Semidiurnal tidal signatures in microbarom infrasound array measurements

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Recent studies on infrasonic signatures related to atmospheric tides are mostly focused on stratospherically ducted infrasound or on tidal signatures in recorded infrasound signal power.

In the current work, we address microbarom infrasound ducted by mesosphere-lower thermosphere (MLT) waveguides and the associated infrasound apparent velocity (trace velocity) of arrivals at a ground-based array station in northern Norway.

A hypothesis is that the infrasound apparent velocity – which is related to the incidence angle of the wavefront impinging the station – is linked to the altitude of the final refraction of the infrasound waves. This altitude would be affected by the regional MLT tidal pattern.

We apply specialized beamforming and filtering recipes to highlight the MLT-ducted microbarom arrivals and we find semidiurnal patterns in the infrasound apparent velocity measurements.
Array site & microbarom source

Source region → Station
Wave-front & array measurements

Pressure amplitude
[Donn & Rind 1971 ++; Smets & Evers 2014; Smets, Assink & Evers 2019]
- Along-track wind & $T$ sensitivity
- Challenges:
  Sensitive to source strength variations; Long-distance propagation over multiple tide phases

Backazimuth direction-of-arrival
- Cross-wind sensitivity
- Challenges:
  Long-distance propagation over multiple tide phases, as well as vertical integration effects?

Inclination direction-of-arrival
- Along-track wind & $T$ sensitivity
- Prospective advantage:
  Information about final return path, with less long-distance averaging over multiple tide phases?

Celerity / traveltime
- Along-track wind & $T$ sensitivity
- Challenge:
  Continuous-wave microbaroms without “origin time”
Domains

- **Apparent velocity** (trace velocity):
  \[ v_{\text{app}} \in [c_{0\text{ground}}, \infty] \]

- **Inclination:**
  \[ \arcsin\left(\frac{c_{0\text{ground}}}{v_{\text{app}}}\right) \in [0, 90] \text{ deg.} \]

*More favorable for fitting to sinusoids*
Tide-related signatures in infrasound ambient noise recordings?
Tidal characteristics of the middle atmosphere

• Semidiurnal (12h) period would dominate above stratopause
• Diurnal (24h) period would dominate in the stratosphere

But we’re at high latitudes:
Tidal patterns are complex (“tidal weather”):
Non-linear interactions between tidal components (migrating & non-migrating) and between planetary waves and tides, and time-varying sources
Altitude-regime particular interest
(less studied for infrasound)

Mesosphere-lower thermosphere (MLT) tidal signatures

Requires:
  Data processing to isolate the “thermospheric microbarom arrival”, having penetrated the MLT

Approaches:
  – Temporal filtering & window-length settings
  – Spatial filtering (adaptive or conventional beamforming)
  – Rejecting data-points which obviously are not MLT arrivals
Season of particular interest at high latitudes:
Late summer MLT semidiurnal tides

Radar observations:
Late summer peak in semidiurnal tide

- Trondheim meteor radar climatology (Norway) - see figure. Also previously observed over ESRANGE (Sweden) [Mitchell et al., 2002 ] and Andenes (Norway, close to I37NO) [Riggin, et al., 2003]

- Maximises around early September primarily due to the migrating SW2 tide but with contributions from non-migrating modes [Hibbins et al., 2019]
Pinpointing thermospheric microbarom infrasound
Processing pipeline, I37NO data

• Temporal filtering: 0.1 – 0.2 Hz
  Allows for “focusing” onto microbarom hotspot close to Greenland/Iceland

• Long time window, to accommodate for continuous-wave microbarom arrivals

• Find location of slowness space peak with highest coherence ⇒ wave-front parameters (backazimuth & apparent velocity)

• Reject too low array coherence (but stay very tolerant)

• Reject backazimuth outside of relevant sector

⇒ Irregularly sampled time-series of apparent-velocity (inclination angle) estimates
Fit our irregularly sampled inclination angle series to:

\[
y(t; \mathbf{f}, \mathbf{\theta}) = \theta_0 + \sum_{n=1}^{\text{nterms}} \left[ \theta_{2n-1} \sin(2\pi n f t) + \theta_{2n} \cos(2\pi n f t) \right]
\]

Floating-mean method: \( \theta_0 \) compensate for biased average estimate
\( N_{\text{terms}} = 2 \) means including 1\textsuperscript{st} harmonic. [ We first set \( N_{\text{terms}} = 1 \) ]

Moving time-window, calculate L-S periodogram for 5-day chunks

⇒ **Pseudo-spectrogram** showing tidal peaks as function of day
Normalize each periodogram to its max, before packing to pseudo-spectrogram
Resulting semidiurnal signatures
Eastward stratospheric winter vortex

- In winter, stratospheric arrivals dominate in microbaroms from “Iceland / Greenland hot-spot” at I37NO

- In summer, MLT arrivals can dominate, but only if signal processing removes stratospheric arrivals from other directions (Pacific / Barents, etc.)
Five late summers, data piped to pseudo-spectrogram

$C > 0.01$, $\varphi \in [180.0, 330.0]$, $V_{app} \in [320.0, 550.0]$ m/s
Five late summers, data piped to pseudo-spectrogram

\[ C > 0.01, \ \varphi \in [180.0, 330.0], \ \text{Vapp} \in [320.0, 550.0] \text{ m/s} \]
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Late summer pseudo-spectrogram from inclination angle
Pseudo-spectrograms from inclination angle
Pseudo-spectrograms from inclination angle
Whole-year pseudo-spectrograms from inclination angle
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Winter examples: “less semidiurnal”

Pseudo-spectrograms from inclination angle
Reflections

Current study
Focus on *identifying* semidiurnal variations in microbarom data

What’s next?
- Benchmarking against models & other data?
- Apply similar method to other infrasound parameter time-series?
- Evaluate time-of-delay (phase) evolution of the L-S pseudo-spectrogram?
- Evaluate prospective added-value to atmospheric probing of the MLT?
- Infrasound-based wind estimates would be great of great value
References


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  Middle Atmosphere Dynamics: Exploiting Infrasound Using a Multidisciplinary Approach at High Latitudes (MADEIRA)
Appendix A:

Comparison with backazimuth pseudo-spectrograms
Appendix B: data point sifting demo
**Winter:** all frequency bands towards ~ same source towards west

**Summer:**
- Lowest freq. band towards source in west, with high app. velocity $\Rightarrow$ MLT arrival
- Highest freq. band varying direction, with lower app. velocity $\Rightarrow$ Stratospheric arrival
$C > 0.05, \ \varphi \in [180.0, 360.0]$
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