Heat and Salt Conservation in the N.E. Pacific

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Volume, Heat and Salt Conservation in the N.E. Pacific

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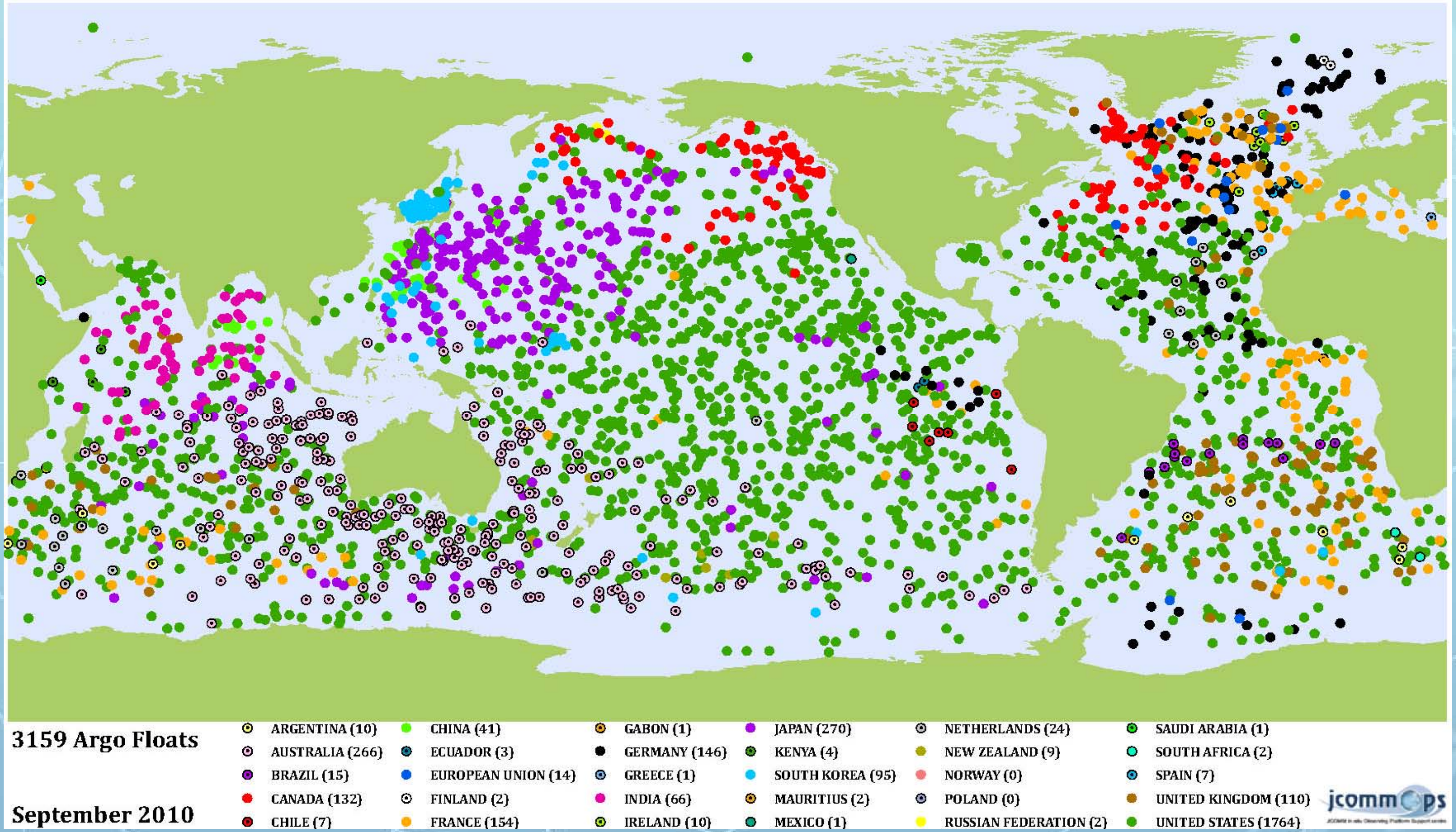
Fisheries and Oceans Pêches et Océans

