Global Air Traffic Modeling for Climate Assessment of Routing Strategies

Leading Graduate School Program on Global Safety
Tohoku University-DLR Workshop

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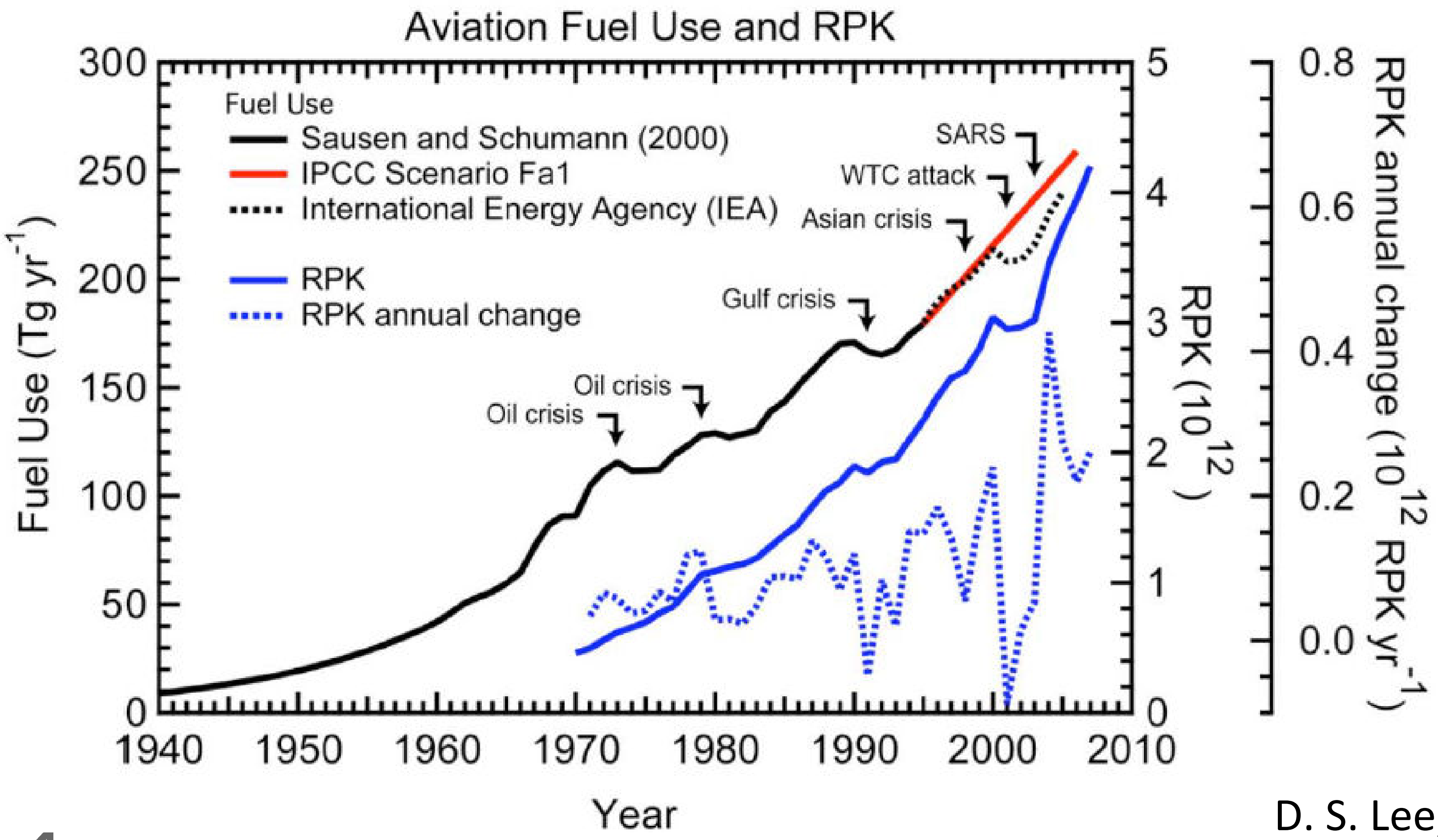
Global Air Traffic in 24 hours

https://www.youtube.com/watch?v=G1L4GUA8arY

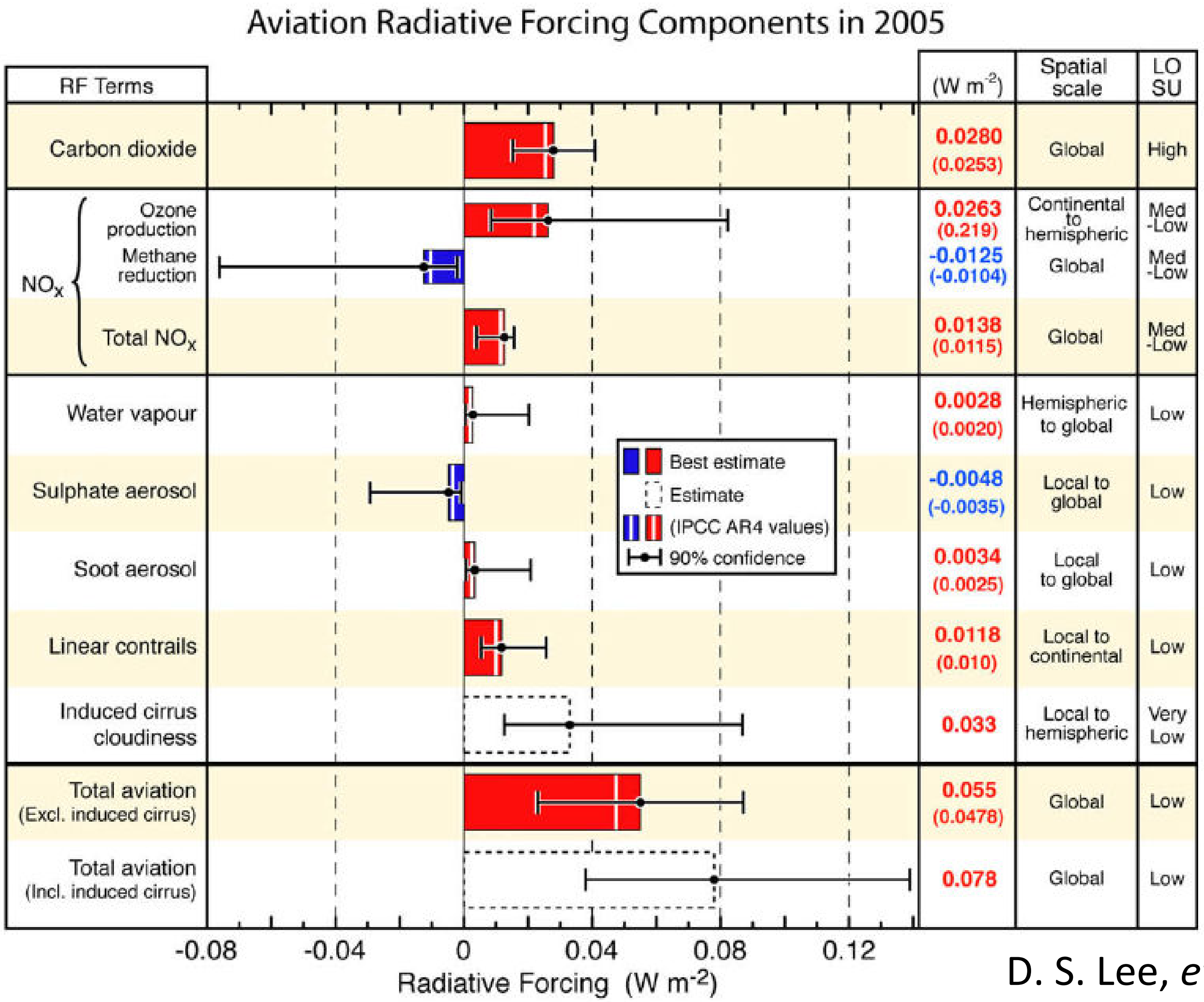
Evolution of World Air Traffic 1940 to 2008

- World annual air traffic growth + 5 %/yr
- Air traffic will be double in the next 15 years



D. S. Lee, *et al*. 2009

Radiative Forcing Values of Aviation Emissions



D. S. Lee, *et al*. 2009

How to Reduce Climate Impact of Aviation Emissions?

