Trace Gas Images of Alaska:
CARVE and GMD Greenhouse gas observations

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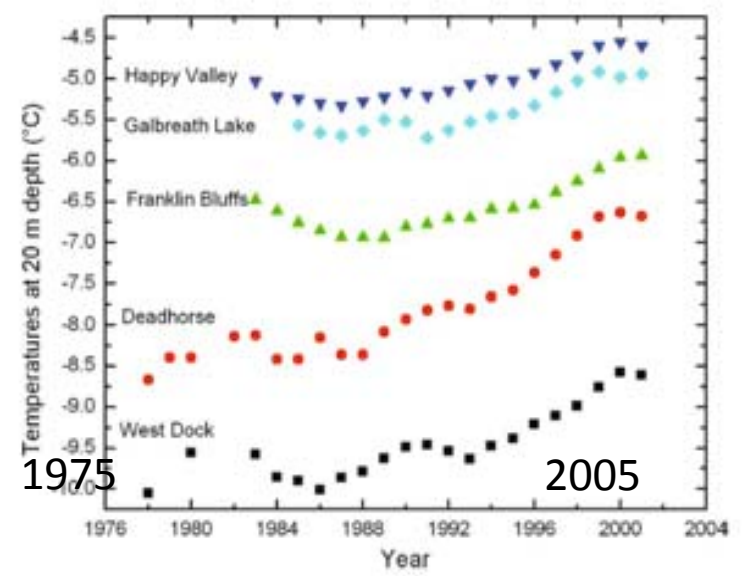
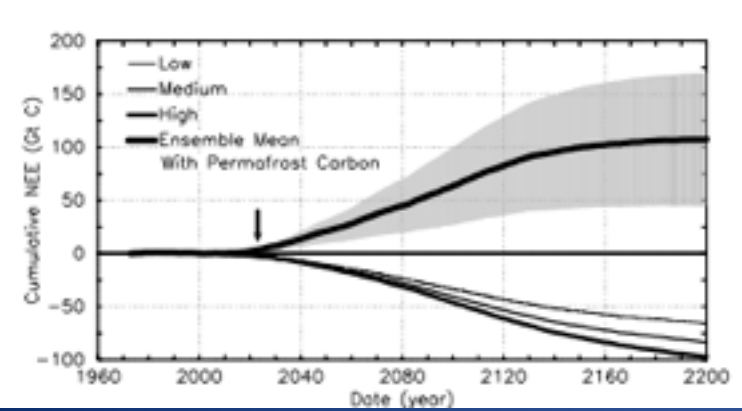
JPL
and the CARVE Science Team

The fate of hundreds of billions of tons of Arctic C is uncertain as soils thaw



Osterkamp, 2003

Soil temperatures are rising

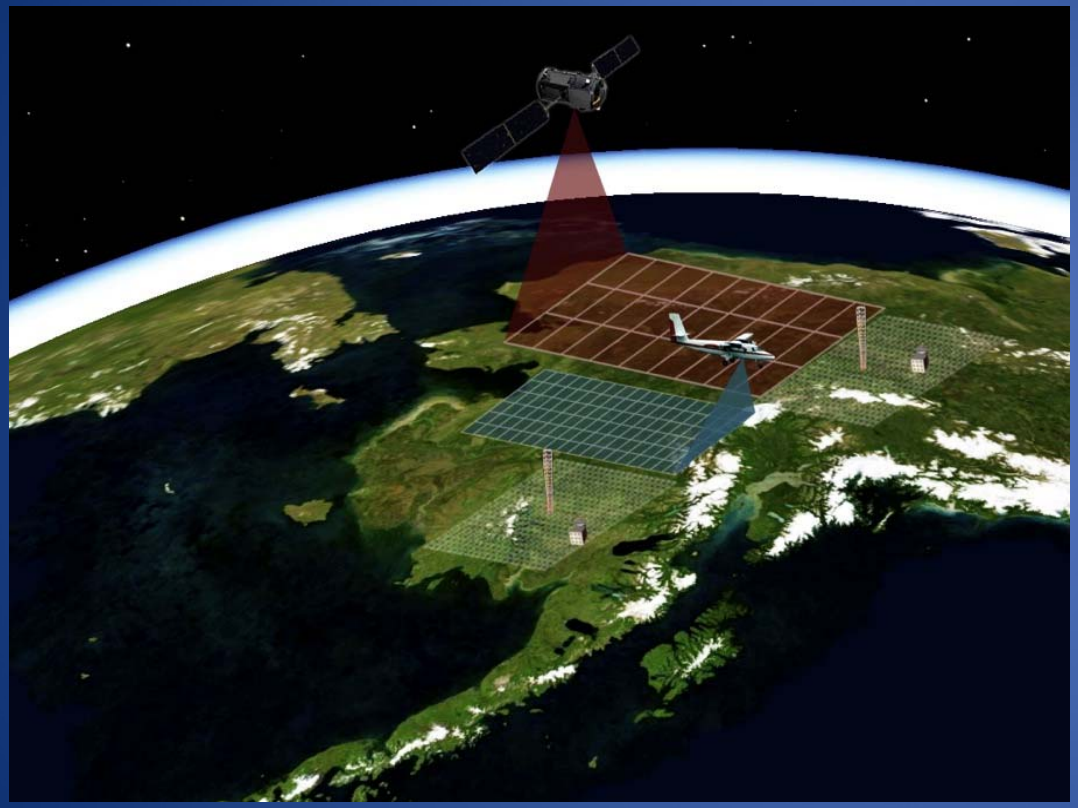


Schaefer, 2011

(Un-coupled) Models predict large C releases

- Permafrost Carbon
  - ~ 2000 Pg C from 0 - 20 m depth
  - ~ 200 Pg C 0 – 30 cm
- Some Big Questions
  - How much C, what depths, ***what regions*** are most vulnerable?
  - How much will come out as CH4? As CO2?
- Other Big Questions
  - Could Boreal/Arctic sinks actually increase in the near term (via woody expansion)?
  - Or might these be gains be wiped out by fire and insect disturbance?
  - What about oceanic clathrates?

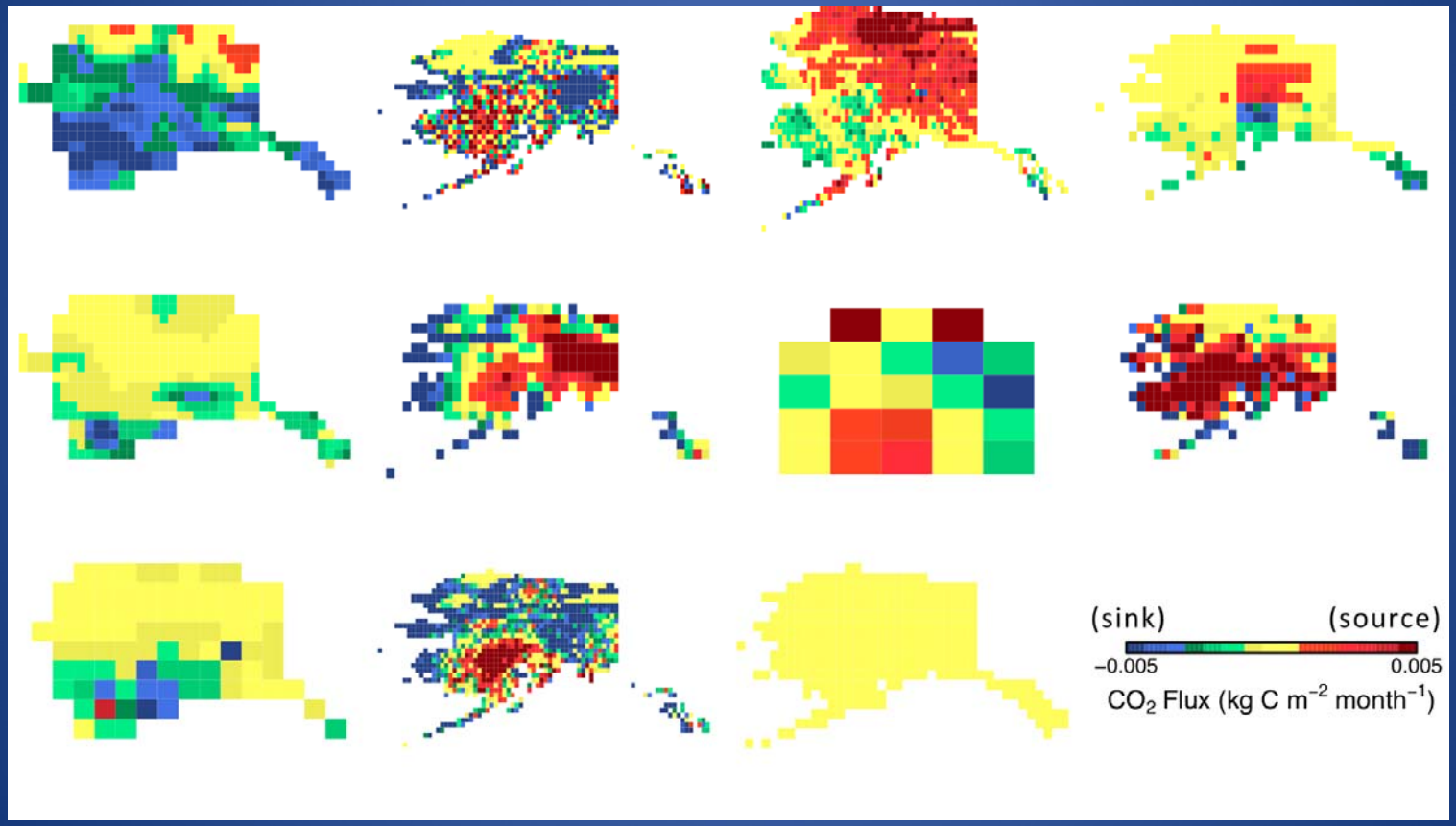
Before we predict the future, let's see if we can understand the present.



