Growth in the seasonal cycle of CO_2 in the Northern upper troposphere between the IGY and HIPPO

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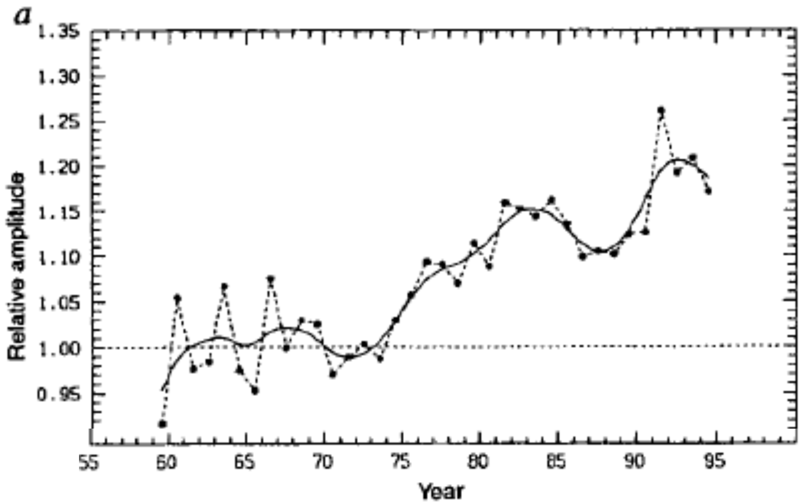
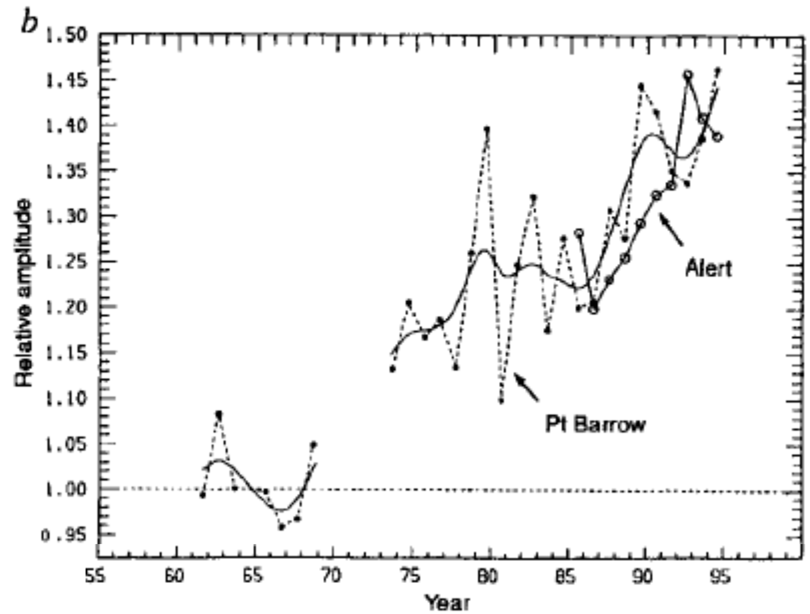
Seasonal amplitudes at Northern Hemisphere flask sites have grown by 20-40%

Mauna Loa



Point Barrow

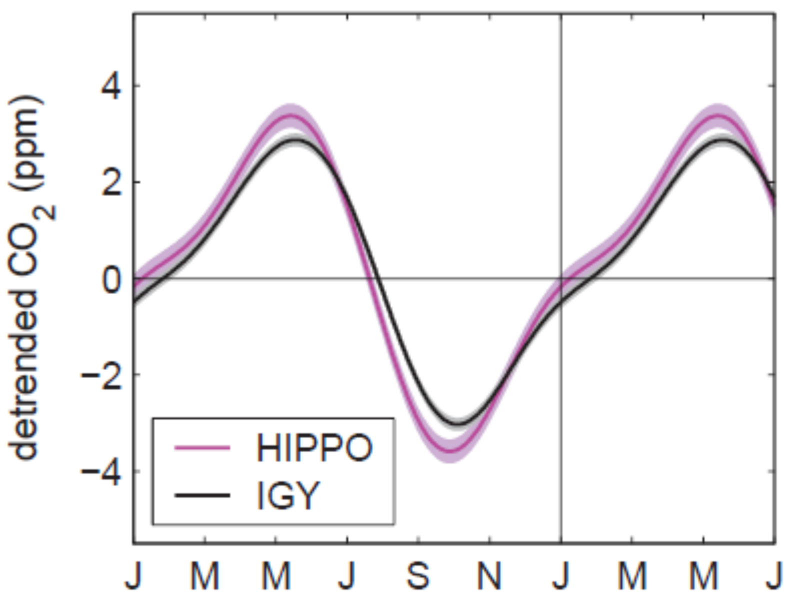


Keeling et al. 1996; Cleveland et al. 1983; Randerson et al. 1997, 1999

Comparison of seasonal cycles between the IGY and HIPPO eras at flask sites

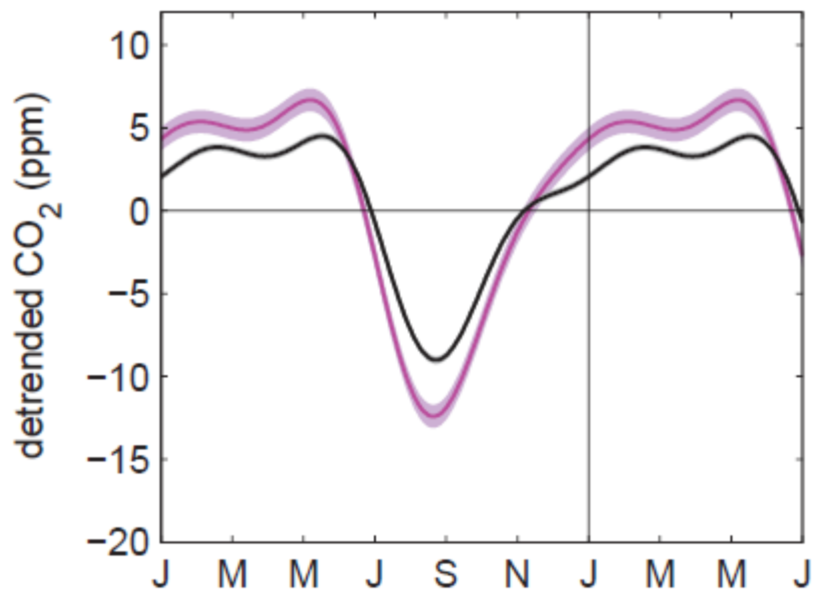
Mauna Loa

1961-64 and 2009-11 means
18 ± 7 % increase in amplitude



Point Barrow

1961-64 and 2009-11 means
41 ± 8 % increase in amplitude



Uncertainties based on biweekly standard error in 3-harmonic fits

Proposed causes of larger CO_2 cycle:

- Plant activity
  - CO_2 fertilization
  - N fertilization
  - Warming-induced spring uptake
  - Warming-induced autumn respiration
- Atmospheric transport
- Fossil fuel emissions
- Disturbance

e.g. Cleveland et al. 1983; Bacastow et al. 1985; Kohlmaier et al. 1989; Keeling et al. 1996; Chapin et al. 1996; Randerson et al. 1997; Piao et al. 2008

Similar observations of a growing cycle in upper air have not yet been possible, but they might:

- Demonstrate that changes are occurring at large scales
- Demonstrate that changes are not a result of varying vertical transport
- Help to identify responsible causes and source regions

International Geophysical Year CO_2 observations

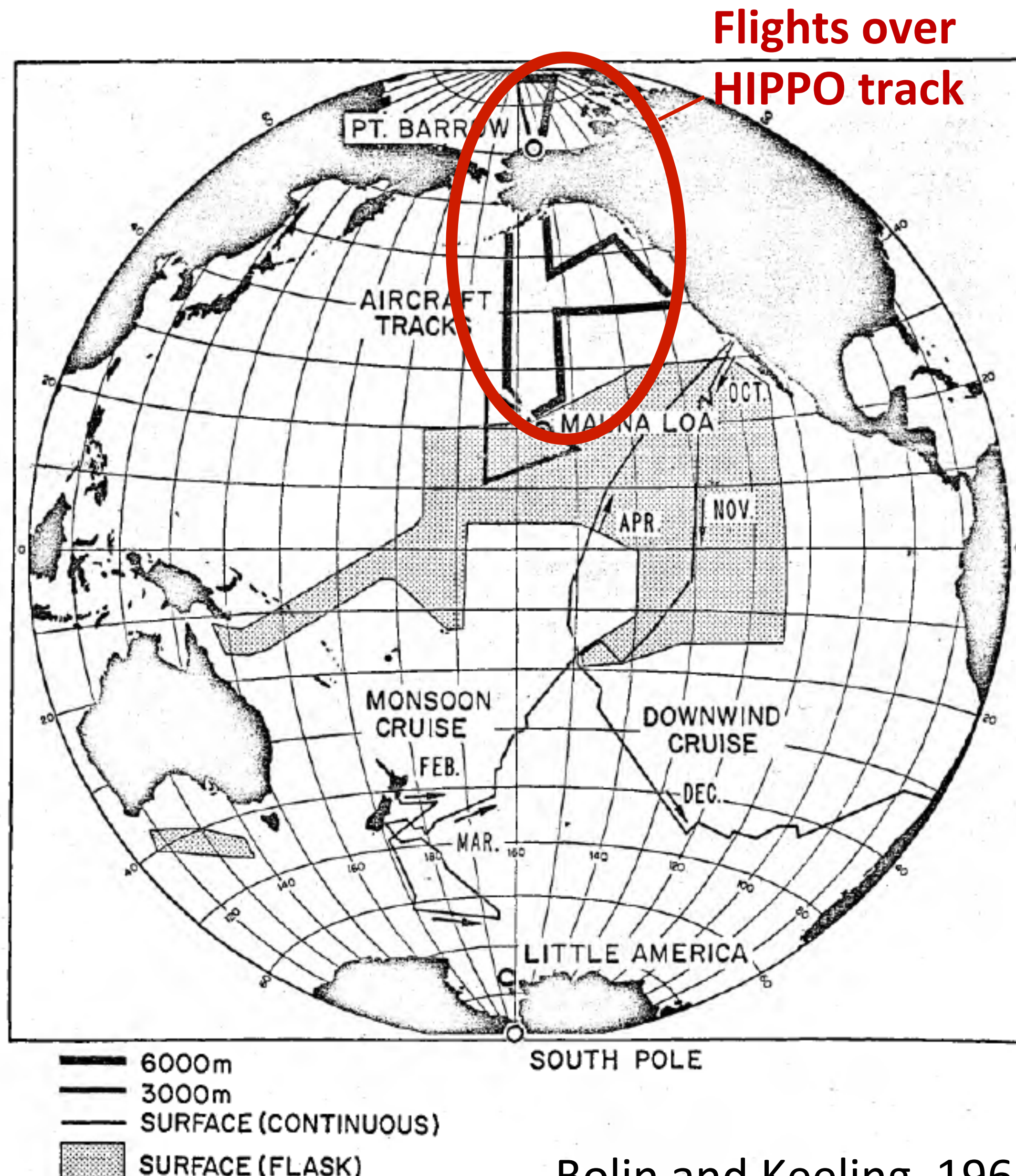
Conducted 1958-61 by US Air Force, weather reconnaissance flights

