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Inverting for Lower Atmosphere Structure using Ambient Acoustic Waves

PRESENTED BY

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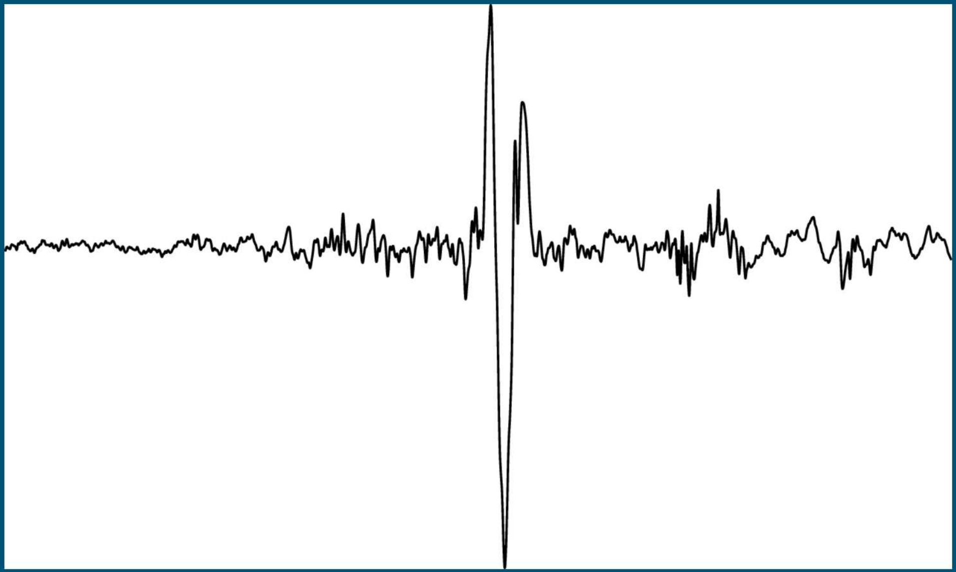
Introduction to Geophysical Acoustics

"Atmospheric seismology" is an attractive analogy, but it can be misleading.

- Frequency range: ~0.003 – 20 Hz (infrasound), > 20 Hz (audio)
- Efficiently generated via surface and aerial explosions
- Propagation velocity typically ***decreases*** with altitude in the lower atmosphere
- **Dynamic transmission medium** varies at the minute to semiannual scale
- A relatively young field



Sources

Natural

- Volcanic explosions
- Earthquakes
- Meteors
- Severe storms
- Colliding ocean waves
- Wind/mountain interactions

