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Characterizing ocean ambient noise using infrasound network

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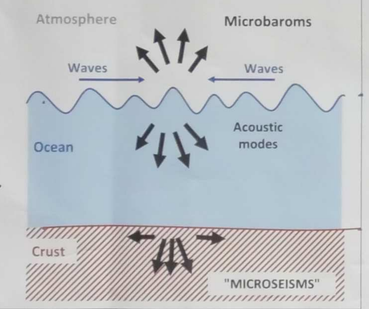
Abstract

The ability of the International Monitoring System (IMS) global infrasound network to detect atmospheric explosions and events of interest strongly depends on station specific ambient noise signatures which include both incoherent wind noise and coherent infrasonic waves. Ocean wave interactions contribute to the atmospheric coherent ambient noise field, therefore we apply wave action models to compute these microbarom sources. We use two-dimensional energy spectrum ocean wave products to build a global reference database of oceanic noise sources. Overall, we compare observed and modeled directional microbarom amplitudes at several stations worldwide distributed. Such studies aim to better characterize the coupling mechanisms at the ocean-atmosphere interface. In return, an improved knowledge-base on ambient ocean noise sources opens new perspectives for enhancing the characterization of explosive atmospheric events as well as for providing additional integrated constraints on middle atmosphere dynamics and disturbances in sparsely covered regions of the world.

Microbaroms

Microbaroms are low frequency acoustic waves (0.1-0.5 Hz) resulting from 2nd order nonlinear interaction of almost opposing ocean waves (Waxler and Gilbert 2006; Ardhuin and Herbers 2013).

They can propagate over thousand of kilometers in the atmosphere, allowing their detection worldwide.



Infrasound signal and atmospheric effects

The detection capability of the International Monitoring System (IMS) network is a key concern for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Microbarom signals dominate in the 0.1-0.5 Hz band and are continuously recorded at global scale (Landés et al., 2012).

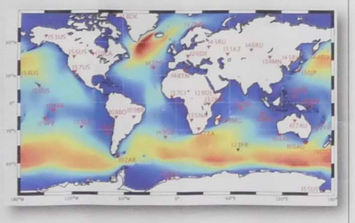
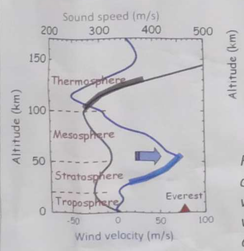


Figure 1 – IMS infrasound network and microbaroms source areas (over 3 years). Red triangles indicate certified stations.



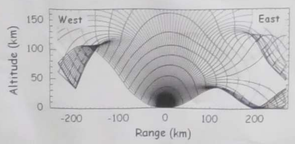


Figure 2 – Left: atmospheric characteristics and atmospheric waveguides. Eastward stratospheric winds. Right: associated propagation of acoustic waves.

The characteristics of the recorded signals strongly depend on the dynamic of the middle atmosphere along the propagation path which is poorly resolved (e.g. Le Pichon et al., 2015).

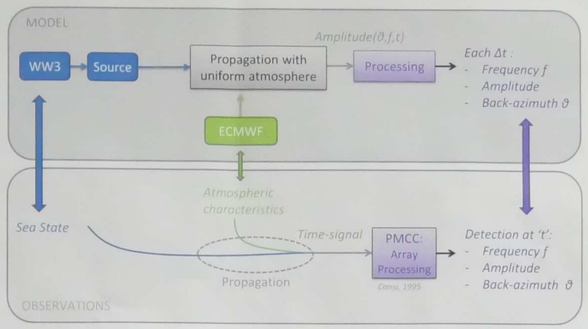
Methods

When and where?

44 IMS stations from April 2014 to August 2017

WW3: wave action model

- Resolution: 0.5 deg – 3-hourly
- Wind forcing: ECMWF operational analyses (WAM HRES)
- ftp://ftp.ifremer.fr/ifremer/ww3



ECMWF: atmospheric model

European Center for Medium-Range Weather Forecasts operational analysis

- Temperature, wind velocity, pressure
- Resolution: 1.5 deg - 6-hourly
- 137 levels

PMCC (Cansi, 1995)

- Progressive MultiChannel Correlation
- Detection (azimuth and amplitude) of the main signal per frequency band

Propagation

- Attenuation coefficient (*Le Pichon et al 2012*)

$$Att = \frac{10^{\frac{\alpha(f)R}{20}}}{R} + \frac{R^{\beta(f,v_{eff-ratio})}}{1+10^{(\delta-R)/\sigma(f)}}$$

$$v_{eff-ratio} = \frac{effective\ stratospheric\ sound\ speed}{ground\ sound\ celerity}$$

- Depends on the distance to the station and the effective stratospheric sound speed (sound speed + projected wind)
- Uniform atmosphere considered (at the station)

