

Vertical Gradients in Atmospheric CO₂ to Constrain Southern Ocean Air-Sea Fluxes

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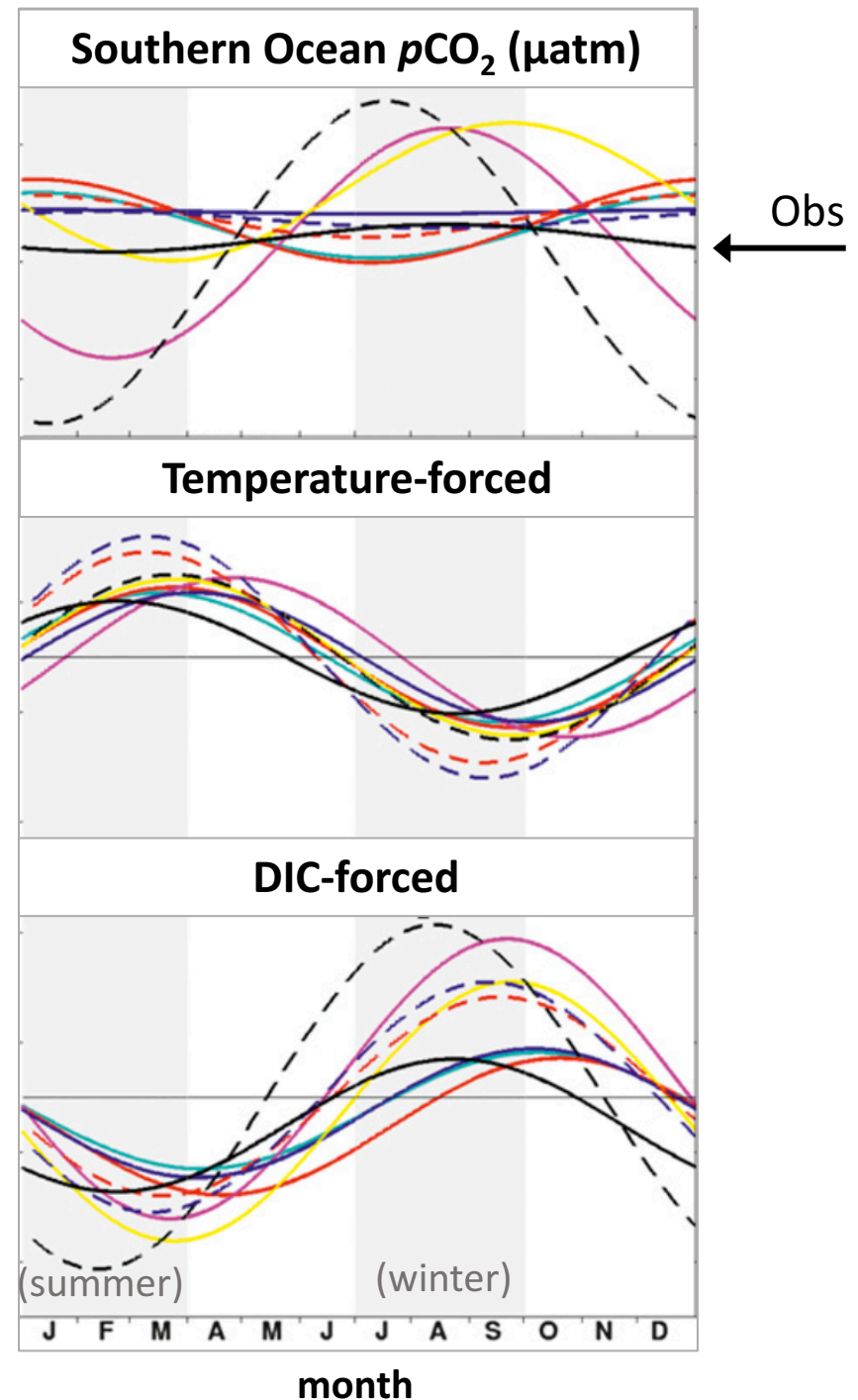




