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NATURAL ENVIRONMENT RESEARCH COUNCIL

FAAM
Facility for Airborne Atmospheric Measurements

# Interpreting Aircraft Observations of Greenhouse Gases

## GHG Summer School 2016 – Southampton

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# This class: Intro & Learning outcomes

- What can (and can't) aircraft data do for GHG science?
- An introduction to the FAAM aircraft and its measurement suite
- Case study examples of FAAM use for measurement-led investigations
- How to analyse and interpret aircraft data

- IDL computer exercise:
  - An intro to real FAAM data
  - Interpretation methods and tools

# Aircraft vs other sampling platforms

| Method | Pros | Cons |
|---|---|---|
| Ground-based in situ | Precision measurement<br>Dense sampling/representivity of the immediate environment | Only represents a point in space and time (relies on air coming to the instrument) |
| Aircraft in situ | Wide coverage (100s km)<br>Precision measurement<br>Mapping<br>Planned sampling | Inability to sample whole areas simultaneously<br>Difficult to plan in a "dynamic" environment |
| Ground remote sensing | Wide spatial coverage (~km) | Less precise<br>Needs knowledge of dynamics |
| Satellite remote sensing (aka Earth Observation) | Global Coverage and mapping<br>Continuous datasets | Long (poor) repeatability<br>Poor precision<br>Poor spatial resolution (100s m – 10km) |
| Regional Models | Able to model processes at scales of human interaction | Unable to scale up to global, long-term impacts |
| Global Models | Able to extrapolate to the far future | Lacks detailed process and scale interactions |

# What science can aircraft facilitate?

## Uses the atmosphere as a natural laboratory for:

- Atmospheric chemistry and air quality
- Source apportionment and fluxes (inc. GHGs)
- Airmass characterisation and transport
- Cloud microphysics
- Radiative transfer processes and energy budgets
- Numerical Weather Prediction
- Land-air-sea interactions
- Coupled processes (e.g. aerosol-cloud interactions)
- Spatial scalability and scale-coupled processes (e.g. gravity waves, cloud evolution, plume chemistry)

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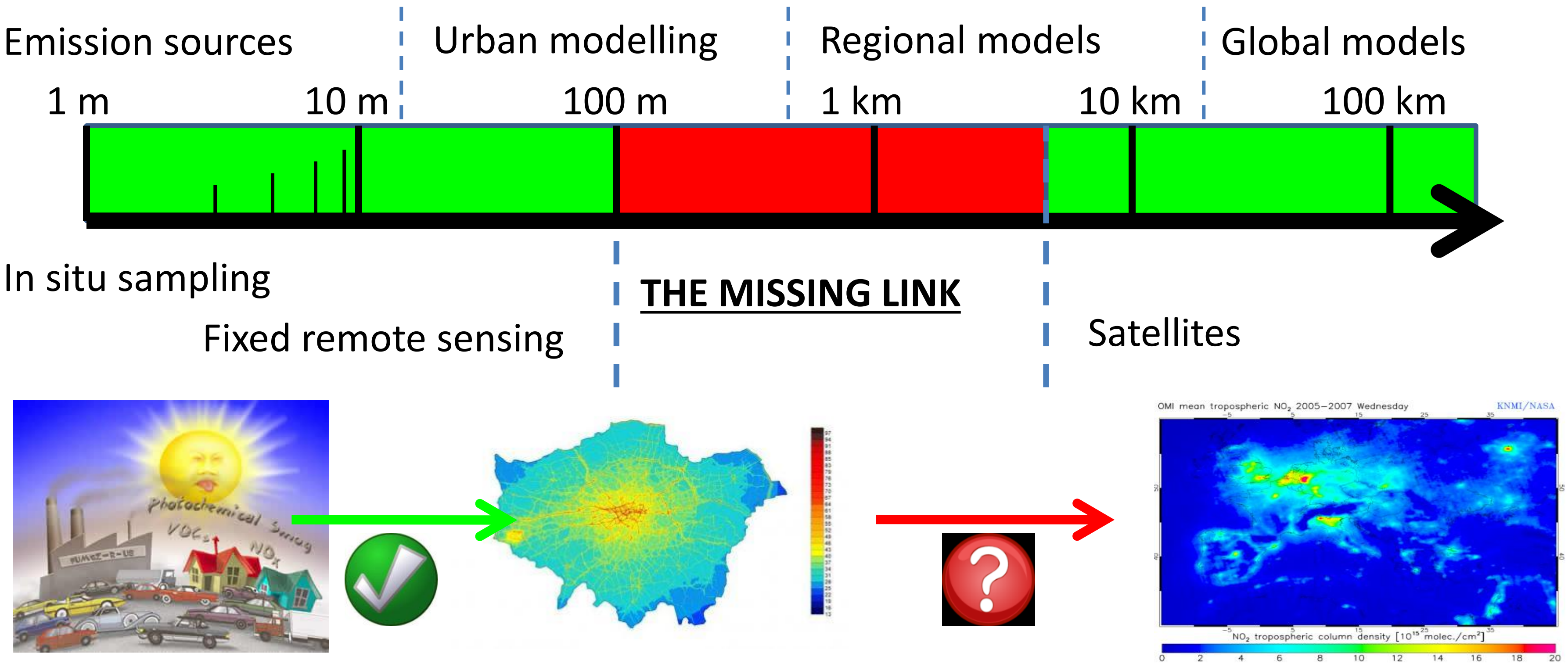
# What science can aircraft facilitate?

- Aircraft are a very useful bridging tool that link datasets at various scales as well as providing tailored datasets that are useful in isolation.

- Careful flight planning is required to make the most of the sampling. This requires:
  - A prior hypothesis to be tested
  - A flight design that tests the hypothesis, constrained by practicalities such as weather on the day, flight area restrictions etc
  - Flexibility for decision-making in the air based on realtime observations

- Careful post-flight analysis is needed to make sense of the data. Aircraft data analysis is unique in that it is multi-dimensional and not uniformly gridded in space and time. As such, it often demands a forensic approach, where the data are the clues that lead the investigation – there is no set formula for aircraft data analysis and every flight is different.

# Quantifying Emissions: The problem of scales




- **The Problem:** Processes/modelling/understanding at small (e.g. urban) scales not easily extrapolated to large (global) scales

- **A solution**: Airborne in situ and aircraft remote sensing at local-to-regional scales: to test models with measurements that link these scales, e.g. Karion et al., Mays et al.

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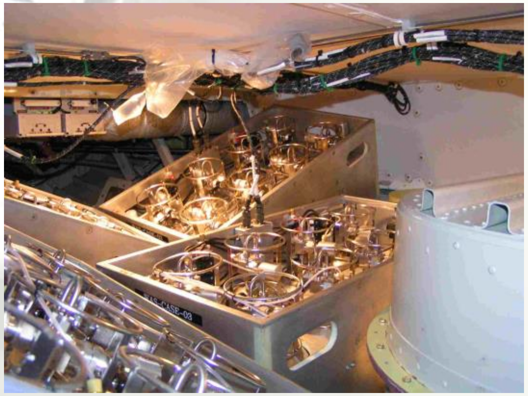
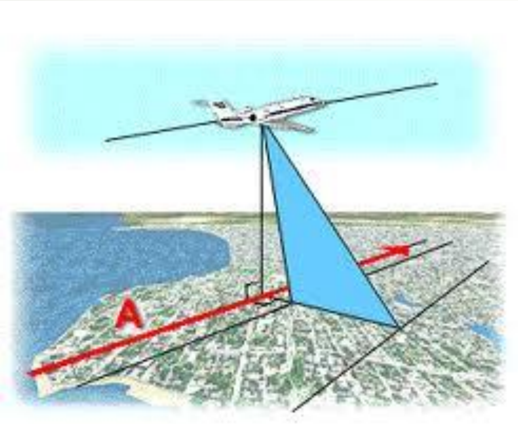
# The FAAM Aircraft


# FAAM Measurement suite

- In situ (1-32 Hz)
  - $CH_4$, $CO_2$, $N_2O$
    (Aerodyne QCL, LGR FGGA)
  - CO, $O_3$, $NO_x$,
  - Dropsondes (T, p, q, winds)
  - GPS, aircraft configuration
  - Chemical Ionization MS (HNO3, HCN, HCOOH)
  - Aerosol size, number, chemical functionality
- Whole Air Sample (WAS) system
  - 64 x 3 litre silico-steel canisters
  - GCxGC: $C_6$-$C_{13}$ NMHC, oxygenated VOCs
  - Continuous flow GC - Trace gases and $CH_4$ $\delta^{13}C$
- Remote sensing
  - Nadir open-path FTIR (ARIES)
  - Vertical profiles of $CH_4$, $N_2O$, $O_3$ etc
  - Cloud/Aerosol lidar



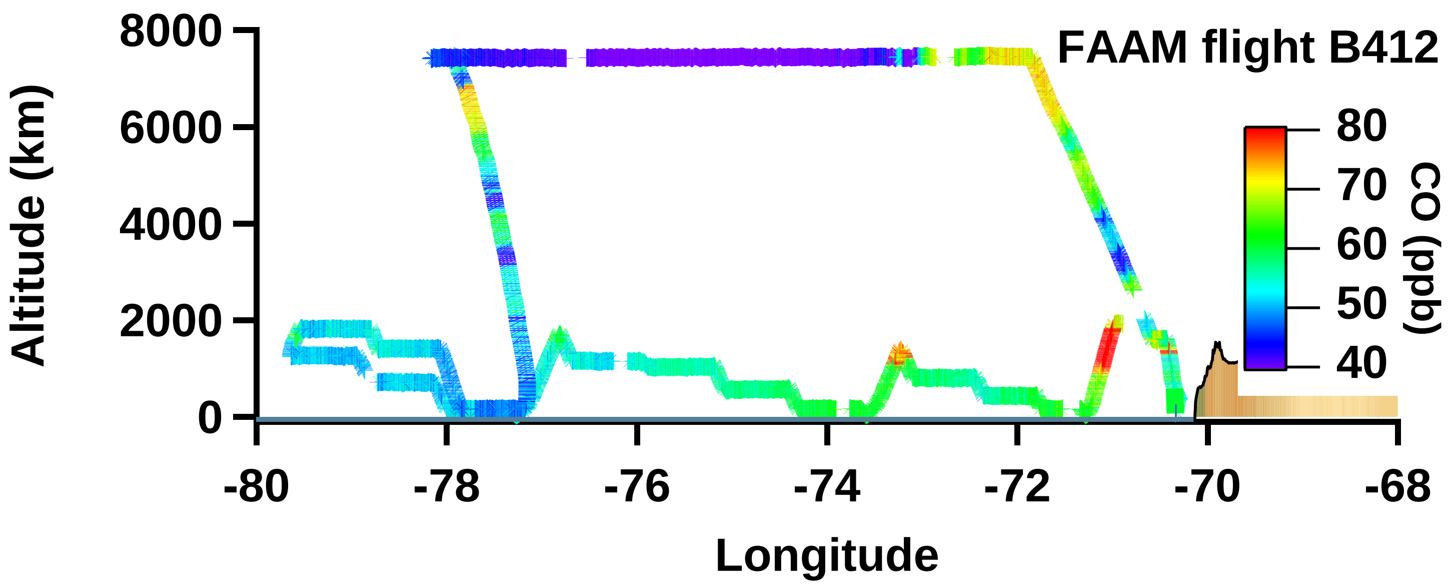


# Aircraft analysis: An example from VOCALS

Two meteorological periods:

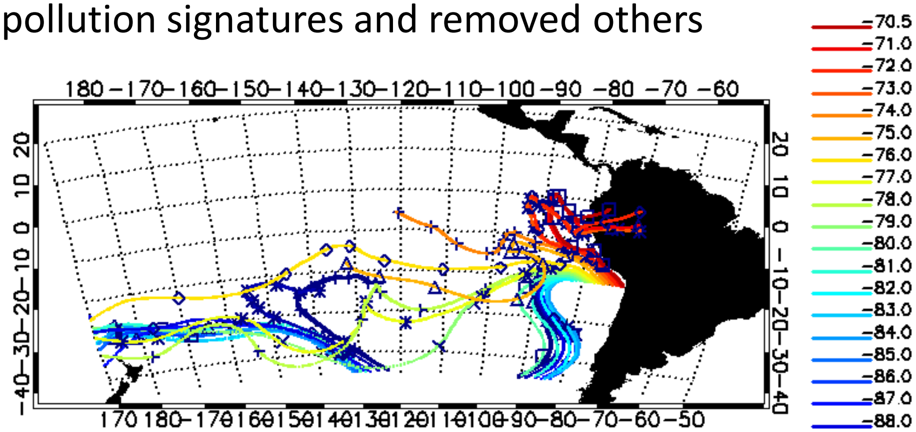
- Period 1: 15th-31st Oct → Surface anti-cyclone, unstable STJ, Variable FT airmass history
- Period 2: 3rd-12th Nov → UT anti-cyclone, steady STJ, consistent FT history.

