

## Volcanic Ash Part 2 – Talking Points

**Slide 1** - Photo: Christina Neal – USGS/AVO April 4, 2009 – Mt. Redoubt

**Slide 2** – Objectives (from Slide)

**Slide 3** – Redoubt case – Title slide

**Slide 4** – Map location and info - **Map from: Janet Schaefer, AVO/ADGGS**

**Mount Redoubt** is located in the Cook Inlet Region of south-central Alaska approximately 103 miles southwest of Anchorage. The elevation of Mount Redoubt is 10,197 feet. Seismically monitored with 10 seismic stations, one pressure sensor, and three Web cameras. Also, the volcano is monitored by airborne and satellite gas measurements, thermal imaging, two real-time Global Positioning Satellites (GPS), and several campaign stations for GPS and broadband seismicity. Visual observations by aircraft photography is used as well. **It is important for the NWS to monitor the Mount Redoubt volcano because of its recent history of eruptions, proximity to a metropolitan area, potential national impact on nearby fossil fuel energy facilities, and potential serious disruption to air and marine transportation, including airports.**

**Slide 5 – Recent Redoubt History (1989 – 1990)**

The last significant eruptions on Mount Redoubt took place from December 14, 1989, to April 21, 1990. These series of eruptions produced a pyroclastic flow (fast moving current of hot gas and rock – from part 1) down the Drift Glacier. The resulting debris flow entrained ice blocks as large as 10 m in diameter and crested about 8 m above the river channel near the Drift River Oil Terminal (MODIS image later), 35 km downstream.

These 1989 eruptions were also famous for the Boeing 747 (KLM) near miss – while en route from Amsterdam. (flew into the ash cloud several hours after the eruption, experienced complete engine failure and narrowly avoided tragedy when the crew successfully restarted the engines and safely landed in Anchorage – also in part one). The aircraft sustained \$80 million in damages.

**Overall**, there were some 23 major explosive events between December 1989 and April 1990. The 1989-90 eruption of Redoubt seriously affected the population, commerce, and oil production throughout the Cook Inlet region and air traffic as far away as Texas. **Total estimated economic costs were \$160 million, making the 1989-90 eruption the second most costly in U.S. history after Mount St. Helens in 1980.**

### **Slide 6 – Most Recent History (2008)**

Beginning in late July 2008, an unusually strong hydrogen sulfide (H<sub>2</sub>S) odor was noted near the volcano, which persisted through mid-September 2008. In late September 2008, volcanic tremors began, along with steaming. A 50 m-wide hole was detected on upper Drift Glacier. During the month of October, H<sub>2</sub>S, sulfur dioxide (SO<sub>2</sub>), and carbon dioxide (CO<sub>2</sub>) were all measured above background levels. On October 3, 2008, AVO sent out an Information Statement describing unrest and event possibilities. On November 5, 2008, the color code changed from GREEN to YELLOW, and the alert level changed from NORMAL to ADVISORY. The NWS uses the USGS Volcanic Activity Alert-Notification System for designations of volcano alert levels.

### **Slide 7 (3) – Recent History continued...**

On November 5, 2008, the color code changed from GREEN to YELLOW, and the alert level changed from NORMAL to ADVISORY. The NWS uses the USGS Volcanic Activity Alert-Notification System for designations of volcano alert levels. During the week of January 22, 2009, seismicity dramatically increased and new mudflows began to appear along the margin of the Drift Glacier and at the north base of the volcano. SO<sub>2</sub> levels were elevated along with seismicity. Seismic events reflecting magma displacement were occurring every hour at volcano monitoring stations. **ORANGE/WATCH alert level was declared on January 25 and AVO began 24/7 staffing.**

### **Slide 7 – Page 2 – Map Location of Earthquake/pre-eruption.**

**Slide 7 – Page 3** - 1109z Sunday January 25, 2009 – AVO raised aviation color code to ORANGE and alert level to WATCH. AVO began 24/7 staffing. Seismicity began to decline at ~1430z Sunday January 25, 2009 – however still well above background levels. AVO conducted an overflight of the volcano on Sunday afternoon January 25, 2009 and observations confirm that an eruption has not occurred. Increased steaming through previously observed sources in the snow and ice cover were seen and sulfur gas emissions were noted. There was no significant disruption of the glacial ice, nor any apparent increased water discharge down the Drift River. Another overflight will be scheduled later this week. AVO dropped the alert level back to YELLOW/ADVISORY on March 10, 2009, after six weeks of little change.

### **Slide 8 – The Eruption - Photo: Kristi Wallace - U.S. Geological Survey/AVO**

[Photo: Mount Redoubt volcano eruption on March 31, 2009. Plume height is no more than 15,000 feet above sea level on this day. However, the small amount of ash in the plume is creating a haze layer downwind of the volcano and dustings of fine ash are falling out of the plume.]

**Ironically, only a few days after dropping from orange to yellow (alert) the eruption began. (which shows just how unpredictable volcanoes can be...active or not!) Beginning on March 15, 2009, at approximately 1 p.m. Alaska Daylight Time (AKDT), an explosion took place when magma neared the surface. The explosion resulted in a small ash eruption with high levels of gas. A water vapor plume was observed during an over flight. An ORANGE/ WATCH alert level was declared. The alert level was again downgraded to YELLOW/ADVISORY on March 18, however, by March 21, a high rate of seismicity was noted and AVO returned to ORANGE/WATCH alert level. Beginning on March 22, a series of major explosive events took place.**

The eruptions consisted of a series of explosive ash-producing events resulting in immediate action on the part of the NWS Alaska Regional Headquarters, Anchorage Weather Forecast Office (WFO), Alaska River Forecast Center, Alaska Aviation Weather Unit/Volcanic Ash Advisory Center (AAWU/VAAC), and the Anchorage Center Weather Service Unit (CWSU). Primary threats from Mount Redoubt include its proximity to a metropolitan area and surrounding communities, the potential national impact an eruption might have on the fossil fuel energy facilities in the area, and significant impacts to international airspace and sea lanes.

**On March 22, 2009**, Mount Redoubt volcano, 106 miles southwest of Anchorage, Alaska, began a series of eruptions after persisting in Orange or “Watch” status since late January 2009. Plume heights were observed at or above 60,000 feet during two of the six significant eruptions. Ashfall occurred over south central Alaska, including in Anchorage, with amounts ranging from a trace to one-half inch in depth.

The Redoubt eruptions also disrupted air traffic in the region. Hundreds of commercial flights were cancelled and cargo companies were significantly impacted. This resulted in employees being placed on unpaid leave during periods when airport operations were shut down. Anchorage is Alaska’s major population center; its airport serves as a critical strategic transportation hub as the third busiest cargo airport in the world.

