Stress changes along the Sunda trench following the 26 December 2004 Sumatra-Andaman and 28 March 2005 Nias earthquakes

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[1] The 26 December 2004 M_w = 9.2 and 28 March 2005 M_w = 8.7 earthquakes on the Sumatra megathrust altered the state of stress over a large region surrounding the earthquakes. We evaluate the stress changes associated with coseismic and postseismic deformation following these two large events, focusing on postseismic deformation that is driven by viscoelastic relaxation of a low-viscosity asthenosphere. Under Coulomb failure stress (CFS) theory, the December 2004 event increased CFS on the future hypocentral zone of the March 2005 event by about 0.25 bar, with little or no contribution from viscous relaxation. Coseismic stresses around the rupture zones of the 1797 and 1833 Sunda trench events are negligible, but postseismic stress perturbations since December 2004 are predicted to result in CFS increases of 0.1 to 0.2 bar around these rupture zones between 2 and 8 years after the December 2004 event. These are considerable stress perturbations given that the 1797 and 1833 rupture zones are likely approaching the end of a complete seismic cycle. **Citation:** Pollitz, F. F., P. Banerjee, R. Bürgmann, M. Hashimoto, and N. Choosakul (2006), Stress changes along the Sunda trench following the 26 December 2004 Sumatra-Andaman and 28 March 2005 Nias earthquakes, *Geophys. Res. Lett.*, *33*, L06309, doi:10.1029/2005GL024558.

1. Introduction

[2] The 26 December 2004 M_w = 9.2 Sumatra-Andaman earthquake ruptured about 1300 km of the Sumatra megathrust with more than 5 m average slip [*Banerjee et al.*, 2005]. Portions of the megathrust south of about 2.5°N latitude, the southern termination of this earthquake [*Lay et al.*, 2005], are similarly prone to large earthquakes, as witnessed by the occurrence of M 8 earthquakes in 1797, 1833, 1861, and the recent 28 March 2005 M_w = 8.7 Nias earthquake (Figure 1). These earthquakes released large amounts of accumulated strain on portions of the megathrust known to be highly locked based on coral morphology and geodetic data [*Simoes et al.*, 2004]. A recurrence interval of 230 years is estimated by *Sieh et al.* [2004] for the central Sunda trench. This suggests that the region south of the 28 March 2005 event is presently stressed highly enough to produce 1833-type events, and that the subduction interface may therefore be sensitive to small stress perturbations.

[3] Each earthquake alters the state of stress in its surroundings, and it is natural to investigate the stress changes associated with the 26 December 2004 and 28 March 2005 events in order to evaluate the potential for future earthquake triggering along the remaining Sumatra-Sunda megathrust [*McCloskey et al.*, 2005]. In the context of Coulomb failure stress theory [*Harris*, 1998; *Stein*, 1999], *Nalbant et al.* [2005] suggest that coseismic and postseismic stress changes from the 26 December 2004 event acted to trigger the 28 March 2005 event with an estimated Coulomb failure stress (CFS) change of ~0.1 bar. *Nalbant et al.* [2005] note that the compounded stress changes from the 26 December 2004 and 28 March 2005 events should increase CFS along much of the Sunda trench south of the equator (roughly the southern termination of the March 2005 event). Here we investigate this issue in greater detail by employing fault models of the 26 December 2004 and 28 March 2005 events [*Banerjee et al.*, 2005; P. Banerjee et al., Coseismic slip distributions of the 26 December 2004 Sumatra-Andaman earthquake and 28 March 2005 Nias earthquake from GPS static offsets, submitted to *Bulletin of Seismological Society of America*, 2005, hereinafter referred to as Banerjee et al., submitted manuscript, 2005] derived from the final static displacement field, combined with postseismic relaxation of the asthenosphere on a self-gravitating, compressible Earth model (F. F. Pollitz et al., Postseismic relaxation following the great 2004 Sumatra-Andaman earthquake on a compressible self-gravitating Earth, submitted to *Geophysical Journal International*, 2005, hereinafter referred to as Pollitz et al., submitted manuscript, 2005). We find that predicted CFS from these perturbations will increase by >0.1 bar over much of the Sunda trench in the coming years, raising seismic hazards along certain portions which likely already have a substantial amount of accumulated stress.

2. Time-Dependent Coseismic and Postseismic Deformation

[4] The time-dependent perturbation to the regional displacement and stress fields depends on source models of the earthquakes and a rheological model of the regional crust and mantle. Slip models of the 26 December 2004 event based on seismic wave analysis at periods 2000 sec [*Ammon et al.*, 2005] underpredict observed static GPS offsets because they capture some, but not all, of the large slip known to have occurred on the Andaman segment [*Bilham et al.*, 2005; *Jade et al.*, 2005]. We use the slip

