Climate Optimized Flight Routes – The Path from Research to Operations

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Simulations, Research & Development

DFS Deutsche Flugsicherung GmbH

German Air Navigation Service Provider

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Hamburg Aerospace Lecture Series

24th of November 2022

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DGLR in cooperation with the RAeS, HAW Hamburg, ZAL and VDI invites to a lecture

Climate Optimized Flight Routes – The Path from Research to Operations

Dr. **Ralph Leemüller**, DFS Deutsche Flugsicherung GmbH

Date: **Thursday, 24 November 2022, 18:00 CET**
Online: https://purl.org/profscholz/zoom/2022-11-24

Studies in research often promise a fast system implementation and usage in operation. But especially in safety critical areas like air navigation services it can be recognized that it takes quite a long time from proclaimed "ready for use" at research level until actual operational use. Why this difference? Often, necessary aspects like safety assessment, certification, and training procedures for operators cannot be analyzed by researcher. The validation under operational circumstances may lead to additional questions.

The presentation will demonstrate several challenges in the actual discussion about avoidance of persistent contrails. The German project D-KULT (Demonstrator klima- und umwelt-freundlicher Lufttransport, Juni 2022 bis Mai 2025) works on several solutions and its ideas are presented during the lecture.

M. Stanislav, pexels.com

Ralph Leemüller has accumulated knowledge from many years in the research and development division at DFS. He has experience in product management of air traffic simulators as well as management of complex systems in national and in international projects. Currently, he works on the evaluation of procedures to mitigate climate impact through air traffic management.

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Hamburg Aerospace Lecture Series (DGLR, HAW Hamburg, RAeS, VDI, ZAL)

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ZAL TechCenter https://www.zal.aero

Why are sometimes evident research results not in operational use?

- Results of research publication show evidence
- An immediately implementation and operational usage is the next step

But:

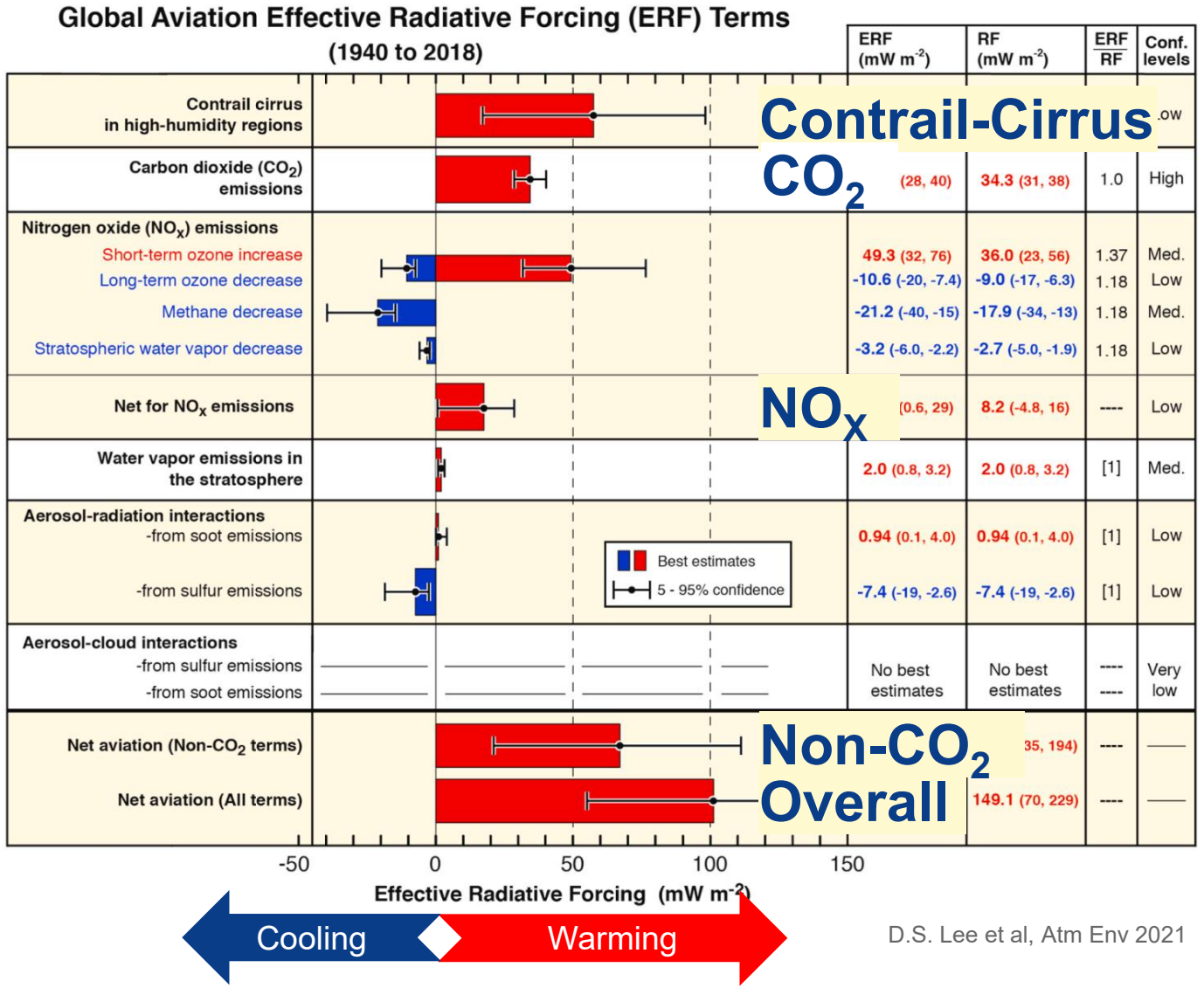
- Necessary aspects cannot be analysed by researchers
- Validation under operational circumstances aren’t often not possible – especially in safety critical environments
- Additional questions may occur to be re-assessed by research organisation

This presentation:

- Actual discussion about avoidance of persistent contrails

Climate Impact of Air Traffic

Effective Radiative Forcing



D.S. Lee et al, Atm Env 2021

Aviation impacts the climate by **CO_2-** and **Non-CO_2-Effects** (NO_x, Contrail-Cirrus, H_2O, Soot, …)

Non-CO_2-Effects compromise about **2/3** of total ERF

Contrail-Cirrus (57%) has the largest contribution regarding ERF

Air traffic counts 3.5% – 5.0% to global climate change*

* Website of BDL; Lee 2021

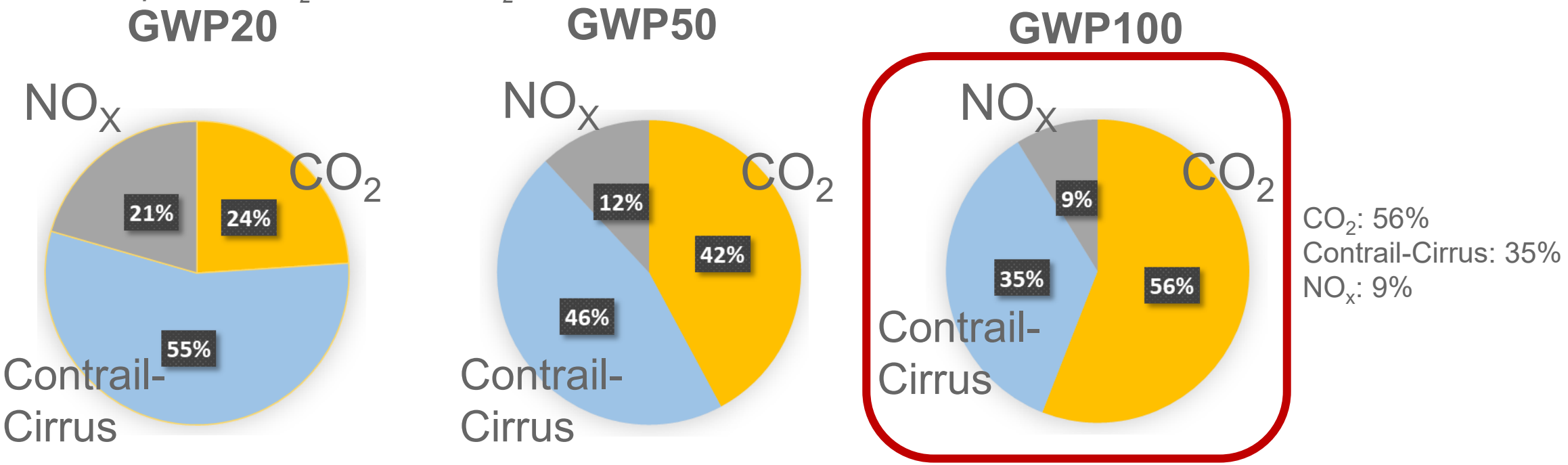
Climate Impact of Air Traffic

Properties of climate effects

- Emitted CO_2 remains several 100 years in the atmosphere
- Non-CO_2 effects have lifetimes between some 10 years (NO_x) and hours (Contrail-Cirrus)
- Different time scales have to be harmonized!
- Impact of Non-CO_2 effects are additionally dependent from weather, geographical location & altitude and time of emission
- Climate metric to compare the impact of emission
  - Global Warming Potential (**GWP100 years**):
    GWP is widely used e.g. in the Kyoto protocol (IPCC) and in EU Emission Trading System (EU-ETS) – short-lived emissions are not well represented
  - Average Temperature Response (**ATR50**):
    ATR is less dependent of chosen time horizon and reflects pulse emissions. But usage is under discussion. A disadvantage is the increased uncertainty of needed climate sensitivity parameter

Climate Impact of Air Traffic

Comparative impact of CO_2 and Non-CO_2 effects for different time scales



Effect	GWP20	GWP50	GWP100
CO_2 [Gt/yr CO_2]	1034	1034	1034
Contrail Cirrus [Gt/yr CO_2-eq]	2395	1127	651
Net NO_x [Gt/yr CO_2-eq]	887	293	163
Others [Gt/yr CO_2-eq]	-188	-88	-51
Total [Gt/yr CO_2-eq]	4128	2366	1797

Non-CO_2 effects on long time scale still present

Impact of Non-CO_2 effects is 44%

D. Lee et al, Atm Env 2021

Climate Impact of Air Traffic

The playing with different values

Different representation of values are currently used

Some Examples:

- Contribution of Non-CO_2 of aviation
  - ~ have **66%** climate **effect** based on ERF
  - ~ have **44%** climate **impact** based on GWP100

Air traffic counts 3.5% – 5.0% to global climate change

Impact of Non-CO2 to global contribution (GWP100): **2.2%**

Influence of ATM to global reduction: **0.4%**

- ATM will contribute in reduction of climate effects till 2050 by **8%** (EASA aviation environmental report 2022)

- All values are right, but it is strongly dependent of the background
  A “not correct” use influences public or political opinion

D-KULT (Demonstrator Klima- und Umweltfreundlicher Lufttransport demonstrator for climate and environmentally friendly air transport)

Aeronautical research programme (LuFo VI-2) of the German government

Investigating the **feasibility of ecologically efficient flight trajectories**

- **Demonstration of** how to avoid transit through ice-supersaturated regions (ISSR)
  - in upper airspace (DFS Karlsruhe control centre)
  - analysis through satellite monitoring
  - clarify whether existing tools & data are already sufficient for cases that can be implemented
- **Simulations** on the feasibility of eco-efficient flight trajectories based on the aCCF (algorithmic climate change function) for selected past situations
  - ensure comprehensive consideration of the environmental impact based on engine emissions and their chemical processes
- Duration of 3 years: June 2022 – May 2025
- Consortium leader: German Aerospace Centre (DLR), Oberpfaffenhofen

Expected result:

✈ **Recommendations for action** for the aviation industry, science and politics

Gefördert durch:

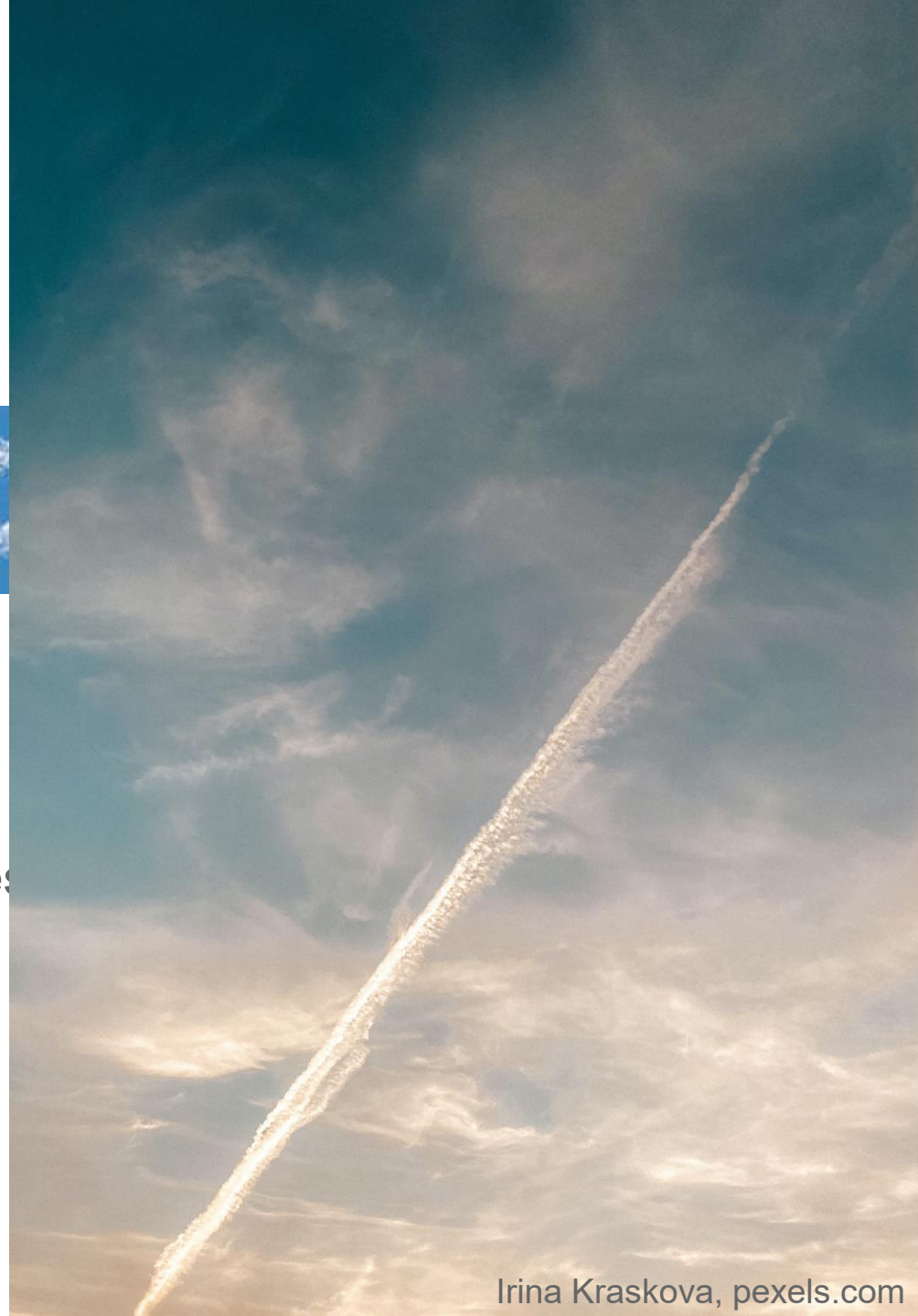
Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages

Contrails

- Contrails occur in higher, cold altitude
  The lifetime are seconds to a few minutes
  → they have no influence on climate change

- Contrails in Ice supersaturated Regions (ISSR):
  Lifetime can be several hours (persistent contrails)
  climate impact will increase during lifetime as contrails
  will be formed to cirrus due to winds and diffusion processes

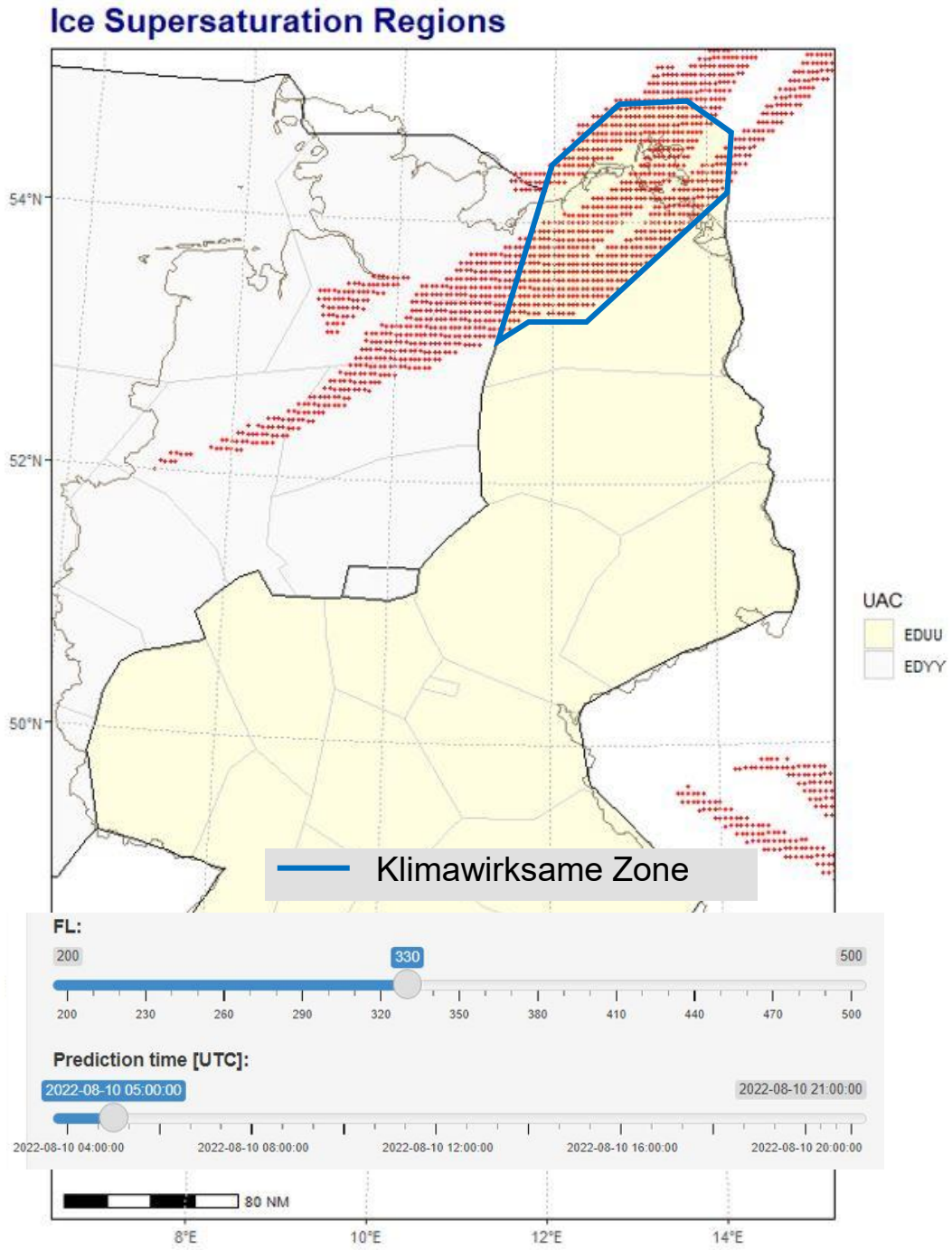


Irina Kraskova, pexels.com

Calculation of ice supersaturated regions (ISSR)

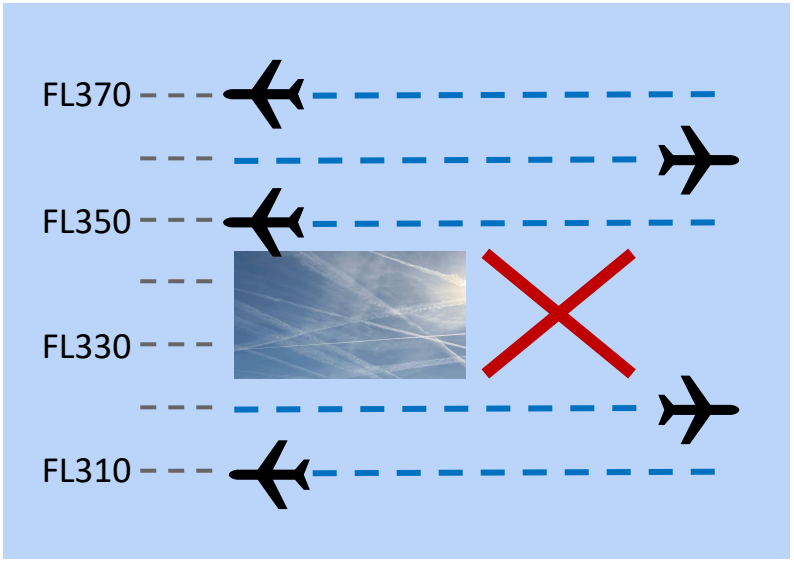
- Basis: weather forecast data of DWD (German weather service):
  - Forecast-Run from 10.8.2022 at 0:00 (UTC)
  - Prediction time +5h,
  - Altitude FL330
- Calculation ISSR (red points) with:
  - Schmidt-Appleman-Criteria
  - Relative Humidity ≥ 100%
- Selected Area in airspace of DFS (blue polygon)

Persistent Contrails occur by flights through ISSR



Available altitudes to avoid ISSR

Exemplary representation



ISSR of example is vertically located in:
FL330 – FL340

Medium vertical thickness if ISSR is 2000ft - 3000ft *

Climate research proclaimed that an altitude change of 2000ft is sufficient to avoid persistent contrails

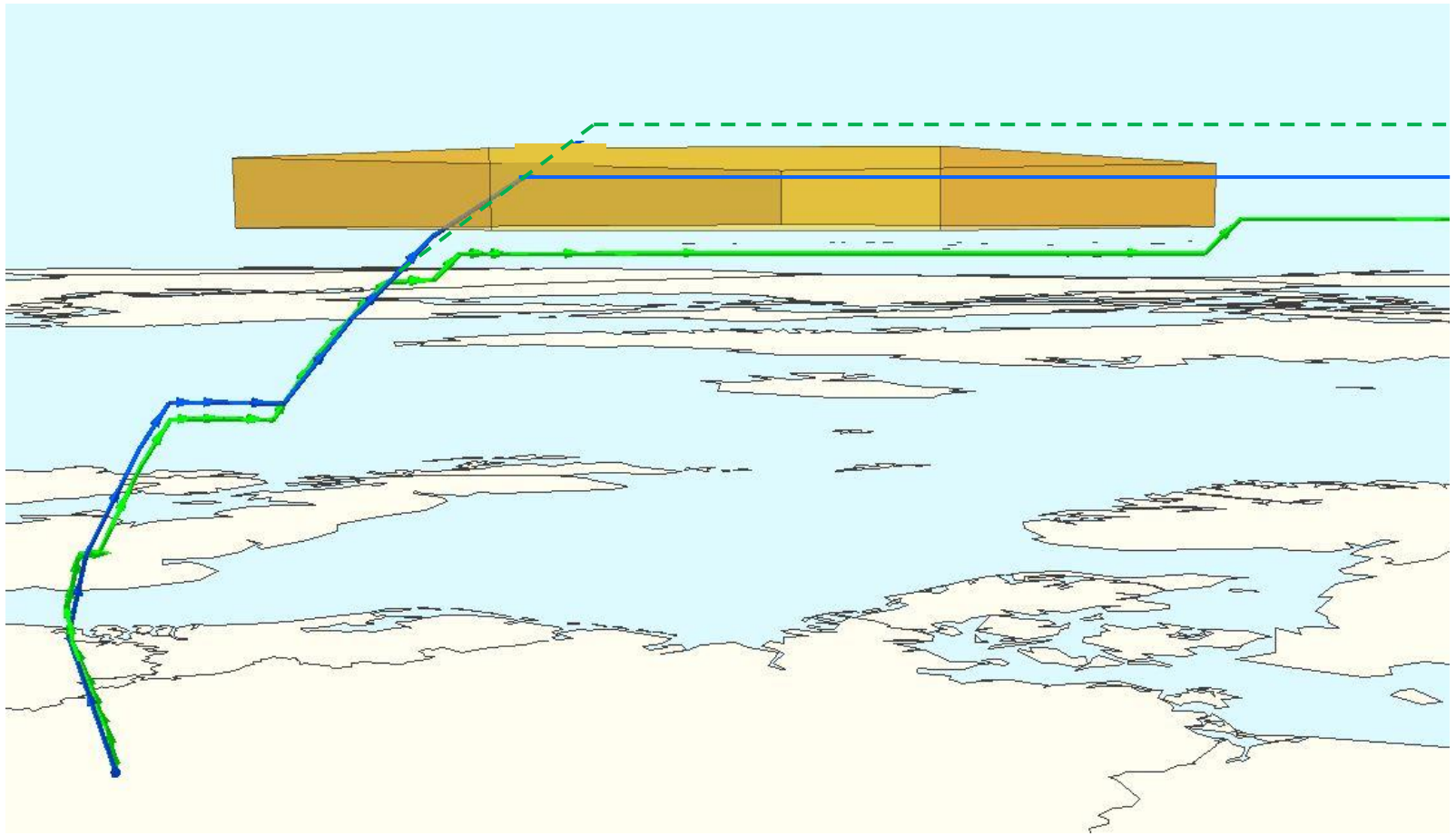
Initial Altitude change at live trial will be +/- 1000ft above/below limits of ISSR

→ Validation of prediction of ISSR limits

*K. Gierens 2020 Meteorol. Z.

Altitude change to avoid ISSR

Exemplary representation of simulation



NEST, DFS

Blue Flight track:
Trajectory originally planned

Orange region:
3D-Polygon of ISSR which should be avoided by flights

Green Flight track:
Trajectory with consideration of climate sensitive area

Flow simulations will analyse capacity question in airspace

Why only vertical avoidance?

