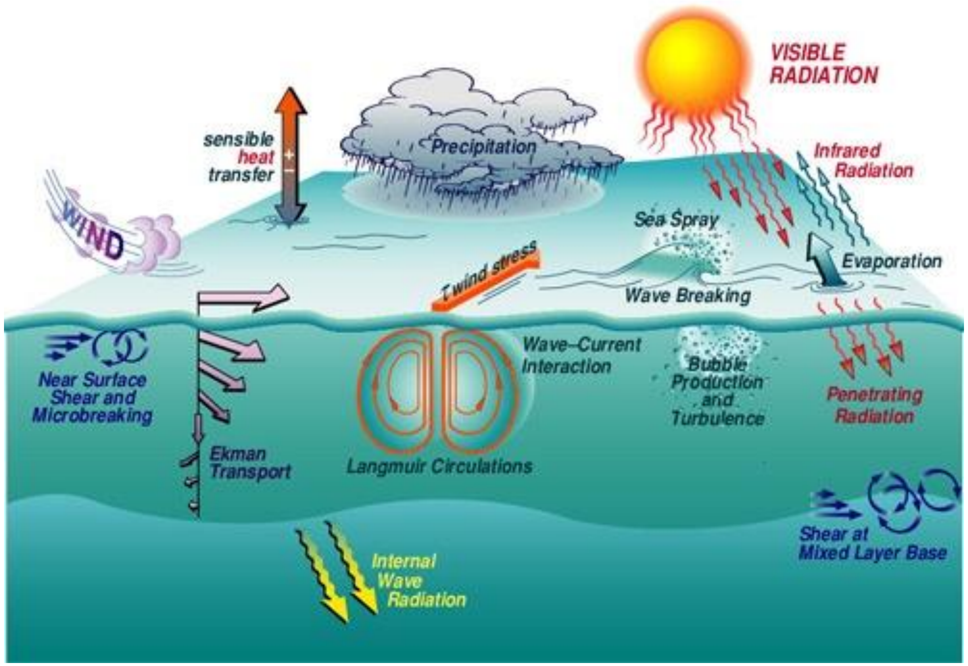
Simulation of the Mixed Layer Depth (MLD) in the Northeast Pacific

Shawn M. Donohue, Michael W. Stacey



Schematic of the mixed layer. (From, www.locanispl.upmc.fr/cdblod/mdl.html, *2008)*

The MLD is one of the most important properties of the upper Ocean, representing the depth of the quasi-homogeneous surface region that interacts with the atmosphere – it has significant climate, acoustic and biological impacts! (*Kara et al.* , 2003)

Winter MLD is **defined** here as the depth at which *sigma-t* is greater than the surface (10 m) value by 0.1

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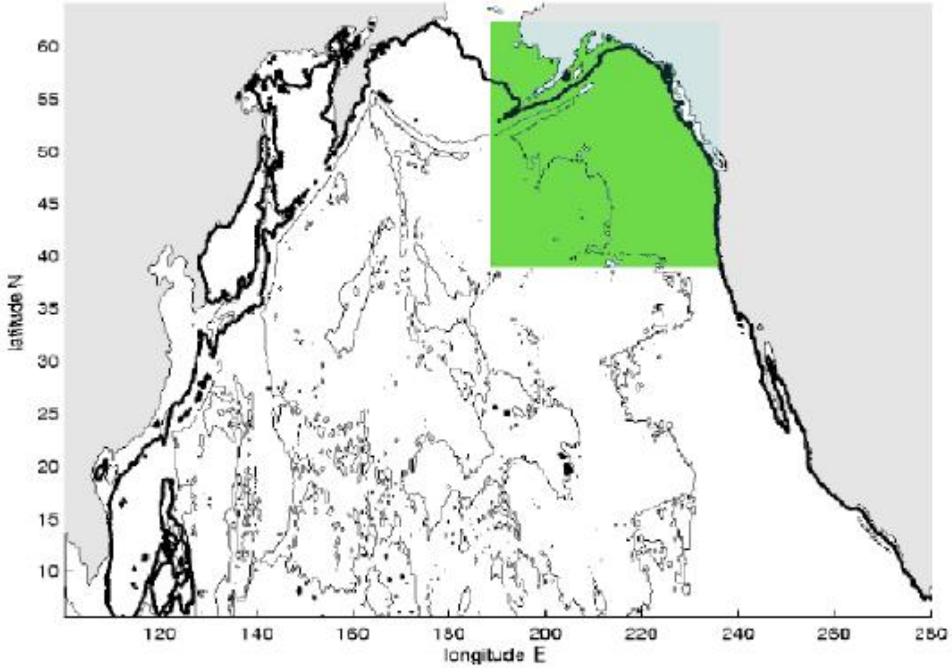
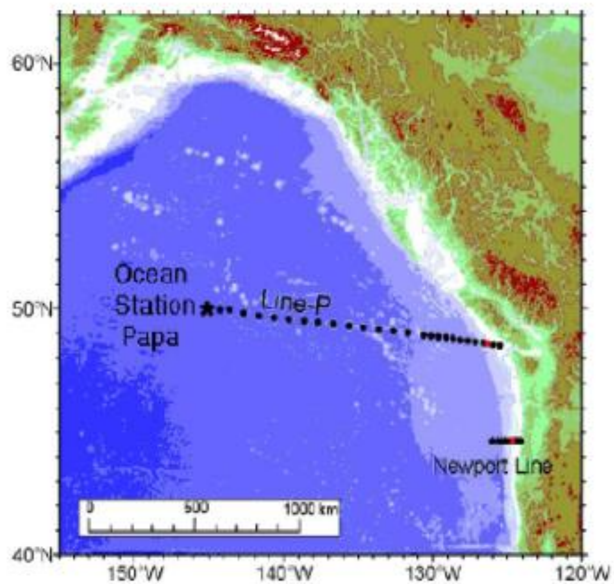
Outline

- 1) Describe the model set-up
- 2) Overview and comparison of spectrally nudged and non-nudged simulations
- 3) Comparison to observations
- 4) Cause(s) of the 2003 MLD Shallow Anomaly
- 4) Interesting new features in MLD trends
- 5) Conclusions

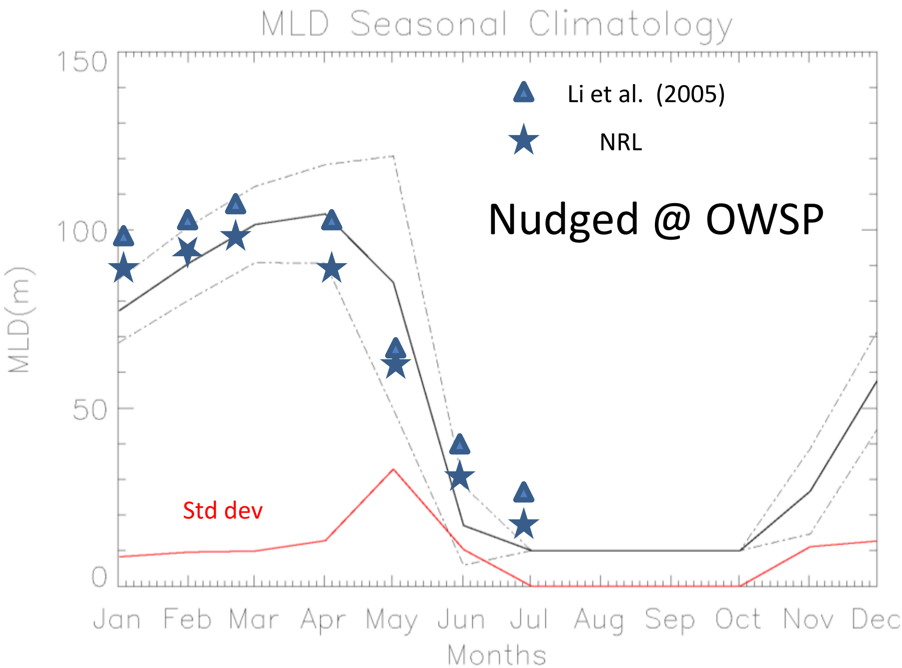
Model Domain whole North Pacific [5N-65 N]

