Höghöjdseffekter - Vad är det och hur undviker vi dem?

Agenda

Välkommen
Helena Gellerman Liberalerna, Victoria Barrsäter Transportföretagen Flyg, David Hild Fly Green Fund

Vad är höghöjdseffekter?
Prof. Ulrich Schumann (DLR)

Klimatanpassad ruttoptimering i Skandinavien
Jana Moldanova IVL

Praktiska försök av klimatanpassad ruttoptimering
Marc Shapiro Breakthrough Energy

Implementering i praktiken
Hartwig Hagena DLR

Publikfrågor & paneldiskussion
Take aways

Statsekreterare Daniel Westlén

CONTRAIL FORMATION AND AVOIDANCE

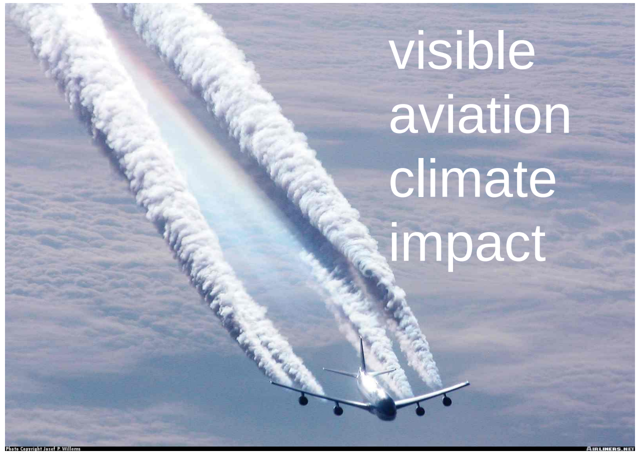
Ulrich Schumann
with input from Axel Seifert (DWD),
Christiane Voigt, Dennis Piontek, Hartwig Hagena (DLR),
Roger Teoh and Marc Stettler (Imperial College, UK),
Marc Shapiro (Breakthrough Energy, USA), and many others.
Ulrich.Schumann@dlr.de

DLR

Overview

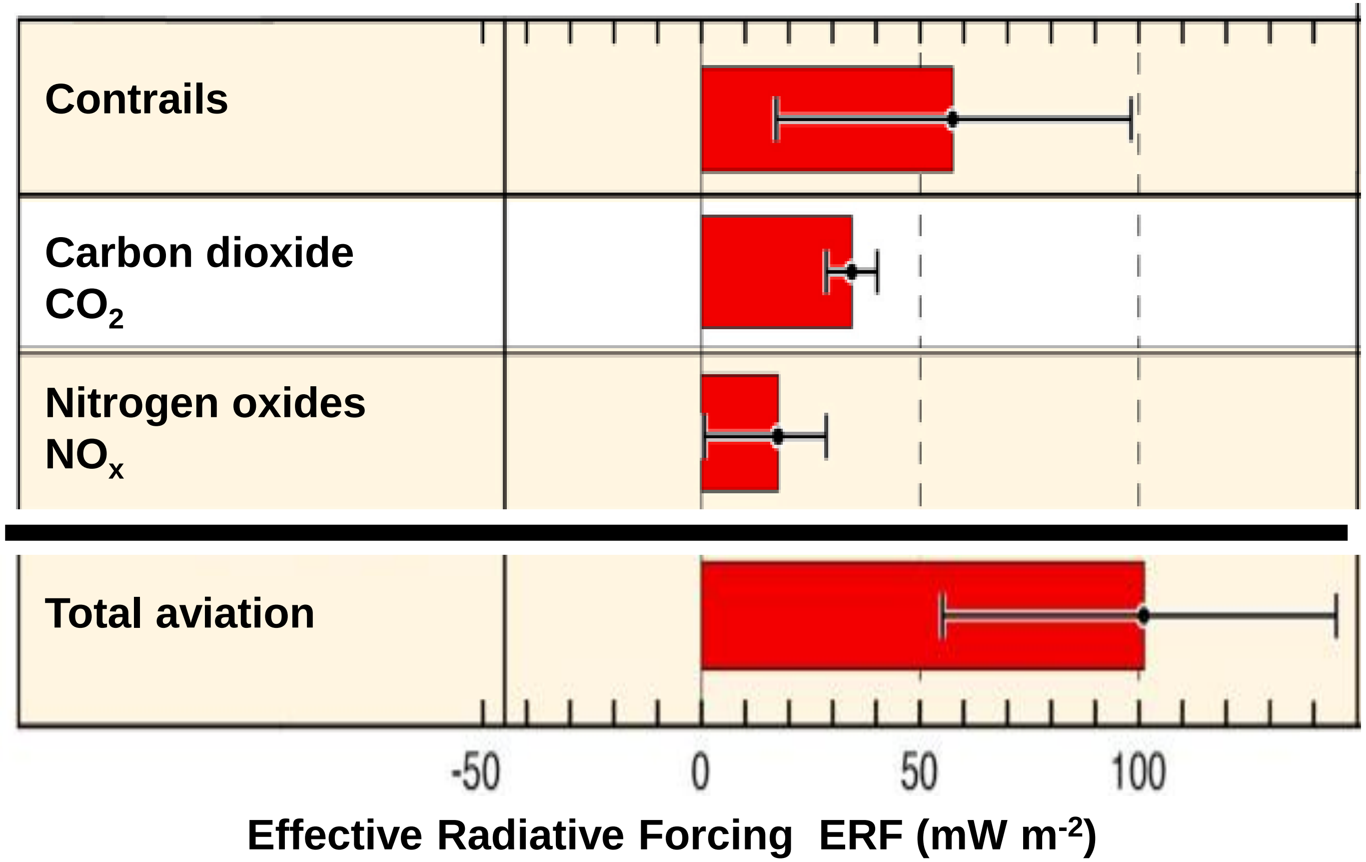
1. Climate Impact of CO_2 and Non-CO_2 Effects
2. How Aviation can reduce its climate impact
3. Contrail Formation: well understood and predictable
4. Contrails are observed globally in main traffic domains
5. State of the art in contrail mitigation (German Projects)

Climate Impact of CO_2 and Non-CO_2 Effects



CO_2: Main man-made greenhouse gas.
Here sum from historic air traffic 1950 to 2018.

NOx: Enhancing ozone (O_3) and reducing methane (CH_4) greenhouse gases

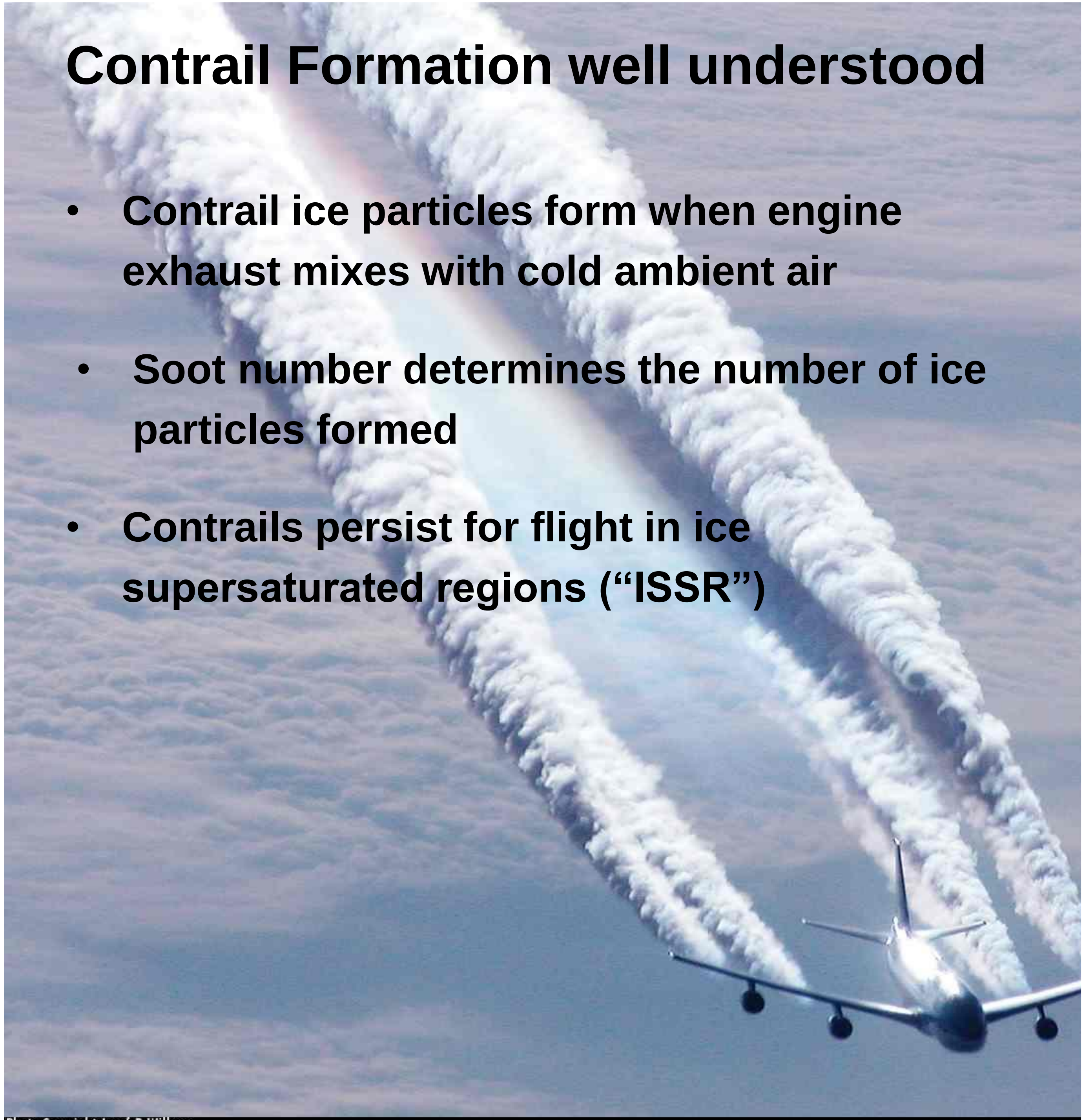


Contrails about 2 x CO_2

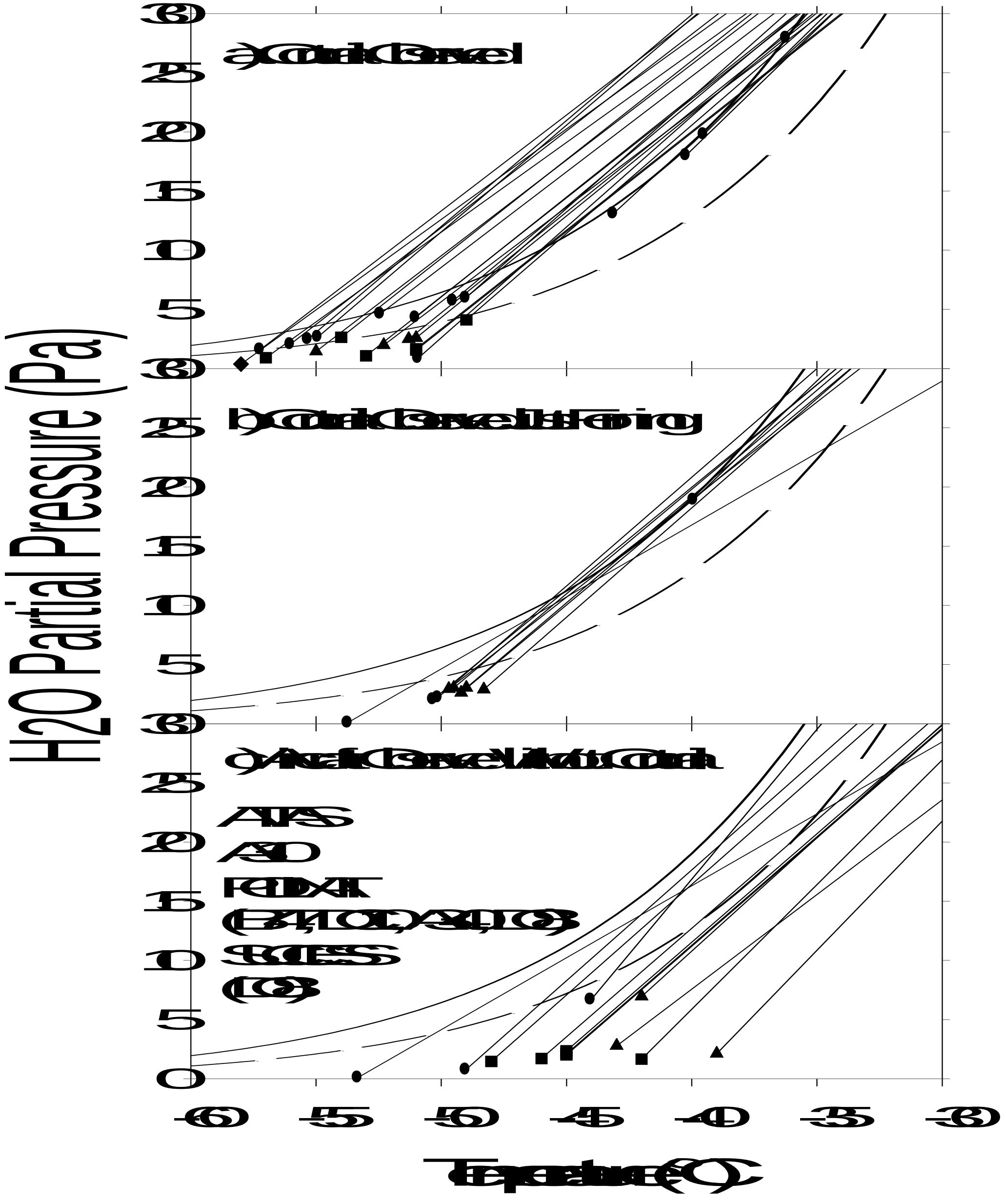
Best estimate for 2018; published by
Lee et al., 2021 (with Burkhardt and Sausen, DLR)
Recent studies (with exceptions) confirm main results with smaller uncertainties

Contrail Formation well understood

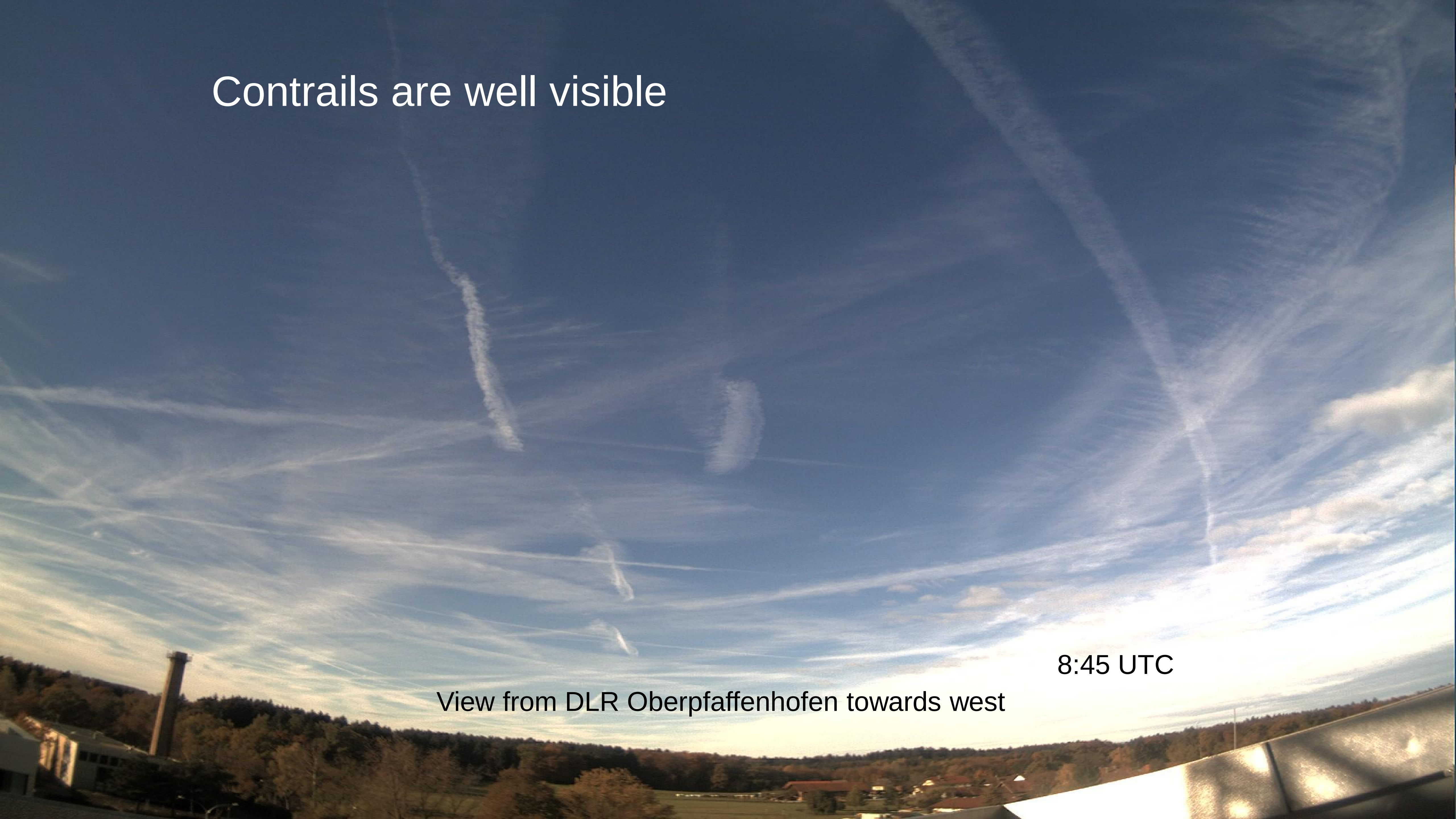
- **Contrail ice particles form when engine exhaust mixes with cold ambient air**
- **Soot number determines the number of ice particles formed**
- **Contrails persist for flight in ice supersaturated regions (“ISSR”)**

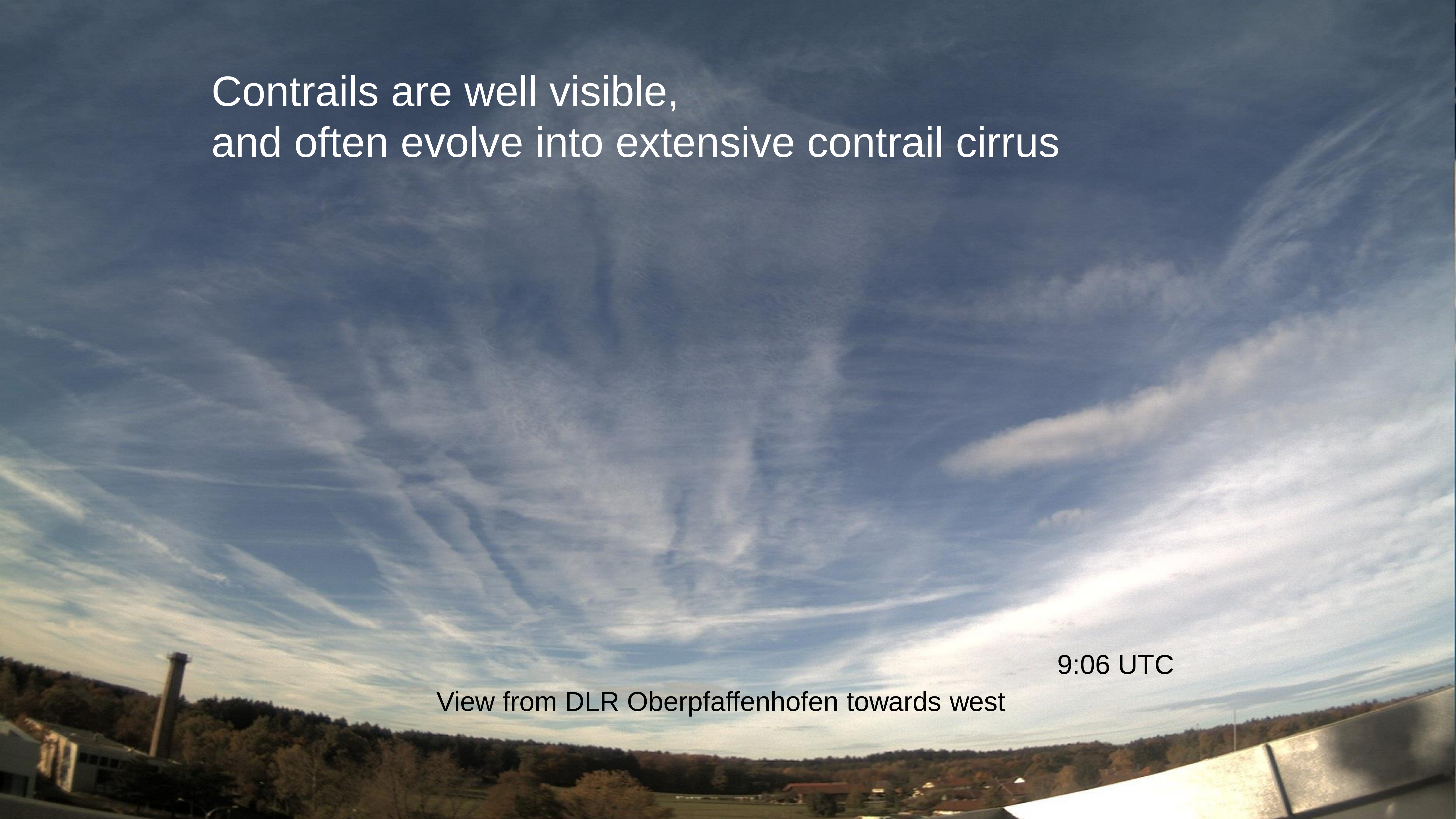


- From DLR Falcon measurements behind aircraft at cruise

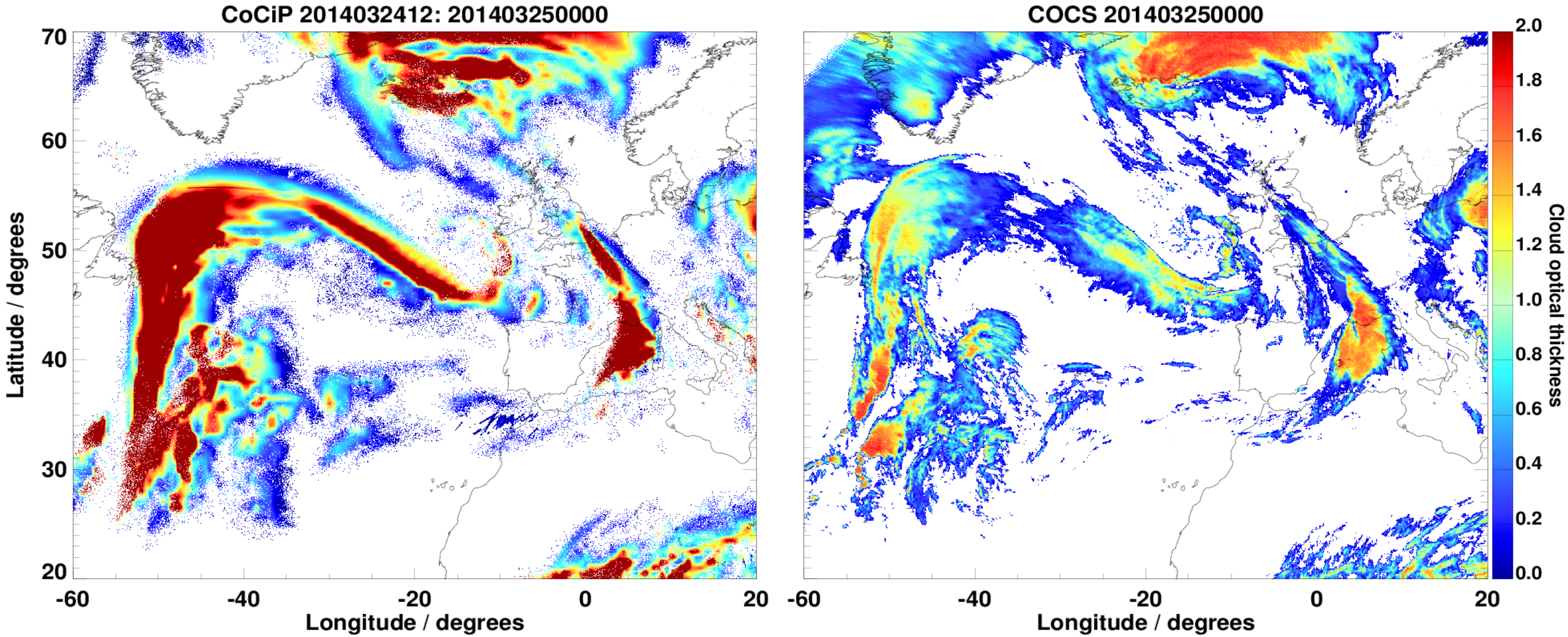


Contrails are well visible




Contrails are well visible,
and often evolve into extensive contrail cirrus
9:06 UTC
View from DLR Oberpfaffenhofen towards west

