MOMENT RATE DURING CASCADIA TREMOR CONSTRAINED BY GPS

Ana Aguiar (CWU), Tim Melbourne (CWU), Craig Scrivner (CWU),

A comparison of GPS and seismic recordings of 22 distinct Episodic Tremor and Slip events located throughout the Cascadia subduction zone over a ten-year period yields a highly linear relationship between moment release, as estimated from GPS, and total duration of non-volcanic tremor, as summed from regional seismic arrays. The events range from one to five weeks, produce ~5 mm of static forearc deformation, and show cumulative totals of tremor that range from 40 to 280 hours. Moment released by each event is estimated by inverting GPS-measured offsets, which are sensitive to all rates of tremor-syncronous faulting, including aseismic creep, for total slip along the North American-Juan de Fuca plate interface. Tremor, which is shown to be invariant in amplitude and frequency both between events and with respect to its duration, is tallied through several different mechanisms that agree internally to within 10%. All known Cascadia events detected since 1997, which collectively span the entire Cascadia arc from northern California to northern Vancouver Island, Canada, release moment at a rate of 5e23+-.1 dyne-cm per hour of recorded tremor. This relationship constitutes a tremor magnitude scale that enables the quantification of moment dissipation within the regions of the Cascadia subduction zone that pose the greatest threat to major metropolitan centers.

POSTER 15

SEISMIC EVIDENCE FOR OVERPRESSURED SUBDUCTED OCEANIC CRUST

Pascal Audet (University of British Columbia), Michael G. Bostock (University of British Columbia), Nikolas I. Christensen (University of British Columbia), Simon M. Peacock (University of British Columbia)

Water plays a key role in the origin and evolution of subduction zones by controlling geodynamic processes such as arc volcanism, lubrication of the plate interface, and by altering mantle rheology. Its seismic signature within the mantle wedge is evident in low shear-velocity anomalies marking serpentinization, however, its transport within the subducting oceanic plate beneath continental crust is less clearly defined. We present observations of converted teleseismic waves that indicate water is pervasively present in fluid form at pore pressures near lithostatic values within subducting oceanic crust from the northern Cascadia continental margin beneath southern Vancouver Island to its intersection with forearc mantle. This observation holds important implications for our understanding of permeability at the plate interface, subduction zone velocity structure and the mechanism of episodic tremor and slip.

POSTER 25

SPATIAL PATTERNS OF NONVOLCANIC TREMOR SOURCE LOCATIONS ALONG THE CASCADIA SUBDUCTION ZONE

Devin Boyarko (Miami University), Michael Brudzinski (Miami University)

Along a convergent margin, there is potential for megathrust earthquakes in the seismogenic zone where strong coupling occurs on the interface between the plates and elastic strain accumulates within the plates. Down-dip from this seismogenic zone, increasing temperatures and metamorphic dehydration reactions generate a transitional zone between the locked and free-slip portions along the subduction interface. Episodic Tremor and Slip (ETS), the correlation of slow slip events monitored by GPS observations and nonvolcanic tremor (NVT) monitored via seismic signals, is believed to be associated with this transitional zone. The processes that govern ETS and its relationship to megathrust earthquakes in space and time remain unresolved, although ETS has been proposed to impact the likelihood of megathrust earthquakes. Given the increased density of seismometers from EarthScope, one can begin to examine the spatial patterns in source locations of NVT all along the Cascadia subduction zone in detail. We analyze NVT signals with a semi-automated process for identifying prominent bursts (S-waves) that are above the background noise levels, and analyst-refined relative arrival times are used to invert for source locations. Further refinement of source locations is achieved when coherent P-waves are observed. Preliminary results from an episode in northern Oregon reveal NVT epicenters that migrate over 200 km from south to north but are restricted between the 30 and 45-km contours of the plate interface, precisely within the expected transitional zone of frictional behavior.