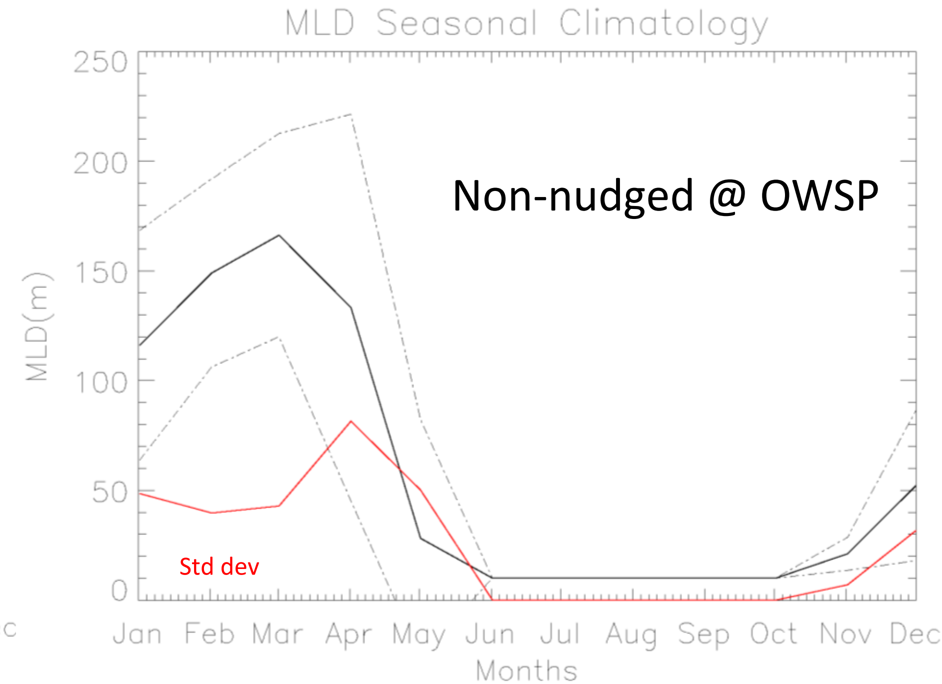


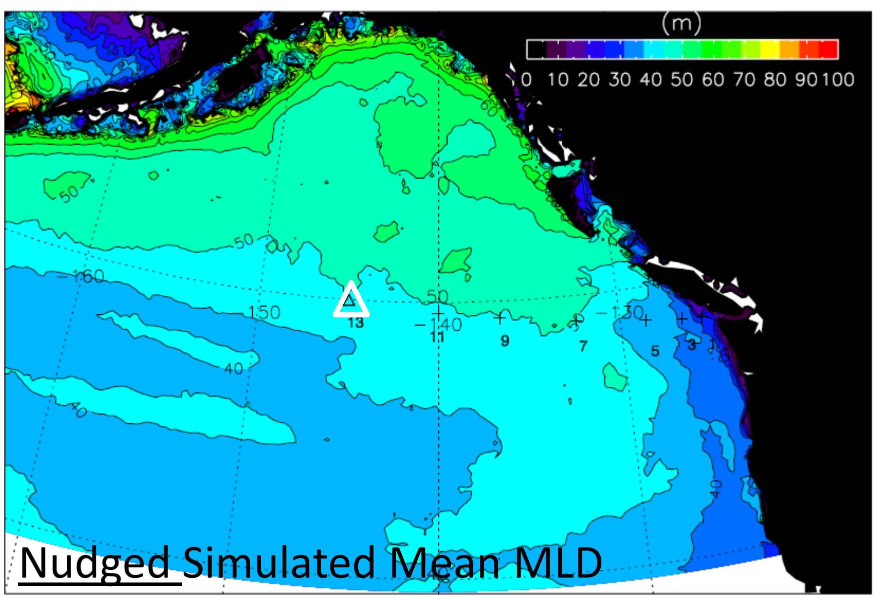


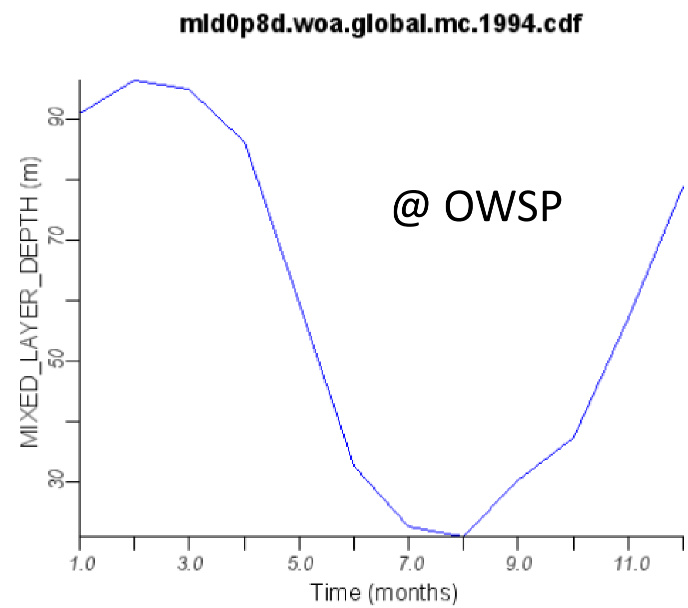
Region of Primary Interest

- *HIGH PERFORMANCE COMPUTING VIRTUAL LABORATORY [HPCVL]*
- 46 YEAR RUN, "SPUN UP" USING LEVITUS CLIMATOLOGY OF T, AND S.
- NCEP FORCING: WINDS, NET HEAT FLUX, PRESSURE, FRESH WATER FLUX
- MODEL HAS HORIZONTAL RESOLUTION OF 0.25 DEGREES
- 741 (long.) X 319 (lat.) GRID POINTS
- 28 VERTICAL LEVELS WITH 10m RESOLUTION IN UPPER LAYERS
- KPP for vertical mixing
- Spectral nudging to only "mean" and "annual" Levitus Climatology.





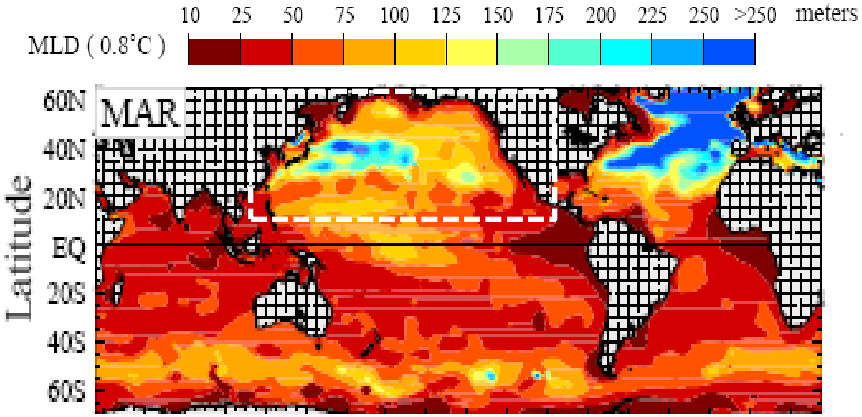




Station 13 (open triangle icon) is OWSP

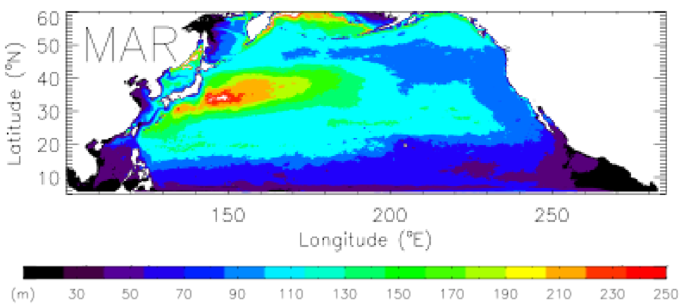
NRL climatology for OWSP

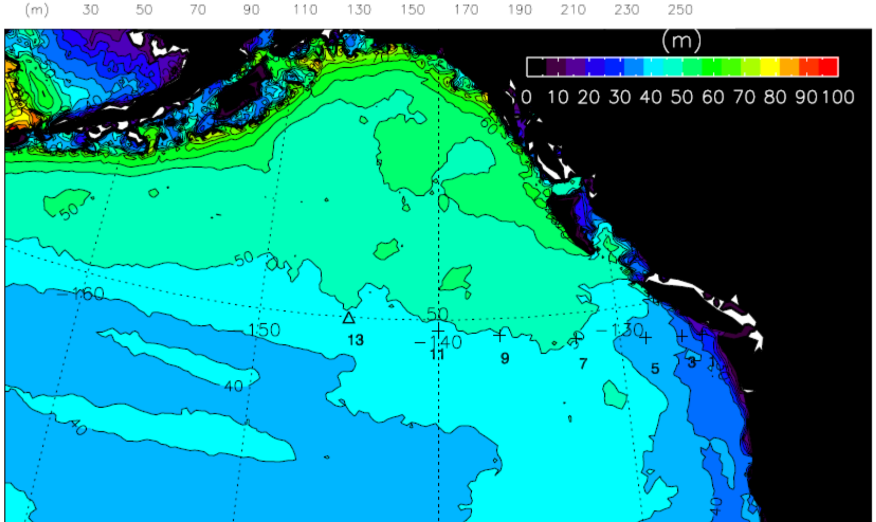
Climatological MLD for March



Kara *et al.* (2000)

