SAND2019-14874C

Infrasound from Coastally-Reflected Ocean Waves Recorded on a Stratospheric Balloon

Siddharth Krishnamoorthy[1], Daniel C. Bowman[2], Marine De Carlo[3], Fabrice Ardhuin[4], Attila Komjathy[1], Alexis Le Pichon[3], Michael T. Pauken[1], James A. Cutts[1]

[1] NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

[2] Sandia National Laboratories, Albuquerque, NM

[3] Commissariat à l'Énergie atomique et aux Énergies Alternatives, Paris, France

[4] Laboratoire d'Océanographie Physique et Spatiale, Brest, France

A33Q
2935

Introduction

Infrasound is the term given to low-frequency acoustic waves that have frequency below 20 Hz, the limit of human hearing. Infrasound is produced by several natural and anthropogenic sources on Earth and can be used to investigate various events on Earth such as seismic and volcanic activity [1,2], thunderstorms and chemical and nuclear explosions [3].

The Earth's oceans are known to produce infrasound, called ocean microbarom, through the collision of opposing waves traveling on its surface. Ocean microbarom constitutes a major noise source for infrasound stations around the world and creates microseism noise at seismometer stations [4].

Here, we present the first ever detection of oceanic infrasound reflected off a coast, which was made possible only by infrasound measurements on a balloon platform.

Flight and Payload Description

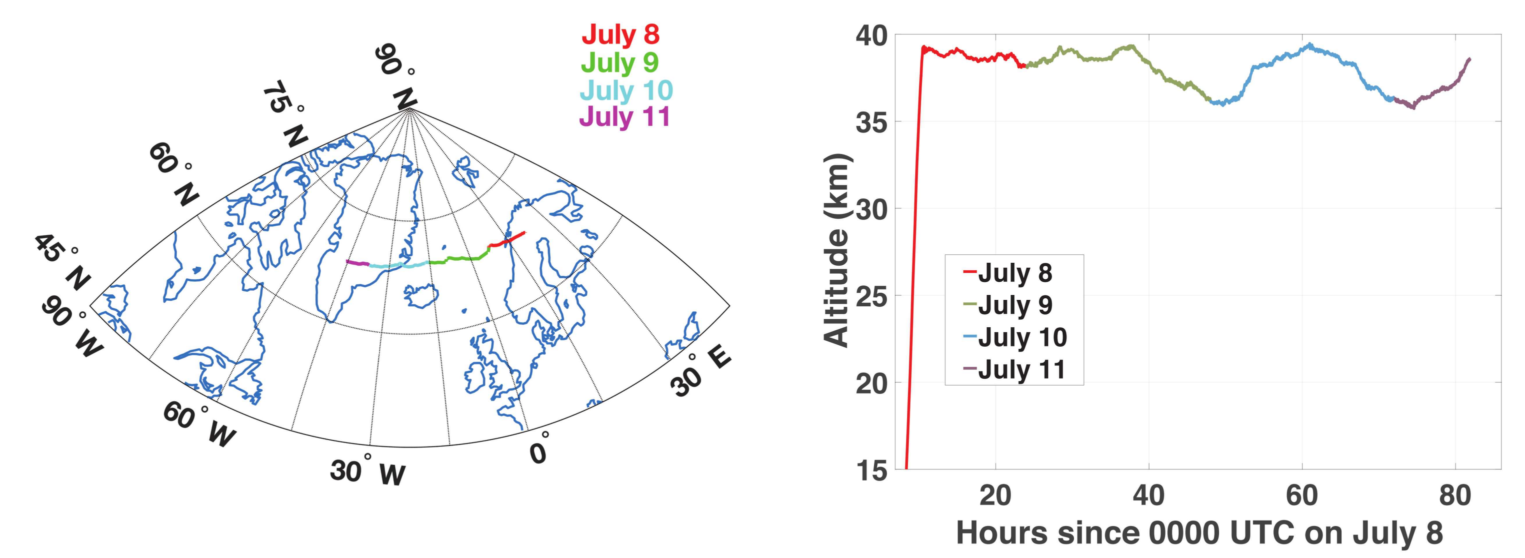

Figure 1: (Left) Trajectory of the LDB as recorded by PIMA (Right) Altitude profile of the LDB as recorded by PIMA

The Payload for Infrasound Measurement in the Arctic (PIMA) and Trans-Atlantic Infrasound Payload (TAIP) flew as secondary payloads on the PMC-Turbo mission on a NASA Long-Duration Balloon (LDB) flight from Sweden to Canada, launched on July 8, 2018. The LDB floated between 36 and 39 km altitude over a period of nearly six days. PIMA recorded pressure and position data for 76 hours, TAIP recorded pressure data for the whole flight.

