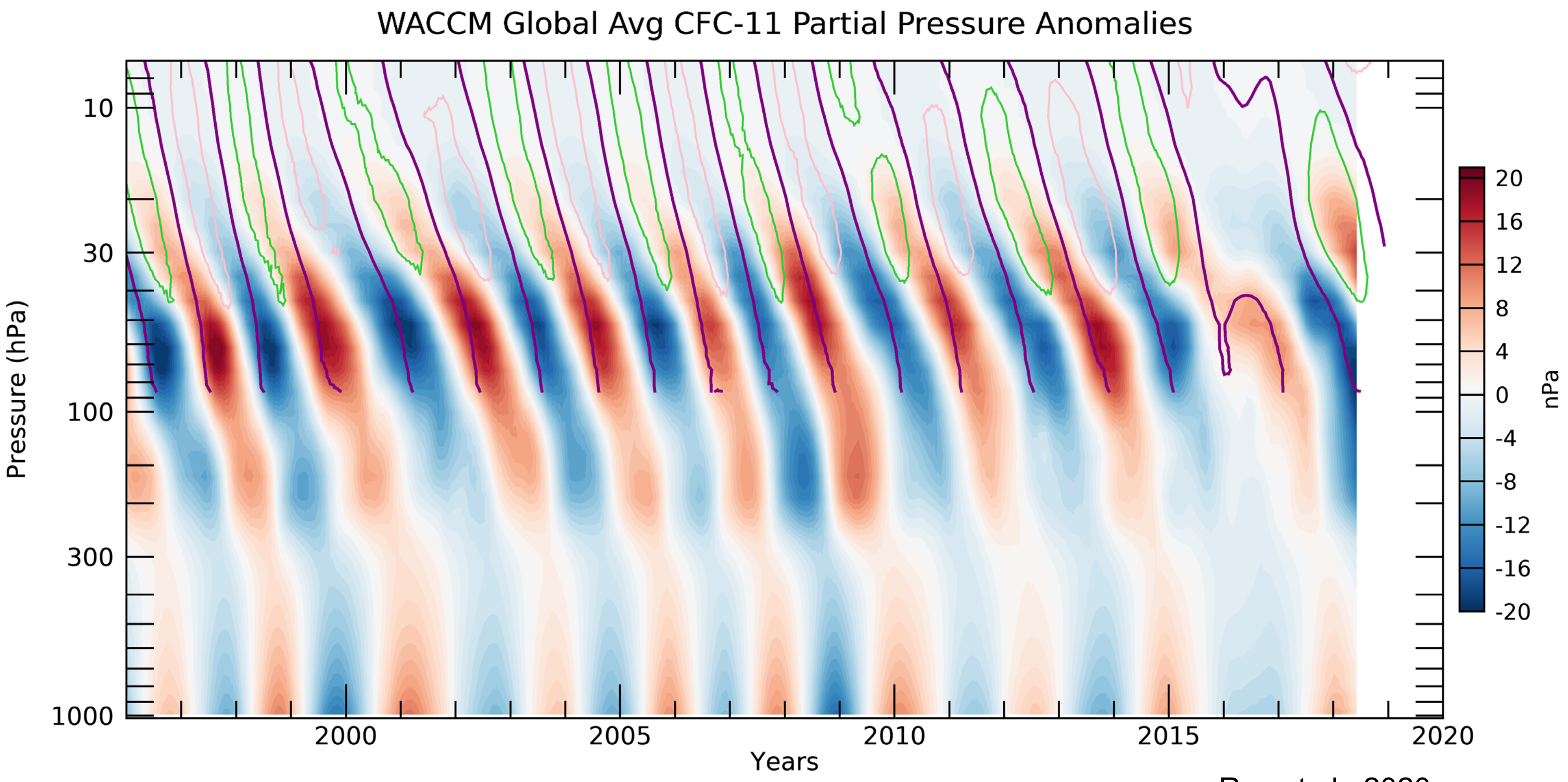
Predicting Interannual Variability of Long-Lived Trace Gas Levels at the Surface From Satellite Measurements in the Stratosphere

Eric Ray, Robert Portmann, John Daniel, Stephen Montzka, Geoff Dutton, Brad Hall, Fred Moore and Karen Rosenlof

NOAA CSL and GML

CIRES, University of Colorado

Modeled Trace Gas QBO Variability

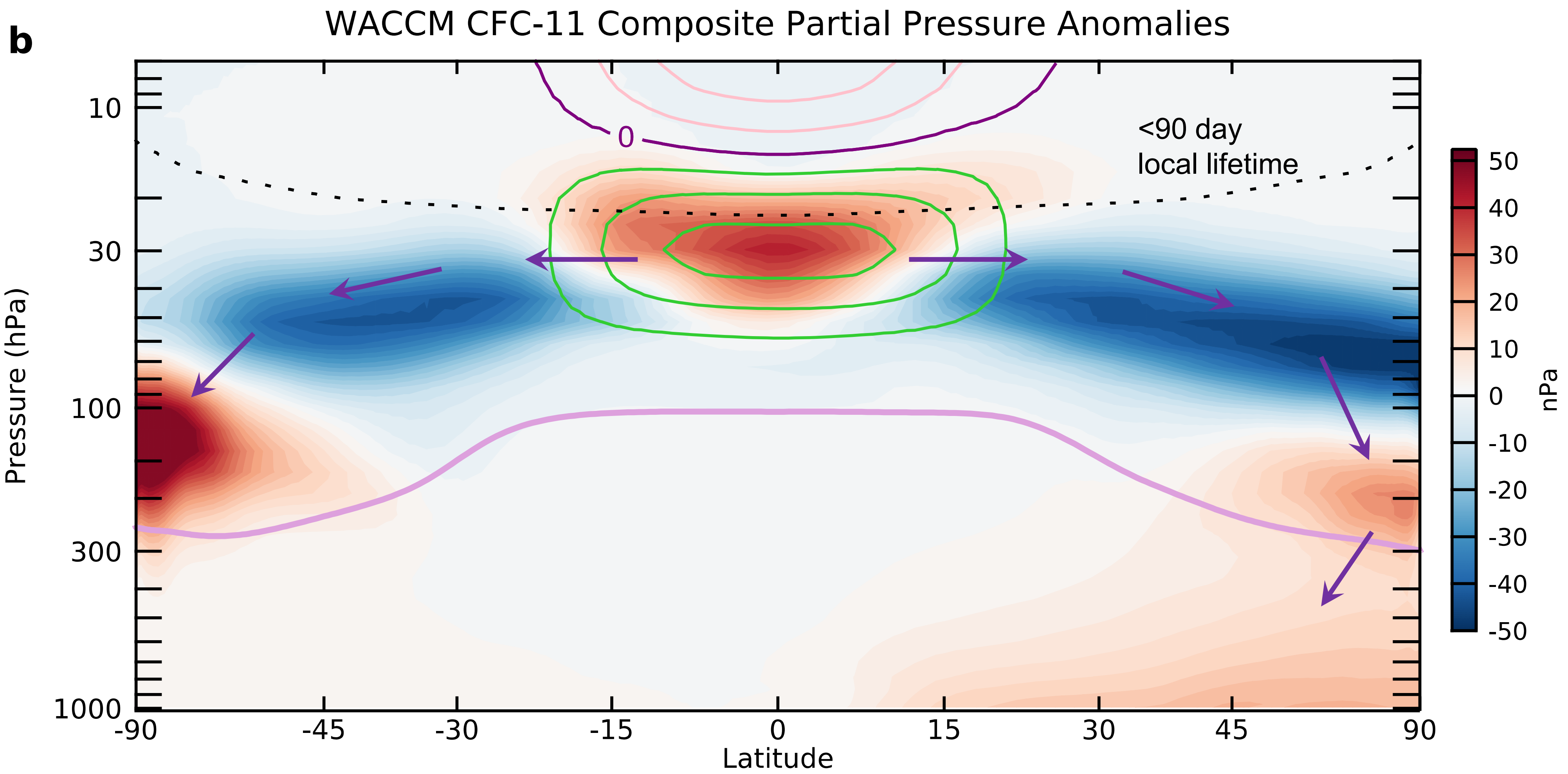


Ray et al., 2020

- 1-5 year bandpass filtered.
- Global average partial pressure anomalies.
- Coherent descent of anomalies through the stratosphere and troposphere to the surface with each QBO cycle.

