Monitoring Trends and Spatial Distributions of Carbon Cycle Greenhouse Gases and Related Tracers

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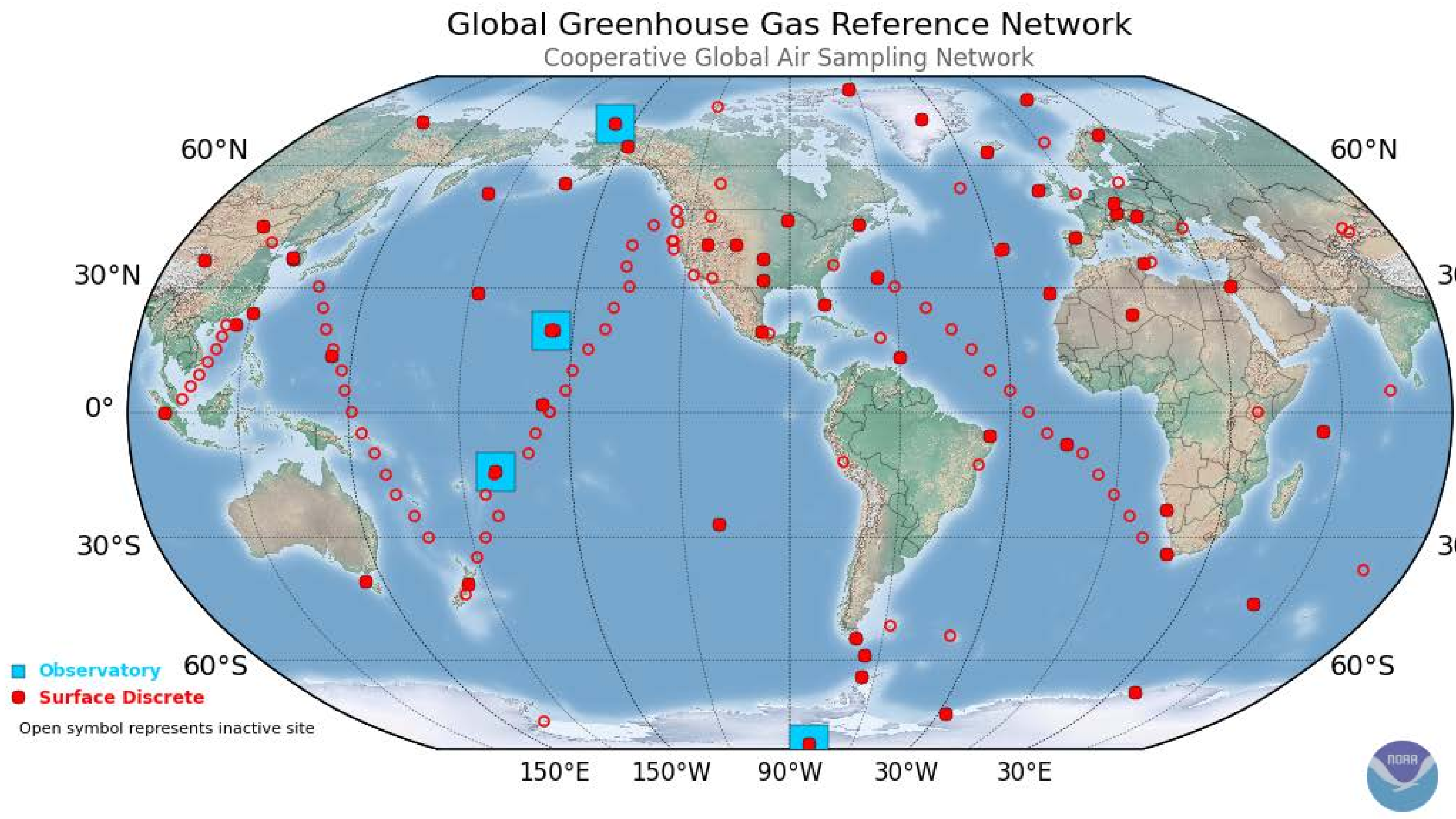
Acknowledgement: GMD Administrative Staff



View recent data: www.esrl.noaa.gov/gmd/dv/iadv/

Cooperative Global Air Sampling Network - unique in its coverage
Weekly samples collected with portable sampler
Sites selected to sample well-mixed air

Scientific Motivation

- Determine budgets and how they change with time
  - Quantify emissions and sinks of LLGHGs at global to large regional spatial scales
  - Determine impacts of climate change on LLGHG budgets
    - Long-term continuity and consistency of observations are important

Approach

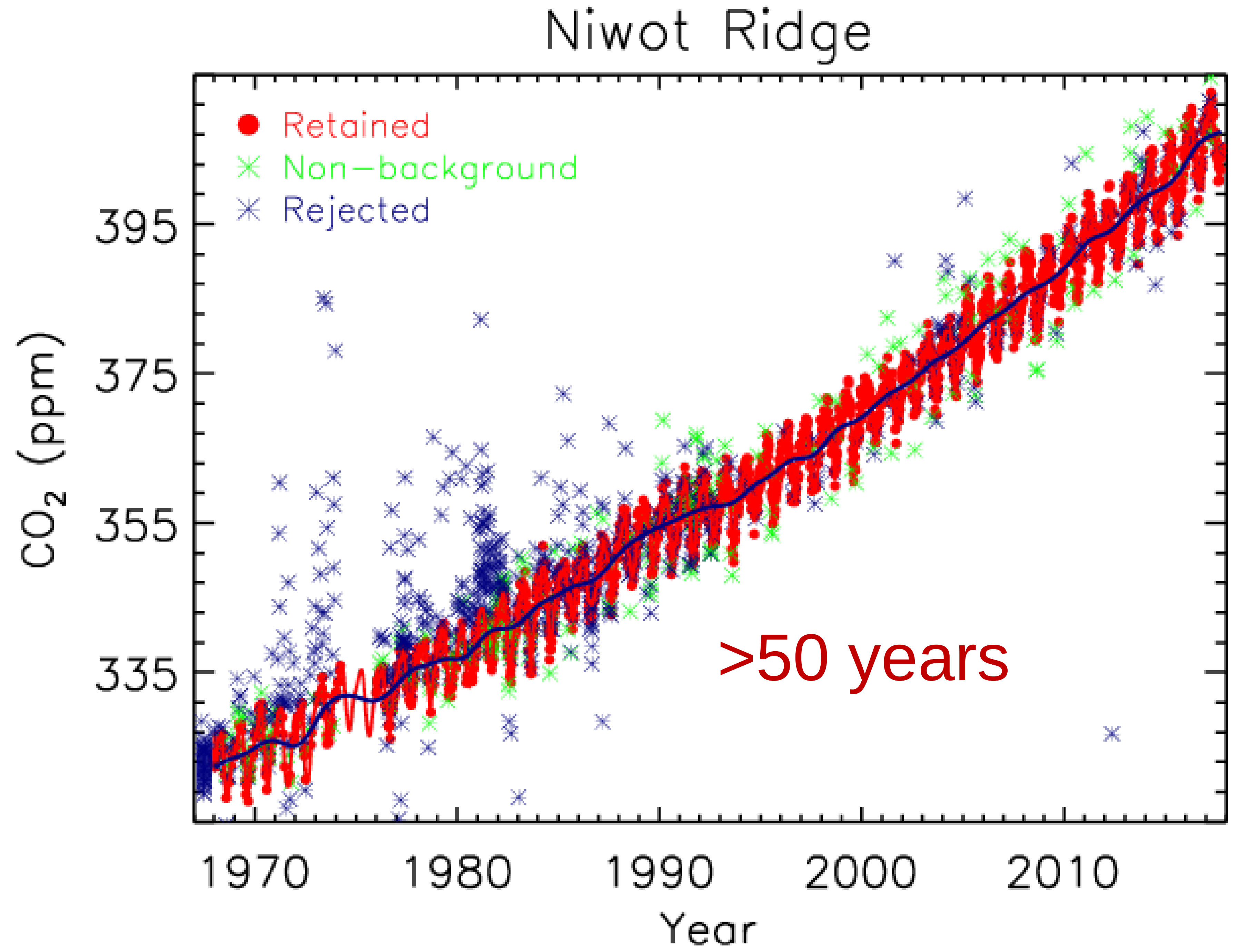
- Accurately, precisely measure spatial, temporal distributions of LLGHGs and related tracers
  - Meaningful temporal and spatial gradients
  - Ensure long-term consistency with QA scheme
    - Developed by Dave Keeling in 1950s

