1. Summary of Activities

This Progress Report presents a summary of the activities of the EOS Volcanology Interdisciplinary Science Team for FY98. With less than one year to go before the launch of AM-1, the Team has concentrated its efforts on the further development of algorithms that will study eruption plumes, surface flows, and volcanic gases. We call these algorithms "Data Products", and in previous Progress Reports we have described the various contributions of each Team Member in their development. In this Report, we focus on the progress that has been made in each algorithm.

We also document our plans for FY99, the interactions that we have had with EOS instrument teams, the support that we have provided to the EOS Project, our community outreach, and our efforts in data validation, Q/A, and data distribution. A budget for FY99 is also provided. We provide a listing (in Section 8) of the 21 papers that were published by the Team in the last year, and 12 papers that are currently in press or under review. Our numerous conference presentations (43 in all) are also listed.

Of particular note is that we organized a Special Session on "Remote Sensing of Active Volcanoes" that was held at the Fall 1997 AGU meeting, which attracted 44 abstracts that were presented in 2 oral and 2 poster sessions. This event was so successful that we were asked by the AGU to edit a Monograph on the topic that showcases many of the techniques that our Team and collaborators have developed. Several major science collaborations have developed within the Team; these have resulted in the preparation of 3 Earth System Science Pathfinder (ESSP) mission proposals.

In many instances, there is considerable overlap between our IDS activities and our Team's other work supported by NASA under the R&A funding. In general, the R&A funding is used for data acquisition, while the IDS funding supports tool development (both the algorithm development and the display capabilities of our web sites). In this way we feel that both programs benefit from the final results (images, conference presentations, and papers).

2. Progress on EOS Algorithms

Here we list the major accomplishments made by Team Members over the last year.

<u>Joy Crisp</u>

A paper (Brown et al., 1998) was published and the new data for H_2S were submitted to the GEISA and HITRAN databases. These new absorption line parameters will make it possible for TES to make more accurate H_2S measurements if it observes an H_2S-rich eruption cloud. Two presentations on the new H_2S data were given at meetings. A paper on the MODIS SO_2 alert is being revised and will be submitted for publication:

Crisp, J.A., Satellite detection of volcanic SO_2 using data from HIRS/2 and future data from MODIS, to be submitted to the International Journal of Remote Sensing.

This is a major overhaul of a paper first drafted in 1993. The new aspects to be included in the revision are: current references; verification of the SO_2 alert during the EOS mission; factors affecting SO_2 detection at thermal infrared, ultraviolet, and microwave wavelengths; radiative transfer tests; more description of the satellite instruments; and a consideration of Luke Flynn's thermal alert which has already been installed for MODIS data as they are processed at the Goddard SCF.

Luke Flynn

All of the software to generate the automatic thermal alerts has been installed within the MODIS SCF at NASA Goddard. The alert is now part of the PGE 03 MODIS software package. Luke has developed an algorithm which will detect thermal anomalies (volcanic eruptions, fires, etc.) apparent in the MODIS Level 1B data stream. The purpose of the Surface Thermal Alert is to provide a rapid means to qualitatively search for thermal anomalies in the MODIS data stream and to display results at a web-site in as close to real-time as possible. Since the product will also detect fires, the generated output will also be very useful to compare with the more quantitatively oriented MODIS Fire Products. The Surface Thermal Alert will also be used for rapid target designation for higher spatial resolution instruments such as ASTER, Landsat 7, and the Hyperspectral Imager.

Description: The entire MODIS Level 1B nighttime data stream will be continuously searched during Level 2 production by a portion of the MODIS Fire Algorithm Code executed at the MODIS TLCF in near-real time, using 5 MODIS bands. Data for alerts that are triggered will be sent to the University of Hawaii SCF. The alert fields will be viewed using a limited interactive display on a Web-site, which will allow display of regional or global maps showing locations of alerts and indicating type (volcano/non-volcano) and severity by color or gray-scale differences. The spatial resolution will be 1 km.

Input: Continuous observation of the MODIS Level 1B nighttime data stream by the MODIS TLCF, conducted as part of a collaborative effort with the MODIS Science Data Support Team and the MODLAND Fire Group. The alert files will be sent directly from the MODIS TLCF to the Univ. of Hawaii SCF, where the classification of alerts will be done. The input for alerts will be Channels 21, 22, 29, 31, and 32.

Output from the Univ. Hawaii SCF: The Surface Thermal Alert will not generate any type of product within the MODIS Fire Algorithm structure. The "output" file of alerts will be transferred to the Univ. of Hawaii SCF for further processing. A copy of the "output" file will not be stored at the DAAC as the other MODIS Fire Products. Alert files will be approximately 50 bytes per record (HDF binary) containing date, time, latitude, longitude, 5 DN values of alert data, an alert qualifier (volcano/non-volcano, severity), and version number of the nighttime alert software. One MODIS global pass per night will yield on the order of 10,000 alerts/night from alerted locations.

