Center for Air Transportation Systems Research

Operationalizing Contrail Avoidance (Virtual) Workshop

FRAMING THE WORKSHOP

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Workshop Purpose

Begin the dialog in the air transportation community about contrail avoidance

- Scientists continue to work to reduce the uncertainty in the magnitude of the contrail contribution to climate change
- What additional information is needed to develop a mitigation approach?
- What incentives/policy changes may be required?
- What operational changes need to be implemented

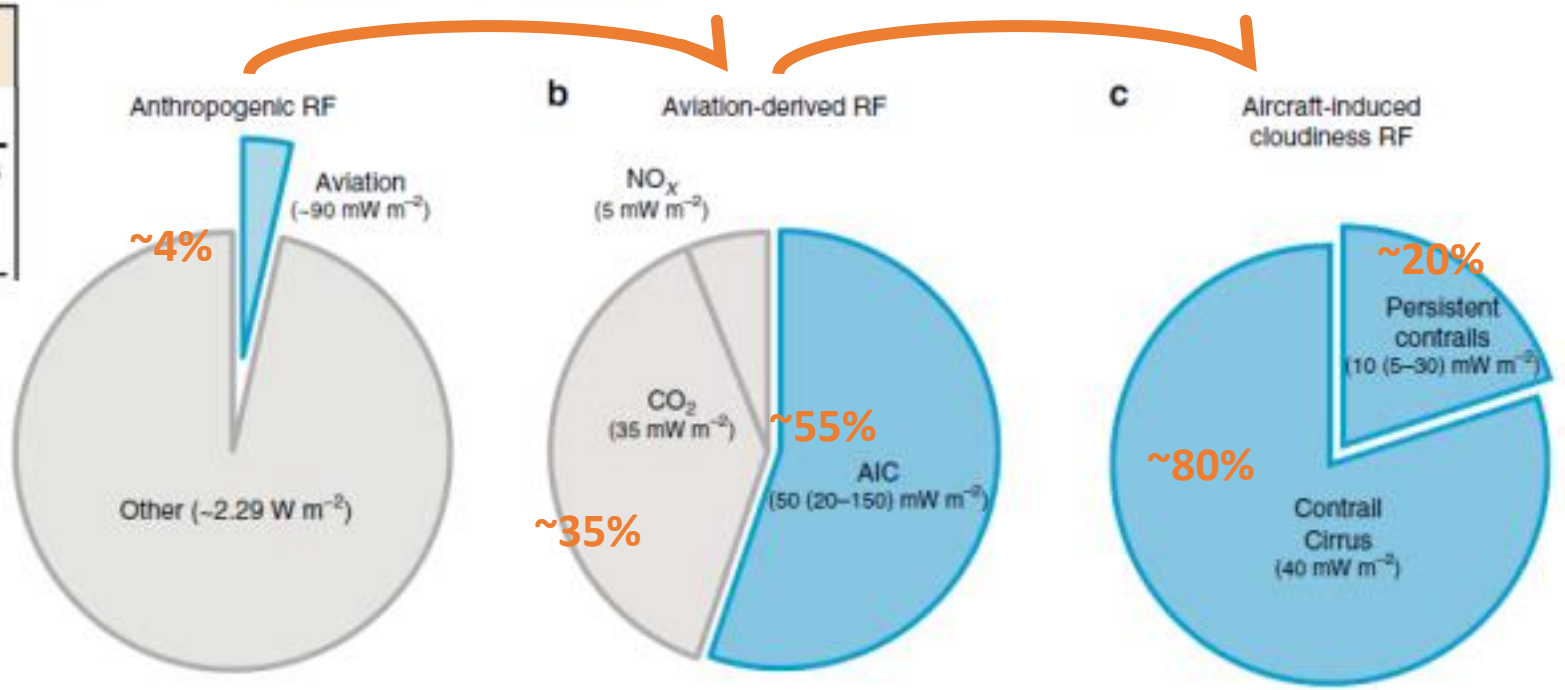
Dialog will inform NASA's aeronautics research plans

