Remote Sensing of Volcanic Ash

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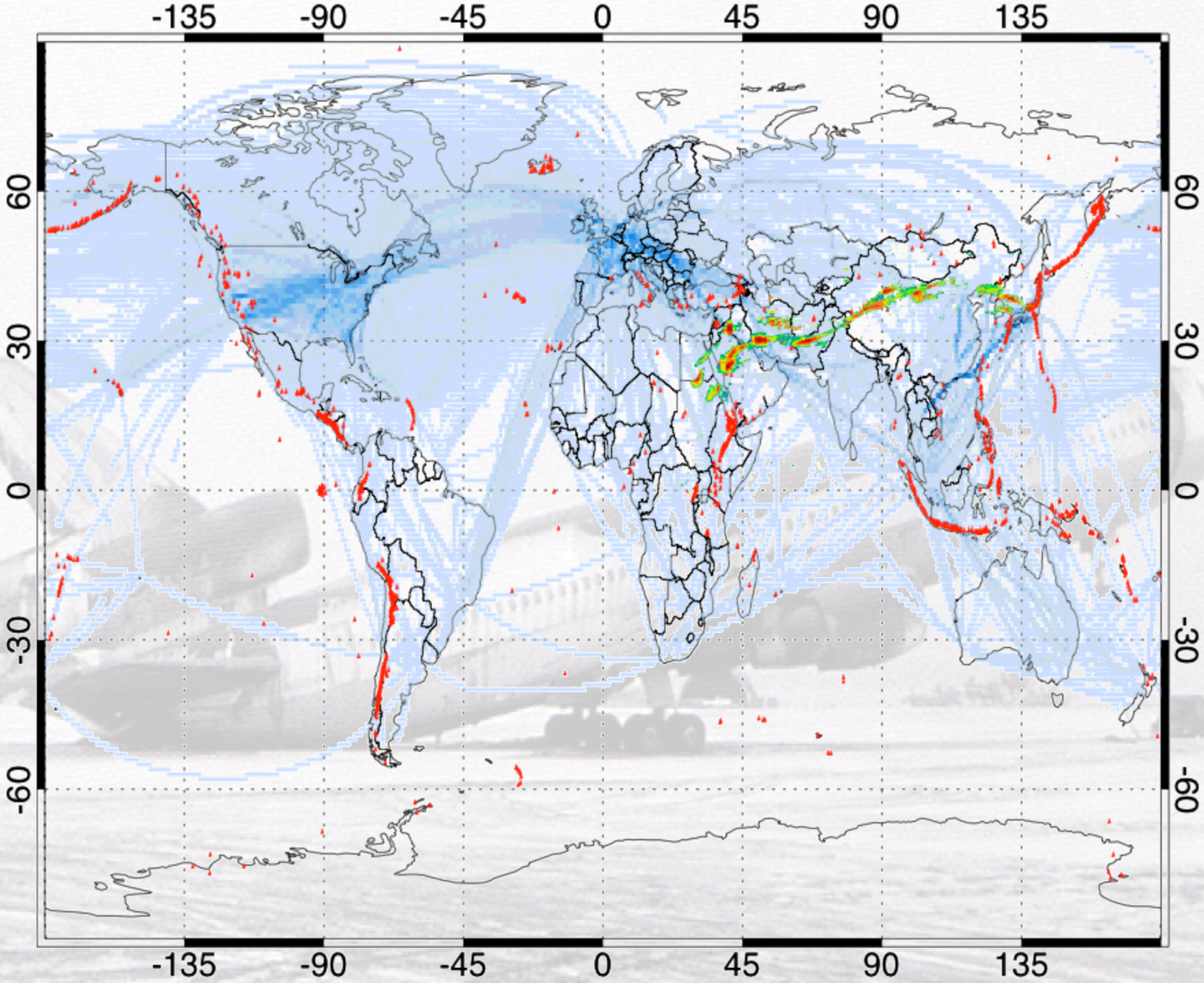
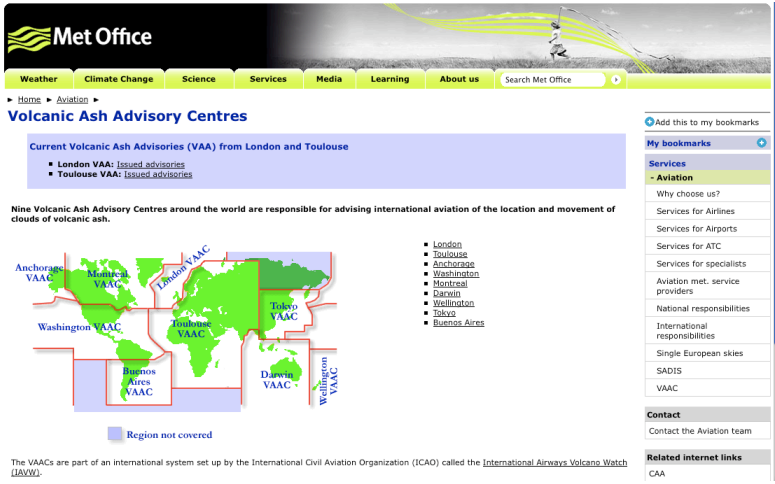
Can satellite data provide a quantitative, timely and useful source of information to support aviation avoid volcanic hazards?

- Where are the gaps?
  - No uniform data delivery system
  - No standardized products (especially IR)
  - No height information
  - *Ad hoc* approach to trajectory/dispersion forecast

Global aviation threat

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Volcanic Ash Advisory Centres
Current Volcanic Ash Advisories (VAA) from London and Toulouse
London VAA: Issued advisories
Toulouse VAA: Issued advisories
Nine Volcanic Ash Advisory Centres around the world are responsible for advising international aviation of the location and movement of clouds of volcanic ash.
Anchorage VAAC
Montreal VAAC
London VAAC
Tokyo VAAC
Washington VAAC
Toulouse VAAC
Buenos Aires VAAC
Darwin VAAC
Wellington VAAC
Region not covered
London
Toulouse
Anchorage
Washington
Montreal
Darwin
Wellington
Tokyo
Buenos Aires
The VAACs are part of an international system set up by the International Civil Aviation Organization (ICAO) called the International Airways Volcano Watch (IAVW).
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VAAC
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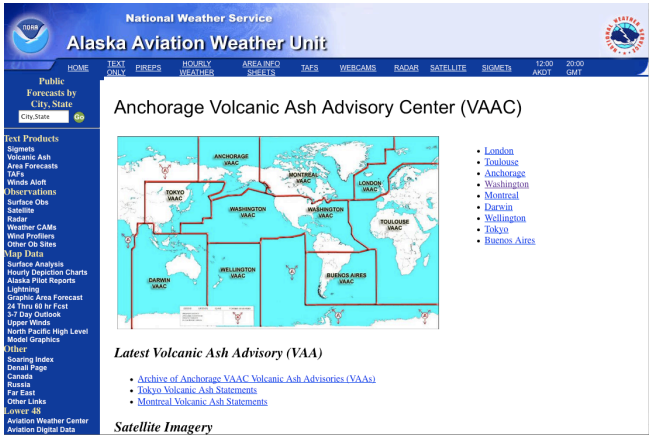
CAA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Alaska Aviation Weather Unit
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WEBCAMS
RADAR
SATELLITE
SIGMETs
12:00 AKDT
20:00 GMT
Public Forecasts by City, State
City,State
Go
Text Products
Sigmets
Volcanic Ash
Area Forecasts
TAFs
Winds Aloft
Observations
Surface Obs
Satellite
Radar
Weather CAMs
Wind Profilers
Other Ob Sites
Map Data
Surface Analysis
Hourly Depiction Charts
Alaska Pilot Reports
Lightning
Graphic Area Forecast
24 Thru 60 hr Fcst
3-7 Day Outlook
Upper Winds
North Pacific High Level
Model Graphics
Other
Soaring Index
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Canada
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Other Links
Lower 48
Aviation Weather Center
Aviation Digital Data
Anchorage Volcanic Ash Advisory Center (VAAC)
ANCHORAGE VAAC
MONTREAL VAAC
LONDON VAAC
TOKYO VAAC
WASHINGTON VAAC
TOULOUSE VAAC
DARWIN VAAC
WELLINGTON VAAC
BUENOS AIRES VAAC
London
Toulouse
Anchorage
Washington
Montreal
Darwin
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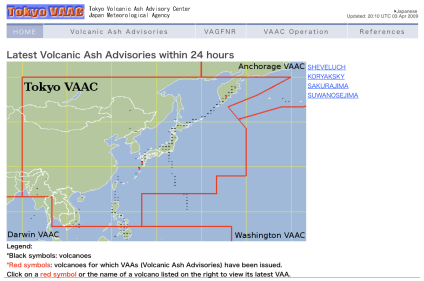
Tokyo
Buenos Aires
Latest Volcanic Ash Advisory (VAA)
Archive of Anchorage VAAC Volcanic Ash Advisories (VAAs)
Tokyo Volcanic Ash Statements
Montreal Volcanic Ash Statements
Satellite Imagery


Tokyo VAAC
Tokyo Volcanic Ash Advisory Center
Japan Meteorological Agency
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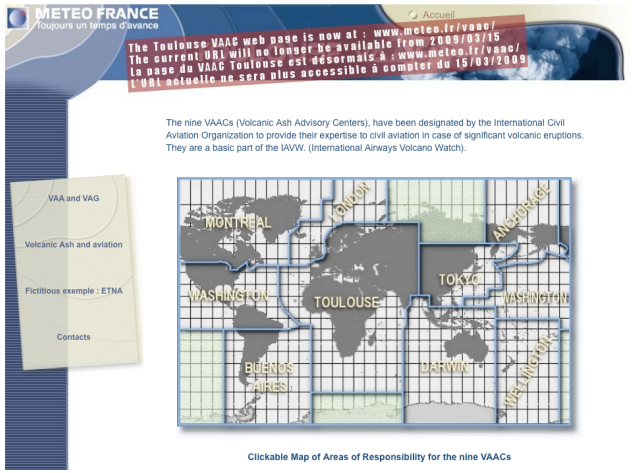
VAGFNR
VAAC Operation
References
Latest Volcanic Ash Advisories within 24 hours
Anchorage VAAC
Tokyo VAAC
SHEVELUCH
KORYAKSKY
SAKURAJIMA
SUWANOSEJIMA
Darwin VAAC
Washington VAAC
Legend:
*Black symbols: volcanoes
*Red symbols: volcanoes for which VAAs (Volcanic Ash Advisories) have been issued.
Click on a red symbol or the name of a volcano listed on the right to view its latest VAA.


METEO FRANCE
Toujours un temps d'avance
Accueil
The Toulouse VAAC web page is now at : www.meteo.fr/vaac/
The current URL will no longer be available from 2009/03/15
La page du VAAC Toulouse est désormais à : www.meteo.fr/vaac/
L'URL actuelle ne sera plus accessible à compter du 15/03/2009
The nine VAACs (Volcanic Ash Advisory Centers), have been designated by the International Civil Aviation Organization to provide their expertise to civil aviation in case of significant volcanic eruptions. They are a basic part of the IAVW. (International Airways Volcano Watch).
VAA and VAG
Volcanic Ash and aviation
Fictitious exemple : ETNA
Contacts
MONTREAL
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DARWIN
WELLINGTON
Clickable Map of Areas of Responsibility for the nine VAACs


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WELLINGTON VAAC
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LINKS
Wellington VAAC HOME
World VAAC Regions
Current Wellington Advisories
Current International Advisories
MONTREAL
LONDON
WASHINGTON
TOULOUSE
TOKYO
BUENOS AIRES
DARWIN
'Click' a region to open that VAAC webpage in a new window.
The hashed area on the map shows regions not covered by a VAAC


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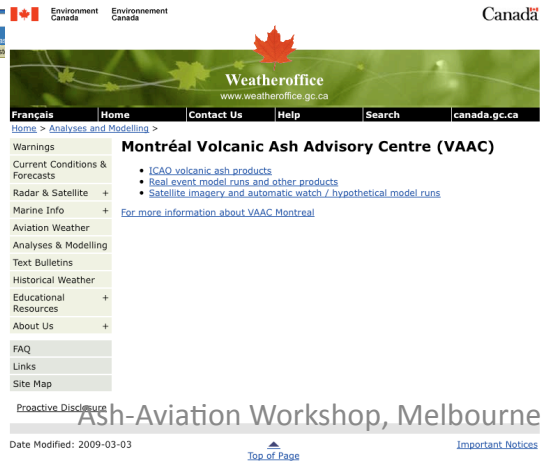
Darwin Volcanic Ash Advisory Centre
VAAC home | Detection | Gallery | Publications | FAQ | Links | Products | Contact VAAC | Acknowledgements
Keeping aircraft clear of volcanic ash
Nine Volcanic Ash Advisory Centres around the world advise the international aviation industry of the location and movement of clouds of volcanic ash. The area covered by the Darwin Volcanic Ash Advisory Centre includes Indonesia, Papua New Guinea and part of the Philippines. This area has seen some of the biggest eruptions known to history.
VAAC ANCHORAGE
VAAC MONTREAL
VAAC LONDON
VAAC TOKYO
VAAC WASHINGTON
VAAC TOULOUSE
VAAC WELLINGTON
VAAC BUENOS AIRES
VAAC DARWIN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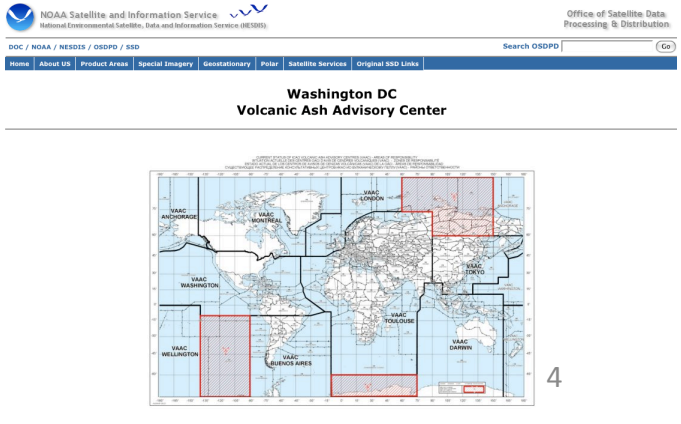
Montréal Volcanic Ash Advisory Centre (VAAC)
ICAO volcanic ash products
Real event model runs and other products
Satellite imagery and automatic watch / hypothetical model runs
For more information about VAAC Montreal
Proactive Disclosure
Date Modified: 2009-03-03
Top of Page
Important Notices


NOAA Satellite and Information Service
National Environmental Satellite, Data and Information Service (NESDIS)
Office of Satellite Data Processing & Distribution
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VAAC LONDON
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VAAC WASHINGTON
VAAC TOULOUSE
VAAC WELLINGTON
VAAC BUENOS AIRES
VAAC DARWIN

Our Approach – conceptual

- Listen to the User Community (VAACs) and aim to meet their needs
- Optimize use of EO data – emphasis on NRT and ESA data
- Provide quantitative products
- Demonstrate system (rather than implement)
- User feedback vital

- NILU
  - IR satellite retrievals
  - Transport/dispersion modelling
  - Inversion
  - Data-base management
- INGV
  - Volcanology
  - User networks
  - Natural laboratories
  - Seismic/remote sensing data
- Bremen
  - Satellite instruments/algorithm experts
  - GOME/GOME-2/SCIAMACHY
- BOKU
  - Inversion theory
  - Error analyses