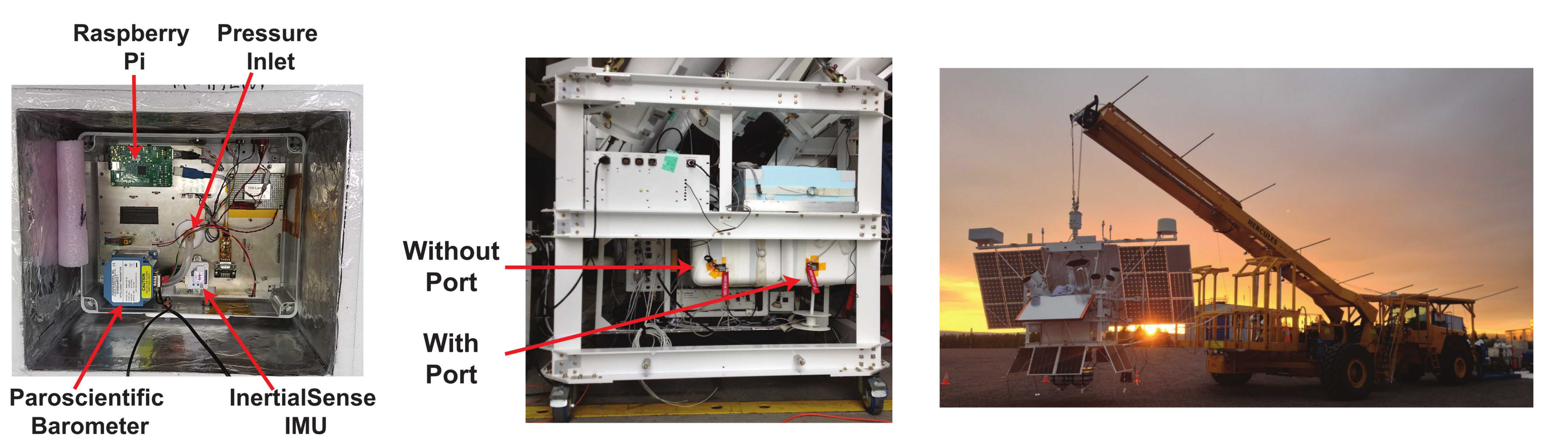

Figure 2: (Left) Assembly of the PIMA payload (Middle) PIMA-1 and 2 integrated on the gondola (foreground, with the red tags) (Right) PMC-Turbo gondola prior to launch (Middle and right images courtesy of Christopher Geach, UMN)

The PIMA payload contained two packages — each package included a Paroscientific Digiquartz barometer and an InertialSense μINS inertial measurement unit (IMU) . One of the packages had a quad-disc wind noise filter and the other flew without any noise mitigation device. The TAIP payload contained a package with the GEM infrasound sensor [5].

A Fleeting Signal Detection

Hourly power spectral density (PSD) estimates of the infrasound sensors reveal that a peak associated with the ocean microbarom was detected between 0600-1000 UTC on July 10 with the strongest episode between 0700-0900 UTC. Shown above is a sample spectrum from 0800 UTC — all three independent infrasound detectors on board detected this peak. Microbarom is typically generated in the 0.13-0.35 Hz band near Greenland [3] and is ubiquitous on balloon-recorded signals [6]. However, in this case it was only detected when the balloon was crossing the eastern coast of Greenland.