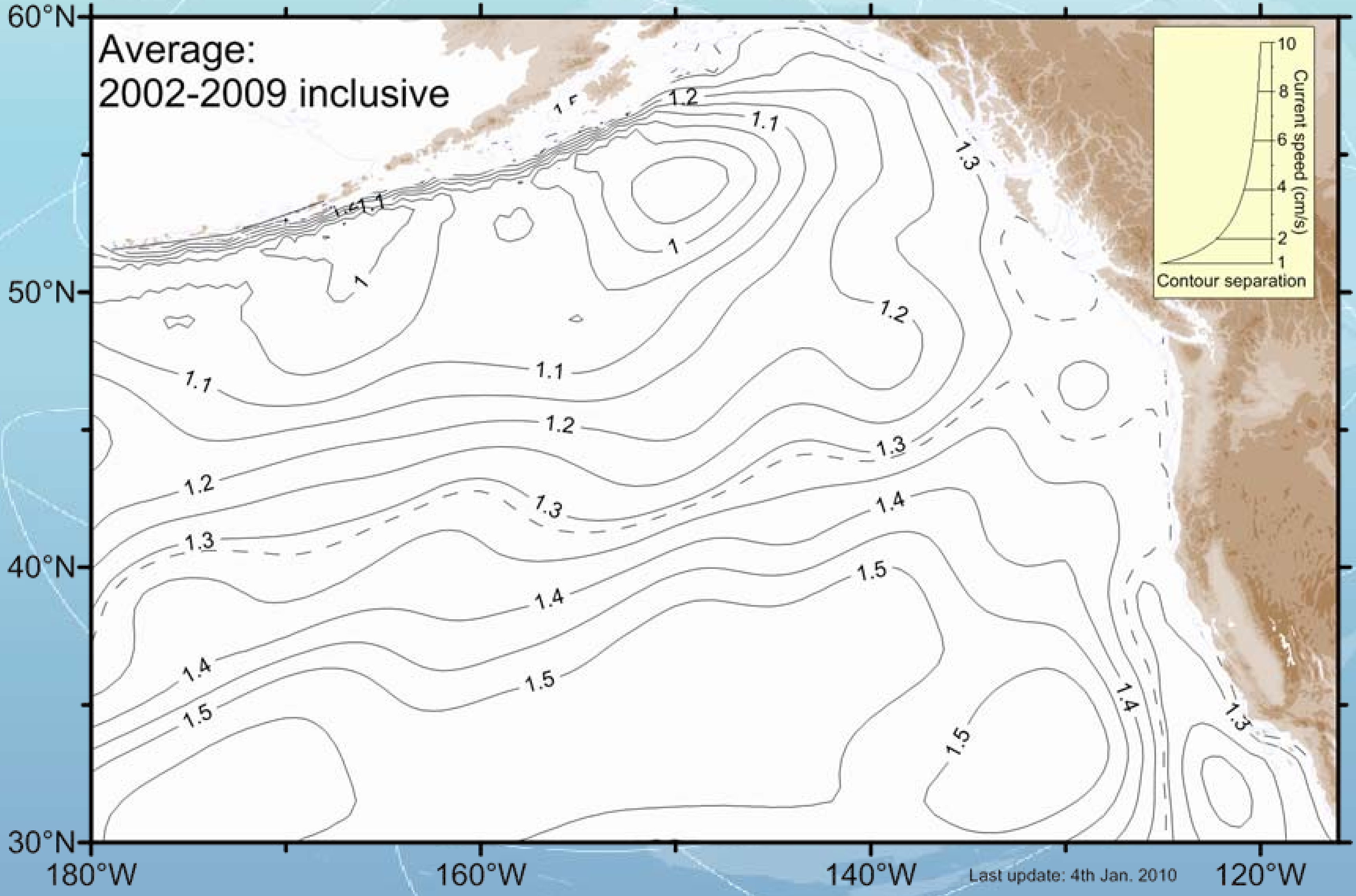
Argo

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



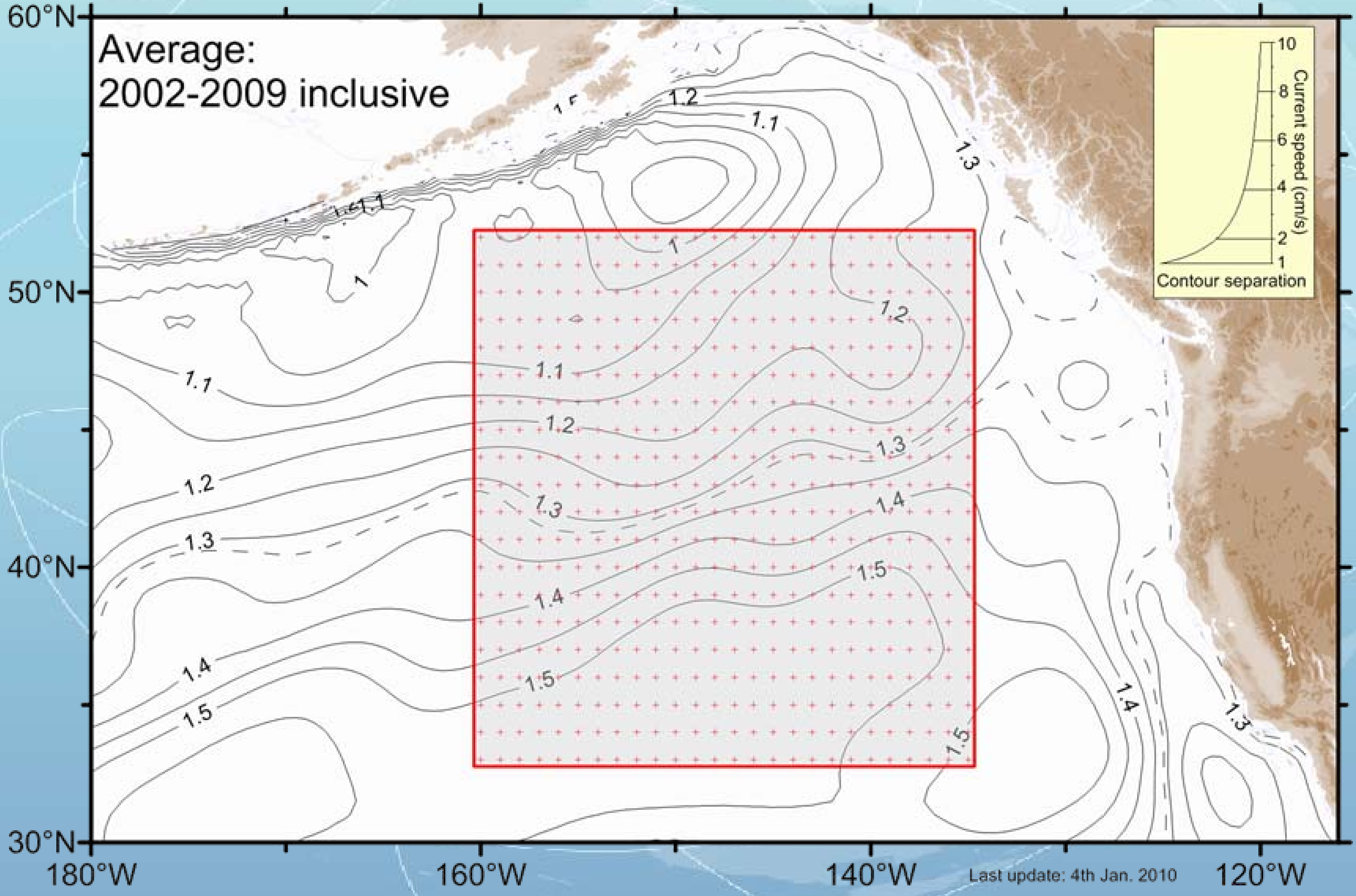
So what can we determine from this array about simple controls on the circulation and balances in the ocean?

