Seismological constraints on ice properties at Dome C, Antarctica, from H/V measurements

Annie Souriau, CNRS-UPS, Observatoire Midi-Pyrénées, Toulouse, France
Jean-Jacques Léveque, Alessia Maggi, IPG-CNRS-UMR7516-Univ.Strasbourg/EOST, Strasbourg, France

Summary

The French-Italian Concordia (CCD) seismological station at Dome C is one of only two observatories installed on the ice cap inside the Antarctic continent. We have analyzed the seismic signal due to the ambient noise at this station, and at 3 temporary stations 5 km from Concordia, in order to determine the ice properties beneath these stations.

We have applied a method based on the horizontal to vertical (H/V) spectral ratio, commonly used to analyze soil response for seismic risk evaluation. It reveals a main resonance peak in the spectral ratios at frequencies between 6.7 Hz and 8 Hz, ascribable to the uppermost ice sheet.

The resonance frequency is well explained by a 30 meter thick unconsolidated snow or firm layer with a low S-velocity of 0.9 km/s, overlying a consolidated layer with S-velocity 2.0 km/s. This sharp velocity contrast is not related to a density contrast. We suggest that it is due to the closure of a large number of bubbles at about 30m depth.

Seismic records

The motion is recorded in 3 directions (one vertical and two horizontal) with broadband seismometers in the frequency range 0.1 to 40 Hz. The sampling rate is 0.05 s.

Seismic noise is a permanent motion of the Earth. It includes:
- Microseisms primarily due to the interaction of oceans with solid Earth, with periods T≤10s. They are mostly Rayleigh waves.
- High frequency noise (T≤1s) due to anthropic activity. It includes body waves (P and S waves) and surface waves (Rayleigh and Love waves).

The H/V method

The H/V method makes use of the behavior of the waves at interfaces with strong impedance contrasts.

Rock site conditions: For a station installed on rock with little topography: H/V = 1

Sedimentary layer over a rocky half space: Resonance peak with fundamental frequency f: ω/2π, where ω is the S-velocity in the layer and h the layer thickness

More complex situations produce multiple resonance peaks in the spectral ratios:
- Presence of multiple layers
- Weak impedance contrasts
- Non-flat layers
- Surface topography

H/V at Dome C

At station CCD

The most prominent feature is a peak at 6.7 Hz. Secondary peaks are observed at 0.40, 0.75 and 1.30 Hz.
A small time variability in the spectra is due to a change in the composition of the noise depending on the day.

The peak at 6.7 Hz is not observed at the buried station QISPA. It is likely to be due to the uppermost ice sheet.

At all the Dome C stations

A small geographic variability is observed. The main peak is at 6 Hz at the temporary stations, denoting slight variations in the ice sheet.

Modelling with synthetic seismograms

Synthetic noise is generated by summing a large number of synthetic seismograms with random properties.

Important parameters are:
- The thickness of the upper layer
- The impedance contrast
- The composition of the noise

Results and perspectives

From synthetic seismograms, we infer:
- The thickness of the upper layer: h≈30 m
- The impedance contrast at the base of this layer: υp = 0.9 km/s, υs = 2.0 km/s
- The composition of the noise: 20 to 30% of shear sources at low frequency, probably due to the wind-surface interaction.

Subglacial lakes are not detectable with this method

The low S-velocity layer of 30 m thickness at the top of the ice sheet is interpreted as a soft, firm or snow layer overlying consolidated ice. The discontinuity at the base of the soft layer is not observed on density or Young modulus and does not coincide with a dielectric discontinuity. The great sensitivity of S-waves to fluid or gaz inclusions suggests that it is due to the closure of pores at about 30m below surface.

The H/V method appears as a valuable tool to investigate the seismic properties of the ice sheet. However, the present study suffers from the low sampling rate, which limits the investigation at high frequency.

A better knowledge of the seismic properties of the ice sheet is necessary to correct the effect of ice on the waveforms of the seismic records for other uses (e.g. determination of local solutions, tomography, etc.). Specific experiments may be planned for this purpose.