Quantum Climate Challenge 2022 - Data Description and QC Hardware Access

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1 Flight data

The file flights.csv contains flight information for 100 flights over Europe, each starting at a time between 6:00am and 8:00am so that each flight can reach its destination point within one day. The departure and landing phases are not considered here, thus the flights are in cruise mode over the whole travel time. The flights start at a given flight level between FL200 and FL340, and a given position and time. As the destination an end position with longitudinal and latitudinal coordinates is given. The ending time and the ending flight level are not pre-defined as they depend on the chosen flight route depending on your solution. In the table below the data columns of flights.csv are listed

Column name	Column description
flight_number	unique identifier for each flight
start_time	time the flight enters the grid Datastructure: hh:mm:ss
start_flightlevel	flight level in which the flight enters the grid. All given start flight levels are within the range FL200 - FL340
start_longitudinal	longitudinal coordinate where the flight enters the grid. Negative values represent coordinates in °W (e.g. -16 is 16°W), positive values represent coordinates in °E (e.g. 28 is 28°E)
start_latitudinal	latitudinal coordinate where the flight enters the grid. Values represent coordinates in °N (e.g. 56 is 56°N)
end_longitudinal	longitudinal coordinate where the flight should leave the grid. Negative values represent coordinates in °W (e.g. -16 is 16°W), positive values represent coordinates in °E (e.g. 28 is 28°E)
end_latitudinal	latitudinal coordinate where the flight should leave the grid. Values represent coordinates in °N (e.g. 56 is 56°N)

2 Fuel consumption and airplane specifics

An approximate fuel consumption and TAS speed at different flight levels of the A320 was published by the European Organization for the safety of air navigation: Eurocontrol. For this challenge the Base of Aircraft Data (BADA) Revision 3.0 is used. This specifies the true air speed, rate of climb/decent and fuel flow for the cruise, climb and decent at a range of flight levels. The data is based on a total-energy model and BADA 3.0 performance coefficients. [NPM10]
All required information can be found in the file bada_data.csv. The table is divided into three sections: cruise, climb and decent. Each section includes the true air speeds (TAS) in knots and the respective fuel usage in $\frac{\text{kg}}{\text{min}}$ for the flight levels in steps of at least 2000 ft. The climb and decent columns further include a rate of climb/descend (ROC/ROD) in feet per minute (fpm). For this challenge a fixed weight of the airplane can be assumed at 62000 kg, so all values are given for nominal weight for this challenge. When routing an airplane through a flight level for which no data is given, please use the data of the nearest flight level listed (e.g. for FL 385 use the data of FL 380). The data was adopted from [Cen14].

3 Athmosheric data and climate effect ΔC

For this challenge a rectangular grid is put above Europe to discretely describe the atmosphere. This is illustrated in figure 1. Each grid voxel is localized using the center point as the position. The horizontal grid points are spaced with 2°E and 2°N. The limits are: south: 34°N; north: 60°N; west: 30°W; east: 30°E. The steps are given in degrees where 'a' are the steps from west to east and 'b' are the steps from south to east. This gives 31 voxels thus 30 steps 'a' from west to east and 14 voxels thus 13 steps 'b' from south to north. Further, the grid has 14 discrete vertical voxels given in FL. The flight levels start at FL100 and go up to FL400 in 13 discrete steps 'c' of FL20 each. Overall there is a total of 6076 voxels making up the total possible air space and the atmosphere.

