Timescales and mechanisms of change in the ocean carbon sink

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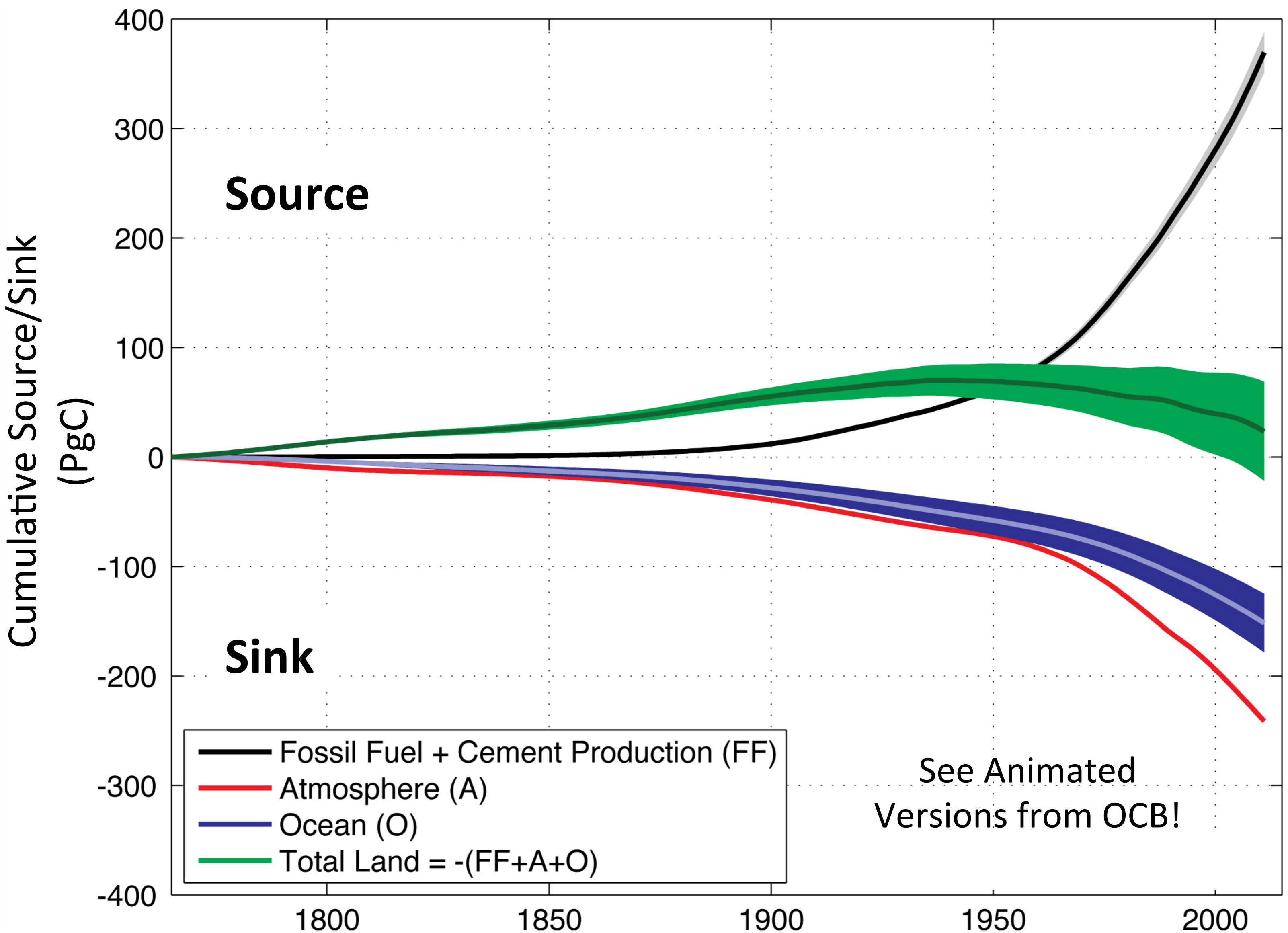
Carbon Hot Spots

Monterey, CA

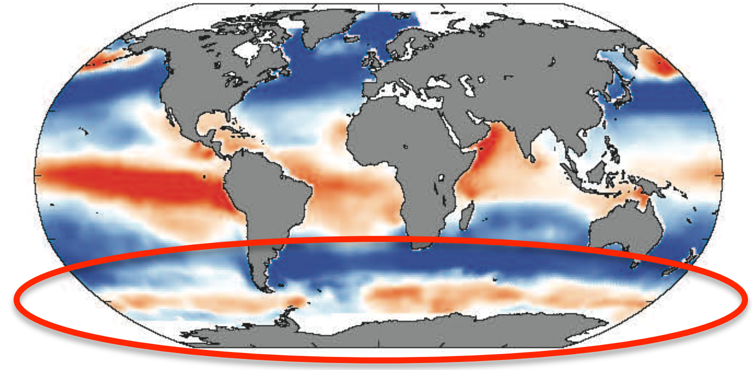
September 25-26, 2017

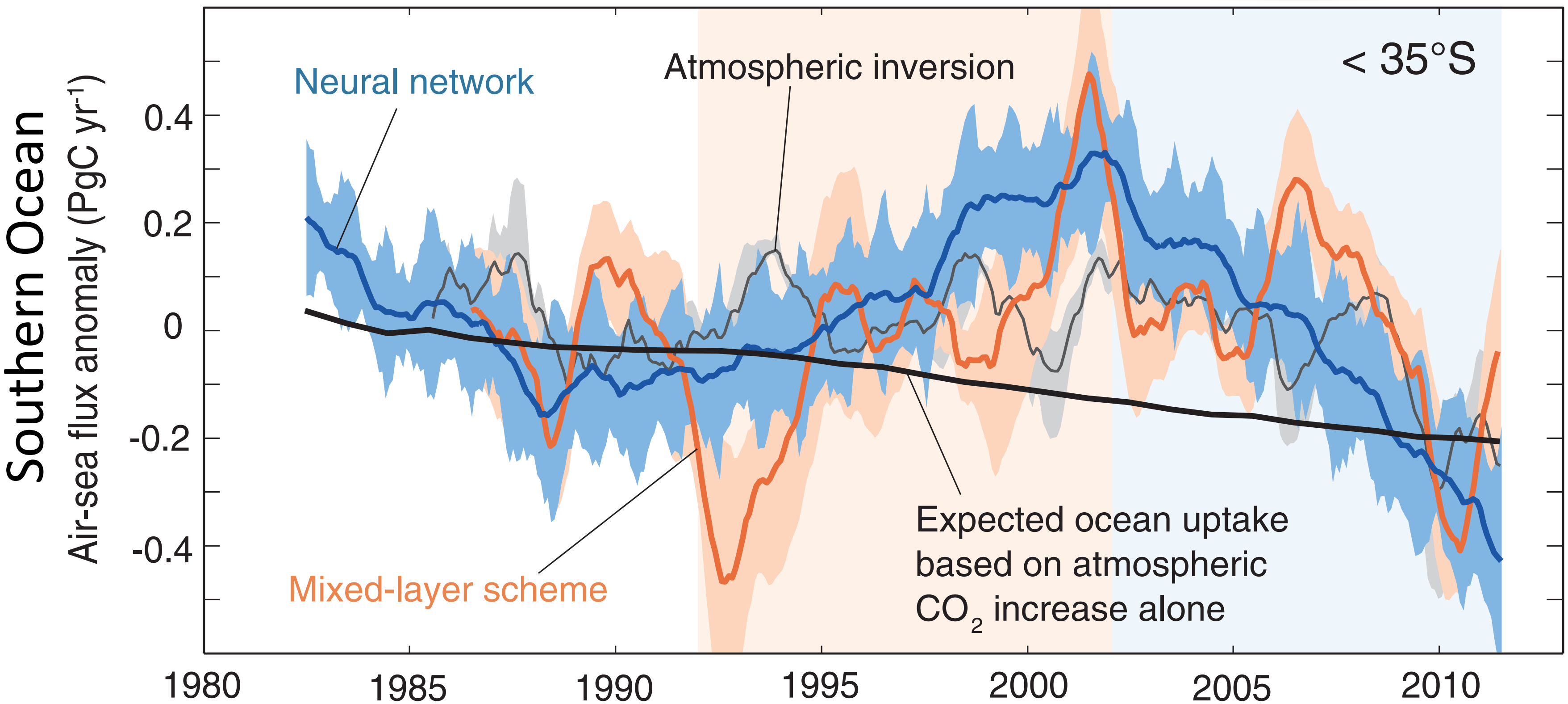
Temporal evolution of carbon accumulation



Khatiwala et al. 2009,2013; *McKinley* et al. 2017

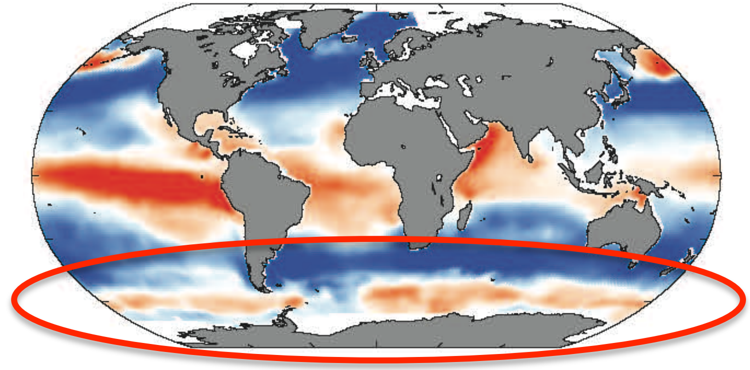
CO_2 sink variability from gap-filled pCO_2

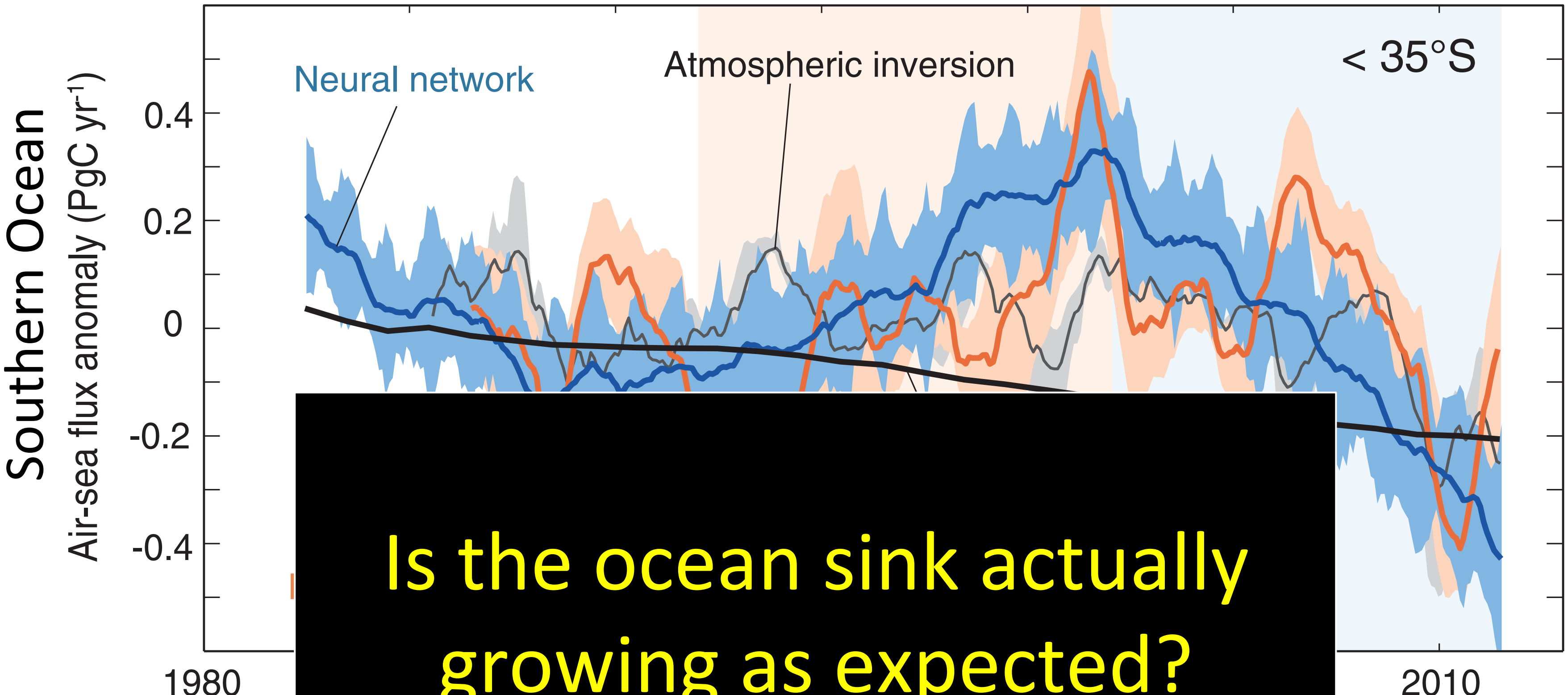




Landschützer et al. 2015 Science

CO_2 sink variability from gap-filled pCO_2



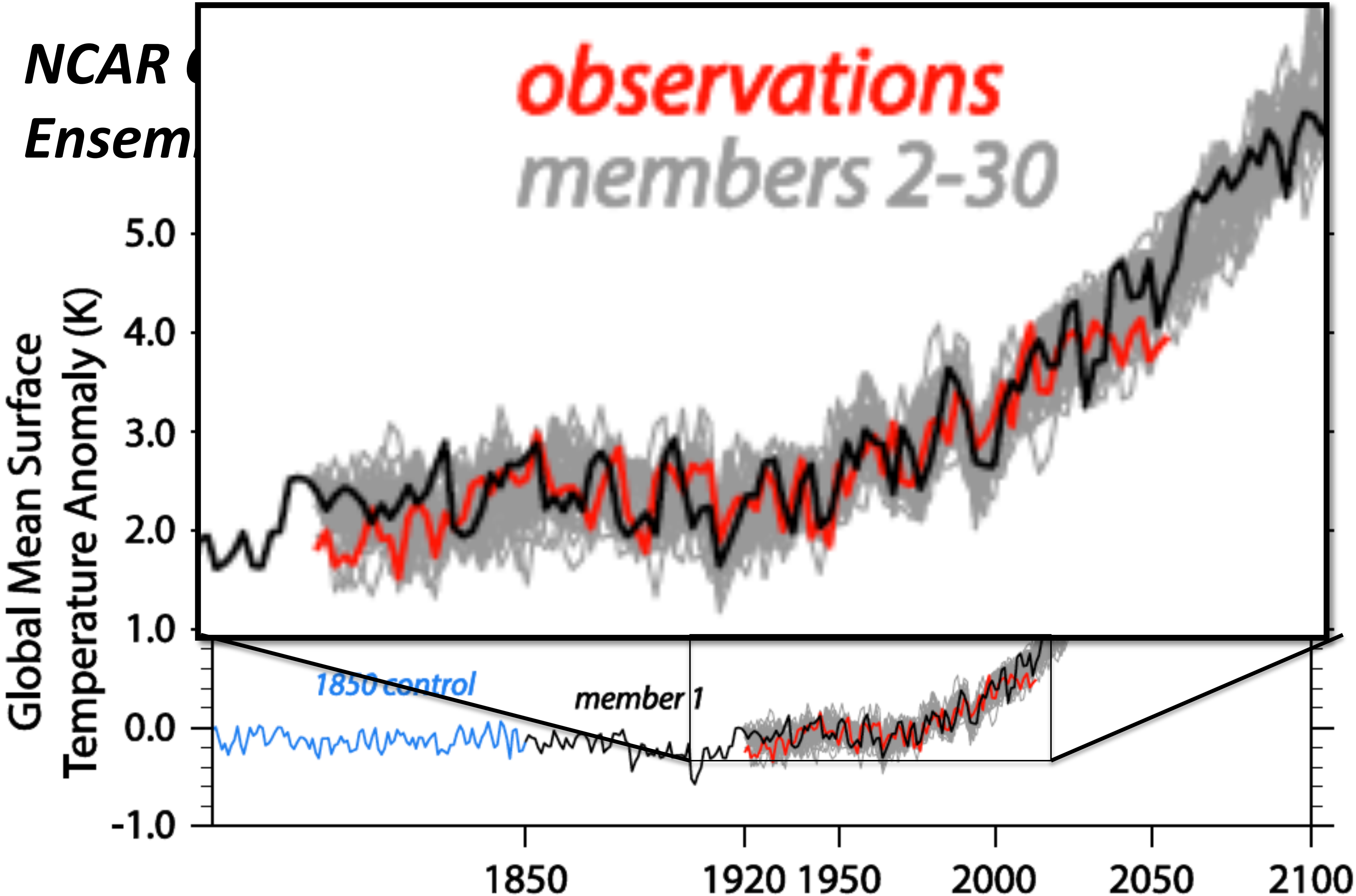


Is the ocean sink actually growing as expected?

