The NASA Applied Sciences Program: Volcanic Ash Observations and Applications

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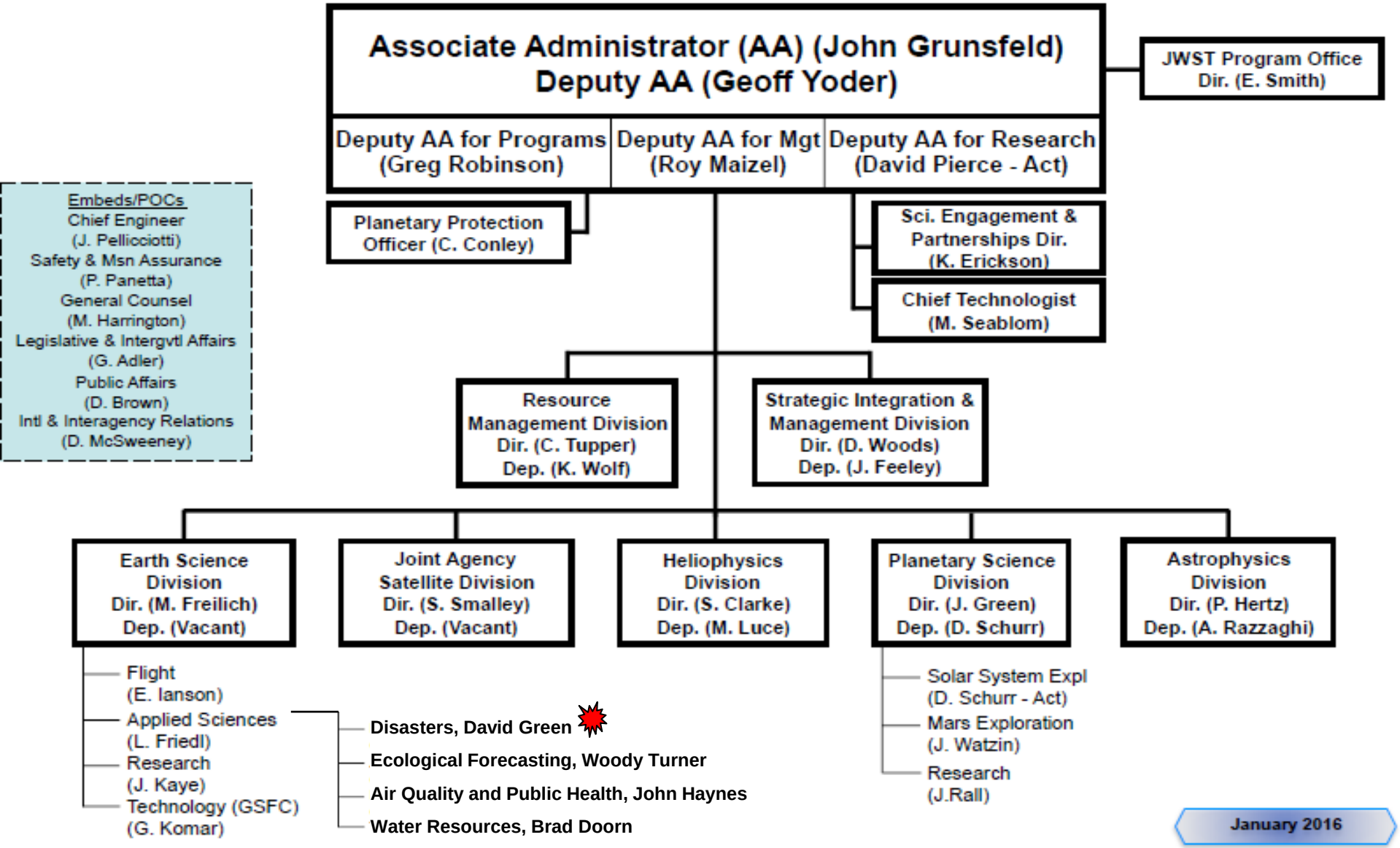
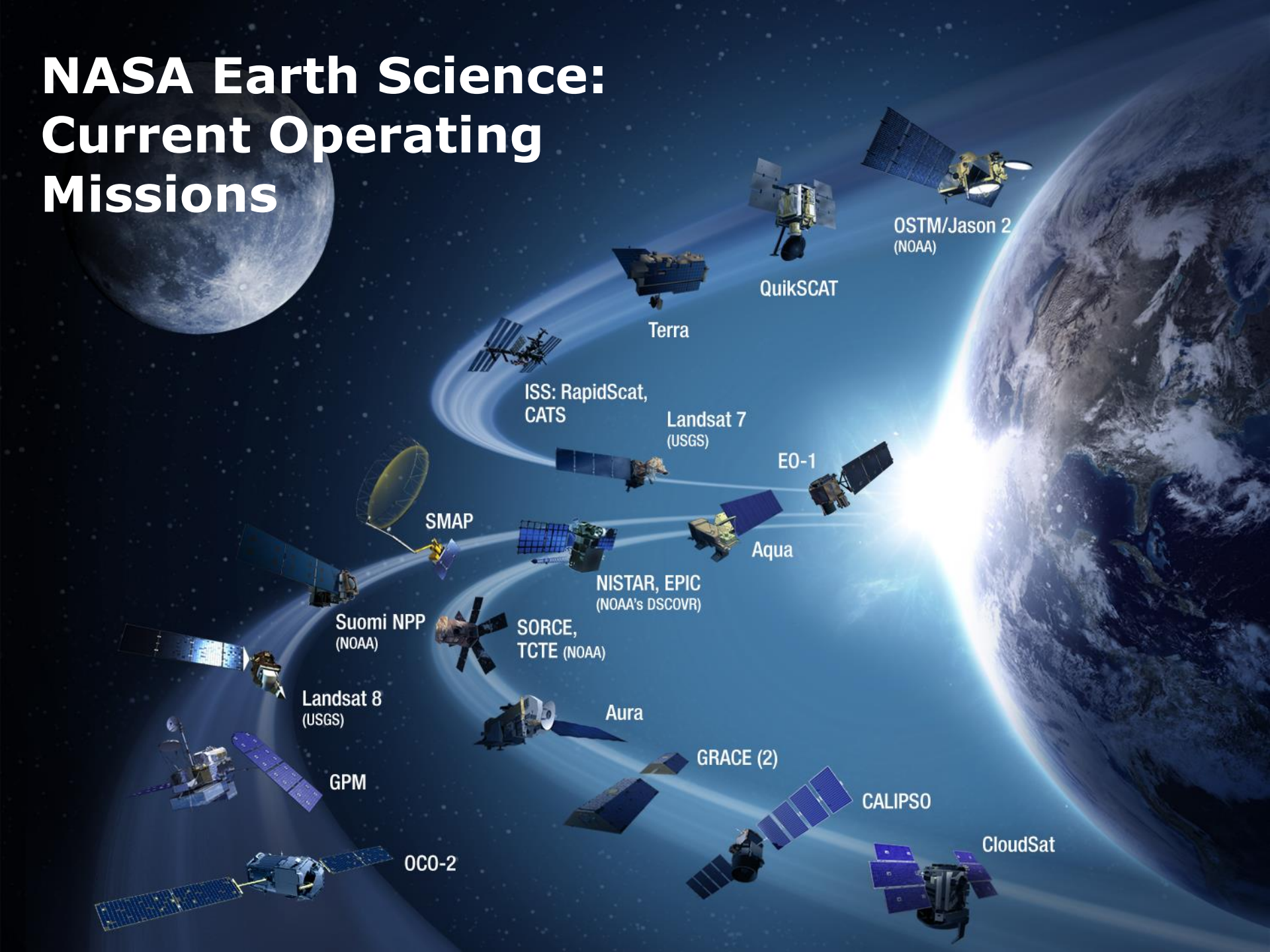
NASA Applied Science Program
Disasters Focus Area



January 2016

NASA Earth Science: Current Operating Missions




Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science:
Current and
Upcoming Missions
Landsat 9,
TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA's DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
SMAP
Terra
Suomi NPP
(NOAA)
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

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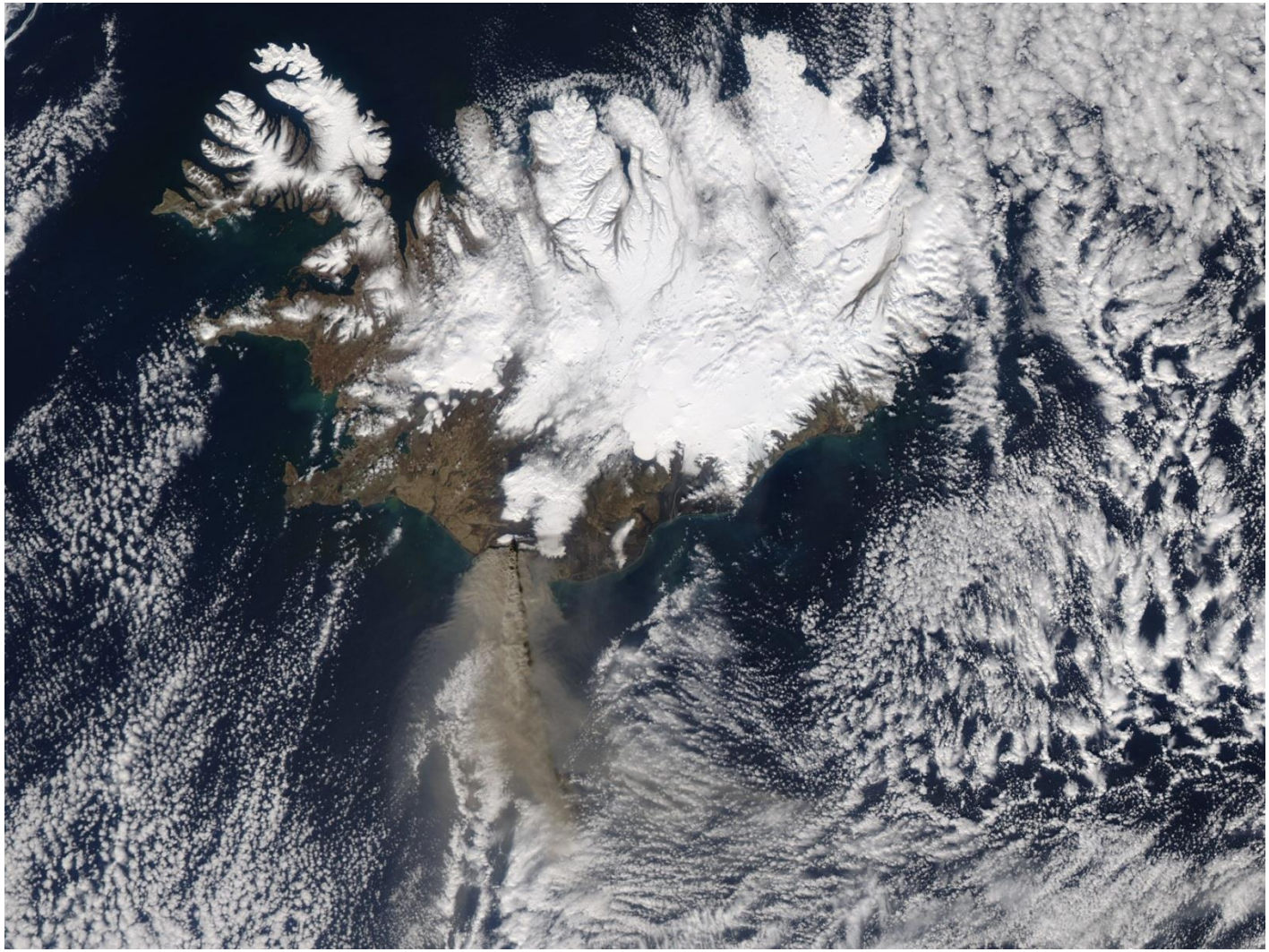
MODIS Image
Eyjafjallajökull Volcano,17 April 2010



Satellite imagers provide the best source of information concerning the location of volcanic ash. When one thinks of imager data, typically this is what typically comes to mind.

