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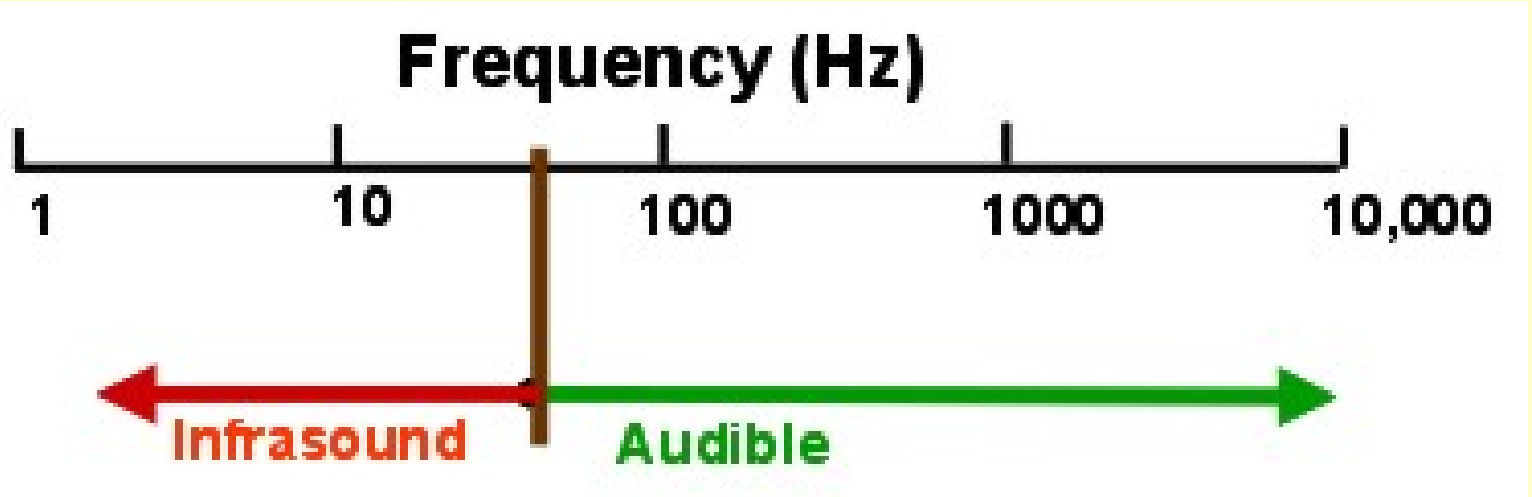
INFRASOUND

What is infrasound?



Infrasound is sound below 6 Hz

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Why the interest in infrasound ?

- *Long-distance propagation*
- *Simple, ground based equipment*
- *Flexible system*
- *But slow, the speed of sound ....*

So, why record?

Monitor a variety of activities

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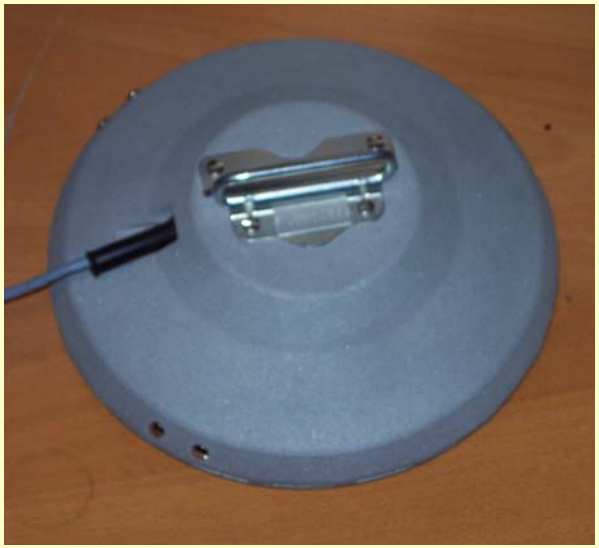
Sensitivity:	3100 mV/PA at 20 Hz
Frequency Response:	-6 dB 2.0 Hz – 200 Hz
Dynamic Range:	110 dB 4% distortion
Equivalent Input Noise:	-18 dB rel 20 μPA/Hz
Amplifier Gain:	31 dB
Operating Temperature:	-40 to +70 deg C



Weight:	690 gram
Diameter:	100 mm
Height:	50 mm
Power:	+-12 V, 100 mA

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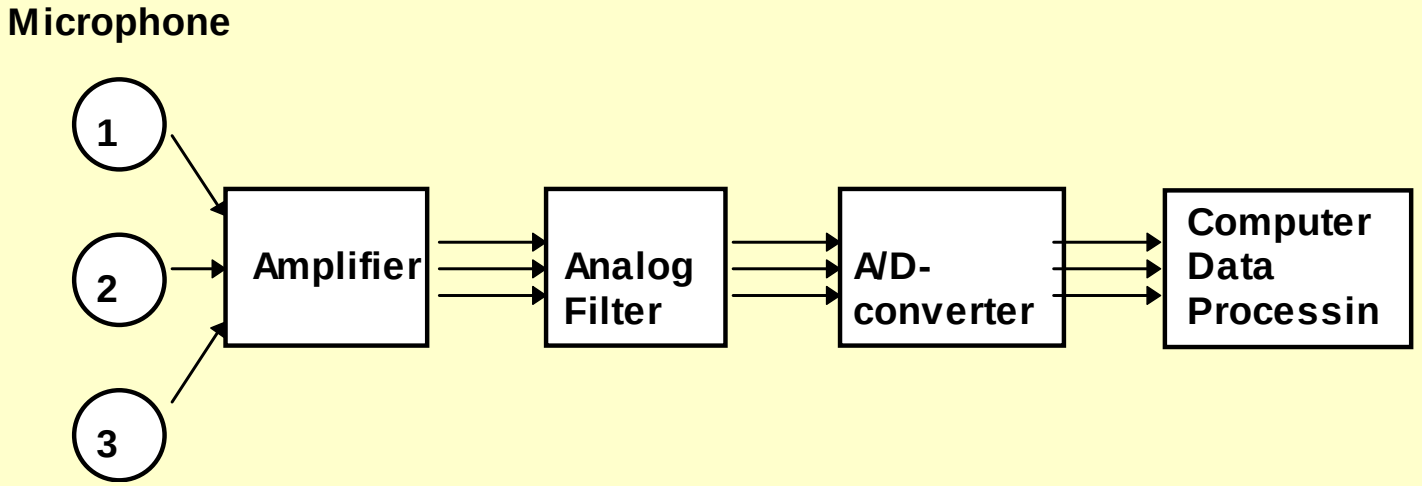

Generally three or more microphones are needed to get directional information.

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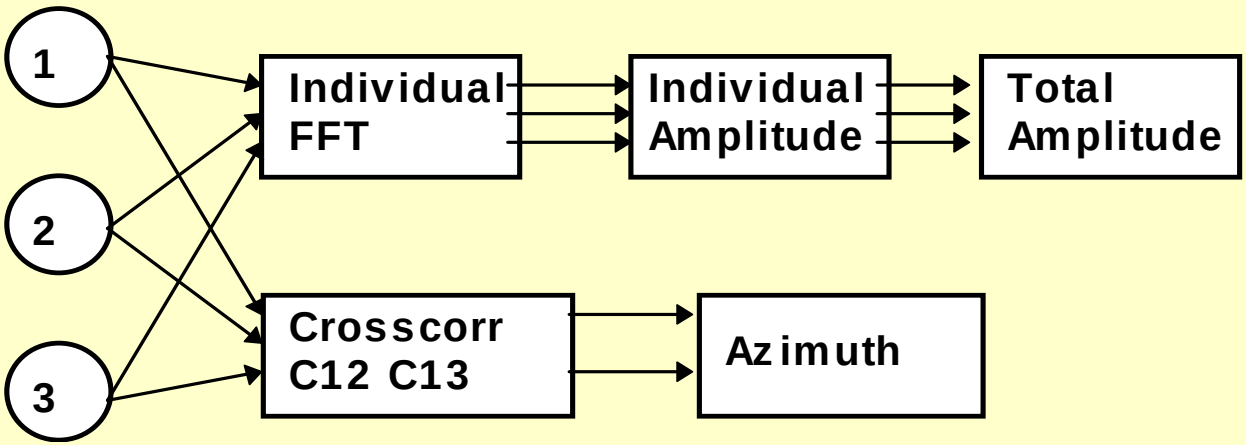
Two different types of calculations are performed for the three signals

128 points time series



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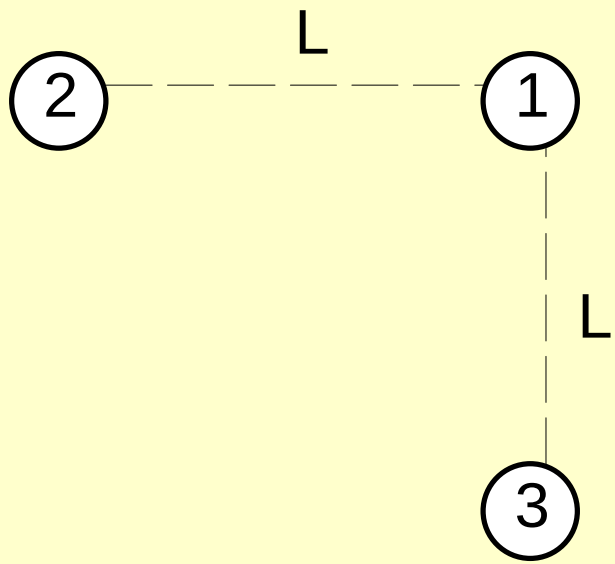
Generally a set of three microphones are used. They are arranged at a right angle. The distance between them, L, depends on the frequency you are interested in. The pair of microphones 1 and 3 are oriented in the North-South direction and the pair 1 and 2 are oriented in the East-West direction



$$L_s \leq \frac{\lambda_{\min}}{2}$$

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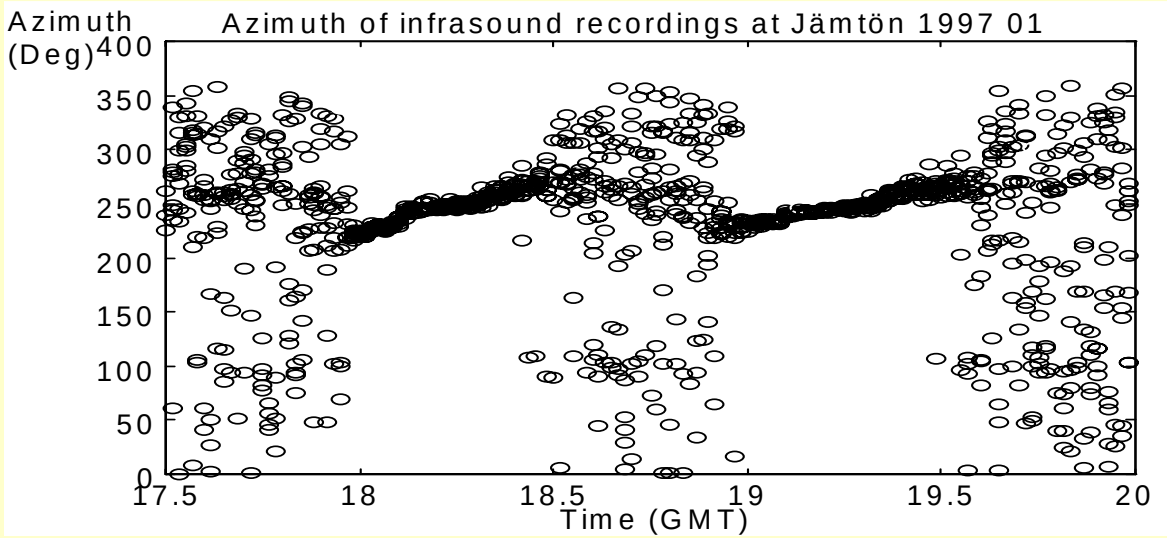
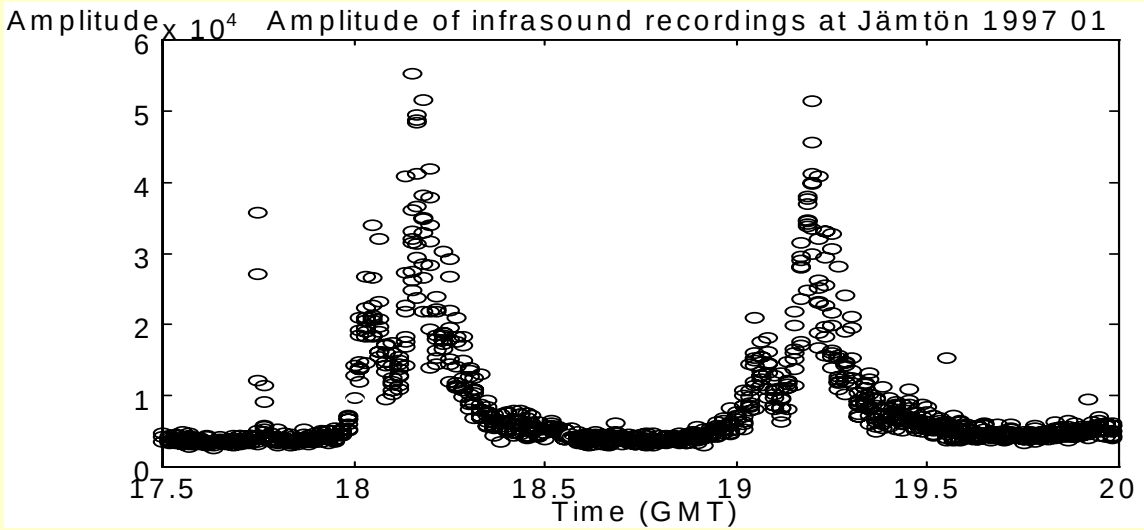
Examples of azimuth and amplitude plots.

From work by
K.Waldemark and
L. Liszka,
IRF, Umeå





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Directional information is obtained from the phase differences of two pair of detectors, 1-2 and 1-3

$$\alpha = \arctan \frac{\Phi_{12}}{\Phi_{13}}$$

Cross-correlation technique is used to determine the phase differences (ρ yields a maximum for Φ)

$$\rho_{xy}(k) = \begin{cases} \frac{1}{N-k} \sum_{n=1}^{N-k} \hat{x}(n+k)_x \, \hat{x}(n)_y \leftrightarrow 0 \le k \le N \\ \frac{1}{N-|k|} \sum_{n=1}^{N-|k|} \hat{x}(n)_x \, \hat{x}(n+|k|)_y \leftrightarrow -N \le k < 0 \end{cases}$$

Estimating the maximum cross correlation by the parabola method

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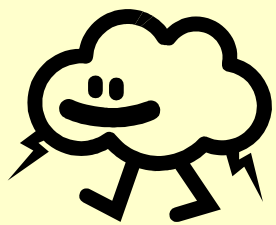
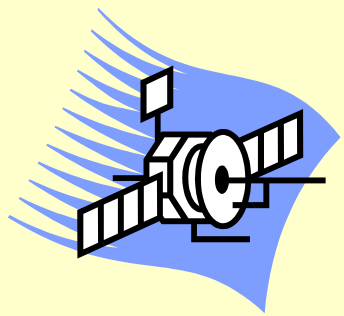
In the single-sensor mode we use a different setup. The aim is to get both the frequency spectrum and the FFT on-line. With the help of other detectors (e.g. lightning detectors, cameras) one can then put a gate on the desired signal (frequency) and make (anti-) coincidence measurements with other detectors.



