An analysis of the time-varying heat, salt and volume budget in an oceanic control volume

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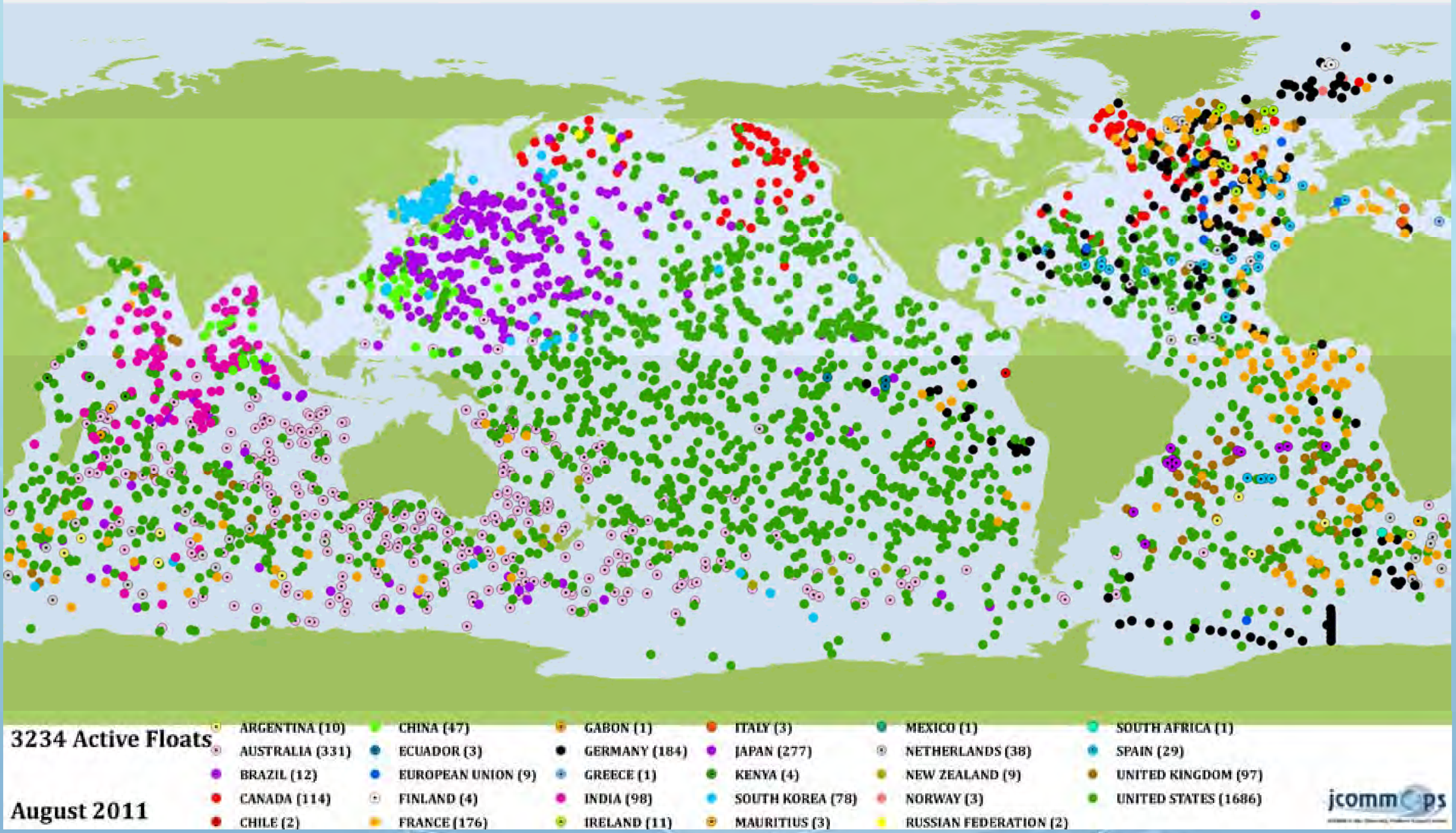
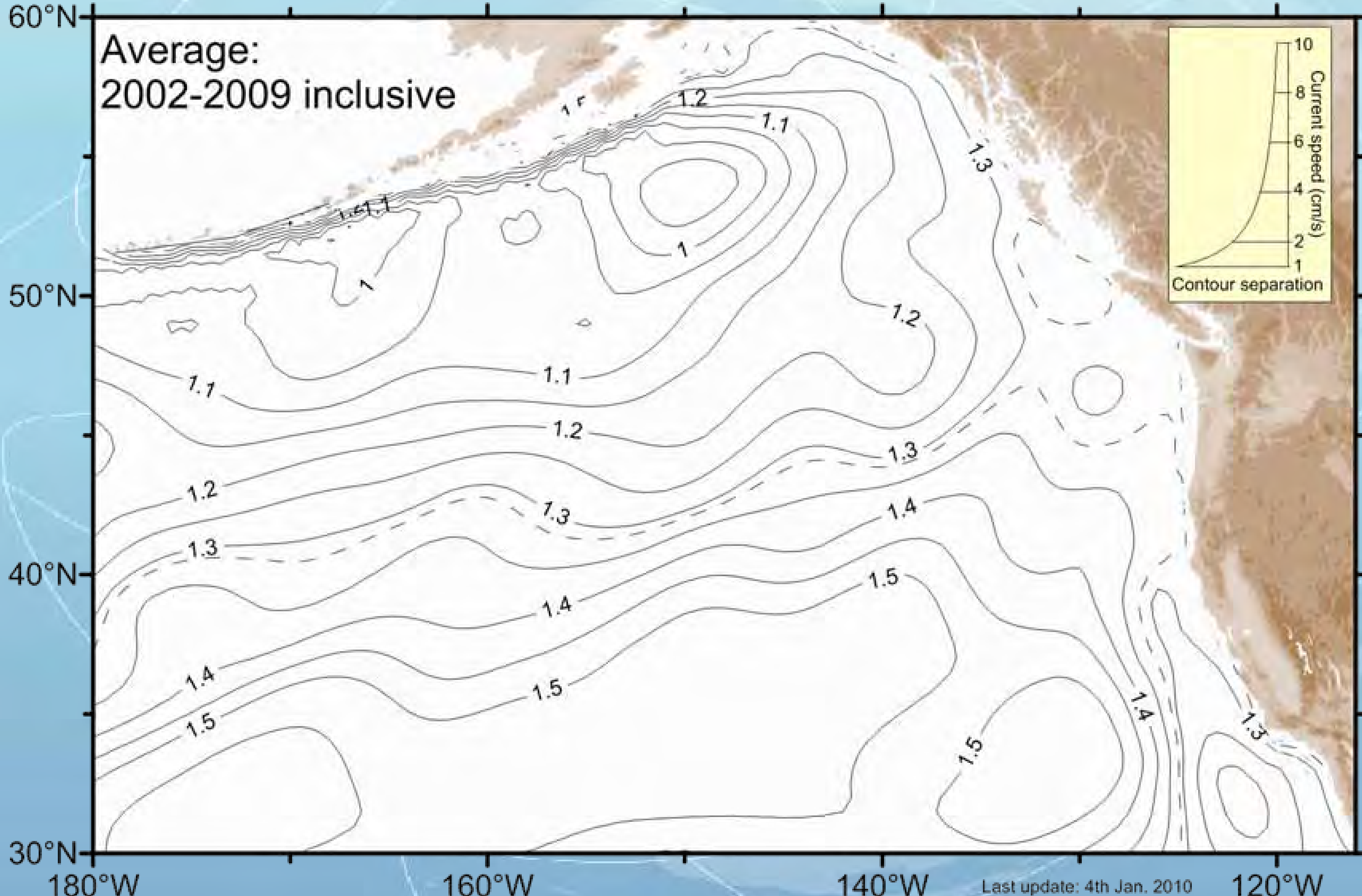
Lots of floats are in the water, and lots of countries contributing



Can we determine the oceanic vertical velocity from this array?

