Altimetry helps to explain patchy changes in repeat hydrography carbon measurements

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Are “climate modes” useful for understanding observed variations in ocean carbon?

Recently connecting flux anomalies to “climate modes” has come into vogue (ENSO, PDO, SAM);

Ocean carbon research to date has largely focused on air-sea fluxes of CO_2 (very little work on subsurface DIC distribution)

Model air-sea fluxes are typically regressed against favourite climate index, giving characteristic pattern

Underlying (but unspoken) assumptions with “modes”:

(1) Carbon (fluxes and sub-surface distribution) “follows” dynamics

(2) As with SST, CO_2 fluxes have a limited number of degrees of freedom, and thus global fluxes can be largely captured by a superposition of mode-response functions

But “modes” are not mechanisms!!!

Alternative Framework:

Can planetary waves help to understand the ocean carbon cycle? (baroclinic Rossby and Kelvin waves)

This will be addressed through the analysis of measurements which occur on a timescale (6 months-2 years) significantly shorter than the sampling frequency of Repeat Hydrography (7-10 years)

Sabine et al. [2006]: Decadal changes in carbon concentrations Reveal "patchy" structures with Repeat Hydrography

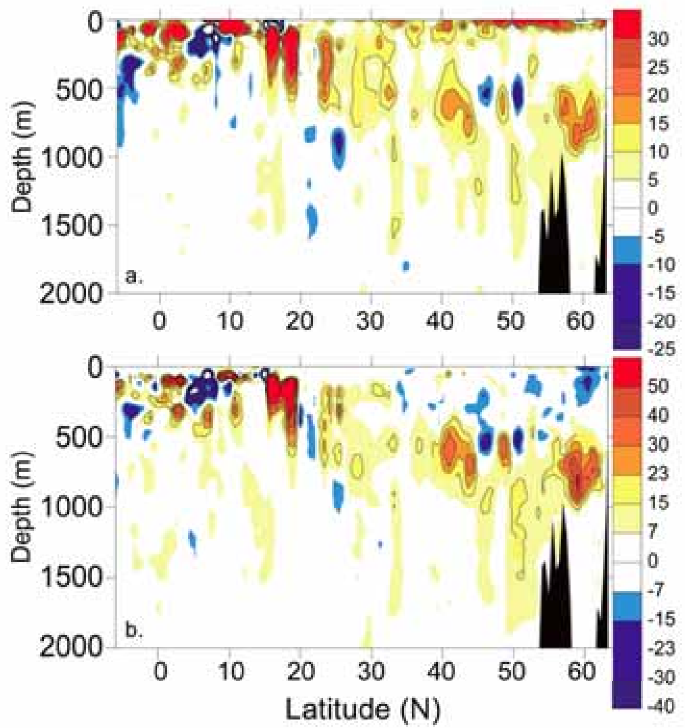


FIG. 3.13. Changes in (a) DIC (μmol kg^{-1}) and (b) AOU (μmol kg^{-1}) in the upper 2000 m between the 2003 and the 1993 occupations of A16N. Positive values are an increase in concentrations between 1993 and 2003 (modified from Feely et al. 2005).

Aliasing in snapshot sampling "complicates" interpretation of time-evolving ocean inventory of anthropogenic carbon

What is driving these changes? Need to understand natural variability in ocean carbon…

Not simply isopycnal heaving

Mechanisms could include (certainly not mutually exclusive!):

(a) Local variations in biology

(b) Variations in non-local subduction

(d) Mesocale eddies

(d) Effect of planetary waves on frontal positions etc.

