$\Delta T = \sim 230°C$, which is similar to or greater than the postulated thermal buoyancy contrast between a hot mantle plume and its surroundings. While the depleted nature of FP has been interpreted to result from subducting-slab dehydration induced high extents of mantle wedge melting, evidence indicates that the depletion of these FP predates the inception of the subduction, thus these FP are not residues of present-day arc magmatism. Hence, the compositional buoyancy contrast already existed within the lithosphere before the inception of the subduction in the western Pacific. Much of the Mariana SAL may be fragments of old continental lithosphere, whereas the Tonga/Fiji plateau and Kamchatka lithosphere may be remnants of buoyant, hence unsubductable oceanic plateaus (mantle plume head materials) for the Louisville and Hawaiian hotspots respectively. Passive continental margins, where the largest compositional buoyancy contrast exists within the lithosphere, are the loci of future subduction zones. Geometrical analysis shows that the compositional buoyancy contrast within the lithosphere under compression (e.g., ridge push) induces transtensional planes. The weakest plane in the vicinity of the compositional buoyancy contrast develops into a reverse fault. The dense NOL (the foot-wall) tends to sink into the hot and less dense asthenosphere. Calculations show that this tendency to sink reduces both the normal stress to, and shear resistance along, the fault plane, thus easing the sinking and favoring the initiation of a subduction zone. This concept also explains other observations and makes testable predictions on important geodynamic problems.

U22B MC: 134 Tuesday 1330h

The Earth's Interactions With the Sun, From Millennia to Minutes

Presiding: **D Strobel,** The Johns Hopkins University; **G Reeves,** Los Alamos National Laboratory; **D E Siskind,** Naval Research Laboratory; **B Thompson,** NASA Goddard Space Flight Center

U22B-01 1335h INVITED

Time scales and Mechanisms of Climate Interactions with the Sun

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Various correlations have been obtained between observed or deduced changes in solar irradiance and climate variations. During the Quaternary, these include: ice age cycles (circa 100,000 years), associated with Milankovitch orbital variations; apparent climate periodicities on the order of 2300, 210, 88, 22 or 11 years, presumably associated with variations of these periods in the activity of the sun, including sunspots; and even daily responses of cyclone intensity related to high energy particles. The problem in each of these respects is to decipher how the relatively small energy variations (at most on the order of 0.5 percent of total solar irradiance, or 1 W/m2) could be responsible for the impacts in the massive troposphere ascribed to them. One explanation is that they cannot: that the correlations are either circular reasoning, associated with dating uncertainties, or quasi-periodicities related to naturally occurring cycles that happen to match solar ones. Alternatively, the climate system could be sensitive to the spectral frequencies or latitudinal distribution of the solar irradiance changes, thereby amplifying the forcing via naturally occurring mechanisms. Our current understanding of this subject will be reviewed, with emphasis on the potential interaction between different levels of the atmosphere as amplifying mechanisms, including impacts on both radiative and atmospheric-dynamical processes.

U22B-02 1405h

Persistent Solar Influence on North Atlantic Surface Circulation During the Holocene

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New evidence from deep sea cores in the North Atlantic suggests that recurring expansions of the subpolar surface circulation were influenced by variations in solar output through the entire Holocene. Five high-resolution records of drift ice from three widely separated sites reveal a series of rapid, centennial time-scale oscillations that are bundled into the millennial duration events of the "1500-year" cycle. The centennial duration oscillations closely match prominent changes in production rates of the cosmogenic nuclides ^{14}C and ^{10}Be as inferred from tree ring measurements and from Greenland ice core records, respectively. Virtually every expansion of the subpolar surface circulation is linked to reduced solar irradiance. The most recent circulation cycle corresponds to the "Little Ice Age-Medieval Warm Period".

Each expansion of the subpolar circulation was associated with cooler surface temperatures and probably with more zonal surface winds. Those changes may reflect an intensified and expanded Polar Cell and would be consistent with recent GCM models of the atmosphere's dynamical response to solar forcing of stratospheric ozone and temperature. The sense of the circulation-driven temperature changes, though, does not exhibit the characteristic dipole pattern of the NAO; rather the pattern resembles that of regional cooling associated with reduced production of North Atlantic Deep Water (NADW), such as during the Younger Dryas although with much lower amplitude. As production of NADW is highly sensitive to changes in surface hydrography, we suggest that the solar forced expansions of subpolar circulation may have triggered a deep ocean response, which, through reduced northern heat transport and increased sea ice, further amplified the climate response to variations in solar output.

U22B-03 1420h

The Earth's Interaction With the Sun Over the Millennia From Analyses of Historical Sunspot, Auroral and Climate Records

K Pang

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A prolonged decrease in the Sun's irradiance during the Maunder Minimum has been proposed as a cause of the Little Ice Age (*ca* 1600-1800). Eddy [*Science* **192**, 1976, 1189] made this suggestion after noting that very few sunspots were observed from 1645 to 1715, indicative of a weakened Sun. Pre-telescopic Oriental sunspot records go back over 2200 years. Periods when no sunspots were seen have been documented by, *eg*, Clark [*Astron* **7**, 2/1979, 50].

