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# A vespagram-based approach to assess microbarom radiation and propagation models

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P1.1-306

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POSTER

Poster No.: P1.1-306

# A vespagram-based approach to assess microbarom radiation and propagation models

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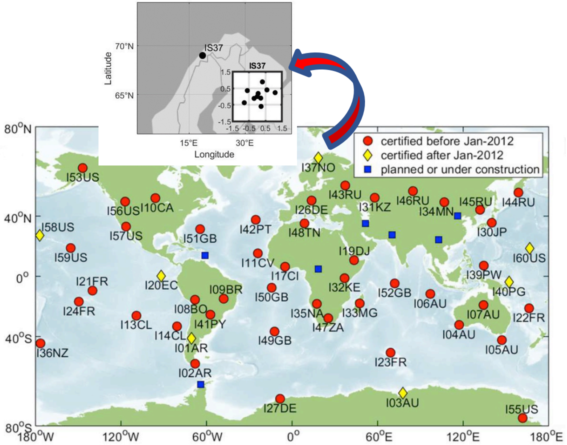
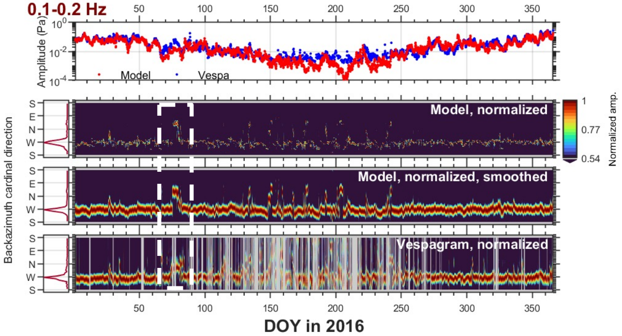
## Data

Microbarom observations at IS37 (69.07 N, 18.61 E) between 2014 and 2019. 5 equally spaced frequency bands between 0.1 and 0.6 Hz.



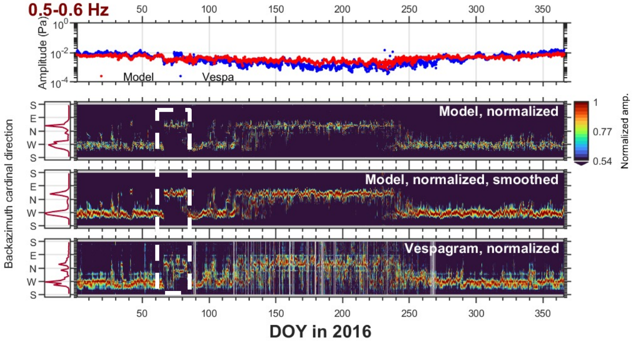

## Results

- Allows comparing data to models for **all directions simultaneously** – not only at direction of maximum power
- Better agreement after smoothing the model;
- Noisier data in summer. Especially for 0.1-0.2 Hz band;
- Different microbarom sources in winter (the Atlantic ocean) and summer (the Barents sea and Greenland sea).
- Good agreement in amplitudes over a year;




## *SSW signatures:*

- Significant change in direction of the infrasound arrival due to change in favorable stratospheric waveguide;
- Significant decrease in the similarity index between model and vespagram during SSWs.




## Material and methods

### *1. Infrasound data processing*

Vespagram processing analyzes recorded signals in terms of signal power as a function of time and backazimuth. We consider apparent velocity of 350 m/s (stratospheric arrivals).

### *2. Microbarom model*

- Ocean wave model: WAVEWATCH III.
- Microbarom source model.
- Microbarom propagation in the atmosphere (semi-empirical transmission loss formula).
- Smoothing model output to account for frequency-dependent resolution of the array.

