T1.2-P21

Illuminating More of the Earth via Sensors on Transoceanic Telecommunications Cables

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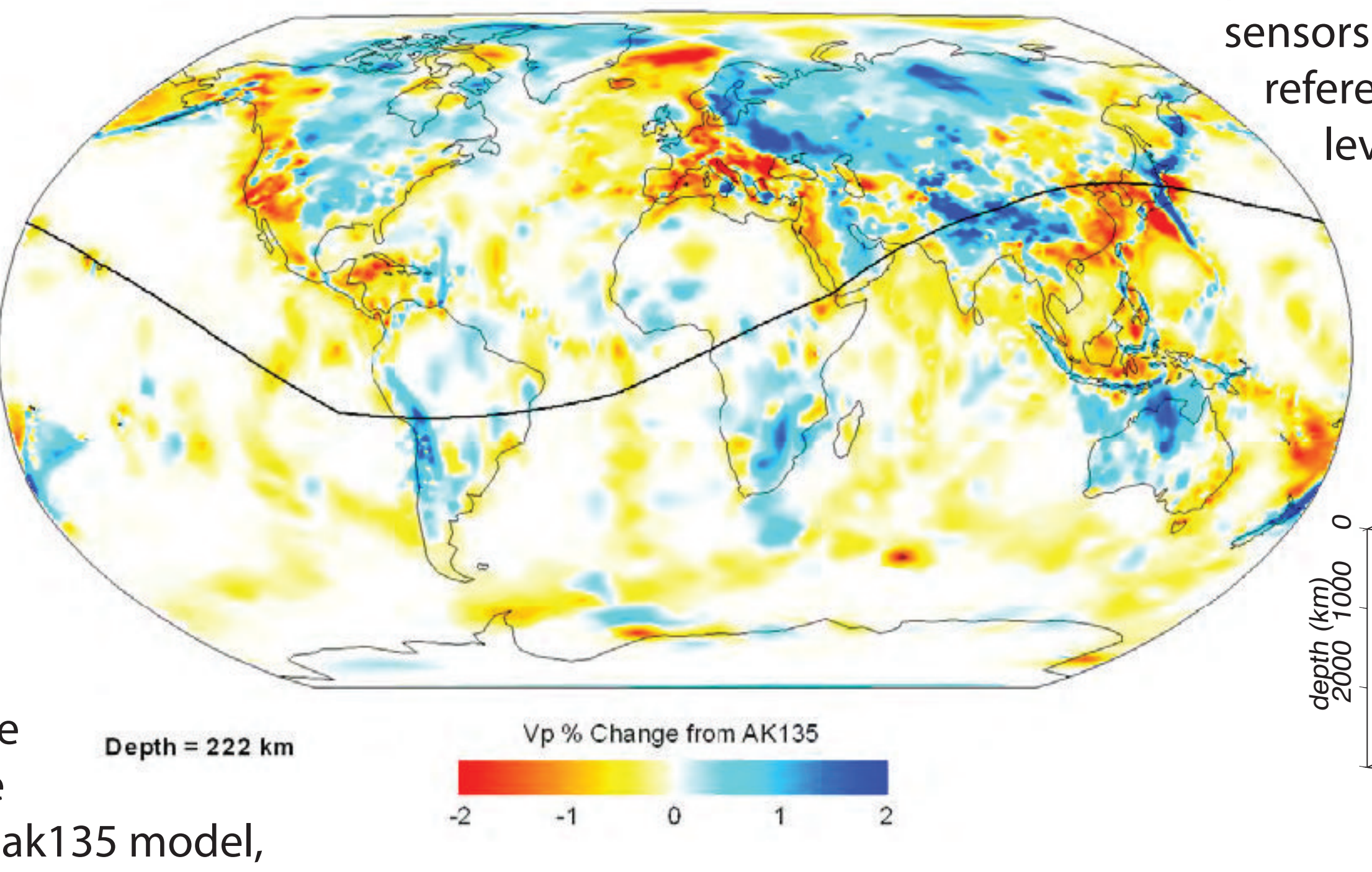
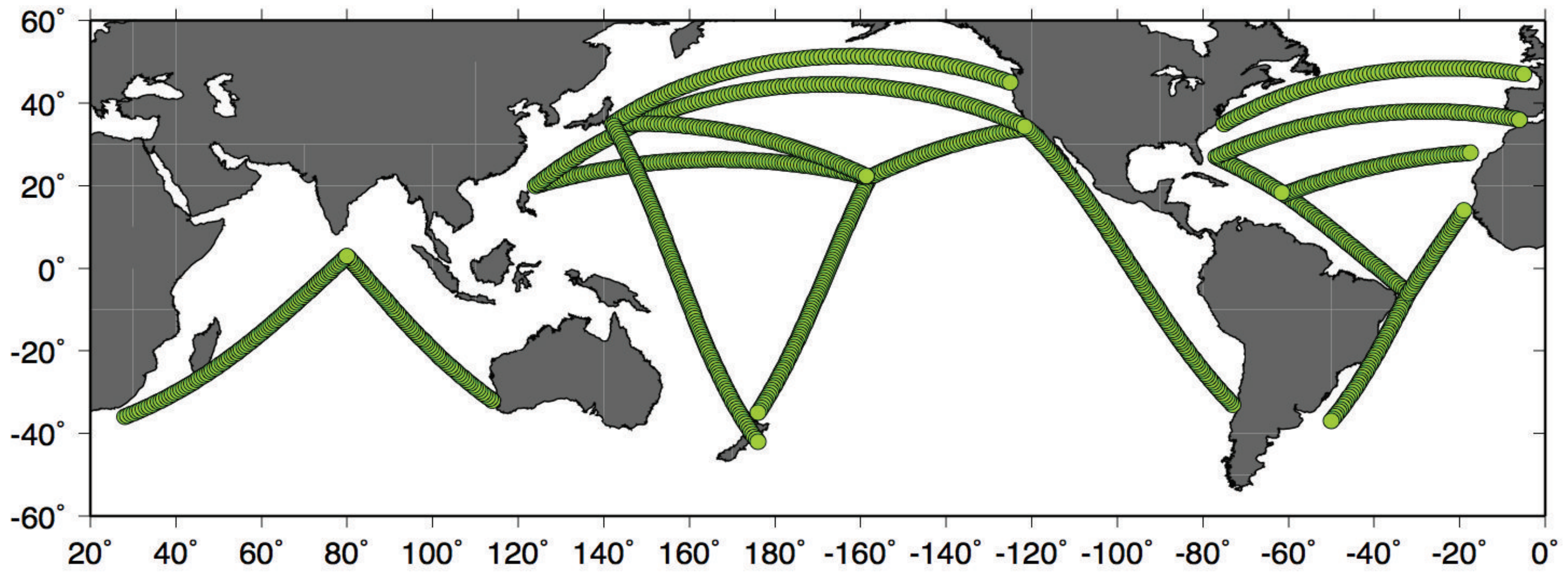
ABSTRACT

