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Validation of modeling the Tohoku 2011 tsunami and flooding

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(Courtesy of www.daydaypaint.com) photo impression of the devastating impact of the tsunami that followed the most severe earthquake in Japan in the spring of 2011, of which the epicenter was 130 kilometers off the east coast of the Oshika Peninsula of Tohoku near Sendai, with the hypocenter at a depth of approximately 30 km. The destructive tsunami waves of up to 10 meters reached Japan in less than 10 minutes after the quake, and travelled kilometers inland. The result: thousands dead, injured and missing, heavy damage to infrastructures like roads, railways, many power outages, fires, a dam collapse and the Fukushima nuclear reactors out of control.

Summary The 2011 Tohoku-Oki earthquake, which occurred on 11 March 2011 at 05:46:23 UTC off the Pacific coast of Honshu, Japan, generated a huge tsunami with disastrous consequences. The Earthquake Joint Survey Group reported that the tsunami reached up to 40m inland. We simulated this tsunami with an unstructured finite volume model (H2Ocean), with extensively tested accurate flooding algorithms. The initial uplift was computed from a large set of regional continuous GPS station data available from the International GNSS Service (IGS) before and after the earthquake. In a multi-disciplinary simultaneous approach also the slip has been estimated. It appeared that the combined vertical motion and horizontal motion of the ocean floor raised the water column by as much as 30m which led to the destructive tsunami. For the tsunami propagation two grids were generated: a Pacific wide grid (500 m to 10km resolution) and a local flooding grid with much higher resolution (80m) along the Japan coast. We ran the model with the Pacific wide mesh for 20 hours with a time step of 2s, to simulate the time evolution of the tsunami over the Pacific Ocean and to estimate the slip. The flooding simulation, with a finer mesh that has 3 million nodes, was only run for 2 hours and used a smaller time step, 0.1s. We compare the model results to seafloor pressure gauges (DART), satellite altimetry, tsunami inundation height and run-up data. Good agreement is found with both the pressure gauge and selected altimetry data. The model also gives accurate estimates of inundation height, however, under predicts the maximum run-up, likely due to the steep and narrow local coastal features, not available for our simulations, but increasing the run-up of tsunami.