Flying at 500 or 700mb

Flights occurred during all seasons

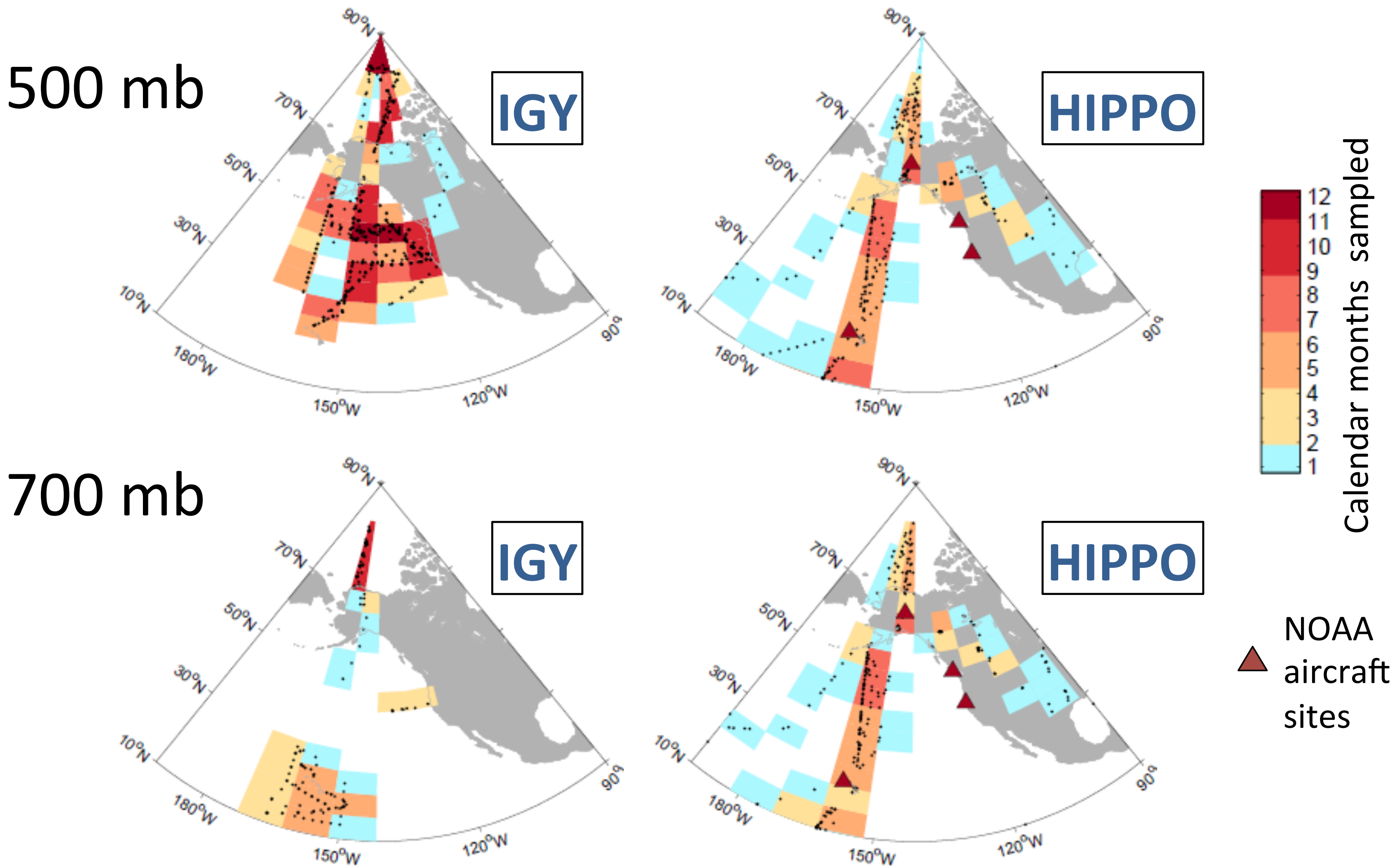
12 flasks sampled each flight, analyzed at SIO

Data updated to current SIO x08A scale



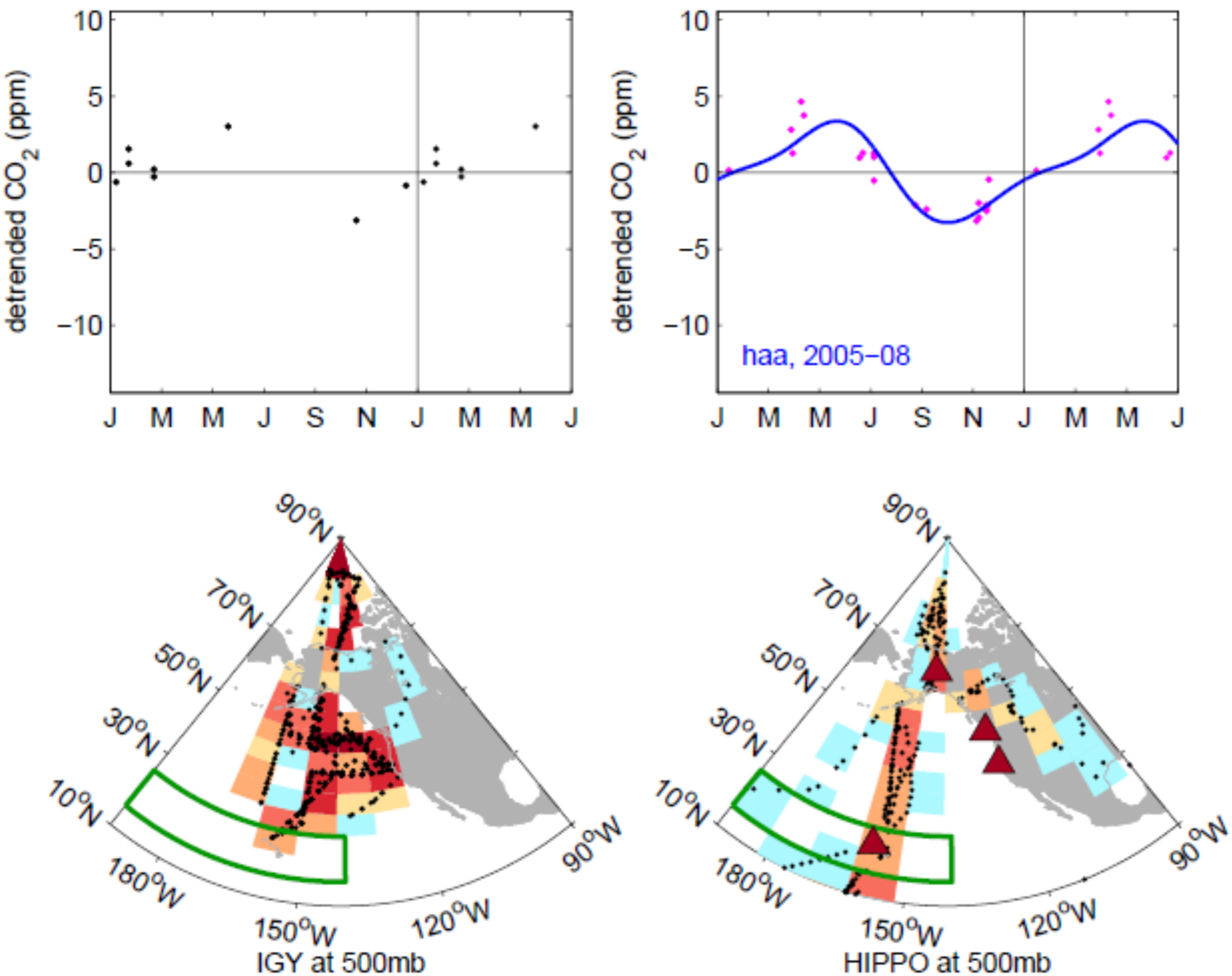
Bolin and Keeling, 1963
Keeling et al. 1968

Sampling locations in each era



Comparison at 500 mb, 15-25°N

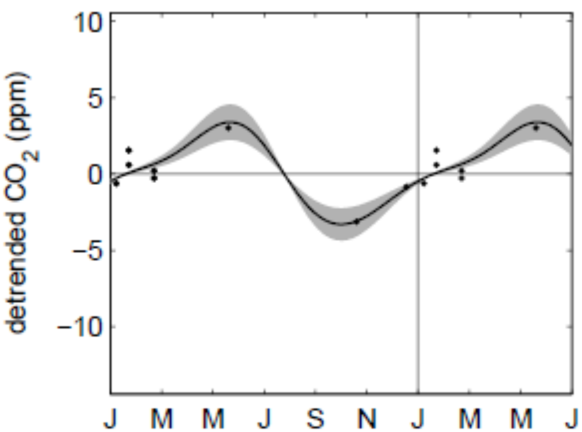
IGY HIPPO (QCLS)



