Selective Detection of Multi-Hazard for Aviation using Satellites Sensors, Ground-Based Networks and Model Forecasts in the context of the SACS/ALARM Early Warning System.

Hugues Brenot[1], Nicolas Theys[1], Erwin de Donder[1], Lieven Clarisse[2], Pierre de Buyl[3], Nicolas Clerbaux[3], Daniel Bannister[4], Riccardo Biondi[5], Sigrun Matthes[6], Simone Dietmüller[6], Volker Grewe[6], Tatjana Bolić[7,8], Igor Mahorcic[7], Michel Van Roozendael[1], and Manuel Soler[9]

(1) Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium.
(2) Université Libre de Bruxelles (ULB), Brussels, Belgium.
(3) Royal Meteorological Institute of Belgium (KMI-IRM), Brussels, Belgium.
(4) SATAVIA, Cambridge, UK.
(5) University of Padova, Italy.
(6) German Aerospace Center (DLR), Oberpfaffenhofen, Germany.
(7) SymOpt, Trieste, Italy.
(8) University of Westminster, UK.
(9) University Carlos III of Madrid (UC3M), Spain.

Friday, November 26, 2021 *15:00 – 15:15*

Contact: **Hugues Brenot** Email: brenot@aeronomie.be

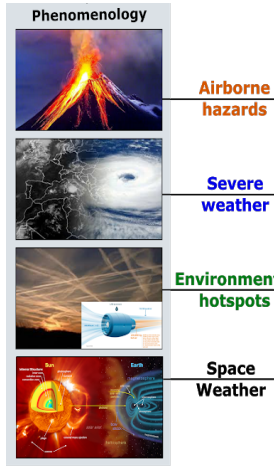
OUTLINE

- Motivation and Overview of ALARM project
- Mechanism of ALARM system
- Examples of Alert products
- Outlook (NRT alert perspertive)

[grant n°891467]

OVERVIEW OF ALARM PROJECT

SAT & GB data for early detection and nowcasting of multi-hazard phenomena are centralised on the hosting platform aiming at
→ the creation of alert products
→ enhancing situational awareness



Phenomena representing different **threats to aviation** or **environmental impact**

