REAL-TIME THUNDERSTORM INFORMATION ENABLES FUEL SAVINGS FOR LONG-HAUL FLIGHTS

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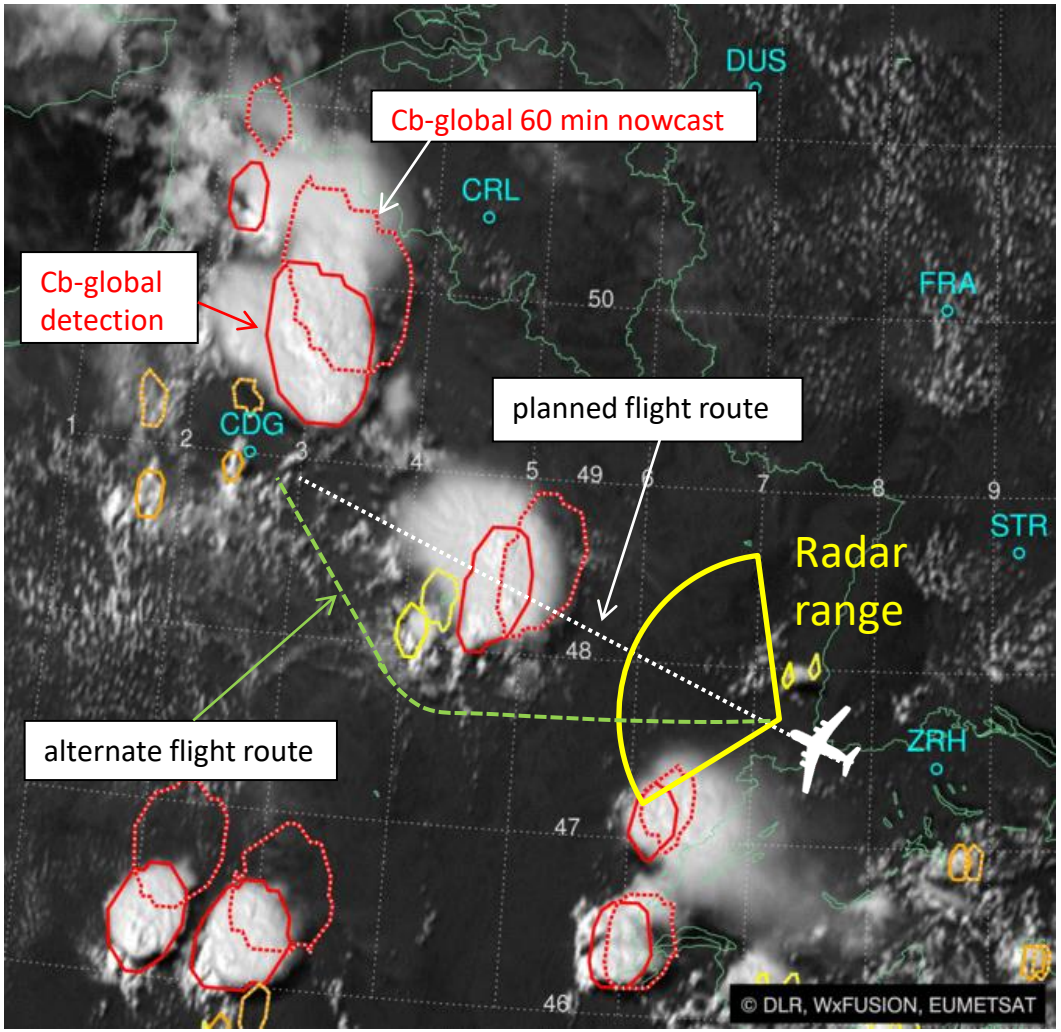
Cb-global detection and nowcasting of thunderstorms based on geostationary satellite data



- Overview beyond the limited view of the on-board radar
- Information on location and time of Cb occurrence
- Near real time
- Frequent updates (5-15 min.)
- Nowcasting up to one hour

→ Avoidance of tactical manoeuvers and unnecessary large detours

Safety! Efficiency!