Data Availability: Alerts of up to 1 week old will be located on a Web-site maintained by the EOS Volcanology IDS Team. Within two days of final processing at the Hawaii

SCF, alert data in 24-hour increments, will be moved to an as-yet undesignated site for archiving and possible data-querying. The GOES web site that Flynn has developed (see Section 6) provides our test case for providing data to the community. To date, we use the GOES web site to monitor 11 sites, including the following volcanoes: Montserrat, Lascar, Kilauea and Mauna Loa, Santa Maria, Popocatepetl, Colima, and the W. Galapagos Islands.

Lori Glaze

It has been an excellent year for the Plume Top Topography algorithm development. Over the past year, a manuscript describing the application of the photoclinometric technique to volcanic plumes was accepted for publication. Version 1 of the plume topography (PT) algorithm was delivered and testing of the software has begun. In addition to the more general plume and illumination geometries allowed by Version 1, additional software has been developed for easily extracting positional information directly from AVHRR level 1B data. Testing of the algorithm has focused on acquiring AVHRR data for a variety of volcanic plumes in an effort to identify problems with the software as well as model sensitivities.

Significant modifications have been made to the PT algorithm to allow for more general lighting geometries. Version 0 was shown to work very well on the Redoubt volcano data set, which had a plume transported to the East and illumination from the South. Modifications to the PT algorithm now allow the user to analyze an image that is illuminated from any direction. Analysis is still optimized, however, for plumes whose transport is perpendicular to the illumination direction. These modifications have been tested on an AVHRR image of an eruption plume from Popocatapetl, Mexico, where the plume transport was to the North and illumination was from the East. A fully functional version 1 of the software was delivered to Joy Crisp at JPL at the end of April.

Efforts since delivery of Version 1 have focused on obtaining a variety of additional AVHRR test data sets. Over the last 4 months, 18 AVHRR images of volcanic eruption plumes have undergone preliminary analysis by the PT algorithm. This analysis procedure involved converting the data into the correct format for the PT algorithm, determining solar and satellite viewing angles, and attempting to derive surface topography for each image. As part of this process, significant time was spent developing several new IDL procedures for converting the AVHRR Level 1B data into a useable size and format, and for extracting satellite positional information directly from the engineering data for each image. We are hopeful that this experience will help in the development of similar procedures for extracting engineering data from the MODIS Level 1B data.

A lot of time this year was spent on the revitalization of a manuscript describing the theory behind the photoclinometric technique employed by the plume topography algorithm. This manuscript was originally written by L. Wilson (Mouginis-Mark and Glaze, co-authors), and submitted to JGR in 1995. The original draft, requiring significant re-organization and other changes, had been dormant for at least two years. At the end of April, the revised manuscript was re-submitted to JGR, and was recently accepted for publication. With the technique finally released in the peer-reviewed literature, Glaze will be making significant changes to the Data Product Document describing the plume topography algorithm. A minor revision of the DPD was submitted to Joy Crisp last October, but has been available only by request over the EOS Volcanology IDS web page. The revision of the DPD will remove the discussion of the basic technique (referring the reader to the JGR paper), and will be made publicly available via the web site.

Arlin Krueger

During this year, Krueger and the TOMS Group at Goddard have worked on algorithm studies, wavelength optimization, ash retrievals and pre-eruptive degassing measurement requirements and techniques. These efforts have improved our capabilities in measuring volcanic emissions with the TOMS instruments and are described below.

Over the last year we have improved our understanding of the capabilities of TOMS instruments for volcanic ash detection. We have used the Aerosol Index (AI) as a measure of the spectral radiance deviation from a Rayleigh-scattering atmosphere. This AI has different signs for absorbing (mineral ash) and non-absorbing aerosols (water and sulfuric acid droplets) and therefore allows discrimination between volcanic ash plumes and water clouds. A detailed radiative transfer model of volcanic ash clouds (Krotkov et al., 1997b) is used to convert measured radiances for each pixel into effective radius and optical depth. The model assumes a particular ash refractive index based on the optical measurements of surface and airborne ash samples. This information in turn allows estimation of the mass of ash in the whole cloud.

The TOMS SO_2 retrievals are biased high when ash is present in the volcanic cloud (Krueger et al., 1995). Thus, a method to measure ash optical depth is of considerable interest in improving the SO_2 retrievals. The current development activity involves analysis of effects of non-sphericity, index of refraction, scattering phase function, and other parameters on the ash retrievals.

During the last year, the TOMS AI ash technique was compared with the AVHRR thermal infrared (IR) split window technique using the August 19, 1992 Mt. Spurr ash cloud as a test case. The total mass of the ash cloud is estimated using both techniques. We have found that the TOMS mass range (0.3-1Mt) agrees reasonably well with AVHRR mass retrievals (0.4 - 1Mt) given the complex observational conditions (inhomogeneous underlying cloudiness) and the uncertainty in ash refractive index.

We have concluded that the lower spatial resolution of TOMS is not a critical limitation for detection of stratospheric ash plumes. This is significant for high-altitude aircraft operations since aircraft may encounter hazardous ash plumes. We have also concluded that the location of UV (TOMS) and IR (AVHRR) instruments on different polar platforms provides only occasional time coincident measurements of drifting volcanic ash clouds, which is inadequate for the study of transient eruption processes. This has led to combined UV and IR channels in one instrument suite on a geostationary platform in a proposed mission focused on volcanic processes and hazards.