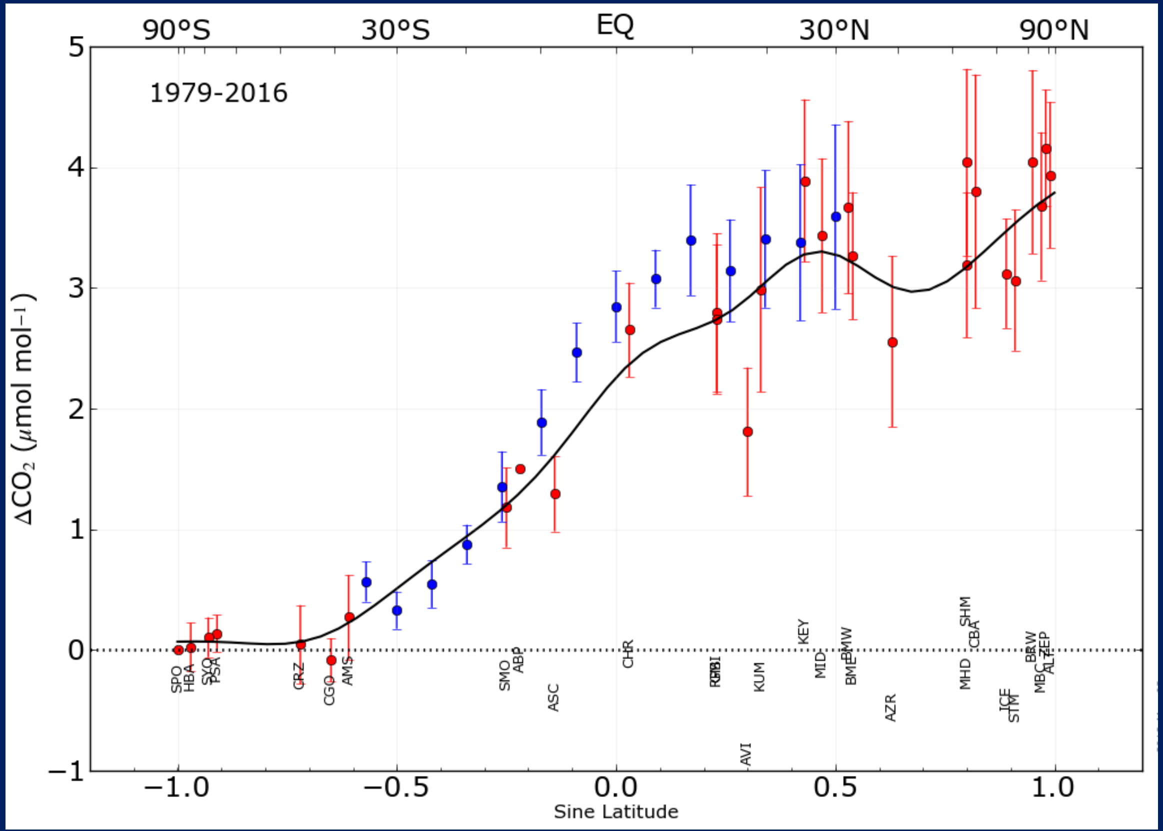
Analytical Capabilities

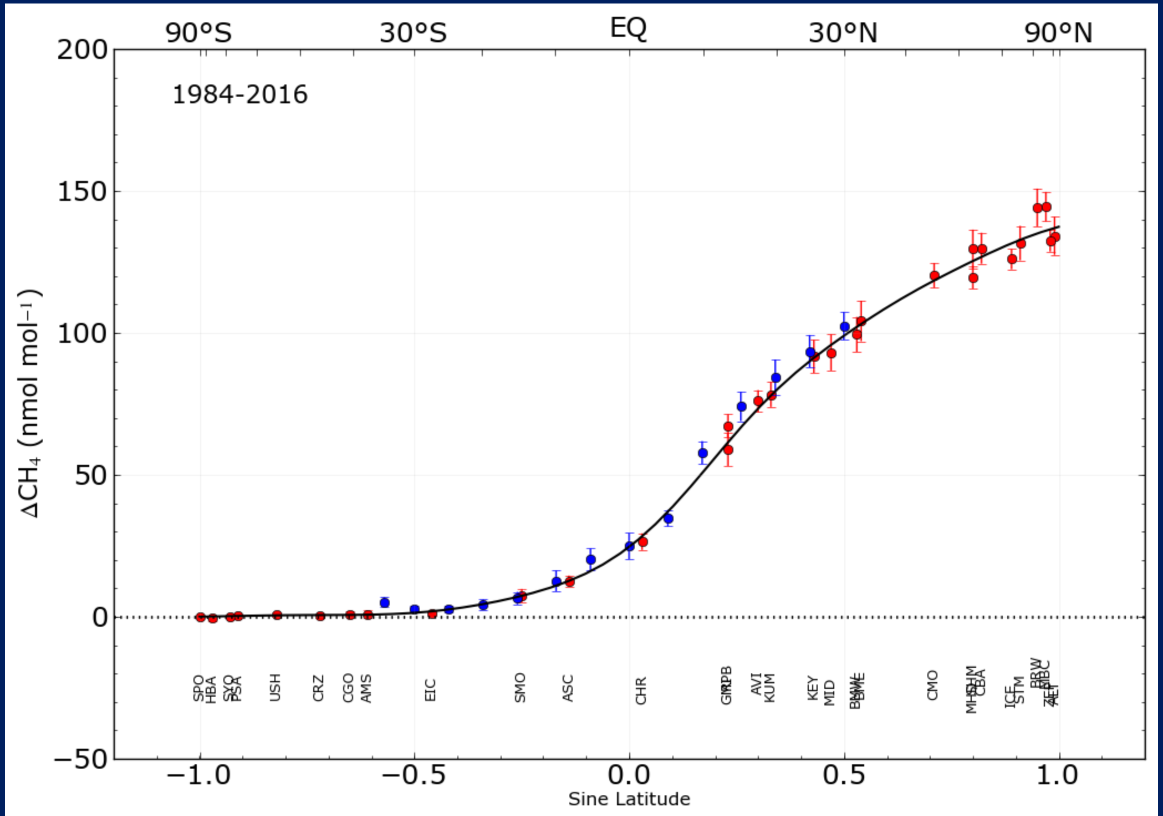
(All flask-air samples)

Gas	Uncertainty (68% CI)	Technique
CO_2	0.08 μmol mol^{-1}	NDIR → CRDS
CH_4	0.9 nmol mol^{-1}	GC/FID → CRDS
CO	1.7 nmol mol^{-1}	VUV-RF → TILDAS
H_2	*0.5 nmol mol^{-1}	GC/PD-HeID
N_2O	0.26 nmol mol^{-1}	GC/ECD → TILDAS
SF_6	0.04 pmol mol^{-1}	GC/ECD
$\delta^{13}CO_2$	*0.01‰	DI-IRMS
$\delta^{13}CH_4$	*0.04‰	GC/CF-IRMS
C_2-C_7 NMHC	†<15%	GC/FID

*Repeatability; †Median pair difference


Niwot Ridge
Retained
Non–background
Rejected
CO_2 (ppm)
395
375
355
335
1970
1980
1990
2000
2010
Year
>50 years



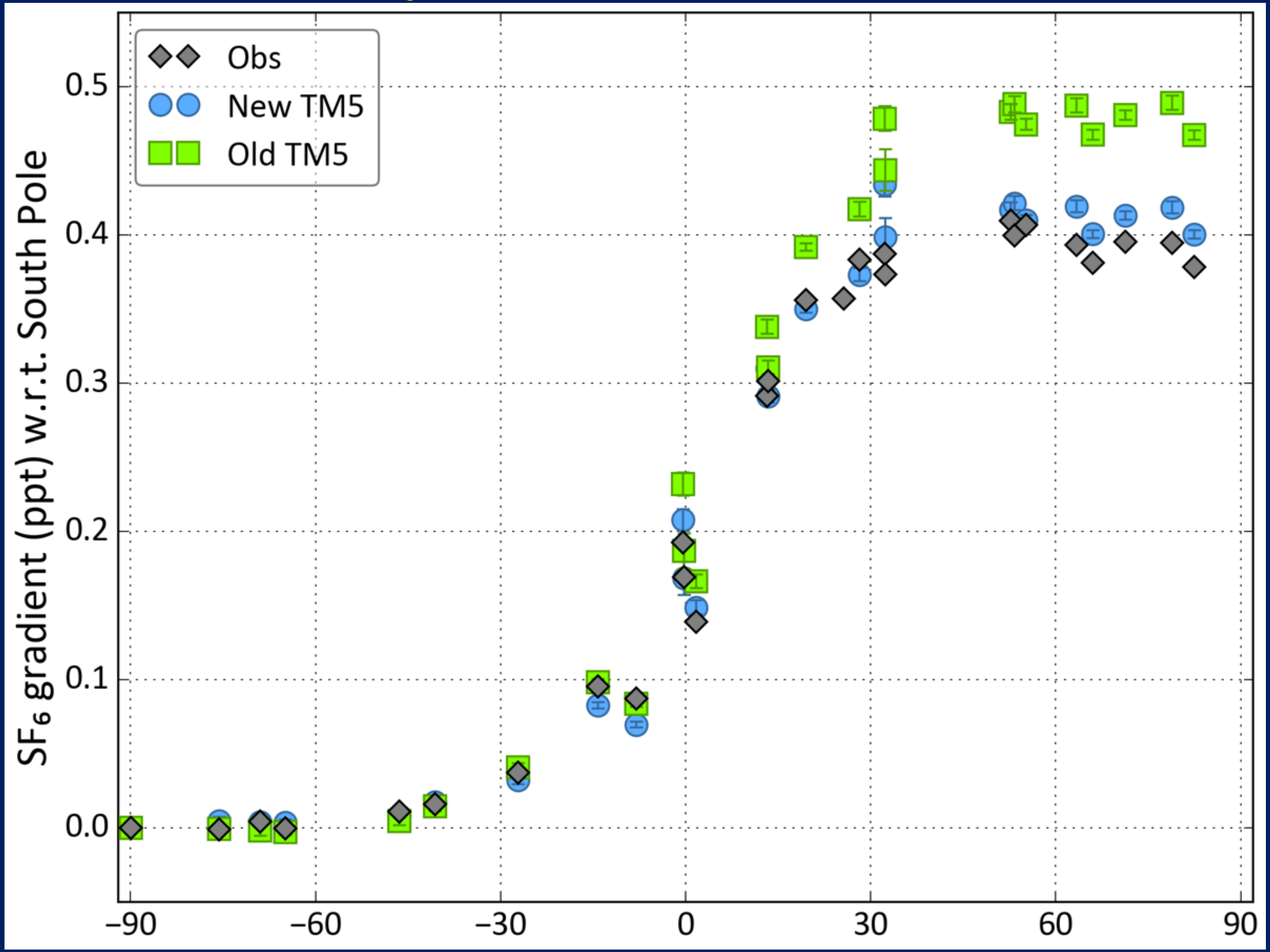


Latitude gradient constrains budgets of emissions and sinks:

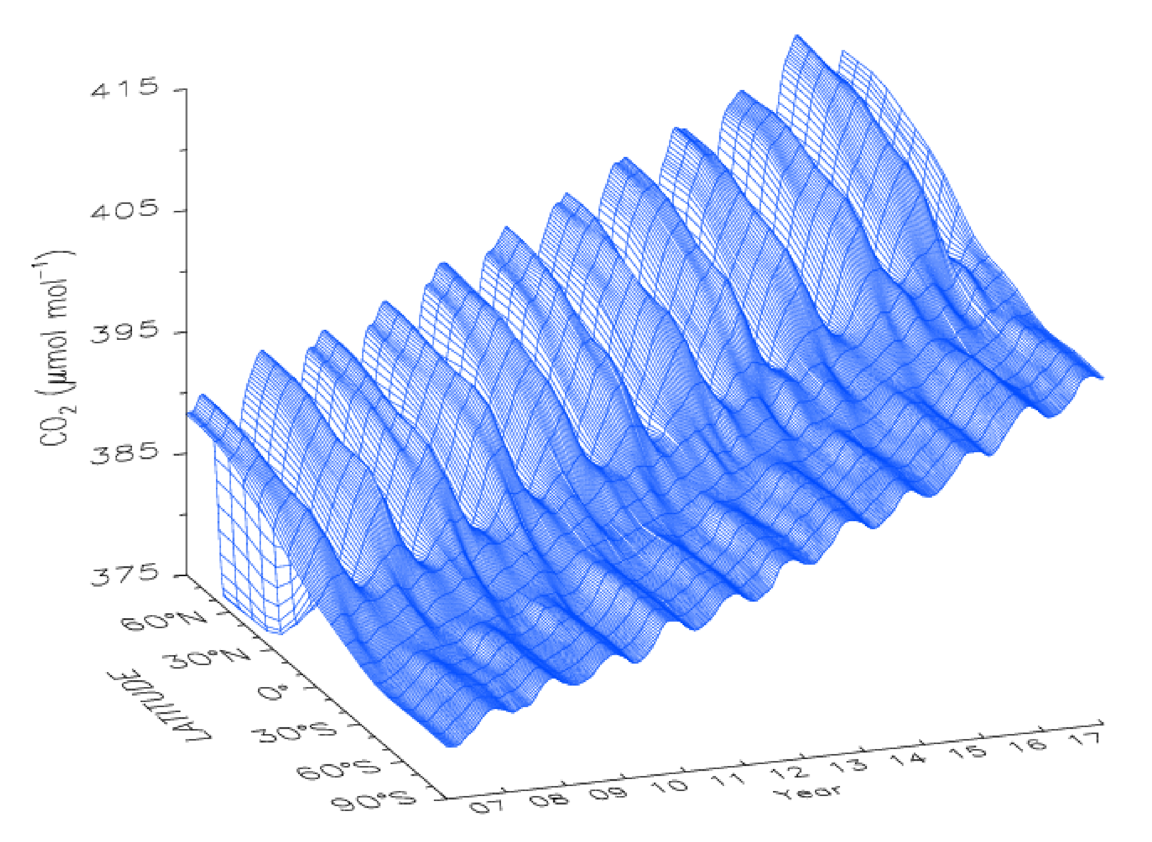
Tans et al., 1990: NH terrestrial carbon sink

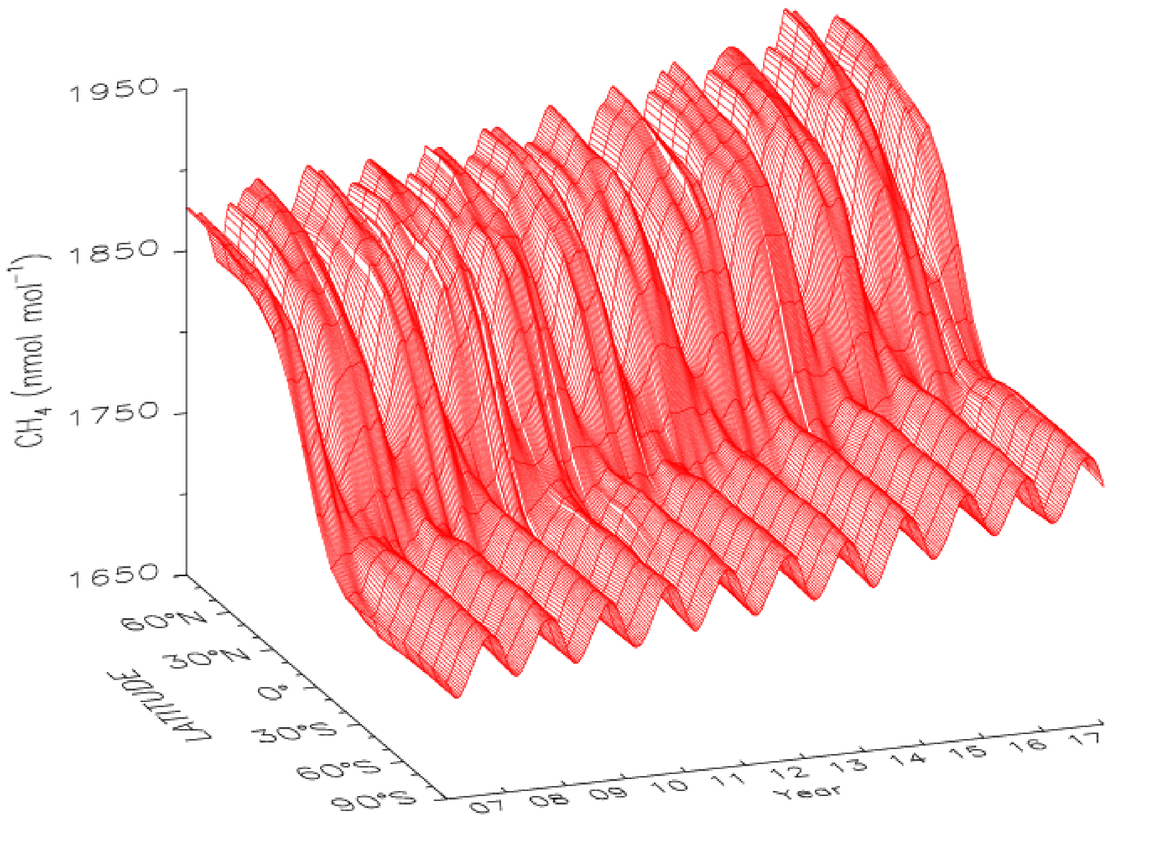
Fung et al., 1991: Less HNH, greater tropical CH_4 emissions