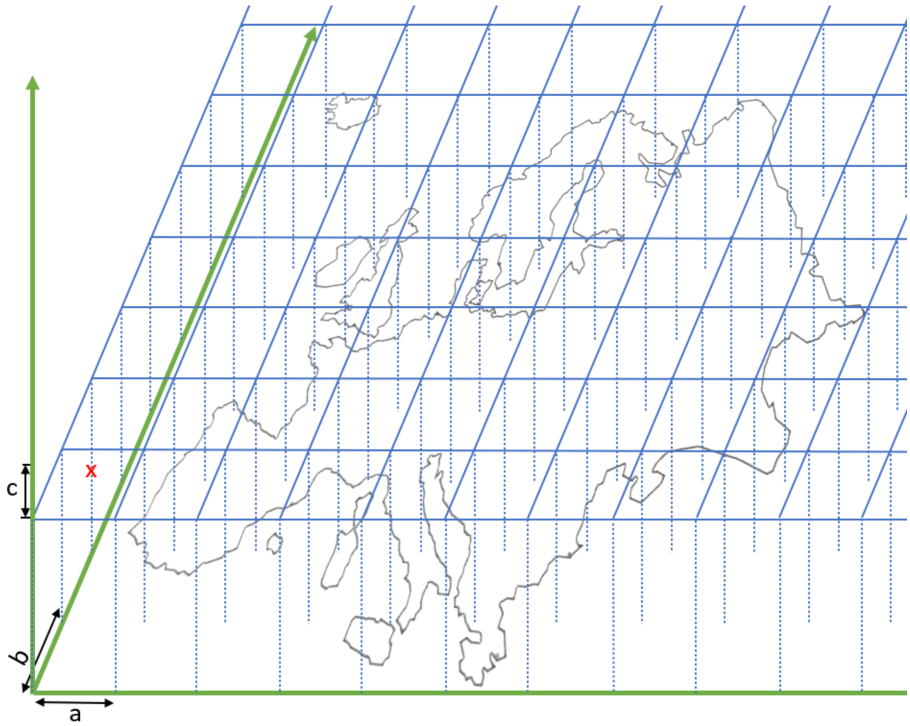

Figure 1: This schematic shows the applied grid over Europe for one flight level. The lowest most south west point is indicated with the red x.

The climate effect ΔC_{CO2} of CO_2 emission is directly proportional to the fuel consumption.

$$\Delta C_{CO2} = 6.94 * 10^{-12} \ \frac{\mathrm{K}}{\mathrm{kg\ fuel}} \tag{1}$$

The modeling of non-CO_2 effects is very complex as they depend on a lot of factors. For this challenge we thus use maps based on ERA5 data and created using algorithmic climate change functions (aCCFs) developed by ATM4E. These maps are provided by the DLR and may only be used for the Quantum Climate Challenge.
The maps are stored in the file "aCCF_0623_p_spec.nc". The aCCF maps show the climate effect ΔC for the effects of water vapor, contrails, and NO_x emissions in $10^{-12}\ \frac{\mathrm{K}}{\mathrm{kg\ fuel}}$ as a 4D grid. In addition to the 3D grid described above, the forth dimension given is time. The maps are given for three times of the day in 6h steps - 6:00am, 12:00 noon and 6:00pm. When routing an airplane through the grid over time, please always use the data of the nearest time set given (e.g. for 11:45am and 1:30pm use the data of 12:00 noon). Please note that the 3D grid given in "aCCF_0623_p_spec.nc" as used by ATM4E is larger than the one we are using in this challenge. Thus you can cut off and neglect some of the data given in the file. This is described in more detail below.
The "aCCF_0623_p_spec.nc" file contains dimensions and variables which are described in more detail below:

Dimension	Size	Description
LONGITUDE	66	longitudinal coordinates in °ranging from 100°W to 30°E in 2 °steps. In this challenge we are only looking at flights over Europe in a grid ranging from 30°W to 30°E. Thus, you can neglect all data for coordinates west of 30°W.
LATITUDE	14	latitudinal coordinates in °ranging from 34°N to 60°N
LEVEL11_24	14	flight levels in hPa ranging from 100 hPa to 600 hPa. These can be transformed to FL using the left side of the table below. Transformed to FL, the range spans from FL138 to FL531. Since we want to focus on FL100 to FL400 in FL20 based on suggestions from Deutsche Flugsicherung (and as given in the BADA data), we map this to "our" voxels using the nearest flight level of the atmosphere data (e.g. for FL100 we use the data of FL138 (= 600 hPa), for FL158 we use that data of FL160 (=550 hPa)). This mapping and thus the data to be used for our flight levels/ our voxels can be found in the right side of the table below. Please be aware that this in done for simplification but results in distortion.
bnds	2	boundary levels, used for illustration of regions when plotting the maps - can be neglected
TIME	3	time stamps.