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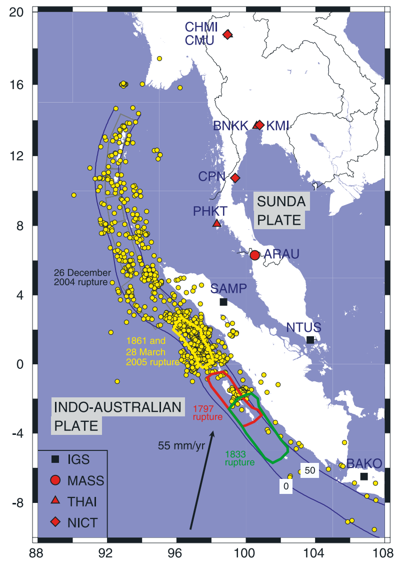

Figure 1. Rupture areas associated with known megathrust earthquakes along the Sumatra-Sunda trench. Gray planes are the coseismic rupture of the 26 December 2004 earthquake from Model M3 of *Banerjee et al.* [2005]. Indicated are the 0 and 50 km slab depth contours of *Gudmundsson and Sambridge* [1998]. Epicenters of $M \geq 4.0$ earthquakes from 29 March 2005 to 1 August 2005 from the NEIC catalog are superimposed. Selected GPS sites from four regional networks are indicated.

model M3 of *Banerjee et al.* [2005] derived from the final static displacement field as measured by GPS; this model involves slip on each of 7 planes spanning the 1300-km-long rupture, with uniform slip on each plane. The 5-day postearthquake averages used in the analysis imply that the model captures all slippage out to ∼2.5 days after the earthquake.

[5] For the 28 March 2005 Nias earthquake we use the source model derived by Banerjee et al. (submitted manuscript, 2005) using 32 regional GPS sites. The fit obtained by the simple 5-plane model is excellent (Figure S1 in the auxiliary material[1]). This model, obtained with a dip of 15°, corresponds to magnitude $M_w = 8.66$.

[6] We use the rheology model for oceanic lithosphere and mantle presented by *Pollitz et al.* [1998], with elastic structure modified to follow the isotropic elastic structure of PREM [*Dziewonski and Anderson*, 1981]. This spherically-layered rheology model (Figure S2 in the auxiliary material) has a low-viscosity asthenosphere of viscosity $\eta_{asth} = 5 \times 10^{17}$ Pa s, with a 62-km thick elastic lithosphere above it and higher-viscosity mantle ($\eta_{UM} = 10^{20}$ Pa s) below it. Coseismic stresses are calculated in a spherical geometry using the method of *Pollitz* [1996]. Time-dependent postseismic relaxation is realized on a self-gravitating compressible Earth model (Pollitz et al., submitted manuscript, 2005).

[7] GPS data from several regional continuous sites (Figure 1) were processed with the GAMIT/GLOBK software package developed at MIT to produce time series of station coordinates in the ITRF-2000 reference frame. Resulting time-dependent displacements are shown with predicted displacements in Figure 2 and auxiliary Figure S3. The simple low-viscosity asthenosphere model with Maxwell rheology satisfactorily predicts the postseismic movements between the December 2004 and March 2005 events and after the March 2005 event. This explanation, however, is not unique. Pollitz et al. (submitted manuscript, 2005) explore a transient asthenosphere rheology, and *Hashimoto et al.* [2006] and *Subarya et al.* [2006] explore afterslip models for explaining the continuous GPS measurements. In this paper we assume that the low-viscosity asthenosphere model with Maxwell rheology is sufficient to predict at least the longer-term future stress changes in the region. Since afterslip and viscoelastic models are designed to explain the early postseismic evolution (∼first 3 months), they are expected to produce similar stress evolution at early times. At subsequent times, however, we expect that asthenosphere relaxation will dominate the stress evolution.

[1]Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2005gl024558.

3. Stress Changes

[8] We use a CFS function given by CFS = $\Delta\tau + \mu'\Delta\sigma_n$, which expresses CFS as a sum of the change in shear stress τ and the change in normal stress σ_n (here assumed positive tensile) weighted by an effective coefficient of friction μ'.

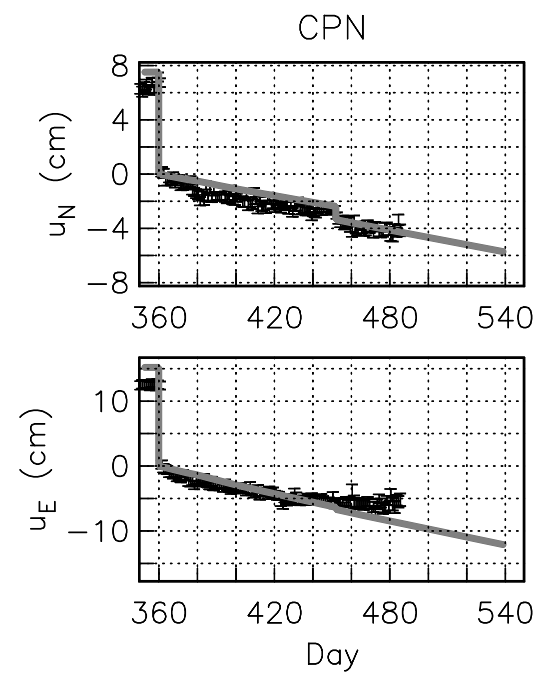

Figure 2. Observed GPS time series following the 26 December 2004 earthquake with 1-σ errors at continuous GPS site CPN (Figure 1). Additional time series are shown in Figure S3. u_E and u_N refer to east- and northward displacement, respectively. Day numbers refer to the year 2004. Superimposed are the predicted displacement curves that include the effects of coseismic and postseismic offsets due to the 26 December 2004 and 28 March 2005 Sumatra earthquakes.

