Observations of the Geminids 2016 with the BRAMS radio interferometer

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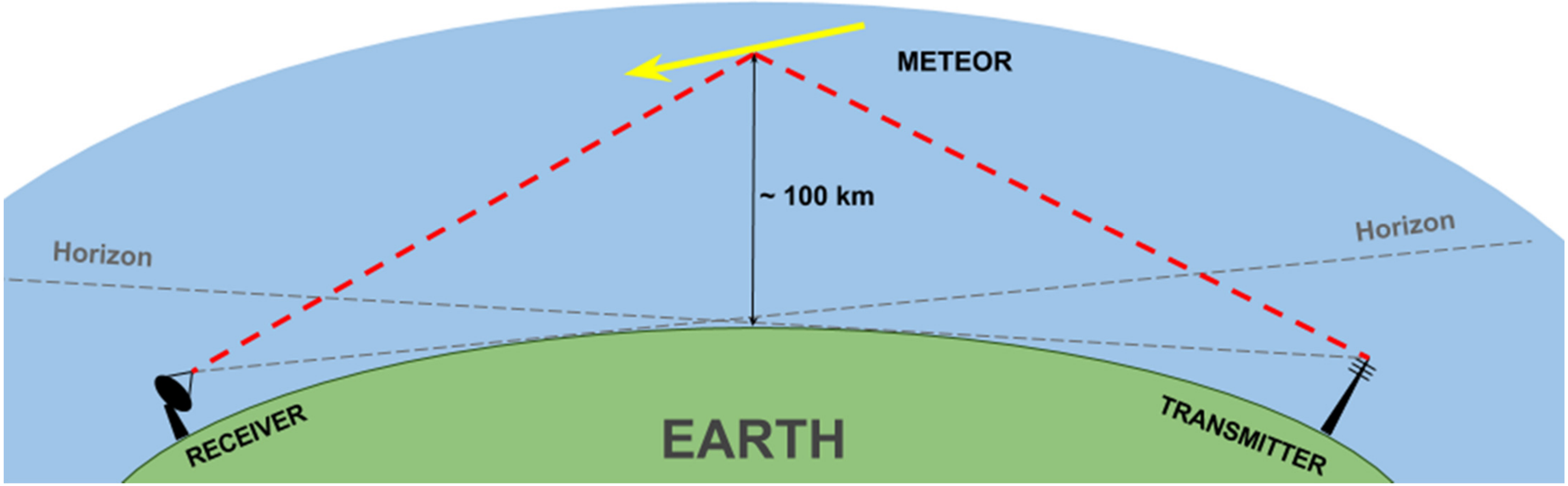
BRAMS


METEOR
~ 100 km
Horizon
Horizon
RECEIVER
EARTH
TRANSMITTER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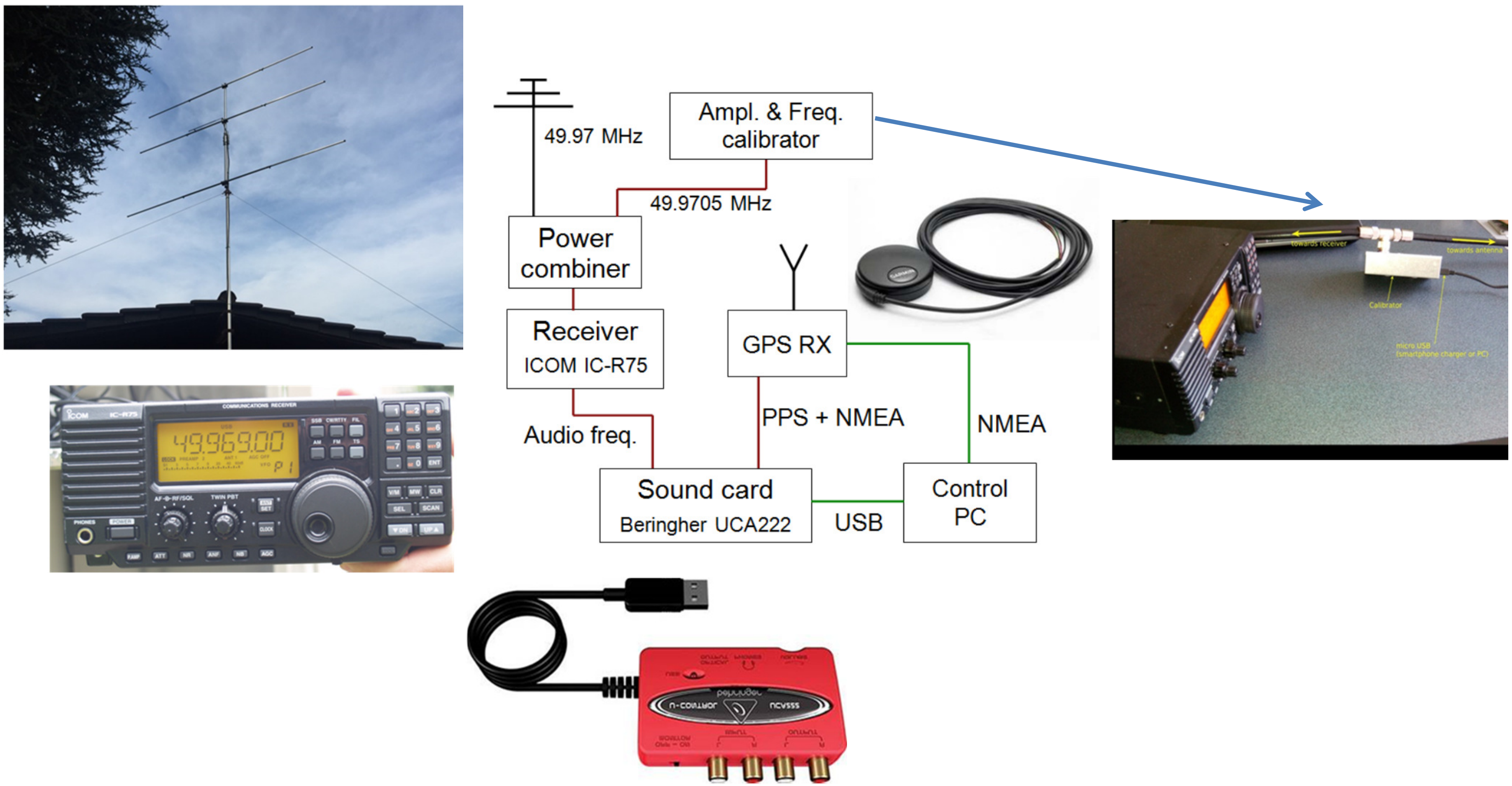
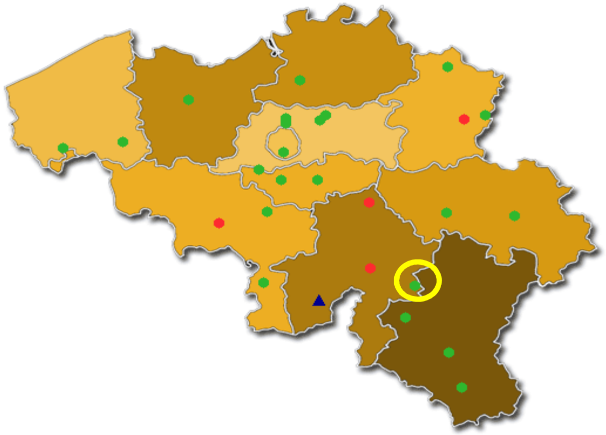
Typical BRAMS receiving station

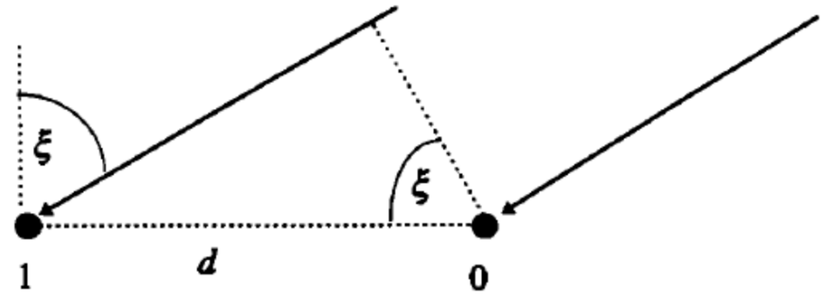


The interferometer in Humain



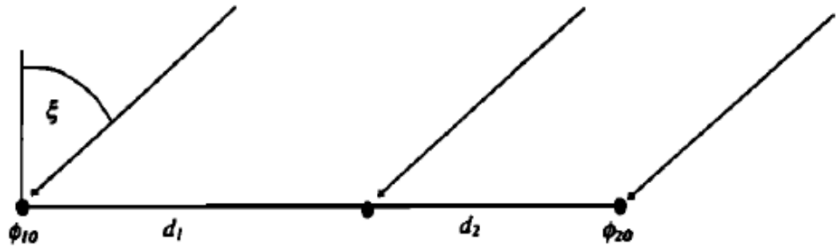
Credit : A. Martinez-Picar

Principle



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

Jones et al (1998)



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

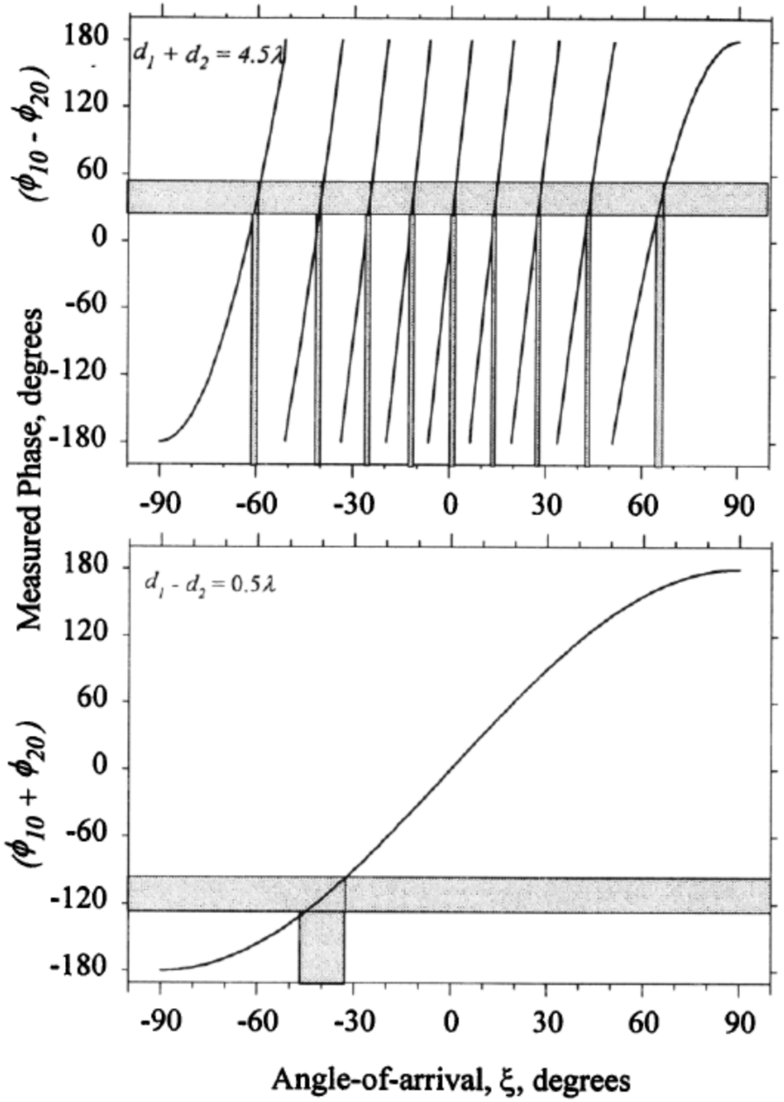
$$\phi_{20} = +\frac{2\pi d_2}{\lambda} \sin \xi$$