Proof of fuel savings with two independent approaches

1. Estimate a mean fuel saving per flight based on a Cb statistics with Cb-global
2. The fuel burn of selected real flown flight routes is compared to the fuel burn, if these flights are laterally optimized on the basis of Cb-global

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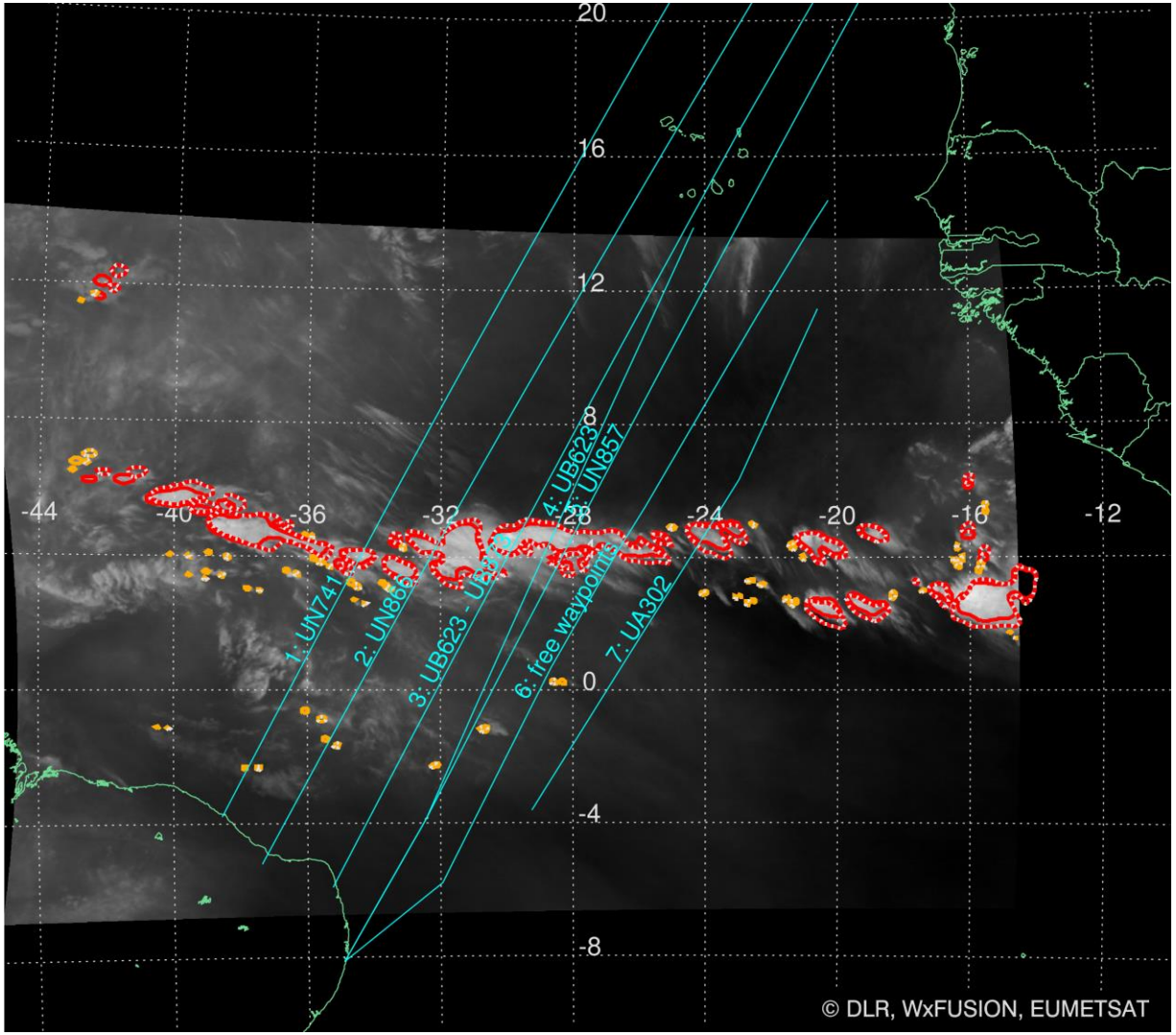
Focus on long-haul flights crossing the Intertropical Convergence Zone (ITCZ) over the Tropical Atlantic

- Cbs are active daily throughout the year
- Choice of avoidance manoeuvers relatively unrestricted
- No take-off and landing procedures to be accounted for

