Pitch

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MDO and Regulations for Low-boom and Environmentally Sustainable Supersonic Aviation

102 Comments

NEWS

Supersonic jet would fly from NYC to London in just 80 minutes

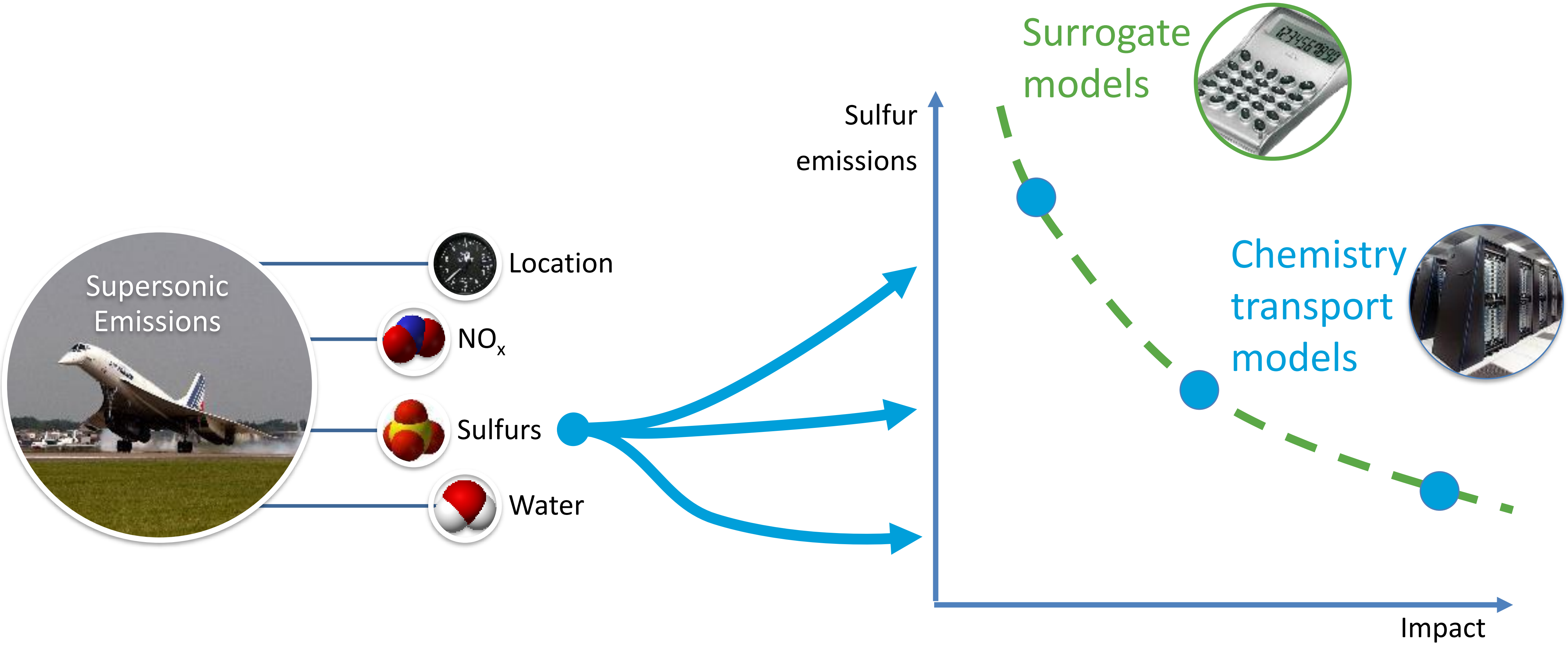
By Patrick Reilly

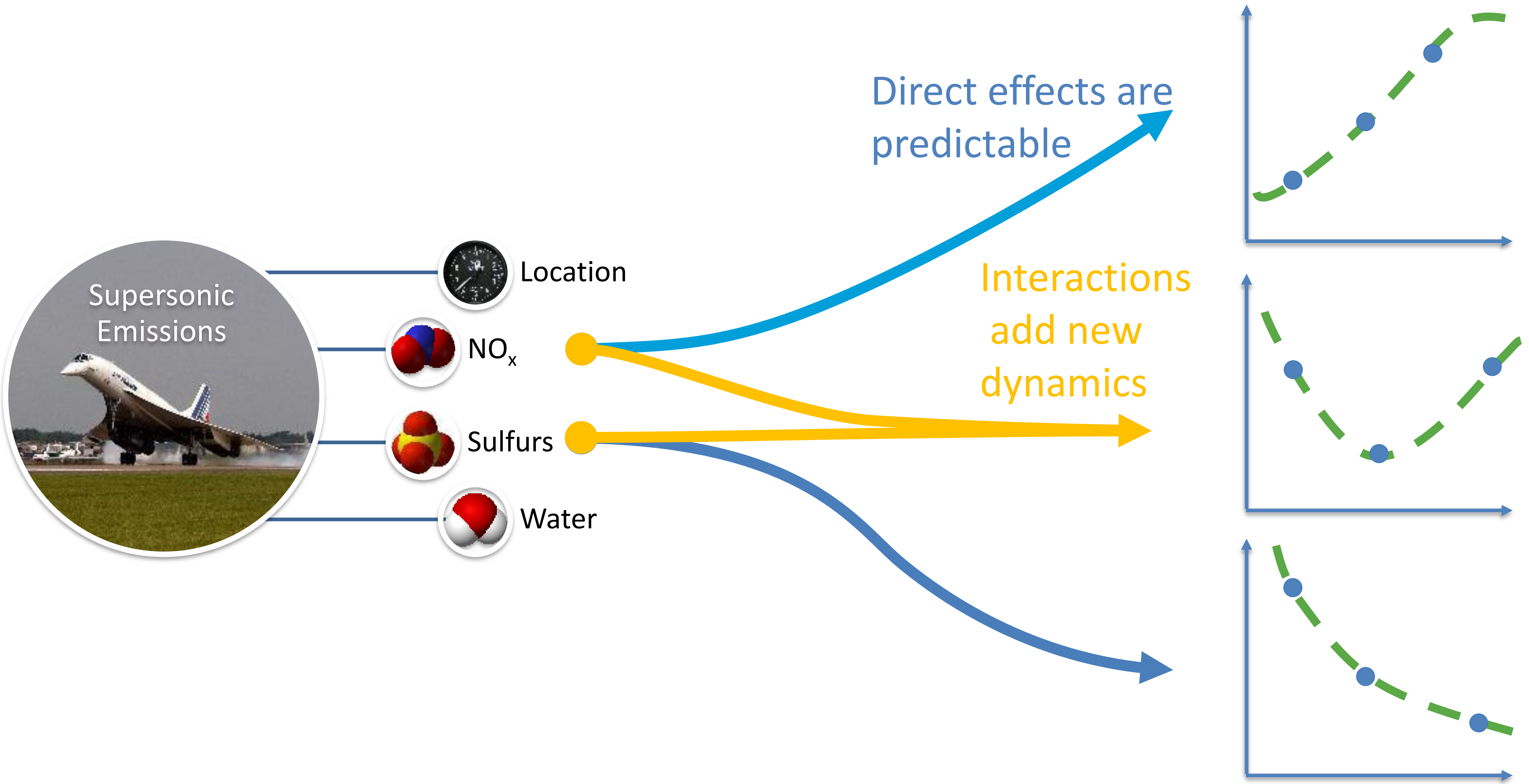
nypost.com

September 30, 2022 | 12:02am | Updated

What will it cost us?

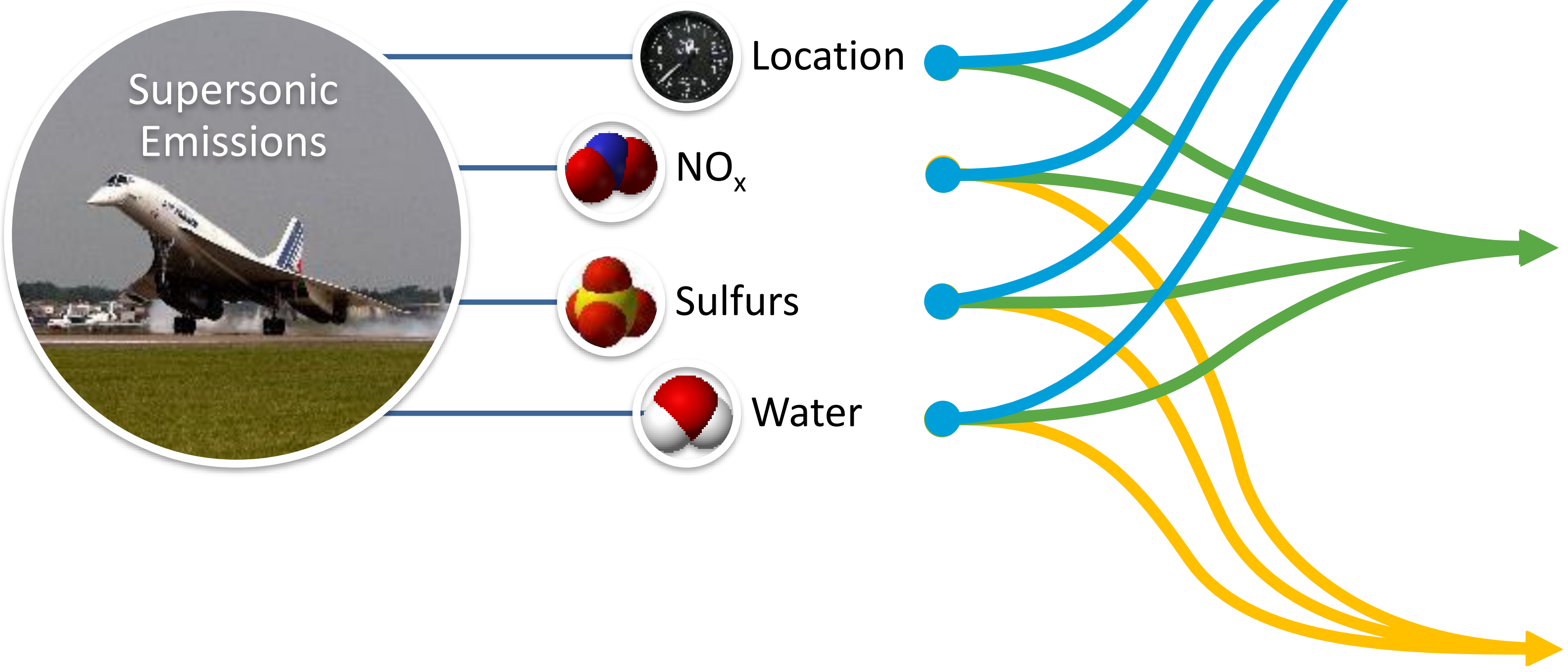
Chemistry transport models


Supersonic Emissions
Location
NO_x
Sulfurs
Water
Sulfur emissions
Impact
Surrogate models
Chemistry transport models


Supersonic Emissions
Location
NO_x
Sulfurs
Water
Direct effects are predictable
Interactions add new dynamics

