First results with the BRAMS interferometer & calibration tests

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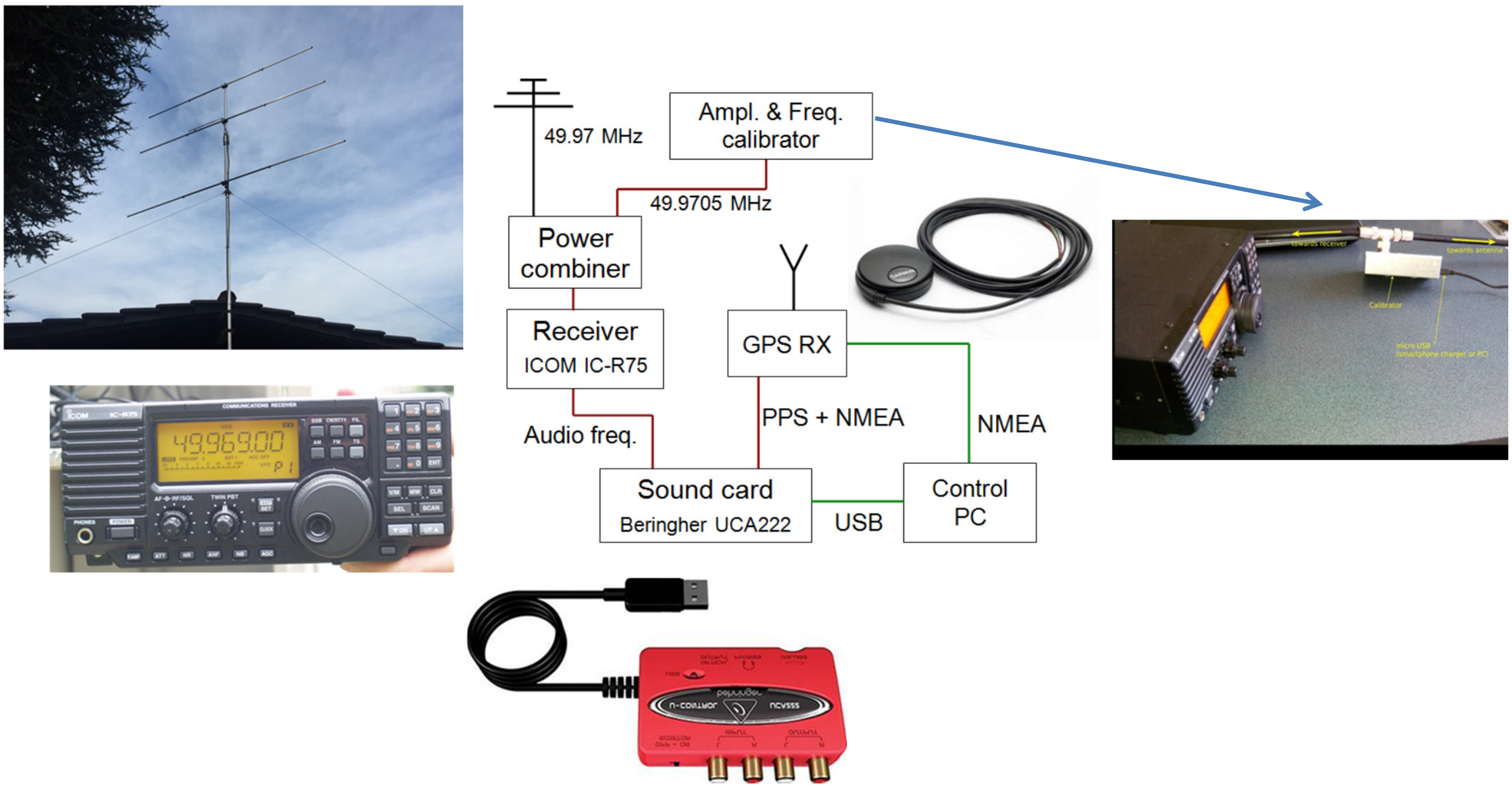
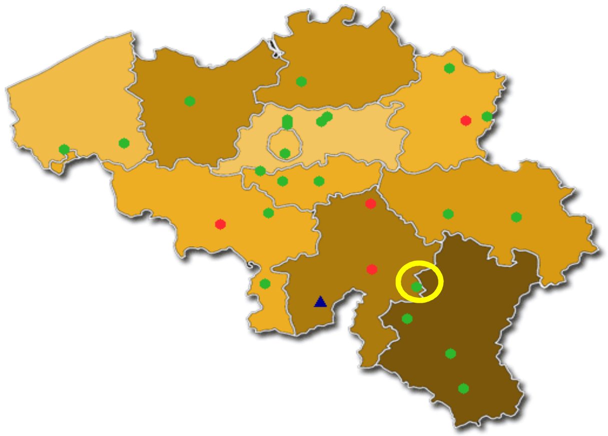
METRO annual meeting 2017

Typical BRAMS receiving station

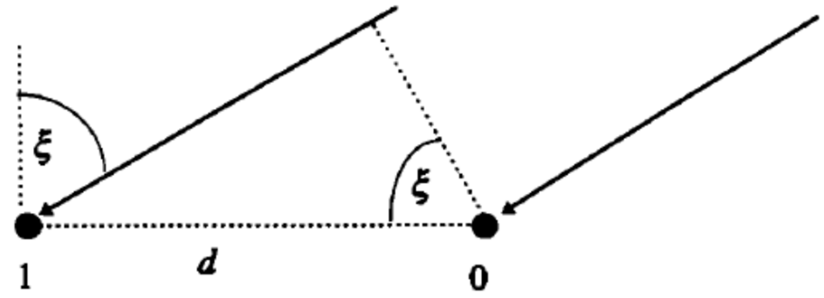


The interferometer in Humain



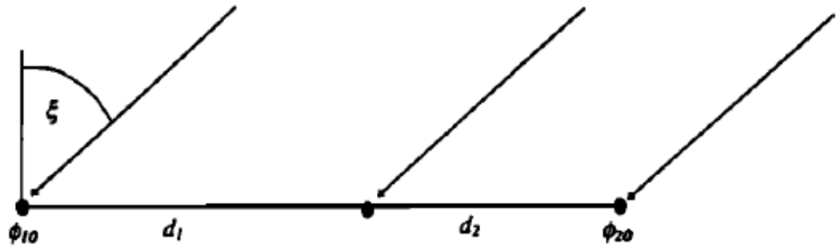
Credit : A. Martinez-Picar

Principle



$$\phi_{10} = -2\pi \frac{d}{\lambda} \sin \xi$$

Jones et al (1998)



$$\phi_{10} = -\frac{2\pi d_1}{\lambda} \sin \xi$$

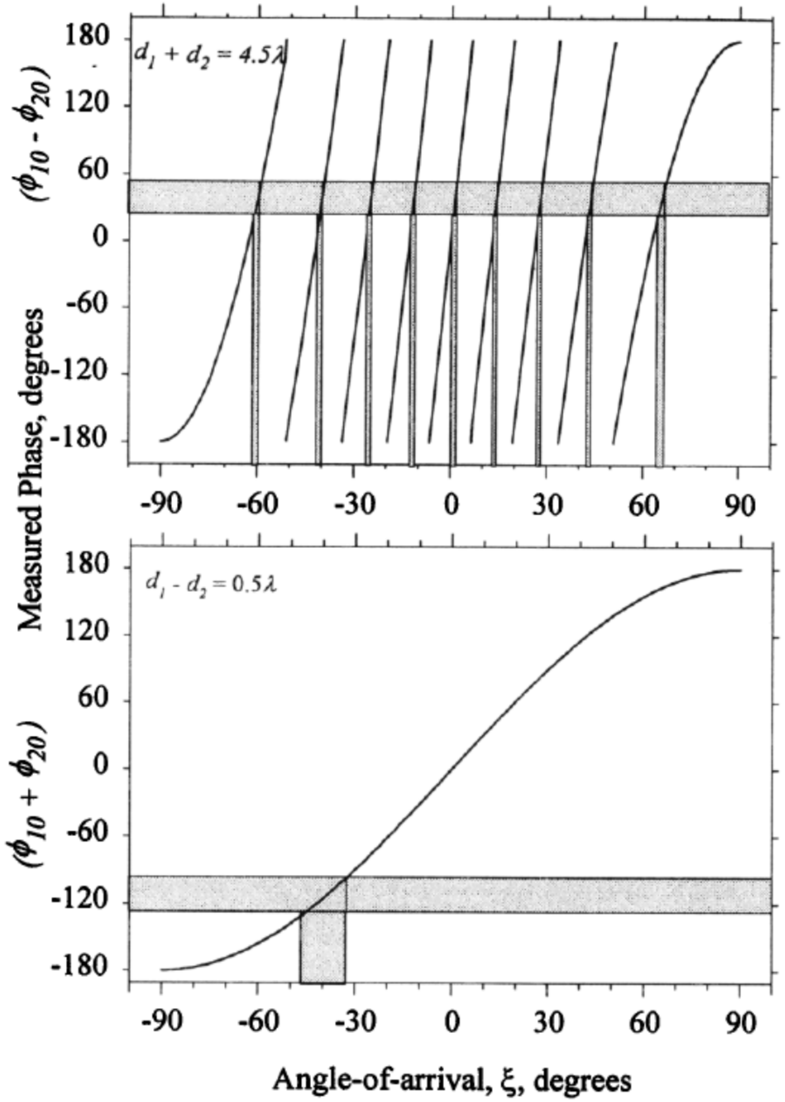
$$\phi_{20} = +\frac{2\pi d_2}{\lambda} \sin \xi$$

$$\sin \xi = -\frac{\lambda}{2\pi} \frac{(\phi_{10} - \phi_{20})}{(d_1 + d_2)}$$

$$\sin \xi = -\frac{\lambda}{2\pi} \frac{(\phi_{10} + \phi_{20})}{(d_1 - d_2)}$$

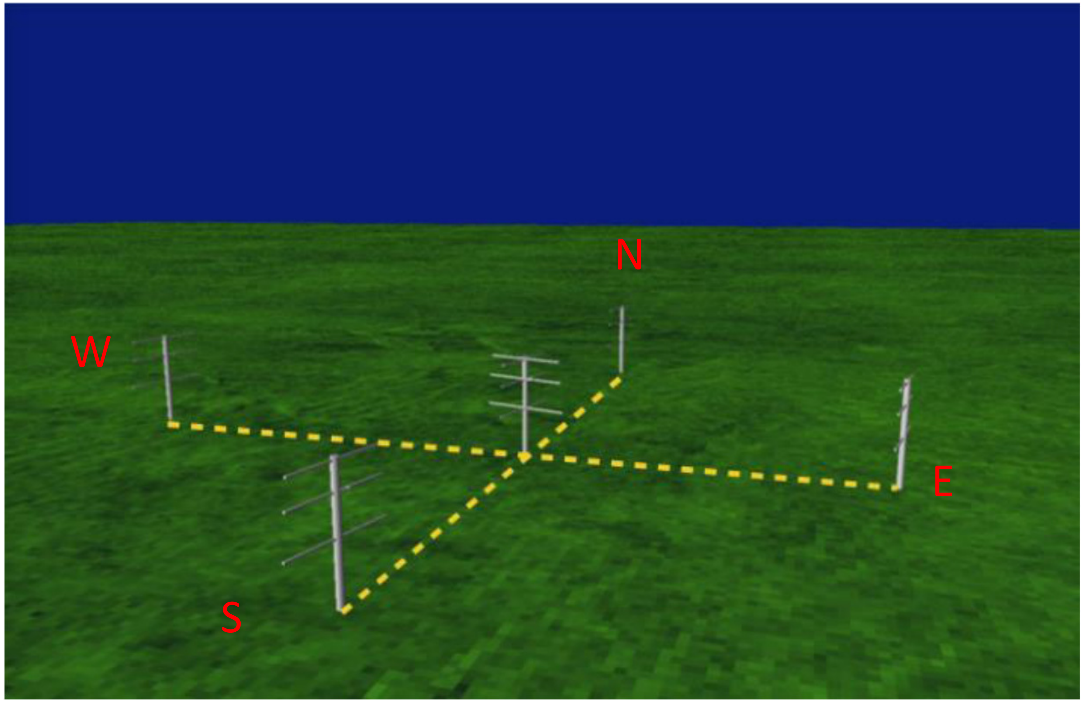
$d_1 = 2.5\ \lambda$
$d_2 = 2\ \lambda$

Principle (2)



Jones et al (1998)

Principle (3)



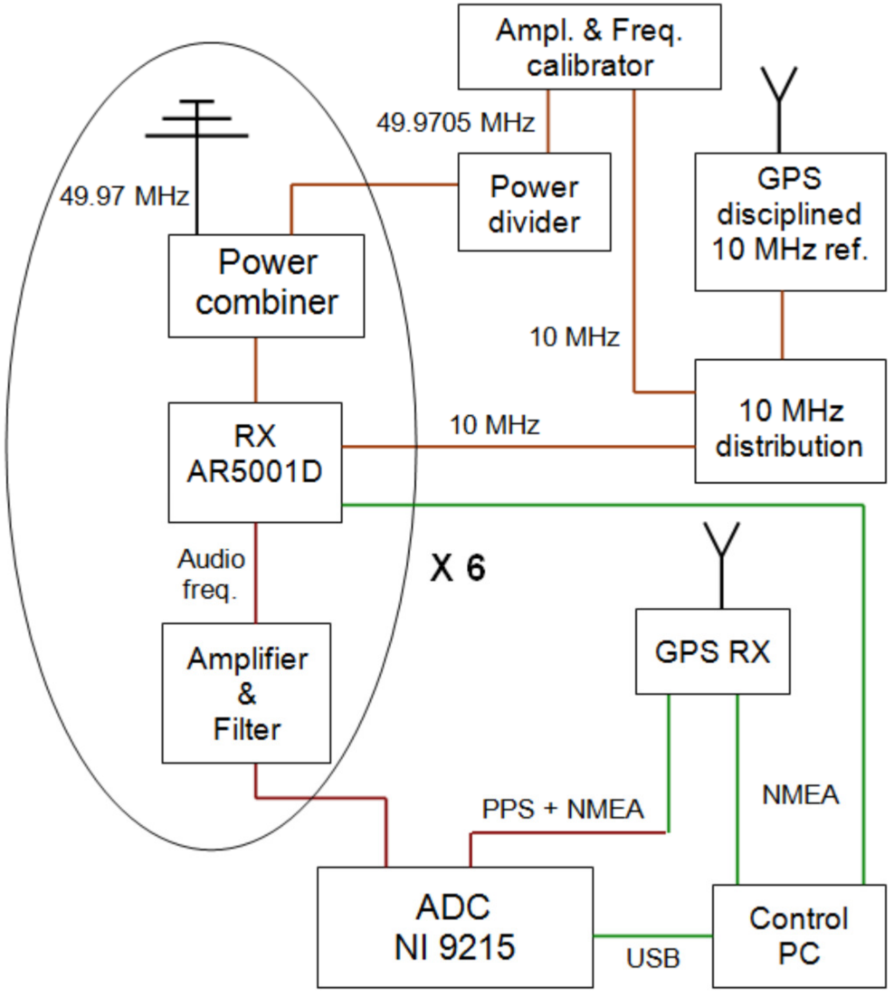
Angles of arrival

$$\beta = \tan^{-1}\left(\frac{\cos \xi_2}{\cos \xi_1}\right)$$

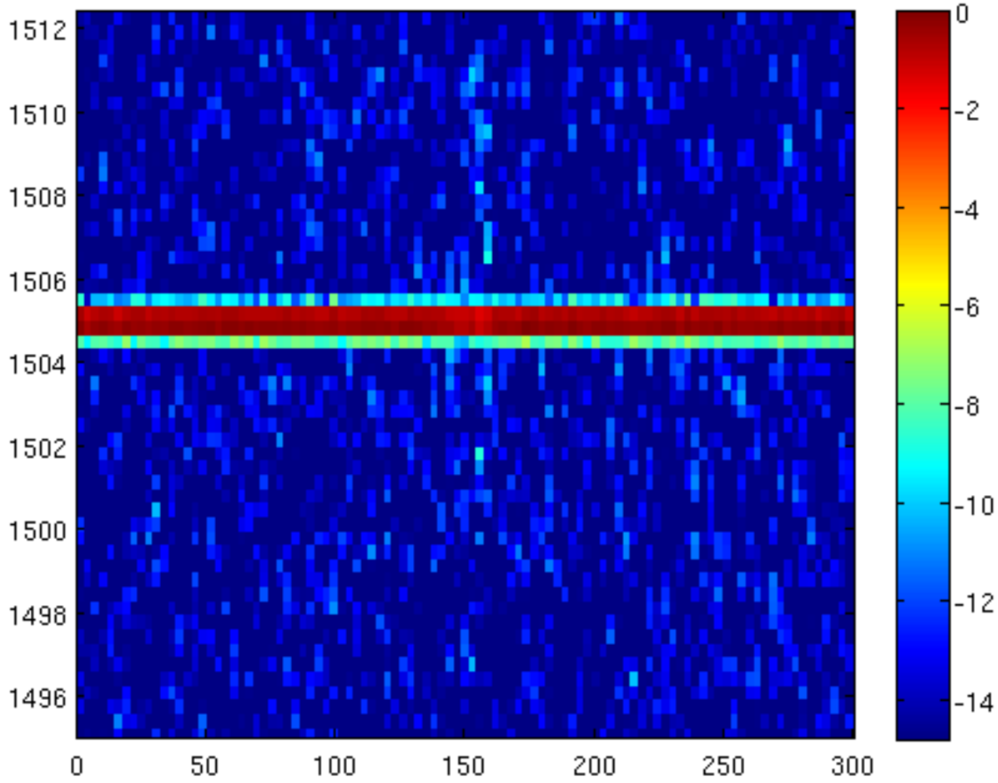
$$\alpha = \cos^{-1}\left(\frac{\cos \xi_2}{\cos \beta}\right) = \cos^{-1}\left(\frac{\cos \xi_1}{\cos \beta}\right)$$