- What is a realistic approach?
  - VAACs are “housed” within complex meteorological centres
  - Regulatory bodies operate at national/international levels e.g. CAA, FAA, ICAO
  - Airlines have final say in “real-world” situations
  - Issues remain around specifying “safe” levels of ash/SO_2
- SAVAA must deliver better products/ methods to VAACs

VAS³

Start Event

- Seismic
- User
- Satellite alert
- Simulation

Trigger

Satellite & Met data

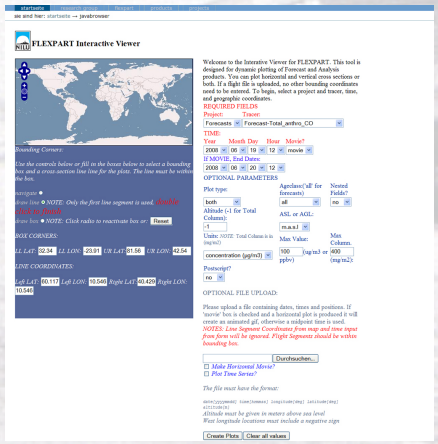
Initiate FLEXVOL run

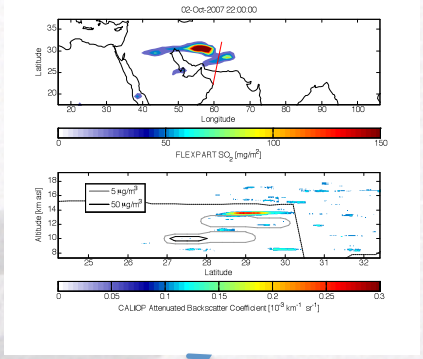
Standard height run

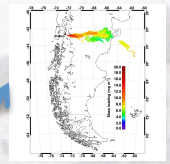
Inversion run

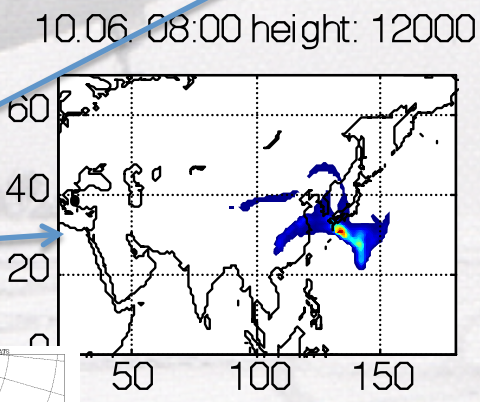
Webportal

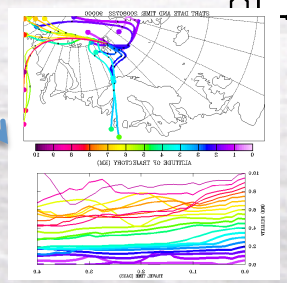
Terminate Event



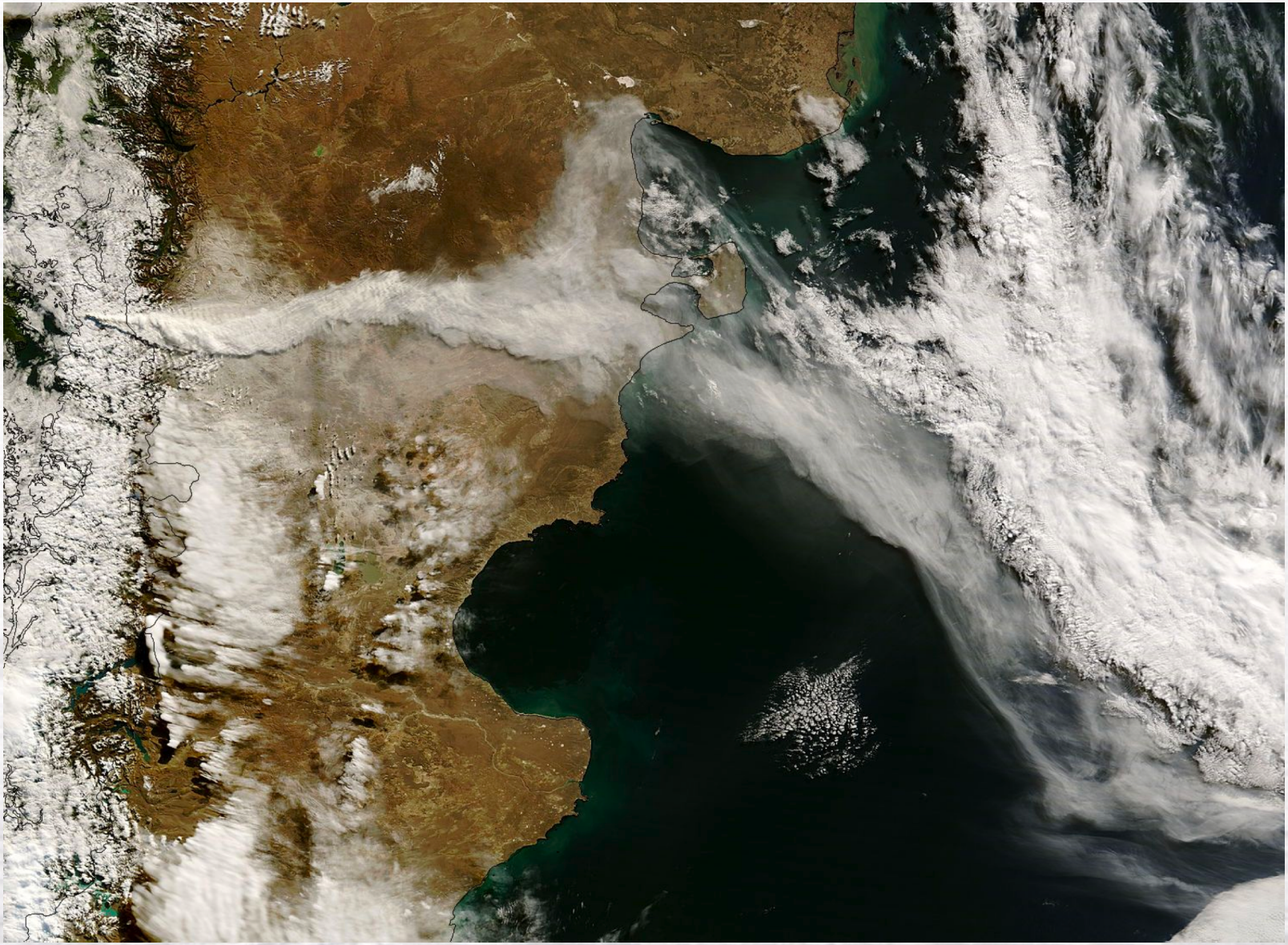




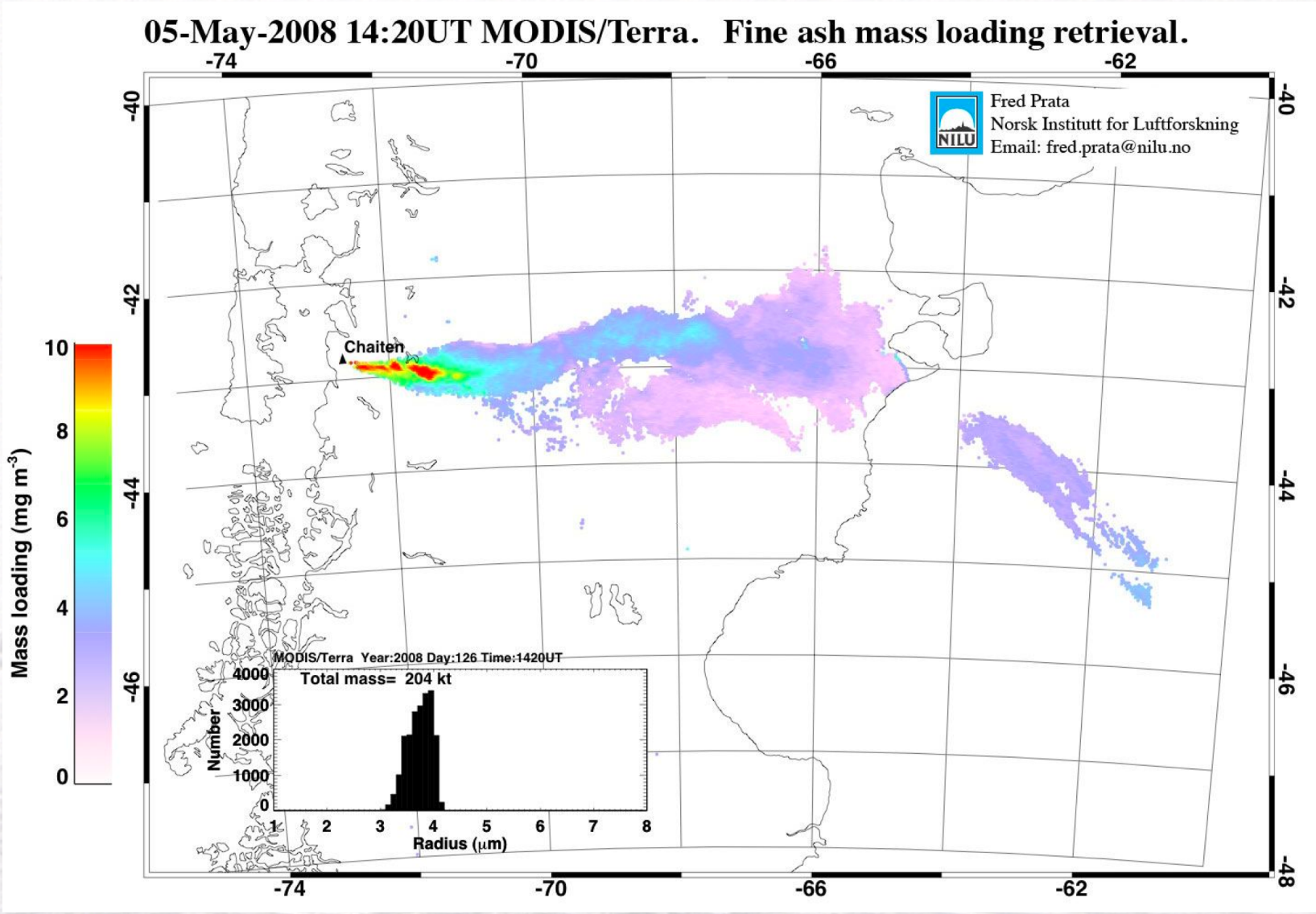




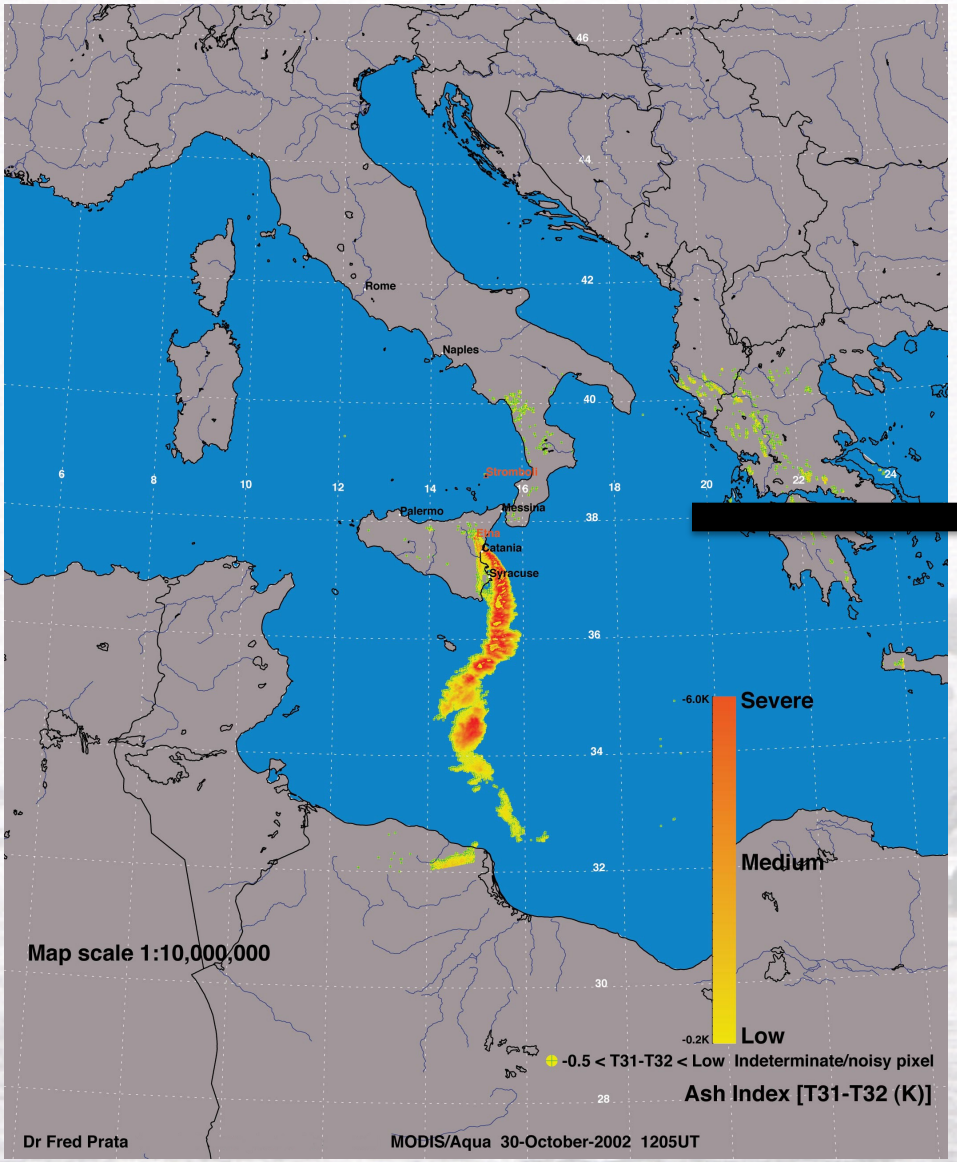
Satellite Products

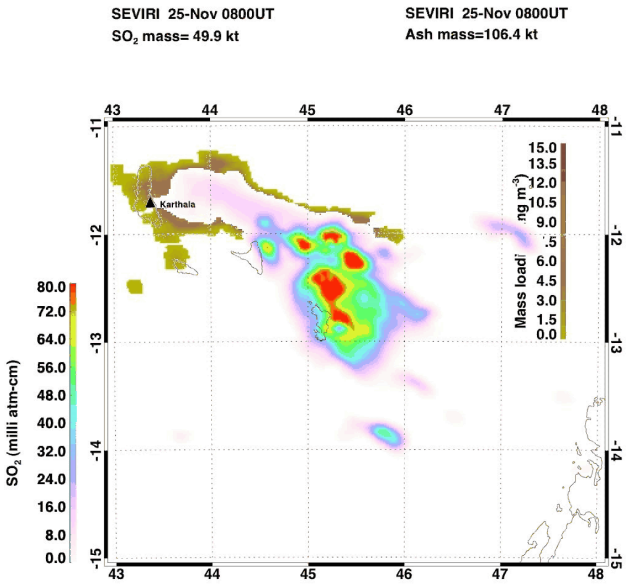