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

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

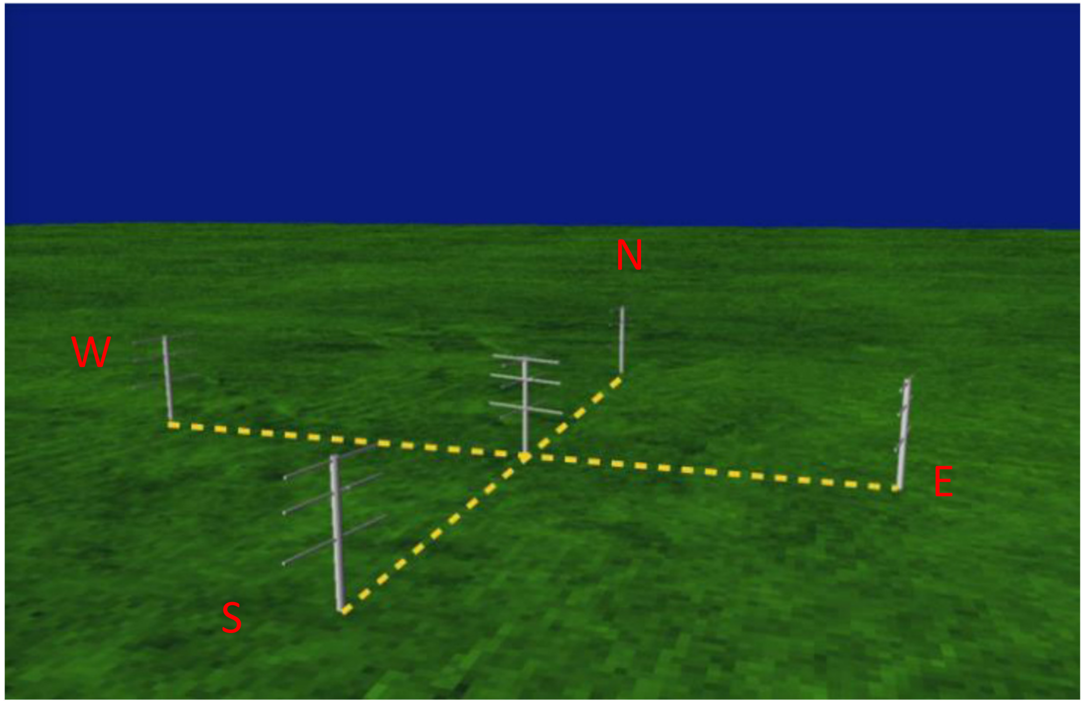
$d_1 = 2.5\ \lambda$
$d_2 = 2\ \lambda$

Principle (2)



Jones et al (1998)

Principle (3)



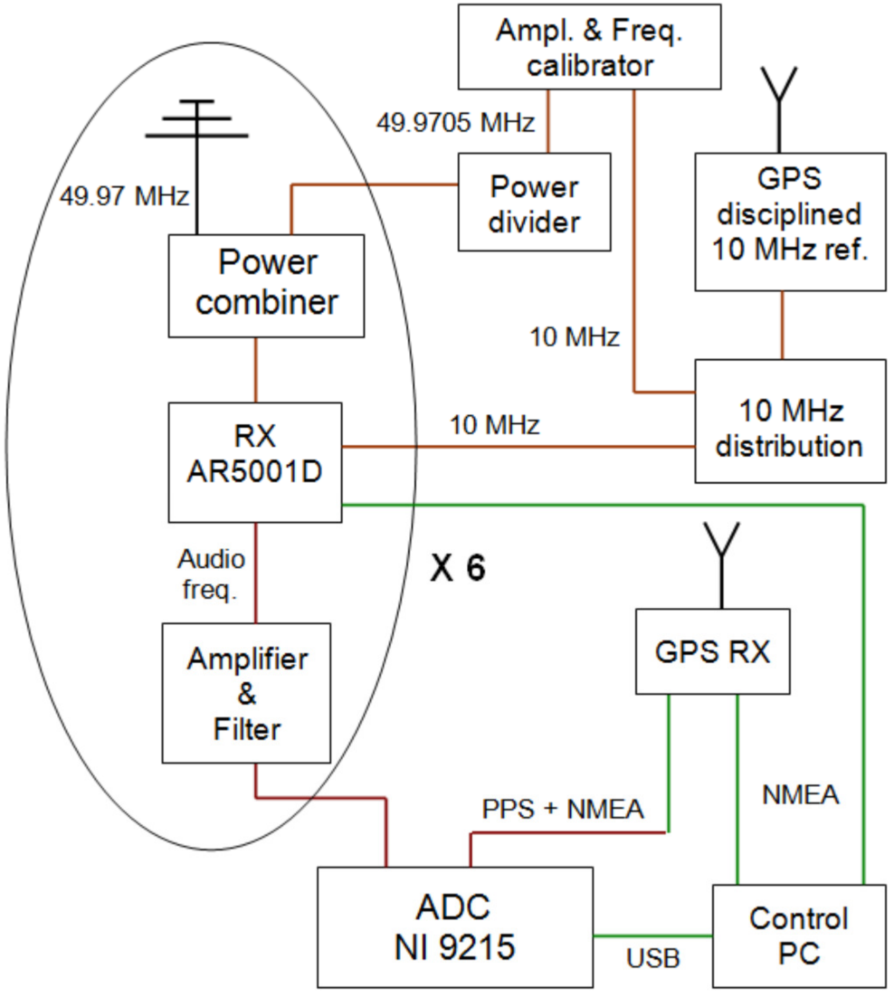
Angles of arrival

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

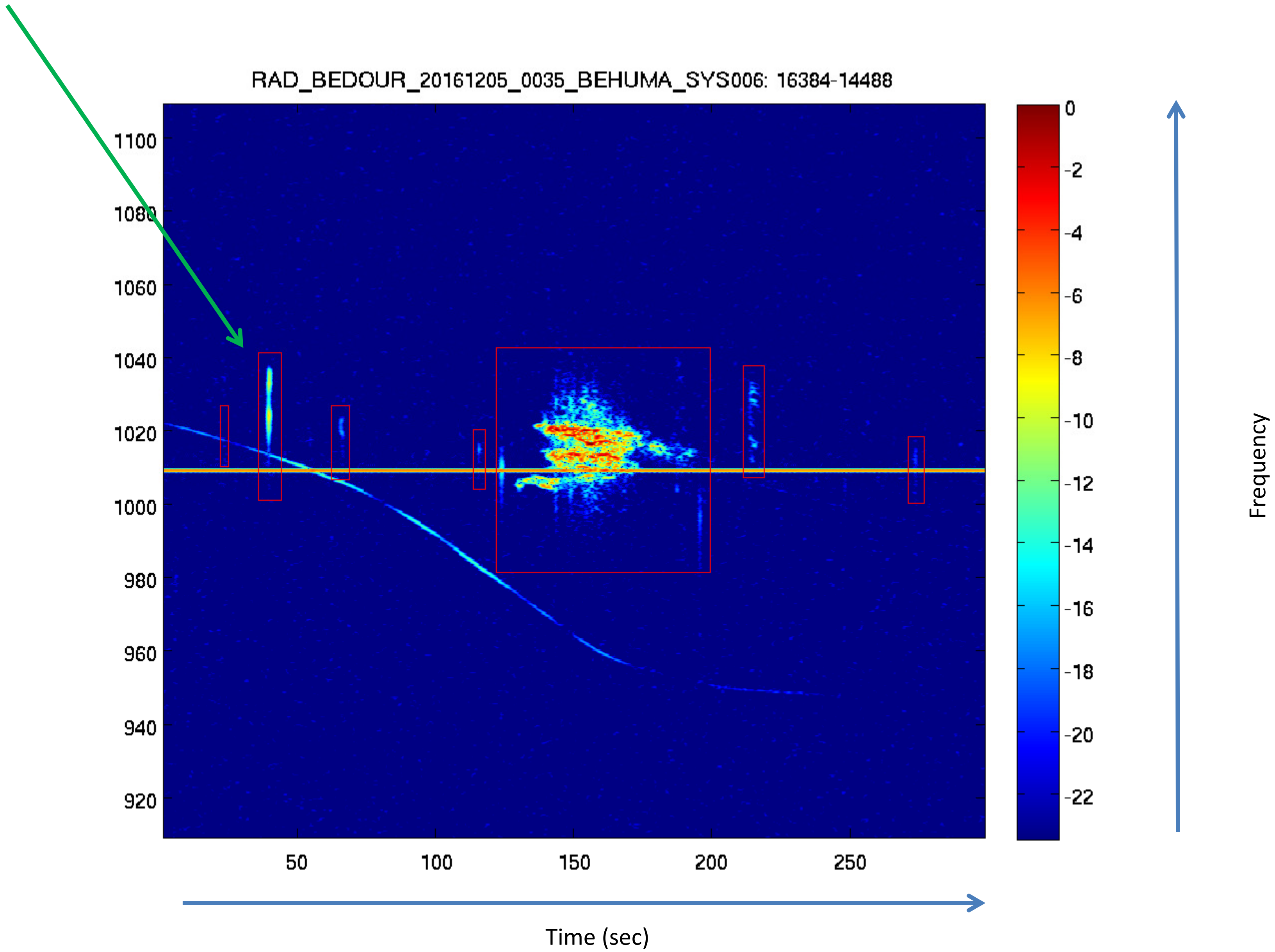
$$\alpha = \cos^{-1}\left(\frac{\cos \xi_2}{\cos \beta}\right) = \cos^{-1}\left(\frac{\cos \xi_1}{\cos \beta}\right)$$

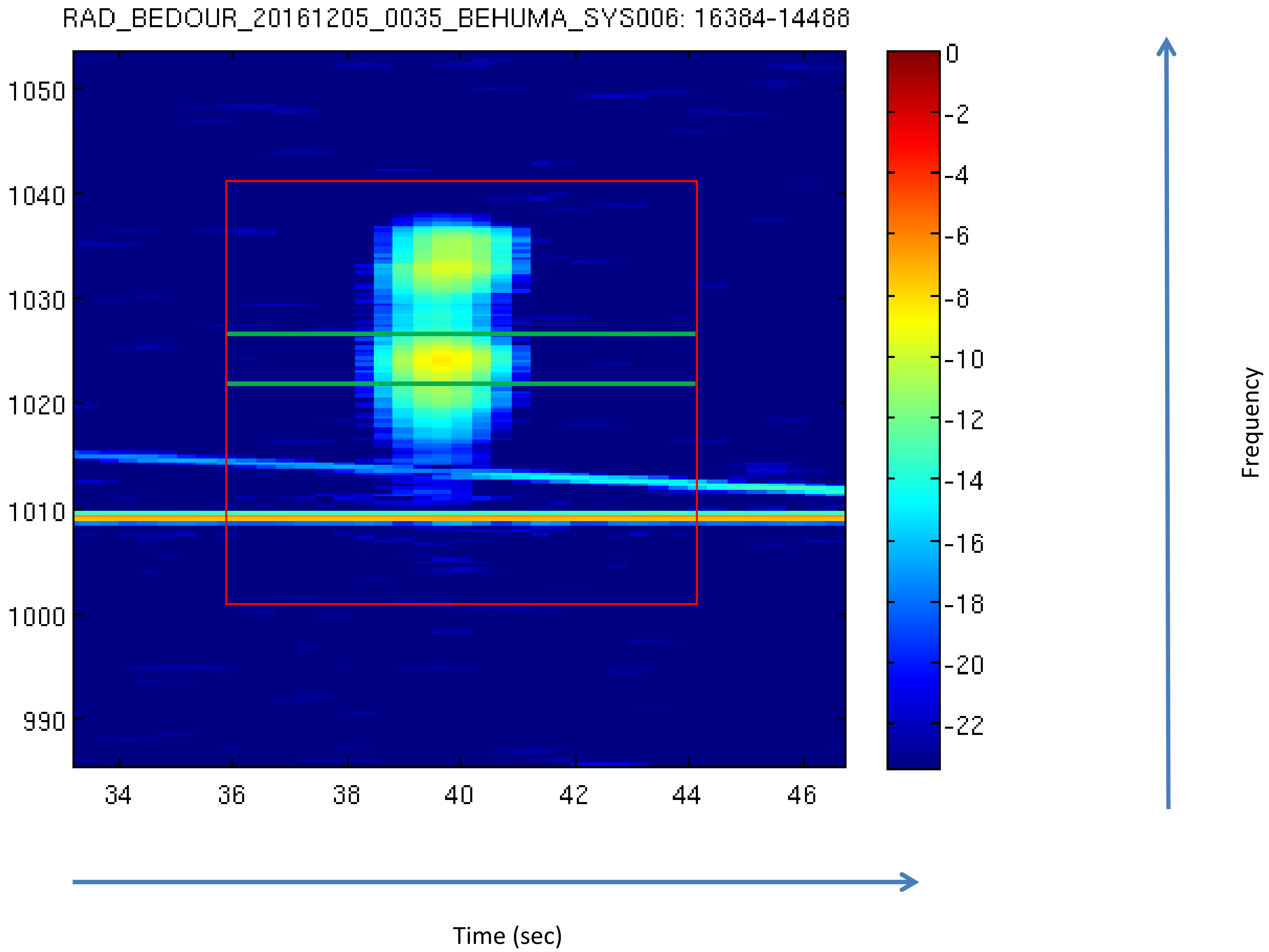
α : elevation β : azimuth (measured from North toward East)

