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JOINT UNDERTAKING

CREATE – SOLUTION2

Multi-aircraft environmentally-scored weather-resilient optimised 4D trajectories in the flight execution phase

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EUROPEAN PARTNERSHIP

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CREATE SOLUTION 2

Multi-aircraft environmentally-scored weather-resilient optimized 4D-trajectories in the flight execution phase

Proposal for a concept of operations (ConOps), to support the update and revision process of the reference business trajectory (RBT) in highly disrupted scenarios due to **weather hazards or climate-sensitive zones**, tackling (near) real-time aspects and the network and safety constraints arising in a multi-aircraft environment.

A trajectory optimisation framework has been designed, addressing the integration of various elements:

a) multiple aircraft considered in the generation of 4D optimised trajectories;

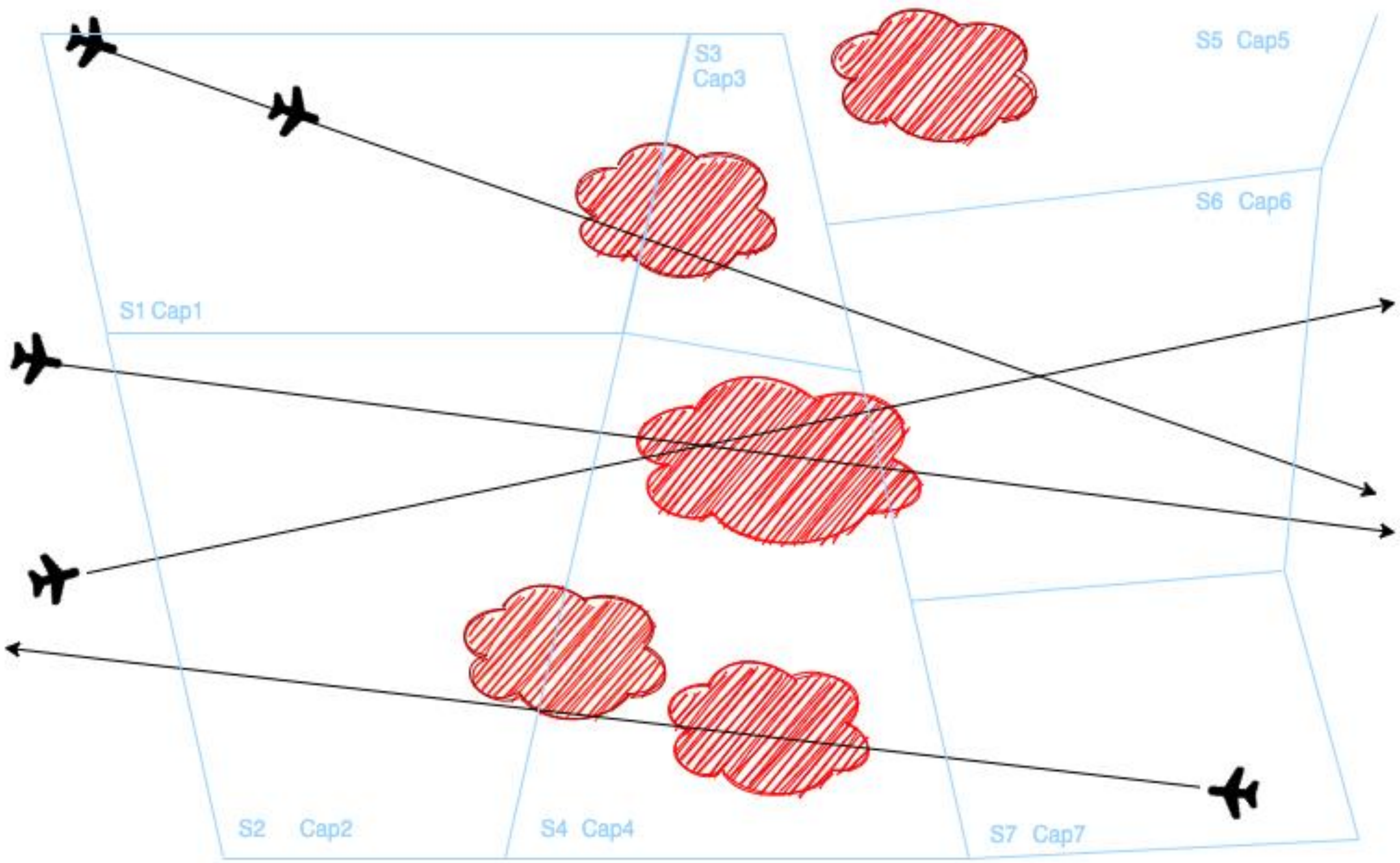
b) Numerical Weather Prediction (NWP) and Ensemble Weather Forecasting (EWF) used for tactical trajectory replanning by predicting weather scenarios a few hours into the future of a given flight;

c) implementing an environmental-score assessment for all proposed candidate alternative trajectories;

d) Air traffic control (ATC) driven decision-making process to select overall optimum of the proposed alternative trajectories within a use-case.

CREATE-SOL-2 involves both en-route and TMA use-cases

CREATE SOL-2: ConOps in a nutshell



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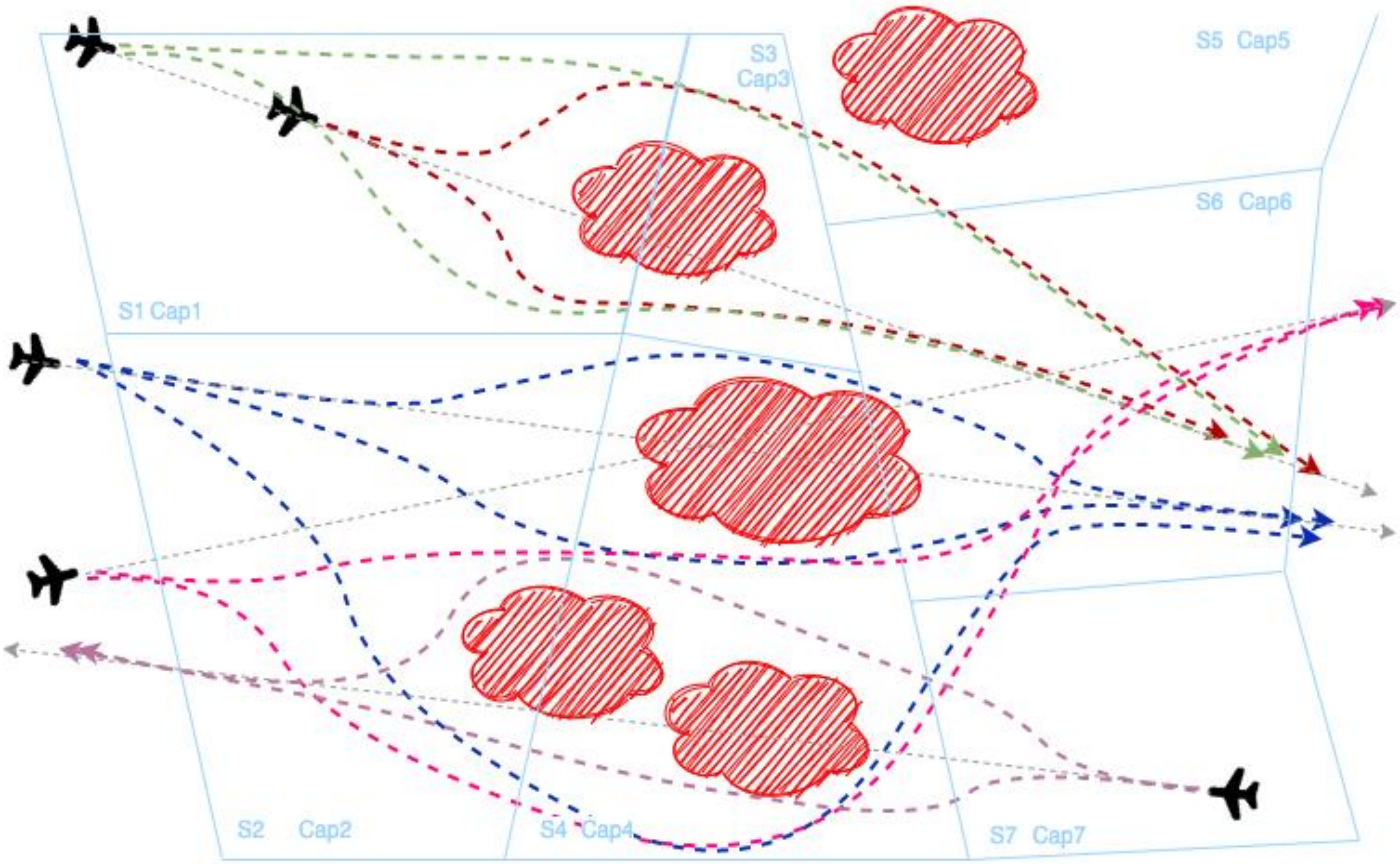
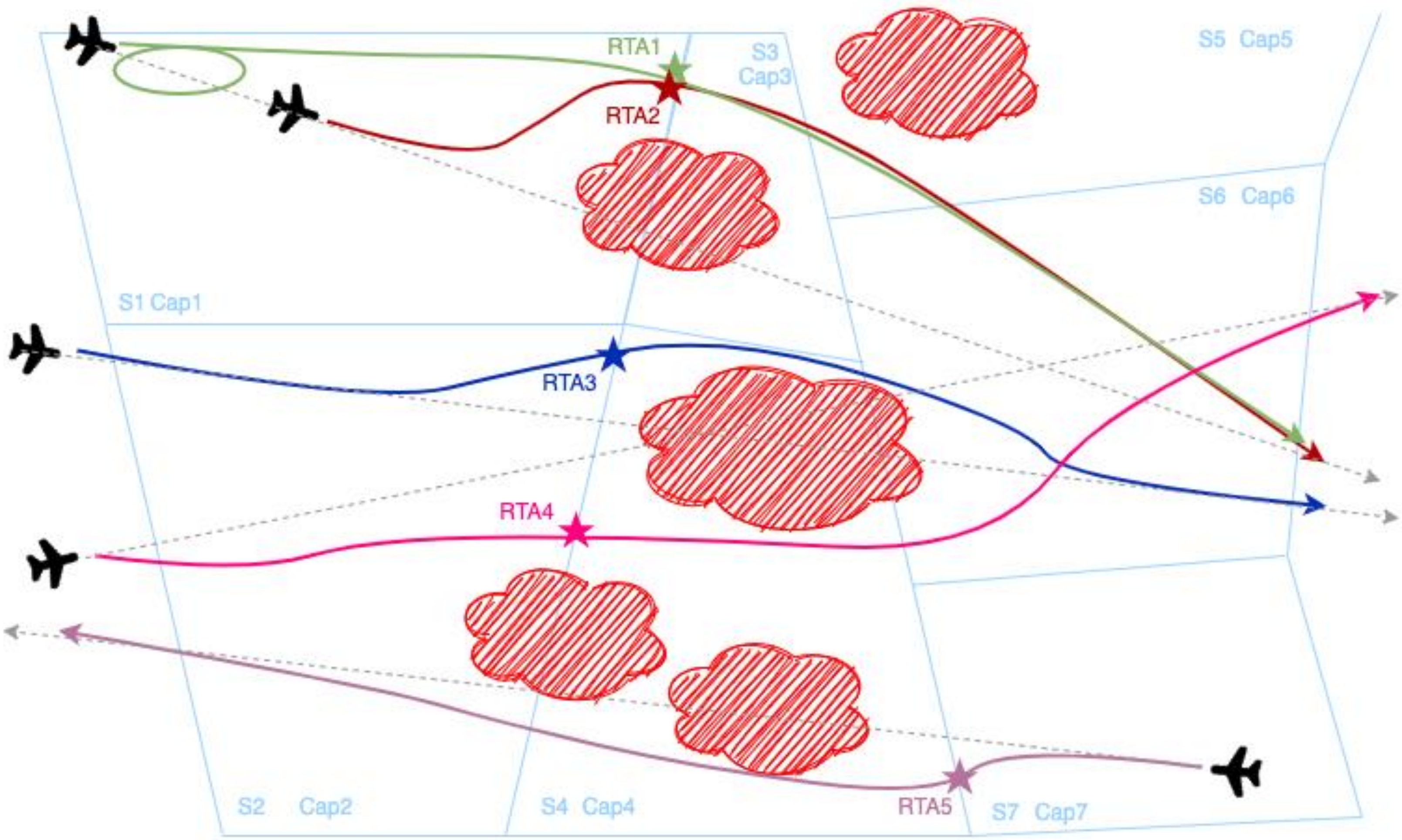