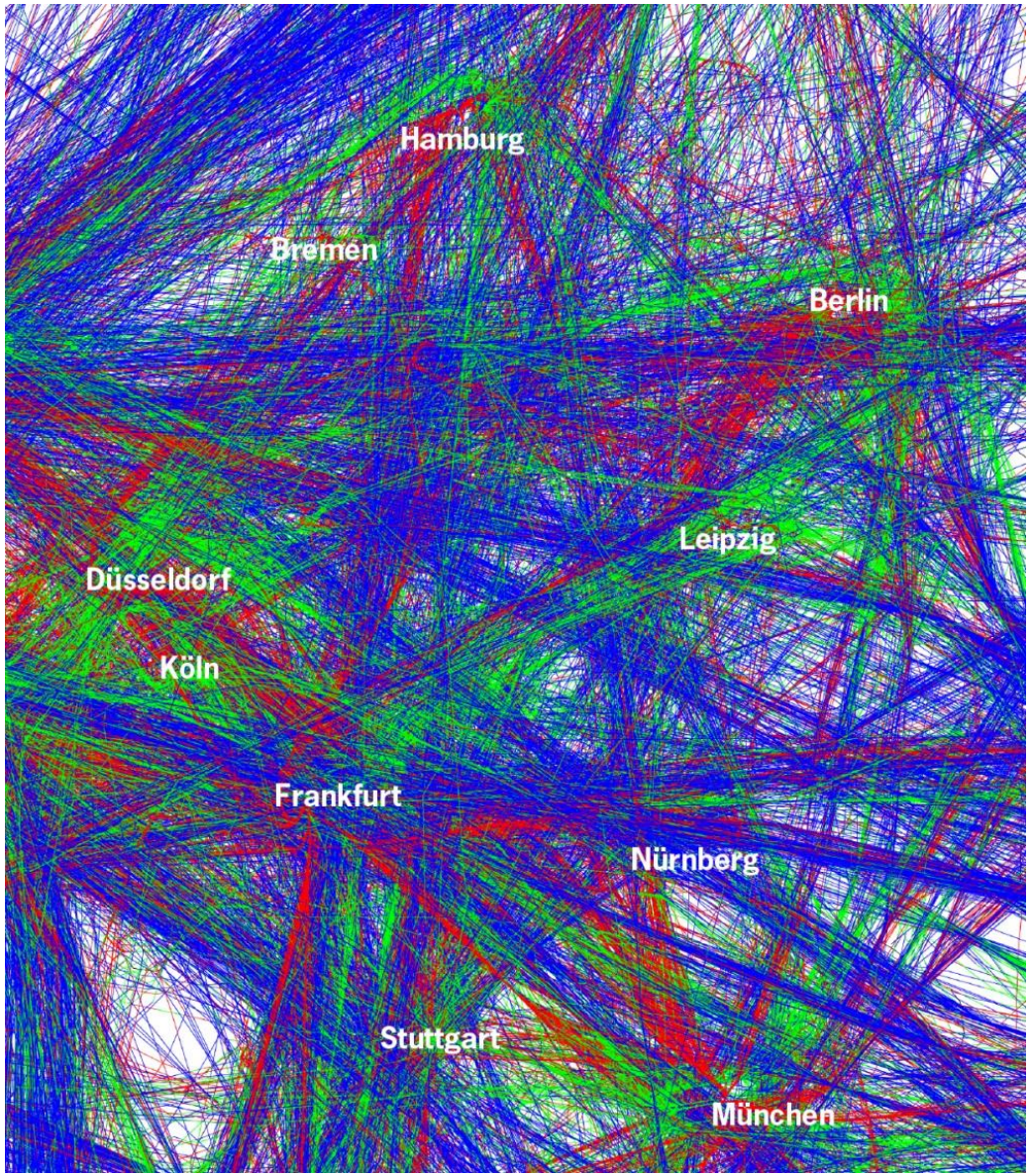
One day in Germany in 2018

Germany is one of the highest congested airspace worldwide

Up to 10.000 flights daily

→ Capacity issue

Altitude changes are much more possible than lateral deviation

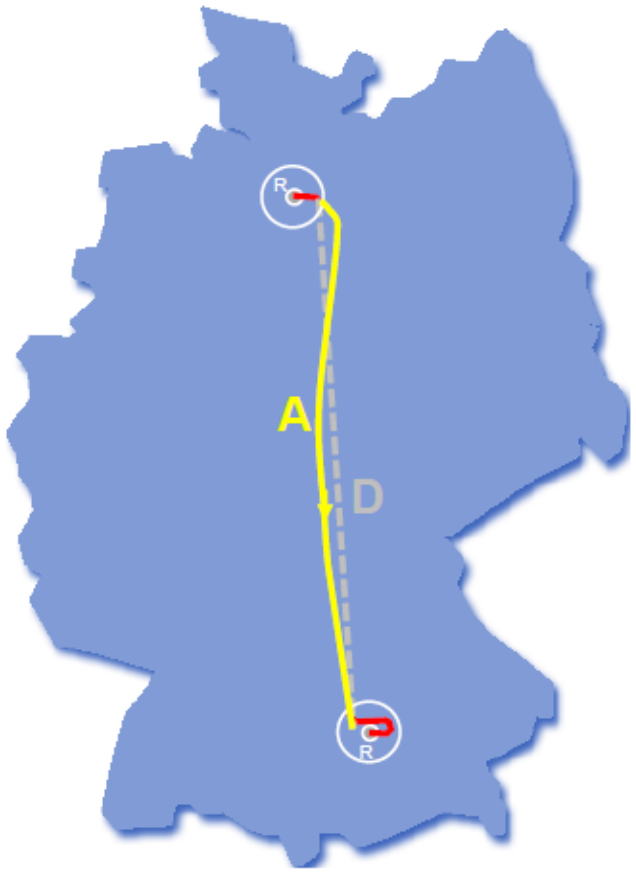


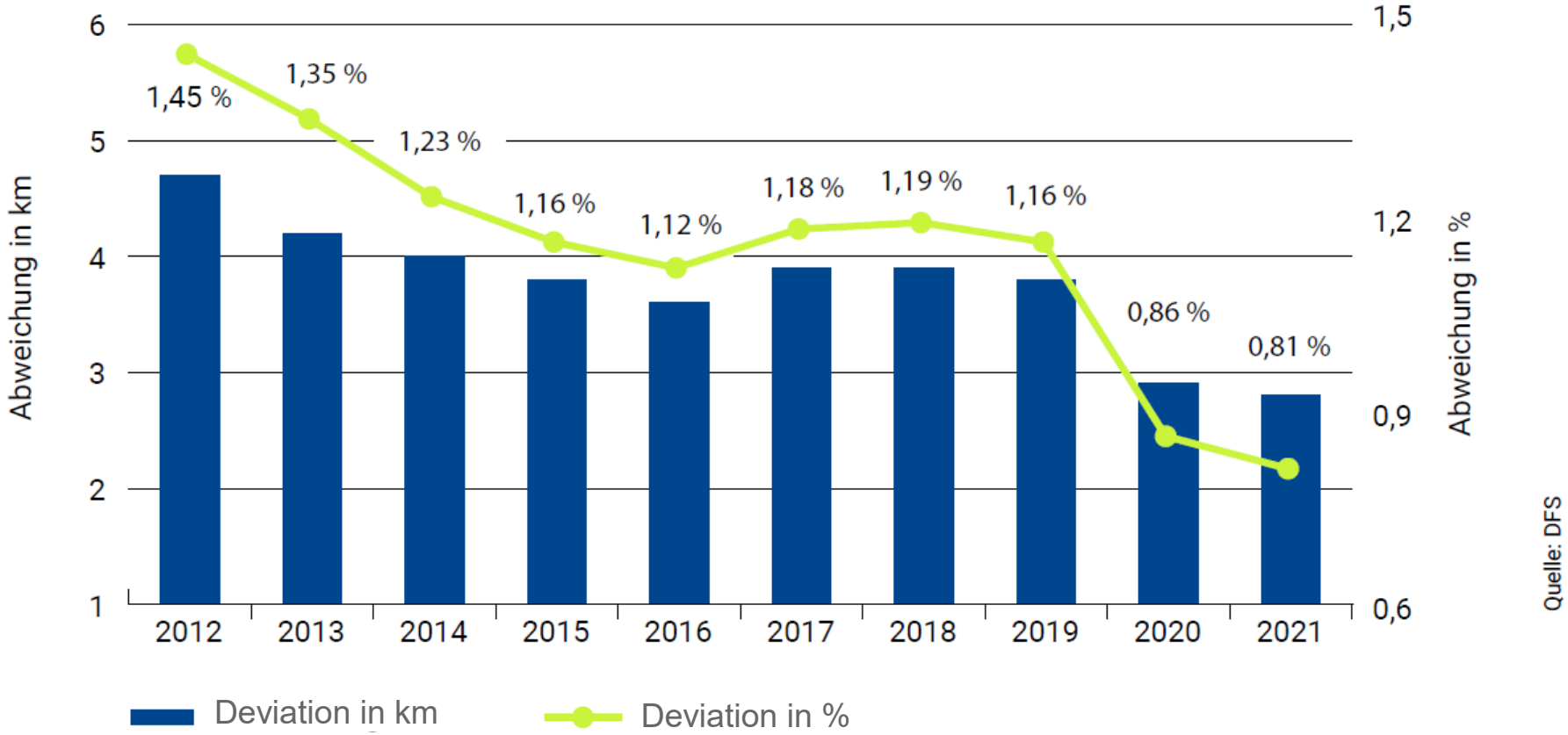
Climb

Cruise

Descend

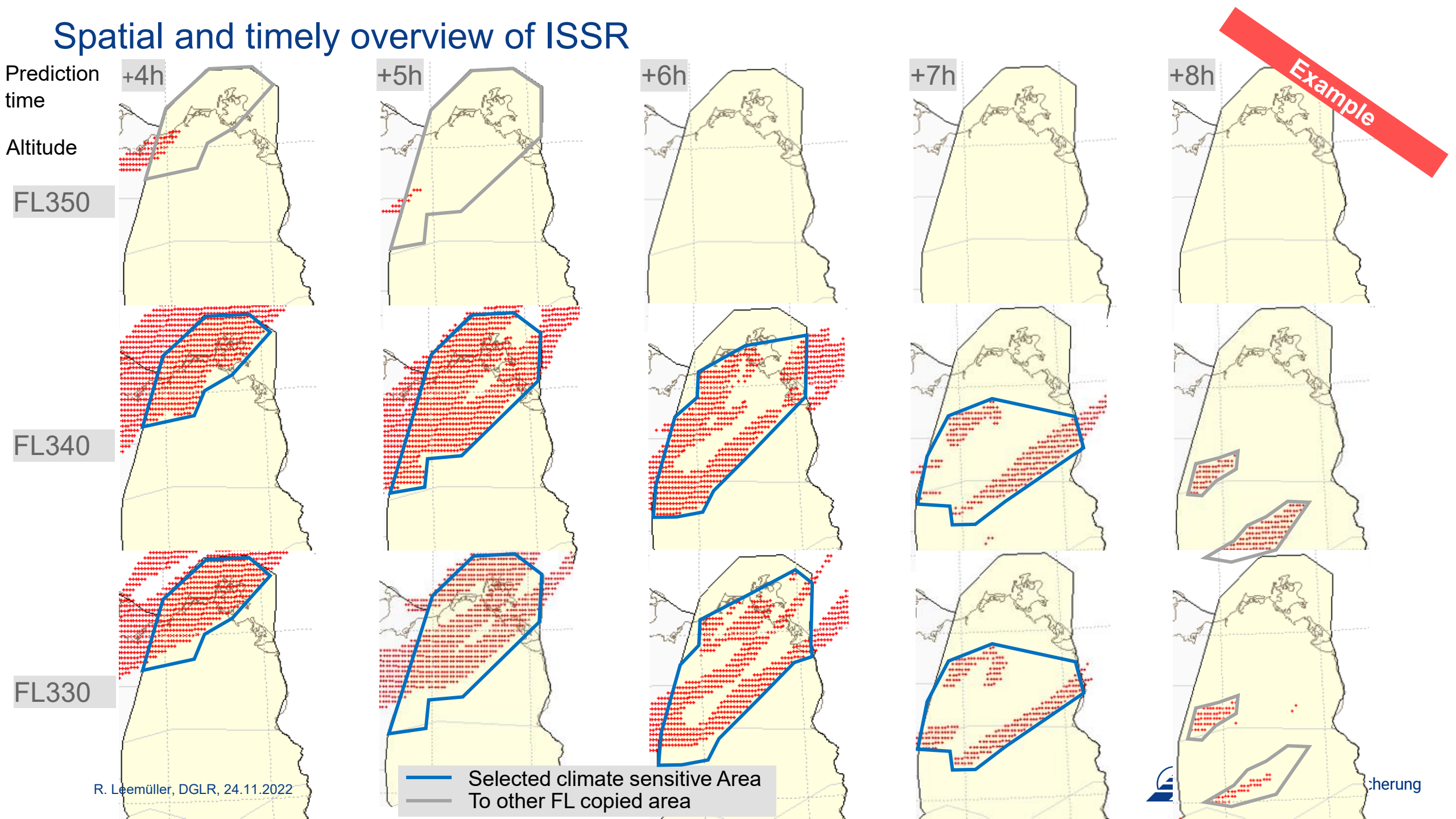
Horizontal Flight Efficiency (HFE)





