September 7, 2022

Using satellite-based observations of contrails to inform contrail avoidance strategies

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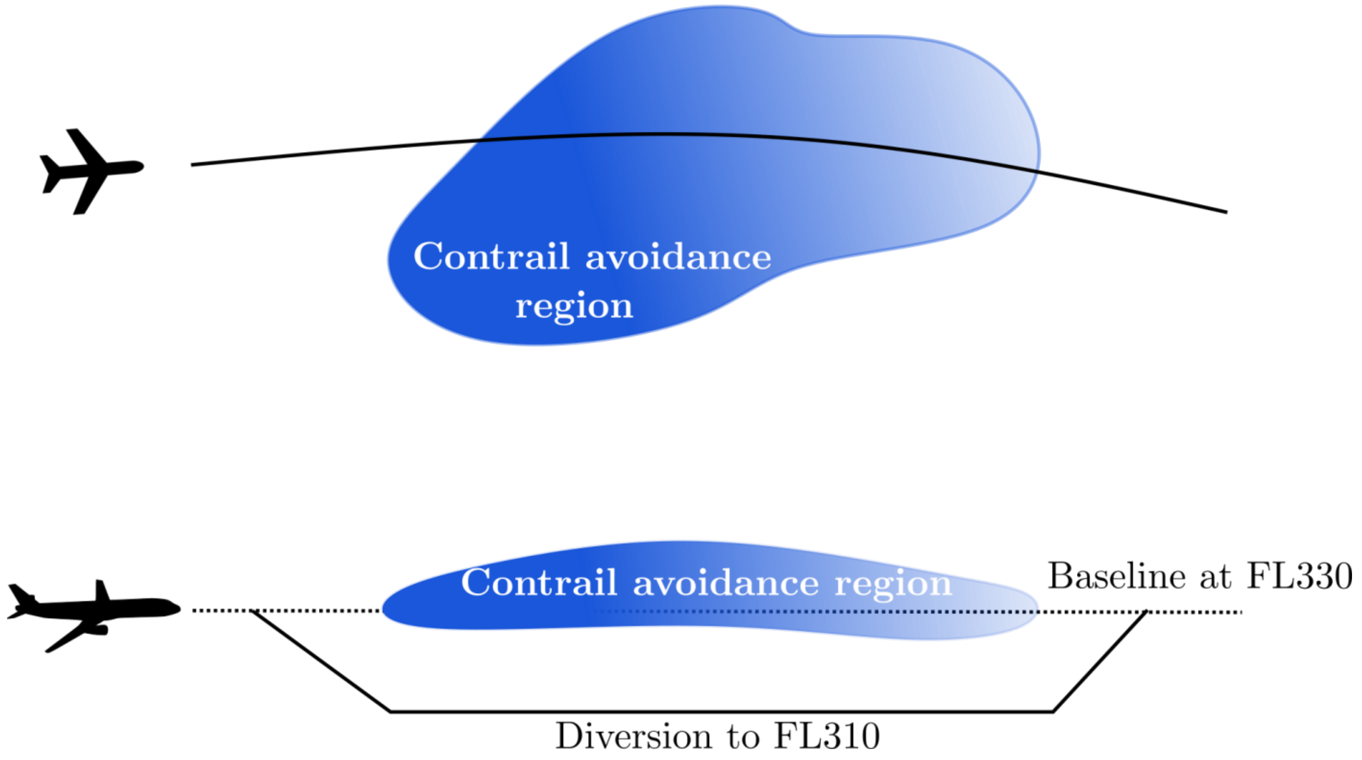
and Steven Barrett (presenter)

Vertical deviations from current flight paths can largely avoid long-lasting contrails



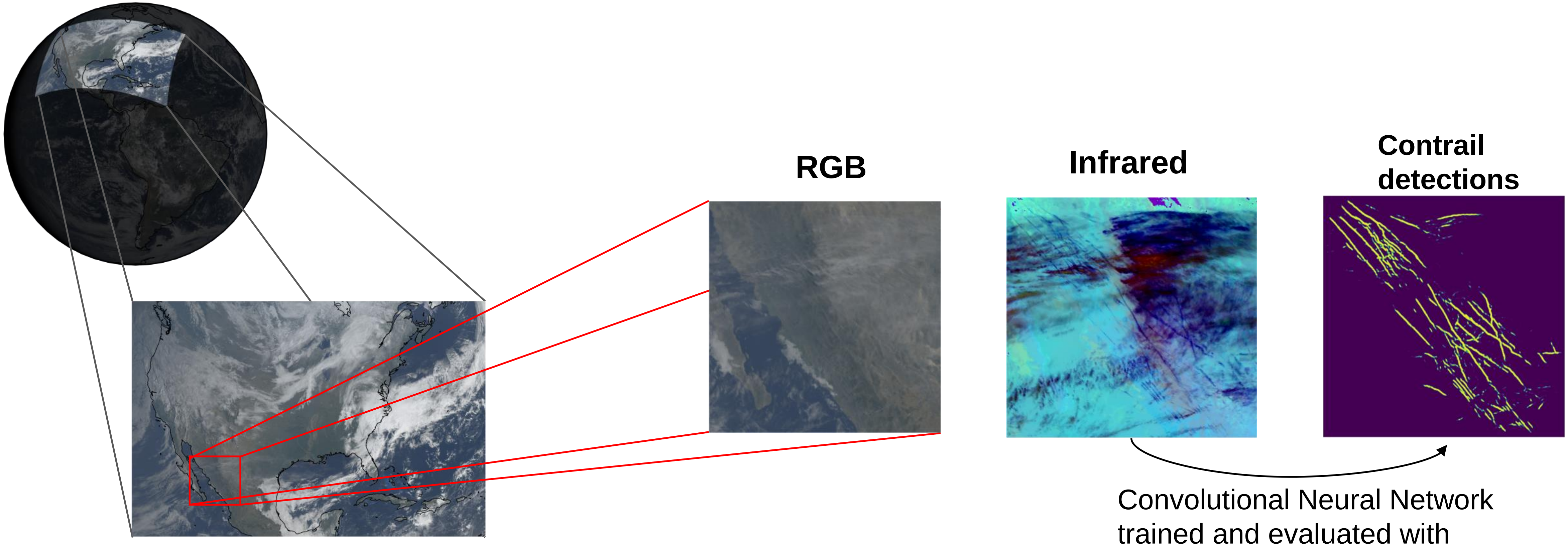
MOTIVATION

- Ice supersaturated regions allow contrails to persist, and thus host the majority of aviation's non-CO_2 climate impact (Schumann 1996, Ponater et al. 1996, Lee et al. 2021)
- These regions are horizontally wide but vertically thin, and could be avoided with minimal fuel burn penalty (Gierens et al. 2000, Spichtinger et al. 2003, Teoh et al. 2020)

