The Role of the Extra-tropical Upper Ocean Mixed Layer in Climate Variability

Clara Deser, NCAR

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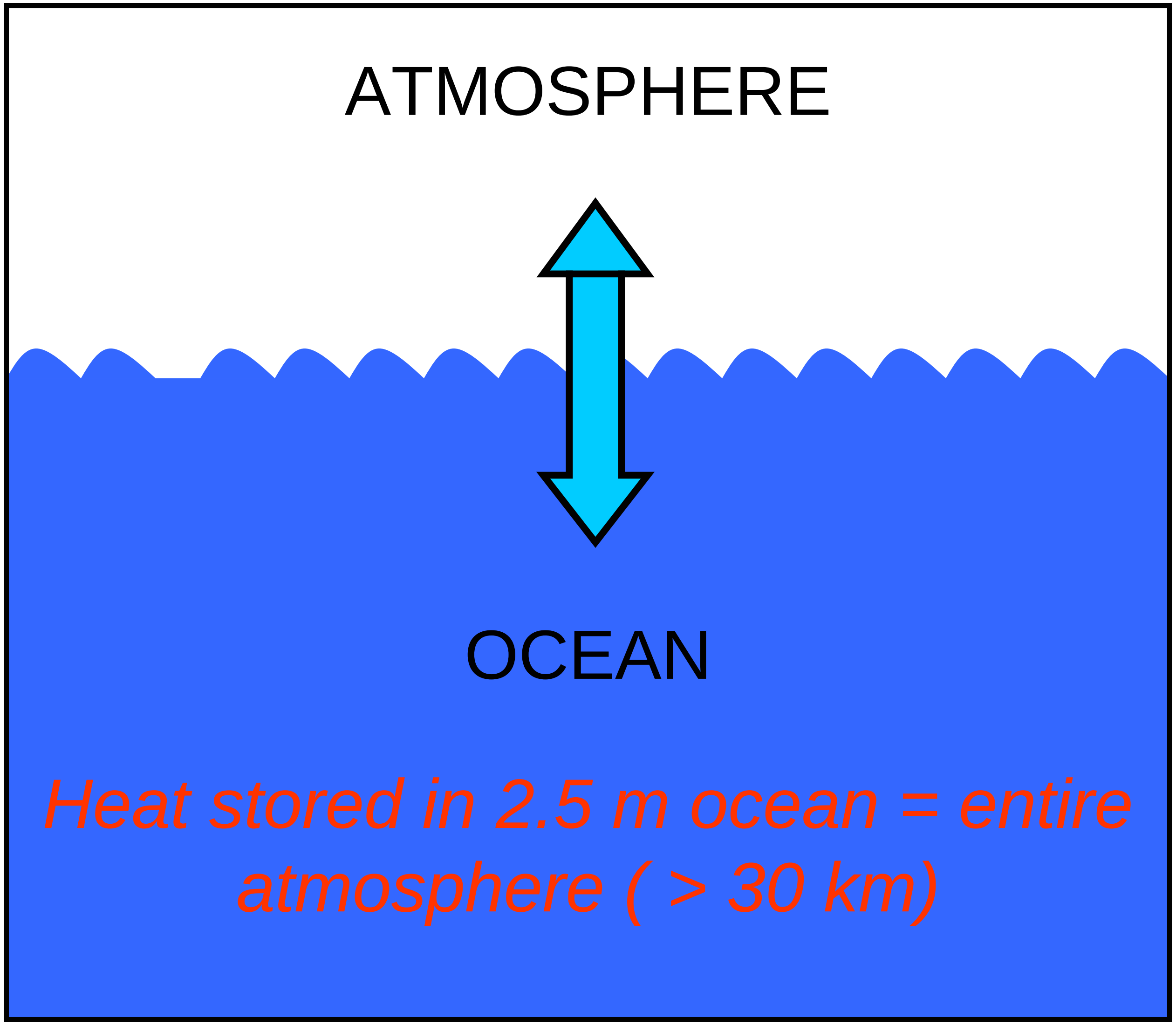
OUTLINE

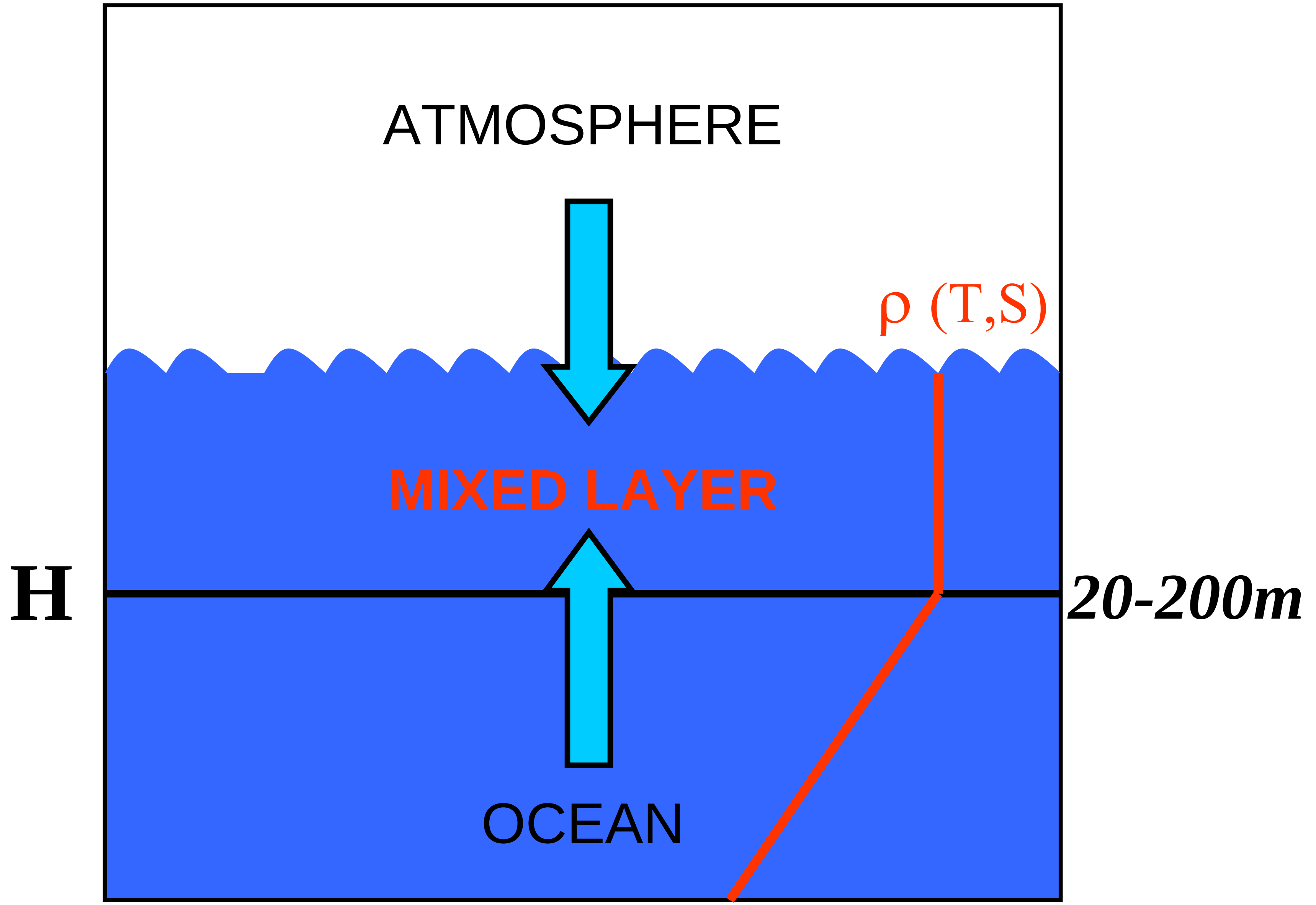
- Overview of key physical processes
- The seasonal cycle of the upper ocean mixed layer and the “re-emergence mechanism”
- Impact of “re-emergence” upon sea surface temperature anomaly persistence and the atmospheric circulation

References at http://www.cgd.ucar.edu/cas/cdeser/

Oceans act as a “flywheel” of the climate system due to their large thermal inertia