SF_6: Test Model Transport



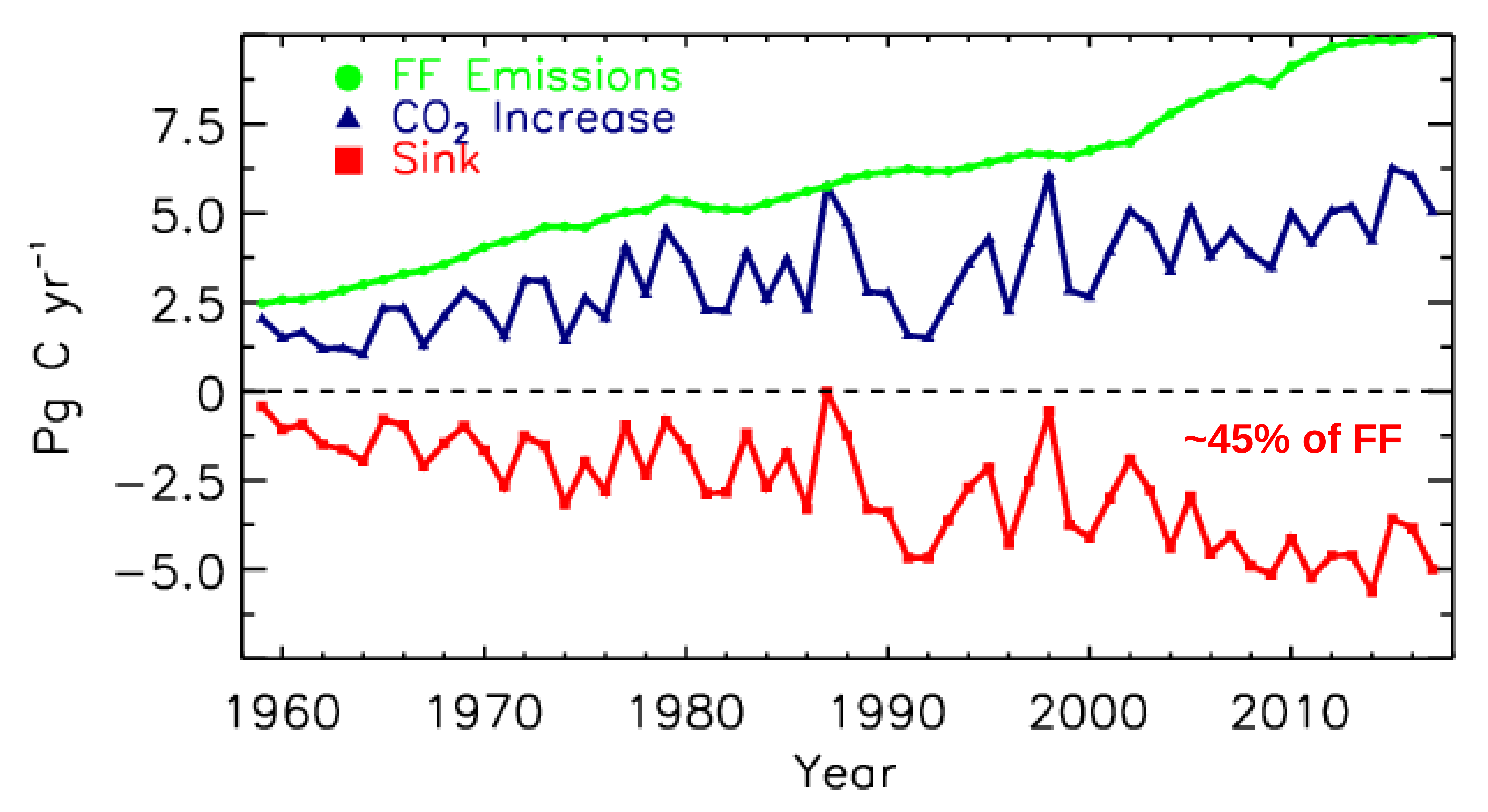
Peters et al., JGR, 2004; Basu et al., ACP, 2016.



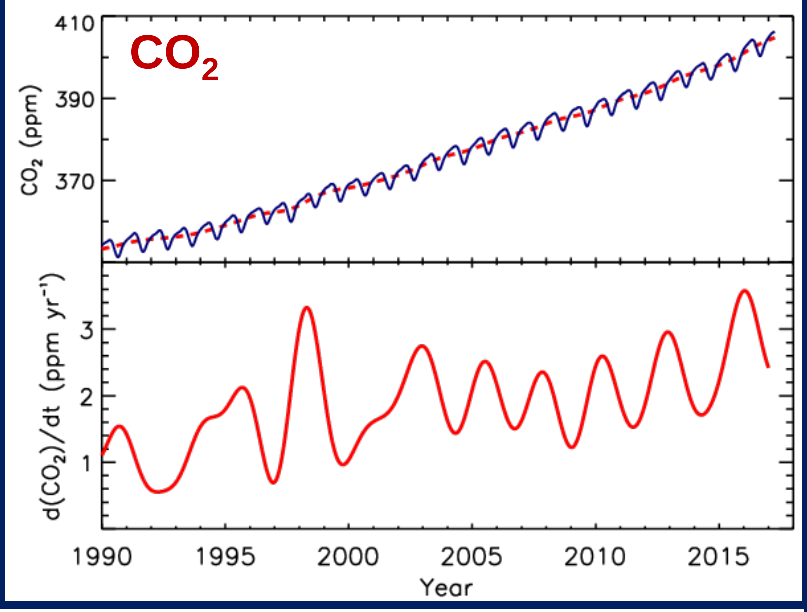


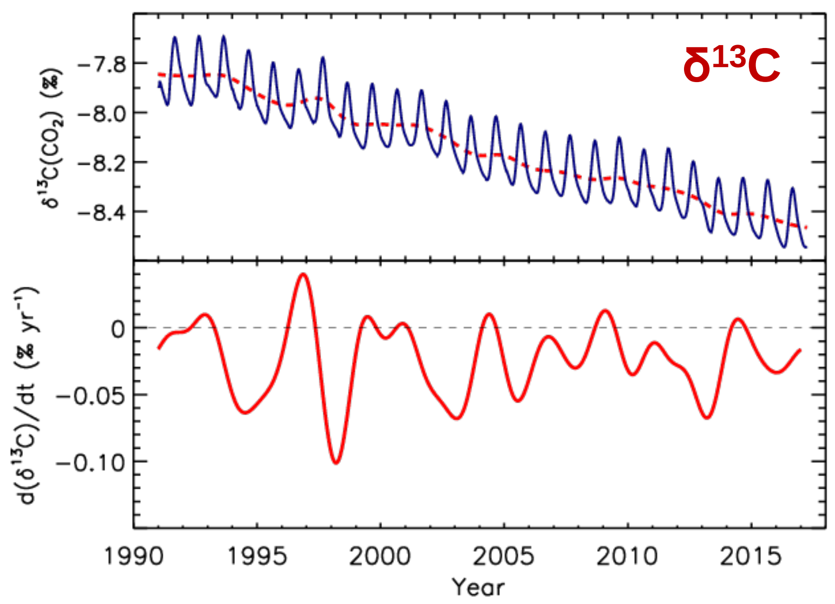
Calculation of global and zonal surface means:

- NOAA global trends web pages (Organizations, e.g., 2º Institute)
- Assessments (e.g., IPCC)
- AGGI (Radiative forcing)
- Peer-reviewed global GHG budget analyses



Based on update of Ballantyne et al., Nature, 2012.