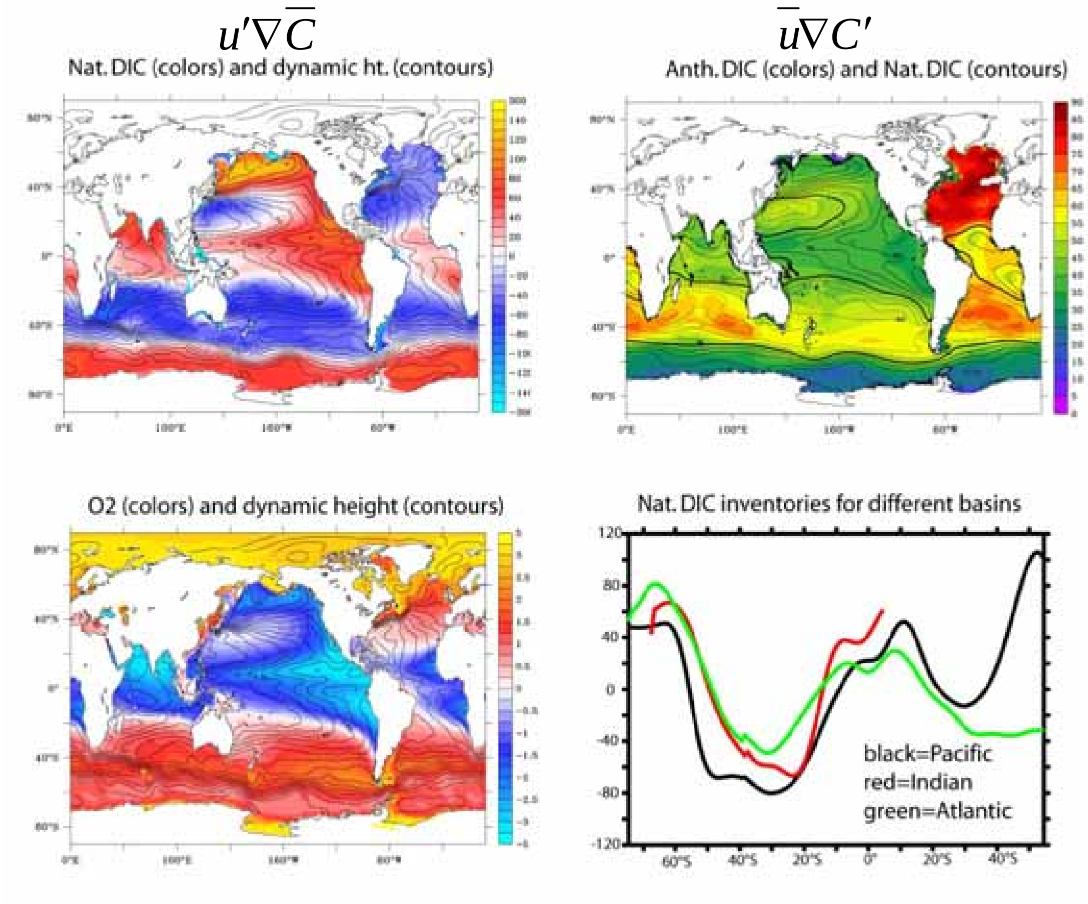
Using a perturbation expansion of the advection-diffusion equation for variations carbon, and then integrating this in the vertical:

$$\frac{\partial C'}{\partial t} = -\overline{u}\nabla C' - u'\nabla\overline{C} + \nabla K \nabla C' + (BIO)'$$

Can we identify from observations when we expect the 2nd term on the RHS to become important? In other words, when is:

$$\overline{u}\nabla C' \approx u'\nabla\overline{C}$$

Vertical integrals of dissolved inorganic carbon (DIC) and density over upper 1km: (taken from GLODAP and WOA05 climatologies)



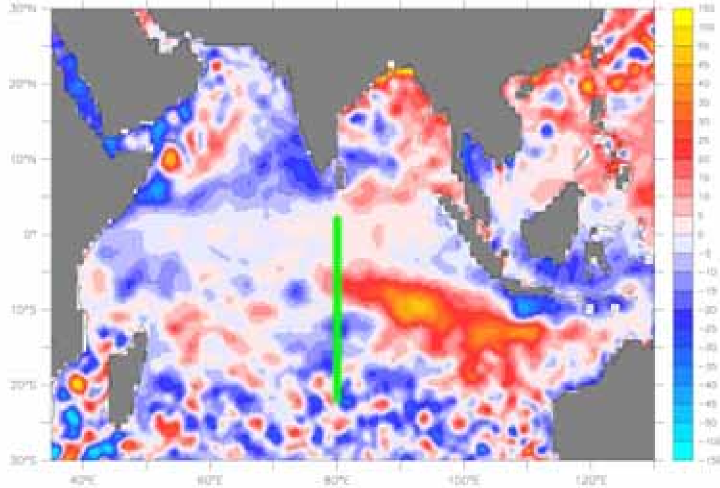
Seeing as $\nabla C' / \nabla\overline{C} \approx 1/10$