Carbon in Arctic Reservoirs Vulnerability Experiment

- CARVE aims to observe the linkages between the surface moisture state and CO2 and CH4 fluxes and concentrations, using:
  - PALS – Airborne microwave and radar sensor.
  - Airborne trace-gas observations
  - North slope eddy flux towers
  - Year-round trace gas tower
  - Airborne eddy flux sensor
- CARVE modeling aims to:
  - Test the realism of CH4 and CO2 flux maps against observations.
  - Improve bottom up models

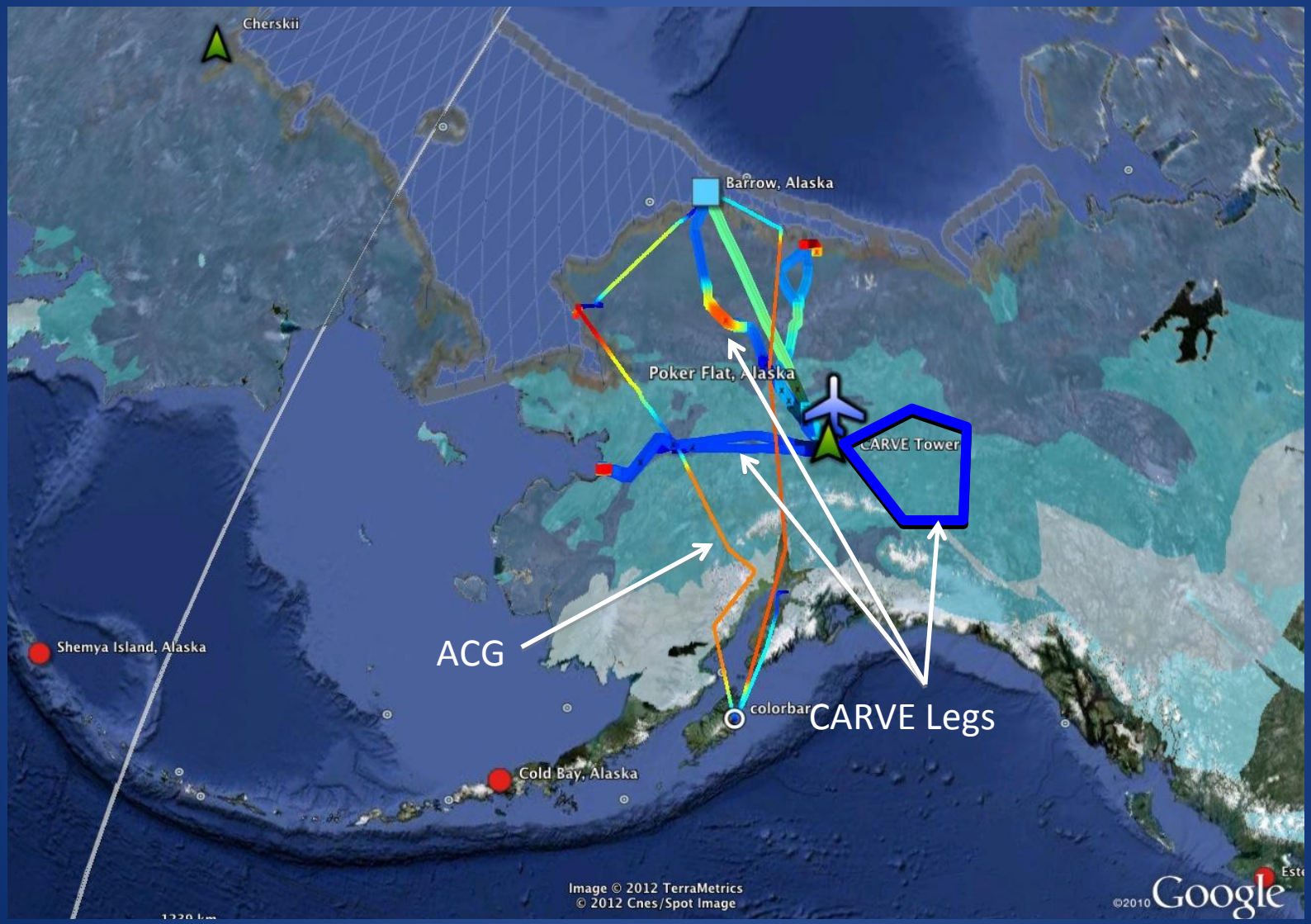
Carbon cycle models show a huge diversity of net carbon balance…
…and they can't all be right!



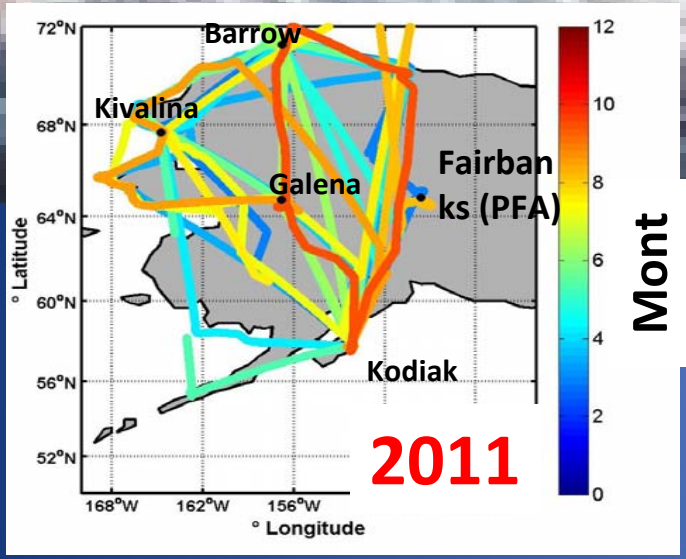
And, experience suggests gross fluxes among models may be worse.