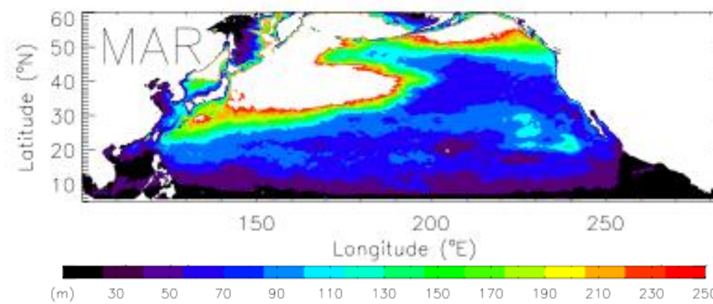
NUDGED

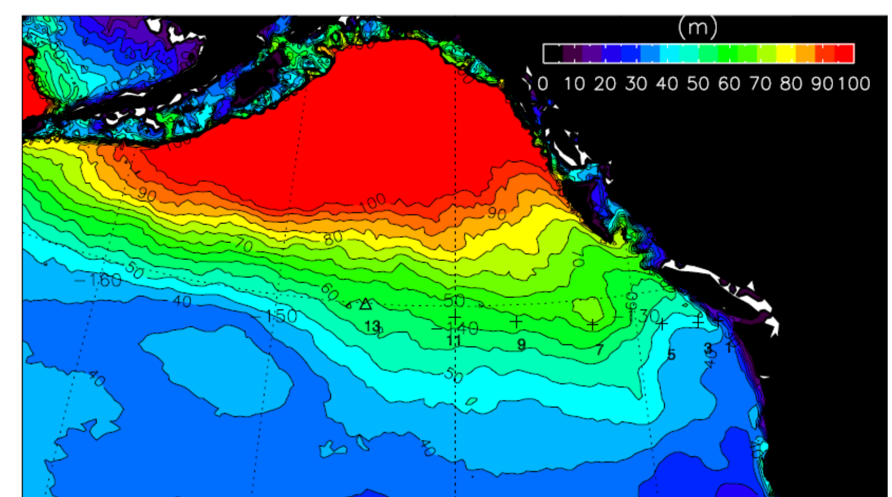




Nudged simulated mean MLD

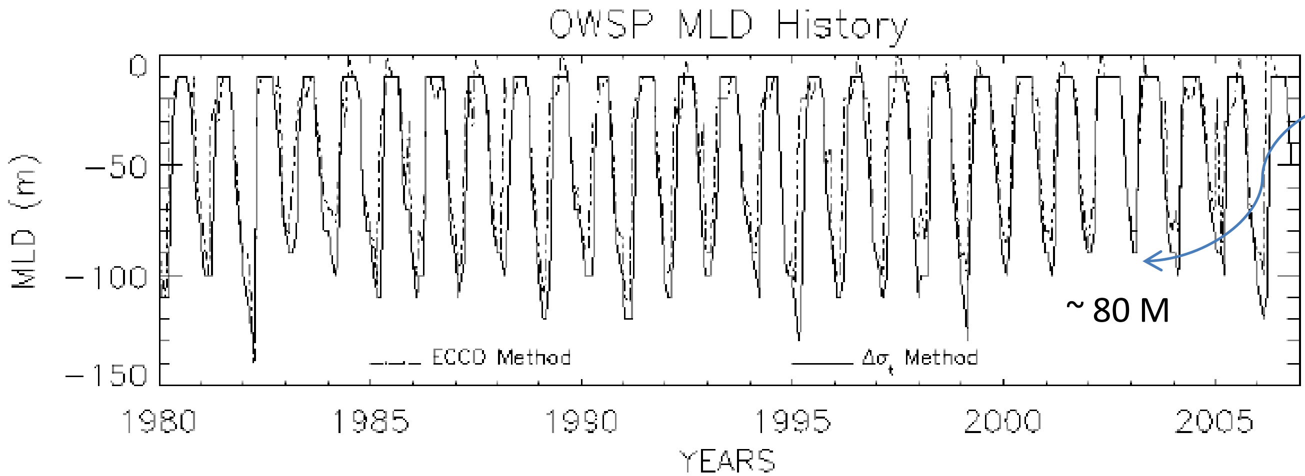
NON- NUDGED



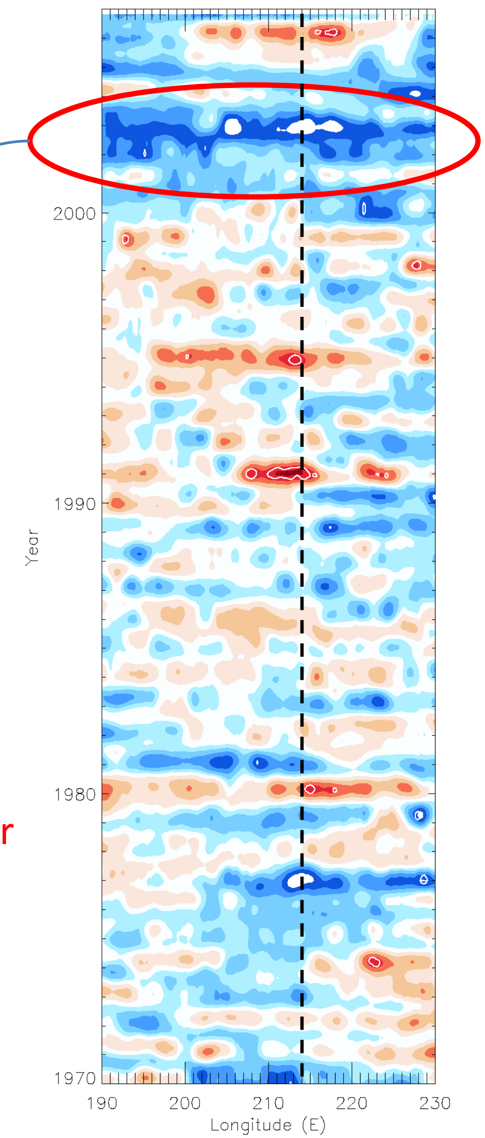


Non-nudged simulated mean MLD

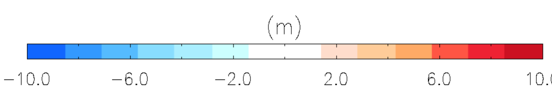
MLD Anomalies (low-passed)



ECCO (Estimating the Circulation and Climate of the Ocean): (*Lorbacher et al.*, 2006)



Dashed line shows OWSP's longitude.