The optical depth of contrail cirrus can be predicted with CoCiP using NWP data and can be observed every 15 min with satellites (Meteosat)



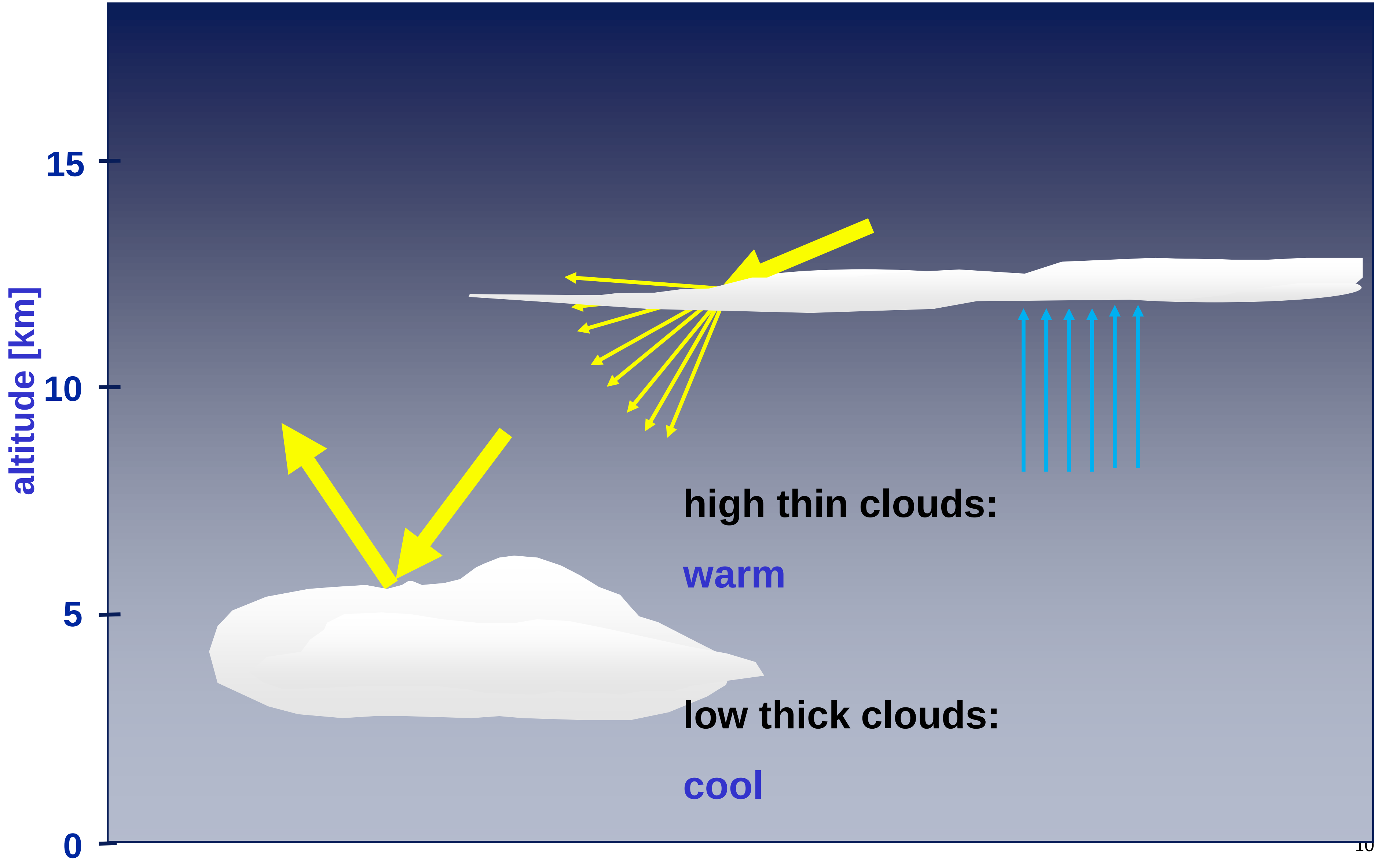
Video

Optical depth of contrail cirrus computed with CoCiP/ECMWF

(Graf and Schumann, 2015;
Voigt, Schumann et al., 2017)

The optical depth of thin cirrus can be derived from METEOSAT SEVIRI IR satellite observation data
(L. Bugliaro, 2015)

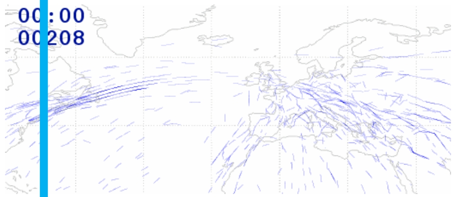
Climate impact of clouds



Contrail formation and climate forcing can be predicted for all flight routes for given weather forecasts

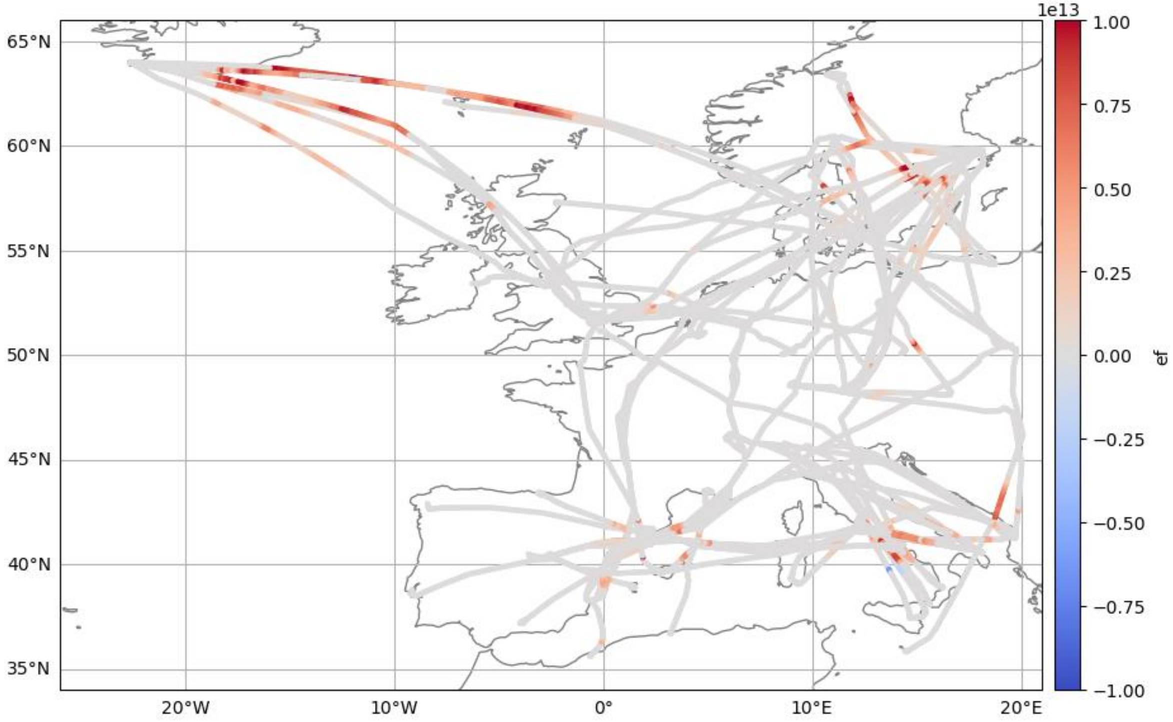
Input:
Aircraft technical and performance data

Flight trajectories



Meteorology from numerical weather predictions

CoCiP: Contrail Cirrus Prediction Model



Energy forcing [J/m]:

$$EF = \int_{lifetime} RF_{nets}(t', s) W(t', s) dt'$$

Output:
Information on formation of persistent contrails

Advected position and total lifetime of contrails

Microphysical properties (e.g., effective radius, ice particle number concentration)

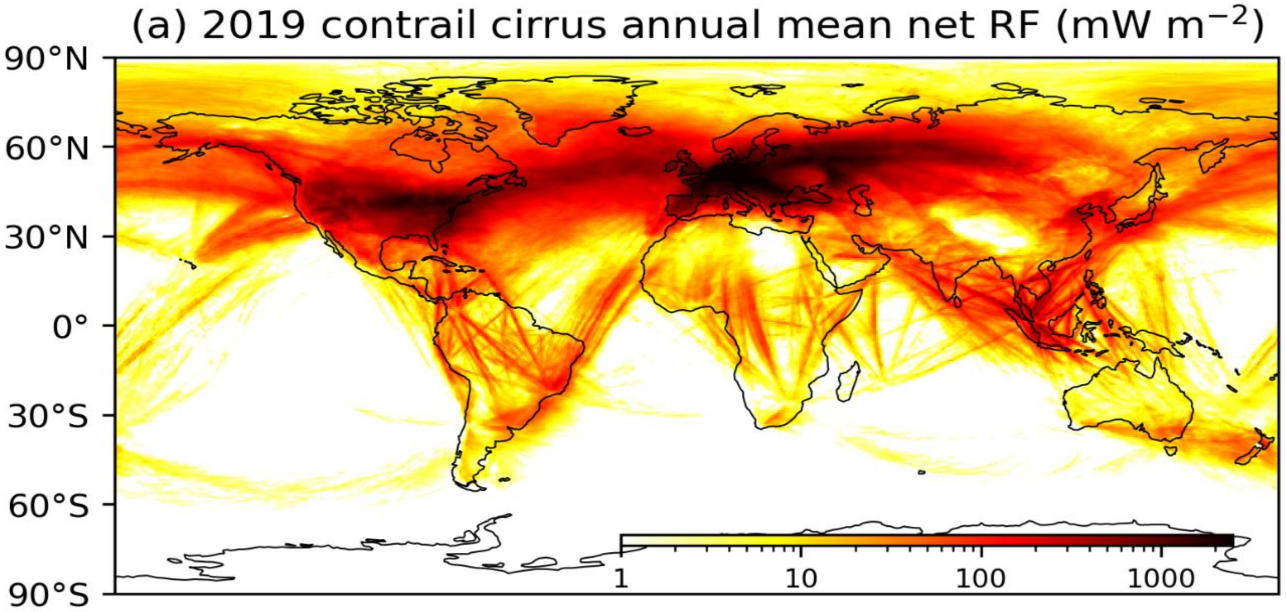
Macrophysical properties (e.g., height, shape)

Instantaneous radiative forcing

Total energy input into the atmosphere (energy forcing)

Schumann, 1996, 2012; Schumann et al., 2011, 2012, Teoh et al., 2024; Piontek, python result, 2023

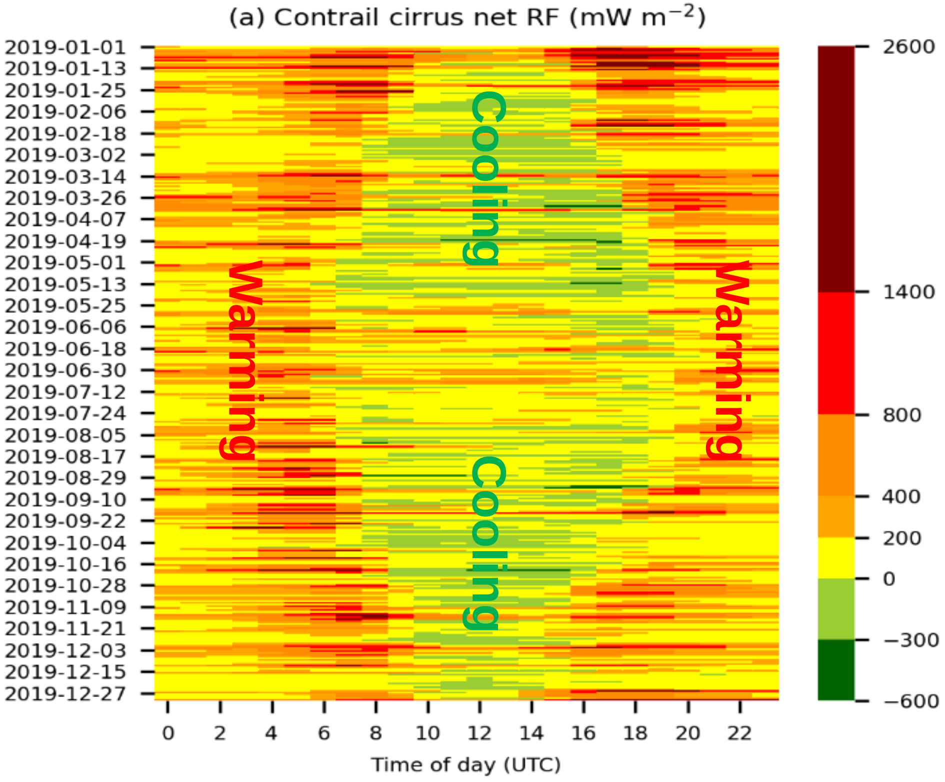
Can be applied globally.
Shows maximum effects at Northern Mid-Latitudes



Top: global map of RF -> contrail warming everywhere

Right: versus time of day and year
maximum warming during night and in winter

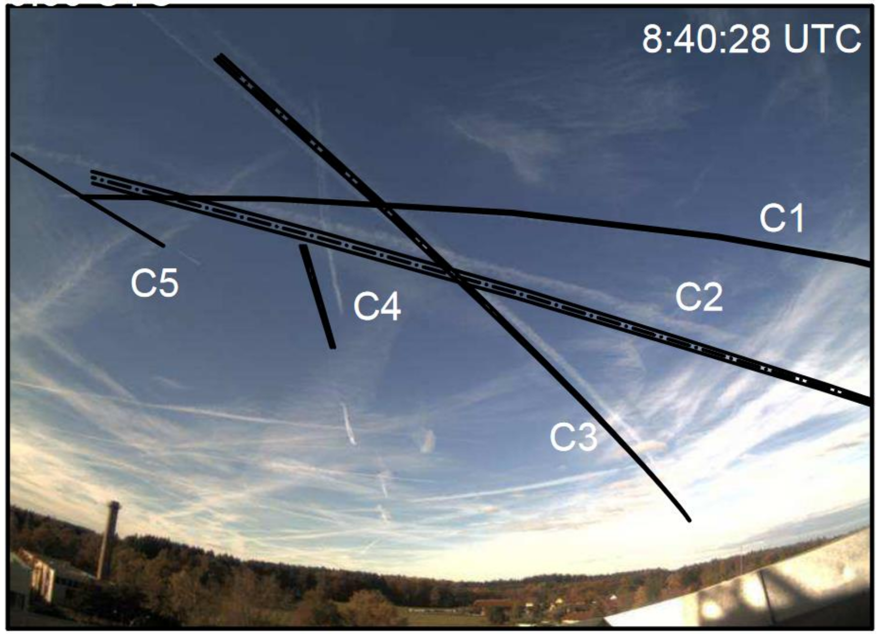
North Atlantic flight corridor



Teoh et al., 2022; Teoh et al., to appear 2024

CoCip has been validated by comparison to many observations

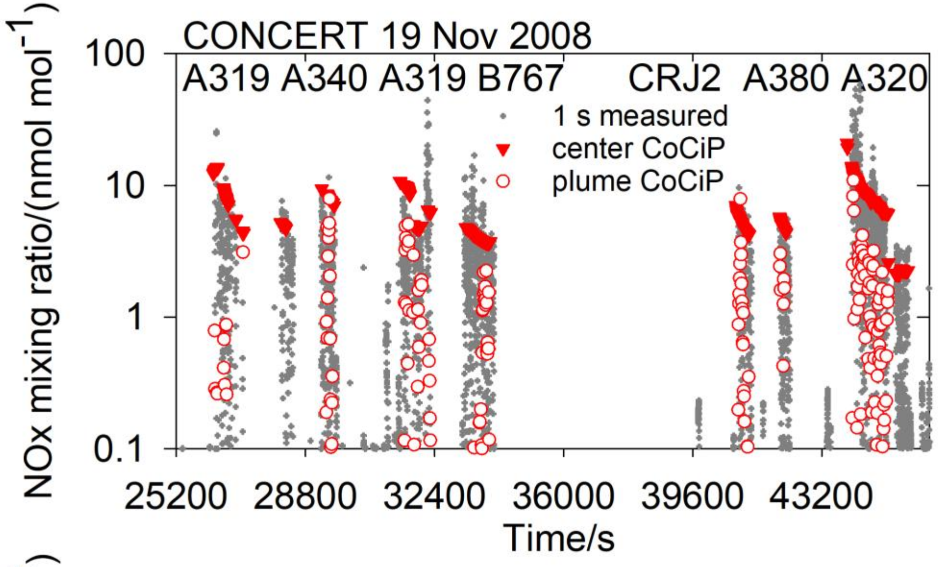
With ground-cameras:

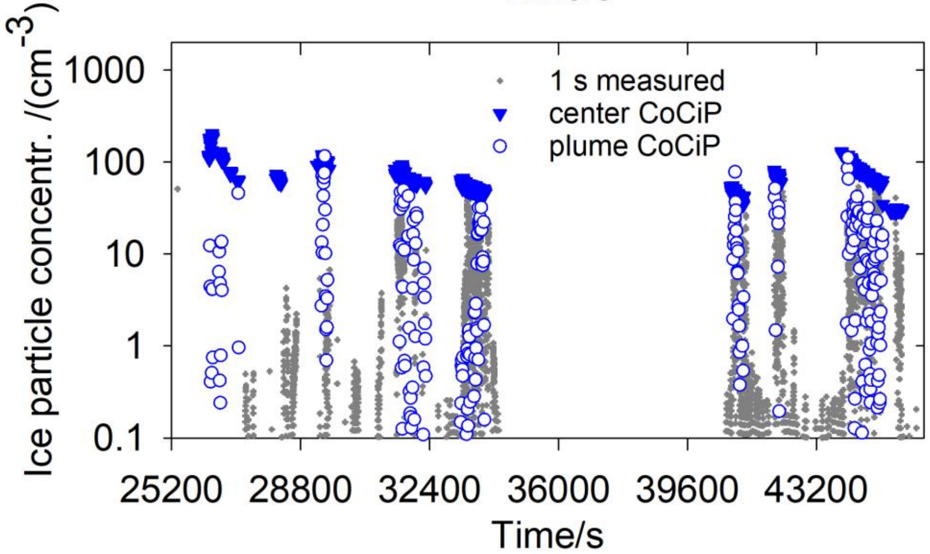


→ **general agreement of contrail positions and approximate dynamics**

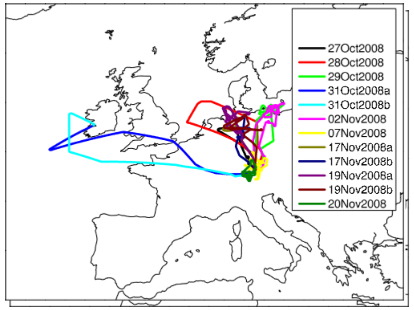
(Schumann, Hempel et al., AMT,2013)

With DLR Falcon airborne in situ measurements:





→ **agreement within the scatter of the in situ data**



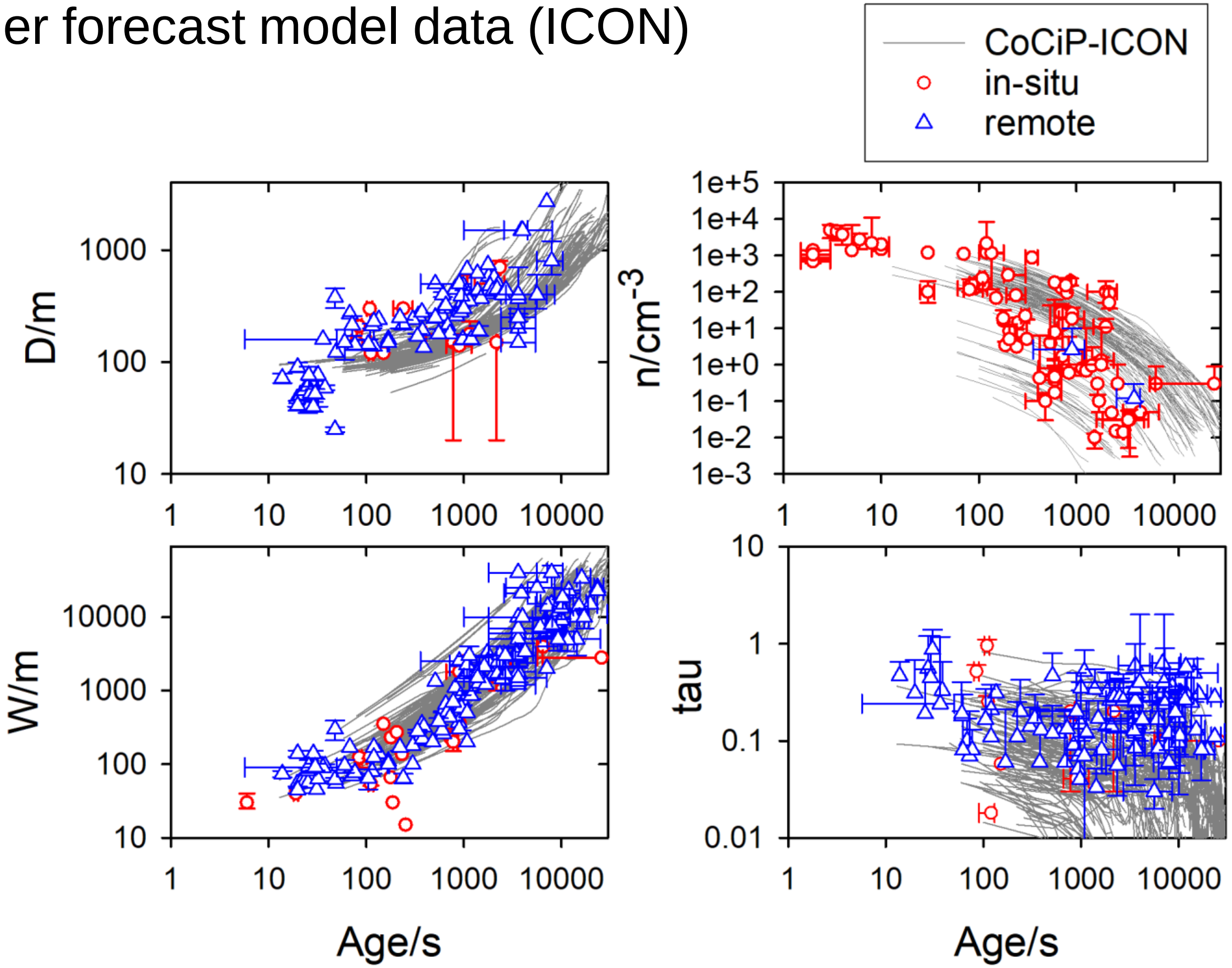
19 November 2008 (CONCERT)

