Climate Impact Mitigation Potential of Formation Flight

3rd ECATS online conference

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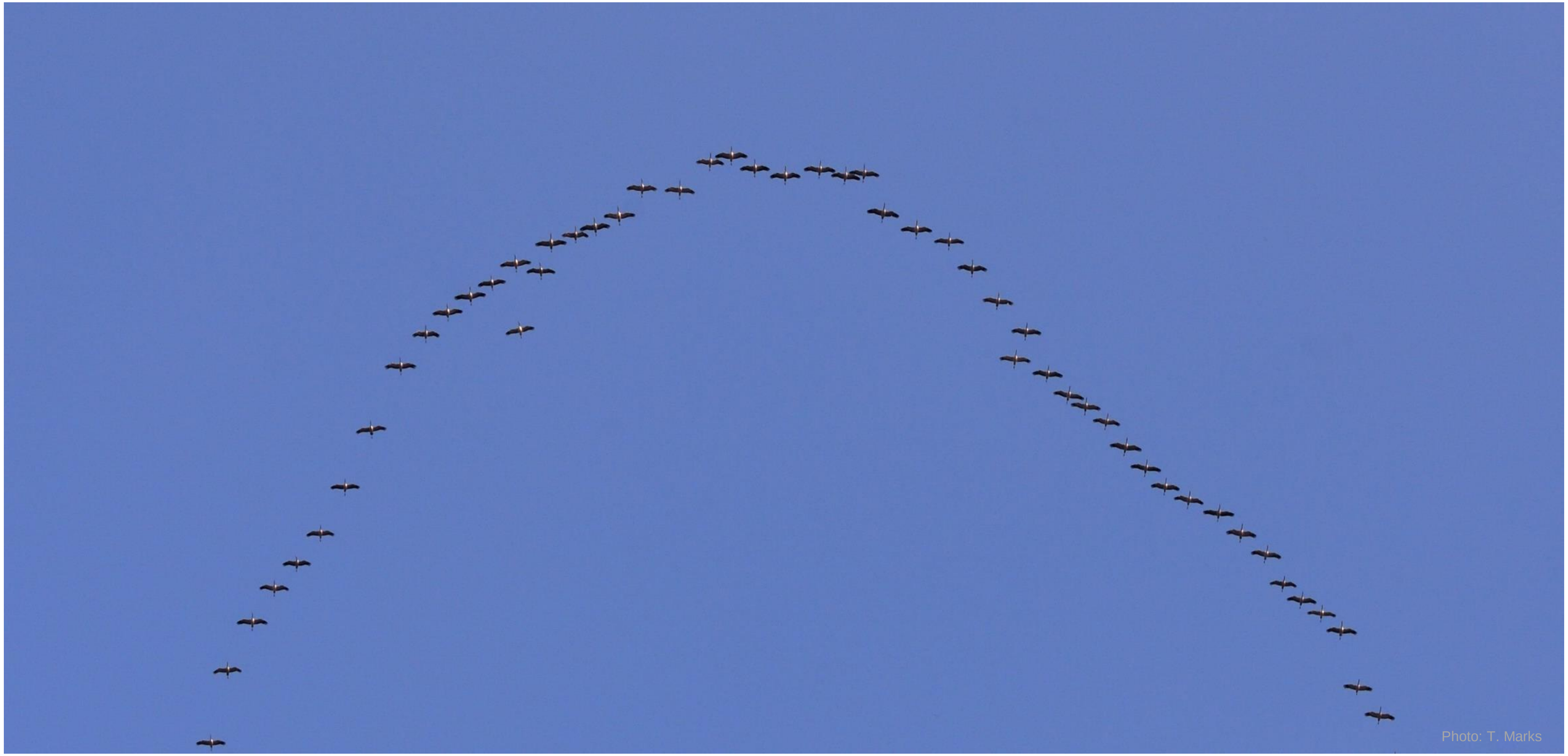
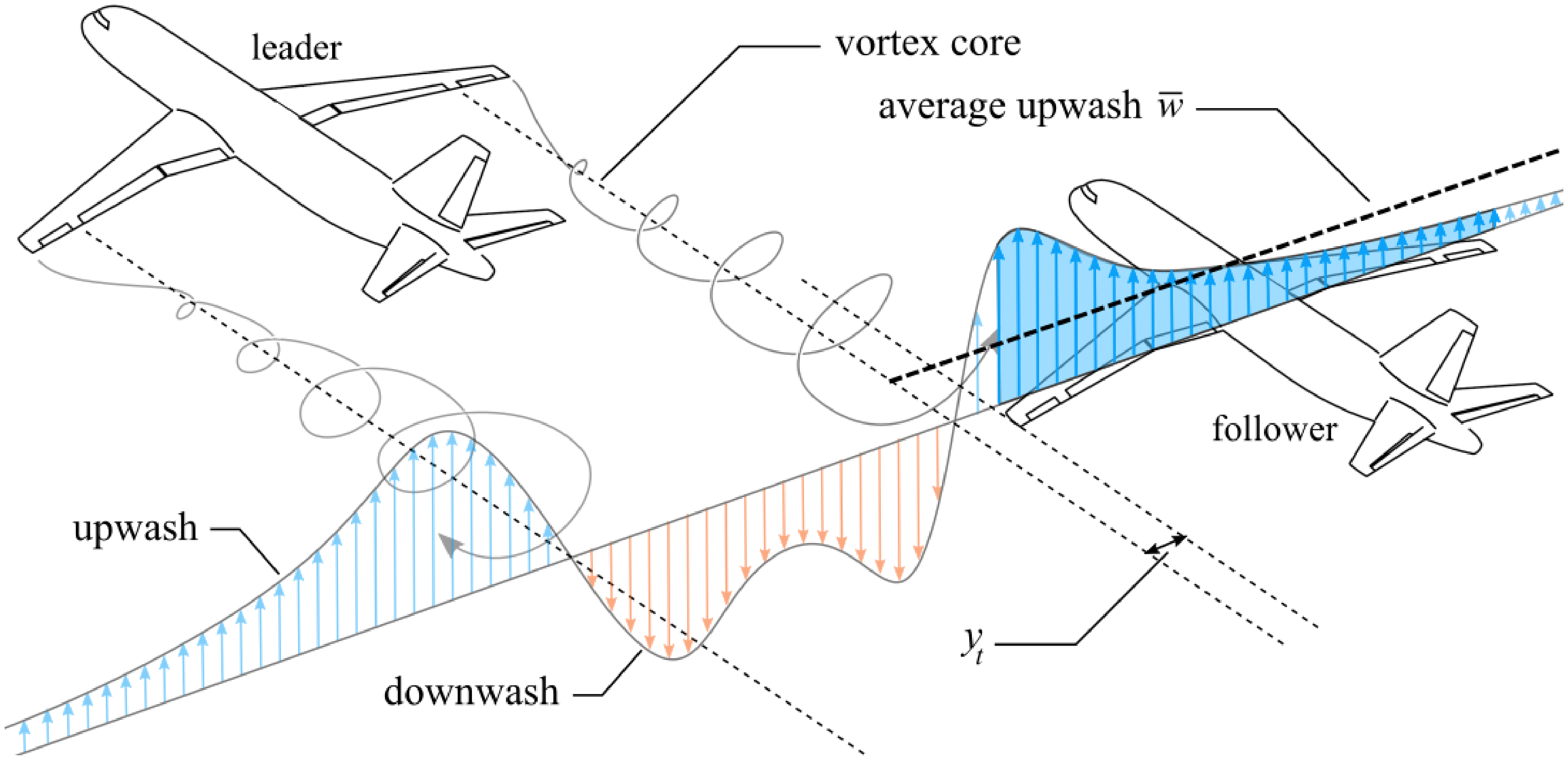
Formation flight in nature



Aircraft Wake Surfing for Efficiency (AWSE)

Aerodynamics in the formation



Research Question

- Formation Flight leads to
  - Adapted routing
  - Adapted timing
  - Changed amount of emissions
  - Saturation effects

How large the climate mitigation potential can be?

