ASCENT Project 78

Contrail Avoidance Decision Support and Evaluation

MIT

PI: Steven Barrett

PM: Daniel Jacob

Objective:

- **Decision support tool** for aircraft routing to avoid formation of warming contrails by evaluating the **likely costs and benefits** of a contrail avoidance action.
- Evaluate the decision support tool under real-world conditions.

Project Benefits:

- **Rapid evaluation** of contrail formation and impacts for different strategies
- Demonstration of **practicality of contrail avoidance** to relevant stakeholders
- Directly advance **sustainable aviation**

Research Approach:

- Develop **software modules** as follows:
  - **Contrail forecasting** to predict contrail-forming conditions prior to and during flight
  - Real-time **contrail identification** in satellite images based on existing deep learning approaches
  - **Contrail radiative forcing** estimation based on recent work at MIT
  - **Trajectory planning** to forecast fuel burn and emissions for a spectrum of flight paths

Future work

- Combine into a **cost-benefit evaluation** tool designed for use on a flight-by-flight basis
- Develop and run **tests** for the tool

Major Accomplishments (to date):

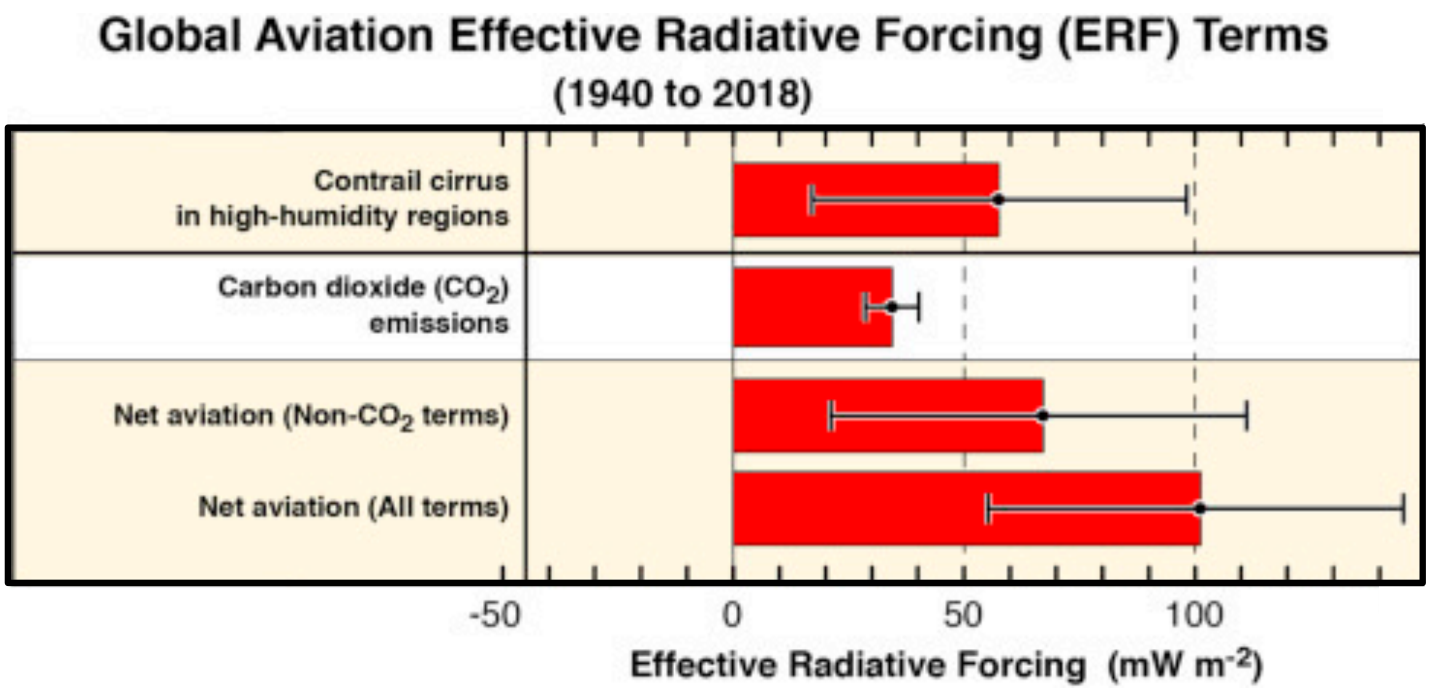
- Instantaneous contrail identification module completed
- Development of an empirical, probabilistic, near real-time estimate of upper atmospheric humidity based on satellite data and flight tracks
- Preliminary trajectory optimization approach developed using aircraft performance modeling

