Research to Operations: From Point Positions, Earthquake and Tsunami Modeling to GNSS-augmented Tsunami Early Warning

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Looking North into the Pacific Ocean, Island of Oahu, Hawaii

Our Goals

Leverage NASA research investments in

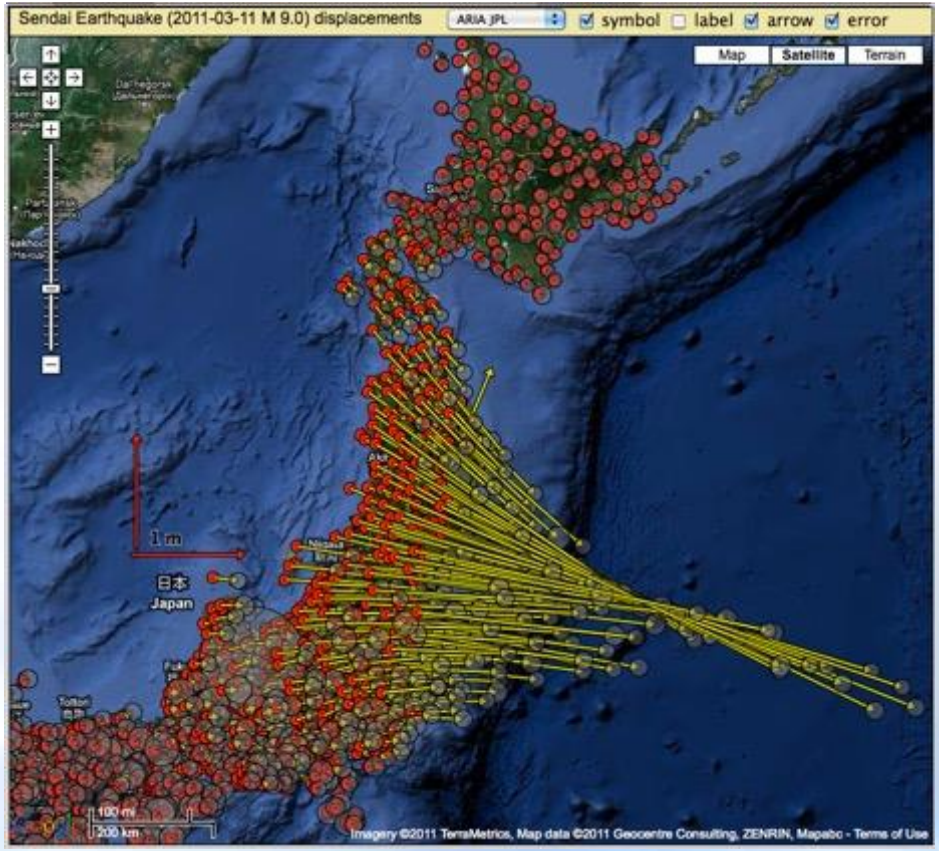
- Real-time GNSS (global navigation satellite system)
- Earthquake early warning
- Tsunami early warning to augment the speed and accuracy of the NOAA National and Pacific Tsunami Warning Centers (NTWC and PTWC) response process.

Advance readiness toward application

- Demonstration of integrated and collaborative science and technology
- Evaluation and Testing with end users
- Transition of research results to operational applications (*R2A*)

Augmenting Tsunami Warning
with GNSS

- Geodetic methods speed up earthquake magnitude and location estimates for large earthquakes
- Can provide information about faulting and ground deformation
- Can inform tsunami risk by understanding the change in the coastline and ocean floor