MOTIVATION

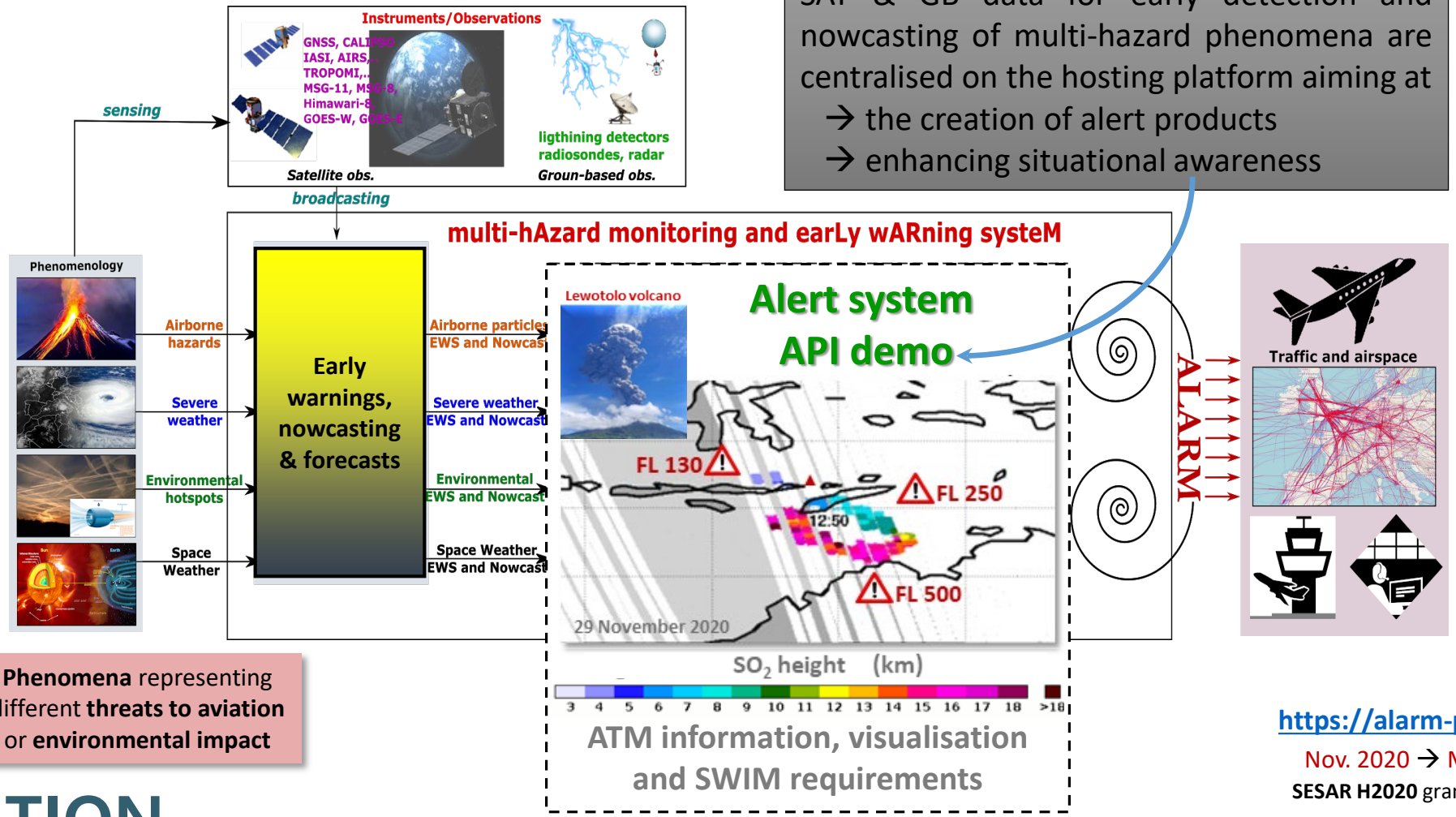
https://alarm-project.eu

Nov. 2020 → May 2023

SESAR H2020 grant n°891467

OVERVIEW OF ALARM PROJECT

SAT & GB data for early detection and nowcasting of multi-hazard phenomena are centralised on the hosting platform aiming at
→ the creation of alert products
→ enhancing situational awareness



Phenomena representing different **threats to aviation** or **environmental impact**

https://alarm-project.eu

Nov. 2020 → May 2023

SESAR H2020 grant n°891467

MOTIVATION

[grant n°891467]

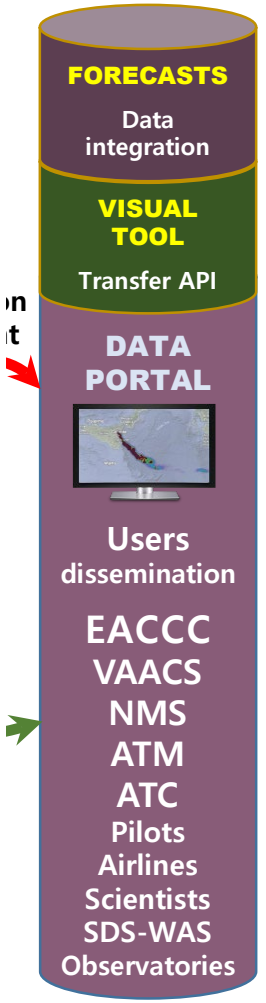
MECHANISM OF ALARM SYSTEM

Starting point concept:

ESA Support to Aviation Control Service (SACS)

https://sacs.aeronomie.be

(Brenot et al. 2014, NHESS)



[grant n°891467]

ALERT PRODUCTS

Space Weather

- Radiation exposure
- HF radio wave disturb.
- Navigation errors
- Avionics errors

Environmental Hotspots

- Area where aviation emissions have a very large climate impact

Severe Weather

- Thunderstroms
- Deep convection
  - In-flight icing
  - Turbulence
  - Wind shear

Natural Airborne Hazard (Smoke, Dust, Ash & SO_2)

- Detection of hazardous clouds
- FL contaminations
- Alert and forecasts contamination airport

NRT images

Email notifications

Data files transfer

[grant n°891467]

BIRA-IASB ULB RMI SATAVIA MAKING AVIATION SMARTER UNIVERSITÀ DEGLI STUDI DI PADOVA DLR symopt UNIVERSITY OF WESTMINSTER uc3m Universidad Carlos III de Madrid

https://alarm-project.eu

ALARM SESAR JOINT UNDERTAKING

EXAMPLE OF ALERT: NATURAL AIRBORNE HAZARD

sacs

ALARM

Email notification

Users

e.g. ***VAACs, Volcano Observatory La Palma, airlines, pilots***

From SACS <sacs@aeronomie.be>
Subject SO2 height -- TROPOMI -- 2021/09/23 22:44 -- region 205
To Toulouse VAAC <vaac@toulouse.fr>

Reply | Forward | Archive

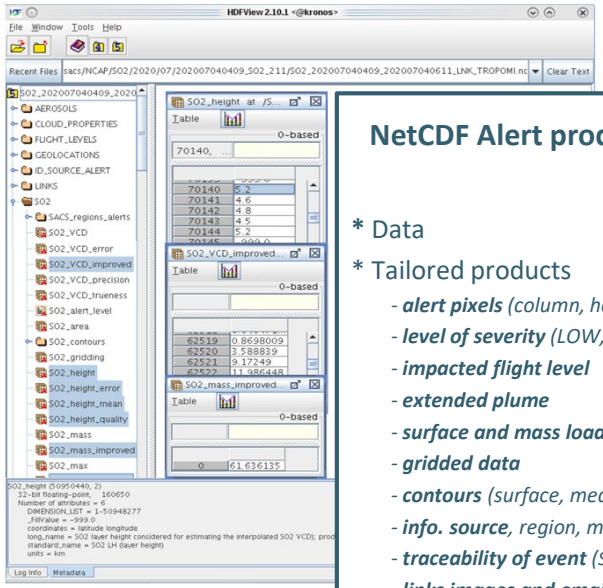
```
SACS multi-sensor notification of SO2 height retrievals
=======================================================

Process date : 2021/09/23
Process time : 22:44 UTC
Instrument   : TROPOMI


Notification region: 205
-------------------------
http://sacs.aeronomie.be/TROPOMIalert/2021/09/alertsTROPOMI_SO2LH_20210923_13h17_205.php?alert=20210923_224456_205

Date                    :  2021/09/23
Time                    :  14:57 UTC
SO2 max                 :  191.0 DU  (lat:  28.59 N;  lon:  -17.50 E;  SO2 height:  3.1 km)
SO2 height a.s.l.       :  2.0 -  4.5 km (centre of mass:  3.0 km)
SO2 mass loading        :   58.984 kt
SO2 plume area          :   543885 km²
Notification level      :     HIGH
Volcano erupting        :  La Palma   (most likely)
```