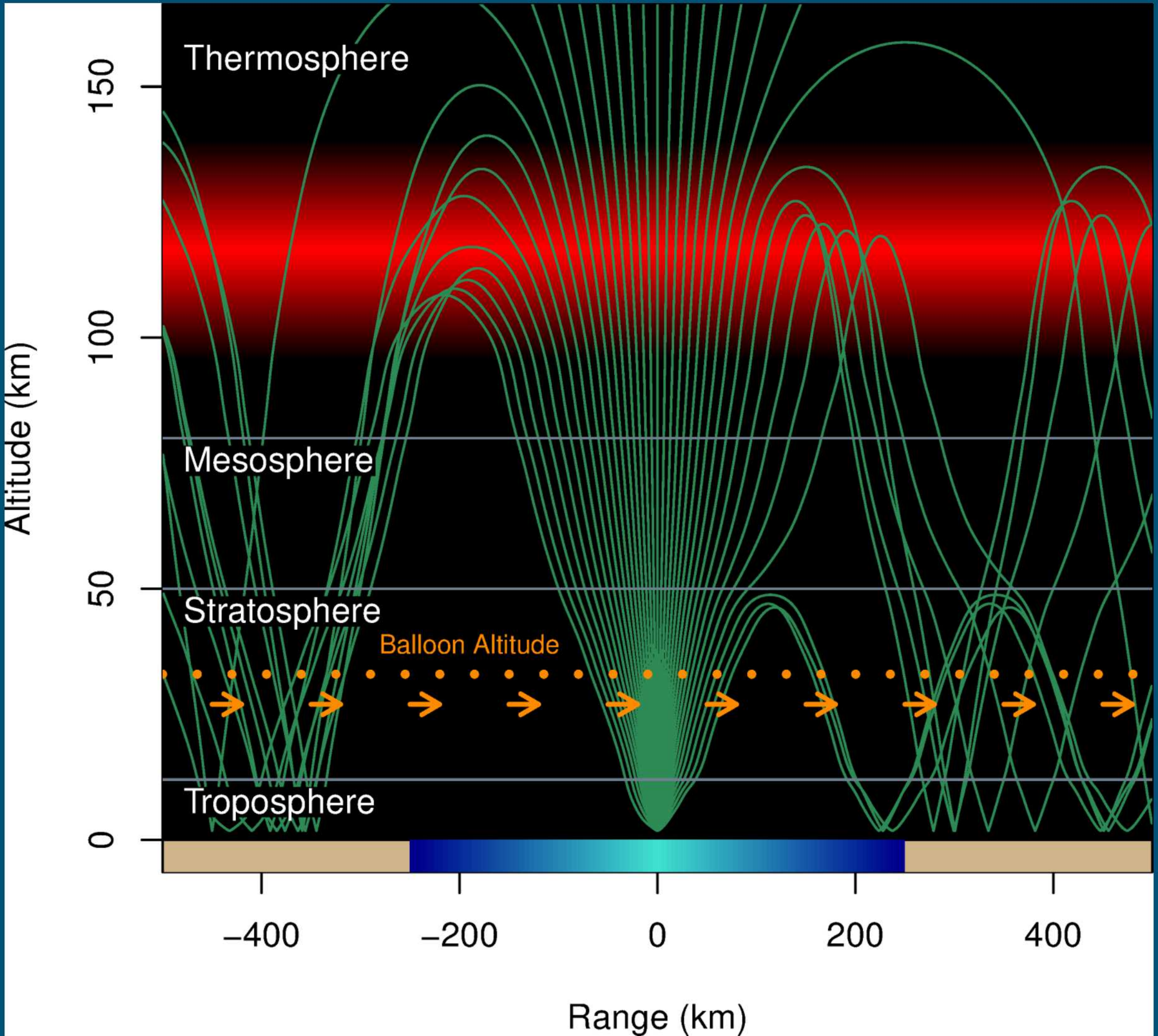
Artificial

- Chemical and nuclear explosions
- Aircraft (especially supersonic)
- Rockets
- Industrial activity
- Bridges
- Dams

Propagation Effects I

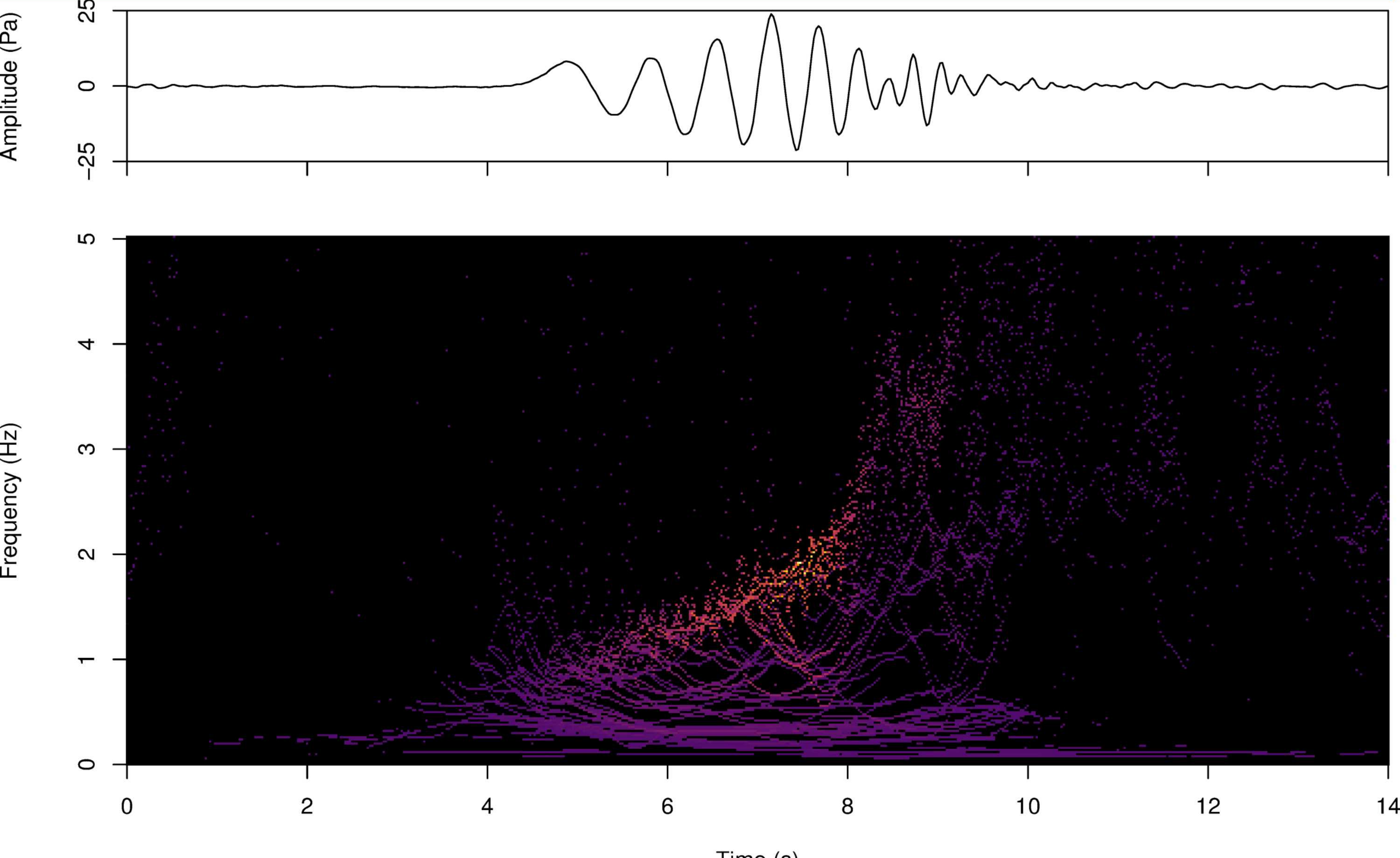
$$\vec{c} = \hat{n}\sqrt{\gamma\, R\, T} + \vec{u}$$