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Multi-spectral Imaging: Making Full Use of Space-based Imagers for Volcanic Cloud Monitoring

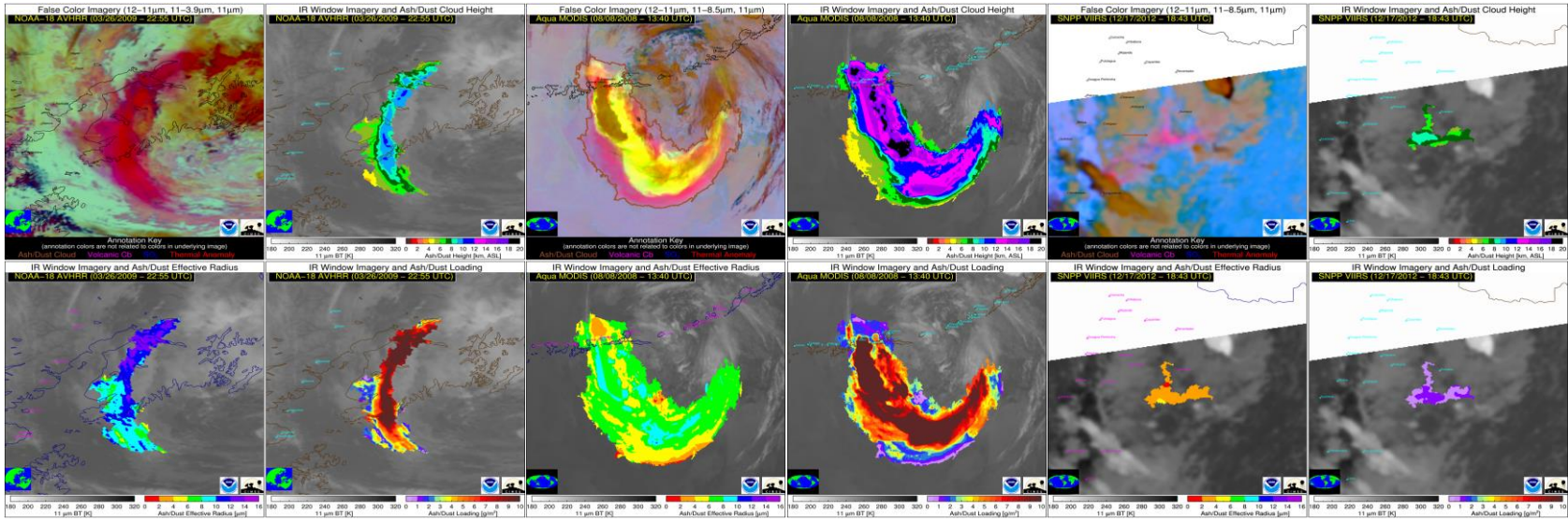
LEO

GEO

NOAA and MetOp AVHRR

Terra and Aqua MODIS

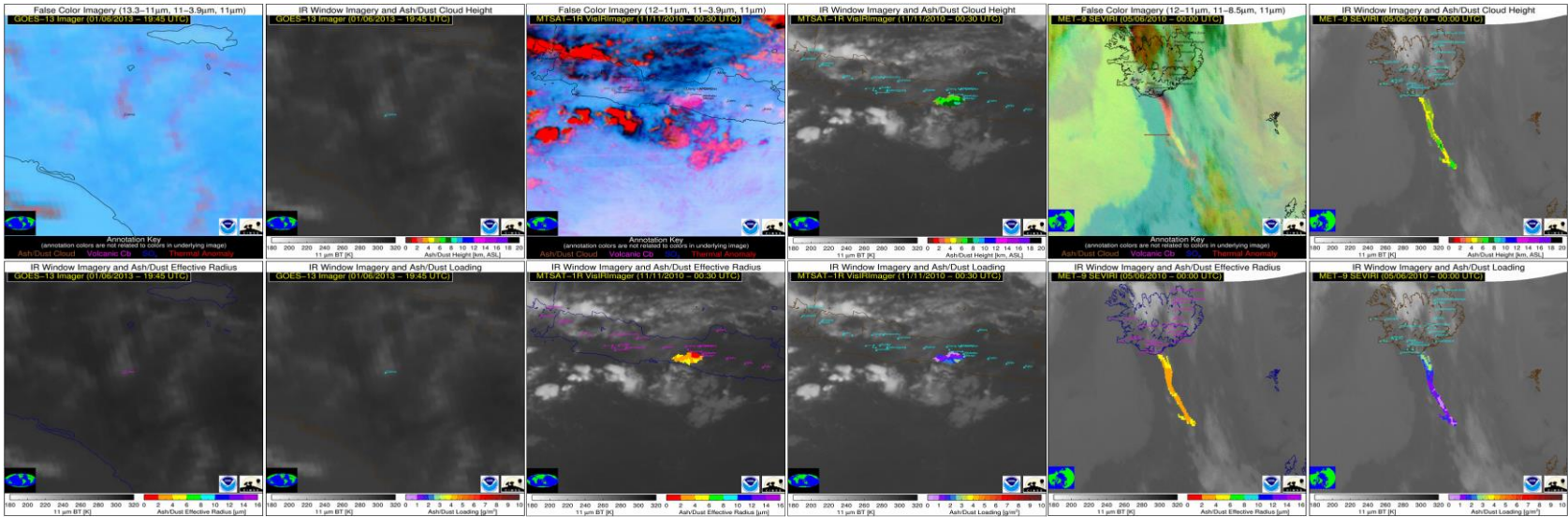
SNPP-VIIRS



GOES-13-15

MTSAT-(1r and 2)

Met-(8,9,10) SEVIRI



Courtesy UW NOAA CIMSS, Madison WI

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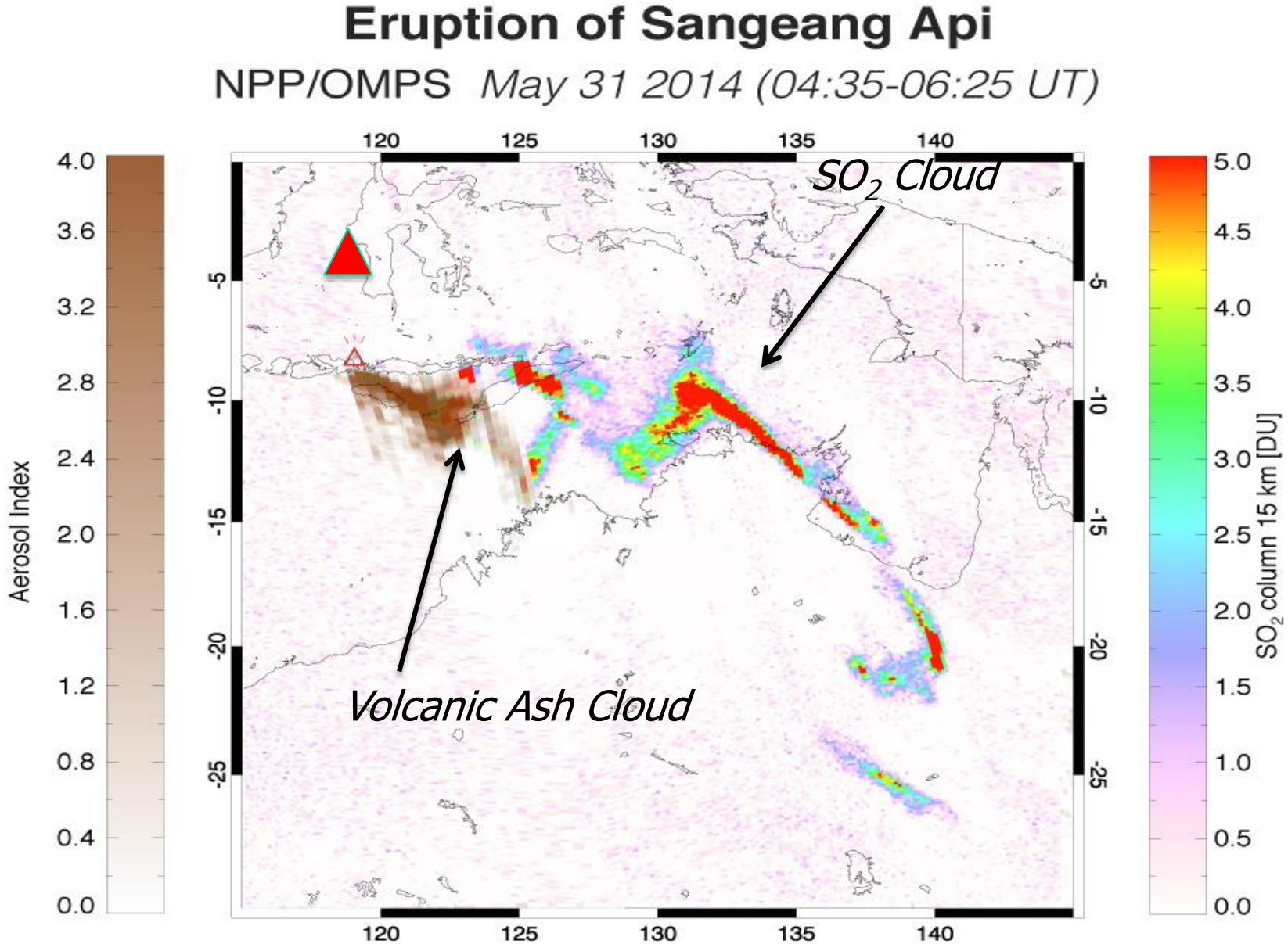
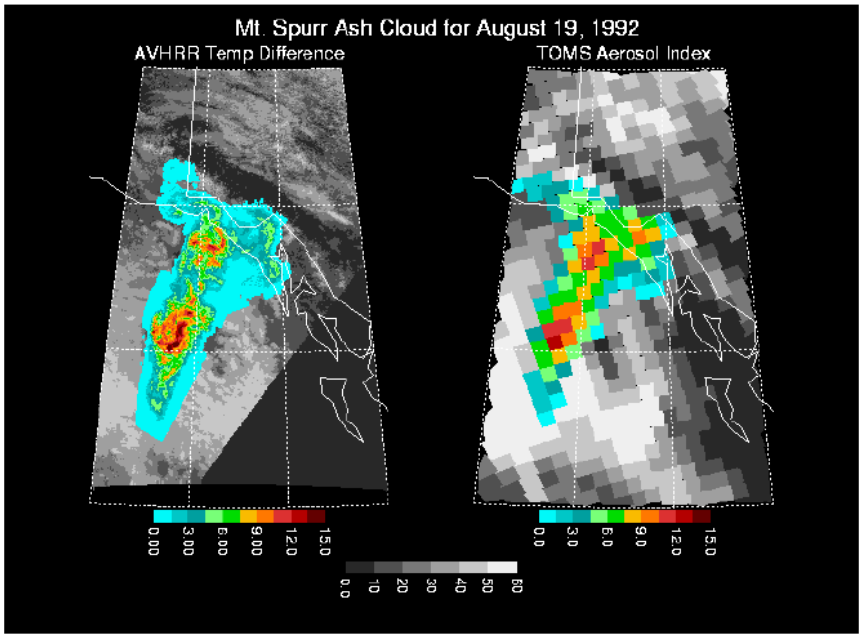
Horizontal Mapping Of Volcanic Ash: SNPP/OMPS NRT SO_2 & Ash Index



Imager and UV Sun-photometer Complementarity

- IR ash detection:
  - Plume must be transparent
  - Water hides ash
  - Plume temperature contrast with underlying surface
  - Detectable day and night
  - Low concentration not detectable
- Fresh ash clouds:
  - Dense, must wait until sheared to thin layer
  - Full of water, ice which masks detection



IR: T11-T12 **UV ash: AI**

- UV ash (AI) detection:
  - Scattering by ash differs from Rayleigh scattering
  - Sunlight necessary
  - Low concentrations are detectable

Fresh ash clouds:

- Detected upon eruption
- Independent of water content
- Not detectable at night

NASA Direct Readout data processing at FMI and UAF/GINA

Direct Broadcast from Aura and S-NPP satellites

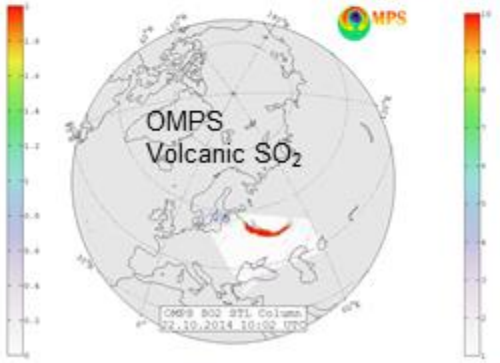
Receiving station in Sodankylä, Finland (FMI)

Receiving station at GINA/UAF in Fairbanks Alaska

OMI and OMPS DR processing in Sodankylä

NASA/GSFC Direct Readout Laboratory and NPP ozone PEATE create software package for local processing of NPP DR data

OMPS DR Processing at UAF/GINA



FMI's WWW and FTP services. Available within 20 min after data reception.