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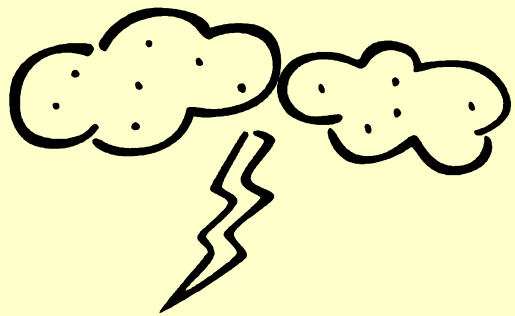
For example: We want to exclude the ligthning infrasound so we take a signal from a lightning detector and exclude the writing to a file of the infrasound results in these cases.

Or, if we are simply interested in infrasound with the strongest component at 2.2 Hz, we simply put a gate in this region of the FFT spectrum.



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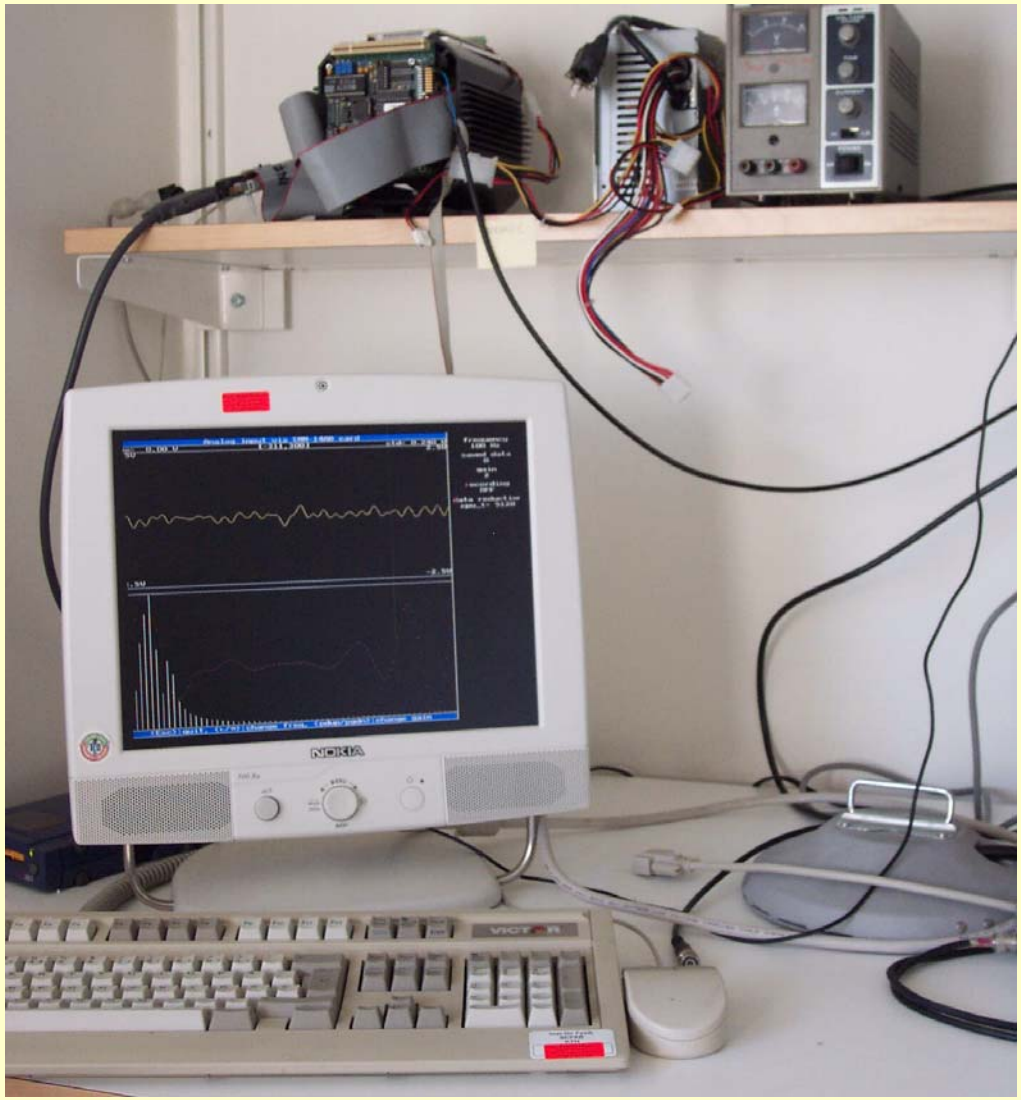
The PC/104 system has a Pentium CPU, a small HD and the usual I/O.



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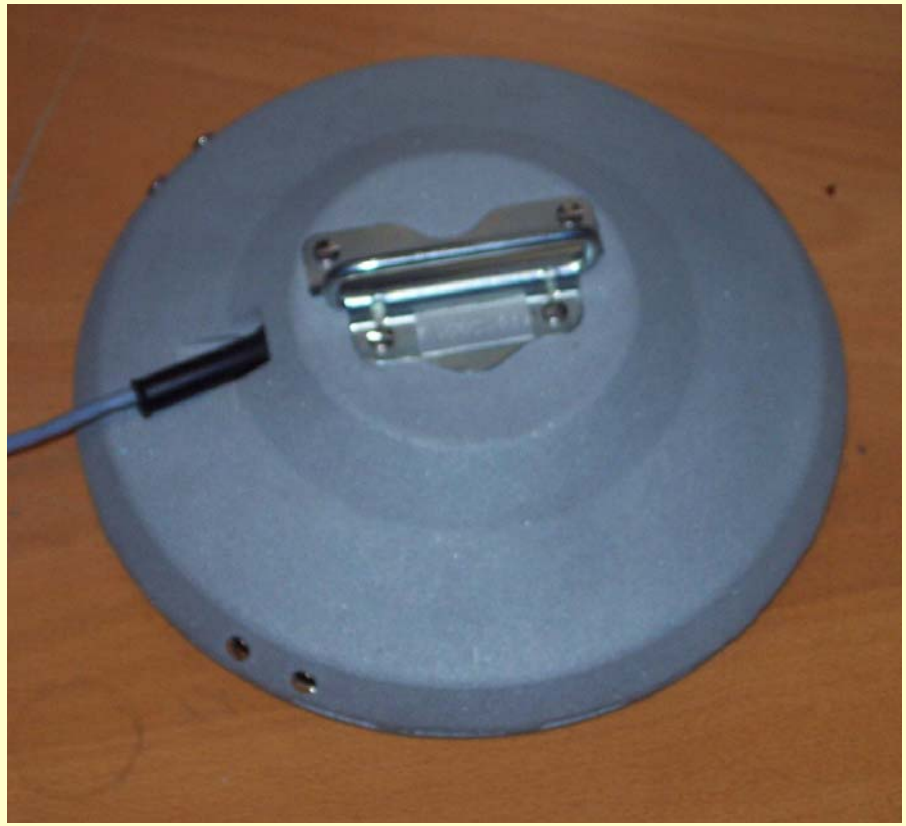
The microphone is much smaller than the cover indicates. This cover is probably for a military version of the microphone (detecting helicopters?).



It has a built-in preamplifier and this signal is fed to ...

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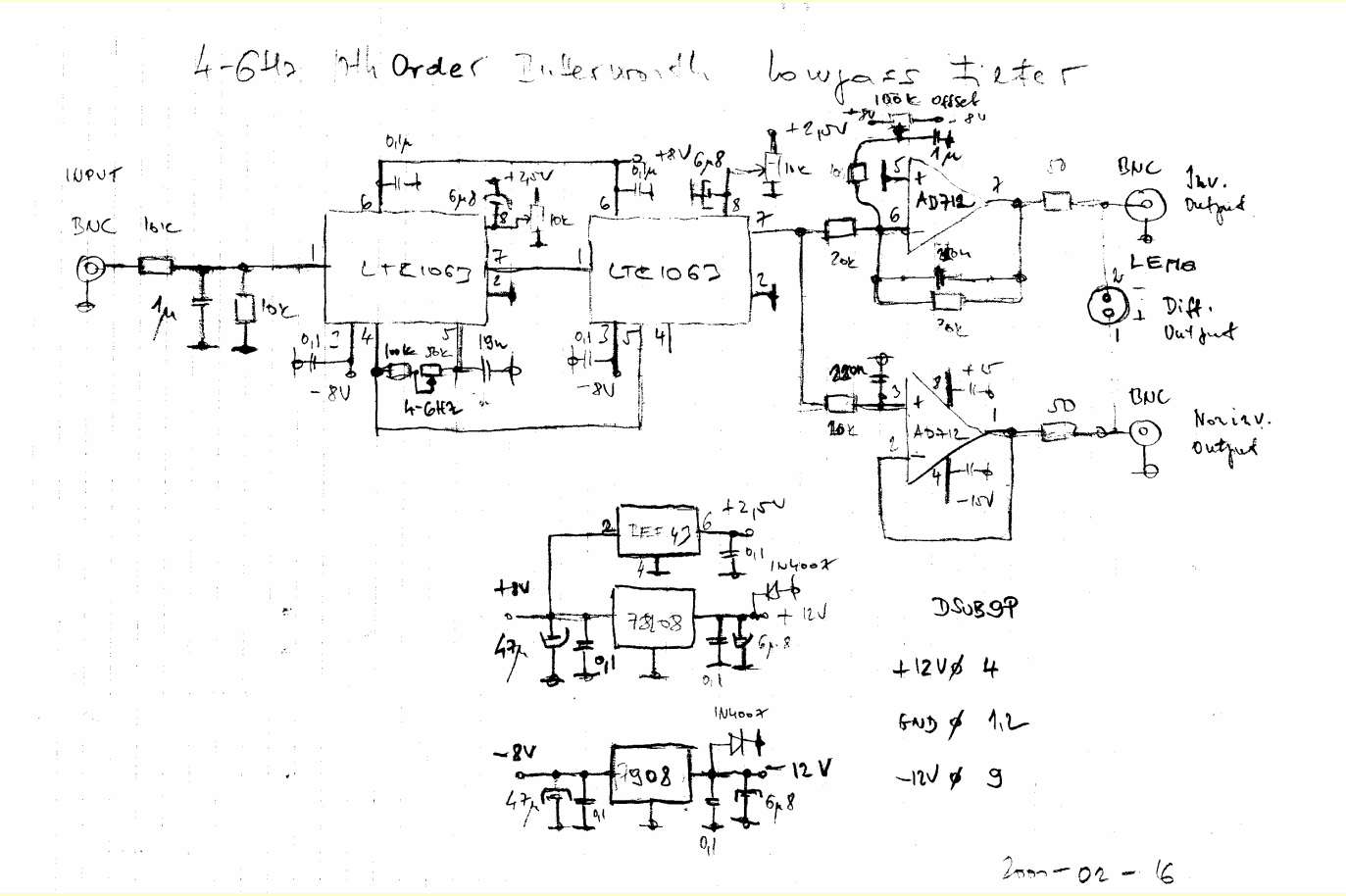
... a 10th Order Butterworth Lowpass Filter and the output ....



With a potentiometer you can change the upper frequency between 4 and 6 Hz

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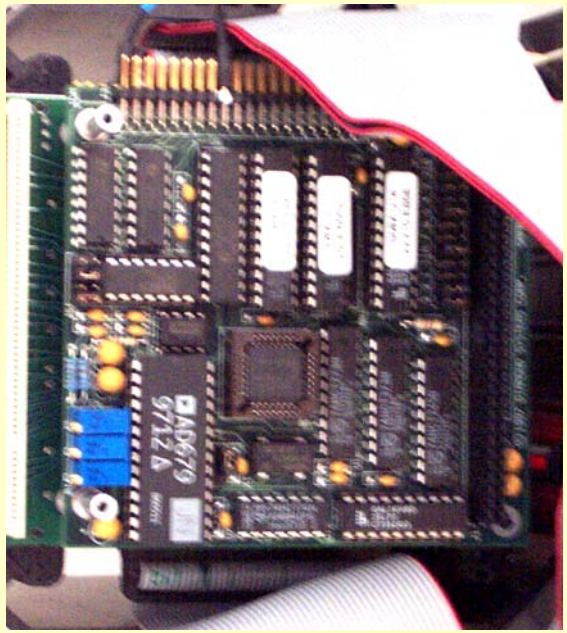
.... from this filter the signal is sent to the PC/104 ADC for signal processing (e.g. FFT, wavelet) and to gate or be gated by other sensor signal(s) before being written to disk.



The PC/104 system is running the DOS 3.11 operating system

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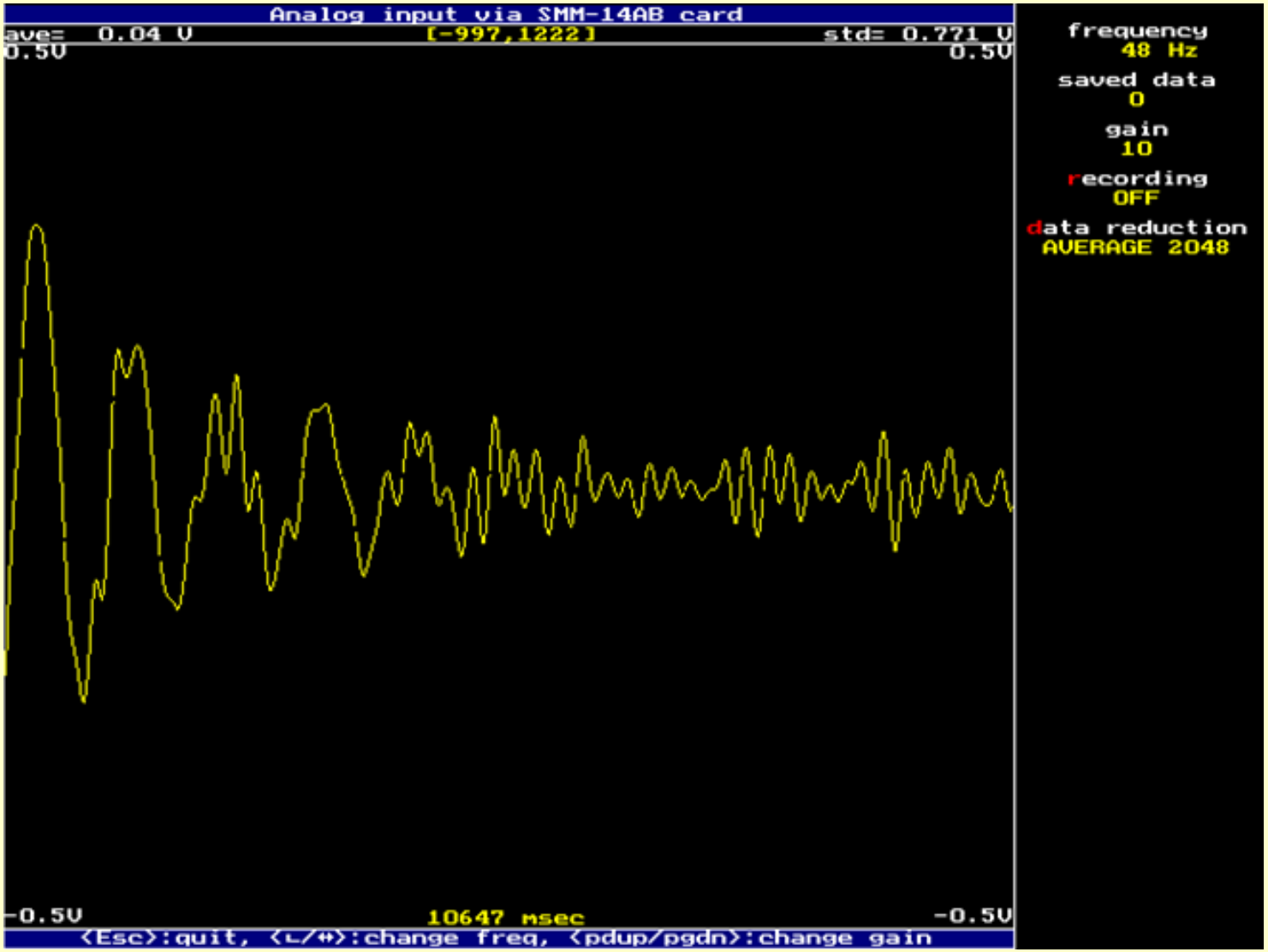