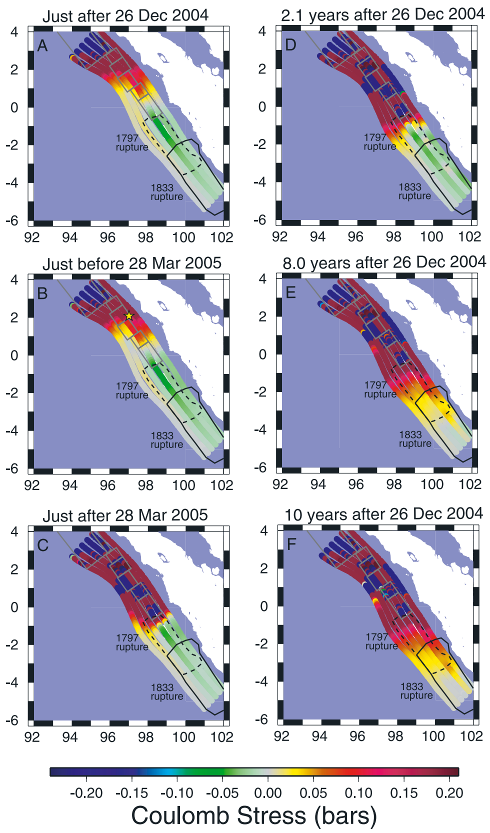

Figure 3. Snapshots of CFS changes from coseismic and postseismic deformation associated with the 26 December 2004 and 28 March 2005 earthquakes. Stresses are evaluated at positions which have been linearly interpolated between the 0 km and 50 km depth contours of *Gudmundsson and Sambridge* [1998]. The receiver fault geometry assumes pure reverse slip on the Sunda trench interface, which is locally approximated with 325°-striking, 15°-dipping planes. (a–c) Cumulative stress changes from just after the 26 December 2004 event to just after the 28 March 2005 event. (d–f) Cumulative stress changes from 2.1 years to 10 years after the 26 December 2004 event. Gray planes indicate the outlines of the fault planes of the 26 December 2004 and 28 March 2005 earthquakes. Yellow star is the epicenter of the 28 March 2005 earthquake.

Figure 3 shows snapshots of CFS on the Sunda trench interface assuming $\mu' = 0.4$. Results are similar for other values of μ' between 0 and 0.8. The receiver fault geometry is assumed to be 325°-striking, 15°-dipping planes with rake = 90°, i.e., pure reverse slip. Figures 3a and 3b show that coseismic deformation from the December 2004 event increased CFS by 0.25 bar near the nucleation zone of the March 2005 event at ~40 km depth (C. Ji, Updated result of the 05/03/28 (*Mw* 8.5) Sumatra earthquake, 2005, available at http://www.gps.caltech.edu/~jichen/Earthquake/2005/sumatra/sumatra.html) and downdip of the nucleation zone down to 50 km. CFS at the 28 March 2005 hypocenter by viscoelastic relaxation during the 0.25 years between the two events did not change (0.01 bar CFS change). The net 0.25 bar stress change at the 28 March 2005 hypocenter is similar to the 0.17 bar net stress change calculated by *Nalbant et al.* [2005], who noted the dependence of the coseismic stress change on the coseismic slip model being used.

[9] Figures 3d–3f shows that CFS continues to increase along the Sunda trench south of the equator for 10 years after the December 2004 event. At time 2.1 years (Figure 3d), postseismic CFS increases to ~0.1 bar around the shallow-depth, northern portion of the 1797 rupture zone. The locus of elevated postseismic CFS migrates southward with time, and by time 8.0 years most of the 1797 rupture zone has stress values of 0.05 to 0.20 bar, and much of the northern portion of the 1833 rupture zone has stress values between 0.05 and 0.10 bar. These values are of magnitude sufficient to potentially trigger large earthquakes in these regions based on stress to seismicity correlations obtained in many tectonic settings [*Stein*, 1999].

4. Discussion

[10] The stress patterns obtained are dependent on the assumption of lateral homogeneity of viscoelastic properties. This condition is not strictly satisfied given the large volume of downgoing slab beneath the Sunda plate which has an asymmetrical distribution around the plate boundary because of its shallow dip. The results obtained with the assumption of lateral homogeneity will be approximately valid if the downgoing slab were a passive feature that moves with the induced postseismic mantle flow. In more detailed studies of viscoelastic flow around a three-dimensional slab structure [e.g., *Cohen*, 1996; *Hu et al.*, 2004], the presence of an elastic slab can lead to substantial differences with a "slabless" viscoelastic structure.