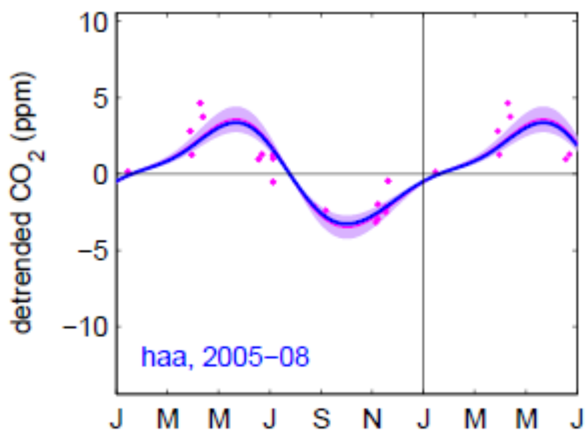
- Bin data by 10° zonal bands
- Assume shape of seasonal cycle using NOAA data
- Optimize gain in seasonal amplitude

Comparison at 500 mb, 15-25°N

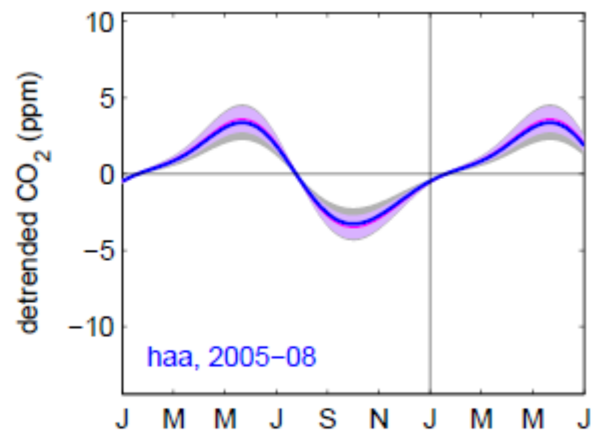
IGY

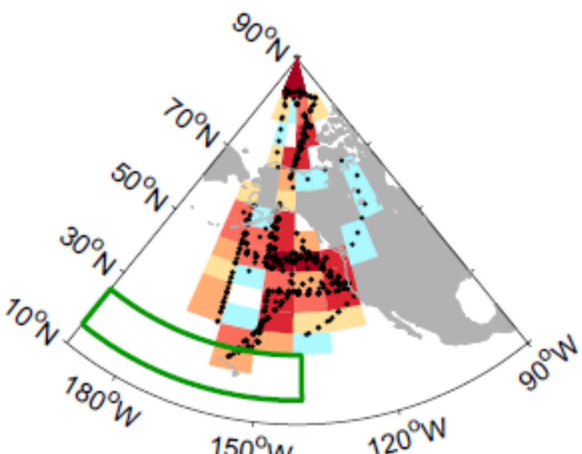


HIPPO

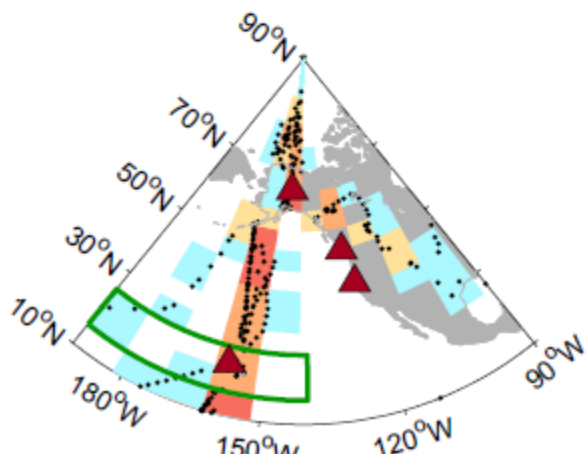


+6 ± 40%





IGY at 500mb

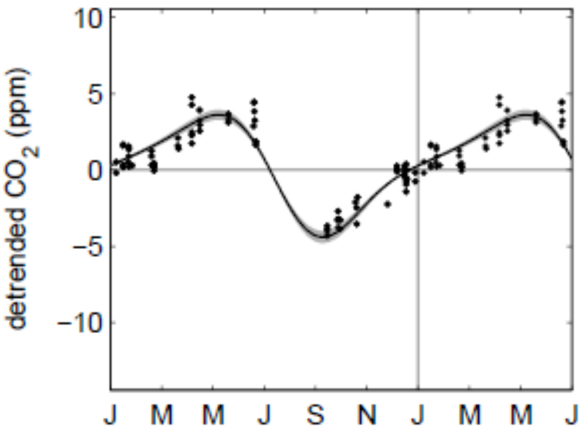


HIPPO at 500mb

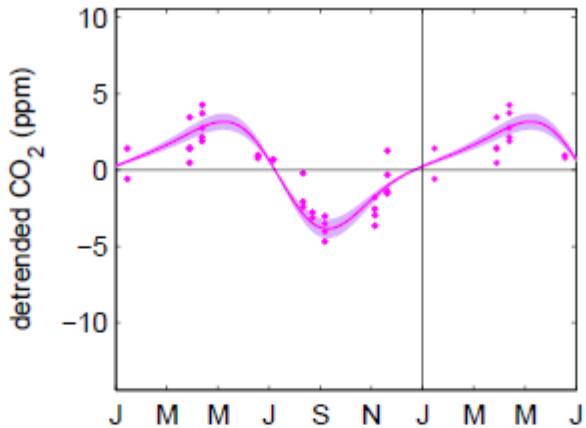
- No detectable change in amplitude

Comparison at 500 mb, 25-35°N

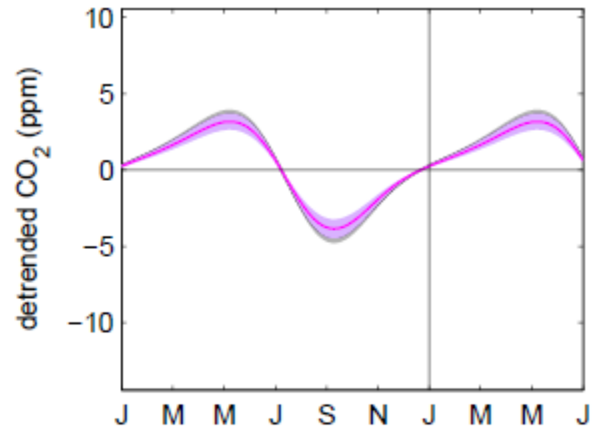
IGY

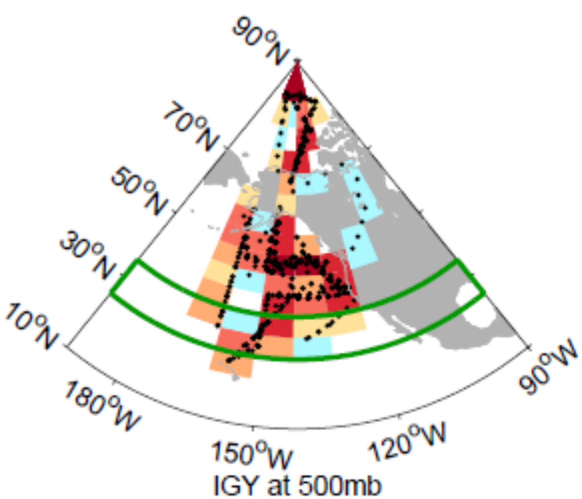


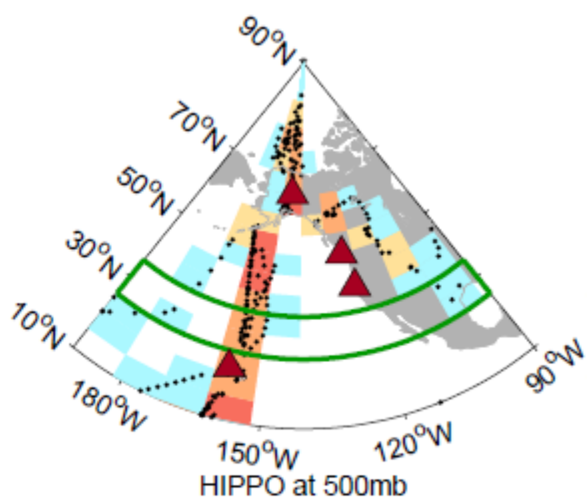
HIPPO



-12 ± 17%



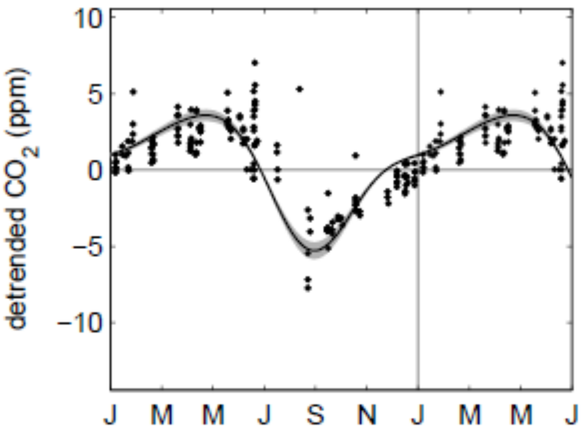




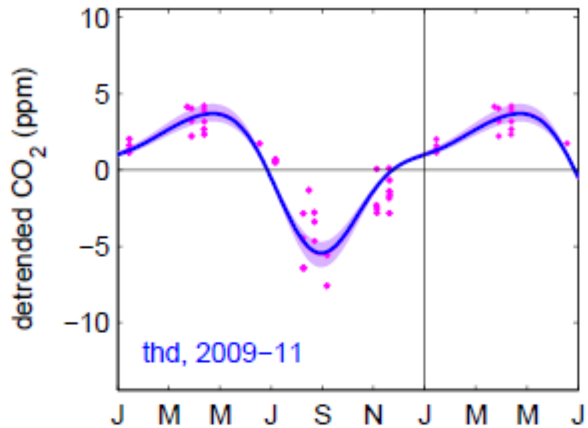
- No detectable change in amplitude

Comparison at 500 mb, 35-45°N

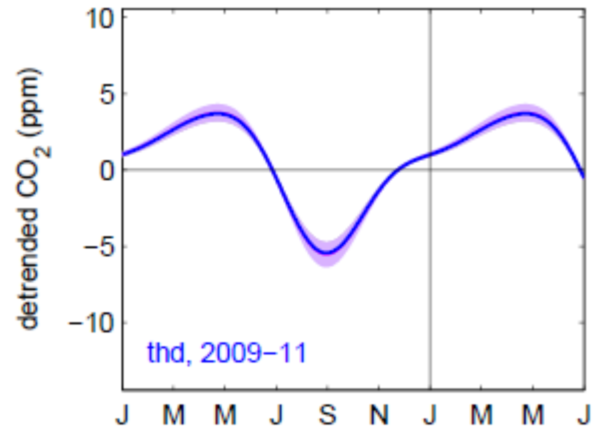
