Seismo-Acoustic Analyses of the DPRK Underground Nuclear Tests for the Estimation of Source Depth

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CTBTO SnT 2017

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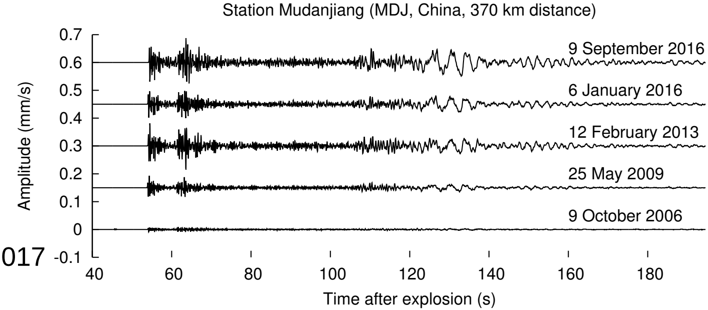
Introduction

- Nuclear tests are globally monitored with the Int. Monitoring System (IMS), in place for the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT)
- KNMI is the National Data Center (NL-NDC) for the verification of the CTBT and advices the Dutch Ministry of Foreign Affairs
- The Democratic People's Republic of Korea (DPRK) conducted underground tests in 2006, 2009, 2013 and 2016
- Estimation of seismic epicenter and yield; depth estimates are more difficult from tele-seismic data



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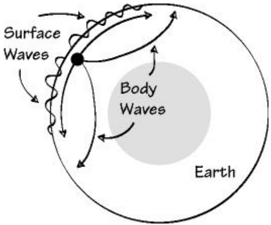
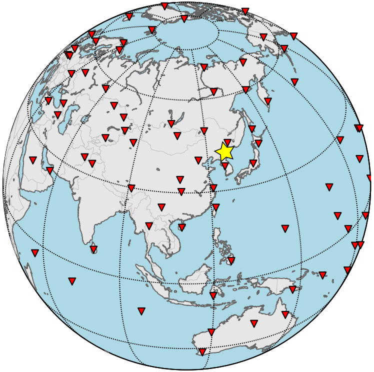
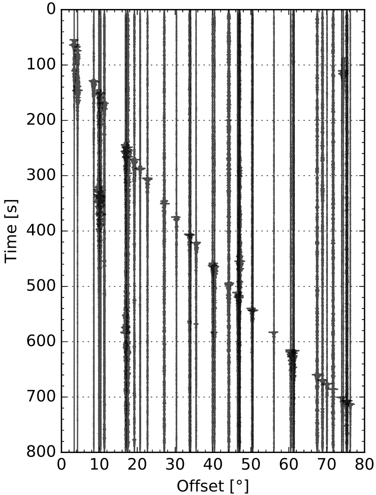
Seismic localization







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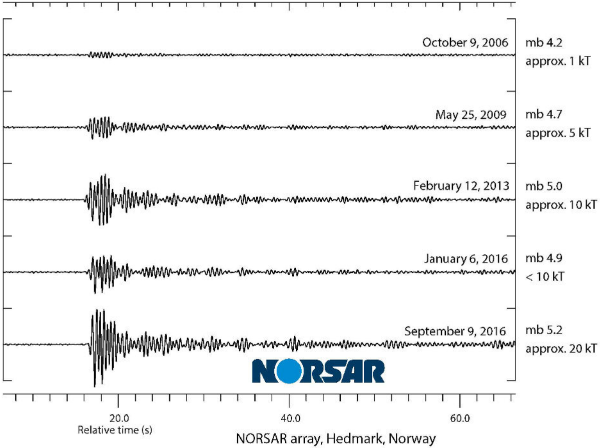
An underground nuclear explosion has a strength of a (minor) earthquake and is recorded worldwide.

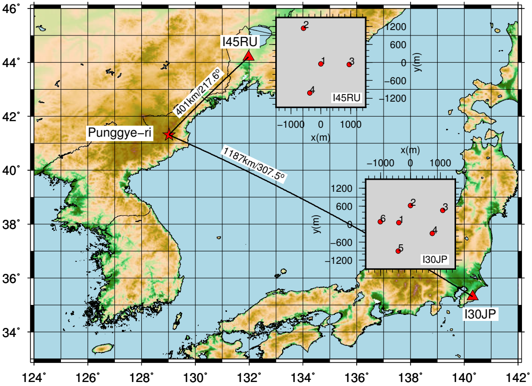
This allows for localization and seismic magnitude/yield estimation.

