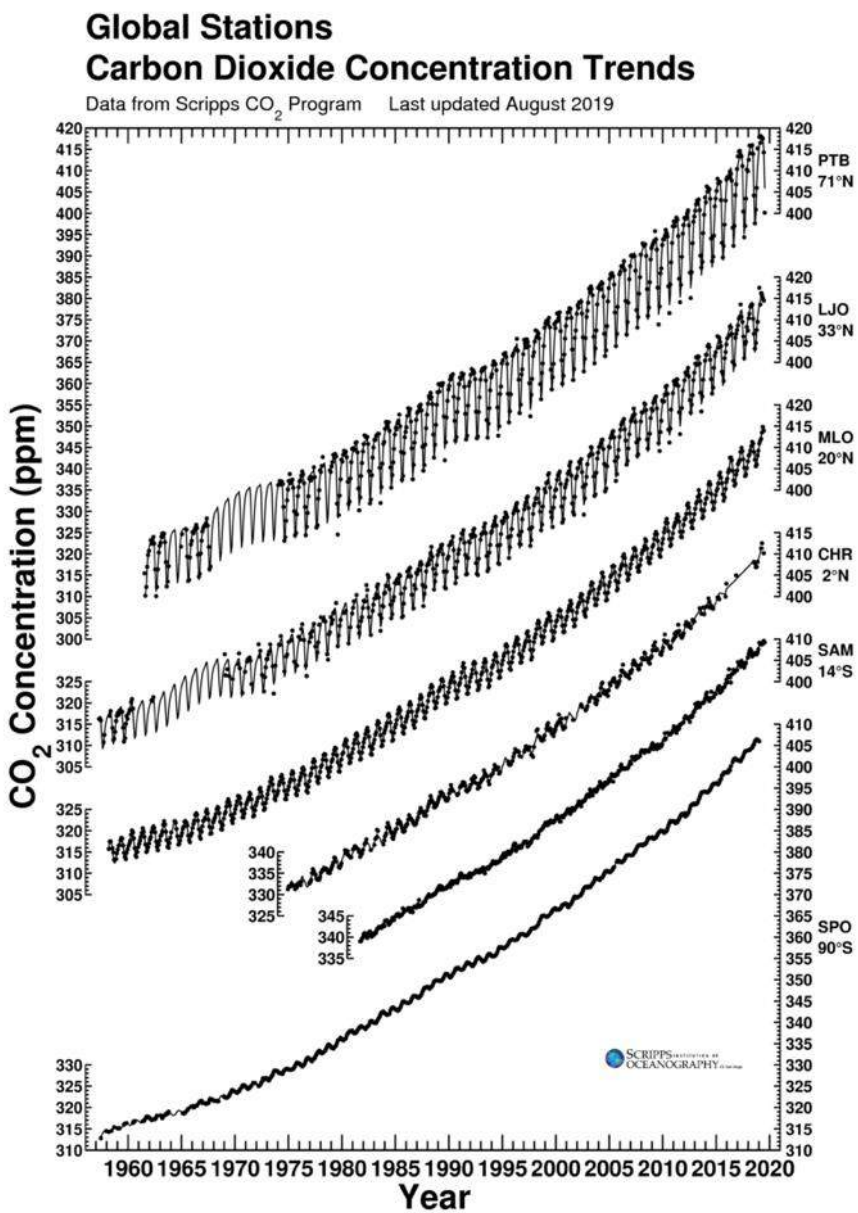
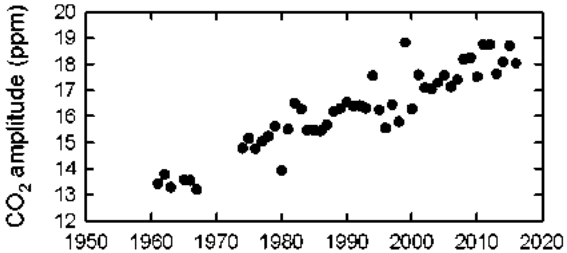
Detection, Quantification, and Analysis of Changes in Boreal and Arctic Ecosystems Using Measurements and Models of CO_2 and Its Isotopes