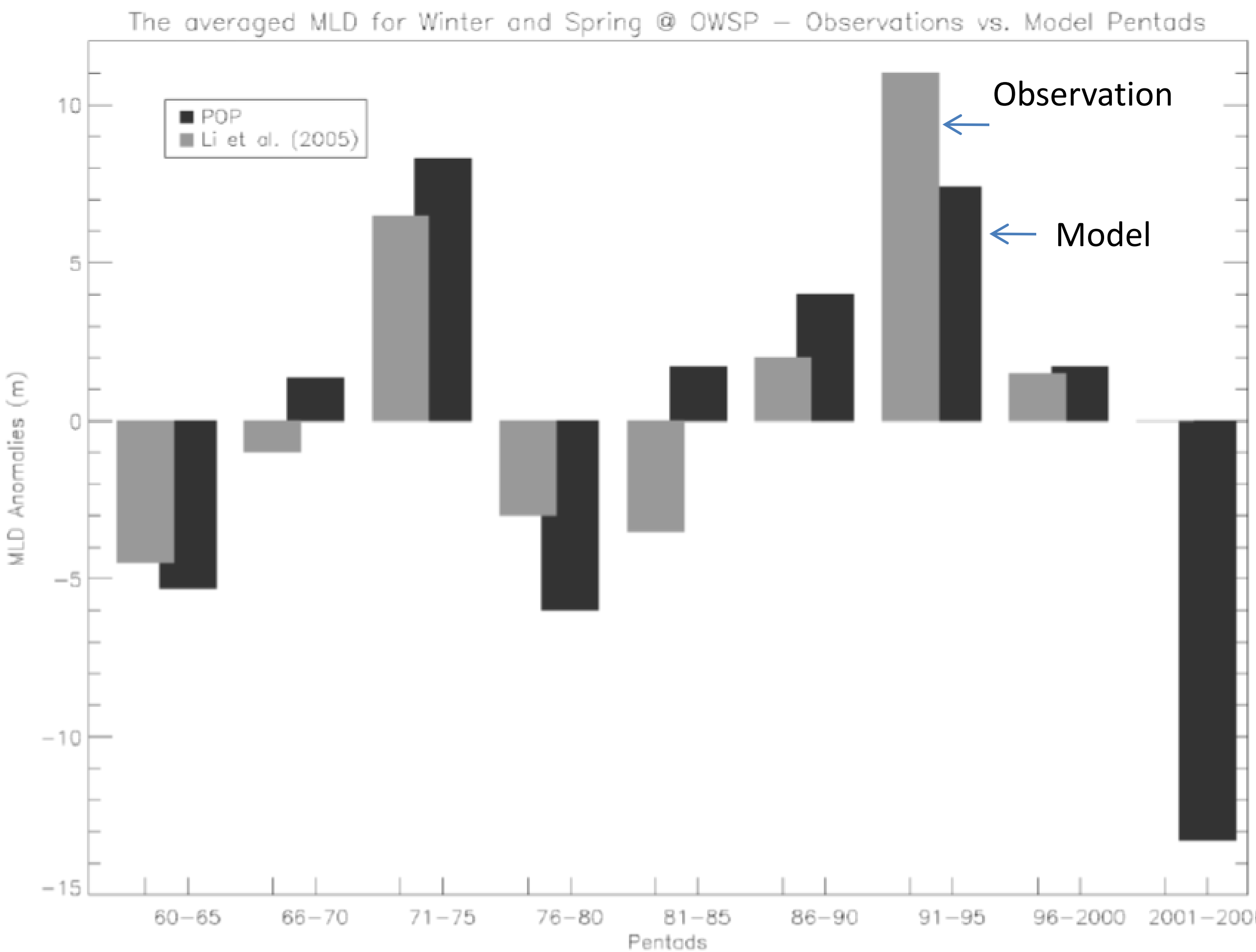


OWSP is correlated with average along *Line Papa* from Hovmoller at 0.63 with zero lag.

OWSP is correlated with average along western portion of GOA from Hovmoller at 0.63 with zero lag.

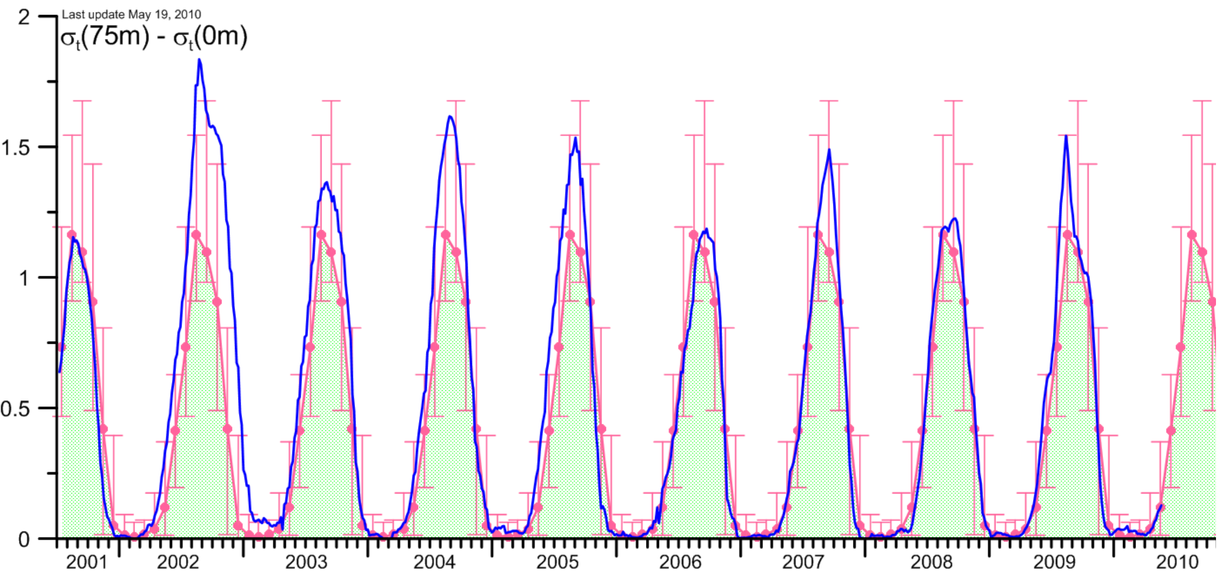
Western GOA average is correlated with average of Line Papa [not including OWSP] at only 0.58 with zero lag.

Coherency analysis indicates much higher values of agreement (0.77-0.9) at > 99% for specific periods of 3, 5, and 8-10 years for OWSP and regions east and west of it.



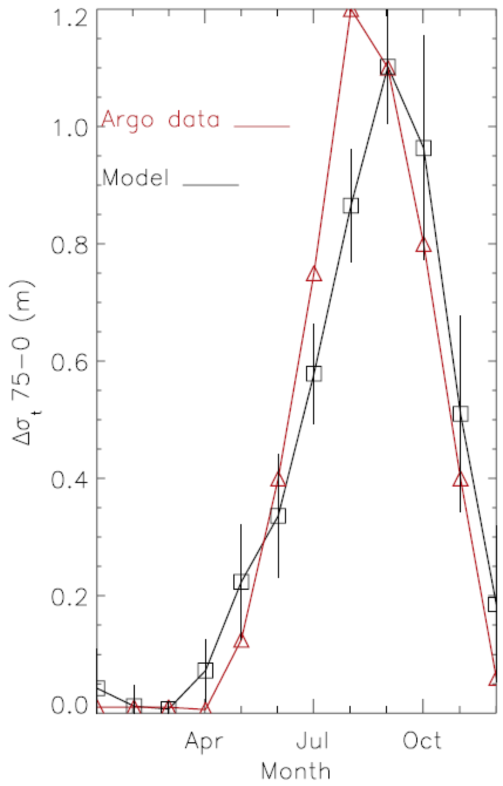
Dec. to May average of MLD anomalies: Observations are from *Li et al.* (2005)

Observed Stratification (Argo)

