Enhancing Infrasound Monitoring in South America through Automated Algorithms

José Luis Palma [1], Christopher Celis Huaiquilaf [2]

(1) Department of Earth Sciences, University of Concepción, Chile. jose@udec.cl
Observatory of Environmental Risks (ORA-UdeC)
(2) Chilean Nuclear Energy Commission, Ministry of Energy, Chile

International Technological Workshop 2024
Vienna, Austria. 4-8 November

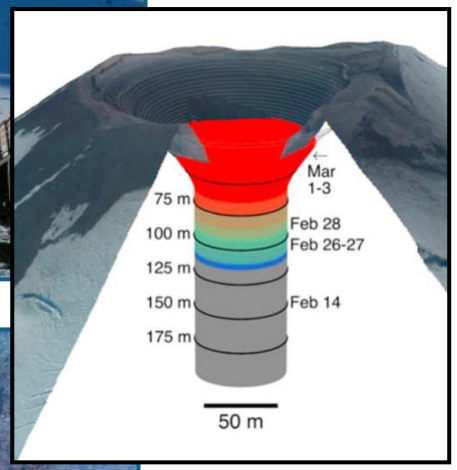
Collaboration between CCHEN-NDC and UdeC, Chile

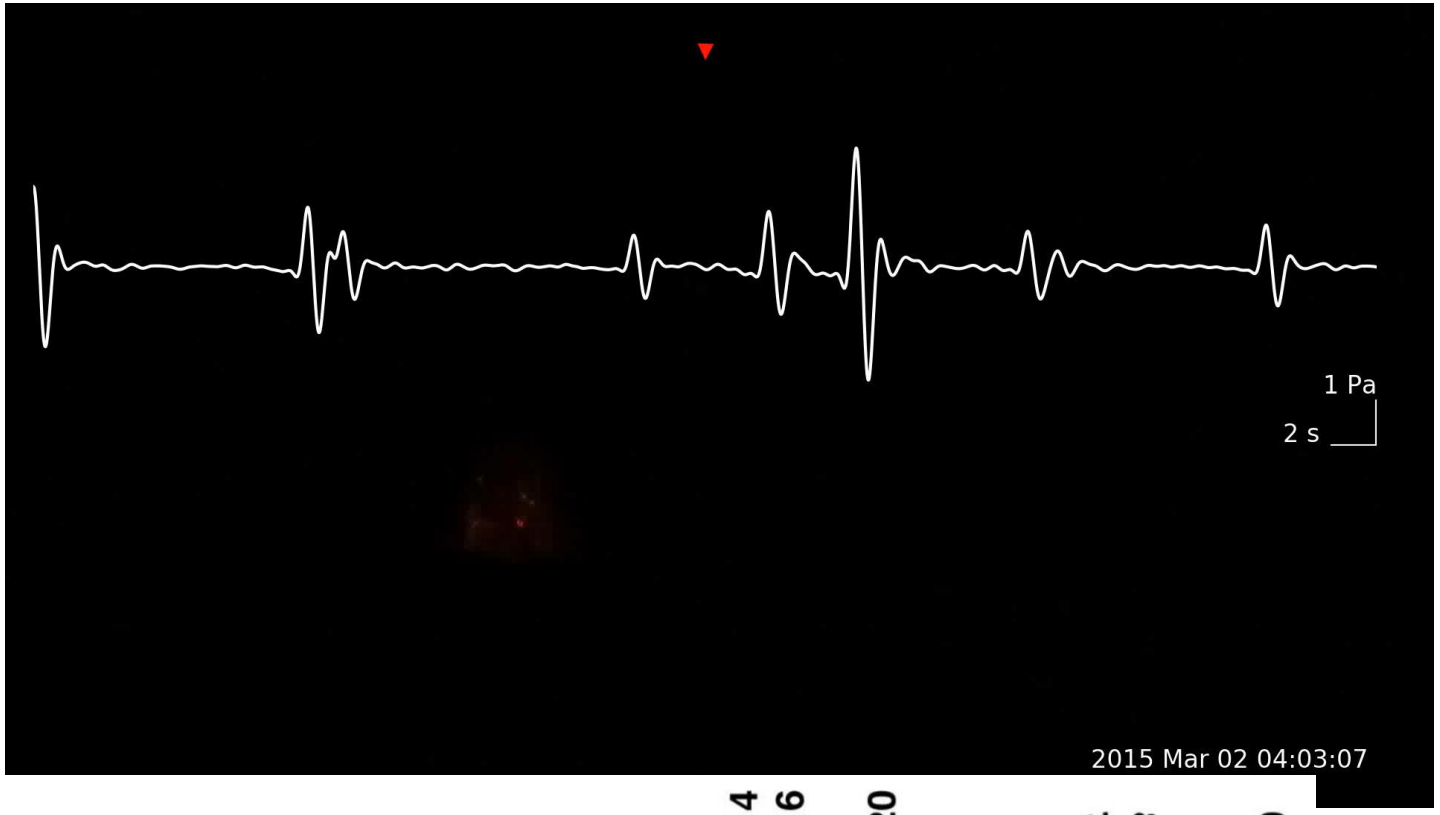
CCHEN = Chilean Nuclear Energy Commission
UdeC = University of Concepción

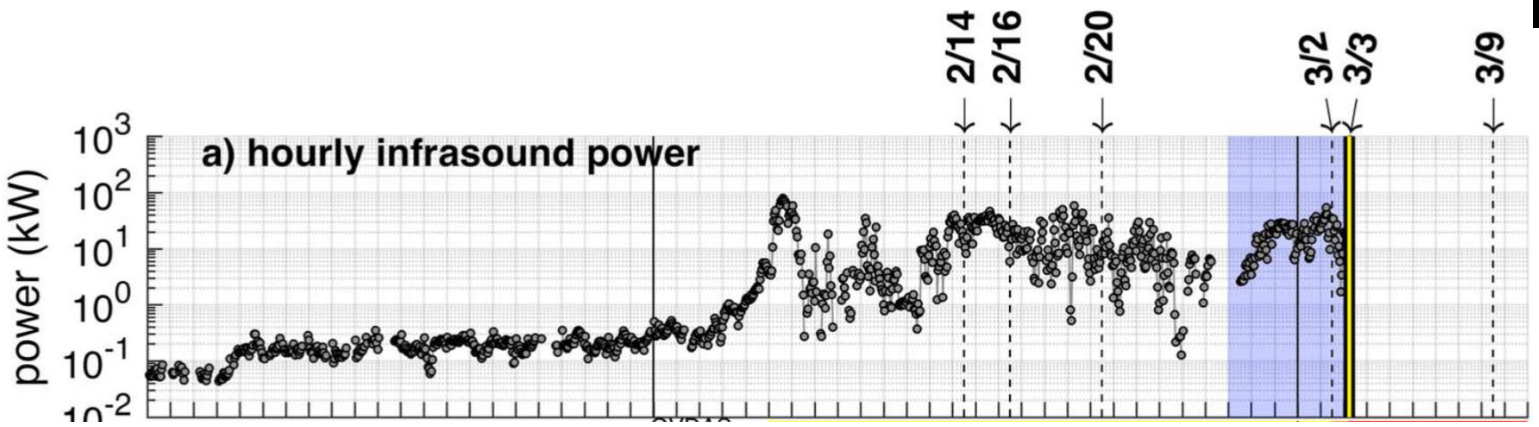
In March 2024, CCHEN and UdeC signed a collaboration agreement that creates the UDEC-NDC Extension.

- Develop scientific research, teaching and outreach on the Comprehensive Nuclear-Test-Ban Treaty, and the use of the IMS data.
- Enhanced Analytical Capabilities: Gain access to specialized expertise.
- Support with the evaluation of the quality and with the interpretation of the data.
- Expanded Data Sources: Integrate regional and local data for improved monitoring.
- Support in Capacity Building: Training and skill development for staff and students.
- Participate in Joint Research and NDC Preparedness Exercises.
- Engage in CTBTO Training Programs for data analysis and protocol compliance.