GEOS-Chem

Calculate 10 year impact across 24 scenarios and 2 locations



Direct sensitivities

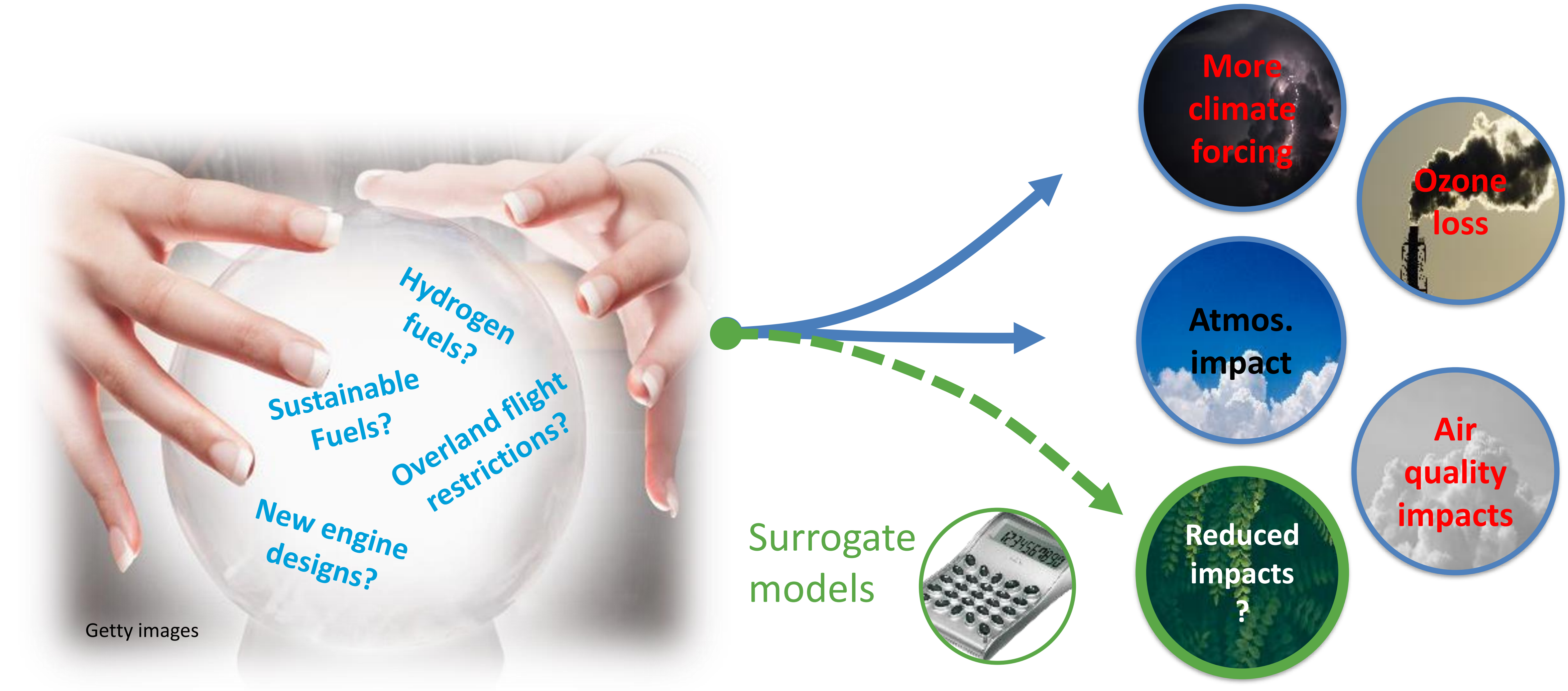
$$\frac{\delta O_3}{\delta L}, \frac{\delta O_3}{\delta NO_x}, \frac{\delta O_3}{\delta S}, \frac{\delta O_3}{\delta H_2O}$$

Location cross-sensitivities

$$\frac{\delta^2 O_3}{\delta NO_x \delta L}, \frac{\delta^2 O_3}{\delta S \delta L}, \frac{\delta^2 O_3}{\delta H_2O \delta L}$$

Chemical cross-sensitivities

$$\frac{\delta^2 O_3}{\delta NO_x \delta S}, \frac{\delta^2 O_3}{\delta S \delta H_2O}, \frac{\delta^2 O_3}{\delta H_2O \delta NO_x}$$



Thank you for your attention!

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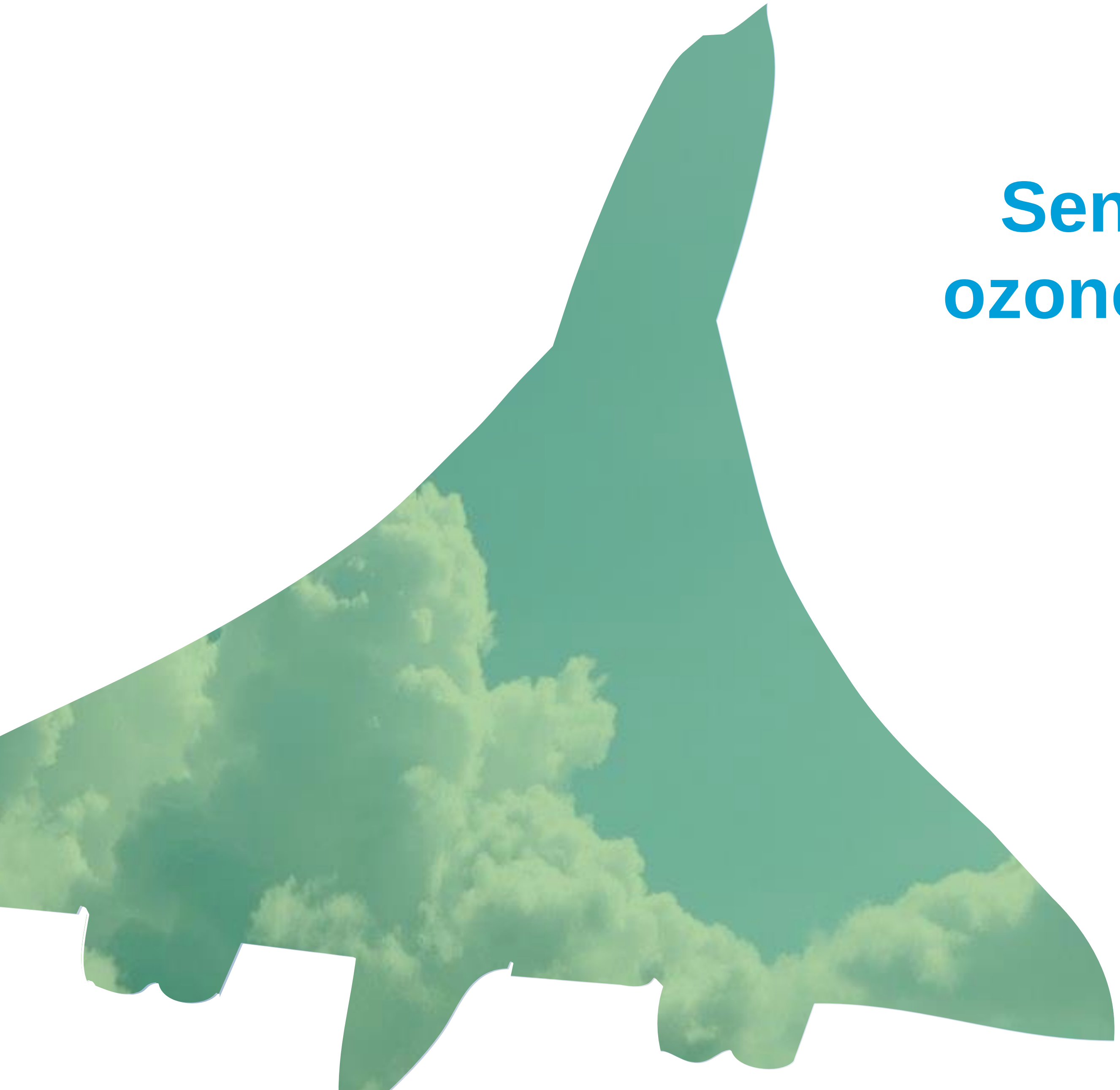
Interactive component

Click these!



Sensitivities of atmospheric ozone to supersonic emissions

J. van 't Hoff, V. Grewe, I. Dedoussi

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Click these!

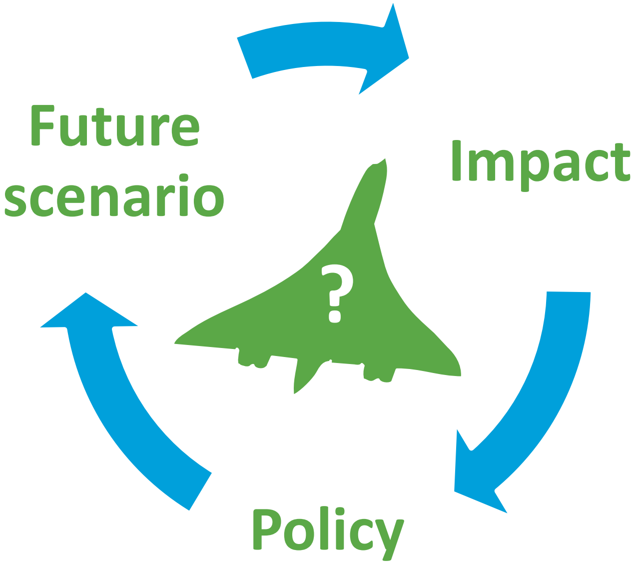
Civilian supersonic aviation may return in the future. Their emissions (especially non-CO_2) have stronger impacts on our atmosphere compared to conventional aviation due to their high cruise altitudes (up to 20 km).

Impacts

Navigate to subsections!


Dublin Airport, 1983 (@DublinAirport, Twitter)

This photo is about as old as the current supersonic regulations!

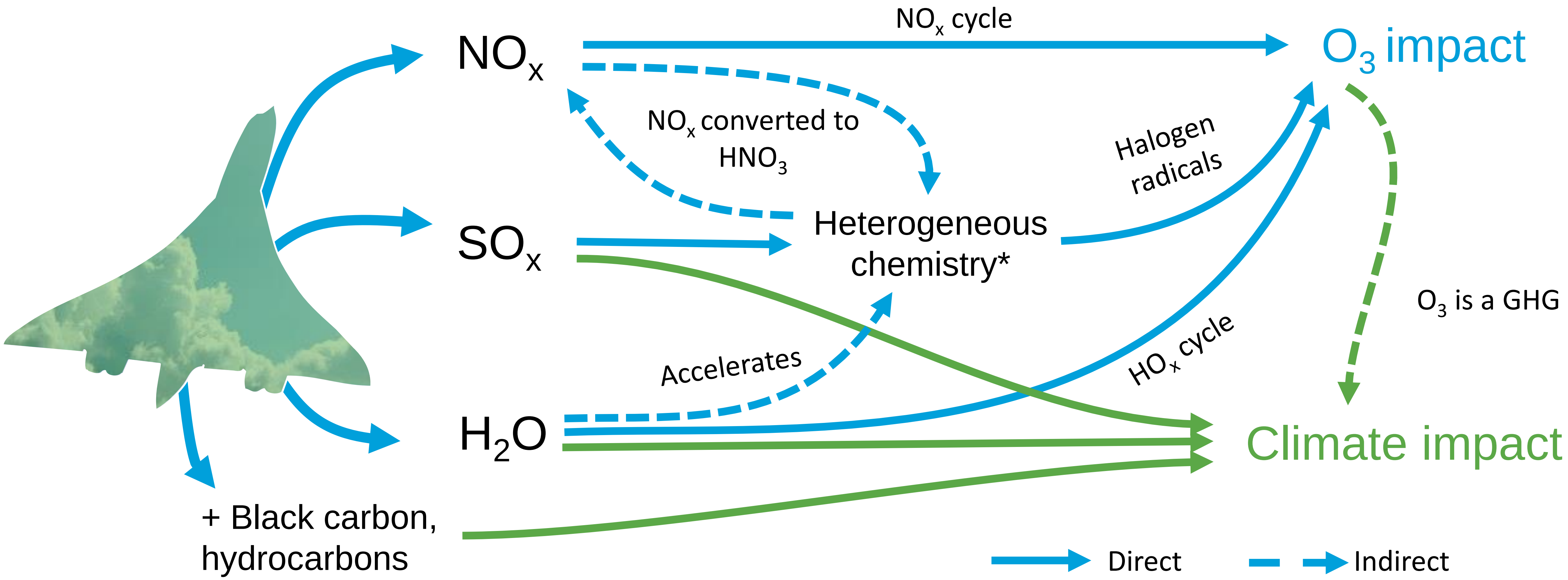


Existing regulations for supersonic aircraft were drafted in 1983. Regulators are looking to update them to account for non-CO_2 emissions and their impacts on the atmosphere.

Updating policy for a future scenario requires a complex iterative trade-off. This process requires the development of faster methods to assess the impact.

Policy cycle

Non-CO_2 emissions of supersonic aircraft have multiple ways of affecting the Ozone layer and climate [1-7].



*Chemical reactions on the surface of sulfuric aerosols

Regulators need to consider a trade-off between different impacts, for which they need tools to assess them.