Each aircraft, on-board, computes **several alternative trajectories** that avoid these “no-go” areas.

If ATC sectorization is made available to the aircraft, the alternatives could avoid *non-operational* ATC sector crossings

ATC: air traffic control

CREATE SOL-2: ConOps in a nutshell



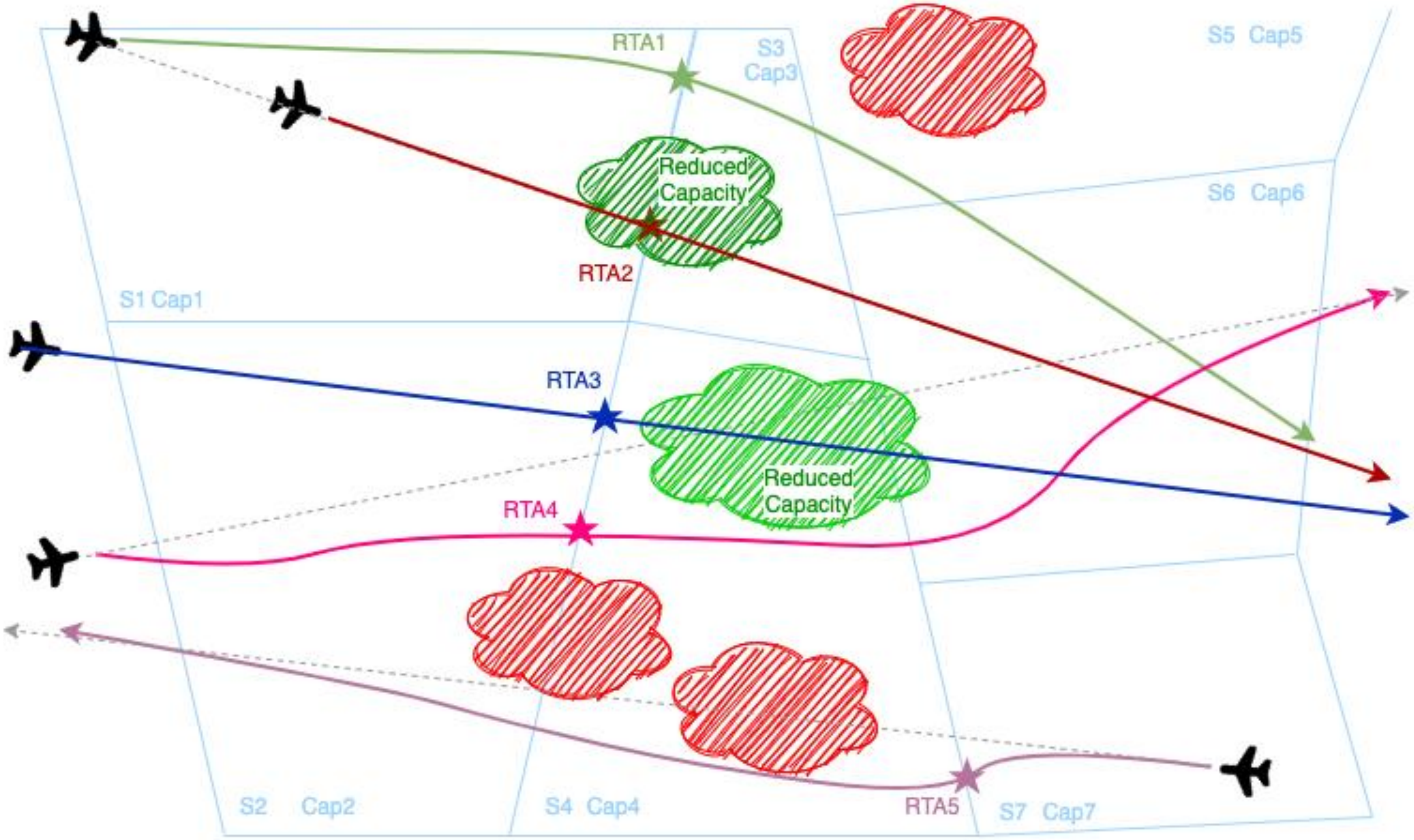
ATC decision support tool(*) selects the **“best” trajectory for each flight** such as:

- Capacity is not overloaded in any sector
- A global optimisation criterion is minimised.

Required Times of Arrival (RTA), or air holdings if required, are assigned to aircraft to avoid too high ATC workloads.

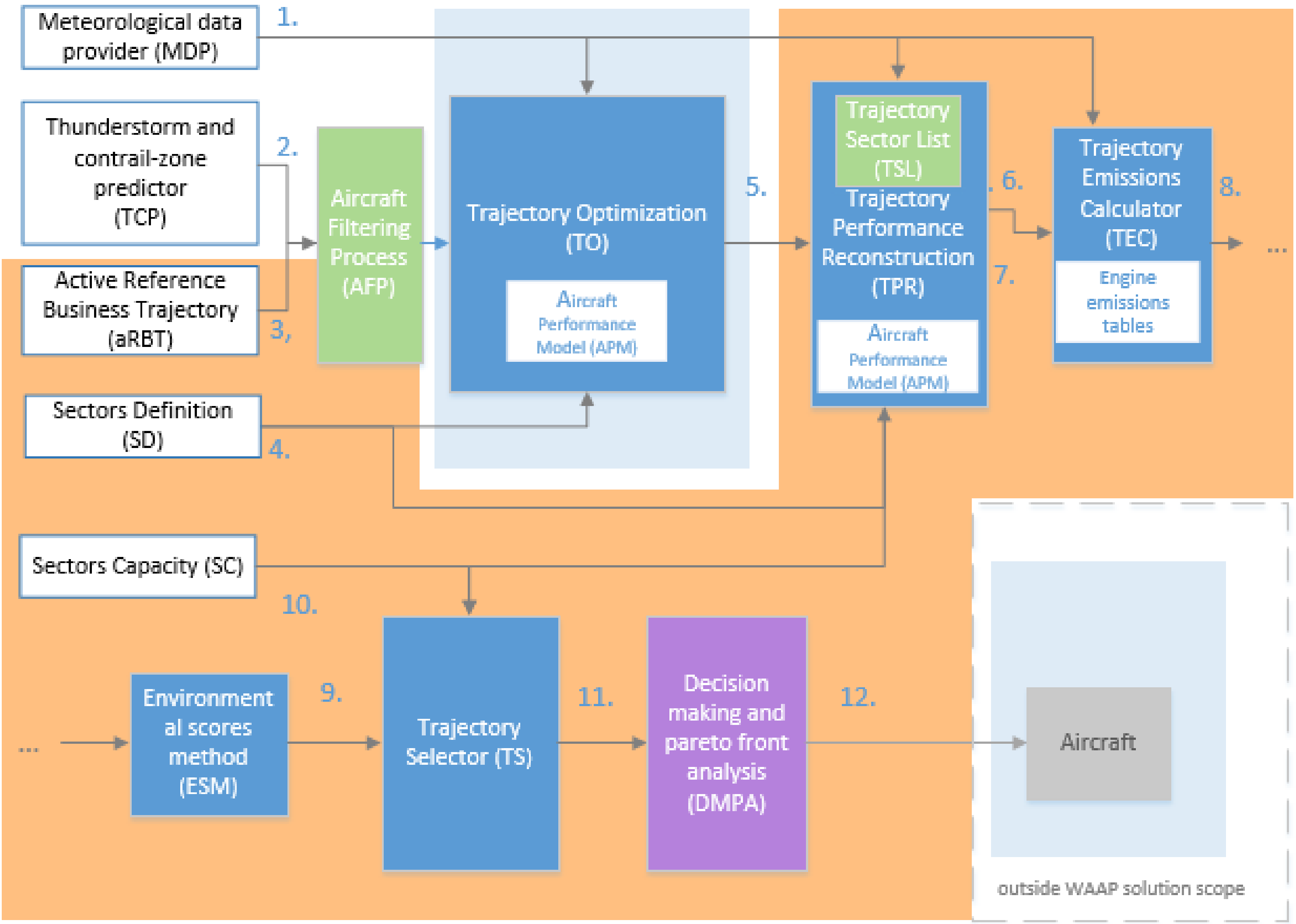
(*)in line with the SESAR "extended ATC planning" concept