QUESTION

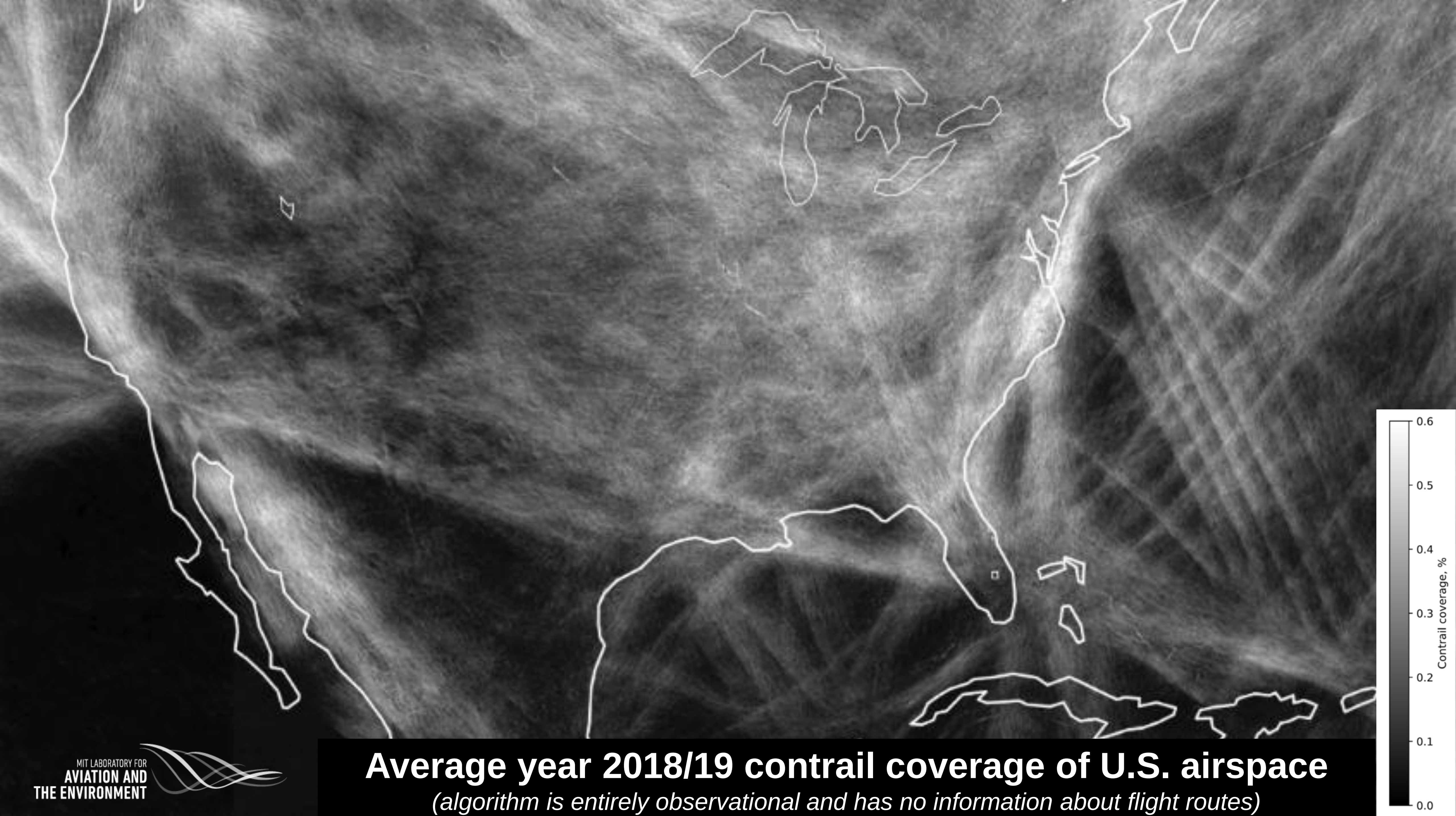
But how well can we predict the regions we want to avoid? (Gierens et al. 2020, Agarwal et al. 2022)

Observing contrails using geostationary satellites



Convolutional Neural Network
trained and evaluated with
human labelled images

Meijer et al. (2022), Contrail coverage over the United States before and during the COVID-19 pandemic



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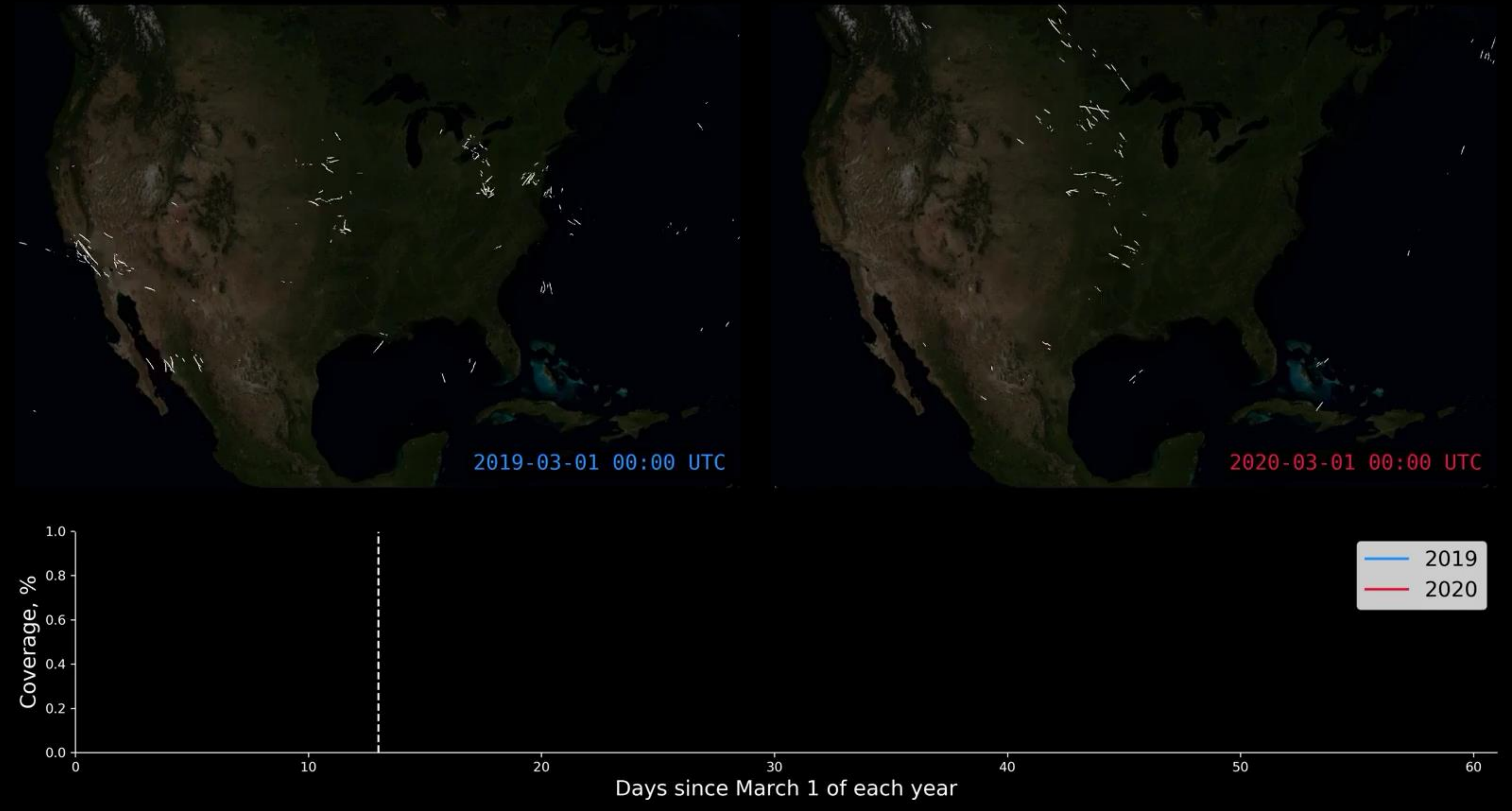
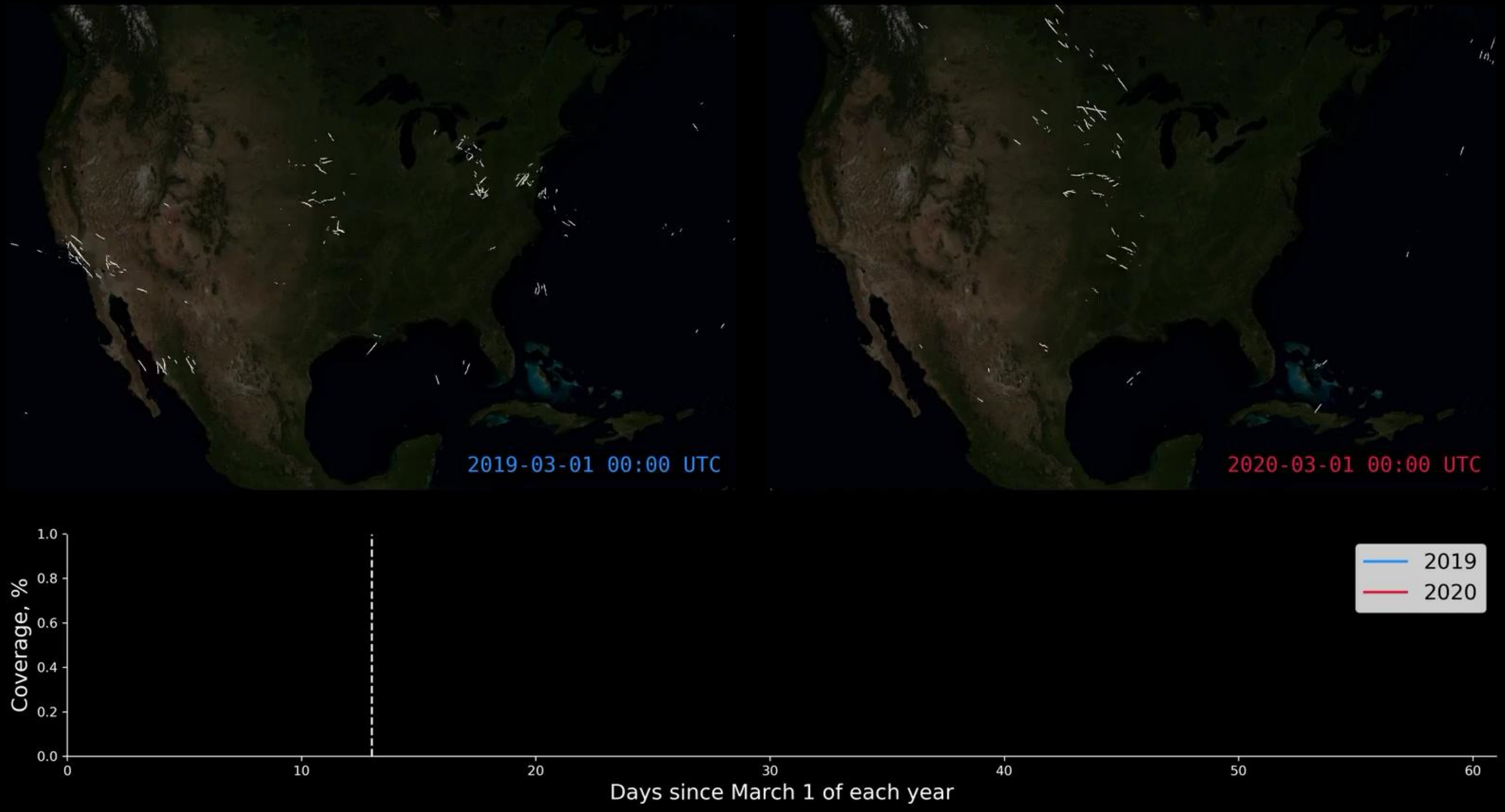
Average year 2018/19 contrail coverage of U.S. airspace