Ralph Keeling, Scripps Institution of Oceanography
& Many collaborators

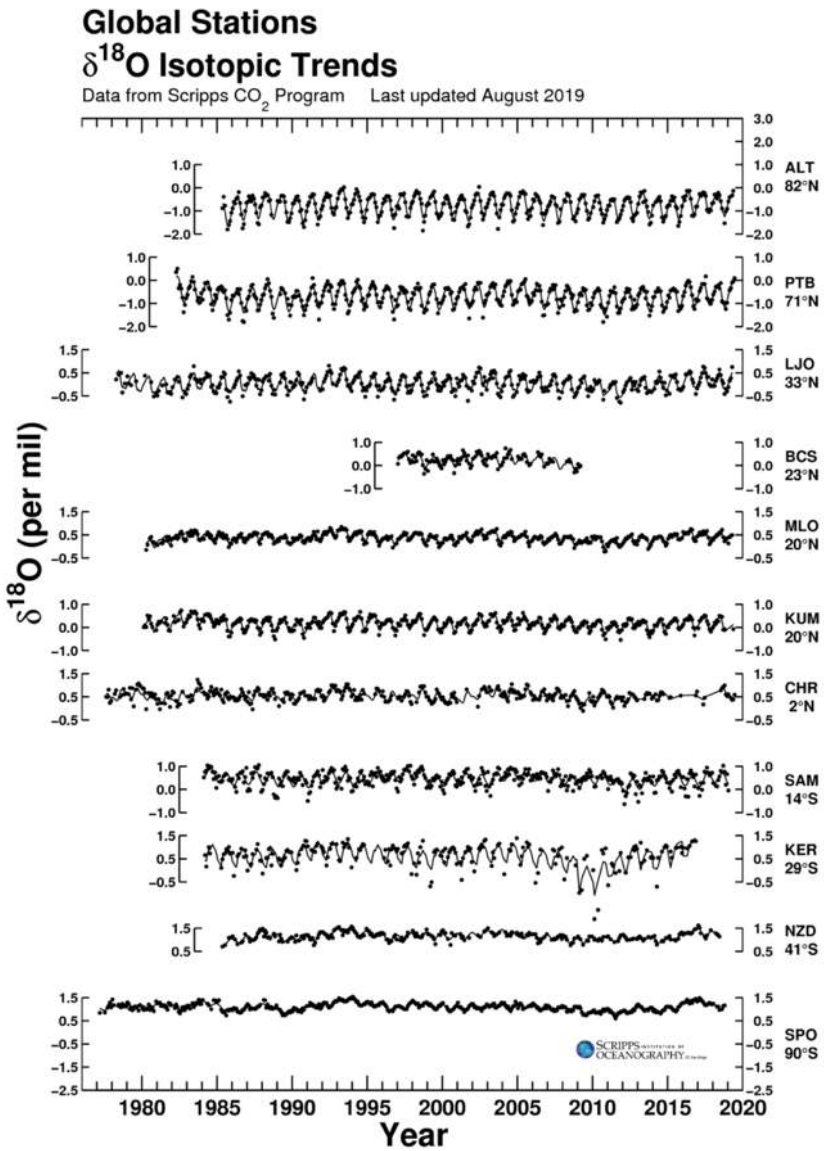
Scripps CO_2 Program observations

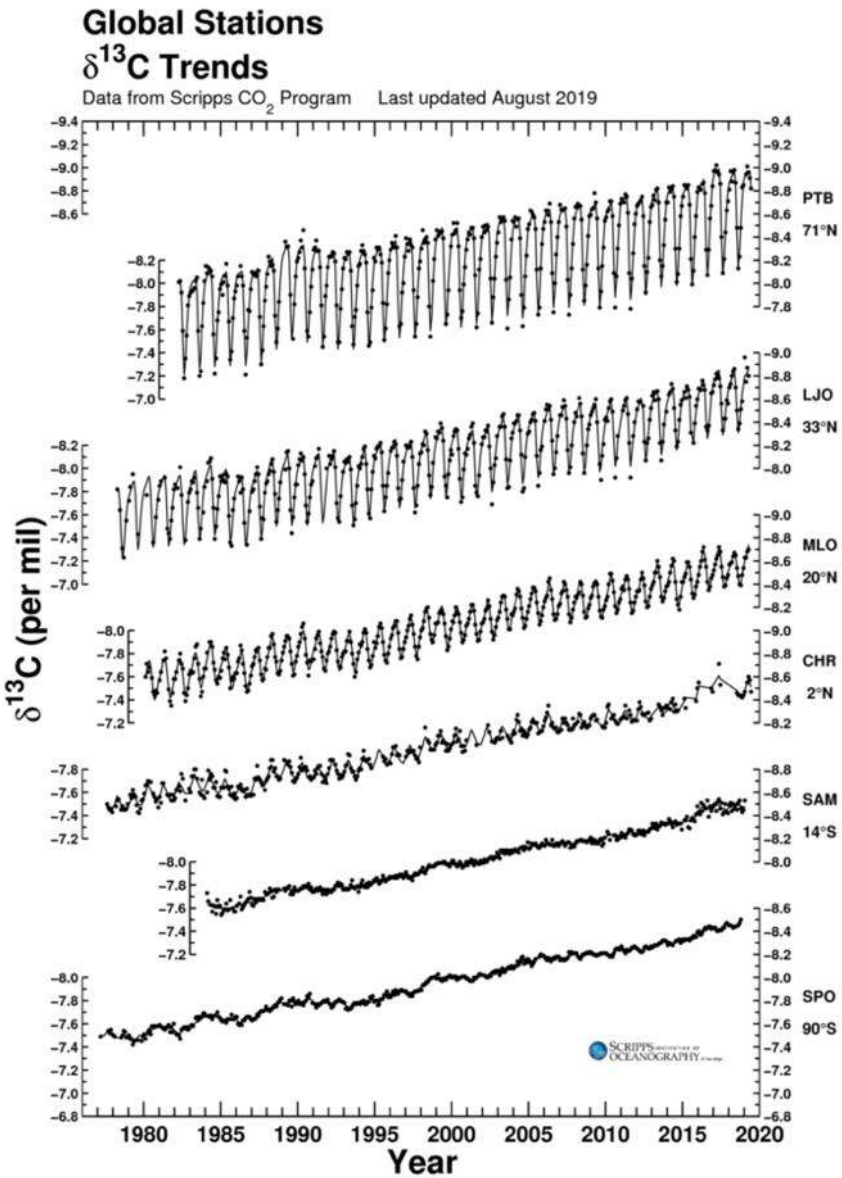


Amplitude at Barrow



Scripps CO_2 Program observations



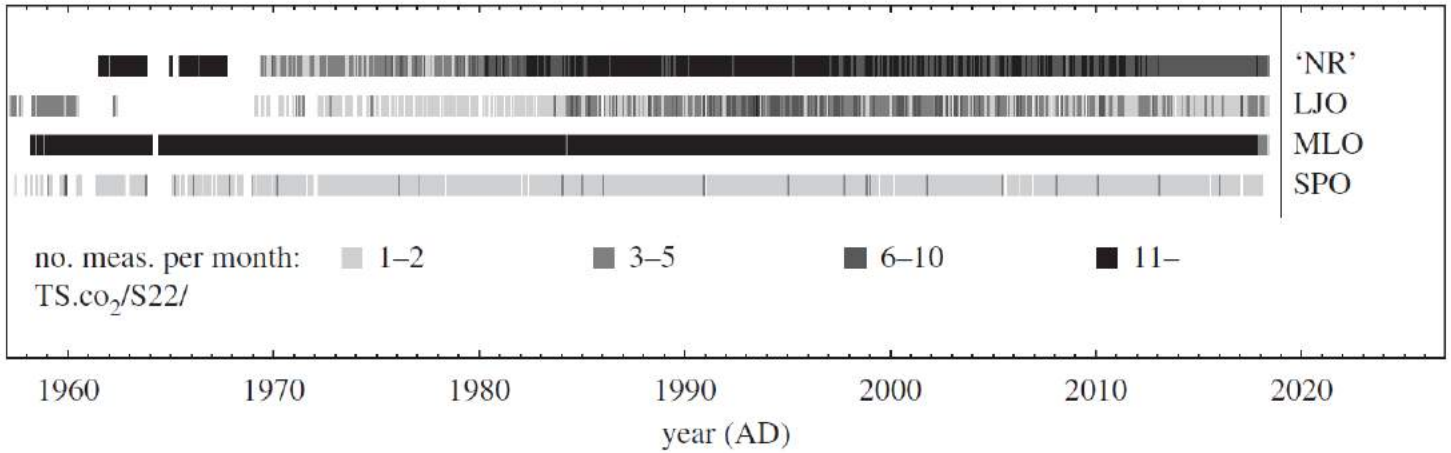


Ongoing synthesis/modelling activities:

- 60-year atmospheric inversions to resolve long-term boreal sink
- Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes
- Signals of long-term changes in the seasonal cycles of $\delta^{18}O$ of CO_2

1. Results from 60 year atmospheric CO_2 inversions

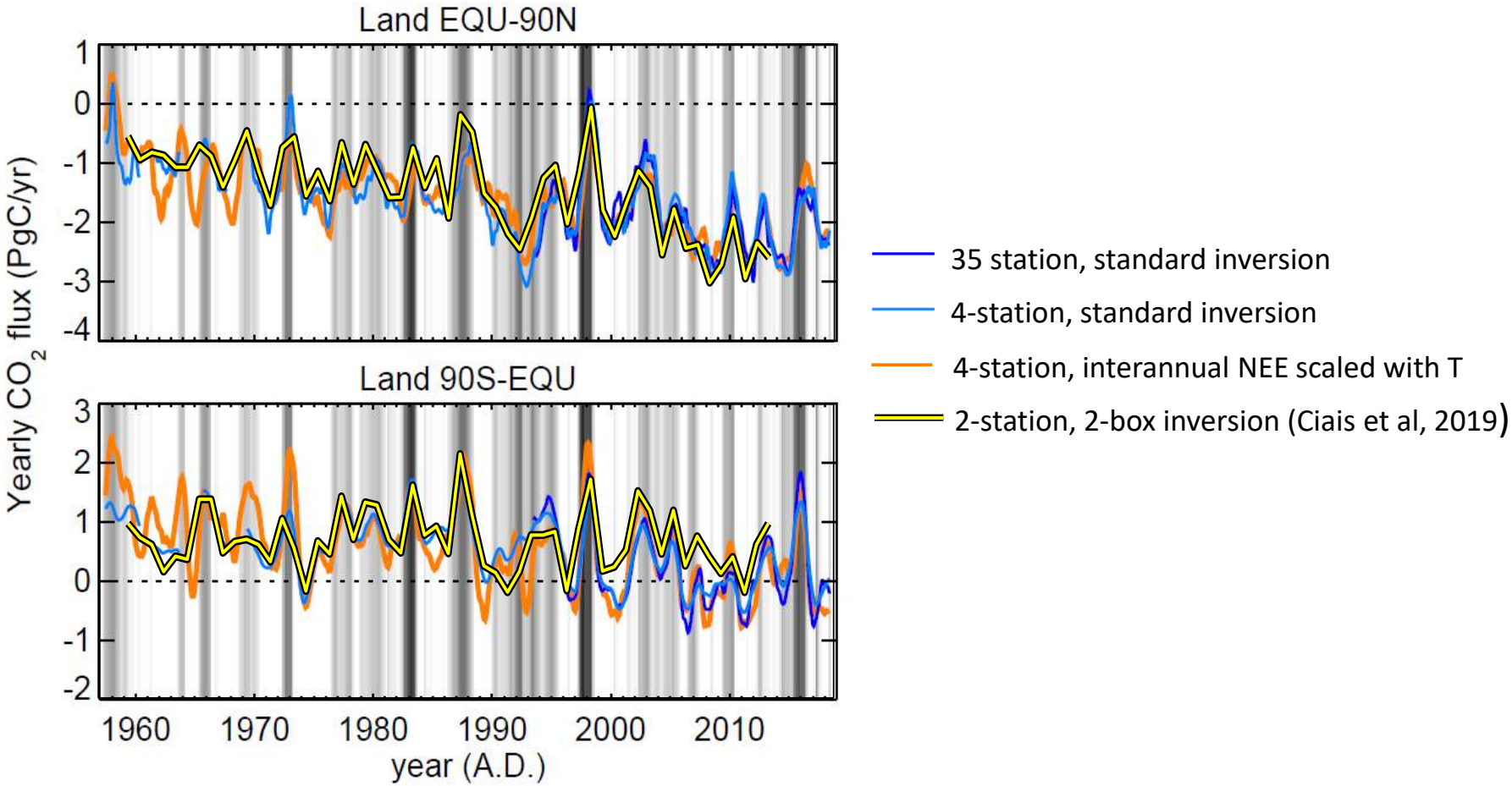
Collaborators: Christian Roedenbeck, MPI Jena
Martin Heimann, MPI Jena
Sönke Zaehle, MPI Jena



