Ocean Carbon and Heat Variability in an Earth System Model

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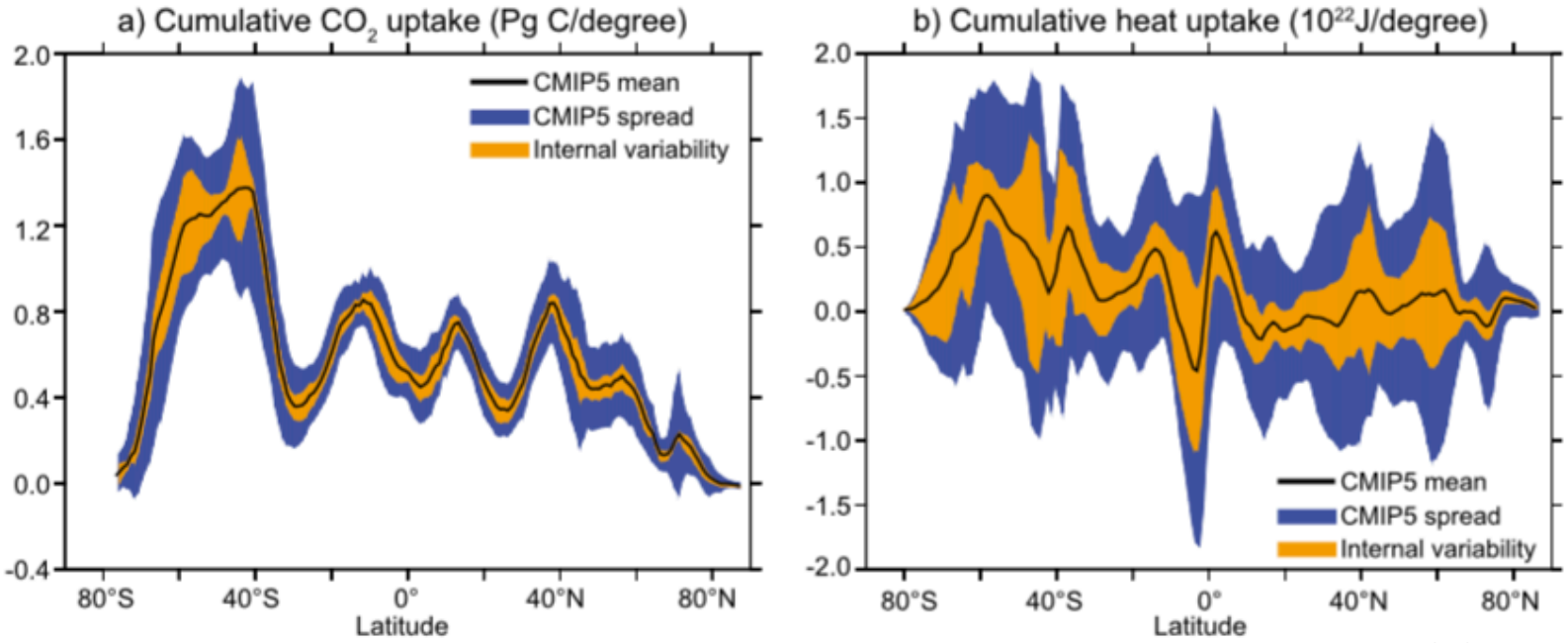
Ocean Carbon and Heat

- Heat and carbon is important in the earth system.
  - The ocean is the largest reservoir of carbon on short timescales.

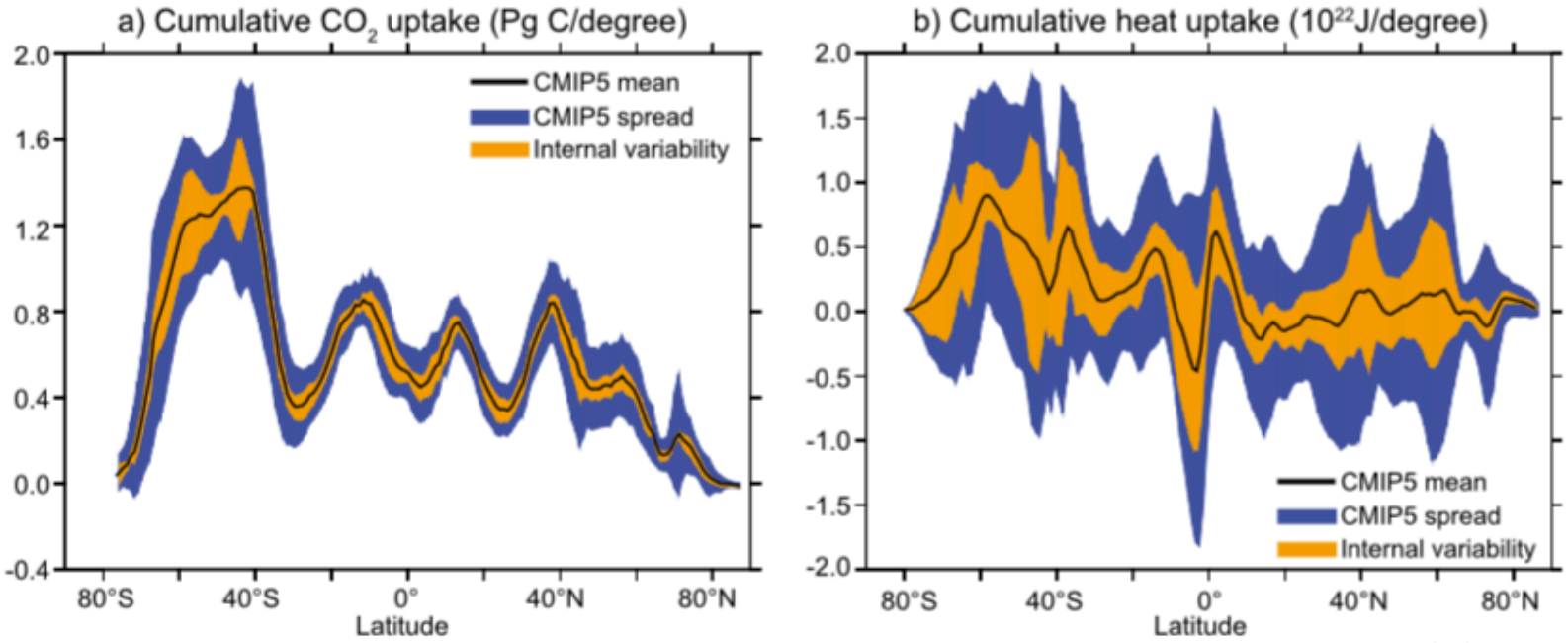
- Most of the heat and carbon that enter the ocean does so in the Southern Ocean (Frölicher et al, 2015; Sabine et al, 2005).
  - Reasonable to speculate that the ozone hole could affect the amount and rate of carbon and heat uptake by the ocean.

Ocean Carbon and Heat



Frölicher et al., 2015

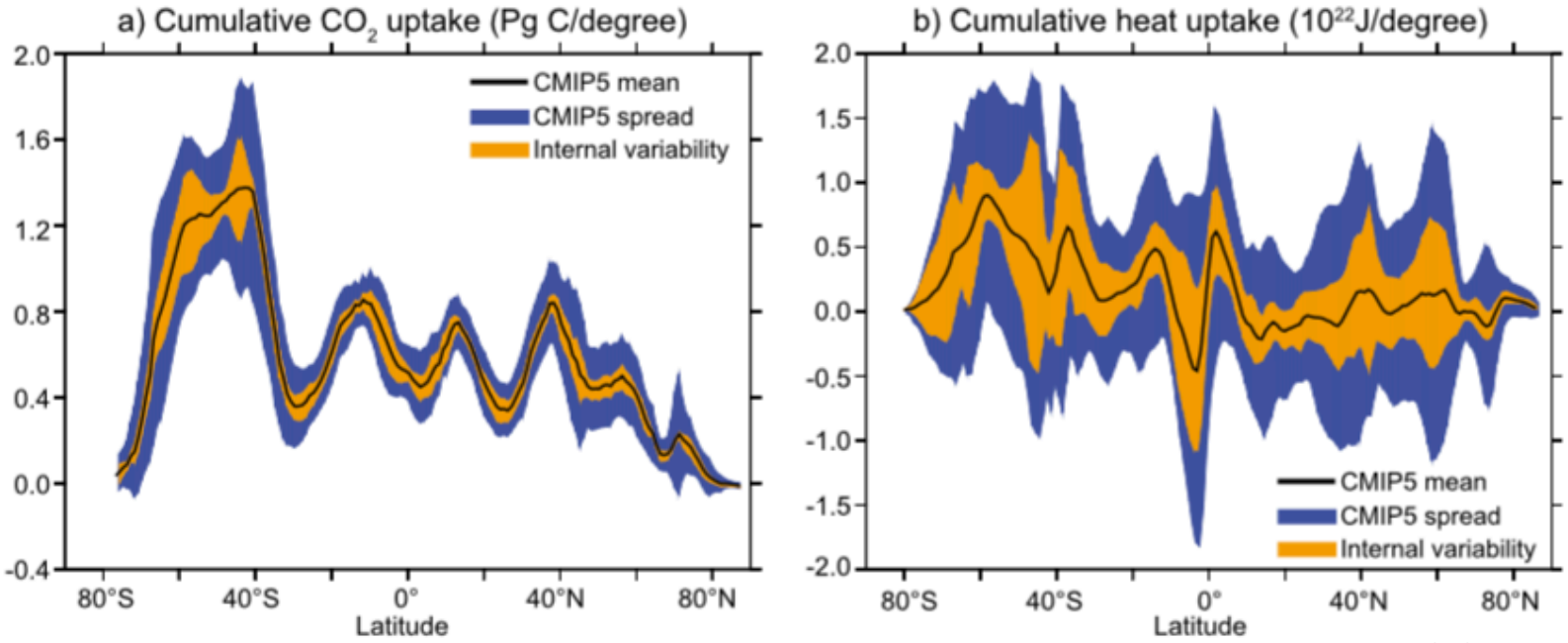
Ocean Carbon and Heat



Frölicher et al., 2015

- High anthropogenic carbon uptake in Southern Ocean.
- High anthropogenic heat uptake in Southern Hemisphere.

Ocean Carbon and Heat



Frölicher et al., 2015

- High anthropogenic carbon uptake in Southern Ocean.
- Decent agreement among models.

- High anthropogenic heat uptake in Southern Hemisphere.
- Not good agreement among models.

Ocean Carbon and Heat

- What is ocean carbon and heat doing in our model?
- How does Weddell Sea deep convection change ocean carbon and heat?

GFDL ESM2Mc

- A coarse-resolution version of GFDL ESM2M (*Dunne et al., 2012*).
  - Atmospheric resolution of 3.875° x 3° with 24 vertical levels.
  - Ocean resolution of 3° x 1.5° with 28 vertical levels.
- Complex biogeochemistry model (BLING) and tracers.
- Full list of specifications in *Galbraith et al. (2011*).