[11] The effects of postseismic mantle flow on time-dependent stress on the slab interface are modest, but the induced stresses may help trigger aseismic slip, which would compound the stress increases from postseismic relaxation alone. Kinematic coupling along this and other subduction zones is commonly heterogeneous, and the stress changes from the viscous relaxation can change aseismic slip rates of the plate interface on "uncoupled" shallow segments, as well as on the sections below seismogenic depths. Aseismic slip on the slab interface downdip of major coseismic slip induced by the December 2004 rupture has been advanced by *Hashimoto et al.* [2006] and aseismic slip downdip of the coseismic rupture is likely the dominant mode of deformation after other recent subduction zone events [*Melbourne et al.*, 2002; *Yagi et al.*, 2003]. Aseismic slip may be plausibly induced not only along the downdip extension but also along the lateral extension of a megathrust event [*Miyazaki et al.*, 2004]. If applicable to the recent events on the Sumatra megathrust, the CFS patterns presented here could act to trigger aseismic slip within the 1797 and 1833 rupture zones. *Melbourne et al.* [2002] noted that at least deep aseismic slip following the M8.0 1995 Jalisco, Mexico (subduction) event could be sustained with a 0.2 bar stress increase. This is comparable with the ~0.1 to 0.2 bar net predicted stress increases 100s of km southeast of the December 2004 and March 2005 Sumatran events. Moreover, if the source regions of the 1797 and 1833 earthquakes were late in their respective seismic cycles, as suggested by the paleo-earthquake history of the region [*Sieh et al.*, 2004], then such a stress perturbation would represent a substantial

fraction of the stress necessary to return to the state(s) prior to the occurrence of these earthquakes.

[12] Another potentially important factor is dynamic triggering induced by the passage of seismic waves [*Freed*, 2005]. Its importance in the aftermath of the December 2004 and March 2005 events is suggested by the occurrence of numerous small events within the 1797 rupture zone within 3 months following the 28 March 2005 event (Figure 1). This region is not predicted to have had any substantial increase in CFS at such an early stage, but the effects of delayed dynamic triggering [*Parsons*, 2005] may play a role in generating this seismicity.

5. Conclusions

[13] Time-dependent stress along the Sunda trench interface is predicted to steadily increase over the next several years from the effects of the 26 December 2004 and 28 March 2005 earthquakes. Coseismic stress changes and postseismic stress changes driven by viscoelastic relaxation of the asthenosphere contribute to the stress changes. In the rupture areas of the 1797 and 1833 Sumatran earthquakes, coseismic stress changes are negligible, but postseismic stress changes amount to 0.1 to 0.2 bars within 8 years after December 2004. This perturbation may be substantial given that these rupture zones are likely late in their respective seismic cycles.

[14] **Acknowledgments.** We greatly appreciate data made available by BAKOSURTANAL (SAMP), IGS (BAKO, NTUS), the Department of Survey and Mapping Malaysia (MASS sites), Narong Hemmakorn at the King Monkut's Institute of Technology Ladkrabang, Thailand (CPN, KMI), Tharadol Komolmis, Chiang Mai University, Thailand (CHMI), Susumu Saito (NICT sites), and the Tectonics Observatory at Caltech, the Indonesian Institute of Sciences (LIPI) and Scripps Orbit and Permanent Array Center (SuGAr network). We also thank M. Hashizume for his efforts of establishing GPS monitoring stations in Thailand. We thank Thora Árnadóttir and Jeff Freymueller for helpful comments.

References

Ammon, C. J., et al. (2005), Rupture process of the 2004 Sumatra-Andaman earthquake, *Science*, *308*, 1133–1139.

Banerjee, P., F. Pollitz, and R. Bürgmann (2005), Size and duration of the great 2004 Sumatra-Andaman earthquake from far-field static offsets, *Science*, *308*, 1769–1772.

Bilham, R., E. R. Engdahl, N. Feldl, and S. P. Satyabala (2005), Partial and complete rupture of the Indo-Andaman plate boundary 1847–2004, *Seismol. Res. Lett.*, *76*, 299–311.

Cohen, S. C. (1996), Time-dependent uplift of the Kenai Peninsula and adjacent regions of south central Alaska since the 1964 Prince William Sound earthquake, *J. Geophys. Res.*, *101*, 8595–8604.

Dziewonski, A., and D. Anderson (1981), Preliminary reference Earth model, *Phys. Earth Planet. Inter.*, *25*, 297–356.

Freed, A. (2005), Earthquake triggering by static, dynamic, and postseismic stress transfer, *Annu. Rev. Earth Planet. Sci.*, *33*, 335–368.

Gudmundsson, O., and M. Sambridge (1998), A regionalized upper mantle (RUM) model, *J. Geophys. Res.*, *103*, 7121–7136.

Harris, R. (1998), Introduction to special section: Stress Triggers, Stress Shadows, and Implications for Seismic Hazard, *J. Geophys. Res.*, *103*, 24,347–24,358.