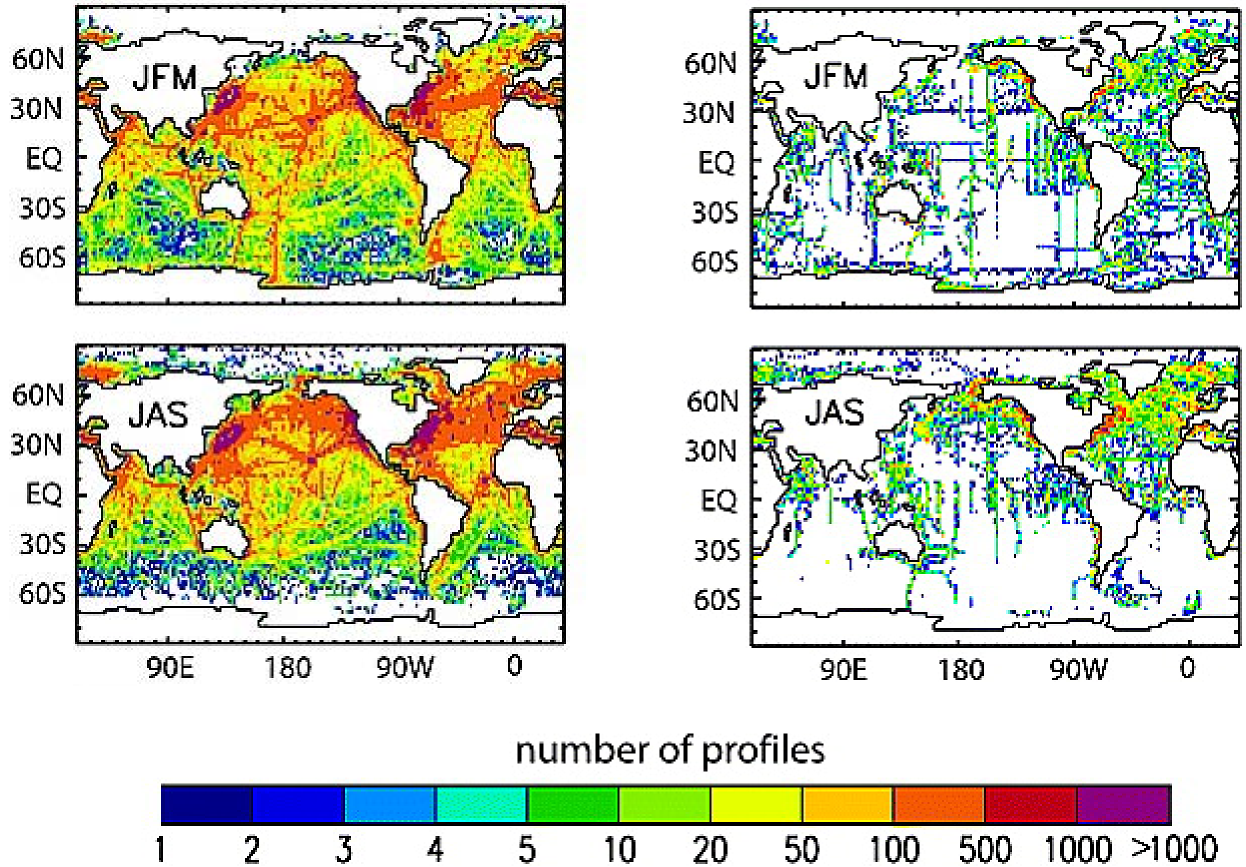


Upper Ocean Mixed Layer



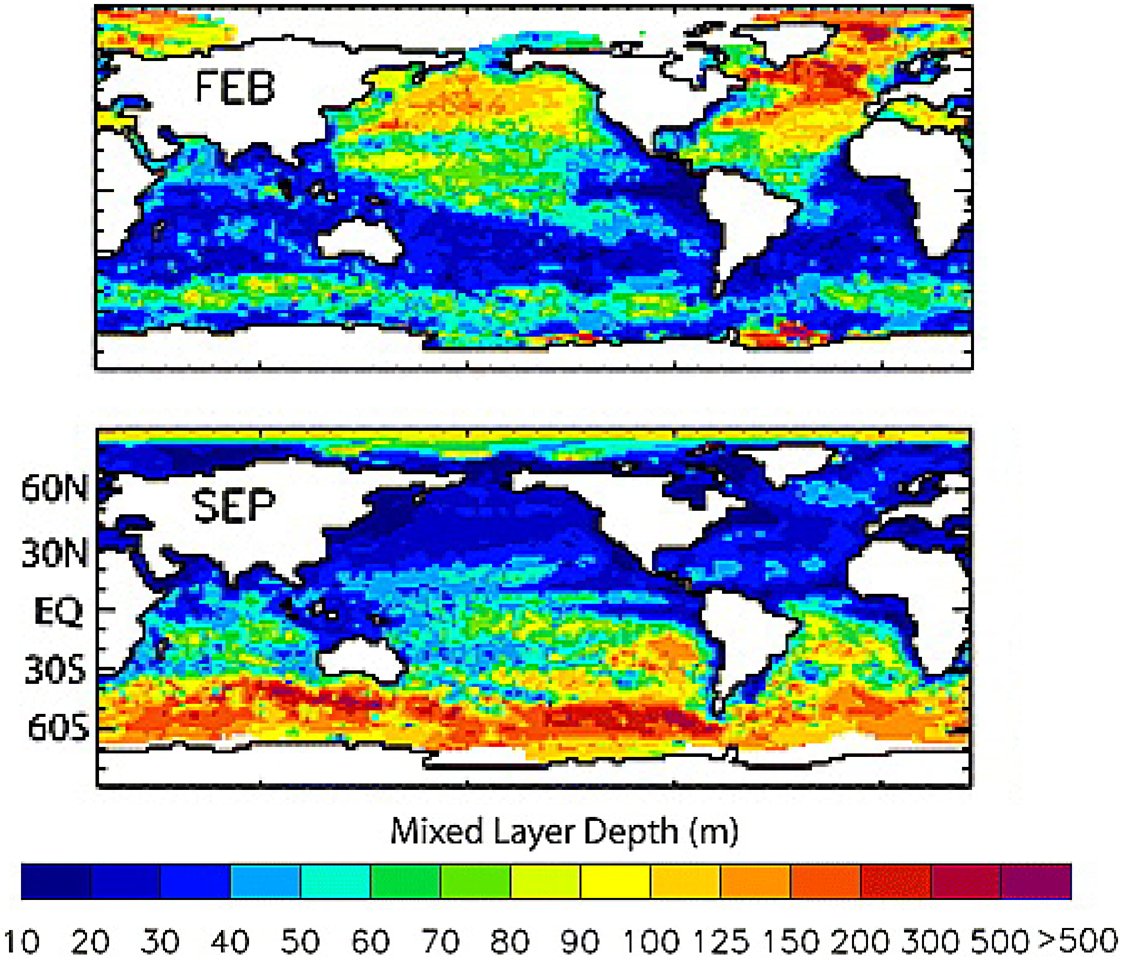
Number of Subsurface Profiles for Mixed Layer Depth

Temperature | Salinity



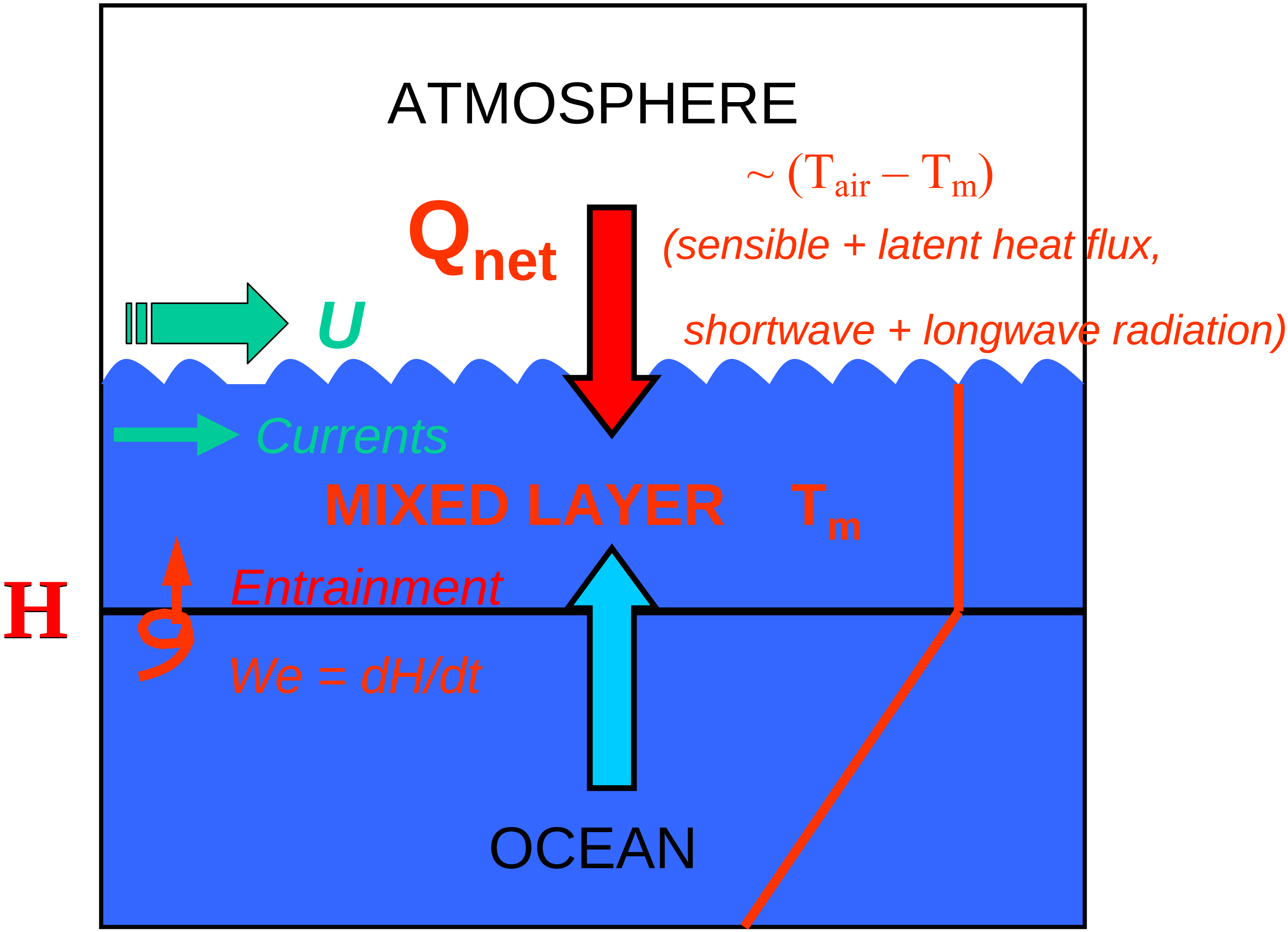
Montegut et al., JGR 2004

Mixed Layer Depth Climatology (ΔT=0.2K)



Montegut et al., JGR 2004

Upper Ocean Mixed Layer



Mixed Layer Heat Budget Equation

$$\frac{\partial T_m}{\partial t} = \frac{\mathbf{Q}_{net}}{\rho C_p H} - \mathbf{U} \bullet \nabla T_m - W_E\left(\frac{T_m - T_{below}}{H}\right)$$

