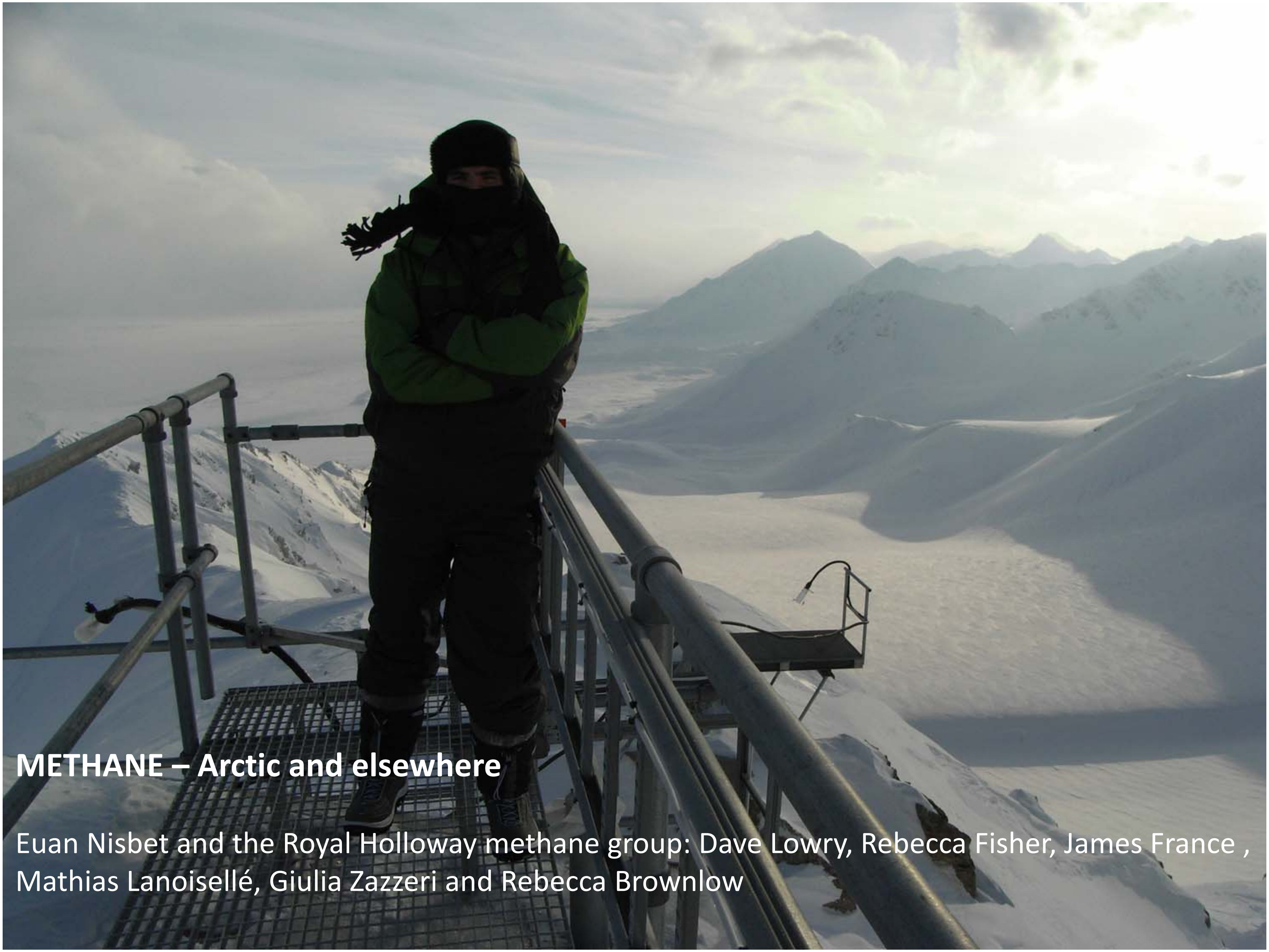
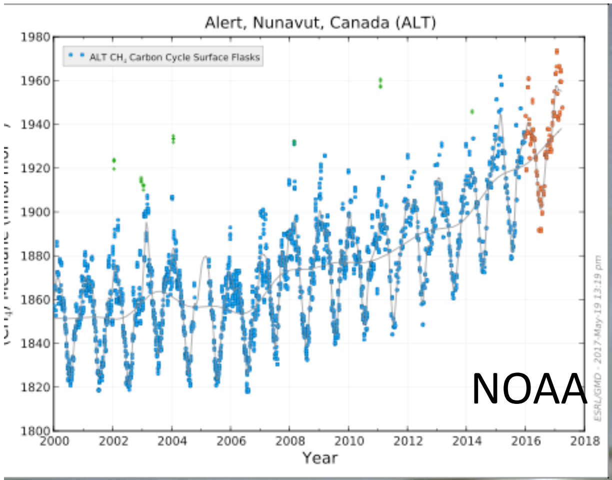
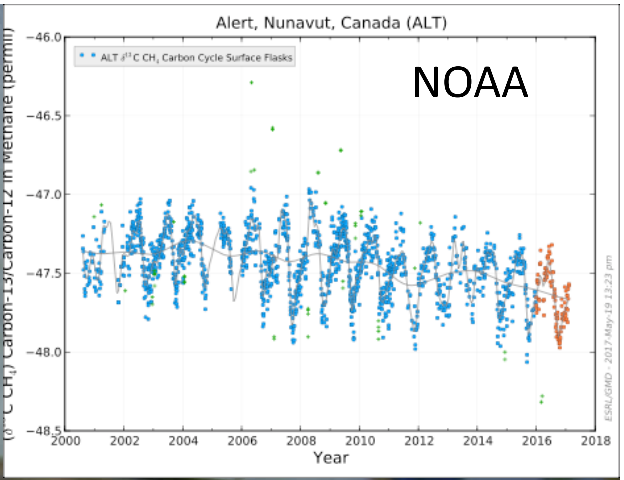


METHANE – Arctic and elsewhere

Euan Nisbet and the Royal Holloway methane group: Dave Lowry, Rebecca Fisher, James France , Mathias Lanoisellé, Giulia Zazzeri and Rebecca Brownlow


Alert, Nunavut, Canada (ALT)
ALT CH₄ Carbon Cycle Surface Flasks
Methane (nmol mol
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Year
ESRL/GMD - 2017-May-19 13:19 pm
NOAA

What next?


Alert, Nunavut, Canada (ALT)
ALT δ¹³C CH₄ Carbon Cycle Surface Flasks
C CH₄) Carbon-13/Carbon-12 in Methane (permil)
−46.0
−46.5
−47.0
−47.5
−48.0
−48.5
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Year
ESRL/GMD - 2017-May-19 13:23 pm
NOAA


RHUL

Peak Beaver, Top Hats, cloaks, methane emission and collapse of Empires.

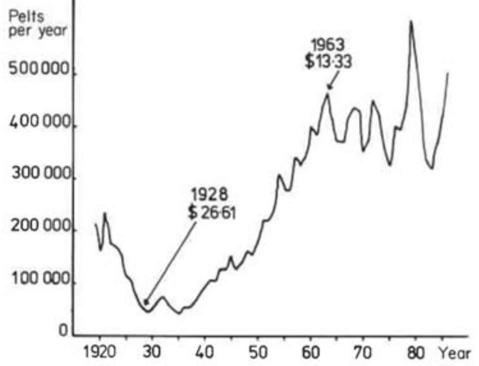
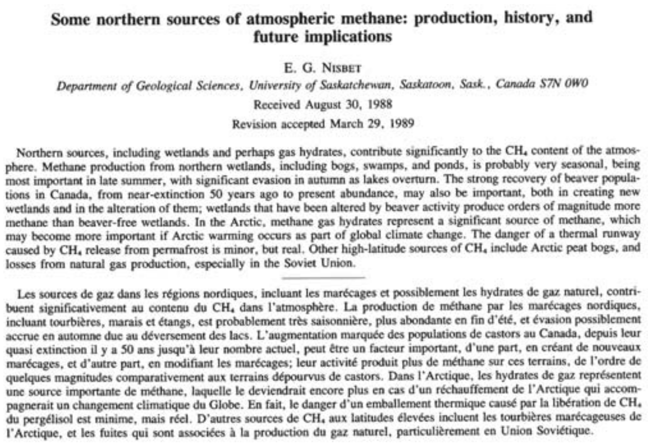


FIG. 2. Beaver fur production in Canada, 1919–1985. Price per pelt in 1928, in 1928 dollars, was $26.61; in 1963, in 1963 dollars, $13.33. Data from Statistics Canada Annual, various years. Fluctuations in harvest during the past two decades probably reflect decreasing importance of furs in the northern economy, price fluctuations, and impact of social welfare payments, as much as abundance of beaver (W. Runge, personal communication, 1988).



Some northern sources of atmospheric methane: production, history, and future implications

E. G. NISBET
Department of Geological Sciences, University of Saskatchewan, Saskatoon, Sask., Canada S7N 0W0

Received August 30, 1988
Revision accepted March 29, 1989

Northern sources, including wetlands and perhaps gas hydrates, contribute significantly to the CH_4 content of the atmosphere. Methane production from northern wetlands, including bogs, swamps, and ponds, is probably very seasonal, being most important in late summer, with significant evasion in autumn as lakes overturn. The strong recovery of beaver populations in Canada, from near-extinction 50 years ago to present abundance, may also be important, both in creating new wetlands and in the alteration of them; wetlands that have been altered by beaver activity produce orders of magnitude more methane than beaver-free wetlands. In the Arctic, methane gas hydrates represent a significant source of methane, which may become more important if Arctic warming occurs as part of global climate change. The danger of a thermal runway caused by CH_4 release from permafrost is minor, but real. Other high-latitude sources of CH_4 include Arctic peat bogs, and losses from natural gas production, especially in the Soviet Union.

Les sources de gaz dans les régions nordiques, incluant les marécages et possiblement les hydrates de gaz naturel, contribuent significativement au contenu du CH_4 dans l'atmosphère. La production de méthane par les marécages nordiques, incluant tourbières, marais et étangs, est probablement très saisonnière, plus abondante en fin d'été, et évasion possiblement accrue en automne due au déversement des lacs. L'augmentation marquée des populations de castors au Canada, depuis leur quasi extinction il y a 50 ans jusqu'à leur nombre actuel, peut être un facteur important, d'une part, en créant de nouveaux marécages, et d'autre part, en modifiant les marécages; leur activité produit plus de méthane sur ces terrains, de l'ordre de quelques magnitudes comparativement aux terrains dépourvus de castors. Dans l'Arctique, les hydrates de gaz représentent une source importante de méthane, laquelle le deviendrait encore plus en cas d'un réchauffement de l'Arctique qui accompagnerait un changement climatique du Globe. En fait, le danger d'un emballement thermique causé par la libération de CH_4 du pergélisol est minime, mais réel. D'autres sources de CH_4 aux latitudes élevées incluent les tourbières marécageuses de l'Arctique, et les fuites qui sont associées à la production du gaz naturel, particulièrement en Union Soviétique.

FIGURE 116.
Beaver Hat and Short Cloak, Middle of Eighteenth Century. Reigns of George II and III.

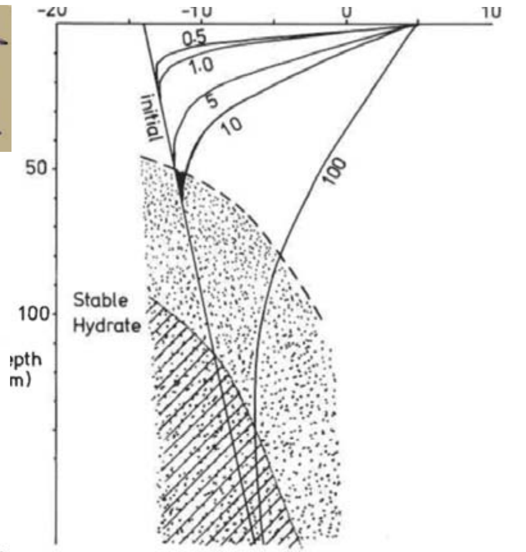
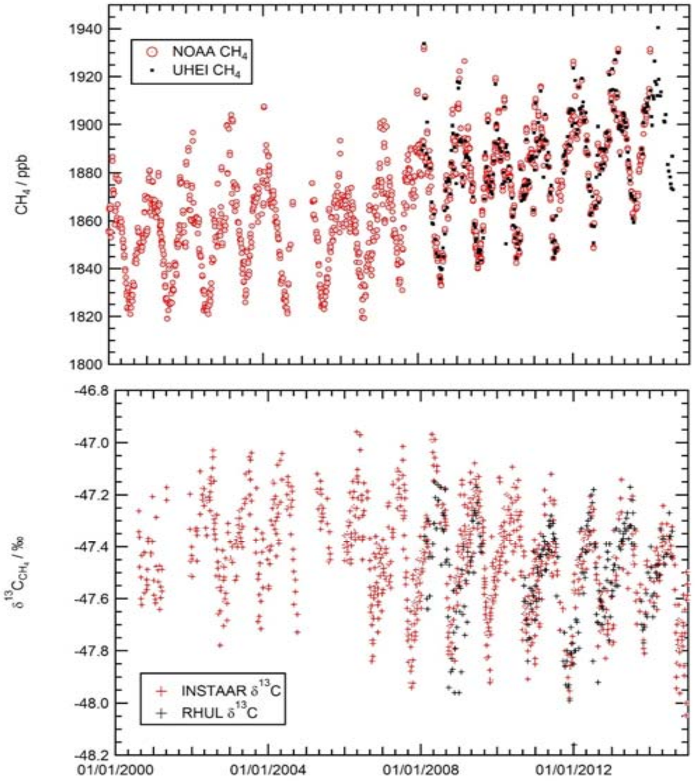


