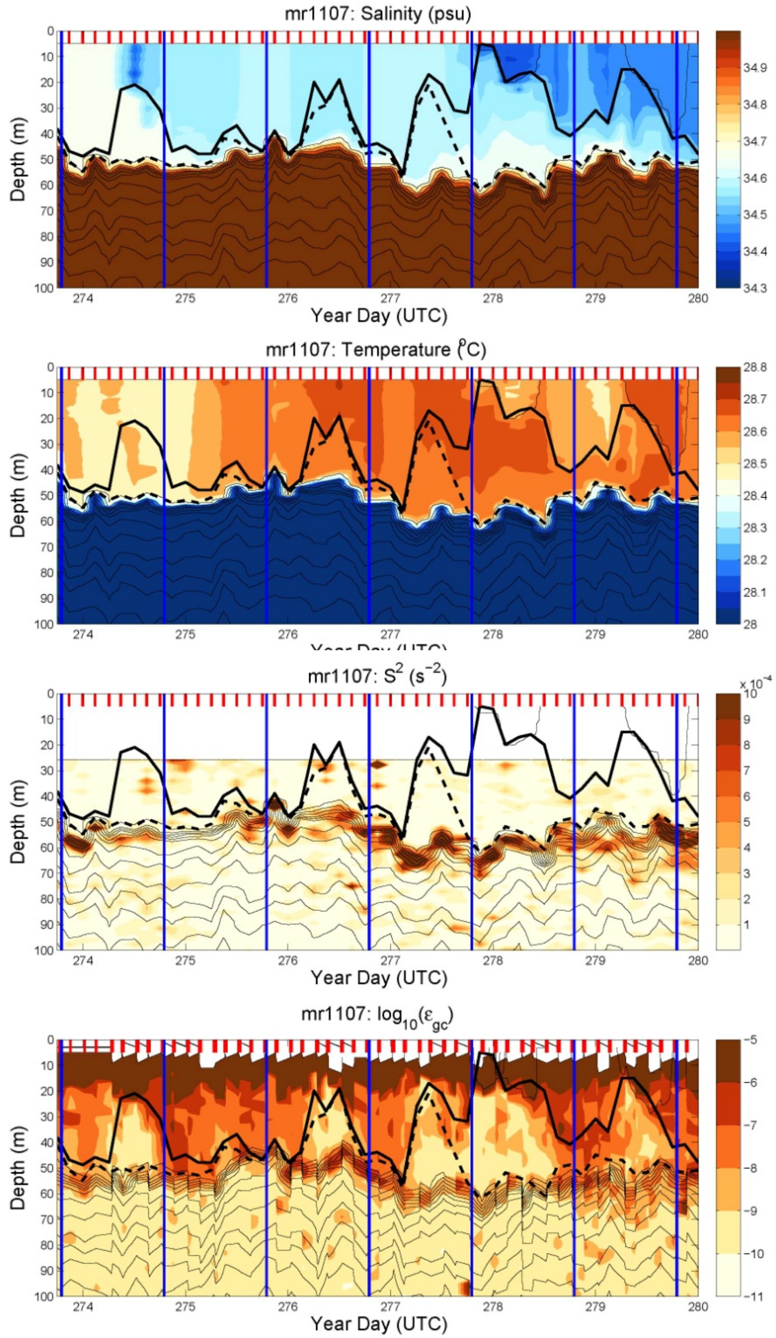
90°E
120°E
36
35.5
35
34.5
34
33.5
33

Indian Ocean, 8^{o}S
October 2011



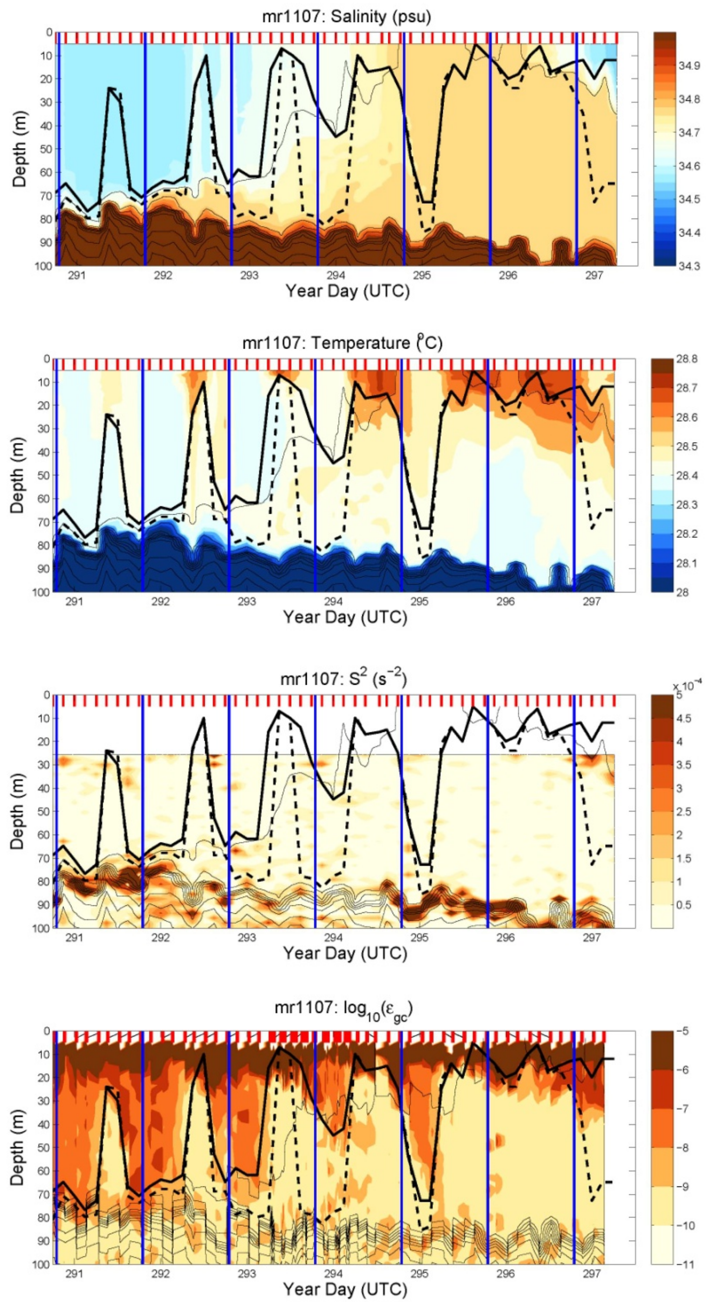
Salinity