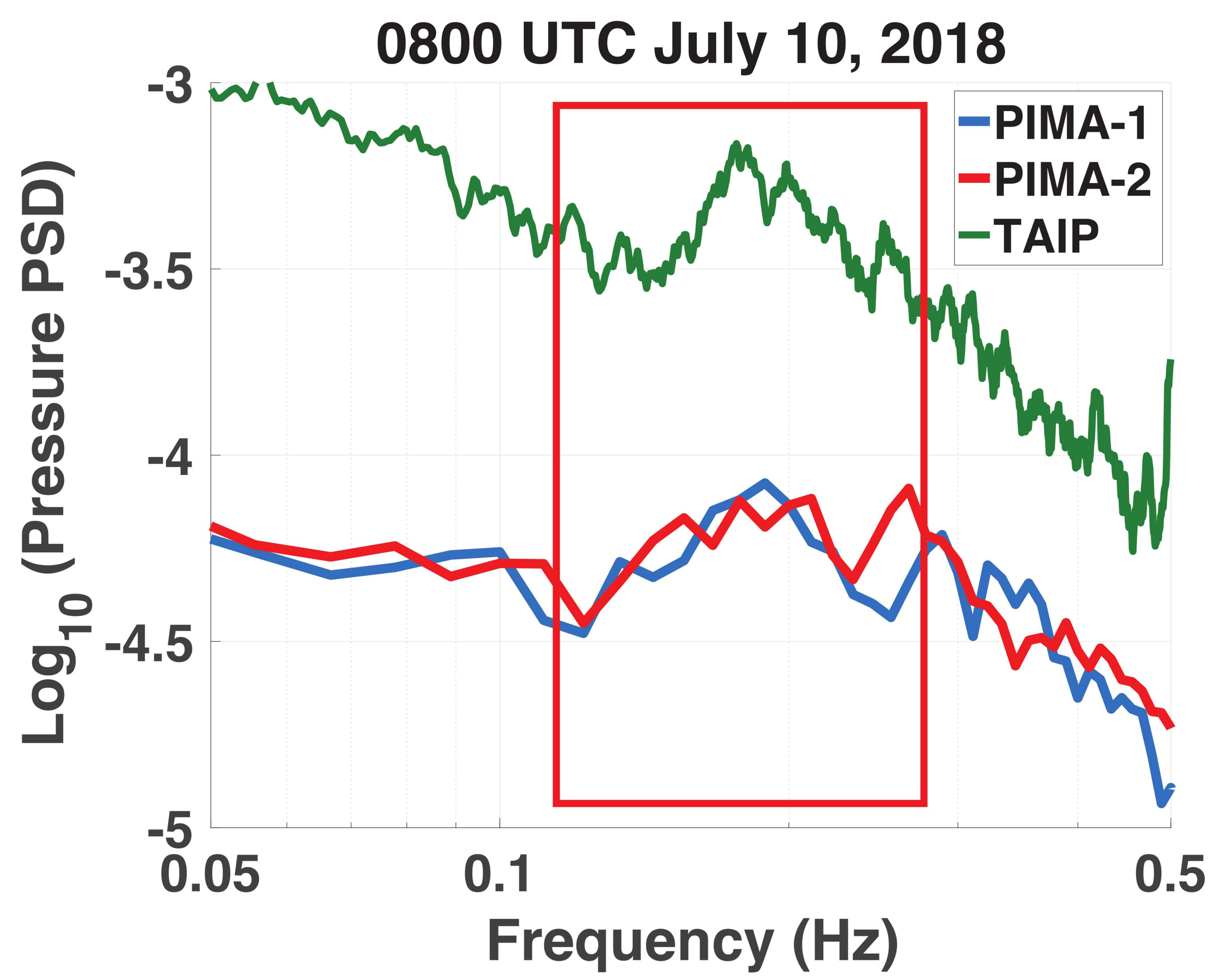

Figure 3: Hourly PSD at 0800 UTC on July 10, 2018 for the three infrasound sensors on the flight shows a microbarom peak that is not present at other times in the flight.

We collected data from six of the nearest Infrasound Monitoring System (IMS) network ground stations. Progressive Multi-Channel Correlation (PMCC) analysis reveals [4] that none of these ground stations detected the weak infrasound signal.