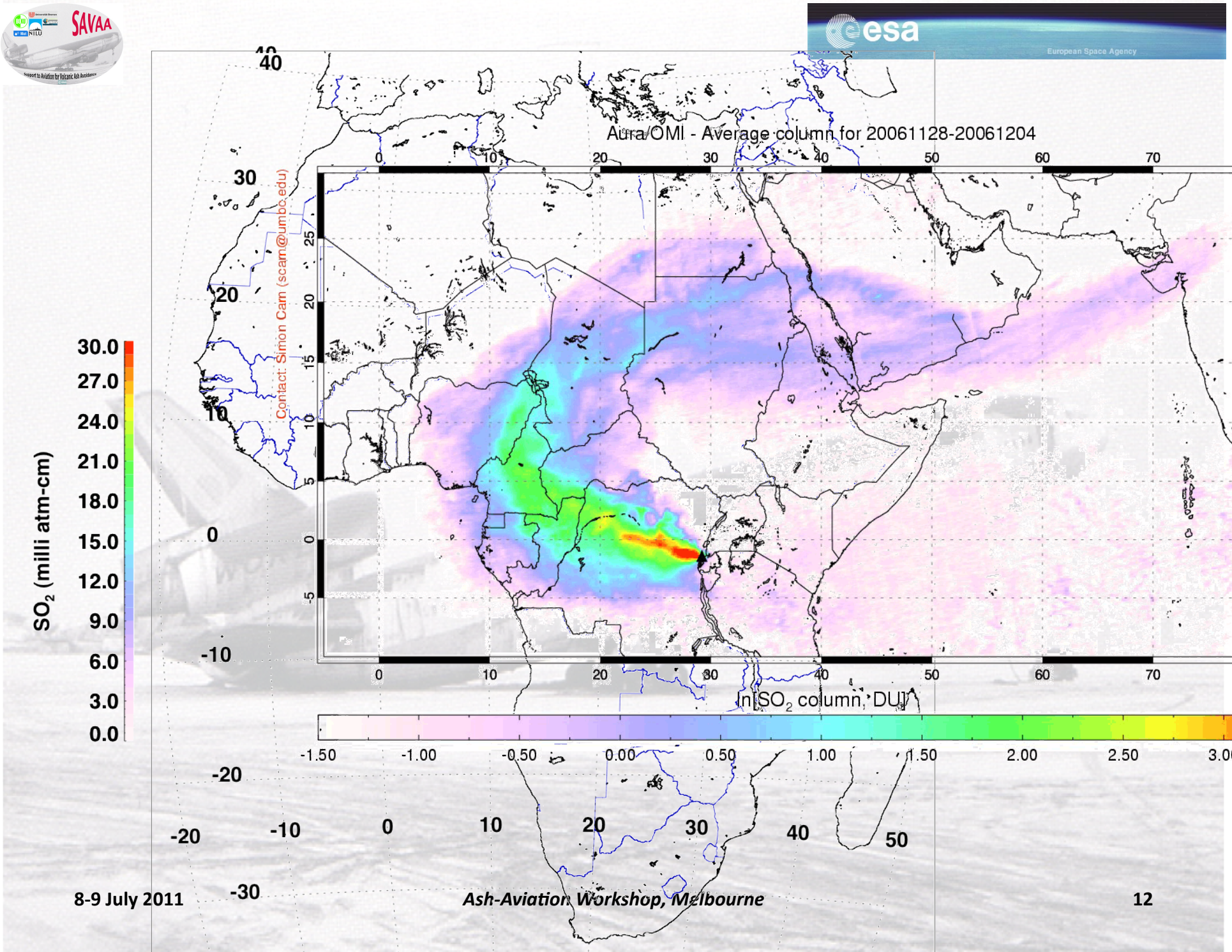
Better Satellite Products–MODIS



Better Satellite Products–SEVIRI

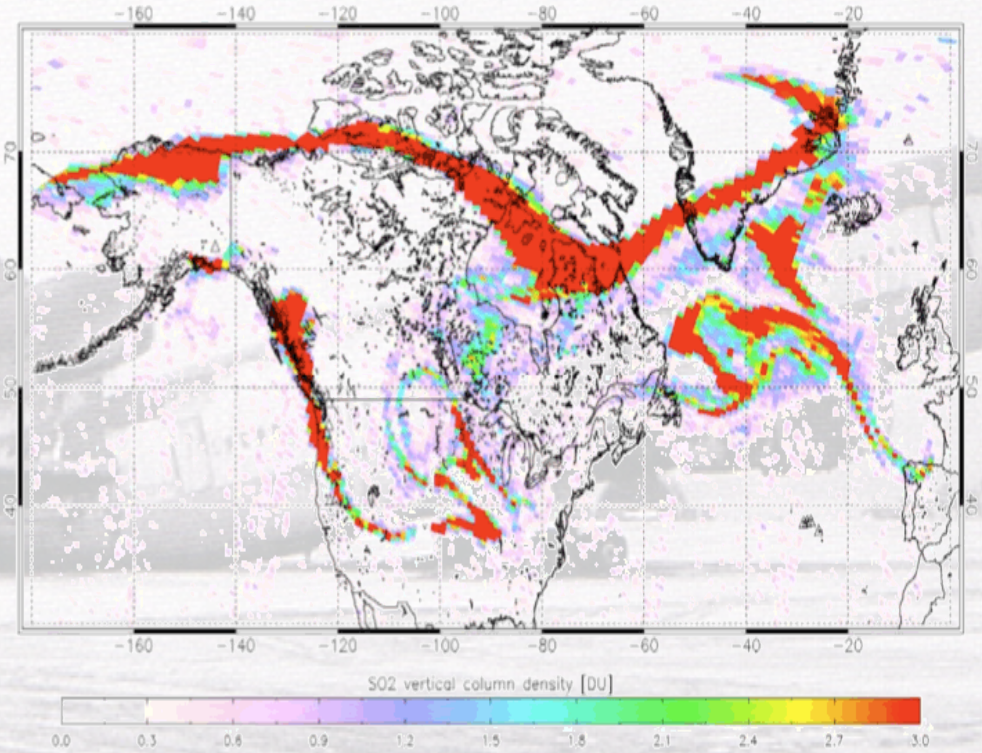





Aura/OMI - Average column for 20061128-20061204
Contact: Simon Carn (scarn@umbc.edu)
SO_2 (milli atm-cm)
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
ln[SO_2 column, DU]
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00

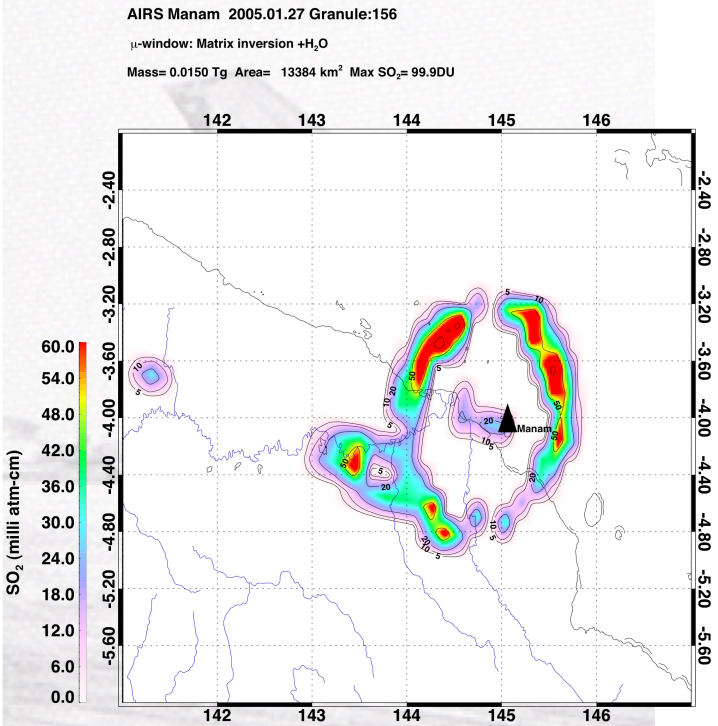
Initial validation of GOME-2 GDP 4.2

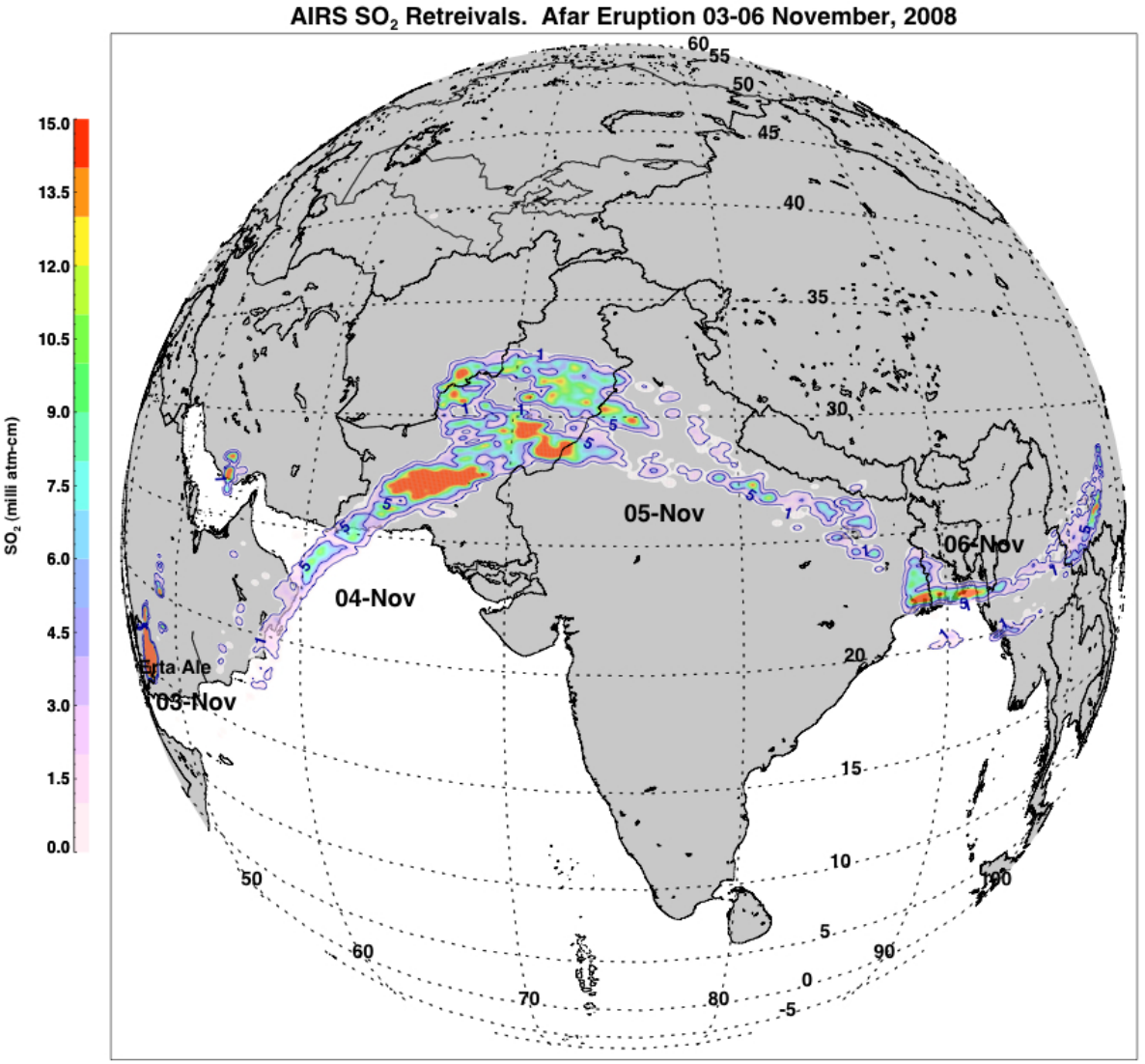
SO_2 total columns (OTO/SO2) – ORR B



Distribution of SO_2 on 14 August 2008 as seen by GOME-2. The SO_2 originates from the eruption on 8 August of the Kasatochi volcano, which is located at 52.17°N, 175.51°W.

Better Satellite Products–AIRS





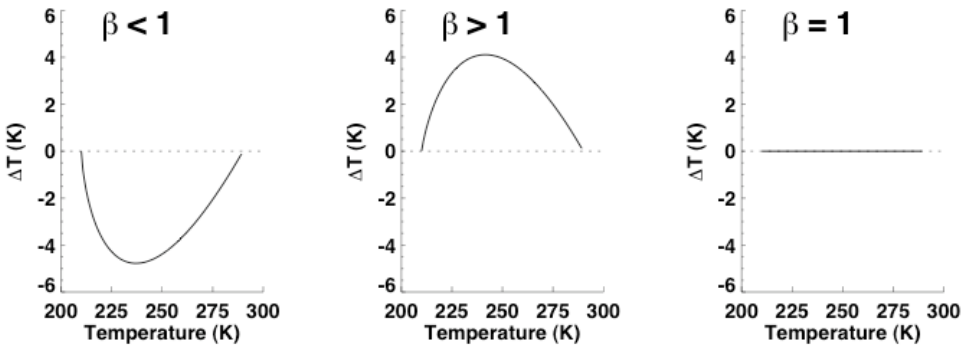
Volcanic ash – Detection and discrimination

Prata, A. J., 1989, Infrared radiative transfer calculations for volcanic ash, Geophys. Res. Lett., 16(11), 1293-1296

