VADUGS algorithm
Volcanic Ash Detection using Geostatonary Satellites

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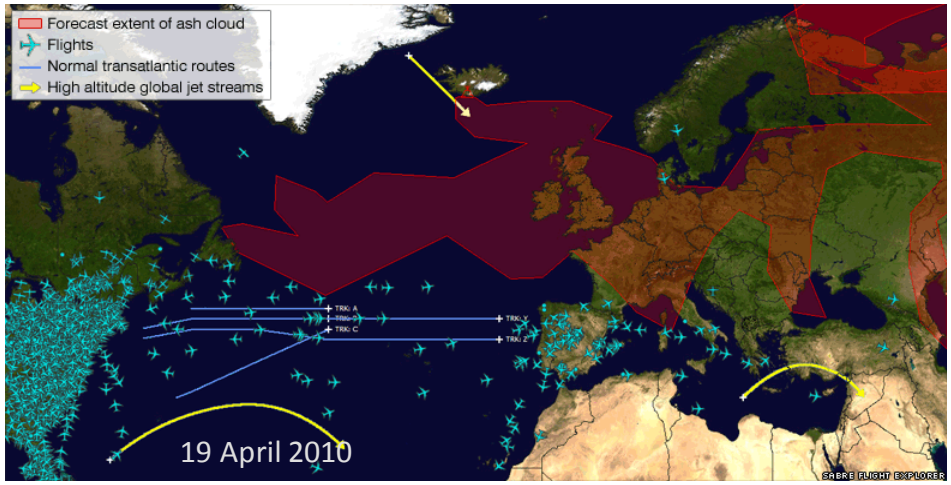
WMO Intercomparison Workshop, Madison, WI
29 June – 02 July 2015

The DLR project VolcATS – idea and goals



- > 100.000 flights cancelled
- 313 europ. airports closed
- Showed gaps in ATC procedures

→ **Volc**anic ash impact on the **A**ir **T**ransportation **S**ystem

1. Nowcasting (Detection + short-term forecasting) of **ash-free** and **ash-contaminated regions** based on satellite data (radiative transfer calculations and algorithm development) + Definition of „visible ash“

2. In-situ SO_2 and **particle sensor development** for airliners

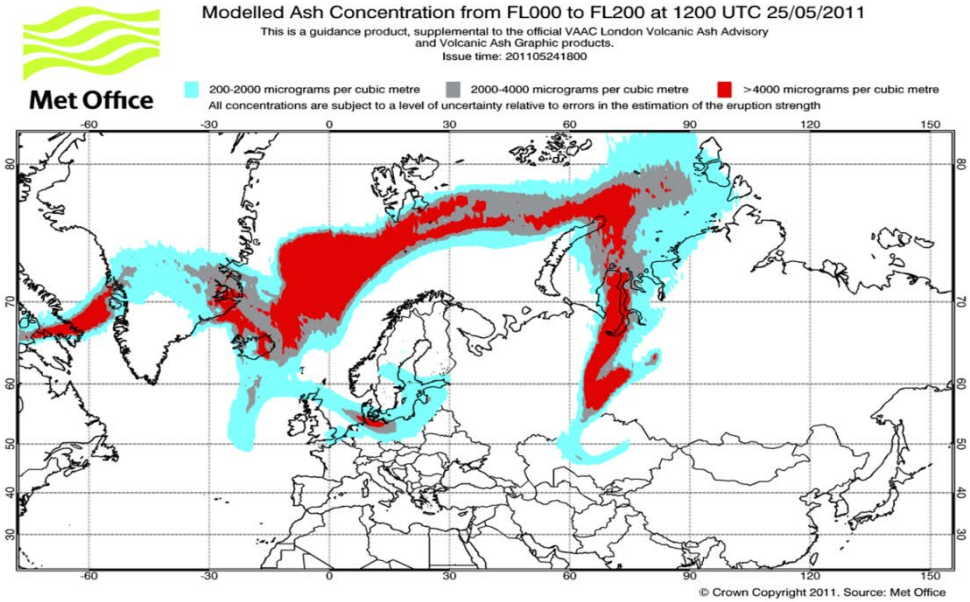
3. Development of **ATM-procedures** for a fast response of the **air transportation system on volcanic ash in airspace**

DLR

TeFiS project: VADUGS as secondary source

- Current regulation in Germany: flights in „grey areas“ (2-4 mg/m³) are allowed (need for special approved risk assessment procedures of the airline).
- Within this risk assessment, secondary source information has to be considered
- Development of VADUGS towards an operational product operated within the DWD facilities and adapted to the needs of end user (e.g. airline dispatcher)

Zonenbezeichnung gemäß ICAO Doc-19 (EUR/NAT)	Zonenbezeichnung gemäß EASA SIB 2010-17R2	vorhergesagte Maximal-Kontamination	Farbcode gemäß VAAC
---	Normal Zone	weniger als 0,2 mg/m^3	kein
Area of low contamination = mit Vulkanasche geringfügig kontaminierter Luftraum	EPZ (b) Enhanced Procedure Zone	0,2 mg/m^3 oder mehr, jedoch weniger als 2 mg/m^3	türkis
Area of medium contamination = mit Vulkanasche mäßig kontaminierter Luftraum	EPZ (a) Enhanced Procedure Zone	2 mg/m^3 oder mehr, jedoch weniger als 4 mg/m^3	grau
Area of high contamination = mit Vulkanasche stark kontaminierter Luftraum	NFZ No Fly Zone	4 mg/m^3 oder mehr	rot



DWD Deutscher Wetterdienst

Lufthansa

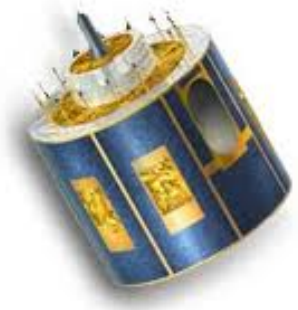
DFS Deutsche Flugsicherung

VolcATS – idea and goals

The VADUGS algorithm for ash detection is based on **SEVIRI** aboard **MSG**, since:

- High temporal and spatial resolution
- 7 channels located in the thermal infrared (day/night)
- Operational and high / fast data availability
- Existing expertise in IPA
- Sensitivity of SEVIRI measurements on VA already proven
- Upcoming SEVIRI-like instrumtens

  → almost global coverage

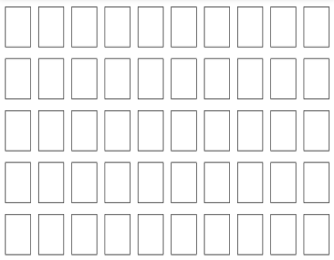


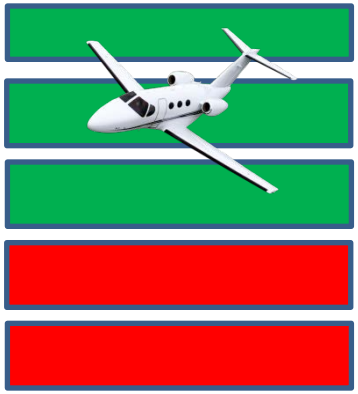
VADUGS
Volcanic Ash Detection Utilizing Geosationary Satellites

Highly sensitive cirrus cloud retrieval (COCS) supports the algorithm

SEVIRI IR
- 6.2 µm
- 7.3 µm
- 8.7 µm
- 9.7 µm
- 10.8 µm
- 12.0 µm
- 13.4 µm

Based on a neuronal network





flight level

products:
- no ash – no info – ash
- Ash column concentration (g/m^2)
- Top altitude of ash layer

Additional input:
T_SURF
LSM

During training:
Based on radiative transfer calculations with different atmospheric situations, types of volcanic ash, and mineral dust