Ash & SO_2

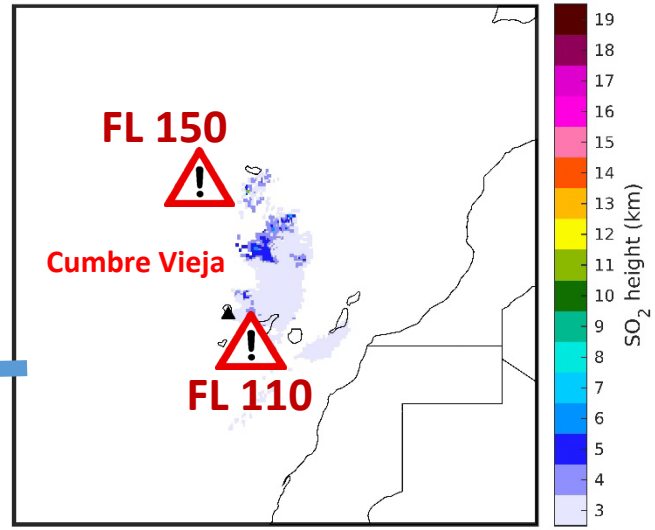


NetCDF Alert products (NCAP)

* Data
* Tailored products
  - ***alert pixels*** *(column, height)*
  - ***level of severity*** *(LOW, HIGH)*
  - ***impacted flight level***
  - ***extended plume***
  - ***surface and mass loading***
  - ***gridded data***
  - ***contours*** *(surface, mean, max, mass)*
  - ***info. source****, region, max values*
  - ***traceability of event*** *(START → END)*
  - ***links images and email notification***
  - ***links images other instruments***

Data file transfer

TROPOMI 2021.09.23



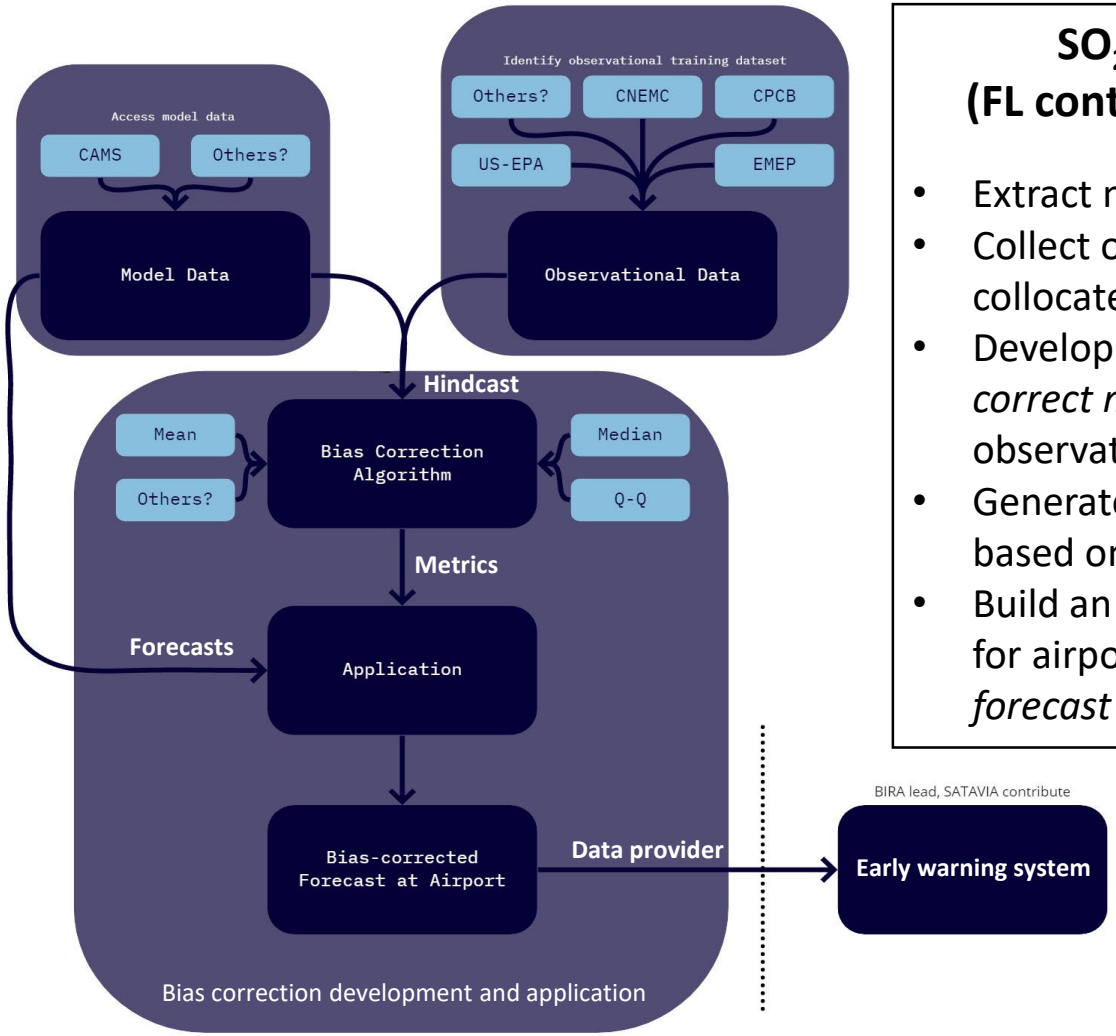
Visualisation

https://sacs.aeronomie.be

[grant n°891467]