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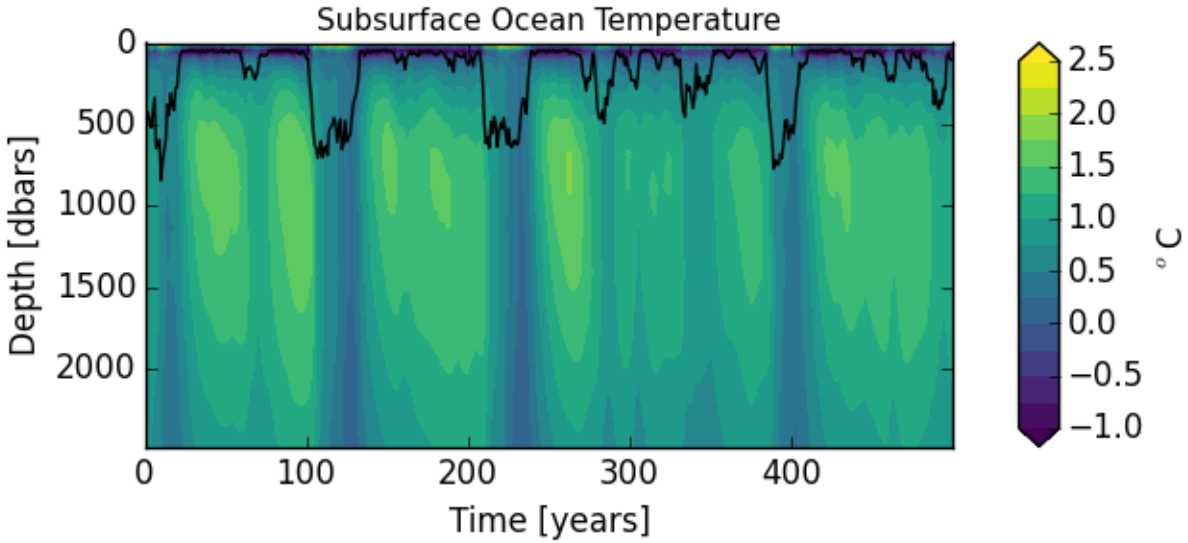
- Complex biogeochemistry model (BLING) and tracers.
- Full list of specifications in *Galbraith et al. (2011*).

- Pre-industrial control model simulation to asses natural variability.

GFDL ESM2Mc

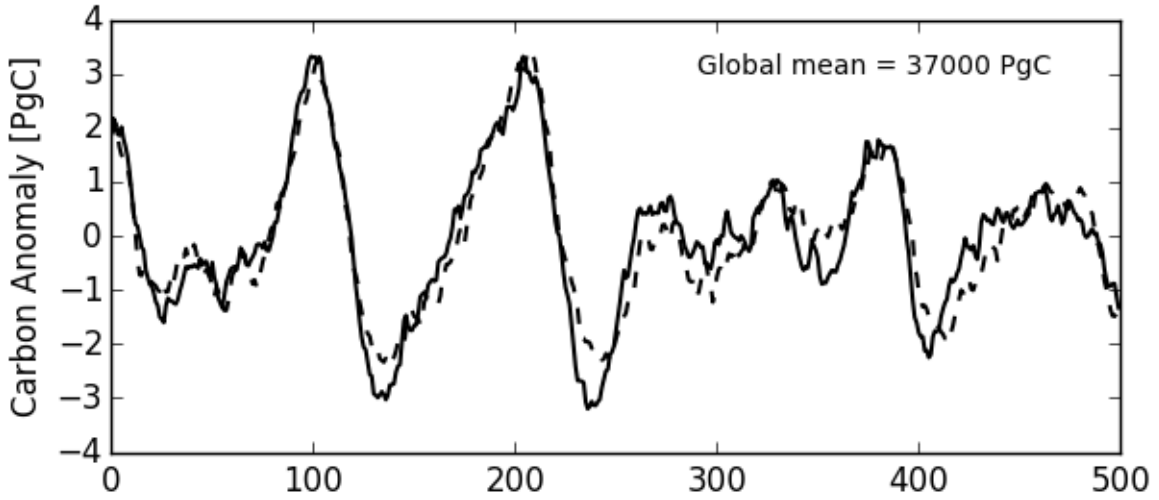
- Intense convective variability in the Weddell Sea.



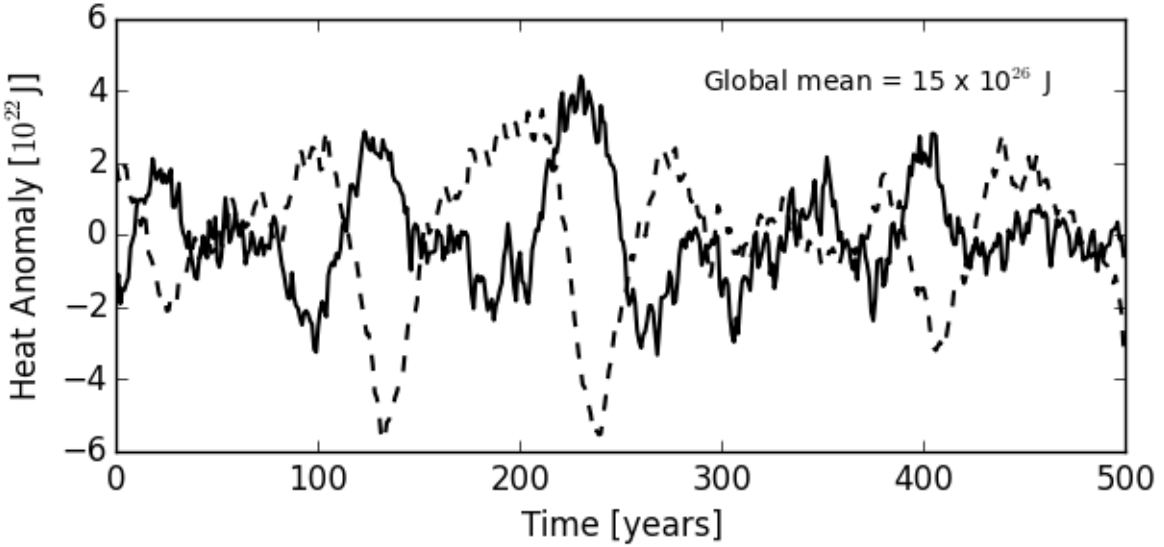
Consistent with:

Bernadello et al., 2015
Martin et al., 2012

Ocean Carbon Content:

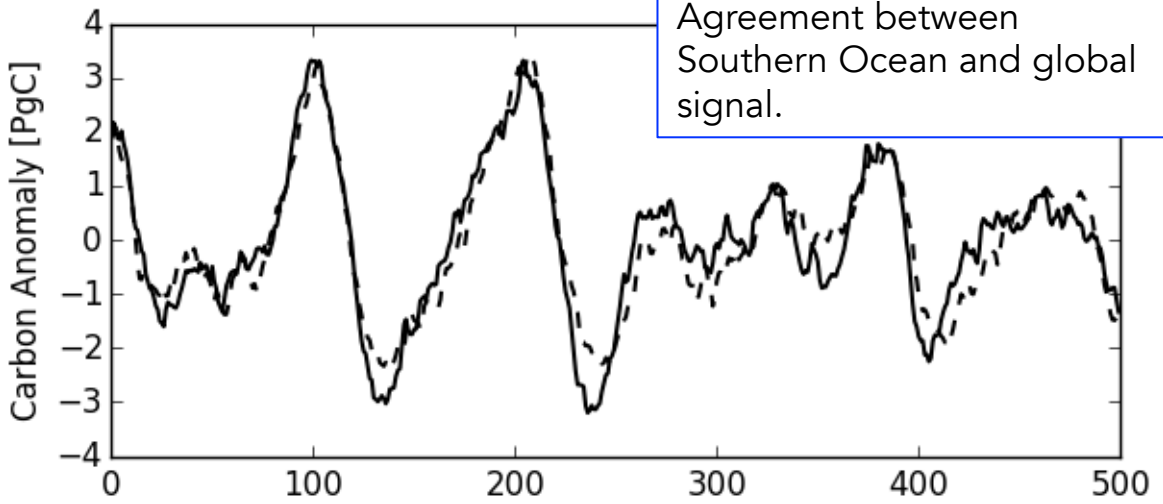


Ocean Heat Content:



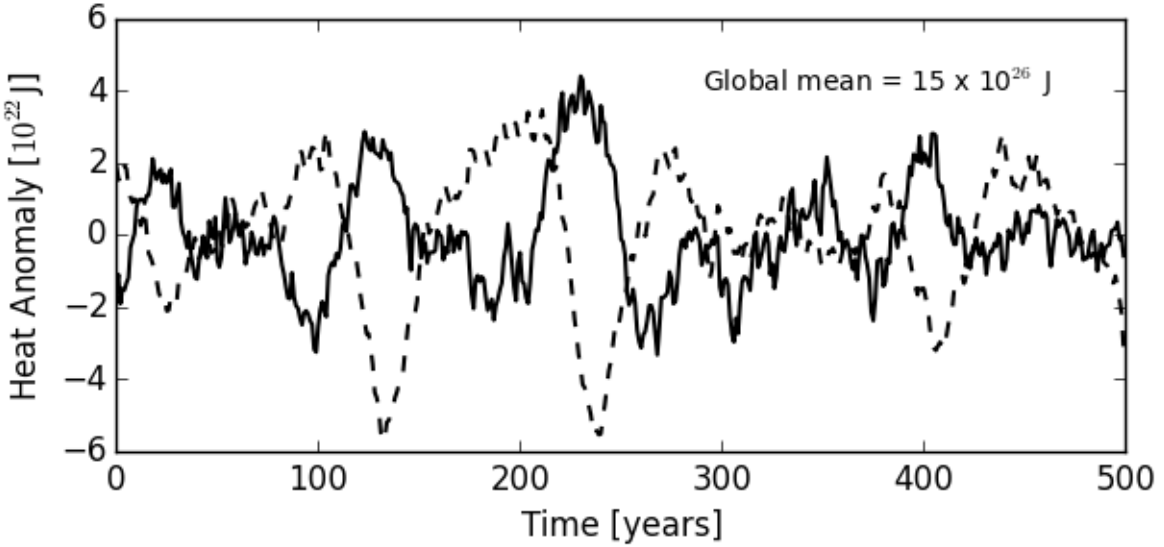
Solid = global
Dashed = Southern Ocean

Ocean Carbon Content:



Agreement between Southern Ocean and global signal.