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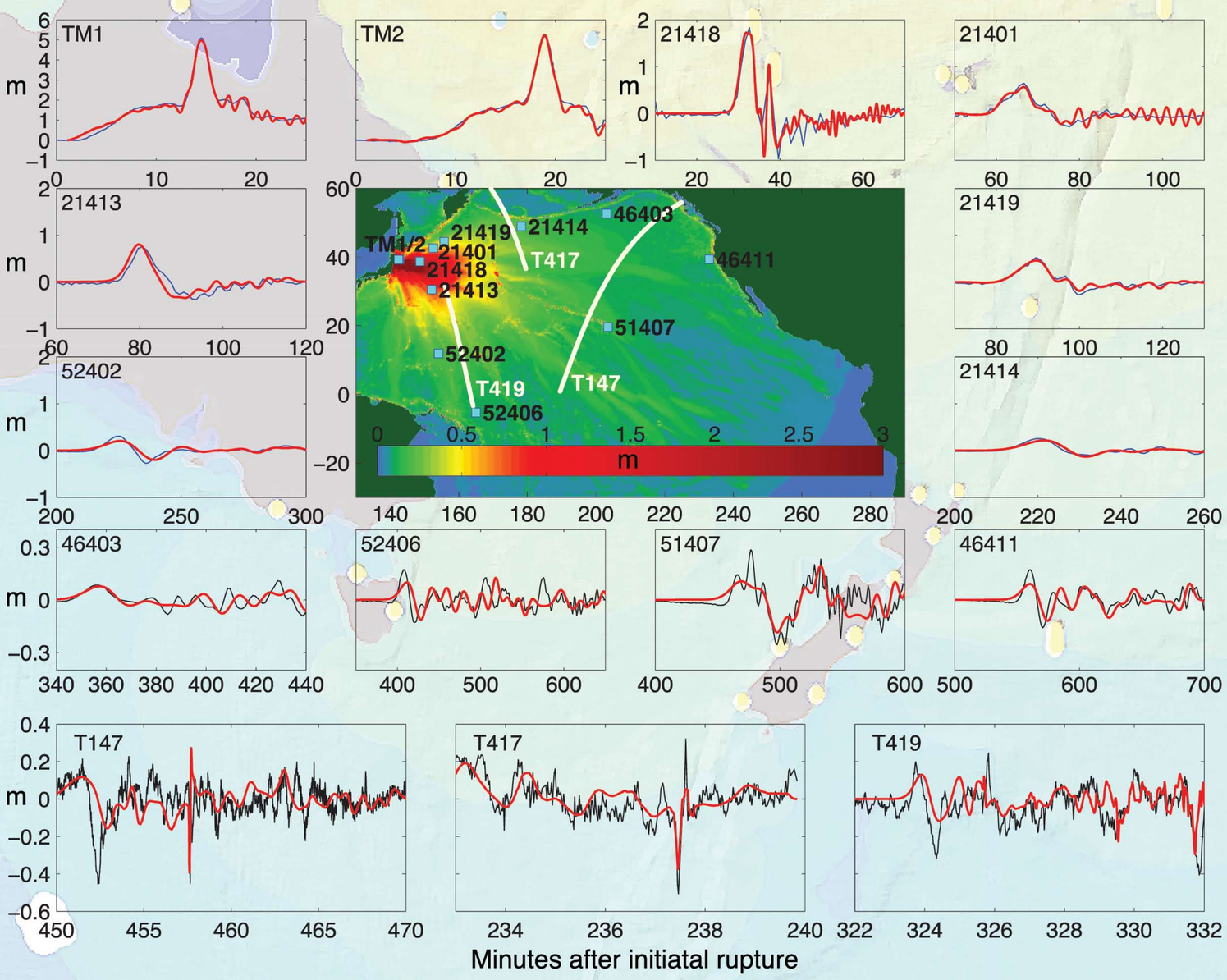
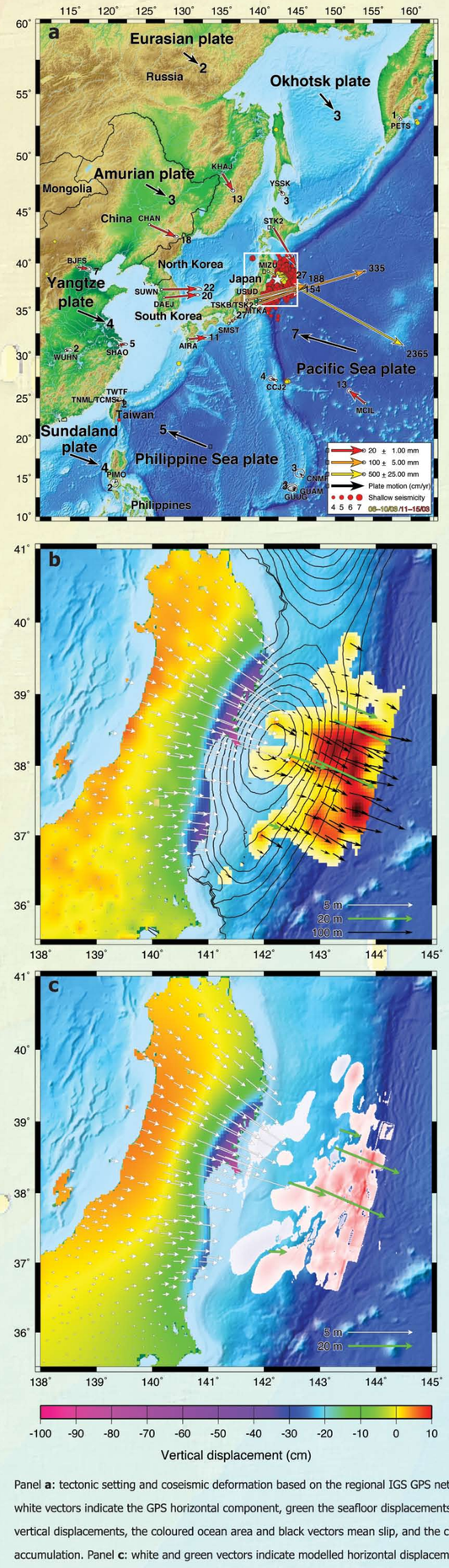
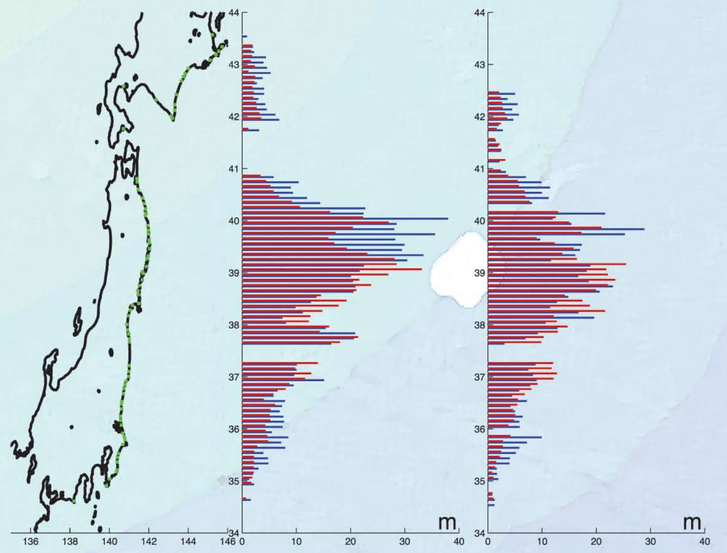


Open ocean tsunami heights. Centre panel shows the geographical distribution of the maximum modelled tsunami heights. The directly surrounding panels show evolution of tsunami height at seafloor pressure gauges (OBPG and DART). Measurements used in the inversion are in blue and those not used are in black. The modelled values are in red. The 3 bottom panels show the comparison of modelled tsunami height with sea level anomalies from altimetry from Jason-1 (T147) and Envisat (T417/T419), all of which were acquired running from south to north (see also centre panel) and referenced to a 30-day averaged mean sea surface centred around 24 February, two weeks prior to the quake.



Panel **a**: tectonic setting and coseismic deformation based on the regional IGS GPS network. Panel **b**: Northern Honshu, white vectors indicate the GPS horizontal component, green the seafloor displacements. Land colours represent GPS vertical displacements, the coloured ocean area and black vectors mean slip, and the contours the interseismic strain accumulation. Panel **c**: white and green vectors indicate modelled horizontal displacements, land colours modelled vertical displacements, and the coloured oean area the total sea surface height change.



Tsunami flooding results: left panel the measured locations, middle panel the tsunami inundation height and right panel the maximum run-up. Measurements are in blue and modeled values are in red.

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