https://alarm-project.eu

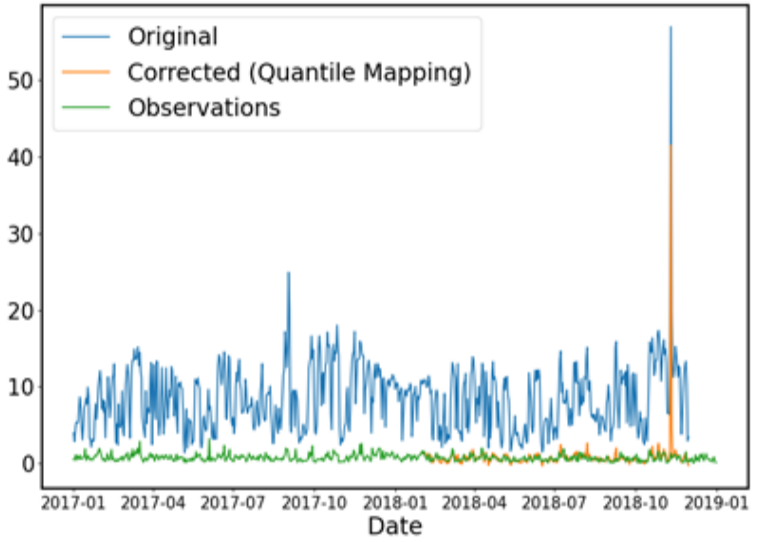
EXAMPLE OF ALERT: NATURAL AIRBORNE HAZARD



SO_2 ALERT at AIRPORTS (FL contamination and forecasts)

- Extract model data at airport locations
- Collect observational data: clean and collocate with airport locations
- Develop bias correction algorithms to *correct model forecast* data based on observations
- Generate measures of *SO_2 extremes* based on observational data
- Build an accurate alarm forecast system for airports based on *corrected model forecast* data and *measures of extremes*

SO_2



Modelled data, observations, and corrected model data at Birmingham Airport, Alabama. Quantile mapping has been applied to the training data (days to correct from the previous years padded by 30 days on each side)

[grant n°891467]

EXAMPLE OF ALERT: SPACE WEATHER

Alert from BIRA system in support to PECASUS

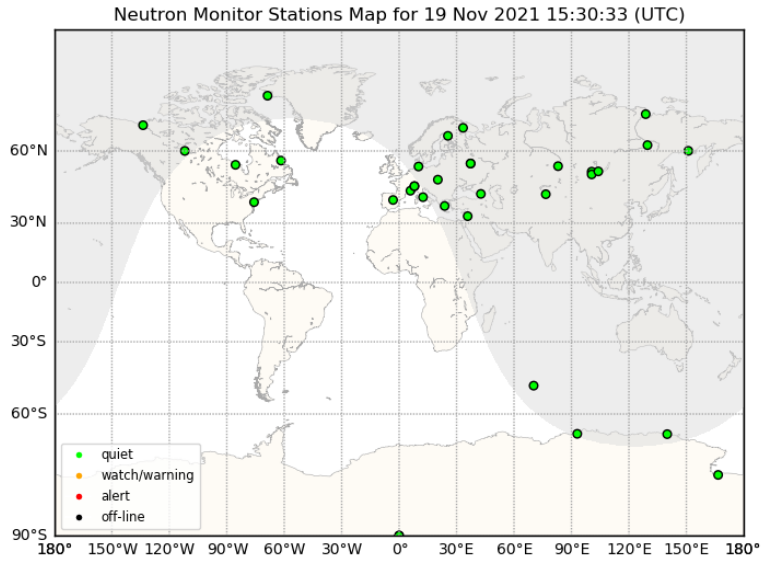
PECASUS: Partnership of Excellence for Civil Aviation Space weather User Services Consortium Agreement

A simple three colour message generated within the ALARM system

What ALARM warnings provide:

Generate (automatically) alert/warning table for geomagnetic and radiation storms with risk indicator (low, moderate, high) for impact on HF, GNSS, SATCOM and Increased Radiation exposure at flight altitude

	Risk		
HF	L	M	H
GNSS	L	M	H
SATCOM	L	M	H
RAD	L	M	H



To generate Space Weather alerts, ALARM system used:

BIRA COMESEP alert system (COronal Mass Ejections and Solar Energetic Particles – SEP), based on data and model, provides SEP forecast to **issue** a **warning** on an increased **risk for high frequency** (HF) **disruption** and for **enhanced radiation exposure** with **impact** on the **radiation dose** and **avionics**.

combined with publicly available products:

proton fluxes in different energy channels (i.e. 10, 50, 100, 500 MeV) **from GOES-16** (geostationary instrument)

Early prediction of >500 MeV events from HESPERIA system (High Energy Solar Particle Events foRecastIng and Analysis), based on **X-Ray** and **proton fluxes observed on GOES-16**