Ocean Heat Content:



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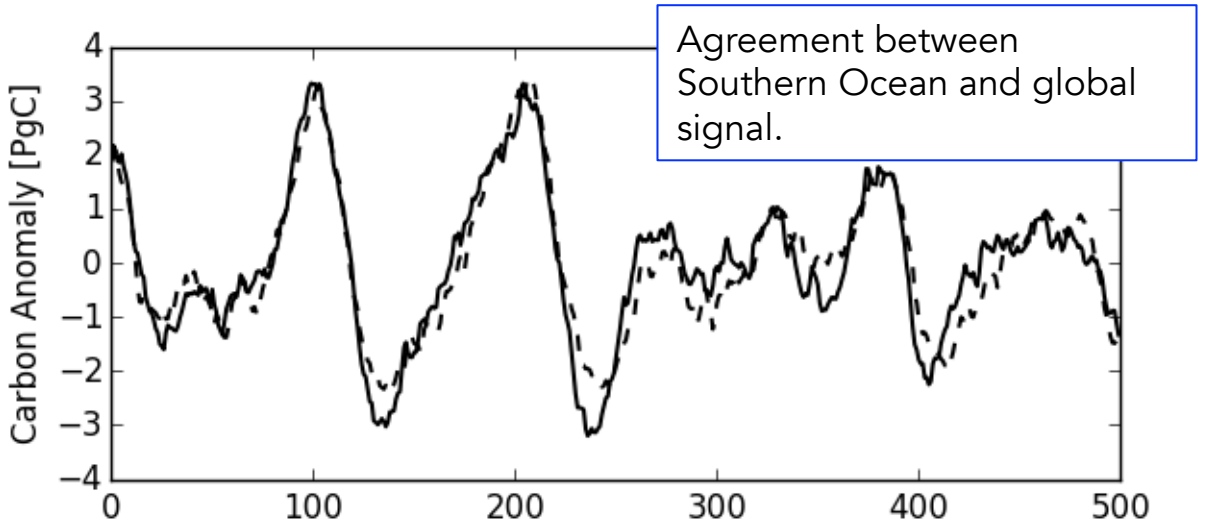

Agreement between Southern Ocean and global signal.

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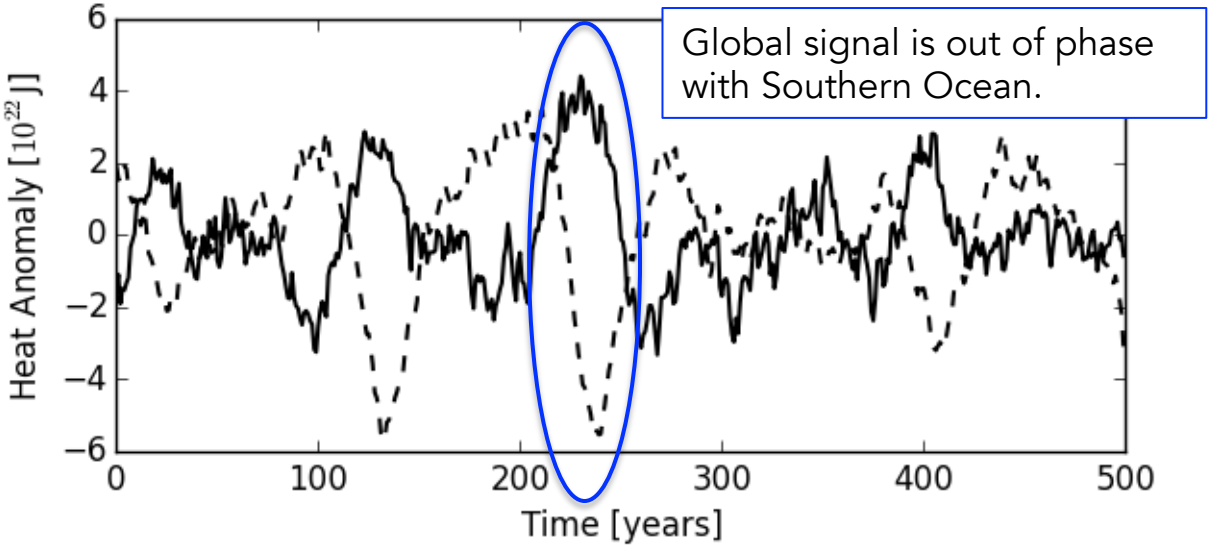
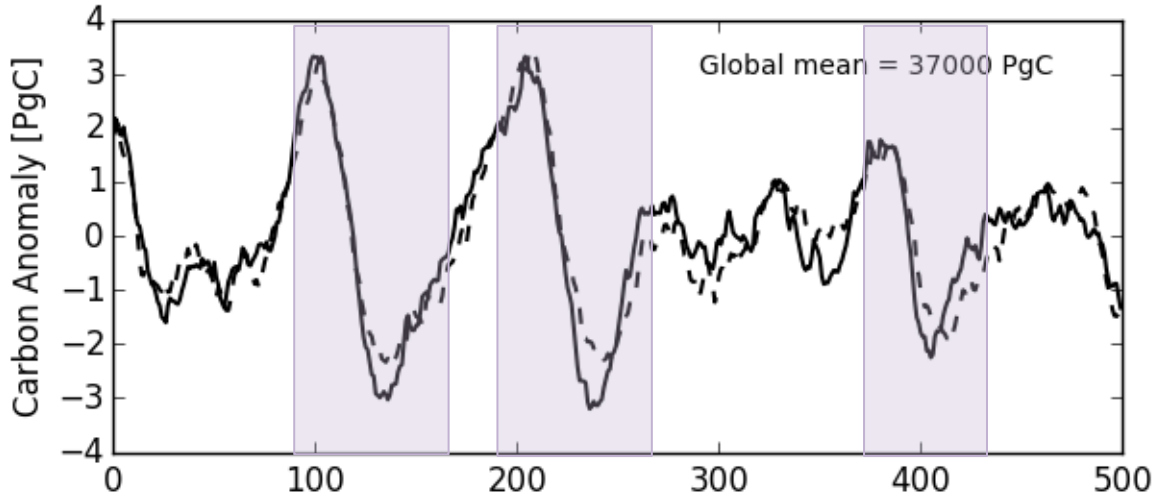


Global signal is out of phase with Southern Ocean.

Solid = global
Dashed = Southern Ocean

Ocean Carbon Content:



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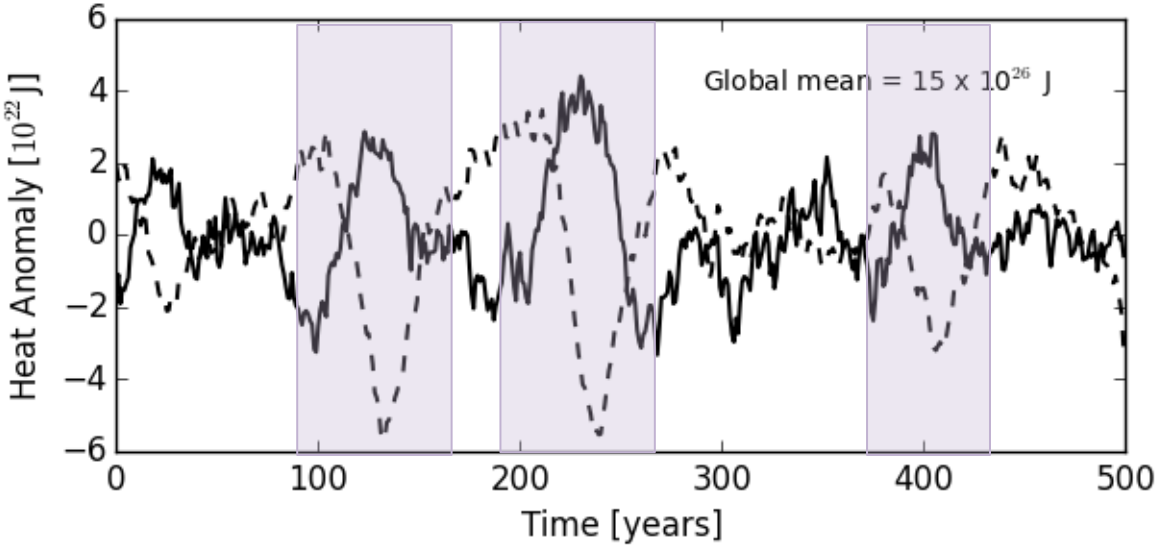

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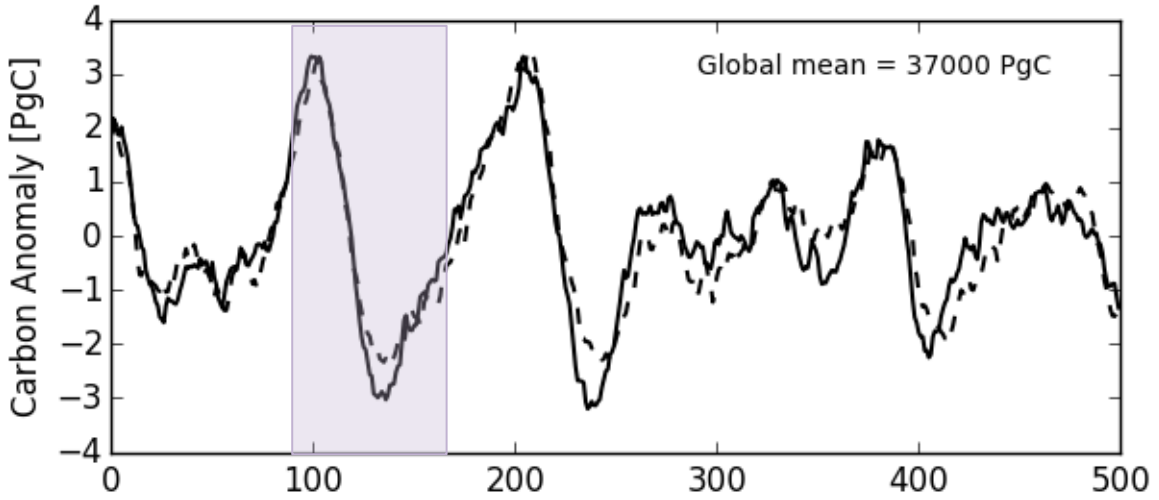

