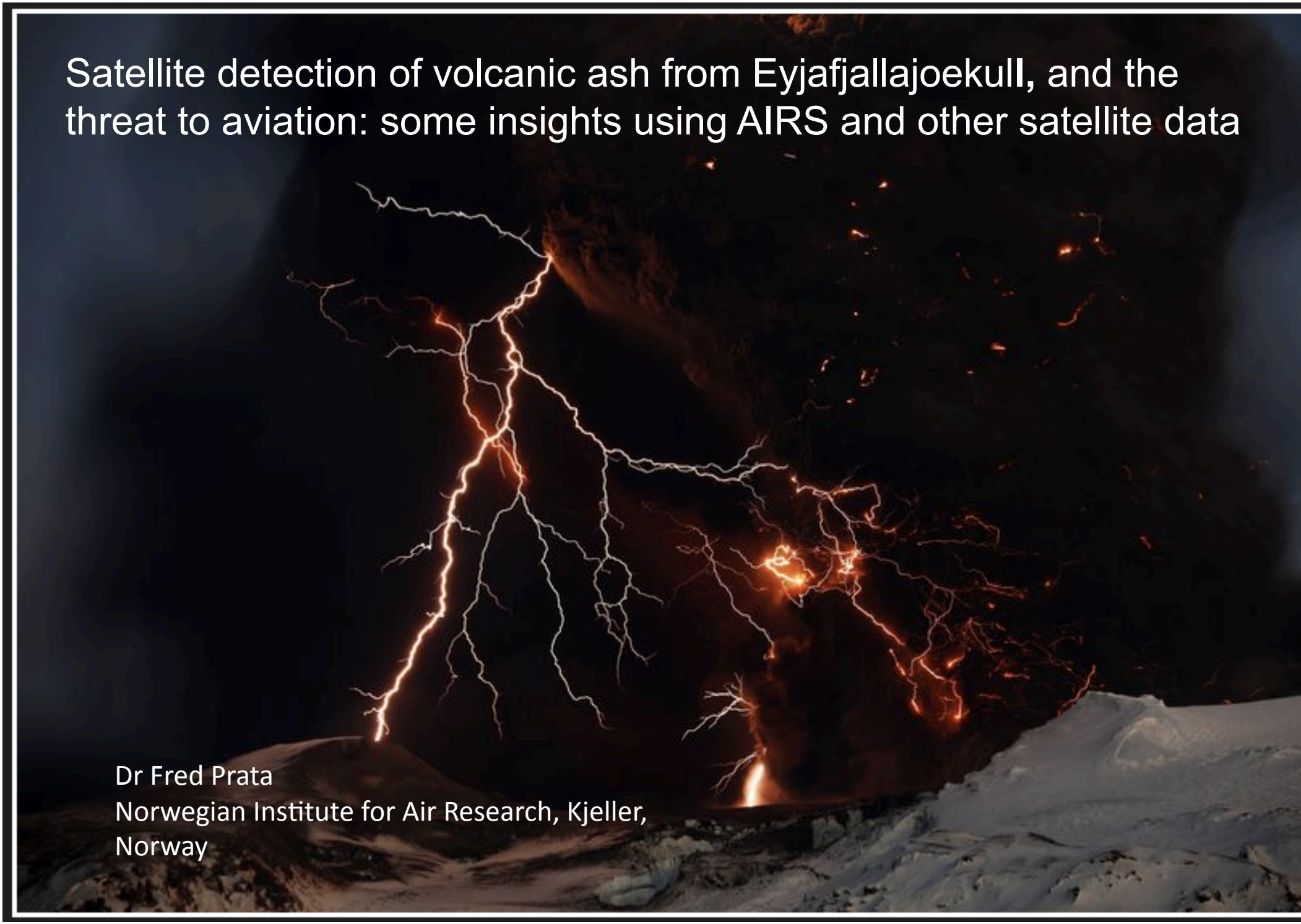
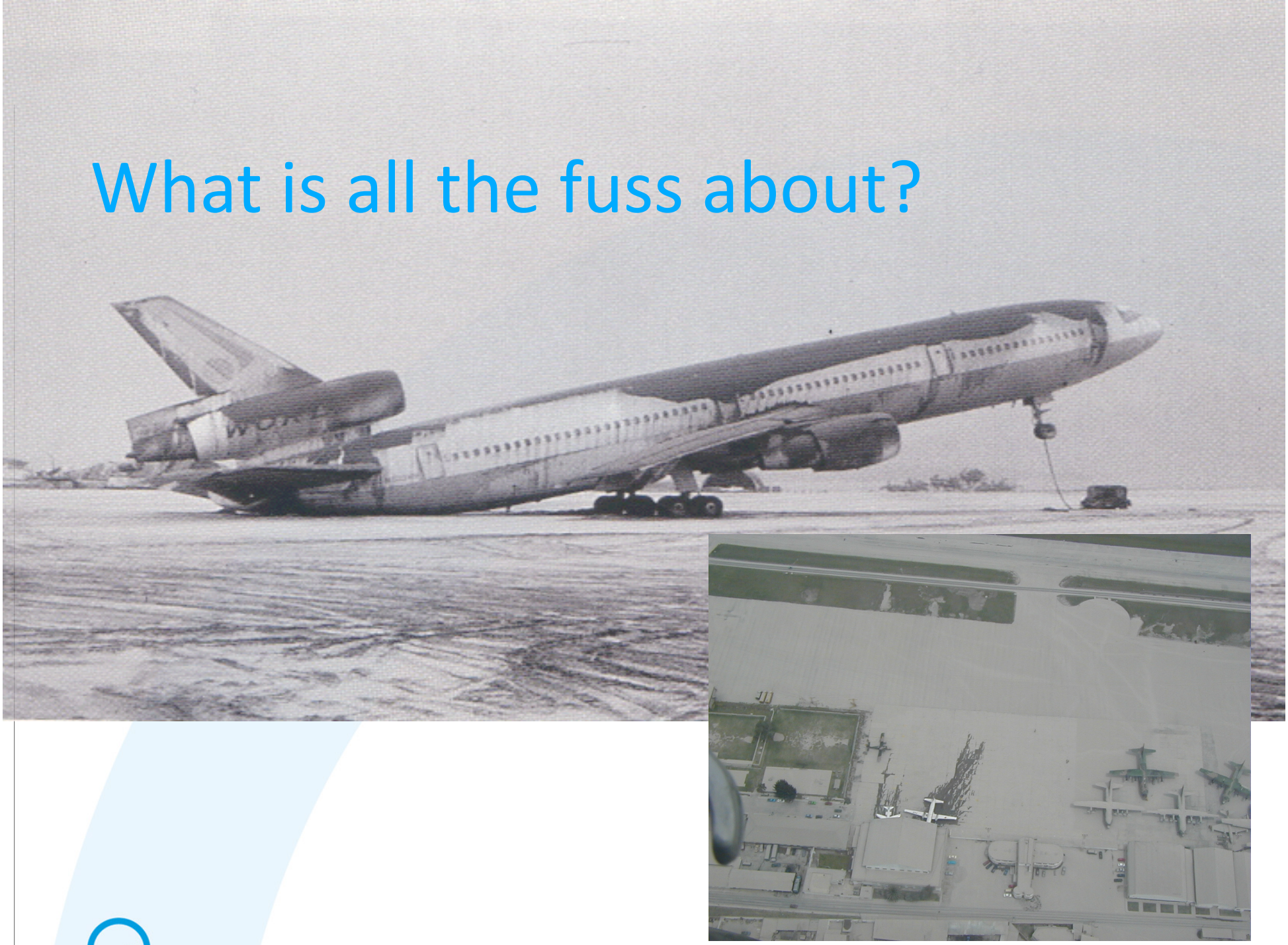
Satellite detection of volcanic ash from Eyjafjallajoekull, and the threat to aviation: some insights using AIRS and other satellite data



Dr Fred Prata
Norwegian Institute for Air Research, Kjeller, Norway

What is all the fuss about?



Nat Hazards
DOI 10.1007/s11069-008-9273-z

ORIGINAL PAPER

Satellite detection of hazardous volcanic clouds and the risk to global air traffic

A. J. Prata

Received: 9 February 2008 / Accepted: 13 June 2008
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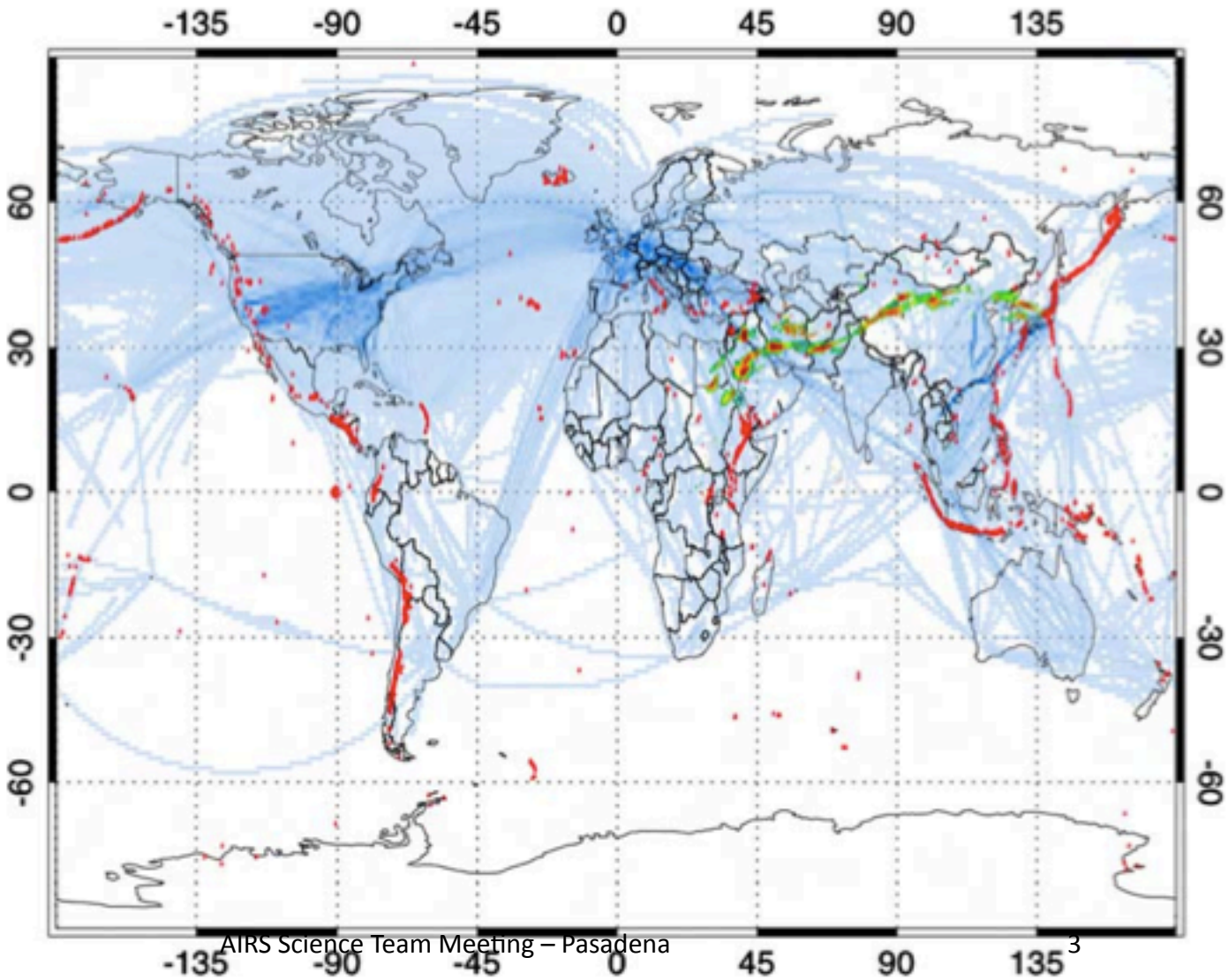


Iceland and Volcanic Ash

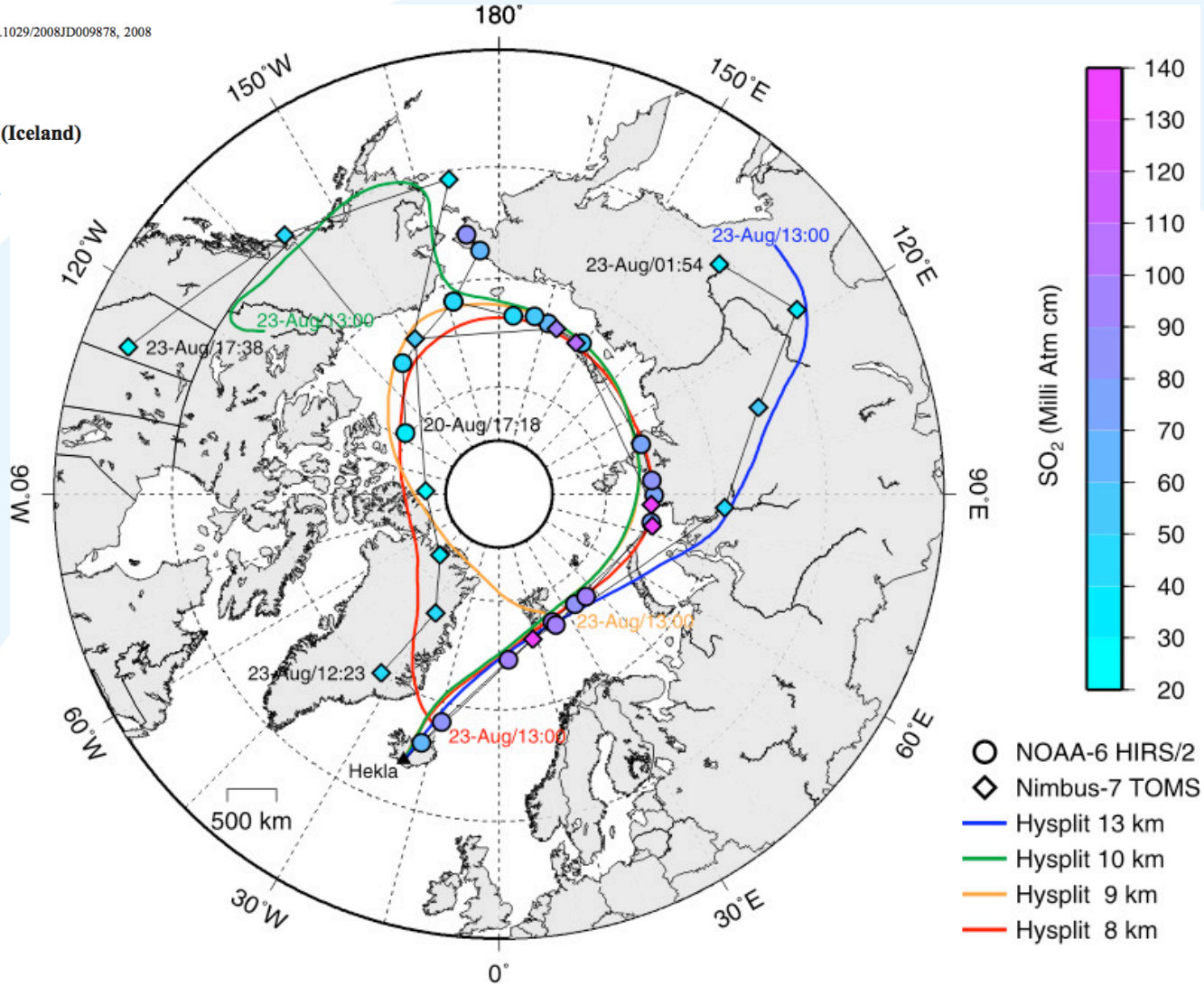
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D14311, doi:10.1029/2008JD009878, 2008

Click Here for Full Article

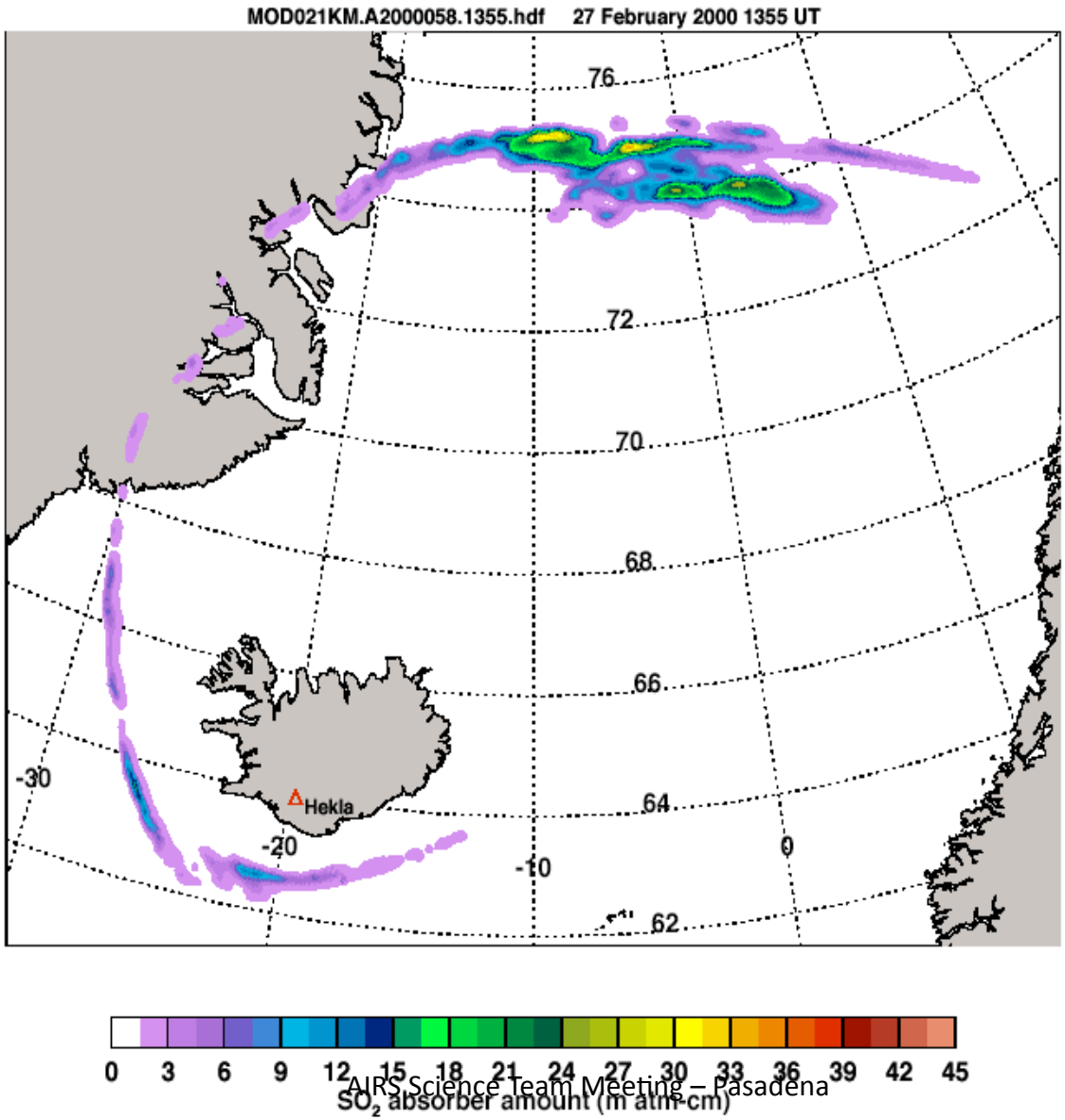
Circumpolar transport of a volcanic cloud from Hekla (Iceland)

S. A. Carn,[1] A. J. Prata,[2] and S. Karlsdóttir[3]

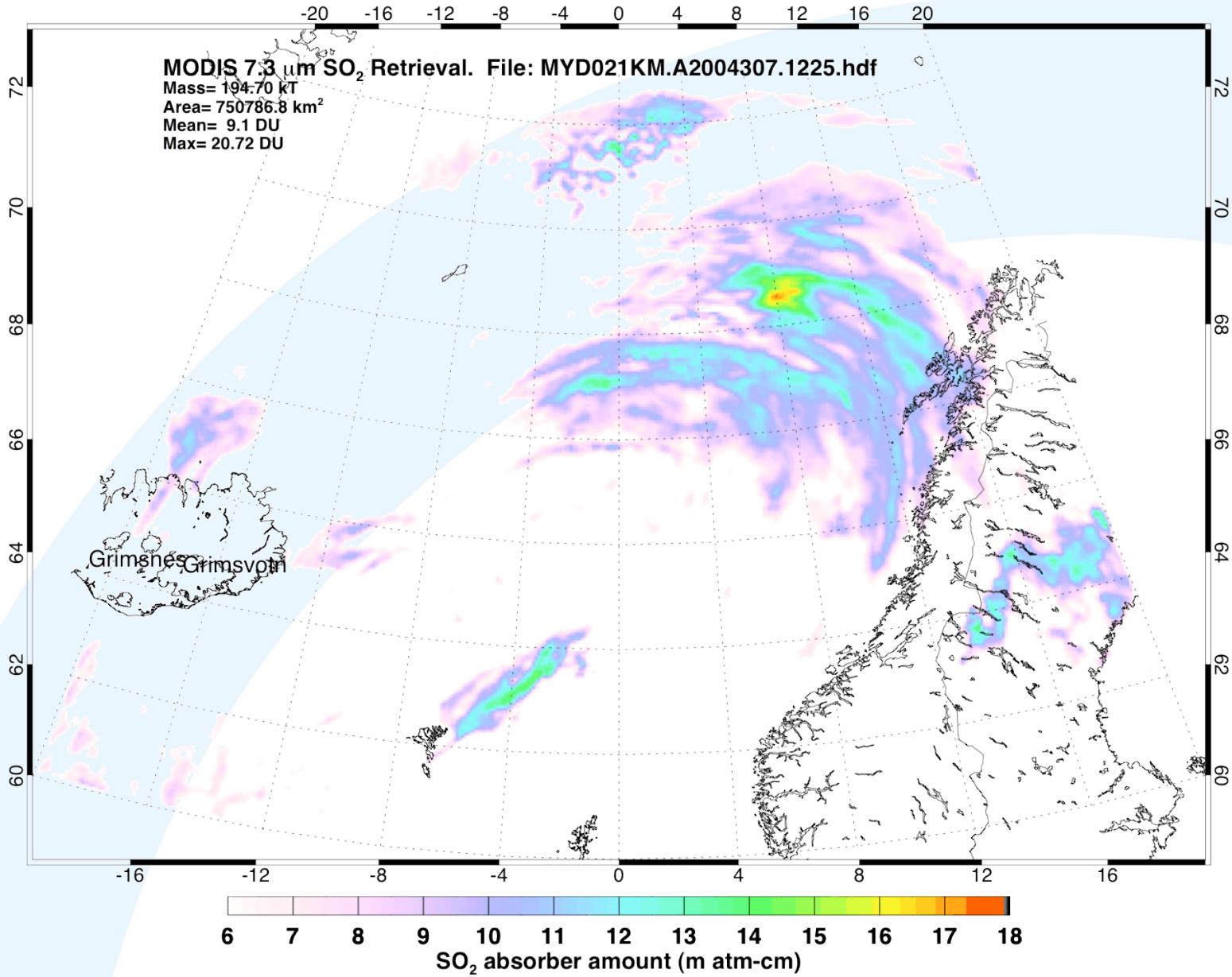
Received 28 January 2008; revised 26 March 2008; accepted 31 March 2008; published 31 July 2008.