(Voigt et al., 2010; see also: Jeßberger et al., 2013)

Validation of CoCiP-ICON details with measurements

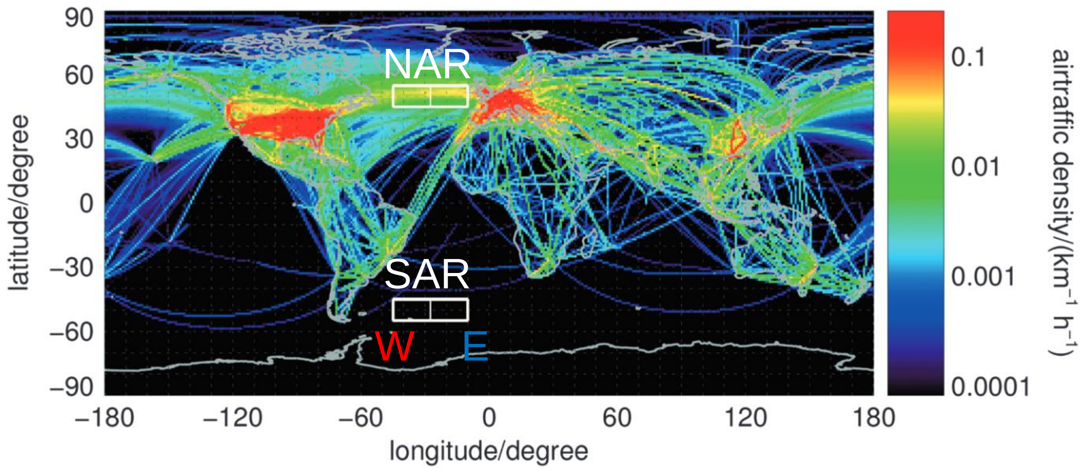
Micro- and macrophysics in CoCiP was validated with **~230 remote sensing (blue)** and **in situ** measurements (red) with climate model data in 2017, and now also with recent DWD Weather forecast model data (ICON)

CoCiP using DWD ICON weather data with new 2-moment ice scheme

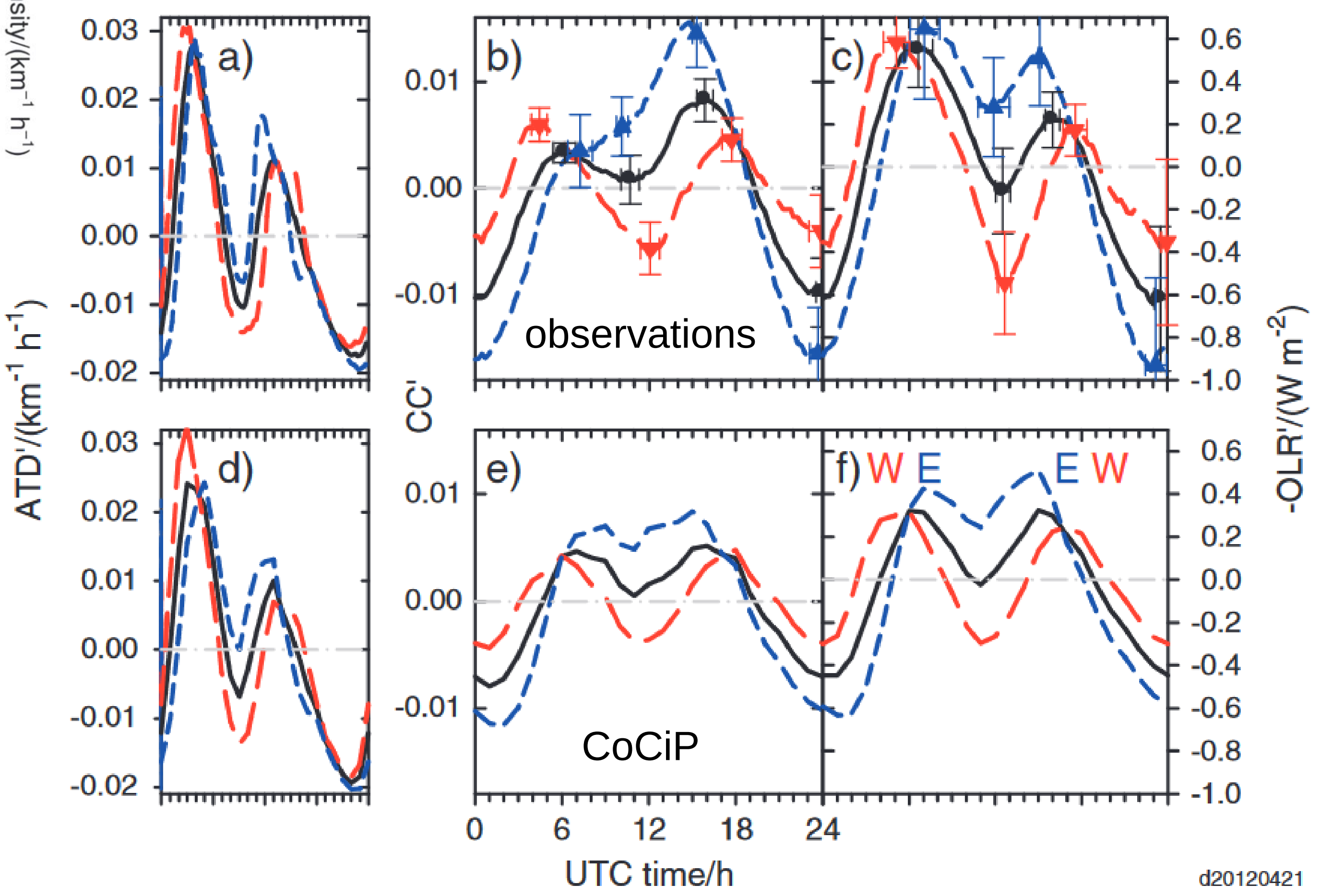


Schumann et al., 2015, 2017; Schumann & Seifert, tbp 2024

Validation of CoCiP with 8 years of Meteosat Satellite data



Diurnal cycle differences between NAR and SAR in west (W) and east (E) halves for 8 years of MSG/SEVIRI observations



Results:

→ **Good agreement with respect to aviation-induced double wave and W-E variability (correlation larger than 0.9)**

→ **Maximum OLR underestimated by 35 to 45% (e.g., NAR-W)**

→ **Maximum cirrus cover underestimated by nearly 50% (e.g., NAR-E)**

Schumann & Graf, JGR, 2013

How can aviation reduce its climate impact?

- Lower fuel consumption, soot emissions and NOx emissions
- In the short term: avoid flying in contrail forming domains; in particular predict and avoid warming contrails
- In the long term: in addition, use alternative fuels with less CO_2 and less soot emissions (“sustainable aviation fuels”, SAF, ultimately hydrogen)

Arbeitskreis Klimaneutrale Luftfahrt, AKKL

https://bmdv.bund.de/SharedDocs/DE/Pressemitteilungen/2023/096-wissing-co2-neutrales-fliegen.html

German Working Group "Arbeitskreis AKKL"

German government with core ministries is highly active in contrail avoidance demonstration.

My colleagues will speak about similar programs in Sweden and US.

This is a global problem where we need global cooperation

AKKL: Perform a 100 flight test program for climate optimized flight routing

DWD + DLR provide forecast and evaluate results

Ready to be used: Contrail forcing parameter (CFP) forecasts for global traffic with ICON + CoCiP at German Weather Service (DWD)

Aircraft type

DWD
61-h-ICON
Forecasts (FC)
4 × daily
10 Ensemble-members

→ T, q, p
u, v, w
IWC,
geopot., PV
radiation

→ CoCiP
energy forcing
(EF) for contrail
+ CO_2
+ aCCF for NOx,
H_2O + CC

→ CFPs
for contrail, NOx,
H_2O + CO_2
ensemble
predictions

→ Input for route optimization in flight operations (e.g., Lufthansa Systems)

Route
optimi-
zation

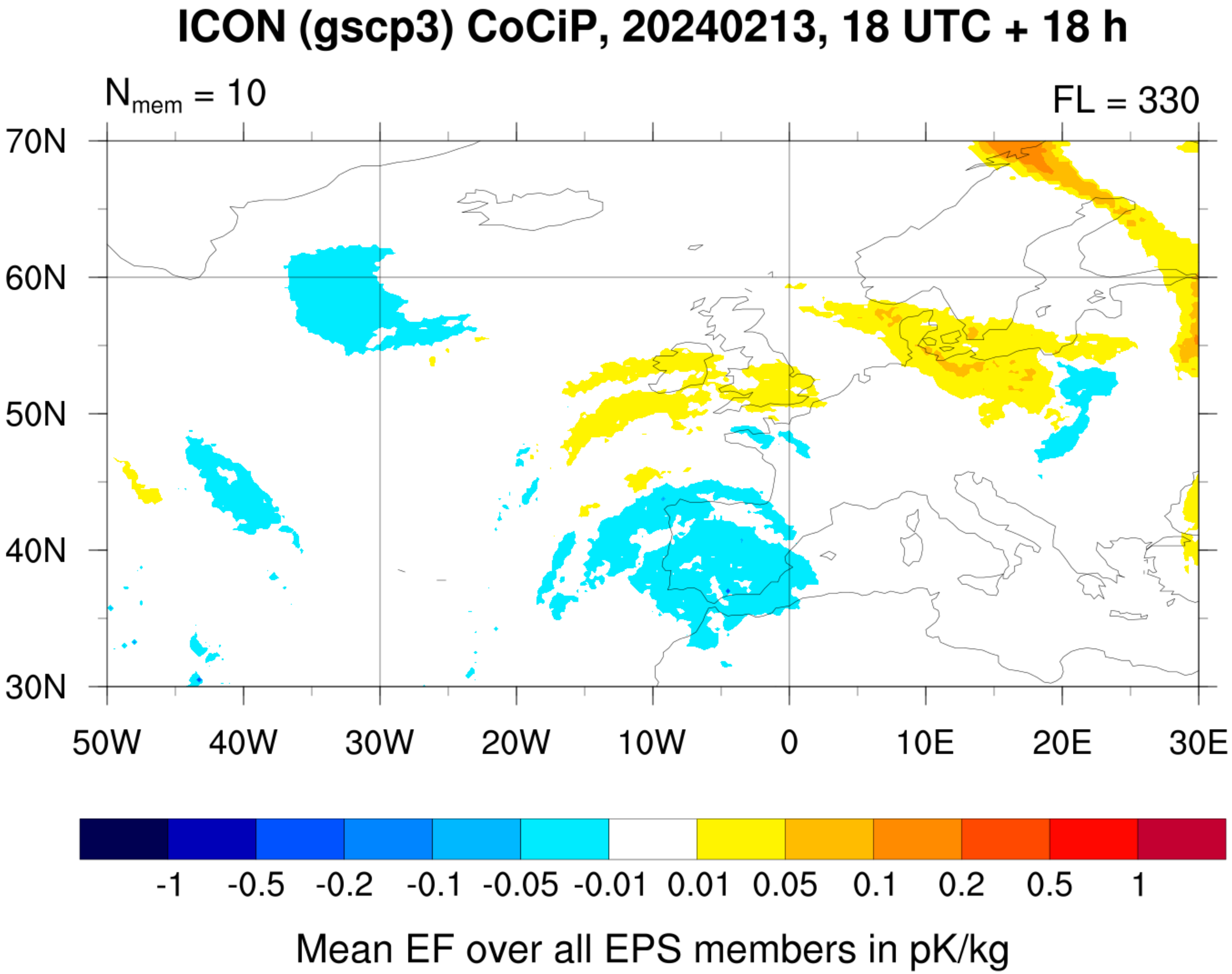
→ Flight routes of minimized sum of CFP + other costs

Example for now, below:
Forecast for Wednesday, 14 February 2024, 12 UTC
with 6, 12, **18, 24, 36,42, 48** h forecast times)
mean CFP (EF)
or Probability of CFP> CFP*
from 10 ICON Ensembles