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

TUHH Technische Universität Hamburg

ILT Institut für Lufttransportsysteme

RWTH AACHEN UNIVERSITY

- **FORMIC**

  Formation Flight Impact on Climate
- German government funded

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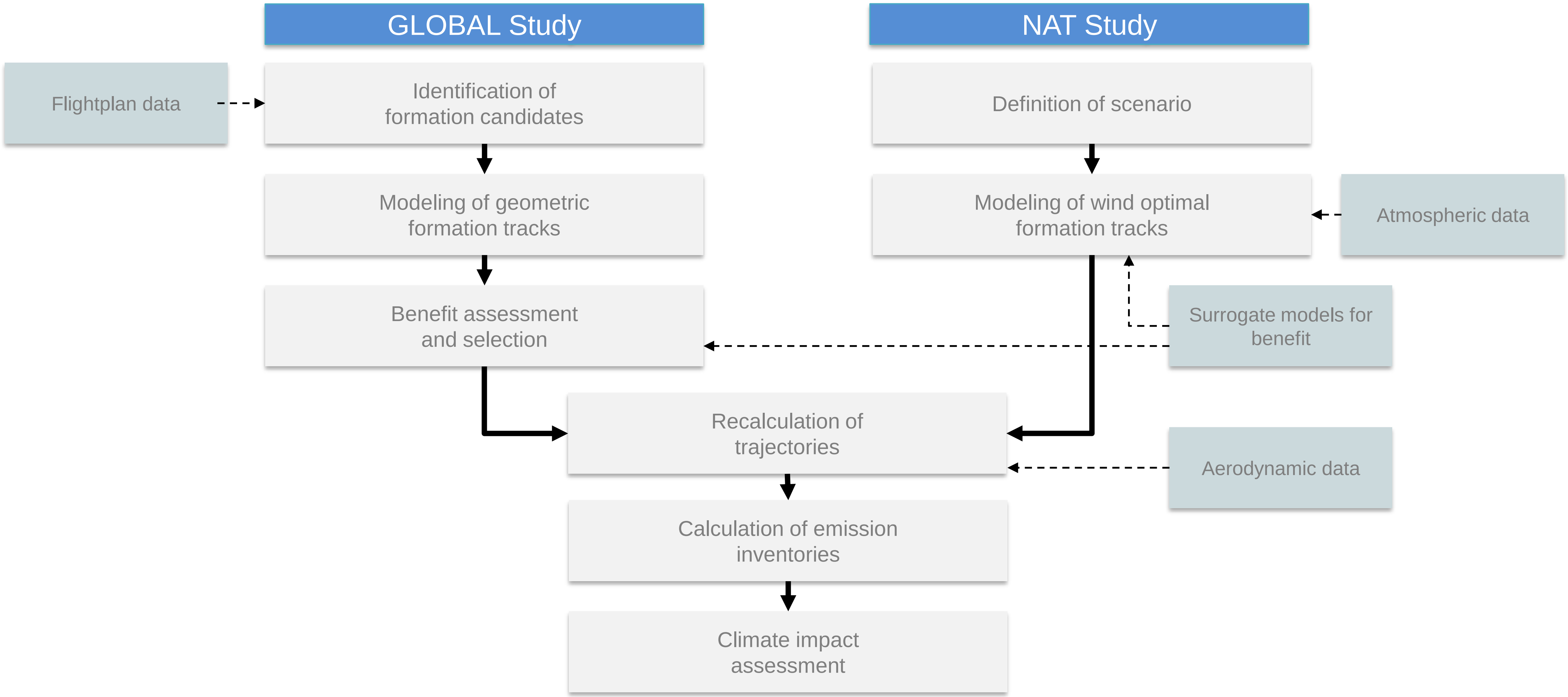
General approach



Scope and settings (GLOBAL)

AWSE Assumptions

- Two aircraft formations
- Extended Formation Flight (EFF)
- No positional changes
- One formation segment
- Fixed cruise altitude and speed