The mean circulation in the N. E. Pacific



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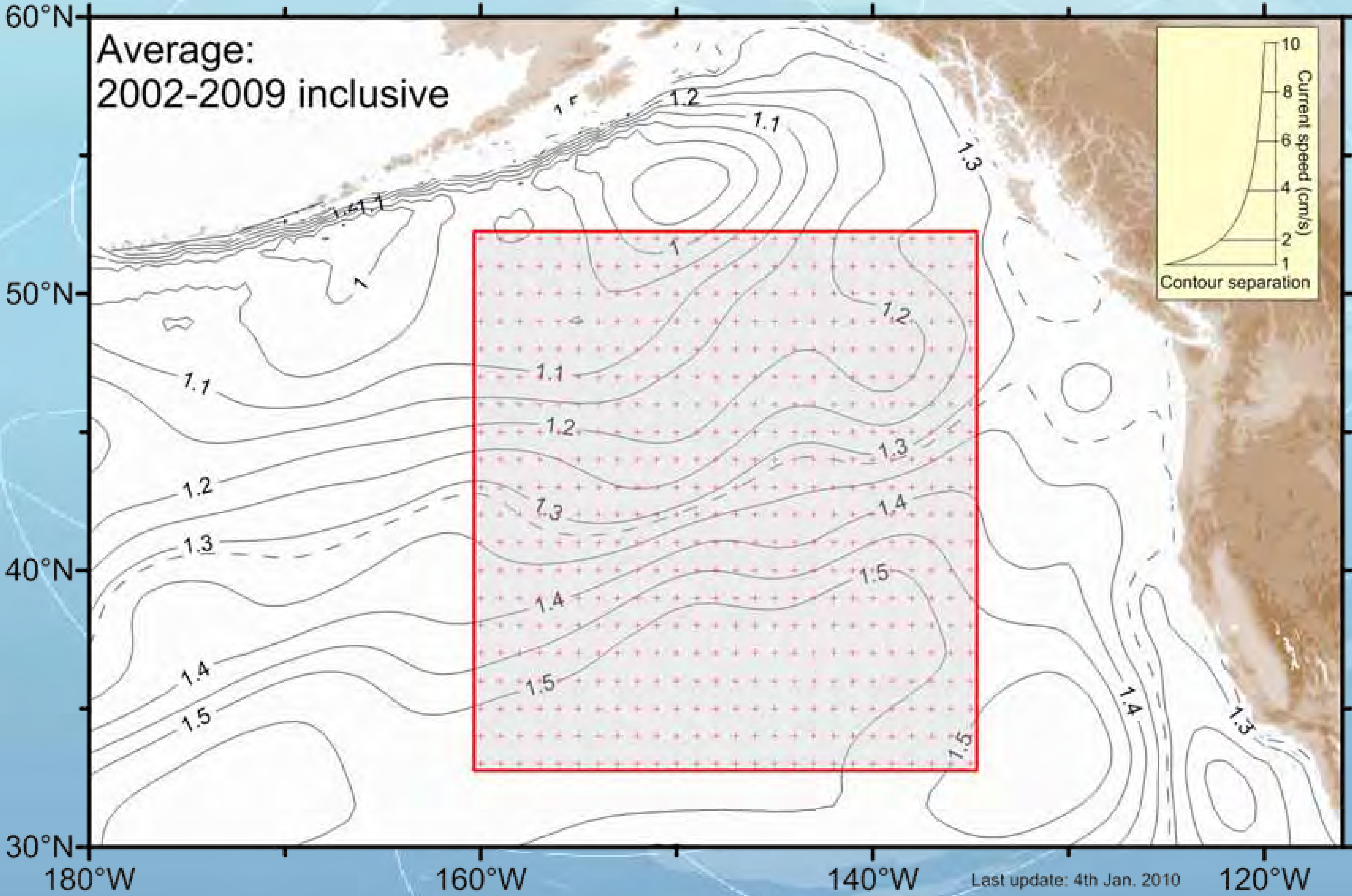
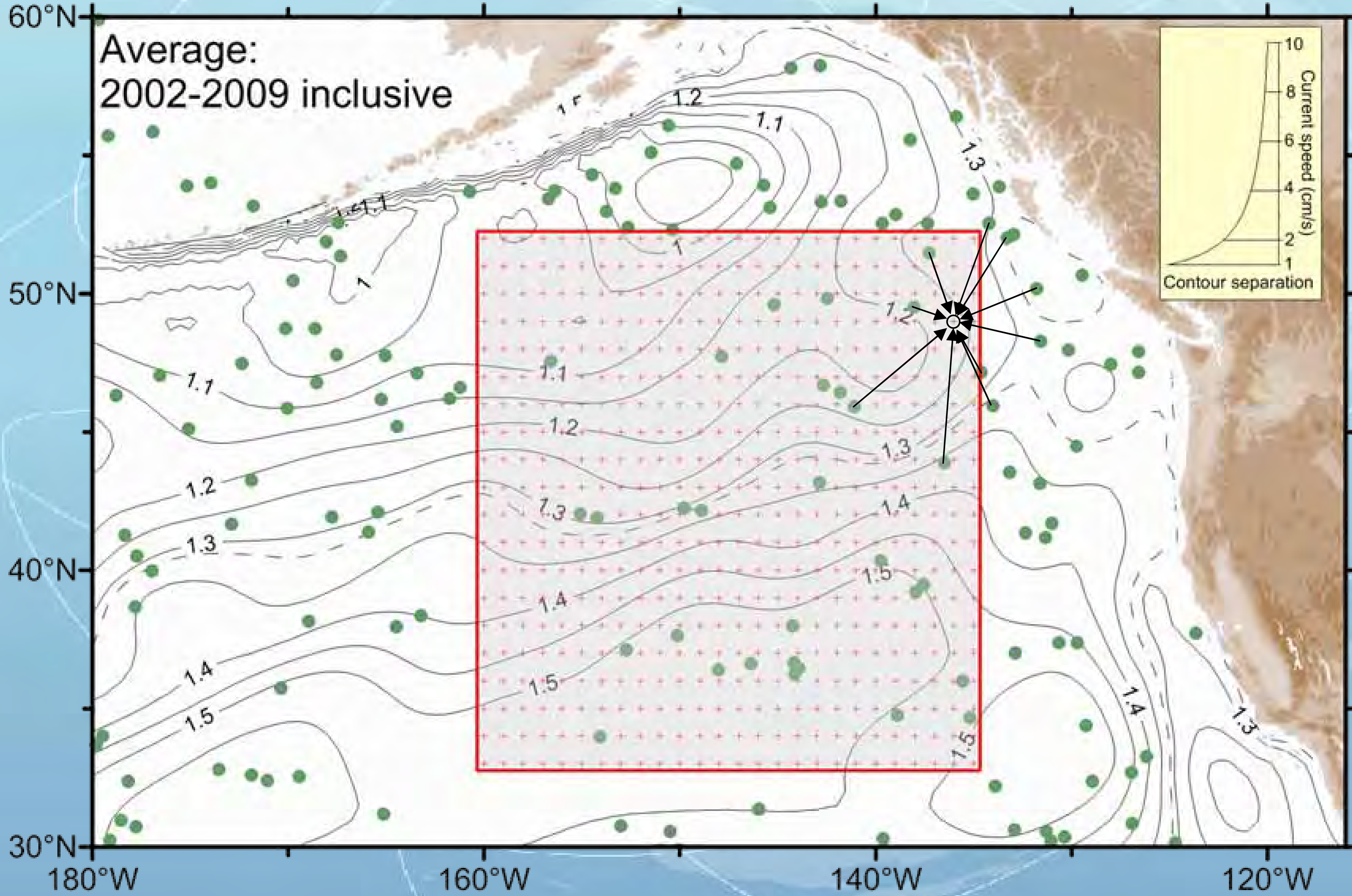
Argo