Winds and temperature gradients control acoustic propagation in the atmosphere.



Propagation Effects II

Lower atmospheric structures can create short-lived waveguides.



Pressure/yield models for explosions

ANSI:

$$\Delta p = 6.526 W^{0.3667} R^{-1.1} (\frac{p}{p_0})^{0.6333}$$

p is in Pascals, W is in kilotons (nuclear equivalent), and R is in km.

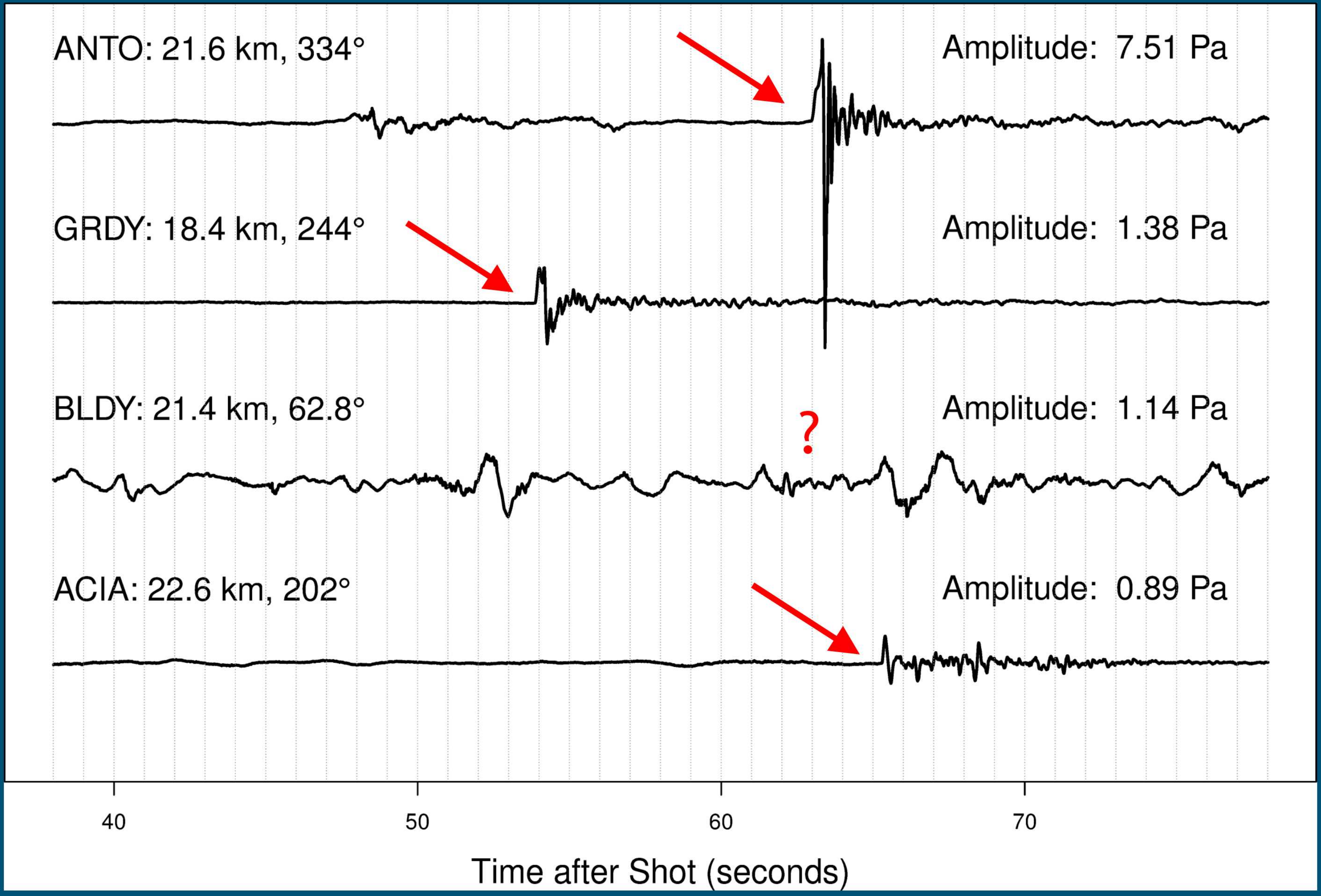
BOOM:

$$L = A + \frac{B}{5.3} + 20 \log \left[\left(\frac{p}{1013}\right)^{0.556} \left(\frac{W}{110}\right)^{0.444} \left(\frac{25}{R}\right)^{1.333} \right]$$

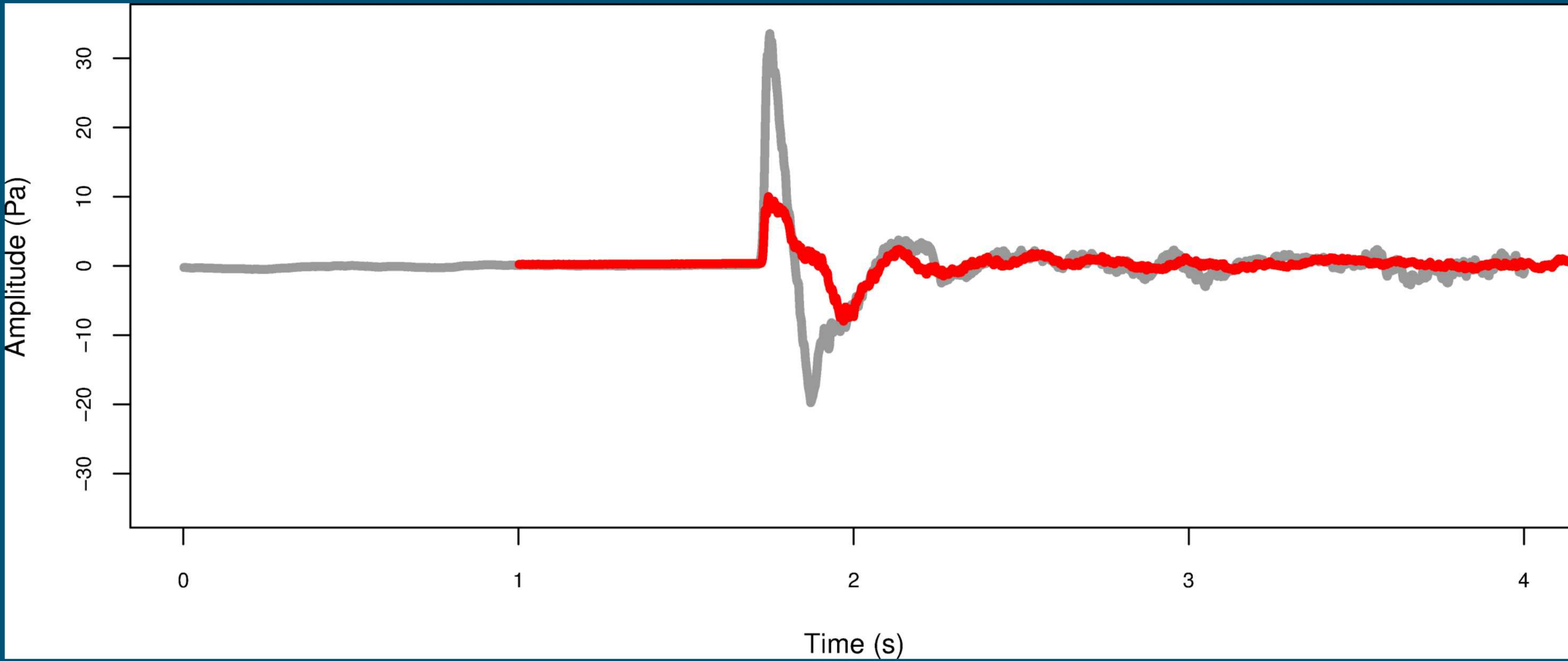
$$B = \tan^{-1} \left[3 \left(\frac{\Delta V}{\Delta Z}\right) \left(\frac{R}{c}\right) \right]$$

L is in maximum peak overpressure (dB), W is in kilotons (HE equivalent), ΔV is the maximum difference between the surface sound speed and sound speeds at higher elevations (m/s), ΔZ is the elevation at which ΔV is observed (km), and c is surface sound speed.

Explosion signatures: distance variability



Explosion signatures: time variability



Two identical co-located explosions (800 kg TNT equivalent yield) detonated 90 minutes apart recorded on the same sensor.