The equatorial zonal wind is shown in the open contours (**0**, -15 (easterly) and 15 (westerly) m/s).

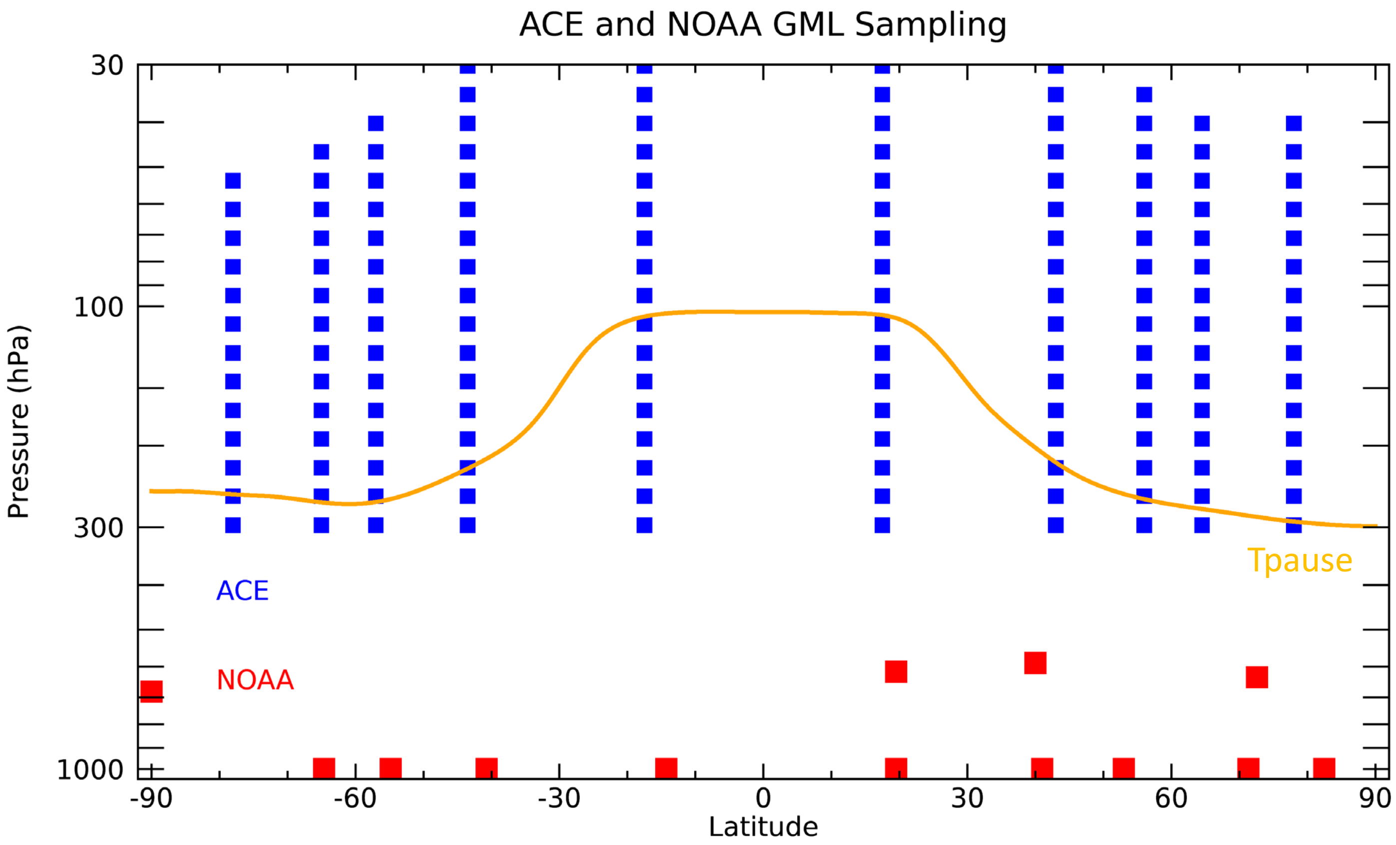
Modeled Trace Gas QBO Variability



The composite tropical zonal wind is shown in the open contours (**0**, easterlies and westerlies).

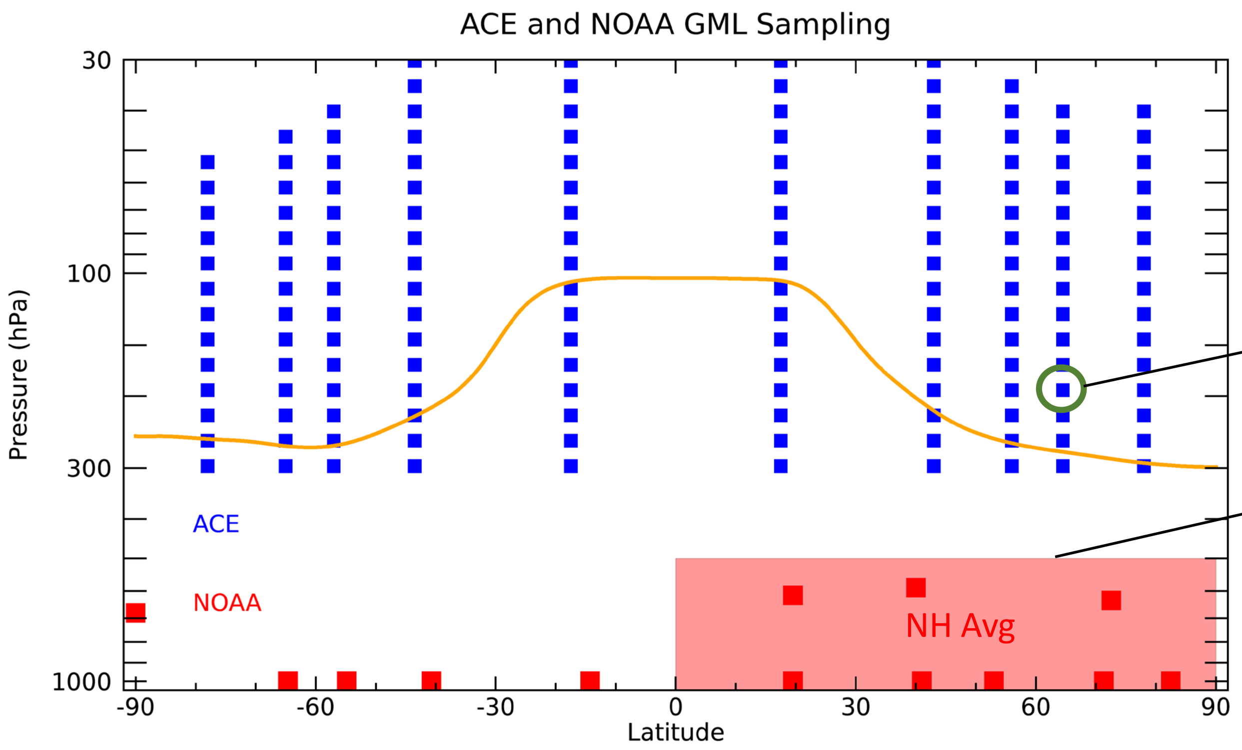
- Composite based on times of maximum global average partial pressure anomalies at 20 hPa.
- Each trace gas will have a different anomaly pattern depending primarily on it's lifetime.
- Models are great but what about measurements?