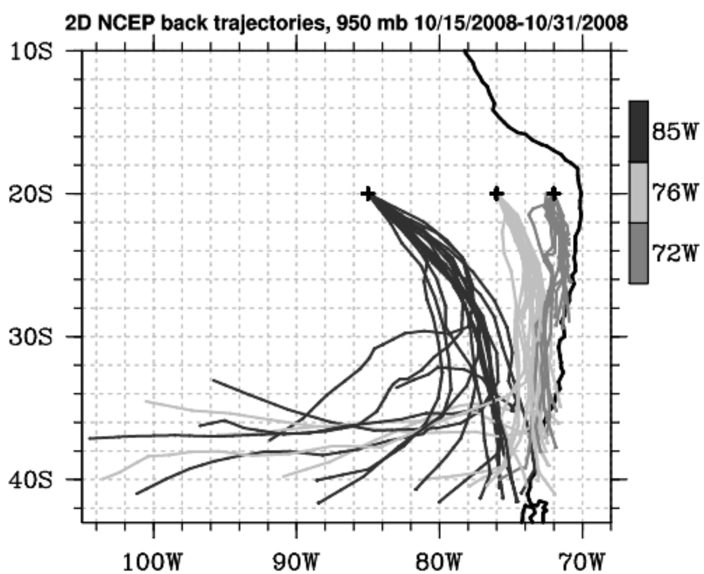
- Frequent pollution layers in the FT were observed (especially near the coast) in Period 1 (below)



## Period 1 – Free troposphere

- FT has a gradient in source origin
Continental PBL sources near the coast
- Descended long-range remote sources west of 75 W.
- Uplift to UT may have frozen in some pollution signatures and removed others

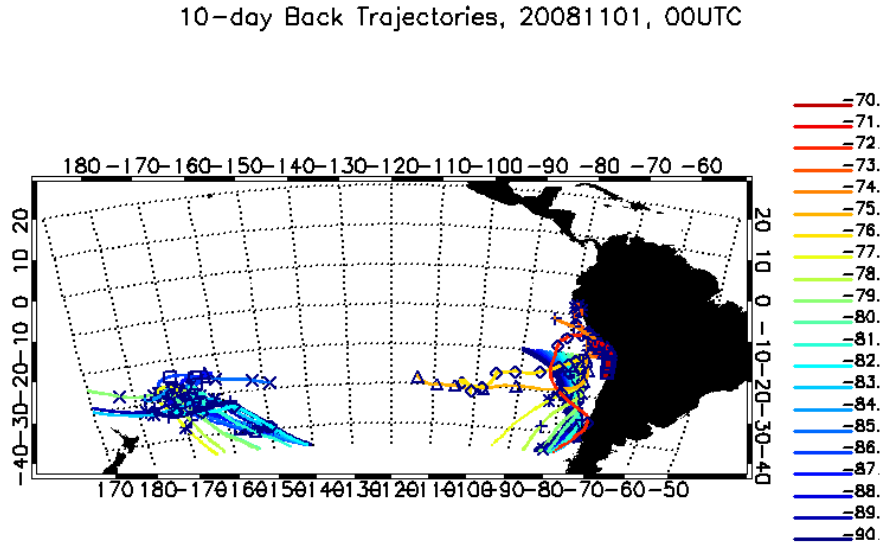


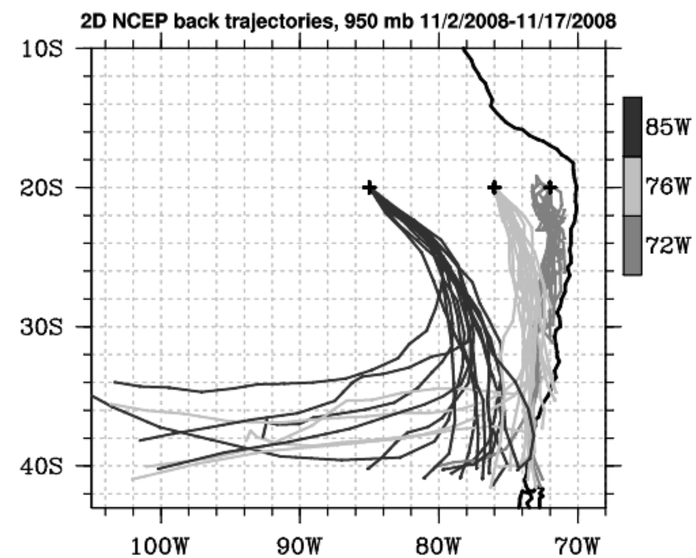




## Period 2

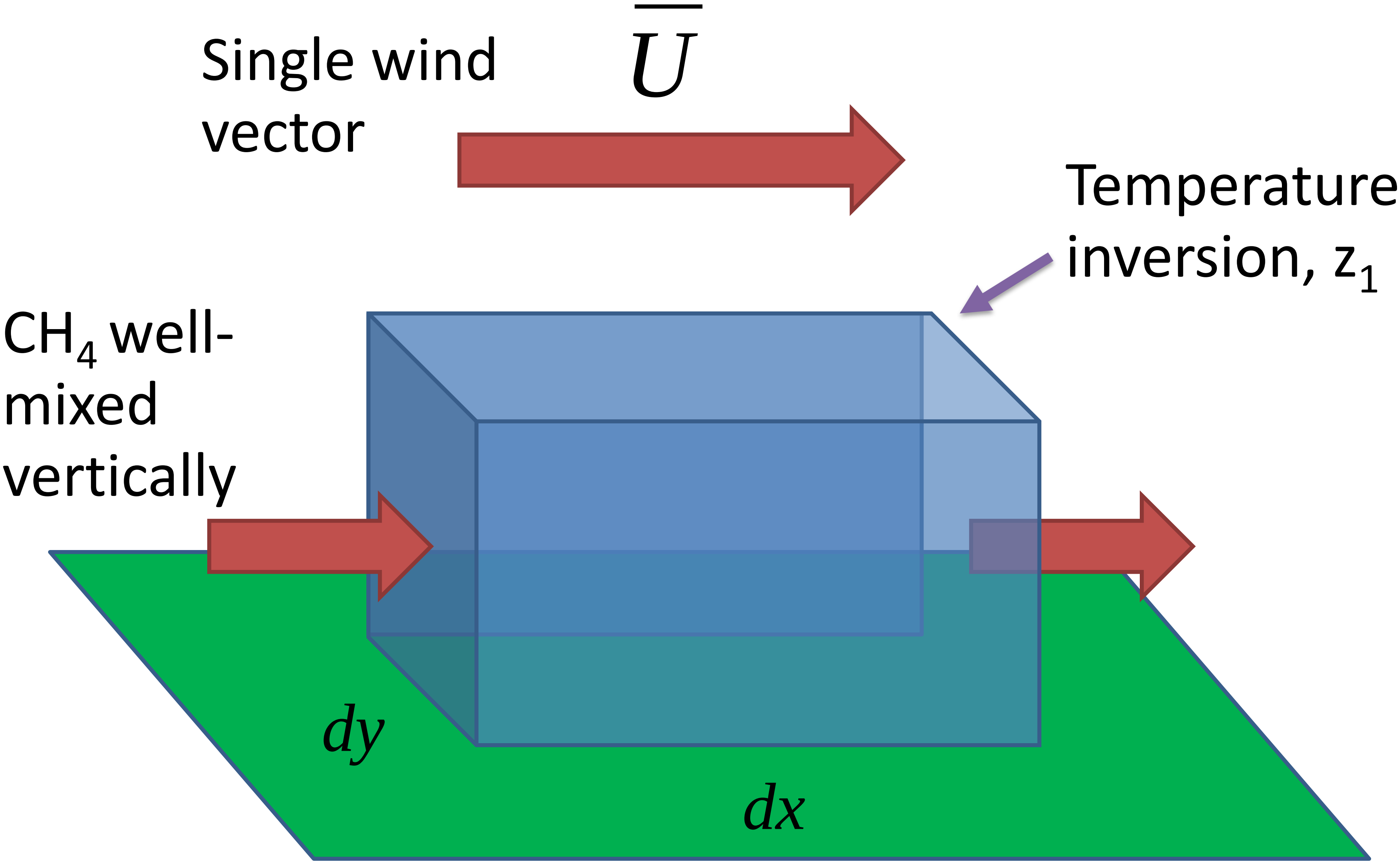
Much more consistent marine MBL origins for all FT air along 20 S

All but the trajectories very near to shore have a remote origin.