One should expect natural variability to be important for detection when:

$$u' \approx (1/10)\overline{u}$$

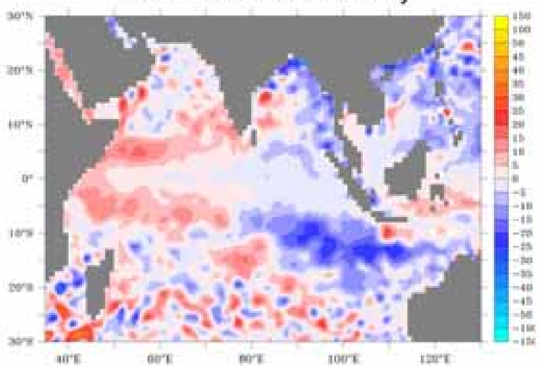
Want to test mechanism in regions where there are repeat measurements on timescales of seasons to 1-2 years

Changes in Sea surface Height (SSH) from TOPEX between March 1995 and September 1995, with cruise track for "repeat section" I8N overlain in green (ΔSSH in cm)

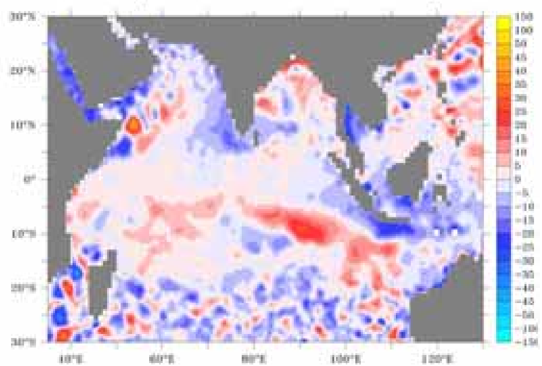


I8N (80°E)