#### **Slide 9 (5) – Models and Remote Observation**

**Page 1** - PUFF model run March 23, 2009.

**Slide 9 – Page 2 – HYSPLIT Model Trajectory Run**

**Slide 9 – Page 3 – HYSPLIT Mass Dispersion Run**

**Slide 9 – Page 4 – HYSPLIT Particle Dispersion Run**

**Slide 9 – Page 5 – AVHRR Image of same time period.** Picture Date: March 23, 2009 14:30:29 UTC .  
Image Creator: **John Bailey. Image courtesy of the AVO/UAF-GI.**

**AVHRR** (Advanced Very High Resolution Radiometer) false-color satellite image showing the eruption cloud from an explosion at Redoubt Volcano at 3:31am AKDT on March 23rd 2009. Image was captured two hours later at 5:30am AKDT and shows the ash cloud passing over other volcanoes and heading NE towards/north of Anchorage.

AVHRR is currently aboard the polar orbiting satellites NOAA 14 through NOAA 19.

### **Slide 10 (2) MODIS Imagery**

**Page 1 - Modis Terra - NASA images created by Jesse Allen, using data provided courtesy of the MODIS Rapid Response team.** Moderate Resolution Imaging Spectroradiometer.

**Earth Observatory Images of Ash plumes ejected by Redoubt Volcano.** This image is from March 23, 2009, 2030 UTC (12:30am AKDT). The image was captured just 16 minutes after the third large eruption. Two plumes of ash are visible: a long white plume reaching north, and a smaller one just northeast the volcano. This eruption occurred in darkness, which meant that photo-like visible images from satellites weren't possible. However, the plumes were detectable in thermal infrared imagery and captured by MODIS on NASA's Terra and Aqua satellites. "Color table" temperatures range from warmer (black) to colder (white).

It might seem counterintuitive that the plumes of volcanic ash are the coldest things in these images—after all, aren't volcanic eruptions hot? The cold temperatures of the plume are a sign of how high it reached in the atmosphere (match with any nearby sounding to approximate the plume top elevation).

[FYI additional - Terra and Aqua can't see through clouds or thick smoke or ash. When no clouds are present, Terra and Aqua see the thermal infrared energy (heat) radiated by the Earth's surface. (This ability frequently makes it possible for the sensors to detect volcanic eruptions.) But when clouds or thick ash block the satellites' views of lower altitudes, then the heat the satellites see is the heat from the top of the cloud or ash plume. The stronger the eruption, the higher into the atmosphere the plume climbs, and the colder its top becomes.]

## Slide 10 – Page 2 - Modis Aqua

This Aqua MODIS image was captured four hours later (from the Terra image), at 4:30 a.m., just as the fifth large eruption began. At that time, the new ash plume was located directly over Mt. Redoubt. Just beneath the plume is a black dot, which is probably heat from the eruption.

## Slide 11 – MODIS visible image, later on the 23<sup>rd</sup> of March

**MODIS image from Terra, 23 March 2009, 2149Z.** Courtesy of the Geographic Information Network of Alaska (GINA). Ash on the snow to the NNE of Redoubt. **Image Creator: Jonathan Dehn.**

## Slide 12 – EOS-Aura OMI image

OMI sulfur dioxide satellite image from the March 23 2009 eruptive events at Redoubt volcano. Colors represent relative amount of gas with dark orange/red being the highest and blue/purple the lowest. This combined image is from 2 OMI orbits for March 23 2009. AURA/OMI: 03/23/2009 20:43 – 22:34 UTC, **SO<sub>2</sub> mass: 42.152 kilotons; affected area: 285,359 km<sup>2</sup>**, SO<sub>2</sub> max: 58.87 Dobson Unit (DU) at 15KM height. (Lon: -149.05, Lat: 61.58). These data are from NASA's EOS-Aura satellite and its Ozone Monitoring Instrument (OMI). (1 Dobson Unit (1 DU =  $2.69 \times 10^{16}$  molecules/cm<sup>2</sup> )

**Slide 13 – GOES 11 10.7µm IR image of March 23<sup>rd</sup> , 2009 eruption. From Scott Bachmeier – Title image of Loop coming next.**

**Slide 14 (LOOP) – Image Loop of GOES 11 10.7µm IR image of March 23<sup>rd</sup> , 2009 eruption. From Scott Bachmeier – Cooperative Institute for Meteorological Satellite (CIMSS), University of Wisconsin.**

GOES-11 10.7 µm IR images showed a few of the volcanic eruption clouds, which exhibited IR brightness temperature values of **-50 to -58° C (yellow to red colors)**. Note that there is a 2 hour gap in the imagery, with no GOES-11 images available from 08:00 to 10:15 UTC — this was due to the fact that the GOES-11 satellite was in a “Spring eclipse” period, where the satellite was in the Earth's shadow (*and the solar panels could not generate the power necessary to operate the instruments*).

The GOES-11 IR imagery indicated that most of the initial volcanic plumes headed toward the northeast, remaining to the north of Anchorage — but the plume from the later (*and stronger*) eruption that began after 12:30 UTC was seen to begin elongating and spreading out in more of a north-south direction, with the southern edge of that plume taking a path that appeared to be approaching Anchorage.

**Slide 15 – Redoubt hazards (2009)** - Image: NASA's Advanced Land Imager (ALI) on NASA's Earth Observing-1 – April 4, 2009 - Graphics – J. Braun (CIRA)

**Mount Redoubt April 4, 2009.** Volcanic Ash Plume, Volcanic Ashfall, and Lahars (Mud/Debris flow)

Two major lahars moved down the Drift River and partially inundated the Chevron oil terminal. The risk and damage inflicted on the Drift River terminal cost Chevron significantly (these data were unavailable at the time of writing). Some WFO staff expressed concern that NWS services were underutilized by those managing the Drift River terminal during this event. Like other oil terminals in the state, the Drift River site is vulnerable to natural hazards. Damage to the terminals poses a risk to the surrounding ecological and human communities. There was also a significant economic impact from halting oil storage at the Drift River Oil Terminal, which affects upstream production wells.

Airborne ash clouds posed a hazard to aviation, resulted in hundreds of cancellations, and rerouted flights in and around metropolitan Anchorage. The repercussions of human and cargo transport delays rippled through the Anchorage, Alaskan, and U.S. economies. Alaska Airlines cancelled approximately 200 flights. FedEx, UPS, and several other cargo airlines rerouted aircraft to Seattle. Ashfall caused the Ted Stevens International Airport in Anchorage to shut down all operations for 20 hours. Disruption to the aviation industry was significant with long-term and far-reaching economic implications .

Minor ashfall affected several communities as far downwind as Delta Junction (400 miles northeast of Anchorage). Emergency managers used NWS products with varying degrees of success to prepare their communities for ashfall threats. Elmendorf AFB temporarily relocated some of its assets.

**Slide 16 – Redoubt Ash Advisory**

Volcanic Ash Advisory beginning 2009-03-24 04:16Z and ending 2009-03-24 13:00Z. This was the largest of 11 VAAs (206,342 KM<sup>2</sup>) issued between March 22, 2009 and April 4, 2009.