Scenarios

- T30: 30 top airports
- T50: 50 top airports
- **ALL: all airports**

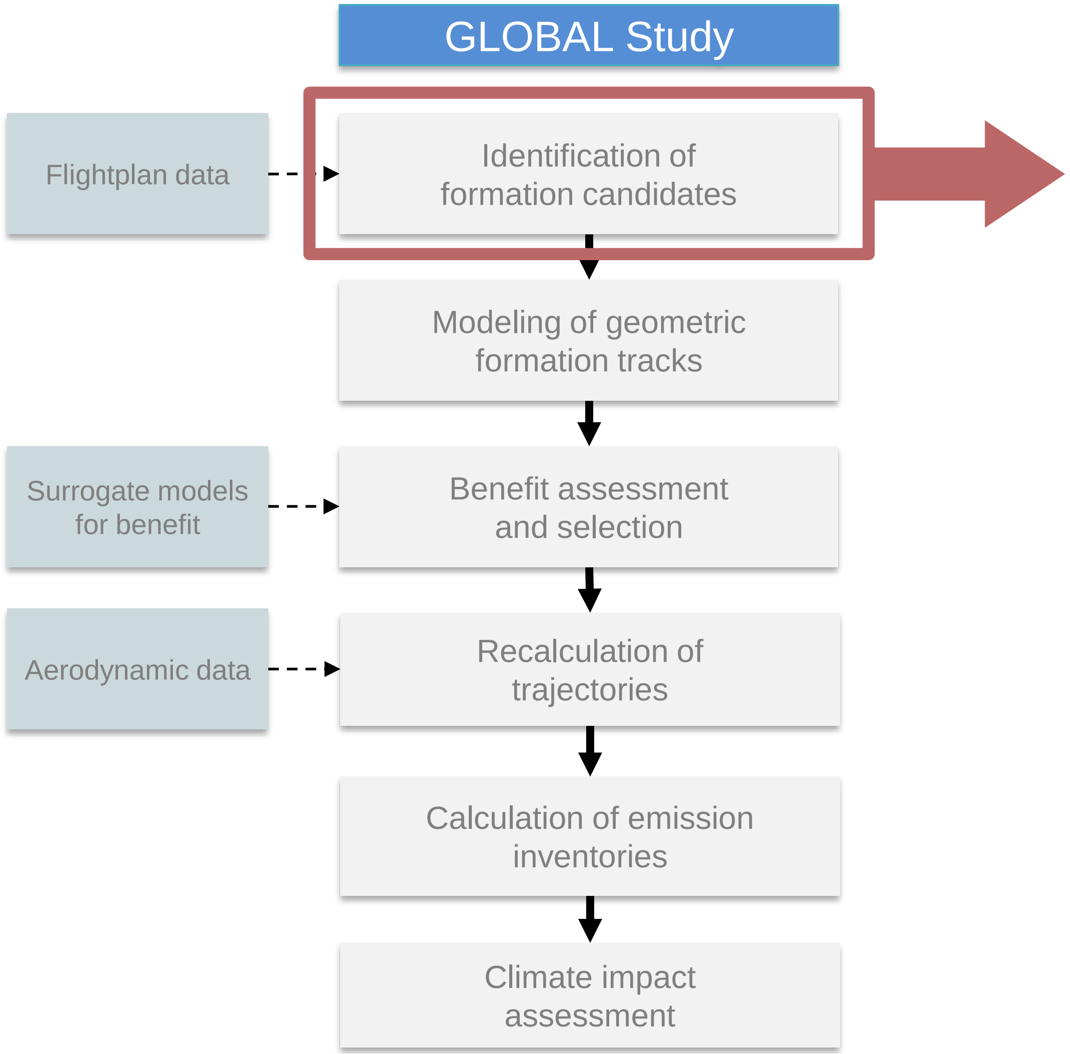
Scope

- Flightplan of October 2014
- Only 777 variants

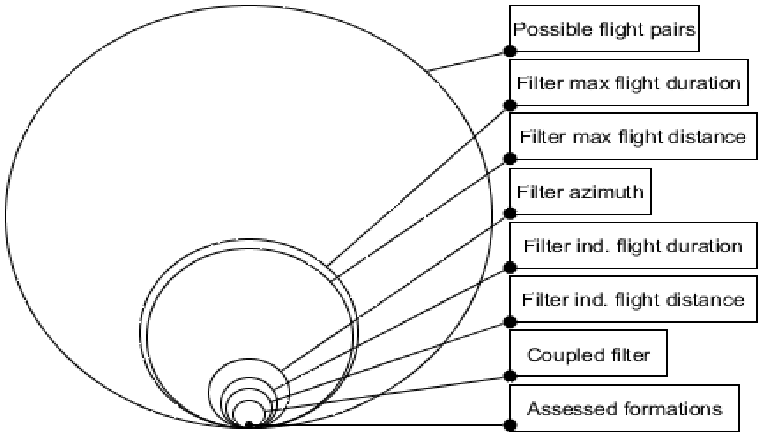
Reference Settings

- **AM: reference speed and altitude are set to formation values (FCA, FCM)**
- XX: reference speed and altitude are optimized

Global Study Approach

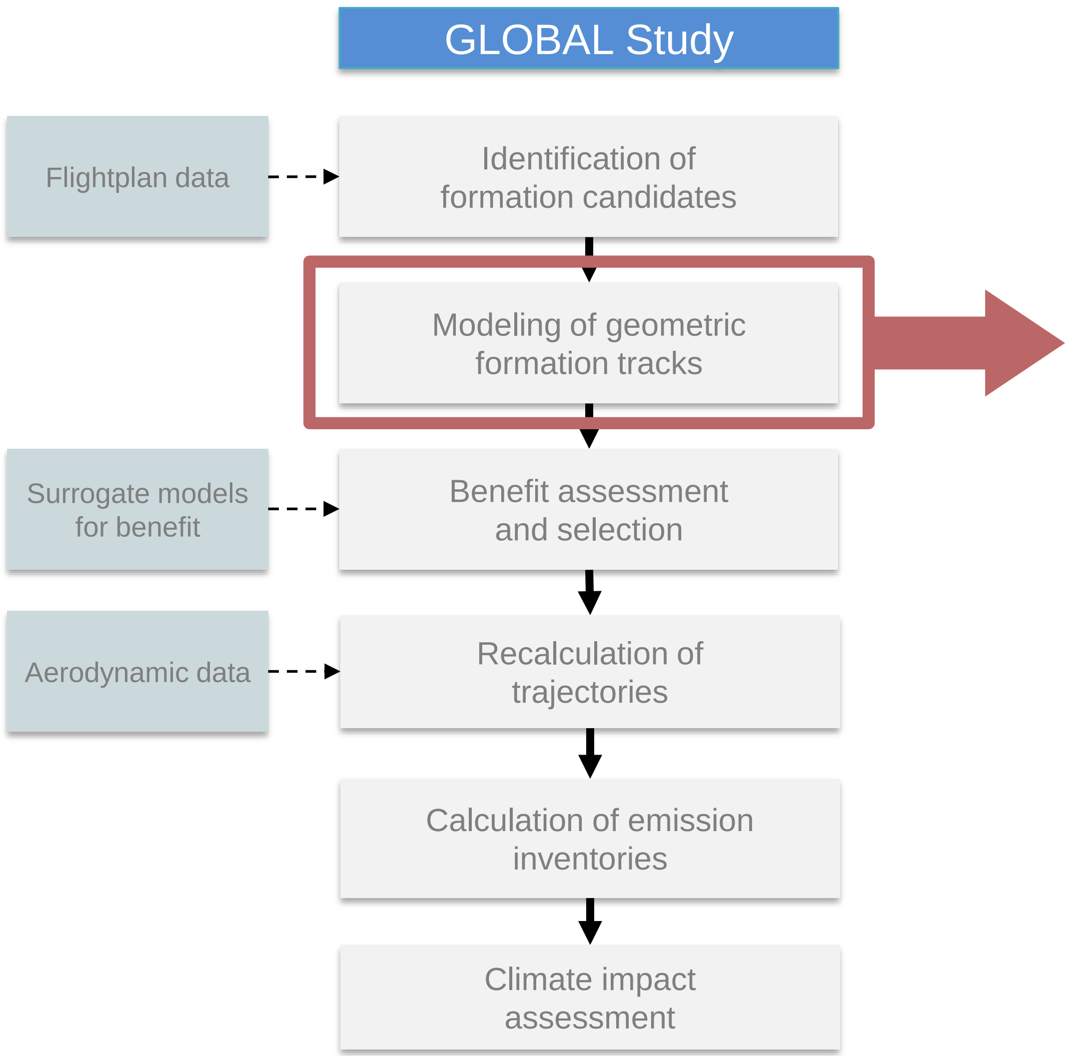


- Filtering the possible formation candidates
  - Time of departure
  - Airport distance
  - Flight direction
  - Etc.

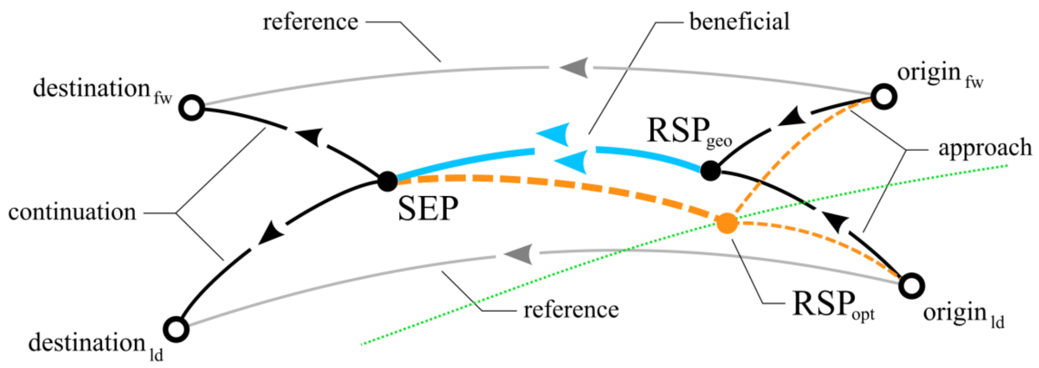


Source: Drews et. al.