March 1995 SSH anomaly



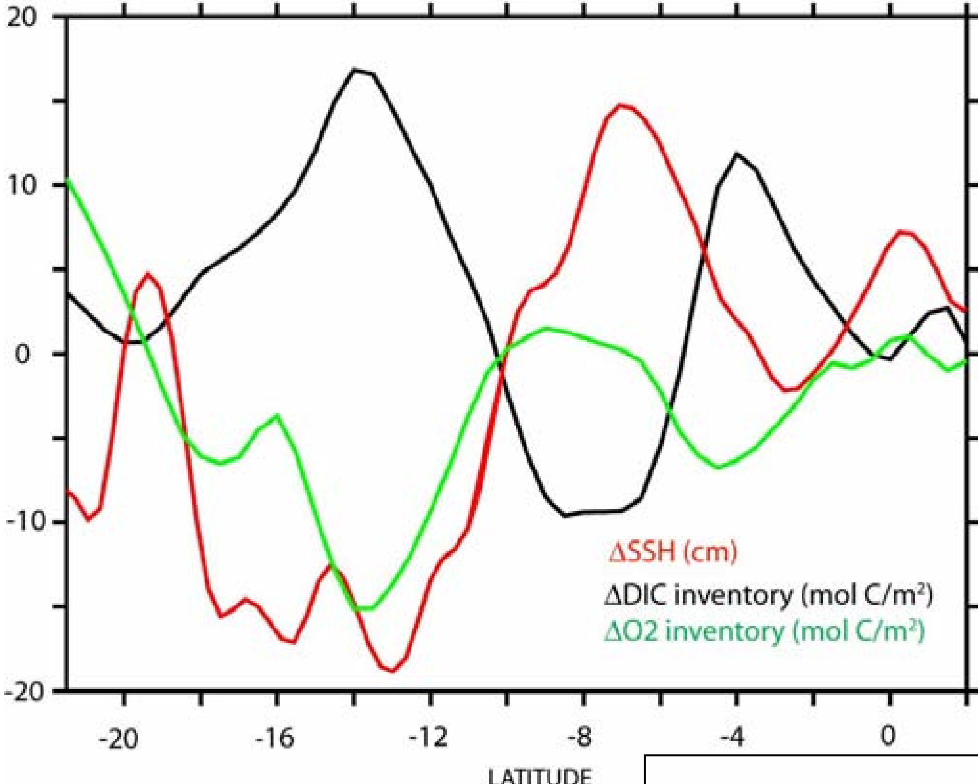
September 1995 SSH anomaly

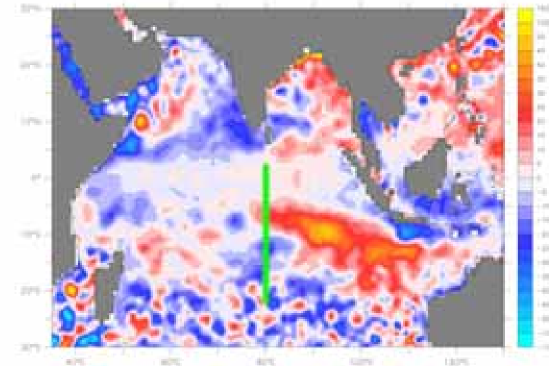


Case (A): Changes in sea surface height (SSH) and CARBON over a six month period in Indian Ocean (3/1995-9/1995)

As SSH reflects vertical integral of density changes, it is appropriate to compare with tracer Inventory changes (over upper 1km)

Changes in measured column inventory of DIC (black, mol/m²), O2 (green, mol/m²), and SSH (red, cm) from TOPEX altimetry data along 80°E (I8N) between March 1995 and September 1995