The mean circulation in the N. E. Pacific



The mean circulation in the N. E. Pacific



Results for ***volume*** divergence of the mean state

$$Divergence = <\bar{u}_e> - <\bar{u}_w> + <\bar{v}_n> - <\bar{v}_s>$$

Relative to an integration pressure of 700 decibars:-

$$Divergence = 3.75\times10^{6}\, m^{3}/s = Area\times w_{700}$$

Hence:- $w_{700} = 8.85\times10^{-7}\, m/s$

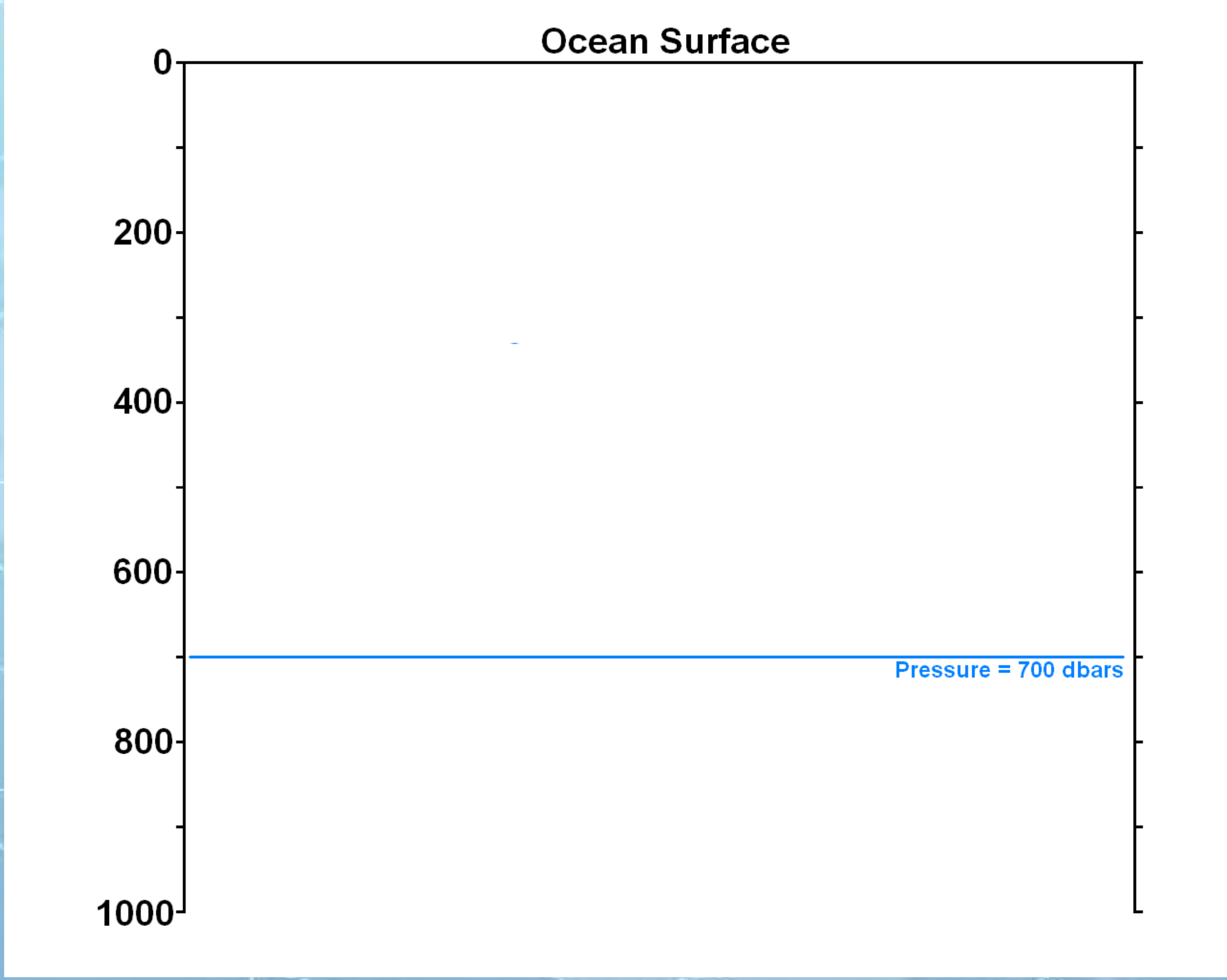
BUT – There are three components to this vertical velocity:

1) Diapycnal component

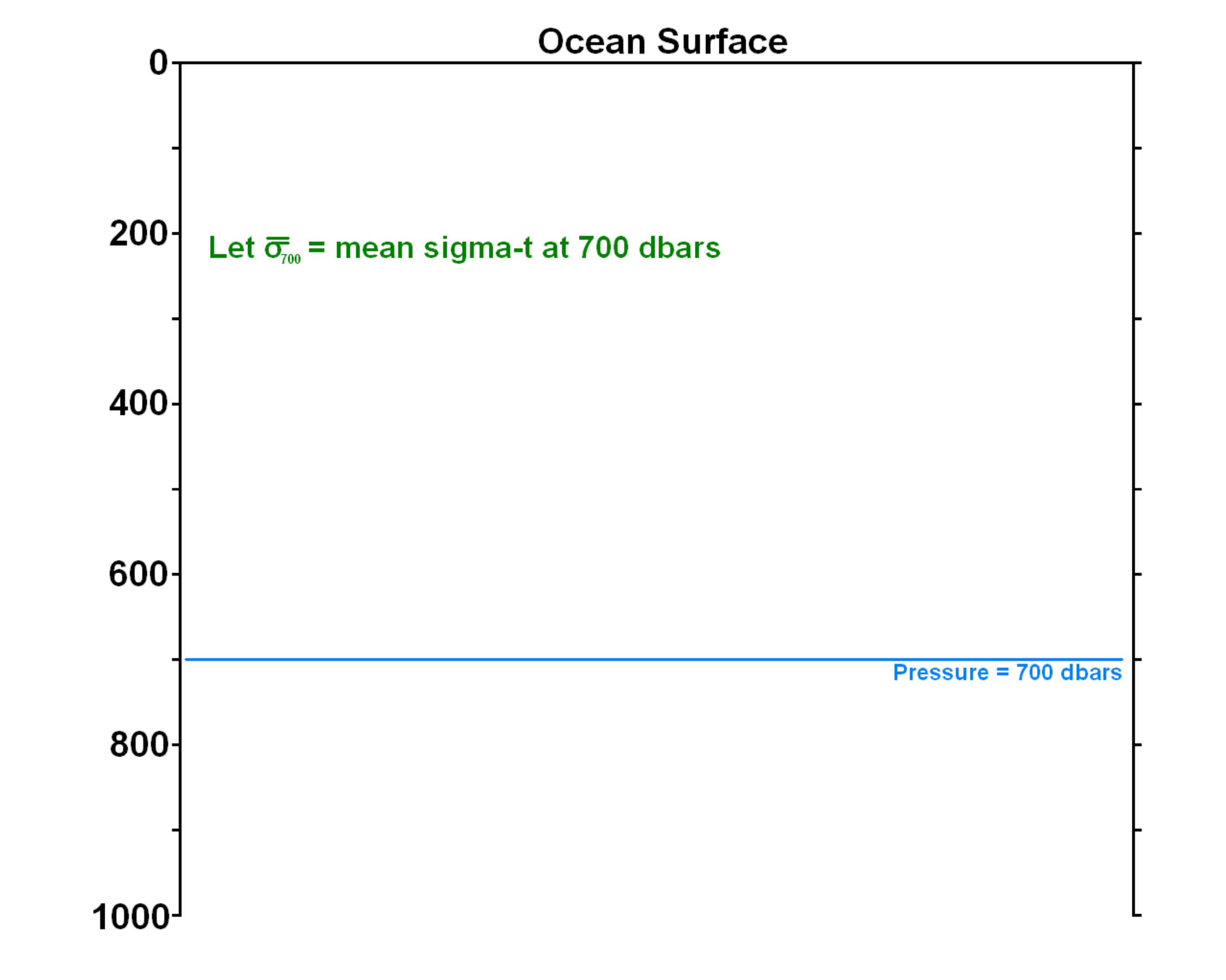
2) Isopycnal component

3) Heave

The three components of vertical velocity



The three components of vertical velocity



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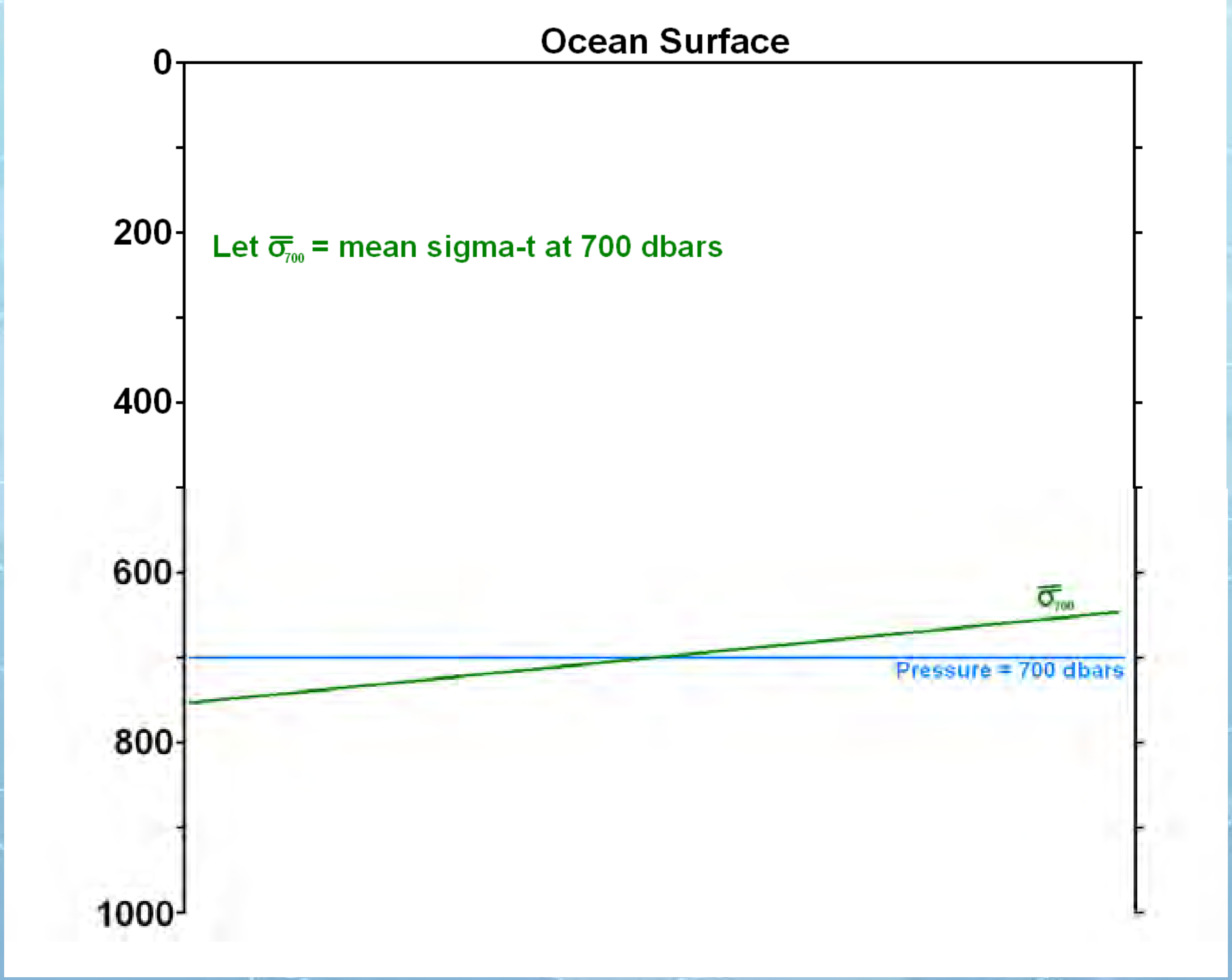
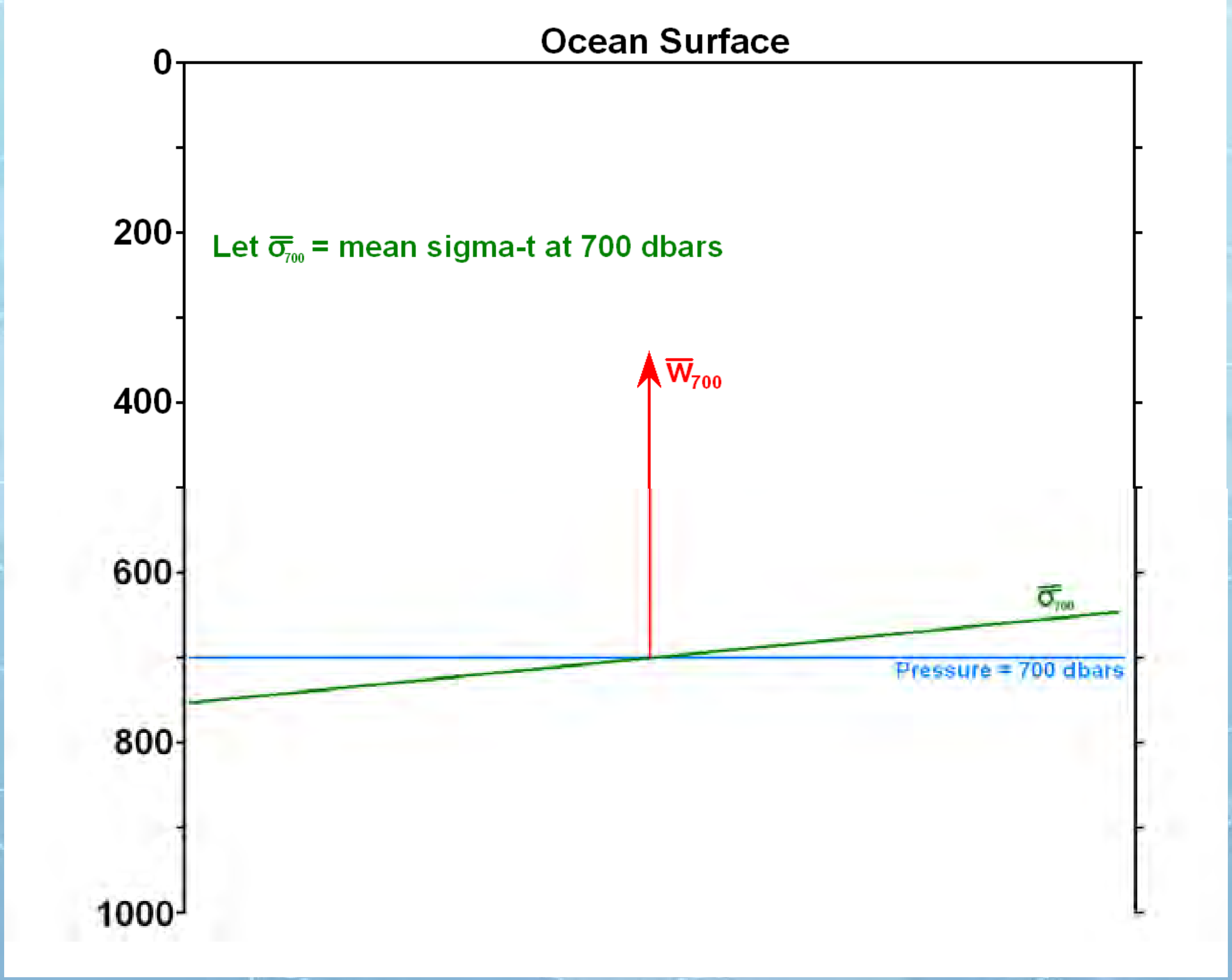
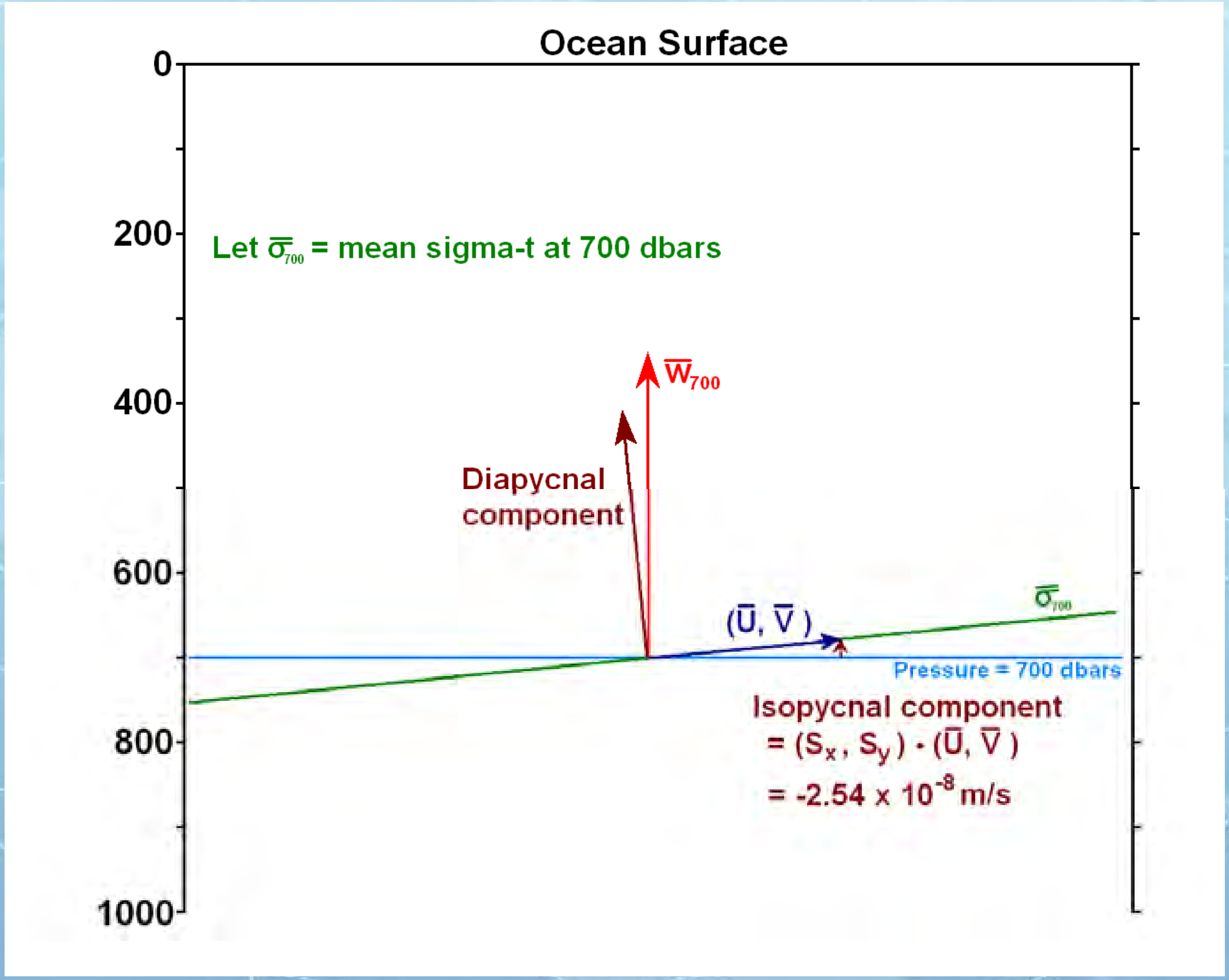