(algorithm is entirely observational and has no information about flight routes)



2019-03-01 00:00 UTC
2020-03-01 00:00 UTC
Coverage, %
1.0
0.8
0.6
0.4
0.2
0.0
2019
2020
0
10
20
30
40
50
60
Days since March 1 of each year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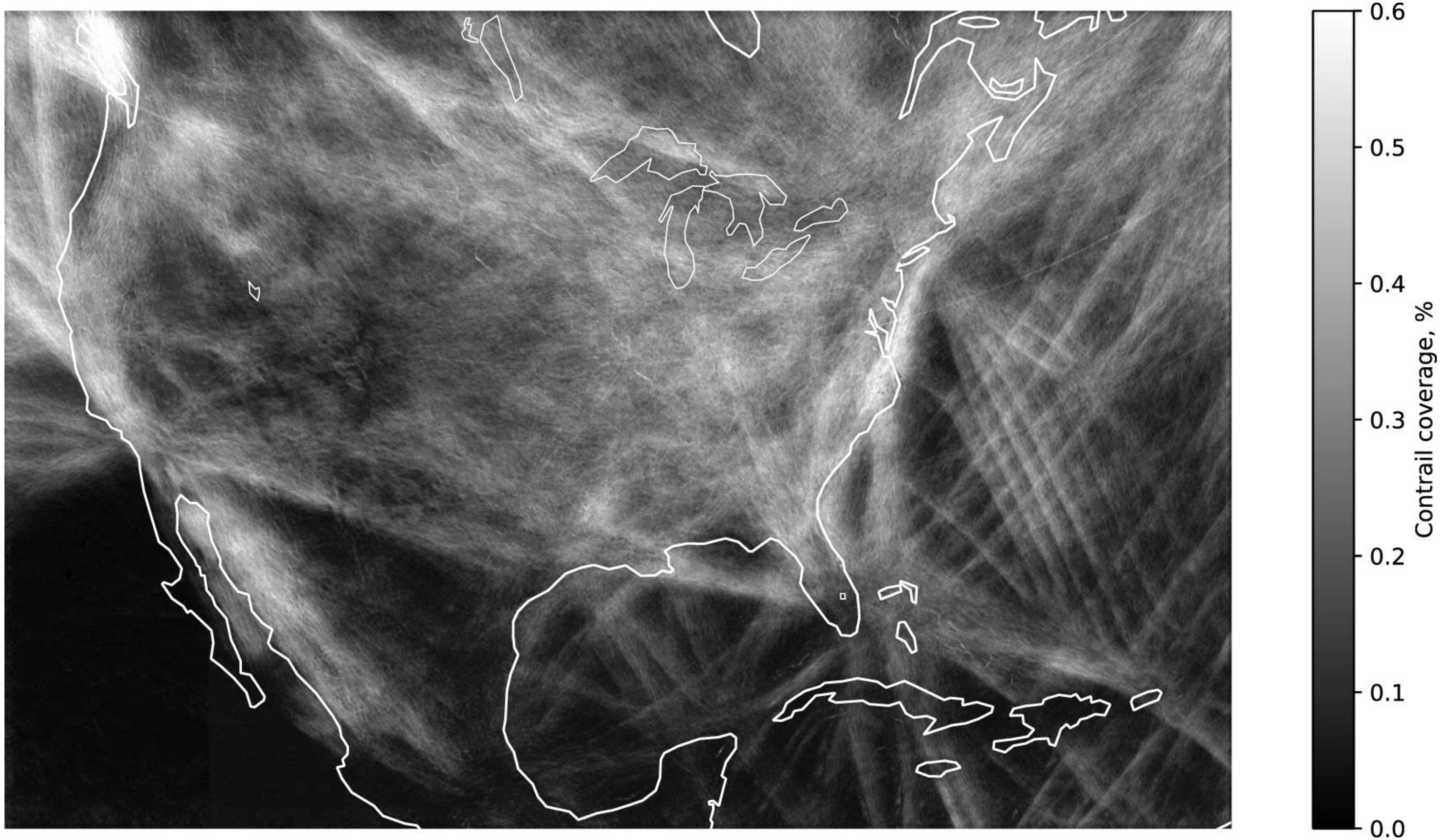
Days since March 1 of each year
2019
2020

Observing contrails using geostationary satellites

- Allows us to observe contrails every ~10 minutes across the United States, in near real-time