Temperature

Shear

Turbulence

Indian Ocean, 8oS
October 2011

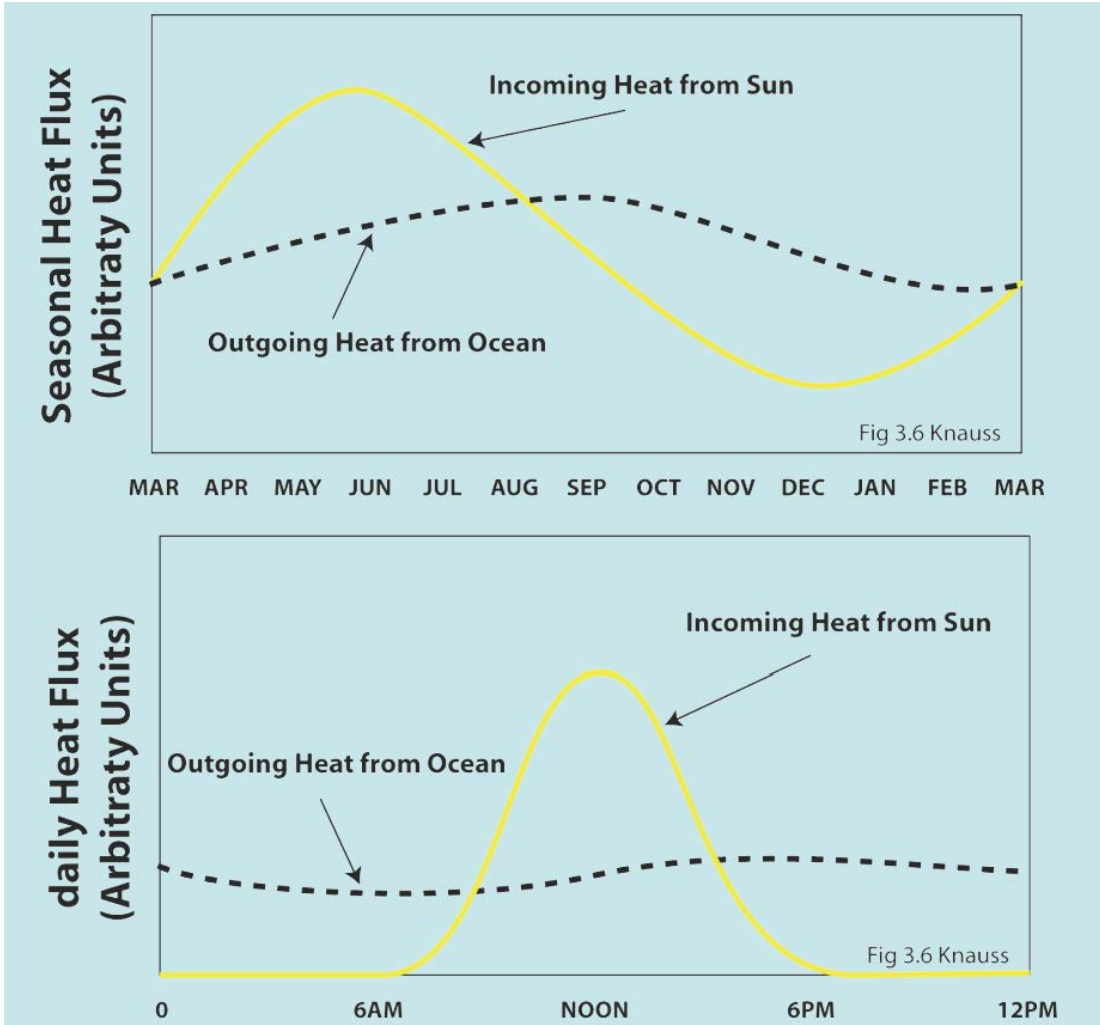


Salinity

Temperature

Shear

Turbulence


Seasonal Heat Flux
