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Sandia National Laboratories

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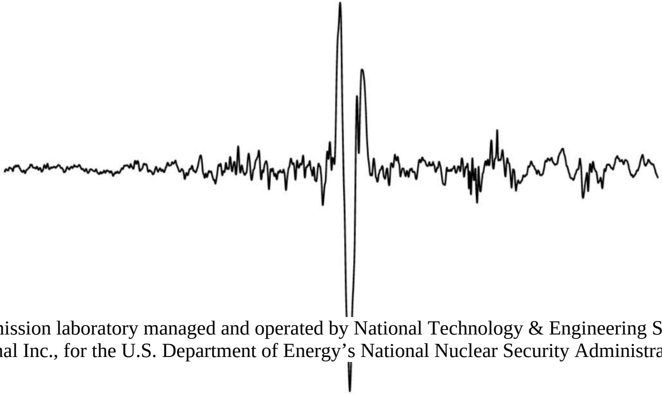

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Introduction to Geophysical and Planetary Acoustics

Geophysical acoustics is the study of sound in Earth's atmosphere

Planetary acoustics is the analogous study on other bodies

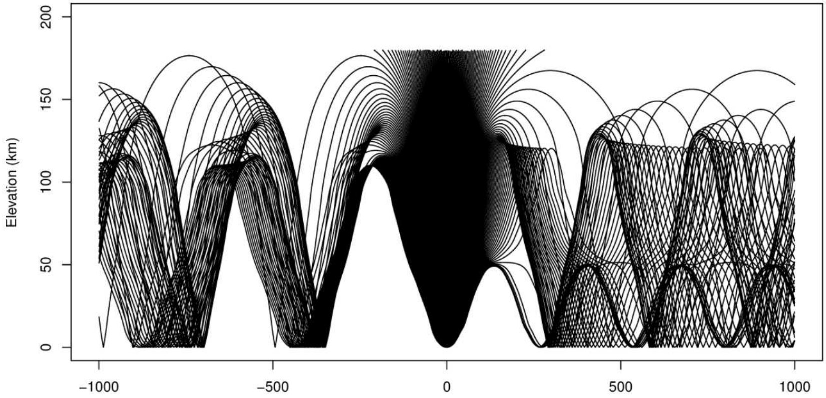
Most of these signals are in the *infrasound* (< 20 Hz) range

Sources

- Volcanic eruptions
- Earthquakes
- Meteors
- Ocean waves
- Wind/mountain interactions
- Thunder
- Aurora
- Explosions
- Rockets
- Aircraft
- Wind turbines
- Dams
- Industrial emissions
- Cities

Propagation

$$\vec{c} = \sqrt{\gamma R T}\,\hat{n} + \vec{u}$$



Ground Stations

Ground stations have drawbacks

- Wind noise
- Local sounds
- Two dimensional
- Some signals missed

Microbarometers on high altitude balloons experience **negligible wind noise**, are **far from local sound sources**, can maneuver in **three dimensions**, and may capture **signals that cannot be seen from the ground**.

History

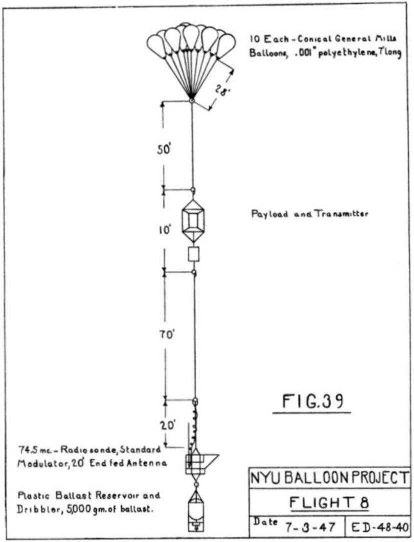
Late 1940s/early 1950s: Project MOGUL

Early 1960s: Wescott

Late 1970s/early 1980s: Banister

Project MOGUL

- Recognition of "SOFAR" channel in the stratosphere
- Detect Soviet nuclear tests and ballistic missiles
- Active late 1940s - early 1950s
- The "Roswell Incident"
- **No extant data**



