Submarine Cable Systems for Future Societal Needs

The JTF SMART Subsea Cable Initiative:

Science Monitoring And Reliable Telecommunications, Climate Monitoring and Disaster Mitigation

Bruce Howe, Chair, Joint Task Force (JTF)

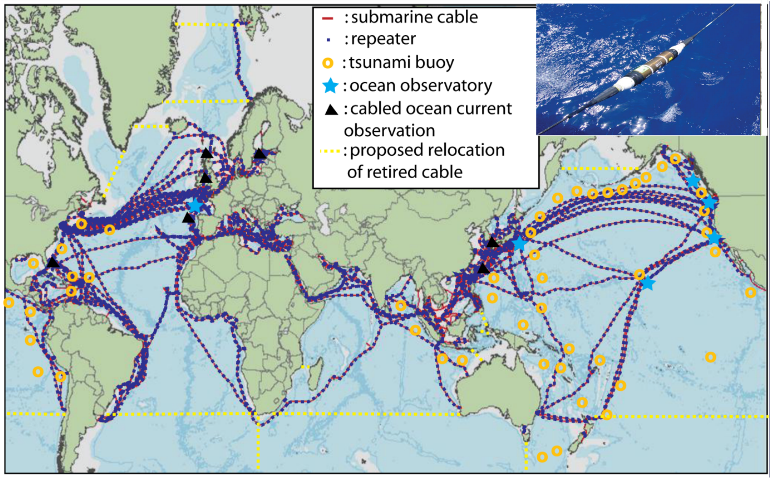
University of Hawaii at Manoa, Honolulu, Hawaii, USA

bhowe@hawaii.edu

NOAA Central Library Brown Bag Seminar
Silver Spring, Maryland
8 November 2016

SMART subsea cables in the ocean and earth observing system

- Telecom + science
- Cable repeaters host sensors
- Potential: 20,000 repeaters, 1 Gm, 50 km, 10-20 year refresh cycle
- Initially: bottom pressure, temperature and acceleration; supplement later



SMART cables will:

- Contribute to understanding of ocean dynamics and climate
- Improve knowledge of earthquakes and forecasting of tsunamis

SMART cables – first order addition to the ocean and earth observing system, with unique contributions that will strengthen and complement satellite and in-situ systems.

John You, *Nature*, 2010 – Harnessing telecoms cables for science

Societal benefits in adding sensors for climate and disaster monitoring

Societal and environmental issues:

- Climate change – ocean temperature and circulation – direct impact on societies
- Sea level rise – hazard for coastal states and cities
- Disaster Warning– tsunami and earthquake monitoring throughout ocean basins and coastal margins

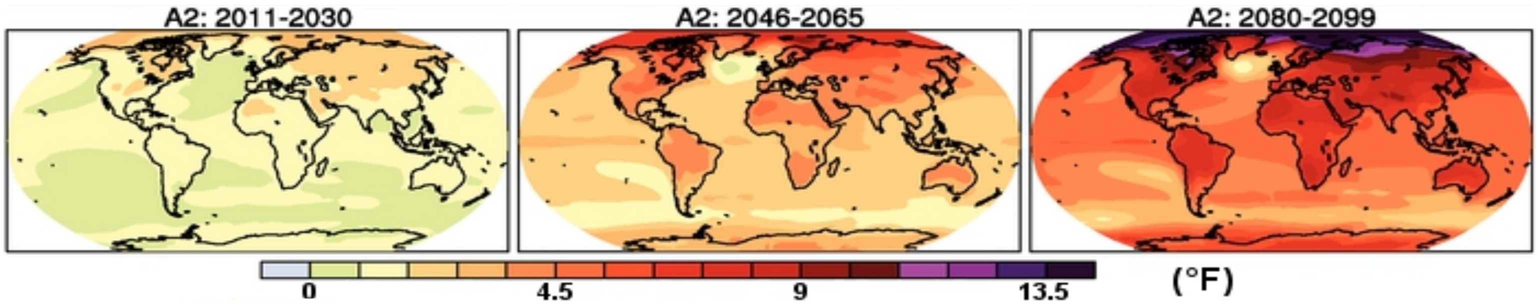
Outline

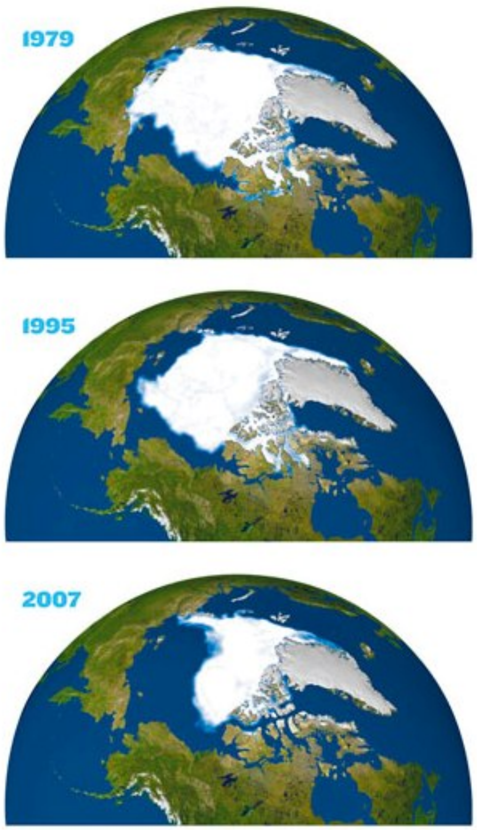
- Overview
- Ocean
- Tsunami
- Earthquake
- Technical
- Programmatic
- Concluding remarks

Will draw on

- Two NASA workshops
- From space to the deep seafloor: Using SMART subsea cables in the ocean observing system
  - CalTech 9-10 October 2014 and University of Hawaii 26-28 May 2015

- GFZ-JTF Workshop
- SMART Cables for Earthquake and Tsunami Science and Early Warning
  - GFZ Potsdam, Germany, 3-4 November 2016 (last week!)

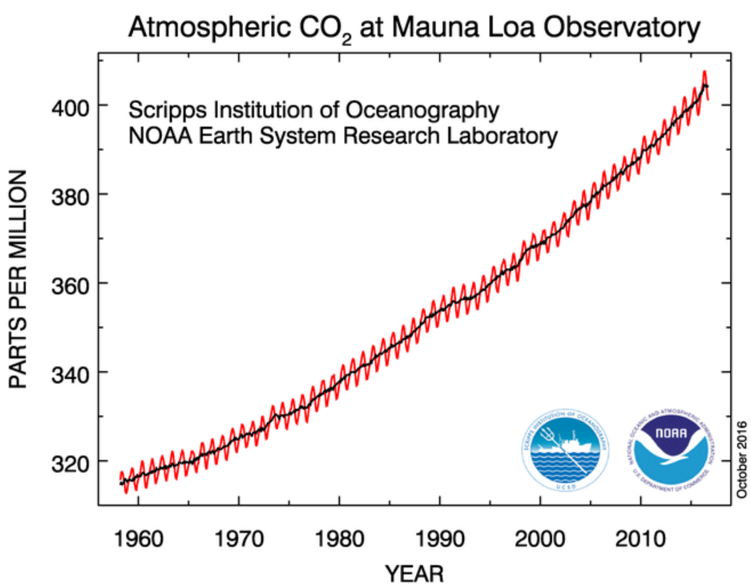




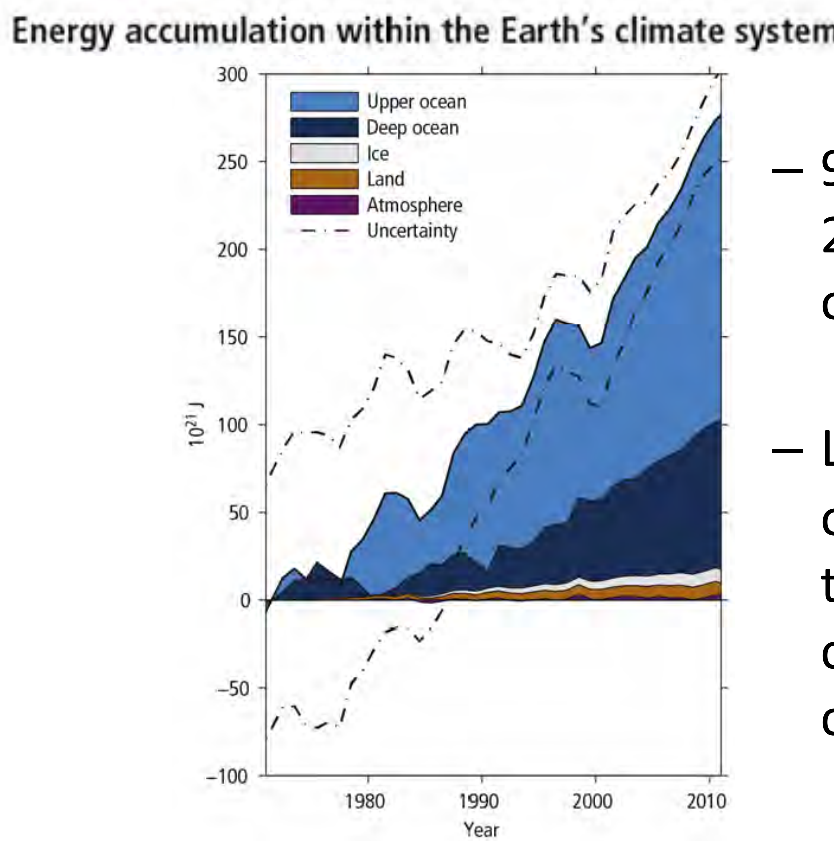
Global Change

- Global temperature increase
- Polar ice melting
- Ocean circulation change
- Sea level rise
- Ocean acidification