The Southern Ocean is a sink for ~10% of global anthropogenic CO₂ emissions

Net flux is the result of processes that induce large opposing fluxes

Large spread among models in magnitude and seasonality



ORCAS

2016 O₂/N₂ Ratio and CO₂ Airborne
Southern Ocean Study

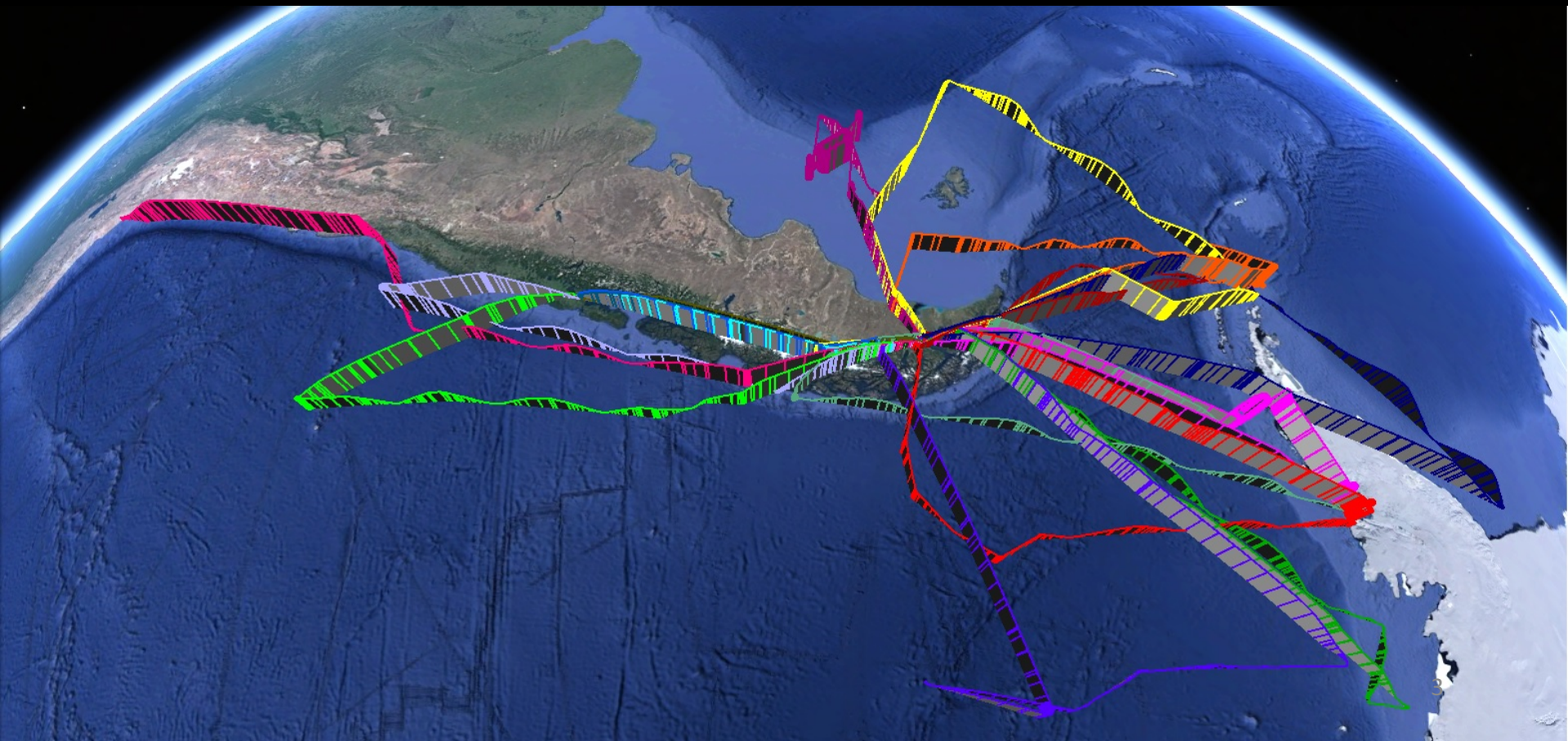


NCAR GV

Punta Arenas, Chile

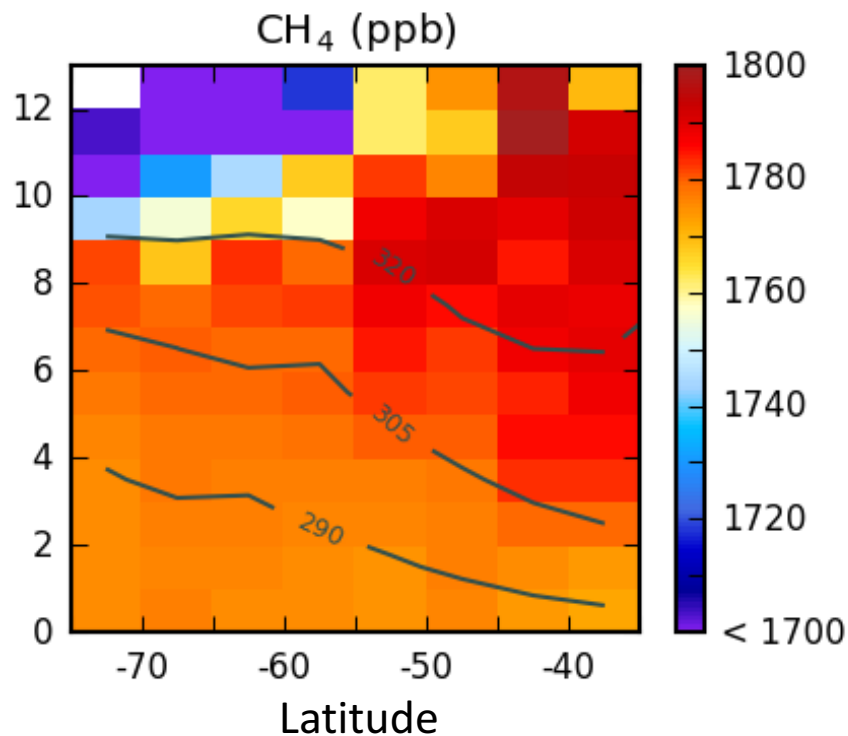
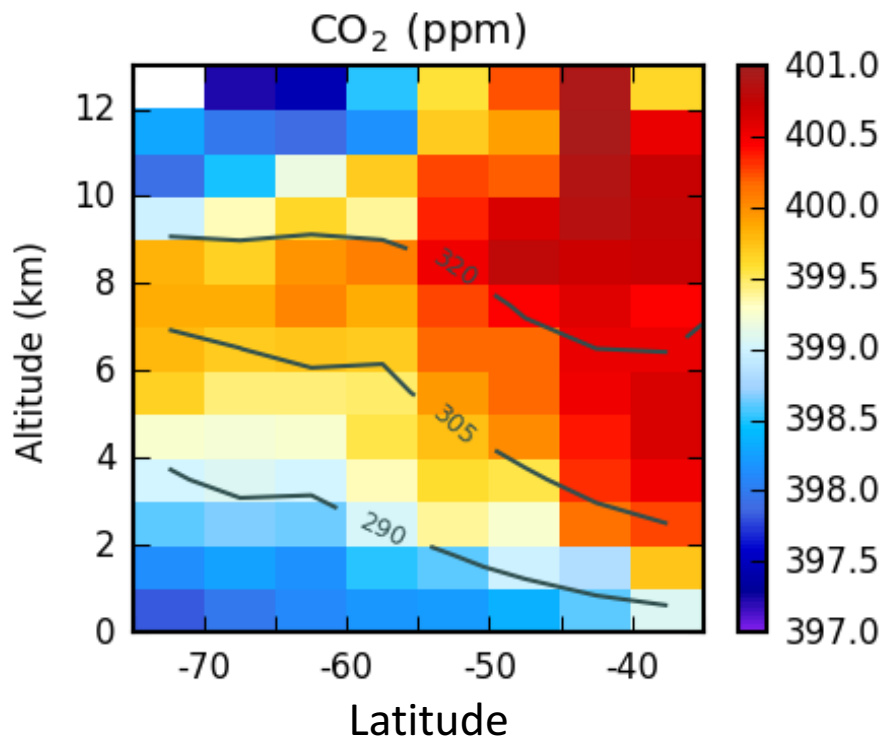
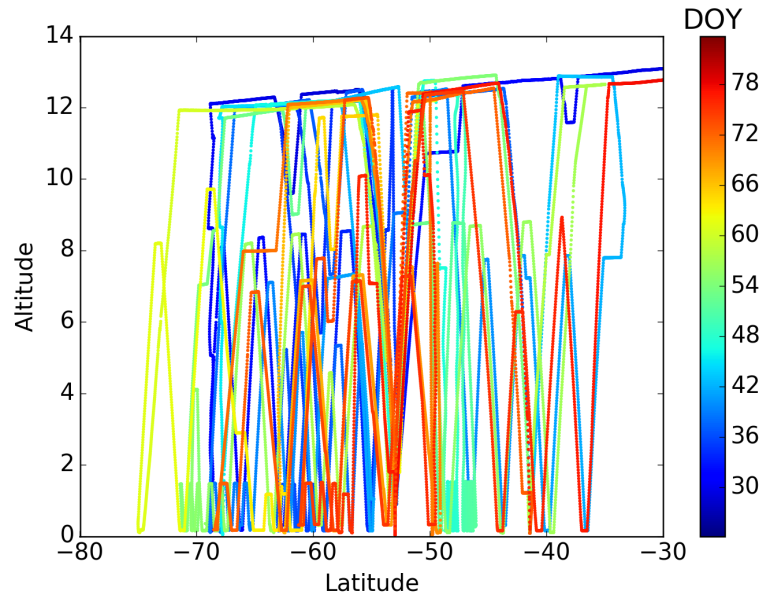
15 Jan to 29 Feb 2016

PI: B. Stephens



Densely sampled the atmosphere at:
35-75° S lat,
0-13 km alt,
for 45 days in summer

Observed:
persistent CO₂ depletion at the surface
Little variability in CH₄
input from the north at altitude