Design of the interferometer



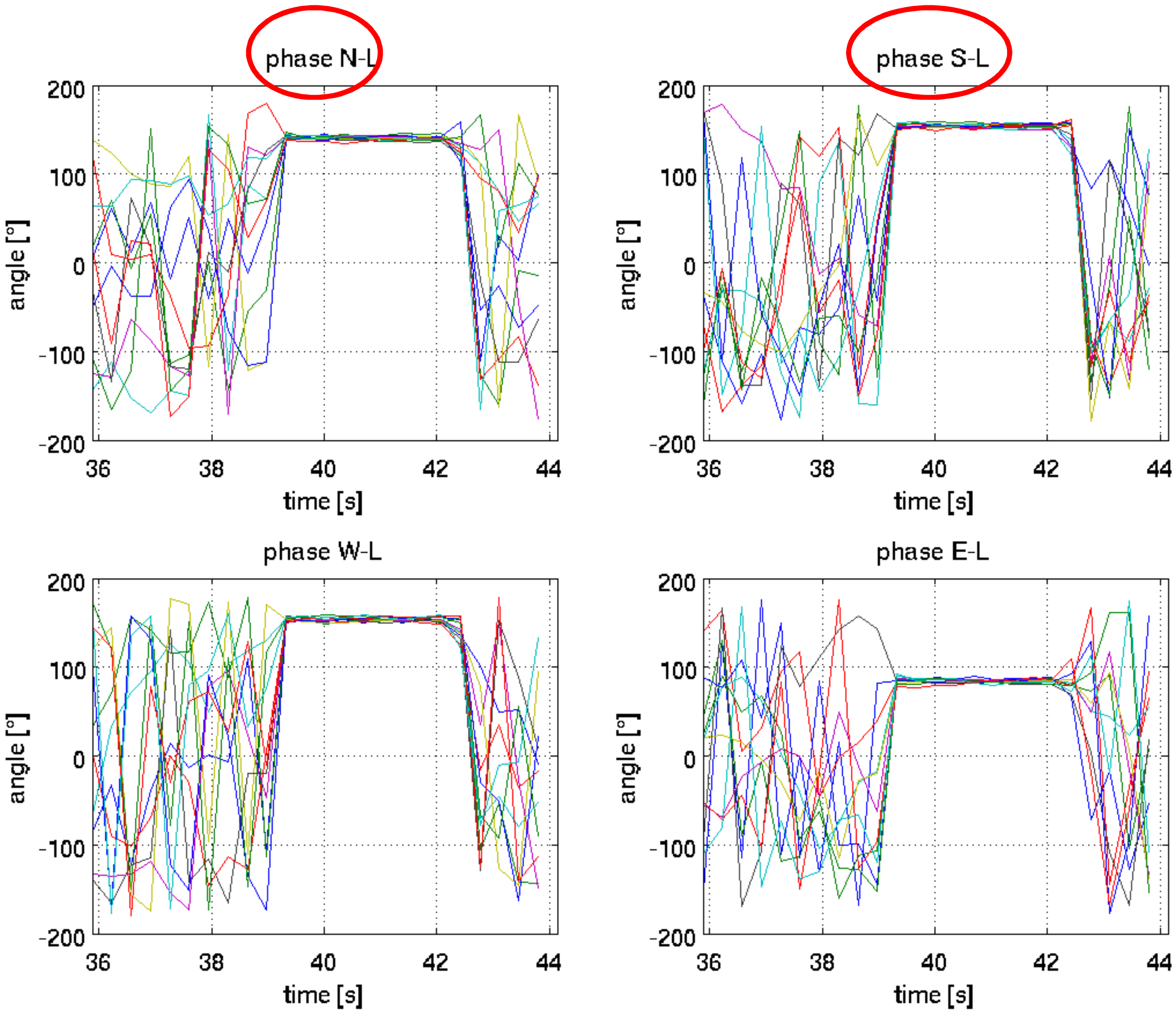
First example





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

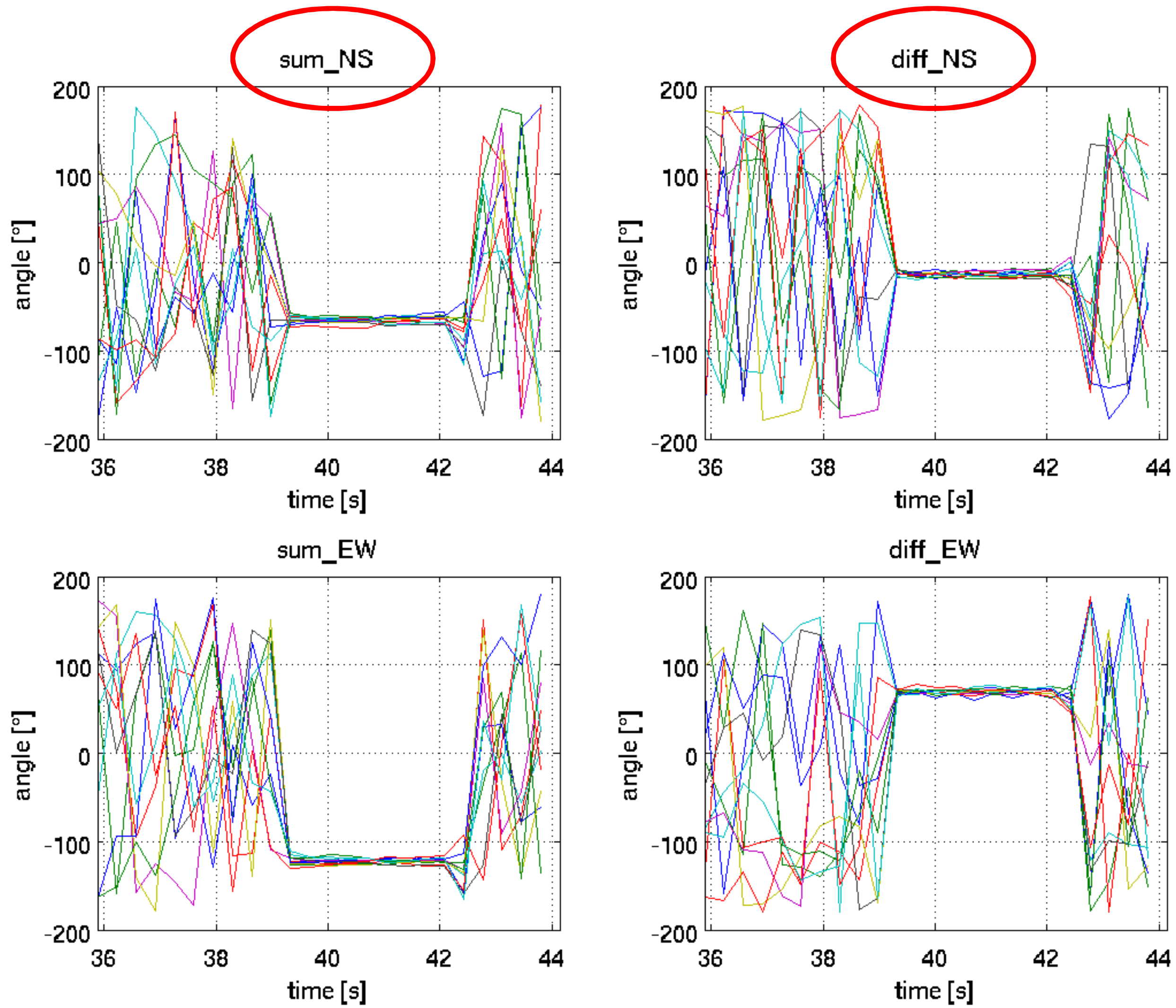


Each color =
1 frequency

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

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

Sum & Diff of phase differences

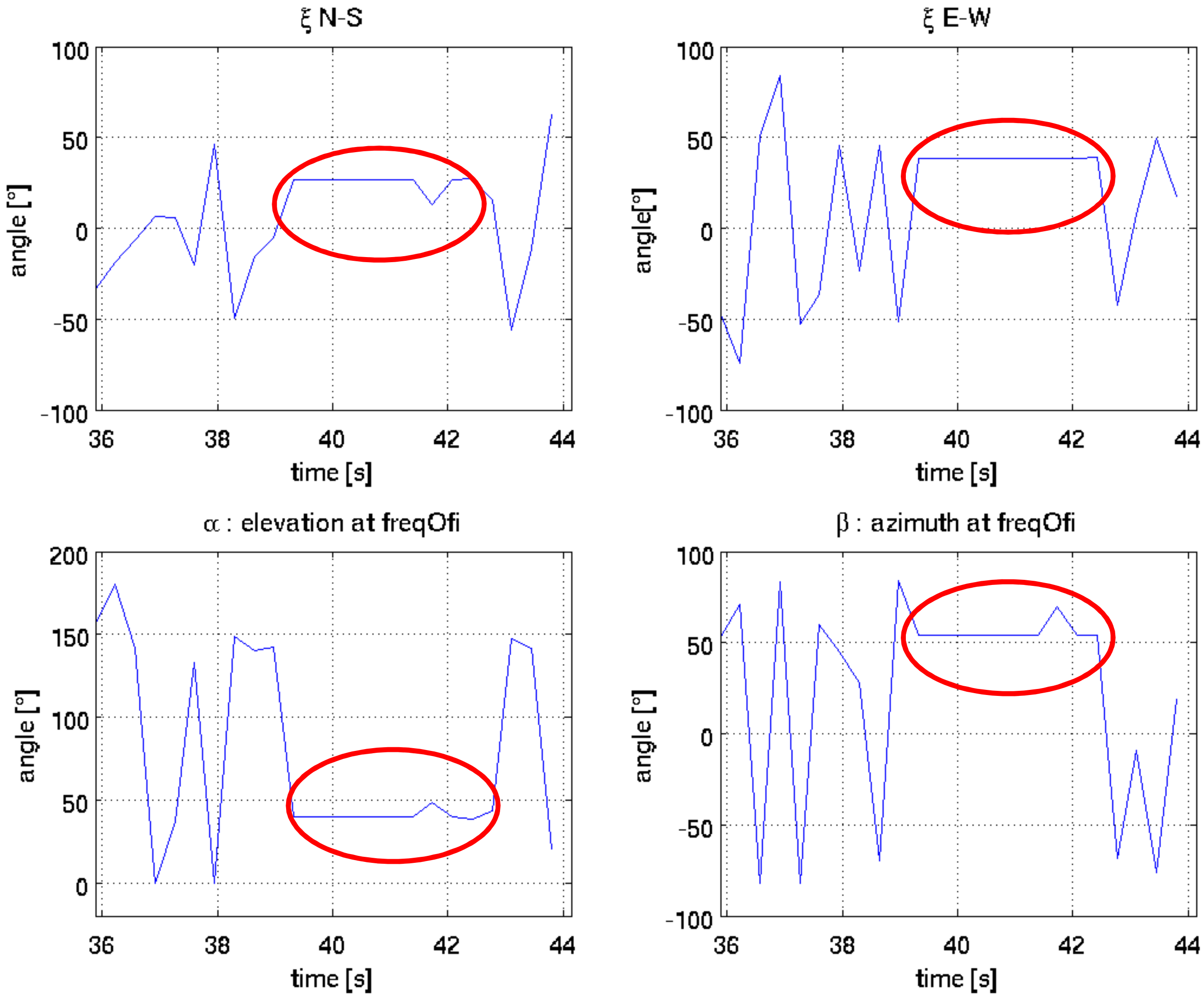


$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10} - \phi_{20})}{(d_1 + d_2)}$$