NR = "Northern Record", mostly based on Barrow, 71N
LJO = La Jolla, 32N
MLO = Mauna Loa, 19N
SPO = South Pole, 90S

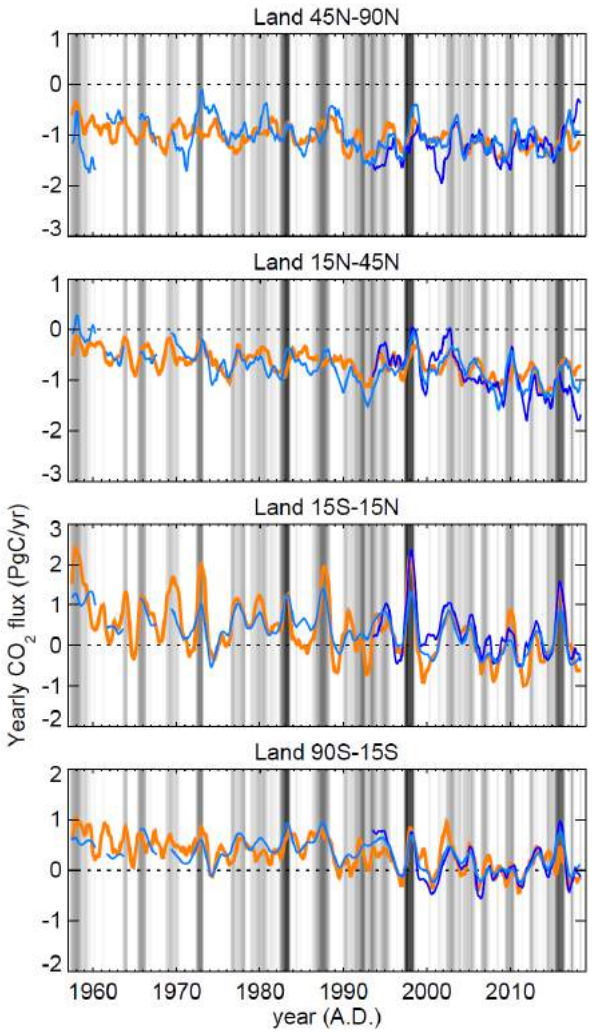
Roedenbeck et al. 2018, Phil. Trans. Royal Soc. B.
Roedenbeck et al. 2018, Biogeosciences, 2481-2498.

1. Results from 60 year atmospheric CO_2 inversions

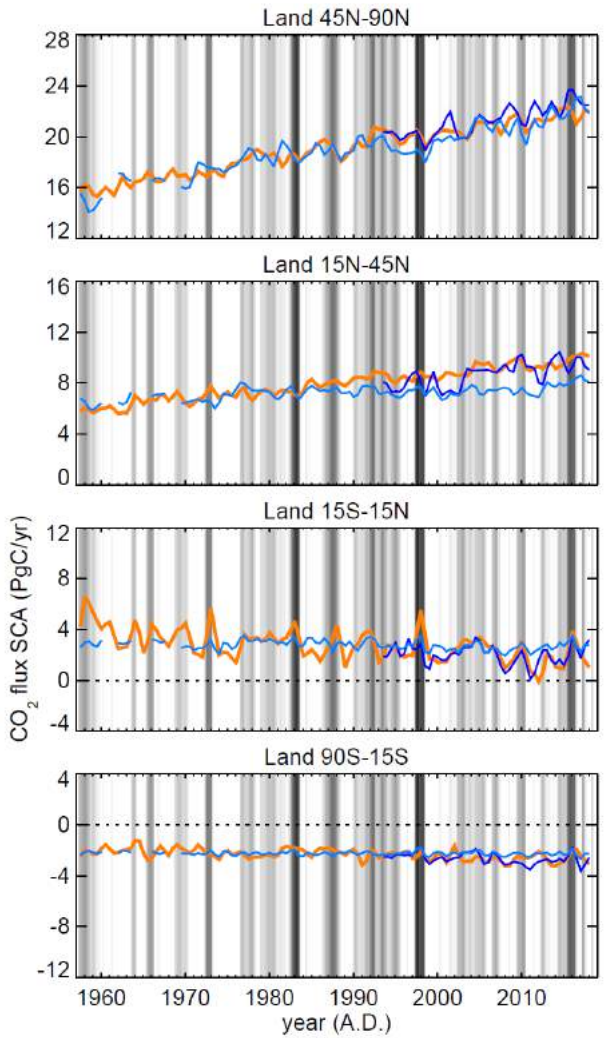


1. Results from 60 year atmospheric CO_2 inversions

Net Flux (NEE)



Seasonal amplitude of flux (DJF-JJA)



Amplitude increase mostly in 45-90 band.