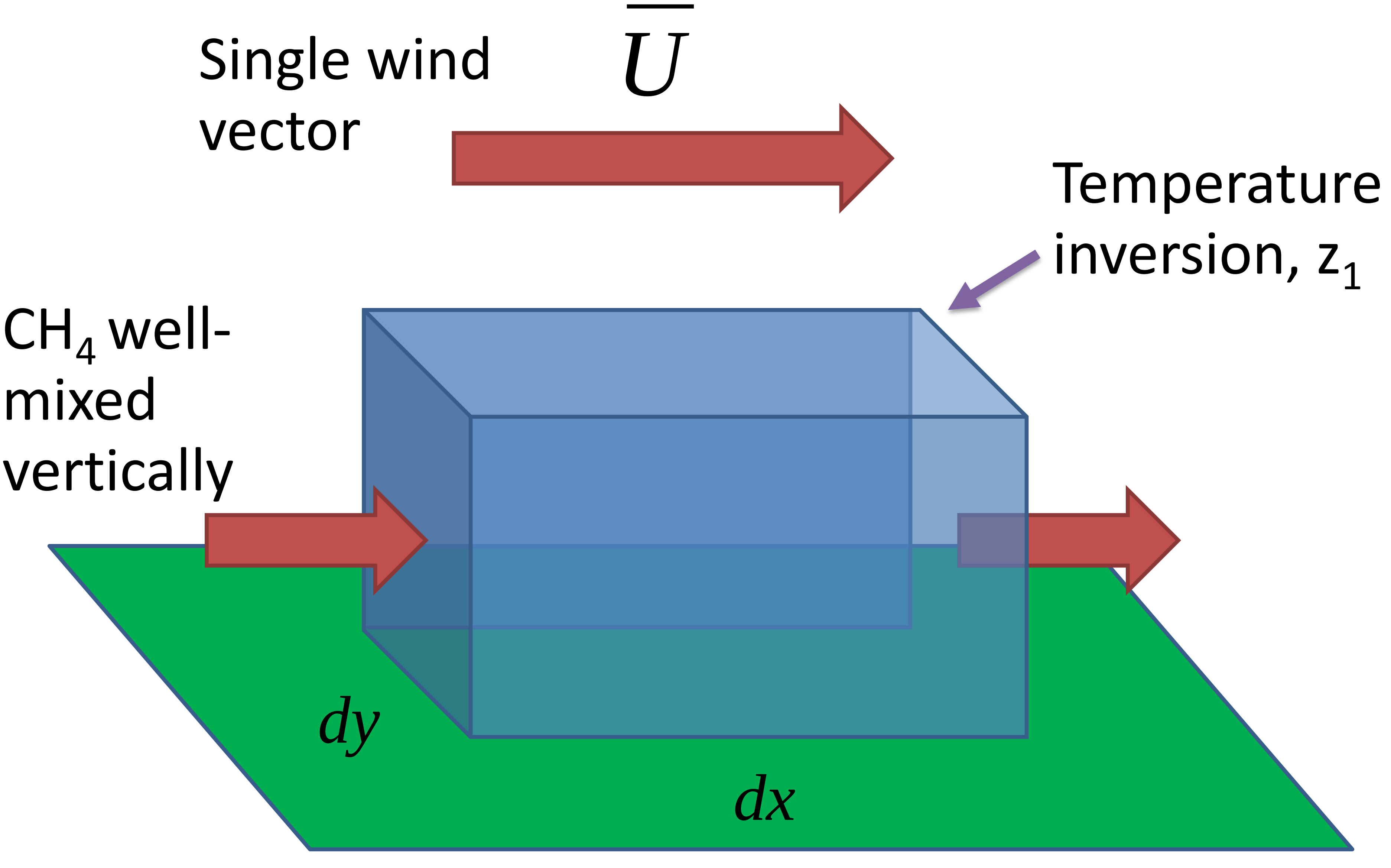


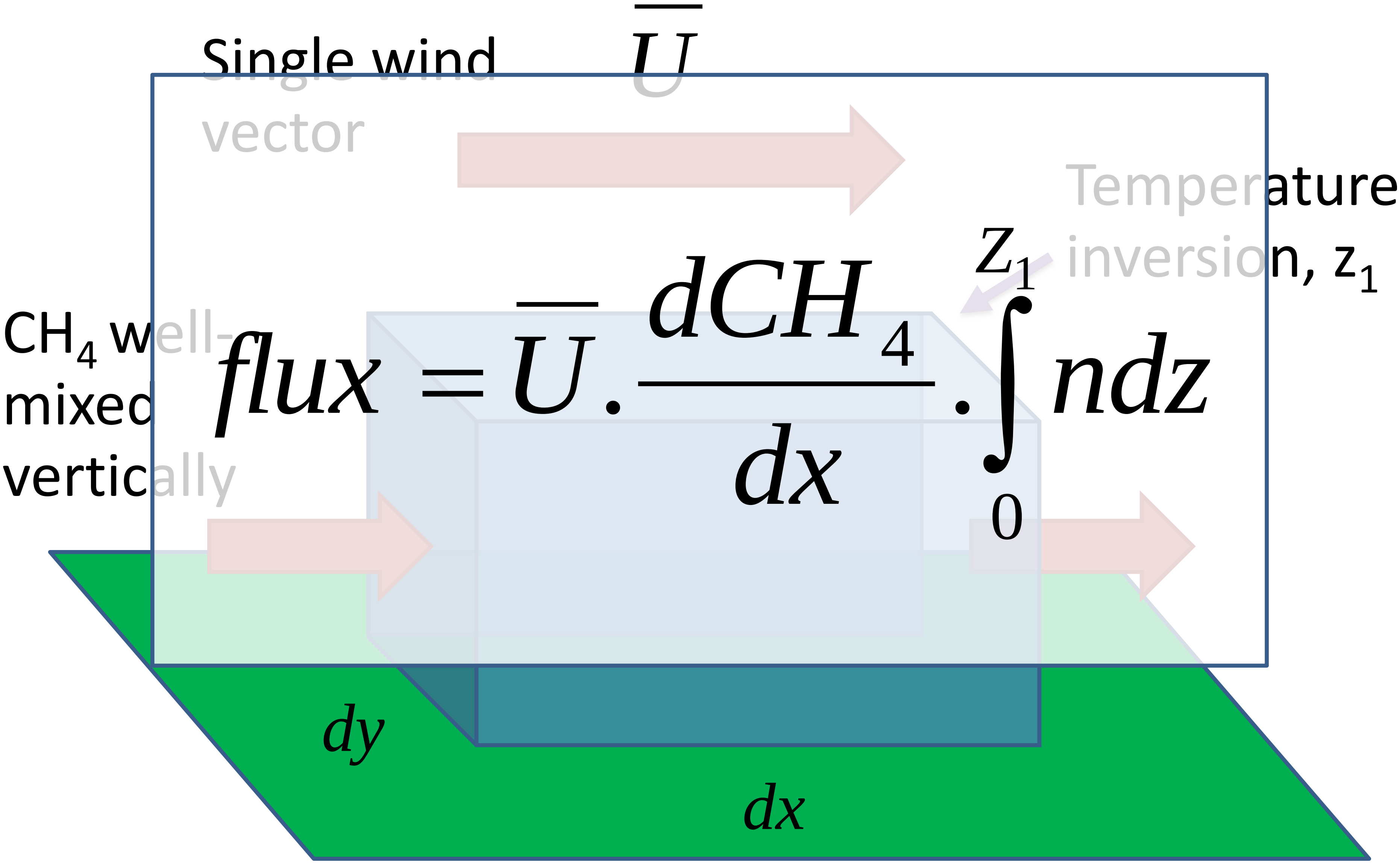
# Boundary layer mass balance



*Surface flux = outflow – inflow*

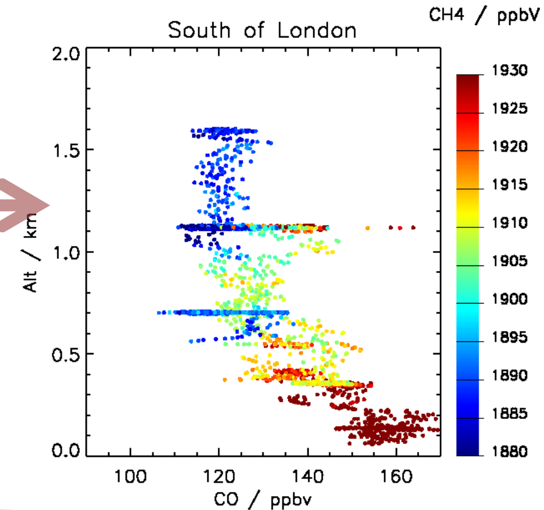


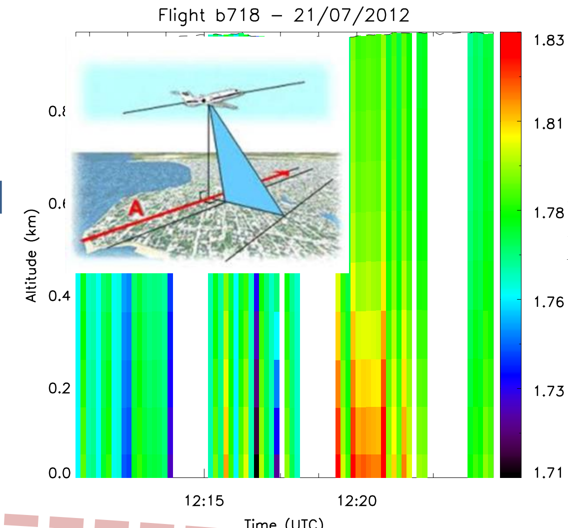
# *Surface flux = outflow – inflow*

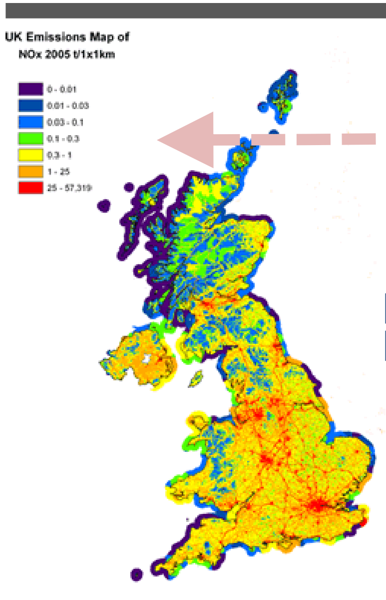



$$flux = \overline{U} . \frac{dCH_4}{dx} . \int_0^{z_1} n\,dz$$

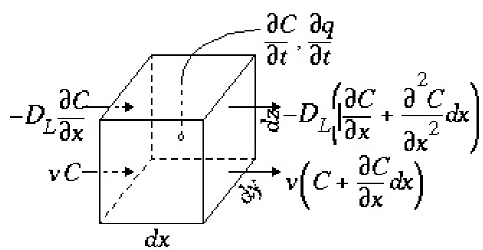
# Mass Balancing Flux Strategy

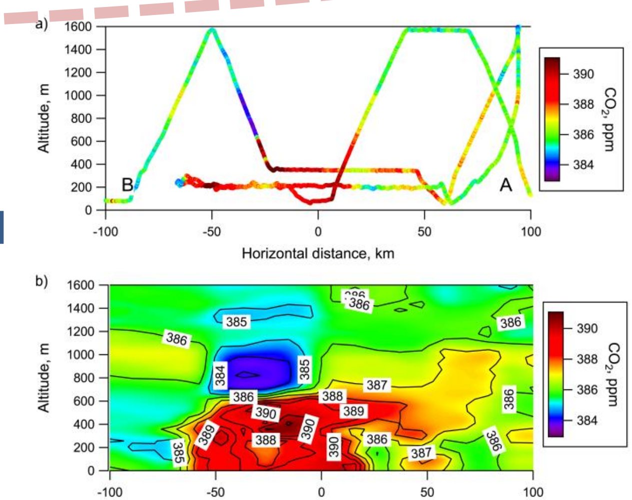




$$Flux = \int_0^z \int_A^B (S_{ij} - S_0).n_{ij}.U_{\perp ij}.dx.dz$$



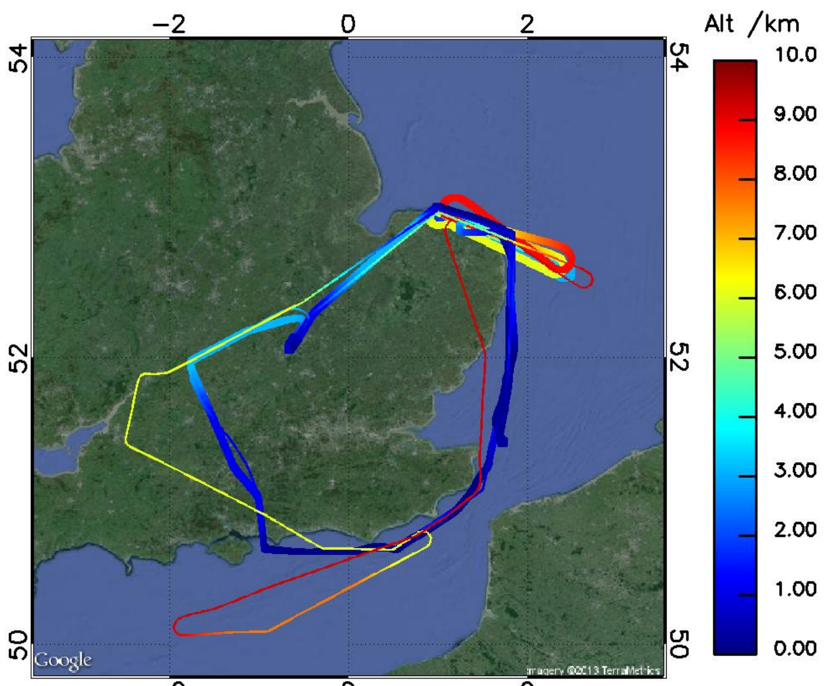



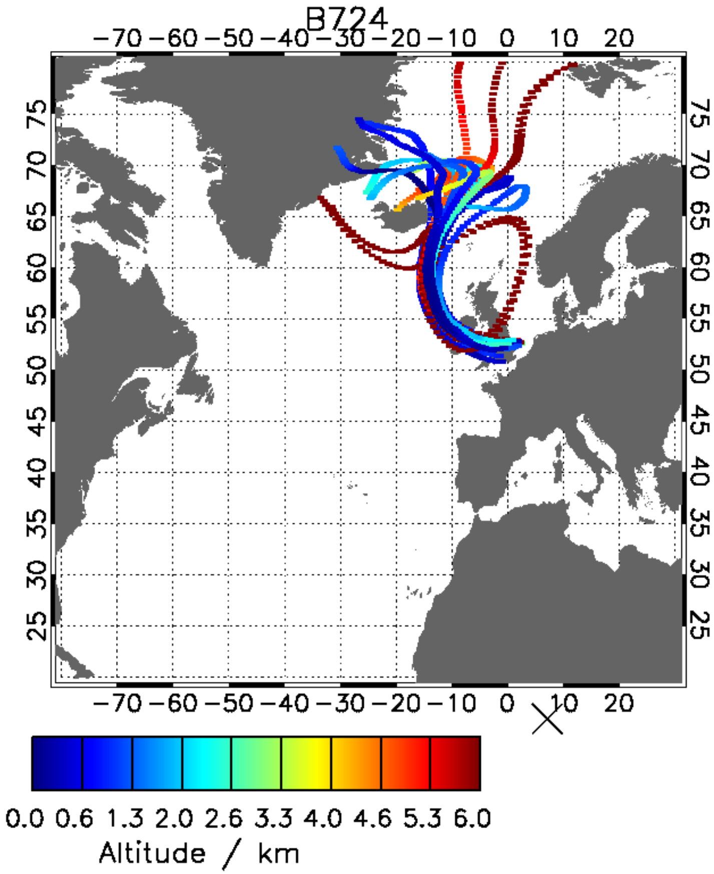
# Flight B724 - 30 July 2012

London Case study during Olympics 2012