ANeMoS (Athens Neutron Monitor Station) **GLE** (Ground Level Event) **alert for enhanced radiation exposure** with impact on the radiation dose and avionics **above minimum flight level (FL250)**

Affected area:

HF disruption in polar region for SEV proton fluxes > 10 MeV

Radiation risk at flight altitude (any region) for SEP > 500 MeV

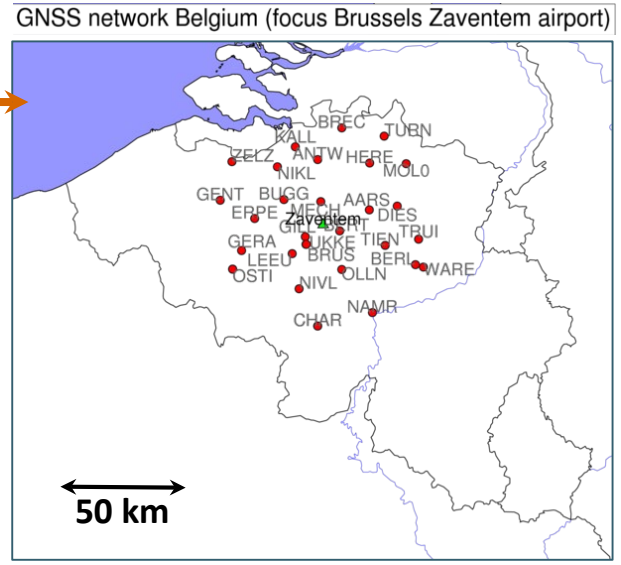
Radiation risk at flight altitude in case of ANeMoS GLE

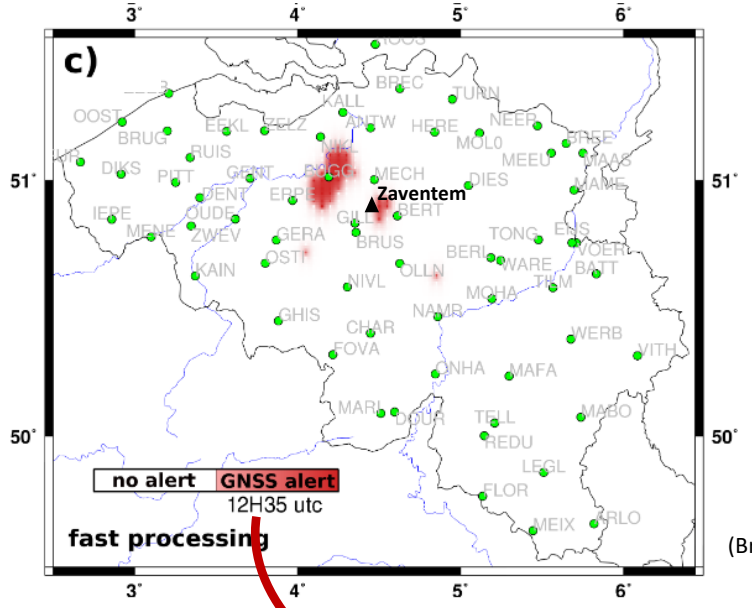
[grant n°891467]

EXAMPLE OF ALERT: SEVERE WEATHER

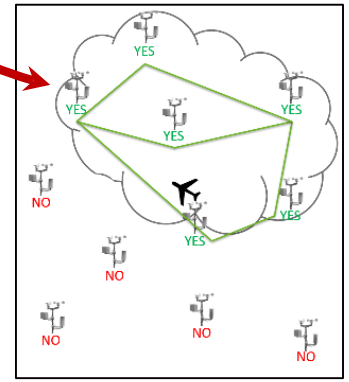
FOCUS on 2 AIRPORTS

GNSS network Italy (focus on Milan Malpensa airport)





(Brenot et al. 2013, ACP)

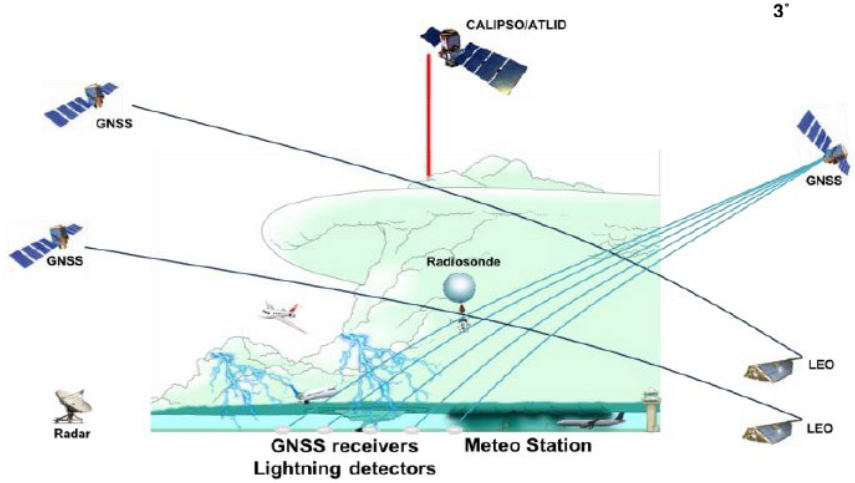


Data availability:

- Ground based GNSS stations
- Weather stations collocated with GNSS
- Lightning data
- Radar data