- **Technological approach**
  - Aerodynamic changes
    - Blended body aircraft, Laminar flow control
  - More efficient engines
  - Alternative fuels
    - Liquid hydrogen, Bio-fuels
- **Operational approach**
  - Efficient ATM
    - Reduced time holding, More direct flight
    - NextGen(USA), SESAR(EU), CARATS(JP)
  - Efficient flight-profile
    - Continuous descent approach
  - **Climate-optimized routing**

D. S. Lee, *et al*. 2009
E. A. Irvine, *et al.* 2012

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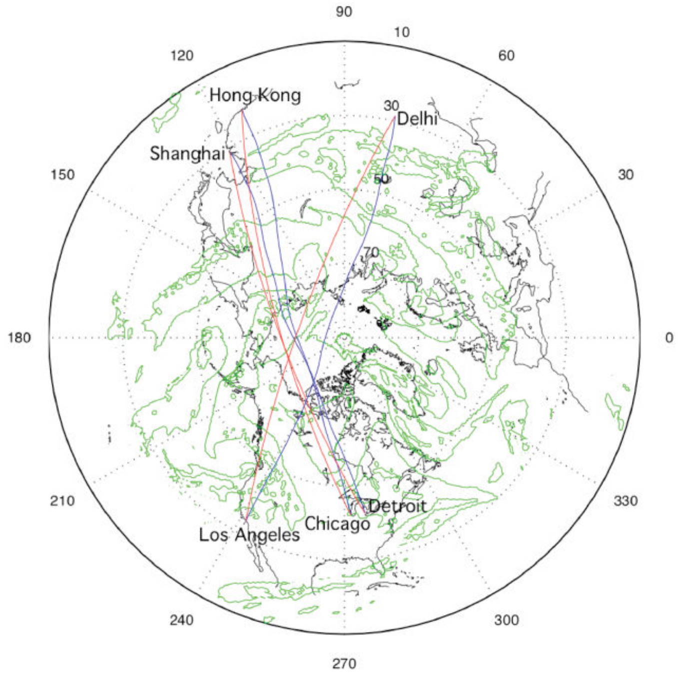
Recent Studies on Climate-optimized Routing (1/2)

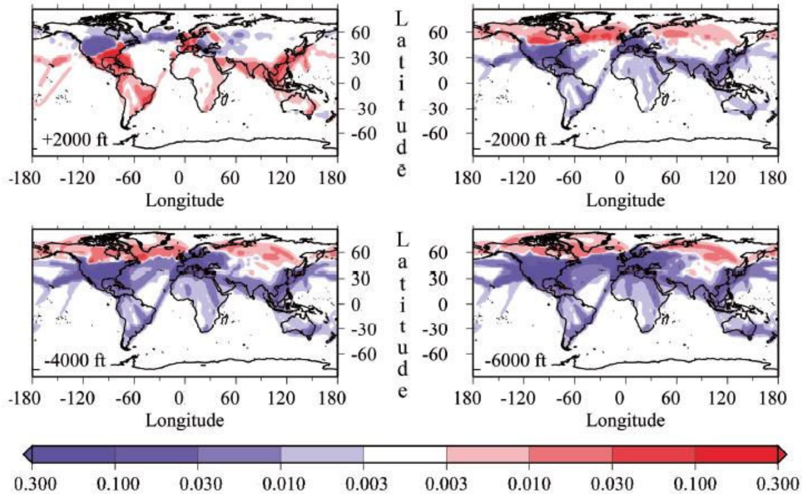
- "Wind-optimal routes reduce average fuel burn of actual routes by 4.4 % on Dec. 4, 2010."

H. K. Ng, *et al*. 2011



- "Almost 45 % decrease in global contrail coverage is achieved by 6,000 ft down-shift of cruise altitude. However 6 % increase in Fuel burn"

C. Fichter, *et al*. 2005



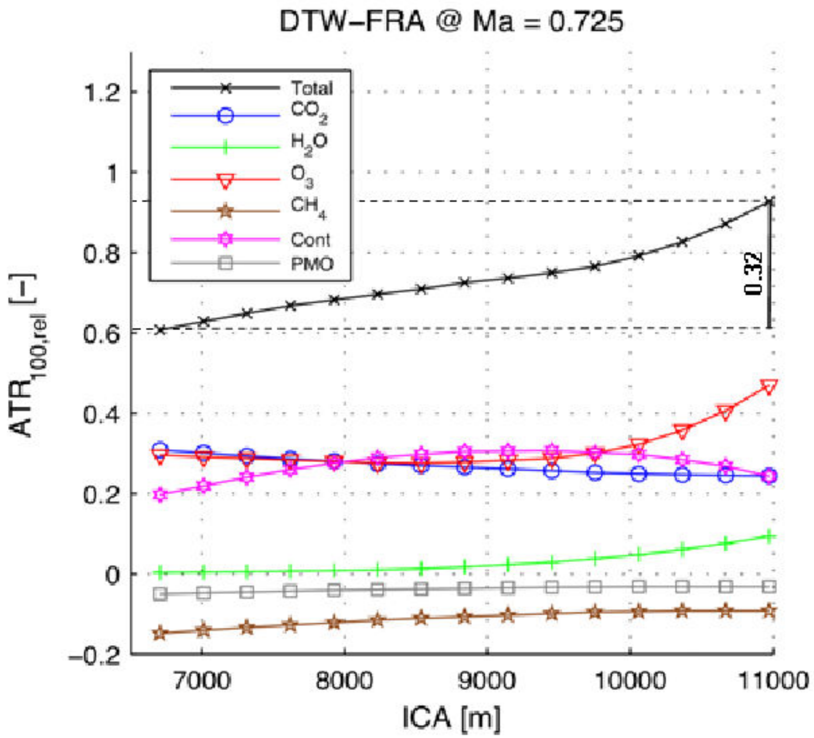
Recent Studies on Climate-optimized Routing (2/2)

- "…a reduction of cruise altitude will results in increased fuel consumption (CO2), counteracting the benefits gained by contrail avoidance and reduction of NOx impact."

K. Gierens, *et al*. 2008

- "…the sole minimization of CO2 (fuel burn) does not lead to the minimum (total) climate impact."

K. Alexander, *et al*. 2011



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Practical Issues on Climate-optimized Routing

- What is the optimum route for total climate impact reduction?
  - Great circle: **min. flight distance**
  - Wind optimum: **min. flight time**
  - **Min. CO2 (Fuel-use)**
  - **Min. NOx**
  - **Contrail avoidance**
  - **Etc…**

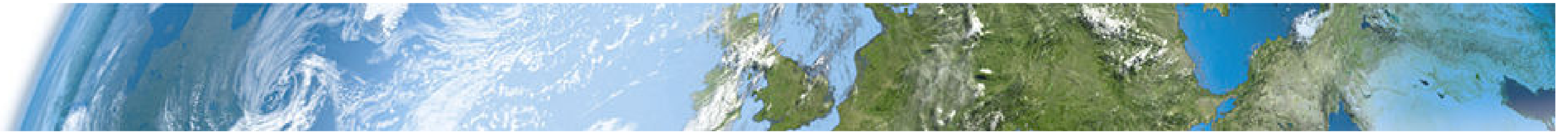
- How effective is the selected strategy for total climate impact reduction?

Research Objectives

- Develop new assessment platform: **AirTraf**
  - Global airtraffic model coupled to Climate-chemistry model

- Simulate global air traffic on routing strategies
  - Trajectory optimization (horizontally and vertically)
  - Local atmospheric conditions
  - Long-term simulation

- Clarify the reduction potential on aviation climate impact



Overview of AirTraf

Base Model

Climate Chemistry Model EMAC

P. Jöckel 2010

Submodels

Aviation data base:

- ICAO engine emission
- BADA aircraft model
- One day flightplan

Optimizer:

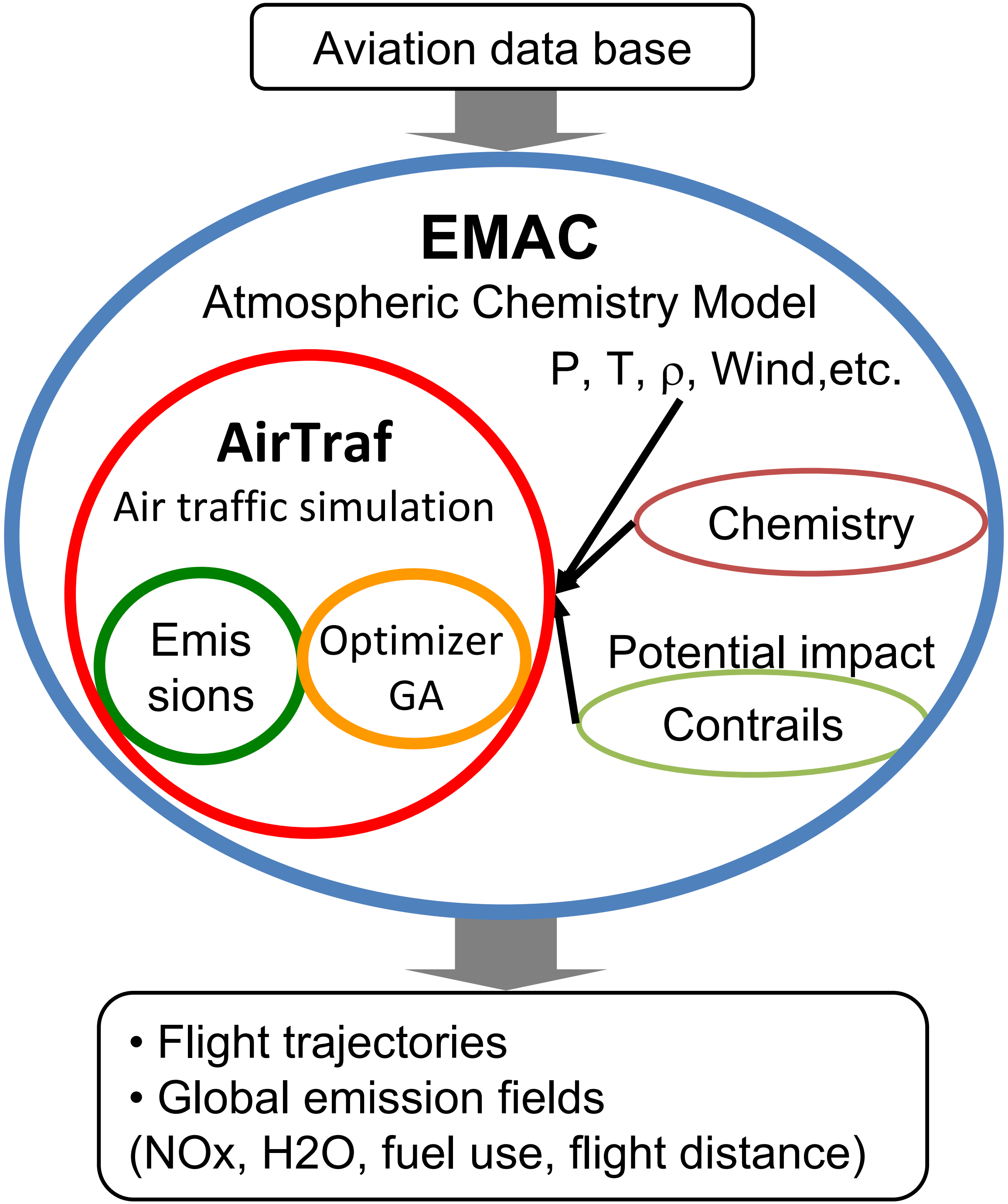
- Genetic algorithms

J. H. Holland 1975, D.Sasaki, 2009

Emissions:

- Total energy model
- DLR fuel flow method

F. Deidewig 1996, M. Schaefer 2012



Flow Chart of AirTraf (1/2)

Init. memory

- **Flight plan inputs**
  - City pairs, timetable, aircraft/engine
- **Decomposition of trajectories**

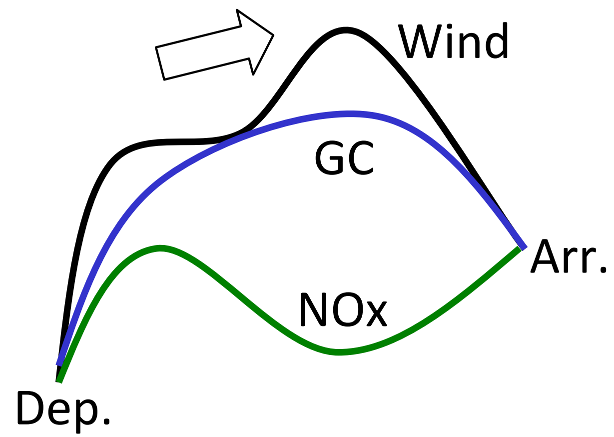
Time loop

- **Departure check**
  - **Calculate trajectory** ⇄ Trajectory optimization
  - Calculate emissions along trajectory
  - Fly aircraft
  - Gather global emission fields
- **Arrival check**

Trajectory optimization

Options

0: Great circle (min. distance)
1: Wind (min. flight time)
2: NOx
3: H2O
4: CO2 (Fuel-use)
5: Contrail avoidance
6: Climate cost functions



Genetic algorithms

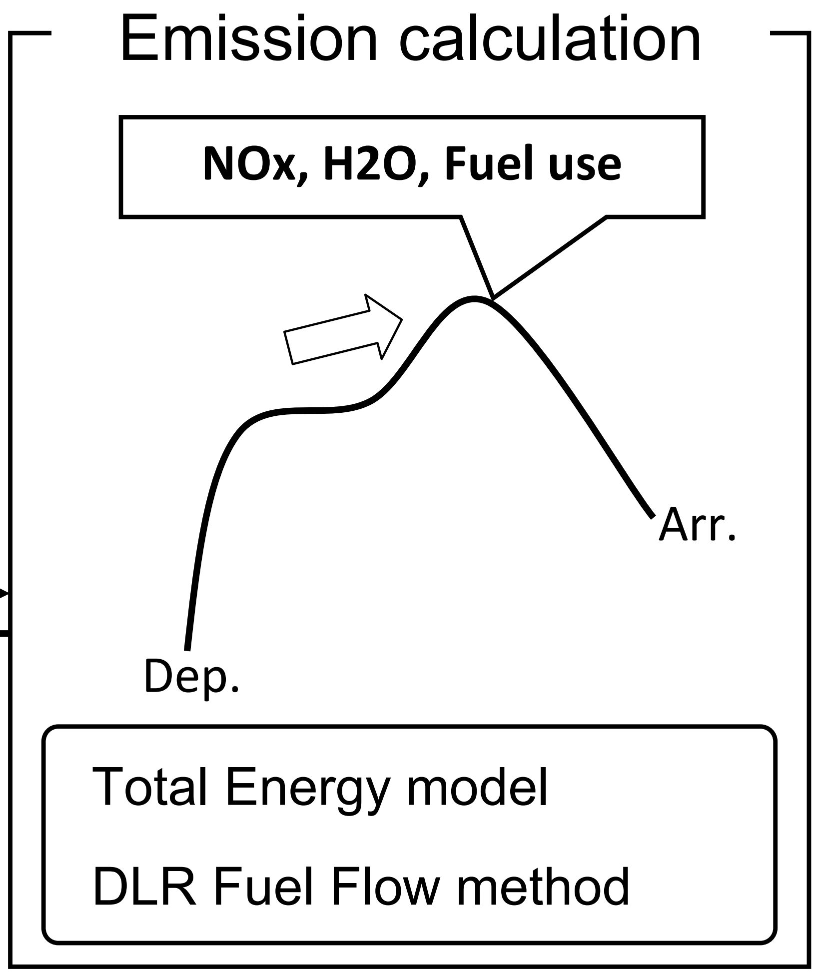
Flow Chart of AirTraf (2/2)

Init. memory

- Flight plan inputs
  - City pairs, timetable, aircraft/engine
- Decomposition of trajectories