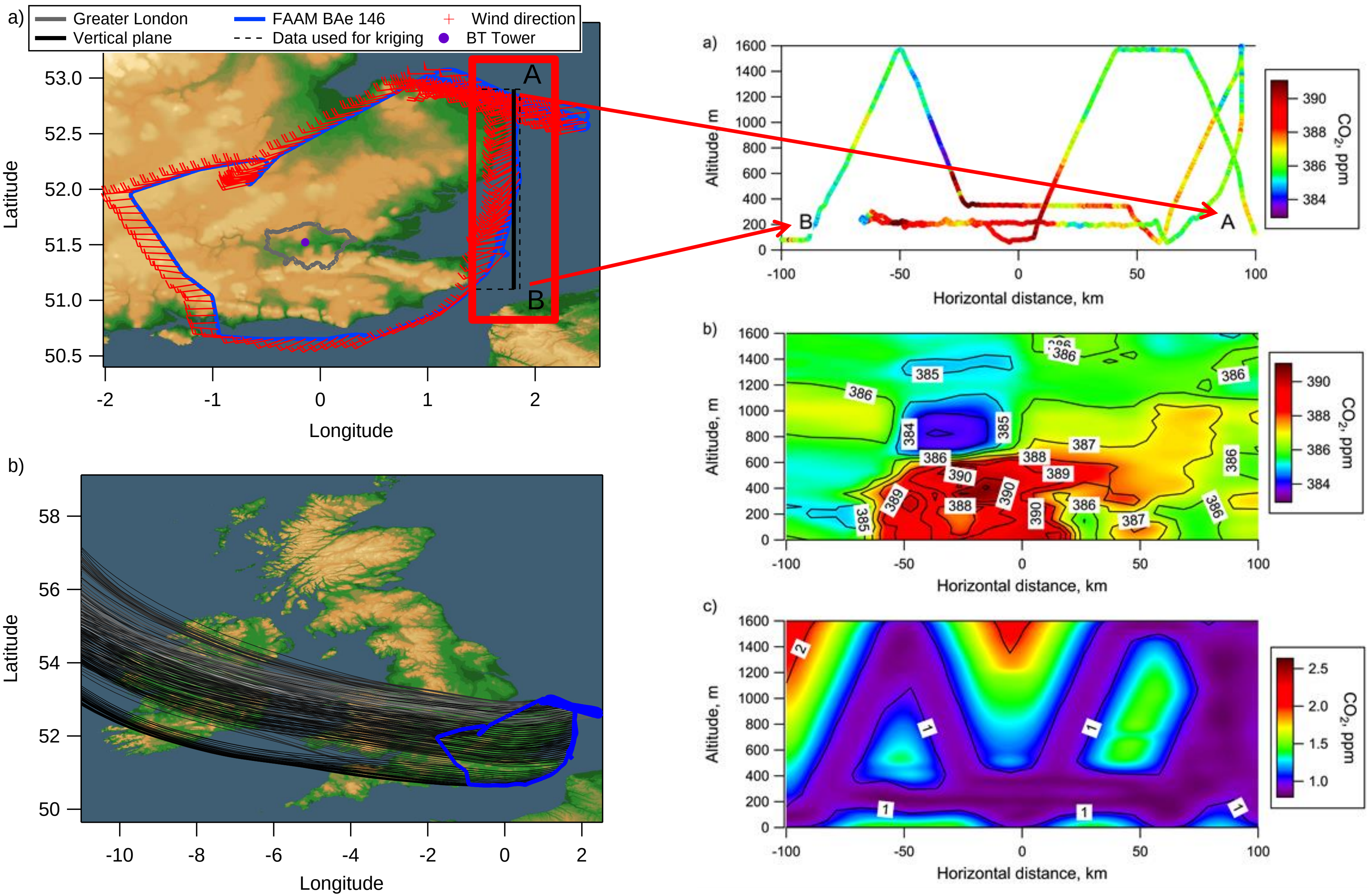
Complimentary to the ClearfLo

Westerly winds from the Atlantic and Arctic

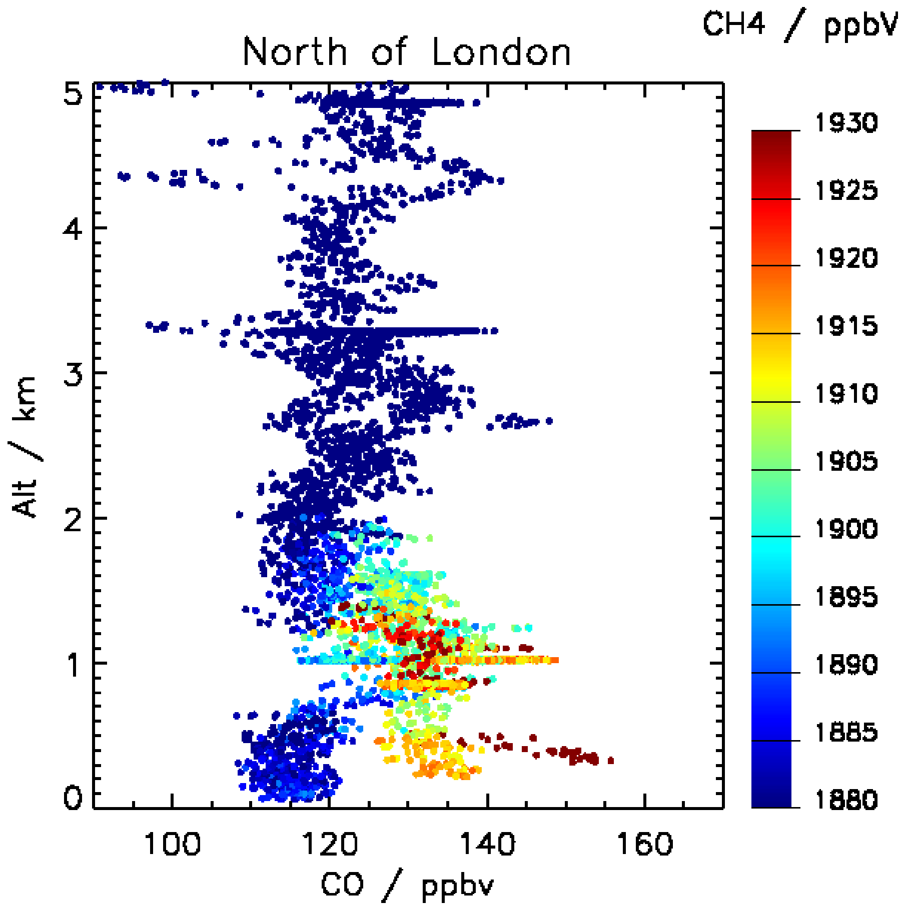


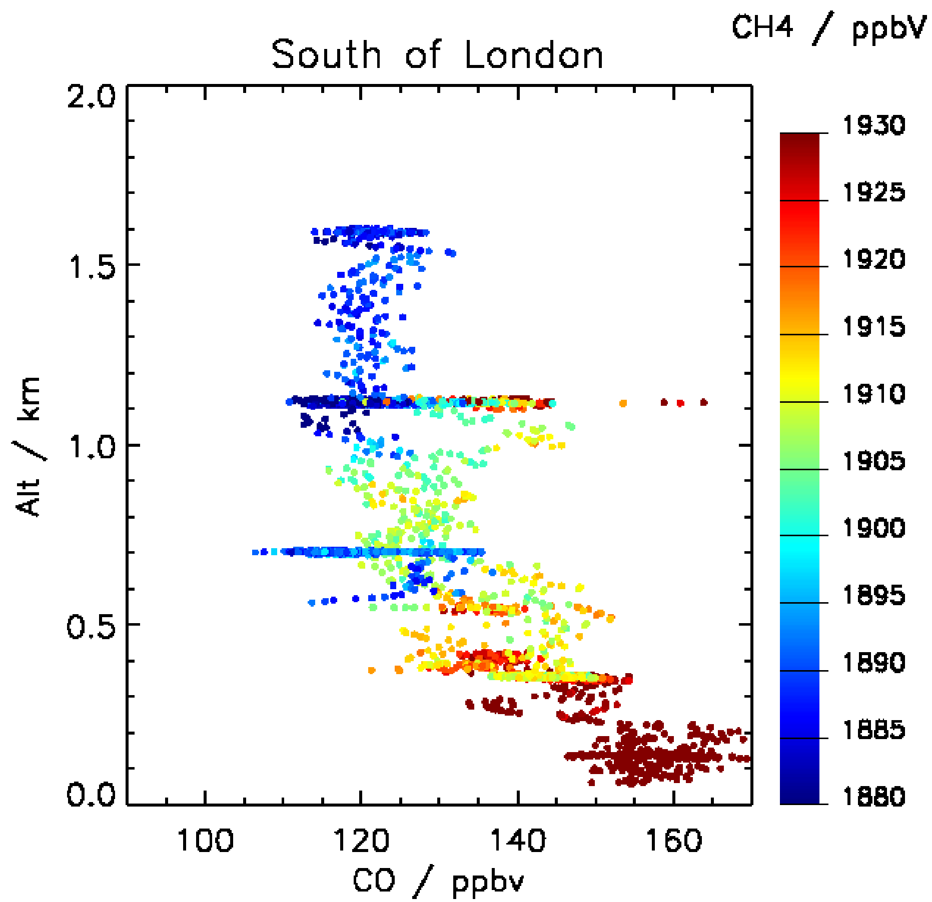



# Flight B724 - 30 July 2012



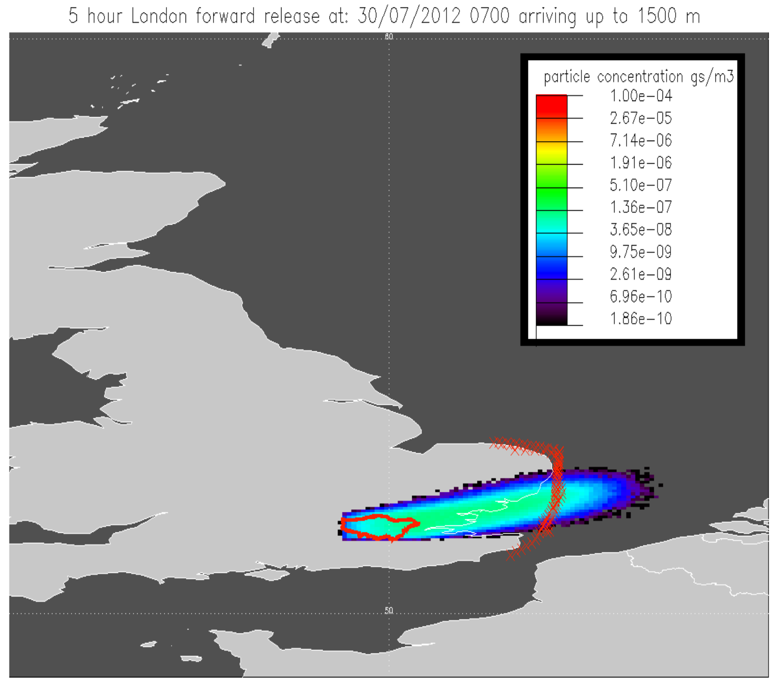
# Flight B724 – 30 July 2012 - Olympics

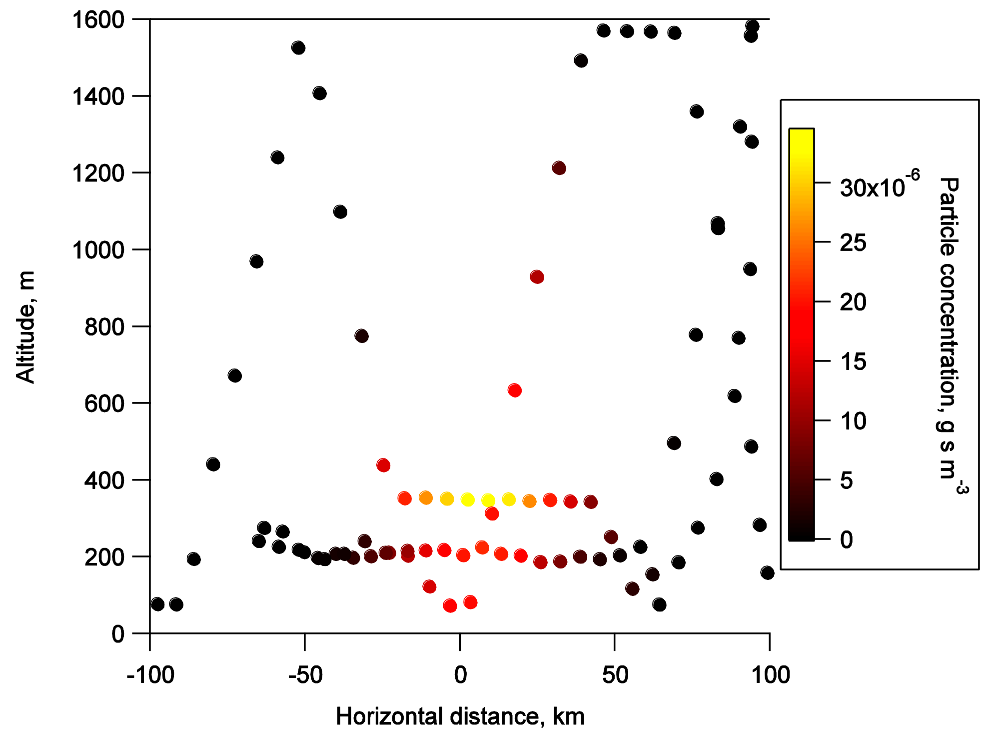



Urban enhancement of $CH_4$ and CO ~50 ppb near the surface

# NAME dispersion modelling




- Influence of London emissions on air sampled by the aircraft along plane AB
- Determined using backwards NAME runs for 10000 particles released from the GPS of the aircraft.
- Warm colours show regions of greater airmass influence from London and vice versa for darker colours.