- Air-sea fluxes (Q_{net})
  - Weather forcing of a single-depth (H) "slab" ocean
- Ocean Mixed Layer Processes (H(t) and W_E)
  - Entrainment and the seasonal cycle of mixed layer depth
- Ocean Currents (U, T_{below})

Weather forcing of a slab ocean: the simple stochastic climate model (*Frankignoul and Hasselmann; Tellus, 1977*)

The "null hypothesis" for extratropical T_m variability *(random* Q'_{net} due to internal atmospheric variability acting on a slab ocean mixed layer)*

$$\left(\frac{\partial T_m}{\partial t}\right)' = \left(\frac{Q'_{net}}{\rho C_p h_m}\right) - \lambda T_m'$$

linear damping
$\lambda \sim 10 - 20\ Wm^{-2}\ K^{-1}$

* *No preferred time scale beyond 1-2 weeks*

Simple Stochastic Climate Model

$$\left(\frac{\partial T_m}{\partial t}\right)' = \left(\frac{Q'_{net}}{\rho C_p h_m}\right) - \lambda T_m'$$

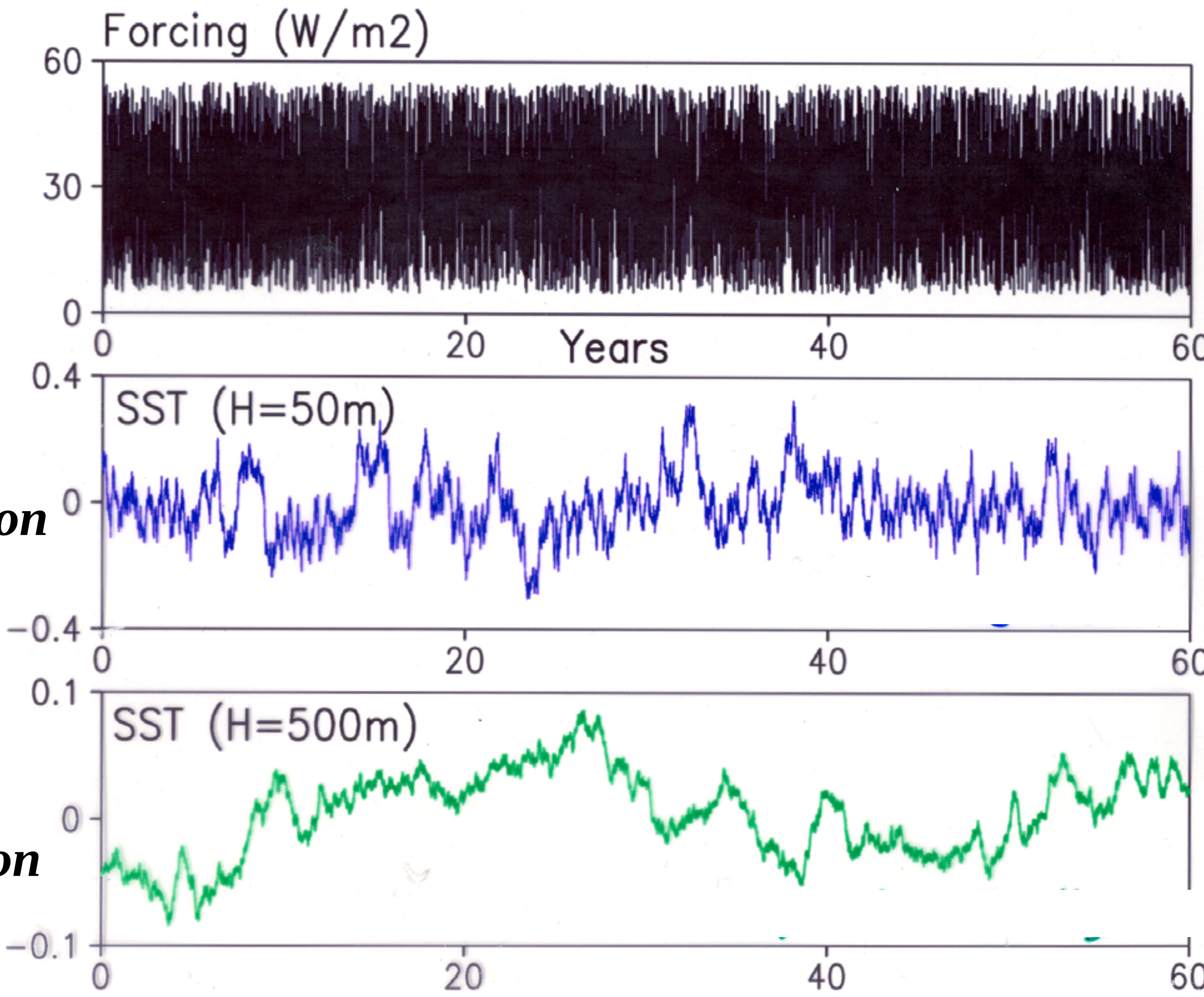
Q_{net}

1 year lag autocorrelation = .1

Decorrelation time = 5 months

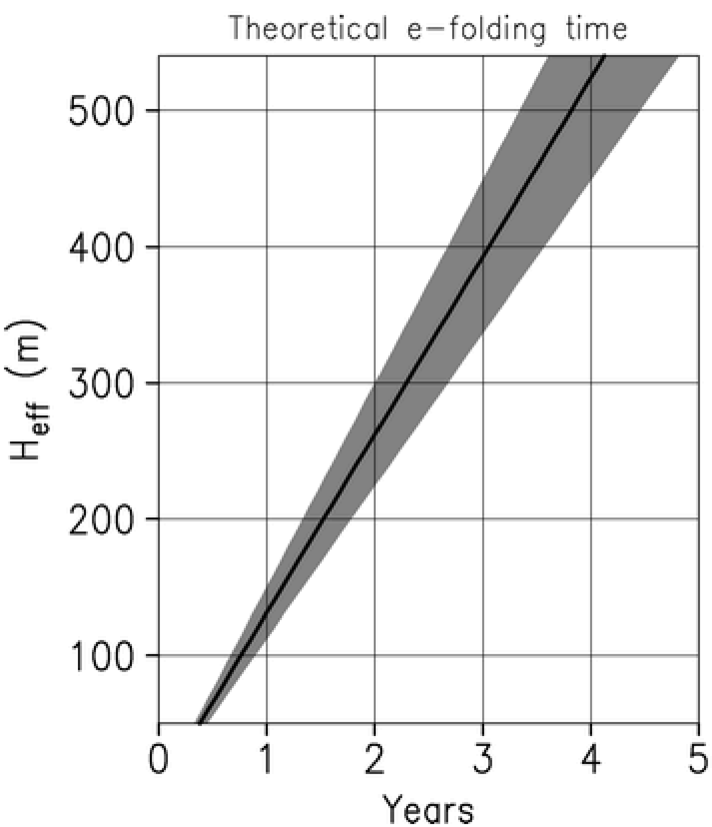
1 year lag autocorrelation = .8

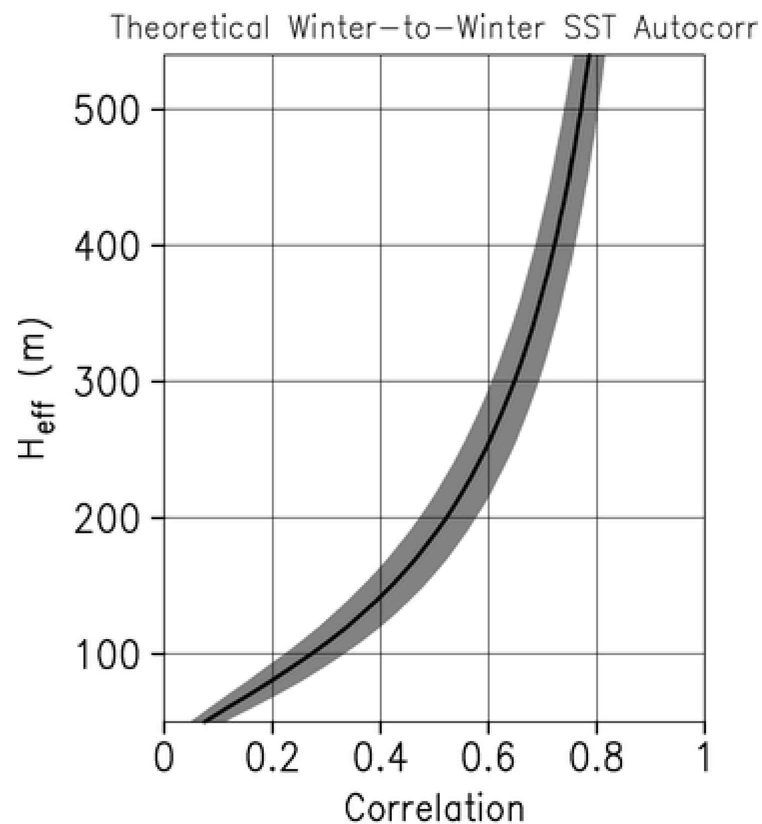
Decorrelation time = 4 years



Simple Stochastic Climate Model

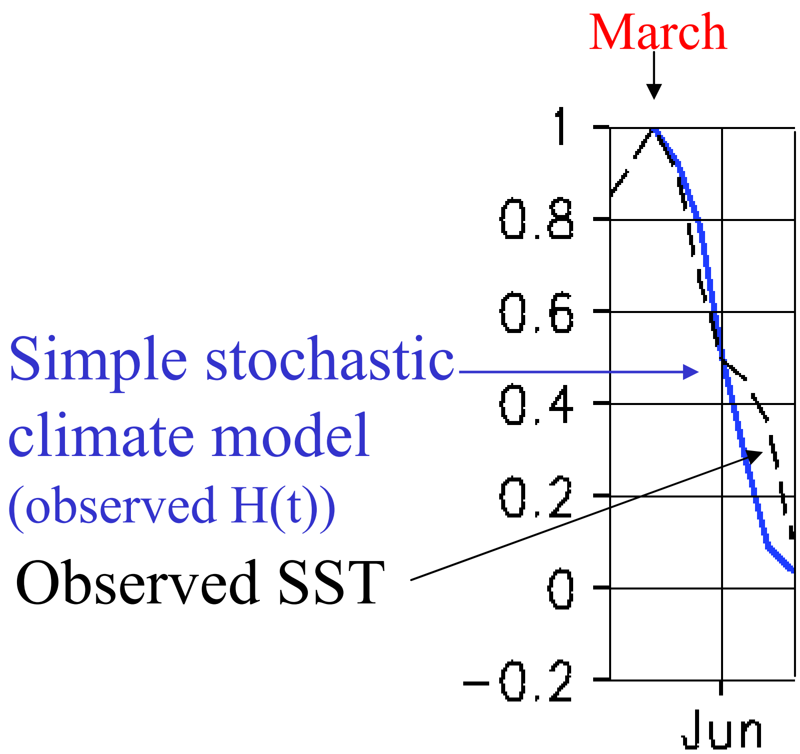
$$r(\tau) = \exp\{-\lambda\tau/(\rho C p H)\}$$