POSTER 19

DANCING WITH THE PLATES: WATCHING FAULTS SHIMMY AND SHAKE

Michael Brudzinski (Miami University)

Tectonic plate boundaries can generate large devastating earthquakes when there is a sudden release of elastic strain energy stored on the locked, seismogenic zone of the plate interface. Recent geodetic observations reveal that at depth, where increasing temperatures and pressure and changing petrology affect the frictional behavior, plate boundary faults can also release their stress through slow slip. In many cases, the slow slip events have been shown to correlate with seismically recorded non-volcanic tremor, forming so-called episodic tremor and slip. Modulation of these signals by tides and passing surface waves imply that very low effective stress is a necessary condition, supported by constraints from frictional modeling and the presence of high Vp/Vs ratios that suggest high pore fluid pressures. The recurrence intervals between episodes of tremor and slip and their source locations can have remarkable regularity, which suggest there are some links to geologic terranes and seismogenic zone behavior. While the majority of initial observations have come from subduction zone environments, some intriguing signals have recently been discovered in other settings suggesting that this phenomenon may also shed light on fault properties in general.

POSTER 11

EPISODIC TREMOR AND SLIP IN CASCADIA

Ken Creager (University of Washington), Aaron Wech (University of Washington), John Vidale (University of Washington), Justin Sweet (University of Washington), Mario LaRocca (University of Washington)

Much of the subduction plate motion at depths near 40 km under the Puget Sound through southern Vancouver Island region can be explained by major Episodic Tremor and Slip (ETS) events that happen like clockwork every 14 months. Tremor locations determined for every 5-minute window provide a detailed view of the propagation of the last three (or four if the next, slightly tardy, ETS gets its act together) events as well as many much smaller tremor episodes. The first two started near the San Juan Islands, migrated updip, then bifurcated and propagated north and south along strike. The third propagated unilaterally to the north. The western edge of well-located tremor is 75-100 km from the down-dip edge of the locked zone as inferred from thermal models and modeling of geodetic data (Wech Poster). If megathrust earthquakes rupture all the way down to the updip edge of the ETS zone, as they appear to in Shikoku, Japan, they will rupture much closer to the major population centers than previously thought. Tremor amplitudes are strongly modulated by the tides implying that tremor is sensitive to very small (10^-5 times lithostatic) stress perturbations. A new method for determining S-P times provides definitive evidence that tremor is located very near the plate interface (LaRocca Poster). We have looked for, and not yet found, shorter S-P times that would be indicative of shallower tremor. The polarization of tremor-induced shear waves is consistent with that predicted for thrust slip along the plate boundary suggesting that, as in Shikoku, tremor and slip are manifestations of the same process. A small-apperture array of 80 geophones coupled with Texan recorders is providing the first good look, in Cascadia, at what appears to be Low-frequency Earthquakes (LFEs) (Sweet Poster and Vidale Poster). LFEs have proven to be extremely valuable in helping to constrain the location and mechanism associated with tremor and slow slip in Shikoku.

PERMEABILITY ENHANCEMENT BY DYNAMIC STRESS FIELDS

Jean Elkhoury (University of California, Santa Cruz), Andre Neimeijer (Pennsylvania State University), Emily Brodsky (University of California, Santa Cruz)

Shaking from earthquakes has been observed to affect hydrological systems in a variety of ways. Water well levels can change dramatically, streams can become fuller, springs discharge can increase and even faults can get lubricated. Most of these hydrological observations can be explained by some form of permeability increase. We use the response of water well levels to solid Earth tides to measure permeability over a 20-year period at the Pi\~non Flat Observatory. At the time of each of nine earthquakes in Southern California, we observe transient increase in permeability as high as by a factor of three. We show a roughly linear dependence of the permeability increase on the amplitude of peak dynamic surface stresses in the range 0.02-0.2 MPa. The large variations of permeability over time indicate that natural permeability is not a fixed quantity but rather an-ever evolving, dynamically controlled parameter. It also shows that relatively small dynamic stresses, 0.2 MPa, can triple permeability and therefore suggests a possible method for active permeability enhancement. We also present preliminary experimental results in a biaxial apparatus where we show permeability enhancements in fractured sandstones induced by dynamic pore pressures at frequencies under 1Hz and peak pore pressure amplitudes in the range 0.01-1.0 MPa.

