The expected impact from the introduction of a new Strut-braced Wing aircraft configuration on global air traffic emissions and climate – Results from the WeCare project

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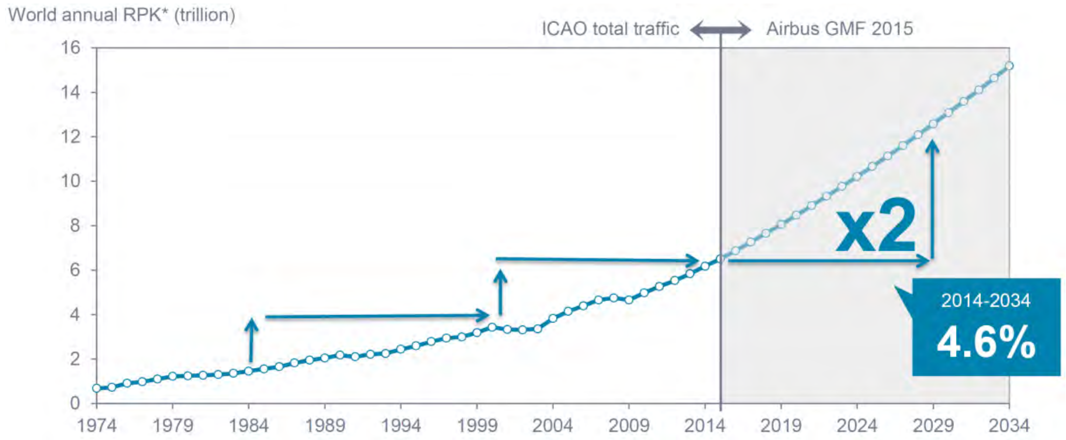
Motivation

- Gradual increase in air traffic demand is expected to result in a **multiplication of aircraft movements** in the coming decades
- **Emissions** from aircraft engines cause **significant changes of concentrations of radiative forcing agents** at usual cruising altitudes

➡ **Aviation's climate impact** an exceptional **challenge** which requires immediate actions

- **Various research projects** going on

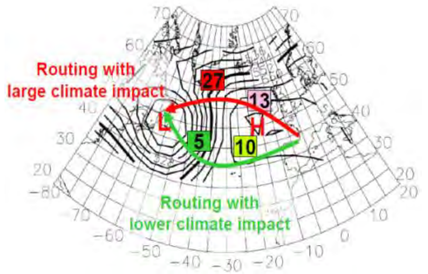


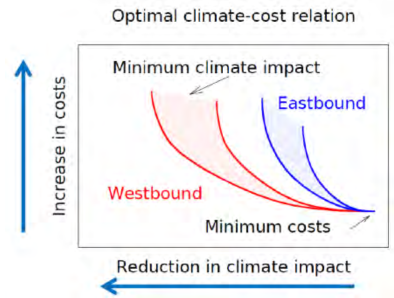
Airbus GMF, 2015


dpa/Handelsblatt

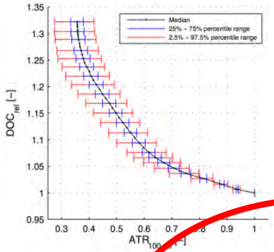
WeCare – Utilizing Weather Information for Climate Efficient and Eco-Efficient Future Aviation

- **Climate optimized routing:**
  - Quantify climate reduction potential of air traffic due to exploitation of varying local climate impact of non-CO_2-components (ozone, methane, contrail-cirrus) in varying weather situations
  - Interrelation with fuel consumption and cost





- **Cost-Benefit-Analysis of mitigation options:**
  - Comparison of cost-benefit potentials: tactical optimization (weather situated) vs. strategic optimization (new technologies and operational concepts)

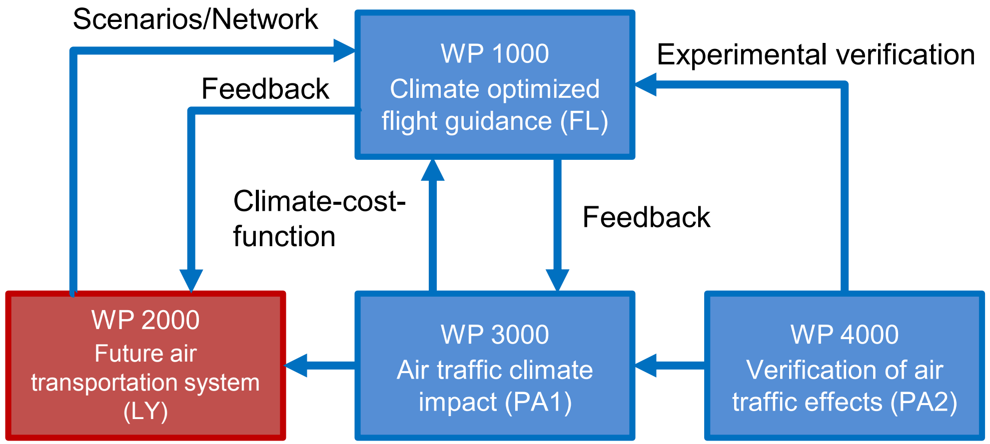


- **Verification of air traffic effects:**
  - Formulation of measuring strategies to determine air traffic effects on atmosphere (cloud formation and ozone)
  - Experimental verification of cloud modification due to air traffic (soot-cirrus effects)

WeCare
Modelling the future Air Transportation System

- Scenario based description of the global future air transportation system
- Modelling of future OD-demand, flight routes, fleet mix and aircraft operation
- Cost-benefit analysis of
  - operational strategies (e.g. flying lower/slower, intermediate stop operations)
  - technical strategies (e.g. BWB or strut-braced wing)

  to reduce the climate impact of the global air traffic



Strut-Braced Wing aircraft
General advantages

- Widely used for General Aviation, like e.g. Cessna 172
- Appearance and aerodynamics
  - supporting struts connecting the wings to the fuselage
  - reduced wing loads
  - allows for thinner wings
  - Increased wing span
  - Increased aspect ratio
  - **Higher aerodynamic efficiency** due to reduced induced drag
  - Reduced weight compared to similar cantilever wing design
- Propulsion
  - Smaller engines
  - **Reduced fuel consumption**
  - **Less emissions**