CO_2 – Ocean Heat Content

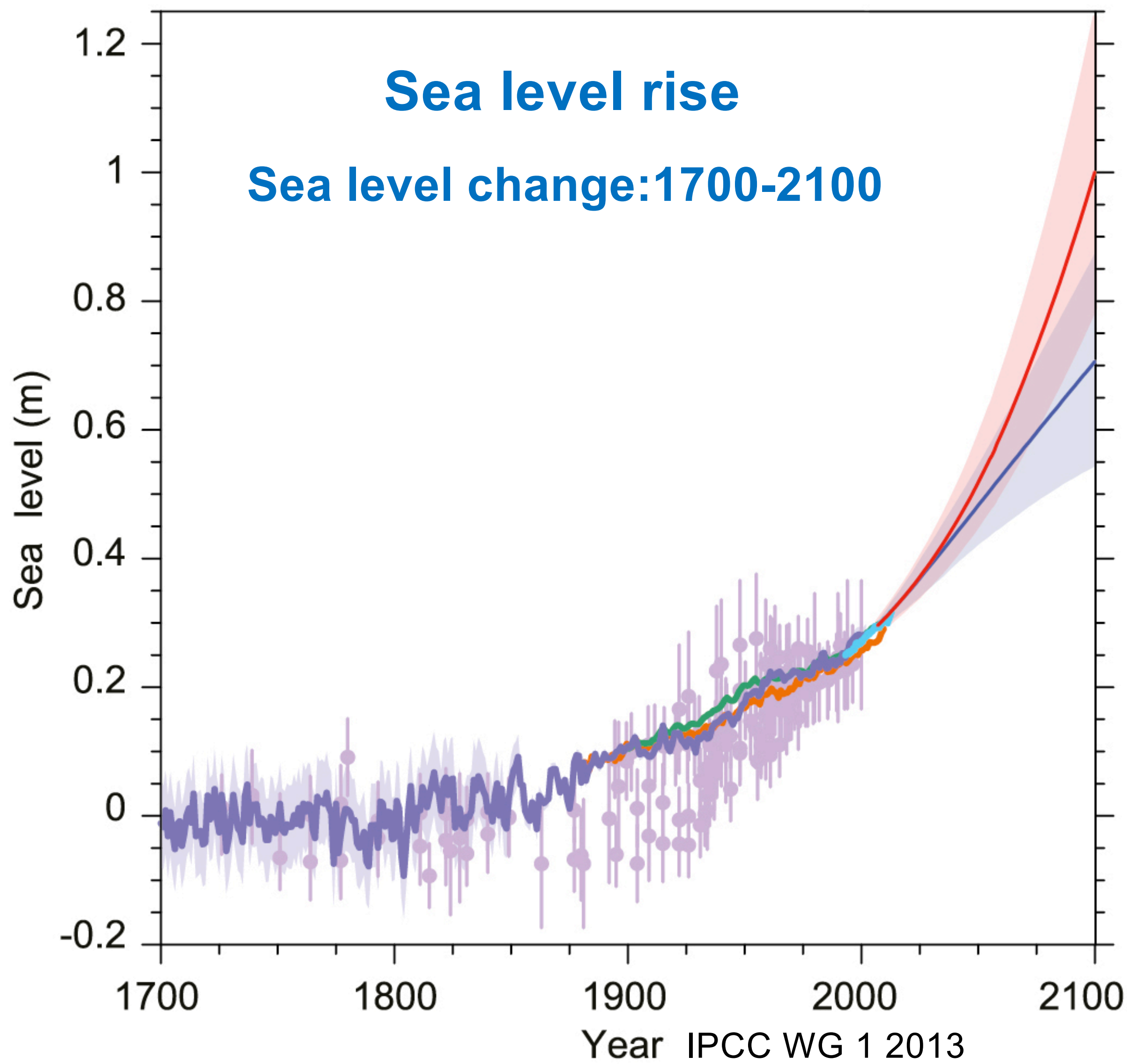


1960-2016
now > 400 ppm



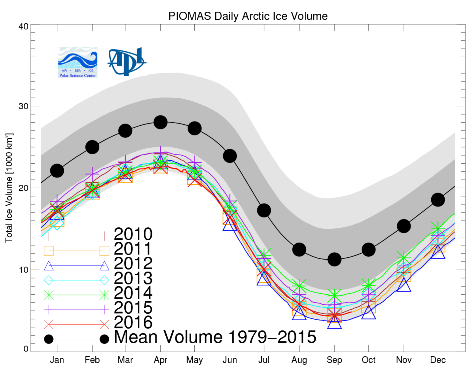
IPCC AR5 SYR

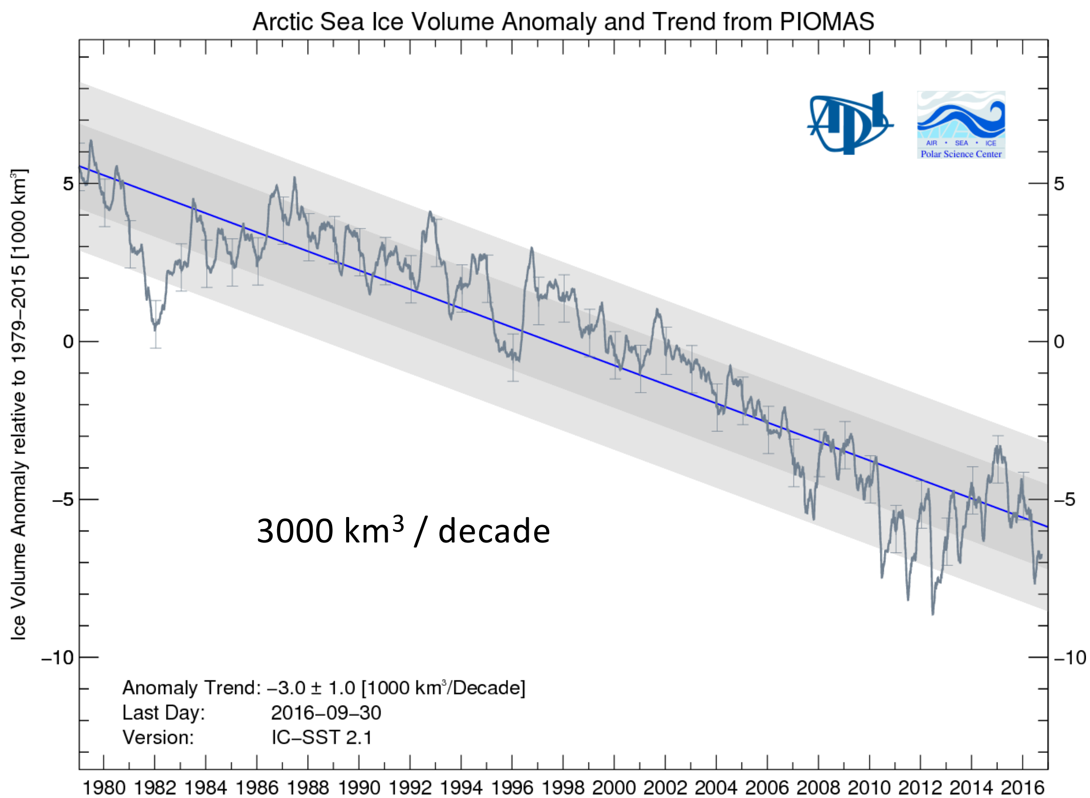
- 90% (1971-2010) in the ocean
- Land and ocean temperatures continue to climb

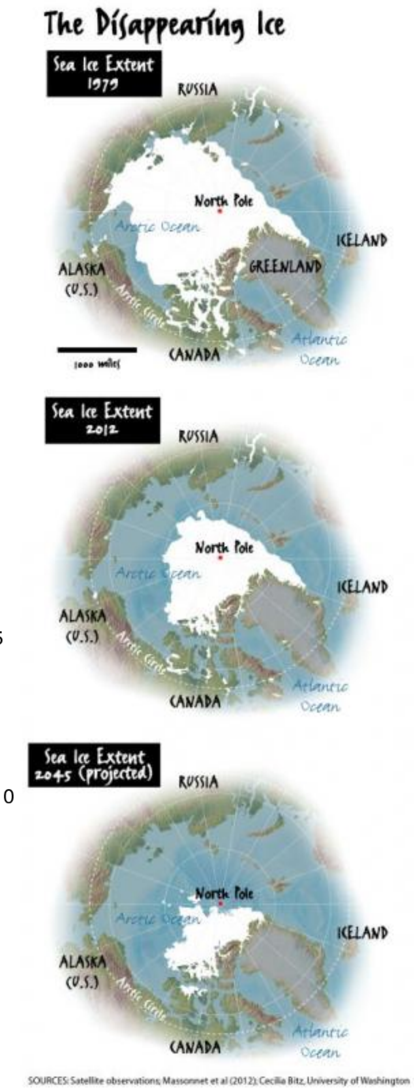


Sea level rise
Sea level change:1700-2100
Sea level (m)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1700
1800
1900
2000
2100
Year
IPCC WG 1 2013

Arctic sea ice loss 1979-2016



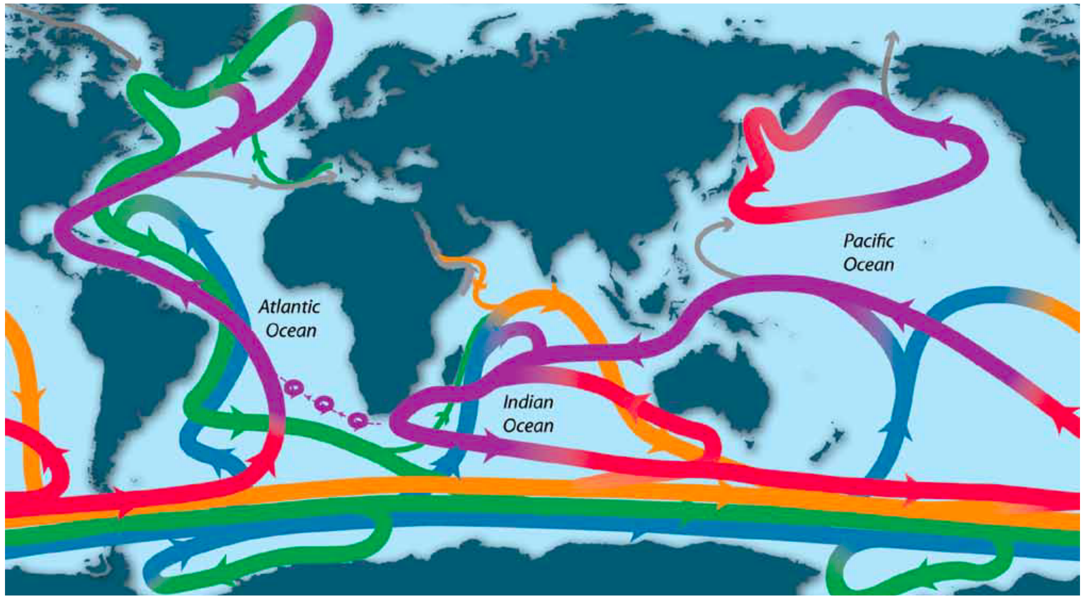




Rate of decline for February extent is 3% per decade.

Ocean climate and circulation

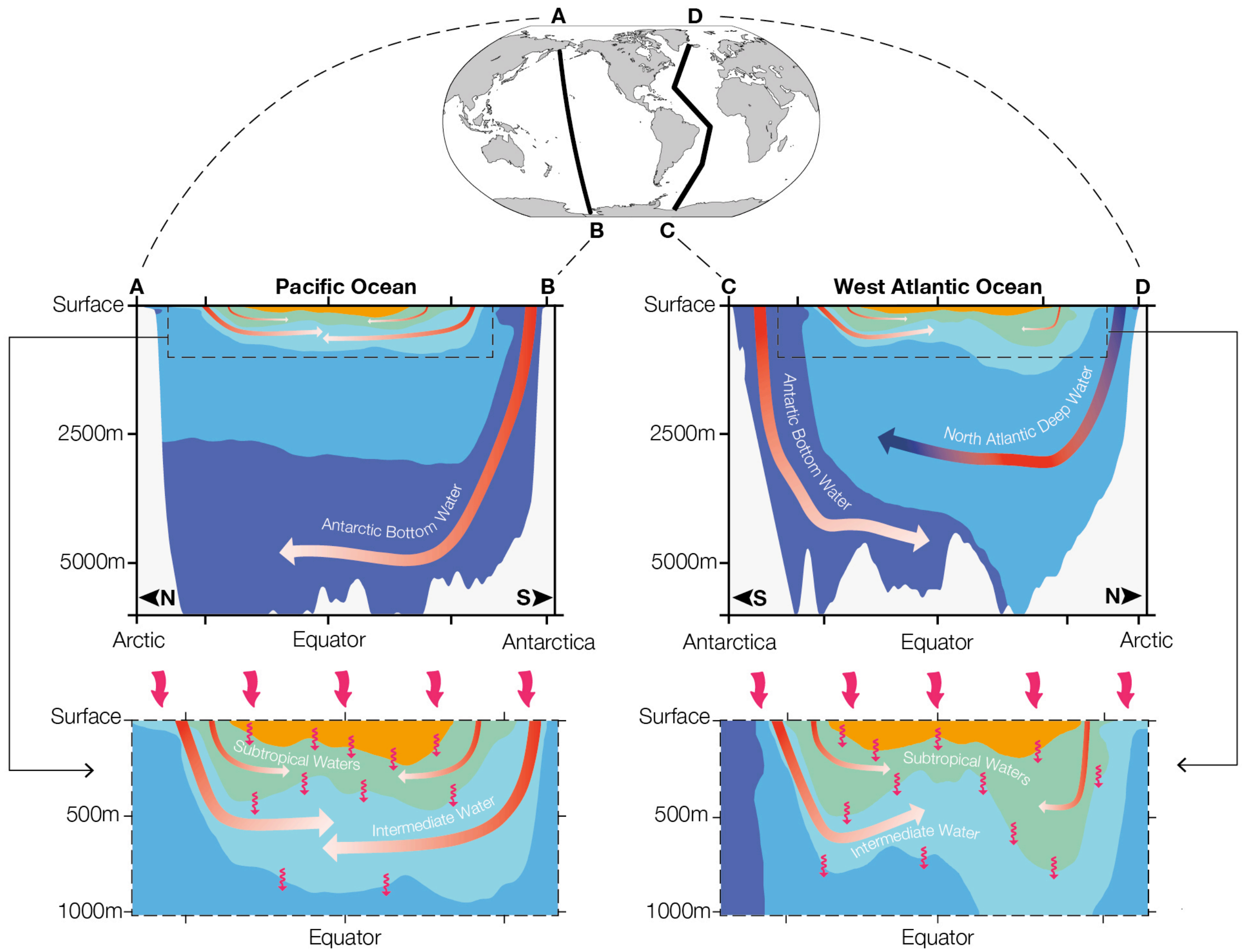
Cartoon!