POSTER 10

TIDAL CONSTITUENTS IN NON VOLCANIC SEISMIC TREMOR ACTIVITY AT THE CHILE TRIPLE JUNCTION

Alejandro Gallego (University of Florida), Raymond Russo (University of Florida), Diana Comte (Universidad de Chile), Victor Mocanu (University of Bucharest), Ruth Murdie (Vienna International Centre), John Vandecar (Carnegie Inst. of Washington)

We present evidence that non volcanic seismic tremor detected at Chile Ridge Subduction Project (CRSP) seismic network correlates with lunisolar tidal amplitude variation. Tremors were detected at 14 broadband seismic stations in the Los Chonos Archipelago and Taitao Peninsula by simple visual inspection of correlated tremor on seismograms at CRSP stations. Time series analysis of two years (2005-2006) of tremor occurrence at one hour sample interval reveals strong power-spectral peaks at semidiurnal (M2, S2), diurnal (O1, K1) and long term (Mm) tidal periods. Spectrograms show harmonic behavior of tremors continuing during the two years with some small gaps. Zonal gravitational traction due to tidal acceleration is maximum near the latitude of the study region (46S), and is enhanced by the ocean loading. At least two hypotheses could explain the correlation: stress cycling on the subducted Taitao and Darwin transform faults due to solid earth tide and ocean loading, leading to tremor generation; or enhanced hydrothermal activity during fluid release in the subducted Chile ridge structure. Tremor sources determined via the source scanning algorithm fall within regions of elevated Coulomb stress changes on the Nazca-South America interplate interface due to slip on the subducted transform faults.

POSTER 21

NON-VOLCANIC TREMOR AT SAN ANDREAS FAULT NEAR PARKFIELD TRIGGERED BY THE GREAT SUMATRA EARTHQUAKE, 2004

Abhijit Ghosh (University of Washington), John Vidale (University of Washington), Zhigang Peng (Georgia Institute of Technology), Kenneth Creager (University of Washington), Joan Gomberg (USGS), Paul Bodin (University of Washington), Heidi Houston (University of Washington)

Passing seismic waves from large earthquakes triggered non-volcanic tremor (NVT) in several instances. But tremor mechanism, and its reaction to the dynamic stressing from different body- and surface-waves remains poorly understood. We found NVT at San Andreas Fault (SAF) near Parkfield ignited by Mw 9.0 Sumatra earthquake, 2004. Complex behavior of the NVT sequence during the prolonged shaking, and dense station coverage at Parkfield area provide an excellent opportunity to study dynamic triggering of tremor. There are primarily two regions on SAF that produce tremors in this sequence. Love wave shows the strongest modulation of NVT with tremor amplitude synchronizing with the surface wave cycles. The Rayleigh waves witness only a rather weak period of tremor, but are immediately followed by strong bursts of tremor activity. At times, tremor shut itself off abruptly; in other times it is still quivering after the waves have passed. Some tremors in this NVT sequence, surprisingly, are associated with the passage of P-wave, not usually recognized for its triggering potential. These observations point towards the potential for resolving the possible sensitivity of tremor sources to both shear and dilatational stress.

POSTER 24

INFLUENCE OF LARGE EARTHQUAKES ON THE NONVOLCANIC TREMOR ACTIVITY IN THE PARKFIELD-CHOLAME REGION, CA

Aurelie Guilhem (Berkeley Seismological Laboratory), Robert M. Nadeau (Berkeley Seismological Laboratory)

Understanding the relationship of nonvolcanic tremor (NVT) activity to the fault zones on which they occur is crucial for a clearer picture of the conditions and mechanisms responsible for their generation. In Cascadia and Japan, NVTs have shown a remarkable correlation between their activity rates and GPS and tiltmeter measurements of transient deformation in the deep (sub-seismogenic) fault zone. It has also been proposed that dynamic stress changes from passing surface waves of distant teleseismic earthquakes and stresses associated with the tides can induce NVT activity. Those observations suggest that tremor rate changes may be closely related to stress changes or transient deformation in the deep fault zone, and suggest that stress changes from near-by large earthquakes may also stimulate tremor activity.