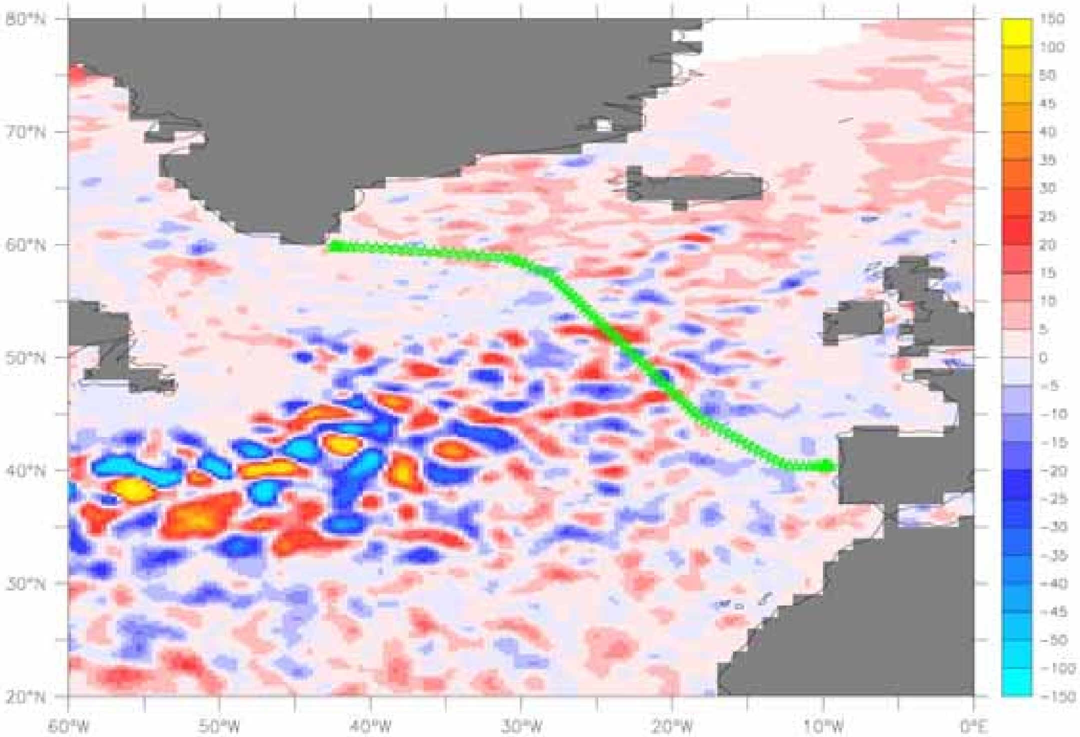




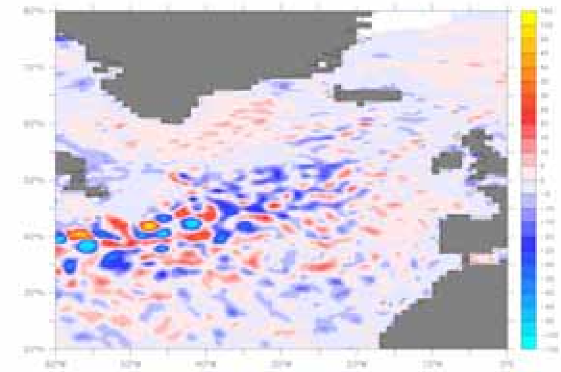
Clearly DIC (and O2) inventory changes are closely related to SSH changes!

Invoking non-local subduction changes as driver would require that correspondence between ΔSSH and ΔDIC is coincidence

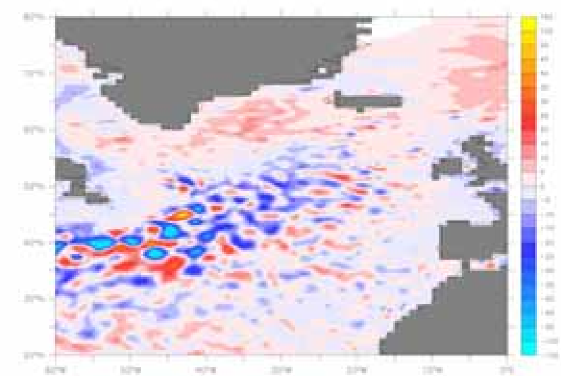
Changes in Sea surface Height (SSH) from TOPEX between June 2002 and June 2004, with cruise track for "repeat section" OVIDE overlain in green (ΔSSH in cm)