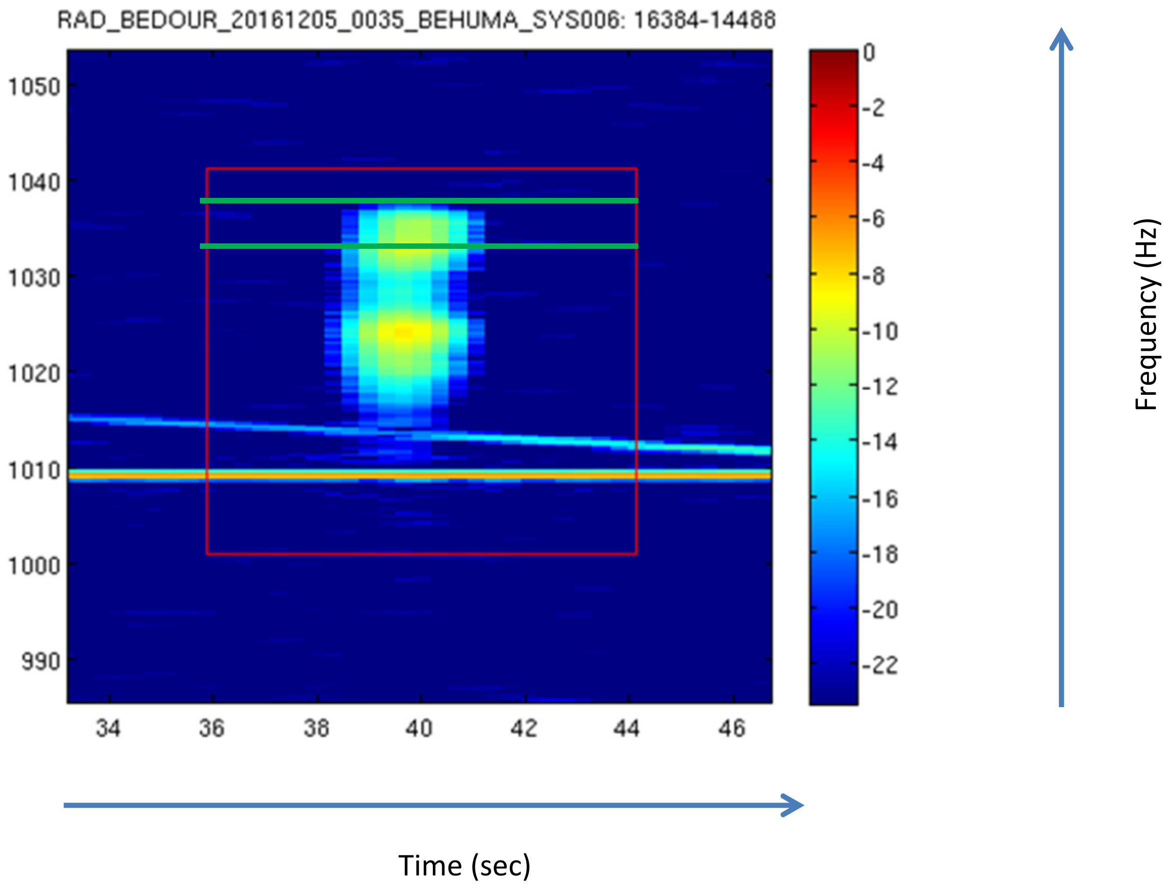
$$\sin\xi = -\frac{\lambda}{2\pi}\frac{(\phi_{10} + \phi_{20})}{(d_1 - d_2)}$$