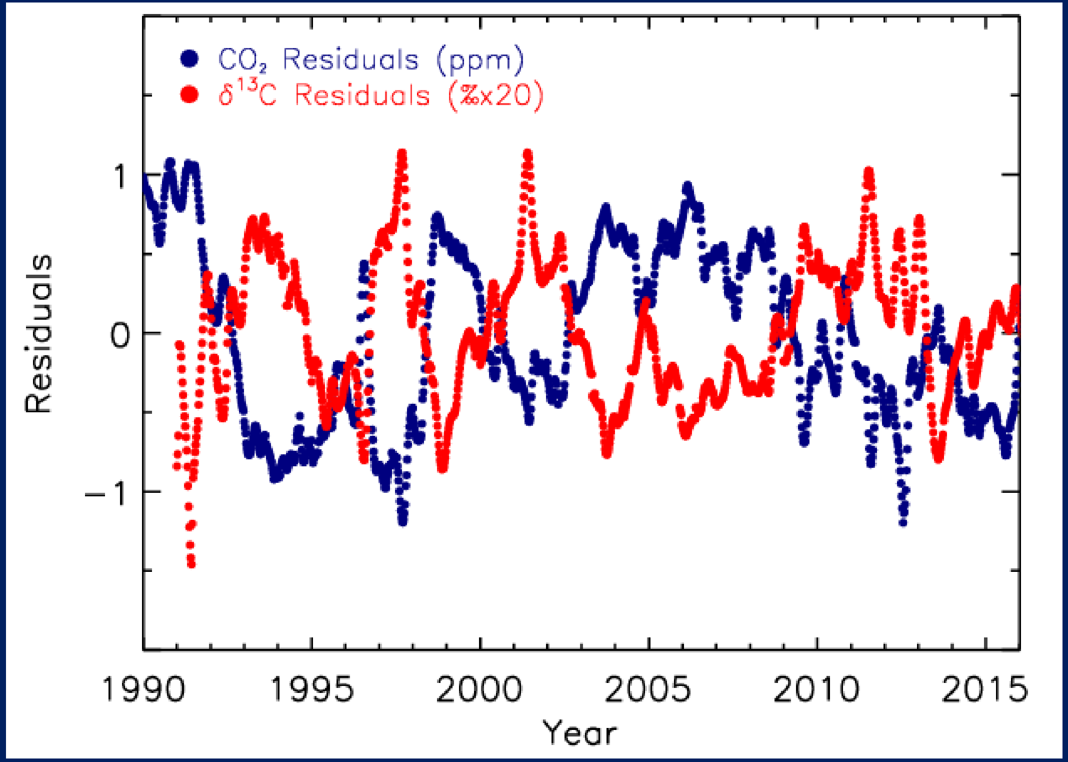


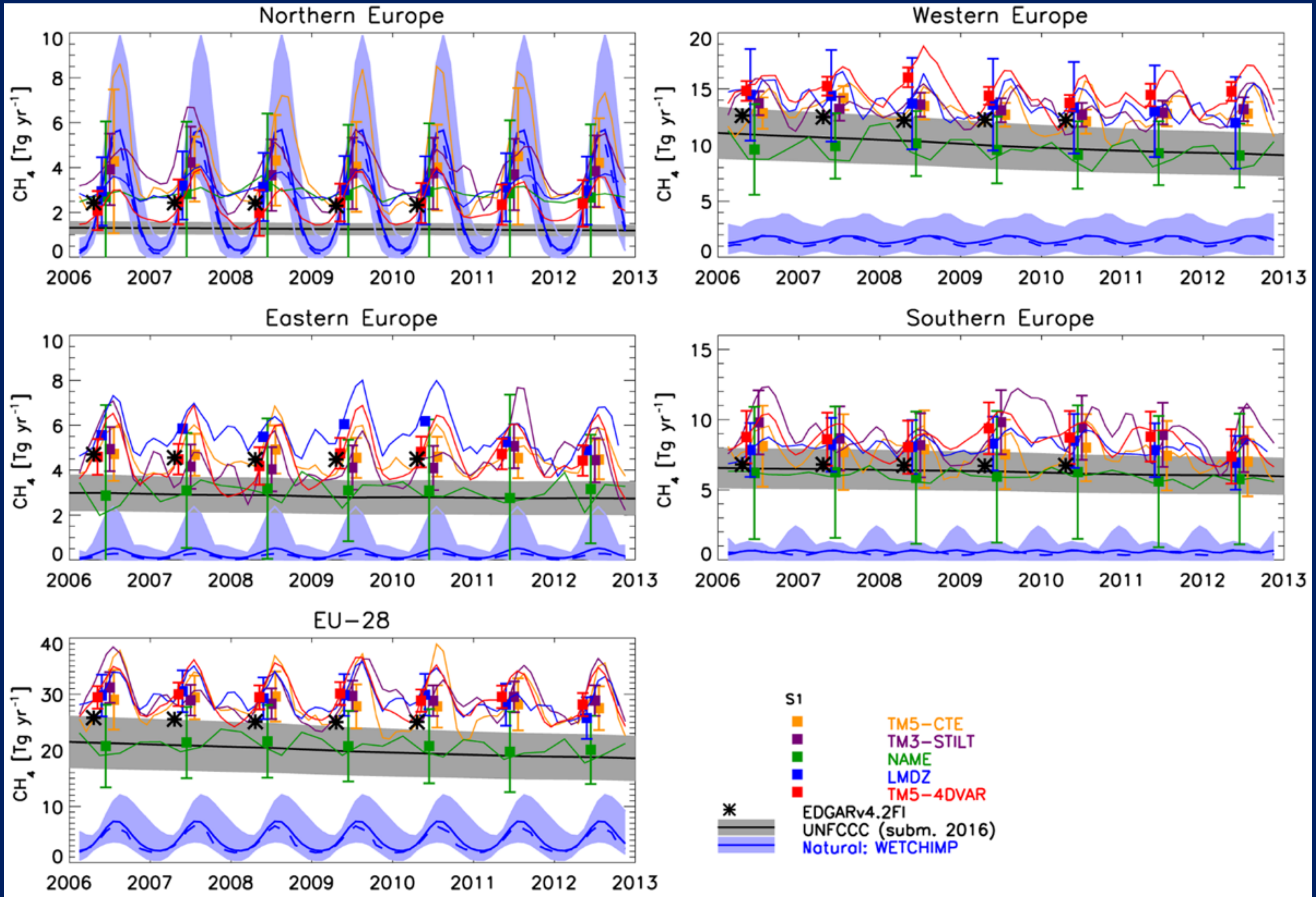


$\delta^{13}C$ as process indicator:

- -Differentiate ocean/terrestrial biosphere fluxes
- -Biosphere: ~0.045‰ ppm^{-1}
- -Ocean: ~0.005‰ ppm^{-1}

$\delta^{13}C$ scaled to match CO_2 residuals:





Use of observations in atm inversion products to study global budgets:

- CT (CO_2 and CH_4)
- CAMS (CO_2, CH_4, and N_2O)
- GCP (CO_2 and CH_4)
- Research studies

Also used in regional-scale studies:

- Bergamaschi et al., 2018

Summary

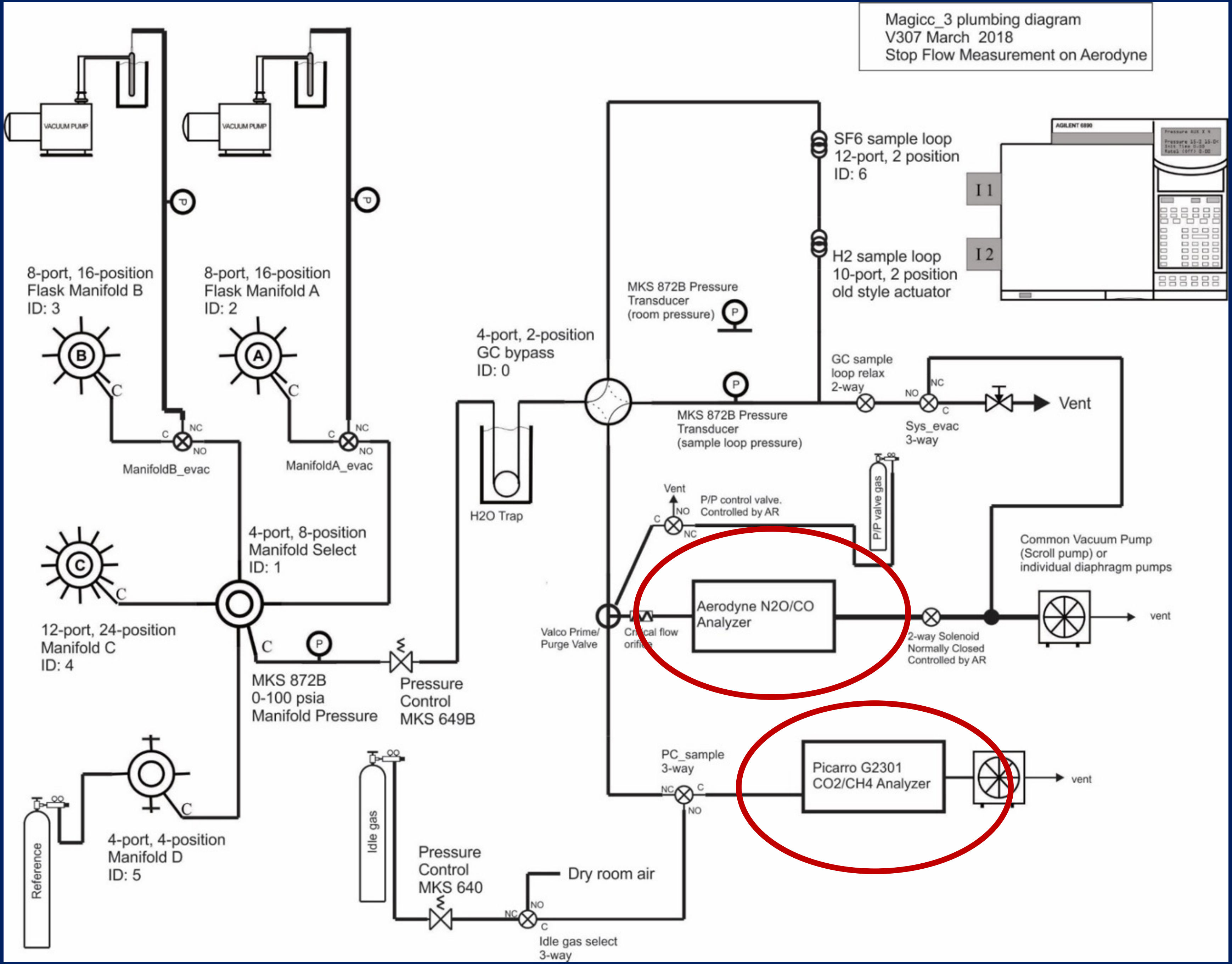
- CCG network is unique in its spatial coverage
- Continually evolving to meet scientific needs
- Delivers internally-consistent, calibrated observations of known quality over long time scales
  - Detailed QA/QC system
- Great scientific benefit at relatively small cost
  - Fundamental constraints on GHG budgets and CTMs

Uncertainties

- Uncertainties on measurements from flask-air
  - Assessing major components of uncertainty (u_i)
  - Other terms, when required
  - $u^2 = u_{st}^2 + u_{lt}^2 + u_{sp}^2 + \ldots.$
- Uncertainties on zonal means
  - Network contribution (bootstrap - random sampling)
  - Potential bias contribution (Monte Carlo – random modifications)

Future of Network

- Enhance spatial coverage
  - Increase sampling from ships (restart POC; add new basins)
  - Add tropical sites (Taiping Is.; Reunion Is.)
  - Improve existing sampling methods
- Improve quality of measurements
  - Testing new flask-air analysis system
- Increase efficiency (w/o sacrificing quality)



Analysis Upgrade:

- Same time/sample
- Less Sample Used
- Improved Precision
- Standard Cal Scheme
- Improved User Interface
- Increased Efficiency

Ensuring Quality of Data

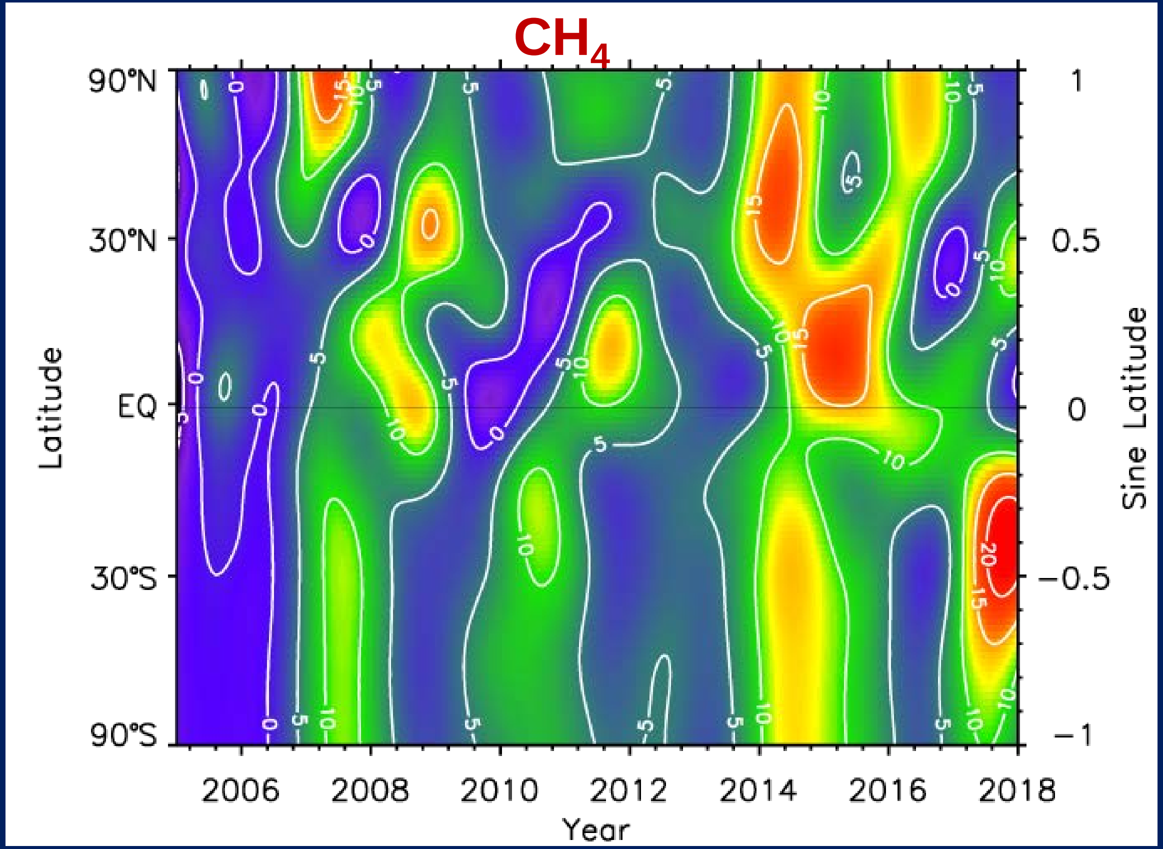
- Quality Assurance
  - Daily test flasks and surveillance cylinders
  - Testing portable air samplers
- Quality Control
  - Inspection of “data” for sampling and analysis problems
  - Comparisons with independent measurements