Our work is motivated by a partnership between the International Telecommunication Union (ITU), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO/IOC), and the World Meteorological Organization (WMO) that is working towards integration of seismic sensors into the next generation of trans-oceanic telecommunication cables. These Sensor Enabled Scientific Monitoring And Reliable Telecommunications (SMART) cable systems offer the potential to improve global geophysical models as well as reduce event detection thresholds and location uncertainties. We present a preliminary picture of the improvement to global seismic sampling through SMART cables and their sensors. We present results for forward ray tracing through ak135 for first-arriving P-waves for paths between 0 and 90 degree distances. We have selected earthquakes of magnitude 6 and larger, recorded by current and former seismic receivers around the globe. To reduce raypath redundancy and computational burden we have used only one source and one receiver per 1-degree by 100 km depth cell. Results are presented as a function of ray density, saturating at 100 rays per cell. We compare ray density obtained for current global seismic station distribution to that afforded by the addition of seismic sensors along the first generation of SMART cables.



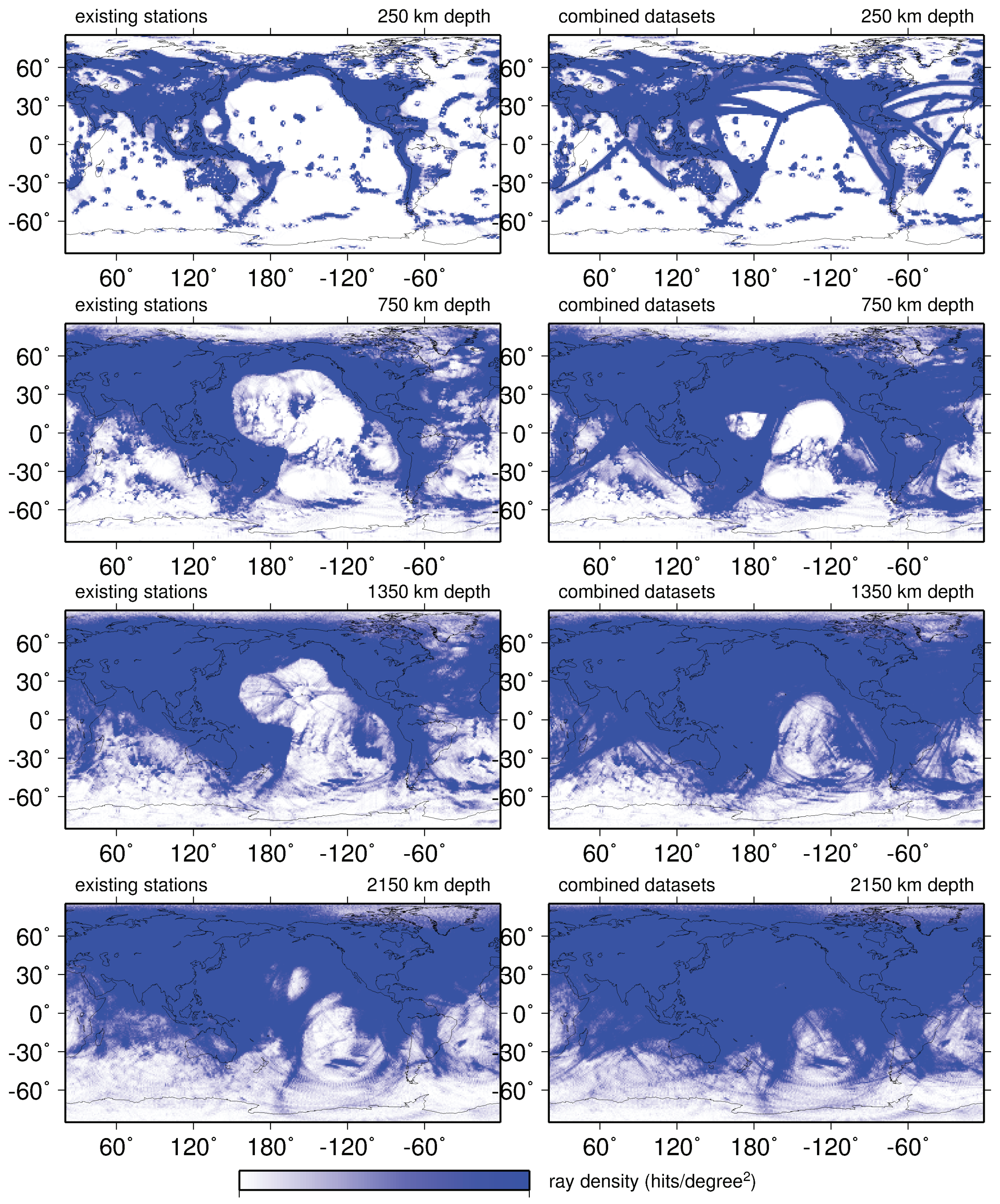
Motivating our analysis, we show a slice at 222 km depth from a Global 3D tomographic model (SALSA3D - Ballard et al., 2016), which was derived by inverting P-wave arrivals from a global earthquake catalog using all available stations. The map is color coded based on % change in P-wave velocity from the starting model, the 1-D ak135 reference model (Kennett et al.,1995). Note that in a tomographic inversion, only areas that are actually sampled by seismic rays will be adjusted during the inversion; if there are no data, the final model is unchanged from the starting model. Thus although there may be some parts of the Earth that are well represented by the ak135 model, most of the white space on this image is the result of lack of resolution (Ranasinghe et al., 2017).