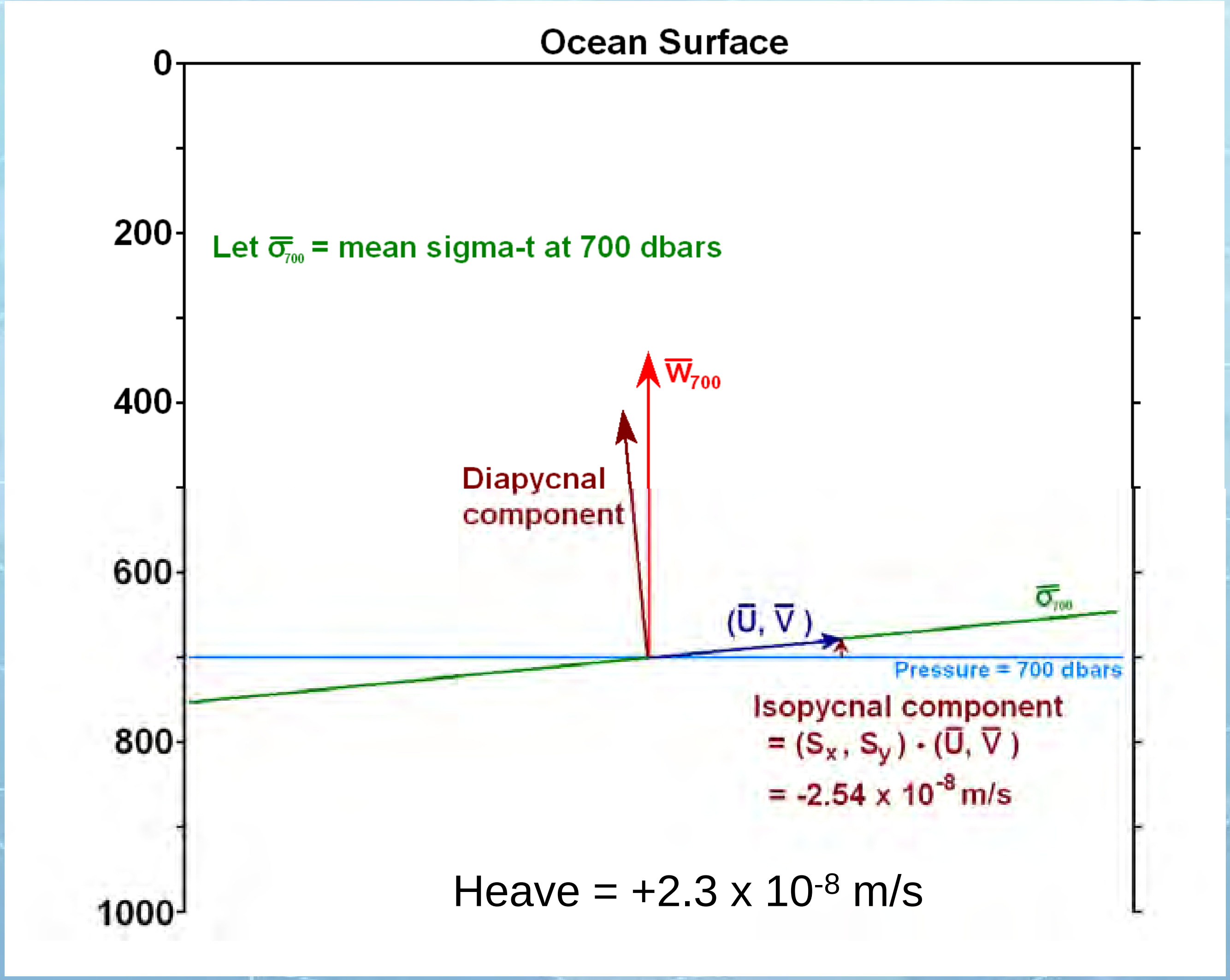
The three components of vertical velocity