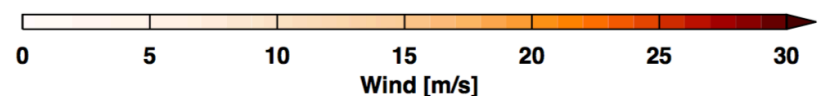
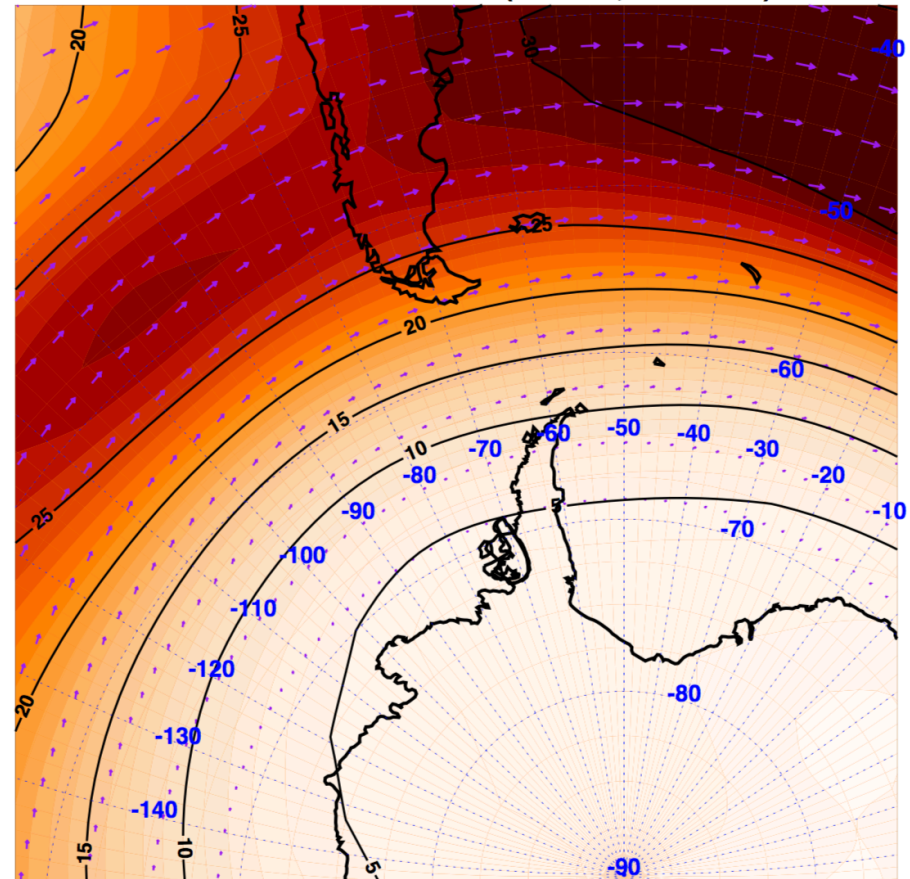
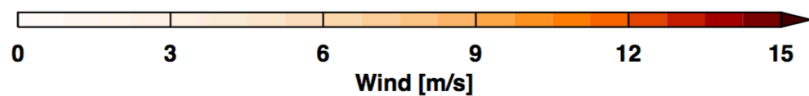
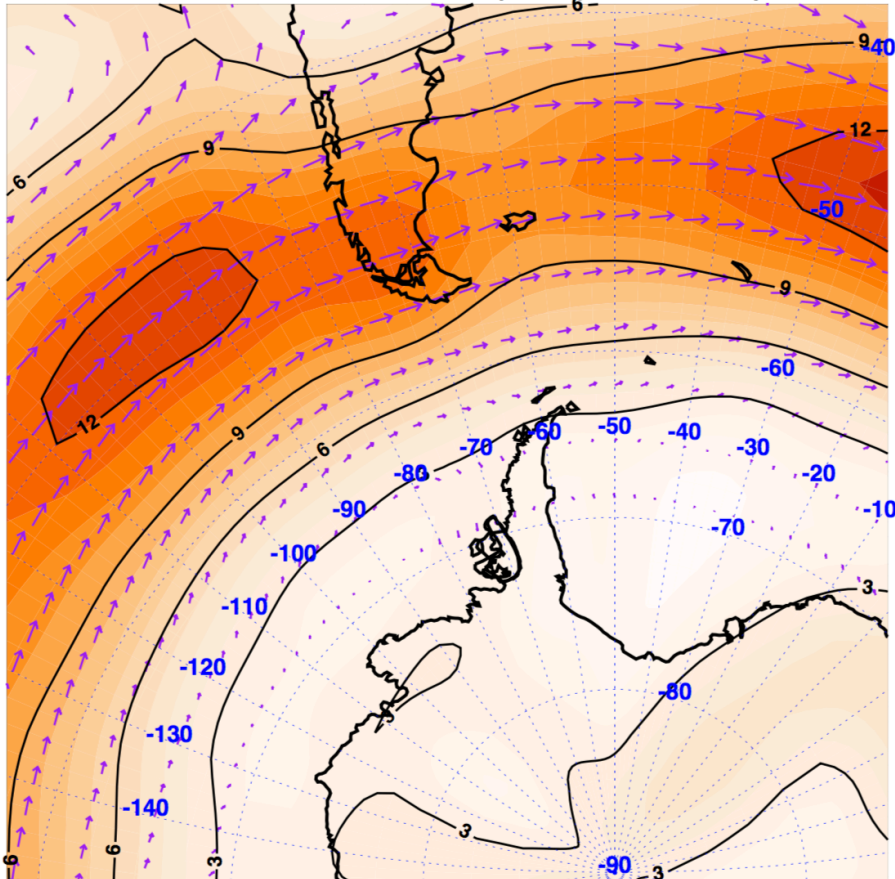


Region is characterized by strong persistent winds and a stable polar tropospheric vortex, and miniscule fluxes from land biomass and humans

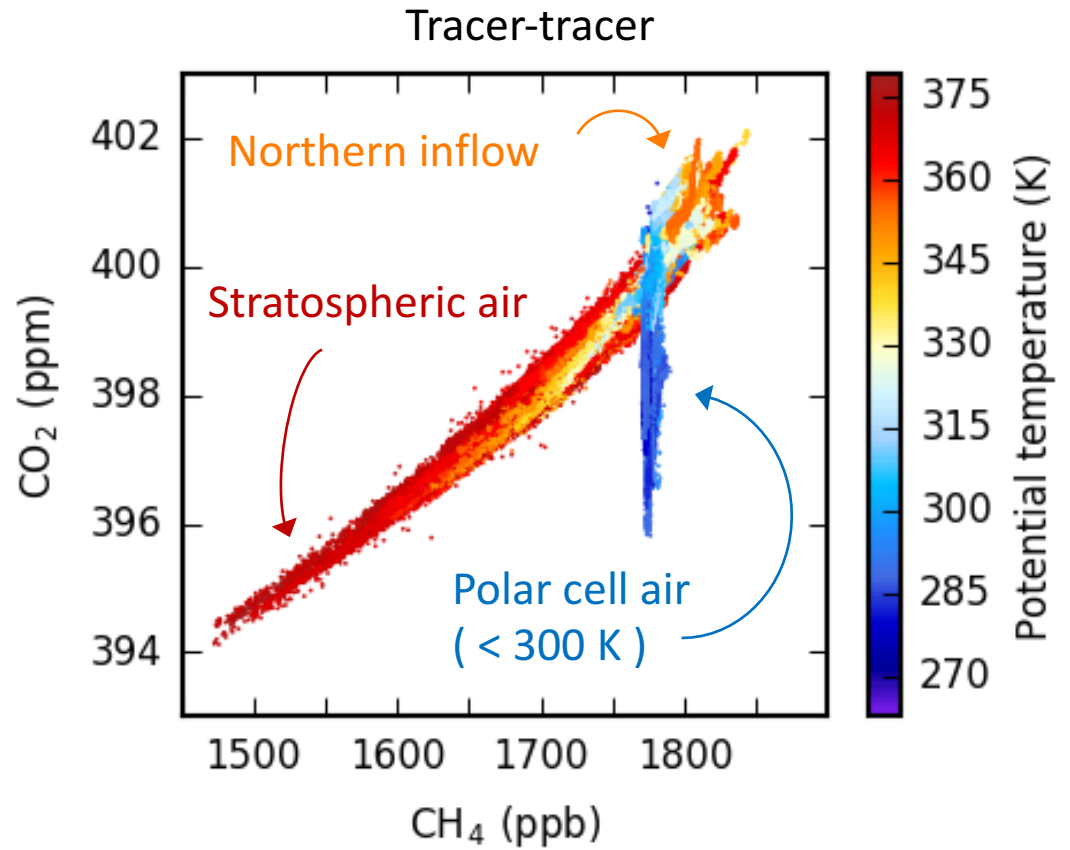
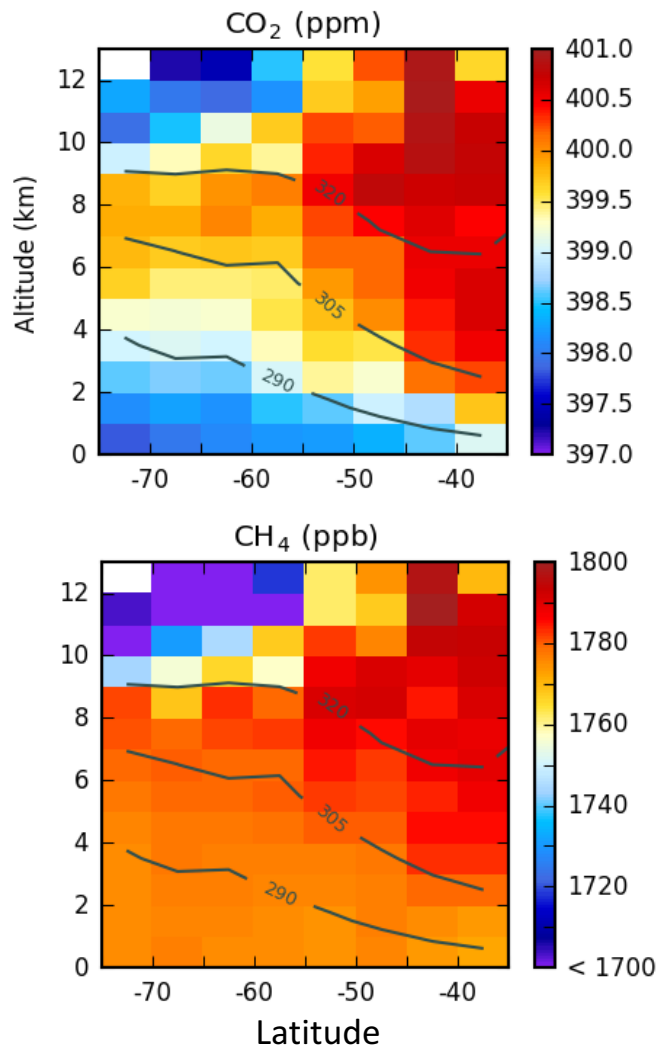
850 hPa

NCEP Winds & GPH (Jan-Feb, 1948-2016)