- Missing piece of information is the height of the contrails

Averaged contrail coverage for 2018 and 2019

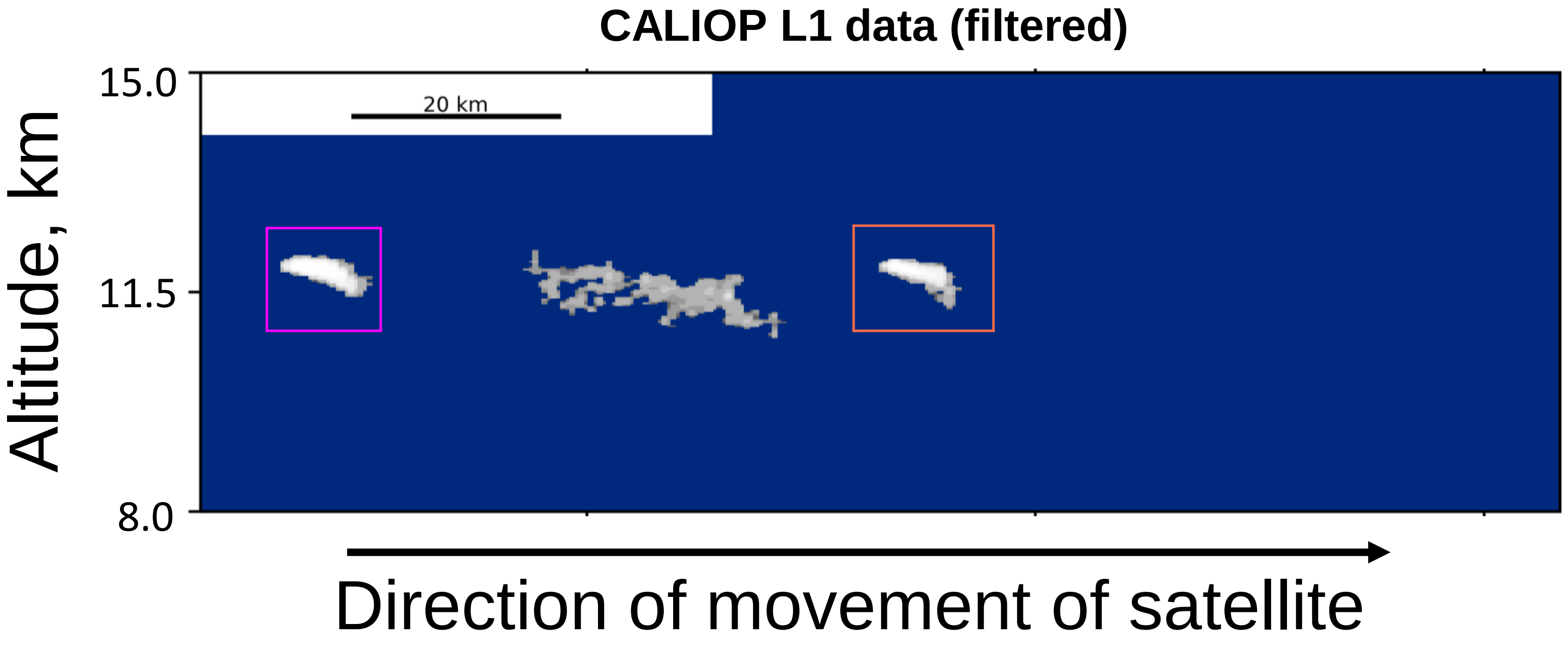


Meijer et al. (2022), Contrail coverage over the United States before and during the COVID-19 pandemic

Finding contrails in CALIOP LIDAR data

- 1500+ contrails detected on GOES-16 found in CALIOP LIDAR data (2018 – 2020)[1]

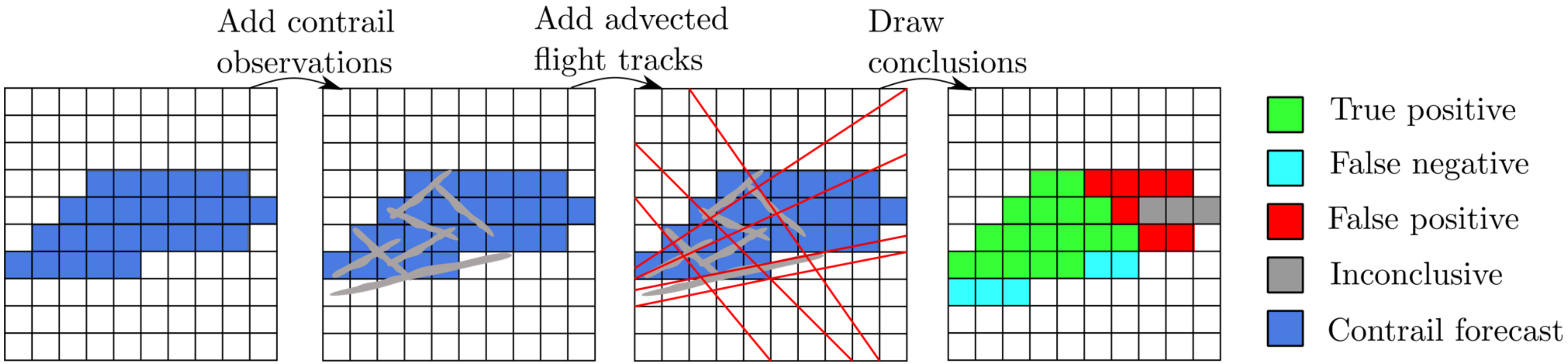
- Use to
  - Quantify weather forecast performance
  - Develop/validate height estimation algorithm[2]



1. Iwabuchi et al. (2012) have done this for contrails detected using the MODIS instrument
2. Cirrus height estimation algorithms for the SEVIRI instrument have been developed this way by Kox et al. (2012) and Strandgren et al. (2017)

Evaluating a contrail forecast using observations

Introduce contrail observations and flight data to identify errors



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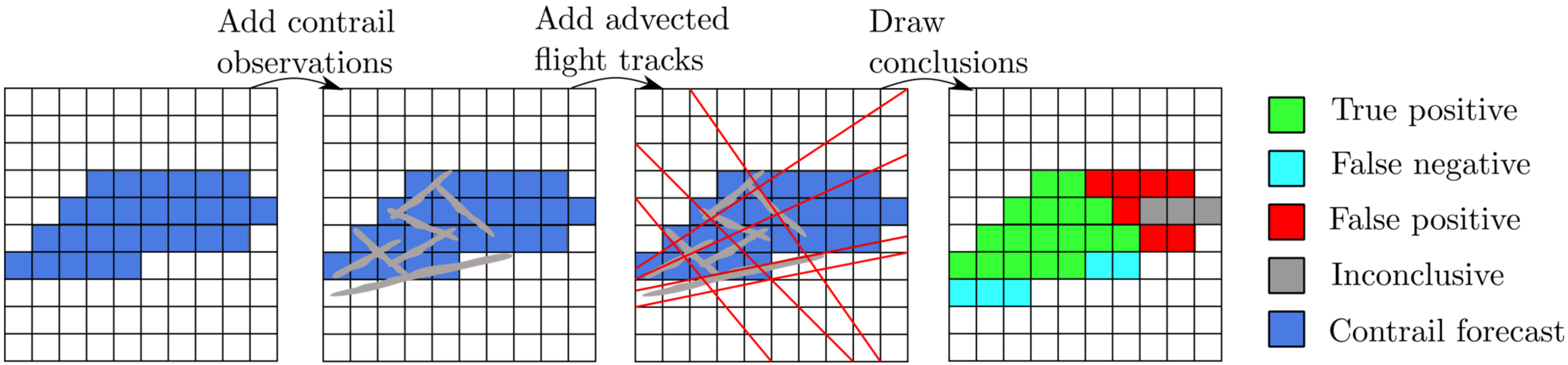
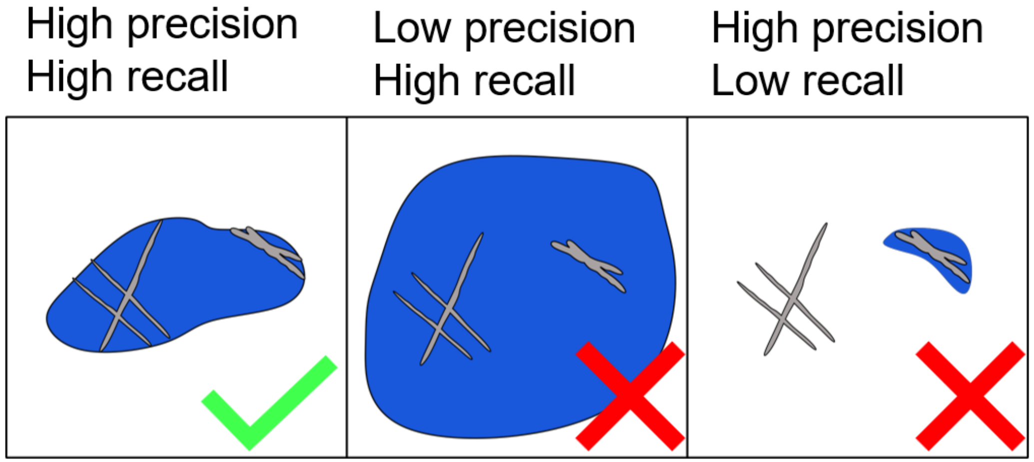