Aviation Contribution to Radiative Forcing

Kärcher, Formation and radiative forcing of contrail-cirrus, Nature Communications, 2018

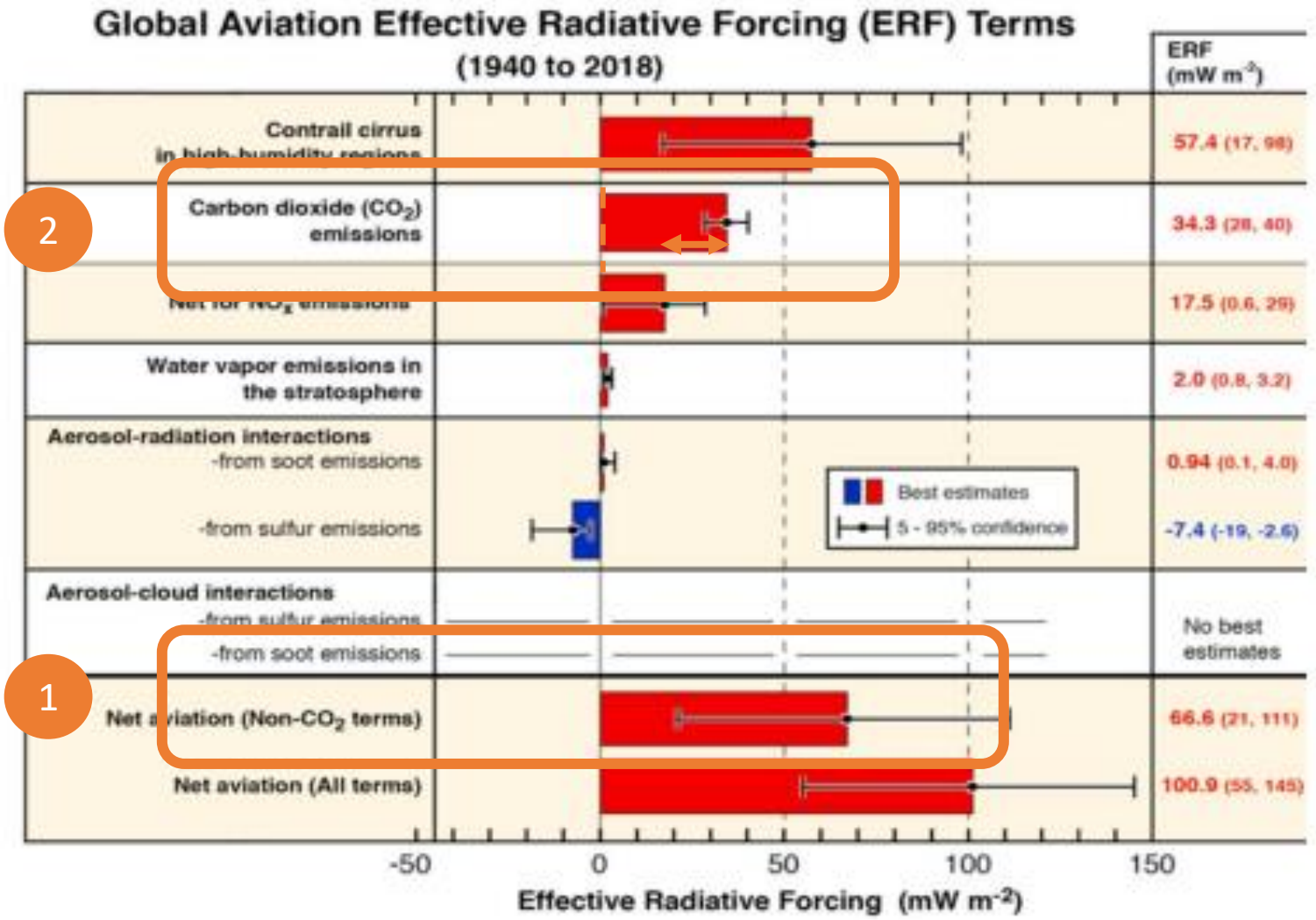
Table 1 Characteristics of contrails and contrail cirrus