IGY

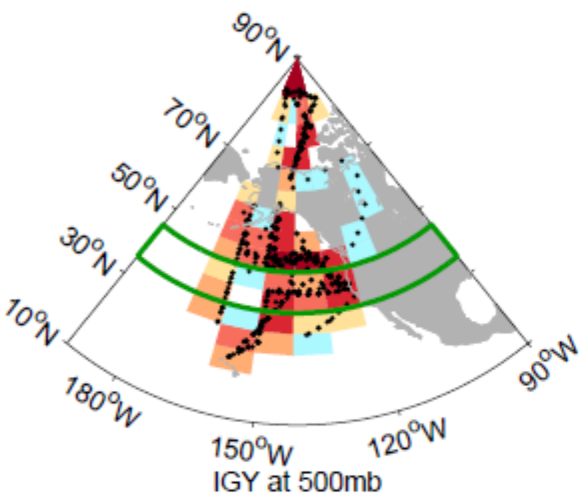


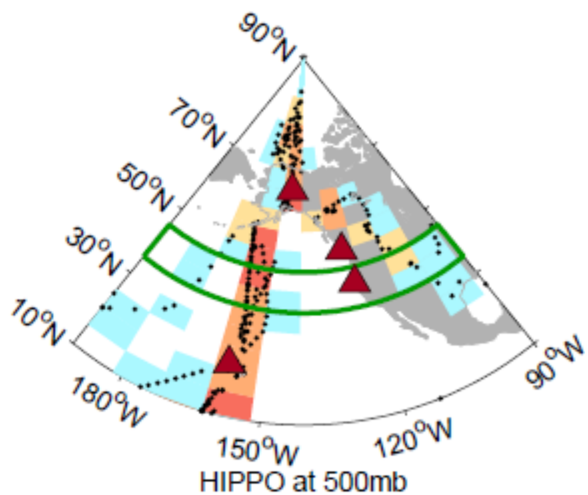
HIPPO



+5 ± 19%



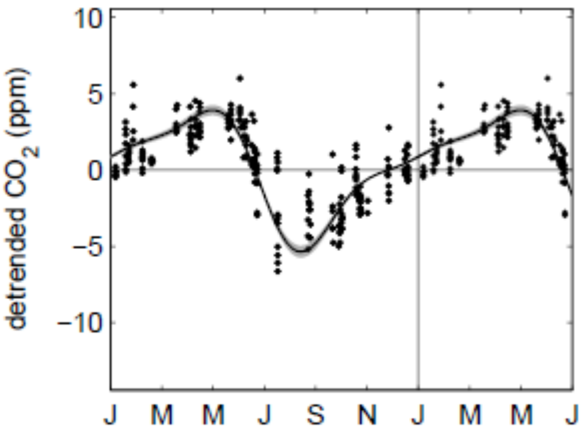




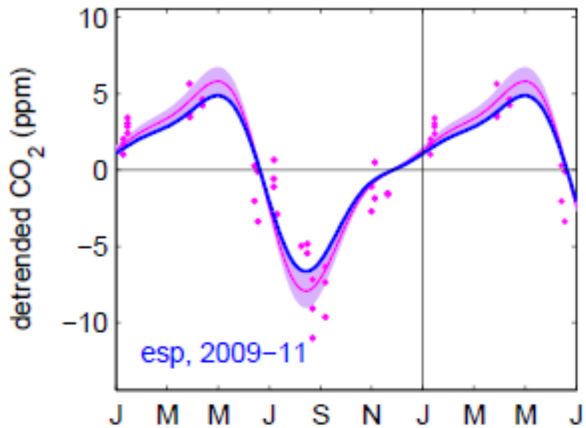
- No detectable change in amplitude

Comparison at 500 mb, 45-55°N

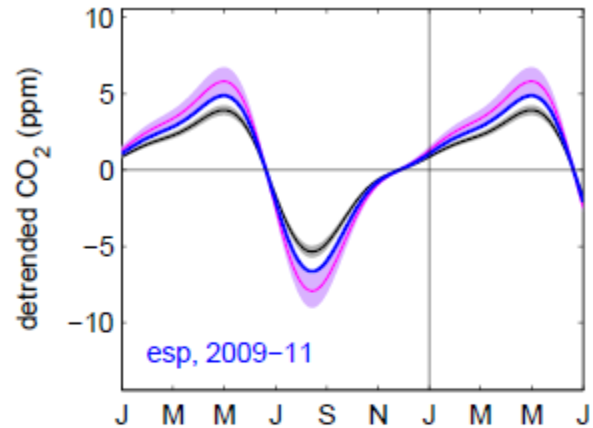
IGY

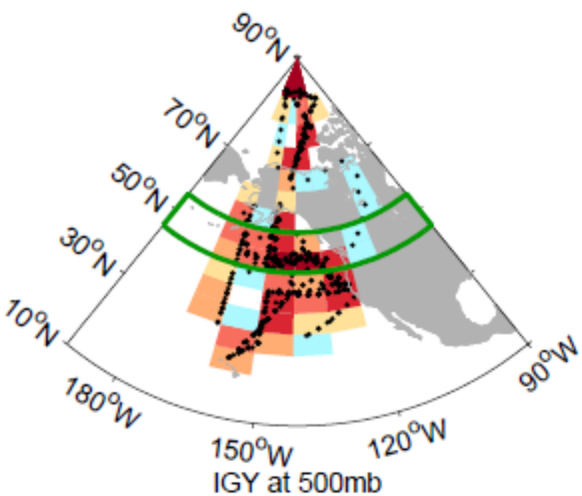


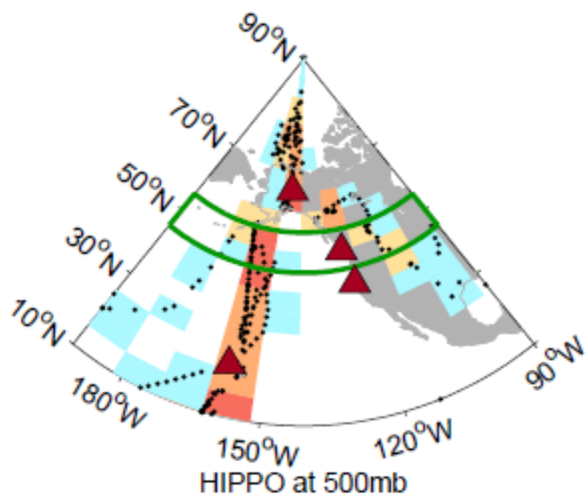
HIPPO



+48 ± 23%



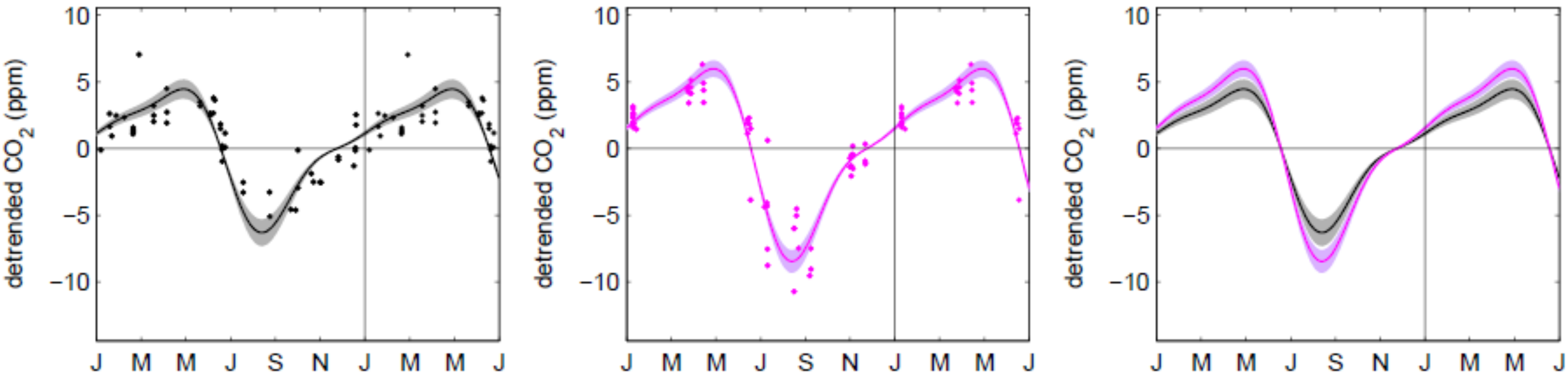


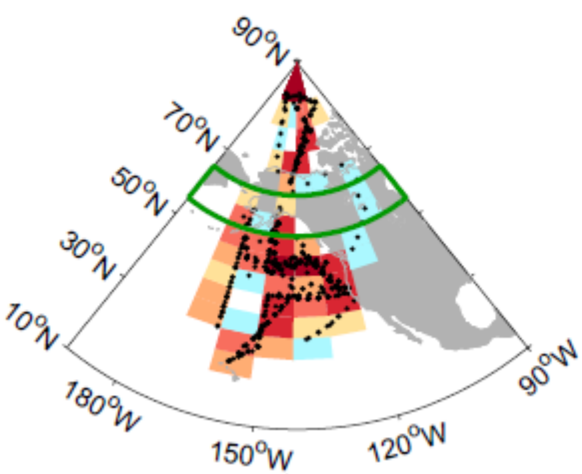


- Detectable increase in amplitude

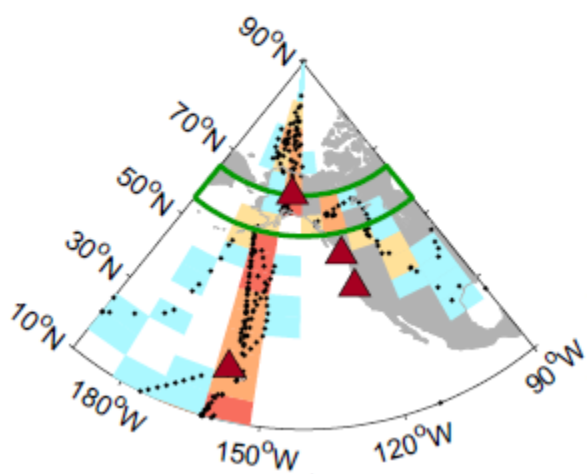
Comparison at 500 mb, 55-65°N

IGY HIPPO +34 ± 21%





IGY at 500mb

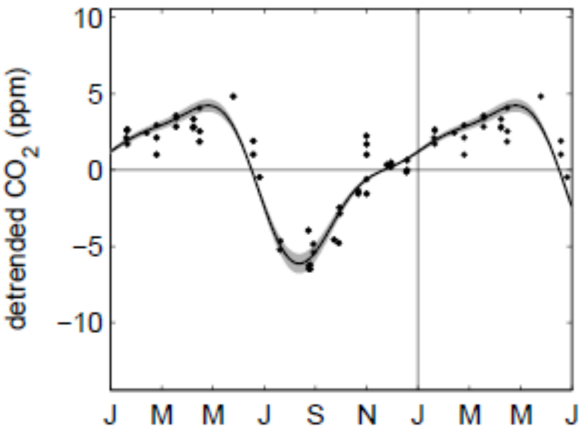


HIPPO at 500mb

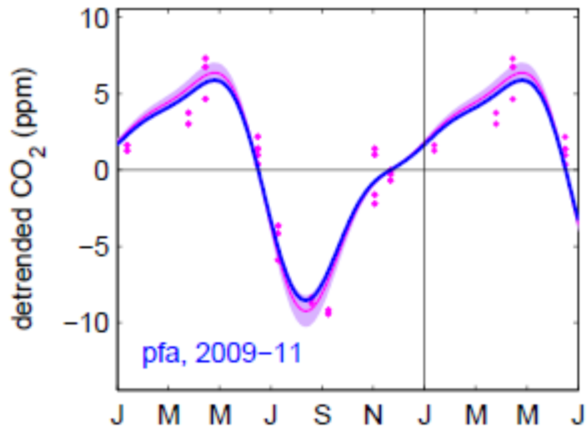
- Detectable increase in amplitude

Comparison at 500 mb, 65-75°N

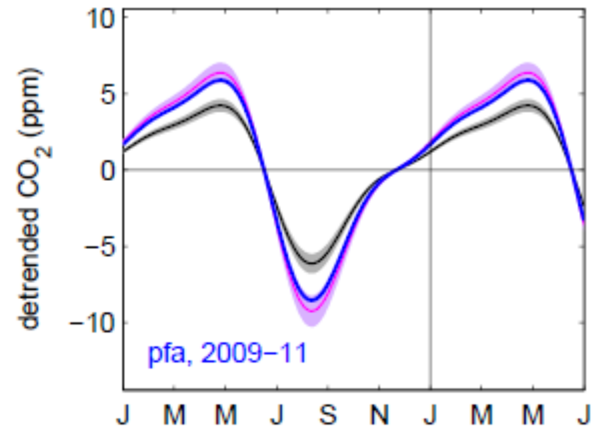
IGY