U. Schumann and Axel Seifert (DWD), tbp

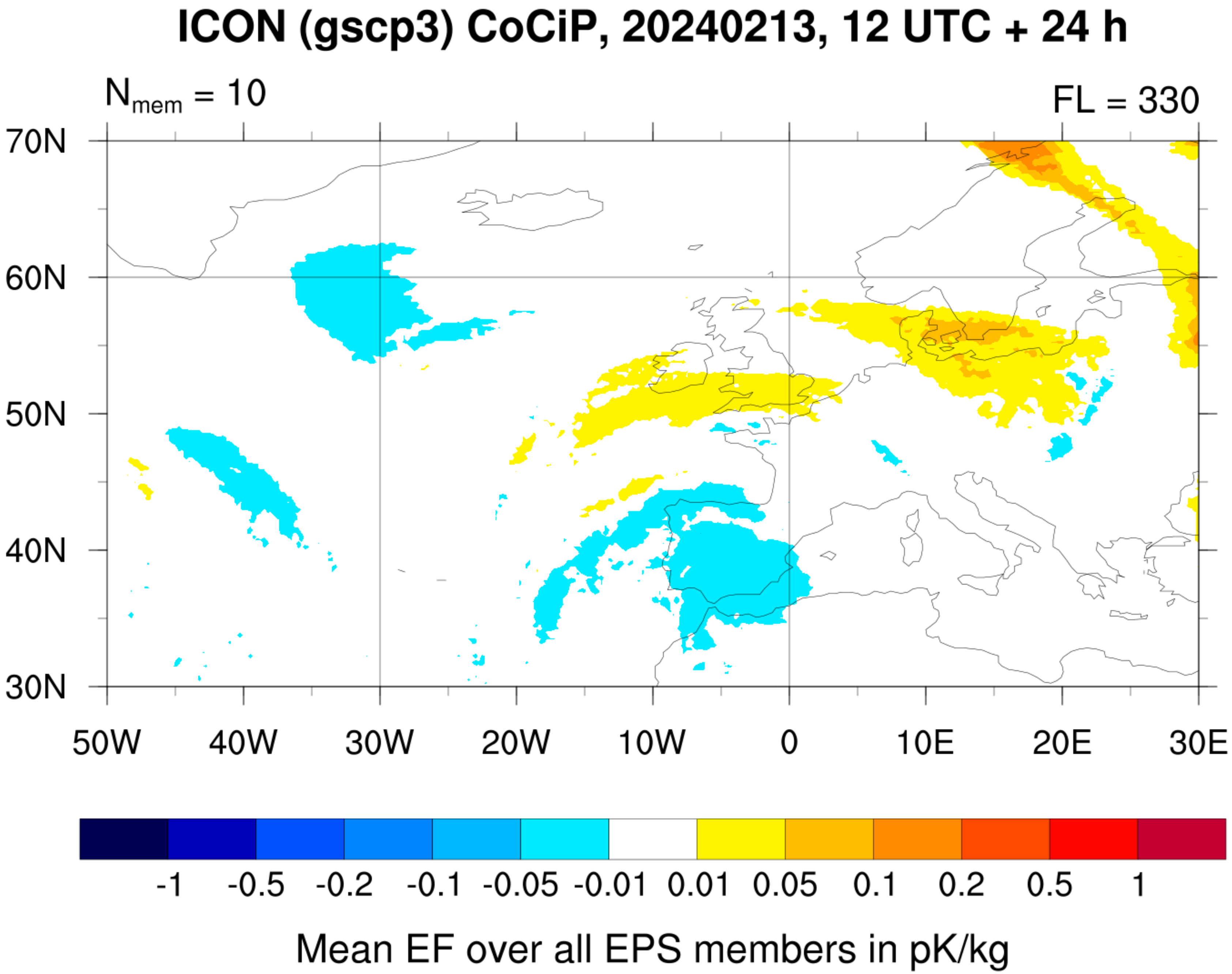
now, 12 UTC
14 Febr 2014

+18 h



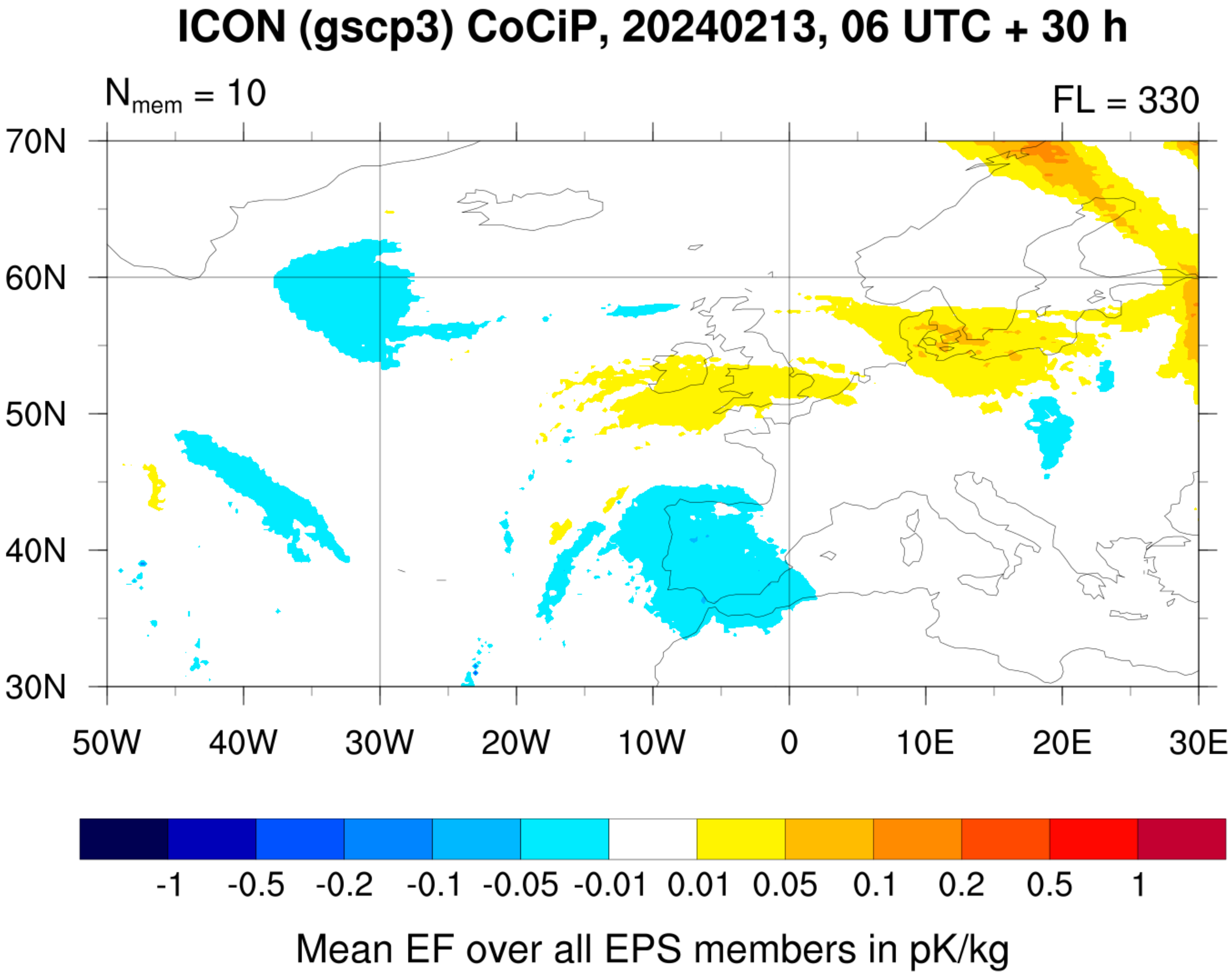
now, 12 UTC
14 Febr 2014

+24 h



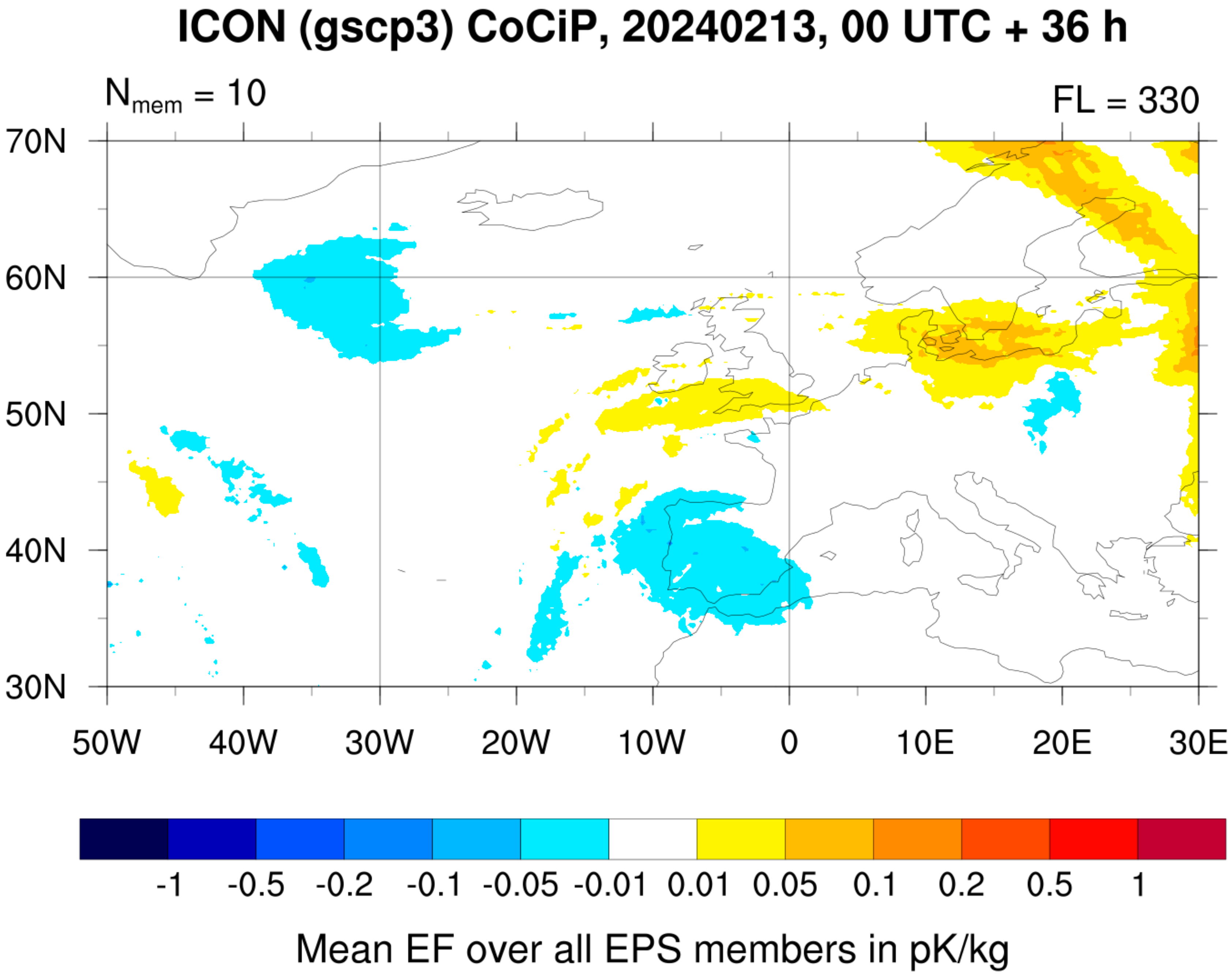
now, 12 UTC
14 Febr 2014

+30 h

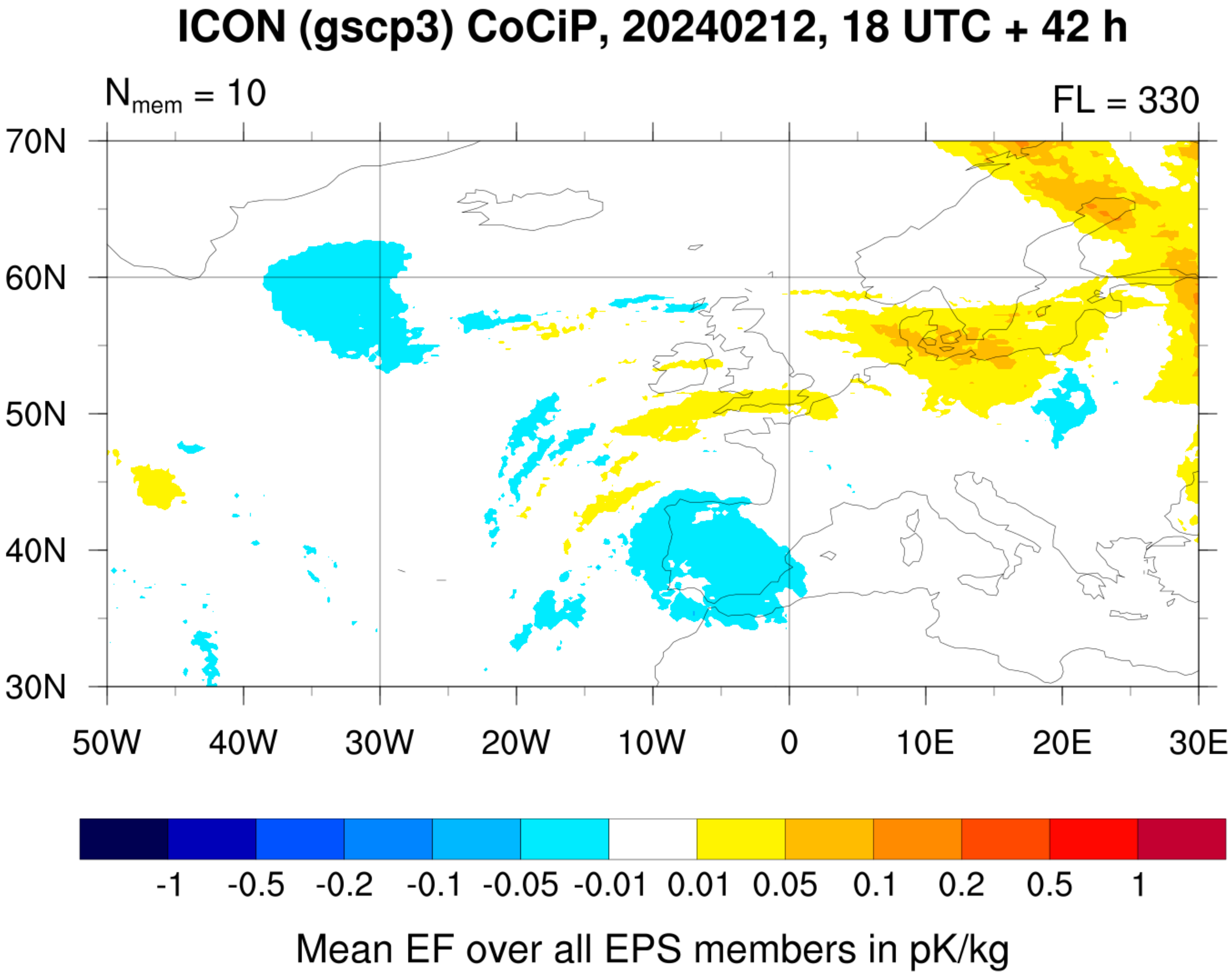


now, 12 UTC
14 Febr 2014

+36 h



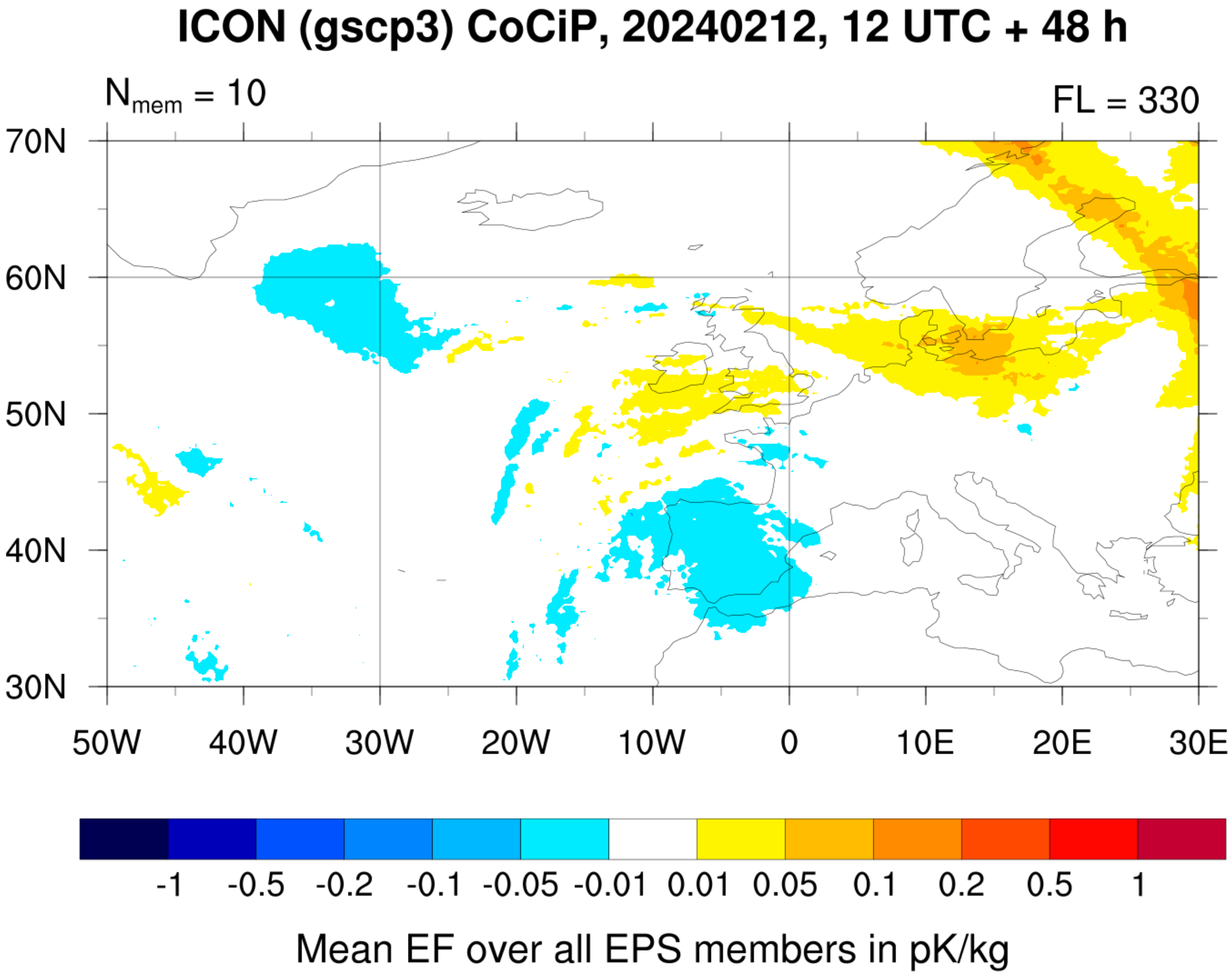
+42 h



ICON (gscp3) CoCiP, 20240212, 18 UTC + 42 h
N_{mem} = 10
FL = 330
70N
60N
50N
40N
30N
50W
40W
30W
20W
10W
0
10E
20E
30E
-1
-0.5
-0.2
-0.1
-0.05
-0.01
0.01
0.05
0.1
0.2
0.5
1
Mean EF over all EPS members in pK/kg

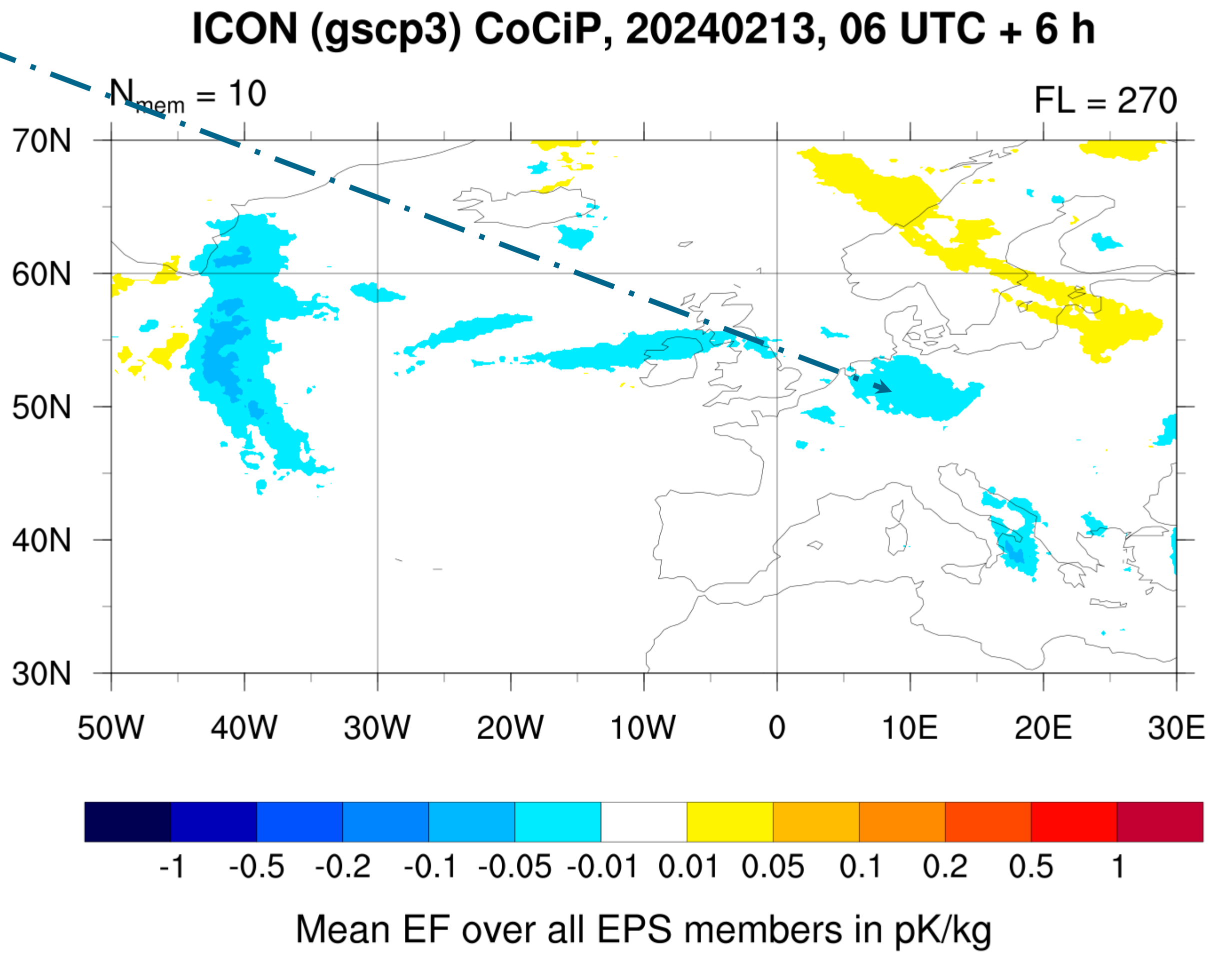
now, 12 UTC
14 Febr 2014

+48 h



DLR

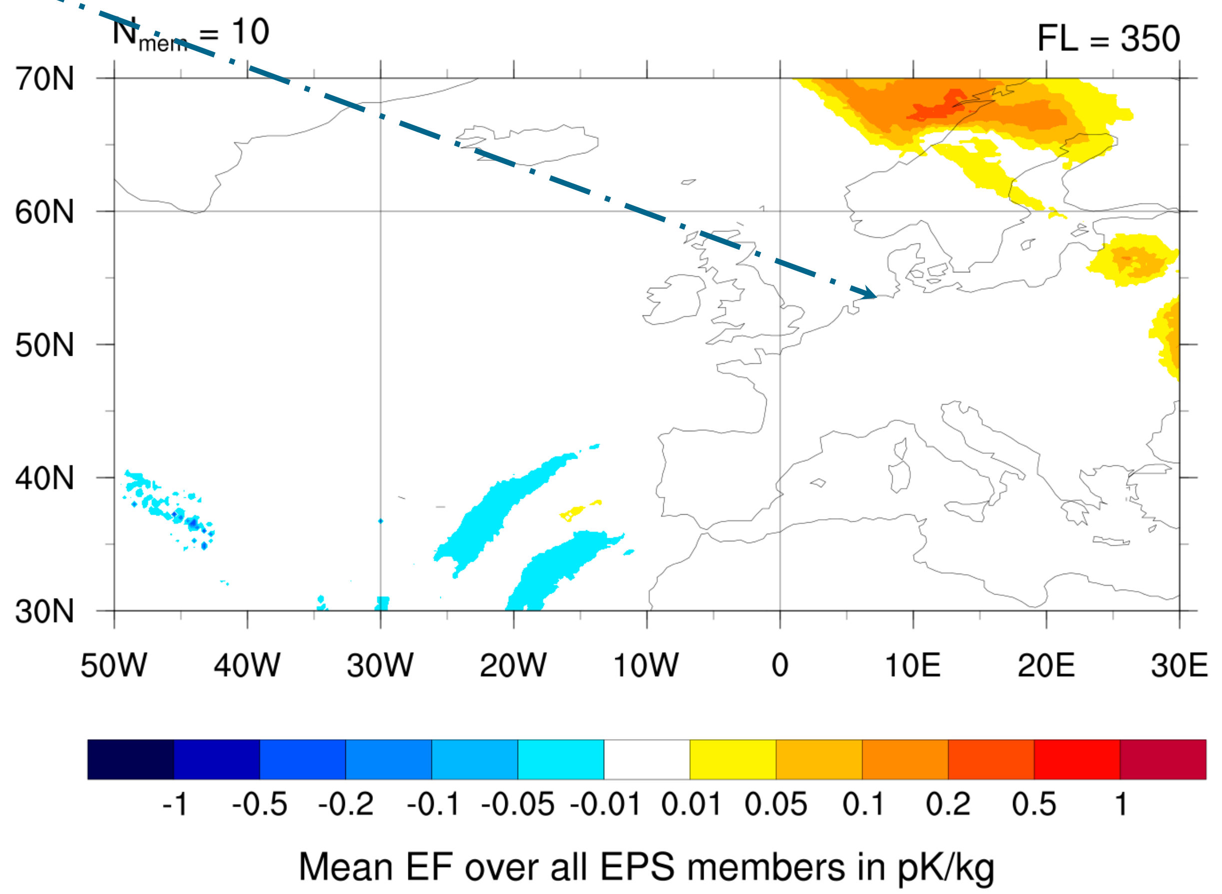
Yesterday (12 UTC 13 February) Cooling contrails predicted by CoCiP-ICON and observed



Yesterday (12 UTC 13 February) Zero contrails predicted by CoCiP-ICON and observed

12:20 UTC 12 February 2024
photo by Hartwig Hagena
on flight
Düsseldorf to Stockholm
at FL 350(?)

ICON (gscp3) CoCiP, 20240213, 06 UTC + 6 h



Conclusions & Outlook

- The aviation climate impact comes from CO_2 and non-CO_2 effects. Both are rising while reduction of forcing is urgent
- Contrail Formation and its Radiative Forcing: well understood and predictable
- Contrails have an immediate and rather larger climate impact, at least regionally and during night
- Contrail climate impact can be predicted by CoCiP and routes can be adapted to minimize the total climate impact
- Only a small fraction of traffic needs to be changed to reduce the climate impact significantly
- Many details of this modeling have been validated against remote sensing, in situ measurements, and other models
- Still uncertainties exist: e.g., precise humidity prediction, warming at the Earth surface relative to upper troposphere, soot re-activation, indirect cloud changes, other climate impact than global mean surface temperature change
- Alternative fuels (SAF) may reduce CO_2 emissions (if produced properly), cause less soot emissions, and hence may reduce not only CO_2 but also contrail climate forcing. Presently, SAF is not yet available sufficiently
- The contrail model (CoCiP) is run quasi operationally for 48 h forecasts, 4 times daily, with 10 ensemble members, using improved ICON model, with 2-moment ice scheme and 13 km resolution at German Weather Service (DWD)
- Persisting uncertainties do not exclude climate impact reduction by route changes, but call for tests and more research

Route optimization – Scandinavian perspective

Jana Moldanová, IVL
with input from Michael Priestley, Jens Wilhelmsson (IVL), Joakim Langner (SMHI), Ulrika Ziverts (Novair) and others

IVL SVENSKA MILJÖINSTITUTET

IVL Swedish Environmental Research Institute

Independent research institute, Sweden's leading organisation for applied environmental and sustainability research

The presentation is based on results of several projects financed by the Swedish Transport Administration, Swedish Transport Agency and the Energy Authority:

- Optimisation of flight routes for reduced climate impact (OP-FLYKLIM)
- Playing field for bio-jet fuels – High altitude-effects, carbon, climate-efficiency
- Emissions from biojet fuel – impacts on environment and climate

Project partners: SMHI, FOI, Novair, Swedavia, LFV

Is there a potential for flights in Swedish controlled airspace to form persistent contrails?

Frequency of ice-supersaturated layers (ISSL) over Sweden based on data from radiosonds 2006-2010 (Björklund, 2011)

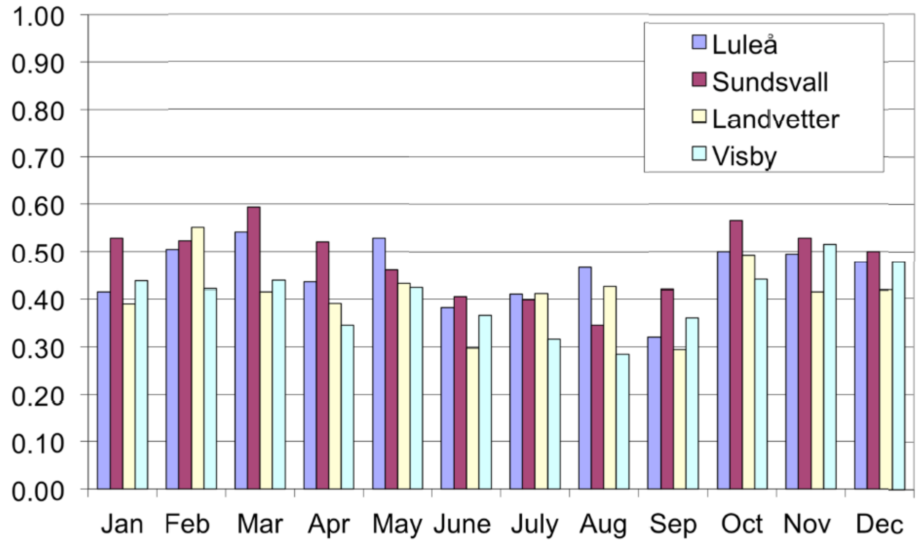


Figure 3 Frequency of occurrence of ISSL 2006-2010 00z soundings for various months

- Available observations and model data for ISSL over Europe and the surrounding area are consistent and indicate a frequency of ice supersaturated layers of about 50% over Scandinavia
- When the simultaneous presence of clouds is taken into account, the frequency decreases to about 40%

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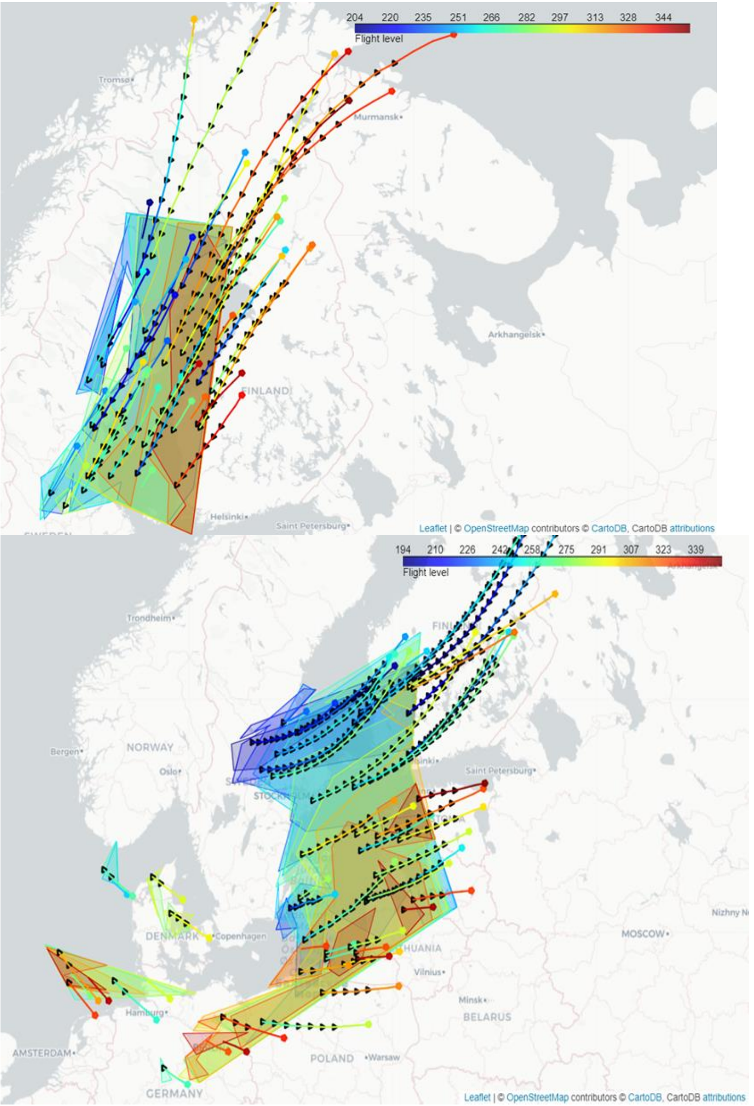
Practical test of route optimization for avoidance of climate impact from contrails

