and Joule heating due to the dissipation of ionospheric currents. These inputs that can vary by three orders of magnitude over time periods on the order of hours or days are redistributed in the thermosphere in the form of changes in the mean circulation, temperature and compositional structure and in the form of waves propagating outward from the auroral zone.

The thermosphere and ionosphere are also influenced by disturbances propagating upward from the lower atmosphere. These include gravity waves, tides and planetary waves that primarily influence the mesosphere and lower thermosphere.

An overall description of our current understanding of the role of the Sun in influencing the outer layers of our atmosphere will be given and simulation results from global models will be used to illustrate various coupling interactions.

U22B-06 1550h

Featured Presentation: Interactions in Space: Geospace and Sun

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There is no abstract available for this presentation.

U22B-07 1620h

From Days to Decades: The Sun and the Earth Linked by a Tenuous Wind

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Recent observational studies have demonstrated a linkage between the Sun and the Earth, driven by the tenuous high speed solar wind streams emanating from solar coronal holes. This linkage extends from the Sun through the near-space environment and the atmosphere to the lower stratosphere. It varies with time scales that range from days to decades. Observations and interpretative calculations suggest that this linkage significantly affects the global odd nitrogen and ozone budgets with the potential to have effects on tropospheric climate. The coupling is described and related observations discussed. Simulations, validated in both the mesosphere and stratosphere, are used to assess the importance of this linkage to stratospheric ozone compared to the effects of solar UV variability. Above 25 km, the present linkage is found to have a larger effect on global ozone than the variations of solar UV during the 11-year solar cycle. The significant variation of the efficacy of this linkage to produce global change in the middle atmosphere between solar cycles 21 and 22, is described. Finally, the potential of this linkage to affect tropospheric climate through ozone-related thermal perturbations of the stratosphere is discussed.

U22B-08 1635h INVITED

The Sun: Source of the Earth's Energy

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The Sun is the primary source of the Earth's energy. However, due to the complexity in the way the energy affects Earth, the various solar sources of the energy, and the variation exhibited by the Sun it is difficult to understand and predict the Earth's response to solar drivers. In addition to visible light the radiant energy of the Sun can exhibit variation in nearly all wavelengths, which can vary over nearly all timescales. Depending on the wavelength of the incident radiation the light can deposit energy in a wide variety of locations and drive processes from below Earth's surface to interplanetary space. Other sources of energy impacting Earth include energetic particles, magnetic fields, and mass and flow variations in the solar wind. Many of these variable energetic processes cannot be decoupled and recent results continue to demonstrate that the complex dynamics of the Sun can have a great range of measurable impacts on Earth.

U31A MC: 134 Wednesday 0830h

Ten Years of Science From the 1991 Mount Pinatubo Volcano Eruption I

Presiding: **A Robock,** Rutgers University**; C Newhall,** USGS**; J Power,** USGS

U31A-01 0830h

Ten-Year Retrospective on the Pinatubo Eruption

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The 1991-92 eruption of Pinatubo Volcano, Philippines was a signal event in the annals of volcanology. For the first time, modern monitoring captured the pre-, syn-, and post-eruption signatures of a sulfur-rich, plinian, caldera-forming eruption. Approximately 5 km3 of magma was erupted, of which slightly more than half became pyroclastic flows, and the balance became tephra fall. Only a negligible percentage of the magma fed early and final-stage lava domes. Ten years later, more than half of the debris on Pinatubos slopes has been washed by lahars and sediment-laden streamflow into the surrounding lowlands, adding to Pinatubos broad alluvial fans.

Other papers in this symposium will give details of the magma, volatiles, eruption dynamics, lahars, atmospheric effects, and other features of the eruption. Here, we reflect on just four lessons. First, the magma of a long-plugged volcano may be saturated with respect to water and other volatiles even at depth, and, when disturbed by regional strain or other change, can rise quickly. Second, up until just before the eruption itself, only the geologic record foretold of how large it would be. Third, because few observatories will monitor dormant volcanoes and few residents will heed long-range warnings, public safety will hinge on a short, urgent campaign of warning and education. Videos, simple alert schemes, and a willingness of both scientists and public officials to move decisively despite uncertainty are essential to win cooperation from a skeptical public. Fourth, post-eruption hydrologic hazards can equal or exceed those of an eruption itself.

