Decrease of anthropogenic emission from aviation and detection of natural hazards with potential application in geosciences using satellite 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], Simone Dietmüller[4], Sigrun Matthes[4], Volker Grewe[4], Sandy Chkeir[5], Alessandra Mascitelli[5], Aikatrerini Anesiadou[5], Riccardo Biondi[5], Igor Mahorčič[6], Tatjana Bolić[6,7], Ritthik Bhattacharya[8], Tim Winter[8], Adam Durant[8,9], Michel Van Roozendael[1], and Manuel Soler[10]

EGU, Vienna, NH6.1: Remote sensing big data analysis and applications in geosciences [27 May 2022]

EUROPEAN PARTNERSHIP

Co-funded by the European Union

ALARM project

https://alarm-project.eu

Project information

- Horizon 2020
- ID: **891467**
- Call: **H2020-SESAR-2019-2** (SESAR 2020 EXPLORATORY RESEARCH)
- **1st Nov. 2020 – 31st Dec. 2022**

ALARM project

https://alarm-project.eu

Space Weather

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

Environmental Hotspots

- Area where aviation emissions have a very large climate impact

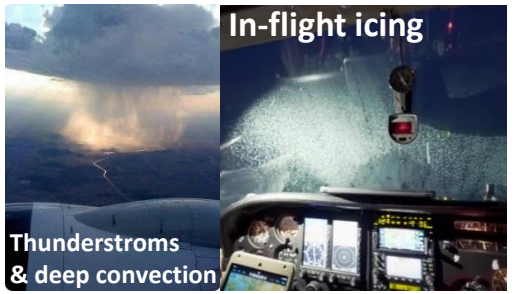
Severe Weather

- 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



ALARM project

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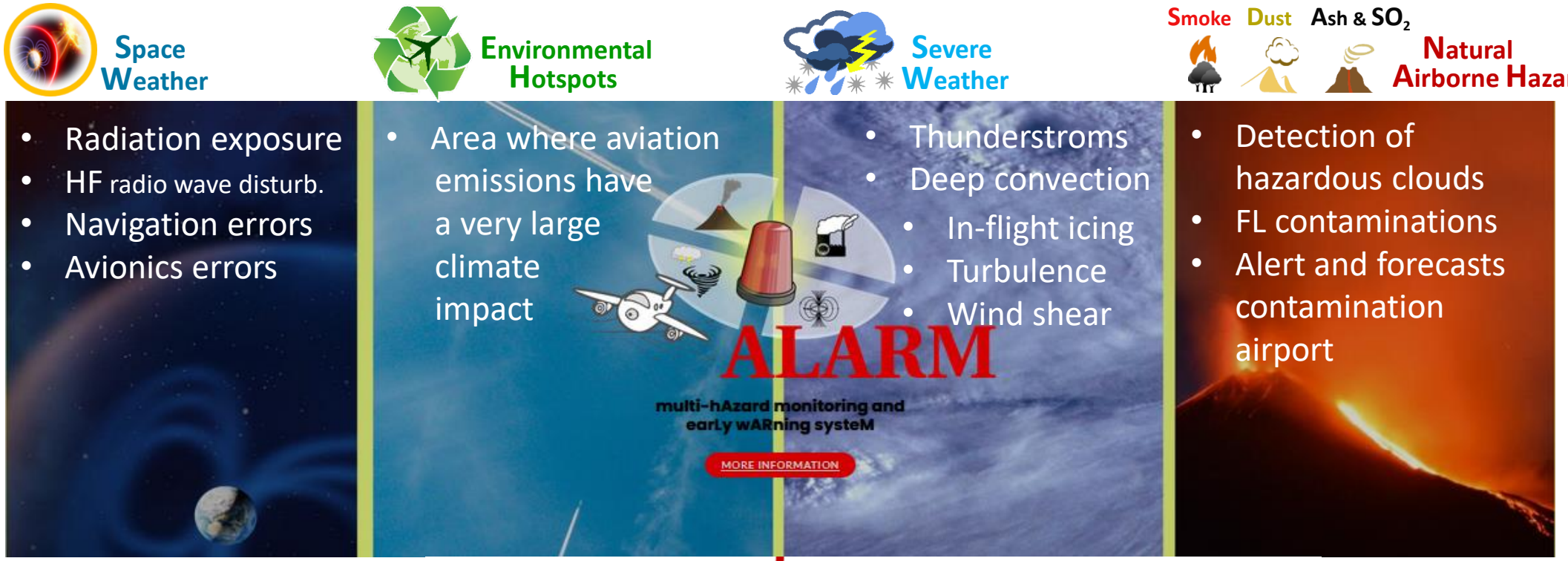
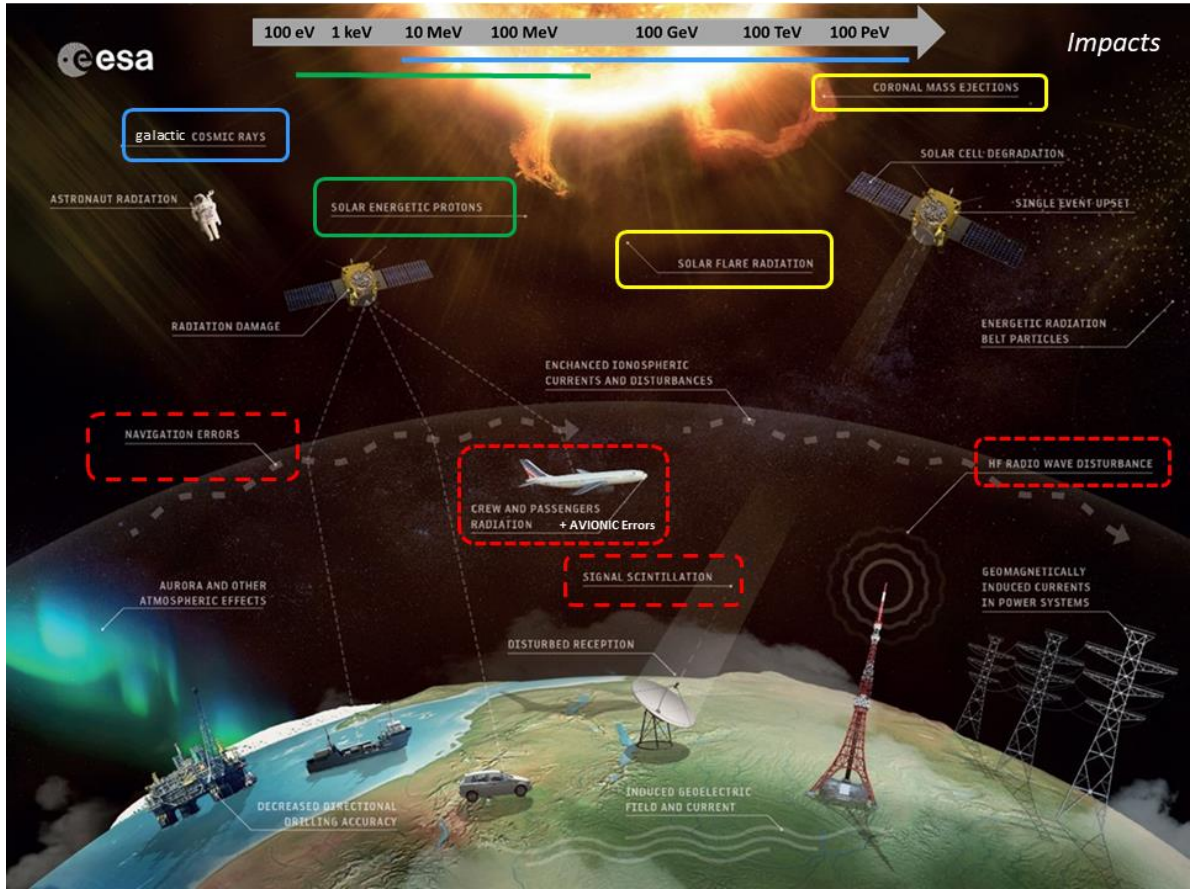


