Min Chen (1978-2021)

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Min Chen, an impassioned and talented computational seismologist, passed away unexpectedly on Sunday July 18th, 2021, at the age of 42.

Born in Lujiang, Anhui, China, Min received her B.Sc. of Geophysics from University of Science and Technology of China (USTC, Class 9607) in 2001. She then started her graduate studies in the renowned Seismological Laboratory at California Institute of Technology (Caltech) where she was awarded the Beno Gutenberg Fellowship, and received her Ph.D. in 2008. Her first work compared the asymptotic formulations for the directional dependence of surface waves and body waves in weakly anisotropic media, and applied *spectral-element* (SEM) numerical simulations to show that asymptotic predictions are in good agreement for anisotropy below the 5% level (Chen & Tromp, 2007). Exhibiting excellent theoretical and computational skills, her work systematically assessed how the elastic parameters affect surface and body-wave propagation, and laid the foundation for the implementation of full 3D anisotropic models in open-source spectral-element codes for seismic wave propagation such as SPECFEM3D_GLOBE.

At Caltech, Min enjoyed the highly stimulating and collaborative environment of the Seismo Lab and was an active participant of the Coffee Hour in the Benioff Conference Room, where many projects were born. In collaboration with seismologists and geophysicists in the Lab, she engaged in various seismological problems, always ready to offer a new perspective through her numerical skills. One such work involved assessing 3D P-wave tomographic models for the Japan subduction zone through simulation of body wave propagation by finite-difference and SEM methods (Chen *et al.*, 2007). Through further waveform modelling work, she suggested the existence of a thin, elongated low-velocity zone (LVZ) atop the slab and extending down to a depth of 300 km, contributing to the increasing body of literature on LVZ observed atop slabs in subduction zones around the globe at the time. It also sowed seeds for her long-time interest in understanding the subduction zone processes through seismic imaging. In another study, she contributed to generating synthetics for 3D tomography models in order to improve trans-Pacific whole-mantle structures through waveform modelling (Liu *et al.*, 2011).

After a short stay as a Research Scientist at Caltech, Min left California in the summer of 2008, and drove across the country to start a postdoctoral fellowship at MIT. There, she engaged in utilizing a novel *full waveform inversion* (FWI) approach adapted to earthquake data (also known as *adjoint tomography*) which had just been successfully applied to image the southern California crust with significant contribution from Min (Maggi *et al.*, 2009). Specifically, she was the first person to use the adjoint tomographic methods to image structures beneath a regional array of stations based on the Empirical Green's Functions (EGFs) extracted from ambient-noise seismic data. With a relatively small array of 26 stations deployed at southeastern Tibet, Min demonstrated the resolving power and future potential of this nascent technique when applied to EGFs (Chen *et al.*, 2014).

In 2011, Min moved to Rice University, first as a Postdoc and then as a Research Scientist, this time for an ambitious project of applying adjoint tomography to a larger scale problem: imaging the crust and upper mantle of East Asia, taking advantage of both the growing number of broadband deployments throughout East Asia and the advances in high-performance computing. In collaboration with several scientists, including researchers from her native country of China, Min presented an impressive 3D radially anisotropic model (*EARA2014*) of the crust and mantle beneath East Asia down to 900 km depth, utilizing a data set of 1.7 million frequency-dependent travel time measurements from waveforms of 227 earthquakes recorded by 1869 stations; the project consumed about 8 million central processing unit (CPU) hours on supercomputers hosted by the Texas Advanced Computing Center (Chen *et al.*, 2015a). This resulting model achieved unprecedented resolution and was the first tomographic model of the region based on full waveform simulations. Many structures in *EARA2014* serve to directly answer important tectonic and geological questions. For example, this model provided high-resolution images for structures beneath the enigmatic Hangai Dome in central Mongolia. Min observed low velocities, high ratios of *P* over *S* velocities, and positive radial anisotropy over a broad region in the uppermost mantle beneath the Hangai Dome, which may suggest partial melting and horizontal melt transport. She also discovered a deep low shear velocity conduit linked to the broader uppermost mantle low-velocity region, and interpreted it as slightly warmer upwelling from the transition zone (Chen *et al.*, 2015b).

Min also explored the *EARA2014* model to understand the interaction between the India plate and the Eurasia plate, and the uplift of the Tibetan Plateau. She observed a high wave speed structure in the lower part of the upper mantle beneath South-Central Tibet, and interpreted it as an upper-mantle remnant from earlier lithospheric foundering which induces an asthenospheric drag force and drives continued underthrusting of the Indian continental lithosphere as well as the shortening and thickening of the Northern Tibetan lithosphere. The Southern Tibet also possesses a high velocity keel with an *S*-wave speed comparable to that beneath the North American craton, suggesting that the plateau is likely to evolve into a craton due to continued under-accretion of the Indian continent (Chen *et al.*, 2017).