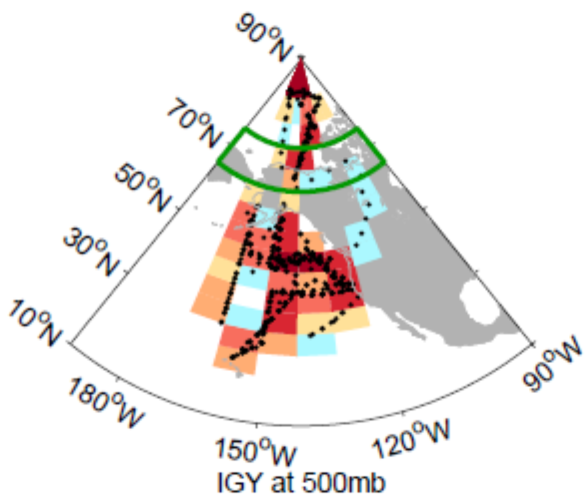


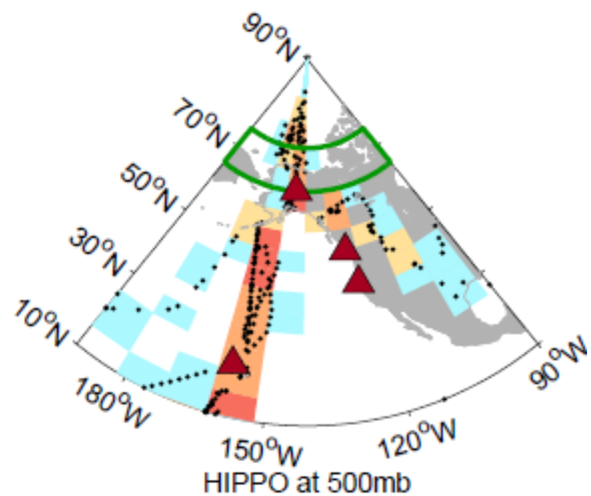
HIPPO



+50 ± 19%

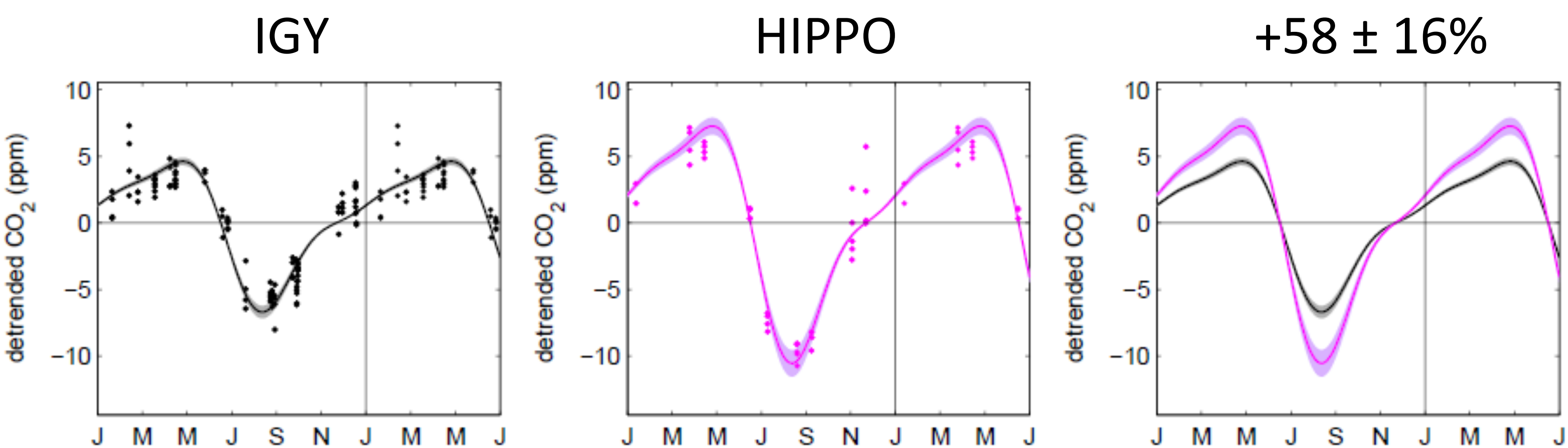


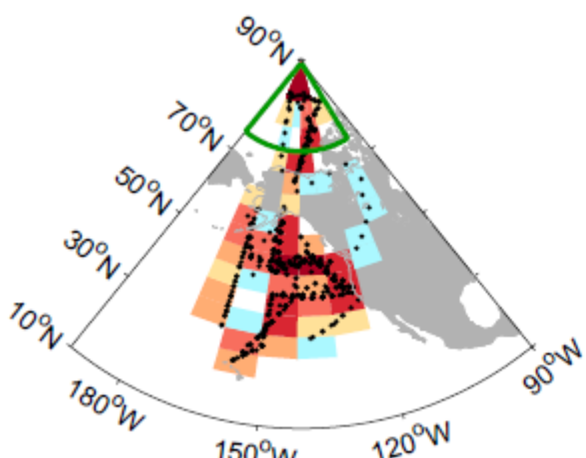




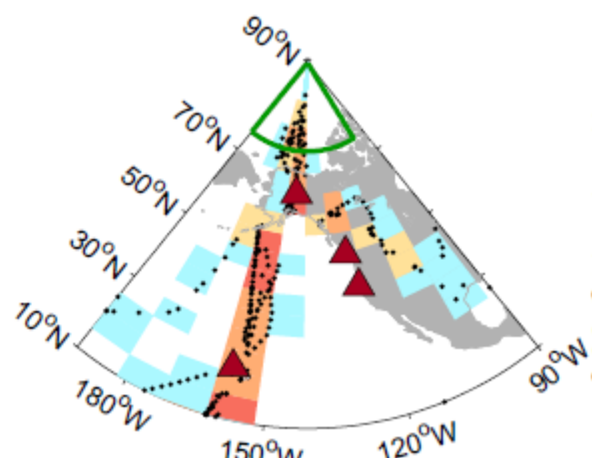
- Detectable increase in amplitude

Comparison at 500 mb, 75-90°N





IGY at 500mb



HIPPO at 500mb

- Detectable increase in amplitude

Observed change in amplitude, by latitude and altitude

in percent

	15-25°N	25-35°N	35-45°N	45-55°N	55-65°N	65-75°N	75-90°N
500 mb	0%	0%	0%	+50%	+30%	+50%	+60%
700 mb	+20% MLO	--	--	--	**--**	+30%	+50%
1000 mb	**--**	**--**	**--**	+30% STP	**--**	+40% PTB	**--**

Observed change in amplitude, by latitude and altitude

in percent

	15-25°N	25-35°N	35-45°N	45-55°N	55-65°N	65-75°N	75-90°N
500 mb	0%	0%	0%	+50%	+30%	+50%	+60%
700 mb	+20% MLO	--	--	--	--	+30%	+50%
1000 mb	--	--	--	+30% STP	--	+40% PTB	--