AIC	Short-lived	Long-lived	
Ice cloud type	Contrail	Persistent contrail	Contrail cirrus
RF potential	Negligible	Small	Large



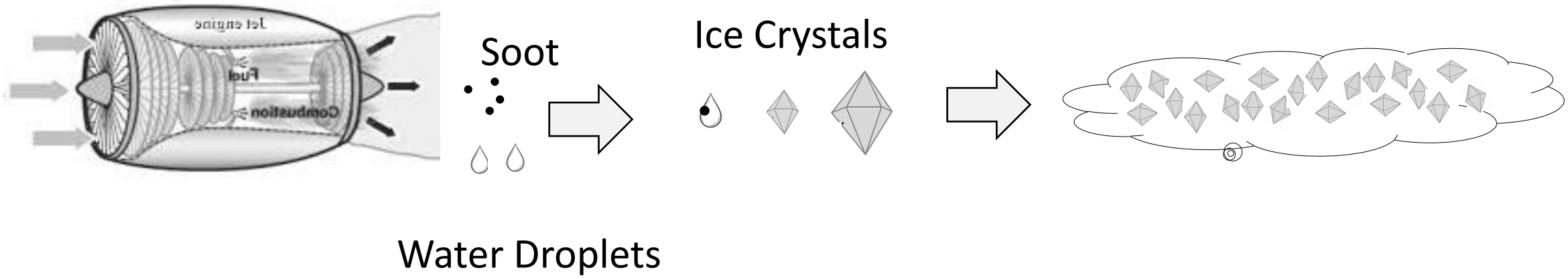
Aviation Radiative Forcing (Uncertainty)