**Slide 17 (2) – Eruption Results – Slide plus below.**

**March 22 – April 4, 2009**

There were several impacts from this series of eruptions from Mount Redoubt. Two major lahars (mudflows) moved down the Drift River and partially inundated an oil terminal. Airborne ash clouds posed a hazard to aviation and caused multiple flight cancellations and reroutes. Alaska Airlines cancelled approximately 200 flights. FedEx, United Parcel Service and several other cargo airlines rerouted aircraft to Seattle. Ashfall forced Ted Stevens International Airport in Anchorage to close for 20 consecutive hours. Disruption to the aviation industry was

significant for passenger travel and cargo transportation between Asia and North America. Minor ashfall impacted several communities as far downwind as Delta Junction, Alaska, 400 miles northeast of Anchorage. Elmendorf Air Force Base assets were temporarily relocated. There were also impacts to oil field operations due to the cessation of oil storage at Chevron's Drift River Oil Terminal. \*\*\*the economic impact is estimated to be less than or equal to the cost of the impact from the 1989-1990 Mount Redoubt event (estimated at \$160 million). \*\*\* - replace with actual figures if available.

**Slide 17 –Page 2 – in addition to the slide, see below**

NOAA's National Weather Service (NWS) plays a central role in providing meteorological observations and analysis in addition to forecast and advisory information for volcanic ash analogous to that which is provided for most other hazards affecting the atmosphere. Volcanic ash, however, presents a unique set of challenges for NWS operations. For instance, another agency - the Department of Interior's U.S. Geological Survey (USGS)/ Volcanic Observatory - has the lead in monitoring and warning of volcanic eruptions. The eruptions often occur with very little advanced warning, requiring very close interagency coordination as well as rapid, cohesive delivery of information to decision-makers in emergency management and air traffic.

**FYI\*\*\*During March and April 2009, the Alaska Aviation Weather Unit (AAWU) evaluated 142 Pilot Reports (PIREPS) and issued 39 SIGMETS that were all volcanic related.\*\*\***

**Slide 18 (2) – Organizational Structure Title Page**

**Slide 18 – Page 2 – NWS Ash Program Structure**

**Slide 19 – Offices and the Products**

**VAAC** – Volcanic Ash Advisory Center

**MWO** – meteorological watch office

**WFO** – Weather forecast office

**CWSU** – Center weather service unit

**SPS** – Special weather statement

**NPW** – Non-precipitation watch/warning

**PNS** – Public information statement

**MWS** – Special marine statement

**CWA** – Center weather advisory

**MIS** – Meteorological impact statement

## **Slide 20 – Organizational Timeline – See slide**

\*With a Memorandum of Agreement (MOA) with the FAA.

## **Slide 21 – Title Slide US Volcanic Observatories**

Volcano Observatories are a very important resource for **pre-eruption, eruption and post eruption** monitoring. Monitoring and research at the five volcano observatories (in conjunction with the Menlo Science Center in Menlo Park) helps advance the understanding of active volcanism and allows the Volcano Hazards Program to provide warnings of impending eruptions in the United States. They monitor earthquake activity, ground deformation, gas chemistry, and other geophysical and hydrologic conditions before, during, and after eruptions. Observations are used to detect activity leading to an eruption, provide real-time emergency information about future and ongoing eruptions, identify hazardous areas around active and potentially active volcanoes, and improve our understanding of how volcanoes erupt and change our environment.

To study active volcanism, the Volcano Hazards Program depends principally on the research and monitoring conducted at three permanent installations: the Hawaiian, Cascades, and Alaska Volcano Observatories. Each observatory provides continuous and periodic monitoring of the seismicity, other geophysical changes, ground movements, gas chemistry, and hydrologic conditions and activity between and during eruptions. They also provide a detailed record of eruptions in progress. These observations serve to characterize eruptive behavior, identify the nature of precursory activity leading to eruption, define the processes by which different types of deposits are emplaced, and specify the hazards that could be unleashed by each kind of eruption. From direct observation of precursory signs, it is possible to anticipate eruptions. Underlying all observatory operations is an ongoing program of fundamental research in volcanic processes, supplemented by collaborative studies conducted at other USGS centers. Such research typically includes direct interpretation of the monitoring and eruption data, and it leads to formulation of conceptual models that can be tested by theoretical or laboratory simulations of volcanic systems.

### **[\*\*\*EXTRA Material on the Observatories Themselves\*\*\***

#### **The Hawaiian Volcano Observatory (HVO)**

HVO is the U. S. Geological Survey's oldest such facility, founded in 1912 by Thomas A. Jaggar and run continuously by the USGS since 1948 (Heliker and others, 1986). It is located on the summit of Kilauea, one of the most active volcanoes in the world, on the Island of Hawaii. With the frequent eruptions at Kilauea and nearby Mauna Loa, HVO is a training ground for most of the volcanologists at the USGS. Many volcano-monitoring techniques used worldwide were originally developed at HVO, which is a testing ground for new techniques and instruments. The existence of HVO gave the USGS the unique capability of responding to activity at other U.S. volcanoes. When Mount St. Helens reawakened in March 1980, the USGS was well prepared to respond to the crisis. Scientists who had previously deciphered the volcanic history of Mount St.



Helens, together with HVO alumni, quickly assembled to monitor the seismic activity and steam explosions. All worked together with the many agencies and public officials who were anxious to know when and if a large eruption was going to occur and what hazards it might create. Guided by USGS information, public officials designated zones of restricted access, and the loss of life from the May 18th eruption was thereby minimized, even though the timing of this event could not be precisely predicted.

### **Cascades Volcano Observatory (CVO)**

After the devastating explosive eruption in 1980, the Cascades Volcano Observatory (CVO), in Vancouver, Washington, was founded and staffed with hydrologists, geologists, geochemists, and geophysicists (Brantley and Topinka, 1984). The observatory quickly broke new ground in its study of the ongoing eruption cycle at Mount St. Helens. In mapping and interpreting the origin of the deposits of the May 18 eruption, scientists had the unique advantage of direct observation of the landslides, eruption, and volcanic debris flows. Monitoring the growth of the lava dome in the crater of Mount St. Helens resulted in accurate predictions, 1 to 3 days in advance, of 16 out of 17 dome-building eruptions-an unprecedented feat in the young science of volcanology.

### **Alaska Volcano Observatory (AVO)**

In 1988, the USGS added a third volcano observatory, the Alaska Volcano Observatory (AVO), in Anchorage and Fairbanks, Alaska, to expand and coordinate existing monitoring of the many active volcanoes along the Alaska Peninsula and in the Aleutian Islands. Many international flightpaths lie directly over Alaska, and the frequent eruptions of these volcanoes pose a serious hazard to aircraft far downwind. Study of Alaskan eruptions also provides more frequent opportunities to study volcanic activity similar to that of the less frequently active Cascade Range volcanoes.