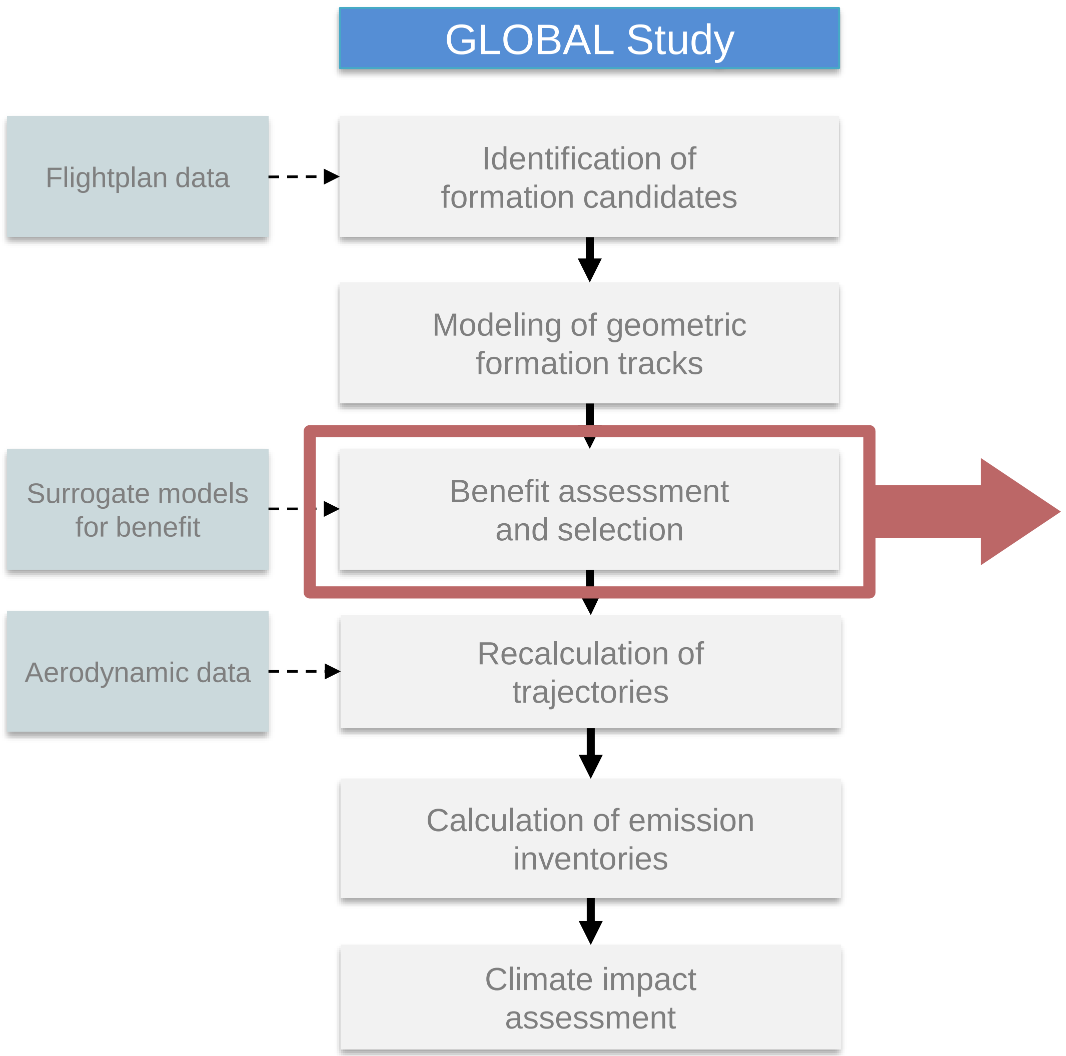
Global Study Approach



- Geometric optimal formation tracks
  - Method by Kent et. al.
- Adaption to timing constraint due to fixed departure times
  - Shift of RSP to closest point on rendezvous line



Global Study Approach



- Estimation of relative and absolute formation efficiency metrics λ_f and Δm_{Bf}

$$\lambda_f = \frac{\Delta m_{Bf}}{m_{Bfref}} = \frac{\sum m_{Bref} - \sum m_{Bawse}}{\sum m_{Bref}}$$

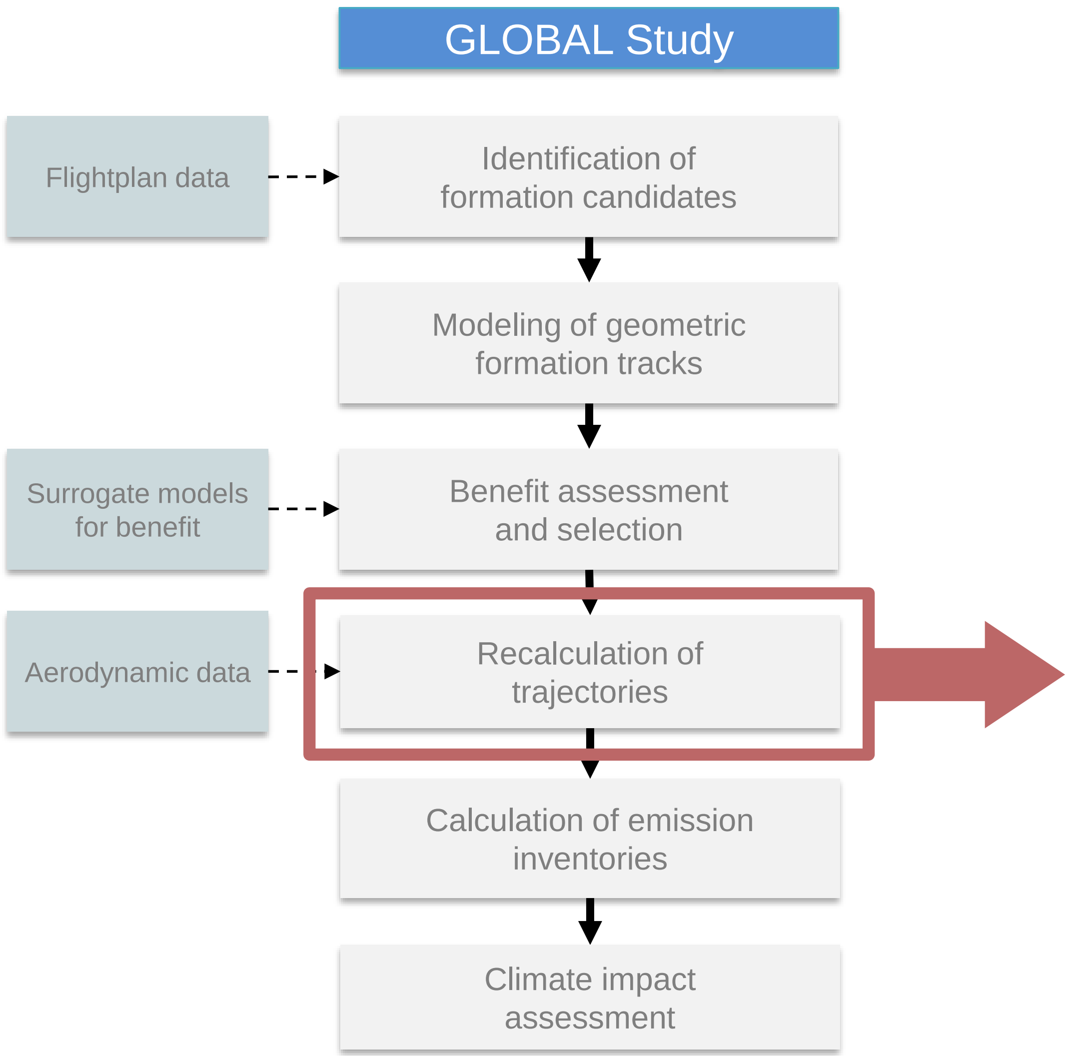
- Surrogate models
  - Based on formation parameters
  - Prediction of metrics
  - Kriging models, MLR etc.based on DoE sample plans