Cessna 172, copyright Olivier Cabaret

Purpose of this study

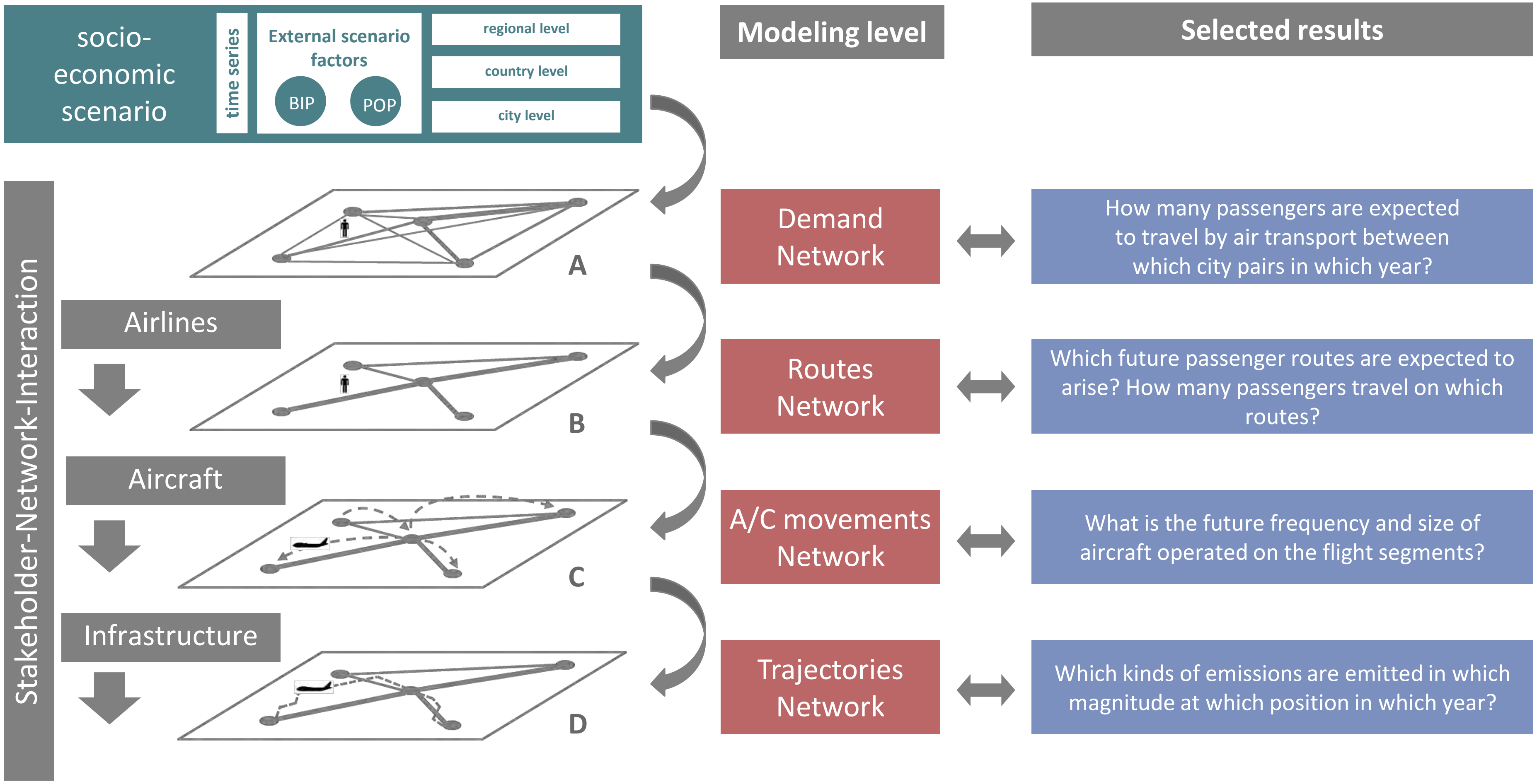
Assess the expected impact resulting from the introduction of the SBW aircraft configuration on global air traffic emissions and climate

- focus on the … ll as on the correspondin… nse over a period of 100 …)

While the environmental benefit due to a reduction of CO_2 emissions by an SBW introduction is straightforward, this is not the case for non-CO_2 effects

- local effects at airports, such as implications on noise and local air quality issues are not considered here

Four-layer approach implemented in WeCare

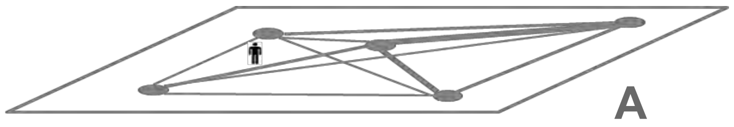


Ghosh et al., 2015

Air Passenger Demand Network
Layer A

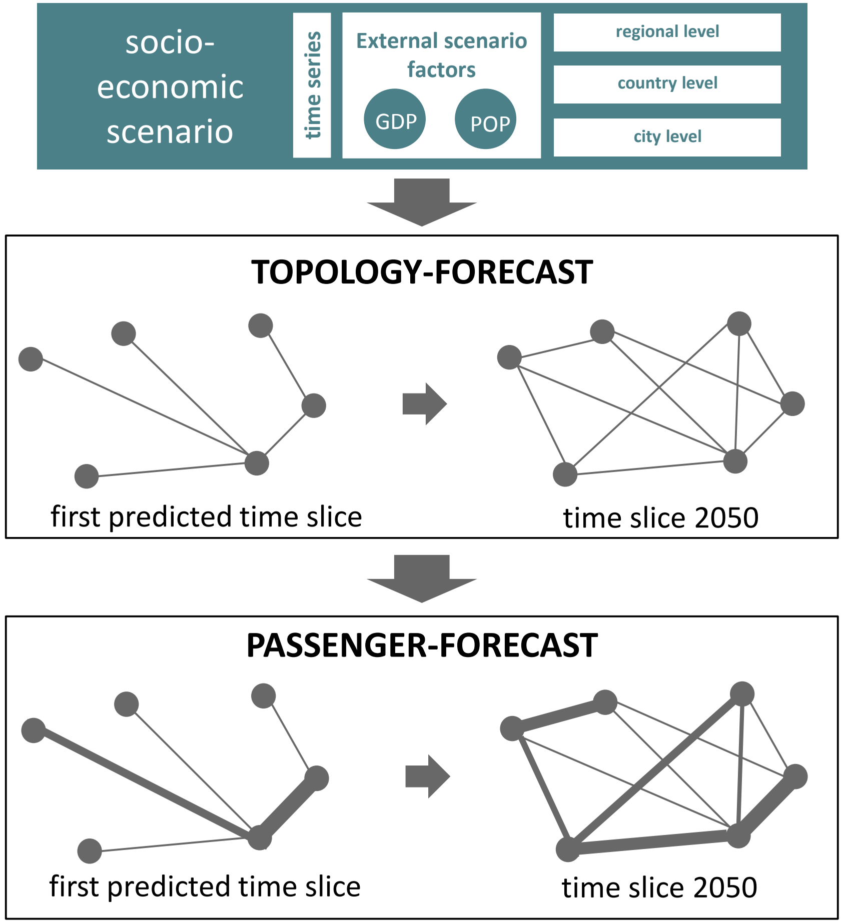
Air passenger demand forecast on city pair level based on predictions of GDP, population and oil price development

- How do cities develop over time?
- How does the mobility of passengers change over time?
- Which are future main demand connections between cities?
- Which future level of demand is expected for individual city pair connections?