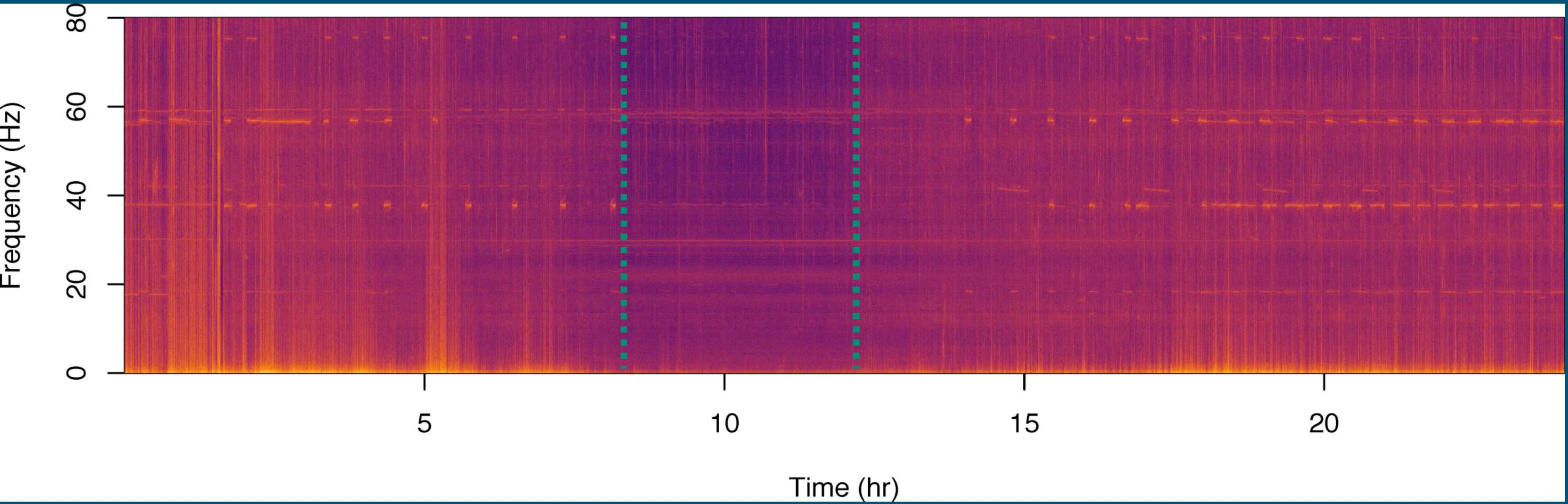
Consequences

An accurate, high resolution atmospheric model is ***required*** for explosive yield.

Options:

- Operational Forecast Models:
  - Continuously and freely available (e. g. NOAA NOMADS)
  - Low resolution
- Local Atmosphere Models:
  - Open source (e. g. WRF)
  - Requires local computing time and in-house weather modeling expertise
- Radiosonde Profiles
  - Snapshot of the real atmosphere from <100 m AGL to the stratosphere
  - Only occurs from certain locations a few times a day
- LIDAR, SODAR, etc.
  - Continuous record of temperature and wind profiles to several kilometers AGL
  - Constant power source, large volumes of data, expensive, restricted to single locations

Atmospheric Structure from Ambient Sound?



One day of urban microbarometer data recorded in Albuquerque, NM

Project Goals

Record several months of continuous acoustic data and correlate it with other atmospheric observables in Las Vegas, Nevada

Can we use the acoustic data alone to determine the structure of the lower atmosphere?

SNL is working with Doug Seastrand and Melissa Wright (MSTS) to field instrumentation, recover data, and analyze results.