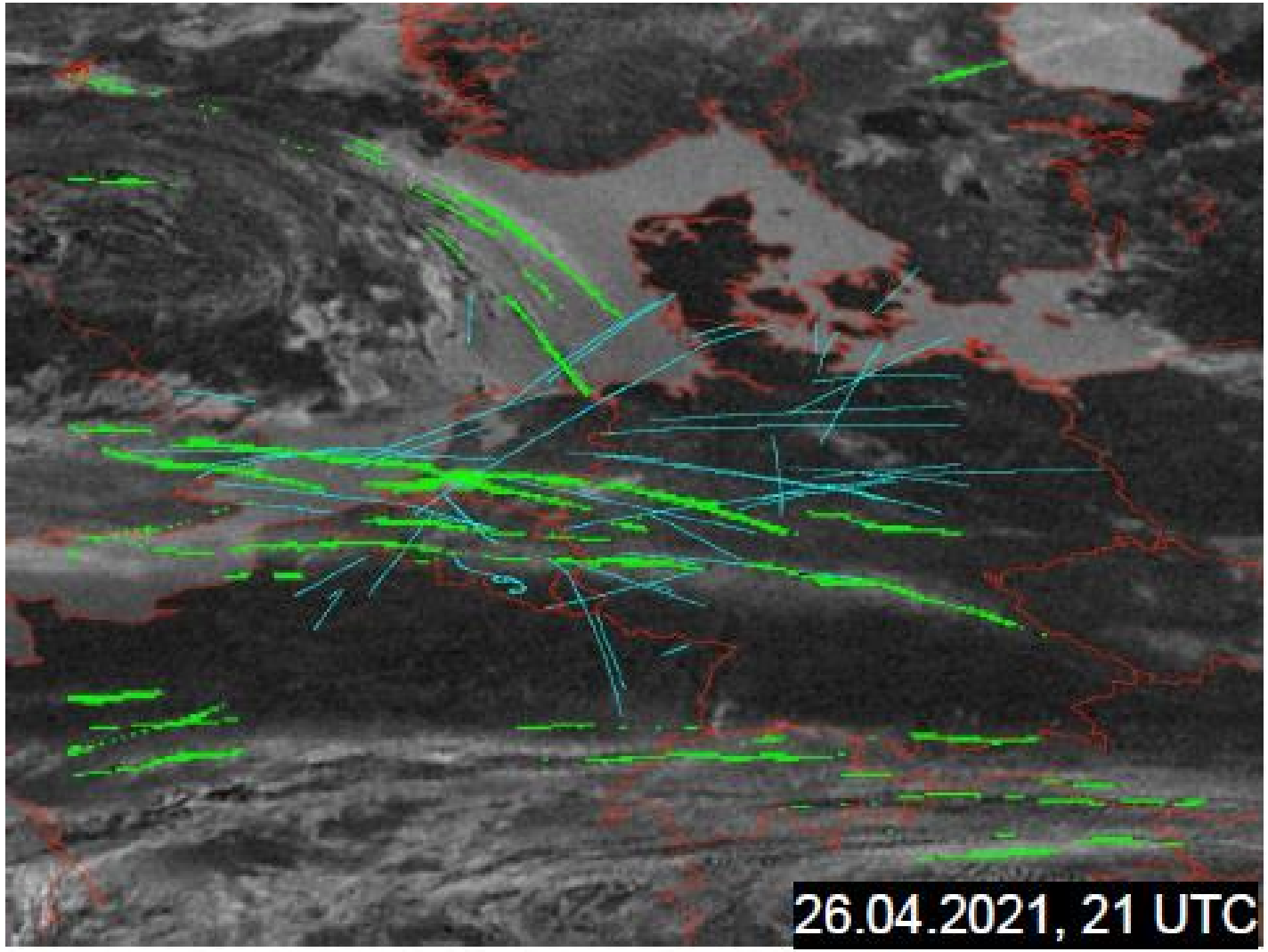
Quelle: DFS

Spatial and timely overview of ISSR



Evaluation persistent contrails

Satellite image contrails with flight tracks



R. Sausen (TAC-5 2022)

Detected Contrails in green

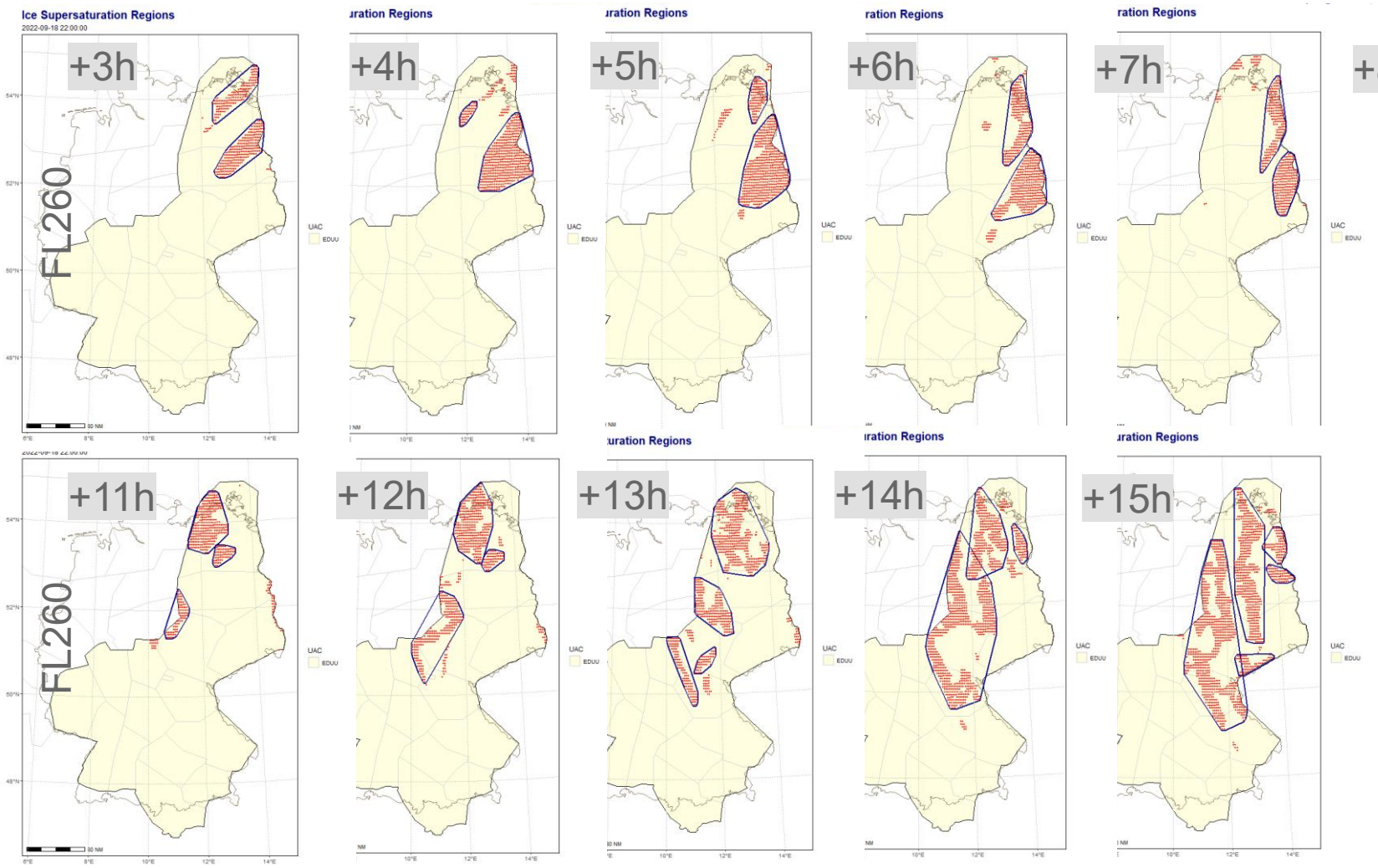
Persistent contrails will be visible in satellite image 60 – 90 min after generation

Due to resolution of satellite sensor

Flight tracks 60 – 90 min prior to satellite image in blue

Analysis of satellite image with contrails and correlation to flight tracks is not such simple

Example of „long existent“ ISSR



Findings:

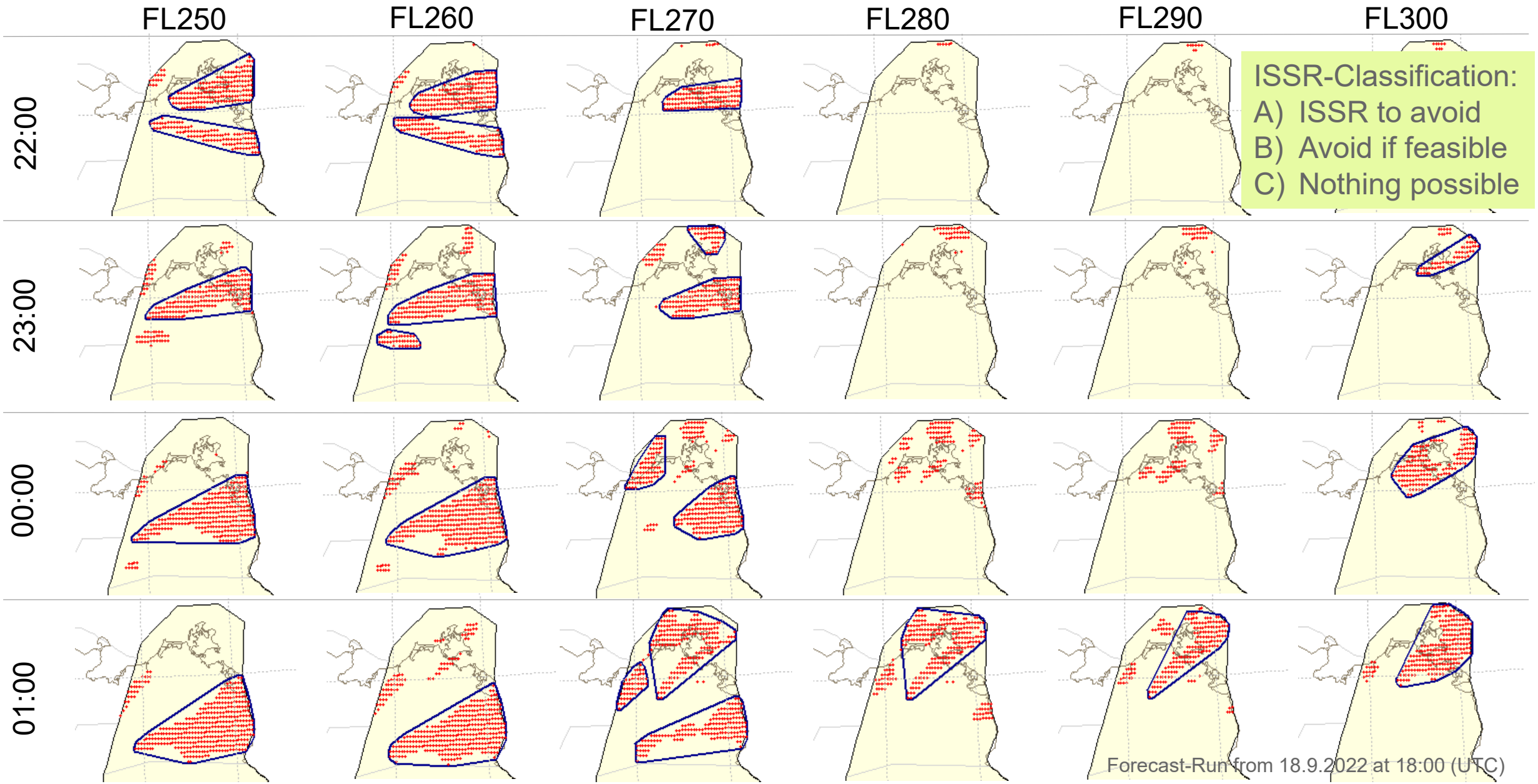
- Great lateral dimension
- Separated areas
- Hourly variable polygons
- Rugged area

First reaction from Ops-Room

- Hourly changed polygon is possible
- Only one area per sector is feasible

Forecast-Run from 18.9.2022 at 00:00 (UTC)