U31A-02 0850h INVITED

Petrology of the 1991-2 Pinatubo Magma System

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The eruption of Mt. Pinatubo in 1991 and 1992 was petrologically very interesting because the magma was very oxidized, S-rich, and crystal-rich (45 v % phenocrysts), and the eruption injected 20 MT of SO2 into the atmosphere. Studies of the erupted magma and seismic data indicate that 90 km3 of dacitic magma at 780 C was present at >7 km below the summit prior to the eruption and 5 km3 were erupted. Matrix glass compositions suggest there was some upward magma movement just prior to the eruption. The dacitic magma was water saturated, possibly containing bubbles of H2O-rich fluid, but was probably too viscous to erupt alone. The first erupted magma in 1991 was andesitic in composition, a mixture of the dacite and a basalt, and the basalt emplacement clearly initiated the eruption. Enclaves of the basalt contain a mixture of olivine and Cpx phenocrysts in a melt that was converted to fine grained hornblende, plagioclase and magnetite when mixed with the dacite. According to new experiments, this assemblage indicates a temperature of ~1150 C and 2 wt % water in the melt assuming an 8 km depth of mixing. Several important questions posed by the 1991 eruption have been answered to some degree, but not completely. The logical source of the S in the dacite and the S released to the atmosphere is the basalt which intruded the dacite periodically. Cooling and crystallization of the basalt would release S to a fluid phase that would tend to move through the overlying dacite causing S-oversaturation and anhydrite crystallization. Such a process might even produce some of the oxidized character of the dacite if SO2 and CO2 were dominant species in the gas released from the basalt. Detailed textural study of anhydrite crystals in the dacite suggest they were growing when gas bubbles were generated, and indicate the S released to the atmosphere may all have been stored in the gas phase. The pulsitory nature of the initial eruption was modulated by degassing and crystallization in the conduit. Another intriguing aspect of the Pinatubo eruption is the presence of the gray, banded pumice with highly fractured phenocrysts along with the dominant coarsely crystalline white variety. Recent studies suggest this textural variation may result from intense shear along the conduit walls during the main phase of the eruption.

U31A-03 0910h INVITED

Seismicity and Forecasting of the 1991 Eruption of Mount Pinatubo: A Ten-Year Retrospective

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The 1991 eruptions of Mount Pinatubo provided a unique opportunity to observe seismicity and magmatic processes associated with a very large explosive eruption. The rapid deployment of a 7-station seismic network around the volcano in April and May of 1991 and deployment of a second network in early July after many of the initial stations were destroyed by the eruptions on June 13 15 were critical to developing these high-quality observations. Data from these networks were recorded and archived using a portable digital acquisition and analysis system. The interpretation of the processes associated with 1991 Pinatubo seismicity is enhanced in many cases by the large size of the eruptions and associated signals, the well-documented magma mixing event that triggered the eruptions, and the associated field studies of deposits.

The precursory seismic sequence included a persistent cluster of Volcano-Tectonic (VT) earthquakes 5 to 10 km NW of the vent, deep (z~30 km) Long-Period (LP) events in May and June, a prominent swarm of shallow hybrid events associated with magma ascent and emplacement of a lava dome on June 3 12, and a rapid increase in the size and occurrence of LP events and volcanic tremor following dome emplacement. Strong swarms of LP events and tremor often preceded and accompanied the plinian eruptions from June 12 to 15, although only one seismic station remained operative during this period. Post eruption seismicity was characterized by widespread VT hypocenters that surround the volcano and may define the magma chamber that fed the eruptions. In late June, as continuous eruptive activity and VTs declined, tremor and LP events resumed in regular 7 to 10 hour episodes that accompanied the production of large ash plumes. Successful forecasts of the 1991 eruptions were based largely on an observed shift in the locus of earthquake hypocenters, increased seismic energy release, a shift from VT to LP seismicity, visual observations of the volcano, and measurements of S02 flux. In retrospect, many of the patterns and processes revealed in the Pinatubo seismicity are frequently observed at restless volcanoes and often form the basis for eruption forecasts and hazard mitigation.