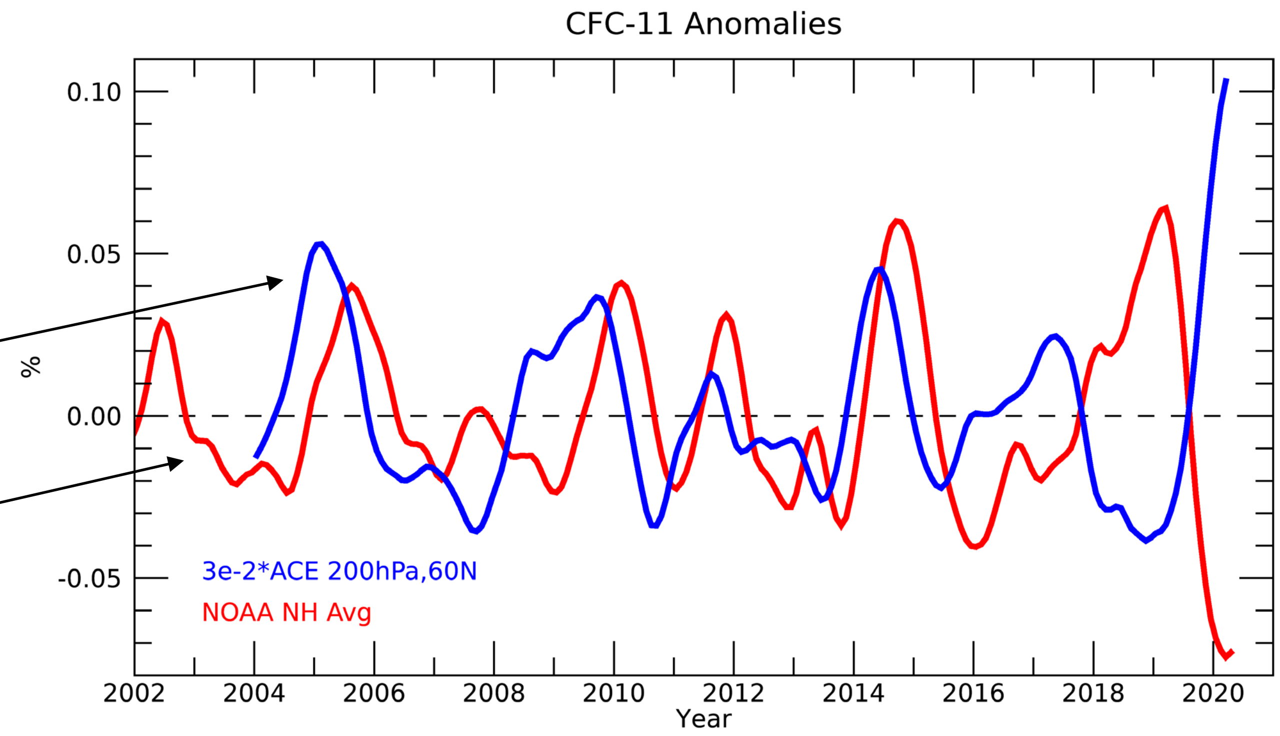
Satellite and Surface CFC-11 Measurements



- ACE sampling is skewed towards extratropics (fine for this study)
- ACE measurements extend down to tropopause (can follow trace gas anomalies into troposphere)

Correlations Between Satellite and Surface CFC-11

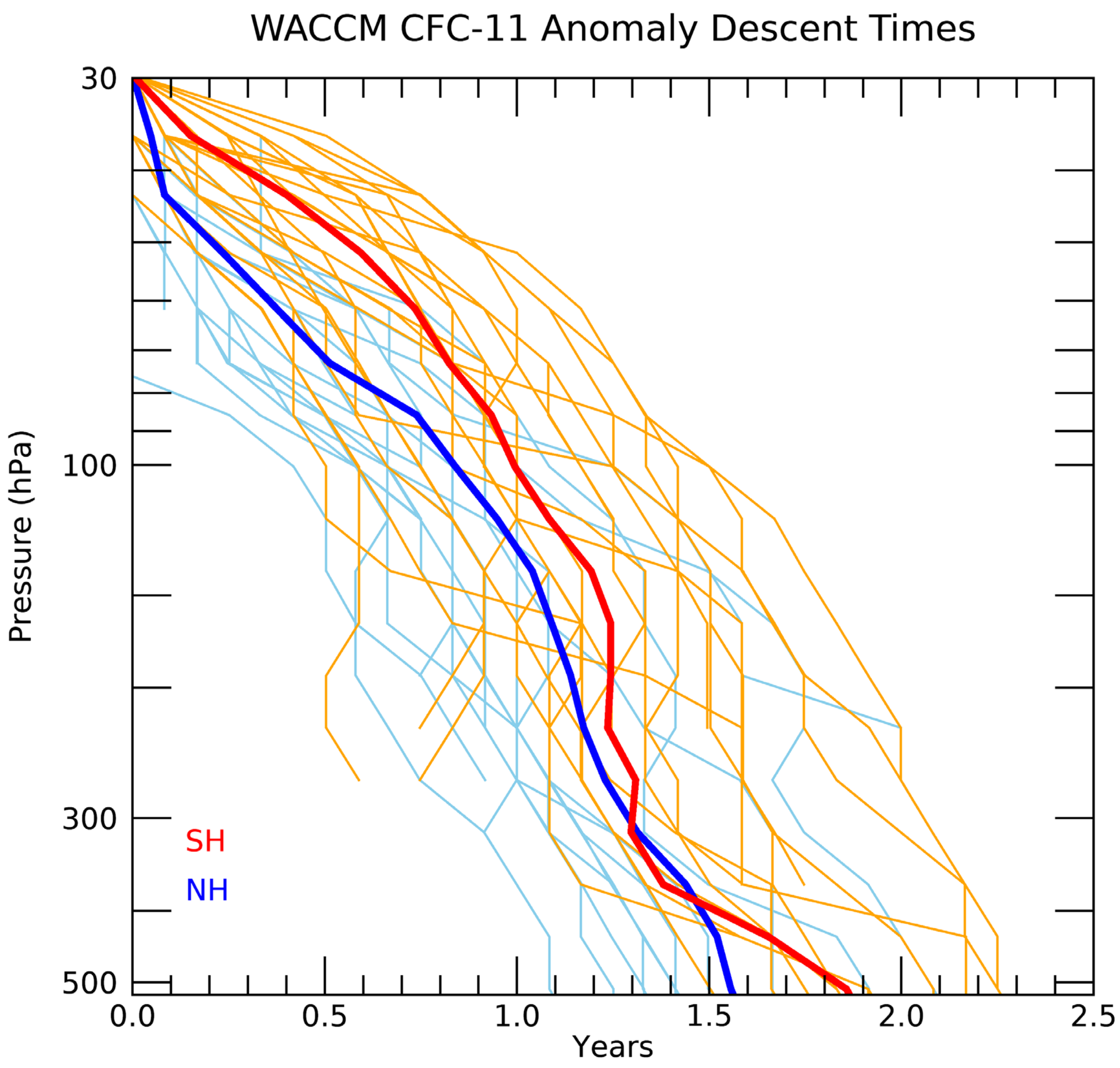




NOAA sites represent hemispheric average of lower troposphere.

ACE anomalies in lowermost stratosphere lead the surface anomalies by a variable amount.

Modeled Descent of CFC-11 Anomalies



- Modeled descent times of each QBO cycle to the mid-troposphere for each hemisphere.
- Highly variable (QBO cycles are like snowflakes).
- Not conducive to correlations with single lag time.