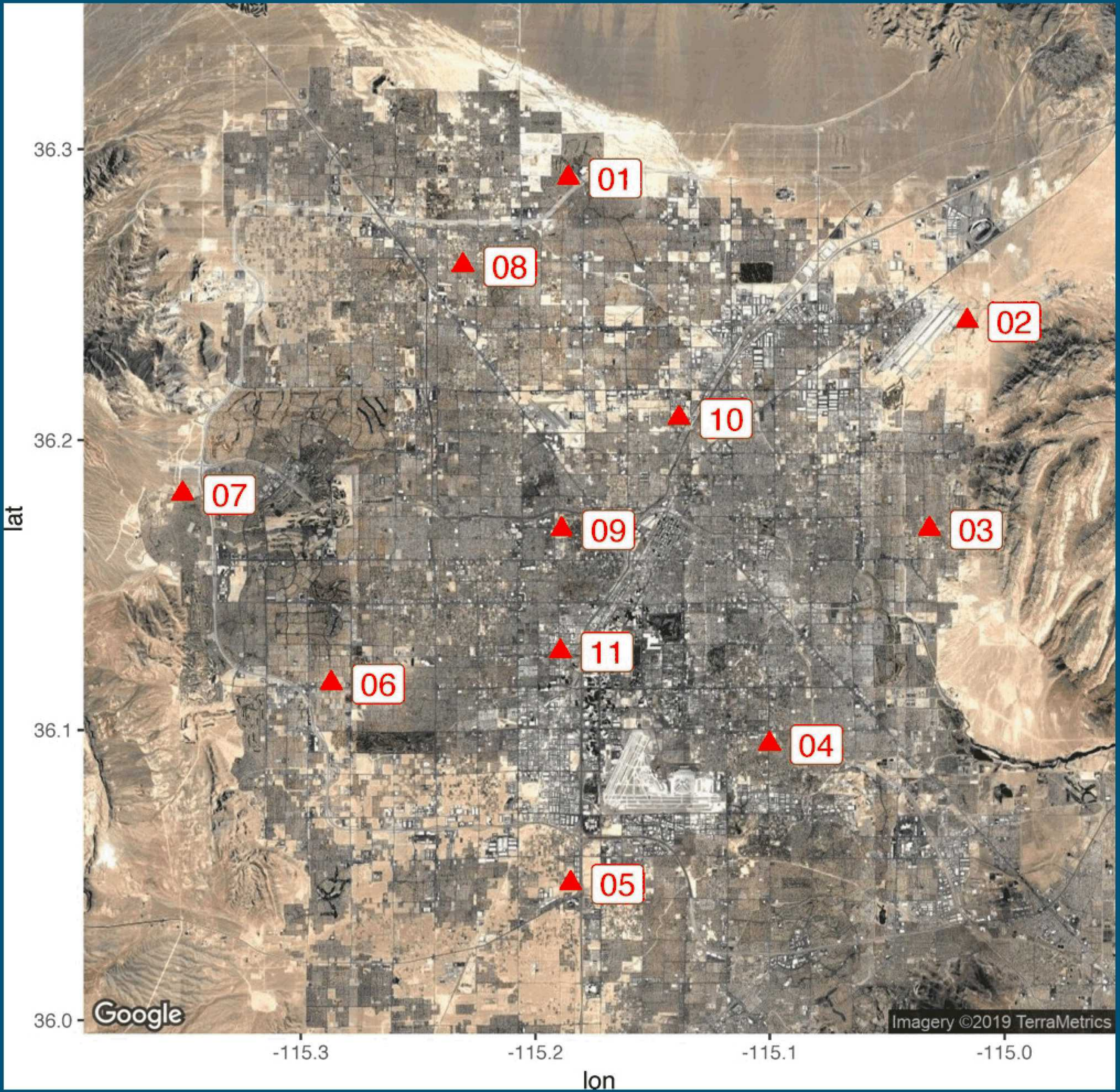
Project Plan and Responsibilities

1. Identify site locations and obtain permissions (SNL/MSTS, complete)
2. Field instrumentation (MSTS, March-April 2019)
3. Recover data (MSTS) and process data (SNL) (monthly)
4. Preliminary data analysis (SNL, July-September 2019)
5. Conference presentations and draft paper (SNL/MSTS, September-December 2019)
6. Continued data analysis to capture winter atmosphere (SNL, January-March 2020)
7. Final publications and results; final report (SNL/MSTS April 2020)

Instrumentation

- Capture temperature data from 0-3 km using the Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST)
- Capture wind data using a Doppler-lidar wind gauge
- Ingest data from radiosonde profiles at McCarran International Airport
- **Compare with infrasound microbarometer data from throughout the city**