The PC/104 system is running the DOS 3.11 operating system

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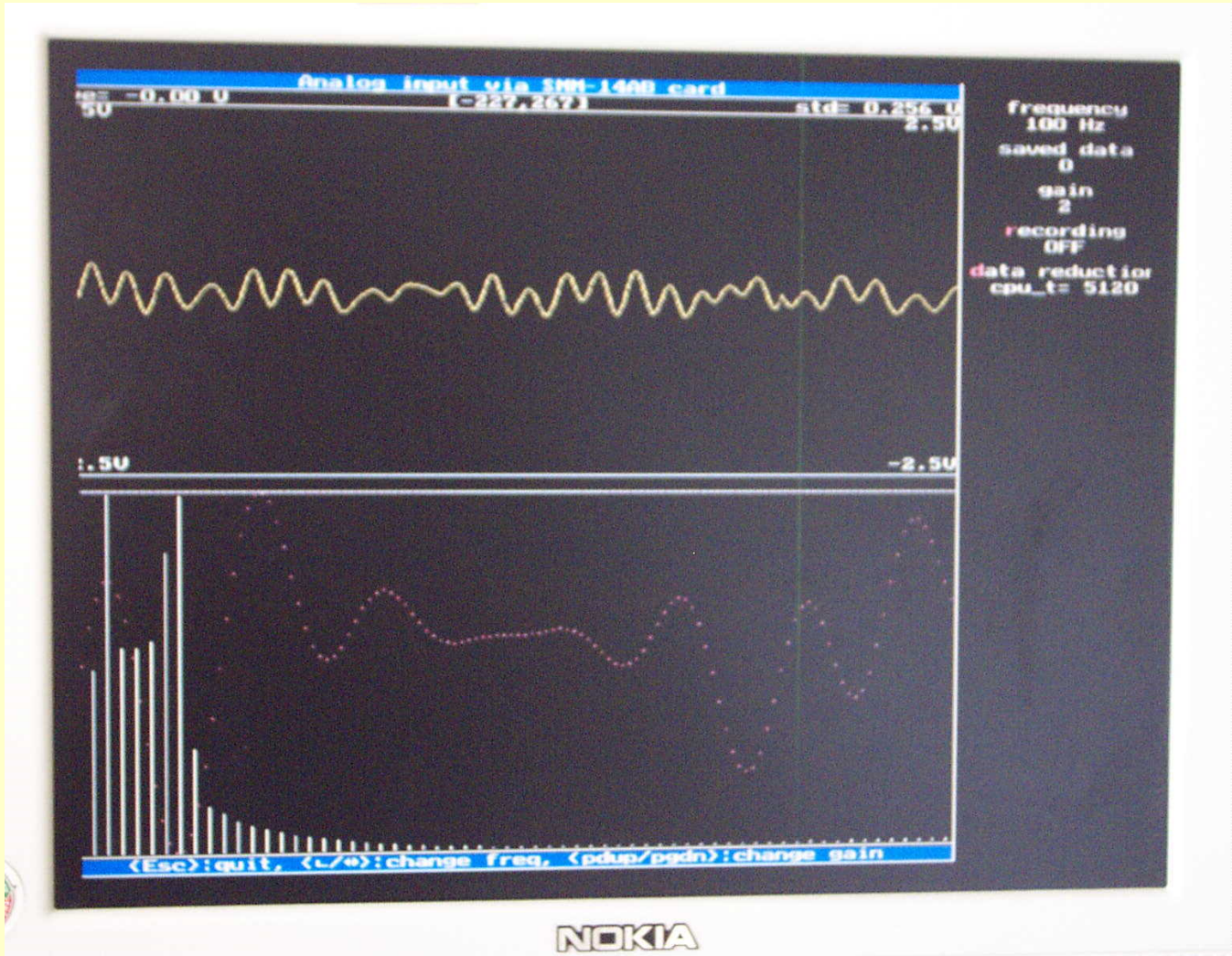
A typical screen when running the software.



The PC/104 system is running the DOS 3.11 operating system

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The idea is to combine the directional (and amplitude) information of the three detector array with a finger-print or signature signal of a single detector, *plus signal from other sensors.*

The PC/104 system is running the DOS 3.11 operating system

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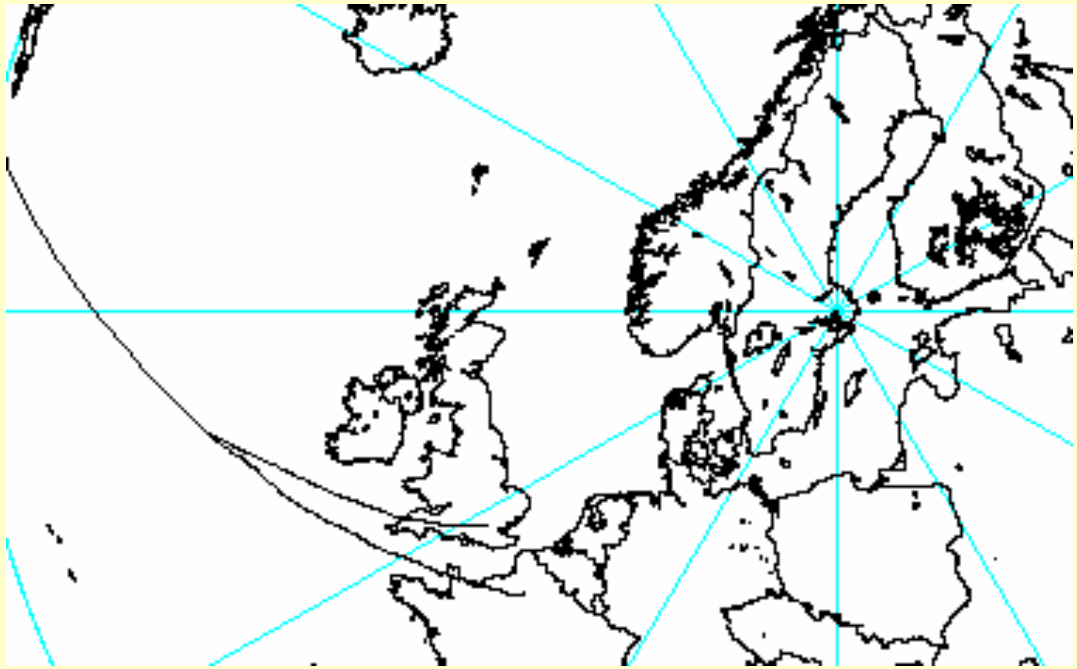
INFRASOUND

What can be done using infrasound?

Example 1: Aircrafts: The Concorde

Following the Concorde from WDC to London or Paris. Recording on February 6, 1995 at midnight.



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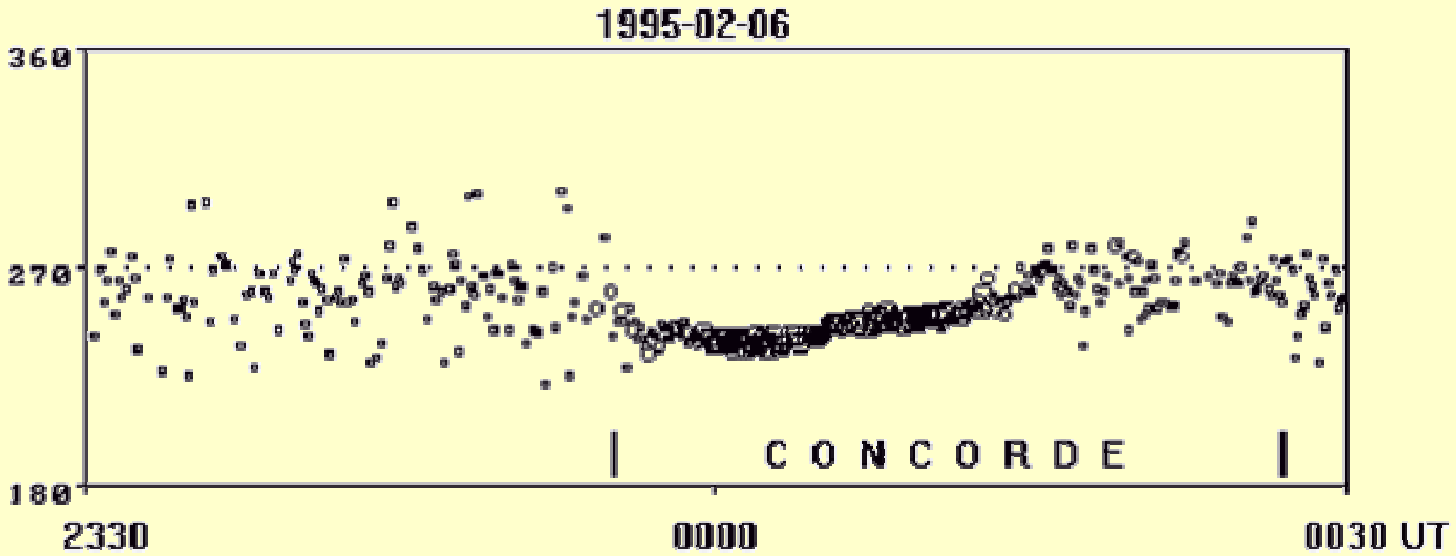
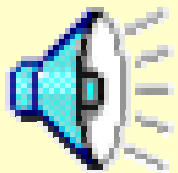
What can be done using infrasound?

Example 1: Aircrafts: The Concorde





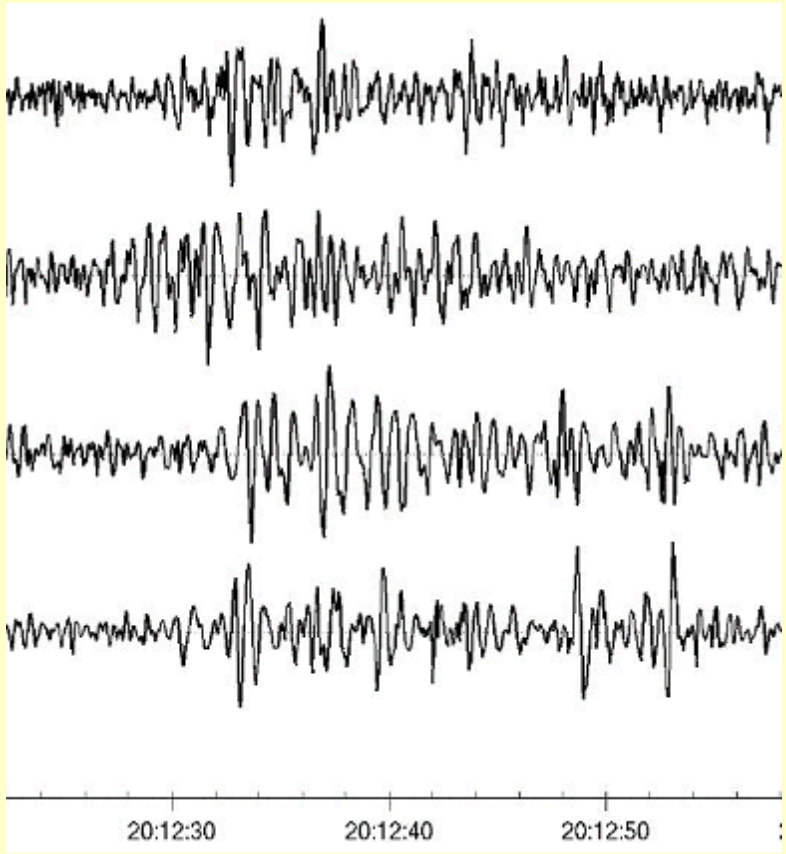
Concorde is frequency transformed (x306) in order to be audible.

INFRASOUND

What can be done using infrasound?

Example 1 (cont´d):
Aircrafts: A nearby airport

Aircraft signals generally arrive from the direction of Kona International Airport. Lasting 20-30 seconds, they characteristically appear as spindle-shaped, emergent events with relatively smooth tapers at each end.



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INFRASOUND

What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty

CTBT uses infrasound systems developed by LANL to supervise the CTBT. It is used in combination with seismic data as well as satellite (FORTÉ) and Xe systems.

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INFRASOUND

What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty

"The goal of the DOE's Infrasound Monitoring Research is to improve the US government's capability to detect and identify low-frequency acoustic signals from atmospheric, shallow buried, or moderately shielded explosions."

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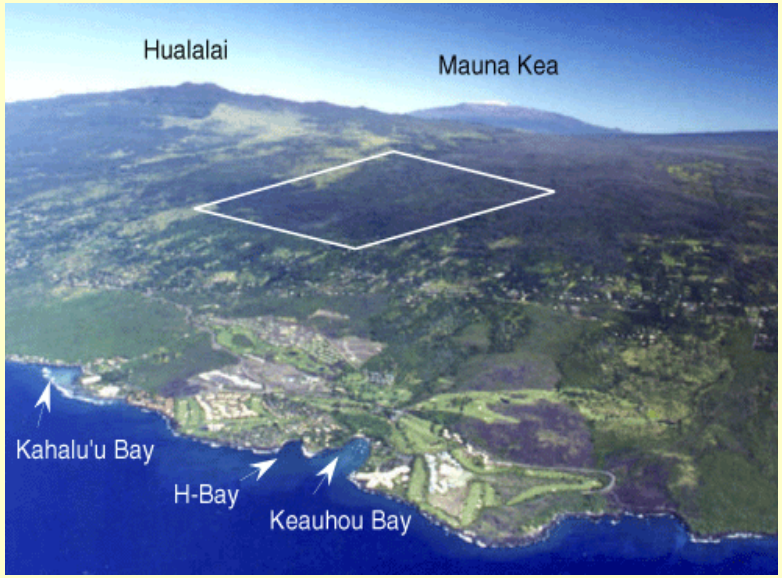
What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty

ISLA of University of Hawaii is responsible for the operation and maintenance of IS59, or KONA, a 4-element infrasound array that will be part of the International Monitoring System (IMS) of the CTBT. Due to its unique location in the shadow of Hawaii's massive volcanoes, the KONA array has exceptionally low ambient noise levels and acoustic detection thresholds.