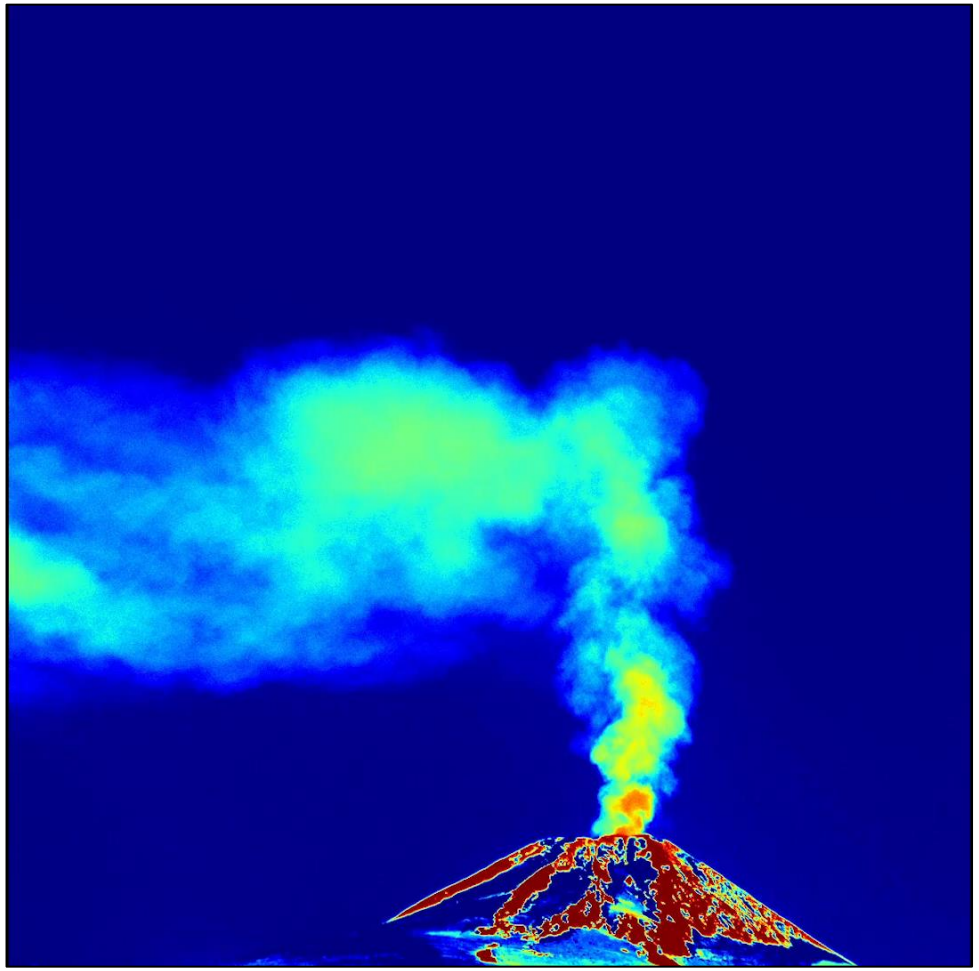
Local infrasound to study the activity of Villarrica volcano



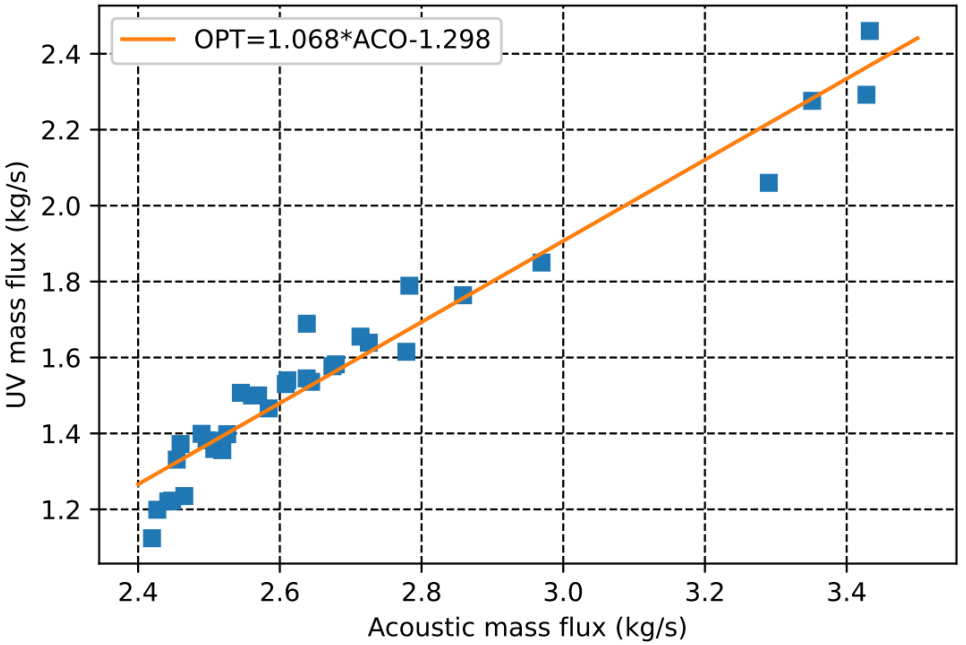




Local infrasound to study the activity of Villarrica volcano



Gas emissions measured with UV spectroscopy



Infrasound-derived gas emissions

Small aperture (30 – 100m) infrasound arrays of 3-6 elements
Sensors: Chaparral 60Vx2, custom-made, Raspberry-boom
Main frequency of interest around 1Hz

So, what's the plan?

- Chilean NDC knows NDC-in-a-Box package software but lacks the resources for reviewing data:
  - Lack of personnel for frequent analysis
  - Lack of expertise in some of the monitoring technologies, including processing and interpreting the data
  - Lack of computing resources
- At UdeC we have knowledge on several monitoring techniques, although we don't know much about the IMS technology.
- Once we learn more about the data and some processing techniques, CCHEN-UdeC can start planning specific projects.
- Learning the Progressive Multi-Channel Correlation Algorithm (PMCC) seems like a good starting point. Can we automate it?

Why an automated processing with My-PMCC?

Advantages:

- Removes the need for manual operation by an operator
- An opportunity to learn the knitty-gritty of the processing algorithms
- Open to modifications to accommodate specific needs:
  - Improvements
  - Requirements from Local NDCs
  - Scientific applications

Disadvantages:

- Automated operation requires consideration of numerous scenarios
- Not “user-friendly”
- The developers need to check for and fix problems from time to time