Lag Autocorrelation of Observed Sea SurfaceTemperatures in the North Pacific

Deser et al. (J. Climate, 2003)



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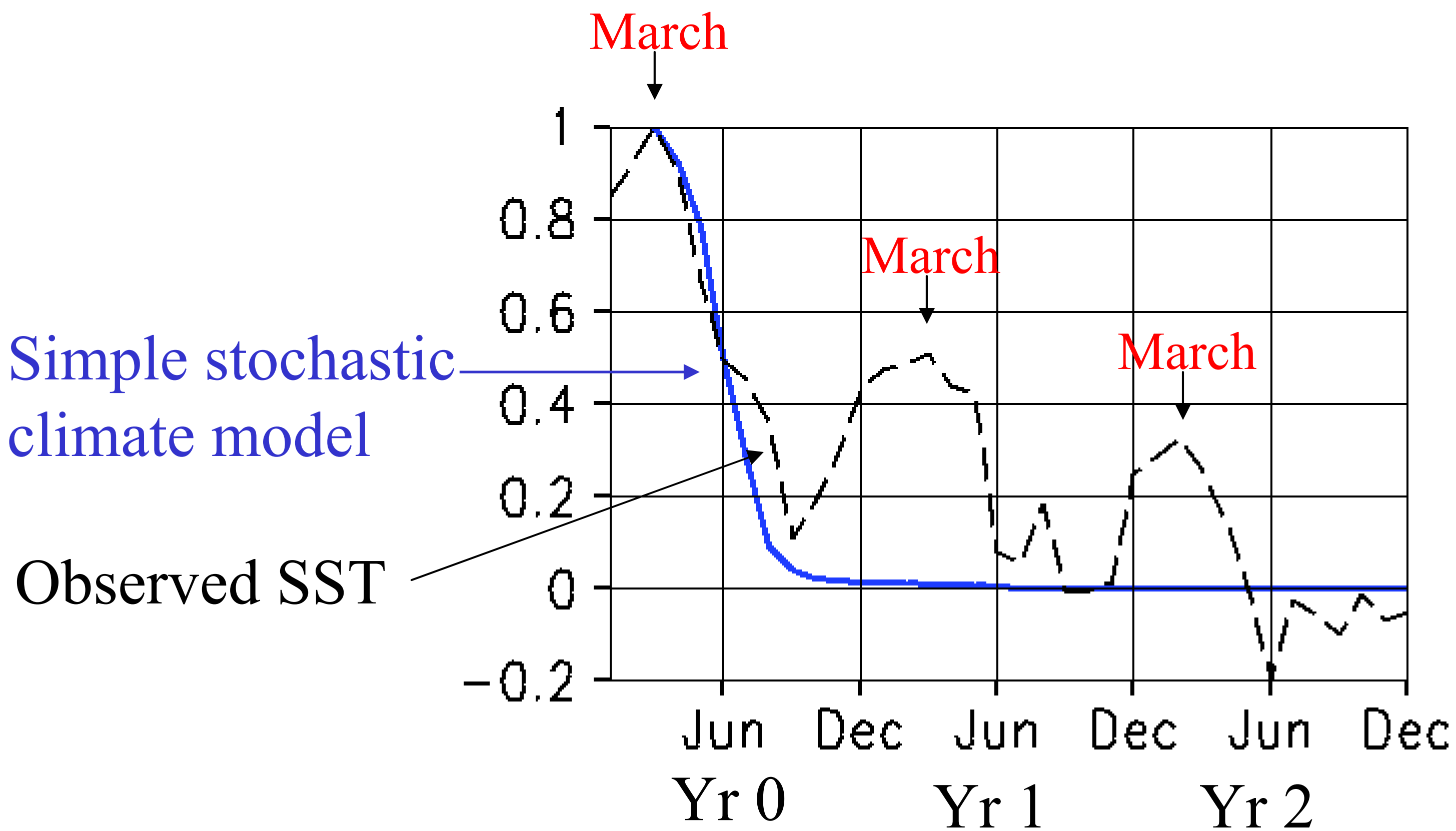

De-correlation time considering all months: ~ 4 months

winter only: ~ 2 years

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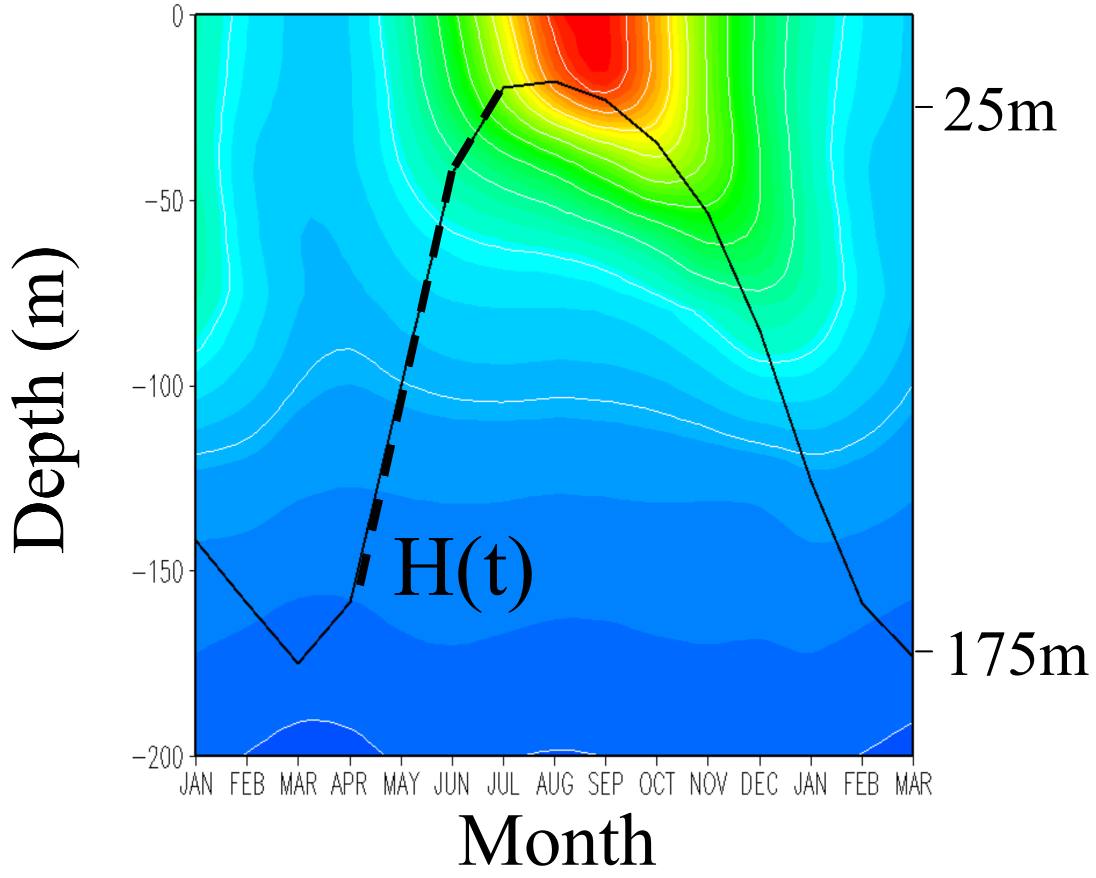
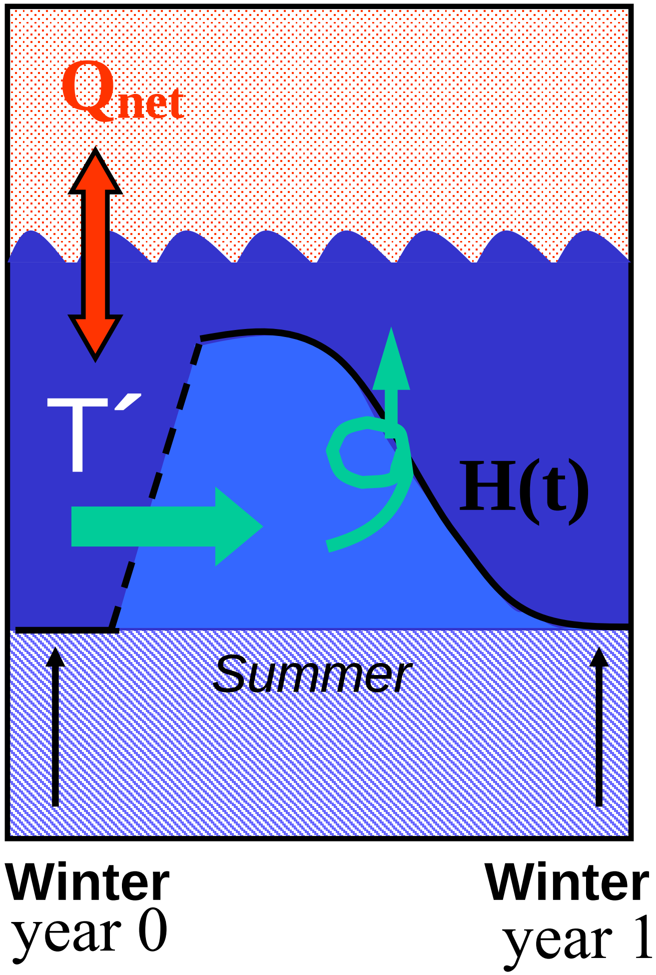
Entrainment and the Seasonal Cycle of Mixed Layer Depth