CREATE SOL-2: ConOps in a nutshell

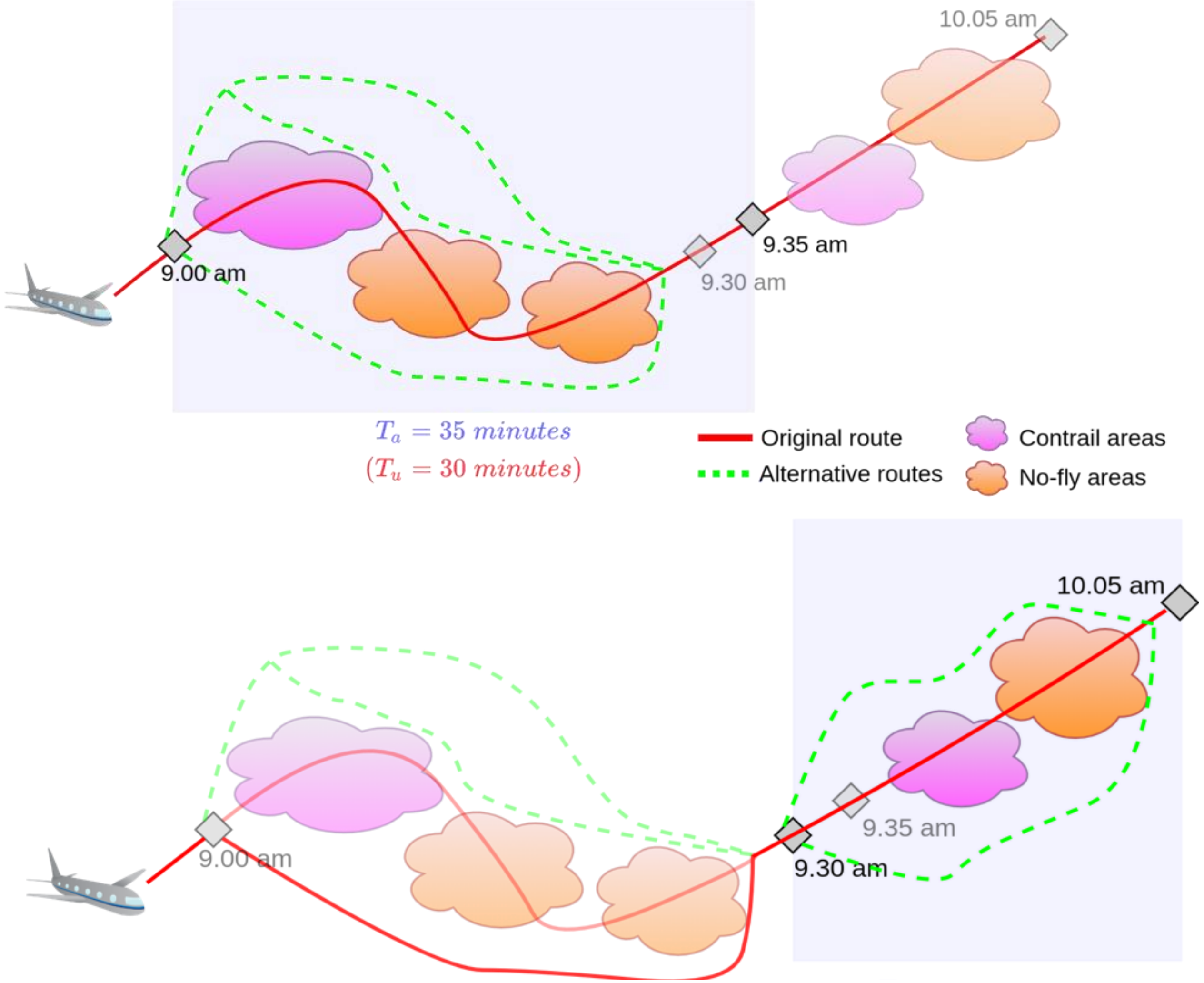


Contrail sensitive zones could be modelled as well (assuming a reduced number of aircraft could cross them).

CREATE SOL-2: framework in a nutshell



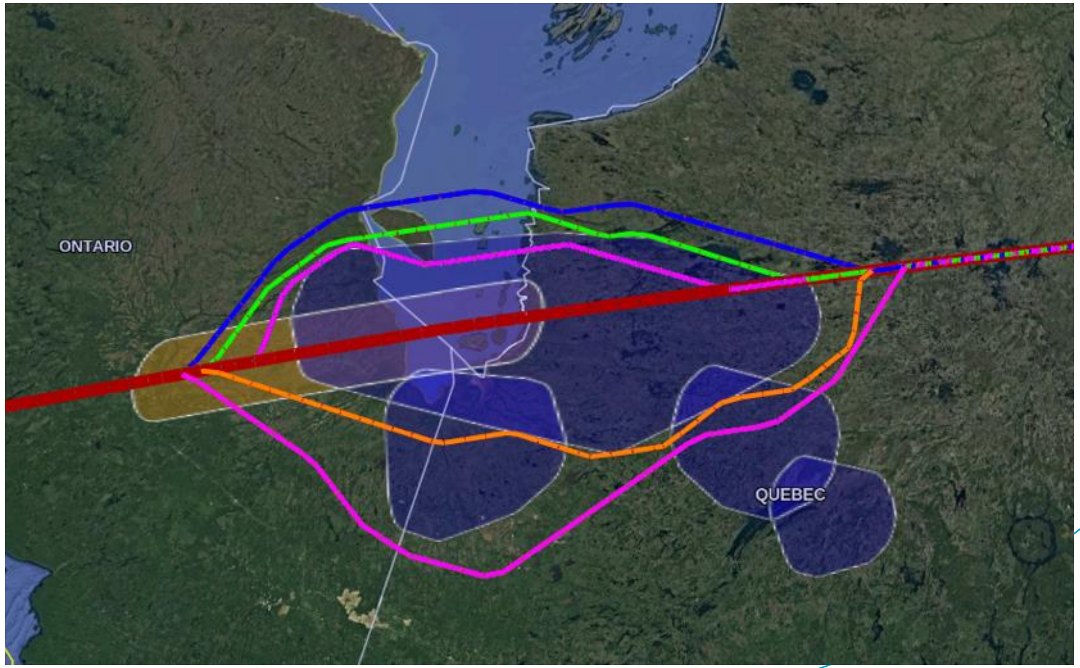
CREATE SOL-2: tactical trajectory replanning (en-route)



Several **iterations** taking into account:

- Update Time (Tu): update frequency of no-fly/contrail areas.
- Look-ahead Time (Ta): only no-fly/contrail areas after that time will be considered.

After avoidance the trajectory shall **reattach** at some point to the original route