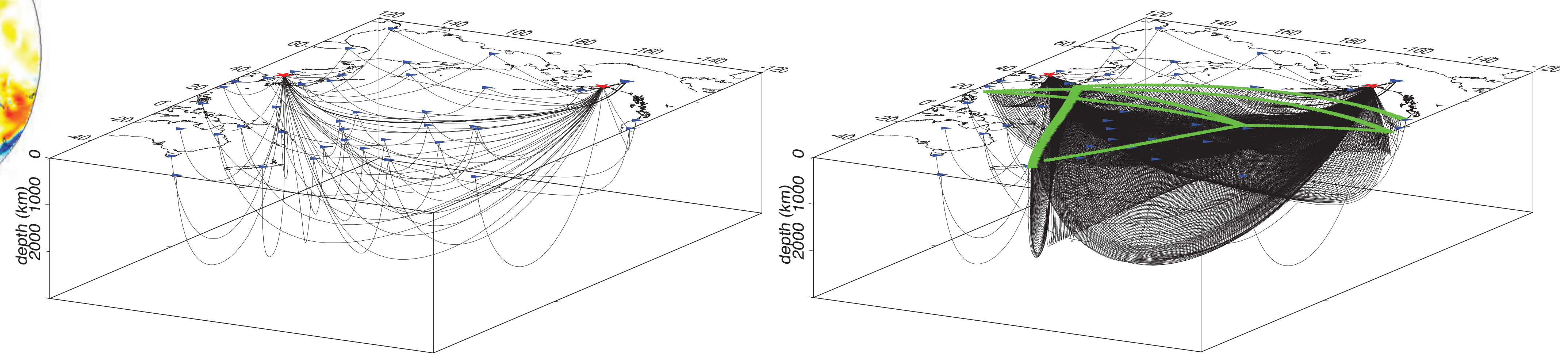


A cartoon, above, of the first anticipated generation of SMART cables populated by sensors every 75 km. We are comparing the P-wave coverage of the Earth for normal seismicity over a ten year period when the coverage afforded by existing (or former) stations is augmented by these lines of sensors across the oceans. Our ray tracing is only approximate, as we are relying on the ak135 reference model, rather than using a