Courtesy Joshua Fisher

NOAA and CARVE GHG Observations

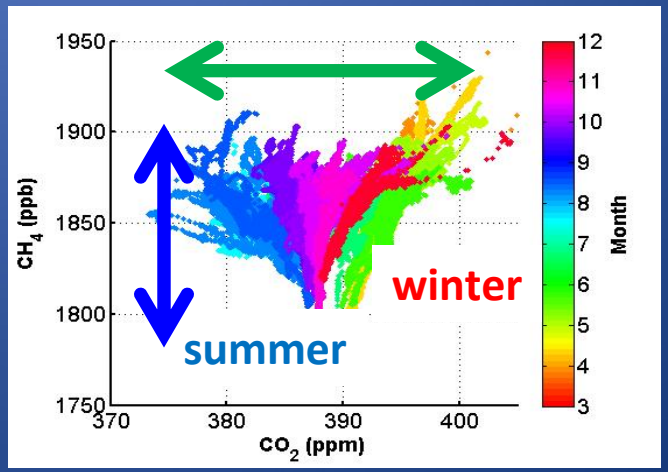


ACG C-130 flights provide regular surveys of the Alaskan atmosphere

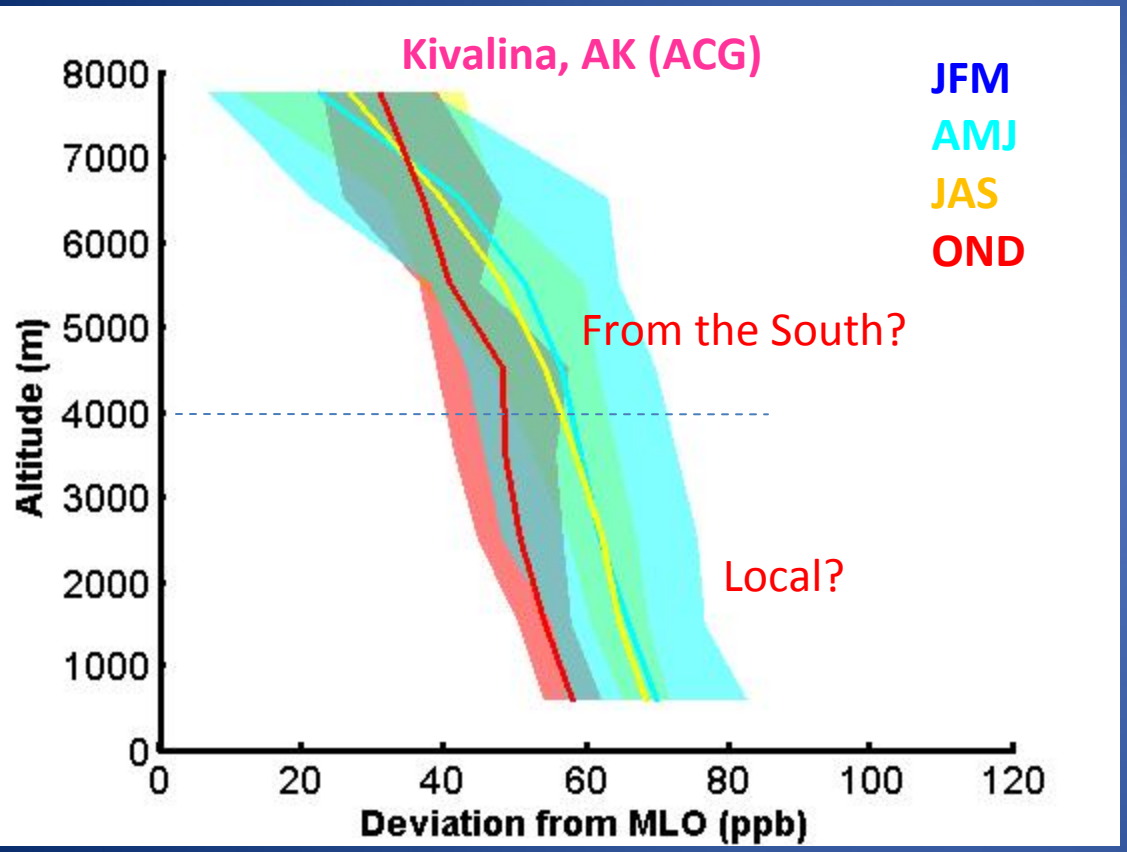


- Bi-weekly 8-hour flights on C-130
- March – November
- **~40 flights since 2009**
- large spatial extent (> 3000 km & 1-3 profiles per flight)
- much of the sampling occurs at high altitude (~8000 m)

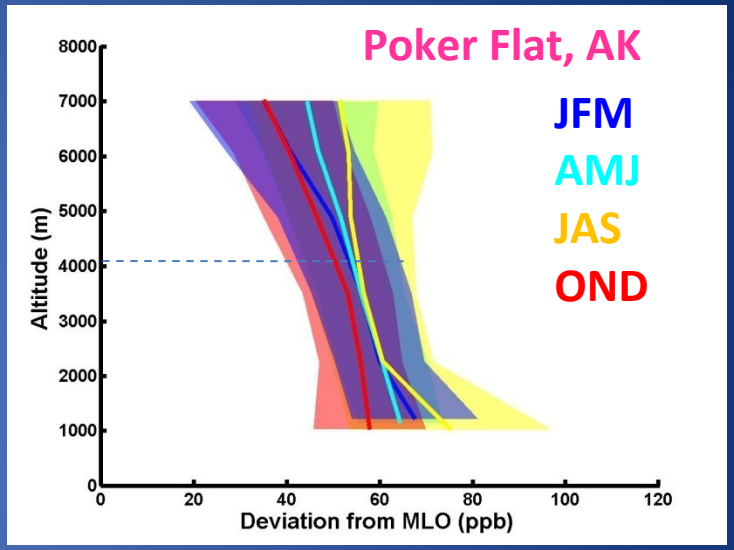
- CH4 range ~100 ppb in all seasons!
- What are the sources of variability?

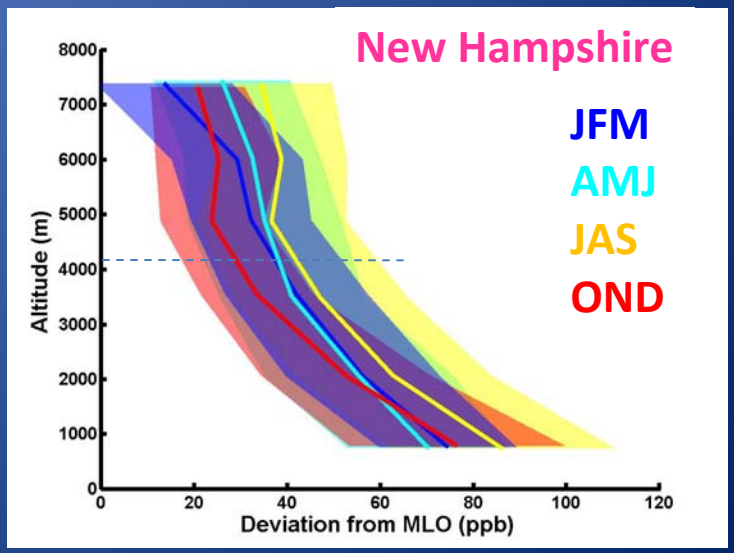


CH4 vertical gradients are surprisingly small, but PBL and free troposphere air may have independent sources.



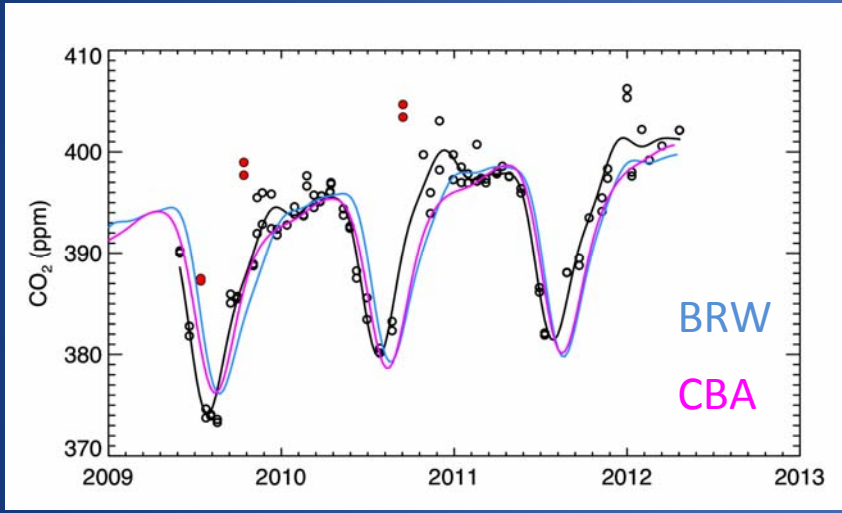
(MLO Seasonal Cycle AND Trend subtracted)

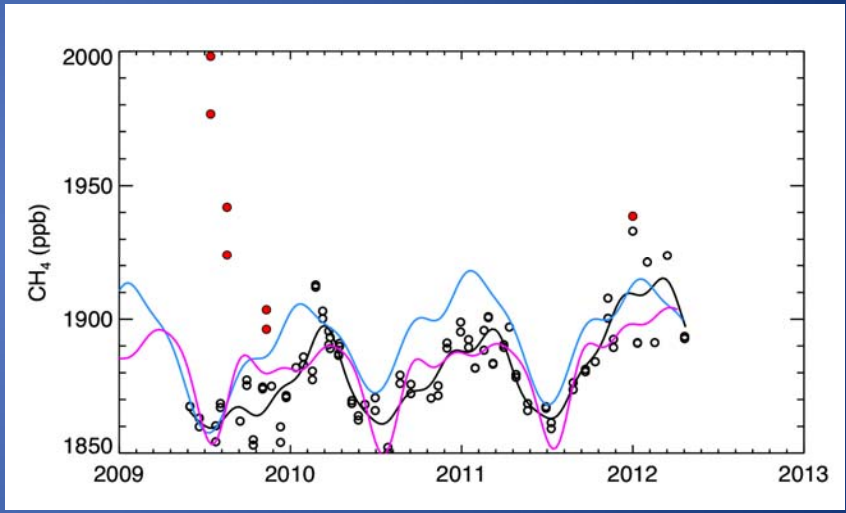




Alaskan surface flux Information needs to be derived from Alaskan observations*

→ Poker Flat (PFA) data (< 500 m asl) are substantially different from BRW and CBA.