U31A-04 0930h

Rainstorm-Generated Lahars in the Pasig-Potrero River, Mount Pinatubo, Philippines: A Ten-Year Perspective

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Lahar and rainfall relations in the Pasig-Potrero River are analyzed using near-complete data from rain gauges and acoustic flow monitors (AFM), with AFM

data as proxy for lahar hydrographs. Data for coincident lahars and rainstorms show the rivers hydrologic response to two major watershed disturbances: the emplacement of 300 million m^3 of pumiceous pyroclastic debris during the June 1991 eruptions, and the capture of the upper Sacobia catchment in October 1993.

Sediment yield, represented by the ratio of lahar-runoff to rainfall, peaked immediately after each major watershed disturbance, followed by an exponential decrease through time. The systematic decline is believed to be related to the development of the drainage network, particularly the decrease in drainage density and increase in channel width. These parameters influence the volume of pumiceous sediments in contact with runoff.

The rainfall threshold at which lahars are generated was found to remain at about the same low level until 1995, after which it increased progressively until 1997. No major lahar has been observed or detected by the AFM since then. The triggering rainfall is postulated to be a function of the erodibility and infiltration capacity of the surface, which are largely controlled by the areal distribution of pumiceous 1991 pyroclastic deposits. Thus, the triggering rainfall increased only when erosion has reached the pre-eruption surface.

The trends in laharic sediment yield and triggering rainfall together demonstrate the progressively increasing rainfall requirement for lahar generation through time. Cautious extrapolation of the data suggests that to trigger and sustain a modest lahar ($<$10 million m^3) now requires a rainstorm with a return period exceeding 100 years.

The foregoing analyses may be applied to other lahar channels with prudence. While similar trends are expected in other rivers, the hydro-geomorphic parameters that control such trends may operate at vastly different rates.

U31A-05 0950h

EVALUATION, PROPOSED SOLUTION AND CURRENT STATUS OF THE CRATER LAKE BREAKOUT PROBLEM, MOUNT PINATUBO, PHILIPPINES

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Rapid rise of Mount Pinatubo's crater lake and recent geological assessments of the crater's lowest point, the Maraunot Notch, raised concern about a breakout lahar down the northwestern slope of the volcano. Three factors indicated a serious hazard. First, the lake rose about 50 m from May 98-August 2001 and was expected to overtop the Maraunot Notch within the last trimester 2001. Overtopping might well have occurred at the height of a strong typhoon or under heavy monsoonal rainstorms. Second, the uppermost 10-20 m of "dam" was erodible ash and poorly indurated coarse breccia, susceptible to failure by overtopping and erosion as at many landslide and other natural dams. Third, the volumes of lake discharge corresponding to 10 and 20 m of erosion would have been 28 and 55 million m3; peak discharges at a breach could have been as high as 3,200 m3/sec to 11,000 m3/sec, respectively. These discharges would have eroded 1991 pyroclastic and lahar material on the volcano's slopes, increased the flow volume by 3-6x, and entered the Bucao River as a large-magnitude lahar. The Municipality of Botolan (pop. ca. 40,000) lies on the delta of the Bucao River valley some 40 km downriver from the notch, and could have been at great risk.

Given this potential risk, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) in early August 2001 advocated three actions. (1) An intentional breaching of the Maraunot Notch by the construction of a spillway or canal, by the Department of Public Works and Highways (DPWH). Early breaching would limit further rise of the lake and thus reduce the magnitude of potential flood. Also, breaching would be scheduled during good weather to eliminate the danger of overtopping at an unknown time and/or under typhoon/rainstorm conditions. (2) An information campaign in Botolan in order to educate and prepare residents for breaching. (3) Evacuation of people at risk, one day before the scheduled breaching. A spillway was excavated by as many as 70 men with picks and shovels, and the specter of a wholly uncontrolled breach through the most erodible debris was averted. Early flow through the spillway was gentle and evacuees quickly returned home. However, 10-15 m of poorly indurated breccia still remains, lake level is still rising slowly, and we are watching to see whether outflow after heavy rains will armor the spillway or catastrophically erode the remaining dam. Insufficient communication between scientists and engineers led DPWH to design for less scouring than expected by PHIVOLCS, and politics and liability concerns at several levels halted digging before the trench could be deepened and outflow increased. Perhaps this is just as well. An inherent conflict arose between short- and long-term risk mitigation. Short-term risk was minimized; long-term risk was reduced but remains a concern. Complete breaching of the dam and thus elimination of long-term risk would have sharply increased short-term risk to Botolan.