high-fidelity 3D model, and our rays are projected to sea level rather than the actual topography or bathymetry. Future work will include use of the SALSA3D model (left) for ray tracing as well as use of later phases.

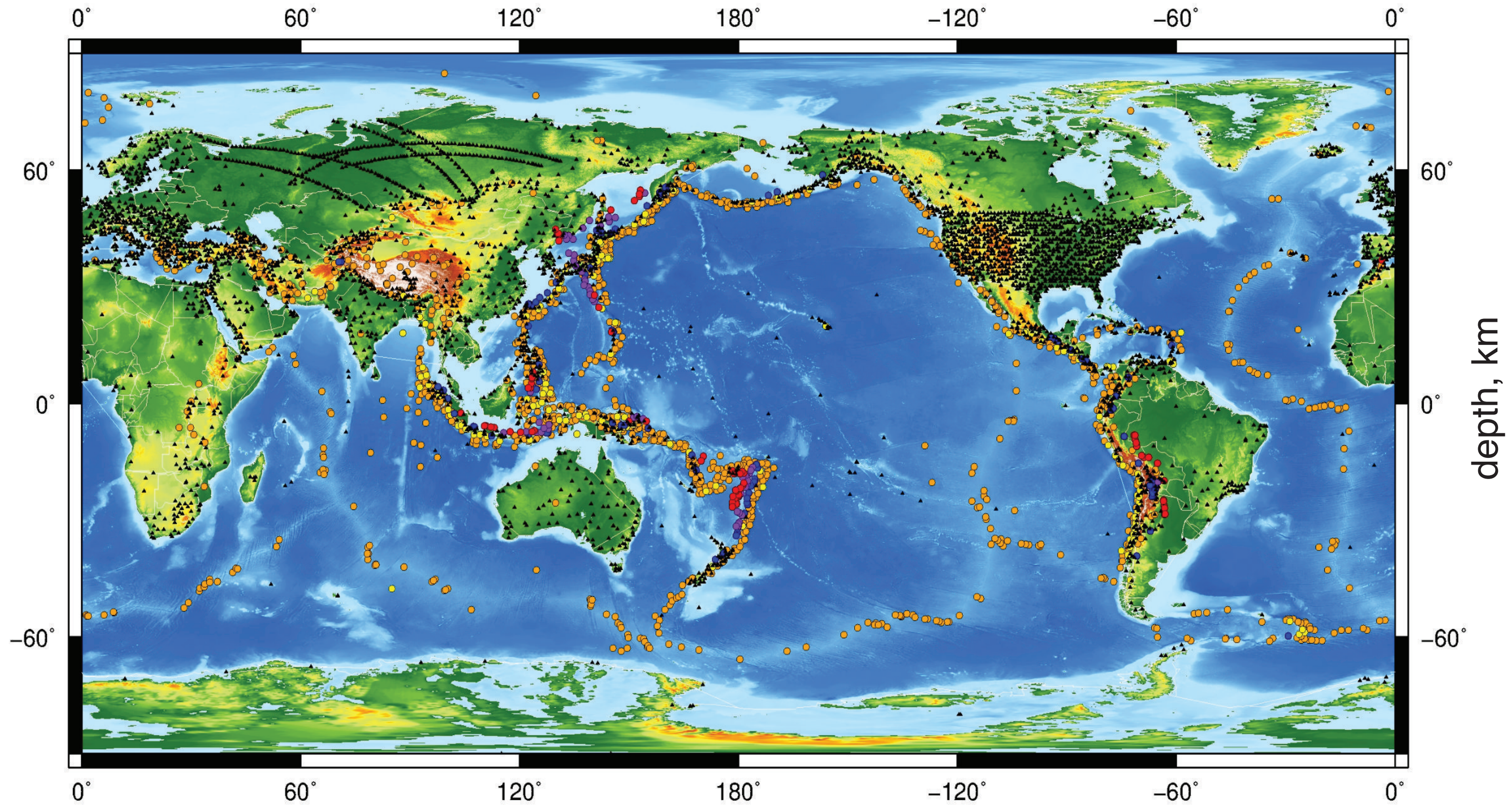
We show map views of the ray density for various depth slices, centered on the Pacific Ocean. Panels show P-wave coverage for existing stations (left), and existing plus the proposed SMART cables (right).