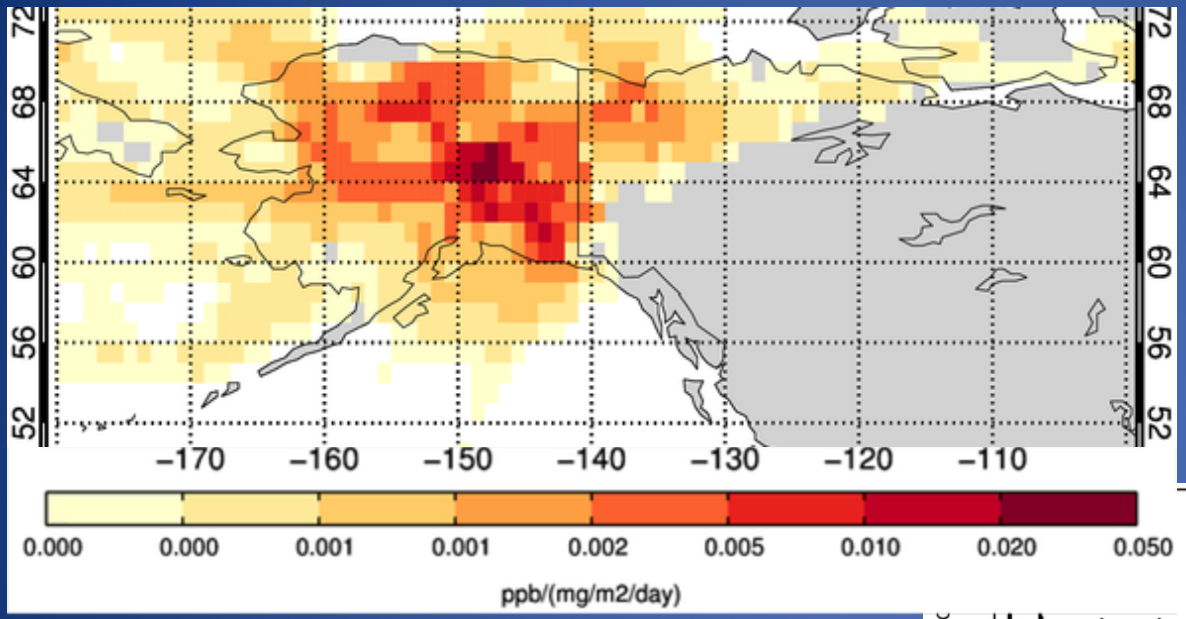


Sparse data, but…
…looks like a consistent phase shift.

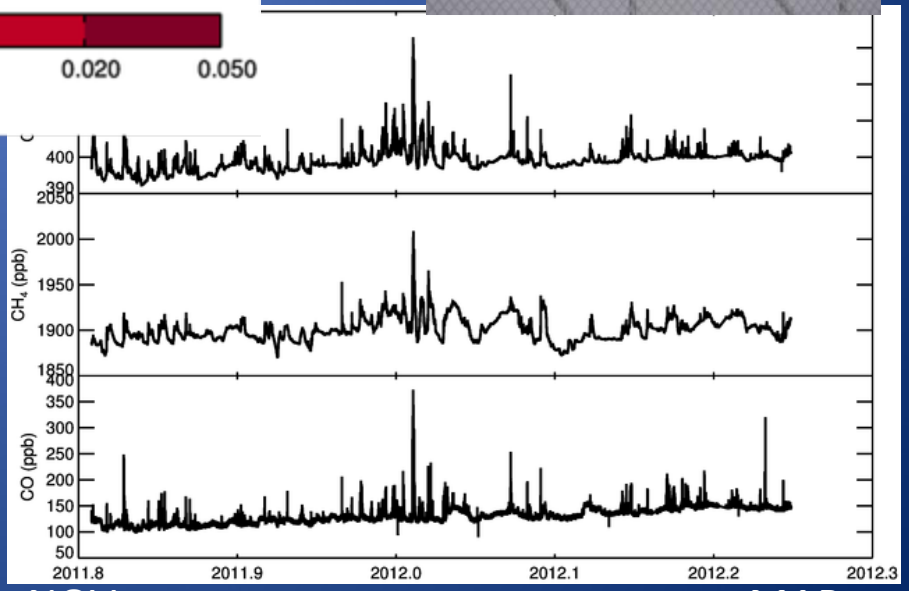
Noisy, but…
…looks like smaller summer trough.

*This may seem like a trivial statement, but it represents the ongoing shift to using more and more continental data in inversions.

CRV Tower is sensitive to large swaths of interior Alaska



(Maybe including Fairbanks)
→ Surprising amount of wintertime signal



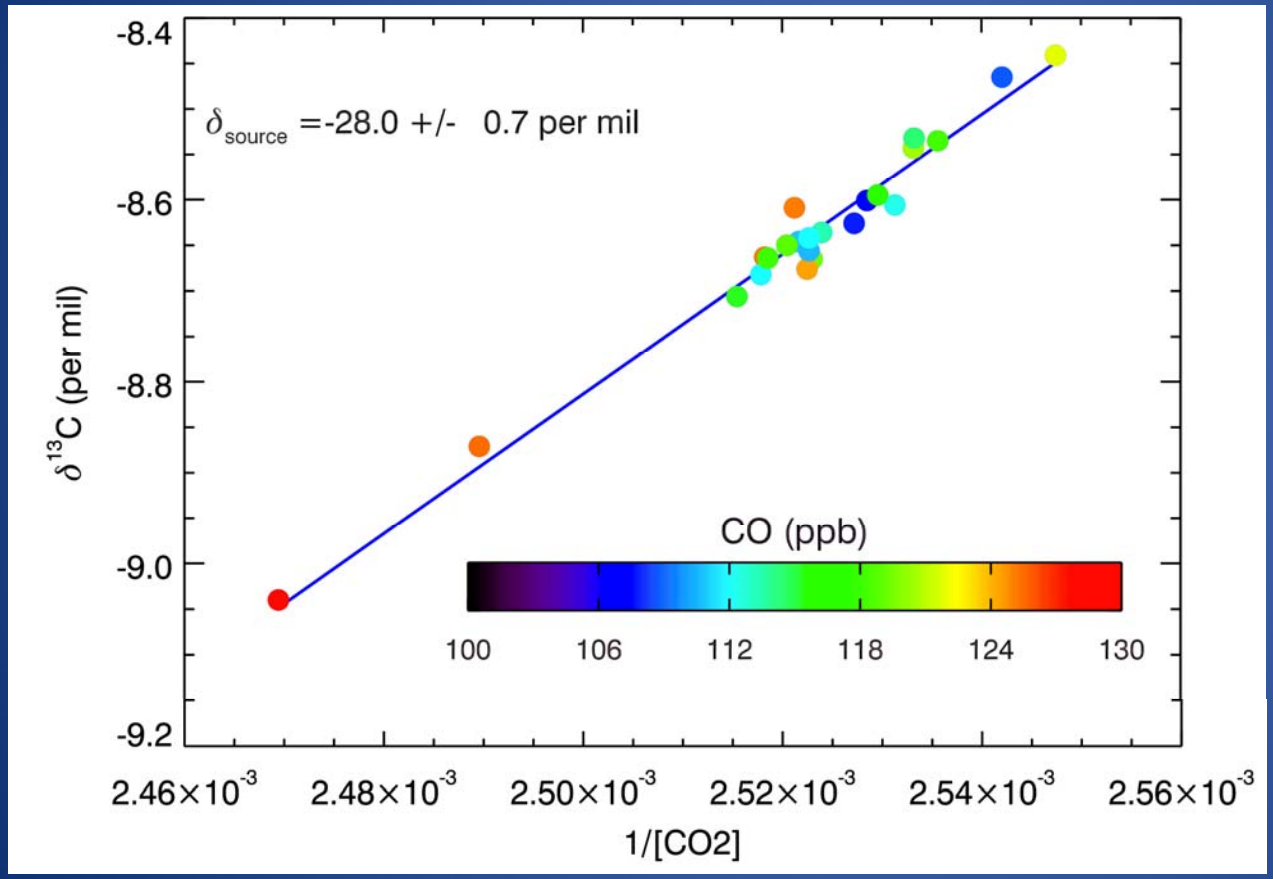
NOV. MAR.