EXAMPLE OF ALERT: SPACE WEATHER

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

Alert from BIRA system in support to PECASUS



EXAMPLE OF ALERT: SPACE WEATHER

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Alert from BIRA system in support to PECASUS

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

using,

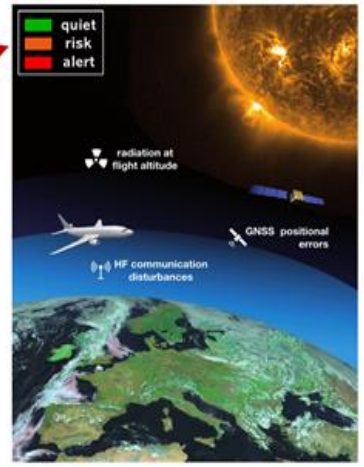
- COMESEP alert system
- GOES16 proton flux data
- HESPERIA UMASEP-500 system
- Neutron Monitor data

What ALARM warnings do not provide:

- effective dose rates
- specification of impacted regions (e.g. FL)

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

COMESEP system



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**.

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

EXAMPLE OF ALERT: SPACE WEATHER

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Risk			
HF	L	M	H
GNSS	L	M	H
SATCOM	L	M	H
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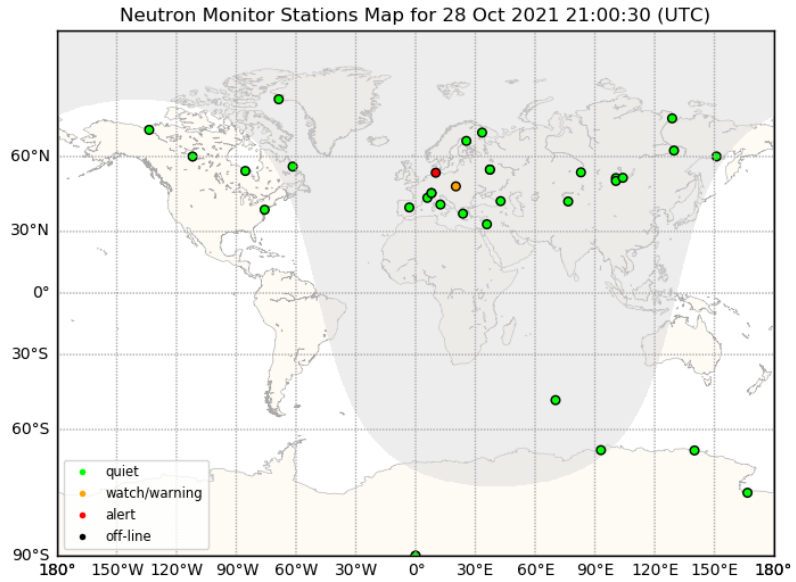
Halloween storm
- Solar flare
- proton event
- GLE event

➔ ALARM issued both warning for HF and RAD
➔ GLE event seen on the NM worldmaps



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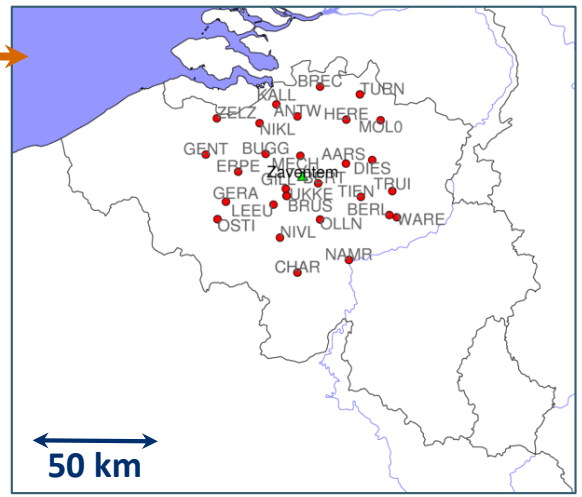
Radiation risk at flight altitude in case of ANeMoS GLE

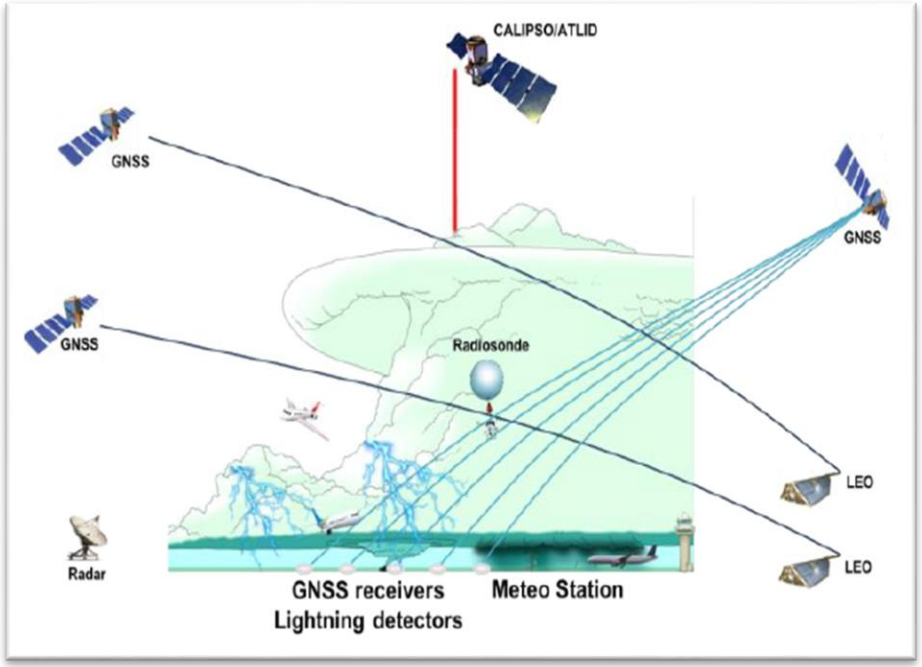
EXAMPLE OF ALERT: SEVERE WEATHER

FOCUS on 2 AIRPORTS

GNSS network Italy (focus on Milan Malpensa airport)