We report here on the spatial and temporal relationships of NVT activity along the San Andreas Fault near Cholame, California, starting in August of 2001. The locations of the NVTs are determined using envelope cross-correlation techniques similar to Obara, 2002, with additional use of redundant station triplet information to identify and remove outliers. Double-difference relocation (hypoDD) of the alignment phases is also used.

We show: 1) that NVT activity rates increase following the 2003 San Simeon earthquake and, more significantly following the 2004 Parkfield event, 2) that the amplitude of the Coulomb stress changes computed for those two large earthquakes are small but correlate with the relative rate changes associated with the events, 3) that since the Parkfield earthquake, a quasi-periodic pattern of the NVT episodes has developed, and 4) that this pattern and an overall increase in the NVT activity following San Simeon and Parkfield events persists. Also, locations of the Cholame NVTs occurring during the 2006-2007 period indicate that the NVTs occur at subseismogenic depths, generally between 15 and 25 km, that they are distributed in the across fault direction over an ~ 10-15 km wide zone that is offset from the SAF by ~ 5 km to the SW.

POSTER 26

SPATIAL AND TEMPORAL PATTERNS OF NON-VOLCANIC TREMOR SOURCE LOCATIONS ALONG THE OAXACAN SEGMENT OF THE MEXICAN SUBDUCTION ZONE

Hector Hinojosa-Prieto (Miami University), Michael Brudzinski (Miami University), Timothy Carey (Miami University), Enrique Cabral-Cano (UNAM), Alejandra Arciniega-Ceballos (UNAM), Charles DeMets (University of Wisconsin-Madison), Oscar Diaz-Molina (UNAM)

Convergent tectonic plate boundaries generate large devastating earthquakes when plate motion accumulates tectonic stresses on the locked, seismogenic zone of the subduction zone interface. Downdip from the seismogenic zone, where increasing temperatures, pressure and slab dehydration affect the frictional behavior, periodic slow slip events appear to occur in a transitional zone. The slow slip events have been shown to correlate with non-volcanic tremor (NVT), forming so-called episodic tremor and slip (ETS). The Oaxacan segment of the Mexican subduction zone is an ideal area for detailed ETS studies due to its relatively rapid convergent rates, shallow subduction angle, short megathrust earthquake recurrence intervals (decades), and short trench-to-coast distances that bring the seismogenic and transition zones of the plate interface as much as 250 km inland from the coastline. Previously analyzed slow slip events in southern Mexico occur over vast, deep areas of the subduction zone interface, and may even extend updip into the seismogenic zone, potentially playing a role in the timing and location of upcoming megathrust earthquakes. In addition to recent expansion of the permanent GPS station network, a new seismic deployment consists of 8 broadband seismometers geographically dispersed inland along the Oaxacan segment, providing the means to examine NVT signals in detail for the first time in this region. We analyze NVT signals with a semi-automated process for identifying prominent bursts (S-waves) that are above the background noise levels, and analyst-refined relative arrival times are used to invert for source locations. Further refinement of source locations is achieved when coherent P-waves are observed. We apply this technique to data recorded over the first year of the deployment to determine spatial and temporal patterns in source locations. Furthermore, we will compare NVT source locations with those of slow slip events, current microseismicity, and previous megathrust earthquakes rupture zones.

POSTER 20

SCALING OF THE TREMOR SOURCE

Heidi Houston (University of Washington)