*Quick Response Team Members: Mabel Abigania, Rene Arante, Onie Arboleda, Maricar Arpa, Mariton Bornas, Edwin dela Cruz, Jojo Cordon, Toti Corpuz, Art Daag, Elmer Gabinete, Del Garcia, Lito Gelido, Lito de Guzman, Sheila Insauriga, Dindo Javier, Rudy Lacson, Bong Luis, Rey Lumbang, Danny Martinez, Mylene Martinez-Villegas, Chris Newhall, Jed Paladio-Melosantos, Mel Pagtalunan, Myla Panol, Jack Puertollano, Raymundo Punongbayan, Gina Quiambao, Andoy Ramos, July Sabit, Noli Sexon, Jimmy Sincioco, Opet Villacorte.

U31A-06 1025h INVITED

Mt. Pinatubo Aerosol: An Historical Perspective Determined from Remotely Sensed Measurements

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Changes in the stratospheric aerosol concentrations brought about by volcanic eruptions are important in determining their effects on radiative forcing and ozone depletion. Several volcanic eruptions have injected aerosols into the stratosphere over the last twenty or so years. One of the best-monitored eruptions during this period is the 1991 eruption of Mt. Pinatubo. Unfortunately, this opportunity was not exploited as well as it could have been. The eruption was monitored by ground and aircraft based lidars and a number of satellite instruments including the Stratospheric Aerosol and Gas Experiment (SAGE) II instrument on board the Earth Radiation Budget Satellite. The eruption of Mt. Pinatubo caused perturbations in stratospheric aerosols that were unprecedented in modern times. The eruption not only provided an opportunity for measurement of the atmospheric effects of an eruption, but also was used to validate and improve chemical and radiative models and predicted effects, e.g. temperature change. This paper will describe this global aerosol event and place it in the context of eruptions over the last two decades. It will use satellite, airborne and ground-based remotely-sensed data to show aerosol optical depth, surface area density, and mass.

U31A-07 1045h INVITED

Climatic Effects of the 1991 Mt. Pinatubo Volcanic Eruption

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Following the June 1991 Mt. Pinatubo eruption in the Philippines, the winter of 1991-1992 was very warm over most of North America, Europe, and Siberia, and cold over Greenland and the eastern Mediterranean. It snowed in Jerusalem that winter and corals at the bottom of the Red Sea died because of the cold surface waters. During the next summer of 1992 continental regions of North America and Eurasia were unusually cold. Global warming halted for several years as the planet cooled temporarily. All these climatic effects were due to the response to sulfate aerosols in the stratosphere from the Pinatubo eruption. In this talk we review the climatic response to volcanic eruptions using Pinatubo as a prime example. Both observational studies and general circulation model experiments support these conclusions. By scattering some solar radiation back to space, the stratospheric aerosols cool the surface, but by absorbing both solar and terrestrial radiation, the aerosol layer heats the stratosphere. For a tropical eruption, this heating is larger in the tropics than in the high latitudes, producing an enhanced pole-to-equator temperature gradient, especially in winter. Together with the forcing from ozone depletion and surface cooling in the subtropics, the dynamical response of the climate system produces temperature changes due to anomalous advection which dominate over the radiative effects in the winter. This atmospheric circulation pattern corresponds to the positive phase of the Arctic Oscillation. In spite of the decrease in surface solar heating, surface air temperature increases in high and midlatitudes of the Northern Hemisphere in the winter because of changes in tropospheric circulation caused by stratosphere-troposphere dynamical coupling. This new understanding will allow us to produce better seasonal forecasts for the Northern Hemisphere winter following the next large tropical eruption. It also shows that stratospheric forcing of the climate system must be considered along with sea surface temperature anomalies when making seasonal forecasts, especially in mid and high latitudes in the winter.