The three components of vertical velocity



The three components of vertical velocity



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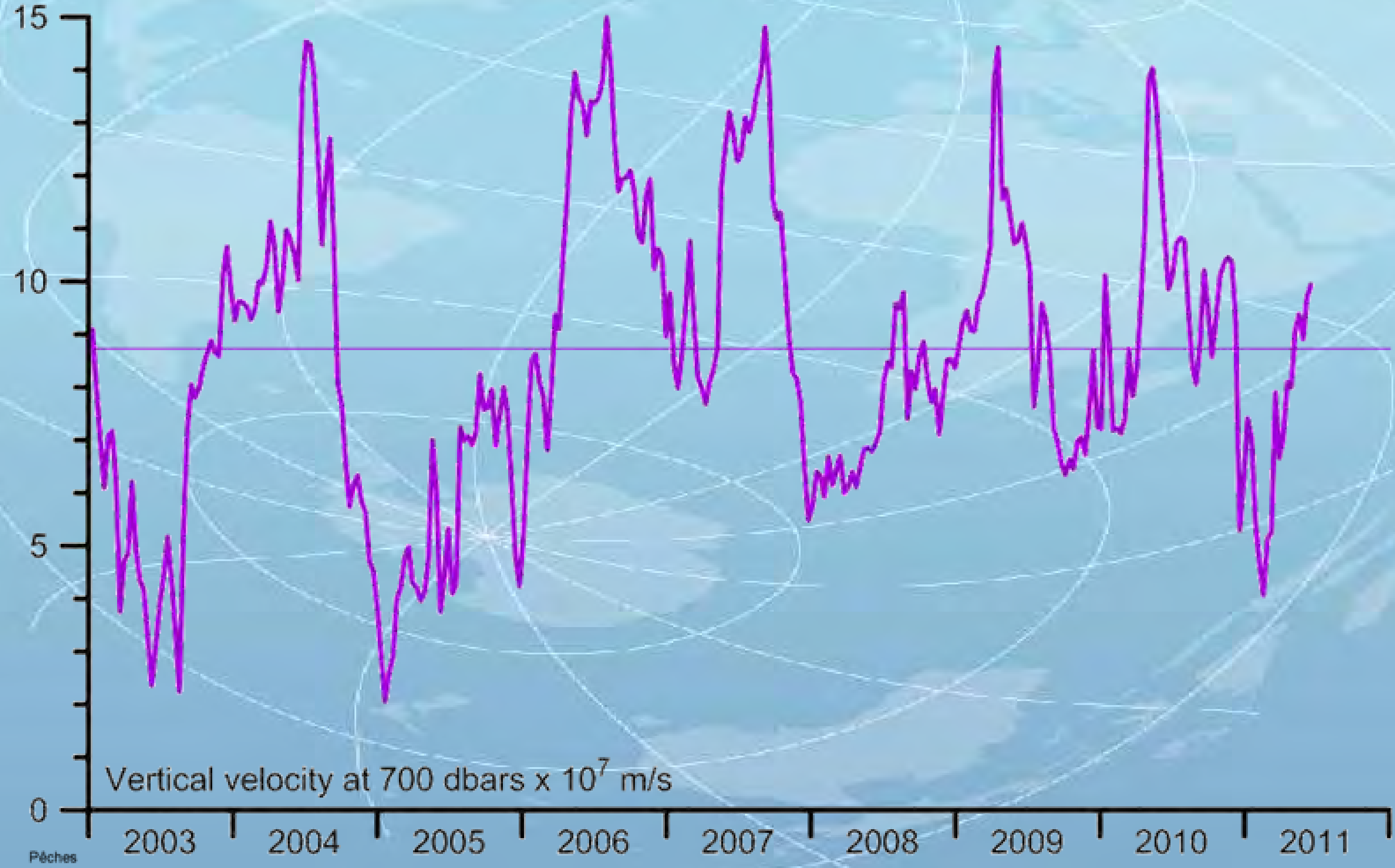
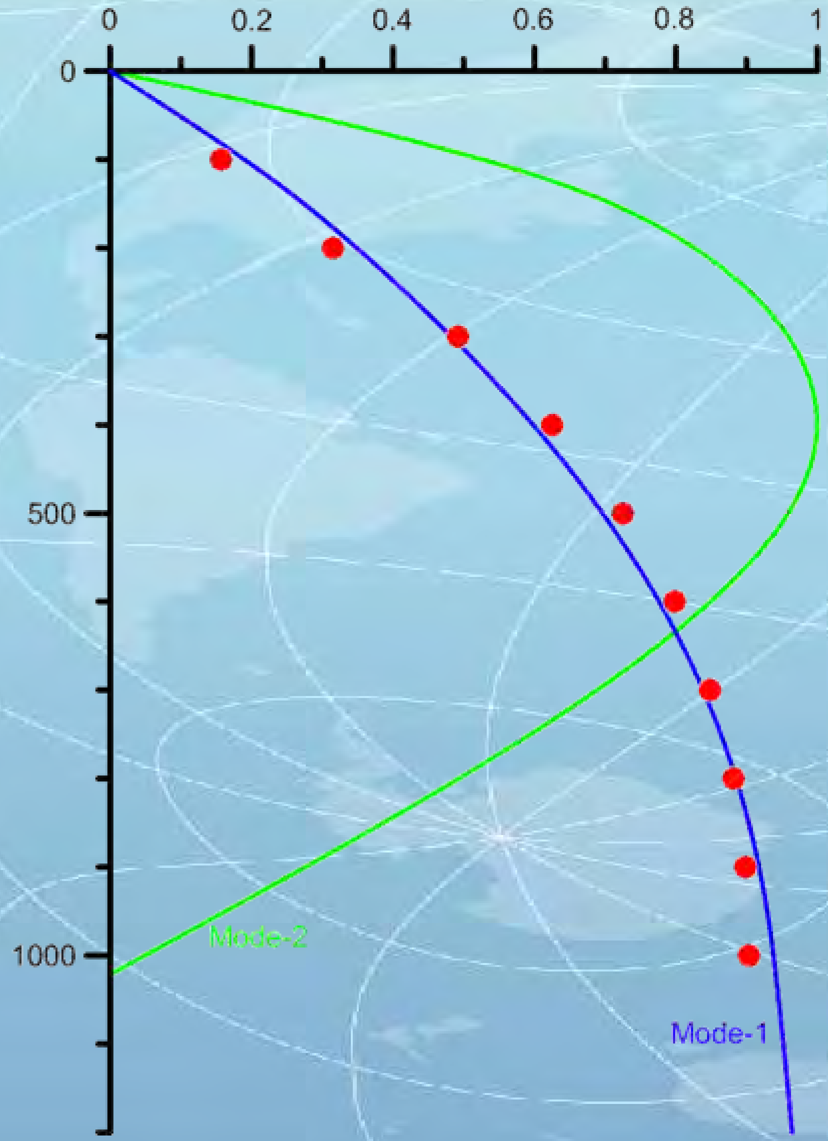
Results for ***volume*** divergence of the time-varying state

Relative to an integration pressure of 700 decibars:-

$$w_{700}(t) = \left(< u_e(t) > - < u_w(t) > + < v_n(t) > - < v_s(t) > \right) / \; Area$$



Plausibility test #1



The vertical structure of w estimates is extremely plausible.