Vincent Realmuto

Extensive modification of thermal infrared (TIR) SO_2 mapping procedure was necessitated by applications of the procedure to a variety of new data sets. Note that the applications of the mapping procedure are funded through the Natural Hazards and Applications Program, while the development and modification of the algorithms is funded by the IDS funds. The work conducted under EOS funding can be summarized as follows:

(1) The mapping procedure has been generalized to accept multispectral TIR image data from any instrument. The modified procedure has been applied to PacRim TIMS data acquired in 1996. Channel 6 of TIMS was inoperable during this campaign, so we must work with 5 channel TIMS data (recall that ASTER will have only 5 TIR channels).

(2) Emissivity spectra are now generated within the mapping procedure. This modification was necessitated by the Navajo Generating Station (NGS) data set acquired by TIMS in 1996. The high TIR reflectance of the quartz sandstone surrounding the NGS accentuated shortcomings in the previous methods of estimating emissivity spectra. The internally generated emissivity estimation algorithm uses an iteration strategy to obtain a more accurate estimate of the contribution of reflected downwelling sky radiance to the radiance perceived at the sensor. The internal generation of emissivity spectra also simplifies the user interface to the mapping procedure. The only required inputs are the instrument-perceived radiance image and tabulated spectral response of the sensor. The user will not have to depend on the ASTER or MODIS science teams to supply an emissivity image. In addition, the internally generated emissivity estimates can be tailored to specific areas within an ASTER or MODIS scene. Users can also save emissivity spectra to disk, read spectra from disk, and manually modify emissivity spectra.

(3) Users can specify irregular, non-contiguous regions of interest for emissivity estimation and SO_2 retrieval. This modification resulted in a large reduction in the time required to map a plume as large areas of the plume can be delineated and the mapping procedure run unattended.

(4) Change Detection algorithm has been ported to Windows NT.

Bill Rose, Larry Coke and Gregg Bluth

(1) Under the development of a multispectral infrared retrieval of sizes and masses of various types of particles in drifting volcanic clouds, they have been studying the El Chichon (1982) clouds. HIRS/2 are being used as a comparison to the AVHRR data.

(2) Via collaborations with other IDS Team Members at Goddard SFC, they have investigated the verification of their radiannet (two-band) results from TOMS reflectivity data. These results have proven to be unexpectedly encouraging when used in combination with AVHRR and GOES data, where the TOMS reflectivity measurements can also be used as the basis of a radiative transfer model for

volcanic ash clouds. Work continues with the estimation of the shape effects of particles in the cloud.

Howard Zebker and Pete Mouginis-Mark

Over the past year we have concentrated on three main algorithms: Volcano Topography, Volcano Surface Deformation, and Lava Flow Area Change. Each of these has been produced in an initial form, and we are continuing development aimed at automating the data reduction procedure so that a great number of potentially active volcanoes can be monitored. The main advances here are the use of the precision orbit files catalogued by the Technical University of Delft to determine imaging geometry accurately and to enhance processing speed. For example, because the precise orbits are accurate to 0.5 m or less, the coarse offsets between interferometric passes can be determined automatically, eliminating the need for laborious hunting by the operator during processing. These orbit files also permit “flattening” of the interferograms with a great deal of accuracy; usually at most one residual fringe is apparent in a 100 km interferogram. This allows rapid data reduction and a significant decrease in the number of false motion alarms.

Initially these algorithms were constructed to use data from the ERS 1 and 2 satellite sensors, and we have modified them to process data collected by the JERS-1 radar and by RADARSAT. We have processed JERS-1 interferograms from data acquired over Hawaii through the University of Hawaii downlink system. This capability promises to allow us to begin deformation studies of the very active Kilauea volcanic area, particularly as both JERS-1 and ERS-2 data can now be collected. We have also processed several RADARSAT interferograms, which required some improvements to the processing code to account for large look angle passes. But with more sensors coming on line during the EOS era, such as ENVISAT, ALOS, and several NASA missions, having the more generalized and automated algorithms is an important step forward.

We have also begun development of algorithms to take the next step from deformation maps to estimates of subsurface motion and mechanisms. This will prove important in our overall EOS strategy of assessing potential eruptions and whether significant hazards are likely to follow. At present the algorithms can readily distinguish between simple Mogi sources and dike emplacements, and can retrieve parameters of the dikes. Correlating these with surface fissure eruptions, for example, can help in estimating the potential damage from a given eruption. These data will be provided to the EOSDIS network along with our other measurements.

3. Plans for FY99

Joy Crisp

As soon as any MODIS data is made available, the SO_2 alert will be tested. The testing will be done on scenes with eruption clouds and scenes with no volcanic activity. Results will be checked for the low false alarm, few alarms method that was developed for HIRS data, and for the higher false alarm, more alarms method using the 8.5 mm channel with adjustable thresholds. If either of the alerts can be shown to be useful and not generate too many false alerts, then it may be possible to have it installed alongside Luke Flynn's surface thermal alert as part of the Level 1 to Level 2 processing. The messages generated would be translated into alert data files (radiance and location) and maps showing the location of alerts, made available on the EOS Volcanology Web site, along with an updated Data Product Document.