Developing My-PMCC

Class Trace → Class Stats (metadata) → Class Stream

Class Signal

\+

.filter()
.normalize()
.plotS()
.plotpsd()
…

\+

.coordinates_geo
.coordinates_utm
.utm_zone
.unit
…

Class Array

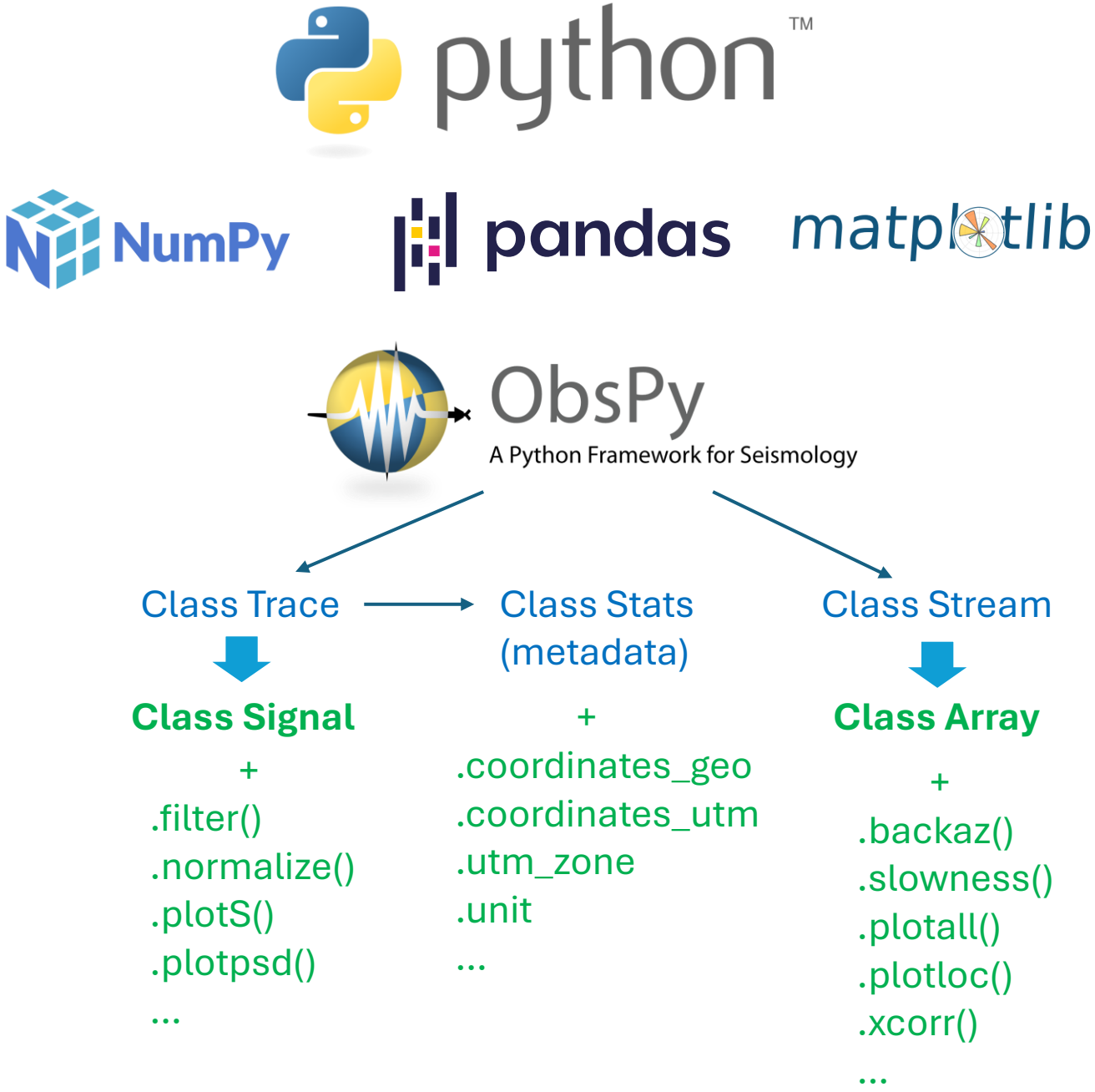
\+

.backaz()
.slowness()
.plotall()
.plotloc()
.xcorr()
…

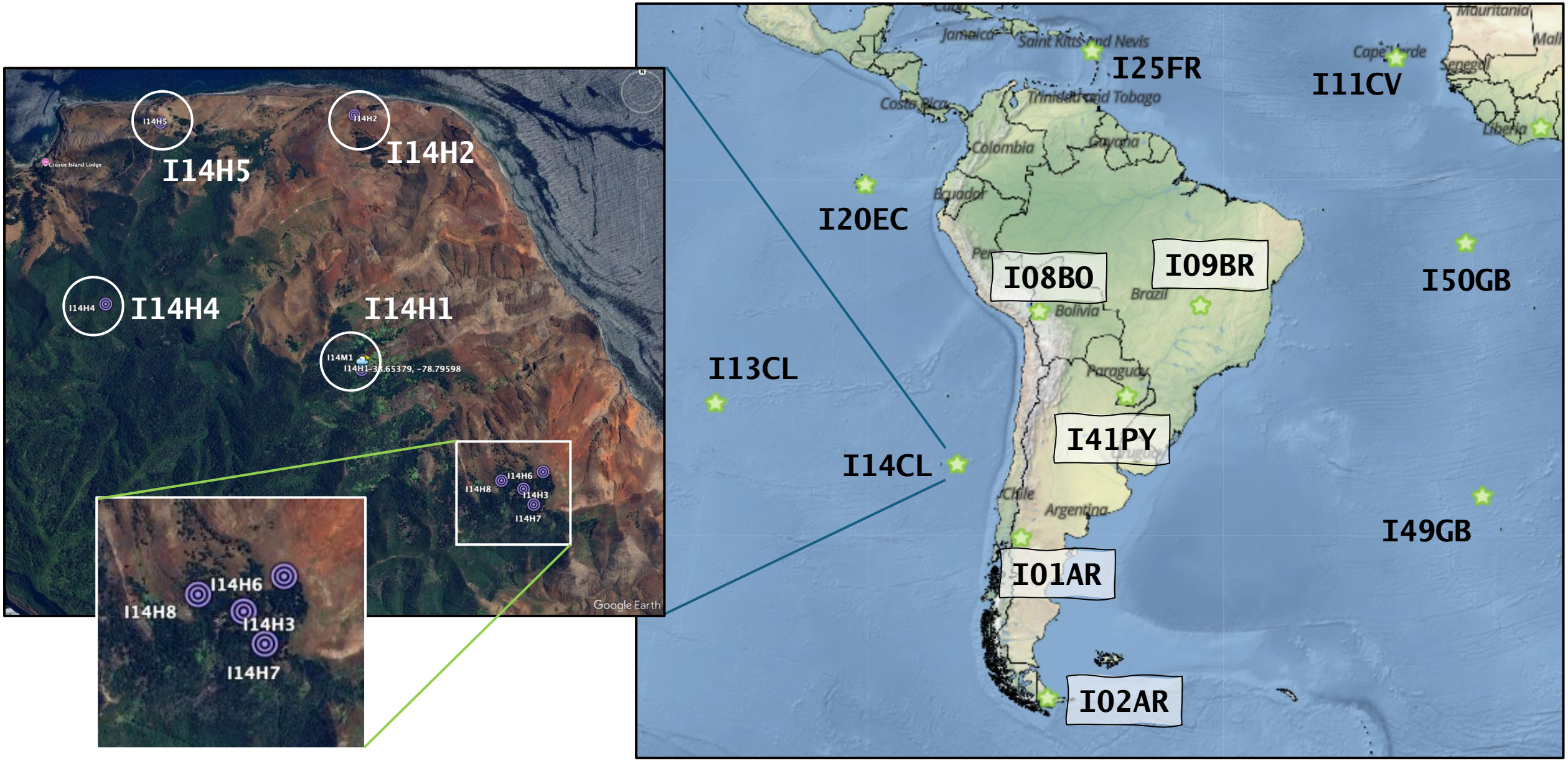
Developing My-PMCC

PMCC algorithm (class)

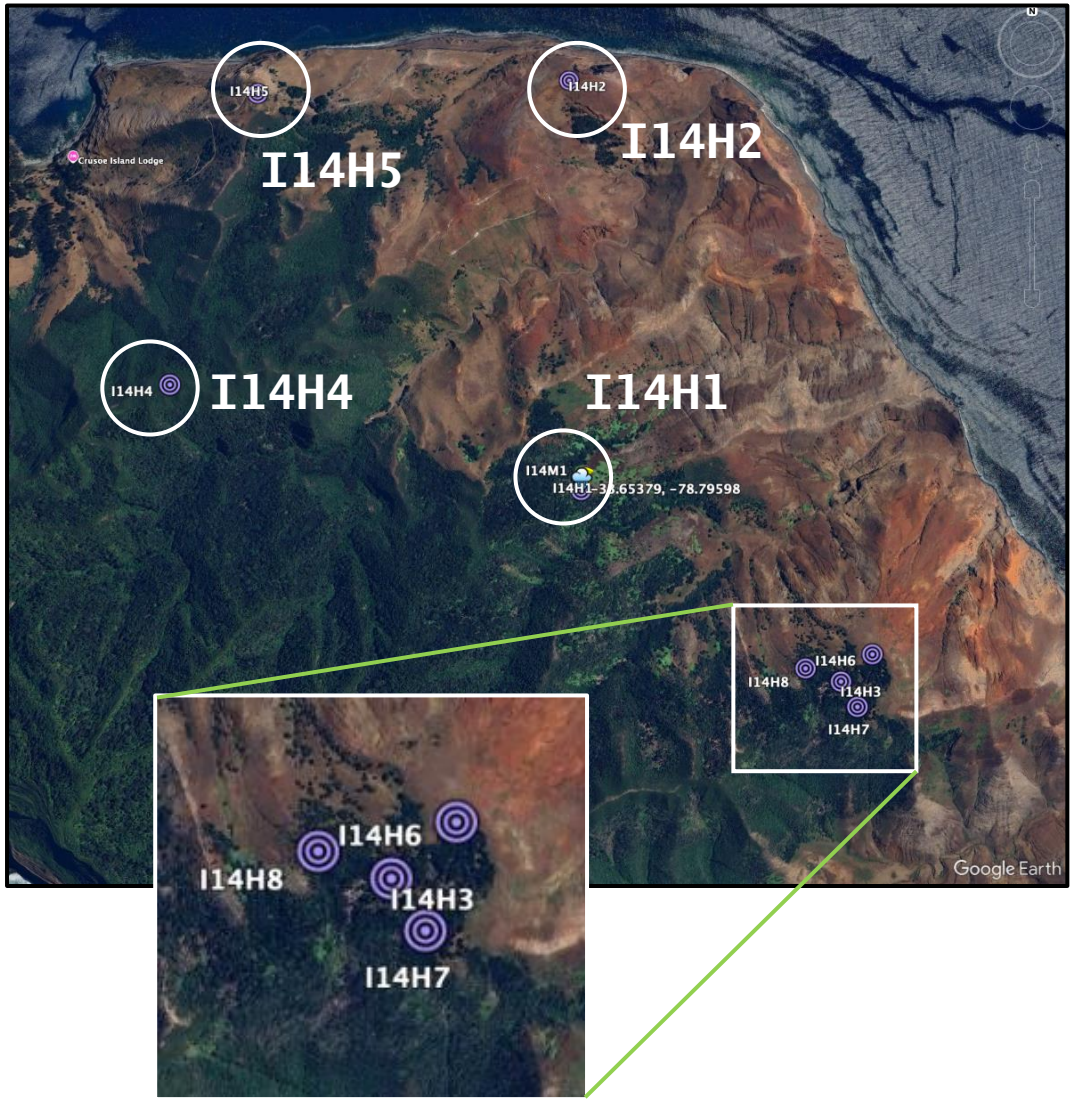
- Define subnetworks
- Define freq bands and window lengths
- **Loop through windows:**
  - **Loop over frequency bands:**
    - Create an array of windows
    - Filter the array
    - Apply x-correlation
    - Select bad channels
    - Get list with subnetworks
    - **Loop over subnetworks:**
      - X-correlation (directed, high def)
      - Calculate mean xcorr, consistency
      - If good consistency:
        - Calculate wave parameters
      - Calculate overall consistency
    - For pixel (freq, time) save results
- Group pixels and define families