Northern sink mostly in 15-45 band

35 station, standard inversion

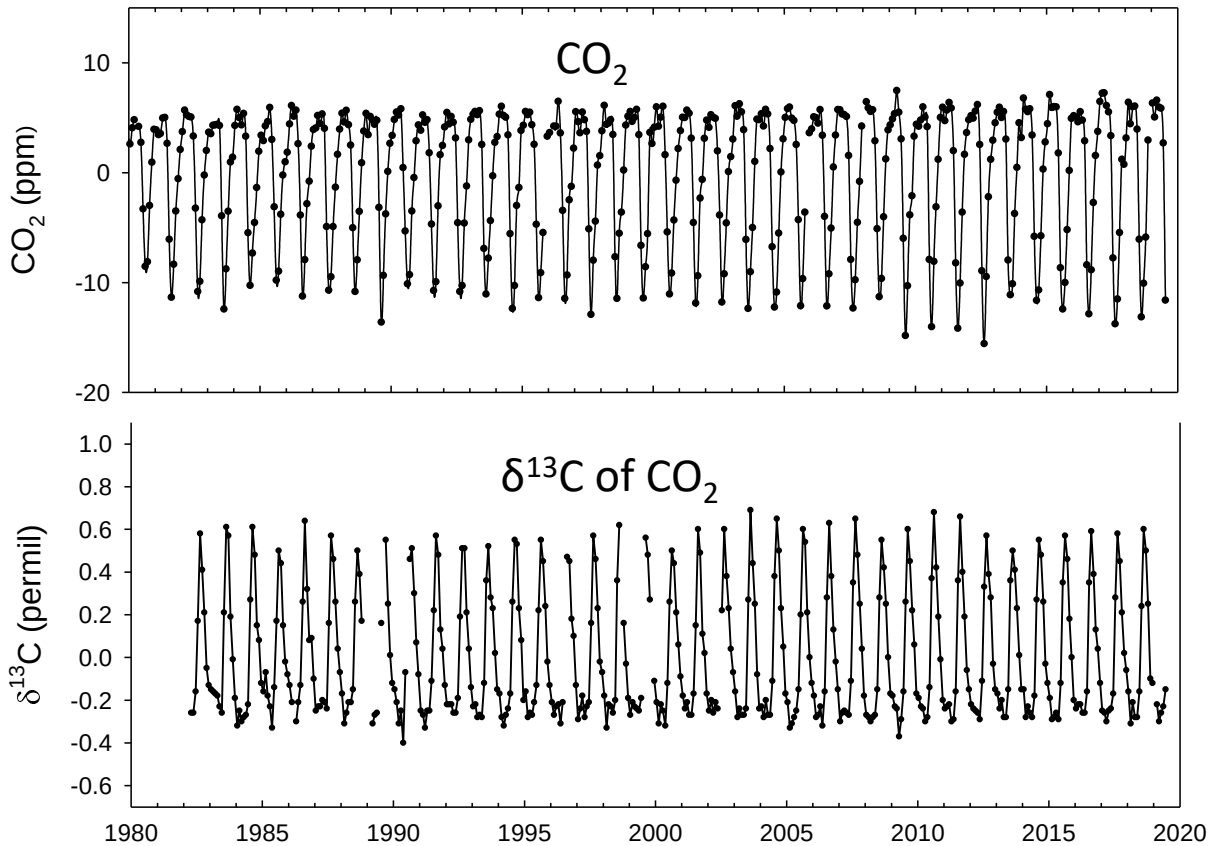
4-station, standard inversion

4-station, interannual NEE scaled with T

2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

Collaborators: Lisa Welp, Purdue U.
Heather Graven, Imperial College London

Interannually-detrended (to emphasize seasonal cycles)



2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

Intrinsic water-use efficiency
(carbon uptake per unit stomatal conductance)

$$iWUE = C_a(1 - C_i/C_a)/1.6$$

Photosynthetic discrimination against $^{13}CO_2$

$$\Delta = a + (b - a)(C_i/C_a) \text{ + smaller terms}$$

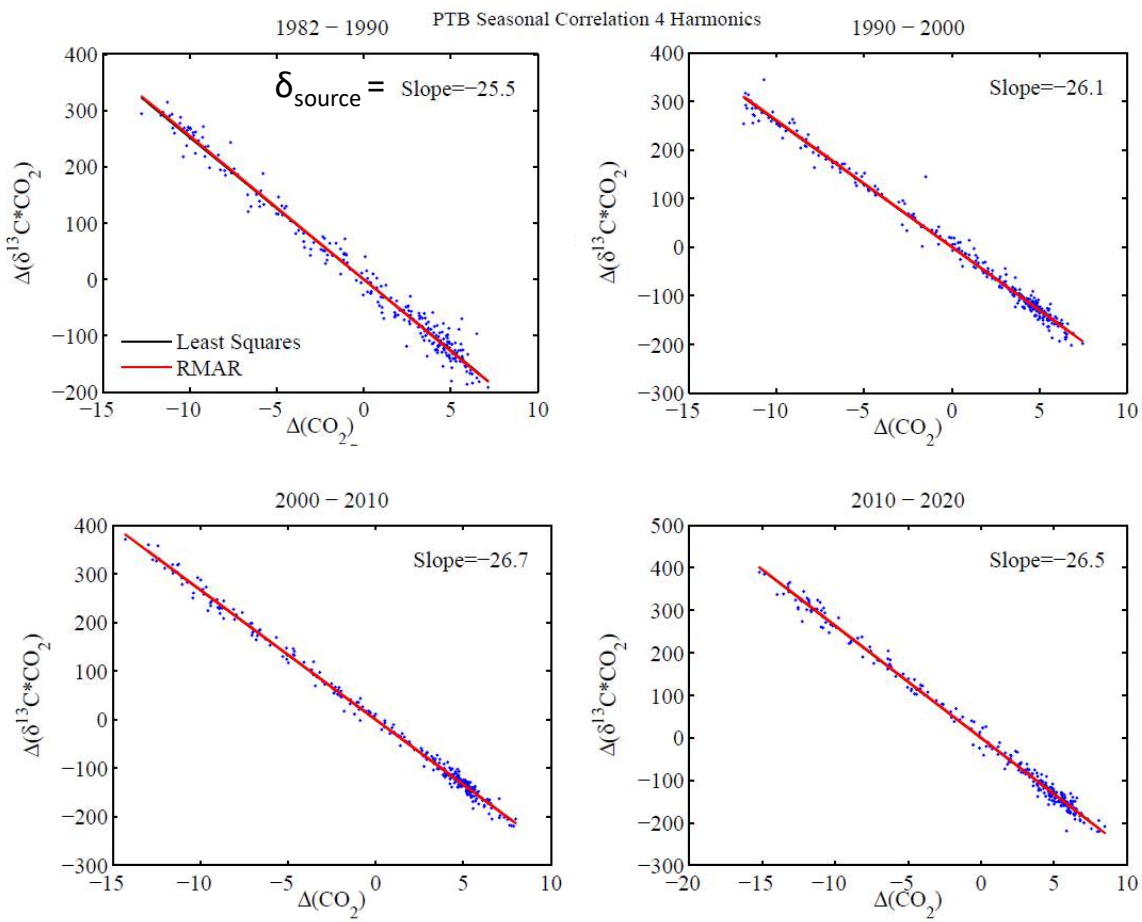
Null hypothesis: Optimal stomatal model.

- C_i/C_a stays nearly constant as CO_2 rises, iWUE ~ C_a
- Δ increases slightly with time due to "smaller terms".

Hypothesis supported by Keeling et al (2017, PNAS): Δ increased by 0.22 ± 0.11 ‰ decade^{-1} globally from 1975-2005.
Caveat: Did not resolve separate boreal versus tropical trends.

2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

Miller-Tans plots to solve for isotopic composition of carbon added and removed seasonally from the atmosphere.



$\Delta_{apparent} = \delta_{atm} - \delta_{source}$

$d\Delta_{apparent}/dt =$

$+0.121 \pm 0.20$ ‰/decade

2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

$$d\Delta/dt = d\Delta_{apparent}/dt + corr_{fossil\ fuel} + corr_{ocean} + corr_{maize}$$

Actual change in C_3 discrimination

2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

$$d\Delta/dt = d\Delta_{apparent}/dt + corr_{fossil\ fuel} + corr_{ocean} + corr_{maize}$$

$d\Delta_{apparent}/dt = +0.121 \pm 0.20$ Units: ‰ $decade^{-1}$

$corr_{ocean} = -0.12 \pm 0.06$

$corr_{fossil\ fuel} = -0.03 \pm 0.20$

$corr_{maize} = +0.17 \pm 0.08$

$d\Delta/dt = 0.25 \pm 0.35$ (1985-2017)

Keeling et al (2017) global estimate: 0.22 ± 0.09 (1975-2005)

2. Long-term trends in leaf-level water-use efficiency from $\delta^{13}C$ changes

Constraint on $d\Delta/dt$ yields iWUE increase of 14 ± 18% from 1985-2017

Over this period CO_2 rose by 18%

Applies for zones driving CO_2 seasonal cycle (temperate to arctic)