T (t, z) Central North Pacific



The Re-emergence Mechanism



- Prolongs memory of winter T_m
  (summer sequestration)

(Alexander, Deser and Timlin, *J.Climate*, 1999)

Lag Autocorrelation of Observed Sea Surface Temperatures in the North Pacific

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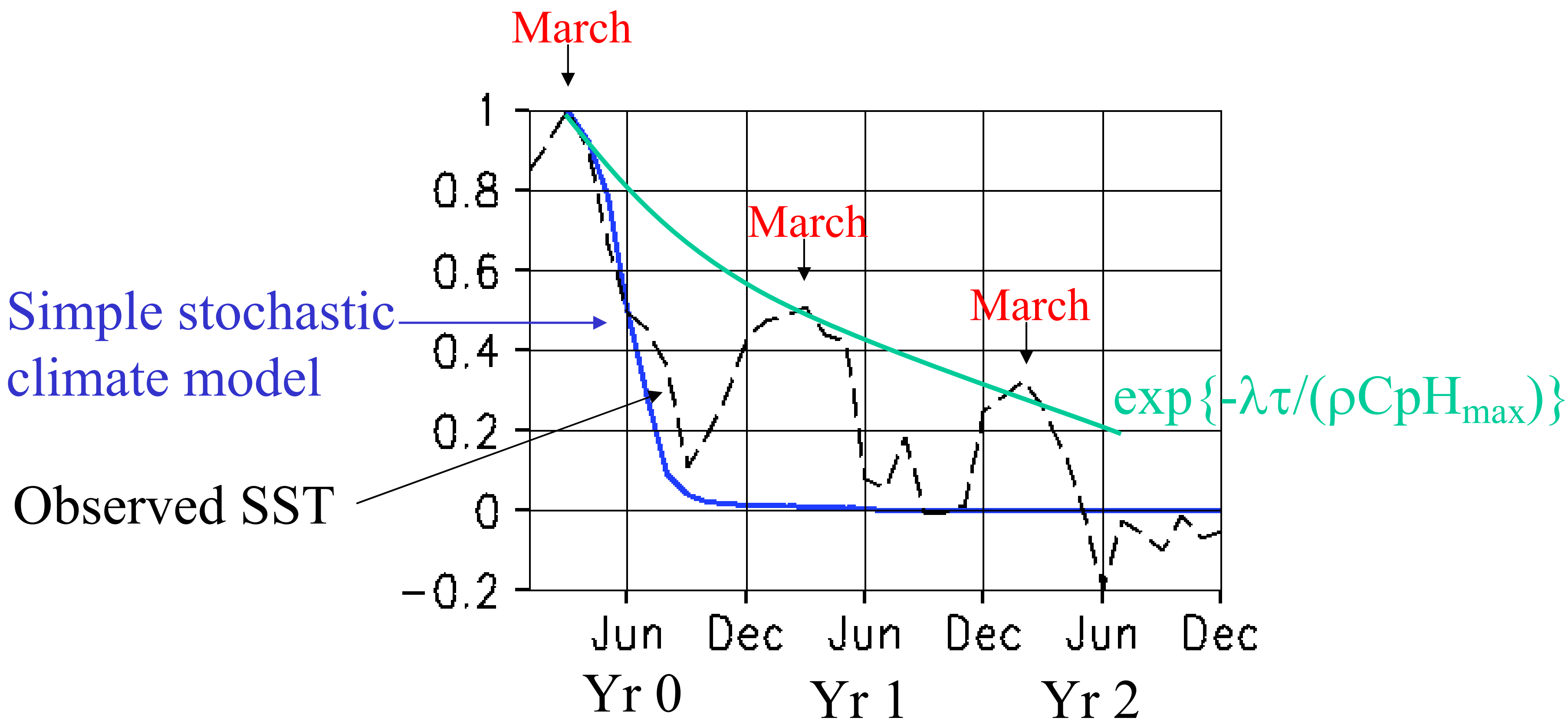

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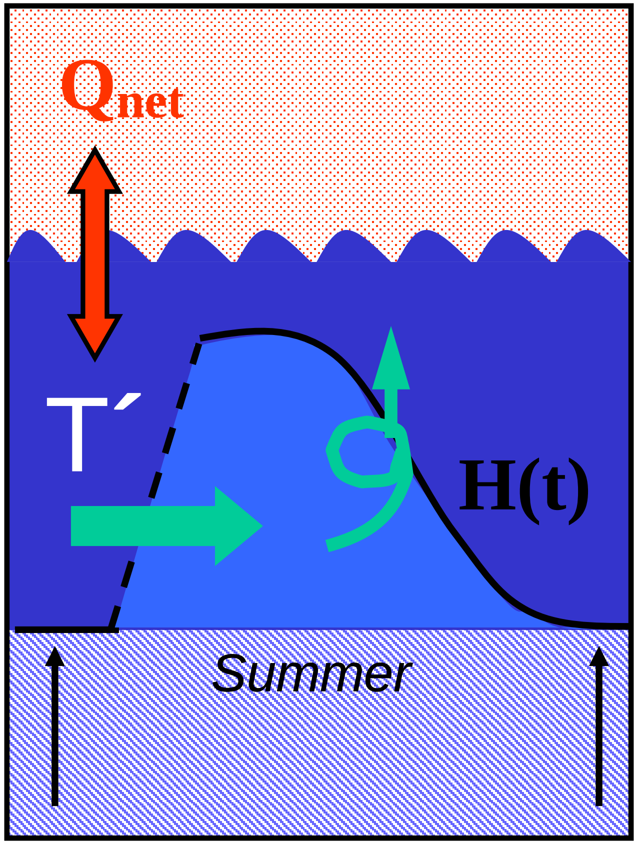
winter only: ~ 2 years

The Re-emergence Mechanism

Does it really happen?



Winter
year 0

Winter
year 1

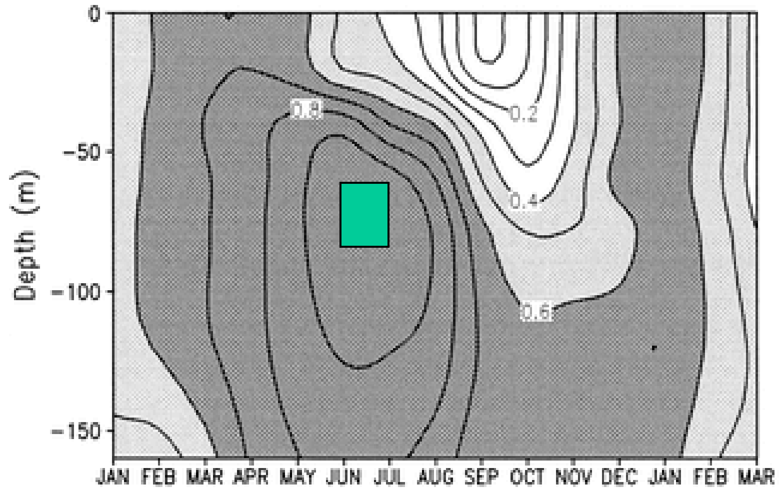
- Prolongs memory of winter T_m
  (summer sequestration)

(Alexander, Deser and Timlin, *J.Climate*, 1999)

Re-emergence in the North Atlantic

(Sargasso Sea, 1955-1995)

Correlations between T in green box and T(z,t)