(Arbitraty Units)
Incoming Heat from Sun
Outgoing Heat from Ocean
Fig 3.6 Knauss
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
daily Heat Flux
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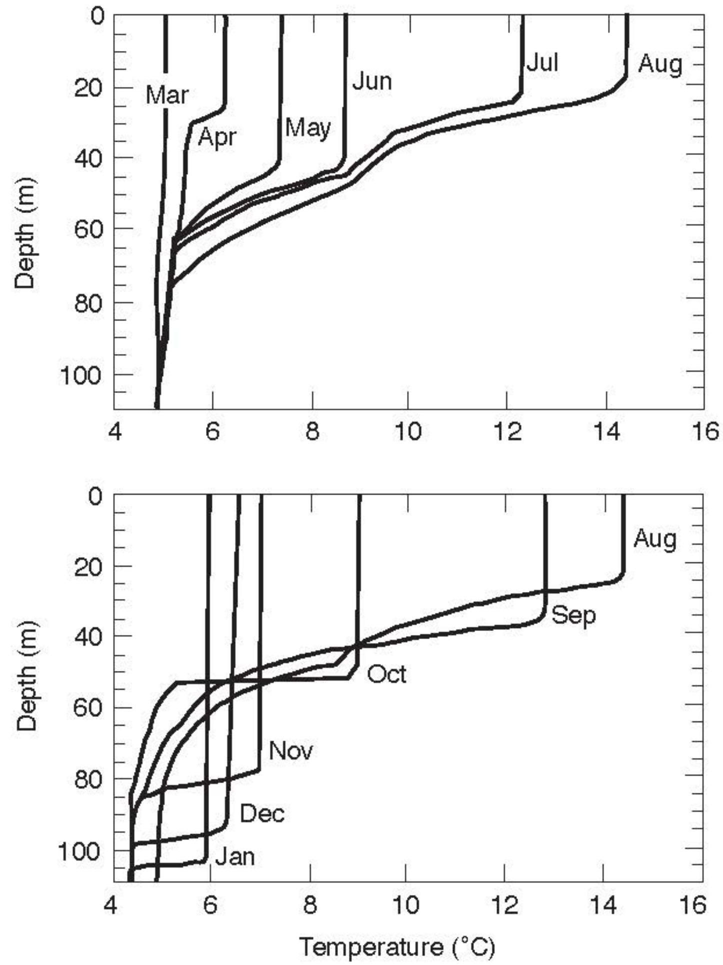
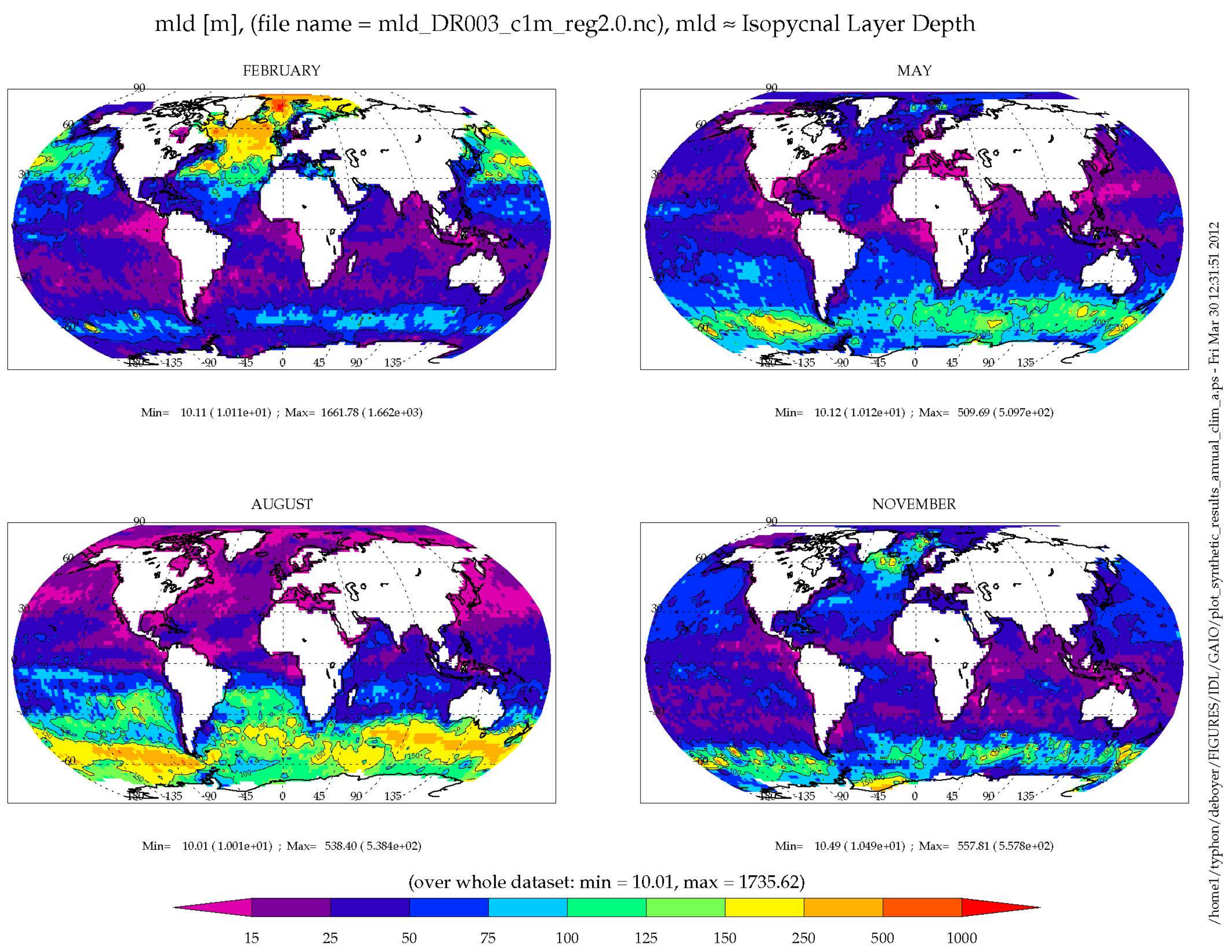
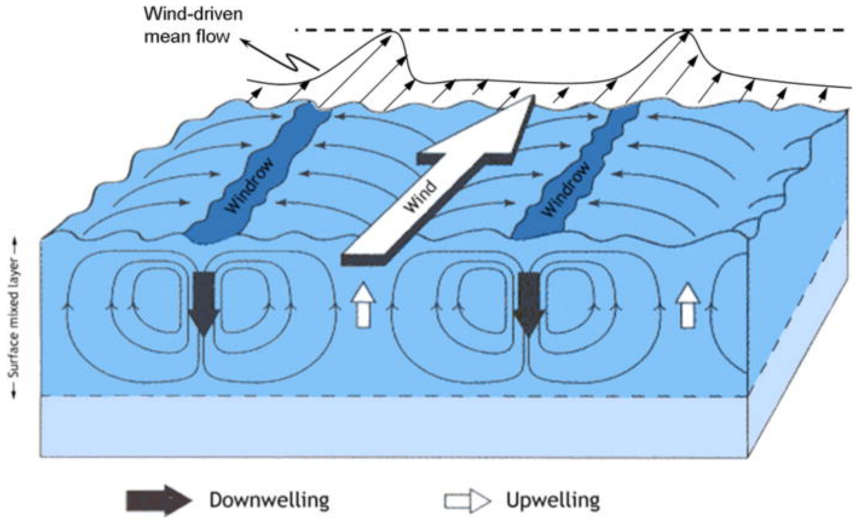