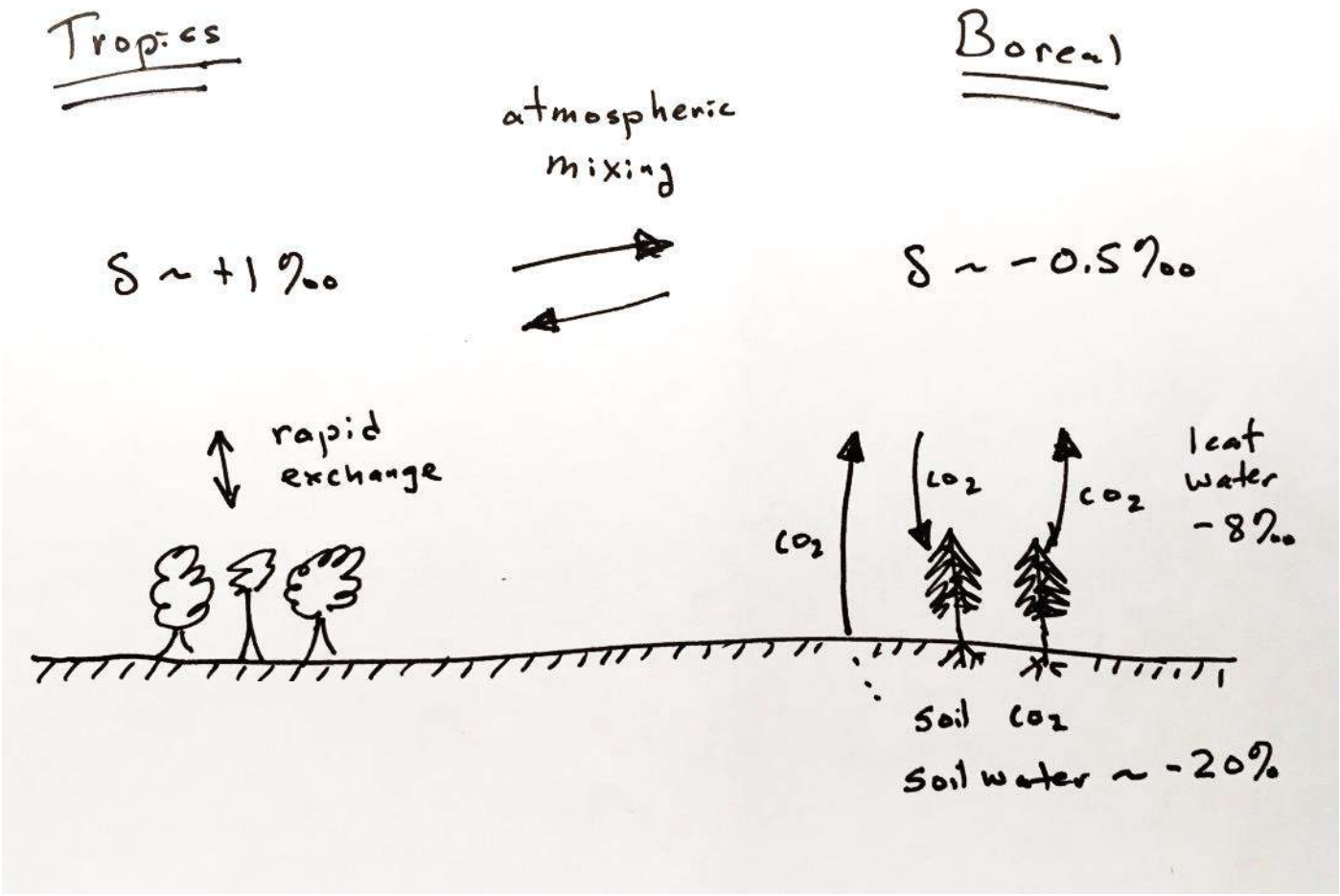
Keeling et al (2017) global estimate: 11 ± 6 % (1975-2005)

Over this period CO_2 rose by 14%

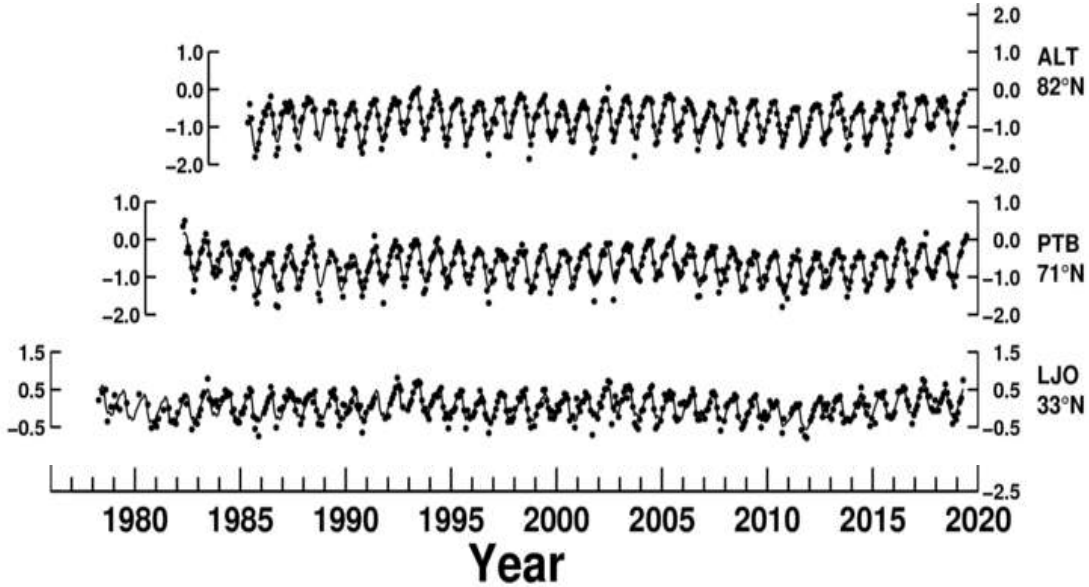
Applies for globe (C_3)

3. Signals of long-term changes in the seasonal cycles of $\delta^{18}O$ of CO_2

Collaborators: Dan Zhu, Philip Ciais (LSCE)