α : elevation β : azimuth (measured from North toward East)

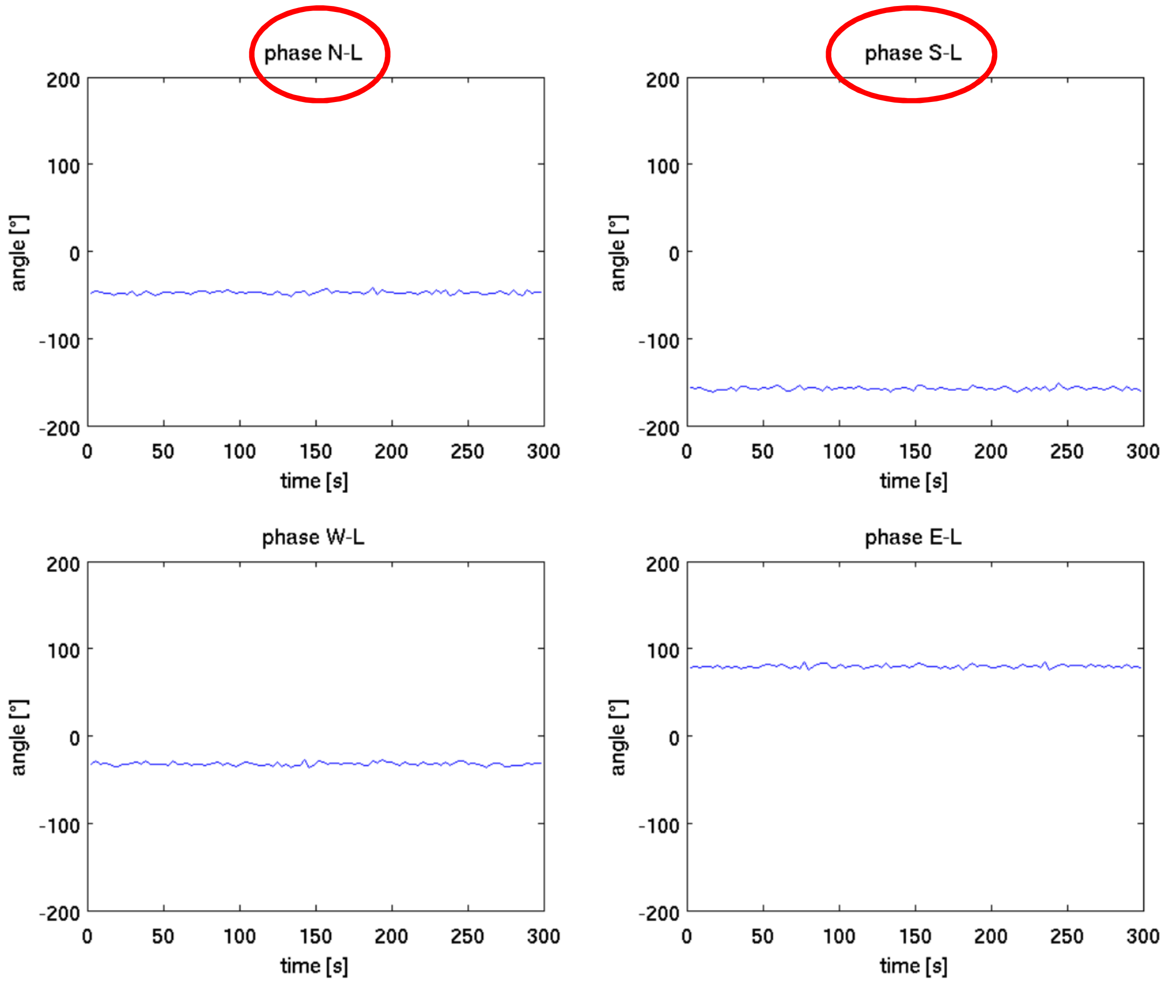
Design of the interferometer



Tests with the BRAMS calibrator

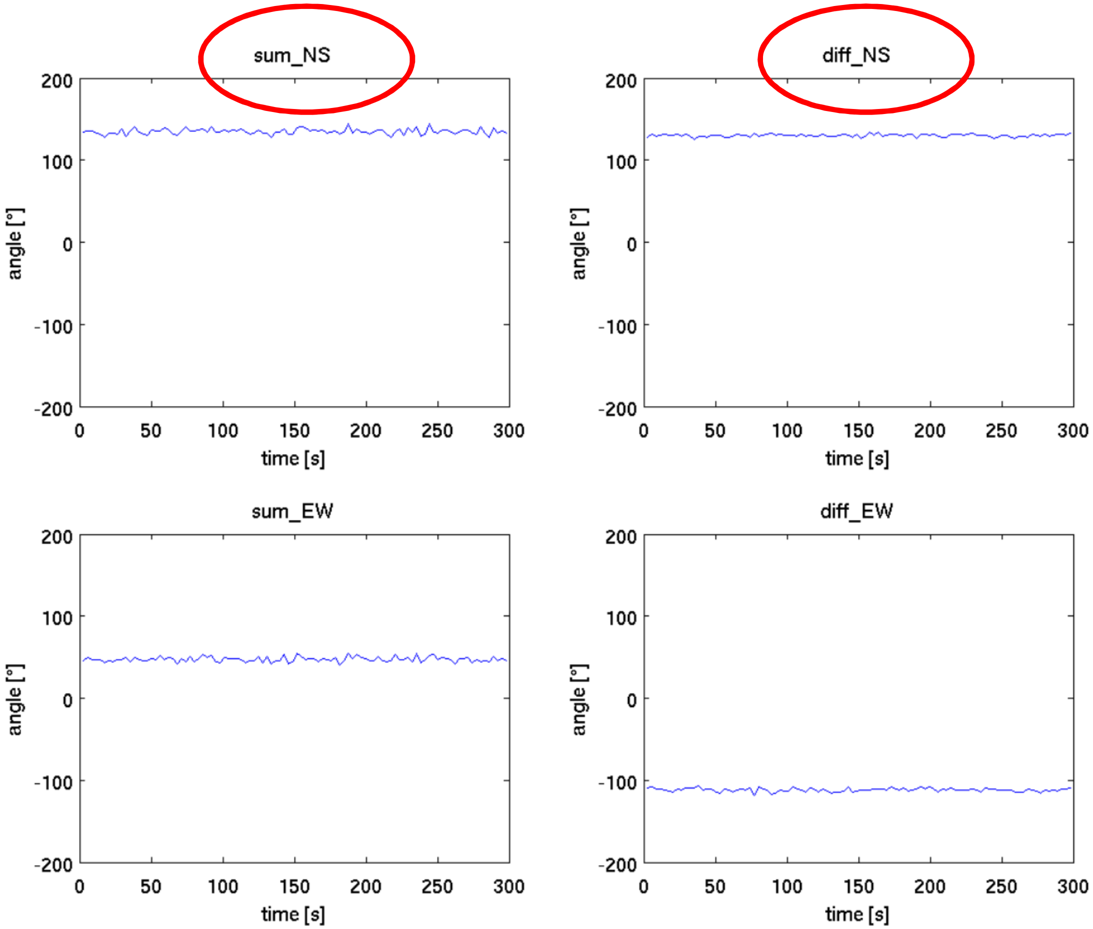


NFFT = 16384 - Overlap = 0%



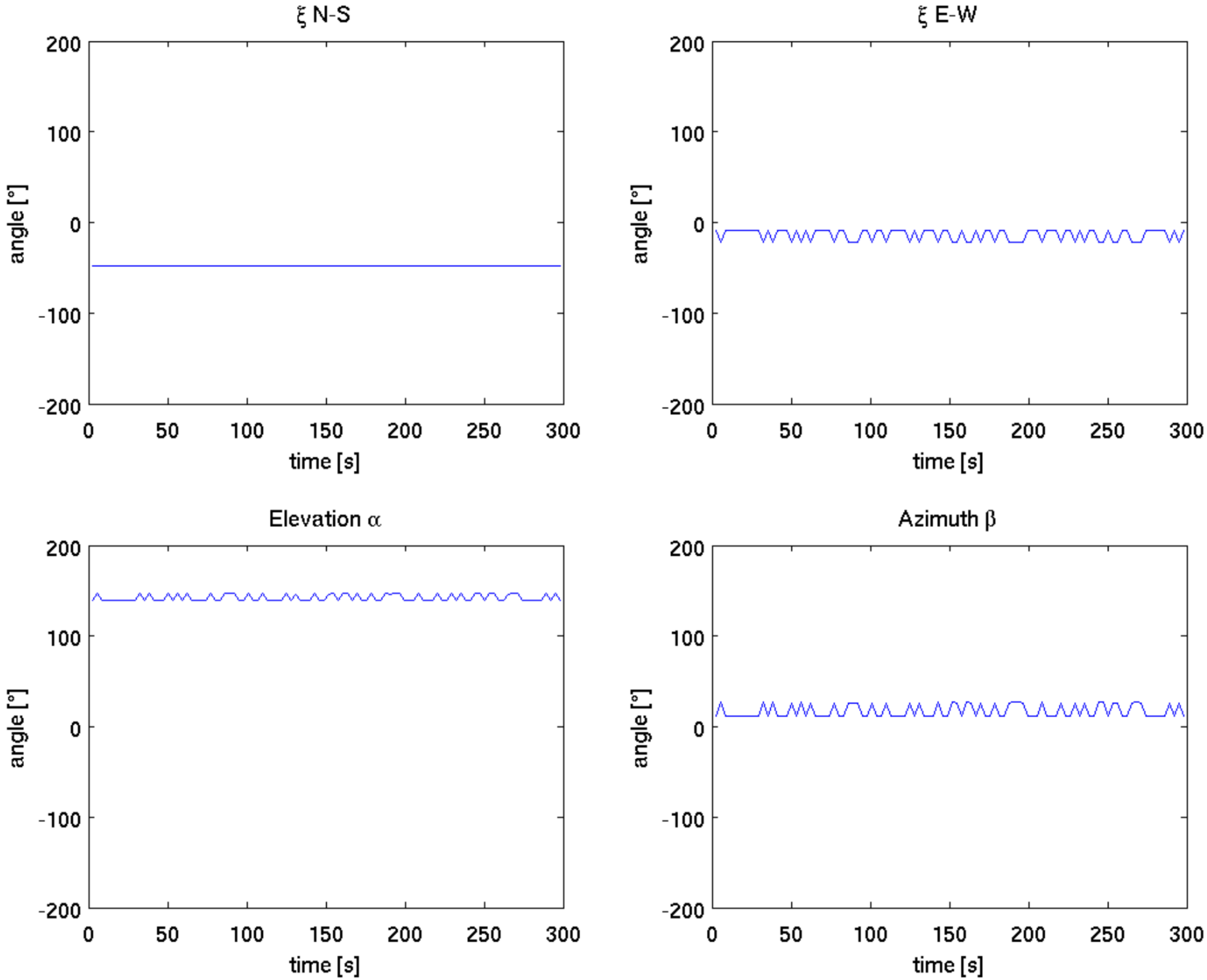
$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10} + \phi_{20})}{(d_1 + d_2)}$$

$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10} + \phi_{20})}{(d_1 - d_2)}$$



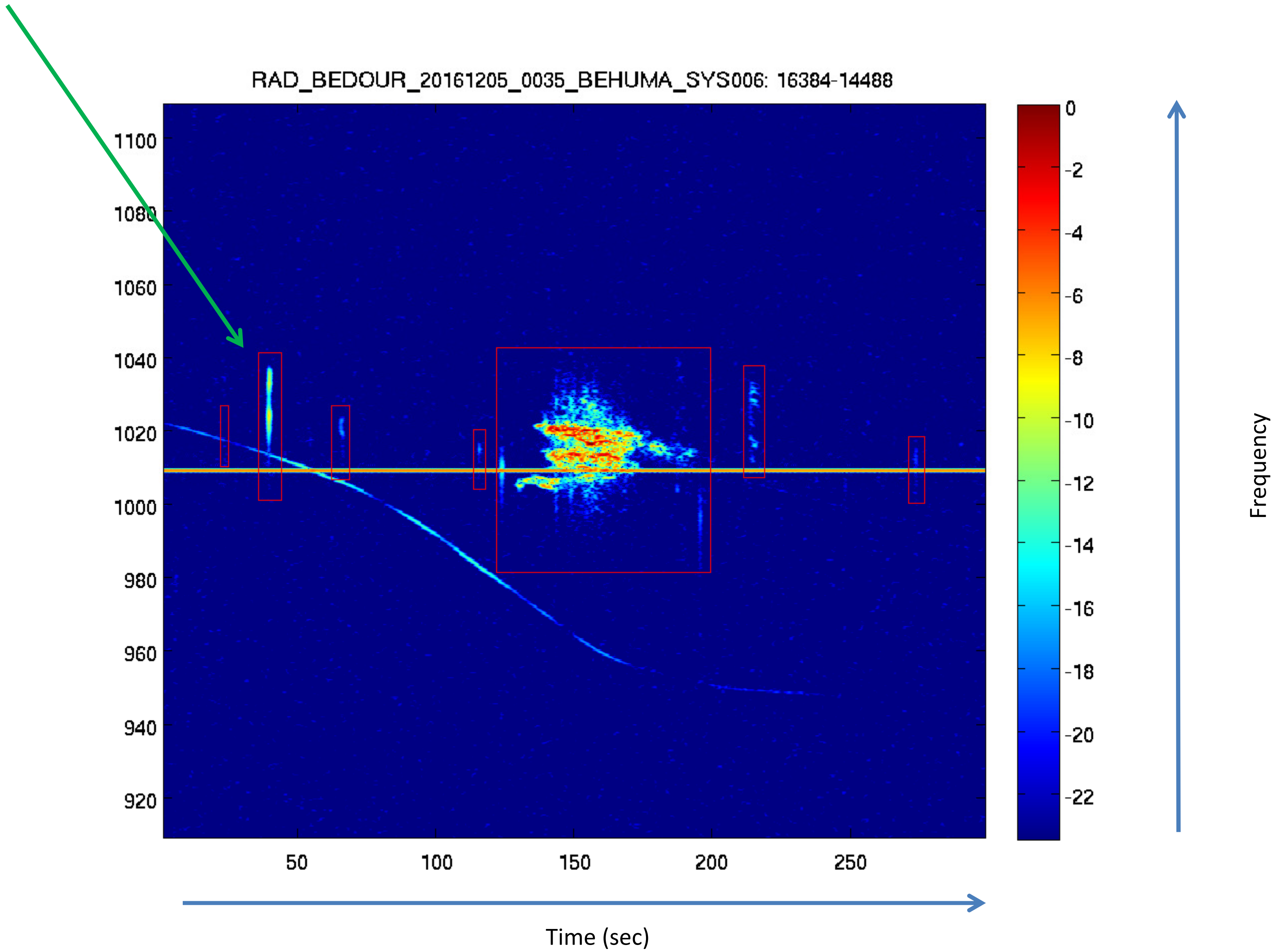
$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10}-\phi_{20})}{(d_1+d_2)}$$

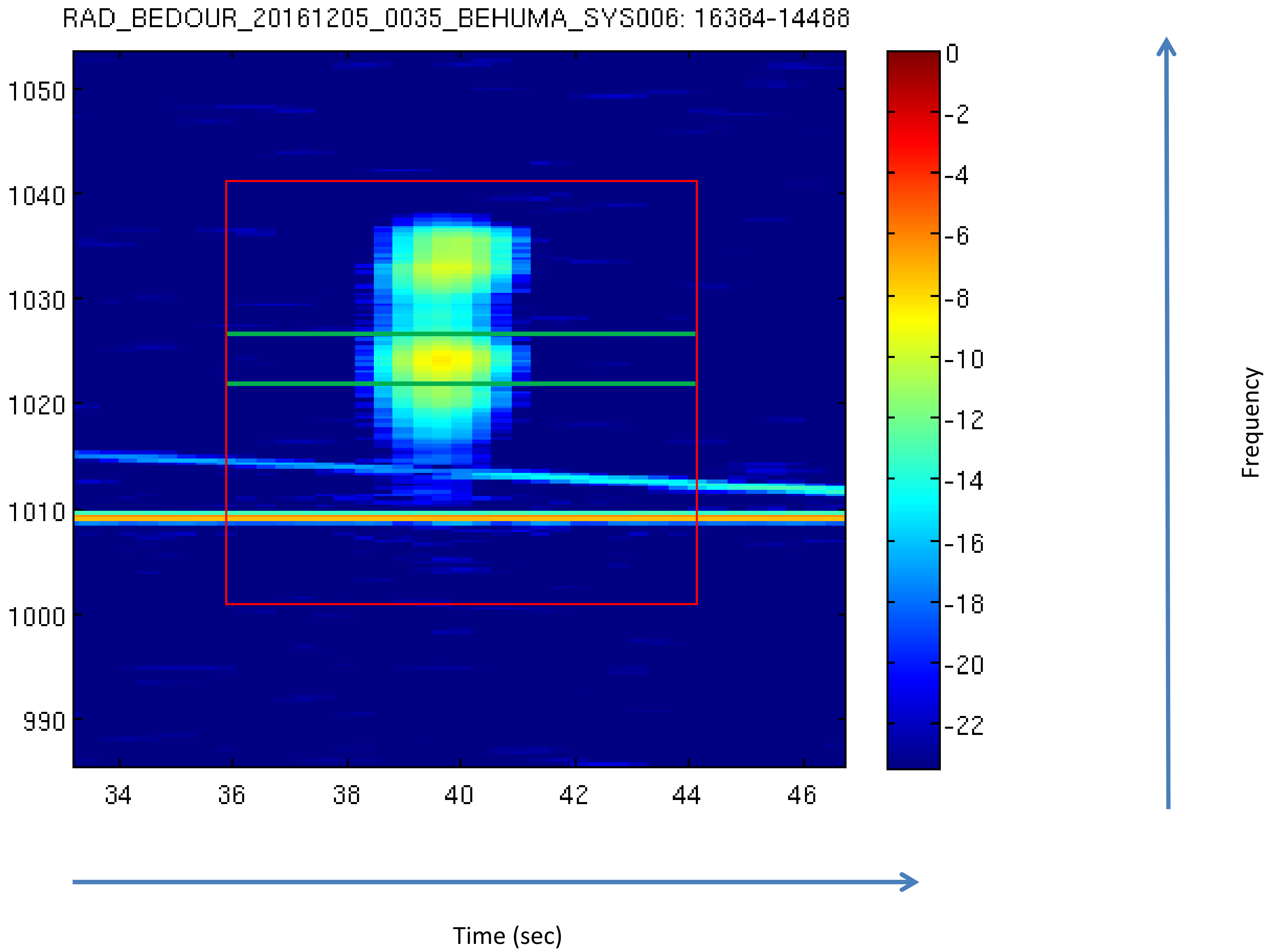
$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10}+\phi_{20})}{(d_1-d_2)}$$