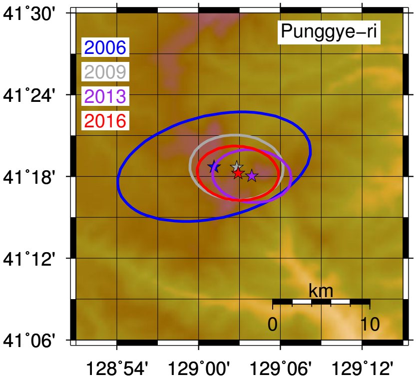
NORSAR's tele-seismic analysis



http://www.norsar.no/norsar/about-us/News/Press-Release—North-Korean-underground-nuclear-test-larger-than-previous-tests

Seismo-acoustic coupling; IMS infrasound arrays



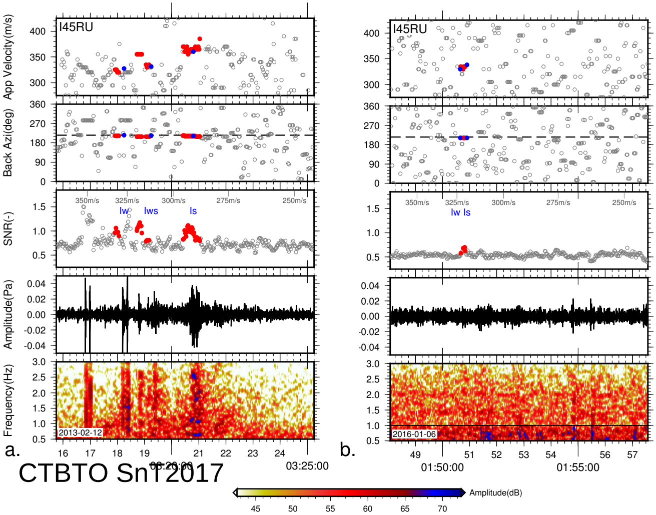


Besides detection on the global seismic network, the 2009, 2013 and 2016 nuclear tests by the Democratic People’s Republic of Korea (DPRK) also generated infrasound *Che et al., GJI, 2014*

The February 2013 and January 2016 tests have been detected on IMS infrasound stations in:

- Russia (I45RU; 2013 and 2016-01) and Japan (I30JP; only 2013)

2013 and 2016 infrasound detections at 400 km (I45RU)

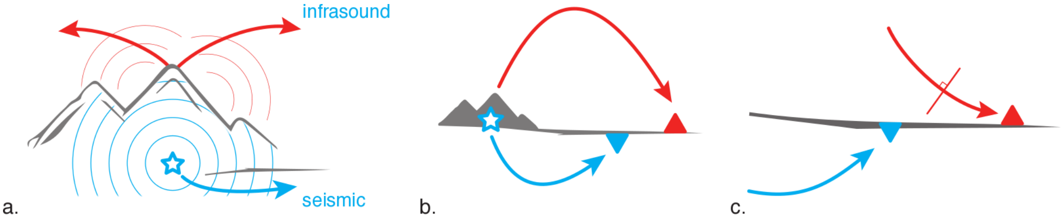


Red dots: detections of interest.
Blue dots: raytracing through 3D atmosphere.

Note that the 2016 detection (similar yield) is much weaker when compared to 2013.

Higher noise levels in 2016: 2.4 m/s compared to 0.9 m/s in 2013.

Seismo-acoustic coupling



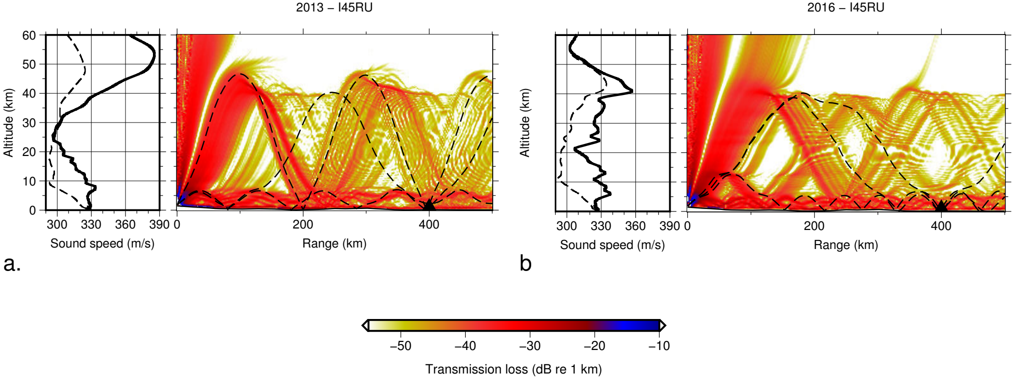
- What does this observation tell us about the source depth?
  This is difficult to constrain with tele-seismic recordings (Bowers and Selby, 2009)

- What is the contribution of the source depth and resulting lithosphere-atmosphere coupling?