et al. 2015 Science

LARGE ENSEMBLE MODELING TO ASSESS DETECTION TIMESCALES

NCAR C
Ensem



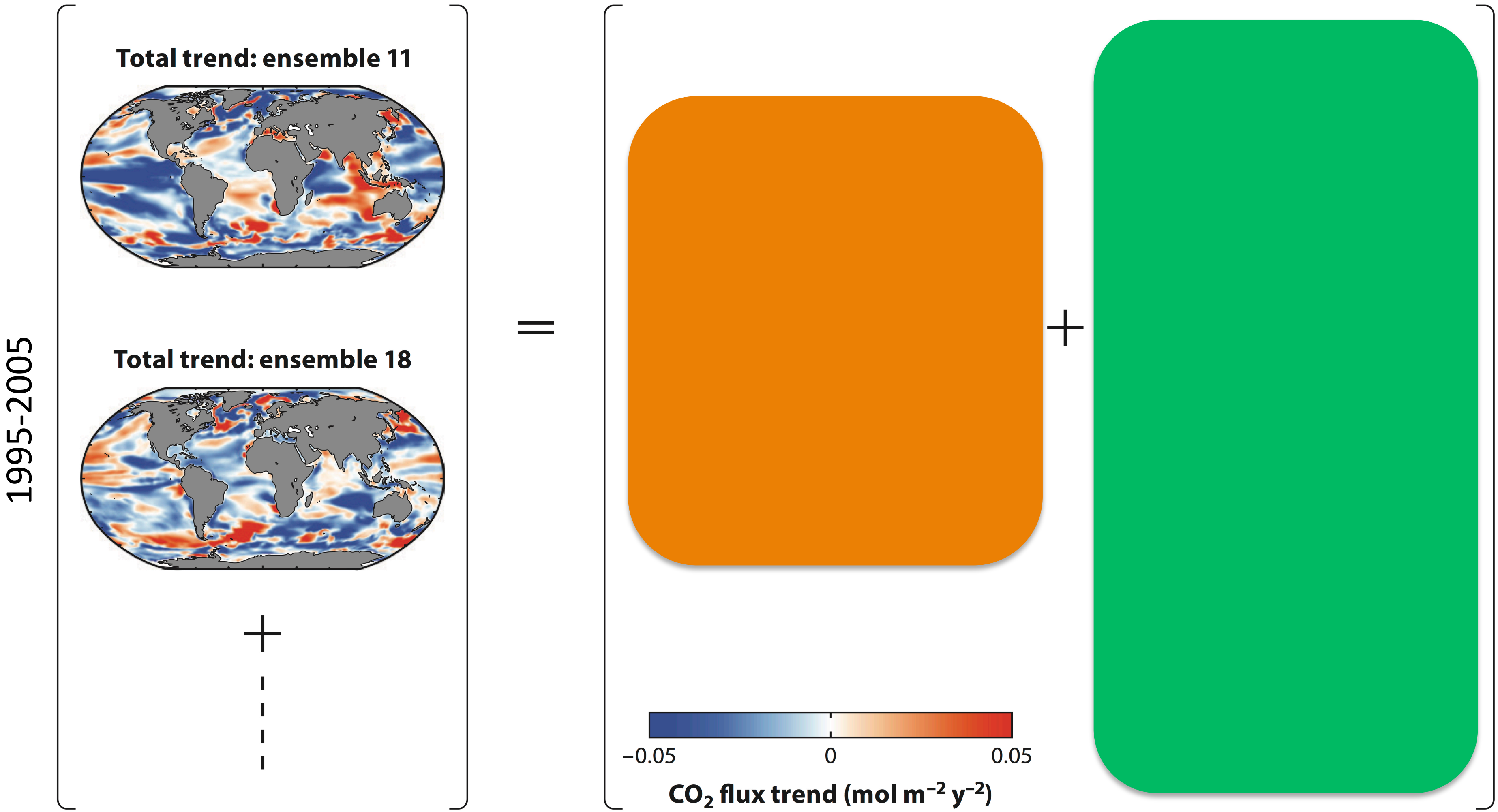
Kay et al. 2014 BAMS

CO_2 flux trend, NCAR LENS, 1995-2005

DECLINING SINK

GROWING SINK

Total Trend = Forced Trend + Internal Trend



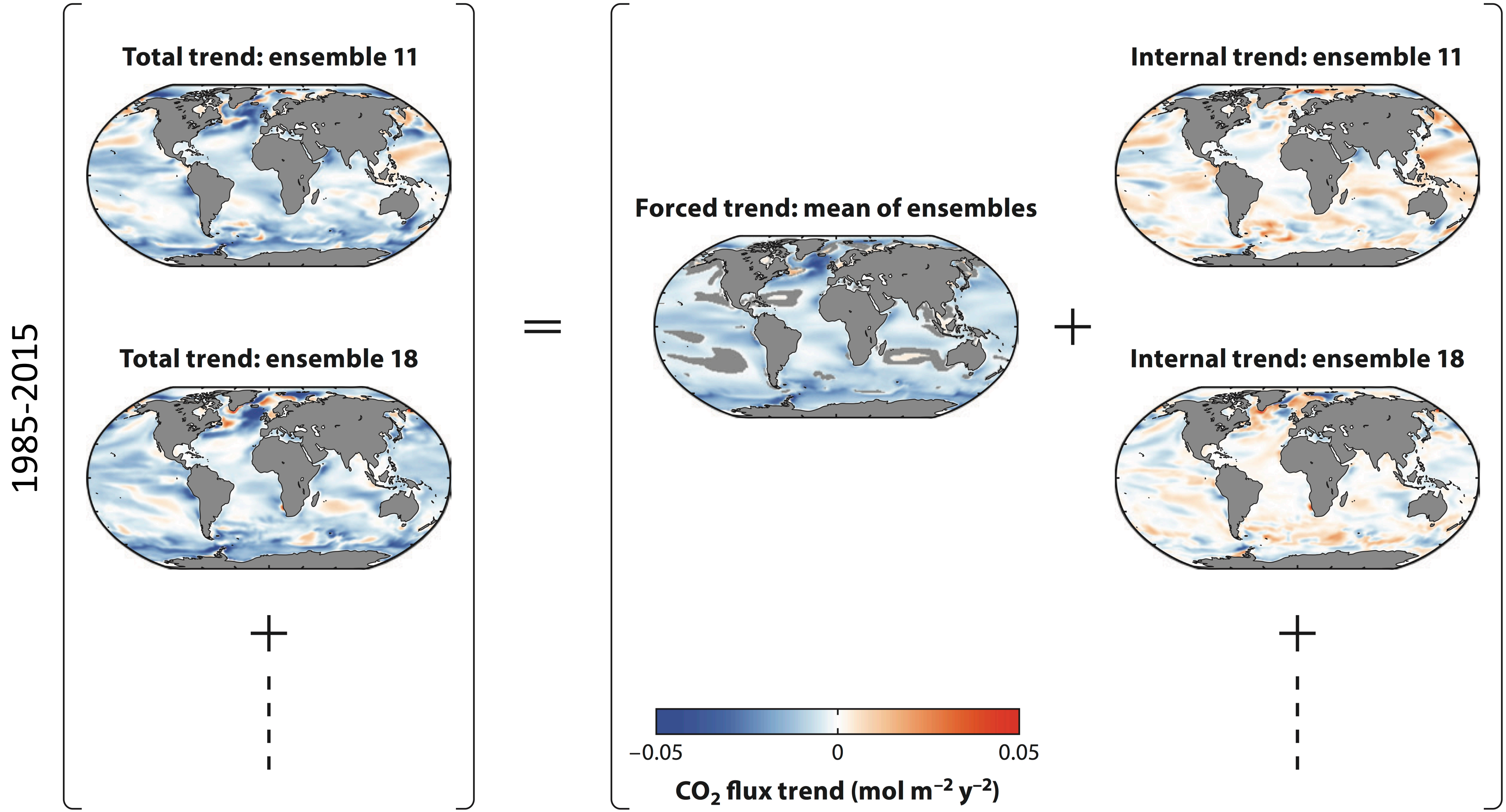
McKinley et al. 2017, ARMS

CO_2 flux trend, NCAR LENS, 1985-2015

Total Trend = Forced Trend + Internal Trend

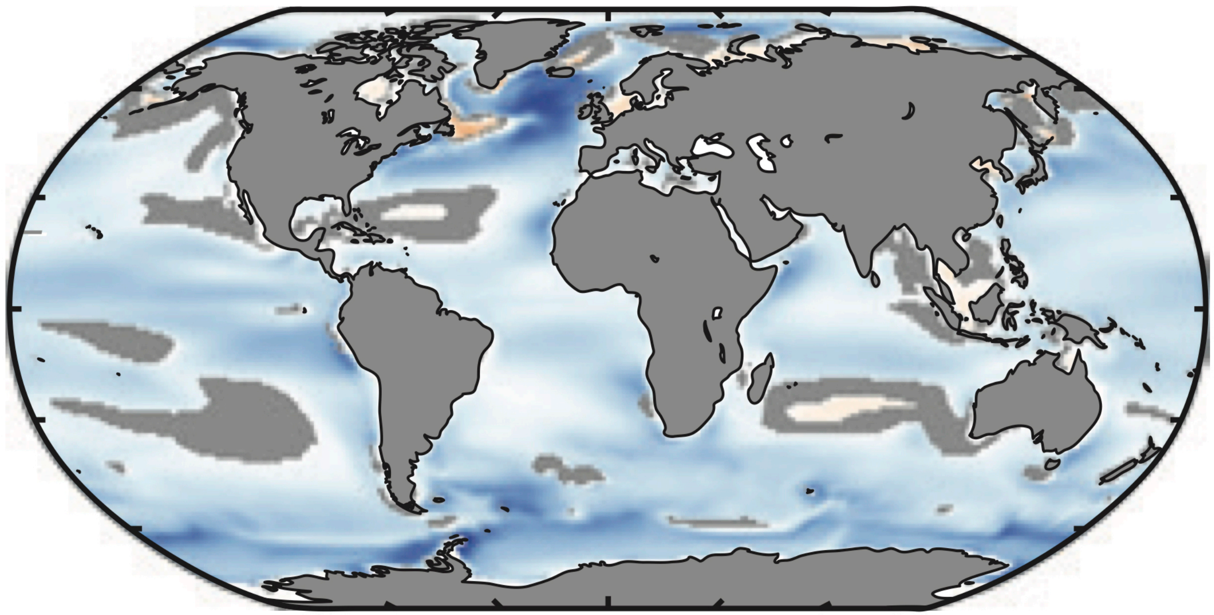
DECLINING SINK

GROWING SINK



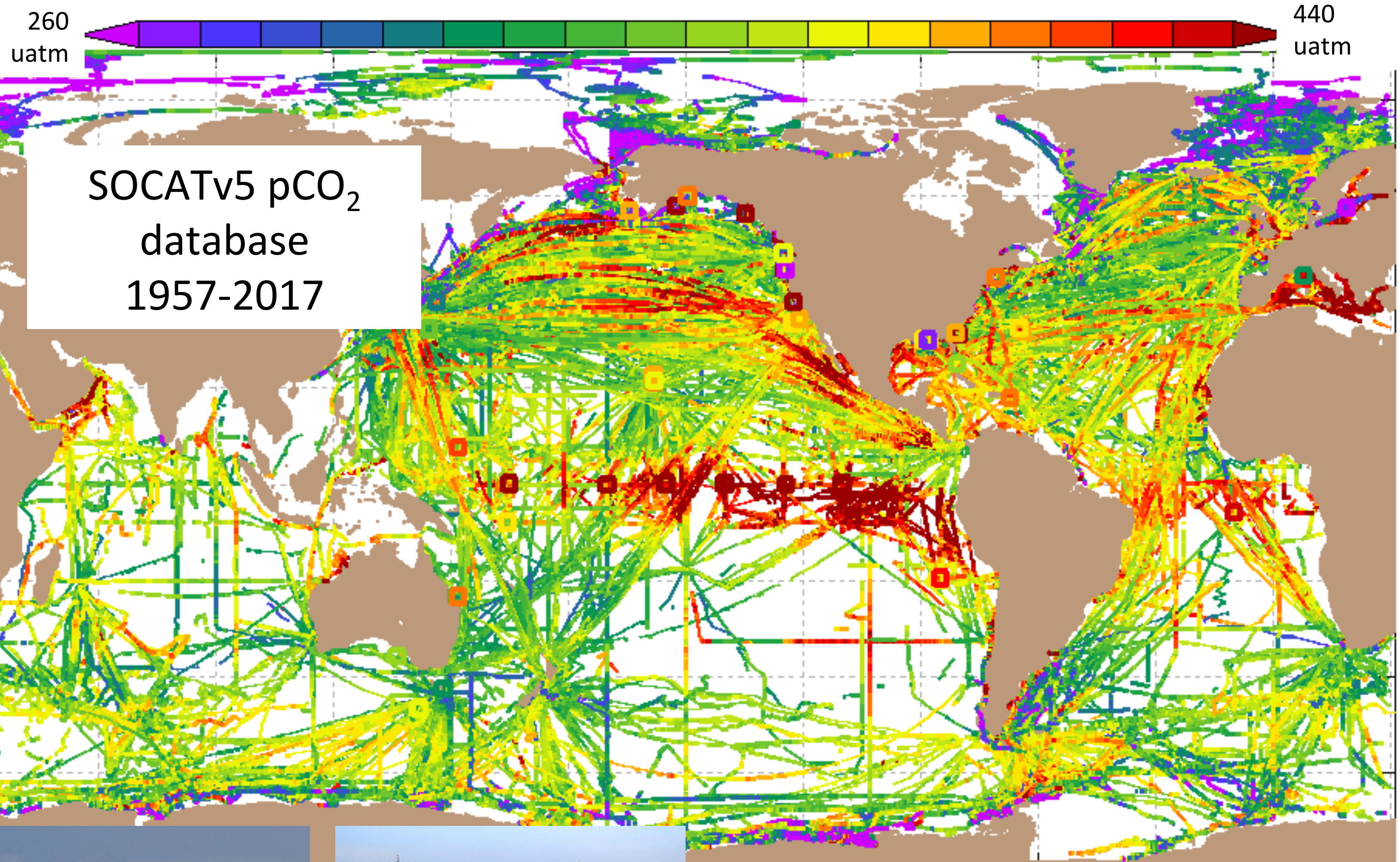
McKinley et al. 2017, ARMS

Forced trend in CO_2 flux, 1985-2015
($mol/m^2/yr^2$)



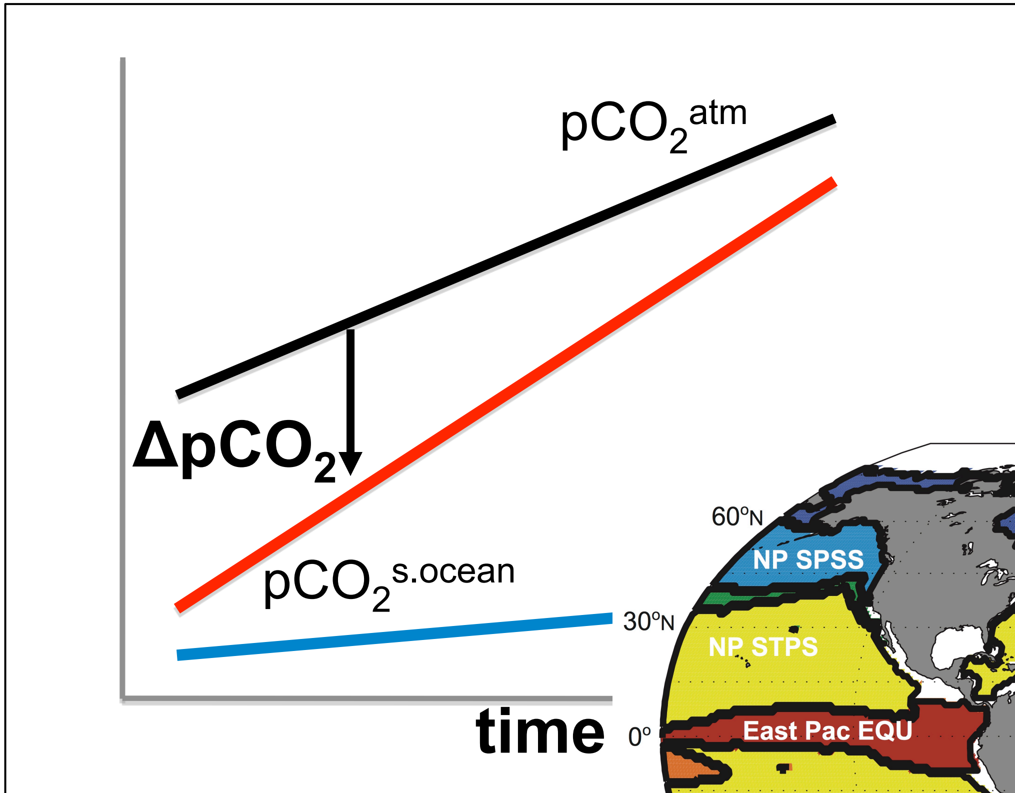
DO 35 YEARS OF SURFACE DATA REFLECT MODELLED FORCED TRENDS?