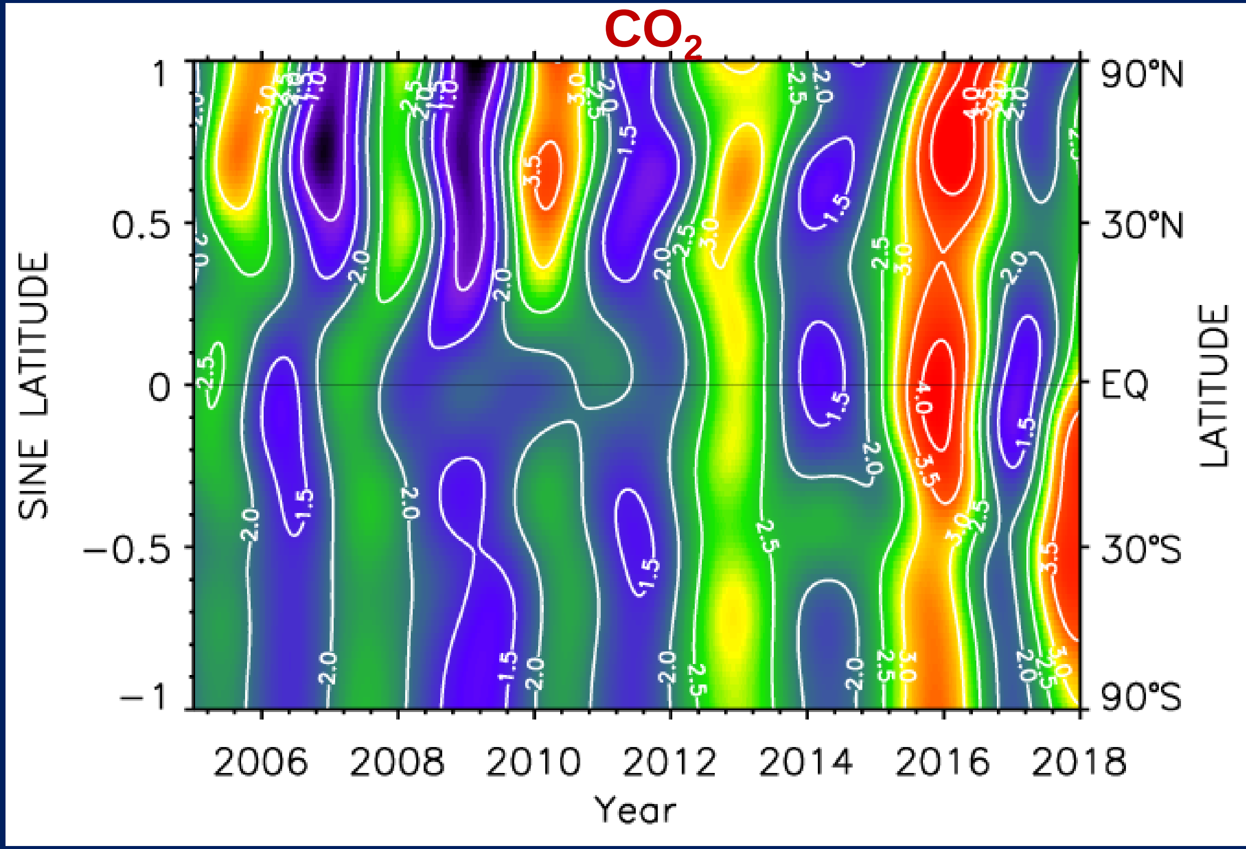
QA/QC

- Test flasks
  - Pair filled from cylinder of calibrated air run daily
- Target cylinders
  - Short-term (close to ambient) run monthly
  - Long-term (wide range in X) run few times/year
- Flask/in situ comparisons at observatories
- Comparisons with GAW partners + others
  - Same air
  - Co-located

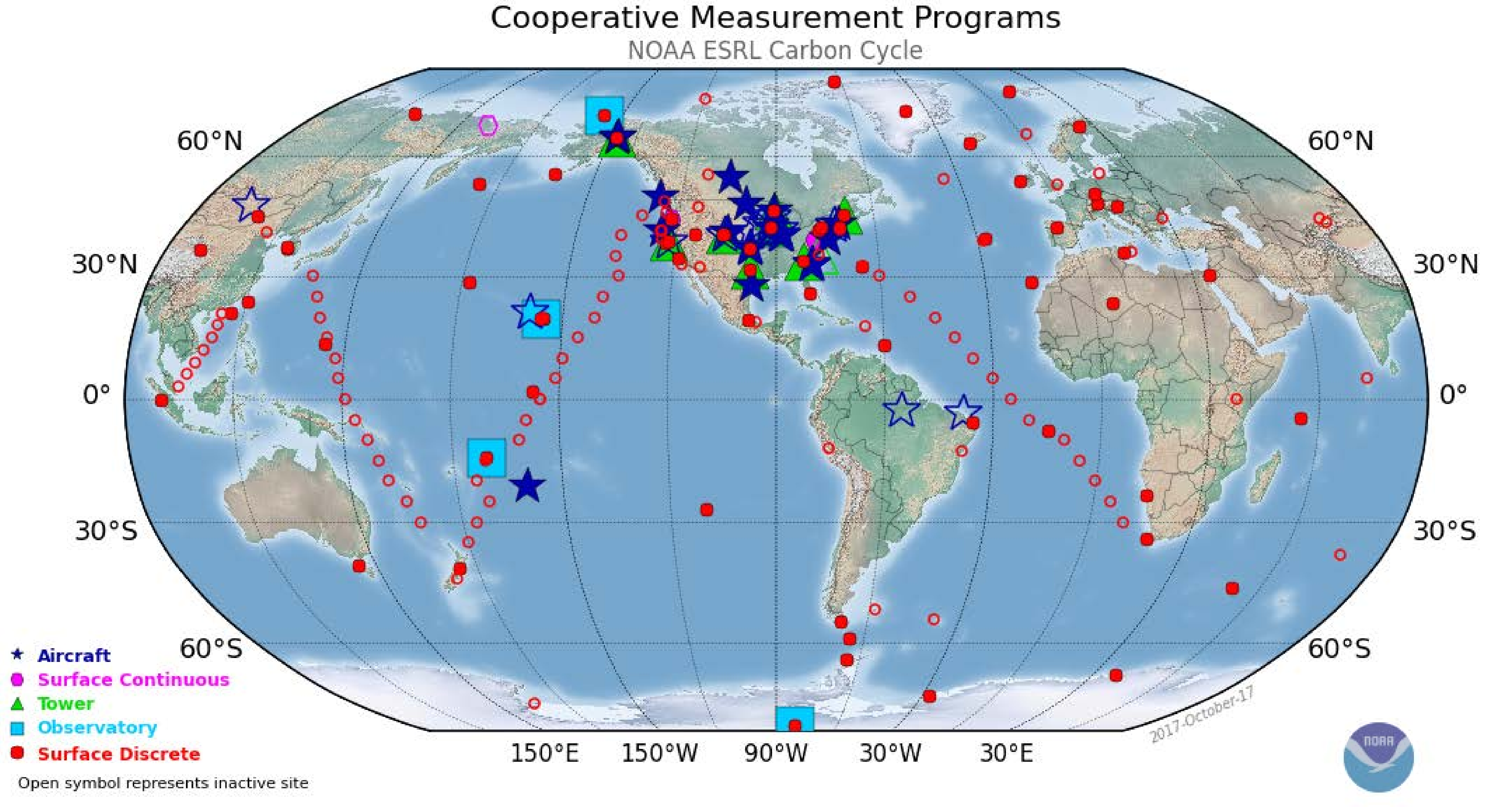
Remote Sensing

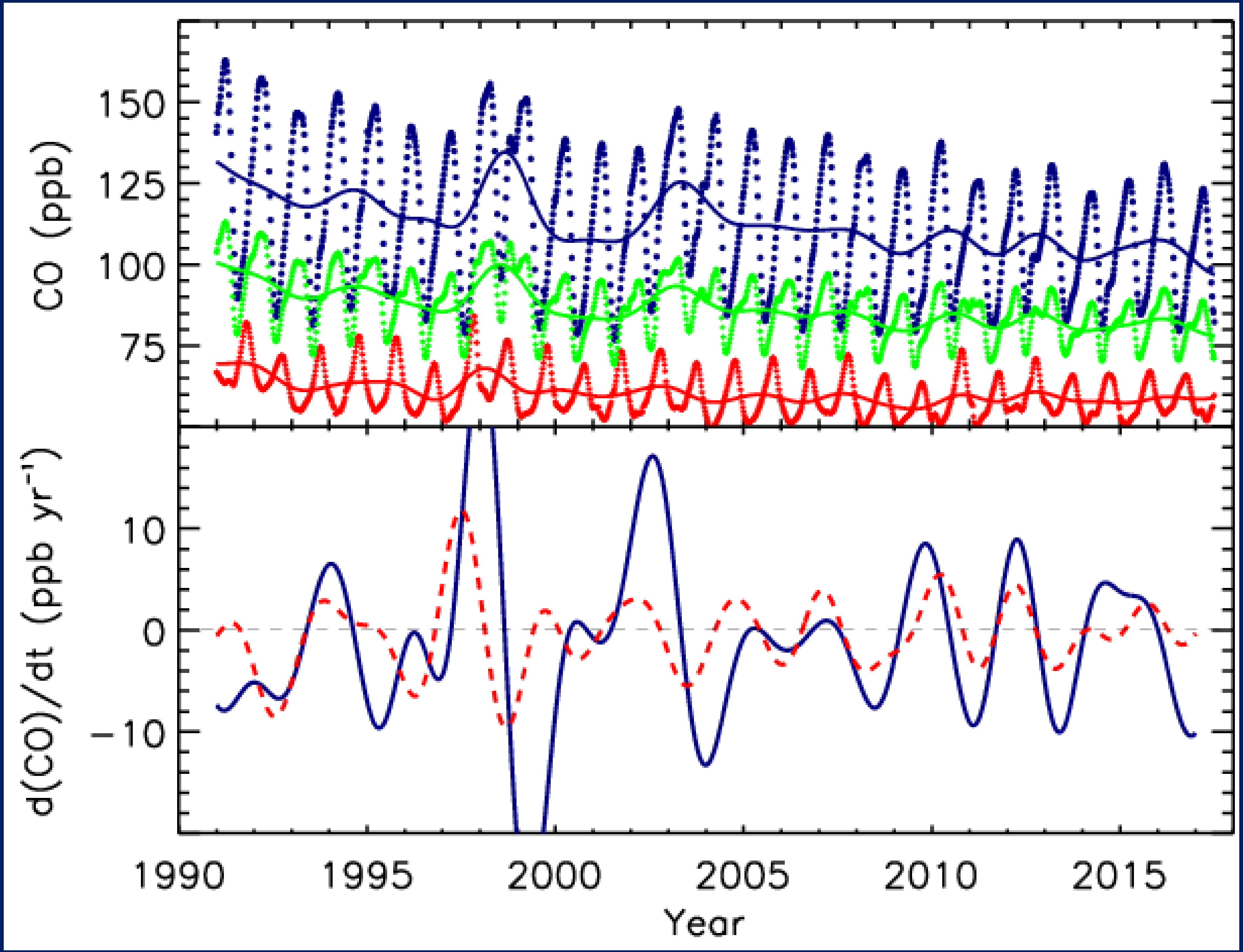
- Never calibrated, only evaluated
  - e.g., with vertical profiles; Aircore
- Sensor degradation over time
- Potential biases (e.g., land vs ocean)
- “Short” deployment for satellites
- Retrieve total column; strongest signals at surface
- Different retrieval versions give very different results
  - e.g., in CO_2 inversions


CH4
90°N
30°N
EQ
30°S
90°S
Latitude
1
0.5
0
−0.5
−1
Sine Latitude
2006
2008
2010
2012
2014
2016
2018
Year