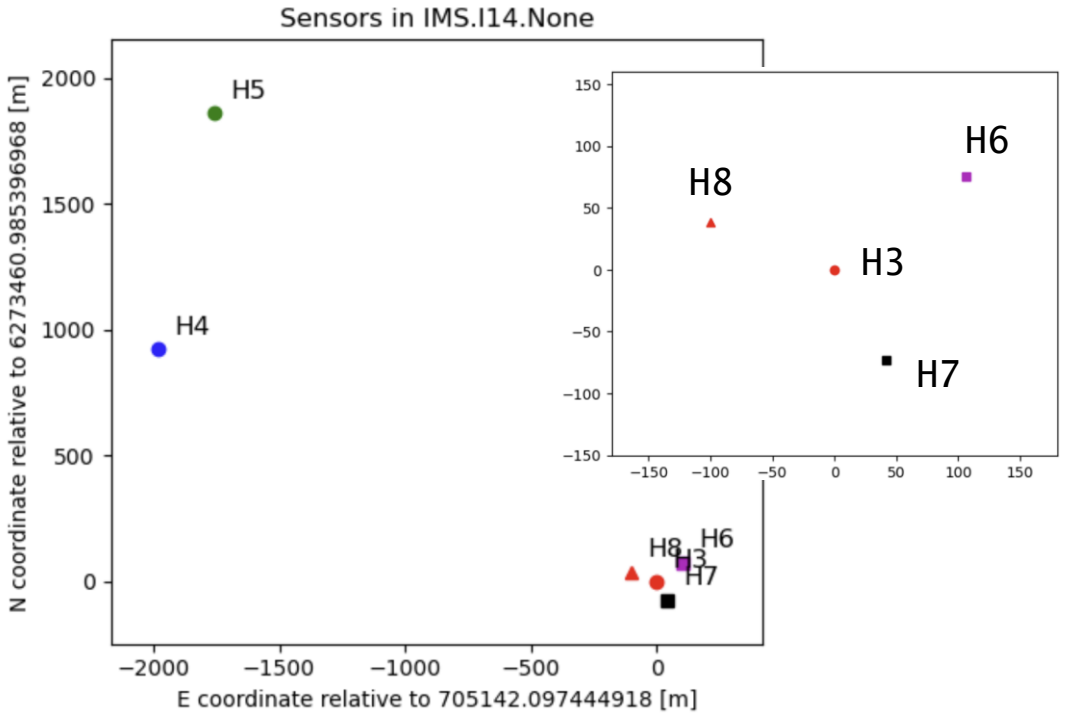


Infrasound stations in SA – Example in Robinson Crusoe island



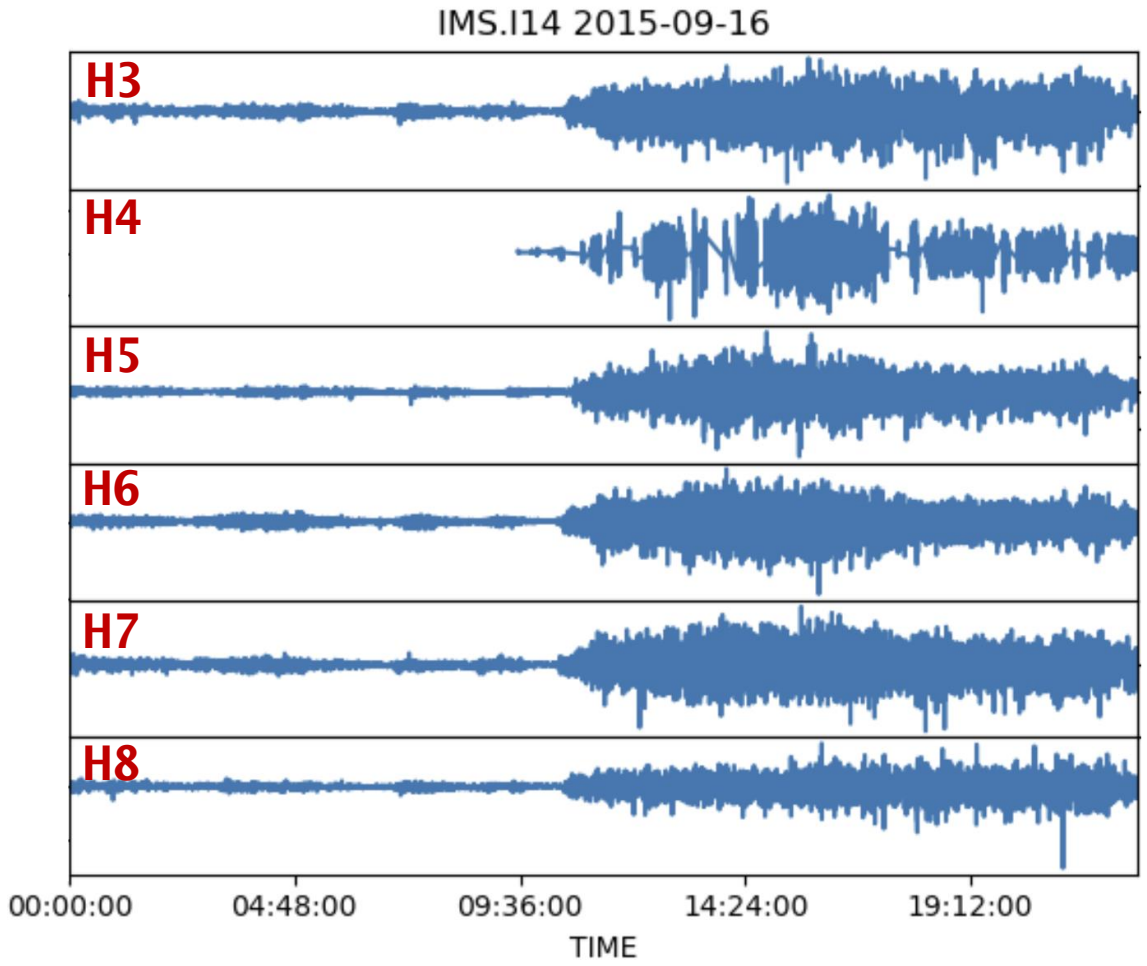
Example of I14CL 2015

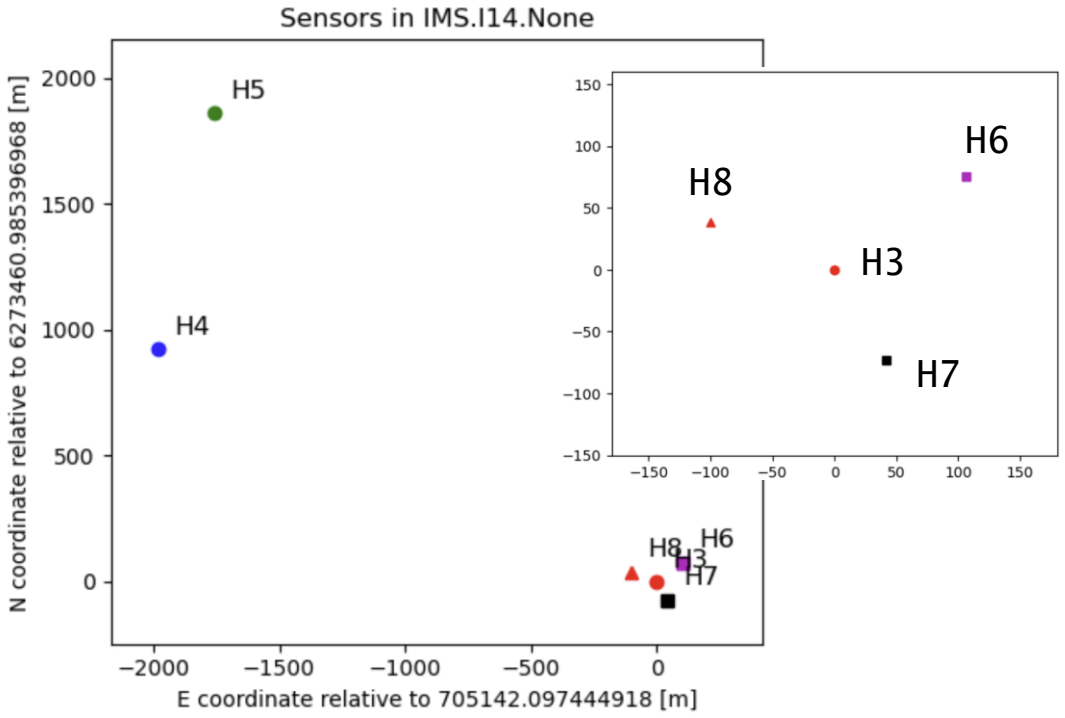




subnet	is1	is2	is3	ch1	ch2	ch3	d12	d13	d23	dmean	idmax	min_ang
0	0	4	5	H3	H7	H8	87.530203	107.886168	183.872103	126.429492	5	17.745265
1	0	3	4	H3	H6	H7	131.097259	87.530203	165.896788	128.174750	4	31.602669
2	0	3	5	H3	H6	H8	131.097259	107.886168	210.030209	149.671212	5	25.607350
3	3	4	5	H6	H7	H8	165.896788	210.030209	183.872103	186.599700	4	49.267199
4	1	2	5	H4	H5	H8	975.186389	2082.457246	2461.567759	1839.737131	5	22.889071
5	0	1	2	H3	H4	H5	2188.961921	2558.184386	975.186389	1907.444232	1	21.988473
6	1	2	3	H4	H5	H6	975.186389	2257.194645	2579.657055	1937.346030	3	21.987132
7	1	2	4	H4	H5	H7	975.186389	2257.028237	2640.404303	1957.539643	4	21.165186

