$\rho C_p \int Tdz$

Mike McPhaden
NOAA/PMEL
25 October 2018
Mixed Layer Temperature Balance Determines SST

\[ h \frac{\partial T}{\partial t} = -hv \cdot \nabla T - H\Delta T w_e - \nabla \cdot \int_{-h}^{0} \hat{v} \hat{T} dz + \frac{q_0 - q_{-h}}{\rho c_p} \]
Mean Seasonal Cycle SST

March

August

SST, wind stress, high and low cloud
Processes affecting ML Heat Storage and SST

Bourles et al, 2008 adapted from Yu et al, 2007

Correlation (R) of Surface Heat Flux and SST

R ≥ 0.9 surface flux forcing
R << 0.9 ocean dynamics important
Z20 along the equator, a measure of upper ocean heat content, leads ATL3 by 2-4 months consistent with recharge oscillator dynamics.
Tropical Cyclone Heat Potential

\[ \rho C_p \int_{z_{26^\circ C}}^{0 \text{ m}} T \, dz \]

Amount of heat stored above 26°C isotherm available to fuel cyclone intensification

Goni, 2005
Tropical Cyclone Heat Potential

\[ \rho C_p \int_{z_{26^\circ C}}^{0 \text{ m}} T \, dz \]

Amount of heat stored above 26°C isotherm available to fuel cyclone intensification

Source: AOML
PIRATA T-Flex Real-Time Hourly Data
Florence: 3 Sep 2018 & Helene: 12 Sep 2018

Hourly Data

- Shortwave Radiation (W m⁻²) 20N36W -4 m
- Precipitation (mm hr⁻¹) 20N36W -4 m
- Barometric Pressure (mb) 20N36W -3 m
- Wind Speed (m s⁻¹) 20N36W -4 m
- Relative Humidity (%) 20N36W -3 m
- Air Temperature (°C) 20N36W -3 m
- Sea Surface Temperature (°C) 20N36W 1 m

Hourly Data

- Barometric Pressure (mb) 20N36W -3 m
- Wind Speed (m s⁻¹) 20N36W -4 m
- Zonal Current (cm s⁻¹) 20N36W
- Meridional Current (cm s⁻¹) 20N36W
SST Trends & 0-700 m Heat Content

SST and Wind Stress Trends
1976-2012

Servain et al, 2014

SST and Heat Content Trends
1964-2012
Global SST Change
1901-2015

Change in sea surface temperature (°F):

-1  -0.5  0  0.5  1  1.5  2  2.5  3  3.5  4

+ = statistically significant trend

Insufficient data
\[ \rho C_p \int \int \int T(t) \, dx \, dy \, dz \]

- Accounts for 94% of the Earth’s energy imbalance
- Delays the equilibrium response of the climate system to anthropogenic forcing
Equation of state for seawater

Density anomaly

\[ \sigma = \rho - \rho_{ref} \]

\[ \rho_{ref} = 1000 \text{ kg m}^{-3} \]

Freezing point of water

\[ \rho = \rho(S, T, p) \]

- The density of seawater is a nonlinear function of salinity, temperature, and pressure.
Dynamic Height related to Density through the Hydrostatic Equation

\[ \frac{dP}{dz} = -\rho g \]

Vertical Integral of Density related to Baroclinic Component of Sea Level

\[ \eta \text{ proportional to } \int \rho(T, S) \, dz \]
Sea Level Rise

SST and Sea Level Rise 1993-2012

SST and Heat Content Trends 1964-2012

Servain et al, 2014
Signal-to-Noise

Shorter time scale variability is noise for studies of seasonal and longer time scale phenomena (but important signals in their own right):

Ocean: tides, diurnal cycle, TIW, eddies, rings, and other mesoscale phenomena

Atmosphere: Storms, wind bursts, MJO/intraseasonal variability...
EOV/ECV Measurement Requirements

For description:
- Measurements of SST, T(z)
- Sea level (Altimetry and tide gauges)

For diagnostics:
- S(z), Winds, ocean velocity, surface heat fluxes (turbulent and radiative)...

For model development: All

For Weather/Climate Forecasting: Next talks
Global Ocean Observing System for Climate

In Situ Components

- **87%** Surface measurements from volunteer ships (VOSclim)
  - 200 ships in pilot project

- **100%** Global drifting surface buoy array
  - 5° resolution array: 1250 floats

- **62%** Tide gauge network (GCOS subset of GLOSS core network)
  - 170 real-time reporting gauges

- **81%** XBT sub-surface temperature section network
  - 51 lines occupied

- **100%** Profiling float network (Argo)
  - 3° resolution array: 3000 floats

- **43%** Repeat hydrography and carbon inventory
  - Full ocean survey in 10 years

**Reference time series** 24%

- 56 sites

**Global reference mooring network** 48%

- 29 moorings planned

**Global tropical moored buoy network** 79%

- 119 moorings planned

**Global Ocean Observing System for Climate**
Tropical Storm Florence 3 Sep 2018
Hurricane Helene 12 Sep 2018