GNSS network Belgium (focus Brussels Zaventem airport)





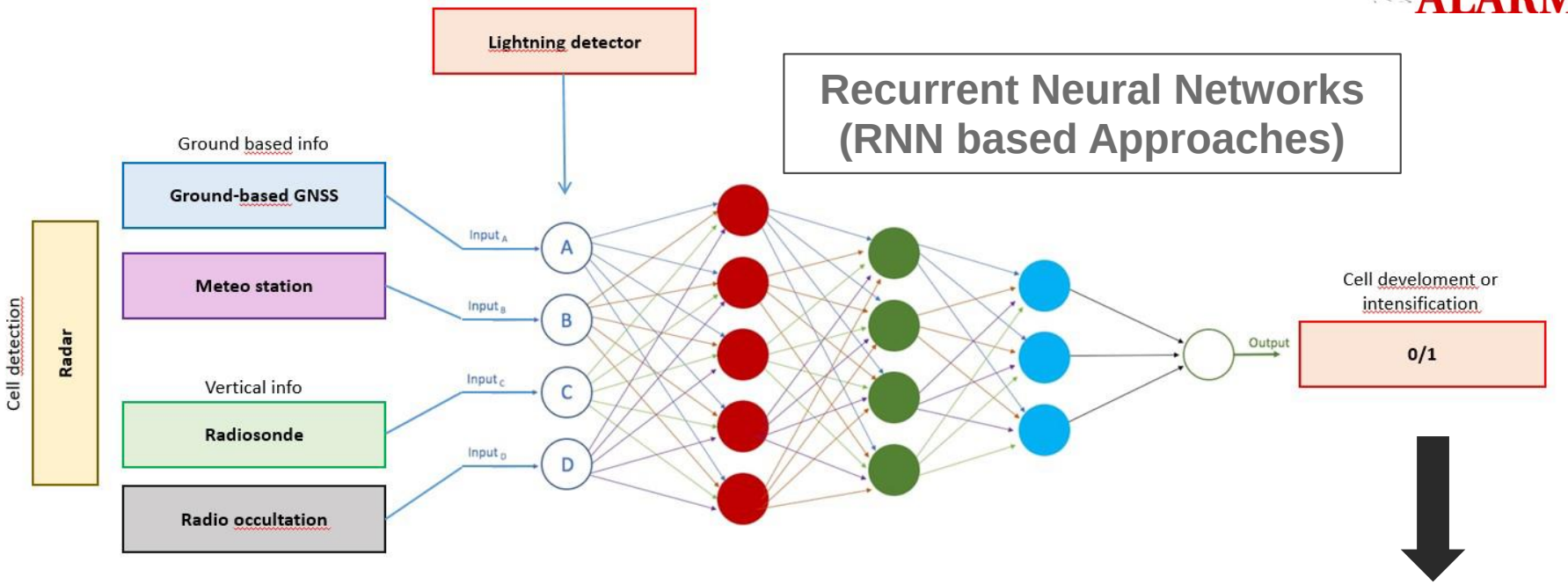
Data availability:

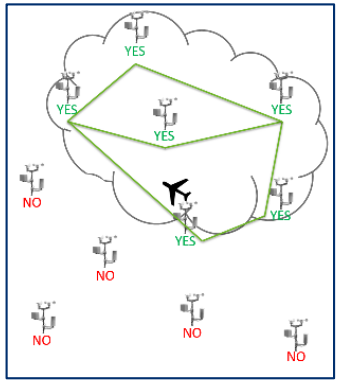
- Ground based GNSS stations
- Weather stations collocated with GNSS
- Radar data
- Lightning data

Vertical information from

- Radiosonde station
- GNSS Radio Occultations

EXAMPLE OF ALERT: SEVERE WEATHER





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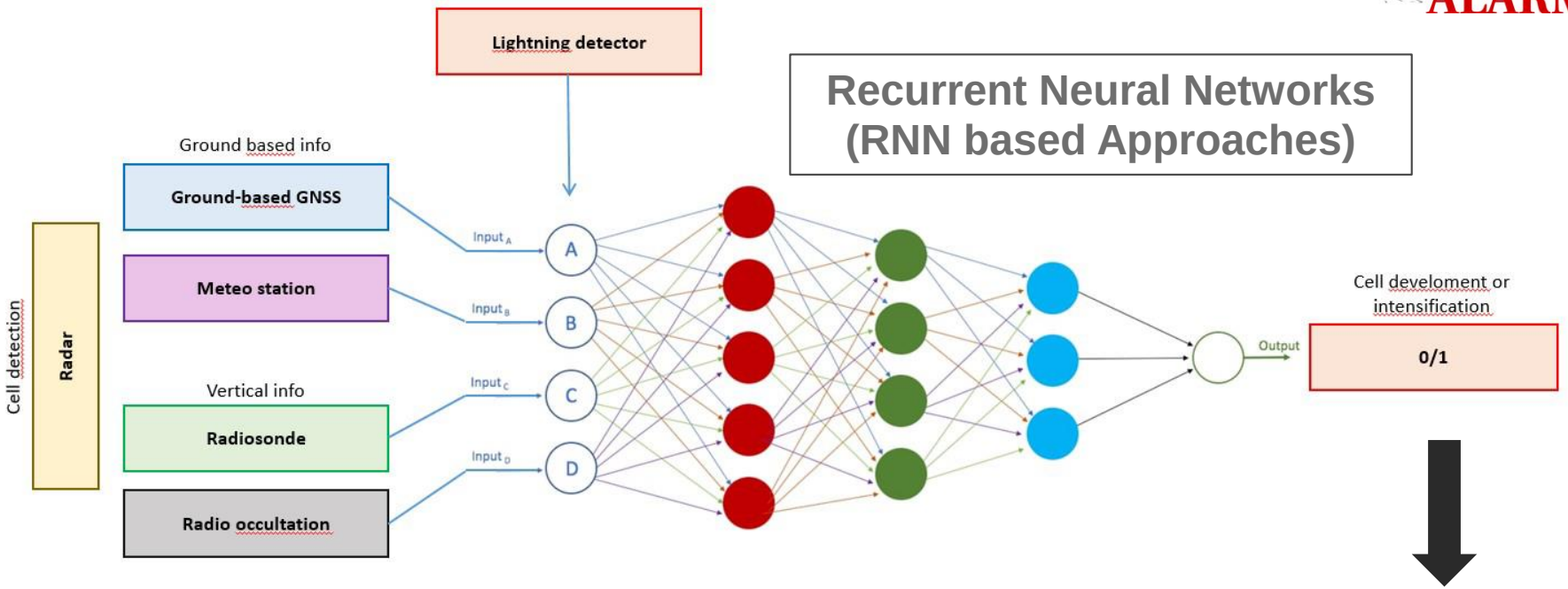