Surface pCO_2 observations
….. since CO_2 flux proportional to ΔpCO_2



Bakker et al. 2016 ESSD
Pfeil et al., Sabine et al. 2013 ESSD

Non-zero ΔpCO_2 trend indicates CO_2 flux change

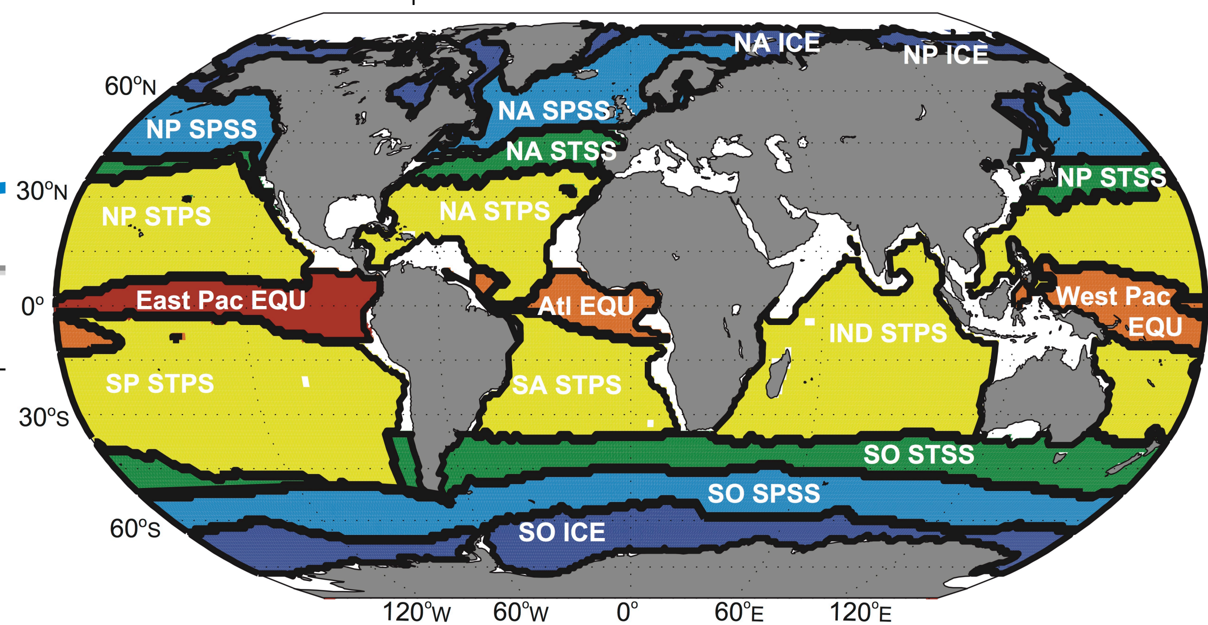


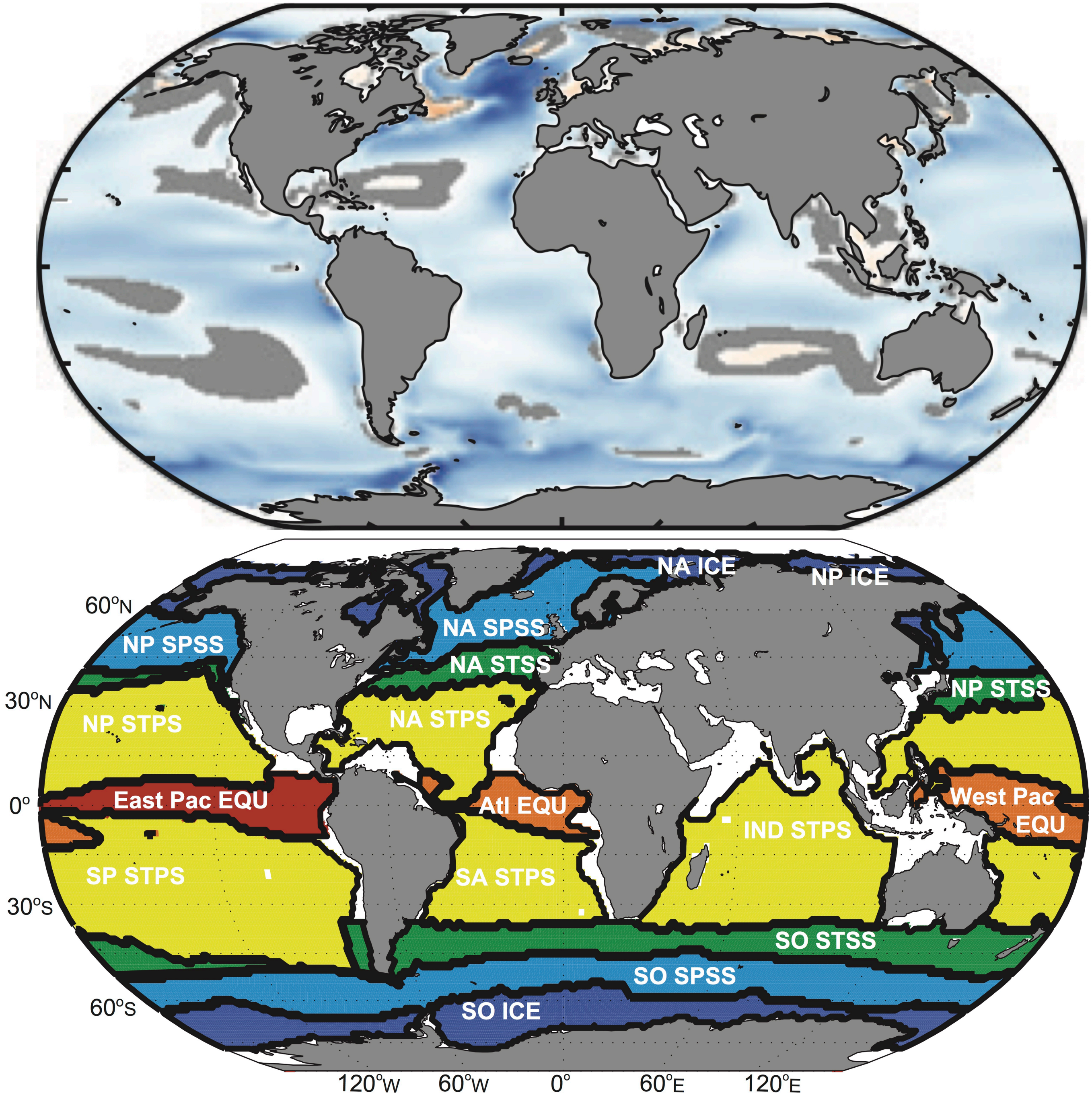
$d\Delta pCO_2/dt > 0$

DECLINING SINK

$d\Delta pCO_2/dt < 0$

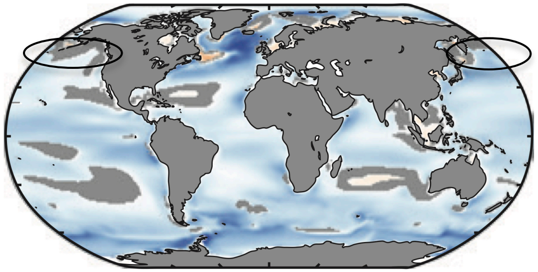
GROWING SINK

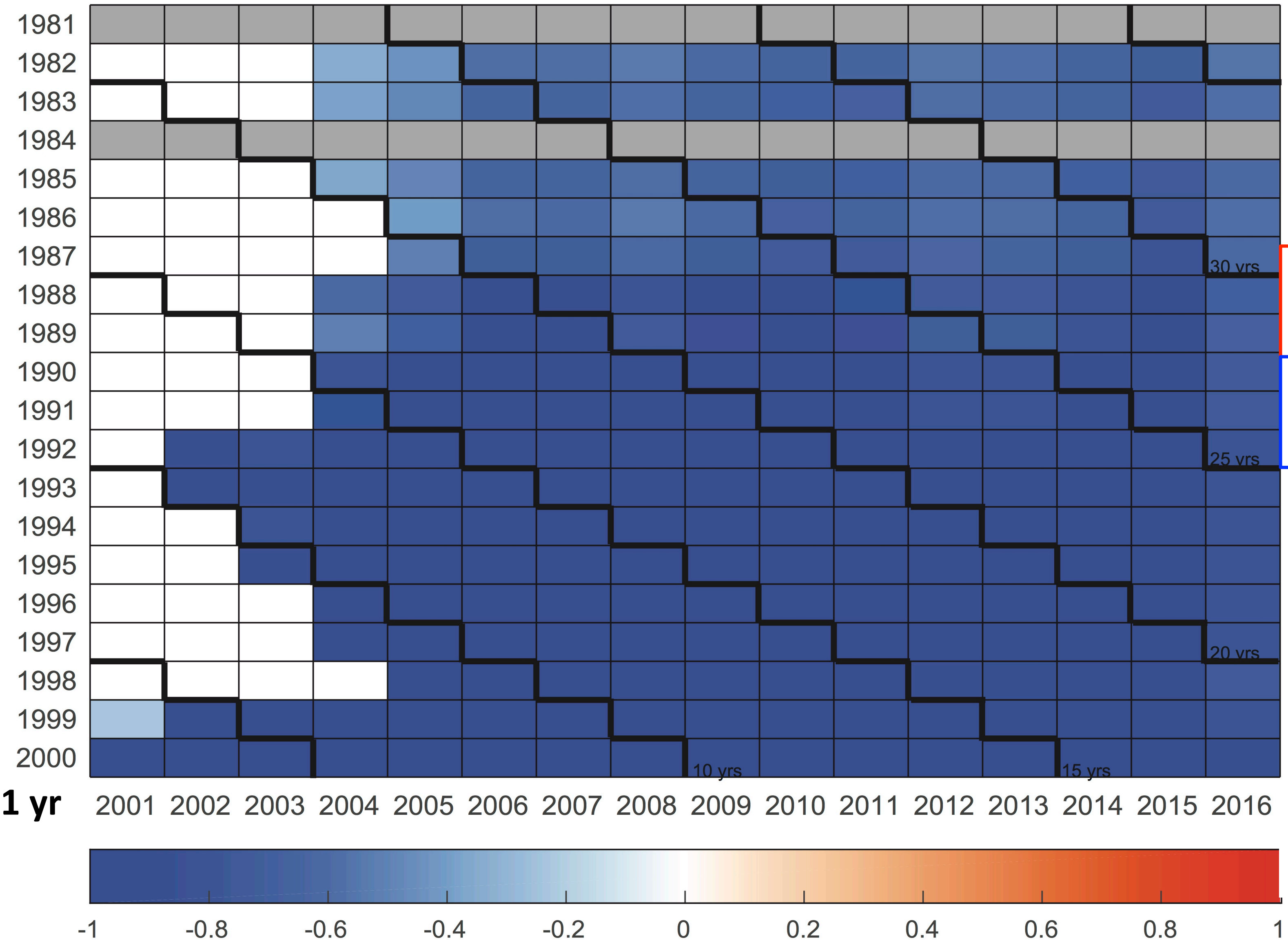




NA ICE
NP ICE
60°N
NP SPSS
NA SPSS
NA STSS
NP STSS
30°N
NP STPS
NA STPS
0°
East Pac EQU
Atl EQU
West Pac
EQU
IND STPS
SP STPS
SA STPS
30°S
SO STSS
SO SPSS
60°S
SO ICE
120°W
60°W
0°
60°E
120°E

N. Pacific Subpolar Seasonally Strat.
Observed ΔpCO_2 trends



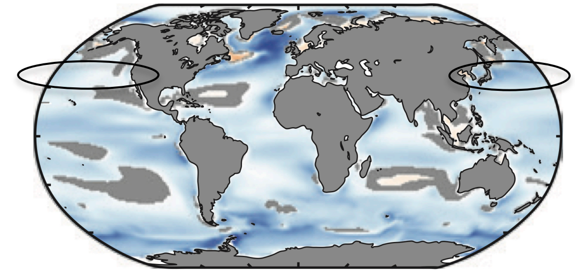


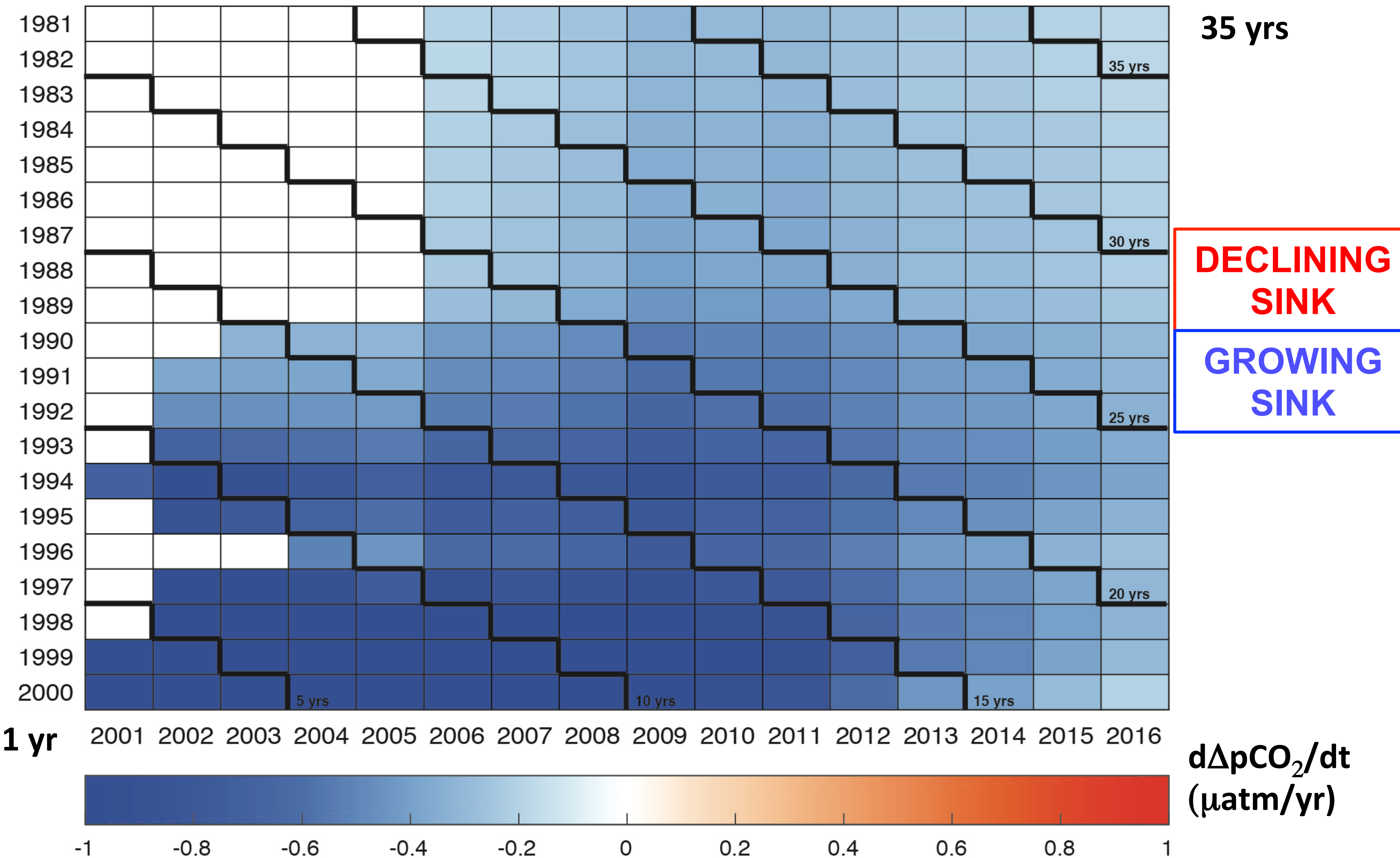
DECLINING SINK

GROWING SINK

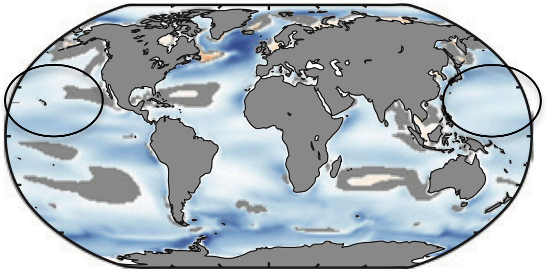
White: $d\Delta pCO_2/dt=0$
Gray: no data

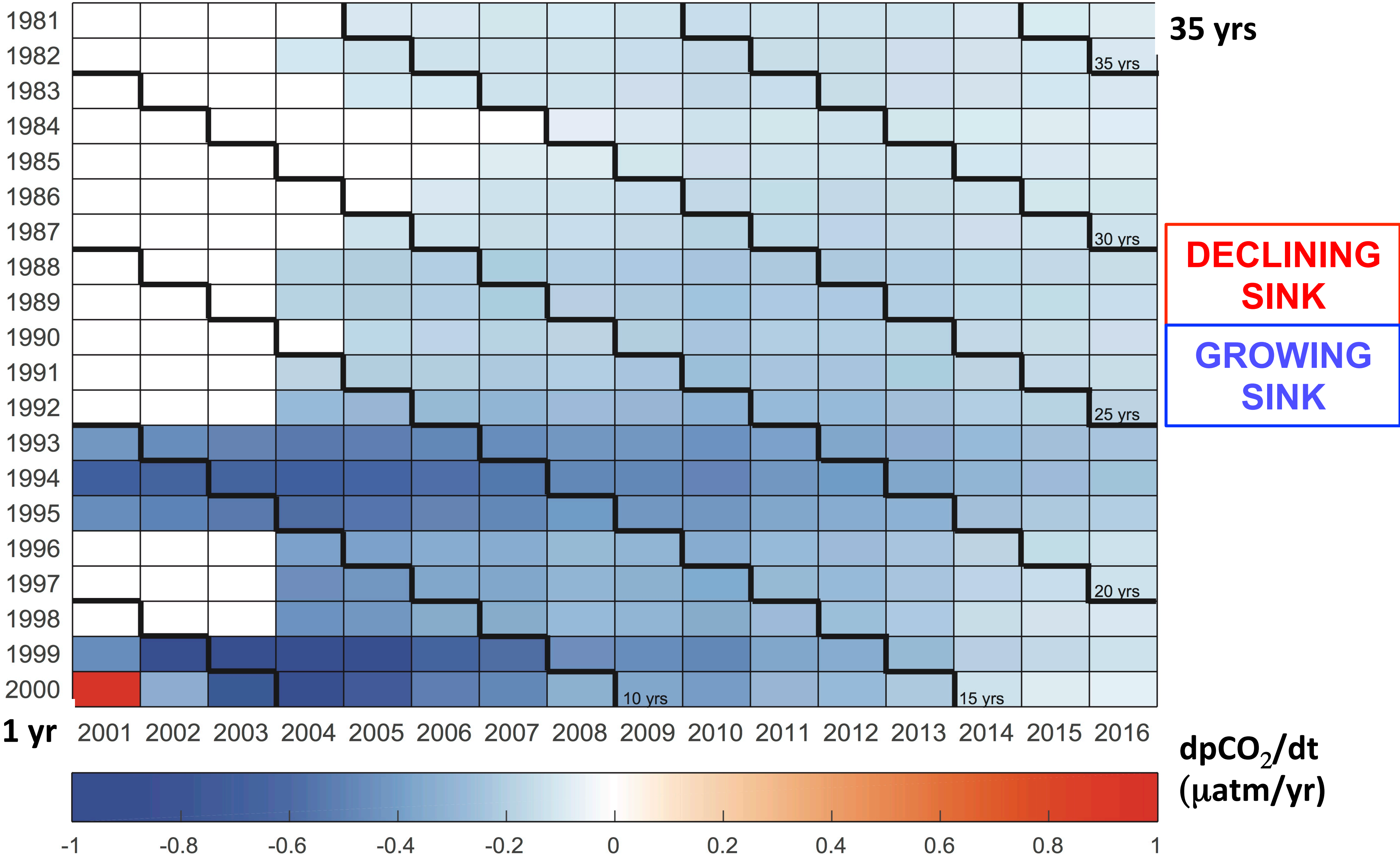
N. Pacific Subtrop. Seasonally Strat.
Observed ΔpCO₂ trends