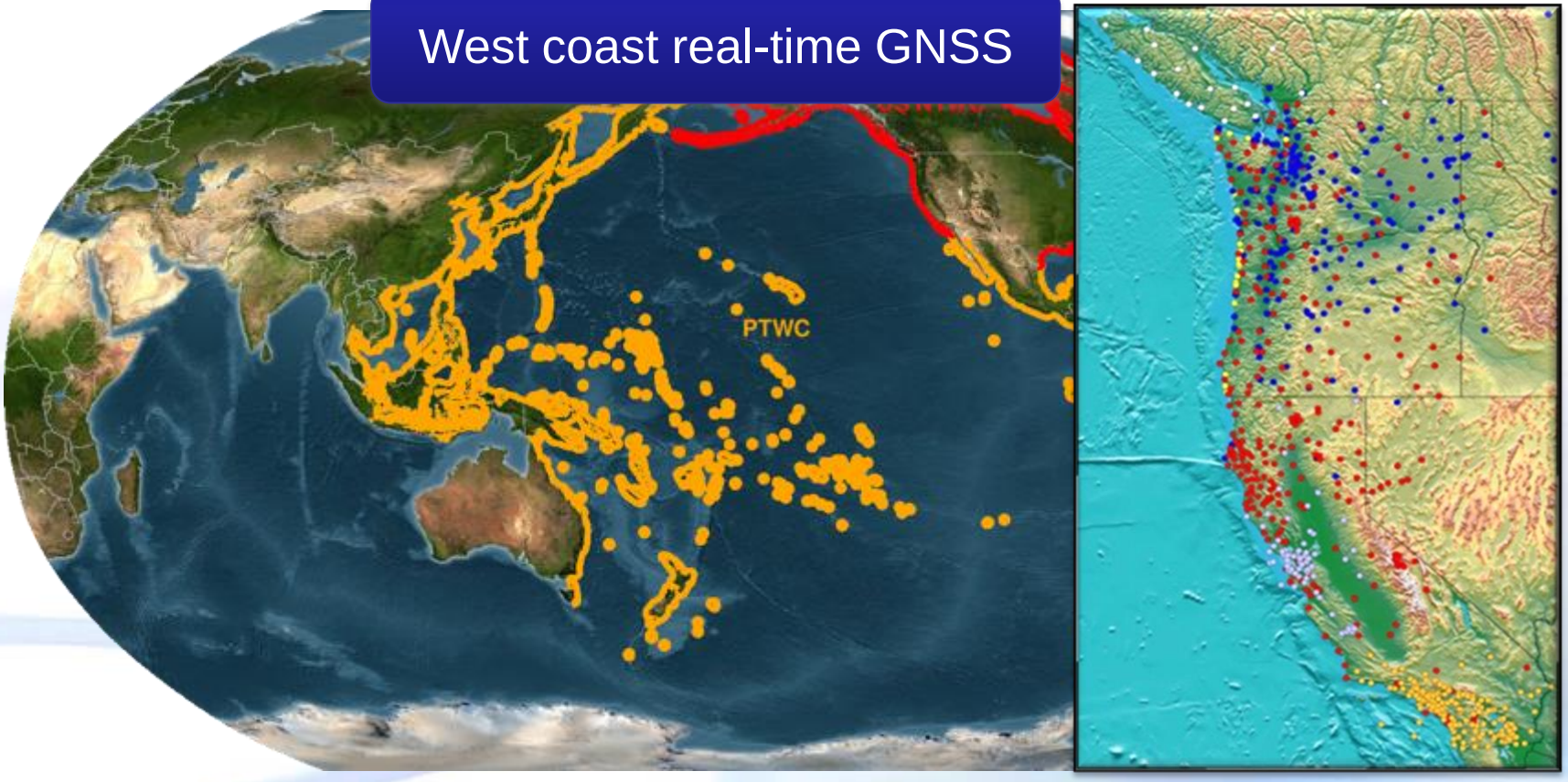


Acknowlegements

- NASA Earth Science
  - Research and Analysis, Technology, and Missions
- NOAA National Weather Service
  - Operational Tsunami Early Warning Centers
- NASA Applied Science - *is what we're all about!*
  - Transition of NASA Earth Science & Technology to end users
- ROSES RRNES
  - Cooperative agreement for Rapid Response and Novel Research in Earth Science