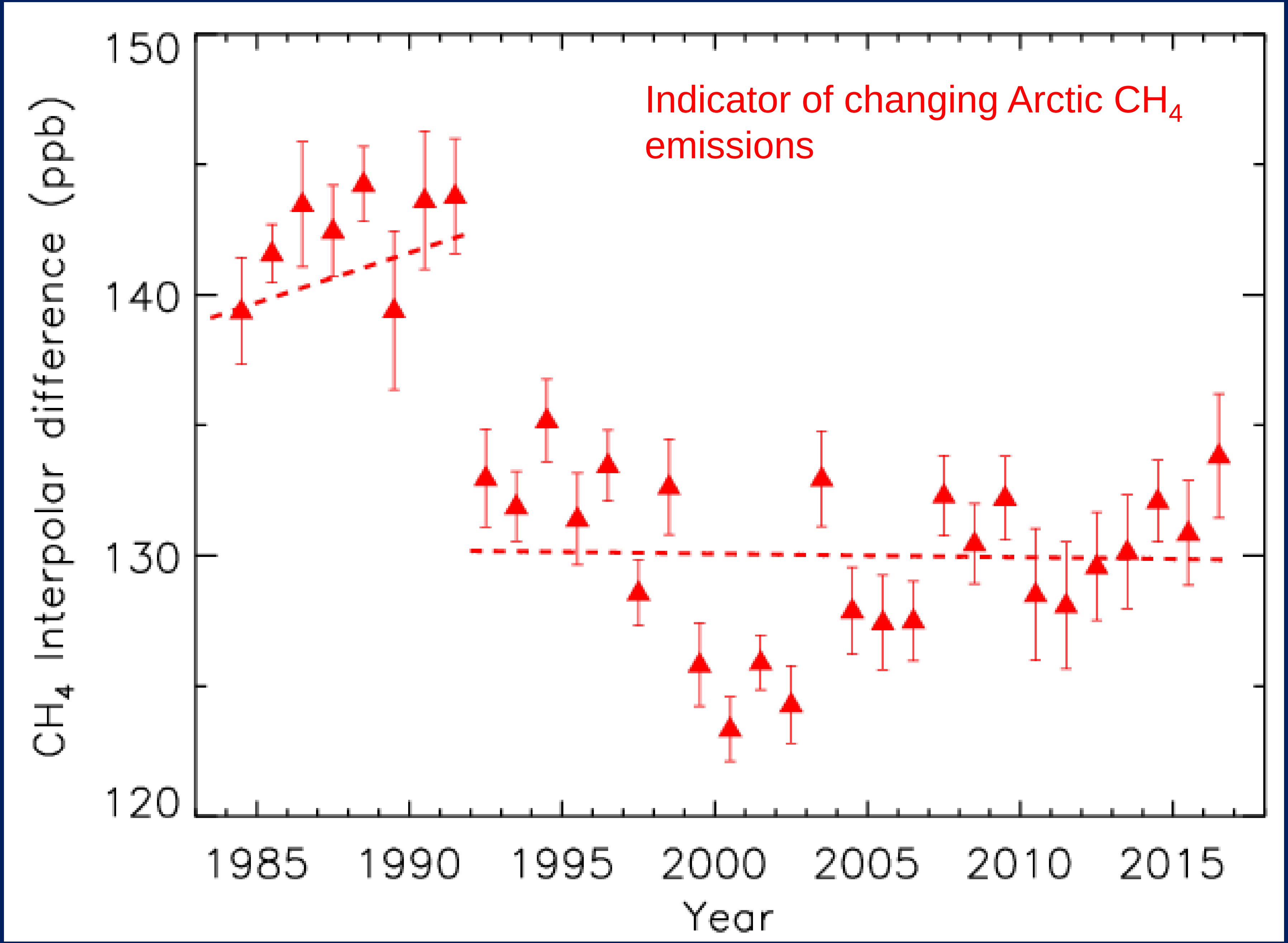

CO2
1
0.5
0
−0.5
−1
SINE LATITUDE
90°N
30°N
EQ
30°S
90°S
LATITUDE
2006
2008
2010
2012
2014
2016
2018
Year

Calibration: Calibration links the measured response of an analyzer, under controlled conditions, to known values of measurement standards (with known uncertainties). That response is used to assign values and uncertainties to other samples. Standards must be linked to fundamental SI units in a single, unbroken, hierarchical chain of traceability.

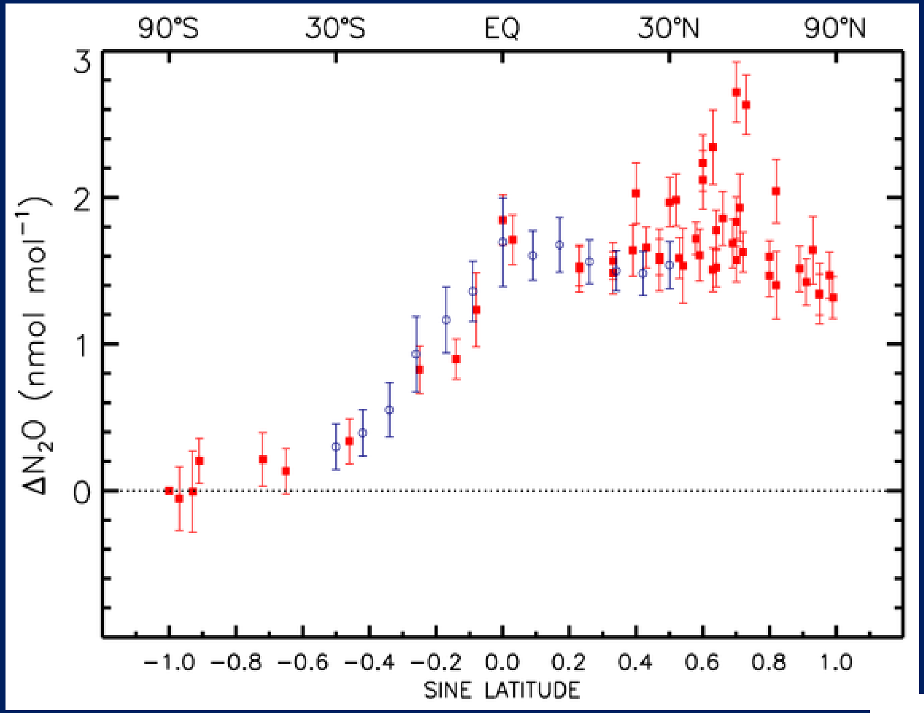

Cooperative Measurement Programs
NOAA ESRL Carbon Cycle
60°N
30°N
0°
30°S
60°S
150°E
150°W
90°W
30°W
30°E
Aircraft
Surface Continuous
Tower
Observatory
Surface Discrete
Open symbol represents inactive site
2017-October-17
NOAA



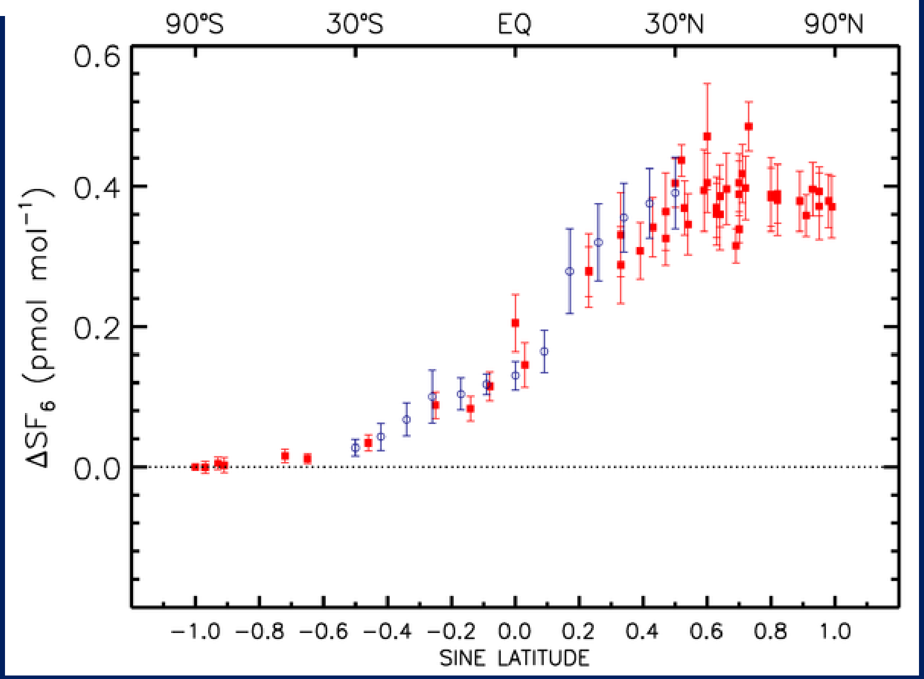
CO (ppb)
150
125
100
75
d(CO)/dt (ppb yr⁻¹)
10
0
−10
1990
1995
2000
2005
2010
2015
Year



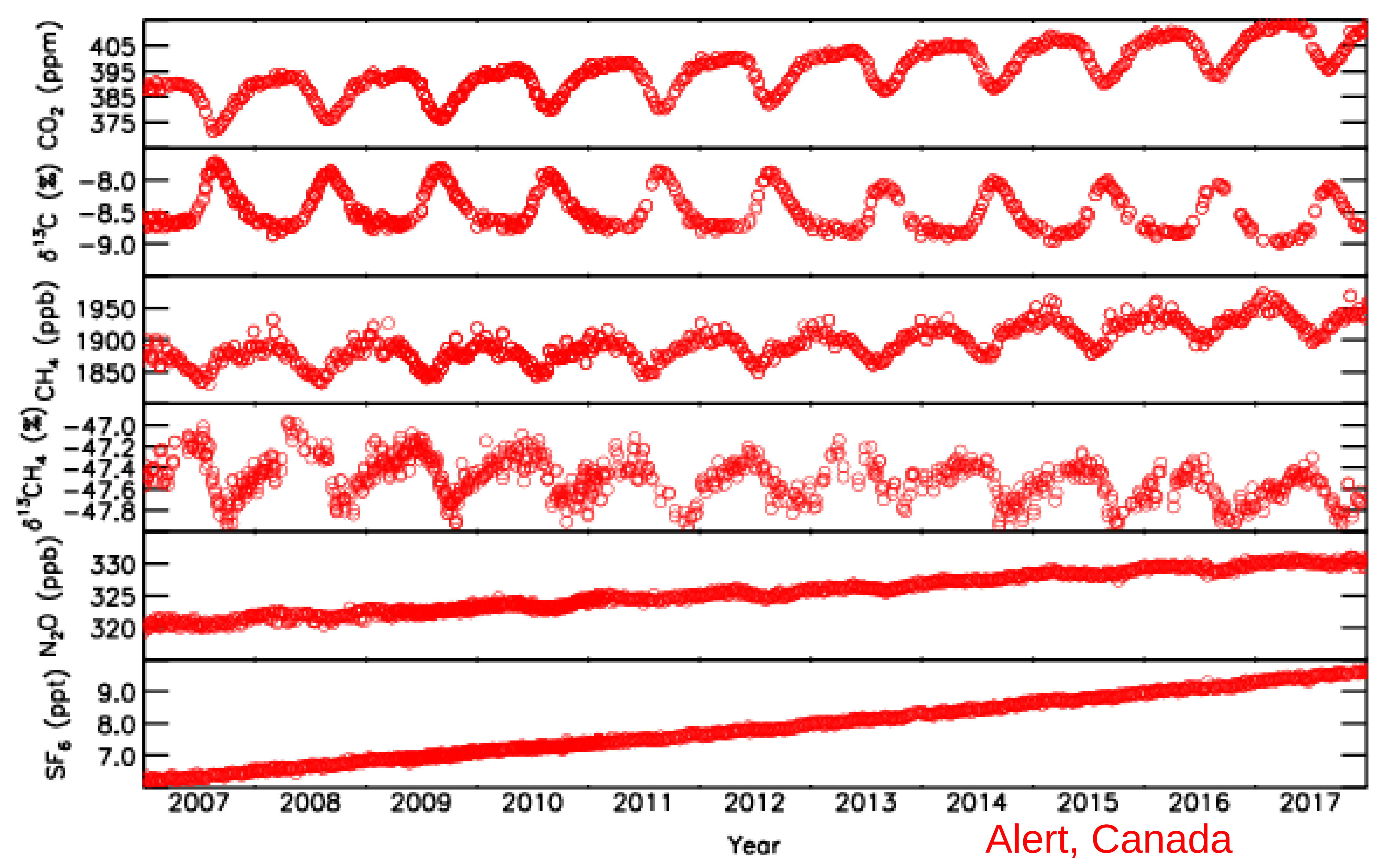
Updated from: Dlugokencky et al., Geophys. Res. Lett., 30 (19), 1992, doi:10.1029/2003GL018126, 2003.