Policy cycle

Impact evaluation

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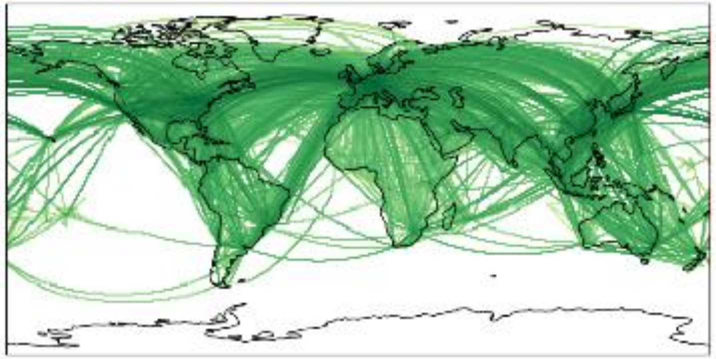

Prediction of future supersonic use and emissions. Pictured: predicted aviation emissions from the SCENIC project [5].

Scientific models calculate future impacts.

In this process the speed of the scientific models is a bottleneck.

Impact evaluation

Future scenario

Impact

Noise

Climate

Air quality

Ozone

In this work we look at Ozone, but this is just one of several impacts that regulators consider

Predicted impacts drive the consideration of policy.

Policy

Policies affect the economic viability of future markets and expected future emissions.

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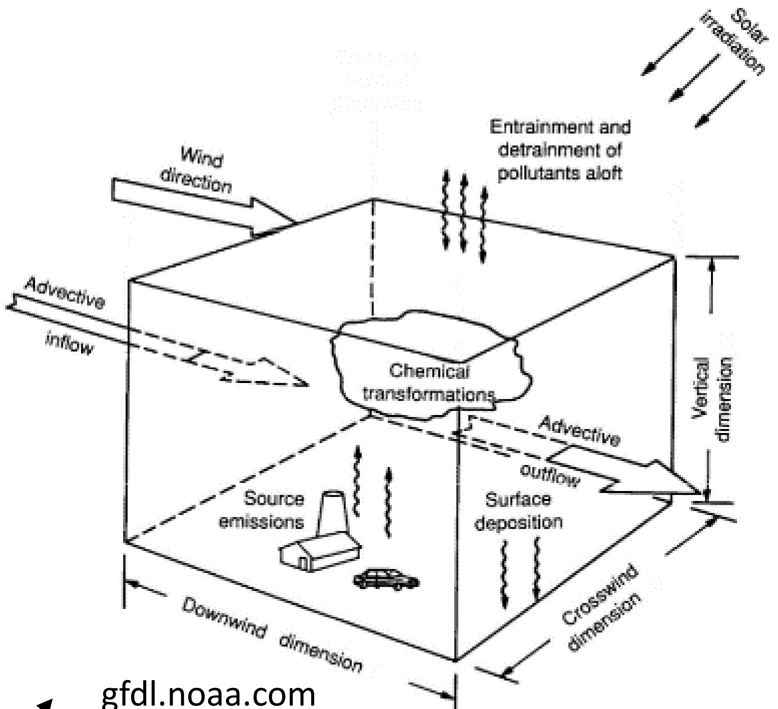
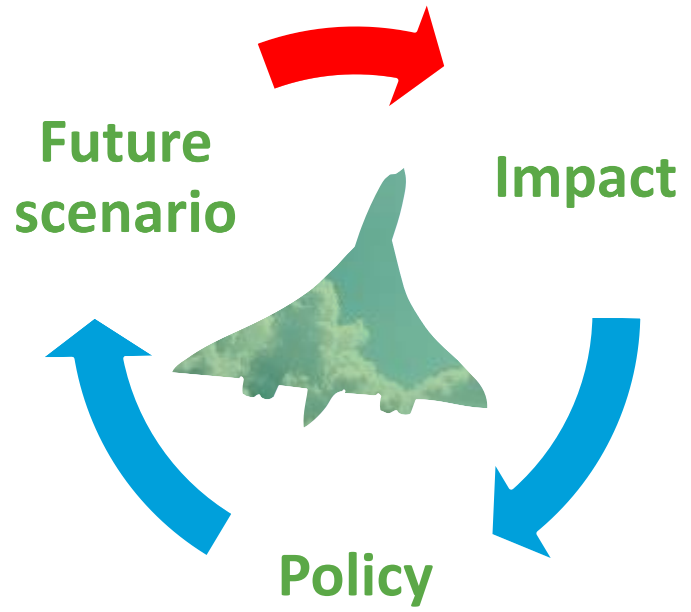
To evaluate the atmospheric impacts of supersonic emissions, we need chemistry transport & chemistry climate models. These model chemistry and transport for hundreds of chemical species across the atmosphere.

We make use of the GEOS-Chem model for our simulations.



gfdl.noaa.com

Overview of processes chemistry transport models solve for thousands of atmospheric cells



Modelling approach

A small part of the Snellius supercomputer, which we use for our research

Due to their complexity, these models need high-performance computer clusters to use.

Even then, a single multi-year model evaluation can take weeks to evaluate.

Because of the resource requirements, these models are unsuitable for in-the-loop applications. For policy development we need surrogate models, and sensitivity studies are a first step towards them.

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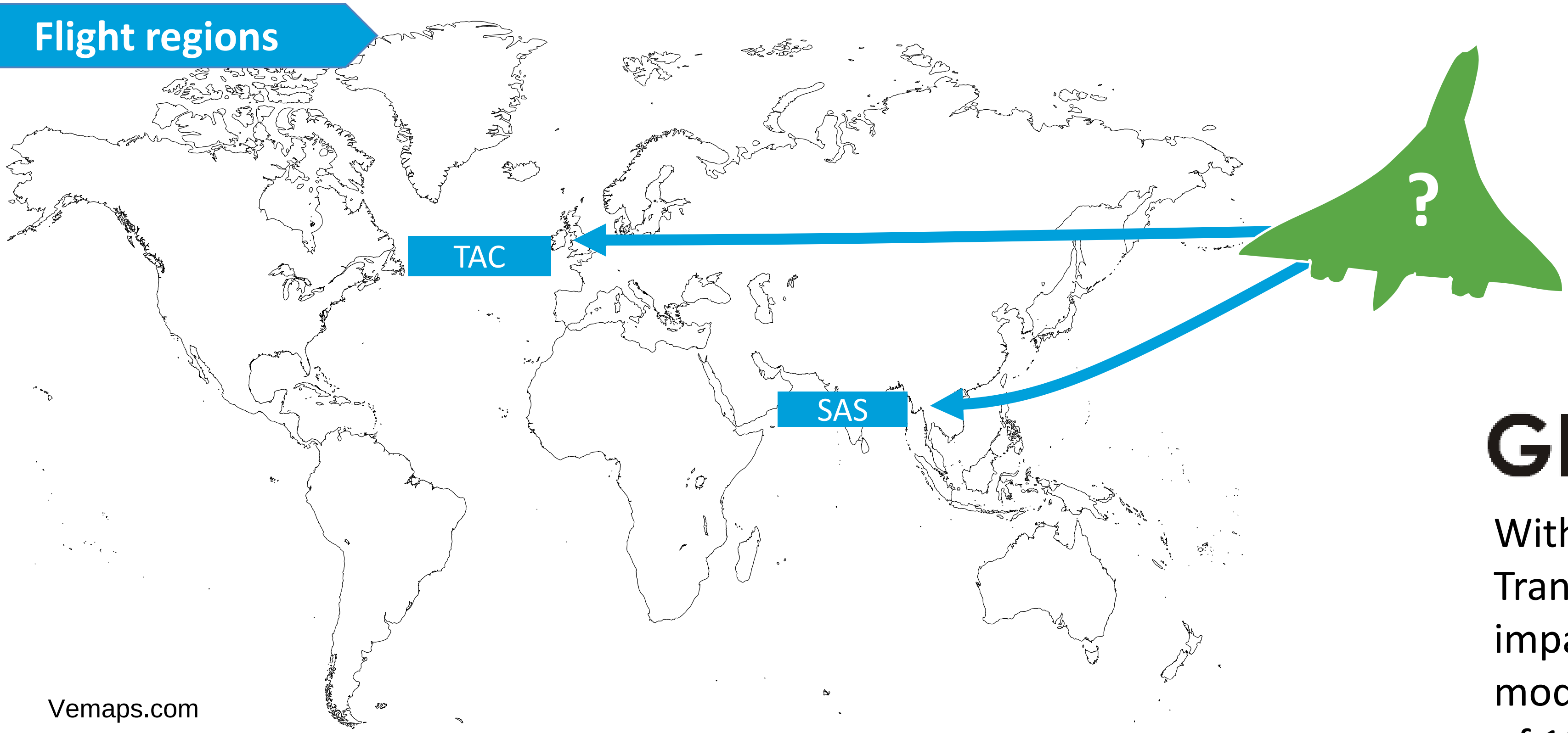
We study the impact of supersonic emissions in two flight regions: the transatlantic corridor (TAC) and south arabian sea (SAS).

Flight regions



In these regions we introduce emissions representing 8 Tg of annual fuel burn of a hypothetical supersonic aircraft.

Emissions profile

GEOS-Chem

With the GEOS-Chem Chemistry Transport Model we evaluate the impact of these emissions on a modern atmosphere over the course of 10 years.

Model setup

x24

We combine over 24 variations of these scenarios to calculate first- and second-order sensitivities of the global ozone response in these regions.

Parametric study

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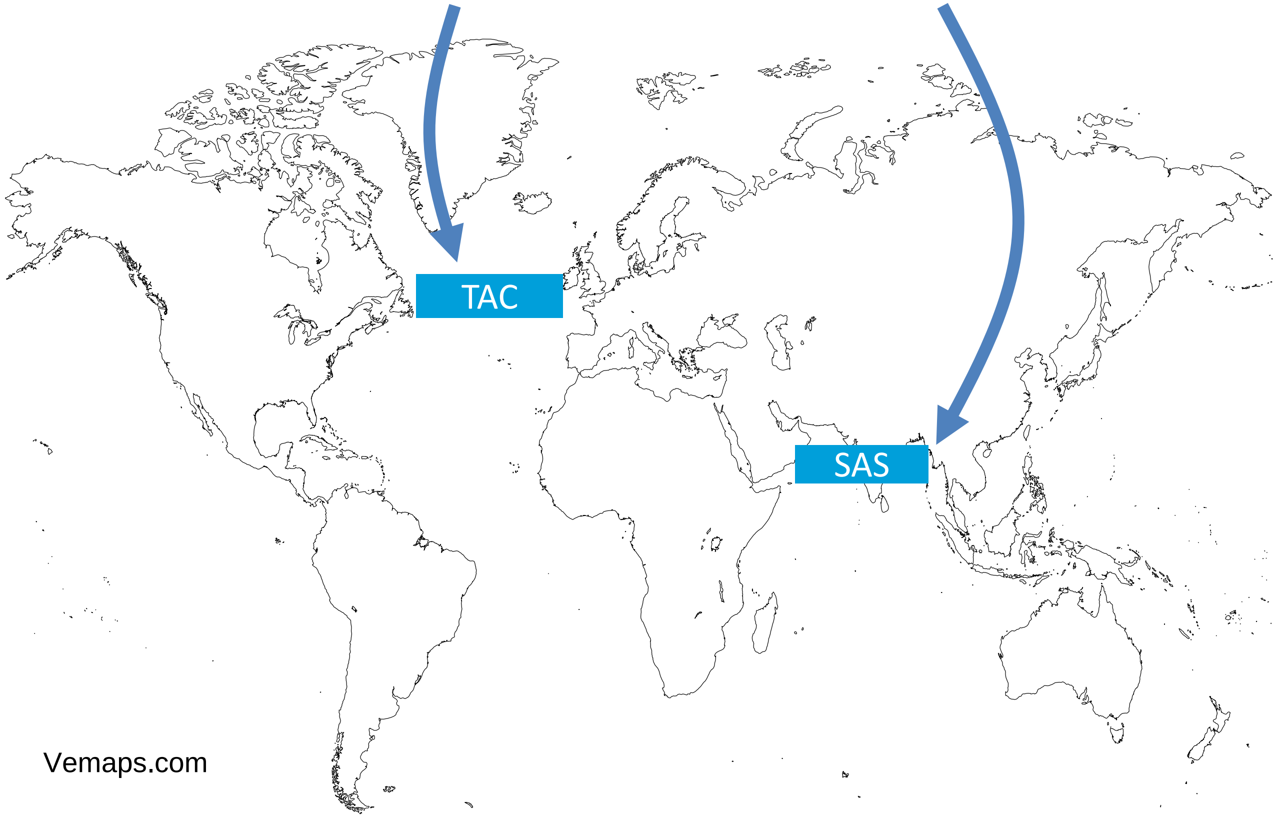
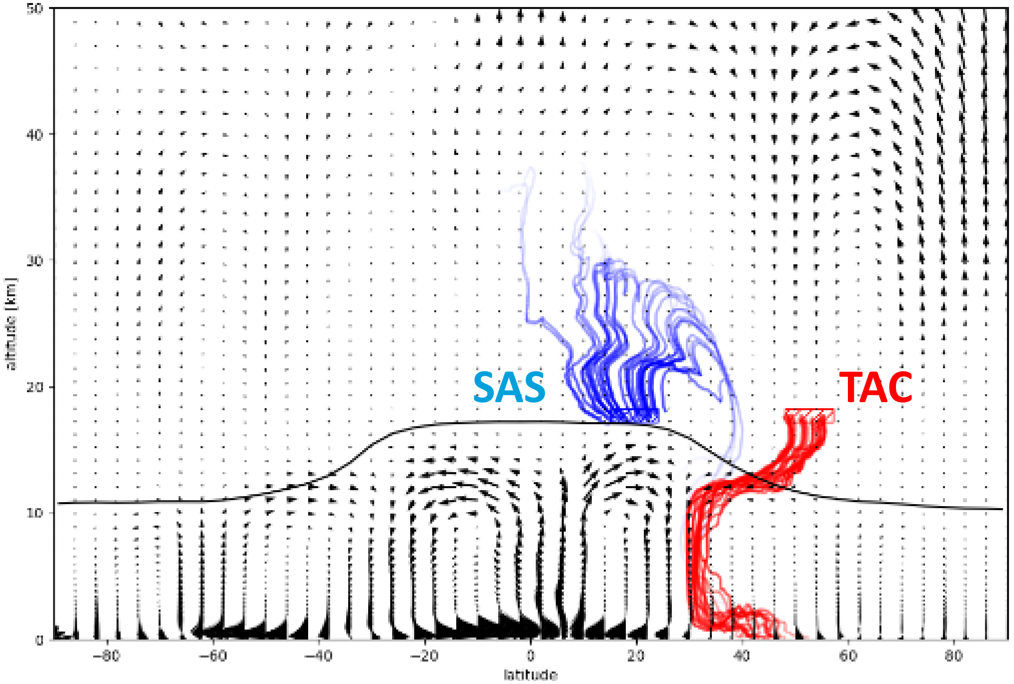
Two regions of anticipated use for supersonic flight are selected: the transatlantic corridor (TAC) and south arabian sea (SAS).