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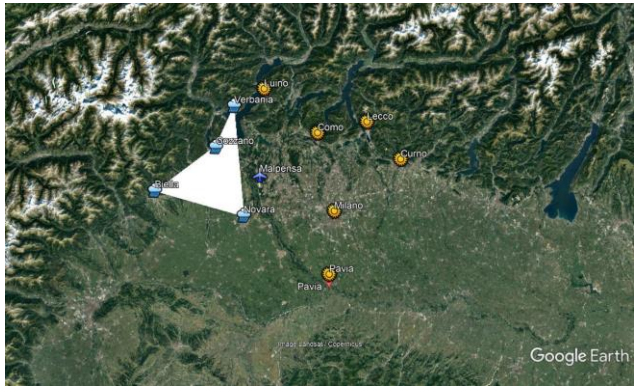
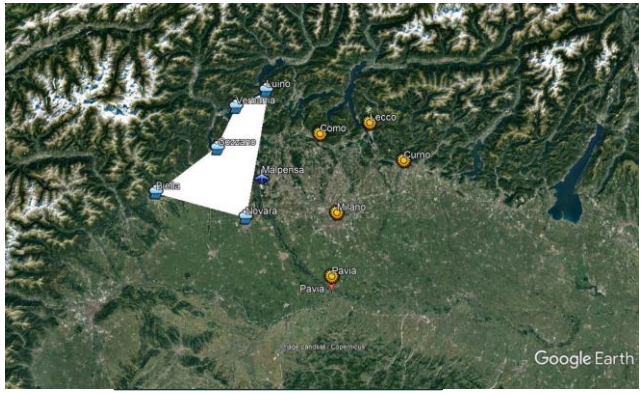


observed

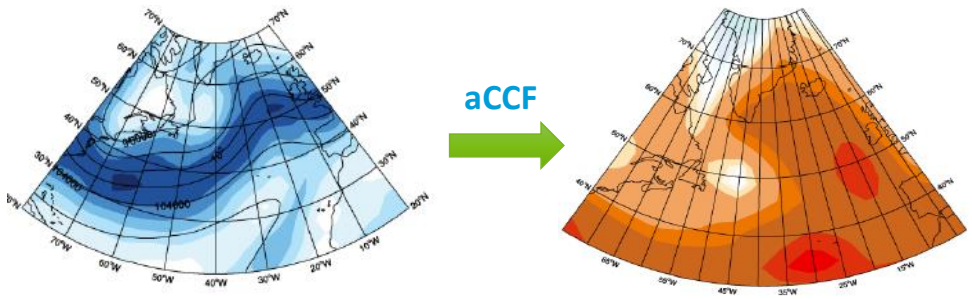


Nowcasted at 10 minutes

EXAMPLE OF ALERT: ENVIRONMENTAL HOTSPOTS

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

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



MET fields

(Matthes et al. 2017, Aerospace)

Climate change from meteorological input data by using aCCFs

- 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.

Environmental hotspot areas over Europe:

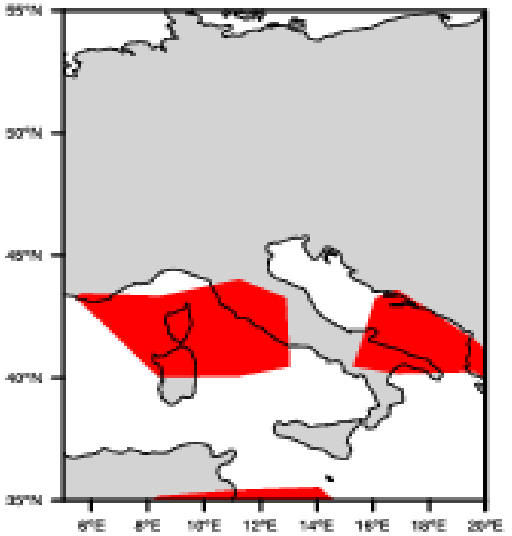
- Regions (contours) with high climate impact are highlighted in red
- Climate impact of non-CO_2 effects (water vapour, NO_x - induced effects, contrail-cirrus) are included
- Case study of a day in summer (daytime), relying on MET data and aCCFs

NO_x aCCF
Water vapour aCCF
Contrail-cirrus aCCF
Merged aCCF

➔ info. on different FL

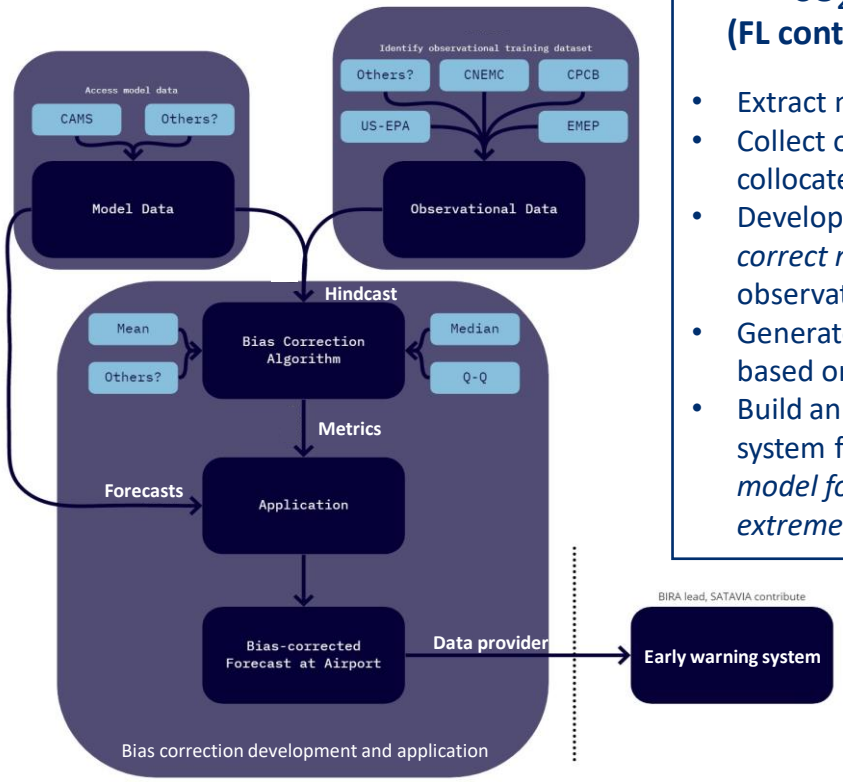
[8 per day / 3h]

[forecasts +24h]



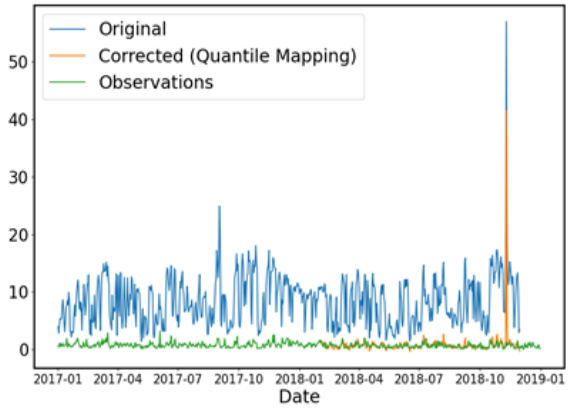
(Dietmüller et al., in prepa.)