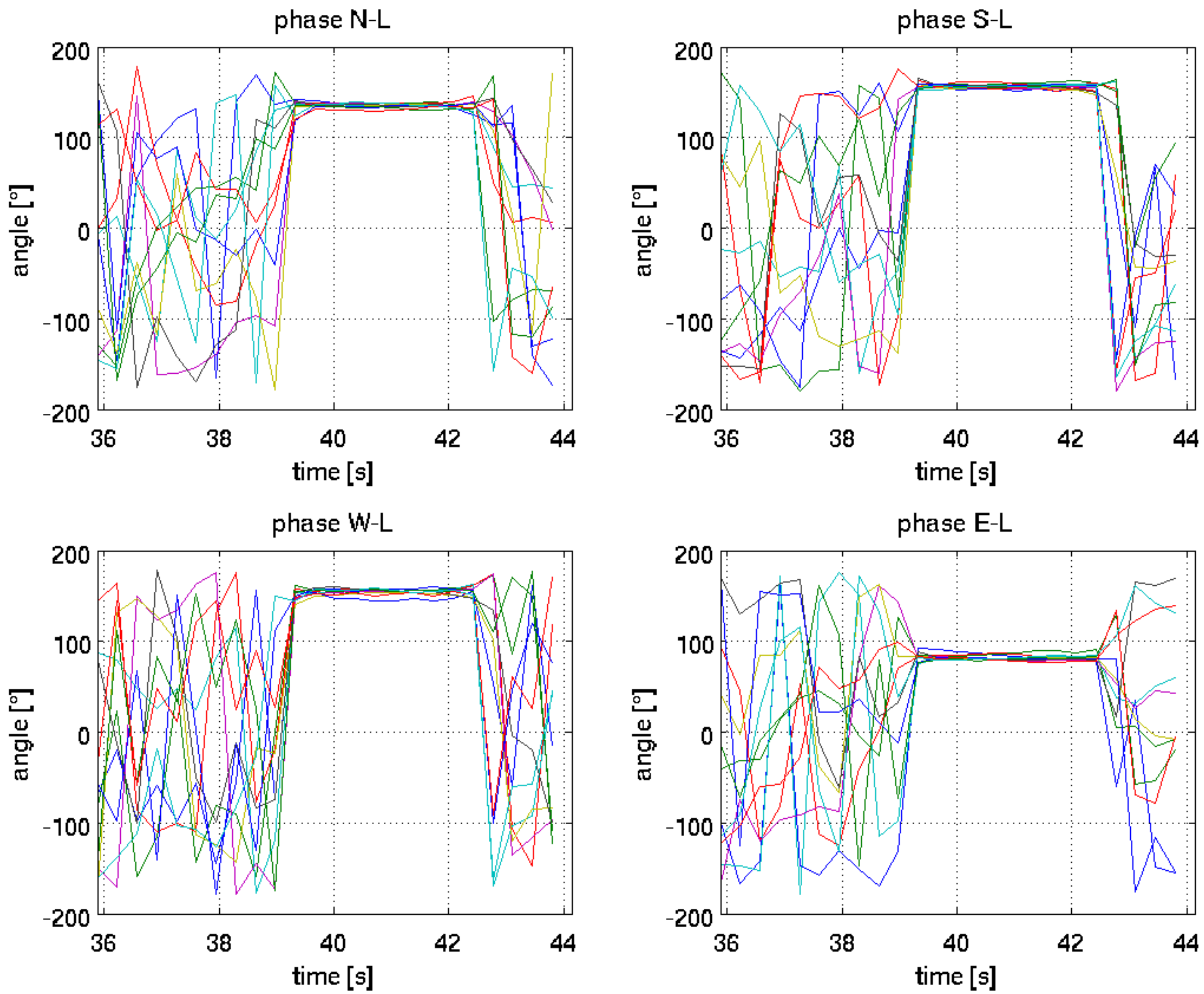
Angles of arrival

Only one frequency

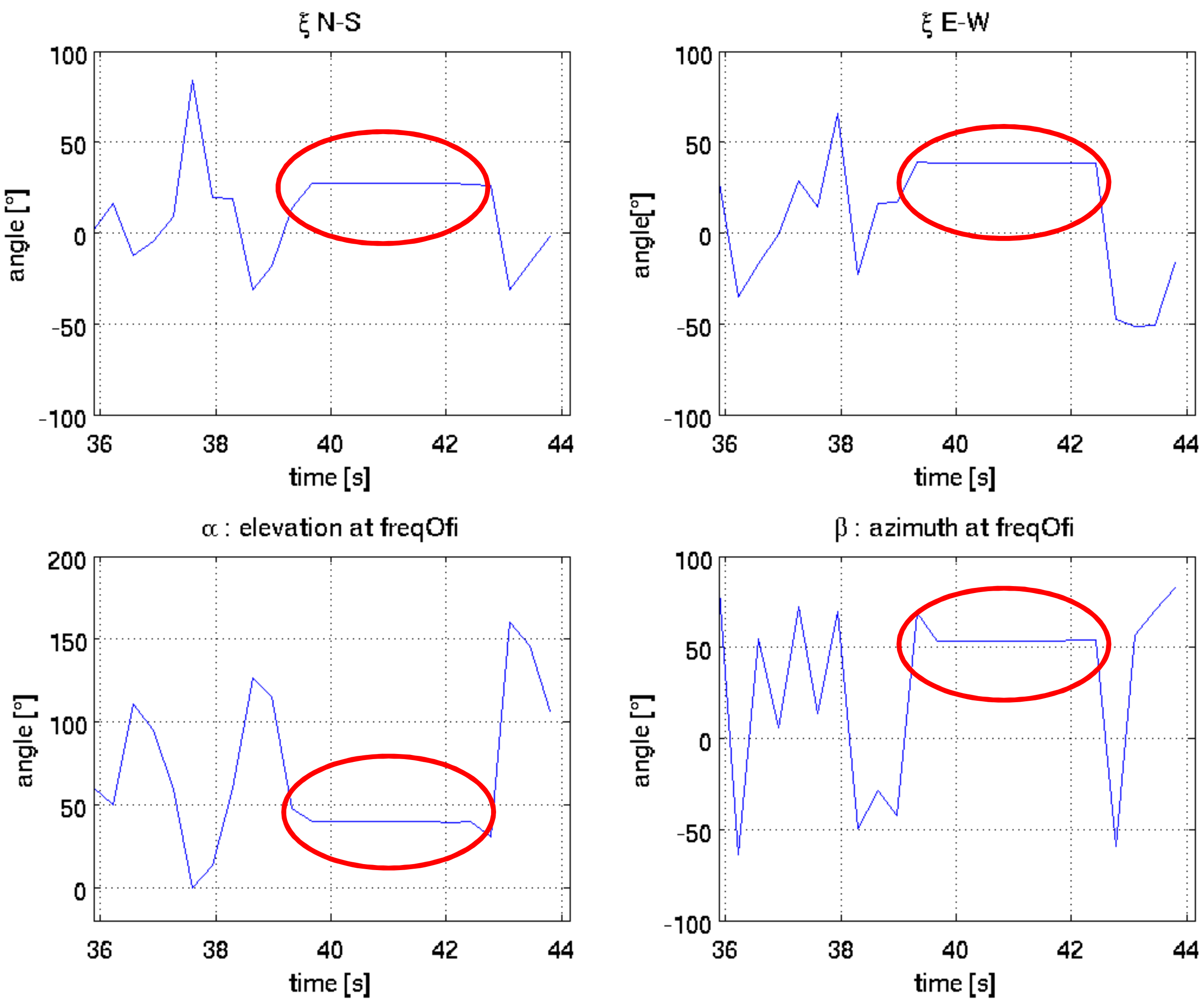


Same example, different frequencies

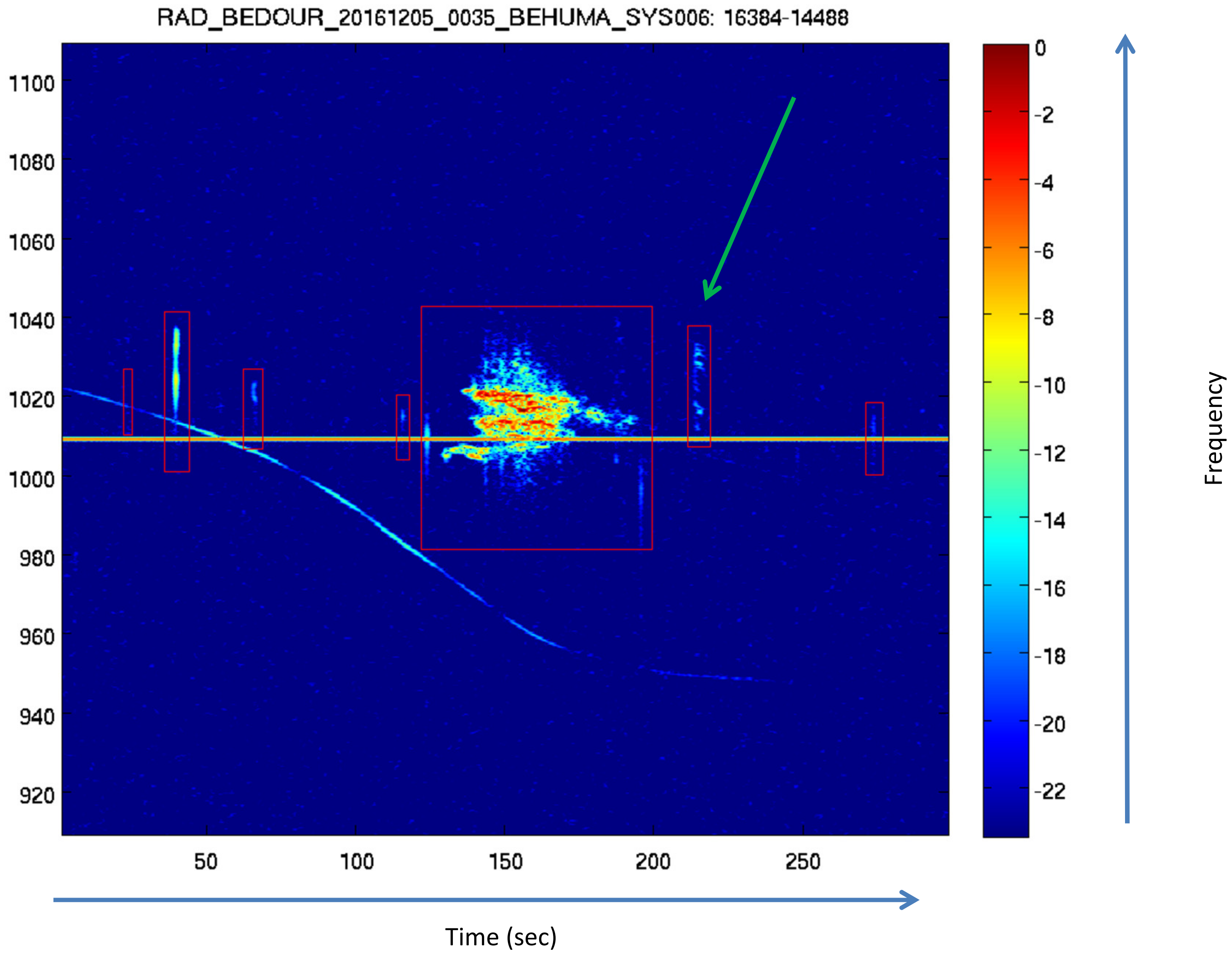


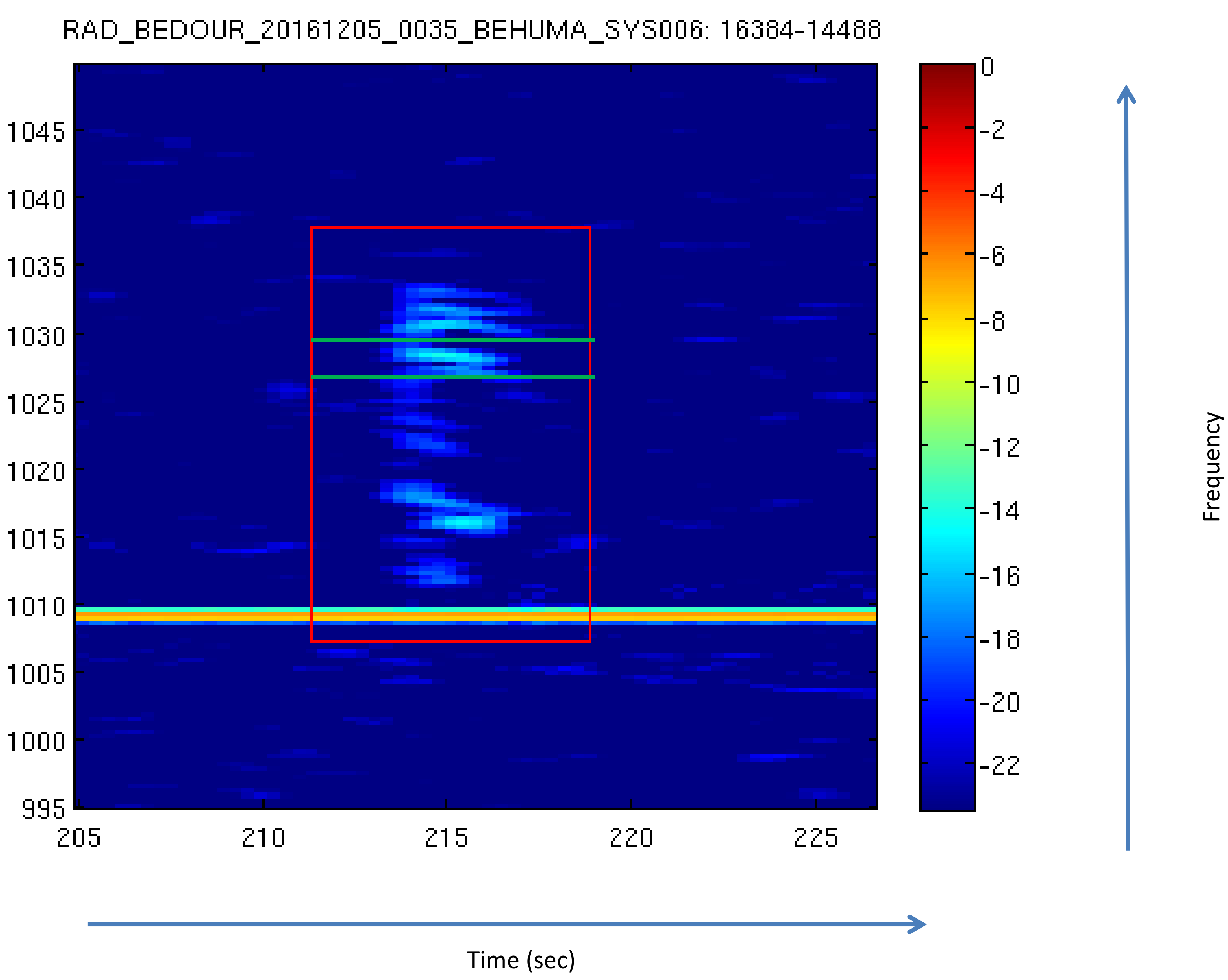

phase N-L
phase S-L
phase W-L
phase E-L
angle [°]
time [s]
200
100
0
-100
-200
36
38
40
42
44