The mean circulation in the N. E. Pacific



Last update: 4th Jan. 2010

The mean circulation in the N. E. Pacific



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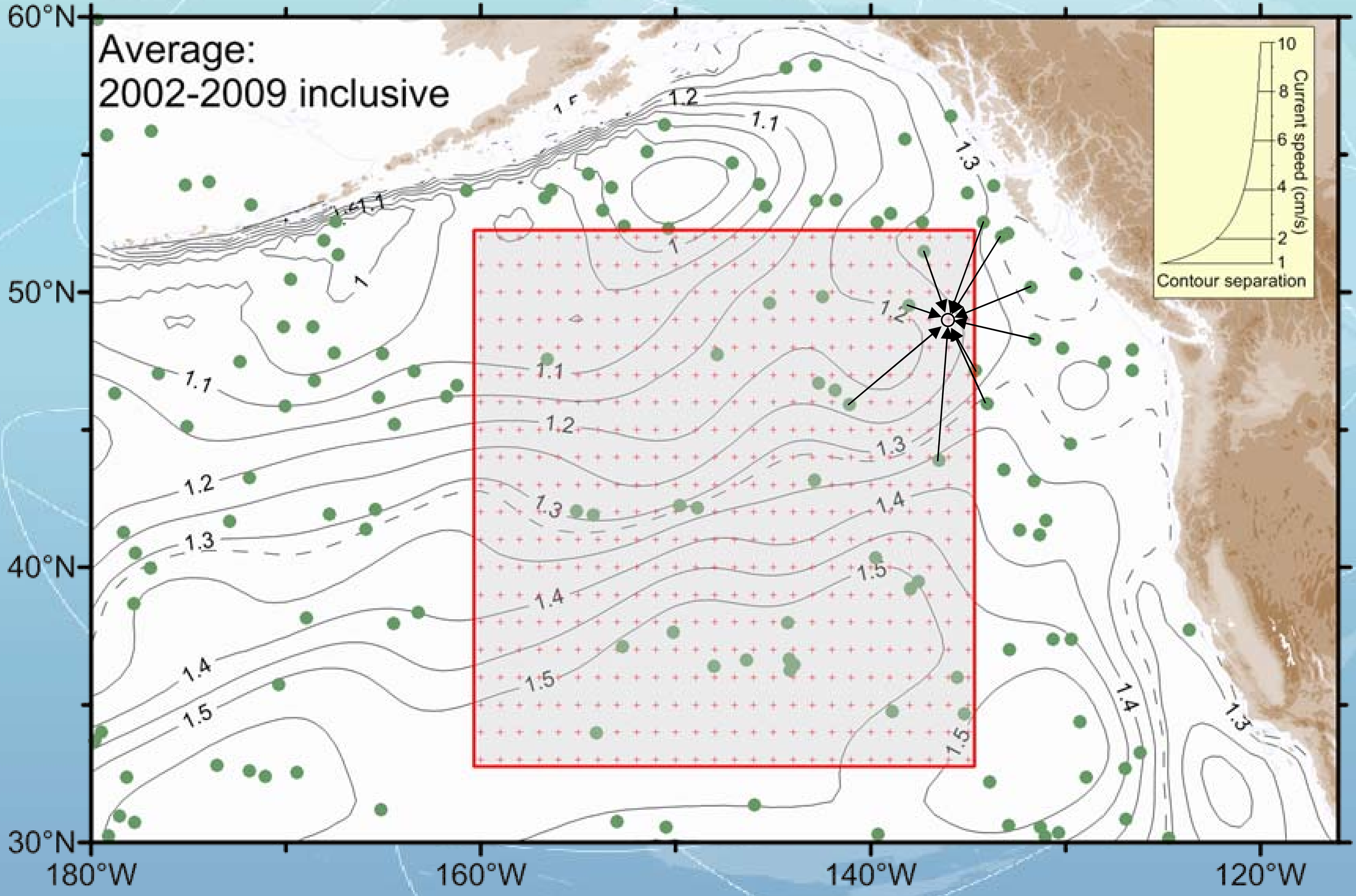
The mean circulation in the N. E. Pacific



Fisheries and Oceans
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Some definitions…

$$T_e(\phi, p, t) = \overline{T}_e(\phi, p) + T_e'(\phi, p, t)$$

Subscript indicates east face, can be n, s, e or w.