3. Signals of long-term changes in the seasonal cycles of $\delta^{18}O$ of CO_2



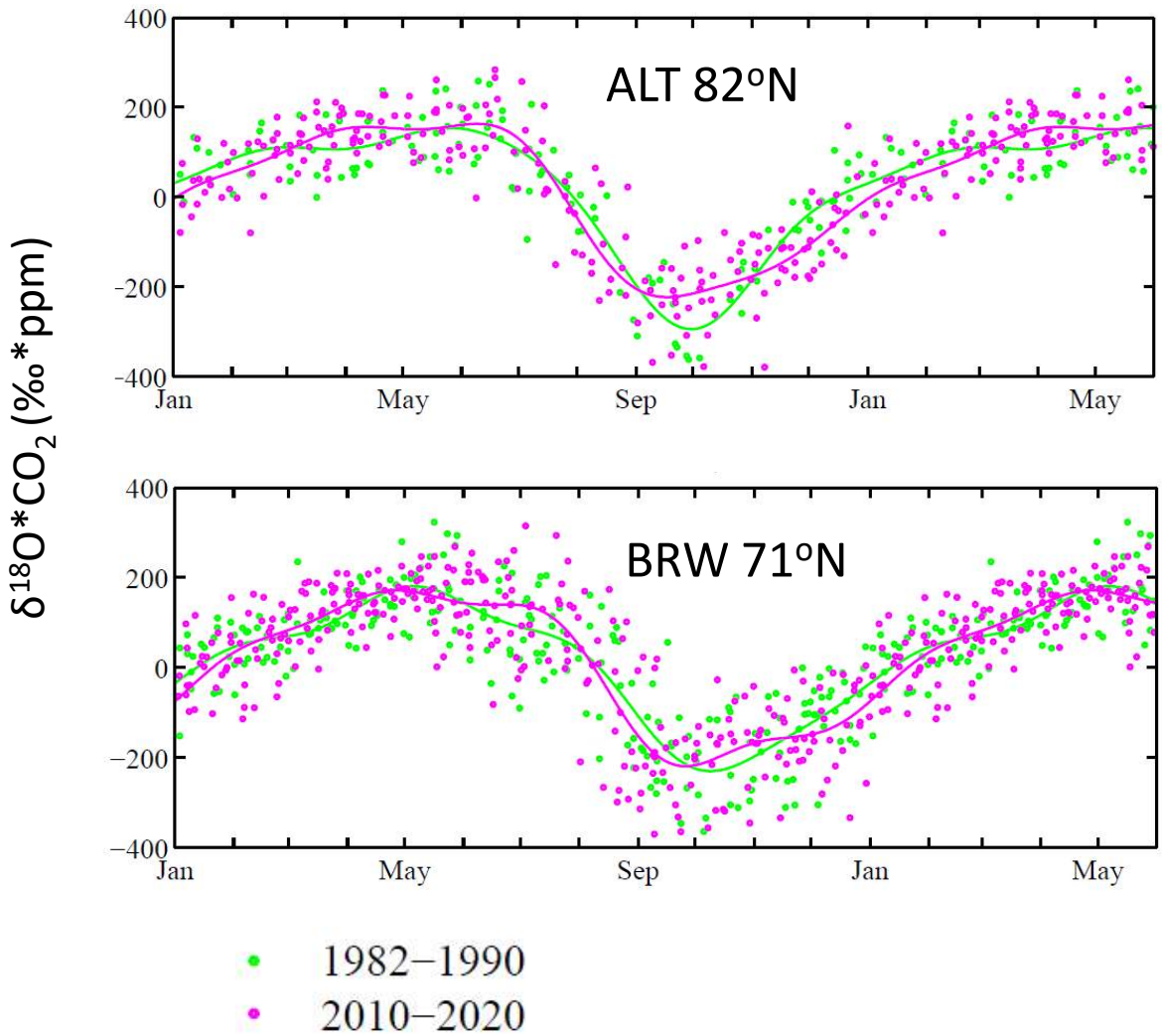
Null Hypothesis:

- No change in water pools.
- All (seasonal) carbon fluxes increase in proportion to atmospheric CO_2

Predicts:

- Cycle in $\delta^{18}O$ stays constant.
- Cycle in $CO_2 * \delta^{18}O$ increases in proportion to CO_2.

3. Signals of long-term changes in the seasonal cycles of $\delta^{18}O$ of CO_2



Seasonal cycle in $\delta^{18}O*CO_2$ dominated by cycle in $\delta^{18}O$, scales with isoflux.

Null hypothesis requires ~14% increase in amplitude from 1986 to 2014

Observed amplitude changes:

- ALT: decreased ~15%
- BRW: No clear change
- Null hypothesis falsified.

At both ALT and BRW:

- Drop starts later
- Drop end earlier
- Slope around Aug. 1st has increased.

Conclusions

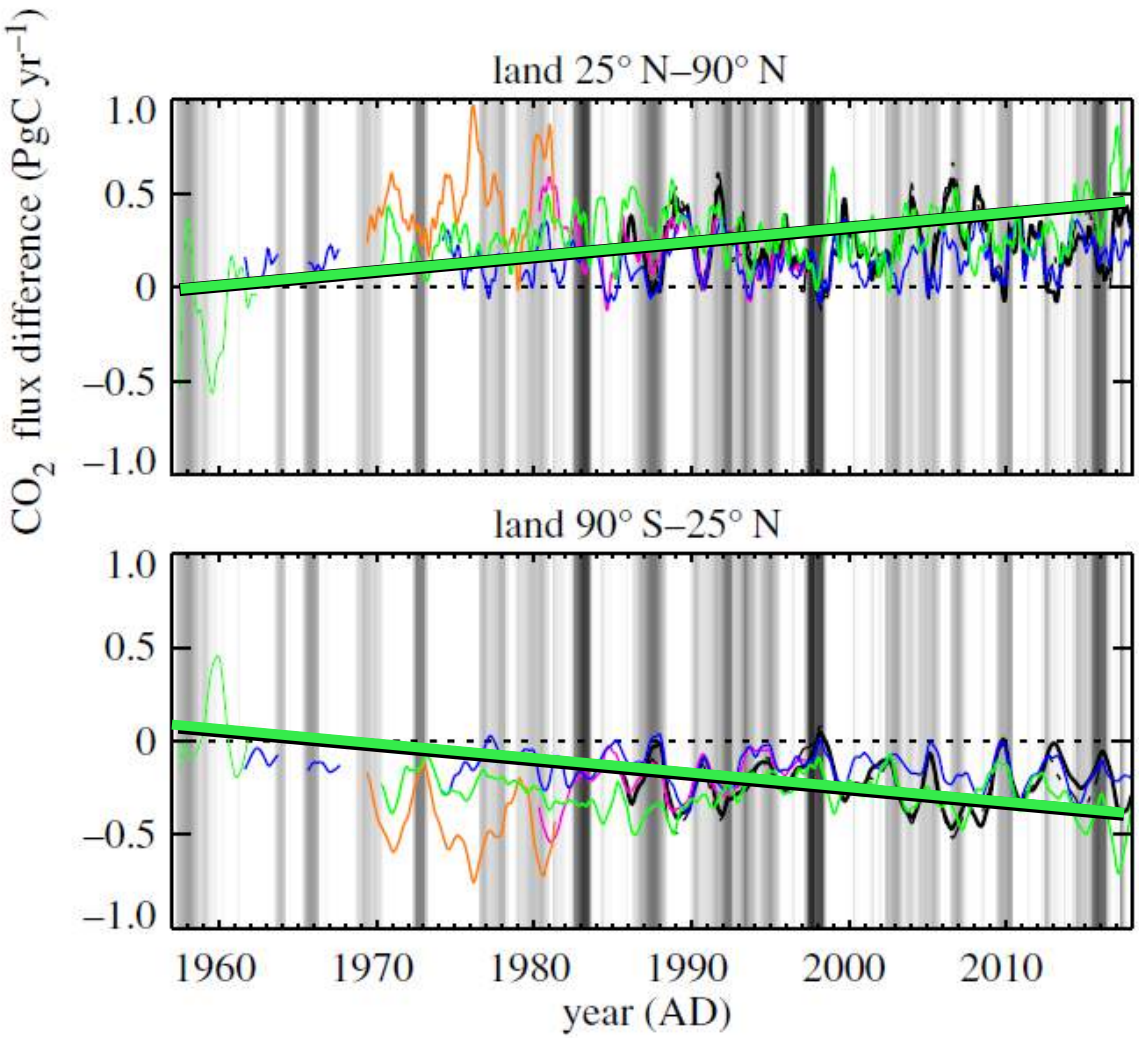
- Longer-term CO_2 records show promise to resolve aspects of northern land sink and its seasonality back to 1960.

- Seasonal cycle in $^{13}C/^{12}C$ of CO_2 provides constraints on long-term changes in water-use efficiency in boreal/arctic zones. These constraints will tighten with time.

- Seasonal cycle in $^{18}O/^{16}O$ has not remained constant. Imply changes at beginning middle, and end of growing season.