- What role does the (upper) atmosphere and station noise levels play in the detectability?

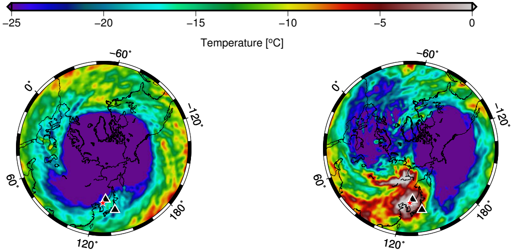
Bowers, D., and N. D. Selby (2009), Forensic Seismology and the Comprehensive Nuclear-Test-Ban Treaty, Ann. Rev. Earth Planetary Sc., 37, 209-236.

Propagation modeling towards I45RU

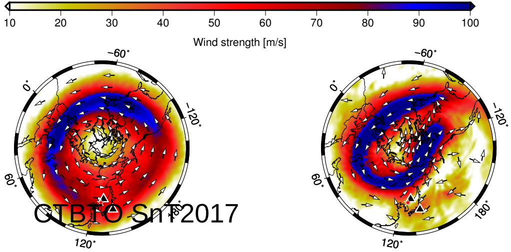


- Propagation (1 Hz) towards I45RU for the 2013 (l) and 2016 (r) tests
- European Centre for Medium-Range Weather Forecast (ECWMF) model
- Significant interaction between the troposphere and stratosphere
- In 2016, the loss is higher by 5.1 dB for the stratospheric arrival

ECMWF atmospheric specifications at 1 hPa (ca. 45 km)



a. 2013–02–12 b. 2016–01–06



c. 2013–02–12 d. 2016–01–06

12 February 2013

- Well developed circumpolar vortex around cold Arctic stratosphere
- Strong down wind condition towards I30JP, I45RU reachable

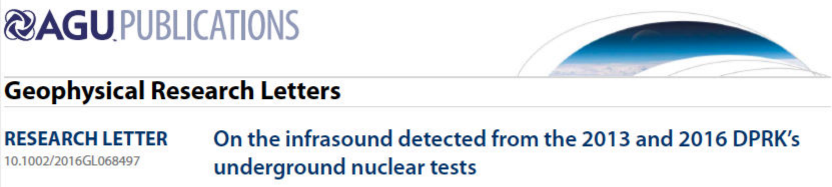
6 January 2016

- Disturbed polar vortex, early stage Sudden Stratospheric Warming
- Vortex is displaced and hot stratosphere over the region of interest
- Mixed conditions towards I30JP, I45RU reachable

A preliminary relative depth estimate

A simple expression (*doi:10.1002/2016GL068497*) that relates the ratio of source depth z to a ratio of far-field pressures, taking into account difference in propagation efficiency ΔTL:

$$\frac{z_{2016}}{z_{2013}} = \sqrt{10^{\frac{\Delta \mathrm{TL}}{20}} \times \frac{p_{r,2013}}{p_{r,2016}}} \quad (1)$$



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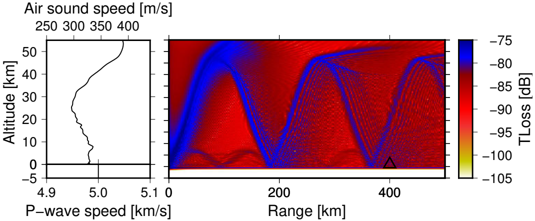
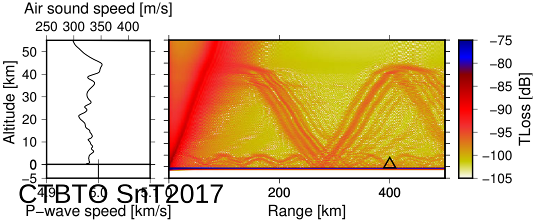
On the infrasound detected from the 2013 and 2016 DPRK's underground nuclear tests

Using the information from the stratospheric arrivals, and assuming a similar yield, we estimate that the 2016 test took place at least 1.5 times deeper than the 2013 test.

Assuming a minimum source depth of 450 m for the 2013 test (*Rougier et al., 2011, GRL*), this would imply that the January 2016 test would have occurred at least 225 m deeper.

