Remote explosive volcanic eruption detection, location, and characterization using the EarthScope Transportable Array in Alaska.

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Photo: Dave Withrow (NOAA/Fisheries)

Alaska stations:

228 infrasound sensors within 2500 km of Bogoslof:

EarthScope Transportable Array (TA) (new) 75%

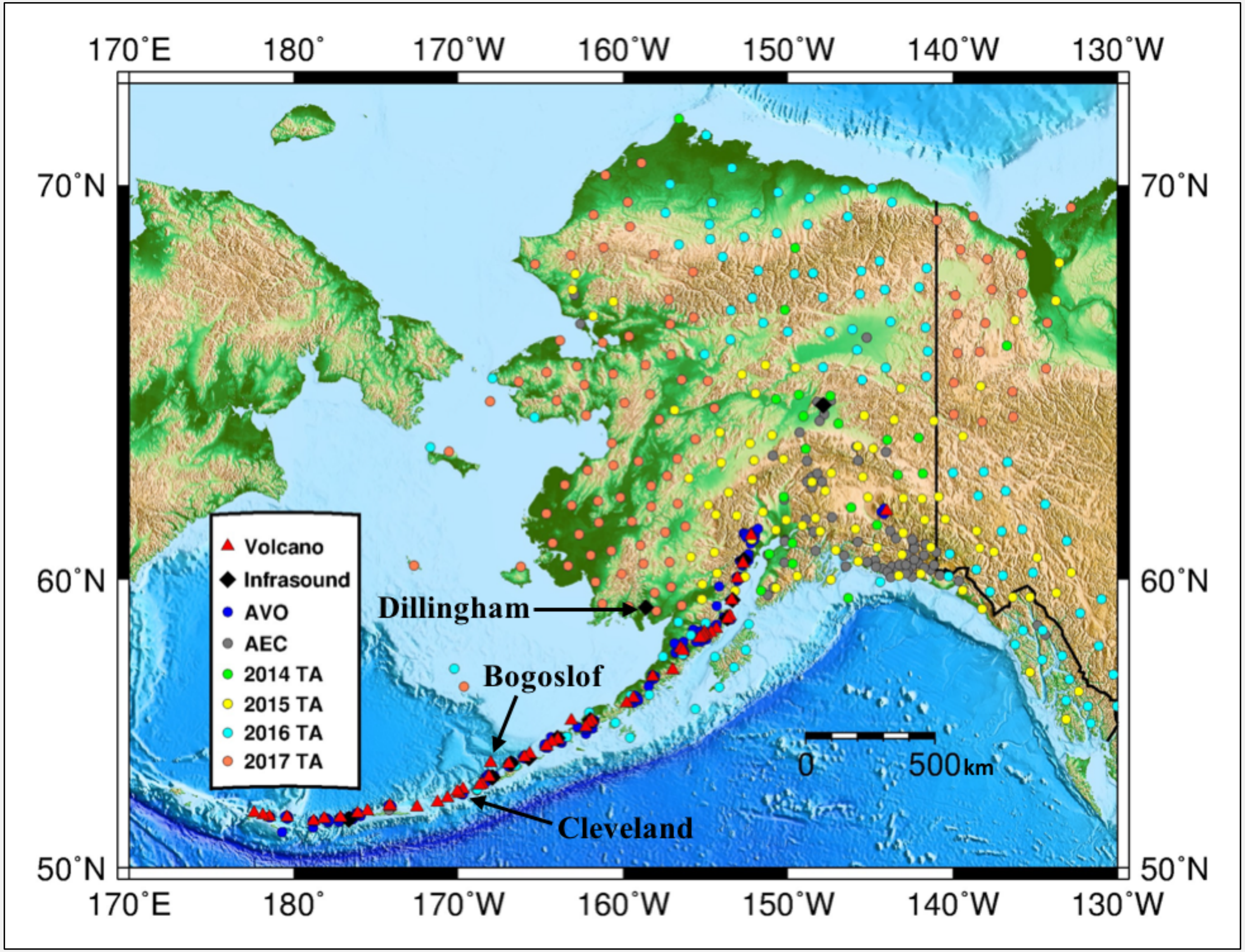
Alaska Volcano Observatory (AVO) 14%

Alaska Regional Network (AK) 4%

International Monitoring System (IM) 3.5%

University of Alaska Fairbanks (DLL) 3% *

IRIS/IDA (II) 0.5%



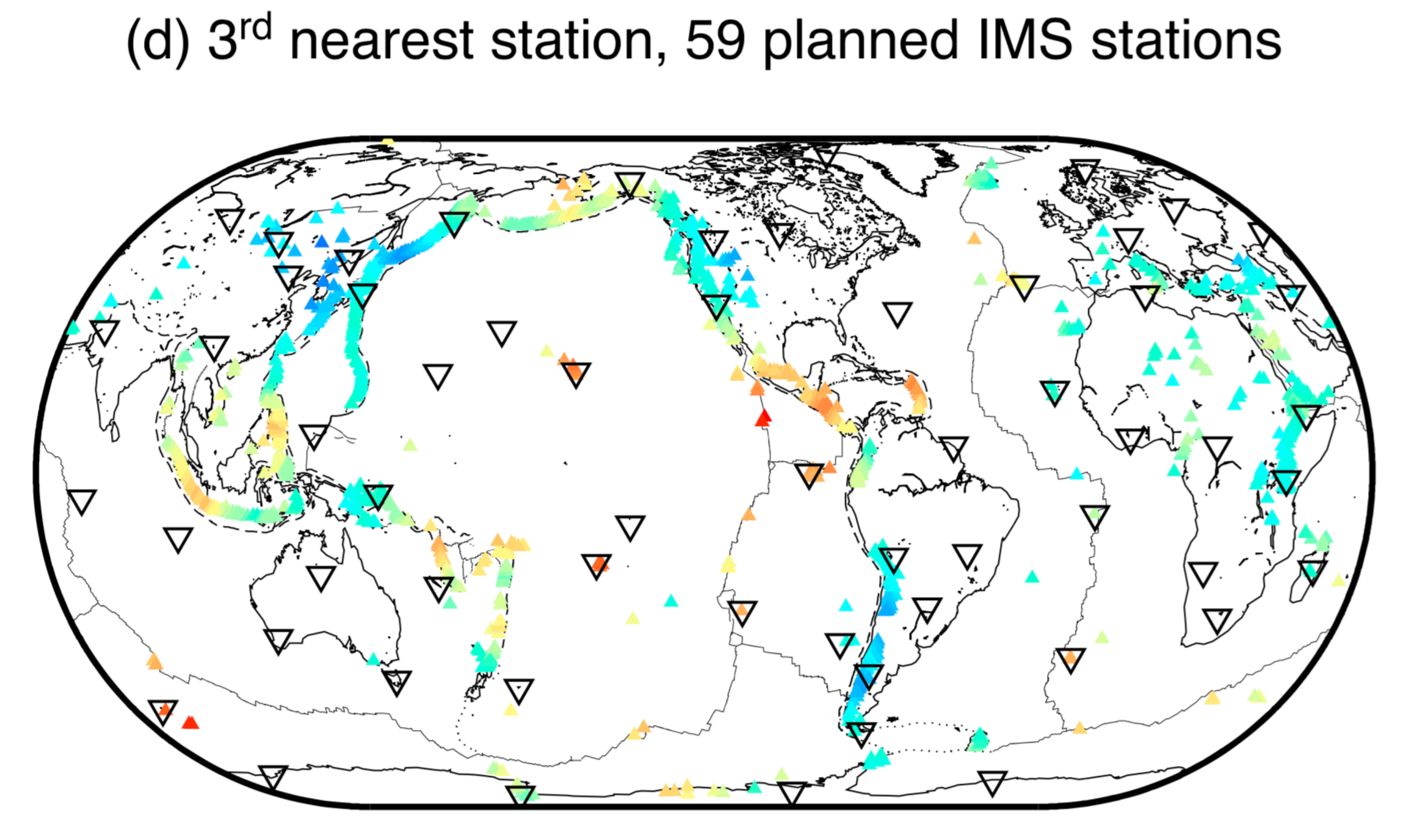
Motivation:

1. Advance the capability of acoustic early warning systems of volcanic eruptions.

2. Quantify explosive volcanism with dense spatial wavefield sampling.

3. Assess the potential contribution of large sensor networks to volcano monitoring.

Network size	Coverage	Sensitivity, accuracy
Local	Low	High
Global	High	Low
Regional	Medium	Medium



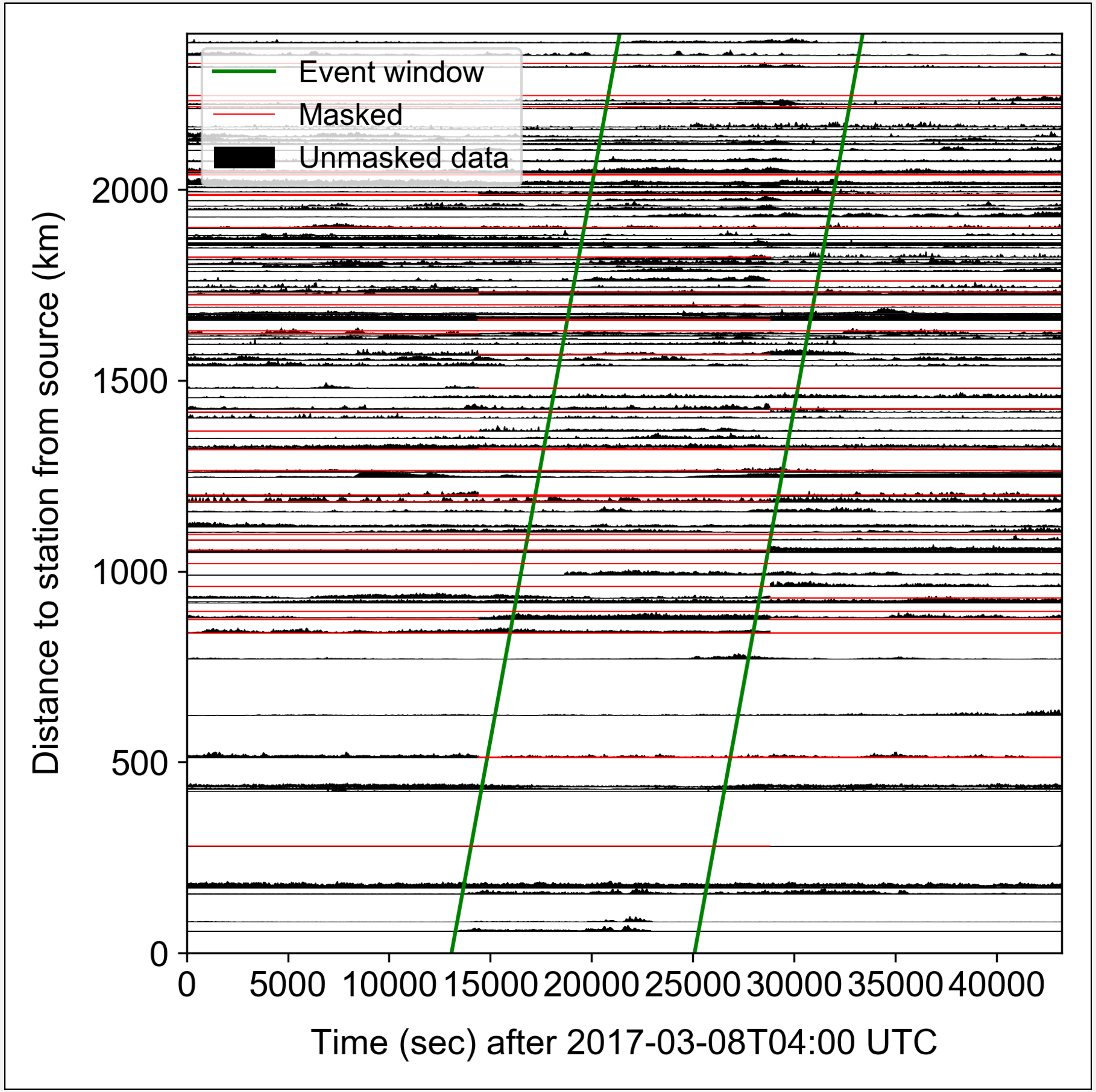
Above figure from: Matoza, et al., 2017

Outline:

- Data sources ✔
- Looking for events
- Detecting events
- Locating events
- Challenges and future work

Pre-processing steps:

- Filter (0.5 - 0.8 Hz)
- Envelopes
- Decimate to 0.5 Hz
- Smoothing (moving avg.)
- Apply wind mask (0.03-0.08 Hz)
- Normalize each trace