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# Fluxes through downwind plane

| | $CO_2$ | CO | $CH_4$ |
|---|---|---|---|
| Background (ppb) | 385.8 ± 1.4 ppm | 96 ± 5 | 1883 ± 8 |
| Peak enhancement (ppb) | 13.3 ppm (3%) | 30 (31%) | 73 (4%) |
| Flux AB (mol $s^{-1}$) | 38453 ± 3346 | 253 ± 11 | 264 ± 16 |
| Flux AB London (mol $s^{-1}$) | 35861 ± 2553 | 219 ± 8 | 238 ± 12 |
| NAEI flight track (mol $s^{-1}$) | 67904 | 462 | n/a |
| NAEI Greater London (mol $s^{-1}$) | 15294 | 98 | 71 |

- Downwind $CO_2$ flux in between London NAEI and regional NAEI aggregate flux
- CO flux lower than both London and regional NAEI
- $CH_4$ flux 3 times higher than London inventory alone

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# Fluxes through downwind plane

| | Location | Year | Season | Flux (μmol $m^{-2}$ $s^{-1}$) | | |
|---|---|---|---|---|---|---|
| | | | | $CO_2$ | CO | $CH_4$ |
| This study (mass balance) | London | 2012 | Summer | 21 ± 3 | 0.12 ± 0.02 | 0.13 ± 0.02 |
| This study (eddy-cov.) [a] | London | 2012 | Summer | 1 to 83 (28 ± 17) | | 0.01 to 0.37 (0.15 ± 0.08) |
| Font et al. (2013)[b] | London | 2011 | Autumn | 46 to 104 | | |
| Helfter et al. (2011)[c] | London | 2007 | Year round | 7 to 47 | | |
| Harrison et al., (2012)[d] | London | 2007/08 | Autumn | | 0.25 / 0.17 | |
| Rigby et al. (2008)[e] | London | 2006 | Year round | 18 ± 28 | | |
| Mays et al. (2009)[h] | Indianapolis | 2008 | Spring | 19.2 ± 15.4 | | 0.14 ± 0.1 |

[a] Range of the fluxes at the BT tower averaged for Summer 2012 (numbers in brackets show fluxes for 30 September 2012).
[b] mass balance flux range using airborne measurements from 4 flights
[c] EC range
[d] EC means for 2 autumn periods
[e] boundary layer model, average emission rate for winter period.
[h] mass balance flux range from 8 flights
[i] EC range of fluxes.
[k] EC mean daytime flux.

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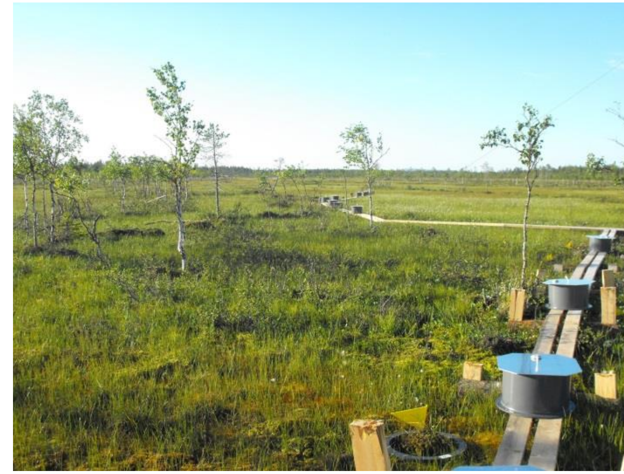
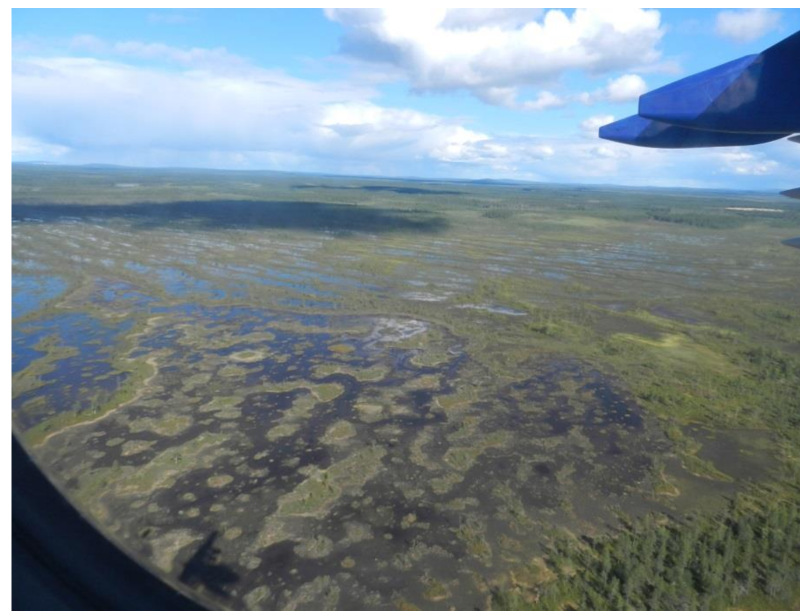
# MAMM, Methane in the Arctic: Measurement and Modelling

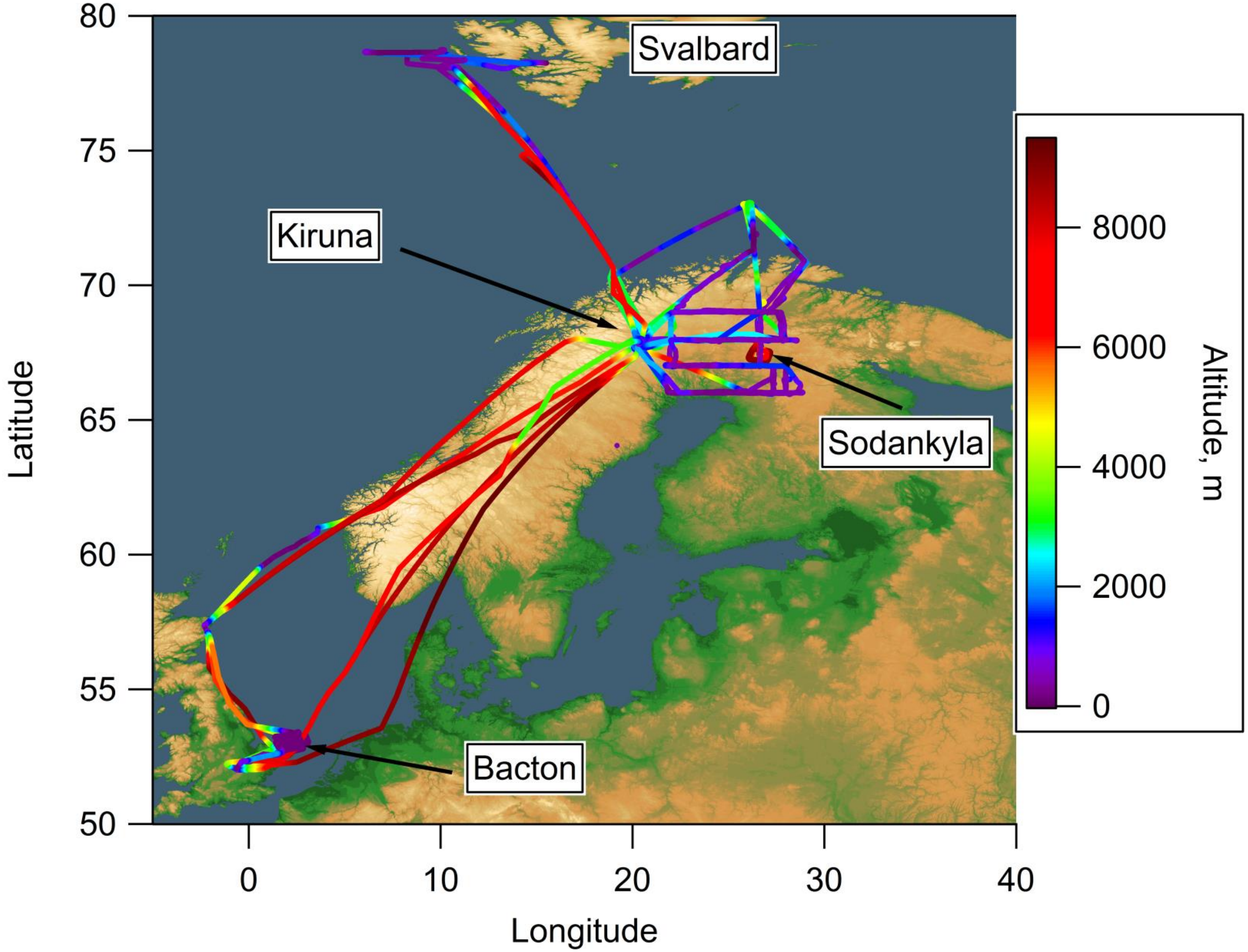




(www.arctic.ac.uk)

(Pyle et al., poster B33K-0613)

