SCIENTIFIC MONITORING AND RELIALABLE TELECOMMUNICATIONS (SMART) CABLE SYSTEMS: INTEGRATION OF SENSORS INTO TELECOMMUNICATIONS REPEATERS FOR CLIMATE AND DISASTER MITIGATION

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Abstract: Ocean observing, especially of the deep ocean, remains difficult and costly. SMART cables can provide new data by integrating sensors into undersea telecommunications cables. As new cables are laid, they will carry oceanographic instruments down to the sea floor where they can provide unprecedented real time, high-resolution ocean science data.
Undersea cables stretch across the oceans and along coastlines and are replaced or expanded every 10-20 years. Cables employ "repeaters" to regenerate the fiber optic signal every 50-100 km, and each of these repeaters can host sensors. By riding on this existing power and communications infrastructure, SMART cable sensors offer the potential for near global coverage at a cost that is a fraction of single-purpose science-only systems. The initial plan to integrate bottom pressure, temperature, and acceleration sensors into future cables can cost-effectively create a cable-based global ocean sensor network within the 10-20-year refresh cycle.
SMART cables complement existing satellite, buoy, and other in-situ systems. Their data with excellent spatial and temporal sampling can improve models of ocean circulation, sea level rise, and mass. SMART cables would increase the existing small number of deep ocean tsunami pressure sensors from dozens to thousands, helping to reduce detection time, improve precision of tsunami warnings, and greatly reducing the potential of unnecessary warnings and evacuations. SMART cables have the benefit of improving ocean data by linking ocean and tsunami monitoring goals to economic infrastructure development.

1. THE SMART CABLES CONCEPT

Deploying oceanographic sensors on new undersea telecommunication cables is a promising technique for obtaining global-scale real-time data that are critical for understanding and managing urgent issues such as climate change and tsunami hazard mitigation. Suitable sensors exist, and dedicated cabled observatories using these sensors have proven the value of cable-based ocean observation.[1]

By investing in this technology, the oceanographic community can leverage the massive and ongoing private sector investment in submarine cables to realize globe-spanning SMART cable systems (Science Monitoring And Reliable Telecommunications) that deliver both telecommunications and ocean science data (Figure 1). A central feature of the SMART cables concept is that it brings together two key themes of the 21st century: the market-based demand for greater connectivity, and the urgent need for coherent, concerted global effort on climate change and ocean management.

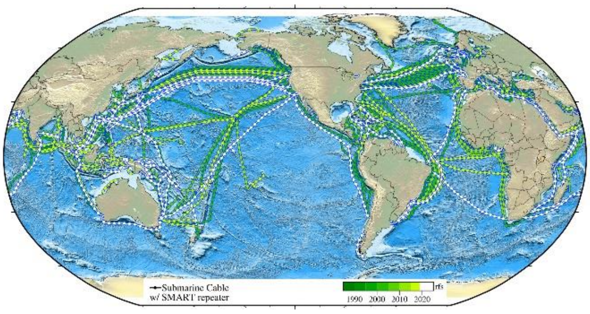

Figure 1. Current and planned cables span the oceans

More than 1Gm and 400 systems enable the global communications system. As they are replaced and expanded over their 10-25-year refresh cycle, pressure, temperature, acceleration sensors can be added to the cable repeaters every ~50-100 km, gradually achieving real time global coverage.

2. HOW SMART CABLES CAN IMPROVE OCEAN SCIENCE

Data from SMART cables would fill critical gaps in our existing in-situ and satellite monitoring systems, complementing existing observations and improving our modeling of its future evolution.

Ocean Temperature

Much of the deep oceans are warming, absorbing heat, and contributing to sea level rise. The Atlantic meridional overturning circulation (AMOC) is changing and those changes are associated with variations in ocean temperature, air-sea heat flux, and sea level, suggesting that this integrating, full-depth ocean circulation feature is important in modulating climate. SMART cables would provide real-time transoceanic sampling of temperature in the bottom boundary layer at roughly 50 km resolution, a much sampling than Deep Argo (approximately 500 km), or even sparser OceanSites moorings.[2-4] The temporal resolution is substantially better (seconds) than Deep Argo (10-15 day) or decadal repeats of GO-SHIP transoceanic hydrographic sections. [5]

Ocean Circulation, Sea Level Rise, and Mass Distribution

Ocean bottom pressure (OBP) measurements on cables spanning an entire ocean basin can measure the pressure differences at many depths between the boundaries of the basin. The pressure differences are directly related to the transports at those depths (Figure 3).