Future Work / Schedule:

- Contrail forecasting modules: *Summer 2022*
- Radiation module: *Fall 2022*
- Trajectory optimization module: *Spring 2023*

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 79 through FAA Award Number 13-C-AFJE-MIT under the supervision of Daniel Jacob. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

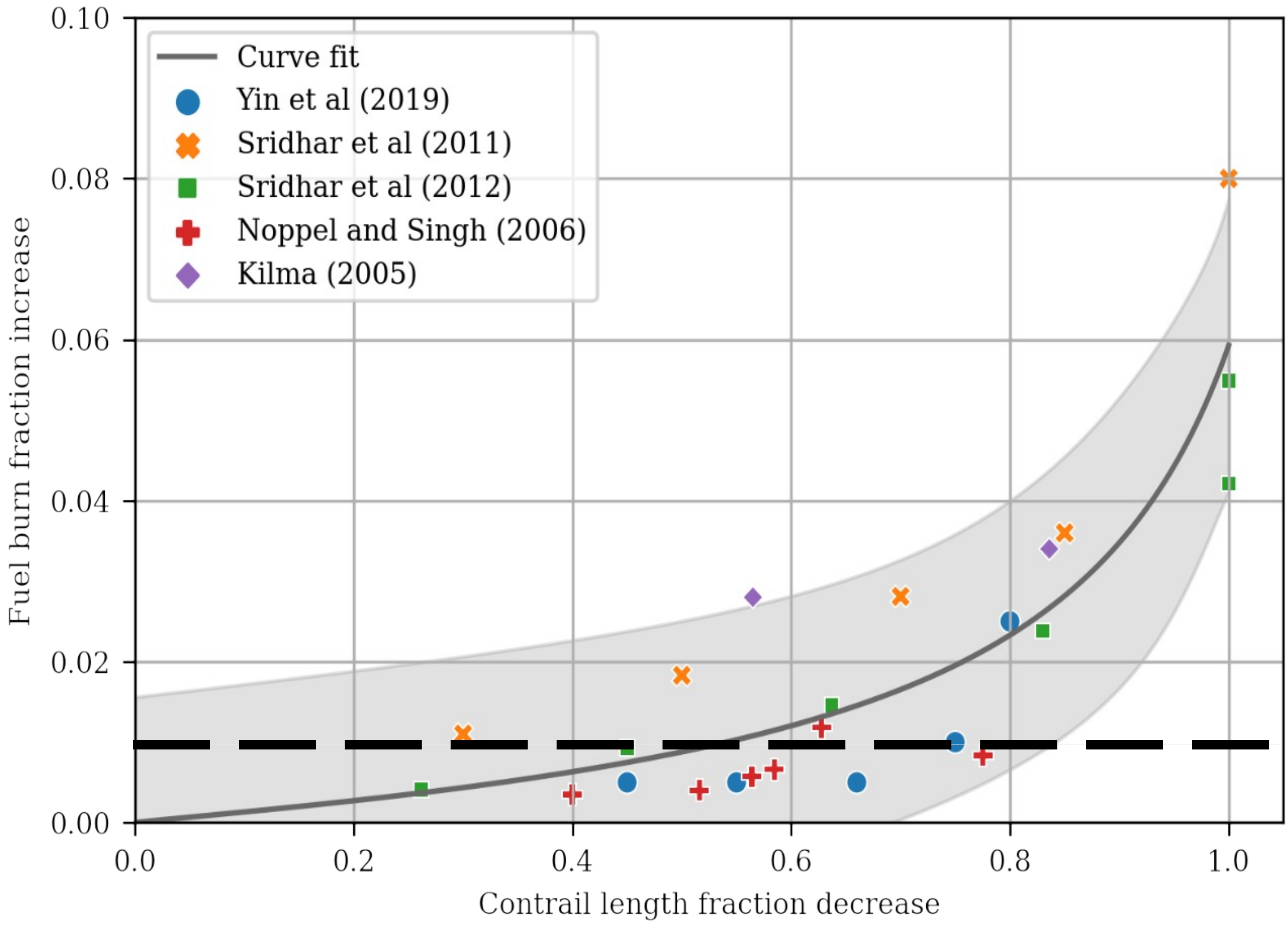
Contrails cause ~50% of aviation attributable climate impacts



- Contrails are consistently found to be one of the dominant contributors to aviation climate impacts
- Contrail avoidance may be a near-term option to reduce this impact substantially