# Arctic Airborne Measurement




July 2012
6 flights

August 2013
9 flights

September 2013
7 flights

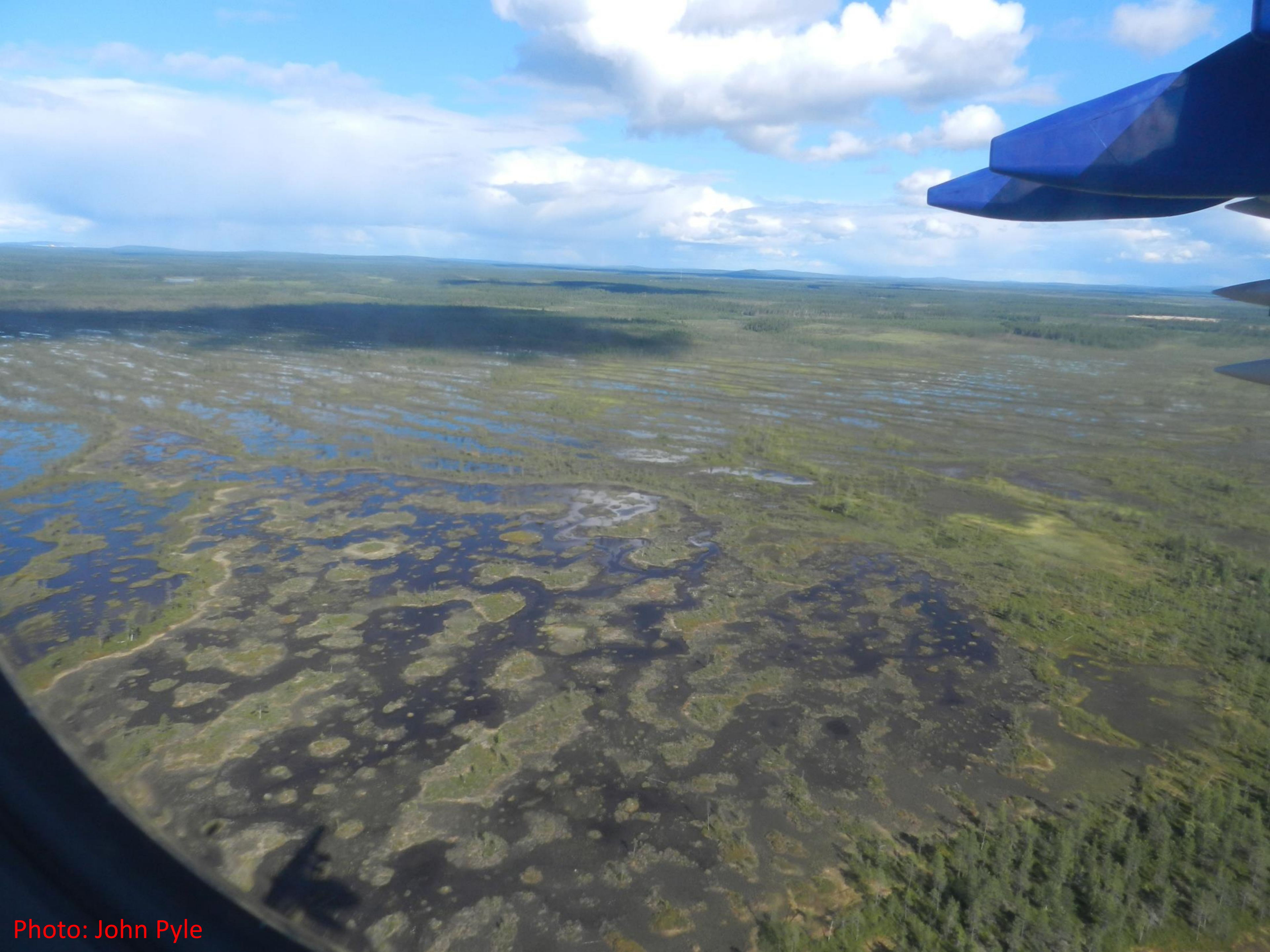


Photo: John Pyle

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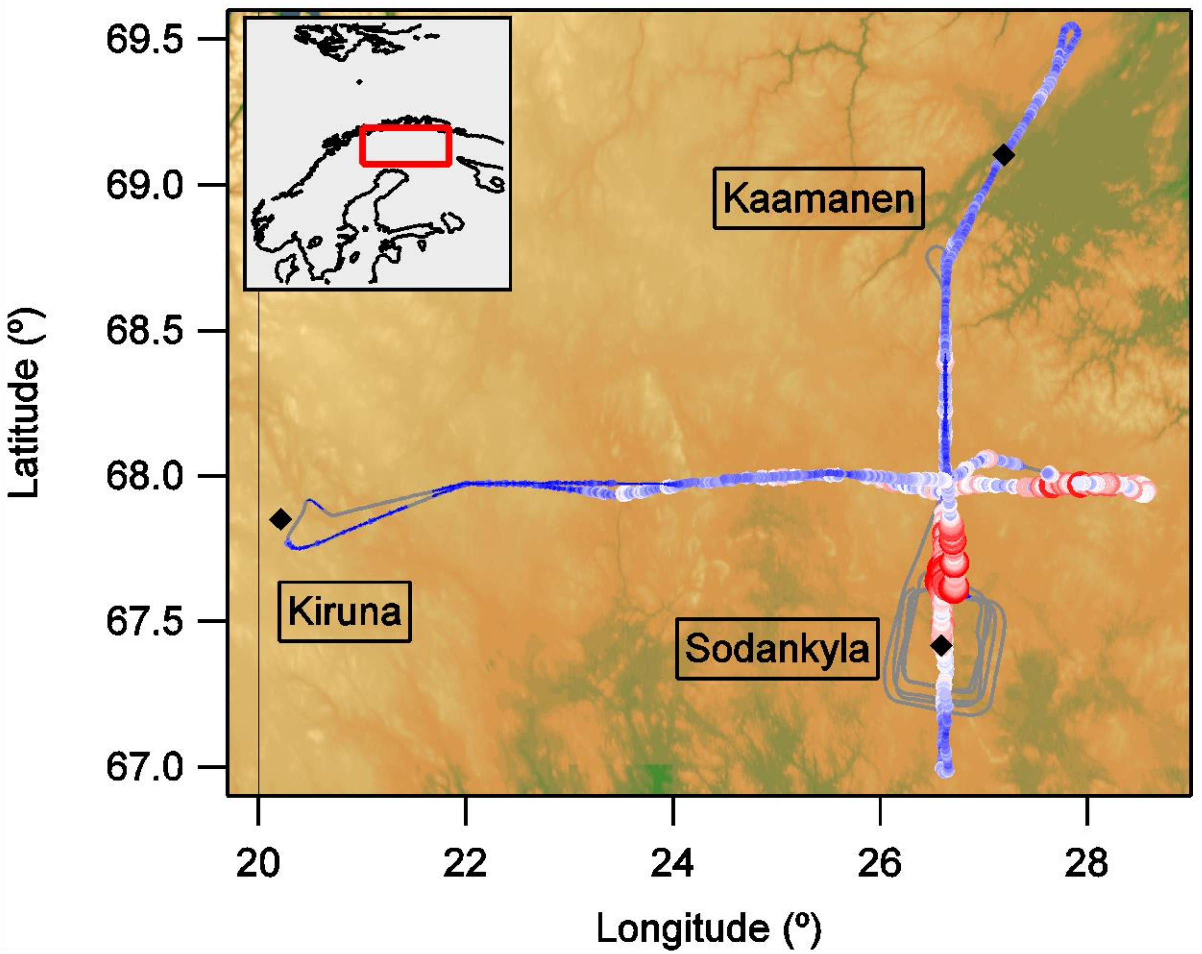
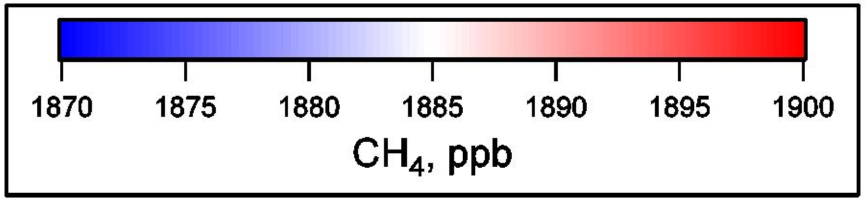
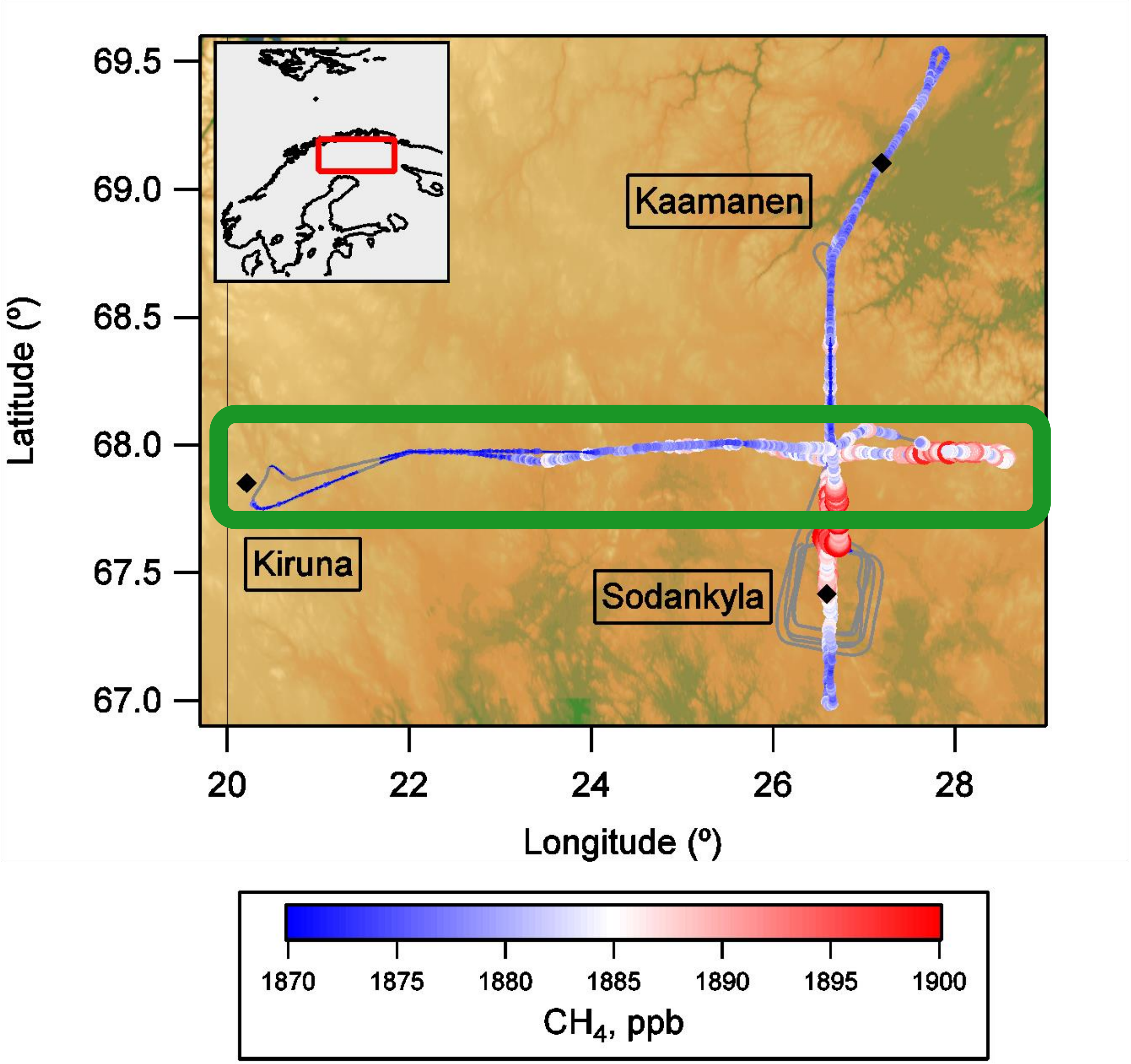
# Wetland $CH_4$ flux Survey