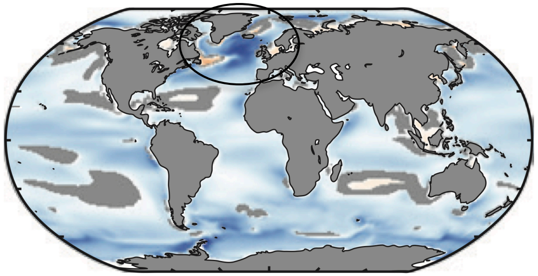


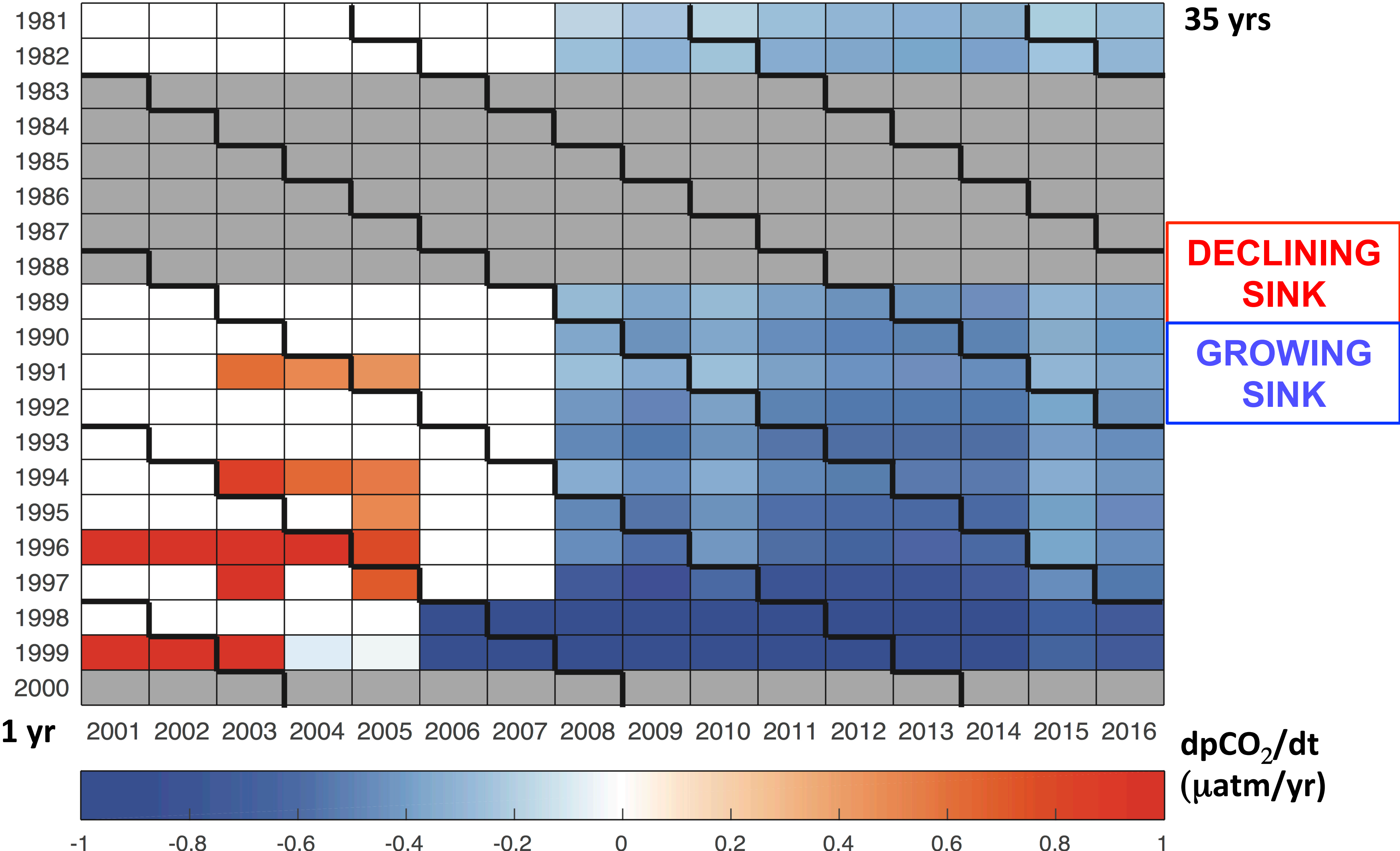
N. Pac. Subtrop. Permanently Strat.
Observed ΔpCO_2 trends



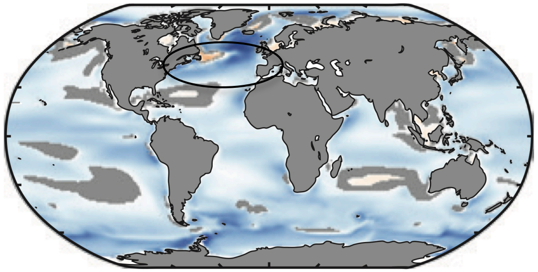


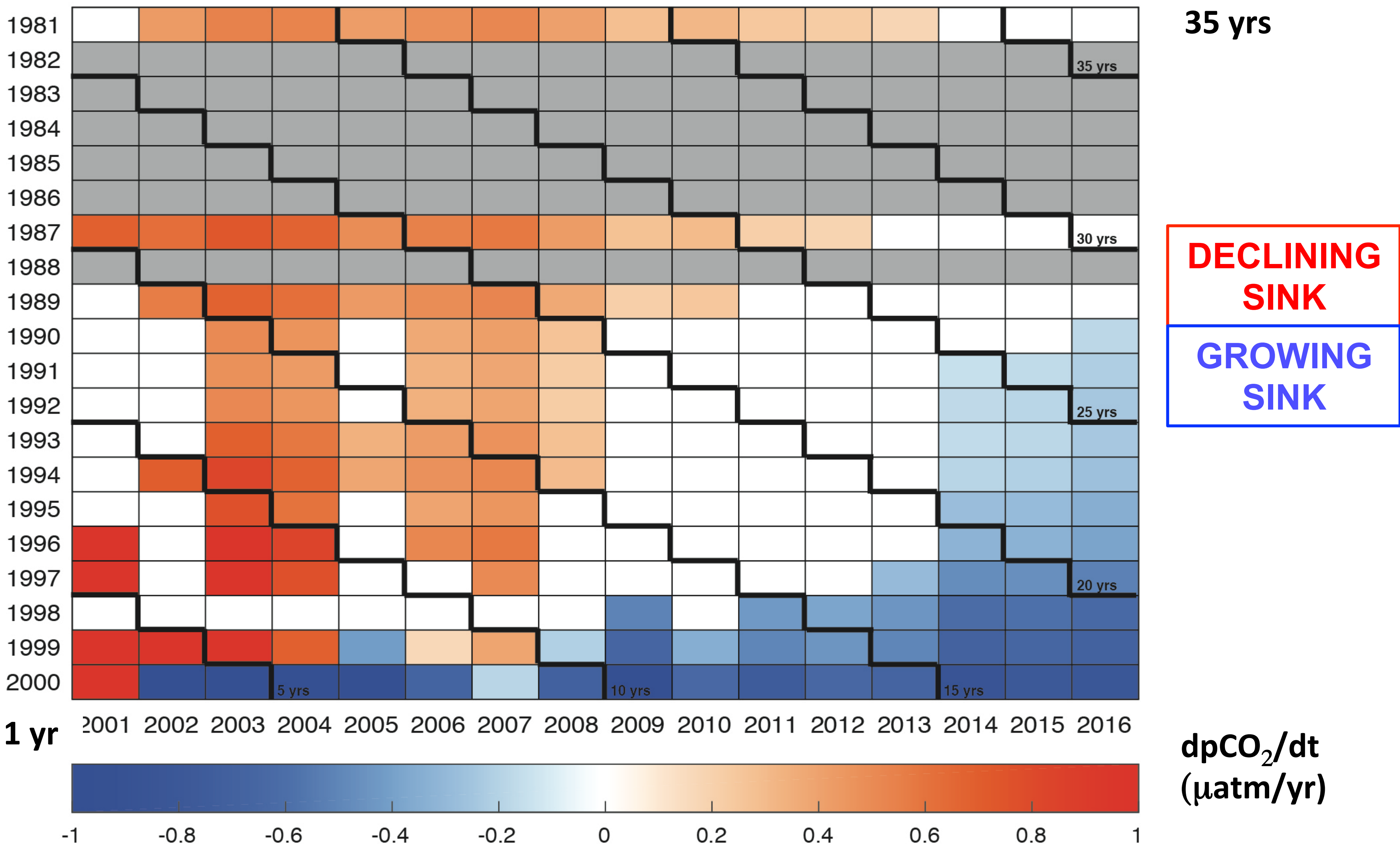
N. Atlantic Subpolar Seasonally Strat.
Observed ΔpCO$_2$ trends



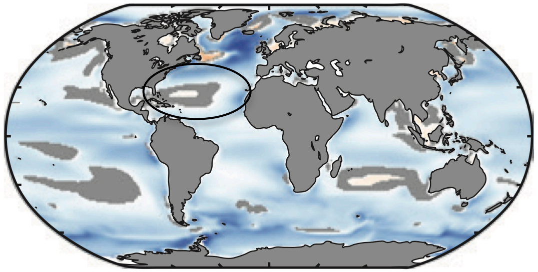


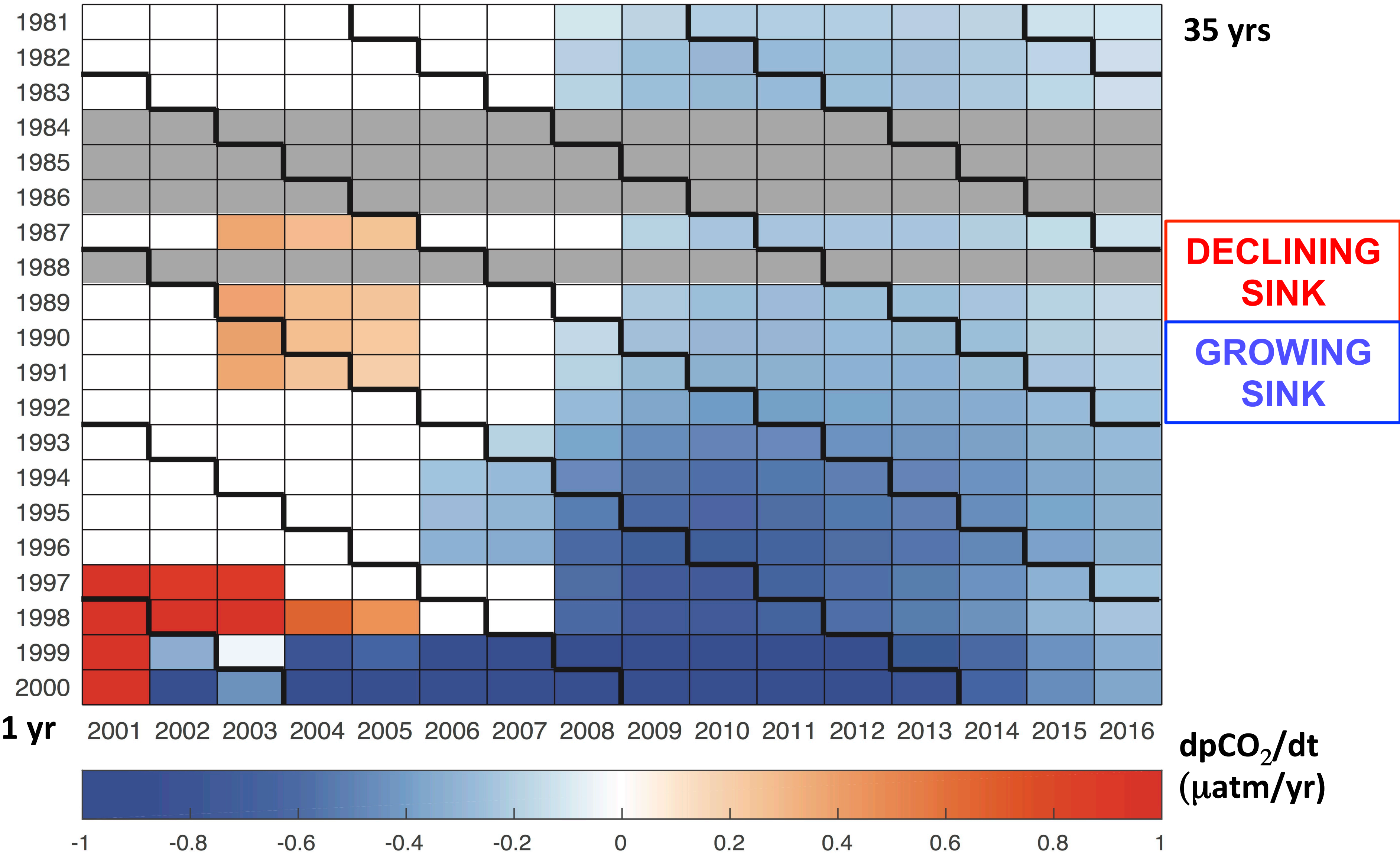
N. Atlantic Subtrop. Seasonally Strat.
Observed ΔpCO_2 trends



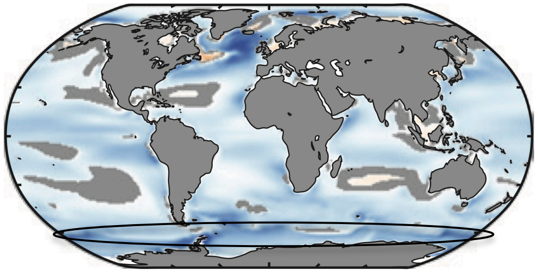


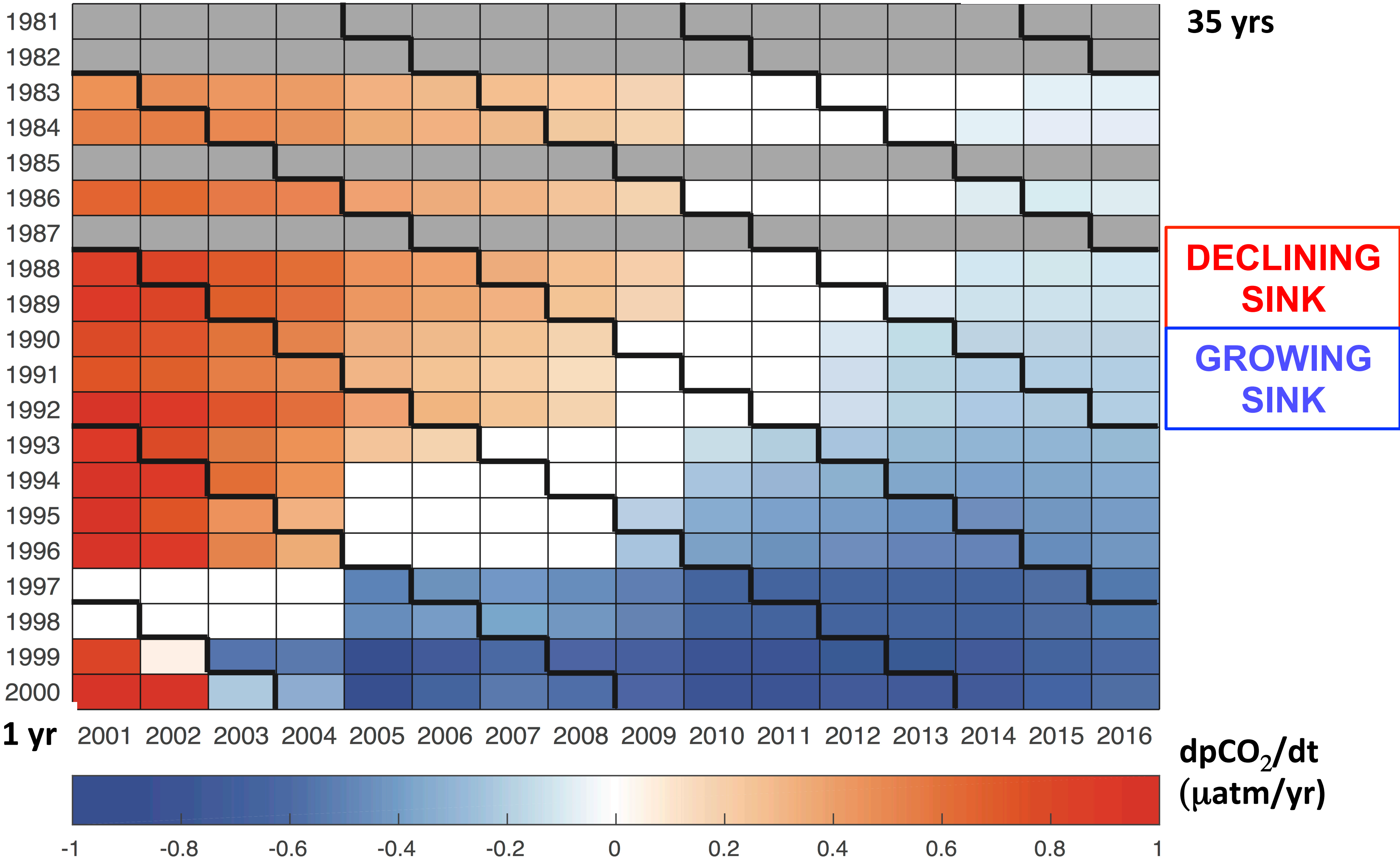
N. Atl. Subtrop. Permanently Strat.
Observed ΔpCO₂ trends