Hashimoto, M., N. Choosakul, M. Hashizume, S. Takemoto, H. Takiguchi, Y. Fukada, and K. Fujimori (2006), Crustal deformations associated with the great Sumatra-Andaman earthquake deduced from continuous GPS observation, *Earth Planets Space*, *58*(2), 127–139.

Hu, Y., K. Wang, and J. He (2004), Three-dimensional viscoelastic finite element model for postseismic deformation of the great 1960 Chile earthquake, *J. Geophys. Res.*, *109*, B12403, doi:10.1029/2004JB003163.

Jade, S., M. B. Ananda, P. D. Kumar, and S. Banerjee (2005), Co-seismic and post-seismic displacements in Andaman and Nicobar Islands from GPS measurements, *Curr. Sci.*, *88*, 1980–1984.

Lay, T., et al. (2005), The great Sumatra-Andaman earthquake of 26 December 2004, *Science*, *308*, 1127–1132.

McCloskey, J., S. S. Nalbant, and S. Steacy (2005), Indonesian earthquake: Earthquake risk from co-seismic stress, *Nature*, *434*, 291.

Melbourne, T. I., F. H. Webb, J. M. Stock, and C. Reigber (2002), Rapid postseismic transients in subduction zones from continuous GPS, *J. Geophys. Res.*, *107*(B10), 2241, doi:10.1029/2001JB000555.

Miyazaki, S., P. Segall, J. Fukuda, and T. Kato (2004), Space time distribution of afterslip following the 2003 Tokachi-oki earthquake: Implications for variations in fault zone frictional properties, *Geophys. Res. Lett.*, *31*, L06623, doi:10.1029/2003GL019410.

Nalbant, S. S., S. Steacy, K. Sieh, D. Natawidjaja, and J. McCloskey (2005), Earthquake risk on the Sunda trench, *Nature*, *435*, 756–757.

Parsons, T. (2005), A hypothesis for delayed dynamic earthquake triggering, *Geophys. Res. Lett.*, *32*, L04302, doi:10.1029/2004GL021811.

Pollitz, F. F. (1996), Coseismic deformation from earthquake faulting on a layered spherical Earth, *Geophys. J. Int.*, *125*, 1–14.

Pollitz, F. F., R. Bürgmann, and B. Romanowicz (1998), Viscosity of oceanic asthenosphere inferred from remote triggering of earthquakes, *Science*, *280*, 26,975–26,992.

Sieh, K., D. H. Natawidjaja, M. Chlieh, G. Galetzka, J.-P. Avouac, B. Suwargadi, and R. L. Edwards (2004), The giant subduction earthquakes of 1797 and 1833, west Sumatra: Characteristic couplets, uncharacteristic slip, *Eos Trans. AGU*, *85*(47), Fall Meet. Suppl., Abstract T12B-04.

Simoes, M., J.-P. Avouac, R. Cattin, and P. Henry (2004), The Sumatra subduction zone: A case for a locked fault zone extending into the mantle, *J. Geophys. Res.*, *109*, B10402, doi:10.1029/2003JB002958.

Stein, R. S. (1999), The role of stress transfer in earthquake occurrence, *Nature*, *402*, 605–609.

Subarya, C., M. Chlieh, L. Prawirodirdjo, J.-P. Avouac, Y. Bock, K. Sieh, A. Meltzner, D. Natawidjaja, and R. McCaffrey (2006), Plate-boundary deformation of the great Aceh-Andaman earthquake, *Nature*, in press.

Yagi, Y., M. Kikuchi, and T. Nishimura (2003), Co-seismic slip, post-seismic slip, and largest aftershock associated with the 1994 Sanriku-oki, Japan, earthquake, *Geophys. Res. Lett.*, *30*(22), 2177, doi:10.1029/2003GL018189.

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Auxiliary material for paper 2005GL024558

Stress changes along the Sunda trench following the 26 December 2004 Sumatra-Andaman and 28 March 2005 Nias earthquakes

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Introduction

This supplement contains information concerning the Earth structure used in viscoelastic modeling of the 26 December 2004 Sumatra-Andaman and 28 March 2005 Nias earthquakes, details of an independently derived coseismic slip model of the Nias earthquake, and GPS time series illustrating coseismic and postseismic motions of the 26 December 2004 earthquake. The coseismic slip model of the Nias earthquake is listed in Table S1 in terms of uniform slip parameters on five distinct planes. It was derived by Banerjee et al. (2005) using 32 GPS measurements of horizontal static offsets. Observed and modeled coseismic offsets are shown in Figure S1. The elastic Earth structure in Figure S2 follows the isotropic PREM model (Dziewonski and Anderson, 1981), and the viscoelastic stratification contains a number of layers including a low-viscosity asthenosphere following Pollitz et al. (1998). GPS time series from several regional sites (Figure S3) record the coseismic offset of the 26 December 2004 and 288 March 2005 events and rapid postseismic motions in the following months. These time series are approximated with a model of postseismic relaxation based on the coseismic slip model and the viscoelastic stratification of Figure S2.