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*

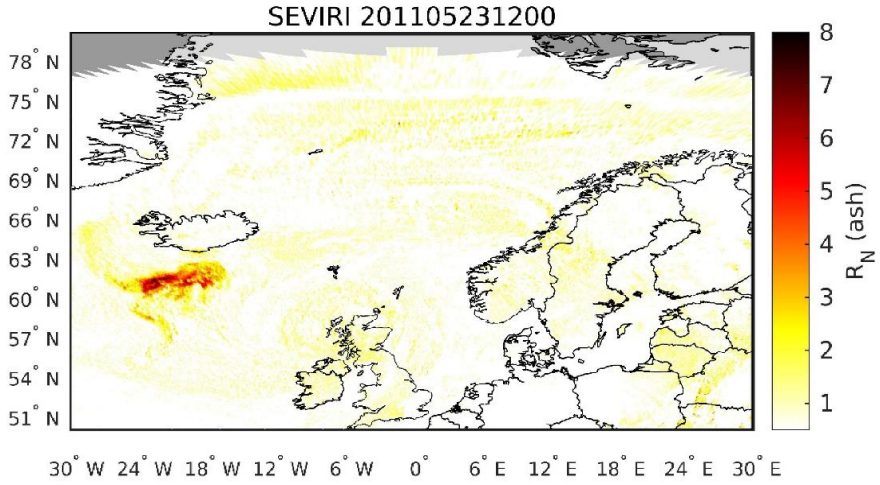


Modelled data, observations, and corrected model data at Birmingham Airport, Alabama. Quantile mapping has been applied to the training data (days to correct from the previous years padded by 30 days on each side)

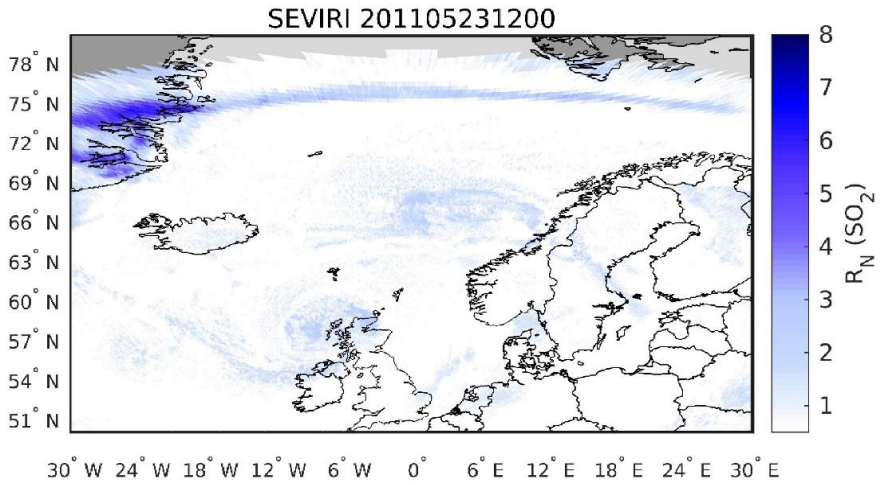
EXAMPLE OF ALERT: NATURAL AIRBORNE HAZARD

Ash & SO_2

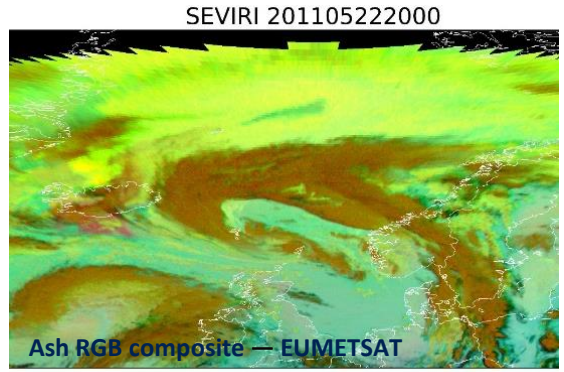
Ash index — BIRA

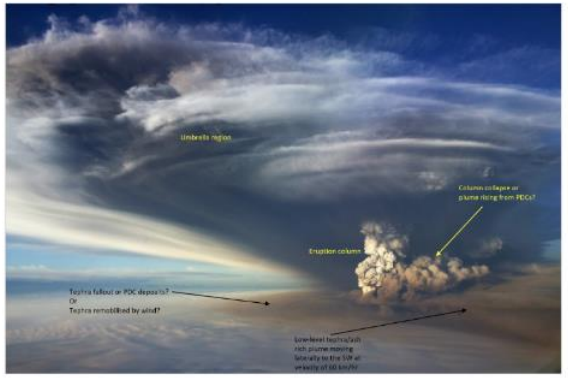


SO_2 index — BIRA



Grímsvötn, May 2011





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**)

EXAMPLE OF ALERT: NATURAL AIRBORNE HAZARD

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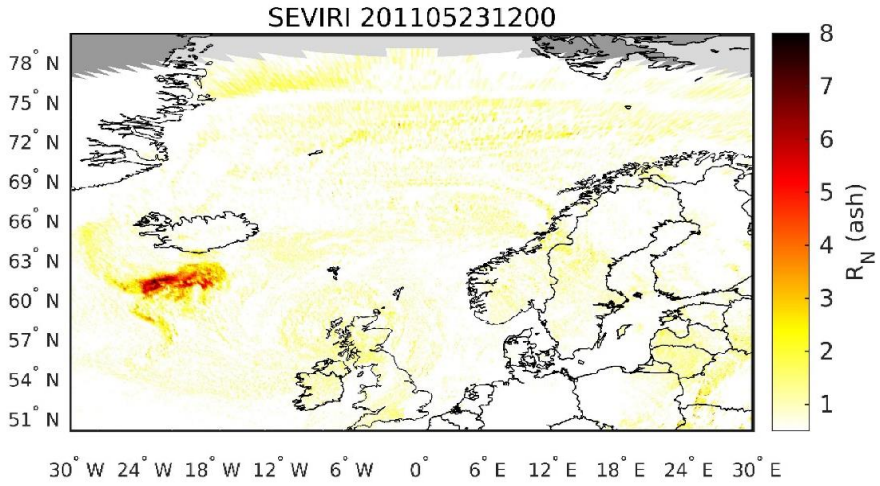