Further radiative transfer modeling will be done over the 3.4 - 15.4 µm range, to simulate a wide variety of types of eruption clouds at high spectral resolution, and then the results will be resampled at the resolution of AIRS and MODIS. This will help with identifying the characteristics of the major components (ash, gases, and aerosols) in eruption clouds observed by these instruments.

The new line parameters of H_2S will be used to demonstrate the potential for remote sensing measurement of this gas at wavelengths in the 2.3-4.6 µm range, in emission mode (hot fumarolic gases observed with ground based FTIR). Capabilities of AIRS and TES to detect and measure H_2S at 3.7 µm will also be determined.

Lori Glaze

(a) Continued algorithm testing: The top priority for the first few months of the next year will be continued testing of the plume top algorithm. There are two major aspects to this testing. The first is to try and find and fix any bugs that exist in the algorithm software. The second is to explore model sensitivities and to examine and quantify sources of systematic error. The images listed in Table I (Section 7) will be examined first. Additional images may be purchased later in the year.

(b) Web page development: As part of the activity described above, Lori hopes to compile data for several case studies. Each of these studies will draw on image data, information from the GVN bulletin, maps, and ephemeris data in order to derive plume surface topography. Her plan is to begin the development of a web site that makes each of these case studies available to the public. This web site will be the precursor to the Plume Top Characteristics Data Product web site. This web site will be the archive and distribution point for all of the Plume Top Characteristics data products.

(c) Use of MODIS data: Assuming an AM-1 launch some time in 1999, her third objective will be to begin testing of the plume top algorithm using real MODIS data. While Lori does not expect to get fully validated data for at least 6 months after launch, she is hopeful that we will be allowed to at least use some unvalidated data in the early months for testing the algorithm. In the case that a suitable eruption does not occur soon after launch, Lori will use the software to analyze other weather phenomena such as thunderclouds or tropical storms.

(d) Explore future mission capabilities: Lori's final activity for the coming year will be to begin looking into the capabilities of future instruments due to launch in the years following AM-1. Of most interest to her is the VCL mission planned for a launch in 2000. In addition to its potential use to validate the plume topography technique, there is a tremendous potential for significantly advancing our understanding of the dynamics of volcanic mass movements (lava flows, debris flows, lahars, etc.) through better measurements of flow profiles.

Arlin Krueger

Post-launch of AM-1, he will coordinate the access of TOMS Level 2 data with the IDS Team and make their utility presentation software (TOMS plot) available to Team members upon request. The TOMS Level 2 data are now available on-line to TOMS Science Team members. They will arrange for Team access to the NOAA operational TOMS data image products in near real time. Scientific analyses will be exchanged with other Team members.

Pete Mouginis-Mark

We recognize that there will be additional spacecraft in the EOS series beyond the AM-1, PM-1 and CHEM platforms. Our Team has had a long-term interest in the topography of volcanoes, since this controls the flow paths of lava flows and mudflows, as well as constrains the shape of features such as flows, cones, and craters. Up until now, our Team's interests in topography have mainly been from the perspectives of the ASTER DEMs (Pieri) and the use radar interferometry (Zebker, Garbeil) to map volcanoes. The selection of the Vegetation canopy Lidar (VCL) as an ESSP mission, as well as the up-coming flight of the Icesat Altimeter, necessitates our preparation for these missions. We need to become familiar with the instrument characteristics, data formats, and the potential uses of these data over both bare rock and vegetated terrain. In particular, we are interested in understanding how VCL data for tropical volcanoes may help us obtain topographic data for the ground surface of heavily vegetated volcanoes; in areas such as Indonesia and Central America, these volcanoes often have explosive eruptions which generate mud flows and pyroclastic flows.

To help understand the instrument characteristics and data attributes, Kalpana Tata (who works with Mouginis-Mark in Hawaii) will initiate interactions with the VCL and Icesat teams in FY99 in order to evaluate the uses of these two data sets for volcanology.

Vince Realmuto

(a) Continued refinement of mapping procedure, in order to: 1) Improve accuracy of retrieval at the expense of an additional run of the MODTRAN retrieval; 2) Use environment variables to simplify the "installation" of mapping procedure on other computers; and 3) Save emissivity region of interest (ROI) maps to disk along with spectra.

(b) Continued validation of mapping procedure through application to existing data sets. This activity will switch to MODIS and ASTER data, as they become available.

(c) Complete the EOS Volcano Team video.

(d) Post AM-1 Plans: 1) Application of mapping procedure to MODIS data will extend past AM-1; 2) Continued collaboration with TES Science Team (TIMS/AES experiments) through CHEM-1 launch, if possible; 3) The JPL Visualization and Earth Science Applications Group, led by Vince Realmuto, is currently involved in visualization/data analysis project with AIRS (as well as MISR and TES). Realmuto has been approached AIRS science team regarding SO_2 and aerosol mapping, and will follow up on this collaboration.