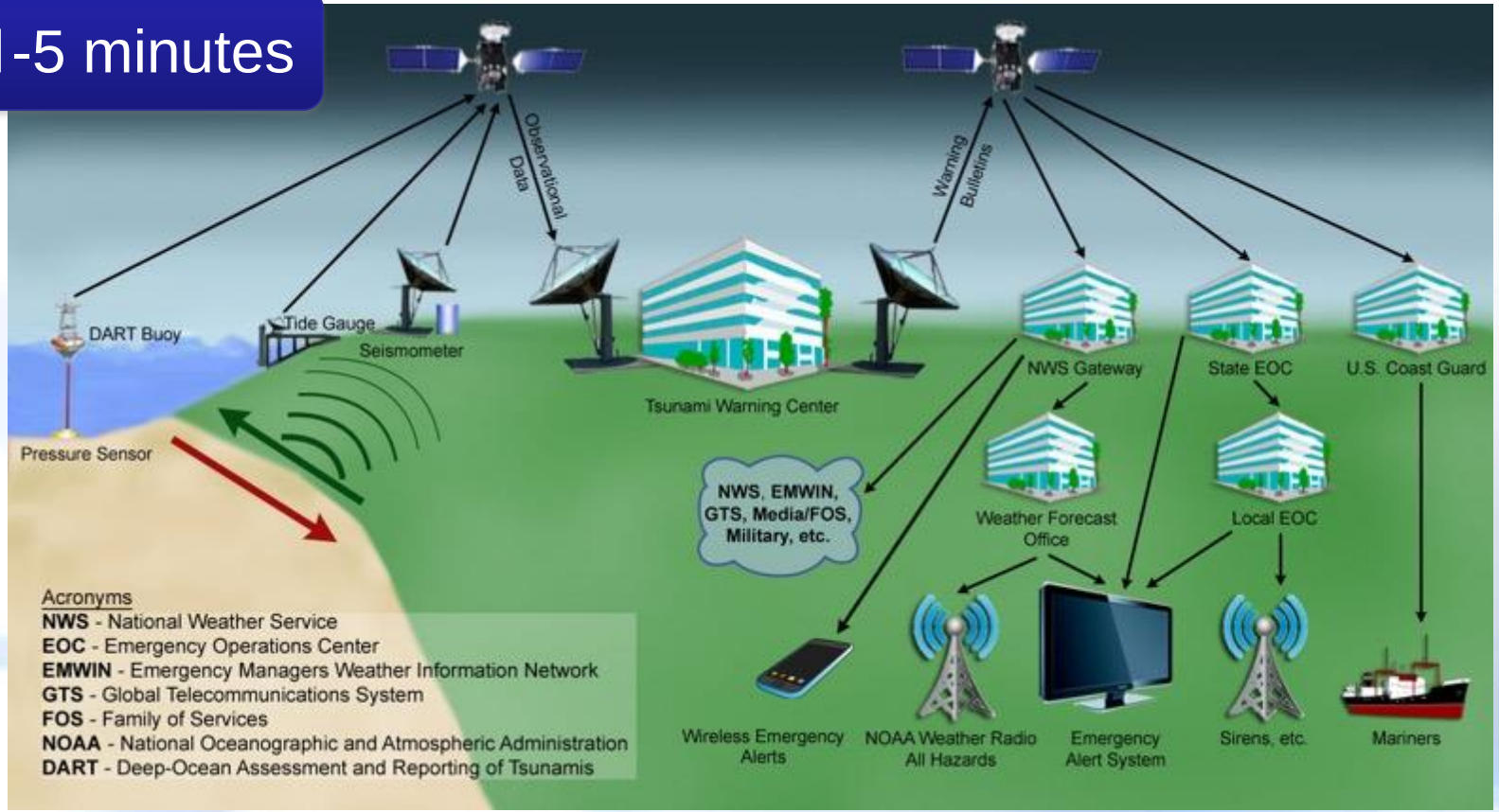
NOAA Tsunami Warning Centers

West coast real-time GNSS



How Tsunami Warning Works

…in 1-5 minutes



NASA Funded Contributors

- **Scripps Institution of Oceanography**
  - Seismodeogetic Sensors
  - GNSS Processing
- **NASA Jet Propulsion Lab**
  - Global Differential GPS (GDGPS) Network/Processing
  - Tsunami Source Function Estimation
- **University of California Berkeley**
  - Historic Data
  - *Fakequake* Scenarios
- **University of Washington**
  - Geodetic Algorithms
- **Central Washington University**
  - GNSS Processing
  - Communication/Merging

A New Approach !
Research to Application (R2A)

- Team Building with Program Management
- Intensive and Tactical Webinar and Face-to-face Meeting Series
  - Gained shared understanding of mature research results, available technologies, data access and operational system opportunities
  - Enabled collaborative design
  - Committed to integrated plans and implementation objectives
- Rapid Response Funding – unique and timely
- On-going Commitment and Engagement

NTWC, Palmer, Alaska

- Shared understanding of an Operational Tsunami Warning Center process
  - Quick Response Dominates
  - State of the Art is Hands-on
  - Where does GNSS Fit In?
- Develop an Architecture
  - Data and Functionality
  - Module Design
- Integration Plan
  - Testbed to evaluate capabilities and transition

Tsunami Response Timeline

0.5-2 minutes:

- First Alert from Seismic Alarms

1-5 minutes:

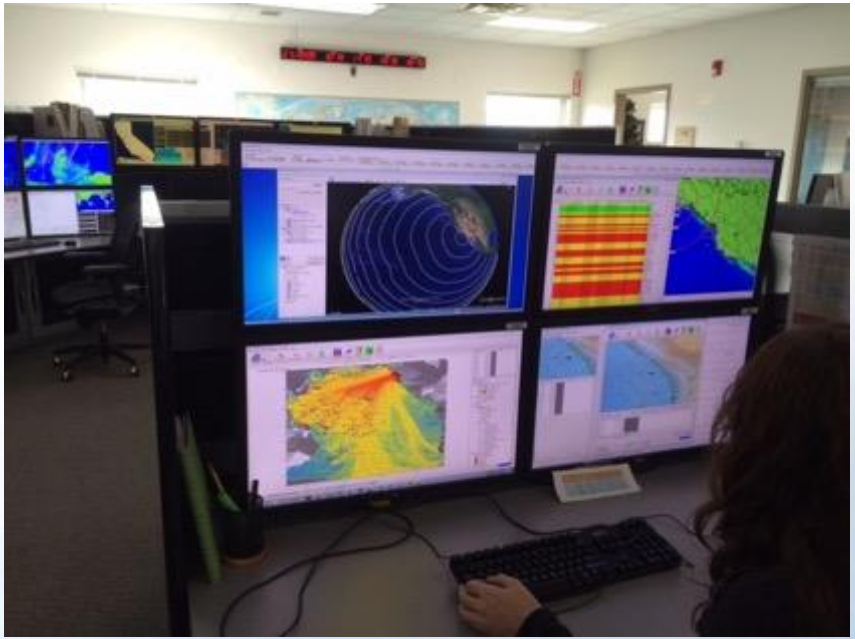
- Initial seismic processing complete and warning issued