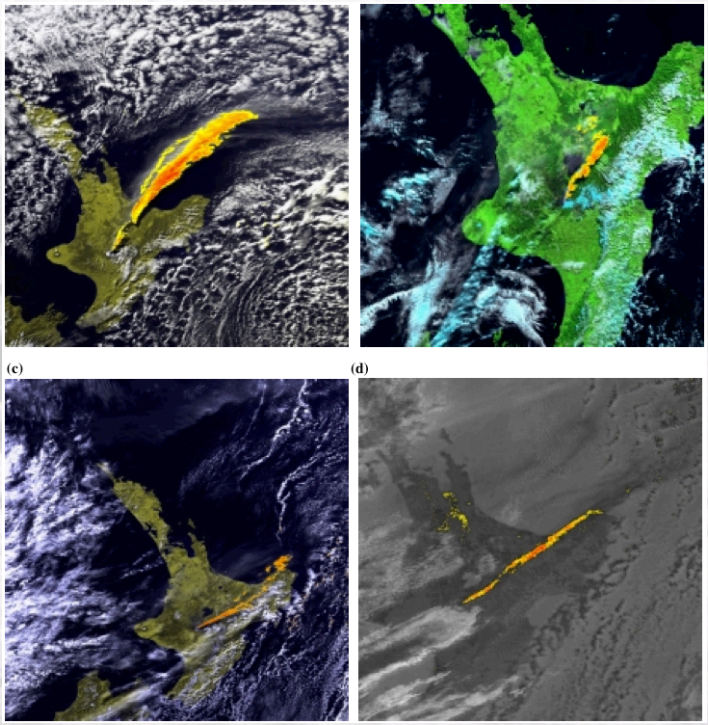
$$\Delta T = \Delta T_c [X - X^{\beta}],$$

$$X = 1 - \frac{\Delta T_4}{\Delta T_c},$$

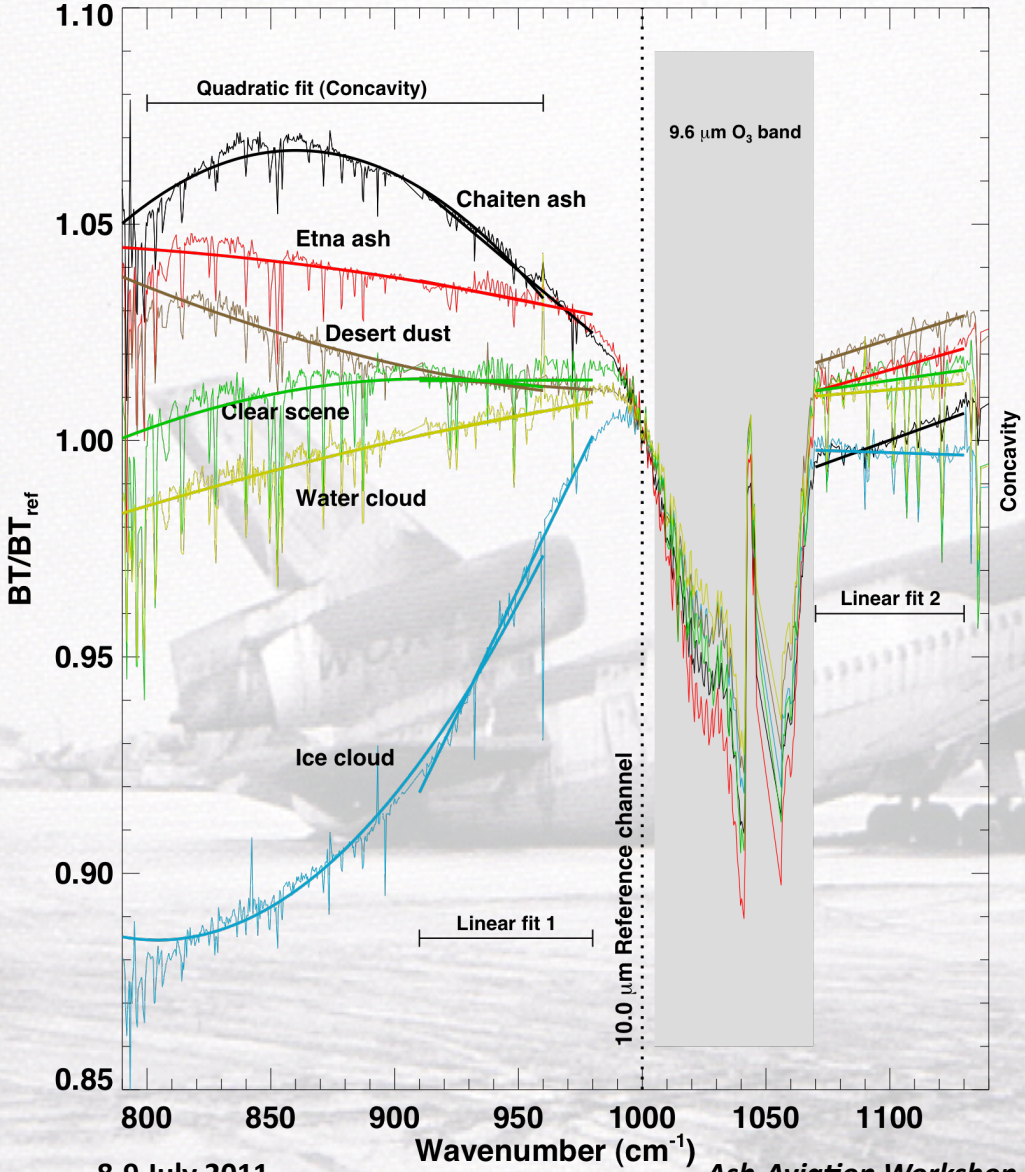
$$\Delta T = T_4 - T_5, \quad \Delta T_c = T_s - T_c, \quad \Delta T_4 = T_s - T_4.$$

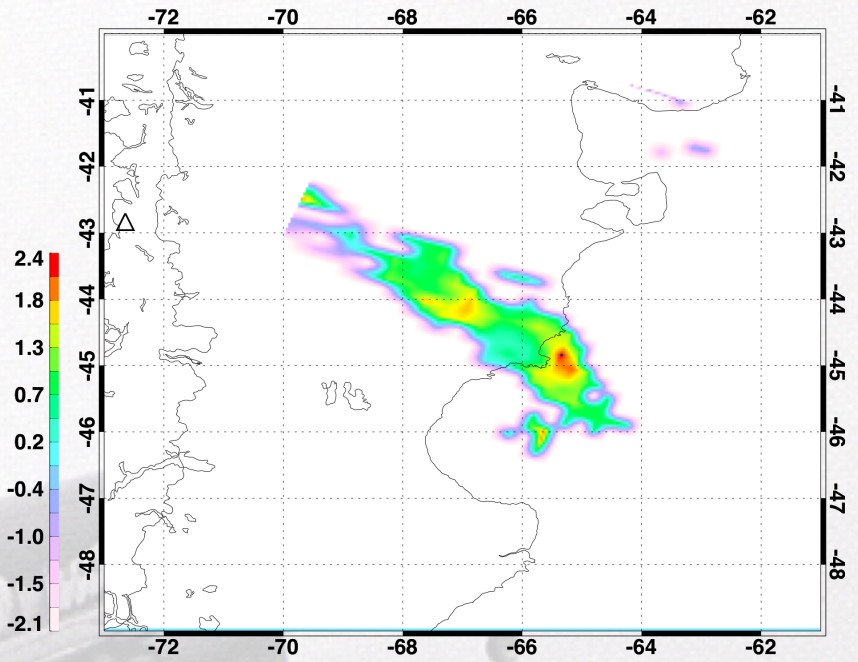


$T_4 - T_5 < 0$

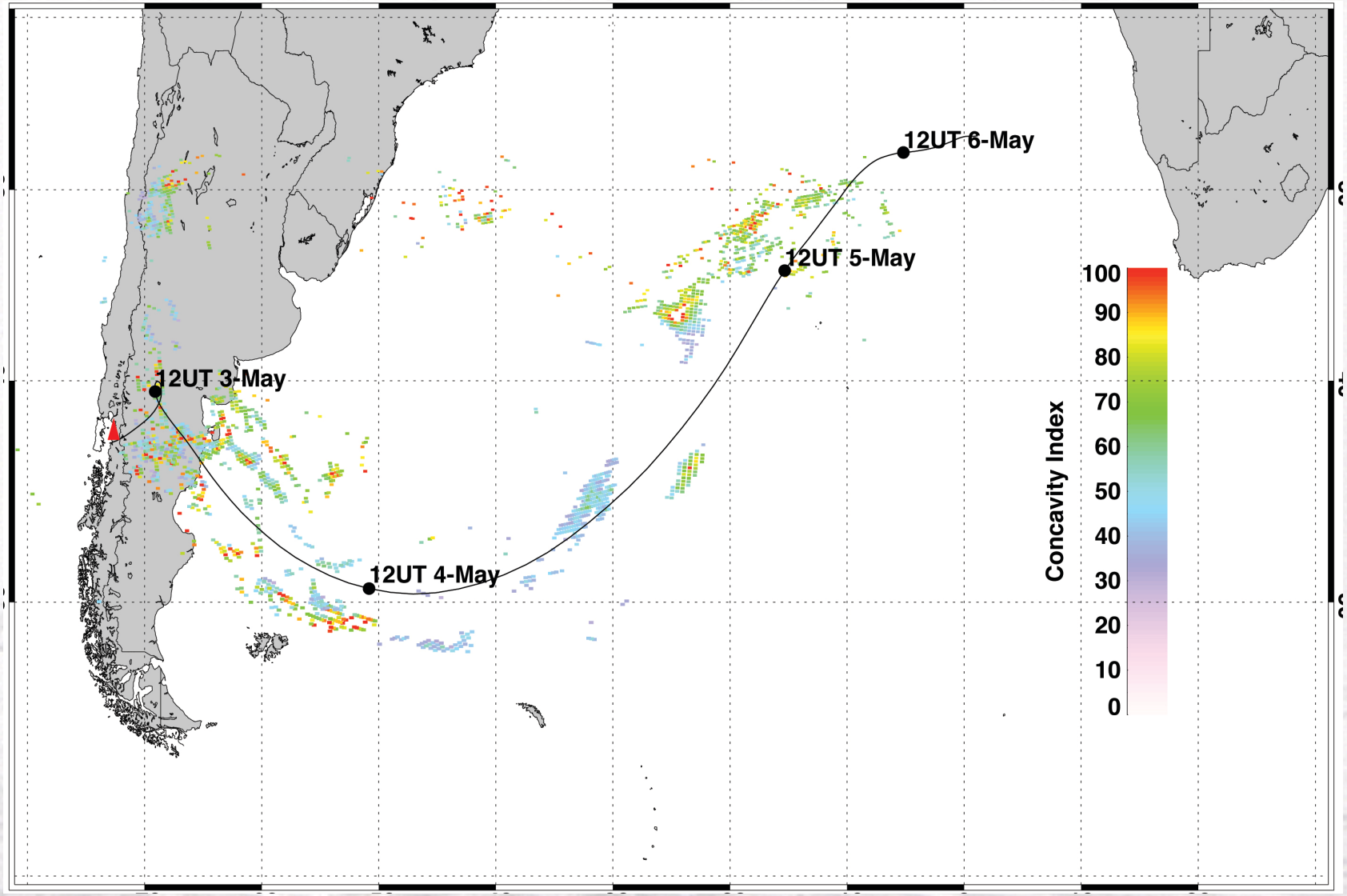


- Better Identification of Ash – Exploiting high-spectral resolution data (AIRS and IASI)



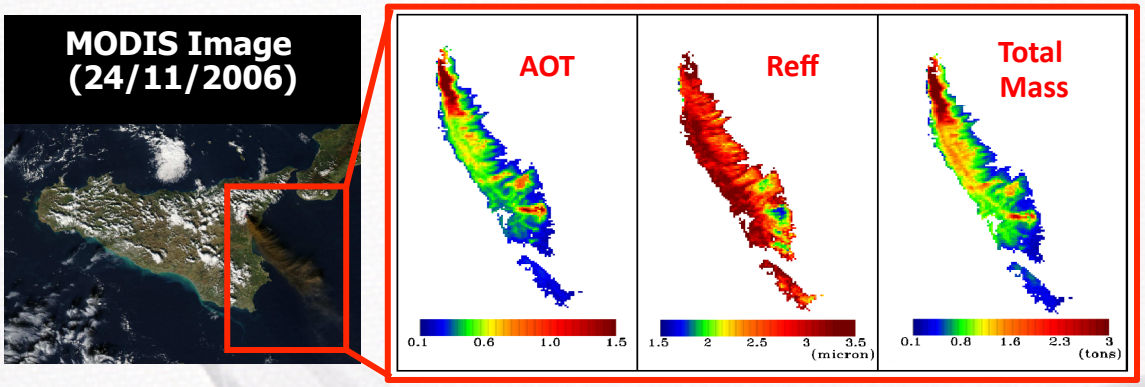


• Better Satellite Products

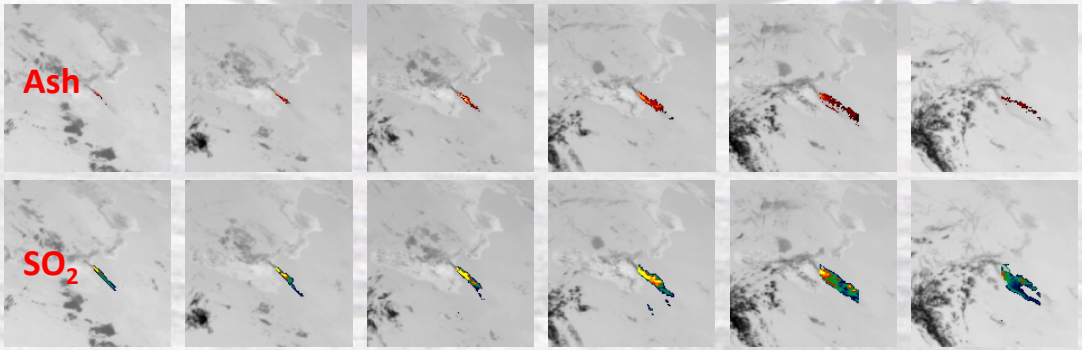


Mt. Etna tropospheric ash retrieval and sensitivity analysis using Moderate Resolution Imaging Spectroradiometer measurements

S. Corradini, C. Spinetti, E. Carboni, C. Tirelli, M. F. Buongiorno, S. Pugnaghi, G. Gangale - *Submitted to JARS, December 2007*

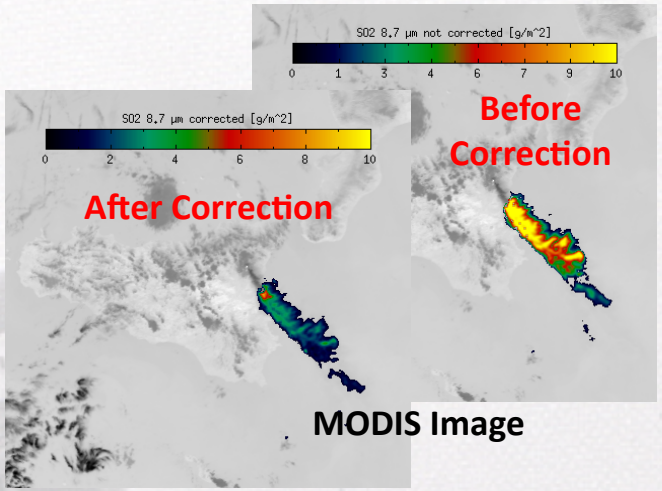


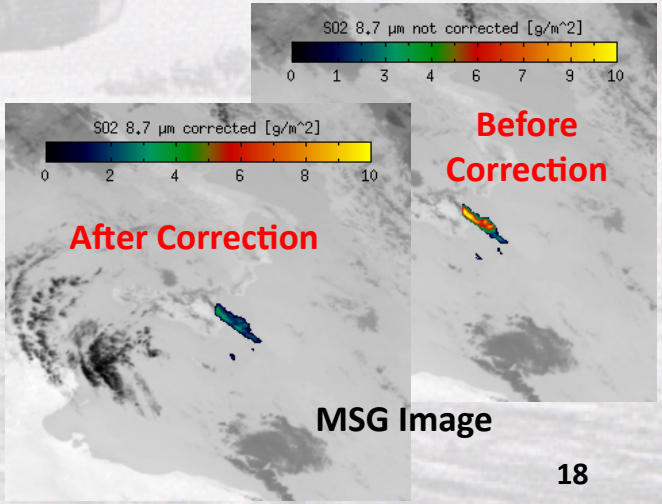
SO_2 volcanic plume evolution during the 24 November 2006 Mt. Etna tropospheric eruption using MSG-SEVIRI data: retrieval procedures and validation



Volcanic ash correction procedure on SO_2 plume retrieval in the Thermal Infrared spectral range from satellite measurements

S. Corradini, L. Merucci, A. J. Prata (submitted to ACPD)





Inverse Modelling – Analytical Method

Sources x (1..n) x^a a priory profile

Satellite observation y^0 (1..m)

M Emission sensitivity Matrix (m × n), as obtained from FLEXPART

σ standard error of observation

$$\mathbf{M}(\mathbf{x}-\mathbf{x}^a) \approx \mathbf{y}^o - \mathbf{M}\mathbf{x}^a$$