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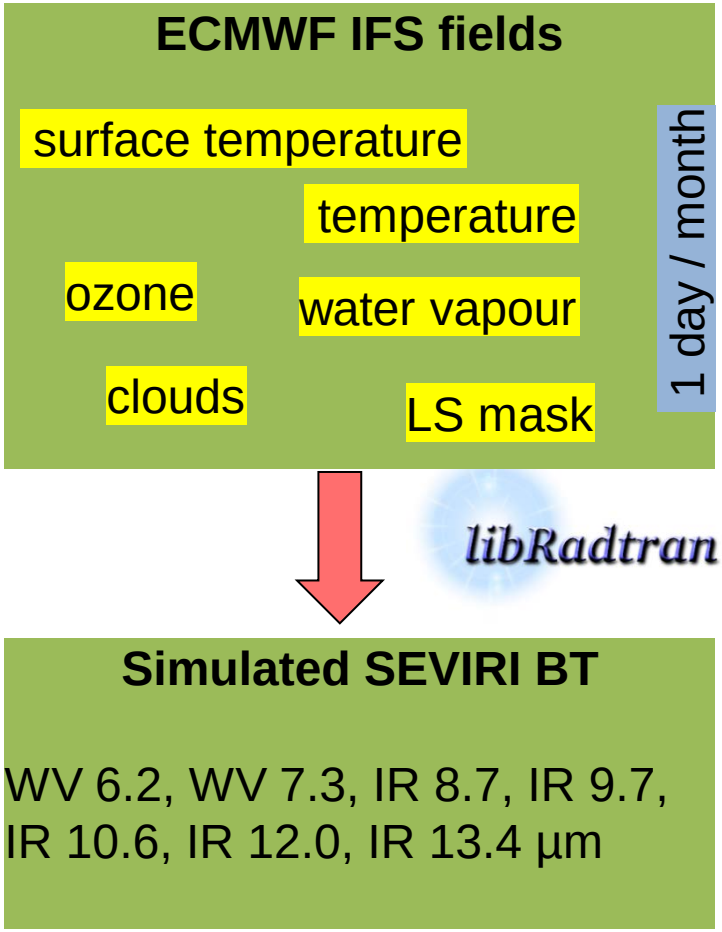
Mayer and Kylling, 2005

VADUGS
Setup of the training data - 1

- Background: Meteorological fields from the NWP model **ECMWF – IFS**
  - Surface temperature, Temperature, ozone, water vapour, clouds
  - Use of one day per month in order to account **for seasonal variability**
  - Radiative Transfer calculation of the brightness temperatures (SEVIRI channels) for the original ECMWF field
  - For water clouds, parameterization according to Bugliaro et al., 2011 (different parameterization for land/sea)
  - Ice cloud parameterization: Wyser (1998) and McFarquhar (2003)



VADUGS
Setup of the training data - 2

- Now, volcanic ash layers are merged with the input meteorological fields
- Different VA types are treated separately
- Different vertical dimensions of the ash layer are represented
- Different mass concentration (g/m³)
- Different top altitude of ash layer
- Different size distributions: accumulation mode (0.4 µm) & coarse mode (2 µm)

Simulated BT representing the original ECMWF IFS fields + artificial VA layers

ECMWF IFS fields

surface temperature

temperature

ozone

water vapour

clouds

LS mask

1 day / month

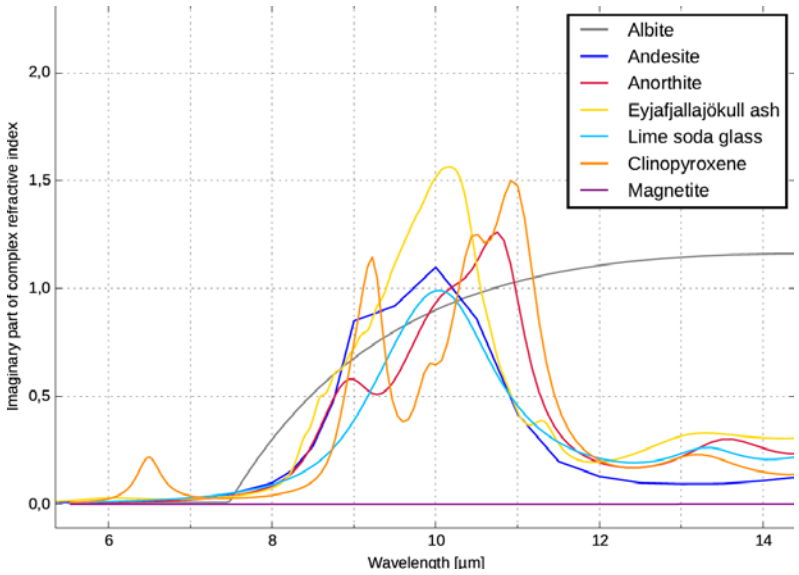
ASH LAYER

libRadtran

Simulated SEVIRI BT

WV 6.2, WV 7.3, IR 8.7, IR 9.7, IR 10.6, IR 12.0, IR 13.4 µm are calculated

VADUGS
List of different ash types



- ANPA Andesite (pure), accumulated
- ANPC Andesite (pure), coarse
- EYPA Eyjafjallajökull ash (pure), accumulated
- EYPC Eyjafjallajökull ash (pure), coarse
- ANMA Andesitic mixture, accumulated
- ANMC Andesitic mixture, coarse
- DCMA Dacitic mixture, accumulated
- DCMC Dacitic mixture, coarse
- RDMA Rhyodacitic mixture, accumulated
- RDMC Rhyodacitic mixture, coarse
- RLMA Rhyolitic mixture, accumulated
- RLMC Rhyolitic mixture, coarse

Material	Source
Albite	Mutschke, 1998
Andesite	Pollack et al., 1973
Anorthite	Aronson and Strong, 1975
Eyjafjallajökull ash	D. Peters, 2012-09-28, personal communication
Lime soda glass	Aronson and Strong, 1975
Clinopyroxene	Aronson, 1986
Magnetite	Glotch and Rossman, 2009

```
<AT>    Volcanic ash type:
Volcanic ash type: andesitic mixture, accumulated (Klüser et al.)
Volcanic ash type: andesitic mixture, coarse (Klüser et al.)
Volcanic ash type: andesite, accumulated (Pollack et al.)
Volcanic ash type: andesite, coarse (Pollack et al.)
Volcanic ash type: dacitic mixture, accumulated (Klüser et al.)
Volcanic ash type: dacitic mixture, coarse (Klüser et al.)
Volcanic ash type: Eyjafjallajökull ash, accumulated (Peters et al.)
Volcanic ash type: Eyjafjallajökull ash, coarse (Peters et al.)
Volcanic ash type: rhyodacitic mixture, accumulated (Klüser et al.)
Volcanic ash type: rhyodacitic mixture, coarse (Klüser et al.)
Volcanic ash type: rhyolitic mixture, accumulated (Klüser et al.)
Volcanic ash type: rhyolitic mixture, coarse (Klüser et al.)
```

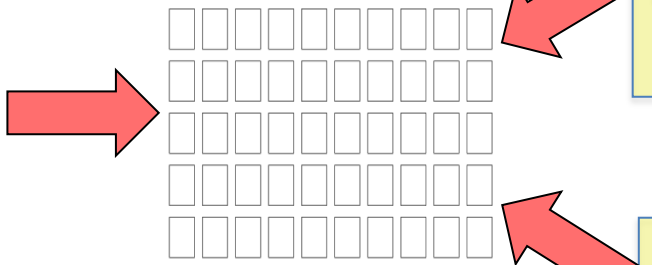
WMO Intercomparision: Eyjafjallajökull ash