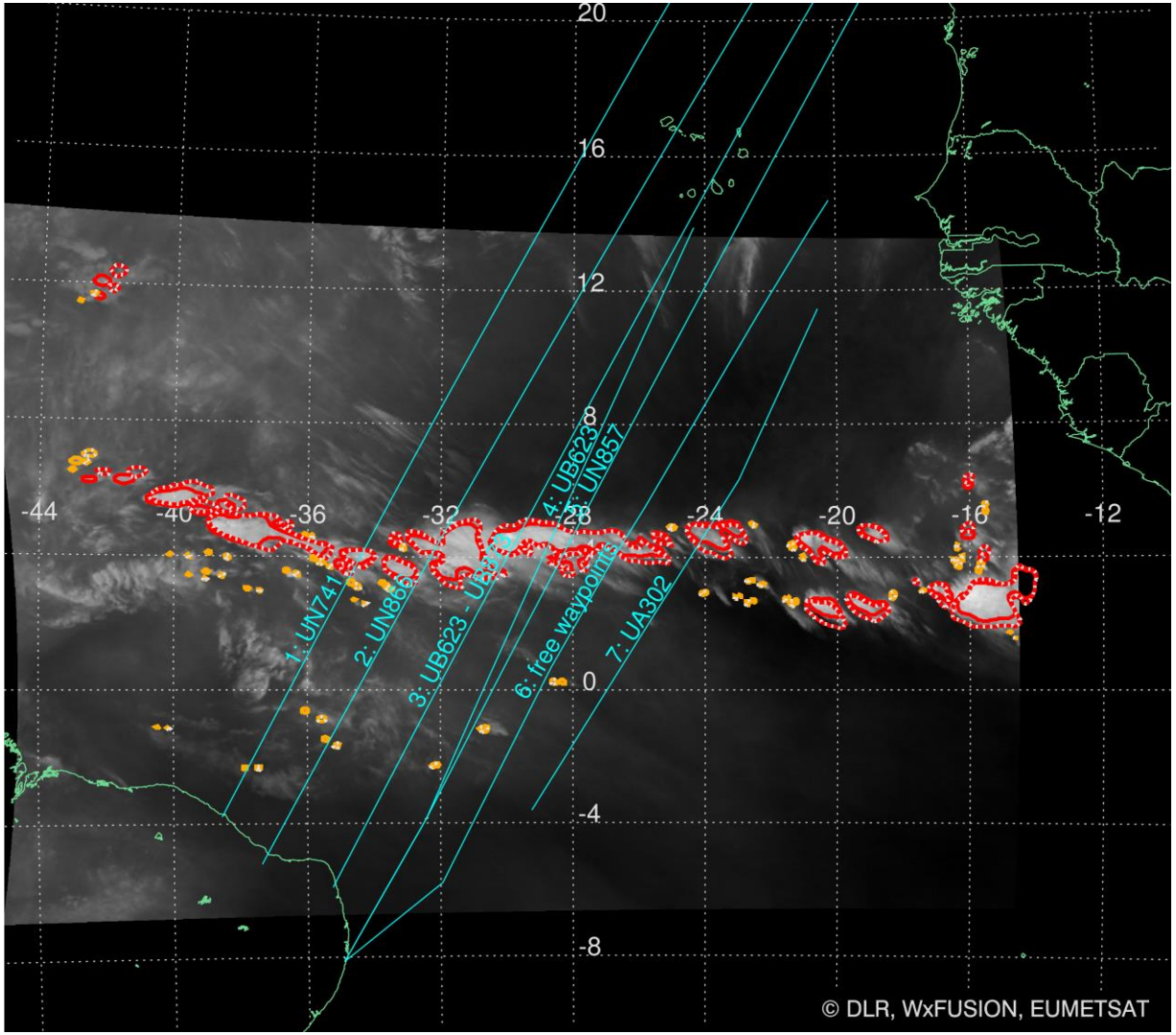
Approach 1: Fuel saving based on Cb statistics



- Cb-global output every 15 minutes for JJA 2015, i.e. 92 days in total
- 7 typical flight routes over the Tropical Atlantic
- 177 daily flights across the Tropical Atlantic

check, how often the flight routes are blocked by thunderstorms (Cb-global objects)

Approach 1: Fuel saving based on Cb statistics



- On 73 days (of 92 days) in JJA 2015, at least one flight route was blocked by Cbs
- On 27 days in JJA 2015, three or more flight routes were simultaneously blocked by Cbs

Avoidance maneouvers can be expected on 79% of all days

Experience for 6-7 blocked flight routes shows:

Approx. 2 tonnes of fuel can be saved, if Cb-global information is used to adjust the flight route to the current Cb situation

See Forster et al. (2017), Journal of Air Transportation, 24 (4), p 113-124. DOI: 10.2514/1.D0055 ISSN 1544-6980.