Demand Network

↳ Evolution of the demand network topology
↳ Evolution of the number of passengers on city pairs

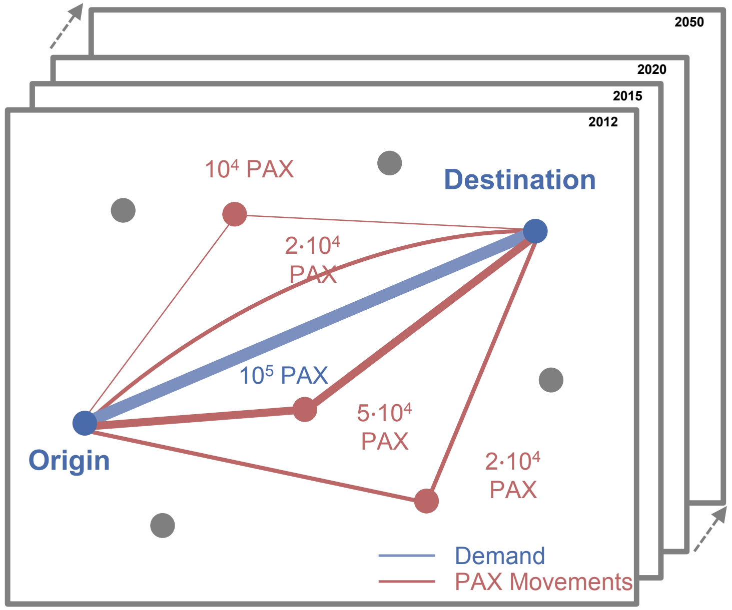


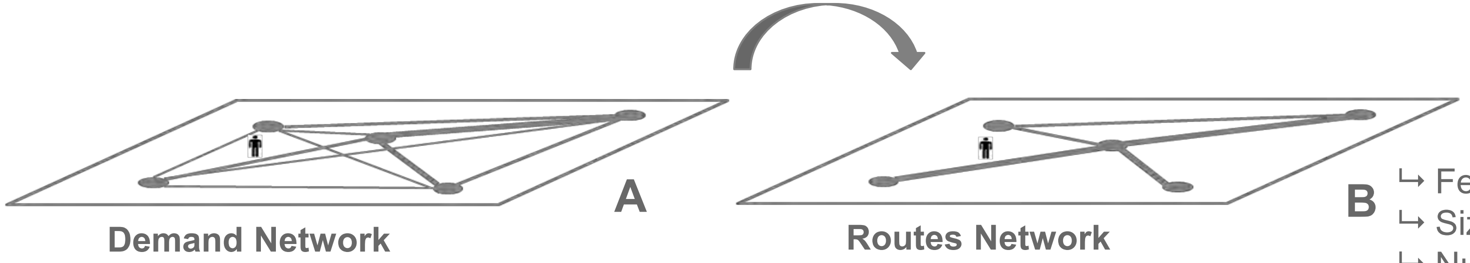
Terekhov et al., 2015

Passenger Routing Network
Layer B

Derivation of passenger routes and detour in between city pairs.
First deduction of the *location* of future aircraft emissions.

- How is the air passenger demand split into different passenger routes? Where arise new routes and connecting airports?
- How large is the probability for the choice of a particular route?
  ↳ *maximum number of transfers*
  ↳ *minimum distance of segment*
  ↳ *maximum detour factor*
- How do the routes on which air passengers travel change over time?





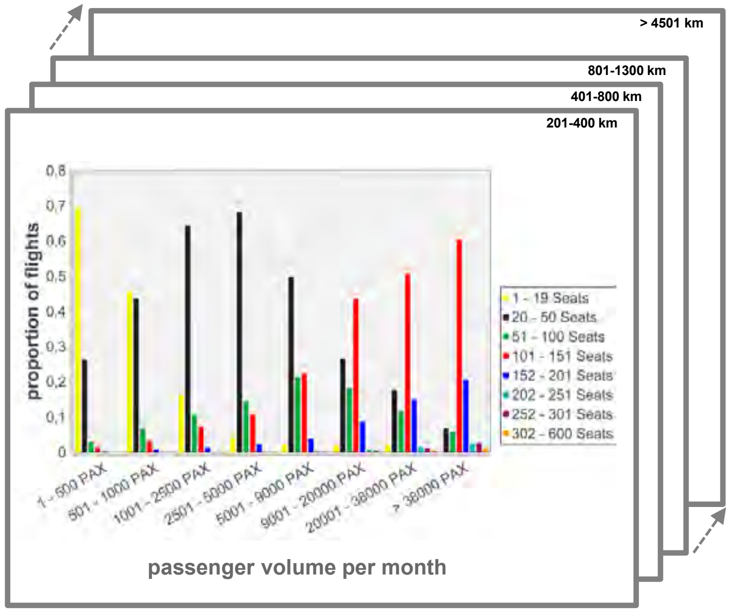
↳ Feasible passenger routes consisting of multiple flight segments
↳ Size of passenger flows
↳ Number of passengers per segment

Kölker et al., 2016

Aircraft Movements Network
Layer C

Deduction of *species* and *specific amount* of future aircraft emissions through the allocation of aircraft types to a flight segment.

- What is the frequency of flights per seat category on segment basis?
- Which size of aircraft is feasible on which route?
- How many aircraft of each seat categories may be required in which year?
- How strong is the demand for new aircraft of which seat categories in which year?
- Which routes are promising for revolutionary new aircraft designs?



Kölker et al., 2016

Routes Network

A/C Movements Network

Number of flights on segment basis
↳ by seat category
↳ by generation of aircraft

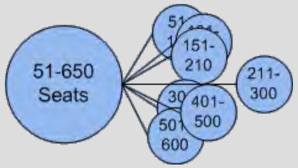
FFWD - Fleet renewal model

Modeling a gradual SBW introduction into global fleet

Fleet renewal model
FFWD (Fast Forward)

1 Status quo

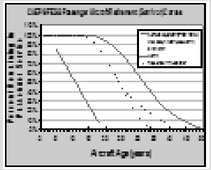
- Current fleet
  - Civil fleet
  - Sub-fleets



ASCEND
fleet data

2 Aircraft categories

- Shares by seat category
- FESG retirement curves



ICAO FESG
forecast

3 Growth scenario

- RPK growth: global and by seat categories
- Shift of market shares by seat categories
- Seat load factor sceanrio by seat categories

AIRCAST
aircraft movements
network

4 Fleet Forecast

- Fleet in service
- Retirements
- Deliveries

5 New aircraft

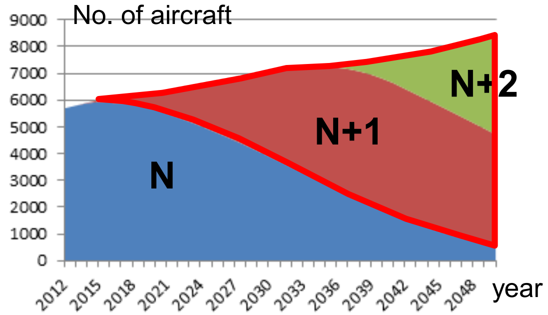
- Technology timeline
- Introduction pattern over all seat categories
- Generic aircraft

AIRCAST
aircraft movements
network

- A fleet renewal model is used to determine **the numbers of aircraft in service** distinguished by type and generation
- SBW aircraft configuration substitute for current aircraft serving 101-150 seat category (e.g. Airbus A320, Boeing B737)