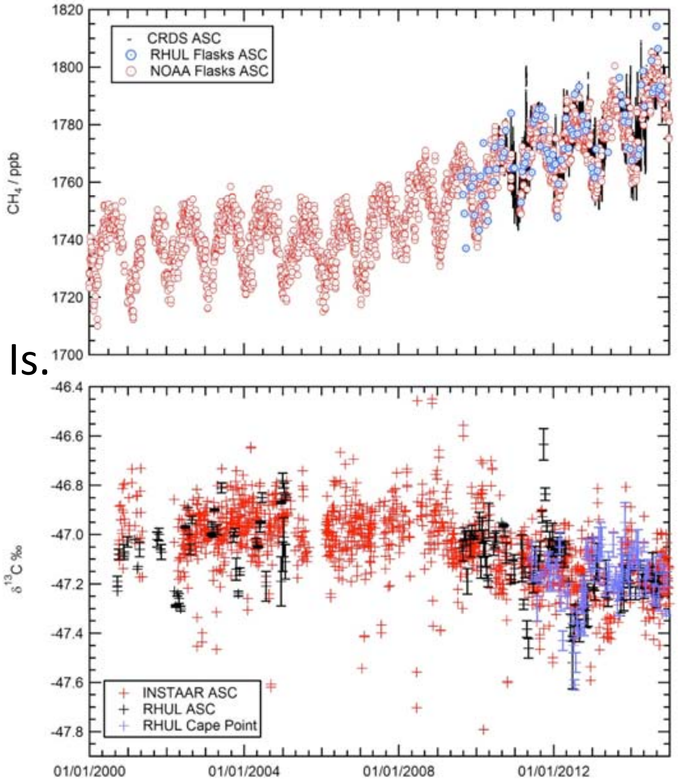
FIG. 5. Stability of methane hydrate in warming permafrost. Diagram shows an extreme case, in which a region with a surface mean annual temperature of −14°C rapidly warms to a surface mean annual temperature of +5°C. This warming is at the top end of the range of predictions for temperature change in the high Arctic in a 4 × CO_2 atmosphere: it provides a rough test of the risk of runaway emission of CH_4 from permafrost. "Initial" geotherm is pre-warming. Curves (0.5, 1, 5, 10, 100) show depth–temperature profile of the ground at various time intervals, in years, after the warming. The curves are calculated for a conductive model (Carslaw and Jaeger 1959, p. 61) with no allowance for latent heat, assuming a diffusivity of 10^{-6} m^2/s. The upper hydrate stability curve and stippled stability area are from Kvenvolden (1983), but assuming an effective density of 2 g/cm^3 in the overburden. This is an extreme assumption. The dotted line and region below it show the more likely upper limit of stability, assuming that the pressure gradient is hydro-

Nisbet, 1989. Some northern sources of atmospheric methane: production, history and future implications. *Canadian J. Earth Sciences*, 26, 1603-11.

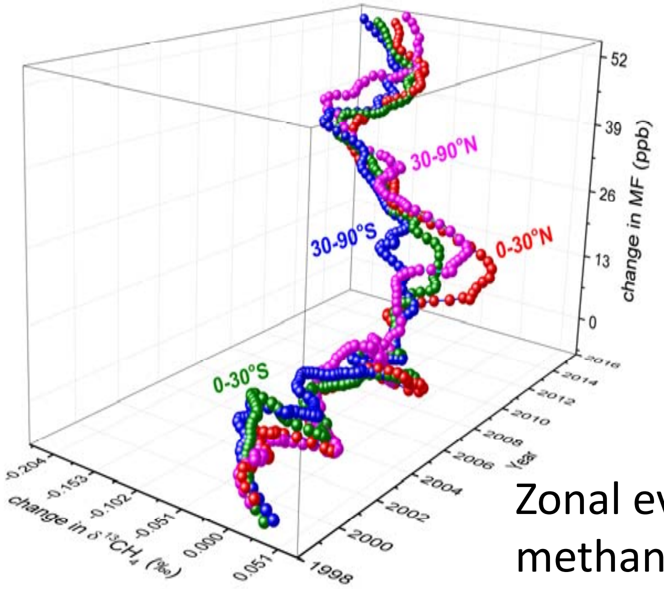


Alert, 82N

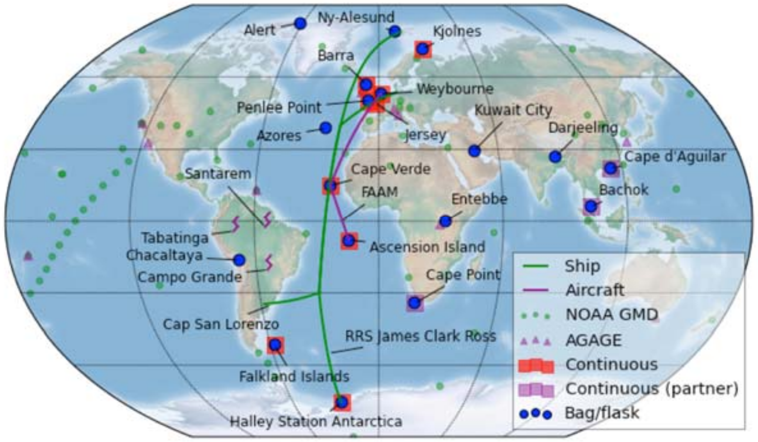
Ascension Is.
8S



Figs from Nisbet et al. 2016



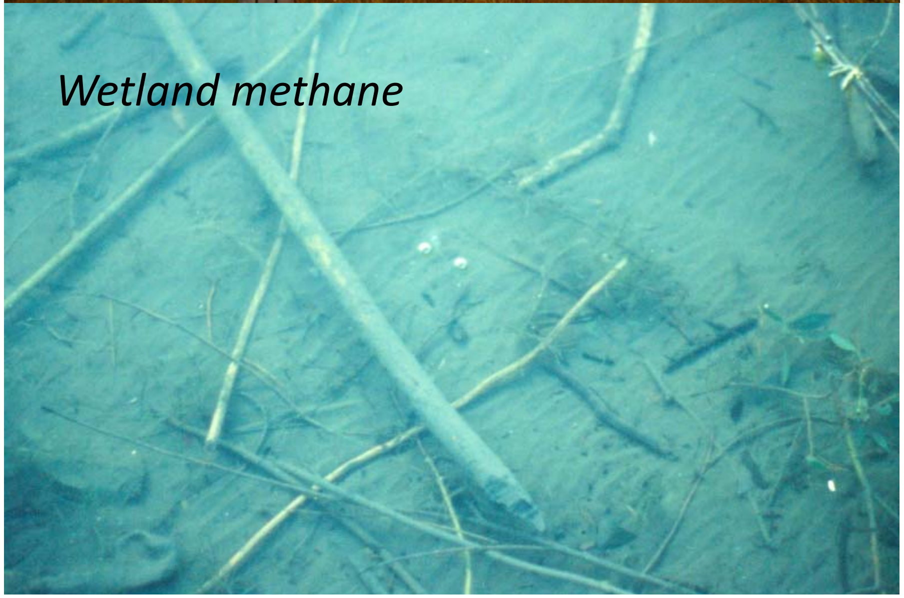
Zonal evolution of
methane and its C isotopic ratio



UK MOYA project 2016-20

Arctic and Boreal natural emissions: exponential response to warming?

Project MAMM (led by John Pyle) - wetland, hydrate, thermokarst, animals



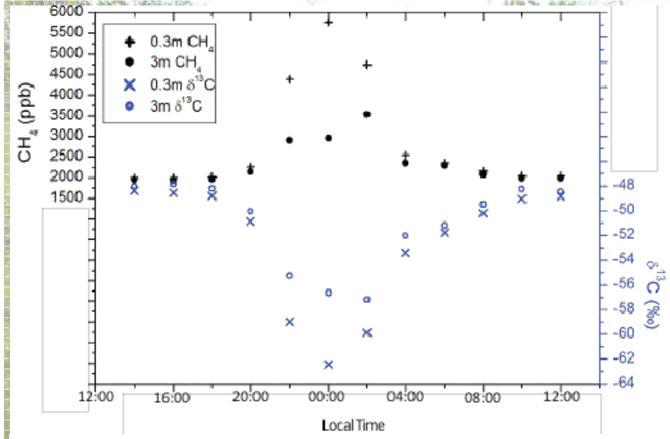
Wetland methane

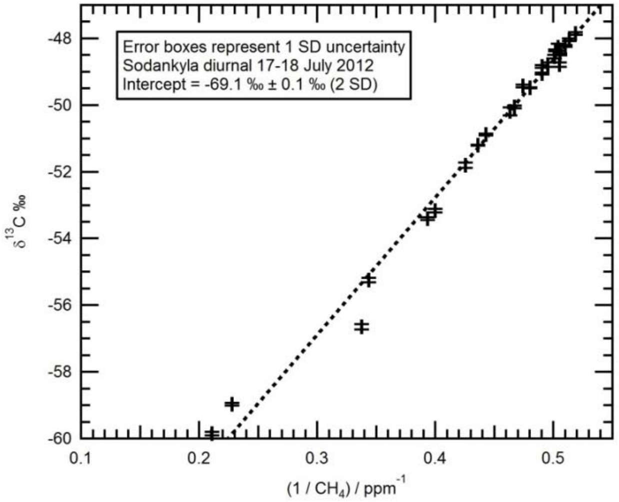
Ruminant emissions

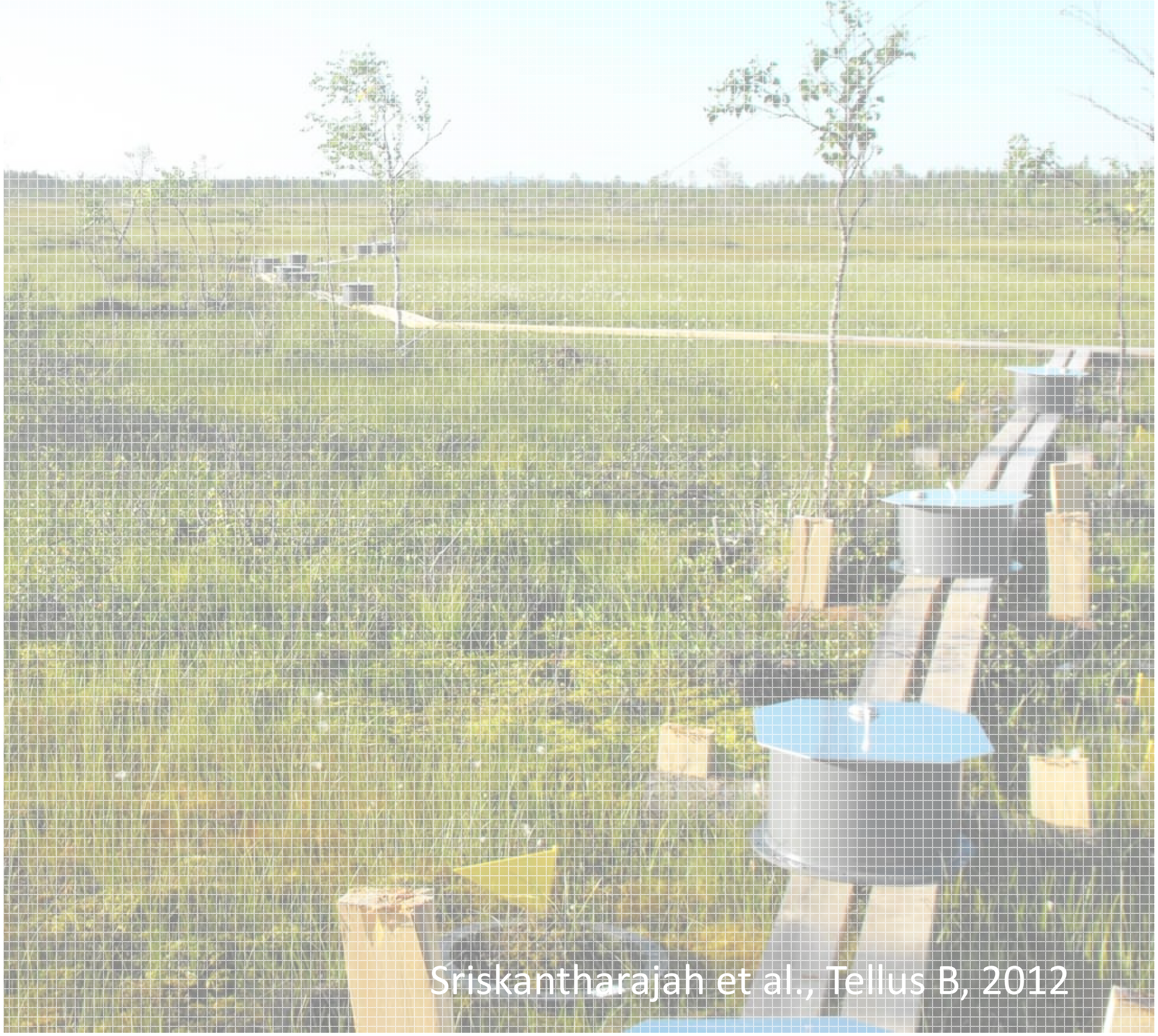
Forest & tundra fires

Identifying the bulk isotopic signature of emissions to the atmosphere from wetland

Air samples collected through diurnal cycles at 3m and 0.3 m above the ground.
'Keeling plot' technique used to identify the signature of the methane source

