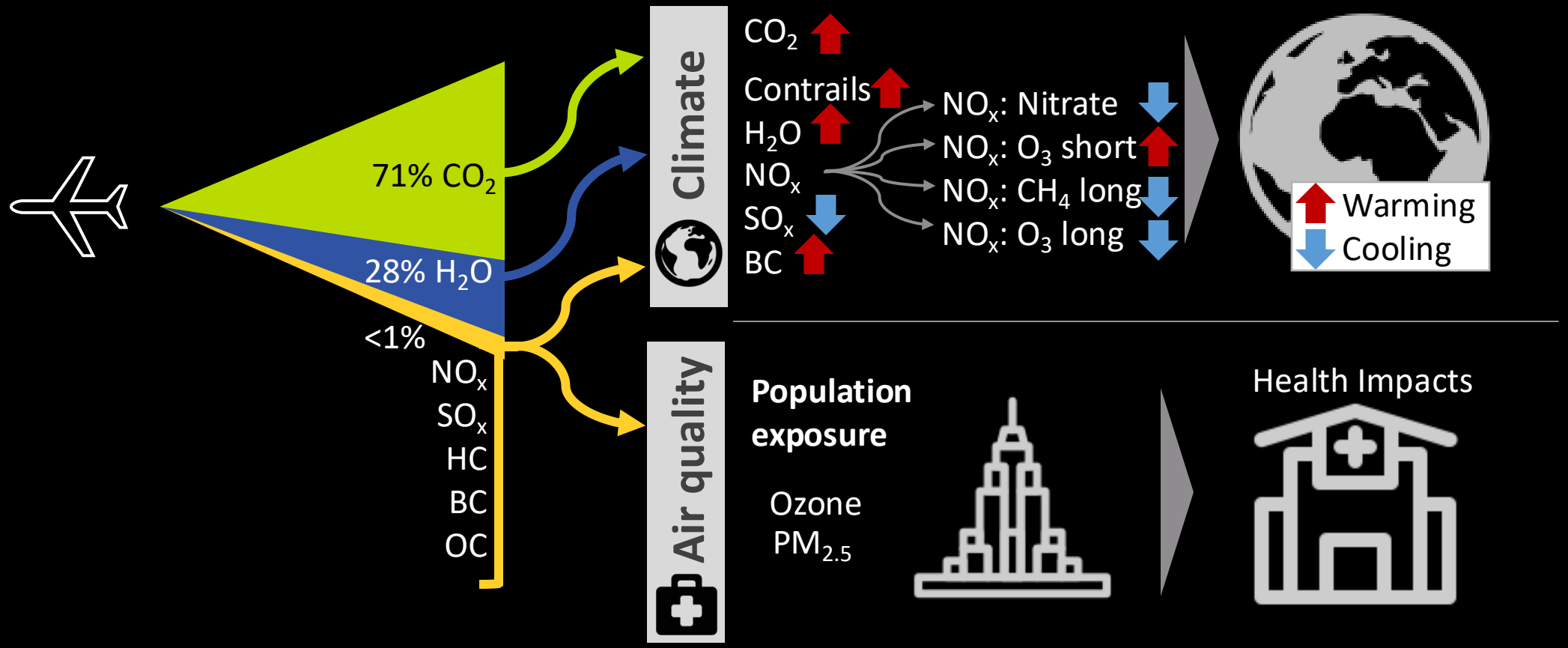
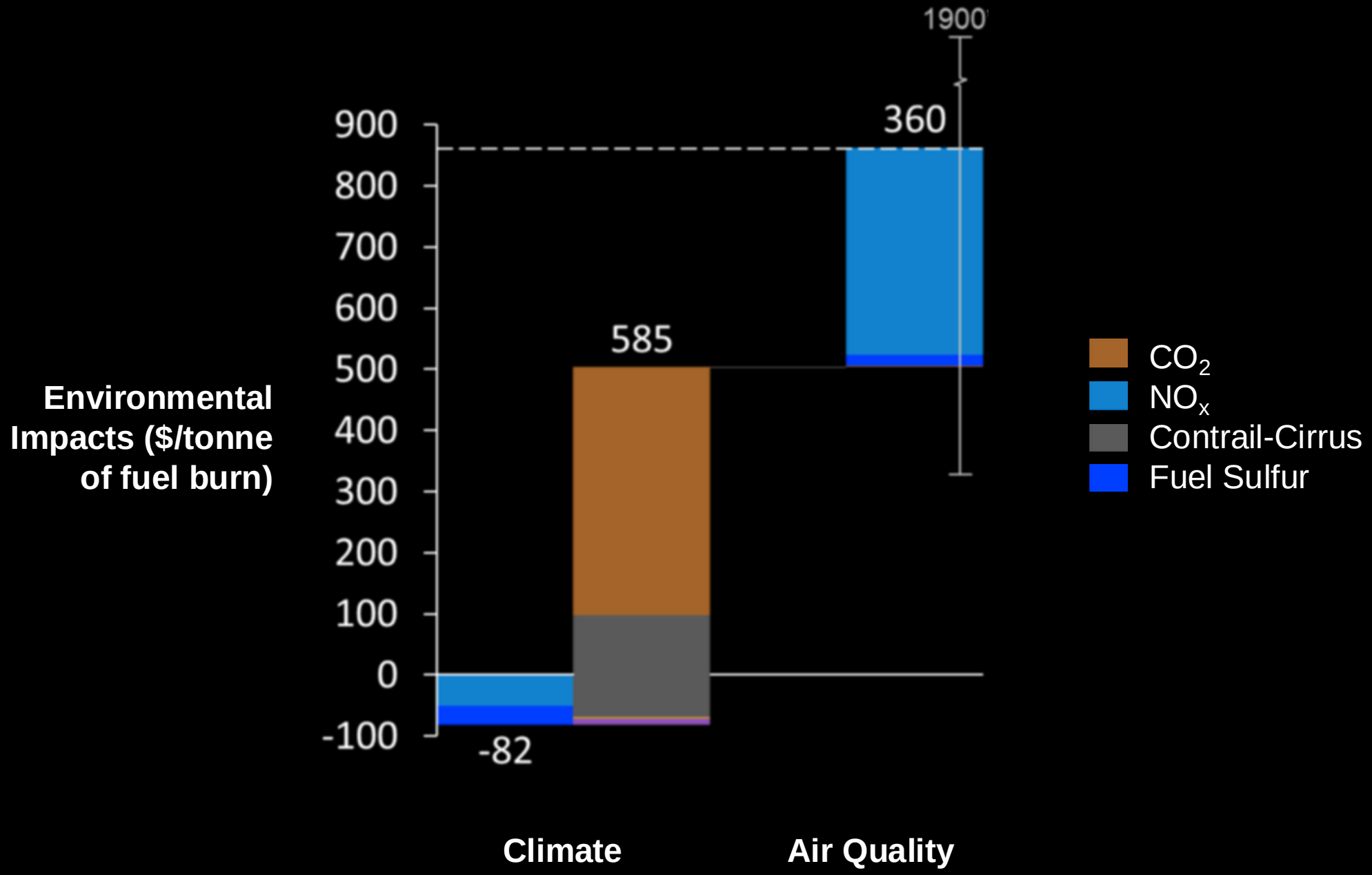
4A7 Aviation and the Environment