At CARVE tower* we measure a wide variety of diagnostic tracers

Gas	Goal		Isotopomer	Goal
CO2	Net Carbon balance (NEE)		13CO2	Ecosystem water stress
CH4	CH4		13CH4	CH4 partitioning
CO	Fire emissions		14CO2	'Age' of CO2
Halocarbons, Hydrocarbons, SF6	Pollution; long range transport from south.		14CH4	'Age' of CH4
H2	Land interaction/Fire			
COS and CO18O	Split NEE into Resp. and Photosynthesis			

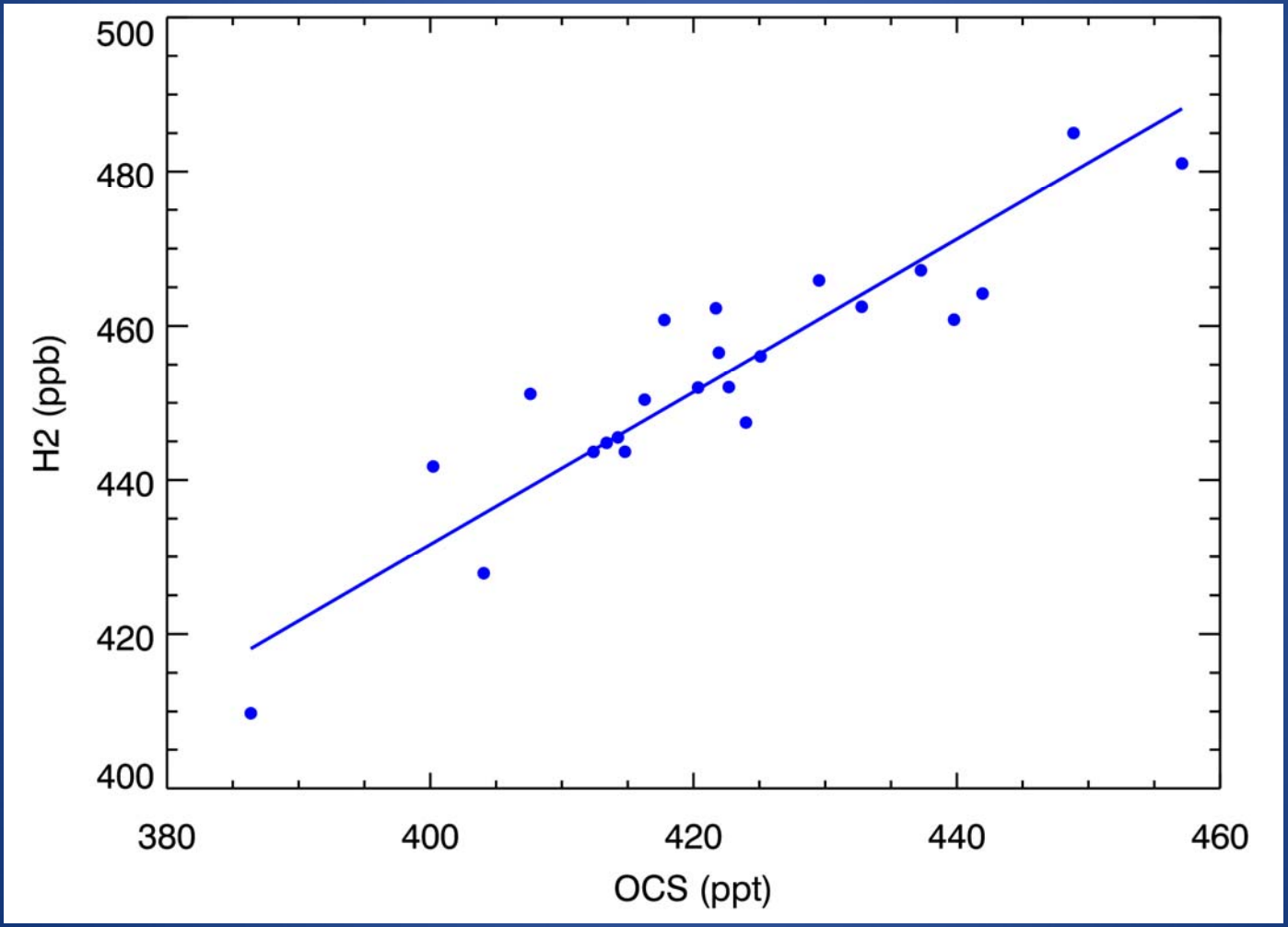
* And for all except 14CH4 on the CARVE aircraft as well

$\delta^{13}C$ and CO_2 are highly correlated, and may be driven by both combustion and respiration…



- Seasonal changes in dsource (not driven by combustion) can indicate regional ecosystem stress. (Ballantyne, 2009)

In October and November, the ‘bugs’ still seem to be active: both OCS and H_2 are consumed by enzymes in soil



The overlooked observation of King et al. leads to an important hypothesis…

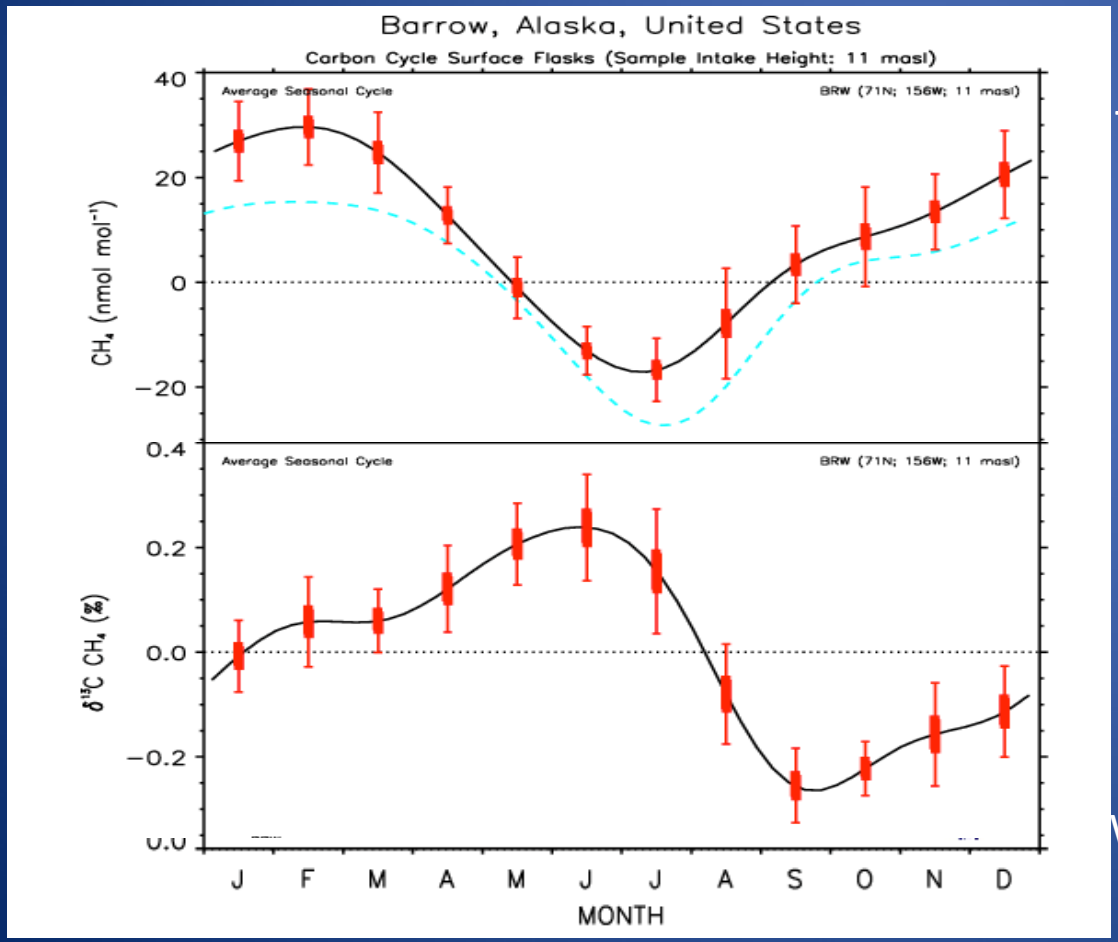
Pulse-labeling studies of carbon cycling in Arctic tundra ecosystems: The contribution of photosynthates to methane emission

J. Y. King,[1,2] W. S. Reeburgh,[1] K. K. Thieler,[3] G. W. Kling,[4] W. M. Loya,[5,6]
L. C. Johnson,[5] and K. J. Nadelhoffer[3]

fate of recently fixed carbon. Carbon fixed by photosynthesis was measured as emitted methane from both moist tussock and wet sedge tundra mesocosms within 2 hours after labeling. Integration of time series measurements of methane emission showed that

…21st Century increases in Arctic and Boreal CH4 emissions may be driven as much by warming-driven ecosystem production as anaerobic decomposition of old carbon.