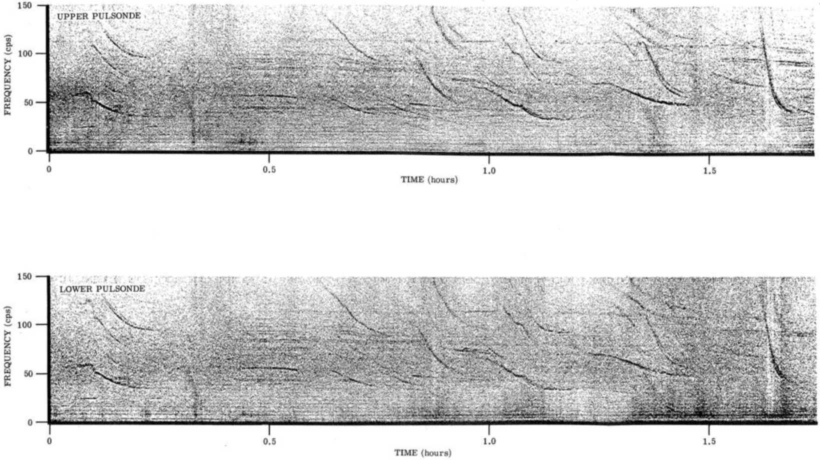
John Wescott

In the early 1960s, a researcher named John Wescott at the University of Michigan, Ann Arbor launched over 30 balloon-borne microphones.

His interests included:

- Acoustic events between 17 and 22 km altitude
- Spectrum of background noise
- Diurnal variations
- Elevation angle determination

Spectrograms



Pressure canisters dropped from aircraft in the vicinity of underground nuclear detonations.

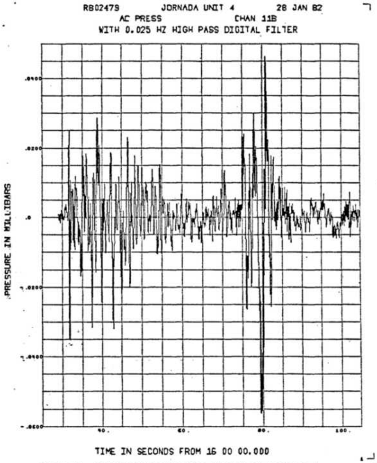
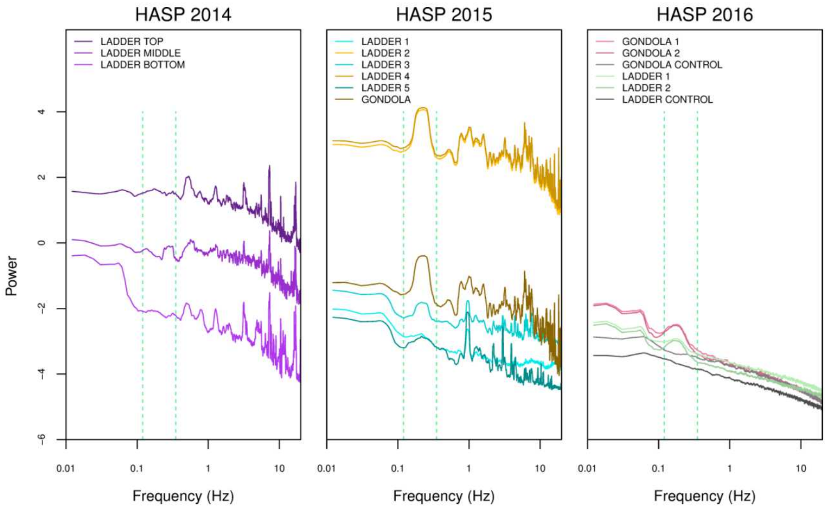


Figure 7. Complete Pressure Time History at Canister 4

The Carolina Infrasound Project

Original Motivation: Volcanoes

The NASA High Altitude Student Platform



Mid 2010s: the program begins

In 2015-2016, high altitude infrasound research takes off

The Venus Seismology Study Team publishes "Probing the Interior Structure of Venus"

Eliot Young develops and presents the ASTERIA concept, then fields SISE

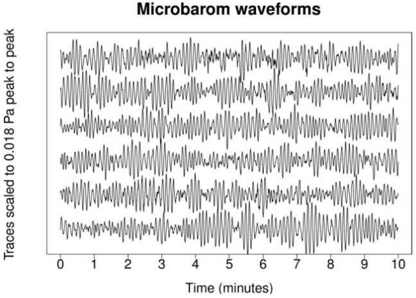
UNC solves interference problem and demonstrates low noise flight

What have we heard so far?