Bill Rose, Larry Coke and Gregg Bluth

(1) As an aspect of the radiannet algorithm development, they will continue the documentation of the two-band ash retrievals under conditions of background water vapor; for example, when the cloud passed over fog and low-lying clouds, which is a fairly common meteorological condition at high maritime latitudes. The current retrieval method has been unable to make consistent retrievals under these conditions. Despite the untimely demise of ADEOS in June 1997, they have several volcanic eruptions upon which to test their data fusion capabilities to study the behavior of ash, gas, and aerosols. Examples will probably include Nyamuragira, Zaire (December 1996), Langila, New Britain (February 1997) and Manam, Paupua New Guinea (February 1997).

Howard Zebker, Harold Garbeil and Pete Mouginis-Mark

Our role is to analyze active and potentially active volcanoes using interferometric radar techniques and data collected by existing sensors. A large part of this is to understand the distortions induced in the observed signatures due to atmospheric propagation and other interfering signals. These must be quantified and accounted for in the data interpretation. The following subtasks will be required:

1. Prepare an archive to ingest topographic reference data to be acquired during the Shuttle Radar Topography Mission (SRTM) in 1999. We will develop an interface to be compatible with SRTM data.

2. Prepare and archive reference elevation data over a selected set of volcanoes from USGS and other digital topography sources. Make these data available over the Internet to volcano investigators.

3. Using alarm algorithms as generated by others on the Team, identify potential new targets of investigation. Automatically recall topographic estimates and any pre-eruption radar data of the newly active volcano, and order new scenes over the volcano using information from the orbital baseline files for each instrument.

4. Compare deformation results with GPS or other measurement sets where possible as part of a verification procedure.

Refine the code to improve performance as suggested by the verification experiments and operational considerations.

4. EOS and NASA Earth Science Instrument Team Interactions

Vince Realmuto has collaborated extensively with Helen Worden on the TES Team. TES Team members Dave Rider and Reinhard Beer are also involved to a lesser degree. The data sets being studied are from the joint TIMS/AES PacRim flights at Kilauea and White Island.

The 1996 PacRim mission, which was funded by NASA's R&A program, has many activities that are related to IDS goals (algorithm development, cal/val, etc). As a result, Realmuto has used PacRim to further some of the IDS Team's EOS objectives. Since TIMS was not performing too well, Realmuto had to modify the SO_2 mapping procedure to accept a new format of data. However, this modification was also scheduled for FY98 so that the procedure could accept ASTER or MODIS data. The validation of TIMS and AES SO_2 retrievals is relevant to IDS, Natural Hazards, and Atmospheric Chemistry (the NASA sponsor of AES). The collaboration with TES is an IDS goal for post-AM1 activities.

Several members of Realmuto's group at JPL are funded by MISR to develop animations and data analysis tools. These efforts require the access of EOS-HDF MISR data sets, so the tools were written to access the meta- and science data. Vince's group is also developing AIRS and TES data tools. Vince is representing the team's interests in the development of these software tools, and keeps the team informed about the status of these tools.

ASTER has given Better Systems Consulting (the authors of the commercial software package ENVI) the specifications of the ASTER and MASTER EOS-HDF formats. Thus, anyone who buys ENVI will be able to open ASTER data sets. Vince has encouraged Diner to release MISR specifications as well. The EOS Volcanology IDS Team and volcanological community should have relatively easy access to EOS-HDF data from these instruments in the future, through the use of ENVI software

The EOS Volcanology Team has also begun to accumulate topographic base maps in radar coordinates for many of the world's active volcanoes, including Popocatepetl volcano near Mexico City, Hawaii, Fogo, Erta Ale, many western Galapagos volcanoes, several Aleutian and Alaskan volcanoes, as well as volcanoes in the Cascades. Saving pre-eruption radar images in a public archive is an important step in facilitating rapid generation of deformation maps should alarm signals be generated by other Team algorithms. We are preparing to save a large number of digital elevation models of volcanoes derived from data acquired by SRTM, due to be launched in October 1999. This will be a valuable resource that enables us to respond to imminent eruptions quickly. The DEMs will be placed in an online archive for use by the entire EOS community.

Dave Pieri has served as a liaison with the U.S. ASTER Team regarding review and modifications to IDS Science Team Acquisition Requests (STARs) on behalf of the Volcanology IDS Team, including creation and implementation of a Volcano Activity Index (VAI) for over 400 volcanoes. The following Initial Checkout Phase STARs have been submitted to the Japanese, and accepted:

Volcanology IDS Team ICO STARs:

Site Name	*STAR#Day*	*STAR#Night*
Kilauea	45	86
Mt. Etna	44	85
Sourfriere Hills	66	90
Mt. Pinatubo	20	
Isola Stromboli	82	88
Lascar	65	87

These STARs listed above have been approved for initiation during the ICO period (i.e., the 65-day period starting 40 days after launch).

Post ICO Volcanology IDS Team STARs

a. There are currently 93 STARs entered in the ASU ASTER-STAR database. CLASS 1, CLASS 2, and CLASS 3 STARs have been checked by Pieri for conformity with the Volcanology IDS Team proposal for post-ICO STARs and corrected where necessary.
b. Pieri has also checked Volcanology IDS STARs for conformity with evolving ASTER mission operations rules, and modified them as necessary (e.g., separation of Day/Night acquisitions; Area of Interest (AOI) size limitations, reset start-stop dates consistent with launch delay, adjust recycle periods).
c. The Volcanology IDS STARs have been checked against a master list that allows a comparison between all volcano STARs (e.g., ASTER Science Team requests, other U.S. requests, Japanese ASTER Science Team request; USGS requests). Overlaps in coverage have been noted, and are being managed, in order to provide maximum data return using a minimum of instrument duty-cycle resources. It is significant that the Japanese side has submitted a Regional Mapping STAR for volcanoes that has 948 AOI's.