Approach 1: Fuel saving based on Cb statistics

Category	1	2	3
Number of blocked routes	6-7	3-5	1-2
Fuel saving per flight [t]	2,0*	1,0 **	0,33 **
Flight time saving [min]	60	30	10
Occurrence in JJA 2015 [days]	7	20	46
Fuel saving in JJA 2015 [t]	2.478	3.540	2.687

- Average fuel saving potential based on the use of Cb-global: **0,55 tonnes per flight**
- Compares well to other studies who found 0,450 – 0,760 tonnes per flight
- Relevance for a major airline with approx. 460 flights per week accross the tropics worldwide:

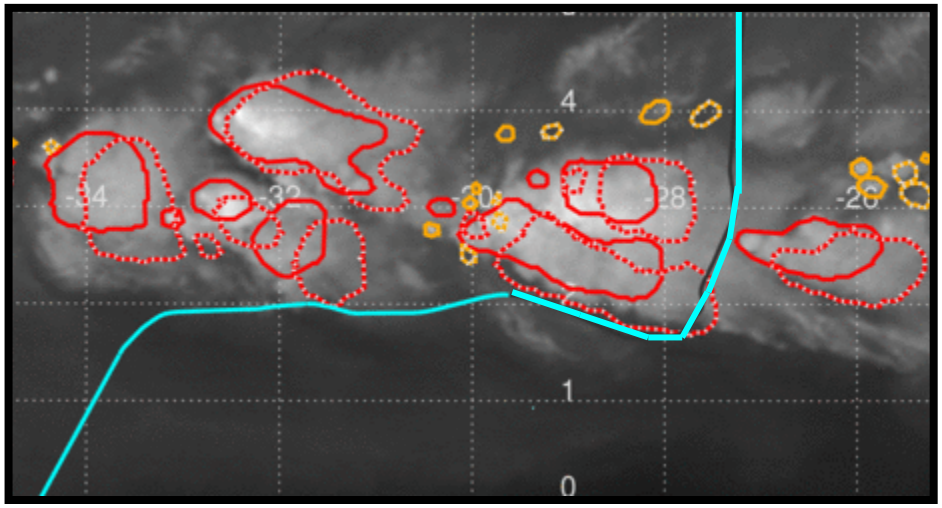
  13.108 tonnes fuel savings per year (≙ **4,7 mio. EUR** positive financial effect)

* Based on experience from Forster et al. (2017), Journal of Air Transportation, 24 (4), p 113-124. DOI: 10.2514/1.D0055 ISSN 1544-6980

** Based on estimates and computations of two test pilots and two pilots from a commercial airline

Approach 2: Fuel savings based on comparison of original flown routes with optimized routes based on Cb-global

- Originally flown flight routes from *IAGOS data base
- Cb-global detections and nowcasts for the IAGOS flights
- Trajectory optimization tool (TOM), cooperation with DLR-LY and TUHH



* IAGOS: In-service aircraft for a global observing system (https://www.iagos.org/)

Approach 2: Fuel savings based on comparison of original flown routes with optimized routes based on Cb-global