A

B



Apffelstaedt et al., 2008

aircraft movements network

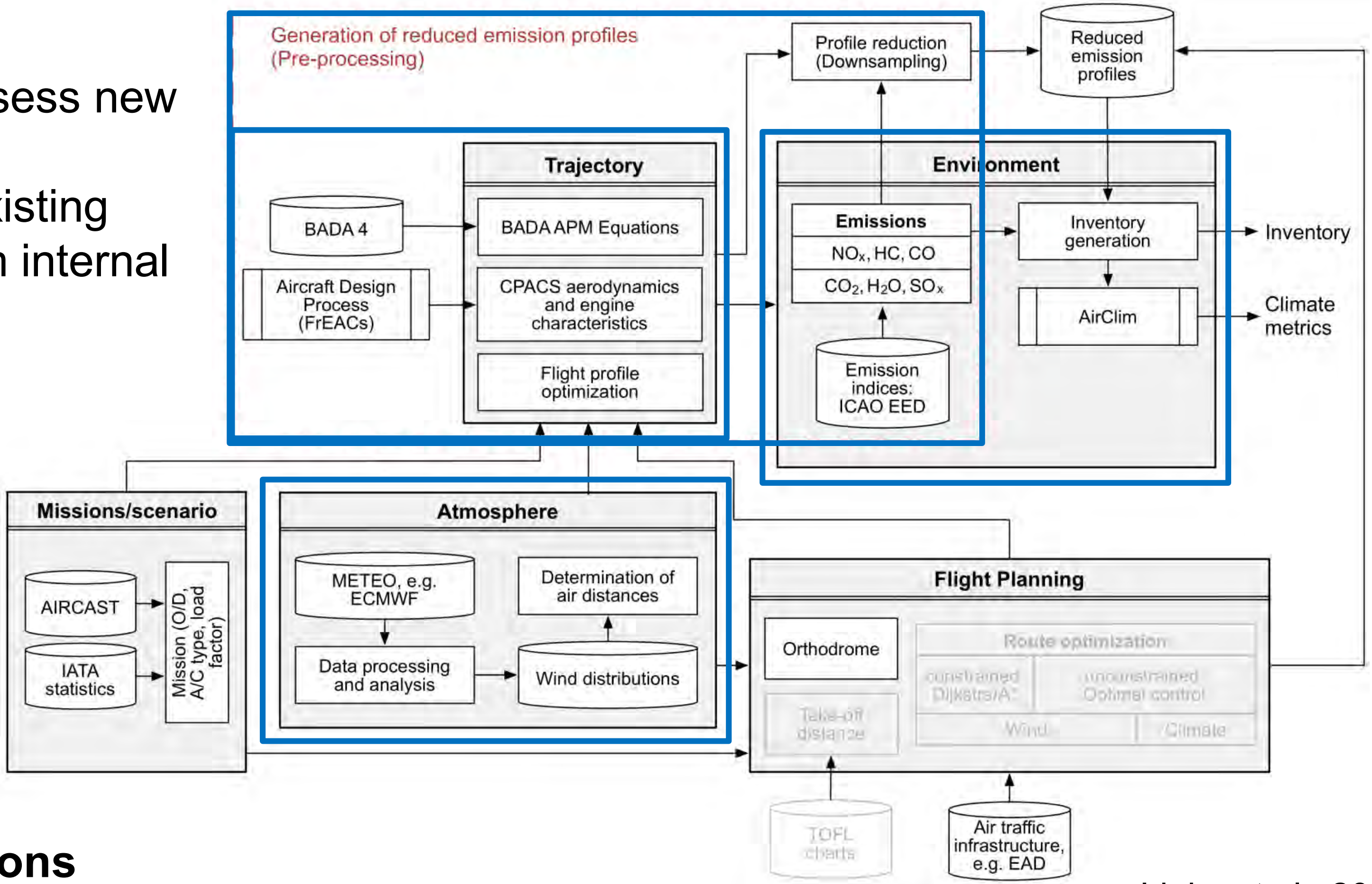
aircraft movements network
with aircraft generation information

Aircraft movements network for SBW operations
Seat category 101-150 seats

- Assumptions:
    - SBW aircraft configuration **substitute** for current aircraft serving **101-150 seat category** (e.g. Airbus A320, Boeing B737)
    - Category contributes today to about 18-19% of globally Available Seat Kilometres (ASK)
    - SBW **introduction starts 2015**
    - Assessment year 2050
    - Gradual **increase of SBW share** according to fleet renewal model
    - Reference case for assessment: **A320 used as reference aircraft**, same technology level maintained until 2050 („Business as usual“)

Methodology
Application of DLR‘s Global Air Traffic Emission Distribution Laboratory

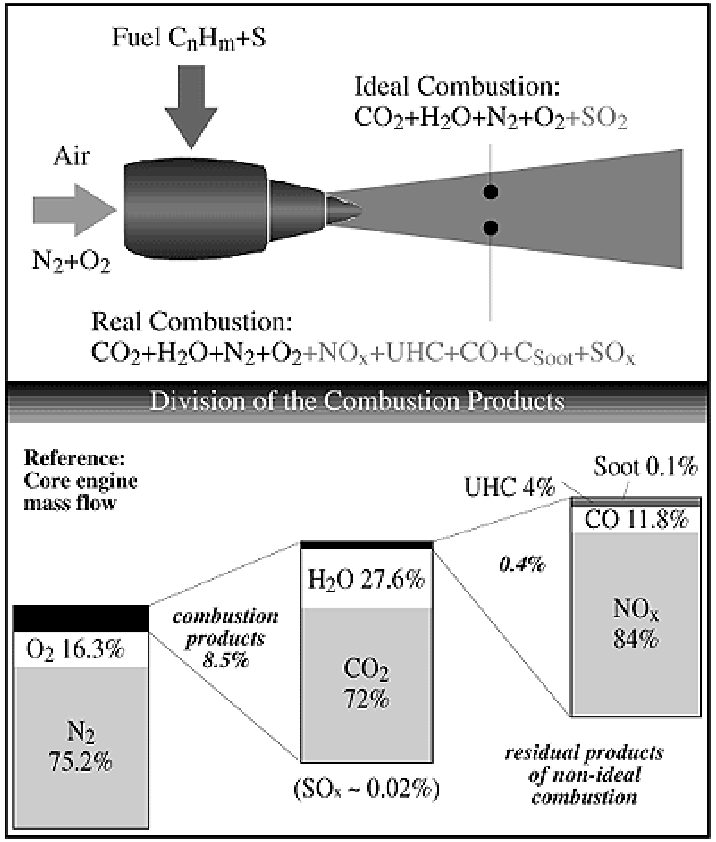
- GRIDLAB includes features capable to assess new technological or operational measures:
  - **A/C performance models** both for existing aircraft (BADA4) and new aircraft from internal design process
  - **Realistic flight operations** through the use of
    - Vertical profile optimization **(step climbs)**
  - **Emission model** (Boeing Fuel Flow Method 2) and **interface to climate model**
  - Complexity reduction by use of **emission profiles**
  - Real atmosphere and **wind distributions**



