monitoring and predicting) and make publicly available data sets of NMs. NMDB has created a real-time NM database that holds data with 1-minute and 1-hour resolution. With this database, cosmic ray data have become available for use in a variety of applications, helping to improve space environment research and monitoring.

To reach this point, many of the contributing NM stations upgraded their software and hardware infrastructure and fully modernized their stations. In addition, applications were combined for the first time. For instance, for the 1-minute-resolution NM data, the previously mentioned Alert algorithm was combined with the NM-BANGLE model, which calculates important parameters of GLEs; their combination led to the MAGNETOCOSMICS and PLANETOCOSMICS codes, which calculate the atmosphere's ionization during a GLE event. In this way, the NMDB project offers an overall picture of the space environment and provides important information on the impact of dangerous solar emissions, based solely on NM data in real-time or quasi real-time mode.

In addition, the NMDB holds data sets from NM stations that cover a period of roughly 50 years, resulting in a reference database for NM and space applications. The most important characteristic of the NMDB, though, is its free usability—all of the data are publicly available through the Web site (http://www.nmdb.eu) for noncommercial use. Furthermore, many other applications have been implemented using the 1-hour-format data (e.g., galactic cosmic ray (GCR) anisotropy, daily and monthly GCR spectra, cosmic ray fluctuations, geomagnetic precursor monitoring).

At this point in the digital age, with the NMDB the worldwide neutron monitoring community has been able to secure 50 years of reliable NM measurements and to extend their use in state-of-the-art applications. Neutron monitoring stations and their worldwide networks are stepping into a new era.

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—Helen Mavromichalaki, Cosmic Ray Group, Physics Department, National and Kapodistrian University of Athens, Athens, Greece; E-mail: emavromi@phys.uoa.gr

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The 2010 Chile Earthquake: Rapid Assessments of Tsunami

PAGES 305–306

After an underwater earthquake occurs, rapid real-time assessment of earthquake parameters is important for emergency response related to infrastructure damage and, perhaps more exigently, for issuing warnings of the possibility of an impending tsunami. Since 2005, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) has worked on the rapid quantification of earthquake magnitude and tsunami potential, especially for the Mediterranean area. This work includes quantification of earthquake size from standard moment tensor inversion, quantification of earthquake size and tsunamigenic potential using *P* waveforms, and calculation of an archive of readily accessible tsunami scenarios.

For the case of tsunami early warning for coastlines at regional distances (>100 kilometers) from a tsunamigenic earthquake, notification is required within 15 minutes after the earthquake origin time (OT) so that coastal communities can be warned. Currently, rapid assessment of the tsunami potential of an earthquake relies mainly on initial estimates of the earthquake location; depth; and moment, M_0, or the corresponding moment magnitude, M_w.

Recently, *Lomax and Michelini* [2009a] introduced a duration-amplitude procedure for rapid determination of a moment magnitude, M_{wpd}, for large earthquakes using *P* wave recordings at teleseismic distances (30°–90° of distance along a great circle path). M_{wpd} can be obtained within 20 minutes or less after the event origin time, as the required data are currently available in near real time. The procedure determines apparent source durations (T_0) by extrapolating from high-frequency *P* wave records. T_0 is an indication of the time the entire fault took to rupture. The method then estimates magnitudes through integration of broadband displacement waveforms over the interval t_P to $t_P + T_0$, where t_P is the *P* arrival time. *Lomax and Michelini* [2009a] also show that any T_0 greater than about 50 seconds is a reliable indicator for tsunamigenic earthquakes.

This result was used to formulate a direct "duration exceedance" (DE) procedure applied to seismograms located between 10° and 30° of distance along the great circle path of an earthquake source. This helps to rapidly determine if T_0 for any given earthquake is likely to exceed 50–55 seconds and thus be a potentially tsunamigenic earthquake [*Lomax and Michelini*, 2009b].

Case Study: The 27 February 2010 M = 8.8 Chile Earthquake

INGV operates a continuous seismic monitoring center that uses a network of about 250 stations spread over Italian territories to monitor the nation's seismic hazards. A senior scientist is on call and will respond to earthquakes greater than magnitude 4 in Italy and greater than magnitude 6.5 worldwide.

Alberto Michelini, coauthor of this brief report, was on duty in the seismic center as senior scientist at the time of the 27 February 2010 M_w 8.8 Chile earthquake, which was sourced south of Santiago, along the coast. He was able to rapidly assess DE and M_{wpd} through procedures newly established at INGV.

On the morning of 27 February 2010, minutes after the origin time of the Chile earthquake, the senior scientist received the alarm. The display for the real-time DE at INGV (Figure 1; http://s3.rm.ingv.it/warning/warning.html) showed clearly that (1) the event was offshore along a major subduction zone and (2) the DE level was around 3; that is, the rupture duration was very likely greater than 50 seconds, and thus the earthquake was probably tsunamigenic, according to *Lomax and Michelini* [2009b]. This high level of warning was further supported at OT + 16 minutes by M_{wpd} magnitude calculations automatically determined at INGV. These calculations showed that the M_{wpd} was likely 8.8 if the event was a shallow, interplate thrust earthquake, which was likely given the event epicenter. If the earthquake was of a type different than a shallow interplate thrust, the M_{wpd} was likely 8.3 (see *Lomax and Michelini* [2009a] for details on the magnitude calculation). Regardless, it was clear that the M_{wpd} was high, indicating that the earthquake was likely tsunamigenic.