Example of „vertical big“ ISSR



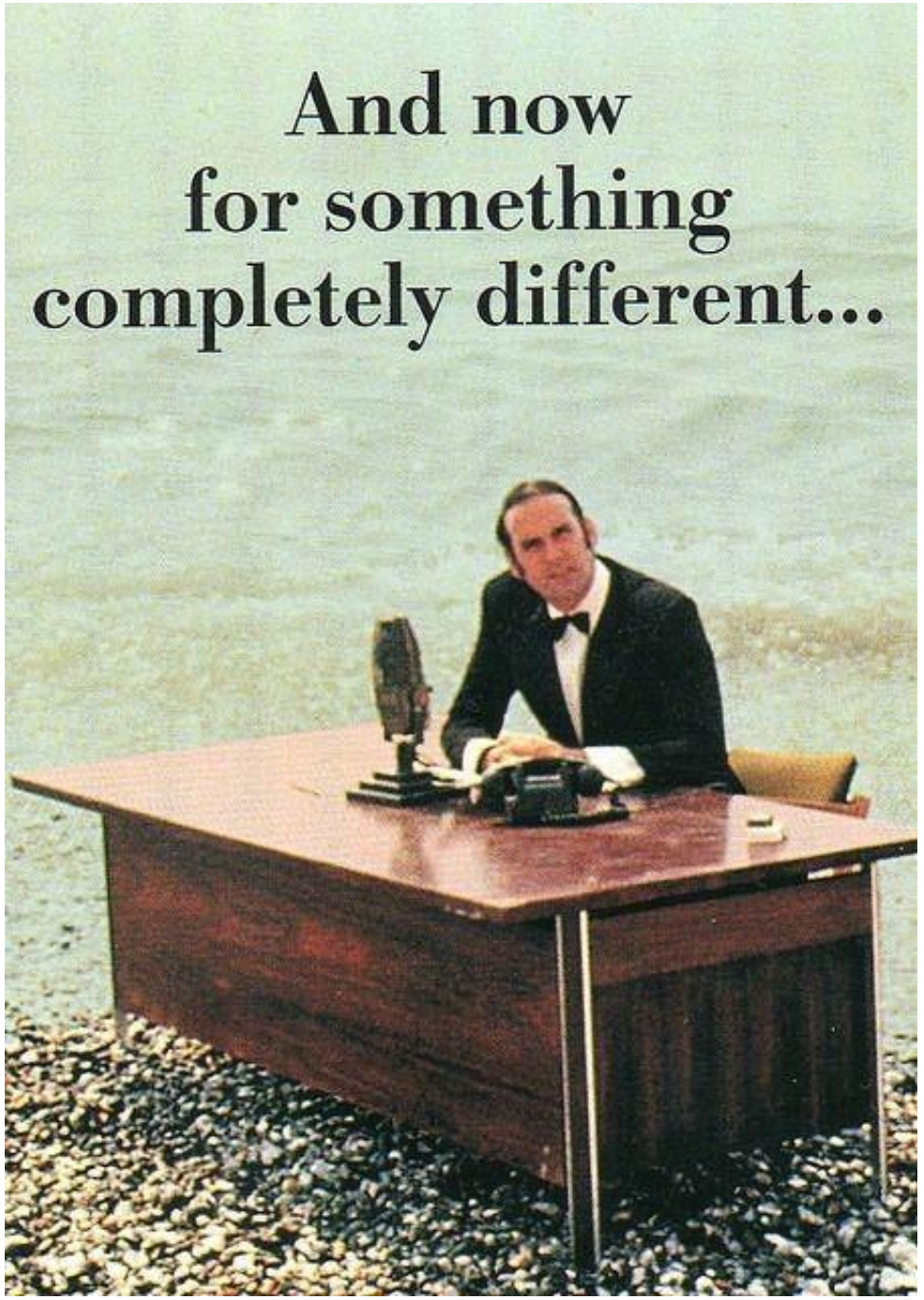
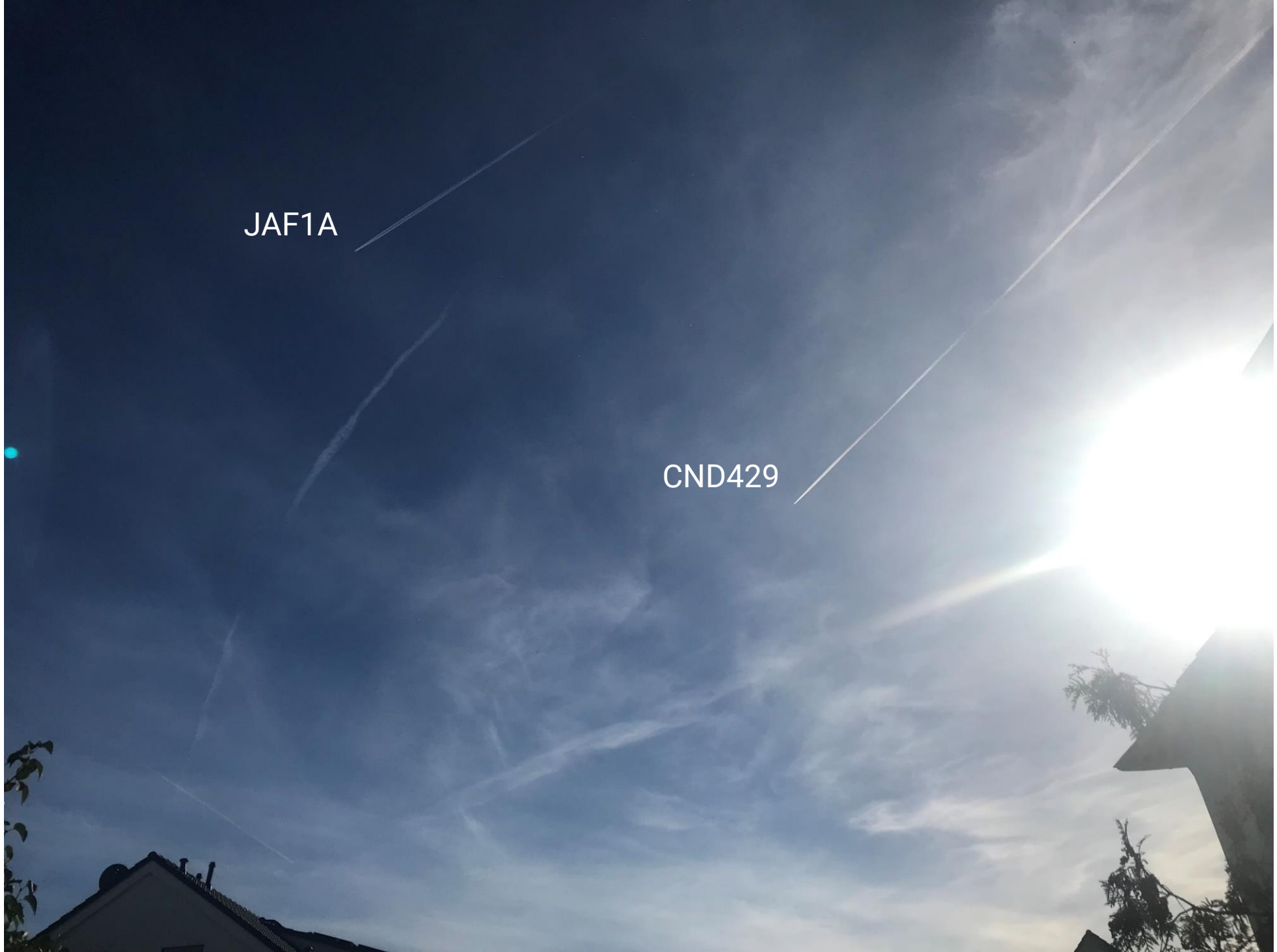
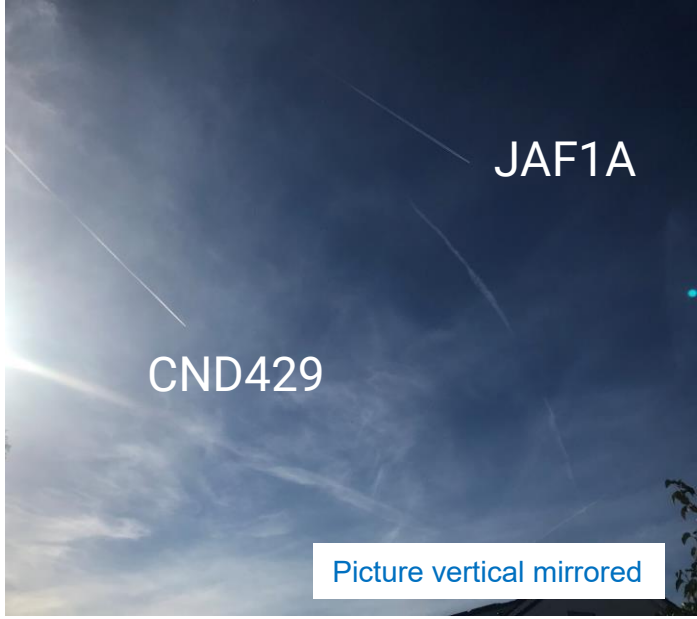

And now
for something
completely different...

Image taken in Seeheim, Germany
[49° 45' 0" N 8° 39' 0" E]

Direction south
Time: 13:42 (UTC)

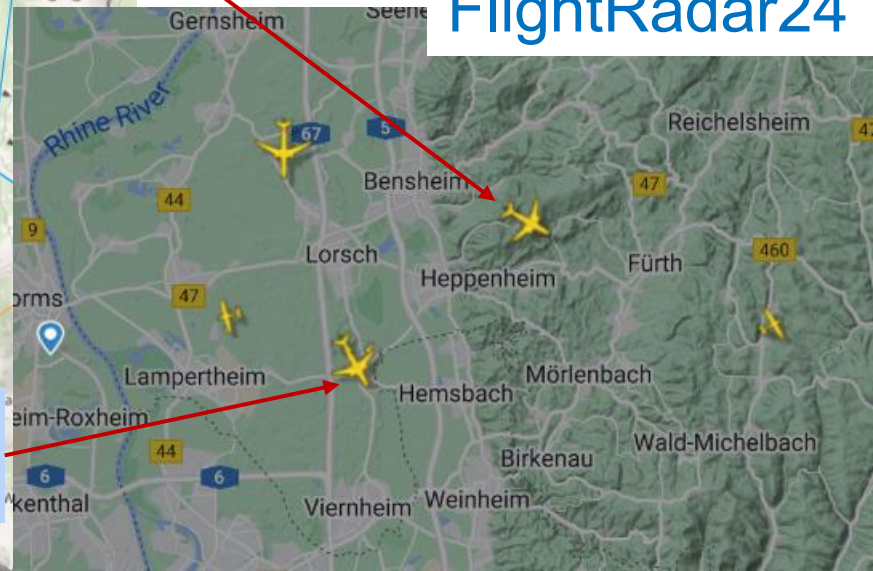


Both flights come from common Fix RIDSU



JAF1A: TUIfly B737-800 from Lille to Heraklion
FL370

FlightRadar24



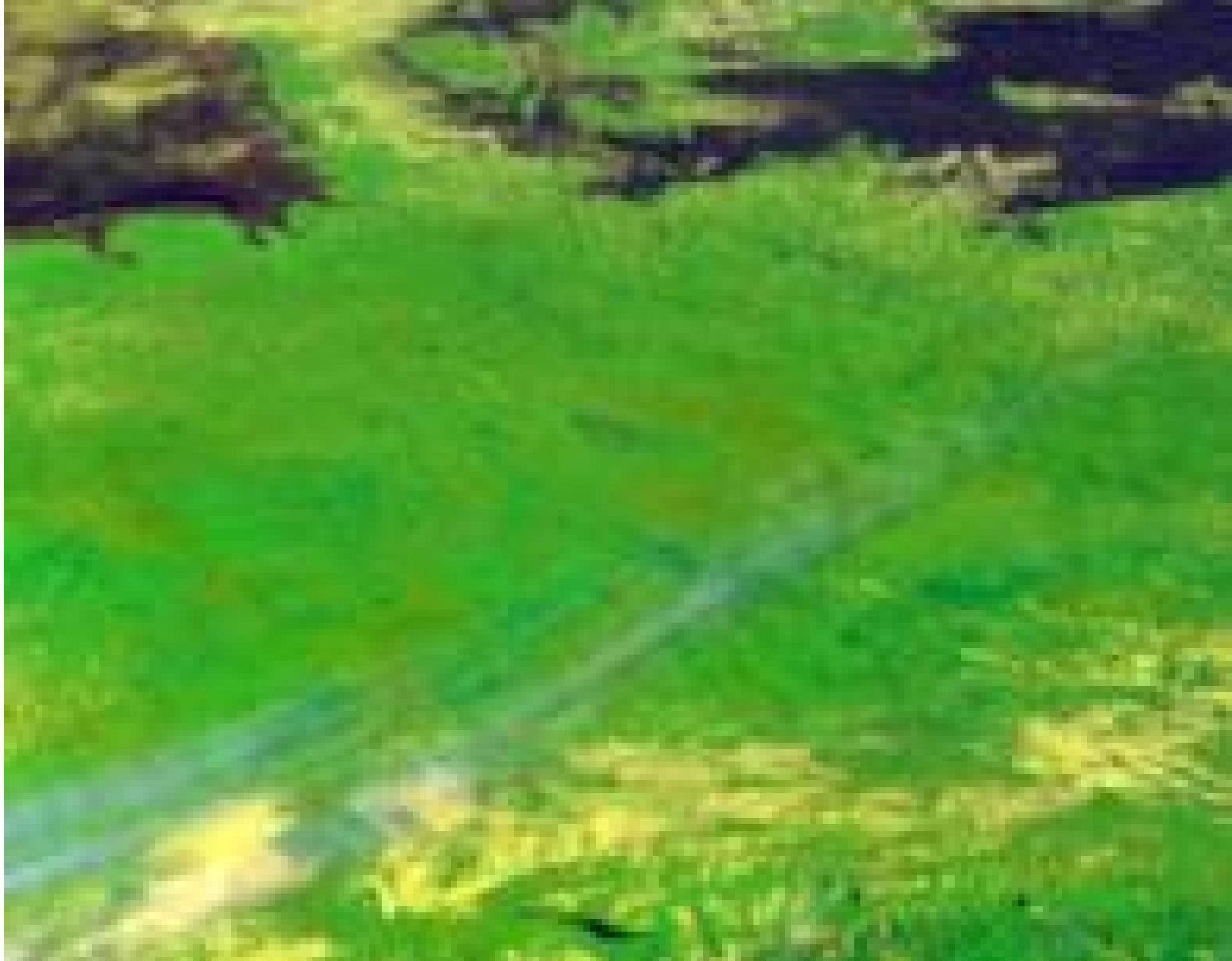
CND429: Corendon B737-800 from Amsterdam to Rhodos
FL350