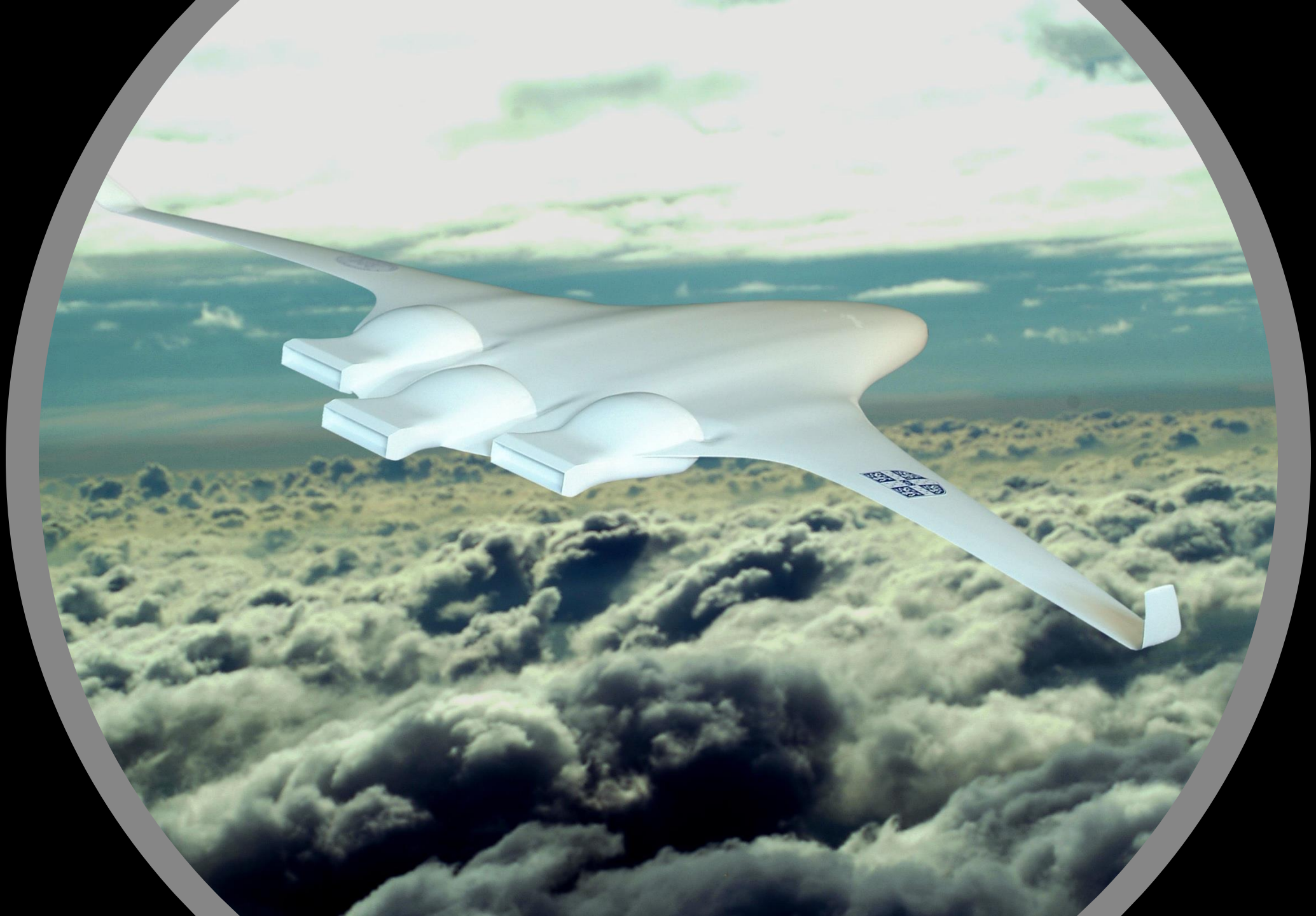
Lecture 1 Introduction

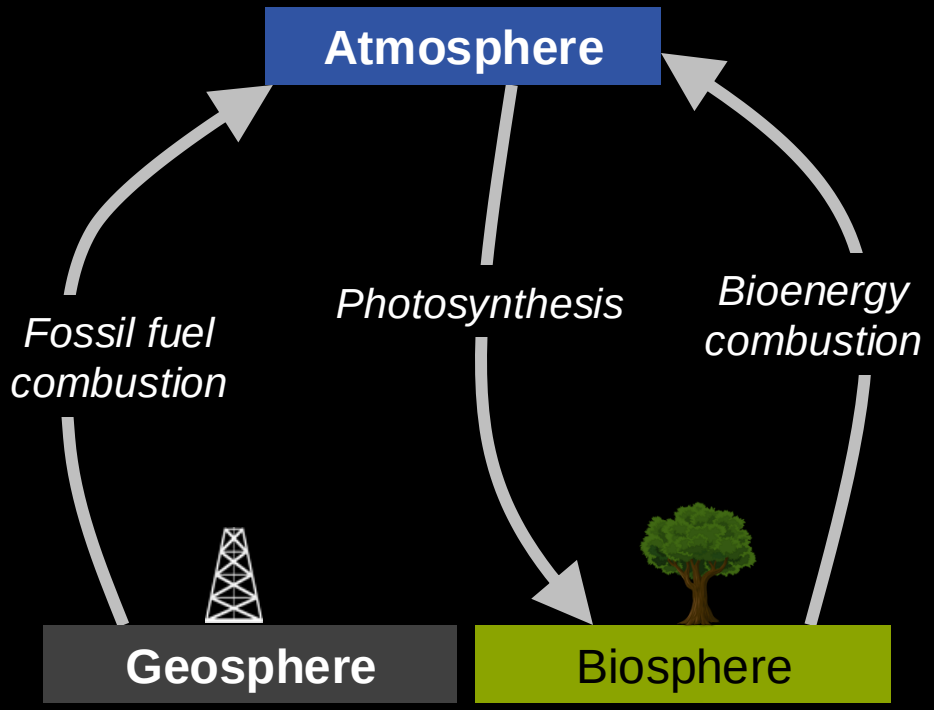
Steven Barrett
Regius Professor of Engineering
University of Cambridge

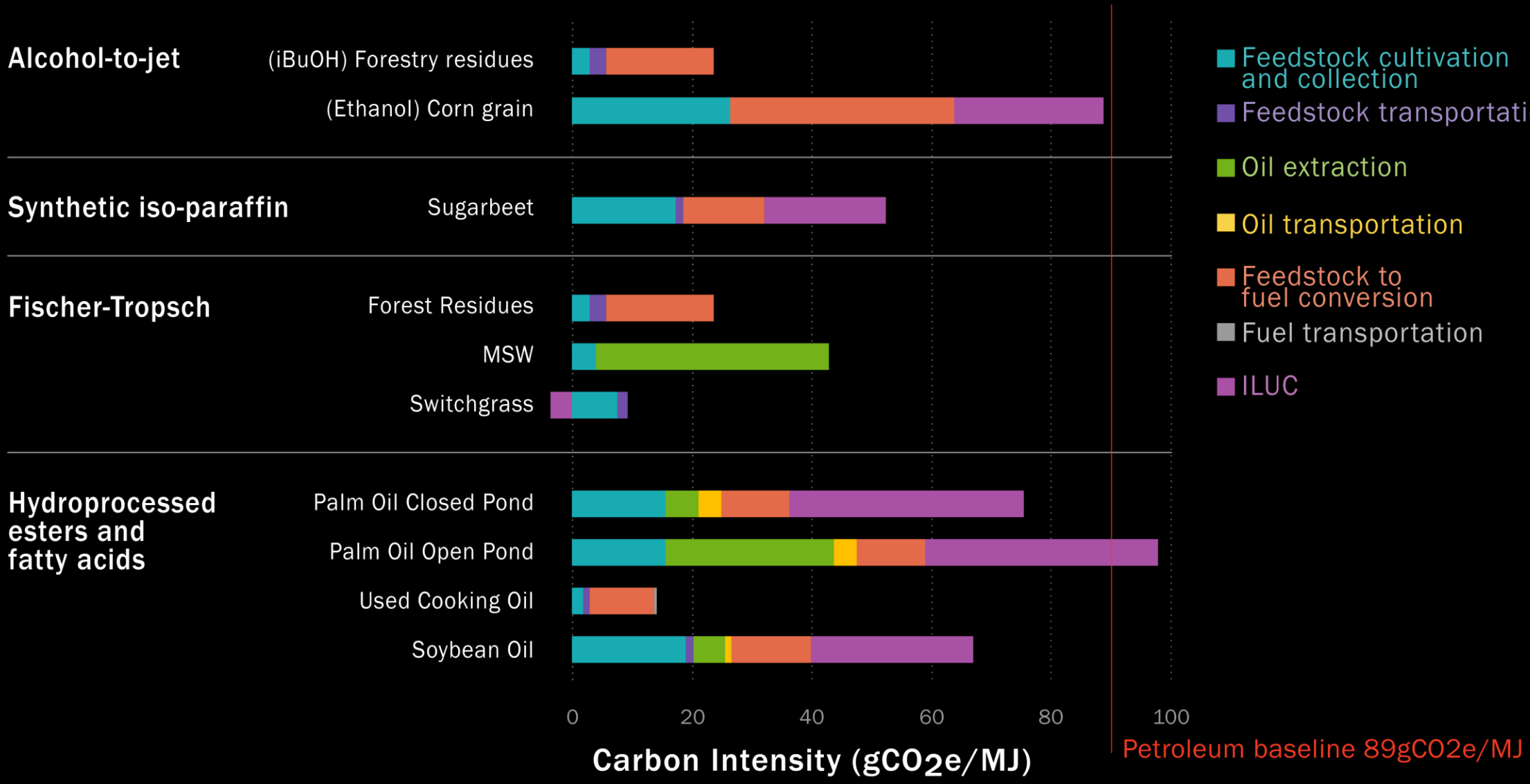

71% CO_2
28% H_2O
<1%
NO_x
SO_x
HC
BC
OC
Climate
CO_2
Contrails
H_2O
NO_x
SO_x
BC
NO_x: Nitrate
NO_x: O_3 short
NO_x: CH_4 long
NO_x: O_3 long
Warming
Cooling
Air quality
Population exposure
Ozone
$PM_{2.5}$
Health Impacts

Lee et al. (2020)


Environmental Impacts ($/tonne of fuel burn)
900
800
700
600
500
400
300
200
100
0
-100
585
-82
360
1900
CO_2
NO_x
Contrail-Cirrus
Fuel Sulfur
Climate
Air Quality




Atmosphere
Fossil fuel combustion
Photosynthesis
Bioenergy combustion
Geosphere
Biosphere


Alcohol-to-jet
(iBuOH) Forestry residues
(Ethanol) Corn grain
Synthetic iso-paraffin
Sugarbeet
Fischer-Tropsch
Forest Residues
MSW
Switchgrass
Hydroprocessed esters and fatty acids
Palm Oil Closed Pond
Palm Oil Open Pond
Used Cooking Oil
Soybean Oil
0
20
40
60
80
100
Carbon Intensity (gCO2e/MJ)
Feedstock cultivation and collection
Feedstock transportation
Oil extraction
Oil transportation
Feedstock to fuel conversion
Fuel transportation
ILUC
Petroleum baseline 89gCO2e/MJ

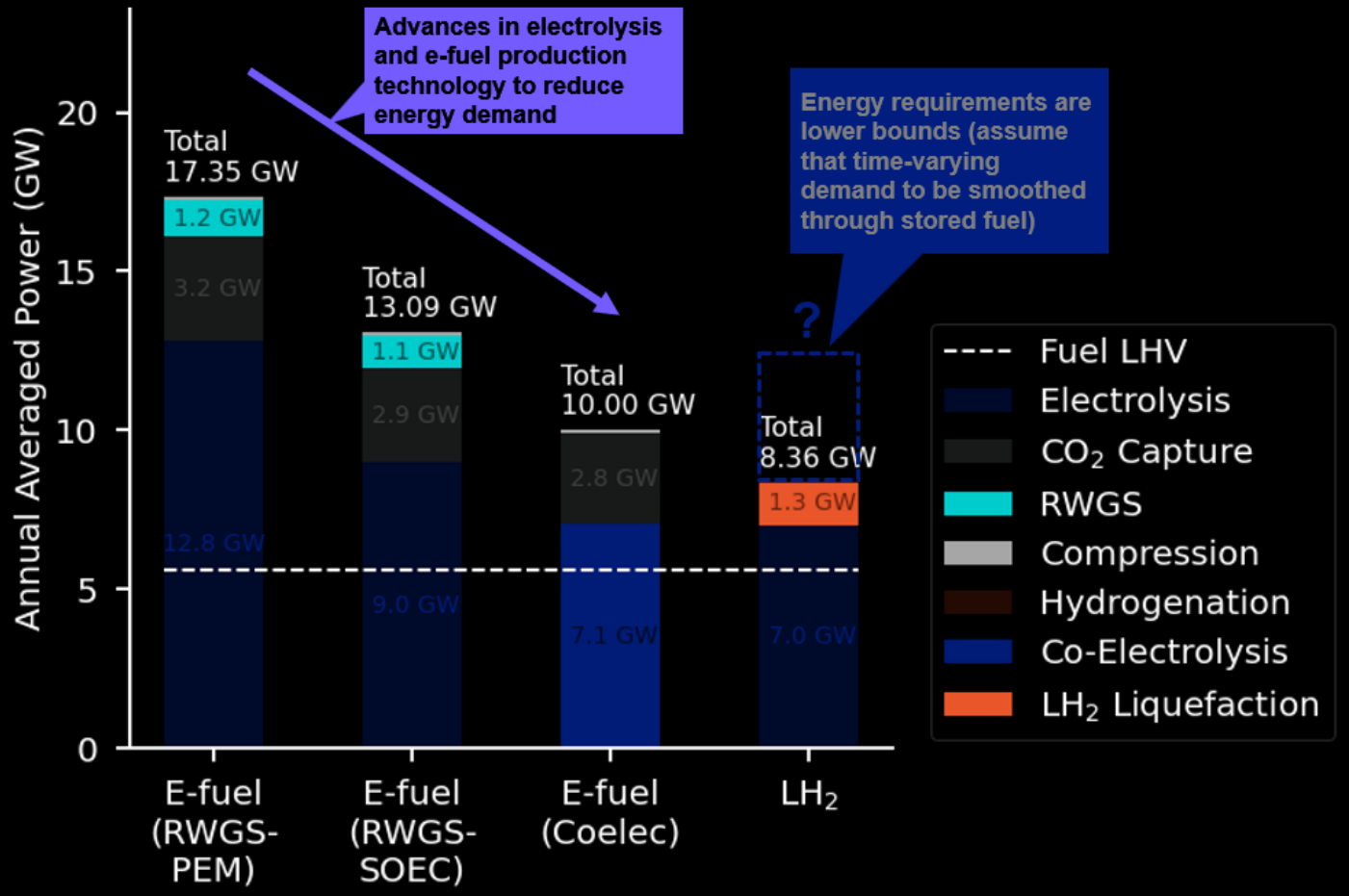
Decarbonization beyond biomass-derived SAF:

1. Direct air capture routes
2. Carbon-free fuels

Example: fueling CDG with PtL

Electric power consumption of fuel production

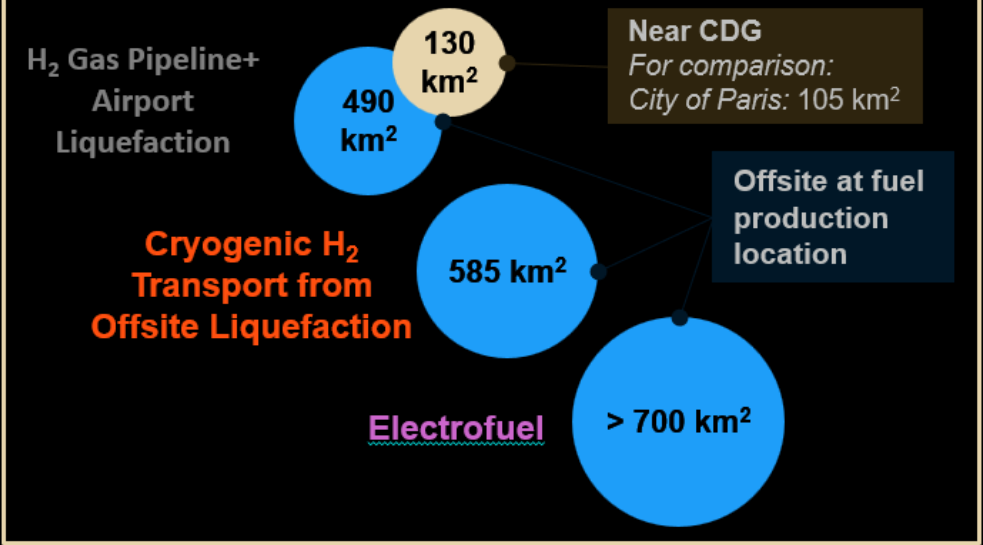
broken down by process step, in GW



For comparison:

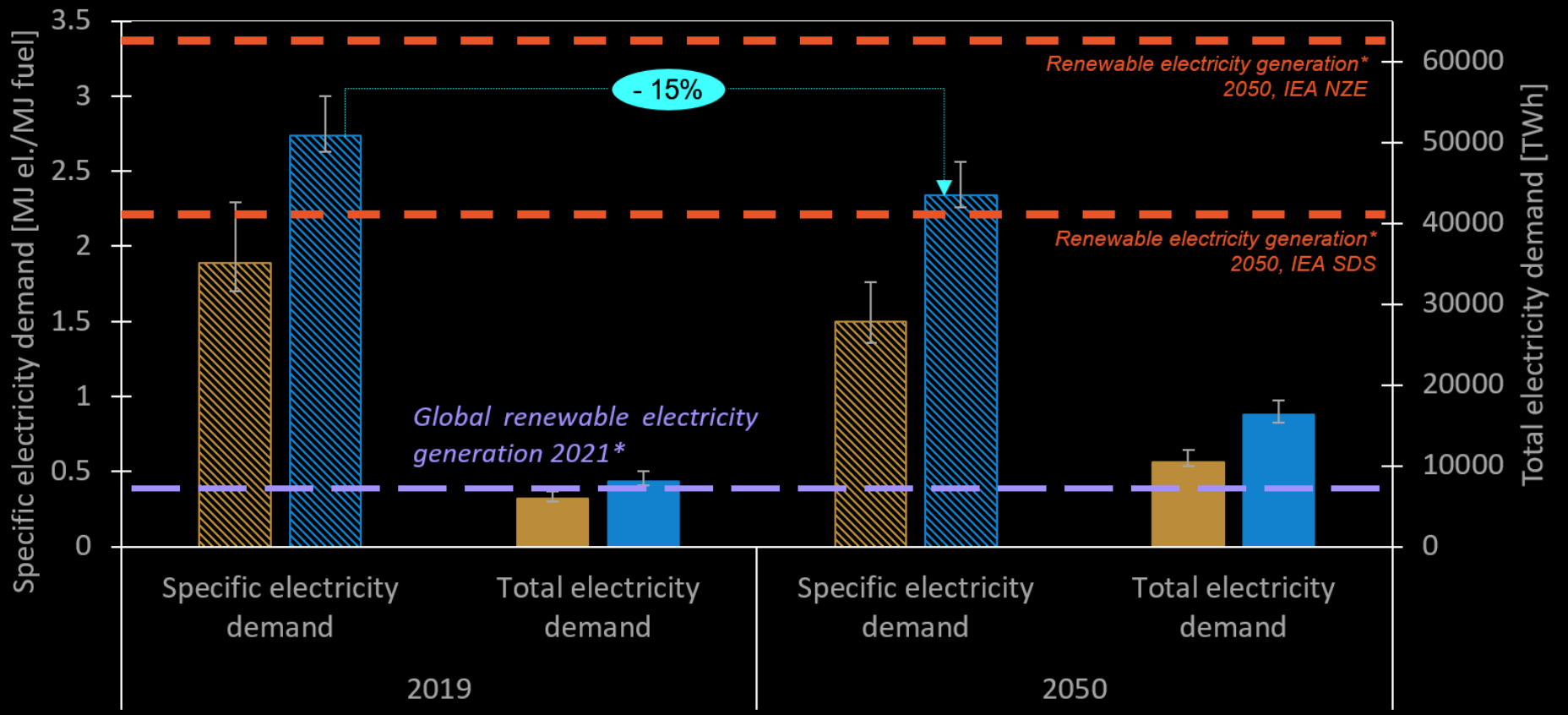
French total installed capacity	~133 GW
Largest nuclear plant in the world (capacity)	~7 GW
Largest solar power plant (capacity)	~2.2 GW

How much land is needed to produce LH_2 using renewable solar?