Case Study: $\delta^{13}CH_4$ and CH_4 used together allow separation of Wetland and OH signals

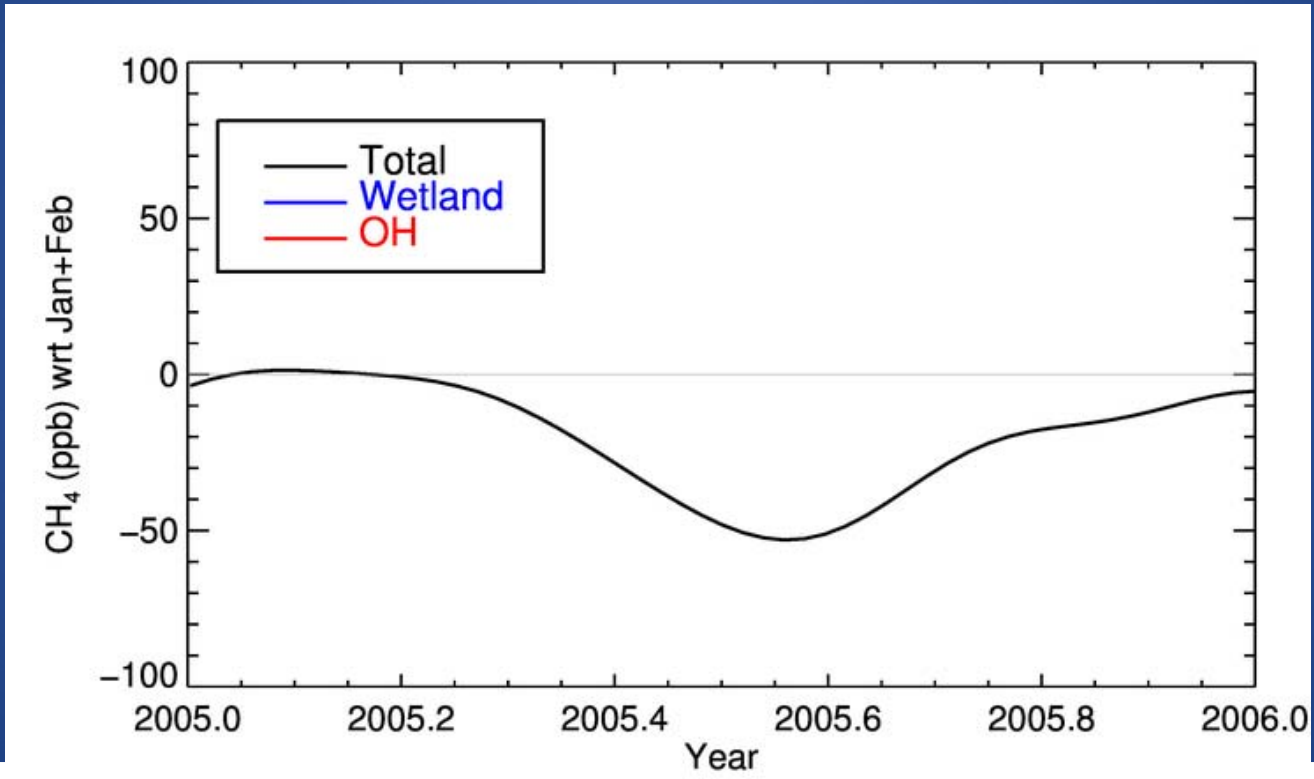


Total Effect

OH destruction (- 51 per mil)

Wetland Emissions (-65 per mil)

Case Study: $\delta^{13}CH_4$ and CH_4 used together allow separation of Wetland and OH signals