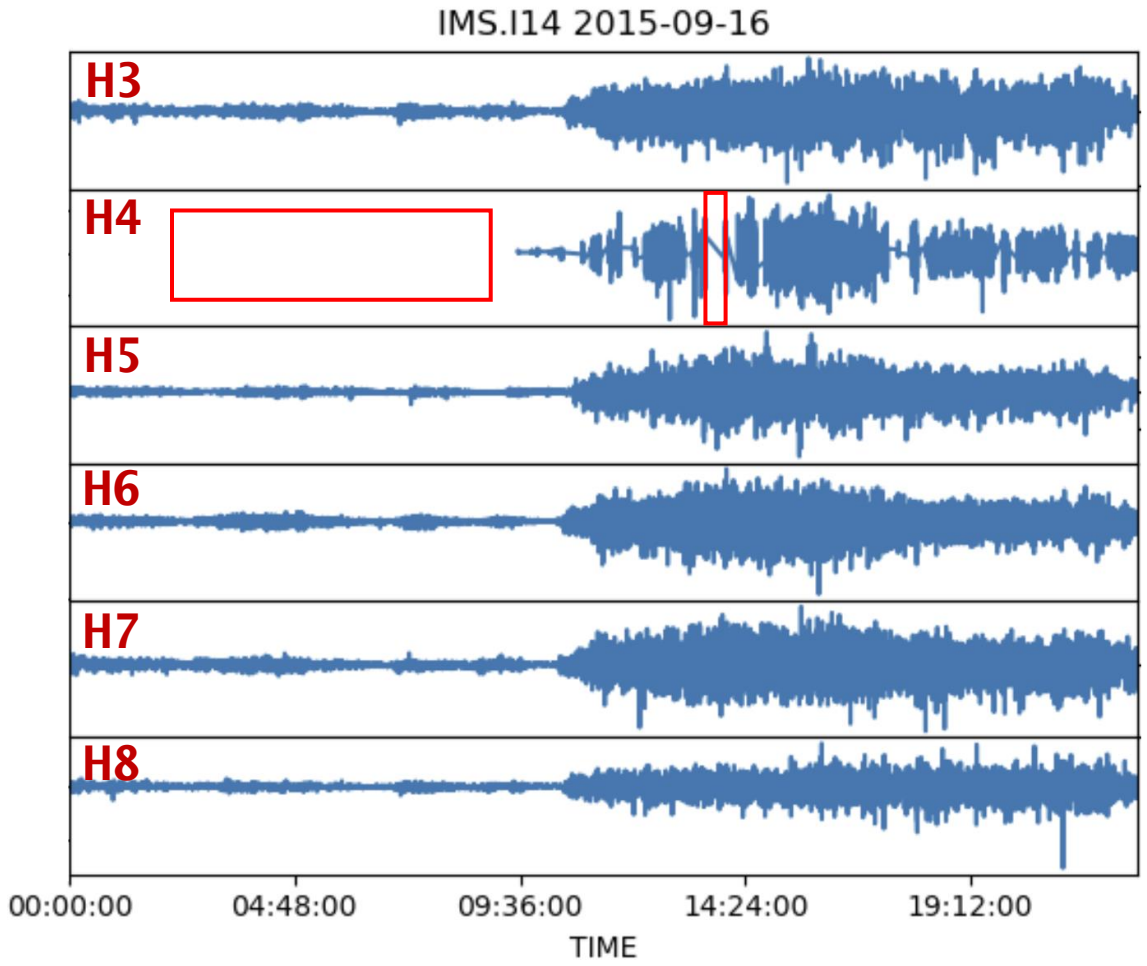
Example of I14CL 2015

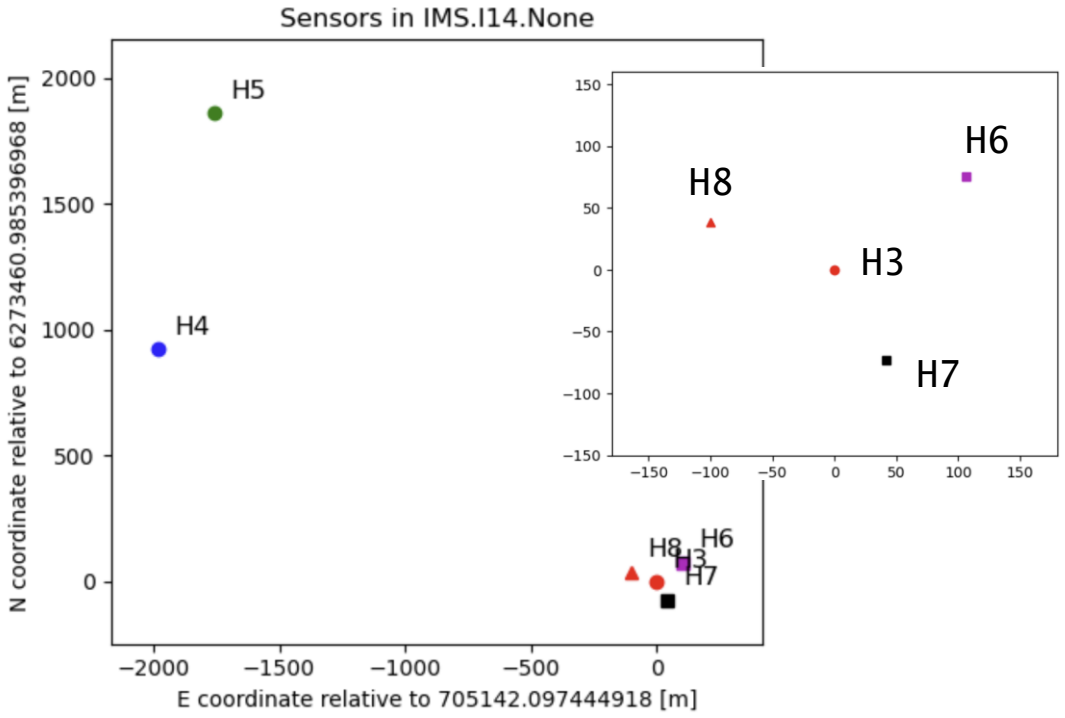




subnet	is1	is2	is3	ch1	ch2	ch3	d12	d13	d23	dmean	idmax	min_ang
0	0	4	5	H3	H7	H8	87.530203	107.886168	183.872103	126.429492	5	17.745265
1	0	3	4	H3	H6	H7	131.097259	87.530203	165.896788	128.174750	4	31.602669
2	0	3	5	H3	H6	H8	131.097259	107.886168	210.030209	149.671212	5	25.607350
3	3	4	5	H6	H7	H8	165.896788	210.030209	183.872103	186.599700	4	49.267199
4	1	2	5	H4	H5	H8	975.186389	2082.457246	2461.567759	1839.737131	5	22.889071
5	0	1	2	H3	H4	H5	2188.961921	2558.184386	975.186389	1907.444232	1	21.988473
6	1	2	3	H4	H5	H6	975.186389	2257.194645	2579.657055	1937.346030	3	21.987132
7	1	2	4	H4	H5	H7	975.186389	2257.028237	2640.404303	1957.539643	4	21.165186