Lee et al., Atm Env, 2021

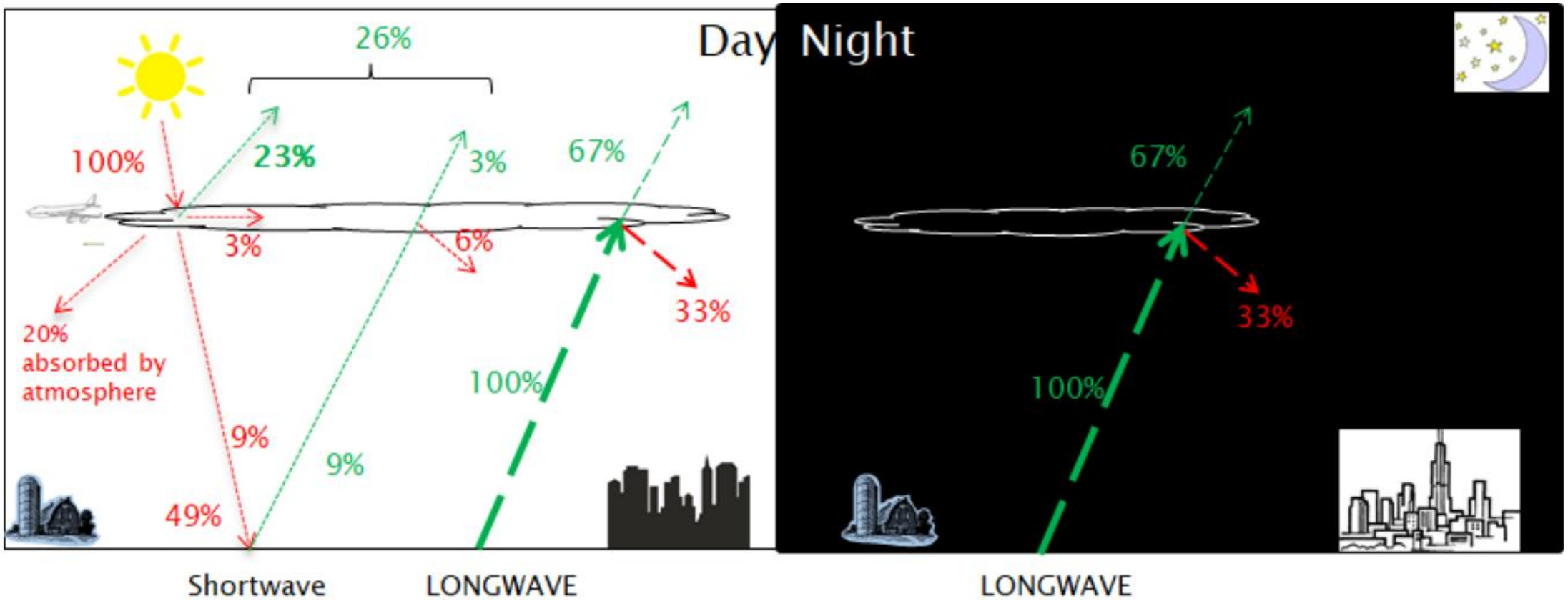


How Anthropogenic Ice Clouds are Formed

$$C_{10}H_{22} + 15.5\ O_2 + 3.76\ (15.5N_2) \rightarrow 11H_2O + 10CO_2 + 3.76(15.5N2) + 10.6\ kcal/g$$



Net Radiative Forcing from (Ice) Clouds



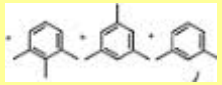
Contrails scatter/absorb/reflect back to Earth 33% outgoing "thermal" radiation

ERF Value Chain

Fuel Source, Feedstock


Fuel Production

Fuel Design & Test



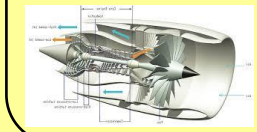
Fuel Additives Design & Test

Fuel Standards

Fuel Distribution and Storage

Fuel Properties
- *Sulphur Content*
- *Aromatic Content*
- *Hydrogen Content*

Propulsion System Design



Engine Design
- *Air-to-Fuel Ratio*

Propulsion System Chemistry

Soot

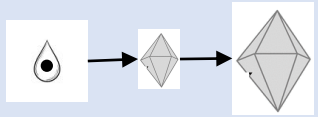
Water Droplets

Aircraft Design
- *Reduced Drag*
- *Reduced Weight*

Emissions Properties
- *Water Vapor*
- *Soot*
- *Soot Count*
- *Soot Size*
- *Emission Temp*

Atmospheric Properties
- *Ambient Temp*
- *Ambient Relative Humidity*
- *Ambient Pressure*

Contrail Formation Physics



- *Ice Crystal Size*
- *Ice Crystal Density*

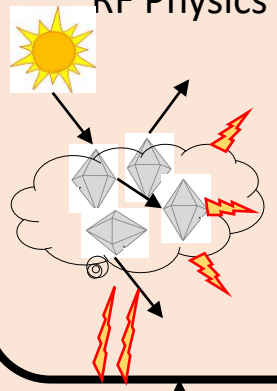
- *Aircraft 3-D Trajectory*

Airline/ Air Traffic Control Flight-planning

Solar Radiation

- *Wavelength*
- *Intensity*
- *Sun Zenith Angle*
- *Sun Elevation Angle*
- *Sun Declination*