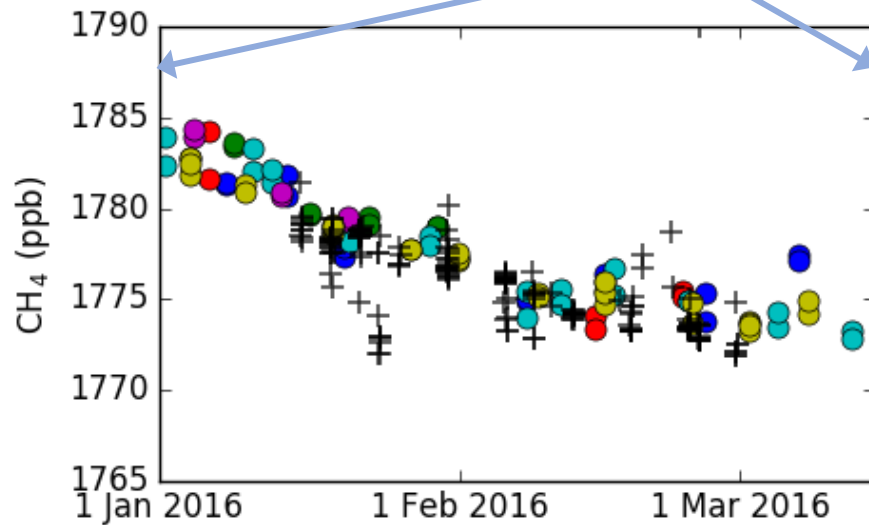
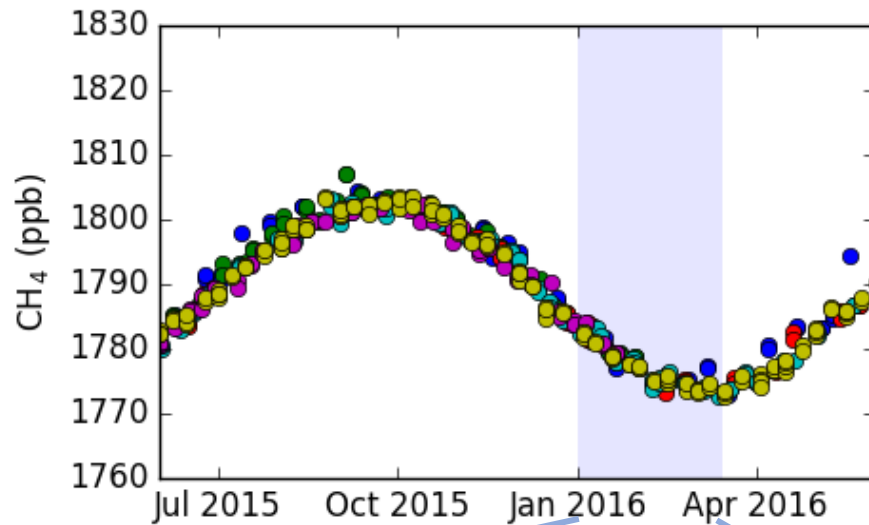
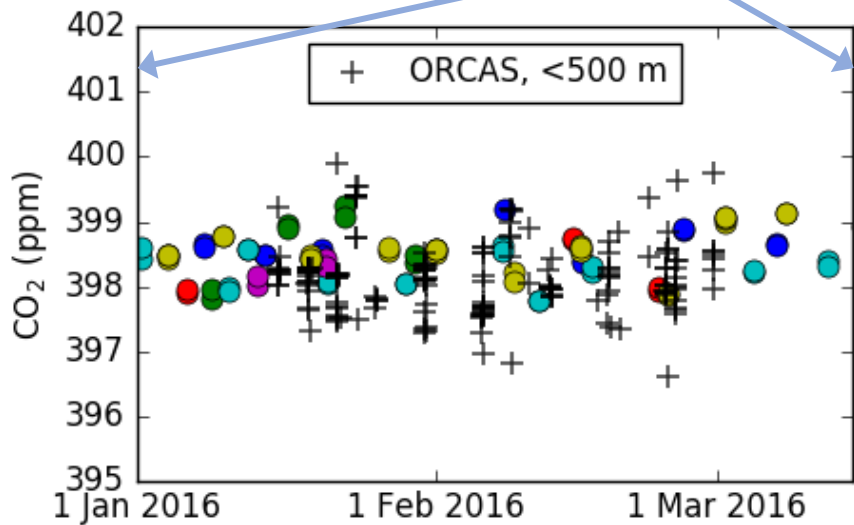
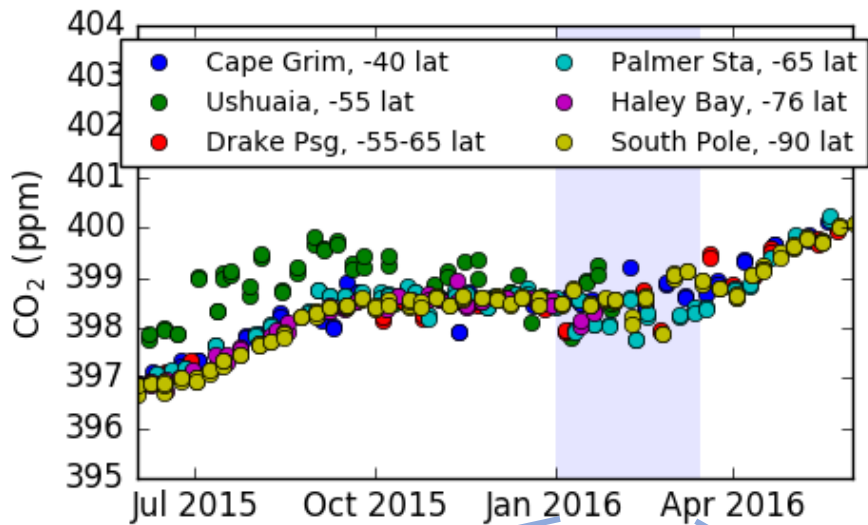
200 hPa