Further, multiple cross-basin transects by SMART cables would allow (coarse) spatial resolution. Geostrophic transports across box boundaries could then be estimated from OBP allowing the mass balance of individual boxes to be calculated. [6]

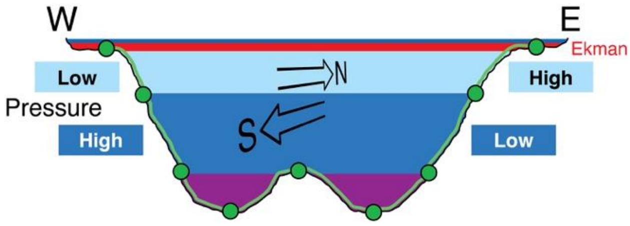

Figure 3. Pressure sensor-enable cables can span depths across the same basin.

As shown in Figure 3, water flows from high to low pressure, deflected by earth's rotation (green dots represent SMART pressure sensors).

Fraternal twin Observing System Simulation Experiments (OSSEs) shows that SMART cable data from a high-resolution regional ocean model can significantly improve coarse resolution global models (Figure 4).

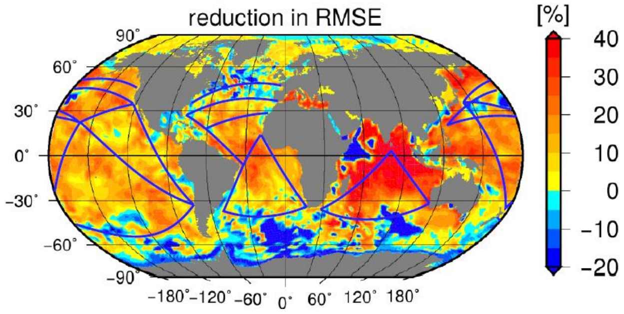

Figure 4. Simulation of model improvements based on data provided by possible SMART cables.

Figure 4 show the reduction of root-mean-square difference between OBP simulated by ROMS and MPIOM for April 2014. Blue lines indicate possible future SMART cable transects. [7]

The comparatively high-resolution ocean bottom pressure measurements from SMART cables, in conjunction with sea level observations by altimetry, or density field observations by Argo floats, would enable separation of the steric (expansion of water, e.g. due to warming) and barystatic (mass change e.g. due to melting land ice) contributions to sea level change at particular locations (Figure 5). This differentiation is required to understand the causes of sea level rise and thus for reliable sea level projections.

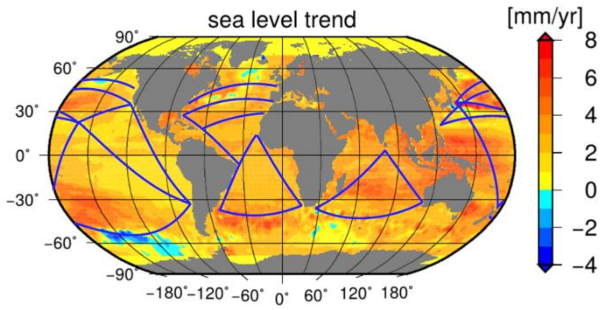

Figure 5. Cable routes run through areas of importance to sea level trends

Figure 5 shows the sea level trend in mm/year as derived from TOPEX, Jason-1, and Jason-2 for 1992-2018. Blue lines denote possible future SMART cable routes.

Ocean Surface (Barotropic) Tides

Many small amplitude tidal phenomena (lesser tidal constituents, seasonal variability, non-linear constituents, rapid variation in shallow water, and shifting sinks of energy as the global environment changes) have global impact on internal tide generation, deep ocean mixing, paleotide descriptions, and Earth structure. Accounting for these phenomena is essential to de-aliasing satellite altimetry data to extract ocean circulation features and long period sea level rise. OBP observations can provide the finer details of the barotropic tides, because the broad band, non-tidal "geophysical noise" is much weaker at the seafloor than at the sea surface. [8-11]

Wind Generated Waves, Microseisms, and Infragravity Waves

Observations of wind-generated waves on the shelves, together with observation of infragravity waves (minutes to hours) and microseisms (1-10 s) in the deep ocean on SMART cables have the potential to inform us about energy flow from the wind and tides into the deep ocean, as well as the source of Earth's “hum” at the same frequencies, a topic of considerable interest to seismologists using Earth's vibrations to explore its structure. OBP measurements on SMART cable repeaters would contribute significantly to this purpose since the number of ongoing OBP sensors is so small. [12]

Tsunami Monitoring and Warning

SMART cables would increase the existing small number of deep ocean tsunami pressure sensors (Figure 6) to hundreds or thousands, helping to improve precision of tsunami warnings for areas >1000 km from the earthquake, and greatly reducing the potential of unnecessary warnings and evacuations. PTWC simulations in the Pacific indicate that SMART sensor data have the potential to substantially reduce time-to-warning (Figure 7): for earthquake epicenter determination (detections on 5 seismic accelerometers) by ~21 percent, and for tsunami wave detection (detections on 3 OBP sensors) by ~25 percent (using the cable scenarios in Figures 4 and 5).