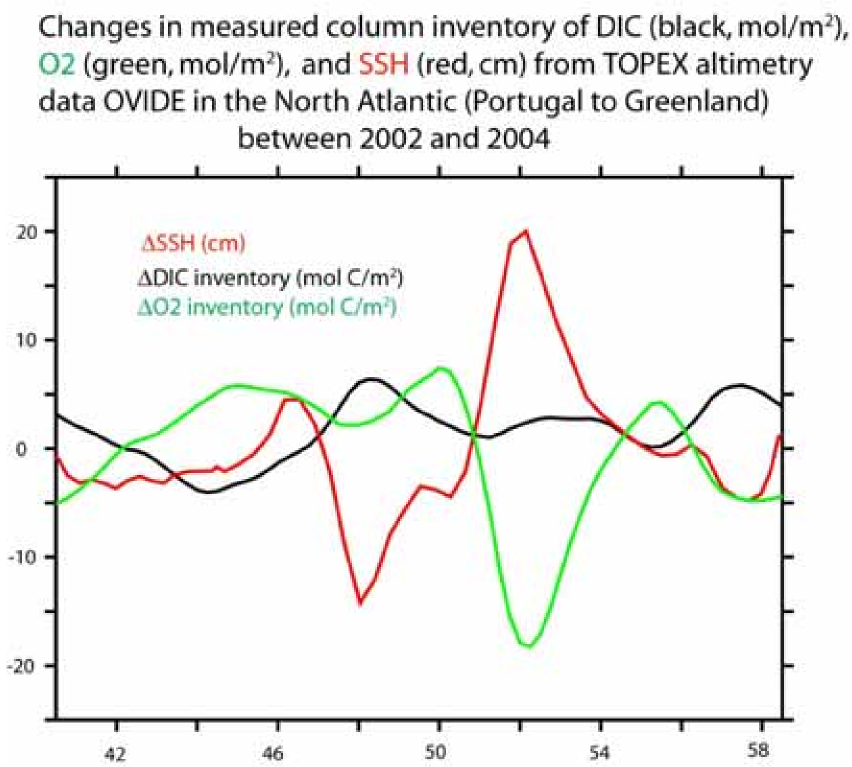
June 2002 anomaly



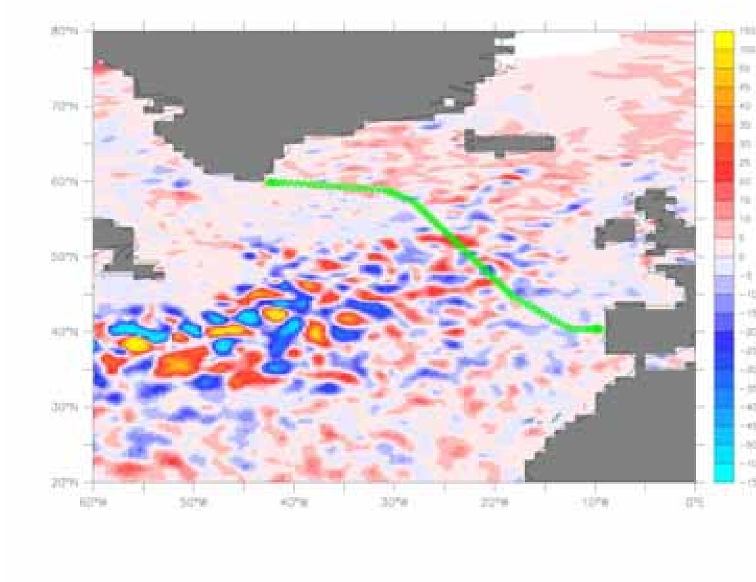
June 2004 anomaly



Case (B): Changes in SSH and CARBON in North Atlantic



Case (B): Changes in SSH and CARBON in North Atlantic



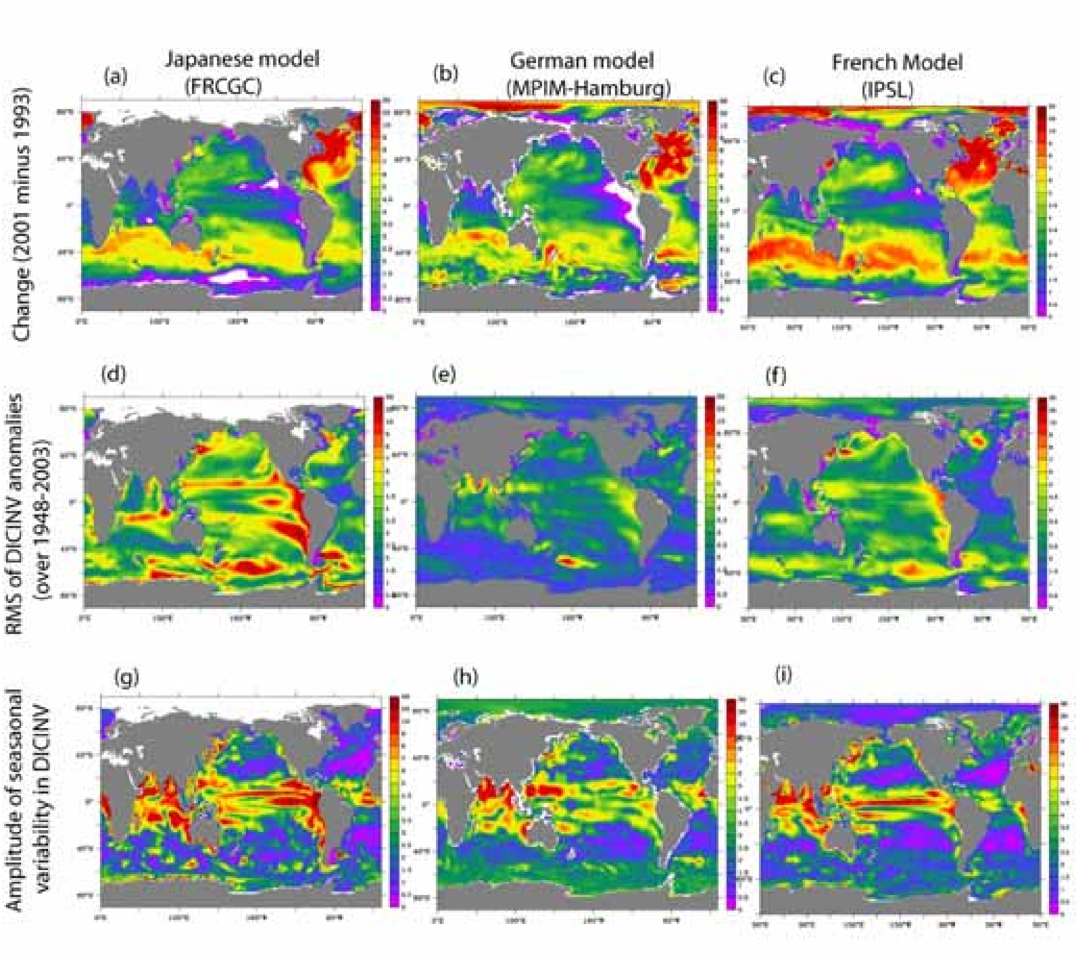
SSH changes are NOT (!!!) reflected in DIC inventory changes, but they are correlated with O2 changes