U31A-08 1105h INVITED

Interaction of volcanic aerosols, ozone changes, and the Quasi-Biennial Oscillation determine the atmospheric response to the 1991 Pinatubo eruption

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Following a large volcanic eruption, the radiative perturbation from stratospheric aerosols exerts a strong influence on the climate system. Volcanic aerosols cool the Earth's surface because of reflection of solar radiation and heat the lower stratosphere because of absorption of thermal IR and solar near-IR radiation. In addition, the ozone depletion that results from the presence of the stratospheric aerosols also perturbs the radiation. Furthermore, these perturbations interact with the Quasi-Biennial Oscillation (QBO) to produce the response of the climate system to volcanic eruptions. The combined effect of all these forcings and resulting complex feedback mechanisms affect the tropospheric circulation and cause a shift to the positive phase of the Arctic Oscillation (AO) (also called the North Atlantic Oscillation) during one or two Northern Hemisphere winters after each strong equatorial volcanic eruption. Previous simulations of the impact of volcanic eruptions had not included realistic ozone and QBO interactions. Here we present simulations of the impact of the June 15, 1991 Pinatubo eruption on the climate system using the Geophysical Fluid Dynamics Laboratory SKYHI general circulation model. We force the model with aerosol and ozone variations from observations, and force a QBO in the model with the amplitude and phase locked to observations, and consider the climate response to these forcings individually and in combination.

Accounting for the QBO improves the structure of the temperature response in the lower stratosphere. We are able to simulate the observed stratospheric temperature variations when aerosols, ozone, and QBO forcings are included. The dynamical response to the Pinatubo eruption, with an enhanced positive mode of the AO, is reproduced by the model in the first and second Northern Hemisphere winters following the eruption when the model is forced with total aerosol forcing or with ozone depletion by itself. Cooling in the North Pole region caused by ozone depletion in boreal winter and early spring produces atmospheric responses in the stratosphere and troposphere comparable with ones produced by aerosols. The QBO affects the stratospheric circulation and temperatures and therefore modulates the AO response. Although in our longest simulation series the stratospheric temperature anomalies in the low and middle latitudes, as well as winter warming at the surface in northern Eurasia are statistically significant, this is not the case in shorter ensembles and in high latitudes. Larger ensembles are necessary to get statistically stable results.

U31A-09 1125h INVITED

Stratospheric Aerosol Simulation

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Disturbances of the stratospheric aerosol load by volcanic eruptions do not only have radiative effects, but also influence stratospheric chemistry mainly via heterogeneous reactions activating halogene species. Hence, aerosol properties like surface density, degree of hydration etc. are important quantities.

Results will be discussed which have recently been derived at MPI for Meteorology using a new stratospheric microphysics module to simulate background

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and volcanically disturbed stratospheric aerosols. The interactive evolution and climate effects of the aerosol from Mt. Pinatubo and from a prehistoric strong eruption in northern midlatitudes (Laacher See) will demonstrate the effect of the volcanic setting on the evolution of the aerosol cloud. Simulations of physicochemical processes in a volcanic eruption plume with the ATHAM model show the effect of environmental and volcanic conditions on the injection of volcanic gases(H2O, SO2, H2S, HCl, HBr) into the stratosphere.

U31A-10 1145h INVITED

Depletion of the Ozone Layer Following the Pinatubo Eruption: A Case Study for Ozone/Chlorofluorocarbon/Aerosol Chemistry

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The abundance of stratospheric ozone decreased substantially over much of the globe following the eruption of Mt. Pinatubo. This spectacular eruption provided direct evidence for chemical perturbations to the reactive nitrogen and chlorine families and hence to ozone loss rates. This talk focuses on the large seasonal and latitudinal variations in the ozone response and their relationship to chlorofluorocarbon chemistry. Finally, the recovery of the stratosphere following the eruption is as important as the depletion, and recent observations of the ozone layer and its relationship to stratospheric aerosols will also be shown to demonstrate the key role of chlorine/aerosol interactions in modifying the state of the stratospheric ozone layer.