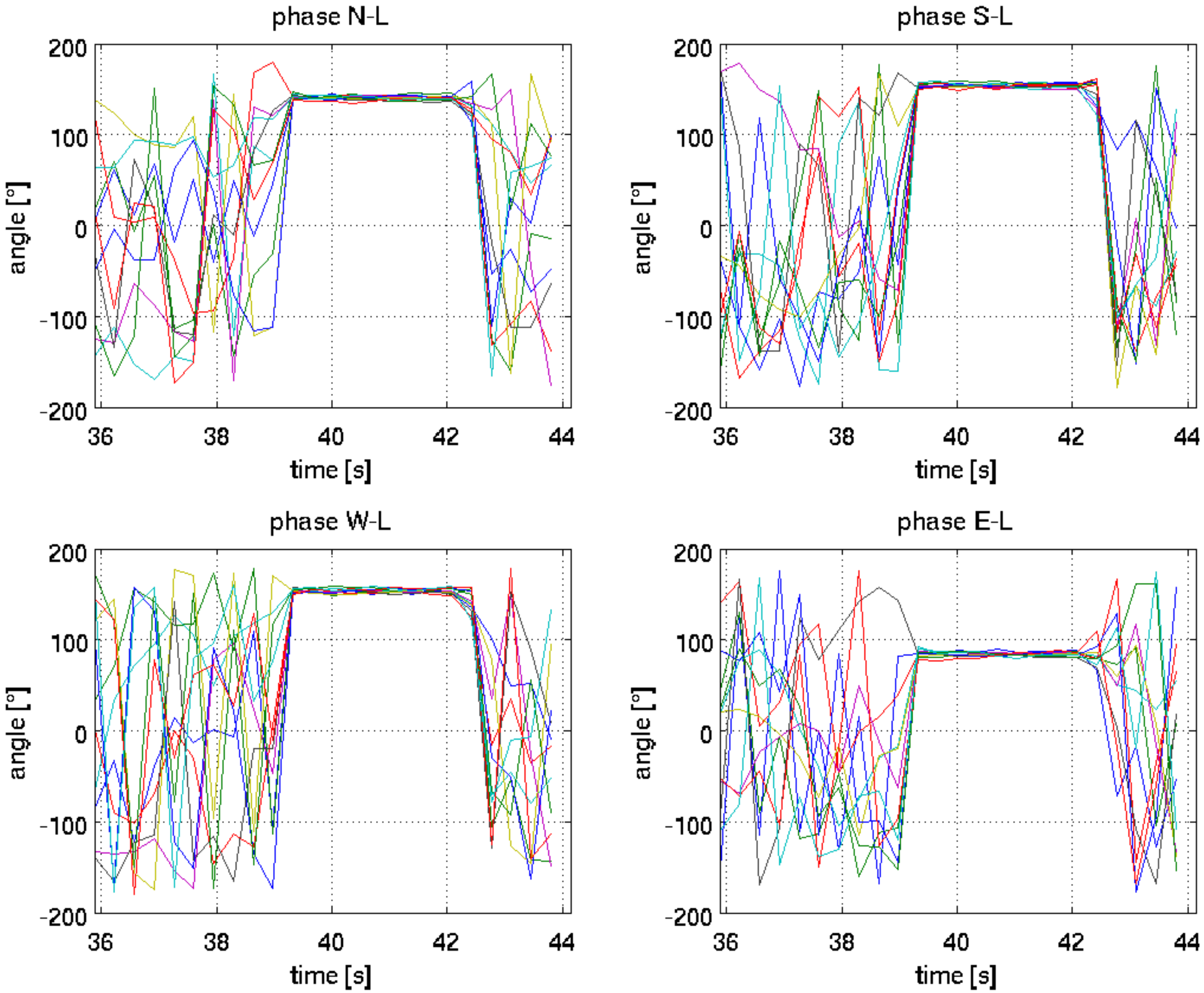
ξ N-S
ξ E-W
Elevation α
Azimuth β
angle [°]
time [s]
200
100
0
-100
-200
0
50
100
150
200
250
300

First example



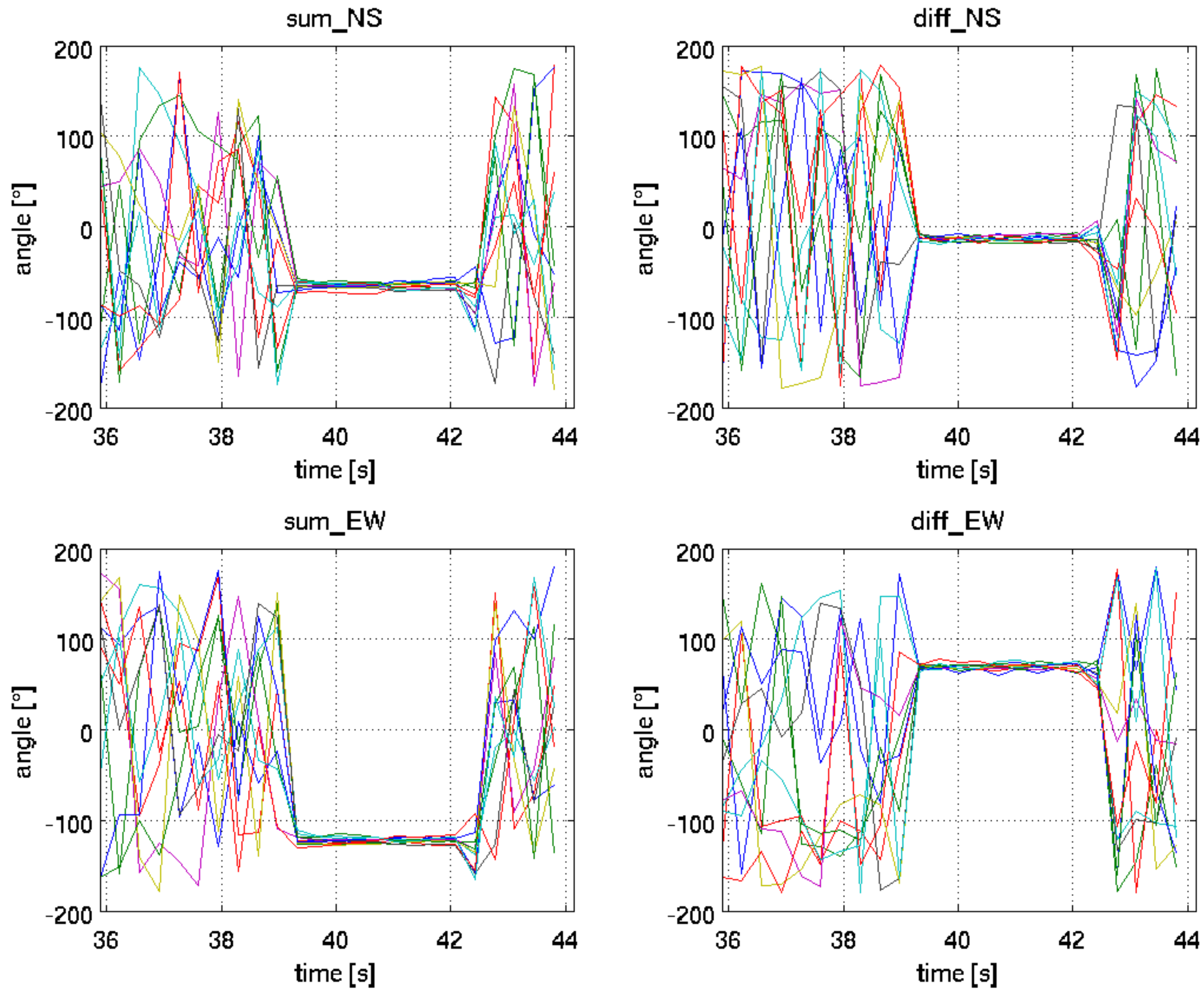

RAD_BEDOUR_20161205_0035_BEHUMA_SYS006: 16384-14488
1050
1040
1030
1020
1010
1000
990
34
36
38
40
42
44
46
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
Frequency
Time (sec)