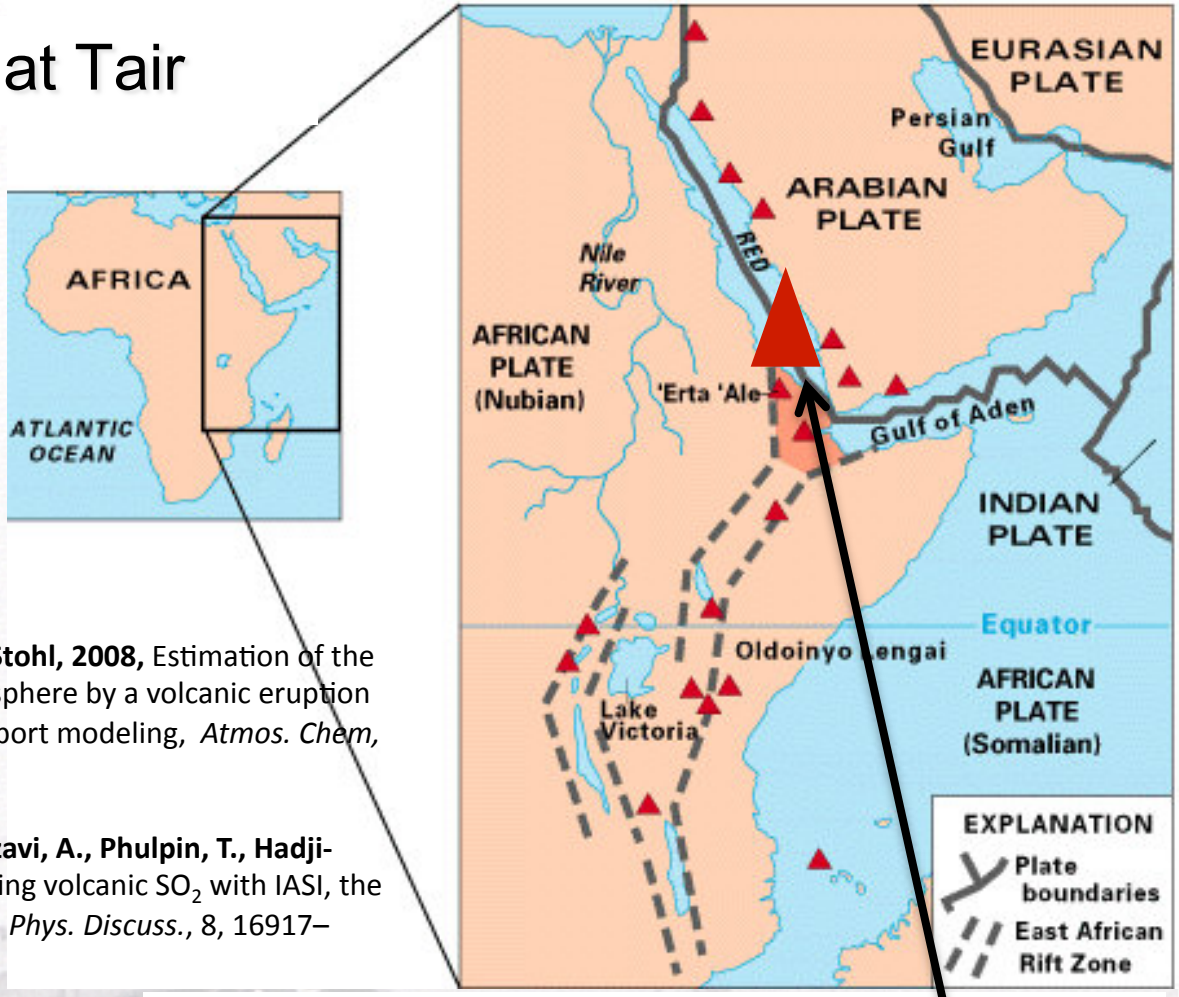
$$\mathbf{M}\tilde{\mathbf{x}} \approx \tilde{\mathbf{y}}.$$

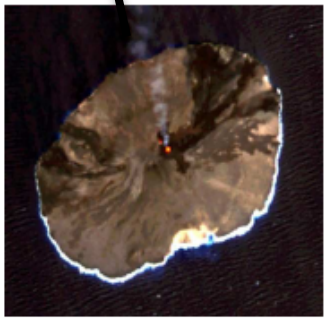
$$J = \underbrace{(\mathbf{M}\tilde{\mathbf{x}}-\tilde{\mathbf{y}})^T \mathbf{diag}(\sigma_o^{-2})(\mathbf{M}\tilde{\mathbf{x}}-\tilde{\mathbf{y}})}_{\text{I) misfit model – observation}} + \underbrace{\tilde{\mathbf{x}}^T \mathbf{diag}(\sigma_{\mathbf{x}}^{-2})\,\tilde{\mathbf{x}}}_{\text{II) deviation from first guess}} + \underbrace{\epsilon\,(\mathbf{D}\tilde{\mathbf{x}})^T \mathbf{D}\tilde{\mathbf{x}}}_{\text{III) smoothness condition}}$$

Source-receptor matrix calculation with a Lagrangian particle dispersion model in backward mode, P. Seibert and A. Frank, ACP, 4, 51-63, 2004.

Eruption of Jebel at Tair

September 30th, 2007 Jebel at Tair erupted, a SO_2 plume was released into the atmosphere, observed from many satellite platforms over a period of 8 days

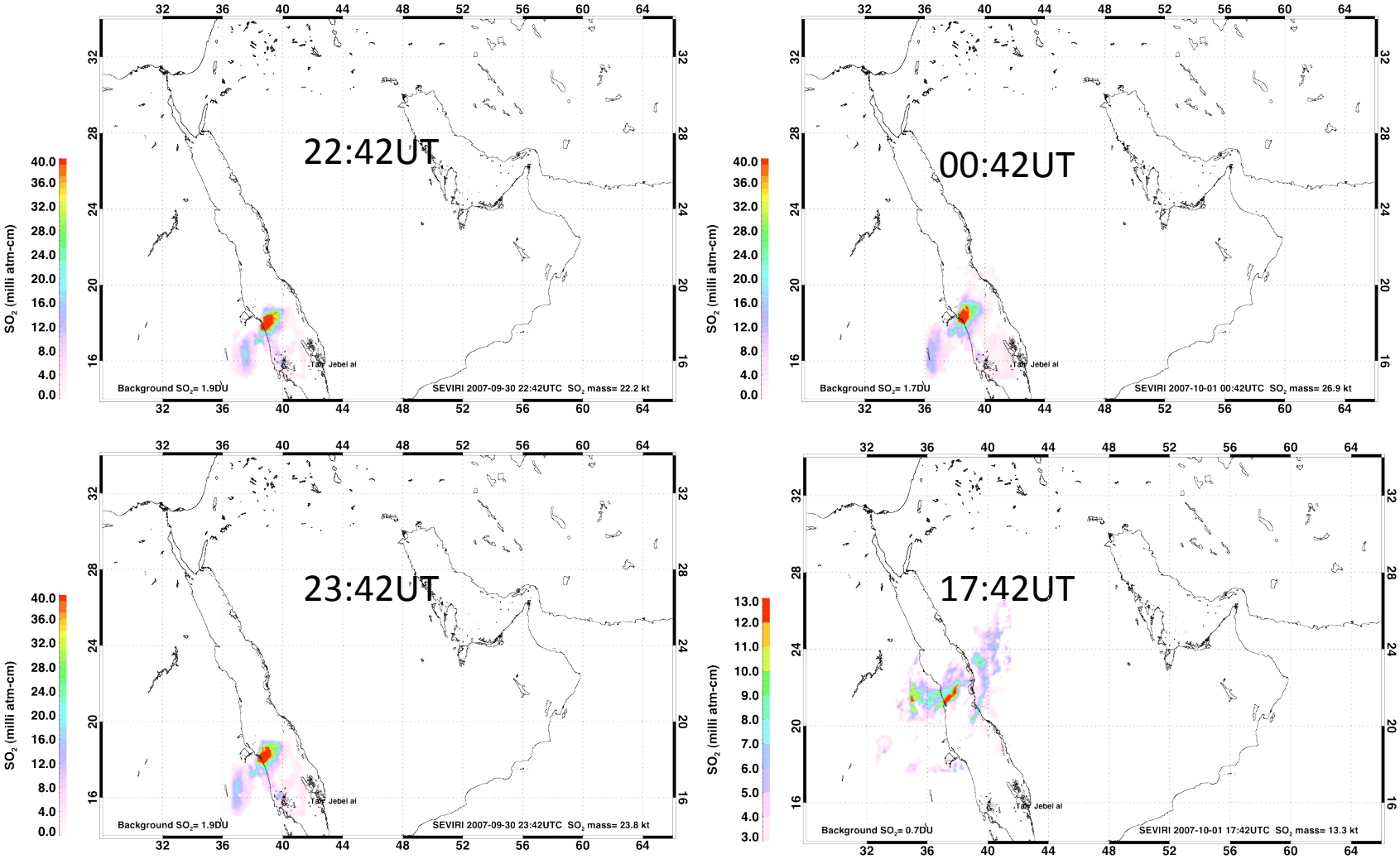




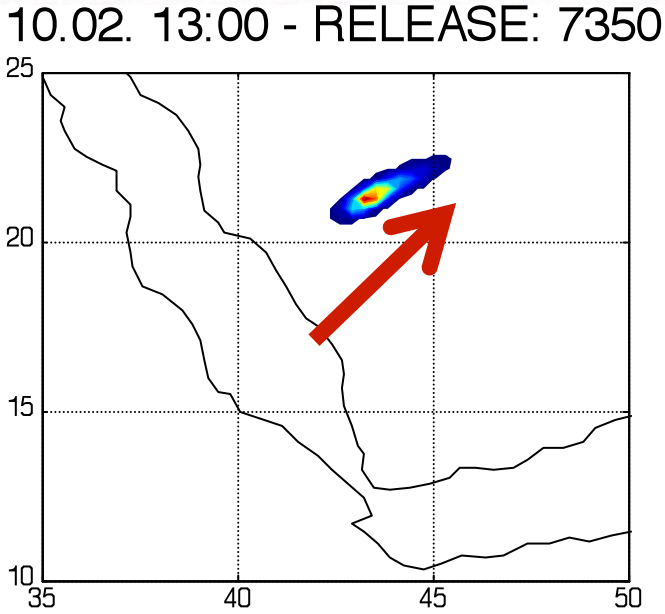
Eckhardt, S., Prata, A. J., Seibert, P., Stebel, K., and A. Stohl, 2008, Estimation of the vertical profile of sulfur dioxide injection into the atmosphere by a volcanic eruption using satellite column measurements and inverse transport modeling, *Atmos. Chem, Phys.,* 8, 3881–3897.

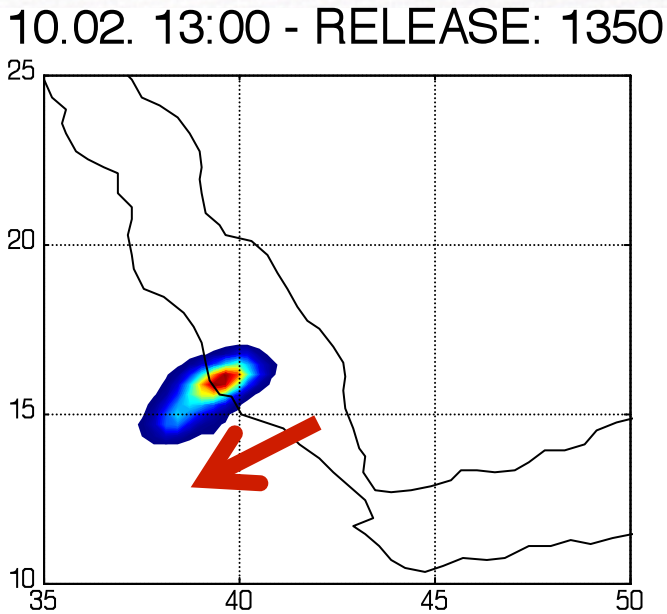
Clarisse, L., Coheur, P. F., Prata, A. J., Hurtmans, D., Razavi, A., Phulpin, T., Hadji-Lazaro, J., and C. Clerbaux, 2008, Tracking and quantifying volcanic SO_2 with IASI, the September 2007 eruption at Jebel at Tair, *Atmos. Chem. Phys. Discuss.*, 8, 16917–16949

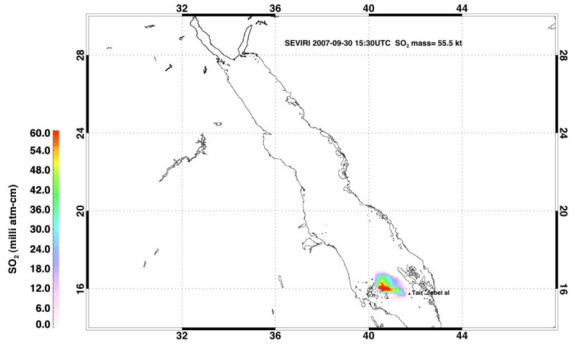
SEVIRI SO_2 retrievals every 15 min



Match Model and Satellite





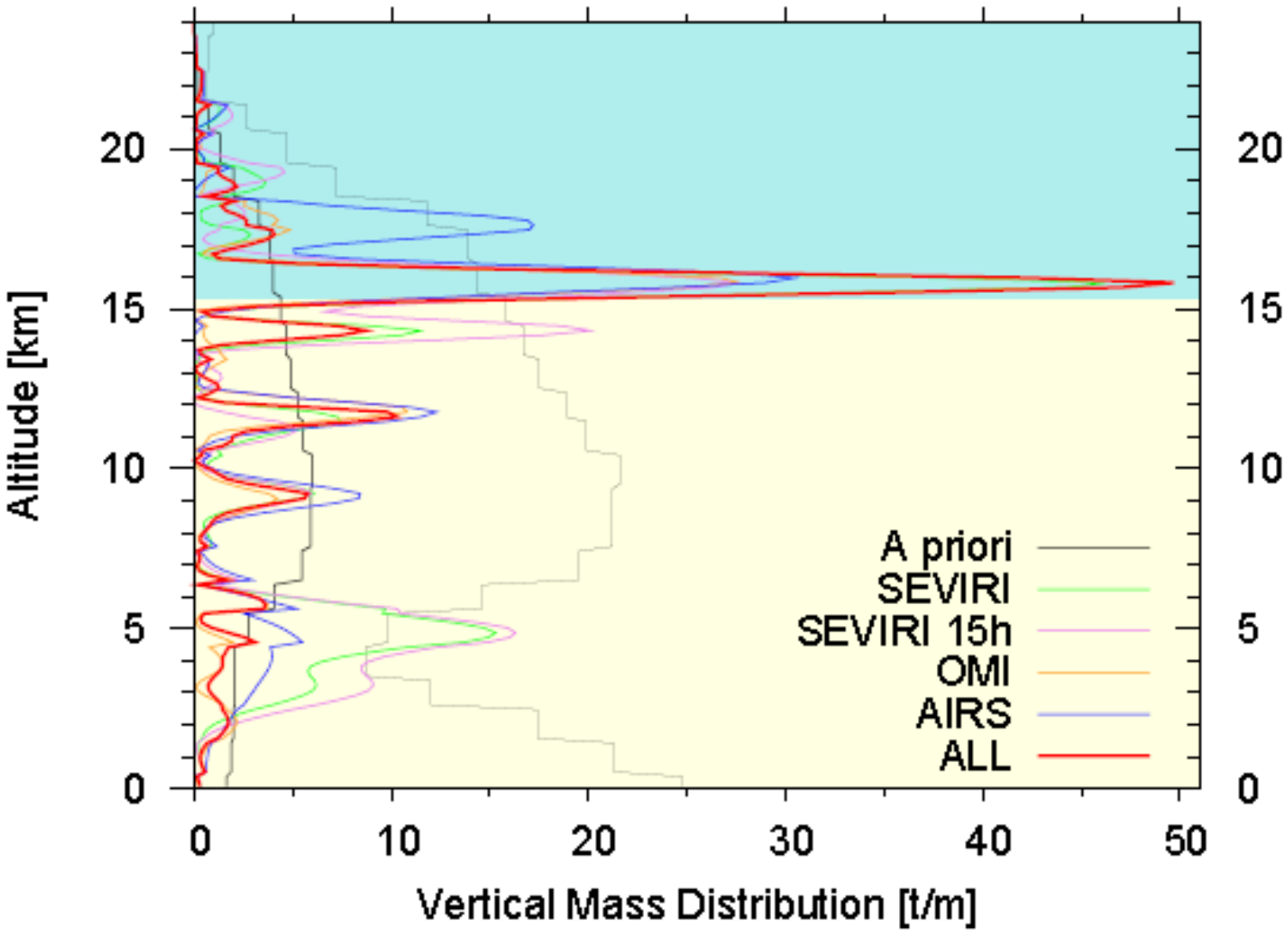


Automatically Match:

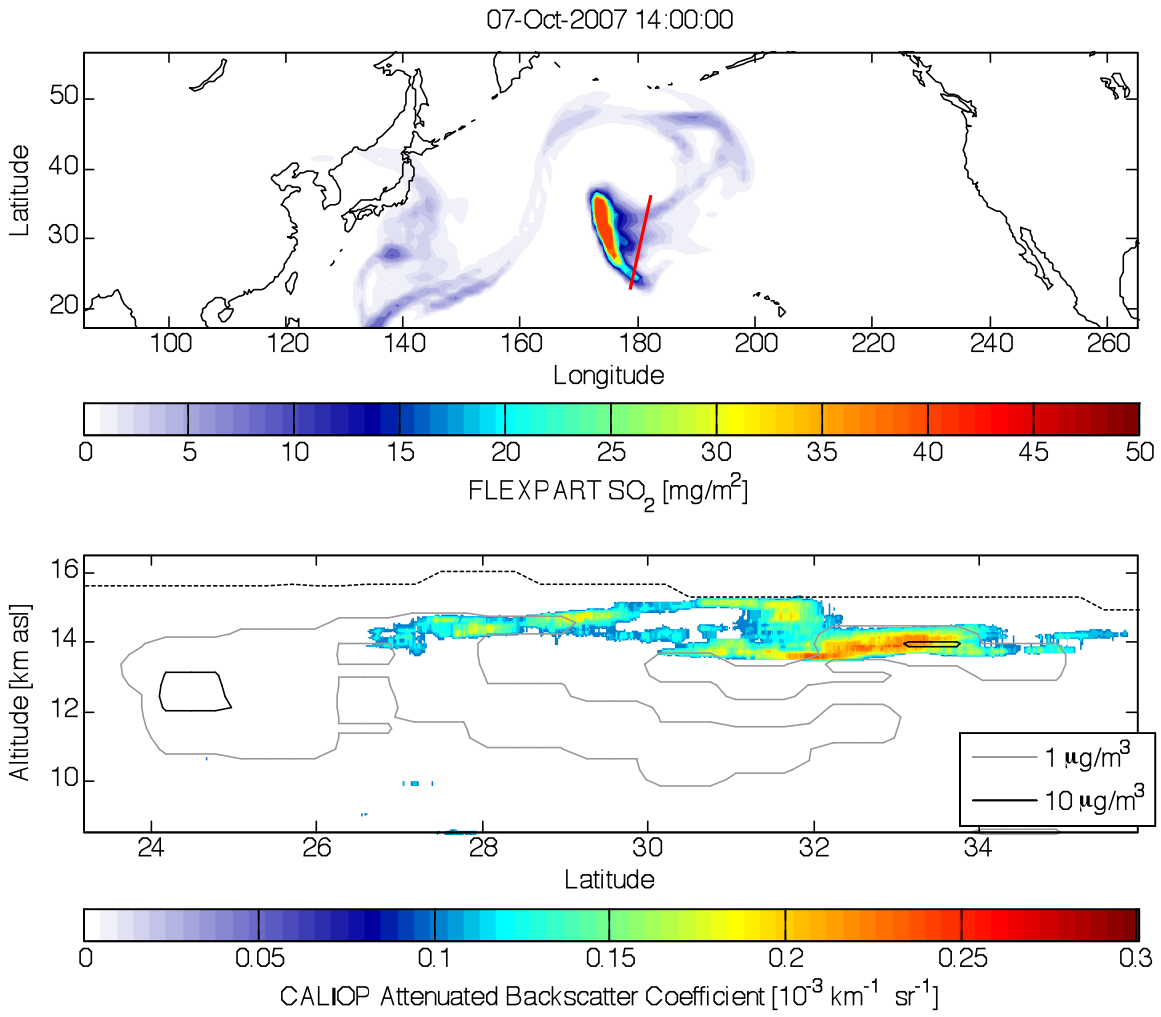
hourly FLEXPART simulation result

hourly averaged SATELITTE image (SEVIRI)

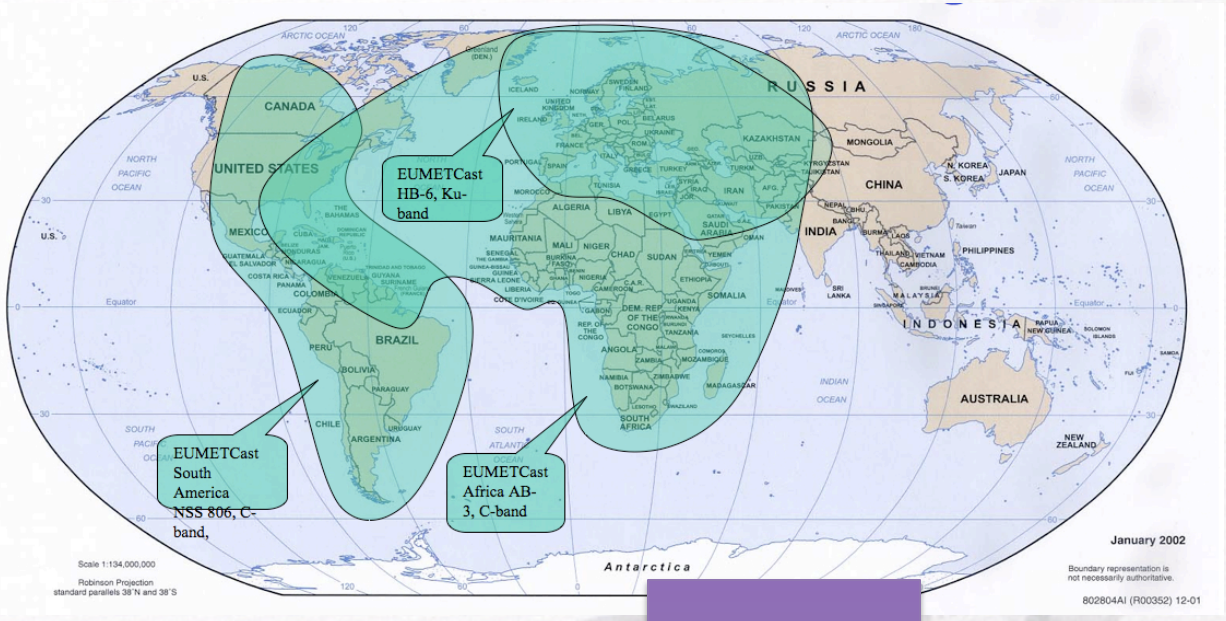
Emission Profile



CALIOP - 8 days after eruption



VAS³



R&D Institutes

Media?

VAACs

General public

Webportal

Workstation

Eumetcast

Flexvol

External links (SACS, AIRS)

SAVAA developers

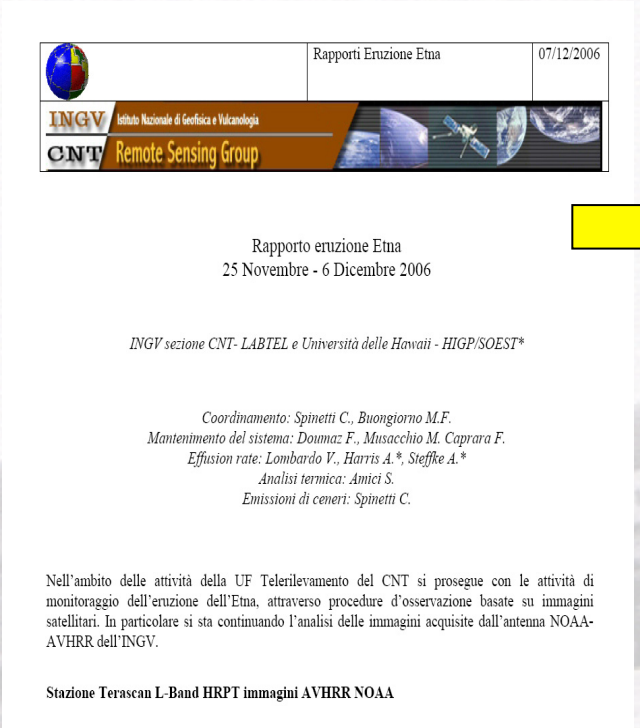
Airlines?

Real time satellite derived information during 2006 Mt. Etna eruption

Hot Spot detection
ER calculation
Avhotrr
Modvolc

Volcanic ash detection

Observation Report



Rapporti Eruzione Etna | 07/12/2006

INGV Istituto Nazionale di Geofisica e Vulcanologia
CNT Remote Sensing Group

Rapporto eruzione Etna
25 Novembre - 6 Dicembre 2006

*INGV sezione CNT- LABTEL e Università delle Hawaii - HIGP/SOEST**

Coordinamento: Spinetti C., Buongiorno M.F.
Mantenimento del sistema: Doumaz F., Musacchio M. Caprara F.
Effusion rate: Lombardo V., Harris A., Steffke A.**
Analisi termica: Amici S.
Emissioni di ceneri: Spinetti C.

Nell'ambito delle attività della UF Telerilevamento del CNT si prosegue con le attività di monitoraggio dell'eruzione dell'Etna, attraverso procedure d'osservazione basate su immagini satellitari. In particolare si sta continuando l'analisi delle immagini acquisite dall'antenna NOAA-AVHRR dell'INGV.

Stazione Terascan L-Band HRPT immagini AVHRR NOAA

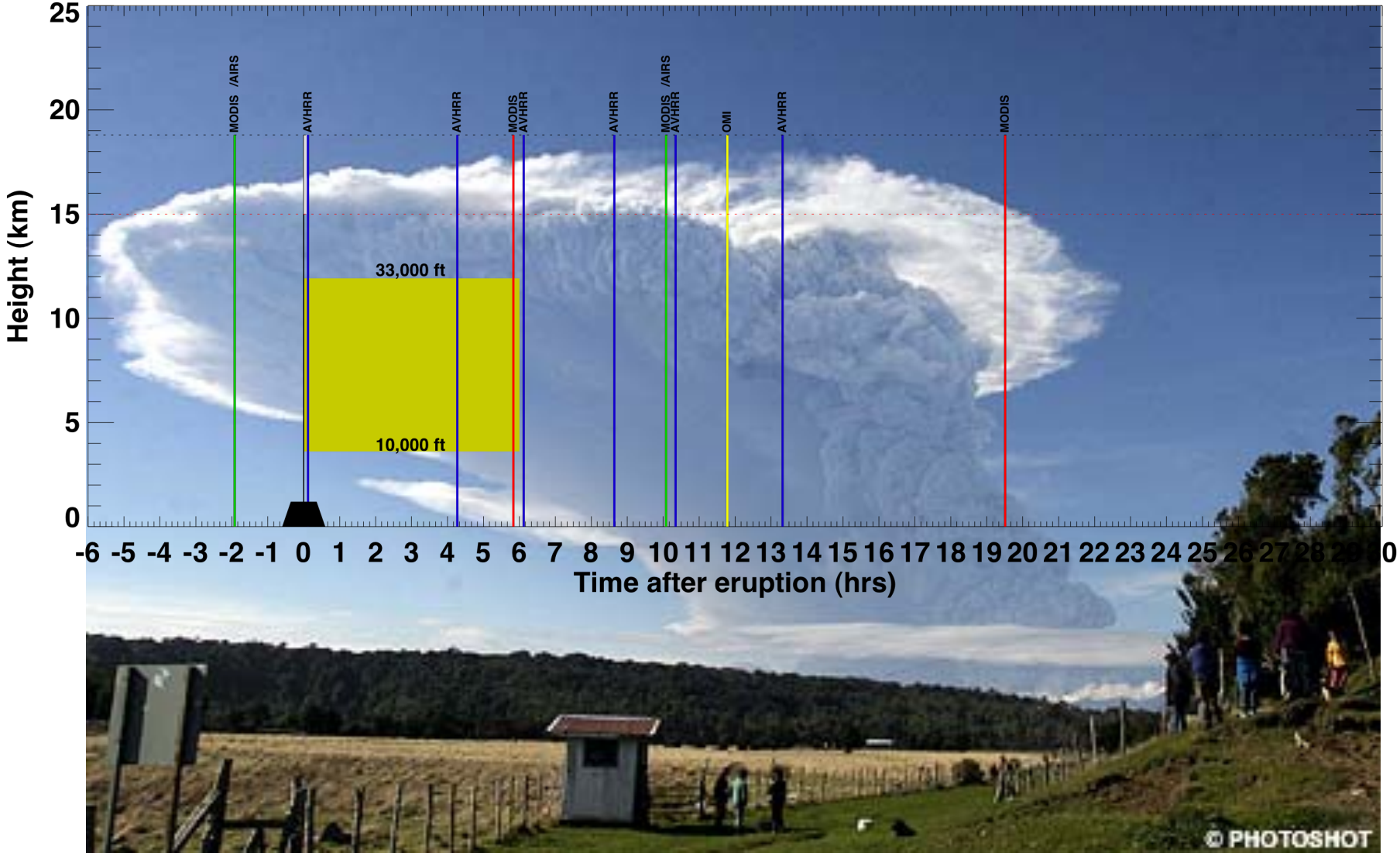
INGV CT
Operative Room

DPC
Synthesis Room

Increasing of explosive events

Volcanic ash information has been sent 2 time per day

Fontanarossa airport


Chaiten 02.05.2008
Height (km)
25
20
15
10
5
0
MODIS /AIRS
AVHRR
AVHRR
MODIS
AVHRR
AVHRR
MODIS /AIRS
AVHRR
OMI
AVHRR
MODIS
33,000 ft
10,000 ft
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Time after eruption (hrs)
© PHOTOSHOT

Redoubt – 23.03.2009-present

Redoubt

Alaska Airlines Cancels Flights After Mount Redoubt Eruption

Share | Email | Print | A A A

By Dinakar Sethuraman

March 29 (Bloomberg) -- **Alaska Airlines** said it canceled flights out of Anchorage International Airport after Mount Redoubt erupted again, prompting authorities to shut down the airstrip for fear of volcanic ash.