*Lee et al., 2020

Theory: 50% of contrail avoidable for +1% fuel burn



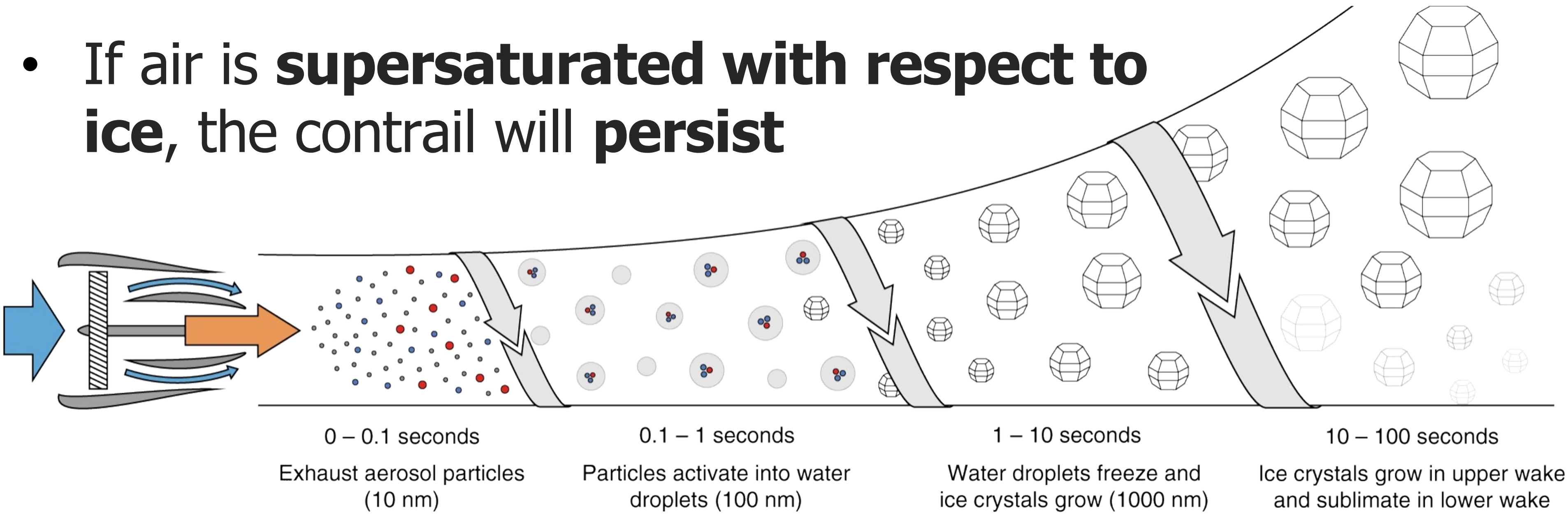
Turning theory into practice

A78 research needs for successful contrail avoidance

1. **Contrail forecasting module**
   Predict where contrails form and persist so that they can be avoided
2. **Contrail radiation module**
   Quantify how much climate benefit would result from avoiding the contrail
3. **Trajectory optimization module**
   Quantify how much climate penalty would result from the additional fuel burn
4. **Cost-benefit evaluation module**
   Perform empirical verification of the effectiveness of the action