$$<T_e> = \int_{\phi}\int_{p} T_e(\phi, p, t)\,d\phi\,dp$$

Thus:-

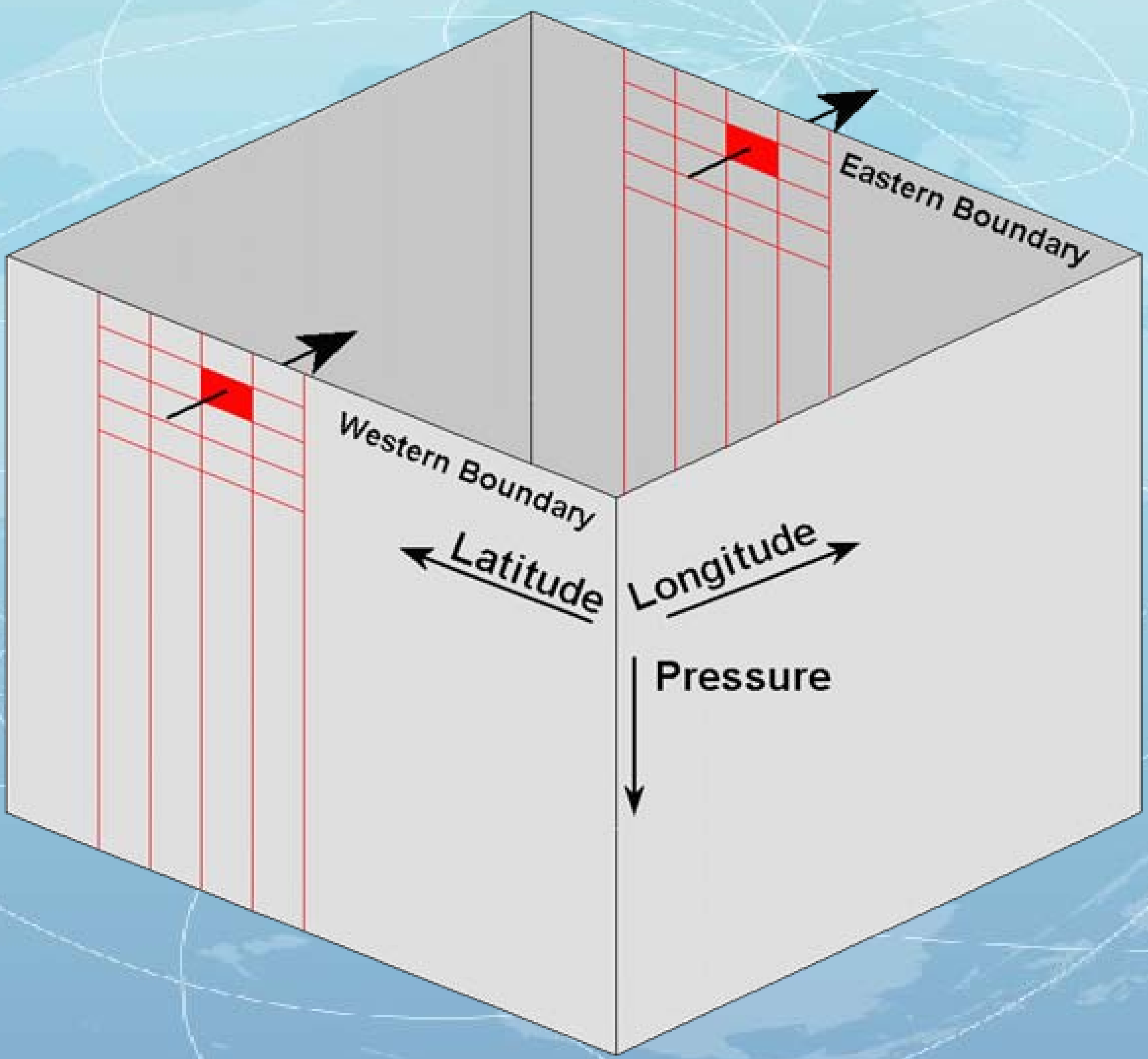
$$<u_e T_e> = <(\overline{u}_e + u'_e)(\overline{T}_e + T'_e)>$$

$$= <\overline{u}_e \overline{T}_e> + <u'_e \overline{T}_e> + <T'_e \overline{u}_e> + <u'_e T'_e>$$