Only one frequency

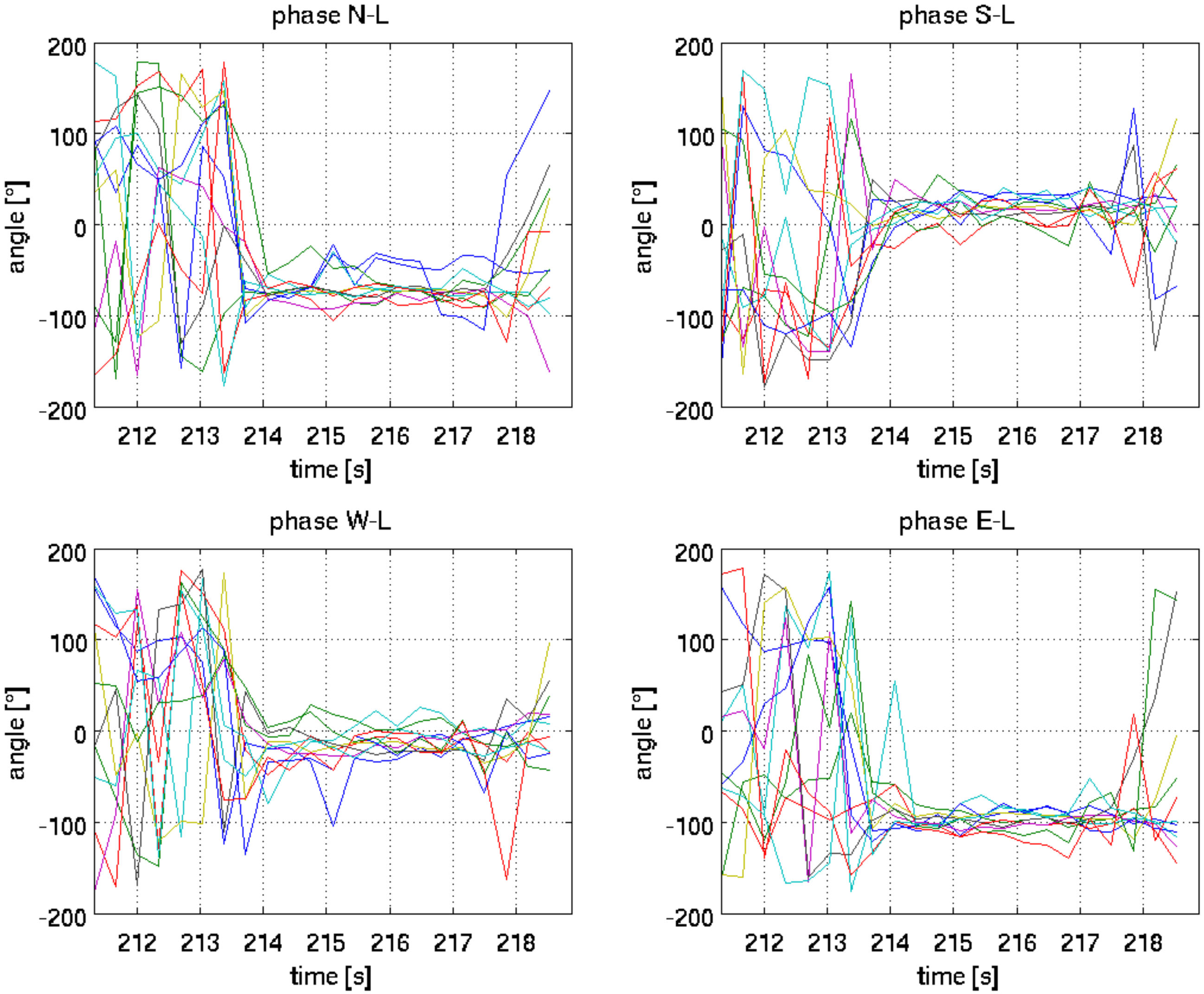


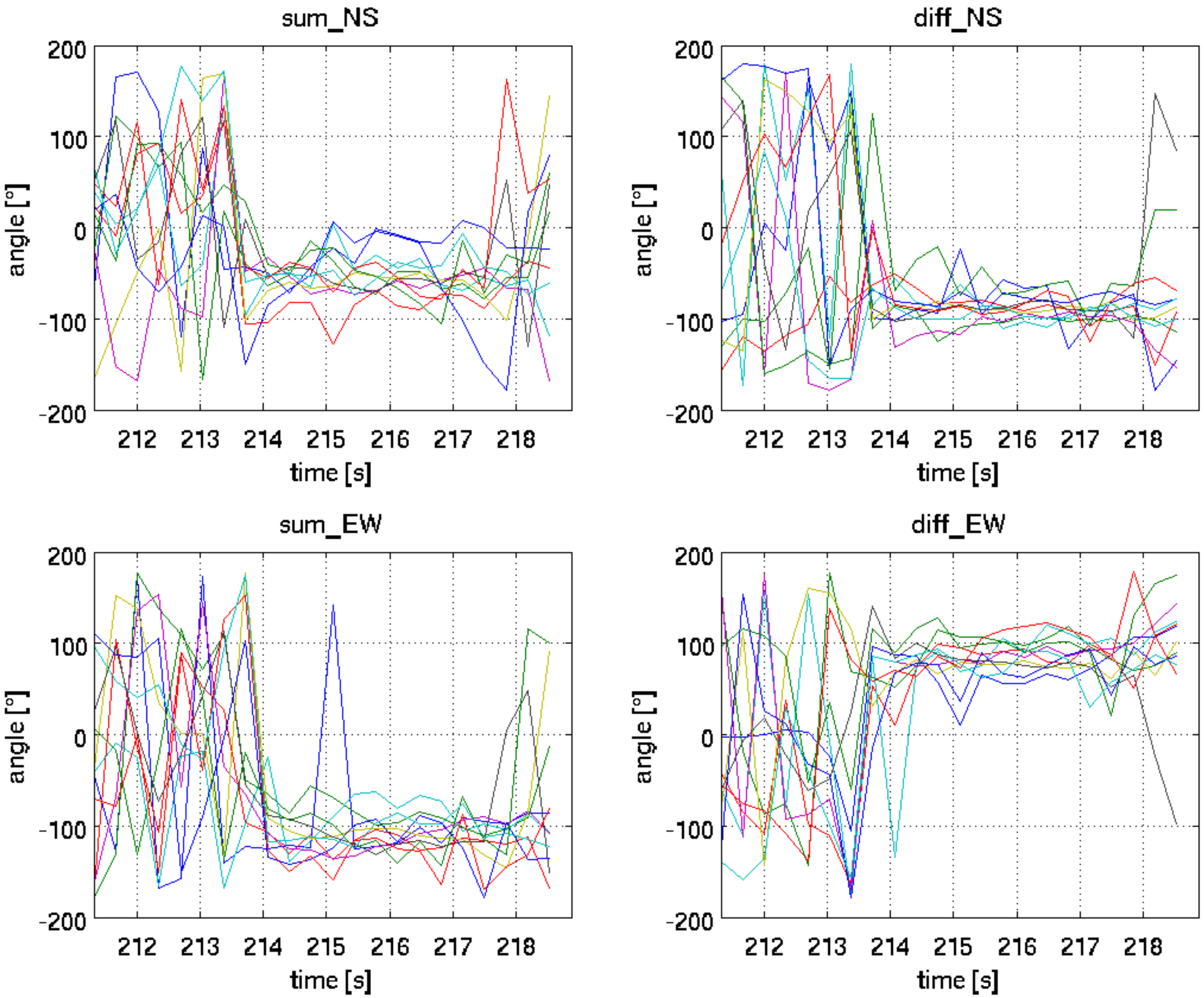
A less intense meteor echo





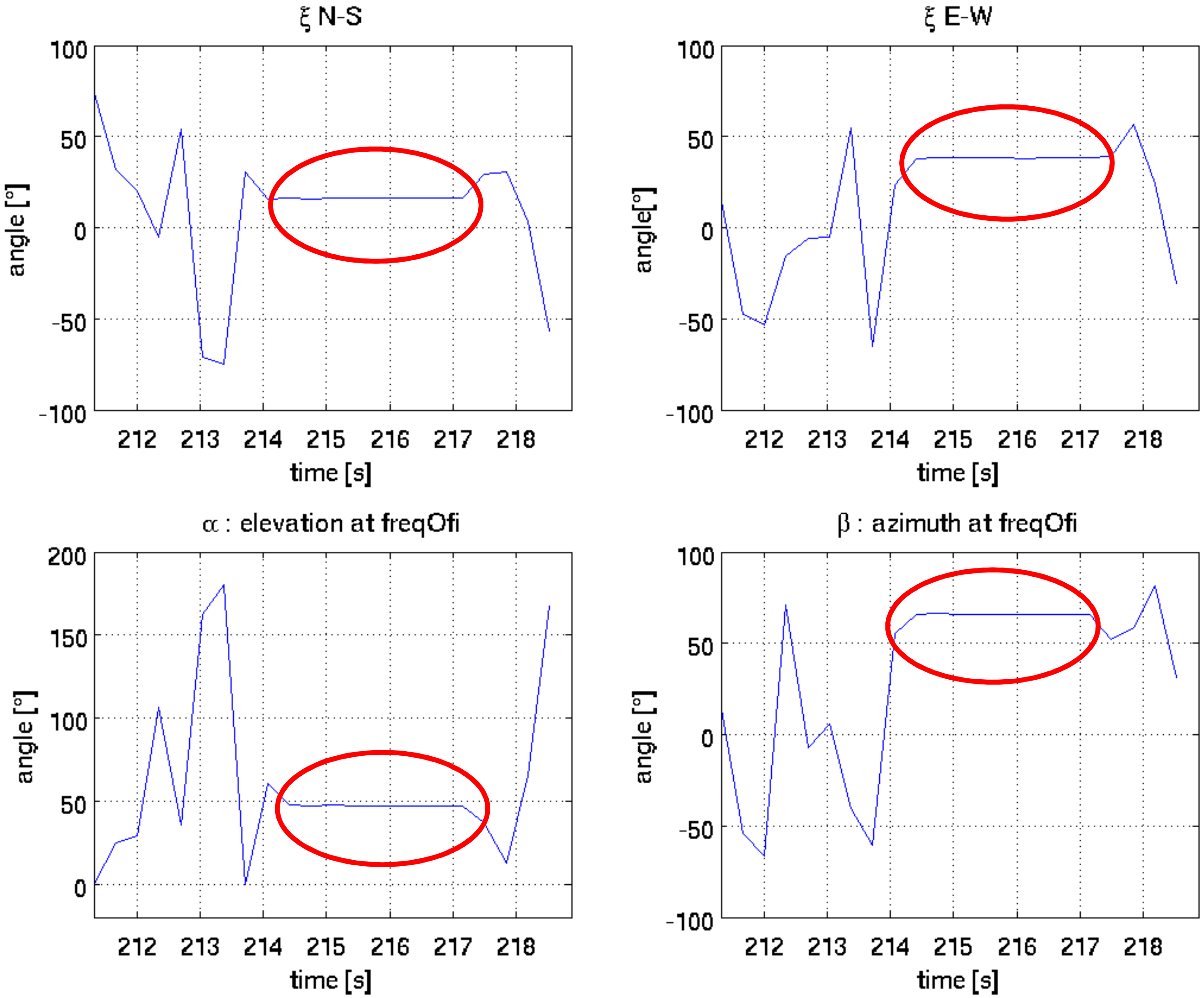
RAD_BEDOUR_20161205_0035_BEHUMA_SYS006: 16384-14488
1045
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
205
210
215
220
225
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
Frequency
Time (sec)


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

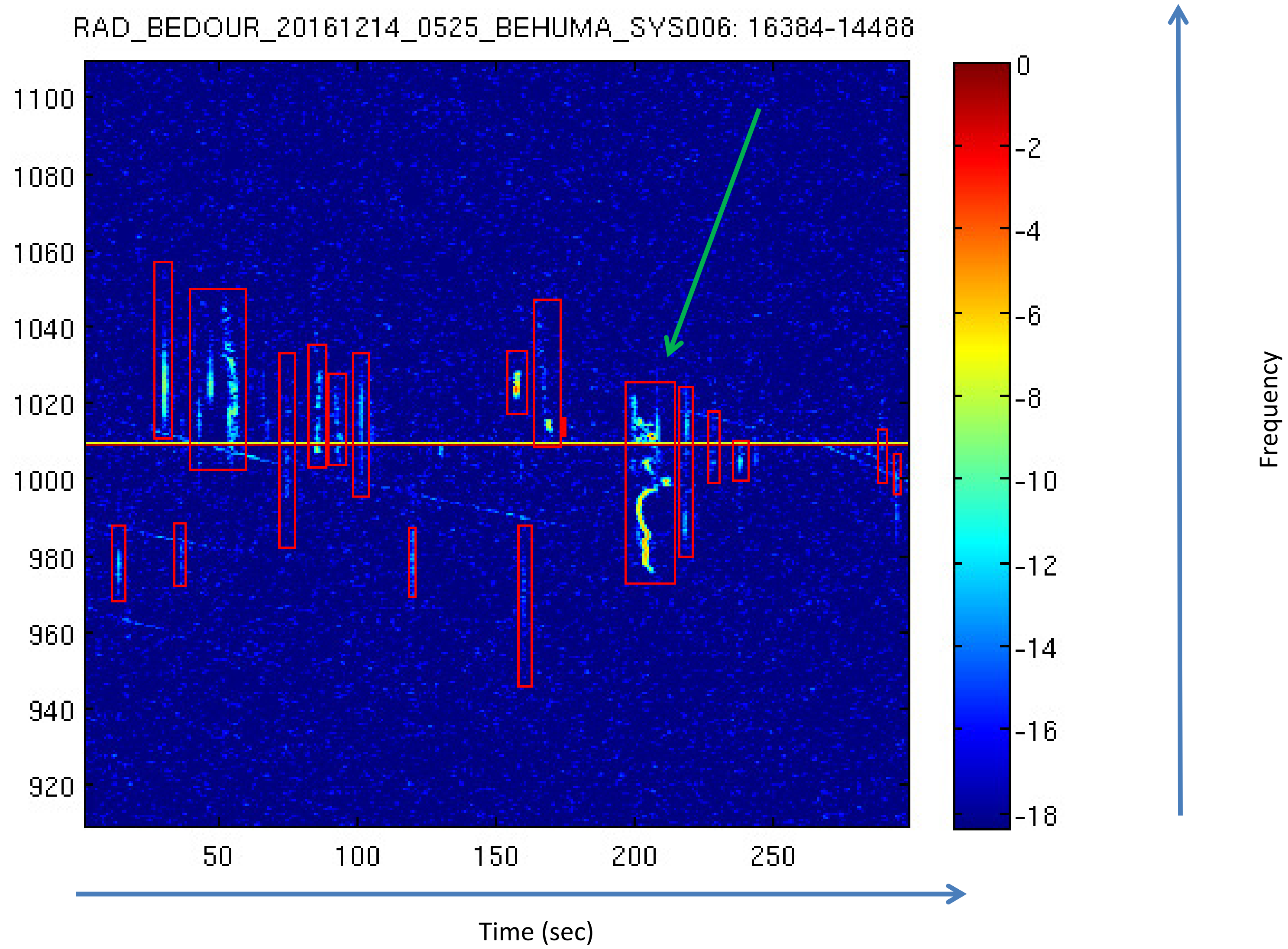


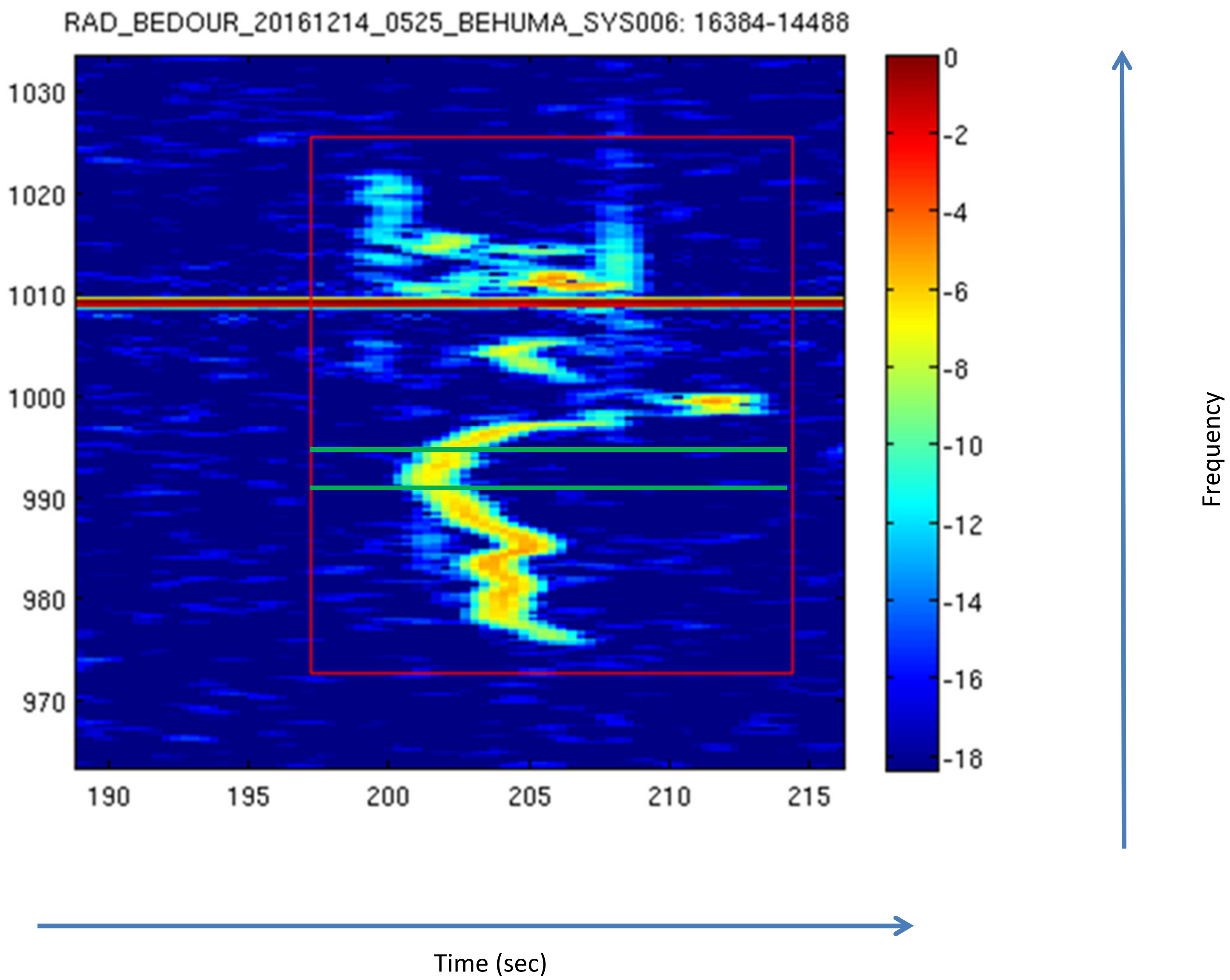
sum_NS
diff_NS
sum_EW
diff_EW
angle [°]
time [s]
200
100
0
-100
-200
212 213 214 215 216 217 218