Recently, a compilation of different types of slow slip events by Ide et al. suggested that durations of such events are linearly proportional to their seismic moments. Here I conduct a systematic study of tremor using a consistent data stream for the 2005 Cascadia ETS. Day-long seismograms from the Port Angeles array are integrated, corrected for gain, and filtered from 1-8 Hz. Envelopes of the horizontal records are stacked and smoothed. Tremor events are defined as intervals during which the envelope exceeds a threshold. To associate moments with tremor events, the envelopes are treated as time functions (moment-rates). Moment of a tremor event is estimated assuming the signal consists of far-field direct S-waves, and applying an empirical calibration to correct for reverberations near the stations (developed by comparing the known magnitude of small earthquakes with that estimated by the processing described above). The exponent of proportionality between duration and moment does not depend on the calibration and varies from 0.8 to 0.9 over a range of thresholds and smoothing periods. This allows for modest growth of the amplitude of tremor events with duration, which is clearly seen in the envelopes. This scaling contrasts strongly with that of regular earthquakes, which follow duration proportional to cube-root of moment over many orders of magnitude, and for which amplitudes grow strongly with moment. That scaling occurs due to the rough proportionality of fault displacement, length, and width, and the imposition of a roughly constant value of rupture velocity by the dynamic stress propagation in earthquakes. One or more of these factors must be missing from the tremor process. The empirical calibration indicates that the minimum moment needed to generate the observed 1-8 Hz tremor on a representative vigorous day of the 2005 ETS is much less than that of the inferred slow slip. Given the abundance of tremor signals observed in the 1-10 Hz range compared to the relative paucity of signals at lower frequencies, the possibility should be considered that the source spectrum produced by episodic slow slip is more complicated than f^-1 at all frequencies from 0-10 Hz. Furthermore, it has been suggested that tremor may consist of numerous tiny regular earthquakes. However, experiments summing up thousands to millions of small f^-2 earthquakes demonstrate the difficulty of modeling tremor as the superposition of such sources.

POSTER 27

EPISODIC TREMOR AND SLIP IN JAPAN

Satoshi Ide (Dept. EPS, University of Tokyo)

Following the discovery of deep low-frequency tremor, low frequency earthquakes (LFEs), very low-frequency earthquakes (VLFs), and slow slip events (SSEs) have been discovered in western Japan. We study these unusual earthquakes mainly in western Shikoku where tremor activity is most active. Among these phenomena, LFE has impulsive nature which allows us to apply developed seismological methods. The double difference tomography and event relocation have shown that these events are located on the subducting plate interface, and P-wave first motion analysis and the empirical Green tensor inversion have determined a low-angle thrust as a typical source mechanism. These facts indicate that LFEs are tiny slip on the plate interface. Low frequency tremor is also considered as successive slip events because the waveforms of tremor are explained as superimposed LFE waveforms. Moreover, larger events, VLFs and SSEs have been identified as low-angle thrust slip. Therefore all these unusual phenomena share the same low angle thrust mechanism consistent with overall plate motion and the Nankai megathrust earthquake. The seismic moment and event duration of these phenomena are proportional, with a characteristic moment rate of 10^12-13 Nm/s. This scale invariance and proximity of location and time suggest that these phenomena are different appearances of a single process of slow earthquake. They are separately discovered on the scaling law due to the limitation of observation controlled by microseism and tidal noises. However, if S/N is good, we can find longer events than VLFs, with duration 20-200s, that satisfy the same scaling law. These events radiate seismic energy in direct proportion to their seismic moment rate, which implies that scaled energy of slow earthquakes is constant. These evidences, together with other features such as periodicity, short- and long-range migrations, and modulation by tidal stress and far-field surface waves, require united explanation by physical models.

CASCADIA TREMOR DEPTHS CONSTRAINED BY S MINUS P TIMES

Mario LaRocca (Osservatorio Vesuviano, Instituto Nazionale di Geofisica e Vulcanologia, Naples, Italy), Ken Creager (University of Washington), Danilo Galluzzo (Osservatorio Vesuviano, Instituto Nazionale di Geofisica e Vulcanologia, Naples, Italy), John Vidale (University of Washington), Steve Malone (University of Washington), Justin Sweet (University of Washington), Aaron Wech (University of Washington)

A key to understanding Episodic Tremor and Slip (ETS) is obtaining accurate tremor depths. In Shikoku, Japan this has been done using S minus P times observed by stacking many hundreds of low-frequency events (LFEs) that are postulated to compose the tremor. In Japan, the tremor sources occur at (or at least very near) the plate interface. In Cascadia, however, LFEs are not yet widely observed, and tremor locations scatter over tens of km. It has not been clear whether this represents uncertainty or true variability. We have developed a method for determining S minus P times that works best using arrays recording tremor that is traveling nearly vertically. For observations across the three arrays deployed to observe the July, 2004 Cascadia ETS, the S minus P times range from about 4 to 7 s. We locate tremor using two methods. The first combines S minus P time constraints with vector slowness estimated from the arrays. The second adds S minus P time constraints to a method that employs cross correlations of seismogram envelope functions. Both methods greatly reduce the uncertainty and scatter in source depth. Our preliminary analysis indicates that, similar to Japan, the Cascadia tremor sources are coming from locations at, or at least very near, the plate interface. In addition, polarization analysis of tremor seismograms indicates that the tremor focal mechanism is consistent with slip on the plate boundary in the direction of relative plate motion. Together this suggests that tremor and geodetically observed slip are both manifestations of the same process corresponding to the two plates slipping past each other along the plate boundary.