Time loop

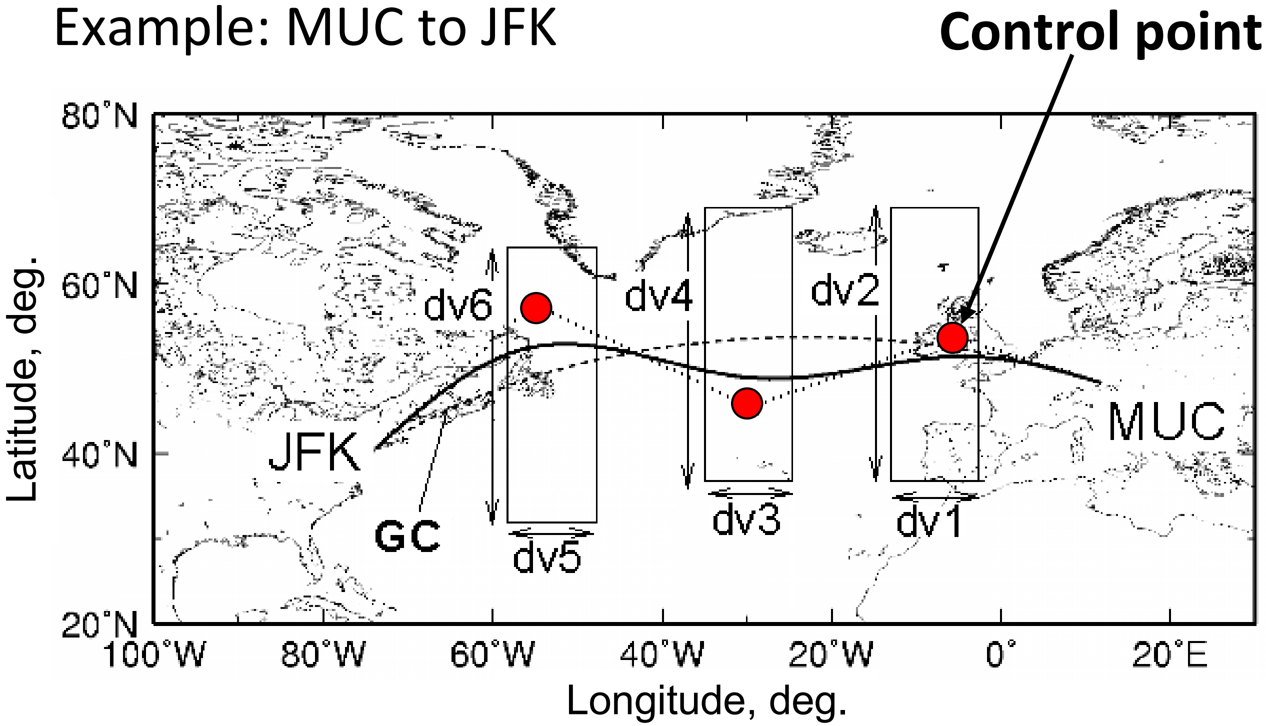
- Departure check
  - Calculate trajectory
  - **Calculate emissions along trajectory**
  - Fly aircraft
  - Gather global emission fields
- Arrival check

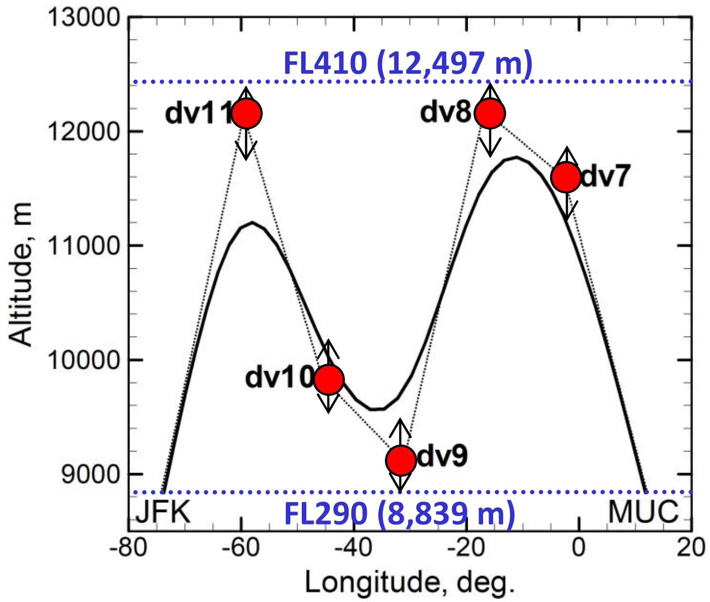


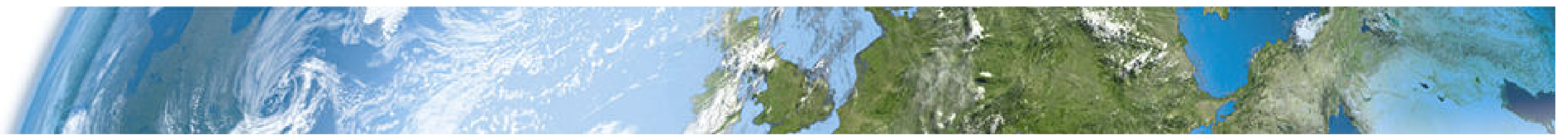
Geometry Definition of Trajectory

- Control points consist of design variables: **location: 6**, **altitude: 5**
- Control points express arbitrary trajectories for city pairs
- Evaluate flight time along trajectories (if wind optimum case)

Example: MUC to JFK







One Day Test Simulation

EMAC/AirTraf

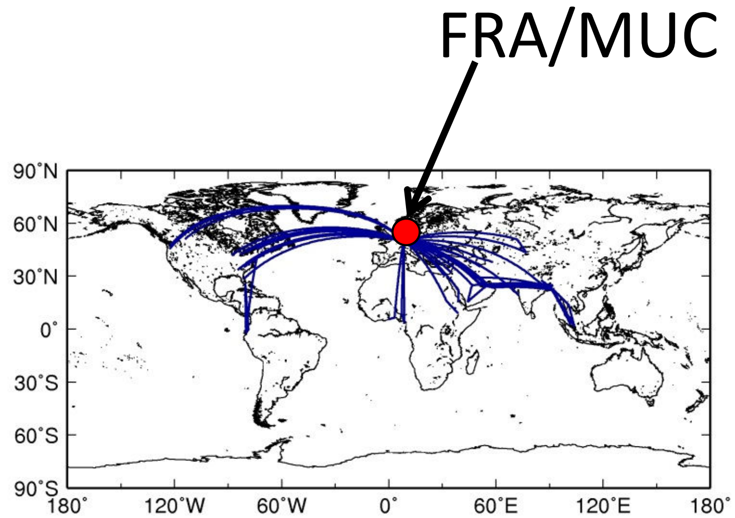
ECHAM5 Resolution : T21/L19
Calculation term : 1 day (JAN.01.1978–JAN.02.1978)
Waypoints : 61
Options : GC, Wind optimum
Flight altitude : FL290, 330, 370, 410 (GC)
FL290 – 410 (Wind optimum)

Aviation data base

Flight plan : 1,840 (FRA/MUC)
Aircraft type : A330-301
Engine type : CF6-80-E1-A2 Jet Engine×2
Flight speed : M = 0.82