- Conveyor belt – thermohaline
- Abyssal ocean long time scales
- Sinking – sequester heat, CO2, Freon, tritium, other
- Upwelling, old waters to surface

Where does all the heat go?

Sensors on submarine cables will track deep ocean circulation and temperature change

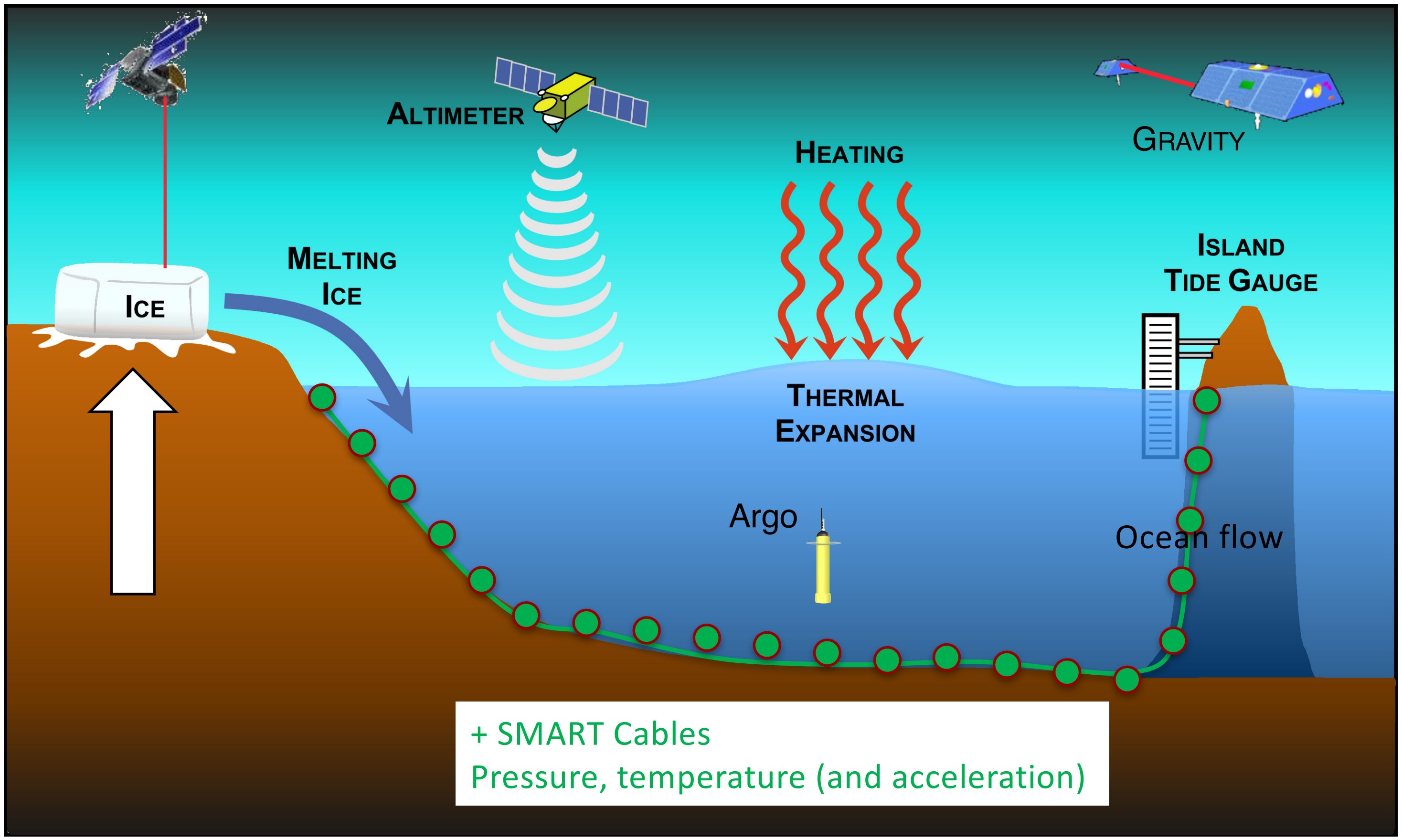


IPCC WG 1 2013

Sea Change: 2015-2025 survey of the ocean sciences (U.S. NRC/NSF)

- The ocean's overturning circulation varies in both space and time, with significant variability on time scales less than a year and with spatially non-uniform upwelling.
- … it is now understood that the overturning circulation is marked by strong temporal and spatial variability and that the deep waters' equatorward pathways include the ocean interior.
- … This more sophisticated view of ocean circulation … opens new avenues for understanding ocean heat, freshwater and carbon transport.
- -> More Observations!

Tools for Measuring Sea Level and Ocean Circulation



Now, essentially no in situ deep or bottom measurements

Plus and minus for each

Adapted from Nerem, 2016

From OceanObs09

- There is a need for technology development focused on improving reliable and cost-effective access of observing platforms and the capabilities of sensors for the deep ocean.
- Other elements are emerging, and will require additional development in technology or methodology to enable them to contribute to the future sustained ocean observing system.
- Satellite and in situ platforms are both key to observing the oceans, measuring them in complementary ways.

SMART cables in the ocean observing system

Summary 1

Report on two NASA workshops

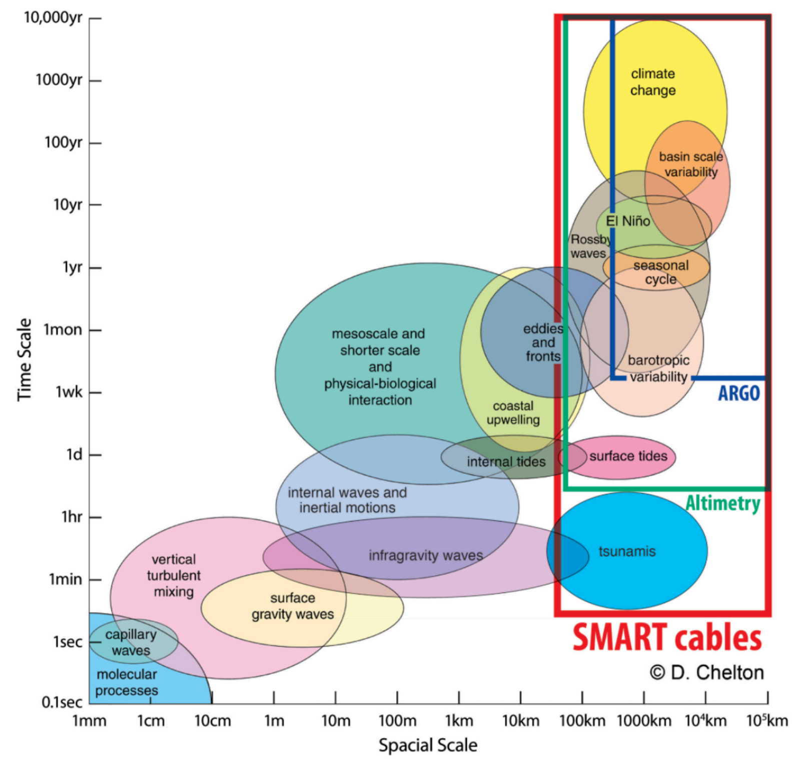
Full report available on web

- Climate relevance of SMART cable measurements
  - Uniquely sample deep-ocean variability
  - Constrain fundamental depth-integrated quantities
  - Provide new capability for high frequency global measurements
- With initial sensors: temperature (T), bottom pressure (BP), acceleration (A)
  - **T:** spatial and temporal variability of deep-ocean temperatures, propagation of heat anomalies through ocean basins and along boundaries
  - **BP:** Temporal variability of barotropic tides, fast (<2 day) ocean response to atmospheric pressure forcing, aliasing from infragravity waves, constrain tsunami amplitudes
  - **A:** improve sampling in the ocean of earthquake parameters much more than the sparse DART array
- Scientific Benefits of initial sensors:
  - Monitor ocean warming with measurements unattainable on similar time/space scales
  - Increase accuracy of altimetry by improving tides and high frequency ocean signals
  - Improve real-time earthquake and tsunami warning systems, including landslide-generated tsunamis

SMART cables in the ocean observing system
Summary 2

- Synergies with satellite observations. Cables provide **increased space/time coverage** to **improve satellite corrections** for fast and small-scale processes.

- Sea surface height
- Gravity/bottom pressure
- Ocean surface wind stress
- Ocean state estimation
  - Deep ocean temperatures
  - Ocean Circulation



Assessment of SMART

"… first order addition to the ocean observing system, with unique contributions that will strengthen and complement satellite and in-situ systems."

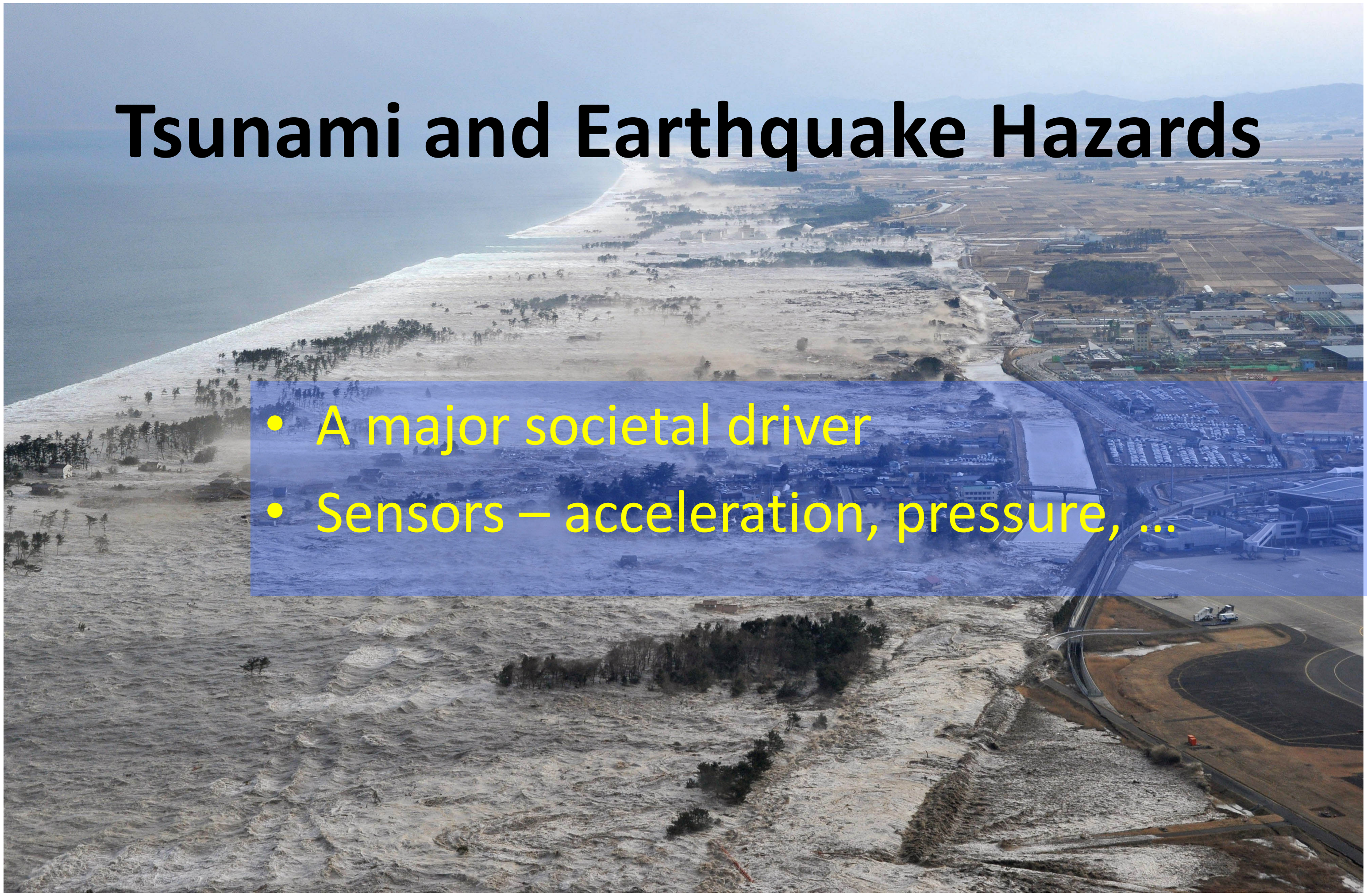
"… the SMART pressure measurements serve as ground truth and de-aliasing for tidal and other high frequencies. SMART pressure data are necessary for ground truth validation of GRACE data, leading to significantly improved precision and global resolution."