ASTER Topographic Data Plans and Progress

Mt. Etna has been officially designated by the ASTER Geology and Digital Elevation Model (DEM) Working Group, as a DEM Test Site, along with several dozen other non-volcanic sites around the world, and within the U.S. (The Japanese Science Team has also identified topography Test Sites in Japan, as well.). Mt. Etna has the advantage of permanent surveyed GPS sites occupied permanently and seasonally, thus the topographic control is quite robust. Radar-derived DEMs have also been produced by Howard Zebker on our Team, as well as by other groups. In addition, there is, and will continue to be, good airborne sub-satellite data sets for correlation and validation of ASTER data on Mt. Etna. The topographic variability of Etna, given frequent and sometimes voluminous effusive eruptions, will most likely periodically provide good tests of topographic change detectability thresholds for ASTER stereo data. Finally, there is an excellent Italian science cadre infrastructure on Mt. Etna to support field validation exercises, and good ground vehicle access. The acquisition of ASTER stereo data has been approved to start during the ICO Phase by the ASTER Geology Working Group and the ASTER STAR Review Committee.

5. EOS Project Support

(a) Pete Mouginis-Mark has continued his interaction with the Alaska SAR Facility, although due to time constraints for other NASA activities (interactions with the Pacific Disaster Center, Maui) he is no longer the ASF User Working Group Chair. Recently, this interaction has been focused on providing advice to the ASF Chief Scientist (Verne Kaupp) about the development of a new ASF initiative to use the already-collected JERS-1 radar images of Ecuador and Columbia for a regional assessment of volcanic hazards. As part of the Global Rain Forest Mapping project, high resolution SAR images can be produced for ~50 volcanoes in these countries. Additional scenes of volcanoes in Cameroon, the Philippines, and Indonesia will also soon become available. We are currently discussing the strategy to enable the community at large to work with these data so that hazard maps for these volcanoes can be produced in a timely manner.

(b) Operational TOMS data production. The utility of TOMS data for volcanic purposes in past years has been limited to scientific analysis because the data were not reliably available in time for field use in eruptions or hazard applications. Two parallel efforts were employed to produce data rapidly that have a positive effect on the broader Earth Science Community. The first effort was development of real-time data collection in the field directly from the satellite. The GSFC developed software was installed at NSF McMurdo Station and at NWS Anchorage, Alaska and operated successfully with TOMS Earth Probe overpasses until the primary EP transmitter failed in early 1998. The program was terminated when data transmissions were limited to twice-daily memory dumps of orbital data due to concern for the backup transmitter. The second effort was implementation of EP TOMS orbital dump data processing at NOAA/NESDIS in an operational system. This produces data that are analyzed on the same time scale as the NOAA and GOES satellite data. The same data will be available to the EOS community following the AM launch.

(c) As IDS Team PI, Pete Mouginis-Mark has responded to numerous requests from NASA Headquarters, Goddard SFC and the media (e.g., National Geographic, NHK Tokyo, and Space News) for information and/or text and images about volcanoes and volcanic eruptions. This includes updating the IDS information for NASA brochures, as well as commenting on the ability of EOS to collect data for eruptions comparable to the events that have taken place this last year (e.g., Kilauea, Cerro Azul, Montserrat, and Piton de la Fournaise).

(d) Luke Flynn served on the NASA committee that provided advice to Associate Administrator Dr. Ghassem Asrar as to the choice of instruments that might fly on the second and third series of EOS platforms.

(e) Several of the IDS Team Members have developed proposals under the NASA ESSP opportunity specifically to provide more observations of volcanoes and solid Earth processes. Arlin Krueger is the PI on VOLCAM, which includes Bill Rose, Gregg Bluth, Vince Realmuto and Steve Self as team members. Anne Kahle is PI on the Sacagawea mission (Mouginis-Mark is a team member), and Howard Zebker was a Co-PI on the ECHO-Elsie radar mission (Mouginis-Mark and the University of Hawaii to provide support via the UH ground station). At the time of writing, full proposals for the VOLCAM and ECHO-Elsie mission concepts are under review. Sacagawea did not get selected for Phase 2.

(f) Howard Zebker has provided help to the research staff at the Alaska SAR Facility on the development of their interferometry capabilities. In particular, the ASF DAAC is trying to build the capability to provide the EOS community with radar interferometry products. Zebker has provided extensive assistance to ASF in the porting of his code to Alaska, and how this might be run under production-mode conditions.