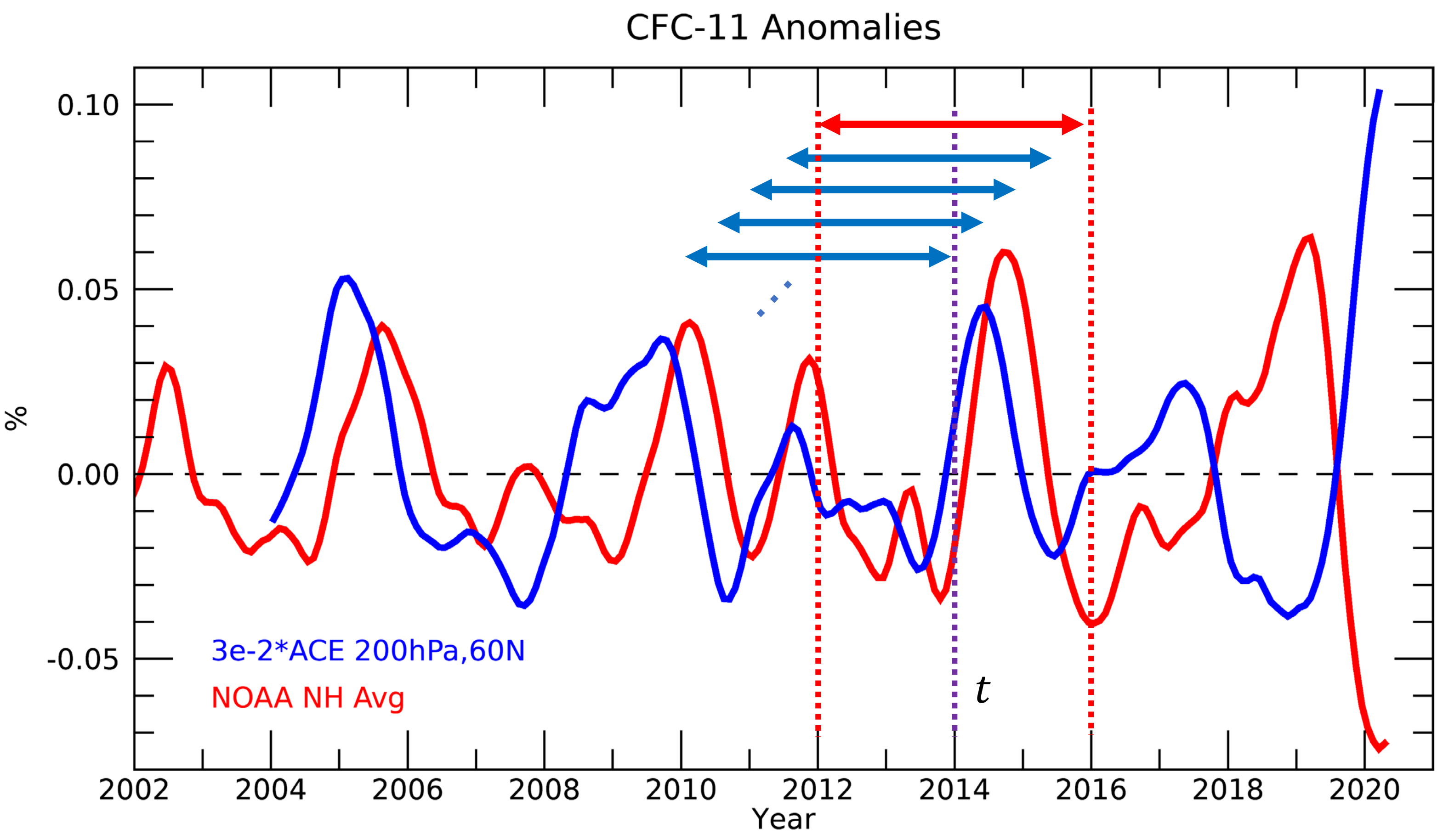
Running Correlations

Running four year correlations with monthly resolution:

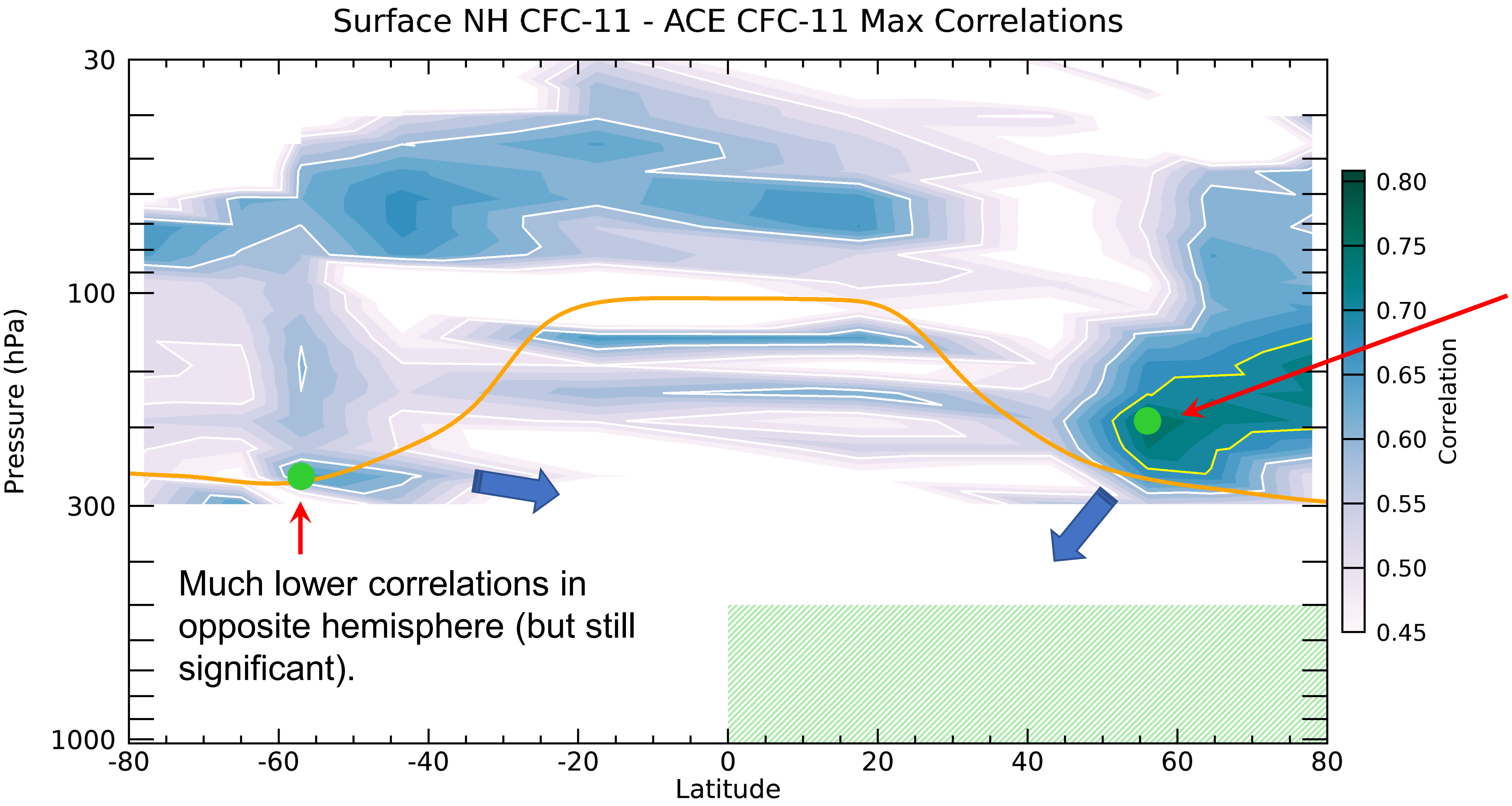
$$r_{y,z,t}\left(\chi_{ACE}(y,z,t-l),\chi_{NOAA}(t)\right)$$

↑ lag

- Lag times up to 48 months constrained by location in stratosphere.
- Compute average correlation and lag over the ACE time period from the monthly resolution running correlations.