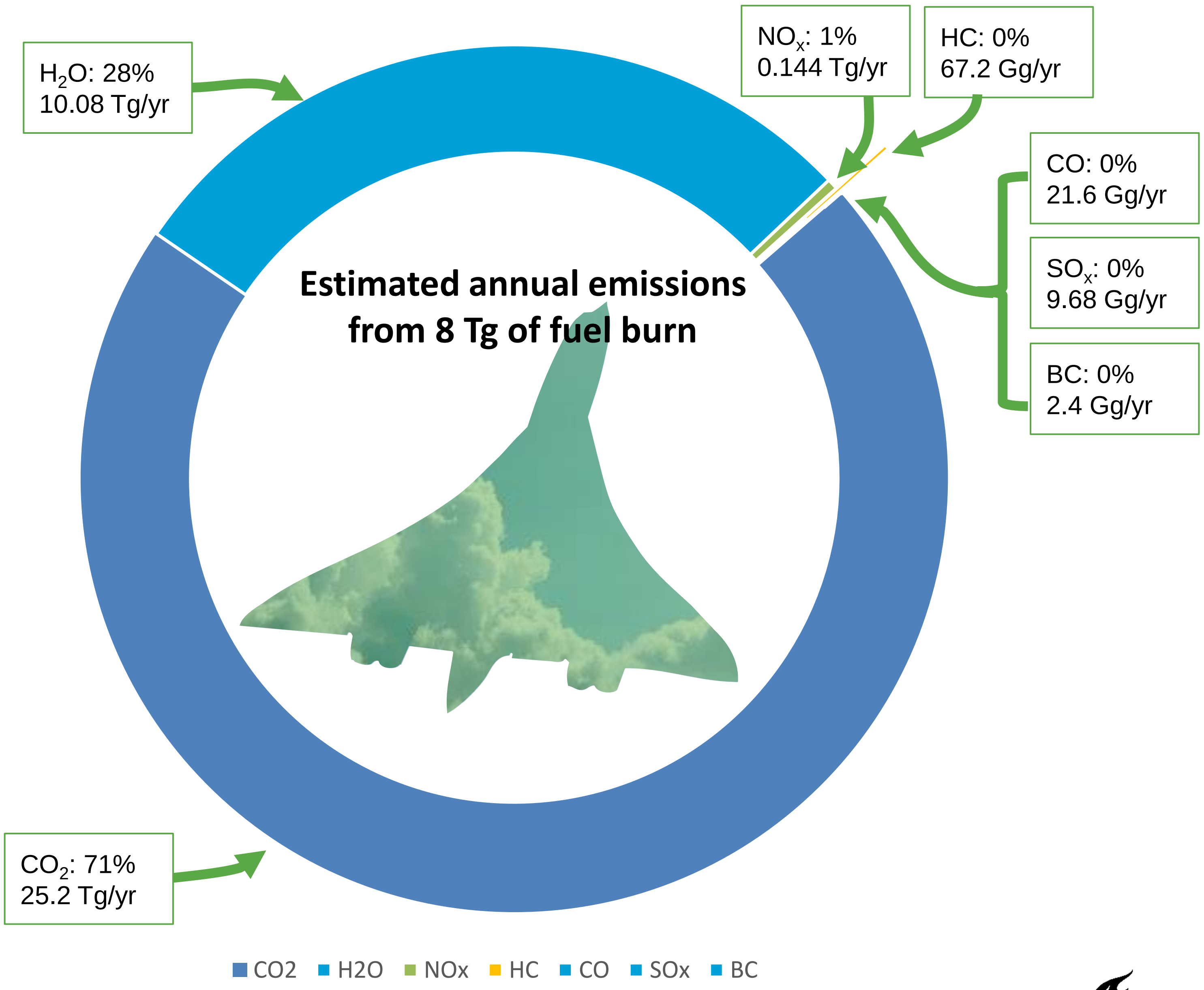
These regions are chosen as they are likely to be used for supersonic aviation, even if overland supersonic flight restrictions are considered [1,5]. Within these regions we introduce emissions representative of 8Tg of annual supersonic fuel burn.

Emissions profile

These regions are located in different parts of the Brewer-Dobson circulation, affecting how emissions and impacts from these regions propagate. This is demonstrated below with a simplified lagrangian model using MERRA-2 meteorology:



Trajectories show average transport of emissions in june from the **SAS** and **TAC**. Vector field shows wind fields averaged over 3 years of data.



The emissions profile estimates cruise emissions of supersonic aircraft using conventional jet fuel. These values are based on estimates of cruise emissions from literature [1-3]

$H_2O : 1.26 \frac{kg}{kg}$

$HC : 2.7 \frac{g}{kg}$ (Hydrocarbons)

$NO_x : 18 \frac{g}{kg}$

$CO : 8.3 \frac{g}{kg}$

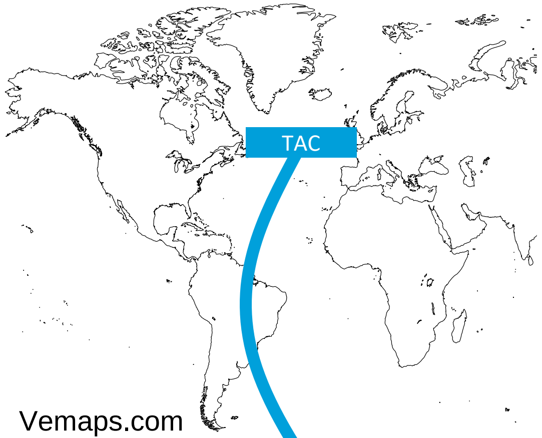
$SO_x : 1.212 \frac{g}{kg}$

$BC : 30 \frac{\mu g}{kg}$ (Black carbons)

$CO_2 : 3.15 \frac{kg}{kg}$

We target the Mach 1.4 to Mach 2 design space, resulting in a cruise altitude range of 16.2 to 20.4 km.

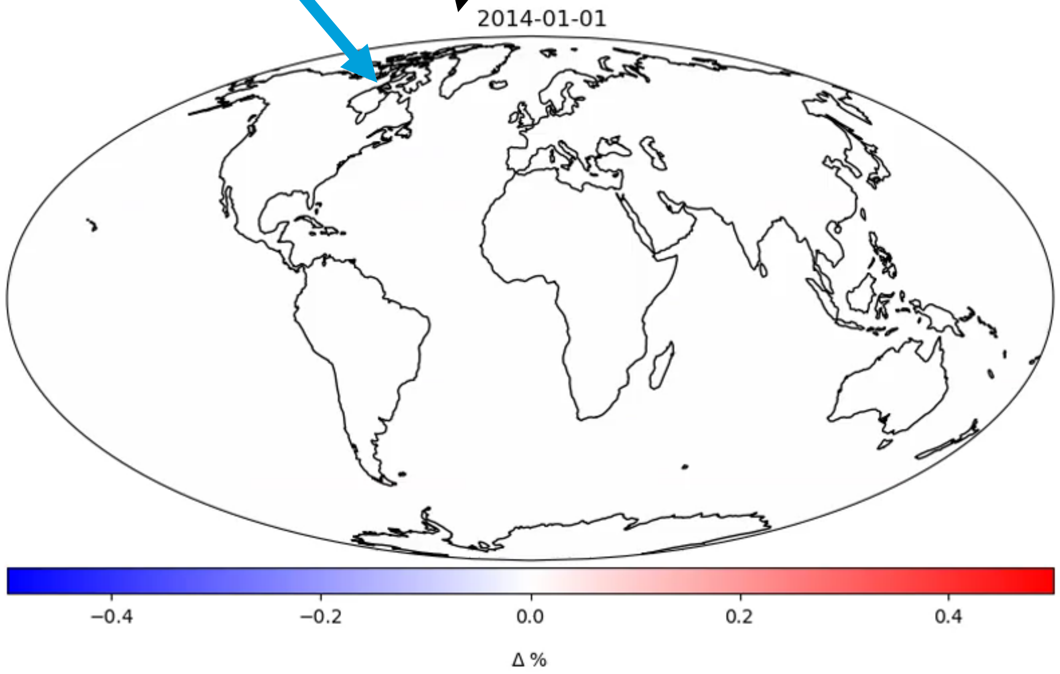
*The emission of CO_2 is not incorporated in the GEOS-Chem model.



Emissions are introduced as a box volume in a 2014 atmosphere. For anthropogenic emissions we use the CEDS v2 anthropogenic surface emissions inventory [8] and subsonic aviation emissions estimated from ADSB data [9].

Part of the Snellius supercomputer

Change in global column ozone (%)from TAC emissions, evaluated by GEOS-Chem



GEOS-Chem

SURF SARA

We use v13.3.1 of the GEOS-Chem chemistry transport model to evaluate the impact of these emissions over the course of 10 years. We use a global resolution of 4° x 5° (lat,lon) with 72 altitude layers and 20 minute timesteps.

The model is ran using the Dutch national supercomputer Snellius, with support of the dutch national e-infrastructure.