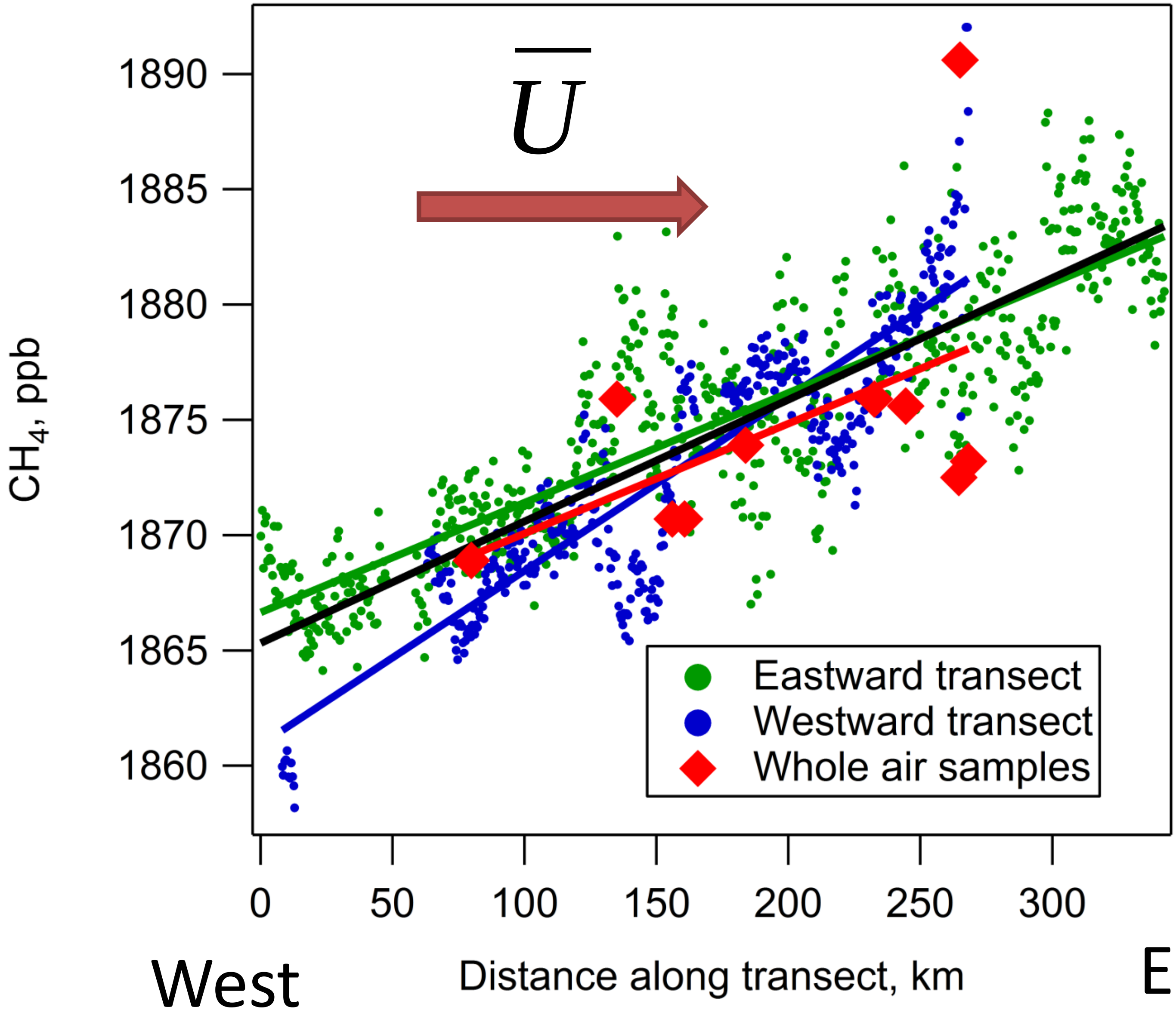

22 July 2012

# Wetland Survey



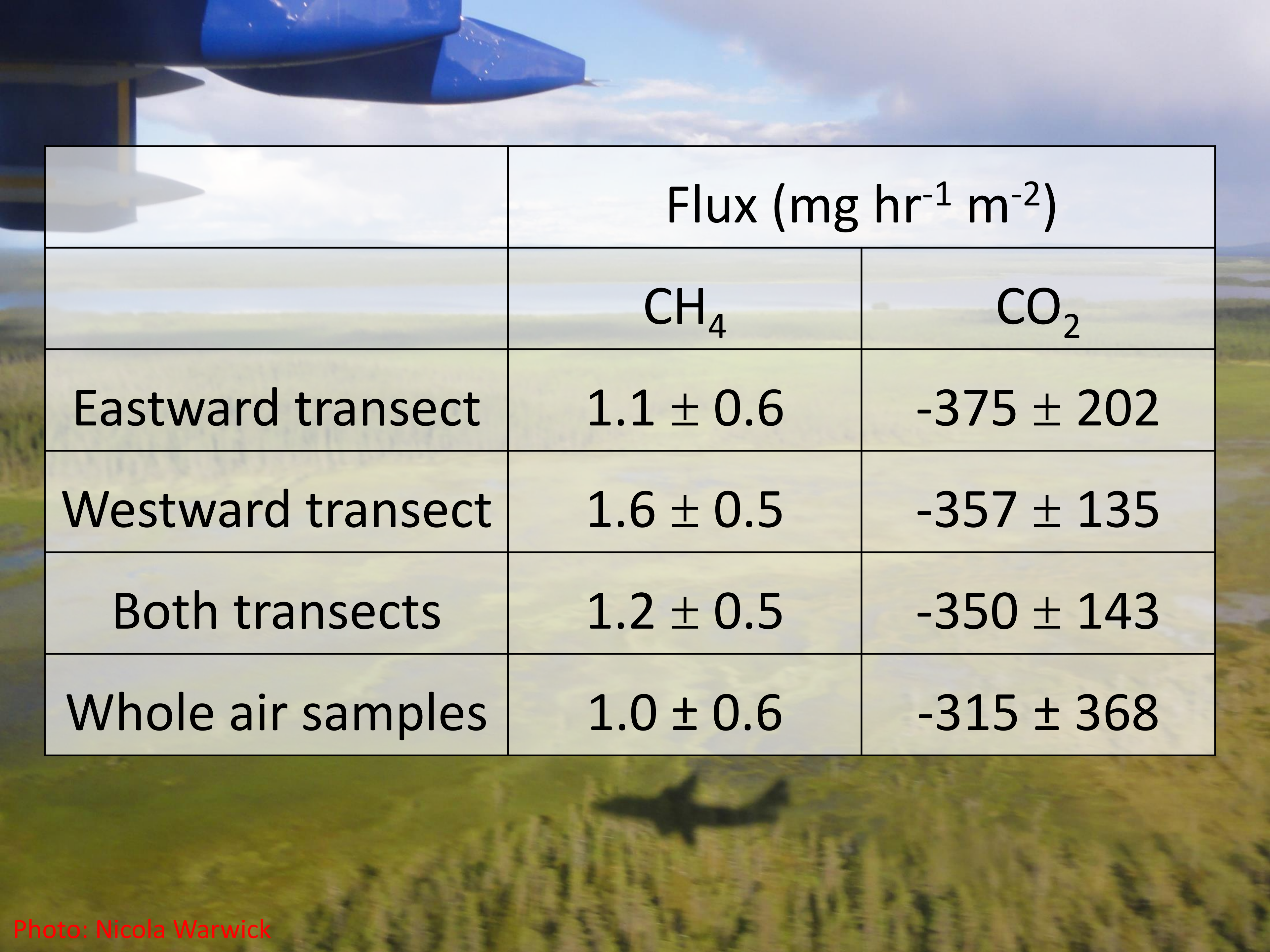

22 July 2012

# Transects parallel to the wind vector




West East

22 July 2012



| | Flux (mg $hr^{-1}$ $m^{-2}$) | |
|---|---|---|
| | $CH_4$ | $CO_2$ |
| Eastward transect | 1.1 ± 0.6 | -375 ± 202 |
| Westward transect | 1.6 ± 0.5 | -357 ± 135 |
| Both transects | 1.2 ± 0.5 | -350 ± 143 |
| Whole air samples | 1.0 ± 0.6 | -315 ± 368 |

Photo: Nicola Warwick

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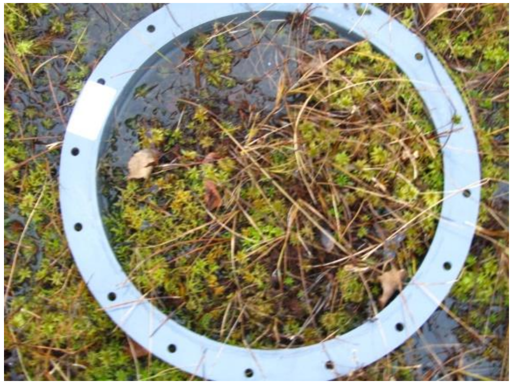
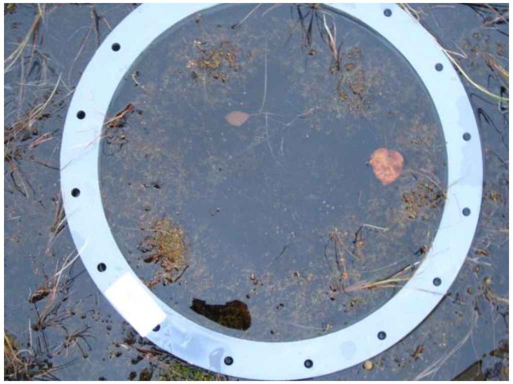
# Spatial Scalability: Sodankyla chamber fluxes

39 chambers in the wetland

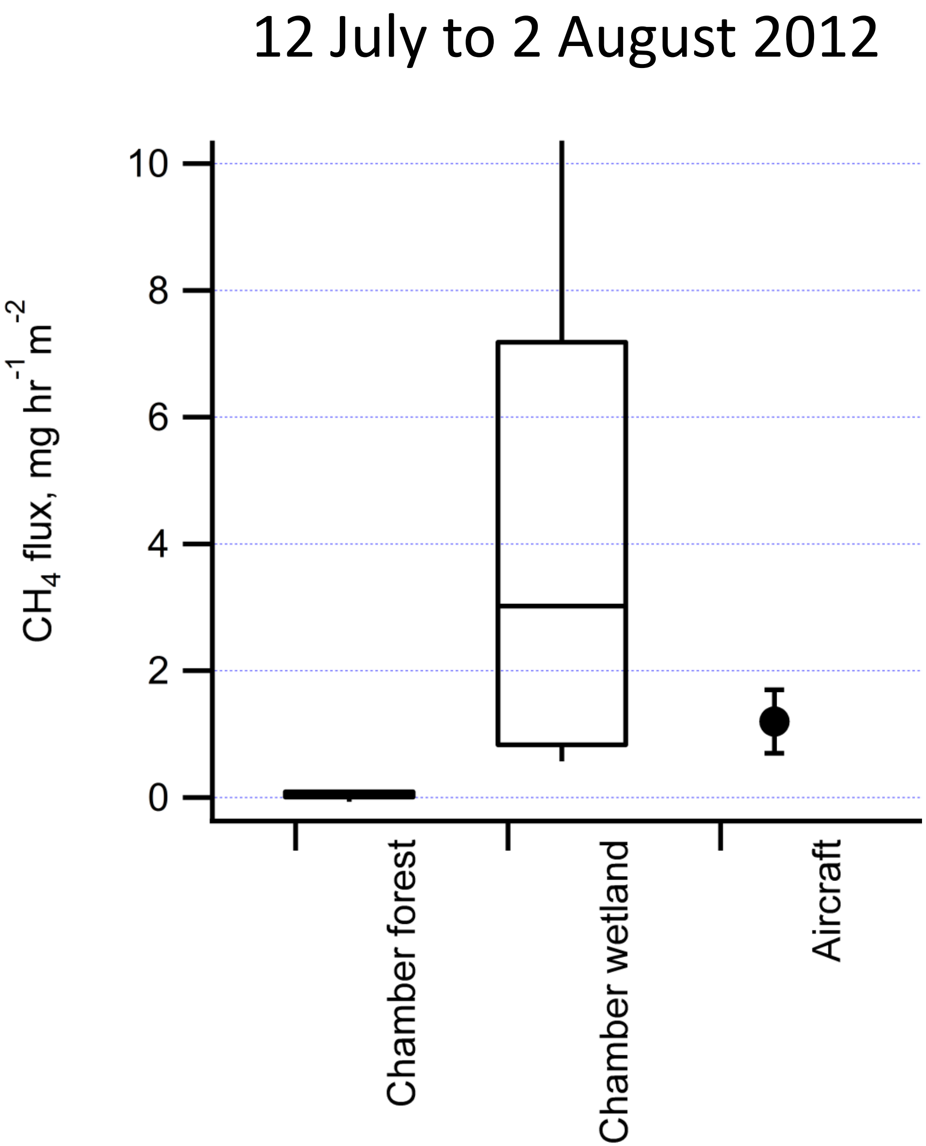




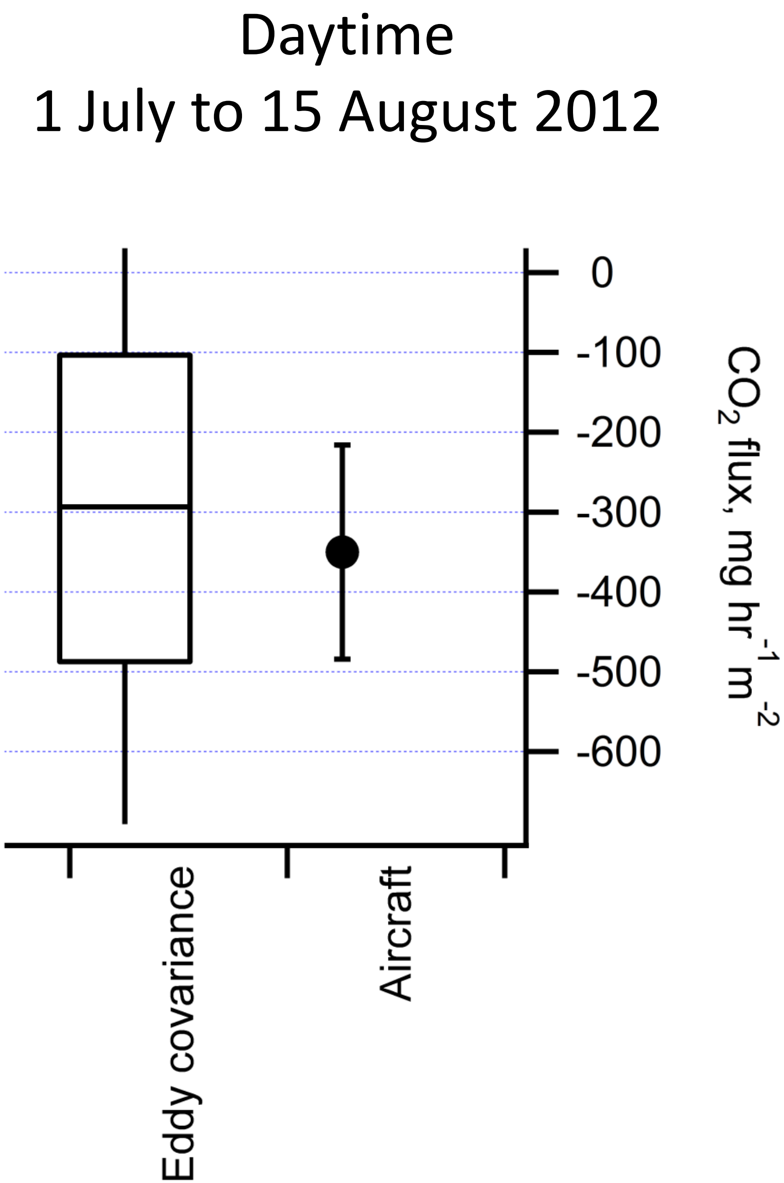
21 chambers in the forest



Photos: Kerry Dinsmore

# Comparison with ground based fluxes



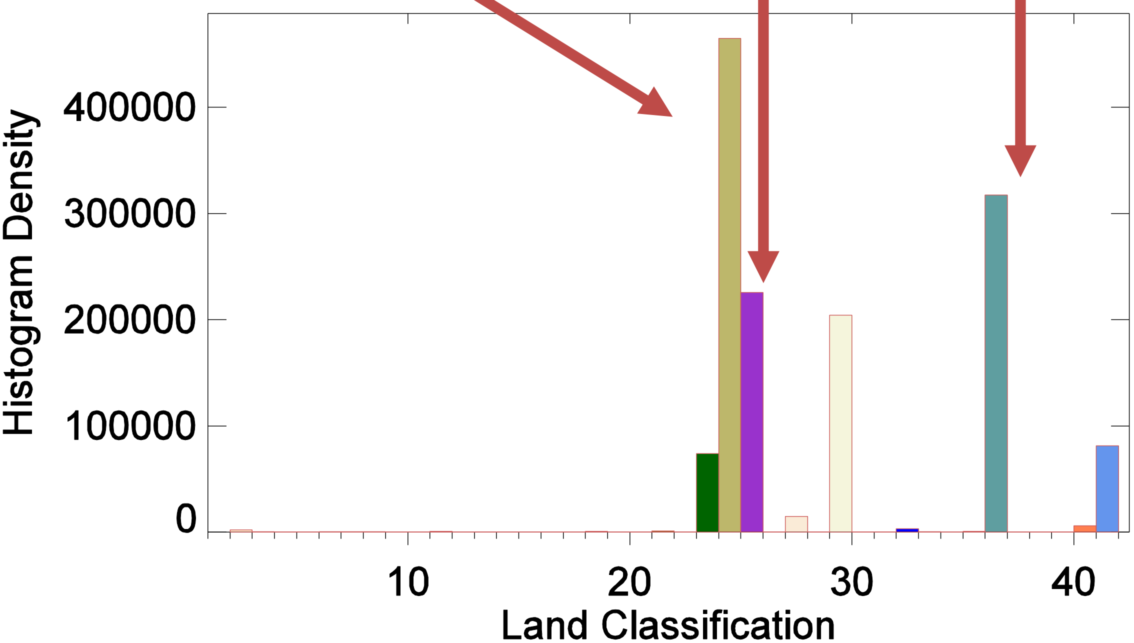



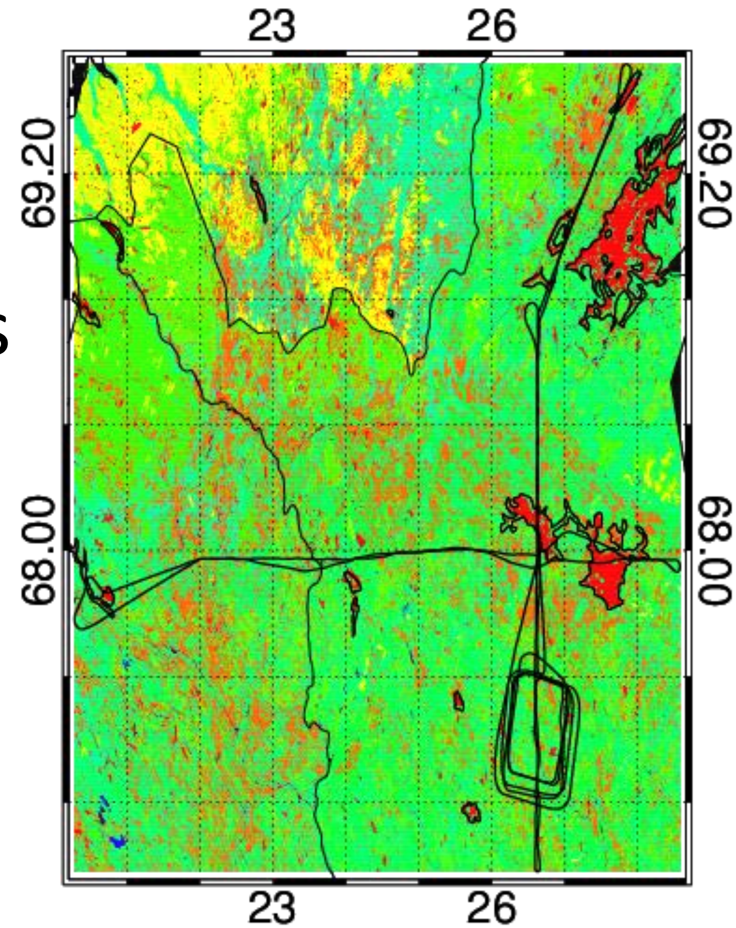
# Corine land use map 2006

Mixed forest

Peat bogs

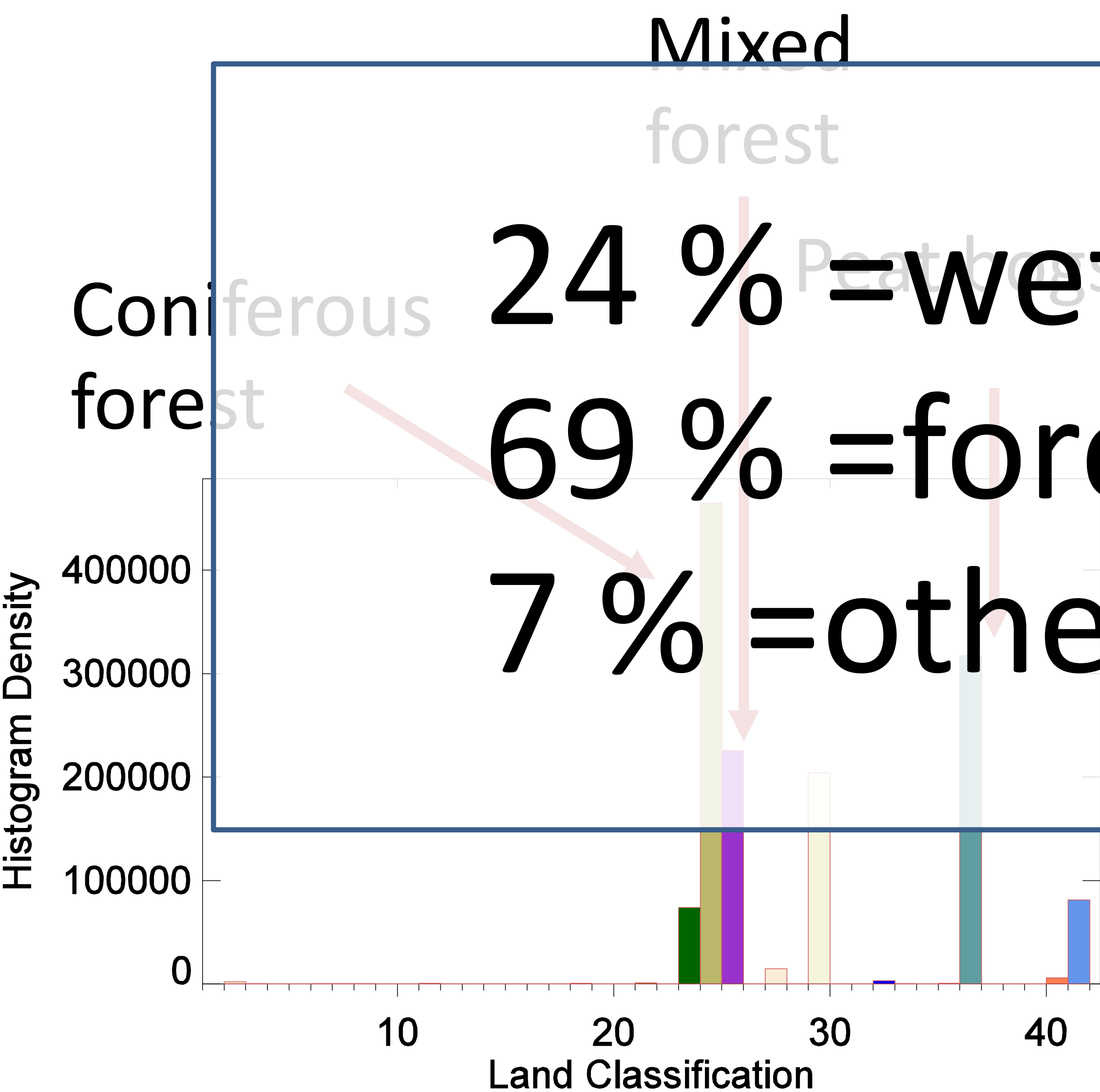
Coniferous forest

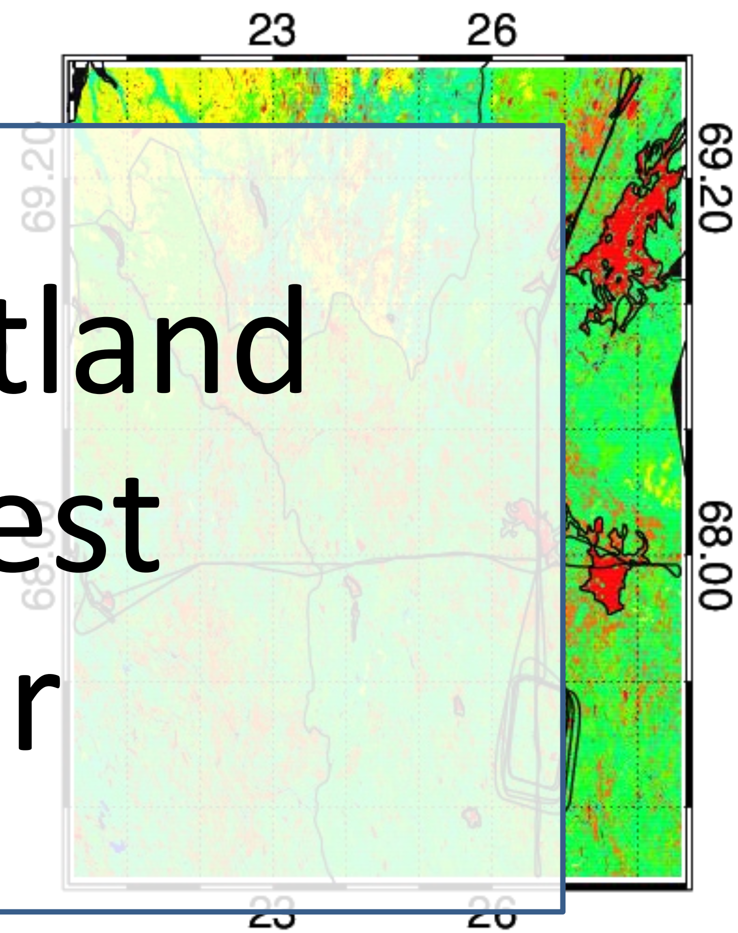



(www.eea.europa.eu)

# Corine land use map 2006




24 % =wetland

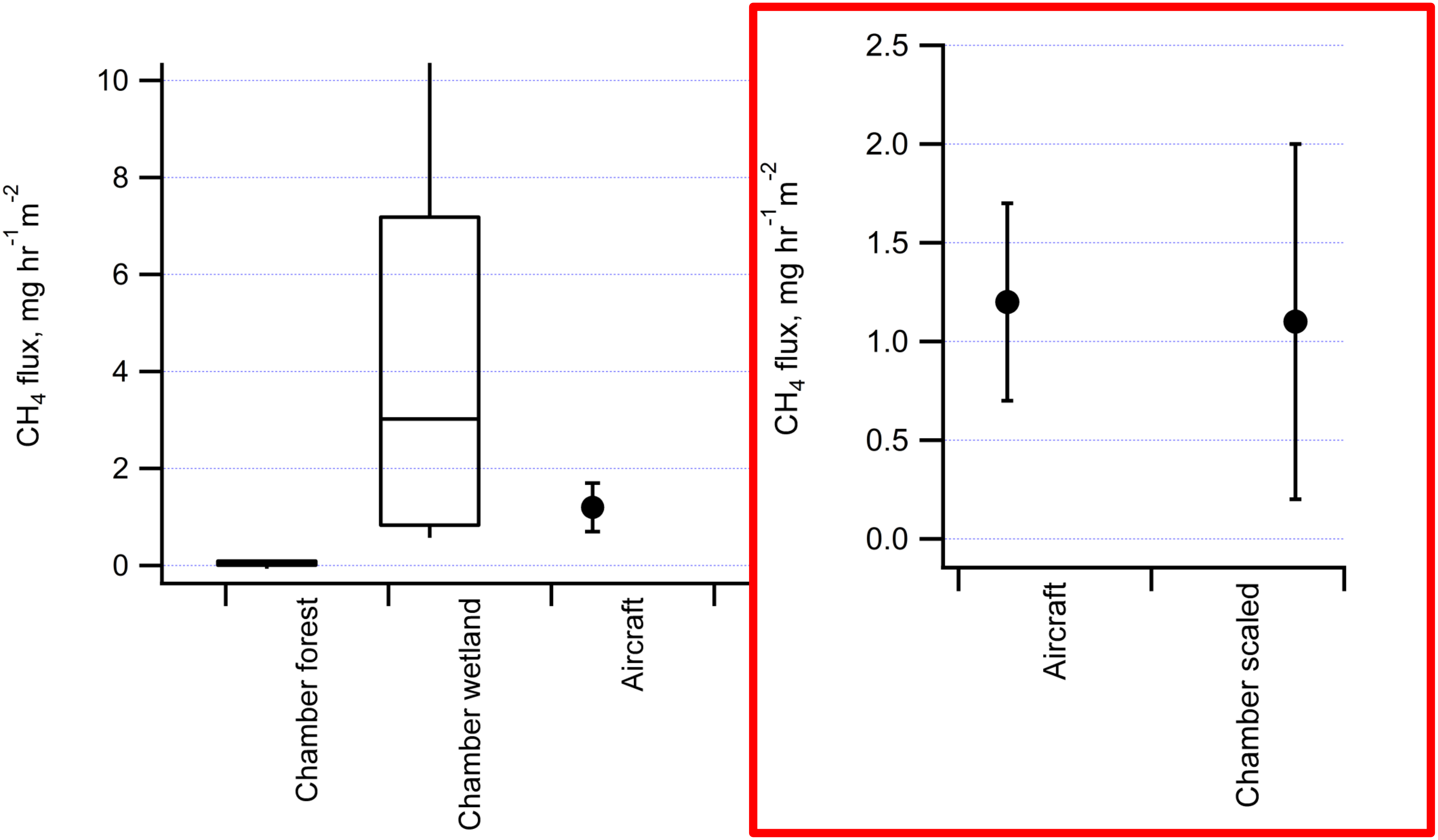
69 % =forest

7 % =other

(www.eea.europa.eu)

# Comparison with ground based fluxes

Scale chamber fluxes using the land types within the aircraft footprint.



# IDL Exercise

- Go to (or navigate to via www.faam.ac.uk):

http://www.faam.ac.uk/index.php/flying-calendar/icalrepeat.detail/2015/05/12/9880/-/b905-b906-gauge-flight

Read the “sortie briefs”

Photo: Nicola Warwick