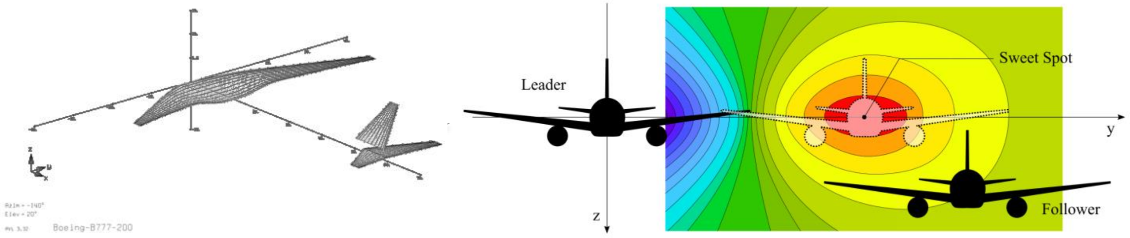
$$\lambda_f = f(\sigma_{ld}, \sigma_{fw}, \xi_{a\,ld}, \xi_{a\,fw}, \xi_{b\,ld}, \xi_{b\,fw}, \xi_{c\,ld}, \xi_{c\,fw}, lf_{ld}, lf_{fw}, S_{awse\,ld}, FCM, FCA)$$

- Selection of best formations

→ Formation flightplan

Global Study Approach

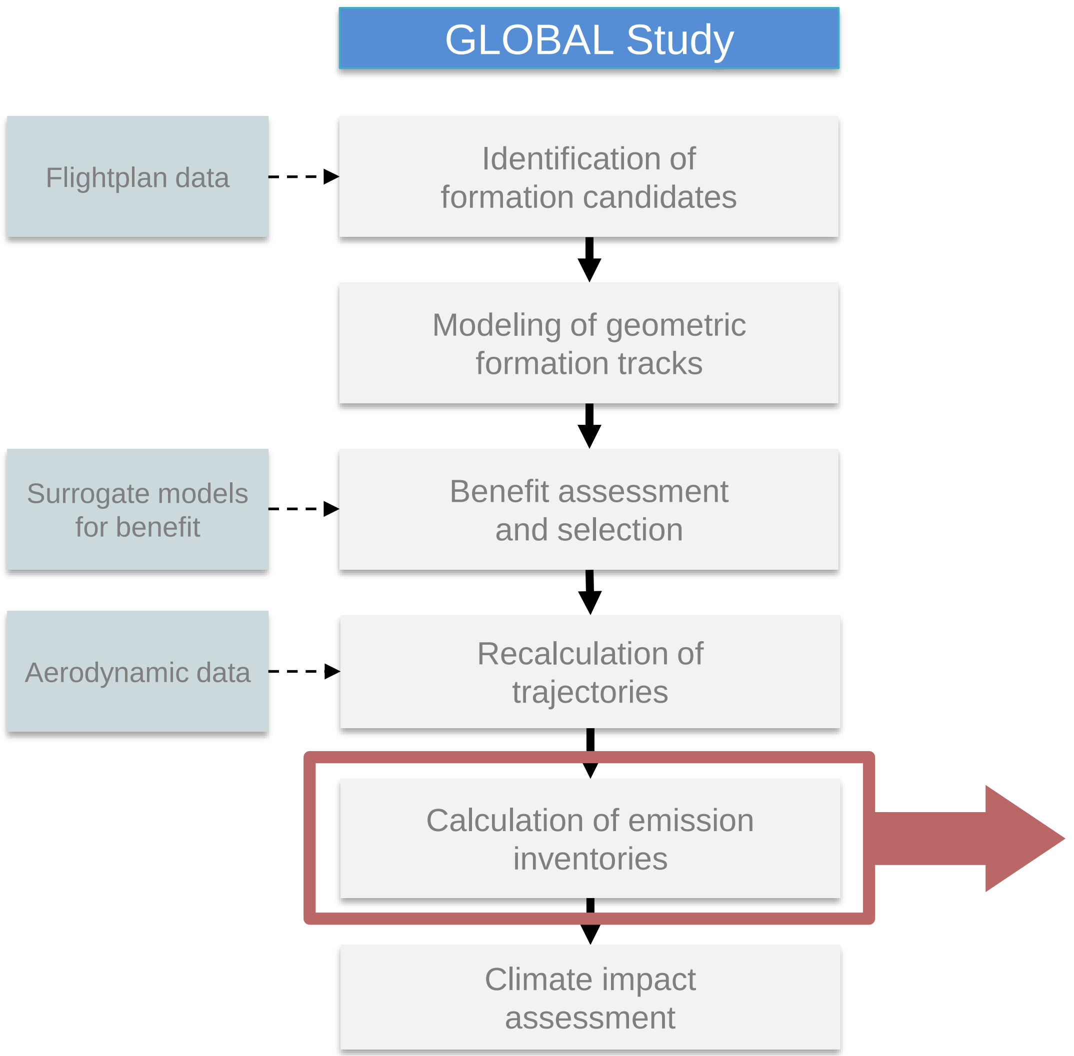




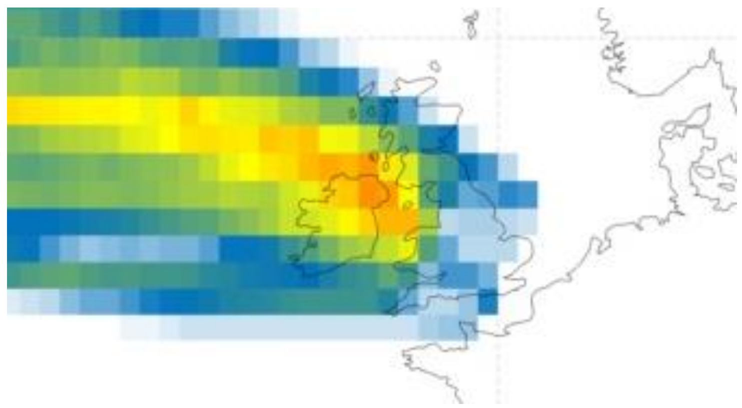
- Recalculation
  - Trajectory Calculation Module (TCM)
- Aerodynamic Model
  - Athena Vortex Lattice Method (AVL)
  - Databases are used for interpolation during trajectory calculation
  - Variation of masses, speed, altitude, position
  - Databases need to be set up for each pairing individually

