An Increase in the seasonal cycle of air-sea CO_2 fluxes over the 21st Century in IPCC Scenario Runs

Keith Rodgers (Princeton)
Laurent Bopp (LSCE)
Olivier Aumont (IRD)
Daniele Iudicone (Naples)
Jorge Sarmiento (Princeton)
Anand Gnanadesikan (GFDL)
John Dunne (GFDL)

Is the seasonal cycle in air-sea CO2 fluxes increasing over large scales?

If it is, then this could have important implications for the detection of anthropogenic changes

Methodological point: much recent work has focused on "modes" as a means of studying variability in the carbon cycle ; This method typically assumes a stationary seasonal cycle and focuses on "anomalies" (deseasonalized) - want to test appropriateness for studying climate change

Science point: Oftentimes assumption is made implicitly that timescales are separated (I.e. seasonal/decadal) - want to test this as well

Data: Case of North Pacific: decadal trend in pCO_2

Takahashi et al., 2006

Reveal structure of decadal evolution of pCO_2
Observations are “deseasonalized”

Importance of Seasonal Cycle:

Analysis performed thus far emphasizes “annual mean” trend

Could incomplete understanding of seasonal variations bias our interpretation of existing measurements?

If the seasonal cycle itself can change in time, might processes important to decadal trends be obscured in this type of analysis?

Previous study with forced ocean model

ORCA2-PISCES model, forced with NCEP-1 reanalysis

ORCA2: global 2° Ocean Model [Madec et al., 1998]
PISCES: Ocean biogeochemistry model [Aumont and Bopp, 2006]

Run spans 1948-2003

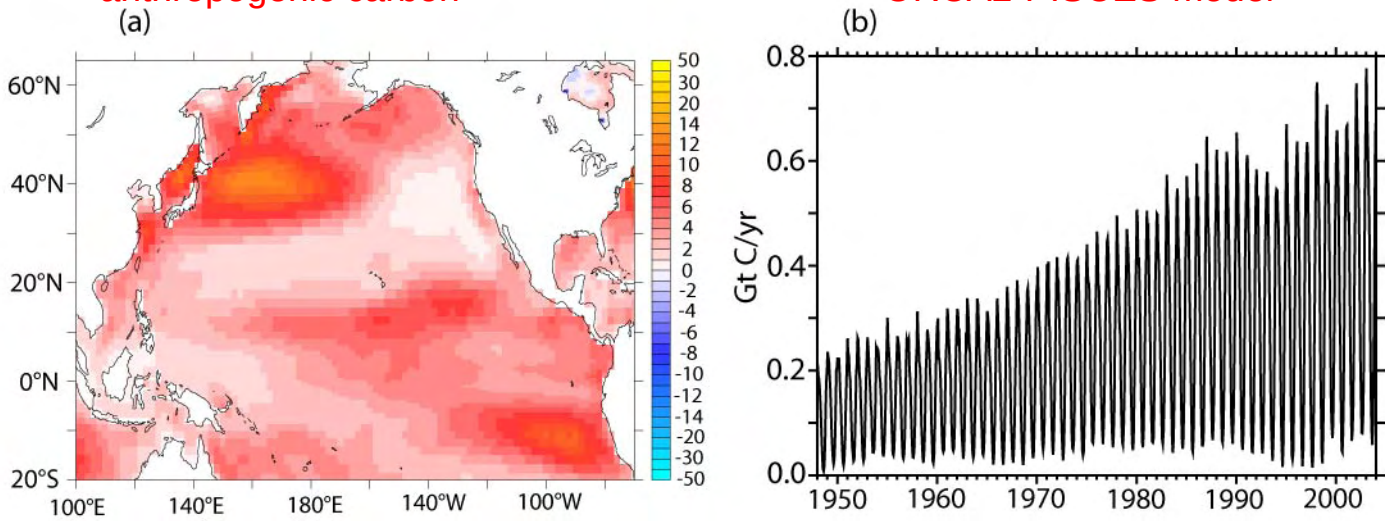
Question:

What are pathways and timescales describing uptake of ***anthropogenic carbon*** in the North Pacific?

"Wintertime uptake window of anthropogenic carbon in North Pacific" [*Rodgers et al*., GBC, 2008]

Spatial structure in ORCA2-PISCES model for annual mean uptake of anthropogenic carbon

Temporal behavior (over 1948-2003) for uptake of anthropogenic carbon in ORCA2-PISCES model



Mechanism in this model (as well as other NOCES models): during summer, sea surface pCO2 largely tracks the atmosphere so that ΔpCO2 changes little with time, whereas in winter vertical exchange brings water with memory of atmosphere with lower CO2 to the surface, so that ΔpCO2 increases with time

Using Earth System Models to understand anthropogenic transient in ocean carbon

(for reanalysis-forced OGCMs and coupled ESMs)

(A)Transient Phys., Transient Tracer b.c.
(B)Transient Phys., PreInd. Tracer b.c.
(C)PreInd Phys., Transient Tracer b.c.
(D)PreInd Phys., PreInd. Tracer b.c.

Clearly “anthropogenic transient” for ocean carbon uptake is represented by (A)-(D)

C4MIP included a comparison of (C)-(A) to evaluate climate feedbacks

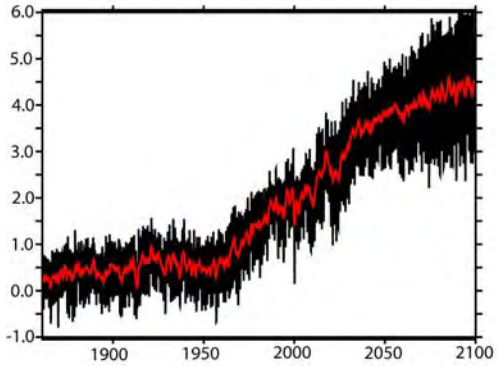
How does seasonality change over 21st century in IPCC scenario runs?

Here we focus on the SRES A2 runs of Laurent Bopp with the IPSL coupled model

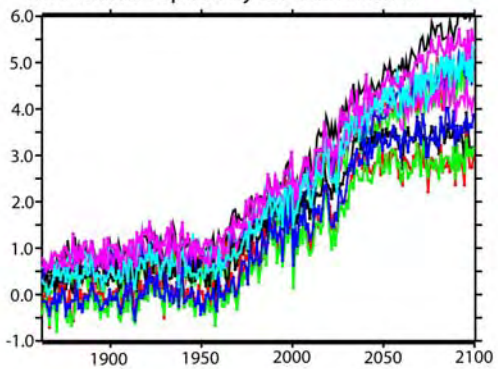
The coupled model was run over 1861-2099, and then monthly mean physical fields were used to drive the PICES model over the same period

Here we focus on runs “A” and “C” on order to address how air-sea ΔpCO_2 and air-sea CO_2 fluxes are modulated by anthropogenic change in the physical state of the ocean

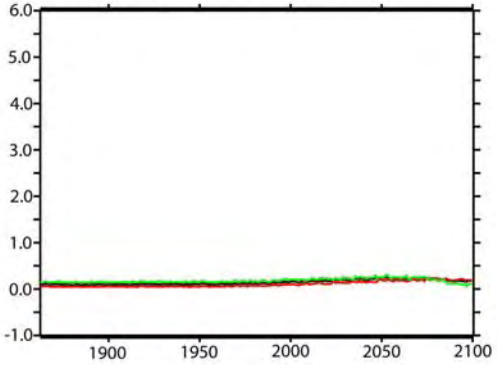
Globally integrated air-sea CO_2 fluxes for monthly mean (black) and annual mean (red)



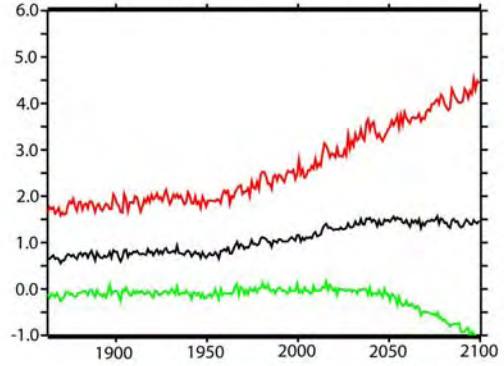
Globally integrated air-sea CO_2 fluxes considered separately for each month



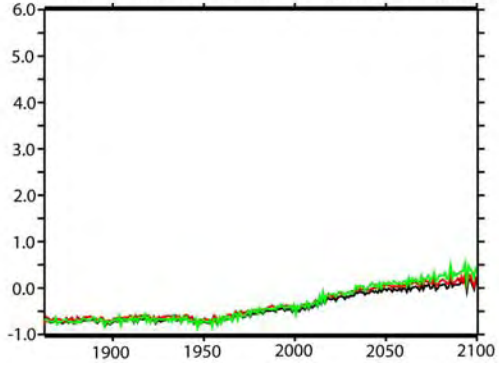
Arctic (Y>65°N) air-sea CO_2 fluxes for annual mean (black), DFJ (red), and JJA (green)



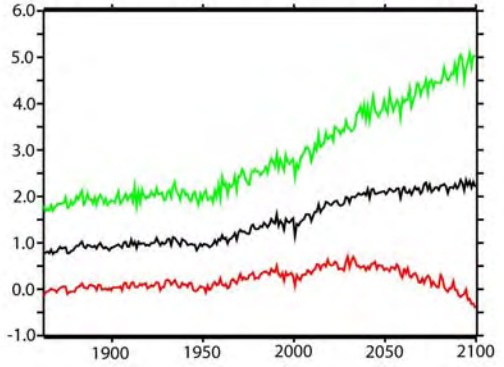
Air-sea CO_2 fluxes over 15°N-65°N for annual mean (black), DFJ (red), and JJA (green)



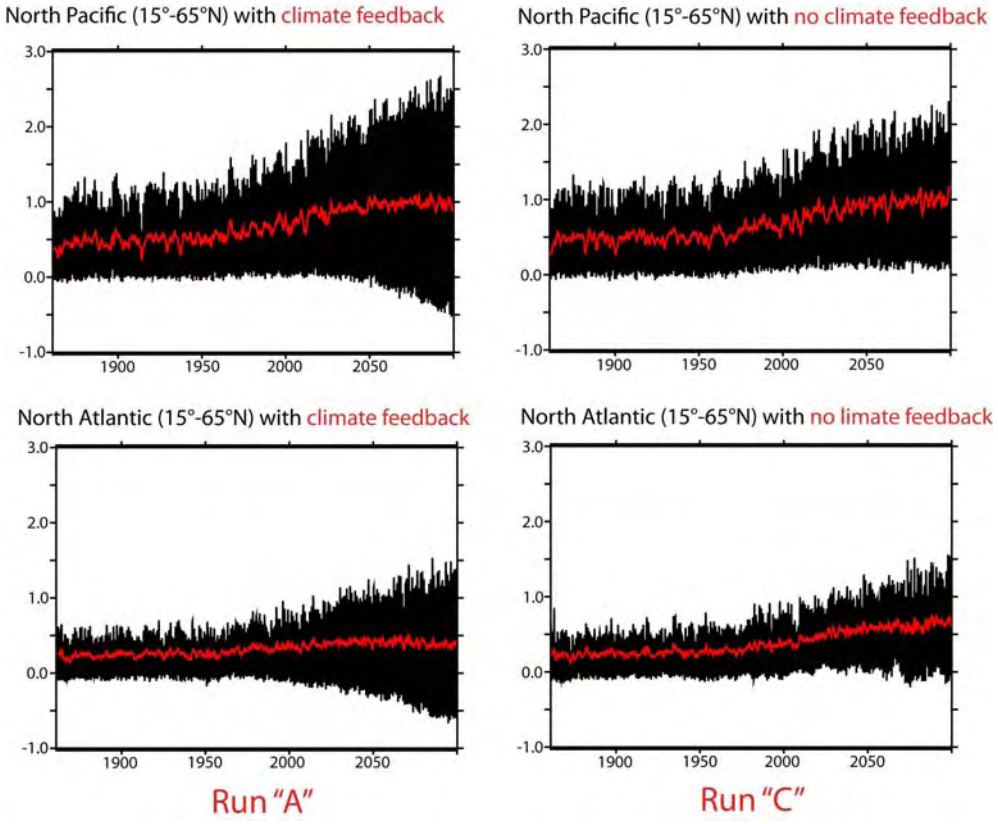
Air-sea CO_2 fluxes over 15°S-15°N for annual mean (black), DFJ (red), and JJA (green)



Air-sea CO_2 fluxes over 15°S-80°S for annual mean (black), DFJ (red), and JJA (green)



Air-sea CO2 fluxes over Northern Oceans
for fully coupled model (IPSL) with and without
climate feedback on physical state variables



Air-sea fluxes of CO2 integrated over extratropics of North Pacific and North Atlantic

Units: Pg C /yr
Sign: positive flux = ocean uptake

Black line: monthly mean CO2 uptake
Red line: 12-month running mean

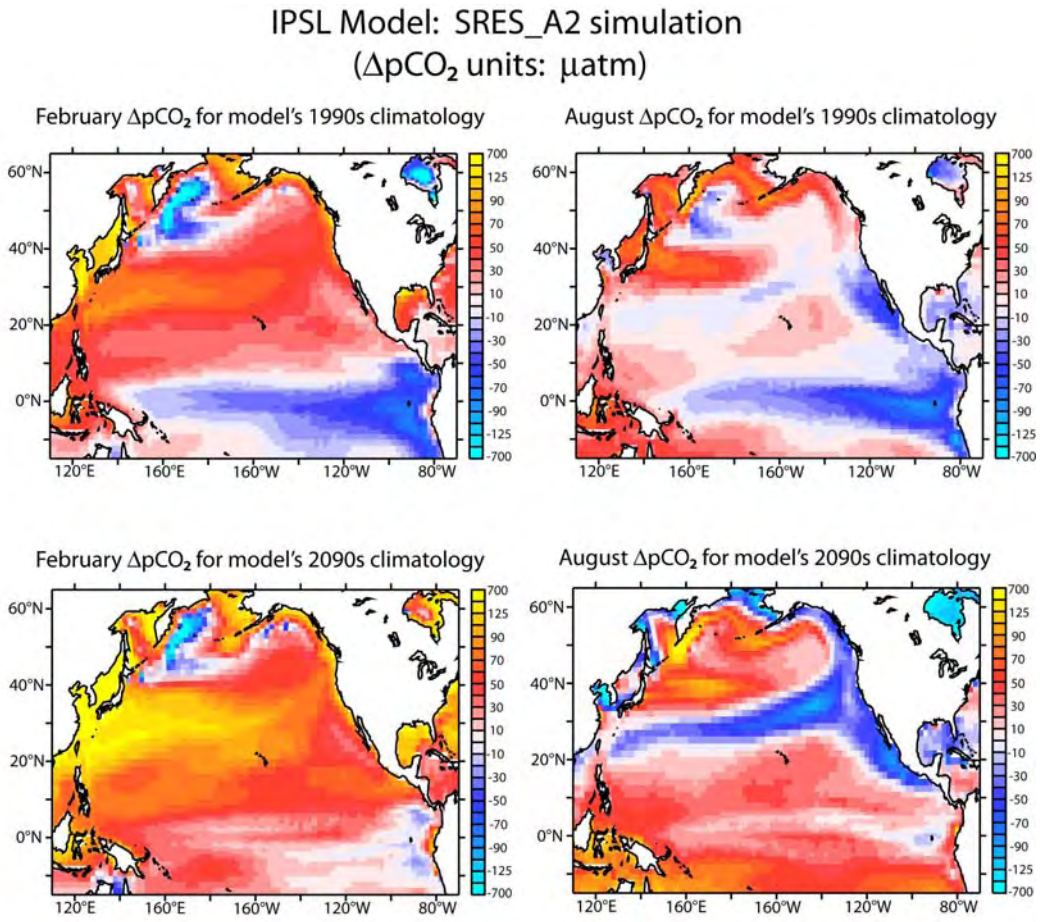
How do structures in ΔpCO2 change for "A" run over 21st century?