Figure 1 Seasonal evolution of temperature in the midlatitude upper ocean. Shallow, warm mixed layers during spring–summer alternate with cold, deep ones during fall–winter. (Kantha and Clayson, 2000.)


mld [m], (file name = mld_DR003_c1m_reg2.0.nc), mld ≈ Isopycnal Layer Depth
FEBRUARY
Min= 10.11 (1.011e+01) ; Max= 1661.78 (1.662e+03)
MAY
Min= 10.12 (1.012e+01) ; Max= 509.69 (5.097e+02)
AUGUST
Min= 10.01 (1.001e+01) ; Max= 538.40 (5.384e+02)
NOVEMBER
Min= 10.49 (1.049e+01) ; Max= 557.81 (5.578e+02)
(over whole dataset: min = 10.01, max = 1735.62)
15 25 50 75 100 125 150 250 500 1000
/home1/typhon/deboyer/FIGURES/IDL/GAIO/plot_synthetic_results_annual_clim_a.ps - Fri Mar 30 12:31:51 2012

Additional influences: Langmuir Circulation



Additional influences: Mixed Layer Instability

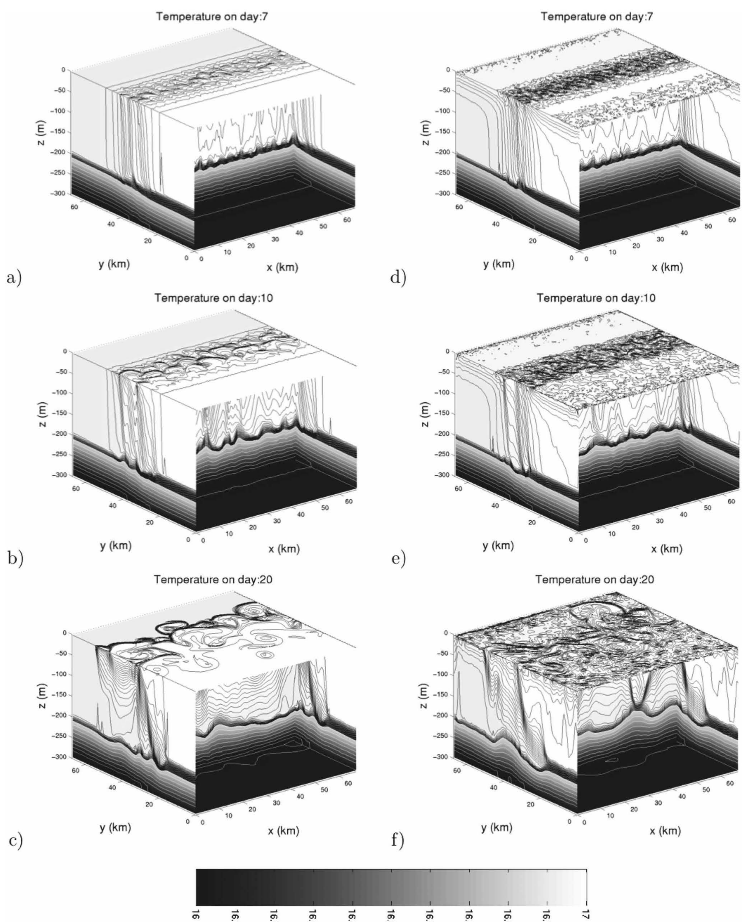
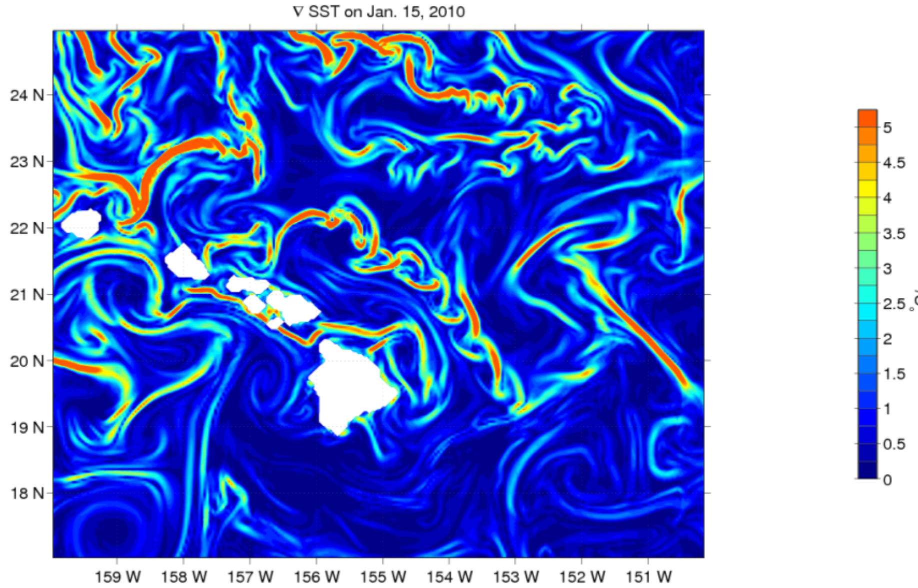


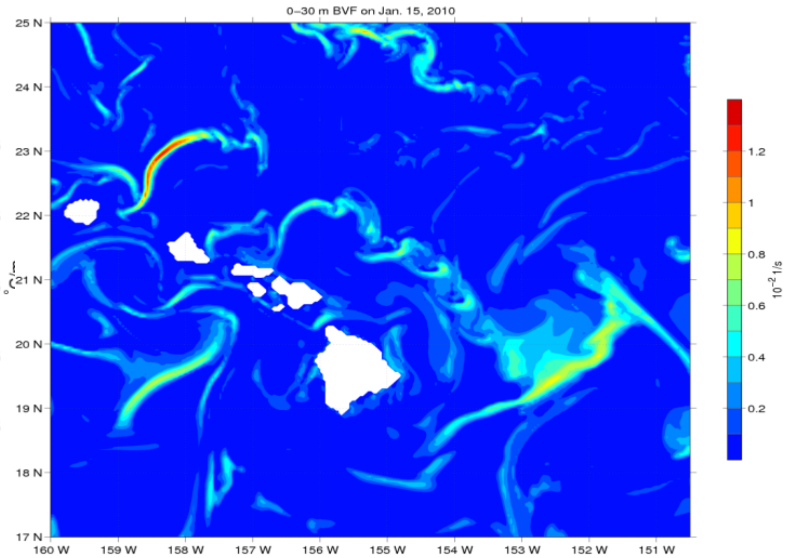
FIG. 2. Temperature (°C) during two typical simulations of a ML front spinning down: (a)–(c) no diurnal cycle and (d)–(f) with diurnal cycle and convective adjustment. (Black contour interval = 0.01°C; white contour interval = 0.1°C.)