Seismo-acoustic coupled propagation modeling





- Further quantification of coupling using finite-element modeling
- Seismo-acoustic modeling with sources at depths of 450 and 675 m
- Explains to first order differences in observed sound pressure level
- Extensions to include shear, topography and range-dependence

Summary

Observations

- The underground tests by the DPRK generated seismo-acoustic signals
- Clear infrasound detections were made in 2013 at I45RU and I30JP.
- In January 2016, only a weak return was observed at I45RU
- The I45RU observations are well explained with propagation modeling

Interpretation

- We estimate that the 2016 test took place at least 1.5 times deeper than the 2013 test
- We assume similar geological conditions and explosion yield
- In such a case, less energy was coupled at the lithosphere-atmosphere interface, which explains the lack of clear infrasonic detections in January 2016.

Since explosion depth is difficult to estimate from seismic data alone, this motivates a **synergy between seismics and infrasonics**.

Acknowledgements

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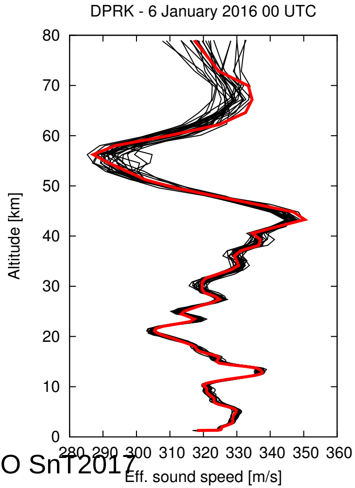
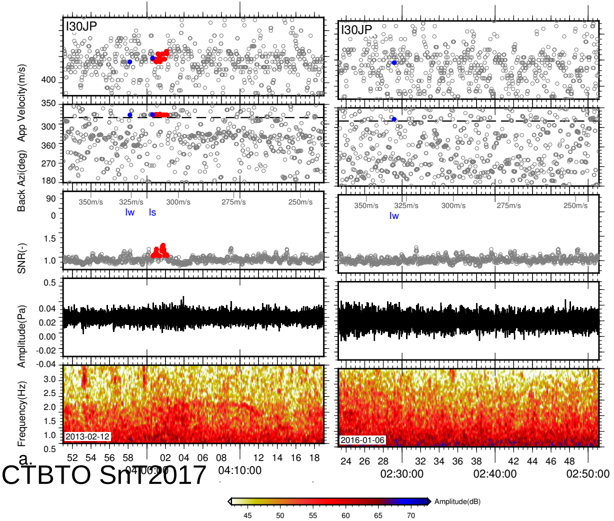
- L.E.'s contribution is partly funded through a VIDI project from the Dutch Science Foundation (NWO), project number 864.14.005

Quantification of propagation uncertainty



- Ensemble of analyses (ECMWF) to quantify uncertainties in data, errors in parameterization, numerics, ..
- Uncertainty due to unresolved small-scale variations (e.g. gravity waves)
- Estimated uncertainty range of 5 m/s around top of stratospheric waveguide
  - estimated limited impact on propagation uncertainty
  - area of further research

2013 and 2016 infrasound detections at 1200 km (I30JP)



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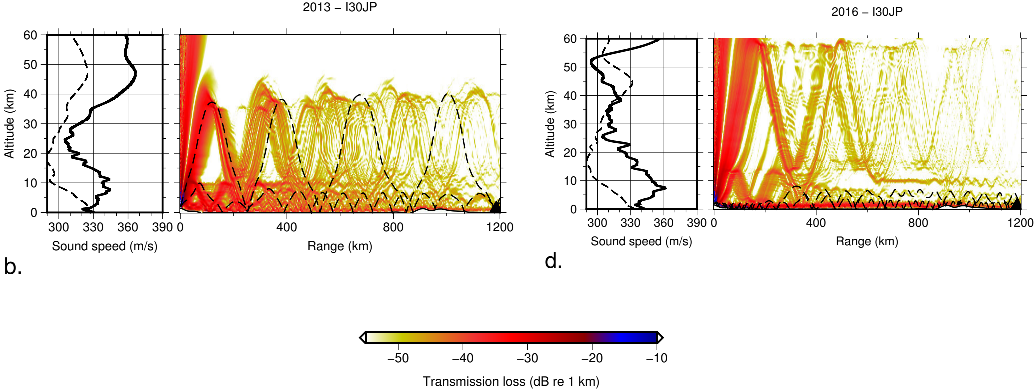
Blue dots: raytracing through 3D atmosphere.

No detections in January 2016

Only the 2013 stratospheric observations are correctly predicted.

Propagation modeling towards I30JP



- Propagation (1 Hz) towards Japan (I30JP) for the 2013 (l) and 2016 (r) tests
- European Centre for Medium-Range Weather Forecast (ECWMF) model
- Stratospheric propagation is inhibited in 2016 due to a Stratospheric Warming