GINA's WWW and FTP services to Alaska Volcano Observatory. Available within 20 min after data reception.

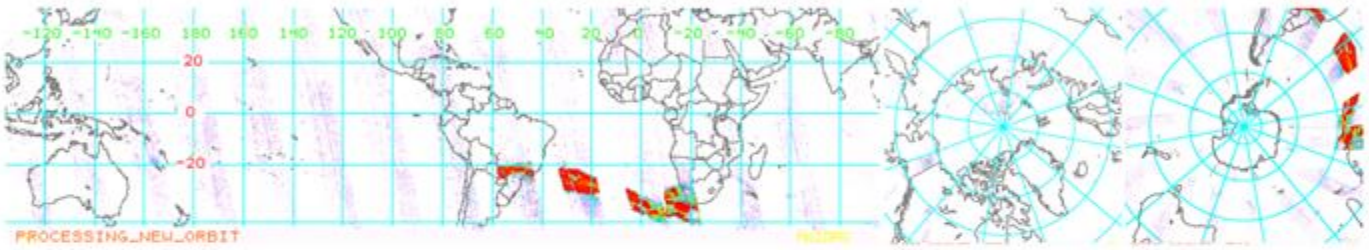
http://sampo.fmi.fi/volcanic.html

Aura/OMI SO_2 data integrated into NOAA/NESDIS volcanic alert system and web site

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

Latest OMI SO2 Column 5Km - 24-Hour Composite Images

Important Information for OMI Data Users



Current OMI SO2 Composites	Tropics	Northern Hemisphere	Southern Hemisphere
Current & Previous Digital Images GeoTiff, NetCDF, McIDAS, GIF	Tropics	Northern Hemisphere	Southern Hemisphere

Latest OMI_SO2 Column 5Km by Volcano

Alaska, USA	Aleutian Islands, Alaska, USA	Anatahan, Mariana Islands	Cascade
Central America	Comoro Islands	Eastern China	Ecuador
Etna, Sicily, Italy	Galapagos Islands, Ecuador	Hawaii, USA	Iceland
Japan	Java, Indonesia	Kamchatka, Russia	Mexico
Montserrat, West Indies	New Zealand	North Western Europe	Northern Atlantic
Northern Chile	Nyiragongo, DR Congo	Peru	Philippines
Papua New Guinea	Red Sea	Reunion Island	Southern Chile
Sulawesi Sangihe, Indonesia	Sumatra, Indonesia	Tanzania	Vanuatu, South Pacific

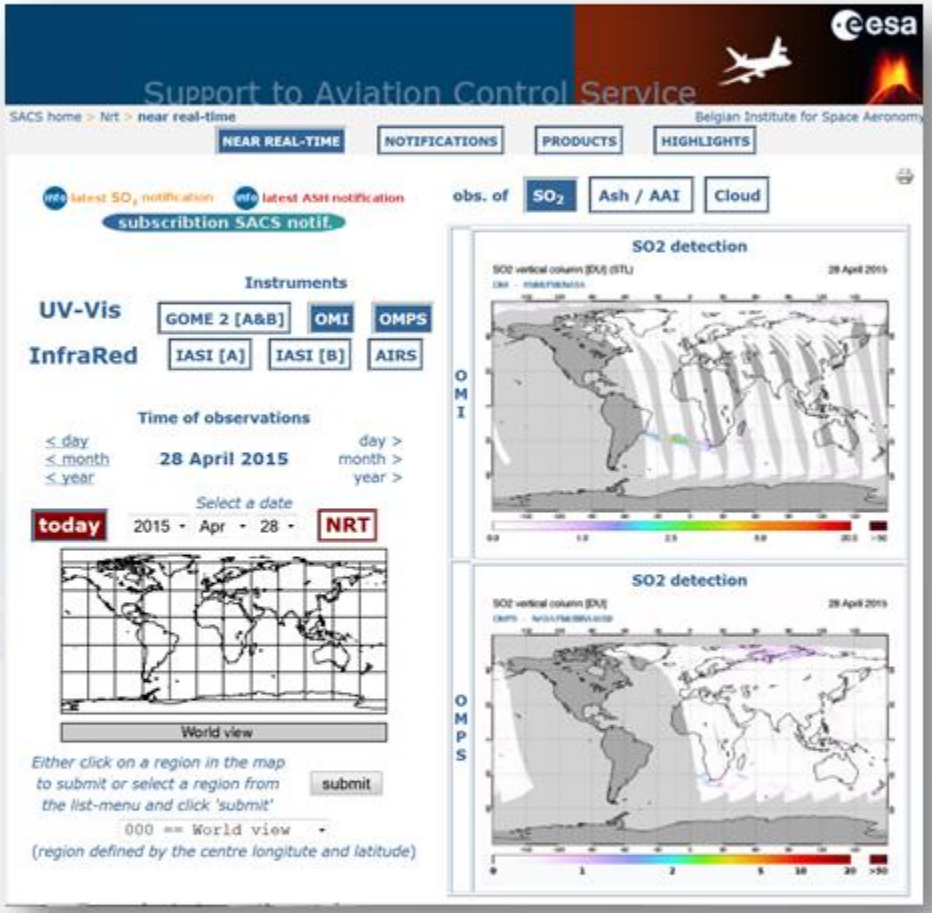
For OMI and AIRS SO2 Alerts check the OMI SO2 Alert Site and the AIRS SO2 Alert Site

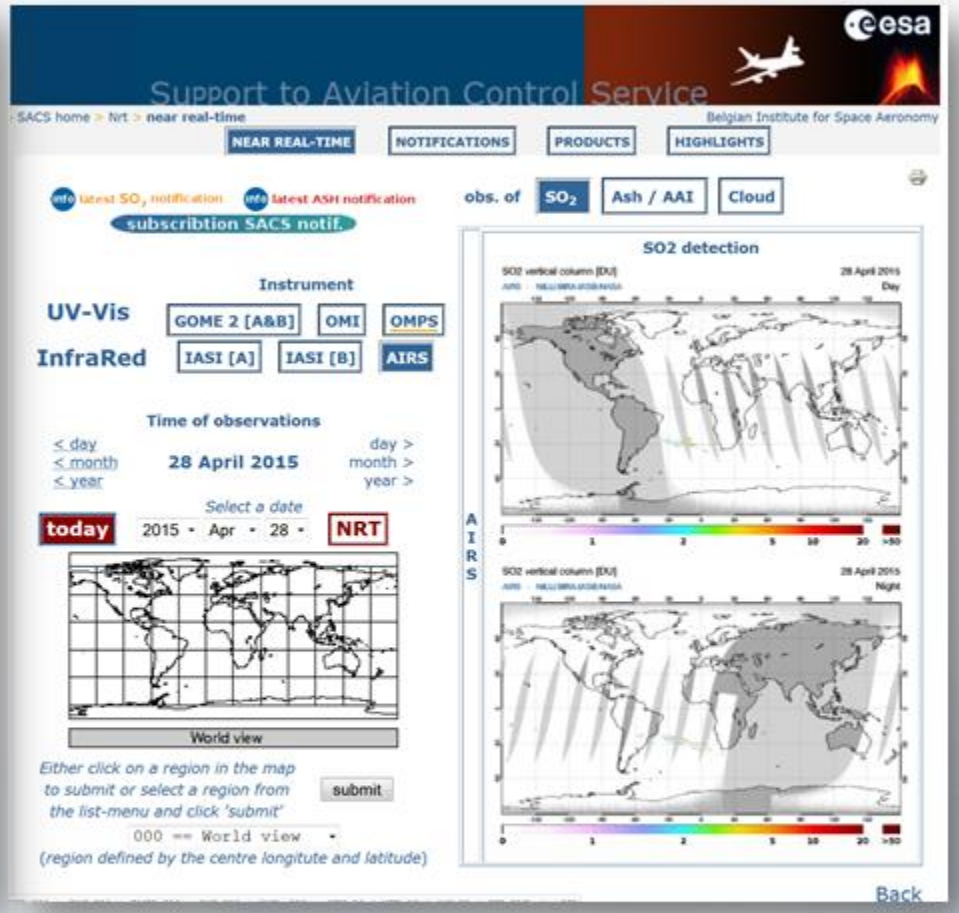
For science quality products check with NASA GES DISC and with the NASA Global Sulfur Dioxide Monitoring

http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html

NOAA/NESDIS distributes NASA volcanic SO_2 data from Aura/OMI to operational users via Washington Volcanic Ash Advisory Center. NOAA issues automatic e-mail alerts notifications

AIRS, OMI, OMPS SO_2 data integrated into European SACS volcanic alert system





The European Support to Aviation Control Service (SACS) is using the operational volcanic SO_2 column and Ash Index data from Aura/OMI and SNPP/OMPS as well as volcanic SO_2 data from Aqua/AIRS produced by NASA to complement the information already available from the morning instruments (GOME-2A/B, and IASI-A/B). The project is supported by NASA applied Sciences Disaster Program: http://so2.gsfc.nasa.gov

NASA NRT data are of utmost importance for Support to Aviation Control Service (SACS)

SACS= global alerting system for volcanic SO_2 and ash

SACS is used by 278 subscribed users for many applications:

- Volcanological observatories
- VAACs/metOffices
- Pilots
- Airlines, private companies related to aviation sector
- National civil protection agencies
- Scientists
- Students, Professors
- Journalists
- Citizens

Adapted from Brenot et al. (2014), Support to Aviation Control Service (SACS): an online service for near-real-time satellite monitoring of volcanic plumes, Nat. Hazards Earth Syst. Sci., 14, 1099-1123, doi:10.5194/nhess-14-1099-2014, 2014.