Final NASA Workshop Report, 2015

Recommendations

1. ***SMART cable concept deserves broad support from the science community.***
2. *Need **seismic and tsunami workshops**.*
3. ***Prioritize cable routes***
4. ***Identify a SMART demonstrator cable system*.**
5. **Ocean modeling and analysis**:
   1. Extract *bottom pressure and temperature from data and high resolution global ocean models to **quantify variability SMART cables would be uniquely capable of measuring**, with impacts on altimetry and gravity.*
   2. ***Sensitivity experiments – quantify***
   3. ***Observation System Simulation Experiments* (OSSEs) to quantify ocean state estimate improvements**.
   4. Develop a **realistic "*SMART cable mission simulator*".**
6. ***Simulations** to quantify the improvement in accuracy and speed for **tsunami** (bottom pressure) and **earthquake** (accelerometer) **warning systems** (OSSEs).*
7. ***Development of sensors for following phases***

Tsunami and Earthquake Hazards



- A major societal driver
- Sensors – acceleration, pressure, …

Great Tohoku Tsunami of 2011 at Sendai

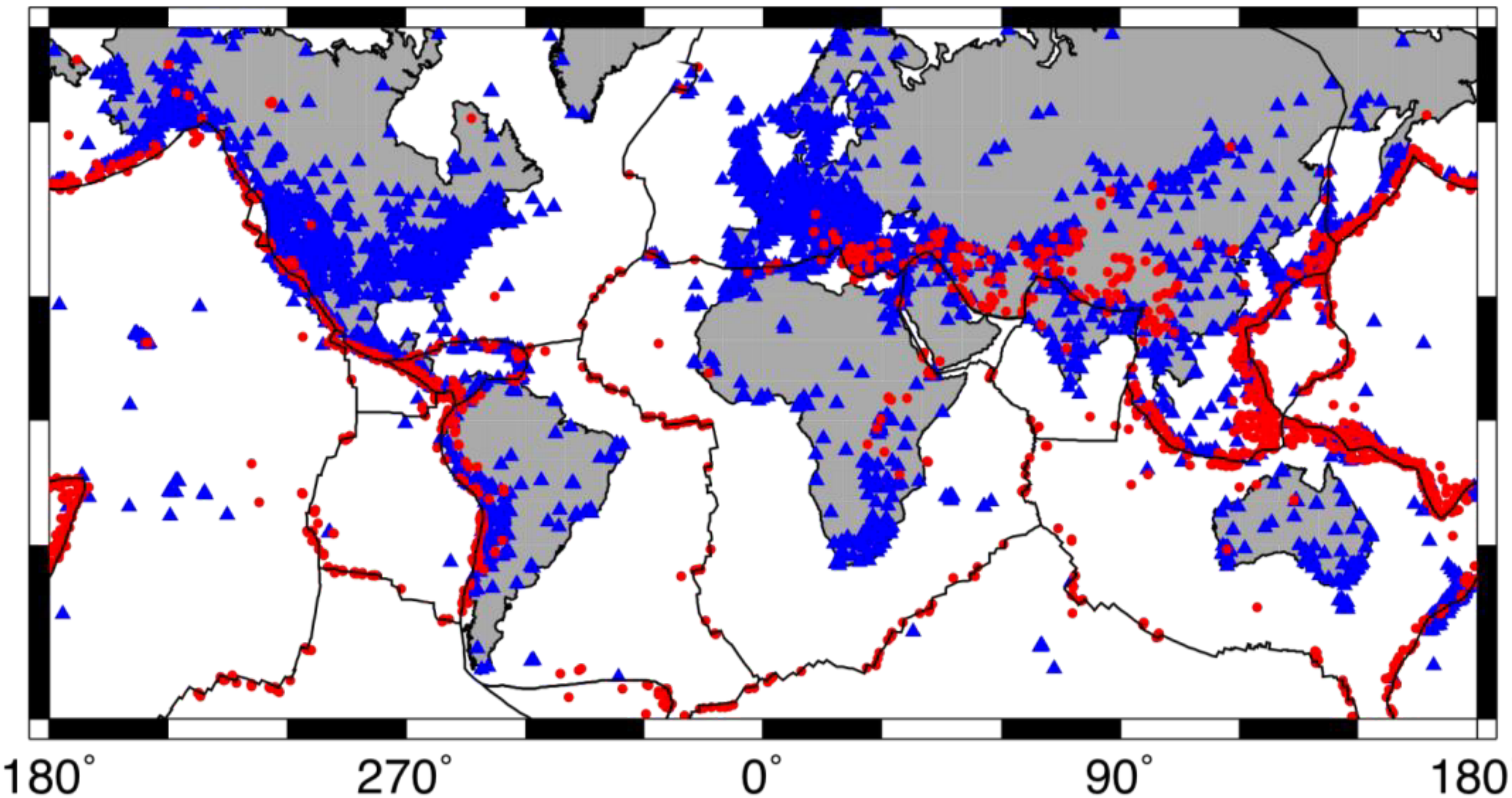







Devastating effects of the 11 March 2011 tsunami, northern Japan, generated by an offshore M_w 9 earthquake

Earthquake sources and seismic stations



Red

Earthquake sources

Blue

Seismic stations

Almost all on land

Figure from J. McGuire, WHOI

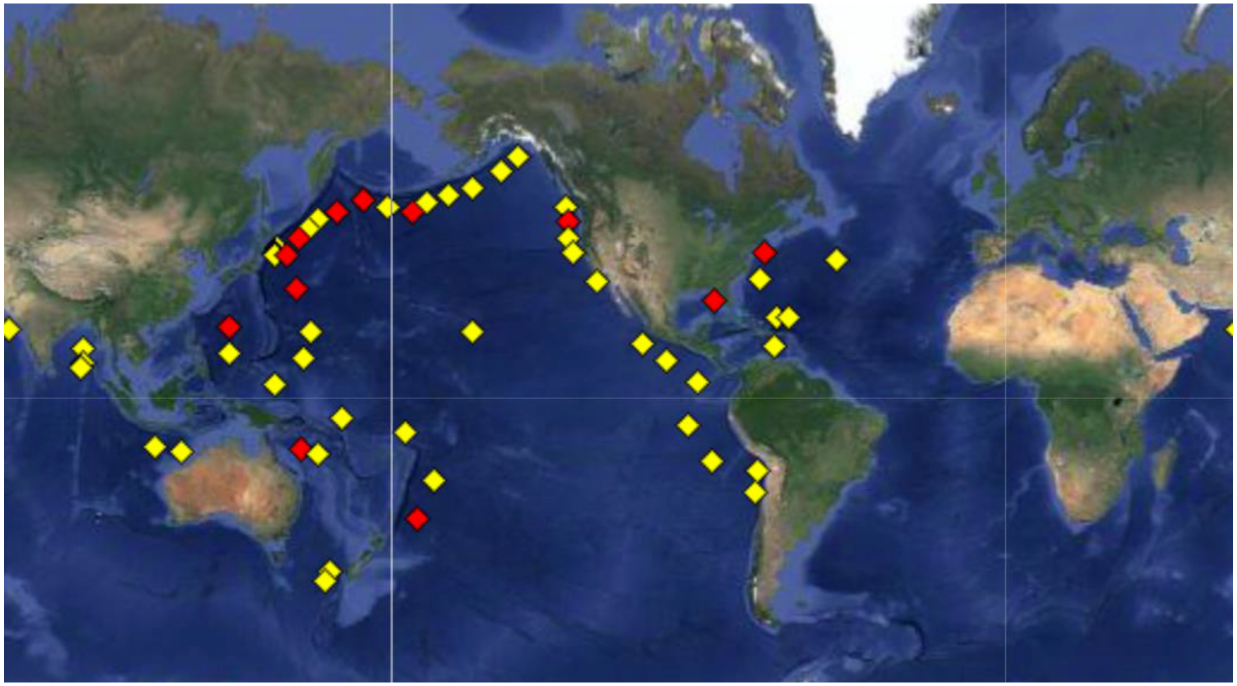
Tsunami warning

- GFZ-JTF Workshop
- SMART Cables for Earthquake and Tsunami Science and Early Warning
  - GFZ Potsdam, Germany, 3-4 November 2016 (last week!)(very) Preliminary calculations
- Presented by Stuart Weinstein, Asst. Director, PTWC
  - Seismic & Sea-Level Stats by Nathan Becker
  - Most Awesome Simulation by Dailin Wang
  - PTWC Performance Stats by Victor Sardina
- All At: NOAA/NWS/PTWC