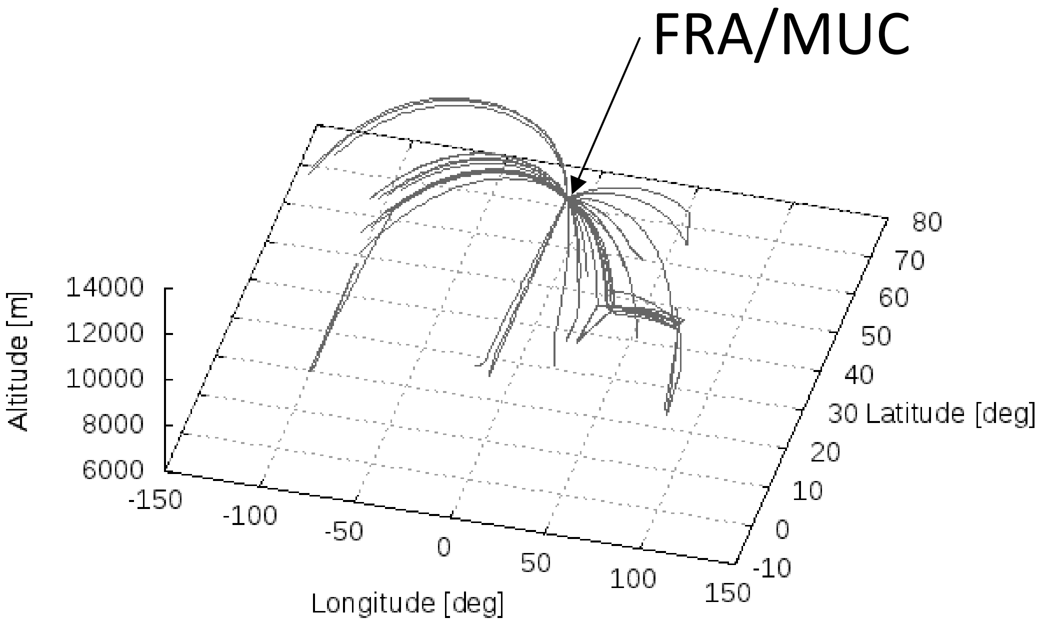
Optimizer

Design variables : 6 (location), 5 (altitude)
Generation : 50
Population : 50

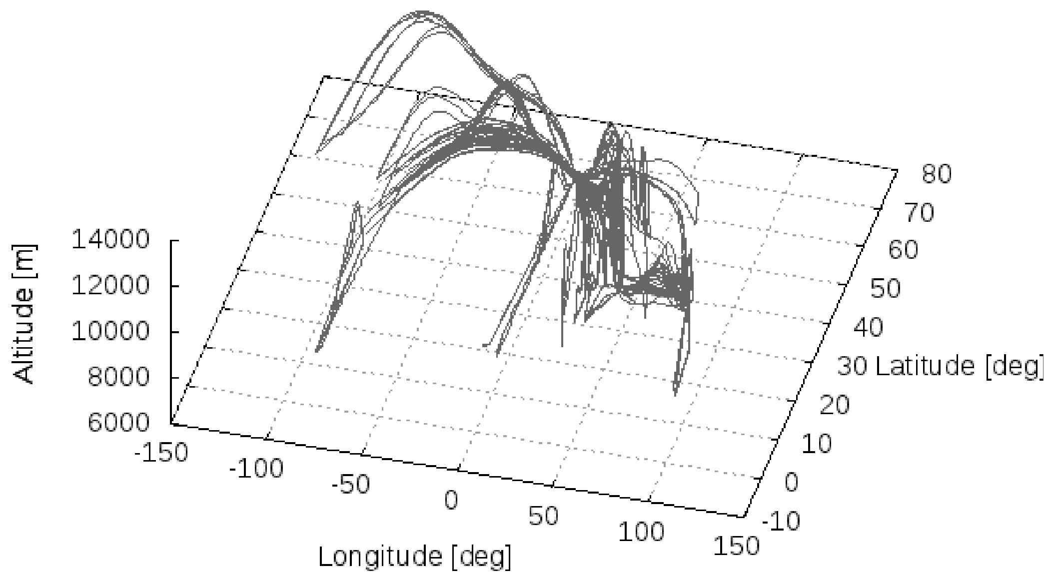


Comparison of Flight Trajectories

GC with winds, FL330



Wind optimum, b/w FL290-410



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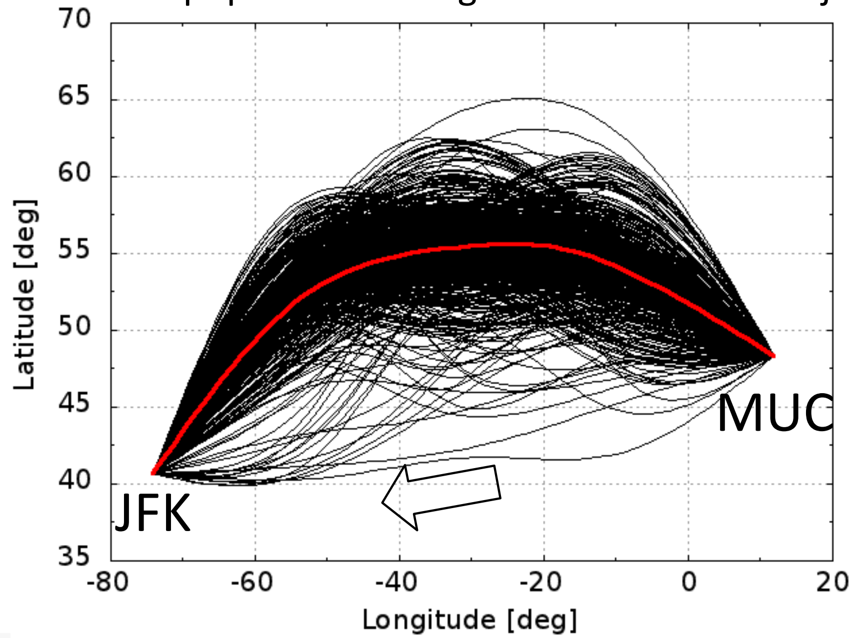
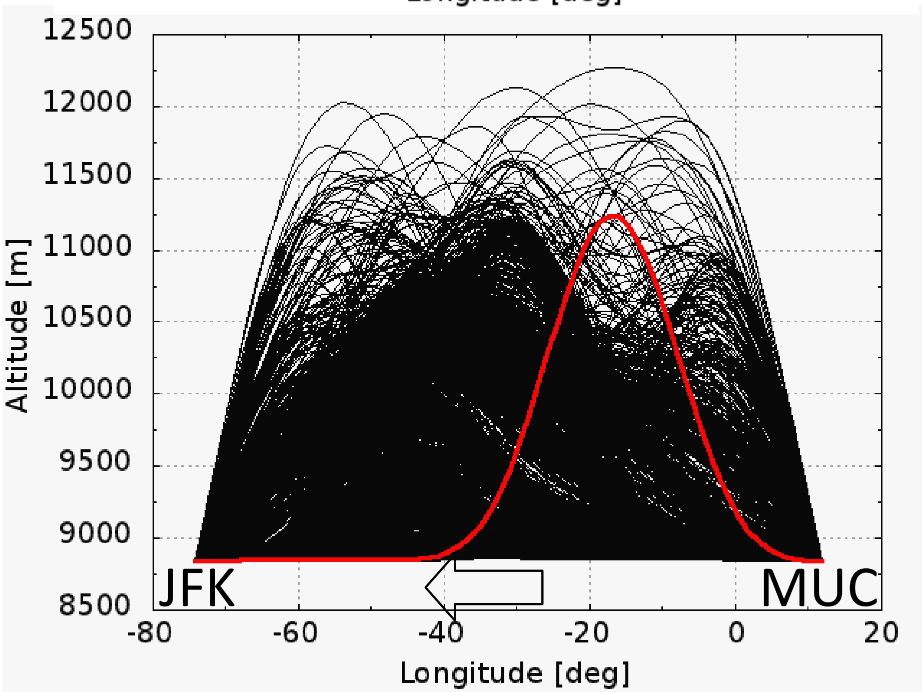
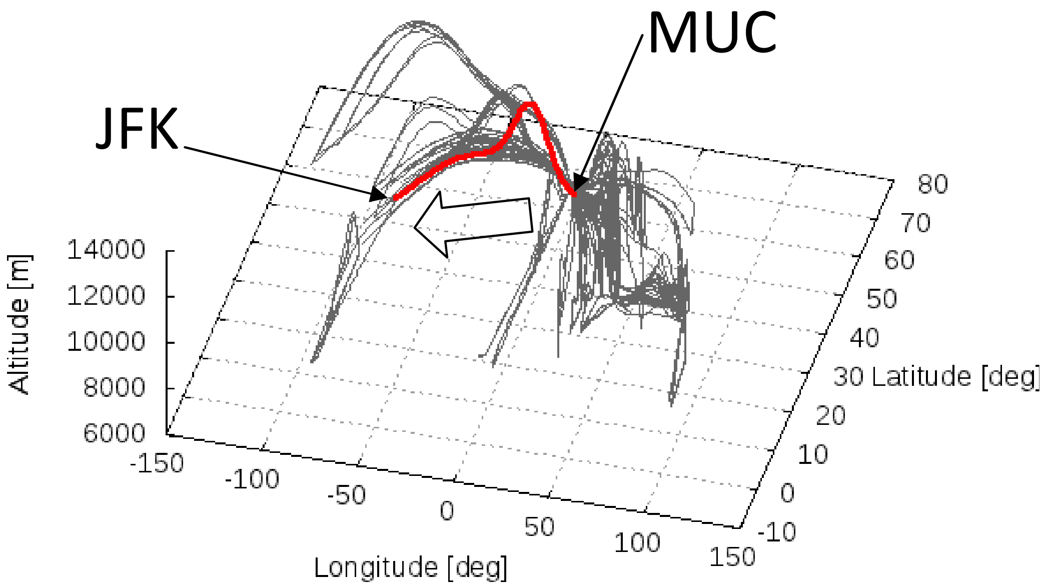
Trajectories Explored through Optimization (MUC to JFK)

50 population × 50 generation = 2500 traj.