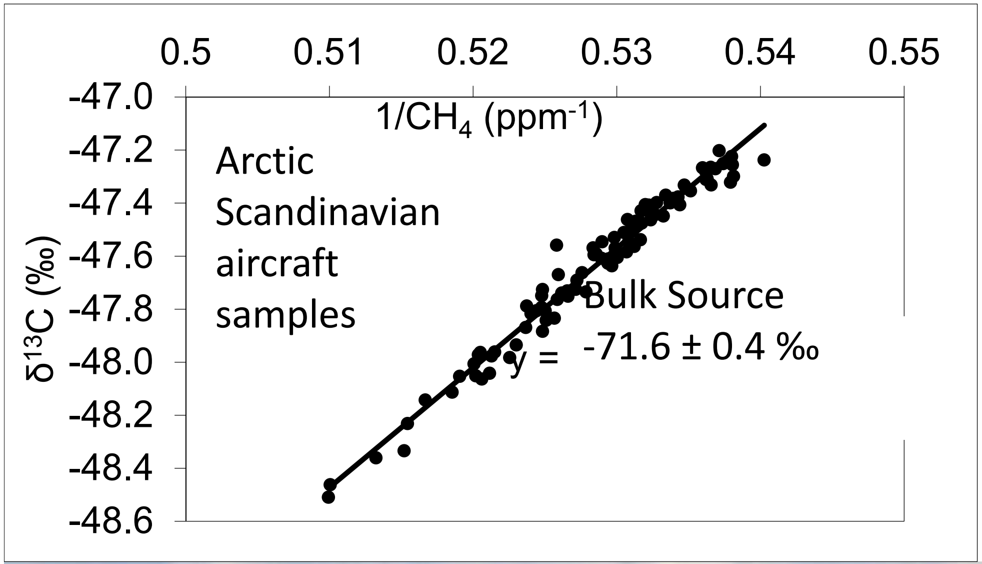




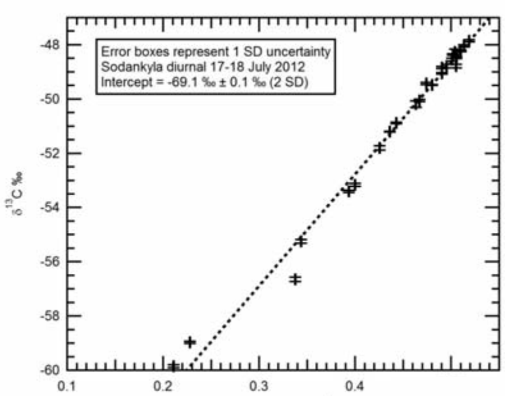


Sriskantharajah et al., Tellus B, 2012

Isotopic tracking of the Arctic methane increment summer 2012-13
- main source is wetland



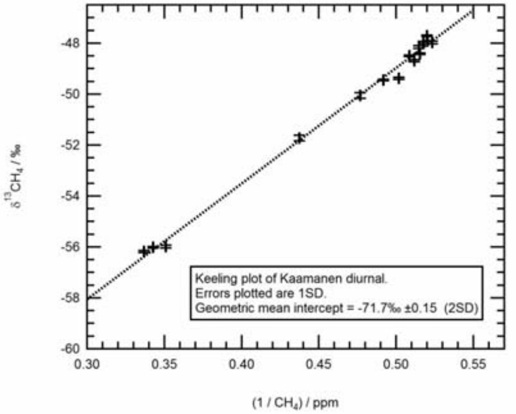
Keeling plots ($\delta^{13}C_{CH4}$ vs $1/CH_4$) measured *in situ* in Scandinavian air, wetlands and bogs.



Sodankylä -69.1±0.1‰

Kaamanen

-71.7‰±0.2



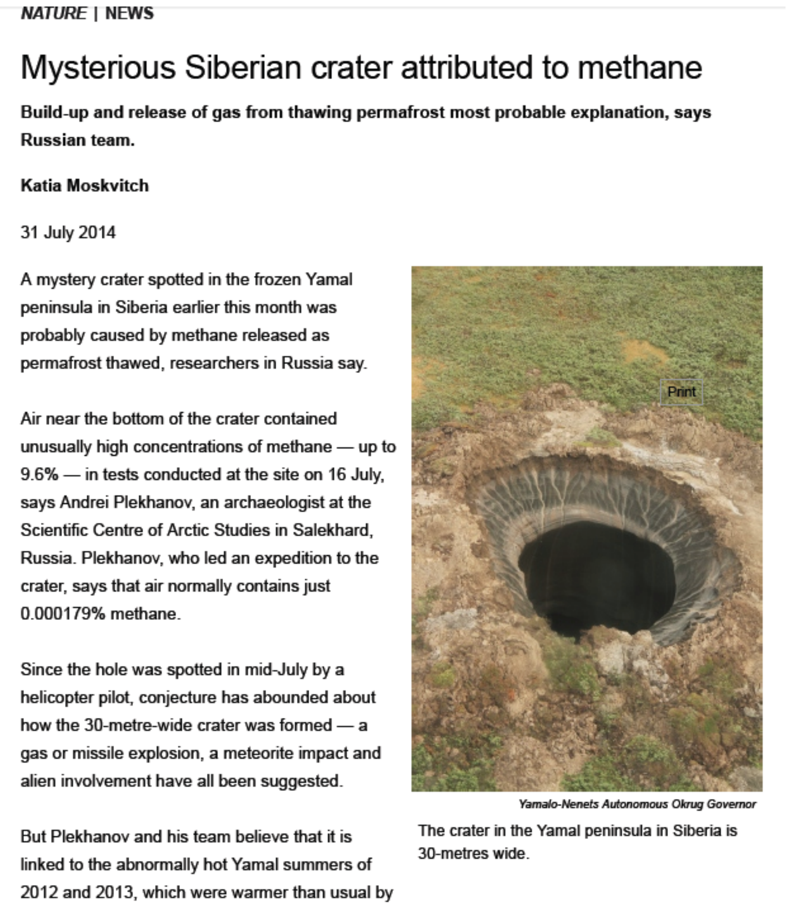
NERC-MAMM- 2012&2013 - FAAM over Sodankylä
Air sampled from 250 to 30 000 ft above N. Scandinavia and also at wetland level 1-2m above surface of wetland

R. Fisher

Intercept gives methane source signature.

$\delta^{13}C_{CH4}$ wetland emissions -75‰ in North Further south, around -65‰.

R. Fisher et al. GBC 2017



NATURE | NEWS

Mysterious Siberian crater attributed to methane

Build-up and release of gas from thawing permafrost most probable explanation, says Russian team.

Katia Moskvitch

31 July 2014

A mystery crater spotted in the frozen Yamal peninsula in Siberia earlier this month was probably caused by methane released as permafrost thawed, researchers in Russia say.

Air near the bottom of the crater contained unusually high concentrations of methane — up to 9.6% — in tests conducted at the site on 16 July, says Andrei Plekhanov, an archaeologist at the Scientific Centre of Arctic Studies in Salekhard, Russia. Plekhanov, who led an expedition to the crater, says that air normally contains just 0.000179% methane.

Since the hole was spotted in mid-July by a helicopter pilot, conjecture has abounded about how the 30-metre-wide crater was formed — a gas or missile explosion, a meteorite impact and alien involvement have all been suggested.

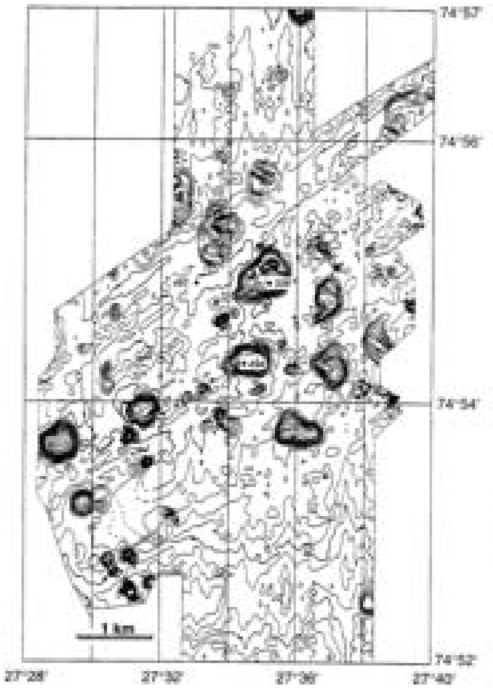
But Plekhanov and his team believe that it is linked to the abnormally hot Yamal summers of 2012 and 2013, which were warmer than usual by

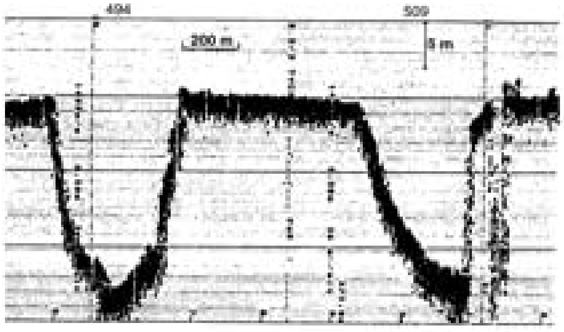
Yamalo-Nenets Autonomous Okrug Governor

The crater in the Yamal peninsula in Siberia is 30-metres wide.

The Yamal blowout, 2014

Strong suggestion of methane-linked hydrodynamic blow out/collapse structure in response to warming.





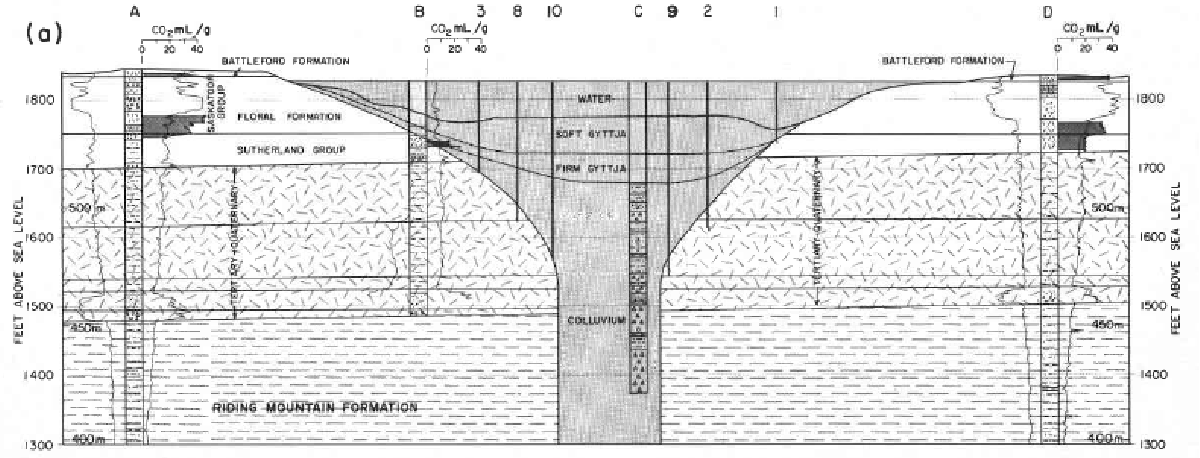
Past example: Arctic Norway

Mienert et al. (1998)

Geol. Soc. Lond. Sp. Publ. 137:275

Howe Lake, Saskatchewan

Christiansen et al, *CJES*, 1982



Methane hydrate in sediment cores from JR211

Source signature of emitted methane from air samples collected in N_2 glove bag as the core was cut onboard the ship

Core JR211-04GC sec 4: $\delta^{13}C$ -51.3 ‰

Core JR211-26 sec 8: $\delta^{13}C$ -50.3 ‰

Methane from hydrate stored in vial onboard ship:

Core JR211-GC33 $\delta^{13}C$ -55.6 ‰

Fisher et al. GRL 2011

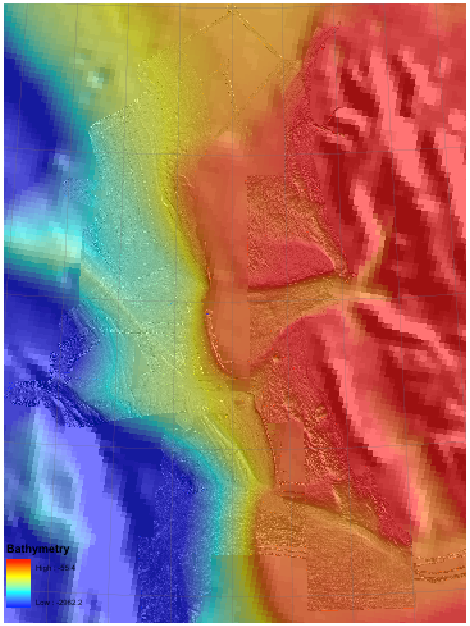
Field of gas plumes (Westbrook et al., GRL, 2009)

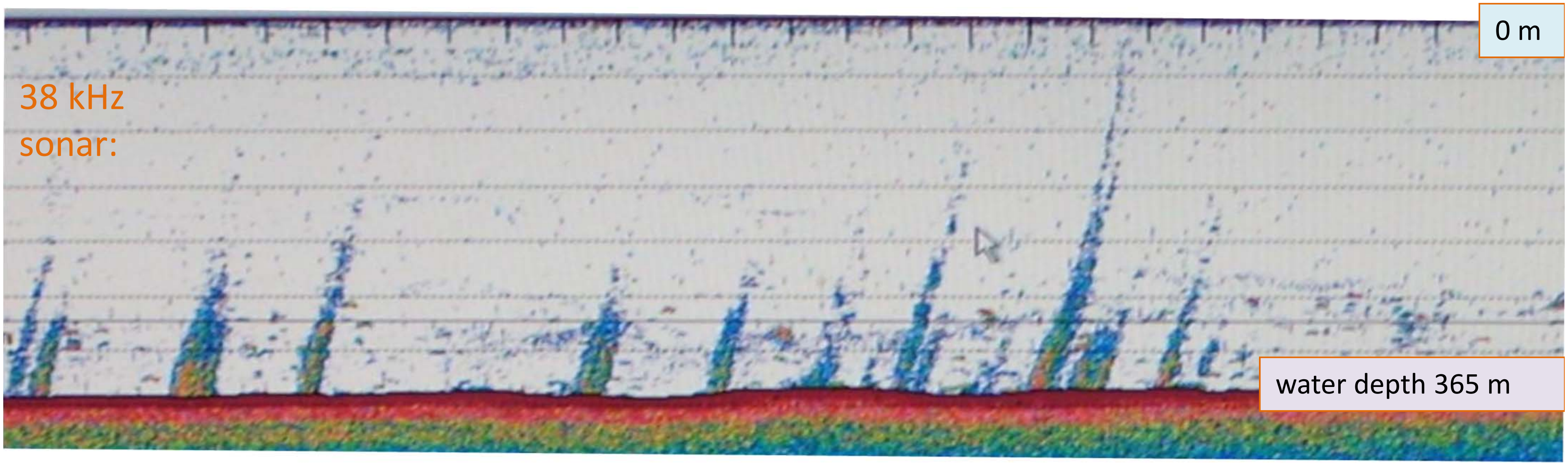
Identified using 38kHz sonar (Simrad EK60 ‘fishfinder’)