CO₂-CH₄ relationship across ORCAS domain

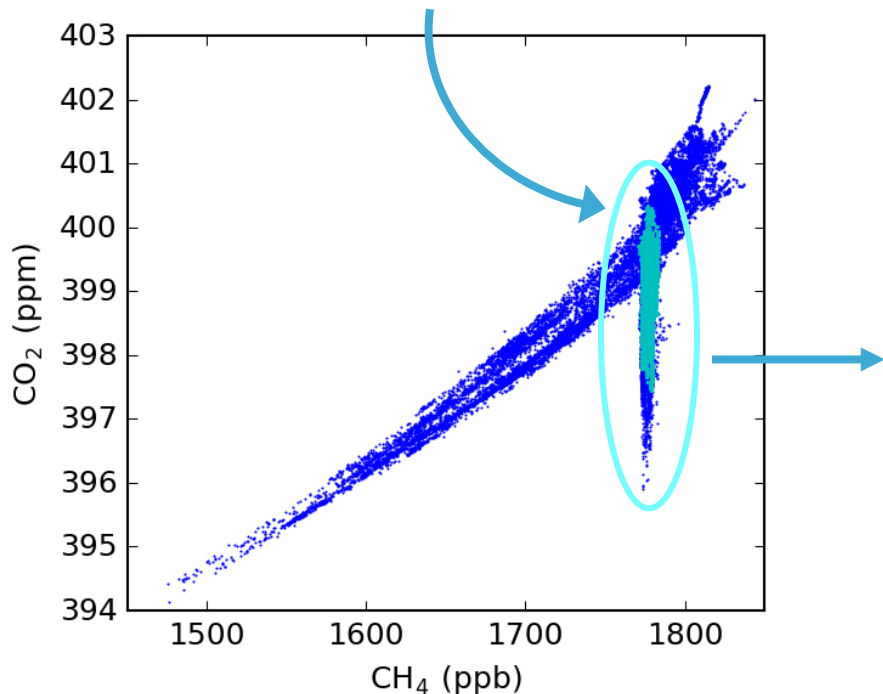


ORCAS near-surface measurements are in-line with GMD Flask Data

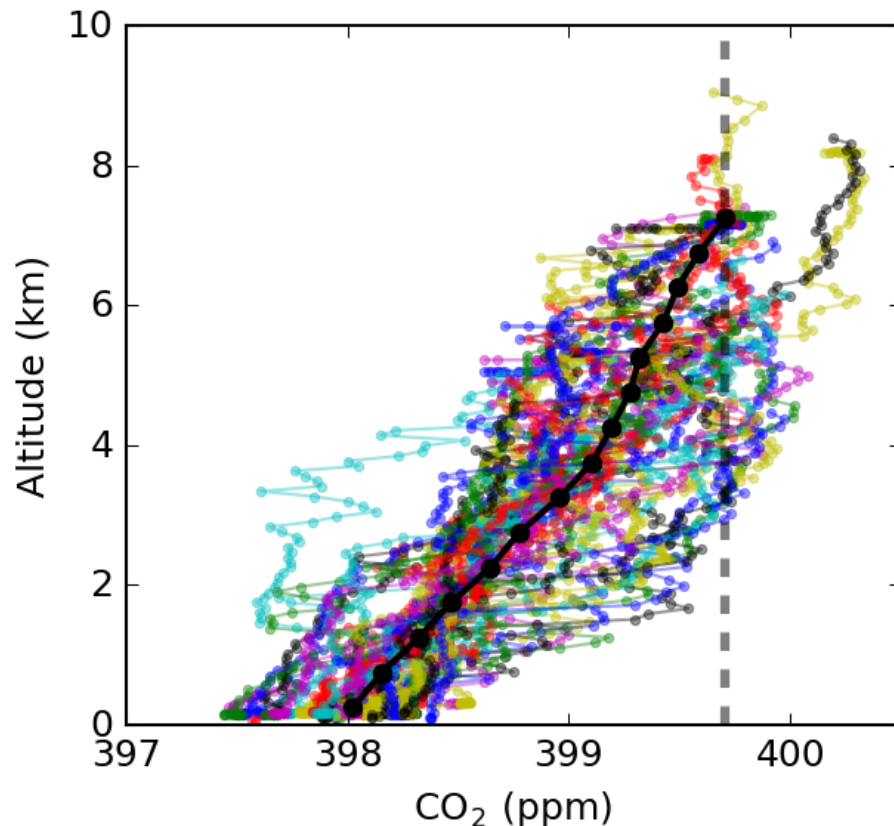


Mean Vertical Gradient in Ocean-dominated Air

selection of Ocean-dominated Air



Individual profiles where $\Delta CH_4 \approx 0$



Mean Column Depletion =

$$\int_0^{7.5 \text{ km}} (CH_4(z) - CH_4(z = 7.5 \text{ km})) \frac{P(z)}{R \times T(z)} dz = 0.2 \frac{\text{mol}}{\text{m}^2}$$

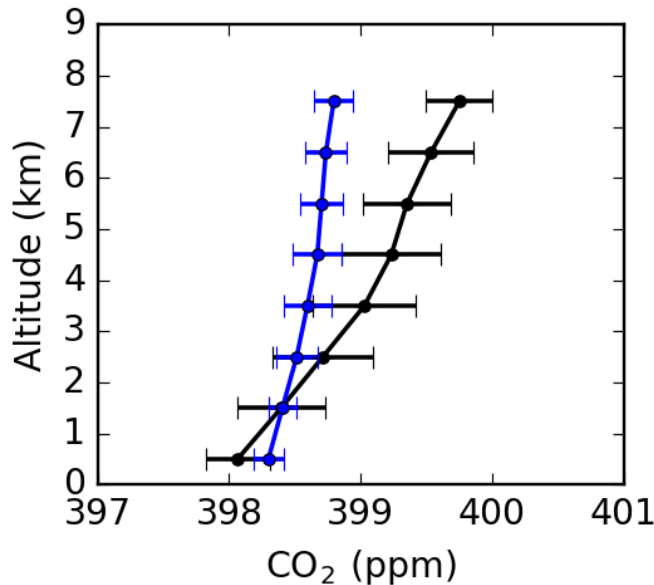
Comparison with CarbonTracker-NearRealTime