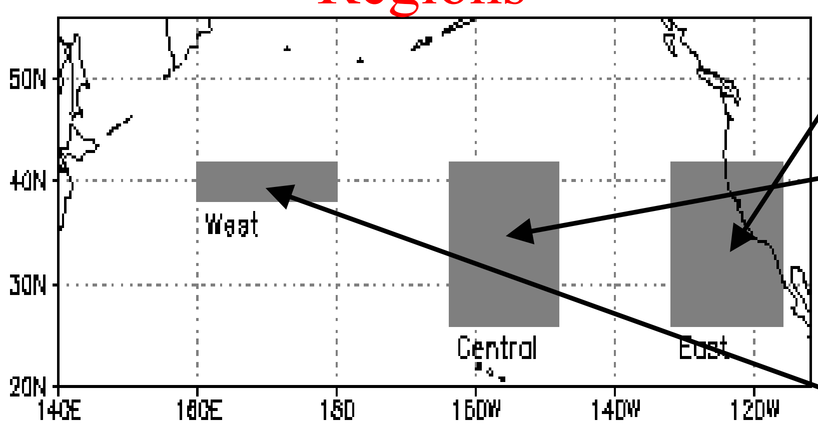


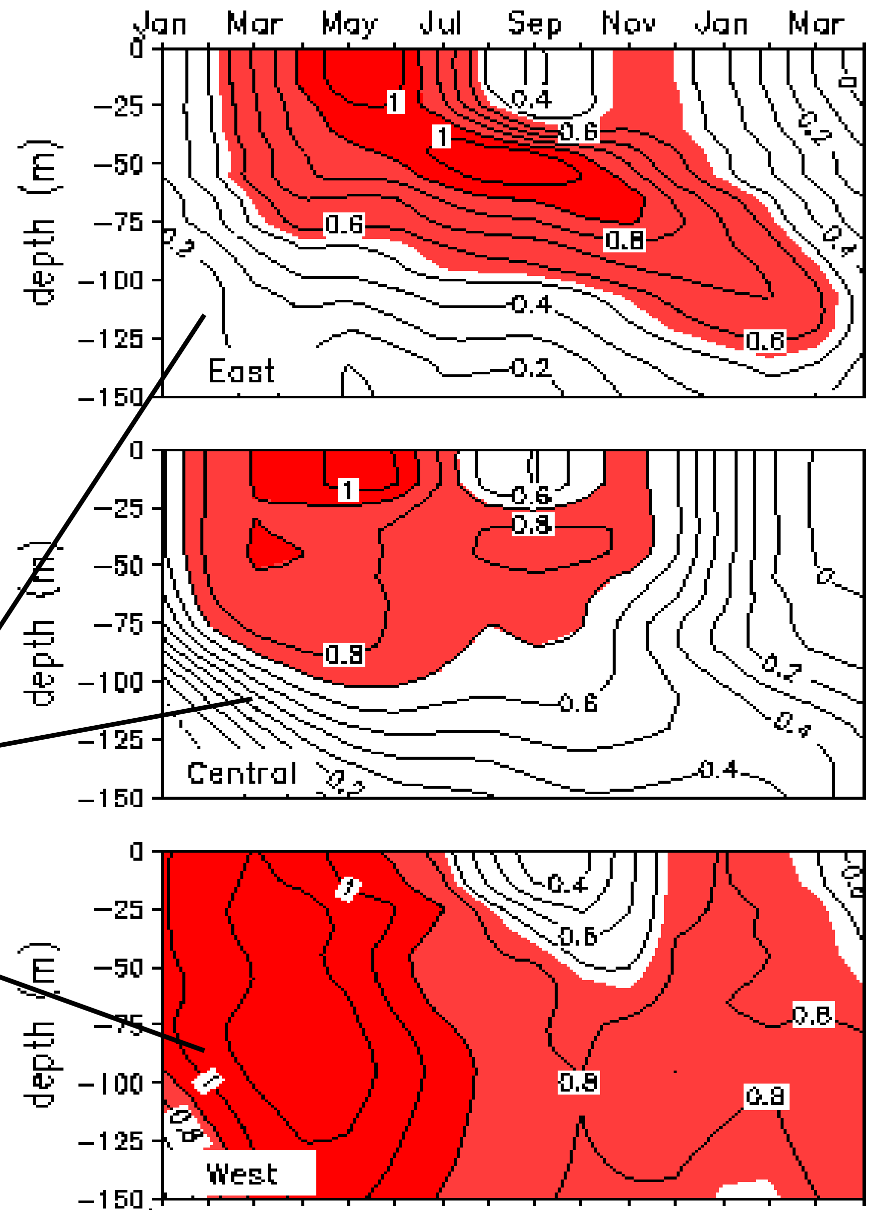
Timlin, Deser and Alexander, 1999

Re-emergence in three North Pacific regions

Lag regression between SST anomalies in April-May with monthly temperature anomalies as a function of depth.

Regions





Alexander, Deser and Timlin (*1999, J. Climate*)

AN ENTRAINING STOCHASTIC CLIMATE MODEL

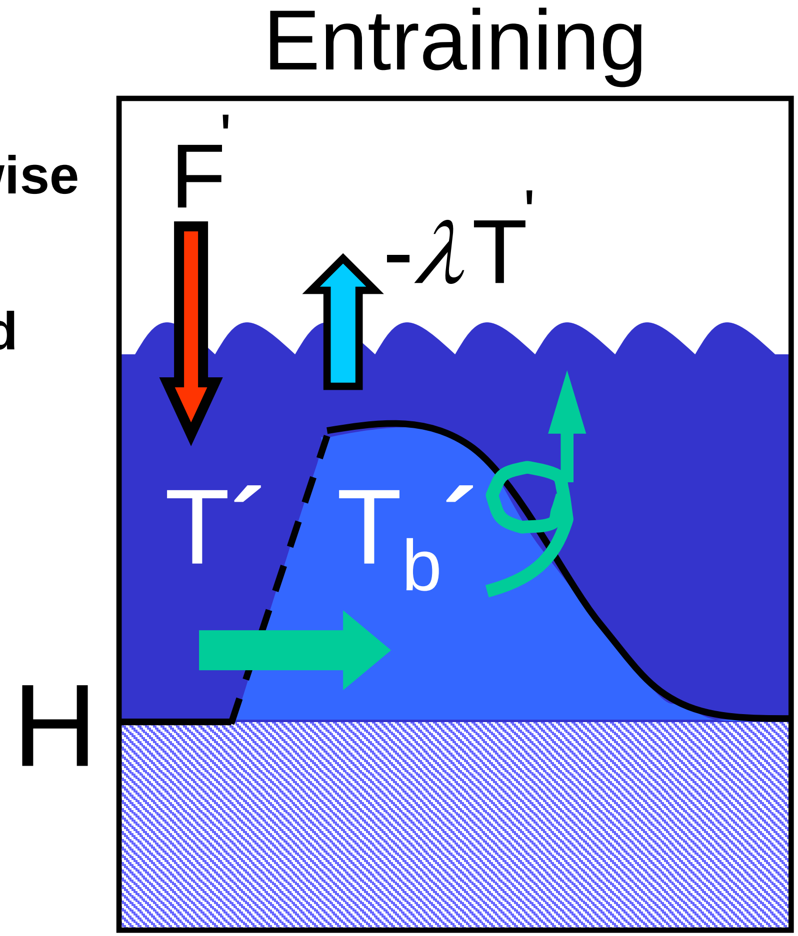
$$\rho C_p \frac{\partial}{\partial t}(HT') = -\lambda T' + F' + \rho C_p W_e (T' - T_b')$$