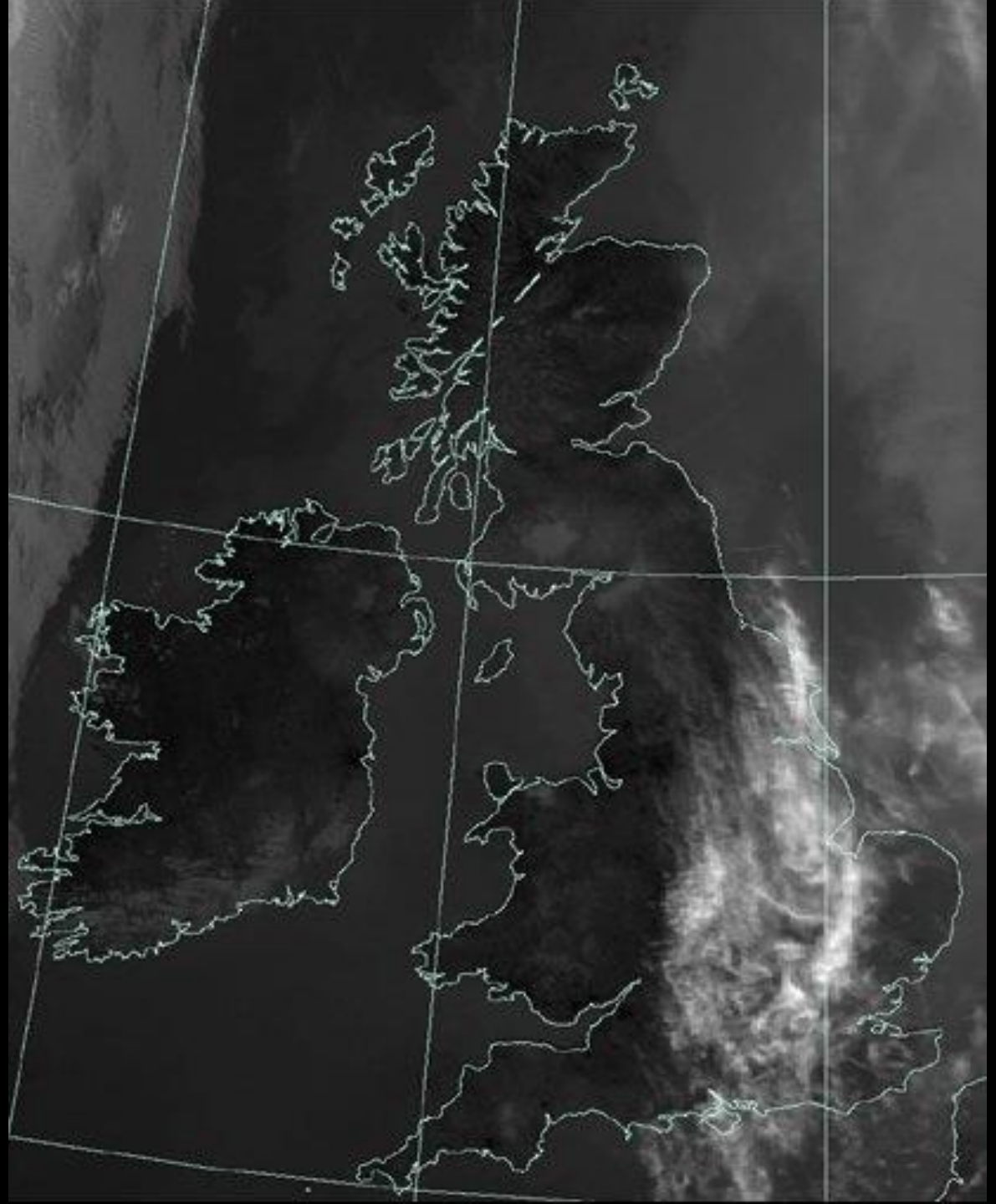


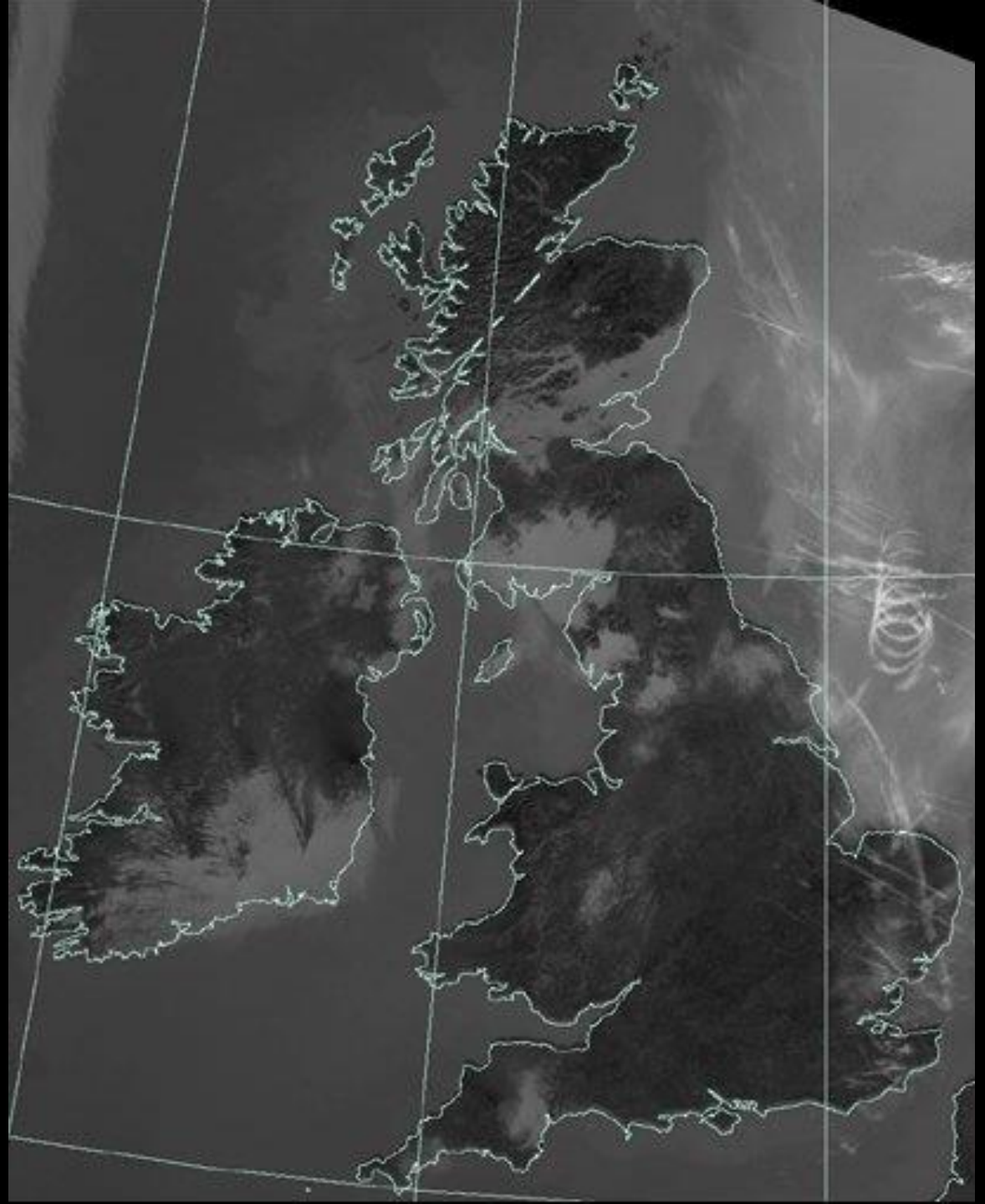
Specific energy demand and year-2019 & 2050 fuel replacement with PtL & LH_2

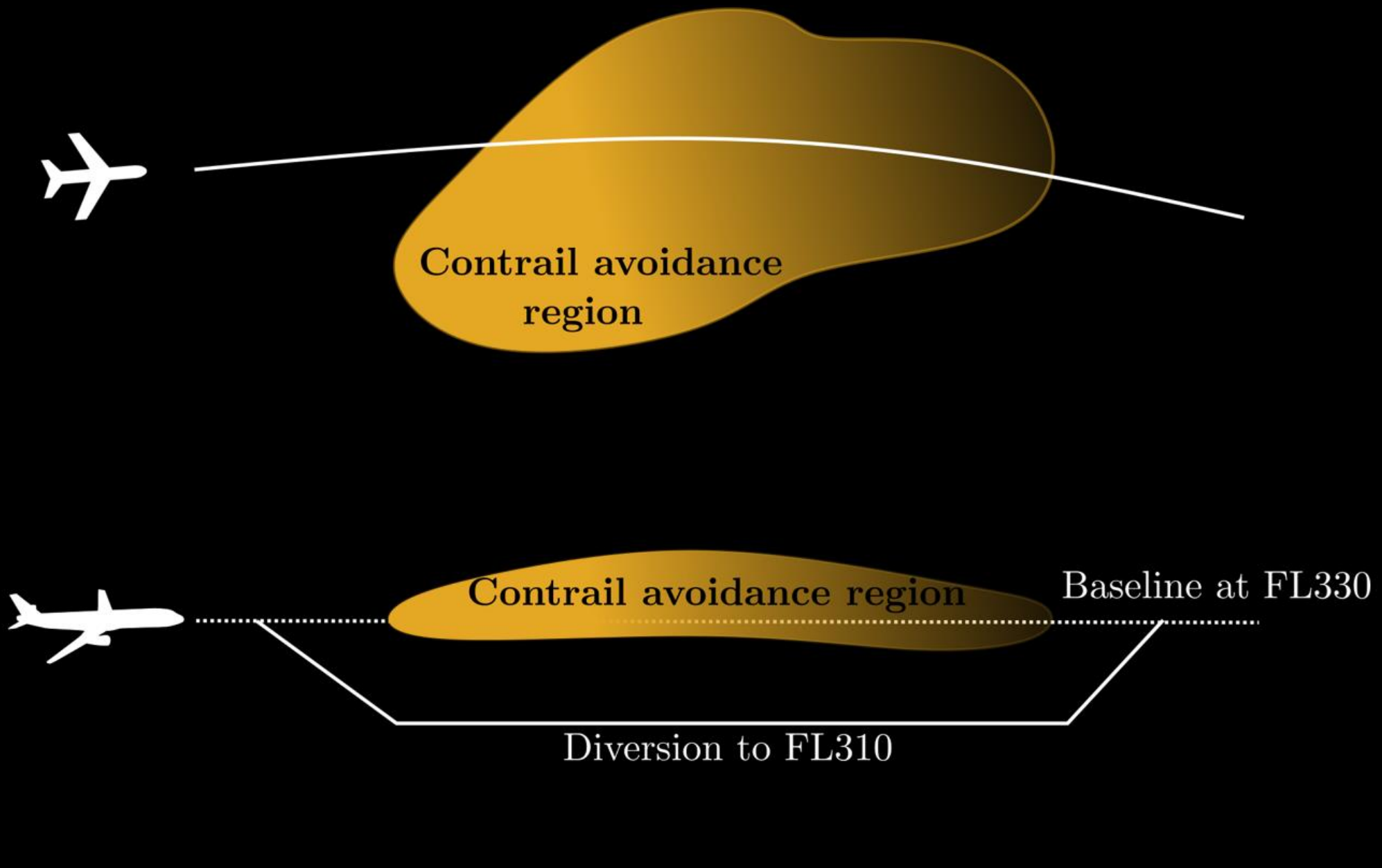
Specific energy demand in MJ (elec)/MJ(fuel), total electricity demand in TWh