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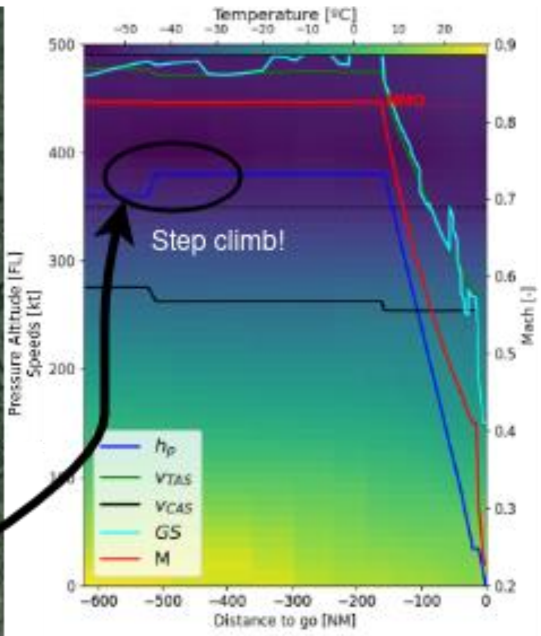
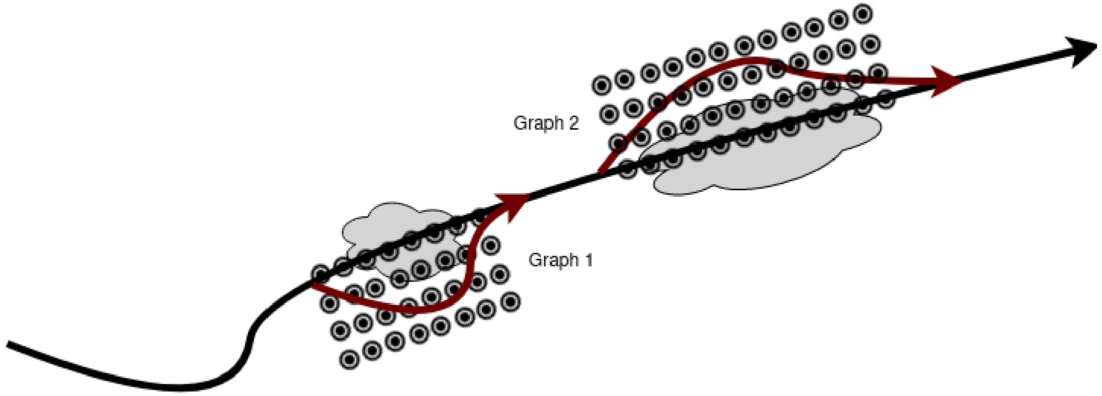
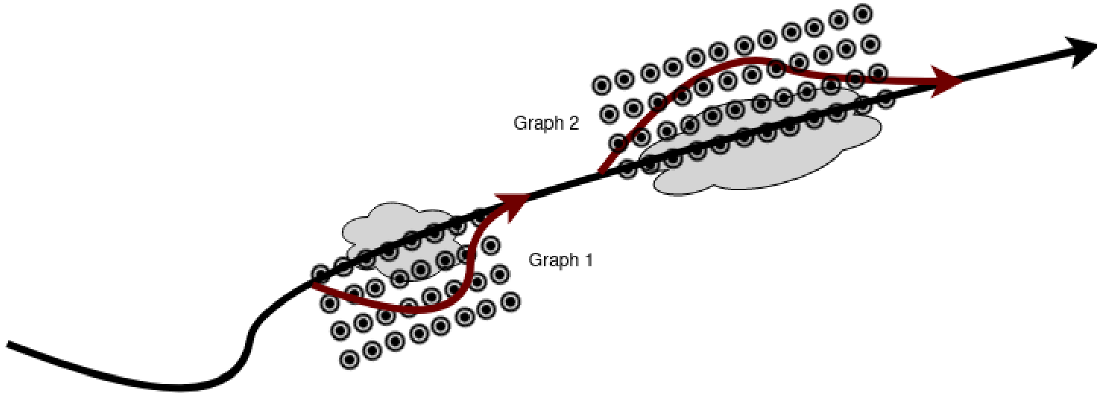


CREATE SOL-2: area avoidance



Dynamic graph generation right and left

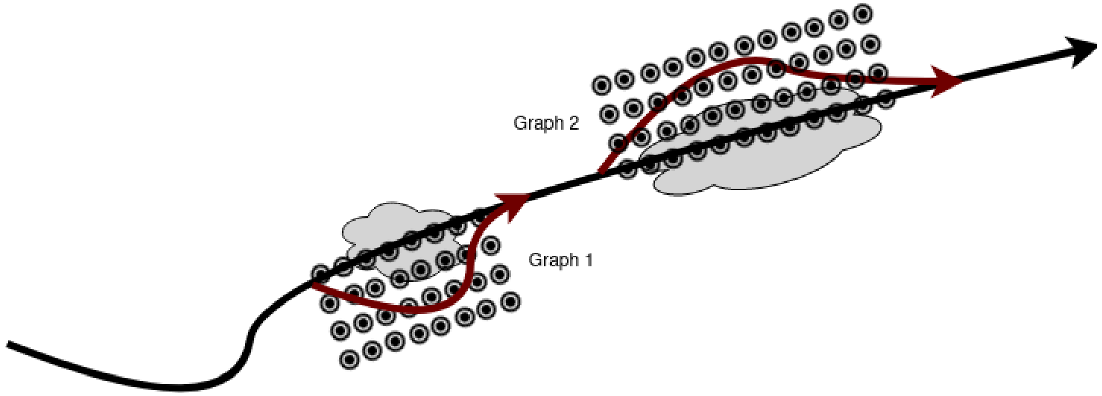
CREATE SOL-2: area avoidance



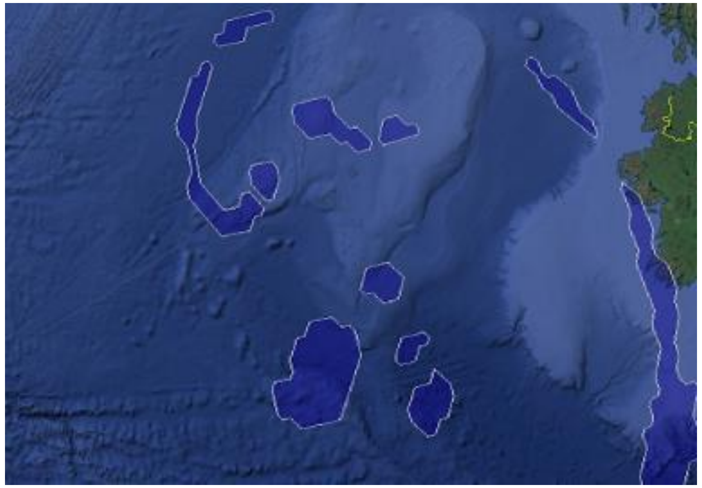
Dynamic graph generation right and left

Buffer areas

CREATE SOL-2: area avoidance



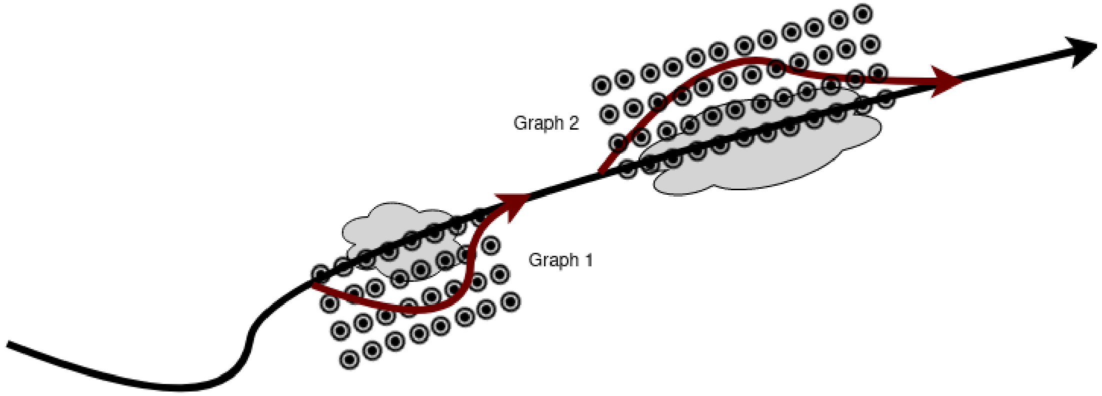
Dynamic graph generation right and left



Buffer areas

Convexifying sectors

CREATE SOL-2: area avoidance



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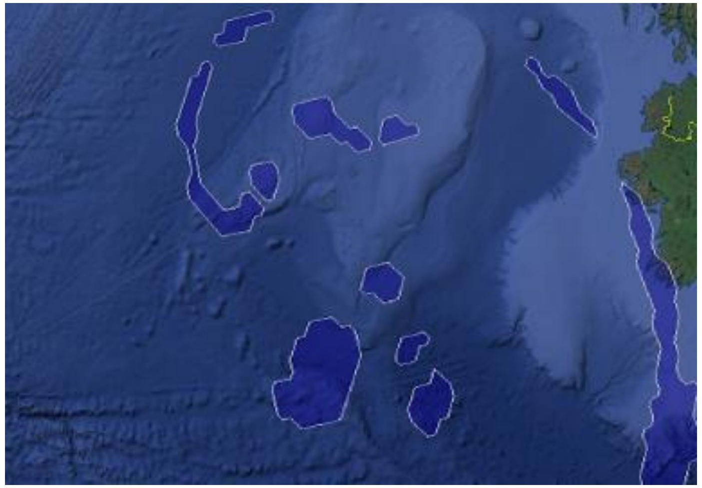
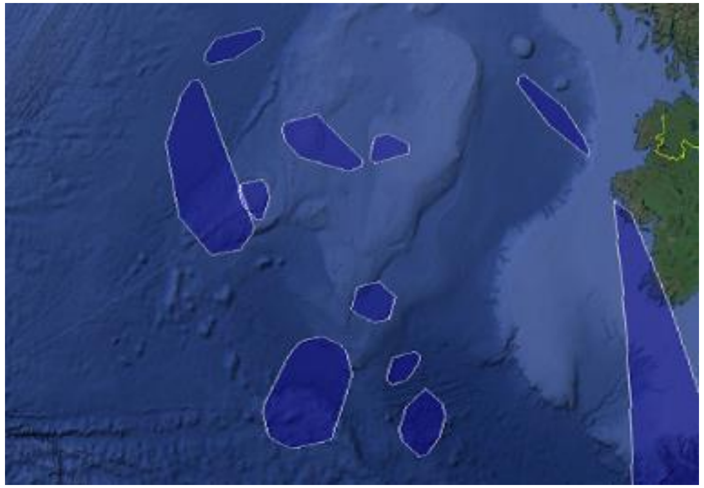