Microbarometers on free flying balloons have detected the following phenomena:

- Ocean microbarom
- Surface explosions
- Underground explosions
- Thunder
- Mountain waves
- Aircraft
- Wind turbines
- Aurora
- Bolides (maybe)

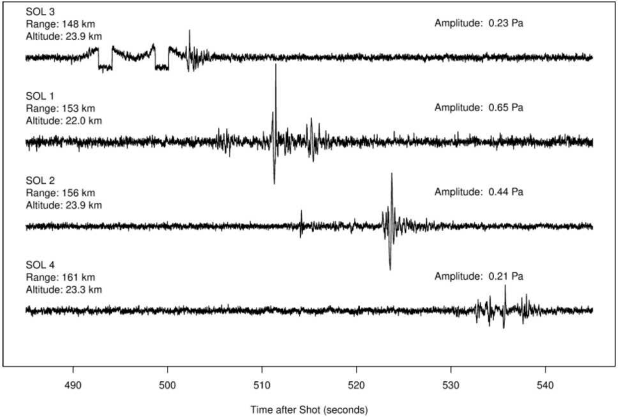
Ocean microbarom



The ocean microbarom is present almost all the time

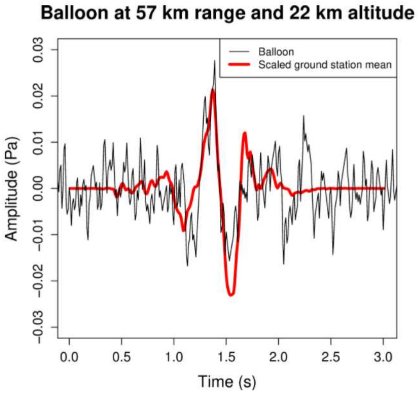
Bowman, D. C. and Lees, J. M. (2017) A comparison of the ocean microbarom recorded on the ground and in the stratosphere, *JGR-Atmospheres*
Bowman, D. C. and Lees, J. M. (2018) Upper air heating from ocean-generated acoustic wave energy. *GRL*

Surface explosions



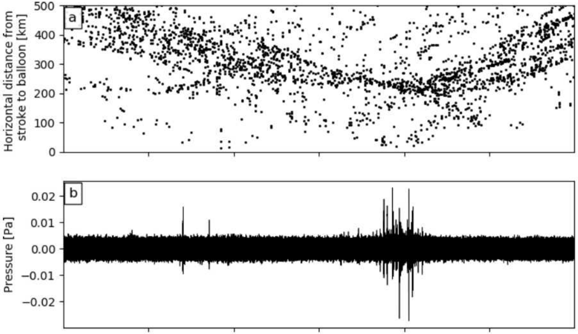
Young, E. F. *et al.* (2018) Explosion-generated infrasound recorded on ground and airborne microbarometers at regional distances. *SRL*
Bowman, D. C. and Albert, S. A. (2018) Acoustic event location and background noise characterization on a free flying sensor network in the stratosphere. *GJI*

Underground explosions



The Dry Alluvium Geology (DAG) Experiment: Shot 4
The August 2019 JPL campaign at EMRTC
ISAE quarry blasts

Thunder



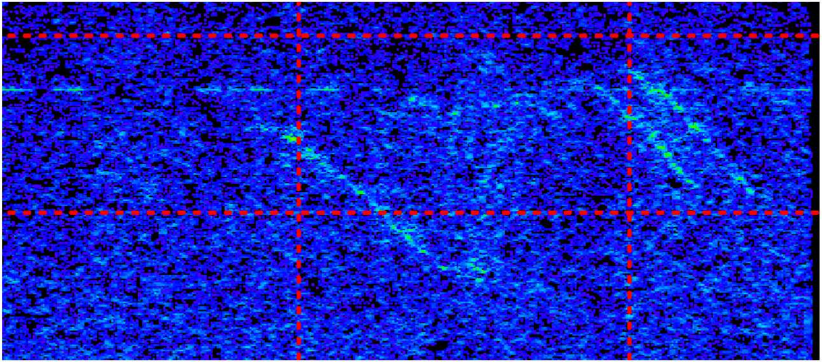
Lamb, O. *et al.* (2018) Detecting lightning infrasound using a high-altitude balloon, *GRL*
Poler, G. *et al.* (*in review*) Infrasound and gravity waves over the Andes observed by a pressure sensor on board a stratospheric balloon *GJR-Atmospheres*

Mountain waves

Analysis by Poler *et al.* indicates an increase in spectral power in the typical wind/mountain infrasound band during a balloon transit over the Andes mountains.