aeronomie.be

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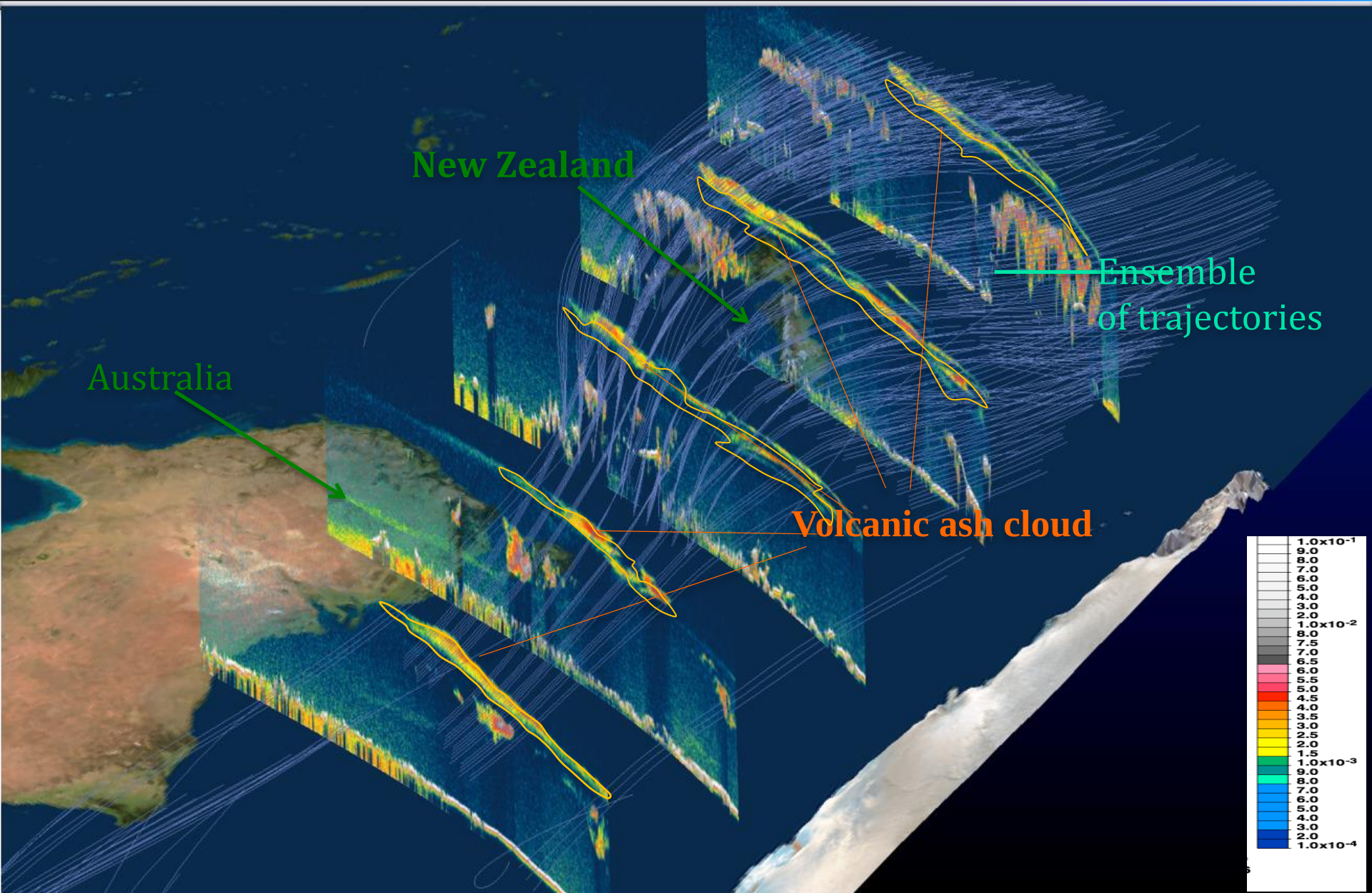
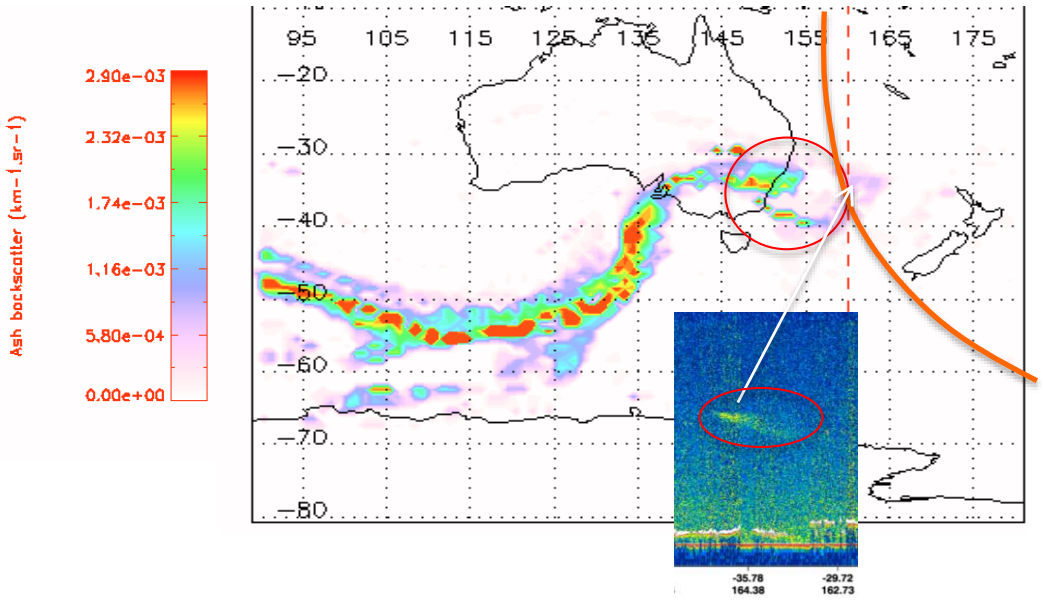
Enhanced Characterization: Assimilating Series of CALIPSO Curtains Into Dispersion Forecast Models

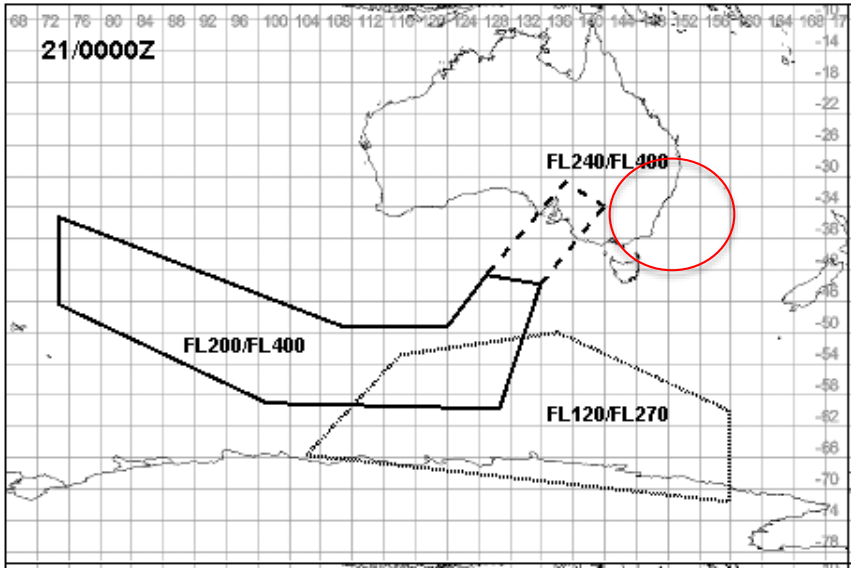


Result: Improving VAAC Advisories

CALIPSO-trajectory mapping

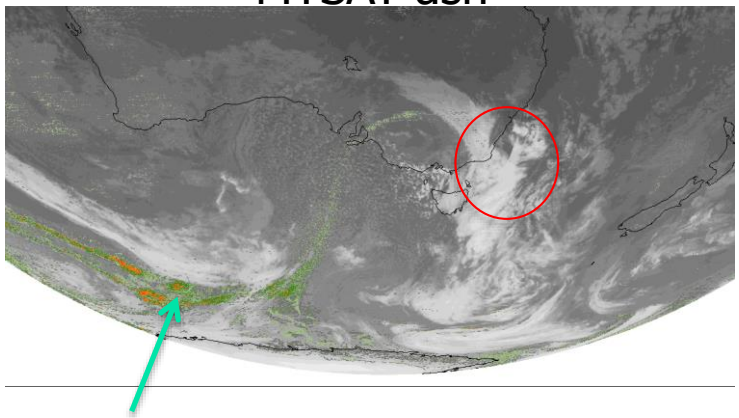


Volcanic Ash Advisory from Darwin VAAC



- Ash cloud masked by ash in MTSAT data over SE Australia (Sydney)
- Ash Advisory misses area over Tasman Sea
- CALIPSO-trajectory map captured the head of the plume on time as validated by a subsequent independent daytime overpass
- n.b. The plume depiction above is 2-D, whereas the model output is 4-D.

MTSAT ash



Visible Volcanic ash cloud

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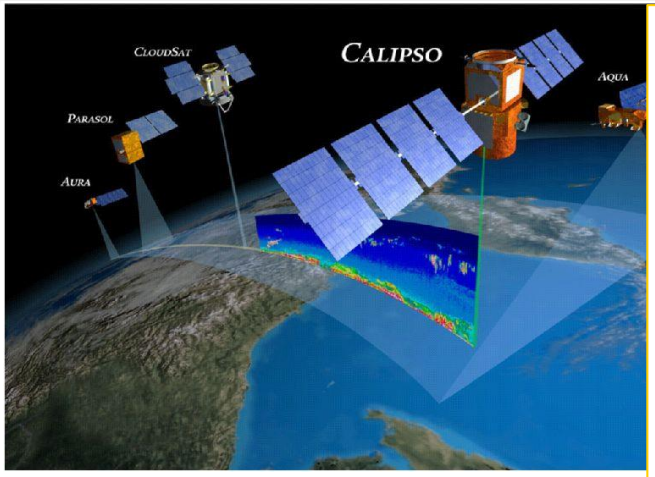
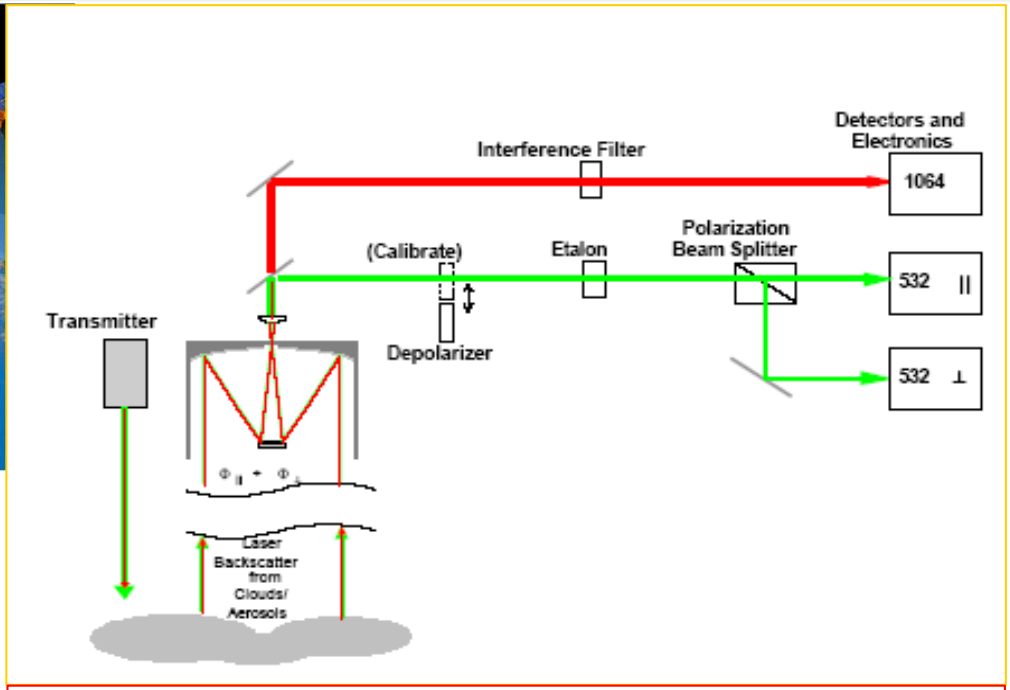
Caliop - The CALIPSO lidar