Tendency to re-stratify the upper ocean: impact on biological production

Sub-mesoscale structures in a regional implementation of HYCOM forced with a regional atmospheric model: Jan 15, 2010

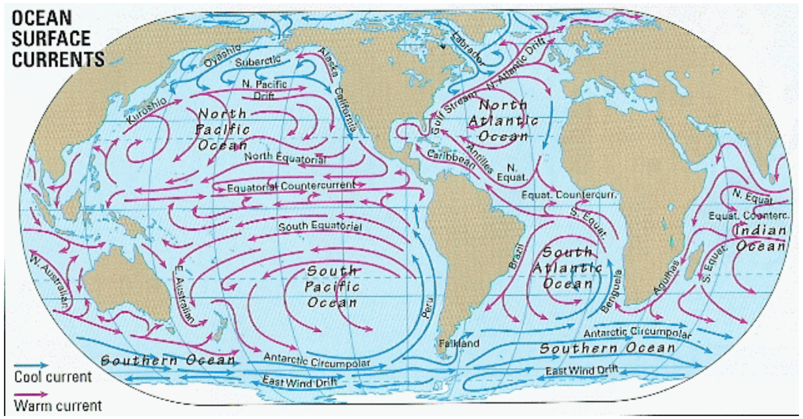


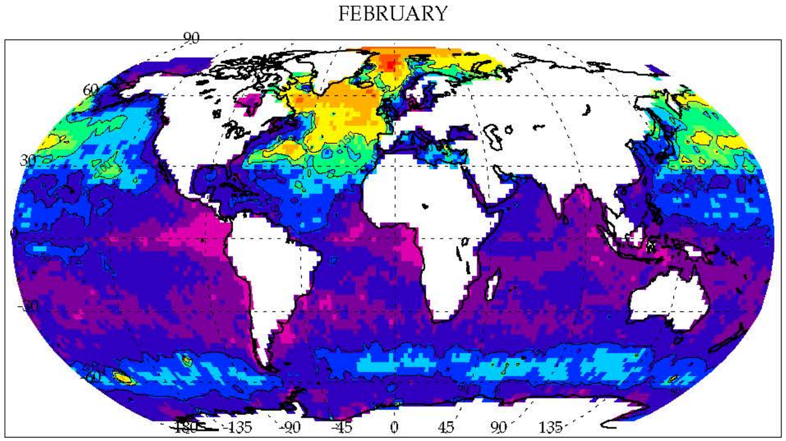
ΔSST



Mean N top 30m

Connection with the interior: Subduction and Ventilation





Subtropical gyres: The combination of the equatorward flow plus poleward increase in mixed layer depth leads to the subduction of water