## Summary

- Microbarom models can be benchmarked against recorded infrasound data for all directions simultaneously.
- Good agreement between the microbarom model and the vespa processing results, especially in winter.
- Vespa processing can track variations in microbarom parameters over extended periods as well as over shorter time windows, e.g., SSWs.
- The current work paves the way for near-real time assessment of atmospheric model products and for developing infrasound-based stratospheric diagnostics.

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## ABSTRACT

This study presents a vespagram-based approach for comparison between infrasound data recorded at the ground and simulated microbarom soundscapes in multiple directions simultaneously. Data recorded during 2014-2019 at the IS37 station in Bardufoss, Norway, have been processed in the framework of velocity spectrum analysis in order to generate images that present a signal power depending on time and direction (vespagrams).

Calculations were performed for several frequency bands within the 0.1 - 0.6 Hz range. The modelled microbarom soundscapes were smoothed to account for the frequency-dependent array resolution. The infrasound data processed and modelled microbarom soundscapes were compared in three different aspects: i) azimuthal distribution of dominating signal, ii) signal amplitude, and iii) ability to track atmospheric changes during extreme events such as sudden stratospheric warmings (SSW).

The results reveal good agreement between model and data and demonstrate the ability of vespagrams to monitor the microbarom azimuth distribution, amplitude, and frequency on a seasonal scale, as well as changes during SSWs. The presented vespagram-based approach is computationally low-cost and can uncover microbarom source variability. There is also potential for near-real-time diagnostics of the atmosphere and microbaroms, especially when applied to multiple stations, e.g., exploiting the CTBTO International Monitoring System network.

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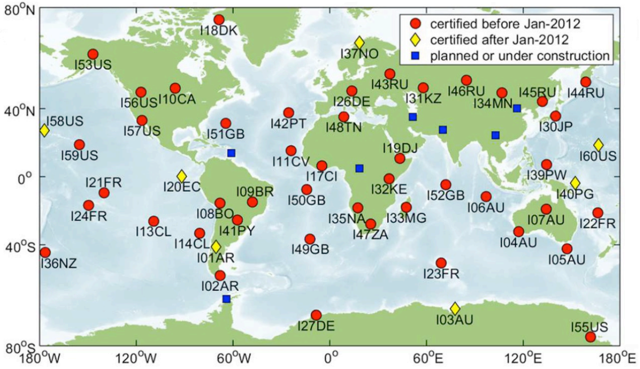
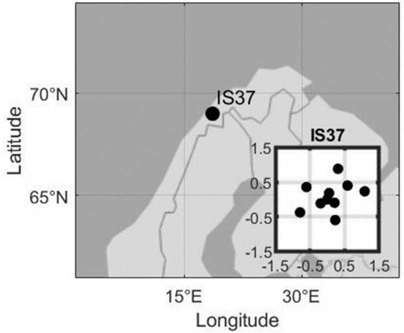
## INTRODUCTION

- Microbaroms are continuous infrasound waves generated by non-linear ocean wave interaction, detected allover the IMS network. In the current study, we consider IS37 (I37NO) data.
- Appropriate data-driven microbarom generation and propagation model validation is necessary when using these data to assess atmospheric model bias.
- Current methods typically rely only on the backazimuth direction of maximum power (Hupe et al., 2019; Smirnov et al., 2021).
- We propose a vespagram based approach which allows to benchmark modeled and observed microbarom soundscapes **in all directions simultaneously**.




Map of the IMS infrasound network. Adapted from DeCarlo et al. (2021).




The IS37 array location and geometry.

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METHODS

## Vespa processing
(Davies et al., 1971)

- 1h moving time window, evaluated every 30 min.
- Remove the mean. Apply bandpass filter.
- Calculate beams for all directions (1 deg step) and the fixed apparent velocity of 350 m/s (stratospheric arrival regime).
- Calculate the mean squared pressure (power) of each beam get a time-backazimuth vespagram.

## Microbarom model

- *Ocean wave model*

WAVEWATCH III (3h temporal and 0.5° spatial resolution).

- *Microbarom source model*

State-of-the-art model by De Carlo et al. (2020).