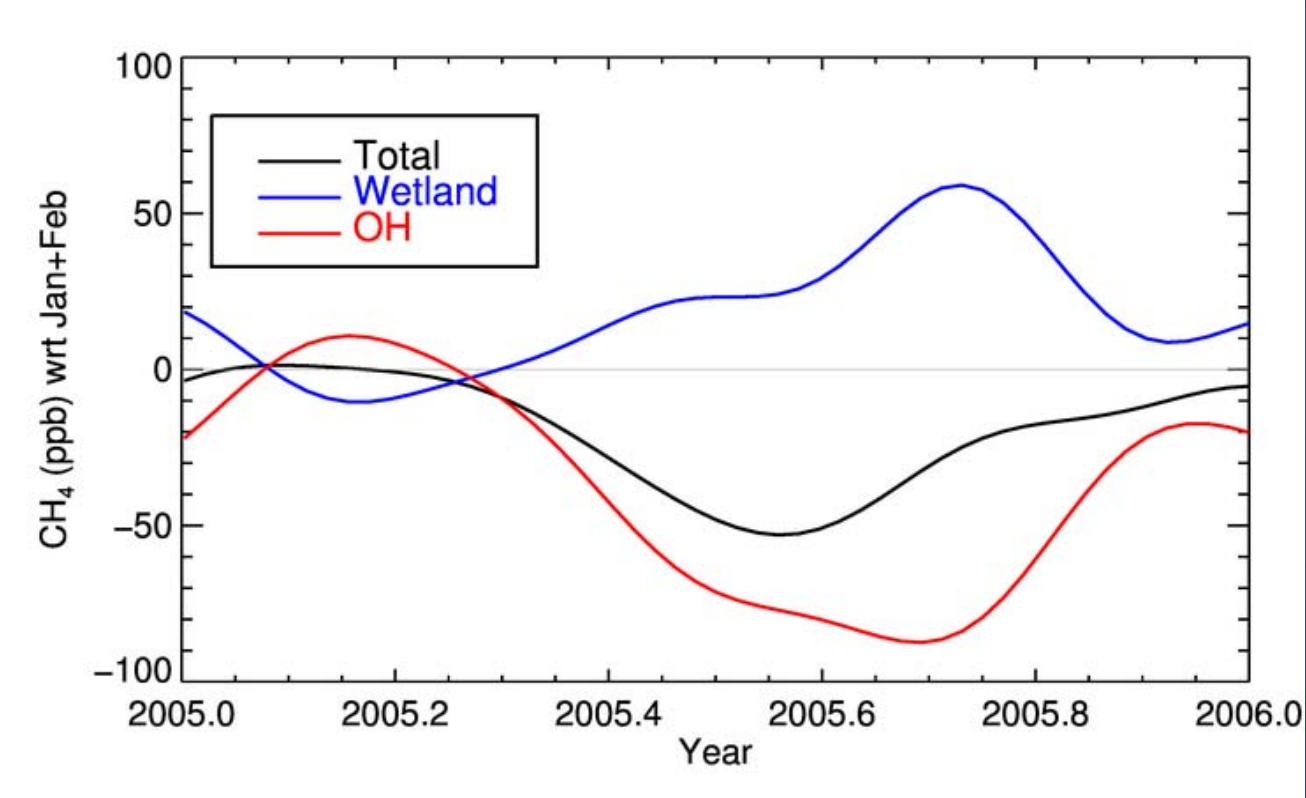
CH4_obs CH4_bg + CH4_wet + CH4_oh

13CH4_obs 13CH4_bg R_wet CH4_wet R_oh CH4_oh

BLUE = known

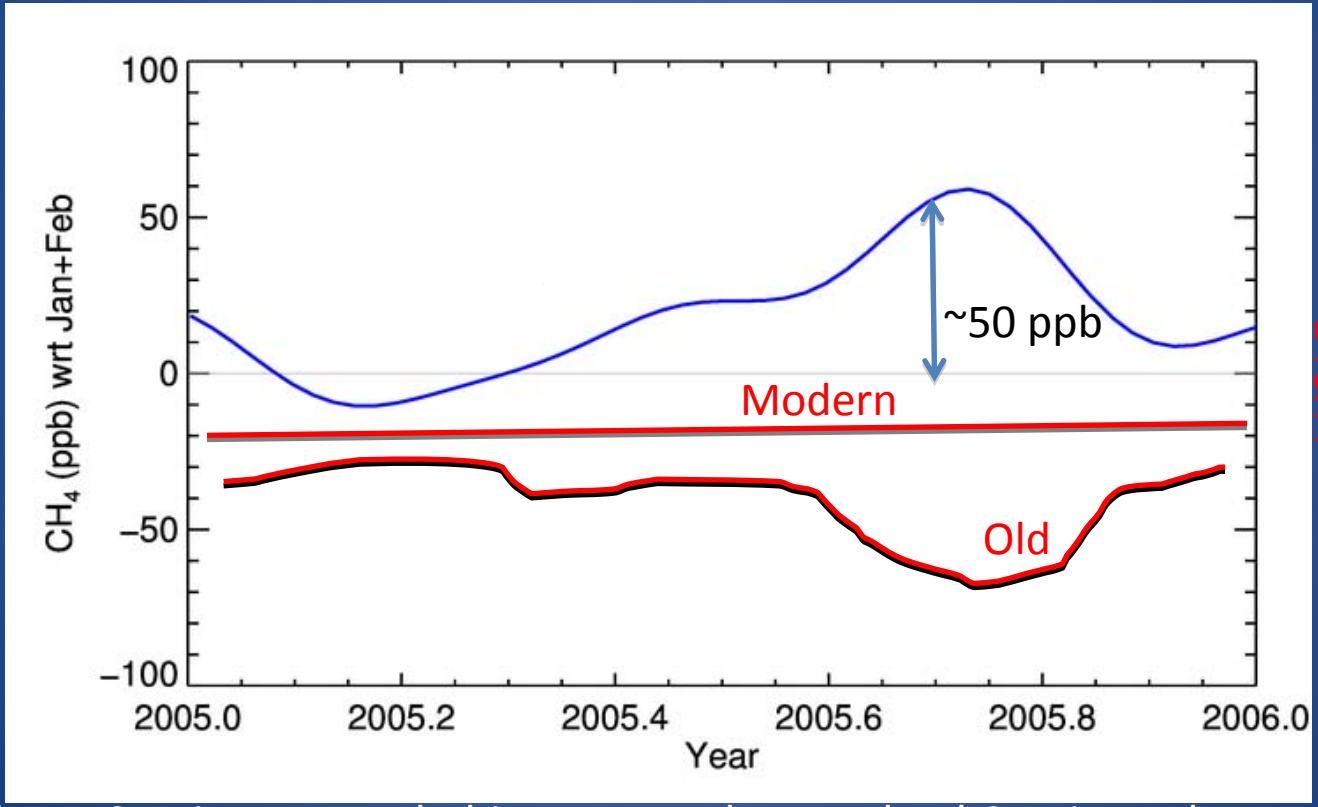
RED = unknown

Case Study: $\delta^{13}CH_4$ and CH_4 used together allow separation of Wetland and OH signals



- Wetland and OH signals are out of (anti-)phase, producing a shoulder
- Biomass burning signal may be aliased into OH curve
- Cartoon version does not account for transport (i.e. variable background)

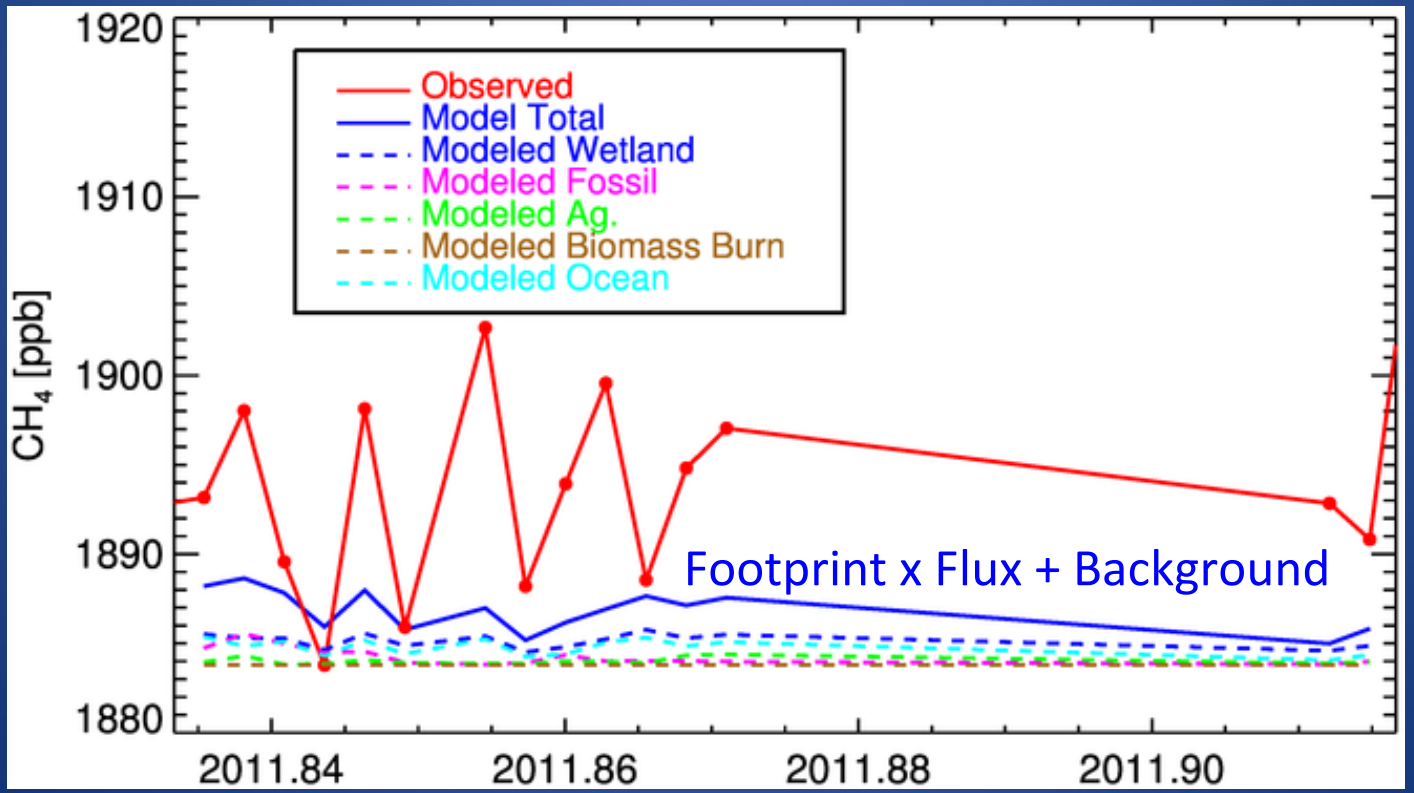
We want to use $^{14}CH_4$ to answer: *Is the wetland signal is modern?*



A. If the 14CH4 is aseasonal, this suggests that Wetland CH4 is modern
B. If 14CH4 dips in fall, this suggests a substantial fraction of old CH4.
C. Quantifying the old CH4 fraction, depends on the 14C of the organic matter.

Observations have significantly more variability than predictions

→ Predict CRV Tower CH4 by convolving CarbonTracker CH4 fluxes with FLEXPART footprints



Summary

- CARVE and new GMD measurement programs will allow much better sensing of Alaskan carbon balance.
- We are still confronted with the Goldilocks issue: (not too close to sources, not too far. Just right.)