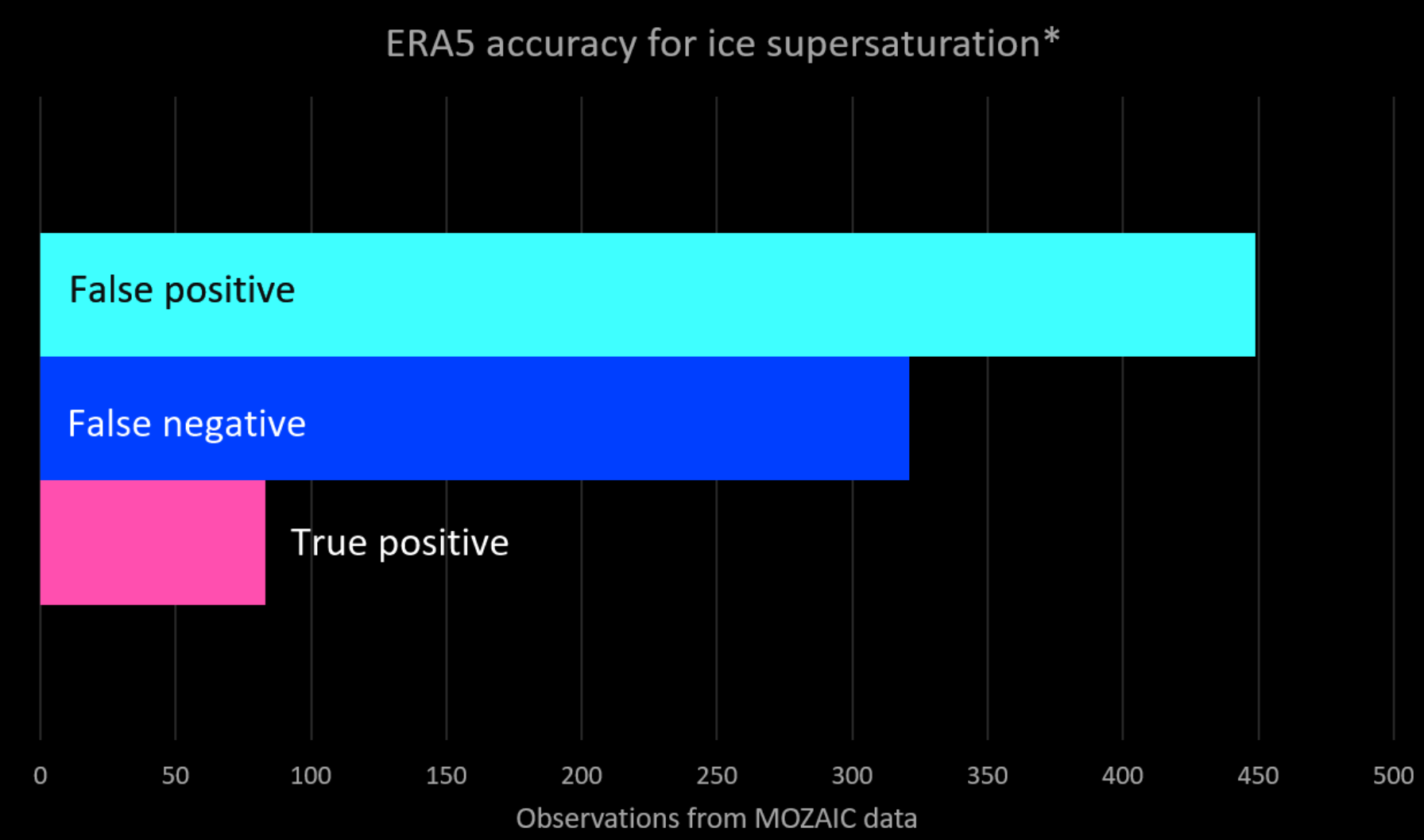


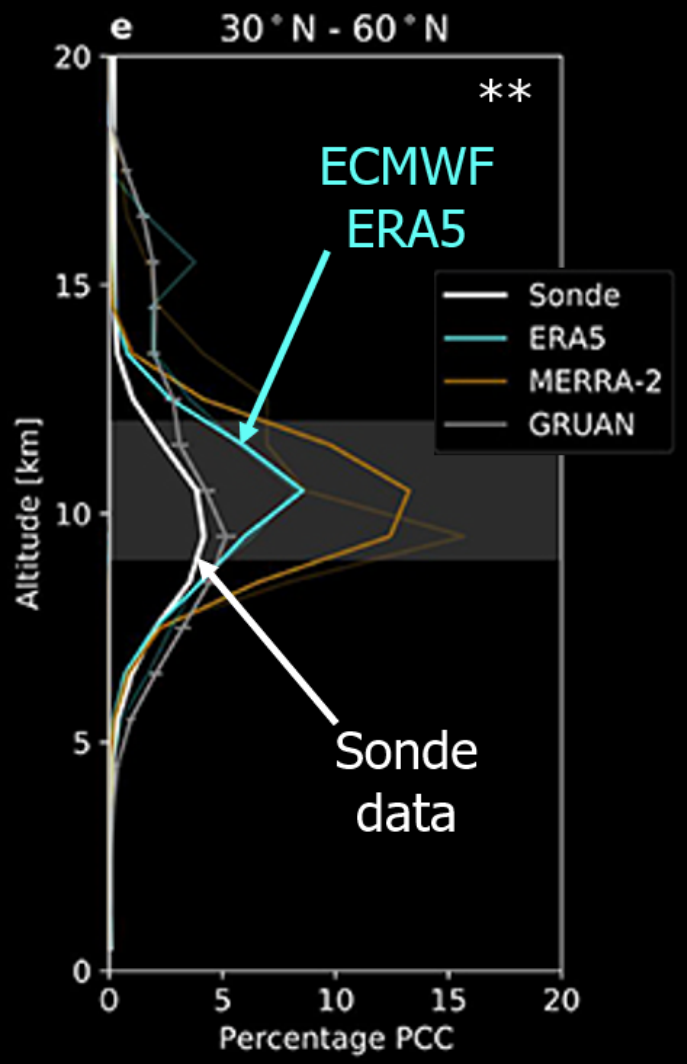

Fossil fuel
Drop-in BtL
Drop-in PtL
Hydrogen
Battery?

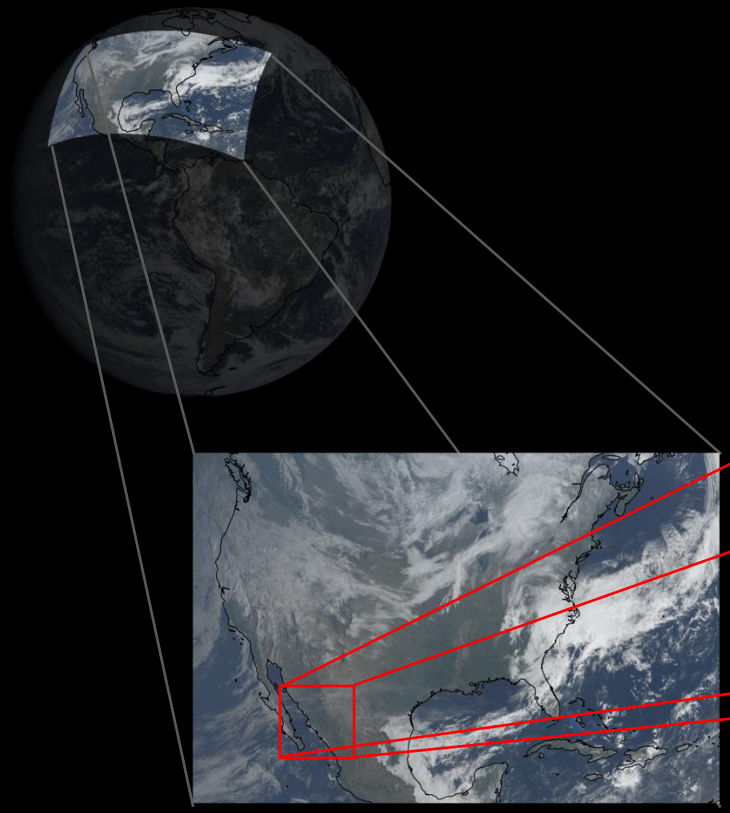




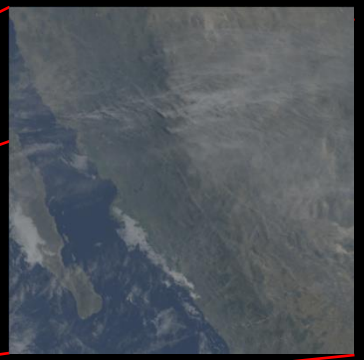

Contrail avoidance region
Contrail avoidance region
Baseline at FL330
Diversion to FL310


ERA5 accuracy for ice supersaturation*
False positive
False negative
True positive
0
50
100
150
200
250
300
350
400
450
500
Observations from MOZAIC data

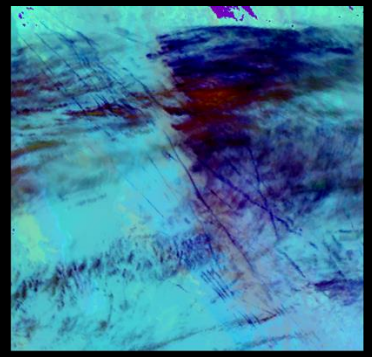

e
30°N - 60°N
**
ECMWF
ERA5
Sonde
ERA5
MERRA-2
GRUAN
Sonde
data
Altitude [km]
0
5
10
15
20
Percentage PCC