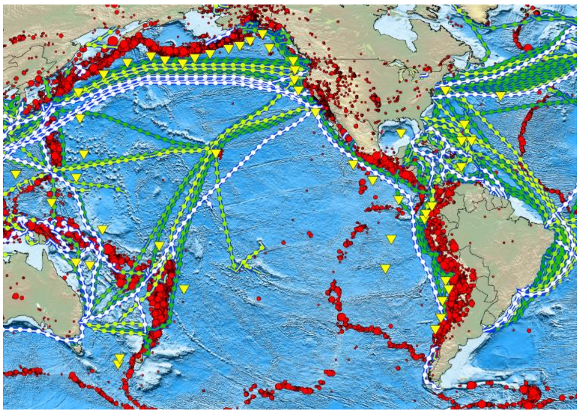

Figure 6. Inset of the Pacific region

The global map of ~1 million km shows present (green) and future (white) cables, with potential SMART repeaters shown every 300 km, super-imposed on historical earth- quakes (red) and DART tsunami buoys (yellow triangle).

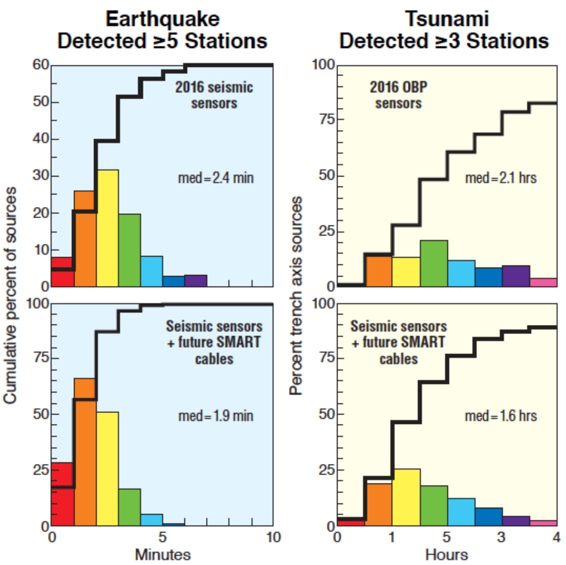

Figure 7. Improved detection time

Figure 7 shows how SMART cable data would reduce the detection time for earth-quakes and tsunamis significantly: (left) reducing median time-to-warning 30 seconds for earthquakes, and (right) 30 minutes for tsunamis.

Seismology

The inclusion of high-sensitivity accelerometers on SMART cables hold great potential for significant advances in the field of seismology by improving our capacity to detect and locate small earthquakes below the ocean floor, by improving our ability to determine the rupture type and dynamics for larger offshore earthquakes, and by enhancing our ability to i1nage the interior of the Earth. SMART sensors would provide coverage for the 70 percent unobserved ocean-portion of the earth (Figure 8).

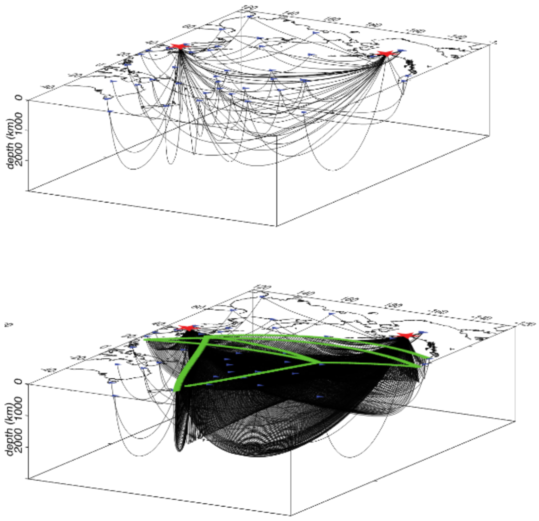

Figure 8. Seismic ray modeling

Figure 8 show coverage for two hypothetical sources (red stars in Cook Inlet, Alaska and Korea). Rays appear as curved lines from sources to receivers. [13]

3. SMART SENSOR TECHNOLOGY AND INTEGRATION

The fundamental premise of SMART cables is integrating environmental sensors into commercial submarine telecommunications cables to leverage the investment and infrastructure. The crucial objectives are: (a) to obtain long term measurements of ocean bottom temperature, pressure, and three-axis seismic acceleration, (b) to have little or no impact on the operation of the telecommunications system that hosts the sensors, (c) to require no special handling or deployment methods, and (d) to be sufficiently reliable that 95 percent of all sensors operate for a minimum of ten years.