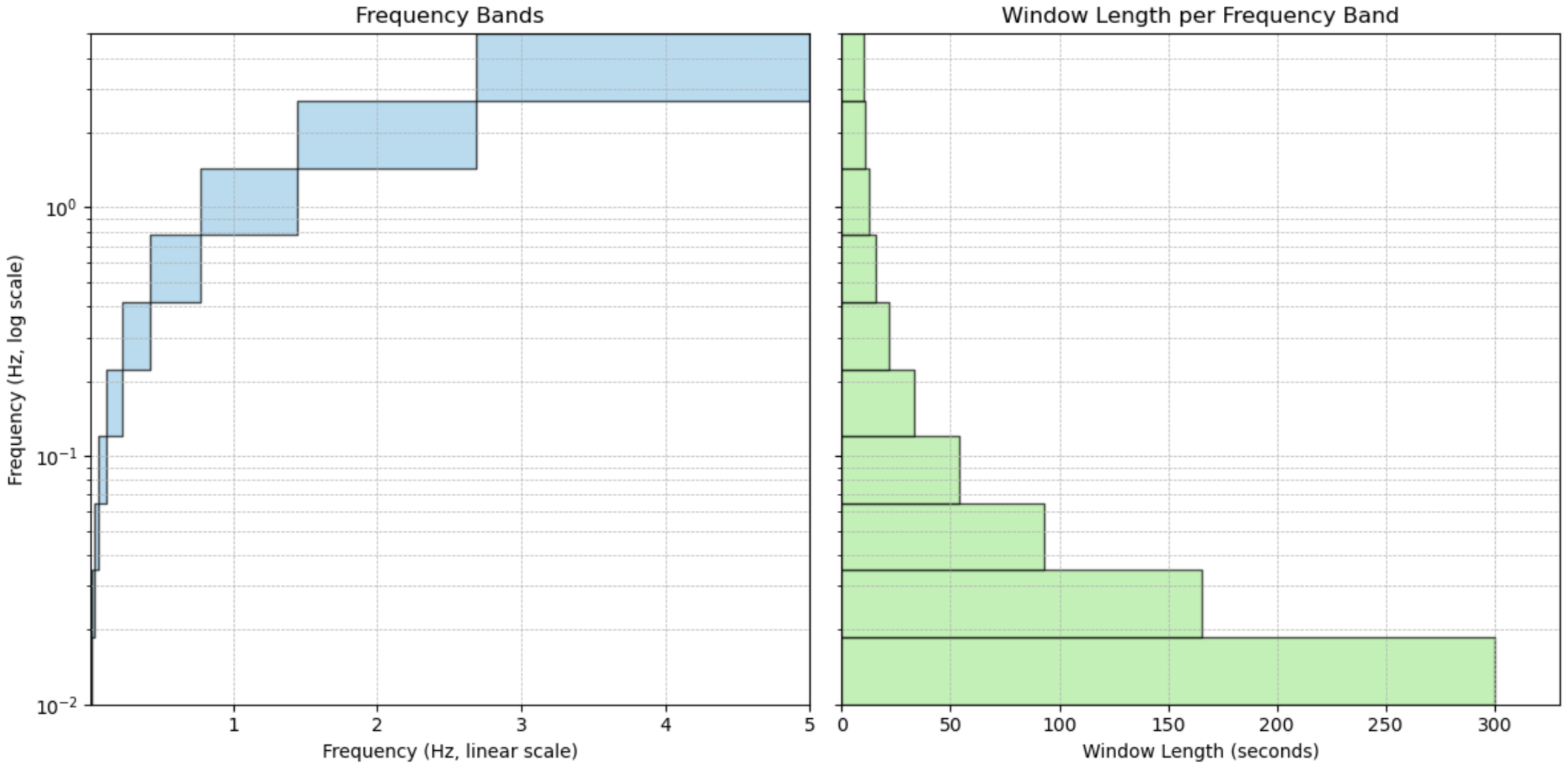
Example of I14CL 2015





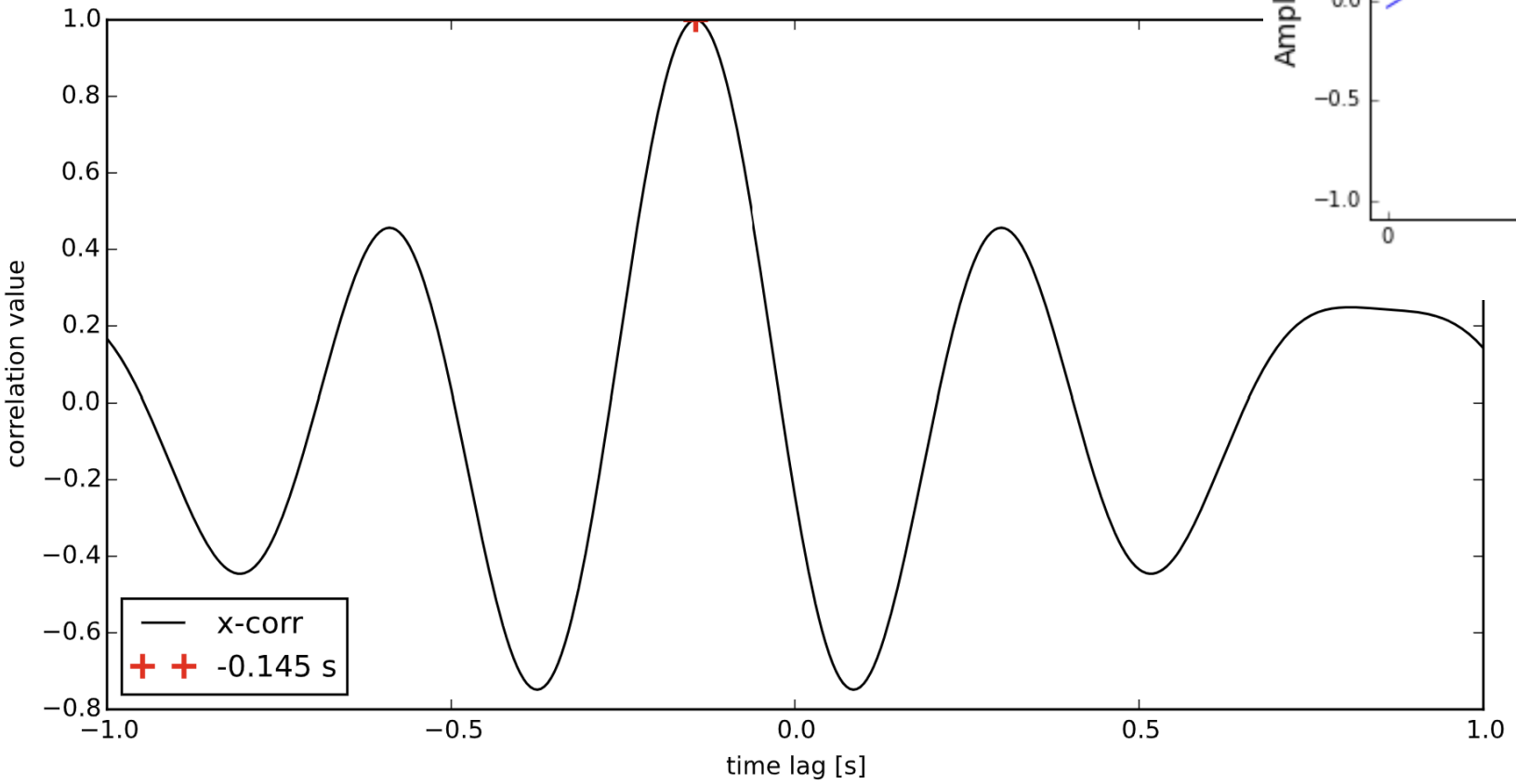
	subnet	is1	is2	is3	ch1	ch2	ch3	d12	d13	d23	dmean	idmax	min_ang
2	0	0	4	5	H3	H7	H8	87.530203	107.886168	183.872103	126.429492	5	17.745265
3	1	0	3	4	H3	H6	H7	131.097259	87.530203	165.896788	128.174750	4	31.602669
4	2	0	3	5	H3	H6	H8	131.097259	107.886168	210.030209	149.671212	5	25.607350
1	3	3	4	5	H6	H7	H8	165.896788	210.030209	183.872103	186.599700	4	49.267199
	~~4~~	~~1~~	~~2~~	~~5~~	~~H4~~	~~H5~~	~~H8~~	~~975.186389~~	~~2082.457246~~	~~2461.567759~~	~~1839.737131~~	~~5~~	~~22.889071~~
	~~5~~	~~0~~	~~1~~	~~2~~	~~H3~~	~~H4~~	~~H5~~	~~2188.961921~~	~~2558.184386~~	~~975.186389~~	~~1907.444232~~	~~1~~	~~21.988473~~
	~~6~~	~~1~~	~~2~~	~~3~~	~~H4~~	~~H5~~	~~H6~~	~~975.186389~~	~~2257.194645~~	~~2579.657055~~	~~1937.346030~~	~~3~~	~~21.987132~~
	~~7~~	~~1~~	~~2~~	~~4~~	~~H4~~	~~H5~~	~~H7~~	~~975.186389~~	~~2257.028237~~	~~2640.404303~~	~~1957.539643~~	~~4~~	~~21.165186~~

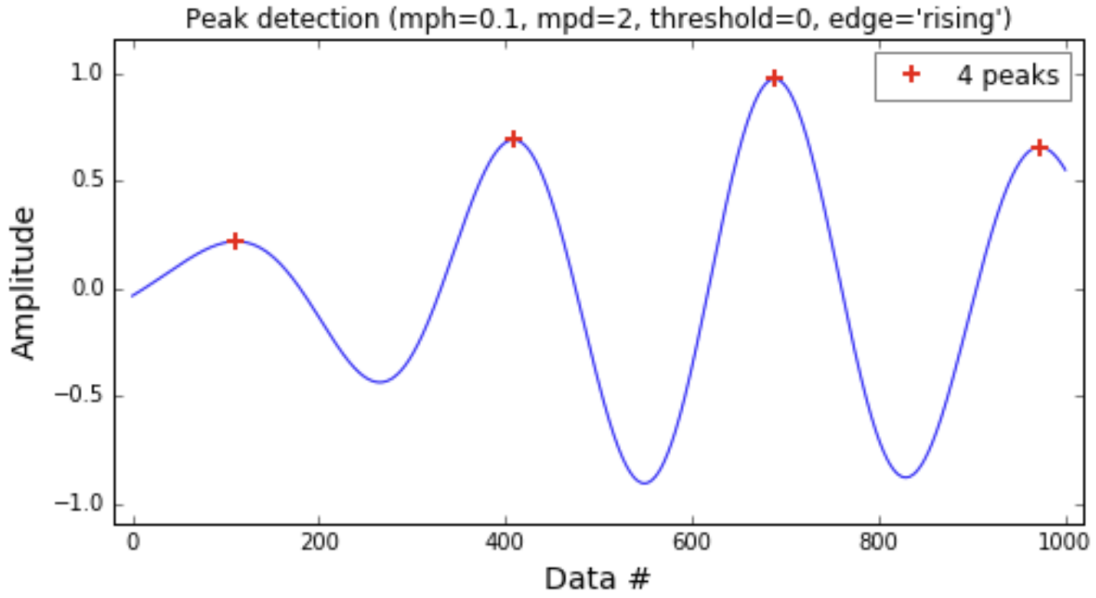
Setting some parameters: frequency bands & windows length