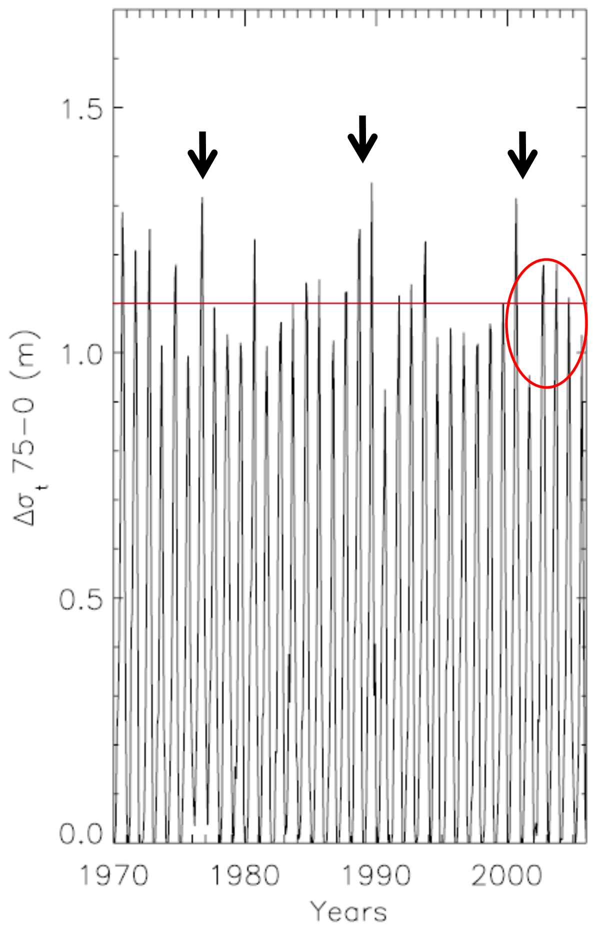


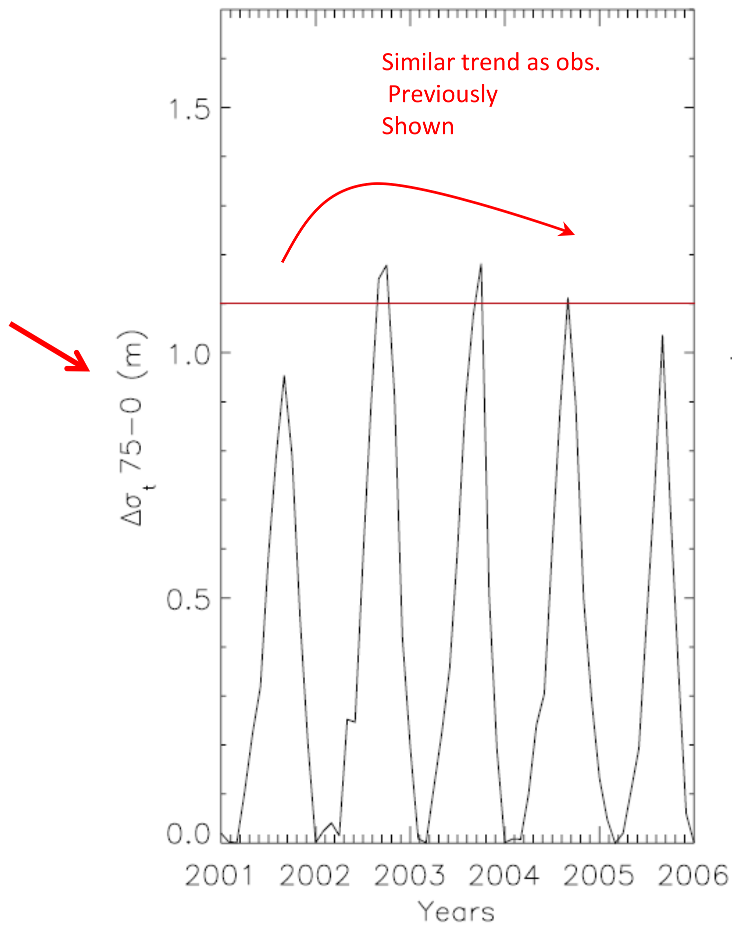
Latest as of **25 May 2010** from Argo web site:
http://www.pac.dfompo.gc.ca/sci/data/projects/argo/Line/P_strat.gif

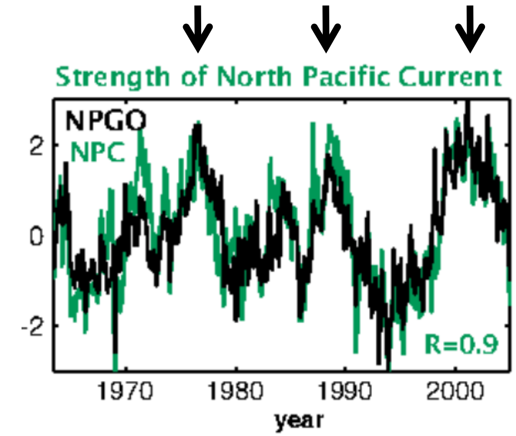
Model vs. Argo stratification climatology at OWSP

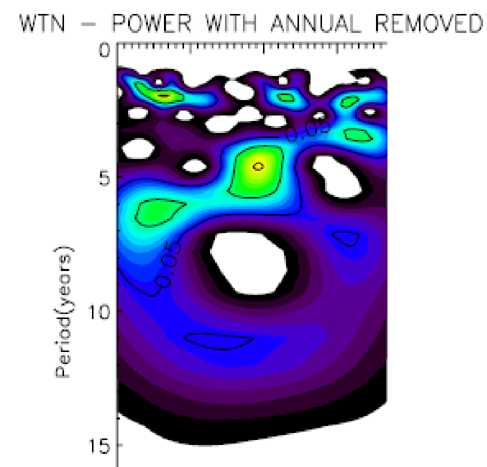


Complete Stratification Timeseries from Model (1970-2006)



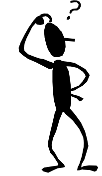






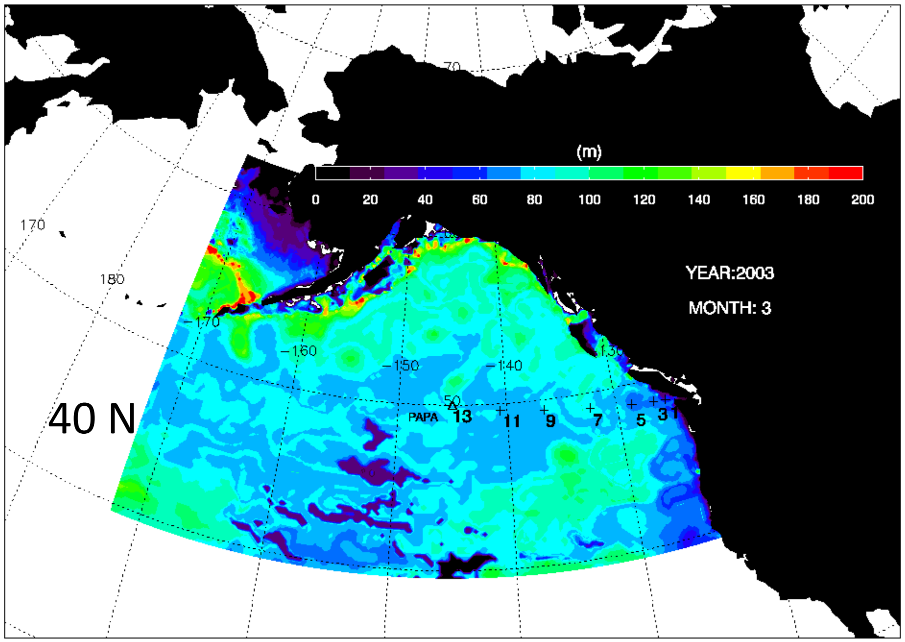
Wavelet transform of stratification

<u>Note:</u> That the NPGO/Vic Mode peaks indicated by black arrows (↓).

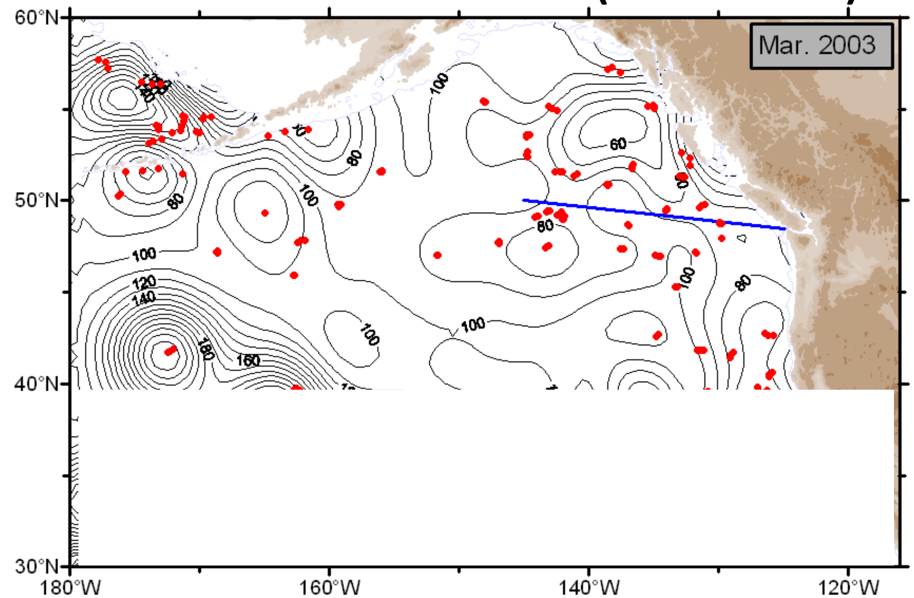


2003 MLD Anomaly

Simulation (March 2003)



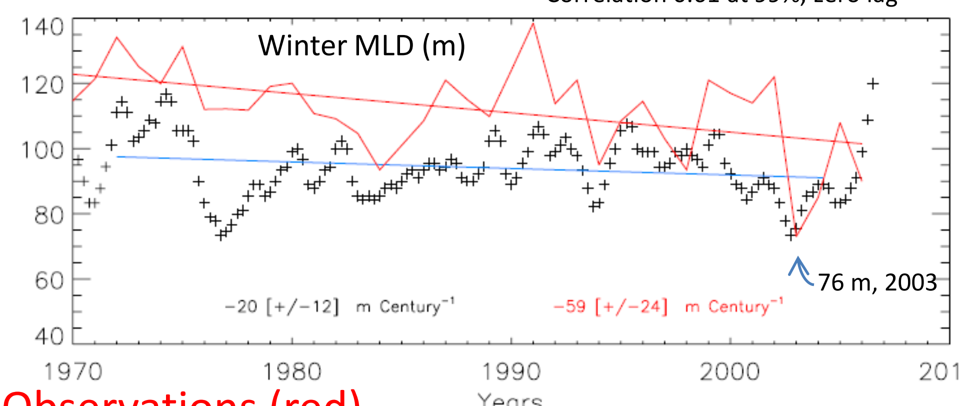
Observations (March 2003)



MLDs are70-80 m along Line Papa, in good agreement with observations.