DLR

VADUGS
Volcanic Ash Detection Utilizing Geosationary Satellites

Simulated SEVIRI IR with / without VA layer

- 6.2 µm
- 7.3 µm
- 8.7 µm
- 9.7 µm
- 10.8 µm
- 12.0 µm
- 13.4 µm

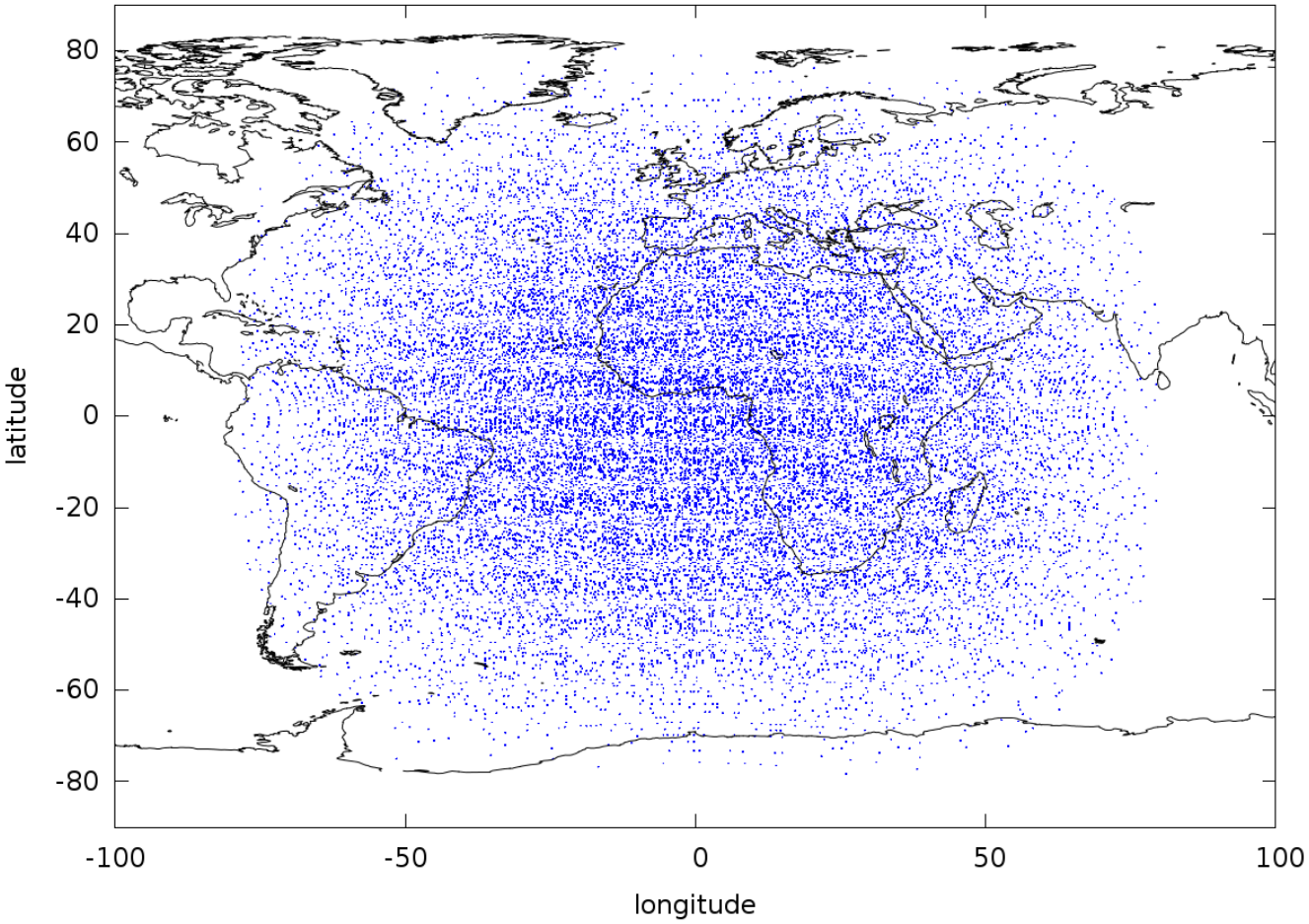


- Known ash column concentration for each pixel
- Known top altitude of each pixel

- Known satellite zenith angle
- Known surface temperature
- Known land-sea-mask state of each pixel

Based on these input information, the neuronal network is able to learn how to derive
- Ash column concentration
- Ash top altitude

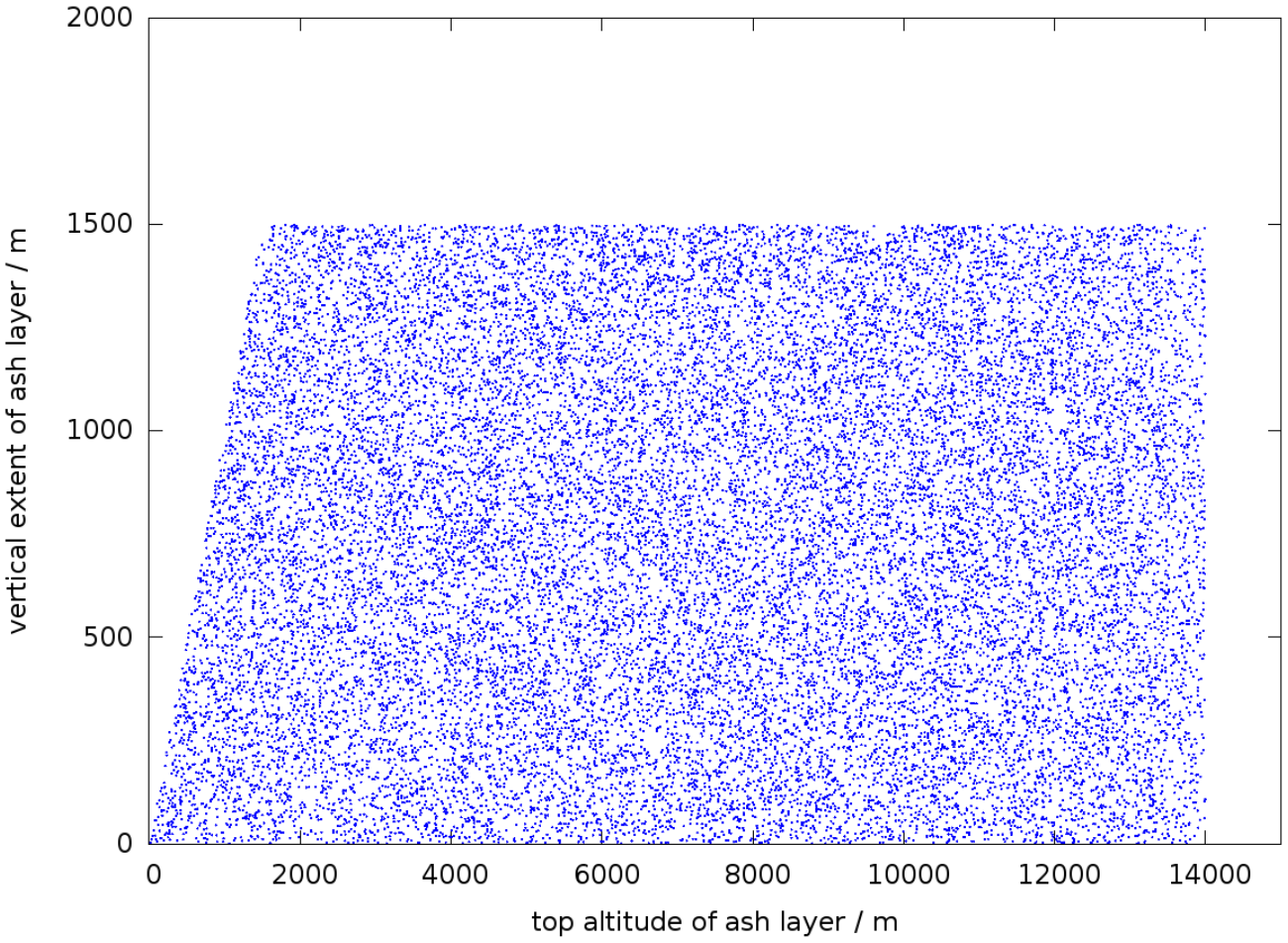
VADUGS
Spatial distribution of training data



Position of the training data profiles are selected in compliance with the SEVIRI field of view