Min also applied adjoint tomography to image the crustal and upper mantle structures beneath Northeast China using Rayleigh wave EGFs computed from ambient noise data recorded by a large broadband array in the area (NECESSArray). The seismic images unveiled low wavespeed conduits in the mid-lower crust and uppermost mantle with a wavespeed reduction indicative of partial melting beneath the Halaha, Xilinhot-Abaga, and Jingpohu volcanic complexes, suggesting that Cenozoic intraplate volcanism in the area has a deep origin (Liu *et al.*, 2017)

In August 2017, Min joined Michigan State University (MSU) as an assistant professor, jointly appointed by the Department of Computational Mathematics, Science and Engineering and the Department of Earth and Environmental Sciences, and started on the ambitious task of building a vibrant and energetic research group. Having a unique position to interface seismology with computational sciences, she strove to build an interdisciplinary and transdisciplinary framework to gain deep insight into plate tectonic processes through high-resolution seismic images, facilitated by the advanced computational modeling and data science methods, and accelerated by graphical processing units (GPUs) and other advanced hardware, while pursuing the broader goal of finding creative solutions to the most challenging energy, resource, environmental, and medical problems.

At MSU, Min continued to explore the *EARA2014* model, and this time worked on using the improved seismic images in the Japan, Kuril, and Izu-Bonin subduction zones to clarify the spatial relationships between the source properties of intermediate-to-deep focus earthquakes and the internal structures of subducting slabs. She observed double seismic zones located within the top 60 km of the subducting Pacific Plate which suggests that the water released from dehydration processes likely raises pore-fluid pressure and facilitates the triggering of slab mantle earthquakes. These observations provided a new set of fundamental constraints to evaluate the viability of proposed triggering mechanisms of deep earthquakes (Chen *et al.*, 2019). She also worked with collaborators to determine the centroid locations of 2015 Mw 7.9 Bonin Islands deep-focus earthquake and its aftershock sequence, and presented the first reported earthquakes that initiate in the lower mantle (Kiser *et al.*, 2021).

In early 2020, she received the prestigious National Science Foundation CAREER award to conduct a five-year project entitled "Modification of a Continent: Seismic Tomography and Imaging of the North American Lithosphere". The project aims at improving the image resolution of the lithosphere of the North American continent from the surface to its root using large seismic datasets and adjoint tomographic methods, and contributing to the understanding of how the North American continent is built, modified, and destroyed.

Min generously imparted her expertise on adjoint tomography to her students and postdocs, and collaborated with them and other scientists to apply the novel imaging technique around the globe, including North American Craton, East African Rift System, Cascadia subduction zone, Yellowstone magmatic system, and the wider region of East Asia continent and western Pacific subduction zone. She also encouraged her students and postdocs to apply complementary imaging techniques to improve the understanding of dynamics processes in the subduction zone and the mantle. For example, in a recent work, her postdoc Jiaqi Li provided constraints to the slab structures and 410 discontinuity in the Kuril subduction zone based on triplication waveforms (Li *et al.*, 2021a; Li *et al.*, 2021b), and compared them to the structures from model *FWEA18* (Tao *et al.*, 2018) which was a recent full-waveform model using *EARA2014* as the initial model. Her group also has several nearly finished research projects. For example, with chosen ray paths parallel to the strike direction of the slab, Jiaqi and Min revealed an ultra-low velocity zone (with at least 20% P-velocity reduction) inside the Kuril slab at around 410 km depth. Her graduate student Ziyi Xi has just finished the construction of a new-generation East Asia model, *EARA2021*, an update from *FWEA18* with more data and at higher frequency. Min just left too soon to see the related papers published and models shared through IRIS-DMC.

Min was an active participant and generous contributor to the wider scientific community. While still a graduate student in 2002, she participated as a Shipboard Scientist in the Pacific geophysical exploration cruise, RVIB N.B. Palmer, NBP0207, from Los Angeles, USA to Lyttleton, New Zealand. She served on the Science Steering Committee of Computational Infrastructure of Geodynamics (CIG) in 2020-2021. During the Pandemic (2020-2021), Min organized a series of virtual group meetings and the bi-weekly MSU special seminars with open invitations to researchers around the globe, with the hope of bringing researchers, many AGU members included, together during this very difficult time. In addition, Min organized the "Life Outside of Academic Work" speaker series, where she invited professionals to share their career experiences and technical skills with students and postdocs in the MSU community in order to enrich their working lives and help them explore potential career paths. She was also a strong advocate for improving diversity, equity, and inclusion in the geoscience community, and passionate about public outreach and education.

Min was known to be a social, warm, welcoming, adventurous, passionate, generous, creative and ingenious person among her collaborators, colleagues and friends. While she spent most of her time dedicated to research work and raising two daughters, her adventurous and inquiring spirit manifested itself in many hobbies, including salsa and tango dancing, skiing, cooking, gardening and travelling, as she often called herself a "life-juggler". She was known to be a formidable force in the soccer fields of USTC, Caltech, Rice, MSU, as well as at numerous meetings and workshops, including those by the Gordon Research Conference, Seismic wave Propagation and Imaging in Complex media: a European network (SPICE), and QUantitative estimation of Earth's seismic sources and STructure (QUEST).

Min is survived by her daughters, Vivian and Mia, and their father Gabriel Ceriotti; her parents Xingchang Chen and Jiacui Jiang and her sister, Beilei Chen.

In honor of Min, the Department of Earth and Environmental Sciences (EES) along with the Department of Computational Mathematics, Science, and Engineering (CMSE) and the College of Natural Science at MSU, have established an endowment, named *The Min Chen Graduate Award for Computational and Earth Sciences*, which serves to remember Min as a talented computational seismologist, advocate for students and diversity, and valued colleague. Her colleagues also organized two conference sessions at the 2021 Fall AGU meeting (S14B and S21C).

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Min Chen’s publications (in reverse time order)

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