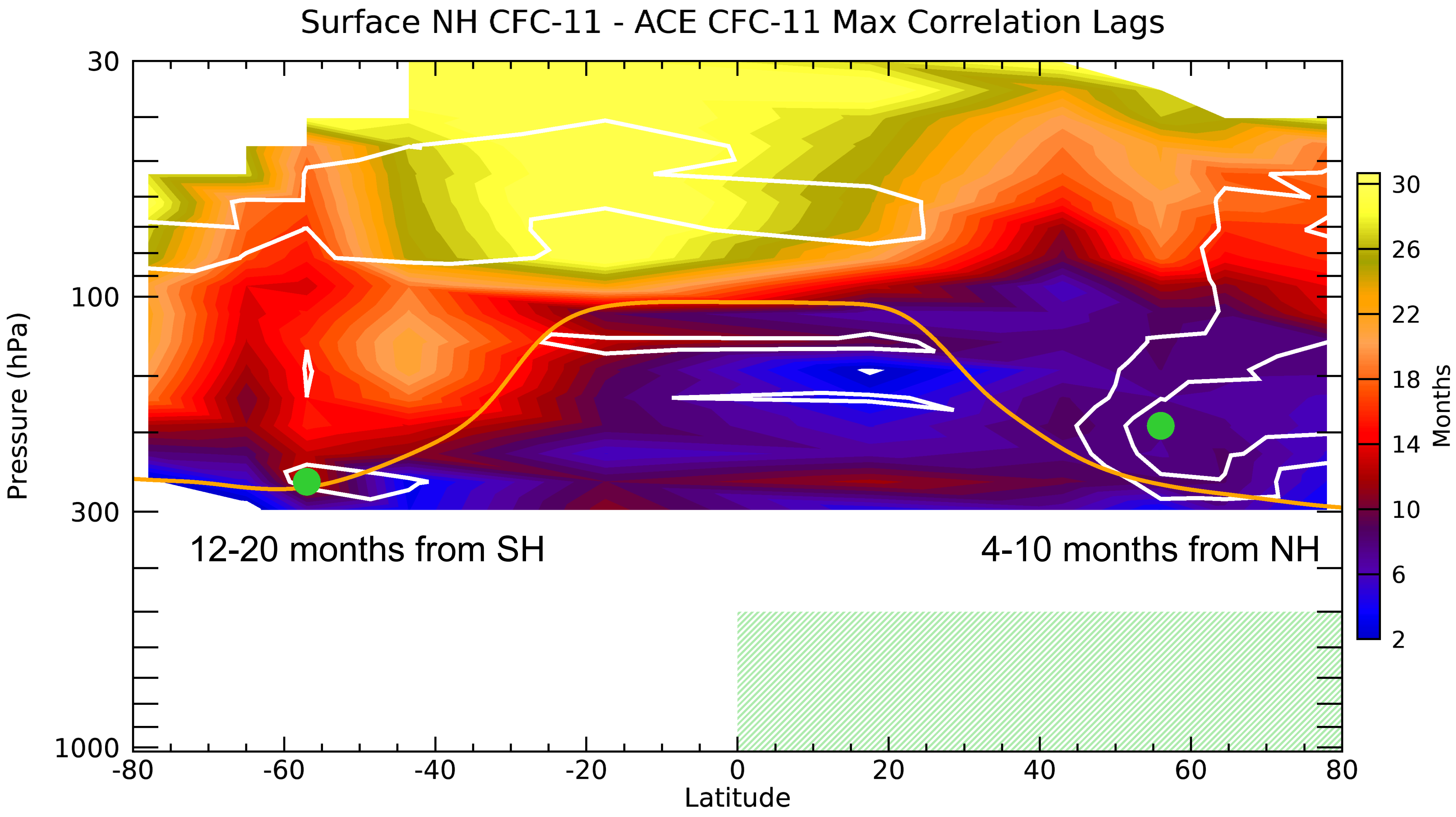


Correlations of NH Surface CFC-11 with ACE



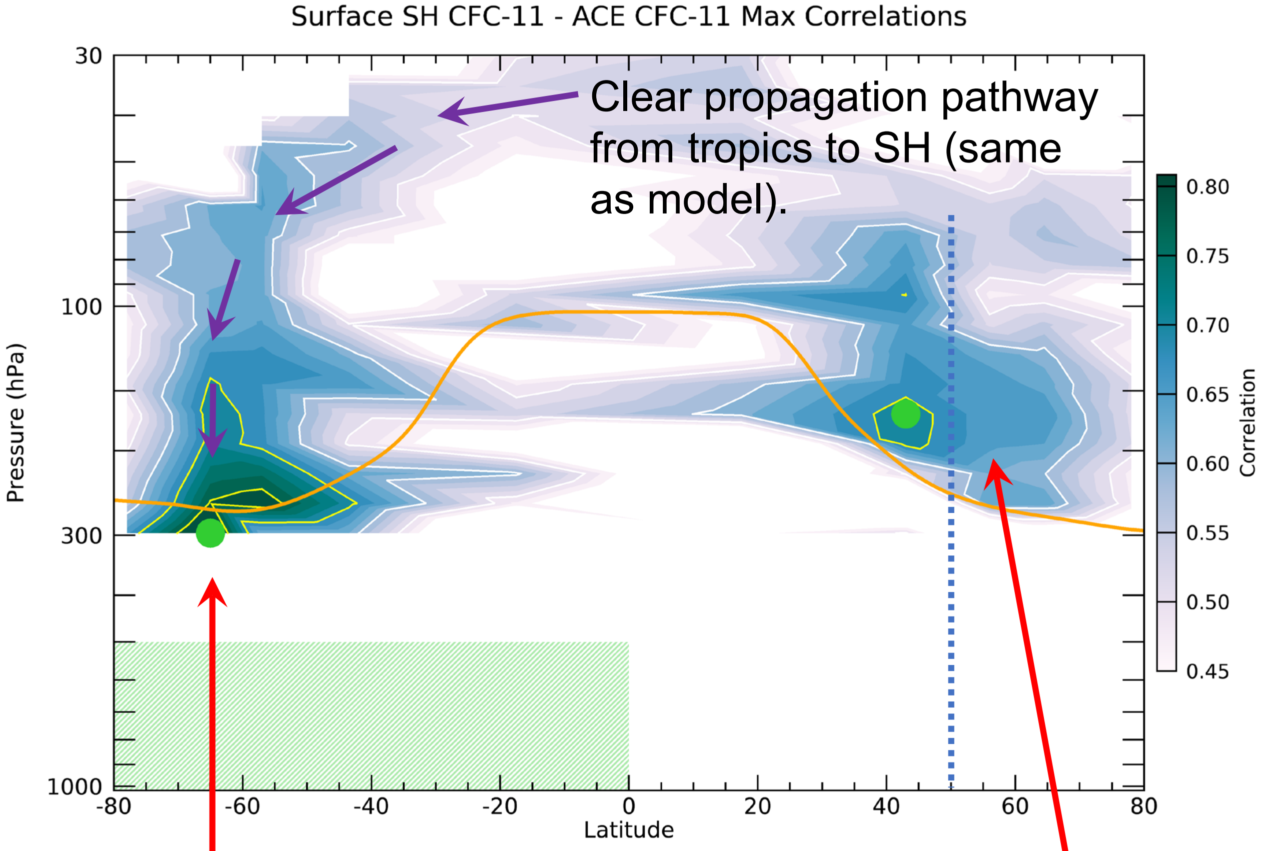
Maximum correlations are found in the NH lowermost strat just above tropopause (where we expect them).