Close agreement of total concentration at the surface

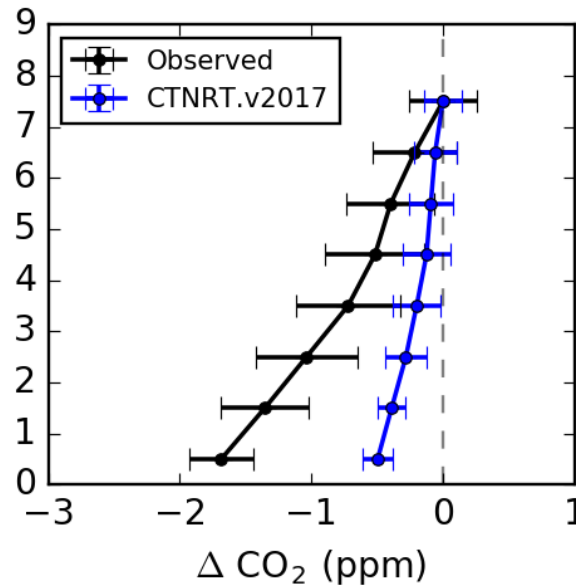
Gradient underestimated by x2

Predicts largest contribution from ocean fluxes, then fossil fuels

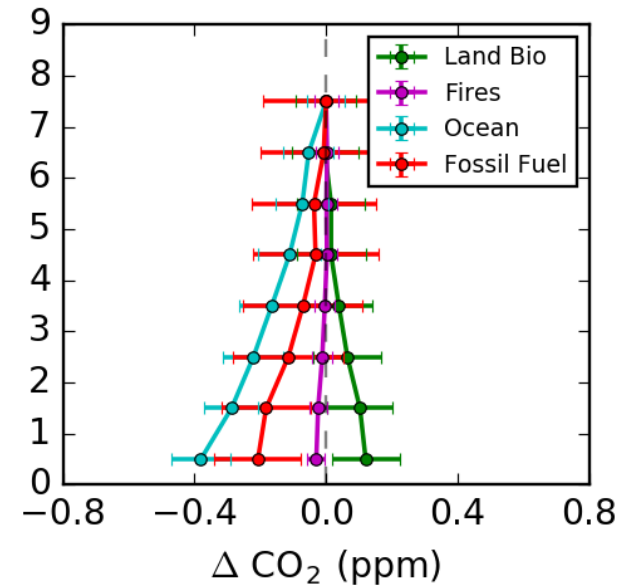
Total concentration



Tropospheric gradient

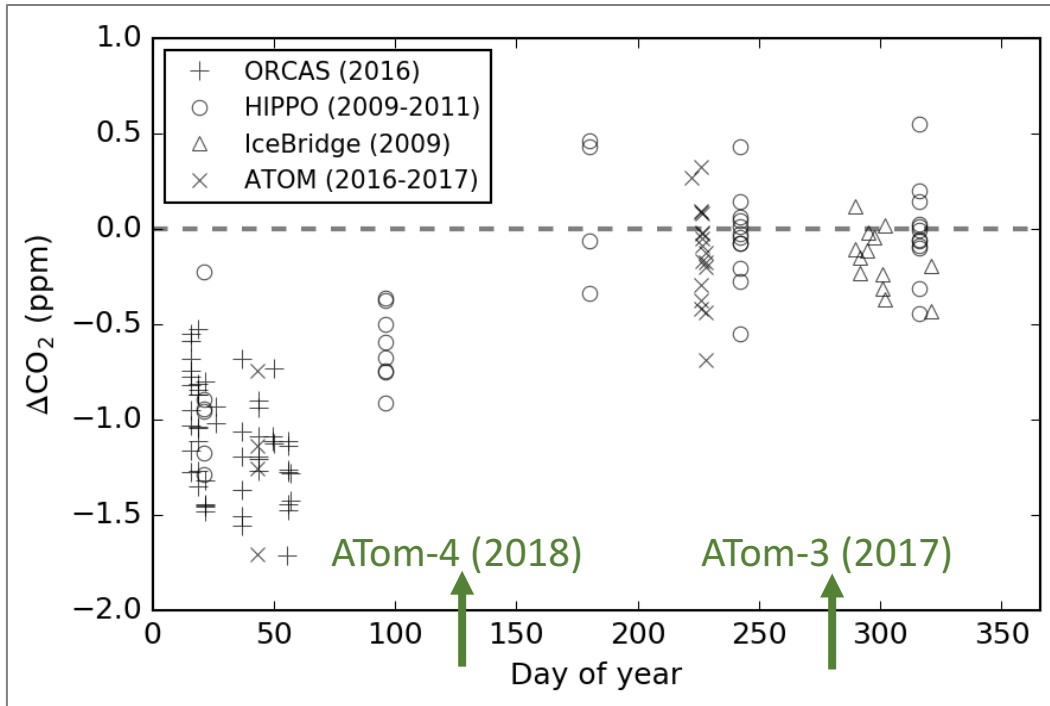


Components



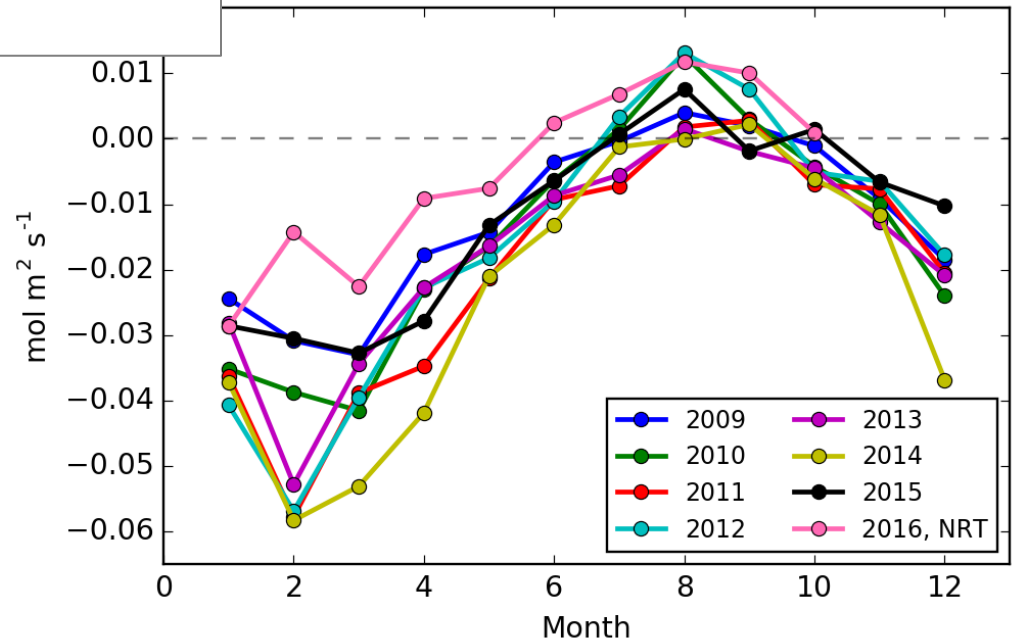
Disagreement possibly related to a) too-small ocean fluxes, b) too fast vertical mixing, c) inter-annual variability (El Nino) in ocean or land fluxes

Seasonal Cycle in Atmospheric Gradient compared to Flux Models



CT-NRT fluxes for 2016 are anomalously high, consistent with the underestimated gradient compared to ORCAS obs

CT2016 Ocean Flux



$0.05 \text{ mol m}^{-2} \text{ s}^{-1} \approx$
 $0.2 \text{ mol m}^{-2} \text{ @ } \tau = 45 \text{ days}$

→ Basic consistency between observed gradients & CT fluxes

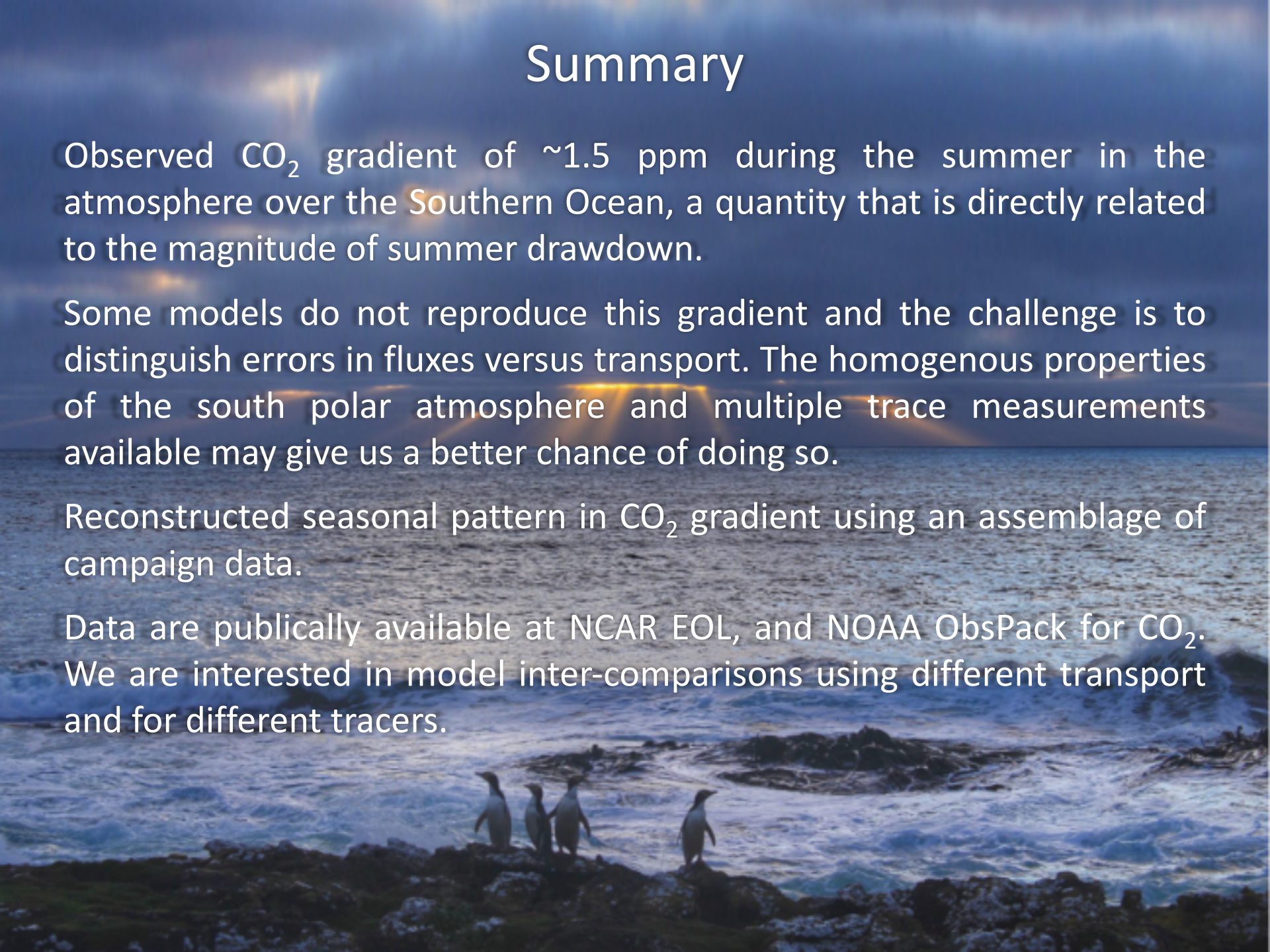
Summary

Observed CO₂ gradient of ~1.5 ppm during the summer in the atmosphere over the Southern Ocean, a quantity that is directly related to the magnitude of summer drawdown.

Some models do not reproduce this gradient and the challenge is to distinguish errors in fluxes versus transport. The homogenous properties of the south polar atmosphere and multiple trace measurements available may give us a better chance of doing so.

Reconstructed seasonal pattern in CO₂ gradient using an assemblage of campaign data.

Data are publically available at NCAR EOL, and NOAA ObsPack for CO₂. We are interested in model inter-comparisons using different transport and for different tracers.