Global Study Approach

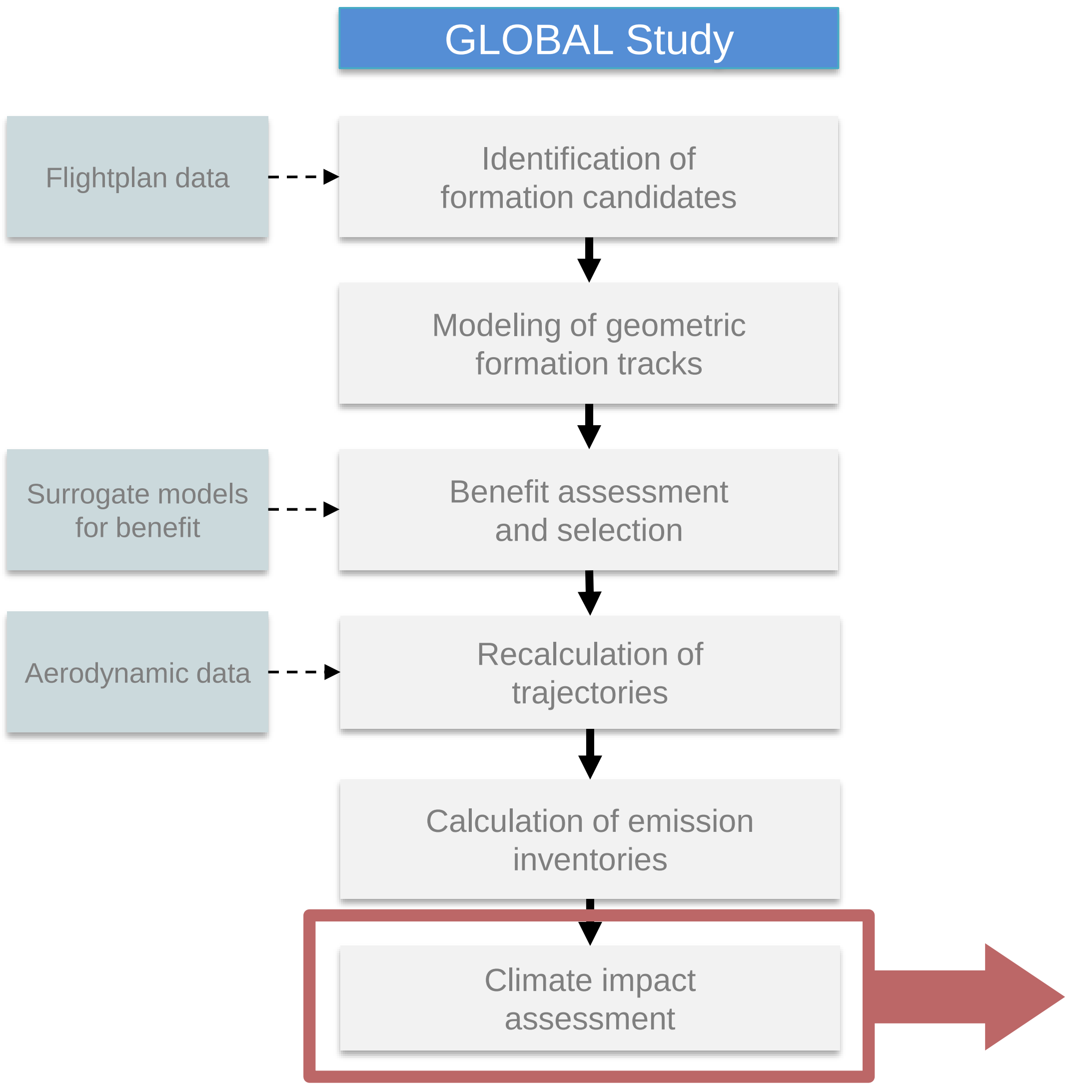
Methods



- Formation Inventories
  - 2-dimensional grids that contain the amount of formations in each grid cell
- Emission Inventories
  - 3-dimensional grids (horizontal and vertical) that contain the amount of emissions per species in each grid cell
  - Evaluation of engine state along each trajectory and from the fuel flow in each trajectory segment the amount of emissions are calculated



Global Study Approach



- AirClim
  - Adapted for formation flight effects
- Climate impact metric
  - Average global near surface temperature (average temperature response, ATR) over 50 years
- Relative change of climate response

$$\delta ATR = \frac{ATR_{awse} - ATR_{ref}}{ATR_{ref}}$$

  - Difference of the temperature responses from the AWSE and the reference scenario related to the reference scenario per species or per total

General statistics

Results

- General Statistics
- Formation Inventories
- Benefits and Parameters
- Fuel Inventories
- Differences
- Climate Impact

	T30	T50	ALL	NAT
dataset entries	**396011**			n/a
after a/c filter	**9958**			n/a
after range filter	**3826**			n/a
after OD filter	974	1625	**3826**	n/a
single flights	10457	16503	**32939**	n/a
beneficial formations	2701	5599	**16046**	n/a
selected formations	1122	1878	**4569**	n/a
unique formations	155	292	**795**	648
feasible formations XX		199	**612**	542
feasible formations AM			**555**	
selected formations	n/a	n/a	**n/a**	334
single flights AM			**6564**	668
percentage AM			**19.9%**	

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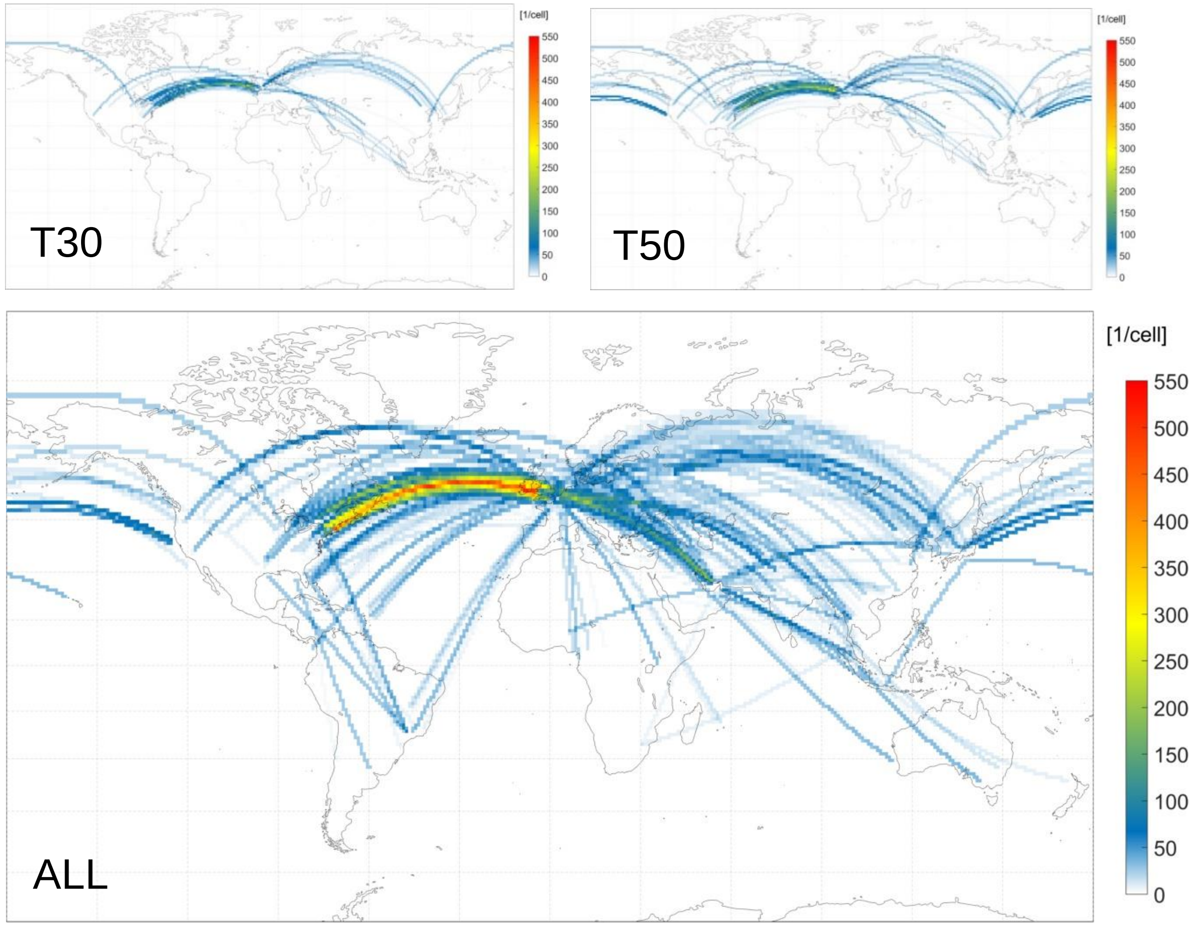
Formation Inventories