- *Microbarom propagation in the atmosphere*

Semi-empirical attenuation law by Le Pichon et al. (2012) that accounts for frequency, distance and wind at the station.

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METHODS

*Smoothing the model*

- The infrasound array resolution depends on the frequency. In order to account for this feature in the model, we smooth the model output with the Gaussian kernel.
- After the smoothing, there is a better agreement in the direction of the maximum power predicted by the model and the vespagram.

*Benchmark the model and the infrasound vespagram*

- Similarity index (SI), inspired by image processing comparison approaches, introduced as:

$$\mathrm{SI}(t) = 1 - \mathrm{MSE}(t) = 1 - \frac{1}{N_\theta}\sum_{\theta}\left[P_{\mathrm{model}}(t,\theta) - P_{\mathrm{vespa}}(t,\theta)\right]^2$$

where MSE is the mean squared error between the normalized smoothed model output, $P_{model}(t;\theta)$, and the normalized vespagram, $P_{vespa}(t;\theta)$, calculated at each time step, where $\theta$ is back-azimuth and t is time.

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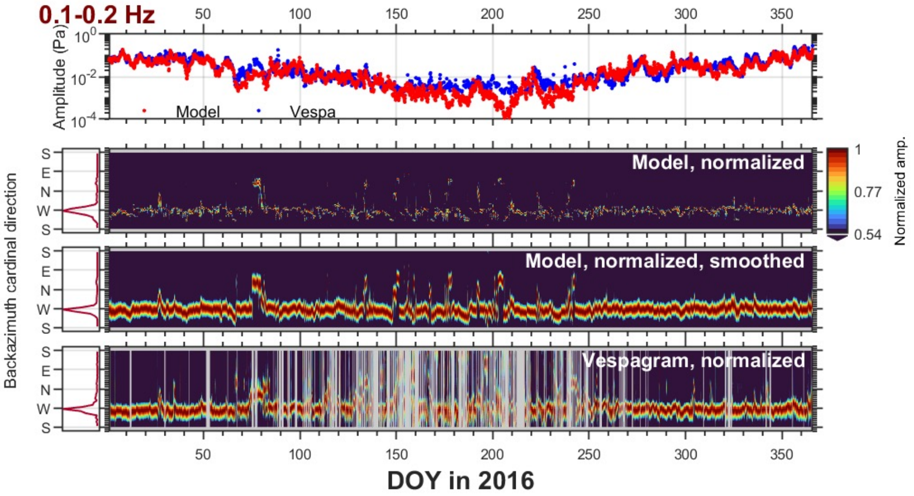
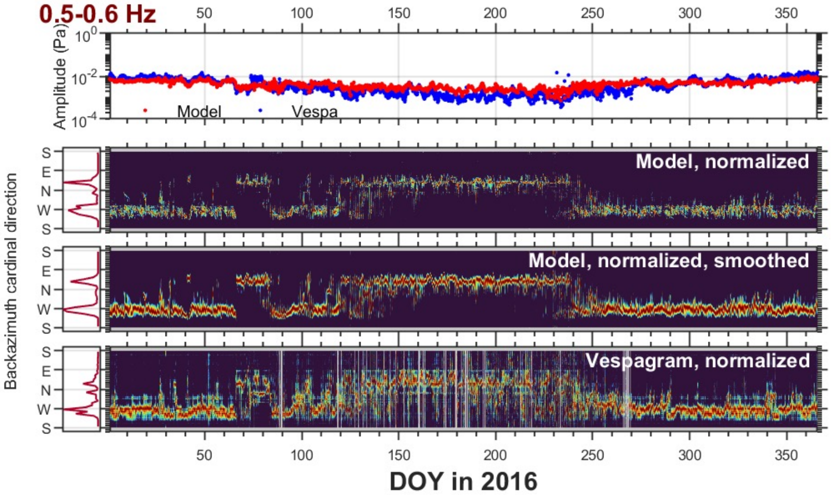
## RESULTS

- Clear seasonal pattern in model and observations: amplitude stronger in winter than in summer.
- 0.1-0.2 Hz. Main source over a year – the Atlantic ocean. In summer can also distinguish signals from the Pacific and Indian oceans.
- 0.5-0.6 Hz. Winter: the Atlantic ocean. Summer: sources in the Barents sea and Greenland sea.