20-90 minutes:

- First observation of tsunami on sea level gage

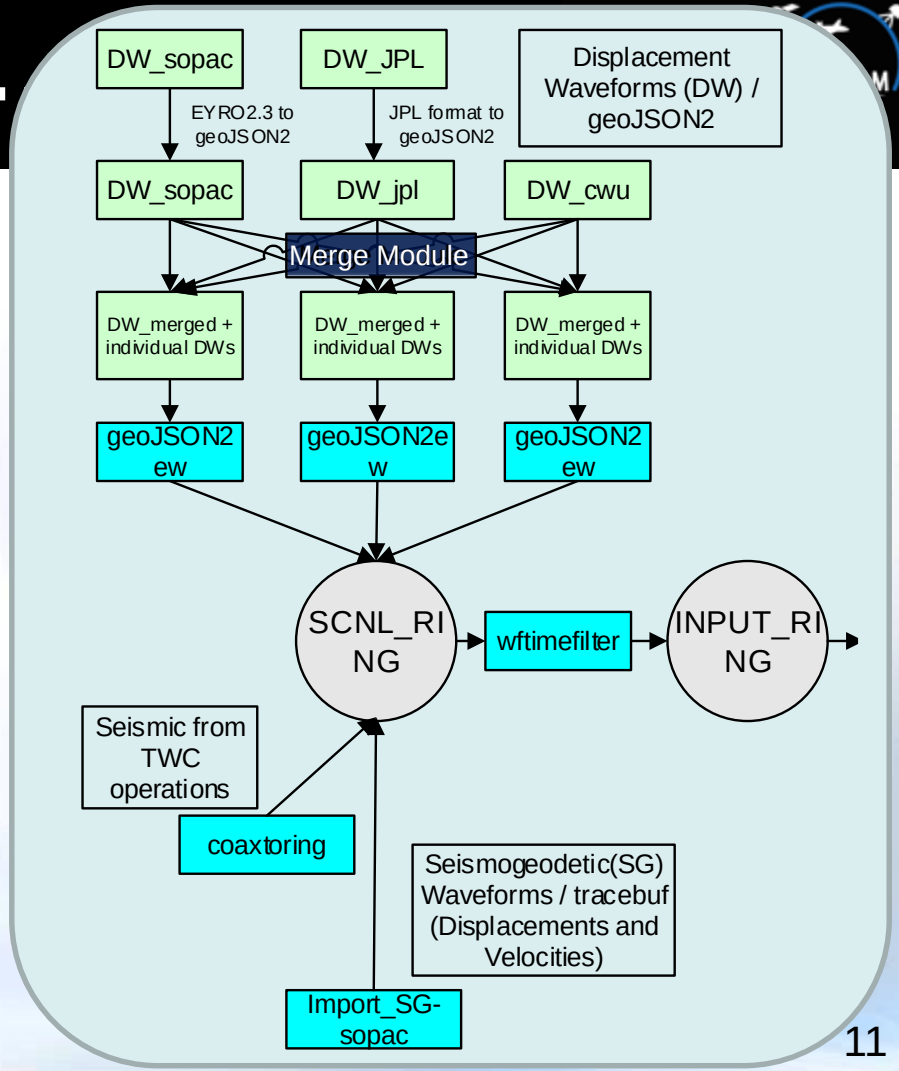
30-100 minutes:

- Forecast based on models with assimilated sea level



Bringing GNSS Data..