$W_e = \dfrac{\partial H}{\partial t}$ **if deepening;** W_e **= 0 otherwise**

$H(t)$ **= Specified monthly from observed climatology**

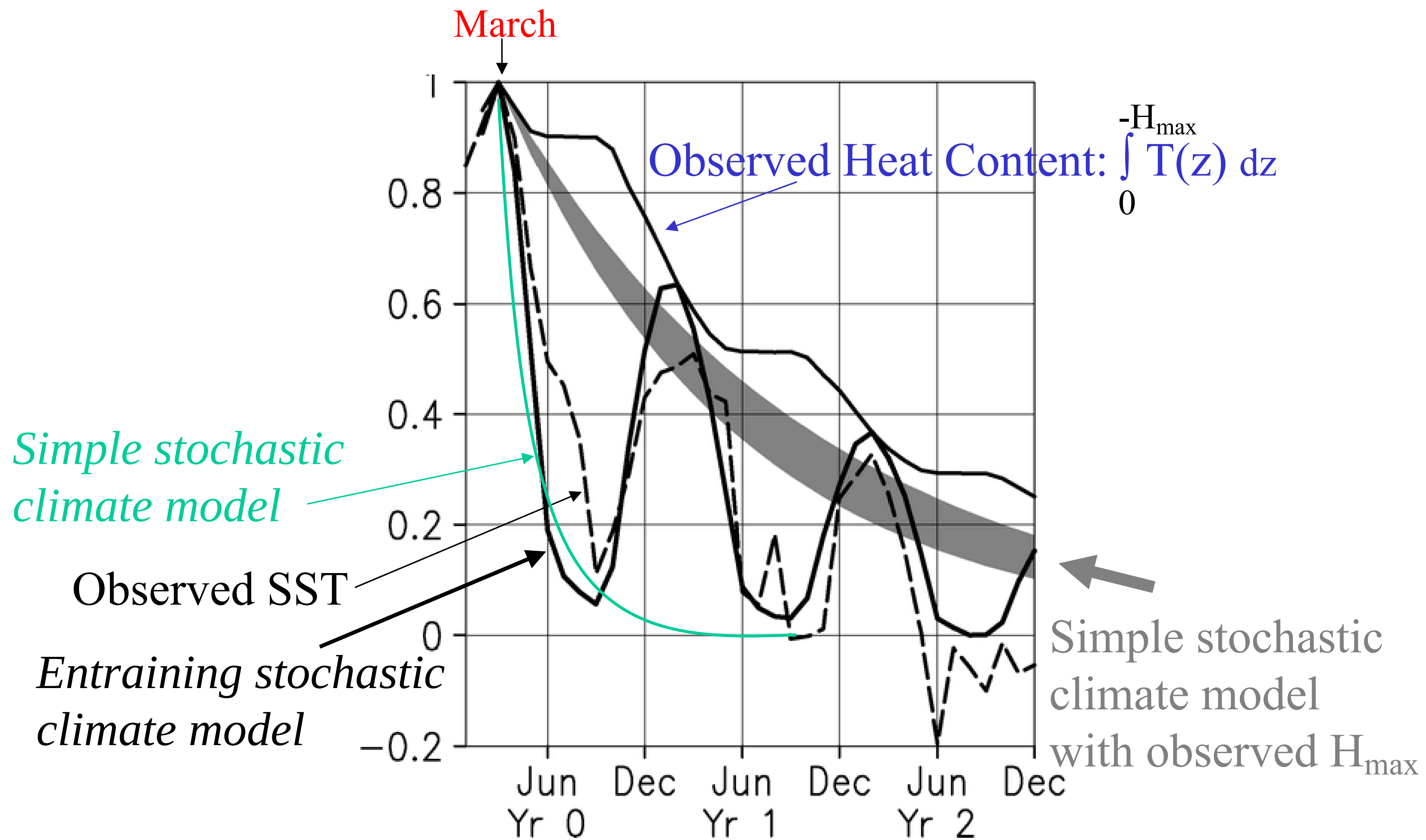
5000 yr integration, 3 day timestep

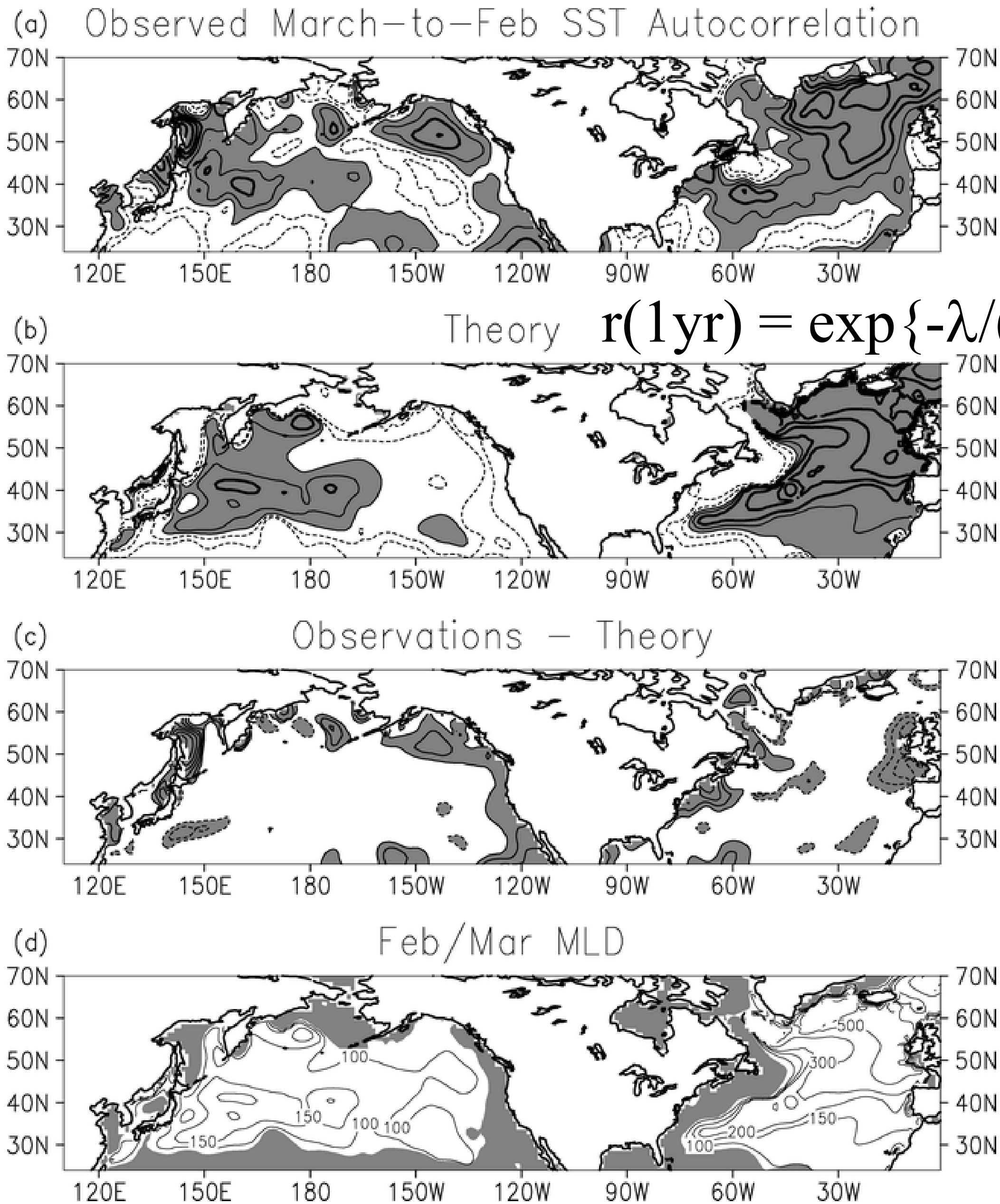
Deser et al. (J. Climate, 2003)



Application of the Entraining Stochastic Climate Model to Observed SST Lag Autocorrelations in the North Pacific

Deser et al. (J. Climate, 2003)





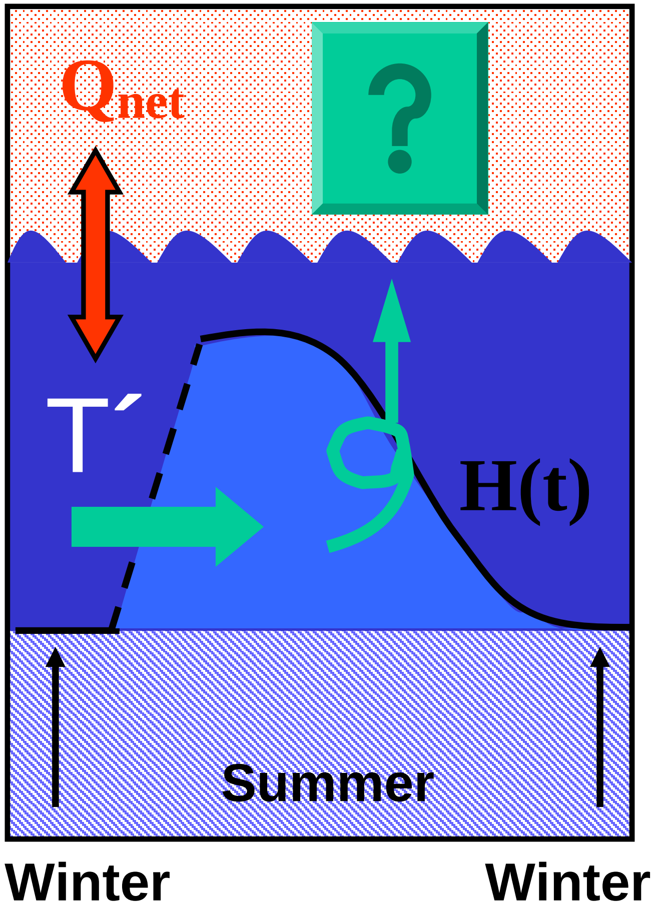
Dashed: 0.1, 0.2
Solid: 0.3, 0.4, …

$$r(1yr) = \exp\{-\lambda/(\rho C_p H_{max})\bullet 1yr\}$$

Dashed: 0.1, 0.2
Solid: 0.3, 0.4, …

Dashed: - 0.2, -0.3…
Solid: 0.2, 0.3, …

The Re-emergence Mechanism: Impact on the Atmosphere?



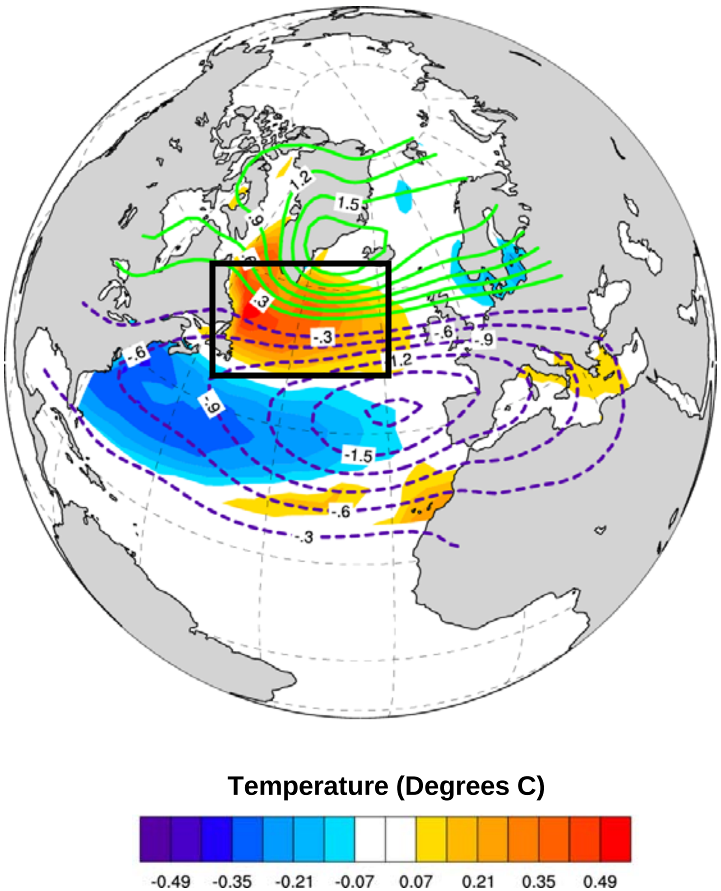
Investigating the Impact of Re-emergence in the North Atlantic upon the Atmospheric Circulation: Coupled Model Experiments

Cassou, Deser and Alexander, J. Climate, submitted 2006

NCAR atmospheric general circulation model
(Community Atmospheric Model Version 2)
coupled to an upper ocean entraining mixed layer model
(no ocean currents)