Thank you

Difference between inversions: Impact of additional stations (relative constraints from Mauna Loa + South Pole)

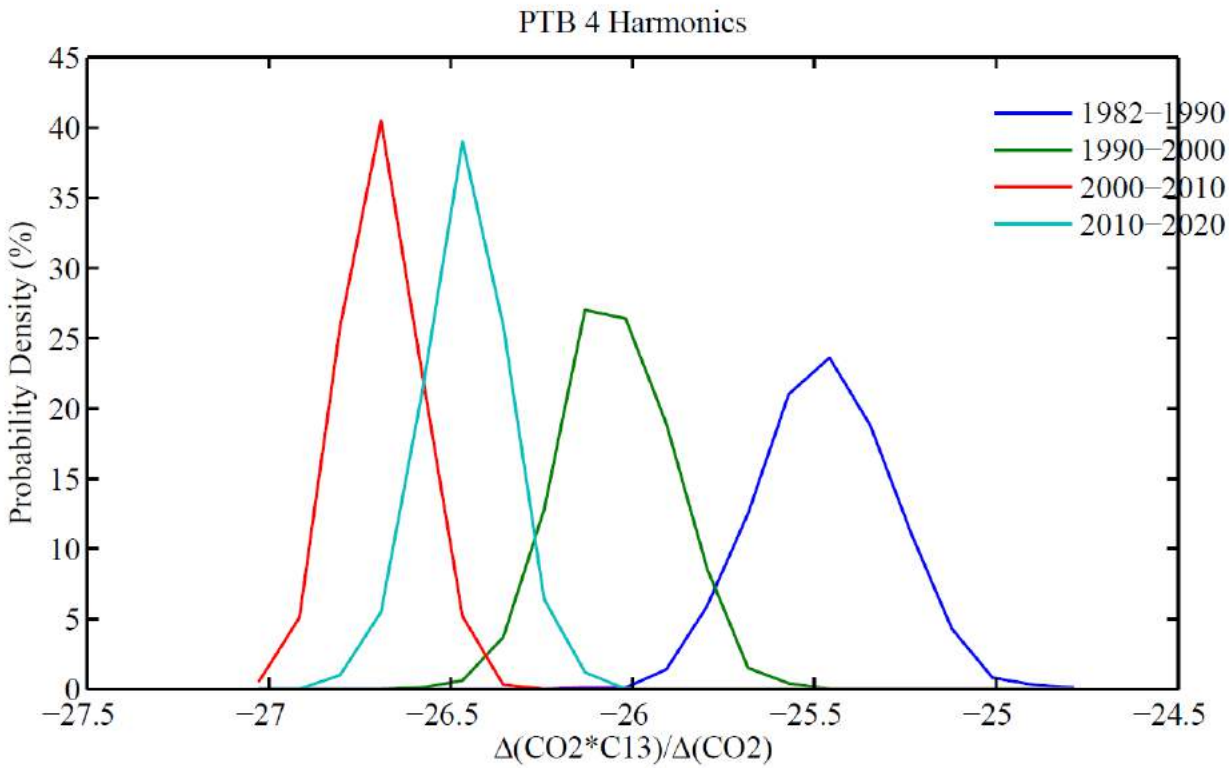


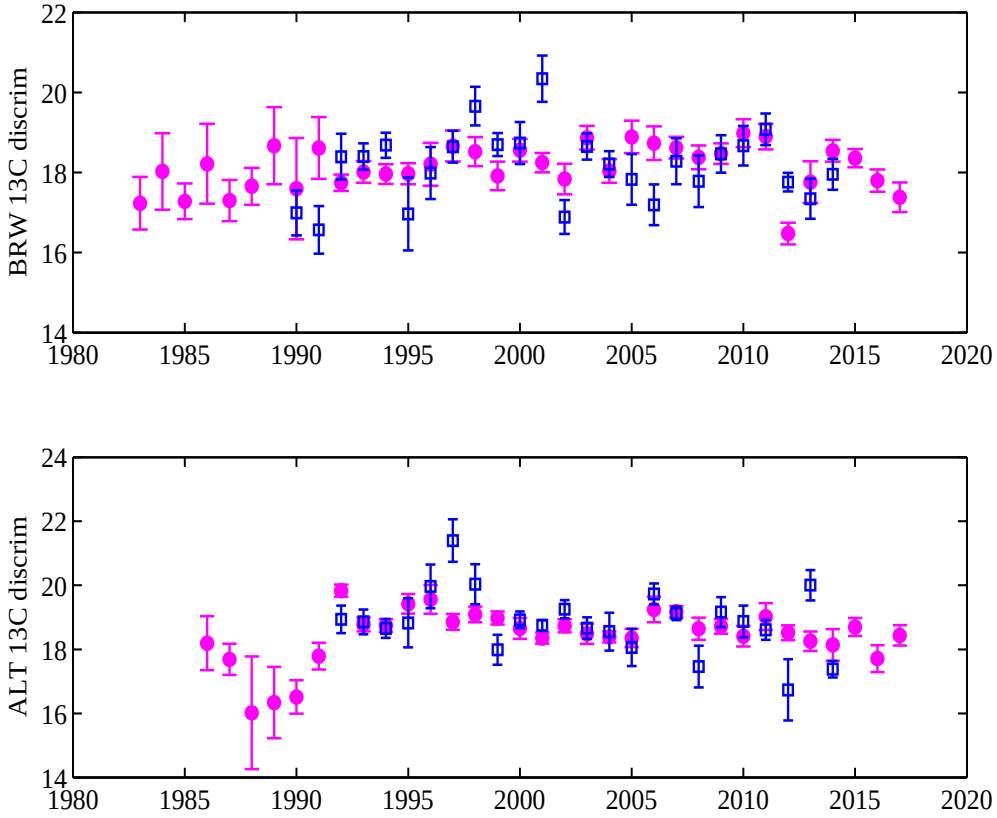
Stations added

- La Jolla, 32N
- Station P, 50N
- Barrow, 71N
- Alert, SIO 82N
- Alert, NOAA 82N

- *Adding La Jolla shifts sink and trend in sink from north to tropics.*
- *Adding Barrow has smaller effect, but in same direction.*

Roedenbeck et al. 2018, Phil. Trans. Royal Soc. B.


PTB 4 Harmonics
Probability Density (%)
Δ(CO2*C13)/Δ(CO2)
1982−1990
1990−2000
2000−2010
2010−2020
45
40
35
30
25
20
15
10
5
0
−27.5
−27
−26.5
−26
−25.5
−25
−24.5

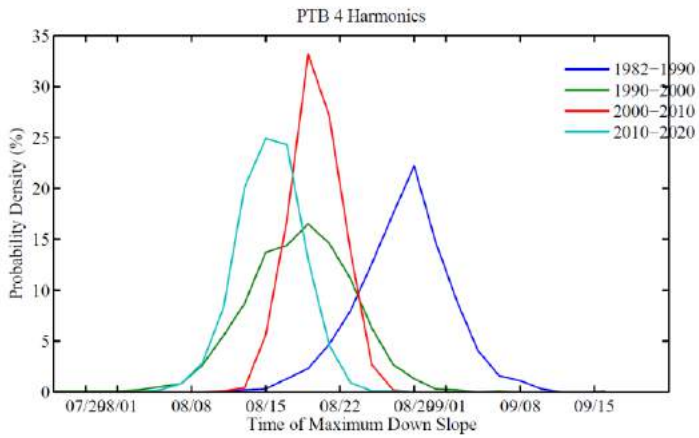

BRW 13C discrim
22
20
18
16
14
1980
1985
1990
1995
2000
2005
2010
2015
2020
ALT 13C discrim
24
22
20
18
16
14
1980
1985
1990
1995
2000
2005
2010
2015
2020