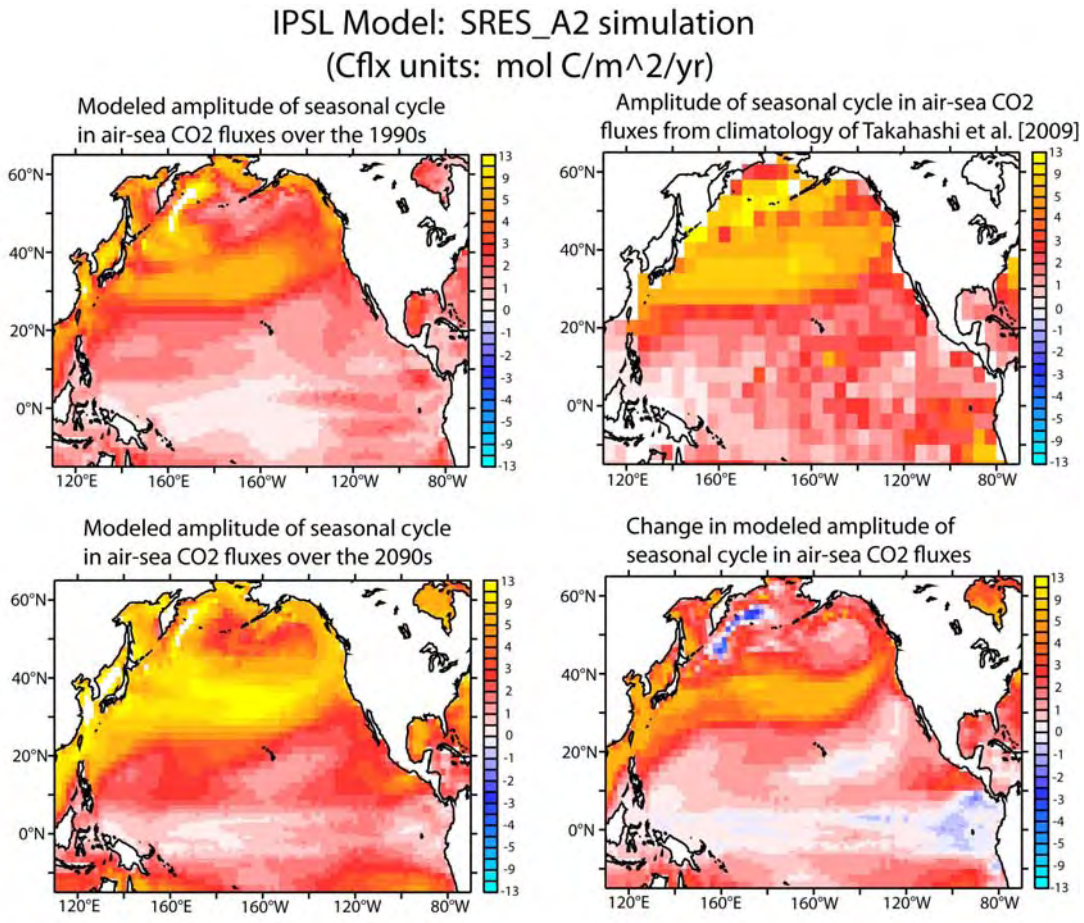
Consider "climatologies" separately for years

1990-1999 (1990s)

2090-2099 (2090s)