The random position are generated from equidistant lat/lon grids

VADUGS
Vertical extent and top altitude



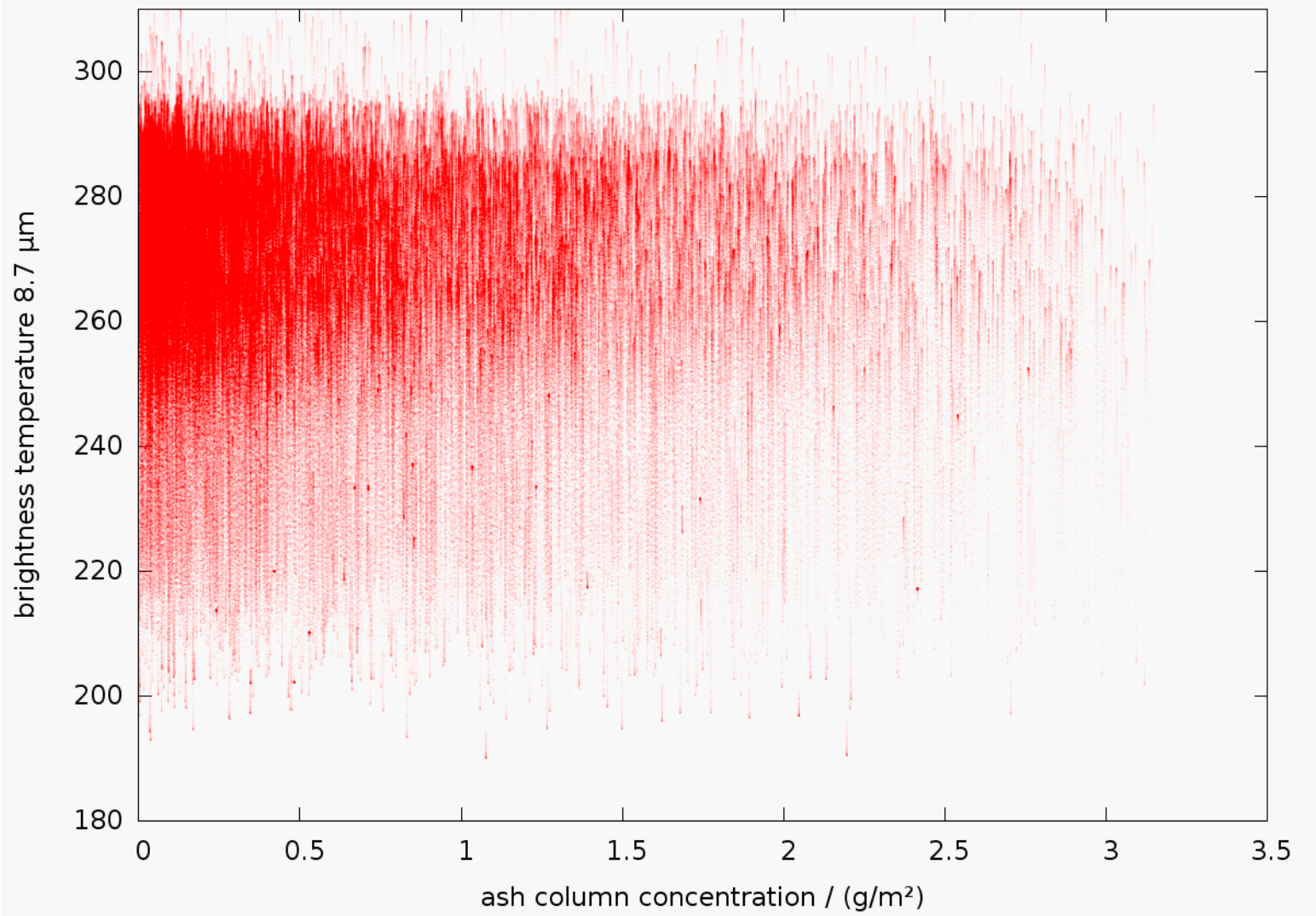
Vertical extent of the VA layer varies between 0 m and 1.5 km

Top altitude varies from 0 m (above ground) to 14 km

This image is just an example – other ranges of VA extent / VA top altitude were considered separately and mixing of training data allows for extension of the ranges