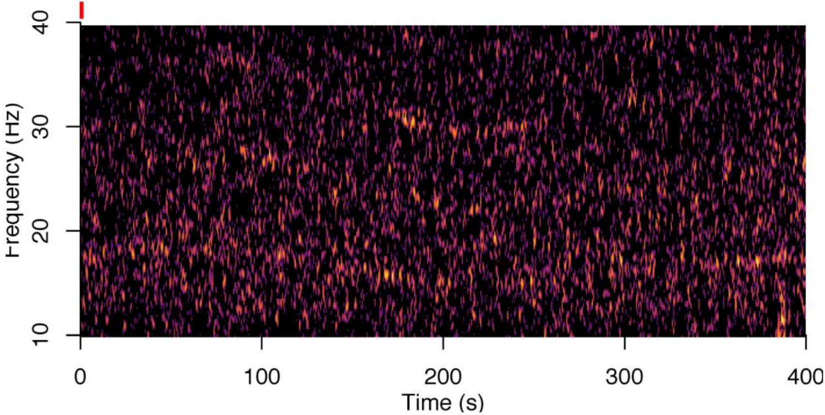
Poler, G. *et al.* (*in review*) Infrasound and gravity waves over the Andes observed by a pressure sensor on board a stratospheric balloon *GJR-Atmospheres*

Aircraft



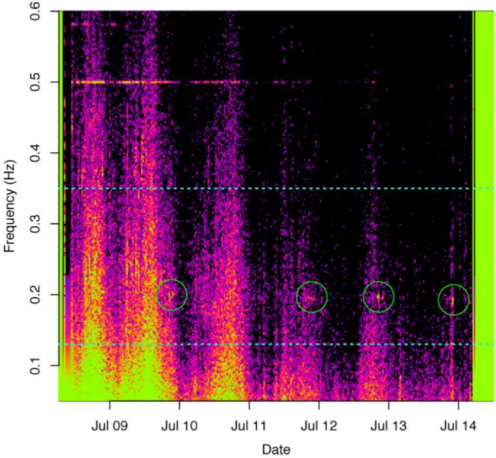
Wescott's work in the 1960s
The RedVox I flight (personal launch)
The RedVox II flight during the DAG Test campaign
One of the DAG 4 balloons

Wind turbines



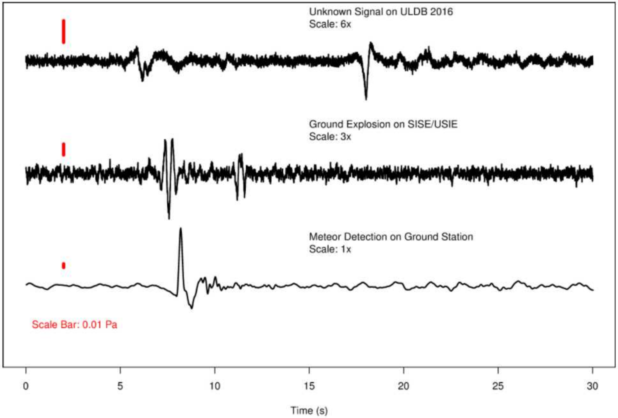
The DAG Test flight during the DAG Test campaign
NASA Ames Bolide Box

Aurora



The 2018 PMC-Turbo flight

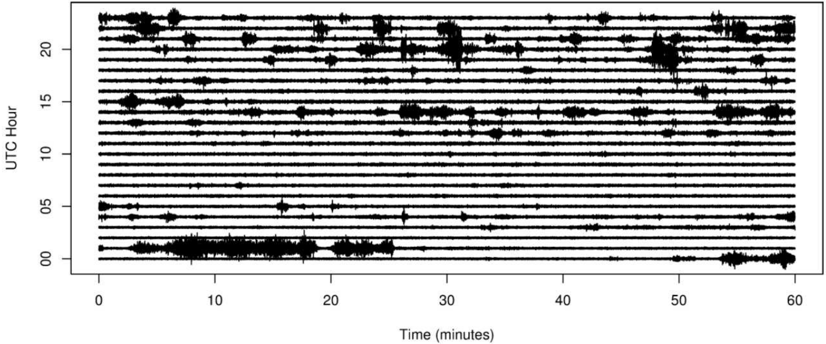
Bolides



The 2016 NASA ULDB flight (this figure)
HASP 2016
Balloons during DAG 4
The JPL "Crazy Cat" balloon

Other things

Many of the signals recorded on high altitude balloons come from unknown source



Conclusions

The field has advanced dramatically over the last 6 years, but many challenges remain:

- Data volume and quality
- Sensor calibration
- Background noise characterization
- Signal identification and localization
- Signal attribution

Acknowledgments

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