We observe with little surprise that at shallow depths, improvement is largely in the immediate vicinity of the cables, due to nearly vertical P-wave arrival. As we move deeper into the mantle, however, the more horizontal rays provide broader areas of increased coverage.

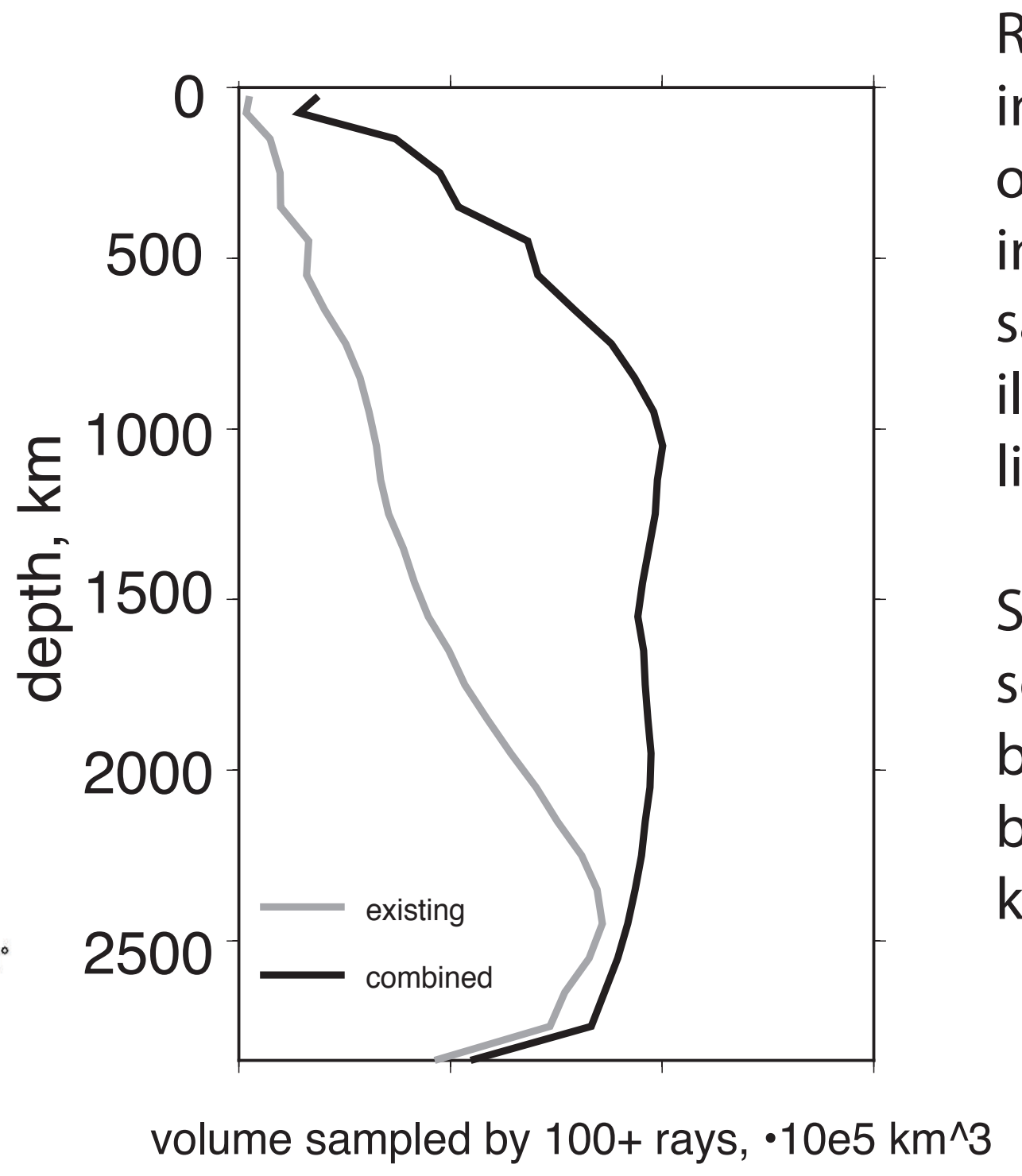




Above, we present two 3D perspective views of the Pacific basin. We illustrate the difference in ray coverage before, and after, addition of the SMART cables sensors. On the left we show projected rays from two seismic source locations of interest (Cook Inlet, Alaska, and the Korean Peninsula), traced through the ak135 model, to stations of the Global Seismological Network (GSN). On the right, we trace rays from the same two events to not only the GSN stations but also to receivers spaced 75 km apart along proposed SMART cables.