Winter MLD Trend Comparison

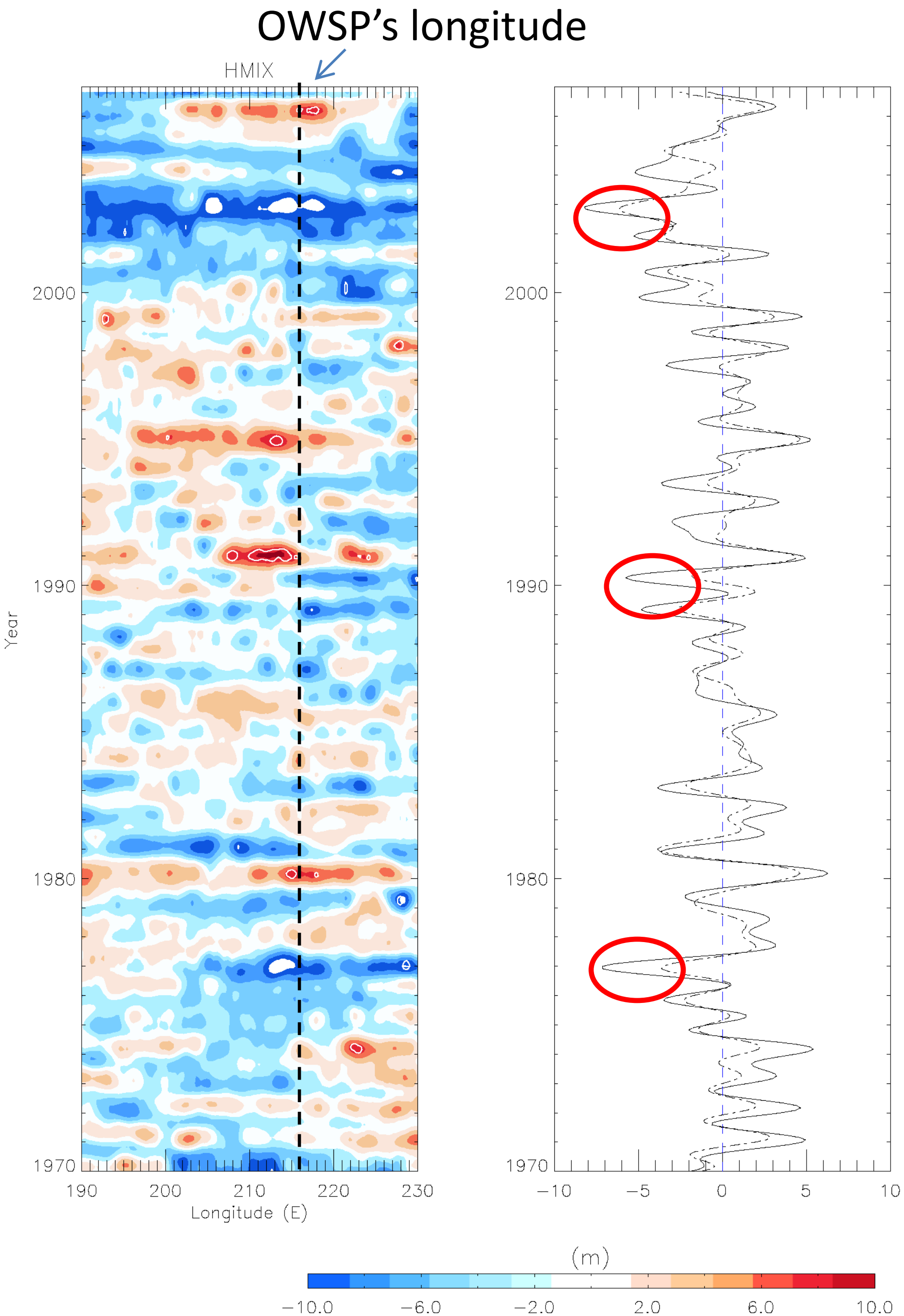
Correlation 0.61 at 99%, zero lag

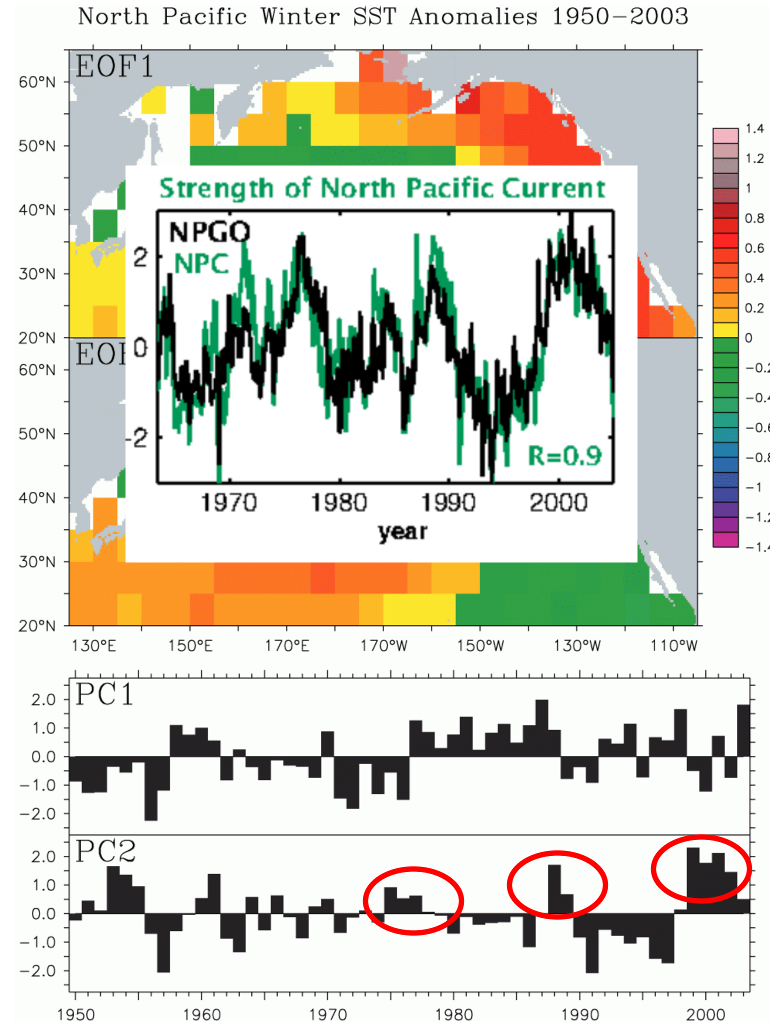


Observations (red)

Model (black)

Ref. H. Freeland (personal Communication 2008)

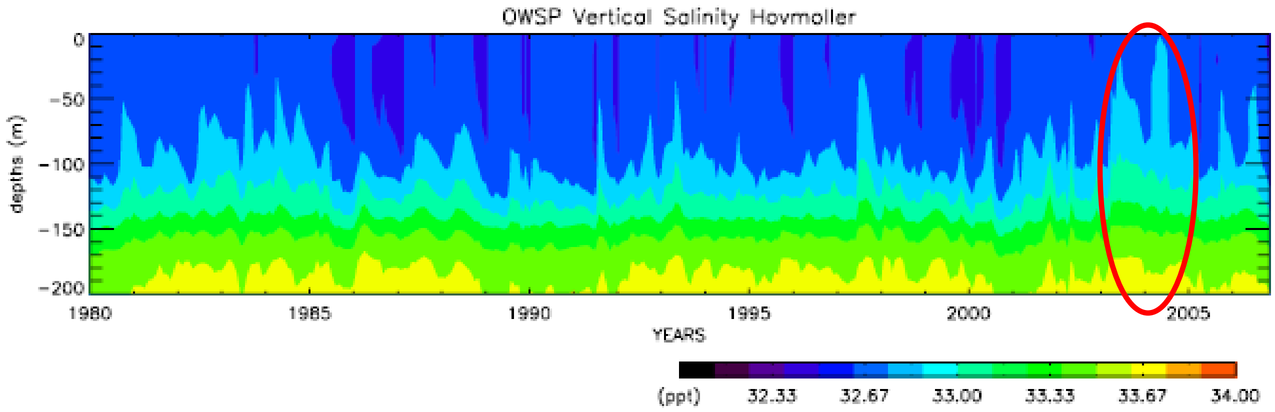




Bond et al. (2005)
Di Lorenzo et al. (2009)
N. Bond (personal communication, April 2010)