RF Physics

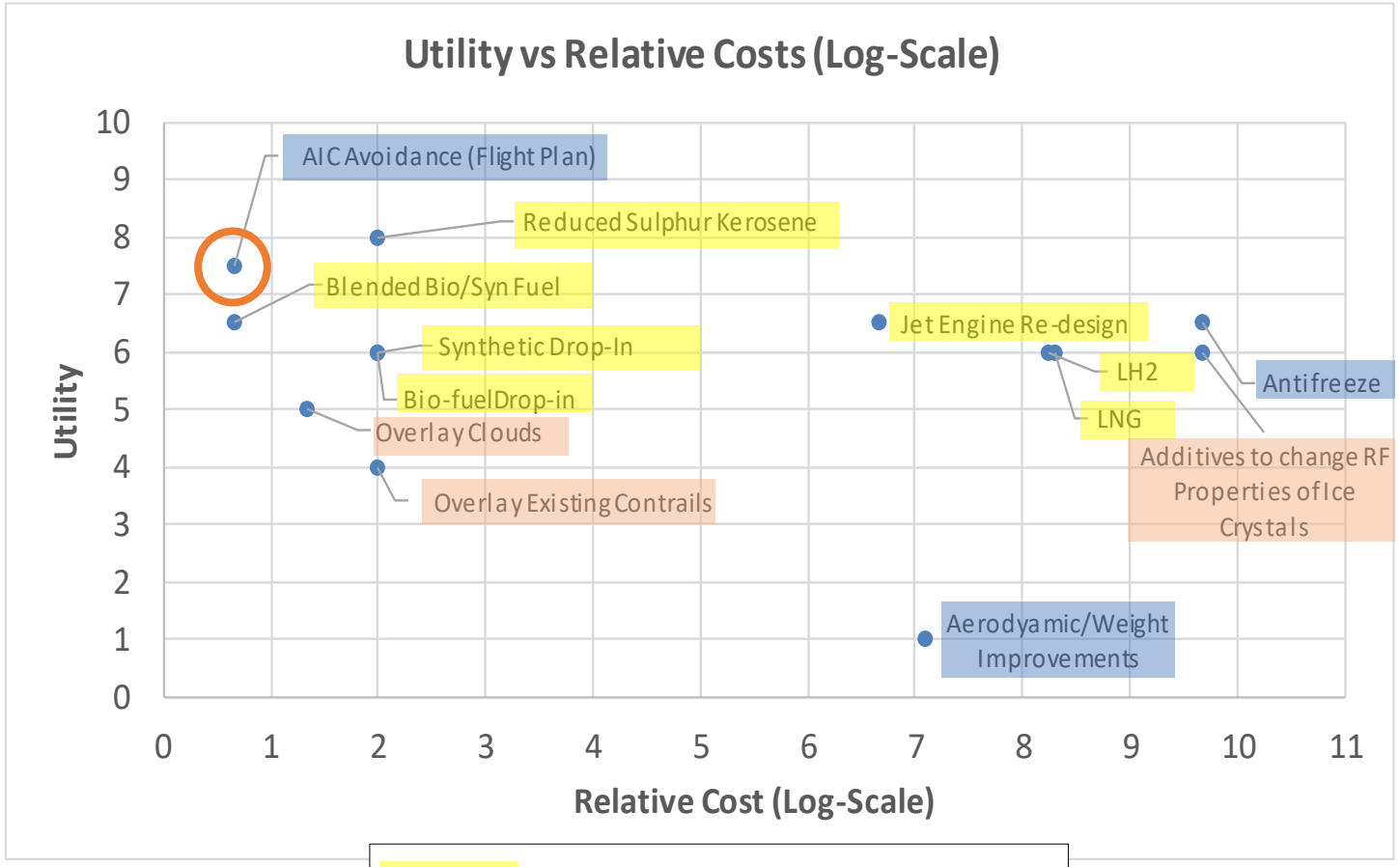


Net RF

- *Wavelength*
- *Intensity*

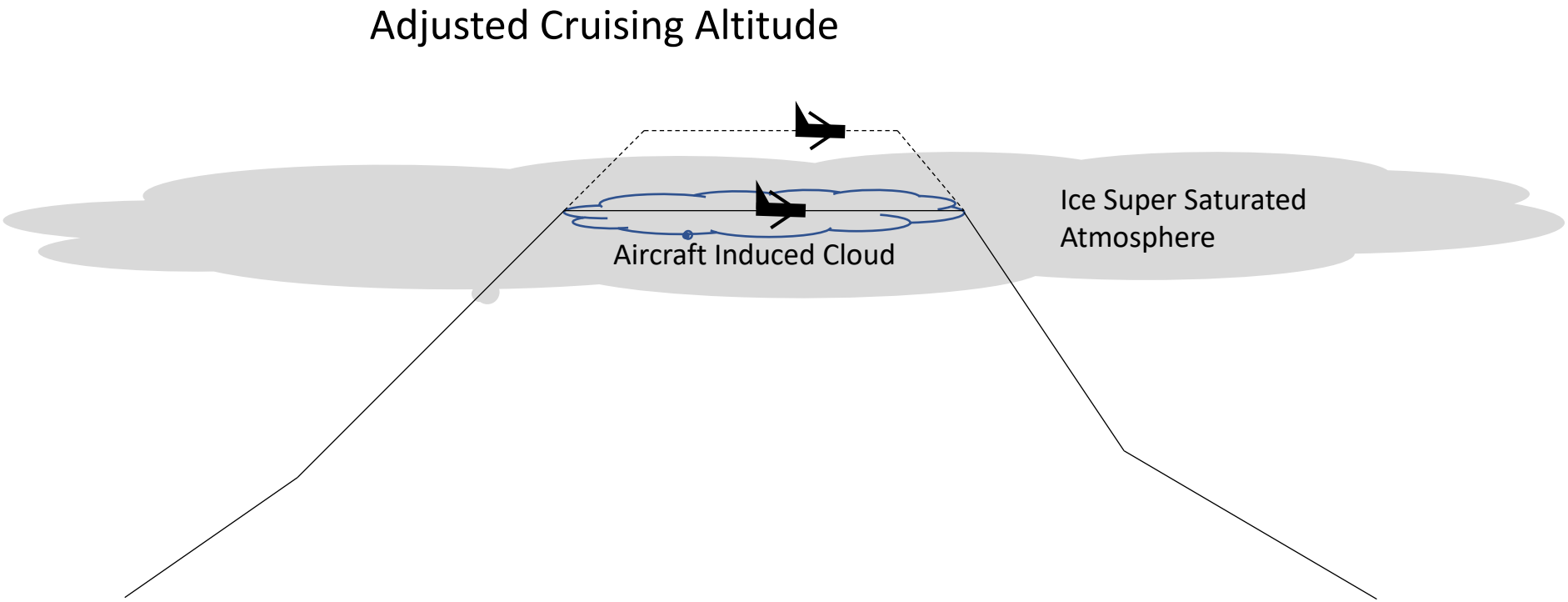
Thermal Radiation

Contrail Mitigations Alternatives



Sherry L, Thompson T. Primer on Aircraft Induced Clouds and Their Global Warming Mitigation Options. *Transportation Research Record*. 2020;2674(11):827-841

Contrail Avoidance by Flight Planning
(Navigational Avoidance)



