POTENTIAL AND LIMITATIONS OF SATELLITE REMOTE SENSING FOR CONTRAIL AVOIDANCE

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sesar
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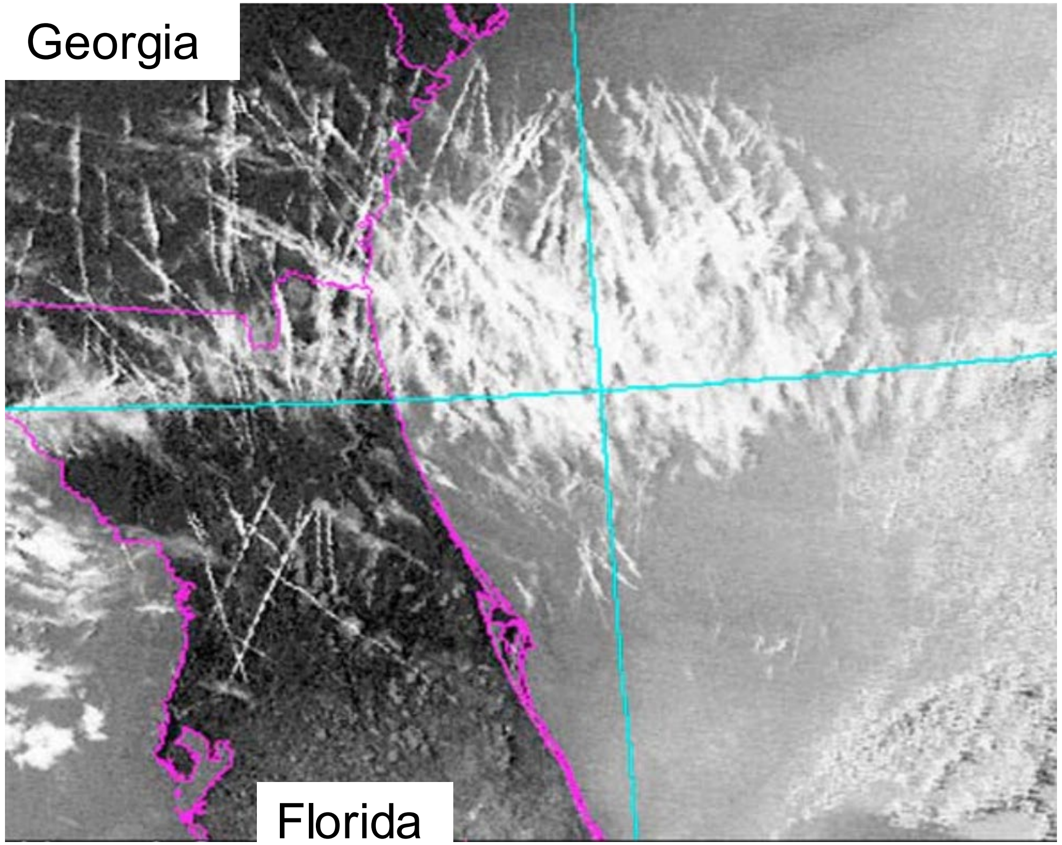
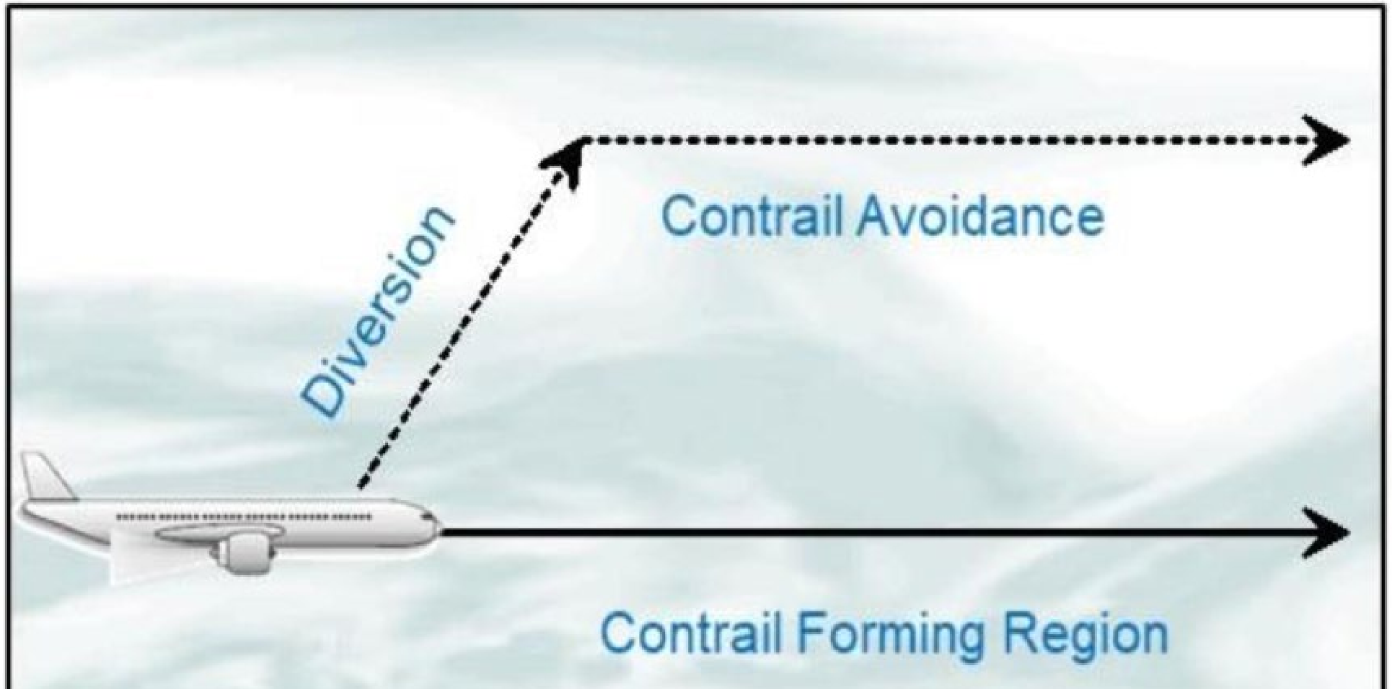
Persistent contrails

- Persistent contrails that form in ice supersaturated conditions spread in the atmosphere, can live for hours and evolve into contrail cirrus.
- Contrail cirrus is responsible for more than 50% of the aviation climate impact in terms of effective radiative forcing ERF (Lee et al. 2021).
- Contrail outbreaks are responsible for the majority of the contrail cirrus ERF (Burkhardt et al. 2018).
- Small vertical or lateral diversions can allow to avoid the formation of persistent contrails.
- Already the re-routing of a small number of flight can significantly reduce the climate impact of contrails (Teoh et al. 2020, 2022).