### **Long Valley Observatory (LVO)**

In May 1980, just 1 week after the eruption at Mount St. Helens, a strong earthquake swarm occurred at Long Valley, California, site of a huge eruption of silicic magma about 700,000 years ago. The most recent volcanic activity in the area resulted in the formation of lava domes 550 years ago, accompanied by phreatic explosions that blanketed much of eastern California and western Nevada with volcanic ash (Bailey and others, 1976; Miller, 1985). Following the 1980 earthquakes, the USGS began monitoring Long Valley by setting up an observatory-like project operated from the USGS center in Menlo Park, California. Studies conducted since 1980 have documented almost 2 feet of uplift of the ground within the Long Valley Caldera and have accurately located earthquakes occurring as swarms in and around the caldera, the most recent of which took place in 1990 and 1991. The work at Long Valley is designed to monitor and interpret the current unrest and to make forecasts of any activity that might occur. Thus, the Long Valley project effectively constitutes a fourth volcano observatory in function and responsibilities, if not in name. The largest possible volcanic event at Long Valley, a catastrophic explosive eruption associated with renewed caldera collapse, is also the most difficult to forecast because of the long time interval between such eruptions and the absence of historically documented large caldera-forming eruptions anywhere in the world.

## **Yellowstone Volcano Observatory (YVO)**

The Yellowstone Volcano Observatory is the most recent U.S. volcano observatory. To strengthen the long-term monitoring of volcanic and earthquake unrest in the Yellowstone National Park region, on 14 May 2001 the U.S. Geological Survey (USGS), Yellowstone National Park, and University of Utah entered into an agreement to establish the Yellowstone Volcano Observatory (YVO). The goal of the observatory is to improve the existing collaborative study and monitoring of active geologic processes and hazards of the Yellowstone Plateau volcanic field and its caldera. The Observatory is supported by the U.S. Geological Survey, University of Utah, and the Yellowstone National Park. The park was the world's first National Park. It contains the largest and most diverse collection of natural thermal features in the world.]\*\*\*

### **Slide 22 (2) – Volcano Observatories in general**

**Page 1 – Information from Christina Neal – USGS/AVO. See Slide**

**Slide 22 – Page 2 – Information from Christina Neal – USGS/AVO. See Slide**

### **Slide 23 – Aviation Color Codes**

The Aviation Color Code notifications are issued in conjunction with the Volcano Alert Levels. The color codes (i.e., Green, Yellow, Orange, Red), as shown in the Table above, are used to provide succinct information about volcanic-ash hazards to the aviation sector. Volcanic activity threatens safe air travel when finely pulverized, glassy, abrasive volcanic material is explosively erupted into the atmosphere and dispersed as airborne clouds in flight paths of jet aircraft. The color codes are in accord with recommended International Civil Aviation Organization procedures and are determined by the (A)VO to help pilots, dispatchers, and air-traffic controllers who are planning or executing flights over broad regions of the globe quickly ascertain the status of numerous volcanoes and determine if continued attention, rerouting, or extra fuel is warranted.

**Slide 24 - AVO Volcanic Activity Notice – See slide for “typical” VAN from the AVO.**

**Slide 25 –The NWS/AVO relationship – See Slide.**

### **Slide 26 (3)**

**Astronaut Photograph - Sarychev Peak Eruption, Kuril Islands – June 12, 2009 – International Space Station. (Intermission).**

**Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center**

<http://eol.jsc.nasa.gov>

<http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS020&roll=E&frame=9048>

A fortuitous orbit of the International Space Station allowed the astronauts this striking view of Sarychev Volcano (Kuril Islands, northeast of Japan) in an early stage of eruption on June 12, 2009. Sarychev Peak is one of the most active volcanoes in the Kuril Island chain, and it is located on the northwestern end of Matua Island. Prior to June 12, the last explosive eruption occurred in 1989, with eruptions in 1986, 1976, 1954, and 1946 also producing lava flows. Ash from the multi-day eruption has been detected 2,407 kilometers east-southeast and 926 kilometers west-northwest of the volcano, and commercial airline flights are being diverted away from the region to minimize the danger of engine failures from ash intake.

This detailed astronaut photograph is exciting to volcanologists because it captures several phenomena that occur during the earliest stages of an explosive volcanic eruption. The main column is one of a series of plumes that rose above Matua Island on June 12. The plume appears to be a combination of brown ash and white steam. The vigorously rising plume gives the steam a bubble-like appearance.

In contrast, the smooth white cloud on top may be water condensation that resulted from rapid rising and cooling of the air mass above the ash column. This cloud, which meteorologists call a pileus cloud, is probably a transient feature: the eruption plume is starting to punch through. The structure also indicates that little to no shearing wind was present at the time to disrupt the plume.

By contrast, a cloud of denser, gray ash - probably a pyroclastic flow - appears to be hugging the ground, descending from the volcano summit. The rising eruption plume casts a shadow to the northwest of the island. Brown ash at a lower altitude of the atmosphere spreads out above the ground at image lower left. Low-level stratus clouds approach Matua Island from the east, wrapping around the lower slopes of the volcano.

**Slide 27 – NWS and the AVO...more...see slide**

**Slide 28 – Volcano Hazards Program USGS/AVO**

The overall objectives of the Volcano Hazards Program are to advance the scientific understanding of volcanic processes and to lessen the harmful impacts of volcanic activity. The Volcano Hazards Program monitors active and potentially active volcanoes, assesses their hazards, responds to volcanic crises, and conducts research on how volcanoes work to fulfill a Congressional mandate (P.L. 93-288) that the USGS issue "timely warnings" of potential volcanic hazards to responsible emergency-management authorities and to the populace affected. Thus, in addition to obtaining the best possible scientific information, the program works to effectively communicate its scientific findings to authorities and the public in an appropriate and understandable form.

**Slide 29 – Original Goals of the Volcanic Ash Program**

Goals Reached? Yes.  
Continuing/Ongoing.  
Including all VAACs, WFOs, WSOs, CWSUs, NESDIS, AAWU  
AWC, USGS(AVO)

**Slide 30 (2) – Recent Goals - 2004**

**Page 1** Goals Reached? Most of them

**Page 2** Goals Reached? Not completely(?).

**Slide 31 – Reason for the five minute warning system**

**Why?** (See slide)

However, remember - **\*\*\*5 minute warnings are only possible with monitored volcanoes.\*\*\***

**And, even with a fully monitored Volcano, this is very hard to do.**

**\*\*\*Everything possible is being done to implement this goal for every eruption when possible.\*\*\***

**Slide 32 – Most Recent (Today's) Goals**

Goals met?

**Slide 33 (2) – Alaskan Aviation Weather Unit**

**Page 1 – Home Page of AAWU**

**Page 2 – Alaska Aviation Weather Unit** has an area of responsibility that extends from Russian airspace to Canada, from the North Pole to the North Pacific Ocean. AAWU provides aviation meteorological support consisting of Area Forecasts, Airmets and Sigmet.

**FYI:** There are four Meteorological Watch Offices cover the United States area of responsibility:

The Alaska Aviation Weather Unit (AAWU) in Anchorage  
The Aviation Weather Center in Kansas City  
The National Weather Service Forecast Office in Honolulu, Hawaii  
The National Weather Service Forecast Office in Guam

## Slide 34(2) – VAACs

### Page 1 – Map of the World’s VAACs - 9 Total

**Anchorage VAAC - Anchorage, AK, United States; Buenos Aires VAAC - Buenos Aires, Argentina; Darwin VAAC - Darwin, Australia; London VAAC - London, United Kingdom; Montreal VAAC - Montreal, Canada; Tokyo VAAC - Tokyo, Japan; Toulouse VAAC - Toulouse, France; Washington VAAC - Washington, DC, United States; Wellington VAAC - Wellington, New Zealand**

**\*Only two VAACs** cover the United States: the Alaska Aviation Weather Unit in Anchorage and NESDIS Satellite Analysis Branch in Washington DC.