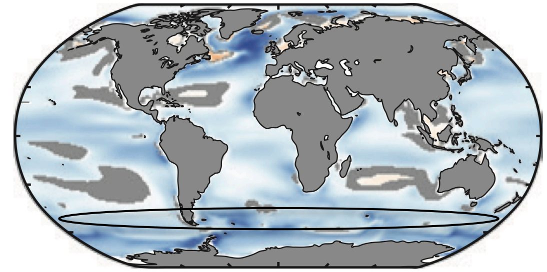


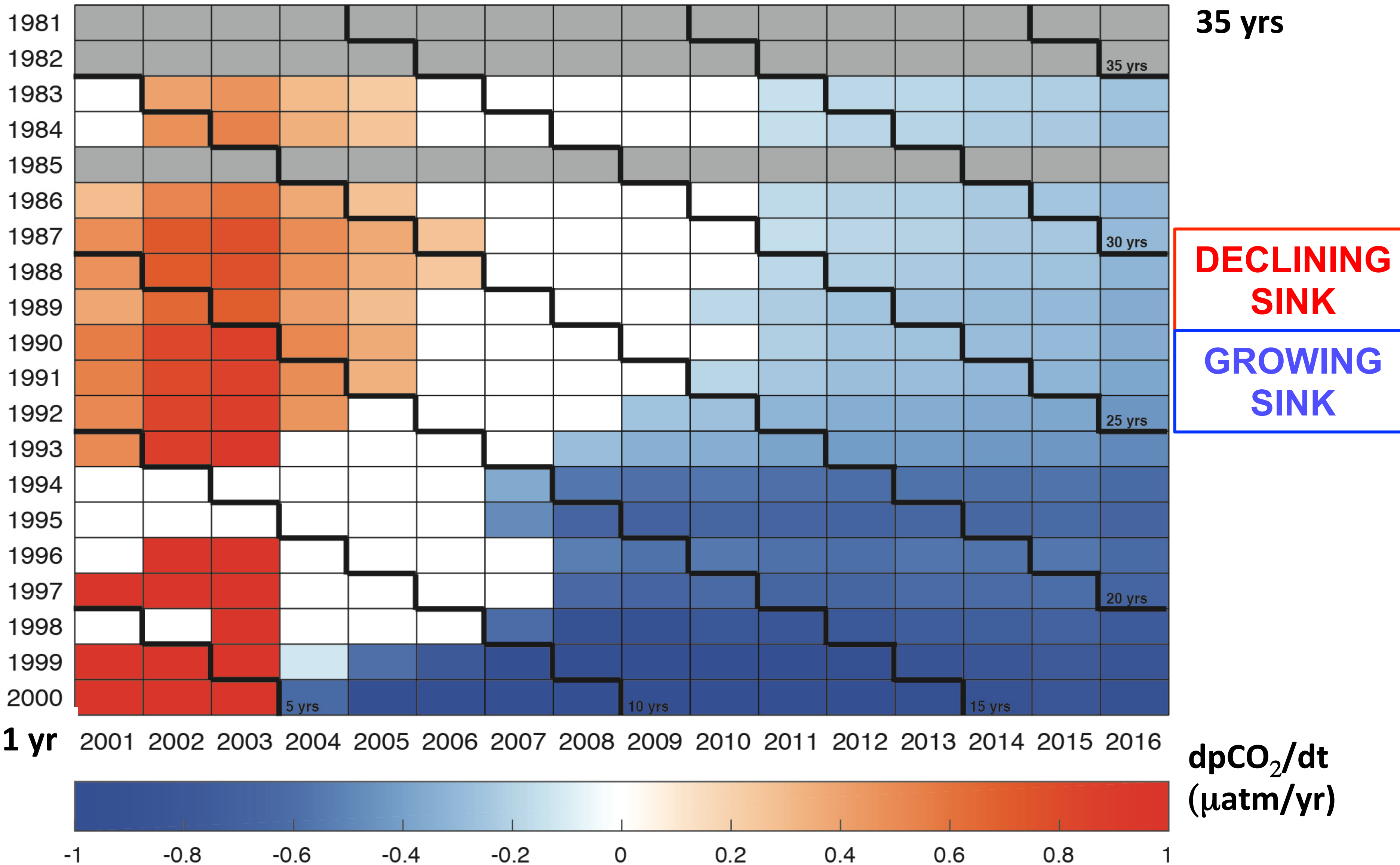
S. Ocean Subpolar Seasonally Strat. Observed ΔpCO_2 trends



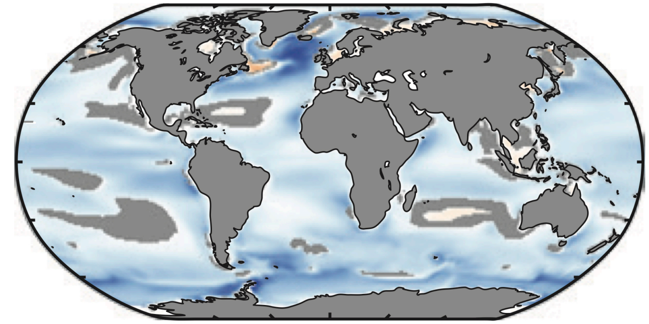


S. Ocean Subtrop. Seasonally Strat.
Observed ΔpCO_2 trends





Take home messages



- Internal variability complicates detection of expected growth in the ocean carbon sink
- 35 years of data reveal
  - N. Pacific: Gradient of strong to weak sink growth from subpolar to subtropical, consistent with forced trend
  - N. Atlantic: Strongest sink increase in subpolar, weak in subtropical, low frequency variability clear in STSS
  - S. Ocean: Low freq. variability, stronger sink growth in STSS
- Data are consistent with emergence in some places, but more decades required to confirm detection

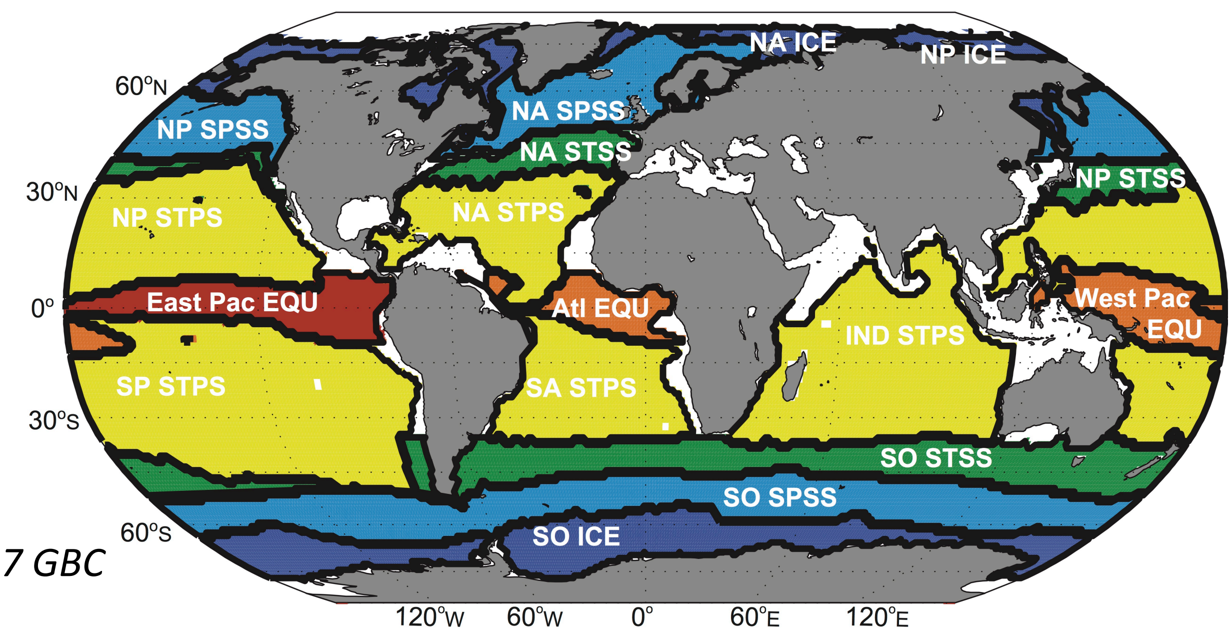
THANK YOU

TO WHAT DEGREE DOES BIOLOGY DRIVE CARBON CYCLE VARIABILITY?

Does pCO_2 correlate to satellite chlorophyll?

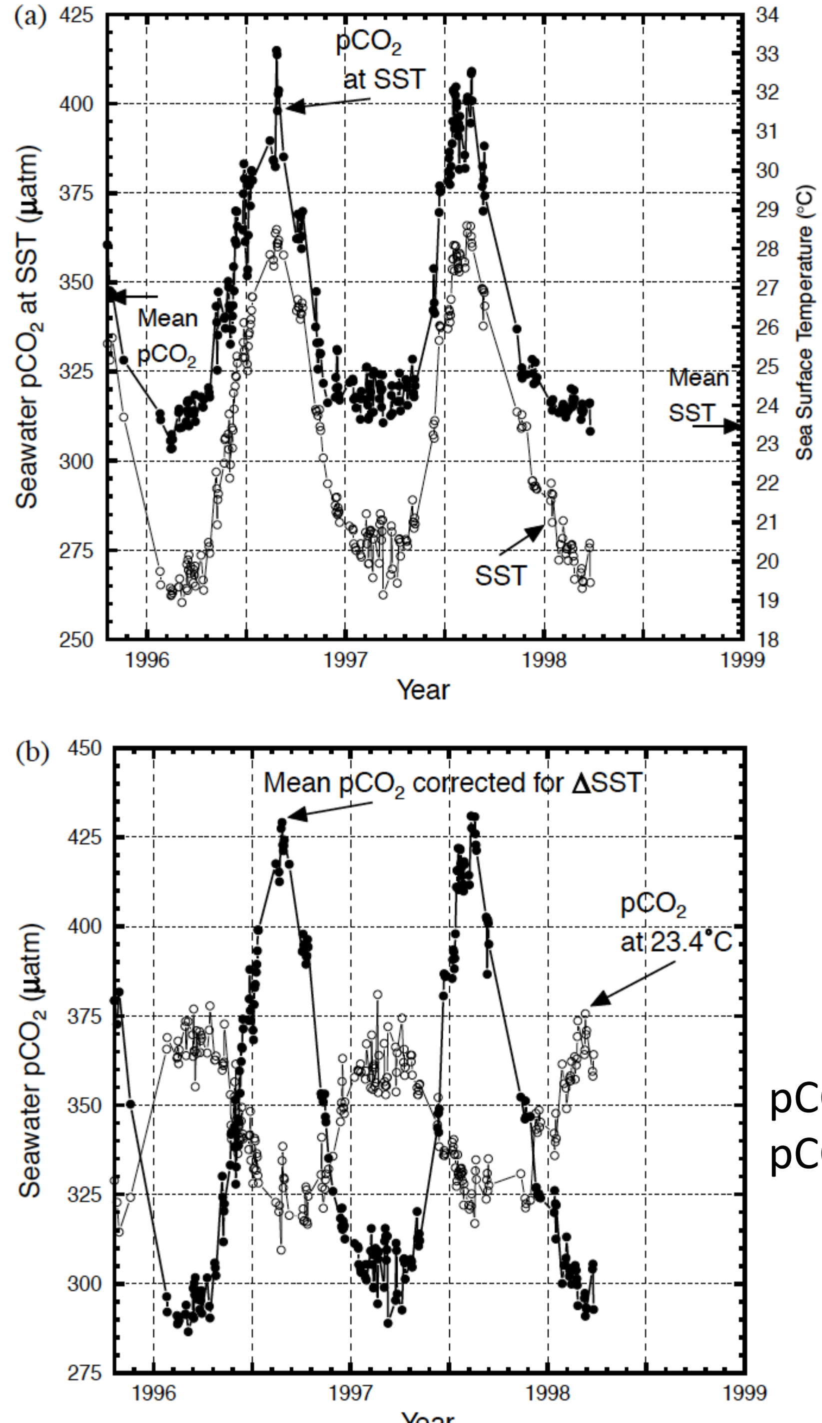
- Co-located (1x1) Chlorophyll, pCO_2, SST, MLD
- Monthly 1998-2014
- **Correlations** at seasonal, monthly anomaly, and interannual timescales
- Spatial scale: 1x1 degree resolution and global biomes

	Source
Chlorophyll	SeaWiFS/ MODIS (Measures)
pCO_2	SOCATv3
SST	SOCATv3
MLD	ECCO2 (state est.)



Fay and McKinley, 2017 GBC

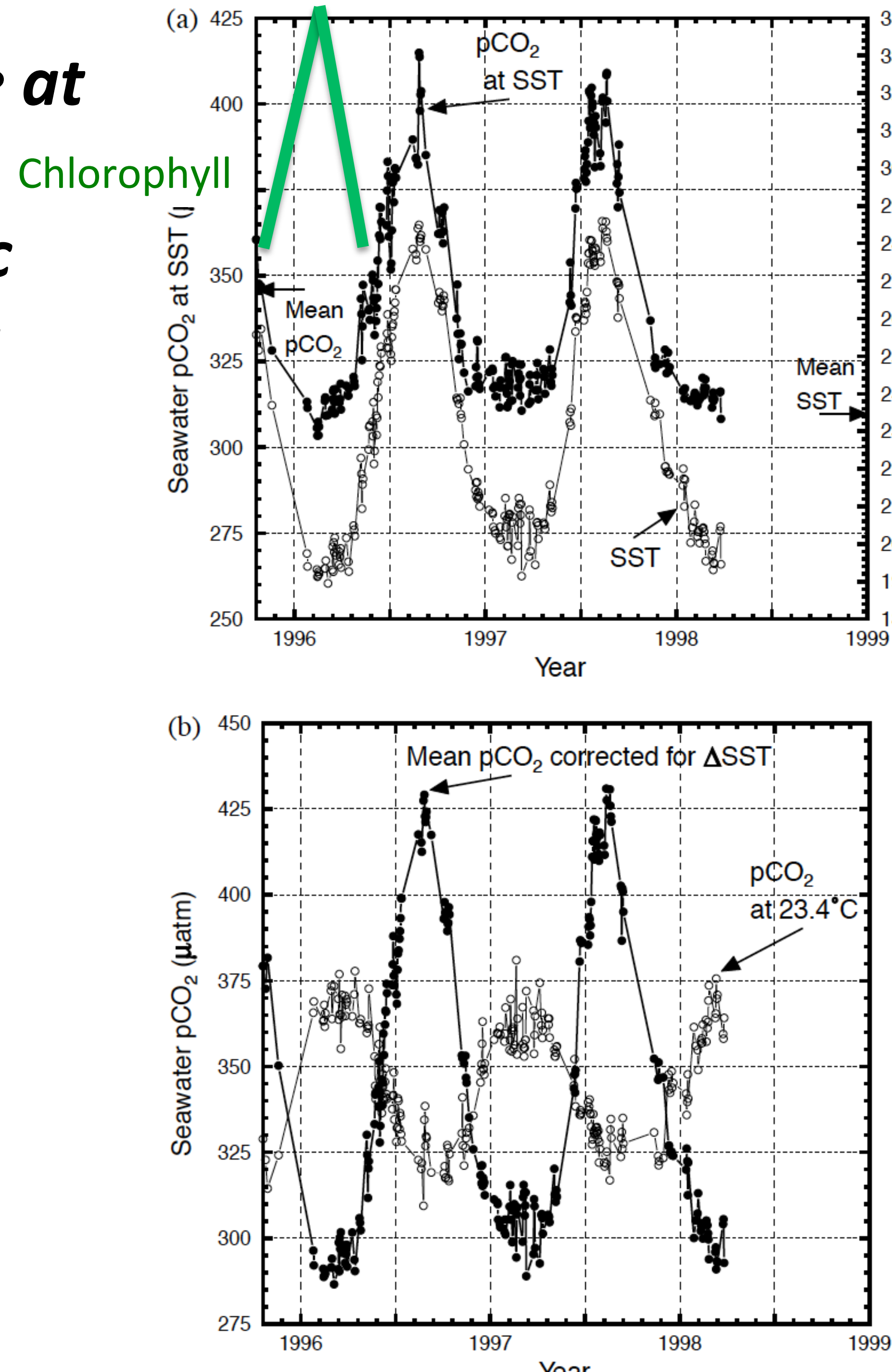
pCO_2 cycle at Bermuda, N. Atlantic subtropics



pCO_2-T (closed)
pCO_2-nonT (open)

Takahashi et al. 2002, DSRII

pCO_2 cycle at Bermuda, N. Atlantic subtropics



pCO_2-T (closed)
pCO_2-nonT (open)