Cross-correlation and correlogram

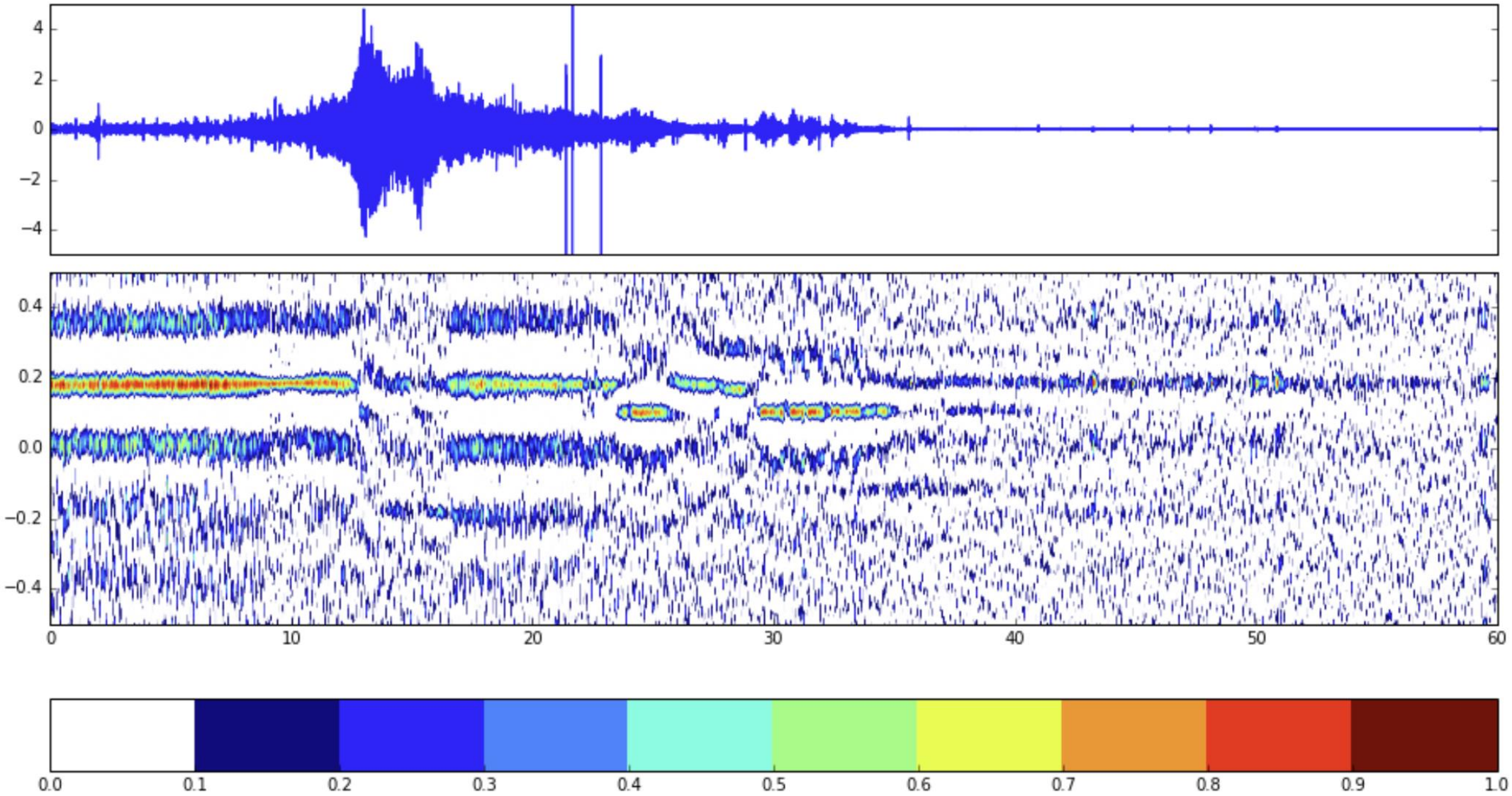
Directed cross-correlation:
Use wave parameters to find coherent peak



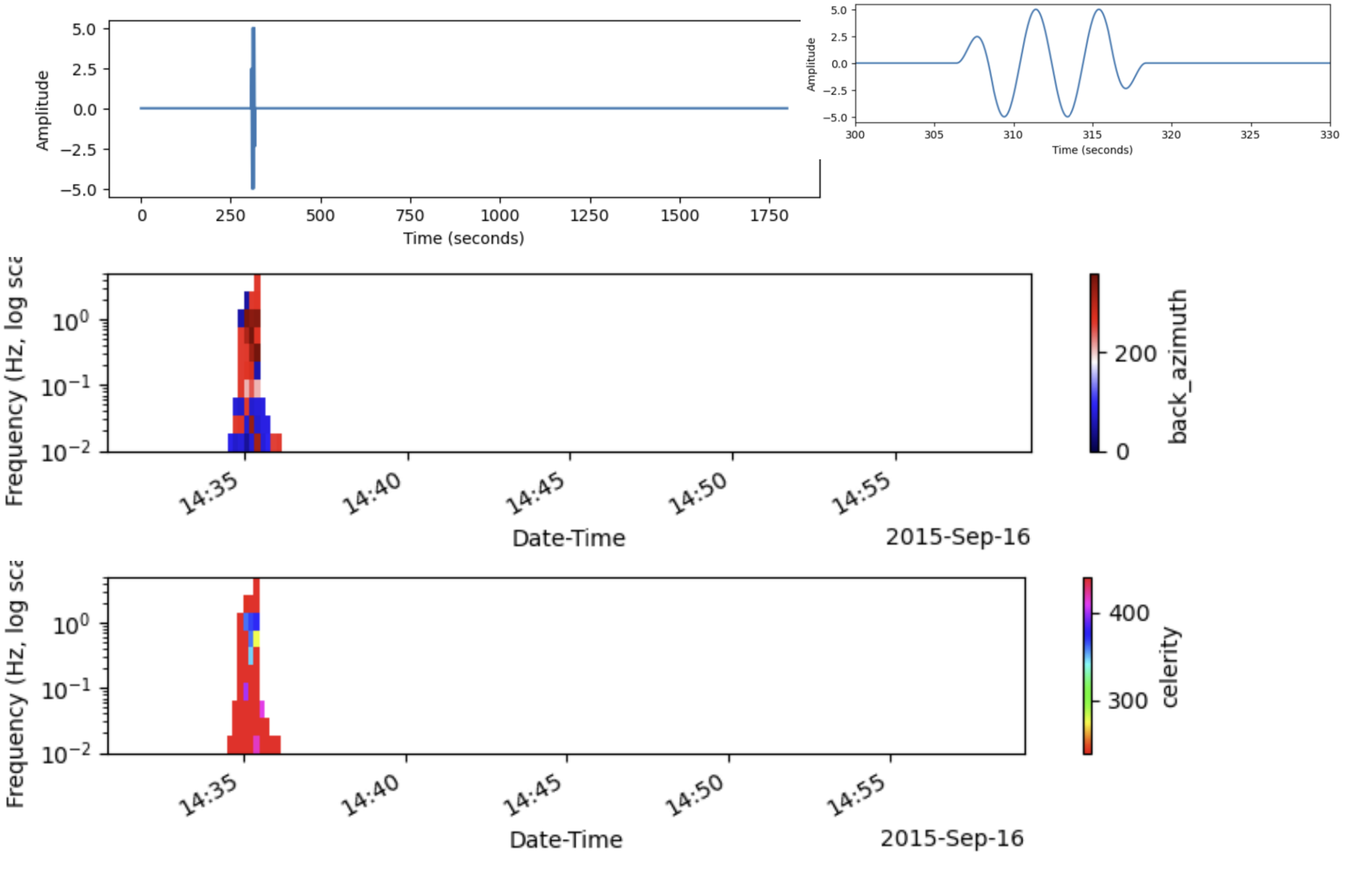


Check for consistency (sum of time-delays) in coherent peak as well as others. Select the one with best consistency.