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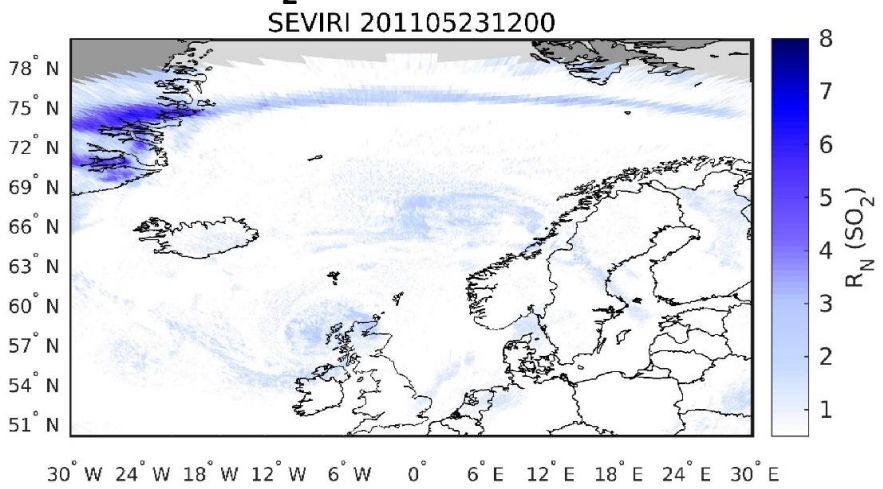

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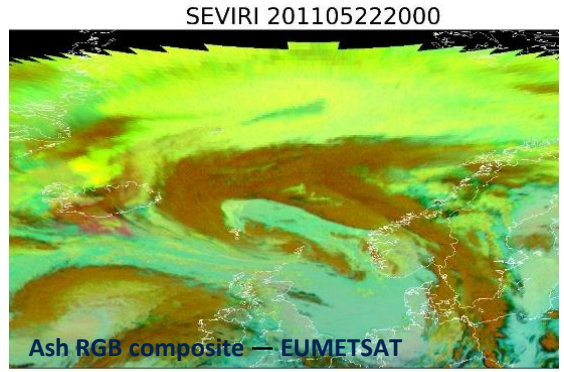