### Page 2 – VAACs – what they do

The International Civil Aviation Organization (**ICAO**) has designated 24/7 volcanic cloud monitoring duties to 9 Volcanic Ash Advisory Centers (VAAC's) around the world. The VAAC's are responsible for issuing Volcanic Ash Advisories, which alert aviation interests to the presence of volcanic ash clouds. The National Weather Service (NWS) is responsible for operating the Anchorage, AK and the Washington, D.C. VAAC.

Volcanic Ash Advisory Centers (VAACs) monitor Volcanic Ash plumes within their assigned airspace. Each VAAC is responsible for providing Volcanic Ash Advisories (VAA) whenever an volcanic event occurs in their area of responsibility.

## Slide 35 (2) – (\*\*Not Available in the Articulate Presenter Version\*\*)

### Page 1 – Communication Lines

#### Typical Lines of Communication within the USA

VAAC - Volcanic Ash Advisory Center; VO – Volcano Observatory; MWO - Meteorological Watch Offices; NWS – National Weather Service; CWSU - Center Weather Service Unit; WFO - Weather Forecast Office; AWC - Aviation Weather Center; FAA - Federal Aviation Administration; ICAO - International Civil Aviation Authority; FEMA - Federal Emergency; DoD - Department of Defense; ATCC - Air Traffic Control Center ; DHS - Dept. Homeland Security;

## Page 2 - Alaska VAAC Home page

Showing yellow alert for Cleveland Volcano.

2010-11-17 12:15:52 - Status Report

Clear satellite views of Cleveland Volcano today show a thermal anomaly in the summit crater. No evidence of eruptive activity or flowage deposits on the volcano flanks has been observed and AVO has received no reports of activity at the volcano.

Without a real-time seismic network at Cleveland, AVO is unable to track local earthquake activity related to volcanic unrest. Short-lived explosions with ash clouds that could exceed 20,000 ft above sea level can occur without warning and may go undetected on satellite imagery for hours. Low-level ash emissions at Cleveland occur frequently and do not necessarily mean a larger eruption is imminent. AVO continues to monitor the volcano using satellite imagery.

### Slide 36 – Information used at the VAAC

### Slide 37 – VAAC: Volcanic Ash Forecast Process (and Actions)

## From the Alaskan VAAC – Tony Hall, et al.

The source of the initial report can drive the actions taken by the forecaster; generally some quick assessment of the potential threat and validity of the report will drive the first actions taken. In some cases pilot reports (PIREPs) need to be verified, especially for shallow or low plumes which are sometimes incorrectly interpreted—such as lee clouds off of a volcano's dome. Other PIREPs at middle and high levels can usually be taken verbatim and used to immediately contact the CWSU and FAA and to issue an eruption SIGMET. The latter example would be the case for domestic volcanoes; the situation gets more complicated for Kamchatka volcanoes. For this discussion, we will focus on the process used for Alaskan Volcanoes.

Additional information that maybe known ahead of time (i.e. Redoubt 2009, Augustine 2006) is the volcano's status; information produced by USGS which is generally available for monitored volcanoes. In the case of Redoubt and Augustine, many agencies in the state and federal government were aware of an eminent eruption of the volcano. However, the science behind predicting eruptions is still evolving and there are certainly surprises (i.e. Okmok 2008). These situations can dictate the immediate actions taken by a forecaster. In the case of Okmok's initial eruption, it was so explosive there was no doubt to the validity.

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The first action taken is to call the CWSU/FAA to allow them as much time as possible to divert aircraft in potential risk areas. During normal duty hours we would call the CWSU and they would coordinate with the FAA in the ARTCC (they are co-located). After hours, we would call

the ARTCC directly. This is followed by an eruption SIGMET stating that a specific volcano may have erupted to the reported flight level (if known). We strive to have the eruption **SIGMET** issued within 5 minutes. Sometimes that is not possible, but that is the goal.

**Slide 38 (3) – SIGMETs/Watch Offices/SIGMET example**

**Page 1 – Info from: From Clinton Wallace** - VAWG Chair - Deputy Director, Aviation Weather Center Alaska Aviation and Volcanic Ash Workshop – Sept. 2010

SIGMET information has been the staple of aviation meteorological products for decades. In many cases it is the first product that provides warning for airborne aircraft, as well as Air Traffic Services (ATS). A SIGMET essentially is a “no fly” area for aircraft. It’s ultimately up to the individual airlines. Airline operators generally avoid airspace where a Volcanic Ash SIGMET has been issued by a MWO.

SIGMET information is ideal for simple volcanic ash events. Small ash cloud events with uniform distribution of ash can be effectively communicated. However, those events that produce ash clouds moving in different directions at different levels, due to non-uniform wind profiles aloft, pose a problem to the International Civil Aviation Organization MWOs in the production of SIGMET information.

**Page 2 – Meteorological Watch Offices (Remember – there are actually 4 (four) MWOs including Guam)**

**Info from: From Clinton Wallace** - VAWG Chair - Deputy Director, Aviation Weather Center  
Alaska Aviation and Volcanic Ash Workshop – Sept. 2010

**Page 3 – Example SIGMET:** Initial and second SIGMET for the night of March 22 local (23rd UTC) Redoubt eruption. (0700 – 1300 UTC, March 23, 2009)

**During March and April 2009, the Alaska Aviation Weather Unit (AAWU) issued 39 volcanic related SIGMETS.**

**Slide 39 (2) – VAAC Forecast Process Continued: From the Alaskan VAAC**

**Page 1 - Tony Hall, et al.**

From here, it is a fact finding mission to produce the volcanic ash (VA) SIGMET and (volcanic ash advisory) VAA. Meteorological model data, satellite imagery and other tools that are in AWIPS

are used along with the VA dispersion model information. **The forecaster has to make a lot of decisions, often in a short period of time, based on what information he has available at the point in time. The forecaster-in-the-loop is almost an understatement for this type of activity.**

This process generally includes asking the Center Weather Service Unit (CWSU) to provide any additional PIREPs of known ash flight levels, as well as, calling Alaska Volcano Observatory (AVO) for their perspective and expertise in satellite-ash interpretation. This combination can, in most cases, give us the spatial extent of the ash in the atmosphere. This first step in obtaining a good gauge of where the ash is currently located is paramount in our ability to forecast its movement. Determining ash cloud tops-heights is a very important step and can be challenging. The use of satellite temperature techniques and sounding data are most often used. PIREPS are also part of the mix as well as WSR-88D information. When an eruption is in vicinity of RADAR, that information is used as the initial eruption height. The information from the 88-D radar is initially quite accurate; however, the plume height changes with time. For example, the initial eruption height (usually the highest value measured by the radar) will reflect the steam and other particles emitted to a certain level, but within a few volume scans, the main ash plume will be seen at a lower level (i.e. initial eruption height of 50 KT feet and then the bulk of main plume can be seen at perhaps 40 or 45KT feet).