- Operating since 2006
- Polar Orbit
- Equatorial Crossing-time at 0130 and 1330 LET
- Repeat cycle of 16 days



- Total Backscatter at 532 nm (density)
- Depolarization at 532 nm (geometry)
  - Color Ratio (1064/532) (size)

- High vertical resolution (60 m) of backscatter profiles
- Optical parameters provide unique capability to detect volcanic ash and its vertical structure

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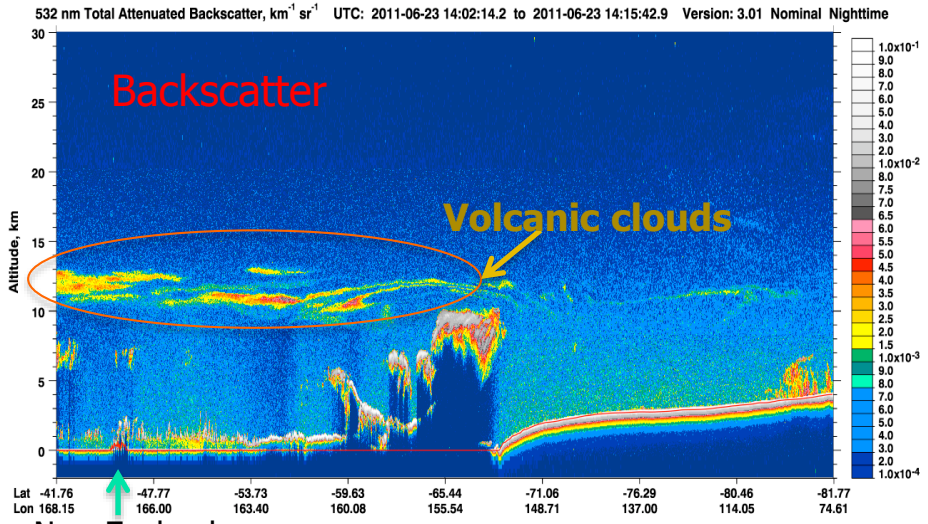
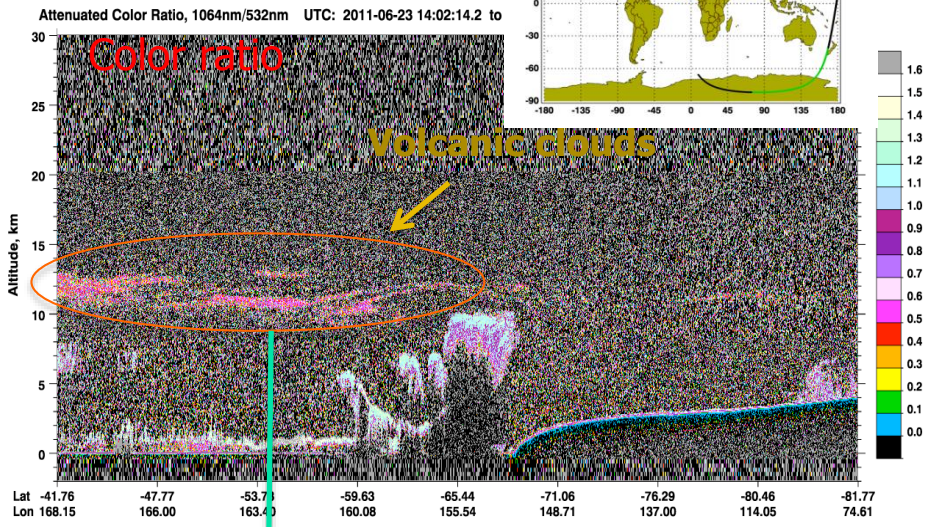
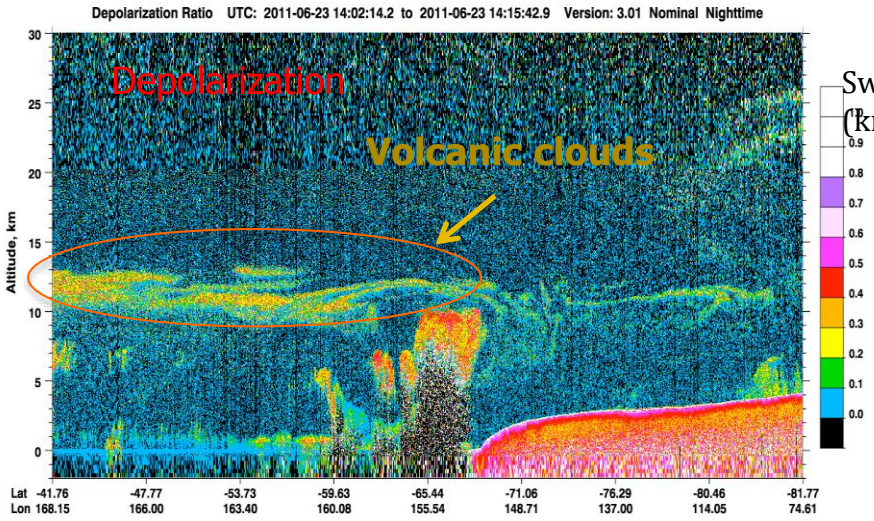
Cordon ash clouds over New Zealand observed by CALIPSO several weeks after the eruption

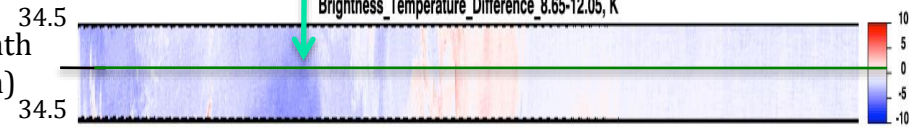


New Zealand





IR imager



- Multi laminar layers with low color ratio (0.5) and high depolarization (0.3-0.4) indicative of ash as opposed to ice
- Negative BT from IIR on board CALIPSO
- Consistent with small volcanic ash from Cordon
- Similar features observed most of June 2011

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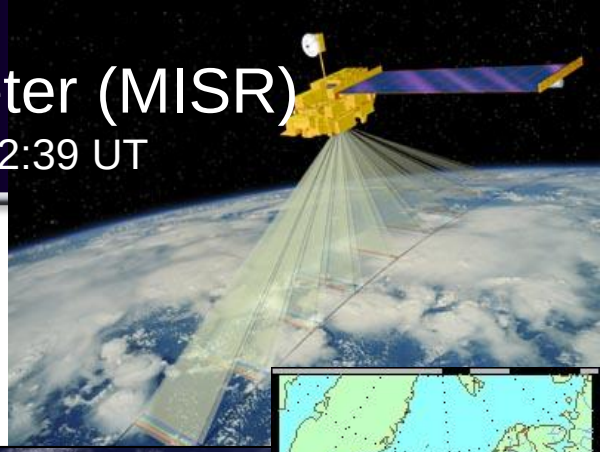
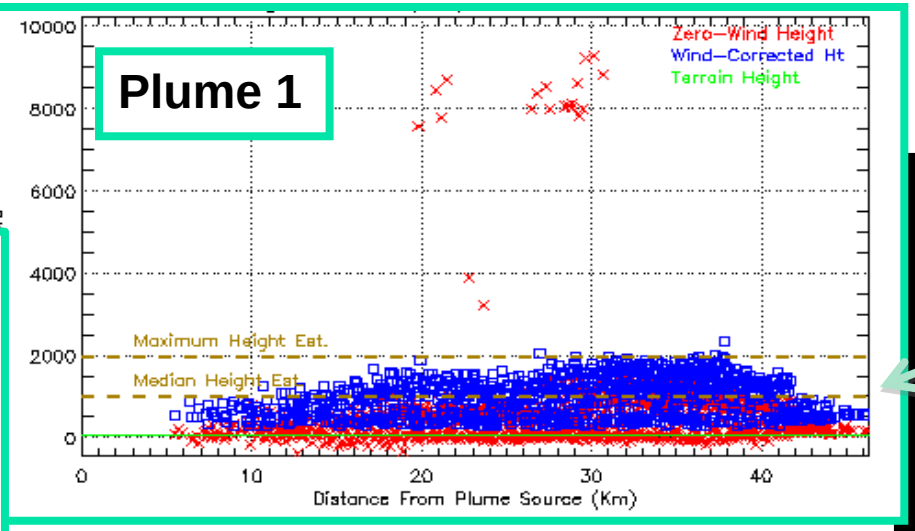
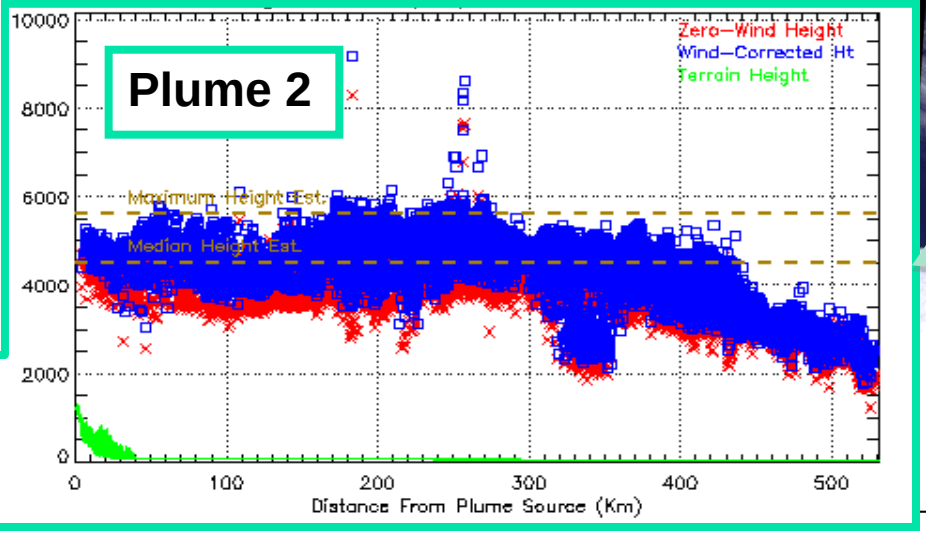
Multi-angle Imaging SpectroRadiometer (MISR)

