Chemical impacts of aviation emissions

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Work based on simulations by C Frömming and analysis by S. Rosanka + REACT4C Team

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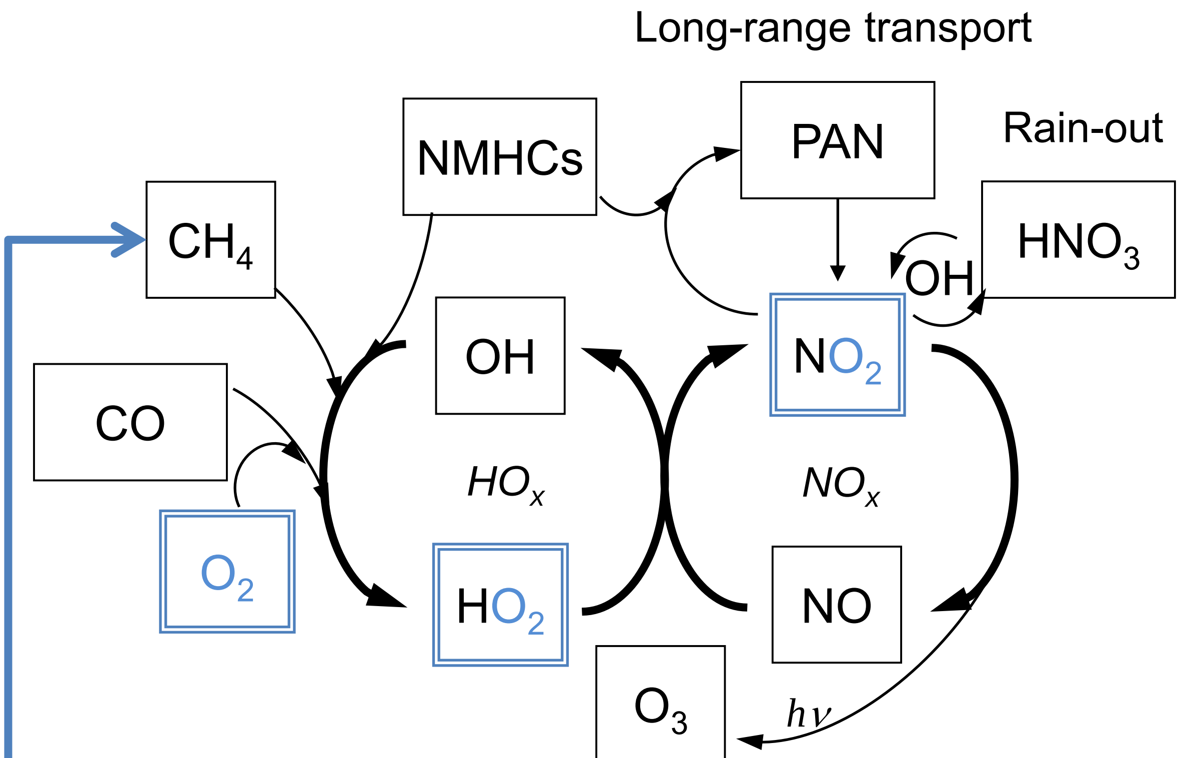
The impact of nitrogen oxides on ozone and methane



Rate limiting step: $NO + HO_2 \rightarrow NO_2 + OH$

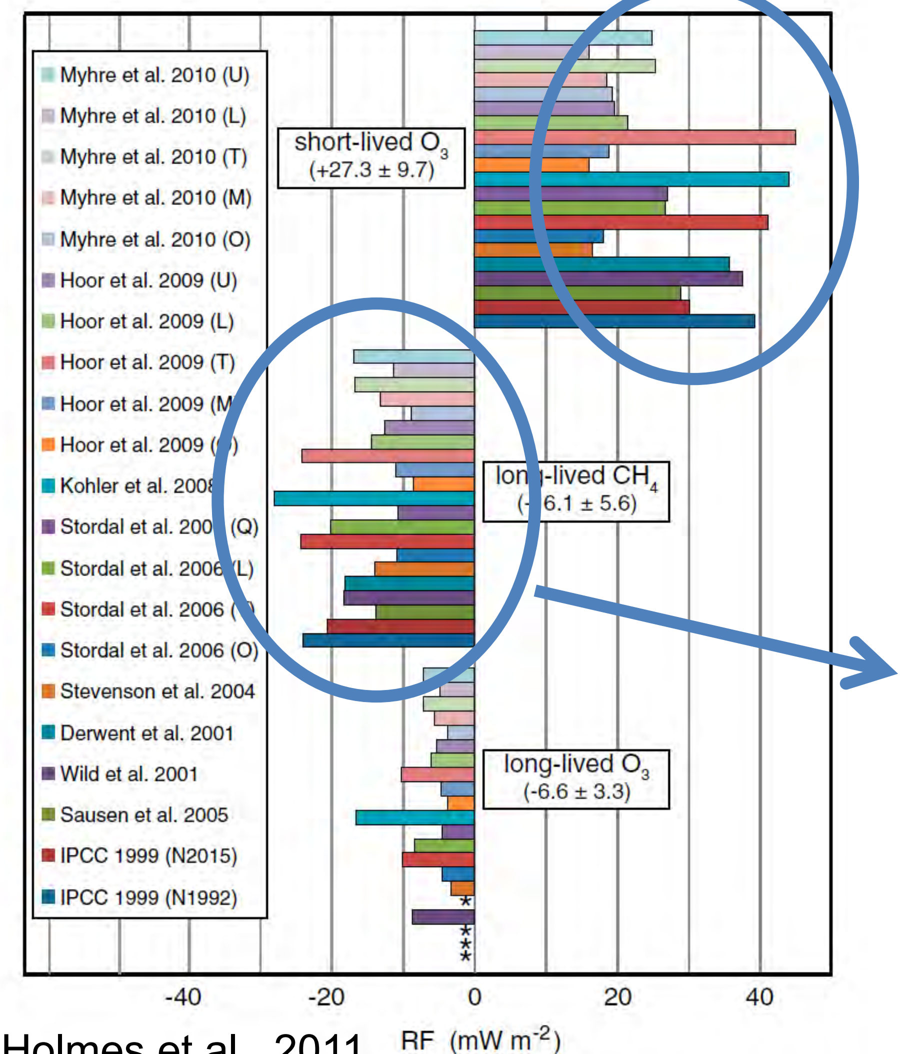
Increase in O_3 = short-lived

Decrease in CH_4

$\Rightarrow$ Decrease in O_3 = long-term effect

- CO, CH_4, NMHC are important to consume O_2 and produce HO_2
- Reaction of HO_2 with NO is rate limiting step for ozone production
- Nitric acid = HNO_3 and its rain out is a major loss for nitrogen compounds
- CH_4, NMHCs are eventually converted into CO
- CO is eventually converted into CO_2

How important are NO_x emissions from aviation?

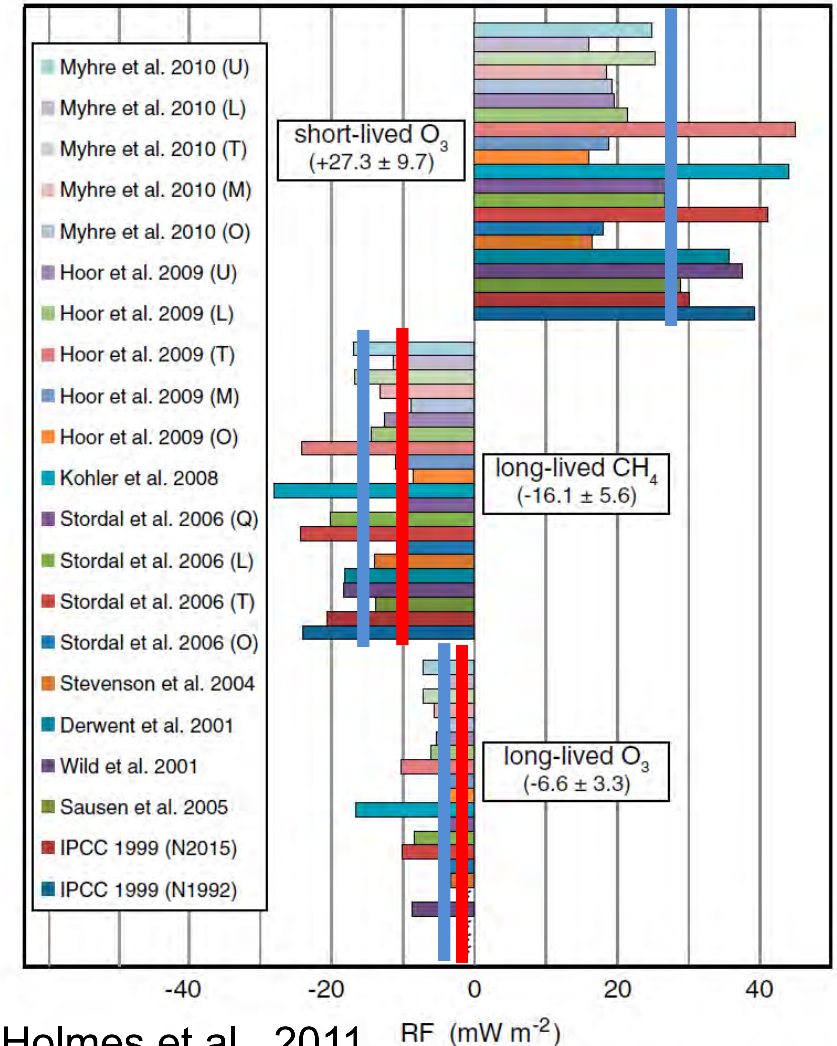


Holmes et al., 2011

Large variation in short-lived ozone

Large variation in methane

How important are NO_x emissions from aviation?



Holmes et al., 2011

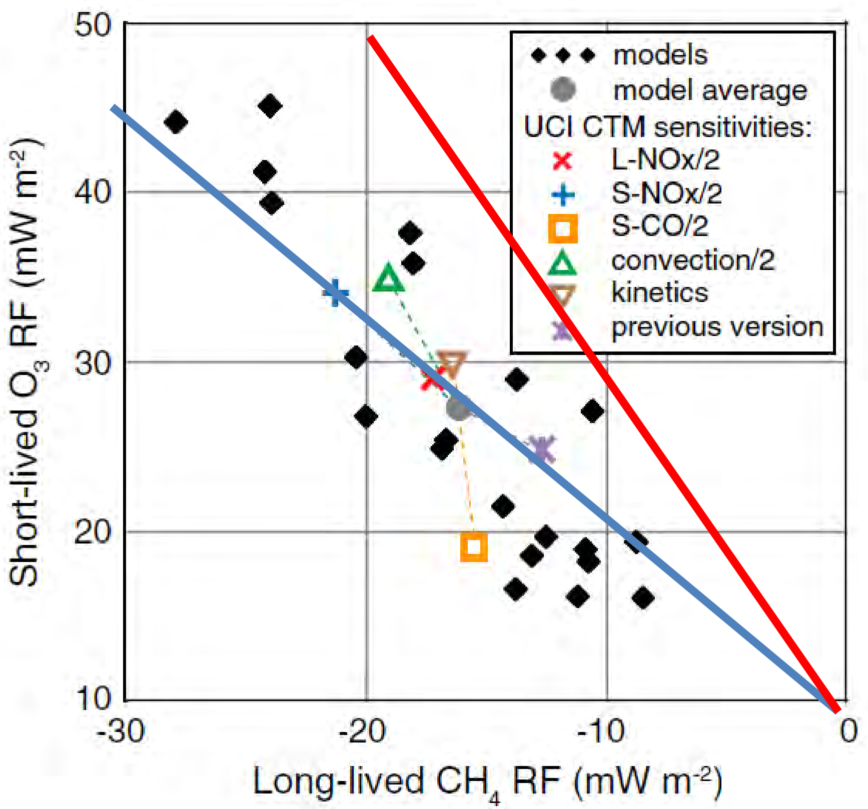
Myhre et al., (2011) noted that RF methane calculations are based on steady-state assumptions on the methane response, which has a 12 year perturbation lifetime.

Roughly 65% of the response will be achieved in the respective year.

Holmes et al. RF NOx: **4.1 mW/m²**

Correction with Myhre **12.2 mW/m²**

Ratio between ozone and methane RF



Holmes et al., 2011

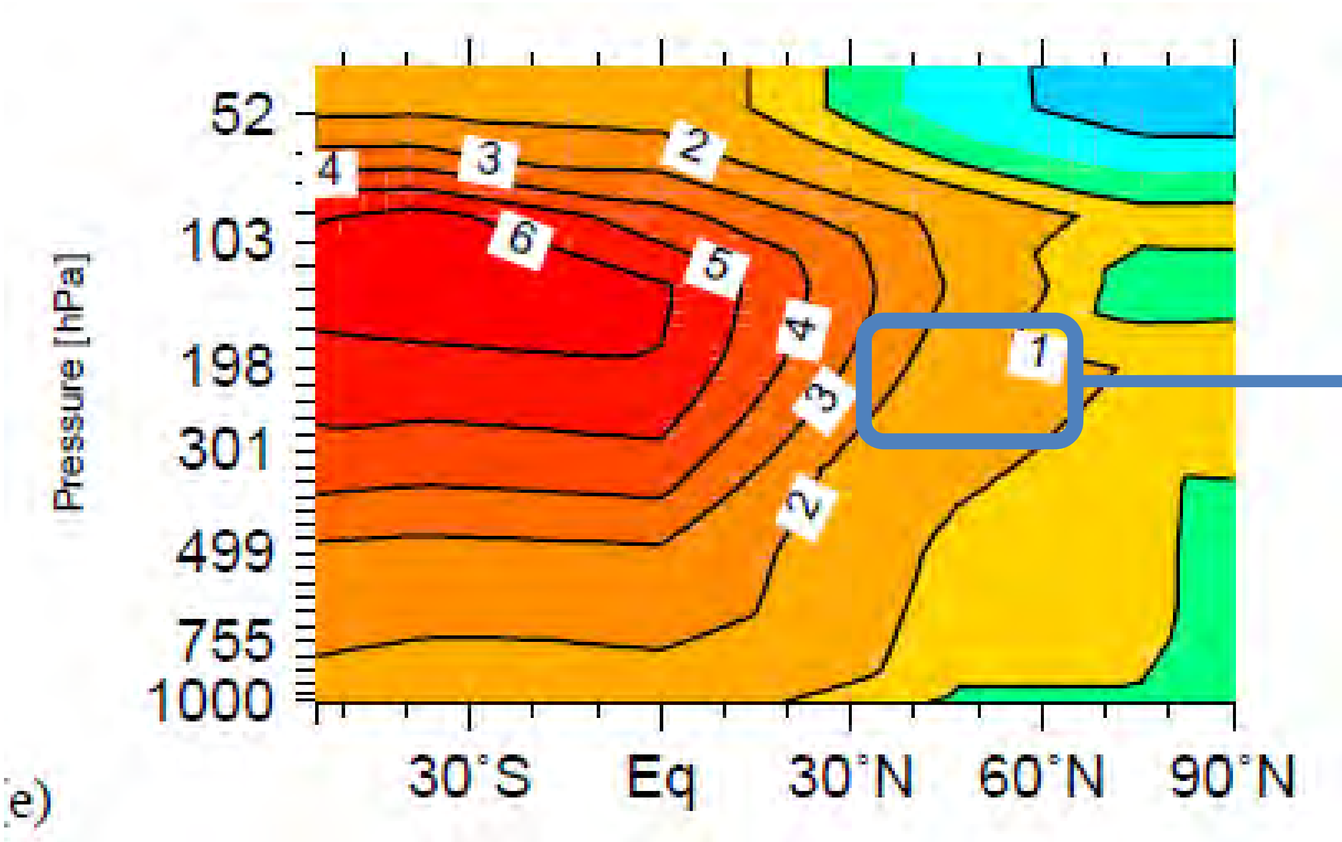
Ratio between ozone-RF and methane-RF from Lee et al. (2011):

Ozone-RF/Methane-RF: -1.65 ± 22%

is consistent with Holmes et al. 2011 (~ -1.7)

With Myhre et al. correction for transient behaviour: -1.7 → -2.6

How does this ratio vary?



Area of main air traffic

Grewe and Stenke, 2008

How large is the ozone to methane ratio varying?

Question:

- Where and when is ozone increasing due to a NO_x emission in the North Atlantic Flight Corridor?
- How much is the ratio varying?

Method:

Analysis of the REACT4C-data, derived with a modelling approach, which is based on a large number of trajectory calculations.

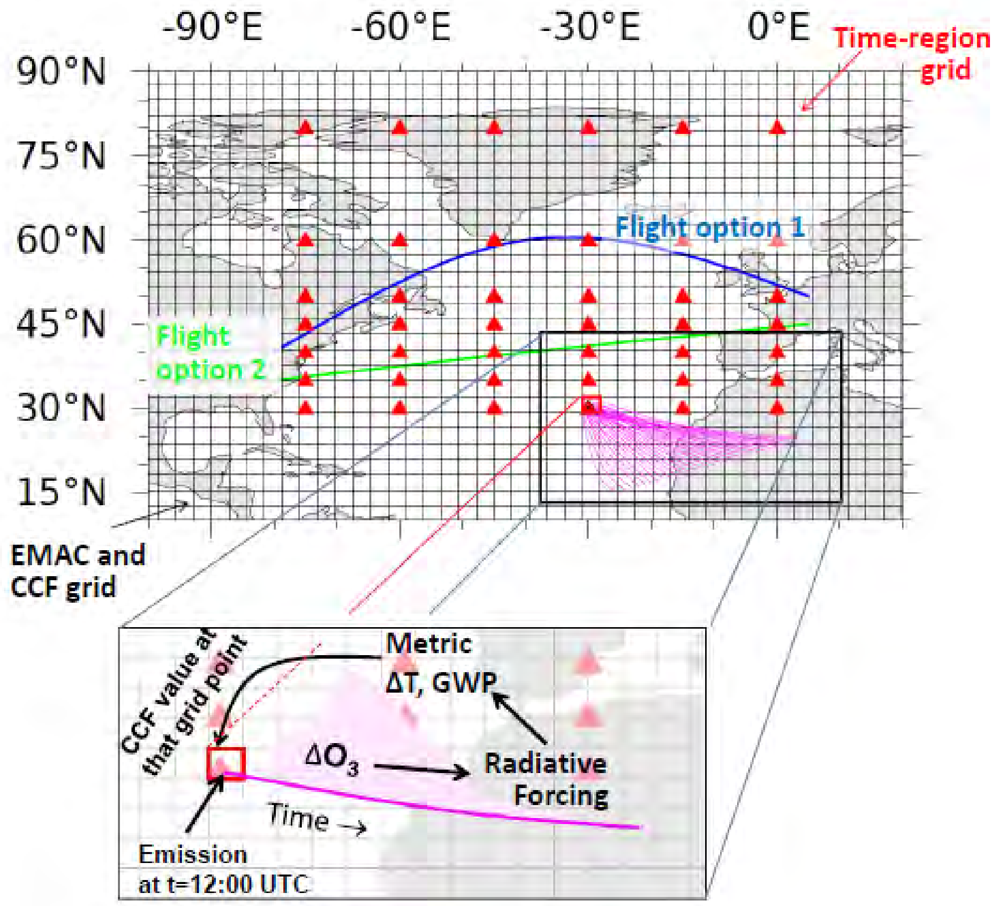
Region: North Atlantic

Number of trajectories: ~25.000

Weather: 5 representative winter and 3 summer situations.
(Weather classification according to Irvine et al. (2013)

REACT4C Modelling set-up

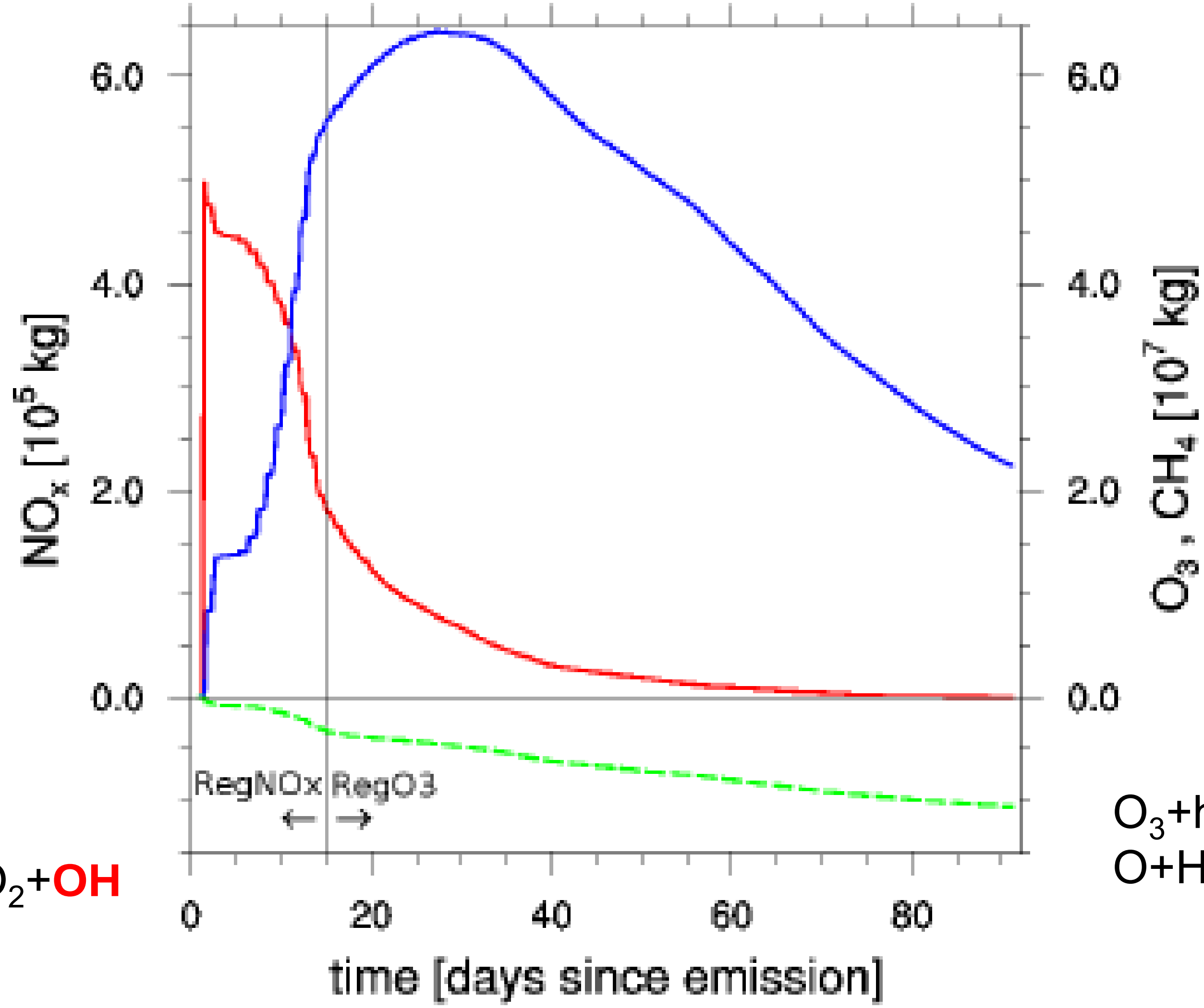
Objective: Determine climate impact of a local emission, to optimise air traffic wrt climate



- Contributions of (unit) NO_x and H_2O emissionen to O_3, OH, and PMO
- Contrail-cirrus
- Adjusted RF
- Climate metrics
- Result: Climate impact/emission

Grewe et al., 2014a

Chemical regimes for methane loss

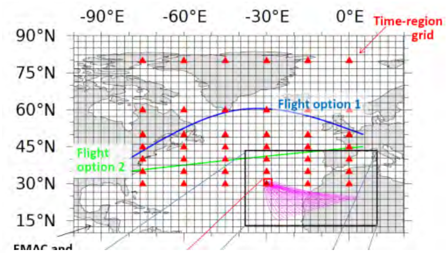


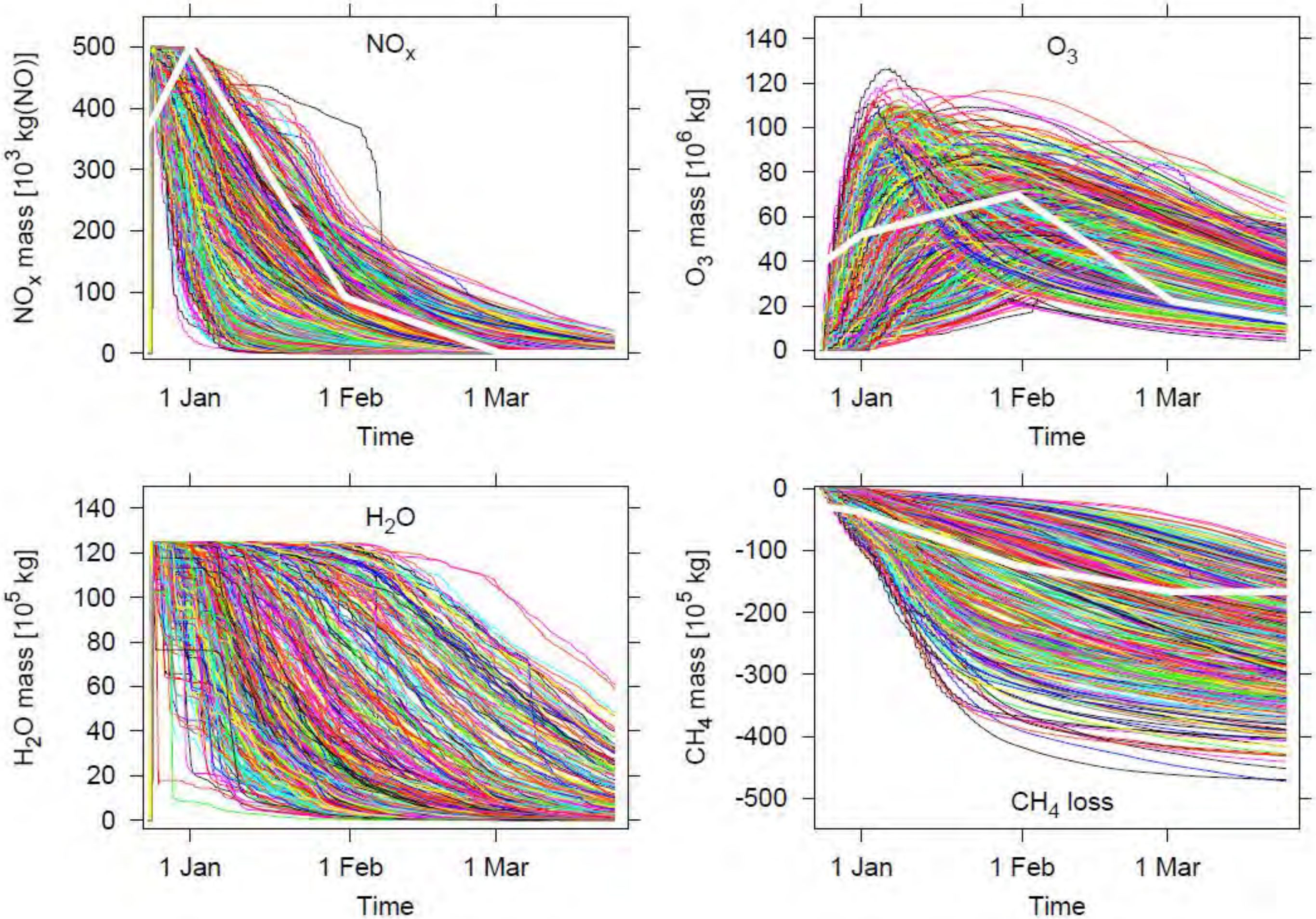
$NO + HO_2 \rightarrow NO_2 + \textbf{OH}$

$O_3 + h\nu \rightarrow O + O_2$

$O + H_2O \rightarrow 2\ \textbf{OH}$

Evolution of atmospheric changes for emissions at the time-region grid points





Each **coloured line** is the mean over 50 trajectories started at one time-region grid point

White lines are monthly mean results from Stevenson et al.

Grewe et al., GMD, 2014

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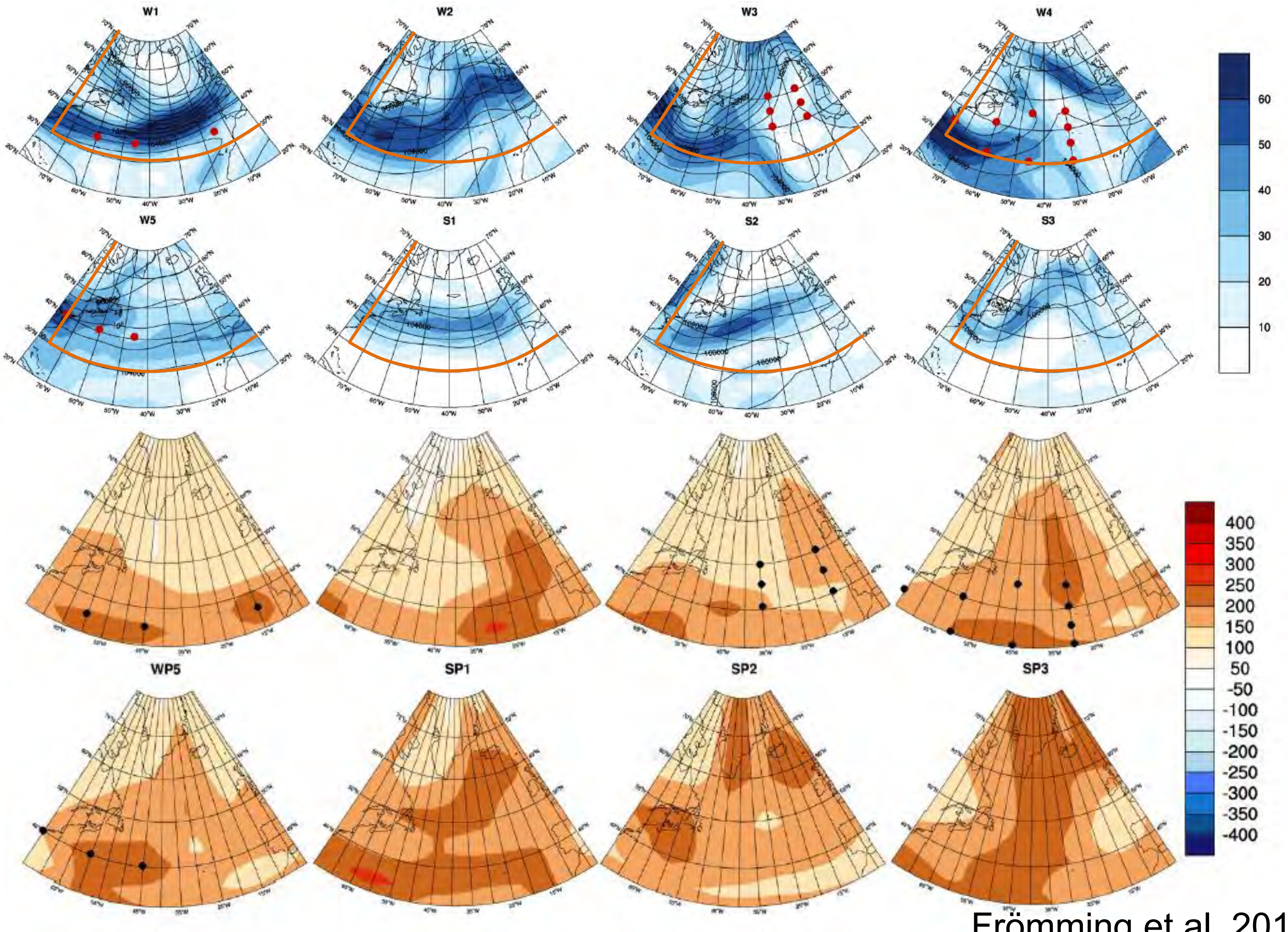
Weather data and Ozone Climate-Change-Functions



Frömming et al. 2016

Where ozone is produced?

Concept of “main ozone latitude, altitude, and time”:

The main ozone gain latitude Φ_j of an emission location (identified with the index j) is defined as the mean latitude at which the air parcel trajectories experience most of the ozone increase.

= Ozone gain weighted latitude:

Latitude of trajectory *I* at time t

$$A_{j,i} = \int \frac{O_3^{Gain_i}(t) \cdot \varphi_i(t)}{\sum_{i=1}^{50} \int O_3^{Gain_i}(t)dt} dt$$

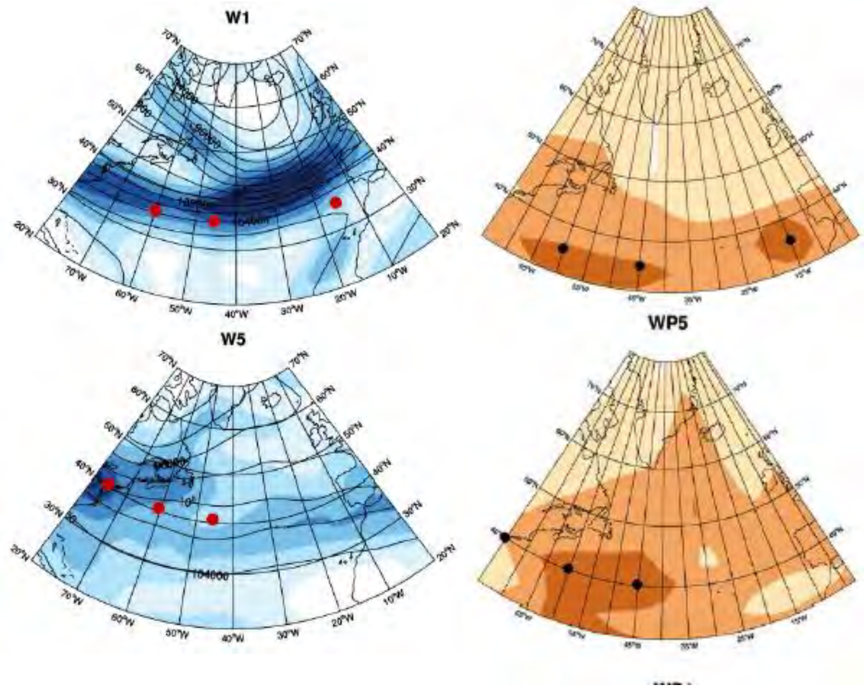
Step 1:
Contribution to the ozone gain latitude from a single trajectory

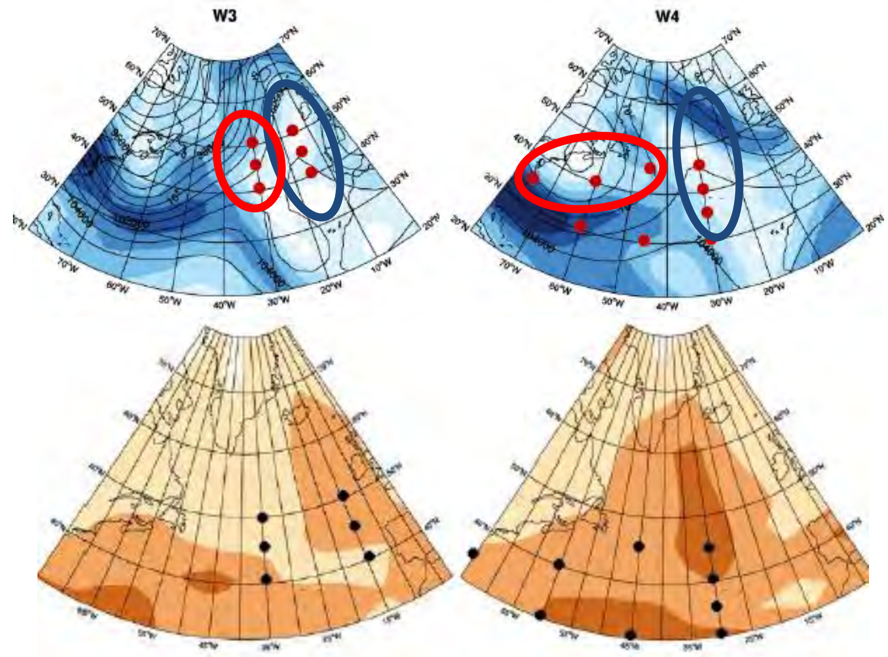
$$\phi_j = \sum_{i=1}^{50} A_{j,i}$$

Step 2:
Contribution to the ozone gain latitude from all trajectories

Frömming et al. 2016

3 Case studies:

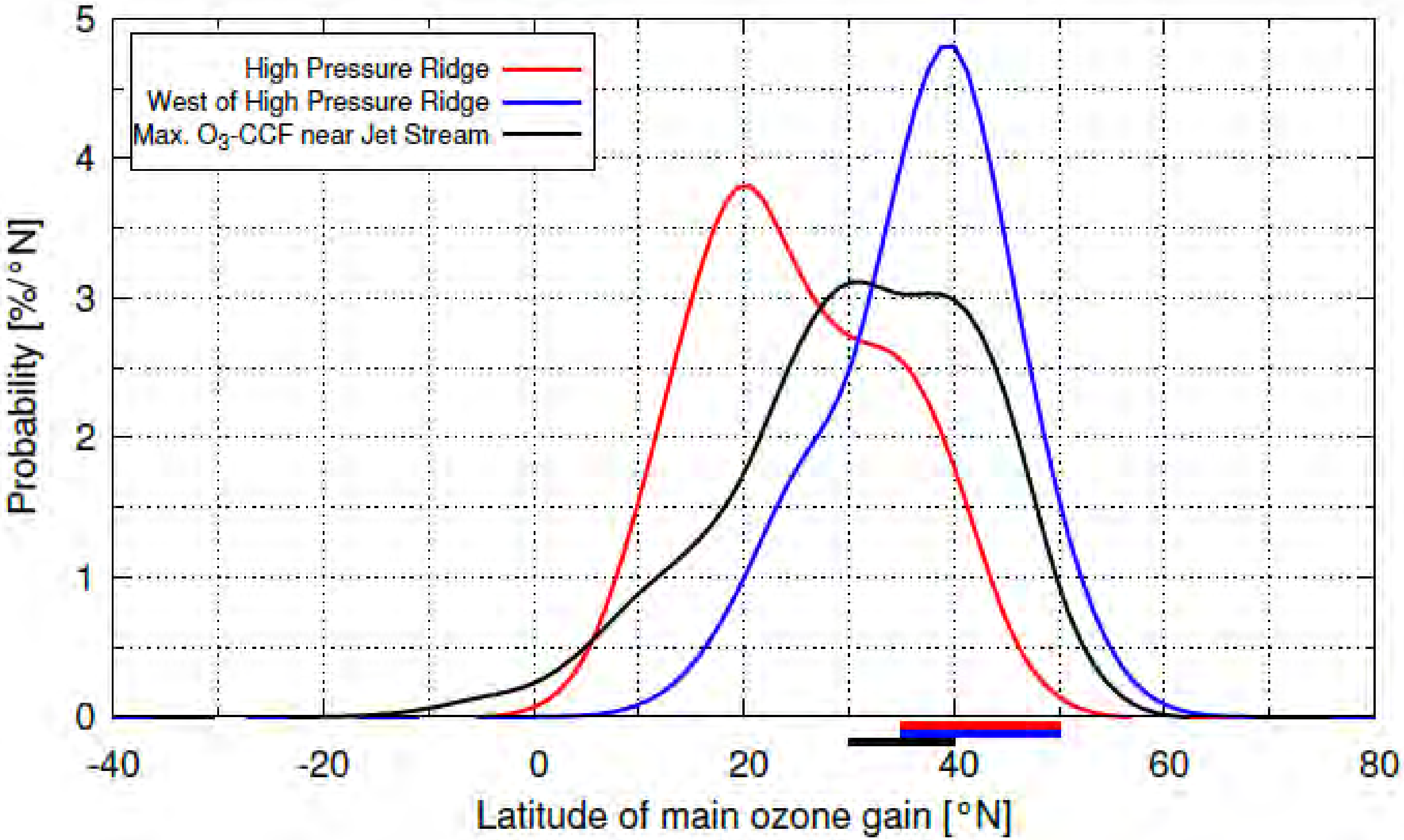




High pressure ridge (HPR)	(300 trajectories)
West of high pressure ridge	(300 trajectories)
Jet stream location	(450 trajectories)

Frömming et al. 2016

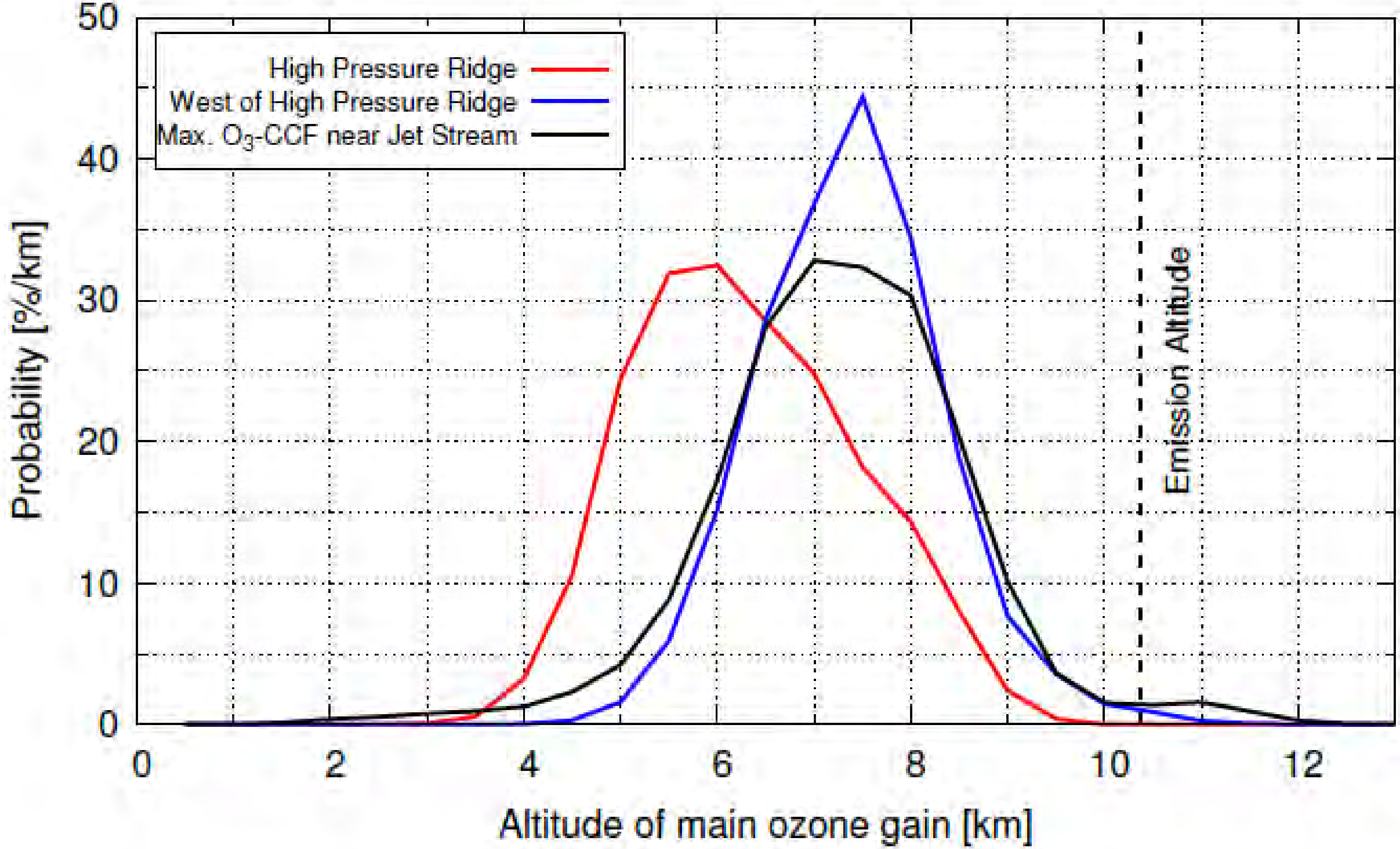
PDFs of the ozone gain latitude



- Emissions in the HPR have a main contribution to ozone far more south
- Large difference between HPR and location west of the HPR

Frömming et al. 2016

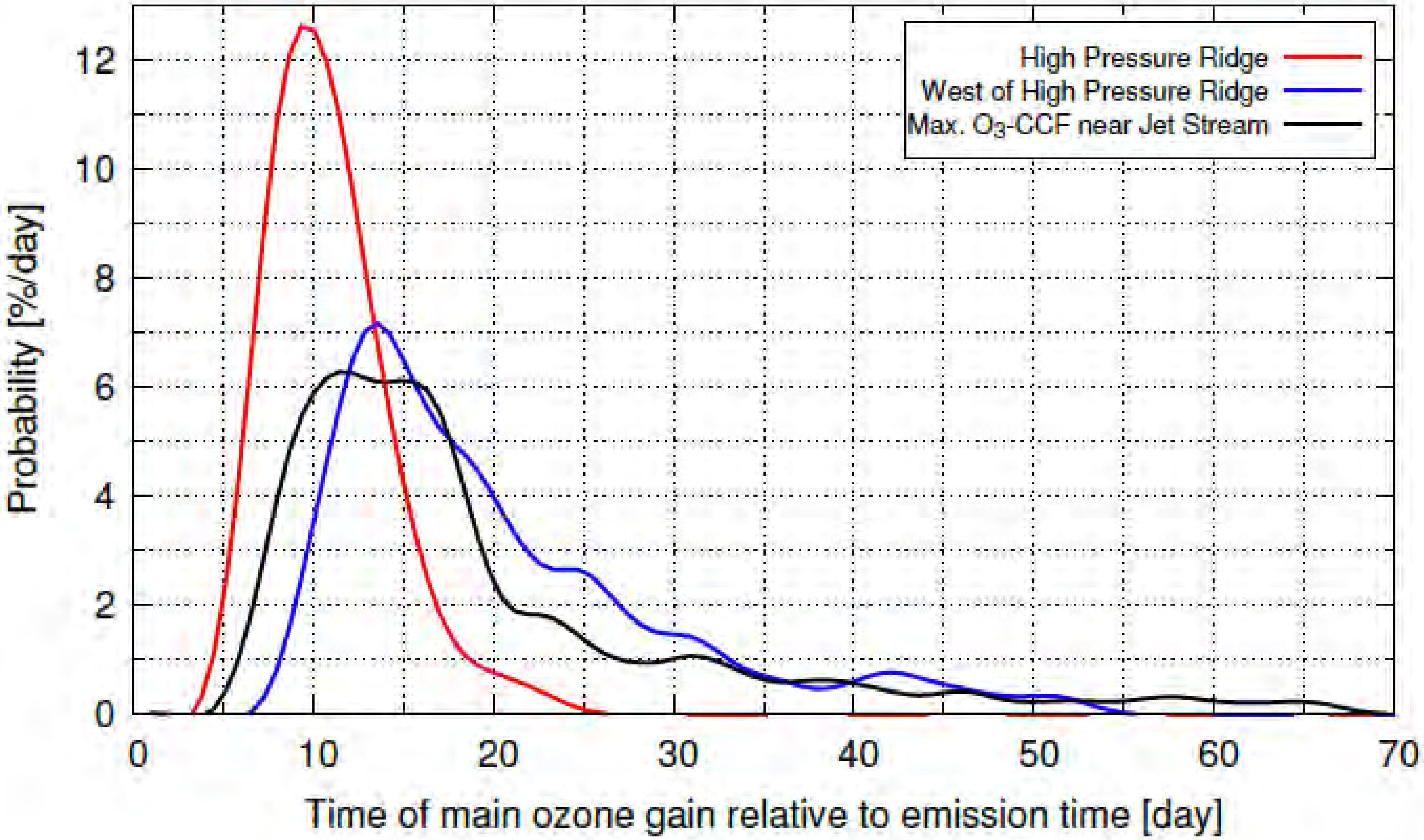
PDFs of the ozone gain altitude



- Emissions in the HPR have a main contribution to ozone at lower altitudes
- Large difference between HPR and location west of the HPR

Frömming et al. 2016

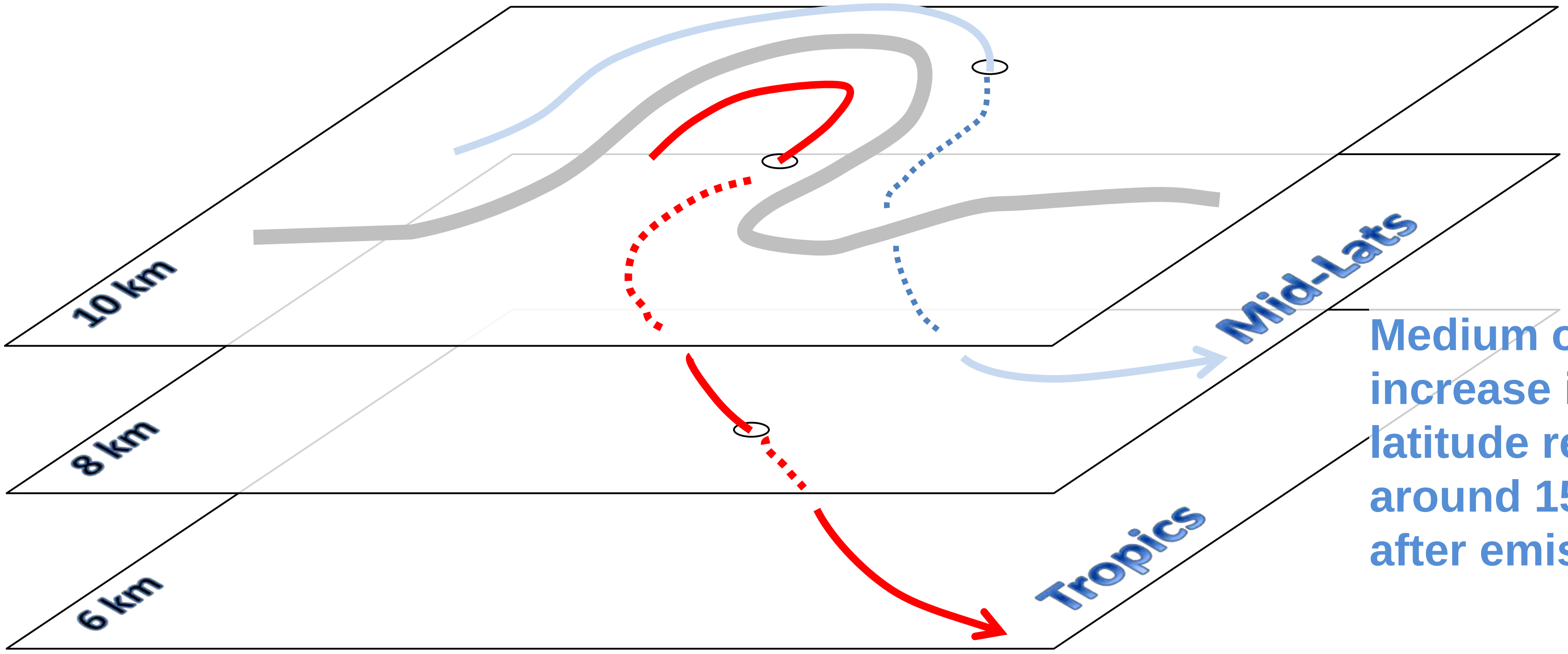
PDFs of the ozone gain latitude



- Emissions in the HPR have a faster ozone gain
- Large difference between HPR and location west of the HPR

Frömming et al. 2016

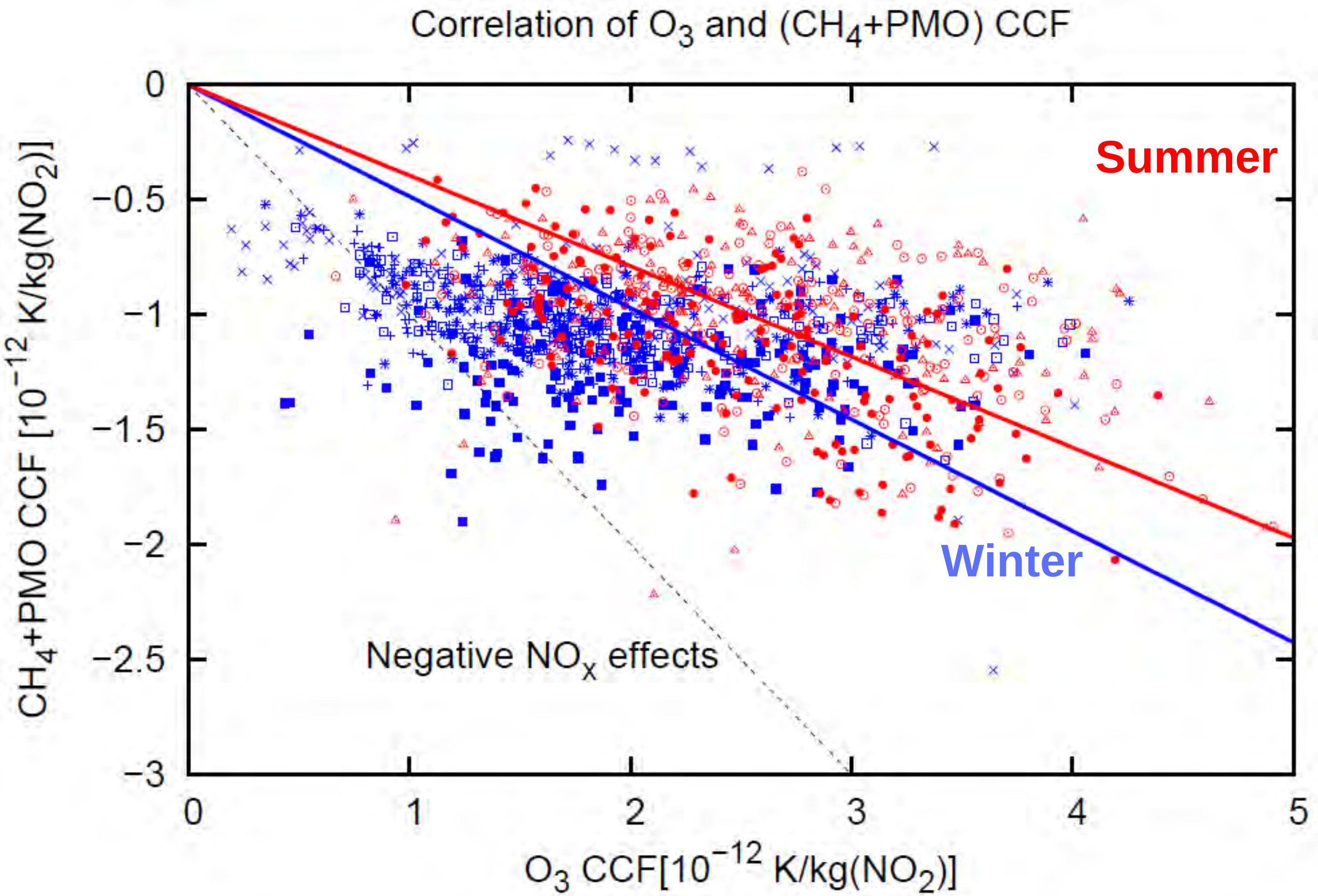
Ozone increase along trajectories



Medium ozone increase in mid-latitude regions around 15 days after emission

Large ozone increase in tropical regions around 10 days after emission

Large variety between ozone RF and methane climate impacts



- Larger ozone climate impact in summer
- Occasionally negative total NO_x impact

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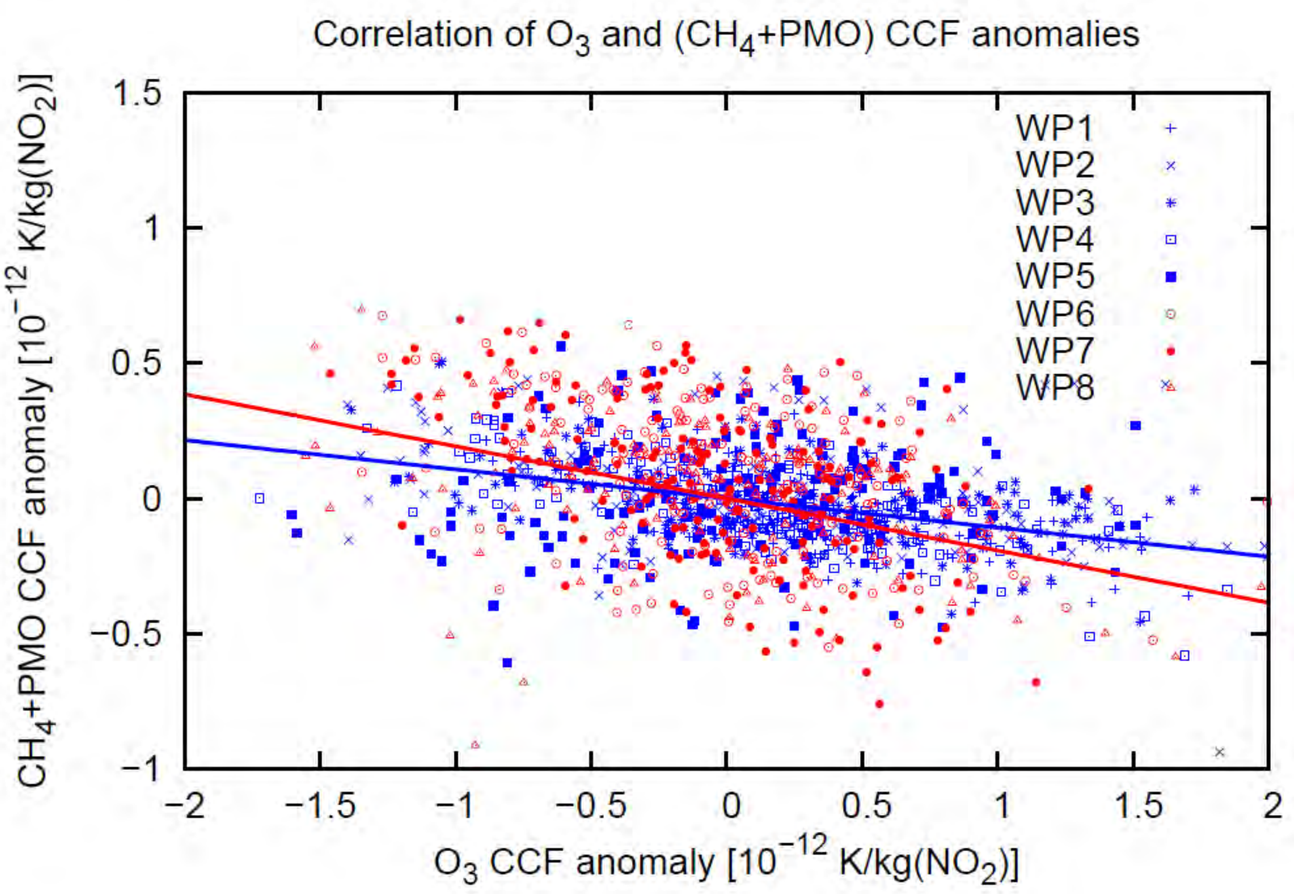
Ozone and Methane Anomalies wrt altitude and weather pattern



There is a tendency that NO_x, which produces a large ozone climate effects, also produces large negative methane effects.

However, large variability.

→ Future work

Frömming et al. 2016

Summary

- Large variations between ozone and methane climate response from aviation NO_x emissions for different
  - models
  - different regions (altitude / latitude)
  - emission location within a weather pattern
    - Largest ozone contribution 10 to 15 days after emission

- Variations result from different transport pathways
  - might be the reason for difference among models

- “IPCC-like” RF figure normally assume an immediate methane response. Only 65% remain when 12 year perturbation lifetime is taken into account (Myhre et al., 2011).