Plausibility test #2 (mean state salt divergence)

$$Divergence = <\overline{u}_e \overline{S}_e> - <\overline{u}_w \overline{S}_w> + <\overline{v}_n \overline{S}_n> - <\overline{v}_s \overline{S}_s>$$

$$Salt - Divergence = +1.206 \times 10^8 \, psu.m^3 / \sec$$

Supply through the bottom surface = mean salinity on the 700 dbar surface x w_{700} (computed from volume budget) x Area

$$Supply = +1.256 \times 10^8 \, psu.m^3 / \sec$$

Plausibility test #3 (mean state heat divergence)

$$Divergence = <\bar{u}_e \overline{H}_e> - <\bar{u}_w \overline{H}_w> + <\bar{v}_n \overline{H}_n> - <\bar{v}_s \overline{H}_s>$$

Where $H = \rho C_p T$ (C_p does vary with T and S)

$$Heat - Divergence = +1.279 \times 10^{11} J/\sec$$

Supply through the bottom surface = mean $\rho C_p T$ on the 700 dbar surface x w_{700} (computed from volume budget) x Area

$$Difference = +0.69 \times 10^{11} J/\sec$$

To maintain the steady state we need to supply through the top surface 17.2 W/m^2.

Does this fit other estimates?

Annual mean heat flux 1950-1990

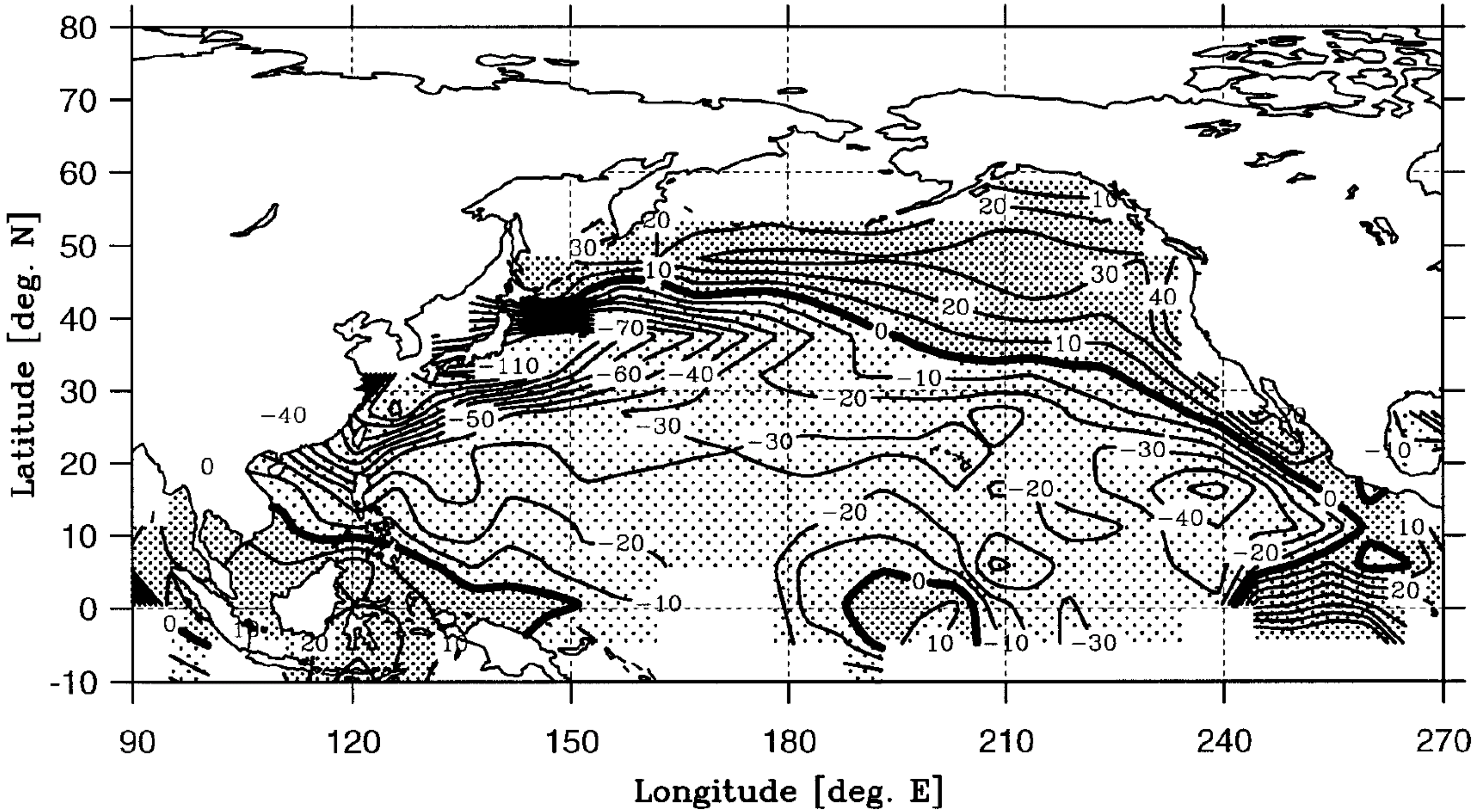


FIG. 11. The annual mean net heat flux between 1950 and 1990. Contour interval is 10 W m^{-2}. Positive contours: solid line; negative contours: dashed line. Shaded region indicates where data was available.