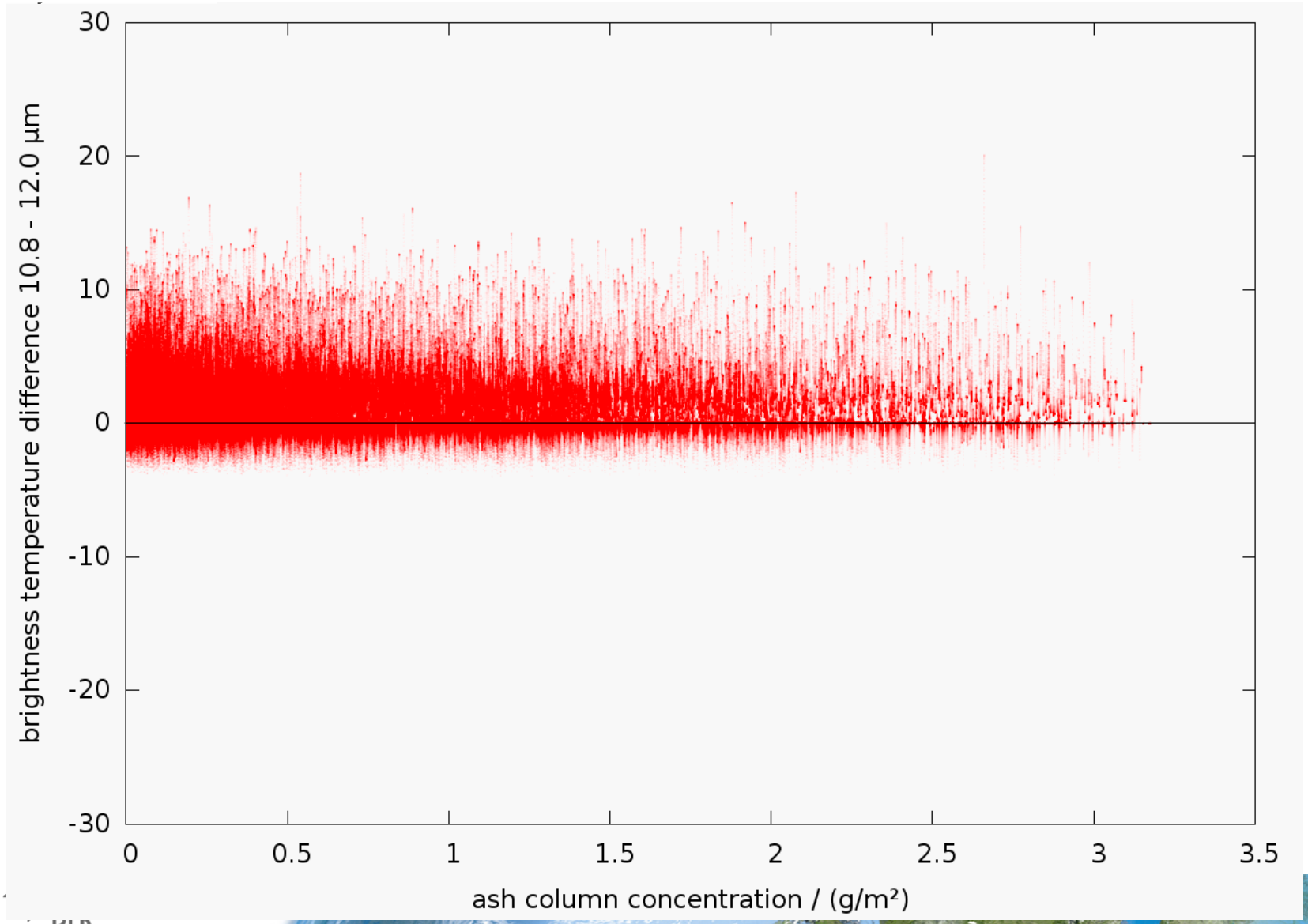
VADUGS

Effect of VA layer on brightness temperature @ 10.8 µm

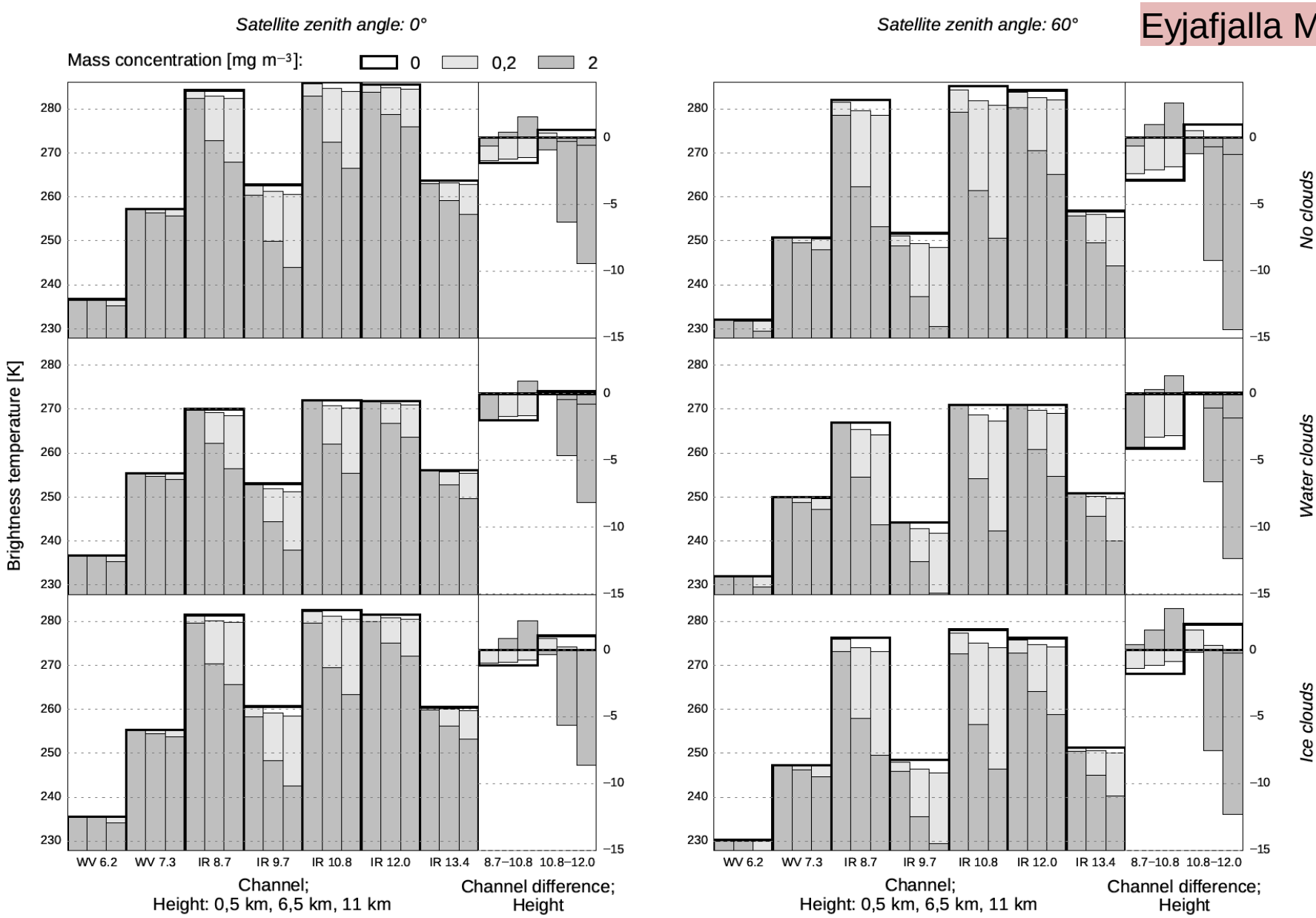


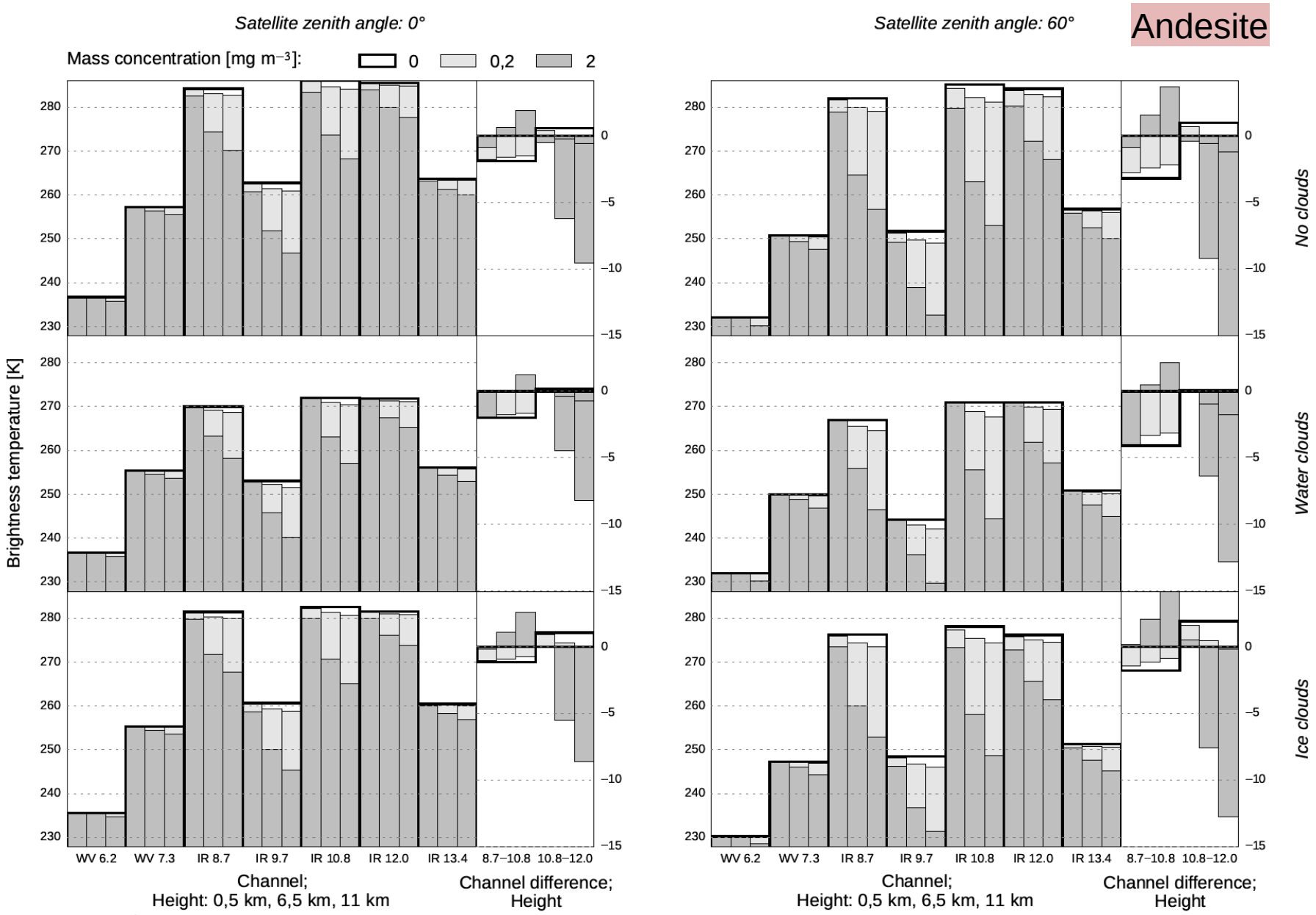
VADUGS

Effect of VA layer on brightness temperature diff 10.8 - 12µm



Eyjafjalla Mix




Satellite zenith angle: 0°
Satellite zenith angle: 60°
Andesite
Mass concentration [mg m⁻³]: 0 0,2 2
Brightness temperature [K]
No clouds
Water clouds
Ice clouds
WV 6.2 WV 7.3 IR 8.7 IR 9.7 IR 10.8 IR 12.0 IR 13.4 8.7–10.8 10.8–12.0
Channel; Height: 0,5 km, 6,5 km, 11 km
Channel difference; Height