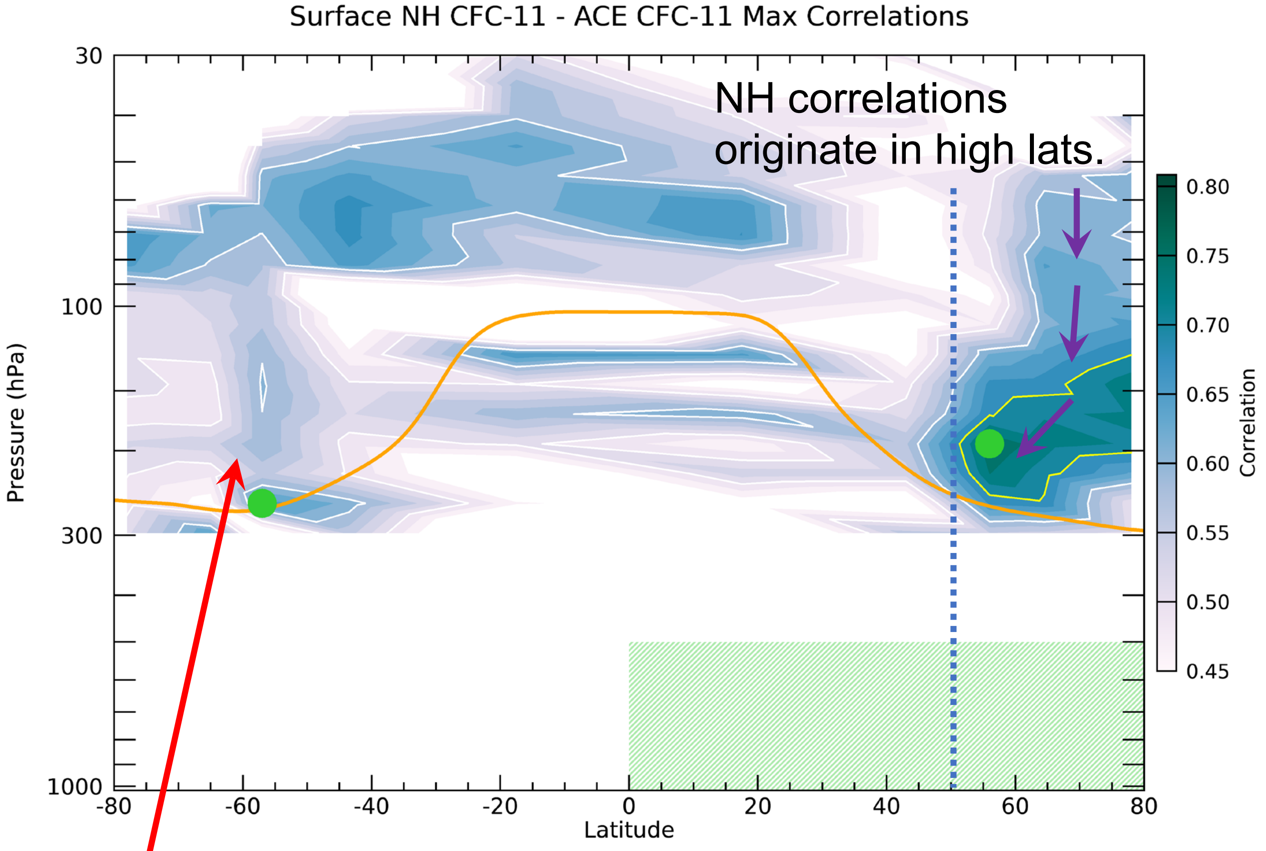
Correlation Lags of NH Surface CFC-11 with ACE



- Lag times approximate the transport times from each location in the stratosphere to the surface.
- Lag times range from 2-30 months.