Minnis et al. 2013

Contrail avoidance



Teoh et al. 2020

Requires:

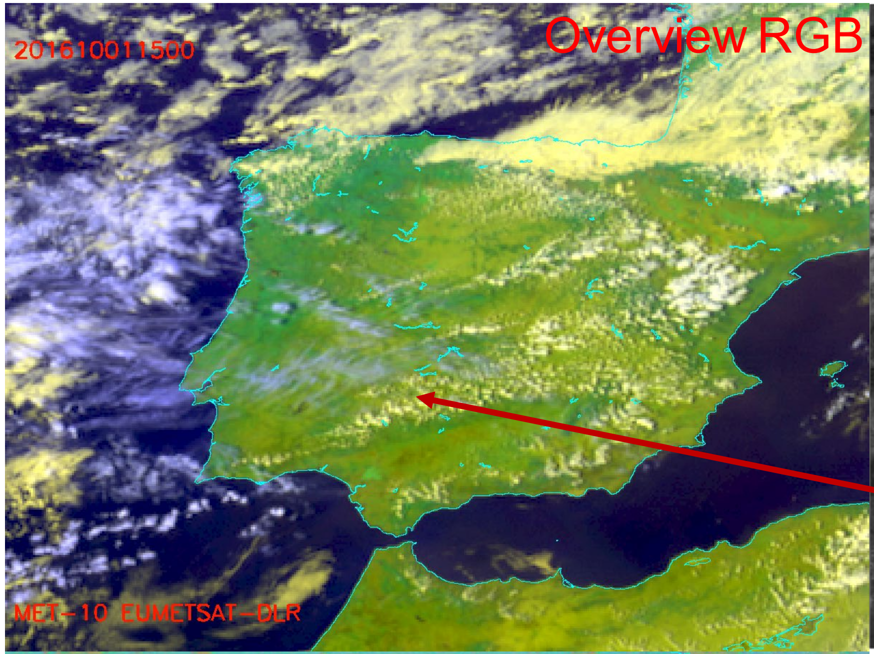
- realistic weather predictions (humidity, clouds)
- realistic contrail prediction models
- adaption of flight planning and ATC procedures
- evaluation of contrail avoidance success

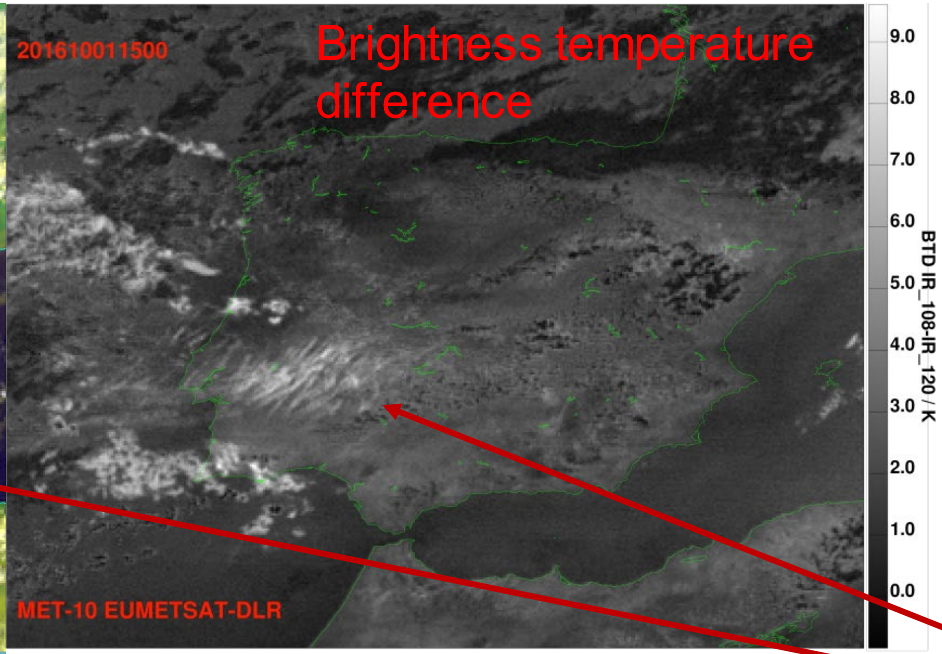
Observations are needed for model evaluation and contrail detection.

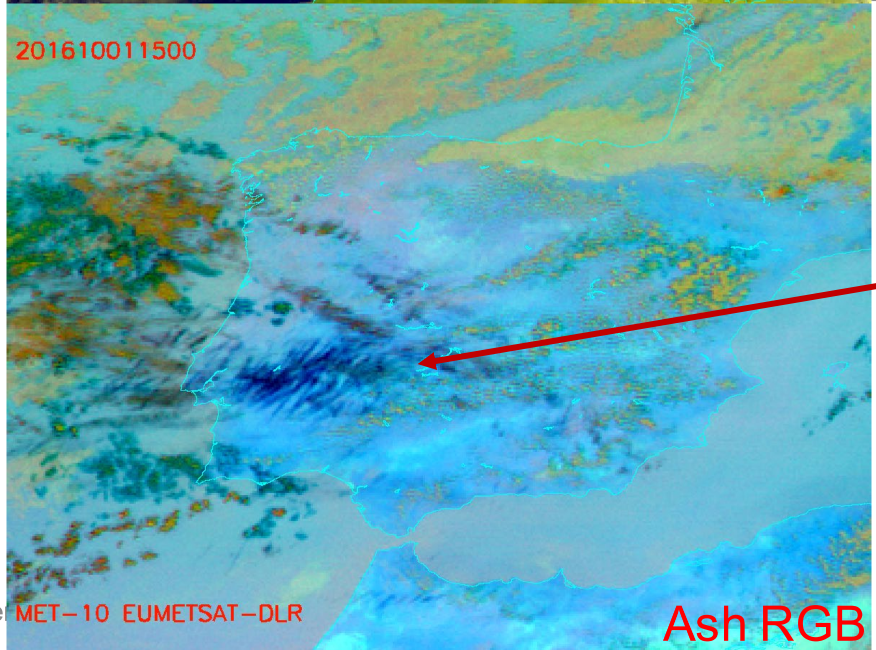
Passive remote sensing can provide an important contribution.

See e.g. LuFo D-KULT

Passive remote sensing of clouds and radiation







Meteosat Second Generation MSG

contrails

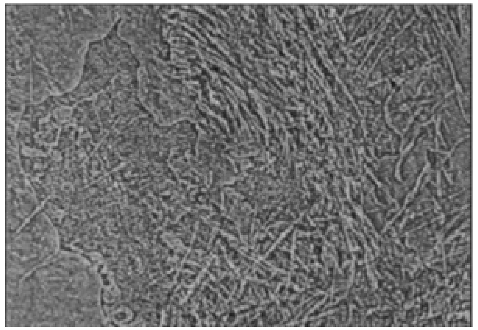
Passive remote sensing

- Observations of reflected solar and emitted thermal radiation in various spectral channels
- Geostationary: moderate spatial and high temporal resolution
- Polar orbiting: high spatial and low temporal resolution
- Contrails, cloud properties, top-of-atmosphere outgoing radiation