6. Community Outreach

6.1: Conferences and meetings: The three main organizations that we continue to interact with the most are the American Geophysical Union, IAVCEI (the international volcanology association), and the professional volcanology observatories. Our Team's efforts in these areas can be summarized as follows:

1) Mouginis-Mark and Crisp, in collaboration with Jon Fink (ASU) organized a special session at the Fall 1997 AGU meeting on the "Remote Sensing of Active Volcanoes". This session was highly successful, with 44 invited and contributed papers. The Special Session extended over three days, and four different sessions (two oral, two poster) were held. This session was deemed sufficiently interesting and successful by the AGU that they have asked us to edit an AGU Monograph on the subject. This Monograph is just at the stage where we are collecting the invited manuscripts prior to sending them out for review. There will be between 10 – 14 papers in this volume, which should be published before the end of 1999. Thus it will be a great way to showcase remote sensing techniques in volcanology at a time when EOS AM-1 will just be starting to deliver new data. We hope that the book will serve as a great resource for members of the volcanology community who are unfamiliar with remote sensing but who want to use some of the new data sets in their studies.

2) During 1997/8, we have continued our outreach to the international volcanology community. Steve Self attended the 1998 IAVCEI Conference in Cape Town (South Africa) and represented our IDS Team at the panel discussions on the activities of the Remote Sensing Commission. Pete Mouginis-Mark attended the Geoscience98

conference at Keele University (UK) and provided an overview of the EOS Team's efforts. Lori Glaze and Chuck wood both served on an advisory committee to the American Geophysical Union. The committee was convened to provide input to the AGU on how to better format their web site to reach the public. They brought their respective experiences with web presentations for a variety of NASA projects.

3) Under EOS and other NASA funding (notably the SENH program funds), we are developing working relationships with several volcano observatories who are interested in how NASA remote sensing techniques can improve their monitoring capabilities. Steve Self and Pete Mouginis-Mark have established ties with PHIVOLCS (Philippines) for the uses of orbital and aircraft radar data in the analysis of Mt. Pinatubo, Taal volcano, and Canlaon volcano. Scott Rowland and Pete Mouginis-Mark traveled to the Galapagos Islands in June 1998 and discussed with the Darwin Station Director the uses of real-time monitoring of the islands using GOES data. This discussion proved to be very helpful during the eruption of Cerro Azul only three months after our visit since we were providing the Darwin Station with daily updates when they were unable to get into the field (the eruption was on a different island from the Station). Luke Flynn has given a similar presentation on the uses of real-time GOES data for volcano monitoring to the Hawaii Volcano Observatory, and Pete Mouginis-Mark gave a similar update to the Cascades Volcano Observatory. Presentations have also been made to other local organizations in Hawaii (such as USGS Water Resources, State Office of Planning, Union of University Presidents) who have shown an interest in satellite observations of Hawaii and how these data may promote economic development and/or enhance on-going studies.

6.2: Web Sites: Joy Crisp has been maintaining the Volcanology IDS site all year. We get a few questions per month from teachers and students asking questions about volcanoes and remote sensing on this site, and Joy sends out materials when appropriate. This site can be seen at:

http://www.geo.mtu.edu/eos/

Luke Flynn, Eric Pilger, Harold Garbeil and Chris Okubo have developed a web site for the automatic display of MODIS thermal alerts once they have been detected at the MODIS SCF. This site is under beta-testing using real-time GOES-8 and –10 data, and can be seen at:

http://modis.pgd.hawaii.edu/

This same group at the University of Hawaii has also developed a Web site that displays near real-time GOES-8 and 10 images for about ten volcanoes and fire sites in the Americas and E. Pacific Ocean (http://virtual1.pgd.hawaii.edu/goes/). The intent here is to develop expertise in the routine processing and display of moderate volumes of satellite data (~0.7 Gbytes/day) for the benefit of the volcanology community. This was best demonstrated during the September 1998 eruption of Cerro Azul volcano in the

Galapagos Islands. Notification of the start of the eruption was sent to our collaborators at the Darwin Research Station (Galapagos Islands) 3 hours before they heard about the event from ground observations. We worked with the team on the ground to provide overviews of the eruption and timing of event occurrence for the three weeks following the start of the eruption. Public information bulletins were distributed to the international volcanology community via Volcano Listserver (run by Jon Fink at Arizona State University). We also created a web site to present a summary of the eruption:

http://volcano1.pgd.hawaii.edu/goes/Azul/

During the peak of activity, we were getting up to 22,000 hits per day on this site.

Finally, we have in beta-testing a java-based web package that enables time series satellite data to be viewed. Chris Okubo (who is a member of the group at the University of Hawaii) is developing this package. The progress to date can be seen at:

http://www.pgd.hawaii.edu/~chriso/cgi-bin/imgview.cgi

6.3 *Team Video*: Led by Vince Realmuto, the EOS IDS Team is preparing a short video presentation of how AM-1 will be able to make observations of volcanic phenomena. The goal of this video is to illustrate several basic volcanic phenomena (ground deformation, gas emissions, lava flows, explosive eruption column, gas and aerosols), the remote sensing signals generated by these phenomena, and the Team's strategies for converting these signals into geophysical parameters that describe the events. Joy Crisp is providing input to Vince on this effort, which is being conducted at the JPL Visualization and Earth Science Applications Group. The storyboard for the video has been created and the animation for the first phenomenon (ground deformation) is underway.

