Aircraft emission effects on atmospheric chemistry and implications for routing options

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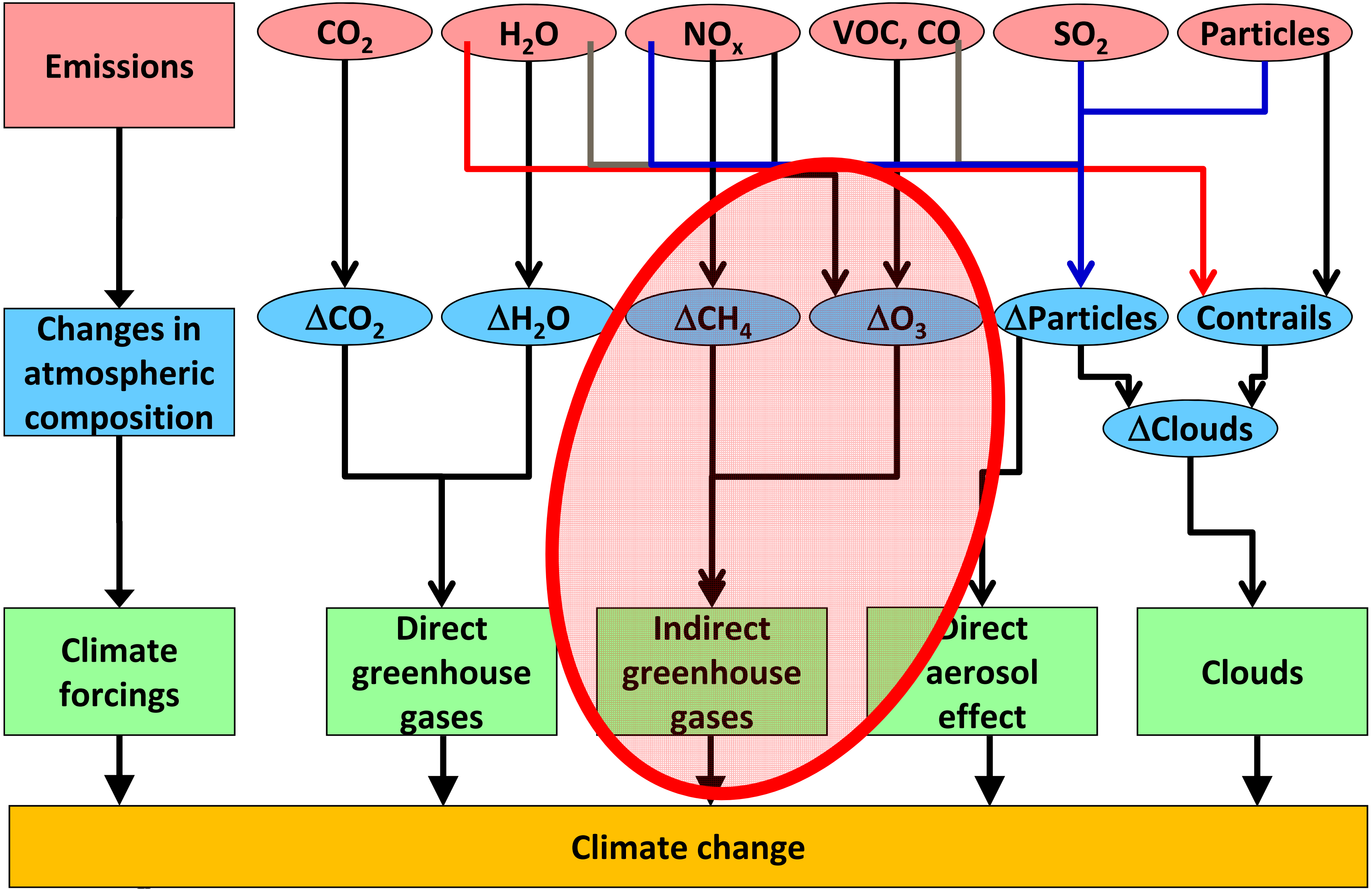
Atmospheric effects of aviation



Overview:

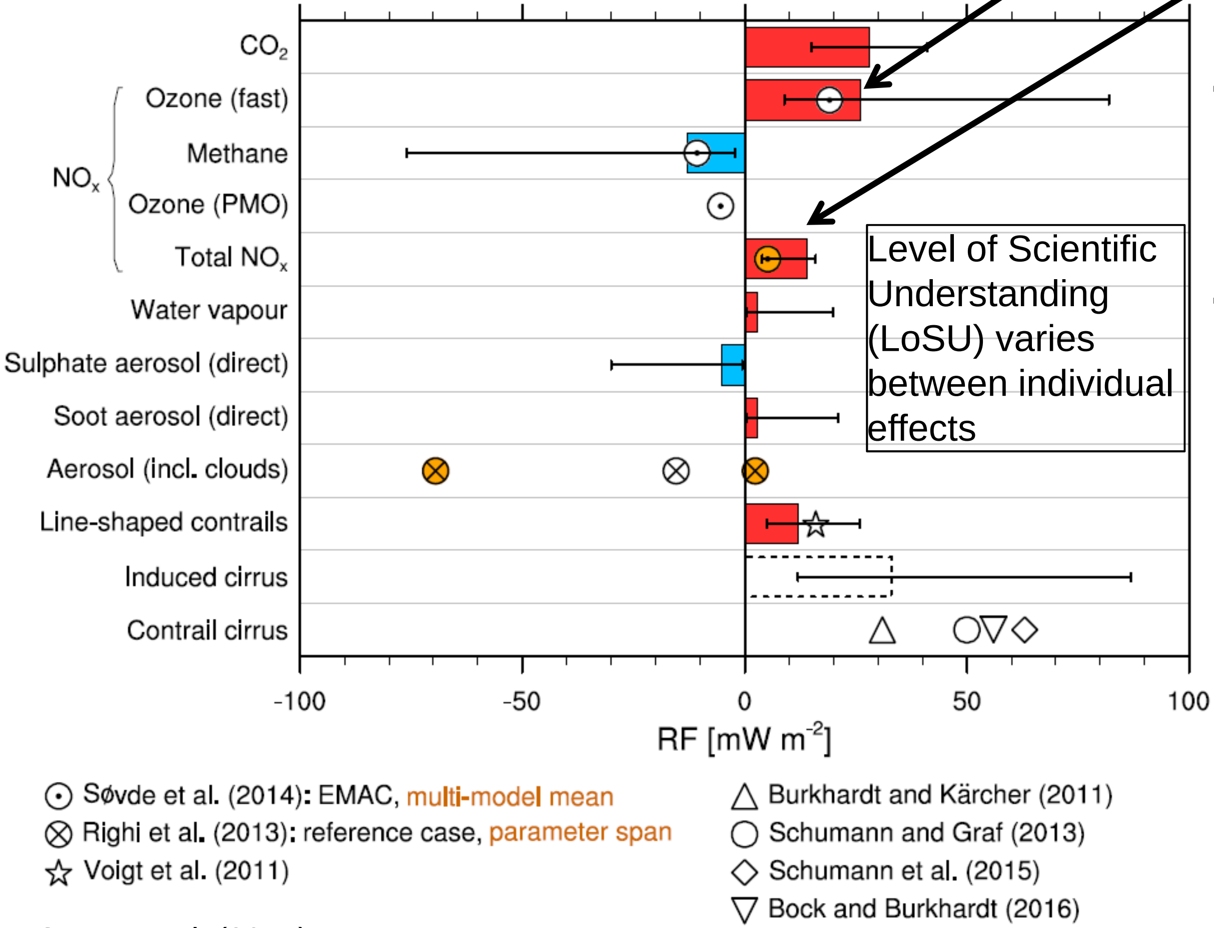
1.) Where is this ozone produced?

2.) News on total RF-NO_x: Is it really decreasing?

3.) Can we predict the RF-NO_x from weather forecasts?

4.) Climate-optimal routing: Updates

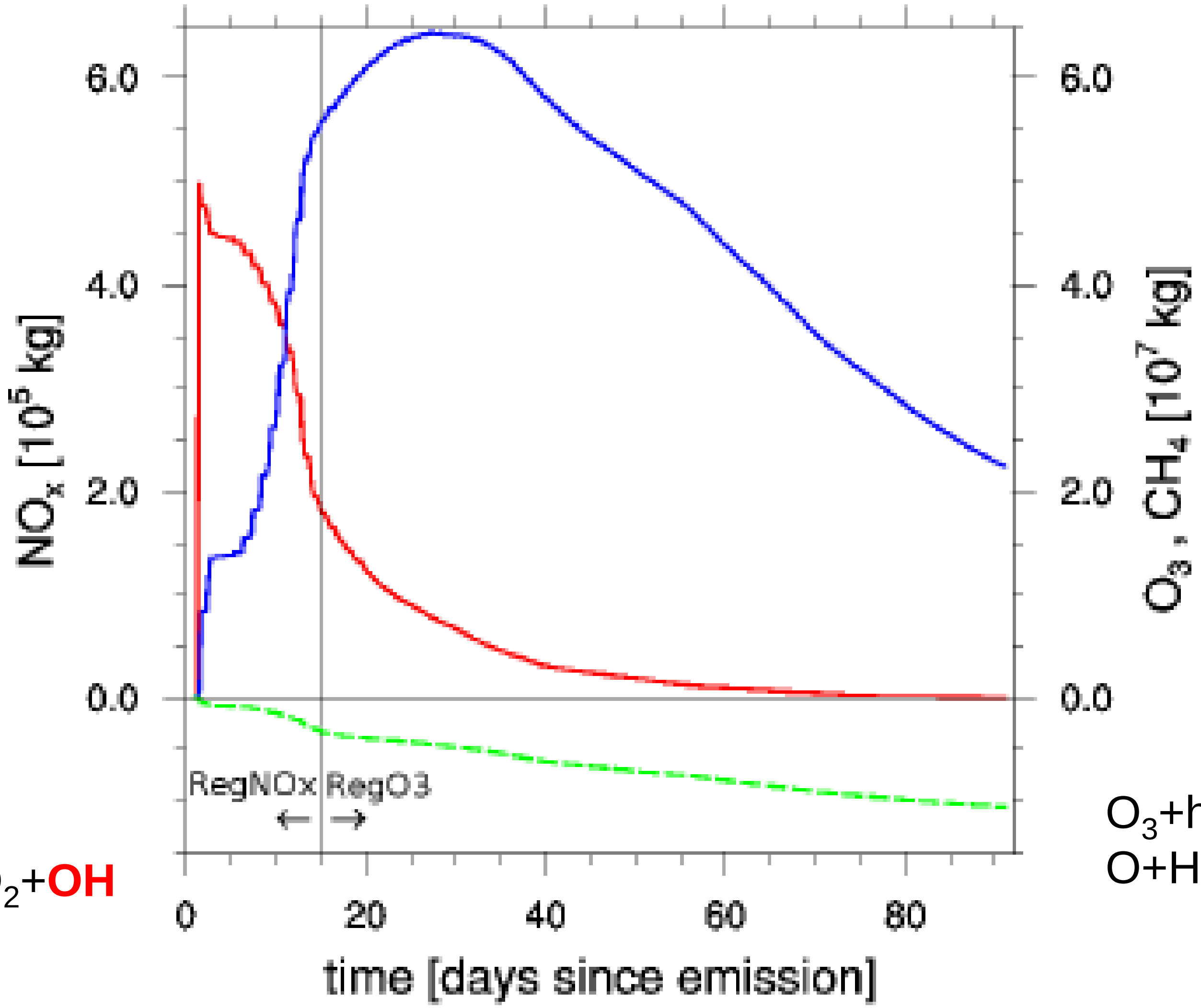
Radiative Forcing in 2005 from historical aviation emission



Grewe et al. (2017)

Data are based on Lee et al (2009) with update from various more recent publications

The NO_x-O_3-CH_4 chemistry



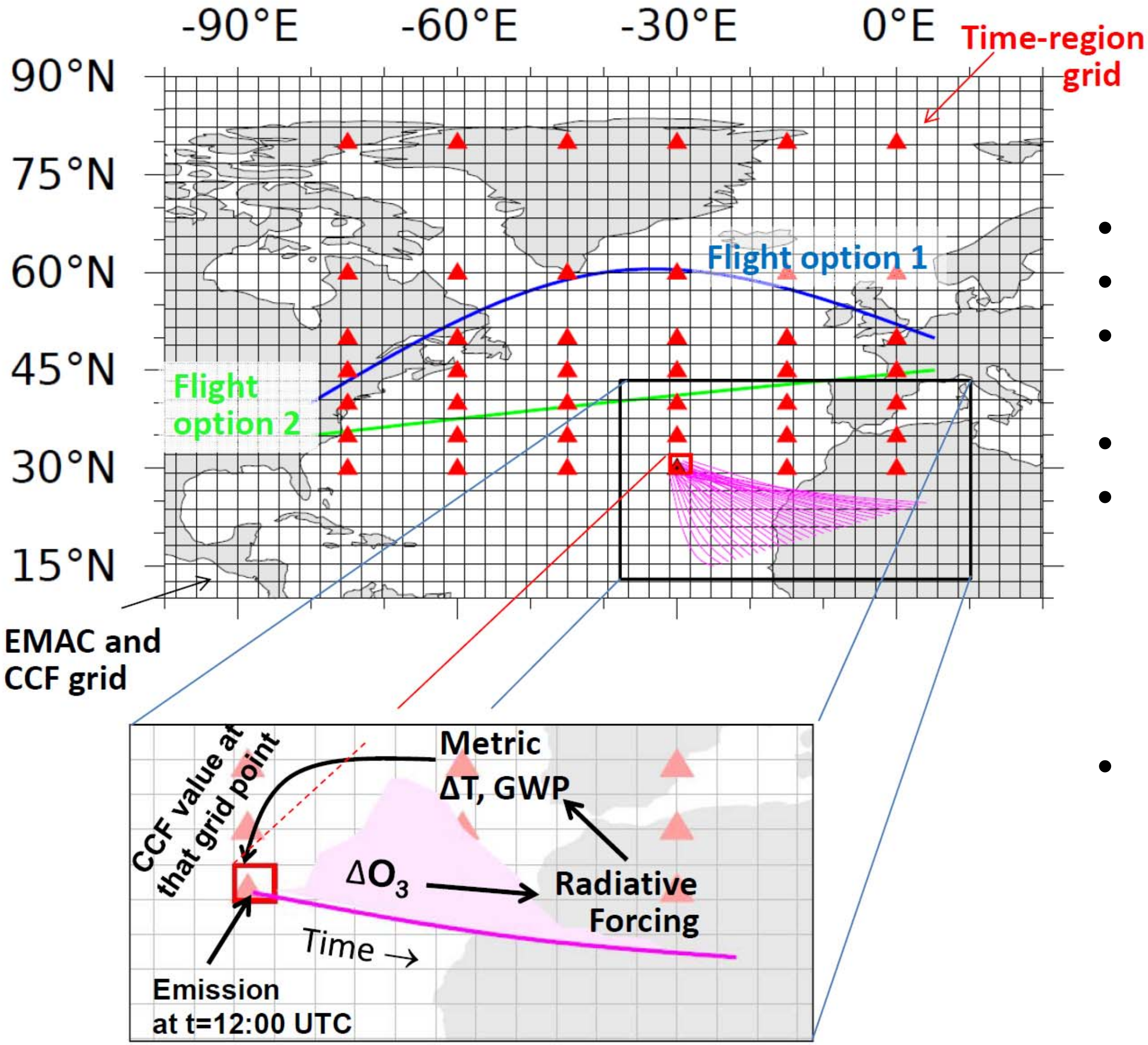
$NO+HO_2 \rightarrow NO_2+$**OH**

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

$O+H_2O \rightarrow 2$ **OH**

Grewe et al. GMD, 2017

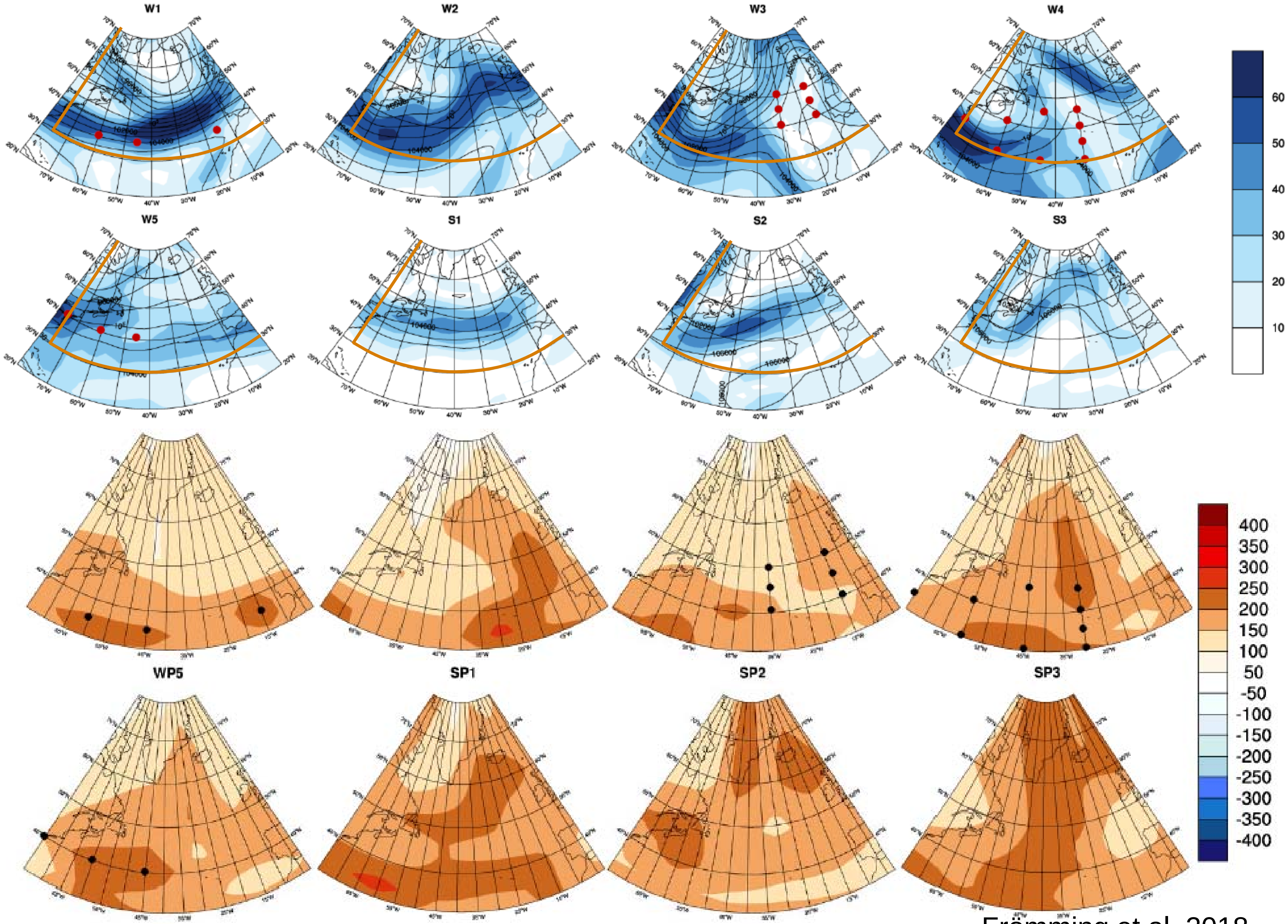
Modelling overview: Grids and processes



- Climate-Chemistry Model
- Locally confined emissions
- Transport calculation with trajectories
- NMHC chemistry
- Calculation of effects of NO_x emissions on
  - Ozone
  - Methane
  - Primary mode ozone
- Calculation of the change in climate metrics

Grewe et al.,GMD (2014)

Weather data and Ozone Climate-Change-Functions



Frömming et al. 2018

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**:

Ozone increase from t-Δt to t

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

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

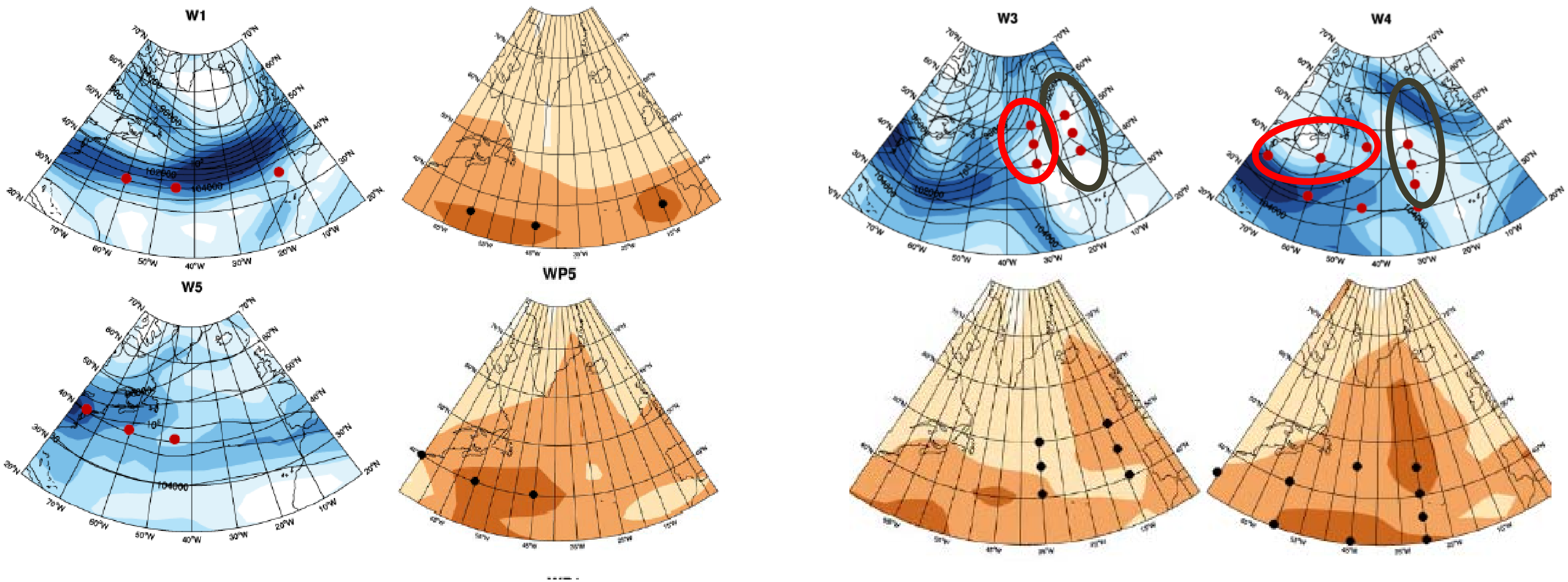
j: emission location

i: trajectory number

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

Frömming et al. 2018

3 Case studies:

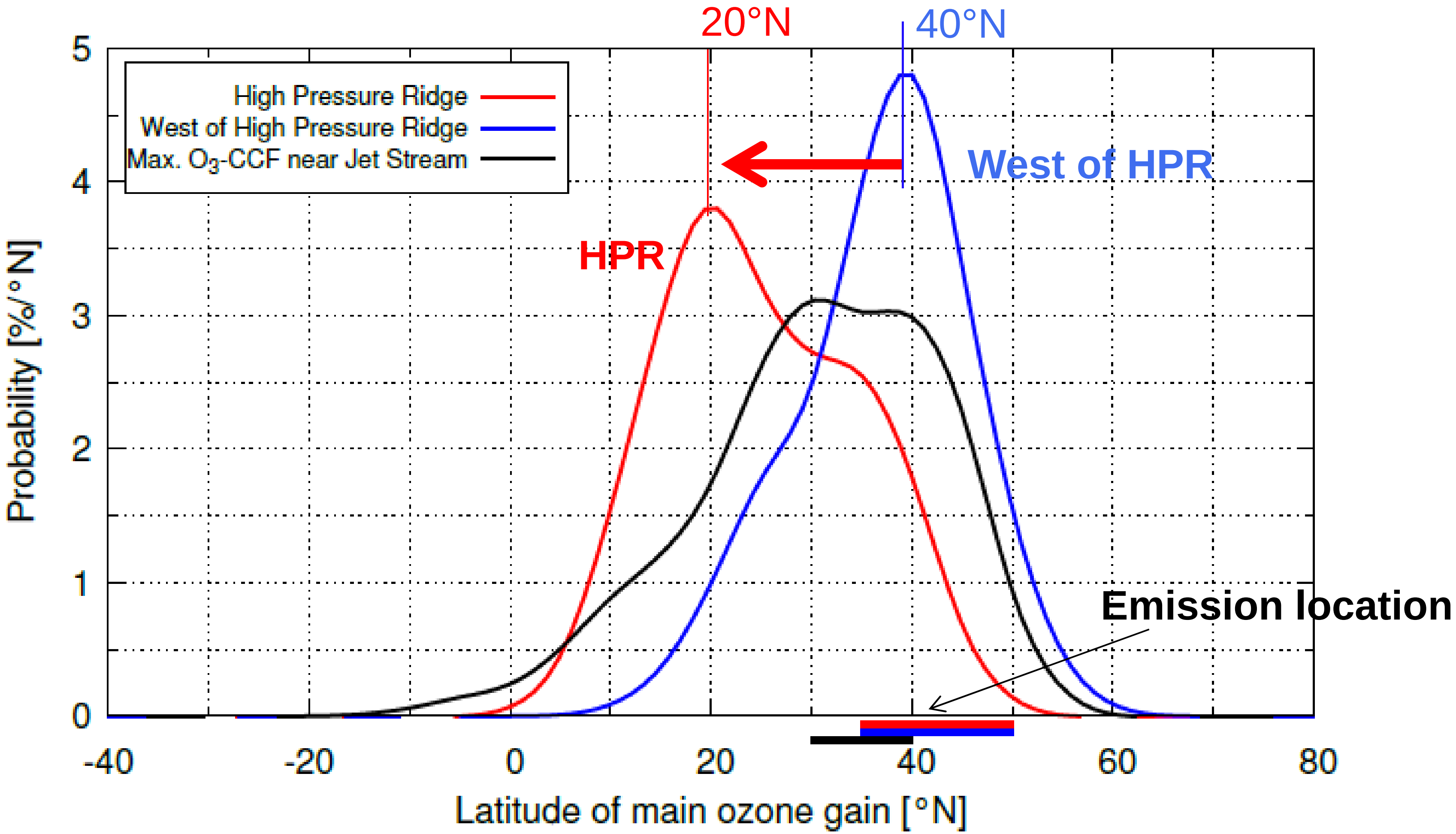


High pressure ridge (HPR)	**(300 trajectories)**
West of high pressure ridge	**(300 trajectories)**
Jet stream location	**(450 trajectories)**

Frömming et al. 2018

HPR=High Pressure Ridge

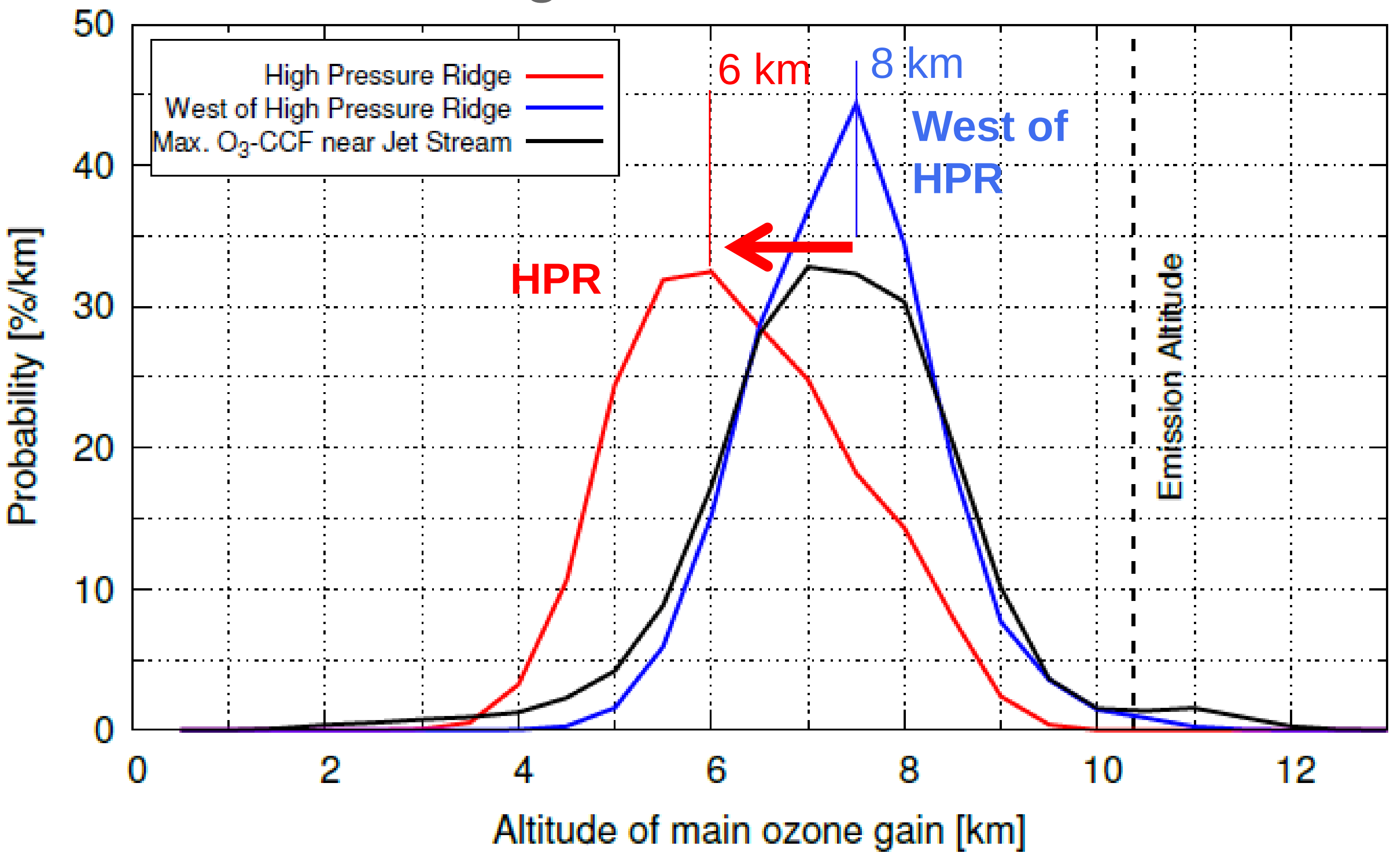
PDFs of the ozone gain latitude



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

Work by Rosanka Frömming et al. 2018

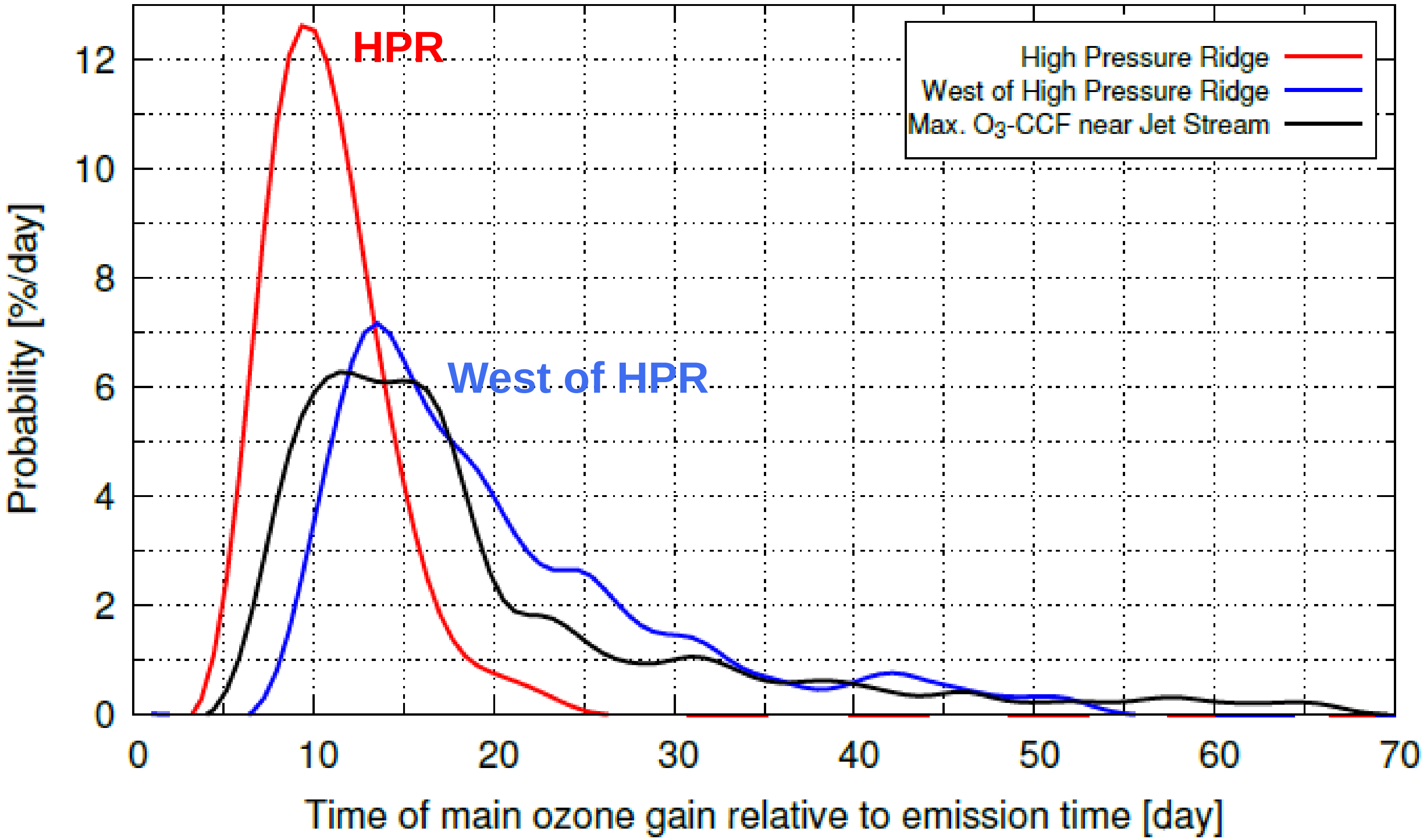
PDFs of the ozone gain altitude



- 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. 2018

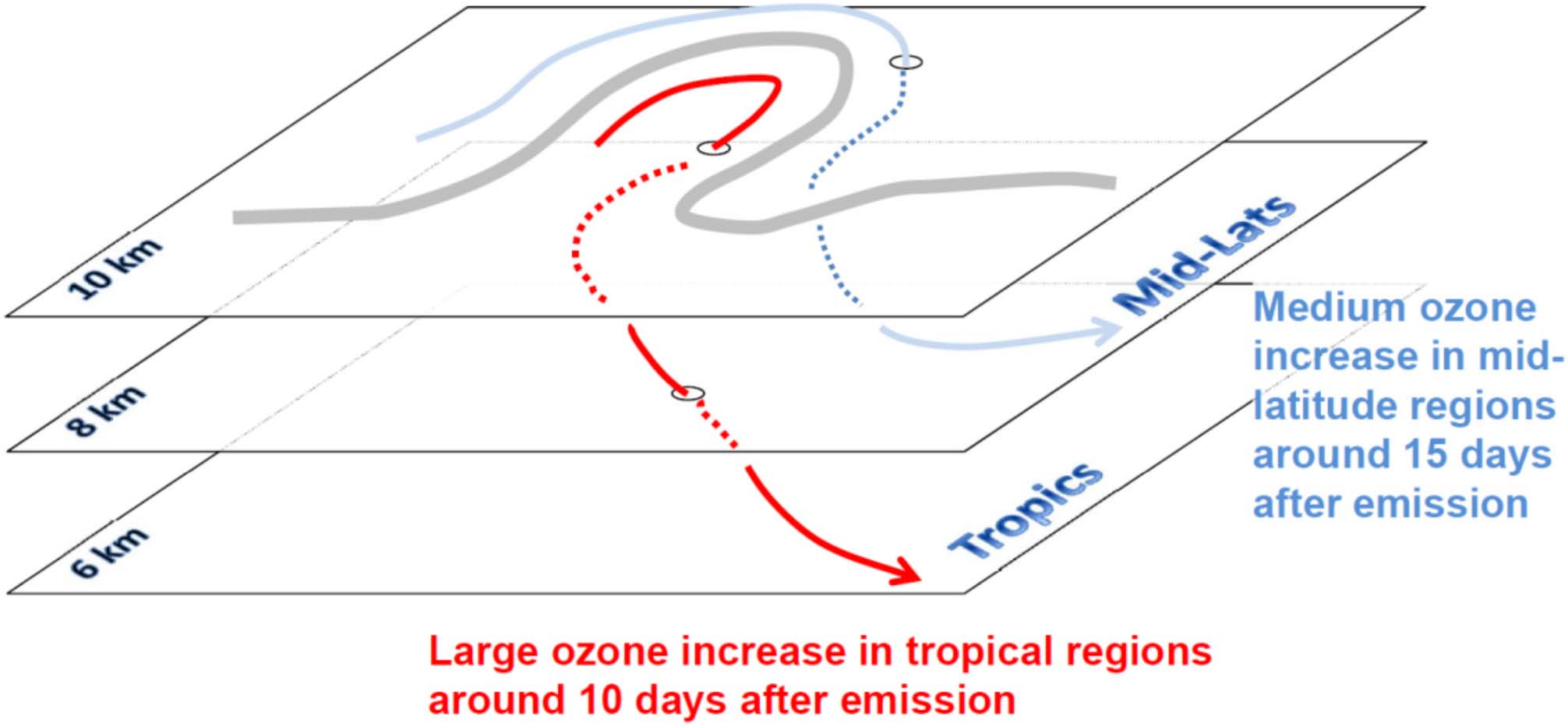
PDFs of the ozone gain latitude



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

Frömming et al. 2018

Ozone increase along trajectories



Frömming et al. 2018
Grewe et al. 2017

2. Part:
News on total RF-NO_x: Is it really decreasing?

Radiative Forcing from aviation NO_x Emission [mW/m^2]

	Lee et al. 2009	Additional Processes	Methane Lifetime
NO_x→Ozone	26.3		
NO_x→Methane	-12.5		
Methane→Ozone			
Methane→H_2O			
Total	13.8		

Radiative Forcing from aviation NO_x Emission [mW/m^2]

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NO_x→Ozone	26.3	26.3	
NO_x→Methane	-12.5	-12.5	
Methane→Ozone		~ -4.0	
Methane→H_2O		~-2.5	
Total	13.8	7.3	

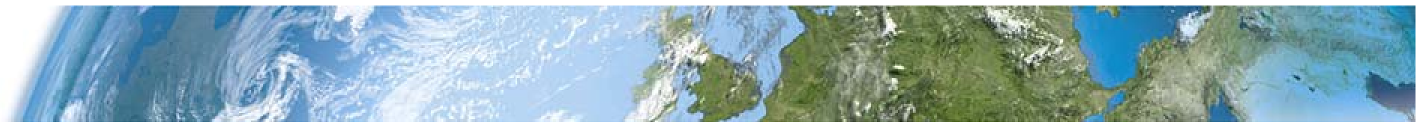
Radiative Forcing from aviation NO_x Emission [mW/m^2]

Methane has a perturbation lifetime of 12 years
Here a steady-state is assumed: Methane responses immediately to NO_x emission
Myhre et al. (2011) (QUANTIFY): Taking the lifetime into account, delays the impact

	Lee et al. 2009	Additional Processes	Methane Lifetime
NO_x→Ozone	26.3	26.3	26.3
NO_x→Methane	-12.5	-12.5	-8.1
Methane→Ozone		~ -4.0	~ -2.6
Methane→H_2O		~-2.5	~-1.6
Total	13.8	7.3	14.0

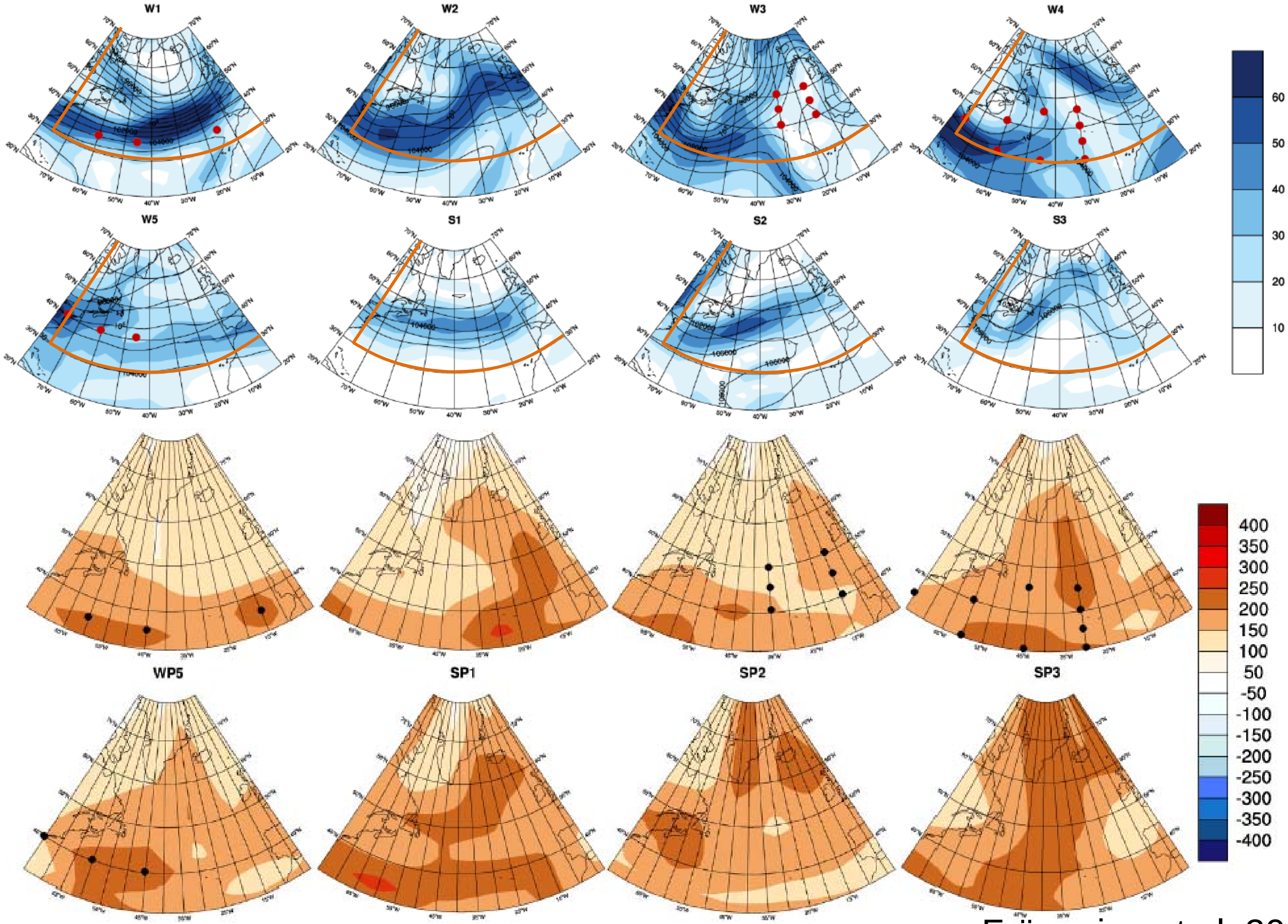
Summary:
- New processes (Methane→Ozone/H_2O) reduce NOx RF
- Appropriate consideration of methane lifetime enhance NOx RF
- EI-NOx generally increases
- Fuel consumption increases

NO_x emissions are relevant



3. Part:
Can we predict the RF-NO_x from weather forecasts?

Weather data and Ozone Climate-Change-Functions



Frömming et al. 2018

Algorithmic Climate Change Functions

ATM4E SESAR JOINT UNDERTAKING

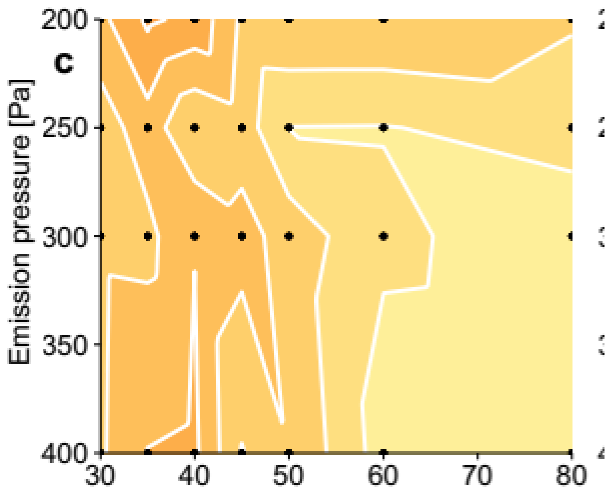
Detailed calculation of Climate Change Functions

↓

Correlation with with weather data at time and location of the emission

↓

Algorithmic Climate Change Functions

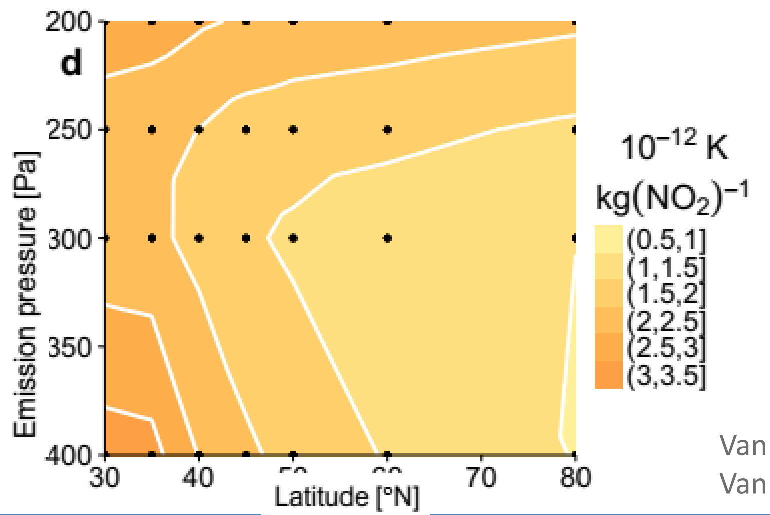


NO_x-Ozone Climate Change Function

Temperature

$$\mathrm{a\widetilde{CCF}}_{O_3}(T,\Phi) = -5.20\times10^{-11} + 2.30\times10^{-13}\times T + 4.85\times10^{-16}\times\Phi - 2.04\times10^{-18}\times T\times\Phi$$

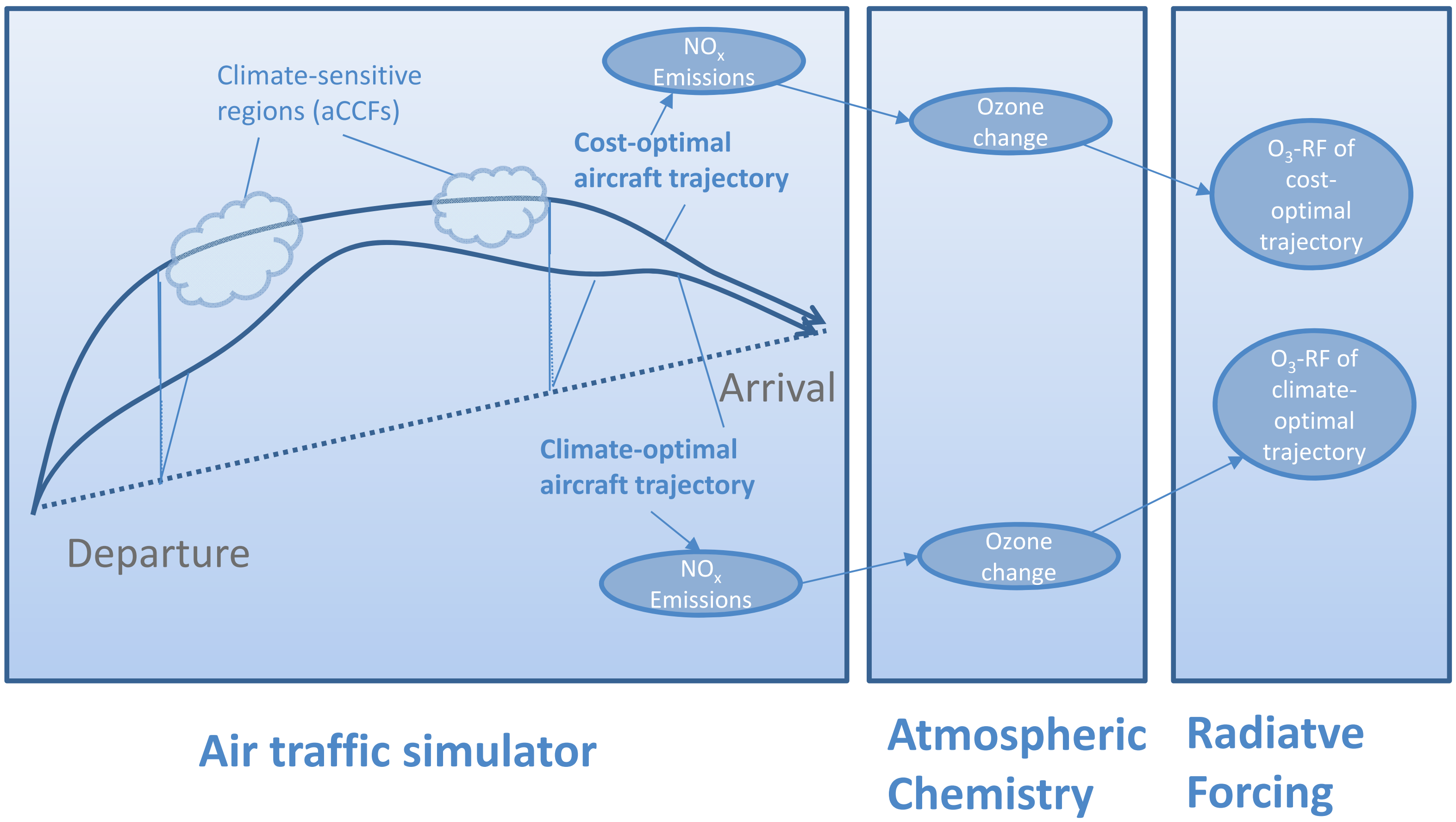
Geopotential



Van Manen (2017)

Van Manen and Grewe (2018)

Verification of the Algorithmic Climate Change Functions: Approach



Yin et al. (2018)

Verification of the Algorithmic Climate Change Functions: Model

Earth-System Model EMAC

ECHAM5/MESSy2.52 Atmospheric Chemistry Model

Including:

Air Traffic Simulator: AirTraf 1.0

- Aircraft/engine performance
- Flight plan
- Optimizer: Genetic algorithm
- Fuel/Emissions

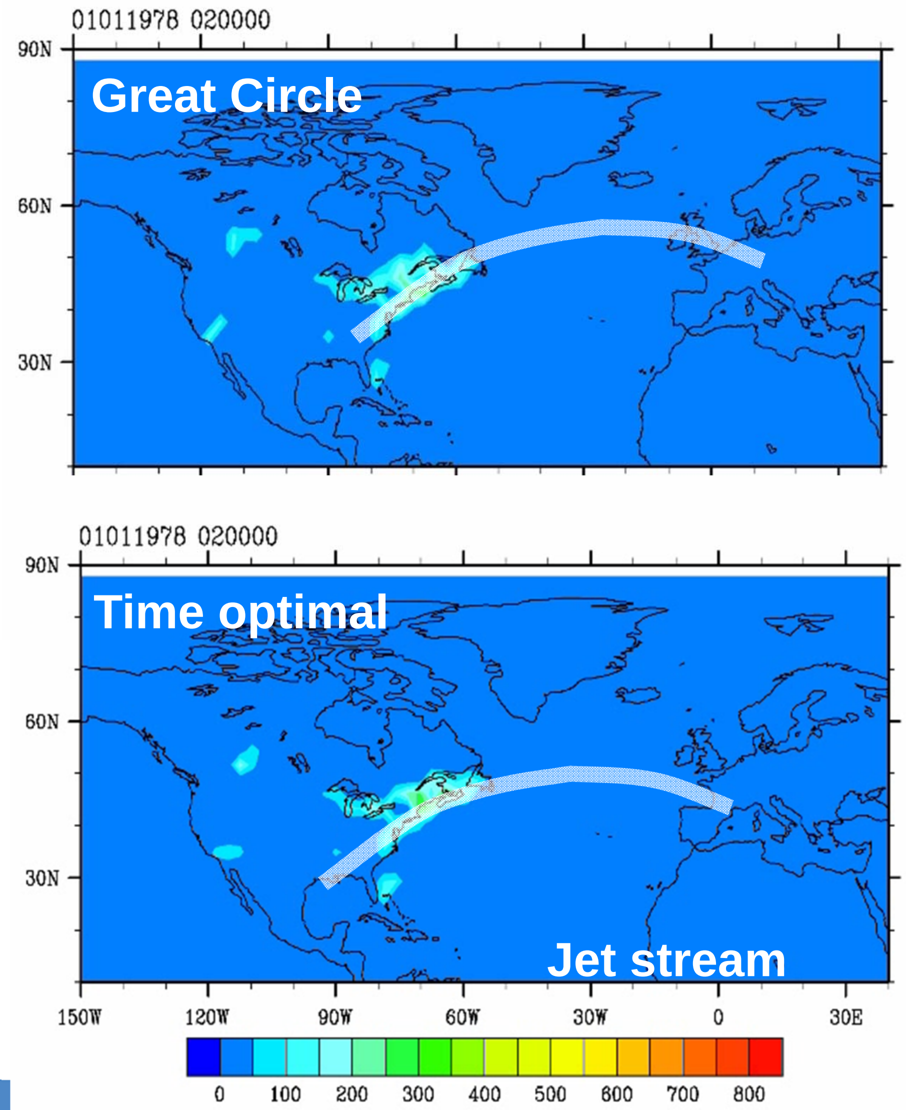
Chemistry

- NMHC Chemistry (MECCA)

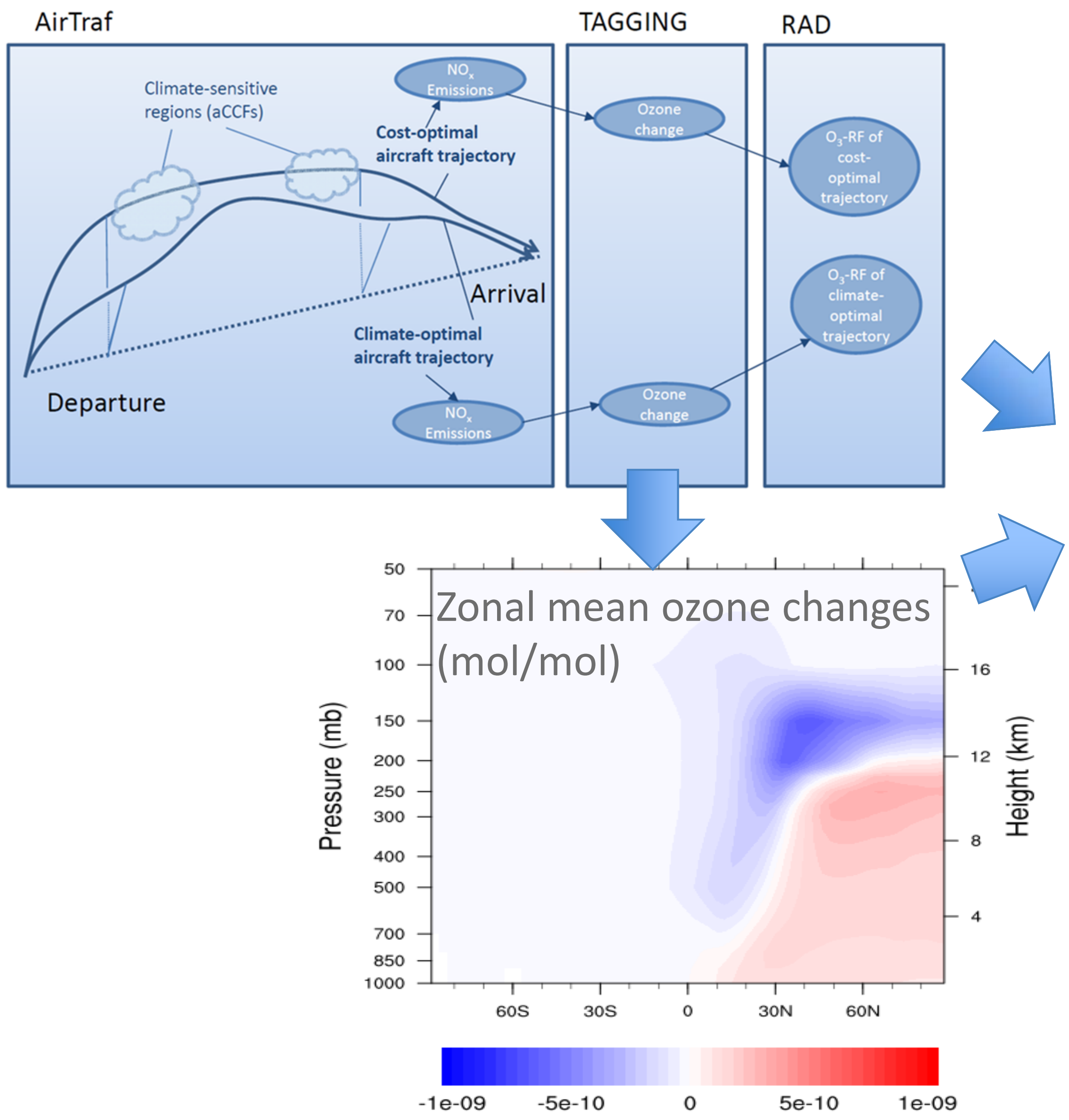
Diagnostics

- Tagging scheme

Yamashita et al. (2016)



Verification result



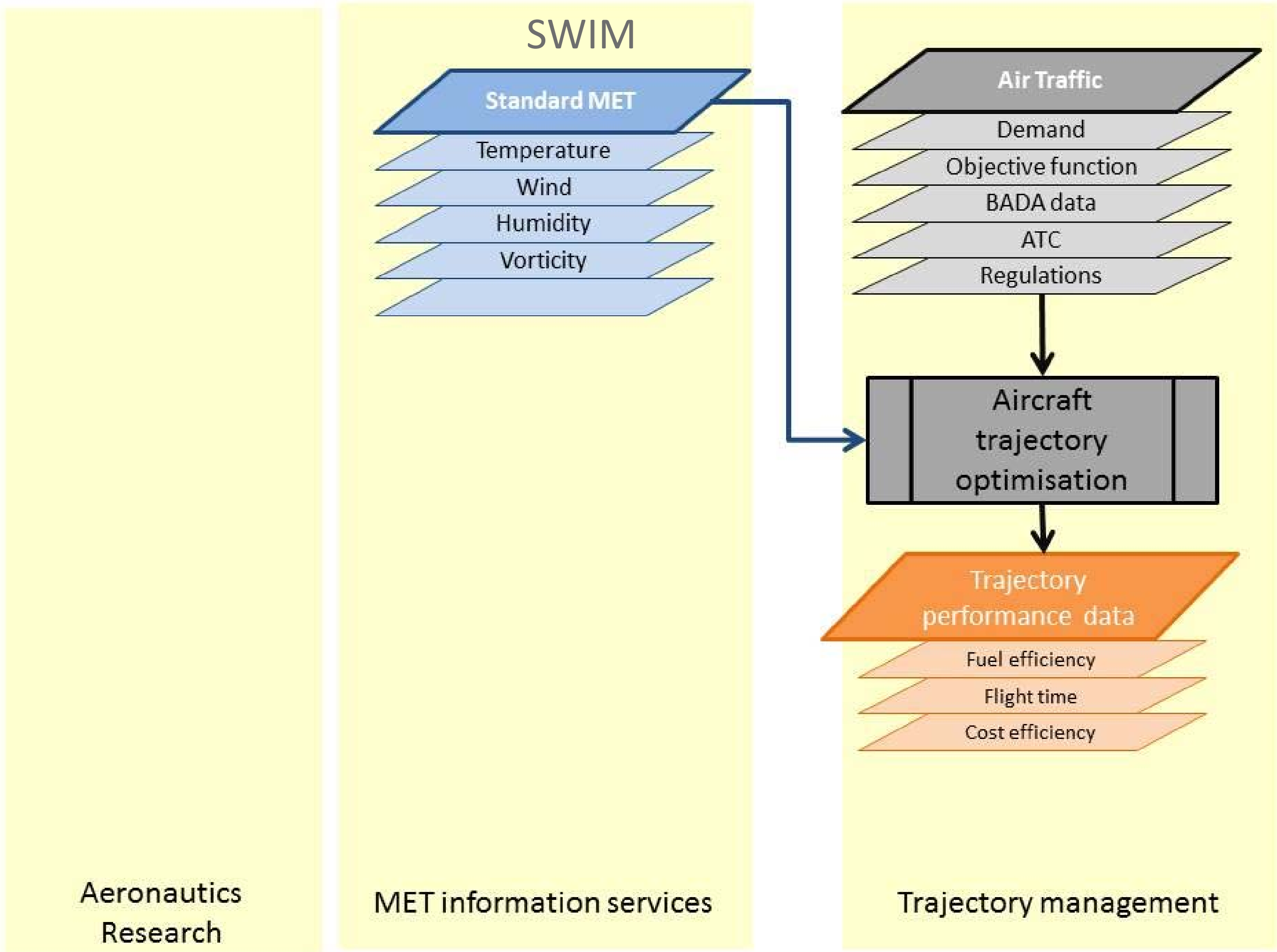
RF: -2%

The trajectories optimized using ozone aCCFs actually reduce the ozone climate impact.
⇒ **Proof of Concept**

Yin et al. (2018)

Air traffic management for environment: SESAR/H2020-Project ATM4E

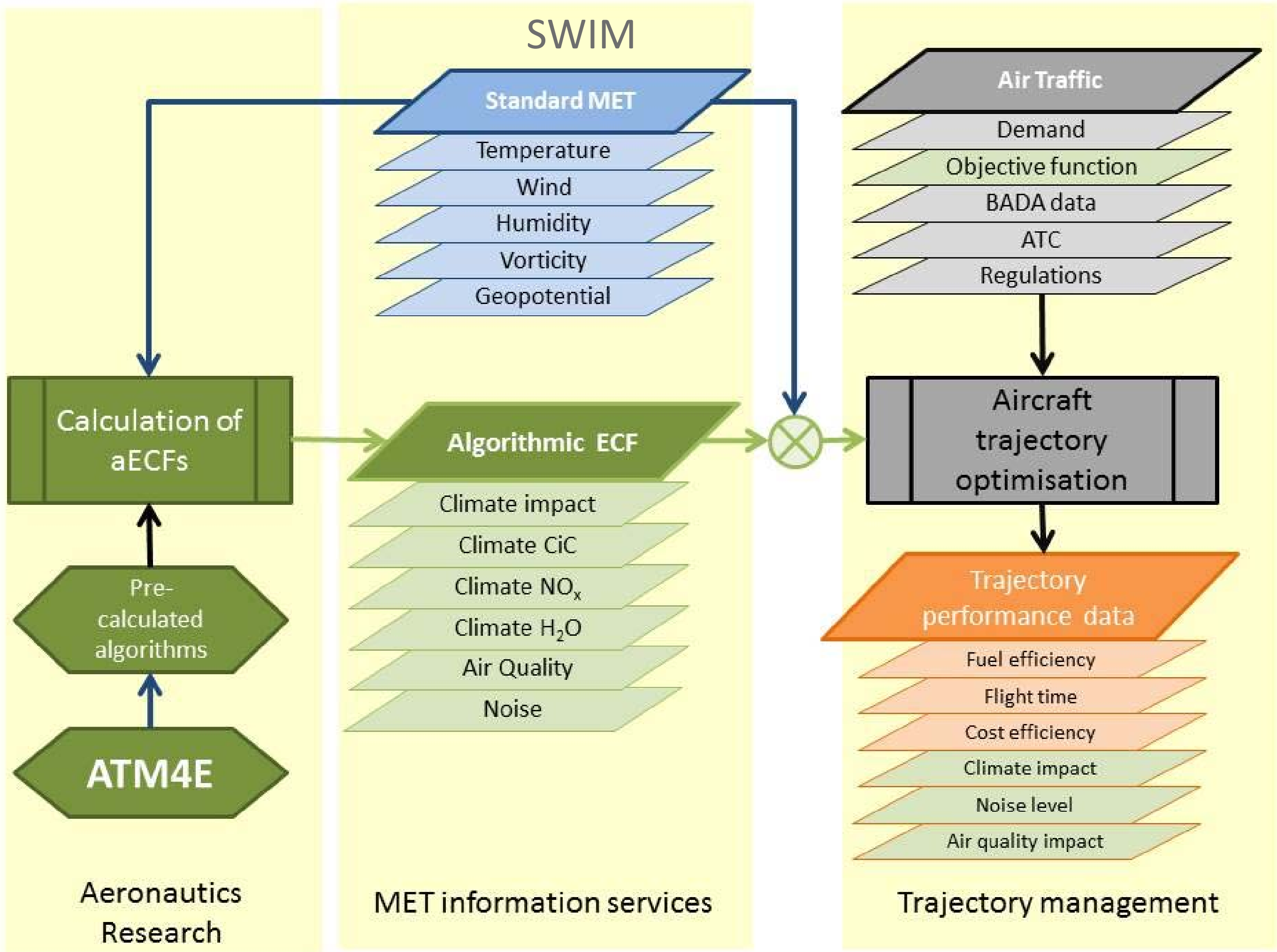
Current situation



Matthes et al. (2017)

Air traffic management for environment: SESAR/H2020-Project ATM4E

Contribution of ATM4E



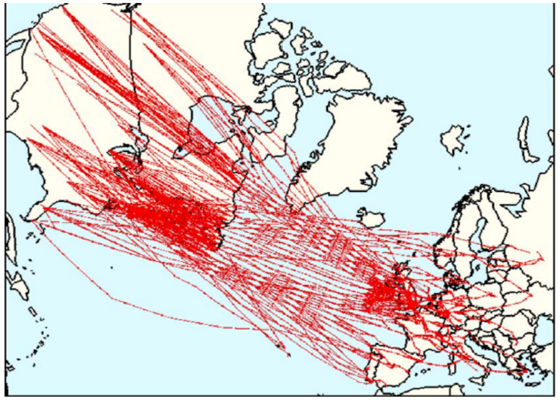
Matthes et al. (2017)

4. Part:
Climate-optimal routing: Updates

Avoiding climate sensitive regions: The approach

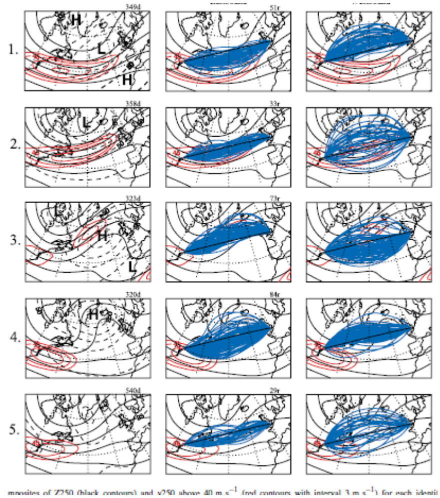
Traffic scenario:

Roughly 800 North Atlantic Flights



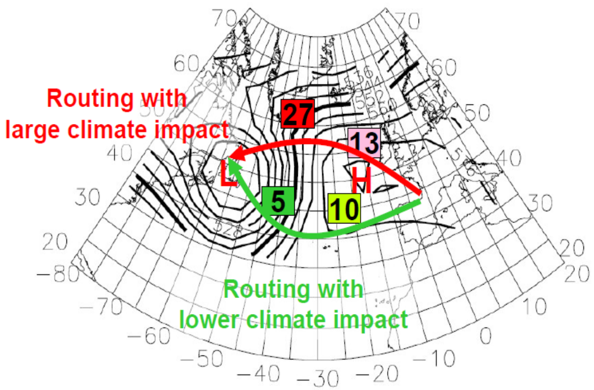
Respresentative weather situations

Climatology based on Irvine et al. (2013)



Climate-Change Functions

Contrails, O_3, CH_4, H_2O, CO_2



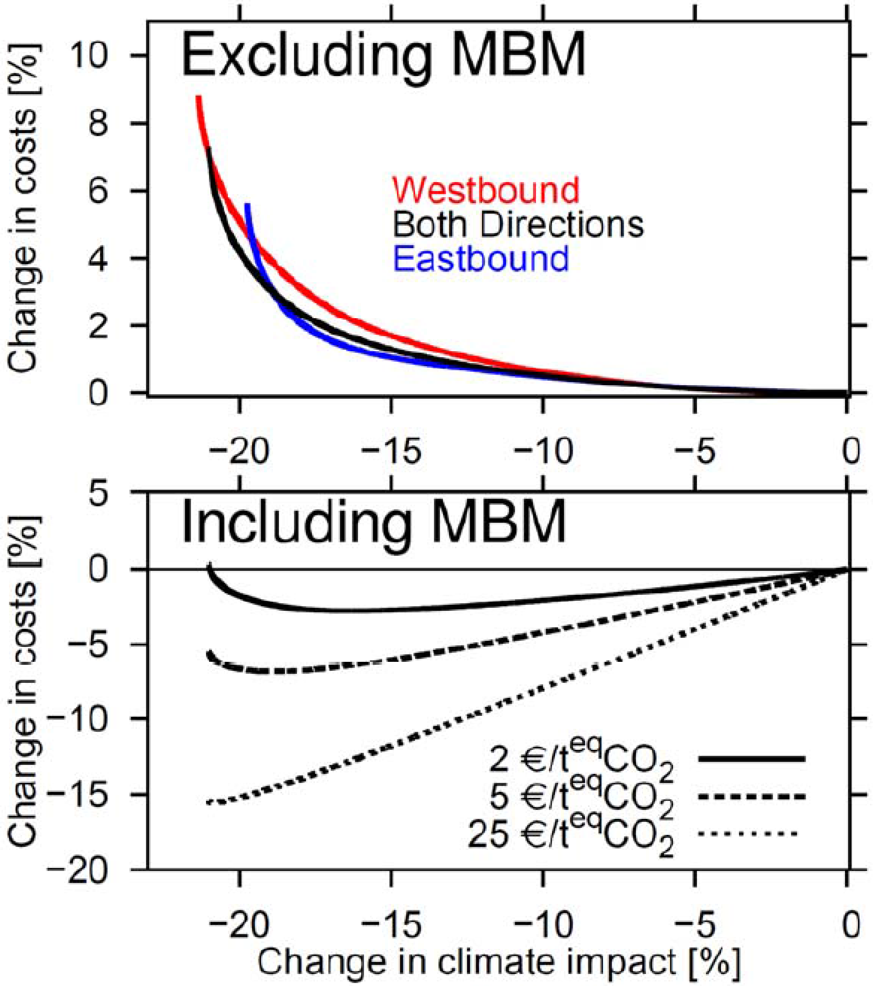
Traffic optimisation:

With respet to costs and climate

EUROCONTROL

DLR

Climatology based on 8 representative weather pattern



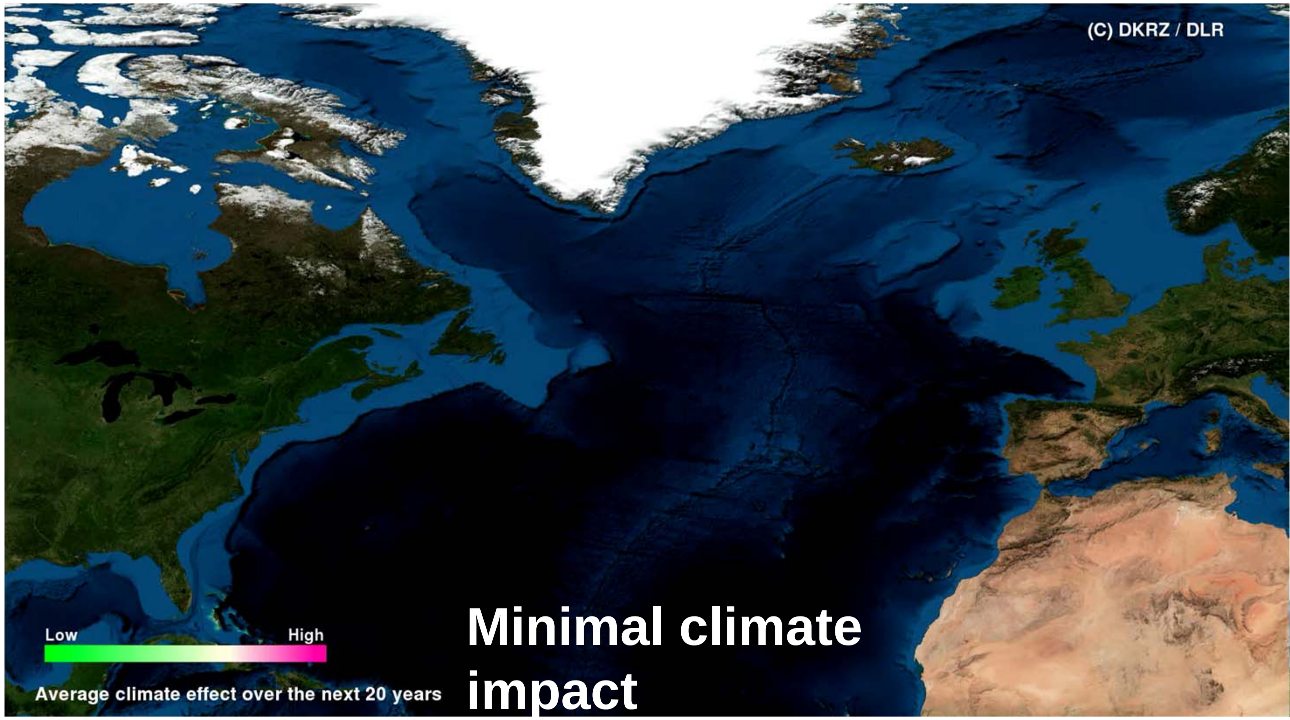
- Very flat Pareto-Front
  ⇒ Large benefits at low costs

- Market based measures (MBM) would enable climate optimised routing, if non-CO_2 effects were taken into account.

Grewe et al., ERL (2017)

Example: New York - London

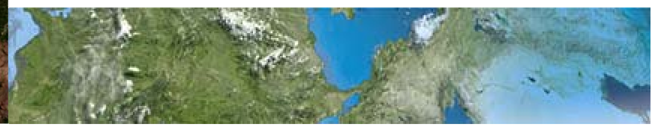
Clear difference between West- and eastbound traffic



Larger overlap of routes

Fleet basis

- Only small differences visible
- Smaller flight corridor
- Difference between flights from and to Europe



Summary

- NO_x has a different impact on climate, depending on where it is emitted within a weather system.
- Taking into account new processes (PMO, Strat H_2O) and corrections in the CH_4 calculation: NO_x-RF should be in the same order as in the 2009 Lee assessment.
- NO_x impact on ozone is largely driven by initial transport pathway: algorithmic climate-change functions
- Verification shows a proof of concept on the basis of an ESM including an air traffic simulator.
- Avoiding climate sensitive regions leads to a reduction of the aviation's climate impact at relatively low costs (eco-efficient).
- A couple of important questions remain before it may become operational
- Outlook: Forecasting of non-CO_2 effects on a daily basis,

Conferences:
2013 (Berlin),
2016 (Athens)
June 2019 planned

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- www.ecats-network.eu

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ECATS Strategic Activities

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