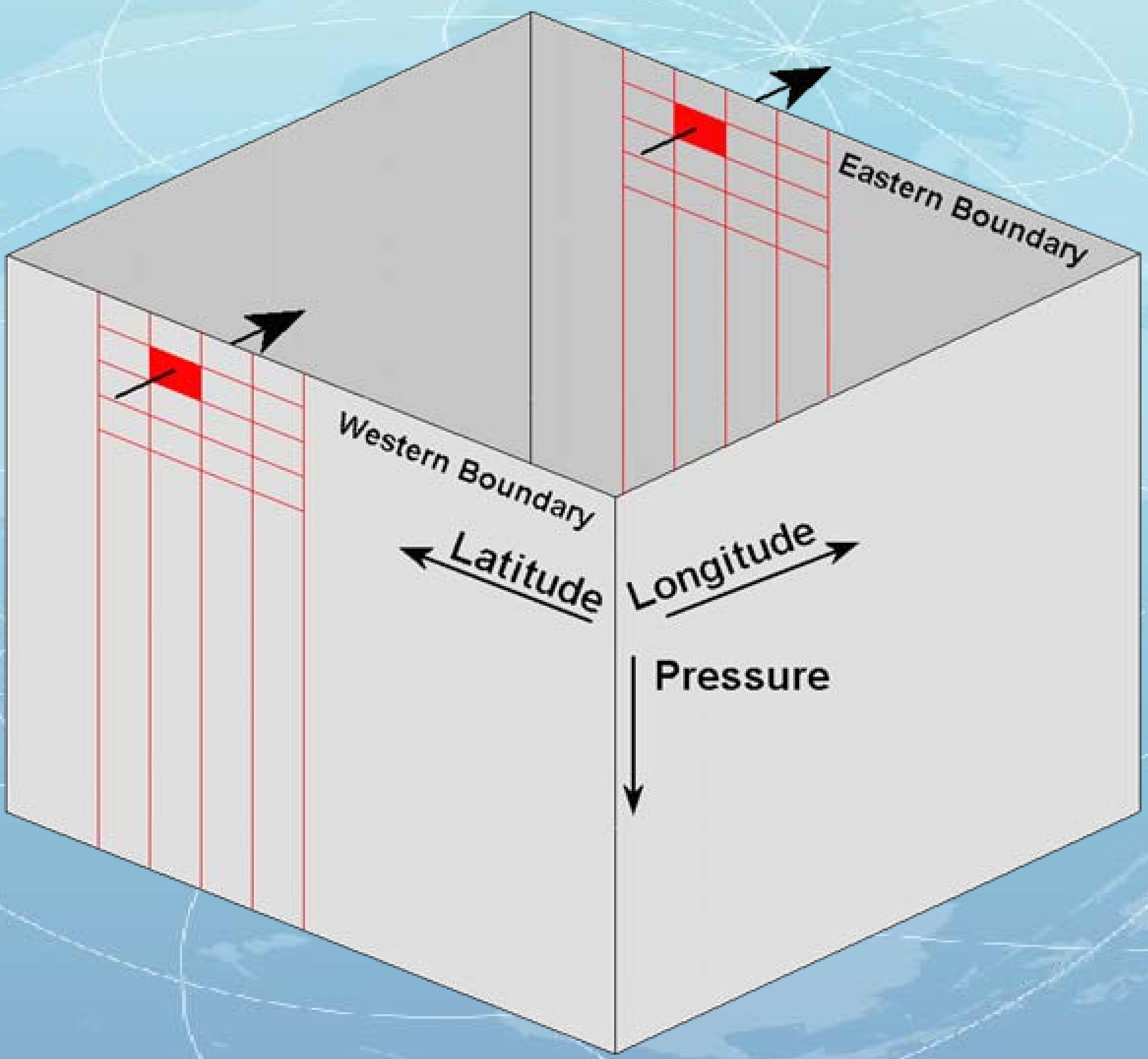
Steady state

Time varying part.

The computation is delicate and requires great care to control round-off error



The computation is delicate and requires great care to control round-off error



What this implies is……

Though the horizontal heat divergence of the mean state looks like:-

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

But I actually compute:-

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

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:-

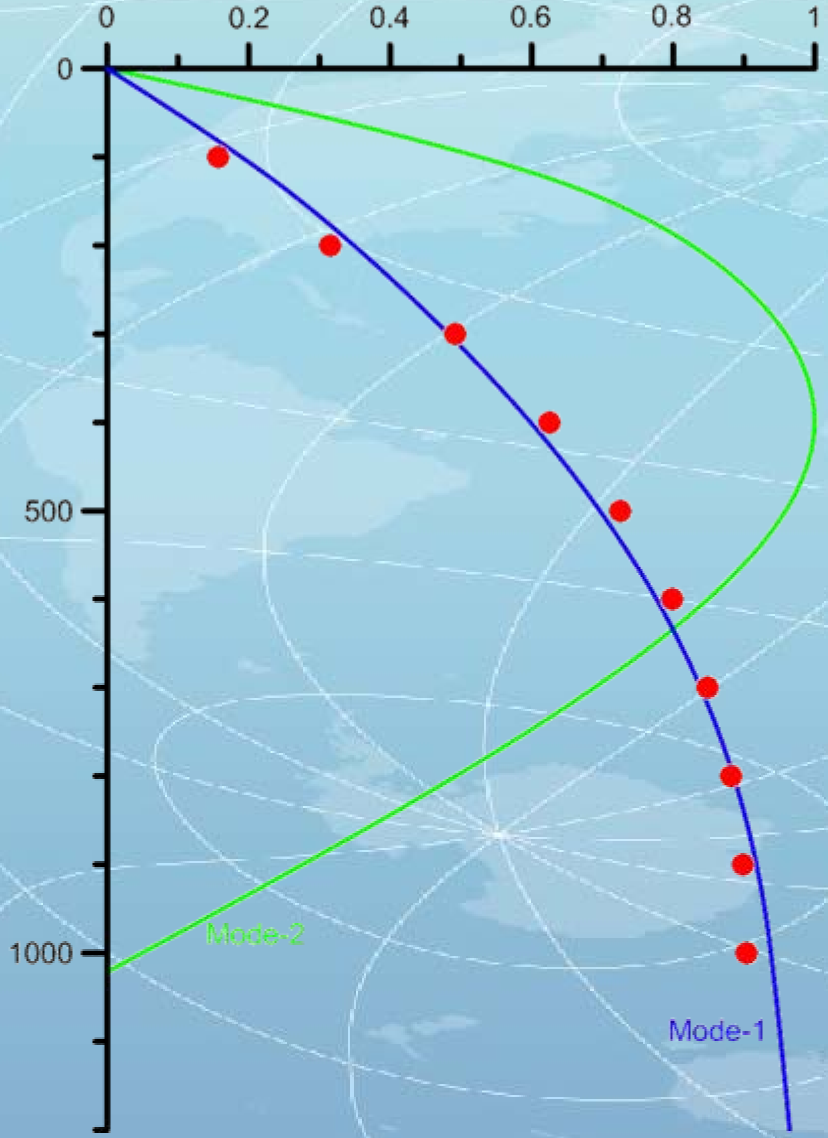
$$Divergence = 3.75 \times 10^6 \, m^3 / s = Area \times w_{700}$$

Hence:- $$w_{700} = 8.52 \times 10^{-7} \, m / s$$

Is this plausible?

Try computing w_P for values other than P = 700, according to Gill this should look like a first internal low-frequency wave mode.

Plausibility test #1



The vertical structure of w estimates is extremely plausible.