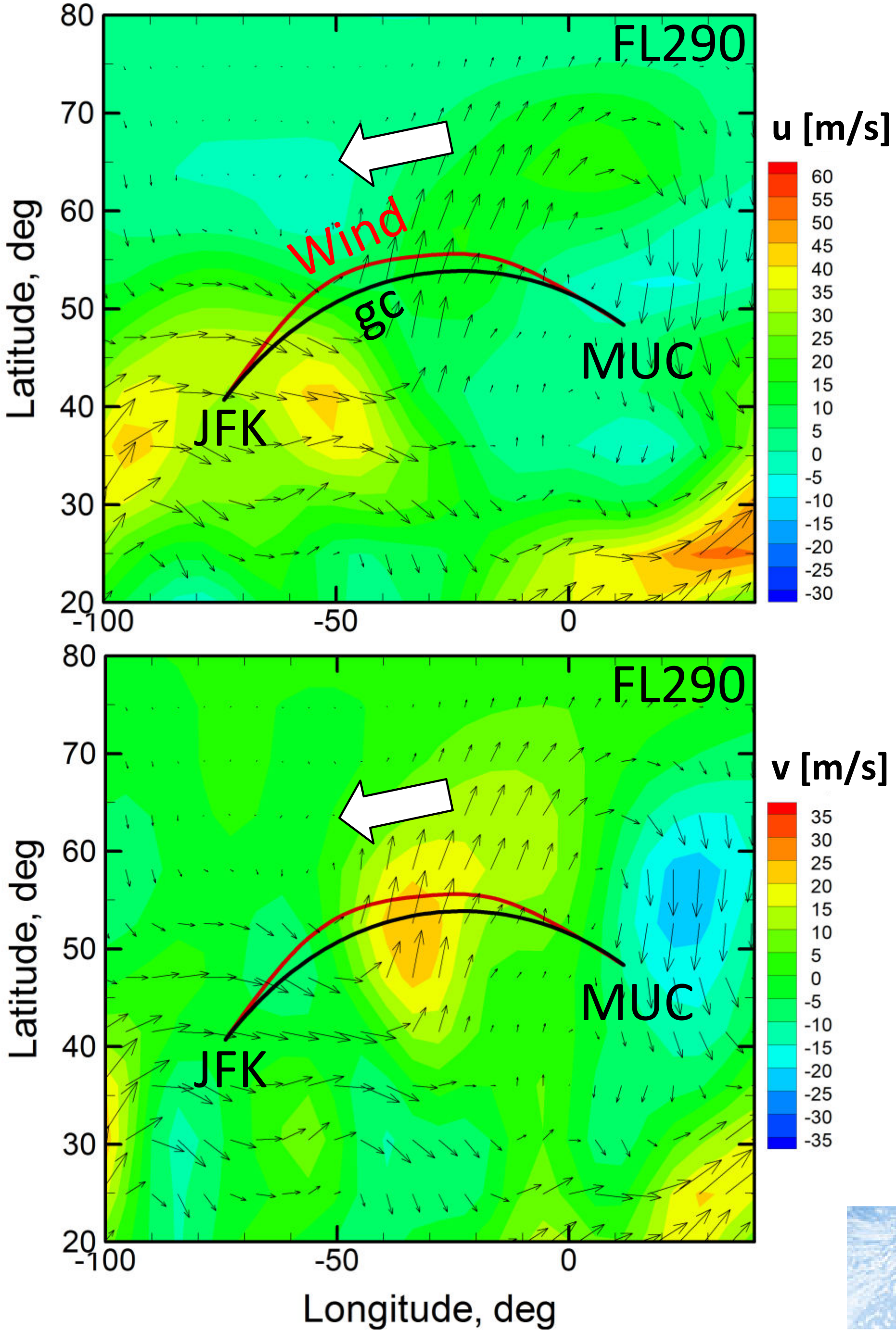


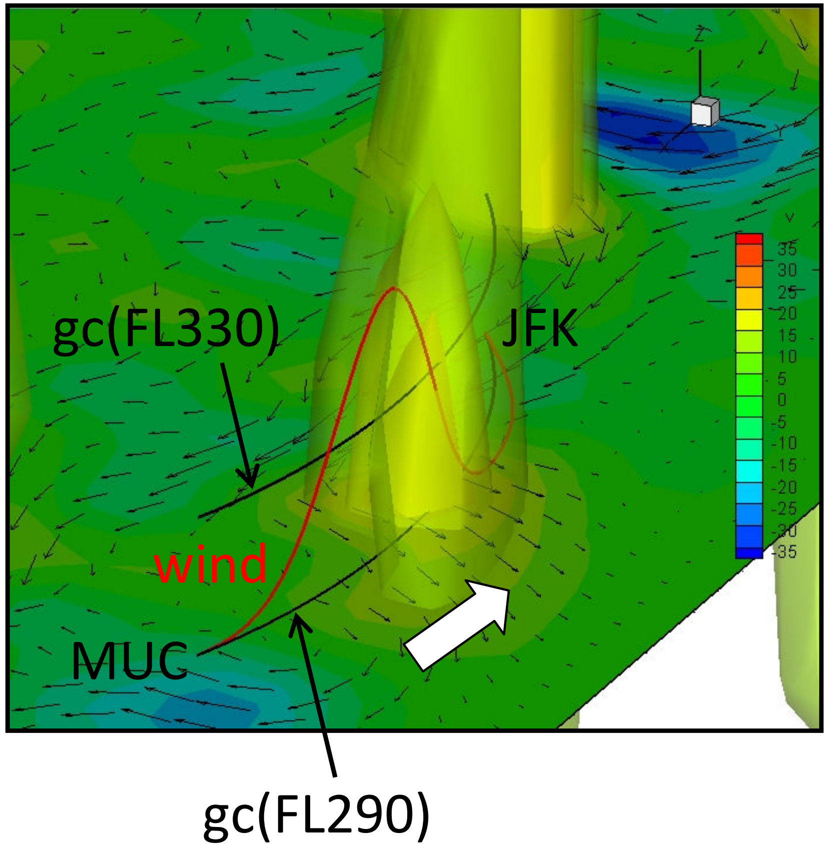


Wind optimum, b/w FL290-410

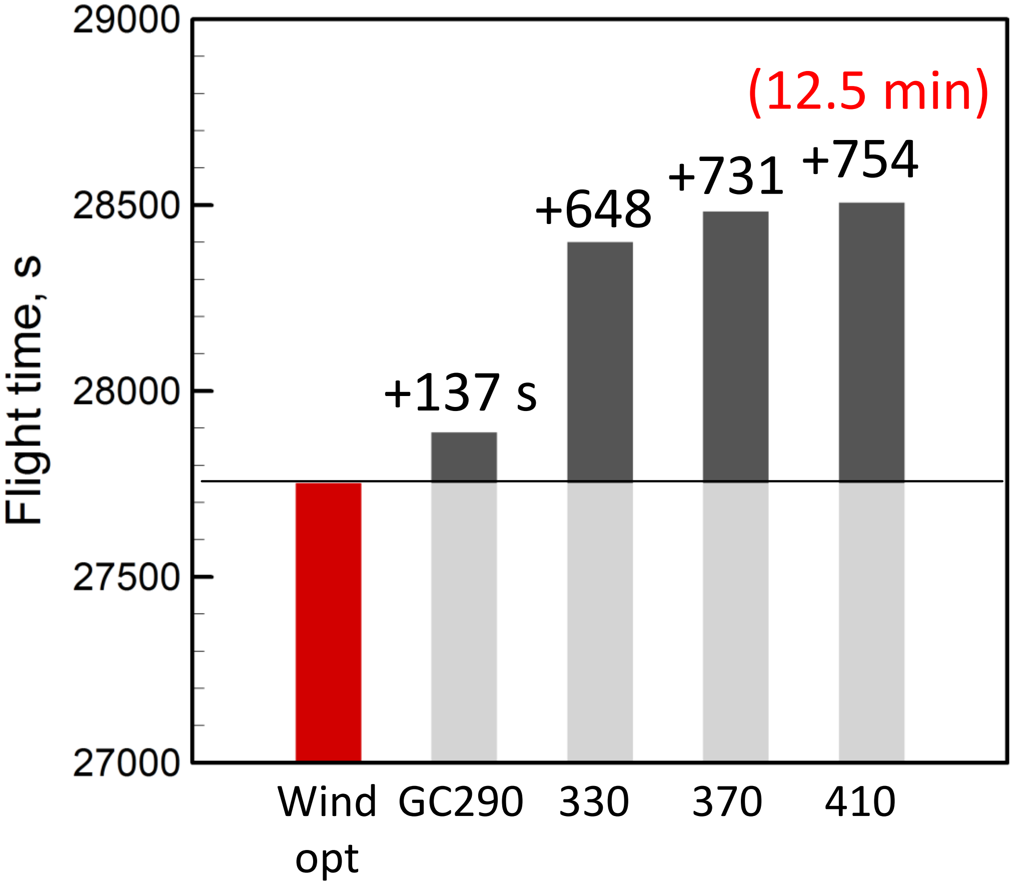


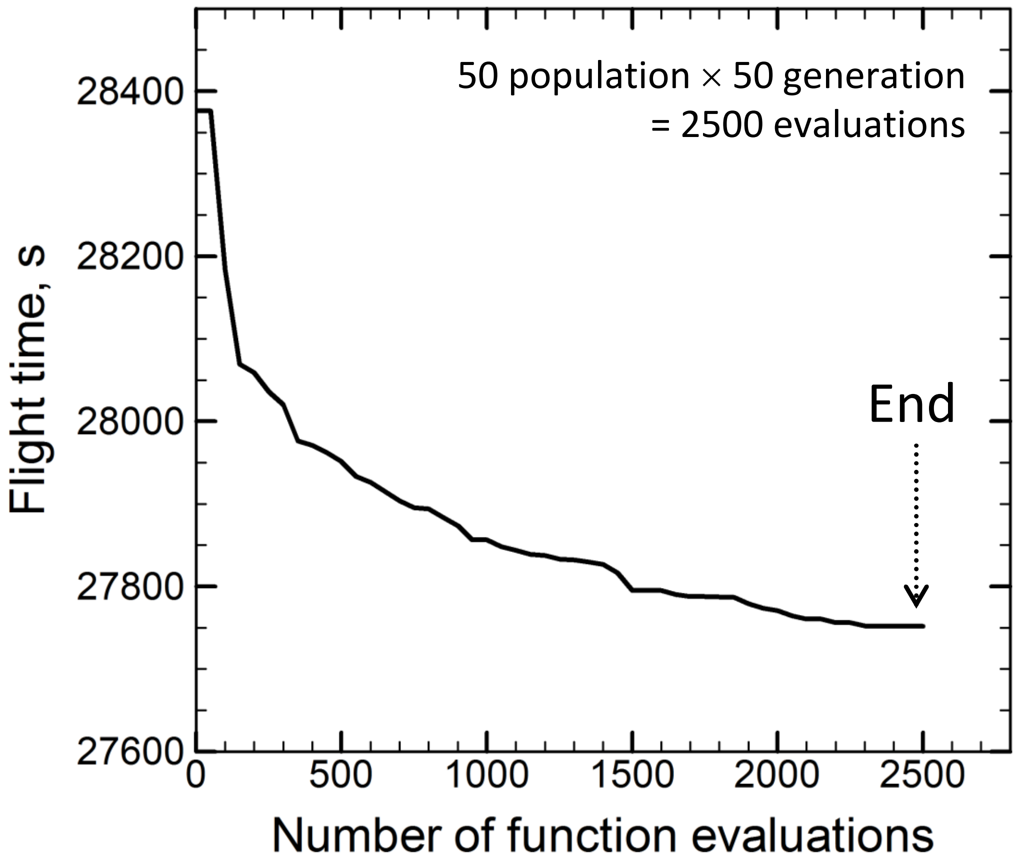