## **Page 2 - From the Alaskan VAAC – Tony Hall, et al.**

At the same time as the coordination is ongoing, we will be running the PUFF and HYSPLIT models for forecast input. The HYSPLIT model (**Hybrid Single Particle Lagrangian Integrated Trajectory Model**) is the “official” model in use by the US VAACs. This involves calling the SDM (Senior Duty Meteorologist) **in Washington DC** to run the model and then they provide us with the output. The PUFF model (not an acronym) is an unofficial web-based model that is quick and easy for the forecaster to use at their workstation. This quick method (PUFF) provides a fairly reliable “first guess” to use for preparing warning and advisory products.

Dispersion models used operationally have a number of set parameters that can produce over or under estimates of the amount of ash in the atmosphere. It is a standard practice for the US VAACs to compare the model’s output to what we can see or infer from satellite interpretation. This quality control often times produces the best combination of forecast tools with observed VA. This assessment is done qualitatively and on-the-fly as time is critical for the issuance of the VAA and VAG (graphical VAA) We would generally like to produce these two products within 20-25 minutes following the eruption SIGMET. Note that new tools that we have recently developed will allow us to get the VAAs and VAGs out sooner than 20-25 minutes. The Washington VAAC is not a Met Watch Office (MWO); therefore they are not required to issue a SIGMET. They will issue the VAAs and VAG right away, usually within about 5 minutes.

Continued assessment of the model’s output is also necessary to assure correct movement and speed of the VA. Generally, an hour or so into the SIGMET time, forecasters can verify that the



spatial and temporal calculations are accurate. In one case (again Redoubt 2009), the ash moved south during an eruption much more quickly than was forecast by the models. This assessment allowed forecasters to re-position SIGMET polygons and VAA forecasts to produce a much more accurate forecast over the next 6 to 18 hours.

Each case is unique when dealing with volcanic eruptions and forecasts. The meteorological activity, the type of volcano, eruption, particles being emitted, location, observation, and data available are all major factors in the threat assessment and the outcome of the forecast.

### **Slide 40 (3) – Volcanic Ash Advisories and Graphics**

#### **Page 1 – Example Volcanic Ash Advisory**

Example: Volcanic Ash Advisory (Text) – March 22 (23), 2009 – Redoubt Eruption

#### **Page 2 - Example Volcanic Ash Graphic**

Example Volcanic Ash Advisory Graphic – Redoubt, March 22 (23), 2009

#### **Page 3 – Cancellation of VAA/VAG**

### **Slide 41 - Volcanic Ash Advisories: General/Statistics**

Anywhere from 3000 to 6000 Volcanic Ash Advisories are issued from the 9 VAACs every year...with 800 to 3000 associated Volcanic Ash Graphics.

Typically the Washington, Darwin, Anchorage and Tokyo VAACs account for the vast majority of Ash Advisories issued every year...accounting for nearly 80% of the annual total. This is primarily due to their proximity to the most active “Volcano Alleys” of the world.

### **Slide 42(2) – The Iceland Volcano (Eyjafjallajökull)**

#### **Page 1 – Title/Main Photo**

**Page 2** - The importance of the air transport industry is very significant accounting for 0.7% of the world GDP and 35% of world trade by value. The total loss of aviation due to the 2010 eruption of Eyjafjallajökull is estimated at 1.7 billion (Euro) – 2.3 billion dollars - and a similar amount is thought to have been lost by the tourist service sector. This event brought out in a clear manner how important air transport is for the modern economy.

#### **Slide 43 – Loop of Eyjafjallajökull Eruption**

#### **Slide 44 (2) – Impact on Air Travel Statistics**

**Page 1** - From: **INTERNATIONAL VOLCANIC ASH TASK FORCE (IVATF)**  
Example of Impact to European Air Traffic – April 15 – April 21, 2010.

**Page 2** - Before, During and After with segment broken out.

From: **Ash-cloud of April and May 2010: Impact on Air Traffic – by Eurocontrol (statistic group)**: the European Organisation for the Safety of Air Navigation, is an intergovernmental organisation made up of 38 Member States and the European Community.

**Slide 45 (2) – The Eruption and Air Traffic Re-routing**

**Page 1** - From: **INTERNATIONAL VOLCANIC ASH TASK FORCE (IVATF)**, April 14, 2010 – the day before the main eruption began (April 15). A look at “normal” traffic at 15 UTC. Grey areas depict outlines of Volcanic Ash Advisories (cumulative)...red, orange and yellow areas depict decreasing air traffic densities respectively.

**Page 2** - From: **INTERNATIONAL VOLCANIC ASH TASK FORCE (IVATF)**, Air traffic on April 18, 2010 15 UTC - 3 days after the main eruption began (April 15, 2010).

**Slide 46 – Ash plume Totals – LOOP: Accumulated Ash over 5 day period here. Accumulated Ash – April 15-19, 2010**

This animation (made by the Norwegian Meteorological Institute) shows the spread of the ash spewed forth by the eruption of the

Yellow indicates ash that has fallen by itself, red ash that has fallen as a result of precipitation, and black where the ash cloud is at that moment in time.

**Slide 47 – Monitoring the Eyjafjallajökull volcano (the “tools”)**

**Slide 48 (2) – Satellite Observation of the Eruption(s)**

**Page 1 - May 7, 2010, NASA’s Terra MODIS**

**Page 2 – Stereo Height determination of May 7<sup>th</sup>, 2010 eruption;**  
Images courtesy of NASA GSFC/LaRC/JPL MISR Team

Left: Close-up of previous May 7, 2010 image (RGB “natural-color”)

Right: Is the stereo-derived plume height of the image. Each pixel in the image shows an area 1.1 kilometers (0.68 miles) wide. The vertical accuracy (height) is about half a kilometer (0.3 mile).

The Multi-angle Imaging SpectroRadiometer (MISR) aboard NASA's Terra satellite has nine different cameras, each viewing the scene below from a different angle nearly simultaneously. By combining all these images using a hyper-stereo technique, scientists can calculate the height of the ash plume. Most of the plume resides between 4 and 6 kilometers (2.5 and 4 miles) above the ocean surface (orange and red color in the right image) however, the ash descends to near 3 kilometers (2 miles) far downwind (yellow-green). Also the smaller patch of ash, within about 1 kilometer (0.6 mile) of the surface (blue), which appears to be traveling to the southwest. This ash was on the ground and was then re-suspended by low-level winds. One problem: the "visible" signal at each point must be relatively strong in order to calculate this height stereoscopically (opaque better than translucent).

**Slide 49 (2) – Aircraft Obs (and PIREPS) –**

**Page 1** - Aircraft observations can give great physical and personal perspective to an eruption. As ash is dispersed in layers and the dispersion is dependent on the local weather conditions...observations close to the actual levels of dispersion become greatly important (but can also be quite dangerous).