Microbarom models

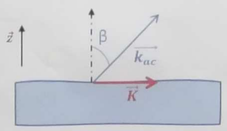
- Microbarom are generated by ocean wave interaction, then their density power spectrum is proportional to the Hasselmann integral (i.e. the interaction coefficient) :

$$H(2f) = \int E(f,\theta)E(f,\theta+\pi)d\theta$$

- 2 main theories in the literature (from Hasselmann integral to radiation in the atmosphere):
  - Brekhovskikh et al 1973 (**BK73**): two semi spaces air/ocean, with a radiation depending on the elevation angle
  - Waxler et al 2007 (**W07**): accounts for finite ocean depth (and possible resonance), however when performing the summation over the source the dependence on the elevation angle disappear (due to the coherency of the wave)
- Theory combining both : **finite depth ocean** + **radiation** depending on the elevation angle.

⇒ Phases of the waves are random, then the phases of the interacting waves are also random and there will not be interference (neither destructive nor constructive) between these acoustic waves when summing over the source region.

*Figure 3 – Definition of the θ angle between the vertical et k_{ac}, the acoustic wave vector exited by **K** – the wave vector resulting from the interaction*



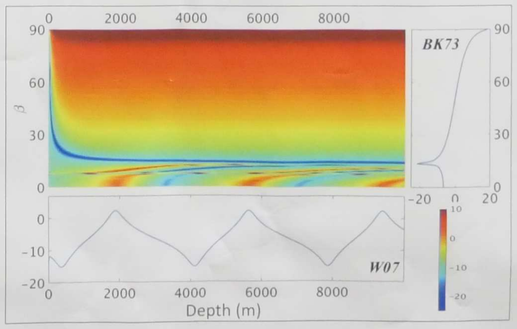
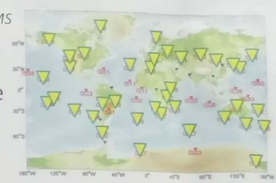


Figure 4 – Normalized pressure amplitude – New theory combining BK73 (right, value for infinite depth) and W07 (bottom, value for θ = 0).

Results

Clear seasonal fluctuations in both amplitude and azimuth due to combined source and propagation effects.

Figure 5 – Considered IMS stations in this study.



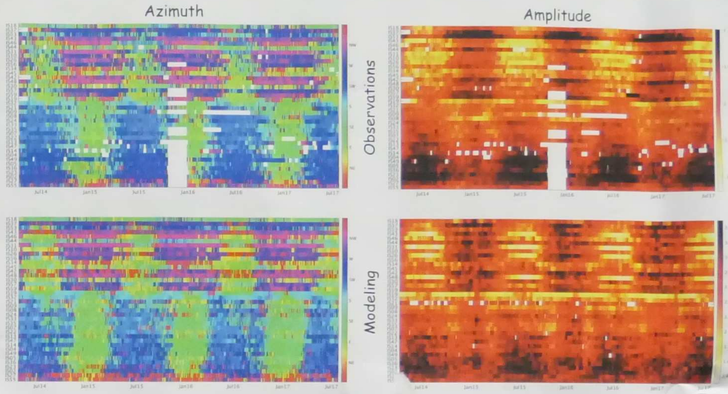


Figure 6 – Comparison between the observed and mode muth (left) and amplitude (right) of dominant microbarom signals recorded at 44 IMS infra tions sorted by latitude.

Detailed comparison at IS37-Norway

- Visualizing all possible modeled microbarom sources that might be detected by IS37 allows further insights for model validation.
- Main differences between W07 and new models are: (i) enhanced microbarom source in Barents when including directivity, and (ii) almost persistent localized sources not observed using W07.

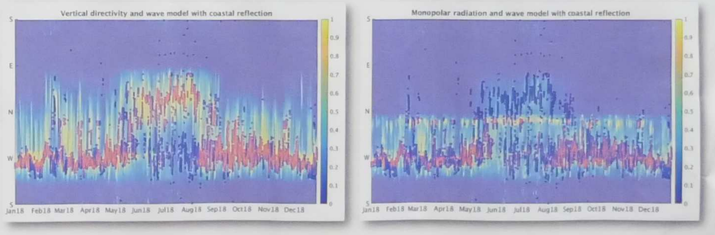


Figure 7 – Comparison of the observed azimuth (dots) versus the normalized predicted amplitude simulated per azimuth (colormap) for the new model (left) and W07 (right).

Summary / perspective

- First order agreement between modeled and observed microbaroms. The bathymetry plays a minor role at shallow propagation angles (e.g. 60-90°)
- Atmosphere is considered uniform (range independent). This assumption is not valid for long propagation range (e.g. involving both hemispheres).
- Need to develop suitable propagation methods.

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PUTTING AN END TO NUCLEAR EXPLOSIONS