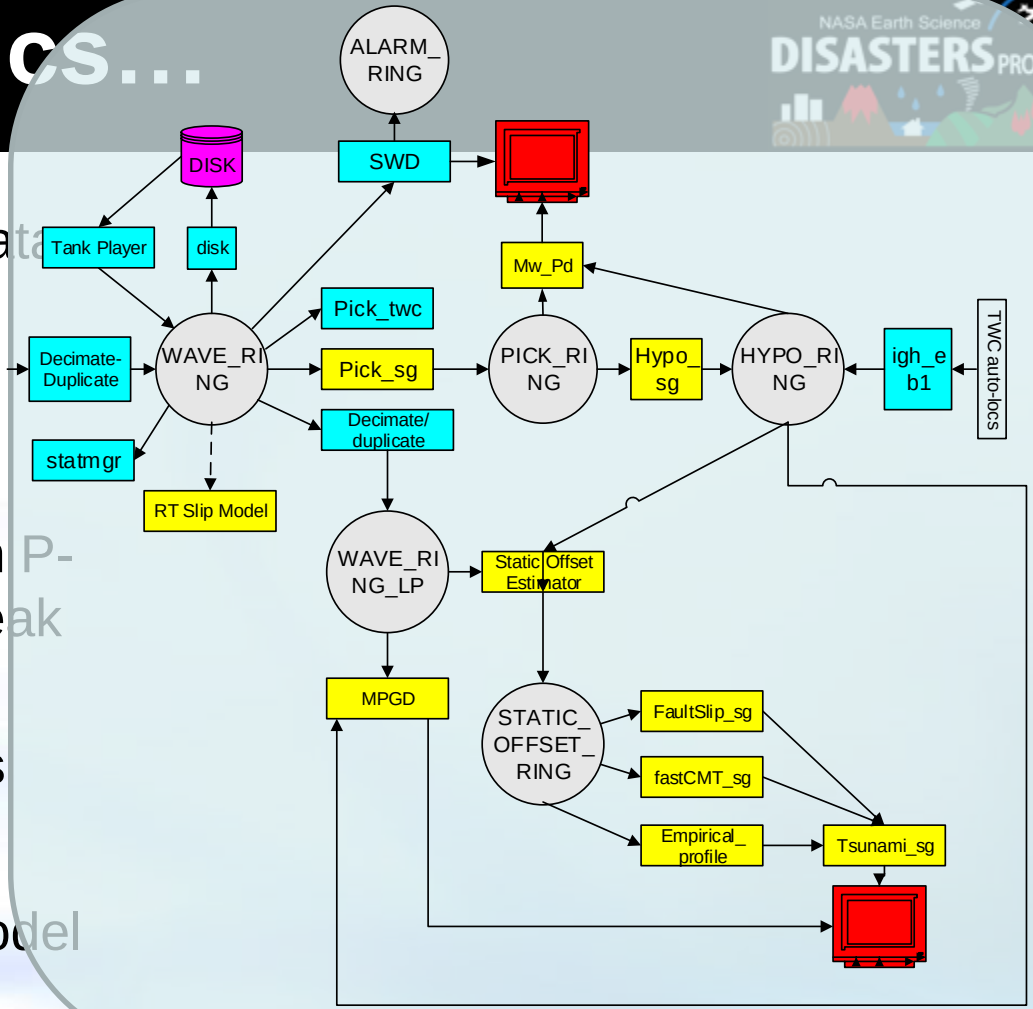
- Three GNSS Data Sources
- Redundant Merged Streams
- Standard Message Passing
- Seismogeodetic Data
- Earthworm Compatibility
- Delivered to both PTWC and NTWC



Bringing Geodetics…

GNSS and Seismogeodetic Data Require Updated Algorithms

- P-wave picking
- Hypocenter estimation
- Magnitude scaling based on P-wave amplitude (Pd) and peak ground displacement (PGD)
- Finite-source CMT solutions
- Static fault slip models
- Tsunami source function model



PTWC, Ford Island, Hawaii

- Compare and understand PTWC process
  - Different computational environment
  - More direct modeling
- Review our efforts
  - Data network established
  - All centers contributing and merging data
  - Demonstrate and Discuss Modules
  - Diagnose data gap/latency issues
- Decide on our path forward
  - Resolve communication issues
  - Install concrete/simple modules

Next Steps and Lessons Learned

Where are we now?

- Data architecture is streaming and merging data from all centers
- GNSS algorithm modules are being tested
- Focusing on integrating high value modules
  - Offsets (instantaneous -> static)
  - MwPGD – Peak Ground Displacement (in 2 min.)

What have we learned?

- The complexity of integration was underestimated
- Experiencing operations was crucial understanding needs
- Hands-on process of communicating needs and capabilities