flight level [hPA] given in the atmosphere data	**Flight Level (FL)** directly transformed/ not used in this challenge		**Flight level (FL)** used in this challenge	**flight level [hPa]** mapped to the Flight Level used
100	FL531		FL100	600
125	FL484		FL120	600
150	FL464		FL140	600
175	FL414		FL160	550
200	FL387		FL180	500
225	FL362		FL200	450
250	FL340		FL220	450
300	FL301		FL240	400
350	FL266		FL260	350
400	FL246		FL280	350
450	FL208		FL300	300
500	FL183		FL320	300
550	FL160		FL340	250
600	FL138		FL360	225
			FL380	200
			FL400	200

All variables have the datatype ‘double’ and the size 66 x 14 x 14 x 3 in the dimensions LONGITUDE x LATITUDE x LEVEL11_24 x TIME. In this challenge we are only looking at flights over Europe in a grid ranging from 30°W to 30°E. Thus, you can neglect all data for coordinates west of 30°W. To simplify this challenge it is assumed that the distance equivalent to one degree is constant disregarding the curvature of the earth. Please use the following constants to translate the longitudinal and lateral degrees to distances:

$$1^\circ \text{ lattitude} = 111 \text{ km} \tag{2}$$

$$1^\circ \text{ longitude} = 85 \text{ km} \tag{3}$$

Variable	**Longname**	**Description**
MERGED	SG_H2O+SG_DCONT +SG_O3+SG_CH4 +1.E12*ACCF_CO2	Combined climate effect ΔC derived by merging ΔC_{H2O}, ΔC_{Cont}, ΔC_{NOX} and ΔC_{CO2} for each voxel. Since this variable thus takes into account all specific climate effects considered, you can use just this variable for your calculation and neglect the other variables.
SG_H2O	.153E12*ACCF_H2O	Climate effect ΔC_{H2O} of water vapor as 4D data in the dimension $10^{-12}\ \frac{\text{K}}{\text{kg fuel}}$. Given for informational background reasons only. Can be neglected.
SG_DCONT	.046E12*ACCF_DCONT	Climate effect ΔC_{Cont} of contrail formation as 4D data in the dimension $10^{-12}\ \frac{\text{K}}{\text{kg fuel}}$. Given for informational background reasons only. Can be neglected.
SG_NOX	SG_O3+SG_CH4	Climate effect ΔC_{NOX} of NO_x gases as 4D data in the dimension $10^{-12}\ \frac{\text{K}}{\text{kg fuel}}$. Given for informational background reasons only. Can be neglected.
E022	1.E12*ACCF_CO2 [L=90:92,K=11:24]	Climate effect ΔC_{CO2} of CO_2 as 4D data in the dimension $10^{-12}\ \frac{\text{K}}{\text{kg fuel}}$ ΔC_{CO2} is proportional to the fuel consumption, thus is constant over the whole 4D grid. Given for informational background reasons only. Can be neglected.

Figure 2 shows as an example how the combination of the maps of SG_NOX, SG_DCONT, SG_H2O and the constant value associated with CO_2 results in the corresponding MERGED map. As stated, it is ok to only use the MERGED maps. The maps for the specific singular effects are given just for information in this challenge.