Only one frequency

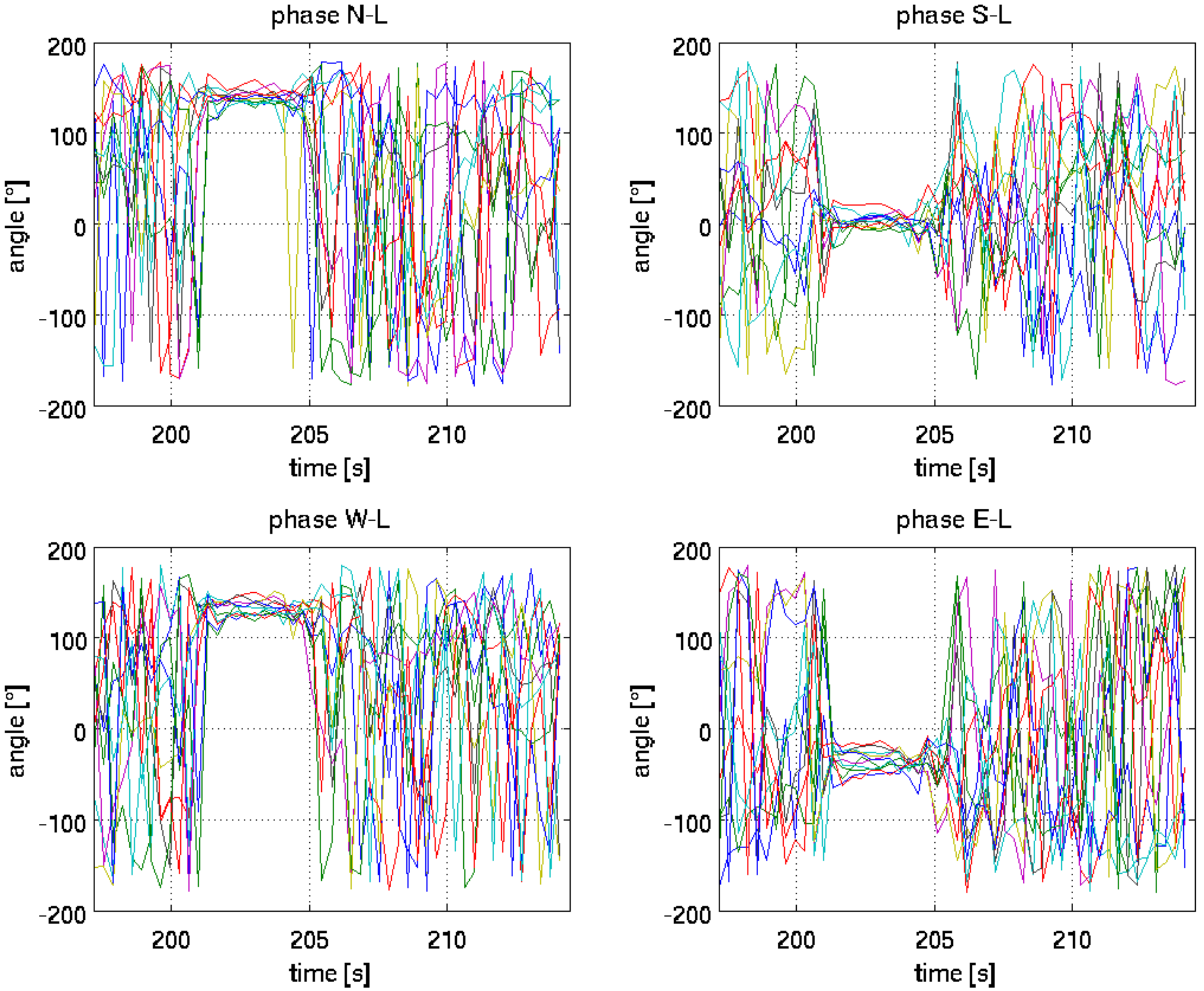


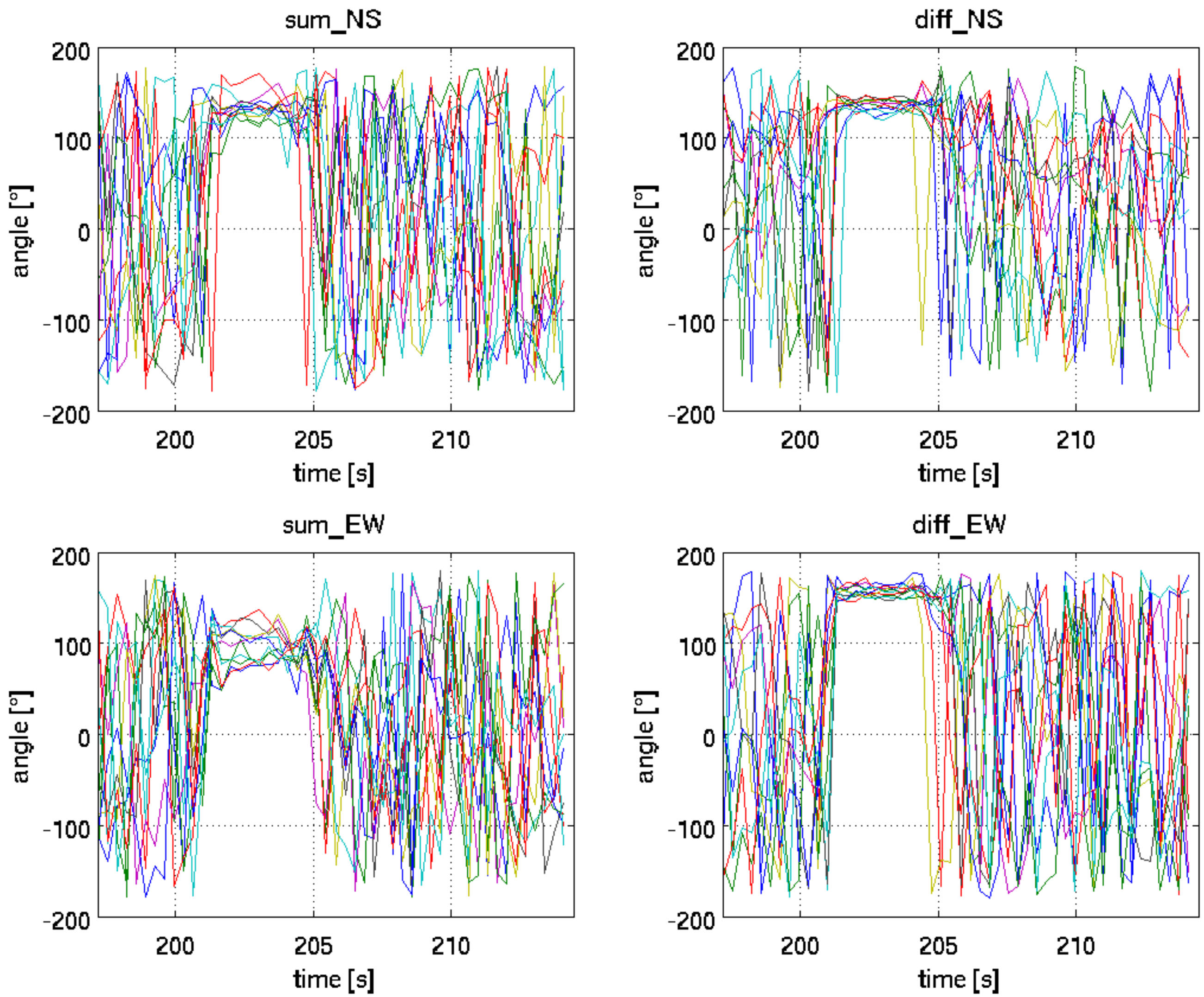
Epsilon echo

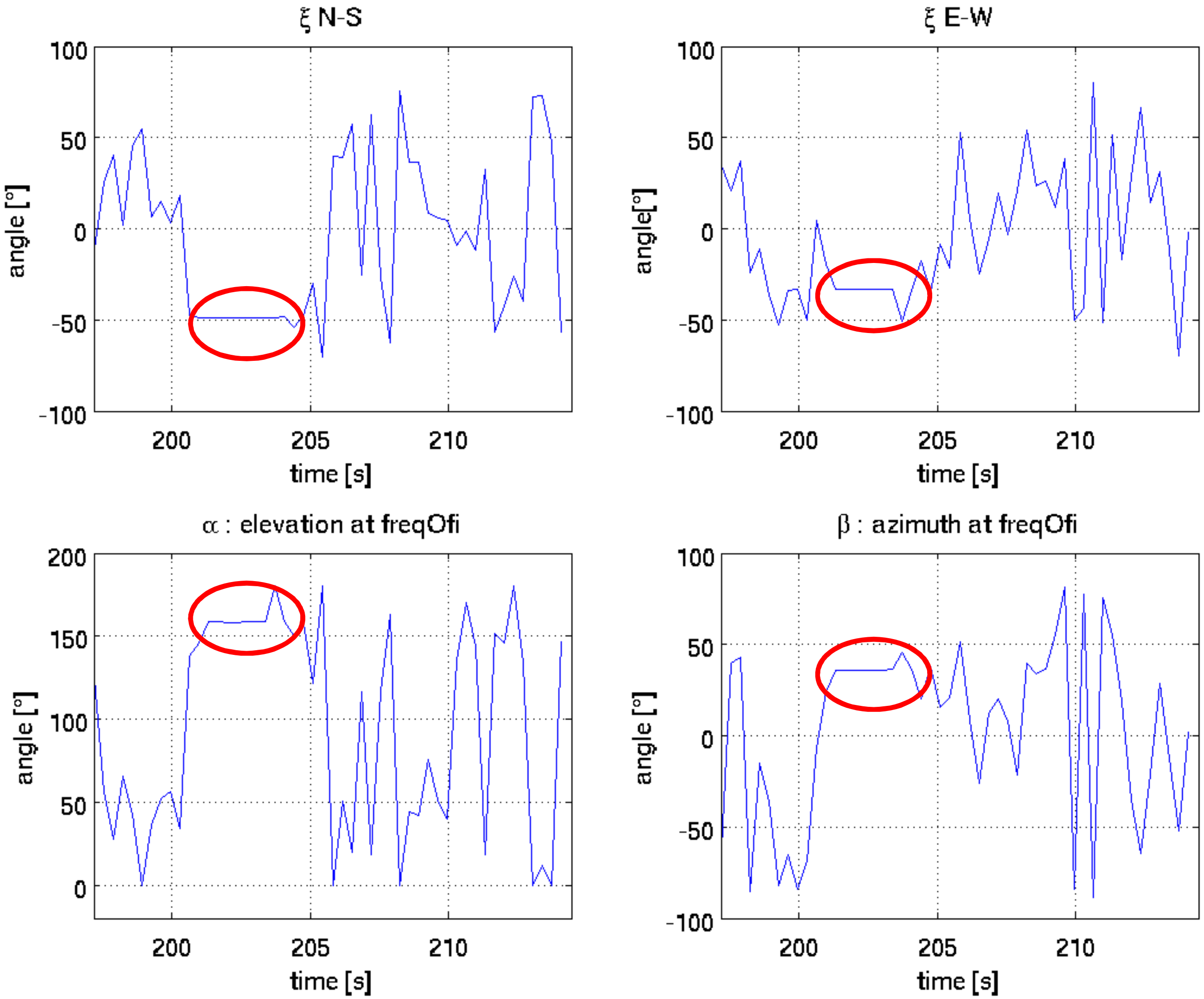


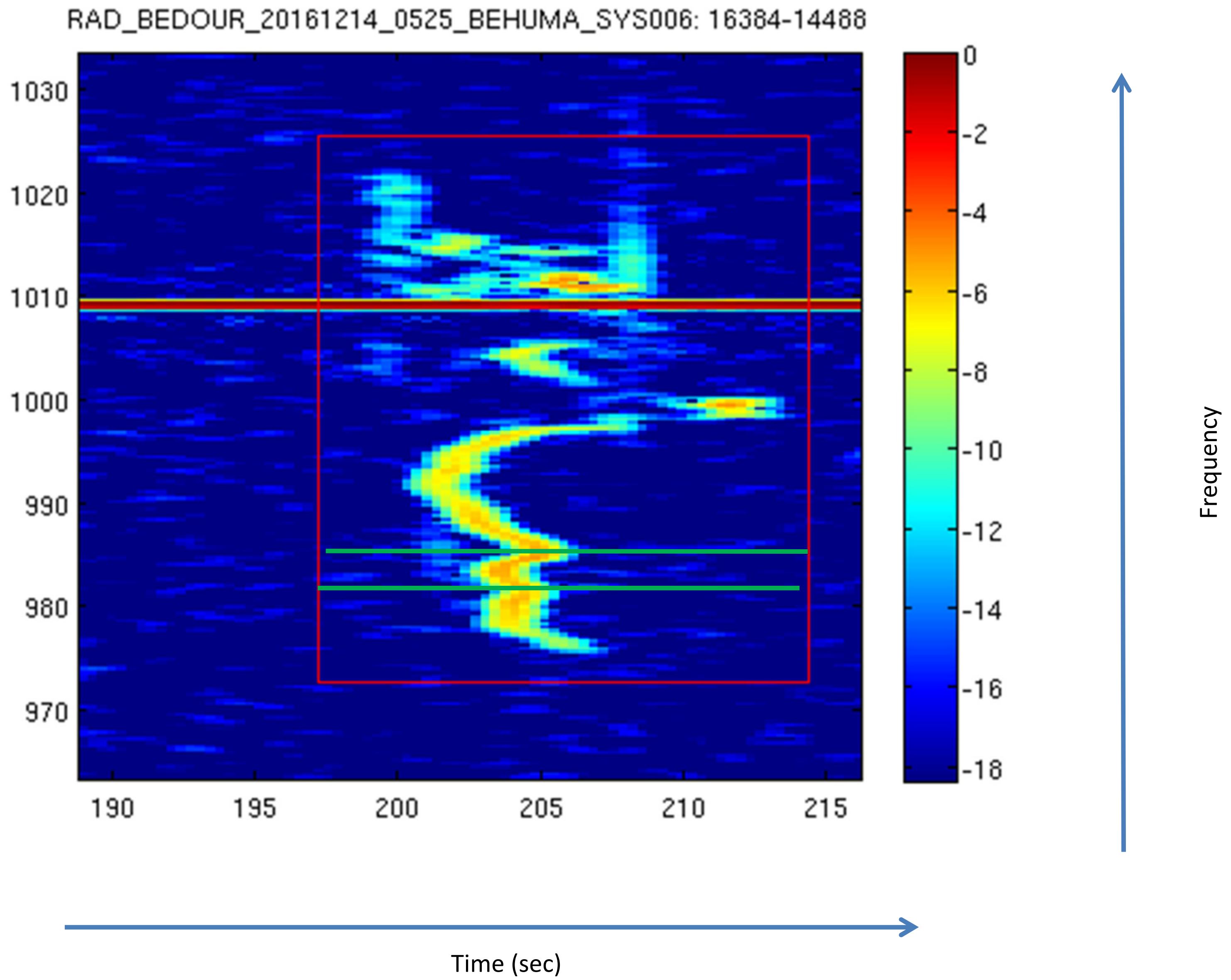


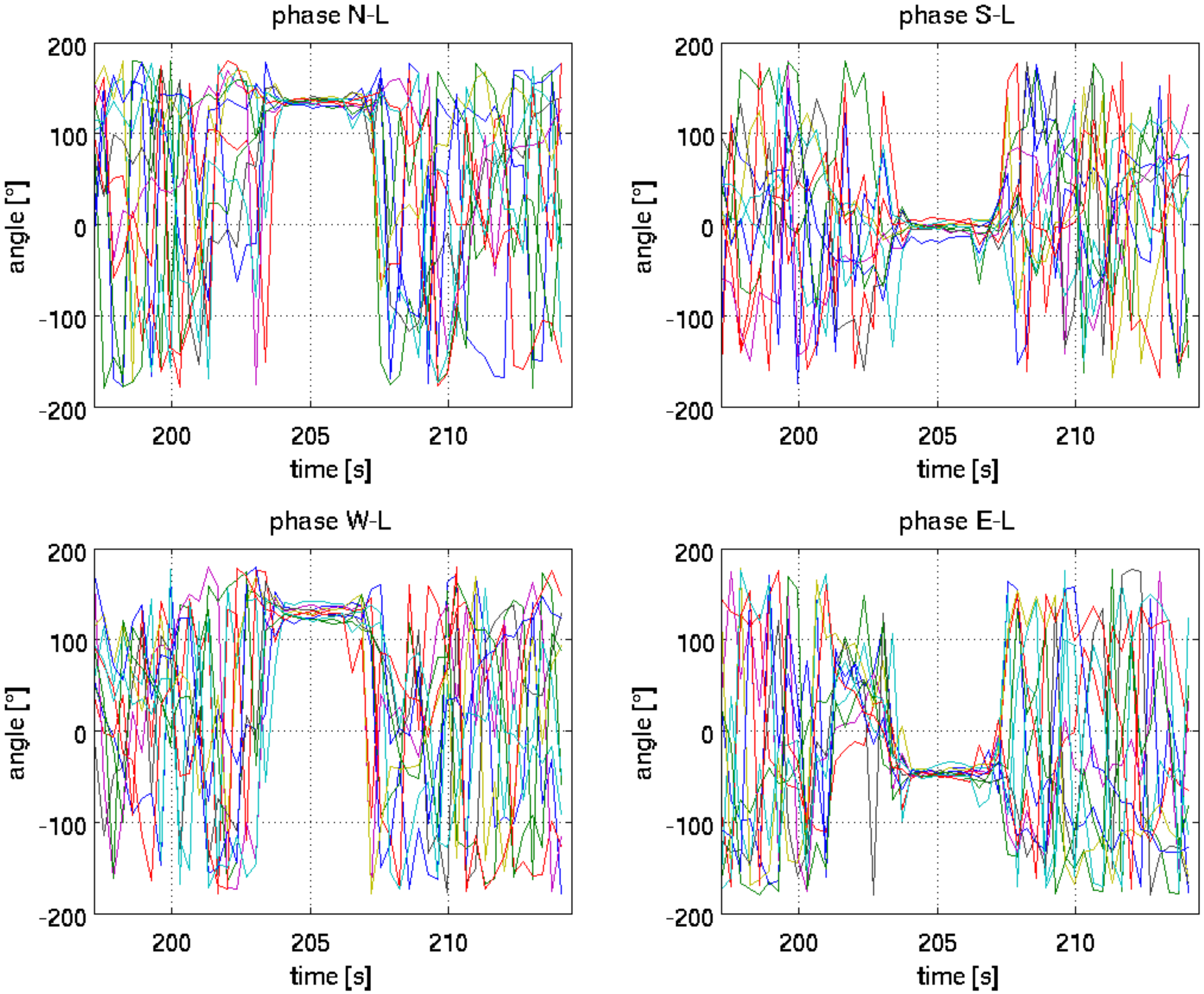
RAD_BEDOUR_20161214_0525_BEHUMA_SYS006: 16384-14488
1030
1020
1010
1000
990
980
970
190
195
200
205
210
215
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
Frequency