Contrail detection

Image processing

- ➢ Convolutions and gradient detection to highlight linear structures

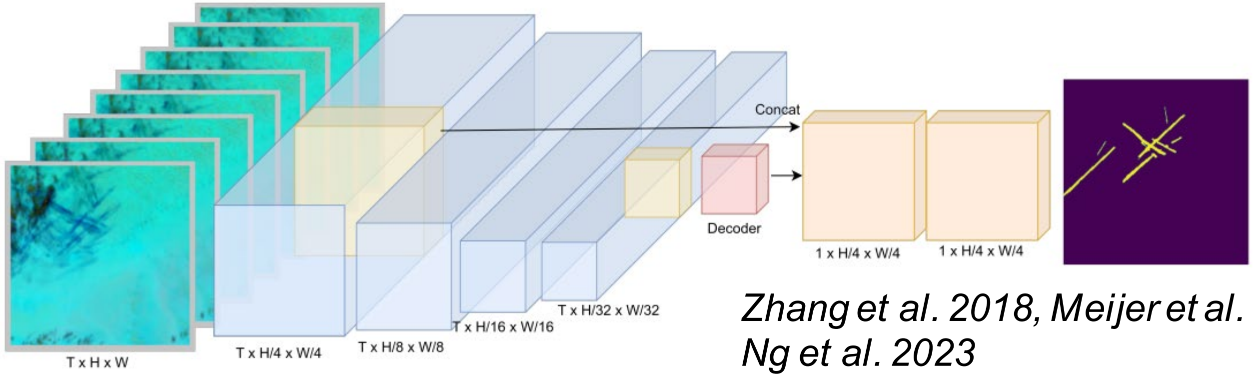


Mannstein et al. 1999: CDA Contrail Detection Algorithm

- ➢ Main advantages: can be easily transferred to new sensors, easy to extend (e.g. spectral information)

Machine learning

- ➢ Convolutional neural networks to identify contrails

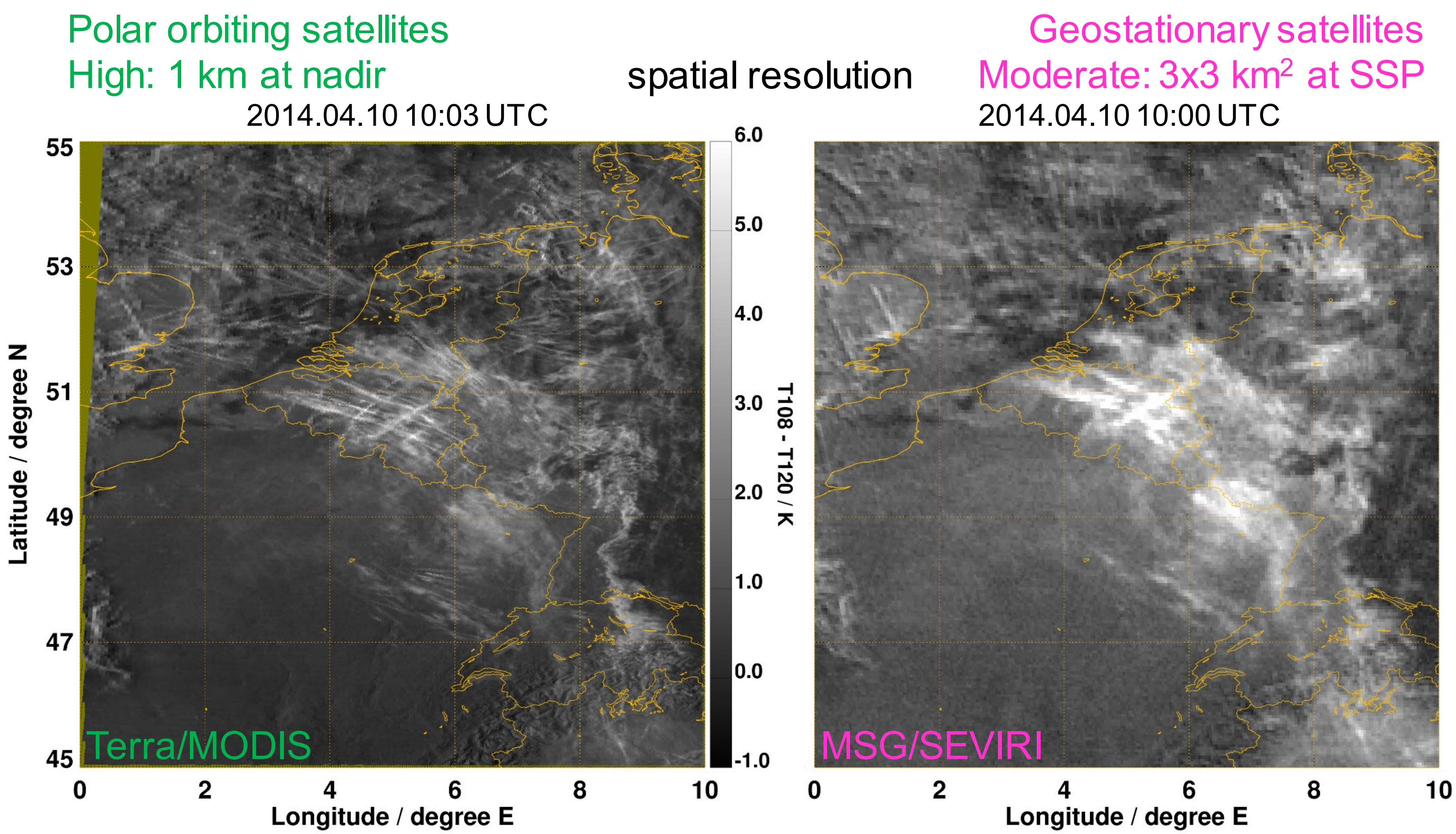


Zhang et al. 2018, Meijer et al. 2022, Ng et al. 2023

- ➢ Higher detection efficiency and less false alarms
- ➢ Main advantages: no need for manual thresholds, learns contrails, can exploit temporal evolution

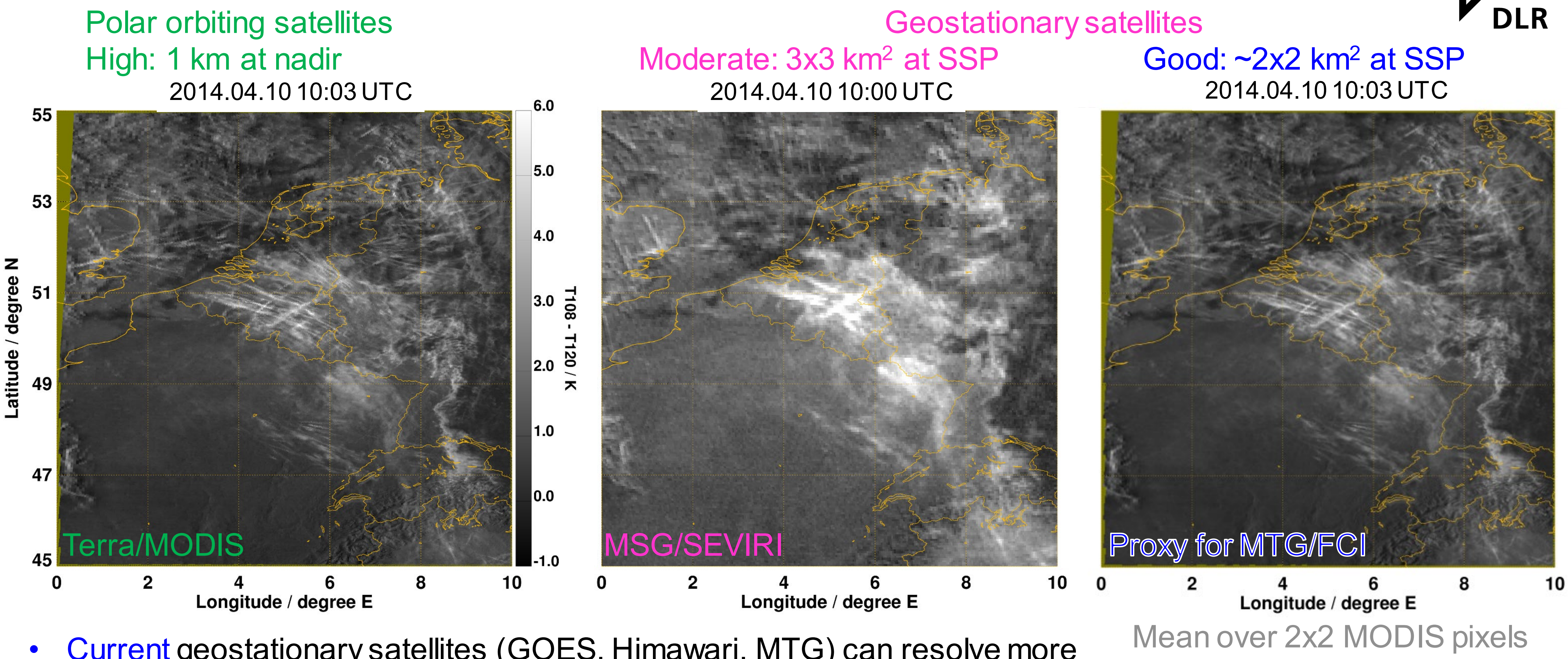
Both methods are based on convolutions and both methods depend on visibility of contrails in thermal observations.