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Simulated SEVIRI IR with / without VA layer

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- 7.3 µm
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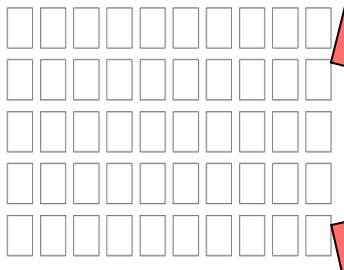
- 12.0 µm
- 13.4 µm

Based on a neuronal network



- Known ash column concentration for each pixel
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- Known satellite zenith angle
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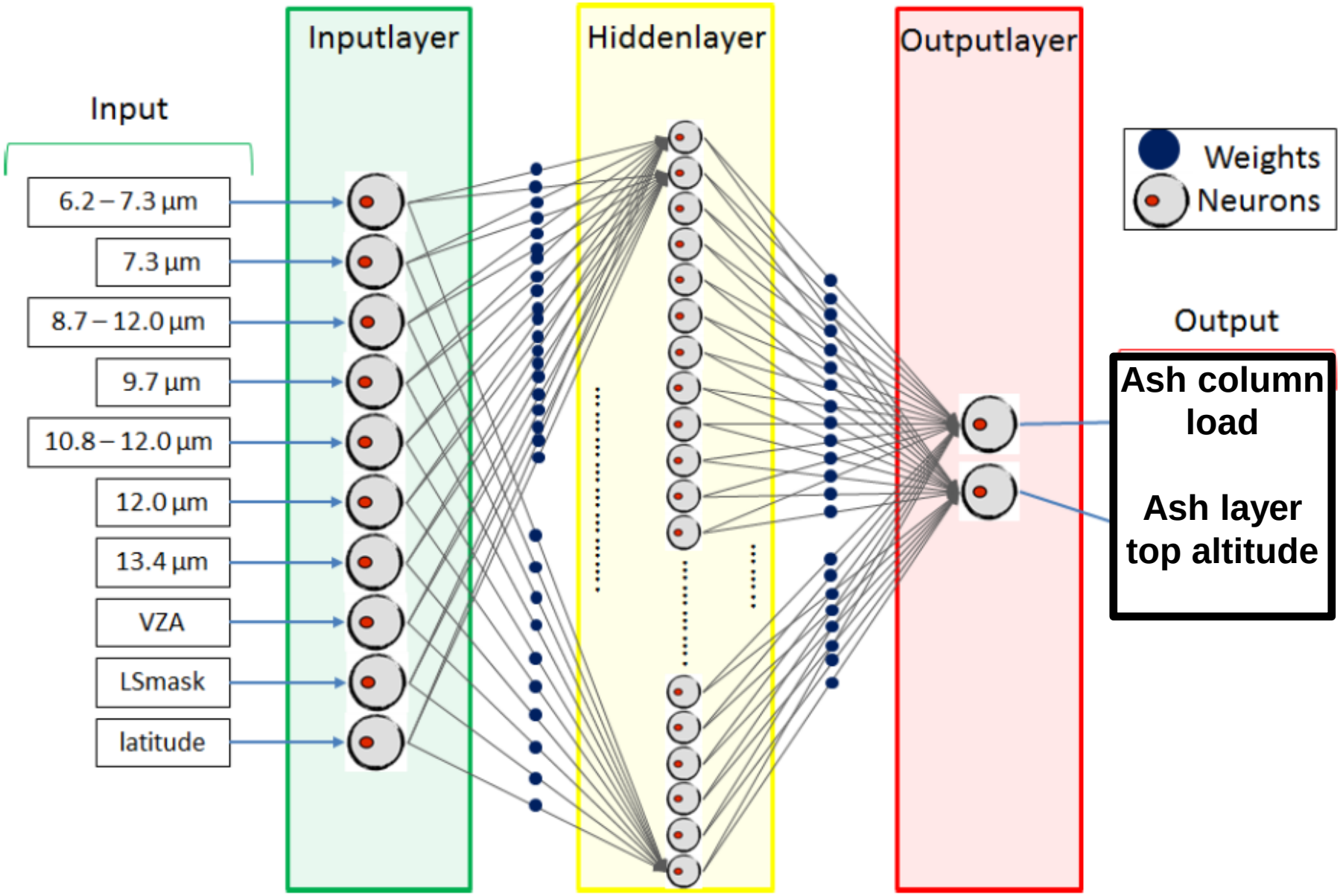
libRadtran

DLR


Inputlayer
Hiddenlayer
Outputlayer
Input
6.2 – 7.3 µm
7.3 µm
8.7 – 12.0 µm
9.7 µm
10.8 – 12.0 µm
12.0 µm
13.4 µm
VZA
LSmask
latitude
Weights
Neurons
Output
Ash column load
Ash layer top altitude

VADUGS
Volcanic Ash Detection Utilizing Geosationary Satellites

SEVIRI IR

- 6.2 µm
- 7.3 µm
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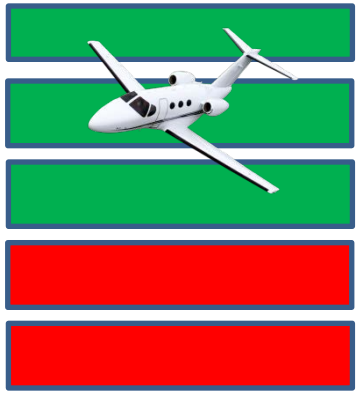
Based on a neuronal network



flight level

products:
- no ash – no info – ash (cloud)
- Ash column concentration (g/m²)
- Top altitude of ash layer

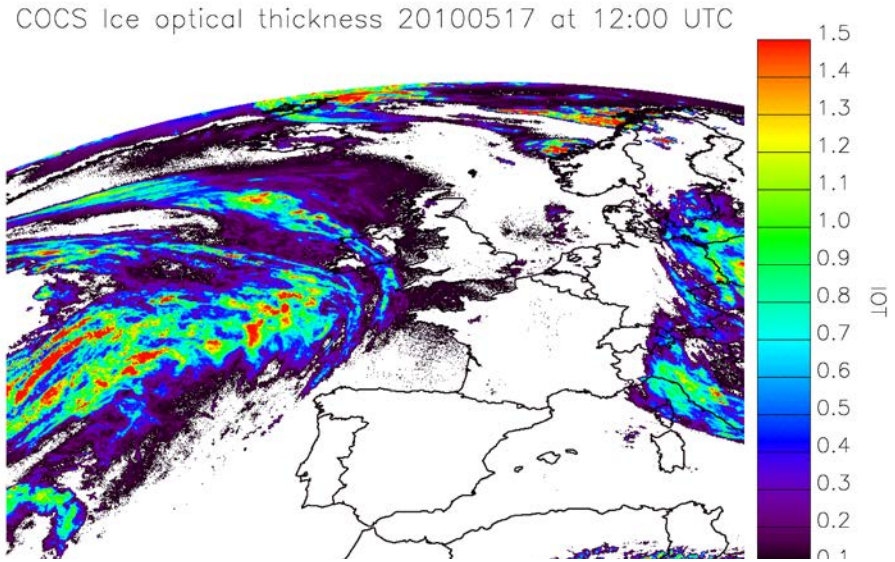
Highly sensitive cirrus cloud retrieval (COCS) supports the algorithm (Kox et al., 2014)