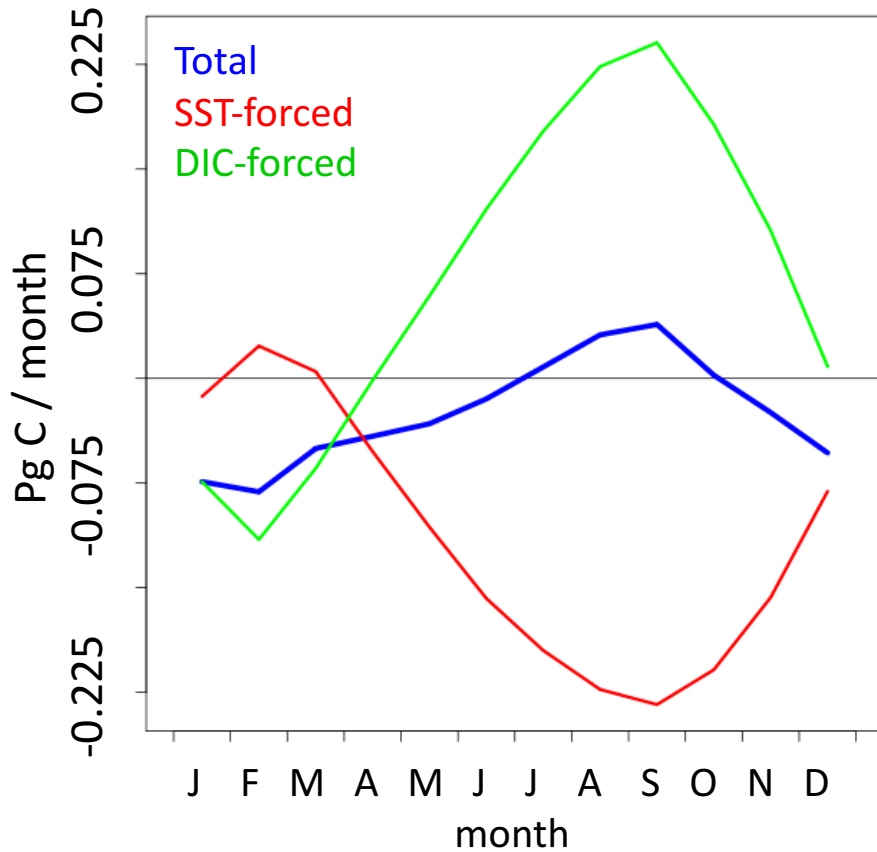
The Southern Ocean is a sink for ~10% of global anthropogenic CO₂ emissions

Net flux is the result of large opposing fluxes
Large spread among process models

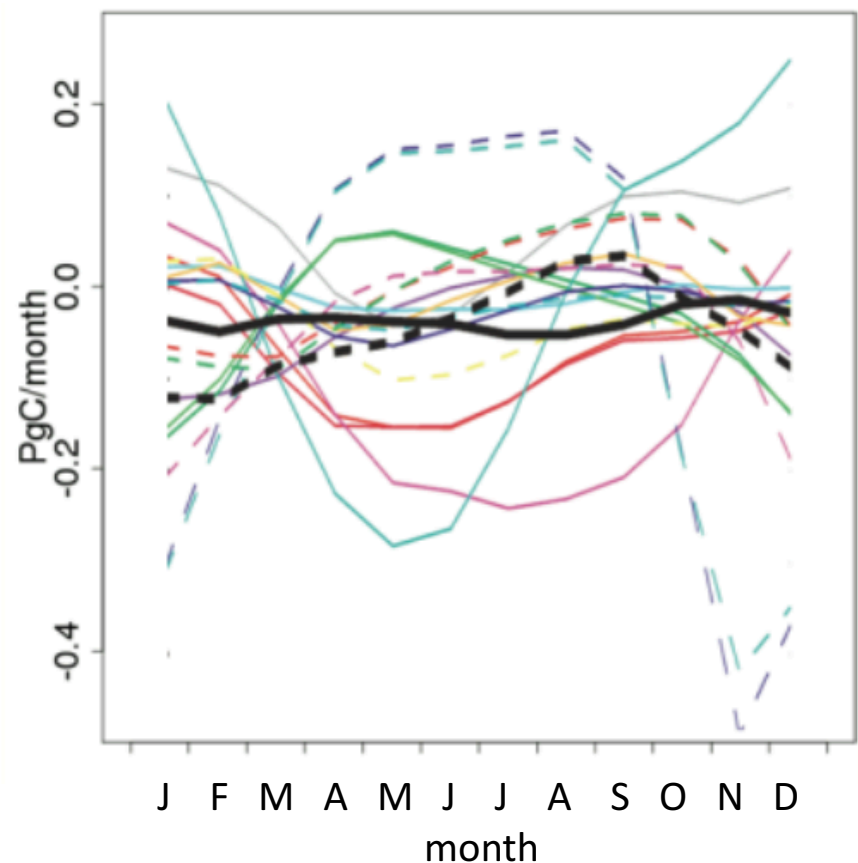


Southern Ocean CO₂ Fluxes

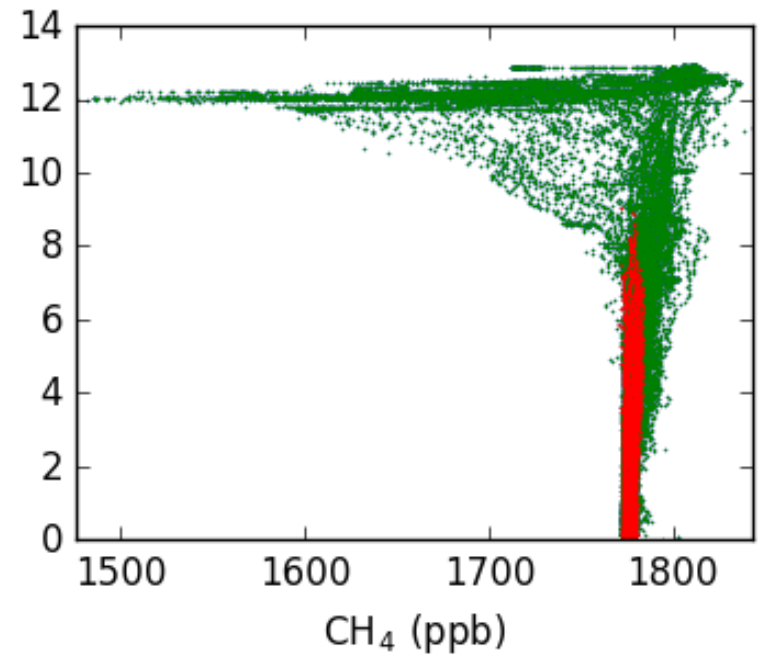
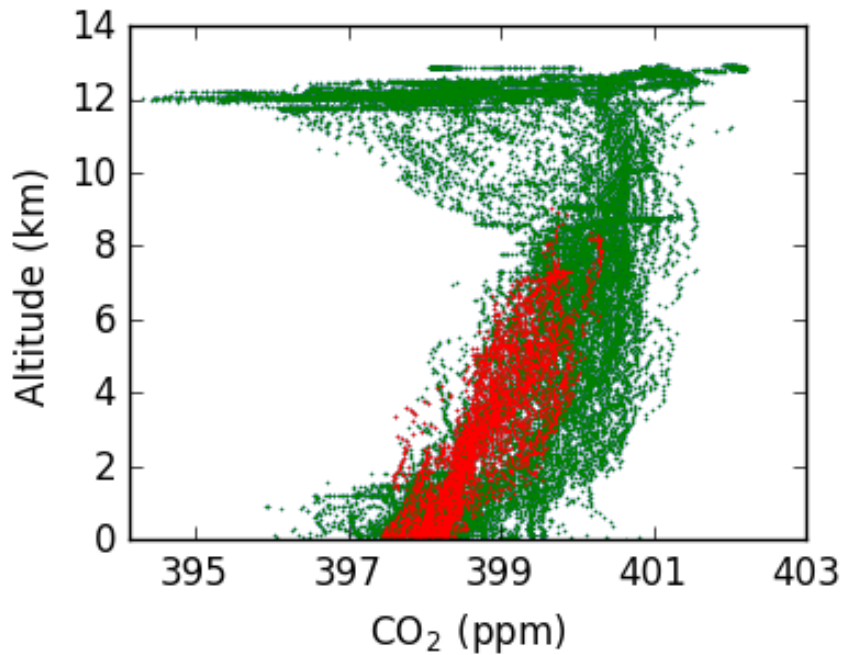
Climatology, Takahashi et al. 2009