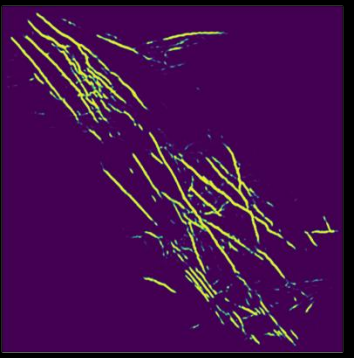
RGB



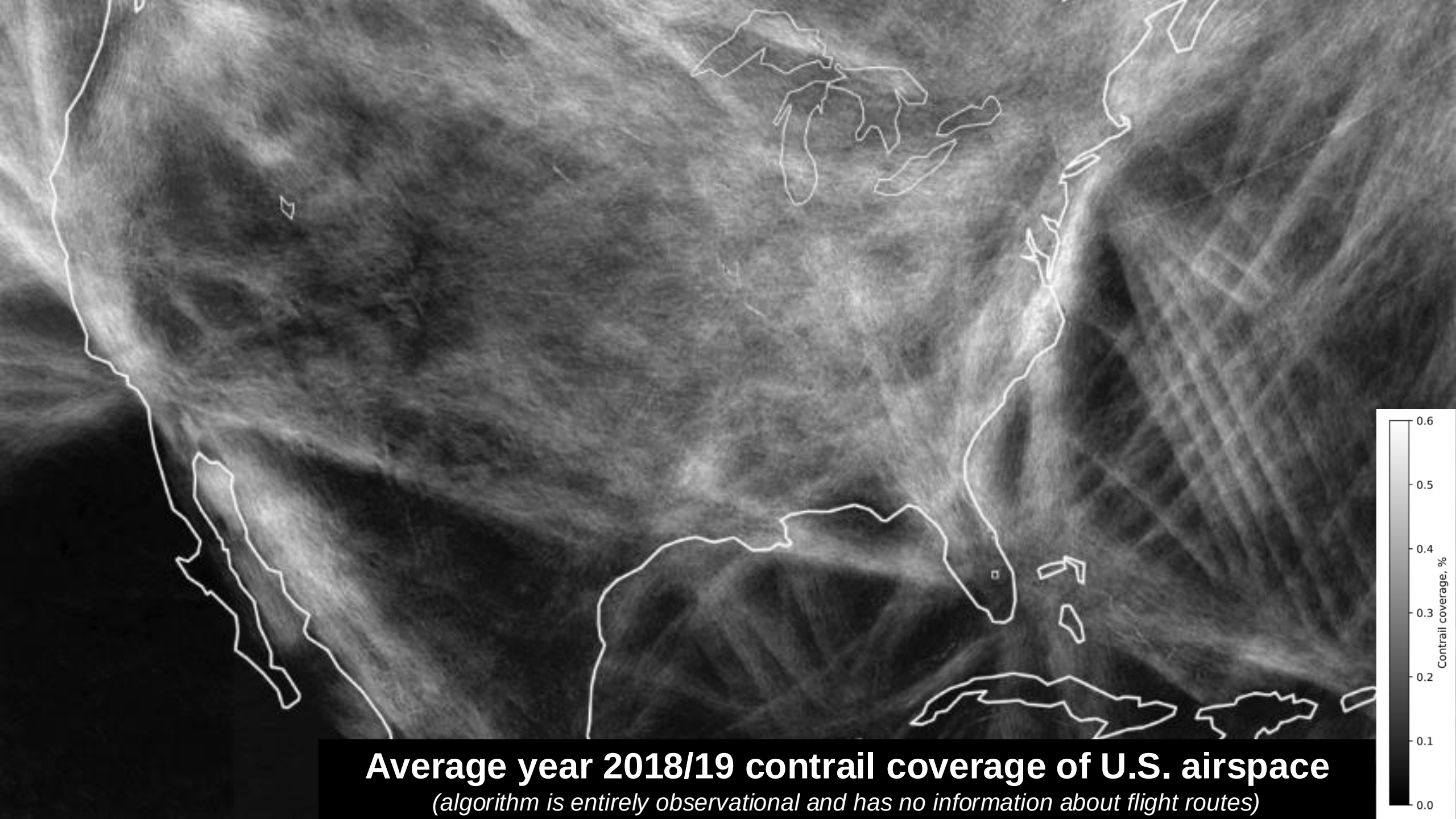
Infrared



Contrail detections

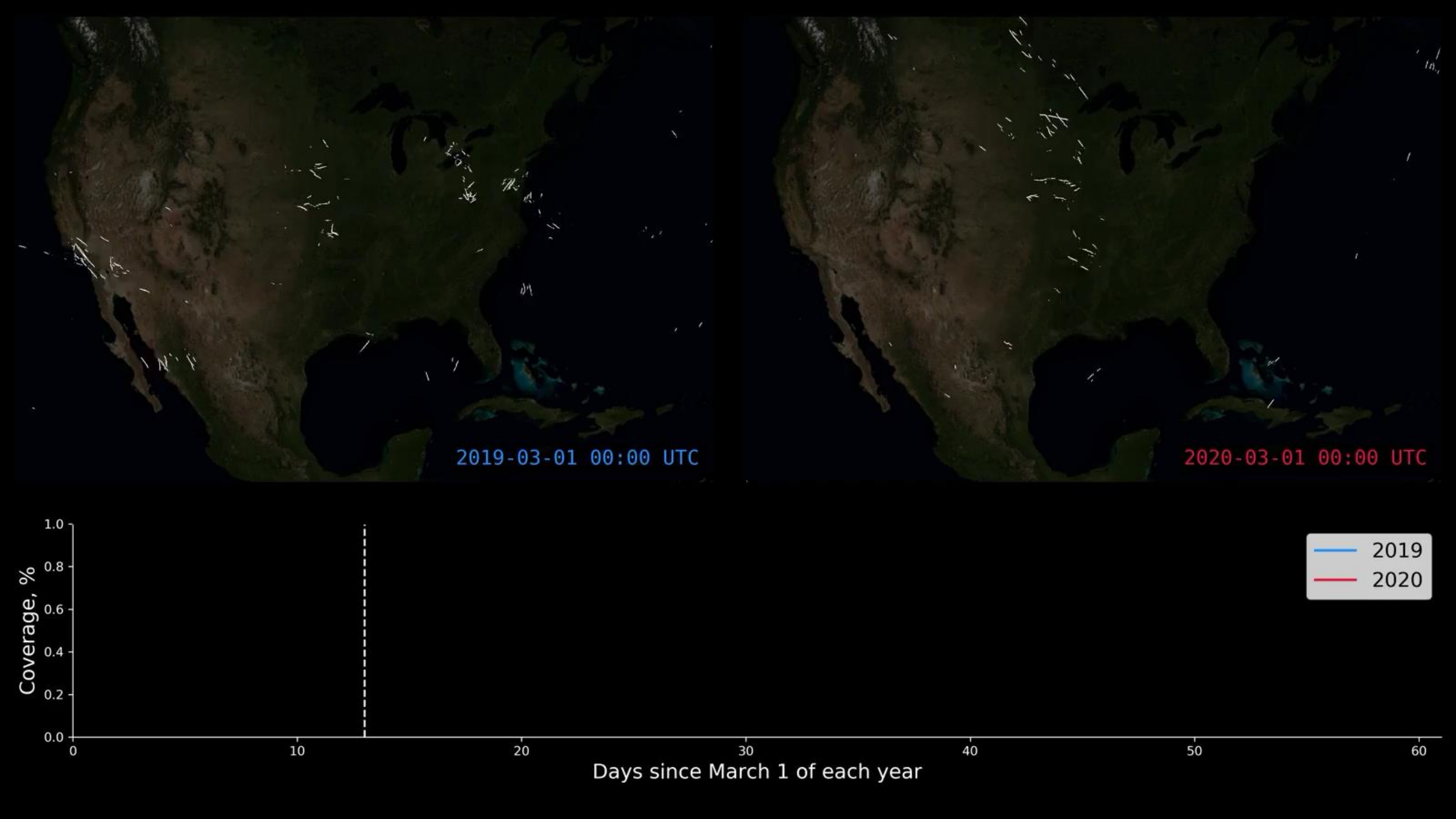


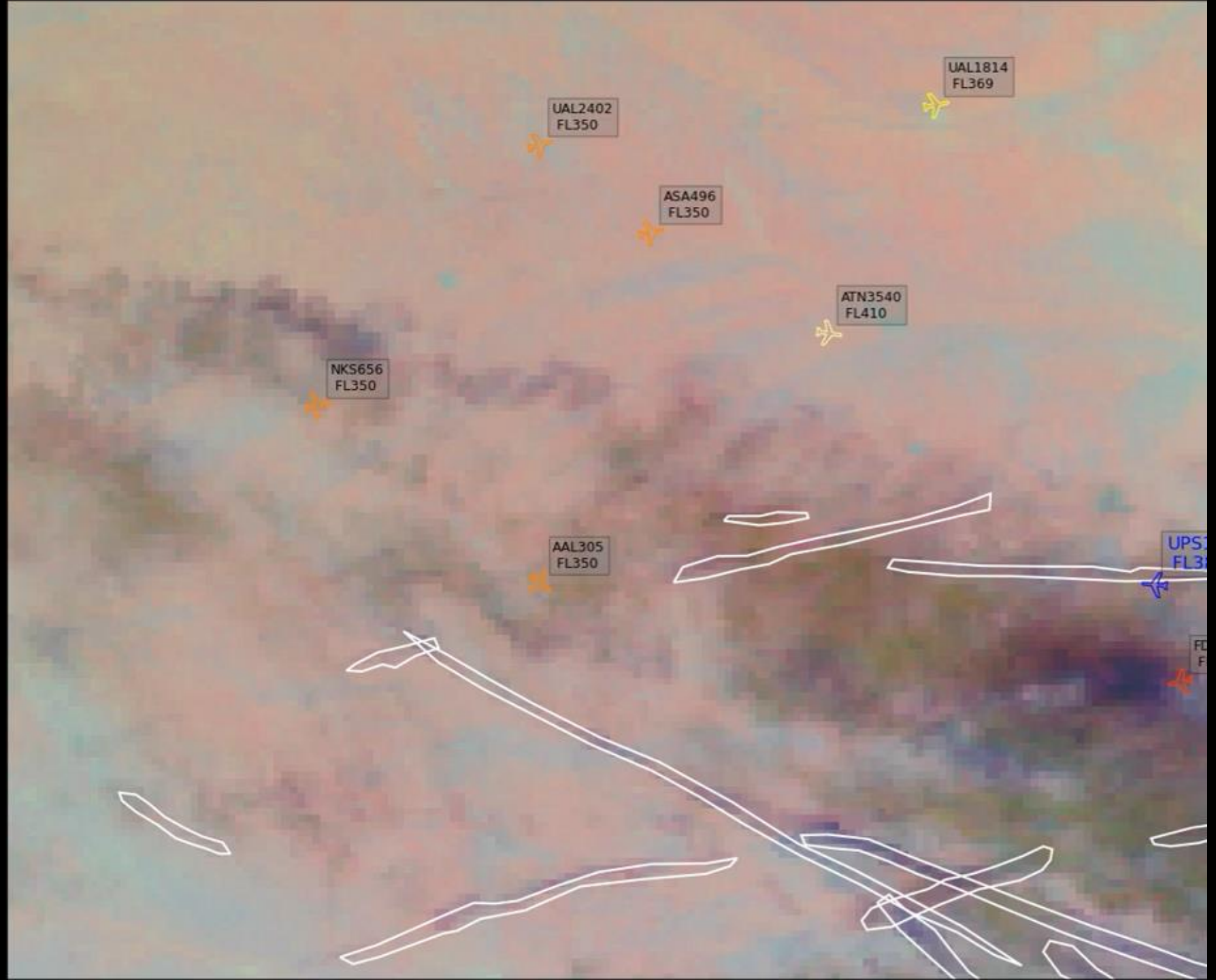
Convolutional neural network trained and evaluated with human labelled images