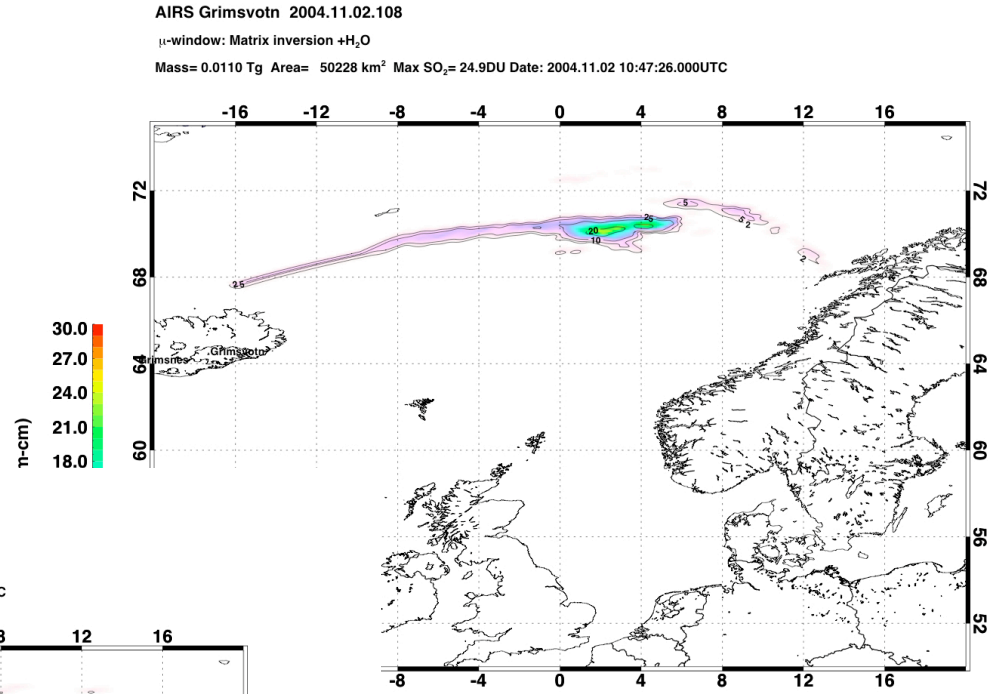
Iceland and Volcanic Ash

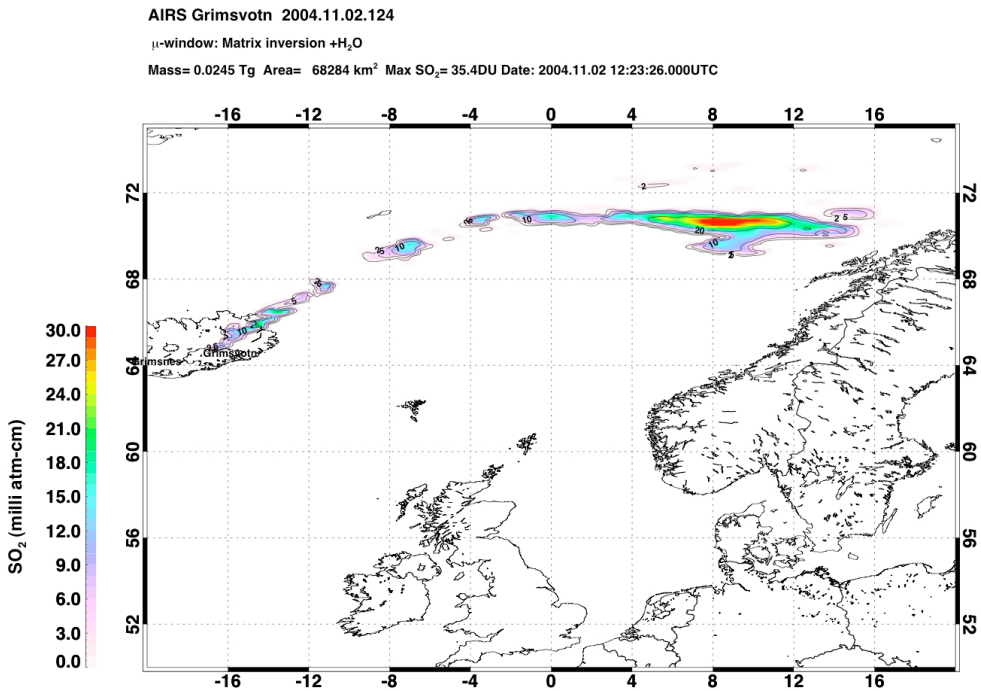


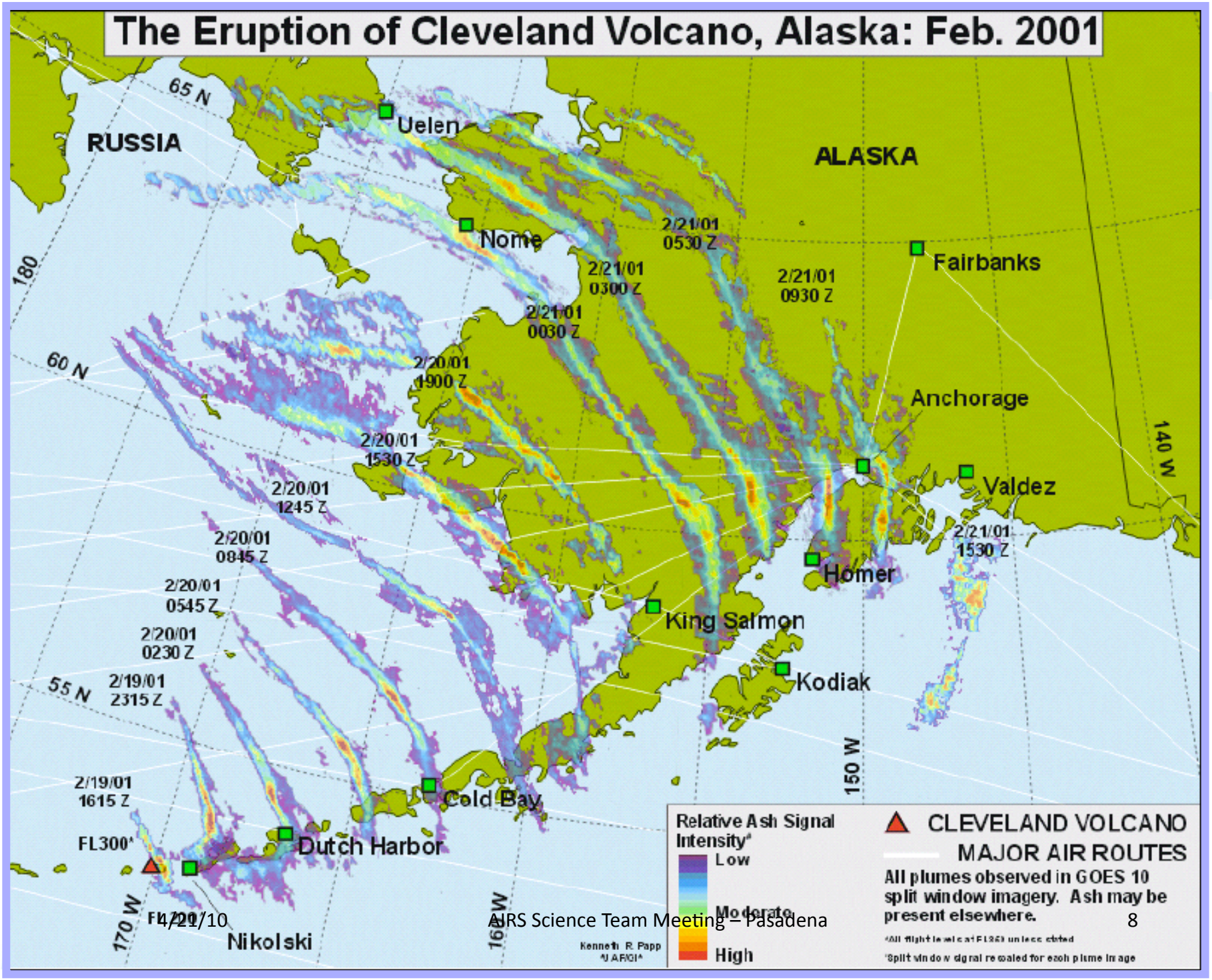
Grimsvotn – 2004



AIRS


AIRS Grimsvotn 2004.11.02.108
μ-window: Matrix inversion +H2O
Mass= 0.0110 Tg Area= 50228 km2 Max SO2= 24.9DU Date: 2004.11.02 10:47:26.000UTC
30.0
27.0
24.0
21.0
18.0
Grimsnes
Grimsvotn


AIRS Grimsvotn 2004.11.02.124
μ-window: Matrix inversion +H2O
Mass= 0.0245 Tg Area= 68284 km2 Max SO2= 35.4DU Date: 2004.11.02 12:23:26.000UTC
SO2 (milli atm-cm)
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
Grimsnes
Grimsvotn


The Eruption of Cleveland Volcano, Alaska: Feb. 2001
RUSSIA
ALASKA
65 N
60 N
55 N
180
170 W
160 W
150 W
140 W
Uelen
Nome
Fairbanks
Anchorage
Valdez
Homer
King Salmon
Kodiak
Cold Bay
Dutch Harbor
Nikolski
2/21/01 0530 Z
2/21/01 0300 Z
2/21/01 0930 Z
2/21/01 0030 Z
2/20/01 1900 Z
2/20/01 1530 Z
2/20/01 1245 Z
2/20/01 0845 Z
2/20/01 0545 Z
2/20/01 0230 Z
2/19/01 2315 Z
2/19/01 1615 Z
2/21/01 1530 Z
FL300*
Relative Ash Signal Intensity*
Low
Moderate
High
CLEVELAND VOLCANO
MAJOR AIR ROUTES
All plumes observed in GOES 10 split window imagery. Ash may be present elsewhere.
*Split window signal rescaled for each plume image
Kenneth R. Papp
UAFGI

Some basics …

- On average 1 volcanic eruption per week
- Horizontal spread ~1000's km
- Vertical extent up to ~50,000 ft
- Duration ~hours to ~days
- Most danger 0-3 hours after eruption
- Some danger ~days to ~weeks after eruption
- Cost of re-routing is significant
- Still no reliable warning system
- First warning is usually from pilots

The Volcanic Explosivity Index (VEI)

VEI	Description	Volume (m^3)	Height (km)	Type	Number
0	Non-explosive	10^4	0.1	Hawaiian	699
1	Small	10^6	1	Strombolian	845
2	Moderate	10^7	5	Vulcanian	3477
3	Moderate-large	10^8	15	Vulcanian	869
4	Large	10^9	25	Plinian	278
5	Very large	10^{10}	>25	Ultra-Plinian	84
6		10^{11}	>25	Ultra-Plinian	39
7		10^{12}	>25	Ultra-Plinian	4
8		10^{13}	>25	Ultra-Plinian	1?