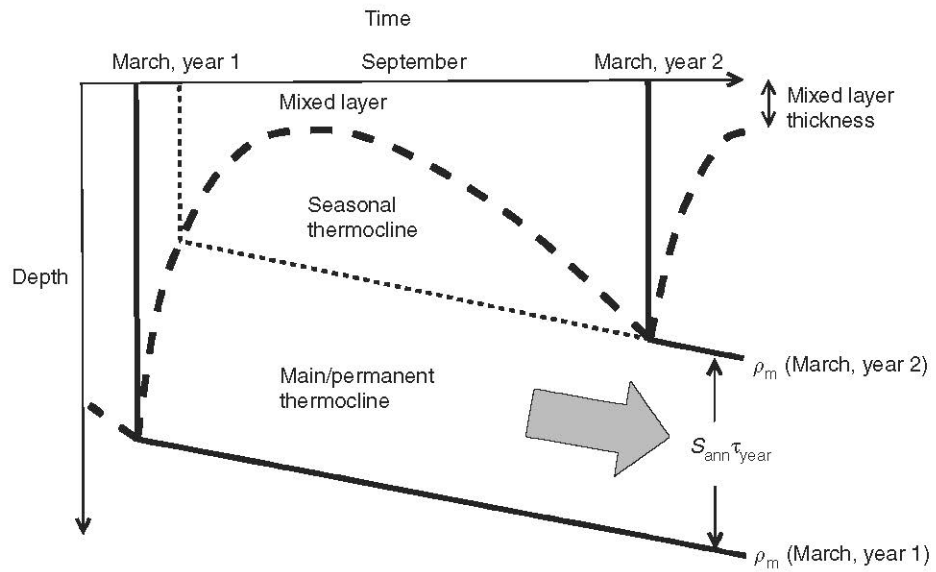
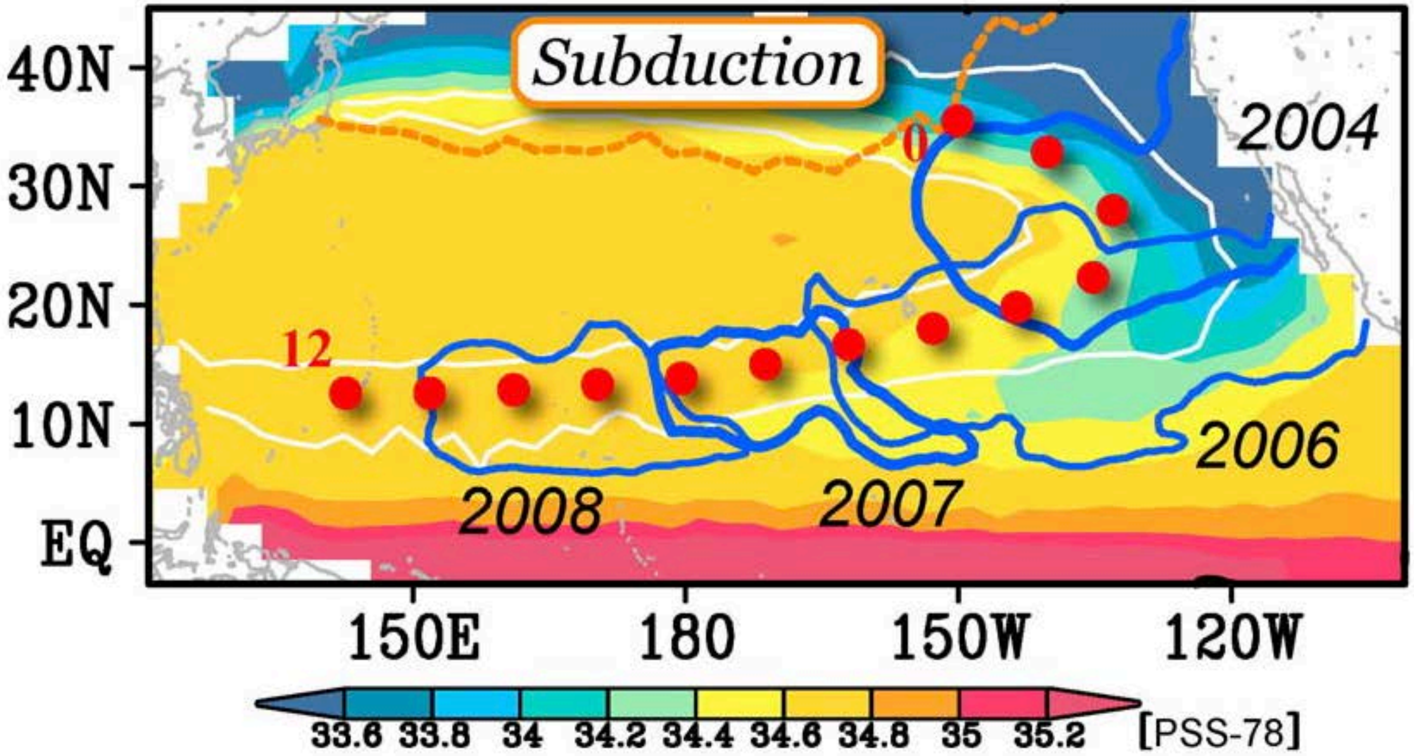


Figure 2 A schematic diagram illustrating the seasonal cycle of the mixed layer following the movement of a water column. The mixed layer thins in spring and summer, and thickens again in autumn and winter. If there is an overall buoyancy input, the end of winter mixed layer becomes lighter and thinner from one year to the next (as depicted here). Consequently, fluid is subducted irreversibly from the mixed layer into the main or permanent thermocline. The mixed layer thickness is marked by the thick dashed line, isopycnals ρ_m outcropping at the end of winter into the mixed layer by the full lines, and the isopycnal identifying the base of the seasonal thermocline by the short dashed line. The annual subduction rate, S_{ann}, determines the vertical spacing between the isopycnals subducted from the mixed layer in March for consecutive years 1 and 2 (τ_{year} is one year).

Williams, 2001



Propagation of cold/fresh anomalies on σ_θ 25-25.5 kg m^{-3} (Data: Argo. Orange dashed line: Feb outcrop of surface)

Sasaki et al GRL 2010