Takahashi et al. 2002, DSRII

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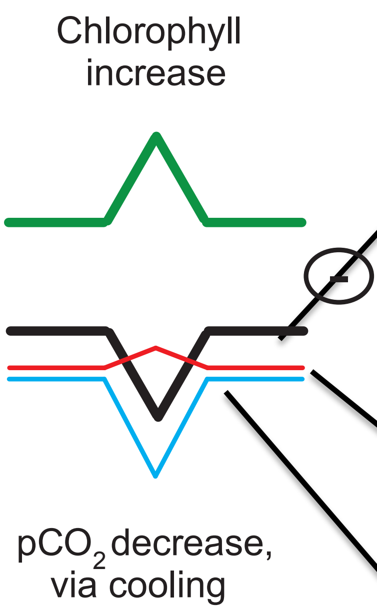
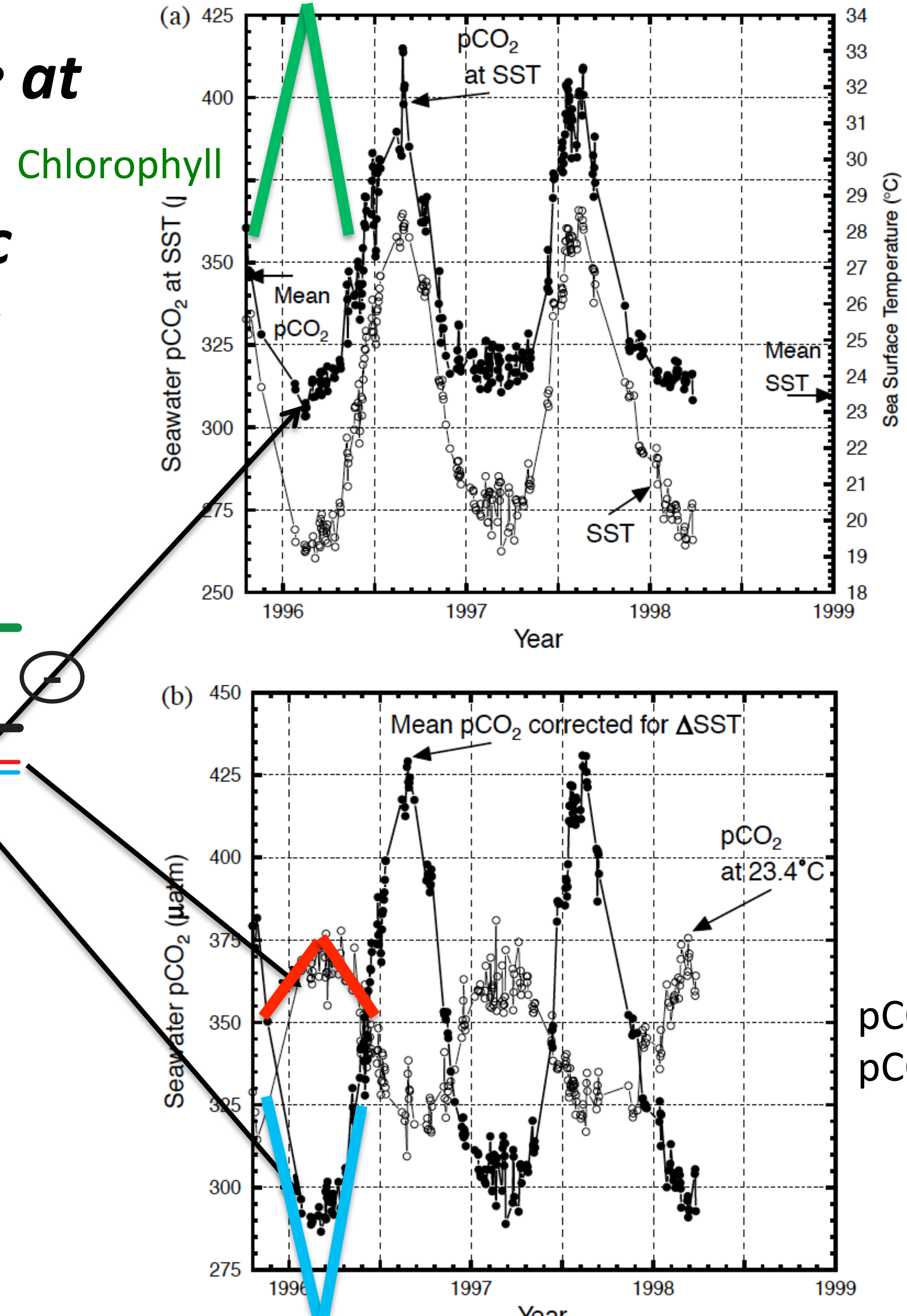
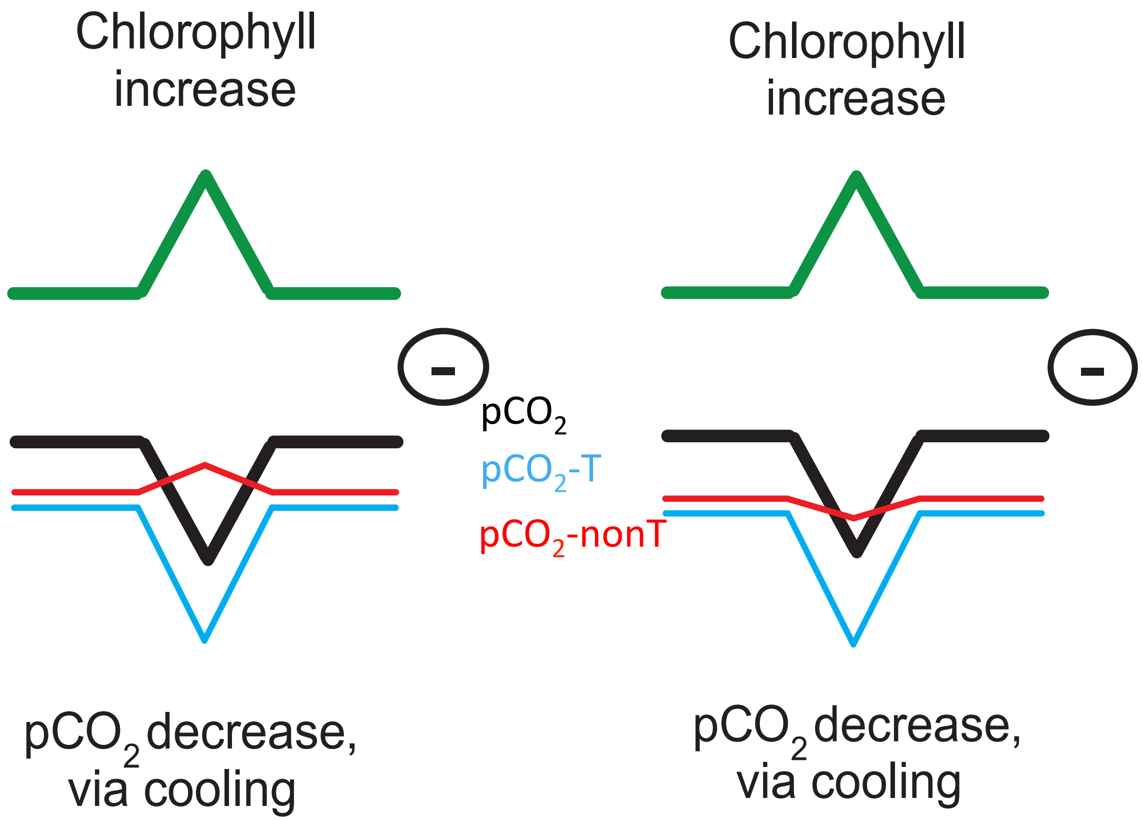




pCO_2-T (closed)
pCO_2-nonT (open)

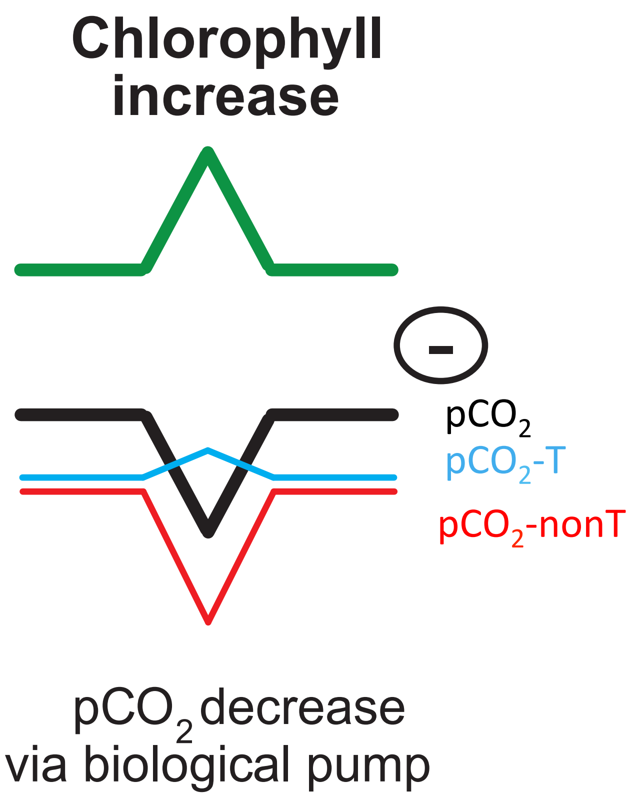
Takahashi et al. 2002, DSRII

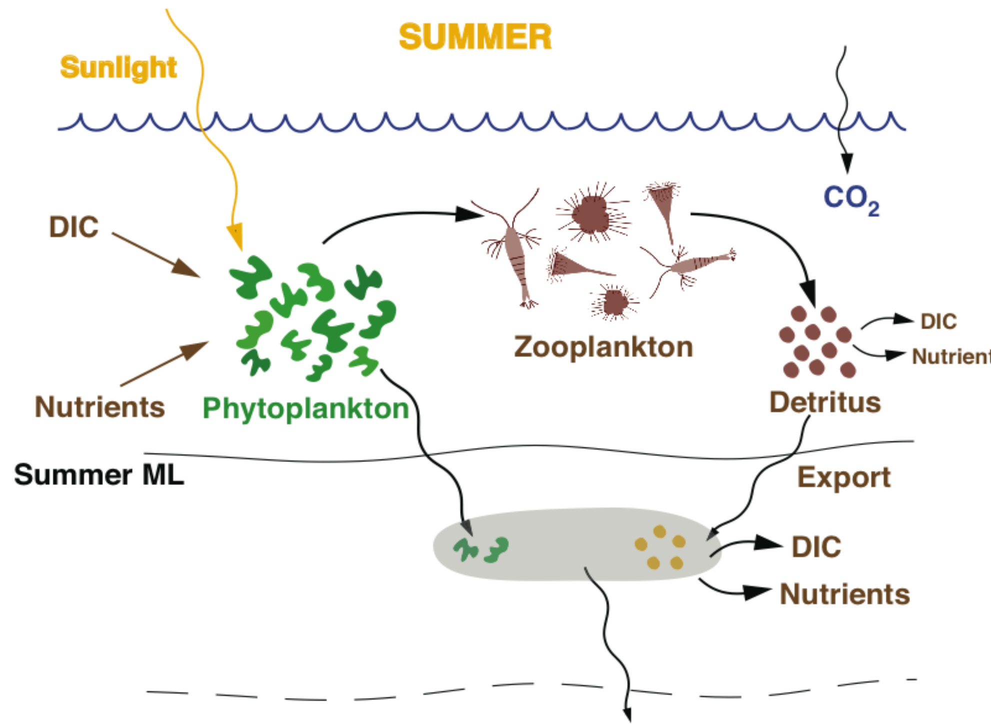
Physics must be primary control if pCO_2-T drives pCO_2, despite a typically negative pCO_2 correlation to Chl



Fay and McKinley, 2017 GBC

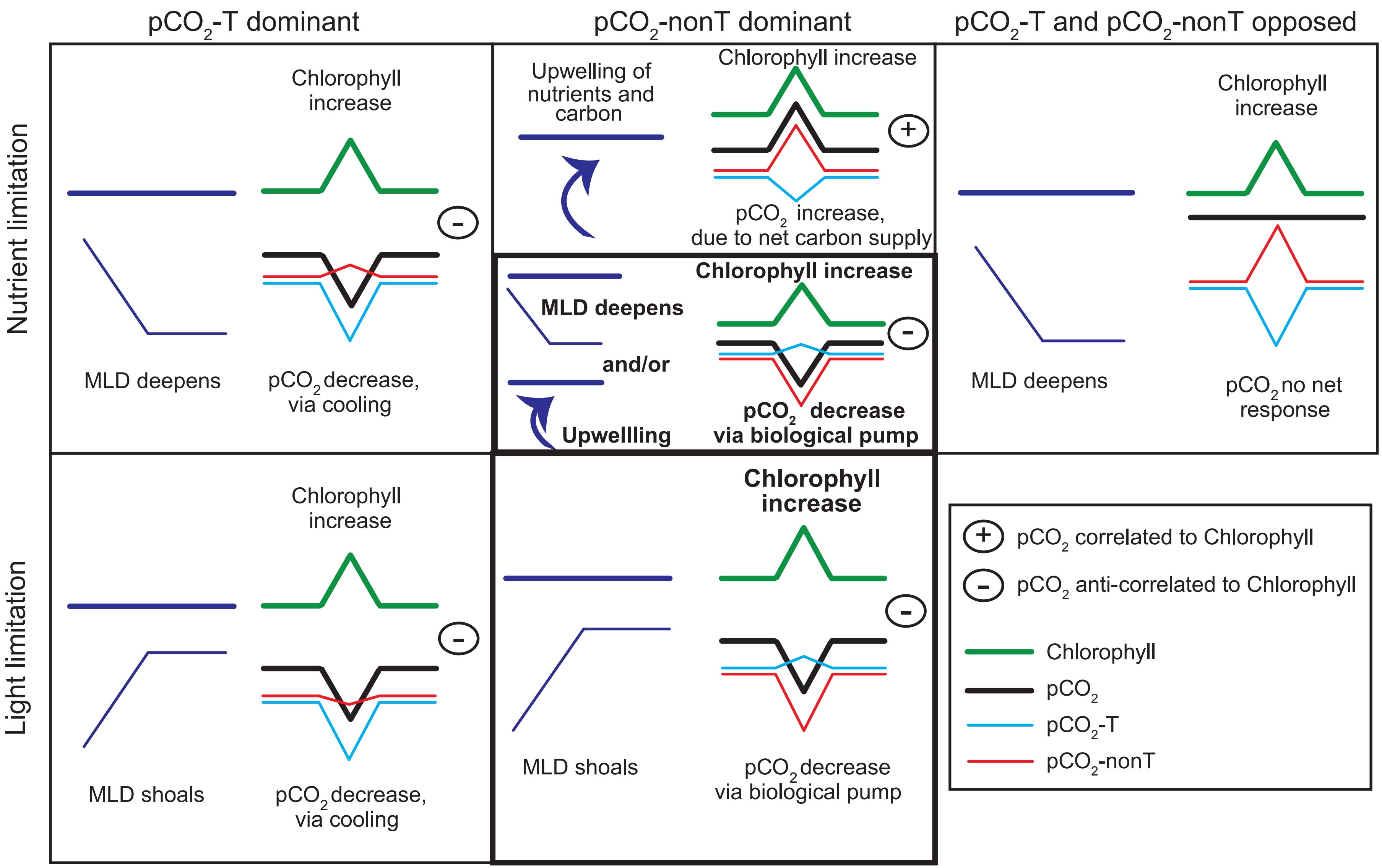
Biological pump potentially driving carbon cycle if (1) negative pCO_2-Chl correlation (2) pCO_2-nonT dominant