Correlations of Surface CFC-11 with ACE



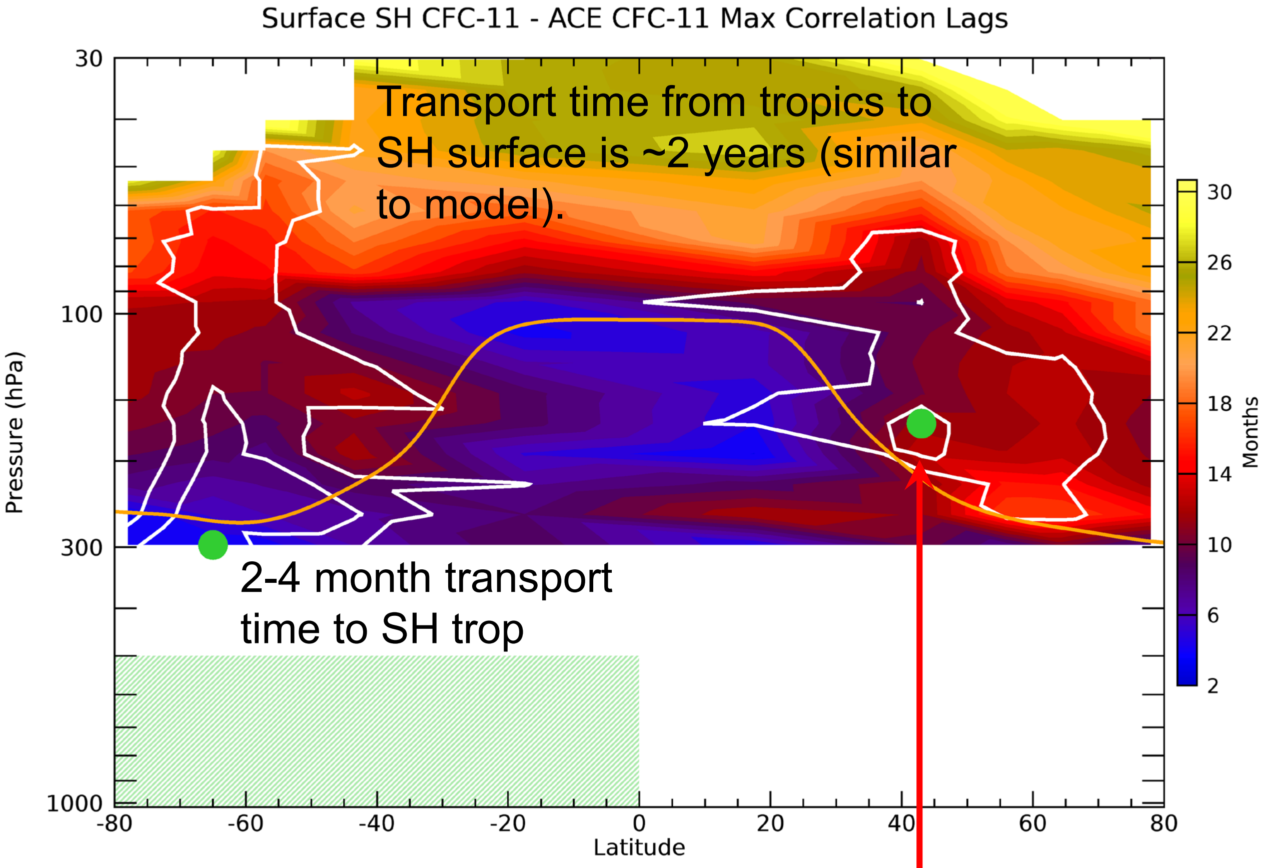


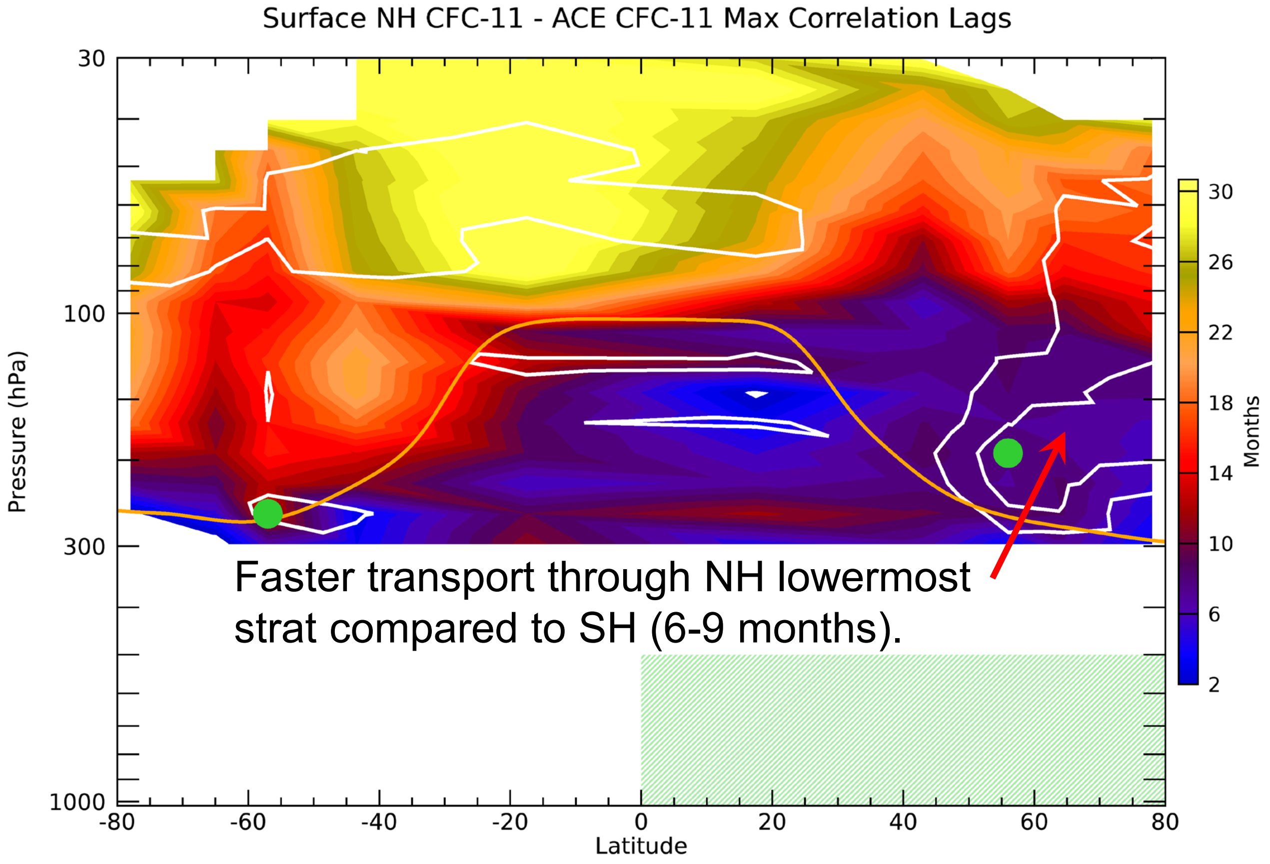
Highest correlations between SH lowermost strat and SH trop.

Relatively high correlations with opposite hemisphere in NH (consistent with stronger strat circulation in NH).

Different latitude pathways in NH to same or opposite hemisphere.

Correlation Lags of Surface CFC-11 with ACE





Relatively short transport times (~1 year) from NH to SH.

We use correlation hot spots near tropopause (green circles) and lag times in a multiple linear regression for each hemisphere.

Predicted Surface CFC-11 Anomalies From ACE Regressions

Running four year ACE-derived surface CFC-11 anomalies based on regressions:

$$\chi_{anom}(t-24{:}\,t+24) = const(t) + a_{SH}(t)\chi_{ACE}\big(y_{SH}, z_{SH}, t-24-l_{SH}(t){:}\,t+24-l_{SH}(t)\big)$$
$$+ a_{NH}(t)\chi_{ACE}\big(y_{NH}, z_{NH}, t-24-l_{NH}(t){:}\,t+24-l_{NH}(t)\big)$$