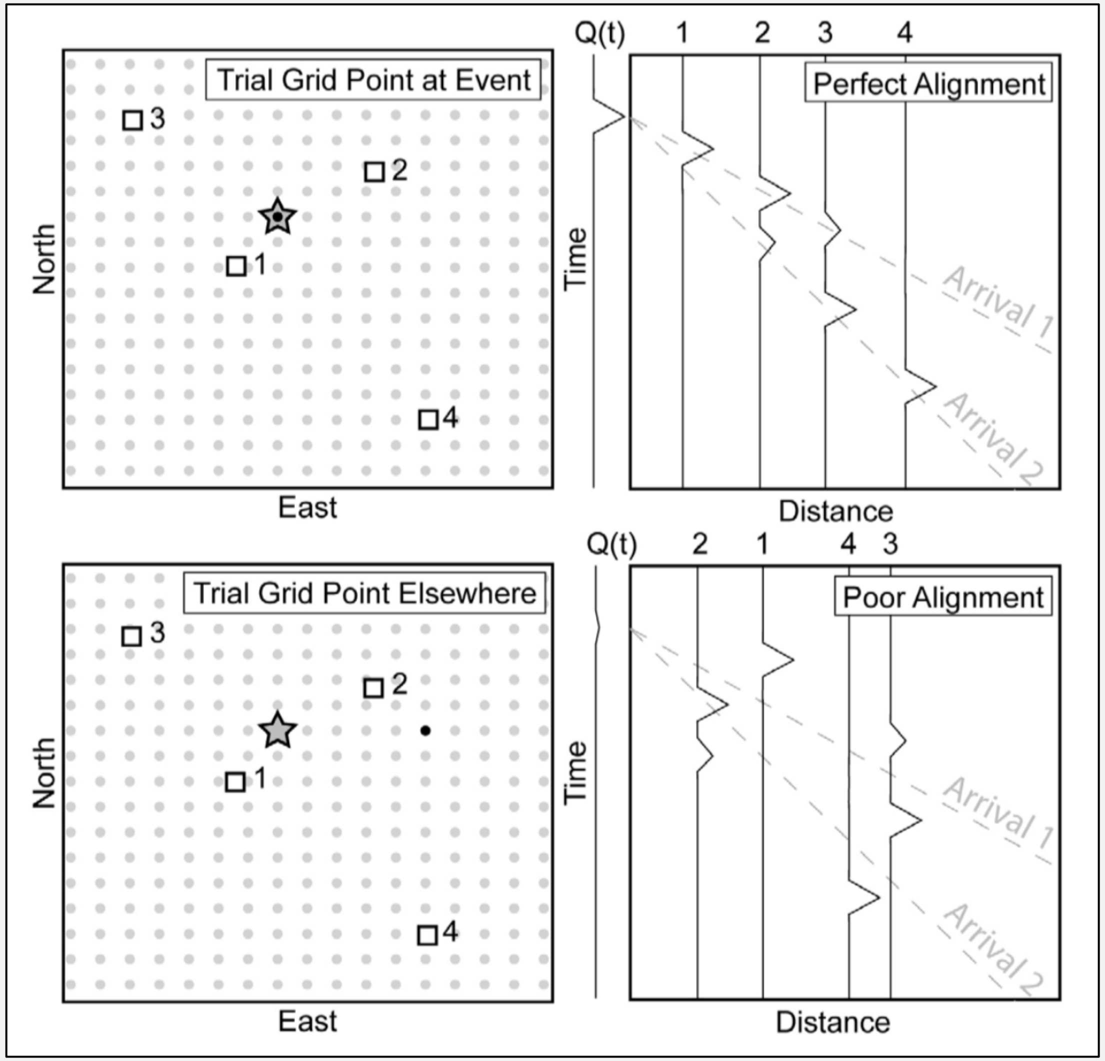


Reverse Time Migration with linear stacking:

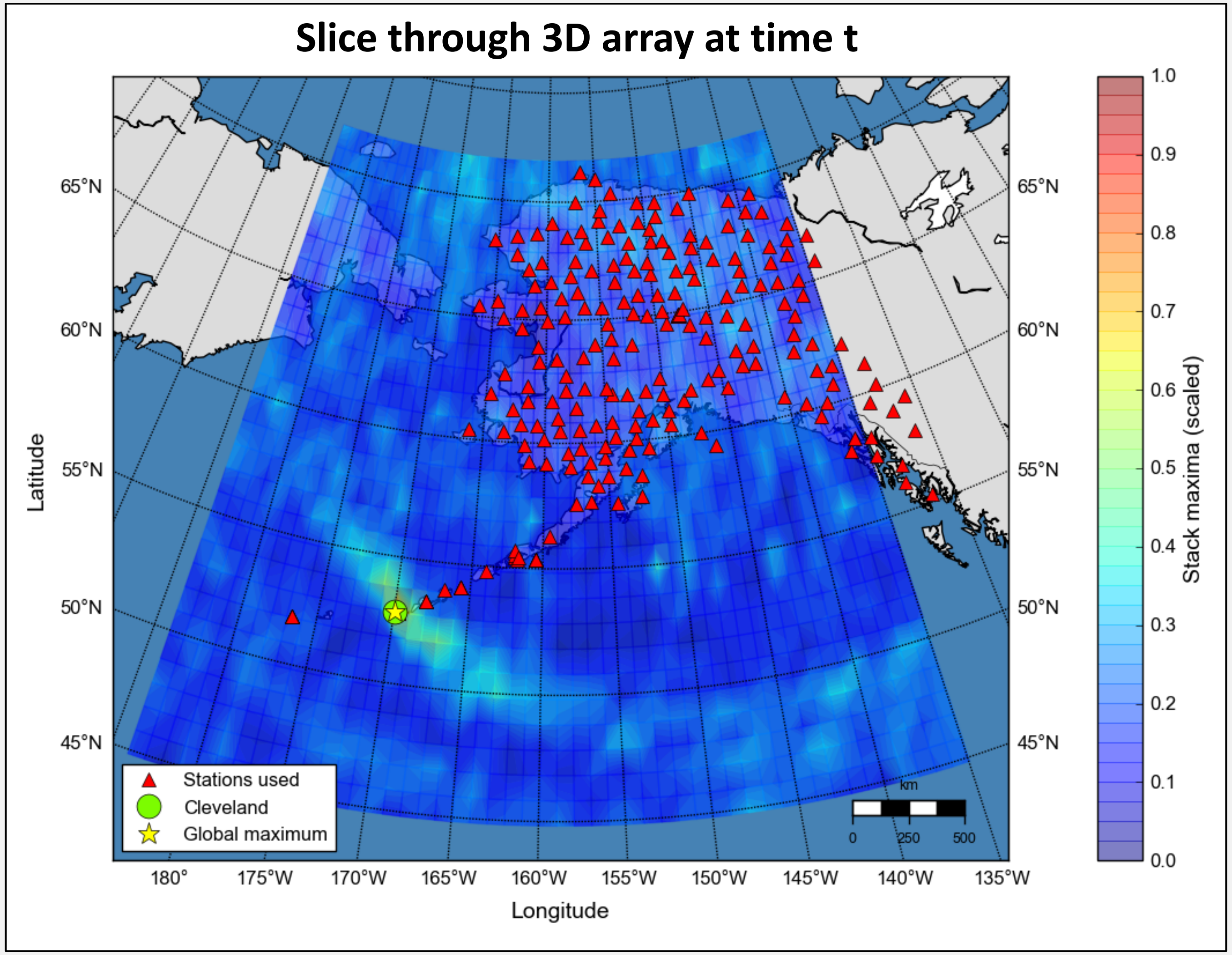
Grid search => 4D array (x,y,t,c)

c = constant celerity (range/time)

Sort 4D array => 3D array (x,y,t)



Above figure from: Walker, et al., 2010



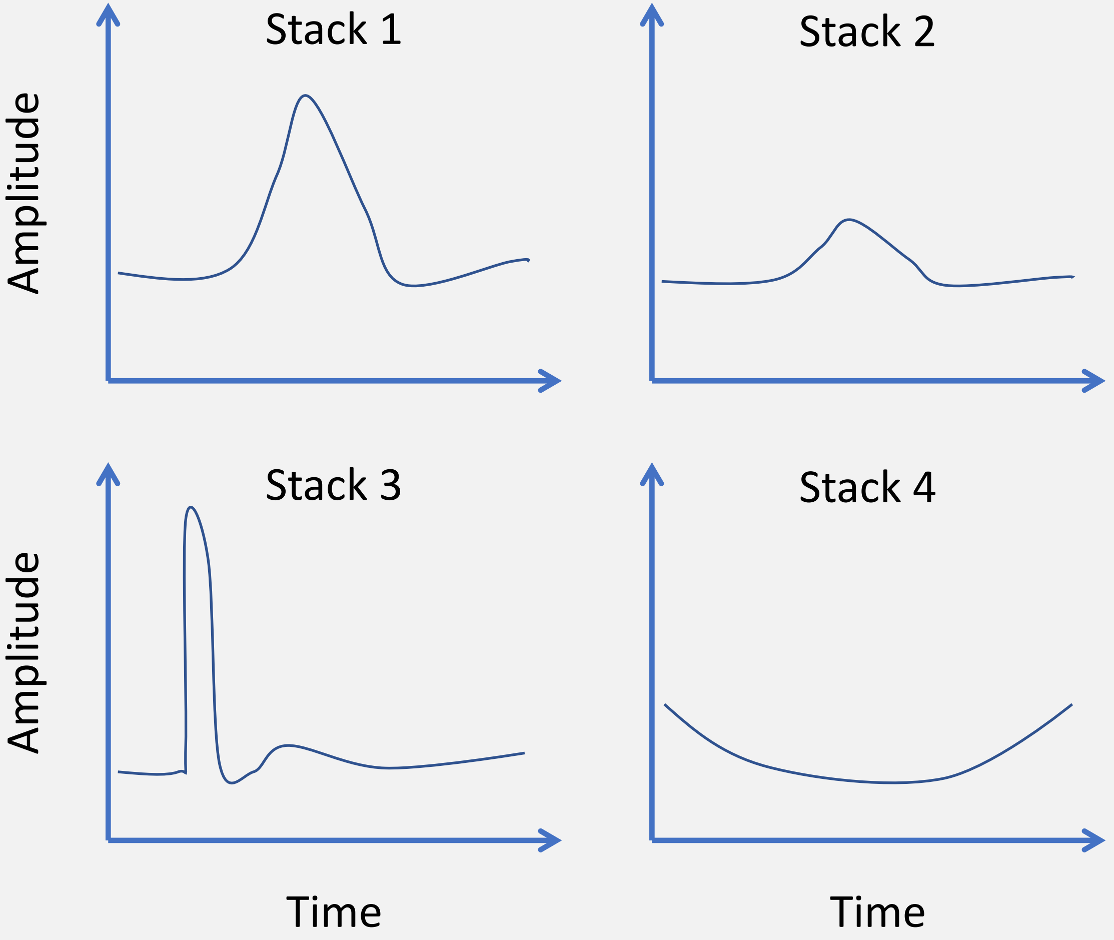
Detecting events:

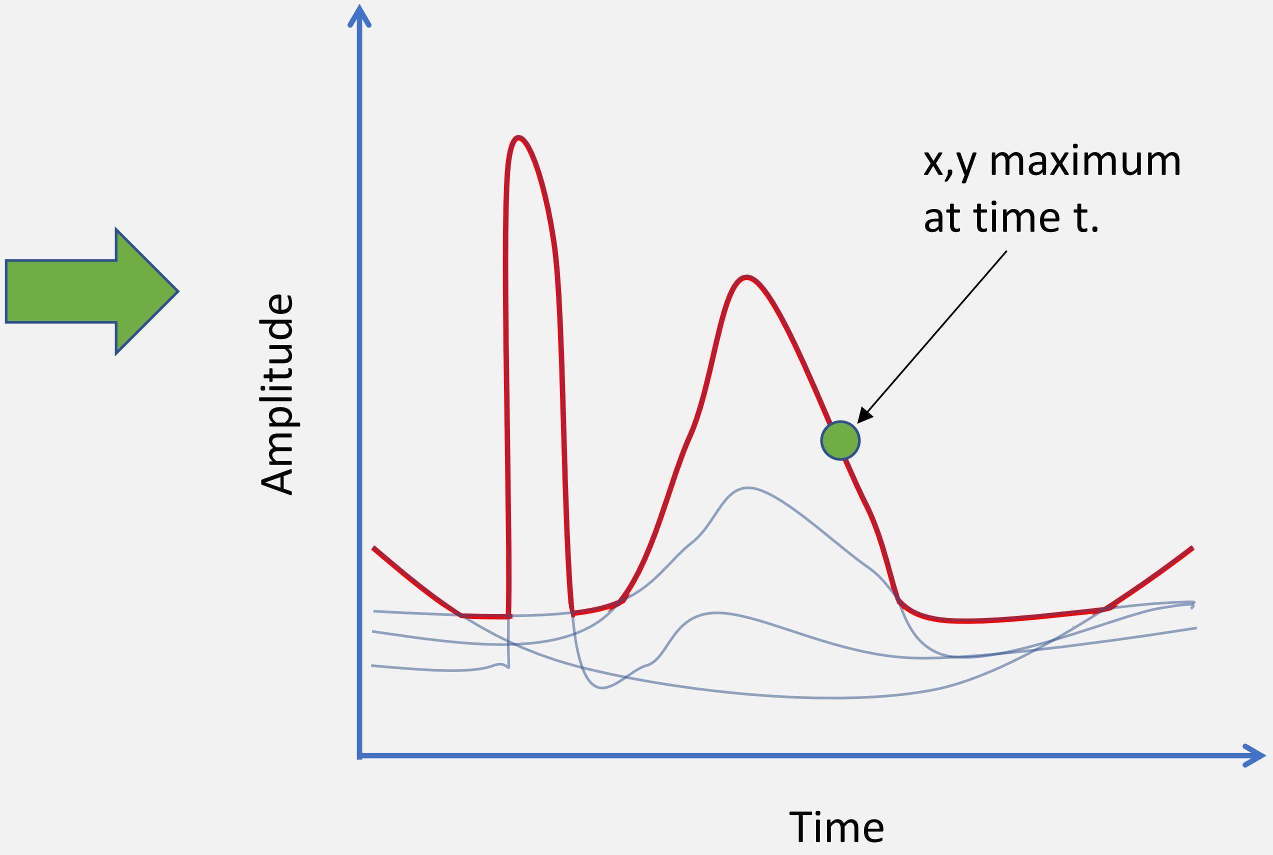
"Detector functions" (Walker et al., 2010)

Walker et al., 2010: Maxima of stacks at **t**

Here: Maxima of stack sums at (**t** + window)