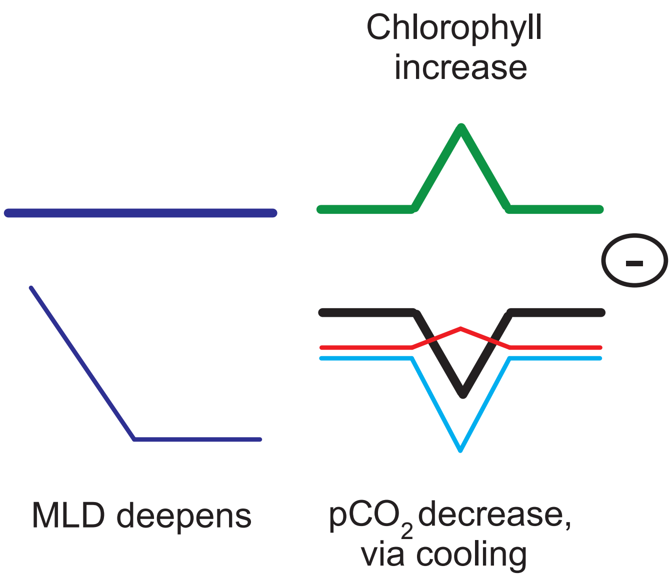
Fay and McKinley, 2017 GBC

MLD analysis identifies nutrient vs. light limitation

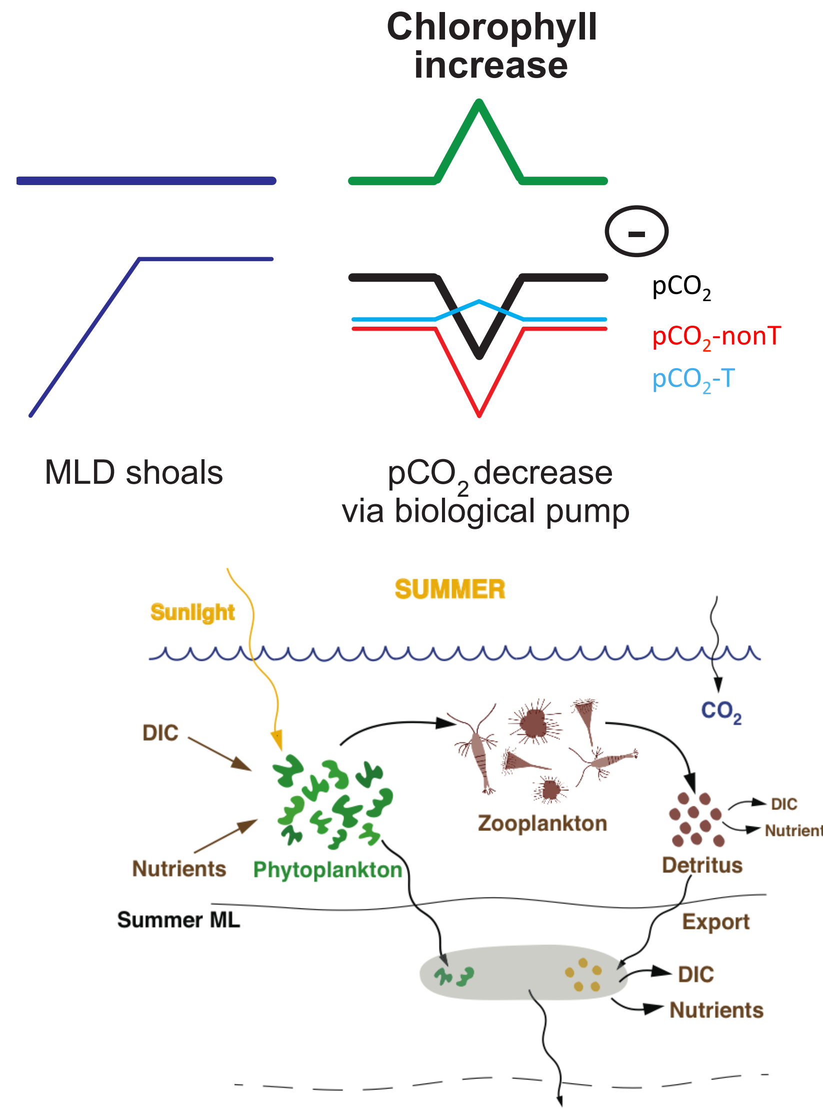


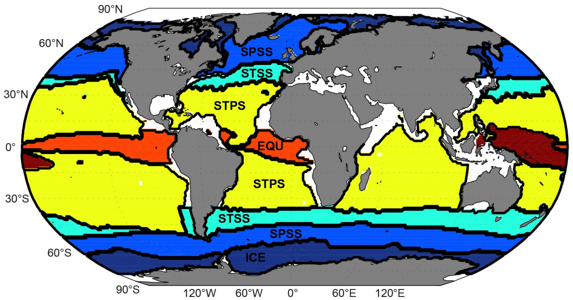
Fay and McKinley, 2017 GBC

Typical Subtropical:
Productive winter, pCO_2-T dominant



Typical Subpolar:
Productive summer , pCO_2-nonT dominant




90°N
60°N
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60°W
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SPSS
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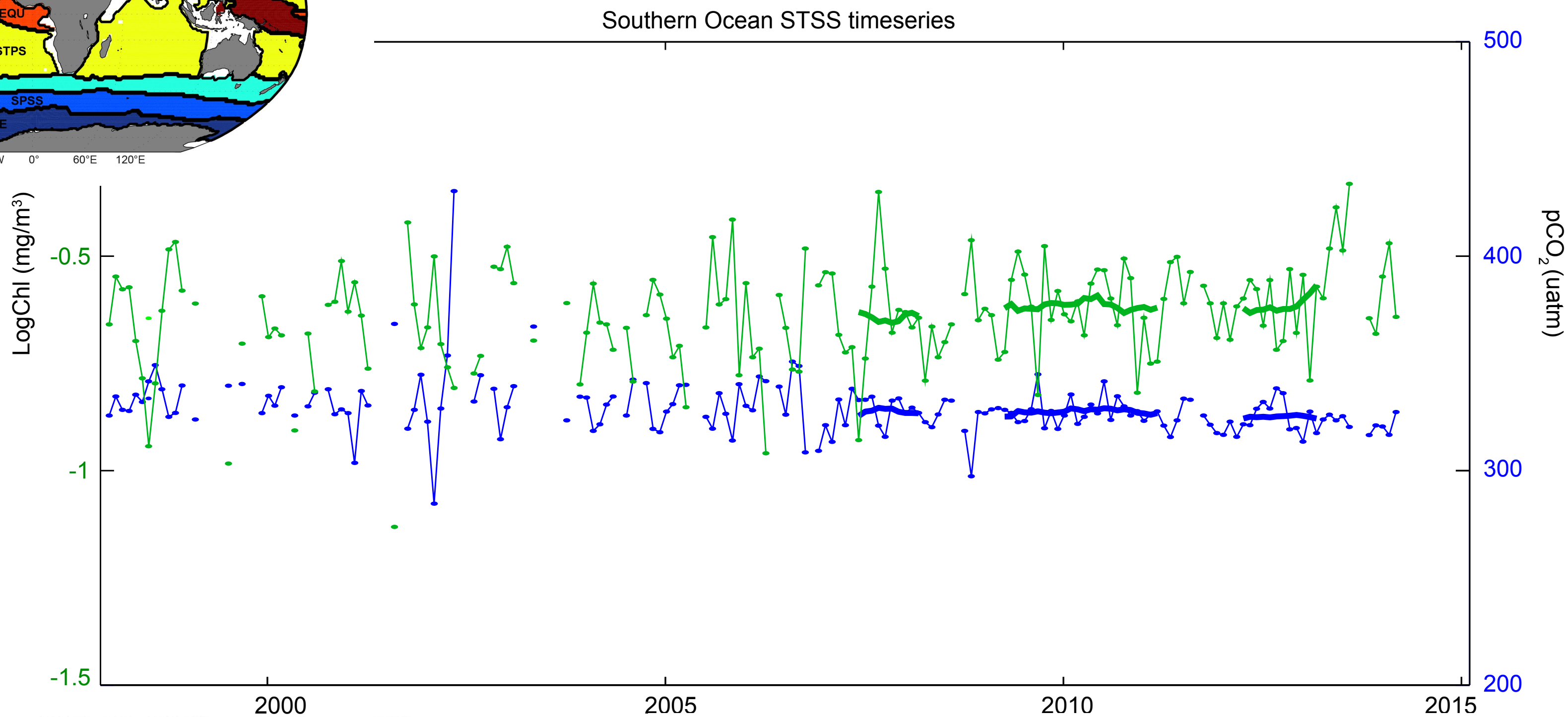
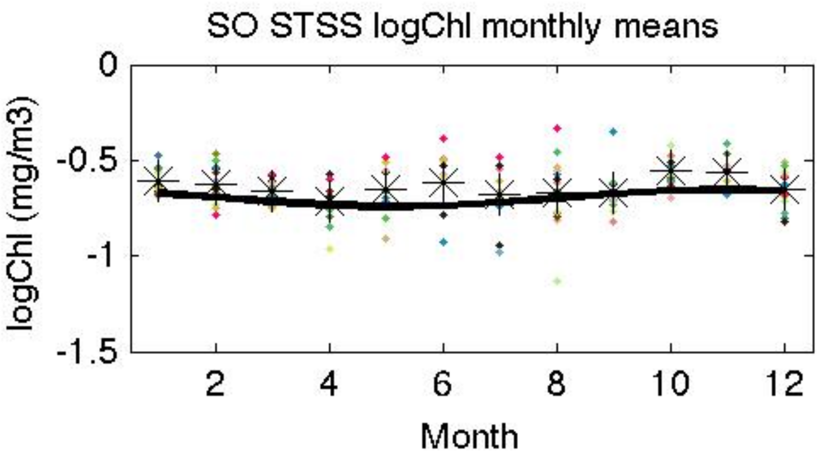
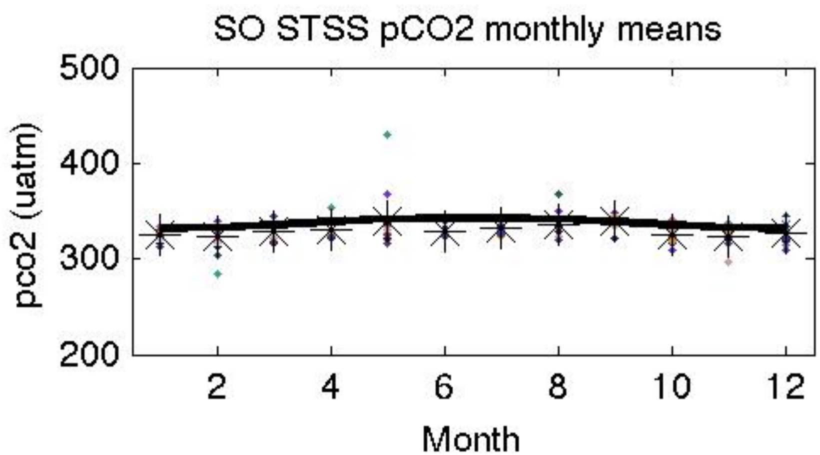
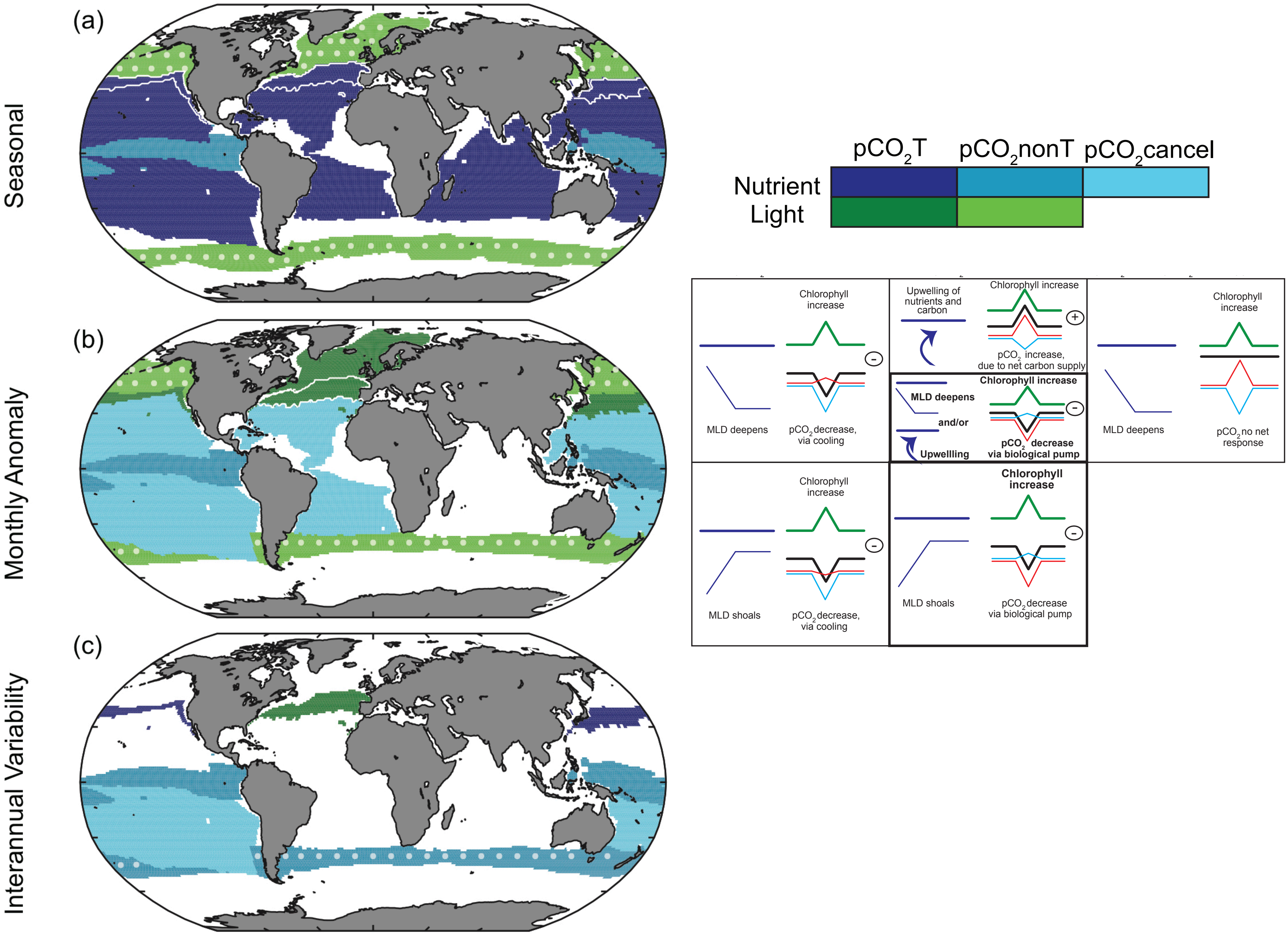
STPS
STSS
SPSS
ICE


Southern Ocean STSS timeseries
LogChl (mg/m³)
pCO₂ (uatm)
-0.5
-1
-1.5
500
400
300
200
2000
2005
2010
2015

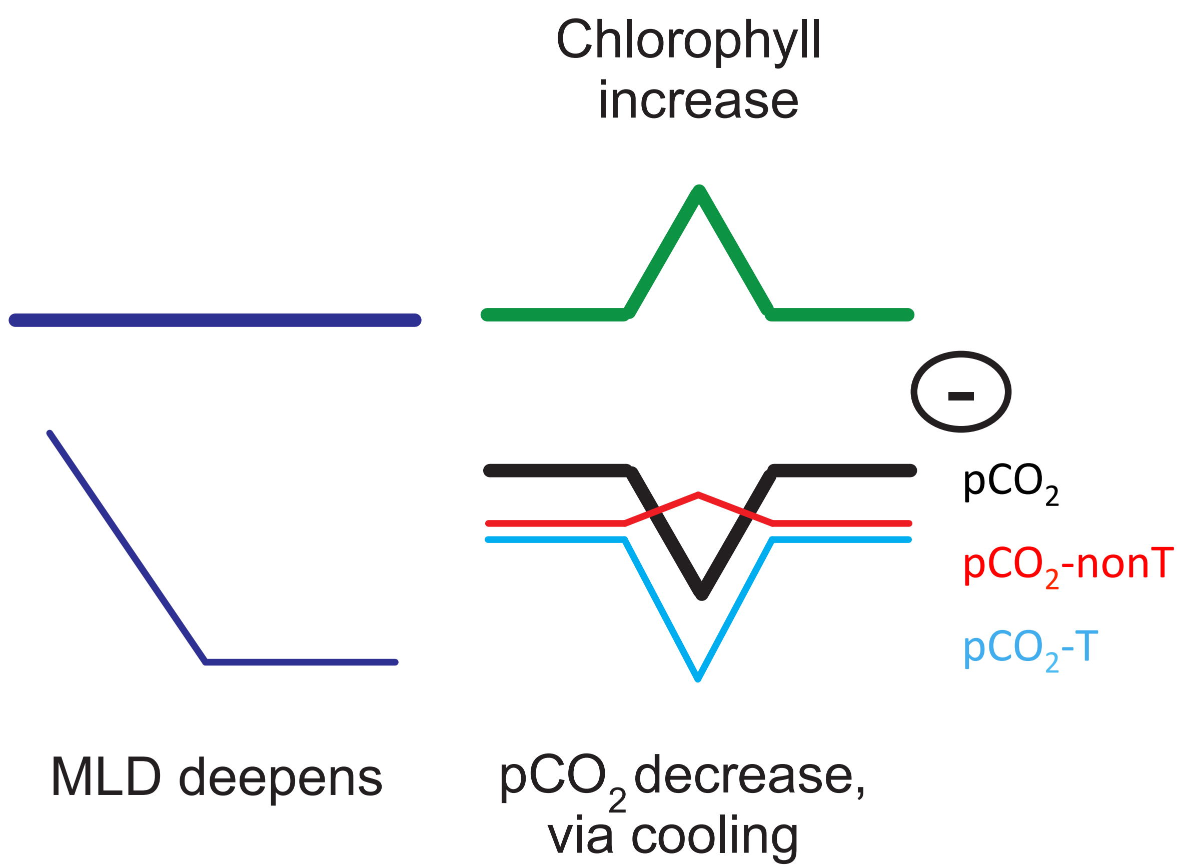

SO STSS logChl monthly means
logChl (mg/m3)
0
-0.5
-1
-1.5
2
4
6
8
10
12
Month


SO STSS pCO2 monthly means
pco2 (uatm)
500
400
300
200
2
4
6
8
10
12
Month

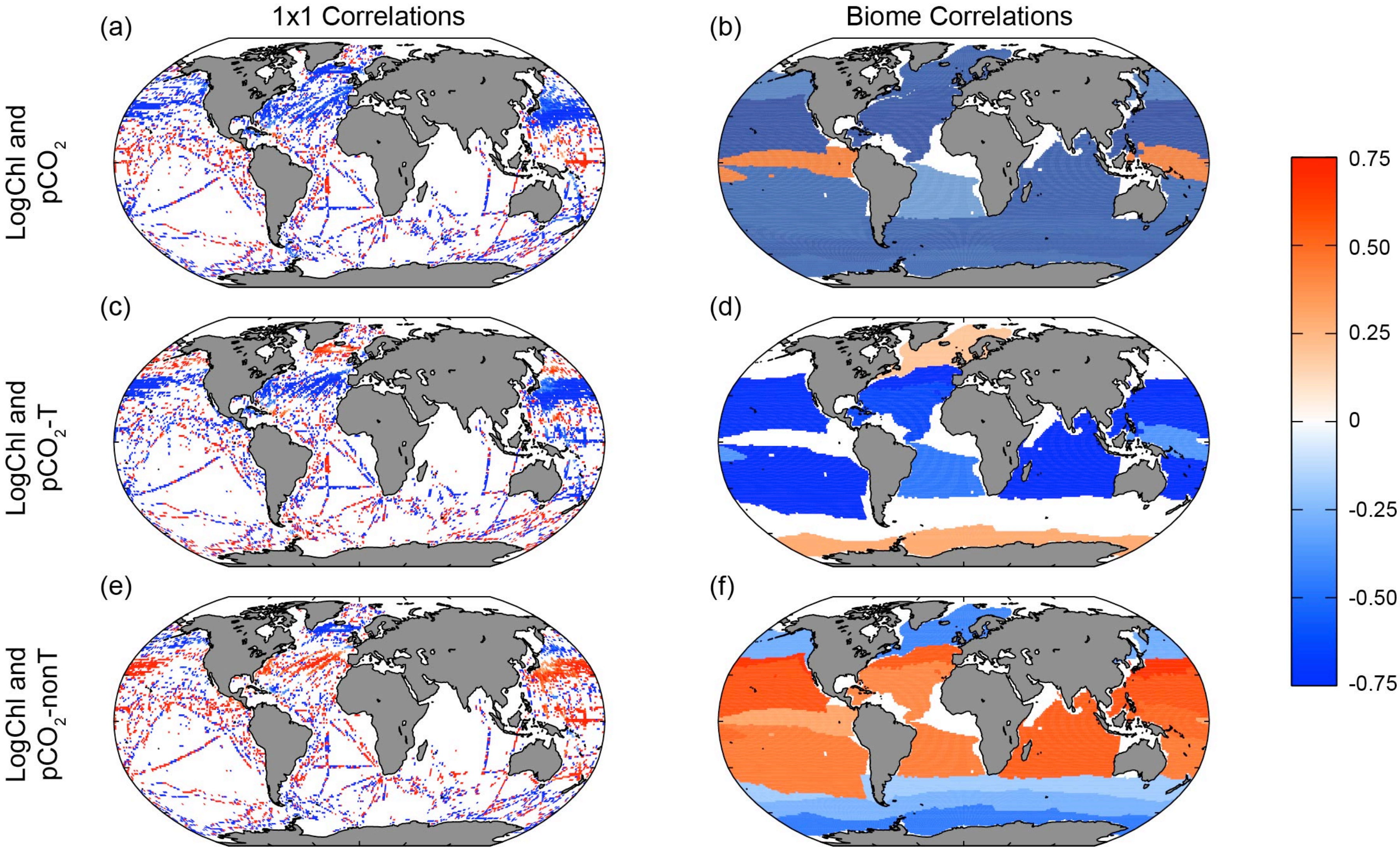


Fay and McKinley, 2017 GBC

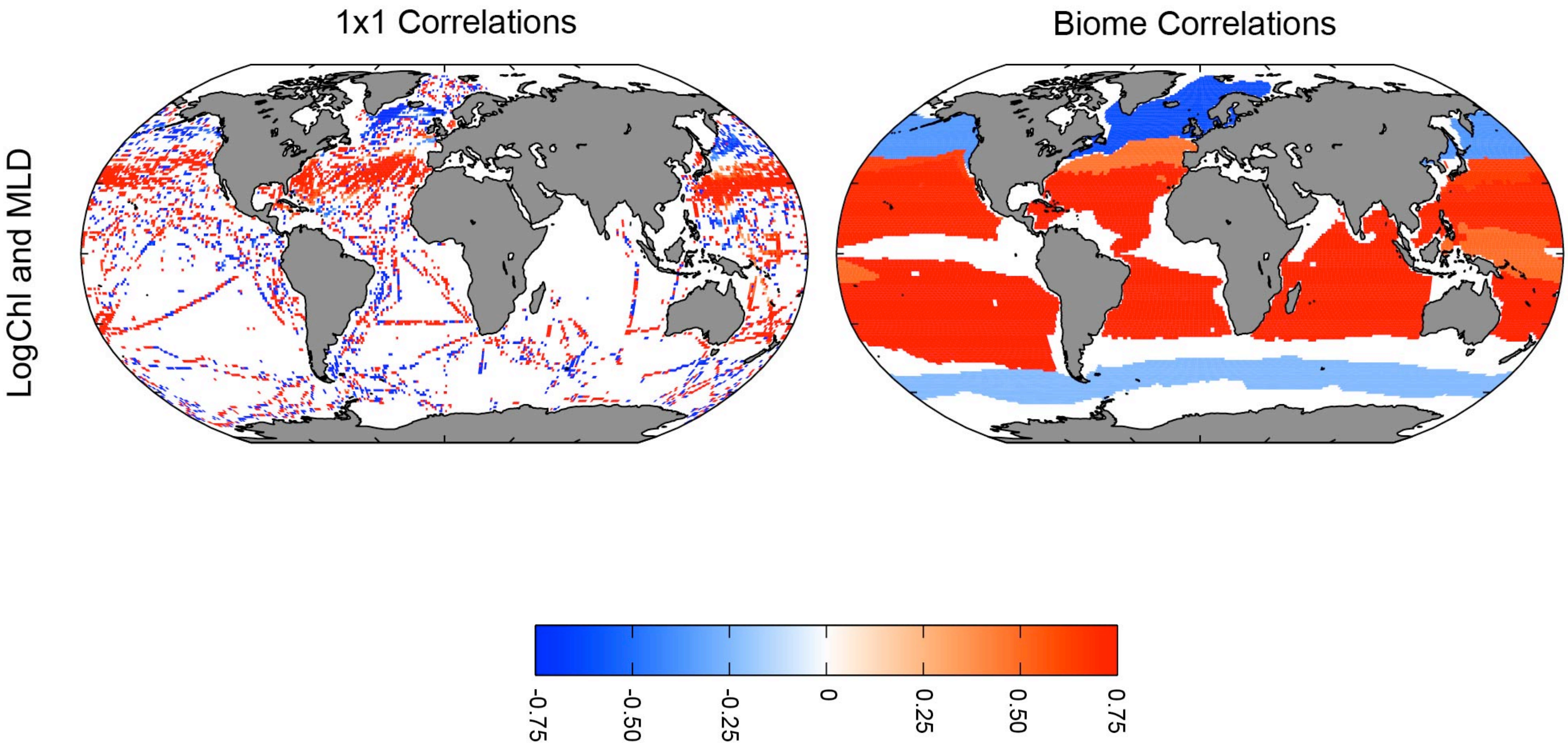
Typical subtropical dynamics
winter productive season, pCO_2-T dominant