U32A MC: Hall D Wednesday 1330h

Ten Years of Science From the 1991 Mount Pinatubo Volcano Eruption II

Presiding: **A Robock,** Rutgers University; **C Newhall,** USGS; **J Power,** USGS

U32A-0001 1330h POSTER

Distal Volcano-Tectonic Earthquakes (DVT's): Diagnosis and use in Eruption Forecasting

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Volcano-tectonic earthquake swarms occurred 5-6 Km from the summit months prior to the catastrophic eruptions of Mt. Pinatubo (1991) and Nevado del Ruiz (1985). Similar earthquake swarms probably occurred beneath distal portions of Mt. St. Helens (1980), El Chichon (1982), and Soufriere Hills (1995-98) months to years prior the eruptions there. Thus these Distal Volcano-Tectonic (DVT) earthquakes were probably the longest-term precursors to those eruptions. Based on close correlation with observed volcanic activity, we show that DVT's result from magma intrusion. Although DVTs are brittle-failure earthquakes along faults, they are generally distinguishable from tectonic sequences by clustering features, most notably a slowly increasing to roughly constant moment release rate. Total seismic moments for DVT swarms appear constrained by magma viscosity, with the largest moments associated with basalts. DVT swarms occur from <3 to >30 Km from summits of volcanoes. Maximum depths increase roughly as the distance out to 10 km then gradually level off, as do depths to the brittle-ductile transition near active volcanoes.

We interpret DVTs as resulting from injection of magmatic fluids into closed aquifers near the base of the brittle zone, over-pressurizing the aquifers out several to many kilometers horizontally. The overpressure may trigger faulting in areas where the intruding magma increased the static stress. We show that the DVT moment rate is proportional to the fluid injection rate and is apparently delayed by only minutes to tens of minutes depending on distance, owing to the rapid hydraulic transmission of pore-pressures. Thus DVT earthquake swarms can provide early warning for major eruptions while possibly providing constraints in near-real time on magma viscosity, depth and ascent rate during intrusion.

U32A-0002 1330h INVITED POSTER

Precise Correlation-Based Phase Repicking of Pinatubo Pre-Eruption Seismicity Illuminates Families of Repeating Earthquakes and a Refined Image of Precursory Hypocenter Locations.

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We applied waveform cross-correlation and hierarchical clustering methods to volcanic seismicity recorded at Mount Pinatubo between 1 May and 14 June, 1991, identifying 155 clusters of up to 50 similar earthquakes each. Relative corrections of initial P-wave picks were as large as 0.563 s within similar event families, although the mean adjustment at our master station was only 0.04 s, with a standard deviation of 0.05 s. Final, absolute picks were obtained by applying an Akaike Information Criteria autopicker to stacks of the aligned waveforms within each cluster. We demonstrate enhanced phase identification for noisy arrivals by application of the cross-correlation, clustering and stacking strategy, and we show refined hypocenter locations following the automatic phase repicking.

Station PIE (6 km ENE of the summit) was selected as our master station because of its longevity and high signal quality. Waveforms for brittle-failure events display great similarity at PIE for much of the activity during May, 1991. Over 80% of the picked seismograms at PIE recorded before 3 June fall into clusters originating some 5 km northwest of the crater. Consistent waveforms at this and other stations suggest similarity in mechanism; however, clear reversals in P-wave polarity within these families at station PPO (5 km NNW of the summit) indicate near-nodal arrivals at this station and my help to constrain focal mechanisms. Families of shallow volcano-tectonic (VT) events beneath the summit begin to dominate on 3 June. Long-period events, mixed with continued shallow VT events beneath the summit, begin to dominate the digital record at PIE from 12 to 14 June, when correlatable signals ceased prior to the station's demise in the 15 June cataclysmic eruption.

U32A-0003 1330h POSTER

Spatial Variations in the Frequency-Magnitude Distribution of Earthquakes at Mount Pinatubo Volcano.

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The frequency-magnitude distribution of earthquakes measured by the b-value is mapped in 3 dimensions at Mount Pinatubo, Philippines, down to a depth of 6 km below the summit. We analyzed 1892 well-located earthquakes with magnitudes ML >=1.4, recorded from May 7 through August 7 1991, and used both the weighted least squares and maximum likelihood methods.