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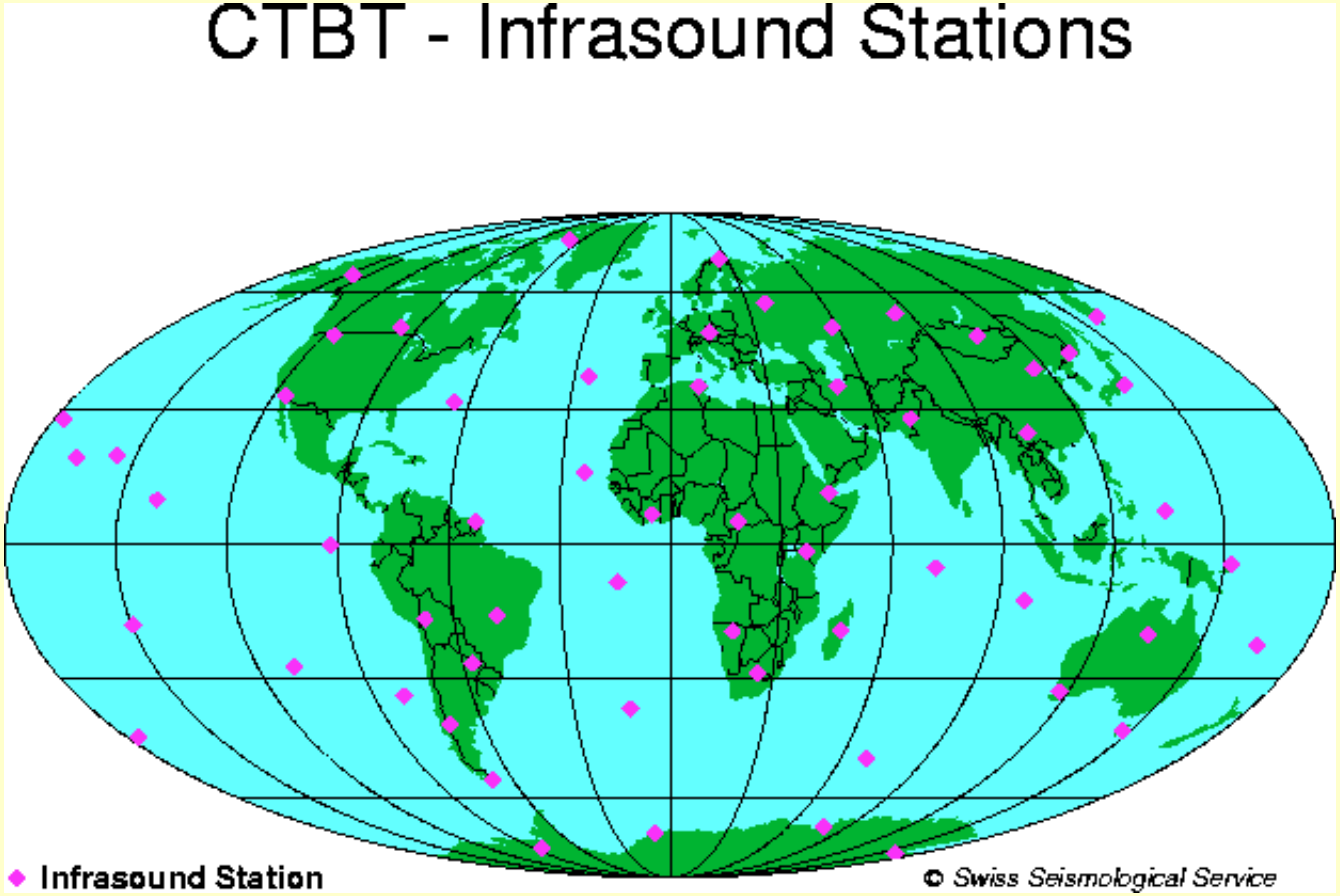
What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty



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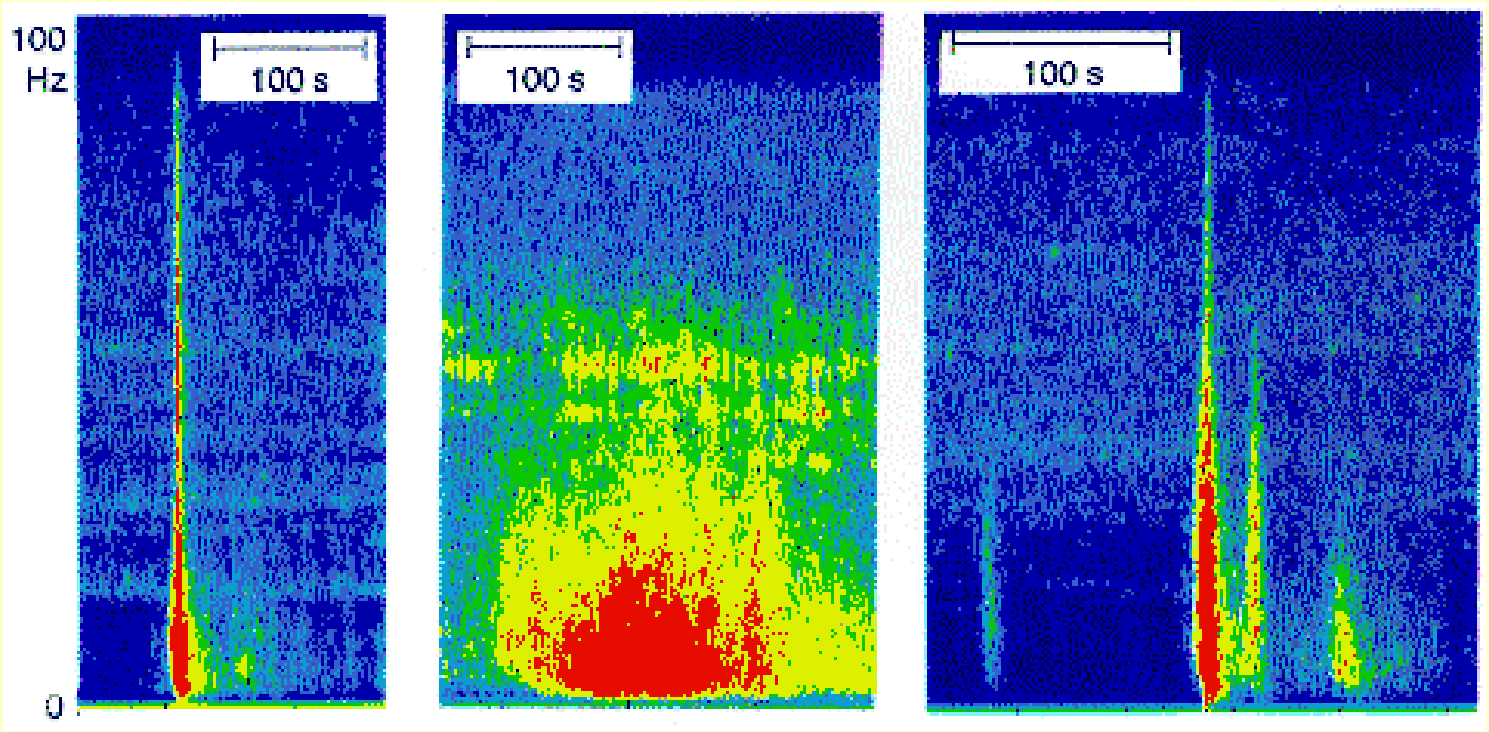
What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty



SONOGRAMS:
Left; A Mururoa Test, middle: A seaquake near Japan
right: A volcanic eruption near Hawaii

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What can be done using infrasound?

Example 2: Nuclear Test Ban Treaty

Nuclear tests under water can be more easily detected than those under ground. Because of the high attenuation of the underground propagation, only the lowest frequency components of about 1 Hz and less of a continental explosion will will propagate distances.

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INFRASOUND

What can be done using infrasound?

Example 3: Meteor Detector

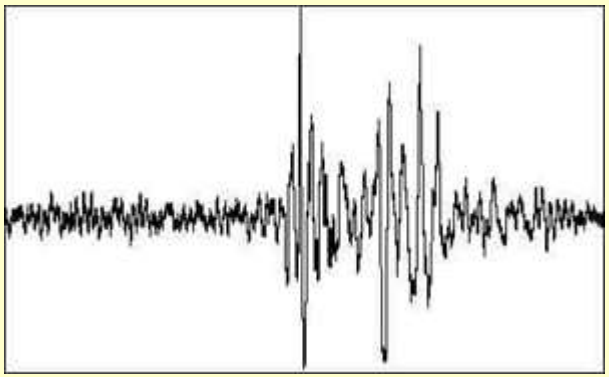
Meteors generate infrasound during their entry in the Earth's atmosphere. Traveling at very high supersonic speeds (e.g. 35 km/s), meteors' Mach cones become cylinders and are therefore called line sources, see figure 2. Infrasound can also be generated at the end of the meteor's atmospheric trajectory. The high speeds combined with an increasing atmospheric density, while approaching the Earth, can lead to a thermal burst. These explosions can have yields similar to nuclear explosions in the order of kilotons TNT equivalent.

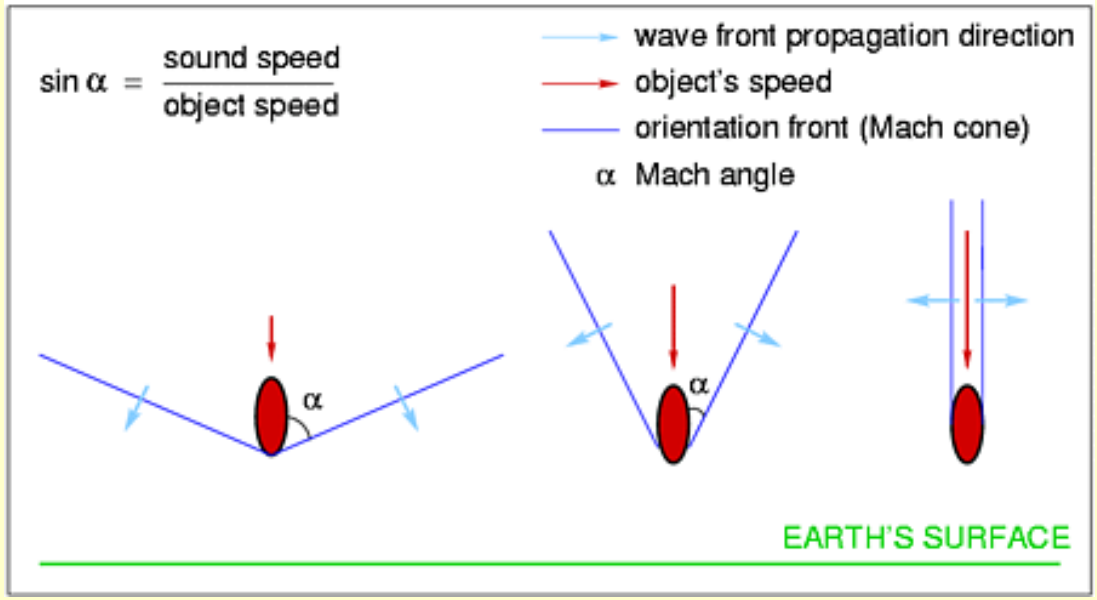
INFRASOUND

What can be done using infrasound?

Example 3: Meteor Detector

The Mach cone transforms to a cylinder with an increasing supersonic speed of the object. The speed increases from left to right as indicated by the red vector. The wave front's orientation becomes perpendicular to the propagation direction (light blue vector) with increasing speed, in other words the Mach angle becomes zero. This picture is a simplified version after [ReVelle, 1975]





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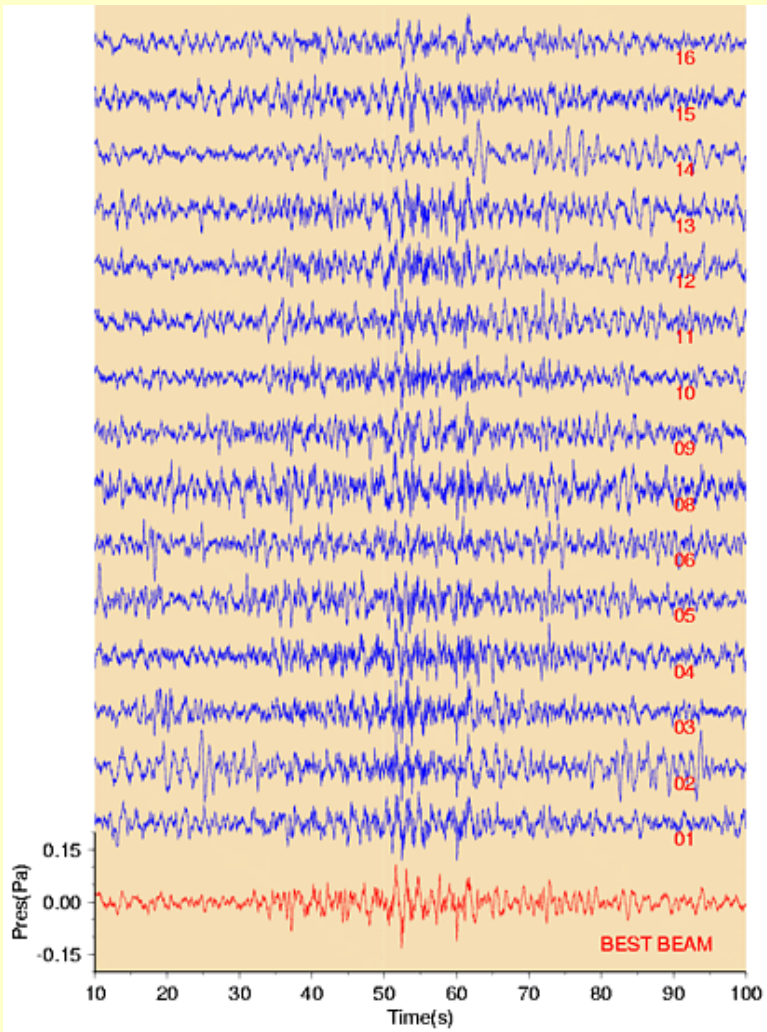
What can be done using infrasound?

Example 3: Meteor Detector



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What can be done using infrasound?

Example 3: Meteor Detector

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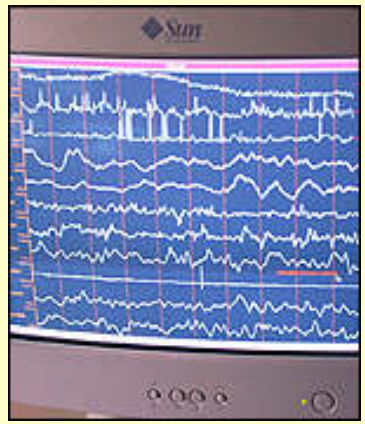
What can be done using infrasound?

Example 3: Meteor Detector (cont´d)

By BBC News Online science editor Dr David Whitehouse One of the first stations of what will be a global "infrasound" listening network, has detected a meteor that exploded over the Pacific Ocean with the force of a small nuclear blast.

The 23 April explosion occurred 1,800 km (1,118 miles) away from the Scripps detector. It was also detected by an infrasound array in Germany, 11,000 km (6,835 miles) away. As well as meteors, infrasonic sound is generated by supersonic aircraft, tornadoes, earthquakes and volcanoes.



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What can be done using infrasound?

Example 3: Meteor Detector

"The infrasonic information takes minutes or hours to reach the stations, which therefore cannot provide advance warning about approaching large meteors. However, the Los Alamos scientists welcome the opportunity to monitor falling space rocks, which allows them to fine tune the instruments to use to detect nuclear blasts."

INFRASOUND

What can be done using infrasound?