Phase differences between antenna pairs



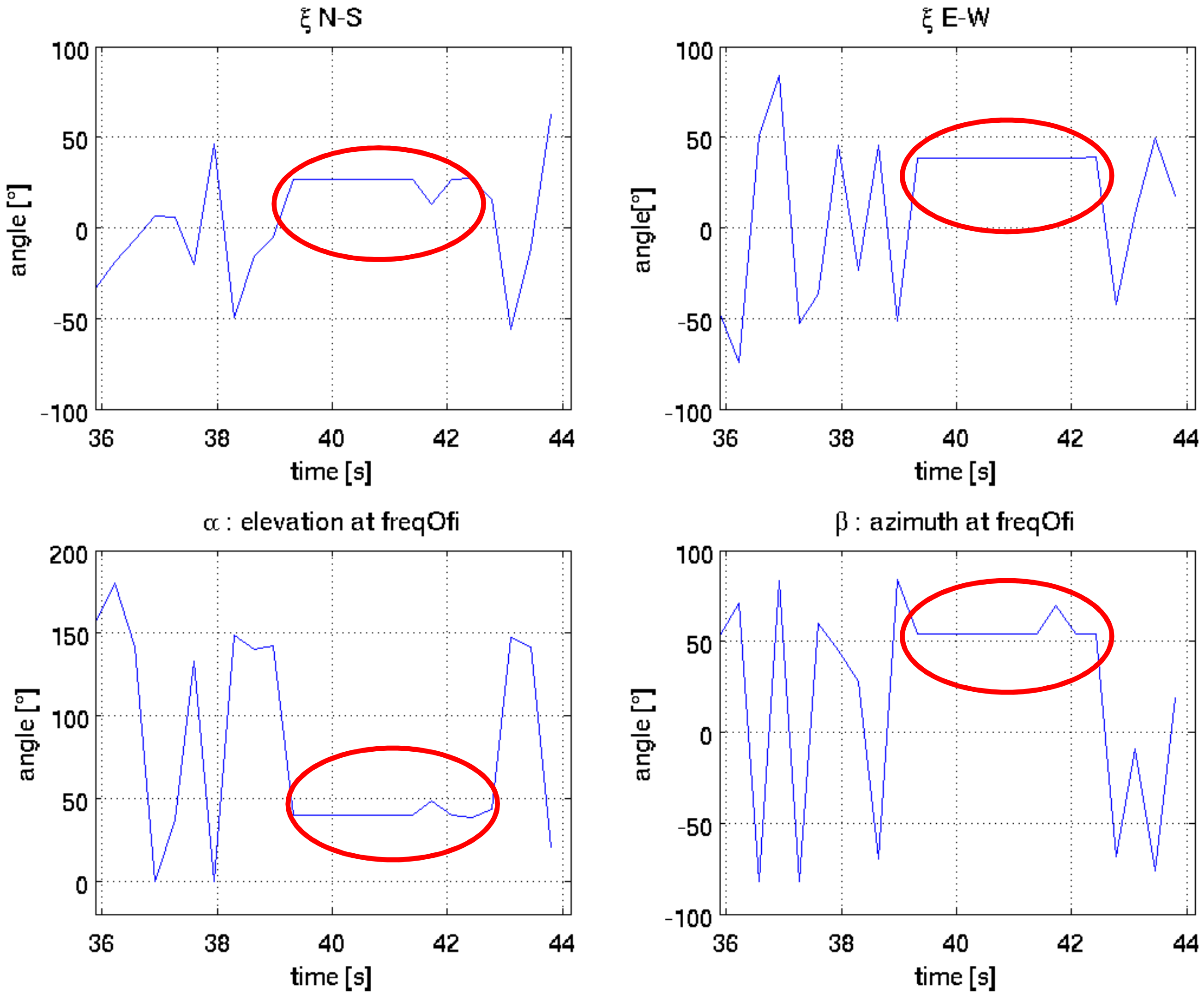
Each color =
1 frequency

Sum & Diff of phase differences

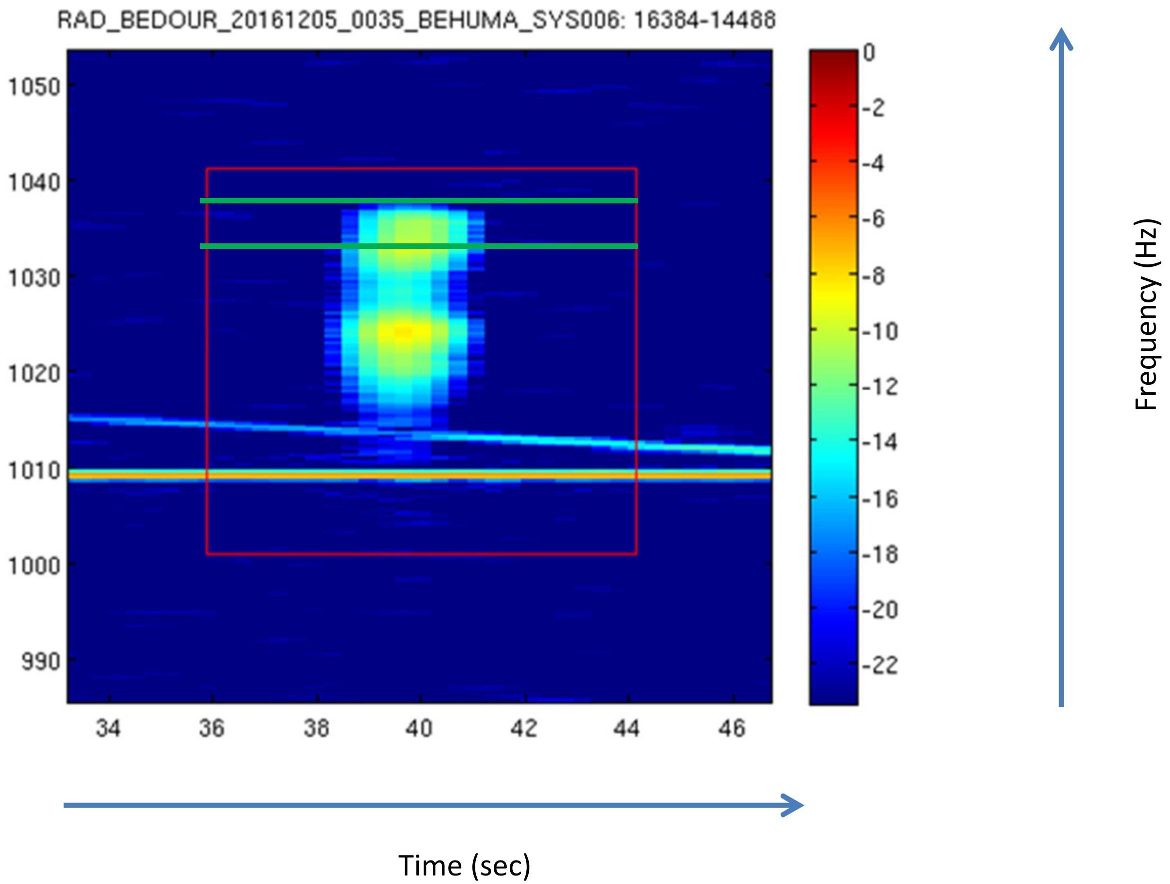


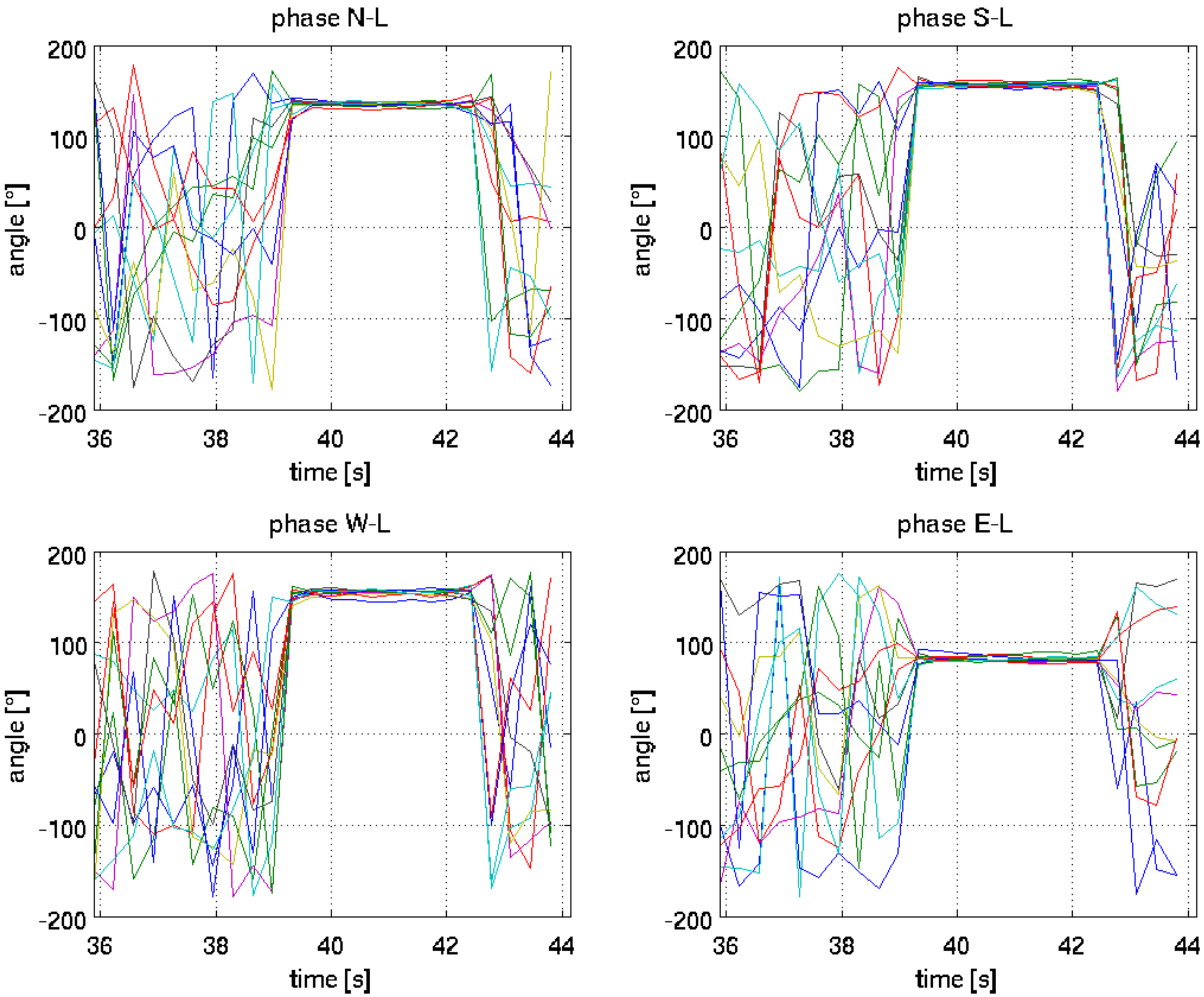
Angles of arrival

Only one frequency



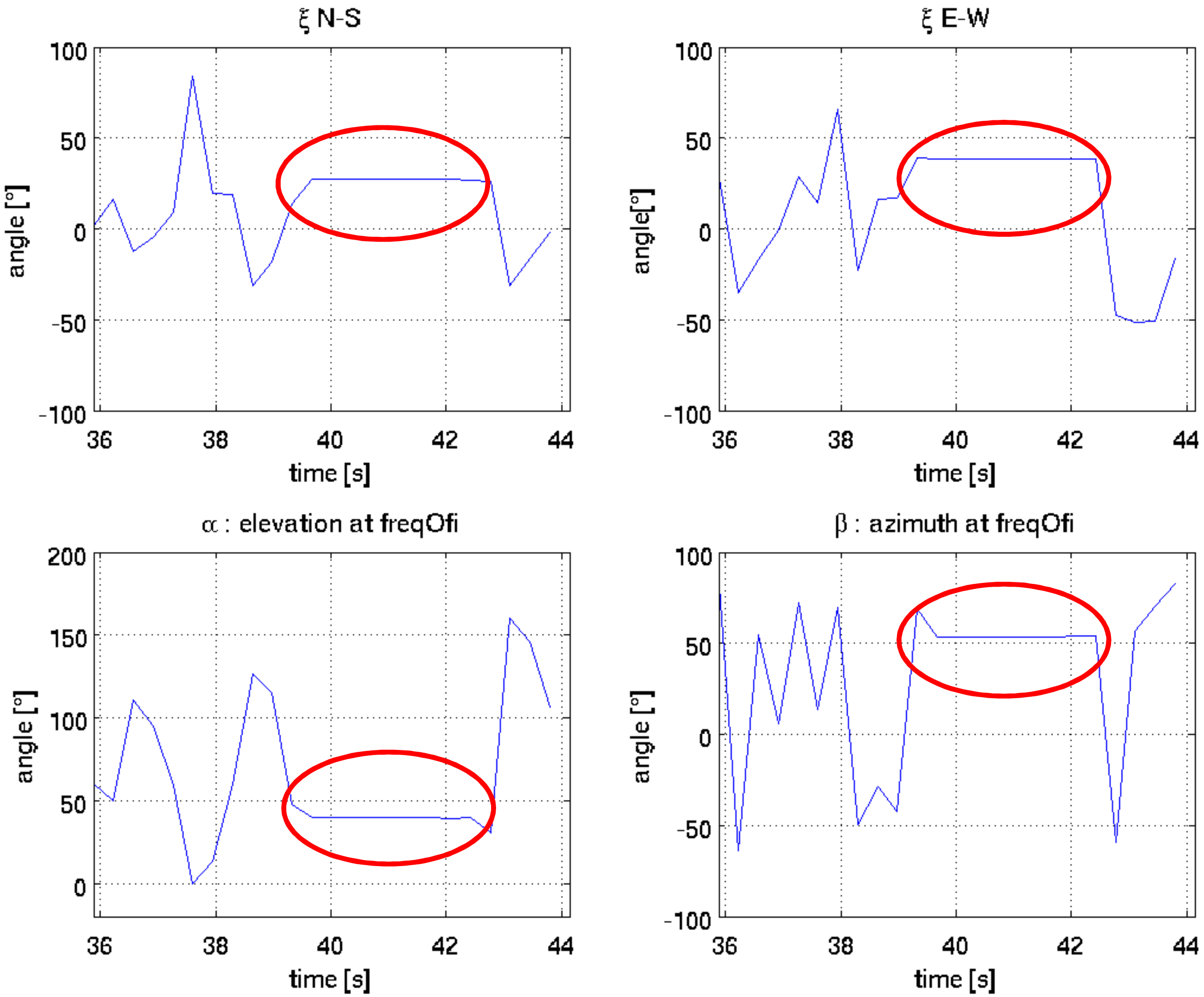
Same example, different frequencies



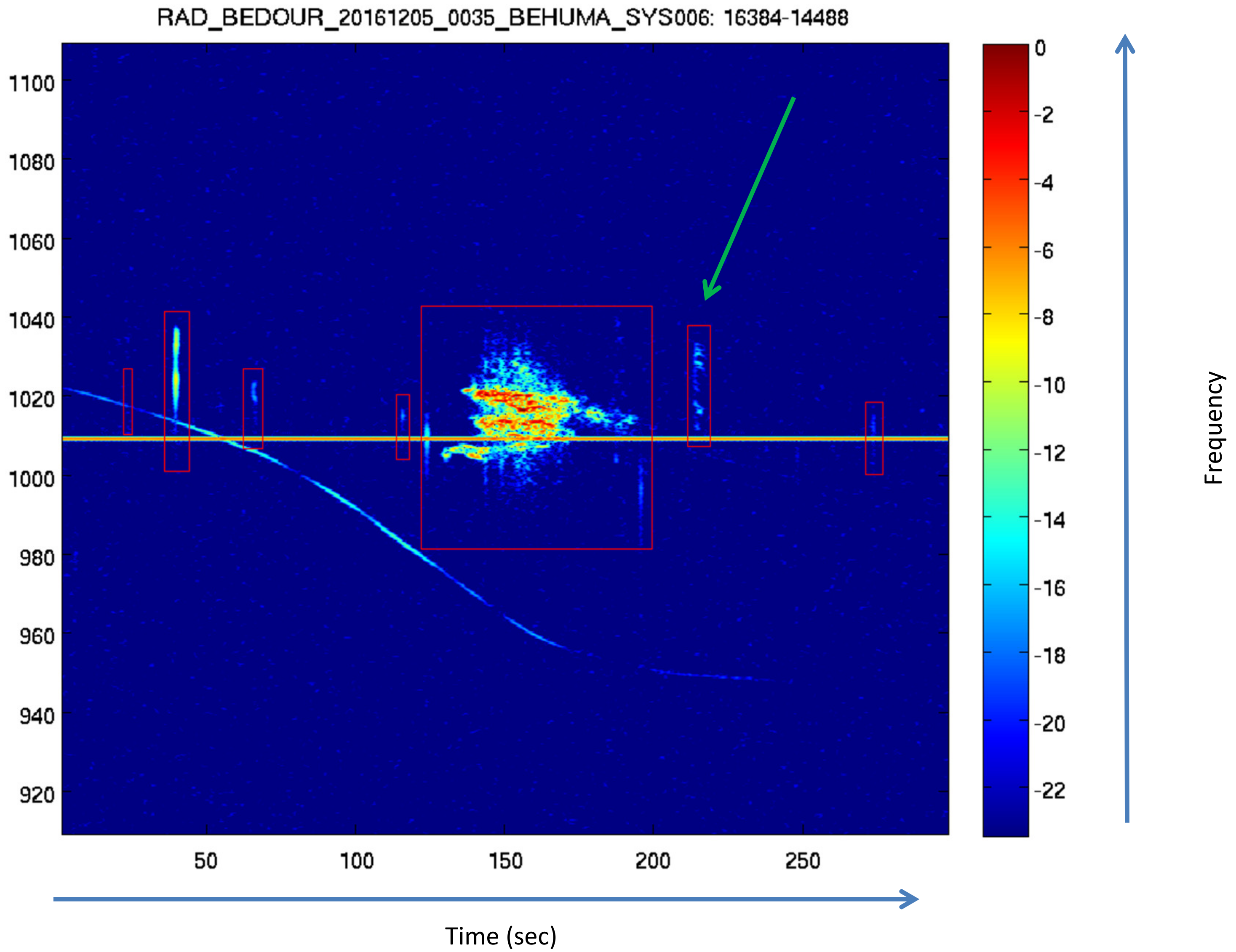


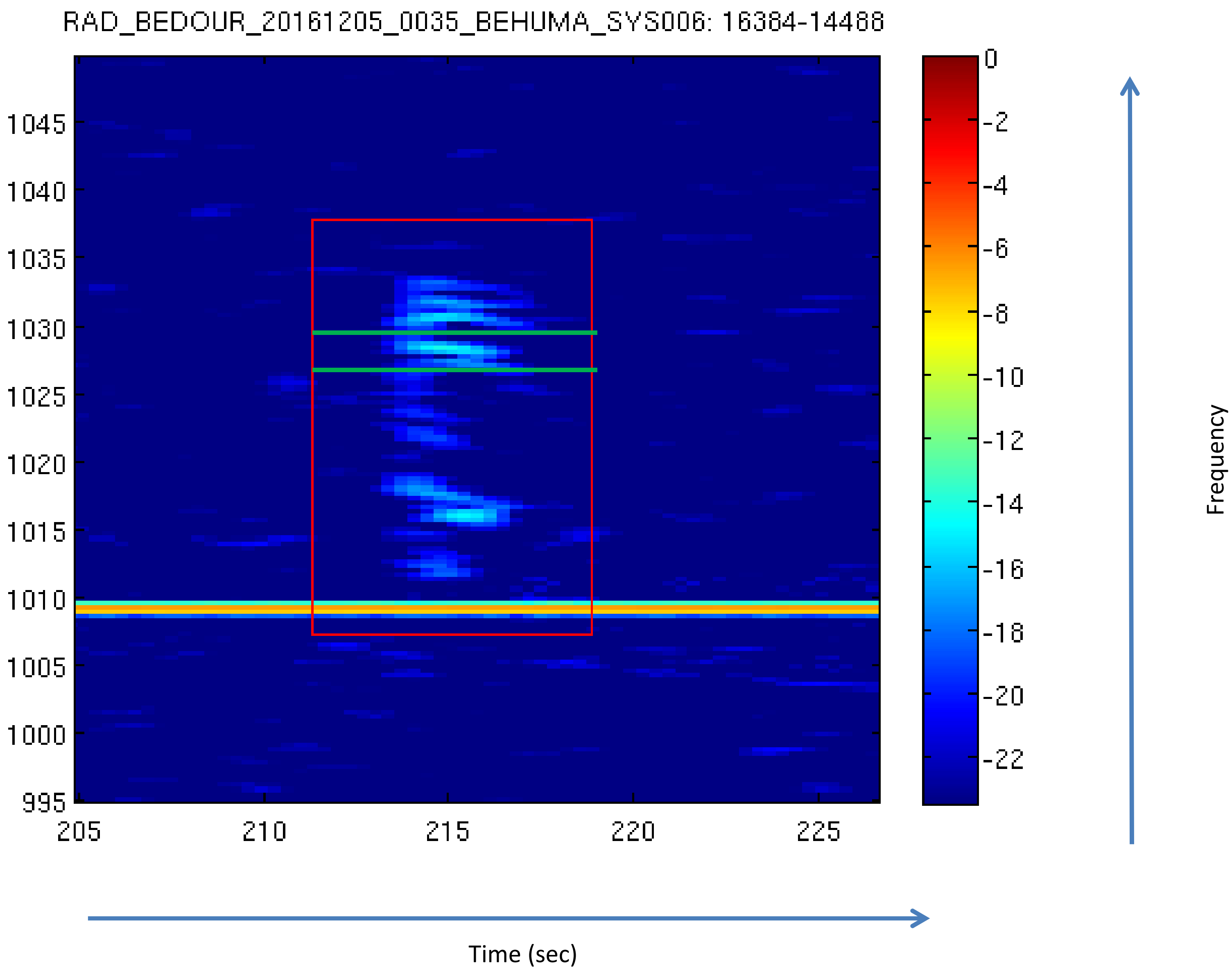
phase N-L
phase S-L
phase W-L
phase E-L
angle [°]
time [s]
200
100
0
-100
-200
36
38
40
42
44