Abundances of C 14 in tree rings and Be10 in ice cores are also good indicators of past solar activity. These isotopes are produced by cosmic rays high in the atmosphere. When the Sun is less active more of them are made and deposited at ground level. There is thus a strong *negative* correlation between their abundances and sunspot counts. Minima of solar activity in tree rings and a south polar ice core have been collated by, *eg*, Bard [*EarthPlanetSciLett* **150** 1997, 453]; and show striking correspondence with periods when no sunspots were seen, centered at *ca* 900, 1050, 1500, 1700.

Pang and Yau [*Eos* **79**, #45, 1998, F149] investigated the Medieval Minimum at 700, using in addition the frequency of auroral sighting7s, a good indicator of solar activity too [Yau, PhD thesis, 1988]; and found that the progression of minima in solar activity goes back to 700. Auroral frequency, C 14 and Be 10 concentrations are also affected by variations in the geomagnetic field. Deposition changes can also influence C 14 and Be 10 abundances. Sunspot counts are thus the only true indicator of solar activity.

The Sun's bolometric variations (-0.3% for the Maunder Minimum) can contribute to climatic changes (0.5° C for the Little Ice Age)[*eg*, Lean, *GRL* **22**, 1995, 3195]. For times with no thermometer data, temperature can be estimated from, *eg*, Oxygen 18 isotopic abundance in ice cores, which in turn depends on the temperature of the ocean water it evaporated from. We have linked the Medieval Minimum to the cold spell, dated to *ca* 700 by Dansgaard [*Nature* **255**, 1974, 24]. Using records of advances and retreats of glaciers, previous researchers have linked it to a cold spell in the previous two centuries instead, thus requiring an offset in timescales.

Our literature search has yielded more records of sunspot sightings, and established the fifth century as a minimum of solar activity, ending in a maximum at *ca* 500. These features and the minimum at 700 match contemporary deviations of atmospheric C 14 from a secular trend, due primarily to long-term changes in the strength of the Earth's magnetic moment [Stuiver, *Radiocarbon* **35**, 215].

Pang has shown that the climate of Eurasia was cold in the 5th century, due partly to volcanic cooling [*Eos* **80**, #46, 1999, F220]. Reduced solar luminosity may have contributed to that too. The cold apparently forced massive southward migrations of Teutonic and Asian barbarians into the Roman Empire, ending it in 476. Europe was plunged into the Dark Age, from which it did not recover until the climate warmed up again toward the end of the millennium.

Finally, climate changes can also be produced by greenhouse warming, reorganization of ocean current systems "Dansgaard-Oeschger events," the Earth's orbital variations "Milankovitch effects," *etc.* Continued analysis of historical records, in conjunction with other proxy data, can help shed light on the nature of the Earth's interactions with the Sun, and the causes of past climate changes.

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U22B-04 1435h INVITED

Solar Photons, Particles and the Earth's Ozone Layer

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The middle atmosphere is sensitive to solar/terrestrial coupling in several ways. Variable photon output from the sun can directly cause changes in the photodissociation of molecular oxygen and thus cause ozone in the upper stratosphere to vary with solar activity. Ozone variations on the 27 day solar rotation and 11 year solar cycle timescales have been observed. Models can reproduce the 27 day variability, but underestimate the 11 year variability. Particle fluxes into the atmosphere can also effect middle atmospheric chemistry. Solar protons with energies from 1-500 MeV can occasionally produce large amounts of odd nitrogen (NOx) and odd hydrogen (HOx) in the polar stratosphere and mesosphere. By increasing the abundances of NOx and HOx radicals, solar proton events can lead to noticeable ozone losses, most recently in the so-called Bastille Day event of July 2000. Depending upon the energy of the solar protons and thus the altitude at which they deposit their energy, these ozone losses can persist for months. Finally, magnetospheric electrons are known to produce large amounts of nitric oxide in the upper mesosphere and lower thermosphere. Through downward transport in the polar winter, the NO can be brought down as low as 25 km where it can cause significant ozone loss. These solar-terrestrial coupling mechanisms will be reviewed with emphasis place upon outstanding issues and controversies.

U22B-05 1520h INVITED

Weather and Climate of the Earths Outer Atmosphere Driven by the Sun

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The outer layers of the Earth's atmosphere, the thermosphere and ionosphere, are strongly influenced by the highly variable components of the Sun's output. The basic temperature and compositional structure and dynamics are set by the radiative output of the Sun in the X-ray, EUV and UV portions of the spectrum from 1 to 200 nm. These are then strongly modified by the plasma inputs into the high latitude thermosphere and ionosphere caused by the interaction of the solar wind with the magnetosphere and transferred to the upper atmosphere in the form of auroral particle precipitation

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