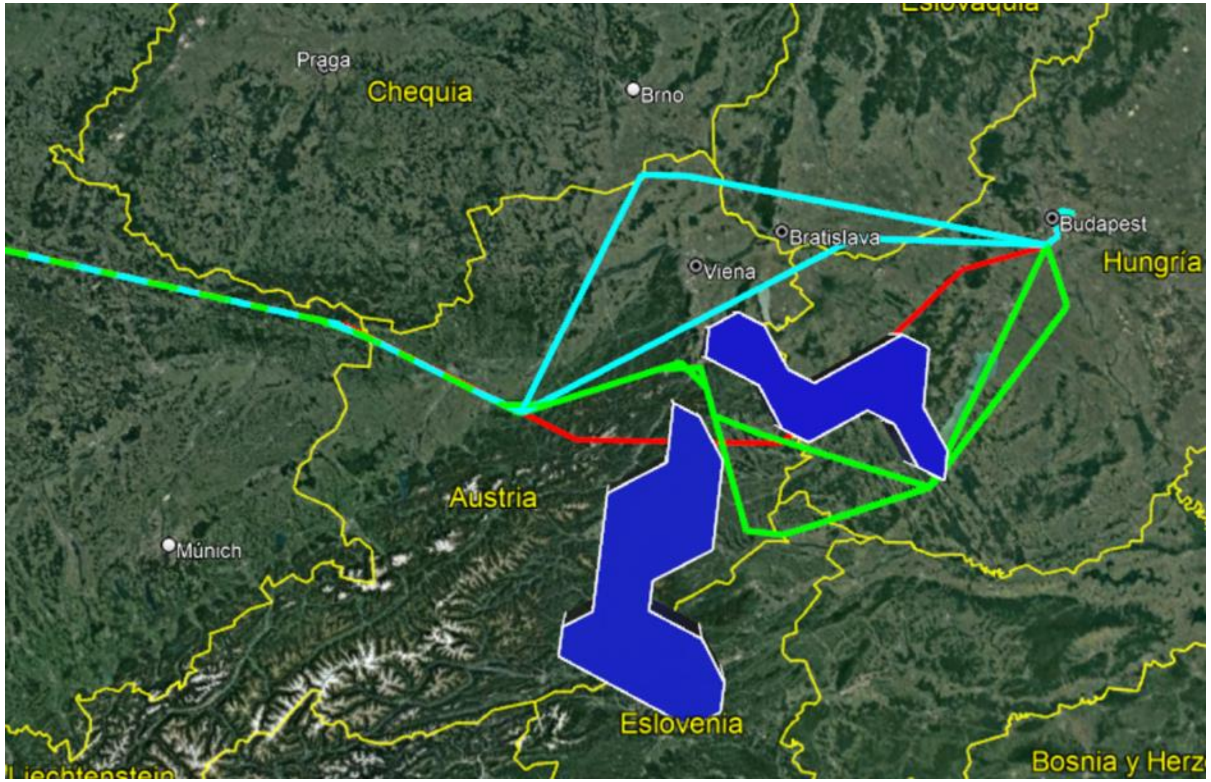
Buffer areas



Convexifying sectors

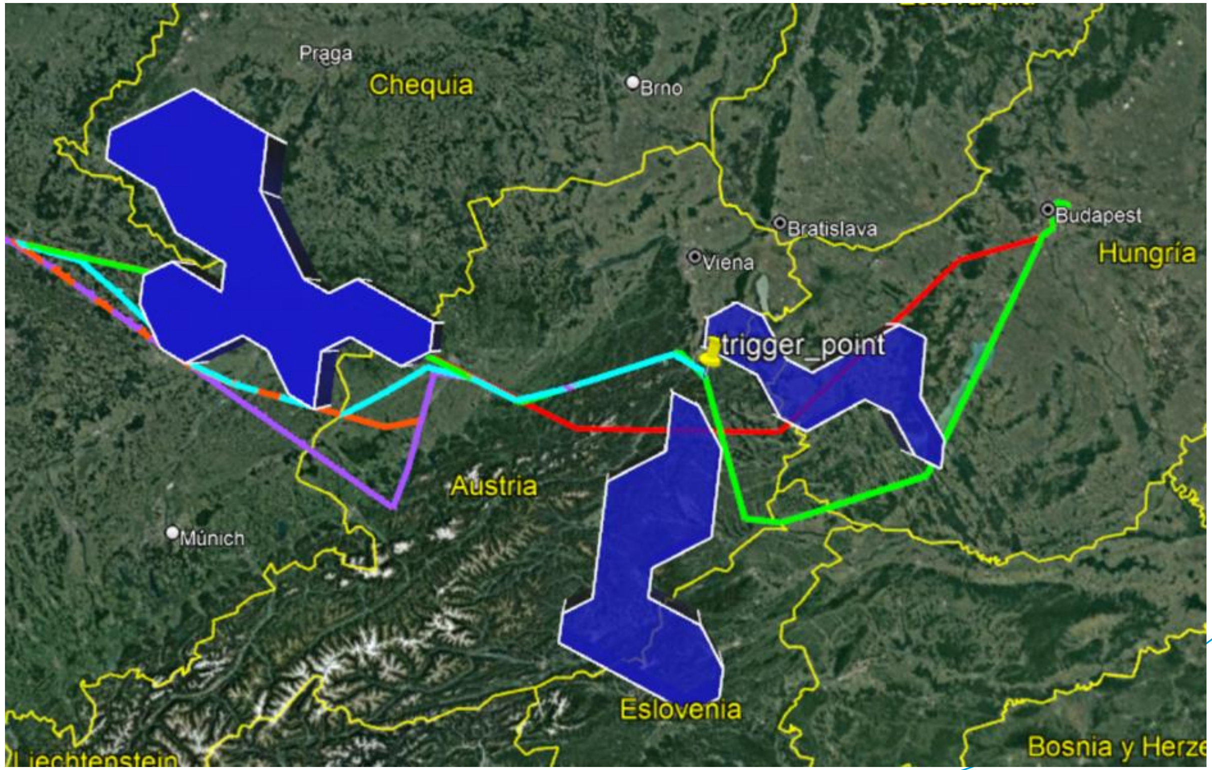
CREATE SOL-2: example of application en-route

LOT33, a Boeing B787-800 flying from Budapest airport (LHBP) to JFK airport (KJFK) on July 27, 2018



Iteration from 10:00 to 10:30

Iteration from 10:30 to 11:00



CREATE SOL-2: trajectory selection (ATC decision support tool)

The TS is based on a MILP (mixed-integer linear programming) model with several constraints to ensure the demand is below capacity for all sectors and with the following objective function, considering the environmental score and the AUs extra costs due to the extra direct operating costs and delay:

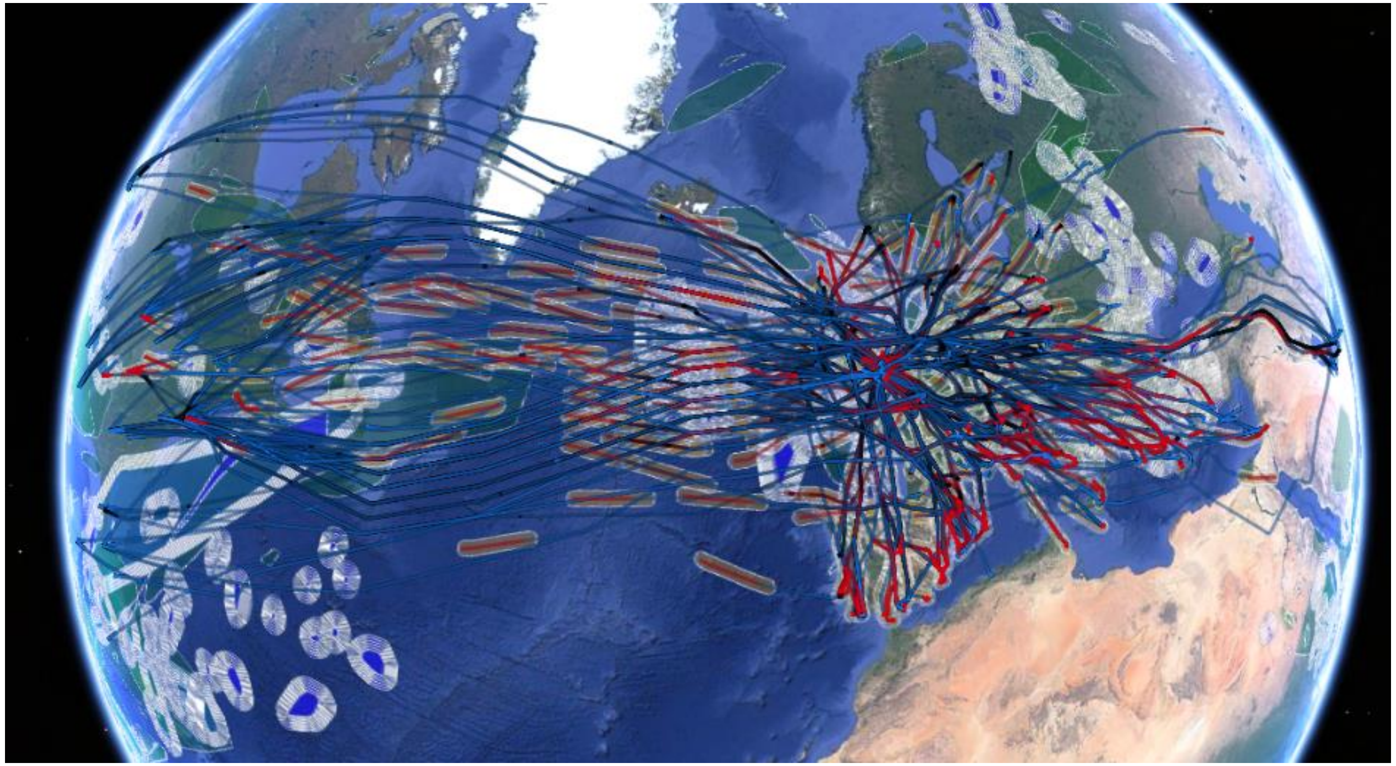
$$J = \sum_{k \in K} \left[\alpha C_k^E + (1 - \alpha) C_k^{AU} \right]$$

In the **DMPA**, the parameter α (a weighted parameter from 0 at 1) is used to increase or reduce the contribution of the environment and the AUs extra cost in the overall objective function.