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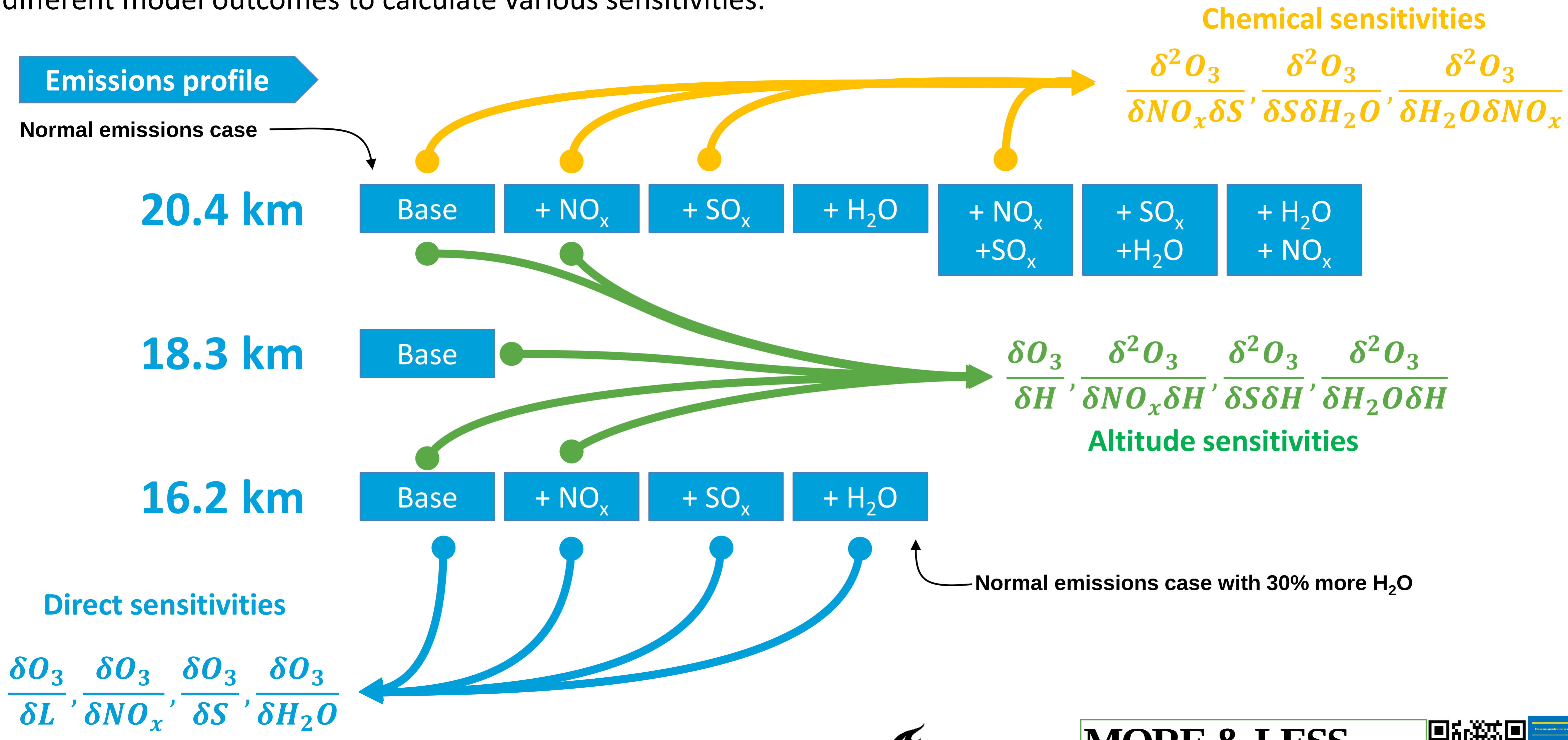
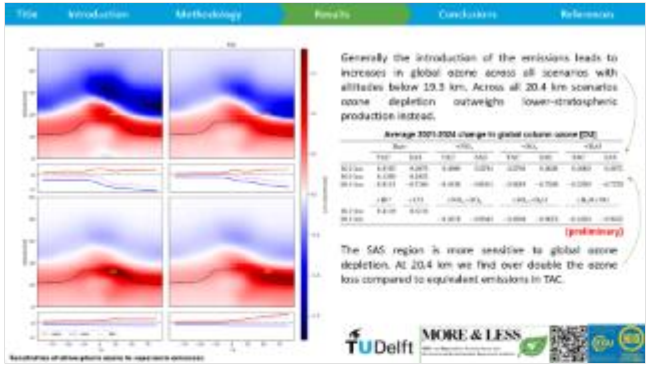
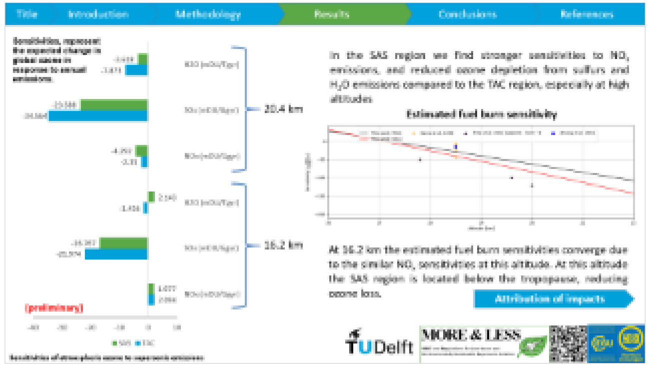
We evaluate 12 perturbation experiments per emissions region, combining different model outcomes to calculate various sensitivities.



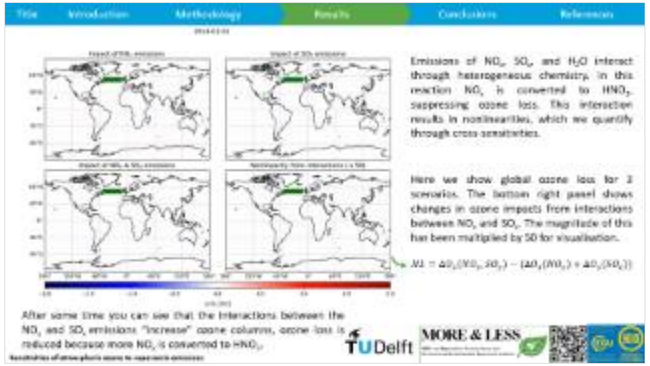
Results are grouped in several categories:



General Ozone response

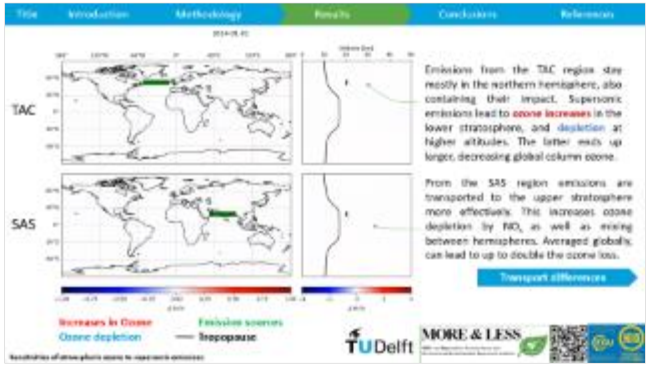


First-order sensitivities

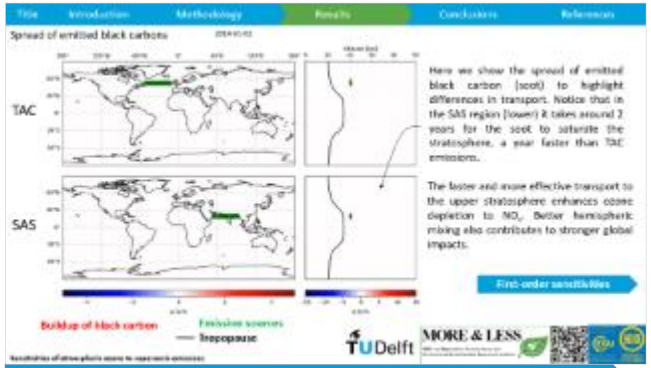


Chemical cross-sensitivies

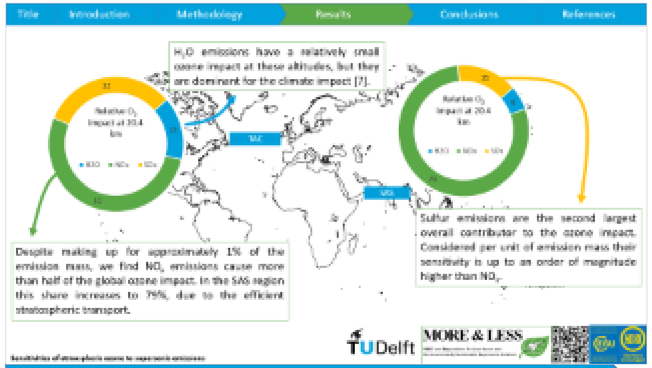
Click these!



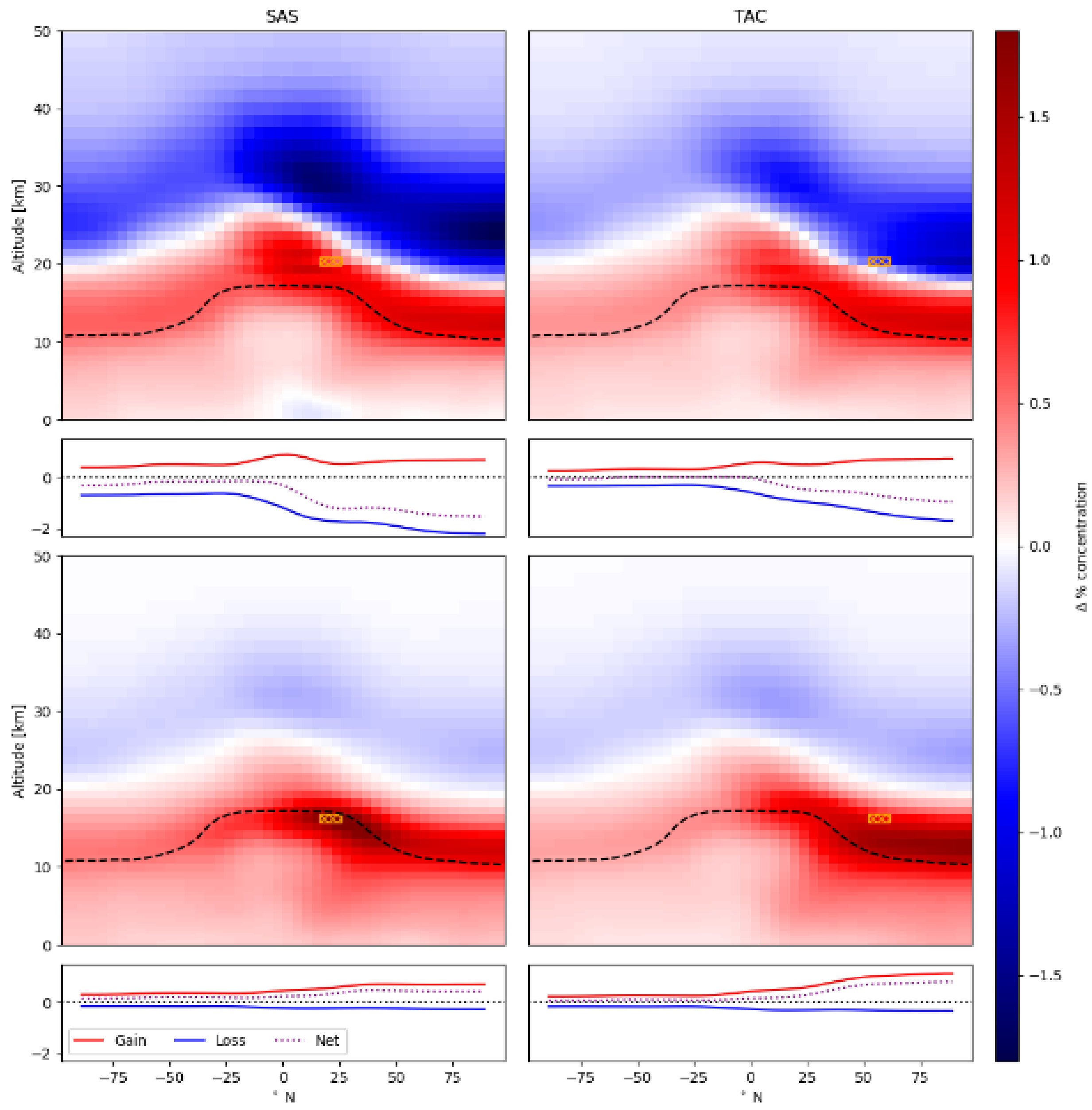
Ozone response animated



Transport differences



Attribution of impacts



Generally the introduction of the emissions leads to increases in global ozone across all scenarios with altitudes below 19.3 km. Across all 20.4 km scenarios ozone depletion outweighs lower-stratospheric production instead.