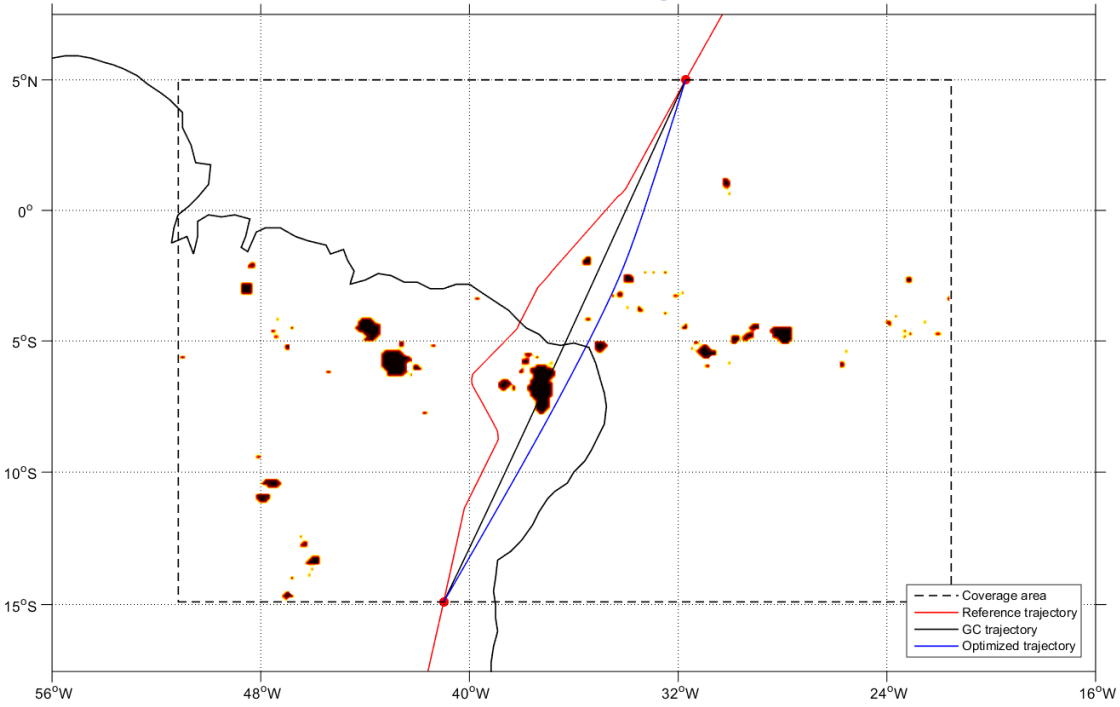
Trajectory optimization (TOM, cooperation with DLR-LY and TUHH)

- Continuous optimal control approach
- Aircraft motion described by state variables (x) and control variables (u)
- Cost function to be minimized

$$\underbrace{J(\boldsymbol{x}(t),\boldsymbol{u}(t),t)}_{\text{Cost function}} = \underbrace{\left(m_0 - m_f\right)}_{\text{Fuel consumption}} + \underbrace{c_\Psi \cdot \int_{t_0}^{t_f} \Psi(\boldsymbol{x}(t),\boldsymbol{u}(t),t)\,\mathrm{d}t}_{\text{weighted penalty function}}$$

- Penalty function 1 for thunderstorms, 0 else
- Dynamic constraints (e.g. equations of motion) as well as control (e.g. thrust limitation), state (e.g. speed) and path limitations (e.g. pressure altitude) have to be fulfilled (boundary conditions defined by Eurocontrol BADA data base)

Approach 2: Fuel savings based on comparison of original flown routes with optimized routes based on Cb-global



In this example case:

1,3 tonnes of fuel can be saved compared to the original flown route (reference)

Red: original flown route (reference trajectory)

Black: great circle route

Blue: optimized route

Black areas: Cb-global objects

Results from 75 inspected IAGOS flights including 5 TOM optimizations:

- In most of the cases a smarter route could have been chosen with Cb-global
- For one flight even 3,3 tonnes of fuel could be saved
- In two cases an avoidance manoeuver would not have been not necessary at all
- In one case a landing at the alternate airport could have been avoided

Summary and conclusions

- Goal: Estimate fuel saving potential en-route by using Cb-global for route adjustments
- Two approaches:
  - Approach 1: Use of thunderstorm statistics and flight statistics
  - Approach 2: Compare fuel costs of originally flown routes with those of routes optimized by taking into account Cb-global
- Results:
  - Approach 1:
    - on average 0,55 tonnes fuel savings per flight (compares well to literature)
    - relevance for airlines: 13.108 tonnes fuel savings per year (≙ 4,7 mio. EUR)
  - Approach 2:
    - fuel saving potential up to 3 tonnes per flight
    - some avoidance manoeuvers were not necessary at all
    - landings at alternates can be avoided

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