POSTER 17

WAVEFORM MODELING OF SANTIAGUITO VOLCANO EXPLOSIONS

Jonathan Lees (Dept. Geological Sciences, University of North Carolina, Chapel Hill), Jeffrey Johnson (Dept of Earth & Environmental Science, New Mexico Tech), Takeo Nishimura (Graduate School of Science, Tohoku University, Sendai , Japan)

In January, 2007, Santiaguito Volcano, Guatemala, erupted explosively approximately once per hour. Over a period of several days we recorded numerous explosions at distances of 1-6 km from the active vent. The active vent erupts frequently, venting gas and pyroclastics for durations of tens of seconds. The explosions can be classified by cluster analysis into at least two or more groups – where the strongest explosions share a considerable similarity in wave form. The explosions have equivalent estimated magnitudes ranging from 1 to 5 based on Tuboi's (1954) formula and peak frequencies ranging from 0.8 to 1.6 Hz. The initiation of these events (explosions/implosions) is associated with LP earthquake generation (of finite source duration: 1-2 s) which we seek to explain using several potential models. We used a discrete wave number method to calculate Green's functions and synthetic waveforms for single force and implosion sources at a distance of 1 km where the closest station (DOM) was located. We used high resolution video recordings of the surface of the dome to estimate dislocations for deriving source time functions for the single force. These are then used in the modeling to derive the best fitting models for the LP waves recorded on a near field station. Estimated force amplitudes from the sesmic modeling are in the range of 5x10e8-4.4X10e9 N as compared to video estimates of 10e8 - 10e9.5 N suggesting that the models are in quite good agreement.

POSTER 14

DYNAMIC TRIGGERING OF NON-VOLCANIC TREMOR EARTHQUAKES AND ETS ON VANCOUVER ISLAND

Justin Rubinstein (USGS), Joan Gomberg (USGS), John Vidale (University of Washington), Aaron Wech (University of Washington), Kenneth Creager (University of Washington), Honn Kao (Geological Survey of Canada), Garry Rogers (Geological Survey of Canada)

With the goal of clarifying the physical mechanism and processes necessary for triggering non-volcanic tremor and earthquakes we examine a catalog of 30 teleseismic earthquakes and 17 regional earthquakes that hit Vancouver Island with the strongest shaking from 1996-2007 and search for non-volcanic tremor and earthquakes that were dynamically triggered by these events. We identify tremor triggered by four teleseismic earthquakes and eight events that likely triggered local earthquakes. Examining the that triggering and those that didn't, we find that the amplitude of the triggering shaking appears to influence whether tremor and earthquakes will trigger, but local conditions also appear to important in determining whether tremor or earthquakes will be triggered. Specifically, earthquakes tend to be triggered in regions with high seismicity rates, while triggered tremor is likely to occur in close proximity to ambient tremor (in both space and time). We also note an interesting correlation between large teleseismic events and ETS in the southern Vancouver Island/northern Puget sound region. All the ETS events that have long inter-event times, have a large teleseismic event that precedes them by a matter of days. This suggests that for ETS events that are "late" and have built up more stress than usual, the slight nudge of the shaking from a large distant event may trigger the ETS.