Vertical information from

- Radiosonde station
- GNSS Radio Occultations



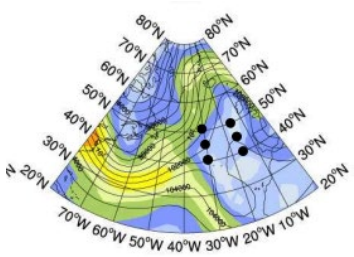
[grant n°891467]

https://alarm-project.eu

EXAMPLE OF ALERT: ENVIRONMENTAL HOTSPOTS

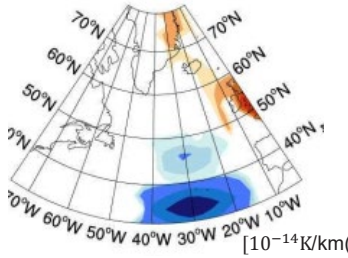
MET service aviation's climate impact Algorithmic Climate Change Functions (aCCFs)

representative winter weather situation, 250 hPa



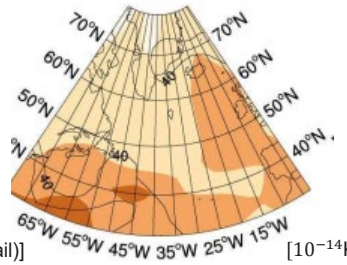
Climate Change Functions = four dimensional functions (space & time)

Contrail CCF



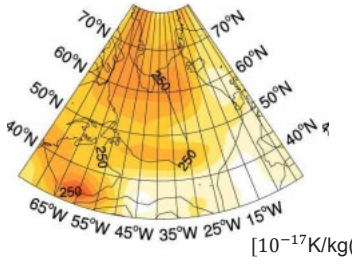
[10^{-14}K/km(contrail)]

Ozone CCF



[10^{-14}K/kg(N)]

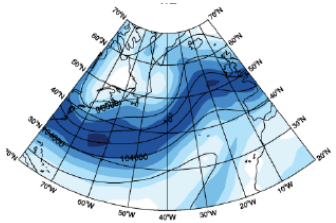
Water vapour CCF



[10^{-17}K/kg(fuel)]

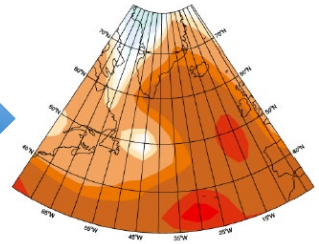
(Frömming et al. 2021, ACP)

- Climate change functions of non-CO_2 effects of aviation (contrail-cirrus, water vapour, NO_x-induced changes of ozone and methane) give climate impact of aviation at a specific location
- Climate change functions provide environmental information to ATM / trajectory planning in order to avoid regions with high climate impact.
- Algorithmic climate change functions (aCCFs) enable calculating climate impact based on meteorological parameters from numerical weather prediction data.



MET fields

aCCF



(Matthes et al. 2017, Aerospace)

Environmental hotspot areas over Europe:

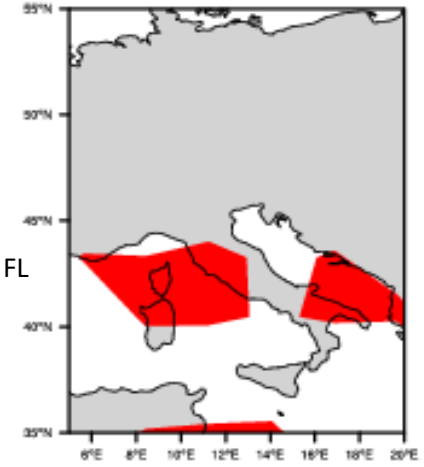
- Regions (contours) with high climate impact are highlighted in red
- Climate impact of non-CO_2 effects (water vapour, NO_x -induced effects, contrail-cirrus) are included
- Case study of a day in summer (daytime), relying on MET data and aCCFs

NO_x aCCF
Water vapour aCCF
Contrail-cirrus aCCF
Merged aCCF

➔ info. on different FL

[8 per day / 3h]

[forecasts +48h]



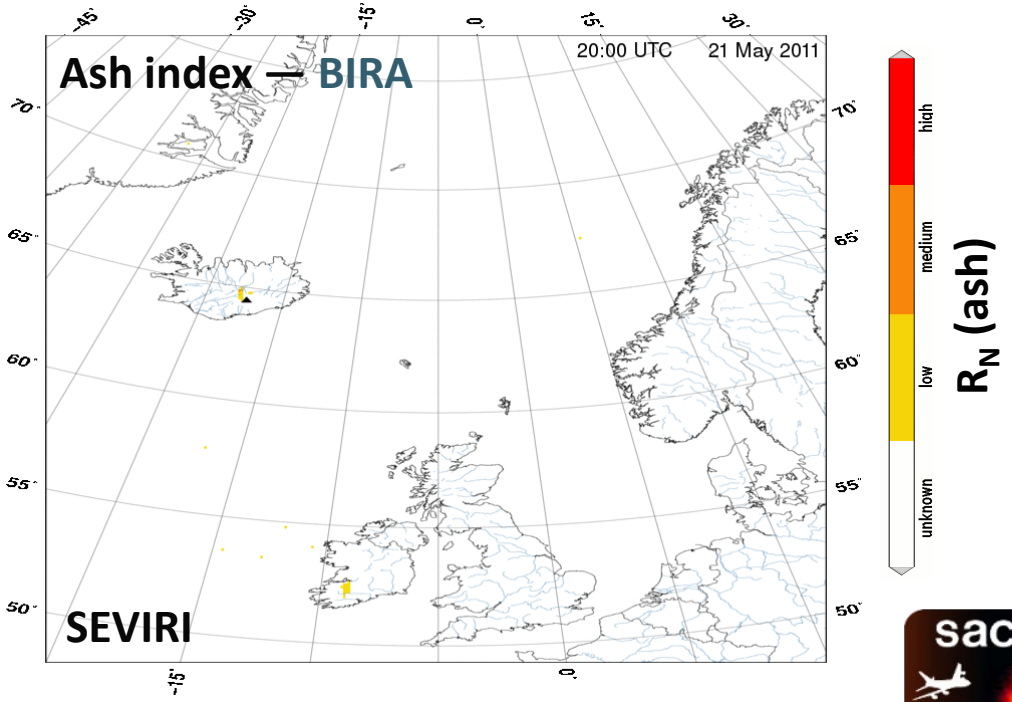
(Dietmüller et al., in prepa.)