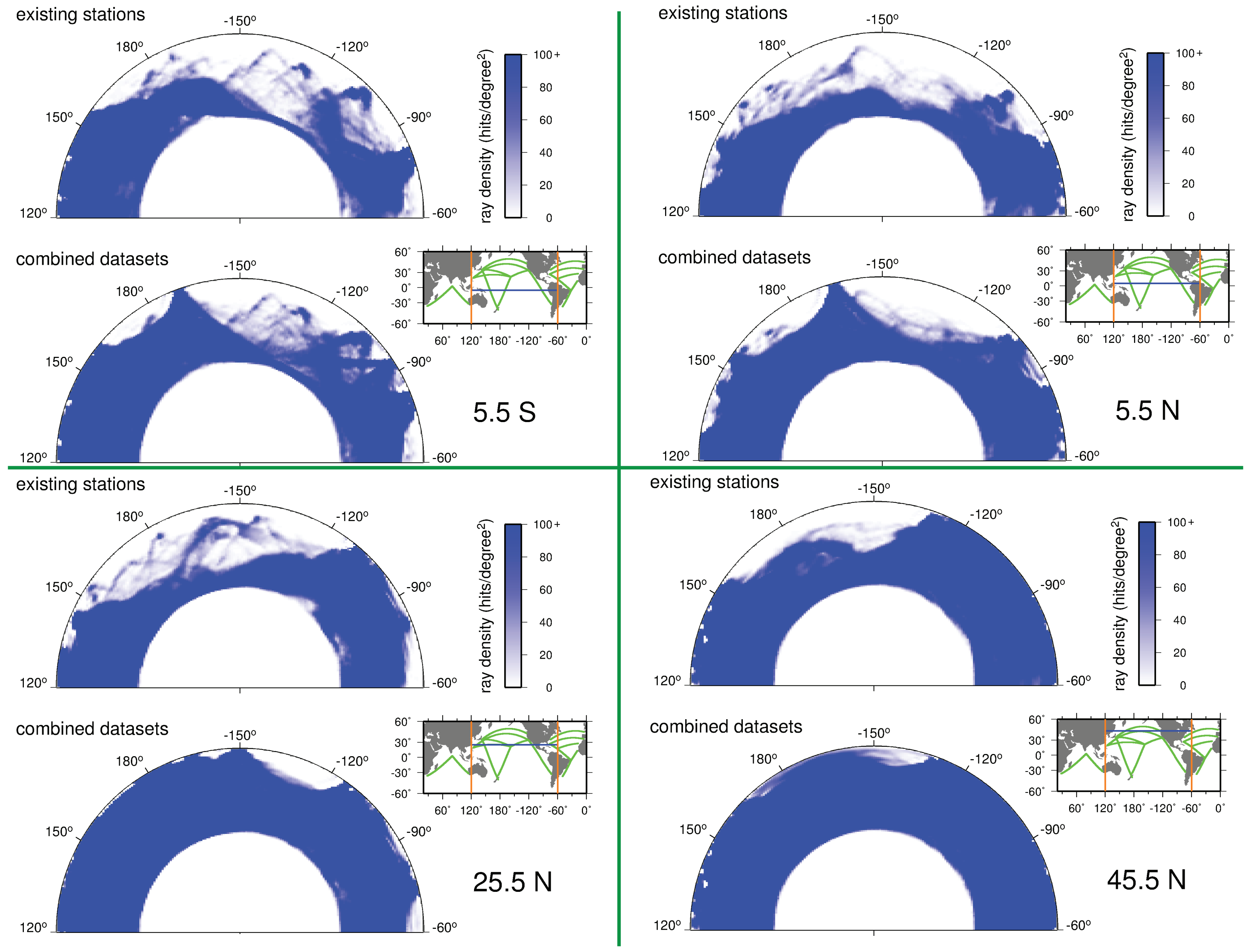


Earthquakes are unevenly distributed around the globe, as are seismic stations. The oceans in particular are vast regions where we lack sensors. Moreover, oceans are also largely aseismic, except at plate margins, leaving large gaps in our seismic sampling of the Earth. Shown above are 4421 existing or former seismic stations and 1681 M > 6 earthquakes unique to 1x1 degree bins. We choose a threshold of M > 6 so that for our modeling we can assume that all stations will see all the earthquakes; the one degree bin size was chosen to reduce raypath redundancy in this exercise. We use the ray tracing code, PCalc, developed at Sandia National Laboratories (Ballard et al,. 2009) to trace first-arriving P-waves through the ak135 reference model. Rays are saved as vectors of points in 3 dimensions. Following the ray tracing, we have collected the rays into bins of 1 degree square and roughly 100 km depth, and we examine the ray density as a function of location and depth. These ray densities are calculated both for the coverage based on existing, largely land-based stations, and then for the combination of these existing stations with hypothetical sensors from the first generation of proposed SMART cables.



Right: Selected cross-sections at various latitudes, illustrating the improvement in ray coverage for the Pacific Ocean with the added SMART cable sensors. Each of the four graphics shows in its top panel the coverage for existing stations, and in its lower panel the coverage when SMART cable sensors are added. Ray density saturates at 100 rays per 1 degree / 100 km bin. We show a map on each panel illustrating the latitude for the cross-section with a horizontal blue line, and the limits of the projection are shown with the vertical orange lines..

Shown at left is sampling without (gray line) and with (black line) SMART cable sensors for our test data set. Geographic area is focused on the Northern Pacific basin, where most of the modeled cables reside. We show Earth volume sampled by 100 P-wave rays for the test data set, as a function of depth. At a depth of 1000 km in this region we observe an increase of 318% in 100-ray volumetric sampling.



SUMMARY

We present results of seismic ray tracing through the Earth for naturally distributed earthquakes recorded by the existing networks, and compare this to the sampling expected for sensors distributed along the proposed suboceanic SMART cables. The improvement in seismic sampling is significant in areas for which we currently have little data. Additional benefits from SMART cables may include opportunities to improve event detection in areas of concern, improve our attenuation models for more robust yield estimates, and enhanced location confidence.

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