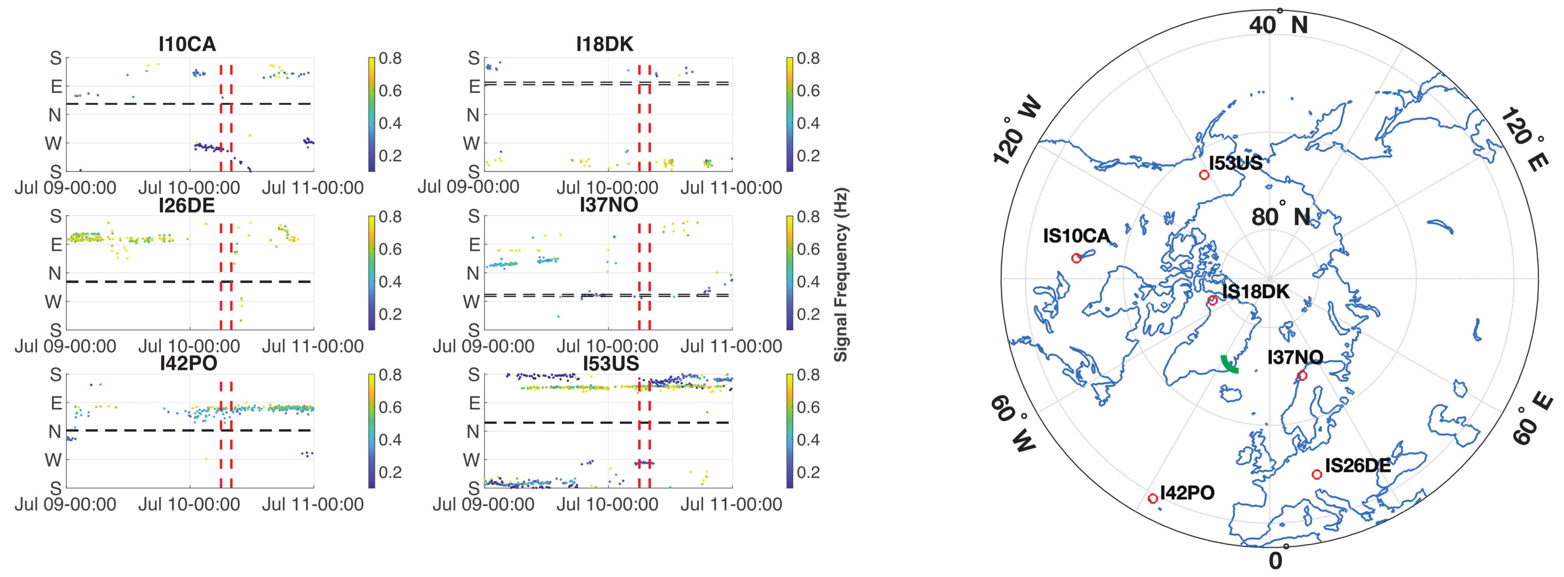

Figure 4: (Left) PMCC analysis of 6 nearby ground-based IMS infrasound stations. The time demarcated by red dotted lines is the time period of signal detection on the balloon (Right) A map showing the locations of the IMS ground stations (red circles) and the balloon from 0600-1100 UTC on July 8, 2018

Microbarom Modeling

We modeled ocean microbarom generation and propagation using the Wave Action Model (WAM) [7] with four cases for microbarom reflection — (1) Sea ice and coastal reflection (2) Only sea ice reflection (3) Only coastal reflection, and (4) No reflection. The WAM computes the Hasselman integral, which is the wave induced air pressure at the surface of the ocean. In each case, we computed the median value of the ocean power PSD within 50 km under the balloon. The figure below shows the time evolution of the median PSD value. It is clearly visible that the model with both coastal and ice reflection shows an increase in power across the relevant frequency band at 0600-1000 UTC on July 10, 2018. This increase is predominantly accounted for in the model that includes coastal reflection but excludes ice reflection. The model with no reflection does not show a power increase in this period.