POSTER 13

REPEATING NATURE AND RELATIVE LOCATION OF SAN ANDREAS FAULT TREMORS NEAR CHOLAME, CA

David Shelly (U.S. Geological Survey, Menlo Park), Robert Nadeau (University of California, Berkeley), Roland Bürgmann (University of California, Berkeley), William Ellsworth (U.S. Geological Survey, Menlo Park), Janice Murphy (U.S. Geological Survey, Menlo Park), Trond Ryberg (GFZ Potsdam), Christian Haberland (GFZ Potsdam), Gary Fuis (U.S. Geological Survey, Menlo Park)

Non-volcanic tremor has been observed primarily in subduction zones but also beneath the strike-slip San Andreas Fault (SAF) [Nadeau and Dolenc, 2005]. We examine the repeating nature of SAF tremor waveforms and the associated potential for determining the relative location of tremors. We initially select a few relatively high-amplitude portions of tremor as "template waveforms" and perform a matched filter search using all available short period and broadband seismic stations within ~60 km of the tremor epicenter. Portions of the tremor that exhibit high similarity to the template waveforms (as measured by the sum of the correlation coefficients across all stations) are considered detected events. We find that, like subduction tremor in southwest Japan, SAF tremor repeatedly exhibits a pattern of similar waveforms across multiple stations. Different templates match with different portions of the tremor signal, possibly suggesting that the overall tremor signal is composed of several families of sources from different locations. Templates that encompass the beginning of a tremor burst, when the recorded amplitude increases noticeably, are typically more successful at matching other parts of the tremor than those selected from similar amplitude tremor within bursts. This might reflect a building complexity of these bursts as multiple sources become active and interfere.

During a day of active tremor, a given template may identify dozens of similar events. By recognizing small shifts in the offset of the waveforms at each station compared to the template, we can estimate the location of the detected tremor relative to the template tremor. Although low signal to noise ratios and a sub-optimal station distribution present substantial challenges to the location process, we hope by this process to obtain new constraints on the fine-scale structure of the tremor sources.

POSTER 22

LOW-FREQUENCY EARTHQUAKES IN CASCADIA

Justin Sweet (University of Washington), Kenneth Creager (University of Washington), John Vidale (University of Washington), Abhijit Ghosh (University of Washington), Maisie Nichols (University of Washington), Thomas Pratt (University of Washington), Aaron Wech (University of Washington)

Low-frequency earthquakes (LFEs) were first reported in Japan and have been observed to occur coincidently with non-volcanic tremor in both time and space. Compared to ordinary earthquakes, LFEs are deficient in frequencies above 5 Hz. The frequency spectrum of LFEs mirrors the spectrum of tremor. Indeed Shelly et al. (2006, 2007, Nature) have suggested that tremor is simply the superposition of many individual LFEs. Accordingly, LFEs have been used to constrain the mechanism and location of tremor. In Japan, LFEs are routinely identified by their S-waves, while their P-waves are typically below noise levels. In March 2008 we deployed a dense array of approximately 80 geophones paired with Texan recorders on the Olympic Peninsula of Washington State to record tremor from the anticipated episodic tremor and slip (ETS) event. Initial analysis of one hour of data reveals nearly 100 LFE-like events with similar spectra to locally observed tremor. Unlike LFEs in Japan, P-waves are clearly seen on the vertical component of many individual stations. Using a clear LFE as a template event, nearly 100 matching events have been found with S minus P times that differ by less than a few hundredths of a second from event to event suggesting that they are all within a few hundred meters of each other. Preliminary locations of this cluster using two borehole stations suggest that the LFEs are at the plate interface east of our array.

POSTER 18

DYNAMICALLY-INDUCED WEAKENING OF THE SAN ANDREAS FAULT BY THE 2004 SUMATRA-ANDAMAN EARTHQUAKE

Taka'aki Taira (University of Utah), Paul Silver (Carnegie Institution of Washington), Fenglin Niu (Rice University), Robert Nadeau (University of California, Berkeley)