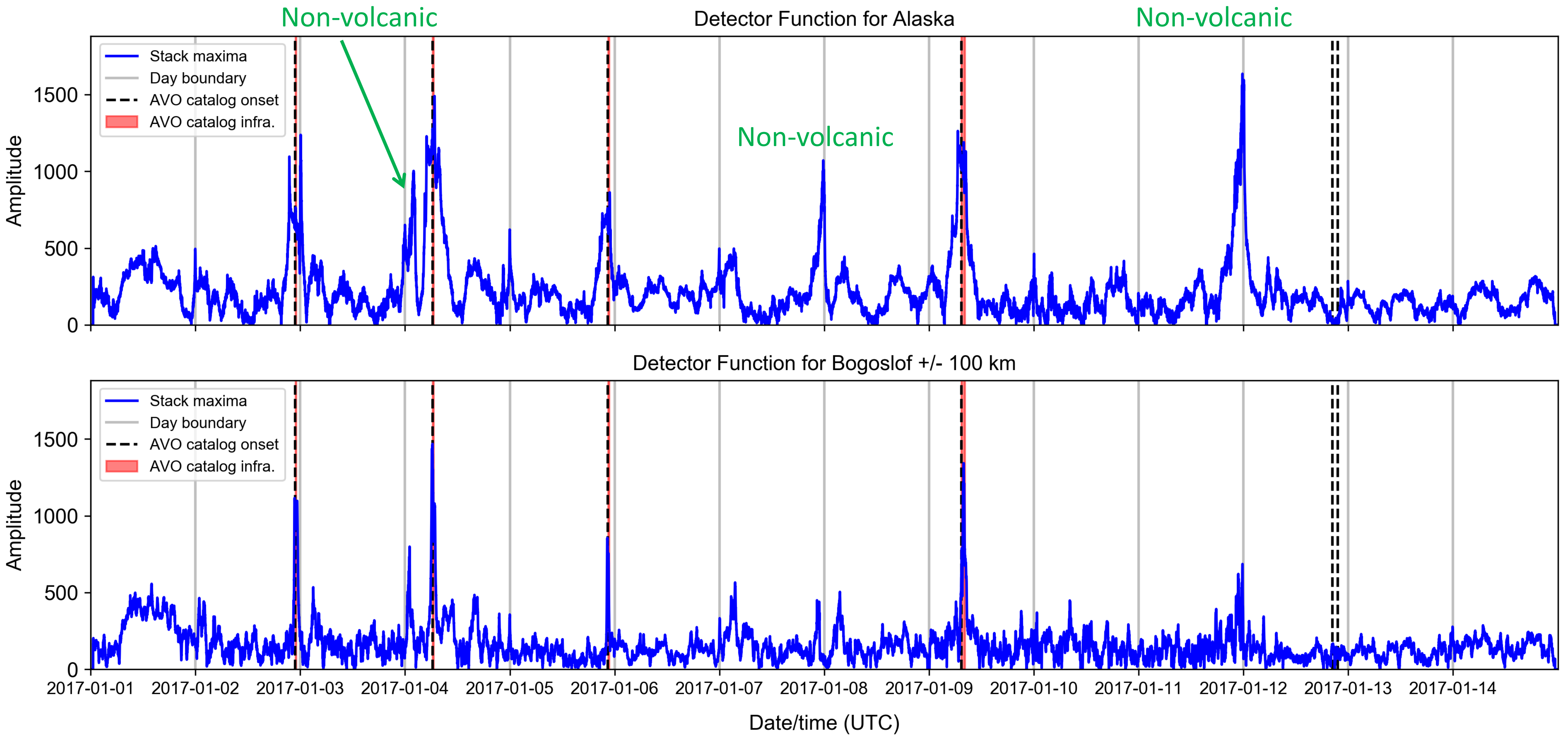
Stack at each grid node



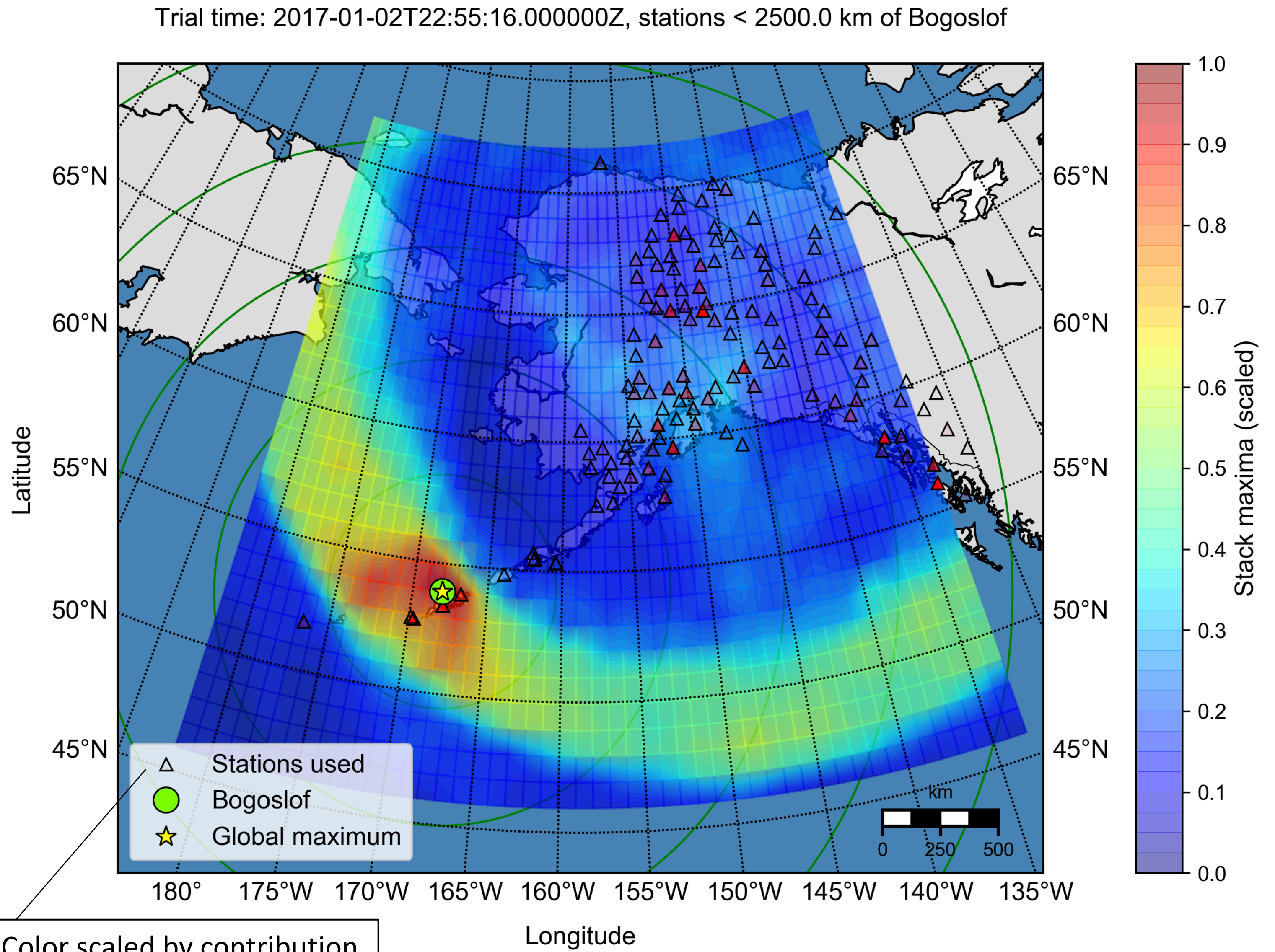


Detector functions:

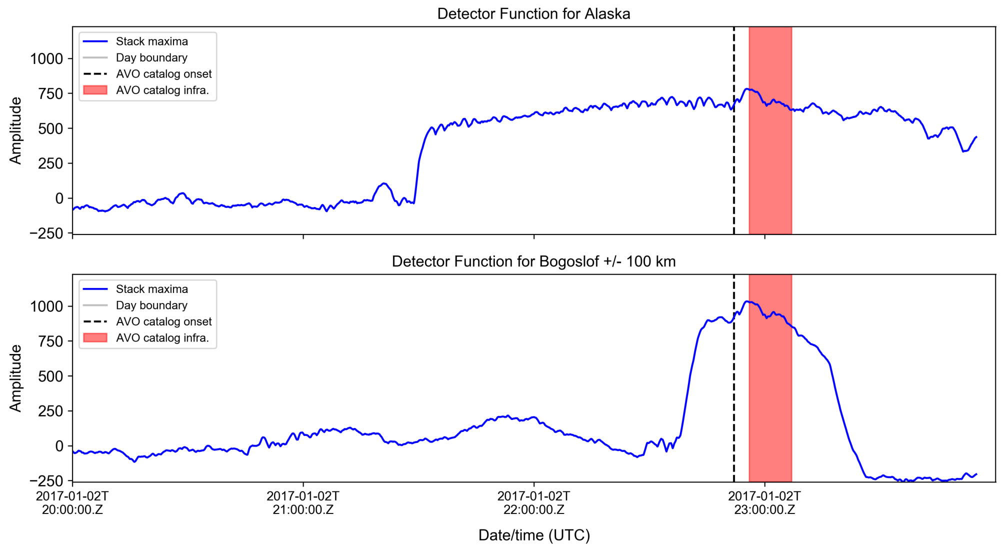
7 events: 4 volcanic, 3 non-volcanic

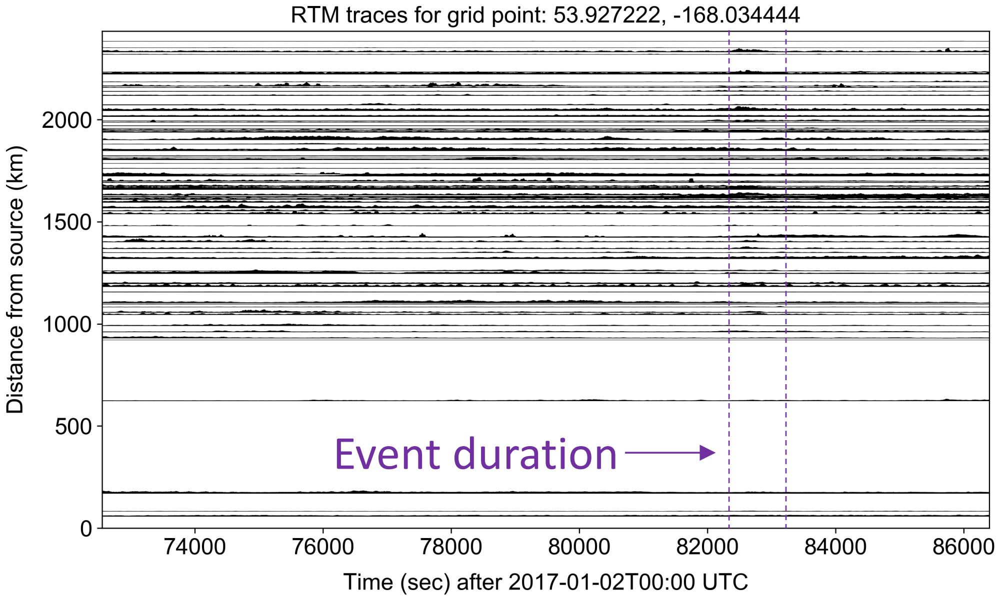


Time-slice - January 4th eruption:



Color scaled by contribution





Assessing detection algorithms:

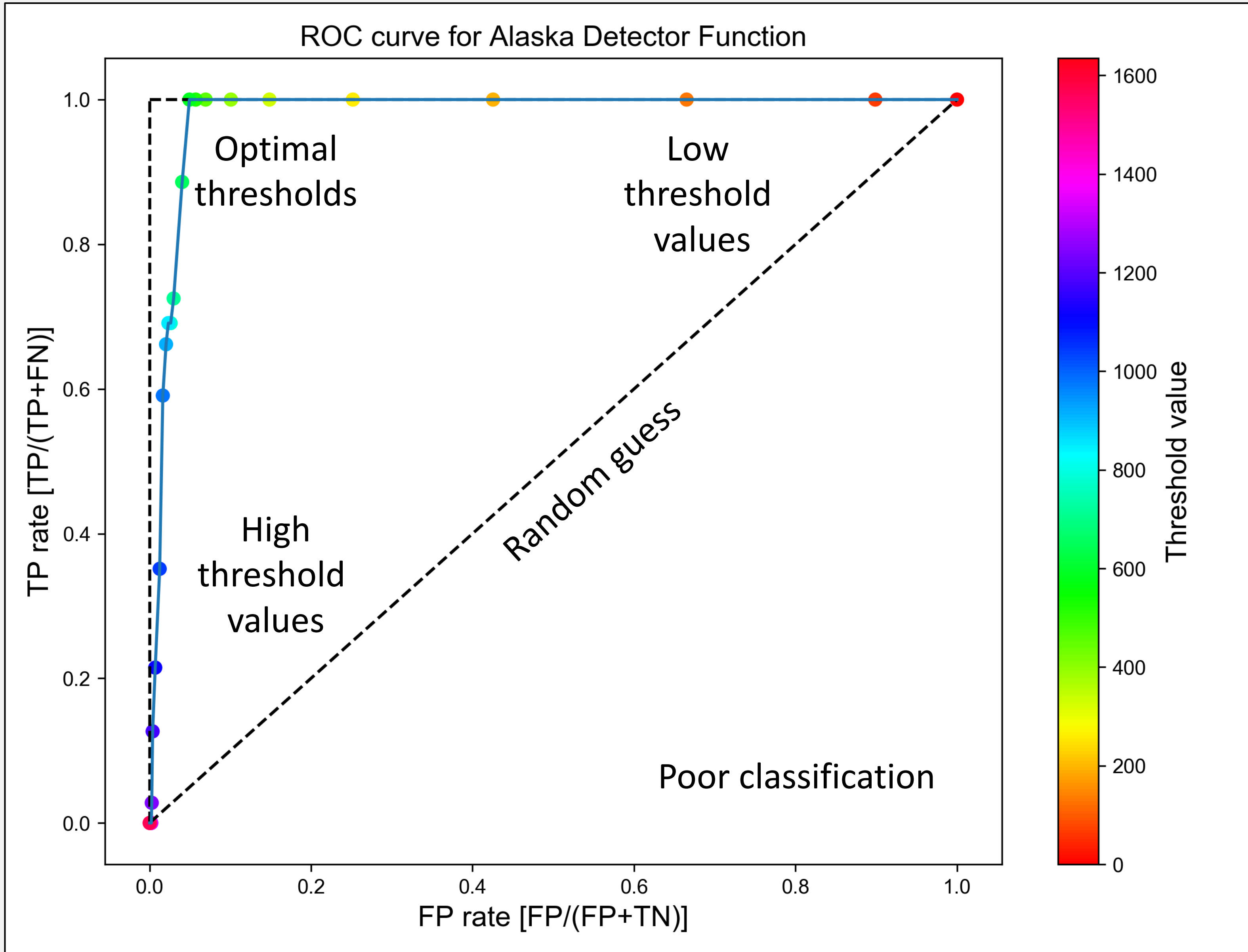
Receiver Operating Characteristic (ROC) curves:

Find optimal True Positive (TP) rate to False Positive (FP) rate.