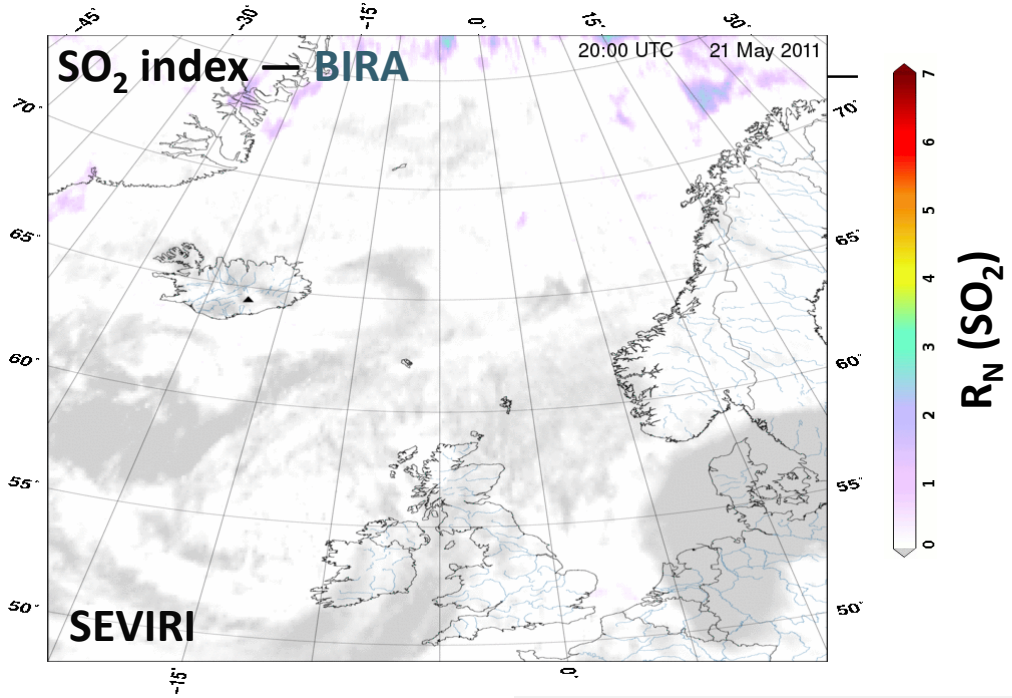
Climate change from meteorological input data by using aCCFs

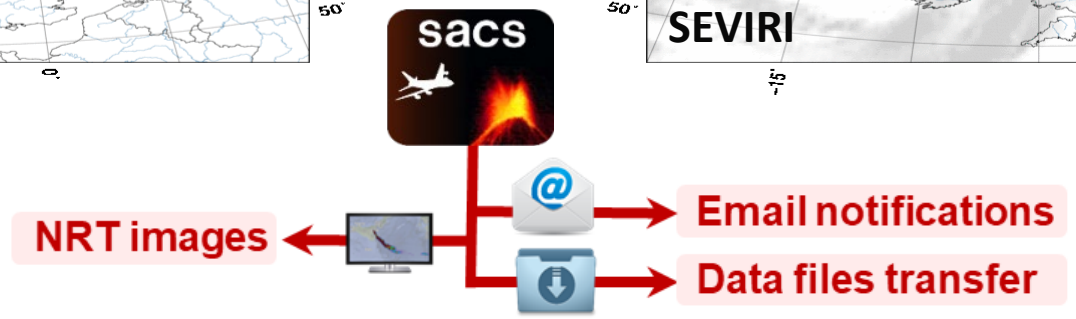
[grant n°891467]

NRT ALERT PERSPECTIVE

Use of GEO data to create SO_2 & aerosols (ash/dust) notifications







R_N = Index of spectral significance

Covariance-Based Retrieval Algorithm (COBRA)
→ spectral fitting approach
see **(Clarisse et al. 2013, ACP)** & **(Theys et al. 2021, ACP)**

[grant n°891467]