"We're continuing to closely monitor the weather and ash from Mount Redoubt and will resume flights when it is safe to do so," **Ben Minicucci**, the airlines's chief operating officer, said in a statement on PR Newswire.

Alaska Airlines has canceled more than 185 flights affecting about 10,000 passengers since the volcanic eruptions began on March 22, the statement said. **Mount Redoubt** rises 10,197 feet (3,108 meters) above the Kenai Peninsula, 106 miles (170 kilometers) southwest of Anchorage.

To contact the reporter on this story: **Dinakar Sethuraman** in Singapore at **dinakar@bloomberg.net**

Last Updated: March 29, 2009 01:41 EDT

Timing

OPS Room Initial Interpretation		Date	Time (local)		Time (UTC)	
	1	3/22/2009	10:38pm	3/22/09	6:38	
	2	3/22/2009	11:02pm	3/22/09	7:02	
	3	3/23/2009	12:14am	3/23/09	8:14	
	4	3/23/2009	1:39am	3/23/09	9:39	
	5	3/23/2009	4:31am	3/23/09	12:31	
	6	3/23/2009	7:41pm	3/23/09	3:41	
AIRS IMAGE from 3-24-2009 UTC 11:35 shows 62.2 kt in image						
	7	3/26/2009	8:34 AM	3/26/2009		
	8	3/26/2009	9:24 AM	3/26/2009		
	9	3/26/2009	11:47 PM	3/26/2009		
	10	3/27/2009	12:29 AM	3/27/2009		
	11	3/27/2009	8:39 AM	3/27/2009	16:39	16:46
AIRS IMAGE from 3-27-2009 UTC 21:50 shows 33.8 kt in image						
	12		5:35 PM	3/28/2009	1:35	
	13	3/27/2009	7:25 PM	3/28/2009	3:25	
	14	3/27/2009	11:20 PM	3/28/2009	7:20	
	15	3/28/2009	1:20 AM	3/28/2009	9:20	
	16	3/28/2009	1:40 PM	3/28/2009	21:40	
	17	3/28/2009	3:29 PM	3/28/2009	23:29	
	18	3/28/2009	7:23 PM	3/28/2009	3:23	

Courtesy: Cindy Werner, USGS

First Notification - via email

[volcanicclouds] Explosive eruption at Redoubt Volcano, Alaska

From: **volcanicclouds@yahoogroups.com** on behalf of **David J Schneider** (djschneider@usgs.gov)
Sent: Monday, 23 March 2009 10:36:36 PM
To: volcanicclouds@yahoogroups.com

Hello all,

Just a short note to inform folks that Redoubt Volcano has had 4 explosive events, three of which were in the range of 40000 to 50000 feet asl. The events were at 0638, 0702, 0814 and 0939 UTC, and lasted for very roughly 10-20 minutes each. Ash has missed Anchorage and was recorded by Nexrad radar and a new USGS C-band Doppler that was made operational just yesterday. More details as they become available.

Dave Schneider

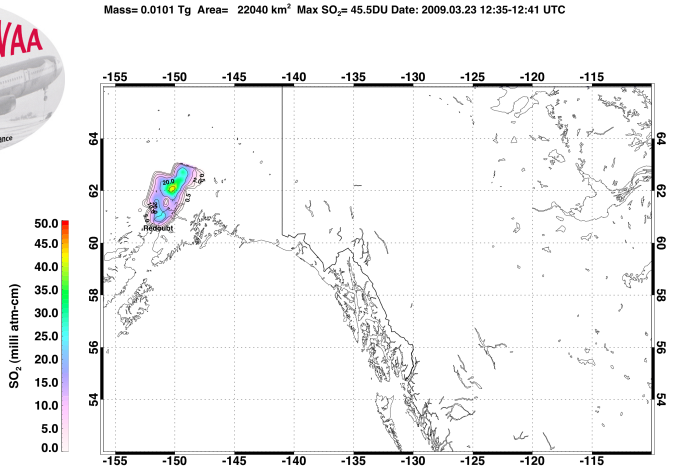
RECENT ACTIVITY

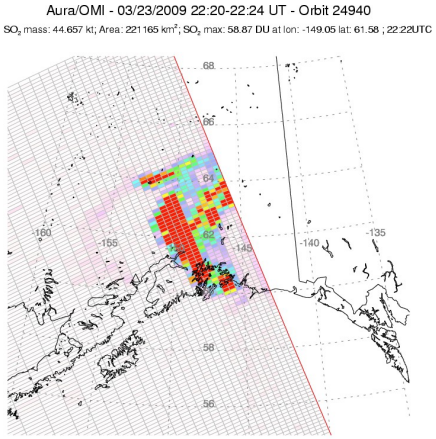
Visit Your Group

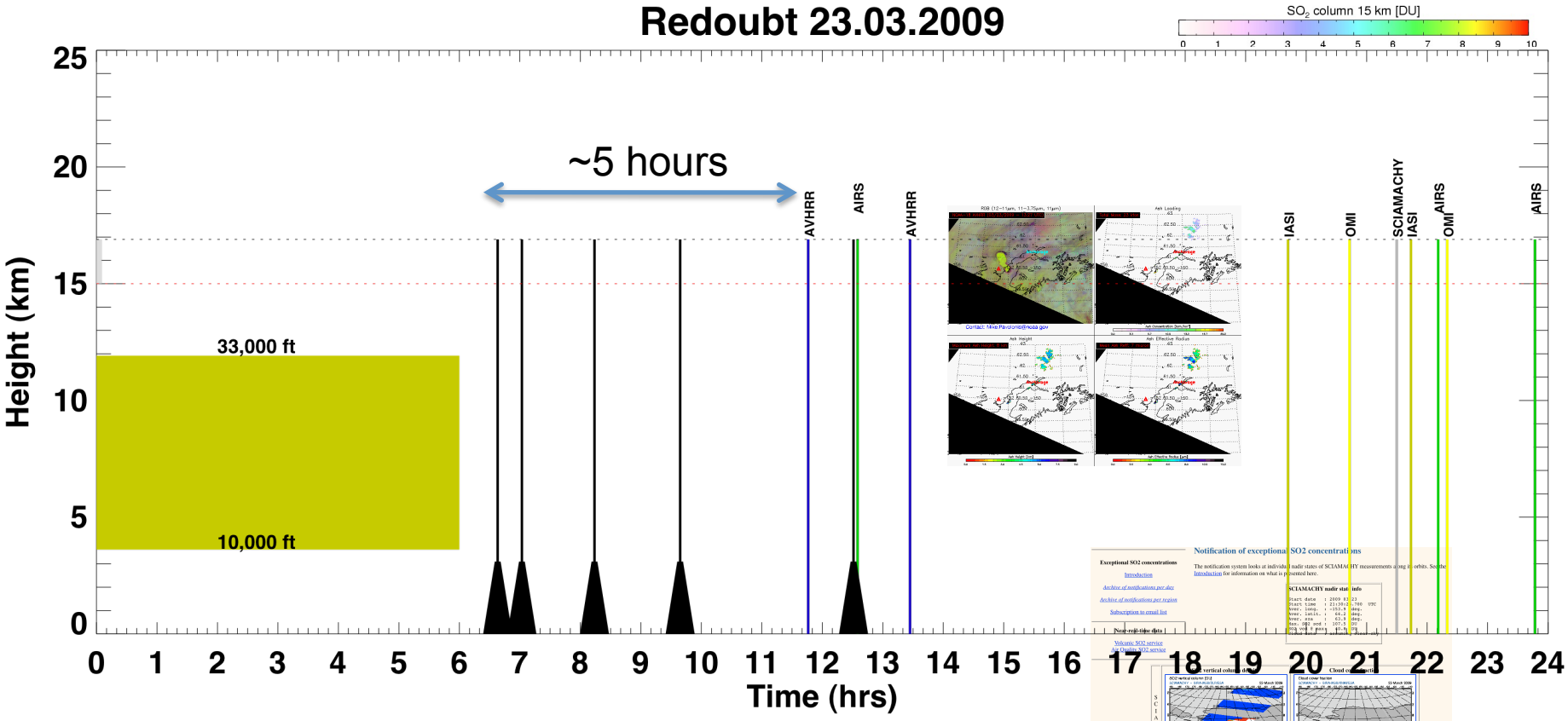
Dog Groups on Yahoo! Groups

discuss everything


SAVAA
Support to Aviation for Volcanic Ash Avoidance
NILU


Mass= 0.0101 Tg Area= 22040 km² Max SO₂= 45.5DU Date: 2009.03.23 12:35-12:41 UTC
SO₂ (milli atm-cm)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Redoubt


Aura/OMI - 03/23/2009 22:20-22:24 UT - Orbit 24940
SO₂ mass: 44.657 kt; Area: 221165 km²; SO₂ max: 58.87 DU at lon: -149.05 lat: 61.58 ; 22:22UTC

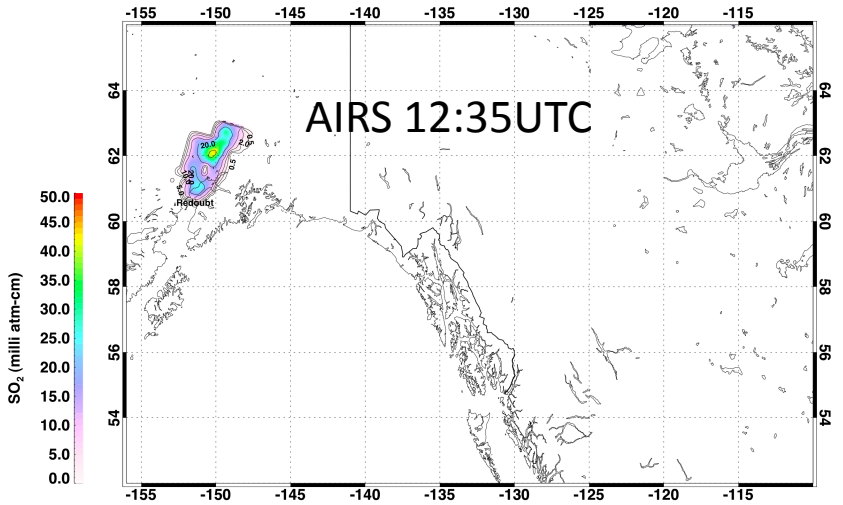

Redoubt 23.03.2009
SO₂ column 15 km [DU]
~5 hours
33,000 ft
10,000 ft
Height (km)
Time (hrs)
AVHRR
AIRS
AVHRR
IASI
OMI
SCIAMACHY
IASI
OMI
AIRS
AIRS

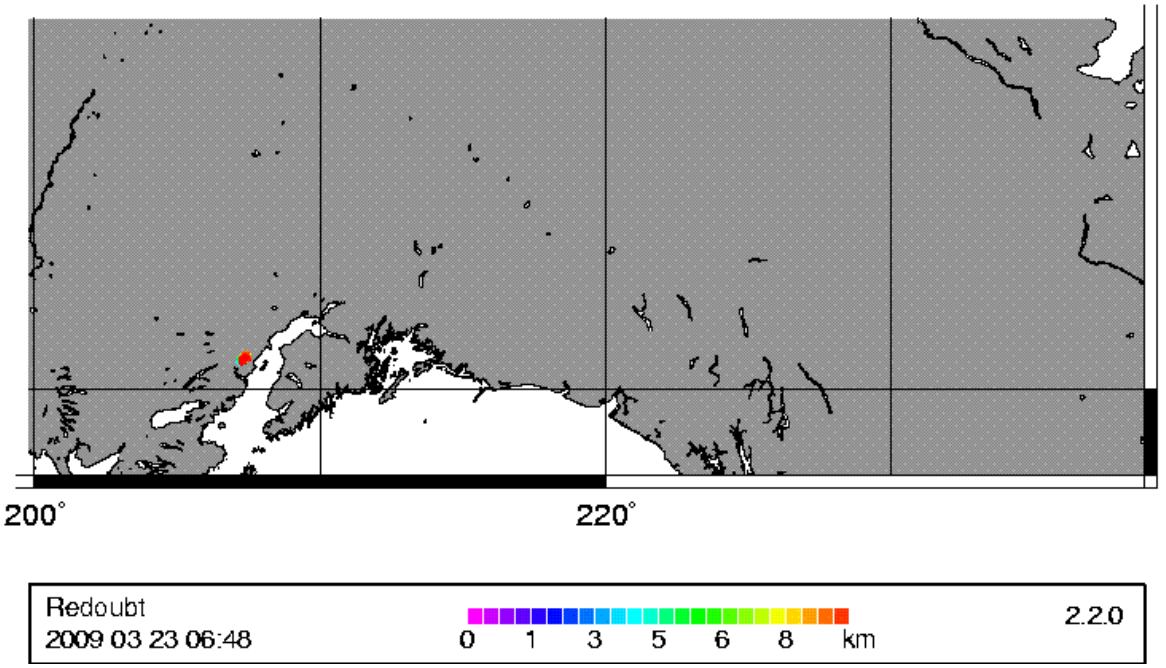
Alerts

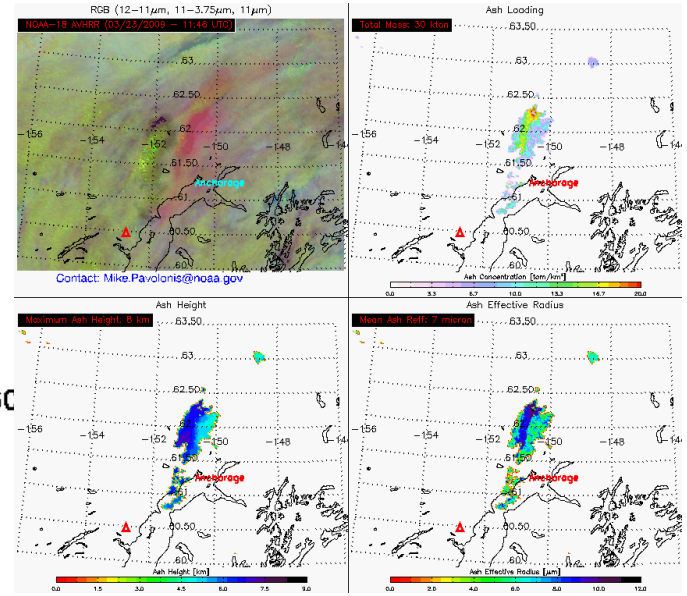
- No AIRS alerts received
- No OMI/NOAA notifications
- 1st SACS alert received at 01:15 24.03.2009 based on SCIAMACHY data at 21:30 23.03.2009
- 1st IASI alert received at 22:46 23.03.2009 based on IASI data at 19:42 23.03.2009.