Contrail Avoidance

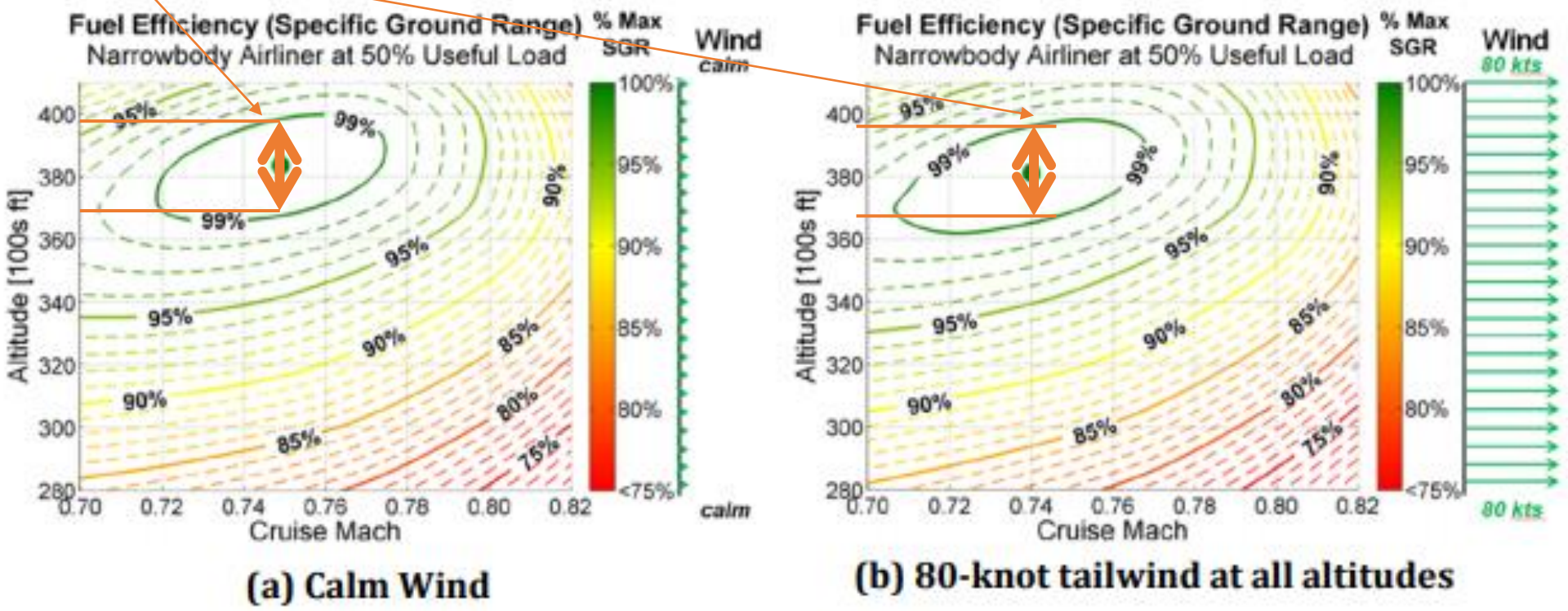
Analysis US Airspace (2017)

- Contrails are generated by only avg. 15% of the daily flights (max 34%).
- Location of contrails depends on atmospheric conditions (ISSRs)
  - south-eastern and mid-Atlantic region
  - Pacific Coast.
- Contrail formation avoided by increasing the Cruse Flight Level by between 2000’ and 4000’ feet
- Due to low air density at Cruise Flight Levels, the additional fuel burn required to climb to the higher cruising altitude is mitigated by reduced fuel burn due to reduced Drag at the higher altitude.

Denis Avila, Lance Sherry, Terry Thompson (2019)
Roger Teoh, Ulrich Schumann, Arnab Majumdar, and Marc E. J. Stettler (2020)
Rosenow J, Fricke H, Luchkova et al. (2018)

Additional Cost of Crz FL Change

Flexibility in Crz FL



Sorenson (1987)
Jensen, Hansman (2014)

Assumptions & Questions

Assumptions

- Magnitude of ERF Contrails *is* Significant
- Magnitude of ERF from Contrails significant impact on Earths Temperature Structure
- Navigational Avoidance of Contrails is pursued

Questions

- Process and Tools for Flight Planning for Contrail Avoidance?
  - ISSR Forecast accuracy?
  - Contrail Formation and Persistence Model accuracy?
  - Fuel-burn, CO2, NOx trade-offs?
- Airspace complexity, congestion?
- Compliance, Verification?
- Incentives?