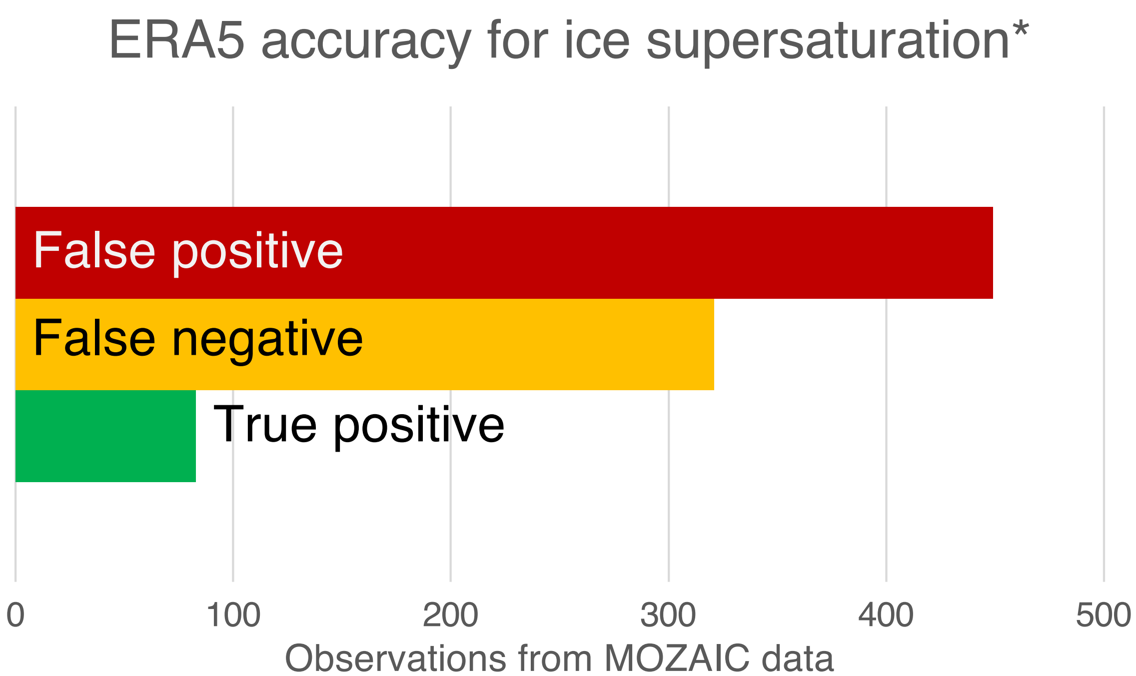
What needs to be avoided

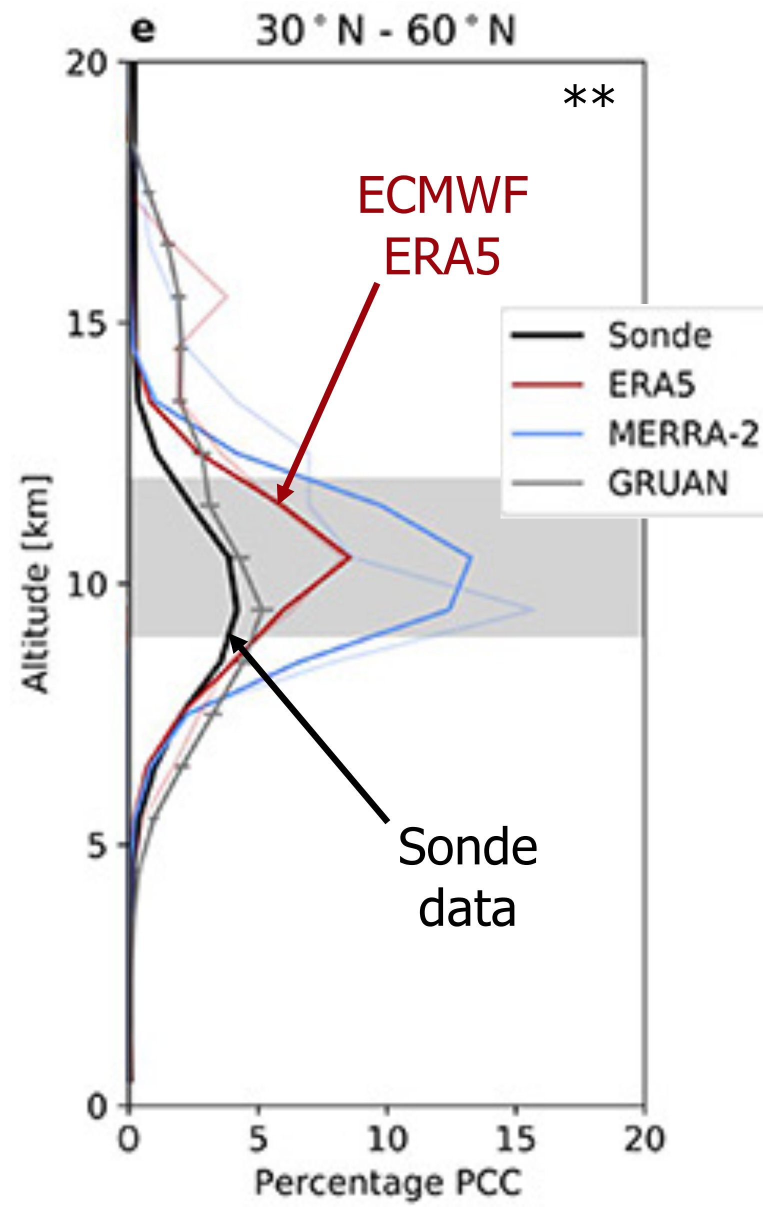
- If air is sufficiently **cold and humid**, a contrail will **form** (Schmidt-Appleman criterion)
- If air is **supersaturated with respect to ice**, the contrail will **persist**