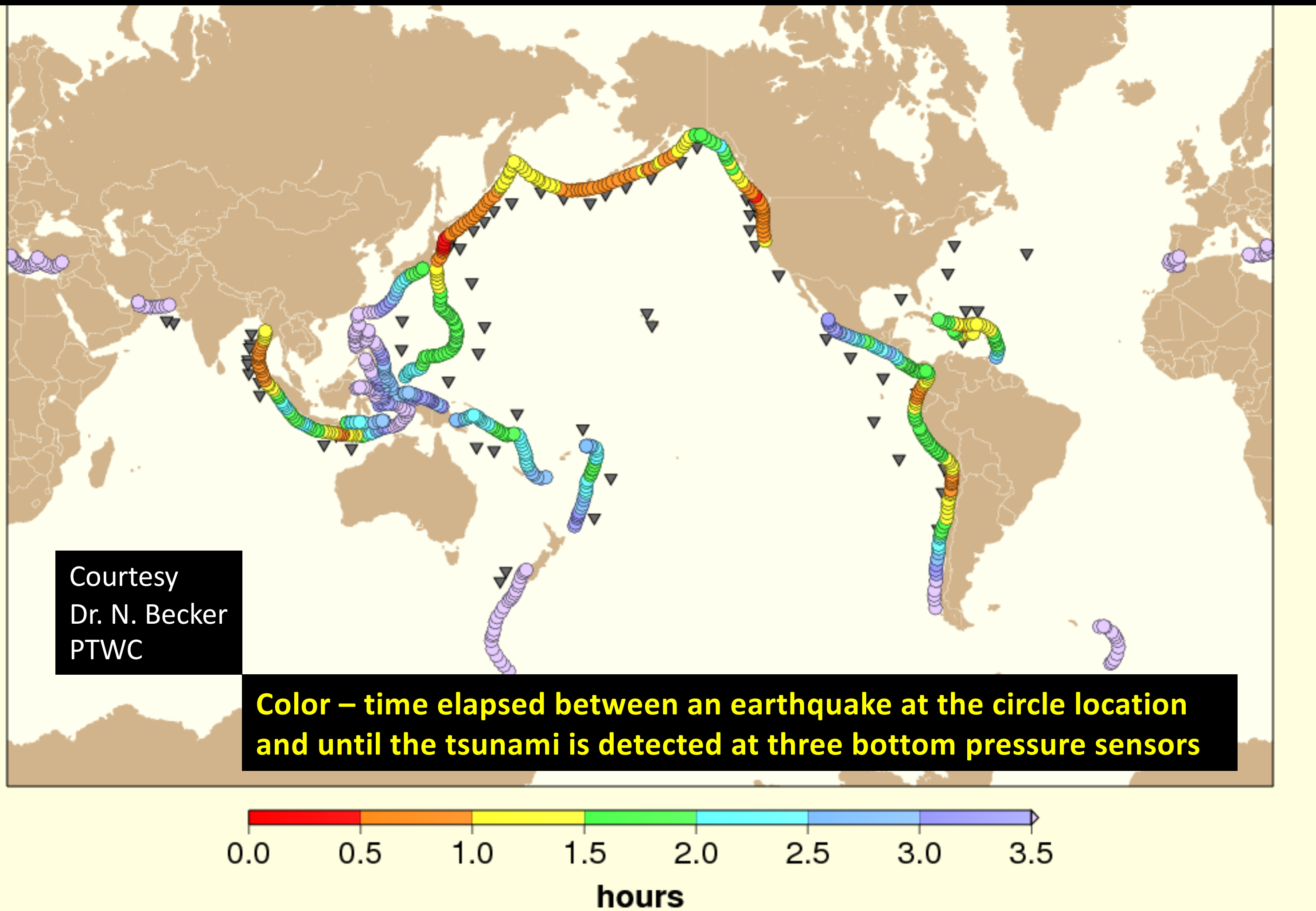
DART Buoy Coverage

- May 2014
- Red – not available
- Yellow – operational

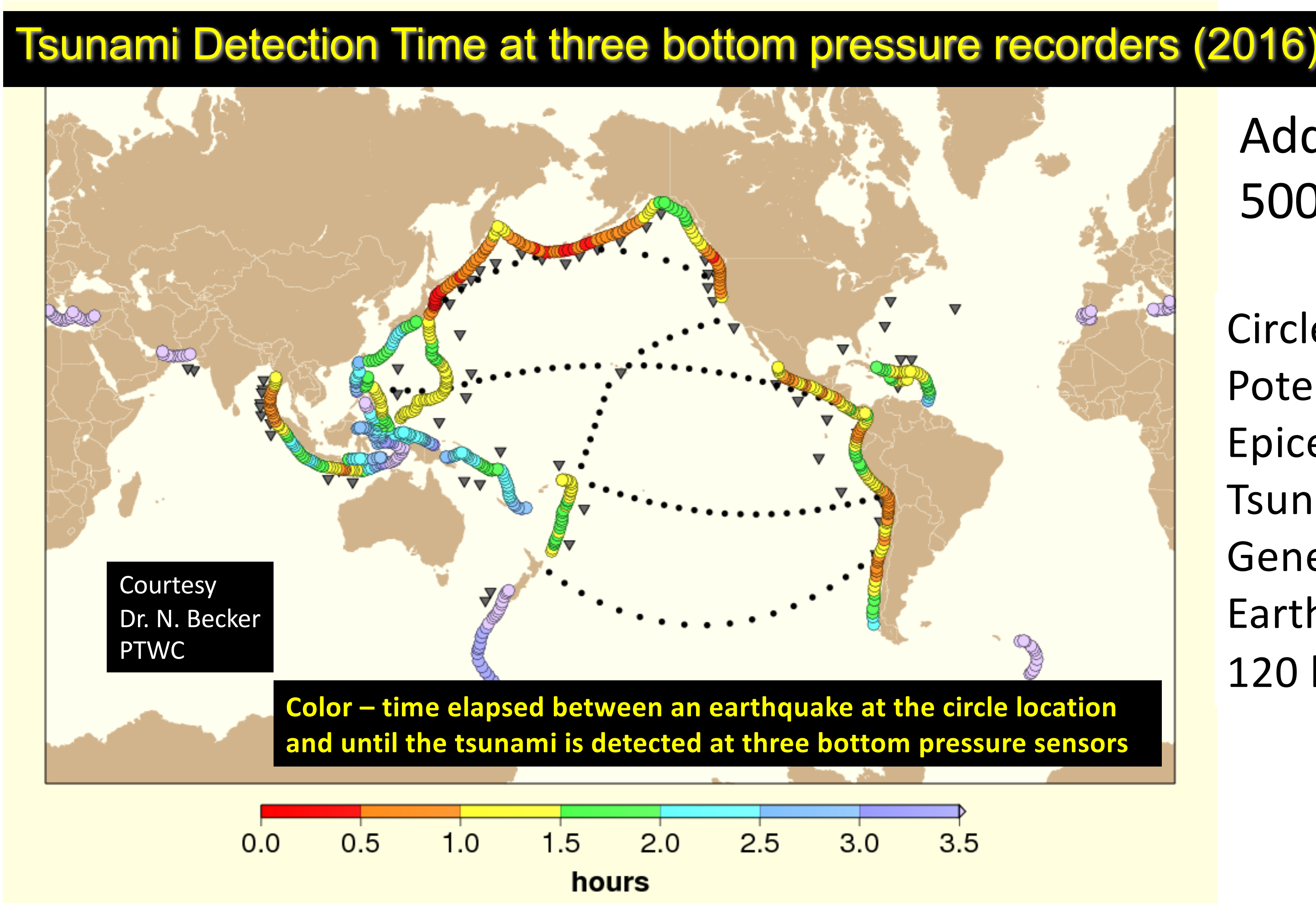
- Expensive
- Less reliable



Tsunami Detection Time at three bottom pressure recorders (2016)

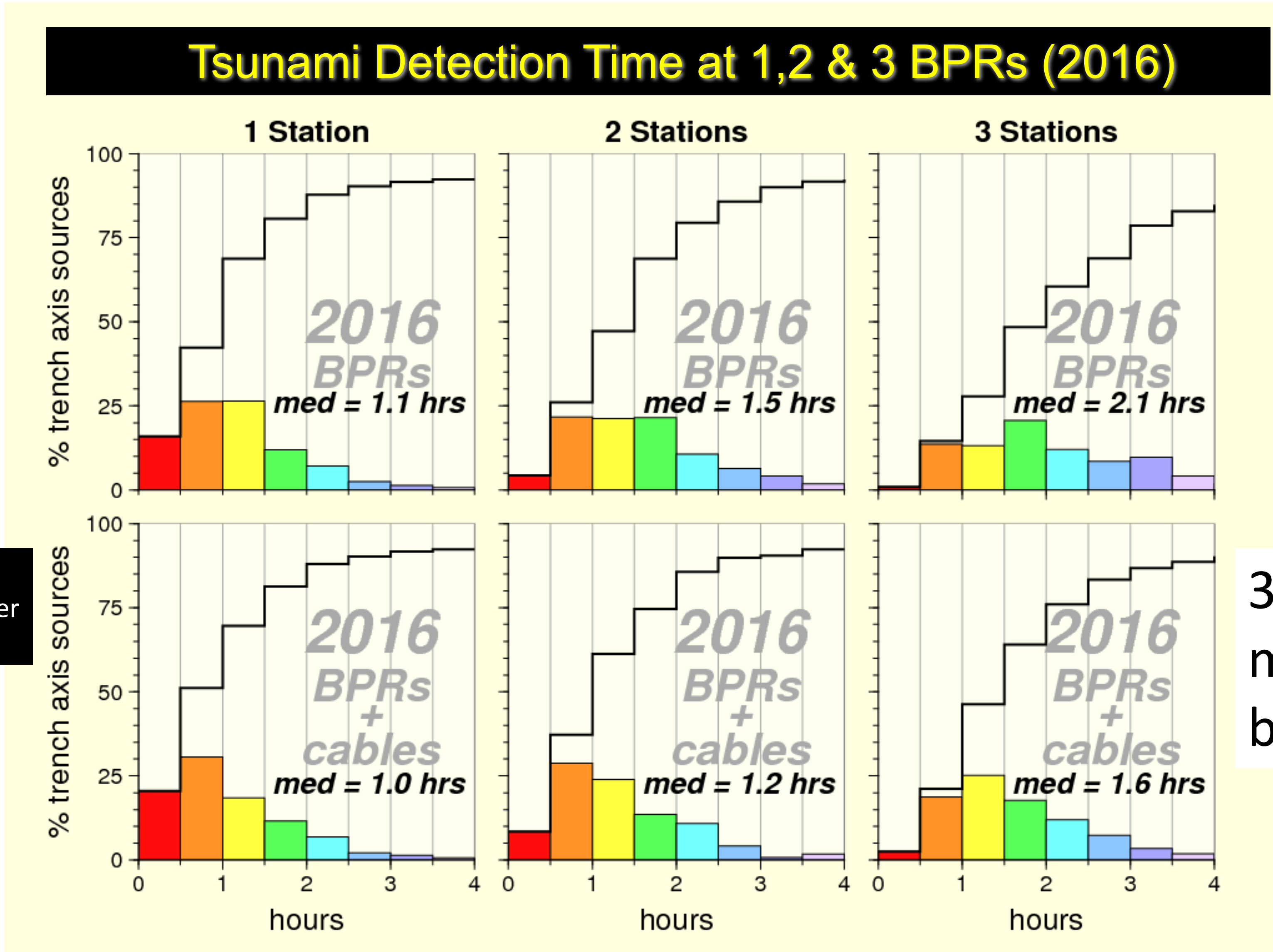


Circles:
Potential
Epicenters of
Tsunami
Generating
Earthquakes
120 km spacing



Add SMART
500 km spacing

Circles:
Potential
Epicenters of
Tsunami
Generating
Earthquakes
120 km spacing



Courtesy
Dr. N. Becker
PTWC

30 minute better

Tsunami warning – Summary

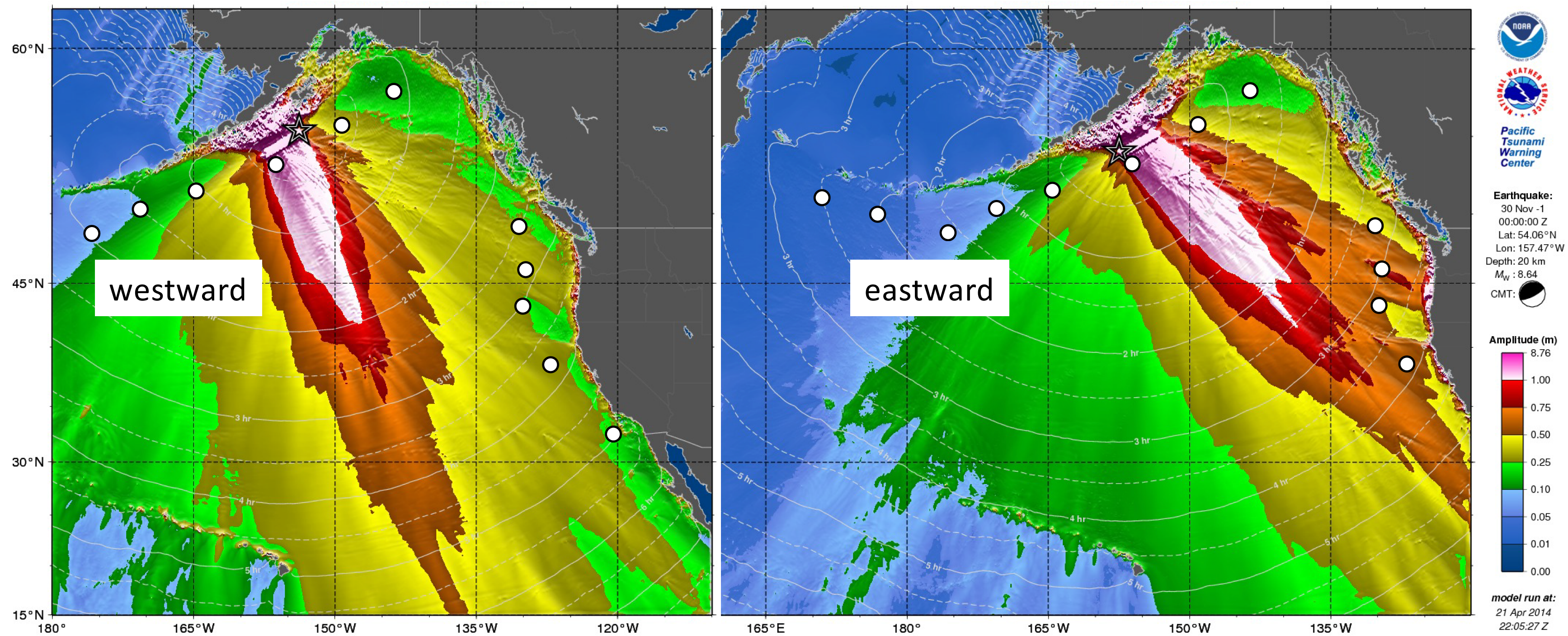
From S. Weinstein:

1. We have made tremendous progress in the development and sharing of seismic and sea-level networks since the Great Sumatra Earthquake and Tsunami
2. Even just a few SMART Cables can speed up the determination of likely tsunamigenic epicenters by 20%.
3. Even just a few SMART Cables can speed up the characterization of Ocean-crossing tsunamis by ~25%, and allow for more rapid assessment of Tsunami Forecasts.