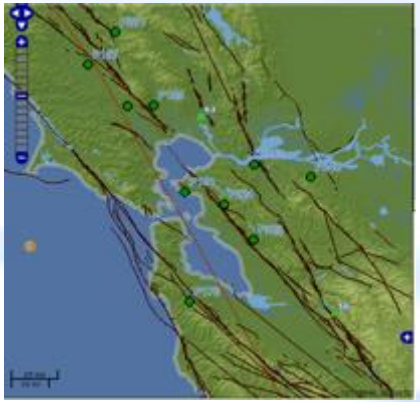
Goals Going Forward

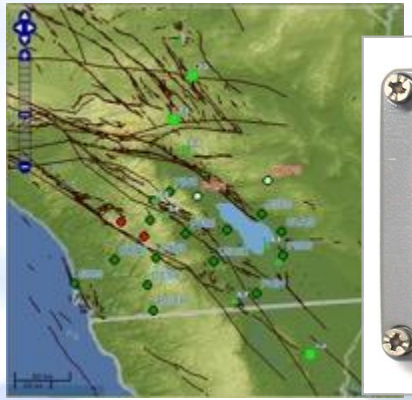
- Create and leverage partnerships among researchers, developers and operational end users
- Enable collaborative evaluation and testing, co-development, integrated planning and program management
- Promote access and availability to critical low-latency data sources characterizing areas of highest risk
- Support unique and urgent opportunities to harvest mature research results, applications, and technologies
- Recognize that Research to Applications requires collaboration around shared objectives and takes considerable time and targeted resources

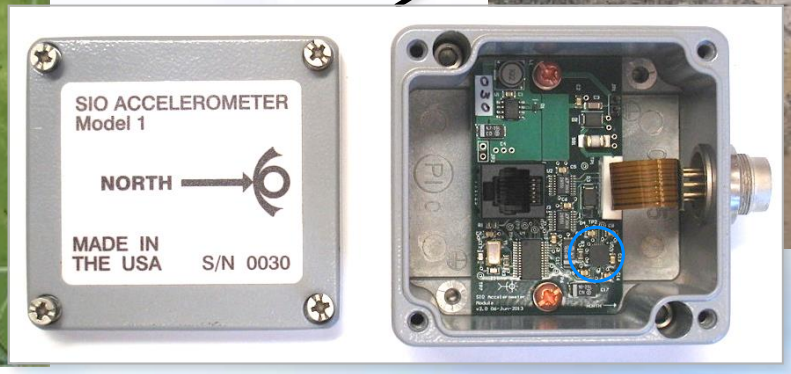
BACKUP SLIDES

Scripps Institute of Oceanography

- Leads the Real-Time Earthquake Analysis for Disaster Mitigation (READI) Network
- Developed MEMS Seismogeodetic Sensors
  - Deployed in Bay Area by UNAVCO
  - Deployed in Southern California on SCIGN