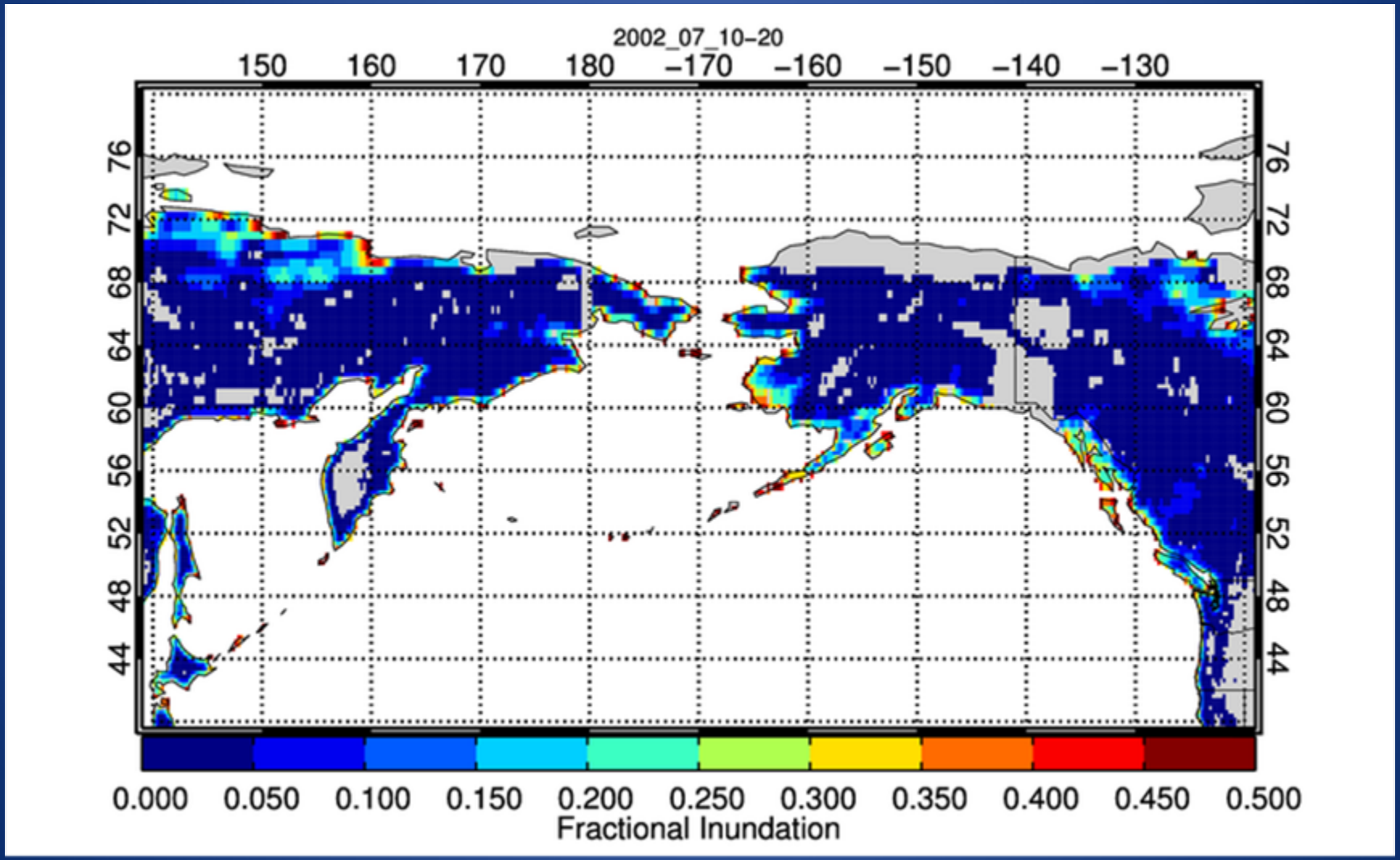
Outline

- Motivation
  - Understanding arctic and boreal carbon cycling: Baselines and sensitivities
- Existing and planned GHG observations
  - Surface sites
    - CARVE tower (CRV)
    - Barrow (BRW), Cold Bay (CBA)
  - Airborne observations
    - Poker Flat (PFA)
    - Alaska Coast Guard C-130-of-opportunity (ACG)
    - (2011 CARVE Aircraft)
- Preliminary data analysis
  - Multi-species (including isotopic) analysis
  - Lagrangian and Eulerian modeling

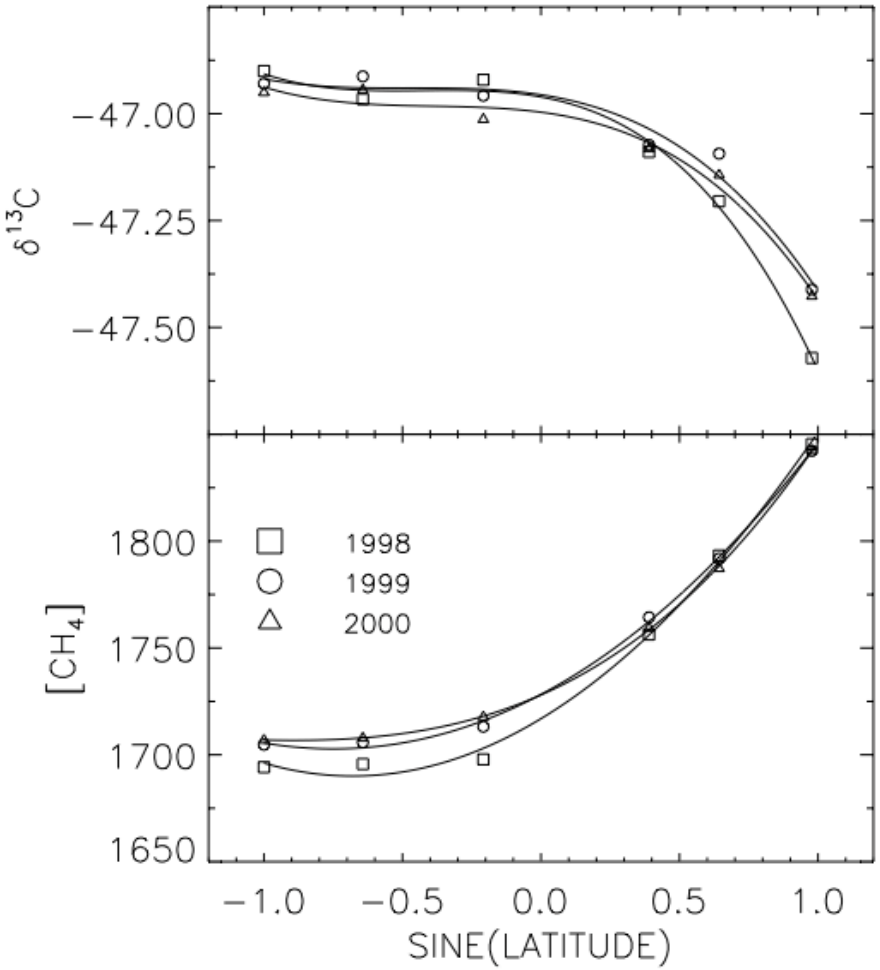
Notes

- What are the big questions for Boreal and Arctic Carbon?
  - Changes in C-cycling with warming:
    - Permafrost release as CO2 or CH4 as active layer increases with depth and time
    - Increased growing season: more NPP: released as CO2 or CH4.
    - Do oceanic clathrates (ch4 . X H2o) play a role?
    - What is the role of fire in carbon balance?
    - Can current models represent the current state; ~decadal trends; seasonal and interannual variability?
  - C-cycle is a **first order uncertainty in climate prediction!!**
- How can existing and planned NOAA+CARVE atmospheric gas obs help to answer these questions?
  - Survey of ongoing NOAA/GMD measurements in Alaska/Motivation
    - GE map with permafrost layer; NOAA site layer (PFA, CRV tower etc.); and ACG flights; and CARVE flights
    - (also CARVE remote sensing obs?)
  - Generally: constrain emission estimates:
    - Test emission models of CO2, CH4 and CO by fwd transport compared to observations
    - Direct calculation of emission by inverse modeling
    - Role of ancillary gases/isotopes for process attribution:
      - 14CH4 and 14CO2: age of released carbon – new NPP or recently emerged buried C.
      - 13CO2: seasonal and interannual water stress
      - 13CH4: CH4 consumption by OH, biomass burning and wetland production
      - CH3D: wetland processes??
      - COS + CO18O: Photosynthesis v. respiration in net carbon exchange.
      - Anthro tracers: long range and local pollution transport – screening and/or deconvolution
    - Correlation of CO2, CH4 fluxes (inverse) or just concentrations with remotely sensed surface observations of temp and moisture – fractional innundation maps from Ronny and Kyle??

--add wind fields
-- also do GFED fires??



CH4 and 13C Latitude Gradients



OH destruction/Biomass Burning

Biogenic Emissions

Warming temperatures are also likely to:

Sequester carbon by:

- extending the growing season
- expanding the boreal (tree) zone

and release carbon by:

- increased fire frequency
- increased insect outbreaks

also physical climate changes:

- changes in albedo (higher – snowshedding evergreen trees)
- sensible heat flux (higher due to boreal forest high WUE/low conductance.) → atmos. Circulation changes