Contrail visibility is affected by spatial resolution



- Single MSG/SEVIRI contrails can consist of more than one contrail.
- Thin/young contrails cannot be seen in MSG/SEVIRI.
- Spreading and/or overlapping contrails can lose their linear shape.

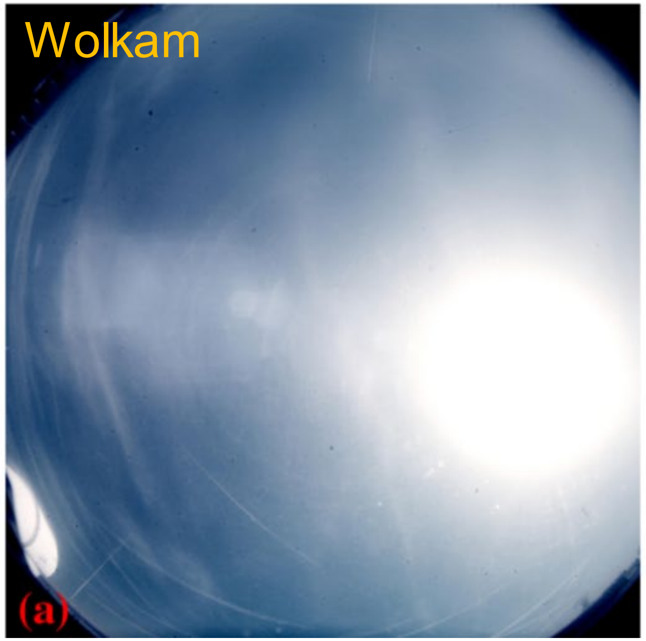
Contrail visibility is affected by spatial resolution

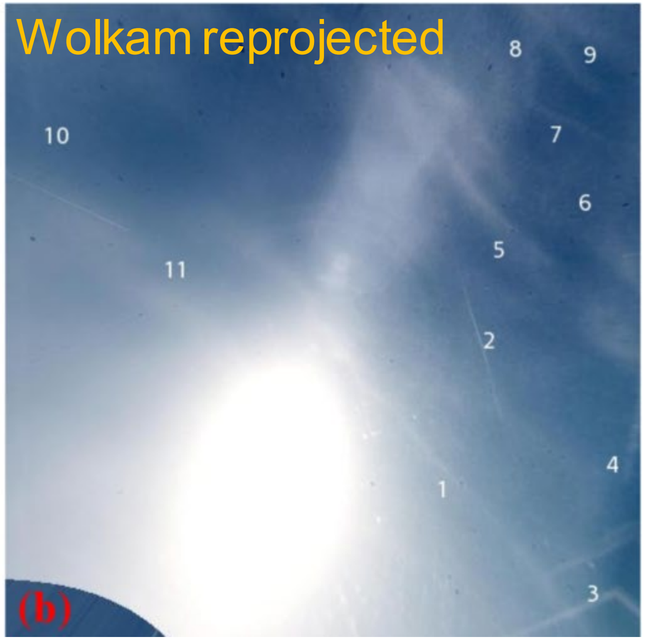


- Current geostationary satellites (GOES, Himawari, MTG) can resolve more (persistent) contrails and earlier than the previous satellite generation.
- Overlapping contrails or contrails very close to each are challenging.

Contrail visibility depends on pixel optical thickness

Mannstein, Brömser, Bugliaro 2010: Evaluation of contrail detection algorithm CDA with a whole-sky camera called Wolkam





Whole-sky camera located at DLR close to Munich

Polar orbiting NOAA/AVHRR

Visual inspection

Width/km	<0.5	0.5–0.9	1.0–1.9	2.0–4.9	≥5.0	total
Wolkam	21	21	33	14	7	96
Temp. difference	1	9	20	9	1	40
Colour composite	0	3	12	7	1	23
CDA	0	0	5	3	0	8