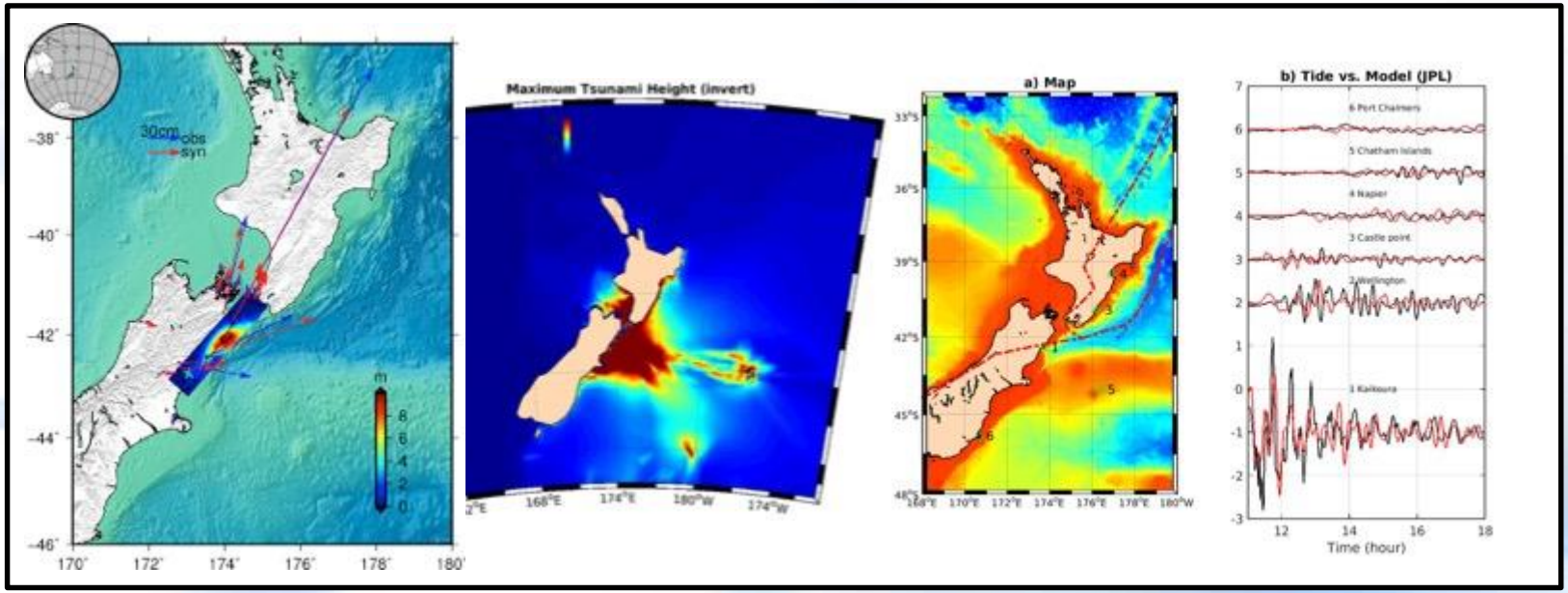






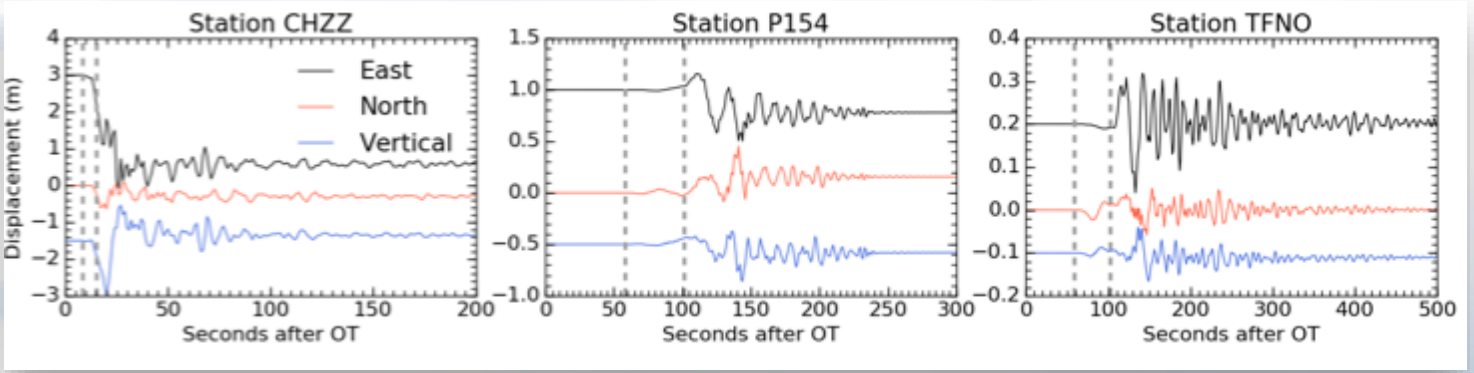
Jet Propulsion Lab

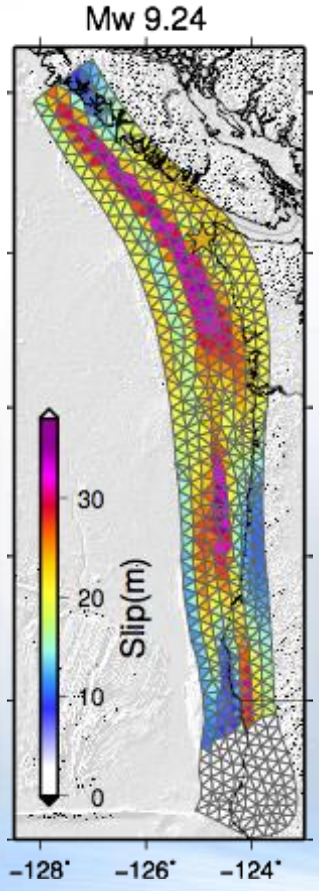
- GPS-Aided and DART-Ensured Real-time (GADER) Tsunami Early Detection System
- Global Differential GPS (GDGPS)
  - 250+ Global and Regional GNSS Stations Currently Served



Univ. of California Berkeley

- Developed *Fakequakes* and Event playback tools
- Contributed to evaluation & testing and exercise participation