More than 250 plumes of gas bubbles from the seabed, some rising to 50 m below the surface

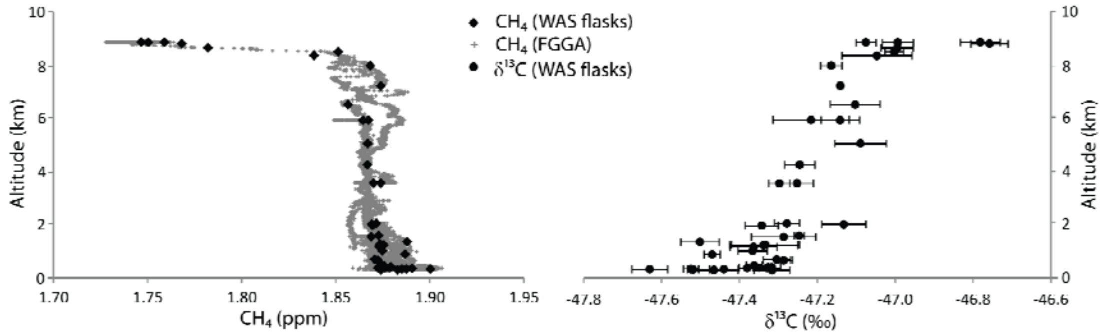
Landward side of gas hydrate stability zone (GHSZ), depth range 150-400 m

Occurrence and activity controlled by the GHSZ, which is sensitive to the effect of changes in water temperature. Increasing temperature will cause the release of methane from the dissociation of hydrate that is present





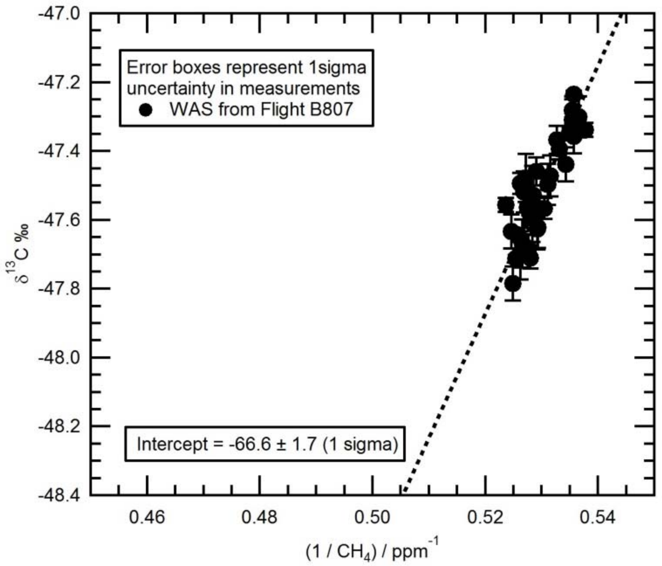
Westbrook et al., Geophys. Res. Lett, 2009

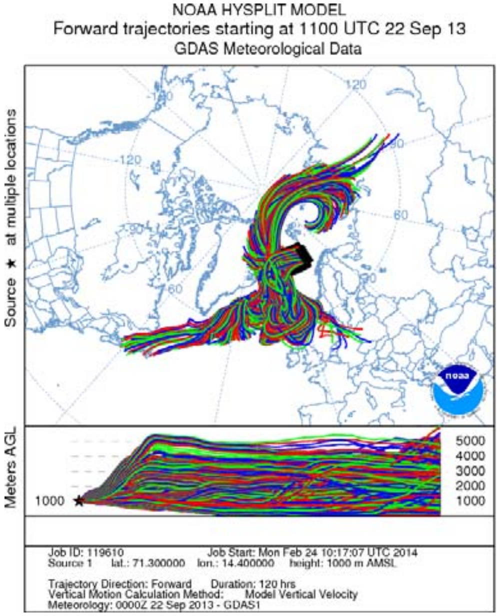


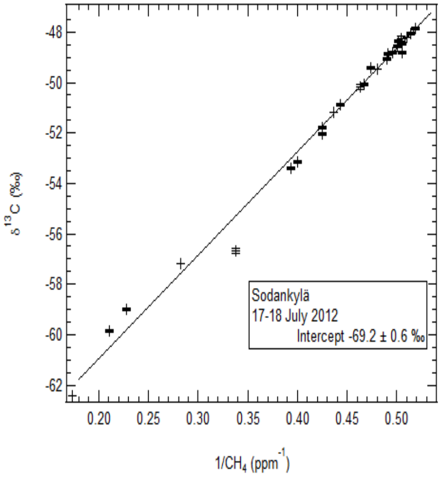
Methane and δ^{13}C , flight B720 July 2012

B807: Norway to Svalbard.

Interception of long range Russian and Atlantic air. Back trajectories from a box at 1000m around the flight path look very mixed.







France et al 2016
Fisher et al 2017

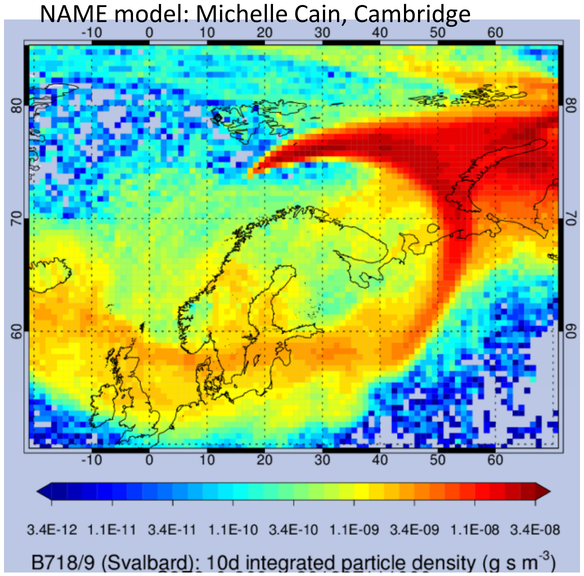
The Arctic problem: hydrate and permafrost emissions

The Arctic has large potential methane sources from hydrate and thermokarst.

Isotopic data suggest -70‰ source implying hydrate emissions to air are small

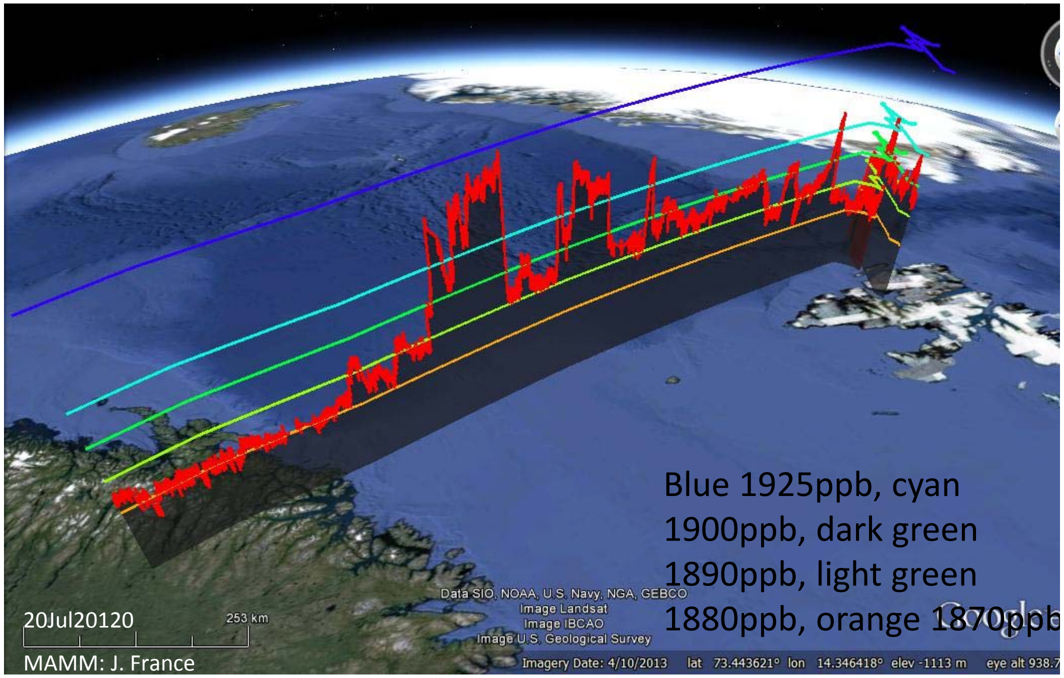
But there may be future sustained moderate release of CH_4 as the sea warms and permafrost decays.

NAME model: Michelle Cain, Cambridge

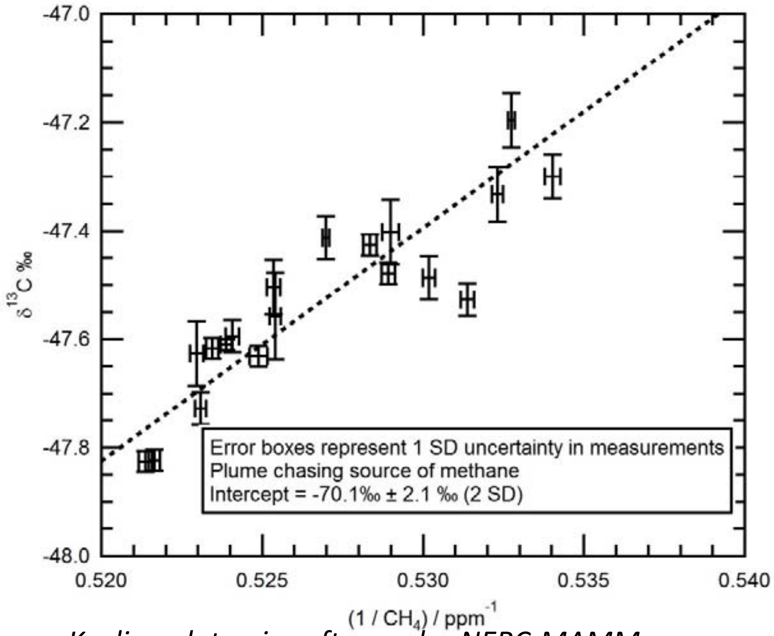


B718/9 (Svalbard): 10d integrated particle density (g s m^{-3})

J. France & MAMM team JGR 2016



Blue 1925ppb, cyan 1900ppb, dark green 1890ppb, light green 1880ppb, orange 1870ppb

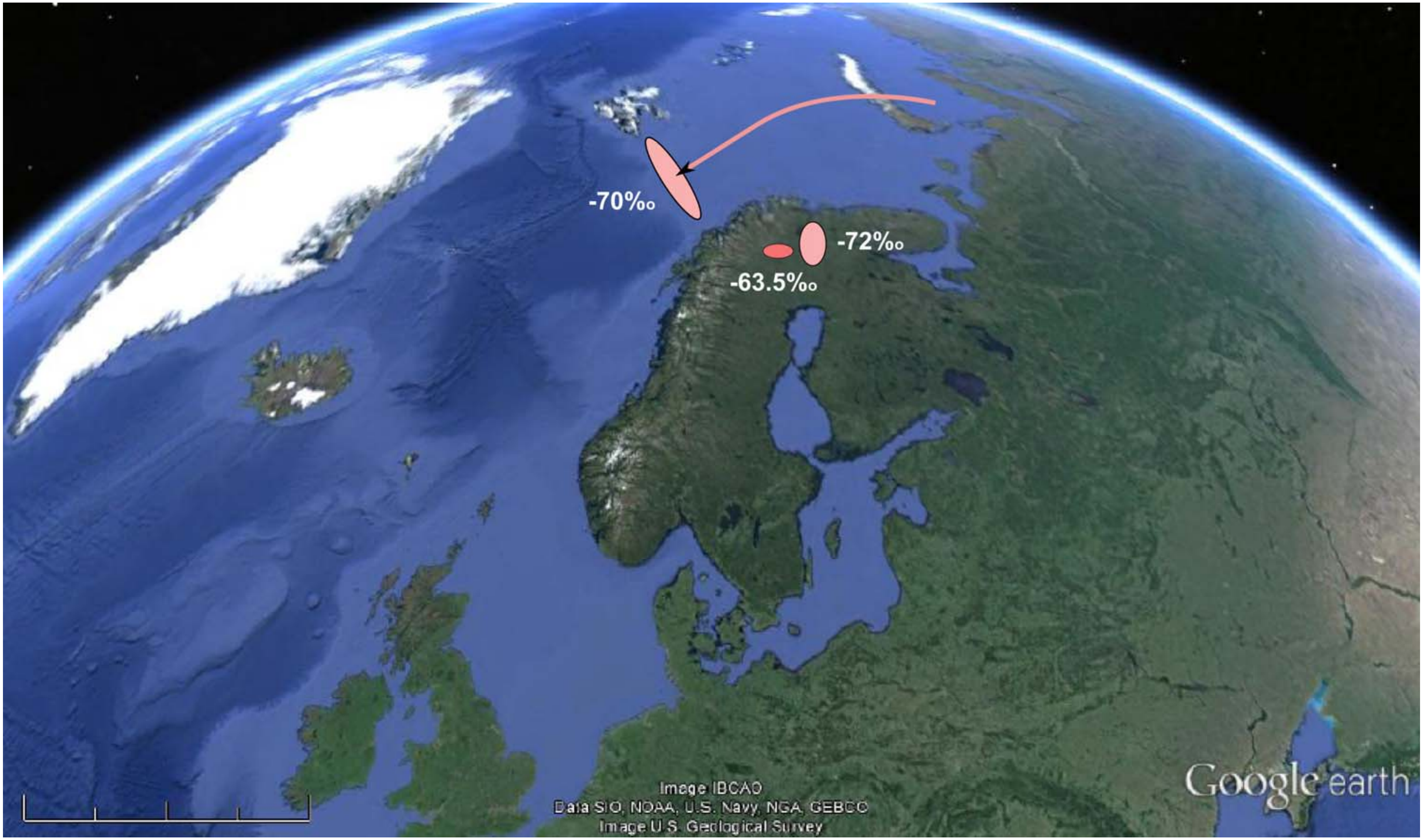


Error boxes represent 1 SD uncertainty in measurements
Plume chasing source of methane
Intercept = -70.1‰ ± 2.1 ‰ (2 SD)