=> Imagine what effect many SMART Cables with 1/10 the sensor interval could have! => more modeling

More to look at …

Simulation



- Mw 8.6
- Unilateral rupture 1 km/s

- “tsunami” earthquake a la West Java 2006
- G. Fryer, NASA Workshop, 2015

Earthquakes

- GFZ-JTF Workshop
- SMART Cables for Earthquake and Tsunami Science and Early Warning
  - GFZ Potsdam, Germany, 3-4 November 2016 (last week!)
- (very) preliminary results
  - Presented by Charlotte Rowe, Los Alamos National Lab with
    - Ellen Syracuse
    - Carene Larmat
    - Michael Bagnaud
    - Nishath Ranasinghe, New Mexico State University
    - AGU Fall Meeting

From Charlotte Rowe et al.

How could SMART Cables help seismology?

Seismology – science of studying the Earth by analyzing elastic waves that have propagated from a variety of sources through parts of the Earth.

Two fundamental applications of seismological studies:

1. Estimation of location and size of a seismic source, and characterizing the seismic activity of different regions
2. Interrogating the material properties within the Earth using seismic waves to evaluate features through which they have passed, where we often have no other observations.

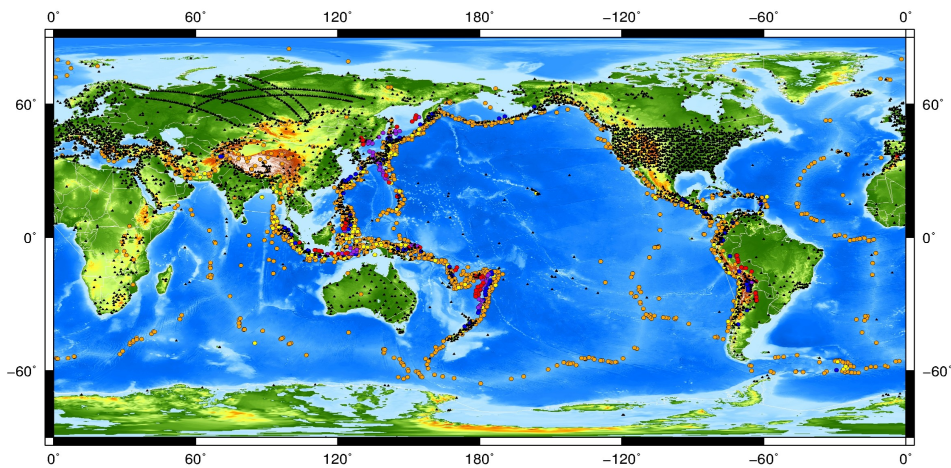
Addressing these can lead to inferences about tectonics, rheology, mineralogy, fluids, economic potential, planetary history and seismic and tsunami risk.

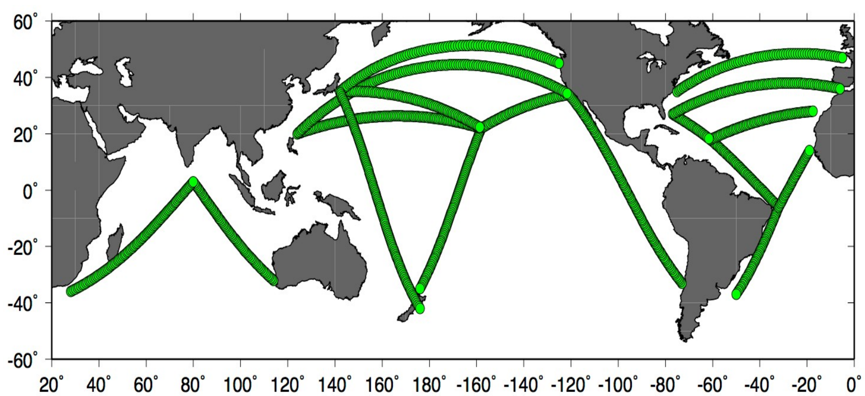
These two problems are inextricably linked.

From Charlotte Rowe et al.

Earthquakes, Land and SMART stations

4421 existing seismic stations and 1681 M > 6 earthquakes unique to 1x1o bins since 1990.

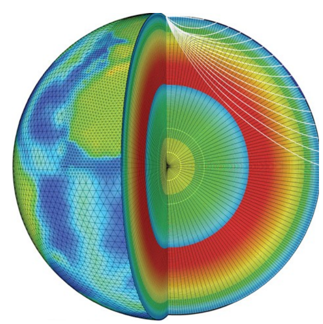


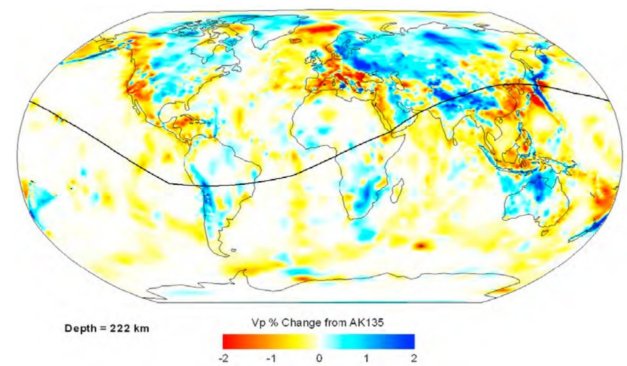


Addition of the SMART cables will, over time, provide significantly improved seismic ray coverage for global velocity models.

Begin by examining the improved ray coverage provided out to 90 deg (direct P-wave arrivals before encountering the “shadowzone” from the Earth’s core) by the first generation cables.

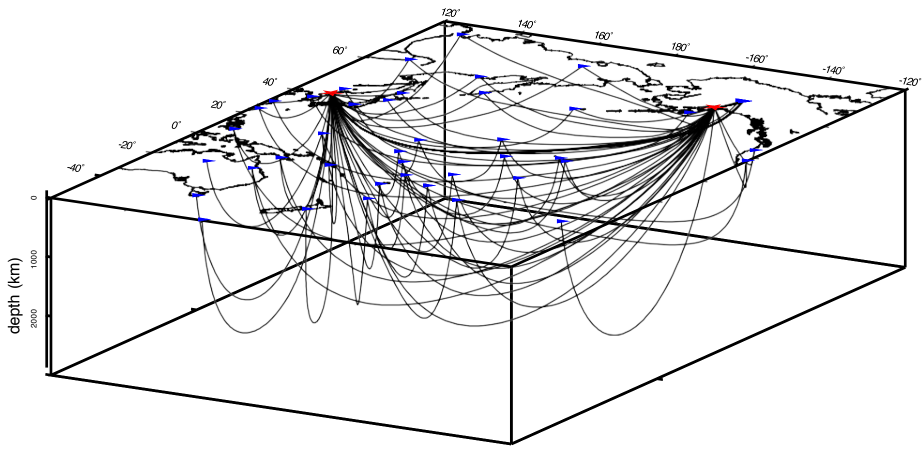
In future work we will include additional seismic phases and their paths in our forward modeling.

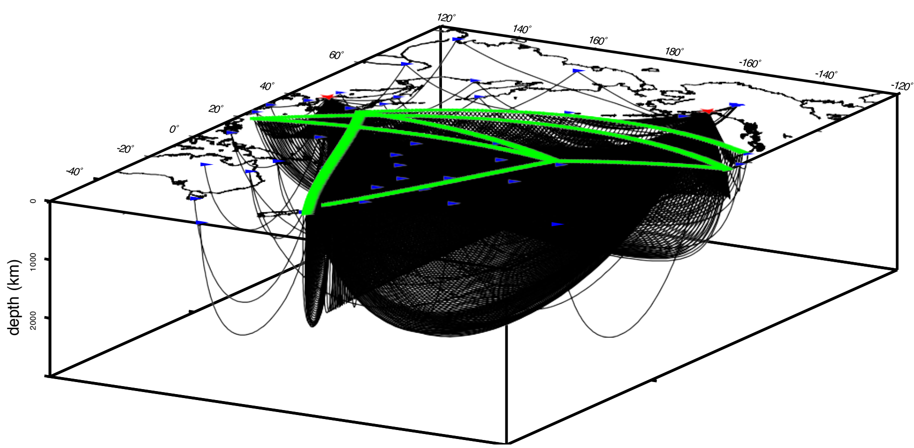




From Charlotte Rowe et al.

Comparison of Seismic Sampling With and Without SMART Cables





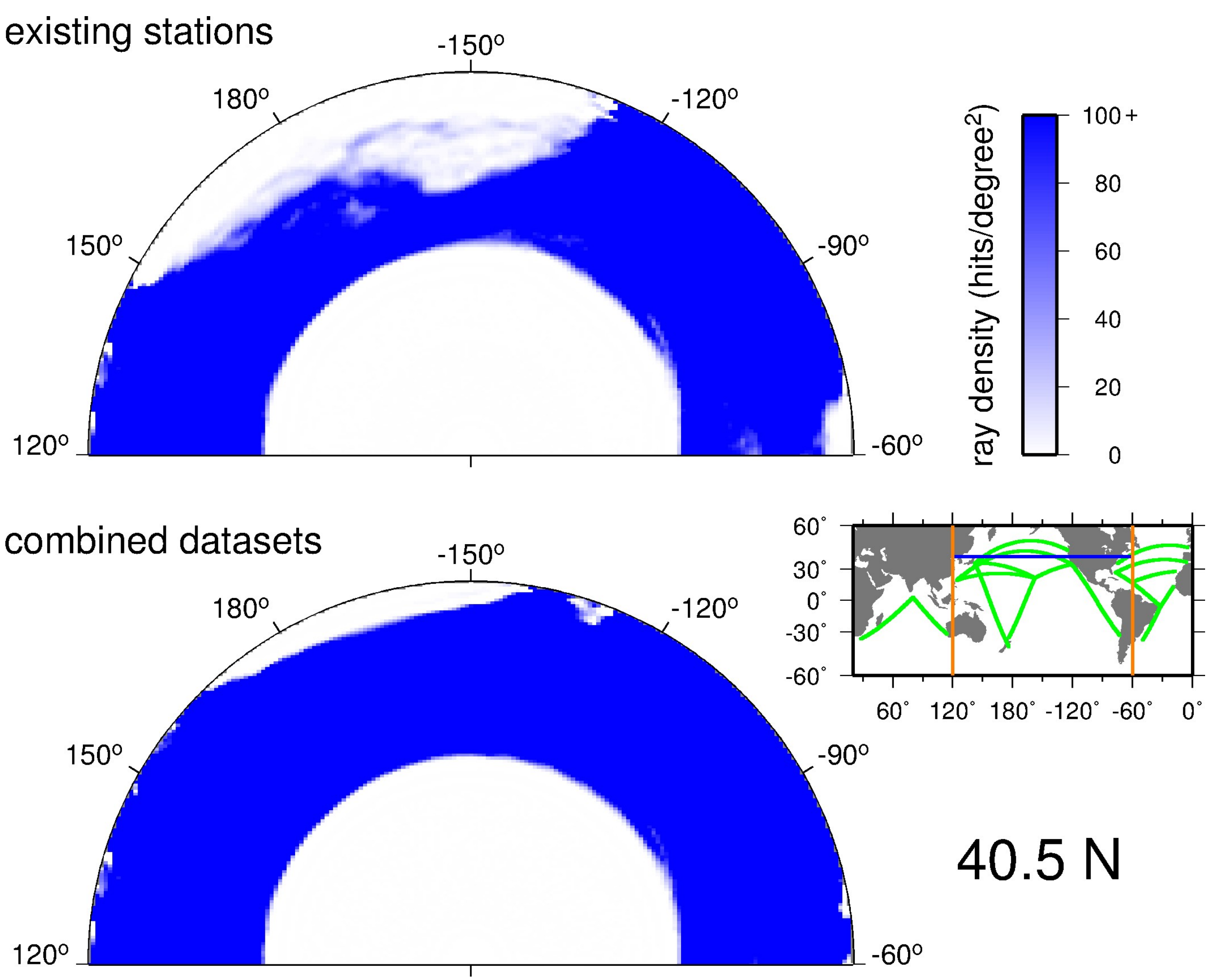
Rays in 3 dimensions for two sources –Cook Inlet, Alaska and Korean Peninsula.

Top: Rays to existing Global Seismograph Network (GSN) stations around the Pacific.