Example 3: Meteor Detector

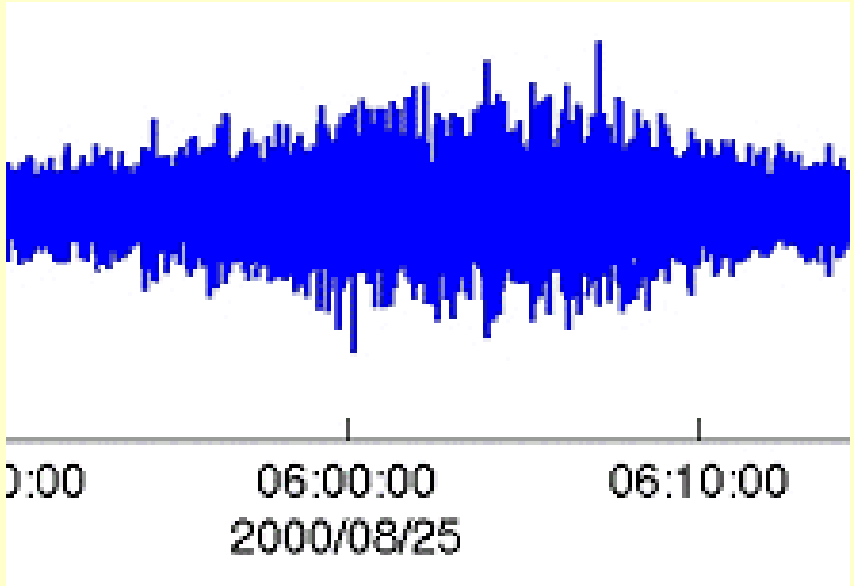
(CNN) – April, 2001:
"Intelligence scientists listening for covert nuclear blasts had their ears rattled by other explosive sounds - the detonation of meteors as they streaked over the Pacific Ocean."

INFRASOUND

What can be done using infrasound?

Example 3: Meteor Detector

Meteor entries are fascinating signals received. These events are characterized by long-duration (>10 minutes), emergent arrivals, consistent arrival azimuths through the duration of the event, and generally high correlation.



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What can be done using infrasound?

Example 4: Meteor Detector

A spectacular event happened on the 17 of January 2004. A meteorit hit the ground 50 km NW Jokkmokk.

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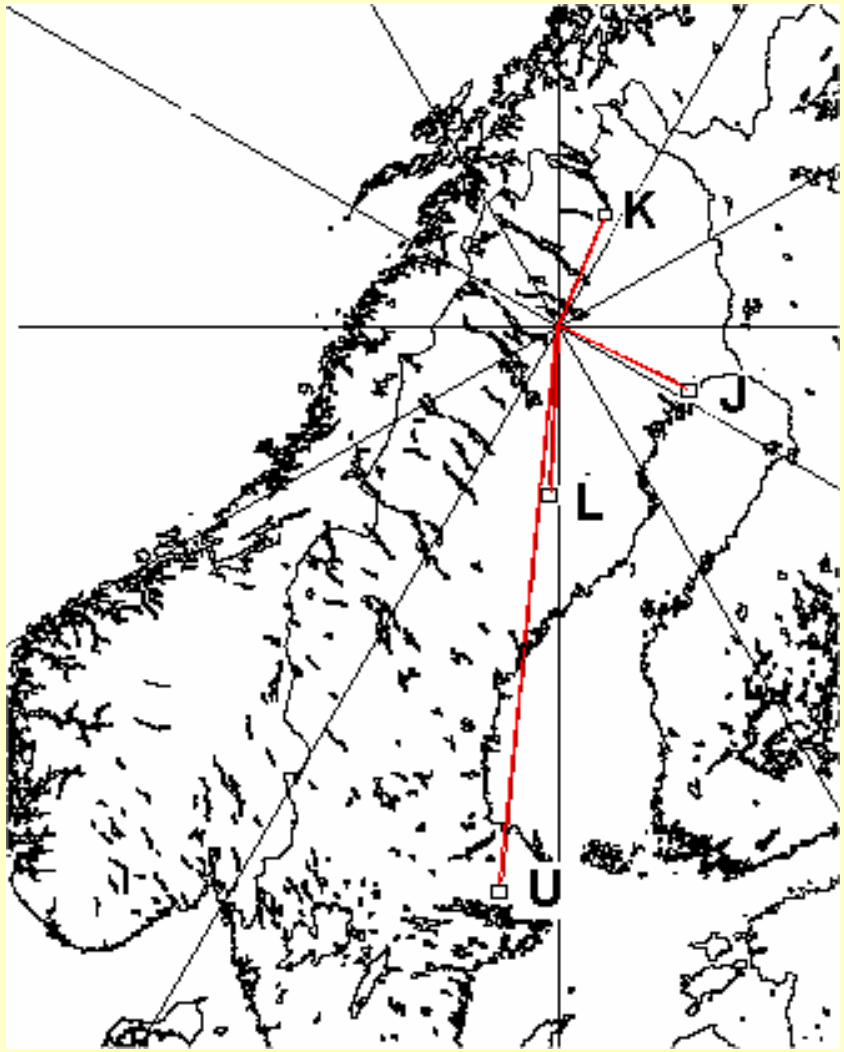
What can be done using infrasound?

Example 4: Meteor Detector

It could be "seen" from several of the IR sites in Sweden.



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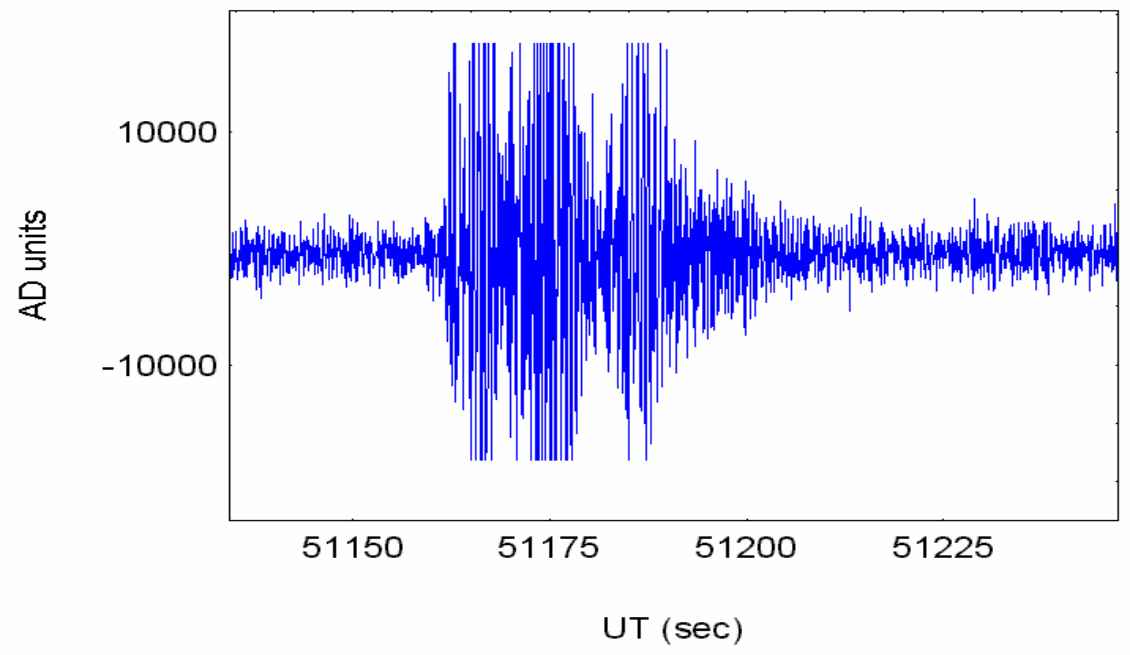
What can be done using infrasound?

Example 4: Meteor Detector

This is how the signal look from Kiruna

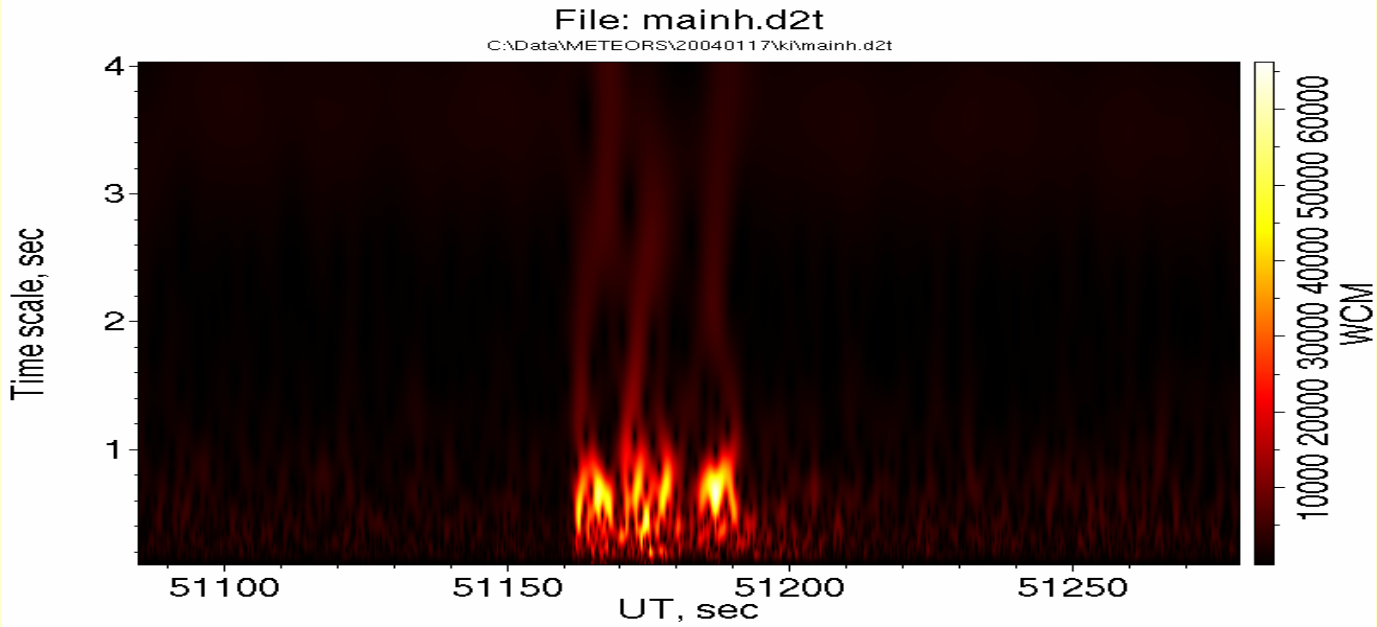


INFRASOUND

What can be done using infrasound?

Example 4: Meteor Detector

… and after a wavelet transform.



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INFRASOUND

What can be done using infrasound?

Example 3: Meteor Detector

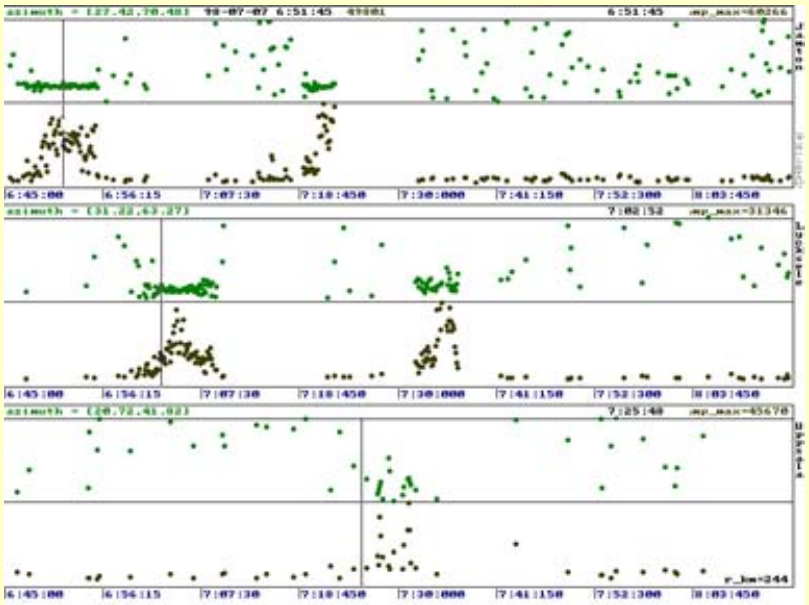
DID A METEOR KILL THE DINOSAURS? A new study provides additional support for the idea that a buried impact basin on the Yucatan peninsula was the site of an impact that was fatal to many life forms 65 million years ago. Scientists from the Lunar and Planetary Institute, the U.S. Geological Survey, and Geophysical Institute report new studies of melted rock, showing that the levels of iridium and the ratios of argon isotopes supports this (Nature, 29 Oct. 1992.). Other scientists, such as Charles Officer of Dartmouth, continue to assert that an impact may not have been the culprit and that instead certain artifacts, such as anomalous iridium, could be produced in volcanic eruptions. (Science News, 7 Nov. 1992.)

INFRASOUND

What can be done using infrasound?

Example 4: Missile Launch (1)

(BBC) – July, 1998: On July 7th, 1998 at 0315 GMT the first launch of satellites from a submarine took place. These were the TubSat nanosatellites of the Technical University in Berlin. The launch vehicle was a Shtil-1, which is a converted Makeyev Design Bureau R-29RM SLBM .



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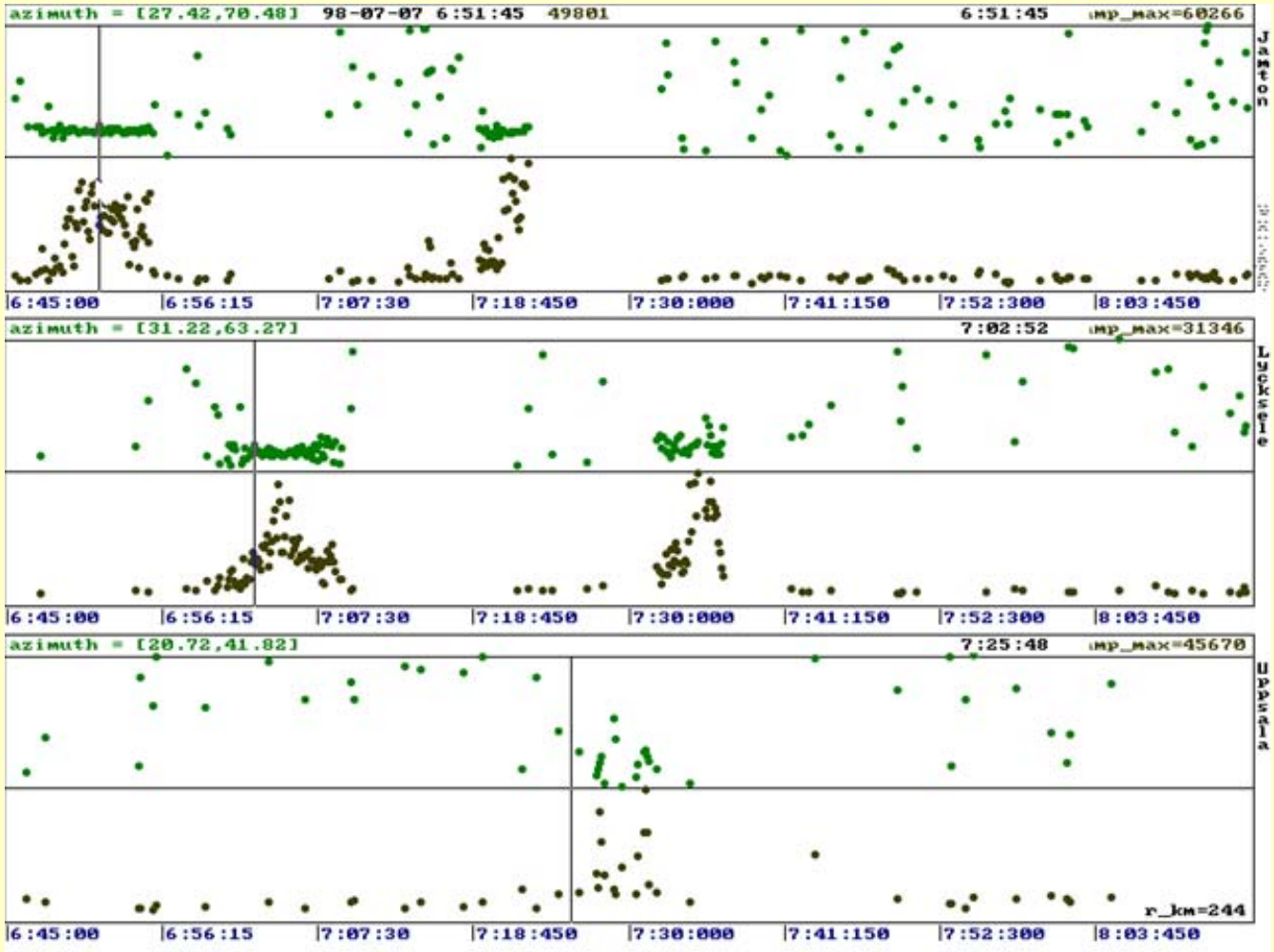
INFRASOUND

What can be done using infrasound?