1. 2005gl024558-fs01.eps Observed coseismic offsets of the 28 March 2005 Nias earthquake with 95% confidence ellipses (black arrows; Banerjee et al., 2005). Fault geometry and slip parameters are given in Table S1 Superimposed are the predicted static displacements on the PREM model (Dziewonski and Anderson, 1981) using a 5-plane slip model derived in Banerjee et al. (2005). Dark blue curves are the 0 and 50 km slab depth contours of Gudmundsson and Sambridge (1998).

2. 2005gl024558-fs02.eps Viscoelastic structure assumed in this study. Discontinuities are present at depth 220 km, 670 km, and 2891 km.

The viscosity of the asthenosphere is [eta_asth], and the upper mantle and lower mantle viscosity are [eta_UM] and [eta_LM], respectively. All viscoelastic layers are assumed to have a Maxwell rheology.

3. 2005gl024558-fs03.eps Left-hand panels: Observed GPS time series following the 26 December 2004 earthquake with 1-sigma errors at selected continuous GPS sites; site locations are shown in Figure 1 of the article. u_E and u_N refer to east- and northward displacement, respectively. Day numbers refer to the year 2004. Superimposed are the predicted displacement curves that include the effects of coseismic and postseismic offsets due to the 26 December 2004 and 28 March 2005 Sumatra earthquakes. Right-hand panels: Predicted time series extended out to 10 years beyond the 26 December 2004 earthquake.

4. 2005gl024558-ts01.txt Fault-plane and inverted-slip parameters of 28 March 2005 Nias earthquake.

References

Banerjee, P., F.F. Pollitz, and R. Burgmann, Coseismic slip distributions of the 26 December 2004 Sumatra-Andaman earthquake and 28 March 2005 Nias earthquake from GPS static offsets, Bull. Seismol. Soc. Am., in prep., 2005.

Dziewonski, A. and D. Anderson, Preliminary reference earth model, Phys. Earth Planet. Inter., 25, 297-356, 1981.

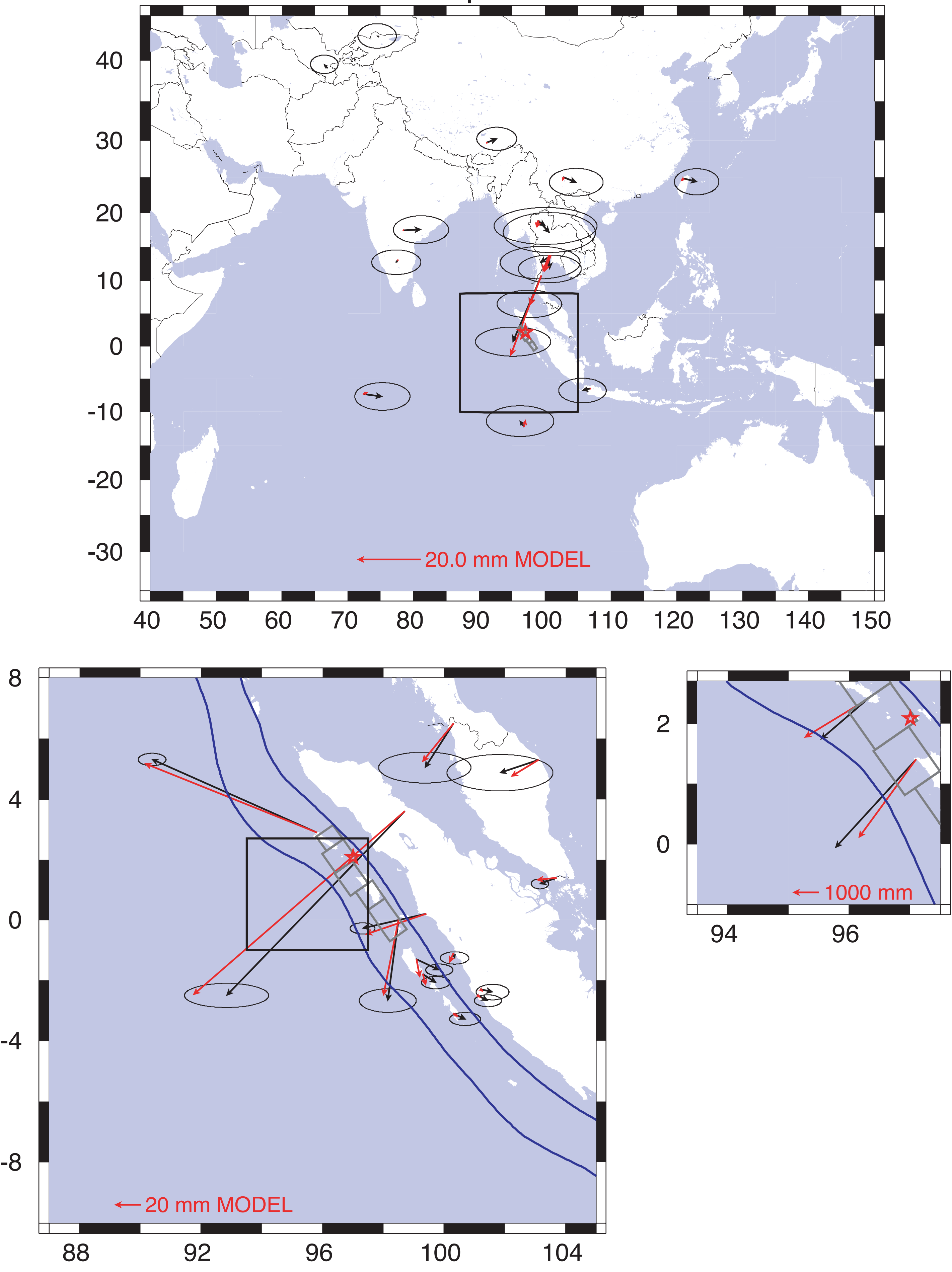
Gudmundsson, O., and M. Sambridge, A regionalized upper mantle (RUM) model, J. Geophys. Res., 103, 7121-7136, 1998.