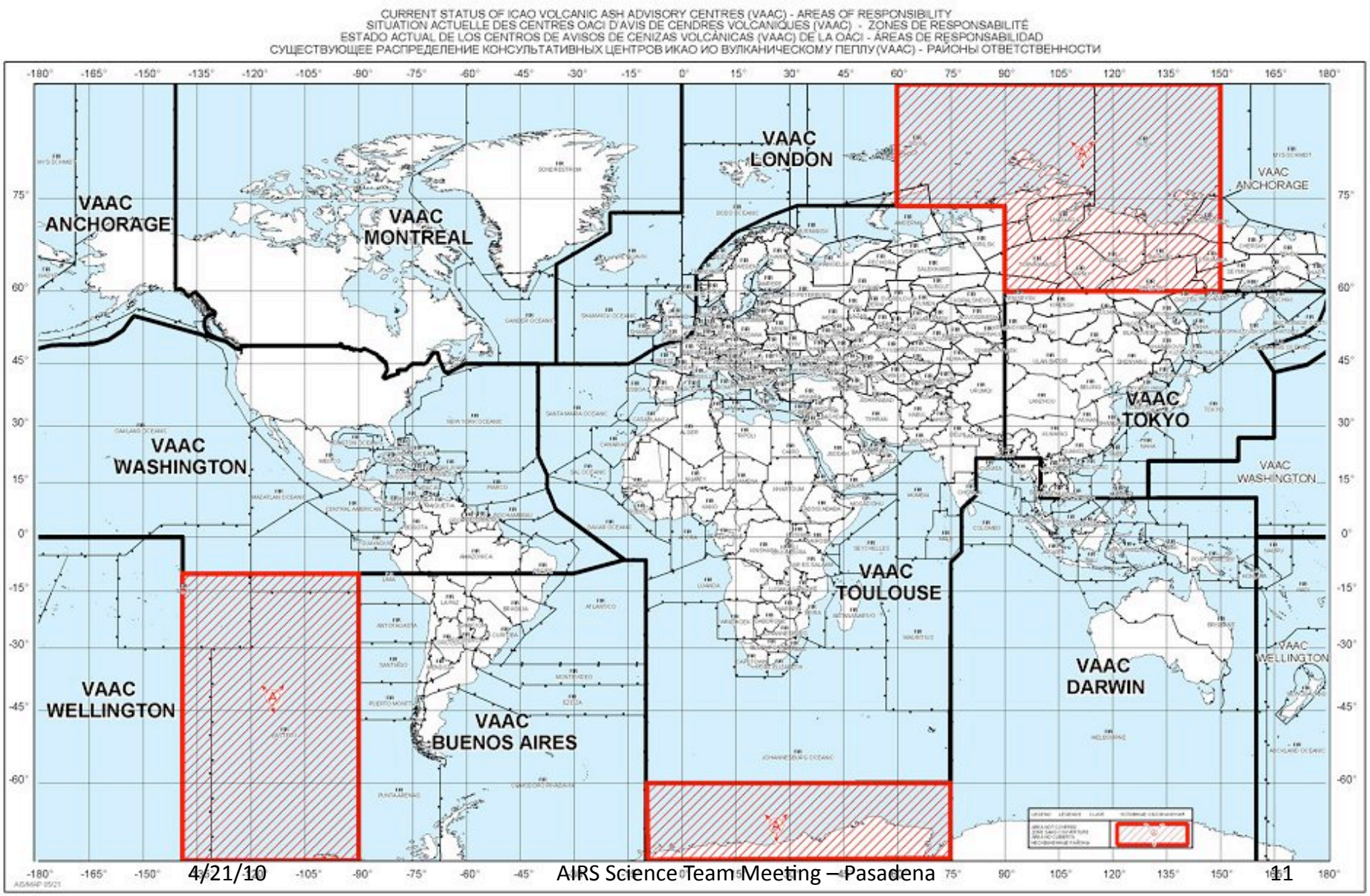
VEI~2 Every 2 weeks

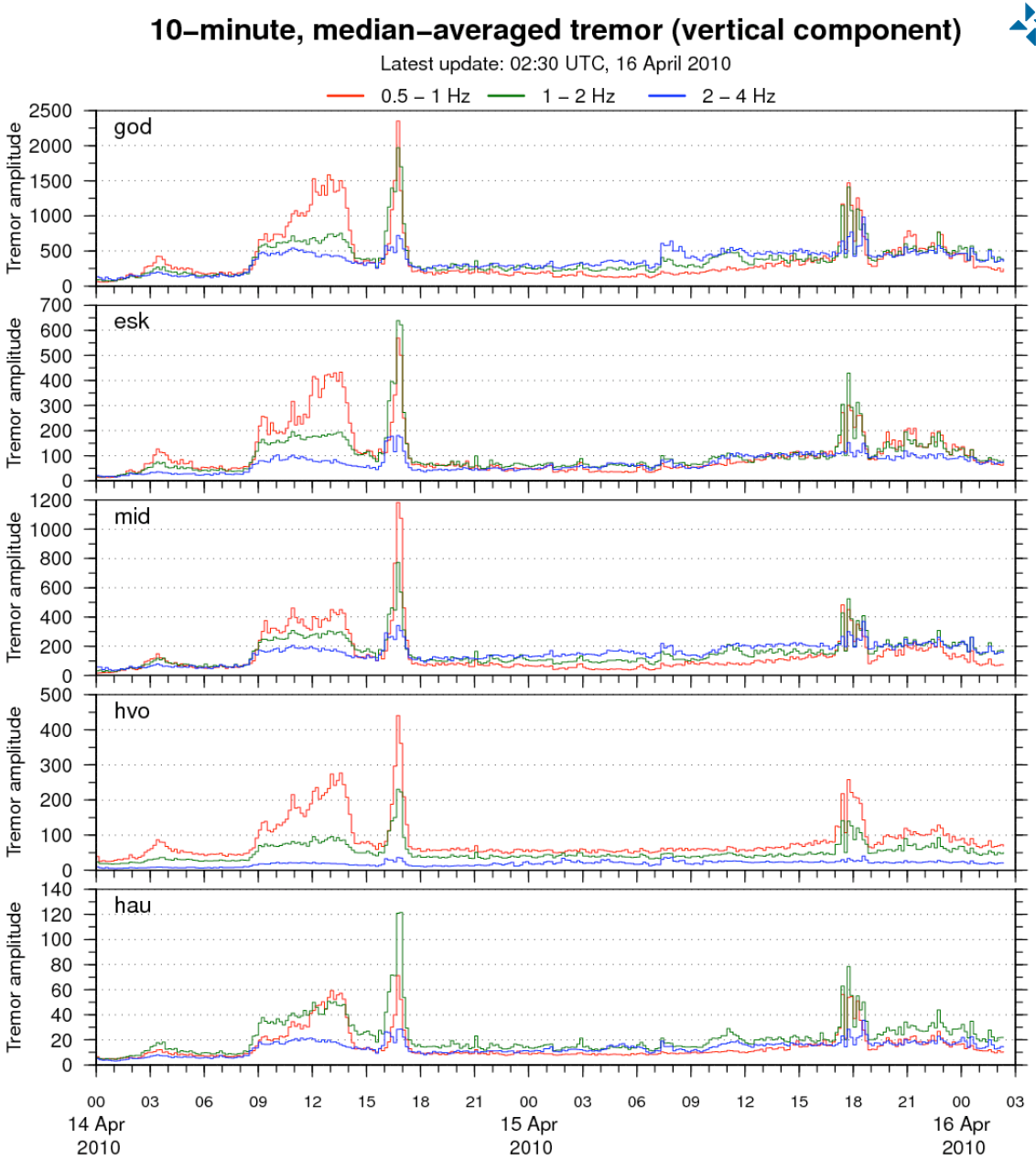
VEI~5 MtStHelens

VEI~6 Krakatau

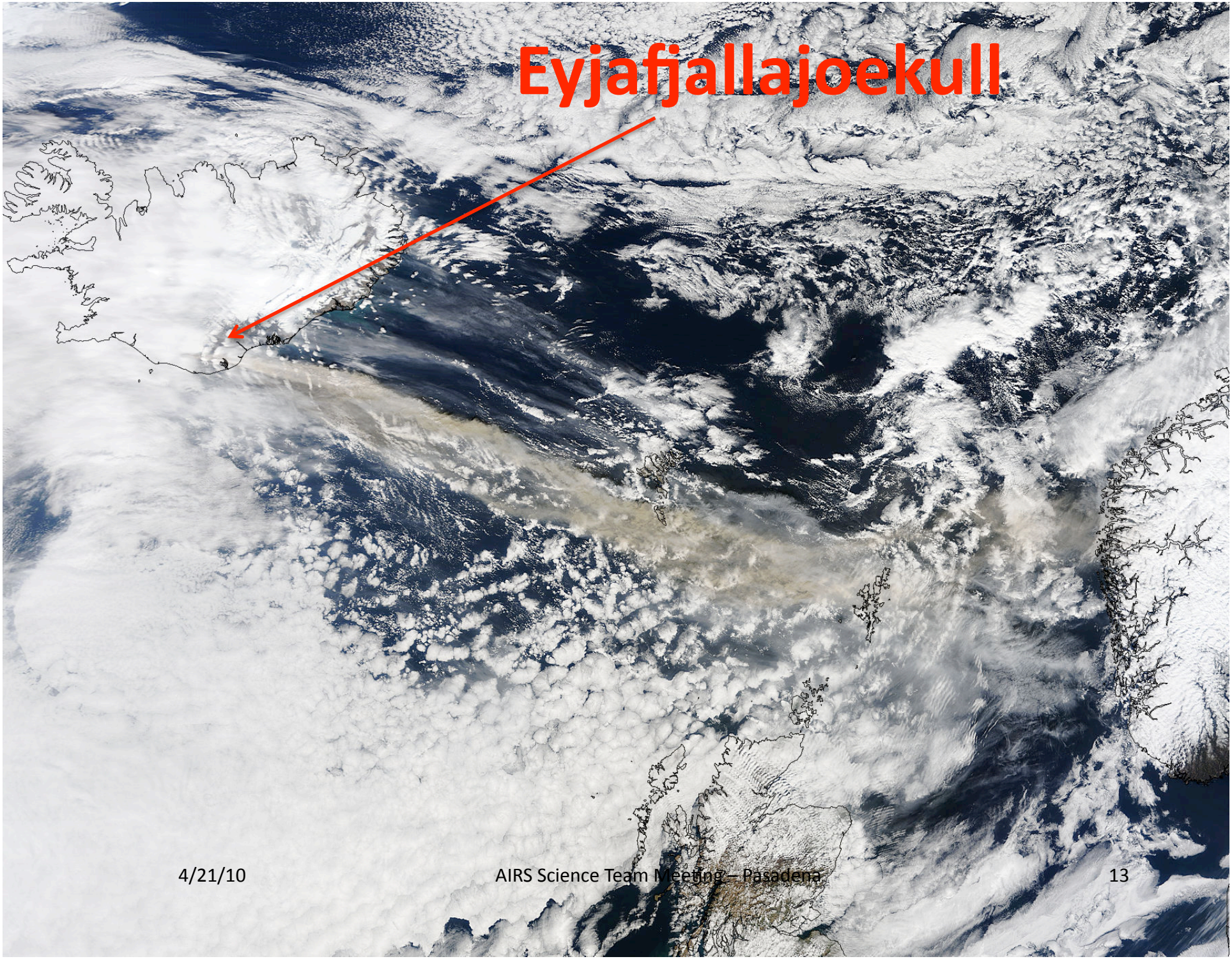
VEI~7 Tambora

VAACs

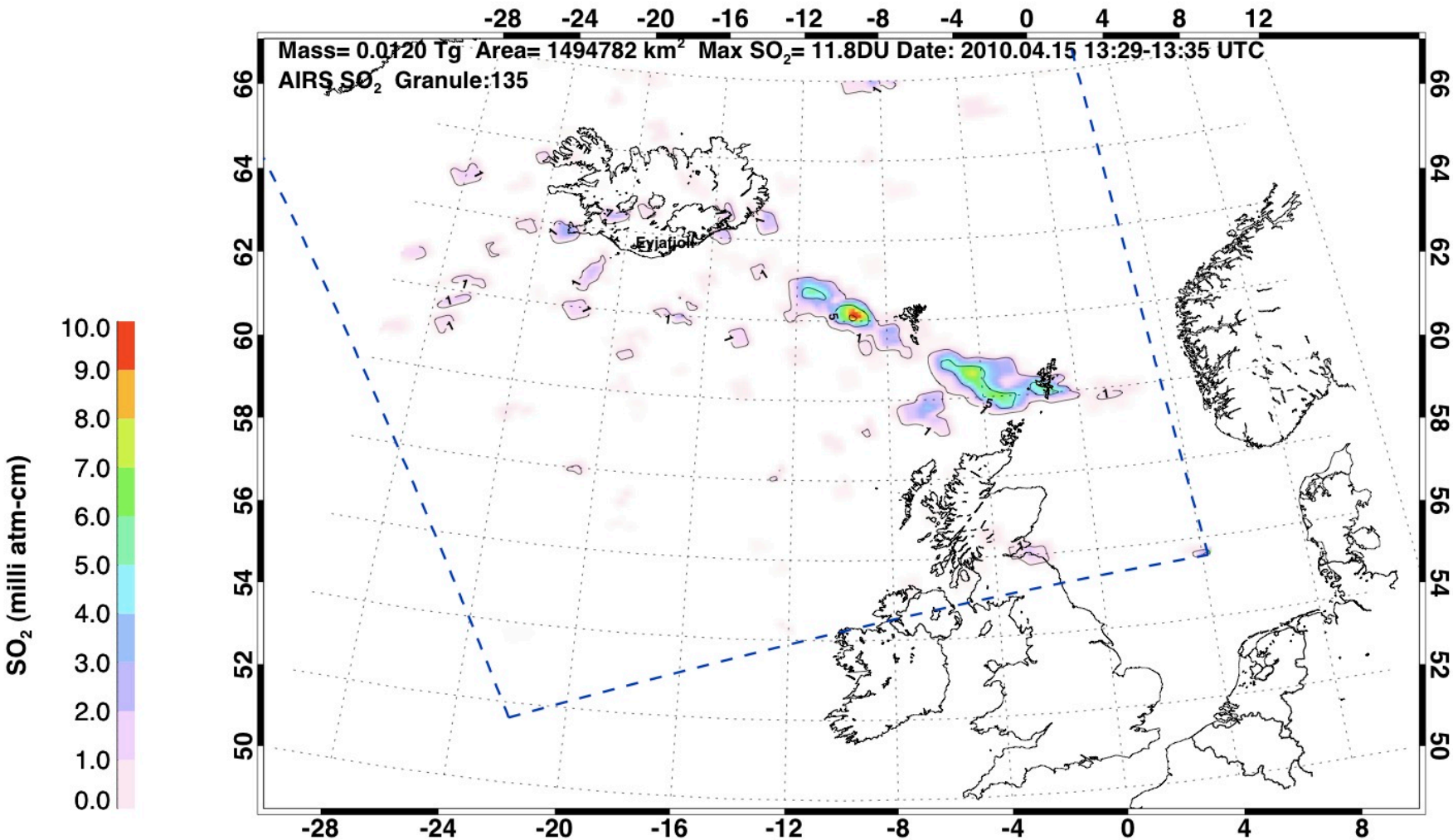

CURRENT STATUS OF ICAO VOLCANIC ASH ADVISORY CENTRES (VAAC) - AREAS OF RESPONSIBILITY
SITUATION ACTUELLE DES CENTRES OACI D'AVIS DE CENDRES VOLCANIQUES (VAAC) - ZONES DE RESPONSABILITÉ
ESTADO ACTUAL DE LOS CENTROS DE AVISOS DE CENIZAS VOLCÁNICAS (VAAC) DE LA OACI - ÁREAS DE RESPONSABILIDAD
СУЩЕСТВУЮЩЕЕ РАСПРЕДЕЛЕНИЕ КОНСУЛЬТАТИВНЫХ ЦЕНТРОВ ИКАО ИО ВУЛКАНИЧЕСКОМУ ПЕПЛУ (VAAC) - РАЙОНЫ ОТВЕТСТВЕННОСТИ
VAAC ANCHORAGE
VAAC MONTREAL
VAAC LONDON
VAAC ANCHORAGE
VAAC WASHINGTON
VAAC TOKYO
VAAC WASHINGTON
VAAC TOULOUSE
VAAC WELLINGTON
VAAC BUENOS AIRES
VAAC DARWIN
VAAC WELLINGTON



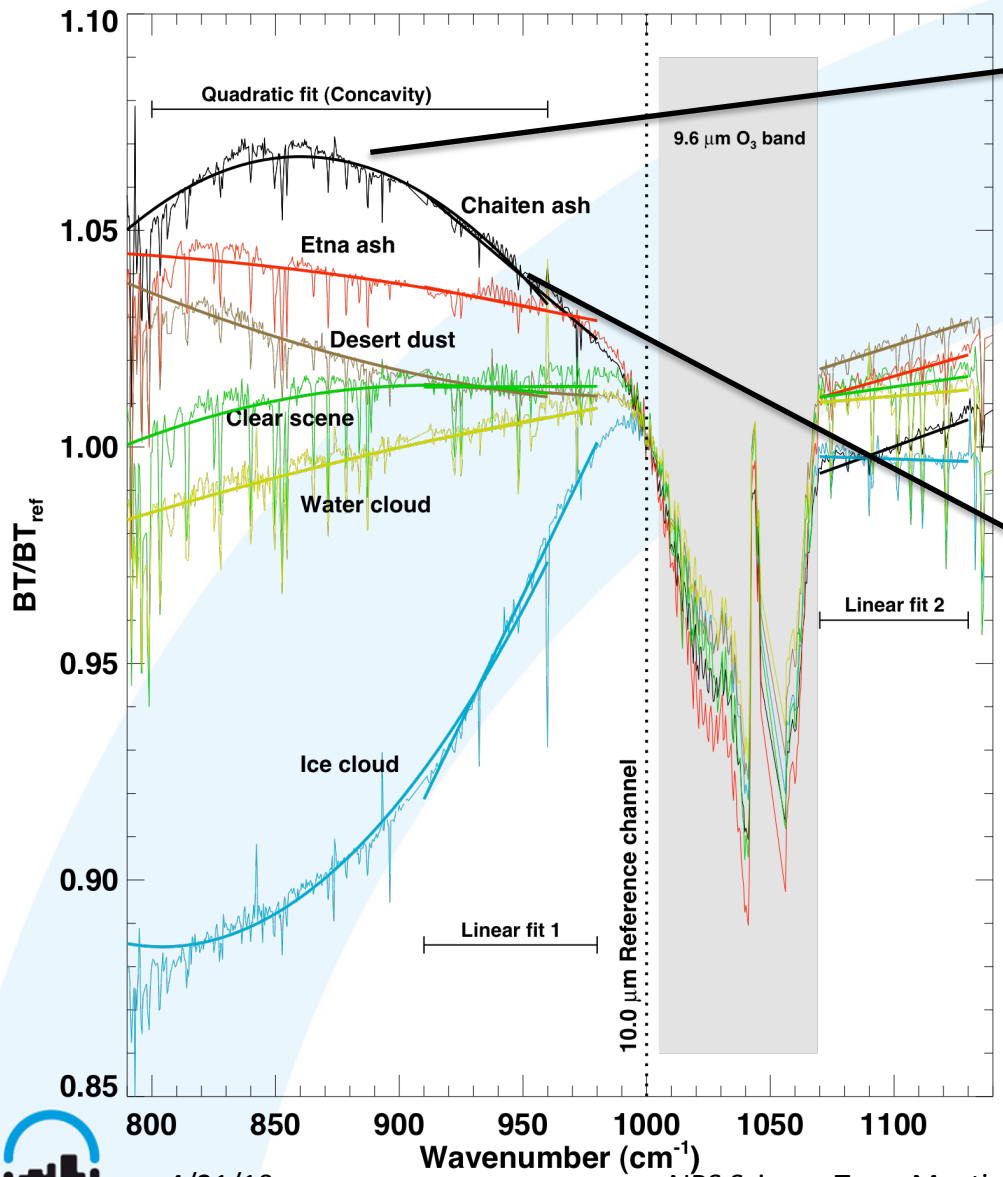
The start of the eruption …

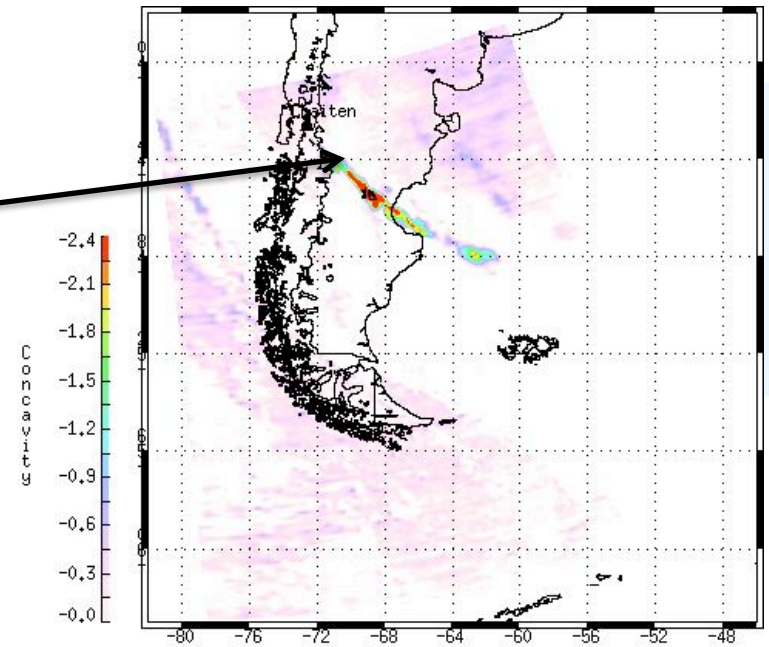

Eyjafjallajoekull

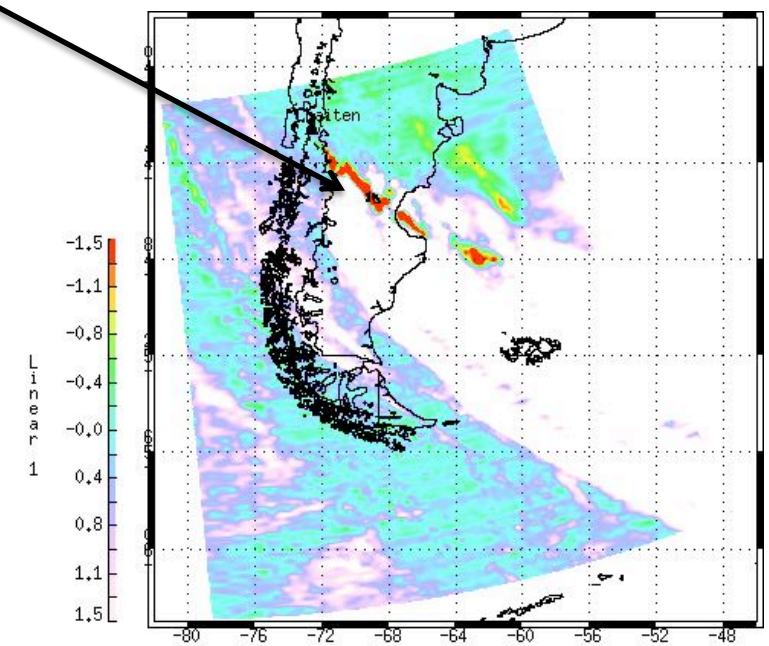
AIRS SO_2 (7.3 µm)

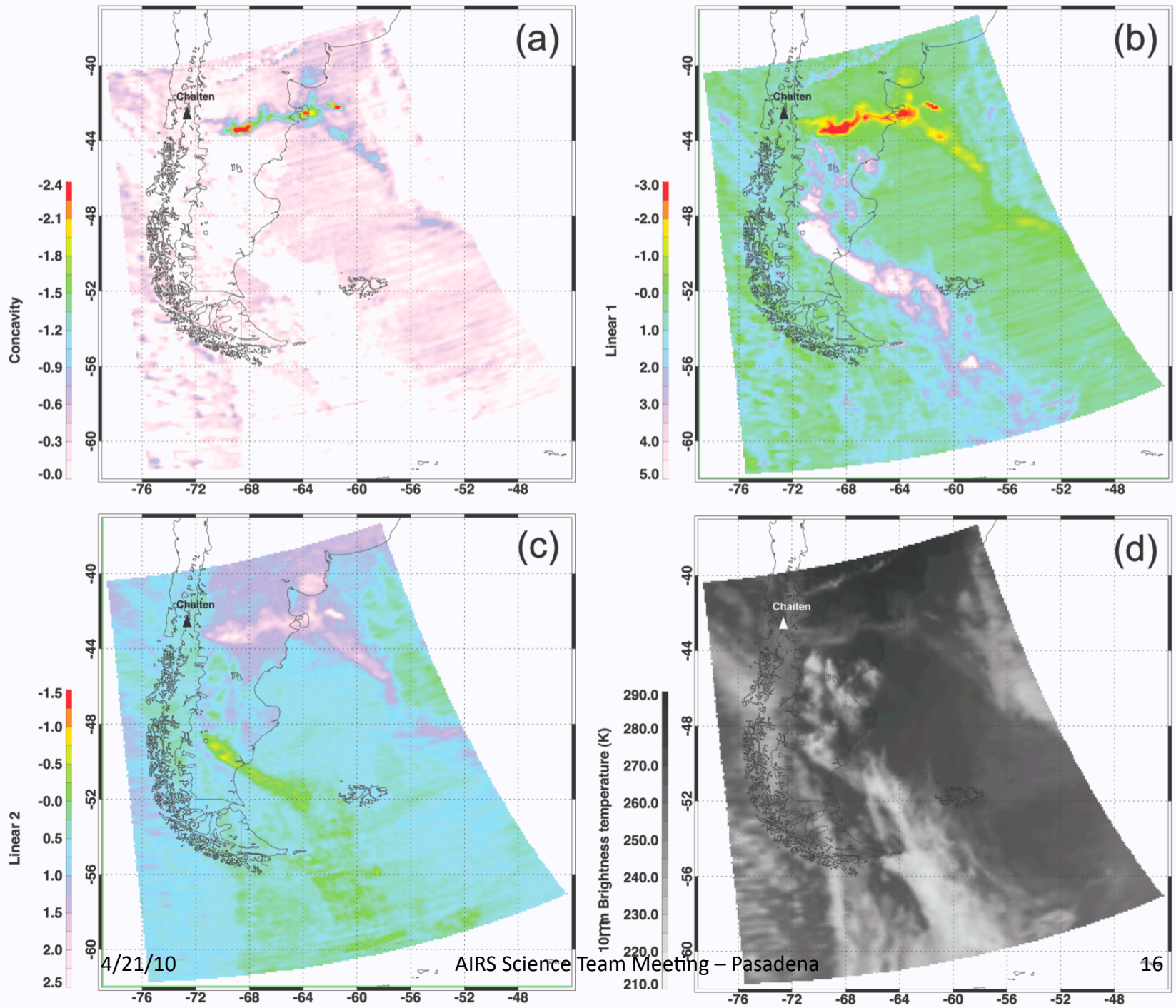


Spectral Signatures



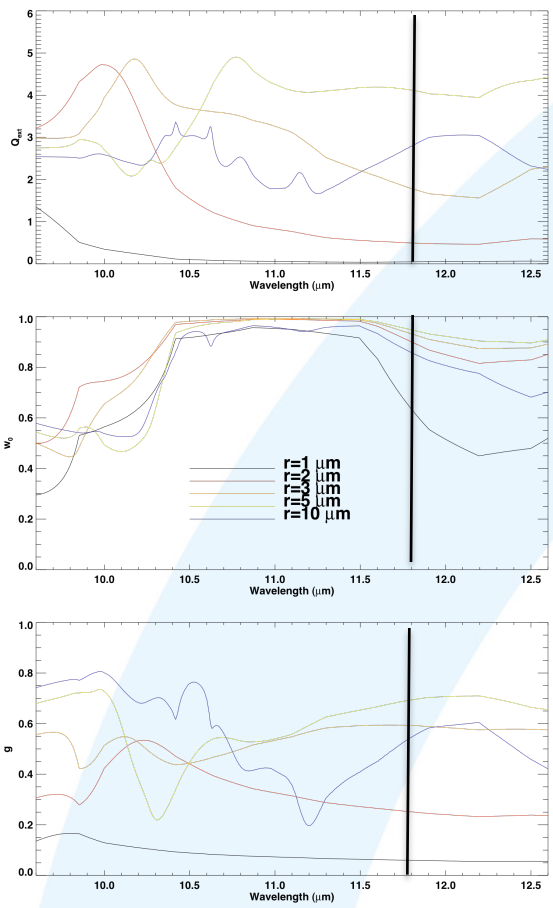


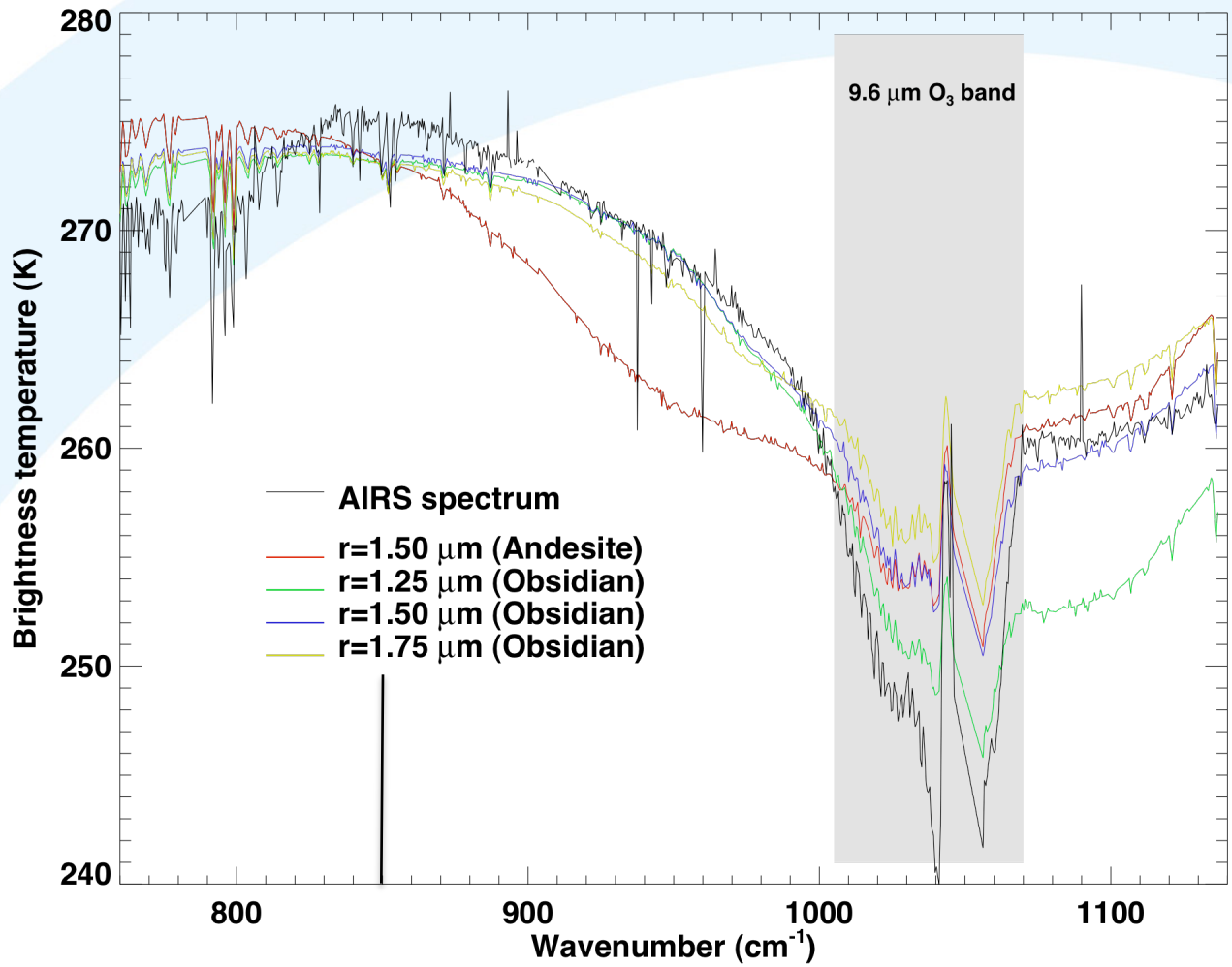



(a)
Chaiten
Concavity
-2.4
-2.1
-1.8
-1.5
-1.2
-0.9
-0.6
-0.3
-0.0
(b)
Chaiten
Linear 1
-3.0
-2.0
-1.0
-0.0
1.0
2.0
3.0
4.0
5.0
(c)
Chaiten
Linear 2
-1.5
-1.0
-0.5
-0.0
0.5
1.0
1.5
2.0
2.5
(d)
Chaiten
10μm Brightness temperature (K)
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
-40
-44
-48
-52
-56
-60
-76
-72
-68
-64
-60
-56
-52
-48