The ESM is designed to emphasize contrail formation in climate sensitive areas and dominates the score if the likelihood is larger than 50%. The overall ESM score is then defined by:

$$ESM = \frac{\left(\frac{CO_{2\,score}}{CO_{2\,score,c0}} + \frac{NO_{x\,score,}}{NO_{x\,score,c0}} + \frac{H_2O_{score}}{H_2O_{score,c0}} \right)}{3} + 2 * Contrail\_score$$

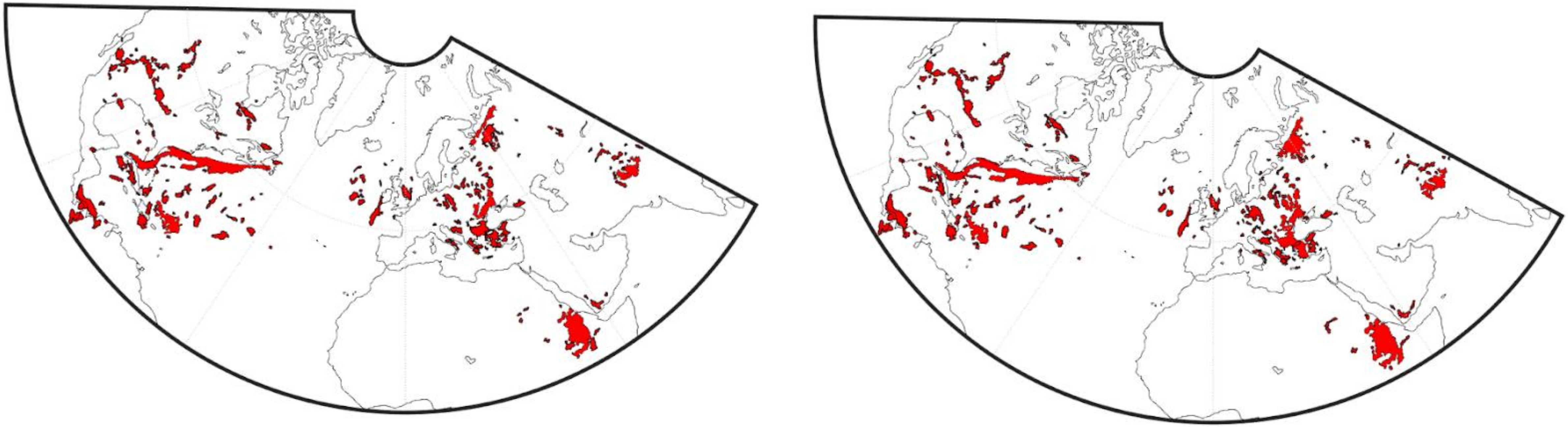
CREATE SOL-2: En-route experimental setup



Date: July 27, 2018
Triggering time: 9 am
Active flights 9am-9.30am: 1308
NetCDF and NFZ update frequency: 30 minutes
Contrail update frequency: 15 minutes
Avoidance configuration: nfz → lateral, contrails → lateral, vertical and cross
Up to 11 alternative trajectories to be computed for each flight!

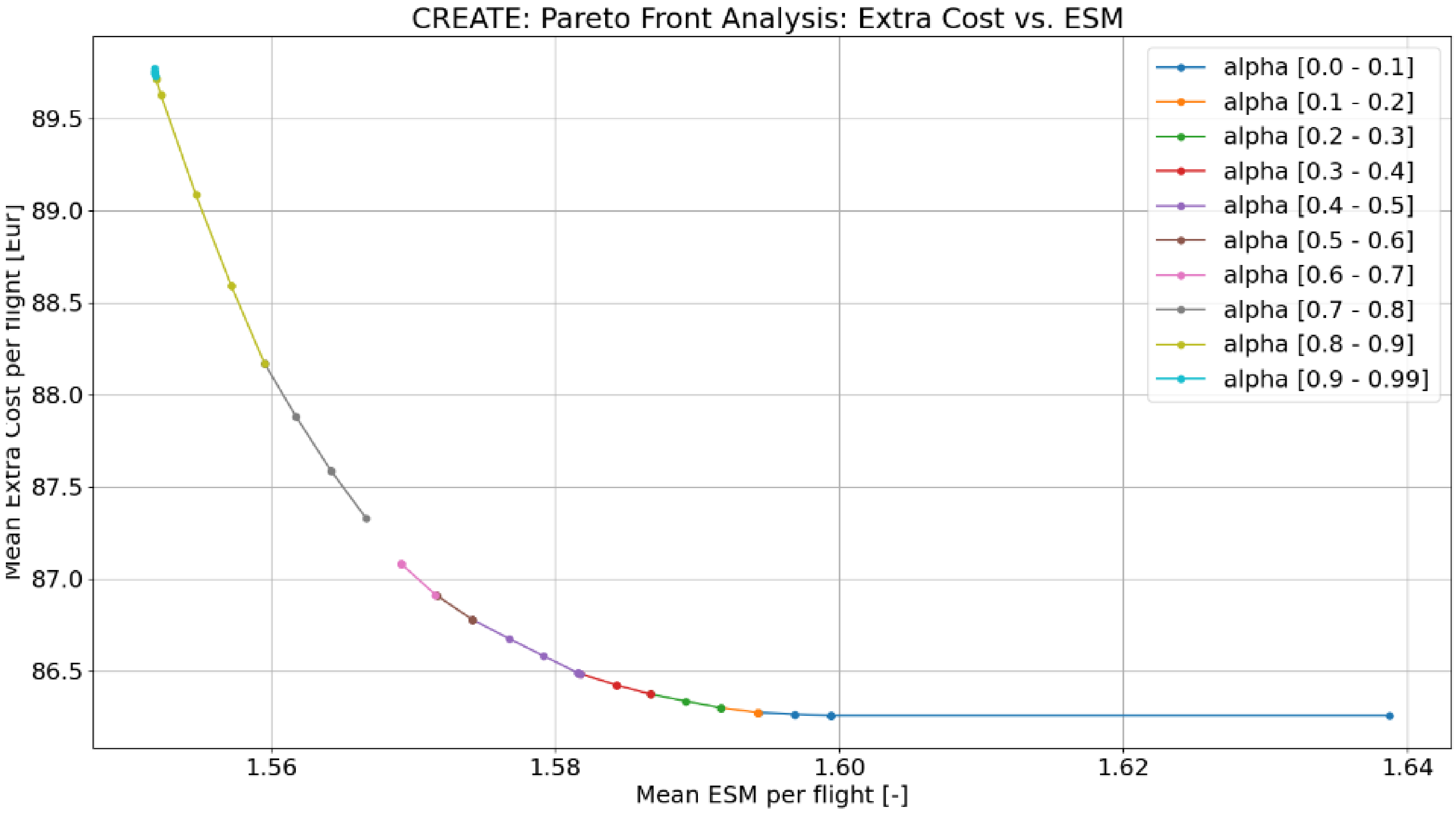
Update Time: 30 minutes
Look-ahead Time: 35 minutes

CREATE SOL-2: En-route experimental setup



Weather related no-fly areas by using CAPE > 120 J/kg and precipitations > 0.3 mm/h (July 27, 2018).
Left: Z09:00; right Z09:30

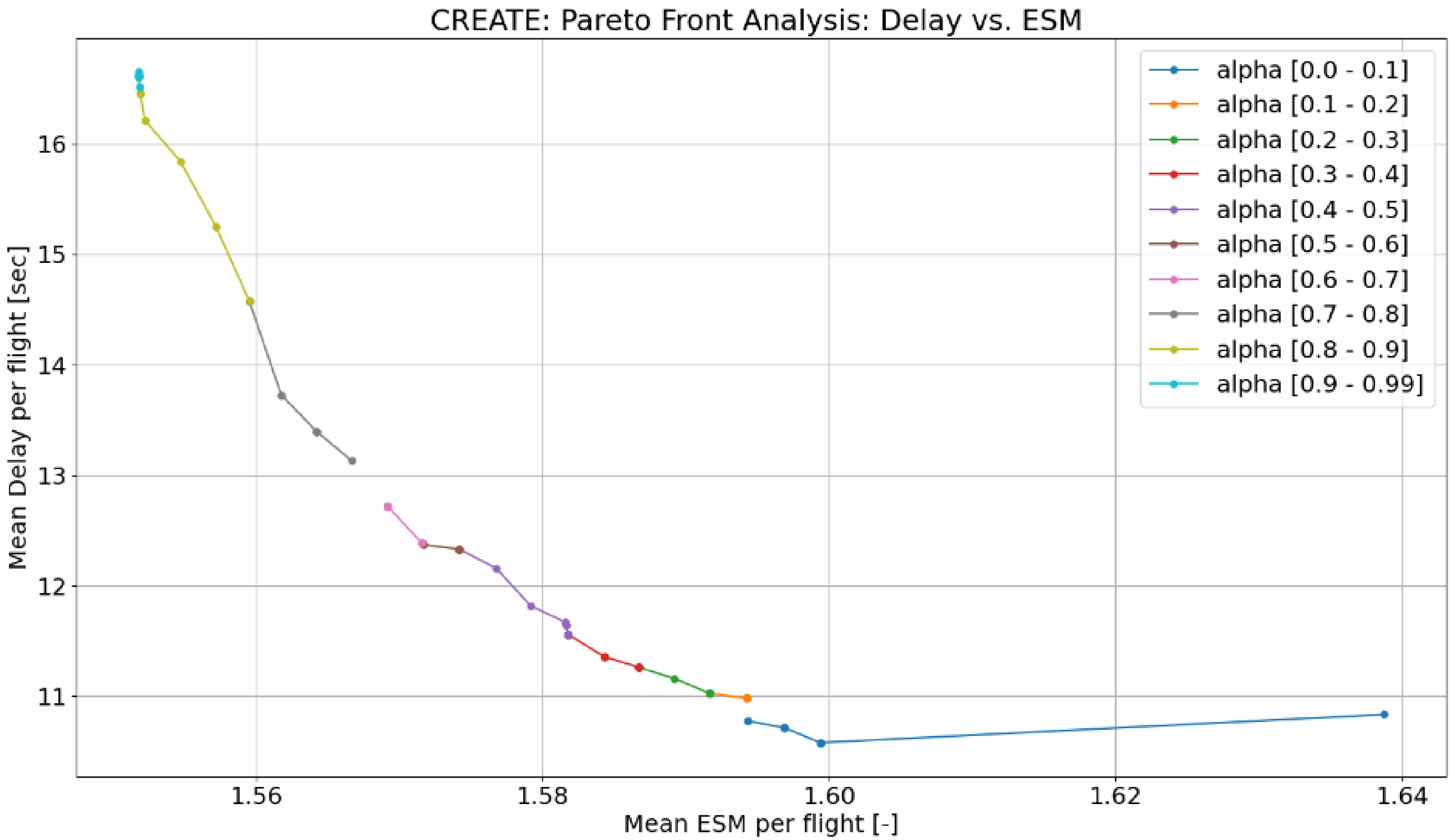
CREATE SOL-2: Results for the en-route experiment