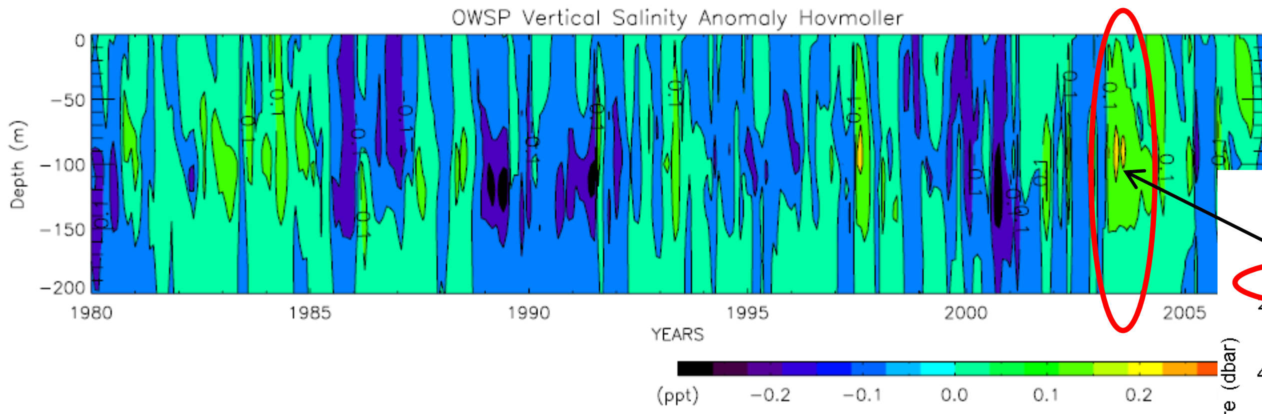
Salinity at OWSP

2003-2004

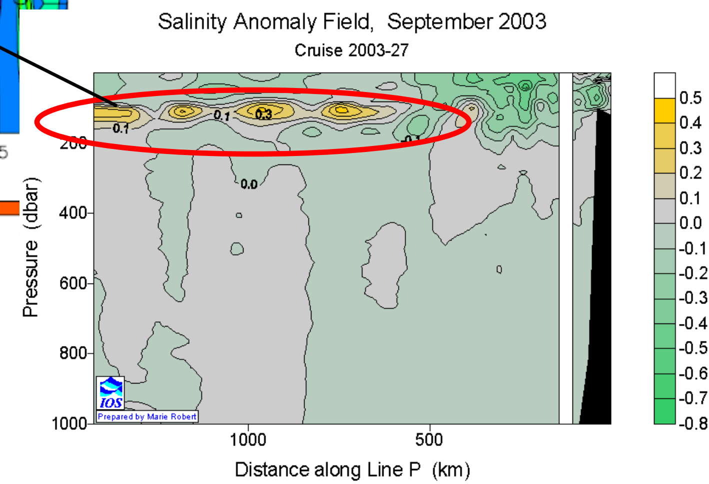


Raised 33 ppt isohaline at OWSP.

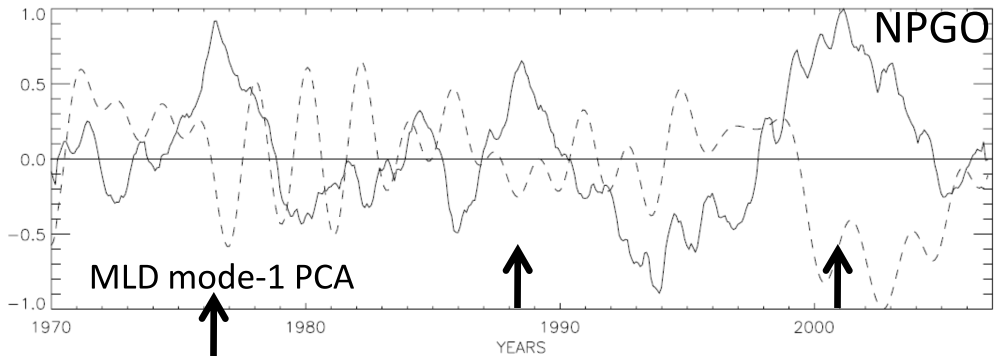
Salinity anomaly at OWSP

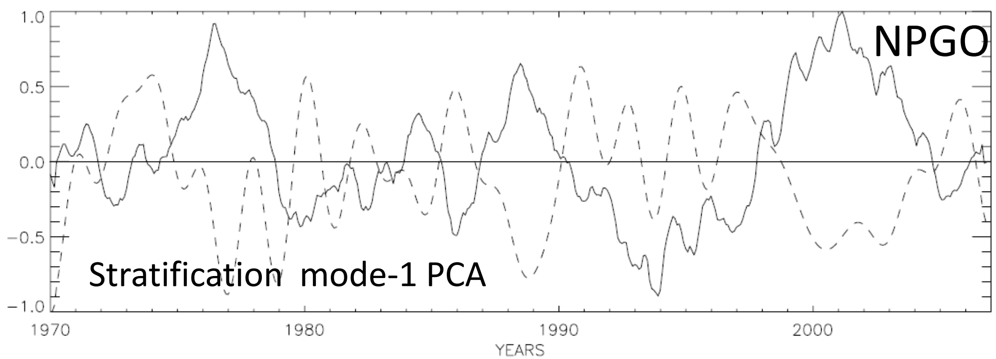


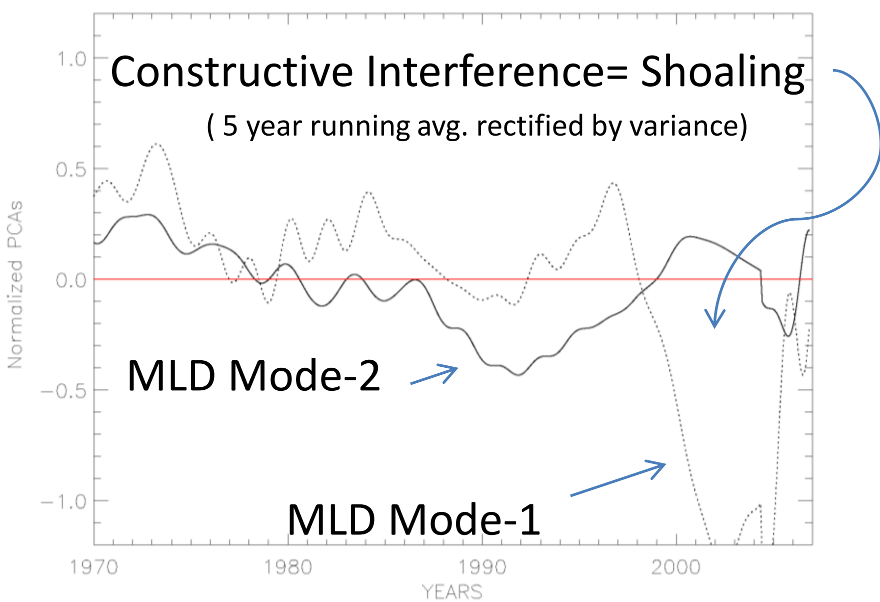
Anomalous core of increased salinity

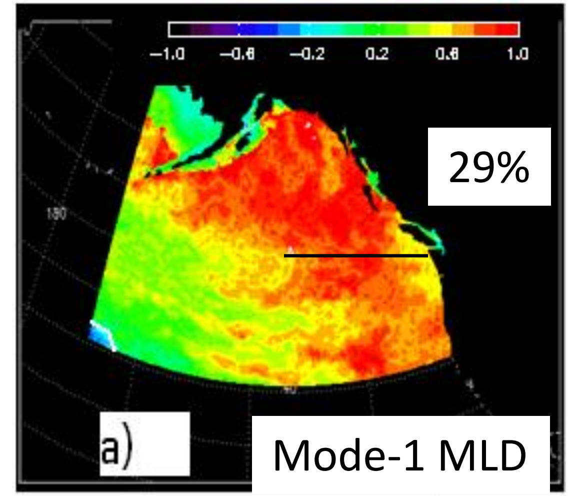


Ref. Institute of Ocean Science (IOS) Archive:
http//:www-sci.pac.dfo-mpo.gc.ca/osap/data/linep