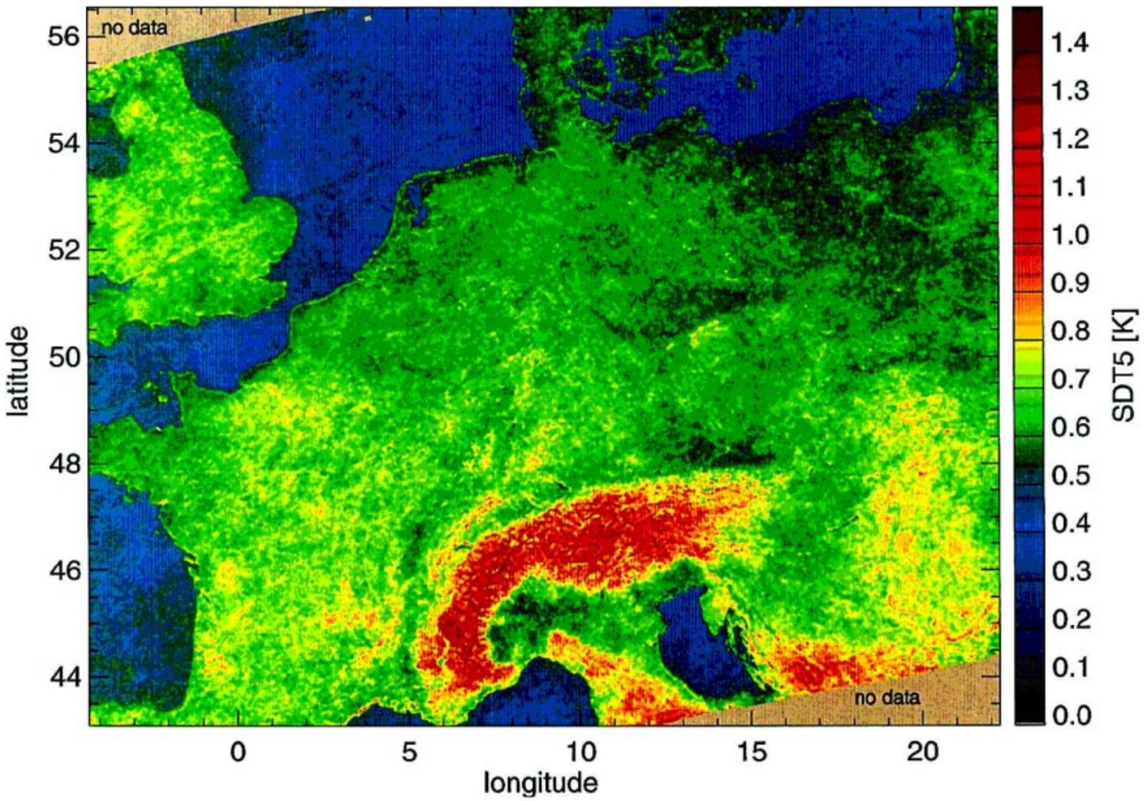
Geostationary MSG/SEVIRI

Visual inspection

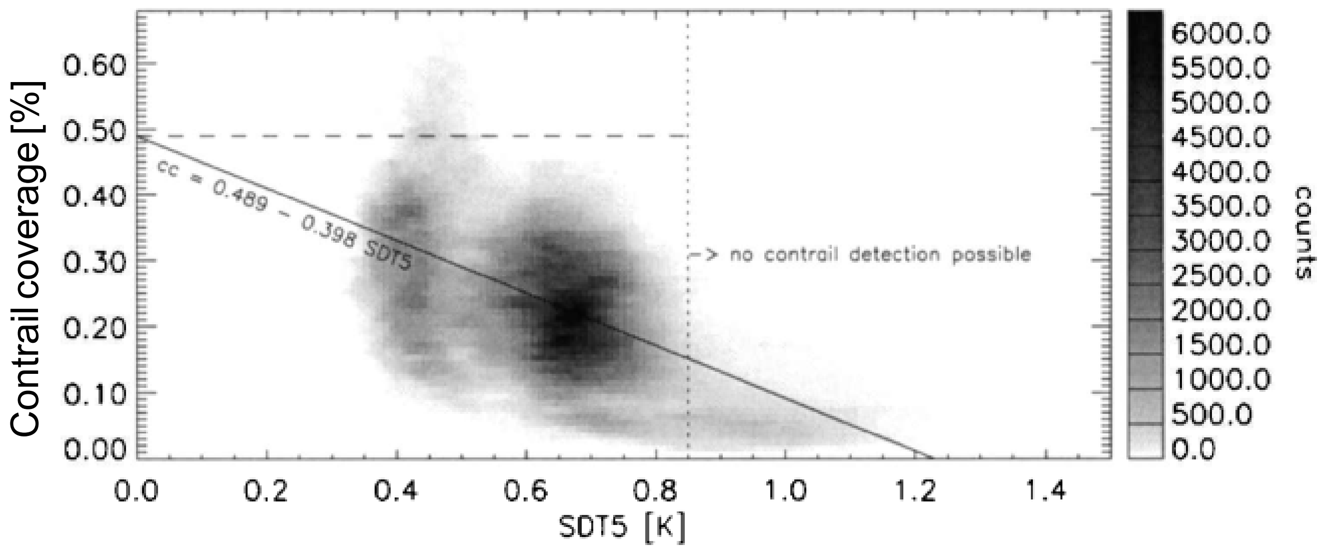
Width (km)	<0.5	0.5–0.9	1.0–1.9	2.0–4.9	≥5.0	total
Wolkam	29	27	14	7	2	79
Temp. difference	0	2	6	4	0	12
Colour composite	0	0	1	4	2	7
CDA	0	1	2	2	2	7

- Many narrow contrails are missed, some narrow contrails are detected, not all wide contrails can be detected
- Contrail visibility depends on pixel optical thickness
- Even visual detection of contrails in satellite data can miss contrails

Contrail visibility depends on the contrast against the background



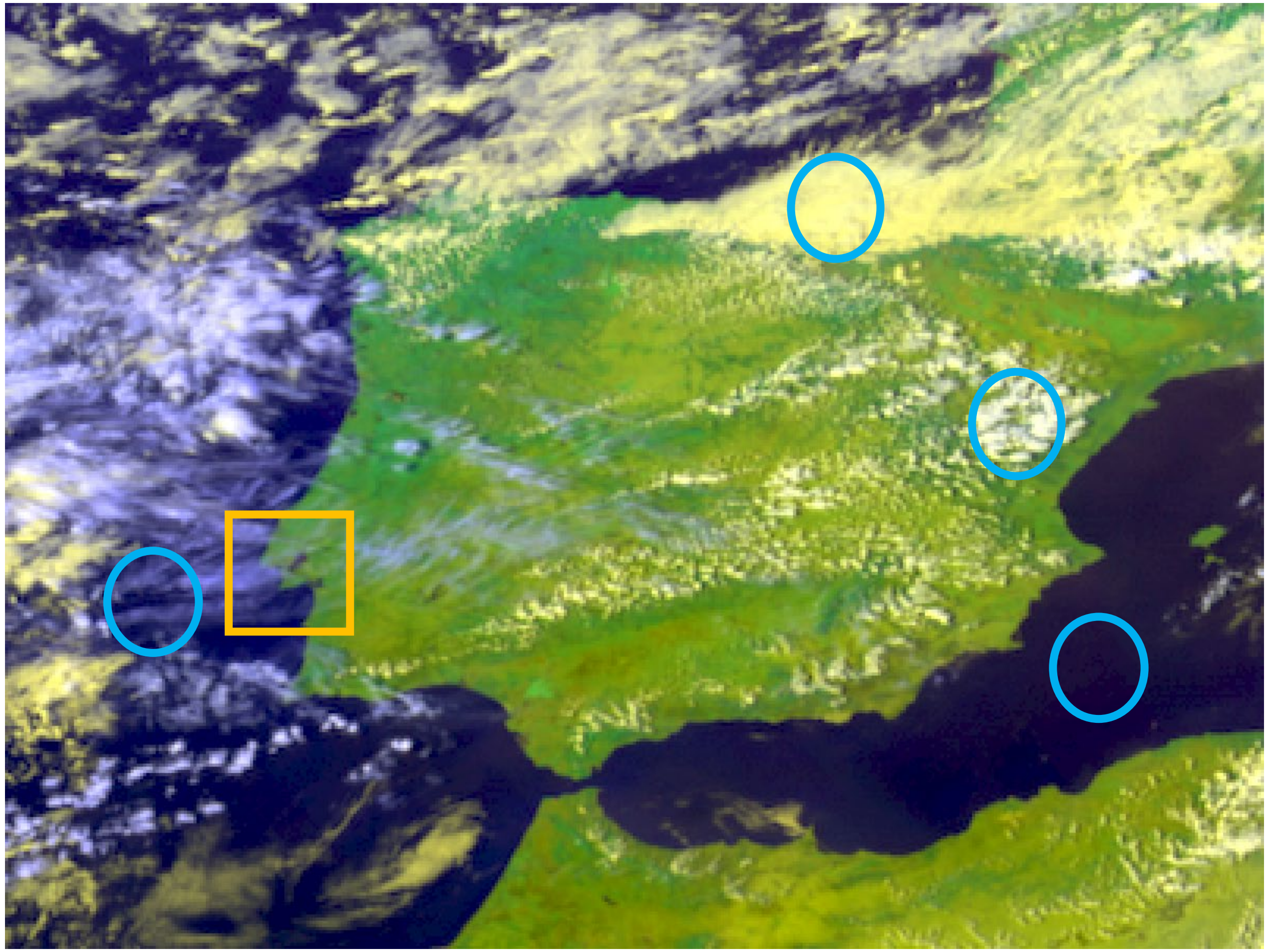
SDT5 = standard deviation of brightness temperature at 11 µm in a 5x5 pixel surroundings

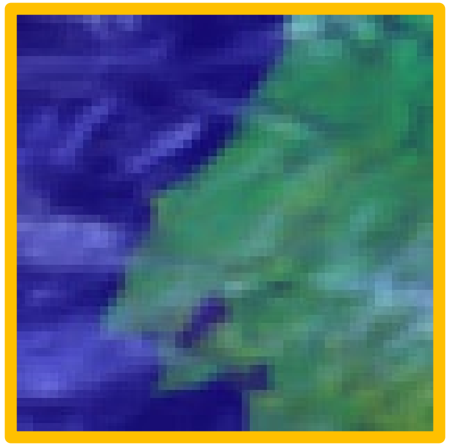


Mannstein et al. 1999

- Background inhomogeneity reduces contrail detection.