Contrail formation can be avoided by avoiding flying through regions which satisfy both criteria – the **persistent contrail criterion (PCC)**

Forecasting the location of “contrail forming regions”



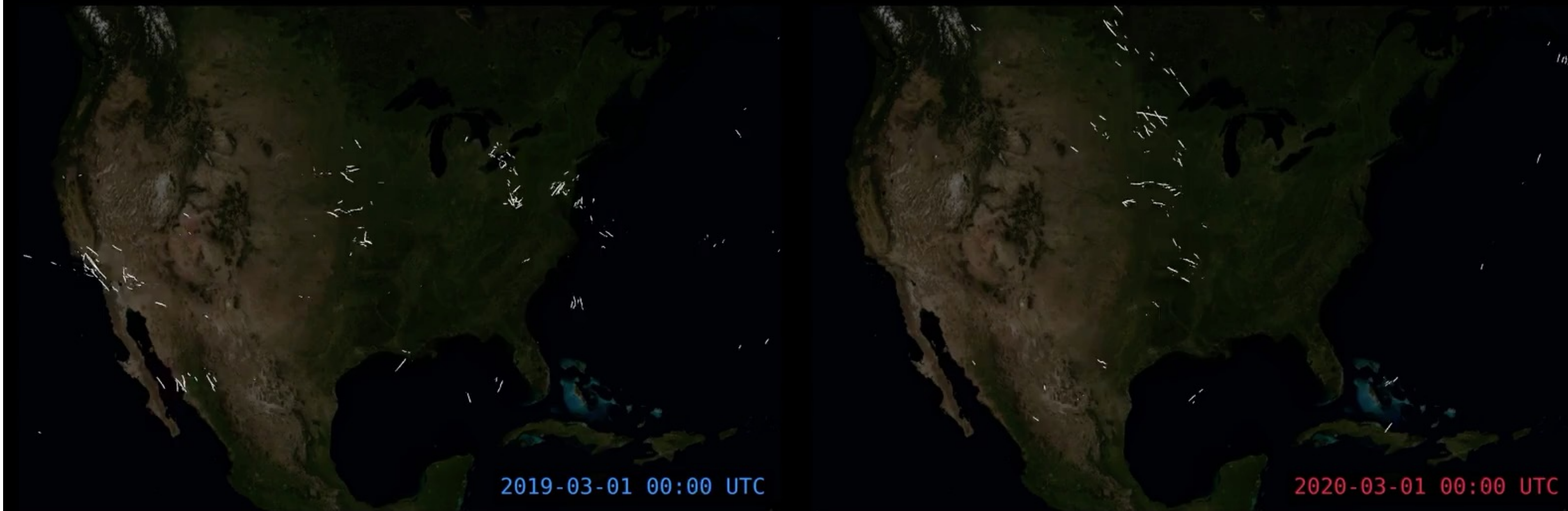


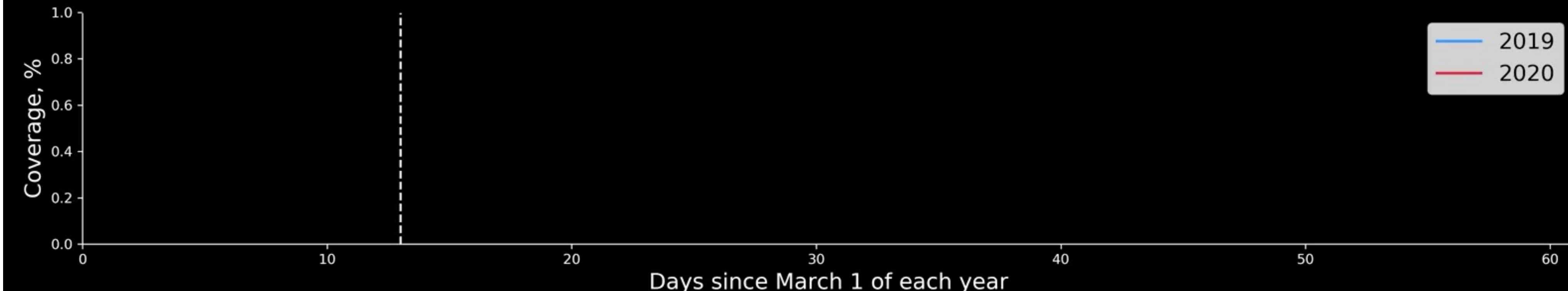
Studies comparing forecast humidity to observational data suggest a skill gap – further advances are needed for avoidance-relevant forecasts