Source Keeling plot - aircraft samples NERC-MAMM

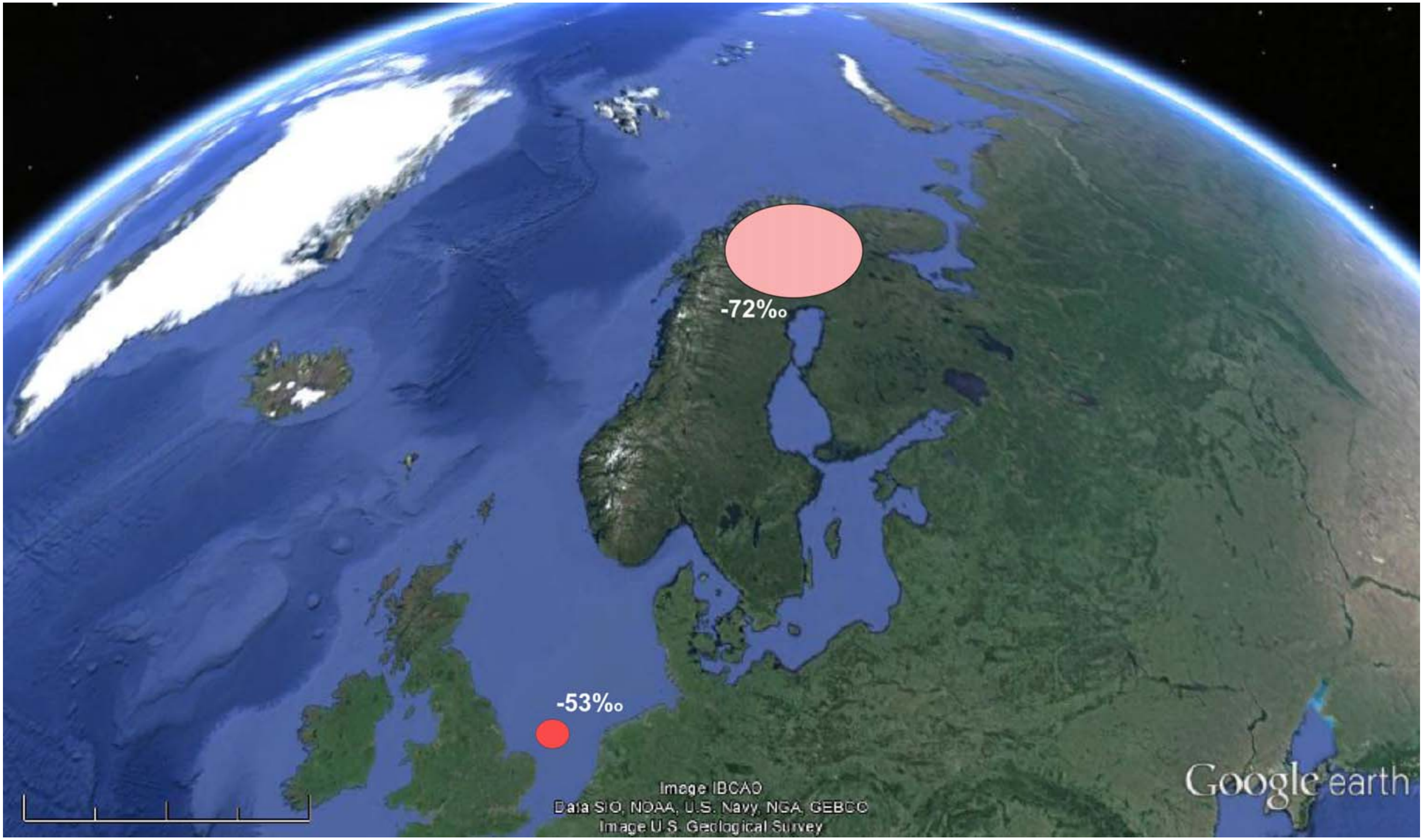
Winter (MEVALI)

James France



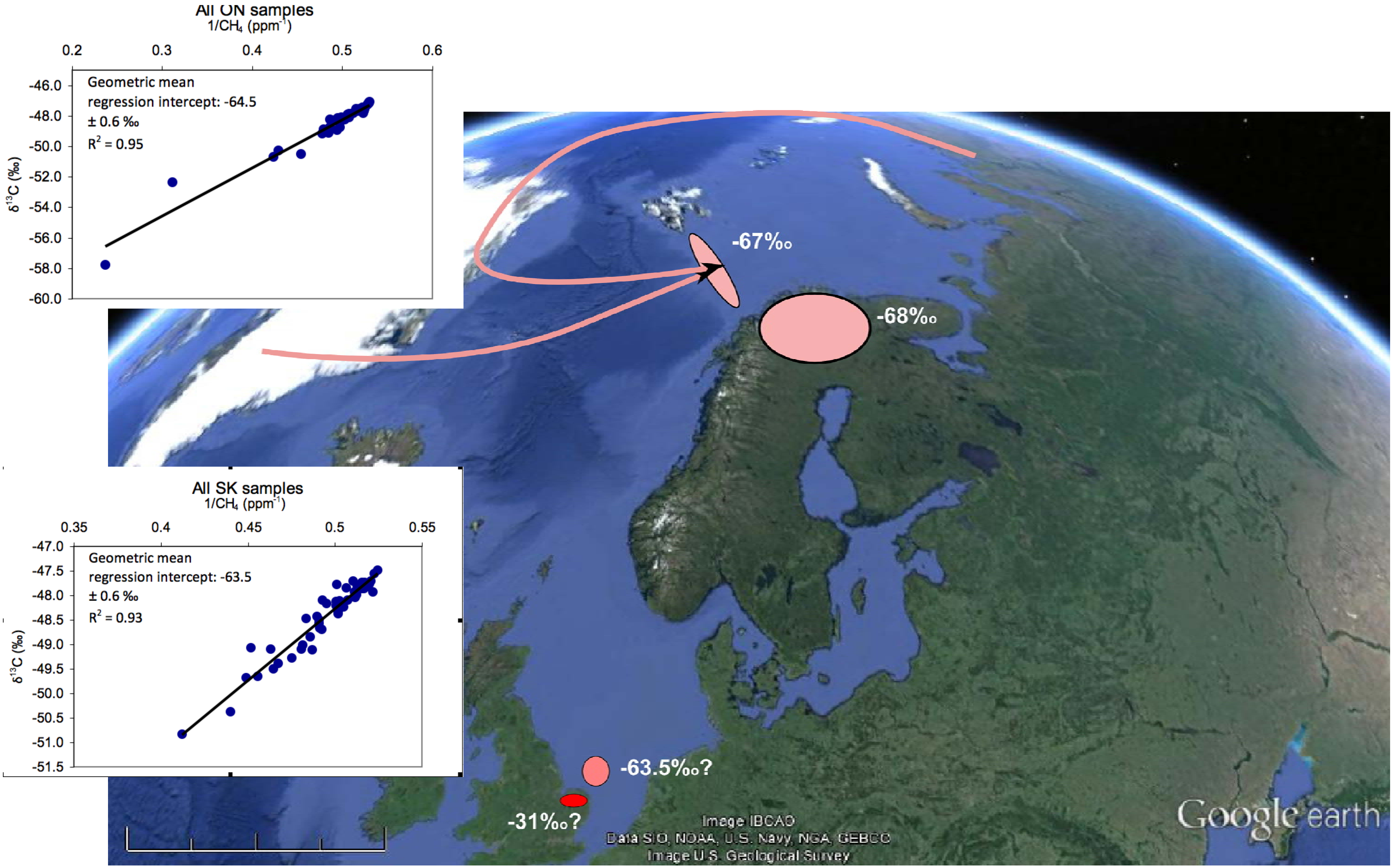
Summer (July 2012)(MAMM)

James France



Summer (August 2013)(MAMM)

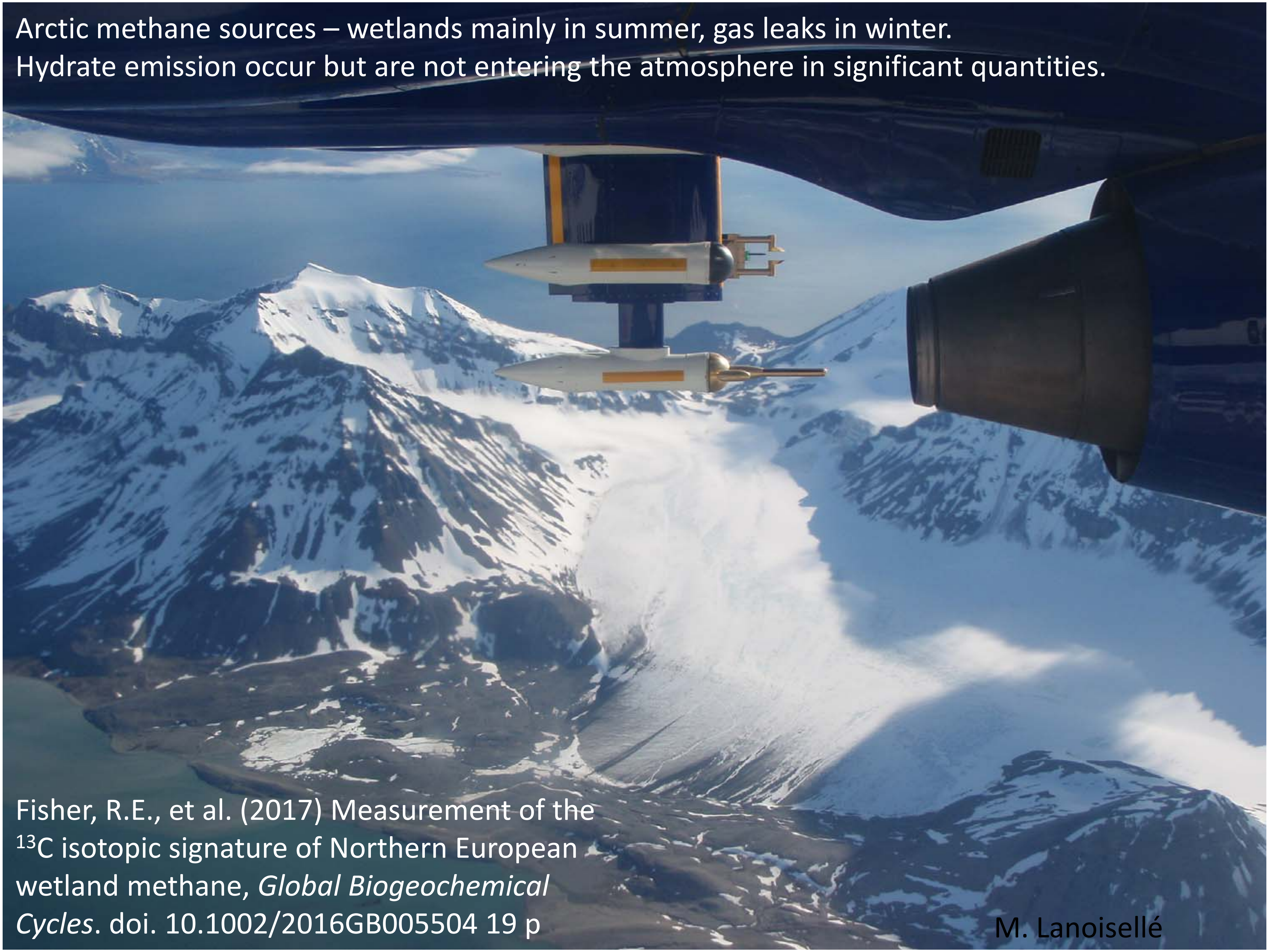
James France



France J.L,et al. (2016) Identifying Sources of Long-Distance Transported Methane to the Arctic using δ13C in CH4 and Particle Dispersion Modelling. *JGR*