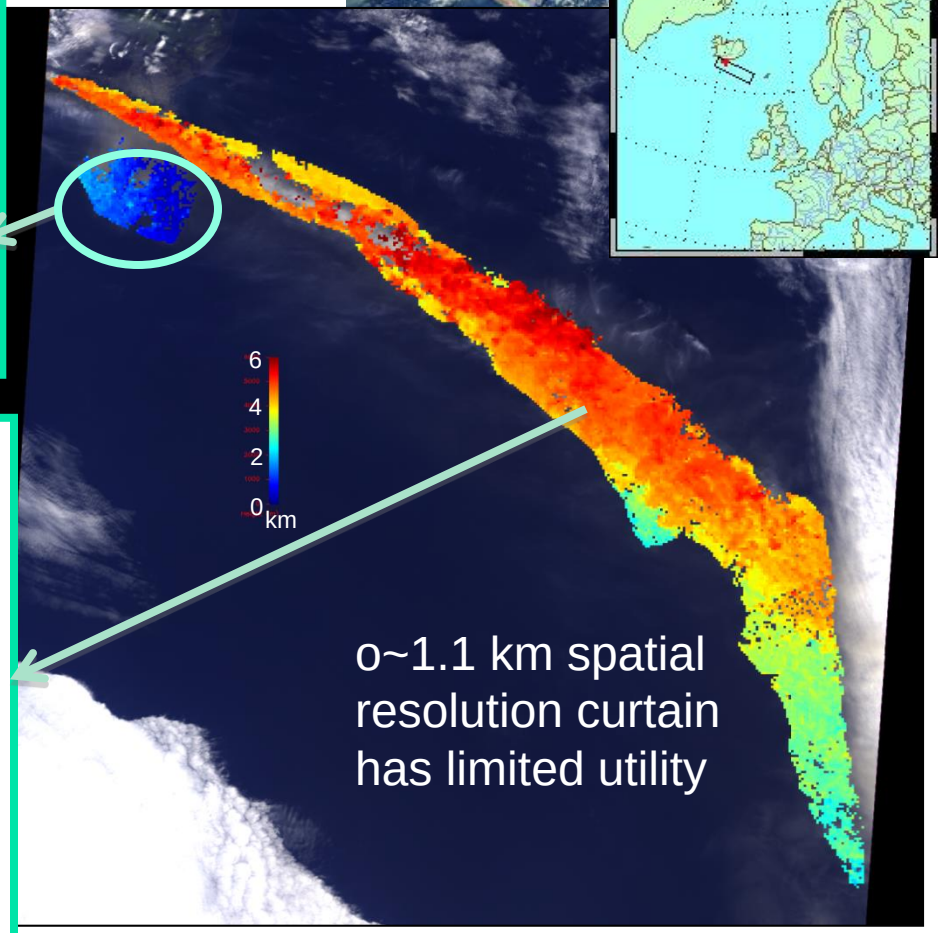
Adding Stereo-Derived plume heights, May 7, 12:39 UT





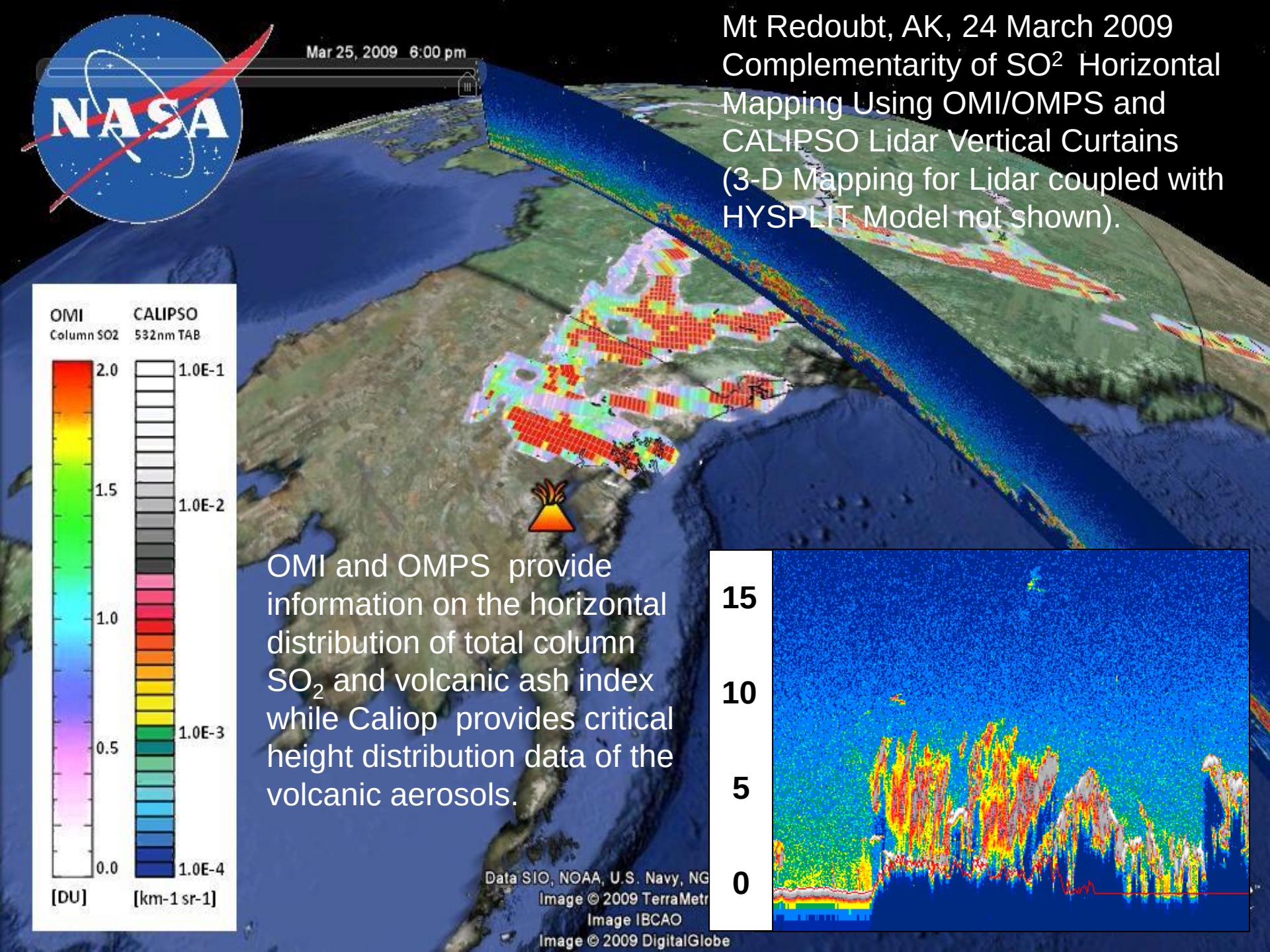


Height: Blue = Wind-corrected



R. Kahn, D. Nelson, and the MISR Team, NASA JPL and GSFC

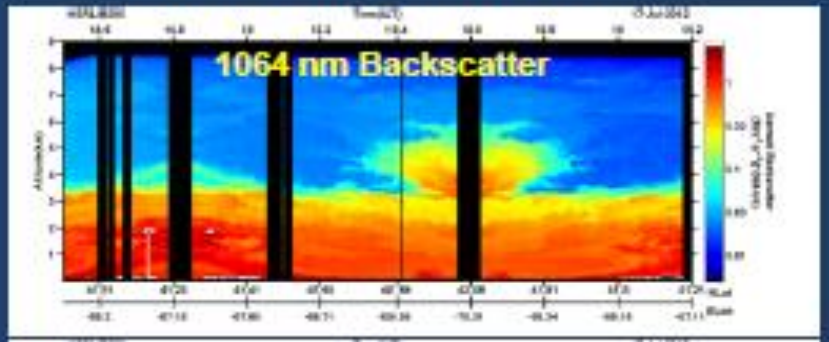
Mt Redoubt, AK, 24 March 2009
Complementarity of SO^2 Horizontal Mapping Using OMI/OMPS and CALIPSO Lidar Vertical Curtains (3-D Mapping for Lidar coupled with HYSPLIT Model not shown).

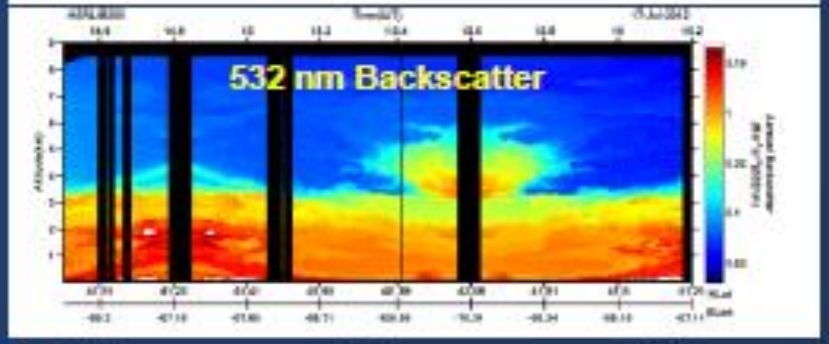


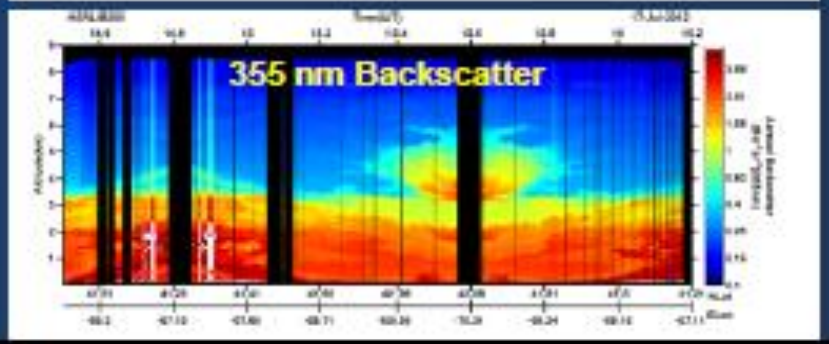
OMI and OMPS provide information on the horizontal distribution of total column SO_2 and volcanic ash index while Caliop provides critical height distribution data of the volcanic aerosols.

LaRC Airborne HSRL-2: World's First Airborne Multi-wavelength HSRL

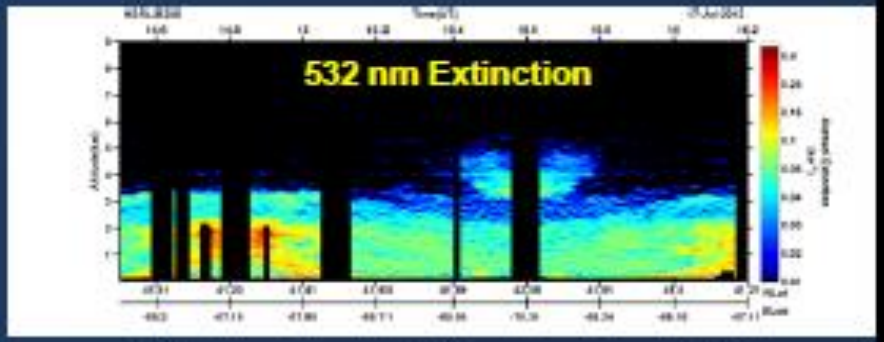
07/17/2012 TCAP flight on B200 aircraft

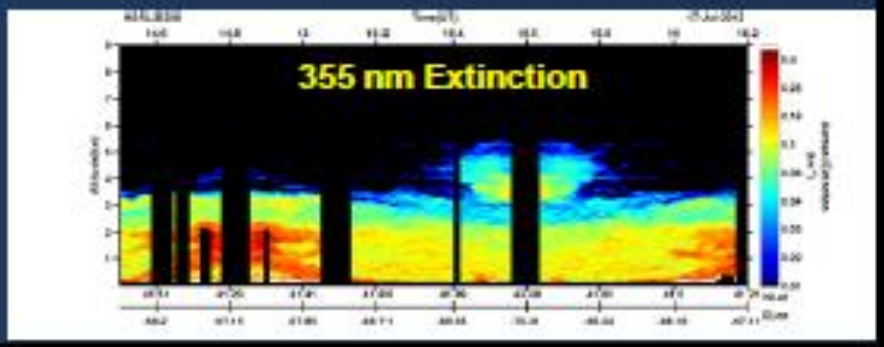






- High Spectral Resolution Lidar (HSRL) provides independent retrievals of aerosol extinction and backscatter
  - HSRL-2 Capabilities
    - Backscatter at 355, 532, and 1064 nm
    - Extinction at 355 and 532 nm (HSRL)
    - Depolarization at 355, 532, 1064 nm





From CALIPSO to HSRL-2 to ACE

Caliop and HSRL*

532 and 1024 nm*
Backscatter
Depolarization
Color ratio
Extinction at 532 nm
Effective radius
Index of refraction
Scattering & Absorption Coefficients
Single Scattering Albedo

* **2 channel lidar are a minimum requirement to characterize volcanic ash. HSRL is the Calipso airborne equivalent**

Eg. ESA EarthCare mission with a single 355 nm channel will provide improved signal to noise performance for plume heights, limited microphysics, and model trajectory validation. It will also provide greater observation frequency with multiple platforms, but it will not be a sufficiently capable, primary volcanic ash assessment tool.