DFS-Stanly

Meteosat (MSG4):
2022-10-06
14:00 (UTC)

Cirrus in high altitude in blue / white colour
Clouds with liquid drops in light yellow

Cirrus from image is quite good visible

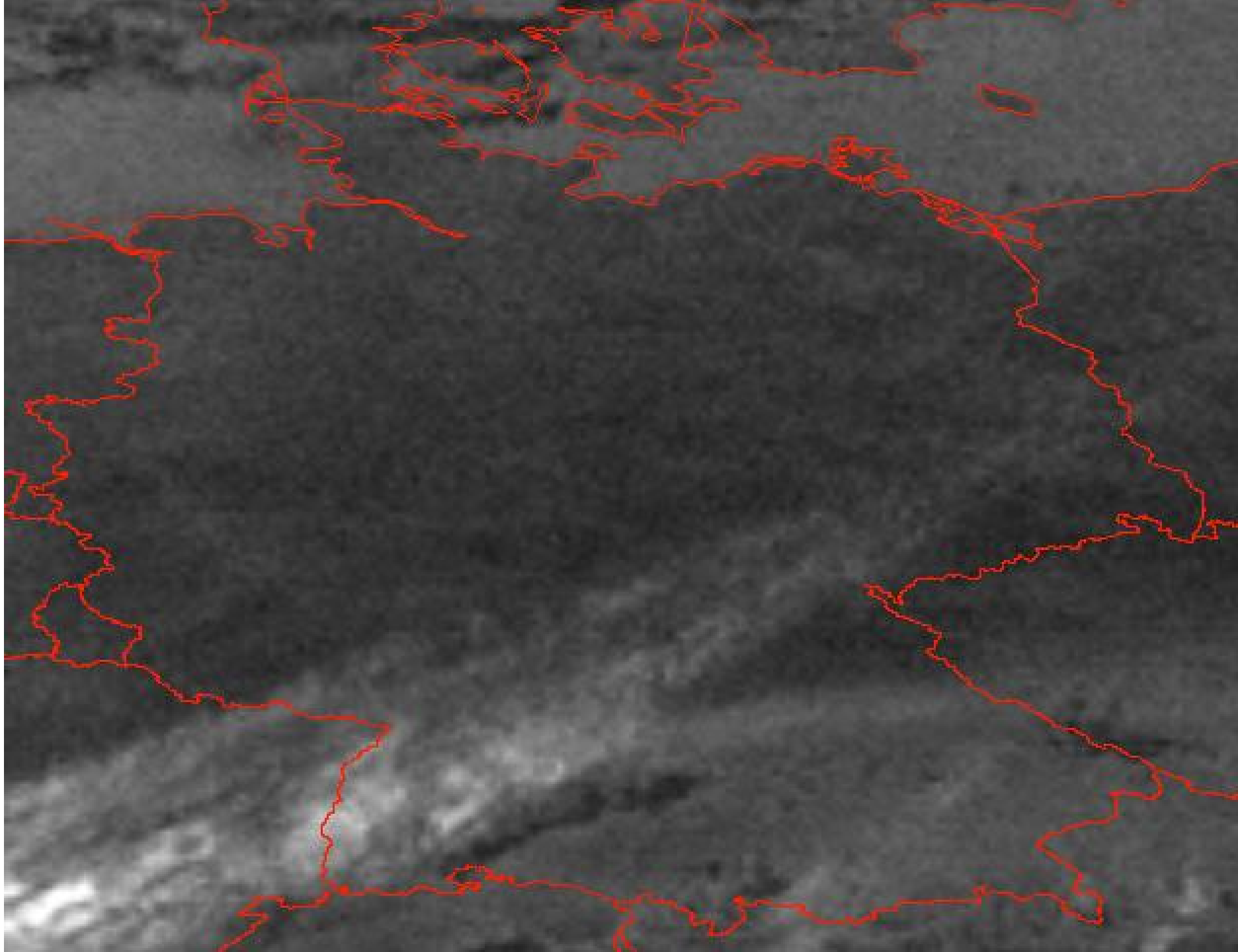


Supported by DLR

Meteosat:
2022-10-06
15:30 (UTC)

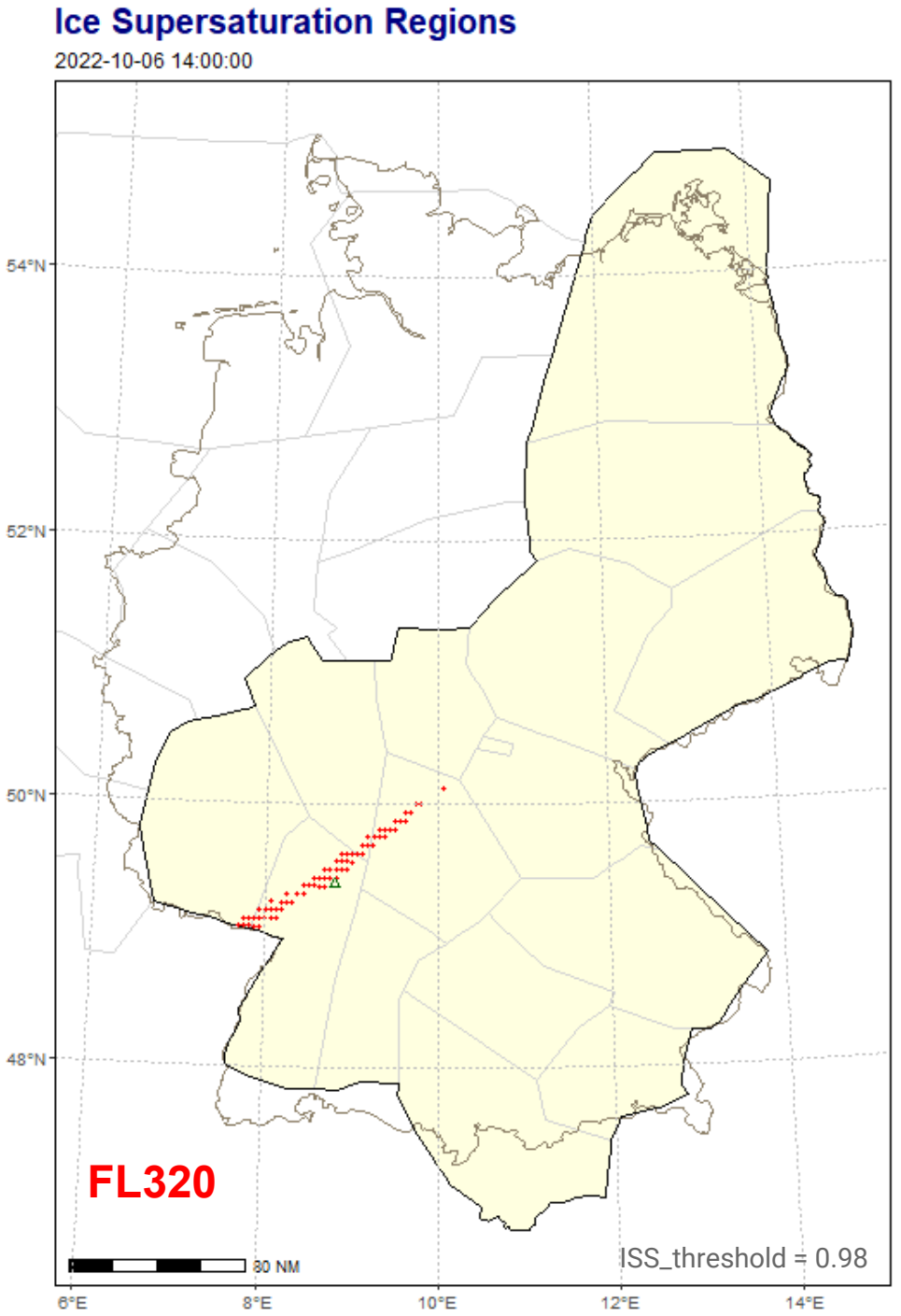
Infrared 10.8-12.0µm

More details of cirrus is visible



Supported by DLR

ISSR-Calculation
Forecast from 2022-10-06
calculated at 12:00 (UTC)
Prediction time +2h,
Altitude FL320



Calculation ISSR (red points) with:

- Schmidt-Appleman-Criteria
- Relative Humidity ≥ 100%

ISSR is matching with position of Cirrus from image

But it is only in FL320!

Flight of interest with persistent contrail was in **FL350**

A Mismatch

Calculation is already using threshold for
Relative Humidity ≥ 98%
(ISS_threshold = 0.98)