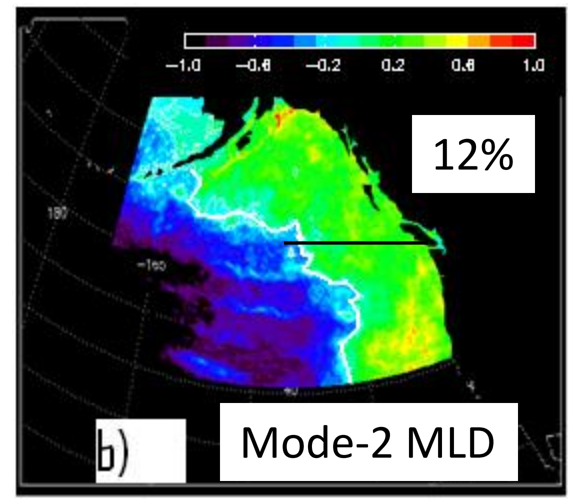








Line P is solid black line

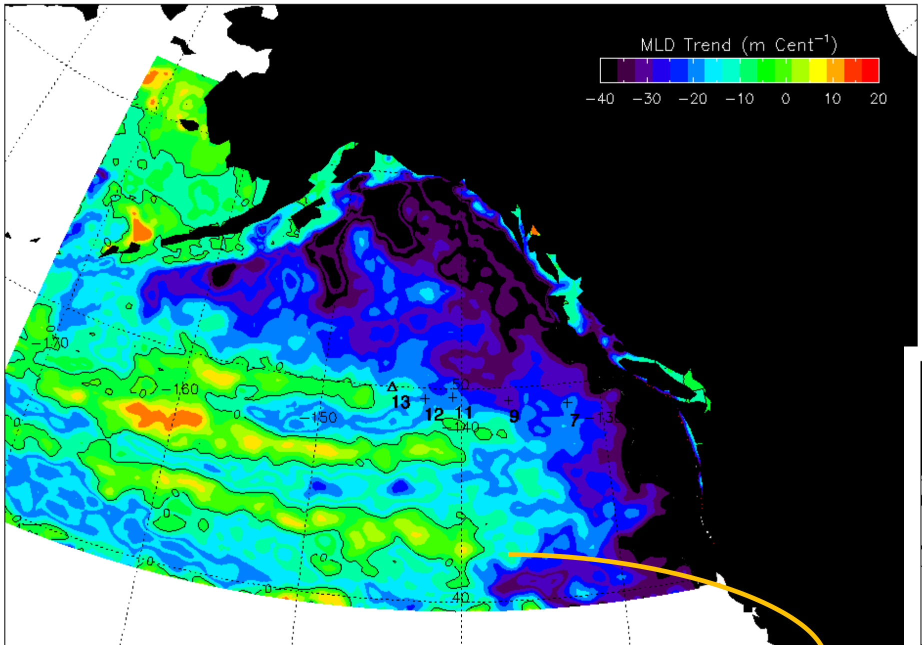


	SOI	PDO	NPGO
Mode-1	X	X	-0.5 [1 year]
Mode-2	0.4 [0, 2.5 years]	-0.5 [0, 2 years]	0.4 [0 years]

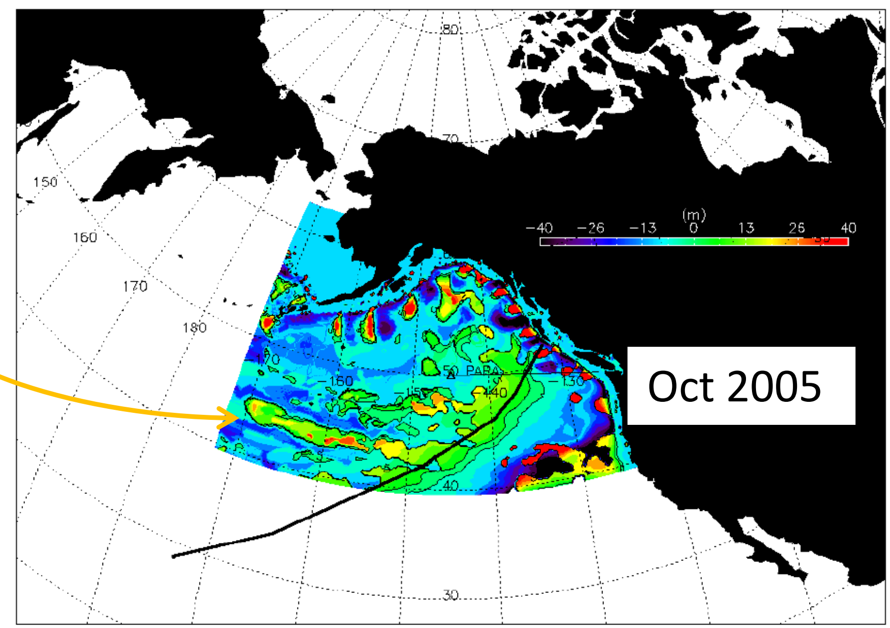
X Signifies no (statistical) correlation

Interesting Features in MLD Trends

Winter [Jan through April, 1970-2006] MLD Trends (m/Century)

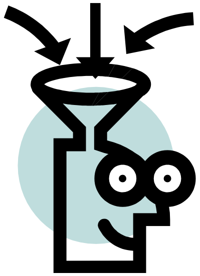


Model 26.0 sigma-t depth anomalies



Deepening limb-like MLD features are suggestive of Rossby waves and 2D turbulence.
(Maximenko et al., 2008).

Separation between arms agrees with the Rhines Scale of about 300-500 km.
(*Rhines* , 1994).



Conclusions

- Spectral Nudging necessary for reasonable simulation of MLD.
- Low frequency MLD variability along Line Papa can be reproduced.
- 2003 MLD anomaly was due to:
  - Increased stratification triggered by the NPGO (Victoria Mode).
  - the accompanying strong positive Ekman pumping (due to windstress curl constructive interference), and
  - the anomalous prolonged net surface heat flux between 2000-2004 providing positive buoyancy flux, and increasing upper layer stratification, and
  - a strong salinity (hence density contrast) anomaly core near historical base of winter MLD resulting in increased stratification in 2001-2003.
- MLD estimates at OWSP are somewhat representative of those along Line Papa (correlation 0.63). However, there is considerable variability throughout the Gulf of Alaska as a whole.

THANK-YOU

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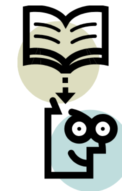
Key References



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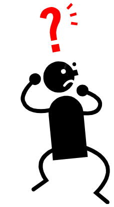
What is *Spectral Nudging*?

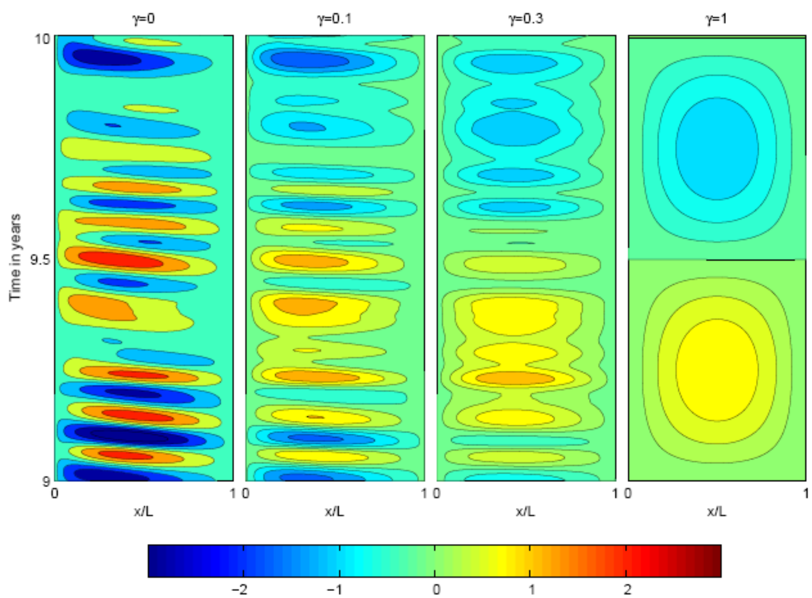


Thompson, K. R., D. Wright, Y. Lu, and E. Demirov (2006). A simple model for reducing seasonal bias and drift in eddy resolving ocean models. *Ocean Model*., 13(2), 109-125.

<u>ONLY</u> SPECIFIED FREQUENCY BANDS ARE NUDGED TOWARD THE CLIMATOLOGY, AVOIDING DRIFT OVER LONG SIMULATIONS ALLOWING THE HIGHER FREQUENCY DYNAMICS TO EVOLVE ACCORDING TO THE MODEL DYNAMICS

<u>Benefits over Conventional Nudging:</u>

1) Eddies are not suppressed
2) Does not introduce artificial lags in model response to forcing
3) Can vary "relaxation parameter" in nudges by frequency without detrimentally affecting other energy bands



Thompson et al. (2006)

As seen here "Conventional Nudging" smears the variability and suppresses ocean dynamics …clearly not desirable

$$\psi_t = \psi_t^f + \gamma(\psi_t^c - \psi_t^f)$$