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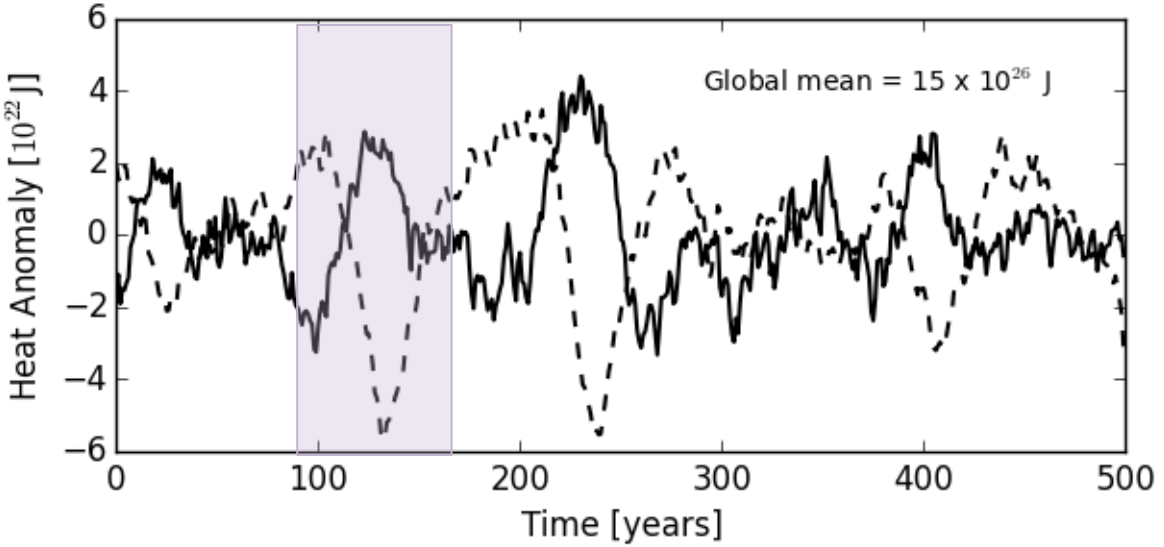

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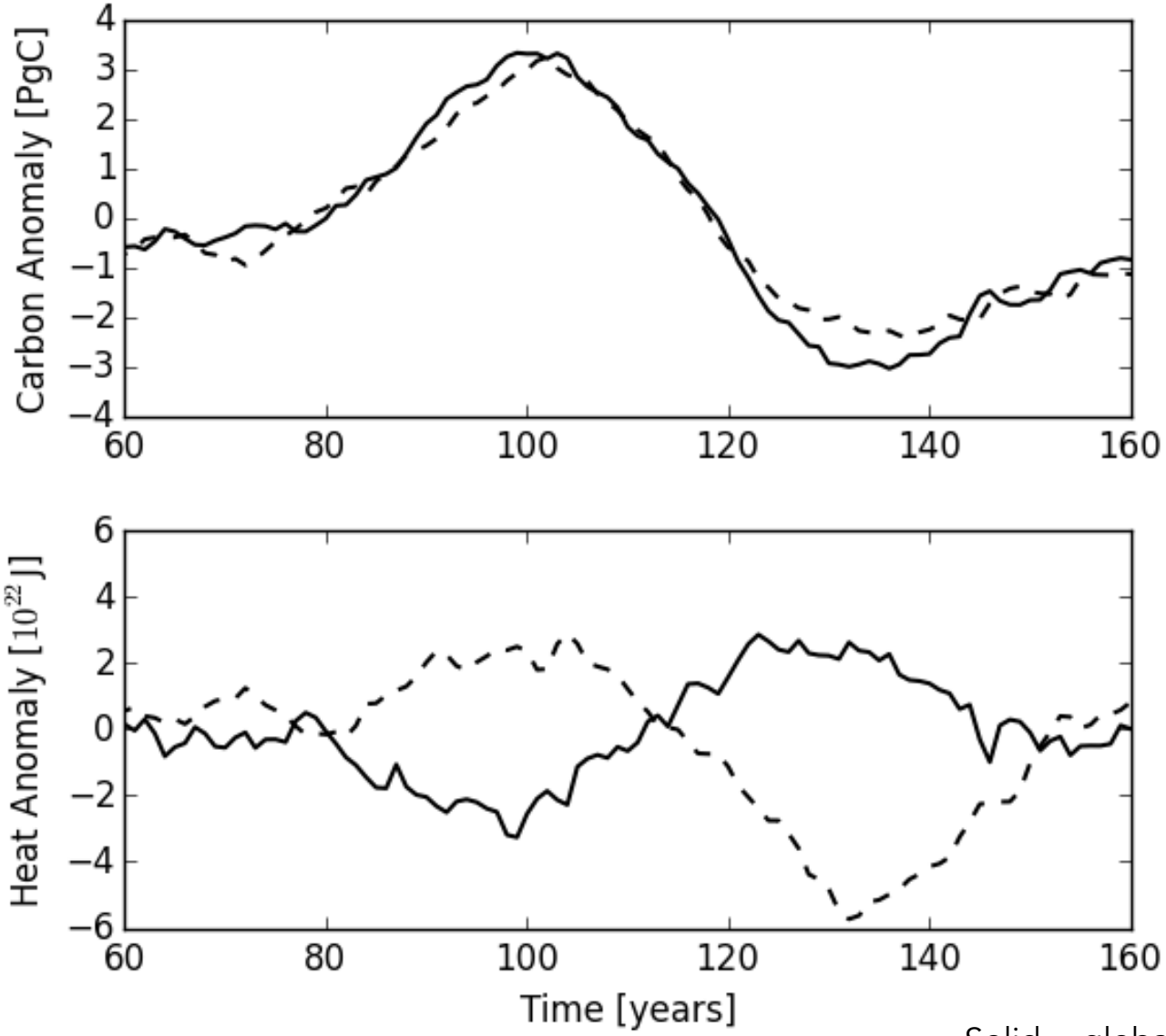

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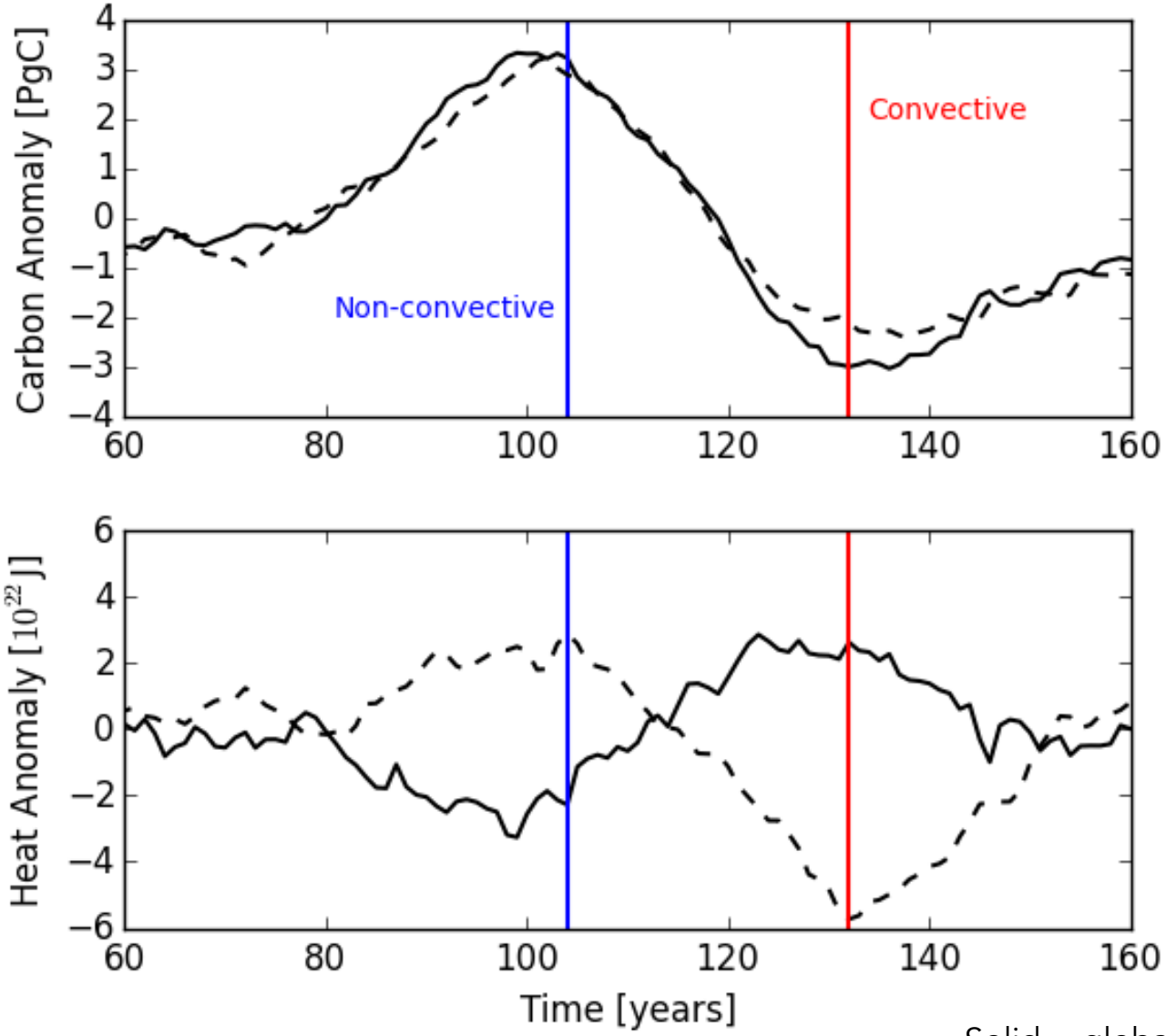
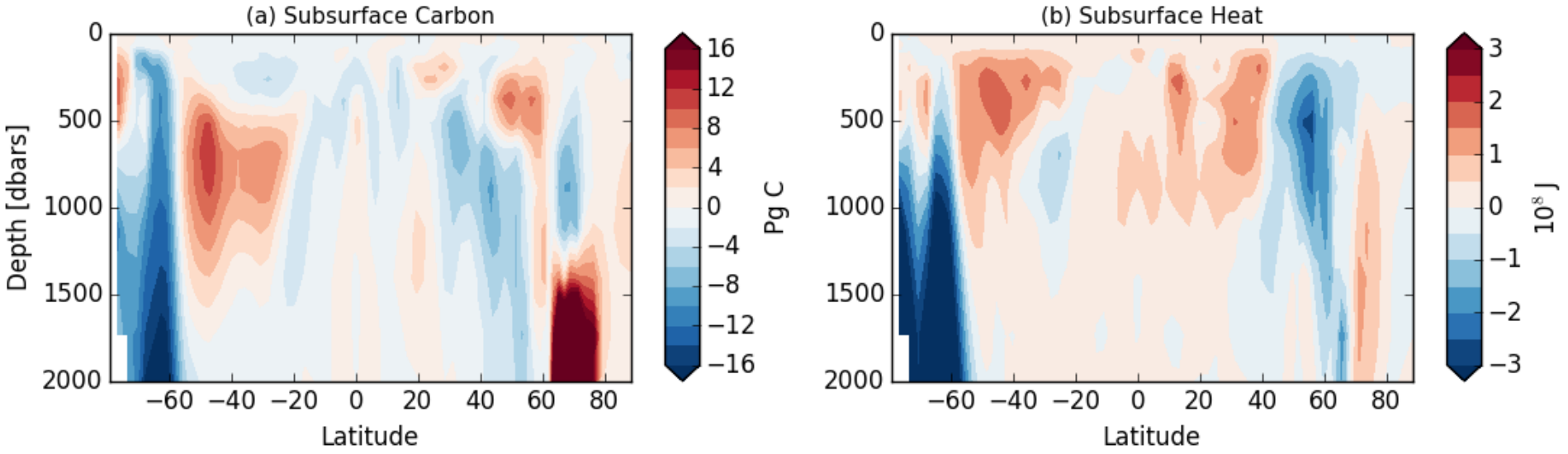
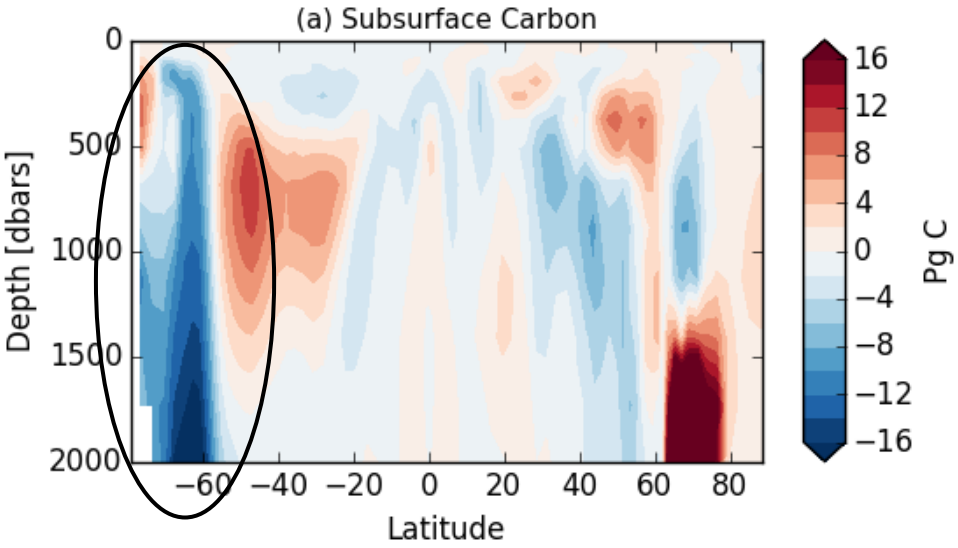
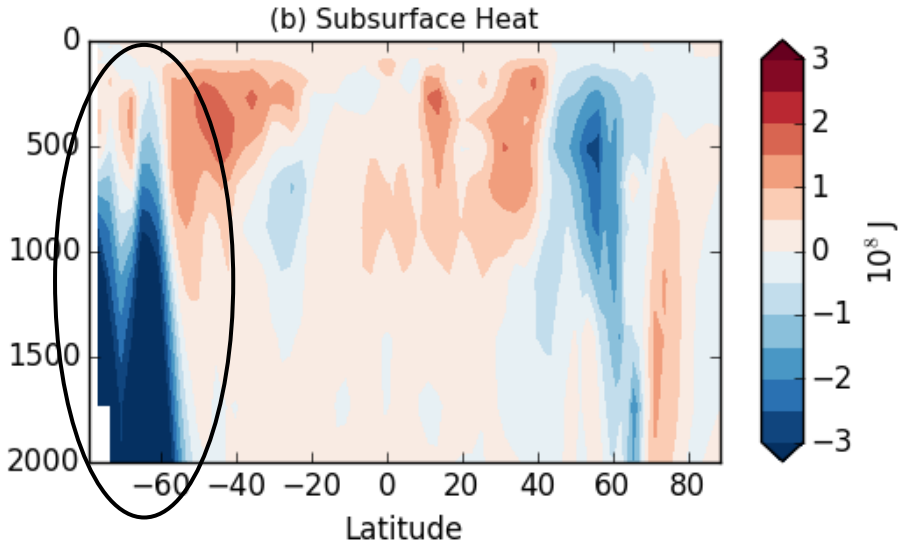