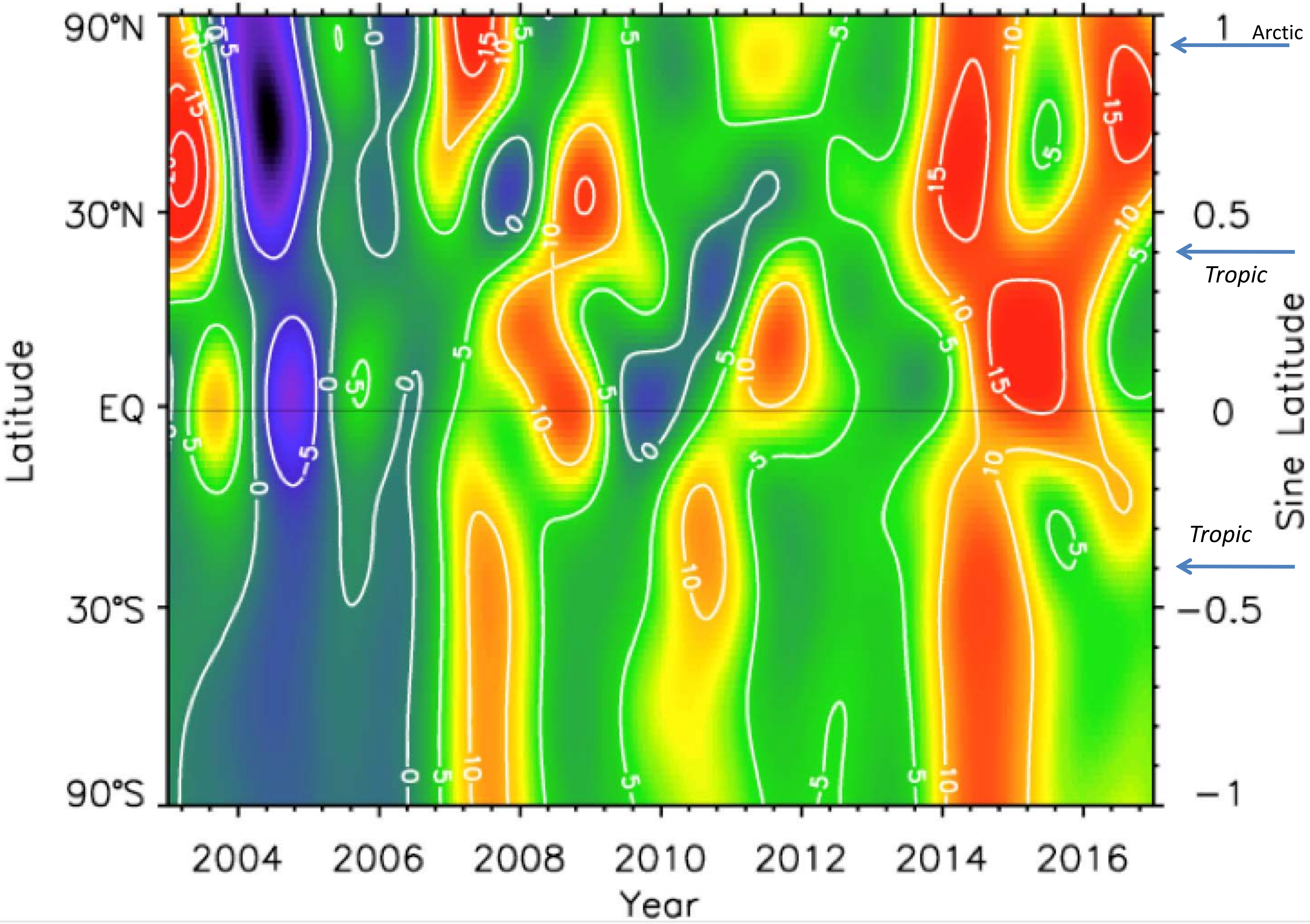
Autumn (Sept 2013)(MAMM)

Arctic methane sources – wetlands mainly in summer, gas leaks in winter. Hydrate emission occur but are not entering the atmosphere in significant quantities.

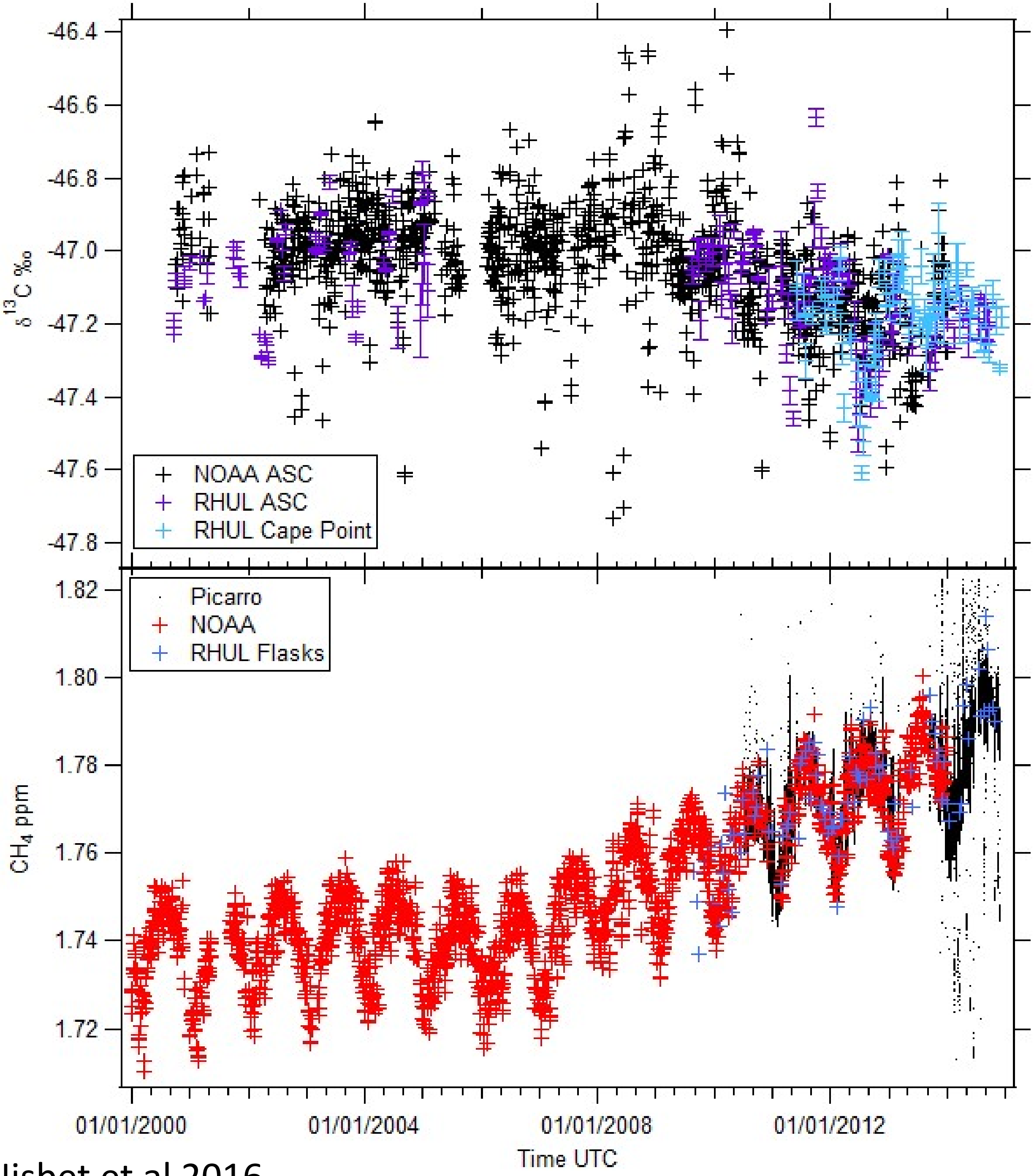


Fisher, R.E., et al. (2017) Measurement of the ^{13}C isotopic signature of Northern European wetland methane, *Global Biogeochemical Cycles*. doi. 10.1002/2016GB005504 19 p

M. Lanoisellé



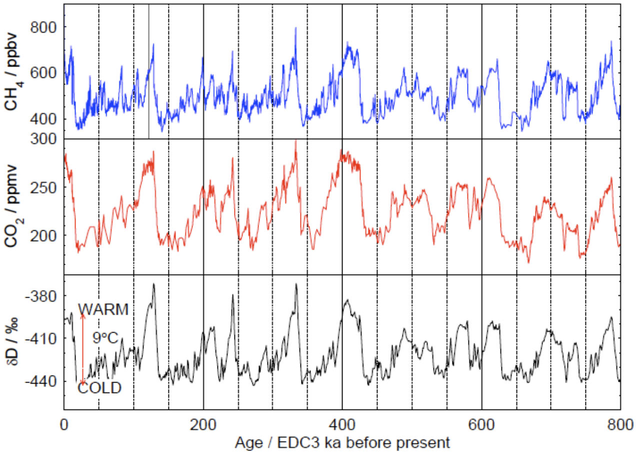
From Ed Dlugokencky, NOAA 2017



Nisbet et al 2016

Ascension Island and Cape Point

Royal Holloway (unpubl.)
and
NOAA-INSTAAR
measurements



Wolff et al

Boening et al. *GRL* 2012

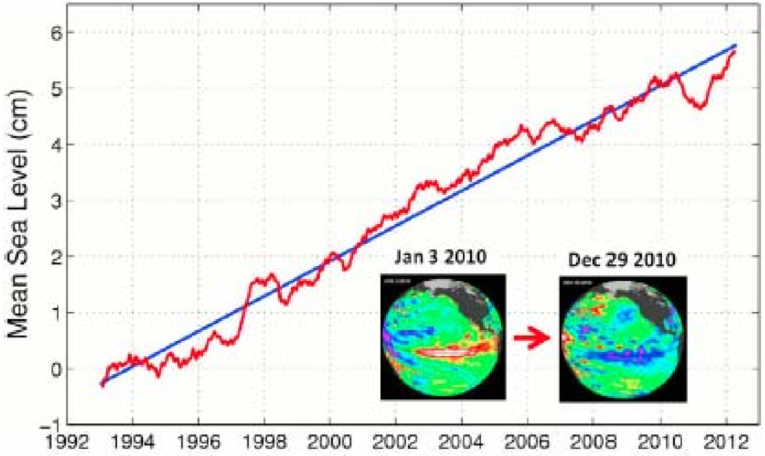
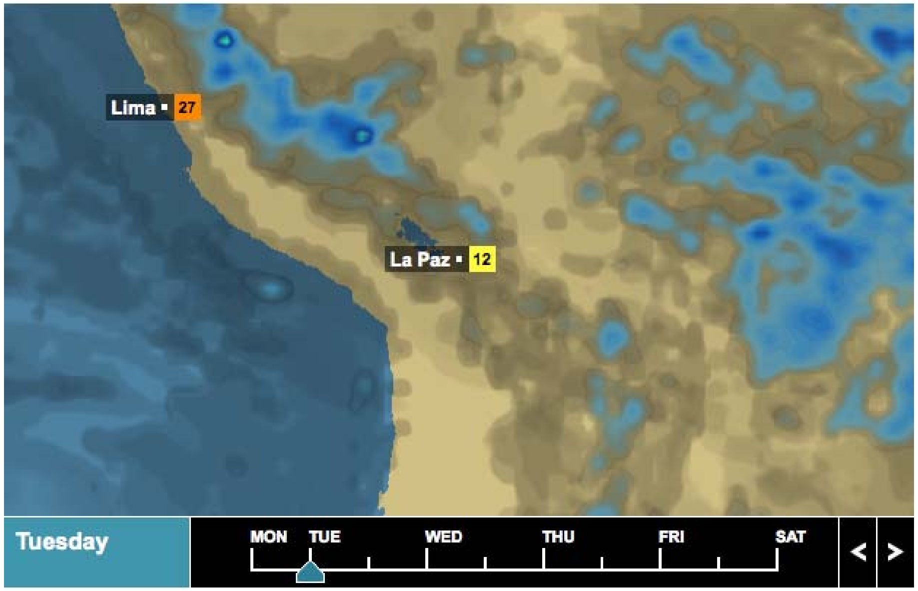


Figure 1. Global mean sea level from altimetry from 1992 to 2012 with annual and semi-annual variations removed