Bottom: Rays for GSN + first generation SMART

Next: cross-section and depth slices global M > 6 earthquakes

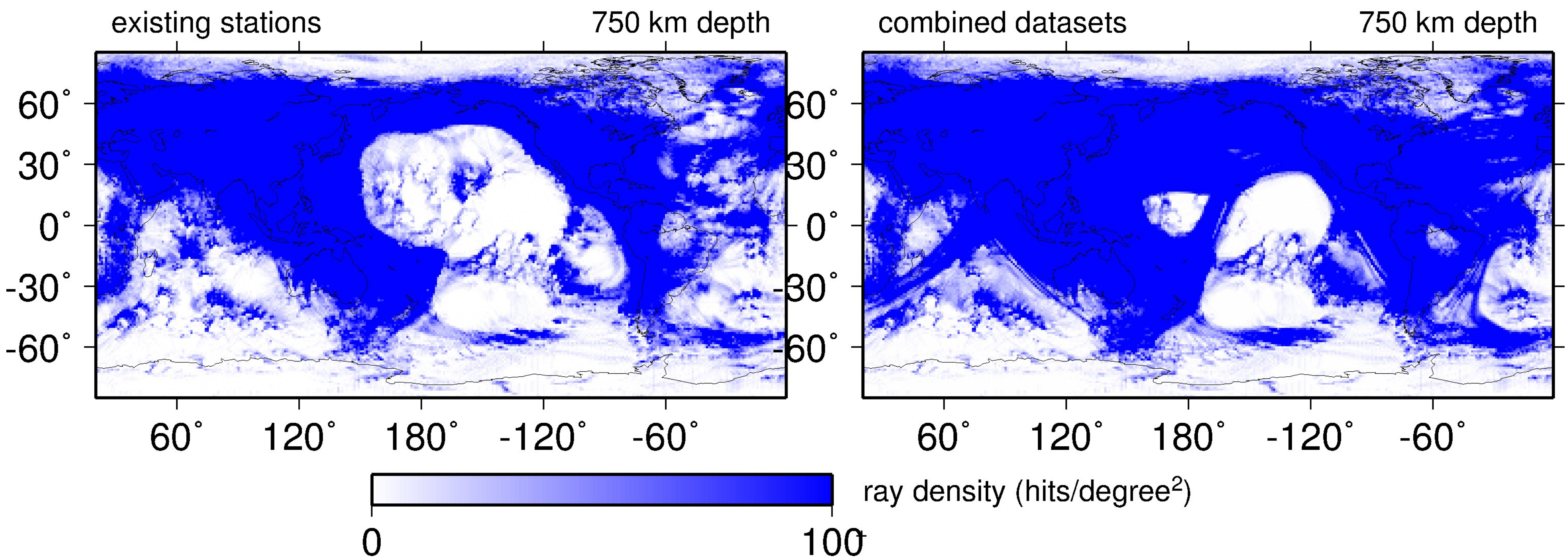
From Charlotte Rowe et al.



Cross-section slice at 40.5 deg N for global M > 6 earthquakes.

Rays are presented as a density function of a 1 deg wide slice.

From Charlotte Rowe et al.



Depth slices at 750 km for the global M > 6 earthquakes. Number of rays in 1x1o by 100 km depth bins.

From Charlotte Rowe et al.

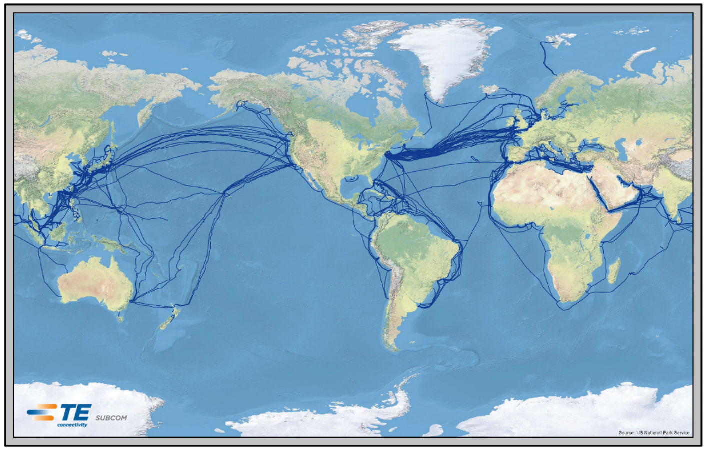
Earthquakes - Summary

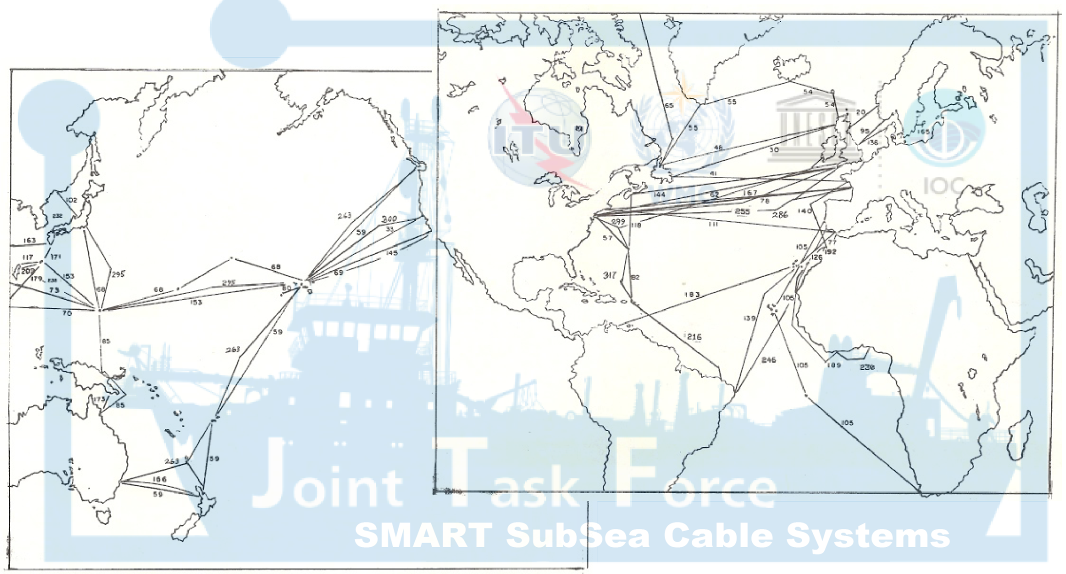
- Preliminary modeling indicates improvements possible – locations, magnitudes, coverage
- More sophisticated forward modeling (phase/waveform/attenuation)
- Forward modeling to predict amplitudes will help us quantify the potential for SMART cables to enhance our detection of small seismic sources in various locations globally.
- Using basic earthquake location parameters we can predict the improvement to seismic source location capability with SMART cables sensors, and enhancements to our Ground Truth (GT) catalogs.

Technical

- A little history
- Implementing – one “package”
- Wet demo

A little history





SMART Cables ?!

Optical cables, 2015

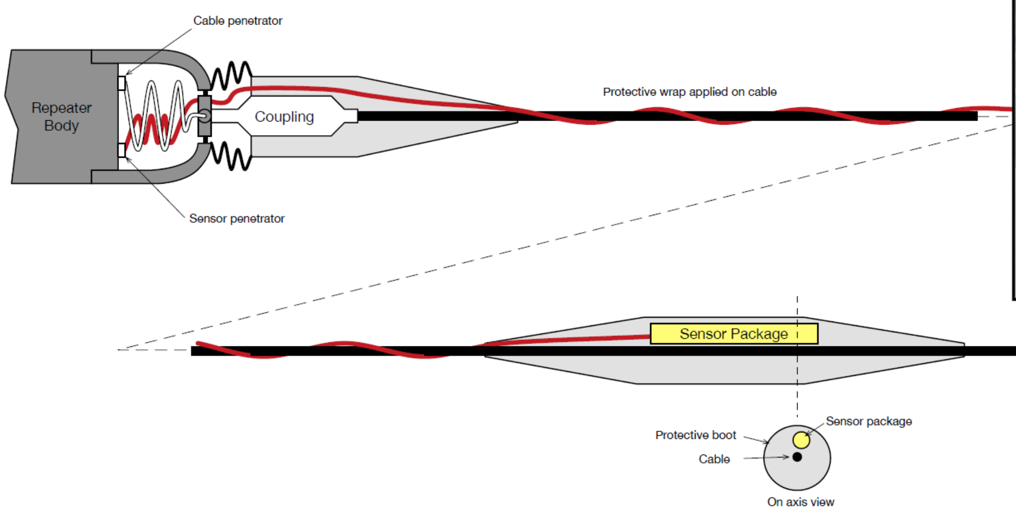
John You, *Nature*, 2010 –
Harnessing telecoms cables for science

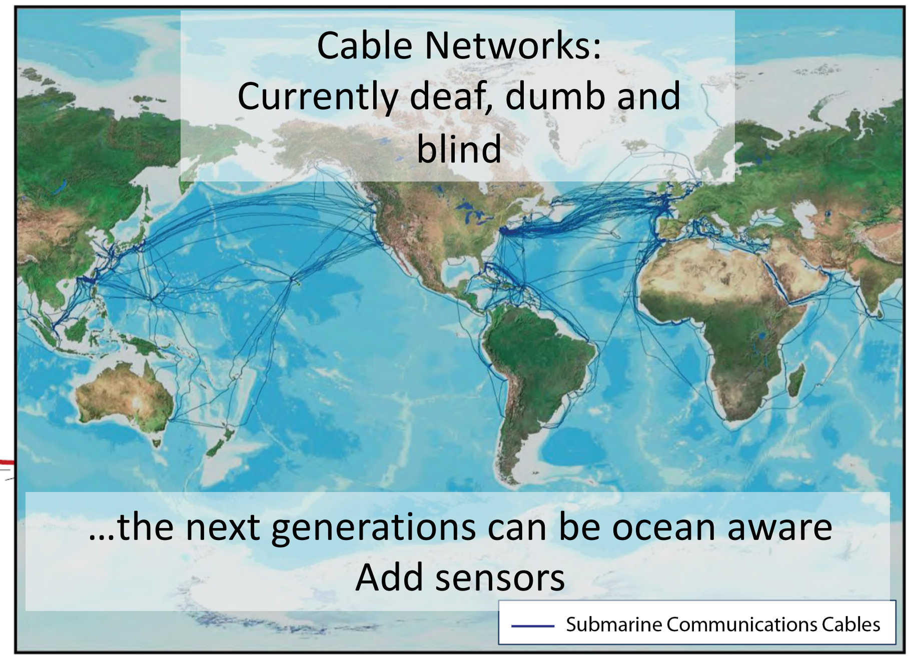
25-year lifetime

Coaxial cables, circa 1990

The basic idea

Joint Task Force
SMART SubSea Cable Systems





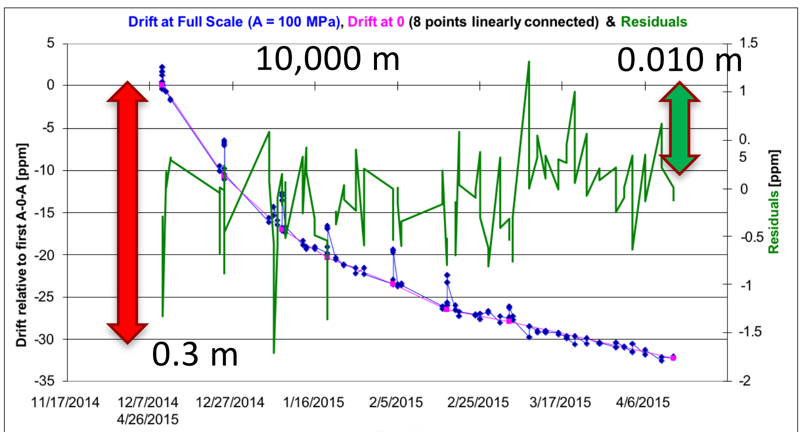
Source: TE subcom

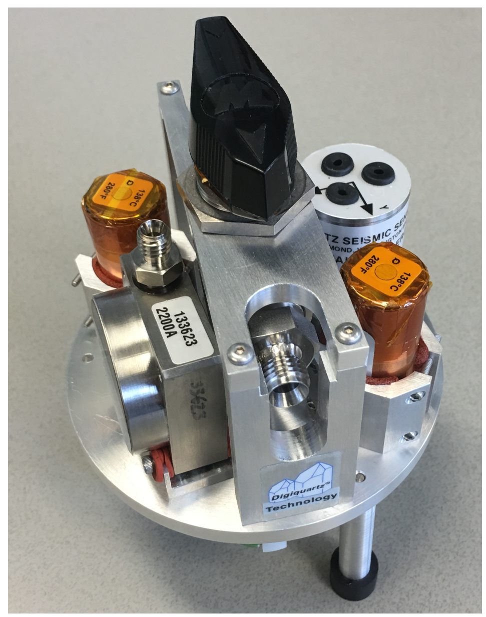
Every ~50 km

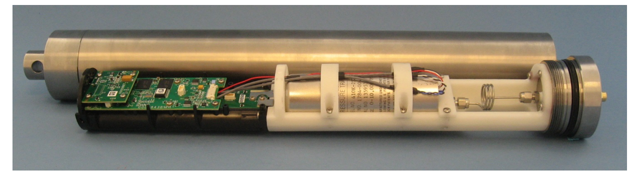
Paroscientific Sensors RBR

- Pressure, acceleration
- Pressure drift solution – wrt internal pressure – "GODS"; ***Testing on MARS in 2017***