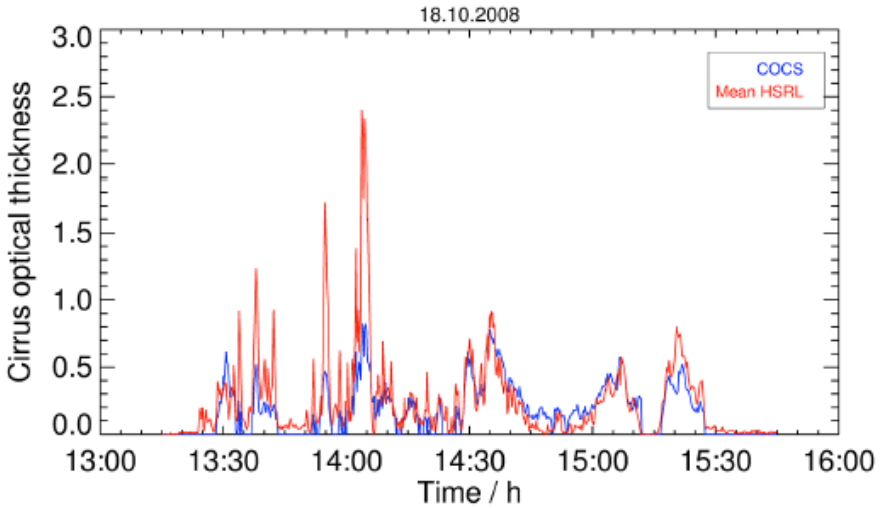
libRadtran

COCS
Cirrus Optical properties derived from CALIOP and SEVIRI during day and night

Based on a **neural network** utilizing the **IR-channels of SEVIRI**
Trained with 8000000 co-incident measurements of CALIOP aboard CALIPSO

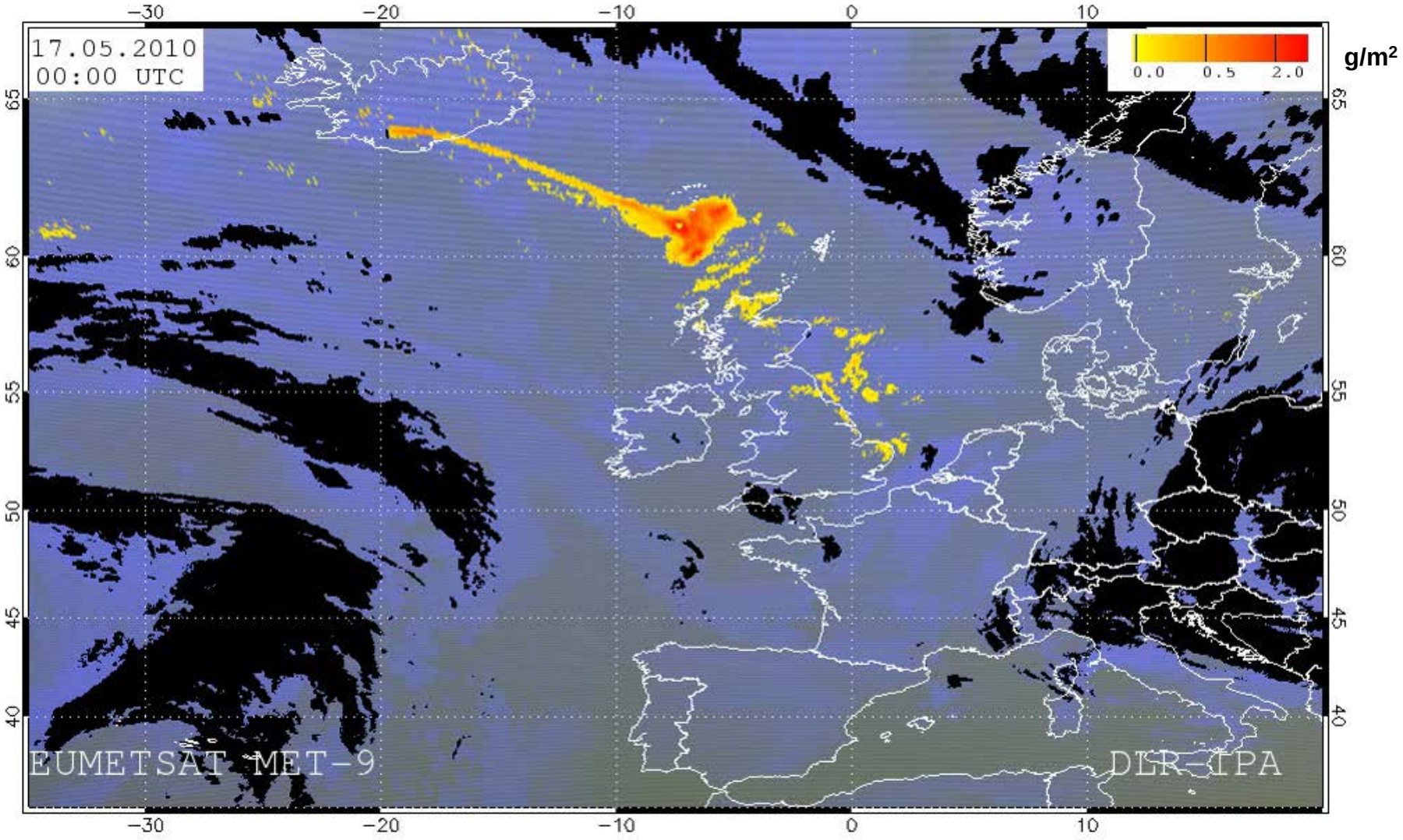
→ Cirrus **ice optical thickness**, **top altitude**, and **ice water path** (under development) in the current version.