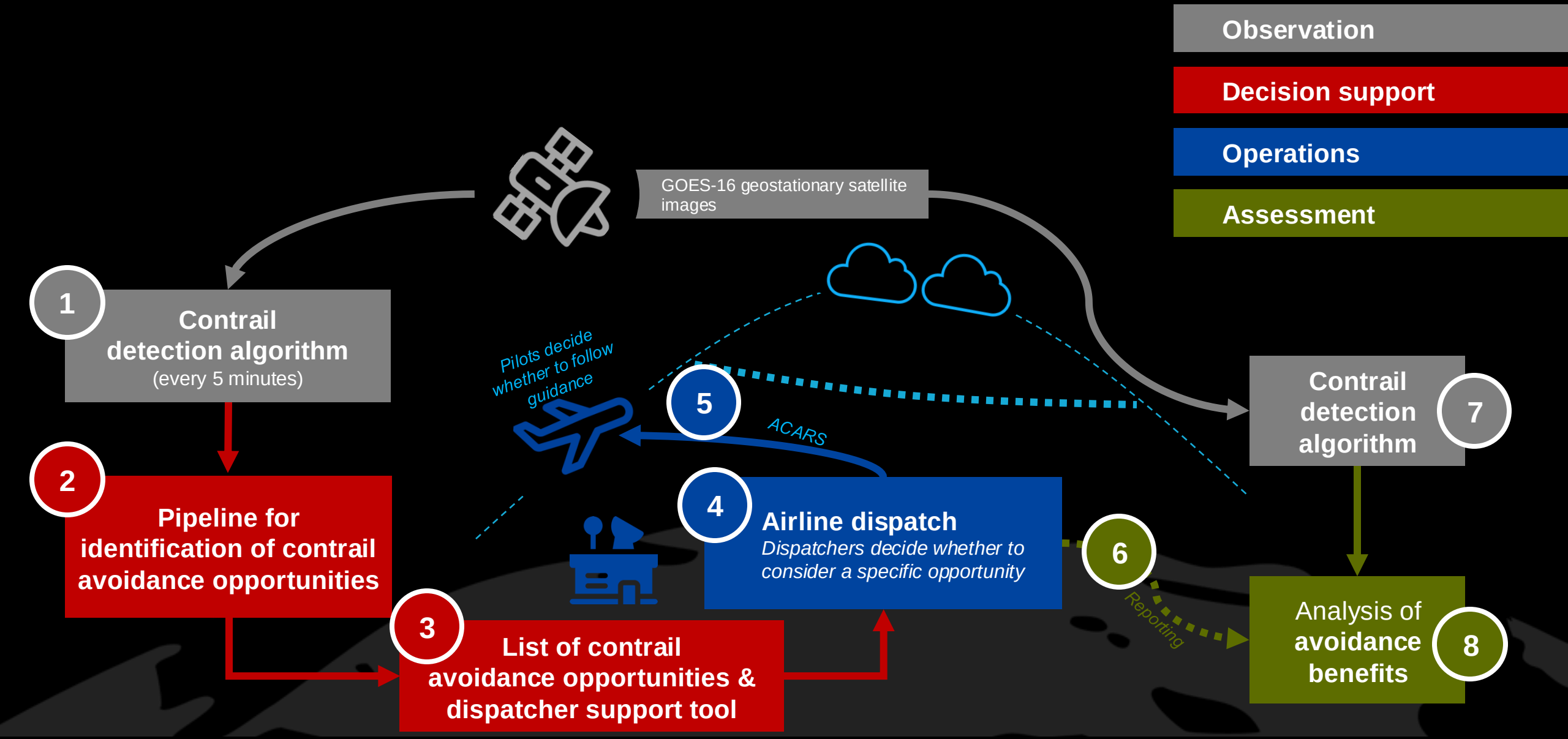


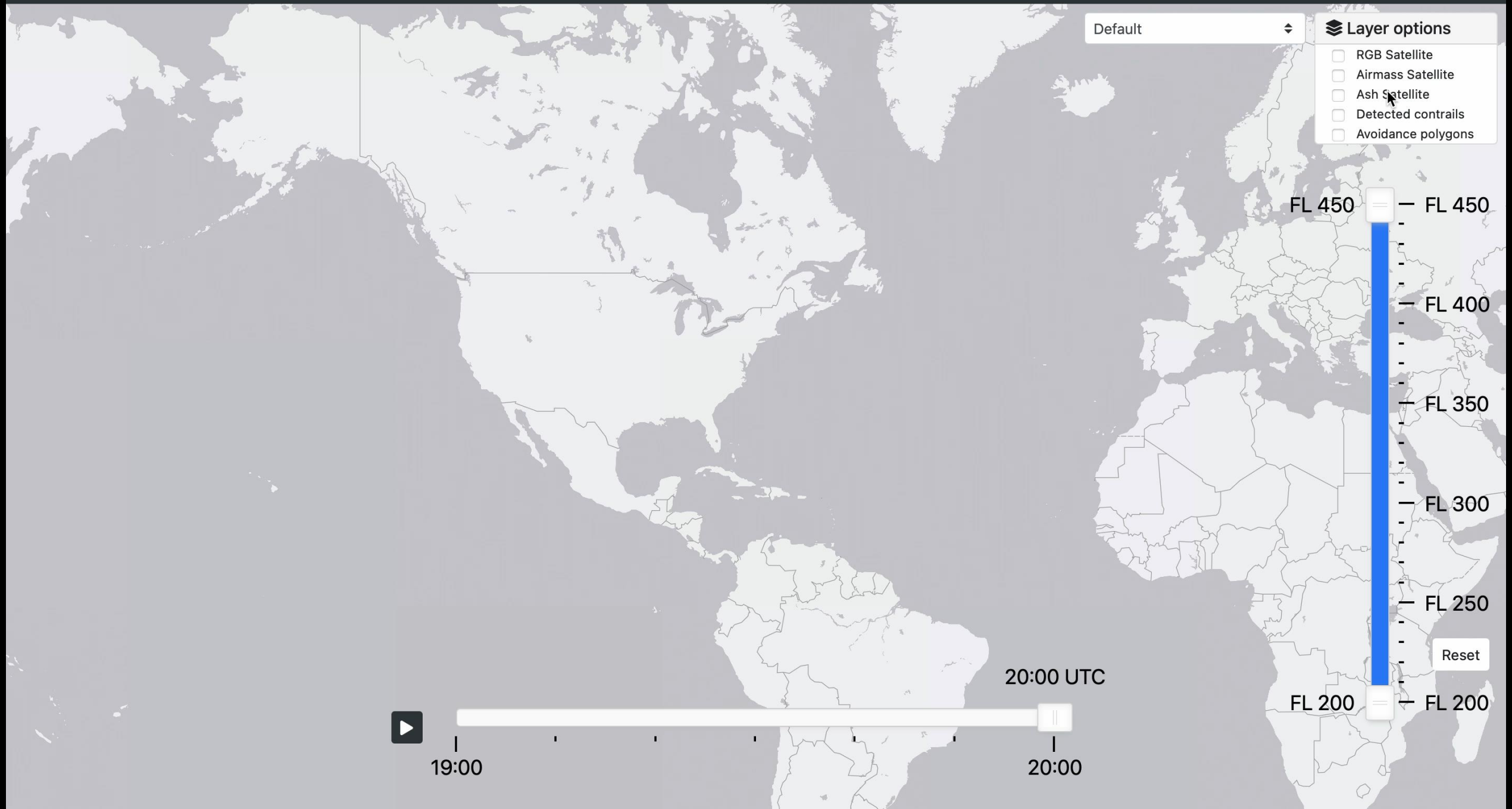
Average year 2018/19 contrail coverage of U.S. airspace

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

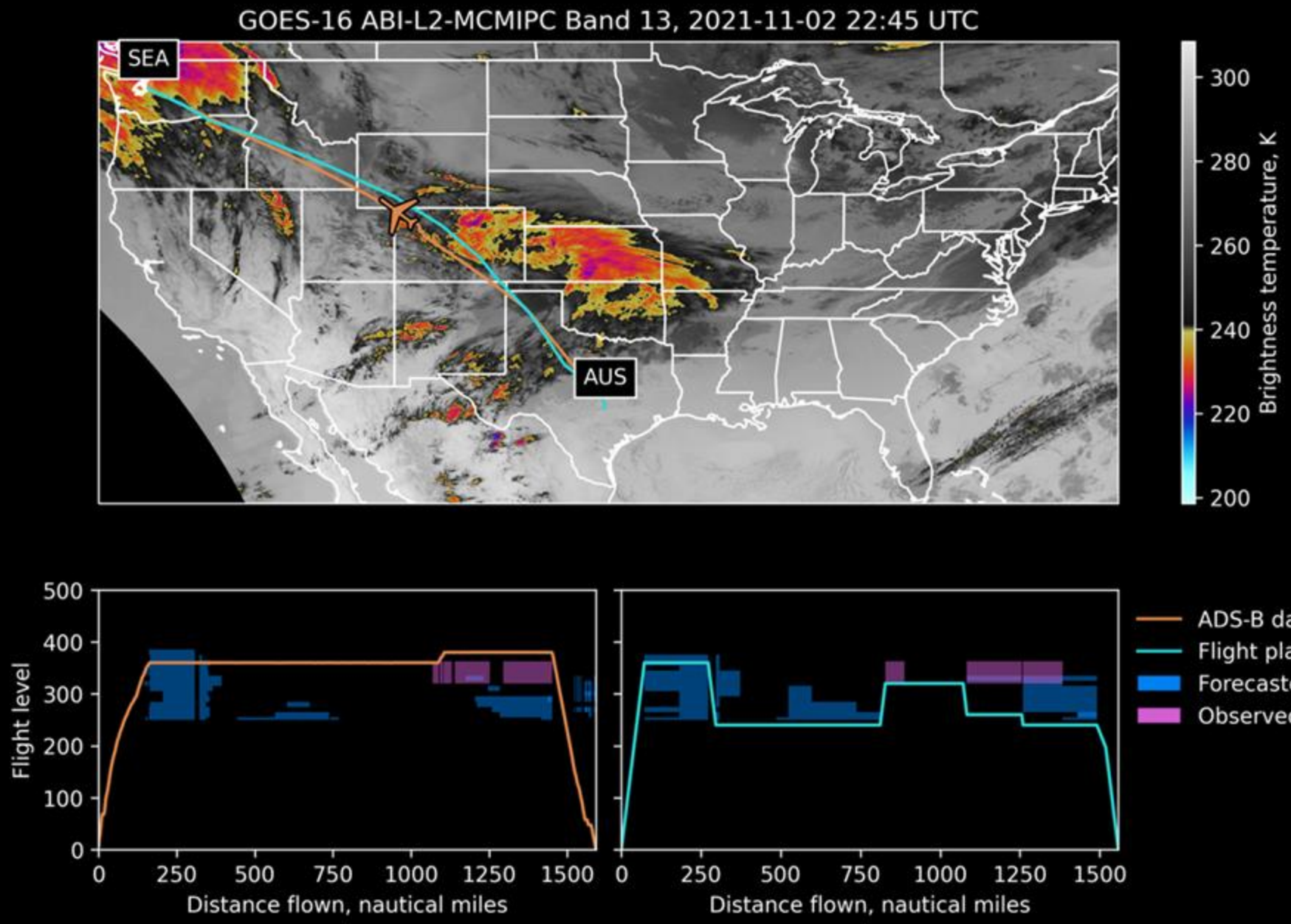

2019-03-01 00:00 UTC
2020-03-01 00:00 UTC
Coverage, %
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
Days since March 1 of each year
2019
2020