Microphysics retrieval

r_e– effective particle radius
t–infrared optical depth
M–mass loading
Si–silicate composition

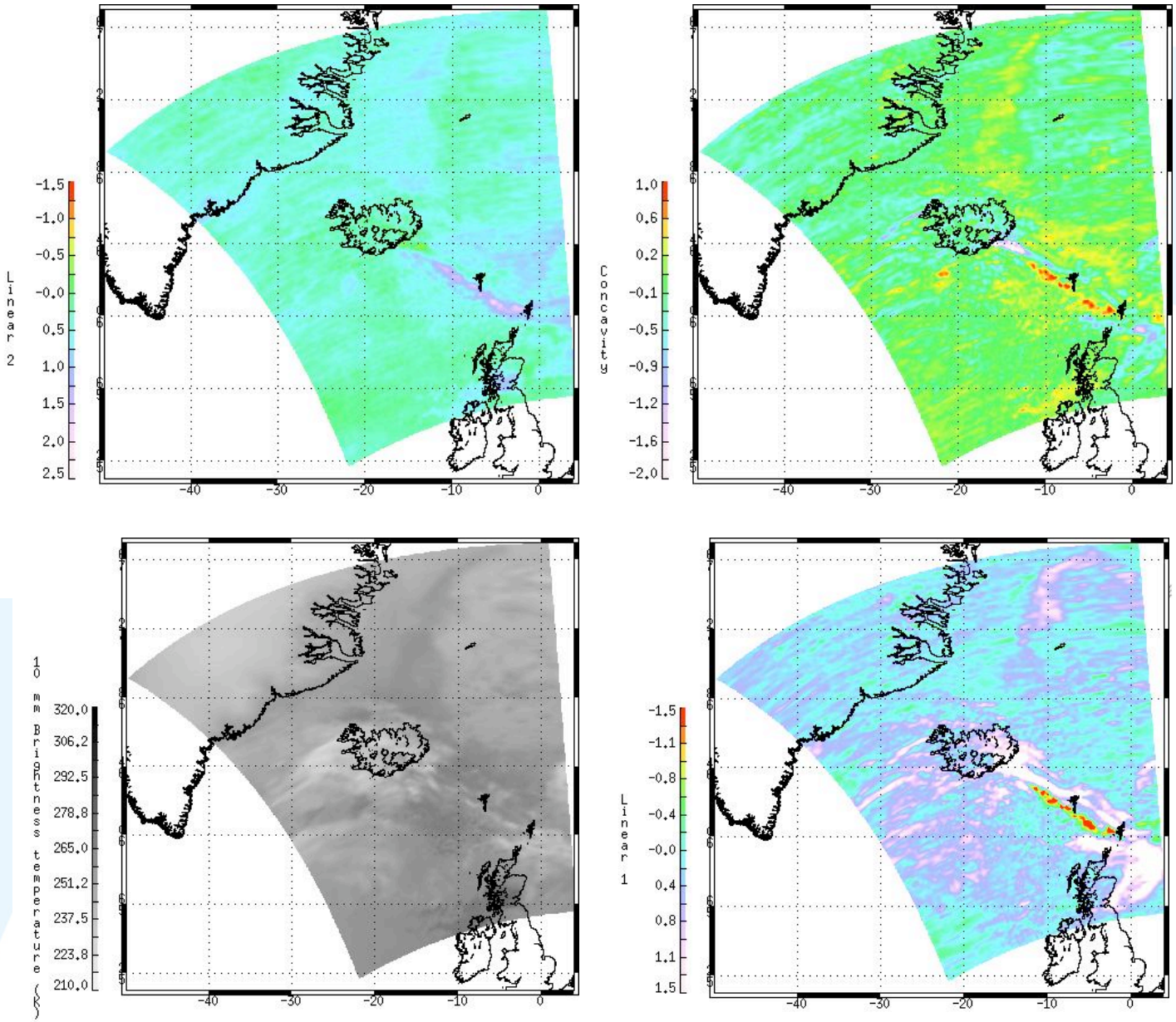


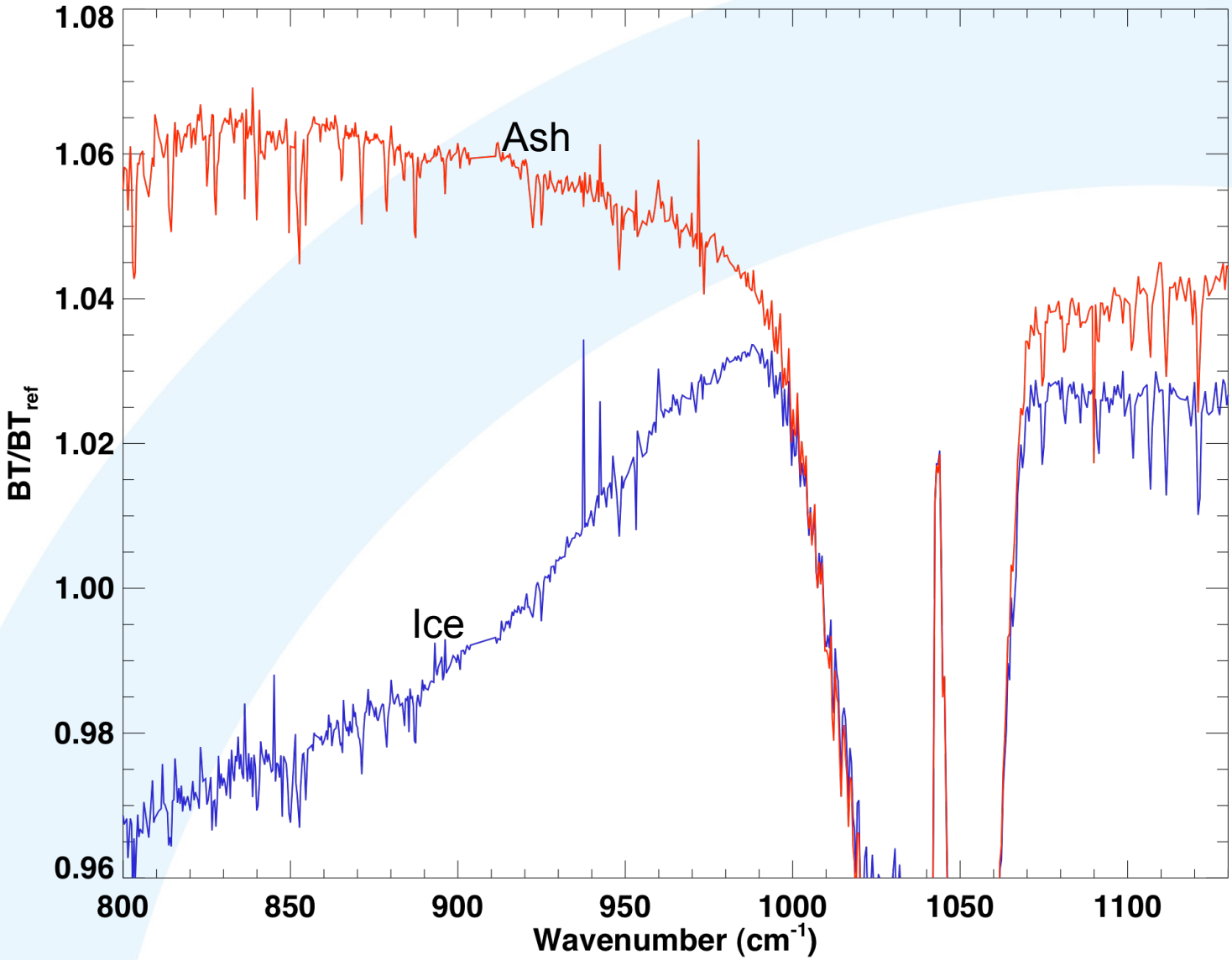


AIRS

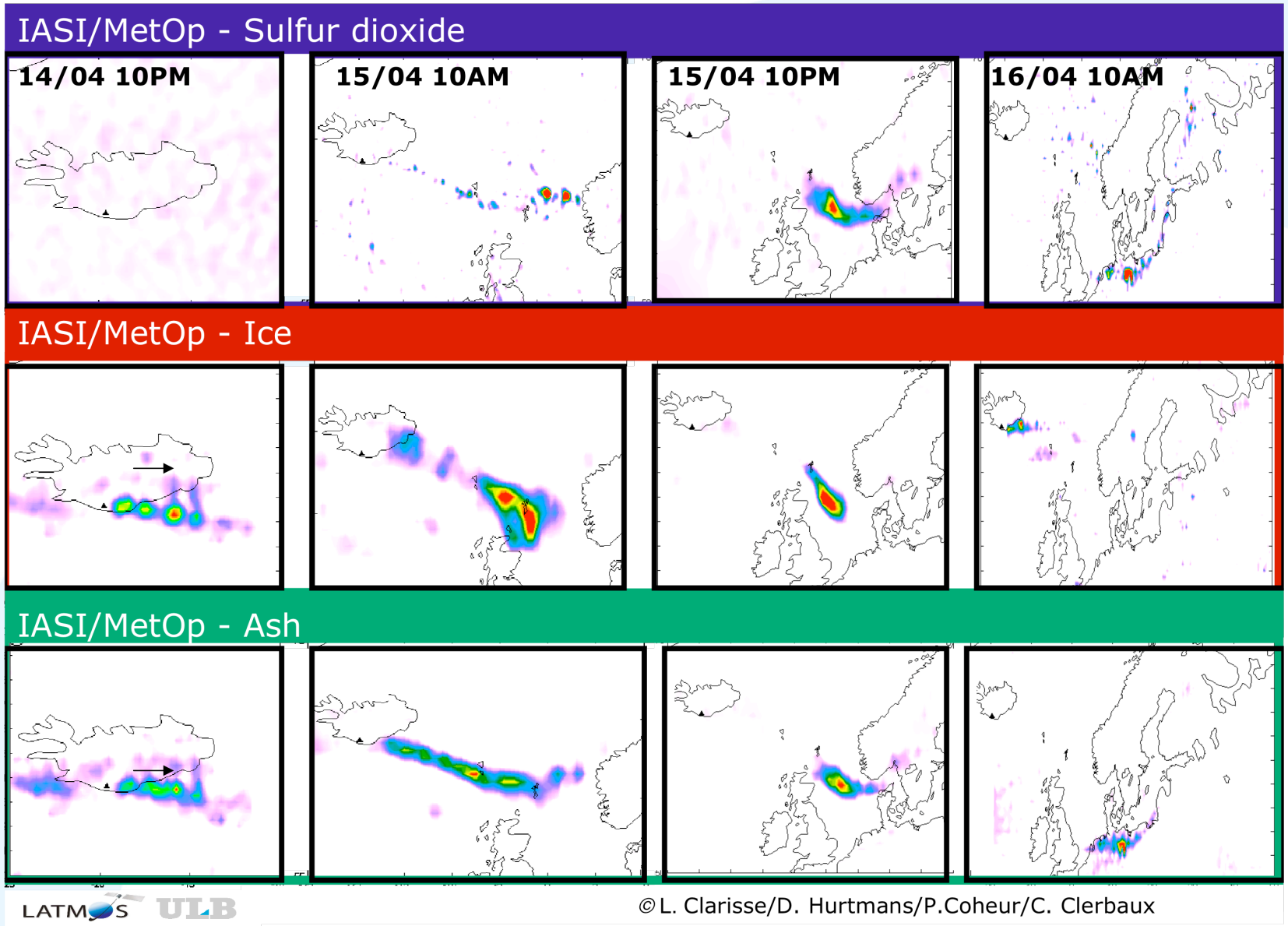
15.04.2010

Granule: 135




1.08
1.06
1.04
1.02
1.00
0.98
0.96
BT/BT$_{ref}$
Ash
Ice
800
850
900
950
1000
1050
1100
Wavenumber (cm^{-1})

IASI



LATMOS ULB

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Retrieving radius, concentration, optical depth and mass of different types of aerosols from high resolution infrared nadir spectra

L. Clarisse,[1,*], D. Hurtmans[1], A.J. Prata[2], F. Karagulian[1], C. Clerbaux[3,1], M. De Mazière[4] and P.-F. Coheur[1]

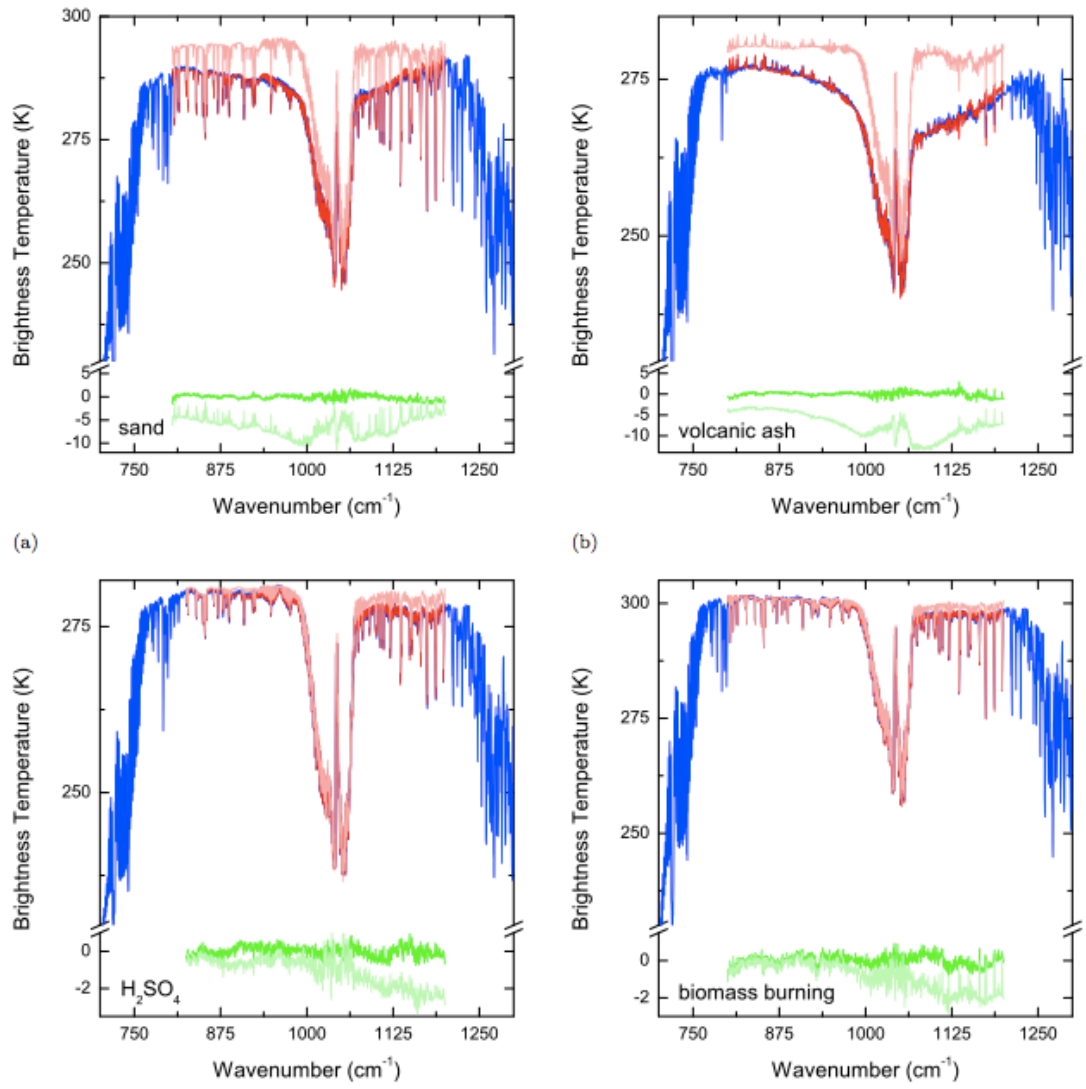
[1] *Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles (U.L.B.), Brussels, Belgium.*

[2] *Climate and Atmosphere Department, Norwegian Institute for Air Research, PO Box 100, 2027 Kjeller, Norway.*

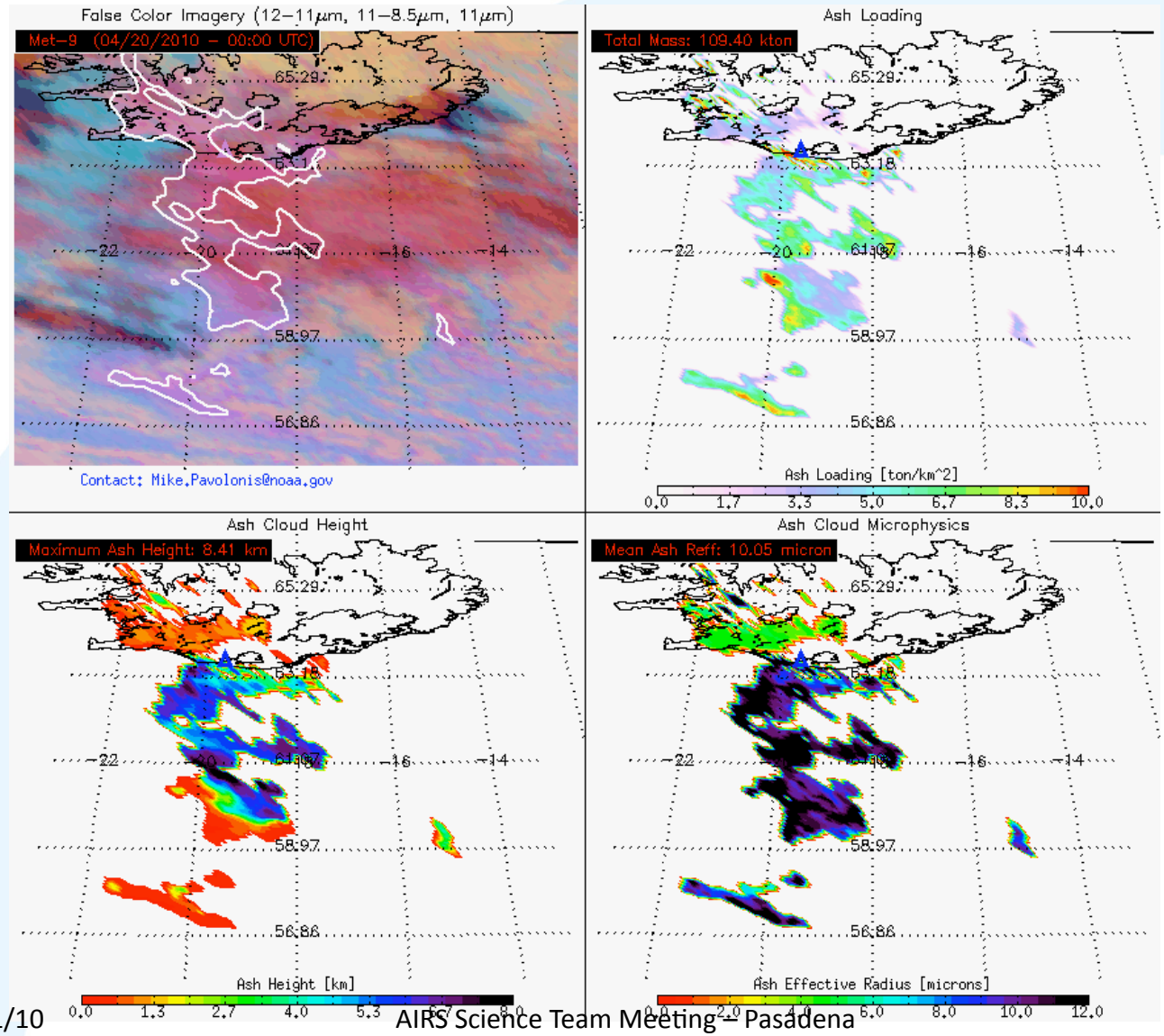
[3] *UPMC Univ. Paris 06 ; Universit Versailles St.-Quentin ; CNRS/INSU, LATMOS-IPSL, Paris, France.*