Plausibility test #2

I find…..

$$w_{700} = 8.85 \times 10^{-7} m/s$$

Munk (1966) in the famous paper “Abyssal Recipes” solves:-

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

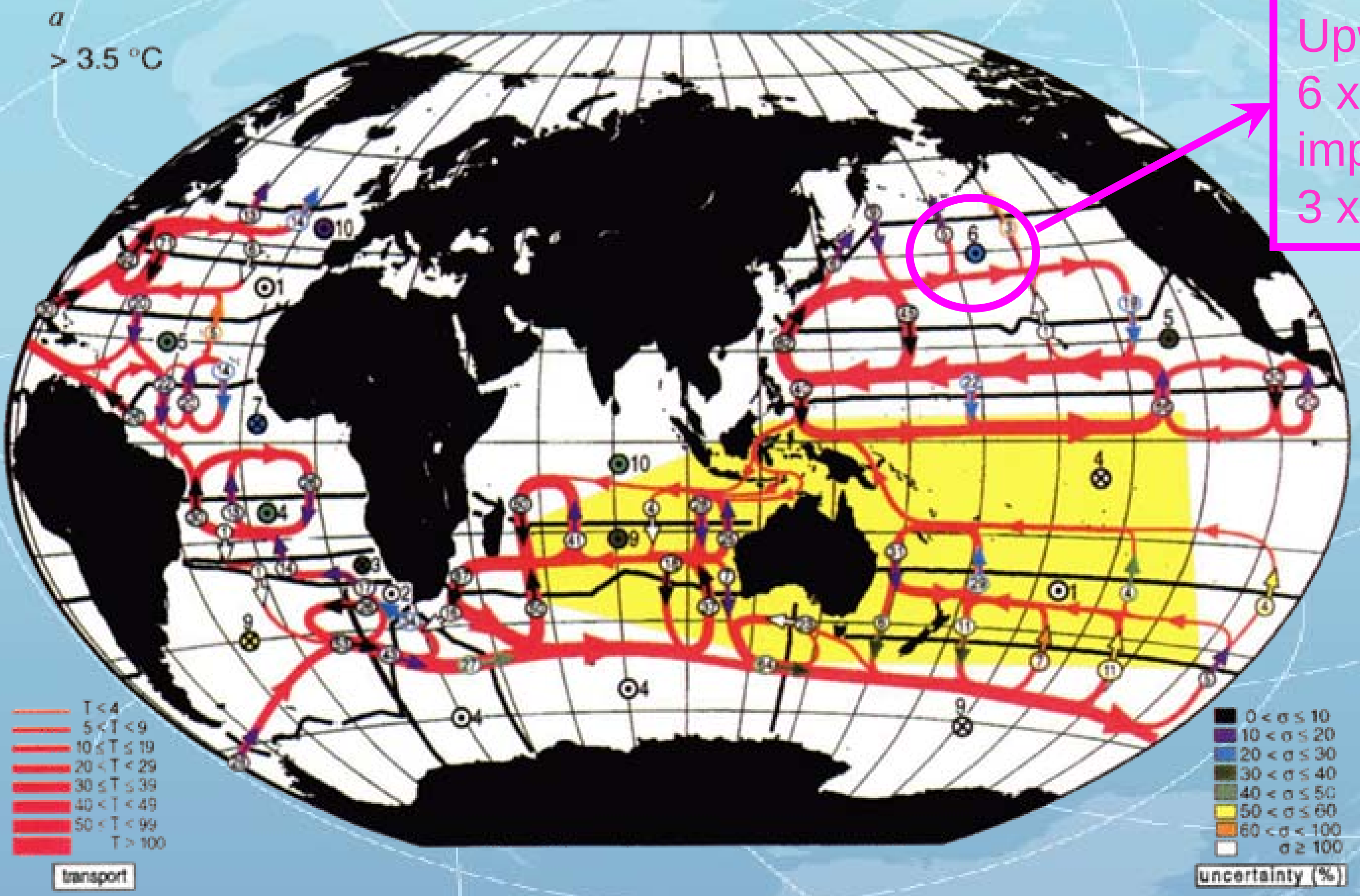
and computes…..

$$w_{deep} = 0.7 \times 10^{-7} m/s$$

Plausibility test #3

I find….. $w_{700} = 8.85 \times 10^{-7} \, m/s$

Macdonald & Wunsch (Nature, 1996) invert data from WOCE surveys and find:-



Upwelling is
6×10^6 m^3/s
implying W_{deep} =
3×10^{-7} m/s

Plausibility test #4 (mean state salt divergence)

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

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

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 #5 (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 $H = C_pT$ (C_p does vary with T and S)