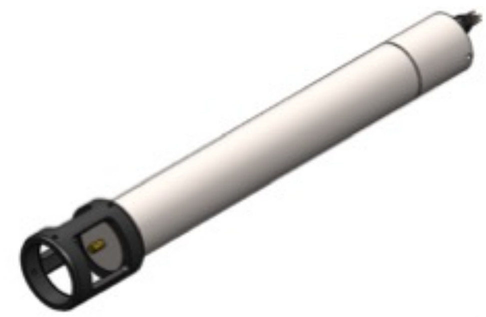
Courtesy J. Paros, P. Migliacio







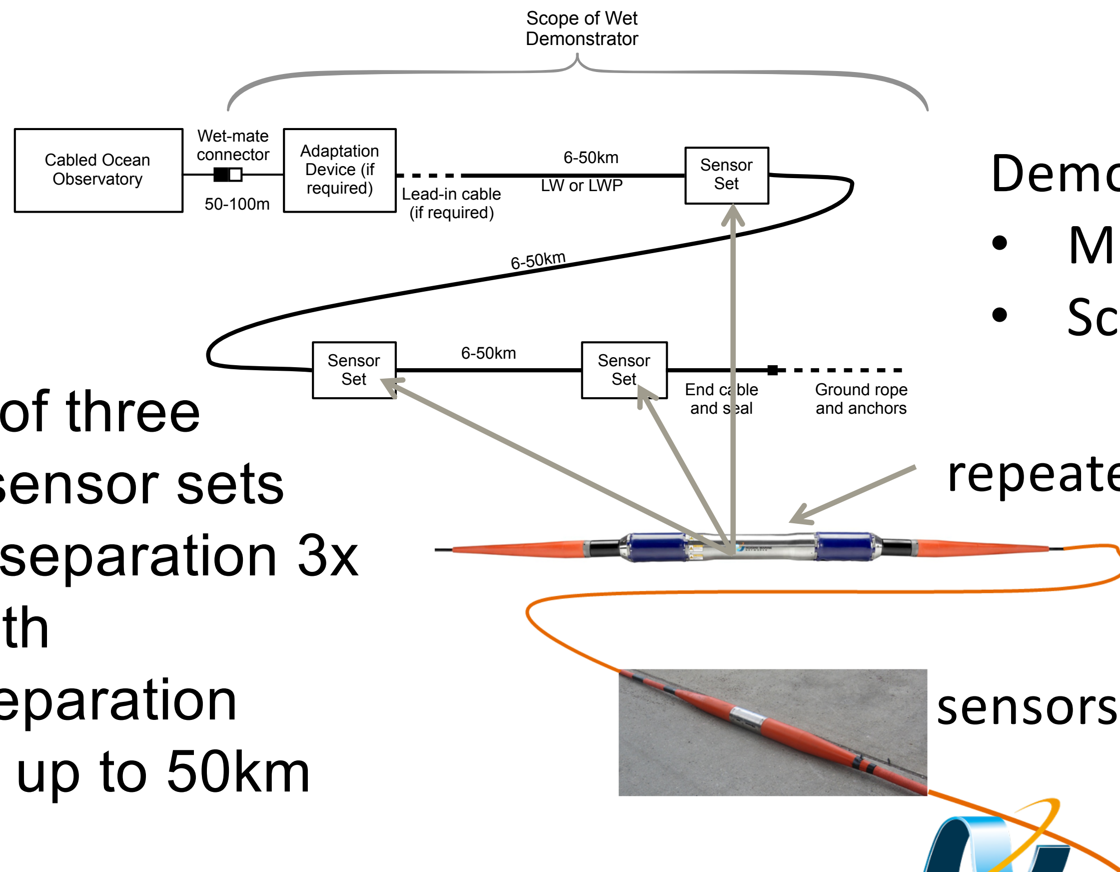
Pressure



0.5 m with P, T, accel

Courtesy C. Kontoes, G. Johnson

JTF Wet Demonstrator – proof of concept



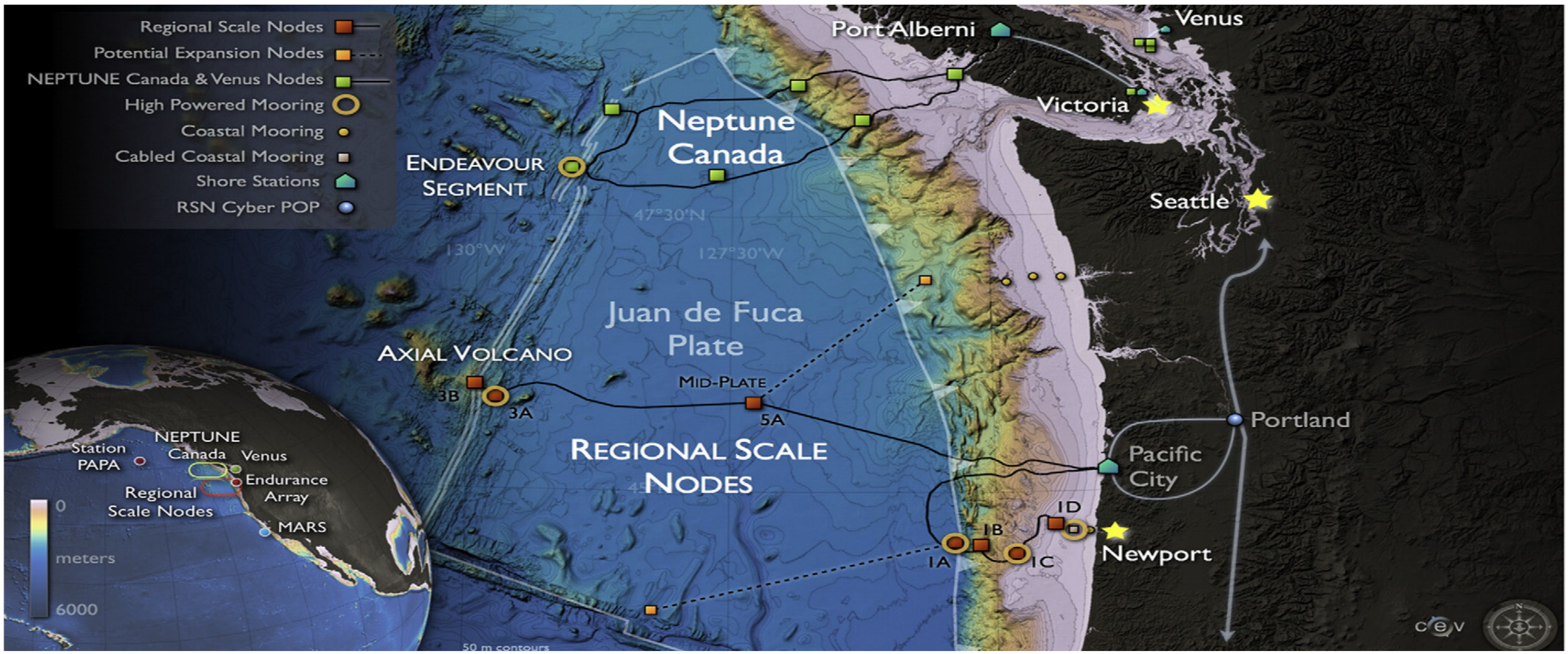
Demo:

- Mechanical deployment
- Science, good data

- Minimum of three repeater/sensor sets
- Minimum separation 3x water depth
- Greater separation preferred, up to 50km

Potential Wet Demonstrator sites

U.S. submarine cabled observatory (Regional Scale Nodes) and Canadian observatory (NEPTUNE Canada)



Kelley et al. (2014)

Programmatic

Facilitation by ITU-WMO-UNESCO IOC's Joint Task Force (JTF)

JTF, and its three sponsoring agencies, will promote, collaborate and facilitate in:

- Helping advocate for and phased implementation of SMART subsea cable systems
- Linking key stakeholders: monitoring and disasters, ocean observing community, with international and national agencies/NGOs responsible for social and economic benefits, cable owners and suppliers
- Wet Demonstrator project: working with observatories, industry and sponsors
- Community involvement: workshops (a la NASA, GFZ-JTF)

Your participation welcome and encouraged!

Challenges for the JTF, research community, and industry

- Raise awareness, educate and publicize (in part why we are here today)
- Search out the funds and potential investors
- Coordinate and collaborate for a universal solution, but tailored to specific deployments
- Educate governments to facilitate permits and funding, and to utilize new environmental data
- Link to other global initiatives and international agencies

114th Congress, 1st Session, H. R. 34

Tsunami Warning, and Education, and Research Act of 2015

Passed by Unanimous Consent:

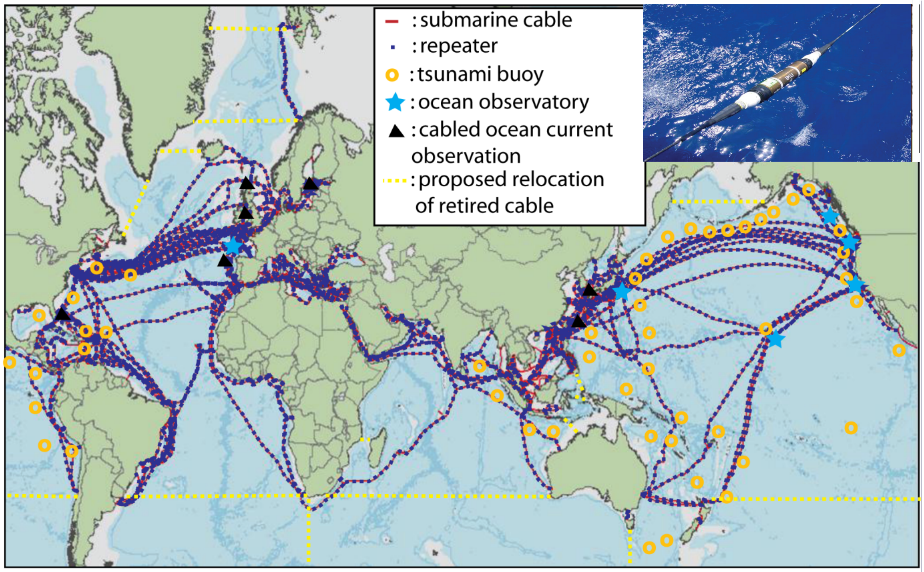
House 1/7/2015   Senate 10/6/2015 amended

- SEC. 4. TSUNAMI FORECASTING AND WARNING PROGRAM.
- (b) COMPONENTS.—The program under this section shall—
- (9) provide and allow, as practicable, for integration of tsunami detection technologies with other environmental observing technologies and commercial and Federal undersea communications cables;

Societal benefits in adding sensors for climate and disaster monitoring

Societal and environmental issues:

- Climate change – ocean temperature and circulation – direct impact on societies
- Sea level rise – hazard for coastal states and cities
- Disaster Warning– tsunami monitoring throughout ocean basins and coastal margins



Enable submarine cables to be ocean aware – a ”new” societal resource