[4] *Belgian Institute for Space Aeronomy, 3 av. Circulaire, B-1180 Brussels, Belgium.*

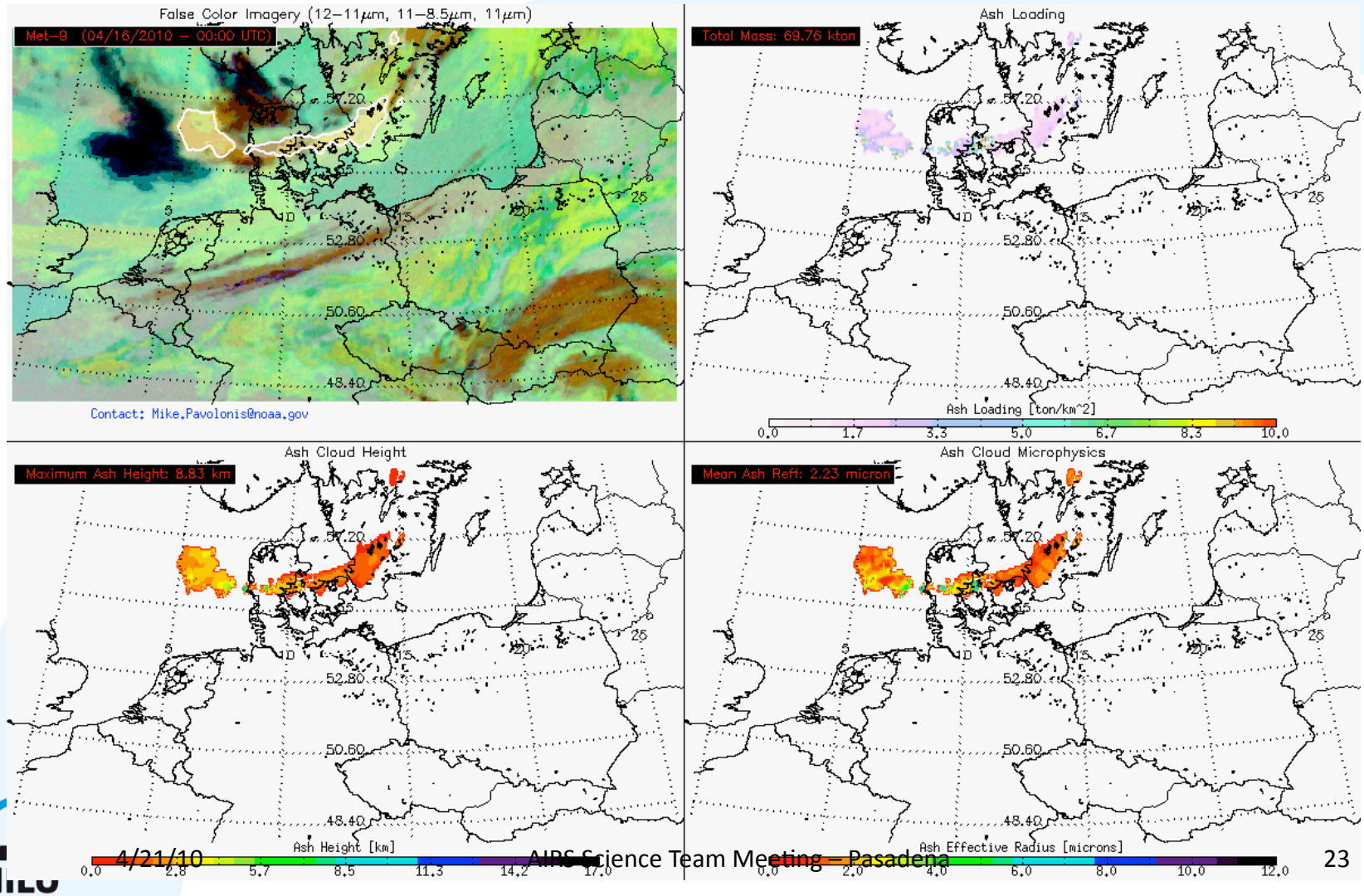
[*] *Corresponding author: lclariss@ulb.ac.be*



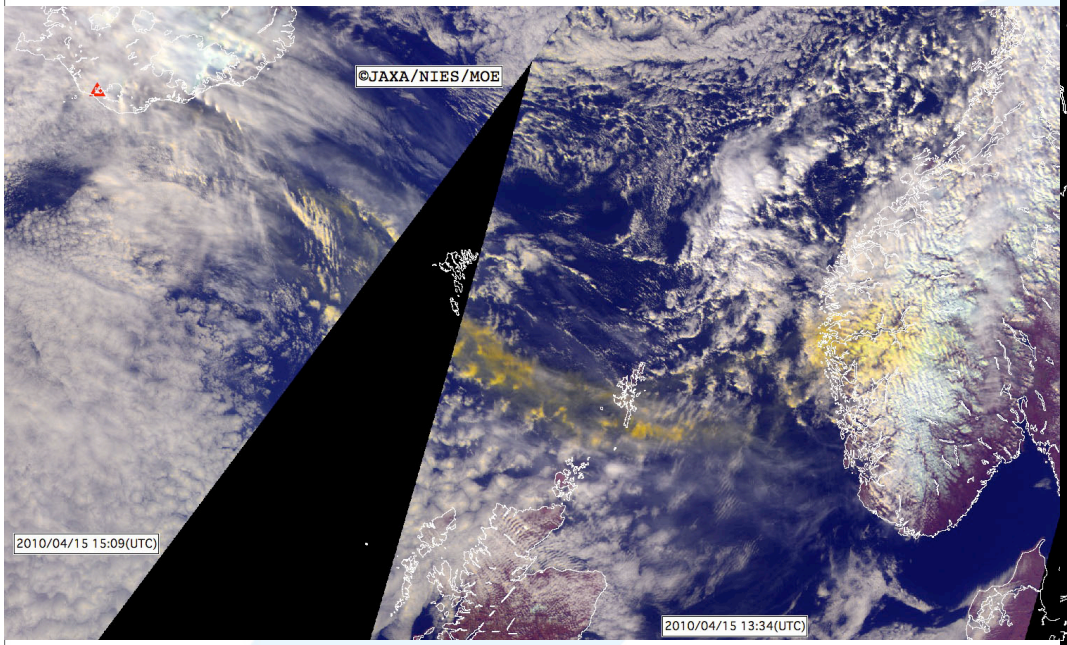
SEVIRI

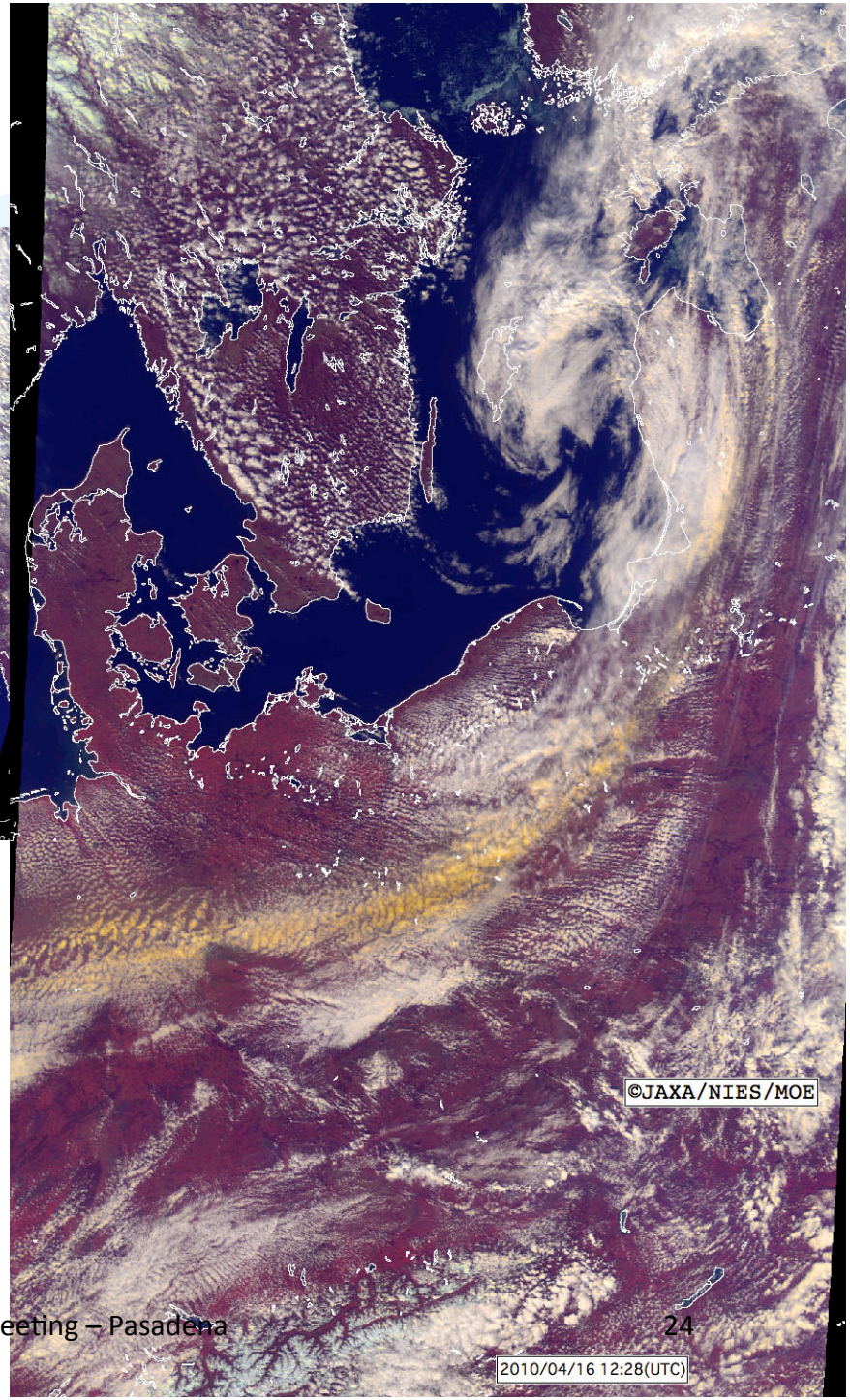

False Color Imagery (12–11μm, 11–8.5μm, 11μm)
Met–9 (04/20/2010 – 00:00 UTC)
Contact: Mike.Pavolonis@noaa.gov
Ash Loading
Total Mass: 109.40 kton
Ash Loading [ton/km^2]
0.0 1.7 3.3 5.0 6.7 8.3 10.0
Ash Cloud Height
Maximum Ash Height: 8.41 km
Ash Height [km]
0.0 1.3 2.7 4.0 5.3 6.7 8.0
Ash Cloud Microphysics
Mean Ash Reff: 10.05 micron
Ash Effective Radius [microns]
0.0 2.0 4.0 6.0 8.0 10.0 12.0

CIMSS/UWISC
Courtesy: Mike Pavalonis

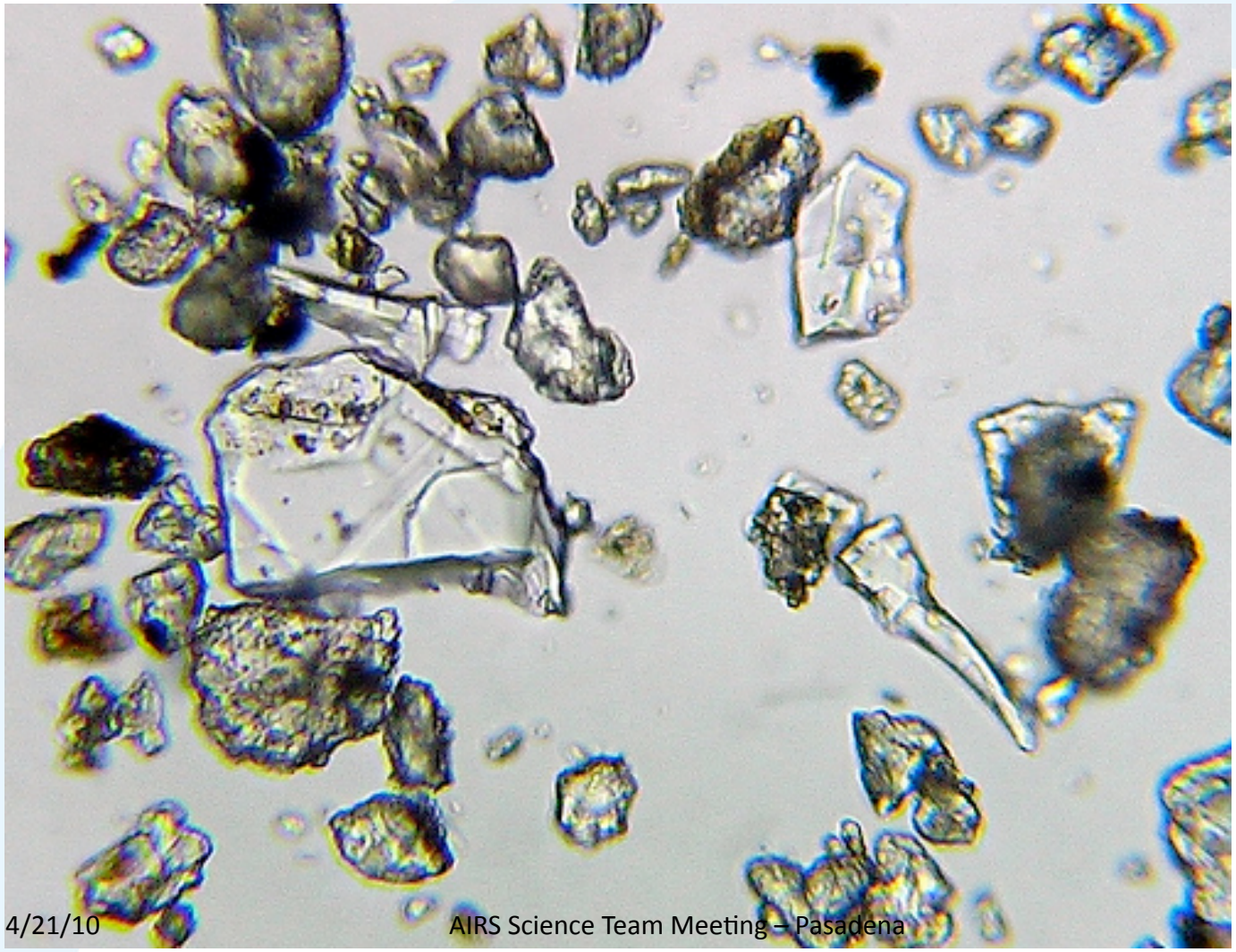


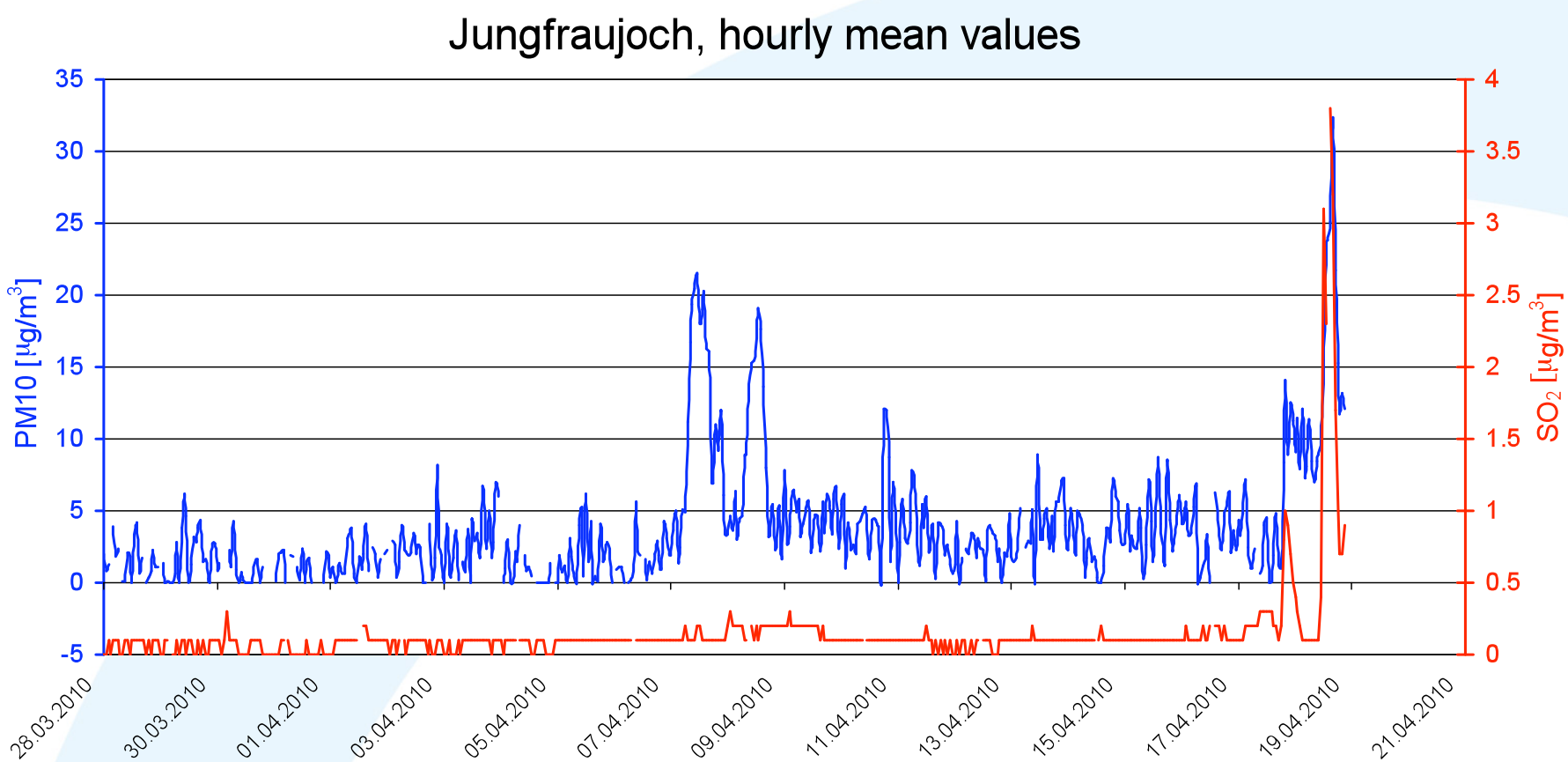
GOSAT


©JAXA/NIES/MOE
2010/04/15 15:09(UTC)
2010/04/15 13:34(UTC)