Solid = global
Dashed = Southern Ocean

convective – non-convective

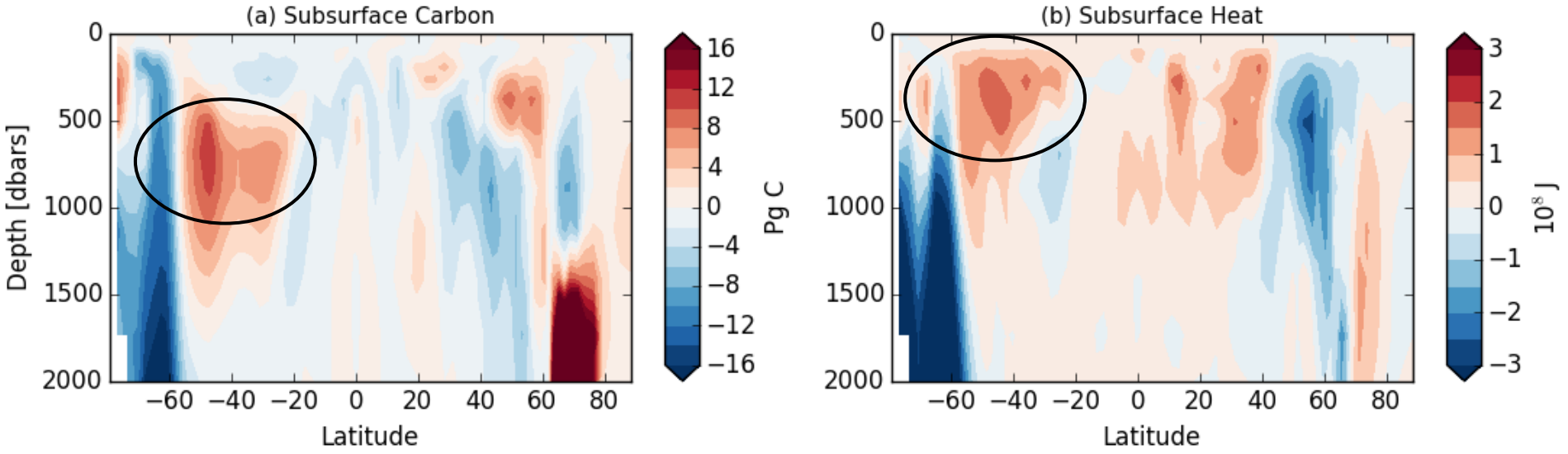






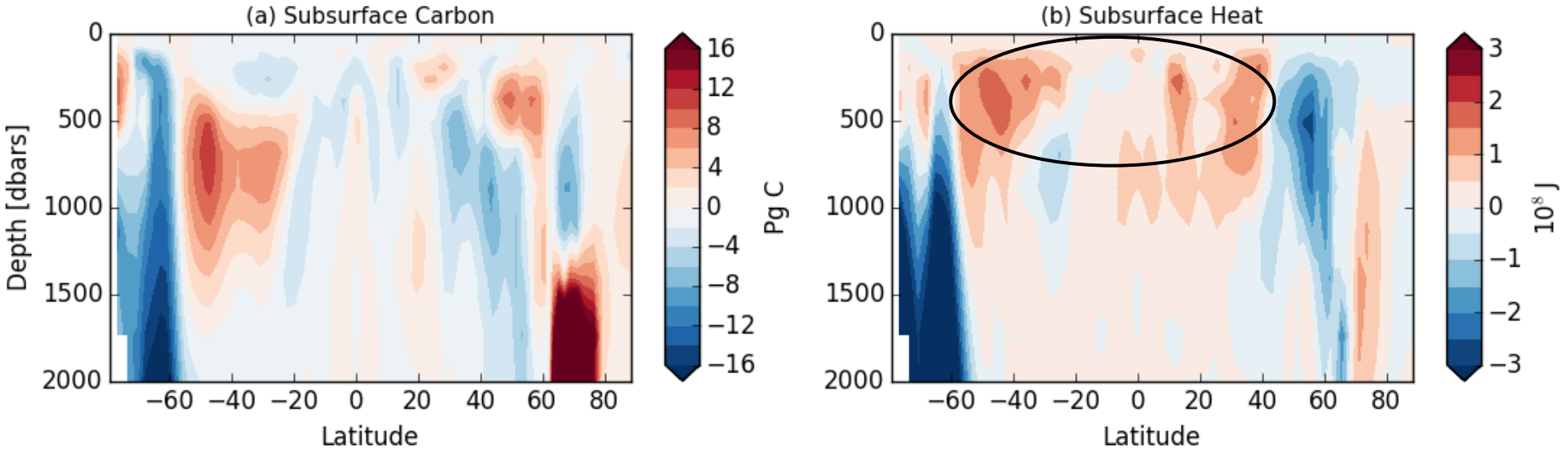
During Convection:

- Southern ocean depletion of carbon and heat



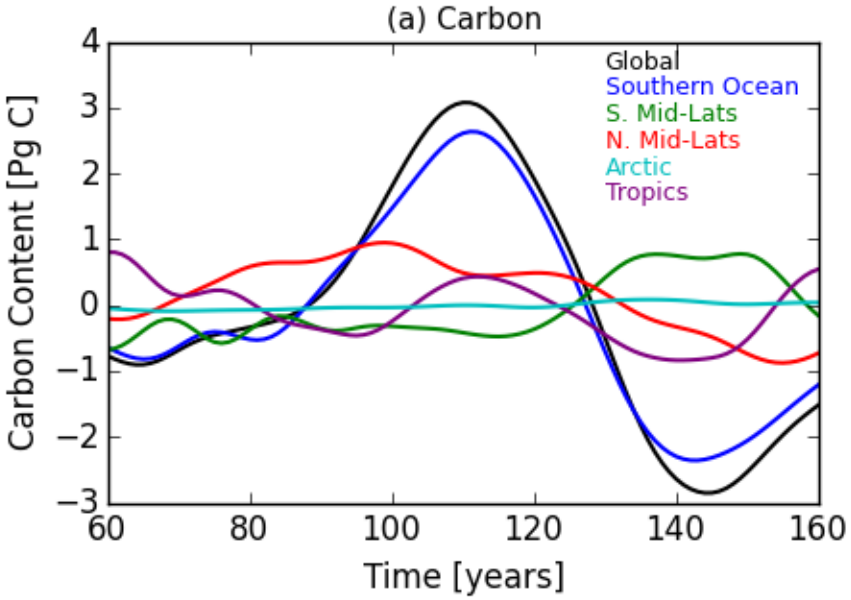
During Convection:

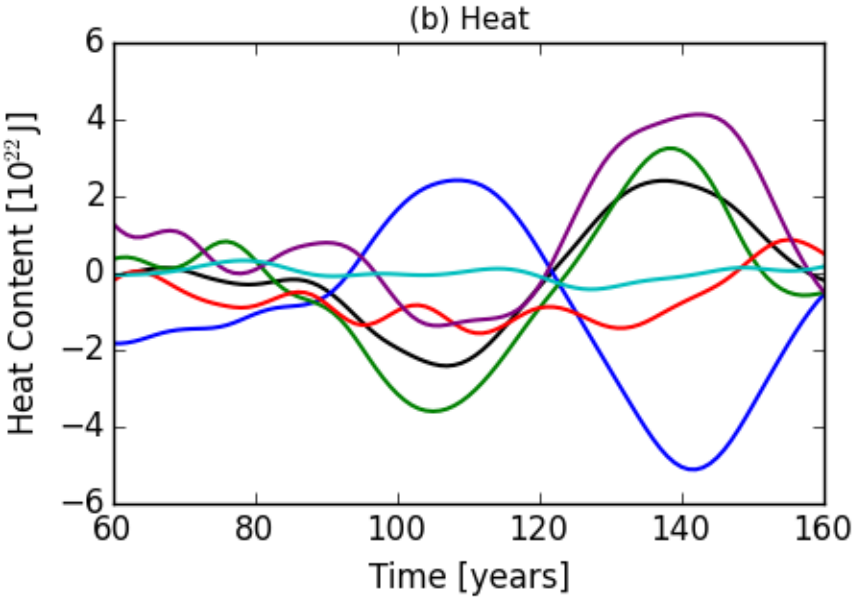
- Southern ocean depletion of carbon and heat
- Mid-latitude increase in carbon and heat – at different depths

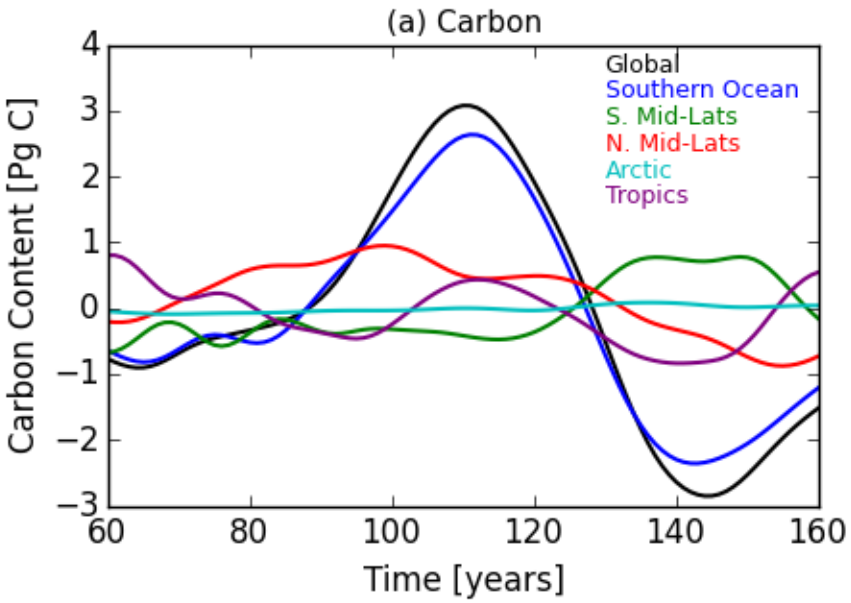


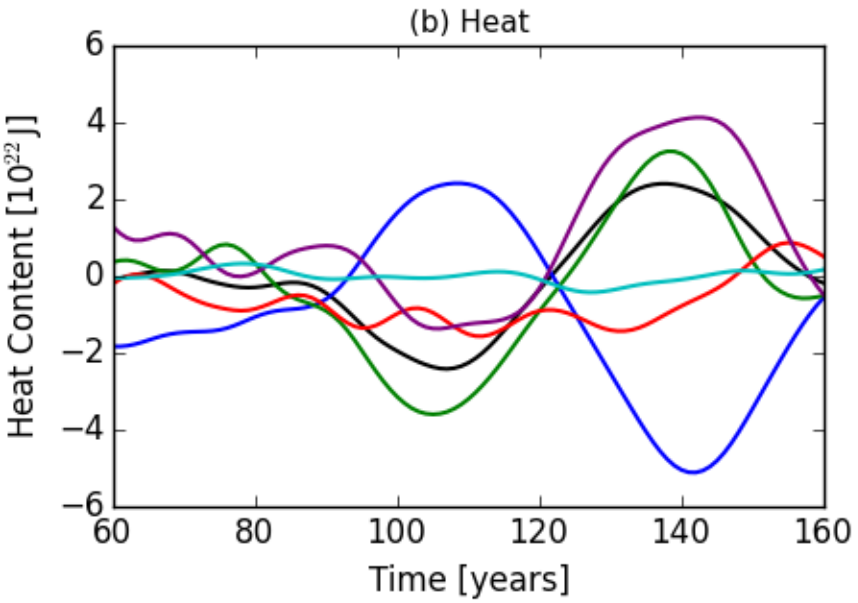
During Convection:

- Southern ocean depletion of carbon and heat
- Mid-latitude increase in carbon and heat – at different depths
- Large scale surface warming

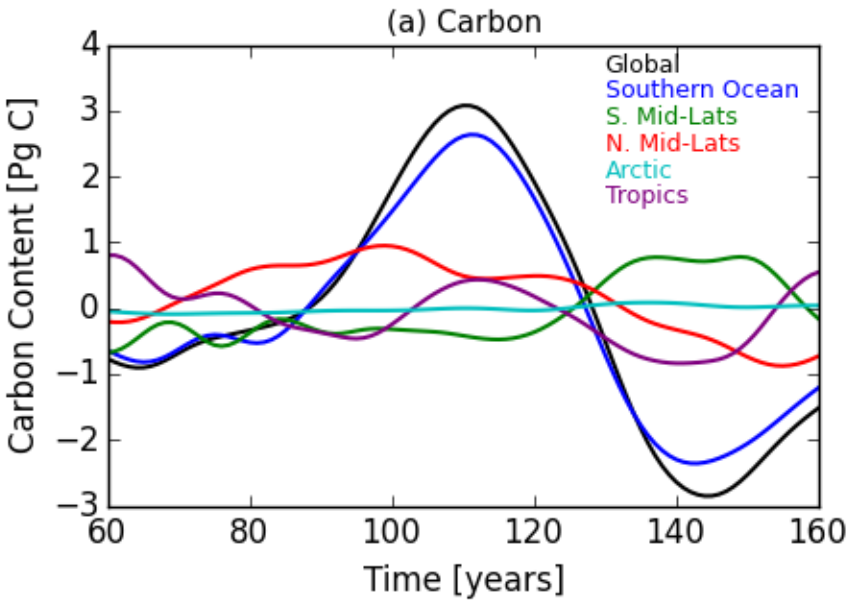

(a) Carbon
Carbon Content [Pg C]
Time [years]
Global
Southern Ocean
S. Mid-Lats
N. Mid-Lats
Arctic
Tropics
4
3
2
1
0
−1
−2
−3
60
80
100
120
140
160

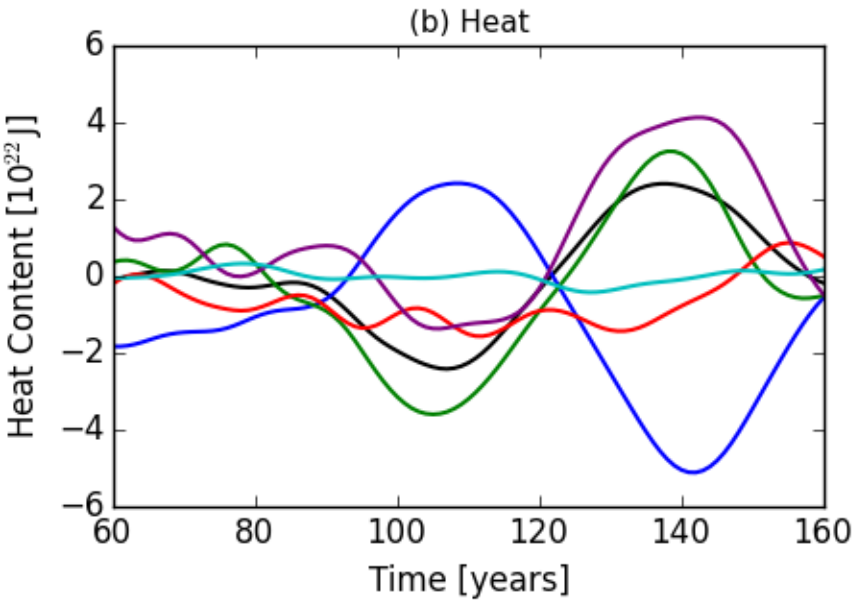

(b) Heat
Heat Content [10^{22} J]
Time [years]
6
4
2
0
−2
−4
−6
60
80
100
120
140
160





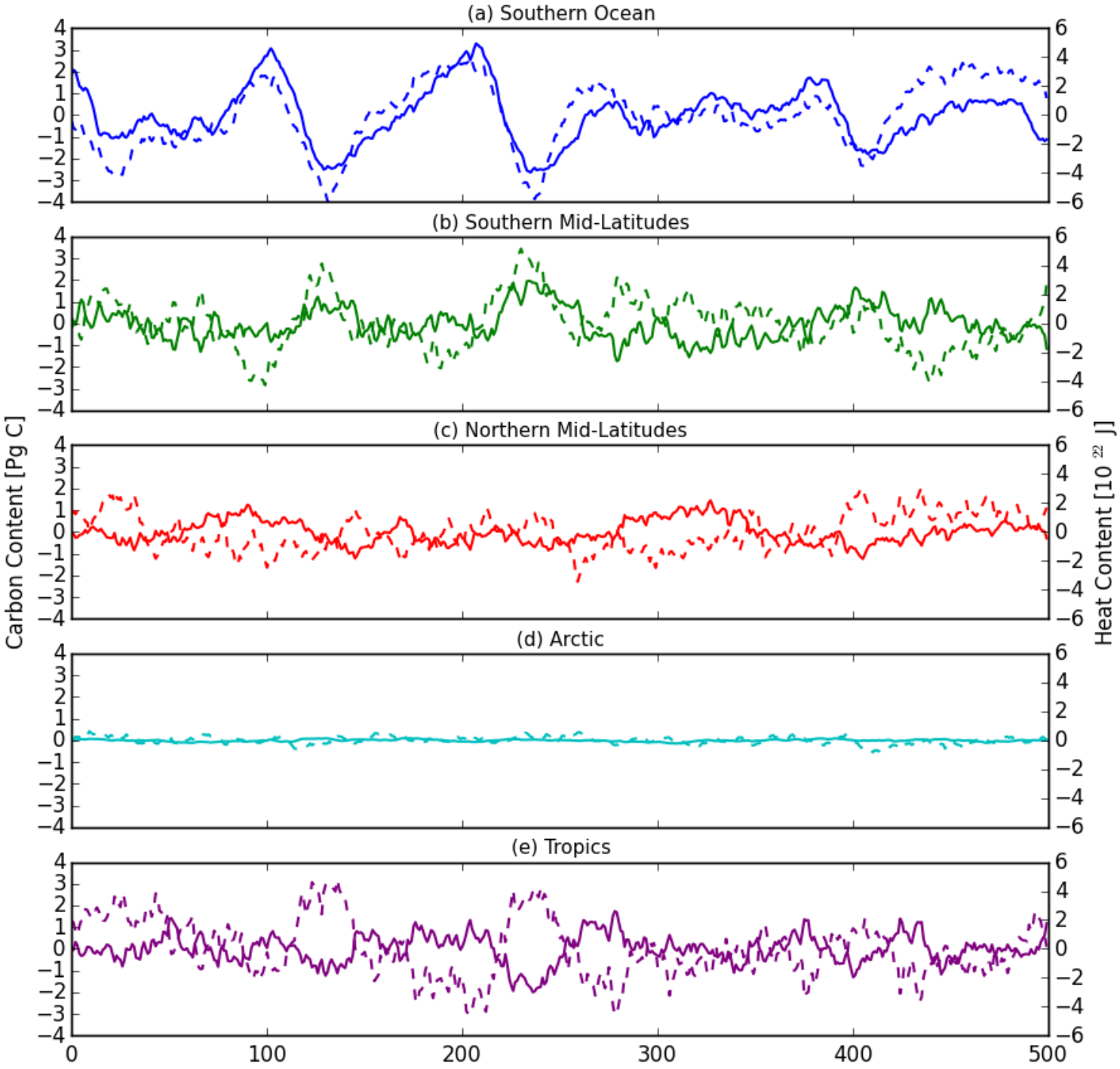
- Southern Ocean dominates variability over the convective cycle.