High alphas → Lower ESM score, but higher extra operating cost per flight

Lower alphas → Lower extra operating cost, but higher ESM score

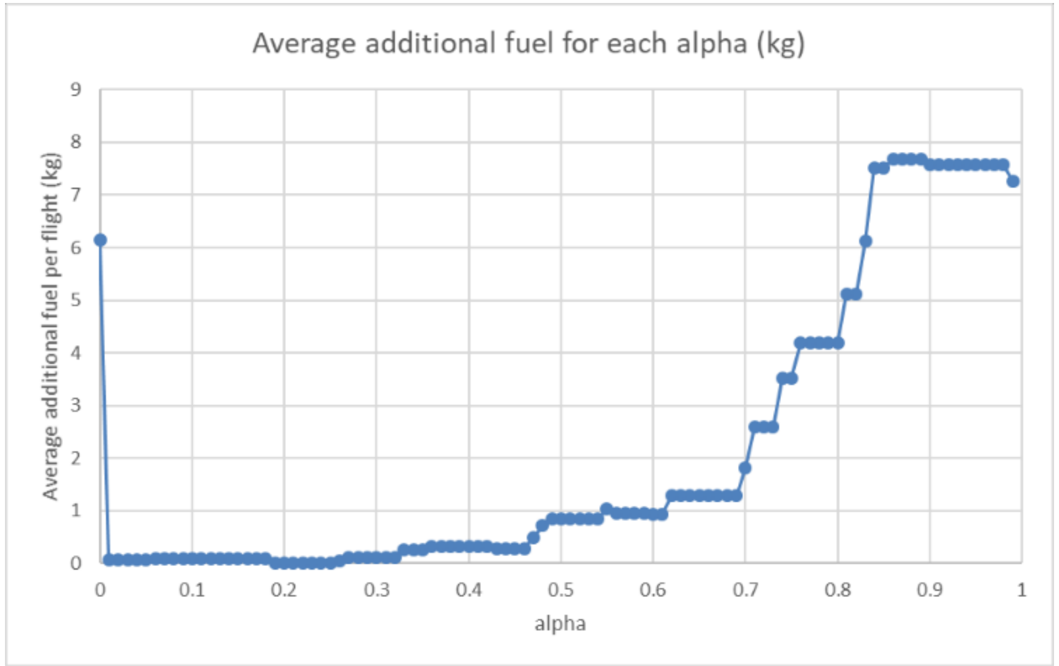
CREATE SOL-2: Results for the en-route experiment

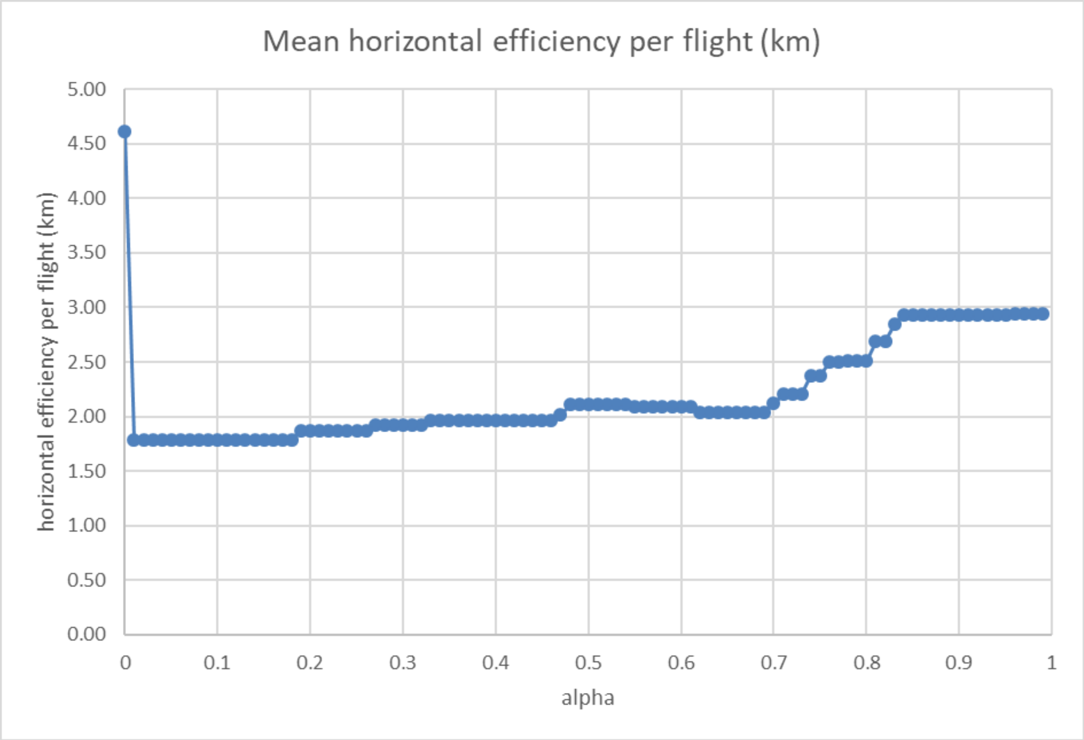


High alphas → Lower ESM score, but higher mean delay per flight

Lower alphas → Lower mean delay per flight, but higher ESM score

CREATE SOL-2: Results for the en-route experiment





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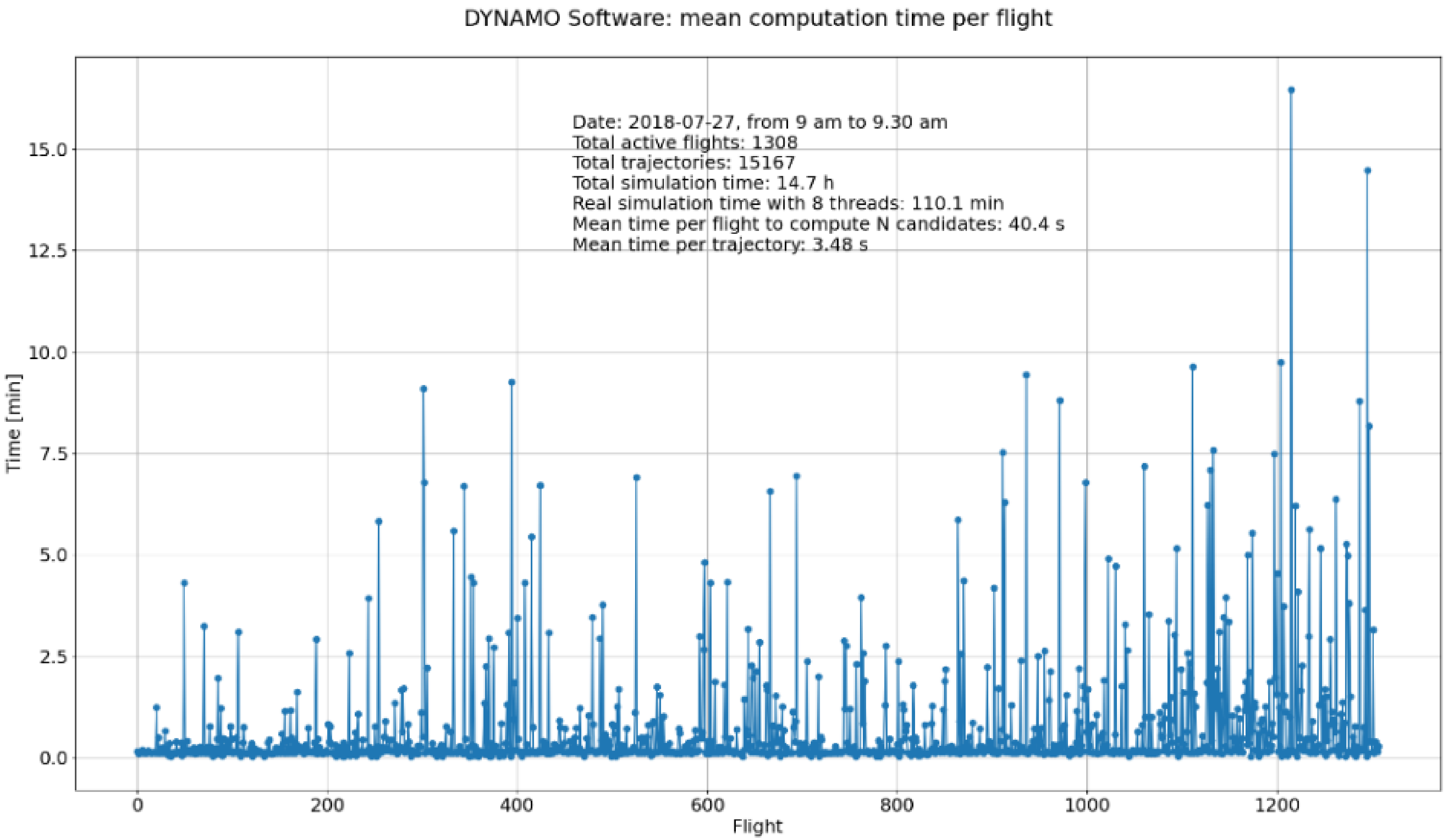