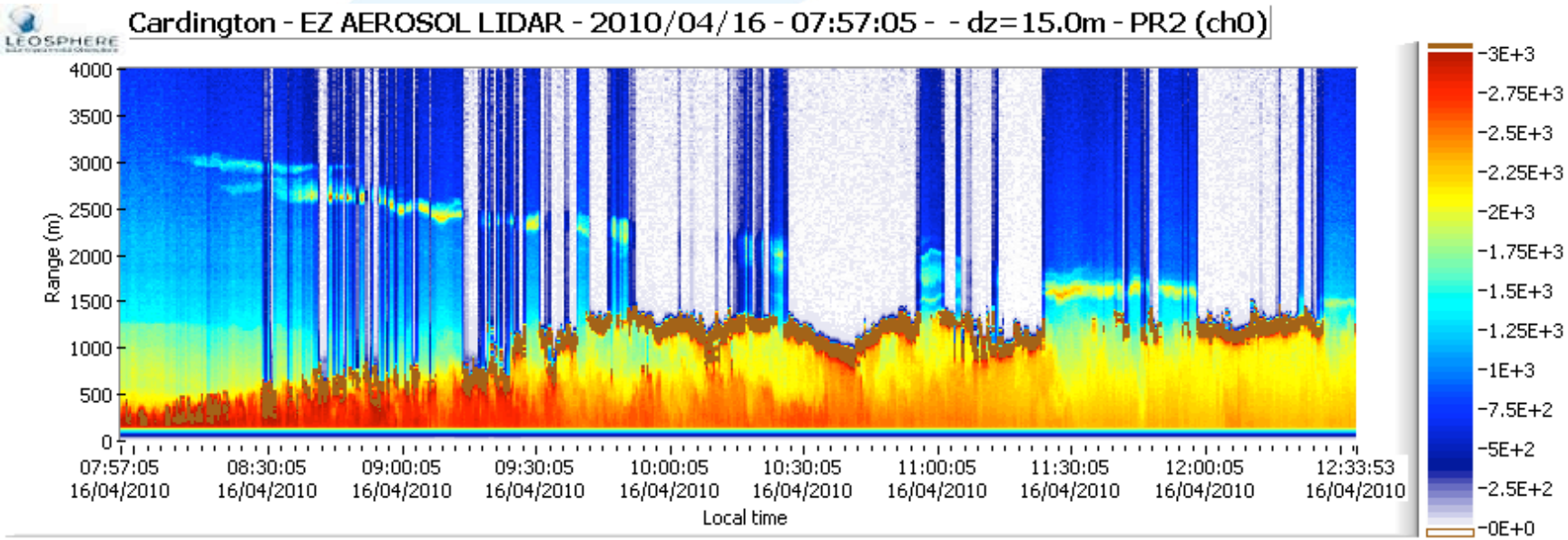

©JAXA/NIES/MOE
2010/04/16 12:28(UTC)

Ejyafyallajokul ash collected in England




Jungfraujoch, hourly mean values
PM10 [µg/m3]
SO2 [µg/m3]
35
30
25
20
15
10
5
0
-5
4
3.5
3
2.5
2
1.5
1
0.5
0
28.03.2010
30.03.2010
01.04.2010
03.04.2010
05.04.2010
07.04.2010
09.04.2010
11.04.2010
13.04.2010
15.04.2010
17.04.2010
19.04.2010
21.04.2010

Lidar


Cardington - EZ AEROSOL LIDAR - 2010/04/16 - 07:57:05 - - dz=15.0m - PR2 (ch0)
LEOSPHERE
Range (m)
4000
3500
3000
2500
2000
1500
1000
500
0
07:57:05 16/04/2010
08:30:05 16/04/2010
09:00:05 16/04/2010
09:30:05 16/04/2010
10:00:05 16/04/2010
10:30:05 16/04/2010
11:00:05 16/04/2010
11:30:05 16/04/2010
12:00:05 16/04/2010
12:33:53 16/04/2010
Local time
-3E+3
-2.75E+3
-2.5E+3
-2.25E+3
-2E+3
-1.75E+3
-1.5E+3
-1.25E+3
-1E+3
-7.5E+2
-5E+2
-2.5E+2
-0E+0

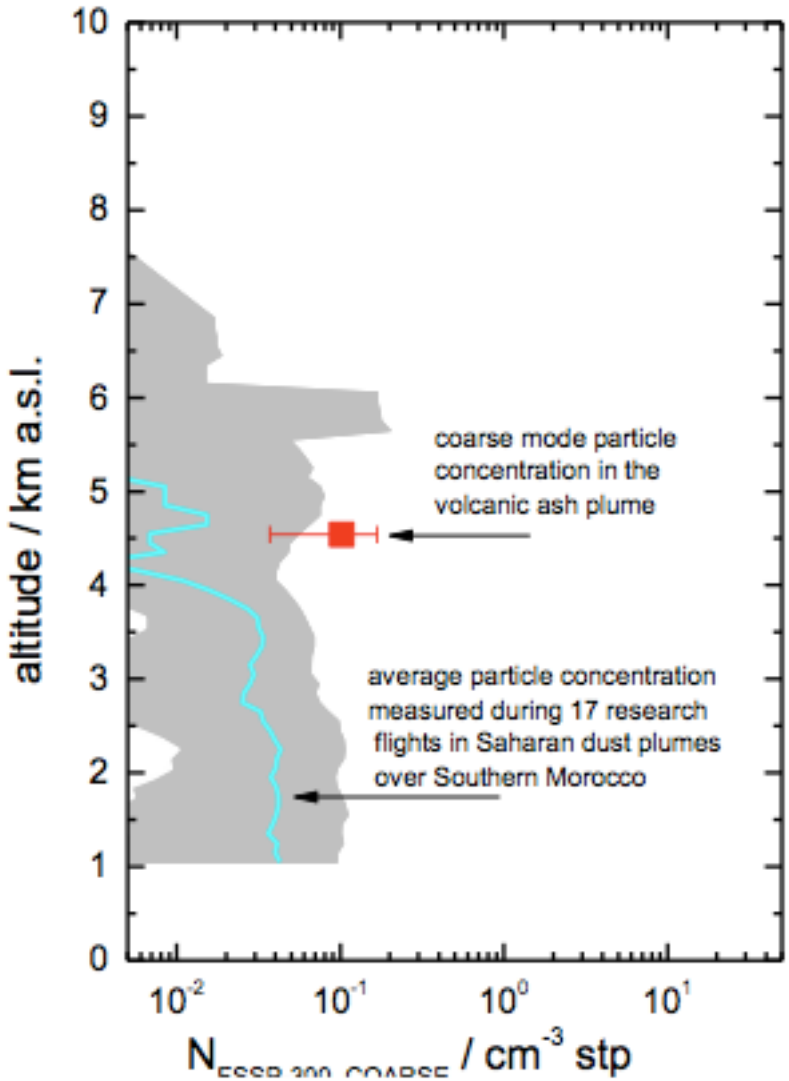
Falcon Flight data

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Report of Falcon Flight 19 April 2010

U. Schumann, H. Schlager, B. Weinzierl, O. Reitebuch, A. Minikin, H. Huntrieser, T. Sailer, H. Mannstein
DLR-Institut für Physik der Atmosphäre, Oberpfaffenhofen

Particle data



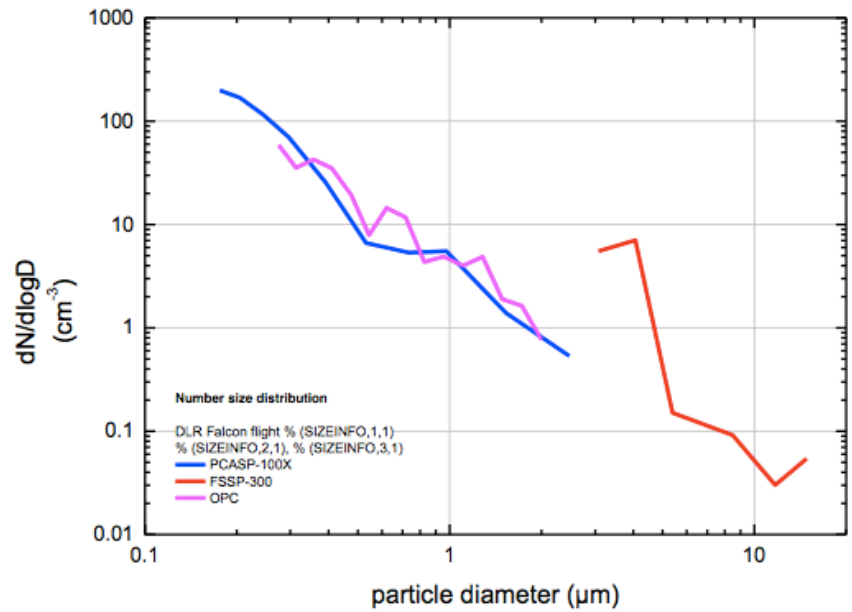


Figure 13: Preliminary aerosol number size distribution in the volcanic ash plume over Leipzig at 4.3 km pressure altitude.

Lidar

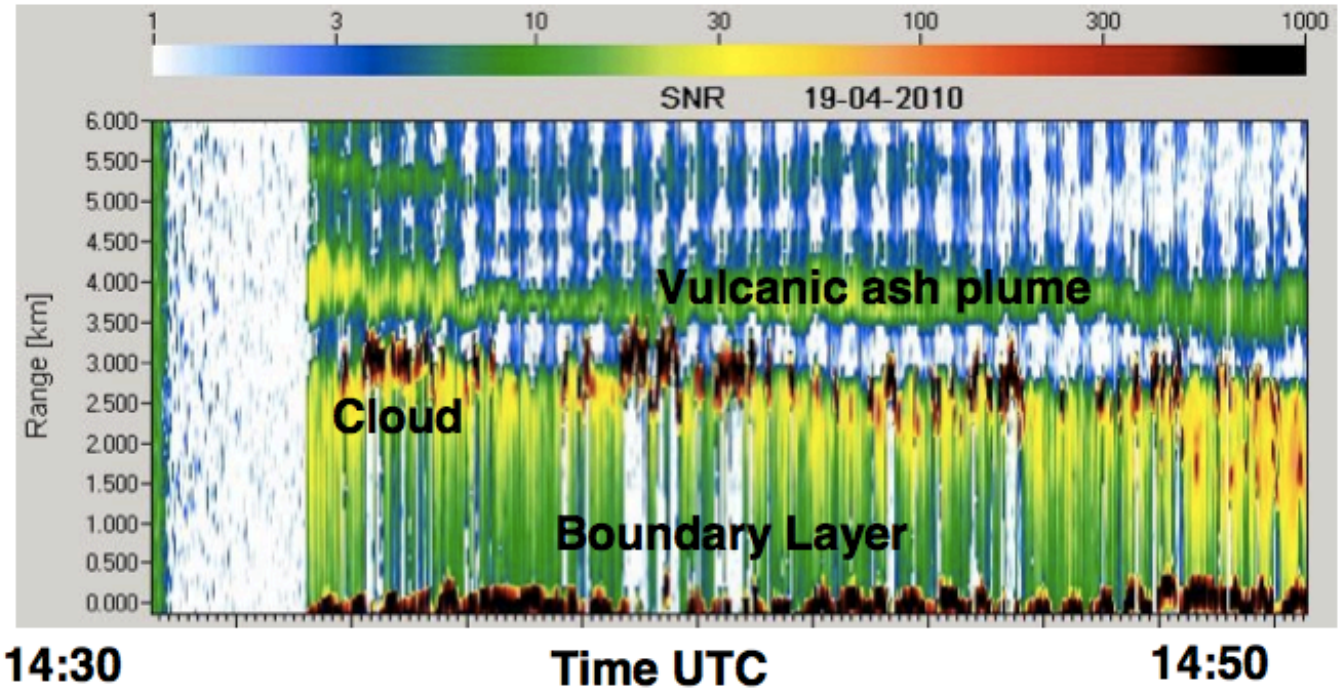
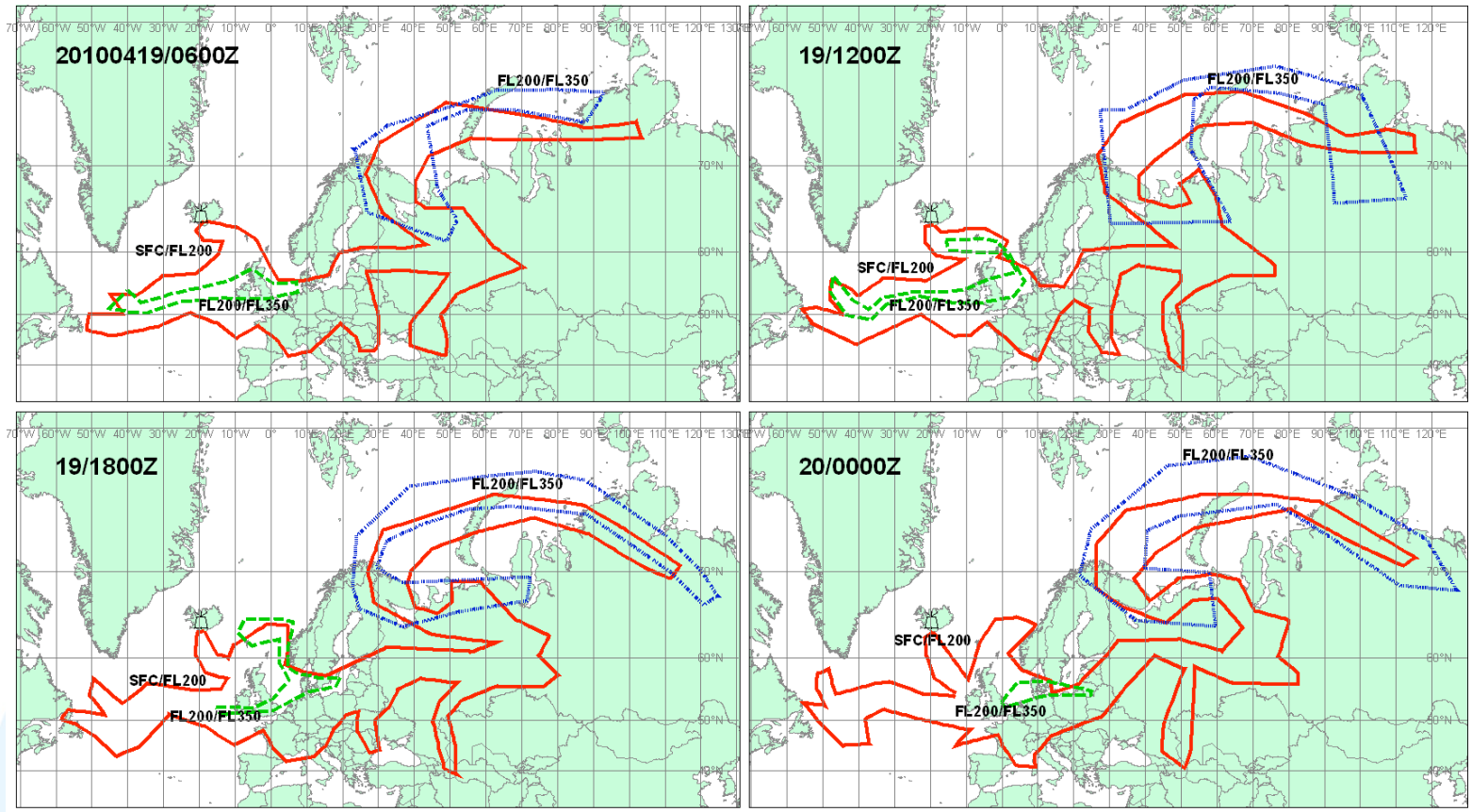


Figure 5: Quicklook from 2-µm lidar measurements from Falcon flight on April 19, 2010 showing Signal-to-Noise Ratio shortly after take-off from Oberpfaffenhofen from 14:30-14:50 UTC (16:30-16:50 LT) going north during 20 minutes (about 200-240 km flight track); red/black colors show high SNR from clouds (around 3 km) and ground (0 km); blue-green colors show layers with aerosol; white/blue colors indicate noise (no valid data); 2 layers of higher aerosol level are visible at 4 km and 5.5 km

London VAAC Advisory 19/20 April

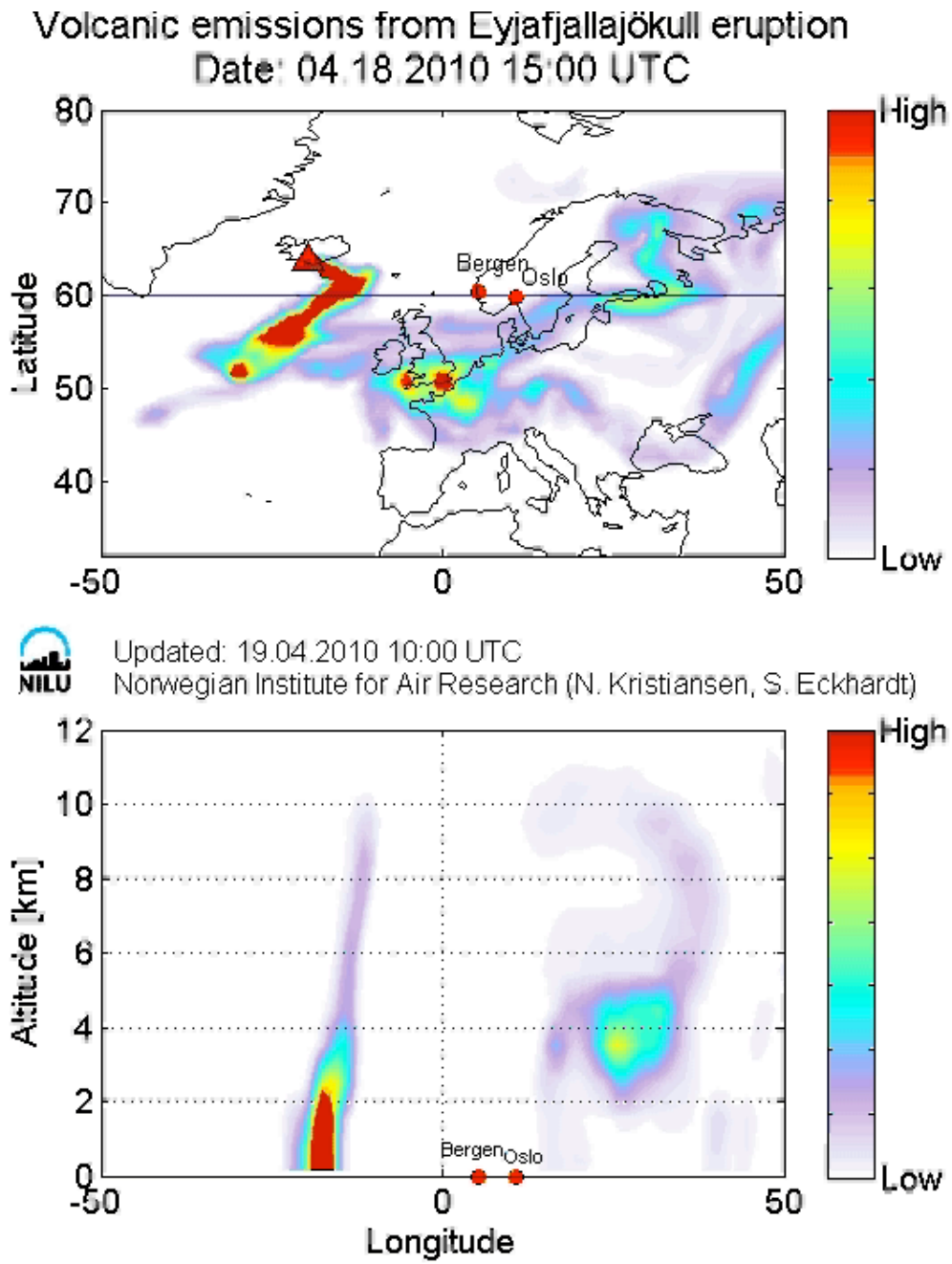


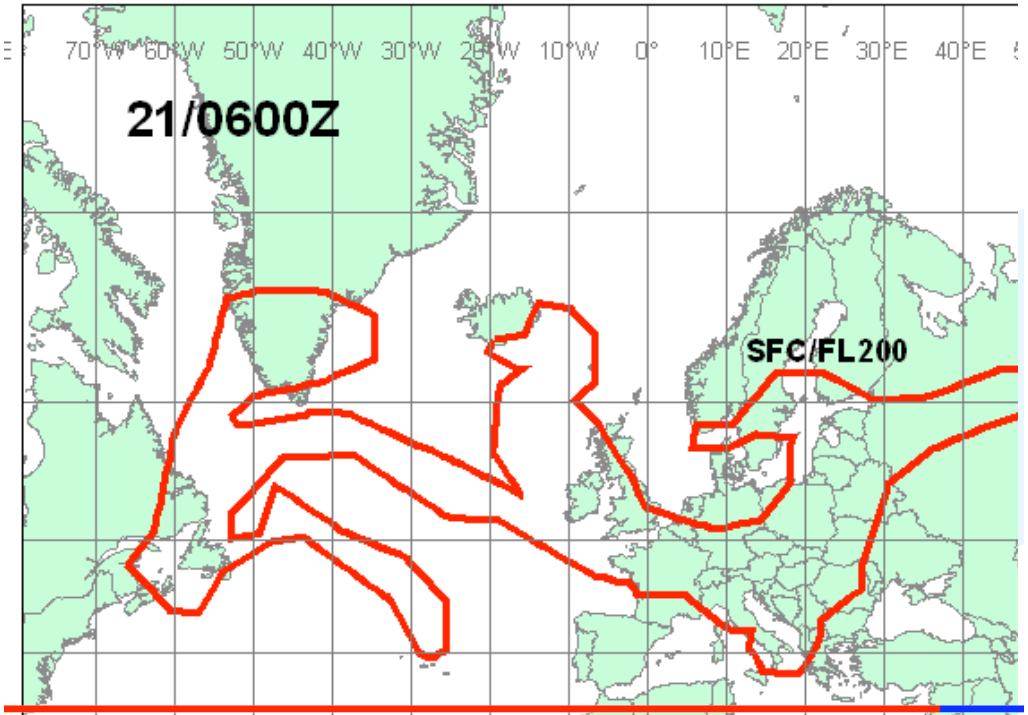
VA ADVISORY
DTG: 20100419/0600Z
VAAC: LONDON
VOLCANO:
EYJAFJALLAJOKULL
PSN: N6338 W01937
AREA: ICELAND

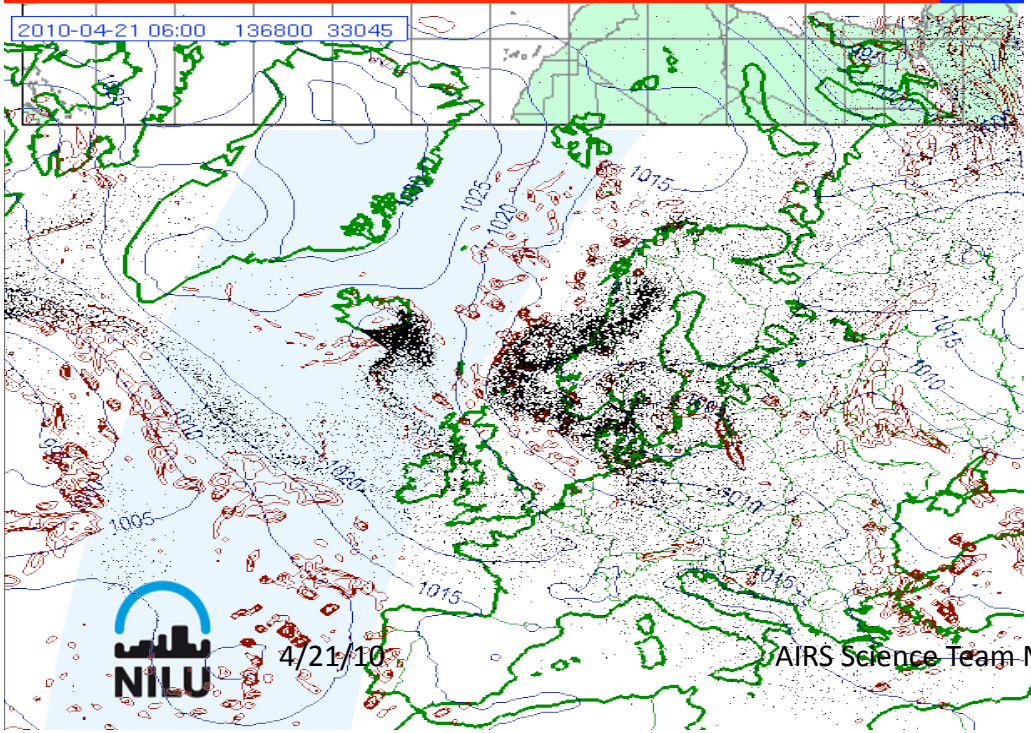
SUMMIT ELEV: 1666M
ADVISORY NR: 2010/021
INFO SOURCE: ICELAND MET OFFICE
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: ERUPTION IS CONTINUING CONFIRMED BY RECENT SATELLITE PICTURES. HEIGHT IS CURRENTLY AROUND 5000M.