- Southern Ocean dominates variability over the convective cycle.

- Southern Ocean out of phase with global heat content.
- Tropics and N. mid-latitudes contribute to the heat content increase seen in the global signal.



Solid = carbon content
Dashed = heat content

- Global carbon content is dominated by Southern Ocean variability

- Global heat content is out of phase with the Southern Ocean.
  - Warming in **tropics** and Southern Hemisphere mid-latitudes.

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Does this relation hold with different convective variability?

What causes tropical and mid-latitude warming during convection?

A_{redi} = 400 m^2s^{-1}: **Low Aredi**

very regular, distinct convective events.

A_{redi} = 800 m^2s^{-1}: **Control**

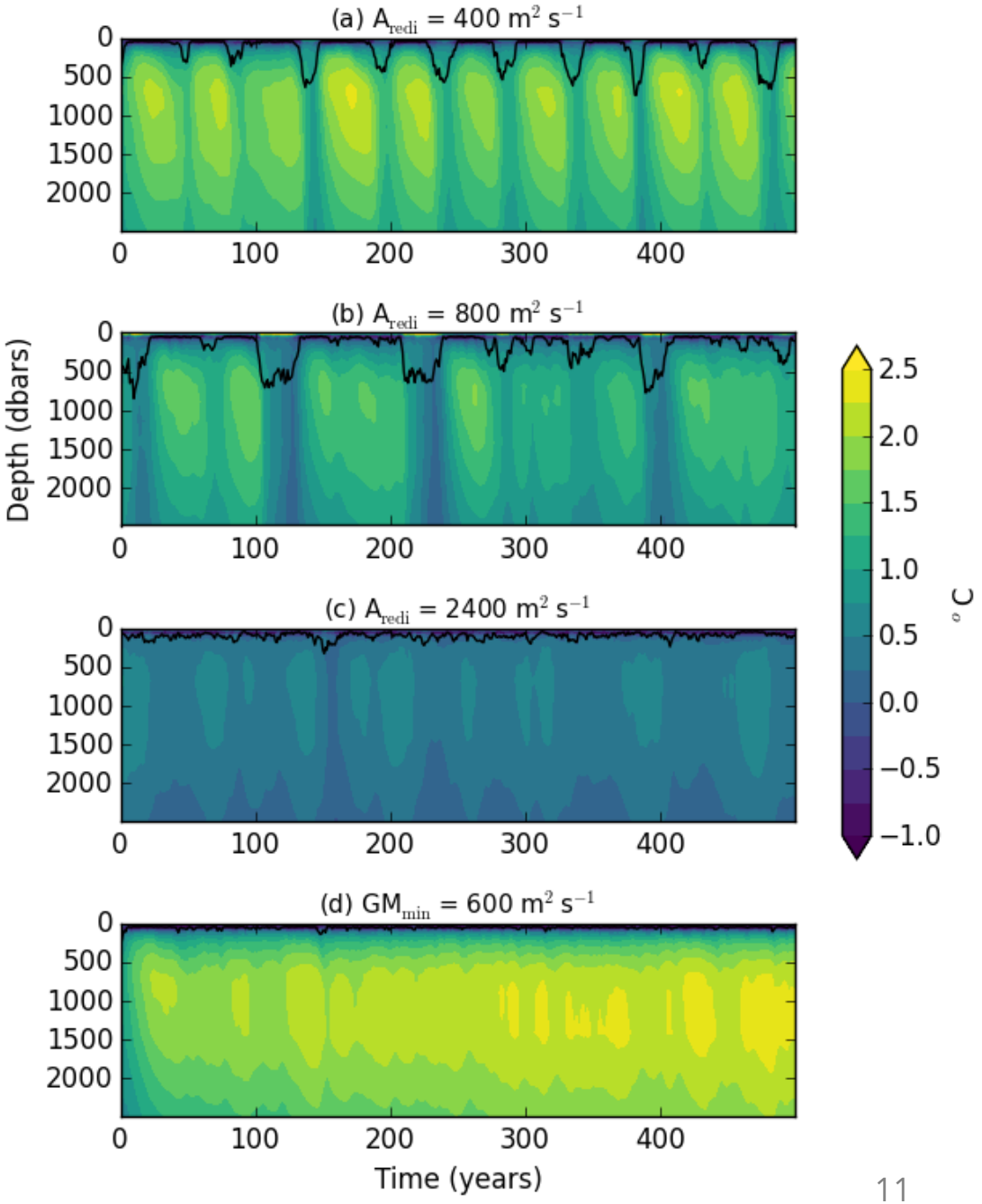
Sporadic strong convective events

A_{redi} = 2400 m^2s^{-1}: **High Aredi**

Constantly convecting

Gm_{min} = 600 m^2s^{-1}: **High GM**

No Convection



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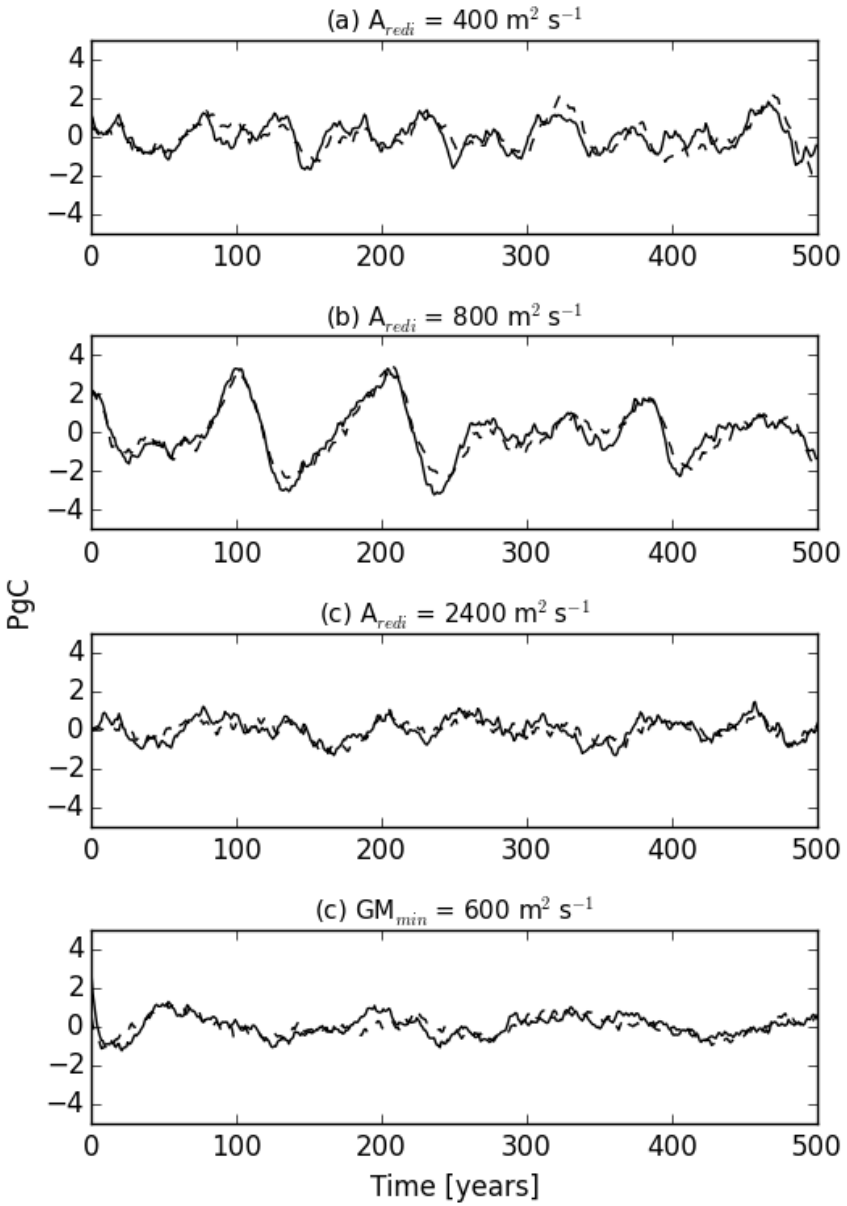