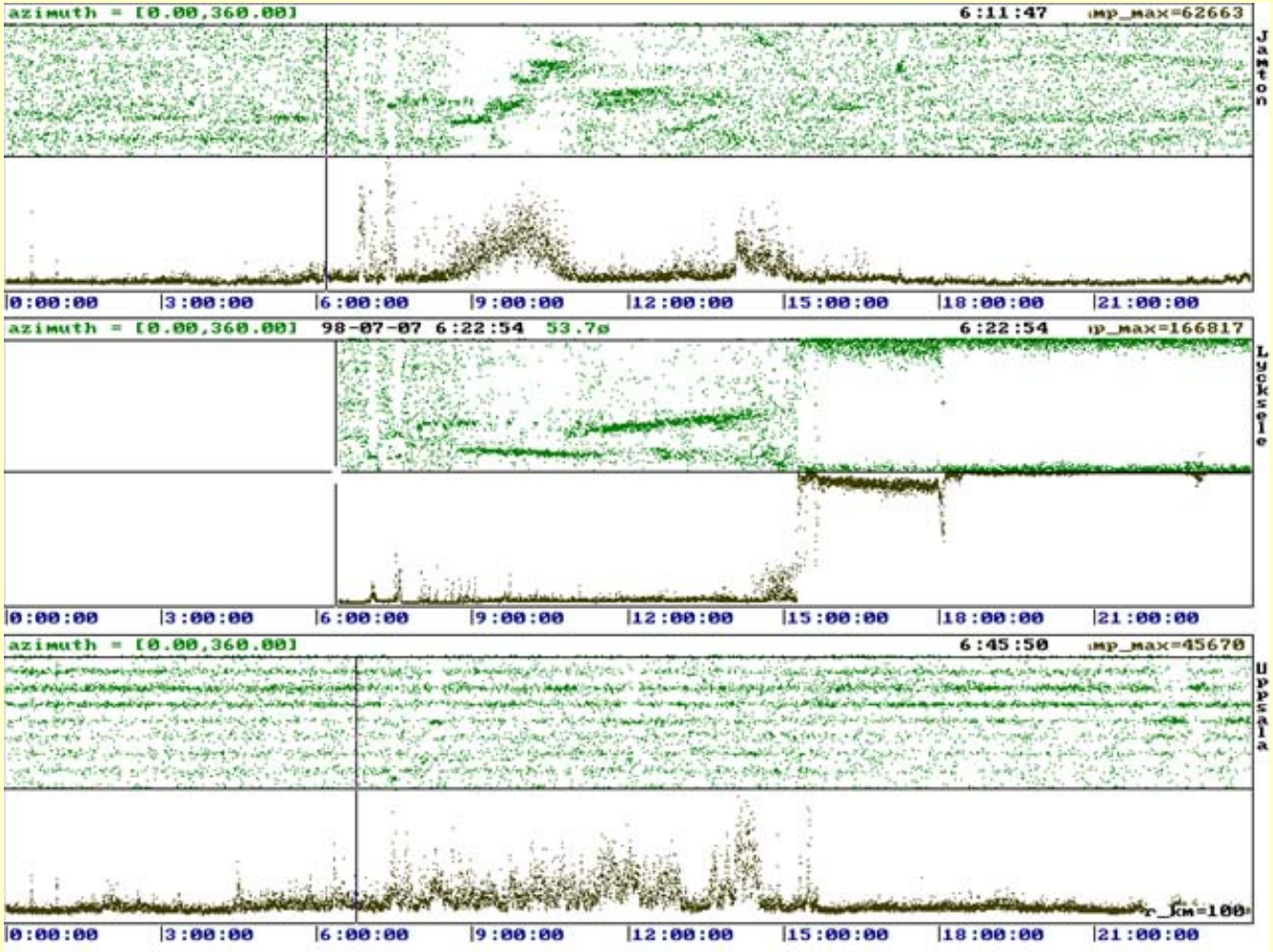
Example 4: Missile Launch (1)



INFRASOUND

What can be done using infrasound?

Example 4: Missile Launch (1)



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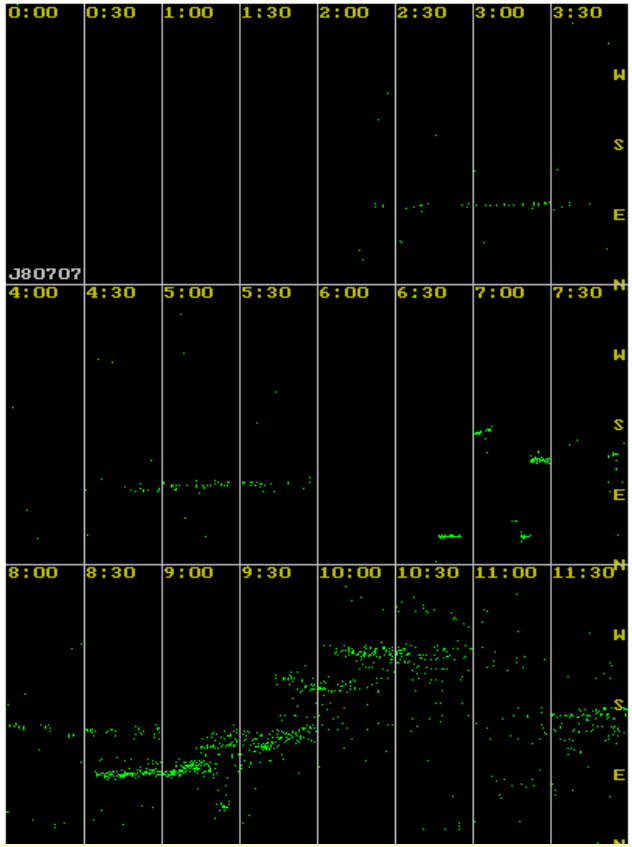
Example 4: Missile Launch (1) cont´d

The sound trace to look for are the one that begins at 0645 in Jämtön and at 0700 in Lycksele.

Jämtön:

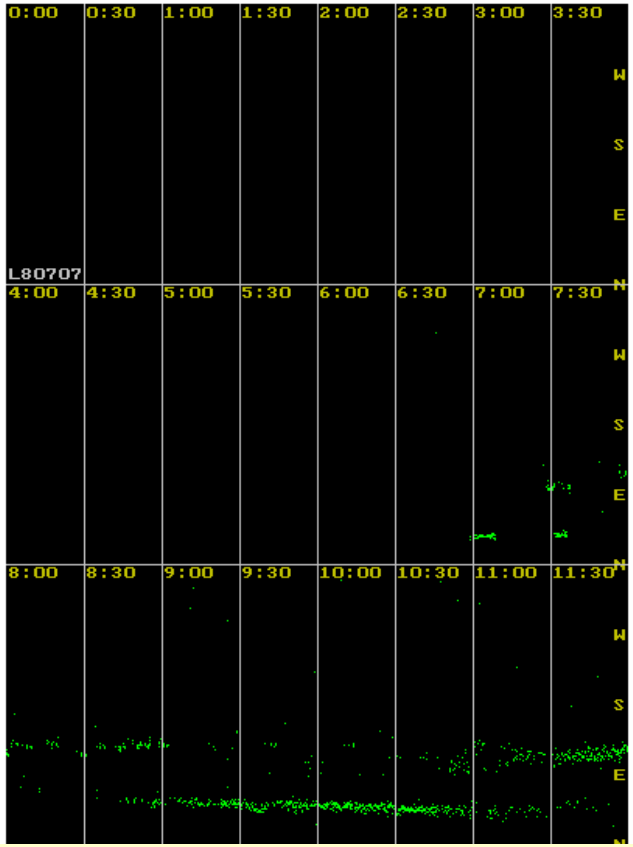
selected direction is 34 degrees
selected time is 06:50



Ljudspåret att titta efter är det som startar kl 06.45 i Jämtön och kl. 07.00 i Lycksele.

Lycksele:

selected direction is 34 degrees
selected time is 07:01



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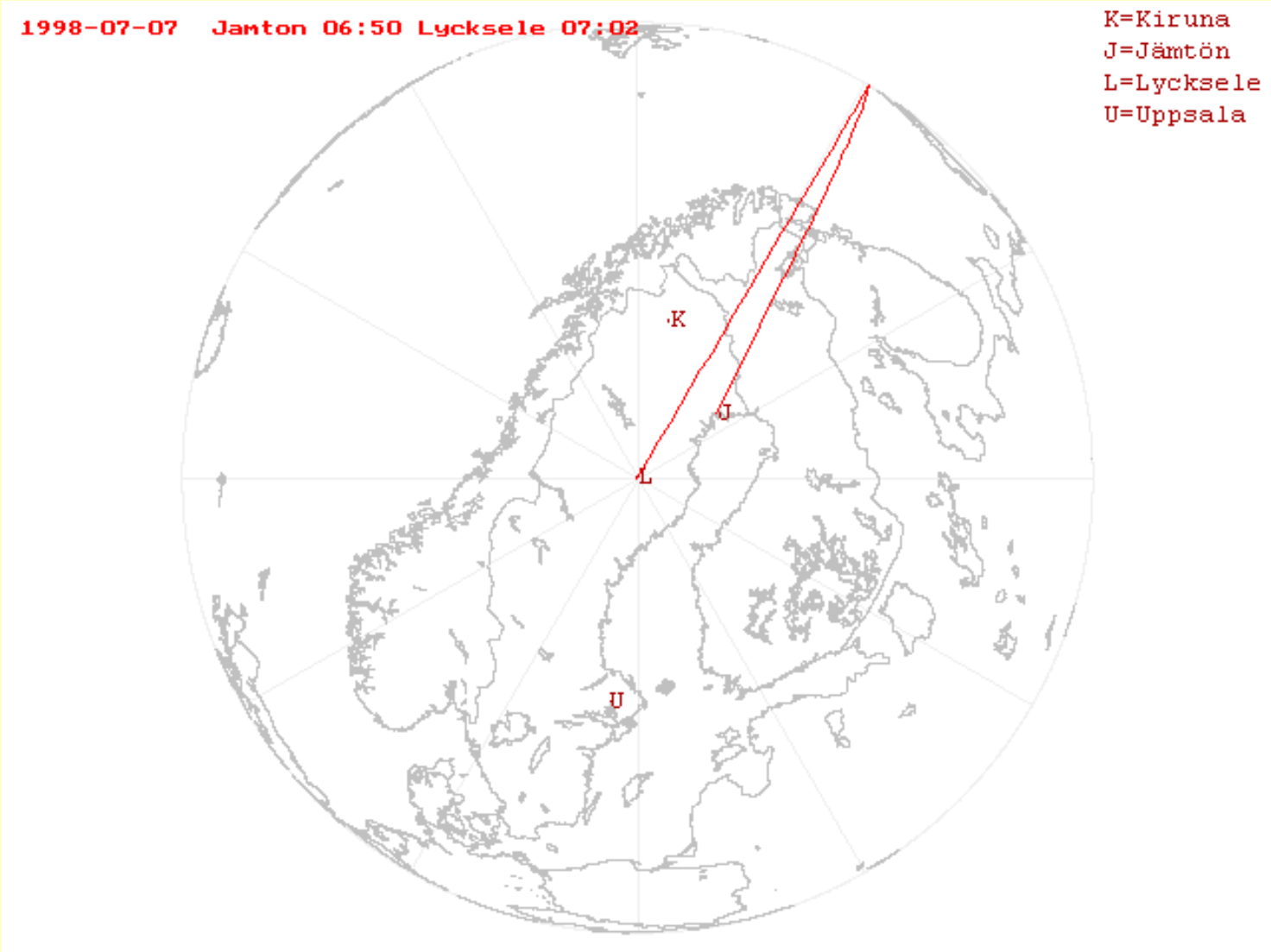
Example 4: Missile Launch (1) cont´d



INFRASOUND

What can be done using infrasound?

Example 4: Missile Launch (2)

(Reuters) - March 27: Russia successfully launched an old submarine-based ballistic missile on Monday as part of a programme to extend the life span of outdated weaponry, a navy spokesman said.

The RSM-54 missile was launched in the Barents Sea at 0700 GMT nuclear submarine, It hit a testing ground in Kamchatka in Russia's Far East at 0733 GMT. "The missile was launched as previously scheduled with the purpose of extending the shelf life of this type of rocket," *the spokesman said by telephone*. President-elect Vladimir Putin, the declared winner in Sunday's election, has said Russia's nuclear arsenal remains the cornerstone….

This event was not observed. Did it really happen?

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INFRASOUND

What can be done using infrasound?

Example 5: Burning gas or oil

Burning oil fields in the Persian Gulf may be considered as an intense source of infrasonic waves. Waldemark and Liszka showed that the propagation of these waves to high latitudes is is possible.

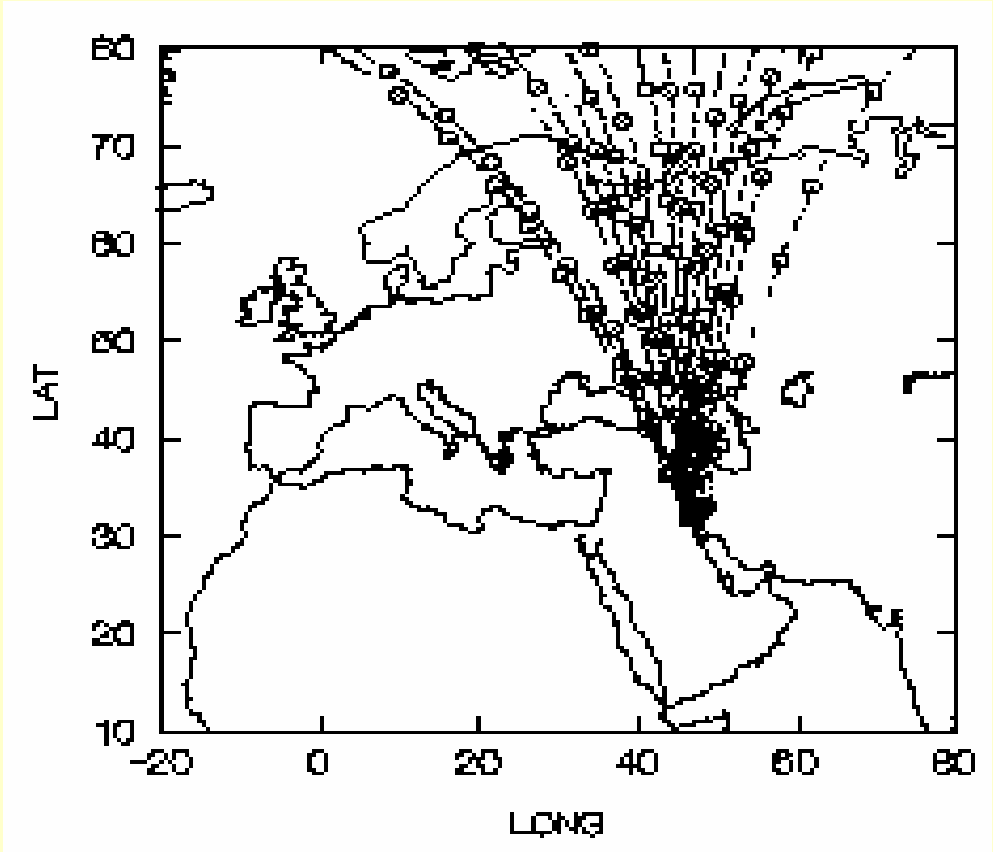
INFRASOUND

What can be done using infrasound?