Network Map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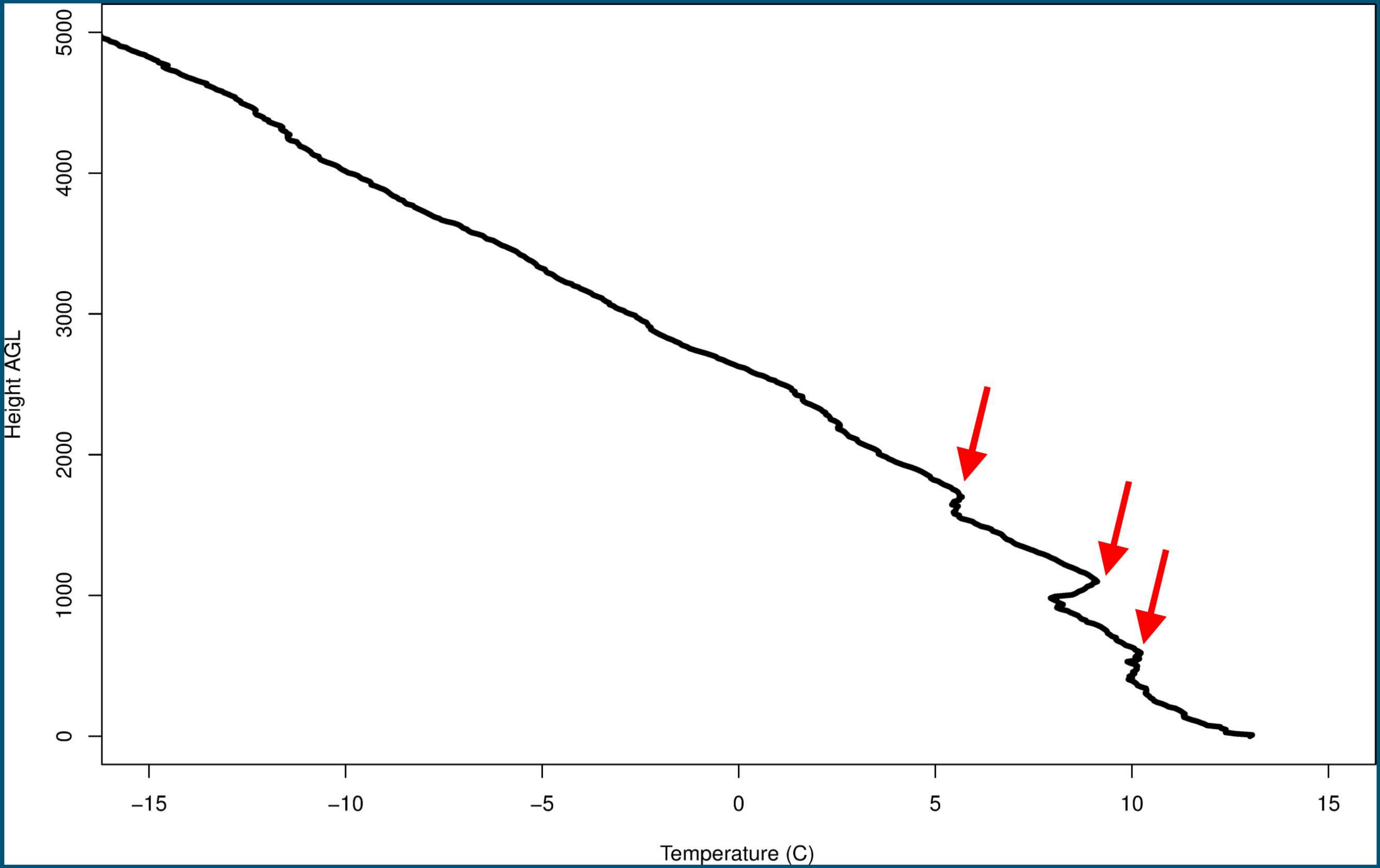
Imagery ©2019 TerraMetrics

Analysis

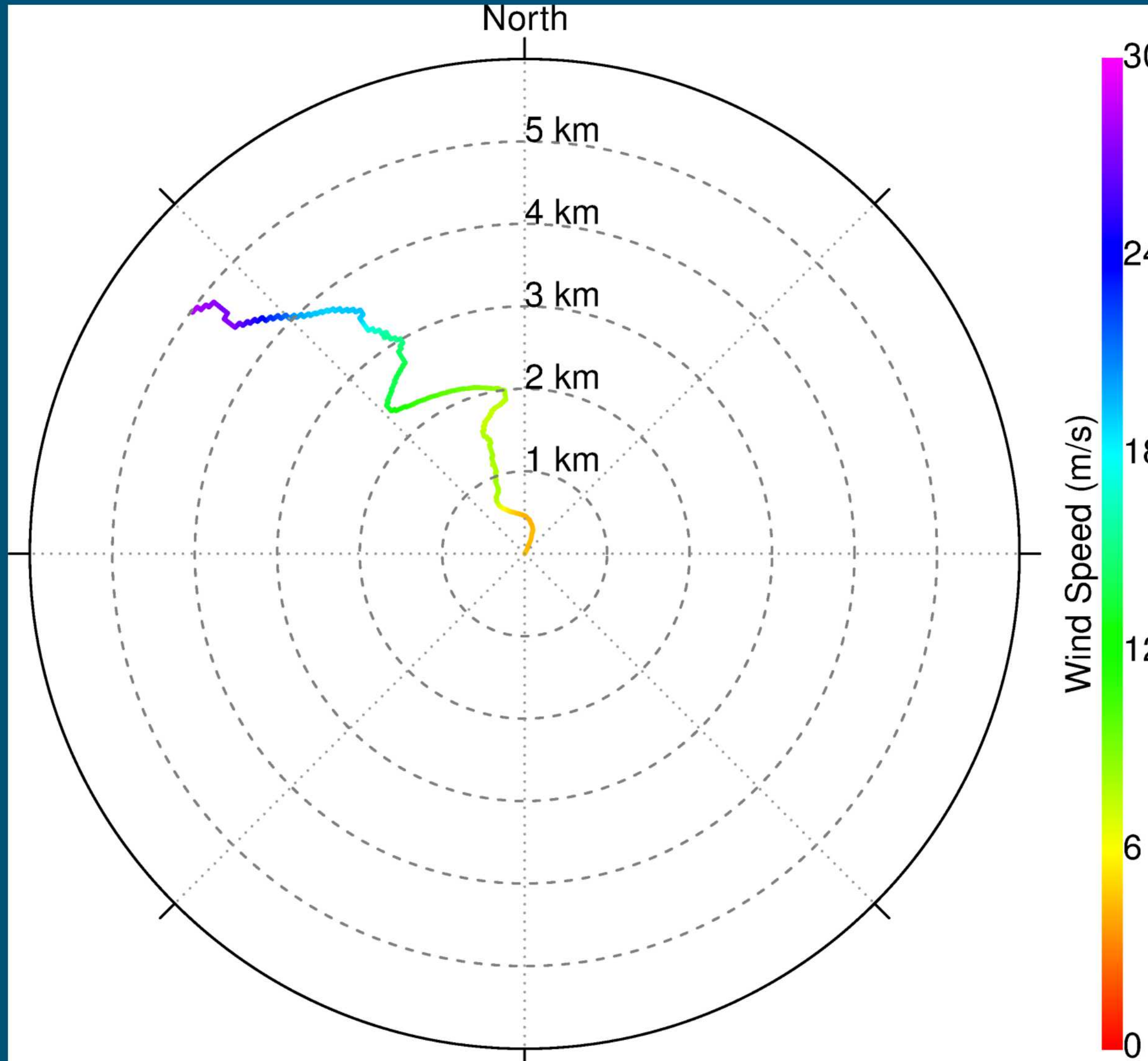
1. Atmospheric inversion detection
2. Refractively-significant wind direction determination
3. Spectrum cluster analysis for atmospheric regime identification