Results

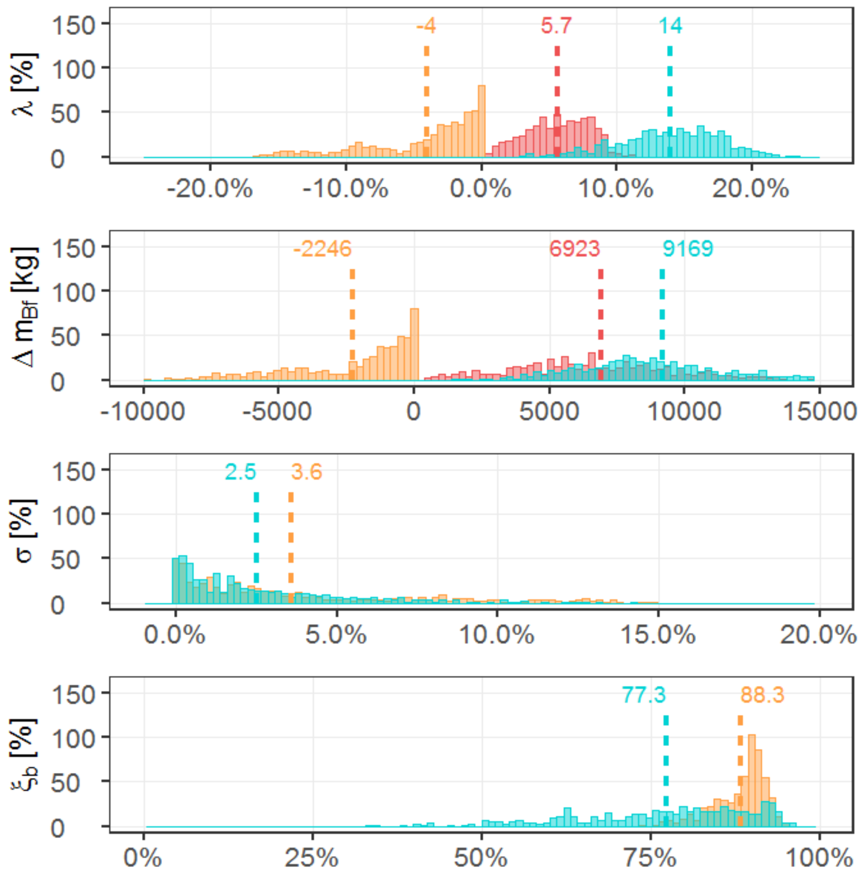
- General Statistics
- **Formation Inventories**
- Benefits and Parameters
- Fuel Inventories
- Differences
- Climate Impact



Formation inventories for studies: T30 , T50, ALL

Formation Benefits

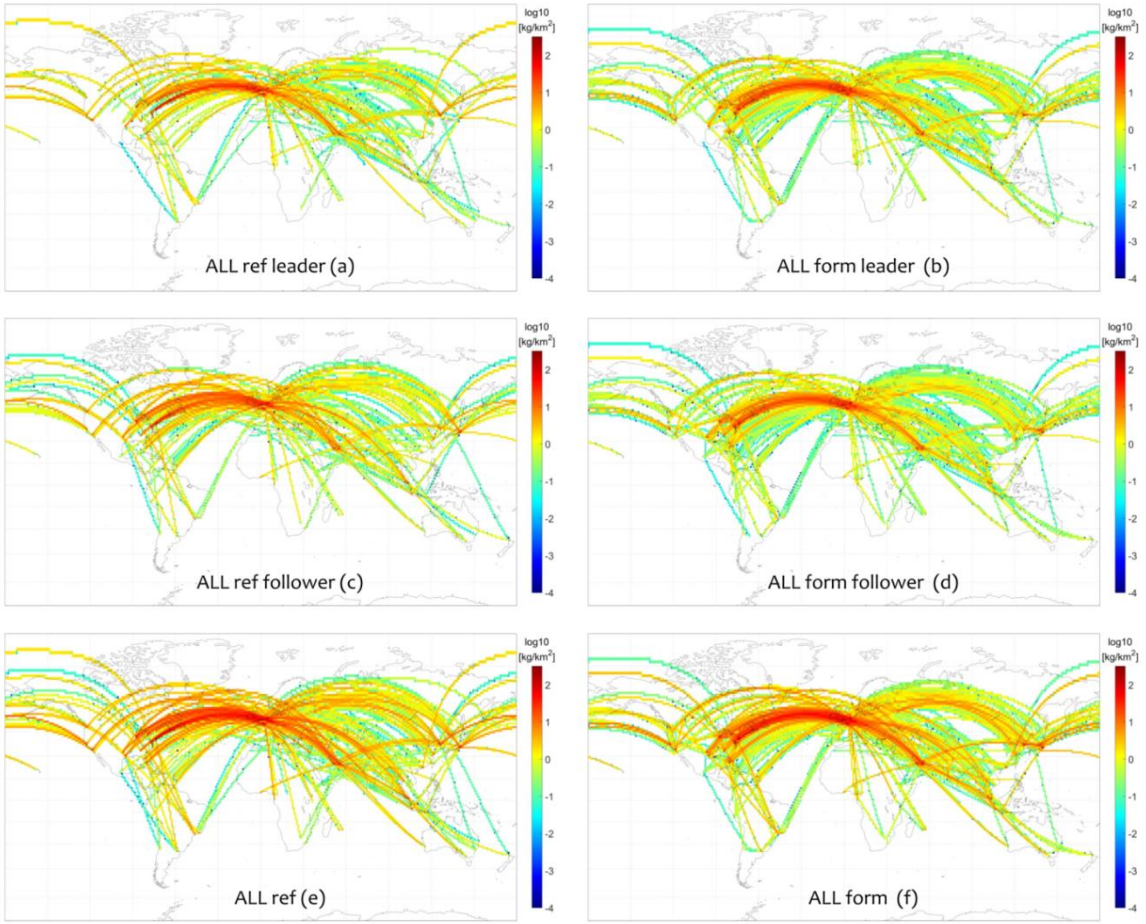
- **Results**
- General Statistics
- Formation Inventories
- Benefits and Parameters
- Fuel Inventories
- Differences
- Climate Impact



Occurrence and mean values of the relative and absolute efficiency metrics, detours and relative lengths of the beneficial segment for leader (orange), follower (green) and combined (red) and the AM setting and the ALL study.