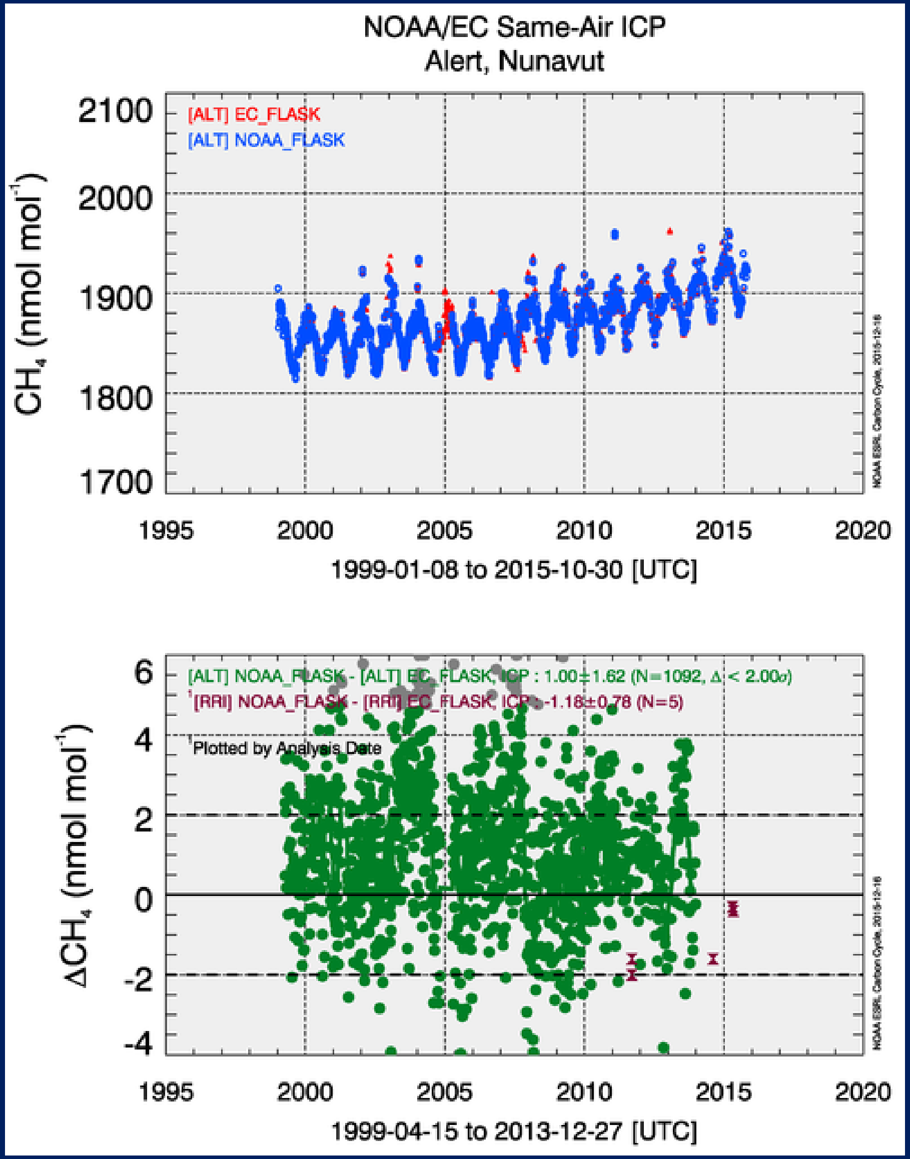


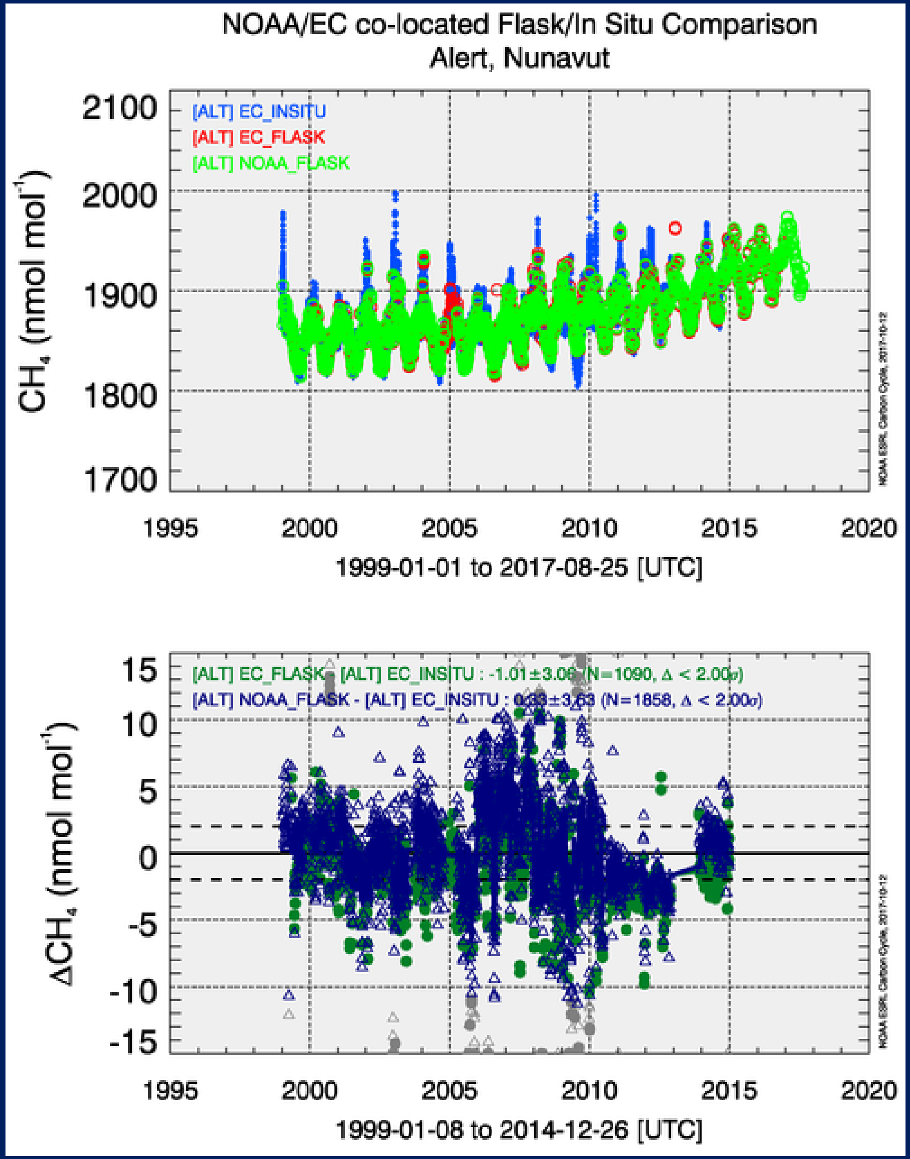
Hirsch et al., GBC, 2006:
Redistributed emissions, doubling those from N tropics



Use SF_6 to:
- show emissions reported to UNFCCC are too small
- test transport in ATM

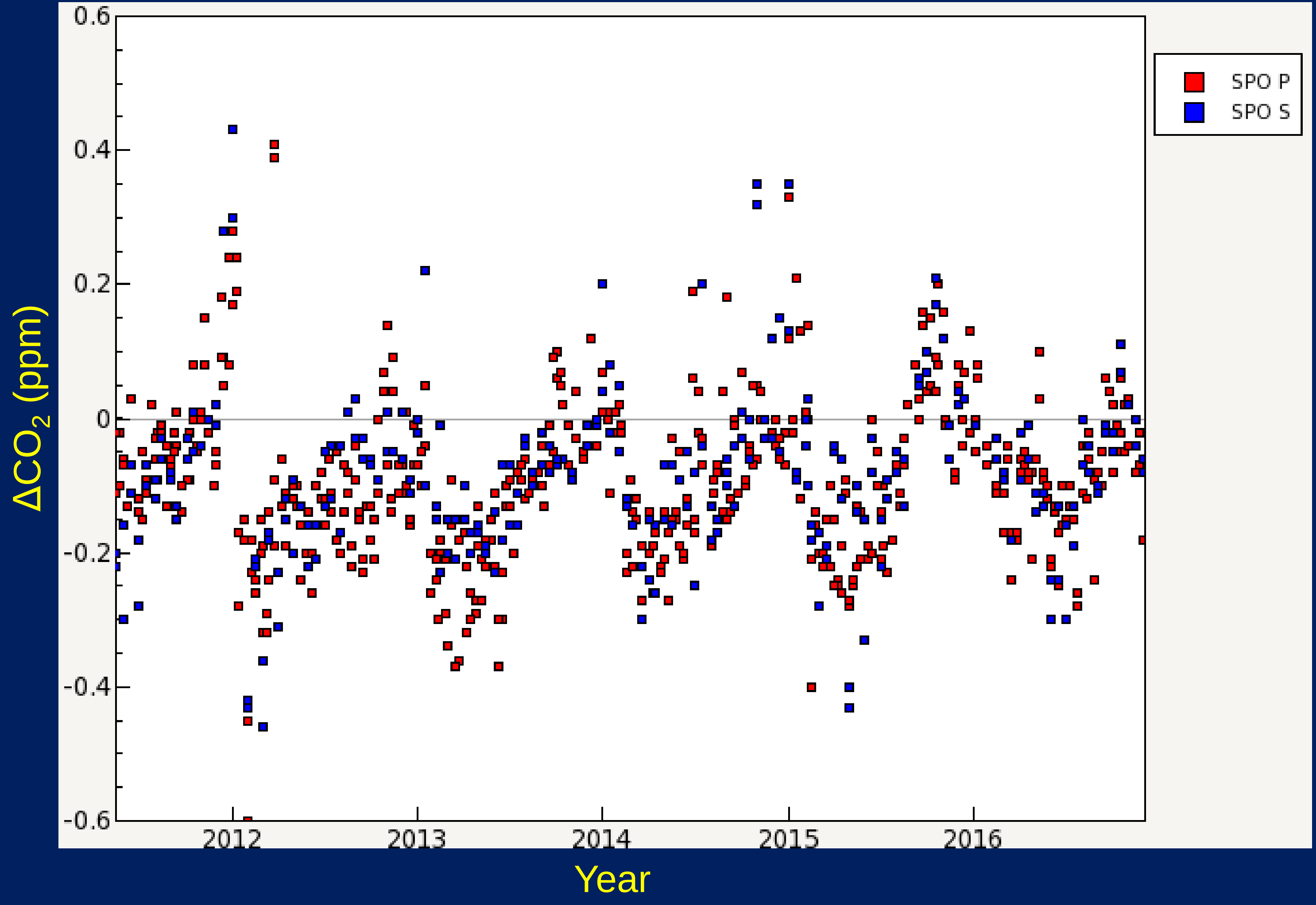

CO₂ (ppm)
405
395
385
375
δ¹³C (‰)
−8.0
−8.5
−9.0
CH₄ (ppb)
1950
1900
1850
δ¹³CH₄ (‰)
−47.0
−47.2
−47.4
−47.6
−47.8
N₂O (ppb)
330
325
320
SF₆ (ppt)
9.0
8.0
7.0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
Alert, Canada