Average 2021-2024 change in global column ozone [DU]

	Base		$+NO_x$		$+SO_x$		$+H_2O$	
	TAC	SAS	TAC	SAS	TAC	SAS	TAC	SAS
16.2 km	0.3105	0.2870	0.4009	0.3724	0.2788	0.2628	0.3062	0.2871
18.3 km	0.1350	0.1025						
20.4 km	−0.3121	−0.7160	−0.4136	−0.9014	−0.3619	−0.7500	−0.3359	−0.7270
	$+HC$	$+CO$	$+NO_x+SO_x$		$+SO_x+H_2O$		$+H_2O+NO$	
16.2 km	0.3118	0.3110						
20.4 km			−0.4576	−0.9532	−0.3850	−0.8073	−0.4353	−0.9331

(preliminary)

The SAS region is more sensitive to global ozone depletion. At 20.4 km we find over double the ozone loss compared to equivalent emissions in TAC.

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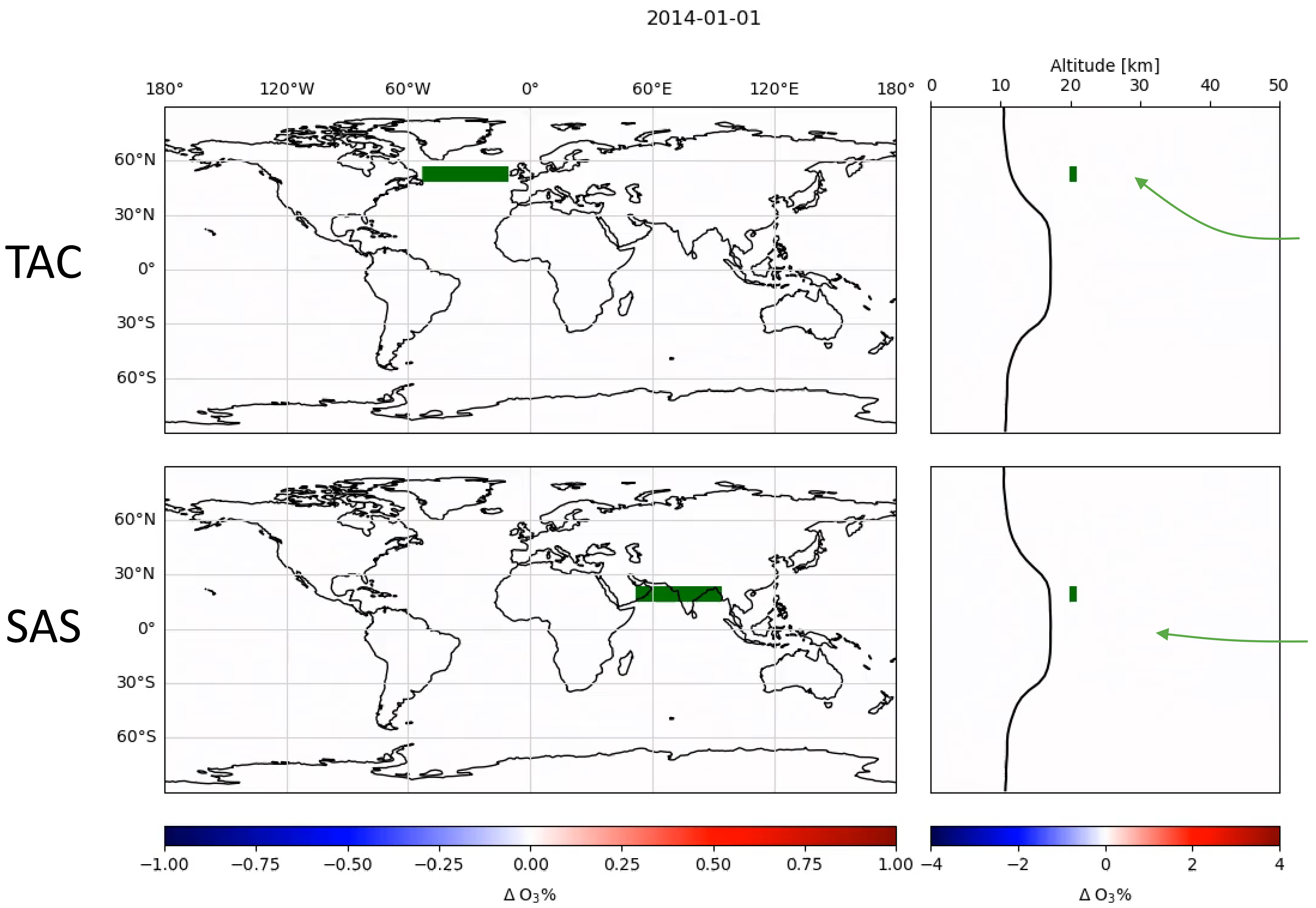

Emissions from the TAC region stay mostly in the northern hemisphere, also containing their impact. Supersonic emissions lead to **ozone increases** in the lower stratosphere, and **depletion** at higher altitudes. The latter ends up larger, decreasing global column ozone.

From the SAS region emissions are transported to the upper stratosphere more effectively. This increases ozone depletion by NO_x as well as mixing between hemispheres. Averaged globally, can lead to up to double the ozone loss.

Transport differences

Increases in Ozone

Ozone depletion

Emission sources

— **Tropopause**

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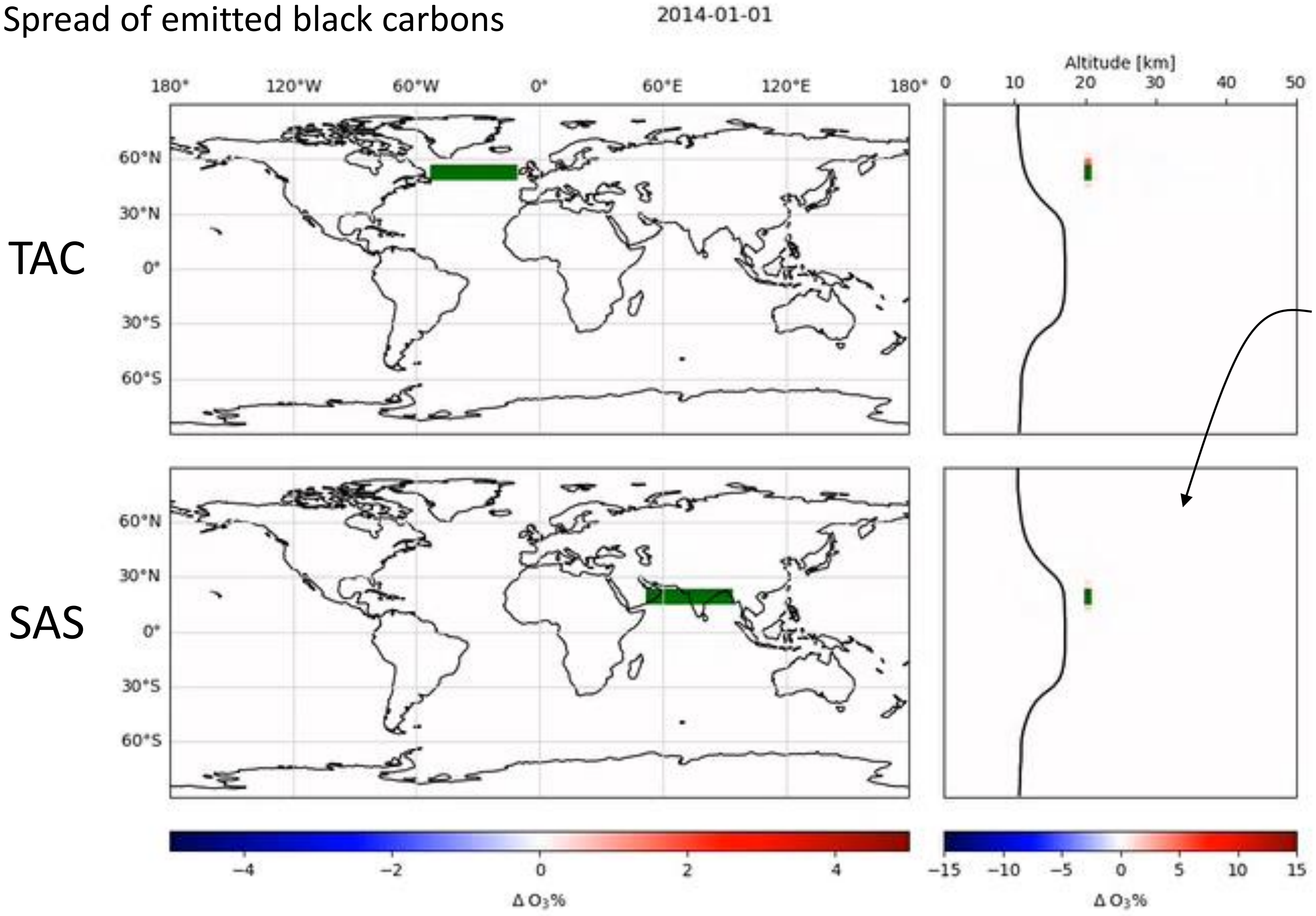
Spread of emitted black carbons



Here we show the spread of emitted black carbon (soot) to highlight differences in transport. Notice that in the SAS region (lower) it takes around 2 years for the soot to saturate the stratosphere, a year faster than TAC emissions.

The faster and more effective transport to the upper stratosphere enhances ozone depletion to NO_x. Better hemispheric mixing also contributes to stronger global impacts.