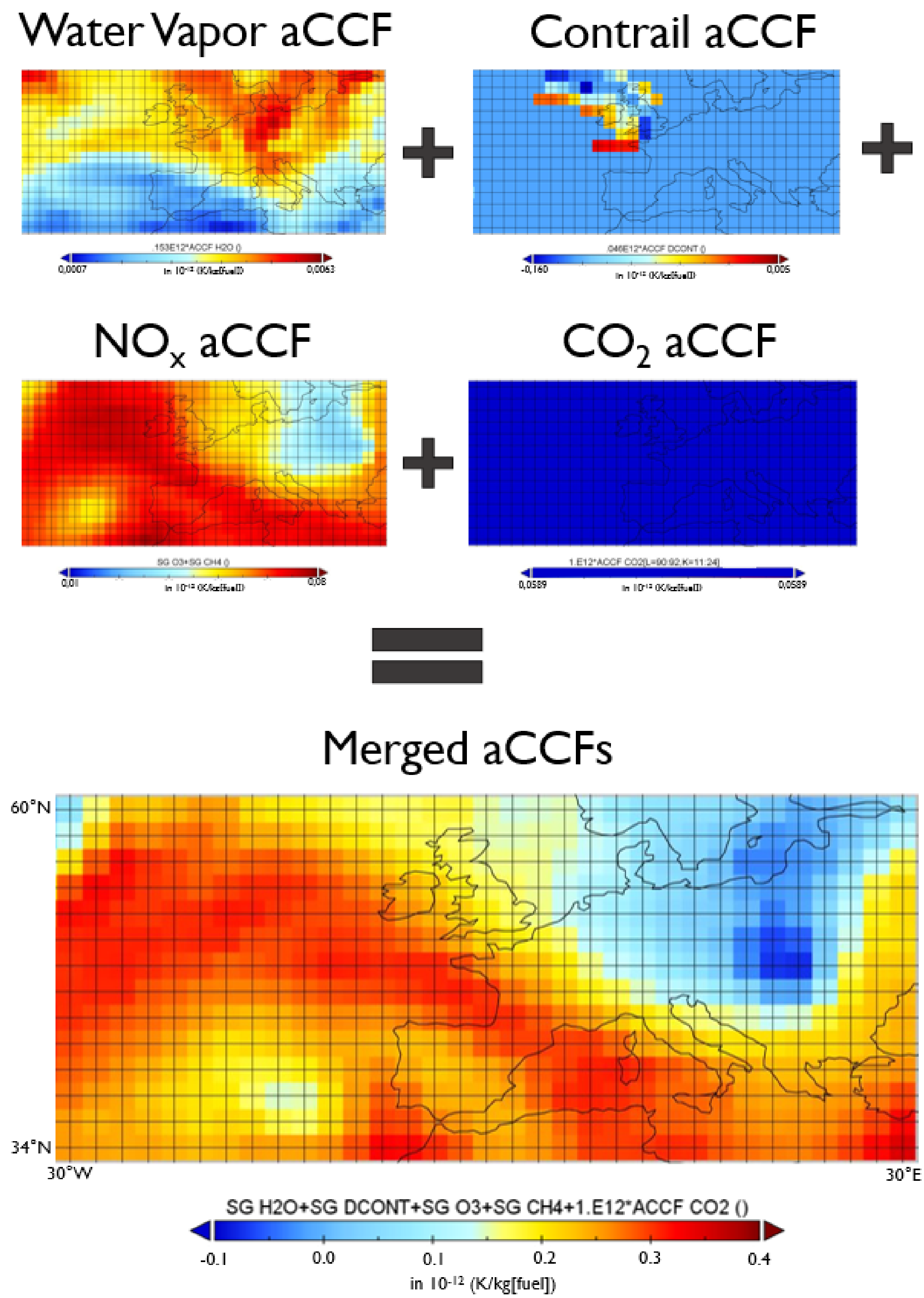

Figure 2: This figure illustrates how the specific singular climate affects are added to derive the merged aCCFs maps. Please note that the color scales for each aCCF map is set to different values here - this was done so that e.g. even smaller variations in the Contrail aCCF map are visible. Usually the contrail aCCF dominates the merged aCCFs drastically. For illustrative reasons here a specific situation with very small contrail effect variation was chosen.

4 QC Hardware Access

As a registered participant you get exclusive access to a 7 Qubit IBM Quantum Computer that you can use to run and test solutions. If selected as one of the TOP 5 finalists you get exclusive access to a 16 Qubit IBM System. Please note that developing a solution for other types of quantum hardware, e.g. Annealers, or usage of simulators or quantum-inspired solutions on classical computers is also encouraged.

To get access to the IBM QC Hardware, send an email to quantum.link@deloitte.de with the subject line “Quantum Climate Challenge QC Hardware Access” stating the following:
“I consent to my data being forwarded to IBM for the purpose of being granted access to exclusive systems during the Deloitte Quantum Climate Challenge: [name] [surname] [email-address] [IBMid]”

If you do not have an IBMid yet, please register at https://quantum-computing.ibm.com/

References

[NPM10] Angela Nuic, Damir Poles, and Vincent Mouillet. “BADA: An advanced aircraft performance model for present and future ATM systems”. In: *International Journal of Adaptive Control and Signal Processing* 24.10 (2010), pp. 850–866. DOI: `https://doi.org/10.1002/acs.1176`. eprint: `https://onlinelibrary.wiley.com/doi/pdf/10.1002/acs.1176`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1002/acs.1176`.

[Cen14] Eurocontrol Experimental Center. *Aircraft performance summary tables for the base of aircraft data (BADA)*. Jan. 2014. URL: `https://www.eurocontrol.int/node/10065`.

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