Comparison of Wind Fields and Trajectories (MUC to JFK)



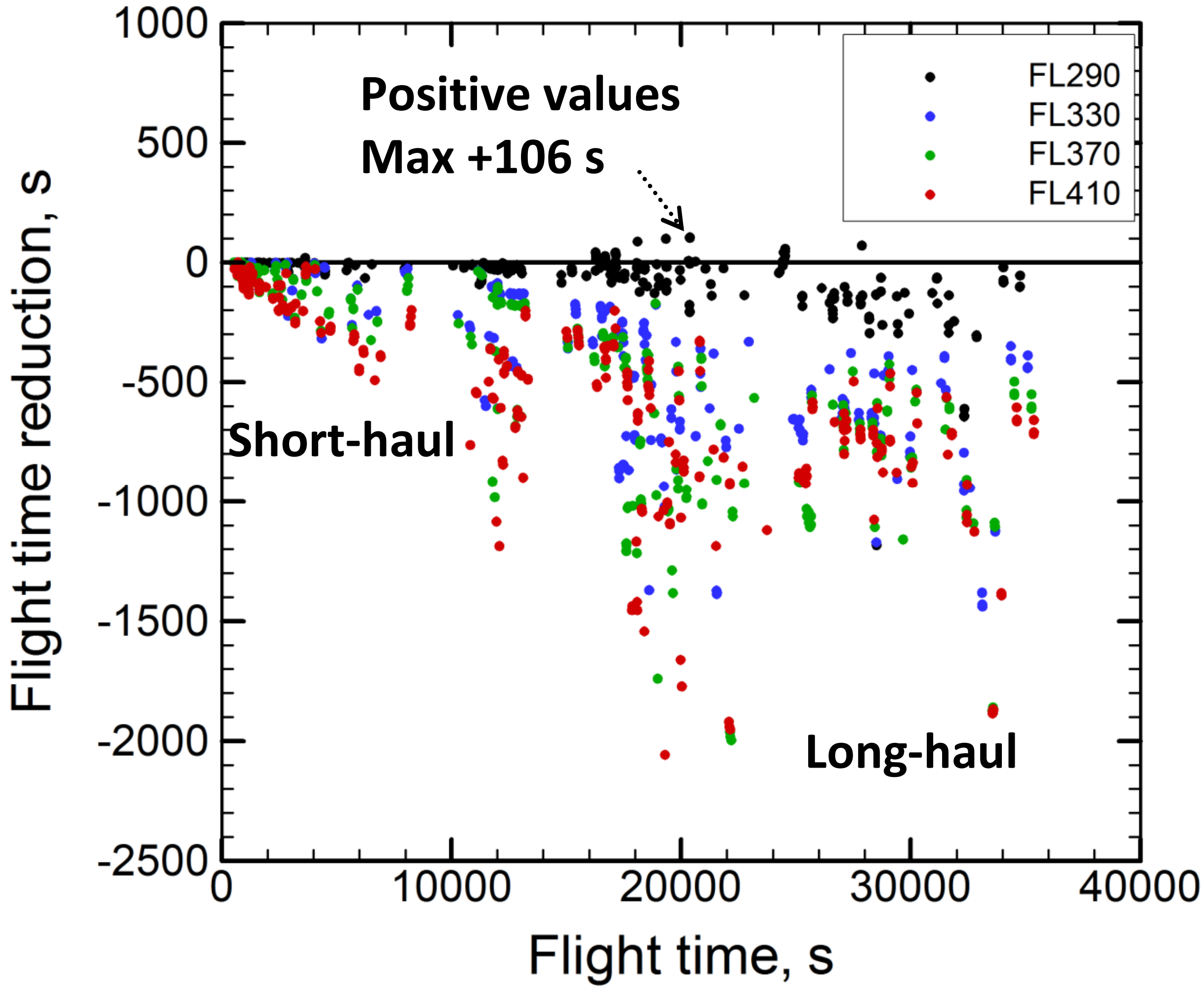


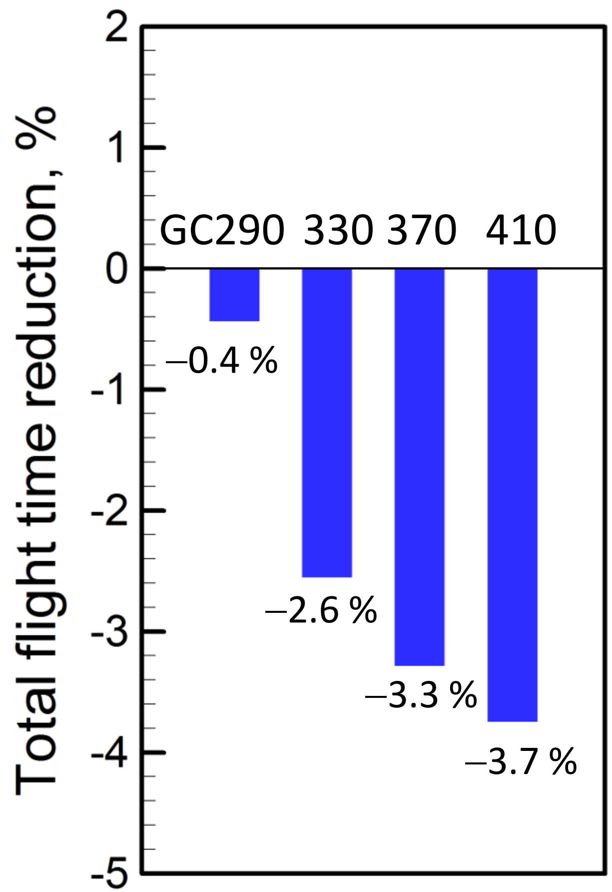
Comparison of Flight Time (MUC to JFK)