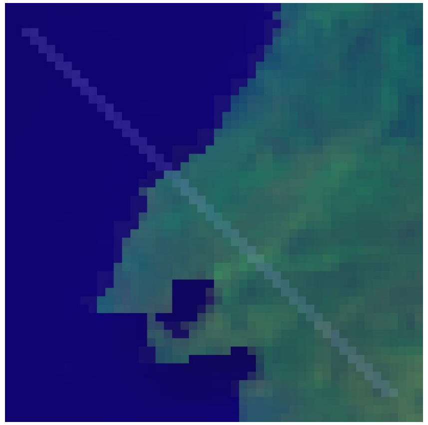
Contrail visibility is affected by cloudiness

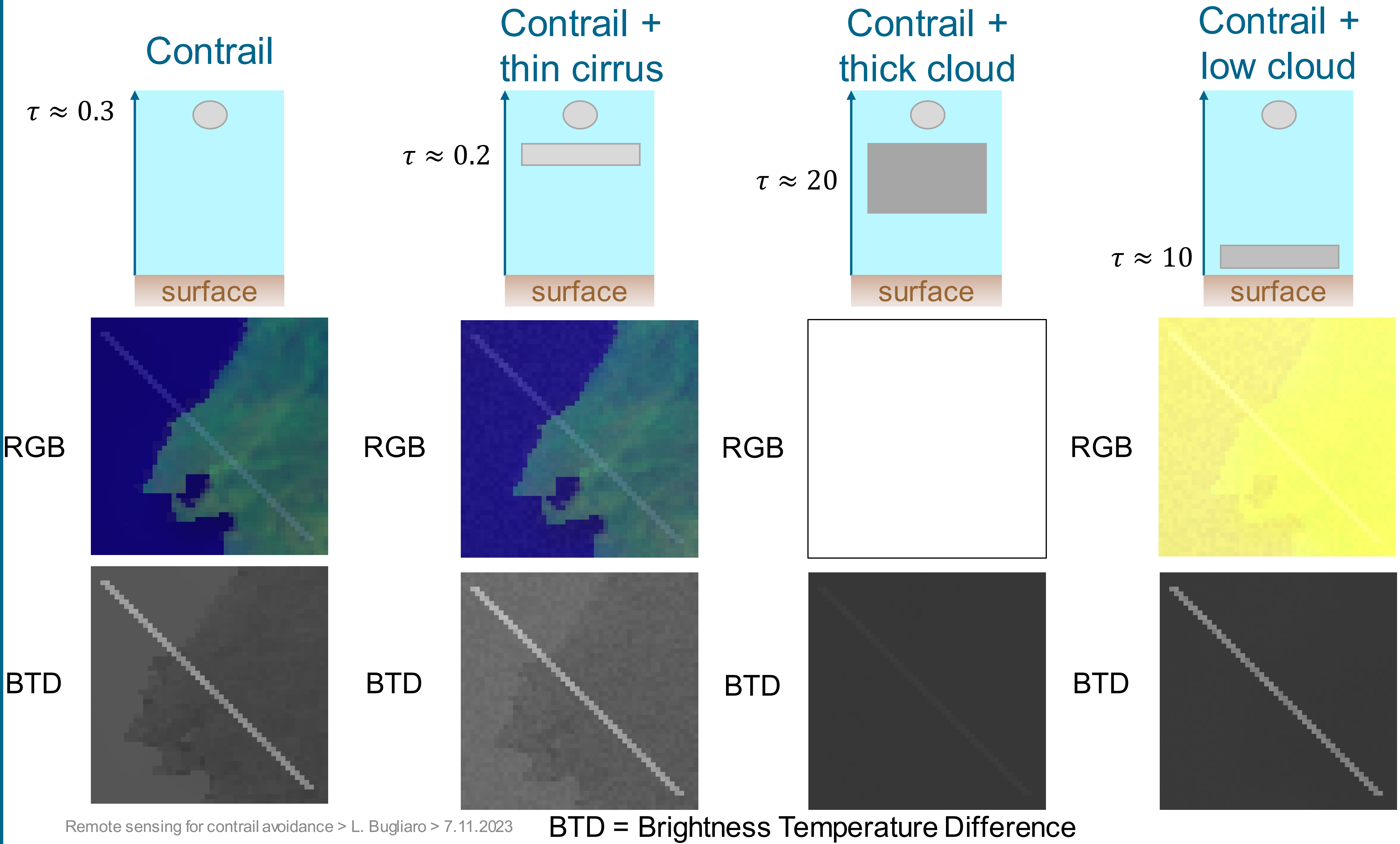


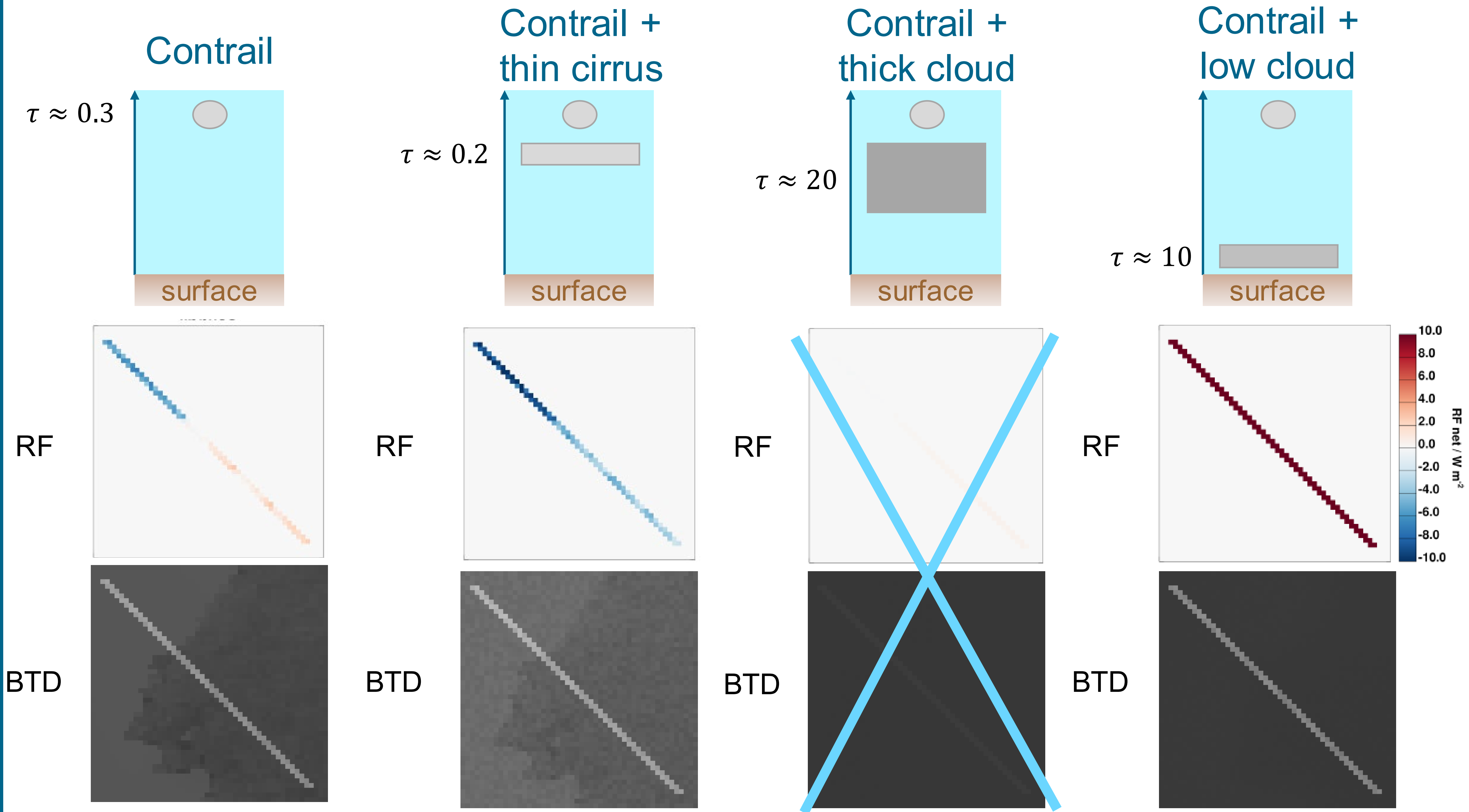


Radiative transfer simulations for a thin contrail in different cloud situations on 01.10.2016 15 UTC:

libRadtran

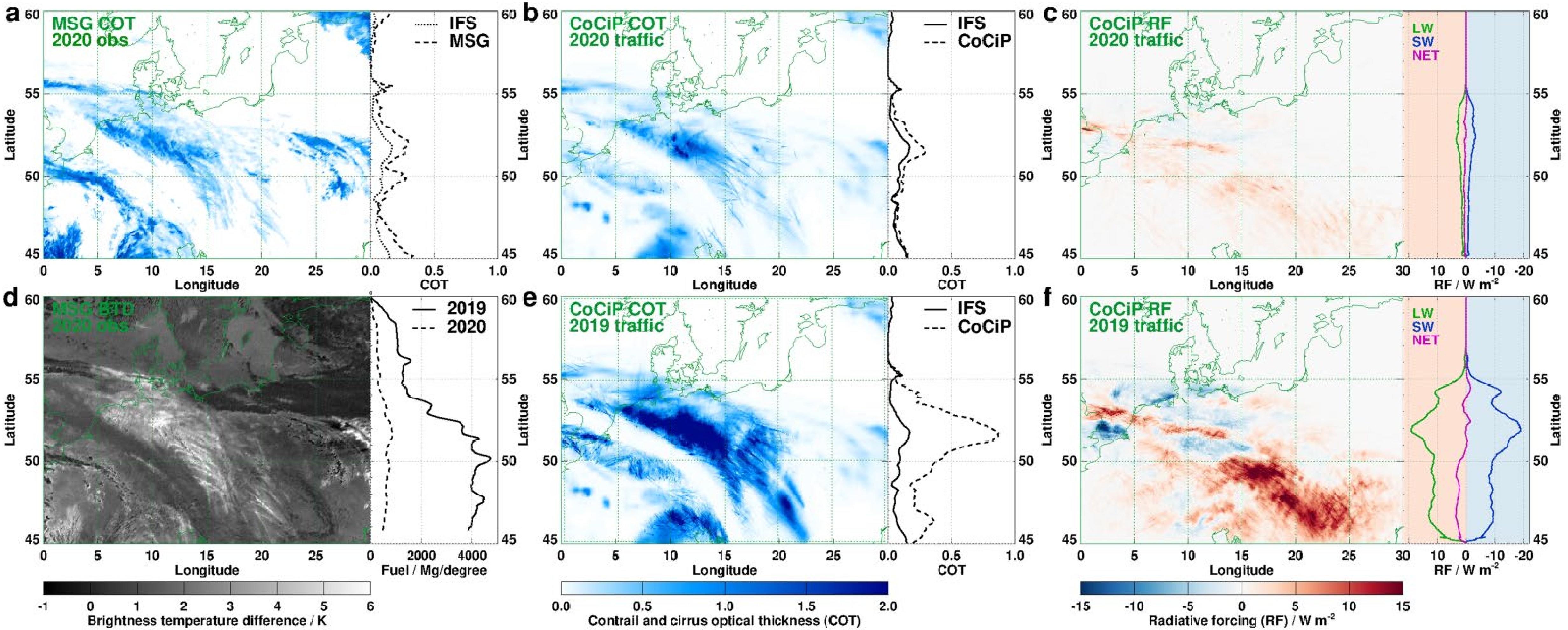



Contrail
Contrail + thin cirrus
Contrail + thick cloud
Contrail + low cloud
τ ≈ 0.3
τ ≈ 0.2
τ ≈ 20
τ ≈ 10
surface
surface
surface
surface
RGB
RGB
RGB
RGB
BTD
BTD
BTD
BTD
BTD = Brightness Temperature Difference