Linke et al., 2016

Determination of engine emissions

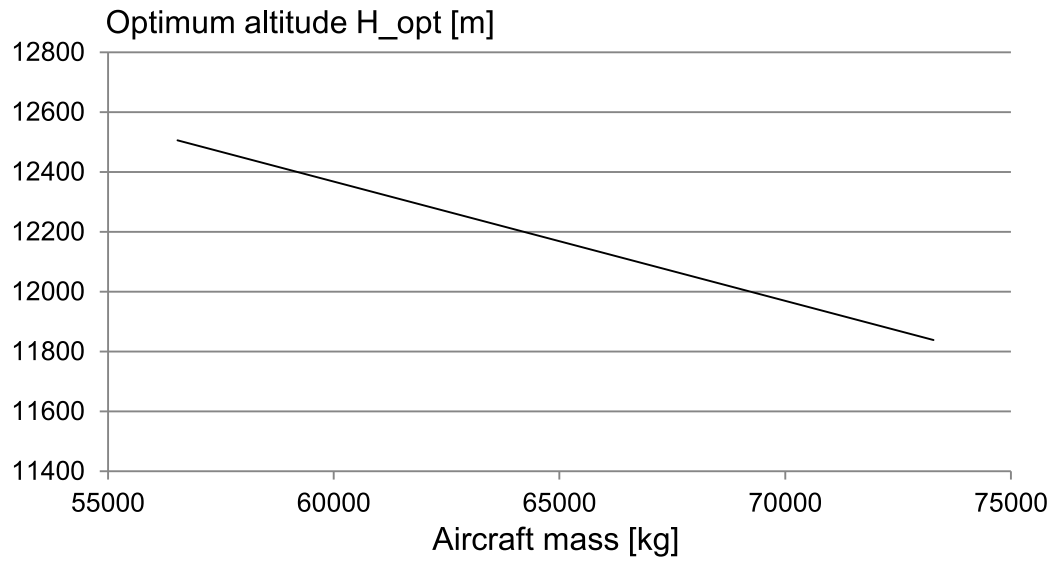
- Based on fuel flow correlation method:
  - **Boeing-Fuel Flow Method 2 (EEC)**
- Emission indices taken from ICAO Engine Emission databank
- Fuel flow corrected to sea level conditions
- Emission species include CO_2, NO_x, CO, HC, H_2O, SO_2
- Emission indices of CO_2, H_2O and SO_2 assumed to be constant

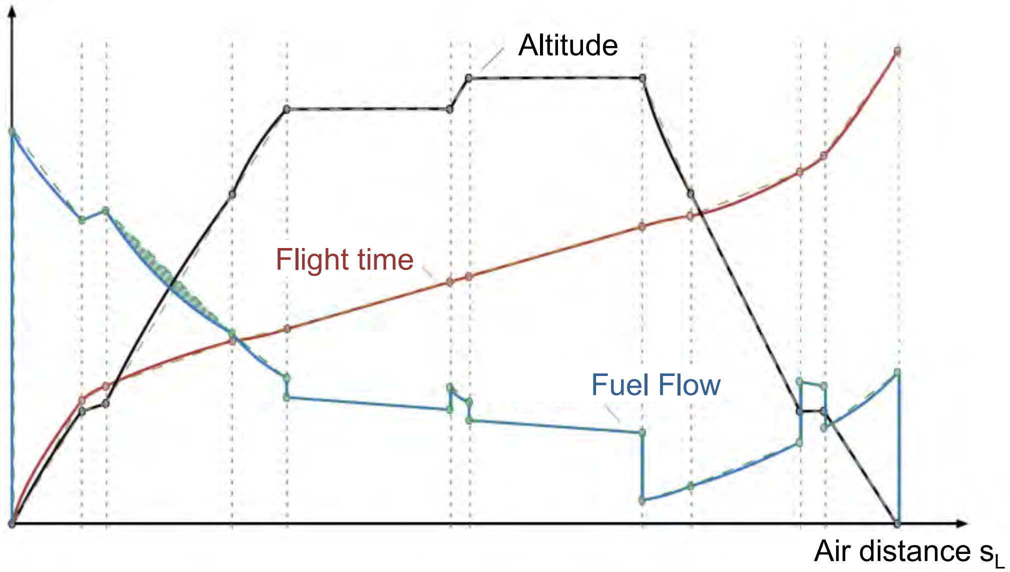


IPCC, 1999

Reduced emission database
Generation of database

- **Complexity reduction** for system-wide analyses
- **Generation** of emission profile **database**:
  - trajectories calculated for a parameter variation of range and load factor using TCM
  - vertically optimized profiles assumed (cruise at H_opt with Mach_LRC, taken from BADA tables and from cruise optimization)
  - emission distributions calculated
  - **A/C state values** (altitude, time, fuel flow, emission flows) **at profile vertices stored** as a function of distance travelled