Figures: Analysis results for 0.1 – 0.2 Hz (left) and 0.5 – 0.6 Hz (right) bands. 1) amplitude of the dominant signal, 2) model amplitude normalized by the maximum at each time step, 3) smoothed model's amplitude normalized, 4) infrasound vespagram amplitude normalized.

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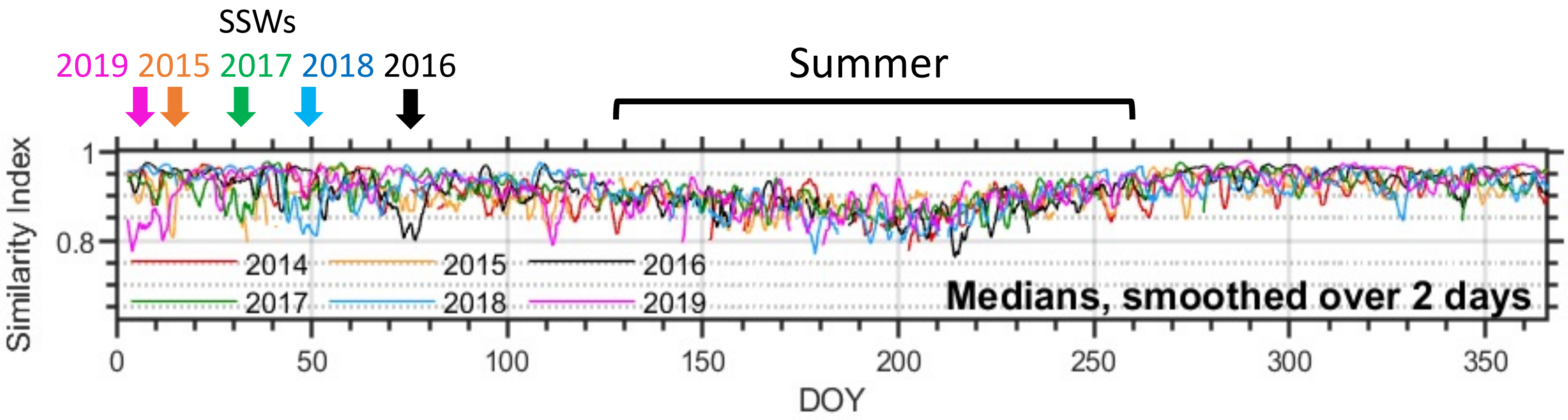
## RESULTS

- Results show that similarity index (SI) is more stable in winter than in summer.
- Possible reason: enhanced number and intensity of summer cyclones in the Arctic and Northern Eurasia (Orsolini et al., 2009) → additional noise.
- Differences between the model and vespagrams during sudden stratospheric warmings (SSWs) lead to a decrease in SI. This feature has potential for the atmospheric model product diagnostics.



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## CONCLUSIONS

- An advantage of the vespagram-based approach is that microbarom radiation and propagation models can be benchmarked against recorded infrasound data **for all directions simultaneously**.
- The analysis reveals good agreement between the microbarom model and the vespa processing results, especially in winter.
- Vespa processing is computationally low-cost and can track variations in microbarom parameters over extended periods and over shorter time windows, e.g., during extreme atmospheric events such as SSWs.
- The approach presented has a potential for near real-time diagnostics of atmospheric models, especially when applied to multiple stations, e.g., exploiting the CTBTO International Monitoring System network.
- Follow (ResearchGate) and (Journal) for more details.