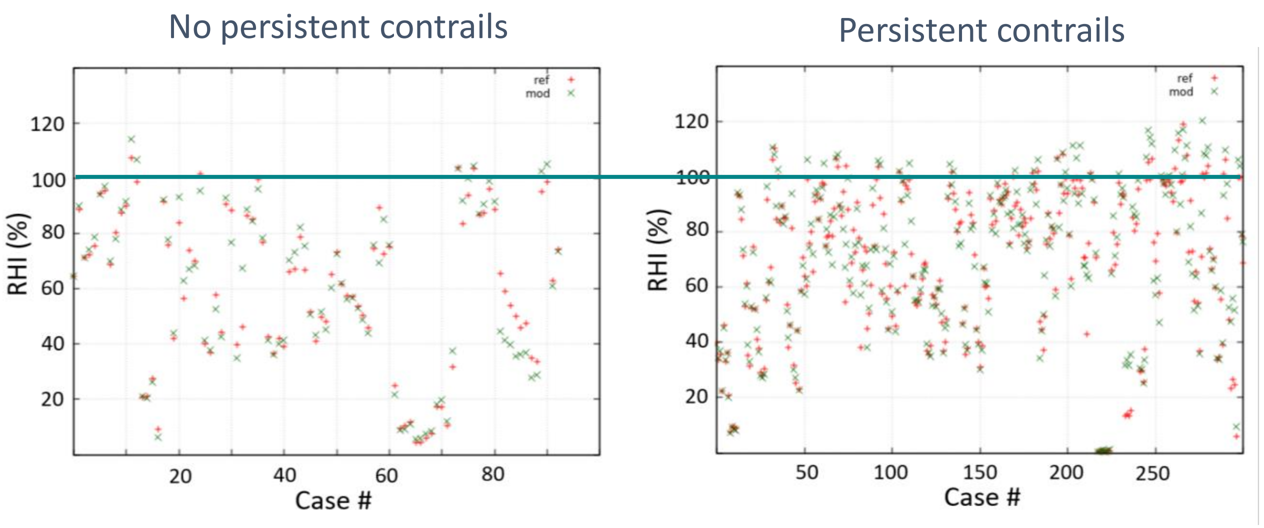
Development of methodology for calculating the climate impact from contrails

- Areas in the airspace that are ice-supersaturated (ISSL) are identified based on meteorological forecast data of the Scandinavian met-offices (Harmonie-Arome meteorology)
- The energy forcing of any contrails (radiative forcing during its lifetime) that would form there is calculated with methodology of the CoCiP model
- The identified ISSL polygons are classified according to their energy forcing potential
- Total energy forcing of contrails formed during a flight is calculated from the route plan of the flight and energy forcing in ice supersaturated areas through which the route passes



Are the predictions of ISSL based on meteorological model correct?

- Ground-based observations test of contrails performed by SMHI observers during the pandemics (low flight frequency) – 267 observations of contrails/no contrails during the period May-August 2020
- The forecast of RHI is higher when persistent contrails are observed, average 73-75% compared to 52% when no persistent contrails
- The fraction of cases with forecast RHI above 100% is quite low, 8-18%, for observations of persistent contrails



+ + Forecasts of ice supersaturation (RHI) calculated with AROME forecast model for observations

RHI (%)	No contrail cases (%)	Contrail cases (%)
>100	3	18
>90	14	38
>80	28	54
>70	38	65
Mean RHI (%)	52	75
Total # cases	143	370

Statistics of forecast ice supersaturation, RHI, with the AROME forecast model

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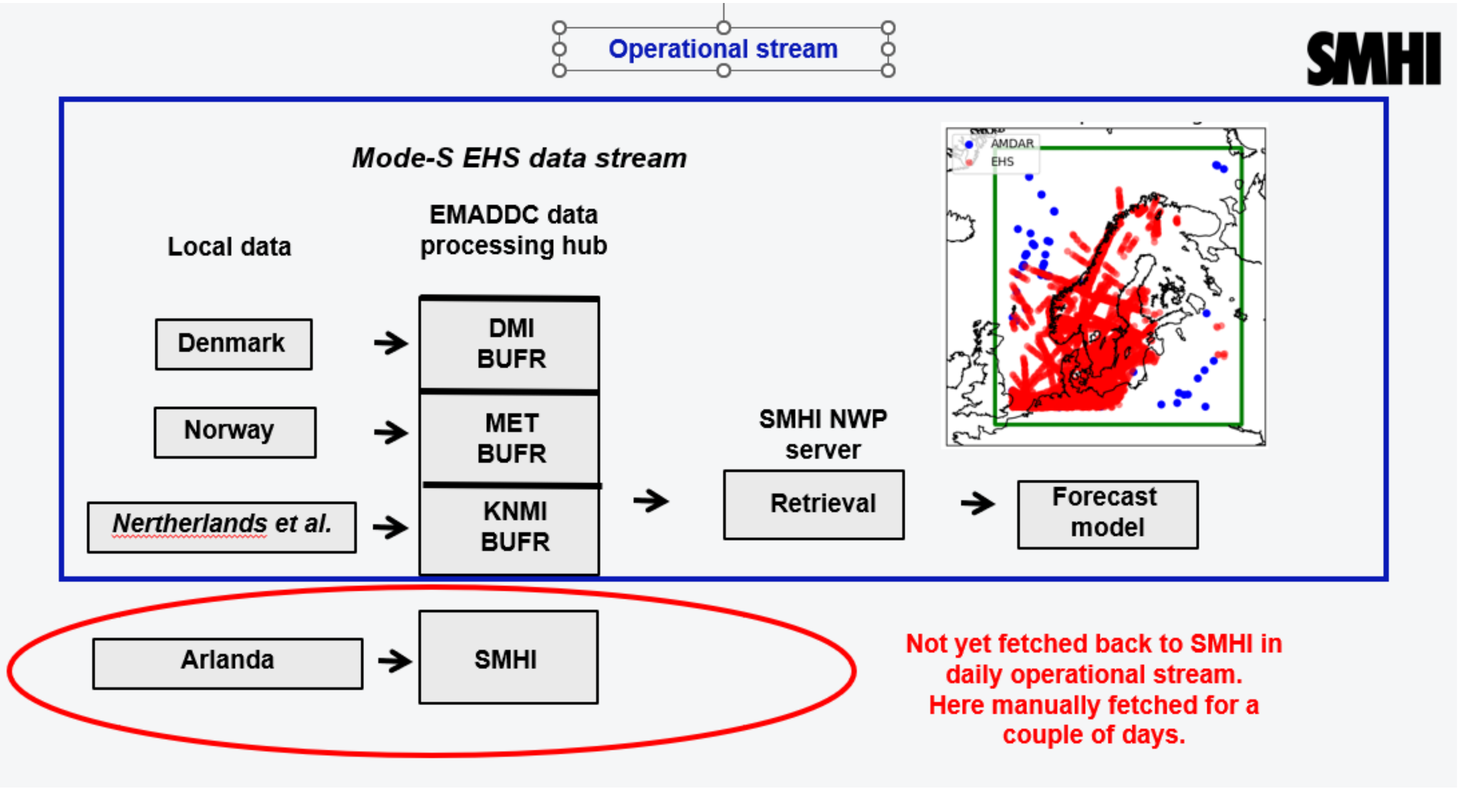
Quality of meteorological forecast essential for route planning and climate optimization

Data from air traffic control systems can be used to improve the meteorological forecast

Data sent by the aircraft include information about winds and temperature



The route planning

- Optimization of route plan for lowest cost – combination of fuel consumption, time cost and overflight charges

- Based on actual meteorological situation/forecast, calculating the aircraft weight, fuel consumption during the trip and costs

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--------------------------------------------------------------------------------
Log Nr.: 45824                       Page 1                     ESSA-ESNQ  NVR1111
--------------------------------------------------------------------------------
                           NOVAIR COMPUTER FLIGHT PLAN
NVR1111  ARN-KRN    FLIGHT TIME: 01:22   CMD:                        PARK:____
08APR20                                  F/O:

AVG WC          :    +9    TEMP TOC: -63   MET: 080006 080009  ACT SOB:____

AIRCRAFT        :  SE-TEST  A321-251N
MASS UNIT       :  KG                    EST PAX: M100/F100/C 21/I  0
COST INDEX      :  CI000
                              ELEV ft    STD      : 06:00  STA  : 07:16
DEP             :  ESSA  ARN    135
DEST            :  ESNQ  KRN   1509      CTOT     :
ALT 1           :  ENDU  BDU    253
                                         OFF BLOCK:_____  TAKE OFF:_____
EN-ROUTE ALT    :
TAKE-OFF ALT    :                        ON  BLOCK:_____  LAND     :_____

PLND ROUTE      :  ESSA RWY-19R RESNA5G RESNA T317 VAGAS VAGAS1S RWY-21 ESNQ

PLND DIST       :  0534 NM

TAXI            :    -     100  ______ ______      +/- 1000 KG: +/- 30 KGS
TRIP            :  01:22  3216  ______ ______
CONT 5%         :  00:05   161  ______ ______
ALT   (ENDU)    :  00:34  1288  ______ ______
ADDITIONAL      :  00:00     0  ______ ______
FINAL RESERVE   :  00:30  1035  ______ ______
COMPANY FUEL    :  00:00     0  ______ ______   MANUAL CORRECTION TO TRIP FUEL:
MIN REQ FUEL    :  02:31  5800  ______ ______   +/-10 NM ROUTE CHANGE +/-  60 KG
EXTRA           :  00:00     0  ______ ______   +/-50 NM ROUTE CHANGE +/- 300 KG
TOTAL FUEL      :  02:31  5800  ______ ______

MASS & BALANCE     PREL    ACTUAL  CG% MAC     ------------CORRECTIONS----------
DOM 02          :  50570                       FL    WC    TIME    TRIP
PAX 221         :  16535   ______              380   +10   01:22   3226
CPT LOAD        :   3000                       360   +9    01:22   3216
ZFM             :  70105   ______  ______      340   +10   01:23   3238
TAKE OFF FUEL   :   5700
TOM             :  75805   ______  ______
TRIP            :   3216
LDG MASS        :  72589   ______
--------------------------------------------------------------------------------
                                   ATIS/MET
INFO:________ TIME:___________ RWY:_________ TL:______ MISC:____________

WIND:________  VIS:________  CLOUDS:___________________ TEMP:____/____ QNH:_____
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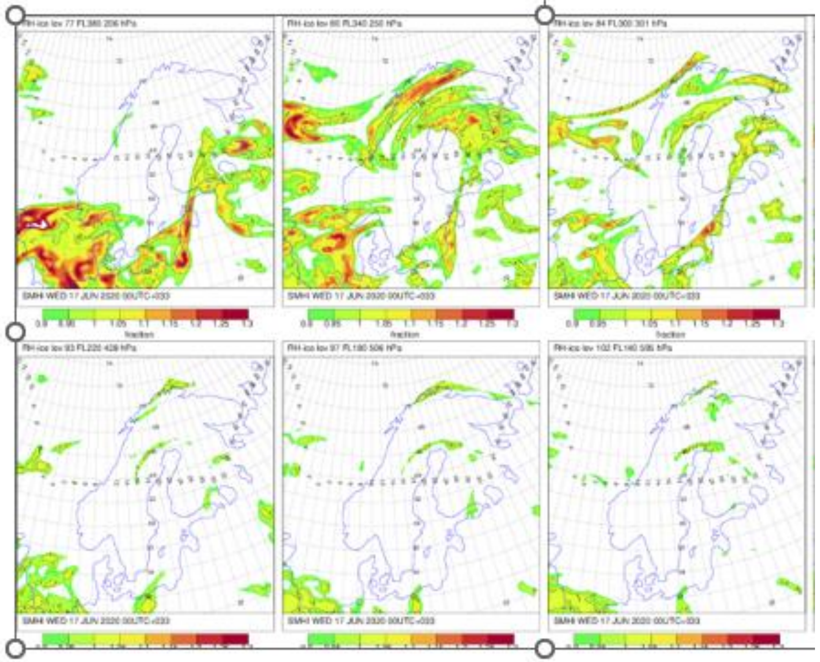
Contrail avoidance test spring 2020 using route planning system of Novair

1st test of manual optimization of hypothetical 2 daily flights Arlanda - Kiruna avoidance of all ISSL with potential to form persistent contrails on route. Tested aircraft was Airbus A321neo

On 42 out of 60 tested occasions (60%) regions with potential to form persistent contrails were forecast along the route. Vertical, horizontal or a combination of both deviations suggested to avoid the regions. The average increase in fuel consumption was 6.5%.

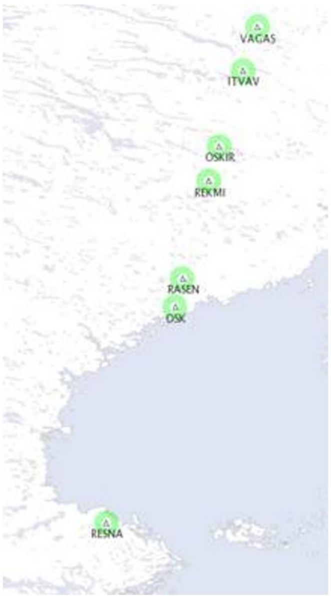


Forecast of relative humidity with respect to ice (fraction) over northern Europe for different flight/pressure levels used for route optimization.

Ice deviation route for Arlanda – Kiruna
2020-06-18 08:00 UTC

RESNA -
OSK –
RASEN -
64000N019008E FL<240
REKMI FL<240
OSKIR FL<240
ITVAV FL<240
VAGAS FL<240

Standard route



Example of ice deviation route for ARN-KRN (left). The waypoints RESNA (south) and VAGAS (north) are the first and last waypoints after leaving ARN and approaching KRN respectively. In between lies four waypoints for the nominal route (right)

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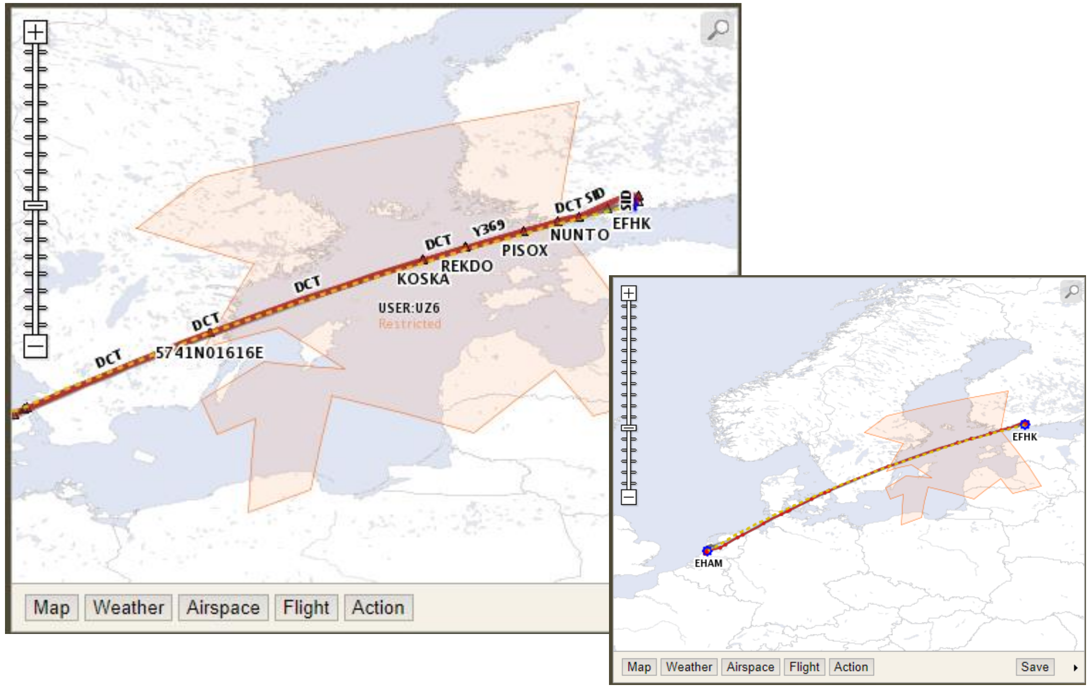
Contrail avoidance test spring 2022 – calculation of energy forcing

- 2nd test of optimization of hypothetical daily flights Arlanda - Kiruna and Helsinki – Amsterdam. Optimization is based on avoidance of areas that fulfil Schmidt-Appleman criterion, are supersaturated with respect to ice, and energy forcing of the potential contrail is positive.
- The route planning tool used for optimisation, the ISSL regions with positive forcing defined as restricted
- Energy forcing of the flight routes calculated



	Flight distance (km)	Cruising FL (100 feet)	Fuel consumed (kg)	Additional fuel	
				(kg)	(%)
Nominal route HEL-AMS	**879**	**360**	**5 186**		
FL 340	879	340	5 212	26	0.5%
FL 320	879	320	5 232	46	0.9%
FL 300	879	300	5 261	75	1.4%
FL 280	879	280	5 322	136	2.6%
FL 260	879	260	5 409	223	4.3%

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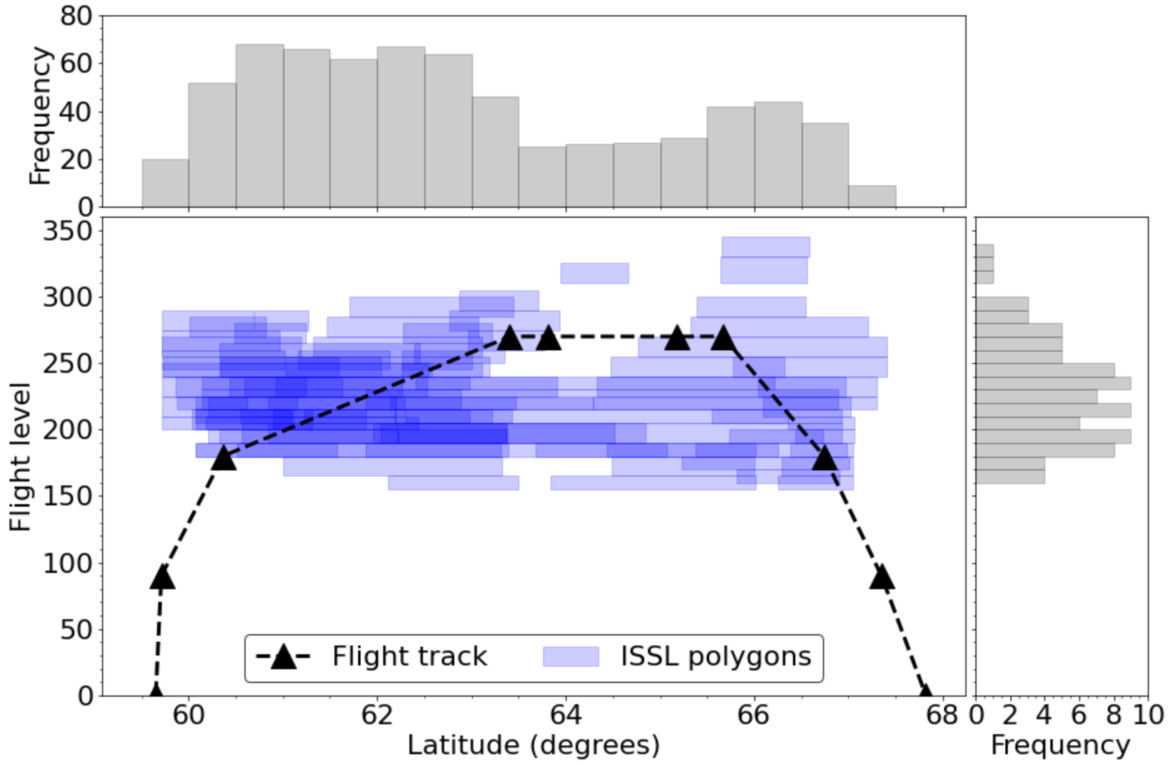
Energy forcing of flights February, Mars, April 2022

- Calculation based on Harmoni-Arome forecast data using Novair's route planning system without optimization for winds
- Energy forcing of persistent contrails is calculated for each flight during the period

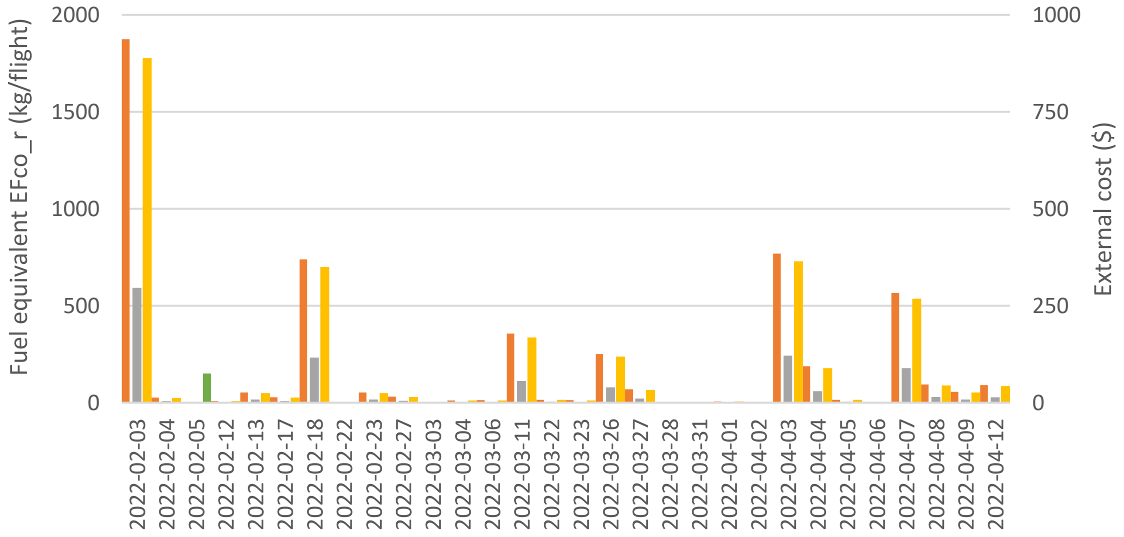


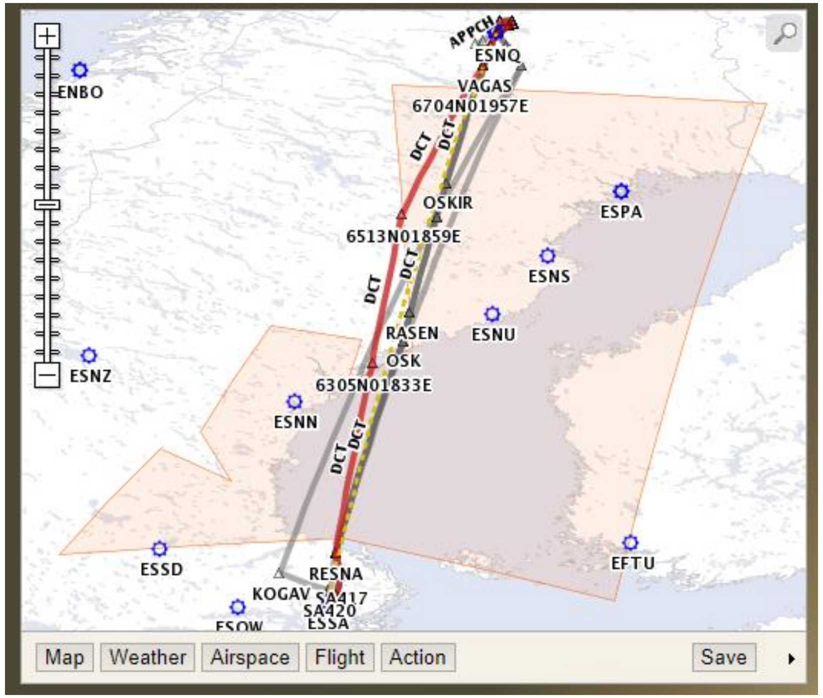
Flight track for the ARN-KRN route (black triangles are waypoints) including representations of all ISSL polygons (n=741) from the months February, March, and April 2022.