HSRL-2 and ACE**

355, 532, and 1064 nm
Backscatter
Depolarization
Color ratio
Extinction at 355 and 532 nm
Mass/extinction ratios
Effective radius
Index of refraction
Scattering & Absorption Coefficients
Single Scattering Albedo
Surface concentration
Volume concentration
Particle size distribution

** **3 channel lidar are required to directly retrieve volumetric concentration without secondary cal/val.**

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UW/NOAA CIMSS Automated Alerts

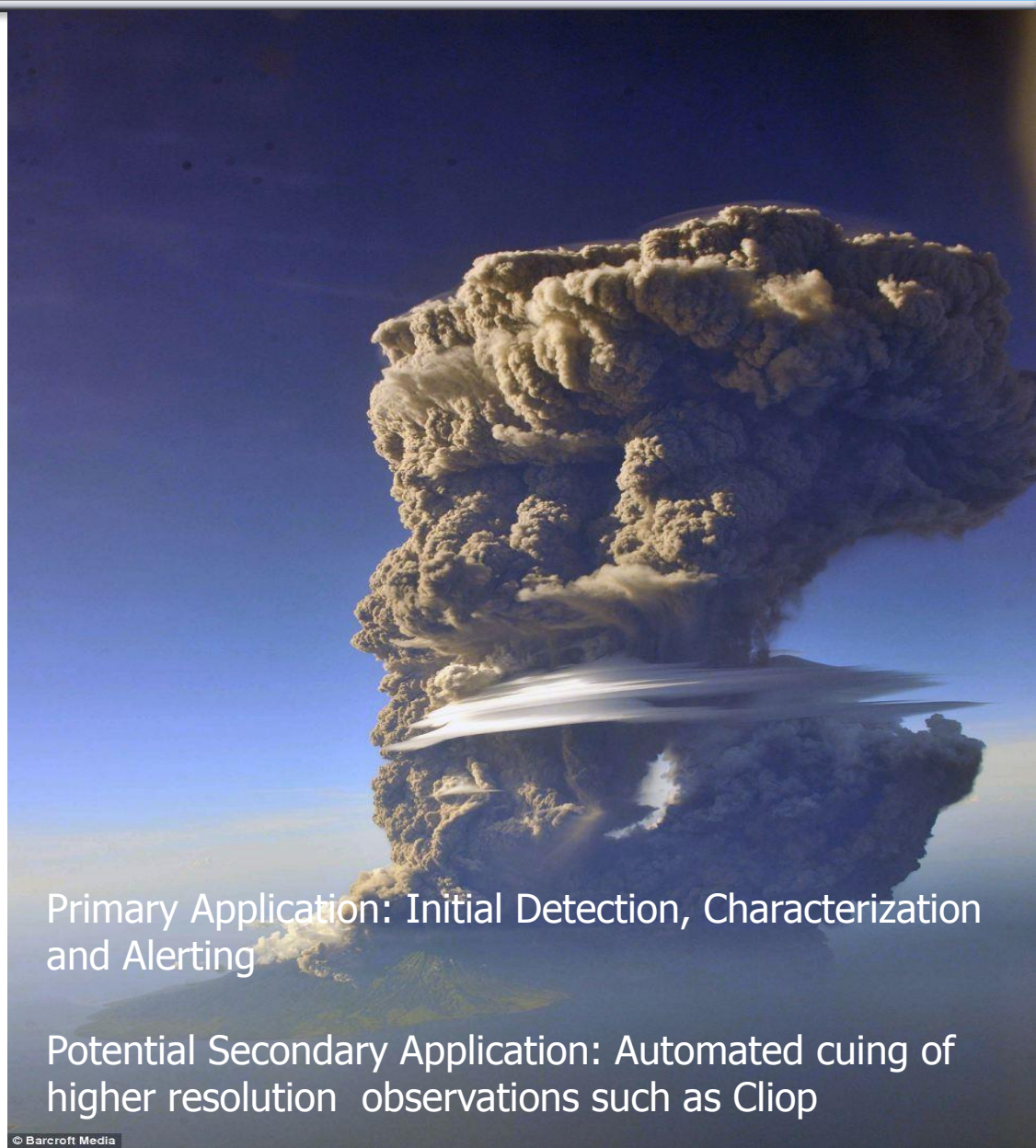
From: Mike Pavolonis NOAA Federal
Subject: **NOAA/CIMSS Volcanic Cloud Alert**
Date: May 30, 2014 6:08:15 AM CDT
To: Mike Pavolonis NOAA Federal

@**********VOLCANIC ALERTS**********
STARTING DATE/TIME OF IMAGE: 2014-05-30 10:32:00 [UTC]
PRIMARY INSTRUMENT: MTSAT-2 Vis/IR_Imager
WMO SPACECRAFT ID: 172
LOCATION/ORBIT: GEO
L1 FILE: mtsat02_1_2014_150_1032.area.gz
VOLCANO DATABASE: /data/common//VOLCAT_DATA/alerts/V
NUMBER OF ASH CLOUD ALERTS: 1
NUMBER OF VOLCANIC Cb ALERTS: 0
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 0
NUMBER OF SO2 CLOUD ALERTS: 0

REPORT WITH IMAGES:
http://volcano.ssec.wisc.edu/alert/report/14318

POSSIBLE VOLCANIC ASH CLOUD FOUND
Alert Status: New Alert Object
Latitude of Radiative Center: -8.421 [degrees]
Longitude of Radiative Center: 119.678 [degrees]
Mean Viewing Angle: 31.21 [degrees]
Mean Solar Zenith Angle: 100.73 [degrees]
Nearby Volcanoes (meeting alert criteria):
Sano, Wai(49.71 km)
Sangeang Api(71.71 km)
Poco Leok(93.32 km)
Ranakah(94.86 km)
Inielika(147.81 km)
Cloud Object Probability: 99.99957 [%]
Median Probability of Object Pixels: 92.45512 [%]
Percent Unambiguous Pixels: 12.30223 [%]
Maximum Height [AMSL]: 10.2 [km] (33355.06 [ft])
90th Percentile Height [AMSL]: 9.6 [km] (31600.68 [ft])
Mean Tropopause Height [AMSL]: 16.5 [km] (54080.38 [ft])
Total Mass: .004477 [Tg]
Median Effective Particle Radius: 5.74 [um]
Total Area: 1281.51 [km^2]

Geographic Regions of Nearby Volcanoes: Lesser Sunda Is
VAAC Regions of Nearby Volcanoes: Darwin
FIR Regions of Nearby Volcanoes: Unknown



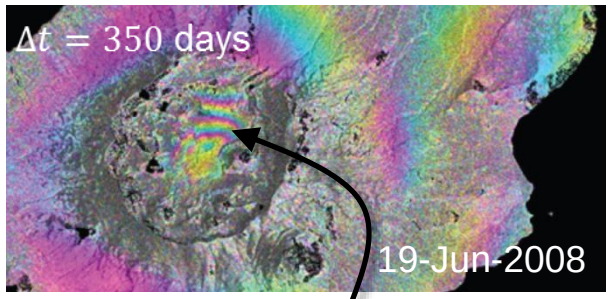
Primary Application: Initial Detection, Characterization and Alerting

Potential Secondary Application: Automated cuing of higher resolution observations such as Cliop

SAR-VIEWS: SAR Volcano Integrated Early Warning System

NASA ASP Disasters Project, PI: *FJ Meyer & University of Alaska Fairbanks*

- **Application of SAR-integrated system to historic eruption of Okmok**
  - Conventional AVO data showed hazard signals only 20 minutes before eruption!
  - SAR **showed changing deformation pattern 25 days prior to eruption**!



Automatic SAR product shows deformation ~25 days before eruption

Jun 12, 19:40: First seismic signals (**only 20 minutes before eruption**)