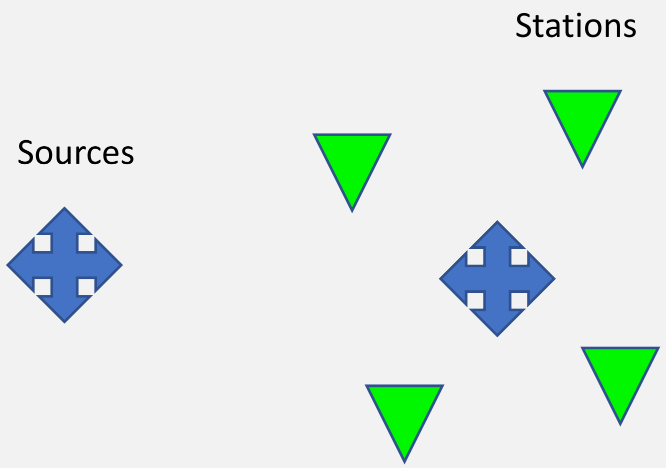
For detector function (DF), vary detection threshold (T) and calc.:

TP – eruption, DF > T
FN – eruption, DF < T
FP – no eruption, DF > T
TN - no eruption, DF < T

Can compare algorithms with ROCs.



Challenges:



1. Network geometry:

Symptom – detection smearing

Impact - location accuracy

Solution – station coverage, methods with directionality

2. Noise:

Symptom – waveform clarity

Impact – missing events

Solution – coherence, wind reduction

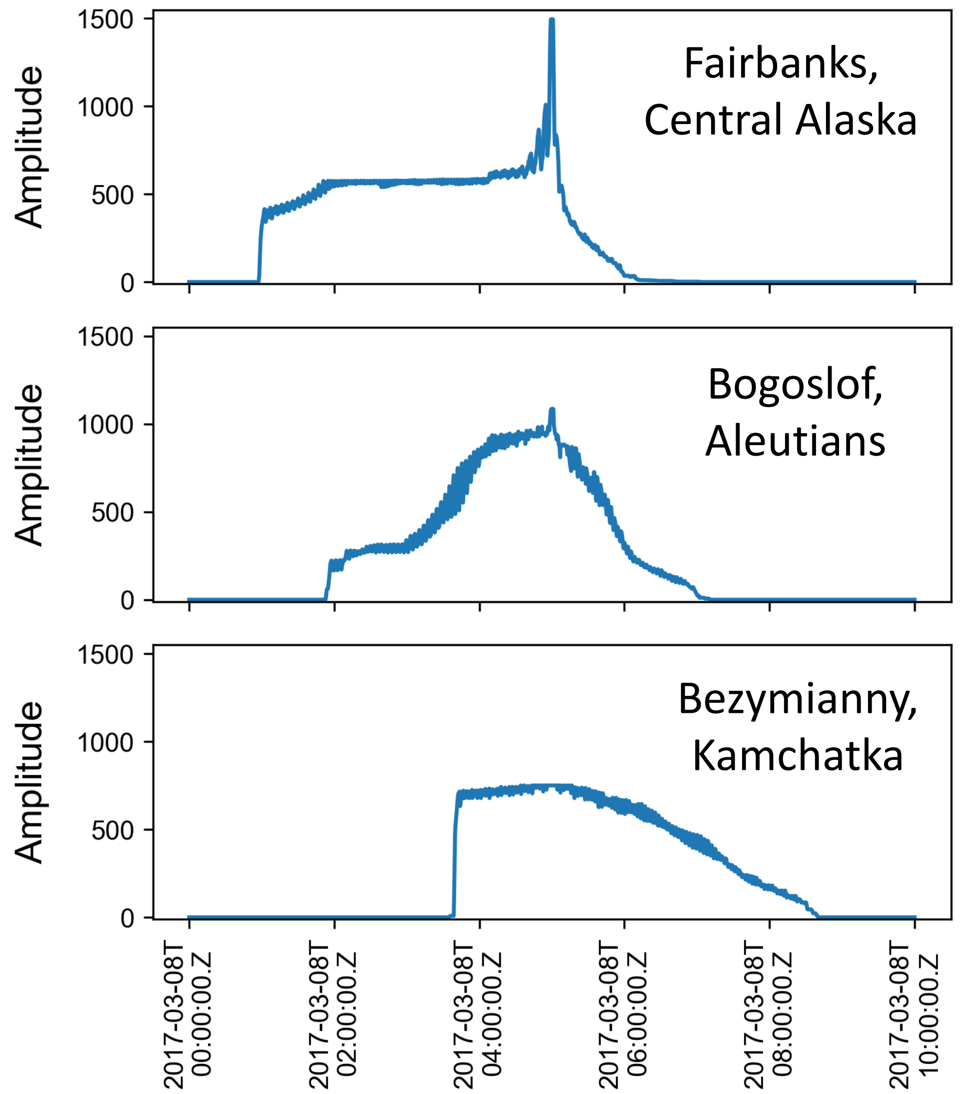
3 . Atmospheric structure:

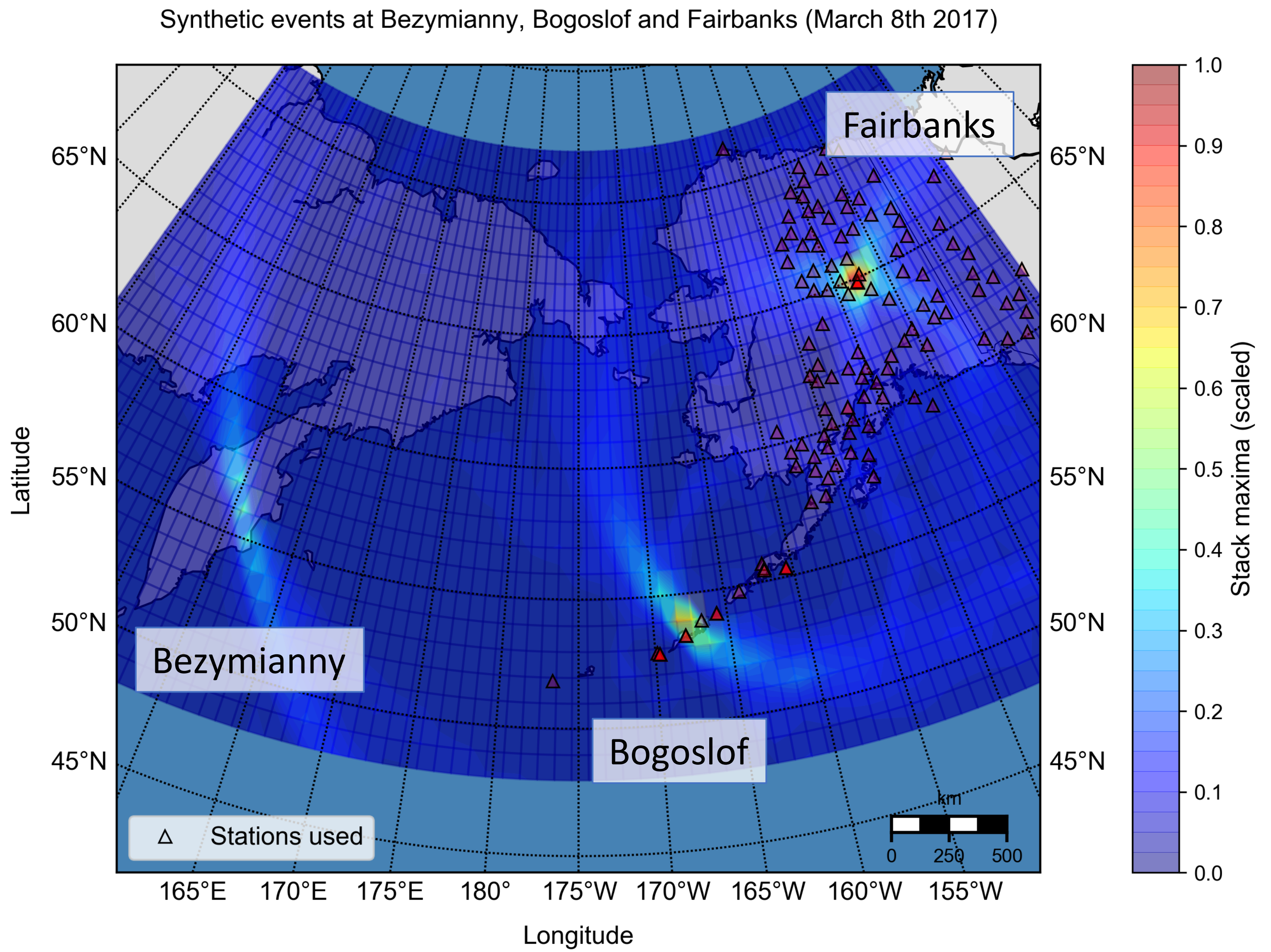
Symptom – phase alignment

Impact – location accuracy

Solution – cross-correlation, atmospheric ray tracing

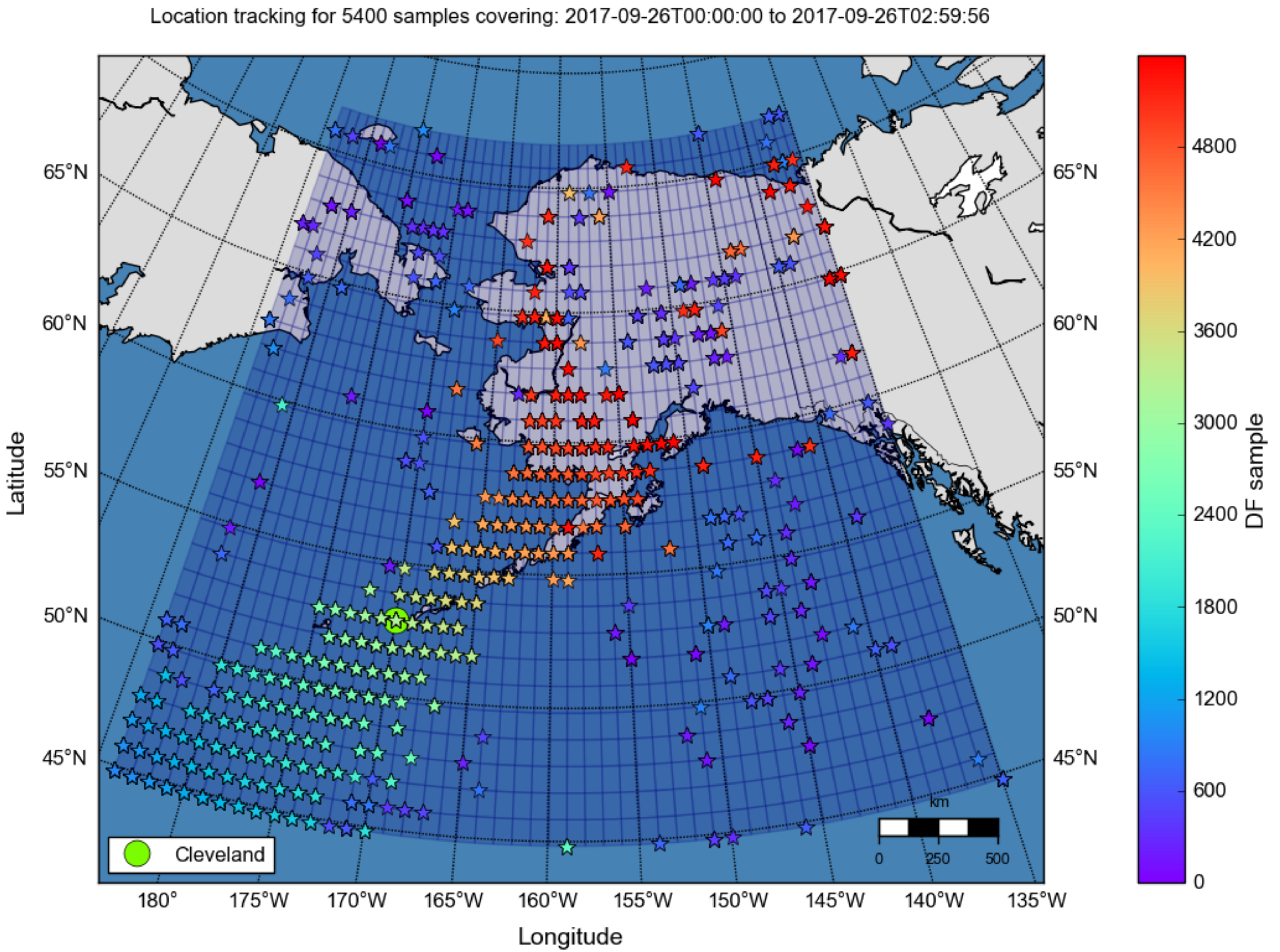
Synthetic detector functions: source 60 s boxcar