Energy forcing (EF) of flights February, Mars, April 2022

- EF calculated for nominal routes for all flights between Arlanda and Kiruna and Helsinki - Amsterdam (accumulted over lengths of intercepts of the route with the ISSL polygons)
- Expressed as equivalent fuel-CO_2 EF on 20-year time horizon (GWP_{20}) and external cost of CO_2-equivalent (we used a unit cost of CO_2-equivalent emission of 50-150 $/t CO_2 (TWG US Government 2021)

EF of flights Arlanda – Kiruna, fuel consumed on nominal route 3140 kg





Conclusions and future outlook

- Over Scandinavia, ISSLs are quite frequent, potential for climate forcing from persistent contrails exists.
- Forecast models tend to underestimate ice supersaturation. Data from air traffic control systems (data sent from the aircrafts) can be utilized to improve the meteorological forecasts used in the route planning
- Methodology for operational route optimization for reduced climate impact has been tested with the route planning tool by Novair. To be able to use the tool's optimization function directly, one would need to include ISSL areas with a certain climate or monetary cost into the route planning tool. This would be possible in cooperation with providers of route planning tools and/or with air traffic control services (LFV).
- Incentive for the aviation companies to optimize the routes for minimal climate impact can be:
  - Including the EF from contrails into future ETS, or
  - Setting price on flying through the ISSL regions proportional to their EF by the traffic control services

Thank you for your attention!

Contrail Avoidance in Practice

Implementation & Trials

February 14, 2024

Breakthrough Energy

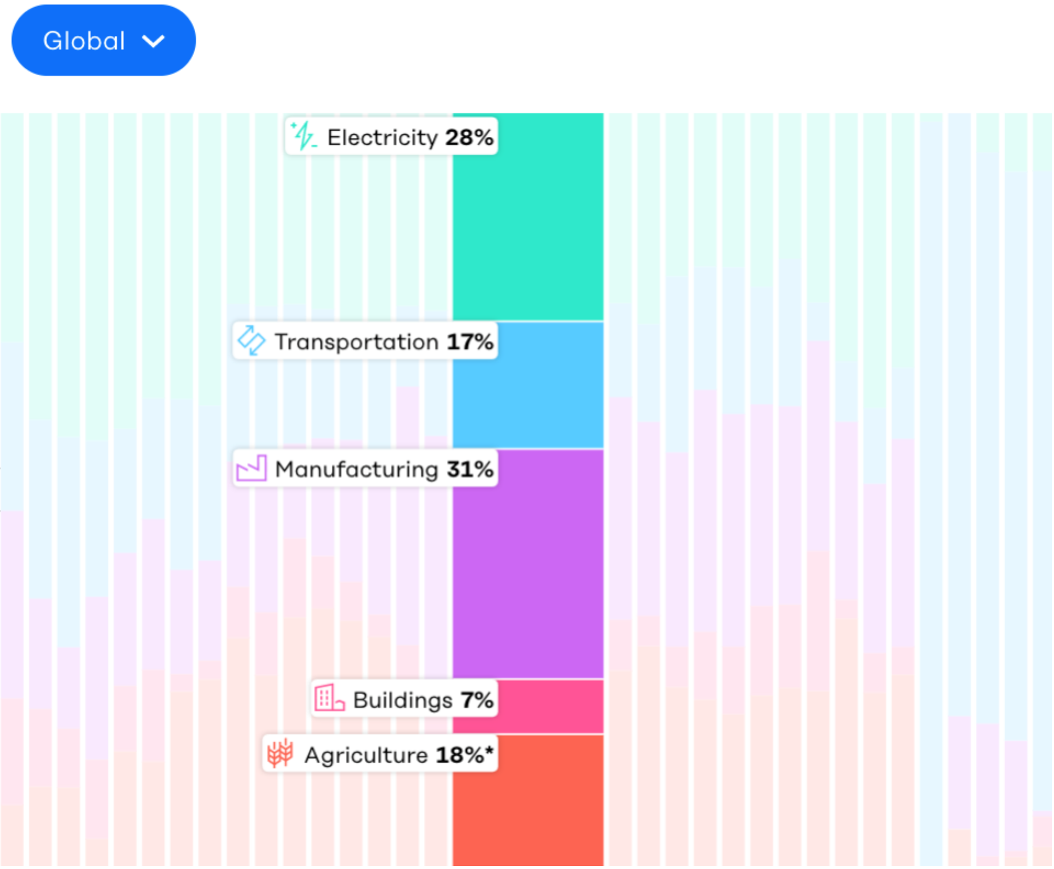
Accelerating climate progress across:

- **Technology.** Climate technologies our world will need to meaningfully reduce emissions.
- **Markets.** Bring together public and private sectors to accelerate market formation, spur further innovation, and reduce Green Premiums.
- **Policy.** Advocate public policies that will give new technologies a chance in the marketplace, incentivize investment, and drive down clean technology costs.

Breakthrough Energy Contrails

BE Contrails established in 2021 to support contrail research and transition

Emissions



Overview

Navigational contrail avoidance

Integration into flight planning and management

Implementation in flight planning and airline trials

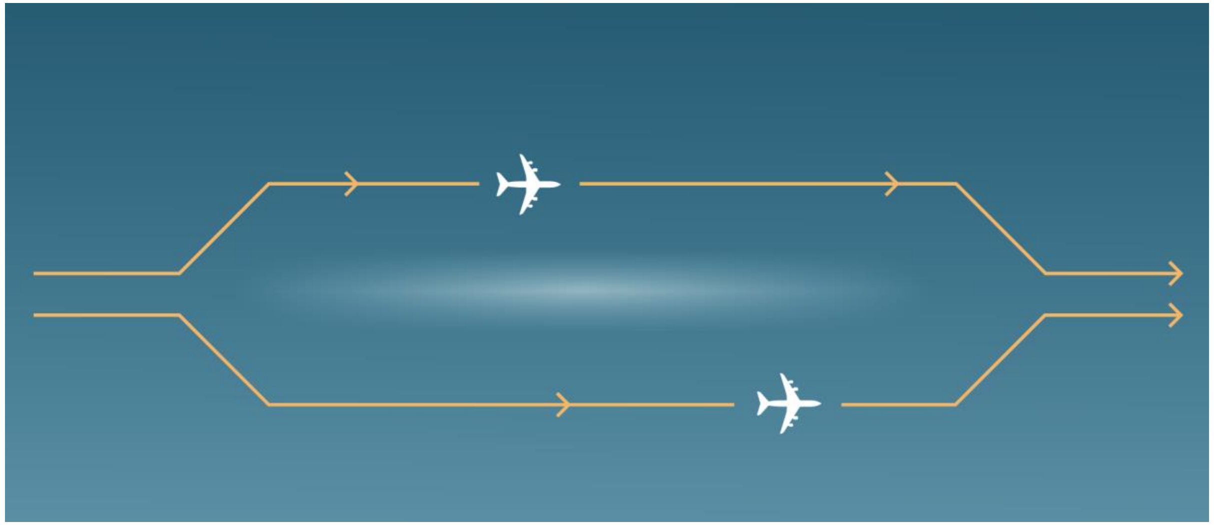
Real-world applications for trial and evaluation

Navigational contrail avoidance

Re-routing to avoid contrail forming regions at key times

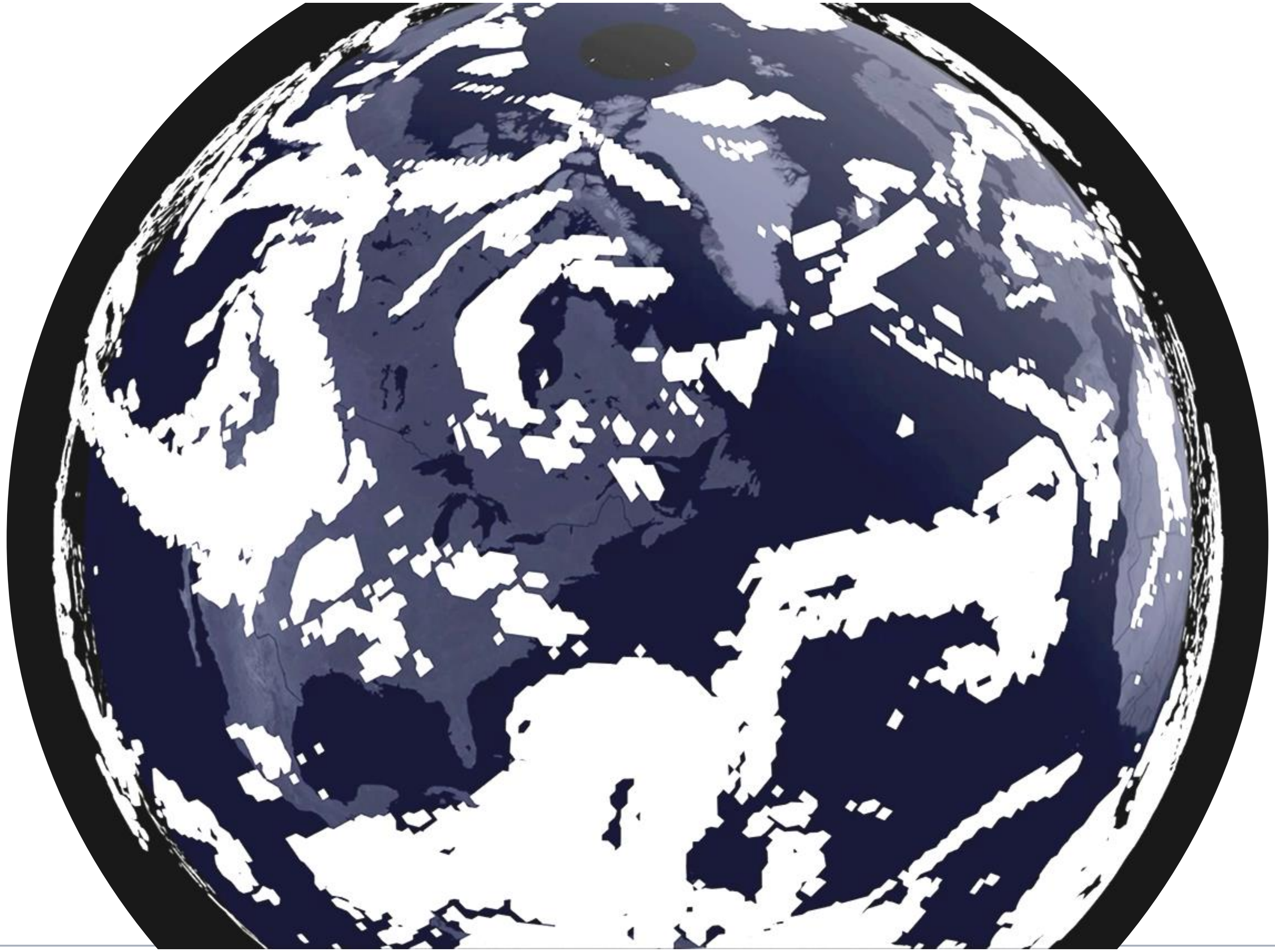
High level approach

1. Understand where contrail-cirrus will likely form
2. Characterize their expected climate effects
3. Integrate into flight planning and execution



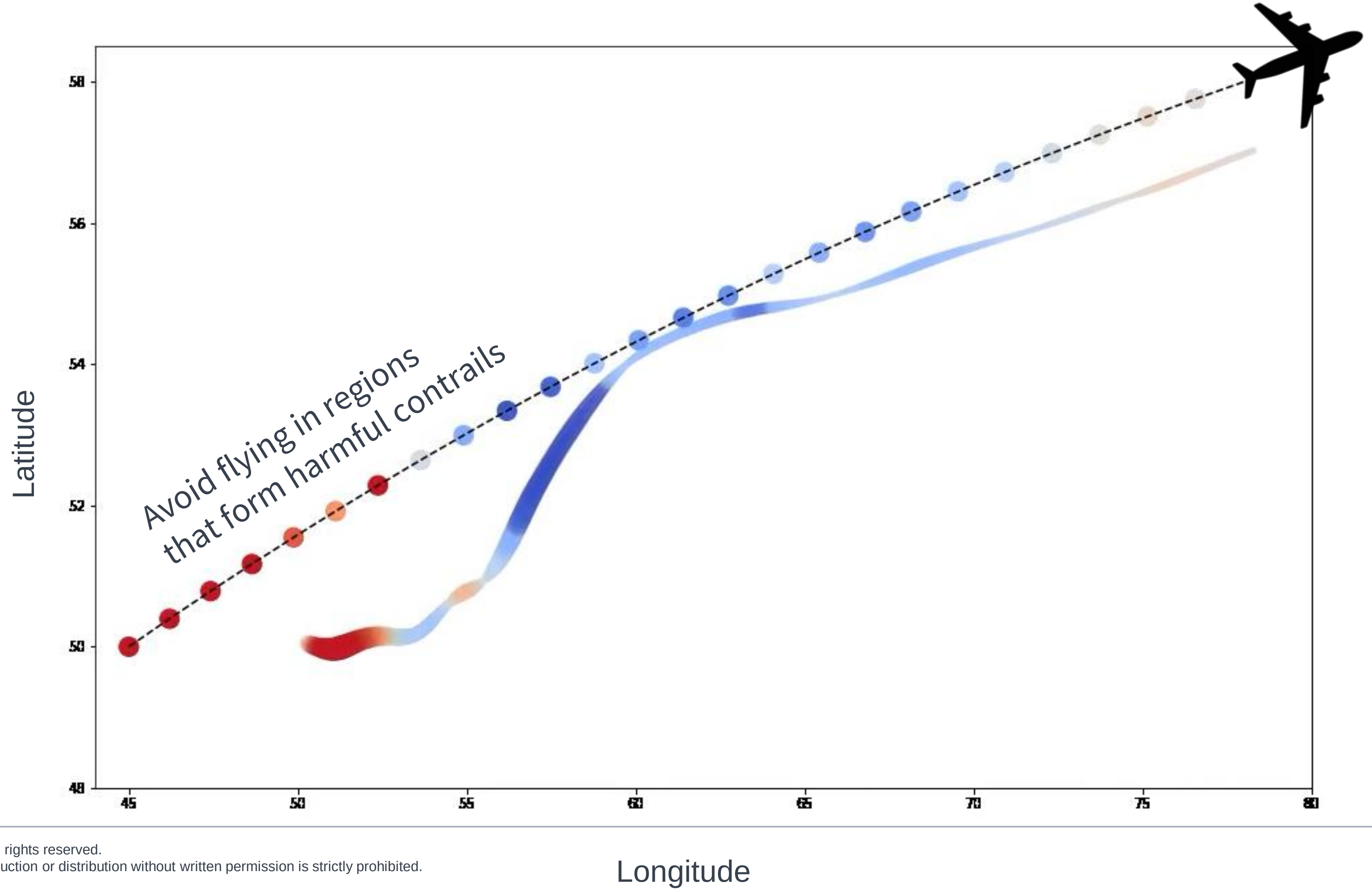
Contrails form in cold, humid regions of the atmosphere

Categorical avoidance would be effective, but completely avoiding persistent contrails regions is impractical



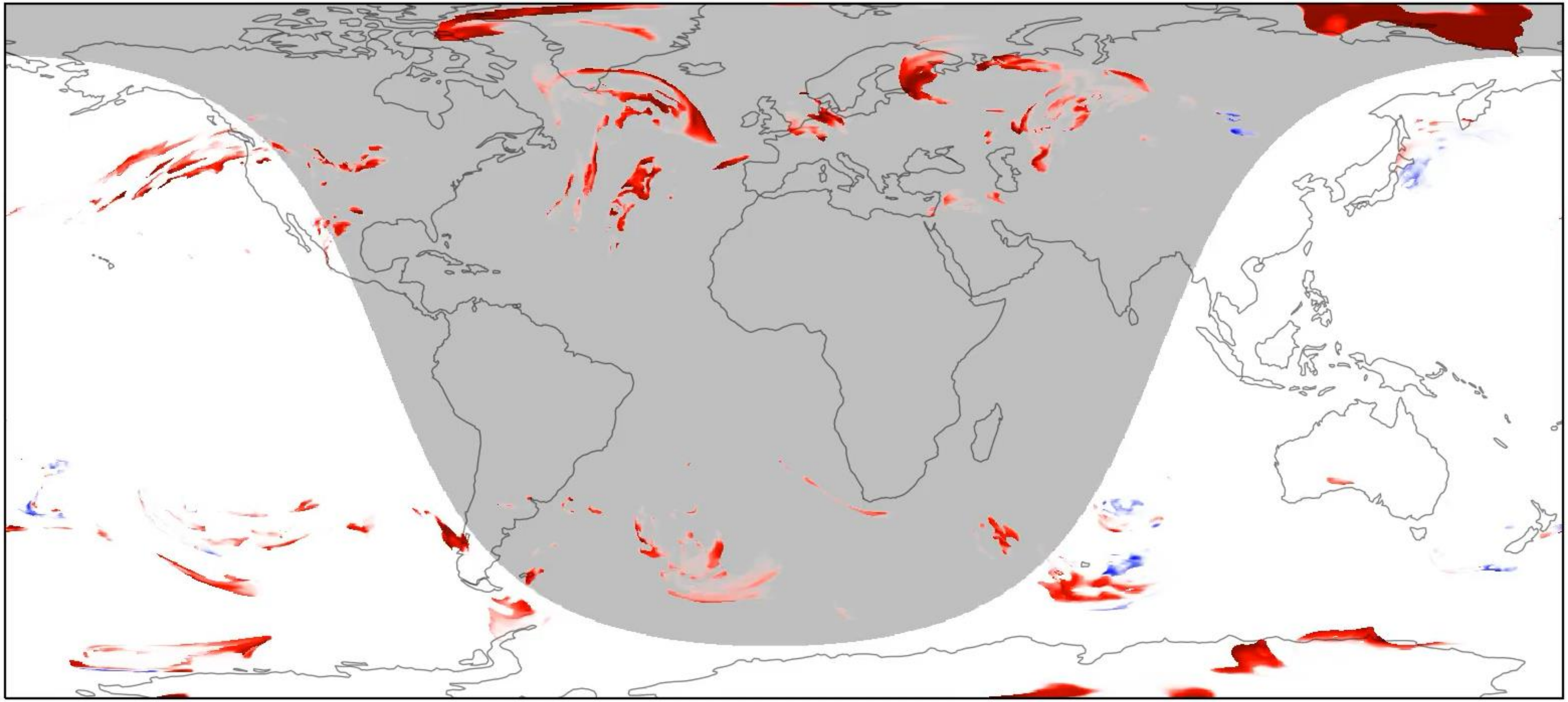
Track contrail evolution to understand climate effects

Avoid harmful regions by understanding downstream contrail forcing



Contrail forecast + nowcast enables trajectory co-optimization

Planning tools ingest and analyze contrail climate-forcing as any other "weather-like" data (e.g. icing, turbulence)



Contrail observations inform forecasts, nowcasts

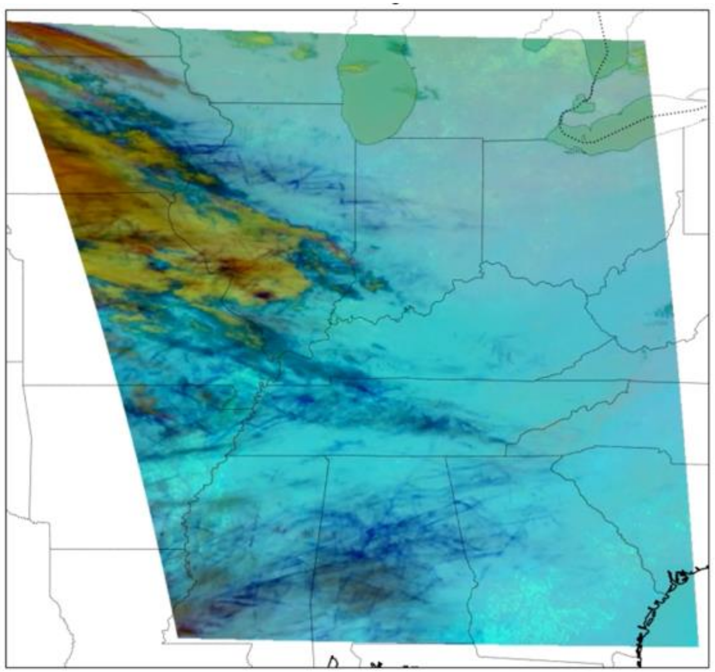
Satellite and ground-based observations improve model accuracy and feed into contrail forecasts / nowcasts

In-situ measurements

Airframe sensors
(IAGOS, WVSS-II)

Ground-based

Fixed sky-observing cameras,
LIDAR (MPLNet)