6.4 *Collaborations with other groups*. Bill Rose has collaborated with numerous other groups who are involved in volcano monitoring. In Alaska, this included the Alaska Volcano Observatory, the US Geological Survey, and the National Weather Service. He has worked with the Canadian Meteorological Centre (Environment Canada), Montreal on the interfacing of GOES data with plume trajectory models, and the Bureau of Meteorology, Darwin and Melbourne, Australia on improvements of the two band algorithm for tropical volcanic cloud remote sensing.

7. Data Validation, Q/A and Data Distribution Issues

PacRim Hawaii: This was the first joint deployment of TIMS and the Airborne Emission Spectrometer (AES), and Vince Realmuto collaborated with Tropospheric Emission Spectrometer (TES) Science Team. IDS and Natural Hazards funding jointly supported this effort. Close agreement between the SO_2 and ground temperature retrievals derived from the TIMS and AES data represent a validation (corroboration) of the image-based TIR SO_2 mapping procedure. Realmuto conducted a similar data validation experiment at the Navajo Generating Station. Analysis of these data continues. Despite modification to the mapping procedure, pathologic errors in SO_2 retrieval still occur over select surface materials. This challenging data set tests the limits of the mapping procedure.

Plume Top Topography: A variety of issues are currently being explored with AVHRR test data (Table 1), including testing the algorithm for a variety of illumination angles and viewing geometries. The plumes chosen for the test data set were erupted from volcanoes at a variety of latitudes, at different times of day and in different seasons. Another important issue being investigated is the importance of plume opacity. One of the primary assumptions of the photoclinometric technique used by the plume topography algorithm is that the plume material has uniform scattering properties. A transparent plume with varying amounts of underlying surface showing through will invalidate the topographic results. Lori Glaze is currently in the process of conducting a more in-depth analysis of the AVHRR images.

Table I. AVHRR images acquired for testing plume topography algorithm

Volcano	Date	Number of images
Popocatapetl	3/96	5
Spurr	7-8/92	2
Kliuchevskoi	6/91	1
	3/97	1
Bezymianny	5/97	1
Montserrat	9/96 - 10/97	3
Sakura-Jima	2/98	2
Soputan	3/96	1
Ruapehu	6/96	1
Manam	12/96	1

Preliminary analyses of the images listed in Table I indicate that at least 8 can be used effectively for plume top topographic determinations. Reasons for failure to qualify for the photoclinometric technique include transparency of the plume material, large off nadir viewing angles, and insufficient illumination (sun too close to, or below the horizon).

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9. Acronyms

AGU	American Geophysical Union
AES	Airborne Emission Spectrometer
AVHRR	Advanced Very High-Resolution Radiometer
AIRS	Atmospheric Infrared Sounder
ALOS	Advanced Land Observation Satellite
ASF	Alaska SAR Facility (an EOS DAAC)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Arizona State University
DAAC	Distributed Active Archive Center
DEM	digital elevation model
DN	Digital Number
DPD	Data Product Document
ENVISAT	Environmental Satellite (European Space Agency)
EP	Earth Probe
ESSP	Earth System Science Pathfinder
FTIR	Fourier Transform infrared (spectrometer)
GEISA	Gestion et d'Etude des Information Spectroscopiques Atmospheriques
GOES	Geostationary Operational Environmental Satellite
GPS	Geophysical Products System
GVN	Global Volcanism Network (Smithsonian Inst.)
ECHO-Elsie	Earth Change and Hazard Observatory – proposed ESSP radar mission.
ENVI	Environment for Visualizing Images (software)
EOS-HDF	EOS-specific HDF data format
ERS	European Remote-Sensing Satellite
GSFC	Goddard Sapce Flight Center
HDF	Hierarchical Data Format
HITRAN	High resolution TRANsmission molecular absorption database
HIRS	High-Resolution Infrared Radiation Sounder
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
ICO	Initial Check-Out period
IDS	Interdisciplinary Science
JERS	Japanese Earth Remote-Sensing Satellite
JGR	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory
MASTER	MODIS/ASTER Airborne Simulator
MISR	Multi-Angle Imaging SpectroRadiometer
MODIS	Moderate-Resolution Imaging SpectroRadiometer
MODLAND	MODIS Land Science Team
MODTRAN	Moderate Resolution Atmospheric Radiance and Transmittance Model
NOAA/NESDIS	National Oceanographic and Atmospheric Administration National Environmental and Satellite Data and Information Service

NSF	National Science Foundation
NWS	National Weather Service
PacRim	Pacific Rim
PHIVOLCS	Philippine Institute of Volcanology and Seismology
Q/A	Quality Assurance
R&A	Research and Analysis
RADARSAT	Radar Satellite (Canada)
SAR	Synthetic Aperture Radar
SCF	Science Computing Facility
TES	Tropospheric Emission Spectrometer
TIMS	Thermal Imaging Spectrometer
TIR	thermal infrared
TLCF	Team Leader Computing Facility
TOMS	Total Ozone Mapping Spectrometer
UH	University of Hawaii
USGS	U.S. Geological Survey
VCL	Vegetation Canopy Lidar (ESSP mission)
VESA	Visualization and Earth Science Applications (JPL Group)
VOLCAM	Volcano Camera, proposed ESSP mission.