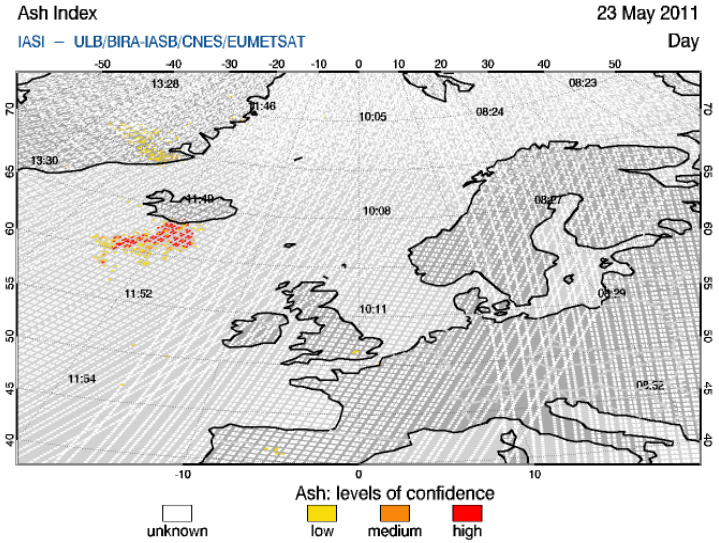

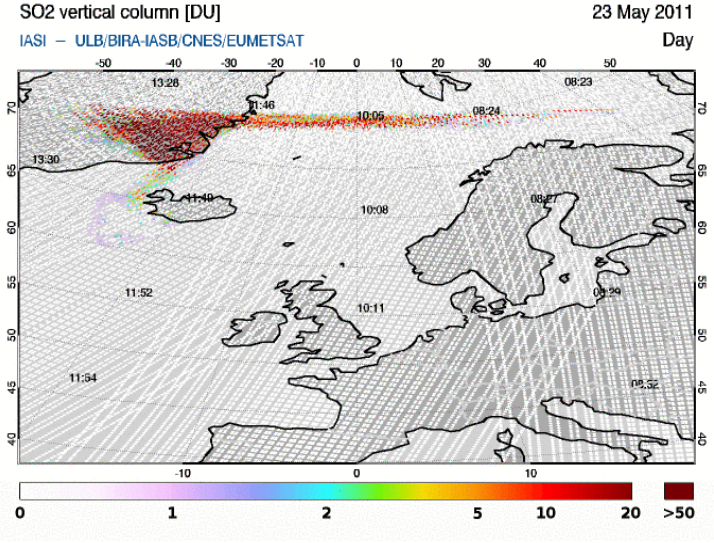

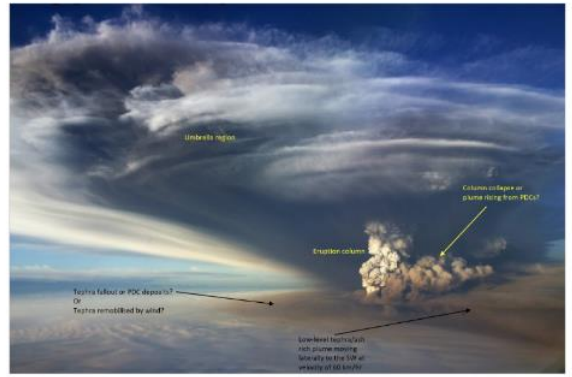

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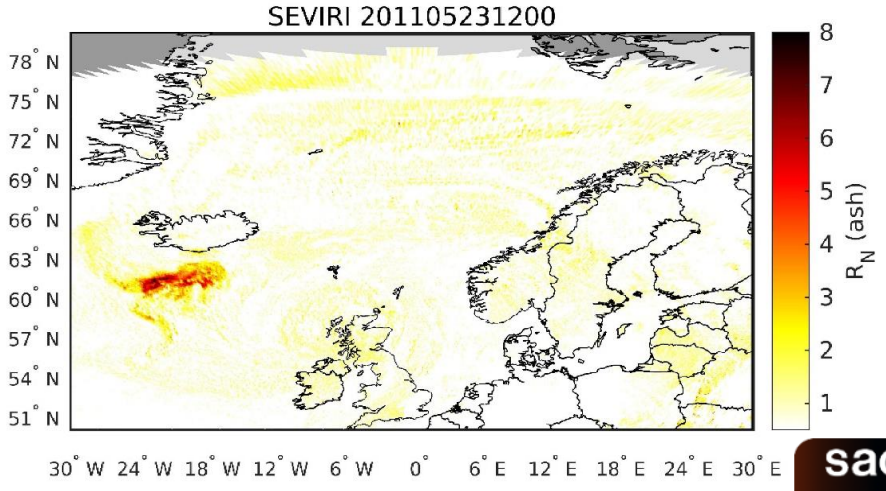
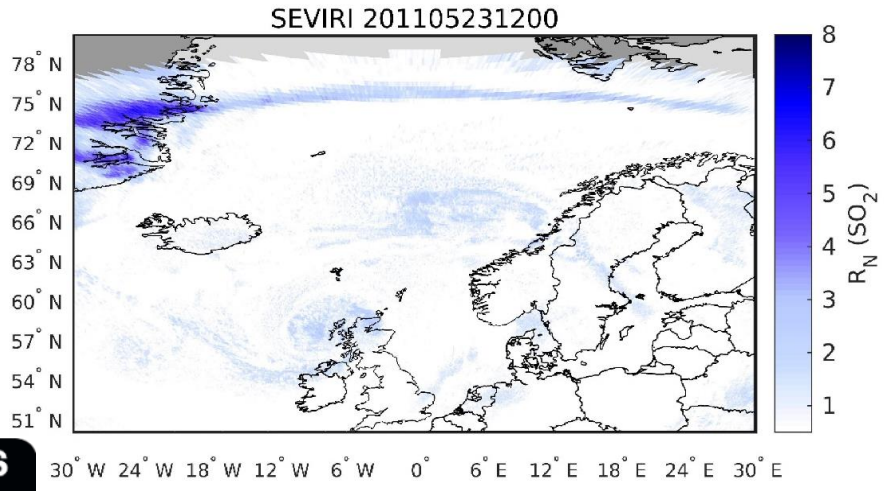
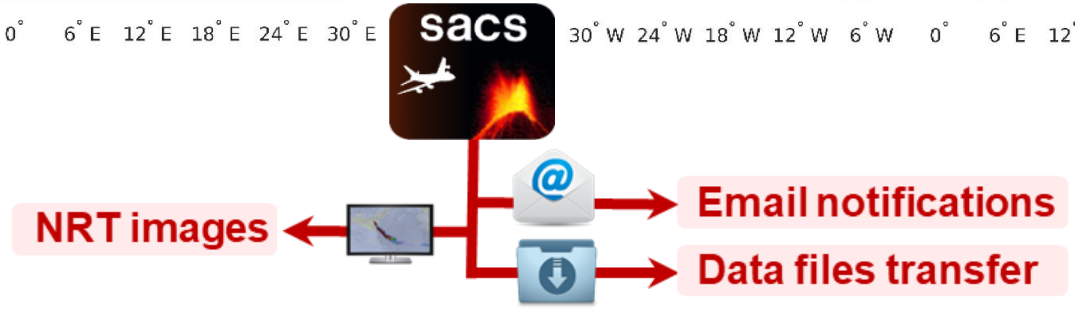


SO_2 index — BIRA





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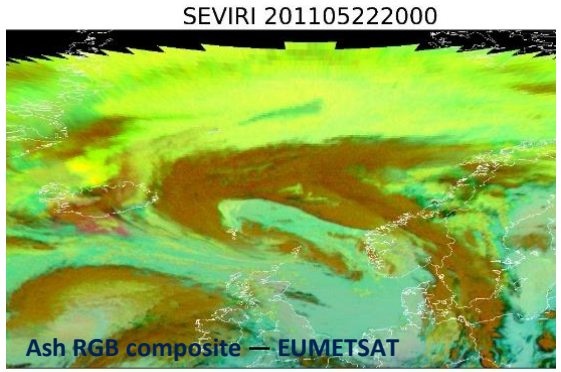
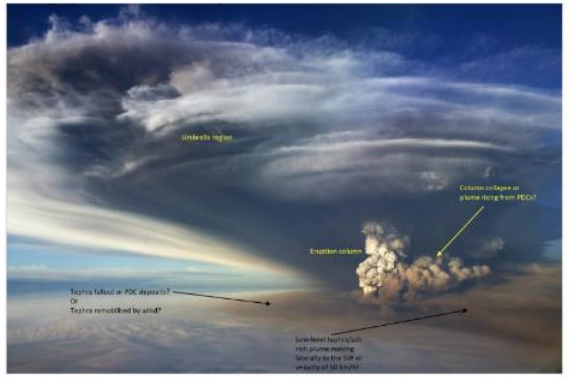




Use of GEO data to create SO_2 & aerosols (ash/dust) notifications

EXAMPLE OF ALERT: NATURAL AIRBORNE HAZARD

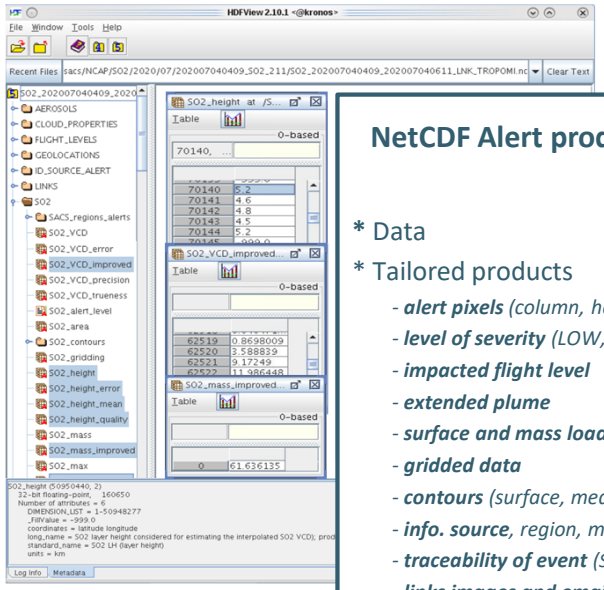
Email notification

Users

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

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

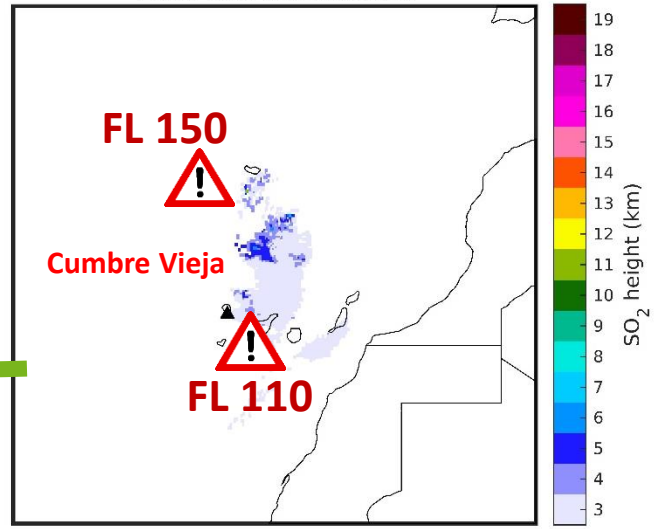
```
SACS multi-sensor notification of SO2 height retrievals
=======================================================

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)
```