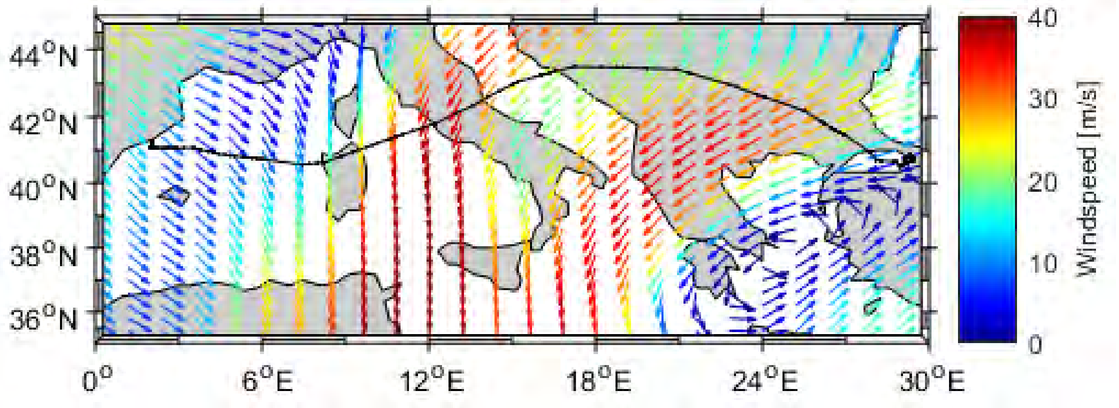


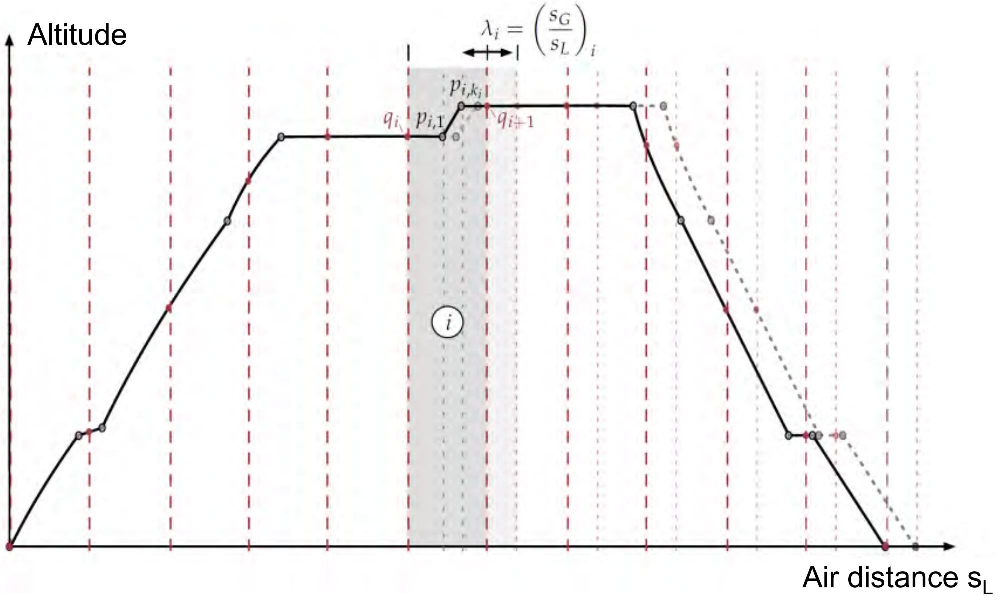


Reduced emission database
Database usage

- **Database usage**:
  - **scaling** (stretching/ compressing) of *nearest neighbor* profile to actual air distance travelled (may account for wind and flight inefficiencies)
  - Actual **air distance** determined based on ECMWF weather data assuming constant mean cruising altitude and speed
  - **projection** into geographical reference system (-> emission grids/inventories)

Wind situation along flight from Barcelona to Istanbul leading to an air distance of 2571,8 km (ground distance: 2542,1 km)





SBW aircraft and engine characteristics

- Preliminary a/c design specifications obtained from DLR project FrEACs
- Aircraft equipped with a **Counter-Rotating Open Rotor (CROR)** engine
    - high propulsion efficiency
    - large rotor diameter and respective ultra-high bypass ratios
    - no additional weight and drag caused by large nacelles as with turbofan engines of similar size
- DLR-CROR is assumed to contain a **Twin Annular Premixing Swirler** (TAPS)
    - two-stage lean combustion technique
    - allows for a **significant reduction of NO_x** emissions under cruise conditions
    - Emission Indices estimated using both LTO data from ICAO's engine emission databank and a thermodynamic process model (cruise) for similar GEnx-1B70 engine at DLR

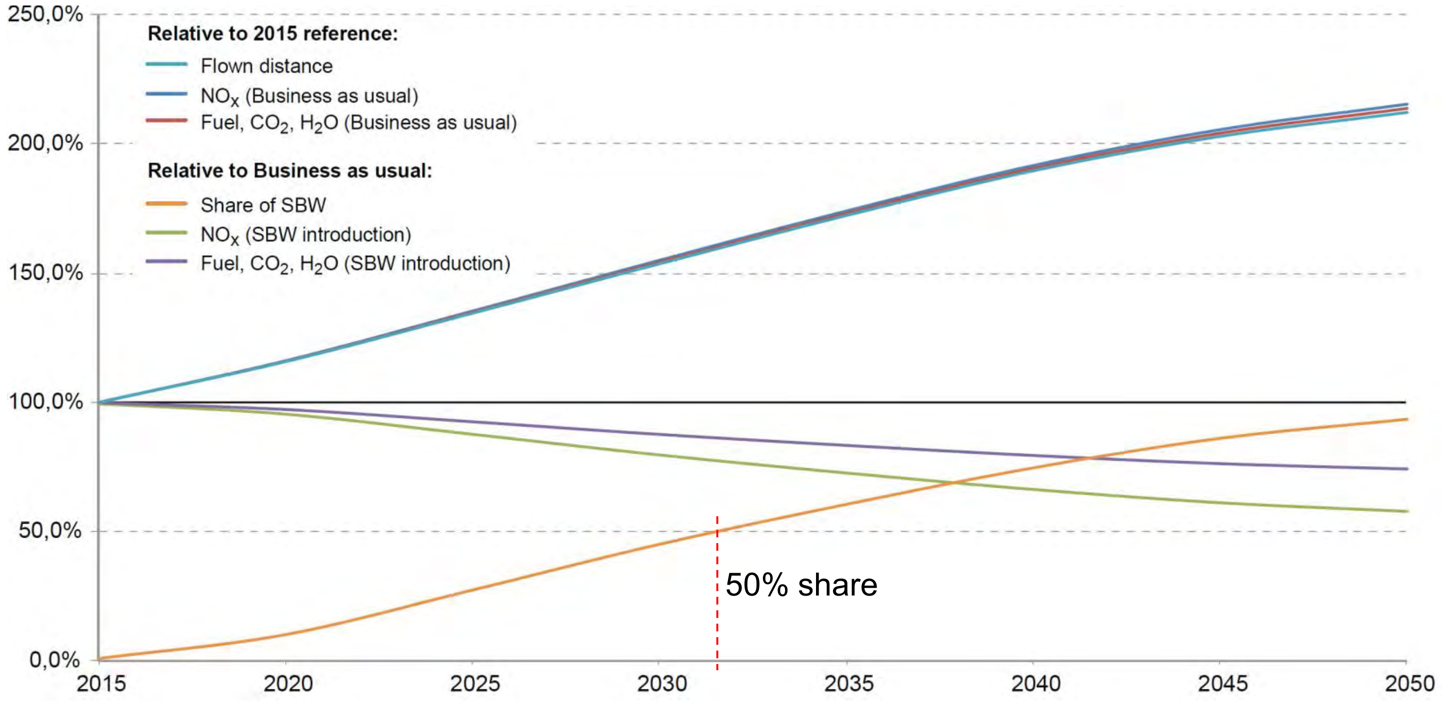
copyright: SNECMA

Design range	2000 NM
Maximum take-off weight	73.2 t
Maximum payload	18.6 t
Maximum fuel capacity	9.8 t
Reference wing area	110 m²
Pax seats (up to)	154
Cruise Mach number	0.72
Take-off field length	1970 m
Engine	DLR-CROR
Thrust	111.2 kN