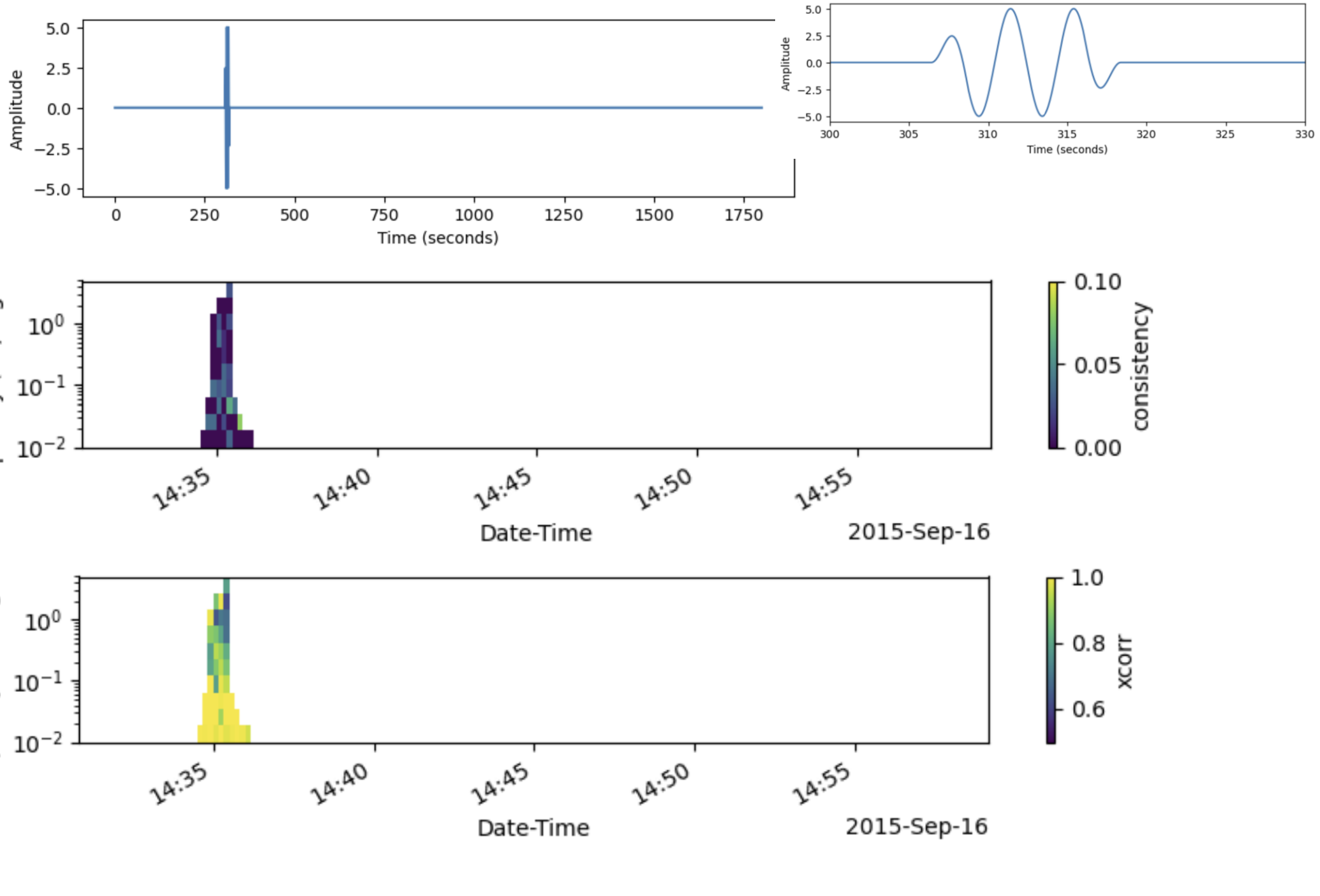
Cross-correlation and correlogram



Runs


Amplitude
Time (seconds)
Frequency (Hz, log sca
Date-Time
2015-Sep-16
back_azimuth
celerity

Runs

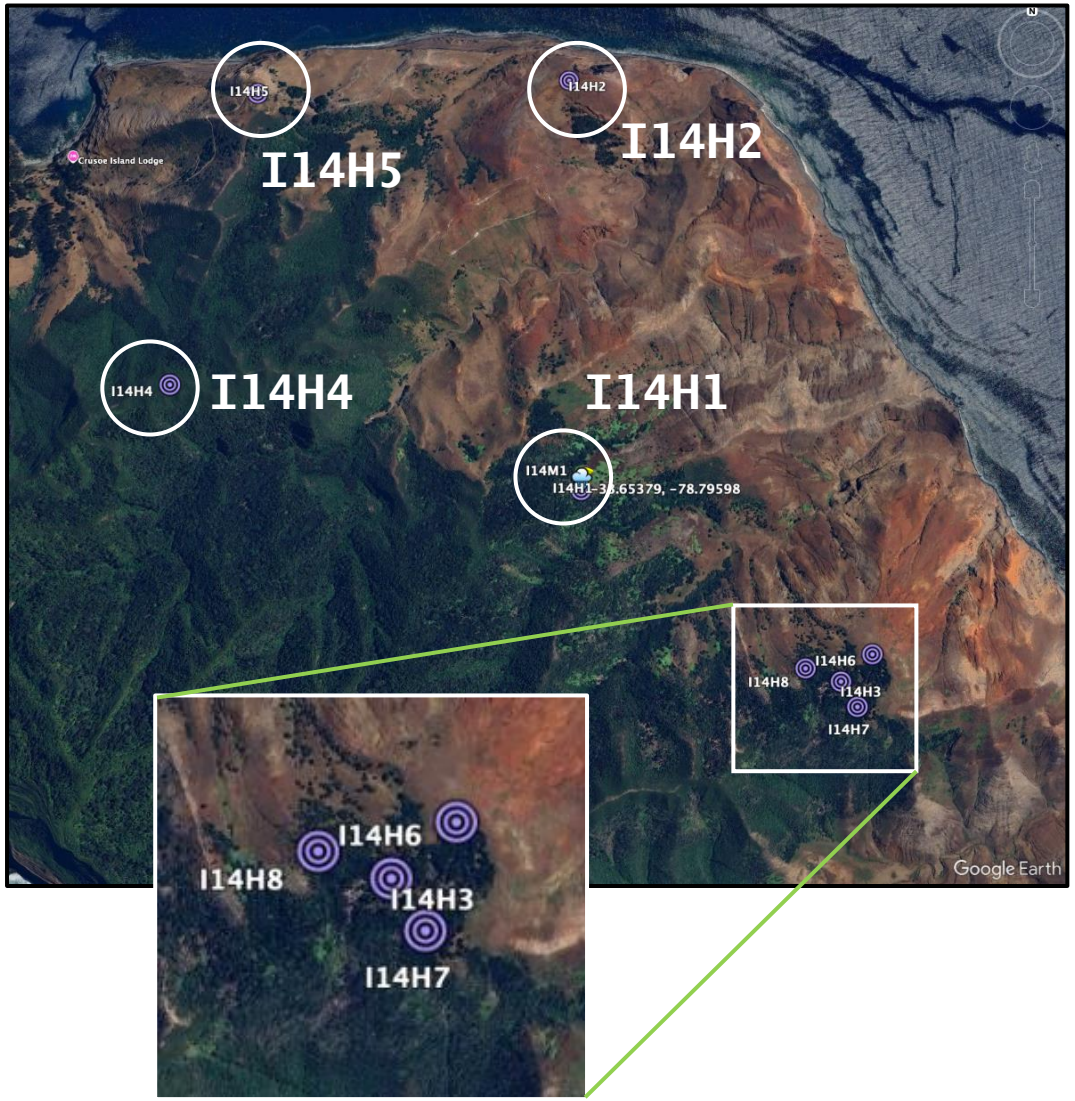

Amplitude
Time (seconds)
Frequency (Hz, log sca
Date-Time
2015-Sep-16
consistency
xcorr

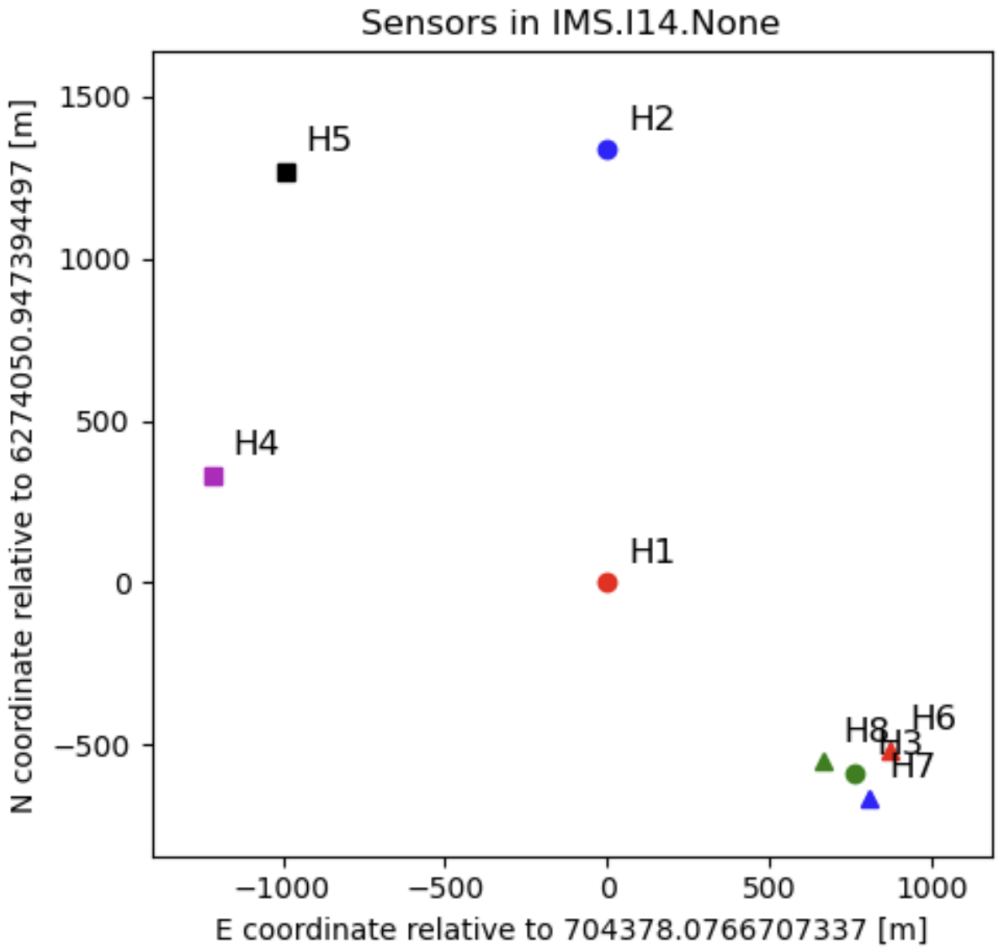
For the future

- Compare with, and learn from, other software (e.g. official PMCC, Infrapy)
- Learn from you!
- Validate the results with known (published) examples
- Develop customized applications for local NDCs.
- Study IMS performance and event detections in South America
- Create algorithms to combine results from multiple stations in SA
- … and many more planned advancements.

Thank you

Example in Robinson Crusoe island, I14CL 2024





Class PMCC

+

.subnetwork_def()
.def_freq_bands()
.def_win_lengths()
.apply_filter()
.get_subnet_list()
.calculate()
...