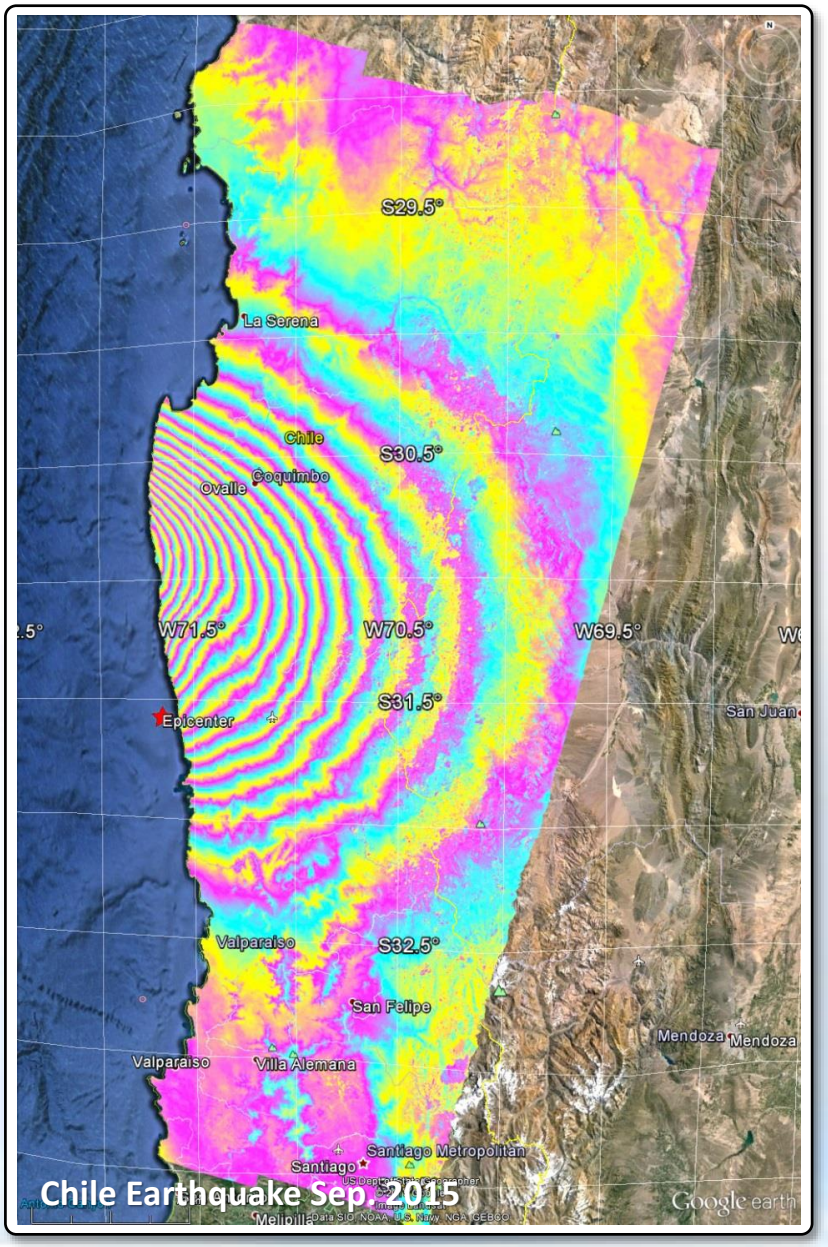
Jun 12, 20:00: Start of eruption

Jun 12, 20:20: First thermal signal in remote sensing data

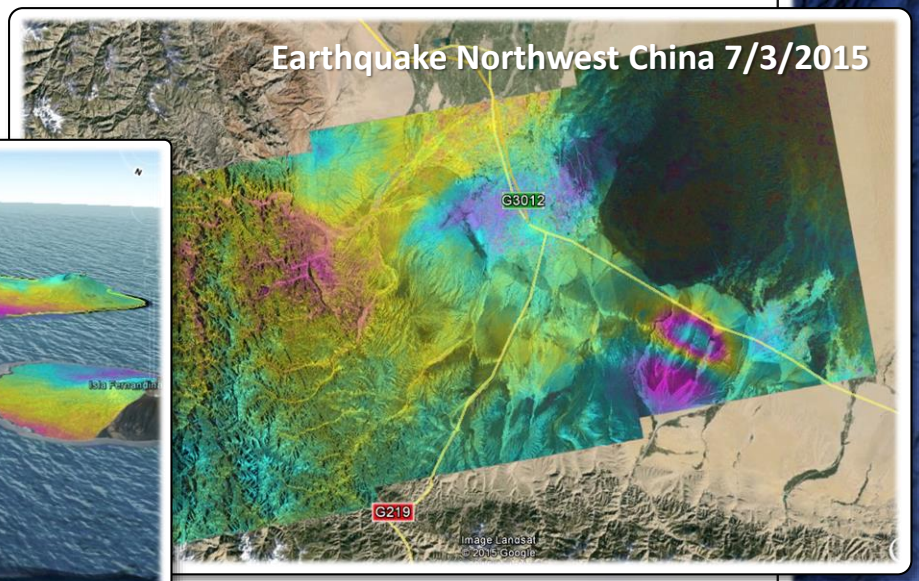
Accomplishment/Result

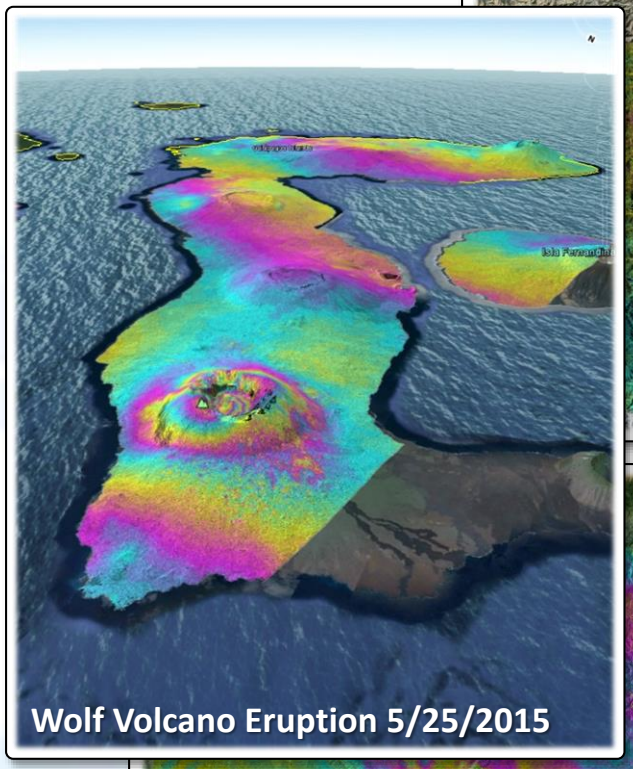
- **While project is aimed at volcanic hazards, we have applied SARVIEWS to disasters of opportunity including:**
  - Nepal earthquake (Apr/May 2015)
  - Wolf Volcano (May 2015)
  - Northwest China Earthquake (Jul 2015)
  - Chile Earthquake (Sep 2015)

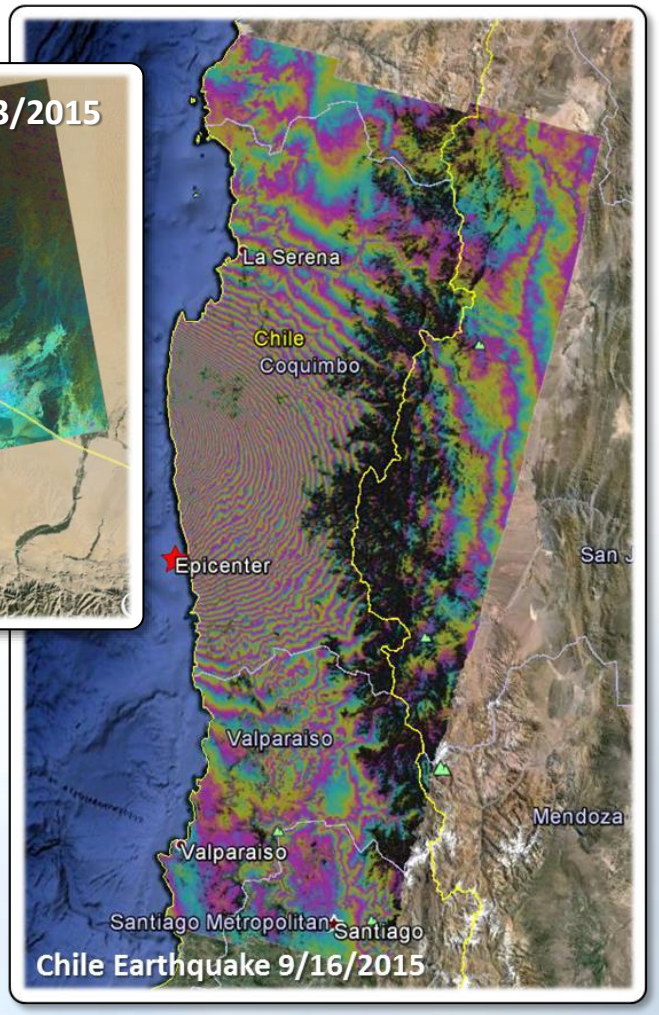
- **Chile Earthquake (9/16/15; mag. 8.3):**
  - SARVIEWS team completed event-capturing SAR interferogram within 24 hours of the earthquake!
  - Image on right shows up to 1.5 meters of surface deformation across an area of 130 miles radius

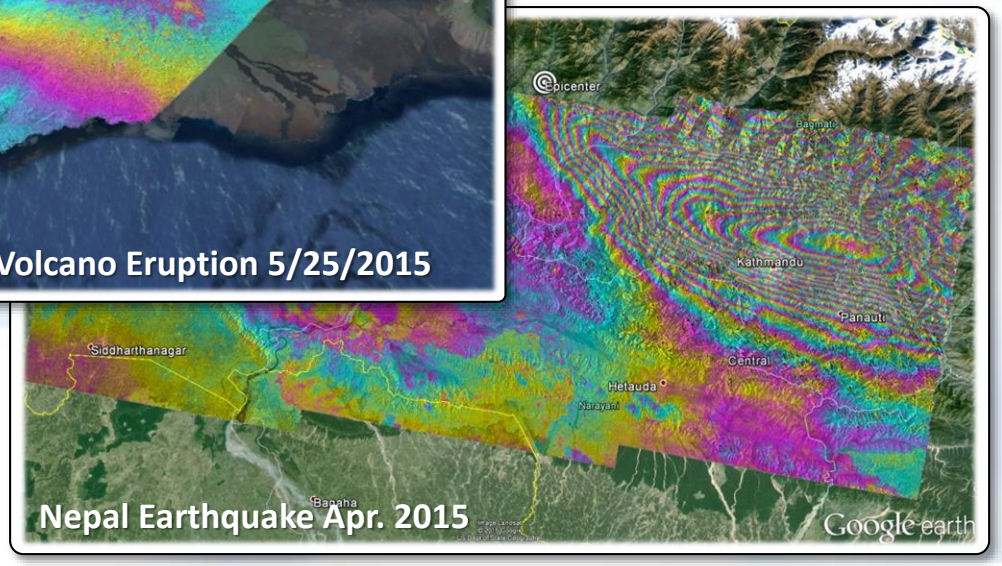


Additional Examples









Hazard products for recent disasters:
GIS-Ready Surface Deformation maps

Langley Research Center

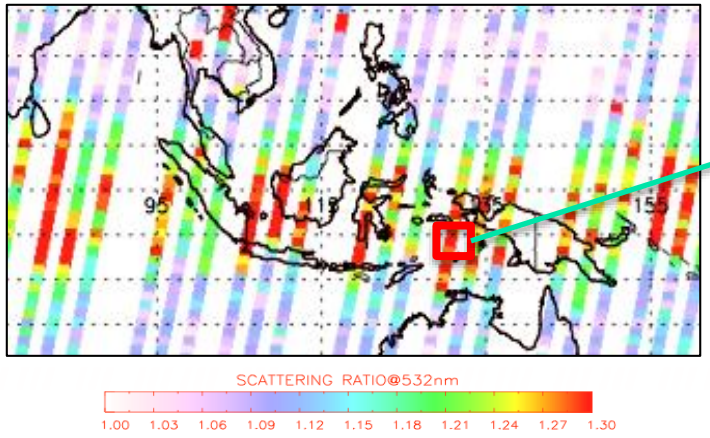
KlAsh deployment after Mt Kelud eruption

(Left). Medium balloon launch with sondes to measure aerosol backscatter . (Right) Preparation of the Optical Particle Counter flight under a large balloon.

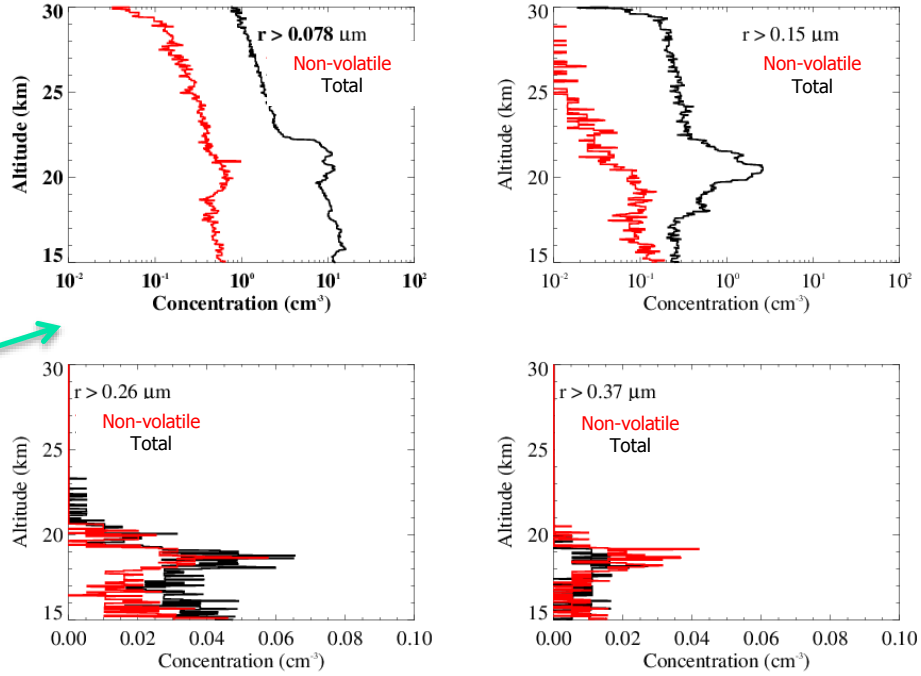
KlAsh campaign

10-day balloon field experiment in Darwin (Australia) May, 2014 to sample volcanic aerosol from the Mt Kelud eruption. *Rapid Response*, with critical support from NASA HQ (Considine, Kaye), CALIPSO (Trepte), SAGE (Thomason), Australian BOM (Atkinson), CASA.

Accumulated CALIPSO observations (14-24 May 2014)



Optical Particle Counter, May 20th



- 3 months after the Mt Kelud eruption, the KlAsh campaign has revealed the persistence of volcanic ash in the lower stratosphere. Current models do not account for the climate impact of volcanic ash.

Marco Fulle - www.stromboli.net

Questions?

Rueters