Toward Quicker Detection

Currently, the M_{wpd} calculation is initiated when INGV receives notification from an external agency that a major earthquake has occurred. Thus, time between the initiation of rupture and the conclusion of the M_{wpd} calculation could be reduced to between OT + 8 and OT + 12 minutes using an internal notification procedure.

The great size and likely tsunamigenic nature of this event were thus evident at INGV within 10–15 minutes after the earthquake OT. This additional information complemented the $M = 8.3$ magnitude and tsunami warning for Chile and Peru issued by the Pacific Tsunami Warning Center at OT + 12 minutes, and further confirmation of a tsunami's likely impact was given by the

U.S. Geological Survey's W-phase inversion magnitude M_{ww} = 8.7 at OT + 48 minutes.

Indeed, a tsunami did result. Though its impact in Chile is not yet well quantified, large tsunami waves occurred along the Chilean coast (i.e., from a few tens of centimeters to more than 10 meters [*National Geophysical Data Center* (*NGDC*), 2010]) and in the facing Juan Fernández Islands (~5 meters). Tsunami wave heights were generally nondamaging (<1 meter) on coastlines across the Pacific [*NGDC*, 2010]. The moderate trans-Pacific wave height was likely due to the location of the fault rupture under and across the Chilean shoreline, resulting in excitation of only the western lobe of the tsunami source (see Phased Array type L-band Synthetic Aperture Radar (PALSAR) scanning synthetic aperture radar (ScanSAR) interferometry published on the Chile Event Supersite Web site; http://supersites.unavco.org/chile.php), and to the shallow bathymetry off Chile (http://news.nationalgeographic.com/news/2010/02/100228-earthquake-in-chile-2010-tsunamis-hawaii-japan/).

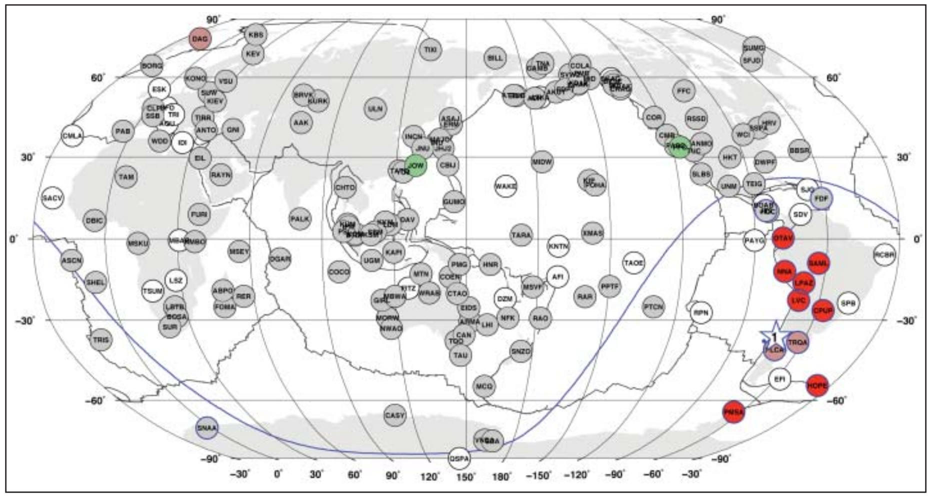

Fig. 1. Snapshot of the duration exceedance (DE) real-time display at Istituto Nazionale di Geofisica e Vulcanologia at about 10 minutes after the origin time of the 27 February 2010 M_w *8.8 earthquake off the coast of Chile. The star indicates the earthquake location, and circles indicate worldwide seismic recording stations and their shorthand identification codes. Circles outlined in blue have recorded the* P *wave; red and pink solid circles are stations where apparent source duration (*T_0*) is greater than 50 seconds; green shows those with* T_0 *less than 50 seconds; and gray or white indicates stations that were not used or did not yet record ground motion. The blue curve shows the position on the globe of the* P *wavefront from the earthquake at the time of the snapshot (i.e., 10 minutes after the event time). See an animation depicting the DE monitoring at http://s3.rm.ingv.it/D-E_data/20100227_061000/movie.mpeg. Original color image appears at the back of this volume.*

At the present time, INGV scientists are working on assessing tsunami potential by combining T_0 with a measure of the dominant period of the *P* wavefield on velocity records, T_d (http://alomax.net/posters/period-duration). This period duration procedure gives improved identification of recent earthquakes that are likely to produce large or devastating tsunamis and will complement the use of the M_w, teleseismic T_0, or DE discriminants.

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—Alberto Michelini, Valentino Lauciani, and Giulio Selvaggi, INGV, Rome, Italy; E-mail: alberto.michelini@ingv.it; and Anthony Lomax, ALomax Scientific, Mouans-Sartoux, France