Fuel Inventories

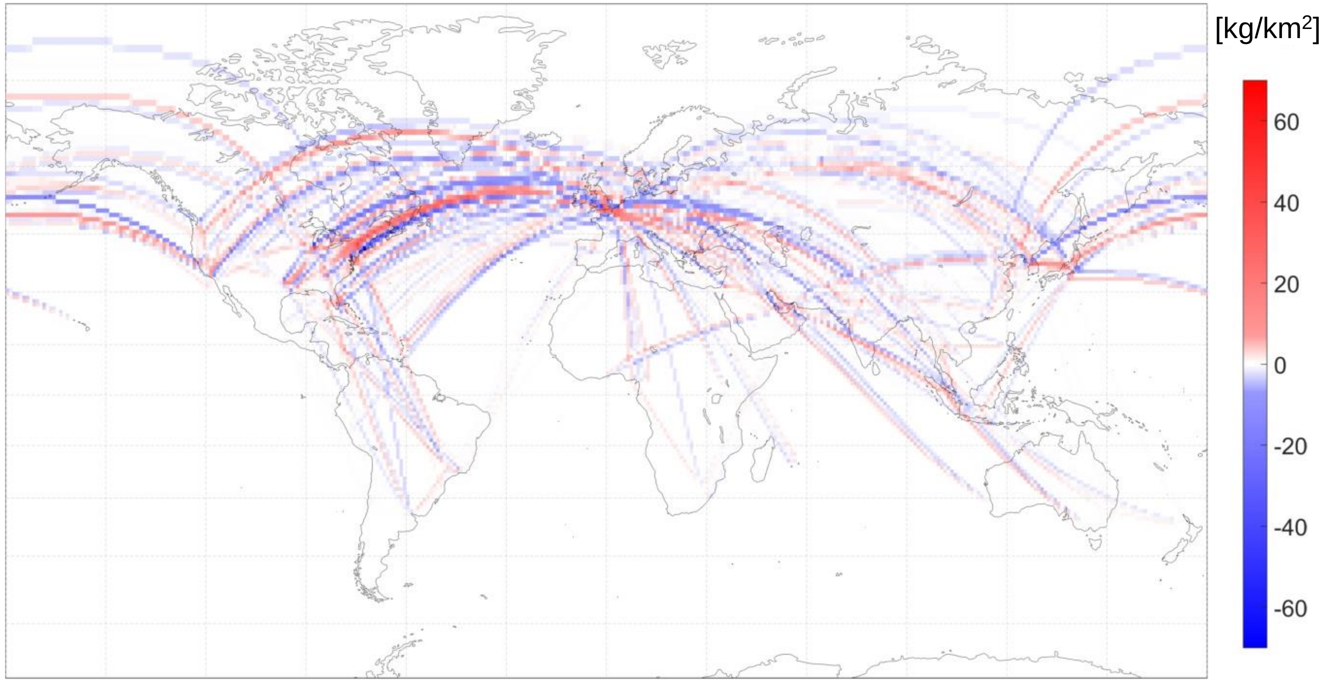
- Results
- General Statistics
- Formation Inventories
- Benefits and Parameters
- **Fuel Inventories**
- Differences
- Climate Impact



Inventories for fuel consumption for the ALL global scenario and the AM setting

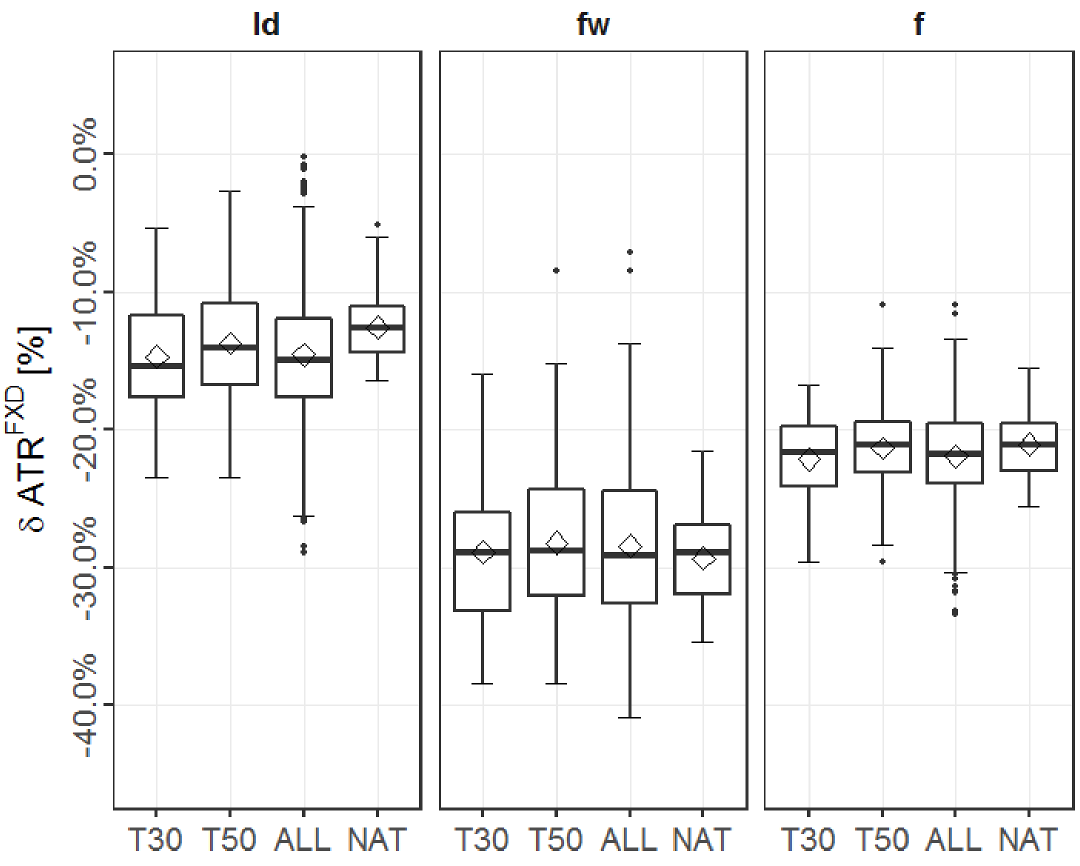
Differences

- Results
- General Statistics
- Formation Inventories
- Benefits and Parameters
- Fuel Inventories
- **Differences**
- Climate Impact



Inventory for difference in fuel consumption for the ALL global scenario and the AM setting, combined for leader and follower

General statistics



Relative change of temperature responses δATR for the AM setting separated by leader (ld), follower (fw) and formation (f)

Conclusions & Outlook

- Studies show that the climate impact mitigation potential of formation flight is larger than just the reduction caused by fuel burn reduction itself

- Further studies including other aircraft types and larger scenarios are currently prepared in order to further substantiate the findings