Source: project FrEACs

Results

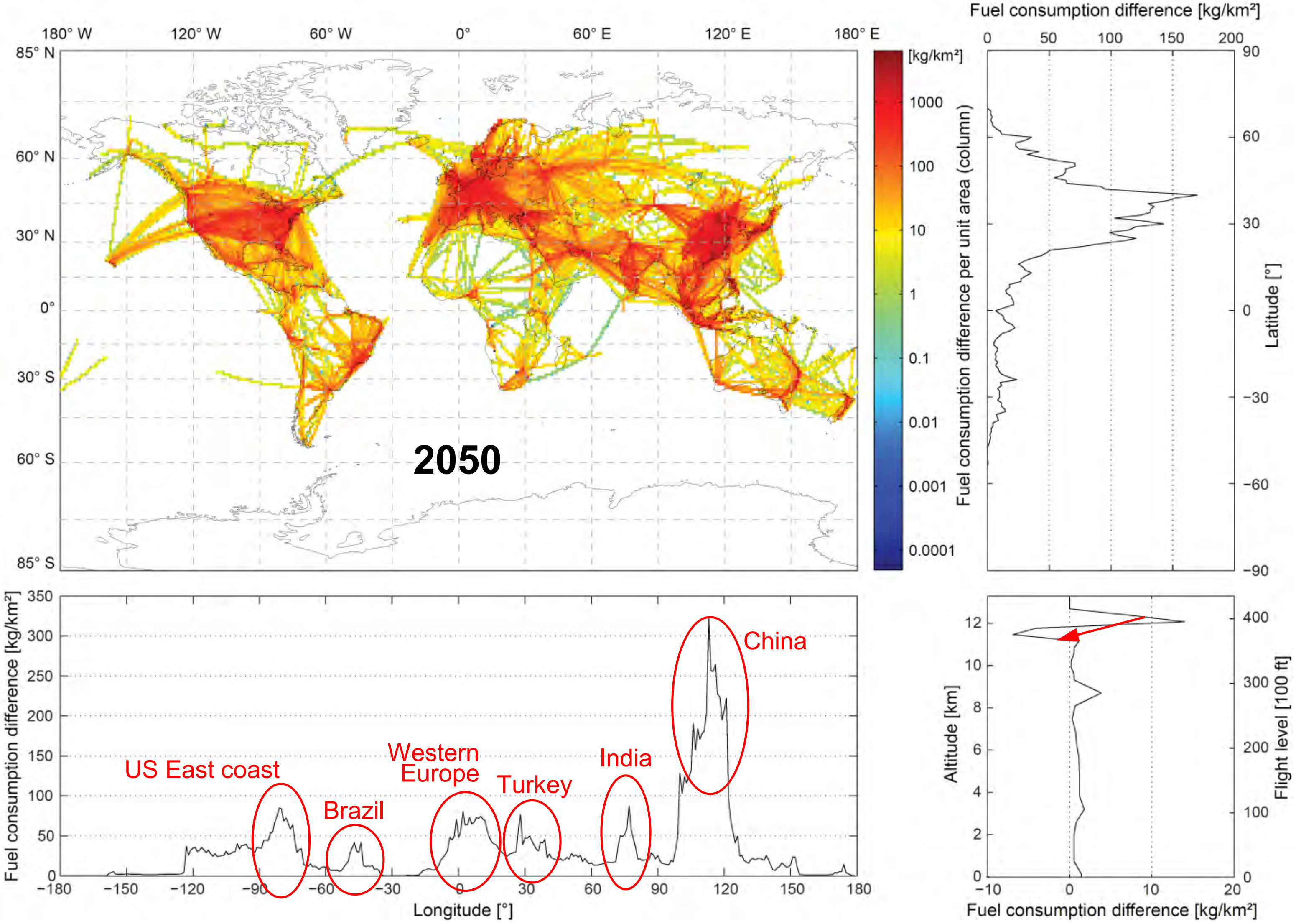
Introduction of SBW aircraft into the global air transportation system



- Share of SBW in the respective category reaches 50% by 2032 and 93% by 2050
- Flown distance more than duplicates by 2050, also fuel consumption and NO_x emissions (business as usual)
- SBW introduction may achieve **26% fuel reduction by 2050**
- even **45% NO_x emission reduction** due to low-NO_x combustion

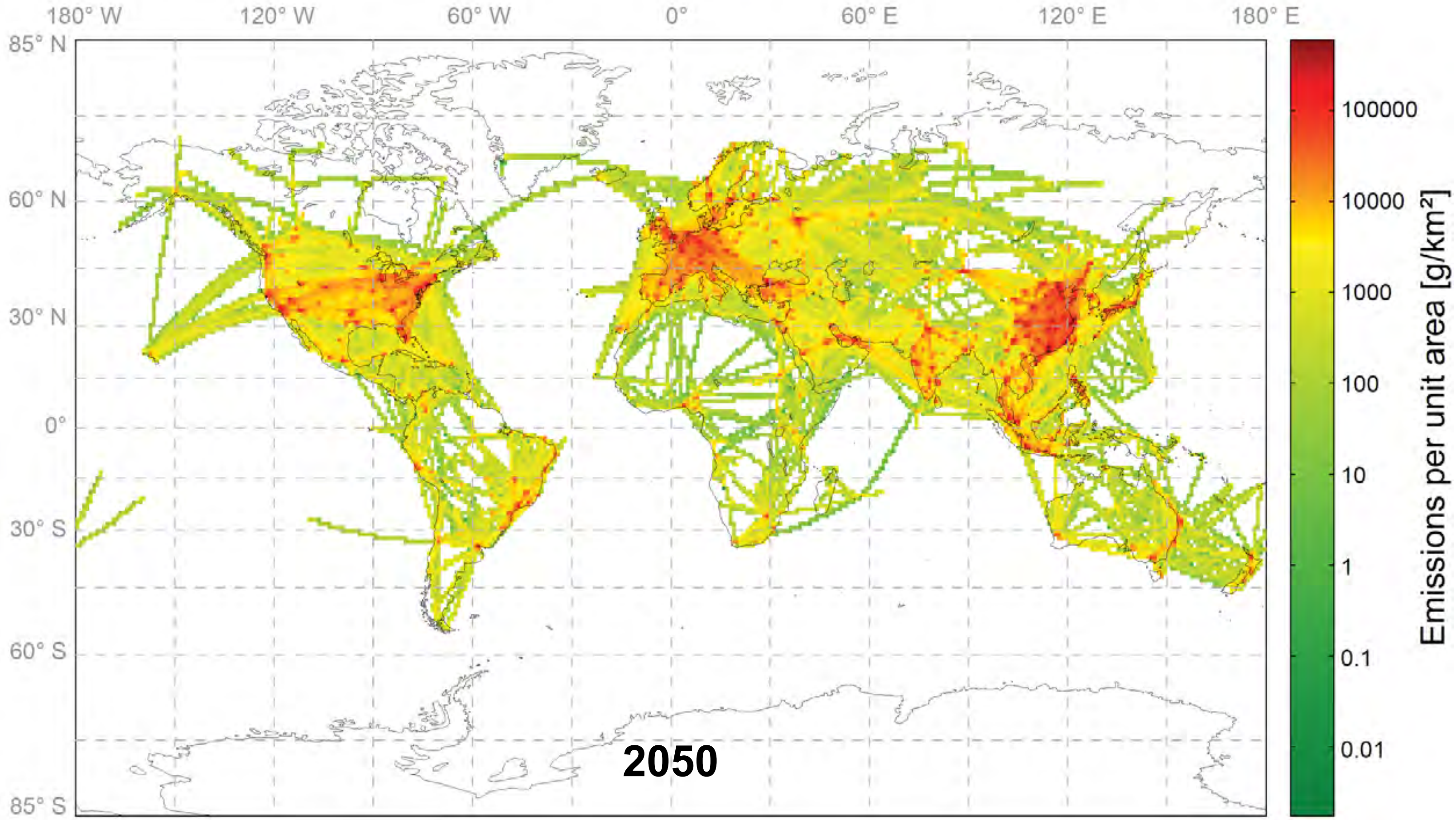
Results
Fuel savings

- Regions of dark red color mark areas of large fuel savings
- The more flights with SBW are operated on those routes, the more fuel can be saved
- **Chinese airspace** is characterized by large potential savings
- Slight **shift of fuel burn** in cruise from 39000 ft altitude **to lower flight levels**
- Lower optimum altitude curves of SBW aircraft compared to conventional (A320)