First-order sensitivities

Buildup of black carbon

Emission sources

— **Tropopause**

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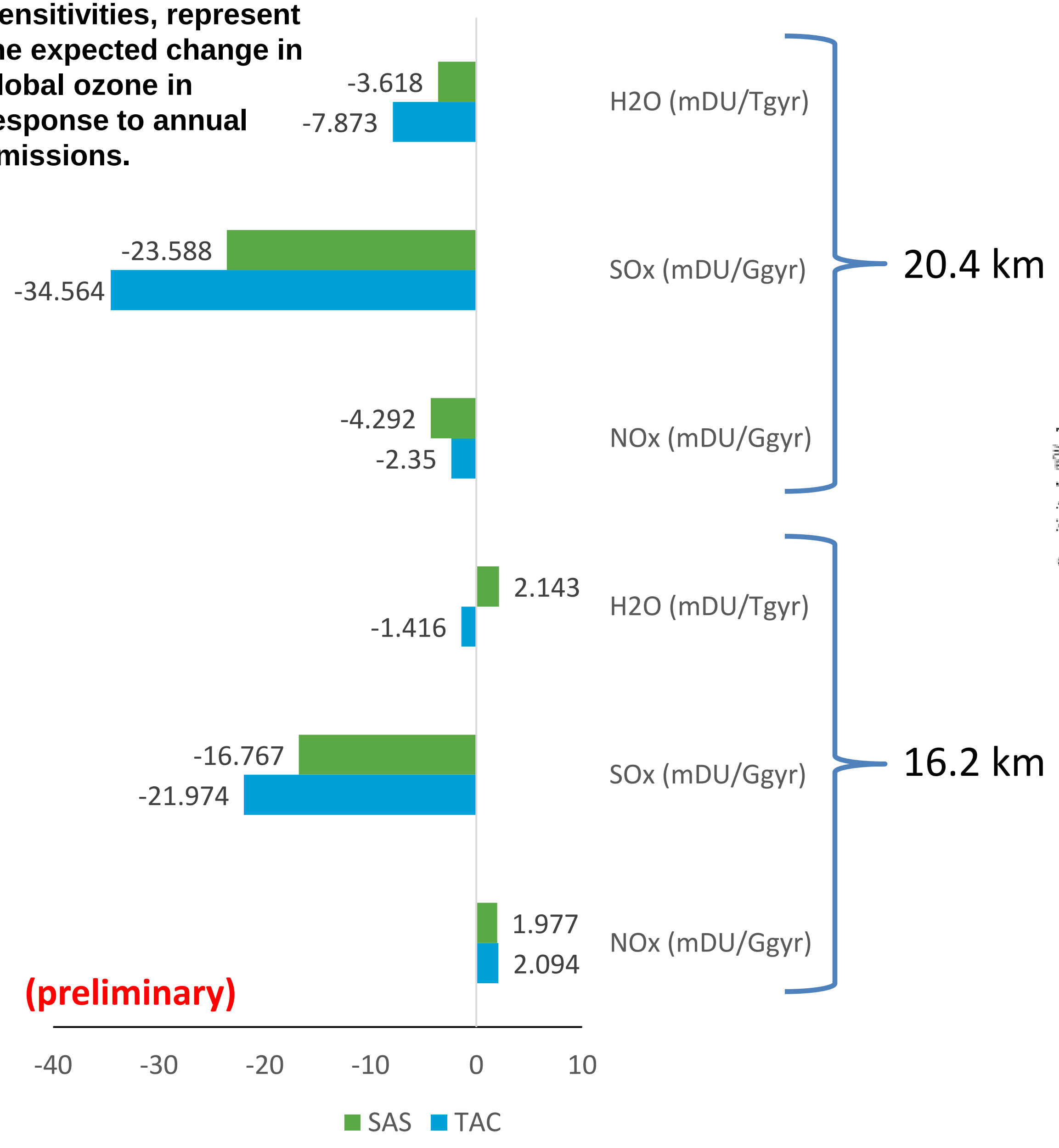
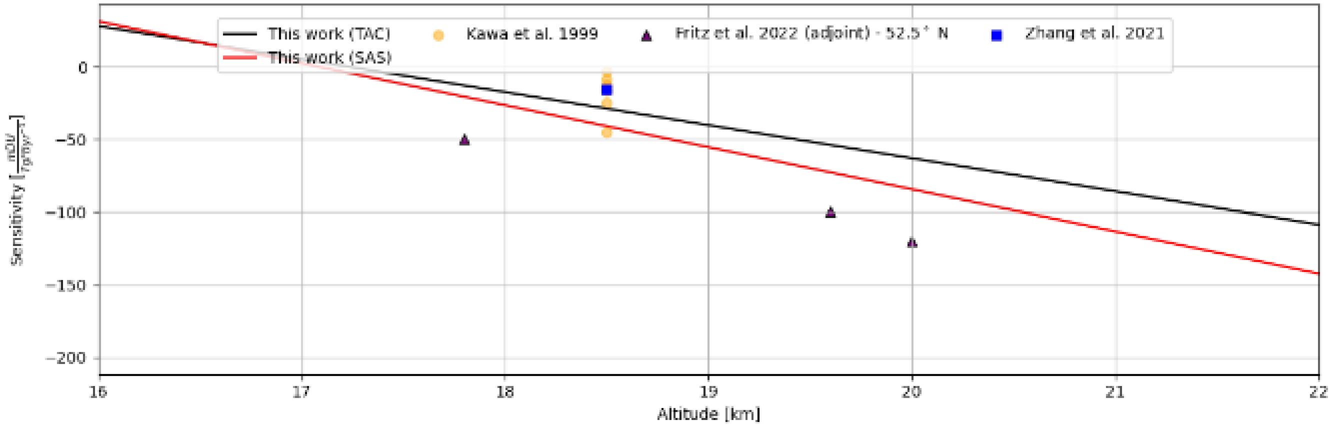
Sensitivities, represent the expected change in global ozone in response to annual emissions.



Sensitivities of atmospheric ozone to supersonic emissions

In the SAS region we find stronger sensitivities to NO_x emissions, and reduced ozone depletion from sulfurs and H_2O emissions compared to the TAC region, especially at high altitudes

Estimated fuel burn sensitivity



At 16.2 km the estimated fuel burn sensitivities converge due to the similar NO_x sensitivities at this altitude. At this altitude the SAS region is located below the tropopause, reducing ozone loss.

Attribution of impacts

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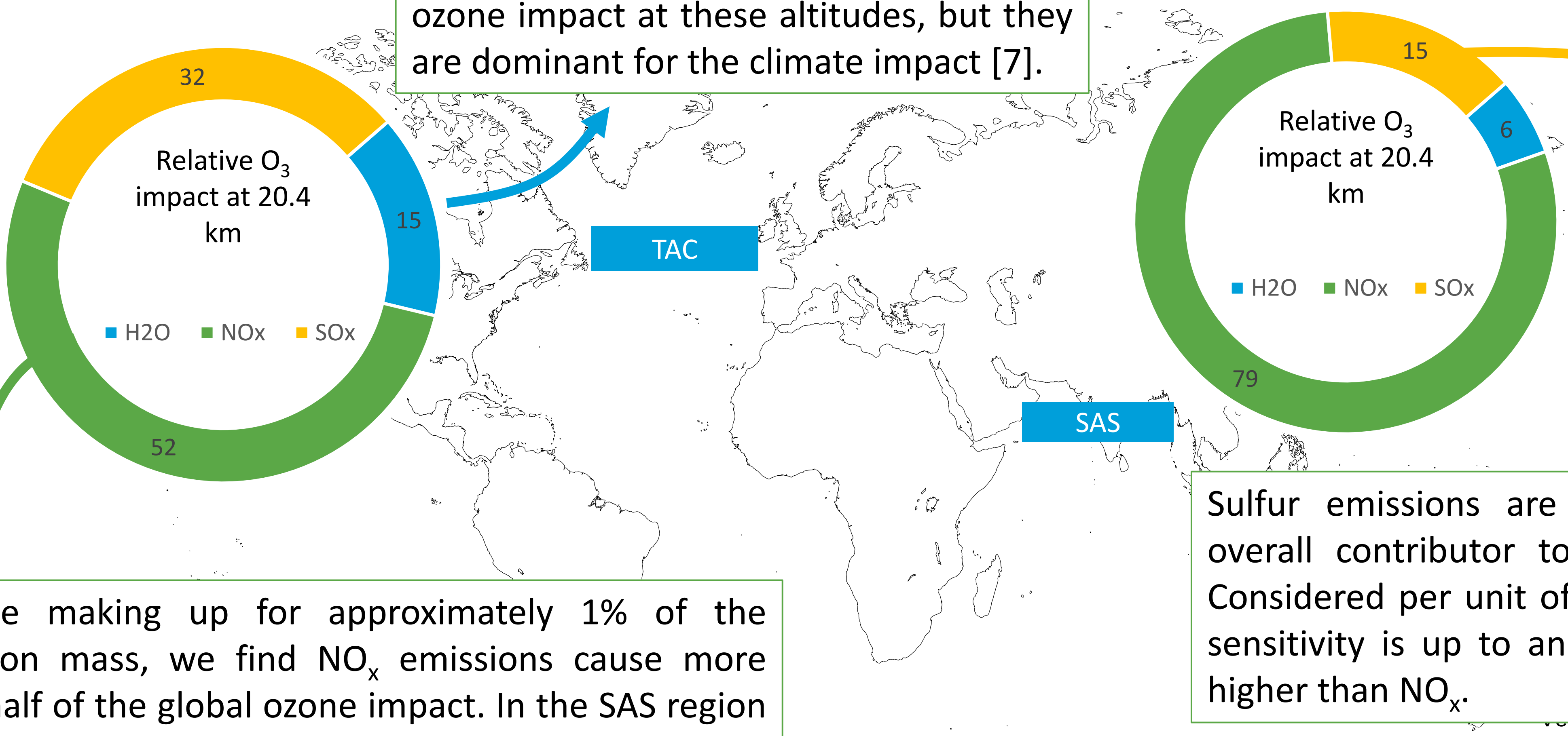
H_2O emissions have a relatively small ozone impact at these altitudes, but they are dominant for the climate impact [7].



Sulfur emissions are the second largest overall contributor to the ozone impact. Considered per unit of emission mass their sensitivity is up to an order of magnitude higher than NO_x.

Despite making up for approximately 1% of the emission mass, we find NO_x emissions cause more than half of the global ozone impact. In the SAS region this share increases to 79%, due to the efficient stratospheric transport.

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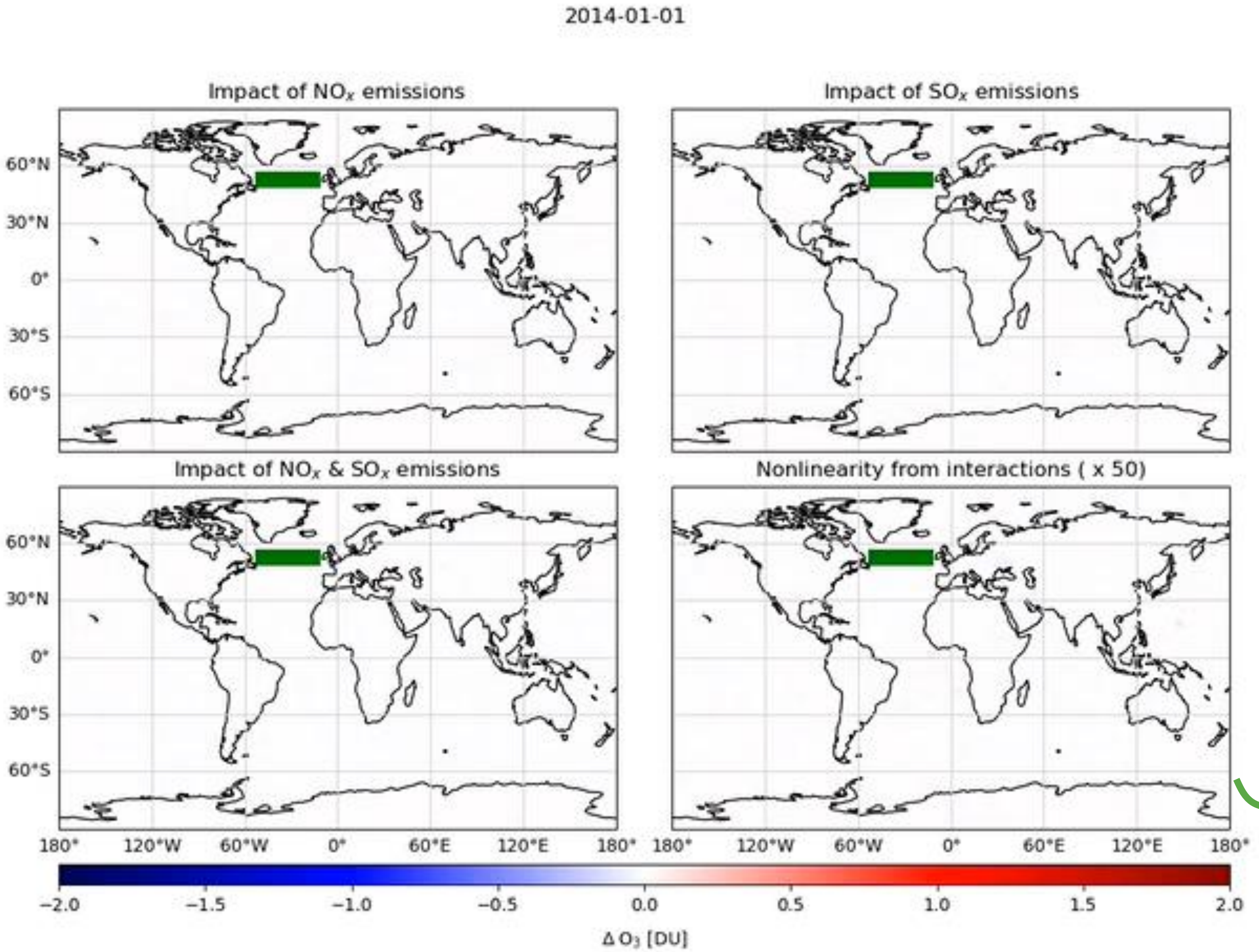