Swimming artifacts:

Location moving with time



Challenges:

1. Network geometry:

Symptom – detection clarity

Impact - location accuracy

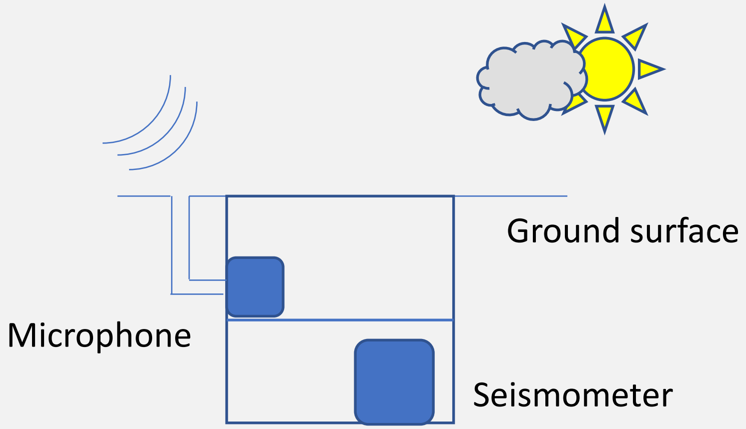
Solution – station coverage, methods with directionality

2. Noise:

Symptom – waveform clarity

Impact – missing events

Solution – wind reduction, spectral coherence



3 . Atmospheric structure:

Symptom – phase alignment

Impact – location accuracy

Solution – cross-correlation, atmospheric ray tracing

Infrasound coherence weighting:

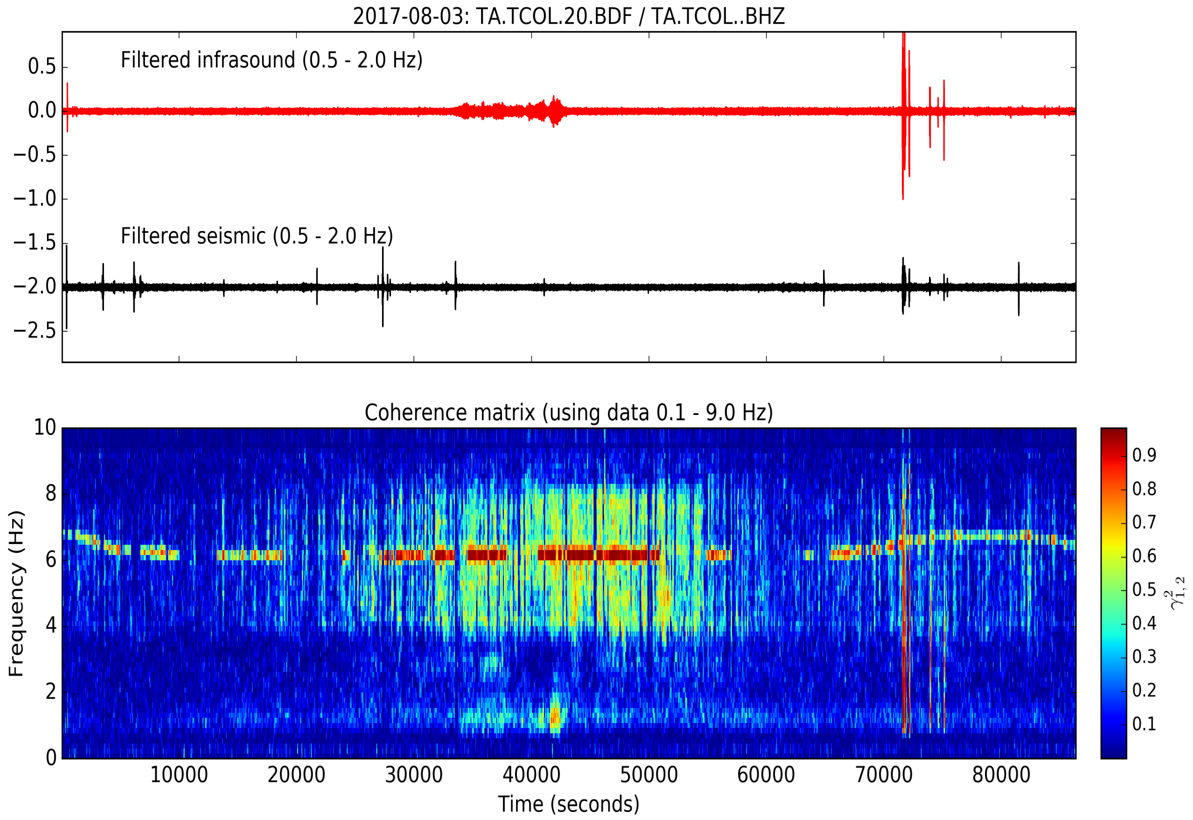
[After: Ichihara et al., 2012; Matoza and Fee, 2014; Fee et al., 2017; McKee et al., 2018.]

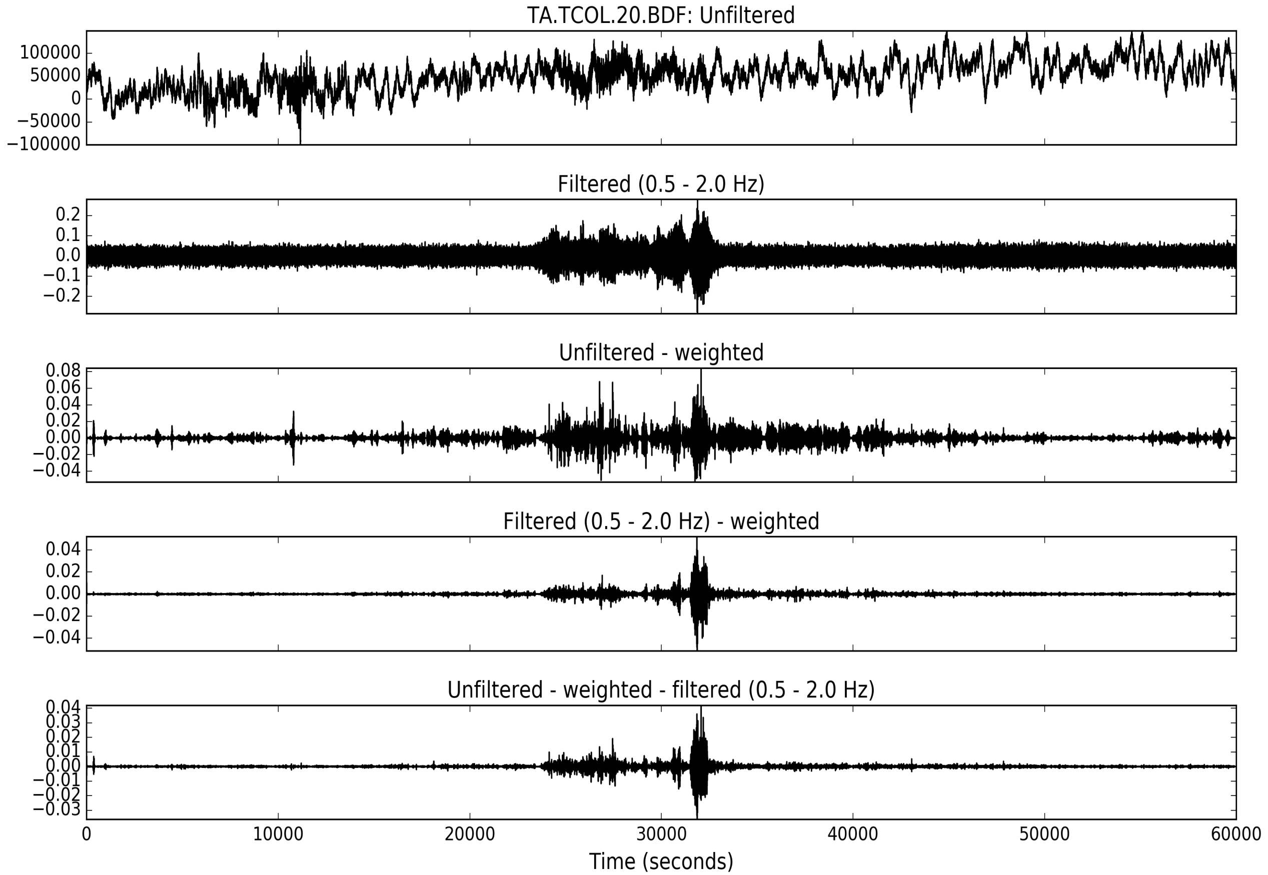
Few ground-coupled air-waves per event

Coherence from non-volcanic events

No clear pattern with distance

Unpredictable use for stacking/RTM





Summary:

Aim –

Develop a basic event detection and location algorithm that exploits infrasound detected on a dense regional array.

Results –

- Infrasound is recorded across the TA depending on conditions
- Simple grid search method can identify events with high TP/FP rate
- Noise suppression improves signal to noise ratios
- Detection clarity/accuracy sensitive to network coverage of source as well as signal phase alignment

Future work/improvements:

1. Further exploring noise reduction, e.g., coherence weighting, block thresholding (*Langston and Mousavi, 2018*).

2. Compensate for atmospheric structure/arrival times using AVO-G2S (*Iezzi et al., 2018*).

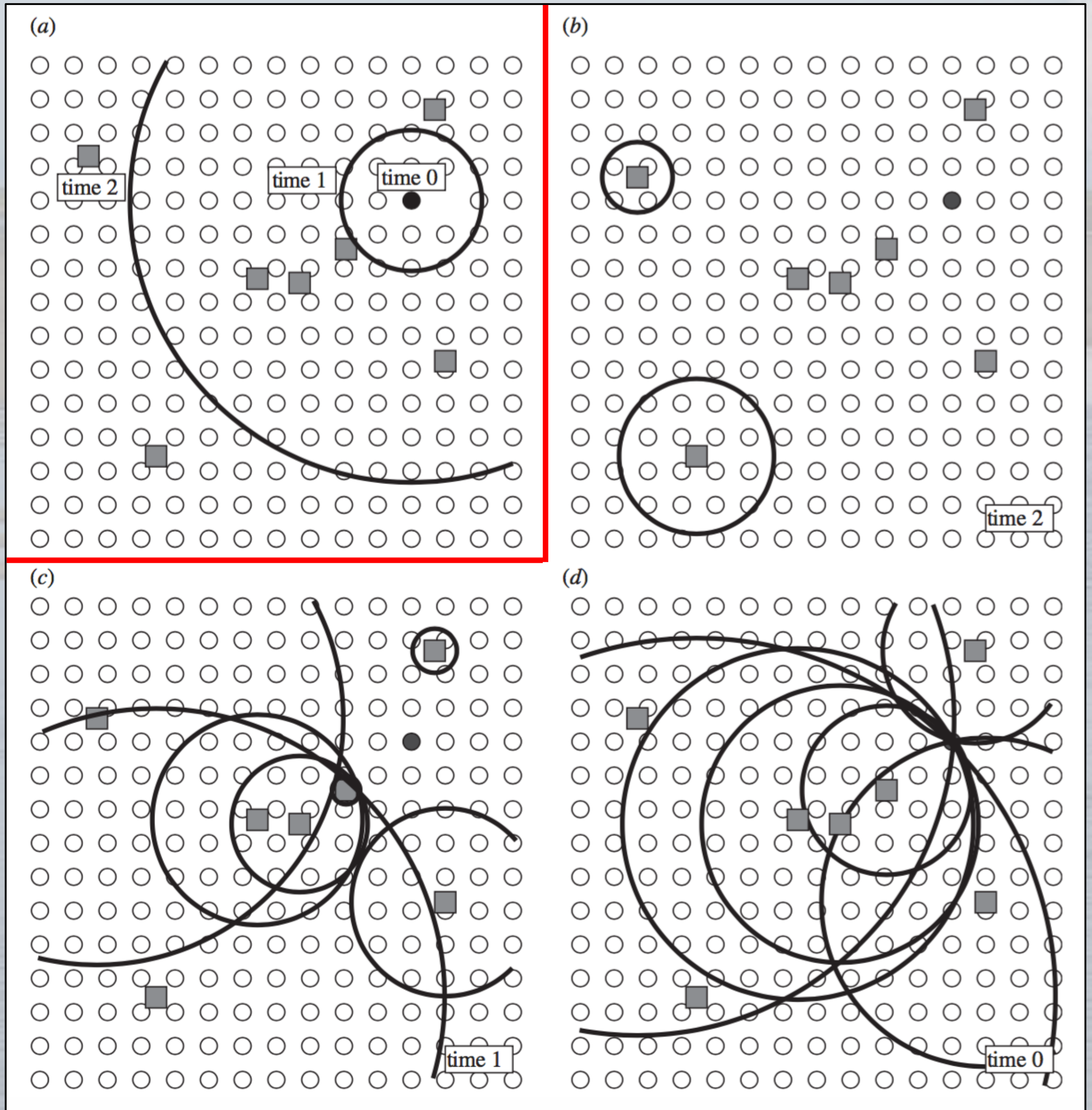
3. Alternate back-projection strategies which may reducing ‘swimming’ (*Meng et al., 2012; Koper et al., 2012*).

4. Incorporating methods that give directional information, e.g., frequency-wavenumber analysis, array meshes (*de Groot-Hedlin and Hedlin, 2015*).