Tropical wetlands 2011-2014

Woe to the land of whirring wings
along the rivers of Cush *Isaiah 18*



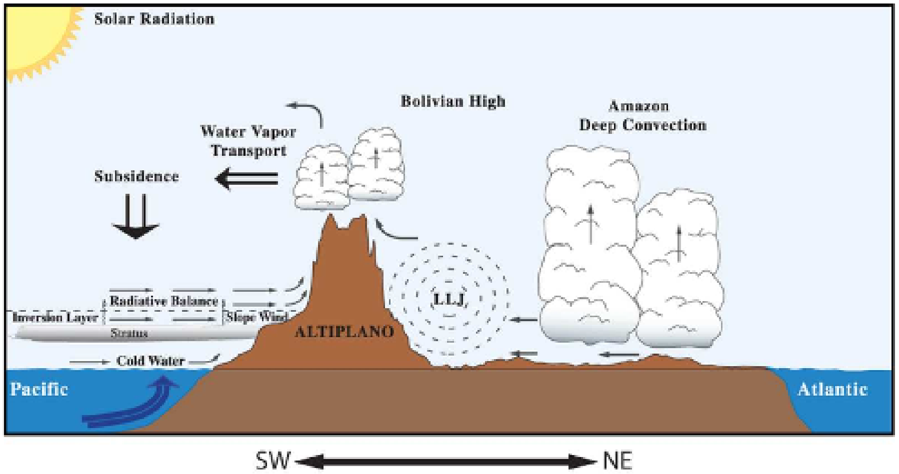
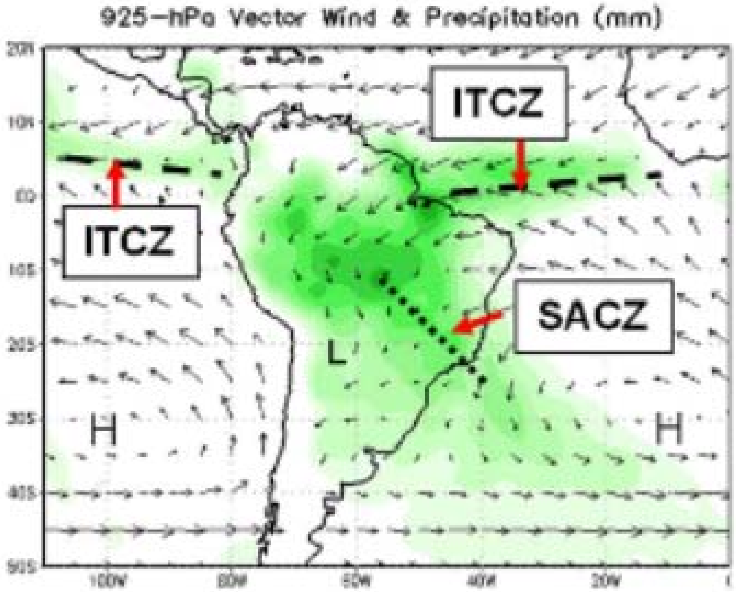
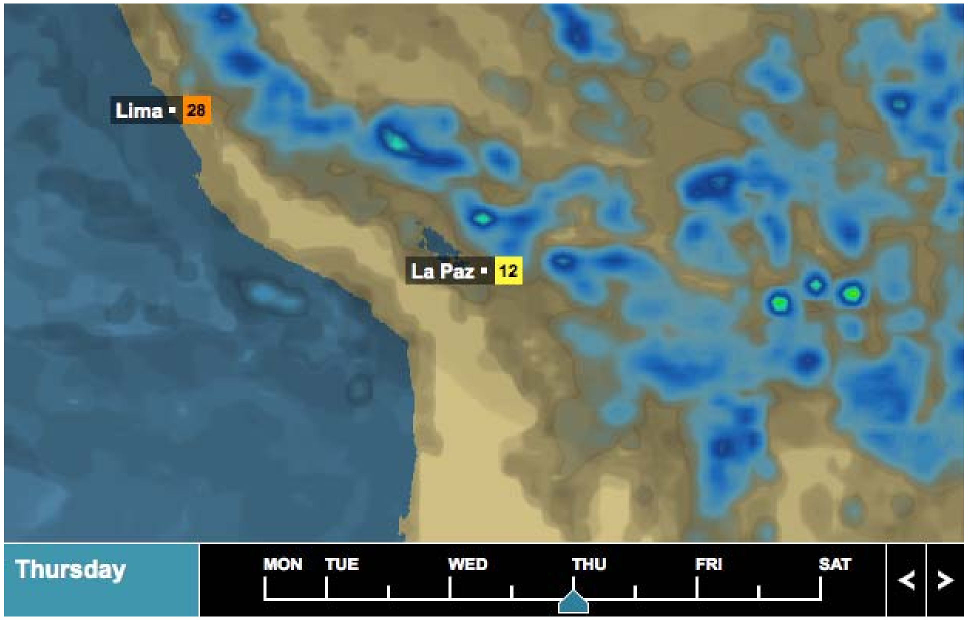


Fig. 4. Section across South America displaying schematically the major large-scale elements related to the South American Monsoon System. Source: Climate Variability & Predictability Program (CLIVAR) (http://www.clivar.com/publications/other_pubs/clivar_transp/pdf_files/av_g3_0106.pdf)

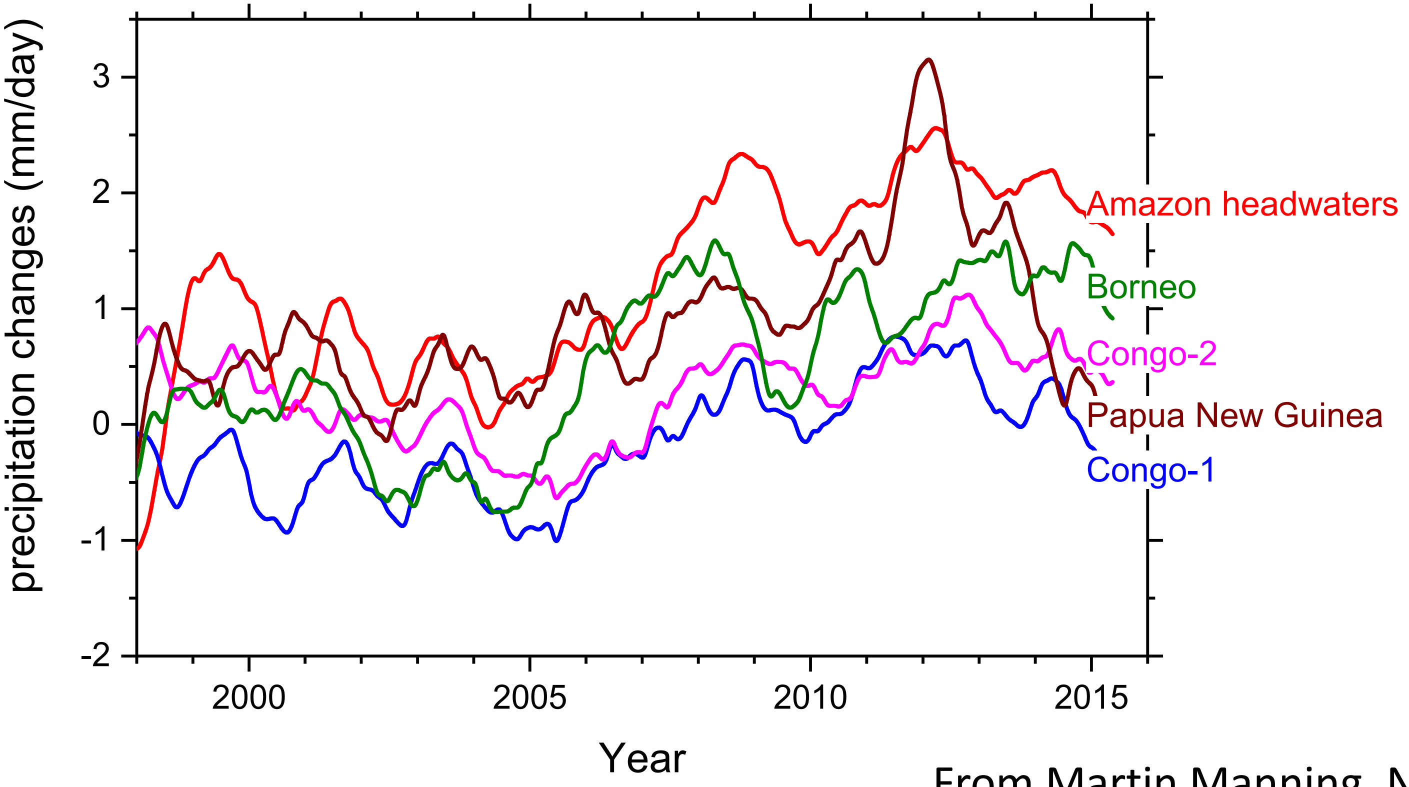




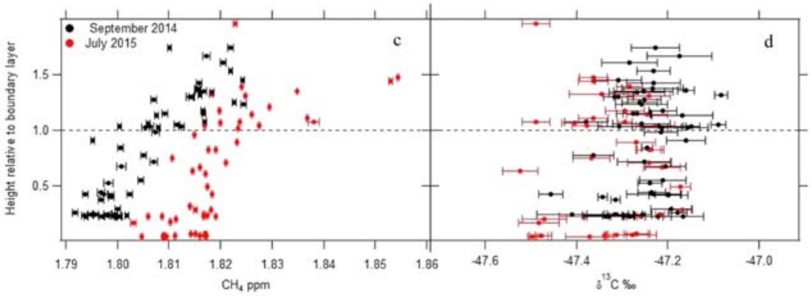
Trends & variability in precipitation

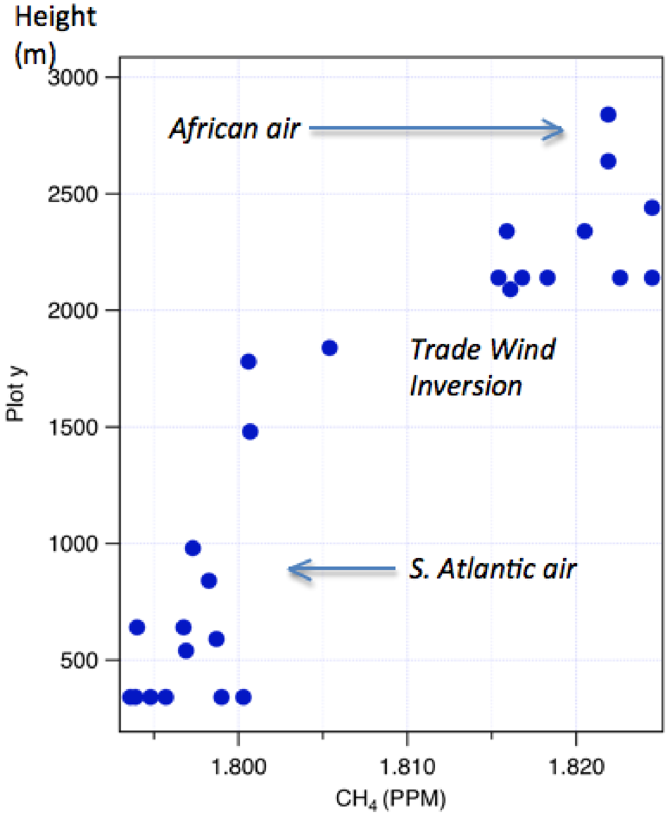
Many studies have linked large scale changes in Hadley and Walker circulation to an intensification of tropical precipitation over 5°S – 5°N. (e.g. Zhou et al, 2011, JGR Vol 116, D09101).

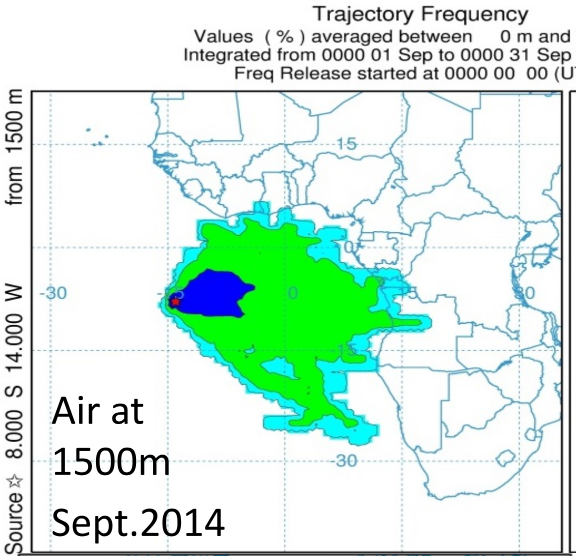
The following shows variations around the 30-year average for NCEP reanalysis precipitation data in five tropical regions associated with wetlands. Widespread changes started around 2005 – 2006. But interannual variations do not match the atmospheric $\delta^{13}CH_4$ anomalies.



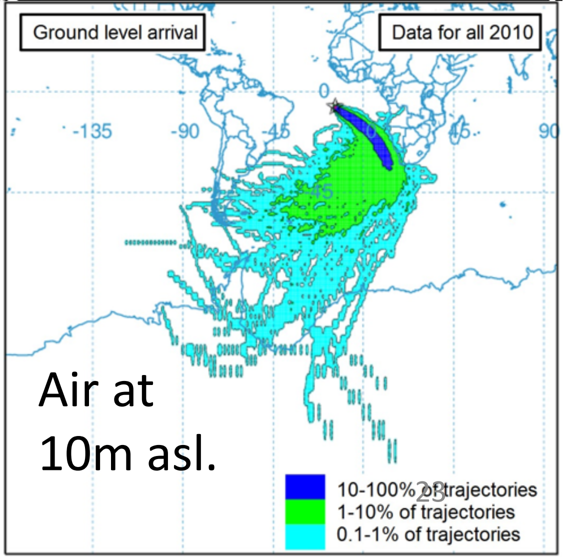
From Martin Manning, NZ







Air at
1500m
Sept.2014



Air at
10m asl.

Ascension as a 3D observatory

Brownlow et al, 2016 GRL

(RHUL group & T. Richardson, C. Greatwood, J. Freer Bristol,
& R. Thomas & R. MacKenzie Birmingham)

Causes of the rise?

Emissions? – isotopically light*, tropical 'leading'*

  Wetlands?

  Agriculture? – cows, rice?

Sinks? – increasing destruction and isotopic shift

  OH in tropical mid-troposhere?

  Cl in trade wind marine boundary layer?

  soil methanotrophy in tropics?