Inversion Detection



General enhancement of acoustic energy throughout the city.

Wind Direction at Refractive Level



Energy focused in one direction, defocused in others.

Spectrum Cluster Analysis

Apply a clustering algorithm to microbarometer Welch spectra, and associate the clusters with a particular atmospheric regime.

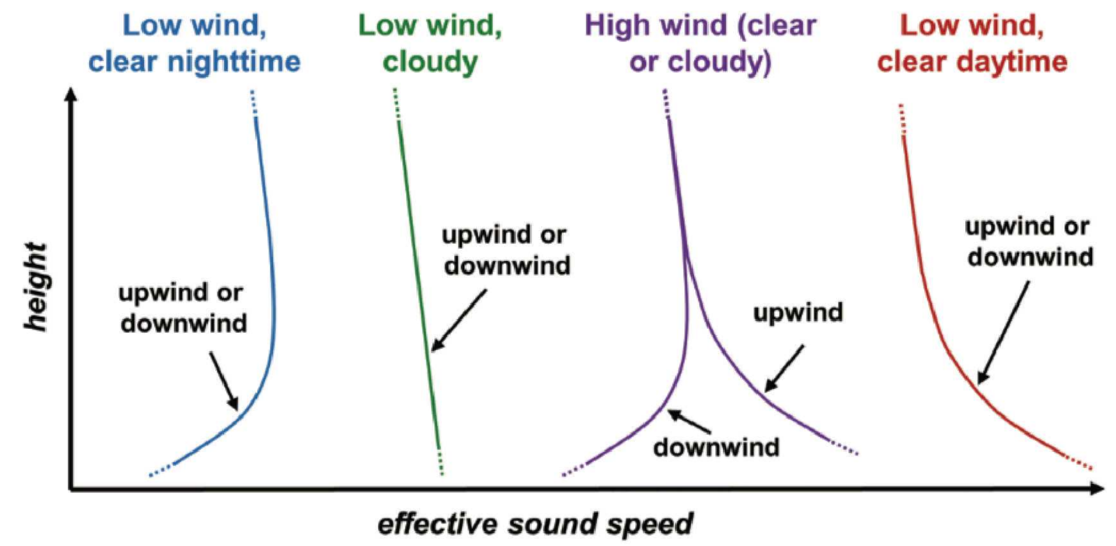


Figure 2. *Characteristic effective sound speed profiles for 4 limiting cases of the ASL. The profiles are arbitrarily offset along the horizontal axis so as to improve visibility.*

From Wilson et al. (2015)

Acknowledgments

The idea to utilize ambient urban acoustic waves to invert for atmospheric state emerged during discussions between D. Bowman (SNL) and S. Arrowsmith (formerly SNL, now Southern Methodist University). The concept was further developed by D. Bowman (SNL), D. Seastrand (MSTS), and M. Wright (MSTS).

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