4 year period centered around each month

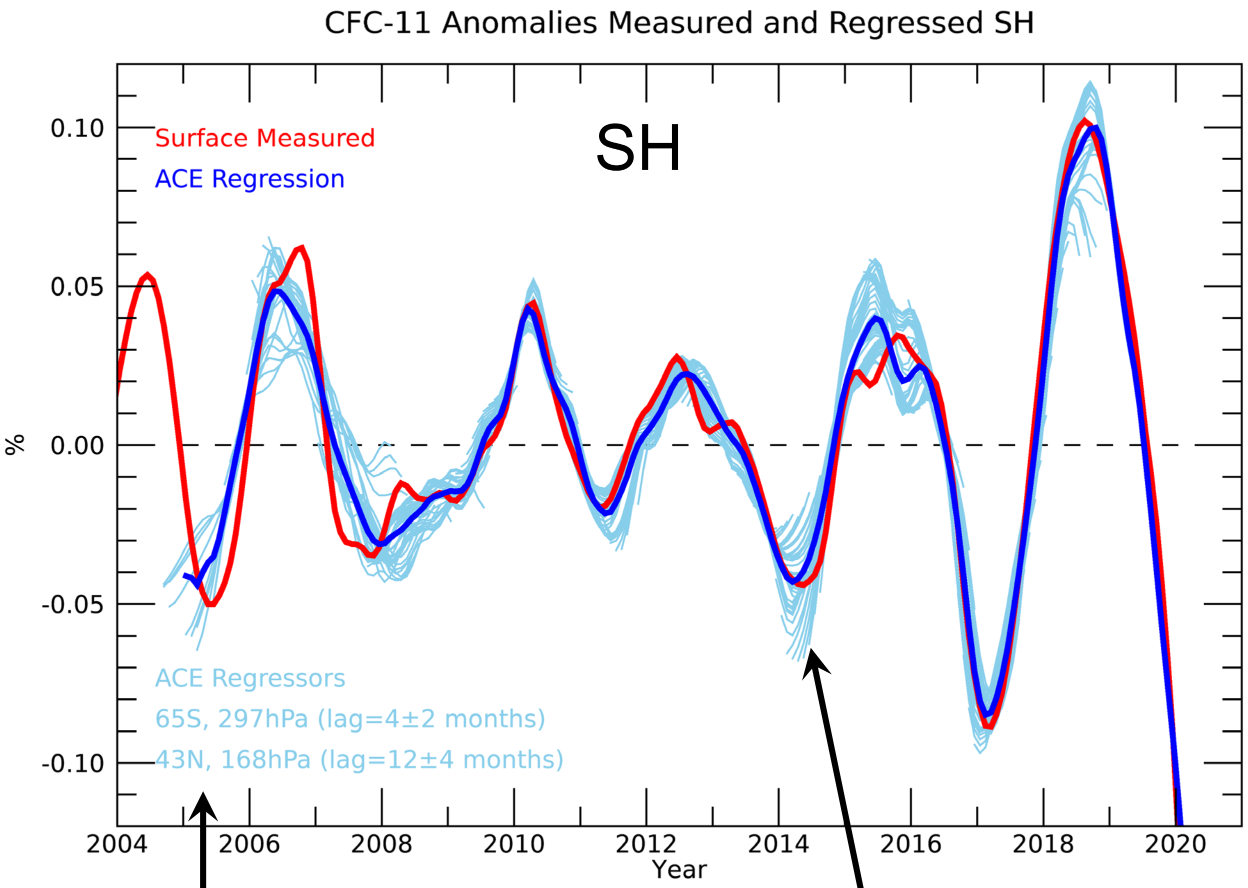
regression coefficients

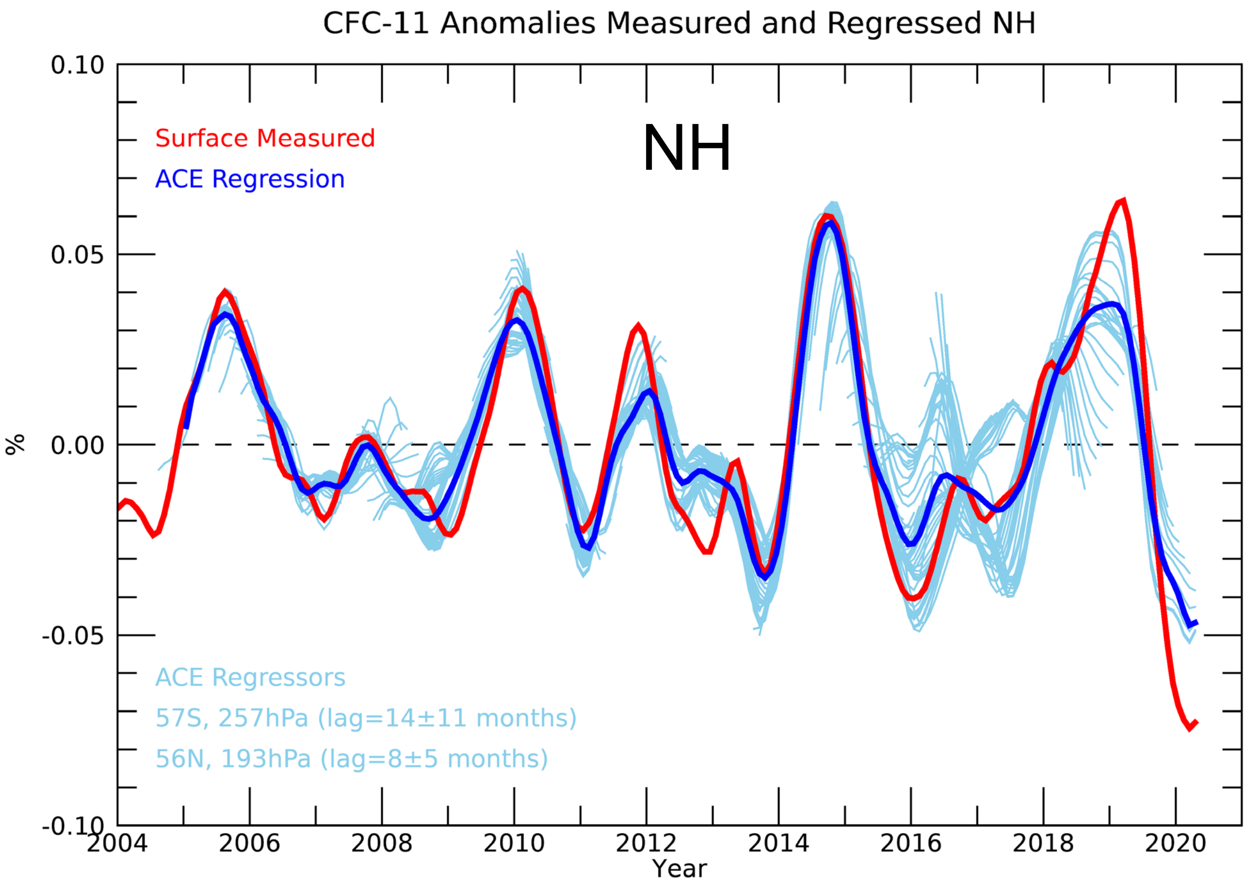
max corr locations (not time dependent)

lag

- Each month has up to 48 anomaly predictions that can be averaged.

Predicted Surface CFC-11 Anomalies From ACE Regressions



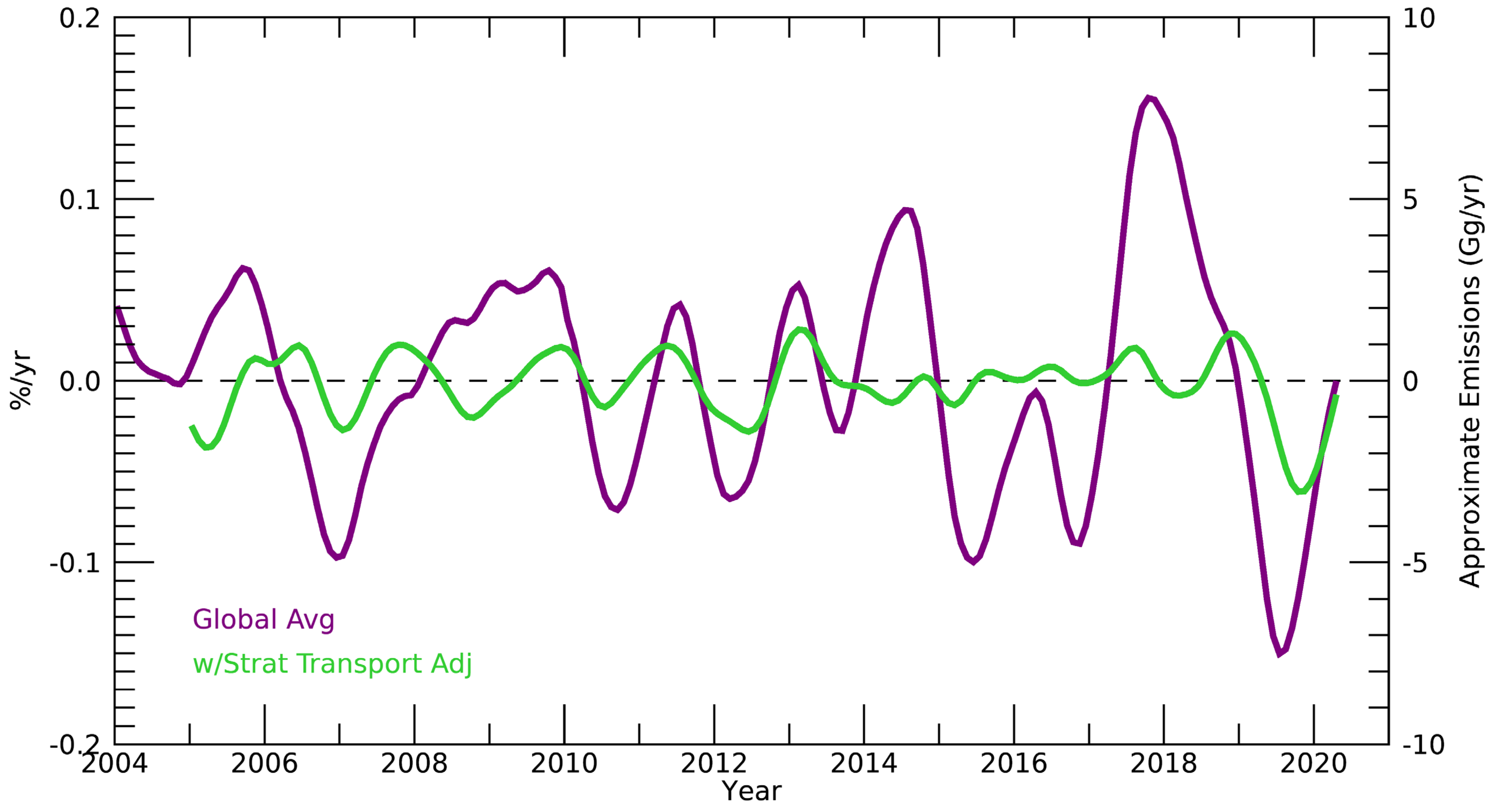


ACE regressor locations and lags

Individual 4 year predictions (spread is an indication of uncertainty and times of lag change)

>90% of the interannual variance can be explained by the average predictions (stratospheric transport)

Global CFC-11 Growth Rate and Emission Anomalies



- Not accounting for stratospheric transport variability can bias emissions estimates by ~5 Gg/yr (8-10%)
- Especially important in early detection of emissions changes

Summary

- Most of the interannual (1-5 year) variability in lower tropospheric CFC-11 can be explained by transport from the stratosphere based on ACE and NOAA GML observations (complements model results).

- CFC-11 is uniquely suited to reveal QBO trace gas transport features from the mid-stratosphere to the surface due to the combination of the location of it’s loss region, lifetime and quality and quantity of measurements.

- The attribution of surface trace gas interannual variability to stratospheric transport has significant implications for emission estimates.