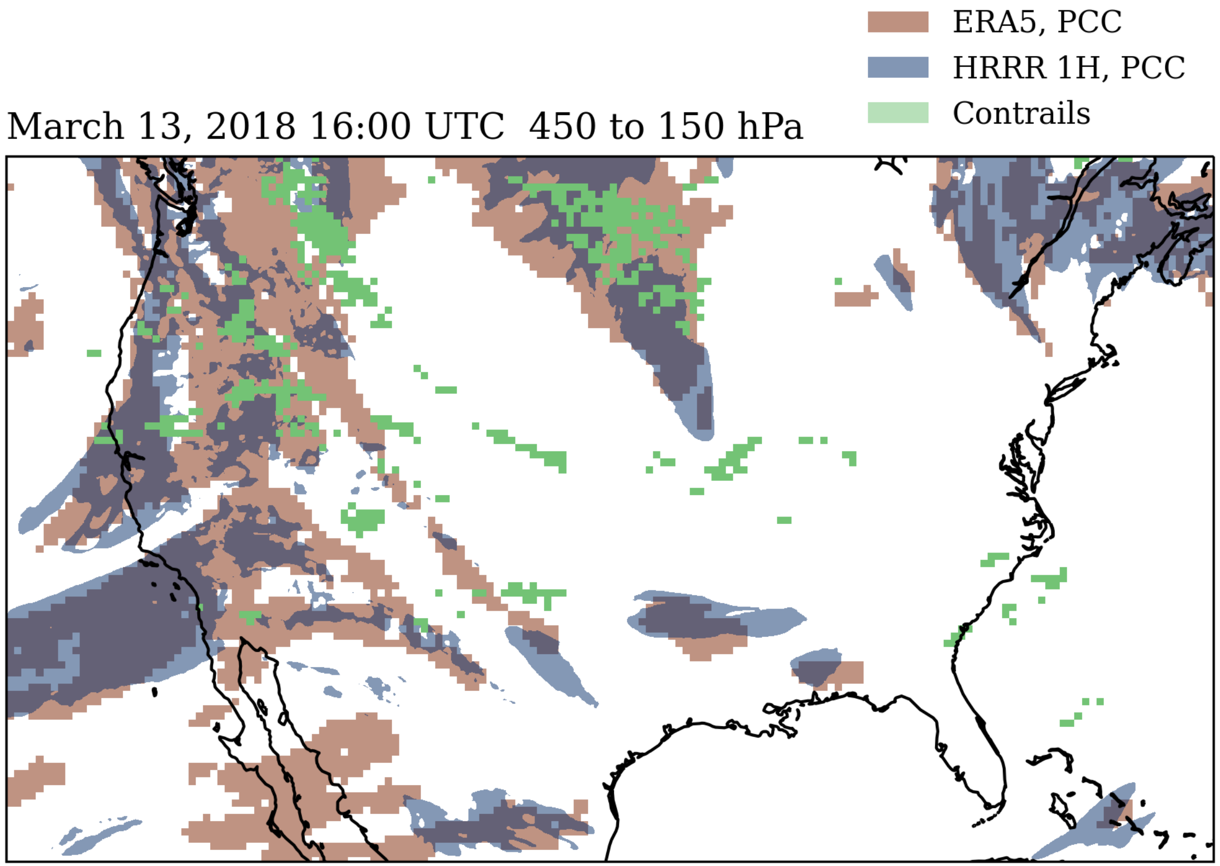
Performance measures

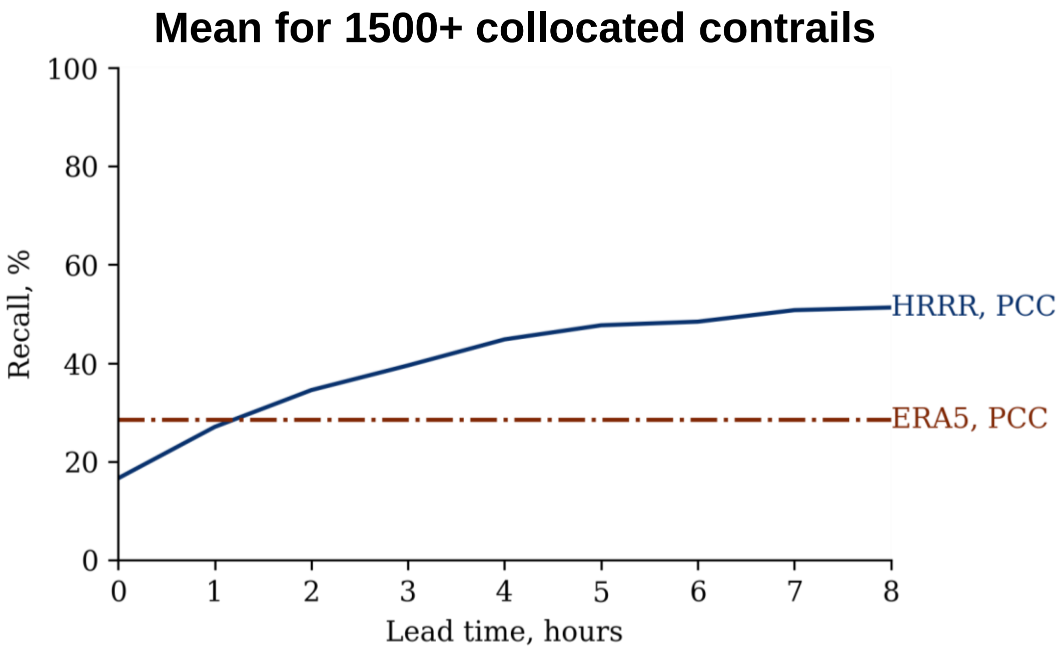
$$\text{Precision} = \frac{\text{True positives}}{\text{True positives} + \text{False positives}}$$

$$\text{Recall} = \frac{\text{True positives}}{\text{True positives} + \text{False negatives}}$$