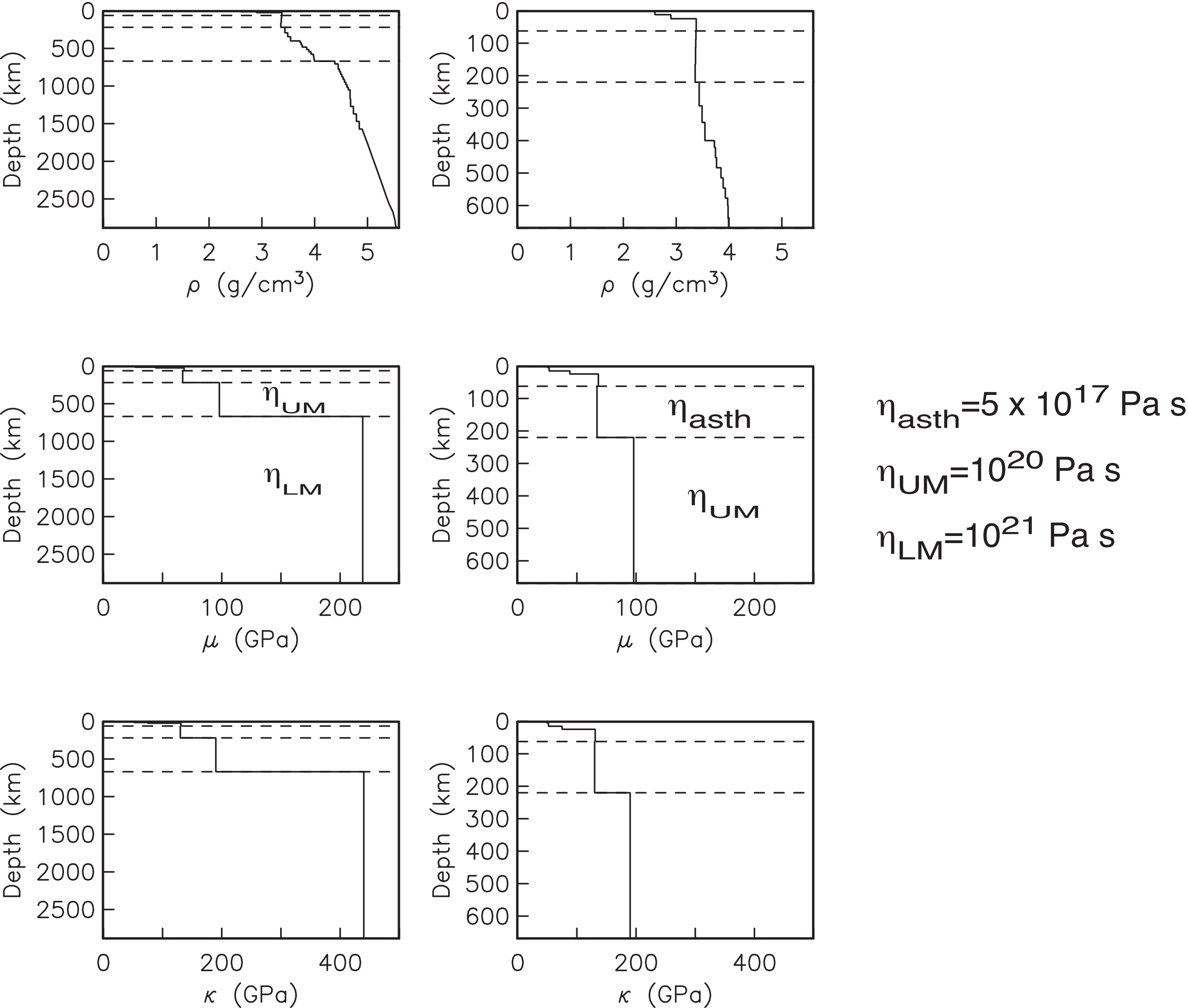
Pollitz, F.F., R. Burgmann, and R. Romanowicz, Viscosity of oceanic asthenosphere inferred from remote triggering of earthquakes, Science, 280, 26975-26992, 1998.