**Page 2** - PIREP is a report of actual conditions encountered by an aircraft in flight. Pilot reports (PIREPS) are critical for air safety especially during volcanic eruptions. Conditions can change quickly, and there's nothing like having a pilot report (pirep) to give you a bird's eye view of what it's really like up there. Pireps may also validate forecast conditions, or they may describe real-time weather that varies from them. **\*\*\*Forecasts are improved as a result of PIREPS being made available to forecasters.** Pilot reports – can give: Uncertainty in plume height estimates.

**EXAMPLE-**

*UUA/OV EGLL 315425/TM 2110/FL120/TP DC10/WX +VA/RM VOLCANIC ERUPTION 2008Z  
Eyjafjallajökull ASH 40S MOV SSE*

**Decoded:**

Urgent Report (UUA) – 425 nm NW of Heathrow Airport, London at 2110UTC – flight level 12,000 in a Douglas DC10 aircraft – Heavy volcanic ash from eruption of Eyjafjallajökull volcano – currently 40 nm S of position with movement to the south southeast.

**Slide 50 – Weather RADAR and the eruption - Volcanic ash plume at Eyjafjallajökull, May 5th at 19:00 UTC. Height of the plume is approximately 8-10 km height.**

Two methods were mainly used to do the monitoring, MAX(Z) and EHT(Z), i.e. maximum reflectivity and echo top height.

The main observation method to monitor the plume height was a C-band weather-radar stationed at Keflavik airport approximately 160 km away from the eruption site. This made it difficult to monitor the plume height below 3 km because of the curvature of the earth and the surrounding

landscape. Also, at this distance the resolution of the radar was around 1 km. The radar did not work well in cloudy condition as the ash plume is less reflective than water vapour and disappears in the clouds. Dry ash was also difficult to monitor due to low reflectivity and the long distance from the site. **\*\*\*The radar worked well during the eruption to monitor the height, but proved to be of little value to monitor other production change parameters such as ash vs water content of the plume.**

**Slide 51 – Web Cameras** - IMO got the assistance of the local telecom companies to put up web cams to look monitor the eruption. These cameras prove to be very helpful in monitoring changes in the ash content of the plume and also gave a good visual feeling of the intensity of the eruption at any given time.

Web Camera views of *Eyjafjallajokull* Volcano – September 10, 2010 at 1845 UTC. **Roughly from the same perspective (aspect)...but not as close.**

Left is visible image

Right is thermal IR image

#### **Slide 52 (2) – Lightning**

**Page 1** - 90 second time-lapse photo of EYJAFJALLAJOKULL – May 16, 2010.

Lightning detection around the volcano proved to be a good estimate of high production rates of ash in the plume. Electrostatic activity increases with increased ash production. This was used as one parameter to estimate the production rate.

**Page 2 – Lightning Detection Data** - Lightning detection near the eruption site of the Volcano (April and May 2010).

**Slide 53 – Physical Measurements of the Volcano:** Measurements of the height, temperature, gravitational field, and chemistry, all in a three-dimensional time-varying space, of the environment around the volcano are made routinely, and along with seismic instrumentation, are used to help forecast future activity of the volcano.

**Geodesy:** the science of determining the size and shape of the earth and the precise location of points on its surface...deals with the measurement and representation of the Earth, including its gravitational field, in a three-dimensional time-varying space. (Also known as geodetics.)

**Seismology:** The fundamental goal of (volcano) seismology is to understand active magmatic systems, to characterize the configuration of such systems, and to determine the extent and evolution of source regions of magmatic energy. Such understanding is critical to our assessment of eruptive behavior and its hazardous impacts.

**Physical Volcanology:** The processes that control when and how volcanoes erupt. Understanding these processes involves bringing together ideas from a number of disciplines, including branches of geology, such as petrology and geochemistry; and aspects of physics, such as fluid dynamics and thermodynamics.

**Petrology:** Particularly Igneous Petrology - The study of all rocks that have crystallized from molten magma, both volcanic rocks that form at the Earth's surface and plutonic rocks that have formed at depth within the Earth. The range of approaches to study these rocks and volcanoes include: chemical analysis, geochronology, thermodynamics, phase diagrams, microscope petrography and other experimental techniques which can give further insight into the eruption processes.

**\*Other:** Also, regularly if possible, direct measurements of the ash plume height are taken by using theodolites. This gives accurate measurements of the plume height. This data is then used to calibrate the estimates from the radar measurements to see if the radar is actually seeing the top of the plume. At times, it was clear that the top was missed by 0.5-1 km, probably due to extremely dry ash in the cloud at the top.

\*\*\*and the conditions in which rocks form.

**Slide 54 (5) – Conferences and Conclusions: Photo: Eyjafjallajökull May 16, 2010, International Volcanic Ash Task Force**

**Page 1 - Montréal, Canada - July 2010**

In response to the unprecedented disruptions to commercial air traffic in Europe caused by the eruption of Iceland's Eyjafjallajökull volcano on 14 April, ICAO has established an International Volcanic Ash Task Force to drive the development of a global safety risk management framework that will make it possible to routinely determine the safe levels of operation in airspace contaminated by volcanic ash.

**Atlantic Conference on Eyjafjallajökull and Aviation Keflavik, Iceland - September, 2010**  
September 15-16, 2010 in cooperation with the President of Iceland, The Icelandic Ministry of Transport, the Civil Aviation Administration, ISAVIA, the Meteorological Office, Institute of Earth Sciences, Icelandair, ICAO, IATA, ATA, AEA, IFALPA, EUROCONTROL, CANSO and the Embassies of the US and Russia in Iceland.

The aim of the Conference was to address the impact of the volcanic eruption of Eyjafjallajökull in April –May 2010 on air transport as well as identifying what could be done to reduce such impact during future volcano eruptions in Iceland and world-wide.

**The Alaska Aviation and Volcanic Ash Workshop, Anchorage, Alaska USA – September, 2010**  
Discussion of Aviation and volcanic ash impact with more of a USA/Alaska airspace slant. Multiple topics including Eyjafjallajökull.

## **Page 2 – Scientific Aspects**

## **Page 3 – Technical Aspects**

## **Page 4 – Lessons Learned**

Point 1: 2mg/M<sup>3</sup>? Need to refine both the spatial and temporal aspects of this concentration. IT'S NOT JUST THE CONCENTRATION!!! (Location and duration!)

Point 2: Research from all parties concerned with health, safety and aviation concerns.

Point 3: (Much) more research needed here.

Point 4: This includes TRAINING EXERCISES!!!