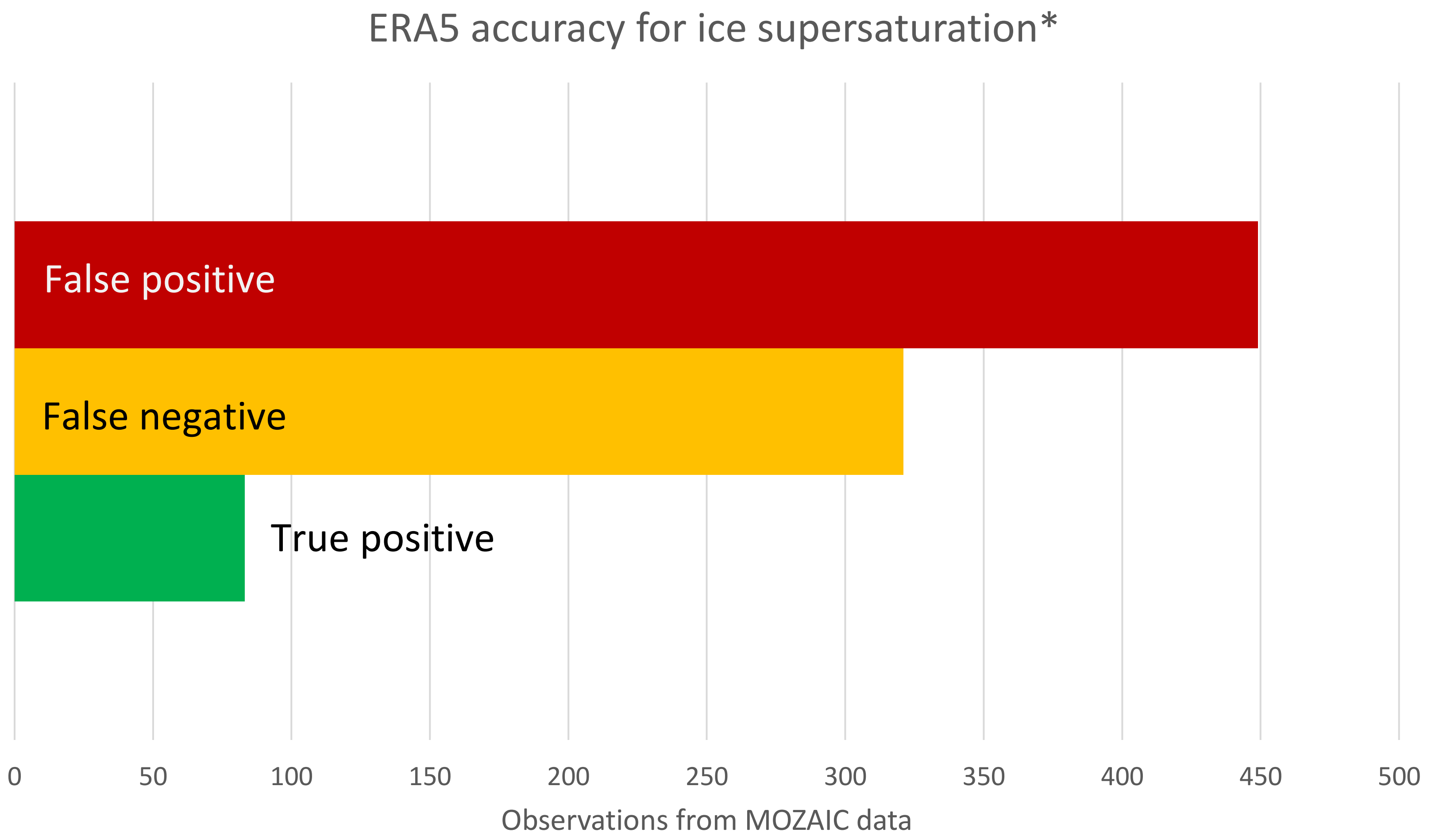
Performance of NWP: HRRR and ERA5

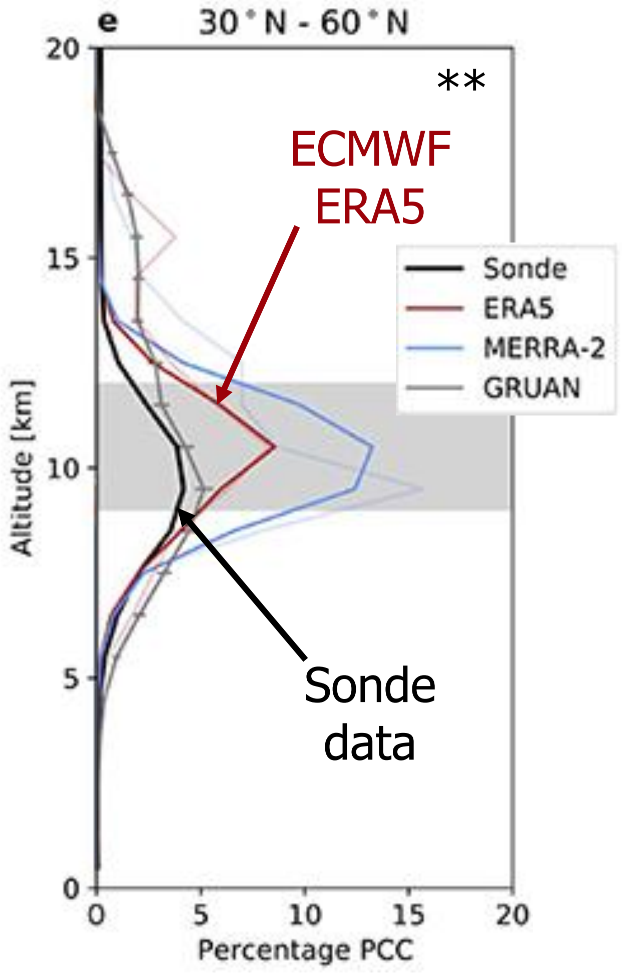




Persistent contrail criterion (PCC) is the combination of the Schmidt-Appleman criterion and ice supersaturation

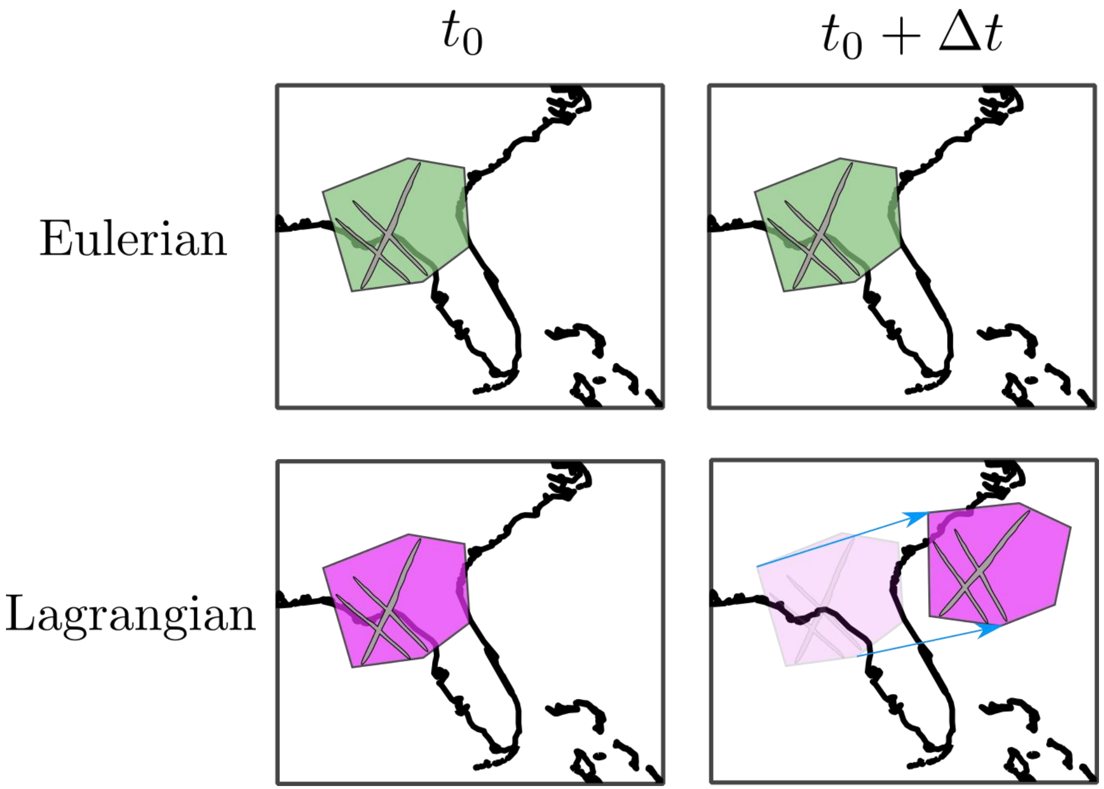
Limitations in contrail prediction using forecast data