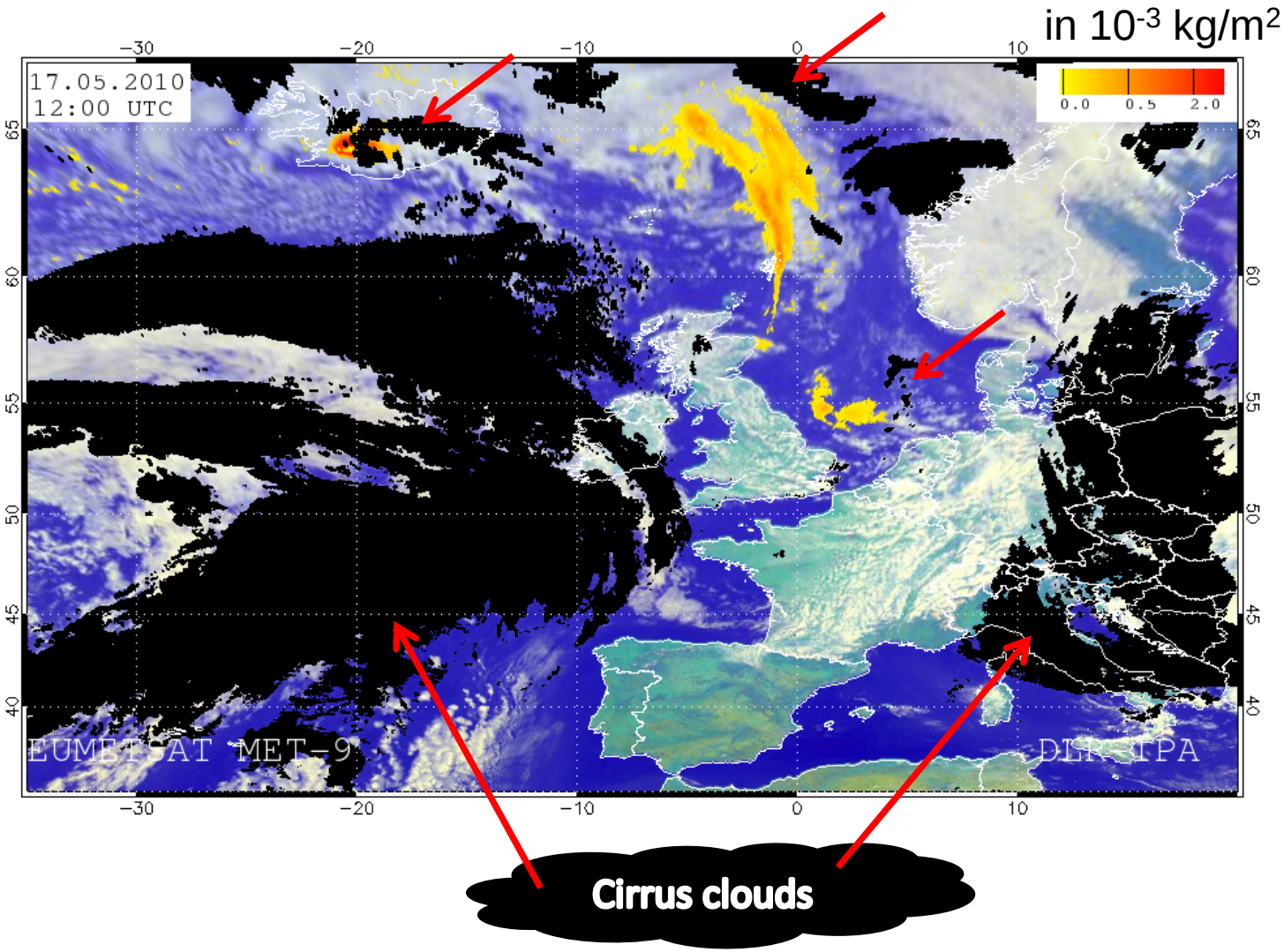


Kox et al, AMT, 2014

VADUGS + COCS on 17th May 2010

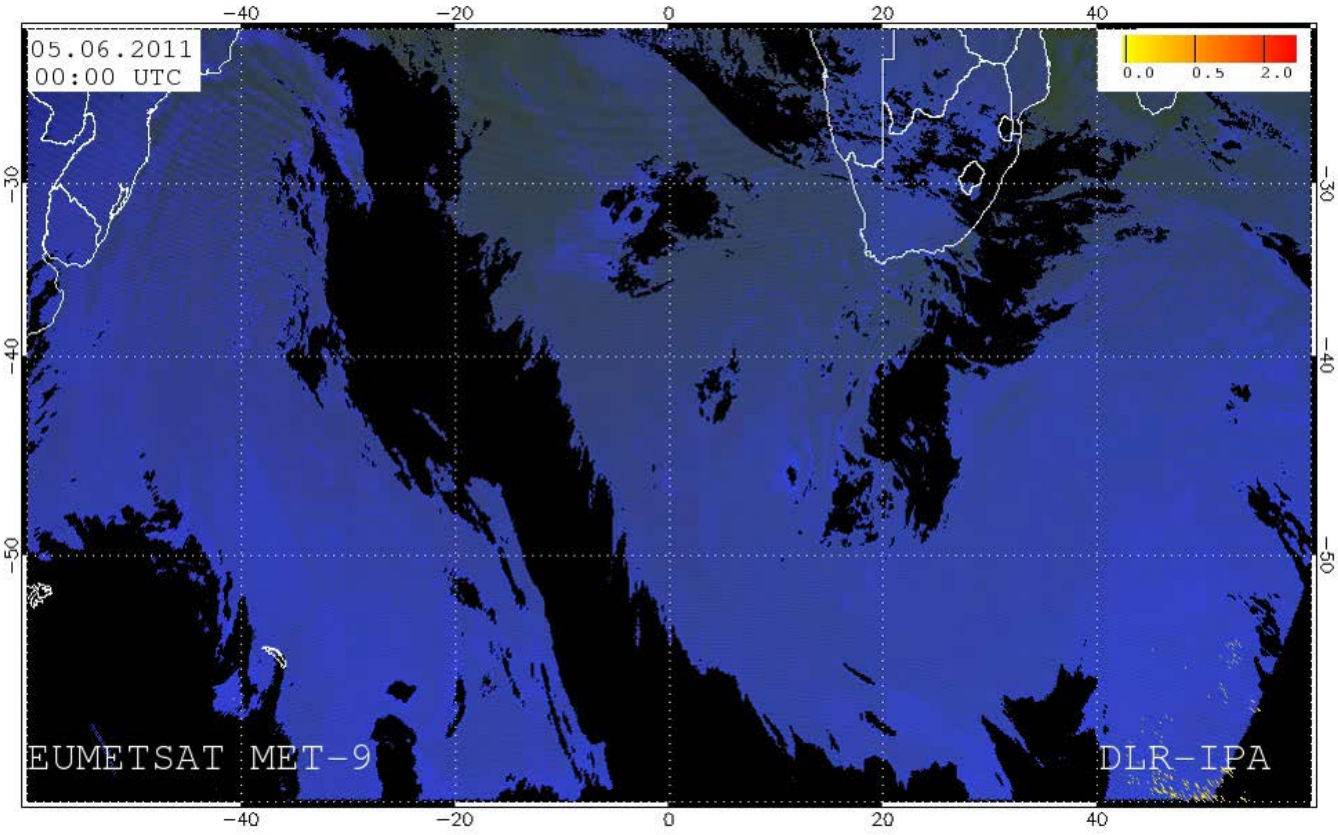


VADUGS + COCS on 17th May 2010



VADUGS + COCS on June 2011

Puyehue eruption



in g/m²

Conclusions and Outlook

- VADUGS is based on a NN utilizing the infrared measurements of SEVIRI‘s IR channels
- Trained by radiative transfer calculations with several different „definitions of ash“, (E15, Andesite, Andesite mix, Rhyolite mix)

- The performance with respect to ash load looks promising; however, quality of top altitude is poorly in some cases

- Low run-time of less than 600 s on a common desktop

Next steps:

- Further training (change in spatial sampling → better representation of higher latitudes)
- Temperature profiles from ECMWF -> this should enhance the quality of ash top altitude retrieval

- Validation of VADUGS and publication

Thank you for your attention

Questions?

Contacts: Kaspar.Graf@dlr.de

Bekanntmachung
der Allgemeinverfügung des
Bundesministeriums für Verkehr, Bau und Stadtentwicklung
über Regelungen für die Durchführung von Flügen in mit Vulkanaerosol (Vulkanasche) kontaminierten Lufträumen

Vom 23.05.2011

A l l g e m e i n v e r f ü g u n g

2. Mit Vulkanasche mäßig oder stark kontaminierte Lufträume

Für Lufträume, die nach SIGMET und NOTAM mäßig oder stark mit Vulkanasche kontaminiert sind, gilt:

2.1 Flüge in mit Vulkanasche gemäß SIGMET und NOTAM mäßig oder stark kontaminierten Lufträumen sind verboten.

2.2 Von dieser Allgemeinverfügung sind folgende Flüge ausgenommen:

- Flüge, bei denen der Luftfahrzeugführer eine Notlage erklärt oder bei denen eine Notlage offensichtlich ist,
- Schutzflüge der Luftverteidigung,
- Flüge von Streitkräften und Polizei,
- Flüge im Such- und Rettungseinsatz,
- Flüge mit kranken oder verletzten Personen, die sofortiger Hilfe bedürfen, einschließlich der Flüge, die zur lebenserhaltenden ärztlichen Versorgung von Kranken oder Verletzten dringend erforderlich sind,
- Flüge für die Erforschung und Messung der Kontamination mit Vulkanasche nach Beauftragung durch das BMVBS,
- Flüge von Luftfahrzeugen mit Kolbenmotoren,
- Flüge von Luftfahrzeugen ohne Motorantrieb und
- Flüge von turbinengetriebenen Luftfahrzeugen in mit Vulkanasche mäßig kontaminierten Lufträumen nach einer Risikobewertung des Luftfahrtunternehmens, welche vom jeweiligen Triebwerkshersteller mitgetragen wird und vom Luftfahrt-Bundesamt als ausreichend anerkannt wurde.