EXTRA SLIDES

Reverse time migration (RTM):

Hedlin and Walker, 2013



Back-projection methods:

Time-domain:

- Linear stacking
- Nth-root stacking
- Semblance
- F-stacking
- Correlation stacking
- Coherence stacking
- STA/LTA stacking

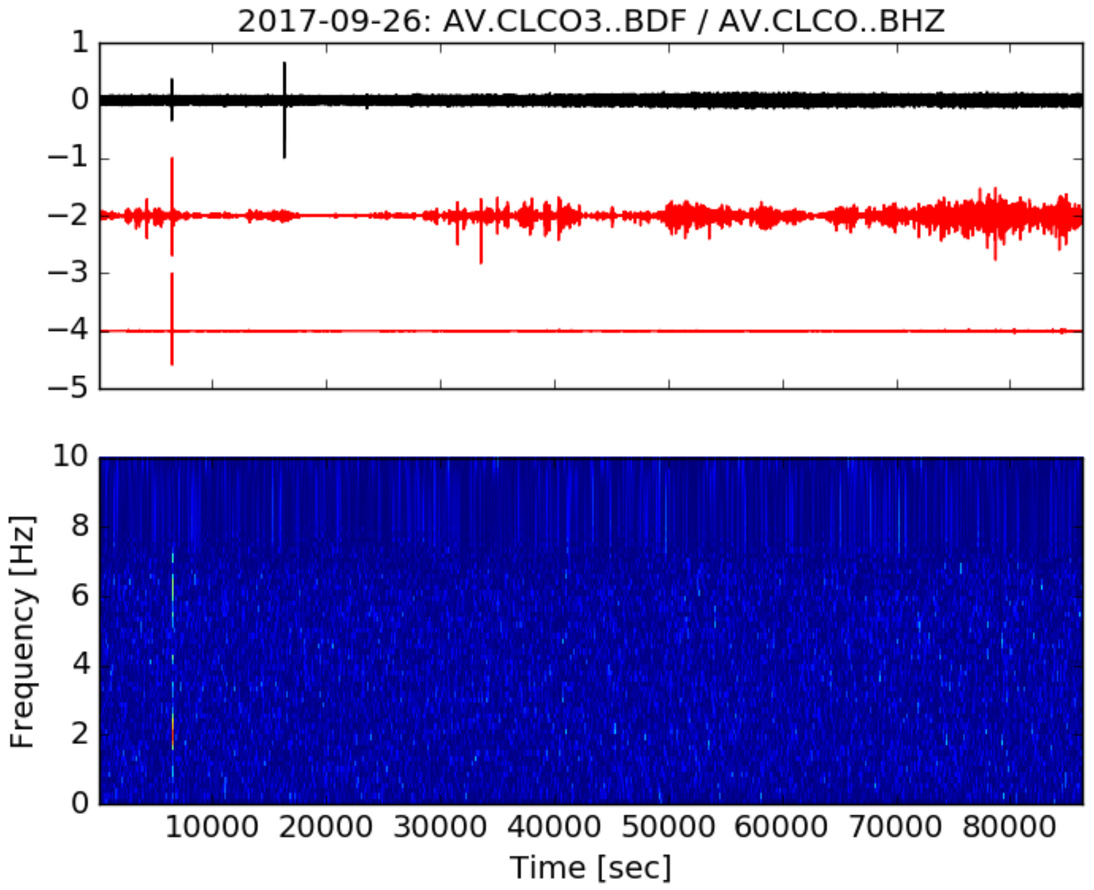
Combined approaches :

- AELUMA (Automated Event Location Using a Mesh of Arrays)

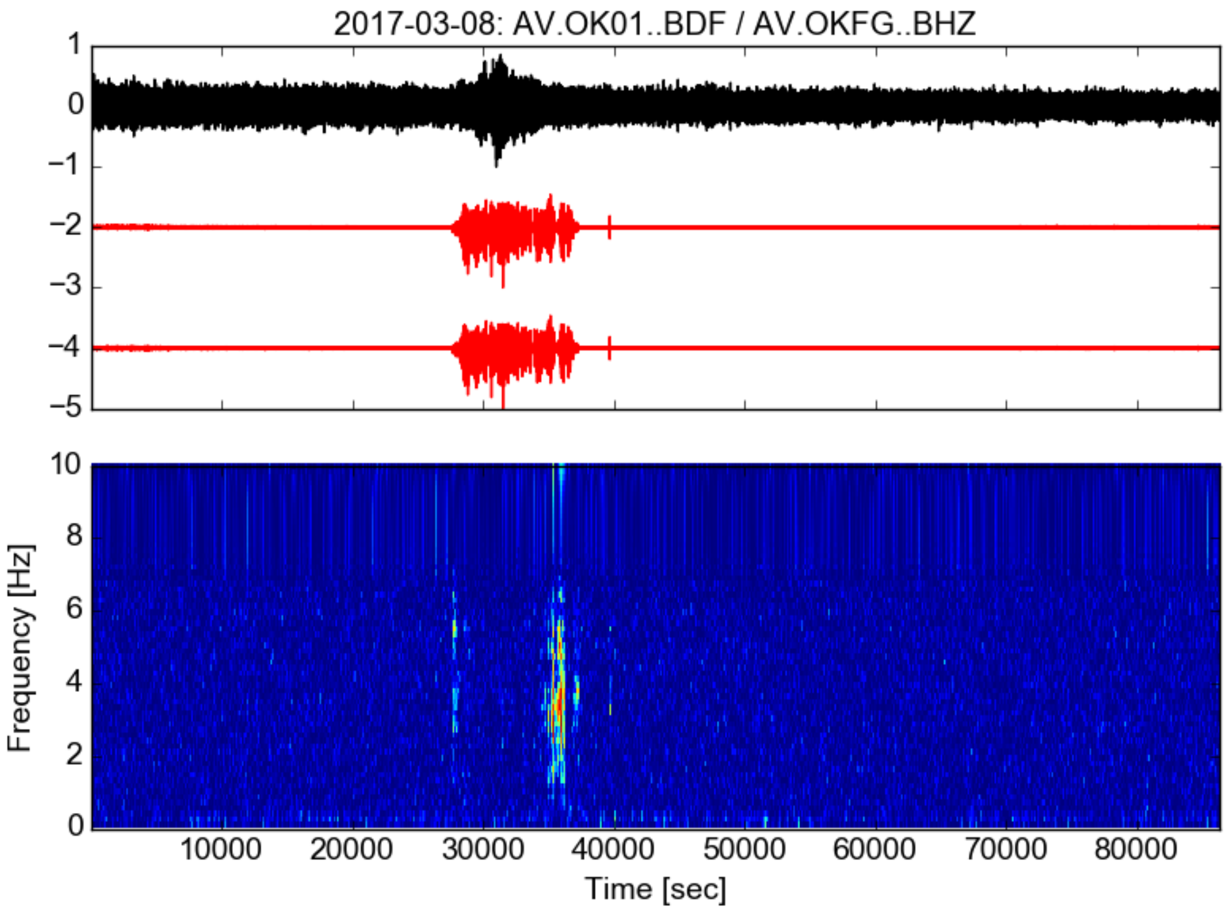
Frequency domain:

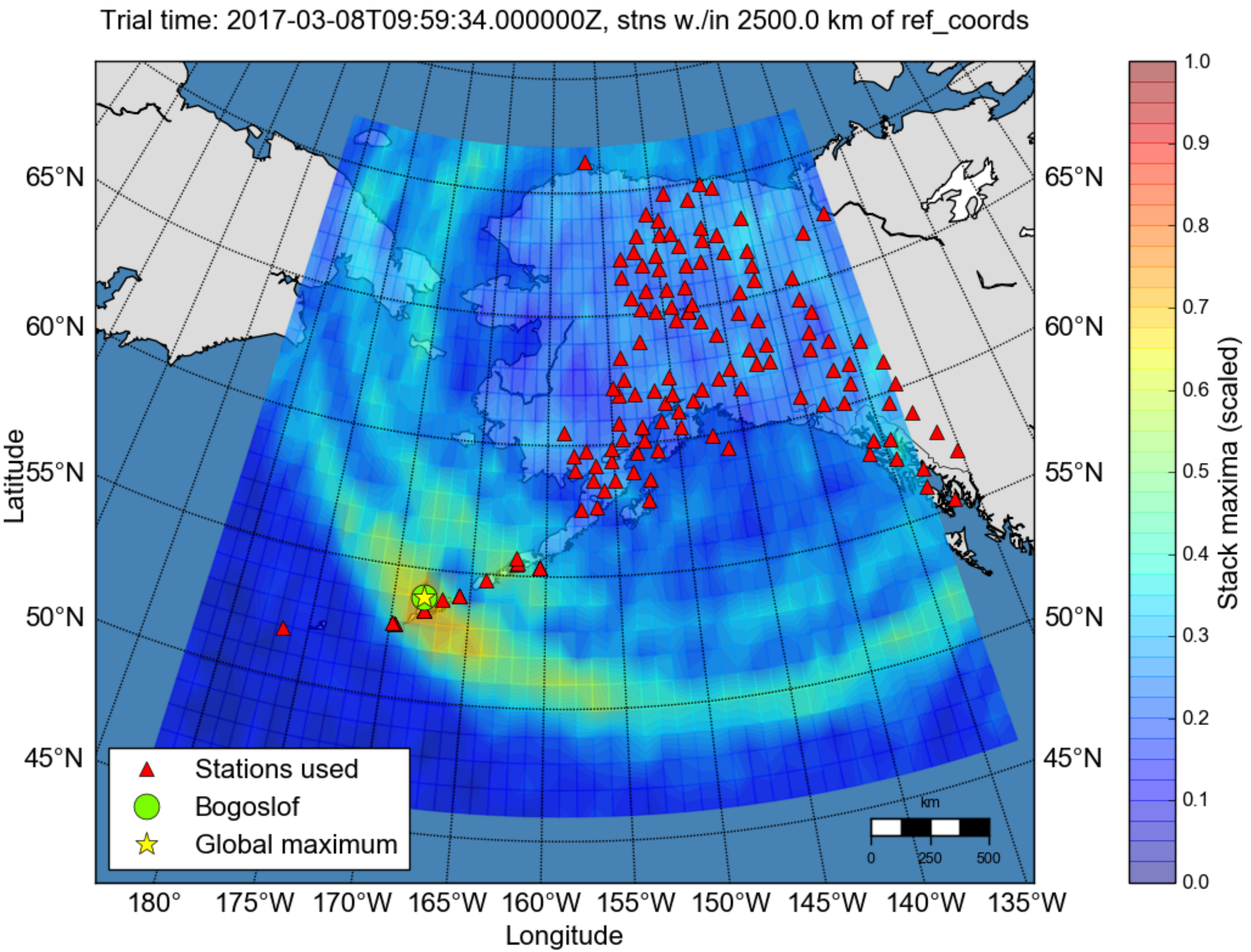
- Spectral STA/LTA stacking
- Frequency-wavenumber (F-K) analysis
    - Multitaper MUSIC (multiple signal classification)