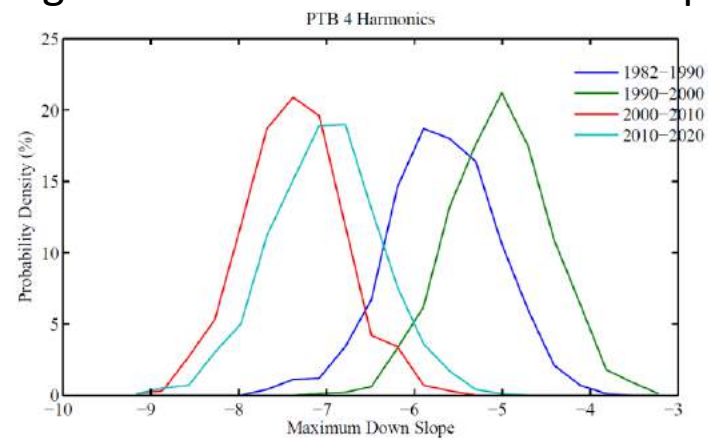
Histograms from jackknifing

Time of maximum downward slope

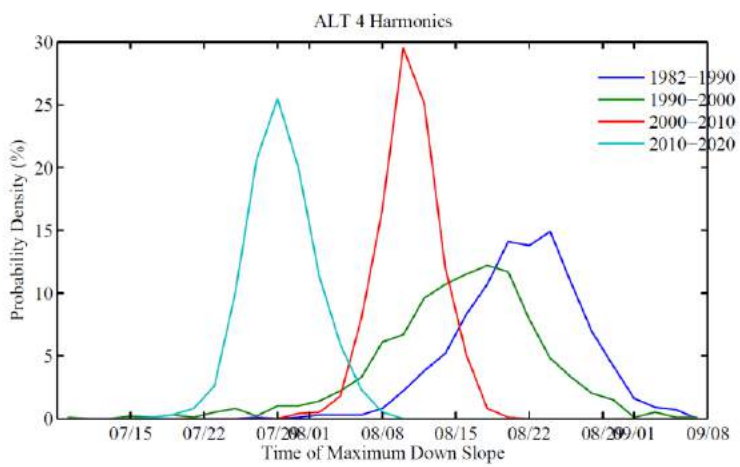
Magnitude maximum downward slope

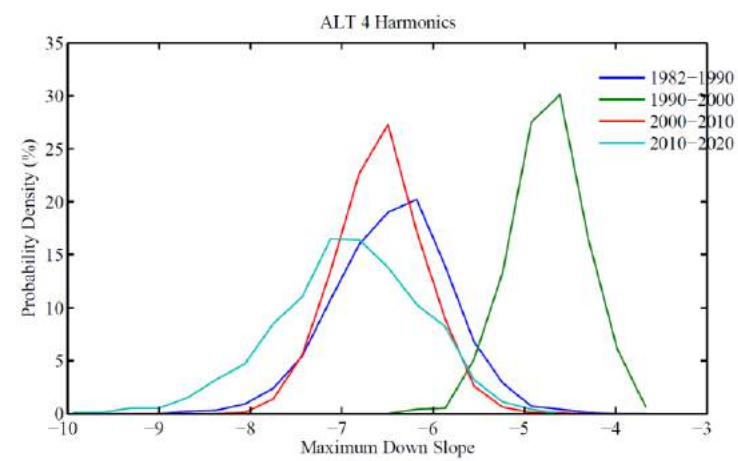
Barrow





Alert



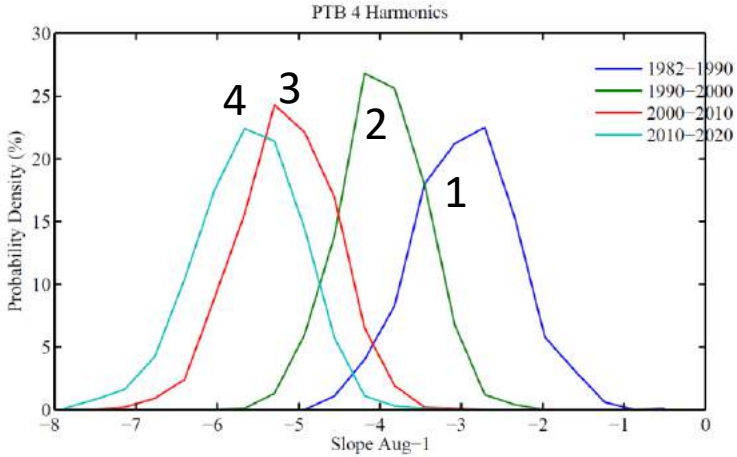


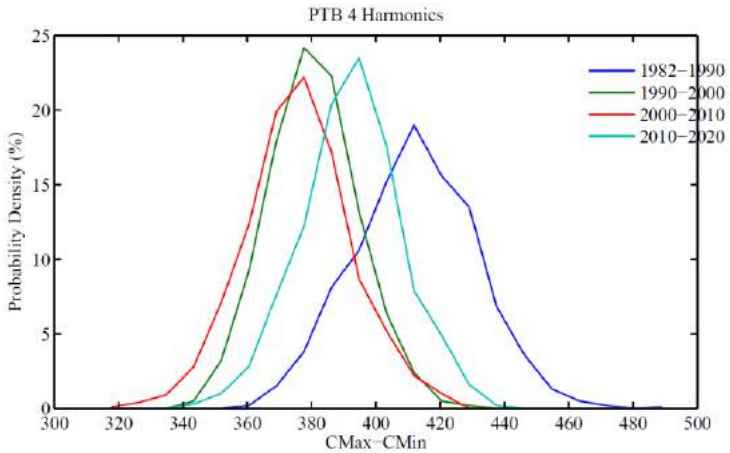
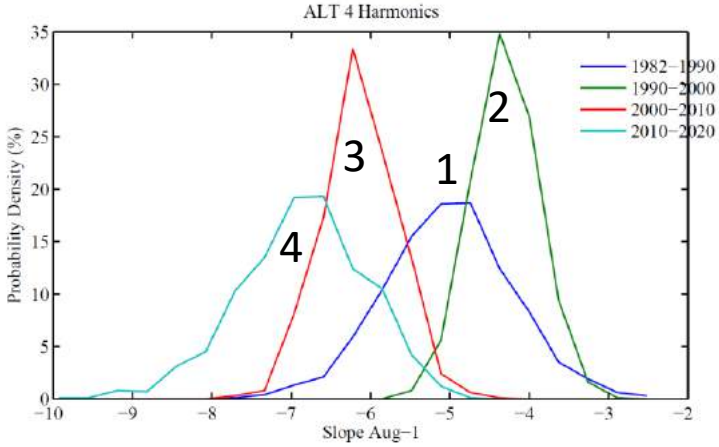
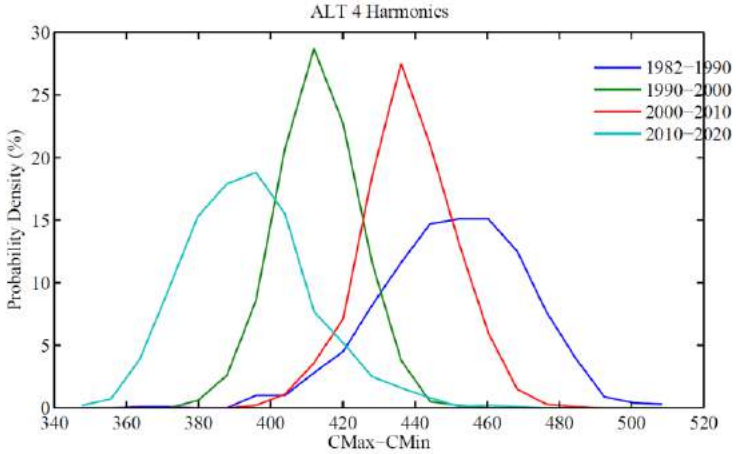
Histograms from jackknifing

Aug 1 slope

Peak-to-Peak Amplitude

Barrow





Alert