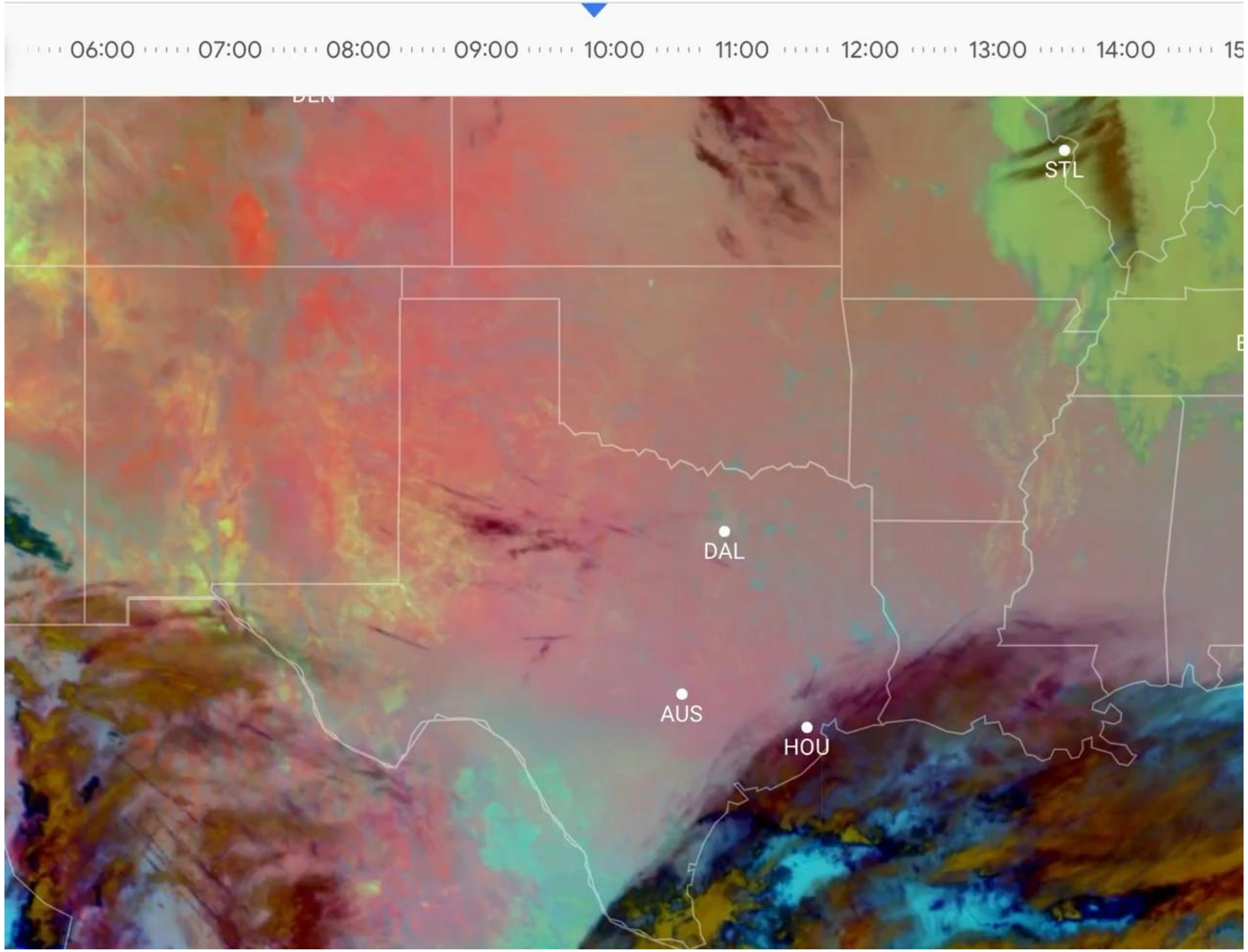


Satellite

Radiometers, LIDAR, Sounders
(GOES, Meteosat, Landsat,
CALIPSO, CLOUDSAT)

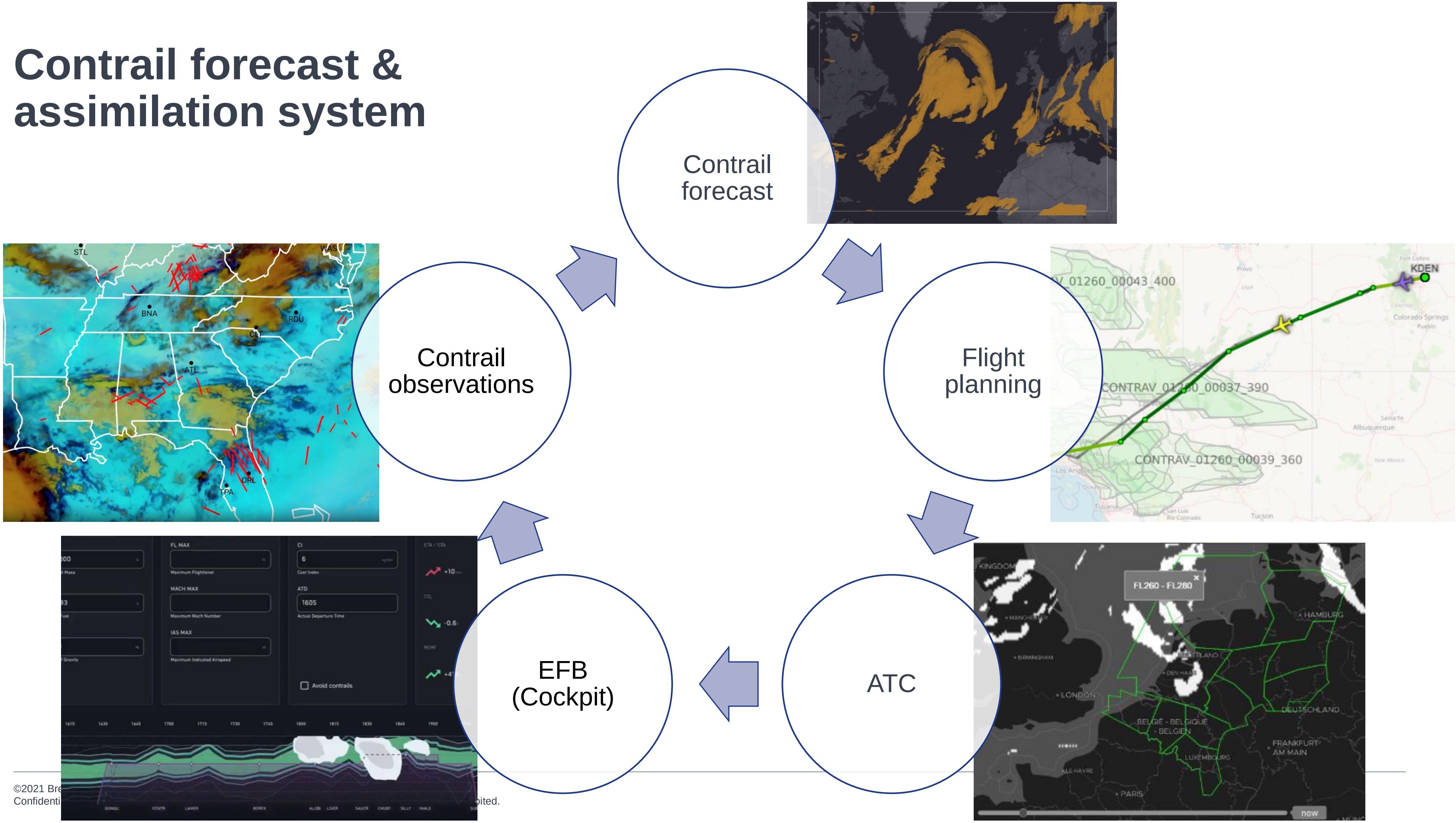
https://www.iagos.org/iagos-core-instruments/

Satellites detect contrail outbreaks in real time



https://contrails.webapps.google.com/main

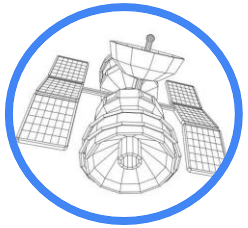
Contrail forecast & assimilation system



2023 AA Feasibility Trial

Skillful contrail forecasts enable contrail avoidance

Forecasts / nowcasts need to answer two distinct questions:



Formation

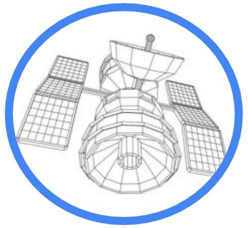
If an aircraft flies through this space, will a persistent contrail form?

Climate Impact Estimate

If a persistent contrail forms, how will it impact the climate?

Skillful contrail forecasts enable contrail avoidance

Forecasts / nowcasts need to answer two distinct questions:



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AA “pilot” study methods

Structure

- 10 pilots participated
- Between Jan 1 and early June, 2023

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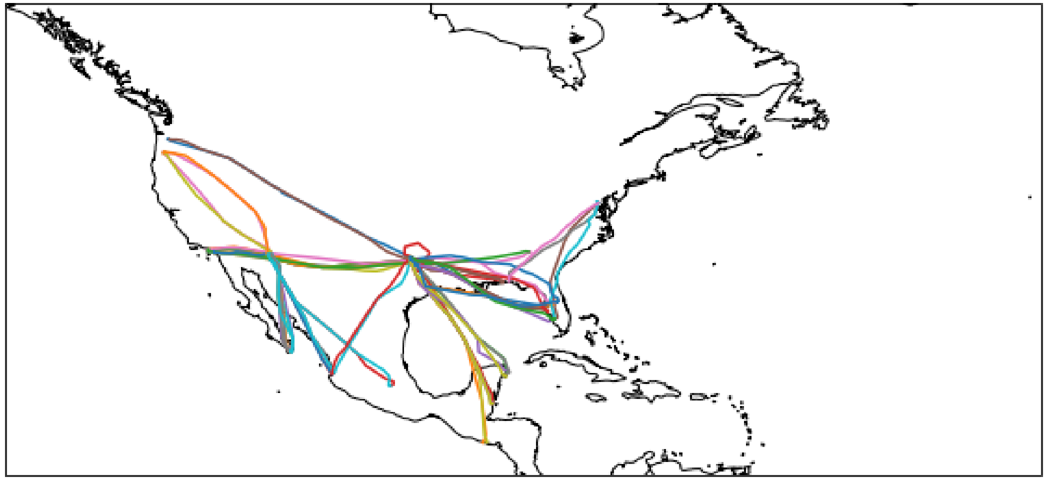
- City A to City B, back the same day



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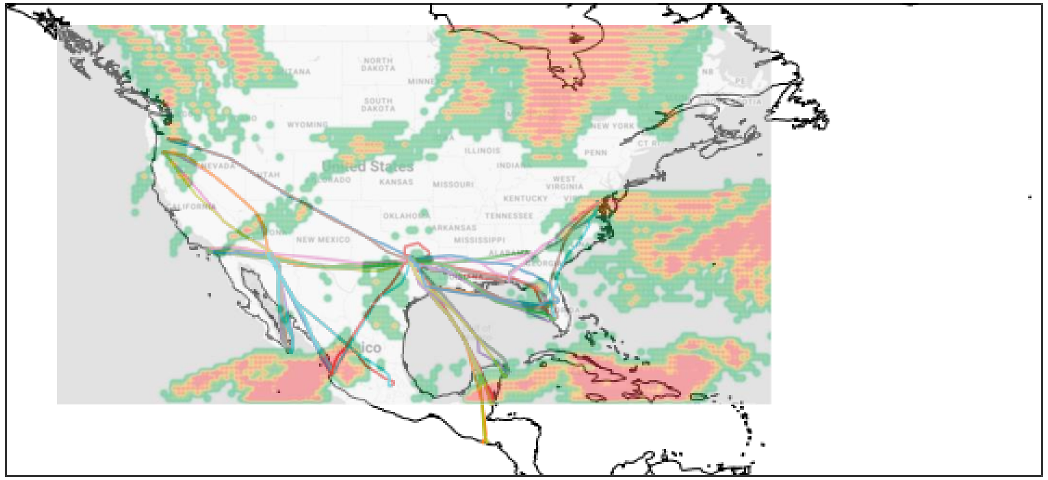
— Contrail Likely Zone (CLZ) on flightpath in/out of city A or B



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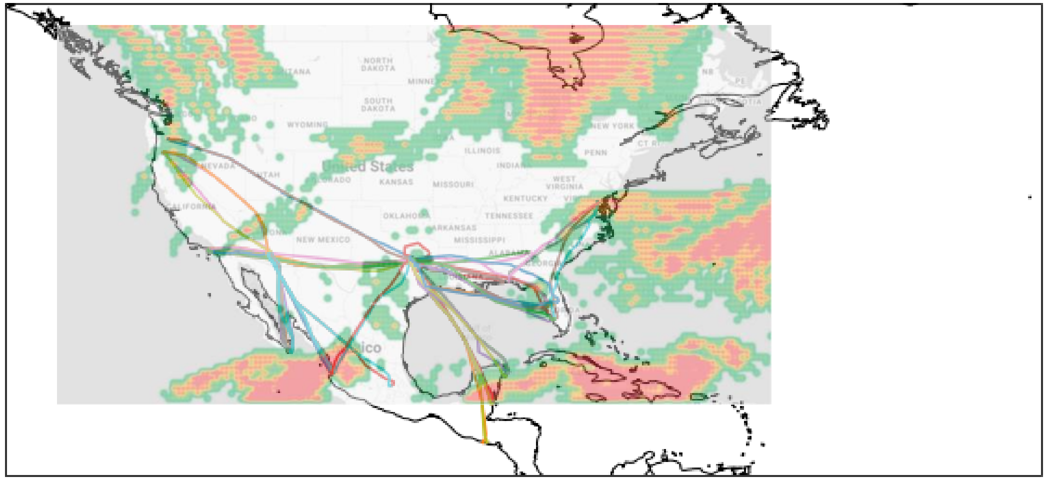
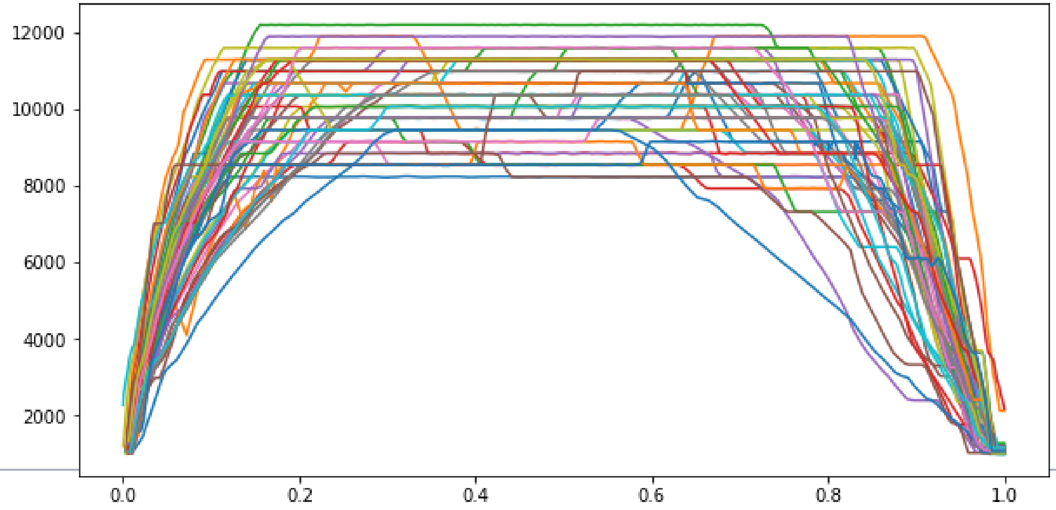
- Avoidance only **early descent or late ascent**





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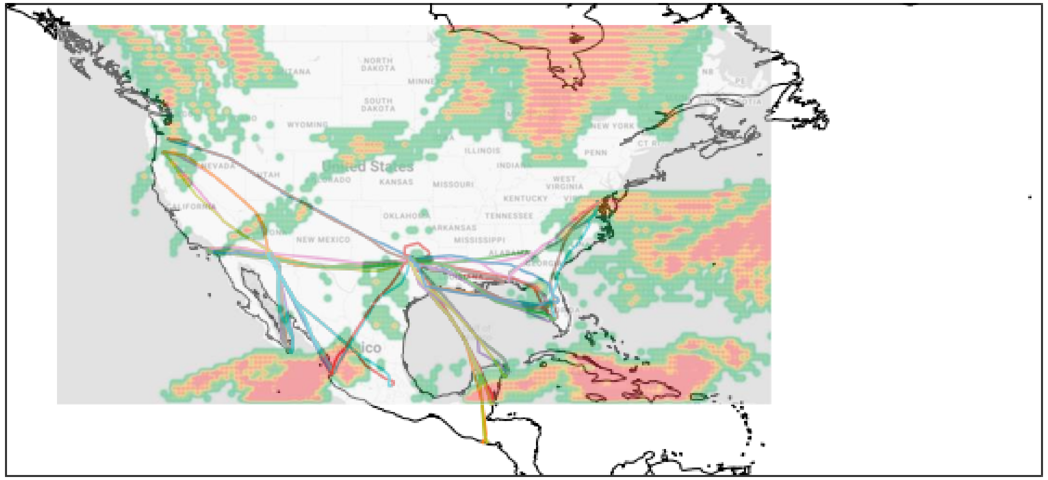
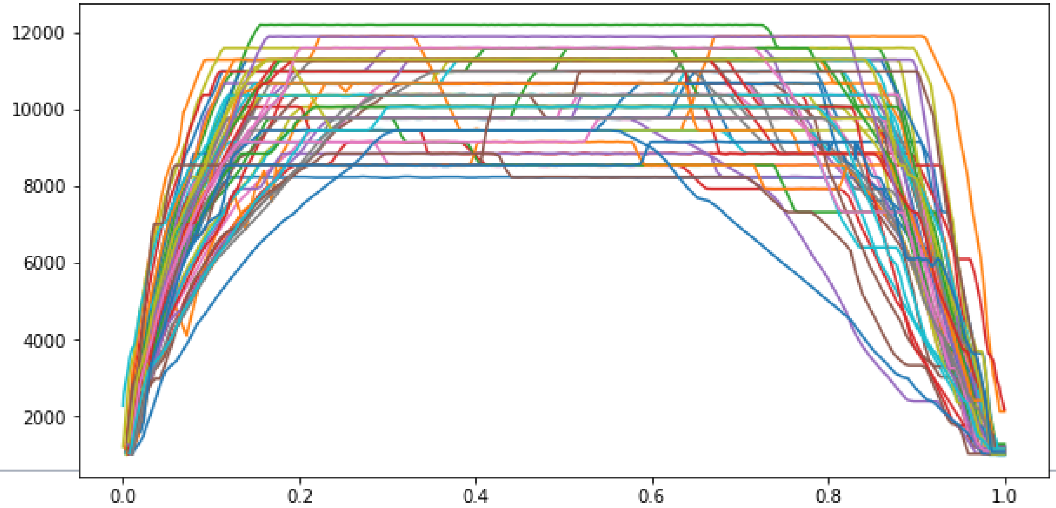
Input

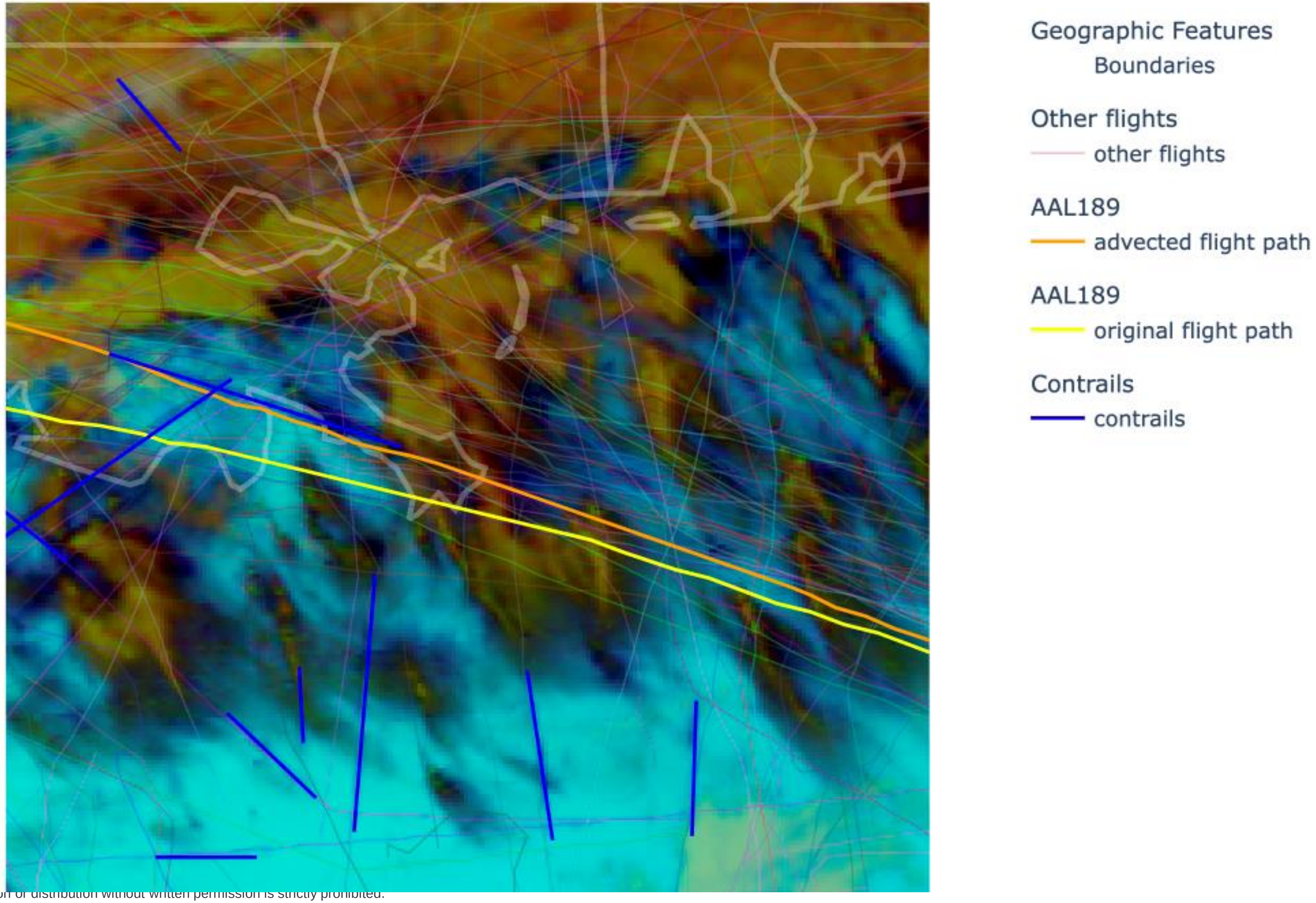
- Manual review of contrail predictions
- PACE-integrated contrail predictions





Example of avoidance using the EFB

Satellite-based verification of contrail formation



Results

35 turns, of which 22 included in analysis (44 flight segments)

	No detectable contrail created	Detectable contrail created	Contrail length [km]	Total flight length [km]
Control	11	**11**	**726**	36802
Experiment	18	**4**	**321**	35729

64% fewer contrails observed

54% reduction in contrail length

Average of **2% more fuel per adjusted flight** (without using an optimizer)