Segment	Lat,Long(1) (deg. N,E)	Lower Edge Depth (km)	Upper Edge Depth (km)	Length (km)	Width (km)	Strike(2)	Dip (deg.)	Slip (m)	Rake (deg.)
1	3.15N 96.34E	42	22	65	77.3	325	15	0.42	90.0
2	2.67N 96.68E	42	17	85	96.6	325	15	12.11	97.2
3	1.95N 96.98E	30	9	100	81.1	325	15	8.30	102.7
4	1.31N 97.63E	42	22	80	77.3	325	15	3.46	99.9
5	0.72N 98.05E	42	22	140	77.3	325	15	0.16	119.2

(1) Latitude and longitude of northernmost point on lower edge.
(2) Segment strike in degrees clockwise from due North.

28 March 2005 Nias Earthquake Coseismic Displacement Field





Depth (km)
ρ (g/cm^3)
μ (GPa)
κ (GPa)
η_{UM}
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η_{UM}=10^{20} Pa s
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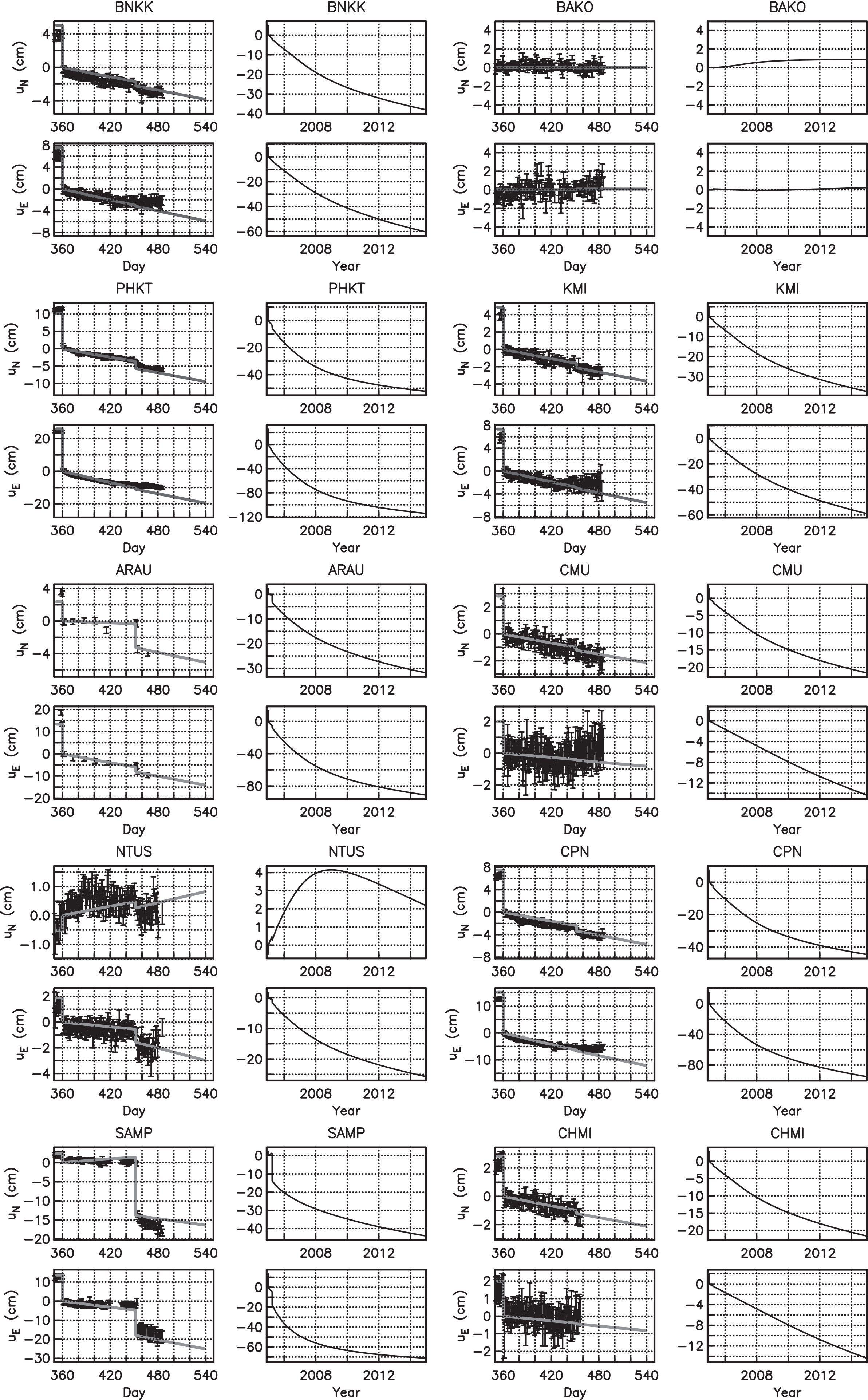
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u_N (cm)
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Day
Year
360
420
480
540
2008
2012