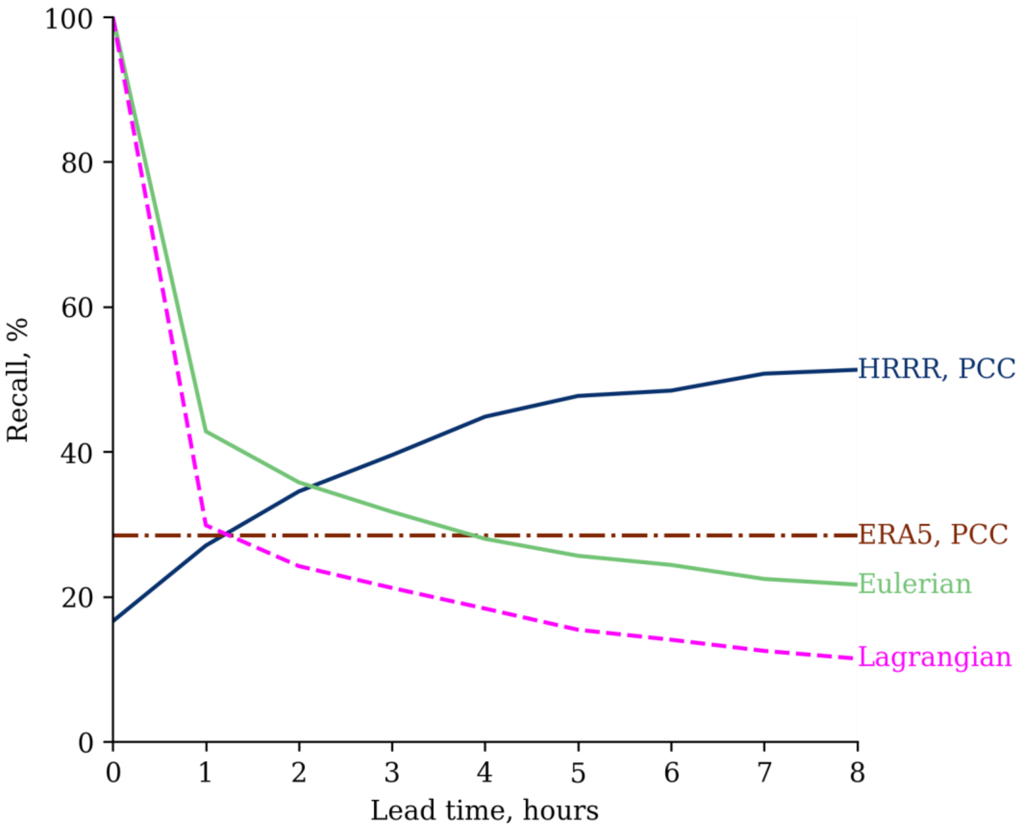




*Gierens et al., 2020
**Agarwal et al., 2022

Extrapolating contrail observations in the future



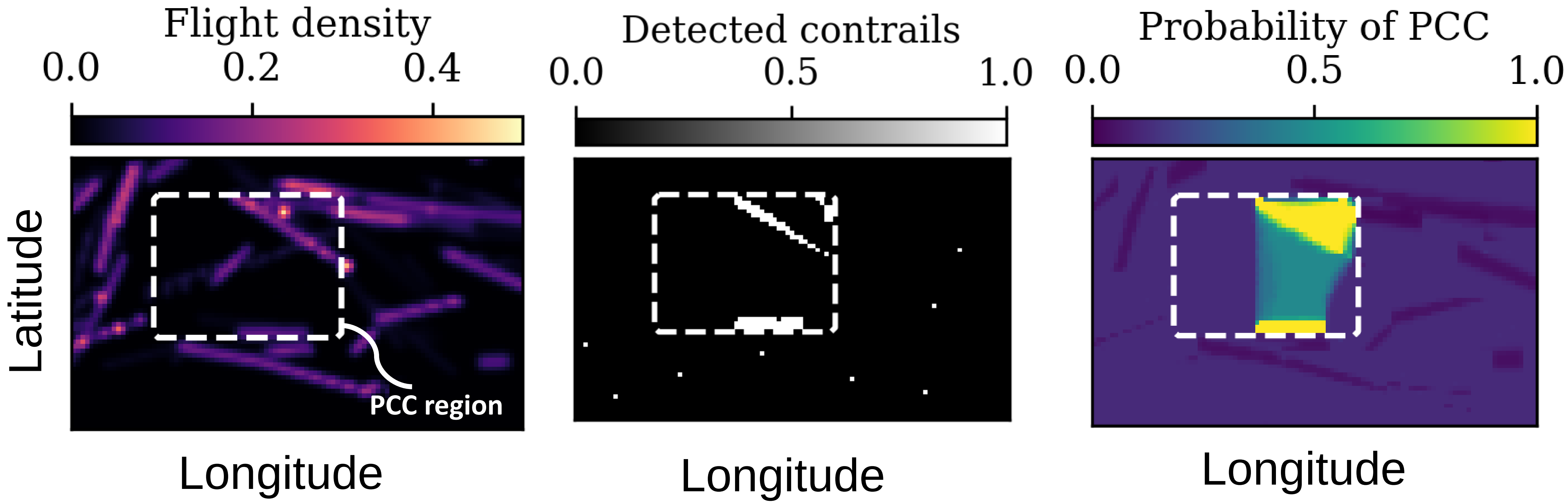


*Uses preliminary height estimation algorithm

Meijer et al. (2022), Contrail coverage over the United States before and during the COVID-19 pandemic