Example 5: Burning gas or oil

Infrasonic data from two Swedish stations (recordings at 2 Hz Luleå and Lycksele) was used during 1991 to demonstrate the reception of these long distance infrasonic waves."

The oil platforms in the North Sea could be monitored.



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INFRASOUND

What can be done using infrasound?

Example 5: Burning gas or oil

POLLUTION FROM THE OIL WELL FIRES IN KUWAIT HAS IMPORTANT LOCAL AND REGIONAL ENVIRONMENTAL CONSEQUENCES. EVEN IF ALL FIRES WERE EXTINGUISHED BY MAY 1992, A BROAD REGION WHICH WE HAVE DIVIDED INTO THREE WILL EXPERIENCE ELEVATED LEVELS OF SULFUR DIOXIDE AND SOOT. THE HARDEST HIT AREA IS LIMITED TO KUWAIT AND NORTHERN SAUDI ARABIA. IN THESE PLACES, POLLUTION CONCENTRATIONS WILL REGULARLY EXCEED US NATIONAL AIR QUALITY STANDARDS.

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INFRASOUND

What can be done using infrasound?

Example 5: Burning gas or oil (cont'd)

IN KUWAIT CITY SULFUR DIOXIDE CONCENTRATIONS WILL REACH LEVELS 10 TIMES ABOVE US STANDARDS AND US PARTICULATE CEILINGS WILL BE SURPASSED ON MORE THAN 100 DAYS. IN AL AHMADI AIR POLLUTION WILL BE THE MOST EXTREME, WITH PARTICULATE LEVELS OCCASIONALLY TOPPING BY A FACTOR OF 200 OR MORE. IN SAUDI ARABIA,

PARTICULATES WILL DEGRADE KHAFJI'S AIR QUALITY BELOW US STANDARDS ON NEARLY 100 DAYS. IN KUWAIT CITY POLLUTION PROBLEMS WILL BE THE MOST INTENSE IN MID-OCTOBER, WHEN SEASONAL WEATHER PATTERNS WILL CAUSE WINDS TO DIE DOWN AND POLLUTANTS BECOME TRAPPED UNDER TEMPERATURE INVERSION LAYERS.

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INFRASOUND

What can be done using infrasound?

Example 6: Elephants

Elephants can hear sounds well below the range of human hearing and probably at least as low as 0.1 hertz (human hearing cuts off at about 20 hertz). This certainly enable them to hear sounds associated with rain.

INFRASOUND

What can be done using infrasound?

Example 6: Elephants

Thunderstorms are sources of very loud infrasound and could be heard by elephants long before they are audible to humans.

Elephants can also produce infrasound. Because it carries over long distances they use it to communicate with distant members of the herd.

INFRASOUND

What can be done using infrasound?

Example 6: Elephants

An elephant's forehead skin will flutter and vibrate as air is passed through the nasal passage. Researchers recognize this as the activity of infrasonic vocalizations. Asian elephants at a zoo in Oregon would exchange calls through a concrete wall

INFRASOUND

What can be done using infrasound?

Example 6: Elephants

This finding offers a solution to many old mysteries about elephant society, particularly the mystery attending the ability of males to find females for breeding, and the ability of separated family groups to coordinate their patterns of movement for weeks at a time without losing communication or converging on the same scarce resources.

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INFRASOUND

What can be done using infrasound?

Example 7: Whales

Blue whales produce sound signals below 100 Hz for long range communication and they don't even need to dive down to channel depth.

INFRASOUND

What can be done using infrasound?

Example 7: Whales

Temperature and pressure variations found at the varying depths will act as ”voice tubes” and ”channel” whale calls further than is usual, which allows for whales on the other side of the ocean to hear the calls. Besides the blue whale many other whales use infrasound to attract mates, warn rivals, communicate between the individuals of their own pods or of another pod, or to find food. Such whales include the Humpback whale, which has been found to have the most complex song of all organisms, where they can use "rhyme" such as humans in order to recall the complex tunes- their infrasound may travel more than 965.6 km

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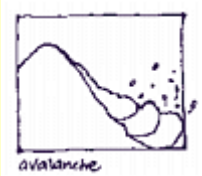
What can be done using infrasound?

Example 8: Avalanche detection

A few seconds before an avalanche happens the is infrasound heard. Most likely this comes from deep down movements in the snow



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INFRASOUND

What can be done using infrasound?

Example 9: Seismic events

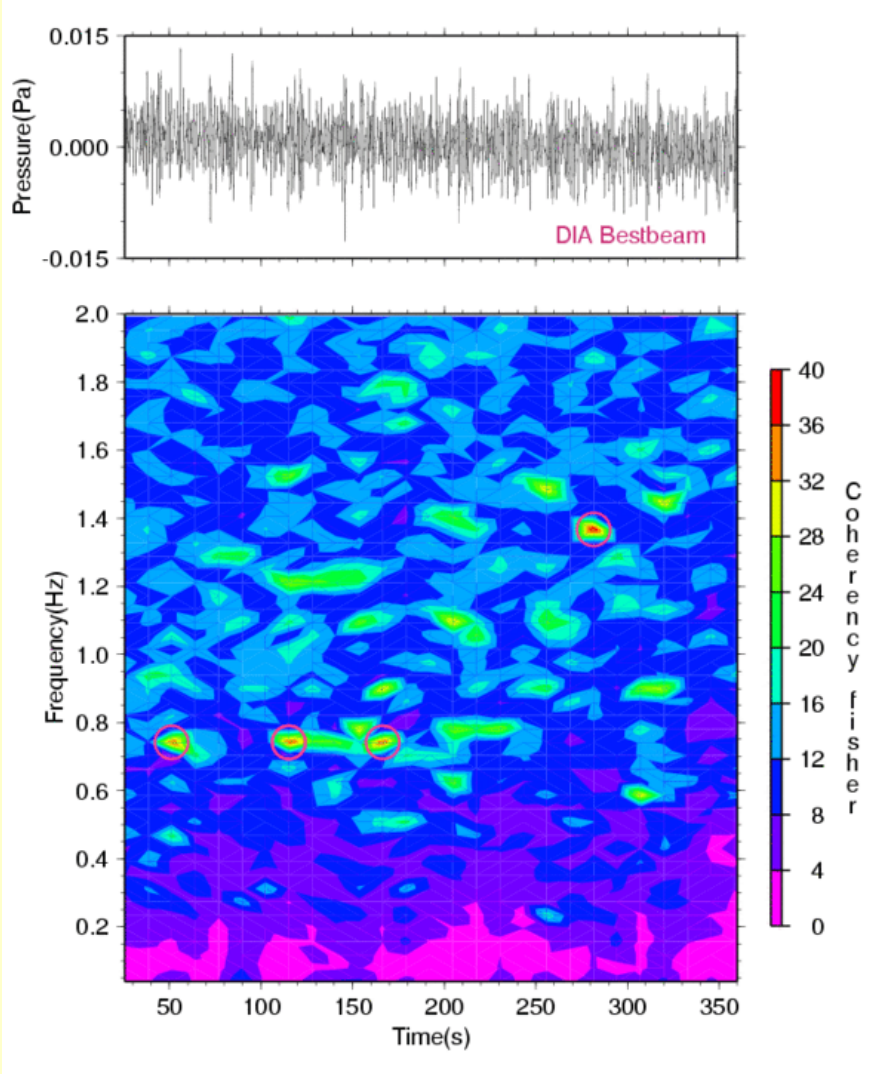
Infrasound has also been heard prior to earth quakes and in connection with eruptions of volcanous

INFRASOUND

What can be done using infrasound?

Example 9: Seismic events

Observation of infrasound from the volcano Etna (Italy)



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INFRASOUND

What can be done using infrasound?

Example 9: Seismic events

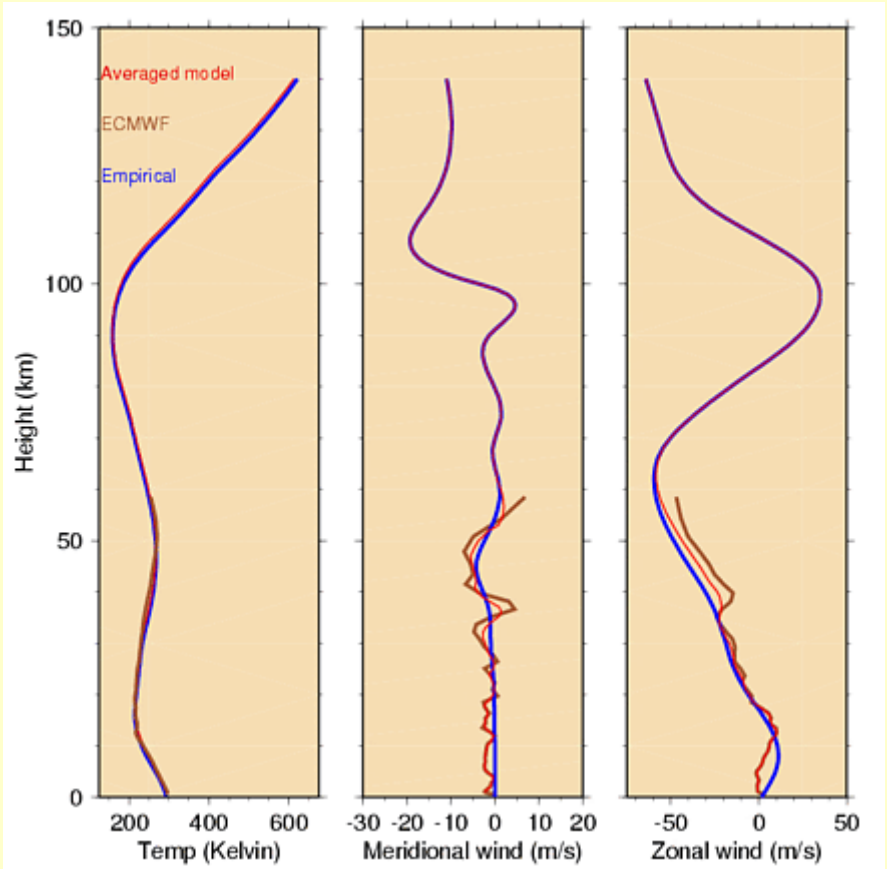
The Deelen Infrasound Array has recorded infrasound originating from the SSE during several hours on the morning of 2001, July 29. An arbitrary time segment of 6 minutes of infrasound data analysis. Coherent signal is found at several times and frequencies, detected through high coherency values. The data are band-pass filtered between 0.5 - 1.5 Hz. The signal is not directly visible in the best beam, however high coherency values indicate the presence of a coherent signal within the incoherent noise.

INFRASOUND

What can be done using infrasound?

Example 9: Seismic events

The atmospheric paths of infrasonic waves depend on the wind and temperature structure of the atmosphere. The lower atmosphere, up to 20 km, is well known. For the higher atmosphere one depends on (empirical) models. The figure shows two models, in blue an empirical model up to 140 km and in brown the ECMWF model up to 60 km. An average model, in red, has been derived. The average model follows ECMWF's model for the first 20 km of the atmosphere. Between 20 and 60 km, the average model is calculated by cubic spline interpolation of the ECMWF and empirical model..



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What can be done using infrasound?

Example 9: Seismic events

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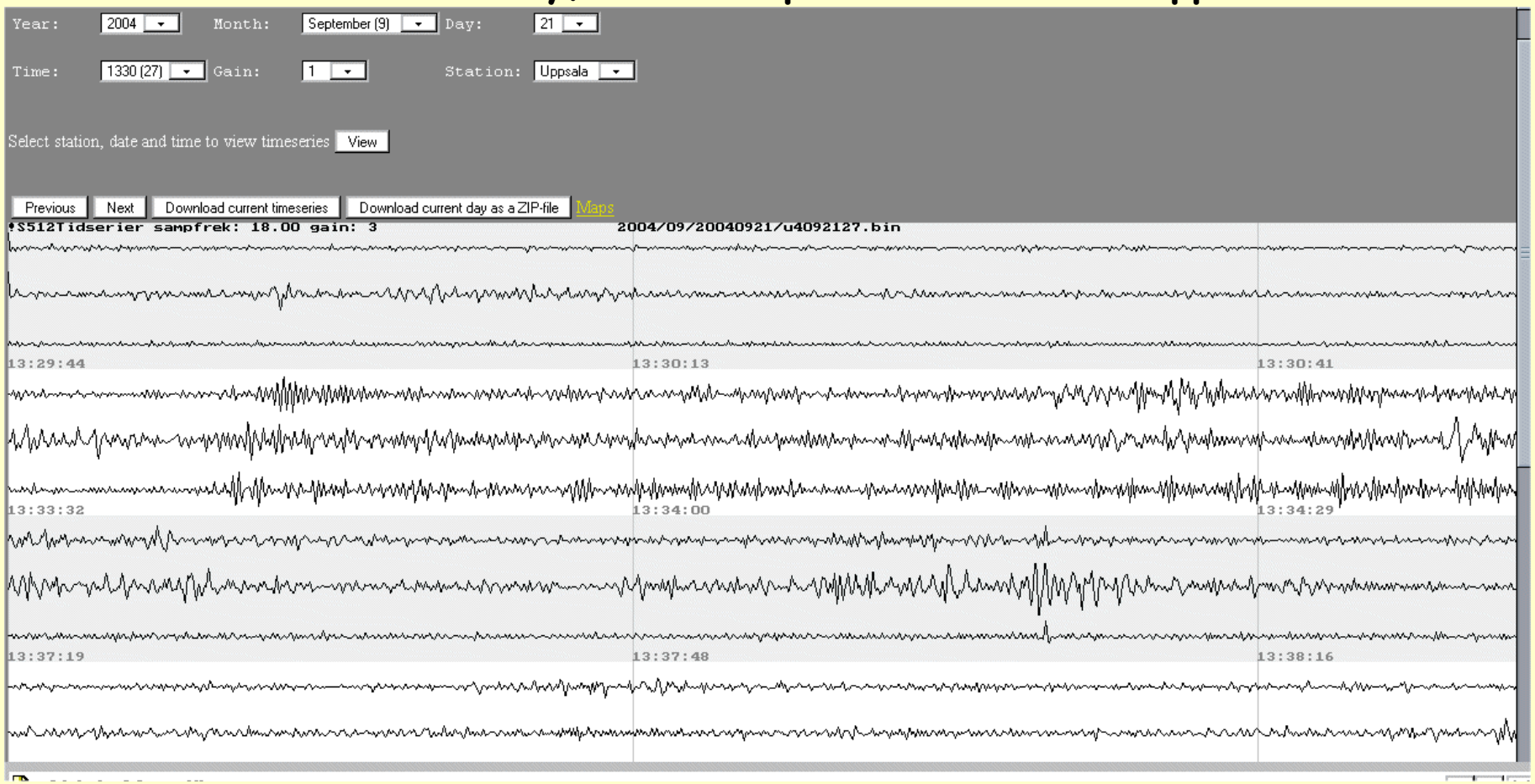
What can be done using infrasound?