The repeater (Figure 9) houses optical amplifiers that provide gain for the telecommunications signals; these are powered over the single conductor at 10 kV. Cable systems can have up to sixteen fibers (eight bi-directional pairs) and work is underway to allow higher numbers of fibers.

Functional elements to be added into the repeater include the sensors themselves, digital signal processing, an embedded processor, an Ethernet data switch, fiber optic transceivers, and power supplies. The most feasible way to transmit sensor data is to dedicate one fiber pair. Several of the sensors must reside outside the pressure case in contact with the water (temperature and pressure). To guarantee absolute electrical isolation, power-over-fiber is suggested.

Work is underway to develop and prove SMART repeaters. Steps in this process will likely include "wet demos" that incrementally approach full SMART functionality. For instance, a branch unit to "T" off a test section of cable with prototype units that extend the ICT Ethernet based design of the Sanriku system could be used.[14]

The design and development of SMART cables will require an unprecedented level of cooperation between scientific organizations, cable system suppliers, and cable system operators. Commercial cable system operators must be persuaded to support SMART cables. Addressing the concerns of the telecommunications industry will require a series of projects that demonstrate that all technical issues have been fully addressed. Smaller projects, particularly those serving island nations that are most at risk from climate and sea level change and tsunamis, are expected to be initially most receptive to SMART cables.

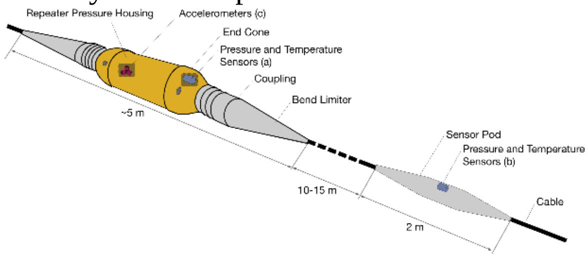

Figure 9. The elements of a SMART cable

4. LEGAL, COSTS, FUNDING, AND NEXT STEPS

Legal

Because SMART cables combine science and telecommunications into a single cable, they do not fit neatly into the international legal frameworks. SMART cable projects will be carried out in the EEZs of cooperating nations and the high seas. As the dual-use cables concept turns from development to deployment, the collective international understanding of their legal status will be refined based on concrete examples, routes, and uses.

Costs

We assume a (conservative) 10-year refresh cycle, 3 systems/year, 200 repeaters/year, US$175k/repeater, ramping up over 9 years, resulting in a steady state of 30 systems, 2000 repeaters, $US20k/year/repeater, and $40M/year. This represents 160 Mm, 4x around the world. Development costs are estimated $10-20M. These costs are similar to those of other existing observing systems. These costs are incremental, over those for the basic telecommunications system

Financing

With longer timelines and a broader range of goals, government-backed cables represent a good opportunity for SMART cables. For example, the Tsunami Act 2017 gives NOAA the responsibility to consider "... integration of tsunami sensors into Federal and commercial submarine telecommunication cables." Early engagement with potential projects is important to influencing the configuration to incorporate SMART requirements and to arrange funding. During the initial stages multilateral development banks are a possible source of funding, as they fund connectivity projects between developing countries as well as projects related to climate and disaster mitigation.

Next Steps

JTF is currently working with national governments and cable consortiums in the Asia and Pacific Rim of Fire regions where the value for sensor-enabled cables is particularly high because of tsunami risk. The Indonesian government is adopting plans for a massive $500M US update to its tsunami early warning systems and have confirmed that the program includes funding for a cabled system based on the SMART cables concept. In the south Pacific, we have identified initial funding for pilot programs via regional development banks, as well as RFPs under consideration with options for SMART capability. The first SMART cable pilot programs will prove the wet technology and data integration systems, and validate a pipeline toward off-the-shelf, matter-of-course availability. JTF is seeking development funding and industry partnerships to move from demonstration to full production.

5. CONCLUDING REMARKS

Consistent with SubOptic2019's Global Citizen theme, SMART cables are one way for the cable industry to "address environmental concerns and considerations" and in particular, are a way to "integrate into [industry] processes conservation efforts that impact installation and maintenance."

SMART cables fill scientific and societal needs, and provide an opportunity to harness market-driven investment in communications infrastructure with urgently needed ocean data improvements. The science described above—climate, ocean circulation and sea level rise, and tsunamis and earthquakes—requires the unique data that SMART cables can provide. SMART cable systems are technically achievable. Although integration and development tasks remain, all of the essential components exist today in some form. Projects such as DONET, S-Net, and Sanriku, demonstrate the capability of the telecommunications industry to deliver ocean observing systems that meet nearly identical goals.

By investing now, we can build up a global ocean network of long-lived SMART cable sensors, creating a transformative addition to the global ocean observing system.

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