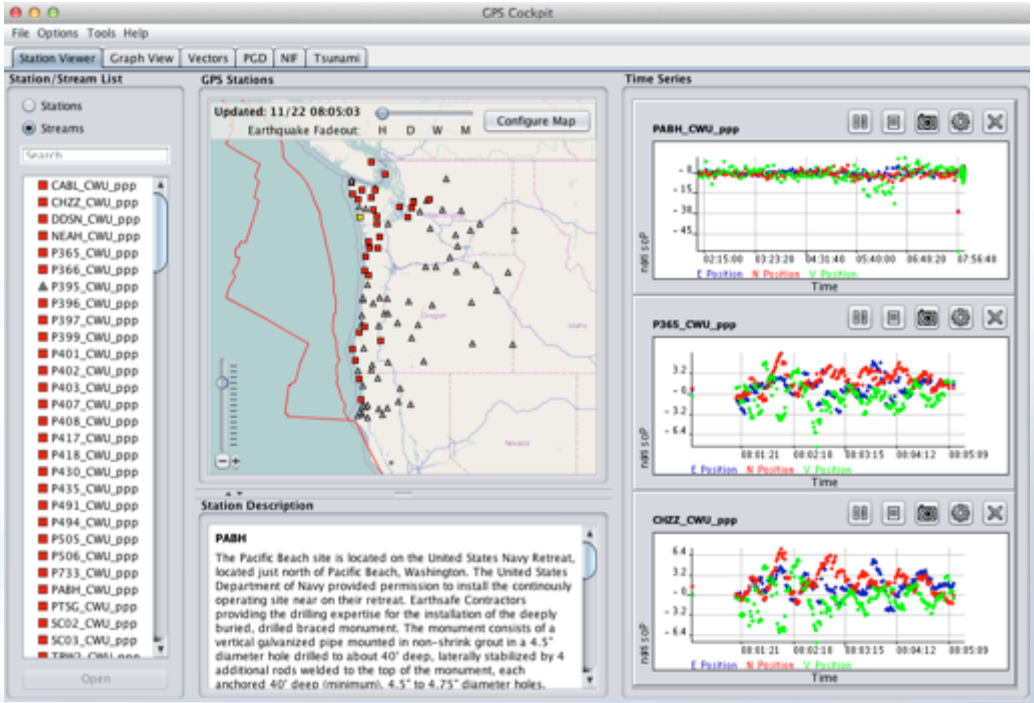




Central Washington University

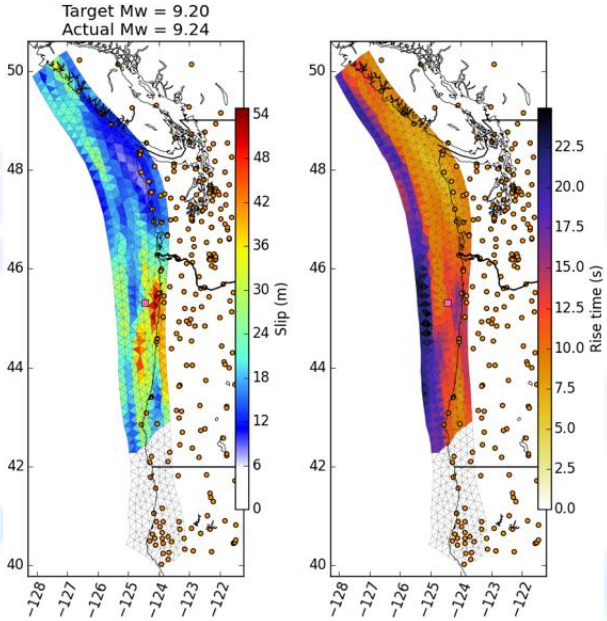
Contributed and Developed

- *RabbitMQ* casting
- Kalman filter based merging of solutions
- *GPS Cockpit* network monitoring
- Cascadia megathrust fault continuous estimation
- PANGA network

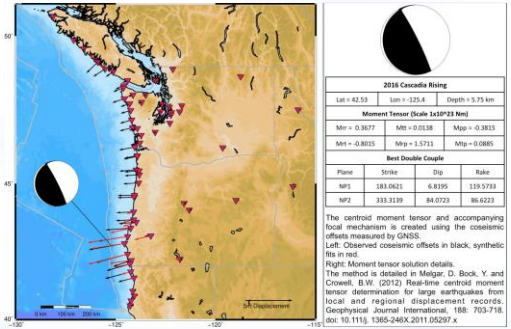


Participation in Cascadia Rising

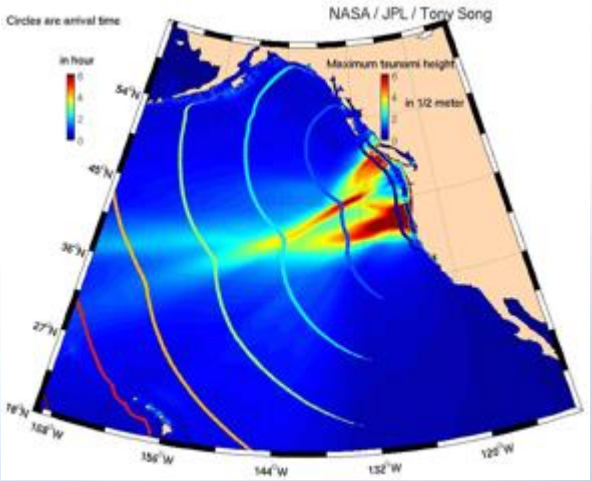
- NOAA and NASA cooperated in developing GNSS tsunami products for testing in the Cascadia Rising National Level Exercise (NLE)



Fakequakes and GNSS Measurements
Melgar, UC Berkeley



Simulated Location and Magnitude Determination
Bock, Scripps



Resulting Tsunami Source Function
Song, NASA JPL

Consistent, Redundant Data Streams