Cleveland

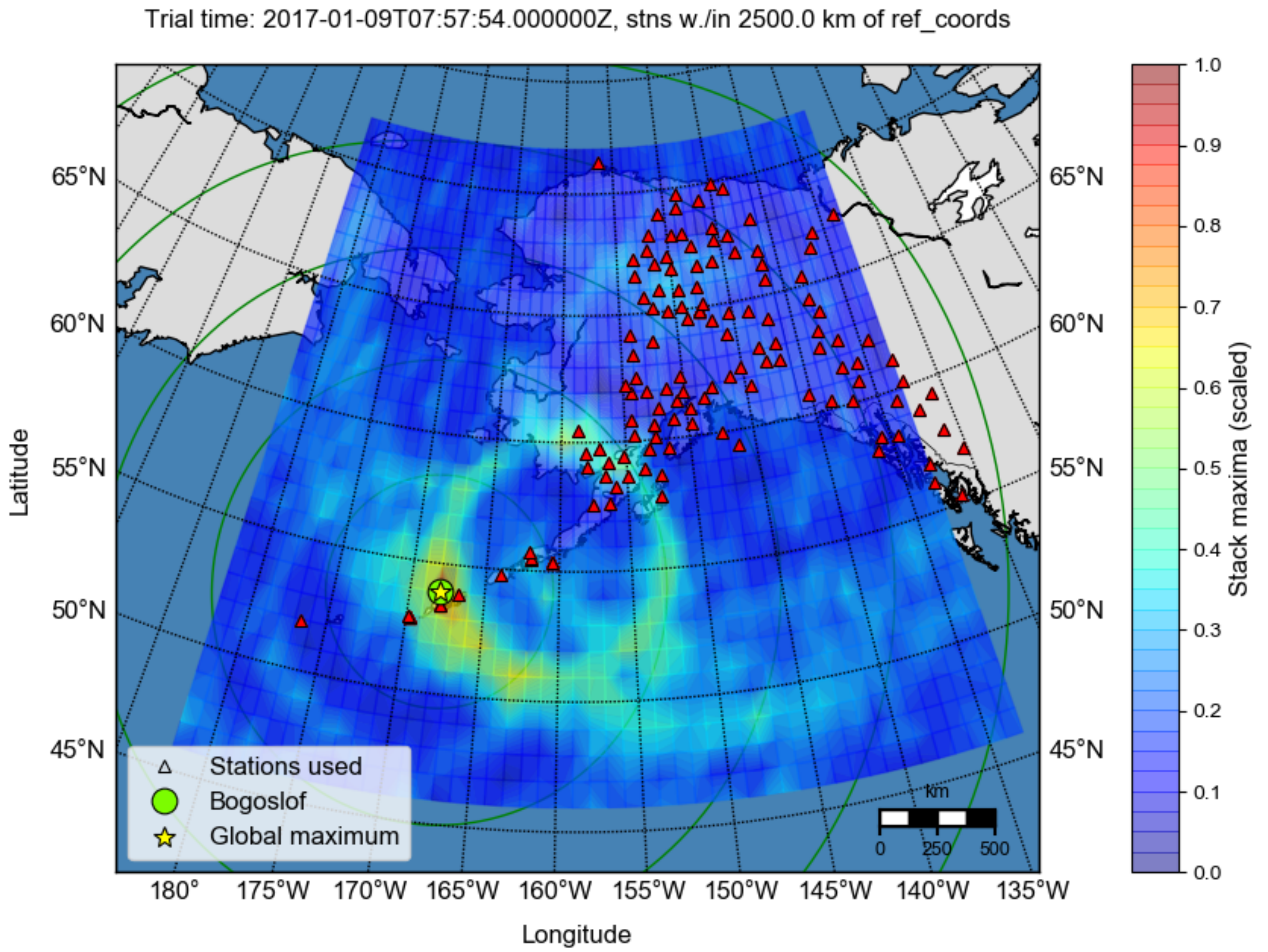


Bogoslof

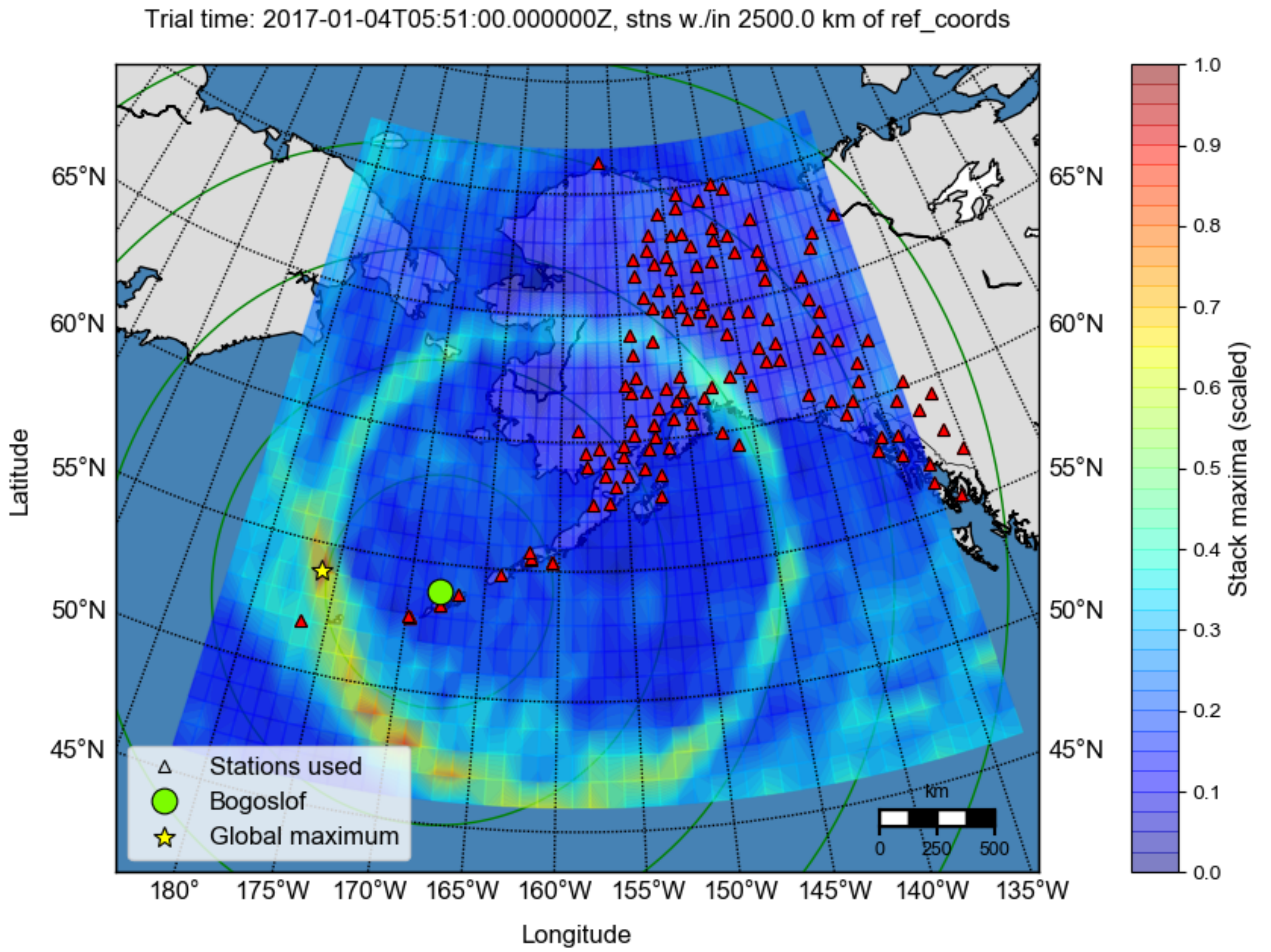




Trial time: 2017-03-08T09:59:34.000000Z, stns w./in 2500.0 km of ref_coords
65°N
60°N
55°N
50°N
45°N
Latitude
180°
175°W
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
Longitude
Stations used
Bogoslof
Global maximum
km
0
250
500
Stack maxima (scaled)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

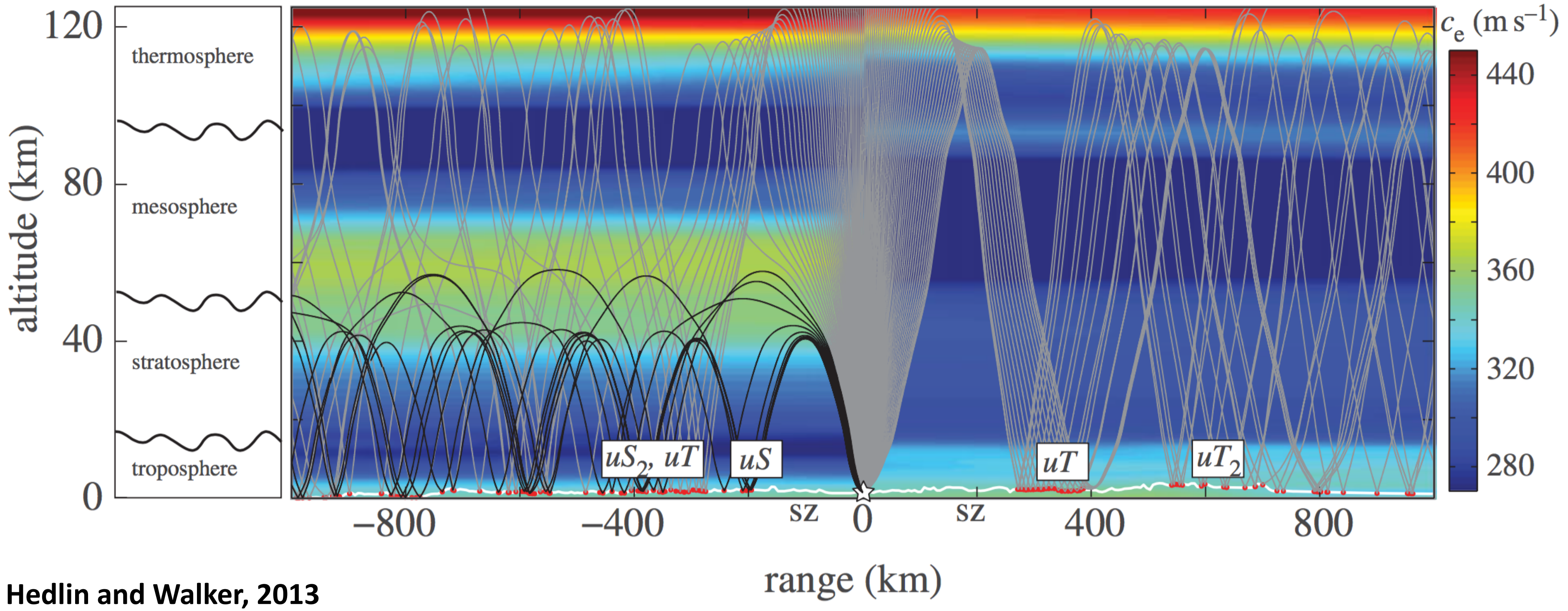


Trial time: 2017-01-09T07:57:54.000000Z, stns w./in 2500.0 km of ref_coords
65°N
60°N
55°N
50°N
45°N
Latitude
180°
175°W
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
Longitude
Stations used
Bogoslof
Global maximum
km
0
250
500
Stack maxima (scaled)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0



Trial time: 2017-01-04T05:51:00.000000Z, stns w./in 2500.0 km of ref_coords
65°N
60°N
55°N
50°N
45°N
Latitude
180°
175°W
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
Longitude
Stations used
Bogoslof
Global maximum
km
0
250
500
Stack maxima (scaled)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

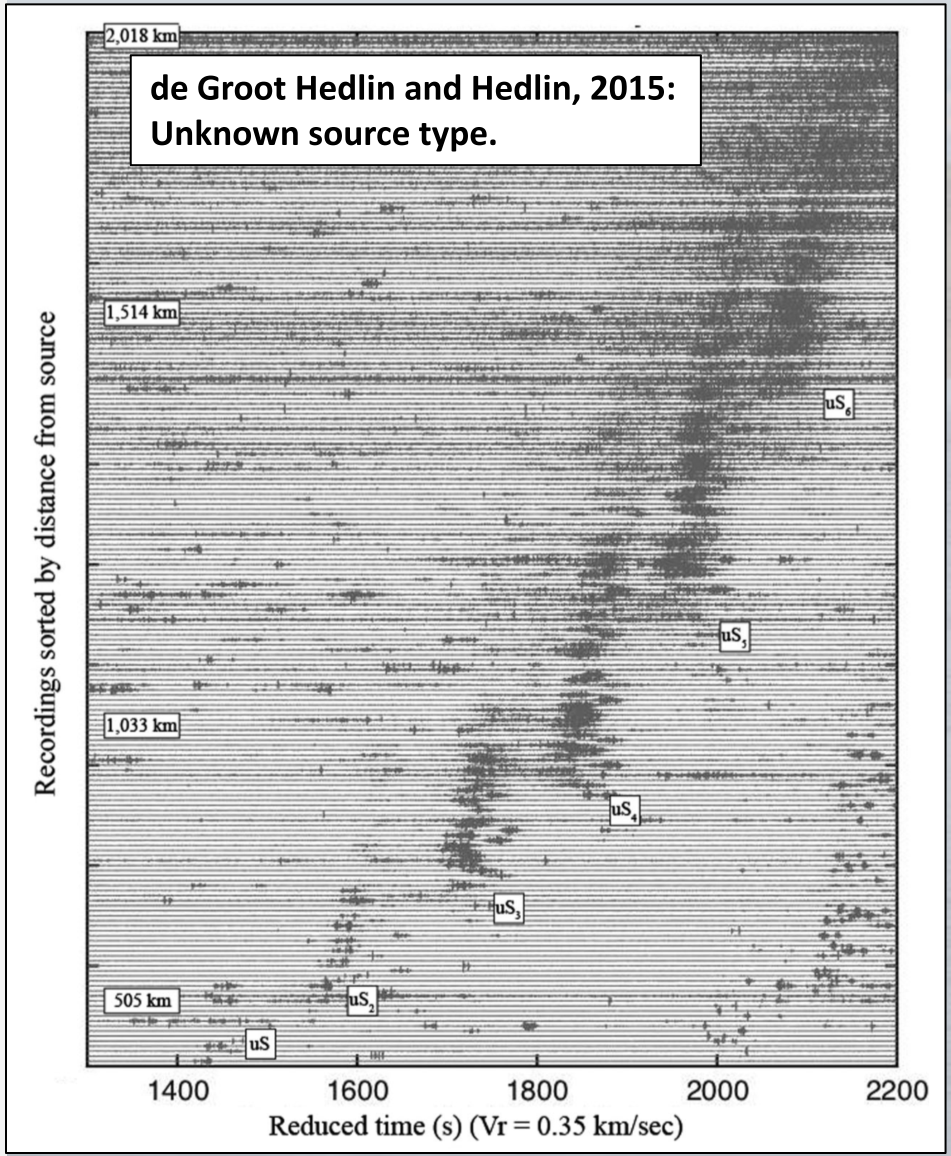
Atmosphere’s velocity structure:

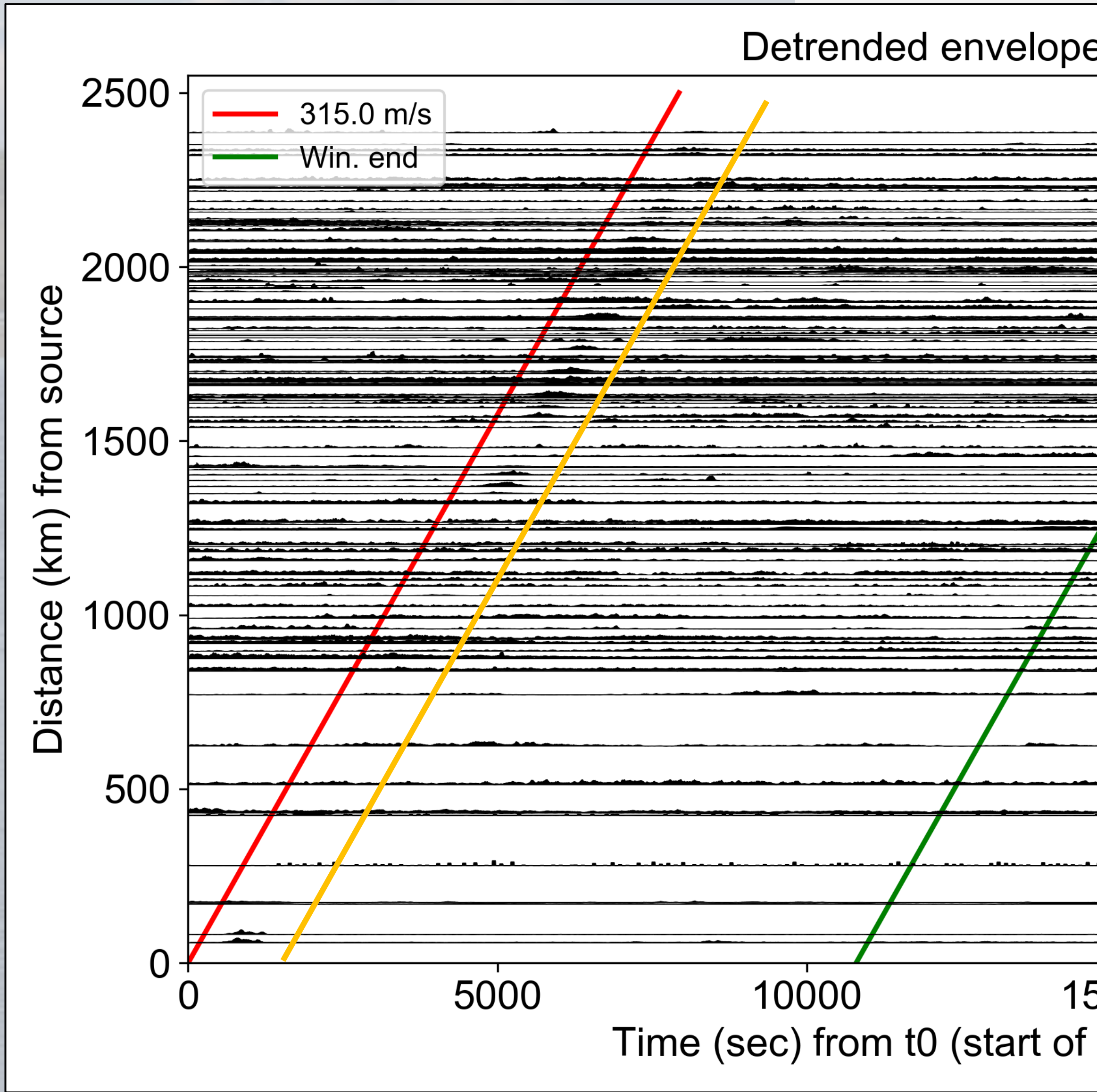


Hedlin and Walker, 2013

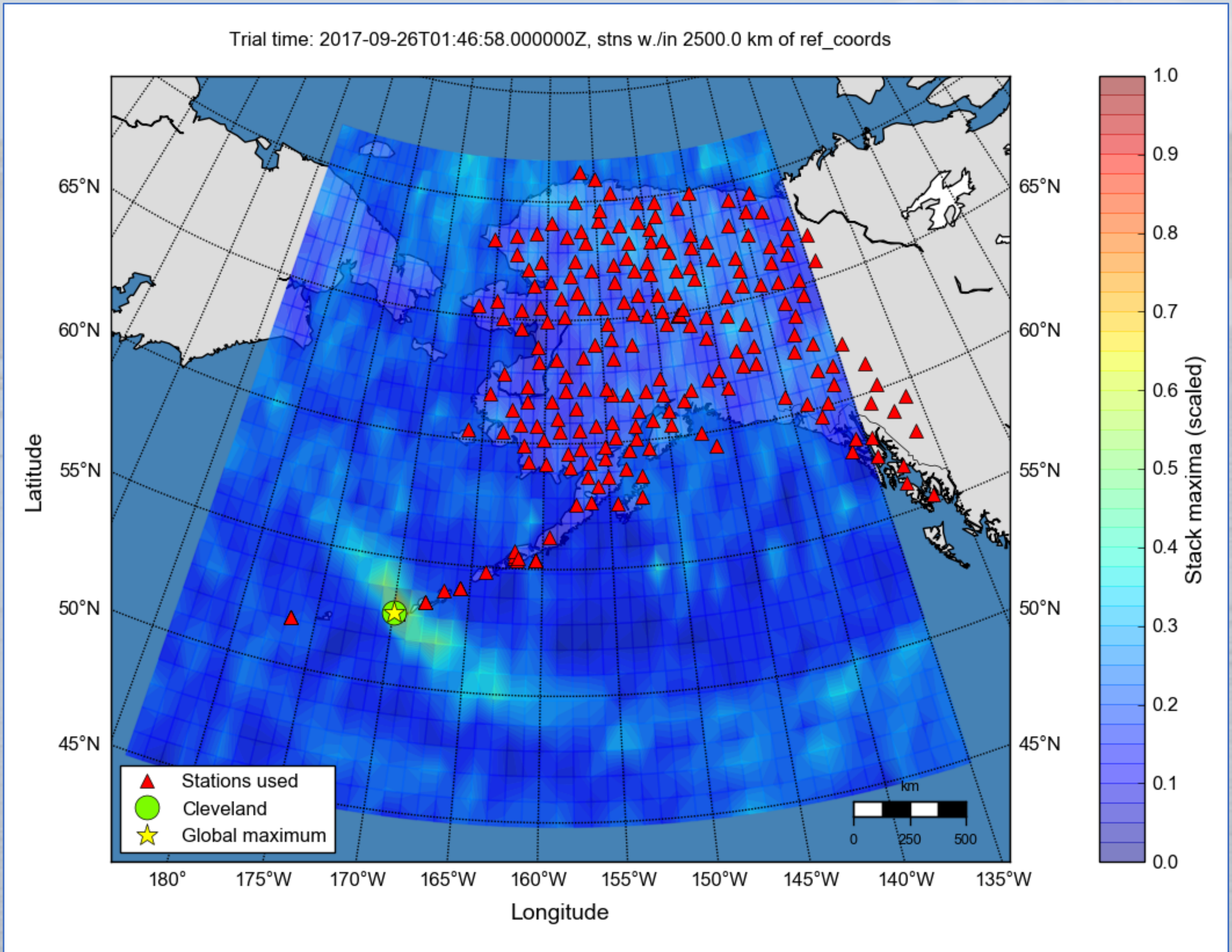
Wind direction

Atmospheric structure: branching

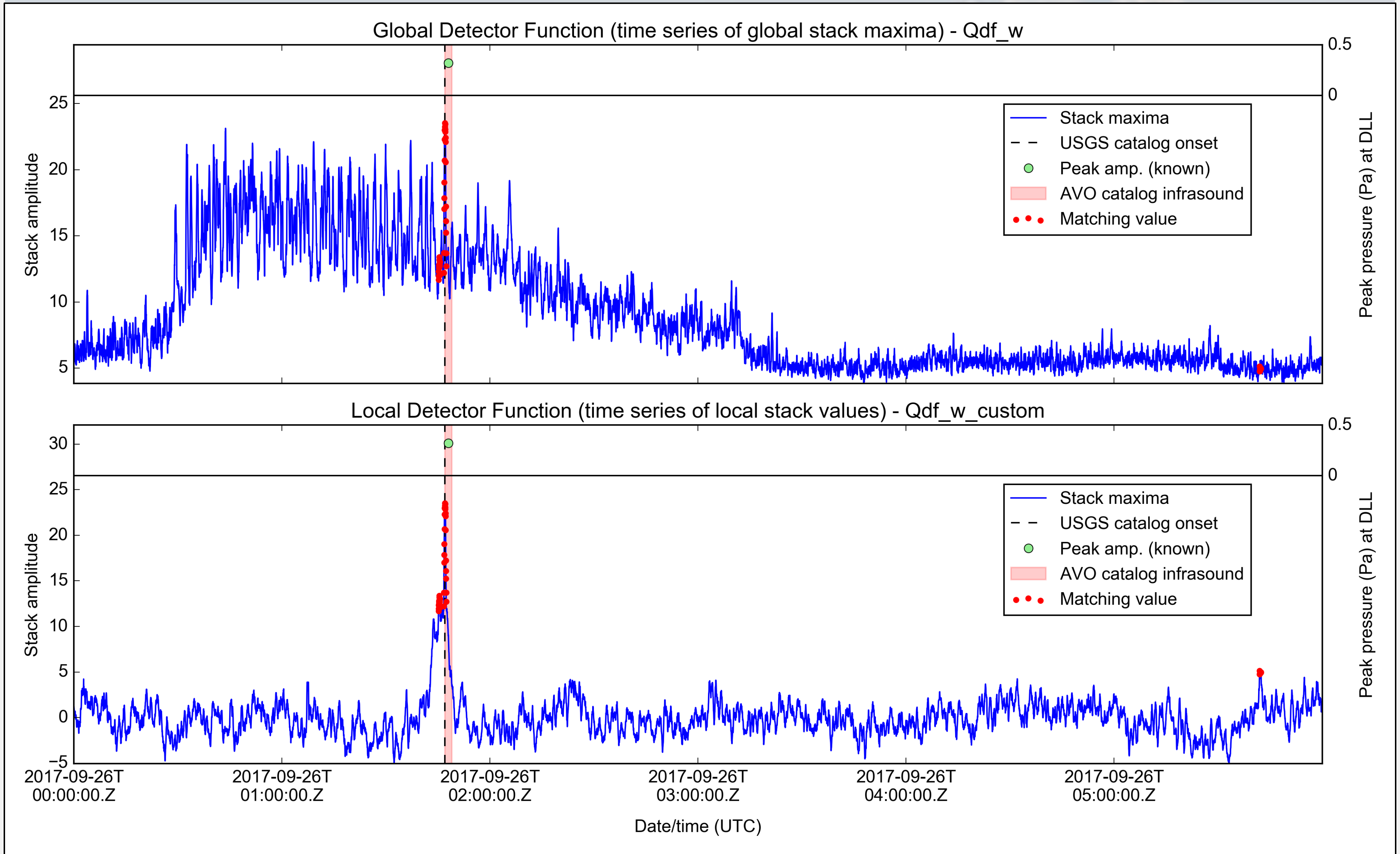


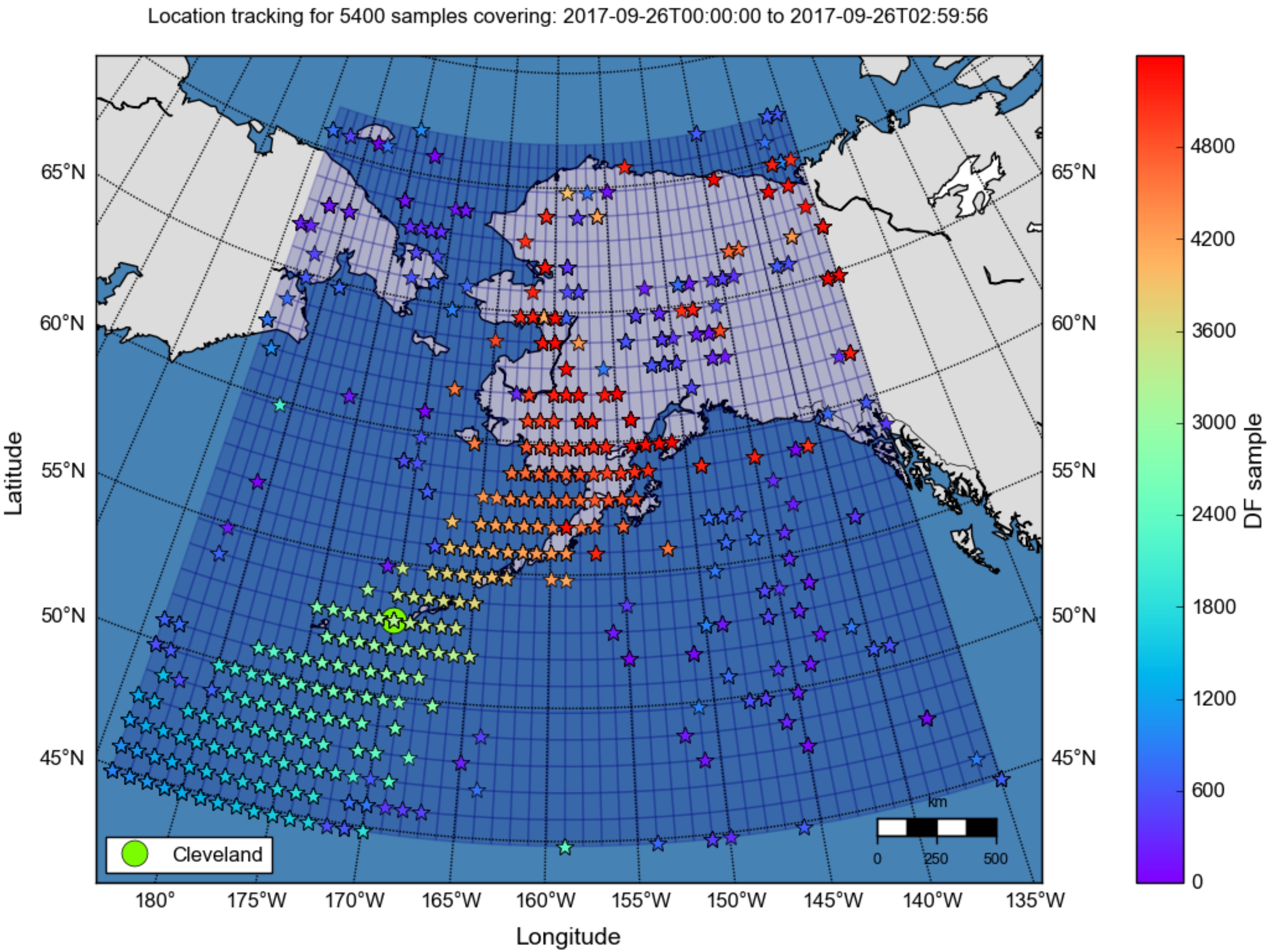


Network geometry



Close-up DF example (Cleveland)




Location tracking for 5400 samples covering: 2017-09-26T00:00:00 to 2017-09-26T02:59:56
Latitude
Longitude
65°N
60°N
55°N
50°N
45°N
180°
175°W
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
Cleveland
km
0
250
500
DF sample
0
600
1200
1800
2400
3000
3600
4200
4800

Synthetic example (at Cleveland)