$$Heat-Divergence = +1.279 \times 10^{11} J.m^3/(kg.\sec)$$

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

$$Difference = +0.69 \times 10^{11} J.m^3/(kg.\sec)$$

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

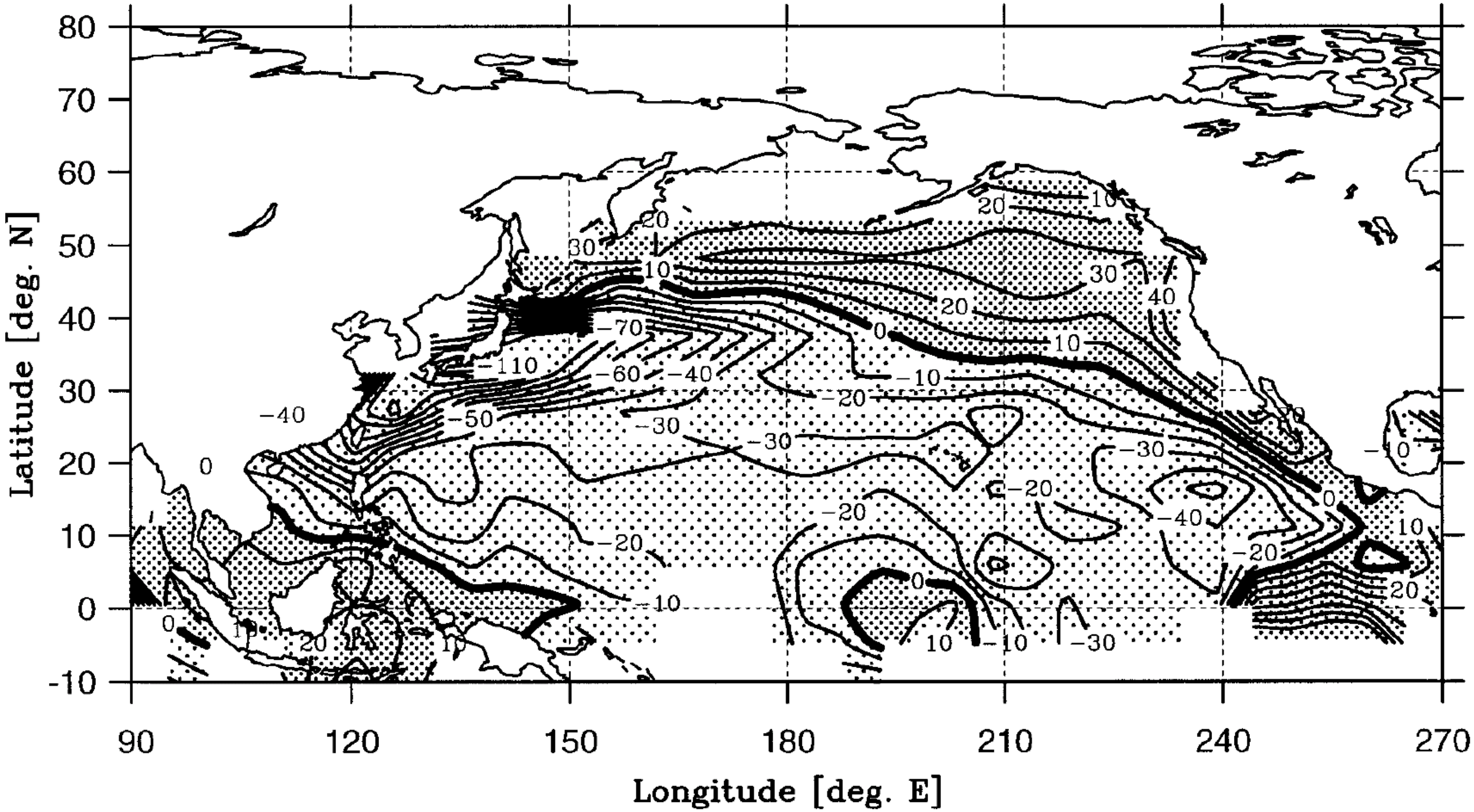


Fig. 11. The annual mean net heat flux between 1950 and 1990. Contour interval is 10 W m^{-2}. Positive contours: solid line; negative contours: dashed line. Shaded region indicates where data was available.

Figure 11 from Moisan & Niiler, JPO 28, 401-421, 1998

Their estimates are available on 5° x 5° grid.