Inference of PCC by introducing flight data

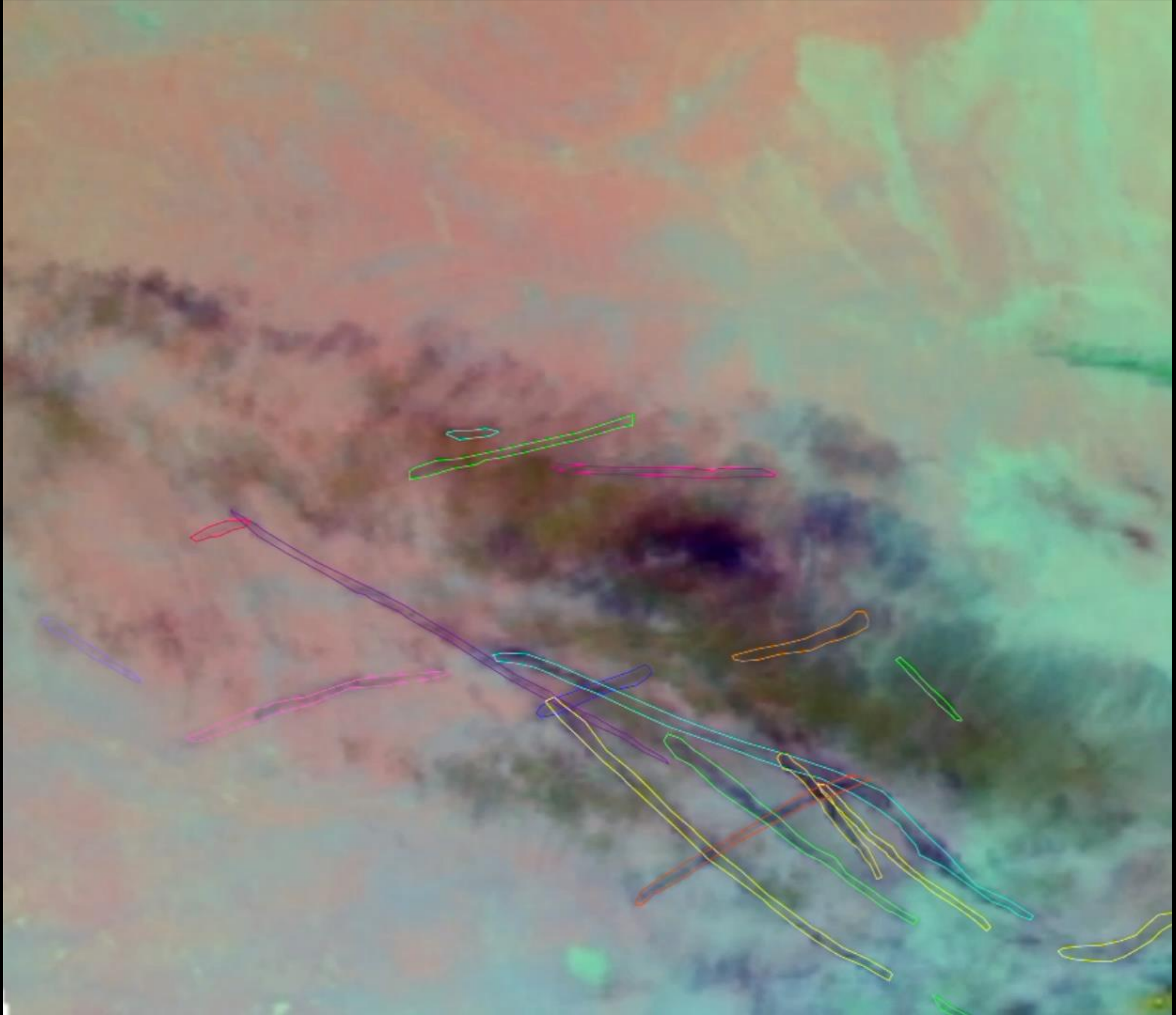
Note: synthetic data



Using satellite-based observations of contrails to inform contrail avoidance strategies

Takeaways:

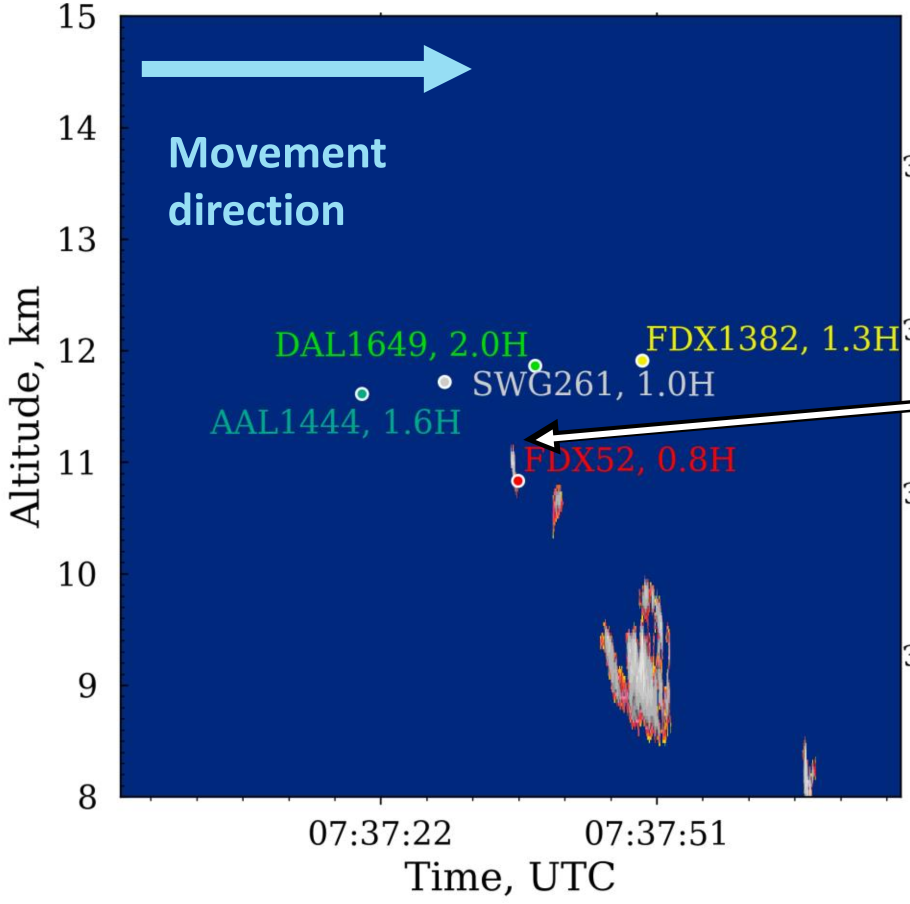
- 4+ years of contrail coverage estimates now available at ~10 minute resolution
- Collocations with LIDAR show that 72% of contrails would not be predicted using ERA5 data
- Observation-based "forecast" outperforms numerical models for up to two hours lead time
- Future work will extend this to include estimation of false positive rates



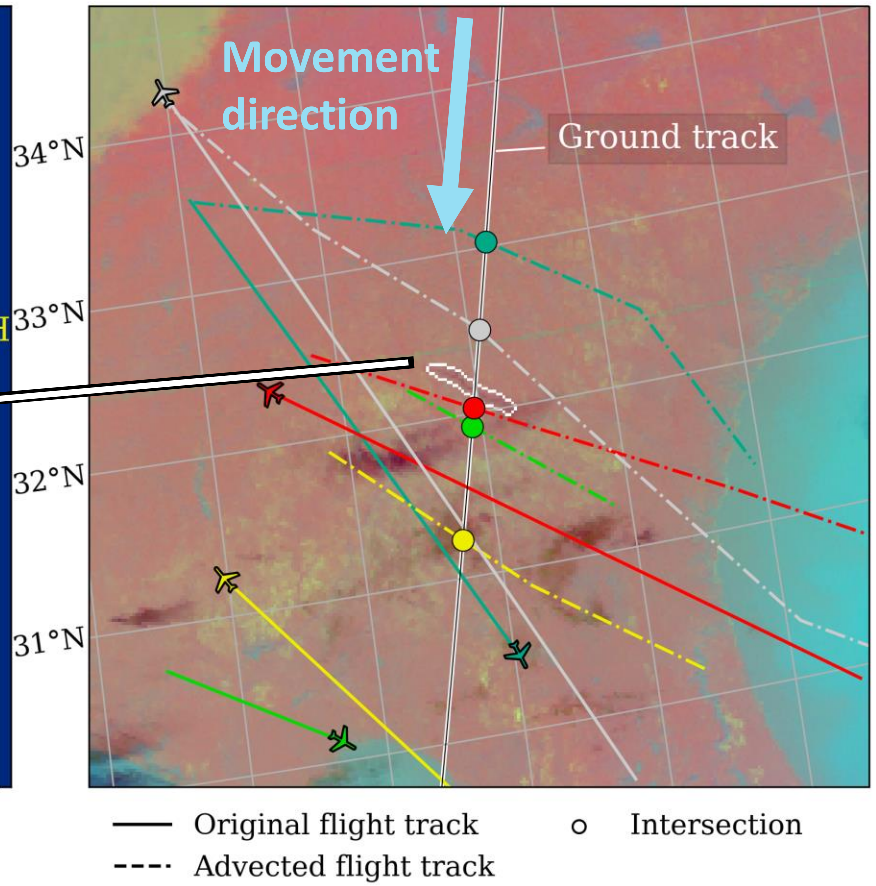
CALIOP data for flight attribution and NWP evaluation

- Intersect advected flight tracks with CALIOP data to
  - Match contrails with flights
  - Evaluate NWP performance

CALIOP L1 data



GOES-16 data, 07:35 UTC



Long-term perspective

- Expect the need for both observational and forecast approaches:
  - Observationally-informed PCC regions for the near-term (tactical, en route avoidance); numerical forecasts for the longer term (flight dispatch)
  - Hybrids and assimilation also possible over time

- Based on where we are now using only numerical forecasts unlikely to yield successful contrail avoidance – needs to be supplemented with observational information

- Observation + attribution will also be needed to verify the efficacy of contrail avoidance with high certainty

Current work

- Development of a contrail avoidance decision support tool (FAA funded) that incorporates these methods
- Trials with major US airline partners demonstrating observationally-informed and verified contrail avoidance
- Key technical components:
  - Algorithm for measurement of contrail radiative forcing from satellite data
  - Algorithm for attribution of contrails to specific flights
  - Height estimation algorithm

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