Flight Time Reduction by Wind-optimum Option (Global, One Day)





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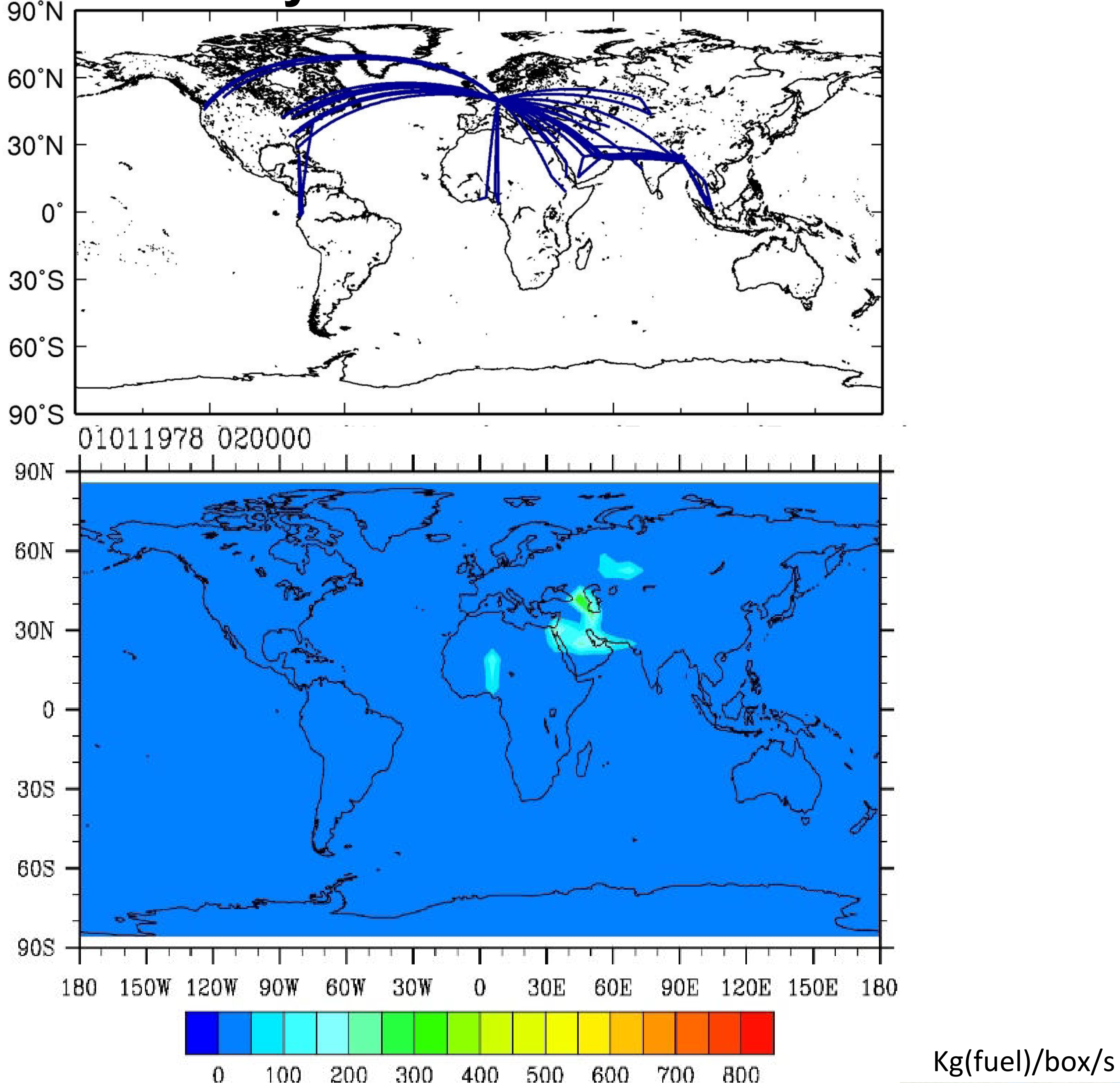
Fuel Usage of One-day Global Air Traffic



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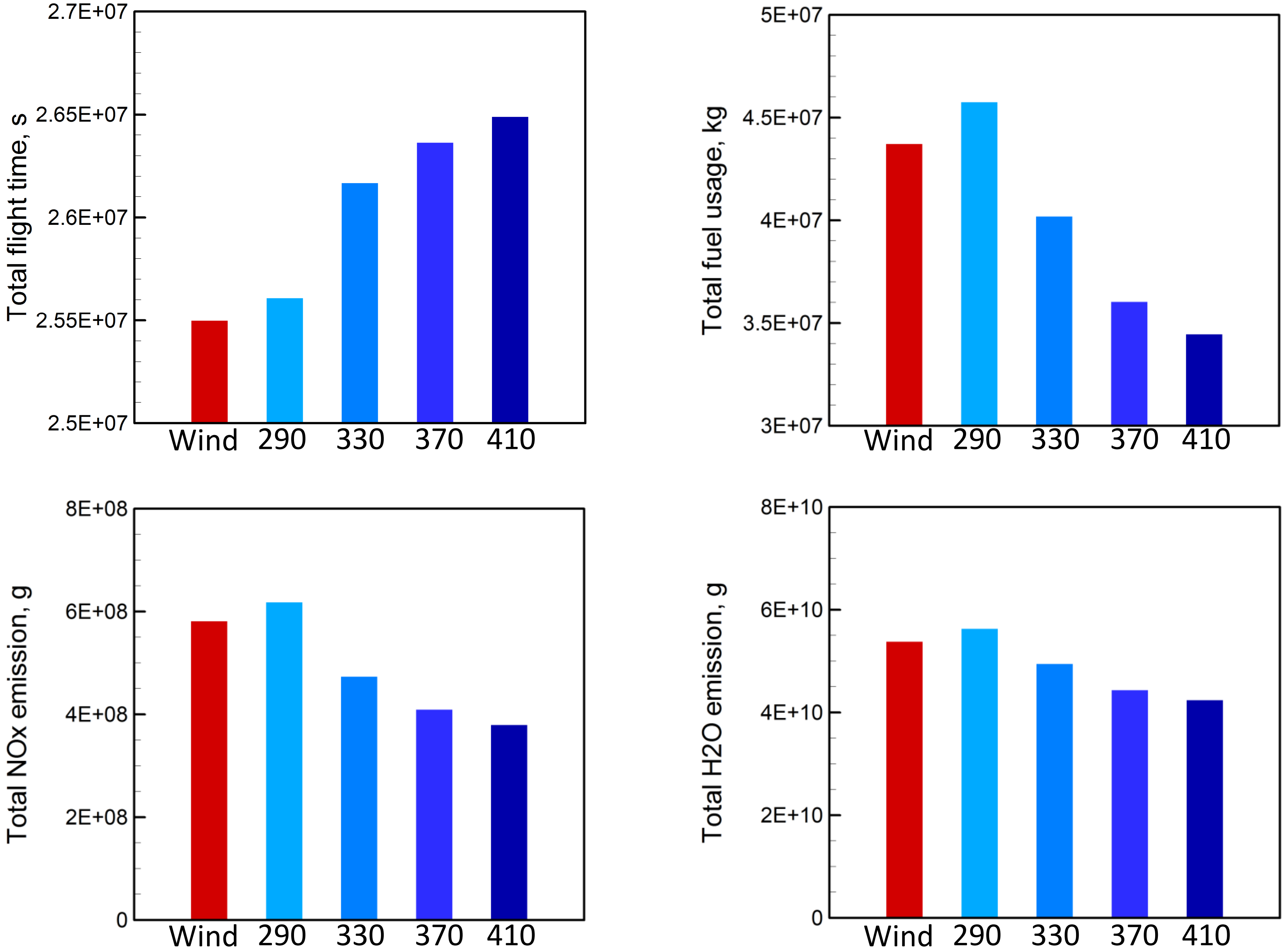
Comparison of Total Flight Time, Fuel, NOx, H2O (Global, One Day)



Summary

- New assessment platform AirTraf is under development to simulate global air traffic and assess routing strategies

- AirTraf can simulate global air traffic correctly with gc/wind optimum options

- One day test simulation was implemented
  - Optimizer could find superior trajectories in most city pairs
  - 0.4 to 3.7 % total flight time reduction by wind optimum option
  - Trade-off between total flight time and total fuel usage (= total NOx, H2O emissions)