Very large changes are found in the subtropics for both winter and summer

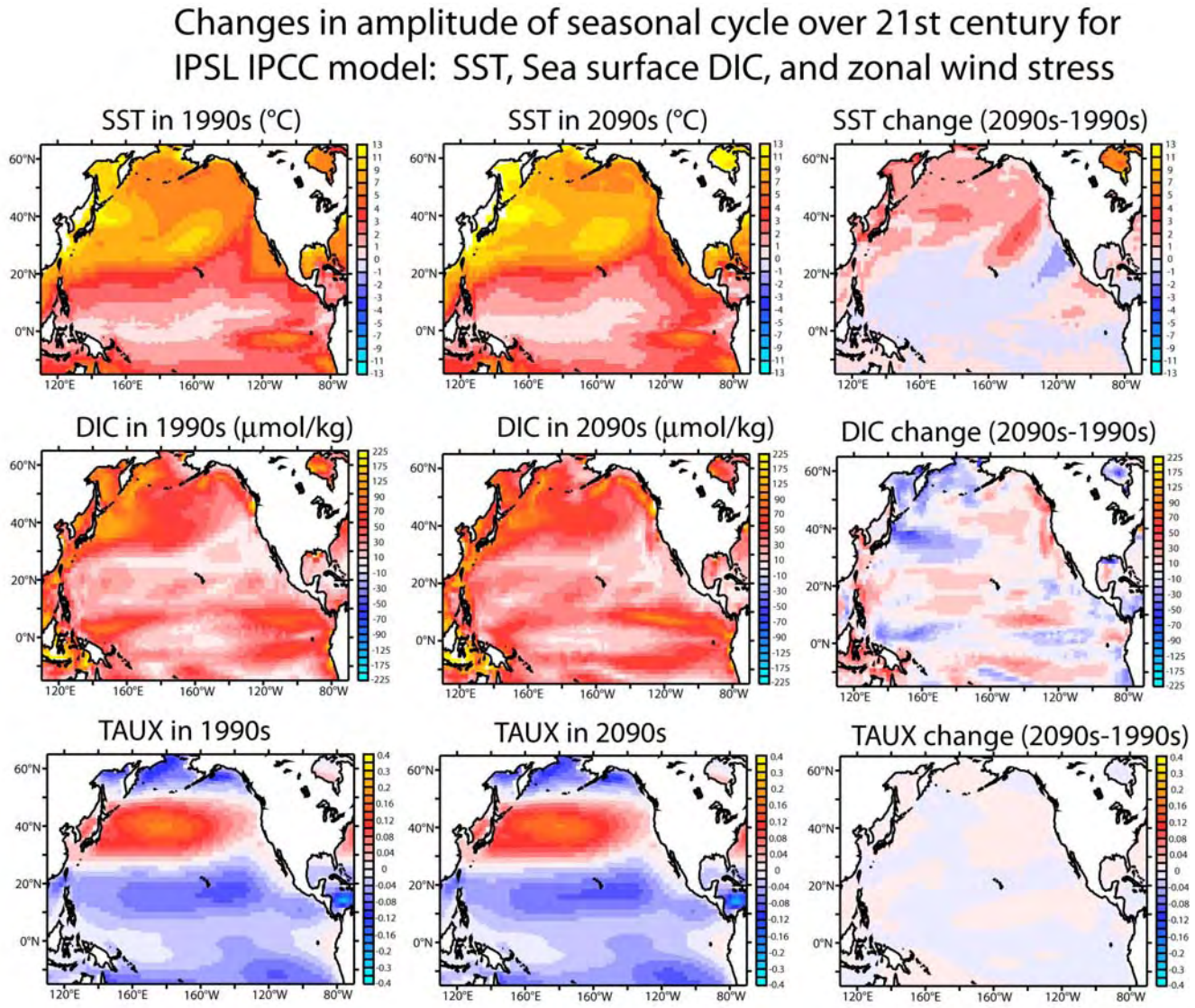


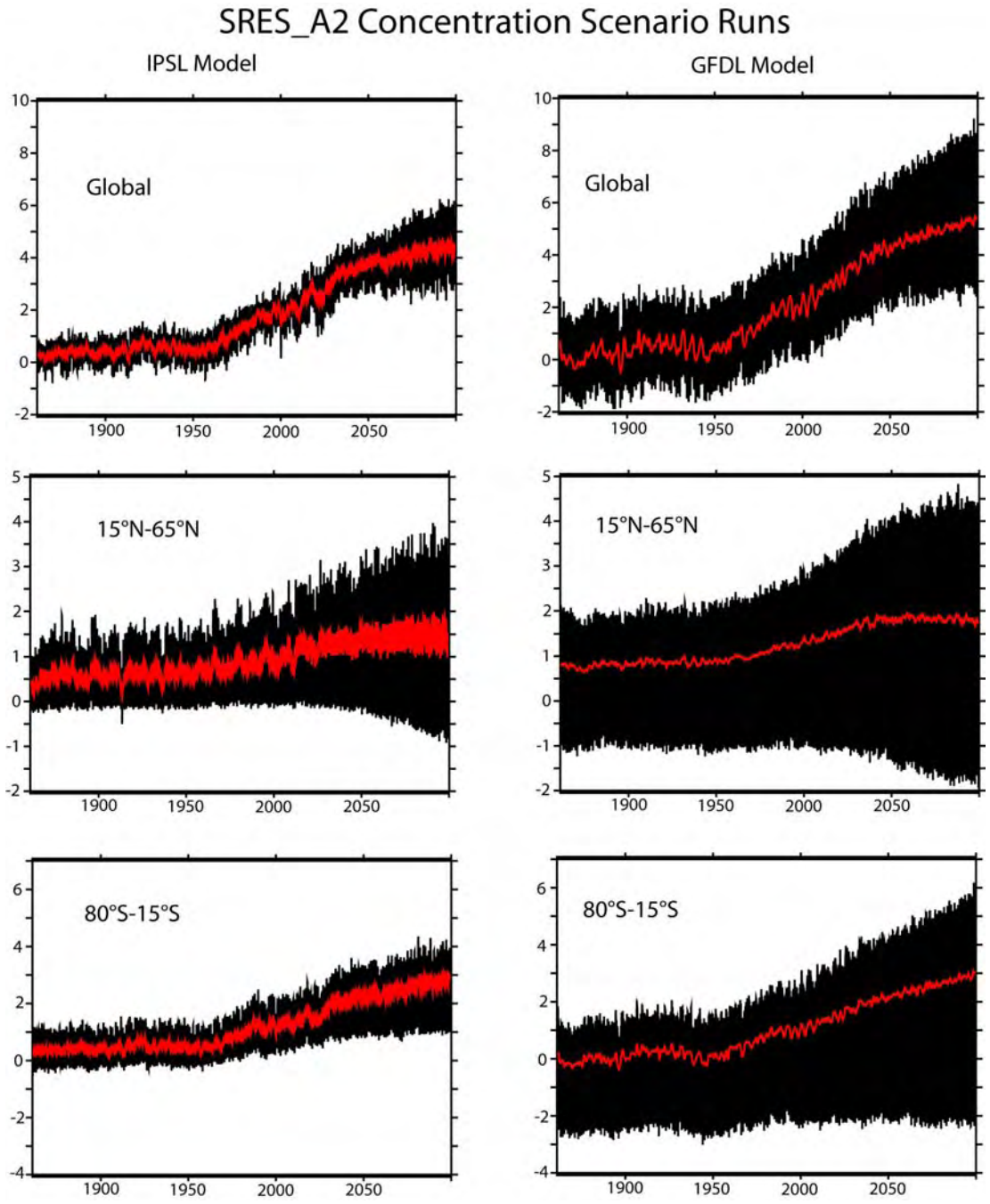


What is the spatial structure of the change in seasonality of fluxes for the "A" configuration?

Changes are clearly largest on the northern side of the subtropical gyre

What is are the structures of the changes in seasonality for SST and DIC over the North Pacific between the 1990s and 2090s?





IPSL and GFDL SRES_A2 runs

Very different behavior with seasonal cycle - seasonality much more pronounced for GFDL model

Conclusions

Large amplification of seasonal cycle in CO2 fluxes over North Pacific during 21st century - Importantly, seasonal/interannual/decadal/centennial timescales should NOT be assumed to be clearly separated

Detection implication: Need winter measurements of oceanic pCO2!!!
Current observing system has very strong bias towards summer
Summer measurements alone may result in underestimate of carbon uptake by ocean

Next step:
How is natural carbon cycle perturbed by climate change?