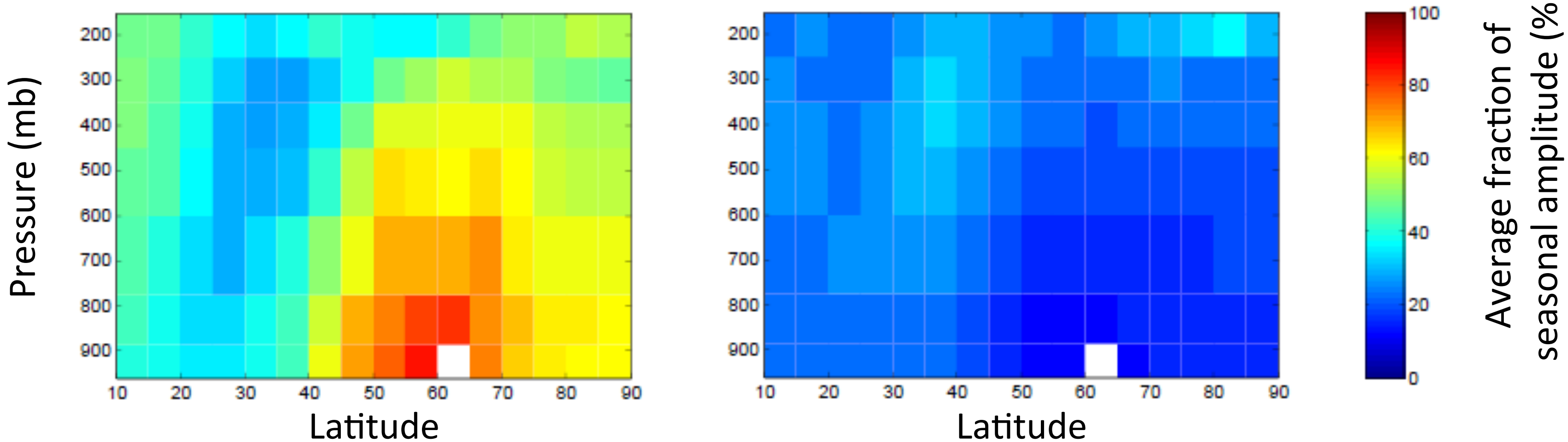
in ppm

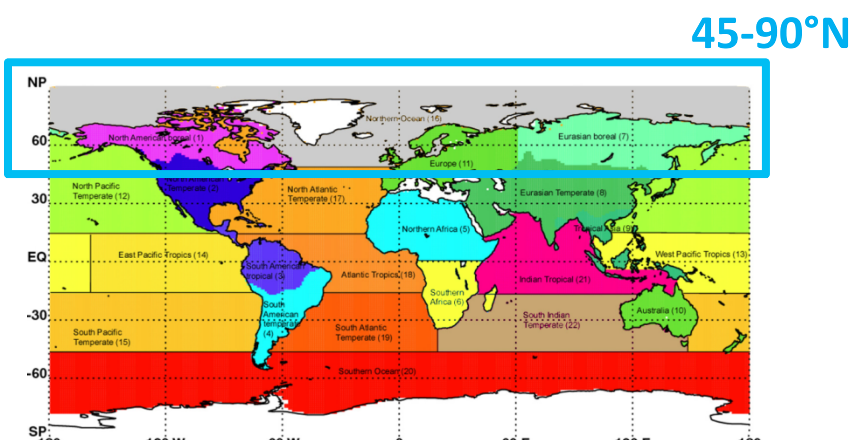
	15-25°N	25-35°N	35-45°N	45-55°N	55-65°N	65-75°N	75-90°N
500 mb	0 ppm	0 ppm	0 ppm	+4 ppm	+4 ppm	+5 ppm	+7 ppm
700 mb	+1 ppm	--	--	--	--	+4 ppm	+7 ppm
1000 mb	--	--	--	+4 ppm	--	+6 ppm	--

Boreal land fluxes are the main influence on Northern Hemisphere seasonal cycles

Boreal Asia, Boreal N. America and Europe

Temperate Asia and Temperate N. America



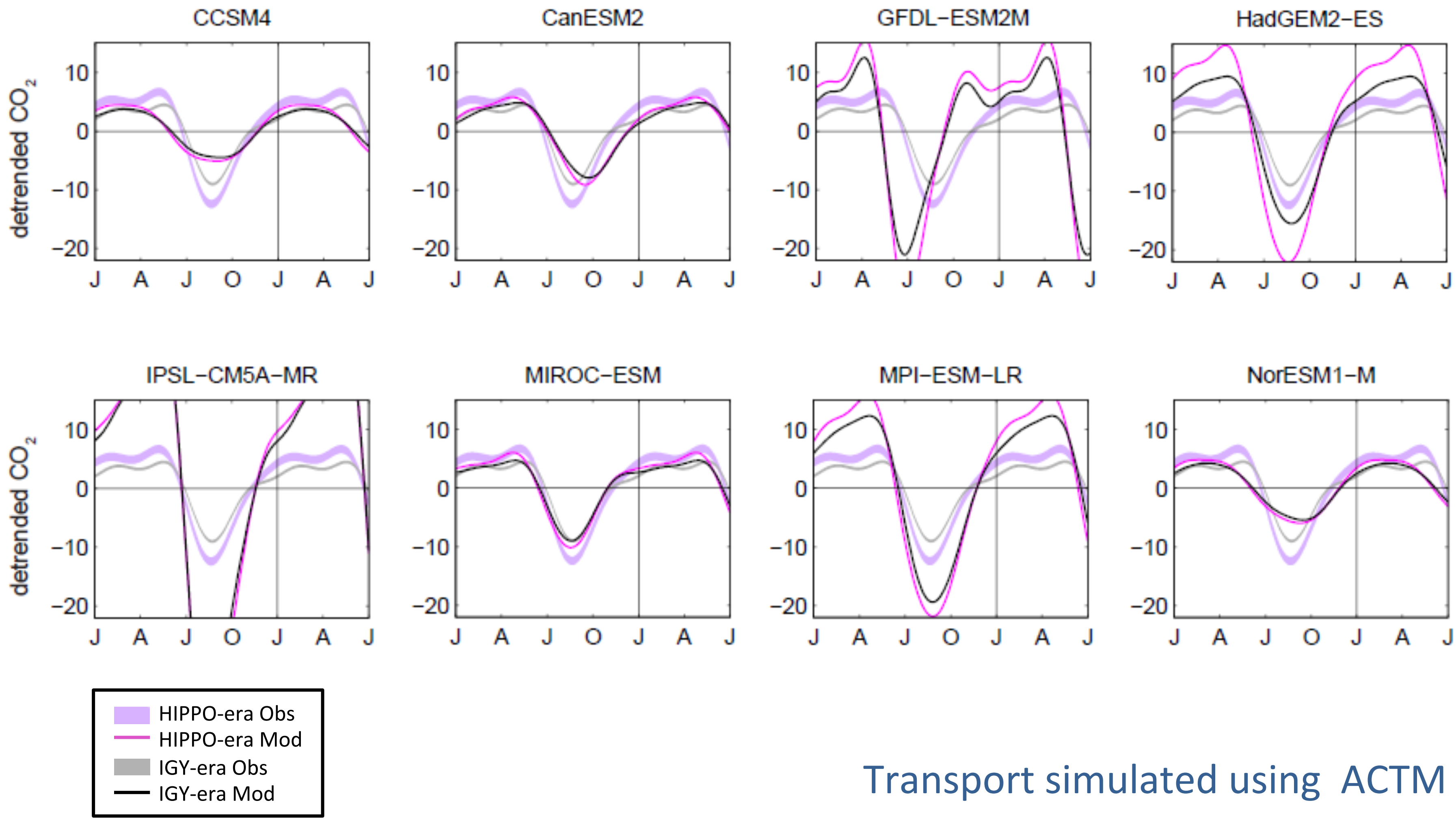


Average contributions to seasonal cycle in 5 Transcom3 models at 140°W, using Transcom3 pre-subtraction fluxes for fossil, ocean and land (CASA) to define total amplitude

Observations suggest a large-scale change in boreal fluxes occurred between the IGY and HIPPO

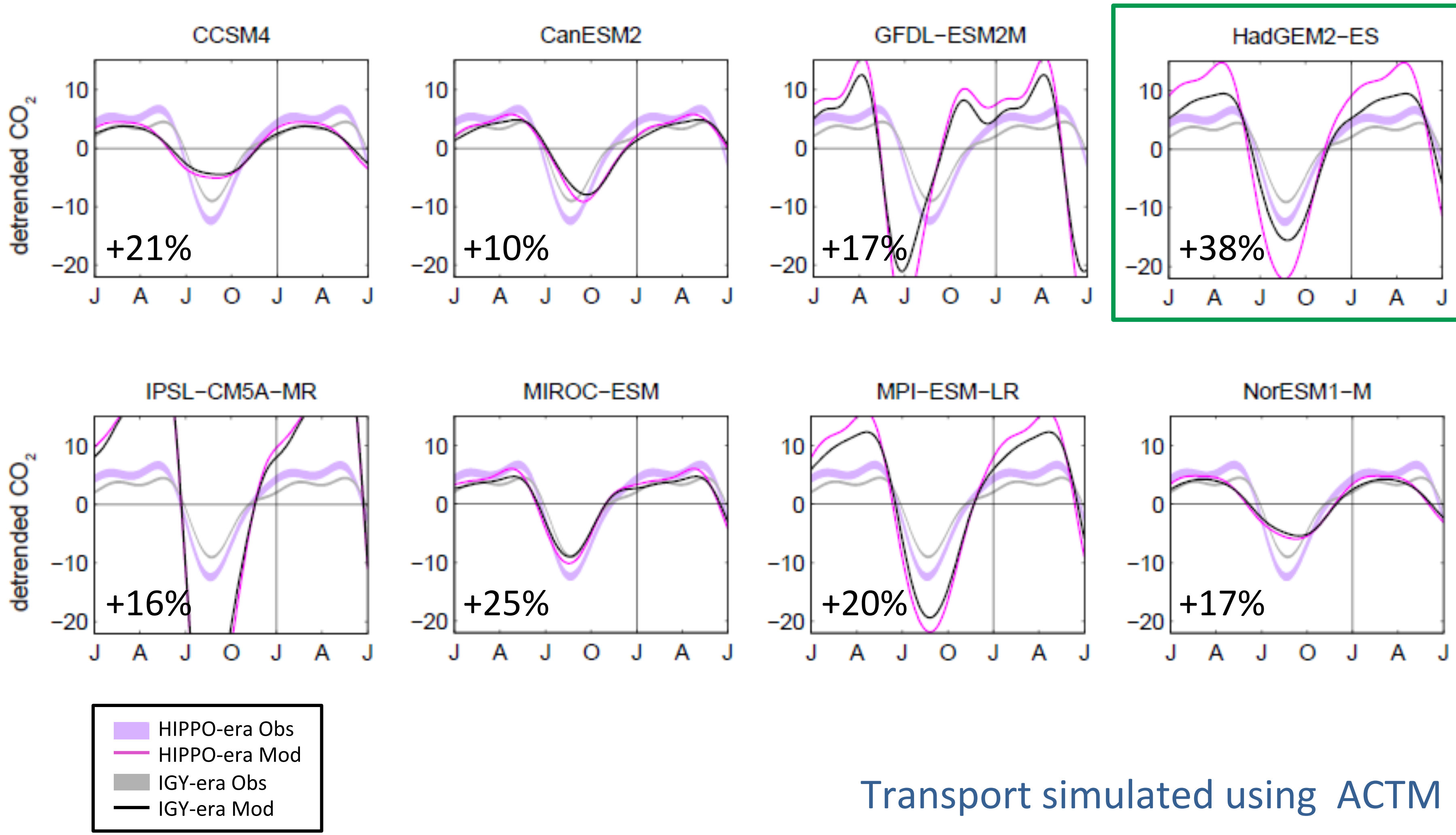
Is this change predicted by the land models participating in CMIP5 for the IPCC AR5?