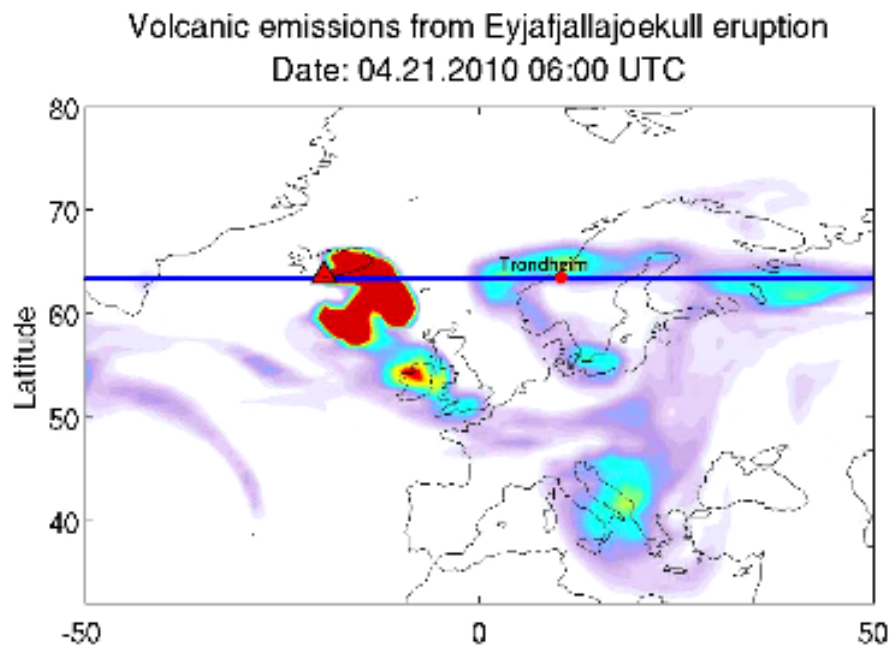
RMK: NO SIG ASH ABOVE FL350. AS BEFORE ISSUED CHARTS SHOW TWO SEPARATE AREAS BOTH AT FL200 TO FL350 BUT IN DIFFERENT COLOURS.
NXT ADVISORY: 20100419/1200Z

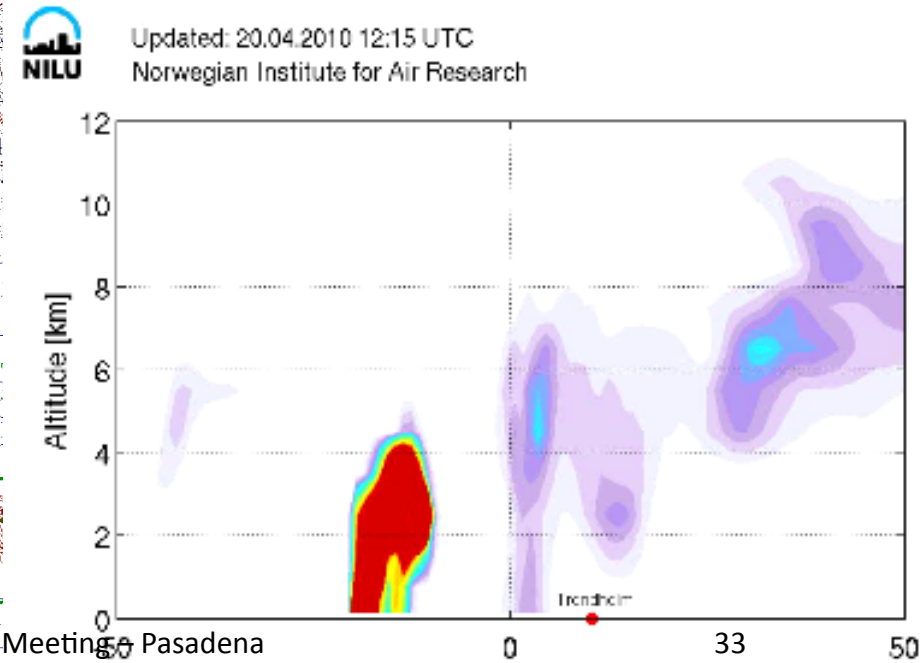
Forecast


Volcanic emissions from Eyjafjallajökull eruption
Date: 04.18.2010 15:00 UTC
Latitude
80
70
60
50
40
-50
0
50
Bergen
Oslo
High
Low
Updated: 19.04.2010 10:00 UTC
Norwegian Institute for Air Research (N. Kristiansen, S. Eckhardt)
Altitude [km]
12
10
8
6
4
2
0
Longitude

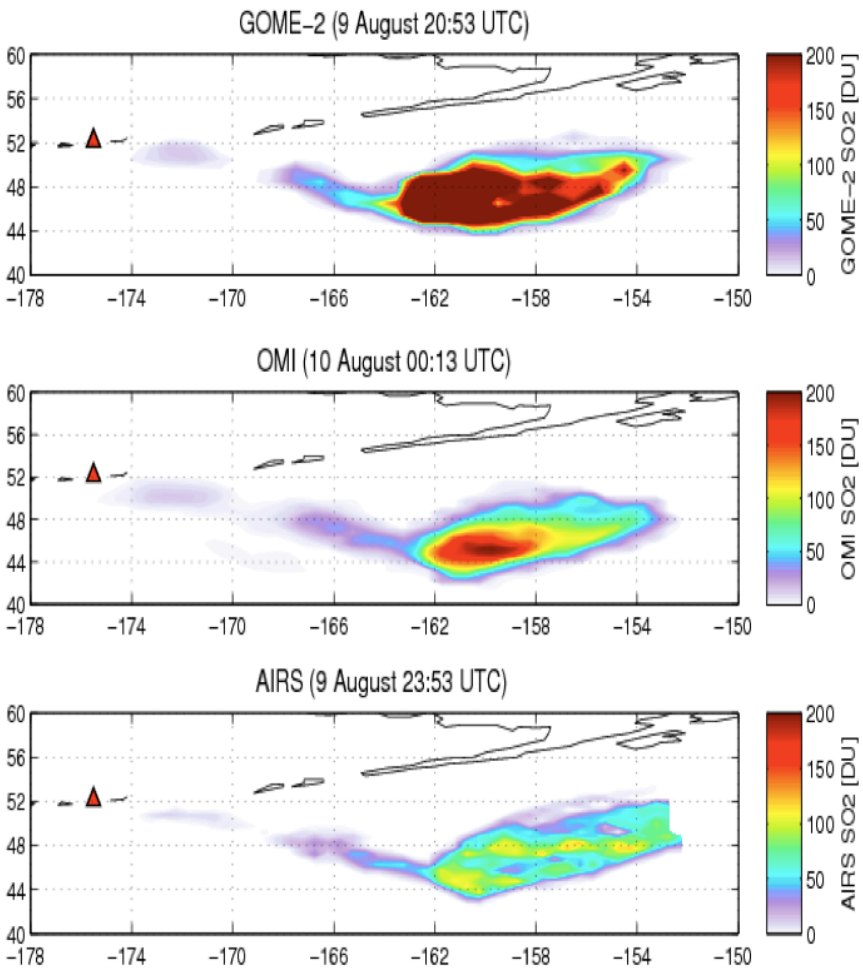

21/0600Z
SFC/FL200
70°W 60°W 50°W 40°W 30°W 20°W 10°W 0° 10°E 20°E 30°E 40°E

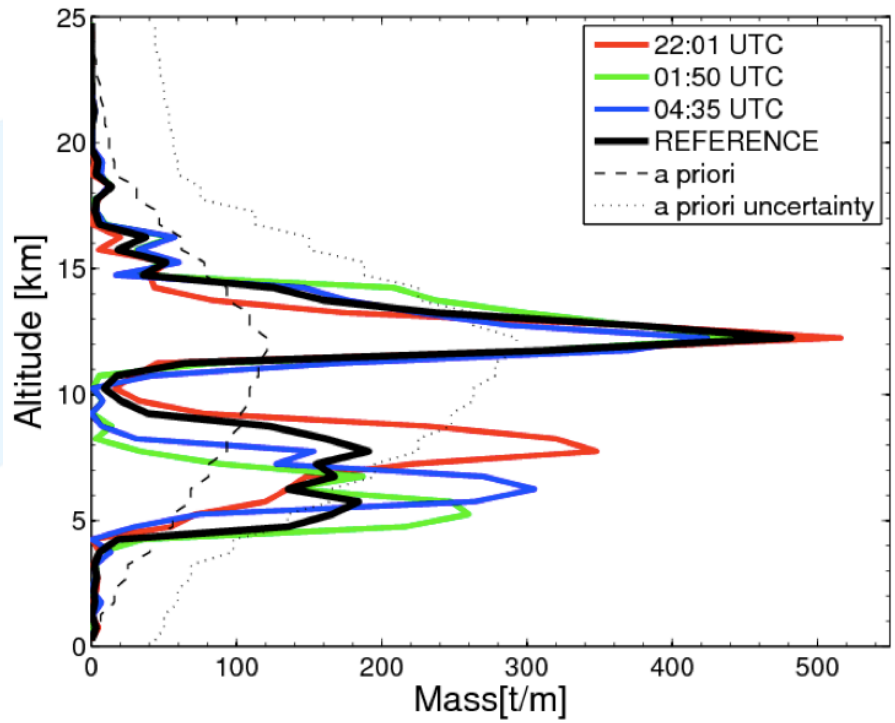

2010-04-21 06:00 136800 33045
NILU

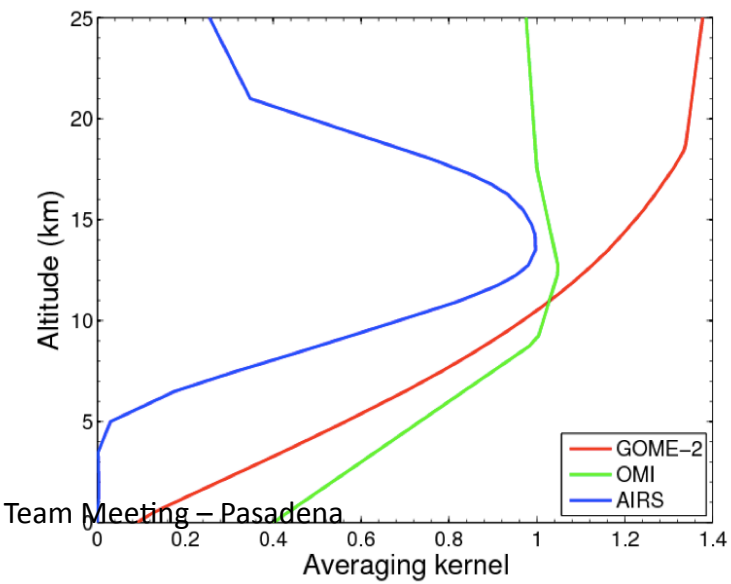

Volcanic emissions from Eyjafjallajoekull eruption
Date: 04.21.2010 06:00 UTC
Latitude
Trondheim
80
70
60
50
40
-50
0
50


NILU
Updated: 20.04.2010 12:15 UTC
Norwegian Institute for Air Research
Altitude [km]
12
10
8
6
4
2
0
0
50

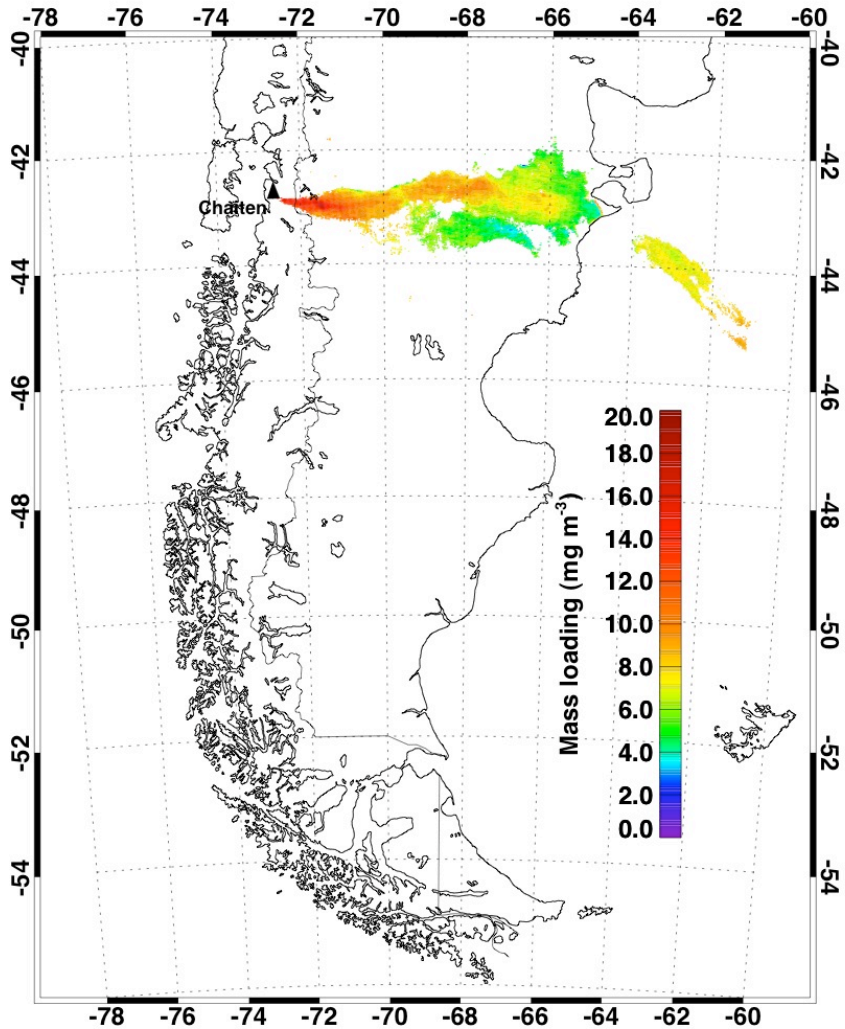
Combining satellite data with dispersion models

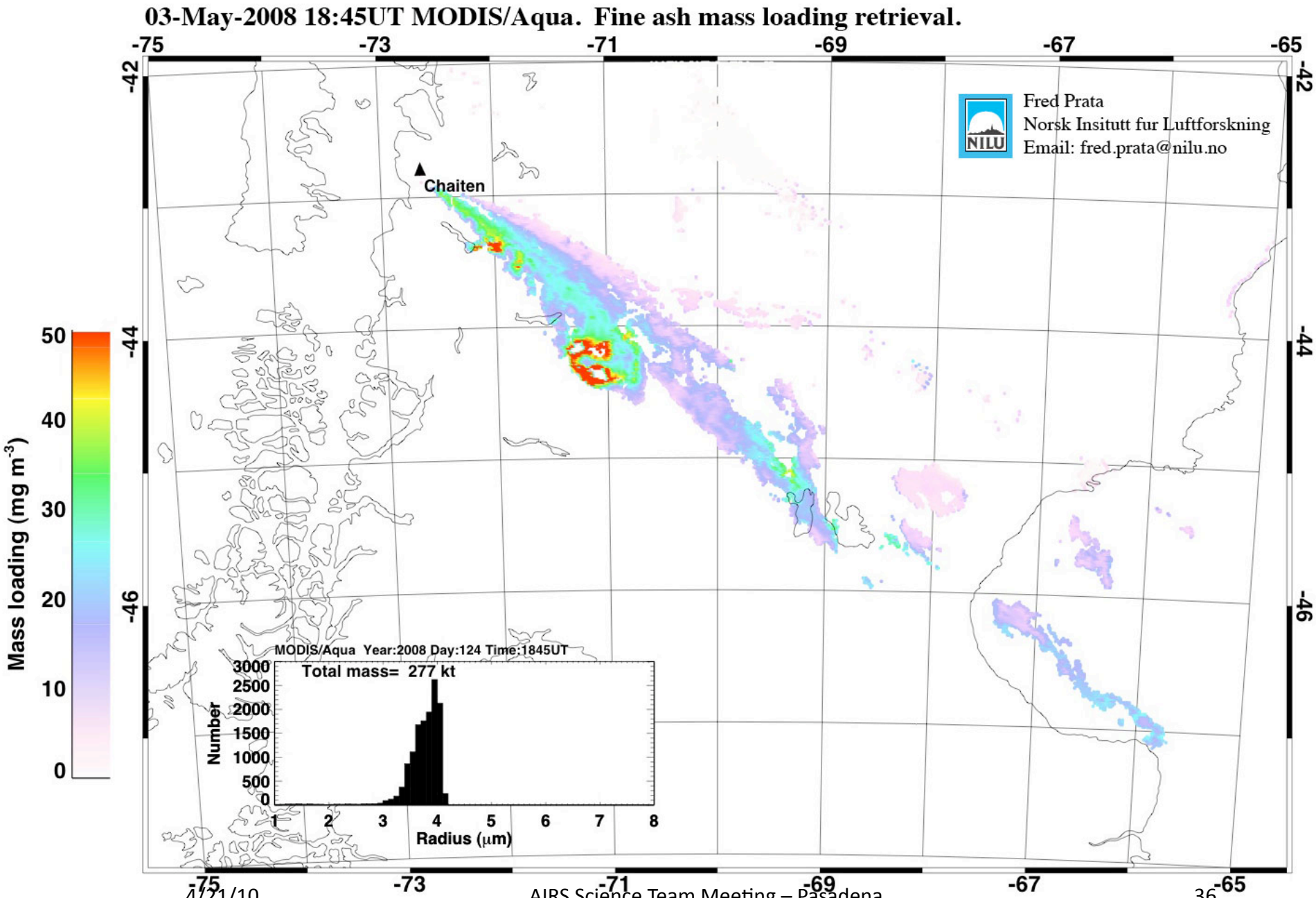






MODIS ash retrievals



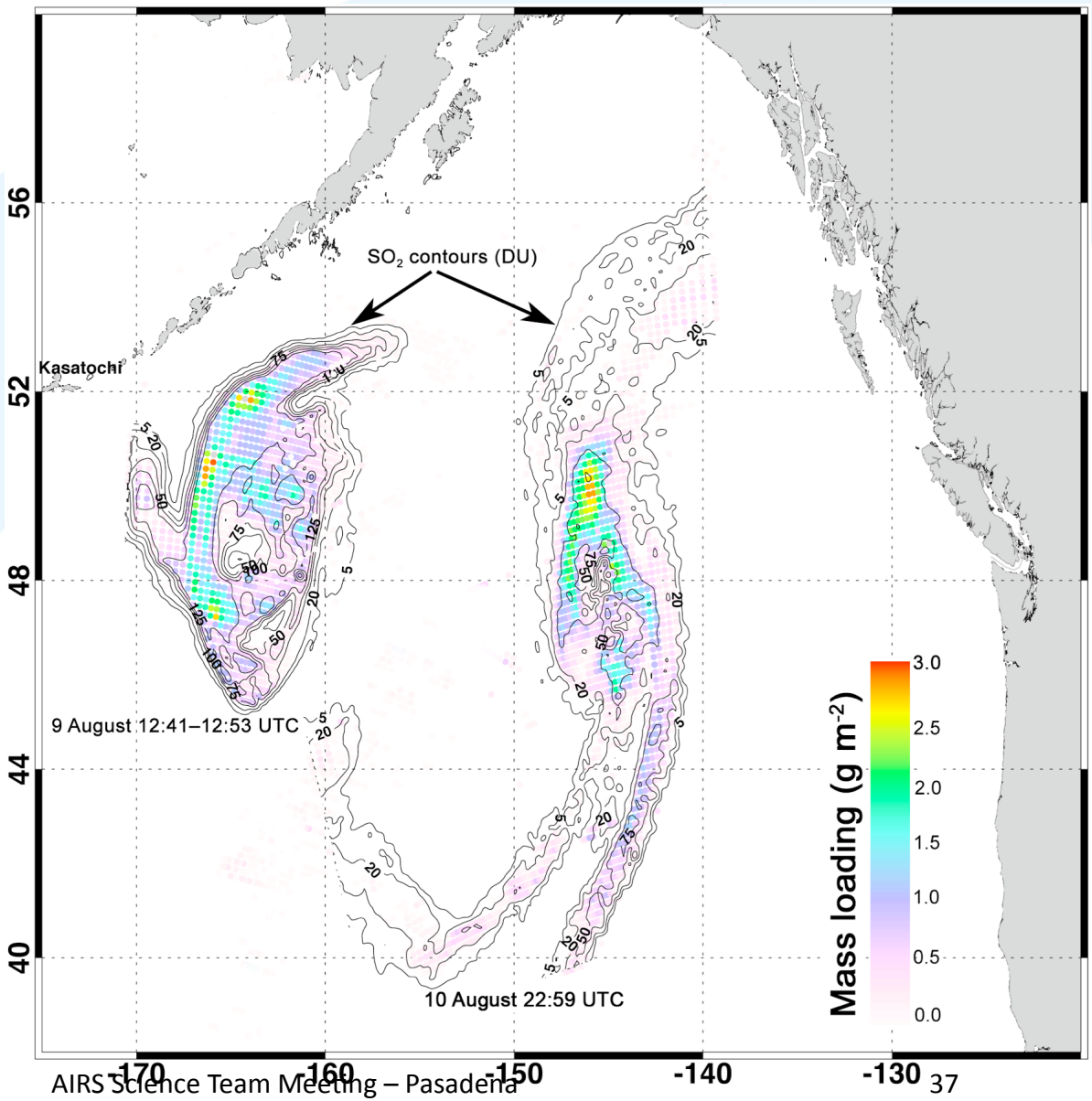

03-May-2008 18:45UT MODIS/Aqua. Fine ash mass loading retrieval.
Fred Prata
Norsk Insitutt fur Luftforskning
Email: fred.prata@nilu.no
NILU
Chaiten
Mass loading (mg m-3)
50
40
30
20
10
0
-75
-73
-71
-69
-67
-65
-42
-44
-46
MODIS/Aqua Year:2008 Day:124 Time:1845UT
Total mass= 277 kt
Number
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
Radius (μm)