Example 9: Seismic events

These are rare in our country, but in September 2004 it happens ….



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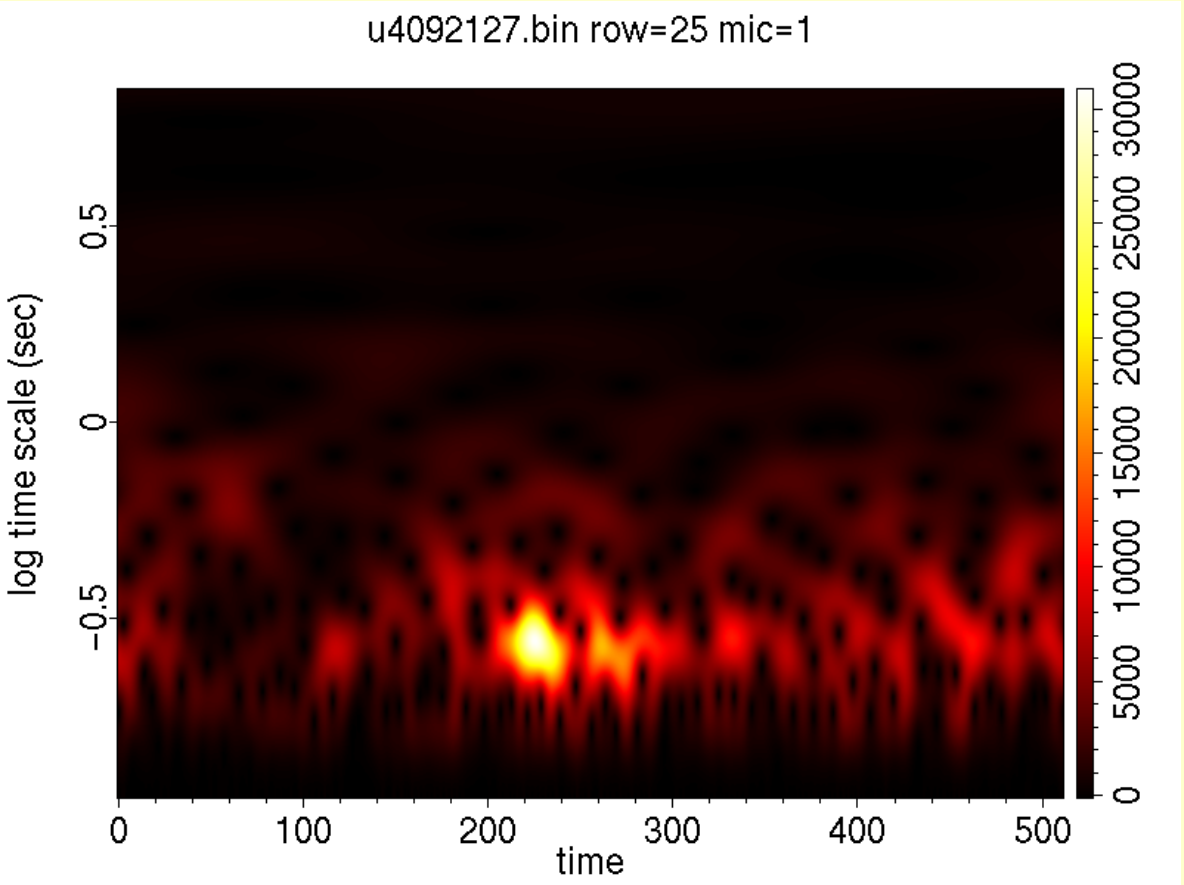
What can be done using infrasound?

Example 9: Seismic events

Using a wavelet transform this event looks like this …



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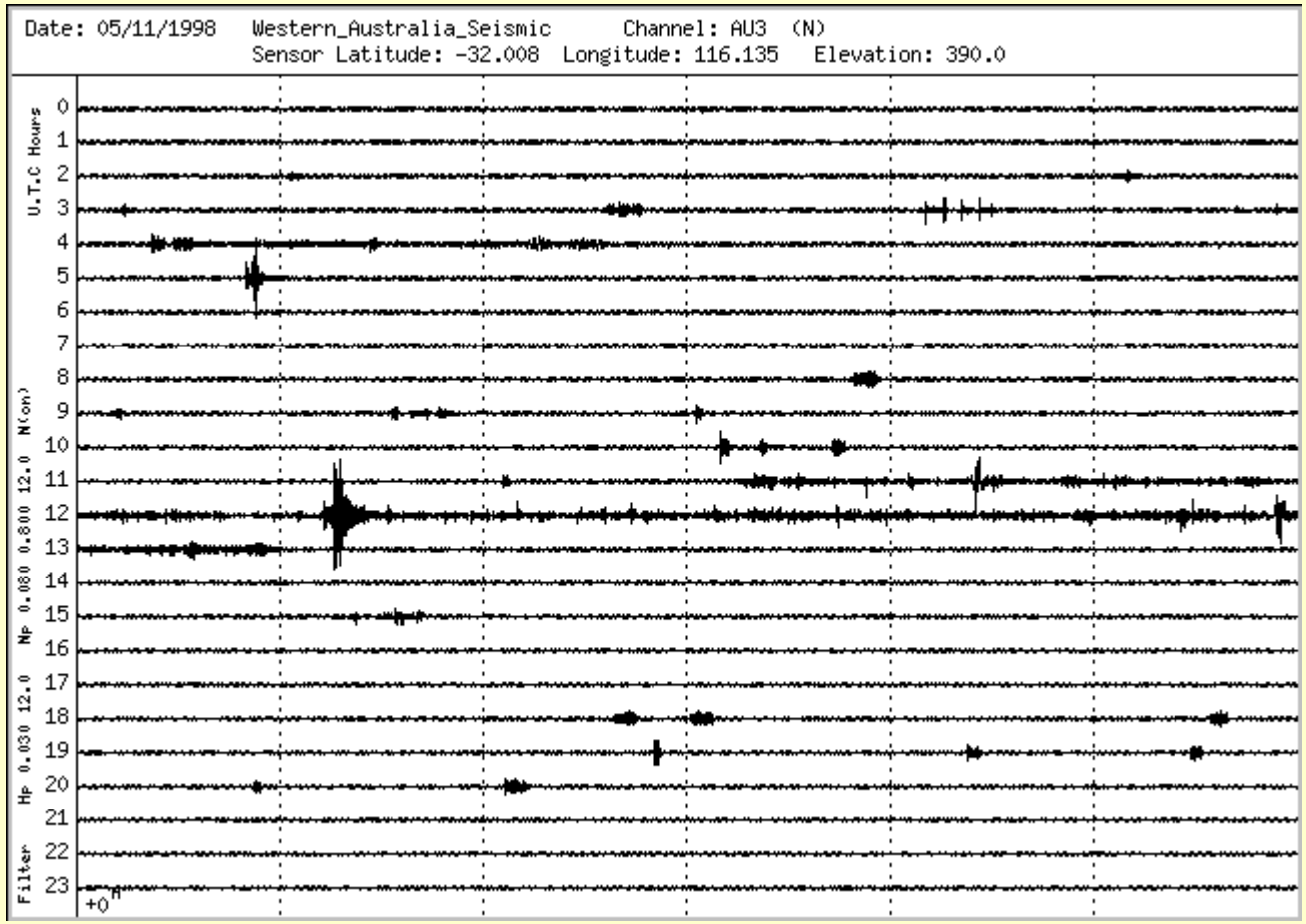
What can be done using infrasound?

Example 9: Seismic events

This diagram is from the monitoring of seismic activities at Kalamunda in Western Australia.



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INFRASOUND

What can be done using infrasound?

Example 10: Vibrations

Vibration is a general environmental problem for many industries and research. Nanotechnology requires special stable rooms and lithography, laser measurements, etc will be affected by vibrations from floors at around 1 Hz. Slamming doors in a building generates a lot of infrasound, too.

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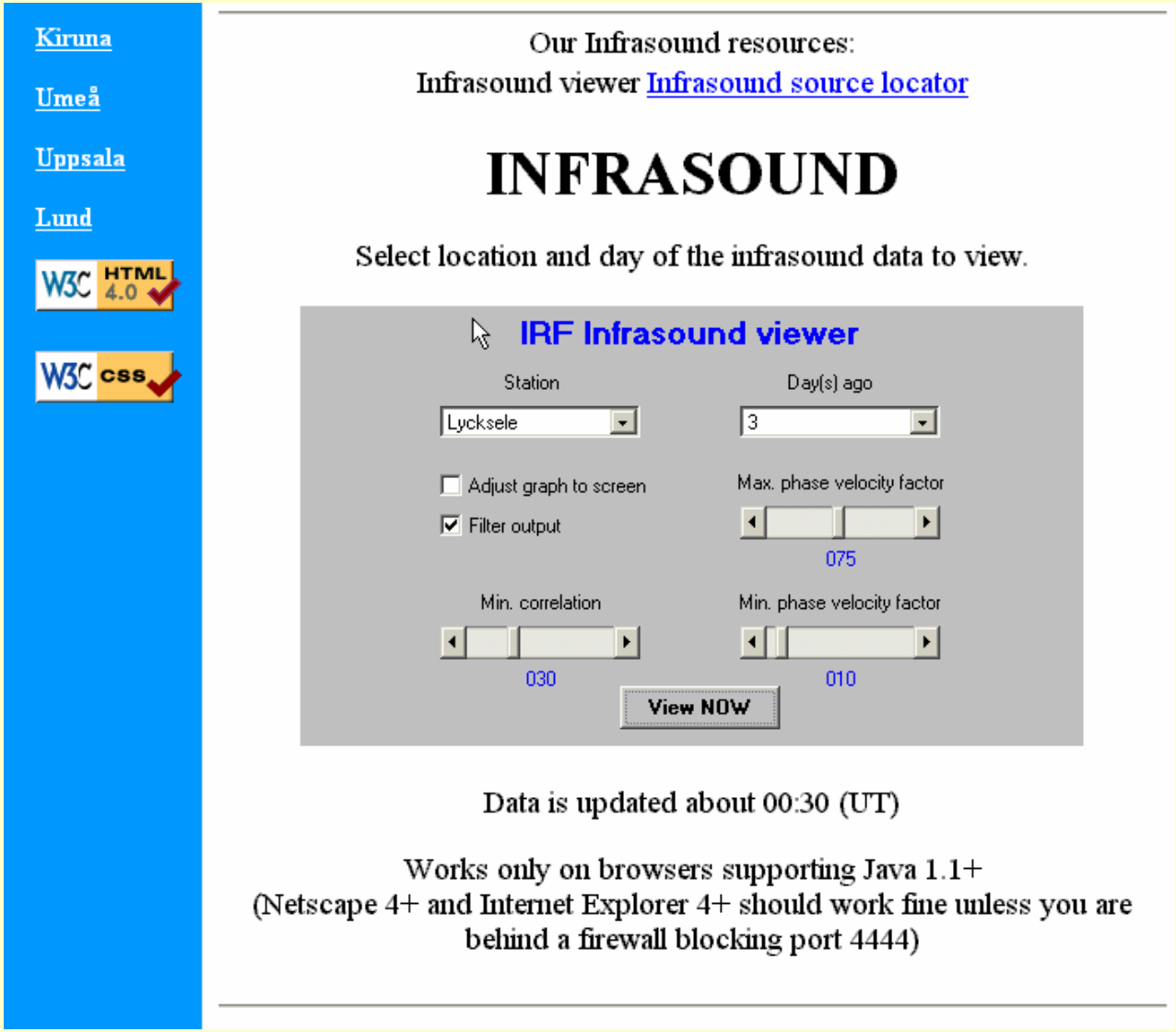
INFRASOUND

What can be done using available on-line data?



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What can be done using on-line data?

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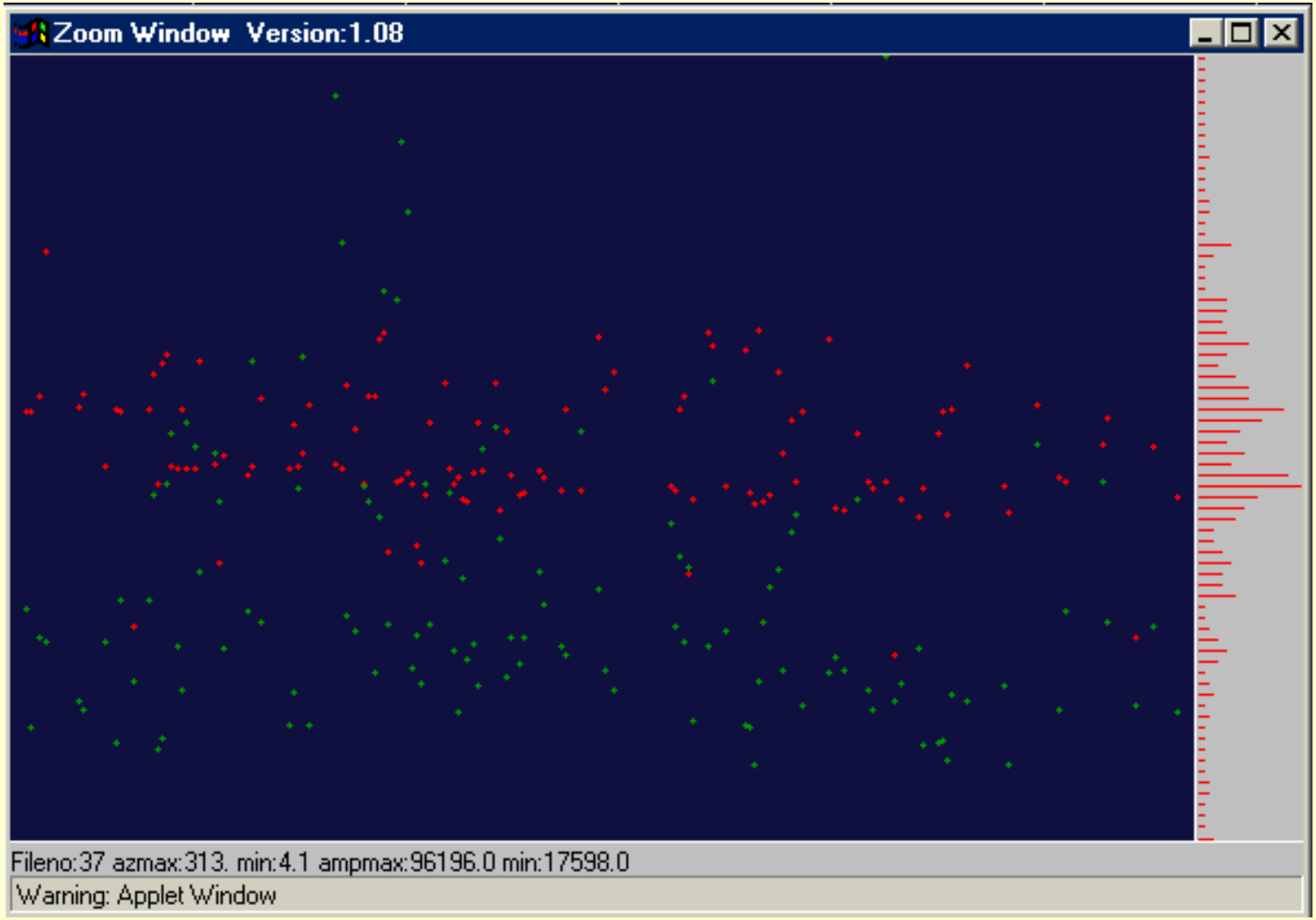

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INFRASOUND