Measuring in situ fault strength at seismogenic depth is one of the most important properties controlling the sequence and nucleation of earthquakes. In situ stress measurements in deep wells and boreholes have been revealed the state of the fault strength, however, its temporally resolving is limited. On the other hand, stress-induced temporal changes in the properties of seismic scatterers at depth can be capable of providing a means of continually monitoring the in situ fault zone properties. We have been monitoring a well-resolved temporal change in the properties of seismic scatterers within the San Andreas Fault at Parkfield, over 20 years (1987-2007), and here we report that the temporal change was observed in late 2004 that is most likely due to the dynamic stresses generated by the 2004 Mw 9.1 Sumatra-Andaman earthquake. This change is interpreted as resulting from the stress-induced migration of fluids and consequent redistribution of pore pressure within the fault zone. At the same time we also observe systematic temporal variations in the recurrence interval and seismic moment of repeating-earthquake sequences that are most consistent with changes in fault strength. We conclude that the maximum reduction in recurrence interval immediately after the 2004 Sumatra-Andaman earthquake constitutes a temporary weakening of the fault. Given that a similar excursion in scatterer properties initiated ~1-4 months after the 28 June 1992 Mw 7.3 Landers earthquake, we hypothesize that the large dynamic stresses from this event weakened the San Andreas Fault through the same mechanism, triggering the 1993 Parkfield Aseismic Transient as well as the cluster of four M4+ earthquakes (1992-1994) at Parkfield. The fault strength change we identify should clearly facilitate the triggering of earthquakes, since it would bring certain sections of the fault closer to failure.

POSTER 23

WHAT DOES TREMOR REALLY LOOK LIKE? INITIAL RESULTS FROM AN 80-ELEMENT ARRAY

John Vidale (University of Washington), Justin Sweet (University of Washington), Ken Creager (University of Washington), Abhijit Ghosh (University of Washington), Aaron Wech (University of Washington), Maisie Nichols (University of Washington), Tom Pratt (USGS)

Aspiring to see more intimate details, we have placed an 80 element short-period vertical array with an aperture of 1km on a hard rock mountain over the path of Cascadia tremor. This site is coincident with a stellar 6-station three-component CAFE array (see talk by K. Creager). We use Texans for logging the seismograms, which are convenient to deploy but require recycling for fresh batteries every four days. So far, we have recorded just eight days. We find most of the arrivals visible are P-waves, due to the network constitution, as S waves are generally a feeble mush at high frequencies.

This interval contains only a smidgen of tremor detectable by the regional network. Activity is less sanguine viewed through the unjaundiced eye of the dense array. We see the already-recognized regional seismicity plus a score more events with the attributes of plain-vanilla earthquakes, but also more. Tremor is visible for much of the time, shifting in location several times, sometimes in multiple locations at once. Also, at least a hundred weak sources on the slab in the tremor zone appear by beamforming in a single hour, probably a first glance of LFEs in Cascadia (see abstract by J. Sweet). In some frequency bands, daylight hours are plagued by bizarre patterns most likely from guttural cultural noise, some with unexpectedly vertical incidence. Very sharp pops apparently without S waves are another curiosity, as well as windstorms, gunshots and chainsaws.

I hope understanding will deepen as we figure it out. If the 14-month-interval tremor roars under the array on schedule, as it is has an appointment to do in May, so much the better. [As this goes to press, tremor has started and the Texans are out on guard duty again.]

POSTER 12

WASHINGTON TREMOR LOCATIONS

Aaron Wech (University of Washington), Kenneth Creager (University of Washington), Wendy McCausland (University of Washington), Robert Crosson (University of Washington)

Precise estimations of non-volcanic tremor epicenters aid in both mapping and better understanding the locations of the locked, transition, and freely slipping zones of the subducting Juan de Fuca plate. We have developed an automated tremor detection and location algorithm to obtain thousands of tremor locations over the past 4-ish major ETS episodes. We obtain locations for every 5-minute window by cross-correlating pairs of band-passed and smoothed envelope functions and performing a 3-D grid search over potential source locations that provide S-wave lag times that optimize the cross correlations. We then use a boot-strap method to determine reliability of locations, yielding error estimates. Solutions with epicentral error estimates < 2km are kept as potential tremor locations. We then analyze these locations for clustering, demanding that at least 10 minutes (2 locations) occur within a 0.1 x 0.1 degree area. The resulting tremor epicenters occur where the plate interface is 30-45 km deep, agree very well with geodetic inversions of accompanying slow slip episodes, and have a well-resolved sharp updip boundary nearly 75-100 km away from current estimates of the downdip edge of the locked zone.

POSTER 16