With the weighted least squares method, we found that generally b-values are higher than normal (b=1.0), with values between b=1.1 and b=3.6. The computed b-values are lower in the areas adjacent to the vent and directly underneath it, whereas high b-values are found in patches located E-SE, and NW of the vent. Two prominent regions of anomalously high b-values (b>2.4) are resolved, the first is located roughly 3 km E-SE of the vent, at depths between 3 and 7 km; the second is located roughly 3 km NW of the summit, at depths between 3 and 8 km. There is also some indication of a deeper high b-value anomaly NE of the summit at depths between 12 and 16 km. The statistical differences between selected regions of low and high b-values are established at the 99% confidence level.

The b-value results agree fairly well spatially with those derived from earlier P-wave tomographic studies. No significant changes in b-values were found as a function of time. We speculate that the high b-value anomalies around Mount Pinatubo are regions of increased crack density, or alternatively high pore pressure, related to the presence of magma bodies nearby.

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Evidence for the Co-Ignimbrite Origin of the 15 June 1991 Mt. Pinatubo Climactic Eruption Ashcloud.

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The Mt. Pinatubo climactic eruption on the afternoon of 15 June 1991 was one of the largest of the 20th century. The eruption has been widely studied, but the origin of the giant ashcloud remains unclear. It is most commonly assumed to have a plinian origin, but field observations indicated unusual features. To evaluate the origin of the Pinatubo climactic ashcloud, we measured new grain-size parameters of our own fall samples collected around Pinatubo, of the PHIVOLCS data, and of distal deep-sea ash samples. In addition, we systematically compared the Pinatubo fallout deposit with the unambiguously plinian 1875 Askja ashfall (Iceland) and with an integrated grain-size dataset of 600 pyroclastic deposits from many eruptive styles (plinian, subplinian, strombolian) and representing the main types of pyroclastic activity (surge, flow, fall and co-ignimbrite fall). The co-ignimbrite fallout deposits are from the 1980 Mt. St. Helens (MSH) and from the 1815 Tambora eruptions.

Instead of using the classical Phi-scale and related grain-size parameters, we calculate grain-size parameters of arithmetic mean (m) and standard deviation (e.g., sorting, m), both defined in the metric scale. We also calculate the bulk specific surface area (SSA) which is the total surface area of a set of grains to their total volume (1/m). We also introduce two new grain-size ratios: (i) SSA/Mean (1/m2) and (ii) Mean/Sorting (dimensionless). The first ratio, SSA/Mean, distinguishes coarse-grained from fine-grained deposits. The second ratio, Mean/Sorting, discriminates gravity-controlled flow from pure plinian-subplinian-strombolian fall deposits. In this SSA/Mean vs. Mean/Sorting plot, co-ignimbrite fallout deposits plot in the surge domain, not in the plinian fallout domain.

Using this approach, we demonstrate that the Pinatubo ashcloud deposit is unusually rich in breathable fine ash (less than 10 micrometers, PM10), from 5-11 wt% of PM10 in Mt. Pinatubo vicinity up to 26 wt% beyond 300km from the vent. By contrast, the plinian Askja deposit shows no PM10 up to 145 km from vent. Furthermore, the variations of metric-mean, metric-sorting and SSA versus distance differ considerably for the Askja and the Pinatubo fall deposits. In the Pinatubo case, grain-size variations with distance are more gradual, whereas they are rapid for the Askja plinian fall deposit. For instance, within 50km of source, SSA increases 100-fold for Askja, whereas it only doubles for Pinatubo. In addition, SSA of most Pinatubo proximal deposits are about 2-3 orders of magnitude higher than most proximal Askja deposits. Pinatubo metric-mean values are an order of magnitude smaller than those for Askja. All the available data indicate that the Pinatubo giant ashcloud deposited dominantly homogeneous fine ash enriched in PM10, while the Askja plinian cloud deposited coarser and heterogeneous fallouts. Last but not least, in the SSA/Mean vs. Mean/Sorting diagram, Pinatubo fallout deposits systematically plot in the co-ignimbrite domain, away from the plinian fallout domain.

From our new grain-size approach and from all the available grain-size data, we conclude that the Pinatubo climactic eruption ashcloud was mostly of co-ignimbrite origin.