Demonstration & API Development in Summer 2022

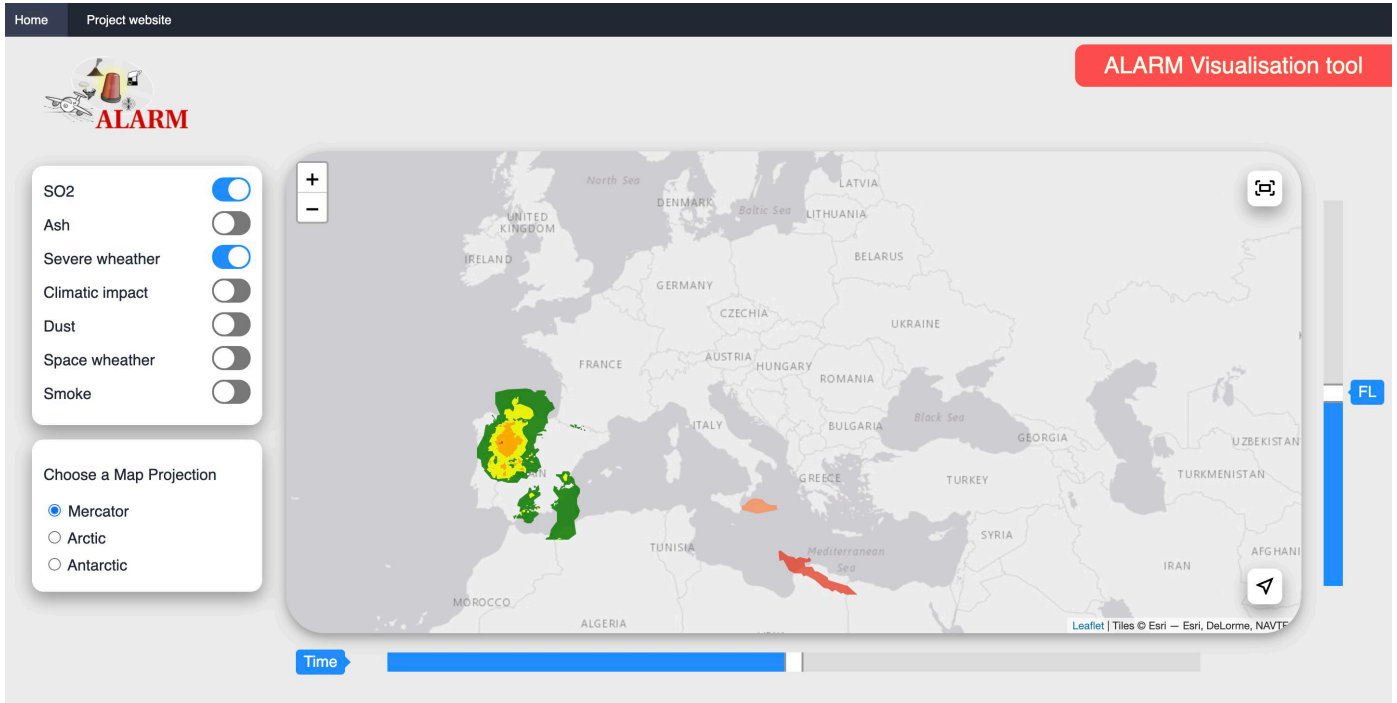
Space Weather

Environmental Hotspots

Severe Weather

Smoke Dust Ash & SO_2 Natural Airborne Hazard

- Alert accessible via a web interface
- Easily quick access to alert products
- User can select a type of alert on interactive map and move in time and among different FLs
- Choice of different map projections
- Further product details available by interacting with visualised products



Visualisation API mock-up

[grant n°891467]

https://alarm-project.eu

OUTLOOK

Space Weather

Environmental Hotspots

Severe Weather

Smoke Dust Ash & SO_2 Natural Airborne Hazard

Alert product related to 4 types of risks for aviation

- Exploratory research for Severe Weather (regional alert)
- Global NRT products for NAH, Space Weather
- Global products for Environmental Hotspots

Notification *Visualisation* *Data file transfer*

NetCDF (NCAP file) data file transfer

- AOD (MODIS) & Aerosol index (TROPOMI,...)
- Link to E-PROFILE data
- Future dev. with EARLINET
- Input for SDS-WAS

WMO EUMETNET EARLINET inDust

COBRA analysis

- **TROPOMI:** New algorithm for SO_2 column
  New algorithm for SO_2 height (improved detection limit; i.e., SO2 > 5 DU)
- **SEVIRI:** New **selective detection** (R_N index) of **SO_2, ash/dust** is successful
  → final improvement of our COBRA algorithm for different scene (SO_2, ash/dust)
  → **NRT alerts** (with **selective detection** of SO_2, ash/dust) and **notifications in SACS**
- Tests using other imagers (i.e., ABI/GOES and AHI/HIMAWARI-8)

sacs

SESAR SWIM notifications service (aviation): OPAS (Operational Alert Products for SWIM)

SESAR SWIM OPAS Early Warning System SO_2 Height

https://eur-registry.swim.aero/services

SWIM: System-Wide Information Management

[grant n°891467]

BIRA-IASB ULB RMI SATAVIA Università degli Studi di Padova DLR symopt University of Westminster uc3m Universidad Carlos III de Madrid

https://alarm-project.eu

ALARM SESAR

Thank you

« Velveteen Monster »
painting by Jess Sutton
http://www.jess-sutton.com

→ ATMOS 2021 - ESA ATMOSPHERIC SCIENCE CONFERENCE

[grant n°891467]

https://alarm-project.eu