Only one frequency

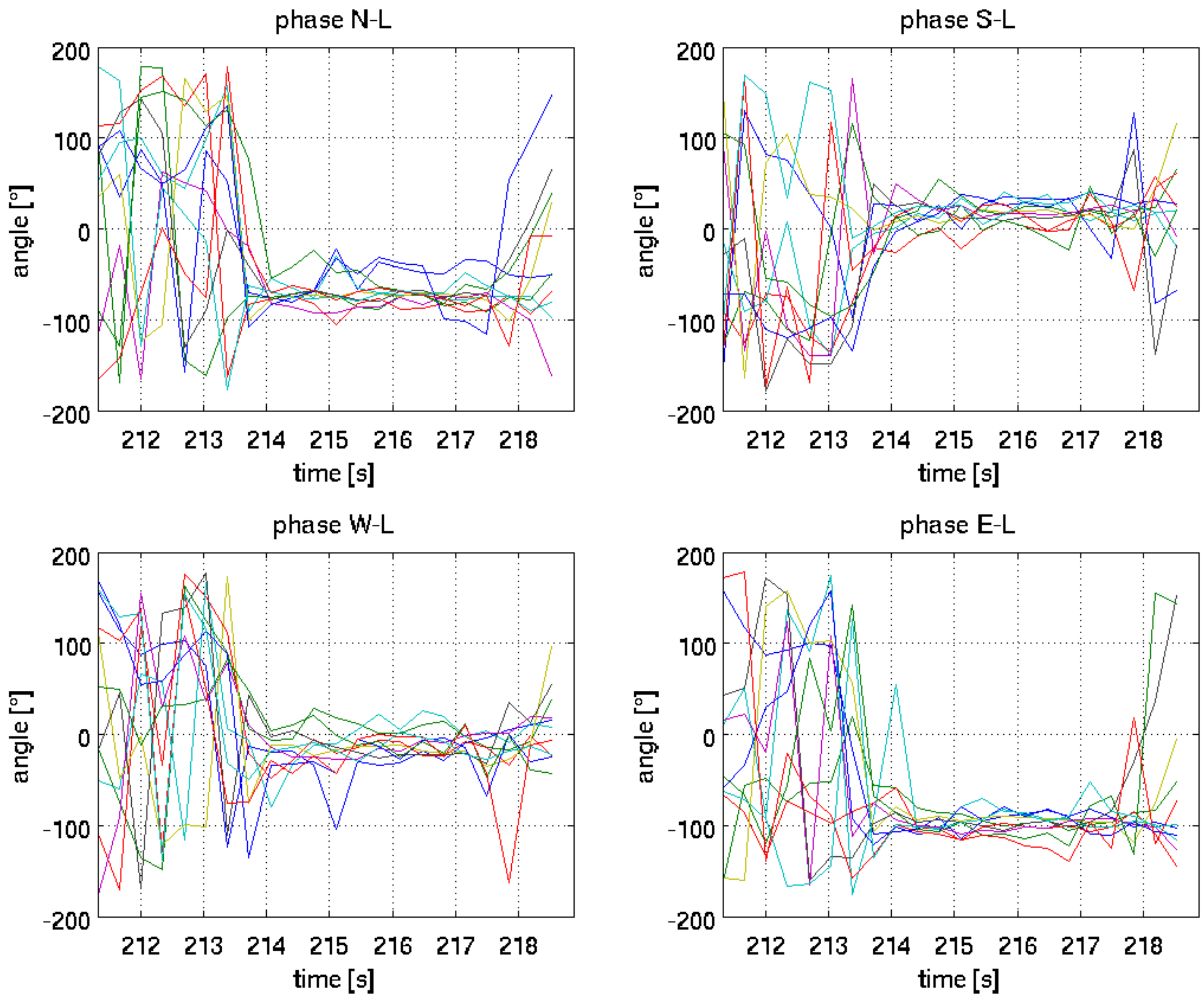


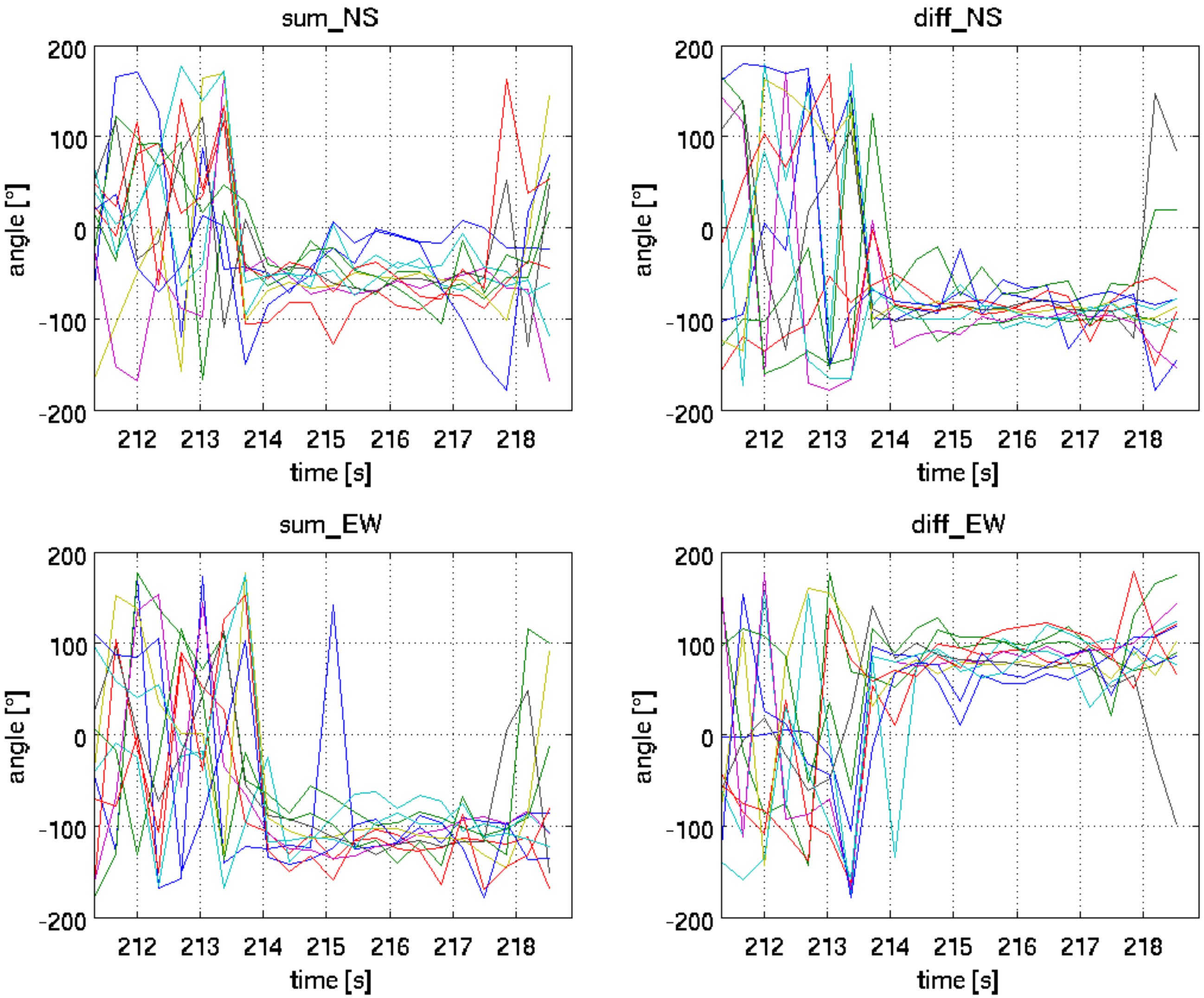
A less intense meteor echo



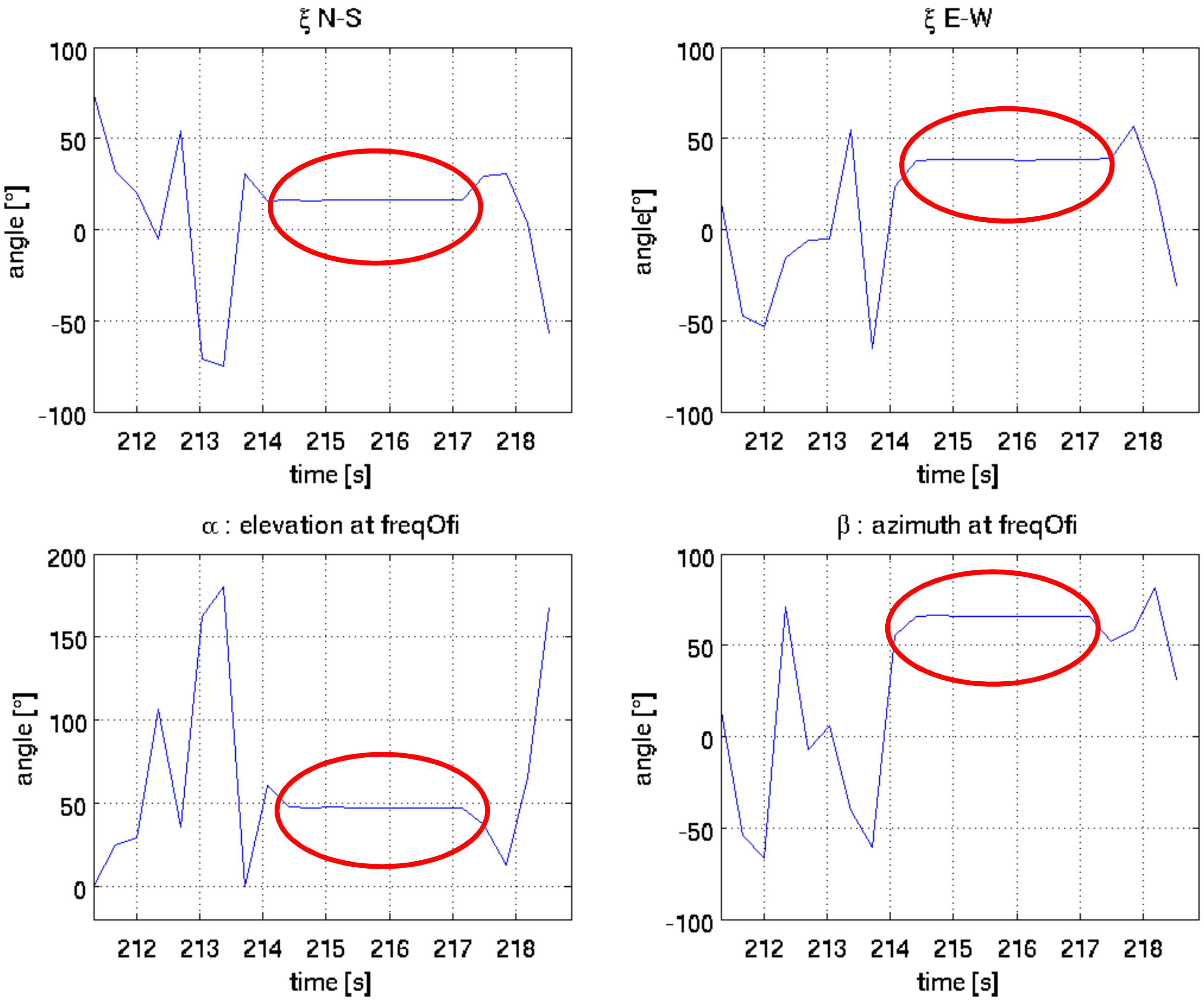


RAD_BEDOUR_20161205_0035_BEHUMA_SYS006: 16384-14488
1045
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
205
210
215
220
225
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
Frequency
Time (sec)

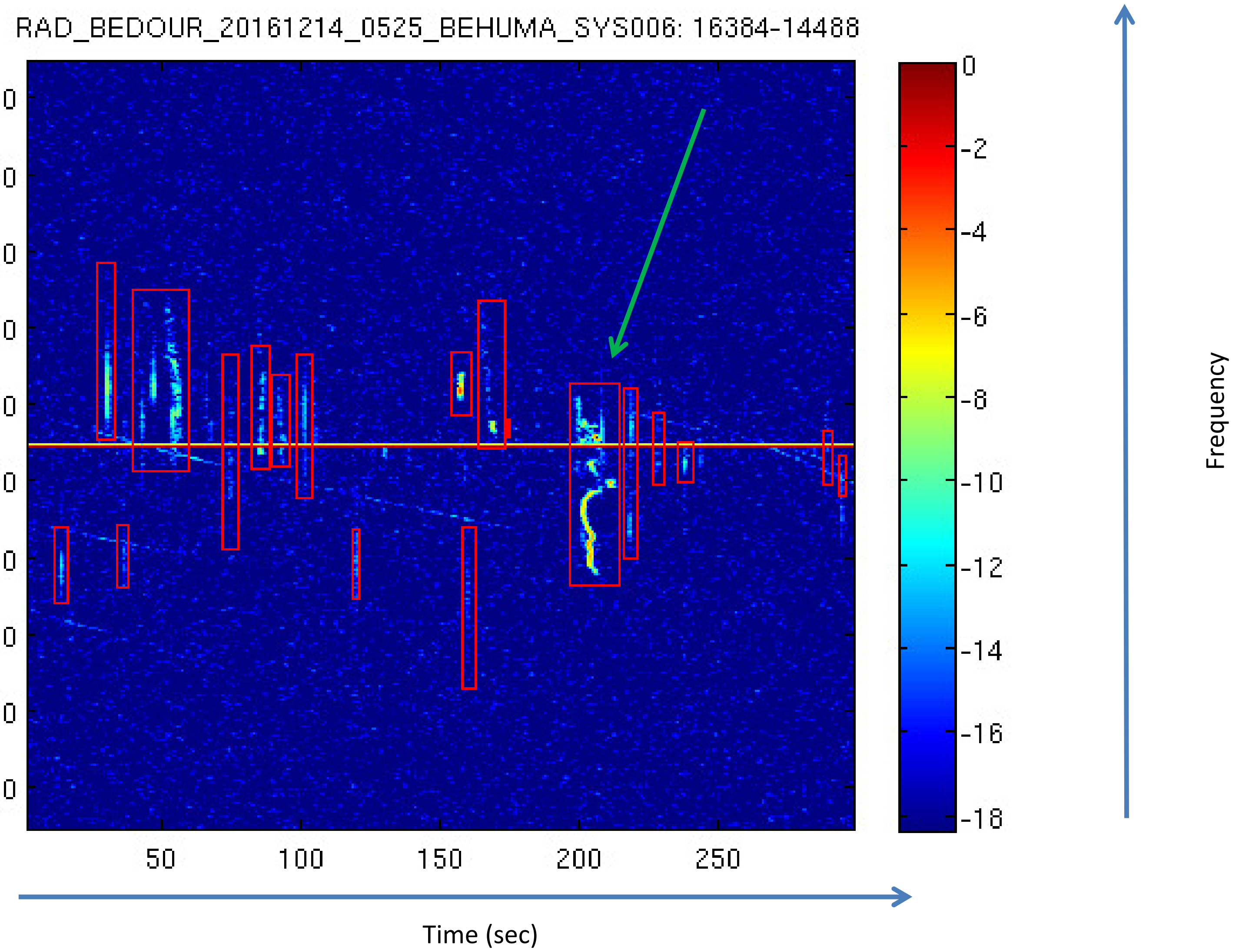

phase N-L
phase S-L
phase W-L
phase E-L
angle [°]
time [s]
200
100
0
-100
-200
212
213
214
215
216
217
218

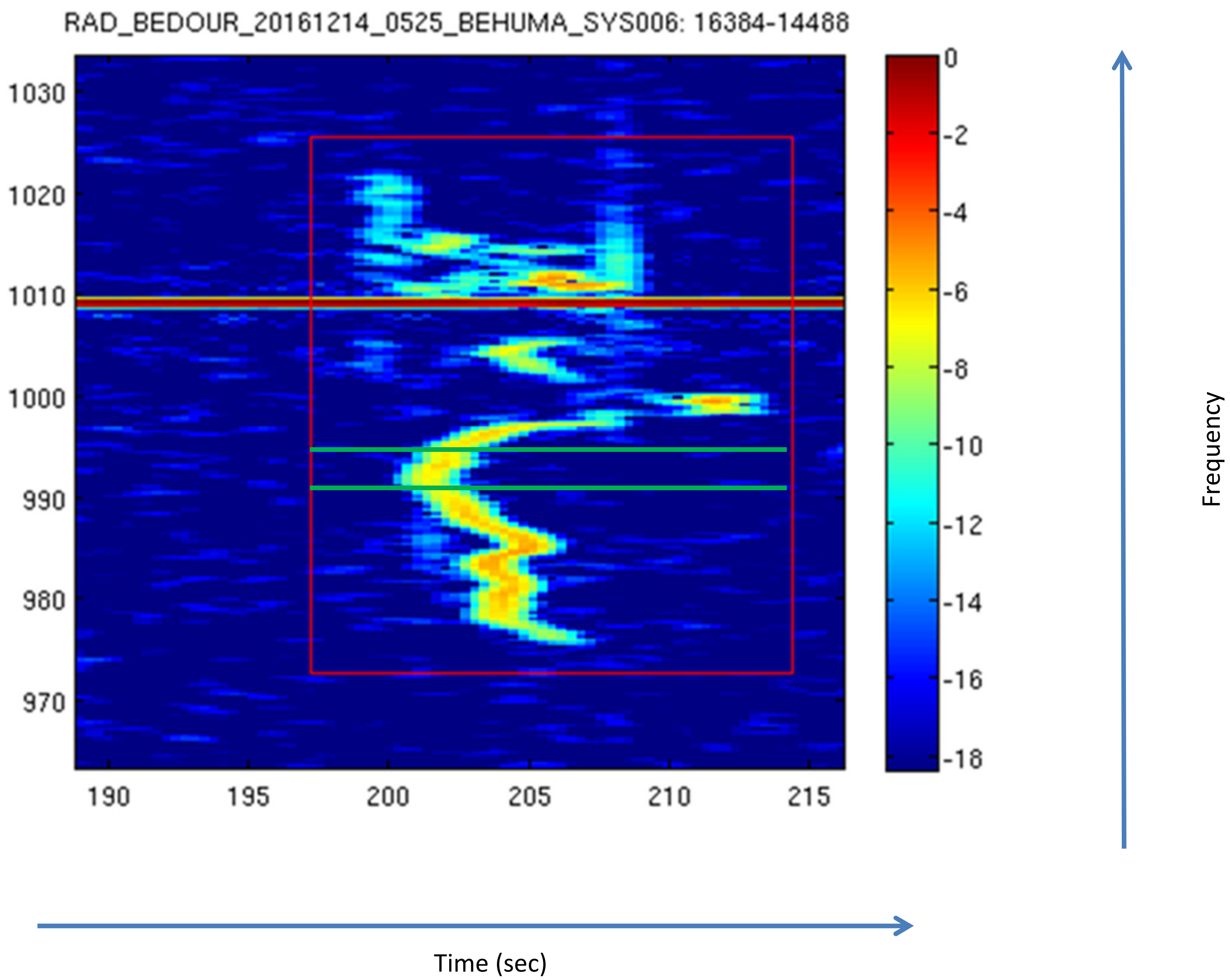

sum_NS
diff_NS
sum_EW
diff_EW
angle [°]
time [s]
200
100
0
-100
-200
212
213
214
215
216
217
218