Seasonal Chlorophyll to pCO_2 correlation

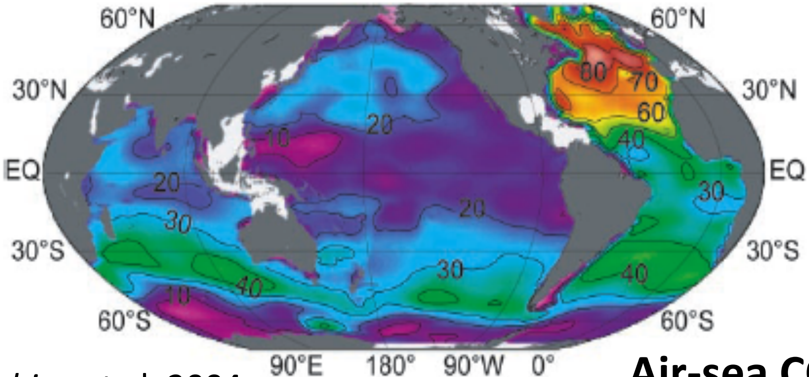


Seasonal Chlorophyll to MLD correlation



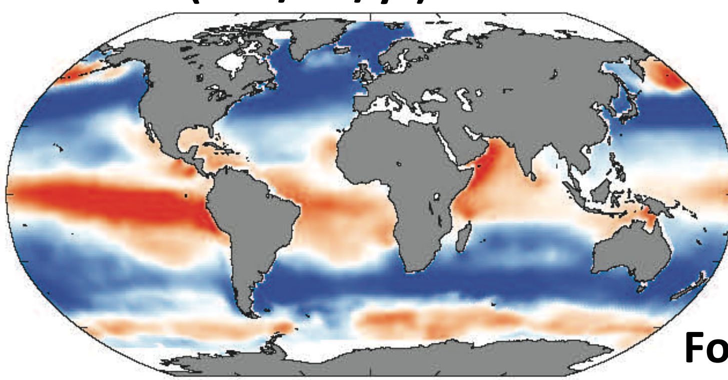
Fay and McKinley, GBC in review

Column-integrated anthropogenic carbon 1994 (mol/m^2) DATA



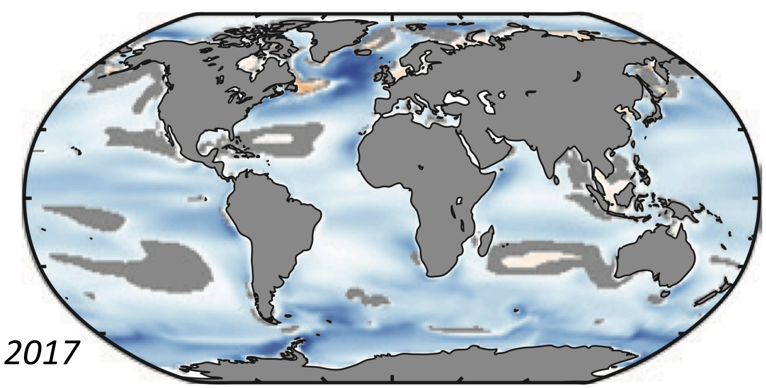
Sabine et al. 2004

Air-sea CO_2 flux 2000 ($mol/m^2/yr$) DATA



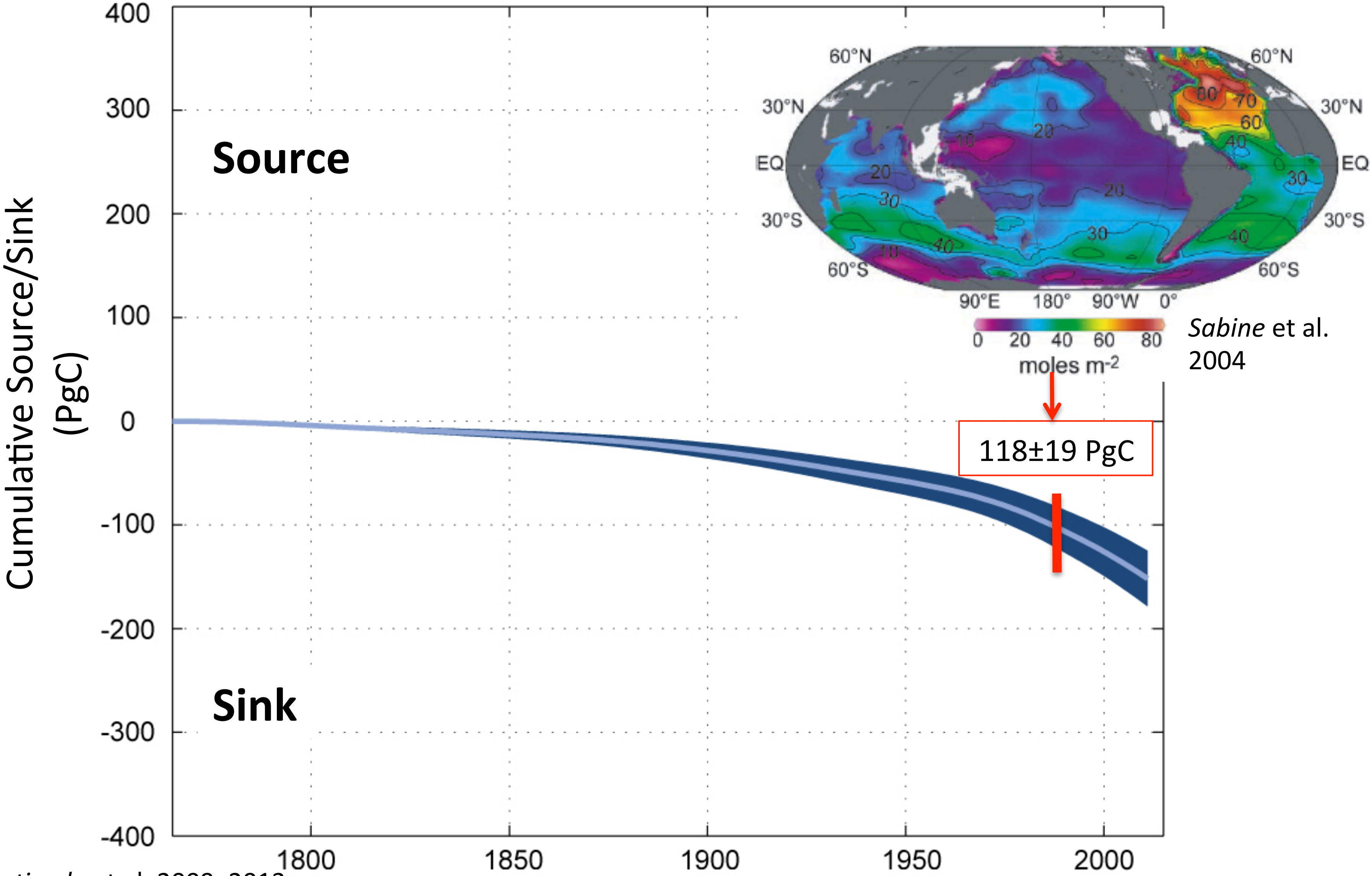
Landschutzer et al. 2014

Forced trend in CO_2 flux 1985-2015 ($mol/m^2/yr^2$) MODEL



McKinley et al. *2016, 2017*

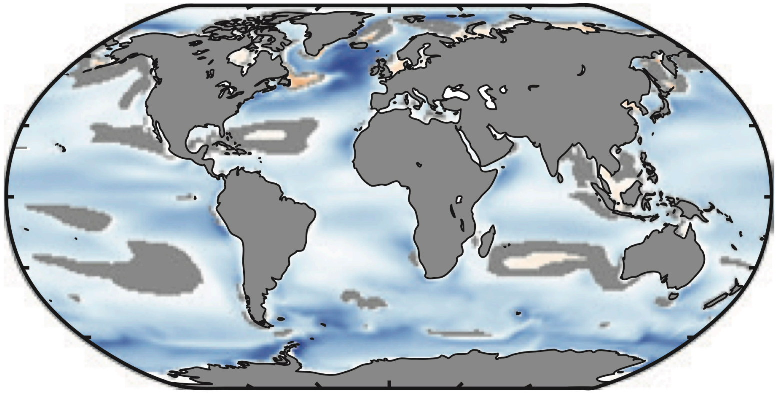
Increasing rate of anthropogenic CO_2 uptake from interior data, ***assuming constant circulation and biology***

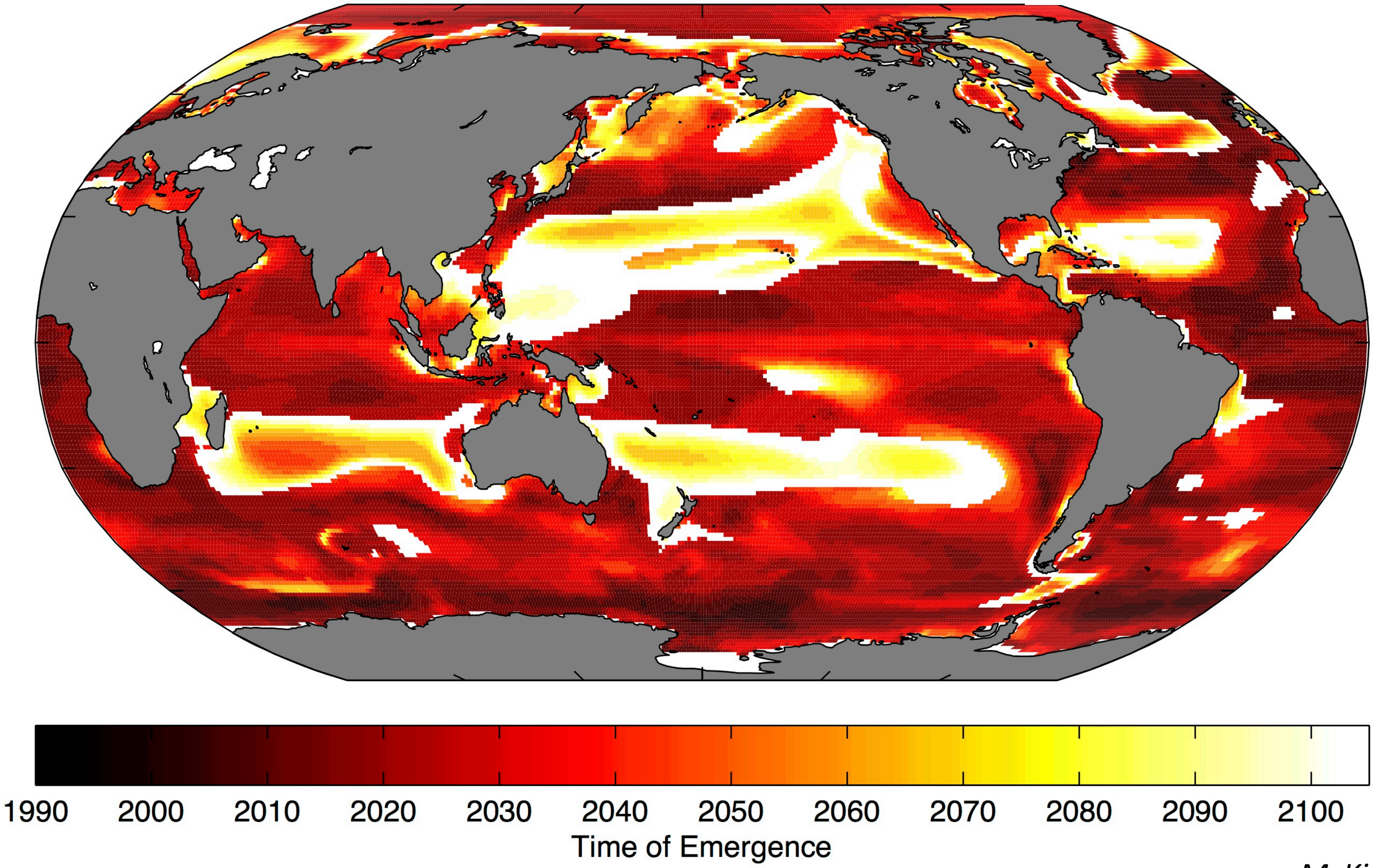


Sabine et al. 2004

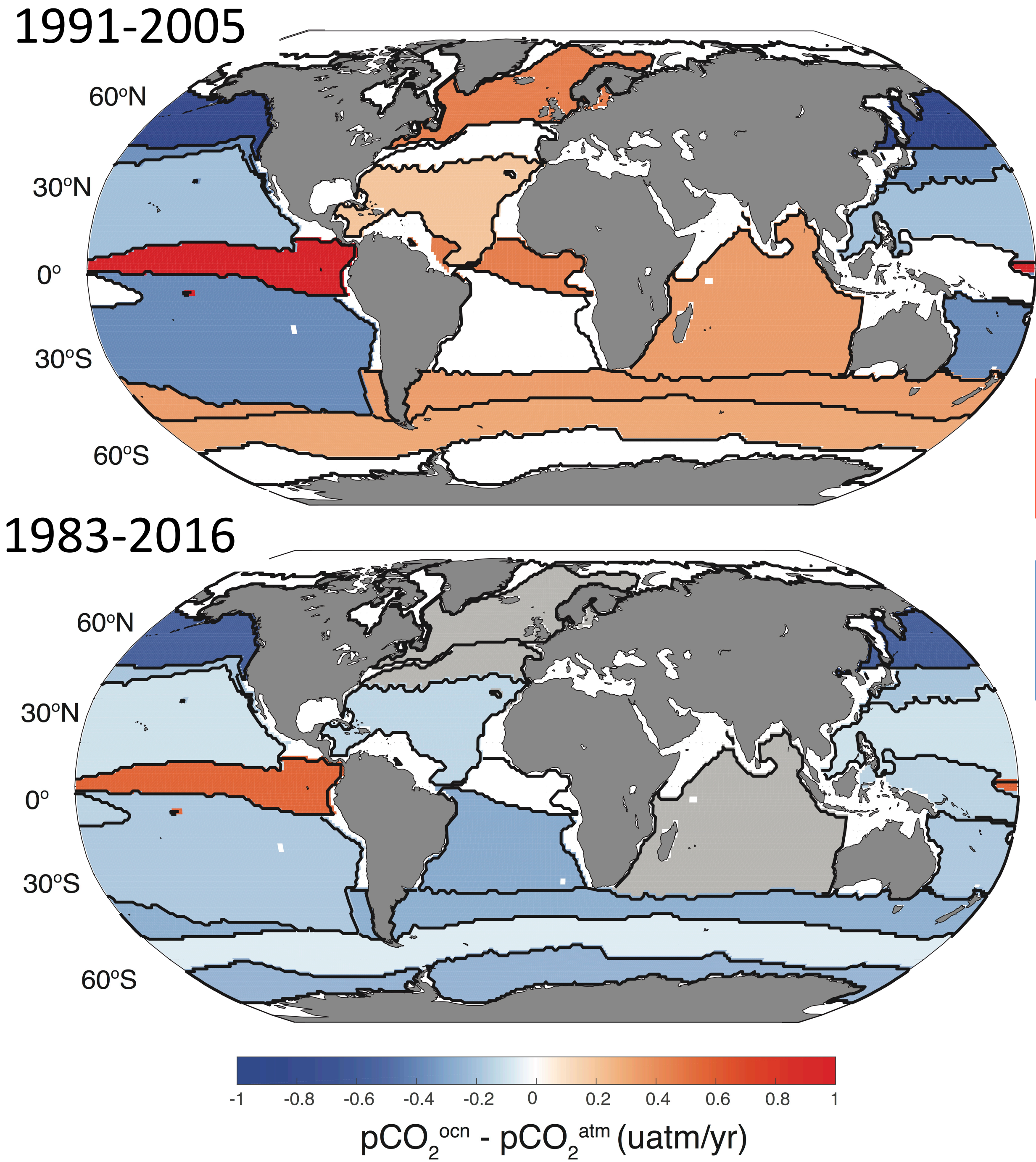
Khatiwala et al. 2009, 2013

Time of Emergence
= year sink change detectable if data since 1990





McKinley et al. 2016, Nature



$d\Delta pCO_2/dt > 0$

DECLINING SINK

$d\Delta pCO_2/dt < 0$

GROWING SINK

White: $d\Delta pCO_2/dt = 0$

Gray: no data for start and/or end year