Do any of the CMIP5 models predict the observed change in the CO_2 cycle at Point Barrow?



Transport simulated using ACTM

Do any of the CMIP5 models predict the observed change in the CO_2 cycle at Point Barrow?



Transport simulated using ACTM

Is the fractional change in CO_2 amplitude in HadGEM2 + ACTM consistent with observations aloft?

Observed

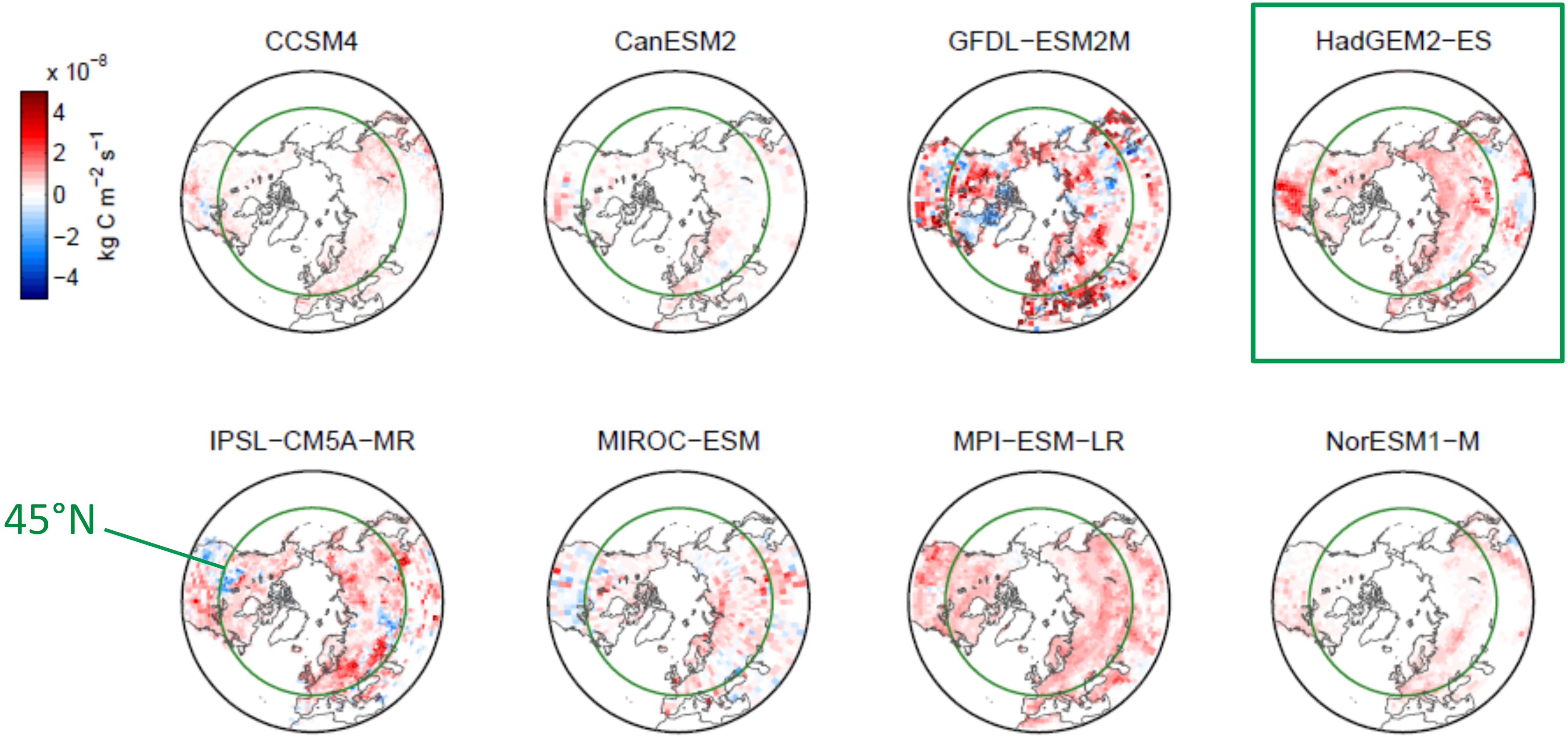
	15-25°N	25-35°N	35-45°N	45-55°N	55-65°N	65-75°N	75-90°N
500 mb	0%	0%	0%	+50%	+30%	+50%	+60%
700 mb	+20% MLO	--	--	--	--	+30%	+50%
1000 mb	--	--	--	+30% STP	--	+40% PTB	--

HadGEM2-ES + ACTM

More intense *Less intense*

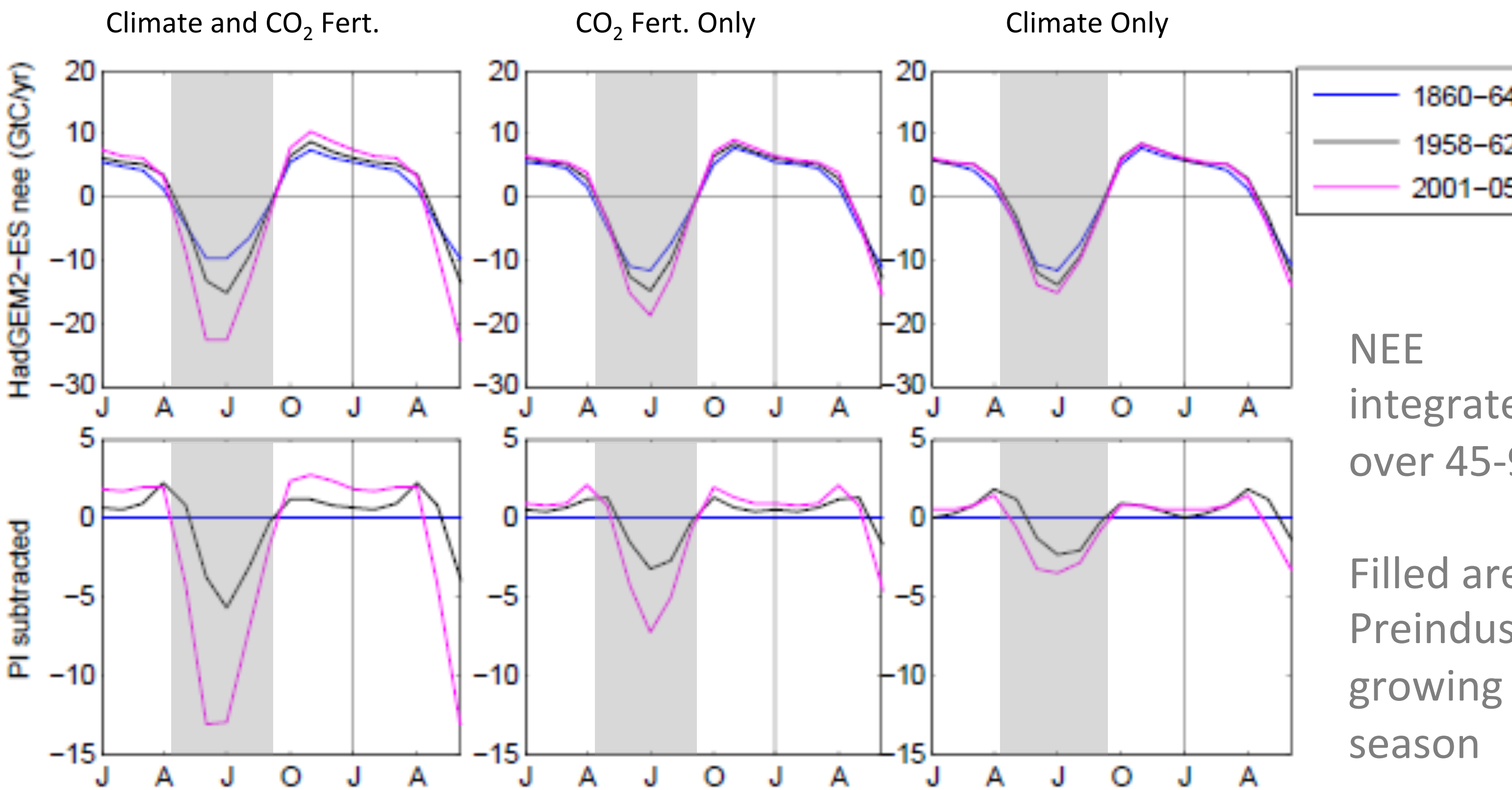
	15-25°N	25-35°N	35-45°N	45-55°N	55-65°N	65-75°N	75-90°N
500 mb	+20%	+20%	+25%	+30%	+30%	+30%	+30%
700 mb	+20%	+20%	+30%	+30%	+30%	+30%	+30%
1000 mb	+35%	+30%	+35%	+40%	+40%	+40%	+40%

Spatial pattern of the change in NEE amplitude



How is the boreal NEE cycle impacted by climate change vs. CO_2 fertilization in CMIP5 models?