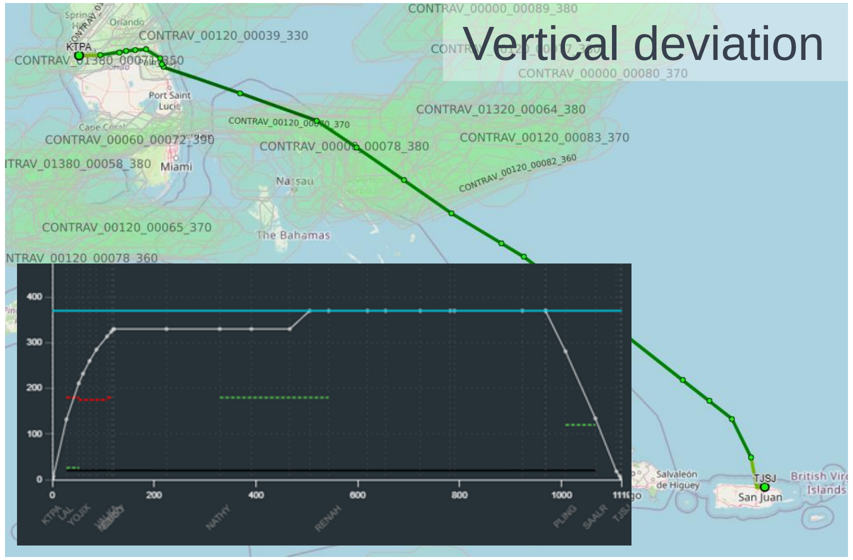
Quantify cost in flight planning systems

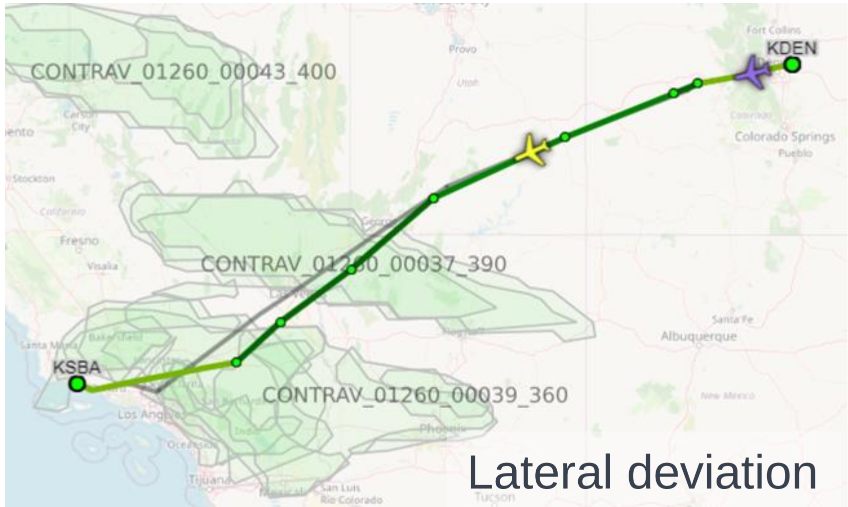
Flightkeys ingests forecast (or hindcast) from API

Simulate 4 weeks of real airline operations (June 2023, Jan 2024)

Shows minimal added cost, no conflicts with ATM constraints or compulsory routes

	American Airlines
Total flights	84,839
High impact flights	2,438 (2.87%)
Fuel (kg)	+0.05%
Time (min)	-0.00%
Cost ($)	+0.03%
Energy Forcing (MJ)	-65.6%
$USD/TCO2_{e,20}$	$0.65





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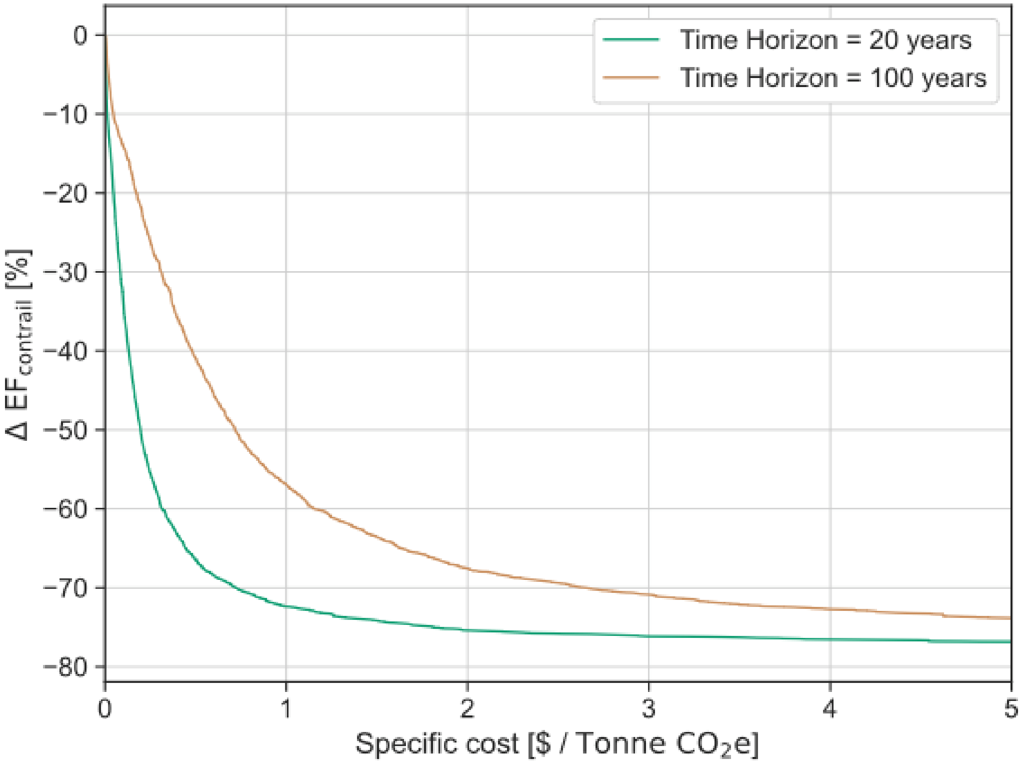
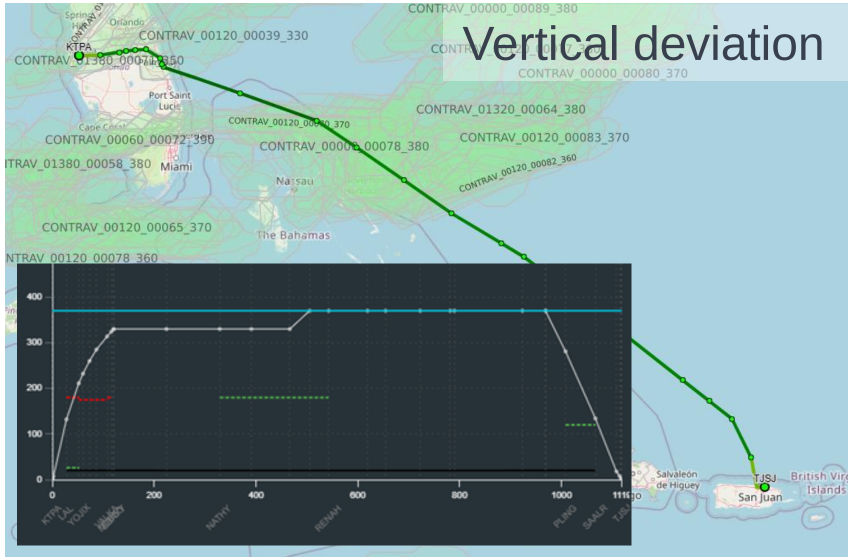
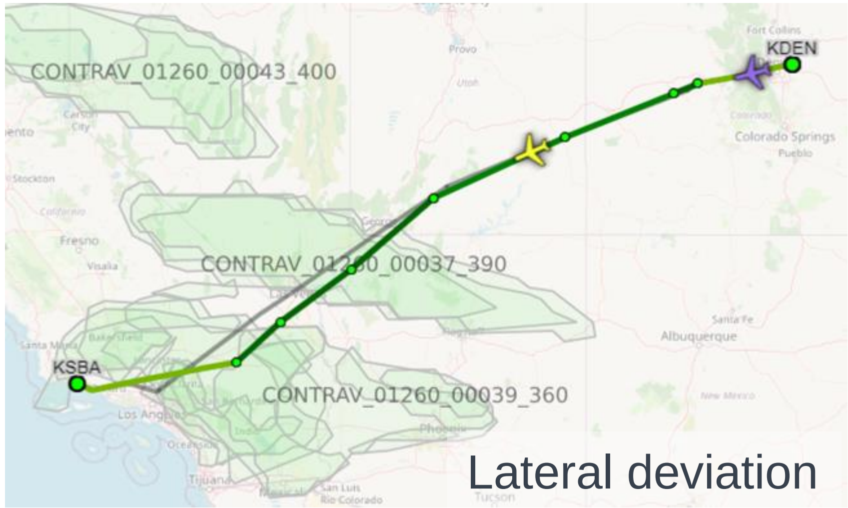






Next: Automate interventions in simulation and trials

Ascent/Descent vs Cruise

- Trial was small, only ascent/descent
- Ascent/descent allows larger altitude changes than mid-flight
- Need to explore feasibility of cruise altitude adjustments

Dispatcher Approach

- Integration into flight planning systems
- We need more simulations

ATC Approach

- Expand on EUROCONTROL (MUAC) trial design

Scandinavian Advantage

Lower density of air traffic

— Contrail interventions more easily identifiable in observations

Satellite observation (MTG-03)

— Operational in early 2024

Centralized air traffic management

— Few air traffic controllers and air navigation service providers to coordinate

Opportunity

Coordinate centralized contrail avoidance trial in an isolated airspace

Breakthrough Energy Contrails

More info

contrails.org

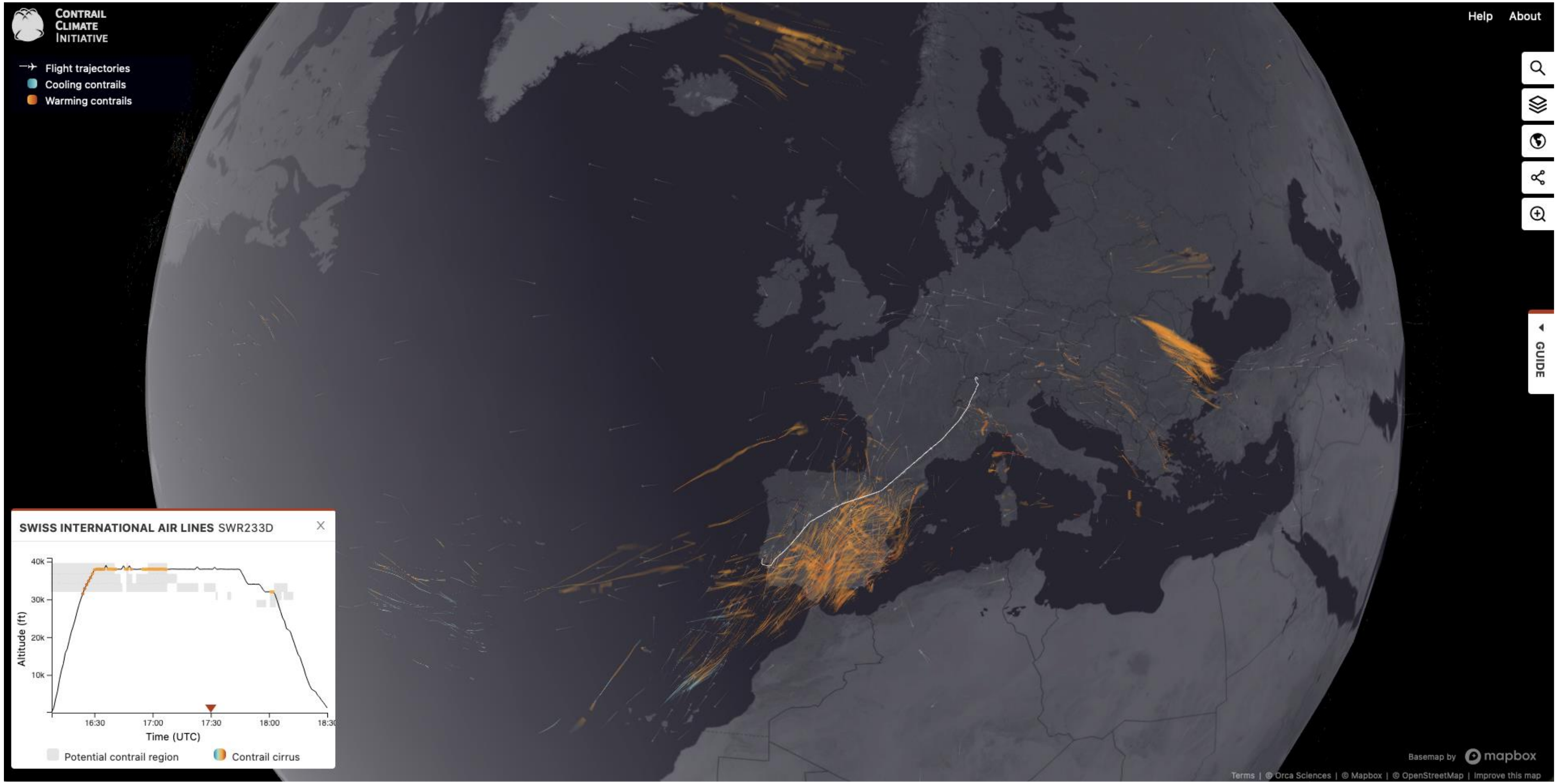
Contact

Marc Shapiro: marc.shapiro@breakthroughenergy.org

Matteo Mirolo: matteo.mirolo@breakthroughenergy.org

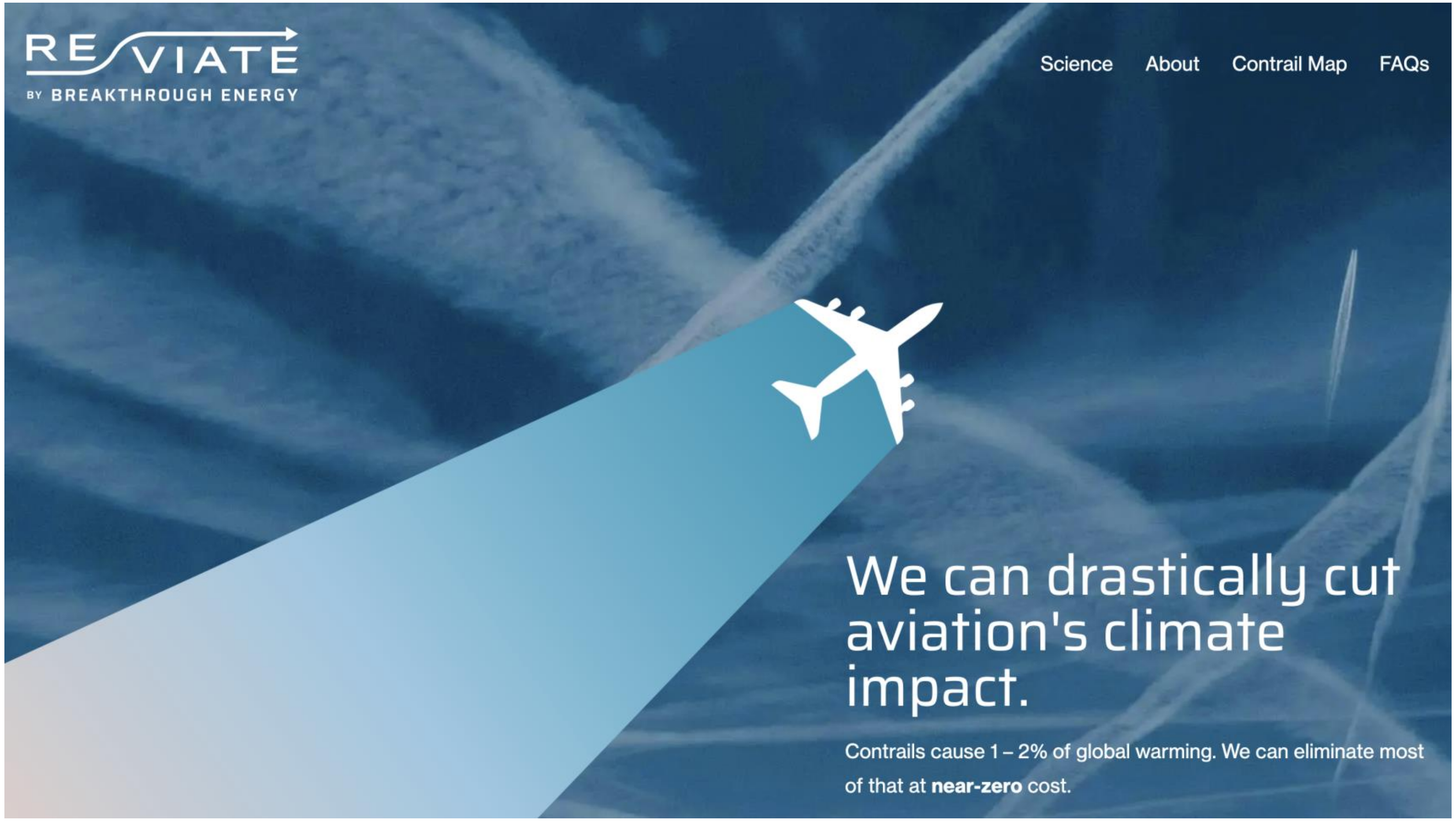
Visualize global contrails on interactive map

https://map.contrails.org



Transition research into industry action

Enable, verify, and accredit contrail aware aviation operations



https://www.contrails.org

"Wait" or "Act Now"?
How to react to the current status of contrail research

Hartwig Hagena, DLR PT-LF, Scientific Associate and German National Contact Point for Aviation

DLR Projektträger Luftfahrtforschung

Lots of information? Confused?

Energy Forcing

Ice-Supersaturation

ECHAM Climate model

SAF

Effective Radiative Forcing

Optical Depth

Metric

warming/cooling Contrail

Big Hits

Contrail Climate Model

CO2 versus Non-CO2

aCCF

ambient Shear

CoCiP

Soot

Surface Albedo

Flux Change

Quoting Hamilton*:

“I don‘t pretend to have the answer, but the question is real“

From the “Hamilton“ musical by Lin-Manuel Miranda, 3rd Cabinett Battle

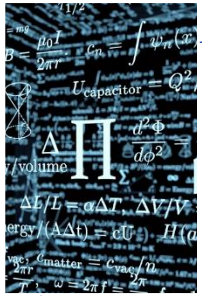
What about the uncertainties?

Living with the unknown:

Go for the 20% risk!

What do we need?

The airlines



The formula

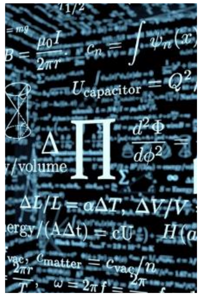
Solution-oriented thinking

Airline Involvement is crucial for success

We need to find the proper way to “motivate“ airlines.

We have to address this now- finding solutions will take time.

To take action we need a science based decision formula



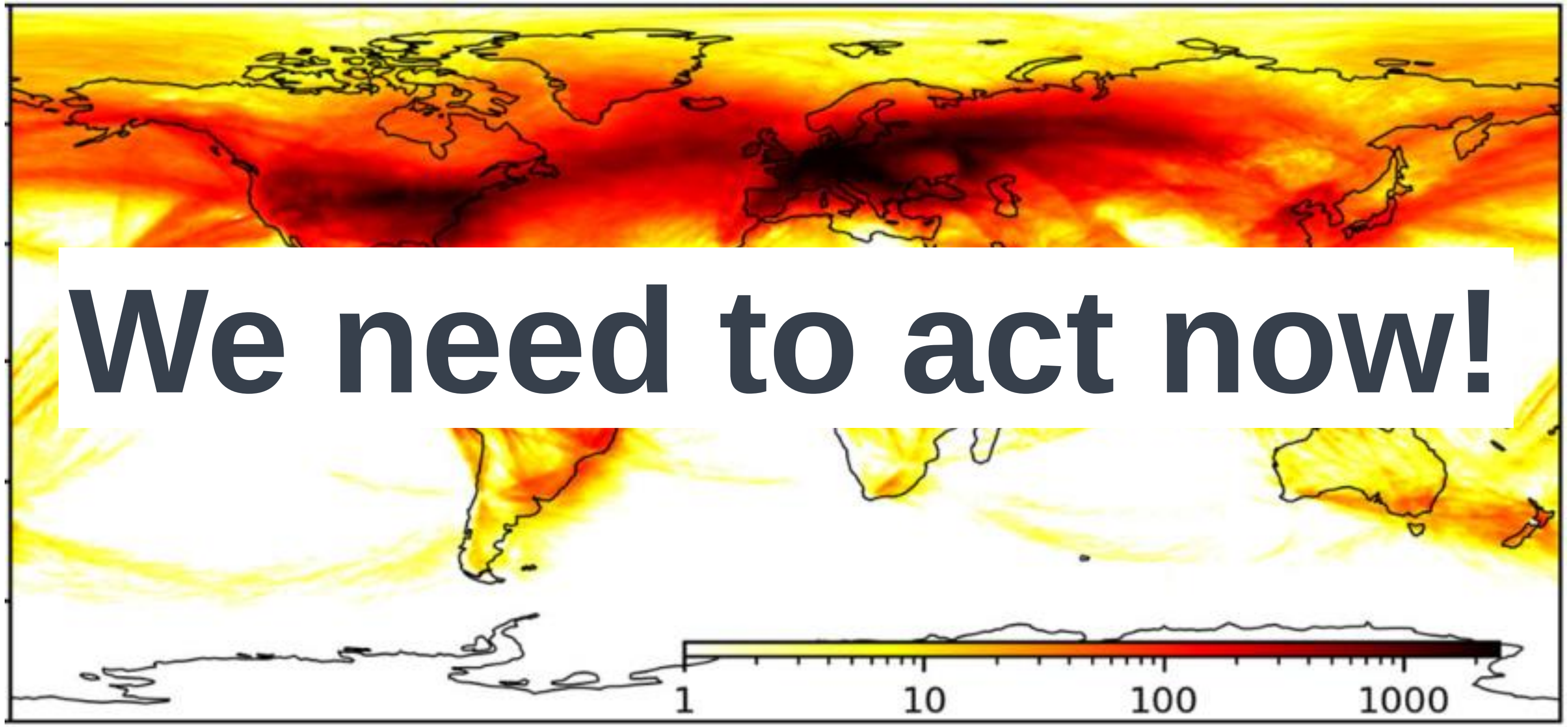
- uncertainties shall not prevent actions
- use existing data even with large error margins
- provide clear criteria to airlines, based on decision theory

Whereever there is a challenge, we need to look for solutions

- There are many things to consider
- We should not stop to wait for "perfect" or "total" mitigation

Don‘t ask "*is it possible?*"- ask "*how can we start?*"

We can‘t wait



We need to act now!

Contact Data

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Mail : Hartwig.Hagena@dlr.de

Backup slides

Contrail Mitigation: current Highlights

EUROPEAN INNOVATION FUND: IF23 CALL: FUNDING OPPORTUNITY FOR CONTRAIL MITIGATION

ROCKY MOUNTAIN INSTITUTE: “ROADMAP TO IMPLEMENTATION“ PROCESS

EU-ETS MONITORING, REPORTING, VERIFICATION (MRV): TWO YEAR DATA COLLECTION

EASA: CREATING A “NETWORK OF EXPERTS“