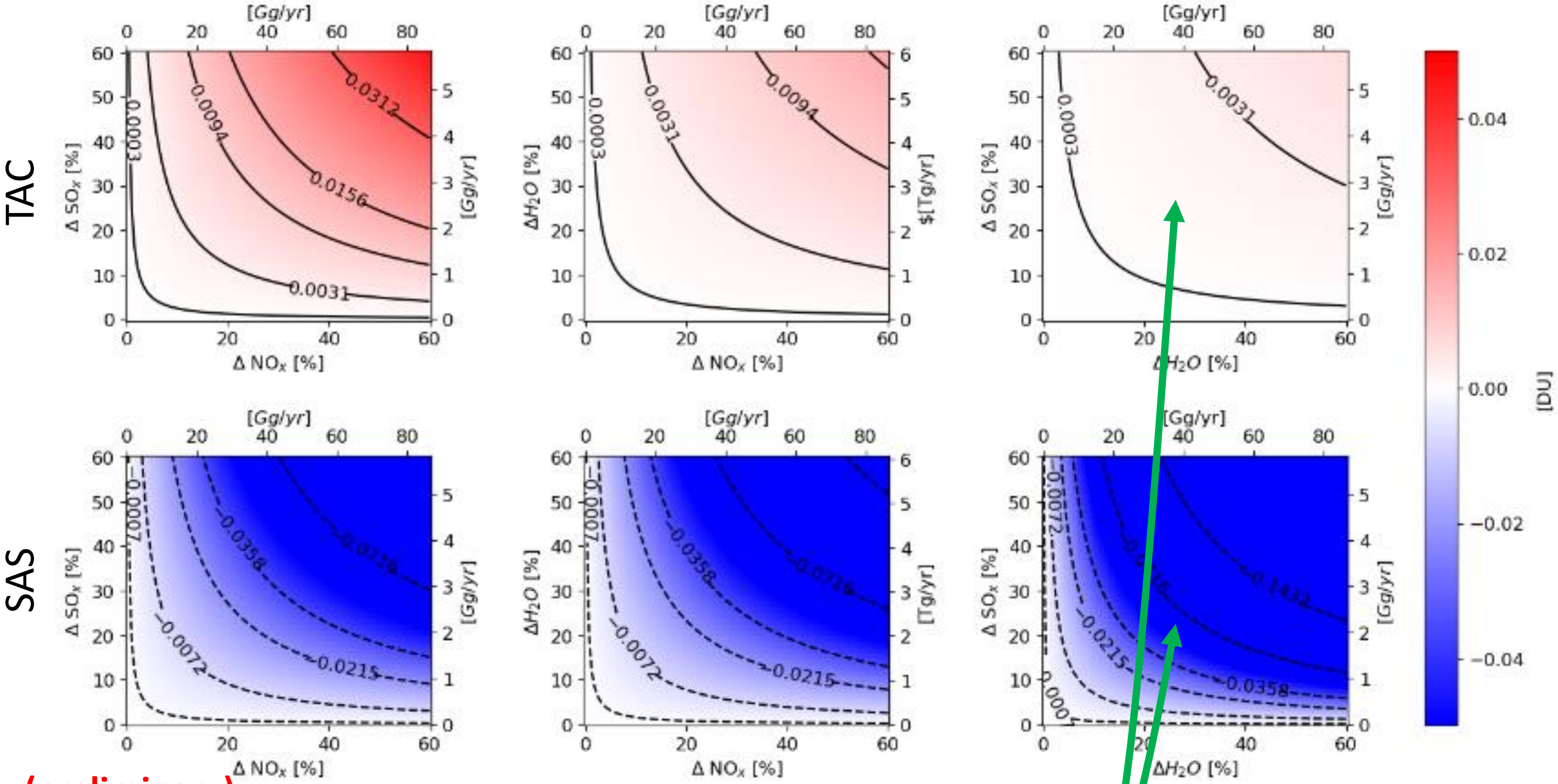
Emissions of NO_x, SO_x, and H_2O interact through heterogeneous chemistry. In this reaction NO_x is converted to HNO_3, suppressing ozone loss. This interaction results in nonlinearities, which we quantify through cross-sensitivities.

Here we show global ozone loss for 3 scenarios. The bottom right panel shows changes in ozone impacts from interactions between NO_x and SO_x. The magnitude of this has been multiplied by 50 for visualisation.

$$NL = \Delta O_3(NO_x, SO_x) - (\Delta O_3(NO_x) + \Delta O_3(SO_x))$$

After some time you can see that the interactions between the NO_x and SO_x emissions "increase" ozone columns, ozone loss is reduced because more NO_x is converted to HNO_3.

Cross-sensitivities characterise how the response to one emission species changes with other emissions.



(preliminary)

If H_2O and SO_x emissions both increase by 30%, their interactions increase O_3 depletion by -0.0716 DU (10%!) in the SAS region. In the TAC region this would decrease ozone loss by less than 1% instead!

In this figure we show the magnitude of the 2nd order sensitivities between NO_x, SO_x, and H_2O emissions.

In the TAC region interactions through chemistry **reduce ozone loss** by accelerated conversion of NO_x. For SAS emissions these interactions **accelerate ozone loss instead**, with a considerably larger effect.

The large differences in these interactions between locations may represent a considerable challenge for surrogate modelling!

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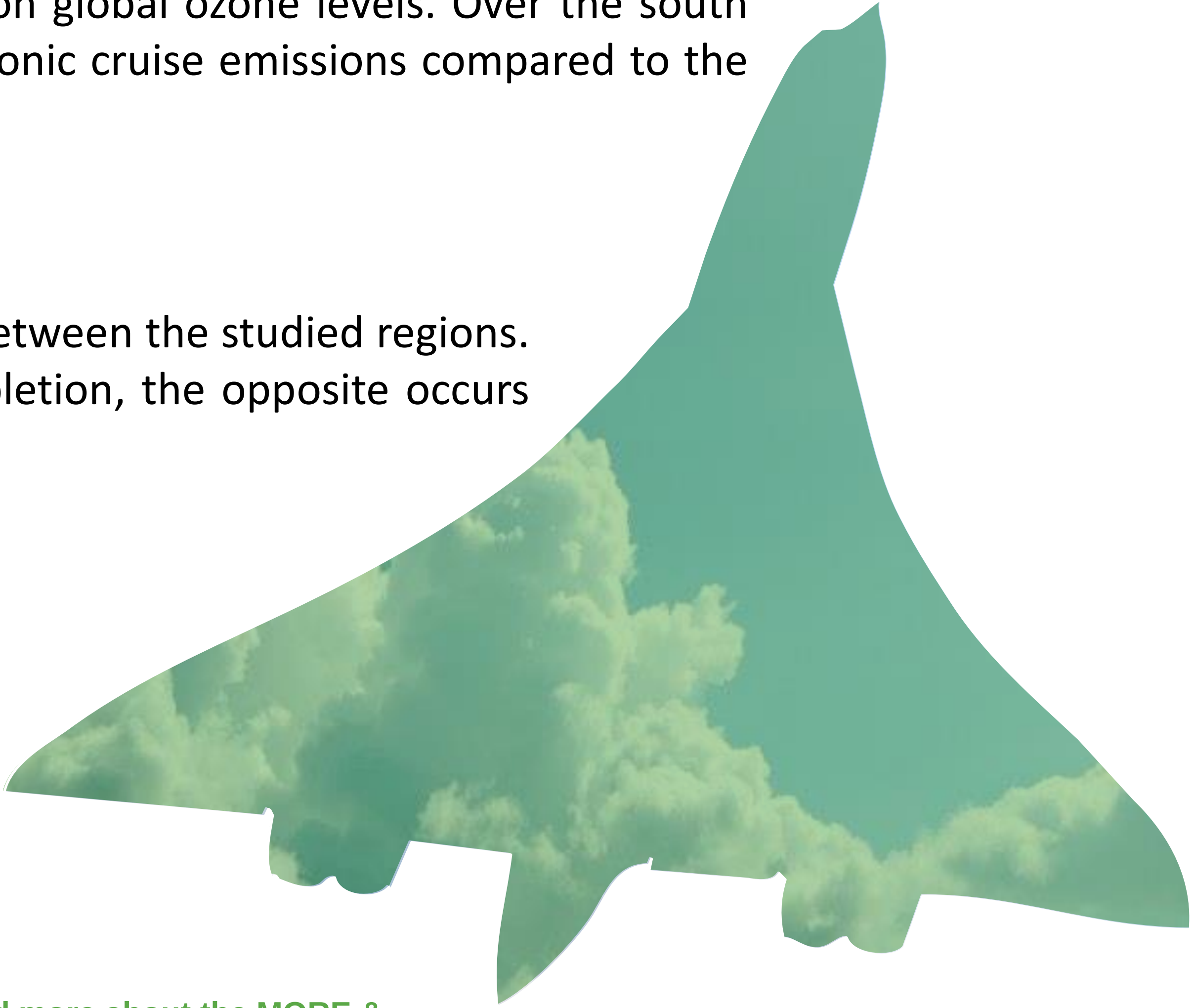
The region of supersonic emissions greatly affects their impact on global ozone levels. Over the south arabian sea we find over double to ozone depletion from supersonic cruise emissions compared to the transatlantic corridor, primarily due to NO_x emissions.

General Ozone response | **First-order sensitivities**

We observe large differences in NO_x-SO_x-H_2O cross-sensitivities between the studied regions. Above the atlantic corridor cross-sensitivites dampen ozone depletion, the opposite occurs above the south-arabian sea.

Chemical cross-sensitivies

NO_x-SO_x-H_2O may have a considerable effect on the impact of emissions in some regions, making it important to include them in surrogate modelling. Before this can be undertaken we first need to better understand geospatial dependencies of these interactions.



Read more about the MORE & LESS project

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MORE & LESS is a European research project focused on assessing supersonic impacts to support environmental policy design. The consortium consists of 16 partners from industry and academia.

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Funded by the European Commission under the Grant Agreement 101006856

*"MORE&LESS aims at maintaining a high level of citizens' and **environmental protection at local, regional and global levels**, and supports the consequent **establishment of regulations and procedures for the future supersonic aviation** through solid technical bases"*

Reaction Engines
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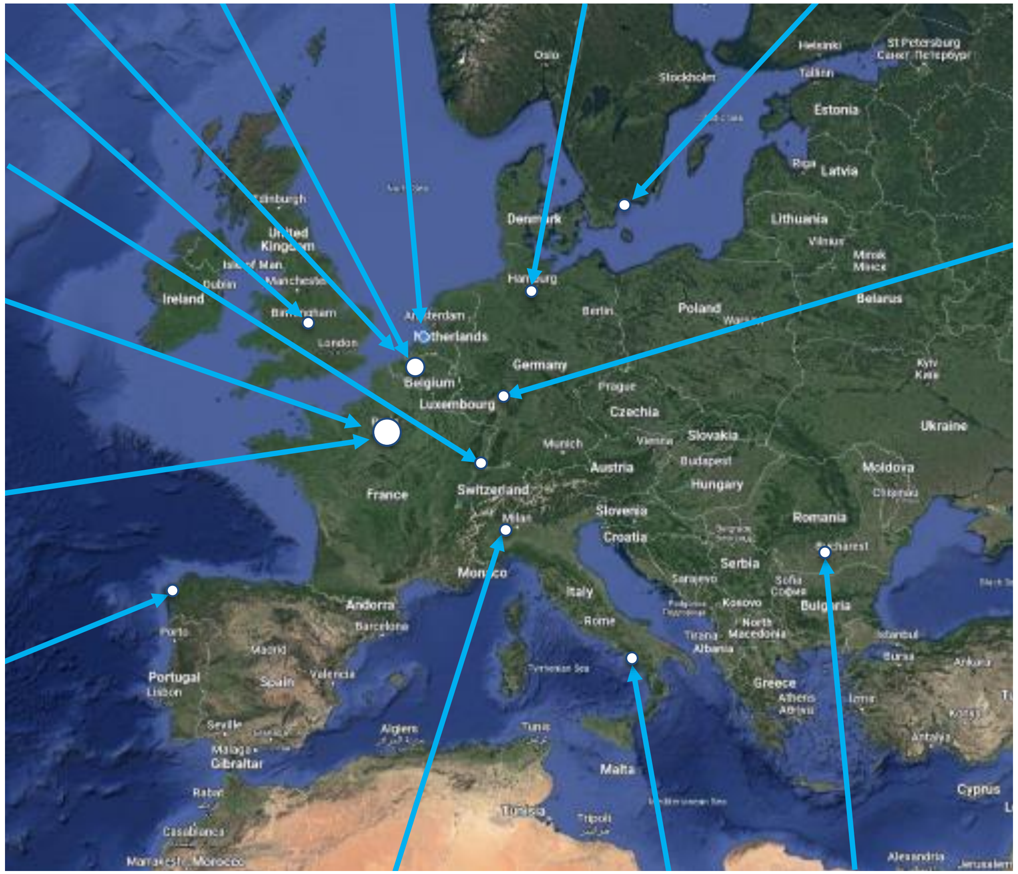

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