to compensate uncertainties in weather data

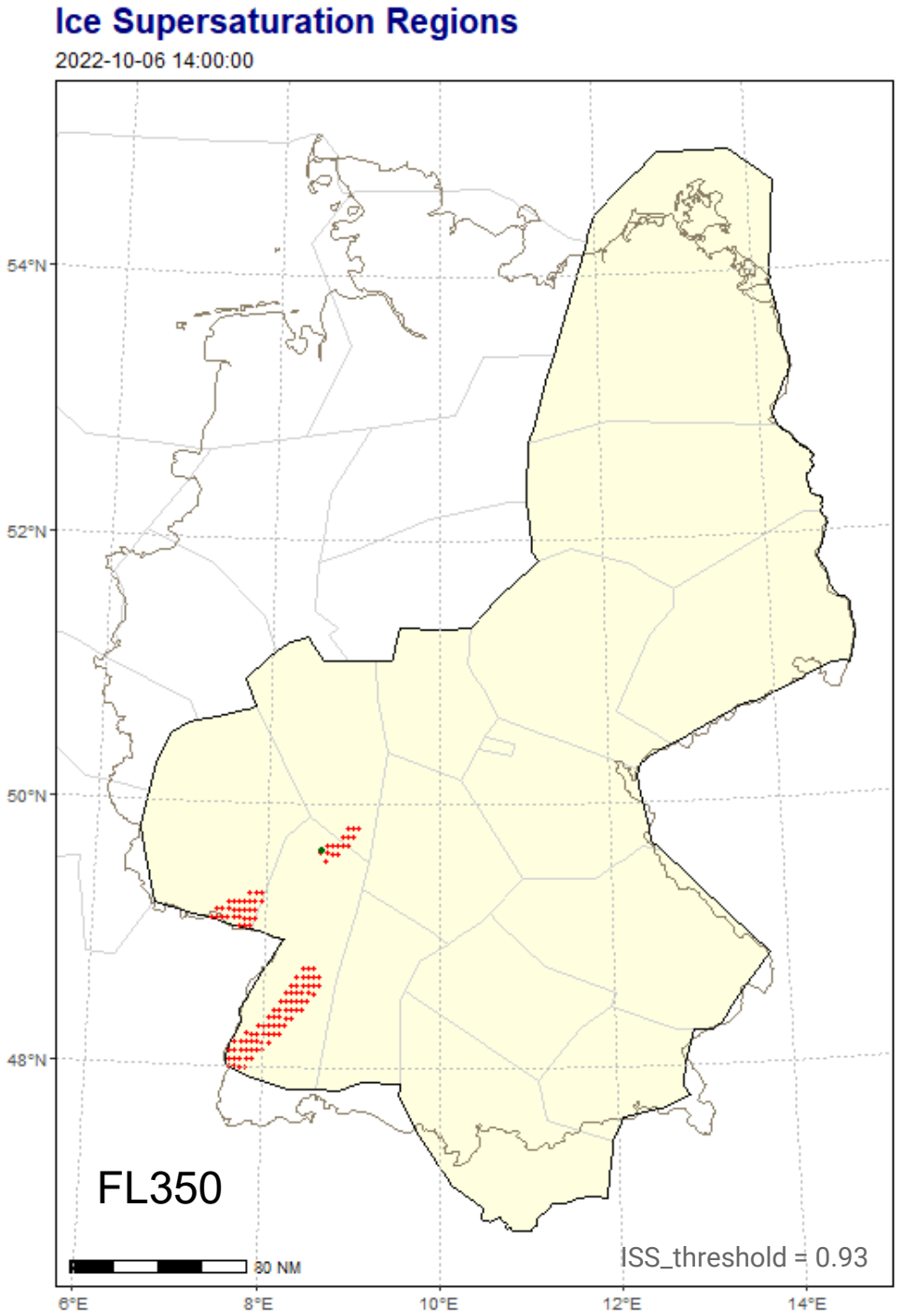
DFS Deutsche Flugsicherung

Variation of ISS-Threshold based on a geographic point

Selected point is
Heppenheim, Germany
Coordinates
Lat=49.625, Lon=8.625

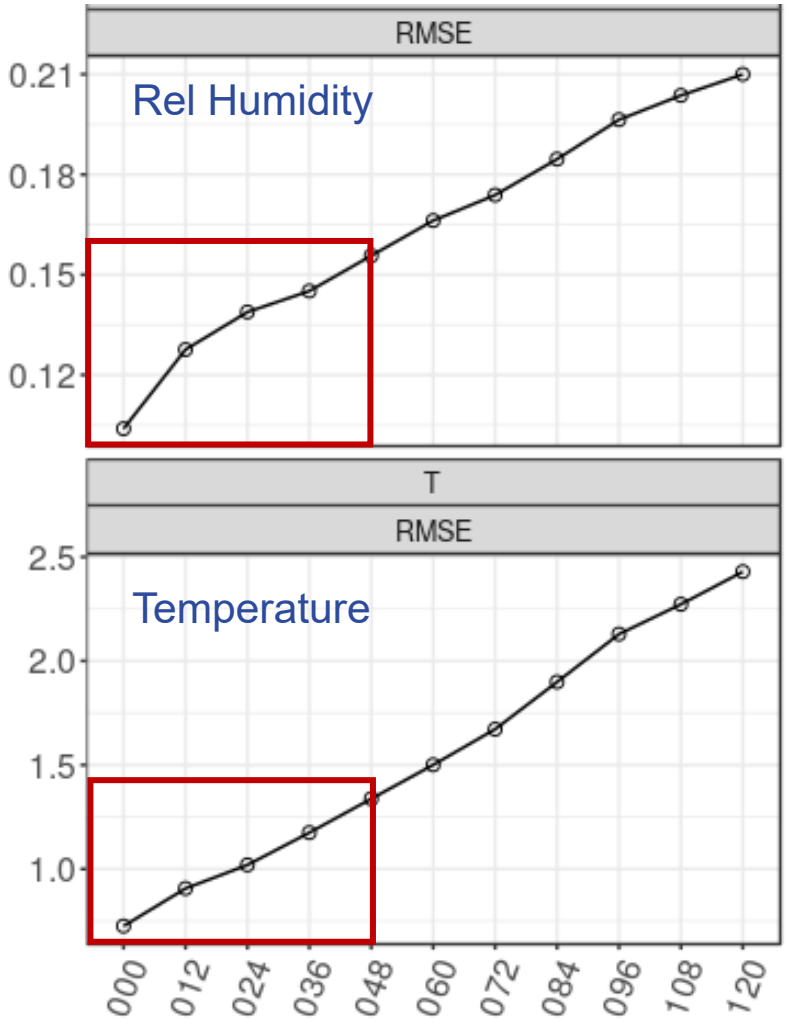
By selection of
ISS-Threshold: 93%

ISSR in FL350 occur



Calculation of DWD about Uncertainties:

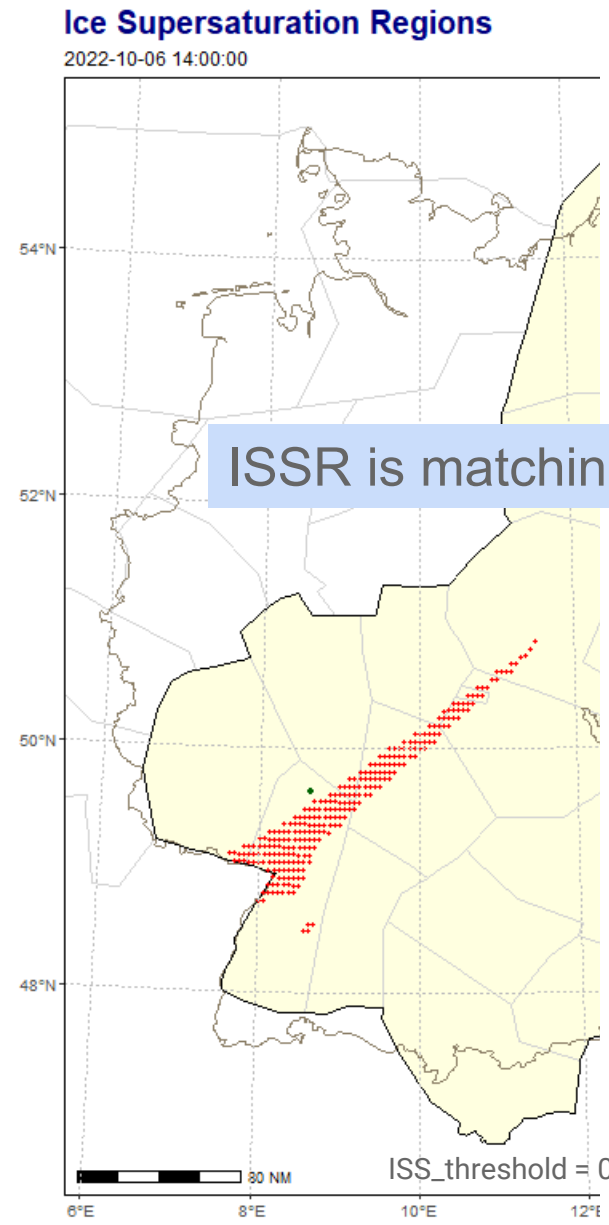
Root Mean Square Error



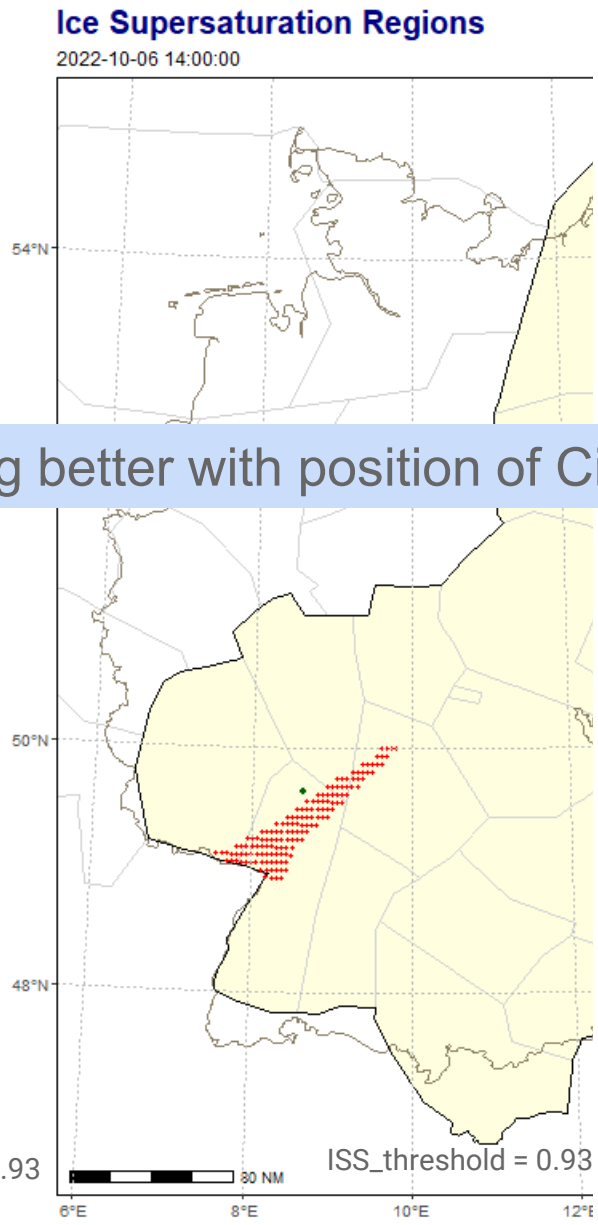
Spatial Overview of ISSR

ISS-Threshold = 0.93

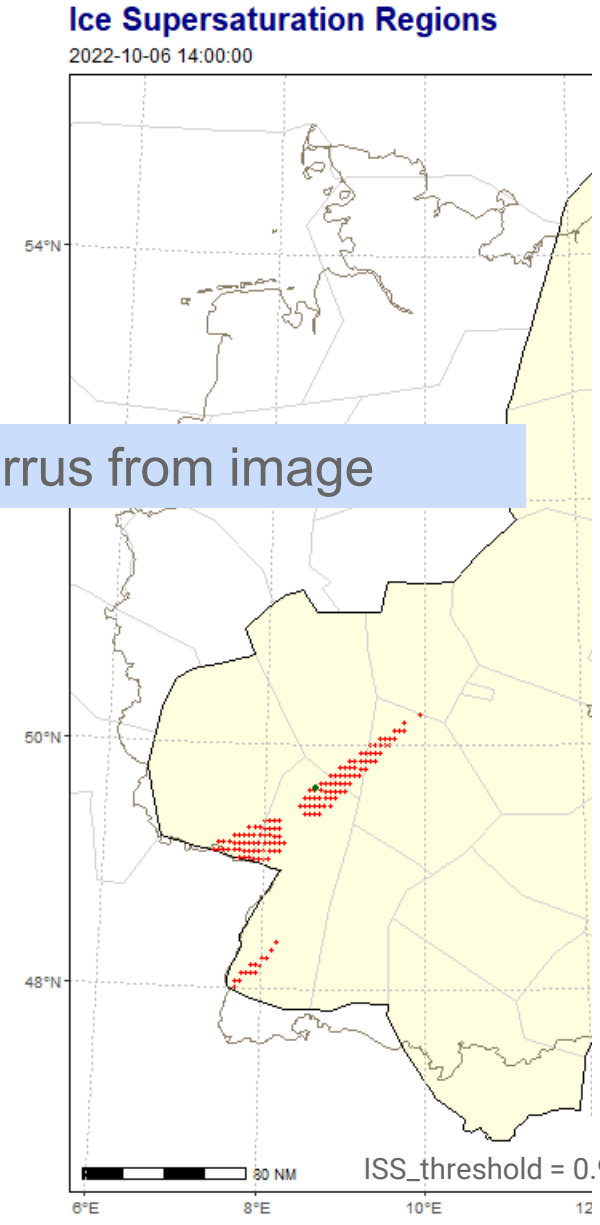
FL320



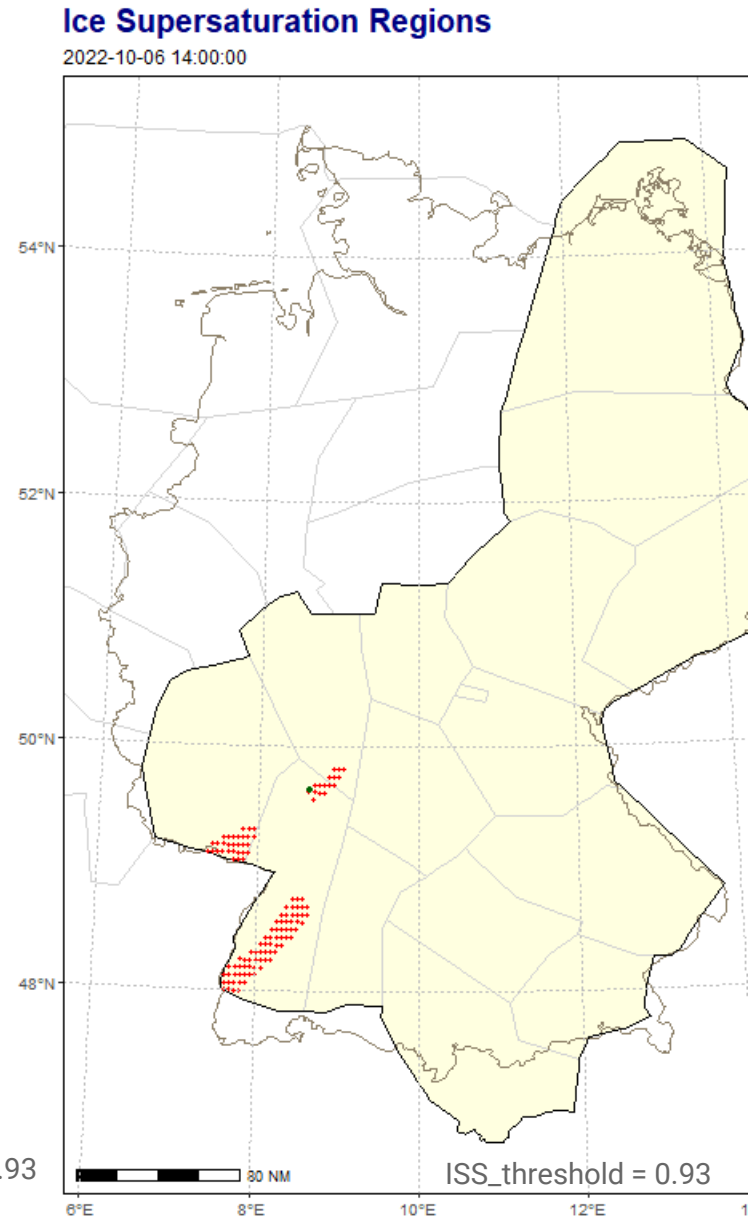
FL330



FL340



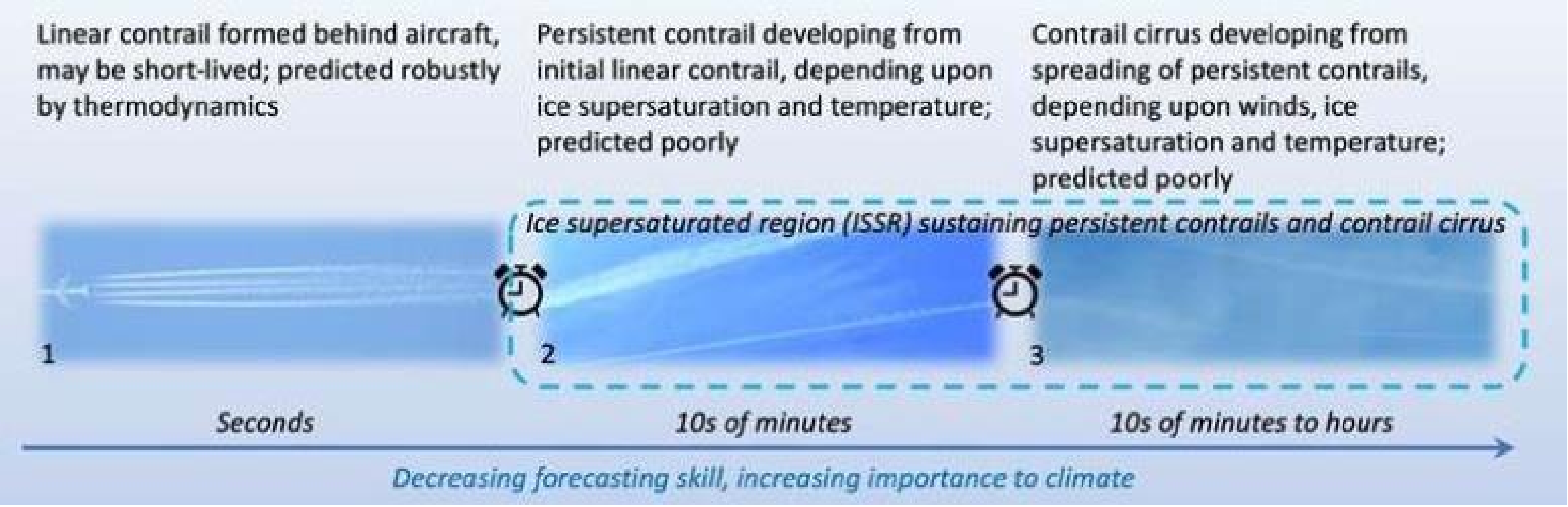
FL350



ISSR is matching better with position of Cirrus from image

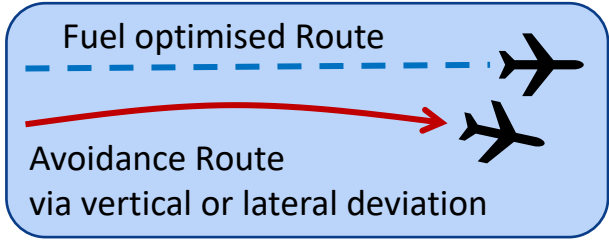
Detected Problems for further work:

- Altitude of ISSR-Calculation does not match with flight level of persistent contrails (FL320 vs FL 350)
  Assessment of uncertainties in cooperation with DWD & DLR necessary.
- It is unknown, if “seen persistent contrail” of image is really persistent. A second image 10-30min later is omitted

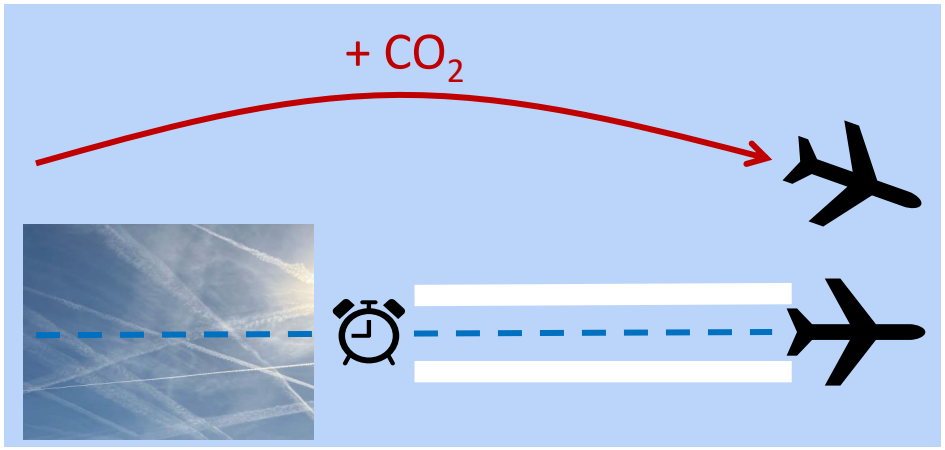


K. Shine, greenairnews.com 2021

Potential Outcome due to spatial & time uncertainity



Successful Re-Routing: Contrail-Cirrus were avoided



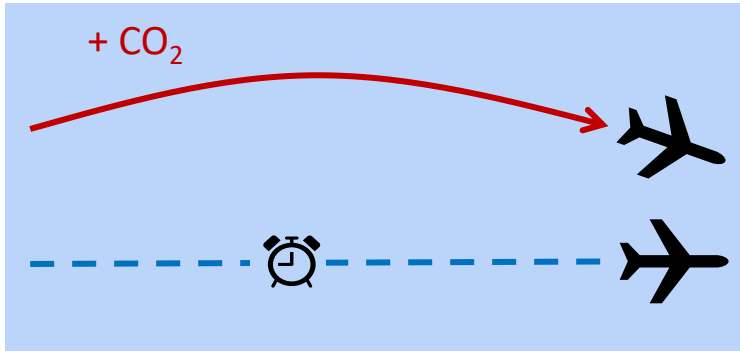
Carbon footprint:

Persistent Contrail does not occur, slight increase of CO_2-emission due to not optimal Route

Reduced overall carbon footprint

Failed Re-Routing

Predicted ISSR does not exist

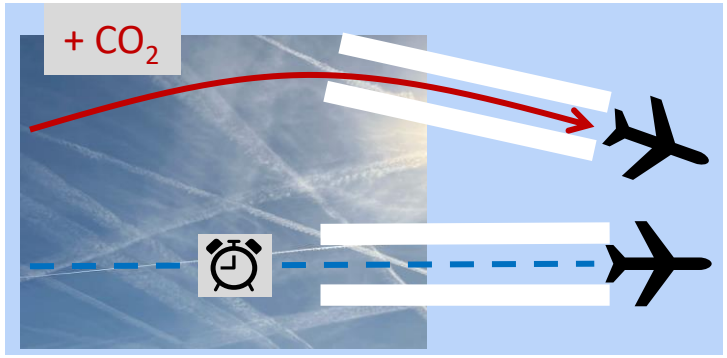


Carbon footprint:

No persistent Contrails generated, but increased CO_2-emission without saving of positive effect of avoided cirrus

Carbon footprint is increased

ISSR is much bigger than predicted



Carbon footprint:

Persistent Contrails were generated on new route plus increased CO_2-emission

Carbon footprint is increased

Modified after D. Lee (FABEC Research Workshop Vilnius 2021)

Constraints for Live Trial

Some necessary formalism!

- Influence on airspace capacity will be assessed with simulations to clarify usable hours of day.
- Validation plan for trial inclusive statistical concept to set up
- Changes to operational procedures for live trial has to be produced
- Safety assessments will take place
- After approval of safety assessment the live trial can happen.
- Several days is needed for above topics
- Training of operational personal is time consuming
  for example: DFS-region east of upper airspace consists of 160 Controllers & Supervisors

Additional aspects for live trial

- Daily information about location of ISSR and mitigation strategy will be adviced to controller of charge.
- Information to airlines about trial.
  Unplanned altitude changes will be cleared to avoid ISSR
- Phraseology in communication between pilot and controller has to be defined.
  An example:

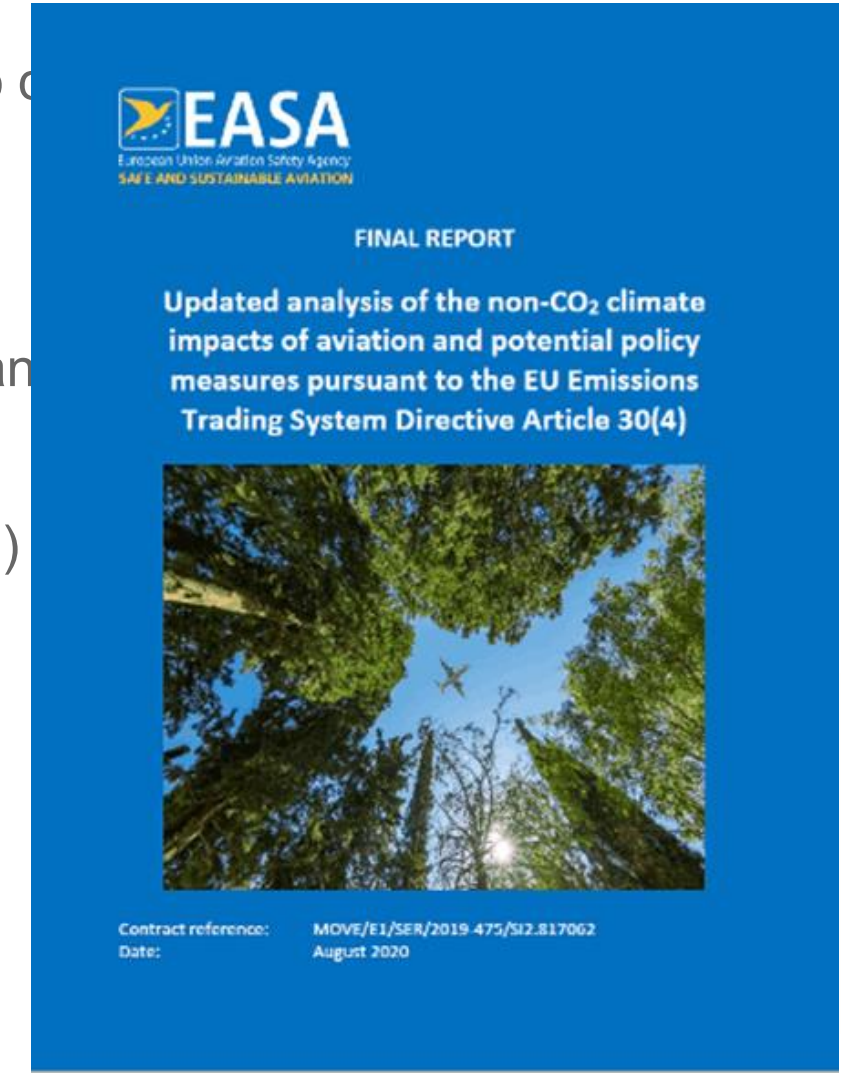
  “For contrail prevention climb / descent to FL xxx.”

  it is necessary to avoid an increase of the workload of controller due to possible discussion on frequency.

Expected results of project D-KULT

- Validation of prediction for limits of ISSR and needed distance to c
- Classification of ISSR based on location, dimension, timing.
  Which ISSR is necessary to avoid for a positive climate impact?
- Only a positive climate impact and feasible application for ATM an
  operation procedure on greater geographic area (i.e. Europe).
- Recommendations for stakeholders (Politics, Aviation, Research)

Well-grounded principles for future operational use in Europe



Arrowsmith et al., 2020

Take home messages

- Air traffic counts 3.5% – 5.0% to global climate change
- Climate impact of Non-CO_2 is around 40%
- Appropriate climate metric is to define
- D-KULT consortium of DLR, DWD, DLH, DFS and many other stakeholder in Germany to assess avoidance of persistent contrails
- Project D-KULT will perform live trials in near future to avoid ISSR
- Prediction of ISSR is a cornerstone – high uncertainties are present
- Validation of assumed parameters to understand uncertainties
- In high congested airspace climate procedures are competing against capacity

Gefördert durch:

Bundesministerium
für Wirtschaft
und Klimaschutz

aufgrund eines Beschlusses
des Deutschen Bundestages

Questions?

ralph.leemueller@dfs.de

Related paper (in German):
https://www.doi.org/10.25967/570064

DFS Deutsche Flugsicherung