## **Page 5 – Overview/Conclusions**

**Slide 55 – Into the Future - Photo: Eyjafjallajökull May 16, 2010**

**Slide 56 (3) – Intro to IC4D –**

**Page 1 (See Slide Title)**

**Page 2 - From: Eugene Petrescu and Tony Hall (NOAA/NWS/AAWU, Anchorage, AK)**

Additionally, algorithms are built into the system to produce derived fields from model data for icing, turbulence, ceiling and visibility, among other significant aviation fields. Tools built into IC4D allow the manipulation of model fields that in turn affect forecast output of the algorithms in cases where the models are in error. To assist in this process PIREP and ACARS observations can be displayed within IC4D. When fully deployed the forecast system will provide a collaborative mechanism that allows the exchange of aviation and surface based sensible weather grids among all Alaska Region WFOs, the AAWU, and the Alaska Pacific River Forecast Office for a seamless four dimensional forecast weather cube.

The development of IC4D is a collaborative effort among several NWS partners, and is a subset of the overarching Joint Planning and Development Office (JPDO) Next Generation Air Transportation System (NextGen) Project. The JPDO NextGen Project is comprised of several public and private partners and their activities in support of the reorganization of the National Airspace System to meet projected air traffic demand, improve safety and reduce environmental impacts. IC4D is initially being tested and deployed at the Alaska Aviation Weather Unit / Volcanic Ash Advisory Center (AAWU/VAAC) in Anchorage, Alaska.

**Page 3 – Overview Graphic – See Slide**

**Slide 57 (4) – IC4D –**

**Page 1 – See Slide**

**Page 2 – See Slide**

**Page 3 – See Slide**

**Page 4 - Tony Hall AAWU/VAAC - Alaska Region-Alaska Aviation Workshop, May 13, 2008  
“IC4D USERS GUIDE”**

The initial PUFF model output is ash concentration values at grid point locations and at every 500m from 0m to 16500m. The ingest process that stores the PUFF model output to the Puff databases in the IC4D performs a vertical averaging to produce average ash concentration in 3 distinct layers: Low (0m-5000m), Mid (5500m-10000m), and High (10500m-16500m).

**For more info:**

**[http://www.arh.noaa.gov/arhdata/access/AviationWorkshop08/IC4D\\_Hall.ppt](http://www.arh.noaa.gov/arhdata/access/AviationWorkshop08/IC4D_Hall.ppt)**

**Slide 58 (2) – GOES- R and Synthetic Imagery**

**Page 1 – Which is fake (synthetic)? Left – synthetic; Right is GOES-13**

**Page 2 – See slide on Synthetic Imagery and Goals**

**Slide 59 – The Advanced Baseline Imager (ABI) - Info courtesy of Tim Schmit**

**Slide 60 (2) – Creating Synthetic Imagery**

**Page 1 – see slide (COAMPS microphysics similar)**

**Page 2 – Building WRF GOES-R - Synthetic NSSL WRF-ARW Imagery**

This product is a combined effort between the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma, and The Cooperative Institute for Research in the Atmosphere (CIRA) in Fort Collins, Colorado, together with the NOAA/NESDIS RAMM Branch.

Daily output from NSSL's 4-km WRF-ARW is provided to CIRA, who then generate synthetic satellite imagery, which is sent to the Storm Prediction Center (SPC)

Every day at 00 UTC, NSSL runs their 4-km WRF-ARW. As soon as the 12-hour forecast is completed, several variables are extracted and scp'ed to CIRA. These variables include temperature, water vapor, and other physical and microphysical parameters which are needed for the next step. When all variables have been received at CIRA, an observational operator is run to generate the synthetic imagery for 4 GOES-R ABI bands (6.185, 6.95, 7.34, and 10.35 microns). The simulated imagery is then converted to McIDAS AREA format and made available for the SPC, who then makes the output viewable on their NAWIPS system. Hourly output between 12-00 UTC is processed daily, providing four 13-hour synthetic satellite loops. The resolution of the output is 4-km to match the input resolution of the cloud model; the real GOES-R ABI bands will have 2-km resolution.

This product has two primary purposes: 1) Synthetic imagery from cloud model output can be used to evaluate each model run. For example, one might compare a simulated water vapor band to observed GOES imagery from 12-18 UTC to see how well the model is handling the timing and location of upper level features, such as shortwaves. 2) Since the simulated bands are based on the GOES-R ABI, looking at the imagery will prepare forecasters for how the actual GOES-R imagery will look when it becomes operational. For example, certain features may be visible at these wavelengths which are not viewable in the current GOES bands.

Advantages of the synthetic ABI imagery include: 1) Satellite imagery can be viewed before the simulated time actually occurs, so forecasters know what to expect, 2) three water vapor bands allow one to view different atmospheric levels since the weighting functions peak at different levels, and 3) forecasters can use this imagery to prepare themselves for what actual GOES-R ABI imagery will look like. The biggest limitation is that the forecast is only as good as the cloud model forecast; if the model does not initiate convection, for example, then the convection will also be absent from the synthetic imagery.

**Slide 61 – The Imager’s bands – see slide**

**Slide 62 – Water Vapor LOOP – Real vs Synthetic** - The synthetic imagery loops are available in real-time starting at 1330 UTC every day. In the example below, the 7.34 micron band is compared to the observed GOES-13 Sounder data at a similar central wavelength. Note how the simulated data is at a better resolution than the sounder data (4 km v/s 10 km; GOES-R ABI will be 2 km), but the largest advantage is that the synthetic loop was available for viewing in the morning, thus providing an excellent resource for forecasters.

Synthetic 7.34 micron imagery from 24 April 2010 at between 12 and 00 UTC, and the observed imagery from the GOES-13 Sounder at a similar wavelength. In this case, the model does a fairly good job with the timing of the convection forming in the southeast U.S., but appears to overdo the coverage. The brightness temperatures in the clear areas match well, but the model has a cold bias with the thin cirrus clouds in the Great Lakes region.

**Slide 63 – California Fires of 2007 - Left - MODIS Satellite Image True color - Satellite: Aqua - Pixel size: 1 km Date: 2007/10/23 (created by NASA)**

Right - **Smoke added to synthetic true color GOES-R image**

GOES-R ABI will have the ability to produce imagery at 0.47  $\mu\text{m}$  (blue) and at 0.67  $\mu\text{m}$  (red). Although GOES-R will be unable to produce any images at 0.555  $\mu\text{m}$  (green), color imagery can still be generated with certain techniques. These techniques can be tested through the use of synthetic GOES-R ABI imagery. Synthetic imagery refers to satellite imagery of numerical model output. Shown in the right figure is an example of synthetic GOES-R ABI color imagery over southern California for 23 October 2007. On this particular day, southern California was experiencing wildfires. As a result, smoke properties were used to include smoke in the



synthetic imagery. Smoke detection with GOES-R ABI will exceed current GOES capabilities as thin smoke plumes are only visible during low sun angle periods, while GOES-R will be able to highlight these areas during the entire daylight period. This is due to the inclusion of a band at 0.47  $\mu\text{m}$  (blue).

**Slide 64 - Synthetic Volcanic Ash plume from hypothetical eruption near Yellowstone, WY for June 27, 2010 – 21Z.**

**Work still need to be done...but this is a start!**

(Date at bottom of image is not correct)

**Slide 65 – End of Part 2**

**Slide 66 - Just a plain really cool photo. Kilauea Volcano, Hawaii – March 2008, Volcano derived water spout.**