Only one frequency

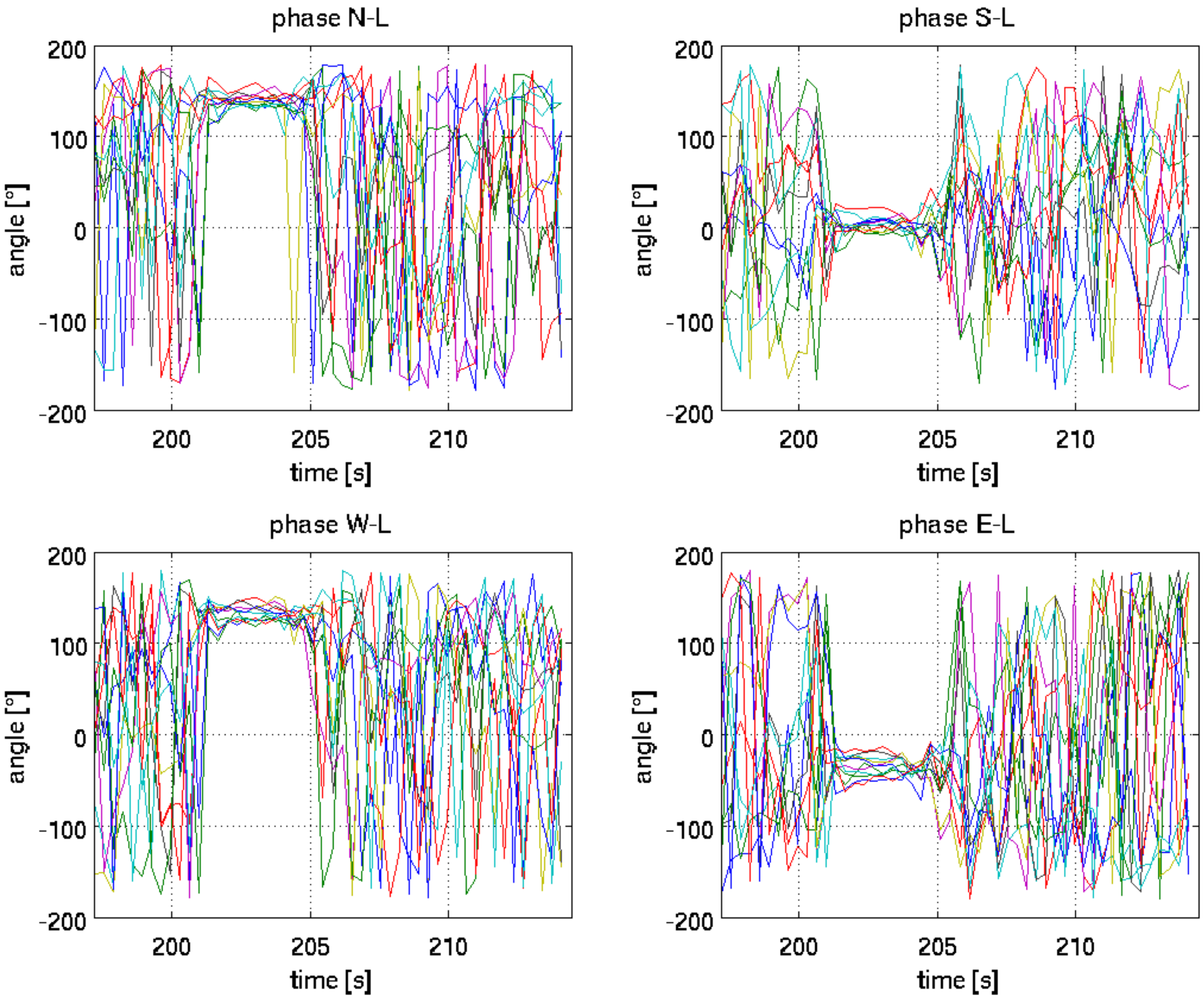


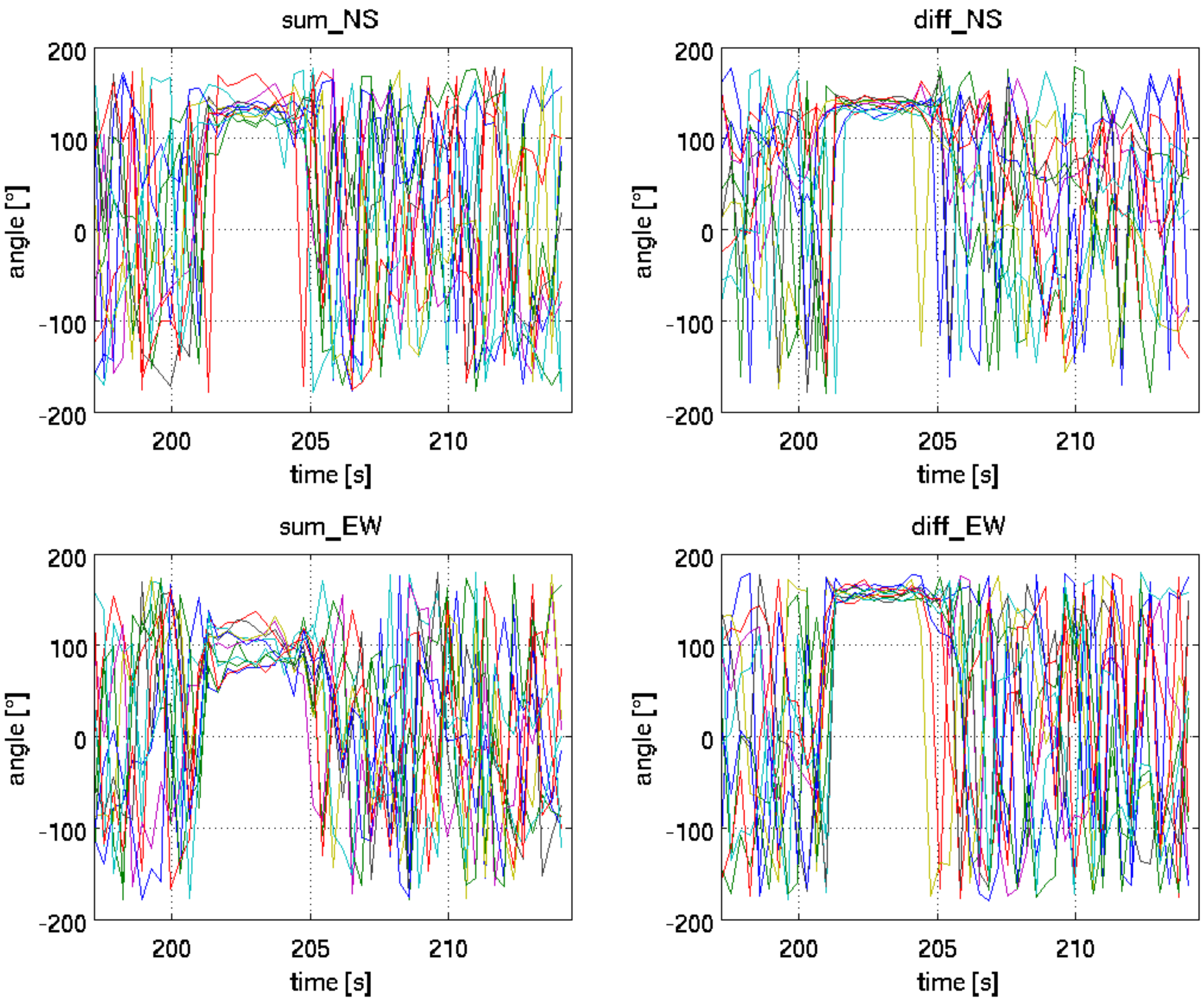
Epsilon echo

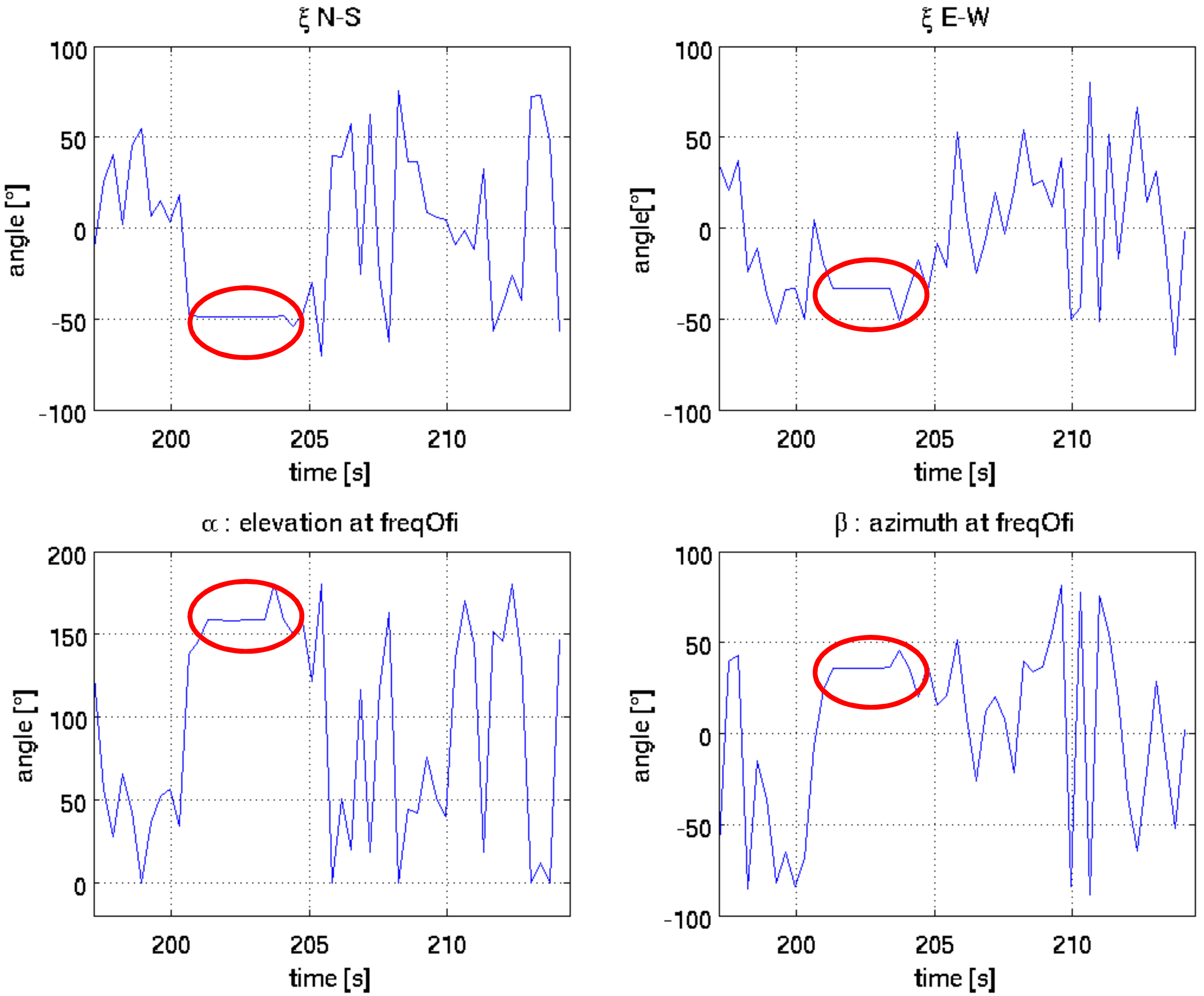




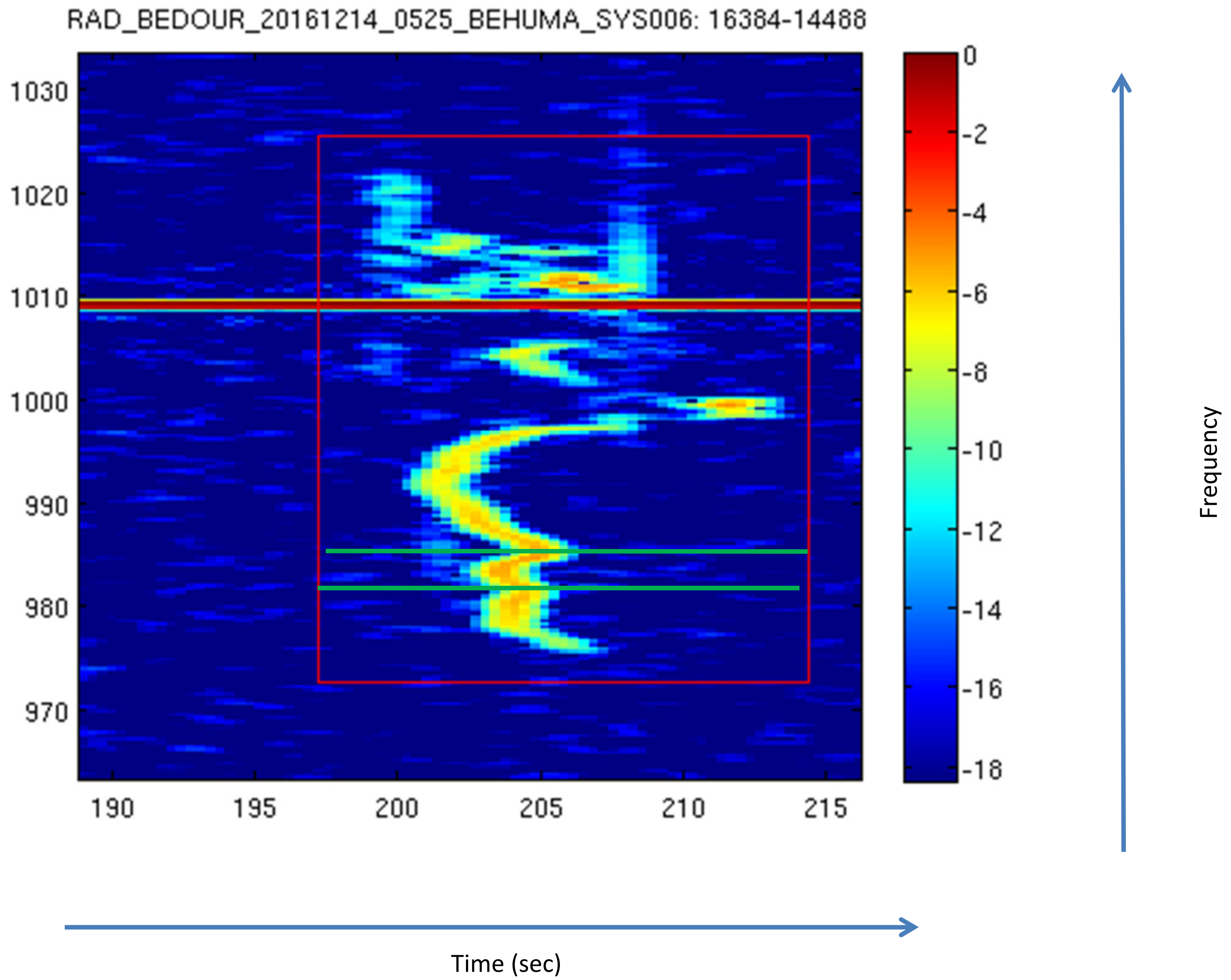
RAD_BEDOUR_20161214_0525_BEHUMA_SYS006: 16384-14488
1030
1020
1010
1000
990
980
970
190
195
200
205
210
215
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
Frequency
Time (sec)


phase N-L
phase S-L
phase W-L
phase E-L
200
100
0
-100
-200
angle [°]
200
205
210
time [s]