AIRS ash/SO_2 retrievals

1 gm^{-2} = 1 mg m^{-3}

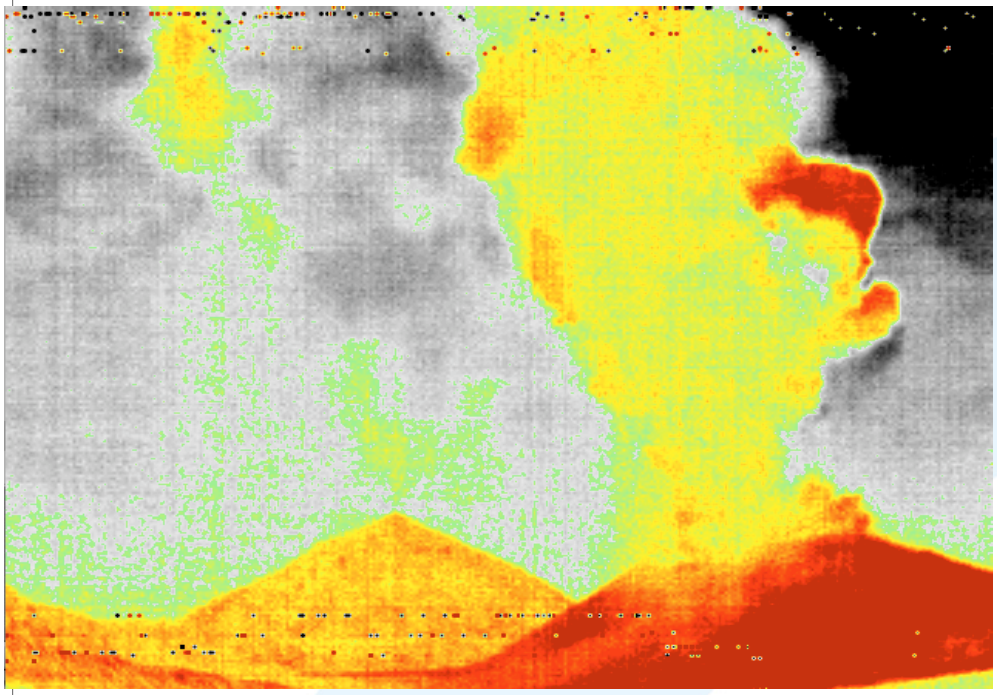
If we assume the cloud is 1 km thick

Falcon measured 0.06 mg m^{-3}



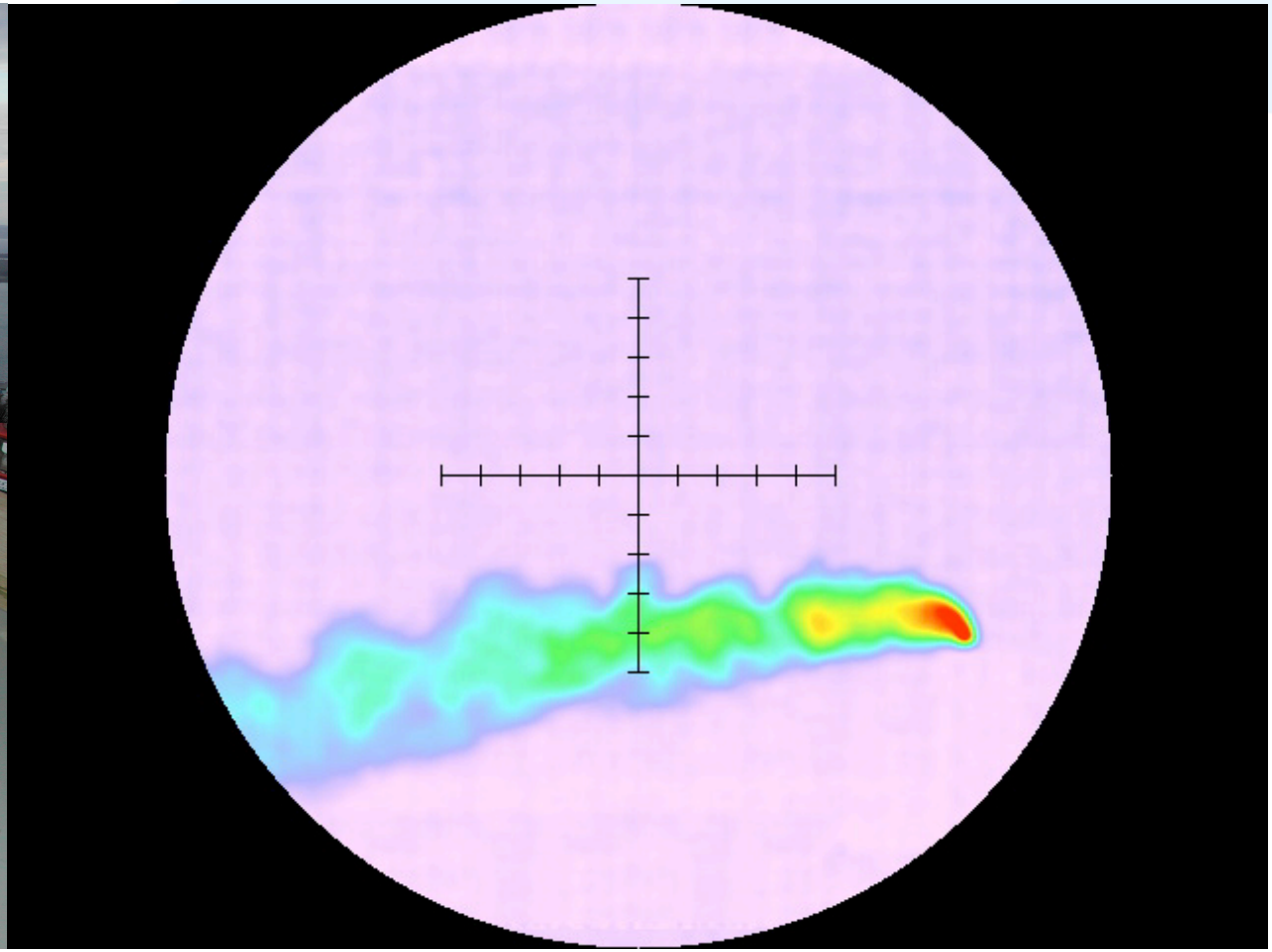
Imaging Ash Clouds at Tavurvur Volcano, Rabaul 26-30 November 2003

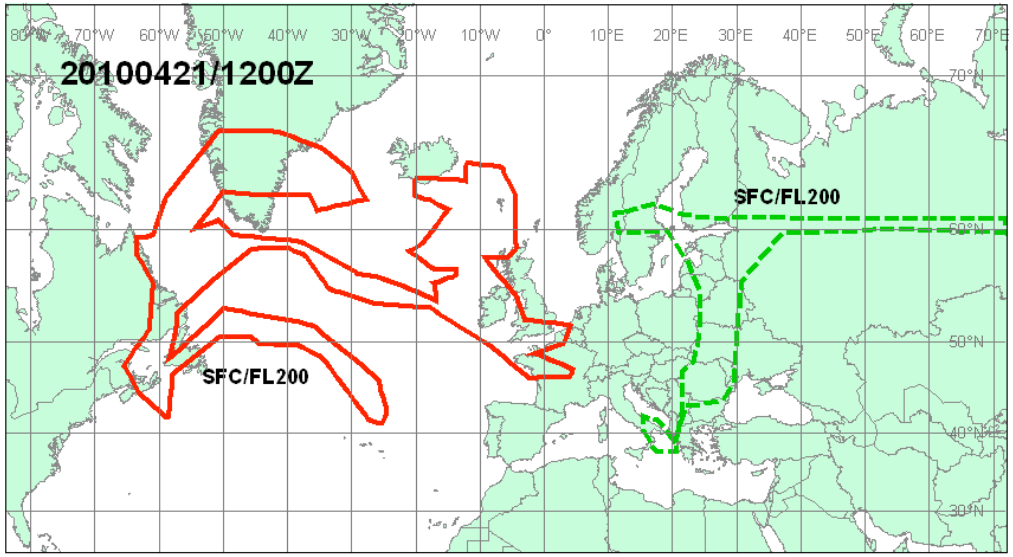
Ash image

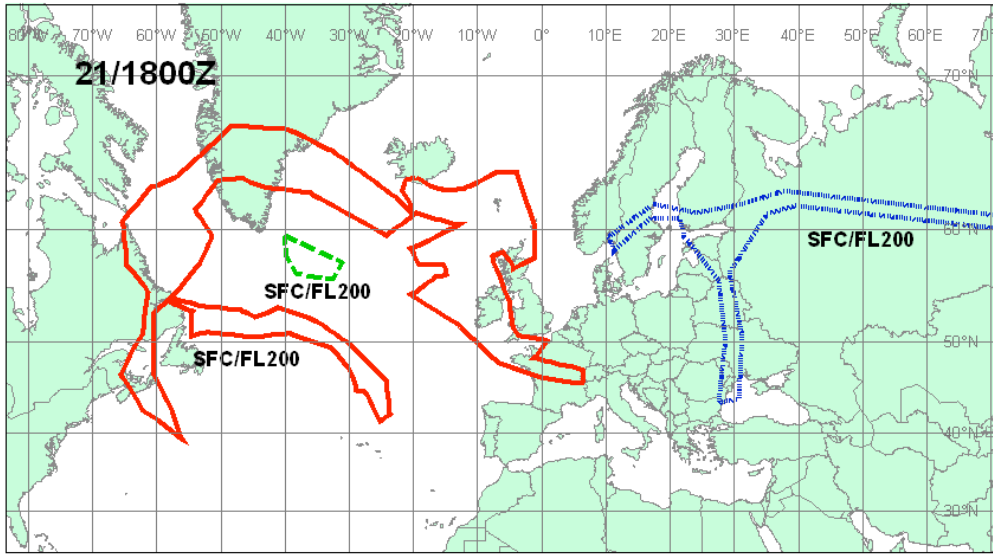


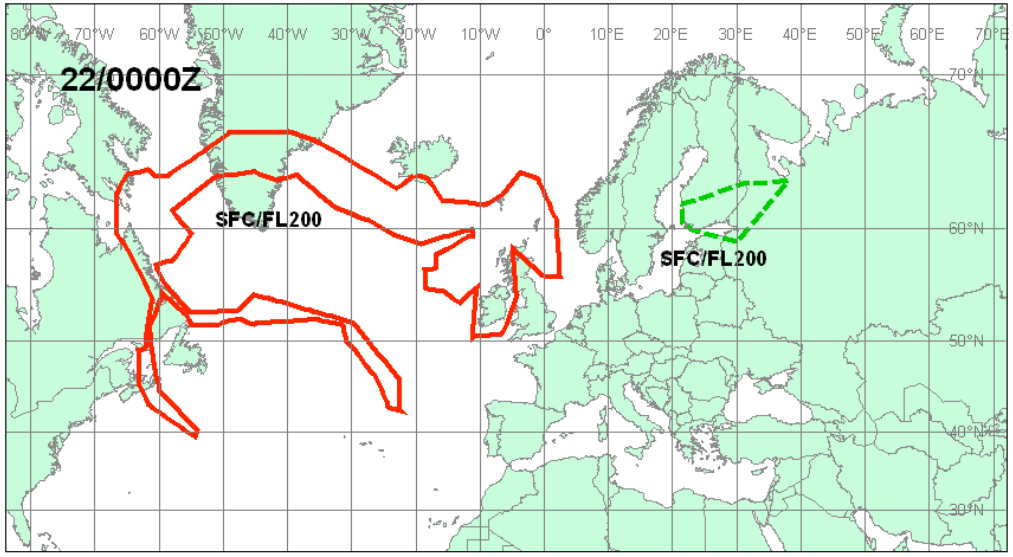
Visible photograph

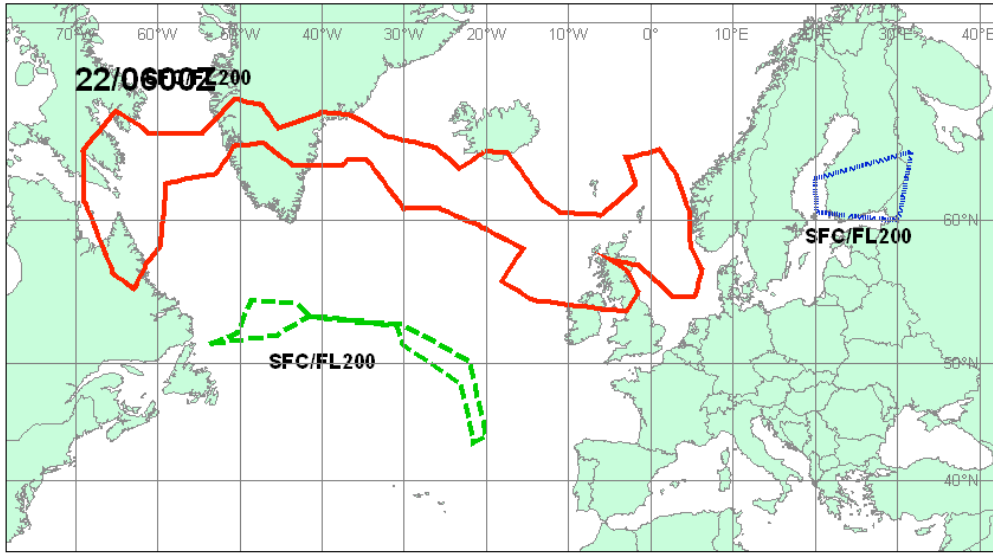
Ground-based and airborne solutions











VA ADVISORY
DTG: 20100421/1200Z
VAAC: LONDON
VOLCANO:
EYJAFJALLAJOKULL 1702-02
PSN: N6338 W01937
AREA: ICELAND

SUMMIT ELEV: 1666M
ADVISORY NR: 2010/030
INFO SOURCE: ICELAND MET OFFICE
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: ERUPTION CONTINUING TO AROUND FL120 TO FL160.

RMK: NO SIG ASH ABOVE FL200. ASH CONCENTRATIONS UNKNOWN. ALL PLUMES ON ALL FOUR CHARTS APPLY TO SFC TO FL200.
NXT ADVISORY: 20100421/1800Z

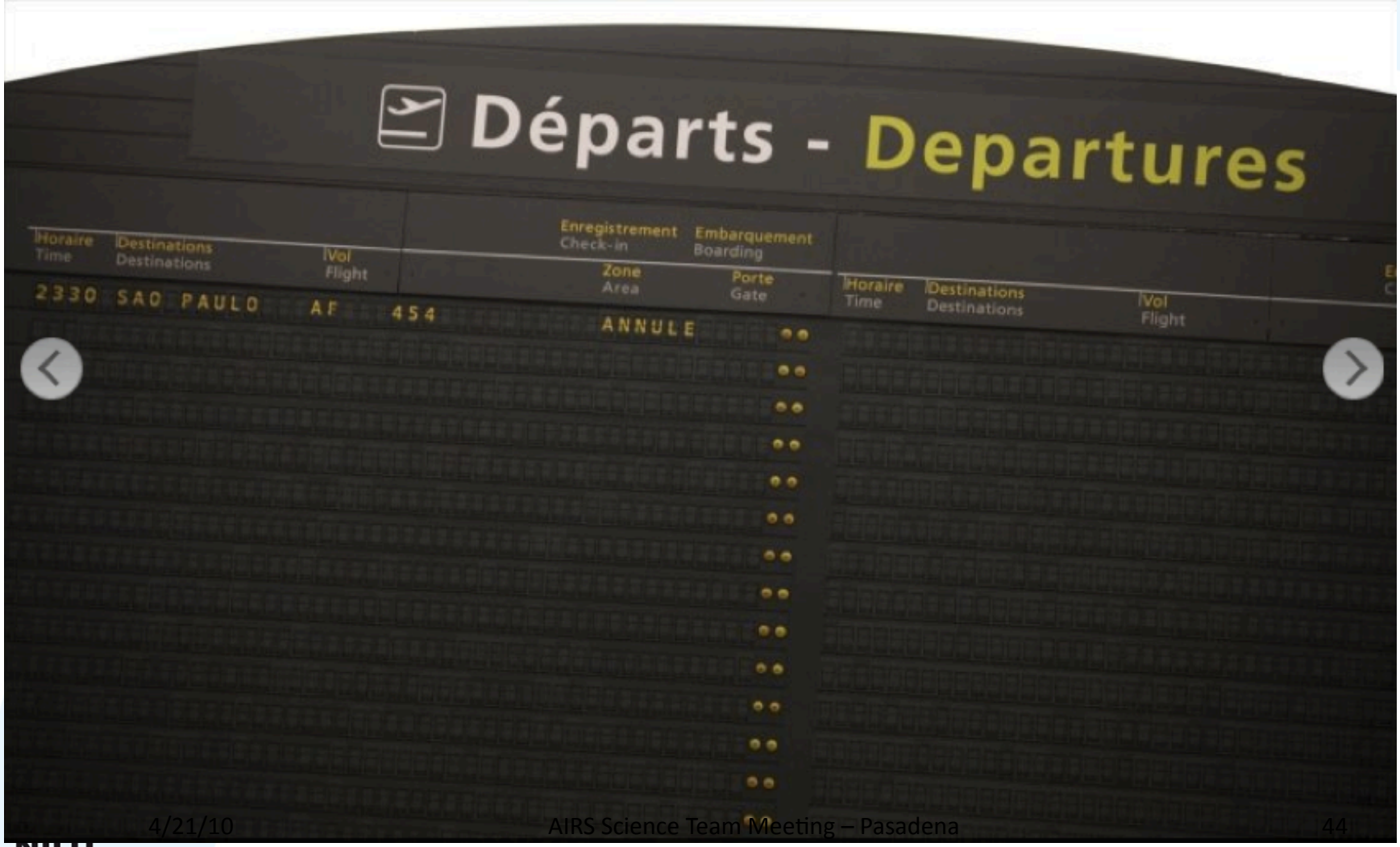
Impacts

IATA: Volcanic Ash Cost Airlines $1.7 Billion
The International Air Transport Association (IATA) estimates that airlines lost at least $1.7 billion in revenue through Tuesday due to the Icelandic volcano crisis. During the three day period of April 17-19, when disruptions were at their peak, airlines lost $400 million per day.

Emirates, has lost about $US50 million during the airport shutdowns

Qantas estimate that this is costing between $1.5 and $2 million a day over the last five days

Flight information – 18 April



Some links

Further reading:

http://savaa.nilu.no/Science/tabid/2678/Default.aspx

http://sites.google.com/site/iavceirscweb/Home

http://www.metoffice.gov.uk/aviation/vaac/index.html