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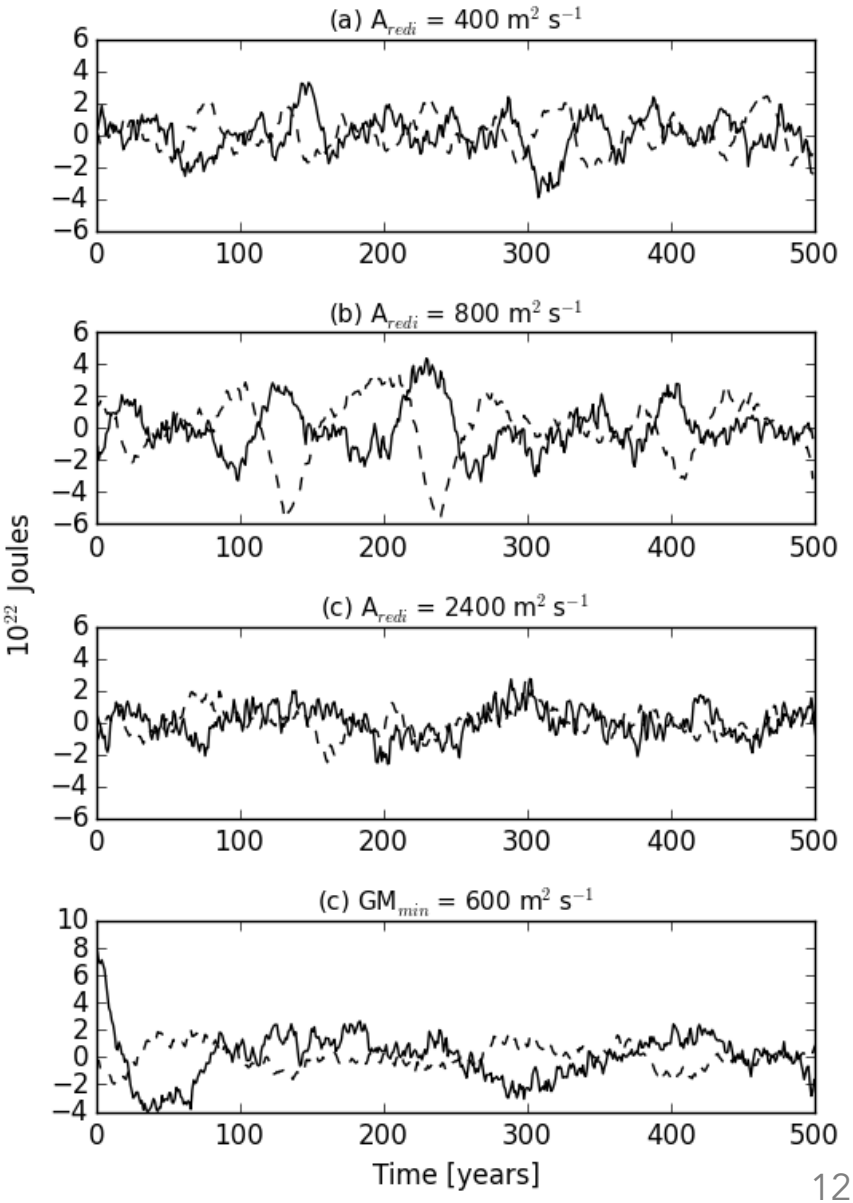


What causes warming in Southern Hemisphere Mid-latitudes and Tropics?

- Strong warming at the surface suggests atmospheric feedback.

- Possible Hypothesis:
  - Heat release in Weddell Sea during convection increases sea surface temperature.
  - Increase in sea surface temperature then increases atmospheric water vapor content, thus causing an increase in greenhouse effect.
  - Warms the upper layer of ocean surface.

Is there an increase in the Greenhouse effect during convection?

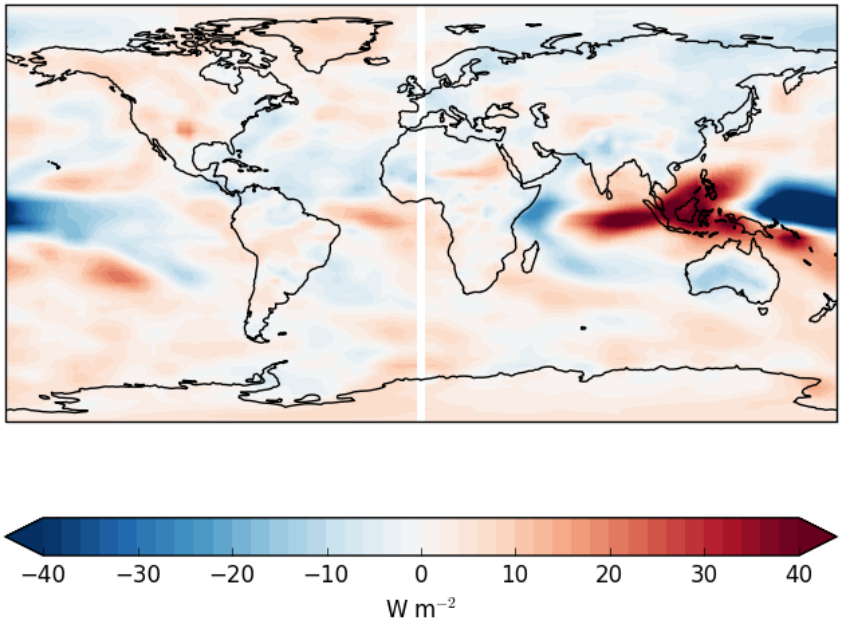
$$G = E - F$$

- G = strength of the Greenhouse Effect
- E = Longwave flux emitted by the Earth's surface
- F = Longwave flux leaving the Earth at the top of the atmosphere.

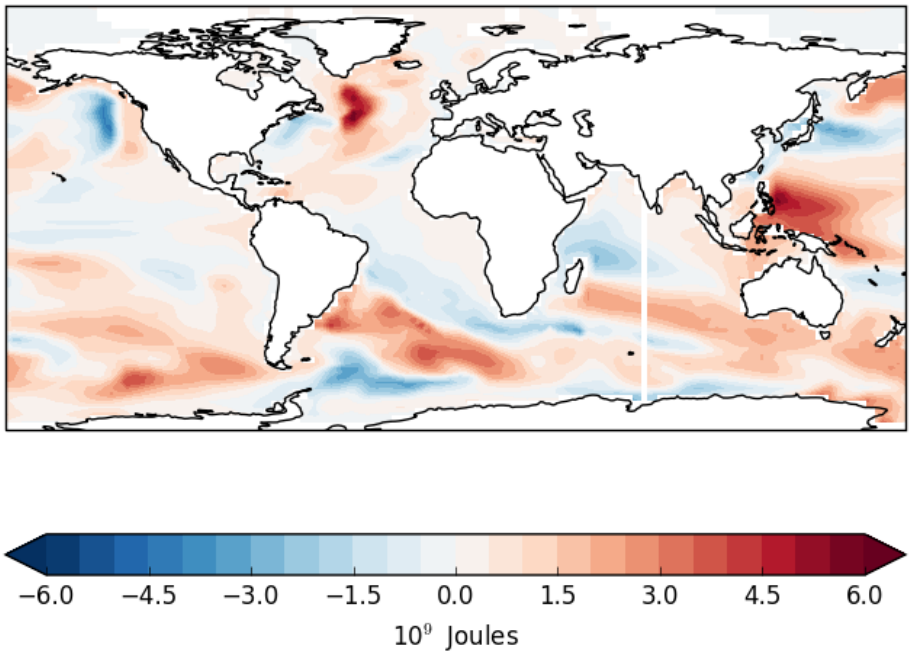
Is there an increase in the Greenhouse effect during convection?

$$G = E - F$$

(a) Greenhouse Strength



(b) OHC top 1000m



Same spatial pattern holds for all 3 convective events.

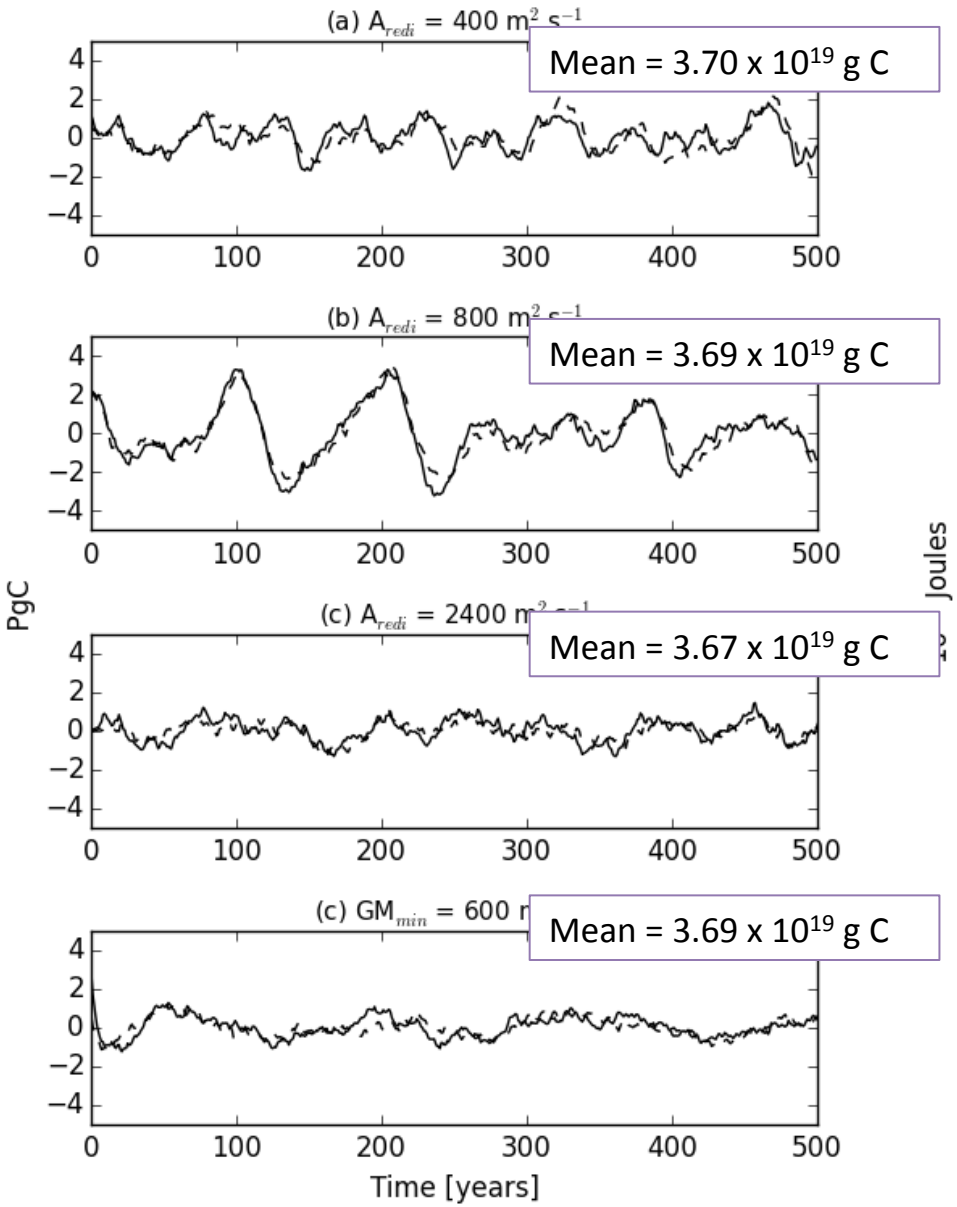
Is there an increase in the Greenhouse effect during convection?

- Evidence for increase in Greenhouse effect strength during convection – especially over Indonesia.
- Doesn't explain surface water temperature increase in Southern Ocean.
- Still need to investigate this hypothesis further.
  - Water vapor content.
  - Surface air temperature.

Summary

- In ESM2Mc, Weddell Sea deep convection dominates the natural variability in heat and carbon content.
- These deep convective events result in a decrease in global carbon content, but an increase in global heat content.
  - Increase in heat content due to increase in tropical surface heat.
  - This pattern is consistent across model runs with different convective variability.
  - Still uncertain about cause of tropical variability.

Ocean Carbon Content:



Ocean Heat Content: