Climate Met Service for climate-optimized trajectory planning

Simone Dietmüller[1], Sigrun Matthes[1], Patrick Peter[1], Christine Frömming[1] and Dennis Piontek[2]

1 DLR, Institute of Atmospheric Physics, ESM department
2 DLR, Institute of Atmospheric Physics, Cloud Physics department

7-8 November 2023

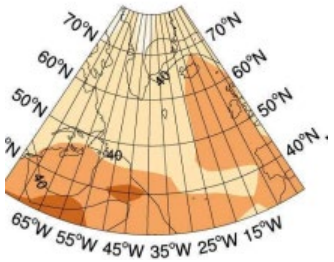
EUROCONTROL's Brussels HQ

Climate MET Service

Climate MET service tailored to individual needs of trajectory planning tools, considering **CO_2 and non-CO_2 effects** of aviation -> provide **climate effect of aviation emissions at a specific location and time**

Climate MET Service tools (DLR)

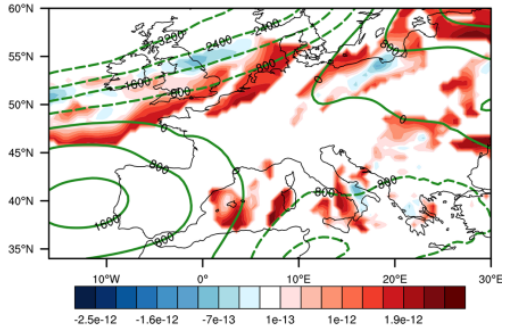
Climate Change Functions, CCFs (Lagrangian Simulation in CCM)



- Climate effects of contrails, NO_x, H_2O
- **computational expensive**

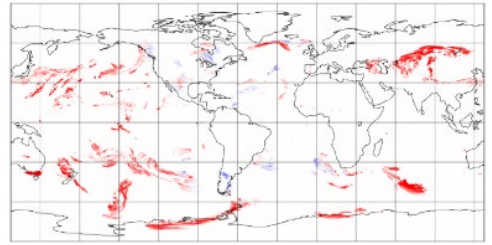
Suitable for trajectory planning

algorithmic Climate Change Functions, aCCFs (mathematical algorithmus)



Climate effects of contrails, NO_x and H_2O

Gridded Contrail Cirrus Prediction Tool, CoCiP (Lagrangian plume model)

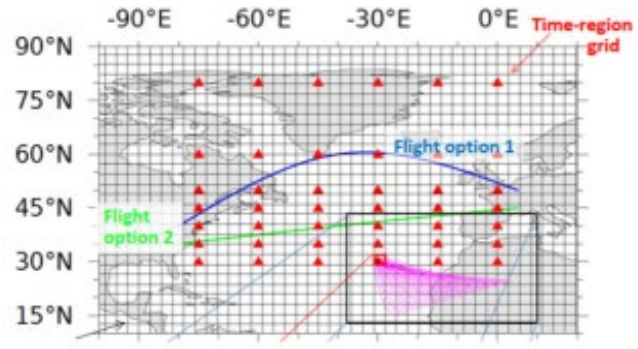


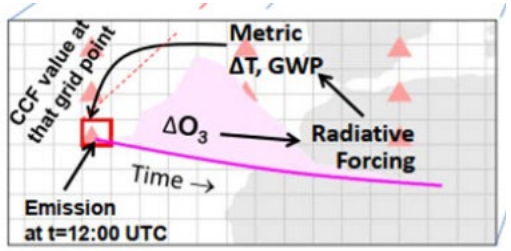
Climate effects of contrails

EUROCONTROL CANSO

Climate Change Functions (CCFs)

Calculation by comprehensive Lagrangian simulations in a climate-chemistry-model:



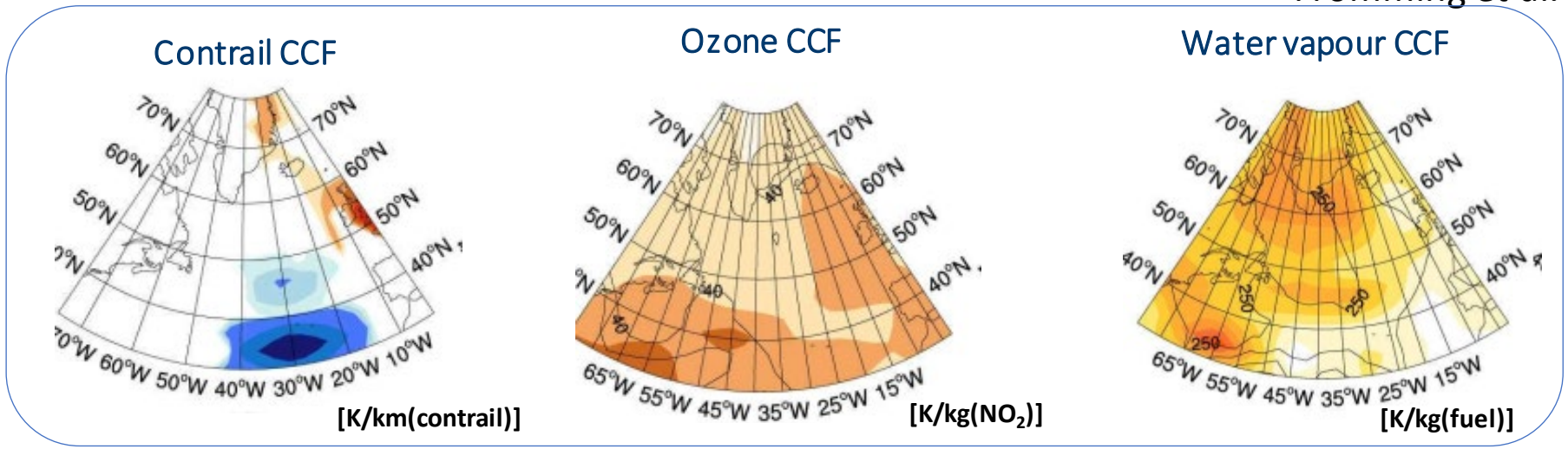


→ Climate effect at specific location and time

Climate change functions (CCFs)

Frömming et al. 2021

respresentive winter weather situation, North Atlantic, 250 hPa

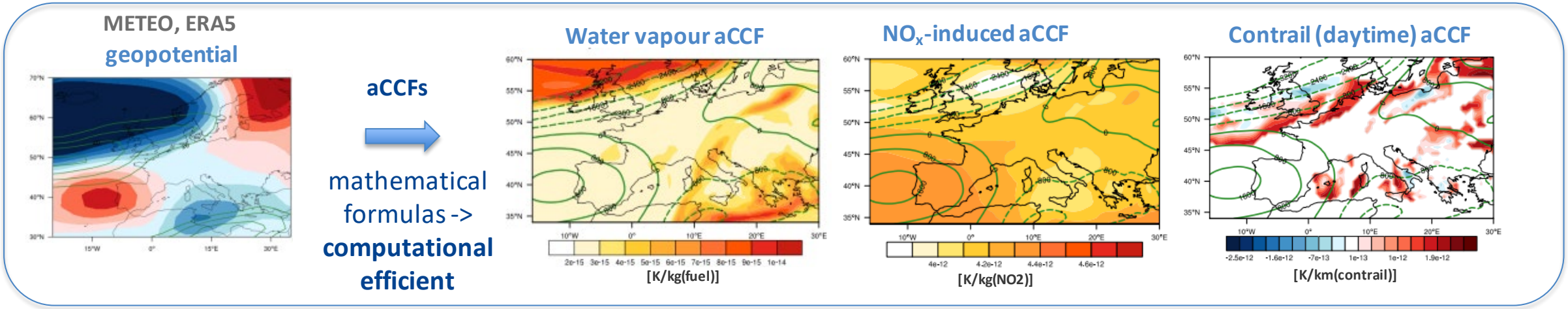


Calculation of CCFs computational expensive -> not suitable as MET Service
-> Development of aCCFs

EUROCONTROL CANSO

Algorithmic Climate Change Functions (aCCFs)

- Prototype algorithmic climate change functions (aCCFs) of non-CO_2 effects give **climate effect of aviation emissions at a specific location and time** (in terms of average temperature response ATR).
- aCCFs provided for contrail-cirrus, water vapour, NO_x-induced changes of ozone and methane.
- aCCFs based on meteorological parameters. Can be calculated from e.g. numerical weather prediction data.



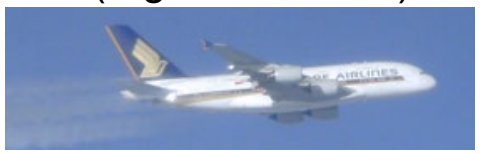
- Open source Python Library CLIMaCCF; Release & scientific publication (Dietmüller et al., 2023)
- **aCCF-V1.0A**: updated formulation of aCCF considering current level of scientific understanding of aviation's climate effects (Matthes et al. 2023)

Contrail Cirrus Prediction Tool (CoCiP)

Input:

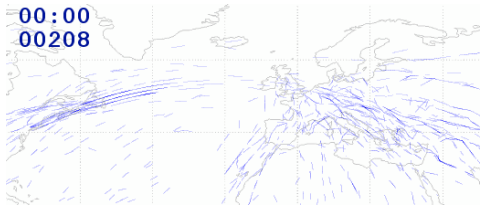
Aircraft data

(e.g., BADA, PS)



Movements

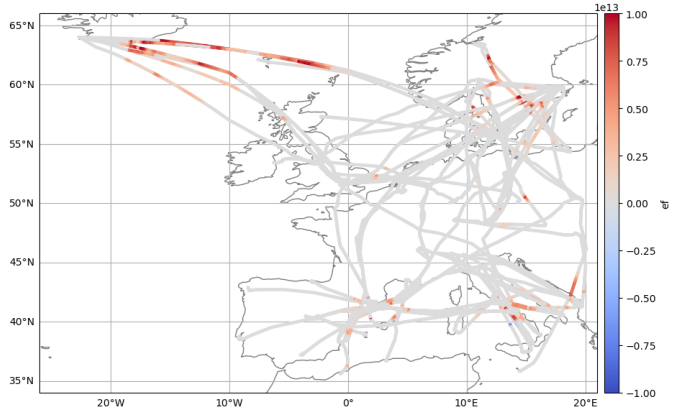
(ATM data, e.g., from Eurocontrol, Spire)



Meteorology

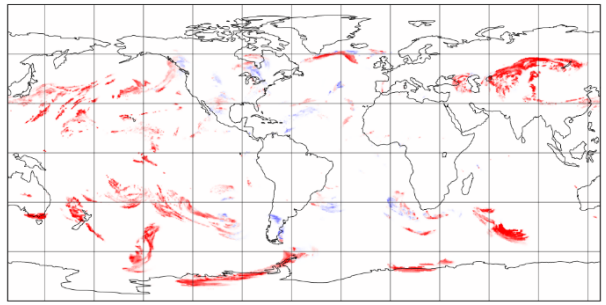
(wind, temperature, specific humidity, ice water content, radiation, etc., e.g., from ECMWF)

Contrail Cirrus Prediction Tool (CoCiP)



fast, parameterized model of contrail formation, lifecycle and properties

Gridded CoCiP



CoCiP applied to small generic flight segments in each grid cell

Usage:

Contrail prediction & mitigation

Schumann et al. (2015),
Teoh et al. (2020, 2022a,b, 2023)

Comparison with observations

Schumann et al. (2013),
Schumann & Graf (2013),
Schumann et al. (2017),
Voigt et al. (2022),

Sensitivity studies

Schumann et al. (2021a,b)

CoCiP has been reimplemented in Python by Breakthrough Energy and became open source → https://py.contrails.org/

Schumann, 1996, 2012;
Schumann et al., 2011, 2012

EUROCONTROL CANSO

Difference in Data Architecture: aCCF & CoCiP

NWP Input Data

Software requirements

MET Product (Contrail)

aCCF

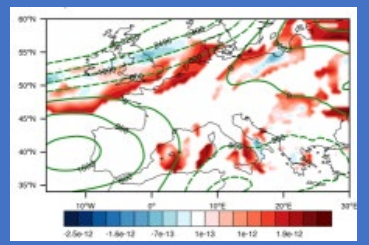
Time t=0

Geopotential, OLR, temperature, Pot. Voricity

Mathematical formula

Different assumptions on e.g. contrail life time, contrail properties, number of started trajectories …

Climate effect (4D) of contrail, H_2O, O_3, CH_4 (ATR in K/kg(fuel)



Gridded CoCiP

Time t=0

Time t=2

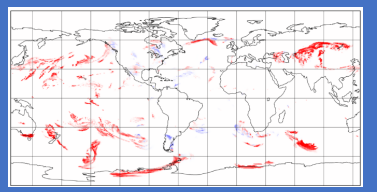
⋮

Time t=n

wind, temperature, specific humidity, ice water content, radiation

Lagrangian plume model applied to small generic flight segments in each 4D grid cell

Climate effect (4D) of contrail (energy forcing J or J/m)



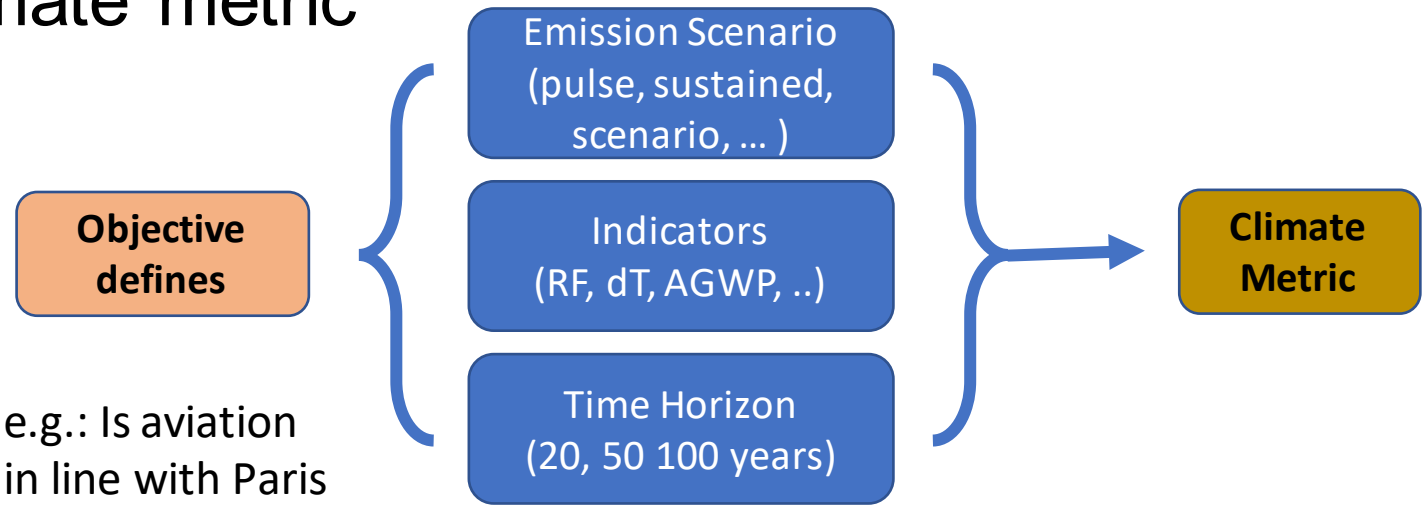
CICONIA EUROCONTROL CANSO

Requirements for Climate MET Services

- Capabilities and limitations clearly described:

	Contrail aCCF /aCCFs	gridded CoCiP
Usage	developed only for North-Atlantic Flight corridor	Worldwide
Other non-CO_2 effects	available for non-CO_2 effects of H_2O, NO_x	No

- Quantitative measure of climate effect provided in a commonly used physical climate metric



e.g.: Is aviation in line with Paris Agreement?

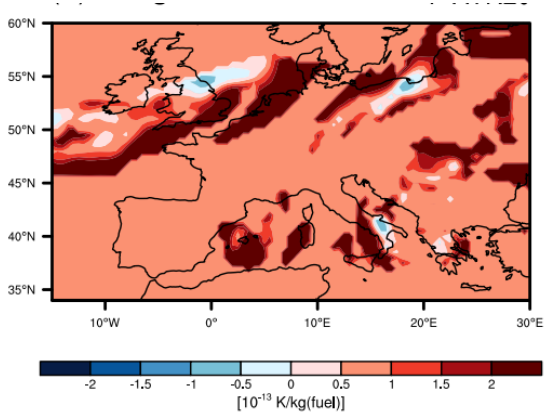
EUROCONTROL CANSO

Example of Climate MET Service: aCCFs

FlyATM4E-Solution-01: "Increased situational awareness on climate change effects relying on algorithmic climate change functions"

Matthes et al. 2022, SID 2022

merged non-CO_2 aCCFs



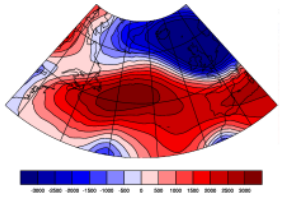
- **advanced MET service** to inform on the climate effect of flight operations comprising CO_2 and non-CO_2 effects
- **spatially and temporally resolved quantitative information on climate effects of aviation emissions** in the airspace -> information can be used by airspace user (e.g. high mitigation potential in areas of high gradients, or avoid regions with high effect)
- Efficient integration (in ATM) relies on **combining aCCFs with numerical weather prediction data & specific aircraft emissions**

Analysis of aCCFs: different typical winter weather patterns

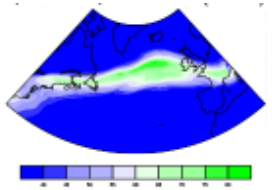
NAO +

17th Jan. 2018, 250 hPa

Anomalie Geopotental

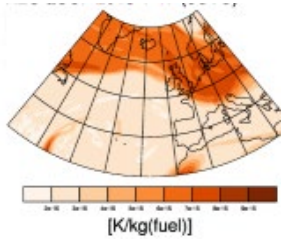


Wind (m/s^2)

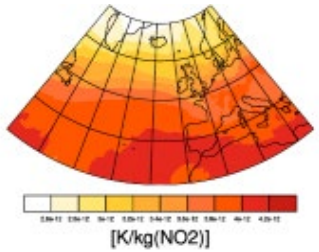


- North-South dipol, NAO: +0.53
- Strong zonal jet over NA

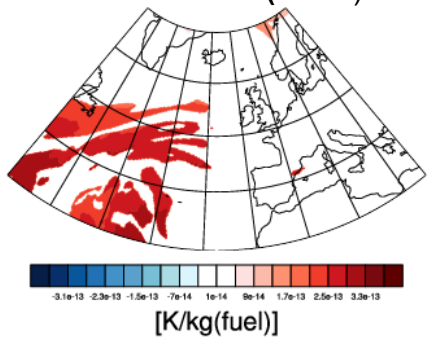
H2O aCCF



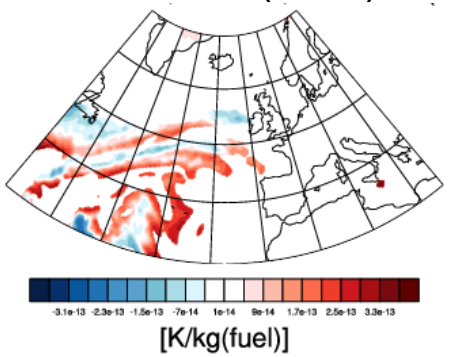
NO_x aCCF



contrail aCCF (6UTC)



contrail aCCF (12UTC)

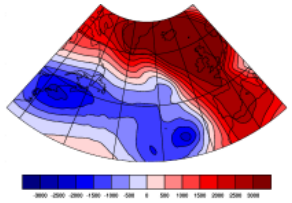


Positive NAO ⇨ aCCFs have lateral structure
⇨ High mitigation potential NAFC (contrail)

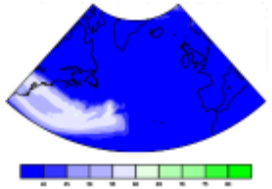
NAO -

25th Dec. 2018, 250 hPa

Anomalie Geopotental

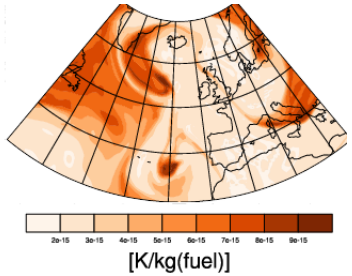


Wind (m/s^2)

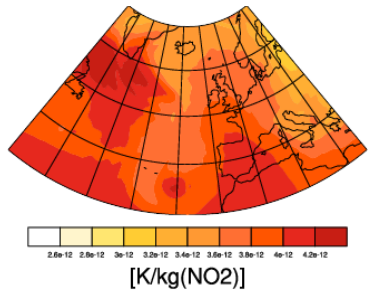


- North-South dipol, NAO: -0.62
- weak jet
- Blocking over Europe

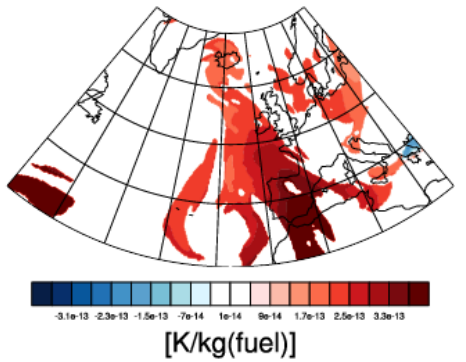
H2O aCCF



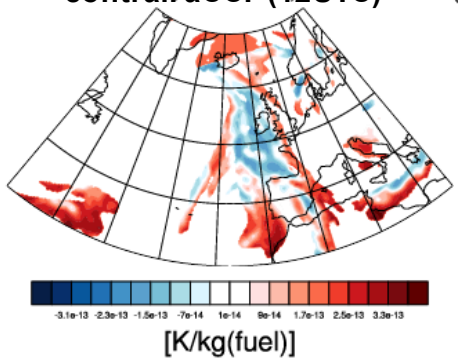
NOx aCCF



contrail aCCF (6UTC)



contrail aCCF (12UTC)



Negative NAO⇨ north-south structure of aCCFs
⇨ Low mitigation potential NAFC, Europe: N-S

EUROCONTROL CANSO

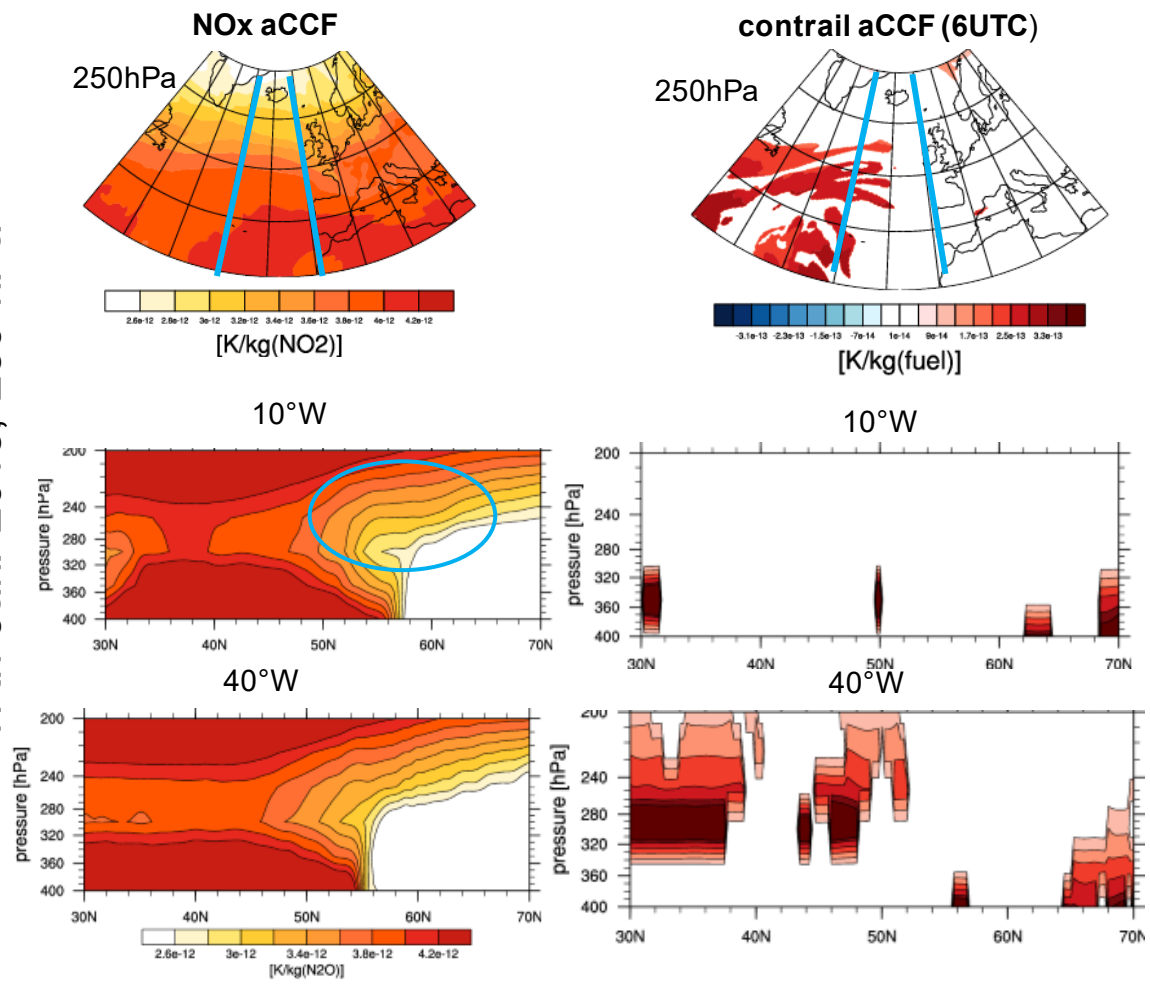
Vertical gradients of aCCFs for different typical winter weather patterns

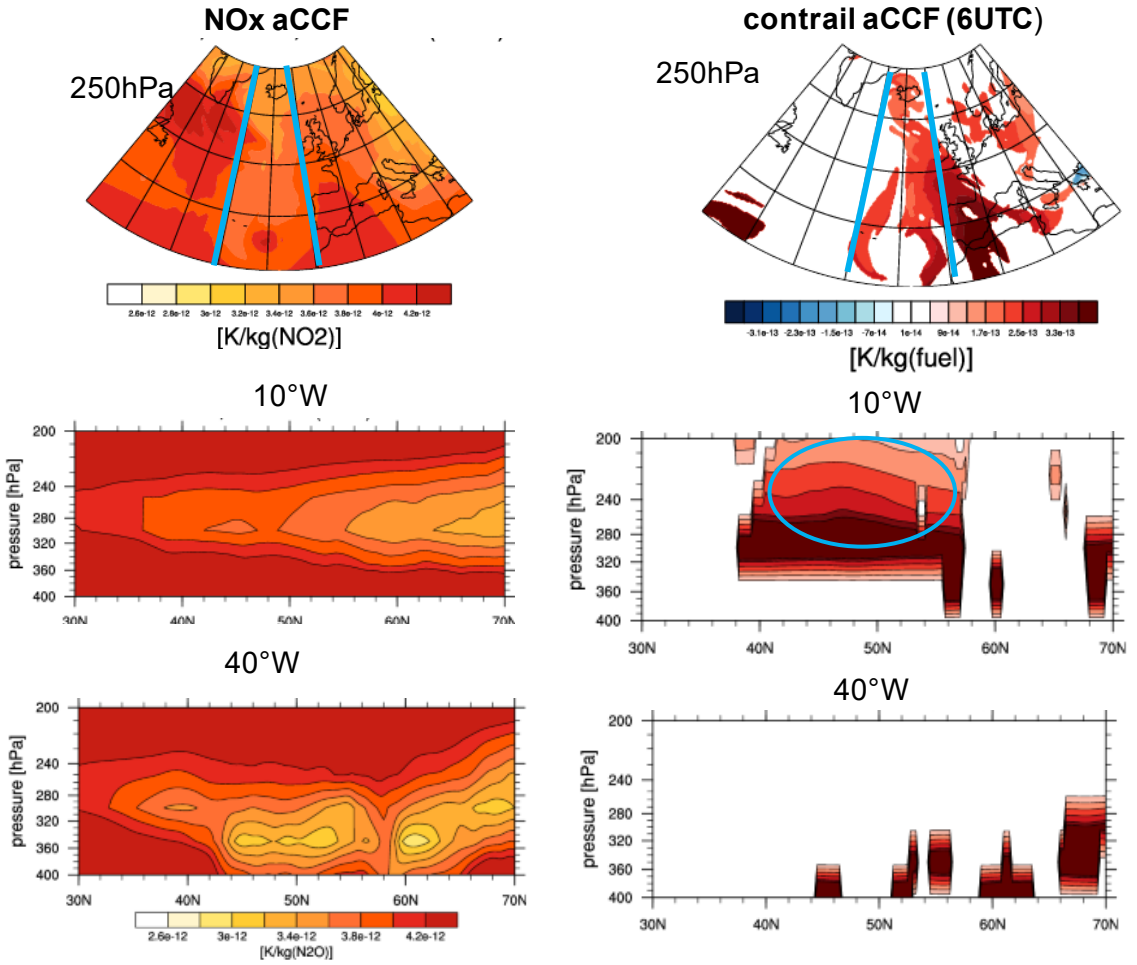
NAO +

NAO-

17th Jan. 2018, 250 hPa

25th Dec. 2018, 250 hPa



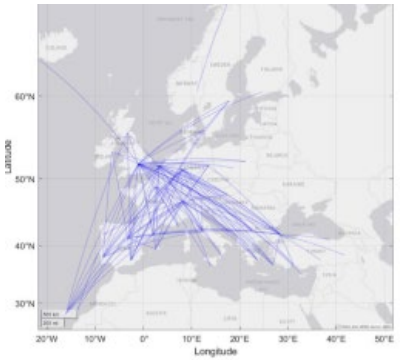


- High variation of contrail aCCFs with cruise altitude
- Thick vertical layer contrail aCCF (10°W, NAO-), but vertical gradient with lower values for higher altitudes
- Variation NO_x aCCFs with cruise altitude. Vertical gradients higher for NAO+ (northern latitudes)

Application of MET Service: Mitigation of climate sensitive regions

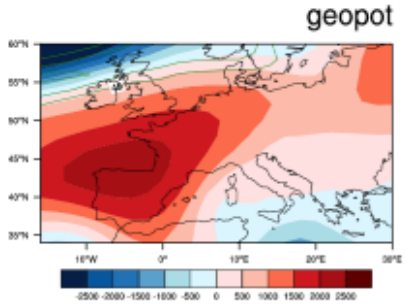
Integration **of an advanced MET-service in trajectory planning** which informs airspace users on climate effects is a prerequisite for climate-optimized aircraft trajectories in flight dispatching and network management.

Traffic scenario



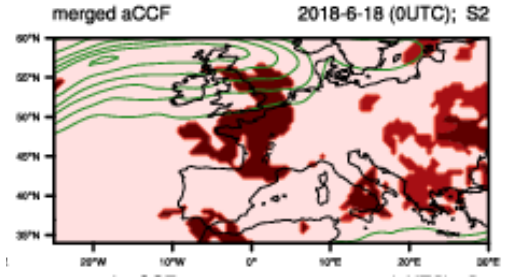
+

Input of numerical weather prediction model data



+

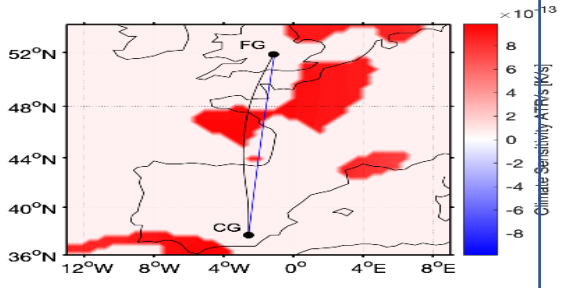
MET Service, e.g. aCCFs



(merged non-CO2 aCCFs, considering effects of Contrails, O_3, CH_4, H_2O)

+

Aircraft trajectory optimisation tool:



Climate-optimizied trajectories

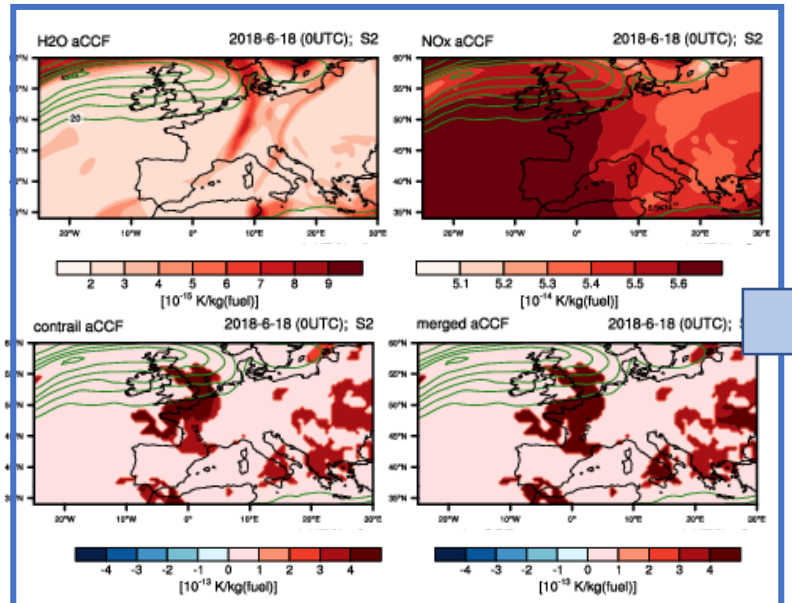
EUROCONTROL CANSO

Mitigation by alternative aircraft trajectories in research project FlyATM4E

18th June 2018 0UTC

Numerical weather prediction

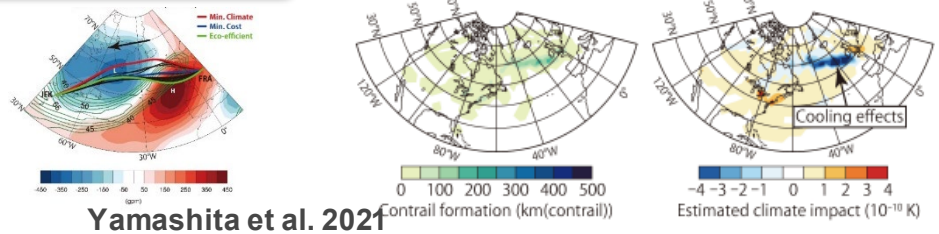
aCCFs



Dietmüller et al. 2022; Matthes et al. 2023 (in prep.)

Aircraft Trajectory Optimization

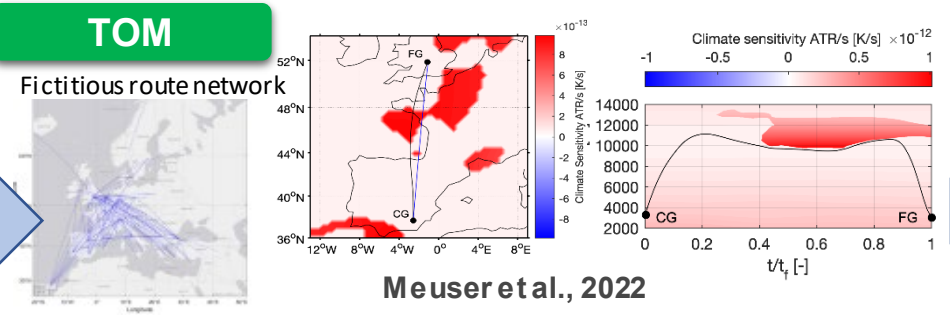
EMAC/AirTraf



Yamashita et al. 2021

TOM

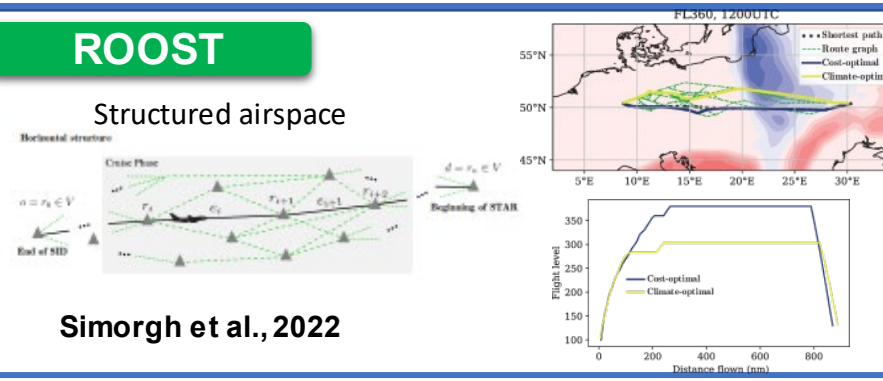
Fictitious route network



Meuser et al., 2022

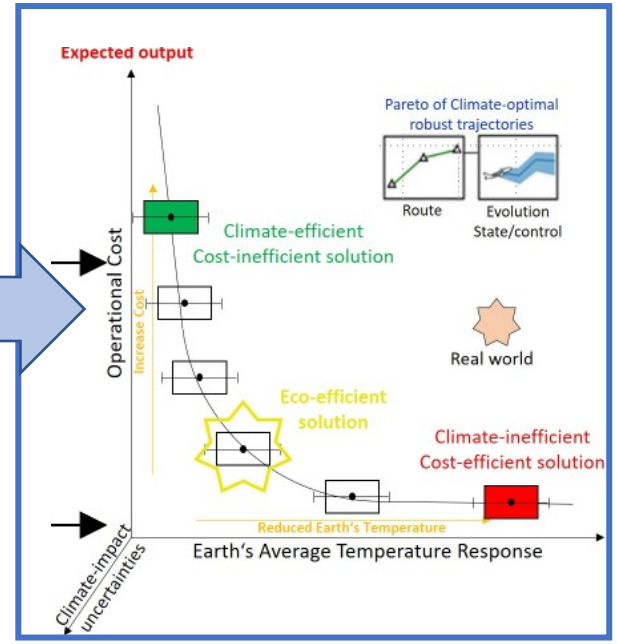
ROOST

Structured airspace



Simorgh et al., 2022

Paretofront



See talk of Sigrun Matthes

Summary

- Climate MET service has to be tailored to individual needs of the trajectory planning tools, considering CO_2 and non-CO_2 effects of aviation
- Climate MET Service describes climate effect of aviation emissions (in a commonly used physical climate metric) at specific location and time (e.g. aCCF, CoCiP)
- Capabilities and limitations of Climate MET service have to be clearly described (e.g. data architecture)
- Climate MET service provides possibility for mitigation by climate optimized trajectory planning
- Analysis of MET service provides insight into regions, seasons and synoptical situations with high mitigation potential

EUROCONTROL CANSO