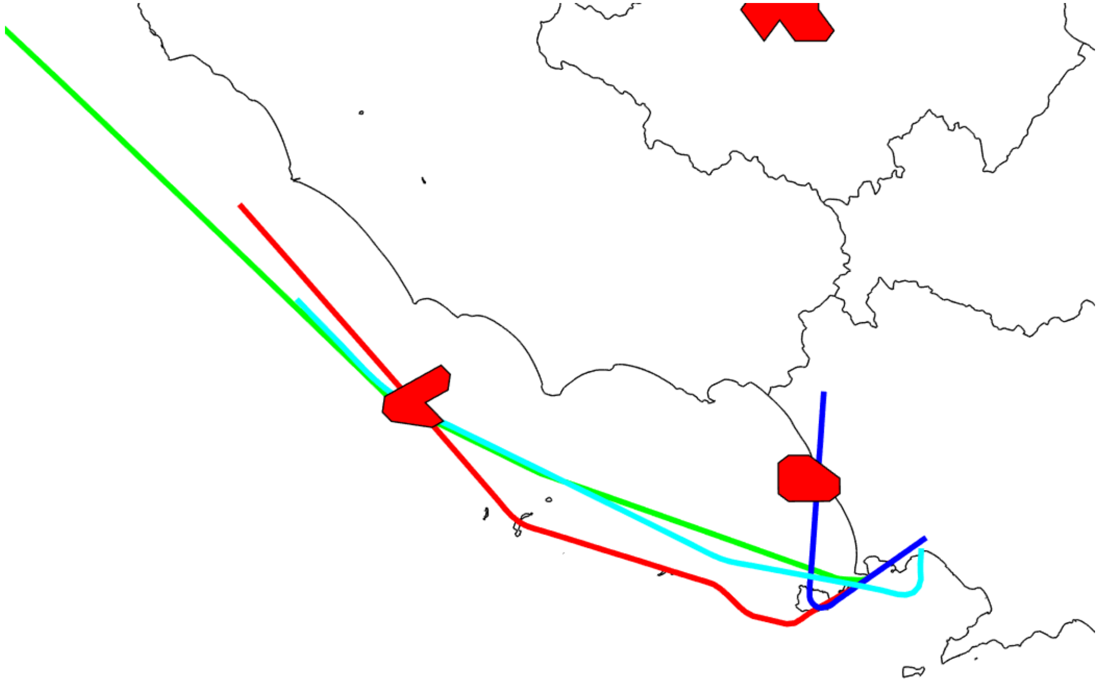
Average computational time per flight = 40 seconds

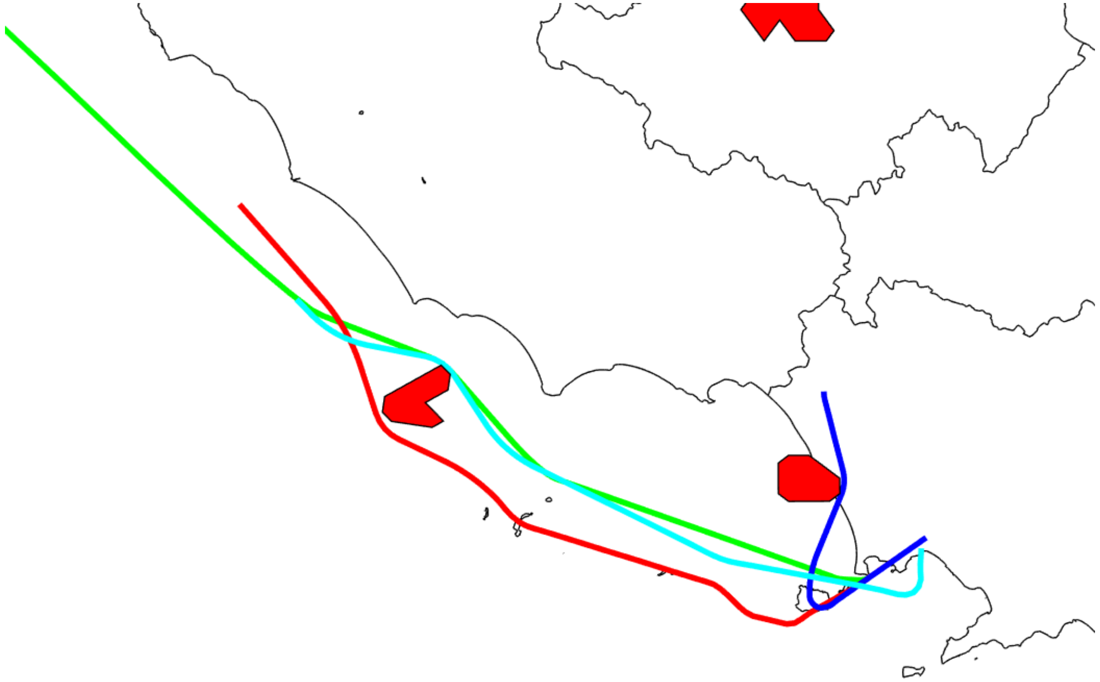
TS computational time: 2 ms

CREATE SOL-2: Results for the TMA experiment

Day	Trajectory start time	Flight	Candidate Flight Plan	Delay (s)	Delay (%)
27-02-2018	09:28:31	ABC1010	3	39	2.1
27-02-2018	10:19:54	VOE1050	3	45	3.0
27-02-2018	10:38:14	CDE1060	2	19	2.7
27-02-2018	11:36:40	ABC1070	2	15	1.1
29-10-2018	09:48:15	ABZ1001	3	17	2.4
29-10-2018	09:56:11	AZA1002	2	5	0.6
29-10-2018	10:20:00	EZY1003	3	17	5.1
29-10-2018	10:40:00	THA1006	3	10	2.6
29-10-2018	10:58:14	VOE1009	3	15	2.1
29-10-2018	11:40:00	ASA1110	3	21	5.9

CREATE SOL-2: Results for the TMA experiment





Trajectories set output for 2nd February 2018 (left) Baseline scenario flight paths and (right) optimized trajectories

CREATE SOL-2: Results for the TMA experiment

Day	Trajectory start time	Flight	Original Length (NM)	Δ Length (NM)	Horizontal Deviation (NM)
27-02-2018	09:28:31	ABC1010	158	2.1	3.9
27-02-2018	10:19:54	VOE1050	124	3.1	7.2
27-02-2018	10:38:14	CDE1060	51	1.2	3.9
27-02-2018	11:36:40	ABC1070	114	1.3	7.8
29-10-2018	09:48:15	ABZ1001	50	1.0	2.5
29-10-2018	09:56:11	AZA1002	62	0.4	1.6
29-10-2018	10:20:00	EZY1003	24	1.3	2.5
29-10-2018	10:40:00	THA1006	25	0.8	1.9
29-10-2018	10:58:14	VOE1009	51	0.9	2.4
29-10-2018	11:40:00	ASA1110	25	1.7	2.7

CREATE SOL-2: Results for the TMA experiment

Day	Trajectory start time	Flight	Trajectory Optimization Execution Time (s)	Trajectory Selector Execution Time (s)
27-02-2018	09:28:31	ABC1010	1.44	0.27
27-02-2018	10:19:54	VOE1050	1.22	0.21
27-02-2018	10:38:14	CDE1060	1.22	0.21
27-02-2018	11:36:40	ABC1070	1.15	0.20
29-10-2018	09:48:15	ABZ1001	1.22	0.21
29-10-2018	09:56:11	AZA1002	1.00	0.20
29-10-2018	10:20:00	EZY1003	1.01	0.20
29-10-2018	10:40:00	THA1006	1.02	0.21
29-10-2018	10:58:14	VOE1009	0.95	0.20
29-10-2018	11:40:00	ASA1110	1.03	0.21

CREATE SOL-2: Conclusions

- The framework allows to generate a set of alternative trajectories per flight in the execution phase with the trajectory optimisation module, avoiding weather related no-fly areas and contrail-sensitive areas located across the original trajectory.
- A system-wide global solution is found by an ATC decision support tool in line with the SESAR "extended ATC planning" concept.
- The algorithm is fast enough to be used (and re-used) also for real-time applications, given the background information on weather and air quality
- An environmental score has been introduced in the optimization goal function, as well as constraints taking into account the capacity of airspace sectors
- The final aim is to develop innovative procedures for the ATM system to reduce the climate and environmental impact of aviation, while increasing the resilience of air operations to weather phenomena.

CREATE SOL-2: Future work

- Integration of all the modules
- Improve computational times
- Perform a higher number of iterations

SESAR JOINT UNDERTAKING

THANK YOU FOR YOUR ATTENTION

Co-funded by the European Union