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



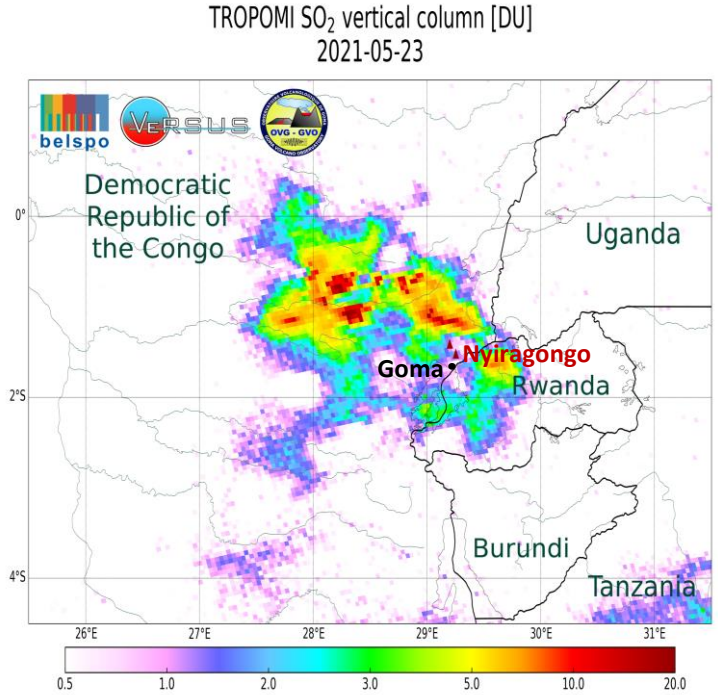
Visualisation

https://sacs.aeronomie.be

POTENTIAL APPLICATION IN GEOSCIENCES: NATURAL AIRBORNE HAZARD

Eruption Nyiragongo
on 22 May 2021

View from Goma city



EUNADICS-AV Engage ALARM sesar JOINT UNDERTAKING esa

Support to Aviation Control Service

SACS home > Notifications > TROPOMIalert > 2021 > 05 > **SO2 confirmation: TROPOMI** Royal Belgian Institute for Space Aeronomy

NEAR REAL-TIME | NOTIFICATIONS | PRODUCTS

BIRA-IASB

SO_2 NOTIFICATION

TROPOMI region 307

Date	:	2021/05/23
Time	:	11:32 UTC
Longitude	:	28.3 deg. East
Latitude	:	-1.1 deg. North
Max. SO2 column	:	17.4 DU (assuming 15 km plume height)
SO2 mass loading	:	4.995 kt (assuming 15 km plume height)
SO2 plume area	:	102254 km^2
Volcano erupting	:	Nyiragongo (most likely)
Cloud data	:	used for VCD
SZA	:	30.7 deg.
Name data source	:	S5P_NRTI_L2__SO2___20210523T113151_20210523T113651_18700_01_020104_20210523T123314.nc

POTENTIAL APPLICATION IN GEOSCIENCES: NATURAL AIRBORNE HAZARD

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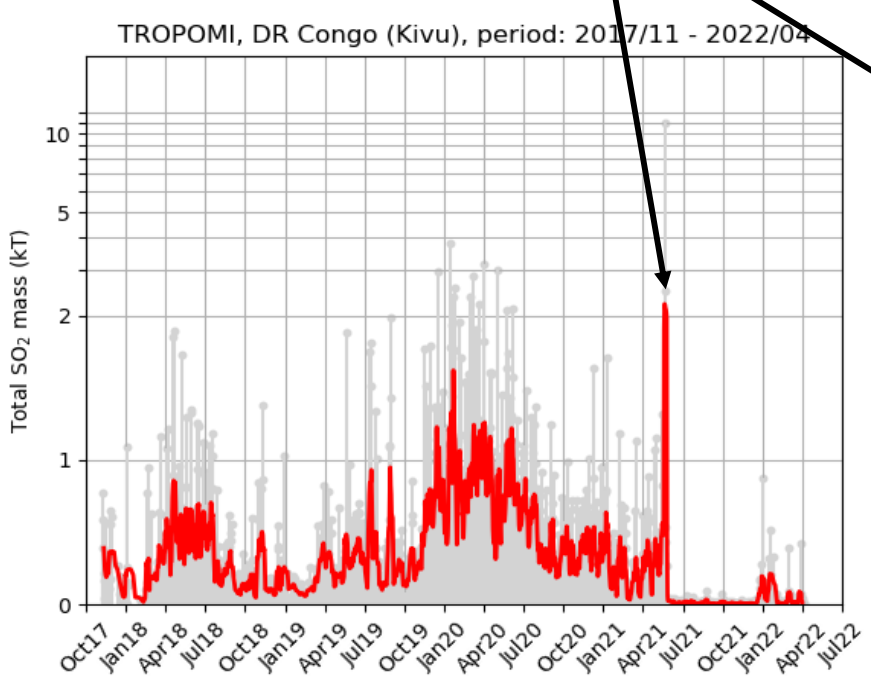

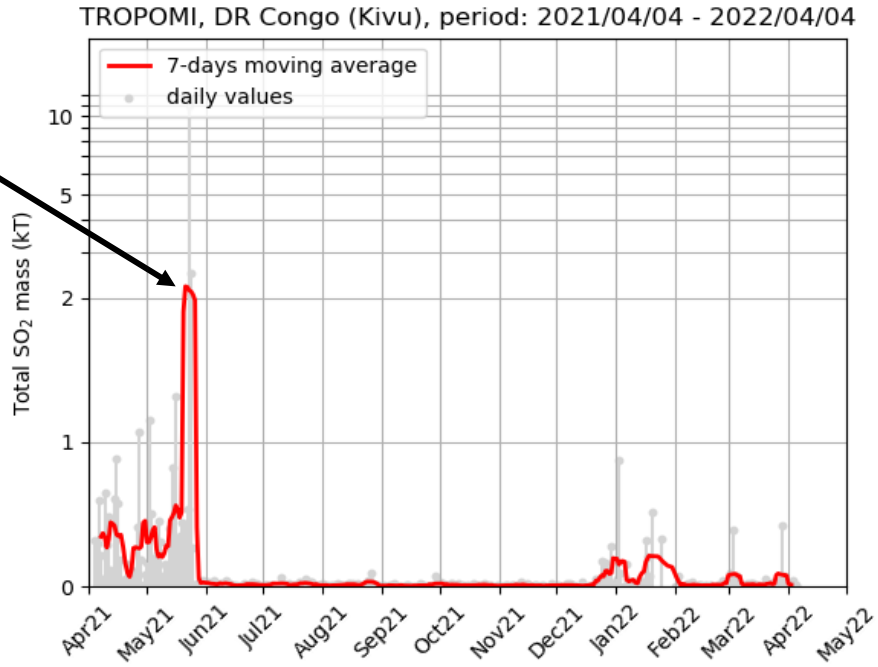

THANK YOU FOR YOUR ATTENTION

brenot@aeronomie.be

EUROPEAN PARTNERSHIP

Co-funded by the European Union