  (Rigby et al. 2017; Turner et al., 2017)

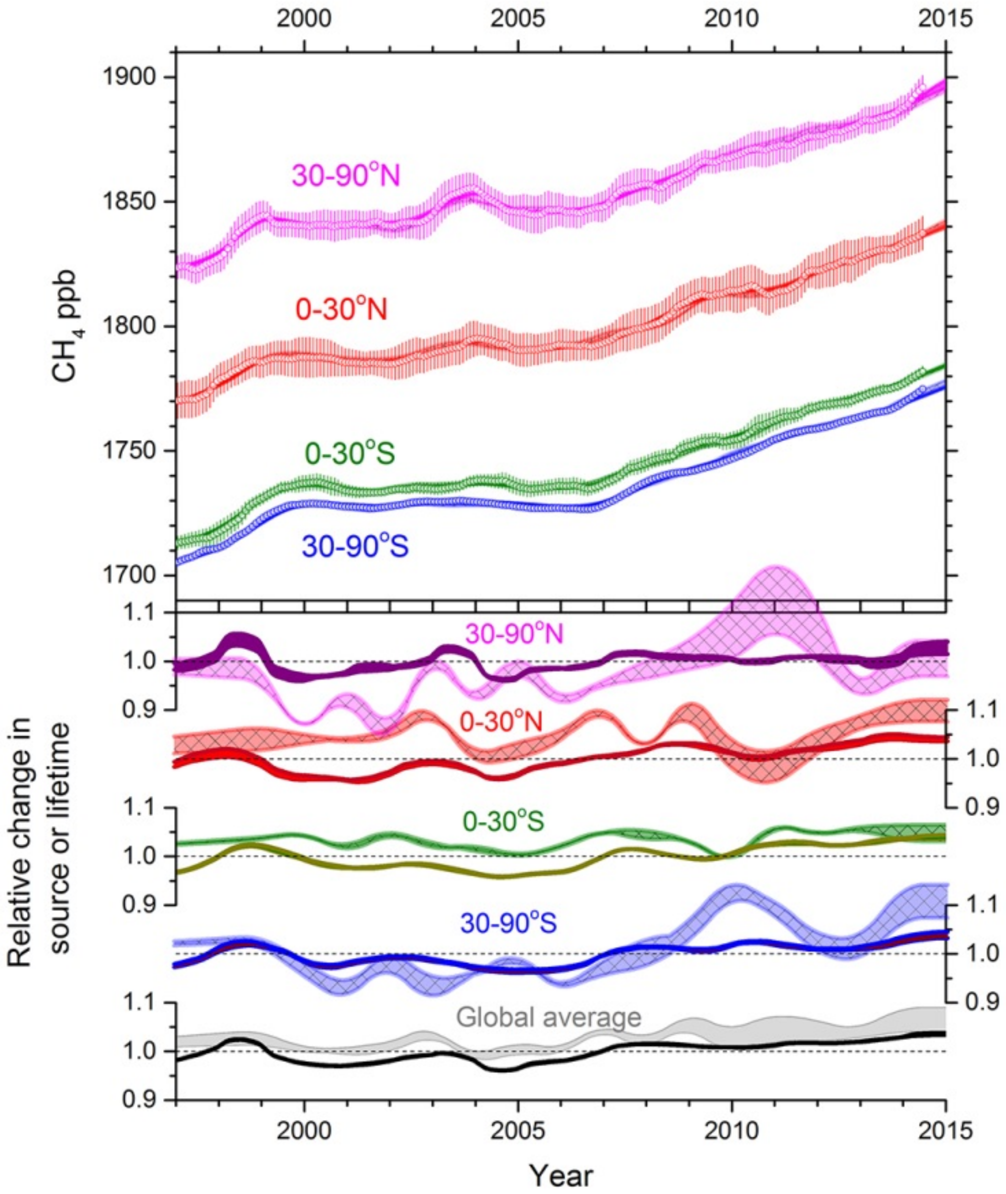
There is currently not enough information to determine the global budget by modelling.

Running Budget Analysis (M.Manning)

1. OH change is not the cause of the rise
Modelling suggests scenarios of reductions in the OH sink are difficult to reconcile with the $\delta^{13}C_{CH4}$record.

2. The negative $\delta^{13}C_{CH4}$ shift implies fossil fuels are a diminishing share of the global methane emissions.
Growth in coal and gas leaks or biomass fires would shift isotopic values to more ^{13}C enriched (*less* negative) ratios. This is contrary to the actual observation of a *more* negative shift.
It is unlikely that the growth in methane is driven by fracking; indeed by closing coal mines, fracking may have reduced emissions. Fracking leaks ~1.5% in Barnett Shale, typically around -46‰ (i.e. around -40‰ in atmosphere after Kinetic Isotope Effect).
Zavala-Araiza, D. et al. (2015) Reconciling divergent estimates of oil and gas methane emissions. *Proc. Natl. Acad. Sci. USA*, **112**, 15598-155602.

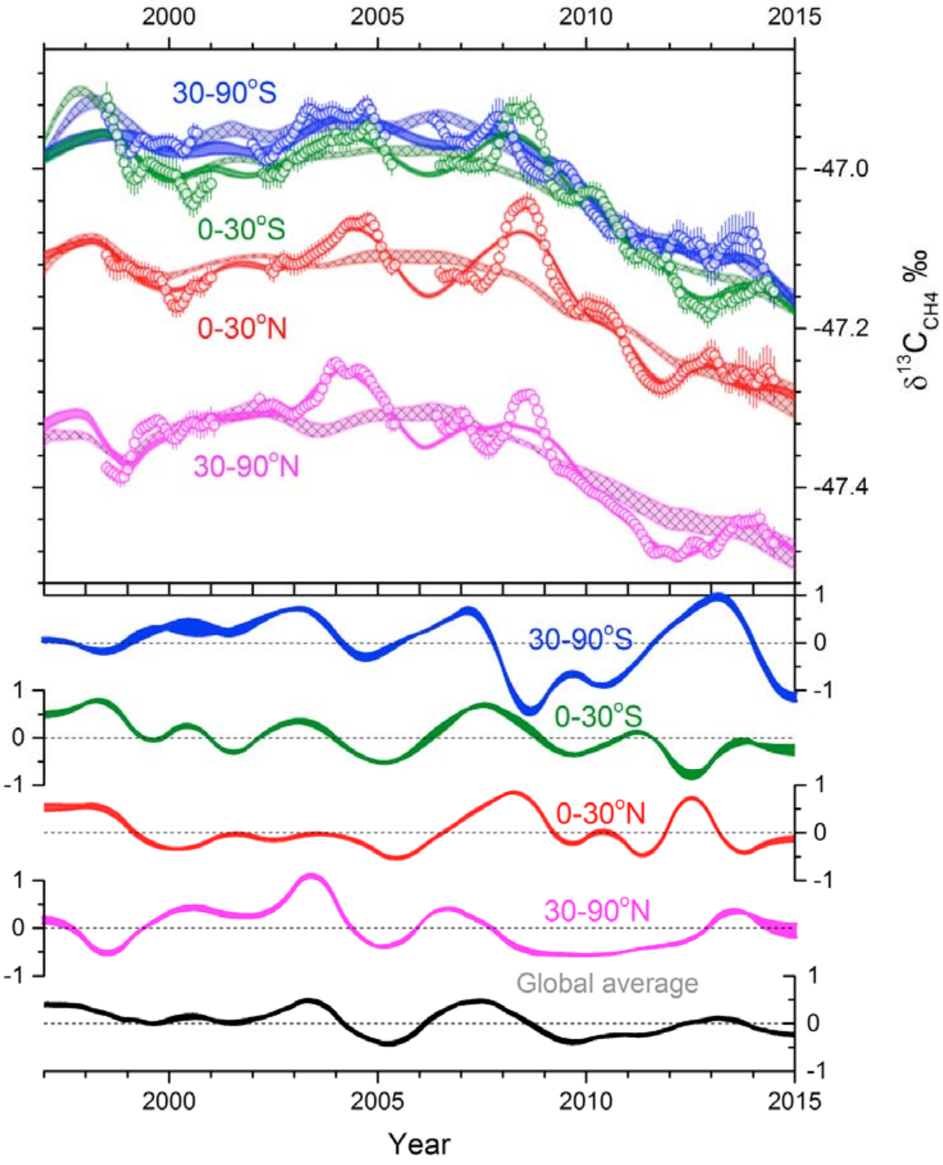
3. The most likely explanation of the negative $\delta^{13}C_{CH4}$ shift is increased emissions from **wetlands** and perhaps also **ruminants** such as cows and water buffalo (a cow is a walking tropical wetland).



Running 12-month means of methane from the NOAA Network averaged over 0-30° and 30-90° bands N and S. Ranges for fits to data shown using changes in either CH_4 sources (darker) or in removal rates (lighter). Both possibilities give good fits to the mole fractions.

Corresponding relative changes in zonal CH_4 sources (darker) or lifetimes, i.e. the inverse of removal rates, (lighter and crosshatched) for each region and for the global average.

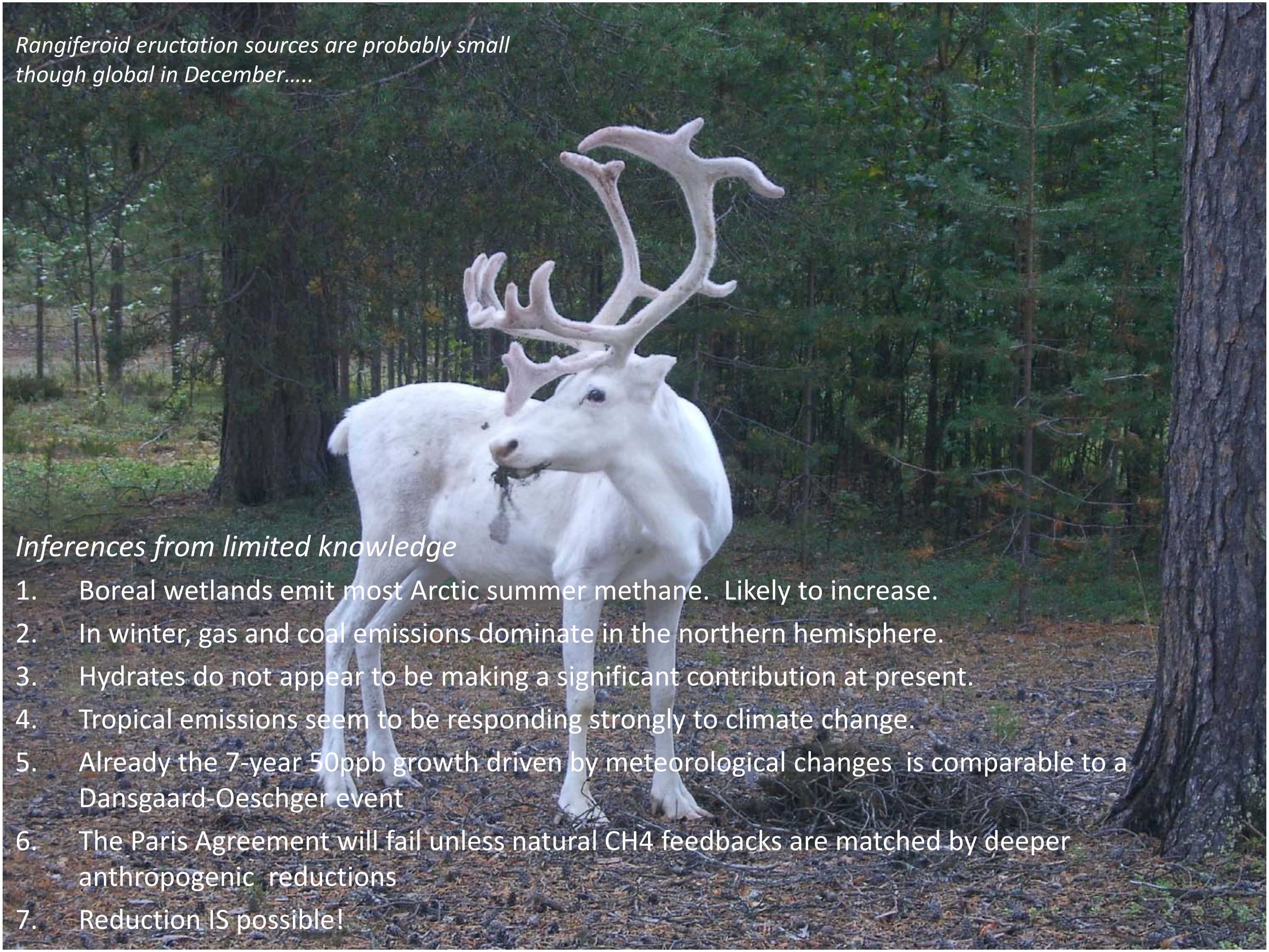
TRENDS Running Budget Analysis (M. Manning in Nisbet et al. 2016),



Running 12-month means for $\delta^{13}C_{CH4}$ values from the NOAA and RHUL sites adjusted to represent averages over four latitude zones.
Results for changes in sources (darker) or removal rates (lighter and cross-hatched)

Corresponding variations in source $\delta^{13}C$ values for the four regions and for the global average source $\delta^{13}C$.

Running Budget Analysis
(M. Manning in Nisbet et al 2016)



Rangiferoid eructation sources are probably small though global in December…..

Inferences from limited knowledge

1. Boreal wetlands emit most Arctic summer methane. Likely to increase.
2. In winter, gas and coal emissions dominate in the northern hemisphere.
3. Hydrates do not appear to be making a significant contribution at present.
4. Tropical emissions seem to be responding strongly to climate change.
5. Already the 7-year 50ppb growth driven by meteorological changes is comparable to a Dansgaard-Oeschger event
6. The Paris Agreement will fail unless natural CH4 feedbacks are matched by deeper anthropogenic reductions
7. Reduction IS possible!

Isotopic signatures of sources

- Different methane sources have different $\delta^{13}C$ source signatures
- Ratio of isotopes depends on temperature, C3:C4, etc.
- Tropical methane sources include wetlands, biomass burning (including C4 grasslands) and ruminants
- Operational Picarro ~ ±1‰
- Bag + GC-CF-IRMS ~ ±0.05‰

Source	**$\delta^{13}C_{CH4}$ ‰**
Biomass burning tropical C4 vegetation	-17 ±3
Biomass burning C3 vegetation	-26 ±3
Gas North sea Gas Russia	-34 ±3 -50 ±5
Coal and industry	-35 ±3
Ruminants C4 diet	-49 ±4
Ruminants C3 diet	-70 ±4
Wetlands: Tropical swamps Boreal forest wetlands	 -55 ±3 -65±5
Wetlands: bogs & tundra	-67 ±5
Rice Agriculture	-62 ±3
Landfills	-53 ±2