UAL1814
FL369
UAL2402
FL350
ASA496
FL350
ATN3540
FL410
NKS656
FL350
AAL305
FL350

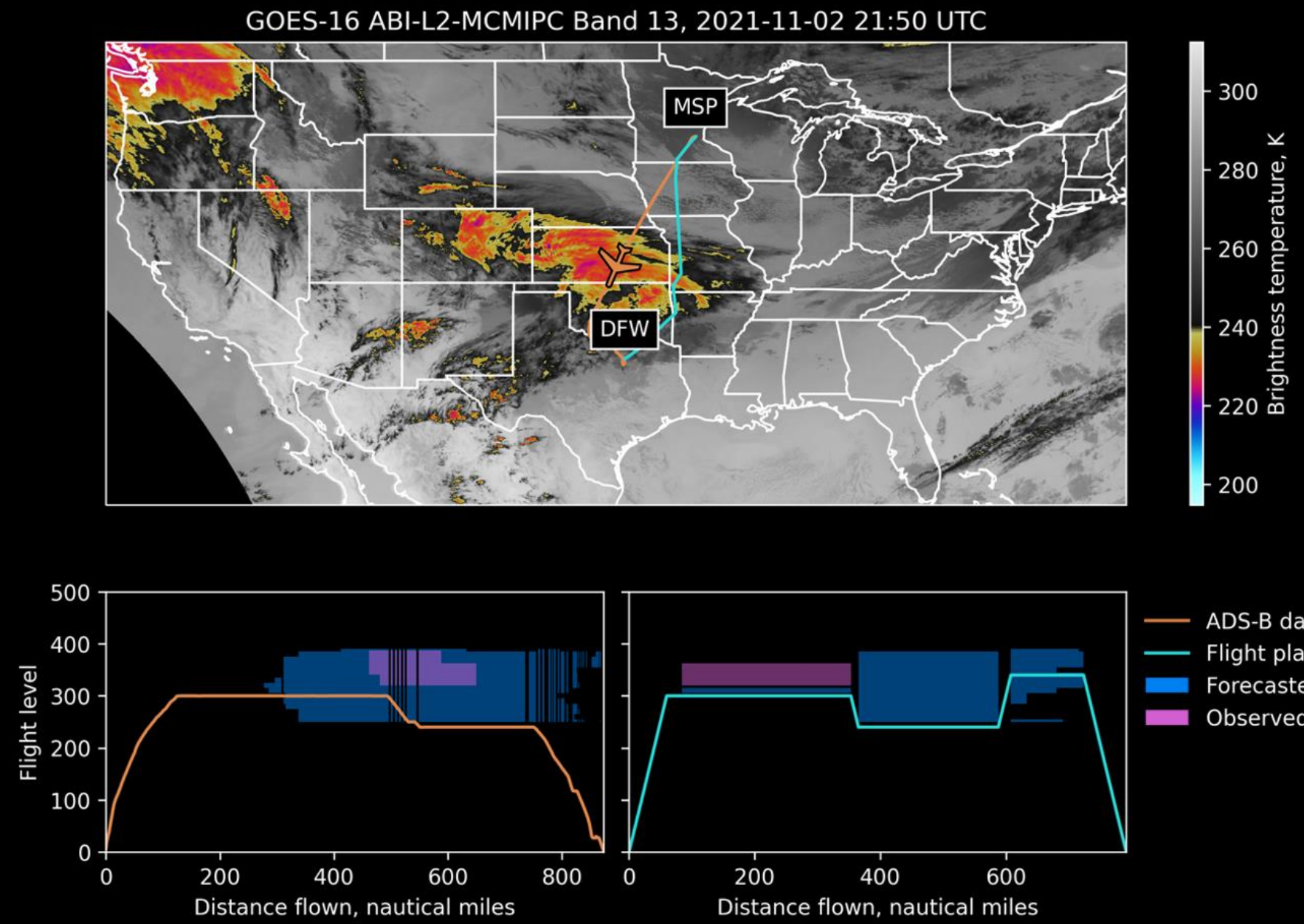

Observation
Decision support
Operations
Assessment
GOES-16 geostationary satellite images
1
Contrail detection algorithm
(every 5 minutes)
2
Pipeline for identification of contrail avoidance opportunities
3
List of contrail avoidance opportunities & dispatcher support tool
4
Airline dispatch
Dispatchers decide whether to consider a specific opportunity
5
Pilots decide whether to follow guidance
ACARS
6
Reporting
7
Contrail detection algorithm
8
Analysis of avoidance benefits


MIT LABORATORY FOR AVIATION AND THE ENVIRONMENT
List
Map
Data
About
admin
Default
Layer options
RGB Satellite
Airmass Satellite
Ash Satellite
Detected contrails
Avoidance polygons
FL 450
FL 450
FL 400
FL 350
FL 300
FL 250
Reset
FL 200
FL 200
20:00 UTC
19:00
20:00

DAL1079 from AUS to SEA, departure time: 2021-11-02 20:41 UTC



DAL1171 from MSP to DFW, departure time: 2021-11-02 20:45 UTC



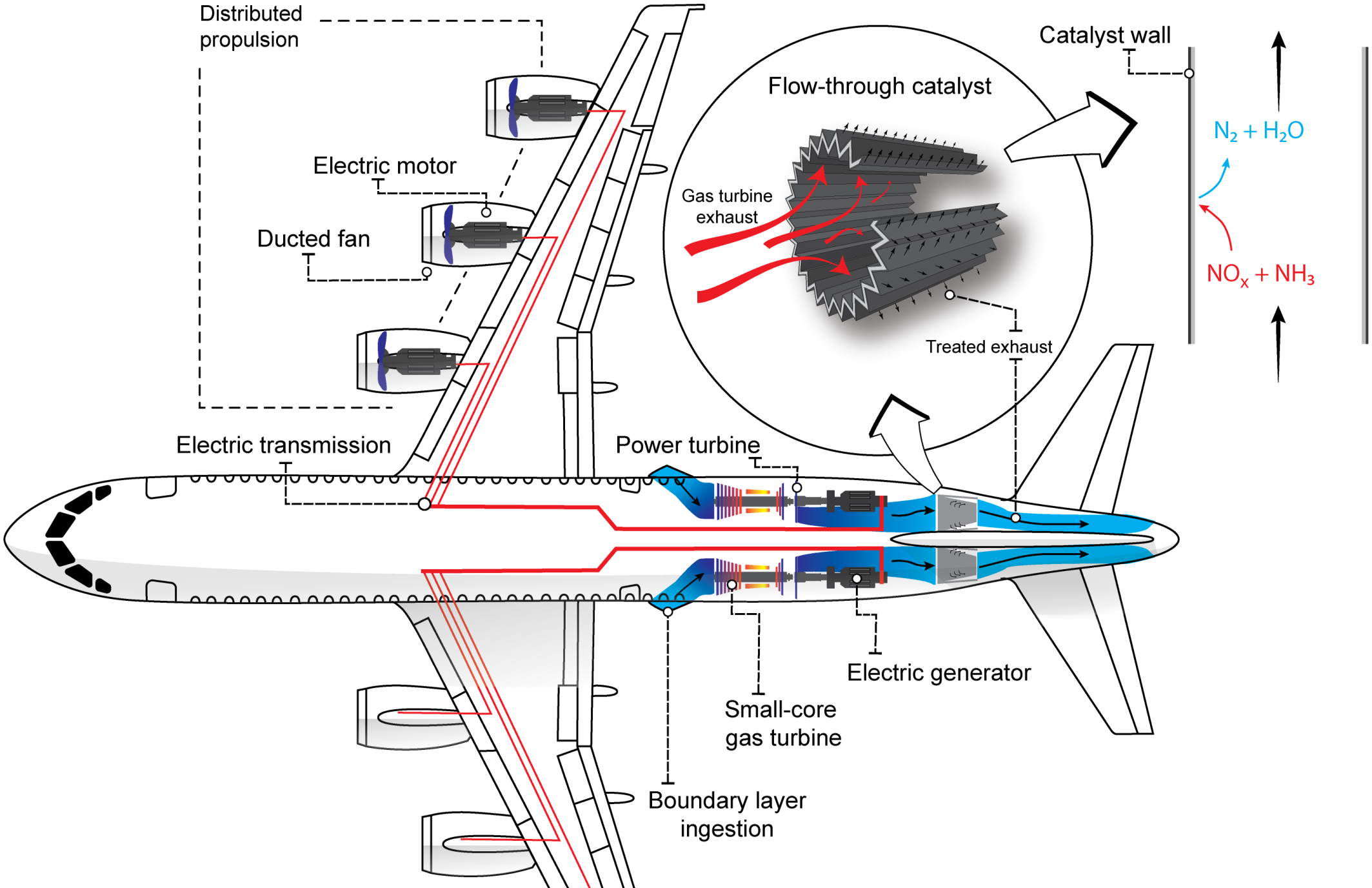
Contrail avoidance:

Potentially the cheapest and fastest way to mitigate *and roll back* the climate impacts of aviation

What about air pollution?

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$$

$$NO + NO_2 + 2NH_3 \longrightarrow 2N_2 + 3H_2O$$


Distributed propulsion
Electric motor
Ducted fan
Electric transmission
Power turbine
Flow-through catalyst
Gas turbine exhaust
Catalyst wall
$N_2 + H_2O$
$NO_x + NH_3$
Treated exhaust
Electric generator
Small-core gas turbine
Boundary layer ingestion

NO_x reduction ($deNO_x$)	95%
Increase in mission fuel burn (due to catalyst, reductant, etc.)	0.5%
Catalyst mass (per engine)	91 kg
Reductant mass (1500 km mission)	21 kg
Additional system mass (pumps, storage tanks, etc.)	128 kg

The challenge for zero impact aviation:

1. Net zero CO_2 emissions
2. Eliminate contrail warming
3. Eliminate NO_x emissions