Fuel consumption changes in 2050 due to a SBW aircraft introduction (positive values depict reductions with respect to business-as-usual scenario)

Results
Distribution of NO_x emissions in 2050

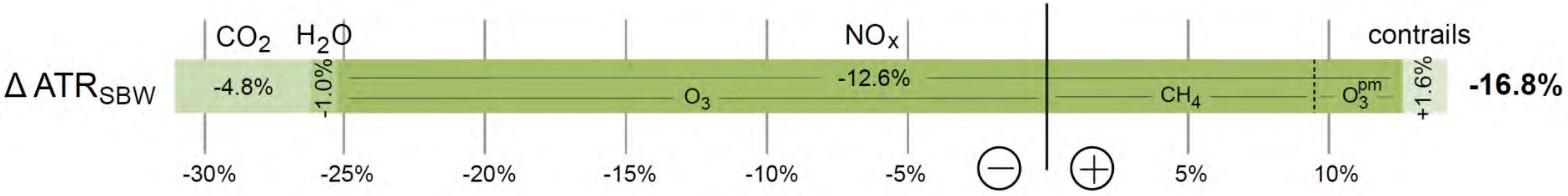


- NO_x emissions primarily develop in **flight phases with a high engine load**, like e.g. during take-off and climb
- Hence, high NO_x concentrations can be found in the **vicinity of airports**
- Logarithmic scale allows for the observation of future “mega cities”

Results - Climate impact assessment

- Climate metric: **Average Temperature Response (ATR^{100})** suitable for the assessment of operational and technological measures (continuous emission production and dynamics of climate system considered)
- ATR determined using the climate response model **AirClim** (*Grewe & Stenke, 2008; Dahlmann et al., 2016*)
- SBW introduction starting 2015
- **Reduction of warming by nearly 17% possible by SBW introduction!**
- Impact of
  - CO_2: decreases
  - O_3: decreases (
  - CH_4: reduced co
  - PMO: reduced c
  - H_2O: slightly decreases (lower altitudes, faster mixing processes)
  - Contrails: slightly increases (lower altitudes)

Overall, reduced fuel consumption, less NO_x emissions and lower average flight altitudes result in a positive climate impact of the SBW introduction!



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Summary, conclusions & outlook

- Global emission distribution and a climate impact assessment for the introduction of a SBW aircraft into the air transportation system have been presented
- SBW have the potential to **reduce the fuel consumption** of the aircraft fleet of the seat category 100-150 seats **by ~26%** in 2050 and **NO_x** emissions even more **by 45%**
- This large reduction potential in combination with a slightly lower cruise altitude compared to today's reference aircraft may **reduce the warming** caused by aircraft of that size (including the projected growth in the future) **by nearly 17%**

- SBW design process not yet fully accomplished and only **preliminary performance data** was available
- CROR NO_x emission indices were estimated based on **simplifying assumptions**
- Aircraft **substitution plan** based on the assumption that the SBW aircraft is directly used to substitute today's short-haul aircraft
- Future research could spend more effort in modeling also **intermediate technology-levels** (i.e. next generation of short-haul aircraft already introduced, like A320neo, B737MAX)

Thank you for your attention! Questions?

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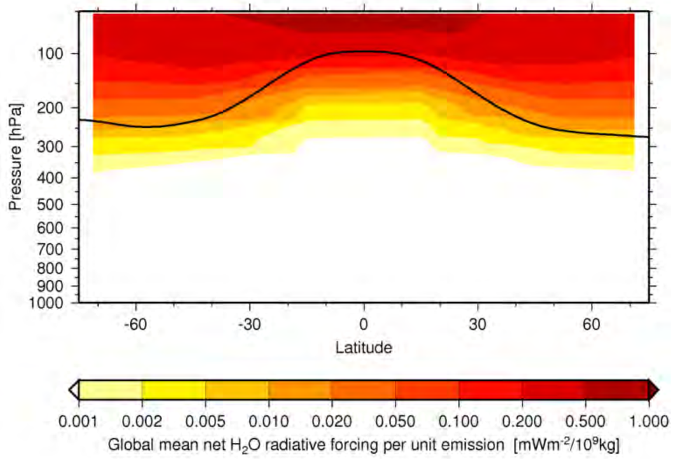
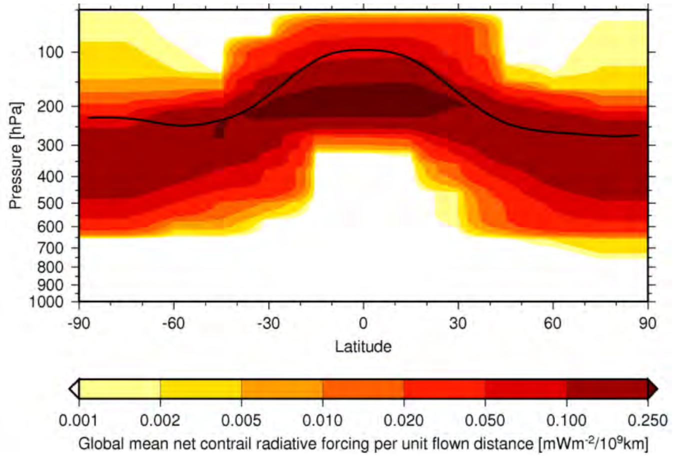
Backup - Radiative Forcings // Fichter et al. 2009

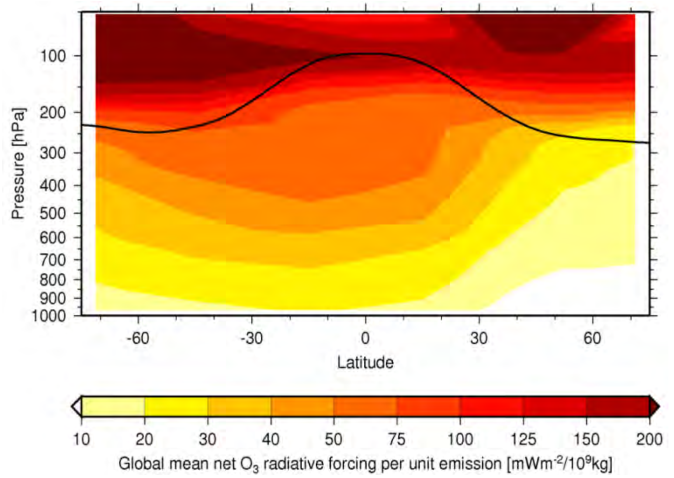
H_2O RF



Contrail RF



O_3 RF



ΔCH_4 lifetime