Figure 11 from Moisan & Niiler, JPO <u>28</u>, 401-421, 1998

Annual mean heat flux 1950-1990

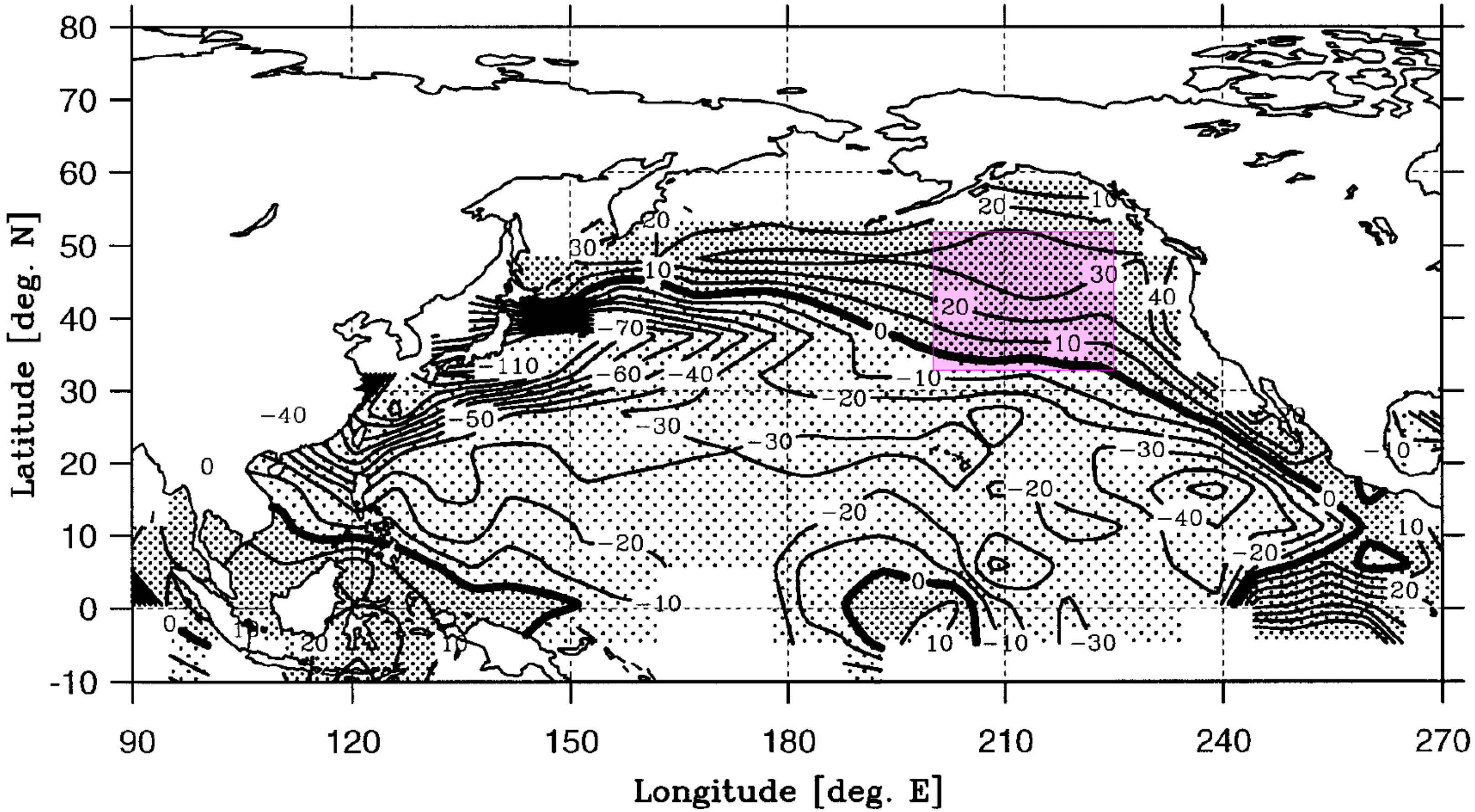


FIG. 11. The annual mean net heat flux between 1950 and 1990. Contour interval is 10 W m^{-2}. Positive contours: solid line; negative contours: dashed line. Shaded region indicates where data was available.

Moisan & Niiler would suggest an expected annual average of about 25 ± 10 W/m^2

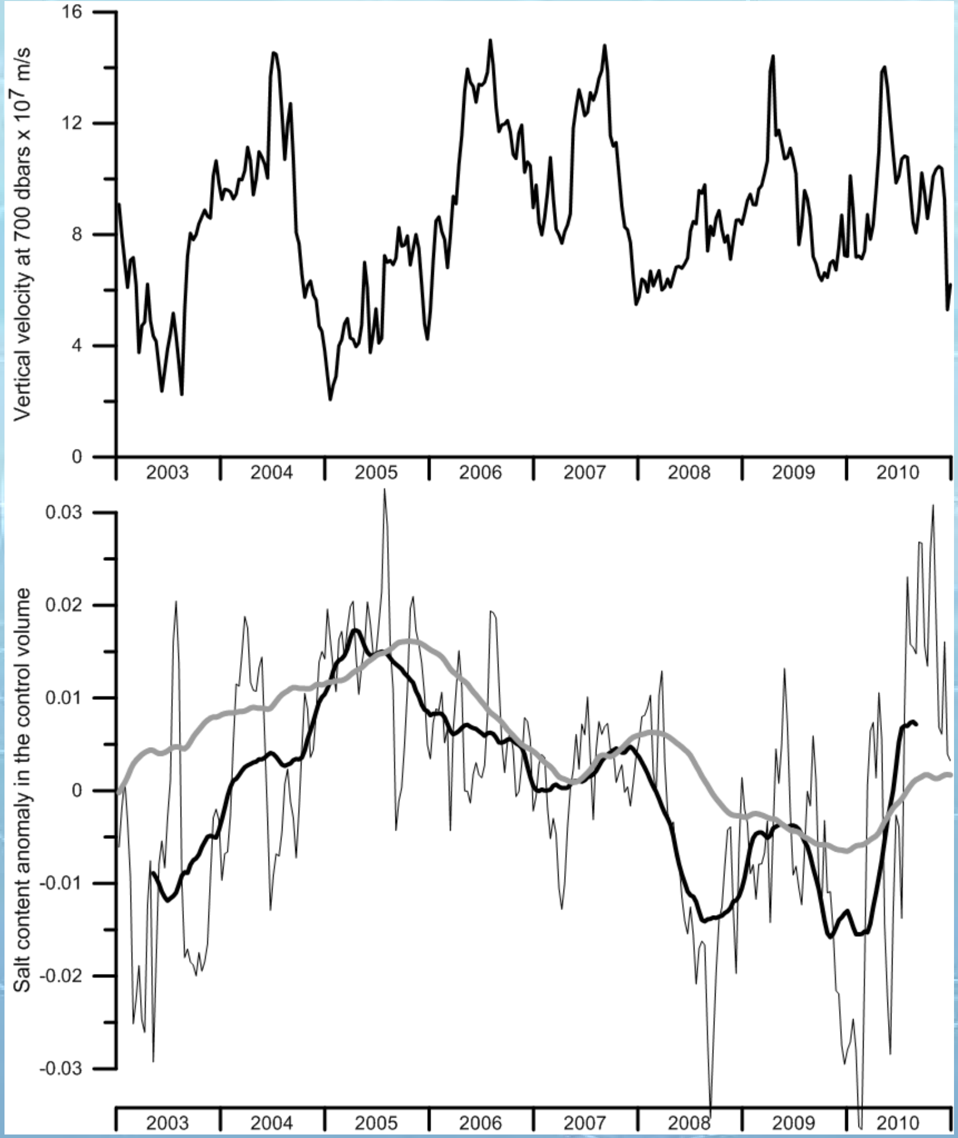
Plausibility test 4: Relationship between w(t) and the time varying salt budget

Let $$\overline{\overline{S(t)}} = \frac{1}{V}\iiint S(x, y, P, t)\,dx.dy.dP$$

and $$\overline{\overline{S}}'(t) = \overline{\overline{S}}(t) - \frac{1}{T}\int_0^T \overline{\overline{S}}(t).dt$$

Then:- $$\overline{\overline{S}}'(t) = \frac{A_0}{V}\int_0^t w_{700}(\tau)\overline{S}_{700}(\tau).d\tau$$

Plausibility test 4: Relationship between w(t) and the time varying salt budget



Implications for the main pycnocline

$$w\frac{\partial \rho}{\partial z} = \kappa \frac{\partial^2 \rho}{\partial z^2}$$

Which implies a simple solution in deep water:-

$$\rho(z) = \rho_0 + \Delta\rho \exp(-z / z_0)$$

Where $z_0 = \kappa/w$

By least-squares fit to the centre of the box, between 300 dbars and 1000 dbars:-

$z_0 = \kappa/w = 598$ decibars

$K = 5.3 \times 10^{-4}\ m^2/s$

Conclusions

1) Argo observations can be used to estimate large-scale heat, salt and volume budgets.

2) The volume budget of the geostrophic flow field implies a net upwelling velocity of about 8.9×10^{-7} m/s, this is overwhelmingly diapycnal.

3) The vertical velocity is highly variable, but can account for the large scale variations in salt content.

4) This w estimate implies a vertical diffusivity about 4 to 5 times larger than previous estimates, but there are no direct measurements. This might change soon, thanks to Jody Klymak.