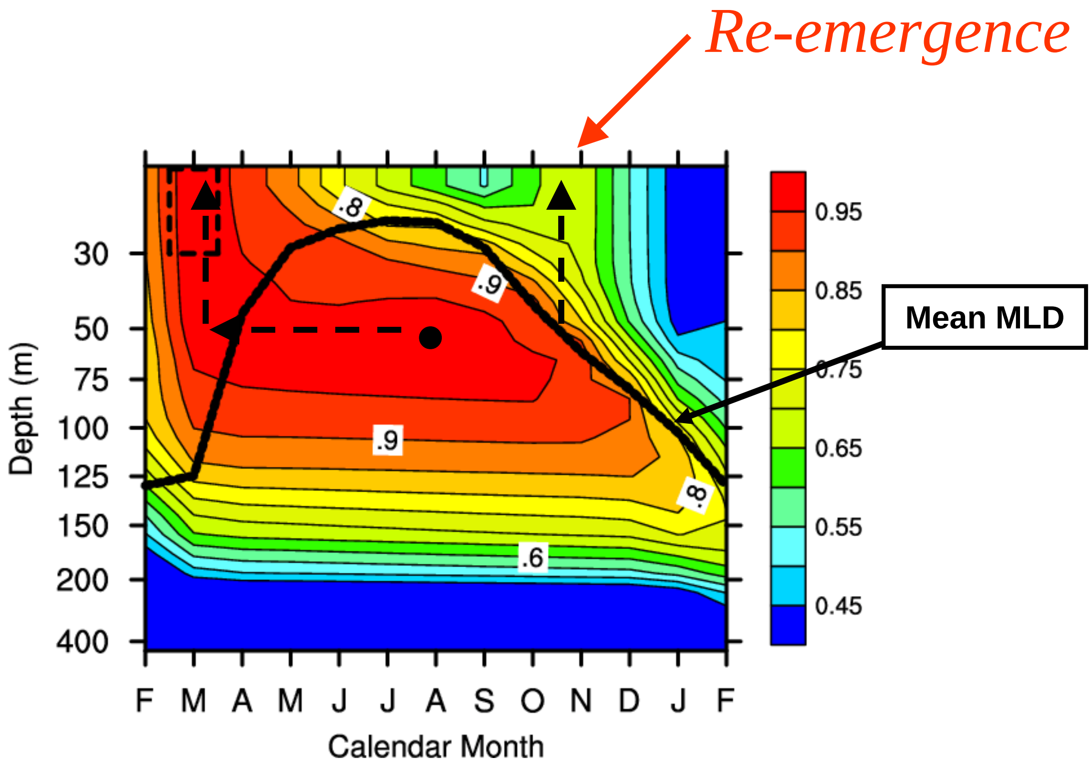
Dominant Structure of Winter Atmospheric Circulation Variability and Ocean Temperature Response (150 year integration of the coupled model)

January-March Sea Level Pressure (contours)
August temperature at 50m depth (shading)



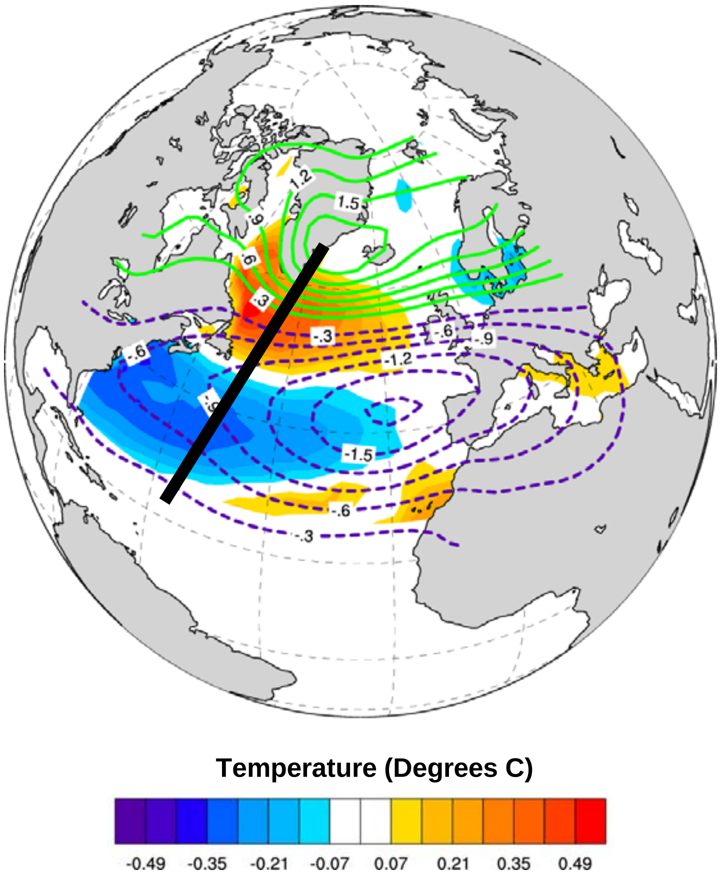
Pattern and amplitude are realistic;
August temperatures at depth are linked to previous winter surface temperatures
(e.g., *via* re-emergence)

Simulated re-emergence in the northern North Atlantic (150 year integration of the coupled model)



Experimental Design

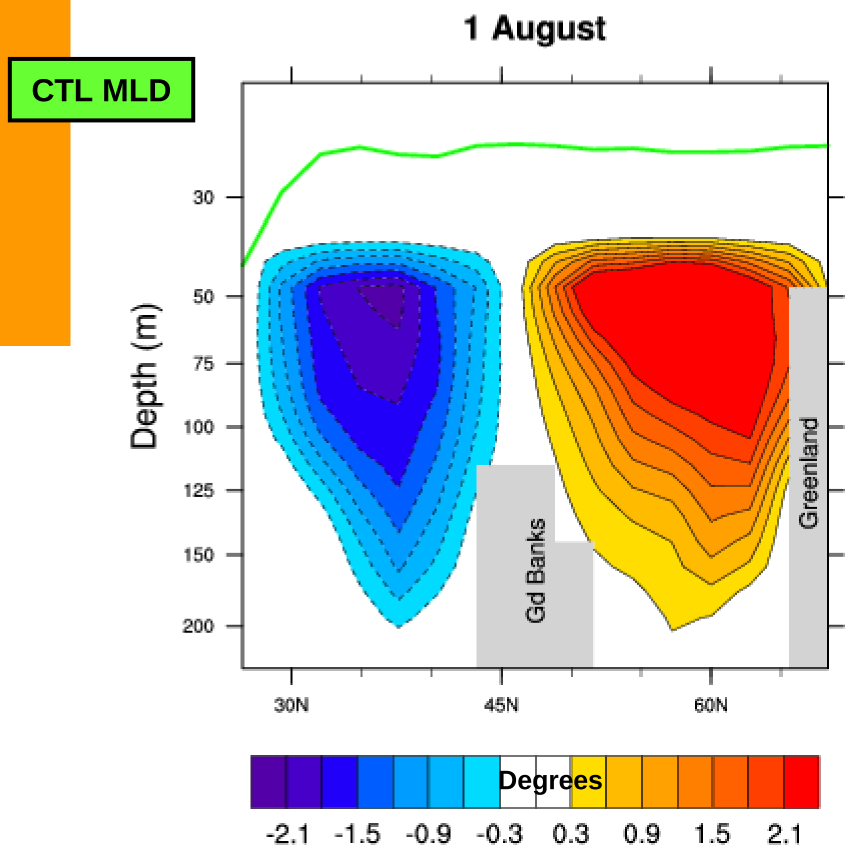
January-March Sea Level Pressure (contours)
August temperature at 50m depth (shading)



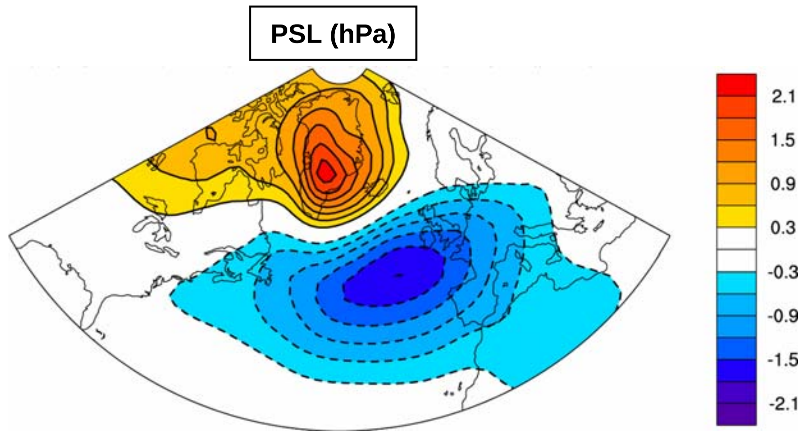
- Specify August subsurface (40-450m) temperature anomalies as an initial value problem, then let the coupled model run

- 60 integrations, Aug 1 – July 31, with positive polarity, 60 with negative polarity. All integrations start from different atmospheric initial conditions

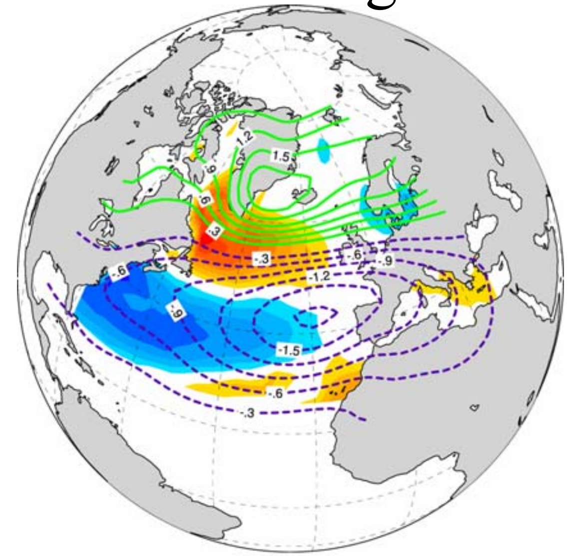
Evolution of the REM anomalies over a year starting in August 1st.
REM=Difference between the REM+ and REM- ensemble Mean
Section @ [60º - 40ºW] from 25º to 68ºN



Winter Sea Level Pressure Response



Forcing



Weak (20%) but significant SLP response that acts as a positive feedback (e.g., in this model, re-emergence enhances the winter-to-winter persistence of the North Atlantic Oscillation).

SUMMARY

The Role of the Extra-tropical Upper Ocean Mixed Layer in Climate Variability

- Importance of the seasonal cycle of mixed layer depth: allows for the “re-emergence mechanism” which in turn enhances the persistence of winter sea surface temperature anomalies

- Sea surface temperature anomalies due to “re-emergence” exert a weak but significant impact upon the atmospheric circulation, enhancing the persistence of dominant weather patterns such as the “North Atlantic Oscillation”