CMIP5 models, Anav et al. 2013

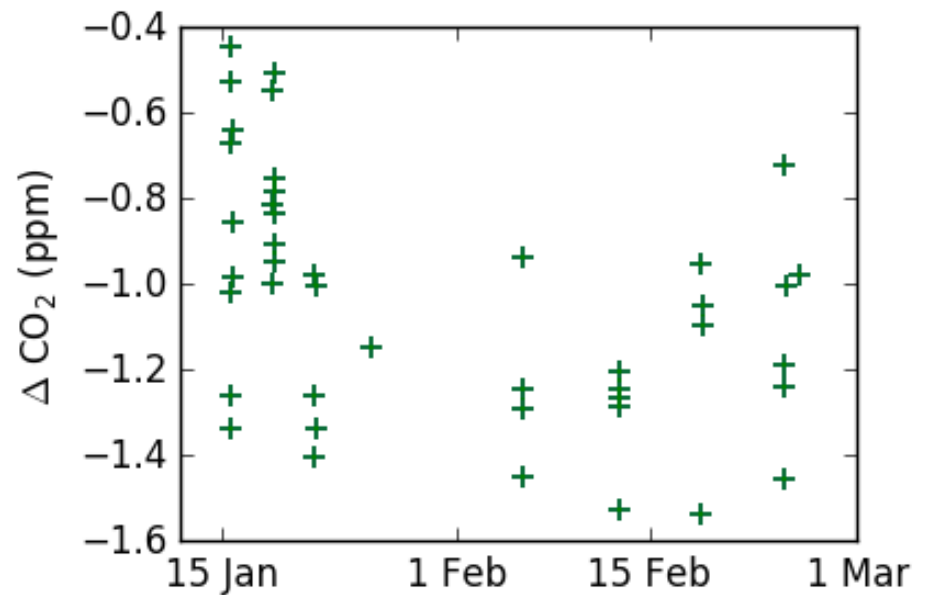


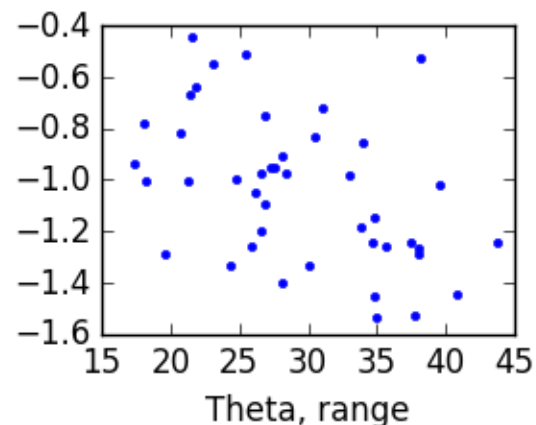
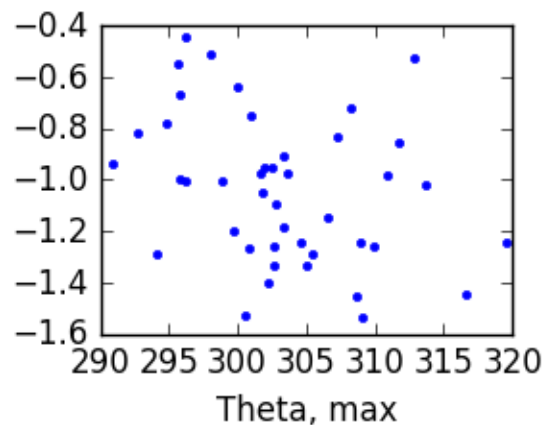
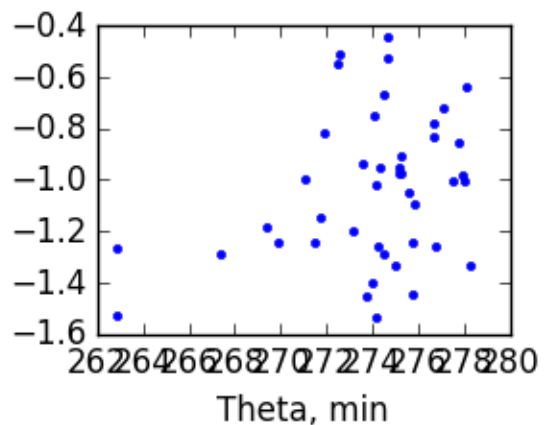
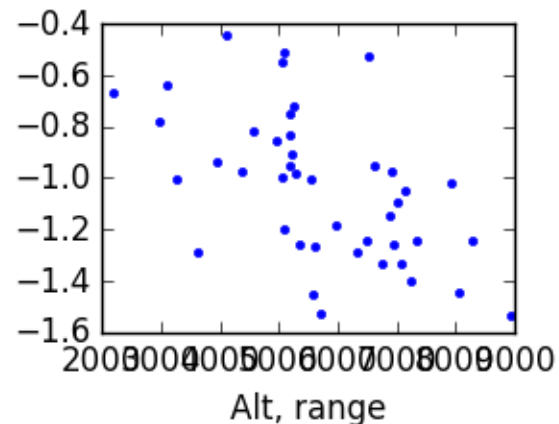
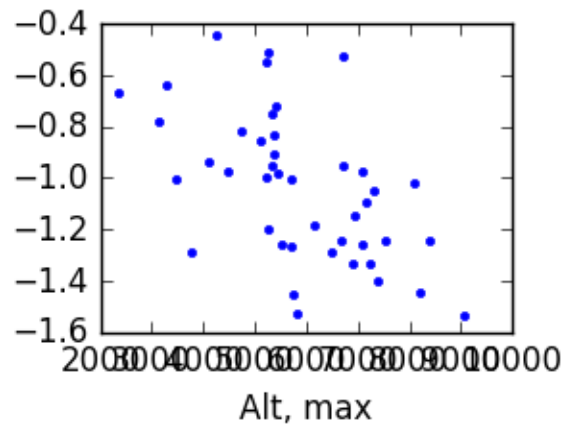
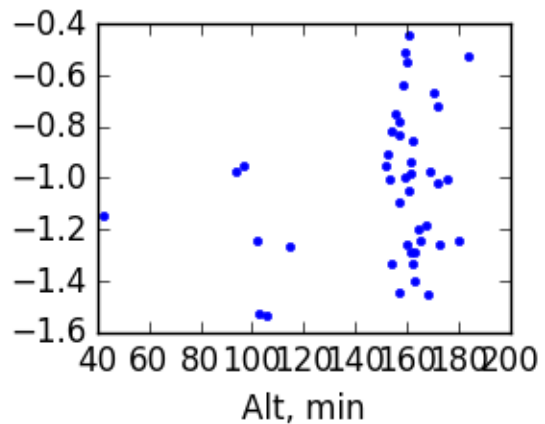
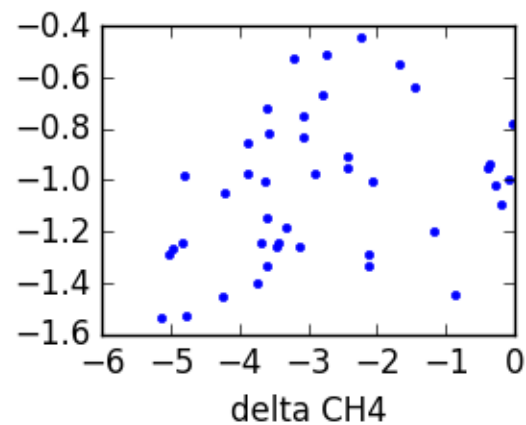
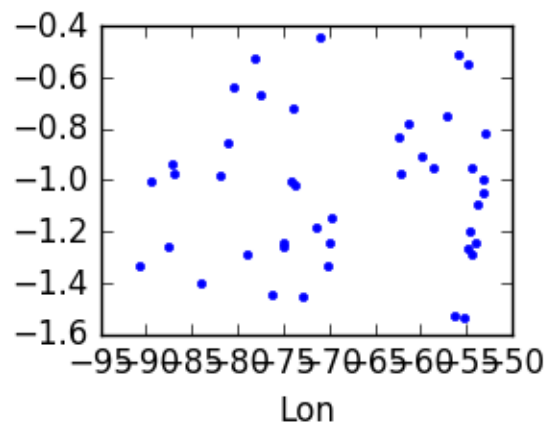
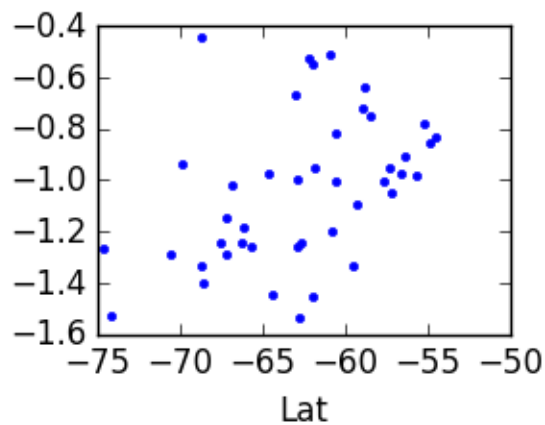
Vertical Gradients in Ocean-Influenced Air



Mean pressure-weighted
partial-column Depletion =
1.0 ($1\sigma=0.3$) ppm

Computed from individual
profiles where $\Delta\text{CH}_4 \sim 0$





Comparison with CarbonTracker-NearRealTime

Close agreement of total concentration at the surface

Gradient underestimated by ~50%

Predicts equal contributions from ocean and fossil fuel fluxes