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

Empirical estimation of contrail coverage: the COVID effect

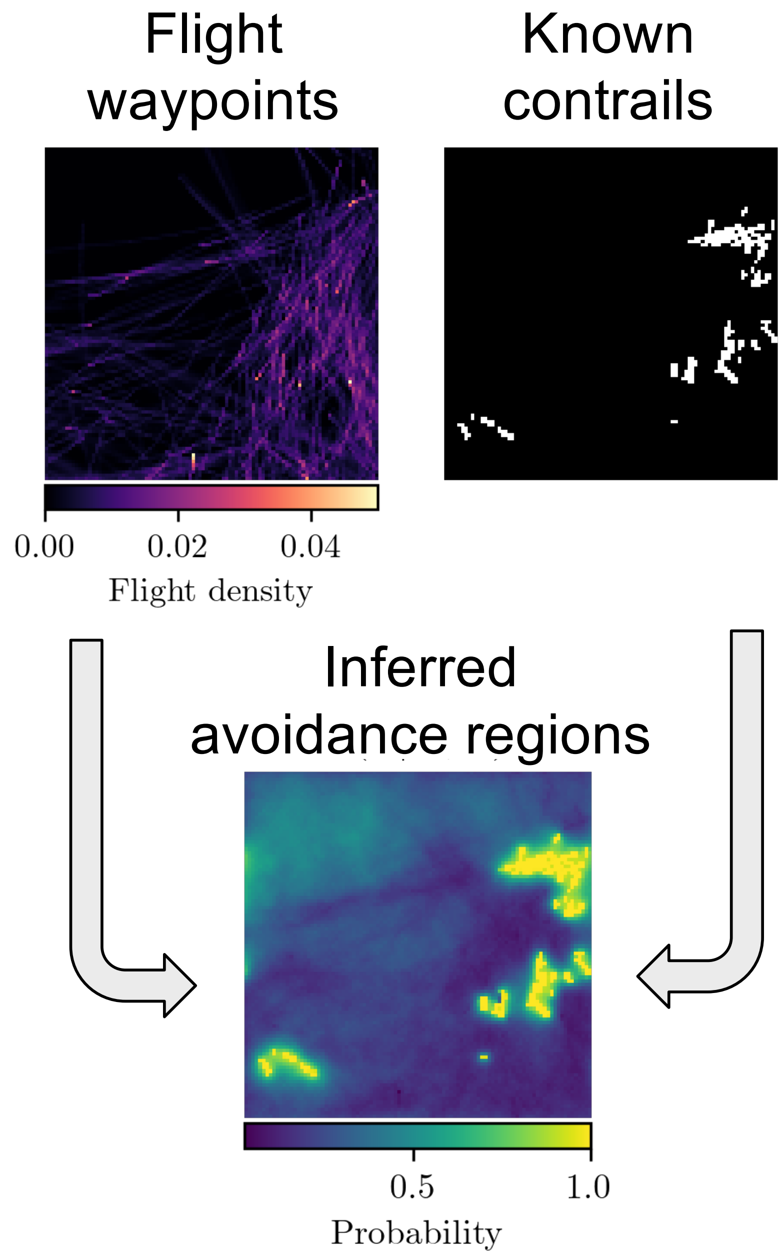
ASCENT
AVIATION SUSTAINABILITY CENTER





Empirical estimation of current contrail coverage

- Satellite observations of contrails show **known avoidance areas**
- Flights which did not result in contrail indicate **known “dry” areas**
- The combination of this data supports both nowcasting and potentially advances in forecasting



Next steps

Contrail nowcasting

- Incorporate Kalman filtering to improve contrail identification
- Evaluate empirical humidity estimation against observations
- Extend the approach to nowcasting using advection modeling and physical constraints on humidity

Developing an operational avoidance tool

- Improve trajectory optimization module to provide accurate fuel burn estimation
- Develop empirically-grounded estimate of contrail radiative forcing
- Merge fuel burn and contrail impacts into cost benefit calculation
- Integrate all sub-tools into a single operational tool

Project team

MIT AeroAstro:
Steven Barrett, Sebastian Eastham, Florian Allroggen, Ray Speth, Jad Elmourad

FAA PM: Daniel Jacob