Annual mean heat flux 1950-1990

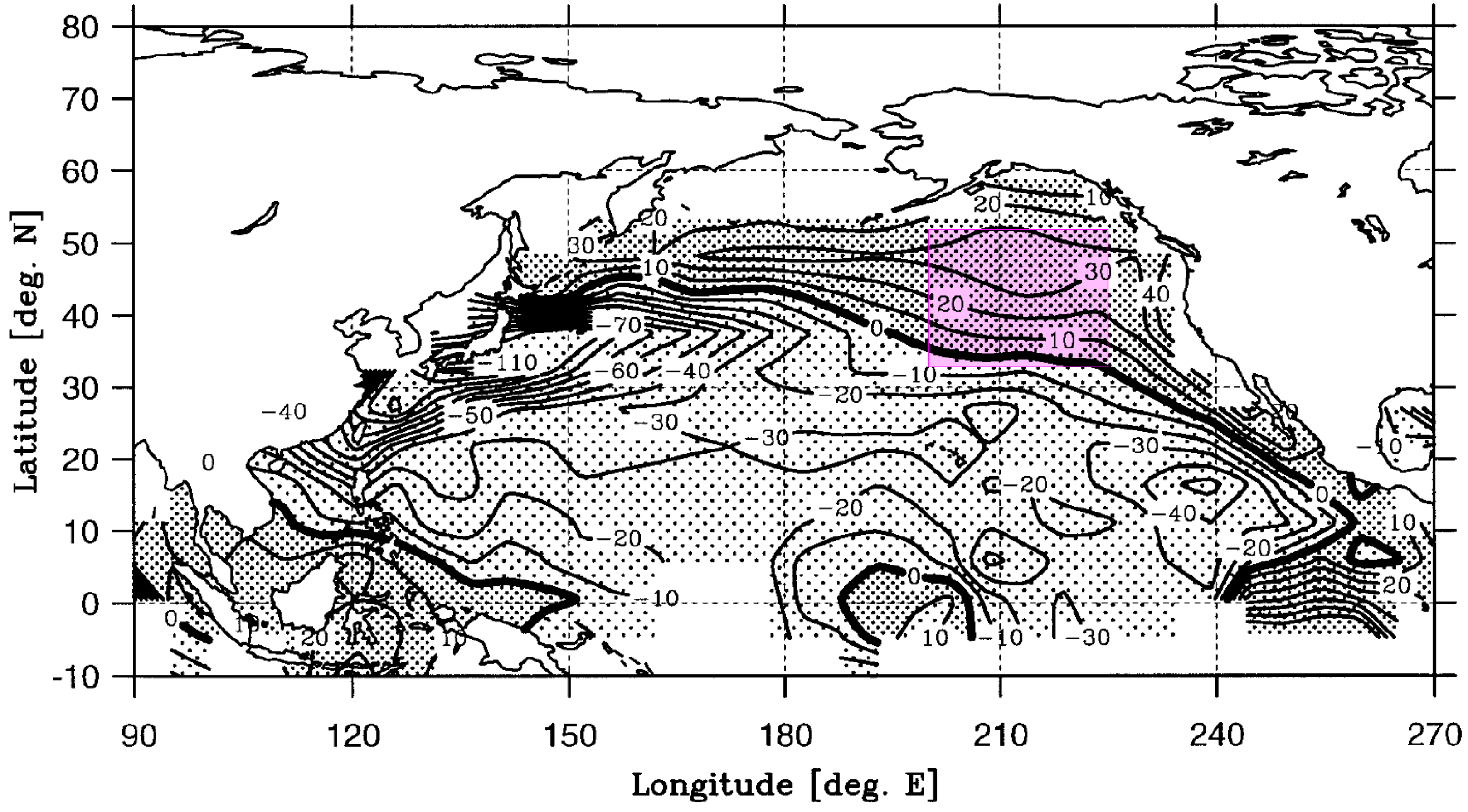
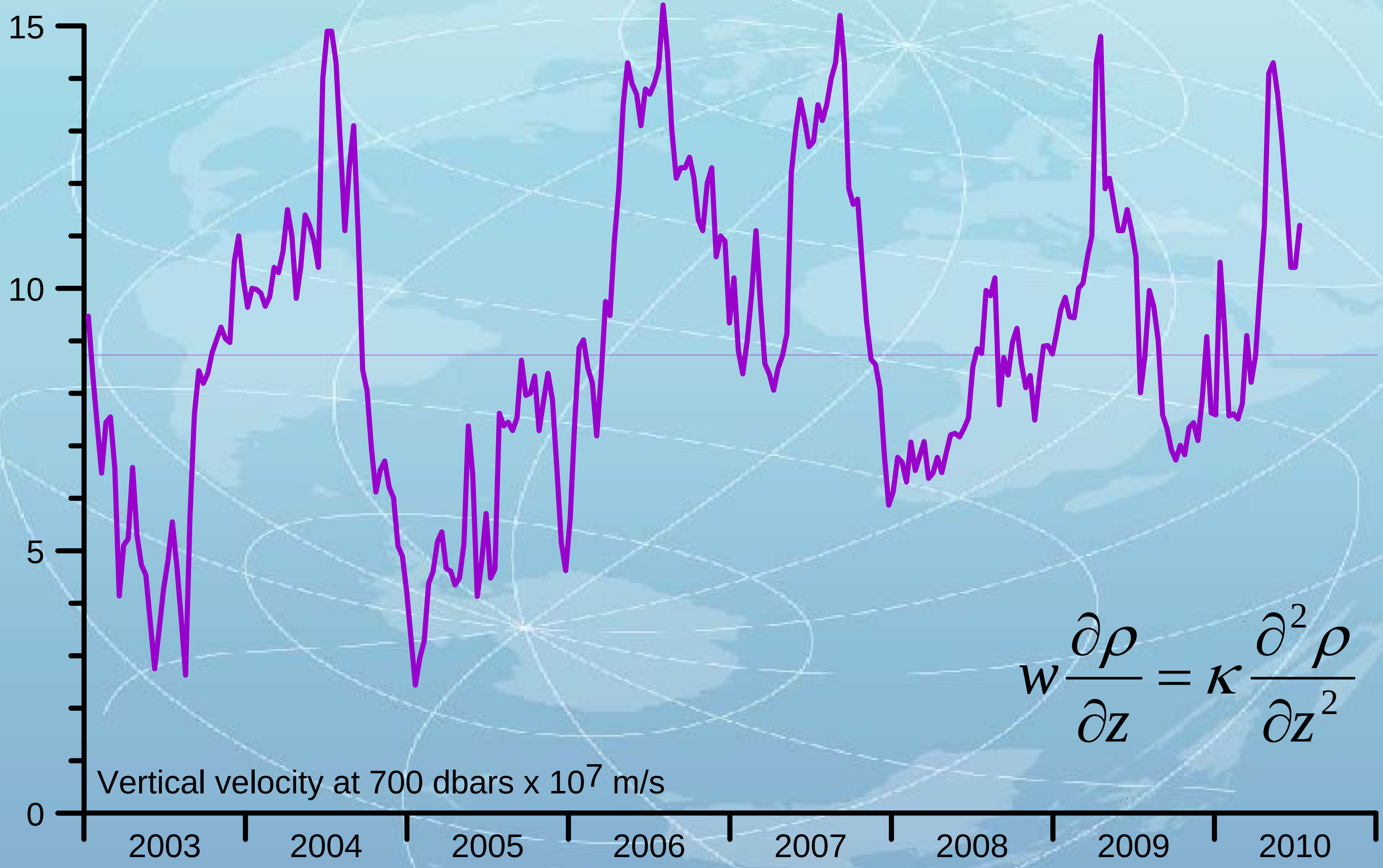


FIG. 11. The annual mean net heat flux between 1950 and 1990. Contour interval is 10 W m^{-2}. Positive contours: solid line; negative contours: dashed line. Shaded region indicates where data was available.

Moisan & Niiler would suggest an expected annual average of about 20.1 ± 10 W/m^2

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



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

Conclusions

1) Argo observations are adequate 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
3) The vertical structure of the vertical velocity behaves almost precisely as theory would require.
4) This is substantially larger than the early estimate of Munk and modestly larger than a recent estimate of Macdonald.
5) The vertical velocity estimated balances the salt and heat budgets closely.
6) Large time variability in the vertical velocity exists and this is a subject for later work.