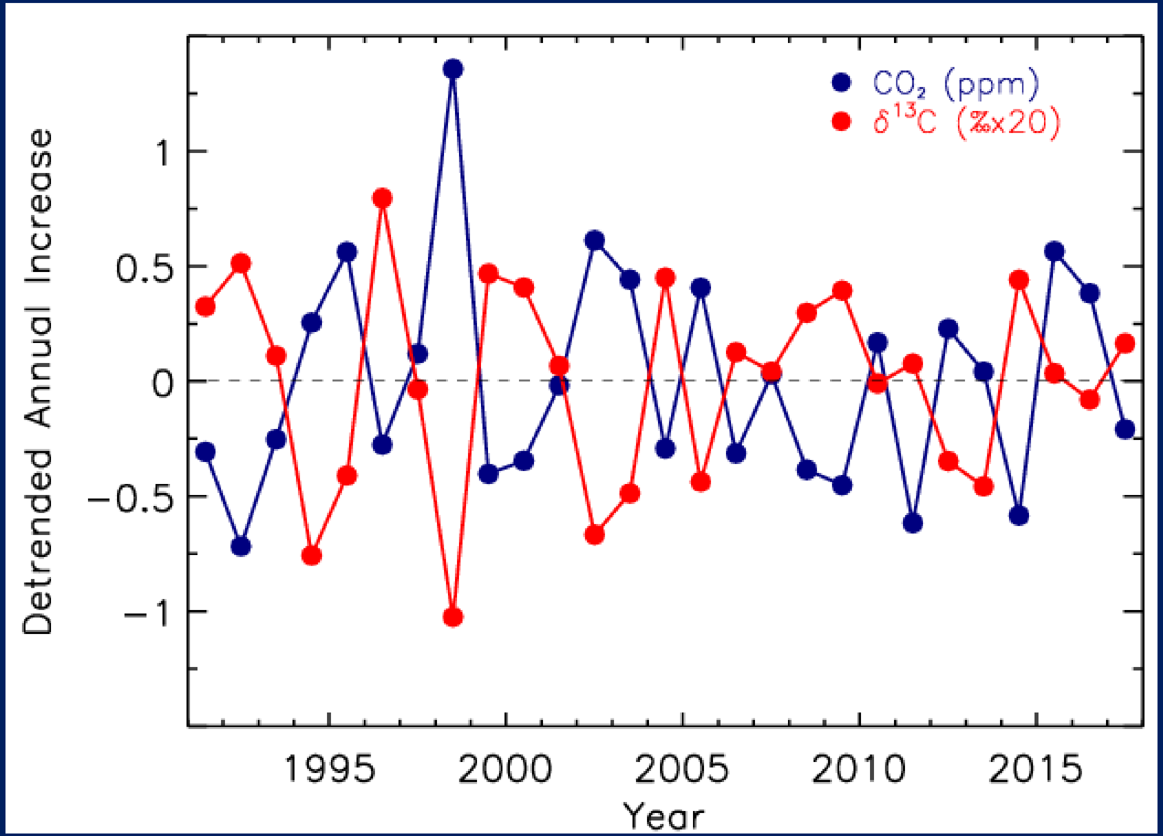




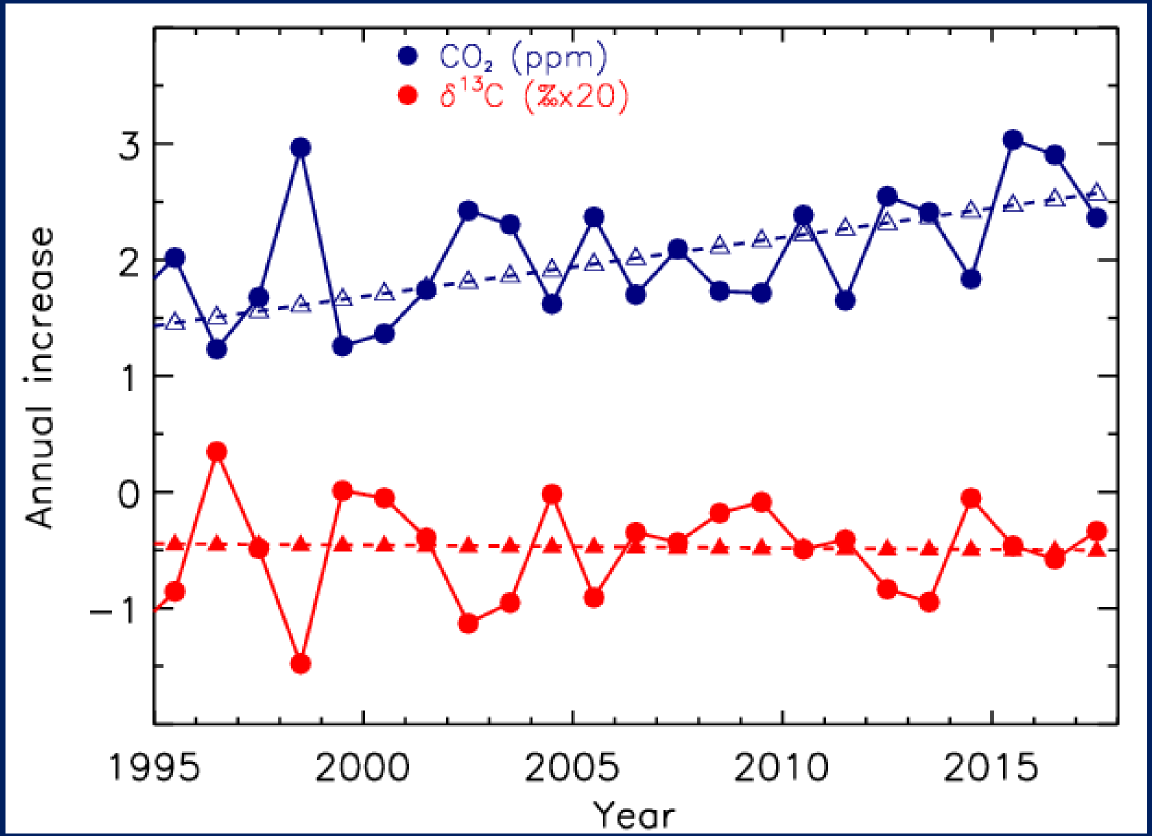
Quality Control

Using *in situ* measurements for CO_2 quality assurance: SPO

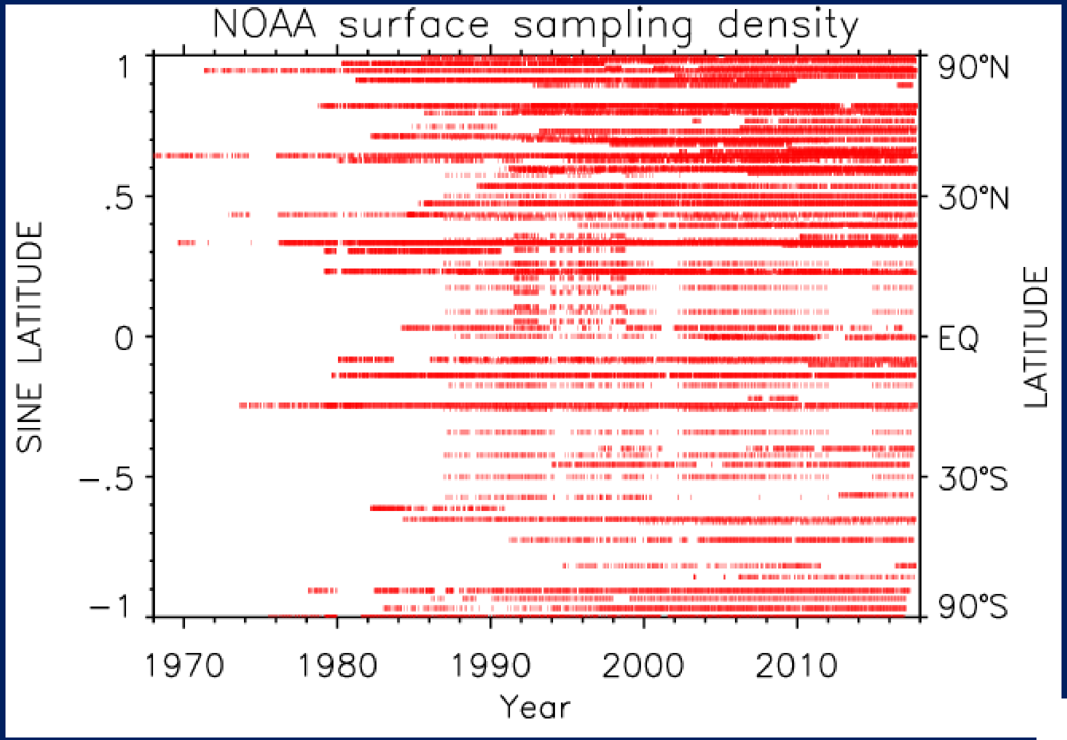




CO2 (ppm)
δ13C (‰x20)
Detrended Annual Increase
1
0.5
0
−0.5
−1
1995
2000
2005
2010
2015
Year

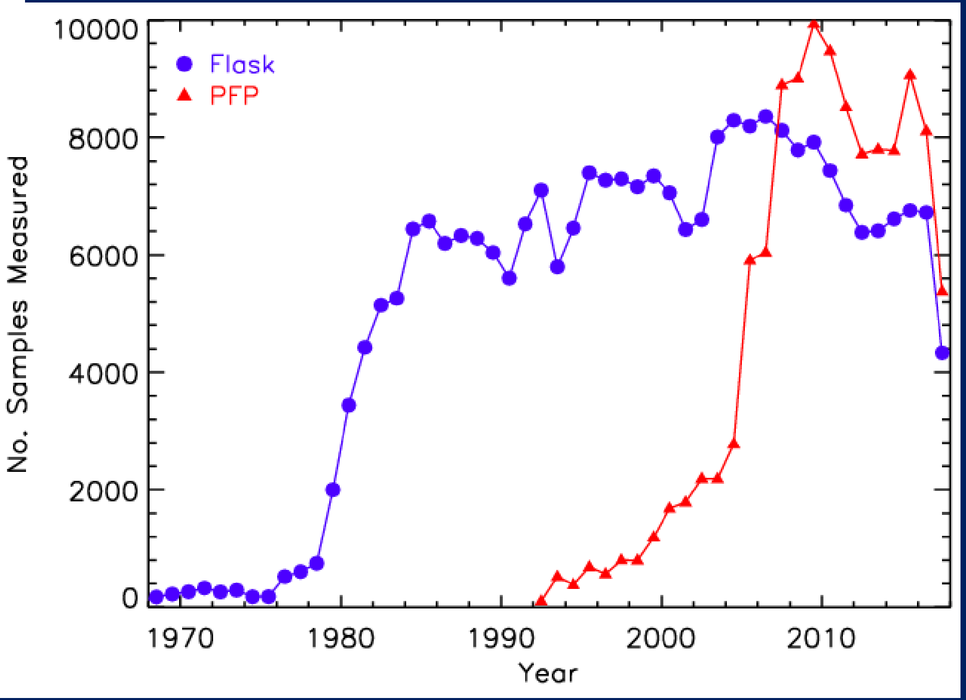


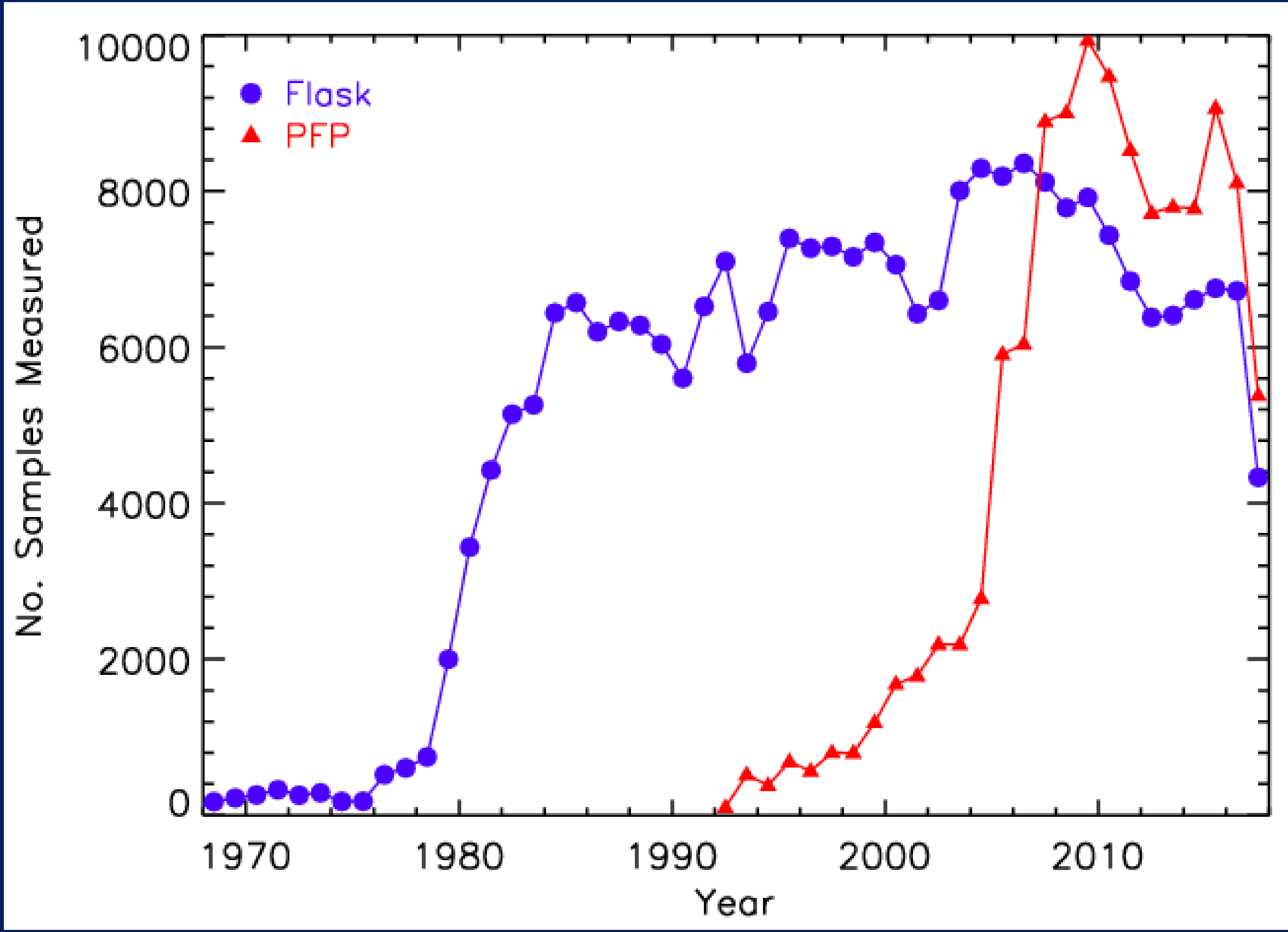
CO2 (ppm)
δ13C (‰x20)
Annual increase
3
2
1
0
−1
1995
2000
2005
2010
2015
Year



-Added CO_2 at obs. in early-1970s
-Expansion through 1980s
-Increasing # species measured
-Addition of N.A. focus (PFPs)

-Measurement load increased with expansion of network and addition of NA projects





Flask
PFP
No. Samples Measured
10000
8000
6000
4000
2000
0
1970
1980
1990
2000
2010
Year

A Dynamic Program

- 1967 – began CO_2 measurements
- 1983 – began CH_4 measurements
- 1988 – began CO/H_2 measurements
- 1990 – began $\delta^{13}CO_2$ measurements
- 1997 – began N_2O/SF_6 measurements
- 1998 – began $\delta^{13}CH_4$ measurements
- 2004 – began halo-compound measurements
- 2005 – began NMHC measurements