Puff simulation

Courtesy: Peter Webley



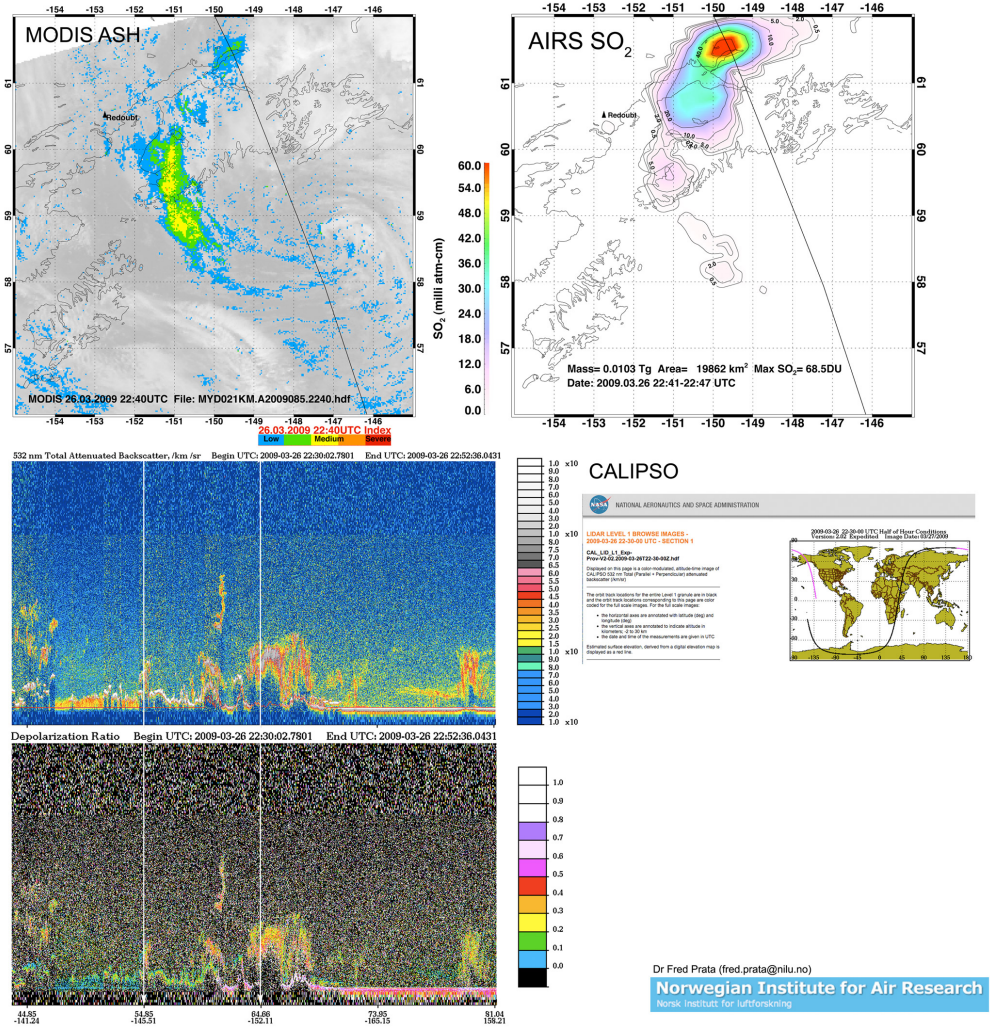




AVHRR 11:46UTC

Courtesy: Mike Pavalonis

Synergistic Use of Satellite Data

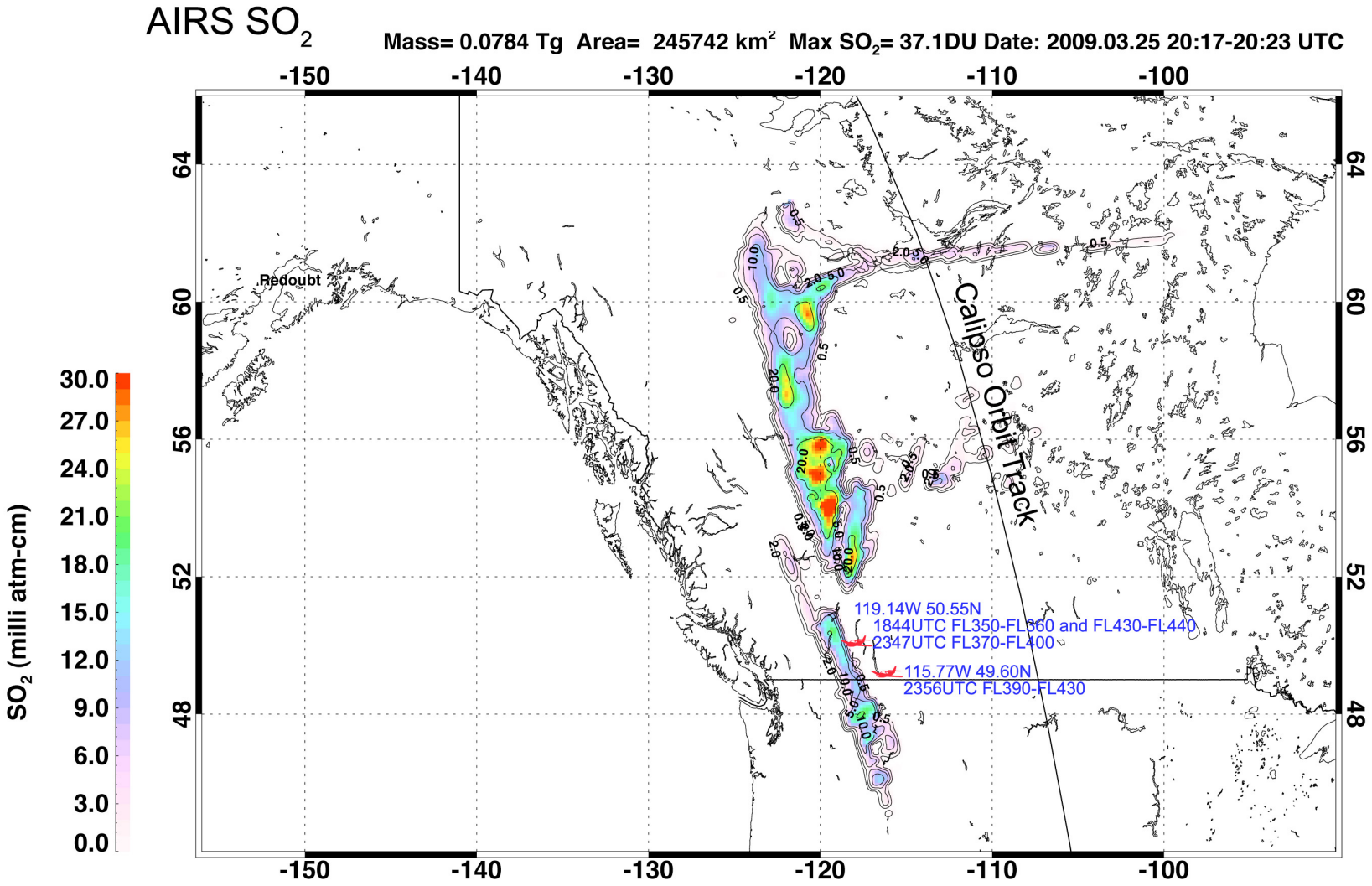


26.03.2009

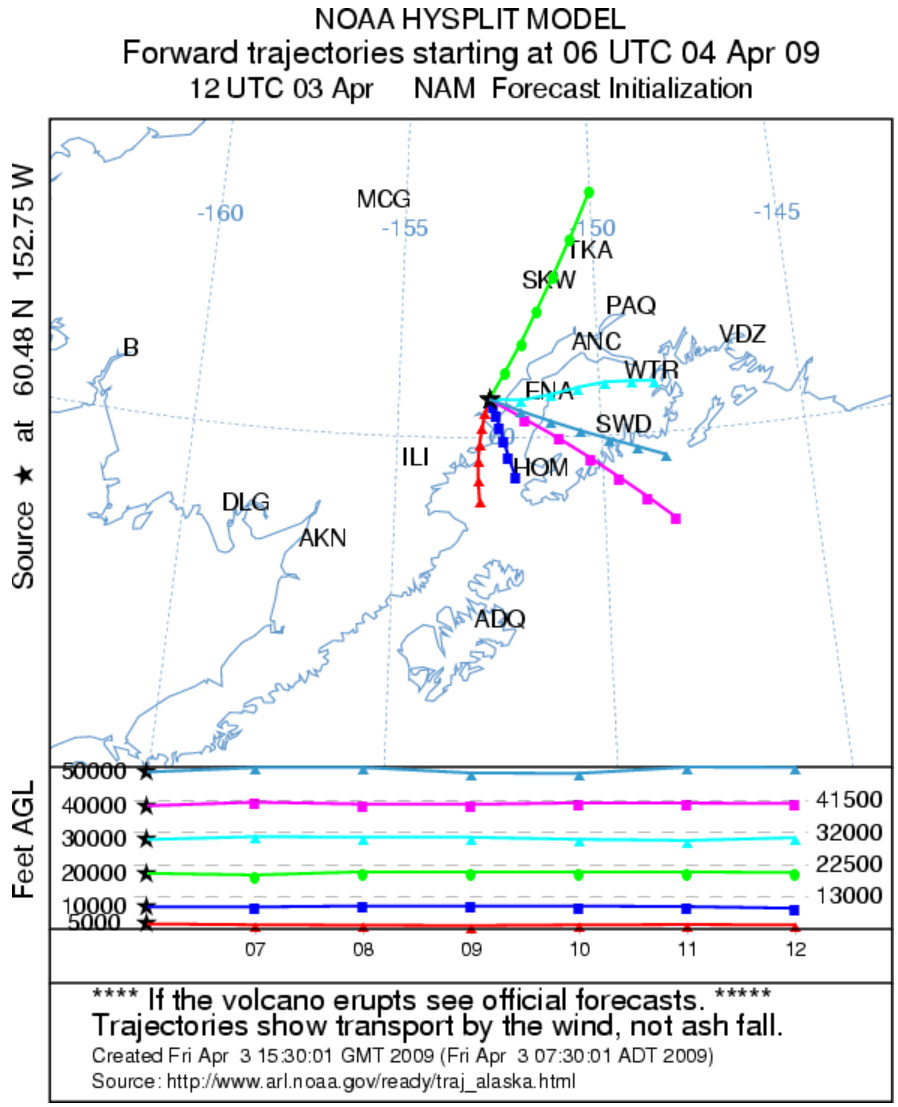
MODIS – Ash
AIRS – SO_2
Caliop - Height

Dr Fred Prata (fred.prata@nilu.no)
Norwegian Institute for Air Research
Norsk institutt for luftforskning

Distal threat



Which height?



The Good

- IASI automated alert system and graphic very good
- 1st NRT use of NOAA AVHRR ash products
- 1st Use of Combined MODIS-AIRS-Caliop
- Use of radar to get height (maybe?)

The Bad

- No AIRS Alerts
- UV data too slow
- Use of SO_2 as a surrogate for ash not warranted
- Early ash detection by IR methods poor
- No objective height estimate

Scientific Basis

- Inverse Theory
  - Seibert, P.: Inverse modelling with a Lagrangian particle dispersion model: application to point re- leases over limited time intervals, In: Air Pollution Modeling and its Application XIV, edited by Schiermeier, F.A. and Gryning, S.-E., pp. 381-389, Kluwer Academic Publ., 2001.
  - Seibert, P. and A. Frank: Source-receptor matrix calculation with a Lagrangian particle dispersion model in backward mode, ACP, 4, 51-63, 2004.
- Dispersion modelling
  - Stohl, A., Forster, C., Frank, A., Seibert, P., and Wotawa, G.: Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2., Atmos. Chem. Phys., 5, 2461–2474, 2005.
- Injection Height Retrieval
  - Eckhardt, S., Prata, A. J., Seibert, P., Steibel, K., and Stohl, A.: Estimation of the vertical profile of sulfur dioxide injection into the atmosphere by a volcanic eruption using satellite column measure- ments and inverse transport modeling, Atmos. Chem. Phys., 2008.
- Satellite Products

SO_2 OMI

SO_2 IASI

Ash/SO_2 IR

Ash AIRS

Ash IR

SO_2 AIRS

SO_2 SEVIRI

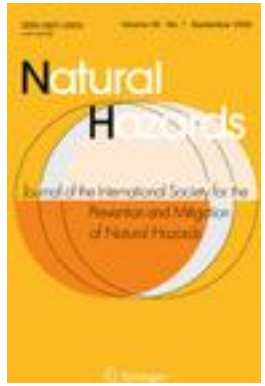
SO_2 SCIAMACHY/ GOME

  - Carn, S. A., Krotkov, N. A., Yang, K., Hoff, R. M., Prata, A. J., Krueger, A. J., Loughlin, S. C., and Levelt, P. F.: Extended observations of volcanic SO2 and sulphate aerosol in the stratosphere, Atmos. Chem. Phys. Discuss., 7, 2857–2871, 2007.
  - Clarisse, L. , Coheur. P. F., Prata ,A. J., Hurtmans ,D., Razavi ,A., Phulpin , T., Hadji-Lazaro, J., and C. Clerbaux: Tracking and quantifying volcanic SO2 with IASI, the September 2007 eruption at Jebel at Tair, Atmos. Chem. Phys., 8, 7723–7734, 2008
  - Corradini, S., Merucci, L., and Prata, A. J.: Retrieval of SO_2 from thermal infrared satellite measurements: correction procedures for the effects of volcanic ash, Atmos. Meas. Tech. Discuss., 2, 303–342, 2009.
  - Gangale, G., Prata, A. J., and Clarisse, L.: On the infrared spectral signature of volcanic ash, Appl. Opt., (In revision), 2009.
  - Prata, A. J. and Grant, I. F.: Retrieval of microphysical and morphological properties of volcanic ash plumes from satellite data: Application to Mt. Ruapehu, New Zealand., Quart. J. Roy. Meteorol. Soc., 127(576B), 2153–2179, 2001.
  - Prata, A. J. and Bernardo, C.: Retrieval of volcanic SO2 column abundance from Atmospheric Infrared Sounder data, J. Geophys. Res., 112, D20204, doi:10.1029/2006JD007955, 2007.
  - Prata, A. J., and Kerkmann, J.: Simultaneous retrieval of volcanic ash and SO2 using MSG-SEVIRI measurements, Geophys. Res. Lett., 34, L05813, doi:10.1029/2006GL028691, 2007.
  - Richter, A., Wittrock, F. and Burrows, J.P.: SO2 measurements with SCIAMACHY, Proceedings of the First Conference on Atmospheric Science, 8–12 May 2006, Frascati, Italy, ESA publication SP-628, 2006.

Natural Hazards–Special Issue

"Aviation Hazards from Volcanoes"

Guest Editors: A. J. Prata & A. Tupper



33. Article — Add to marked items
Russian eruption warning systems for aviation
Christina Neal, Olga Girina, Sergey Senyukov, Alexander Rybin, Jeffrey Osiensky, Pavel Izbekov and Gail Ferguson
PDF (746.2 KB) HTML Online First

36. Article — Add to marked items
Volcano monitoring in NZ and links to SW Pacific via the Wellington VAAC
Bradley J. Scott and James Travers
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96. Article — Add to marked items
El Chichón volcano, April 4, 1982: volcanic cloud history and fine ash fallout
William I. Rose and Adam J. Durant
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100. Article — Add to marked items
Satellite detection of hazardous volcanic clouds and the risk to global air traffic
A. J. Prata
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Volcanic hazards to airports
Marianne Guffanti, Gari C. Mayberry, Thomas J. Casadevall and Richard Wunderman
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102. Article — Add to marked items
Automated forecasting of volcanic ash dispersion utilizing Virtual Globes
Peter W. Webley, Kenneson Dean, John E. Bailey, Jon Dehn and Rorik Peterson
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103. Article — Add to marked items
The United States national volcanic ash operations plan for aviation
Steven Albersheim and Marianne Guffanti
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104. Article — Add to marked items
Tracking volcanic sulfur dioxide clouds for aviation hazard mitigation
Simon A. Carn, Arlin J. Krueger, Nickolay A. Krotkov, Kai Yang and Keith Evans
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