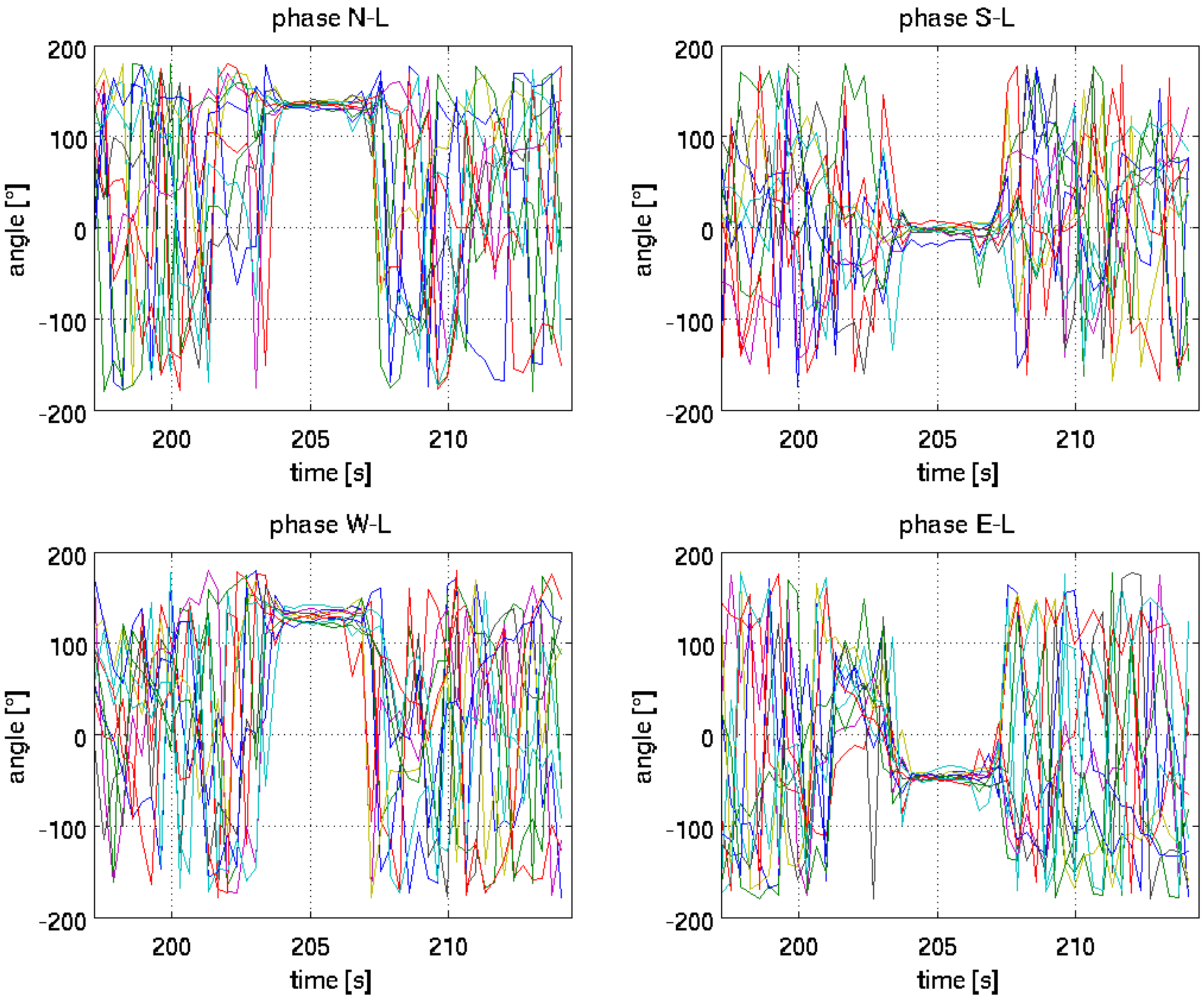

sum_NS
diff_NS
sum_EW
diff_EW
angle [°]
time [s]
200
100
0
-100
-200
200
205
210

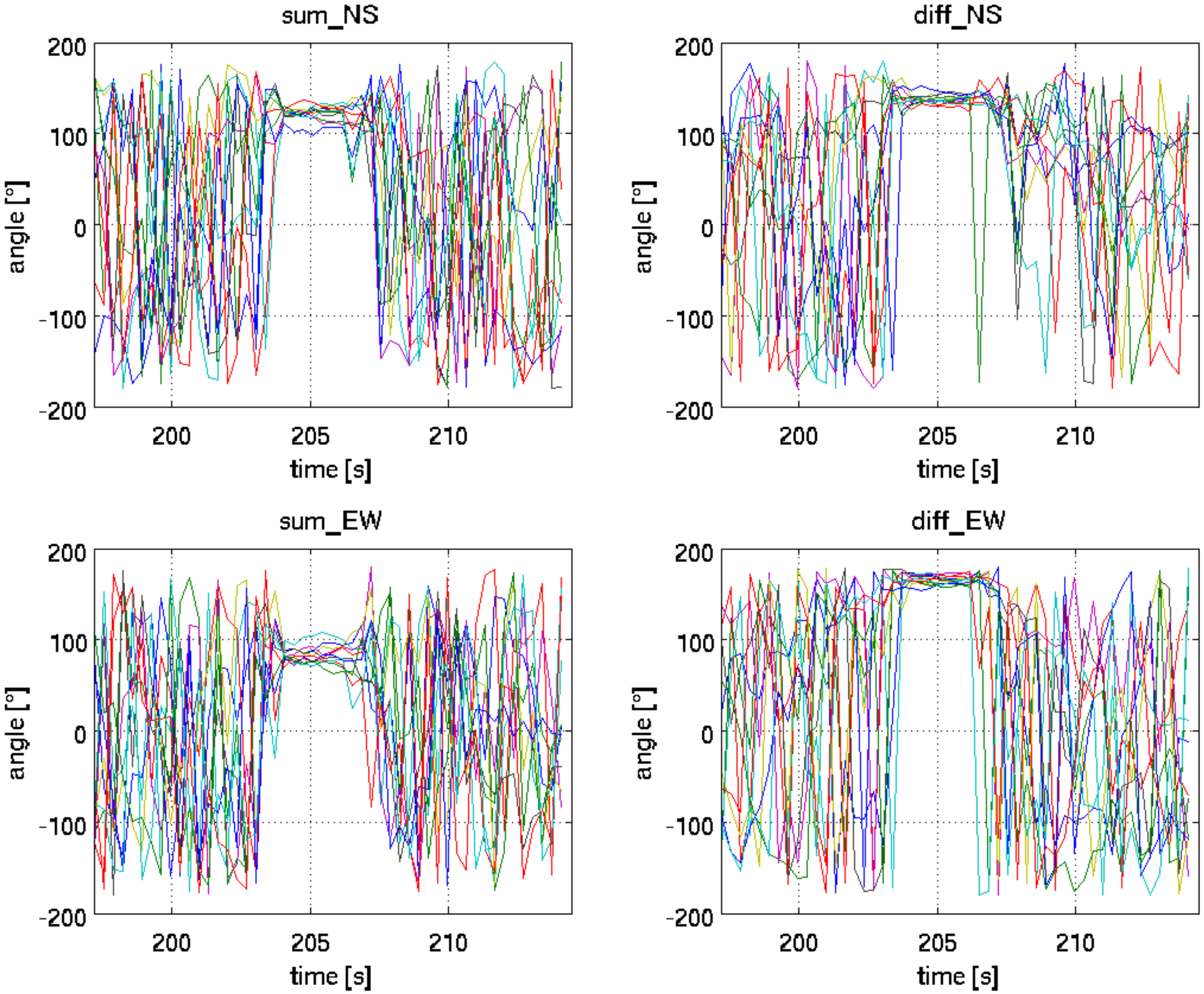


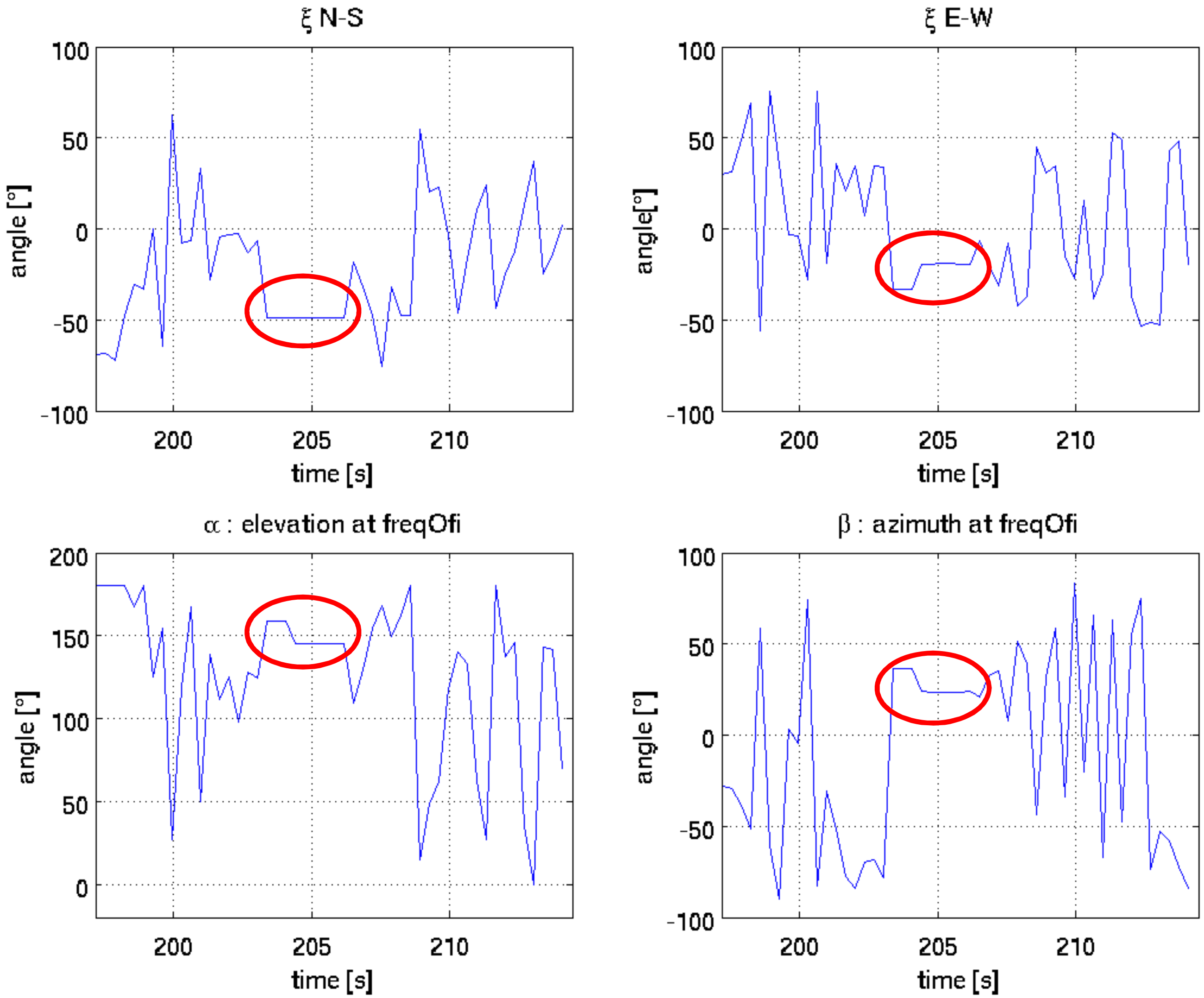
ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
time [s]
100
50
0
-50
-100
200
150
200
205
210



RAD_BEDOUR_20161214_0525_BEHUMA_SYS006: 16384-14488
1030
1020
1010
1000
990
980
970
190
195
200
205
210
215
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
Frequency
Time (sec)

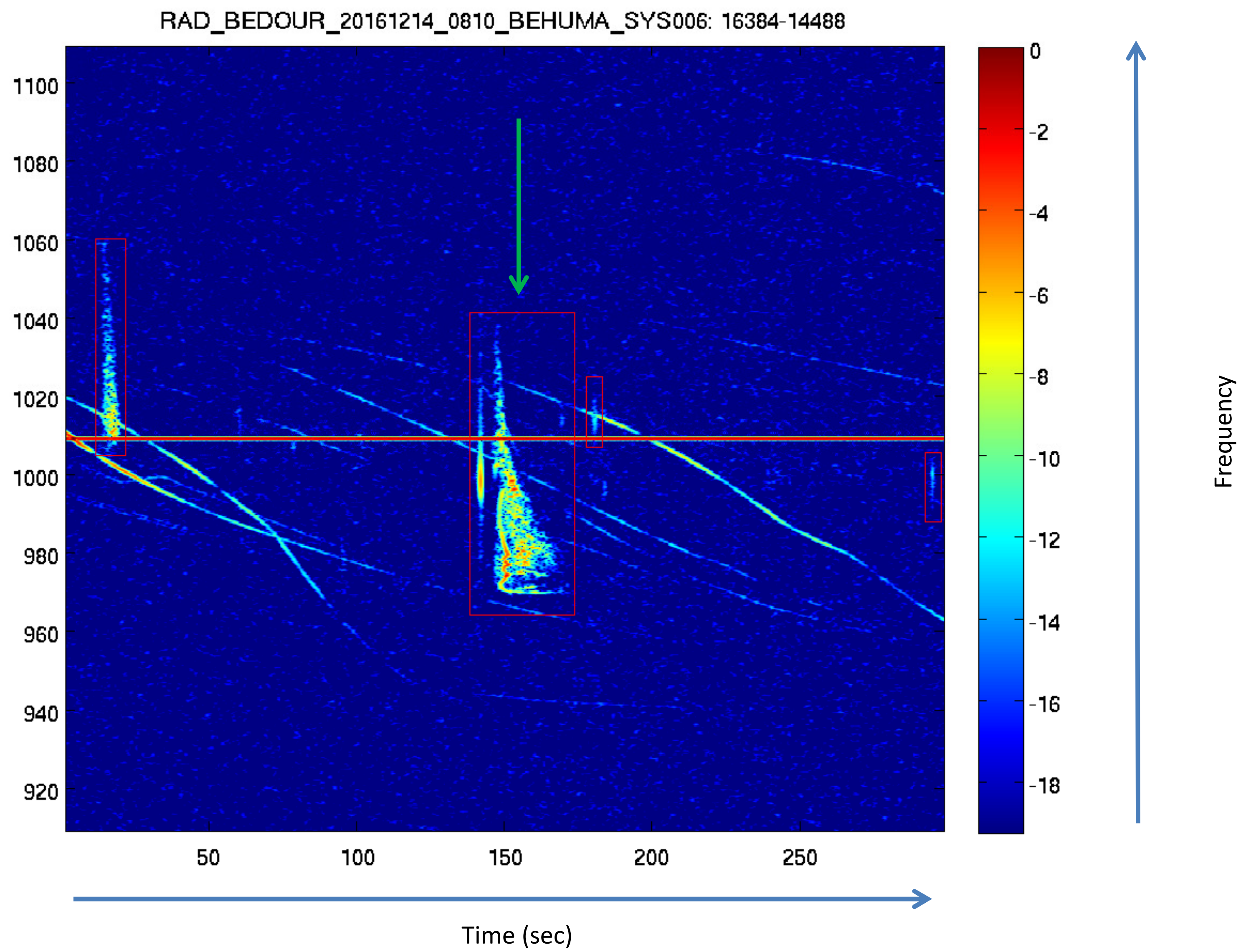

phase N-L
phase S-L
phase W-L
phase E-L
angle [°]
time [s]
200
100
0
-100
-200
200
205
210

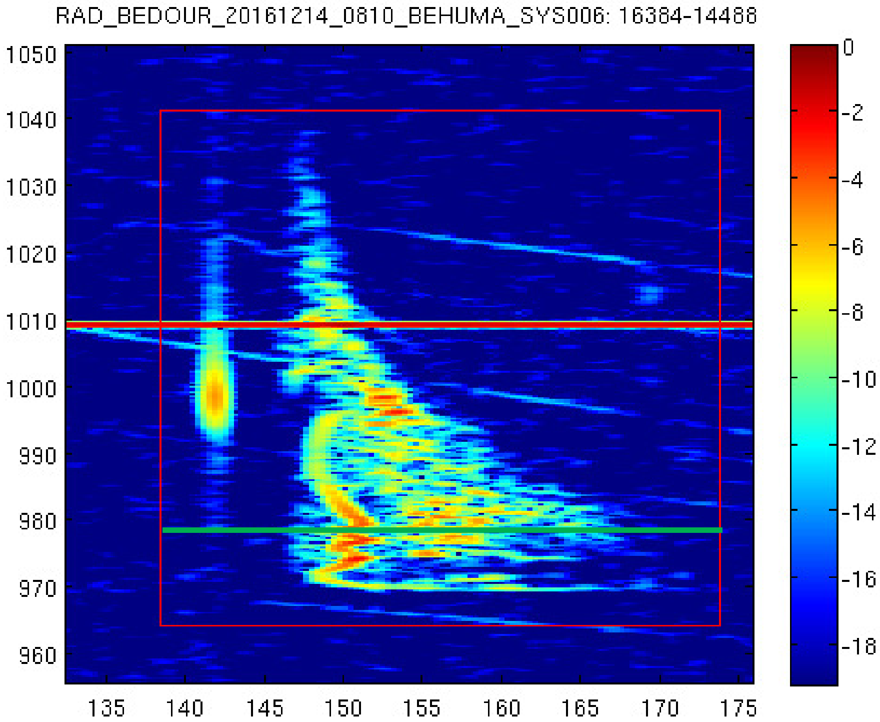

sum_NS
diff_NS
sum_EW
diff_EW
angle [°]
time [s]
200
100
0
-100
-200
200
205
210

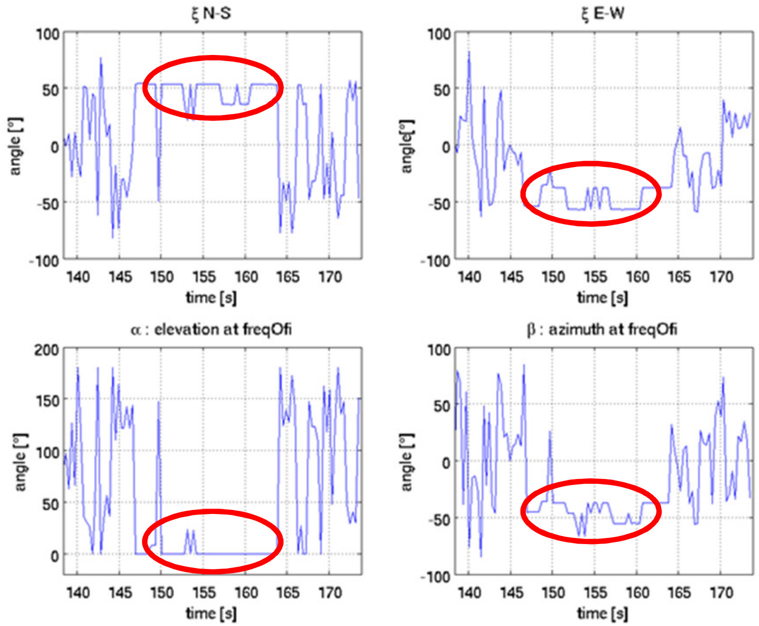


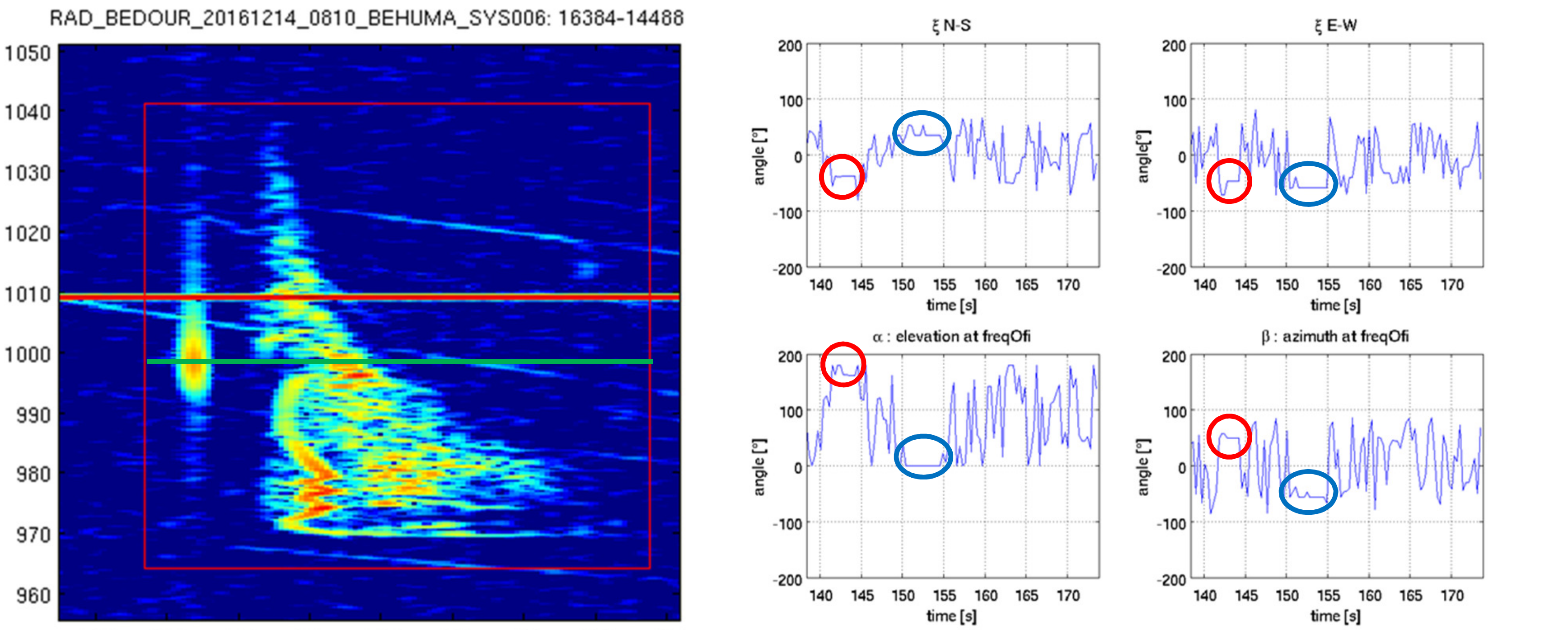
ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
angle[°]
time [s]
100
50
0
-50
-100
150
200
205
210

A long overdense meteor echo




RAD_BEDOUR_20161214_0810_BEHUMA_SYS006: 16384-14488
1050
1040
1030
1020
1010
1000
990
980
970
960
135
140
145
150
155
160
165
170
175
0
-2
-4
-6
-8
-10
-12
-14
-16
-18


ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
time [s]


RAD_BEDOUR_20161214_0810_BEHUMA_SYS006: 16384-14488
ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
time [s]

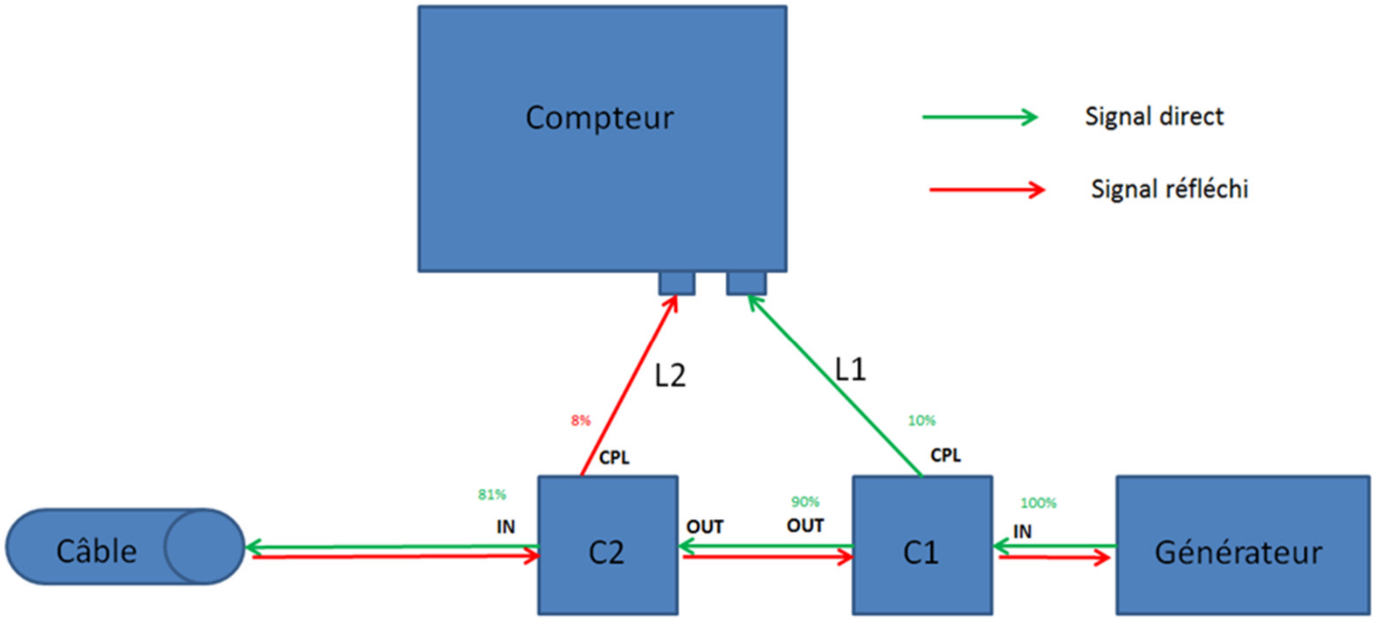
Conclusions

- Phases become coherent as soon as a meteor echo occurs. The higher the S/N ratio, the more stable the results for the angles of arrival
- For the fainter meteor echoes, it might be interesting to sum up the contributions of individual frequencies present in the meteor echo to increase the S/N ratio. This sum must be done in the complex plane before calculating the phases. It is not so trivial …
- The directions of arrival we obtain are not calibrated at all. We find a direction for the meteor echo but have so far no way to check that it is correct. There are a number of systematic errors that need to be taken into account and corrected for.

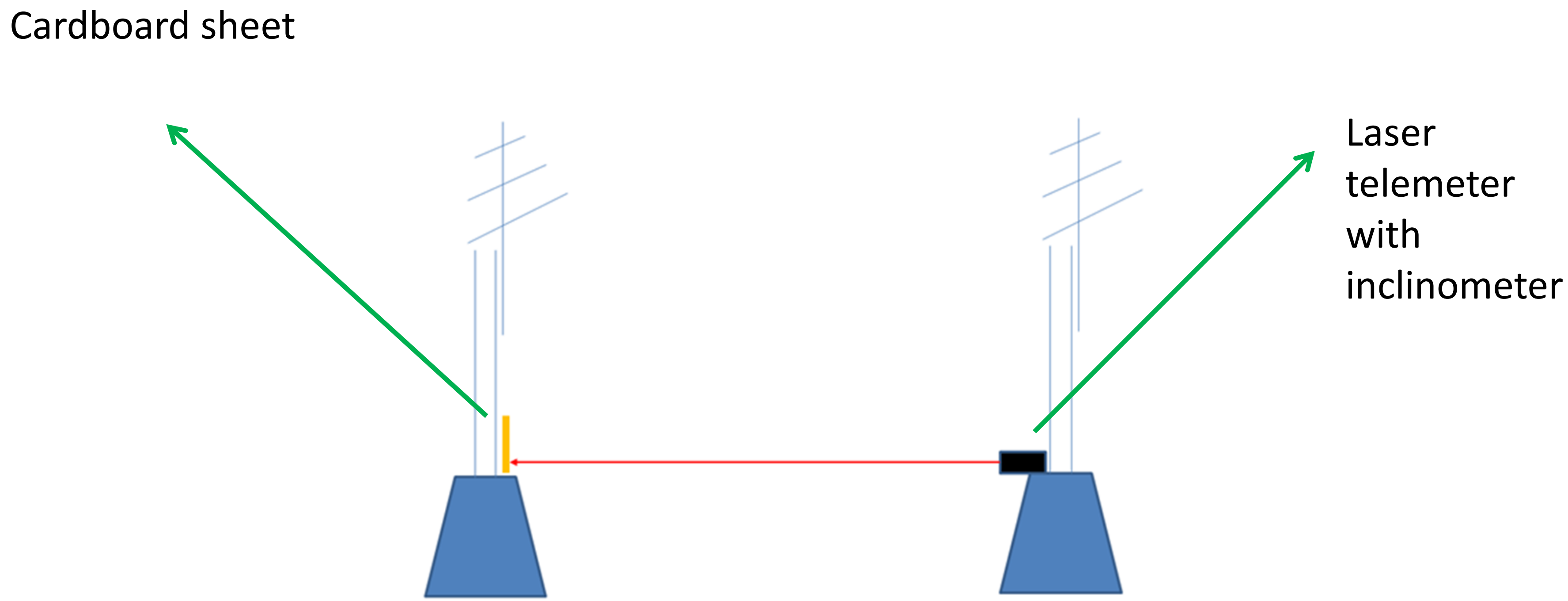
Systematic errors

- Different electric lengths of the cables
- Mis-alignement of the 3 antennas
- Distances between antennas $\neq 2.5\lambda$ and 2λ
- Orthogonal axes not exactly aligned along N-S and E-W

Measurements of the electric length of the cables



Measurements of the relative distances and orientations between antennas



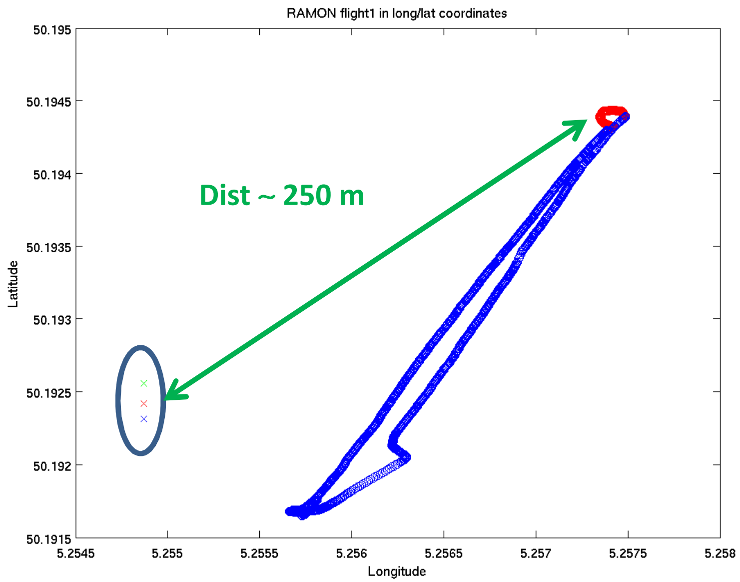
Calibration

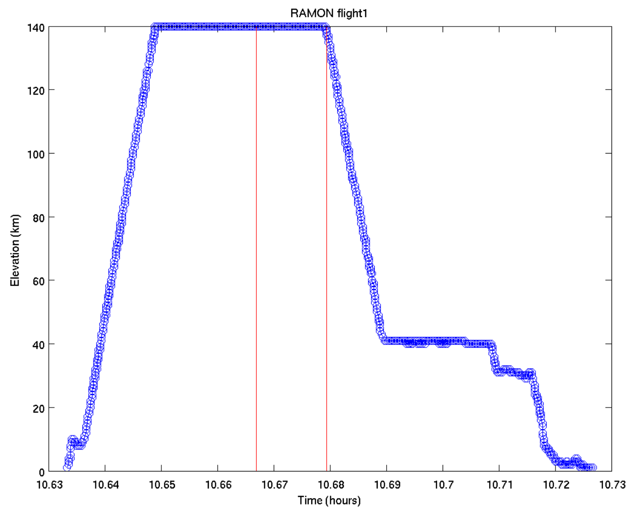
Can be done using one of the following options :

- Using a transmitter on a drone flying in the far-field of the interferometer
- Using the signal coming from a plane whose position can be very accurately known
- Using data from optical cameras such as CAMS

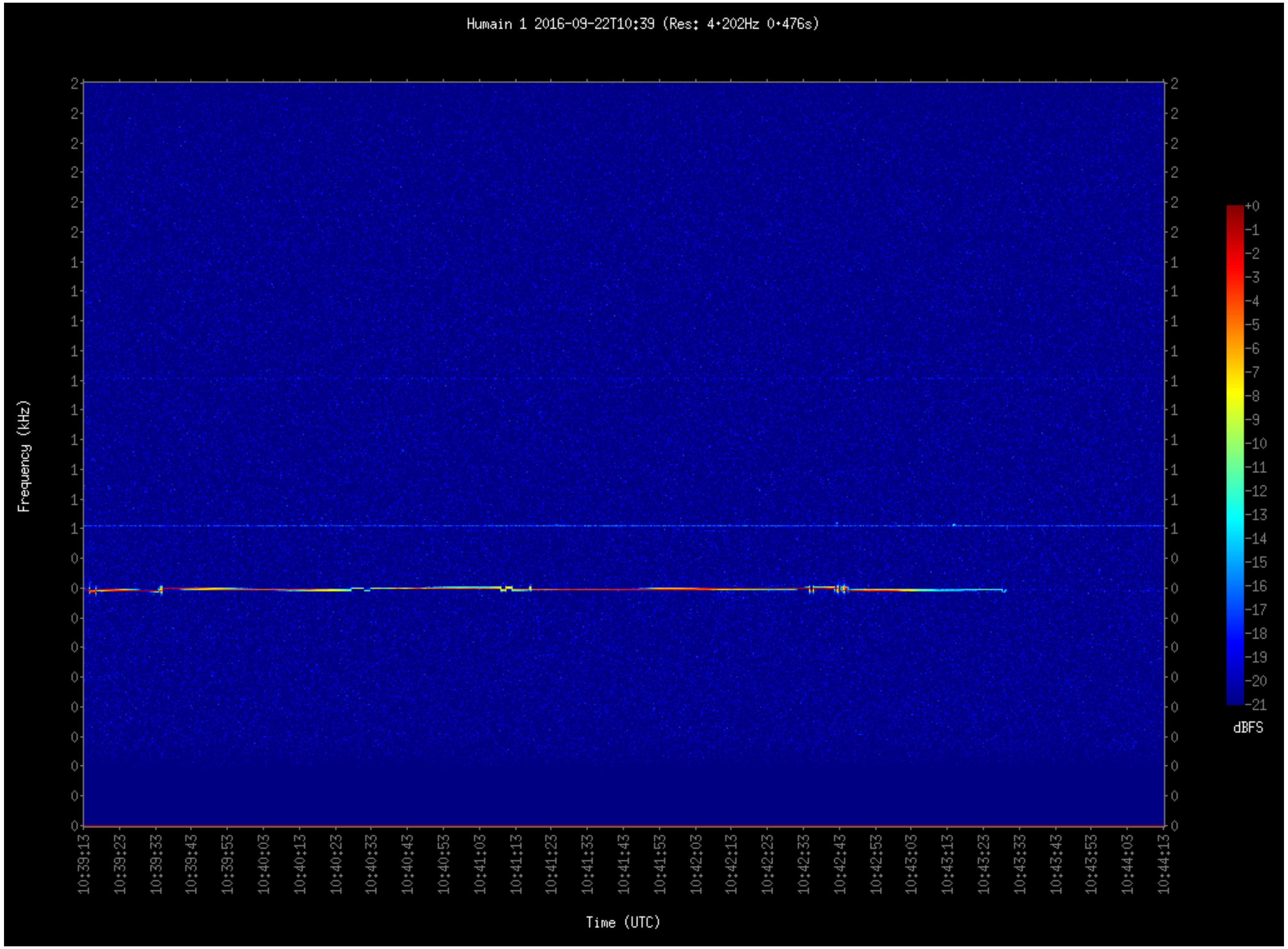
Calibration with a drone

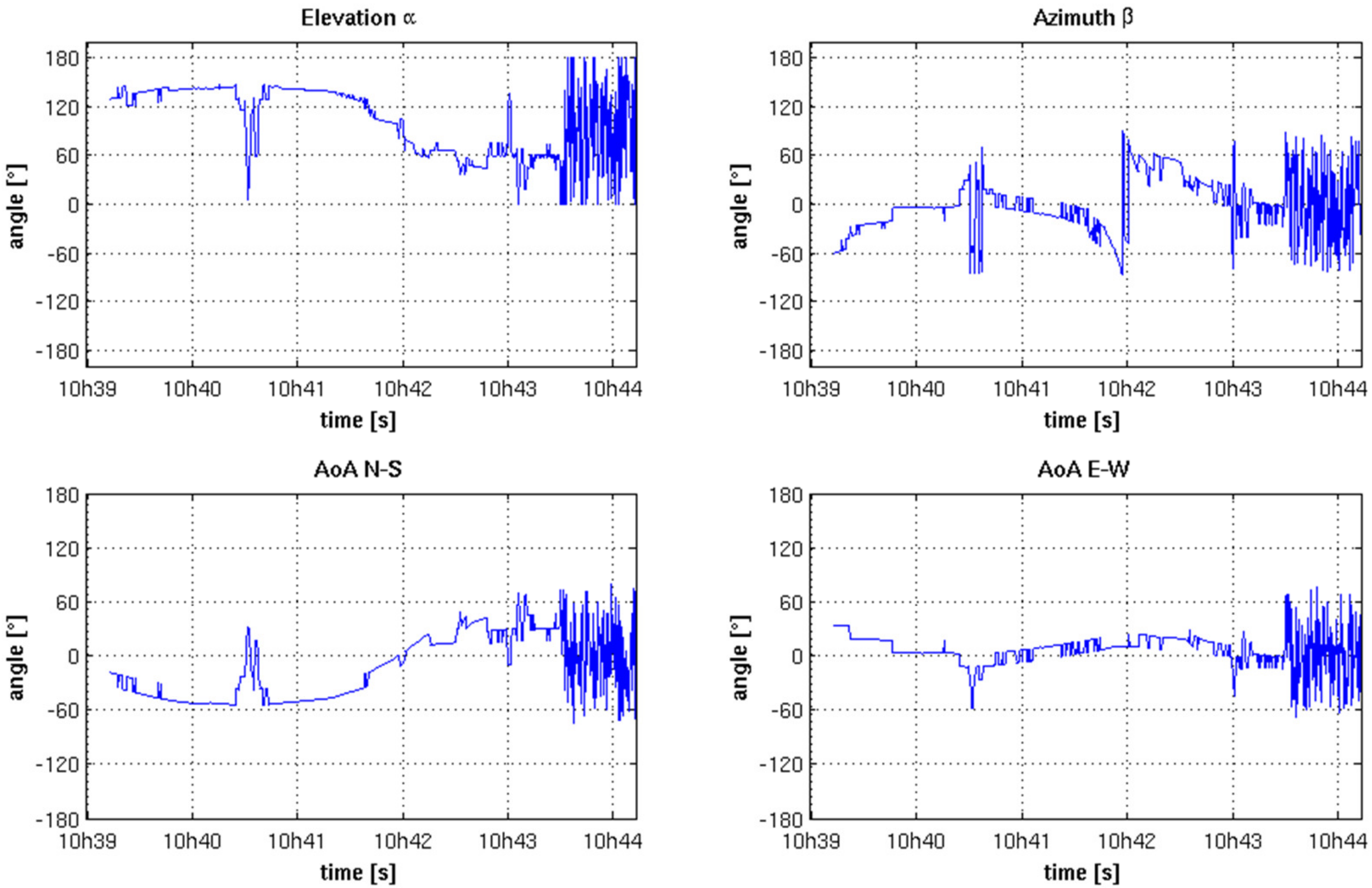
Tx = BRAMS calibrator (see Lamy et al 2015)





Results of the first flight




Elevation α
Azimuth β
AoA N-S
AoA E-W
angle [°]
time [s]
180
120
60
0
-60
-120
-180
10h39
10h40
10h41
10h42
10h43
10h44

Conclusions & perspectives

- The interferometer seems to work very well. Next step is to apply it to a lot of data including faint meteor echoes and complex ones. Tests during a meteor shower.
- Calibration must be ended quickly (end of 2017, at least for the drone)
- Installation of a CAMS camera before end of the year
- Start developing algorithms for retrieval of trajectories using data from Humain + 3 additional stations.
- Installation of 2 new « classical » BRAMS stations within 30 km from Humain.

Thank you