Tsunami Detection from Space using GNSS Reflections

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Tsunami Detection from Space

- Tsunamis are a global phenomenon
- Satellites are predestined for global monitoring

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Tsunami Detection from Space

Radar Altimetry (RA)

- Tsunami detection with RA demonstrated for Sumatra tsunami
- Only few satellites
- Data transmission only once per orbit
- Measurements only along track

Left: Measured and modelled sea surface anomaly (SLA) of 60 cm for JASON-1 pass 129, 1:53 hour after the earthquake that generated the Sumatra tsunami (right).
Tsunami Detection from Space

GNSS-Reflectometry (GNSS-R)

GNSS-R Code Altimetry

- Delay as a measure between direct and reflected path travel time

GNSS-Reflectometry (GNSS-R)

- The interference of the phase shift between direct and coherently reflected signal can be translated into height variations.
- Depends on surface roughness and grazing elevation angles.
Comparison of Two Configurations

**Code Altimetry**
- PARIS concept
- Zenith and nadir antenna, omnidirectional in azimuth
- Reflection path elevation $> 35^\circ$

**Phase Altimetry**
- Coherent reflectometry concept
- Fore and aft looking antenna, $60^\circ$ halfangle in azimuth
- Reflection path elevation $< 5^\circ$
Detection Simulation Assumptions

- GNSS-R on Low Earth Orbit (LEO) satellites
- Walker constellation
  (e.g. 18/3 means 18 satellites on 3 orbits)
- Omnidirectional antenna configuration to receive reflections at all possible elevation and azimuth angles
- GPS, GLONASS, and Galileo available as signal sources
- 20 centimeter altimetric sensitivity to detect tsunami waves (anomalies) of 20 cm and higher, technical feasibility provided
Tsunami Wave Propagation Model

- TUNAMI-N2 tsunami wave propagation model
- 5 arcmin spatial grid, 1 min resolution, 3 hours period
- Reflection point ground tracks crossing the tsunami area

Sumatra tsunami, 2004-12-26, $M_{9.1}$
Tsunami Detection Simulation

- Count number of grid cells crossed by ground tracks matching the sensitivity criterion of $\geq 20$ cm for each time step
- Repeat 100 times with random start time because start of event is unknown a priori
- Cumulate first detections

Simulation parameters:
- 18/3 constellation, 900 km alt., 60° inc.,
- Sumatra tsunami, 20cm sensitivity,
- omnidirectional view

Results:
- 98% detection probability after 15min when using all GNSS together as source
Andaman and Amorgos Tsunami

Andaman, Indian Ocean, 1941

• Medium event
• $M_{8.1}$

Amorgos, Mediterranean, 1956

• Largest event in the Aegan Sea in 20th century
• $M_{7.8}$
• Slides near Astypalaia and Folegandros
Andaman and Amorgos Tsunami

- 91% detection prob. for Andaman event after 15 min using 48/8
- First detections of Amorgos event after 27 min
- Similar detection performance when detecting slides only
GNSS-R Activities from GFZ

- Lake Walchen Experiment

  Waveform and phase GNSS-R measurements with the OpenGPS and the GNSS Occultation Reflectometry Scatterometry (GORS) receiver prototype, a modified geodetic JAVAD receiver.

- GPS-SIDS

  GPS Sea Ice-Dry Snow Experiment
  Winter 2008/2009
  Godhavn, Disko Bay, Western Greenland
  Cliff 670m above sea level
  Phase altimetry: semidiurnal tides
ZOIS
(Zeppelin Occultation Interferometry Scatterometry)

GNSS-R measurements by GFZ and DLR on board of the Zeppelin NT. Zenit and sidelooking antennas at rear engine, nadir antenna at cabin. Next measurement flight scheduled for October over Lake Constance.
GEOHALO

- High Altitude and LOng Range (HALO) research aircraft
- GEOHALO: Gravity, Magnetik and GNSS-Reflectometry, Scatterometry & Radio Occultation
- Aegan Sea, Mediterranean, 2012
- Status: Certification process started
MicroGEM – Phase A/0 Study

GPS-Reflections, Galileo-Reflections, Occultations, TEC, VLBI, SLR and Downlink.
Conclusions

• Simulations show that tsunamis are detectable with GNSS-R LEO satellite constellations within 15 minutes

• The detection performance for tsunamis in the Indian Ocean is good also for medium tsunamis but poor even for strong tsunamis in the Mediterranean.

• GFZ is active in several ground based, airborne and spaceborne experiments to develop a space borne GNSS-R system that can be the basis for a future global tsunami early warning system.
Thank you for your attention
GNSS-R Reflection Point Calculation

- Reflection point calculation for WGS84 using ray path minimization like in Garrison et al., 2002

\[
\rho(\phi_S, \lambda_S) = \sqrt{(X_L - X_S)^2 + (Y_L - Y_S)^2 + (Z_L - Z_S)^2} \\
+ \sqrt{(X_T - X_S)^2 + (Y_T - Y_S)^2 + (Z_T - Z_S)^2}
\]

\[
X_S = a \cos(\phi_S) \cos(\lambda_S) \\
Y_S = b \cos(\phi_S) \sin(\lambda_S) \\
Z_S = c \sin(\phi_S)
\]
Tsunami Detection Performance

- Cummulation of first detections defines detection probability
- Detection performance is high when probability function is steep
- The detection probability function results are significant

Detection probability functions of 24 different calculations for the Sumatra tsunami based on 18/3 Walker constellation at 900 km and with 60° inclination, with all GNSS reflections available.
LEO Walker Constellation Scenarios

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GNSS-R LEO Constellations

- Temporal coverage can be increased by using a GNSS-R LEO satellite constellation
- GPS reflection point coverage of several types of constellations with 18 satellites investigated
- Walker constellations show best reflection point coverage
Magnitude Dependency of Detection

- Good strong tsunami detection
- Only 45 – 60 % within first 30 minutes for medium tsunamis
- Week / local tsunamis not detectable
Dependency from Altimetric Sensitivity

- Tsunami detection simulation with various altimetric sensitivities
- For Sumatra tsunami the detection performance is good up to 100 cm but for Nias tsunami it should be 50 cm within first 15 minutes
Comparison of Various Scenarios

- Performance increases with number of satellites and orbit altitude.
- Within 15 min both perform similar but performance is low.
- Low orbits and few satellites lead to phase altimetry performing better.
Downlink Concept

• Onboard processing, transmission of suspicious tracks via geostationary communication satellites when satellite reaches equator region

• Downlink at stations installed in endangered regions