HadGEM2-TRIFFID



NEE integrated over 45-90°N

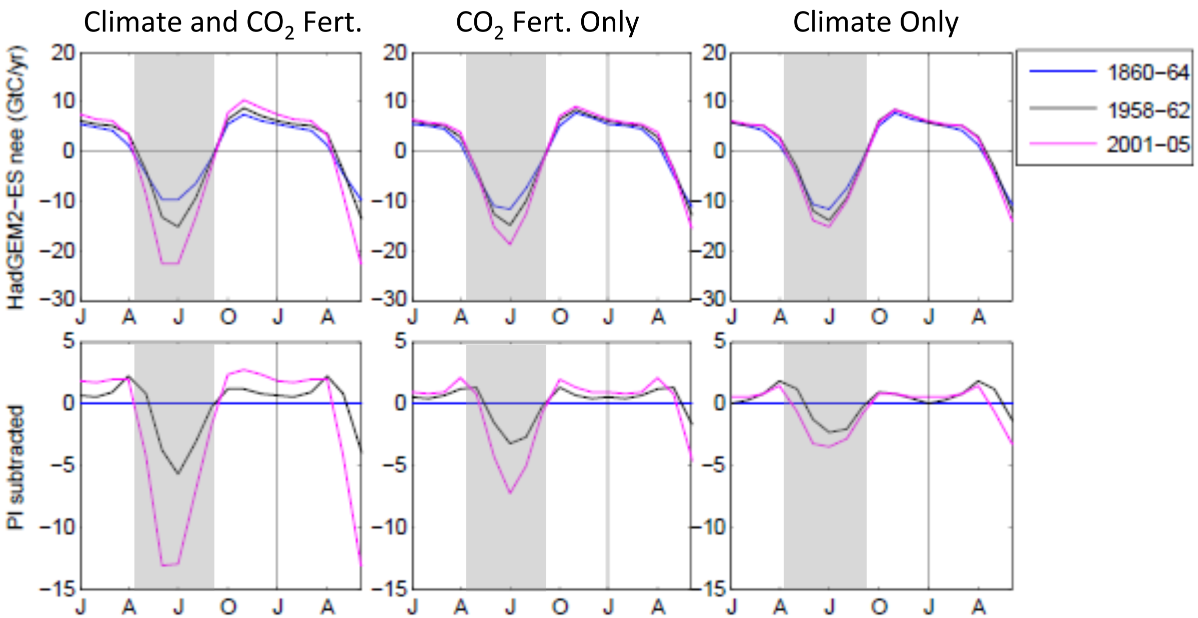
Filled area: Preindustrial growing season

Significant change already by IGY

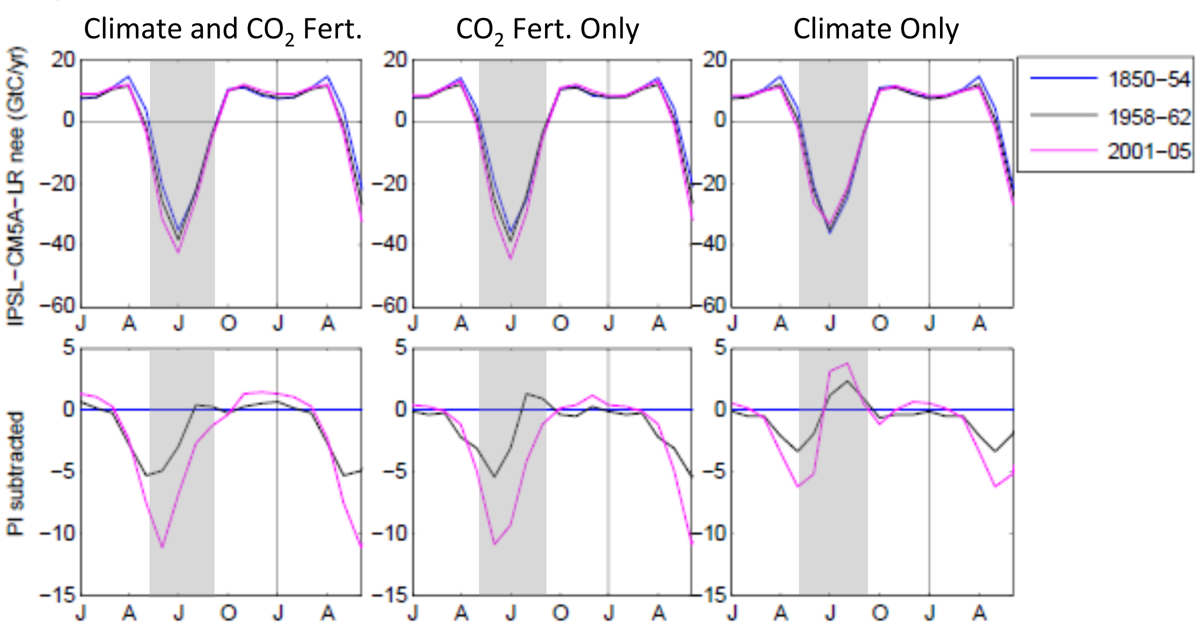
Mainly influenced by CO_2 fertilization, not climate

Good deal of non-linearity and/or internal variability

HadGEM2-TRIFFID



IPSL-ORCHIDEE

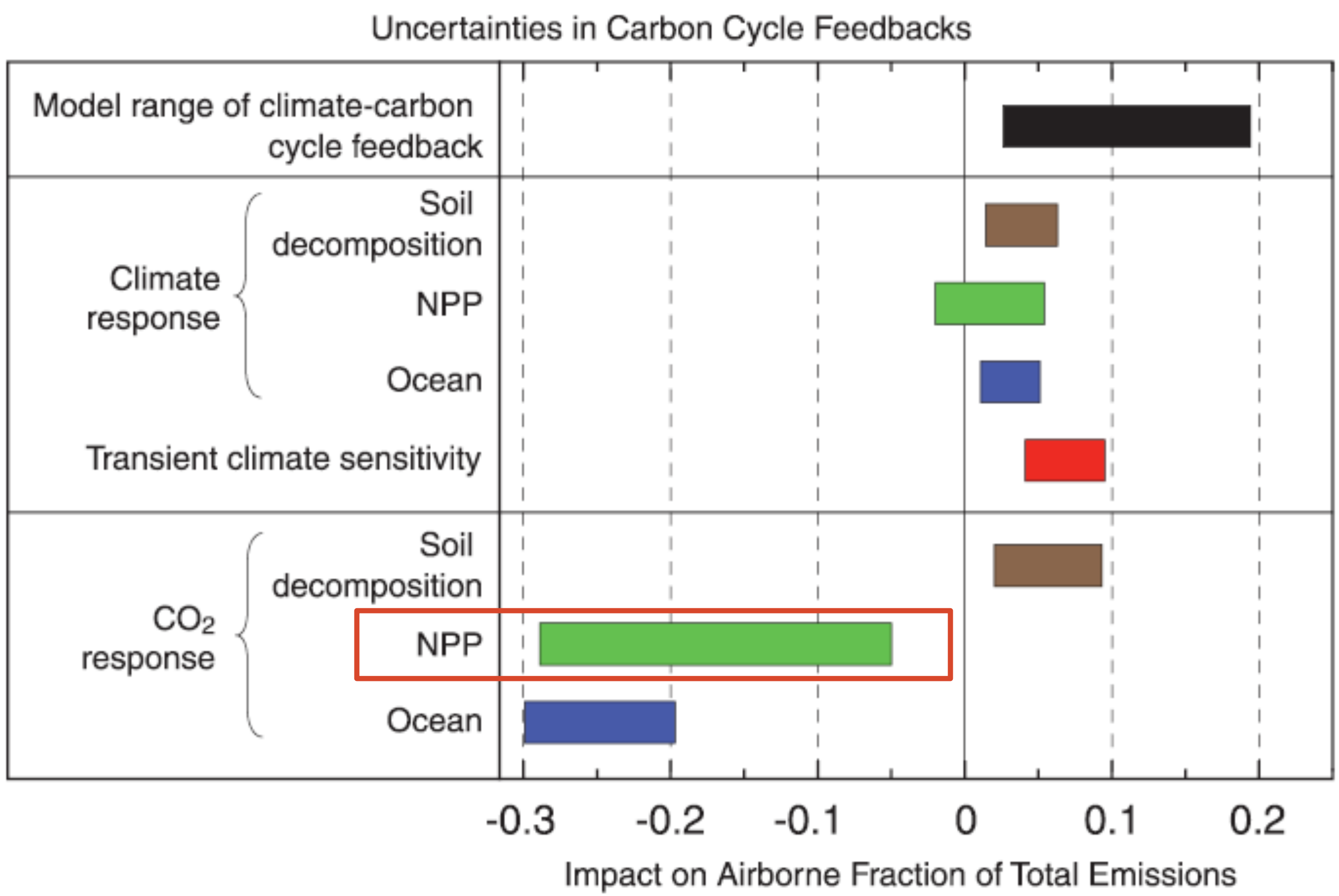


IPSL also mainly influenced by CO_2 fertilization, not climate

Fertilization seems to have a stronger effect on amplitude

Climate seems to have a stronger effect on phase

Uncertainties in carbon-climate feedbacks, based on C^4MIP models, IPCC AR4



Denman et al. 2007

Conclusions

- Large-scale growth in seasonal CO_2 cycle throughout northern high latitude troposphere between IGY and HIPPO
- Likely caused by changing boreal fluxes
- Most CMIP5 models underestimate growth in CO_2 cycle at high latitudes
- Growth in CO_2 cycle could provide a metric for evaluating and improving carbon-climate feedbacks in models

Next Steps

- Test effect of atmospheric transport and synoptic variations on observed and modeled cycles
- Test sensitivity of CO_2 cycles in upper air to amplitude vs. phase of boreal NEE cycle
- IGY-era inversion using available airborne and surface-based CO_2 data