BTD = Brightness Temperature Difference; RF = Radiative Forcing

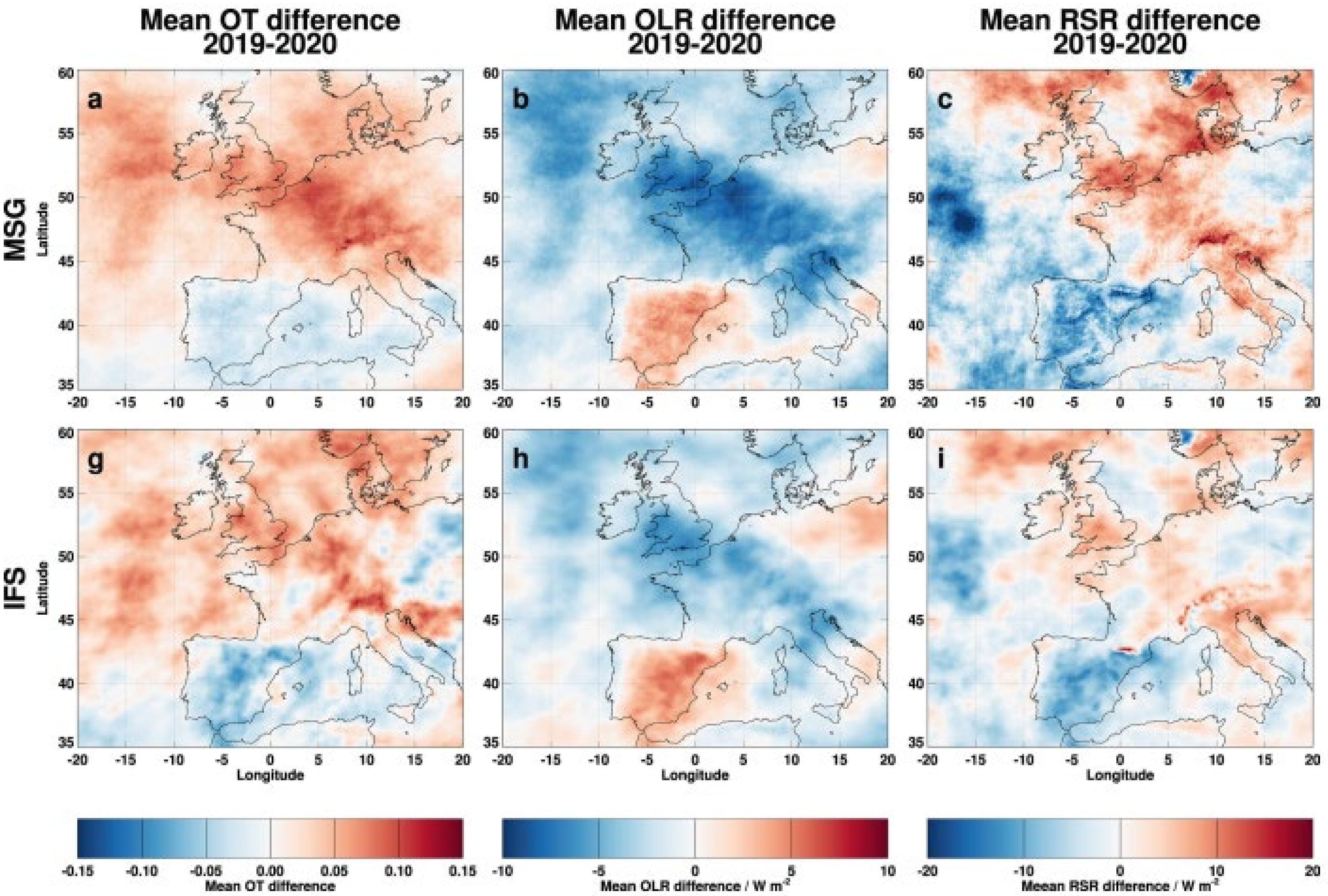
Passive remote sensing for model evaluation



Voigt et al. (Schumann, Bugliaro) 2022

CoCiP (Schumann 2012) simulations

Passive remote sensing for model evaluation



All clouds

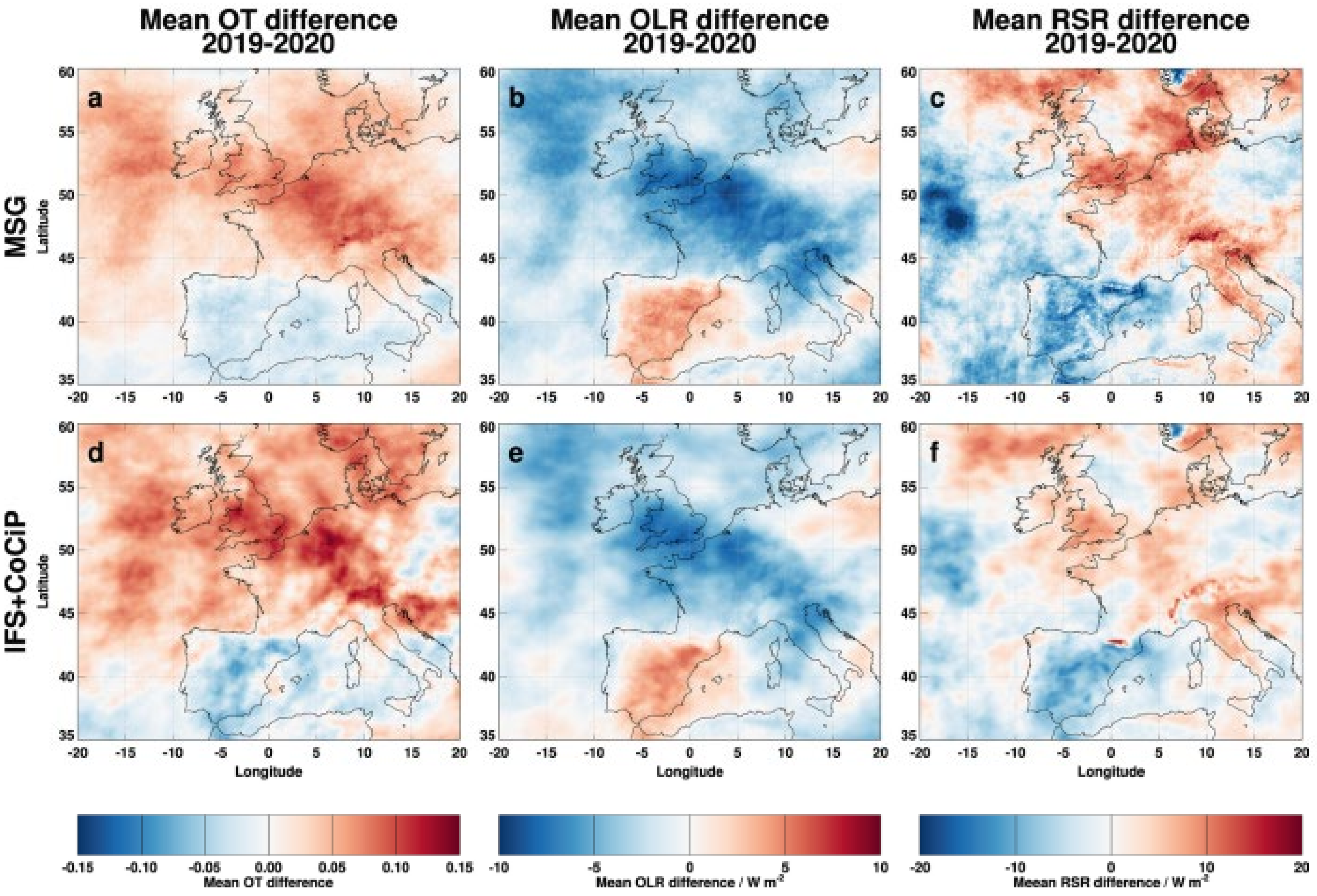
Comparison of model simulations and MSG/SEVIRI observations over 6 months in 2019 (high air traffic density) and 2020 (Covid, low air traffic density):

Differences between the year 2019 and 2020

OT: Optical thickness
OLR: Outgoing Longwave Radiation
RSR: Reflected Solar Radiation

Schumann, Bugliaro et al. 2021

Passive remote sensing for model evaluation



All clouds

Comparison of model simulations and MSG/SEVIRI observations over 6 months in 2019 (high air traffic density) and 2020 (Covid, low air traffic density):

Differences between the year 2019 and 2020

Contrails and contrail cirrus increase the agreement between model and observations.

Schumann, Bugliaro et al. 2021

Conclusions and outlook

- Passive satellite remote sensing is a powerful tool for contrail detection and contrail model evaluation.
- Current geostationary satellites seem to have reached a good spatial resolution for contrail detection.
- However, there are physical limitations on contrail detection.
- Low spatial resolution is a challenge for contrail detection: How far north can we go even with current geostationary satellites?
- Not all persistent contrails have a significant radiative impact: focus of contrail avoidance on „big hits“ is benefitial to ideally exploit satellite observations of contrails (and for climate).
- Contrail detection can also be used to identify ice supersaturated regions (LuFo MEFKON).
- More model evaluation on single contrail basis is needed.

Thank you for your attention!