In fact consistent with what we saw earlier for “mean state” with DIC and O2 ; invoking “non-local” subduction changes would again require that there be a coincidence between SSH and O2 changes

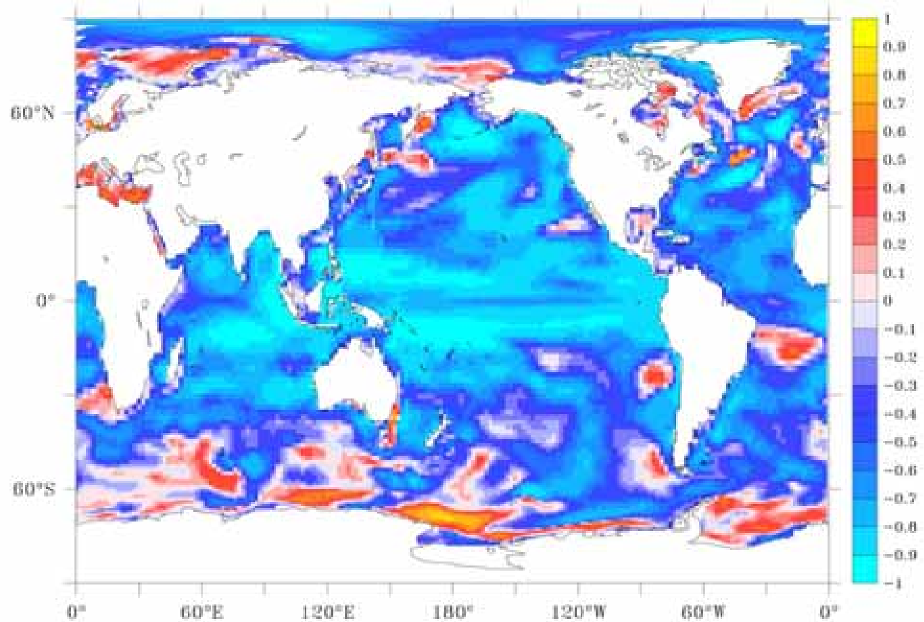
Interpretation of short timescale variability:

- Comparison of remotely-sensed SSH with carbon inventories support hypothesis that “patchiness” in repeat measurements is driven by planetary waves
- Bad news: For detection, potentially significant aliasing problems with omnipresent Rossby waves and eddies
- Good news: remotely sensed SSH has potential to help deconvolve natural carbon variability and anthropogenic carbon transient from Repeat Hydrography

Models are consistent with data in that natural background variability of DIC inventories is of same order as anthropogenic signal as it evolves over decades



Correlation between detrended monthly anomalies of SSH and natural DIC inventories over 1990-2003 for ORCA2-PISCES model (2° resolution)



Conclusions

Planetary waves (Rossby waves) drive considerable natural variability in upper ocean DIC inventories

Nearly continuous TOPEX altimetry data can be used to help in the interpretation of Repeat Hydrography data

This can serve as a complement to empirically-based MLR methods for detection of anthropogenic DIC