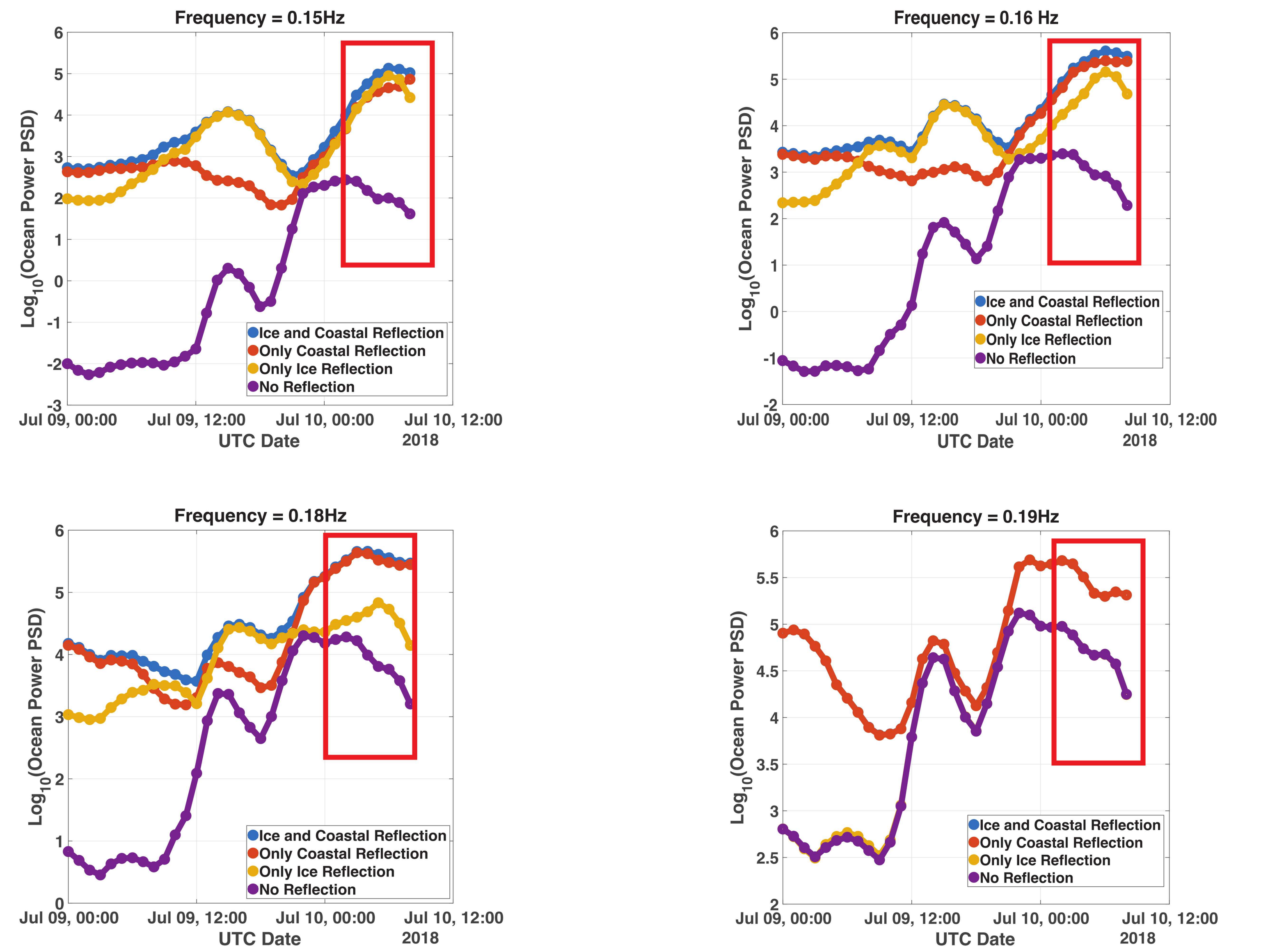

Figure 5: Ocean power as radiated from under the balloon, computed using the Wave Action Model (WAM). Four cases are computed with and without coastal and sea ice reflection. Only when reflection is included, does the microbarom power show a peak at the time of detection. Coastal reflection accounts for most of the microbarom power.

Conclusions

- Balloons offer a unique vantage point for observing geophysical infrasound signals, as demonstrated by the detection of a weak infrasound signal by a balloon-based barometer but not by nearby ground stations
- Balloon measurements demonstrate that ice and coastal reflections may be significant factors in the production and propagation of microbarom and microseisms from the Earth's oceans.
- Balloon observations and simulation models may be combined effectively to study geophysical phenomenology.

References

[1] Krishnamoorthy et. al. (2019), "Aerial Seismology using Balloon-Based Barometers", *IEEE Trans. Geosci. Remote Sensing*, 57 (12) **[2]** Matoza, R. S. et. al. (2017), "Seismo-acoustic wavefield of strombolian explosions at Yasur volcano, Vanuatu, using a broadband seismo-acoustic network, infrasound arrays, and infrasonic sensors on tethered balloons", *J. Acoust. Soc. Amer.*, 141 **[3]** Christie, D. R. and Campus, P. (2009), "The IMS infrasound network: Design and establishment of infrasound stations" in *Infrasound Monitoring for Atmospheric Studies*, Dordrecht, The Netherlands:Springer, pp. 29-75 **[4]** Kedar, S. et. al. (2011), "The origin of deep ocean microseisms in the North Atlantic Ocean", *Proc. R. Soc. London Ser. A*, 464 [5] Anderson, J. F. et. al. (2017), "The Gem Infrasound Logger and Custom-Built Instrumentation", *Seis. Res. Lett.*, 89 (1) **[6]** Bowman, D. C. and Lees, J. M. (2017), "A Comparison of the Ocean Microbarom Recorded on the Ground and in the Stratosphere", *J. Geophys. Res.: Atmos.*, 122(18) **[7]** Ardhuin et. al. (2011), "Ocean wave sources of seismic noise", *J. Geophys. Res.: Oceans*, 116(C9)

 The authors thank the team of PMC-Turbo and the NASA Balloon Program Office for the opportunity to fly the payloads.