Time (sec)

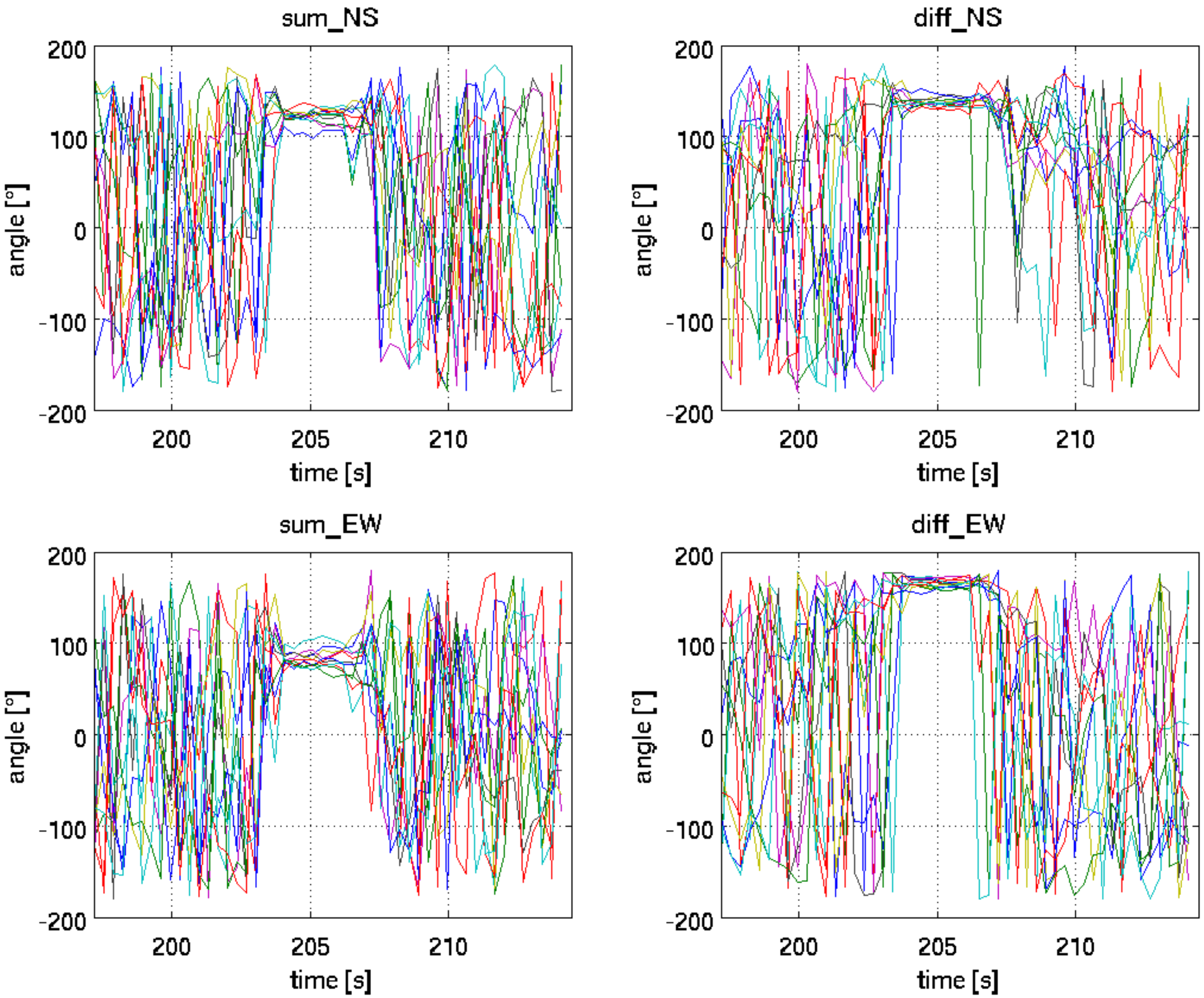

phase N-L
phase S-L
phase W-L
phase E-L
angle [°]
time [s]
200
100
0
-100
-200
200
205
210


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

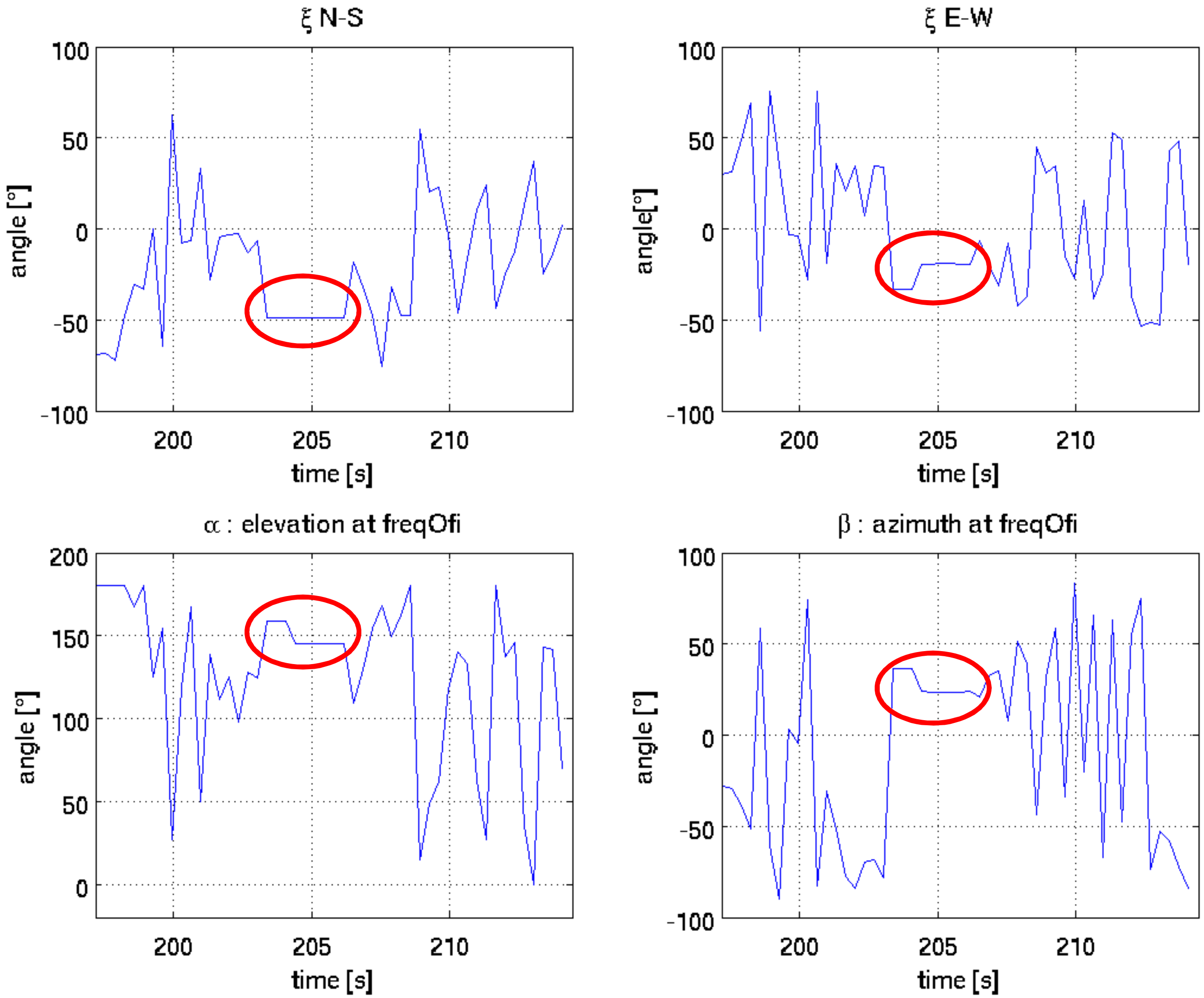

ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
angle[°]
time [s]
100
50
0
-50
-100
200
150
200
205
210


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

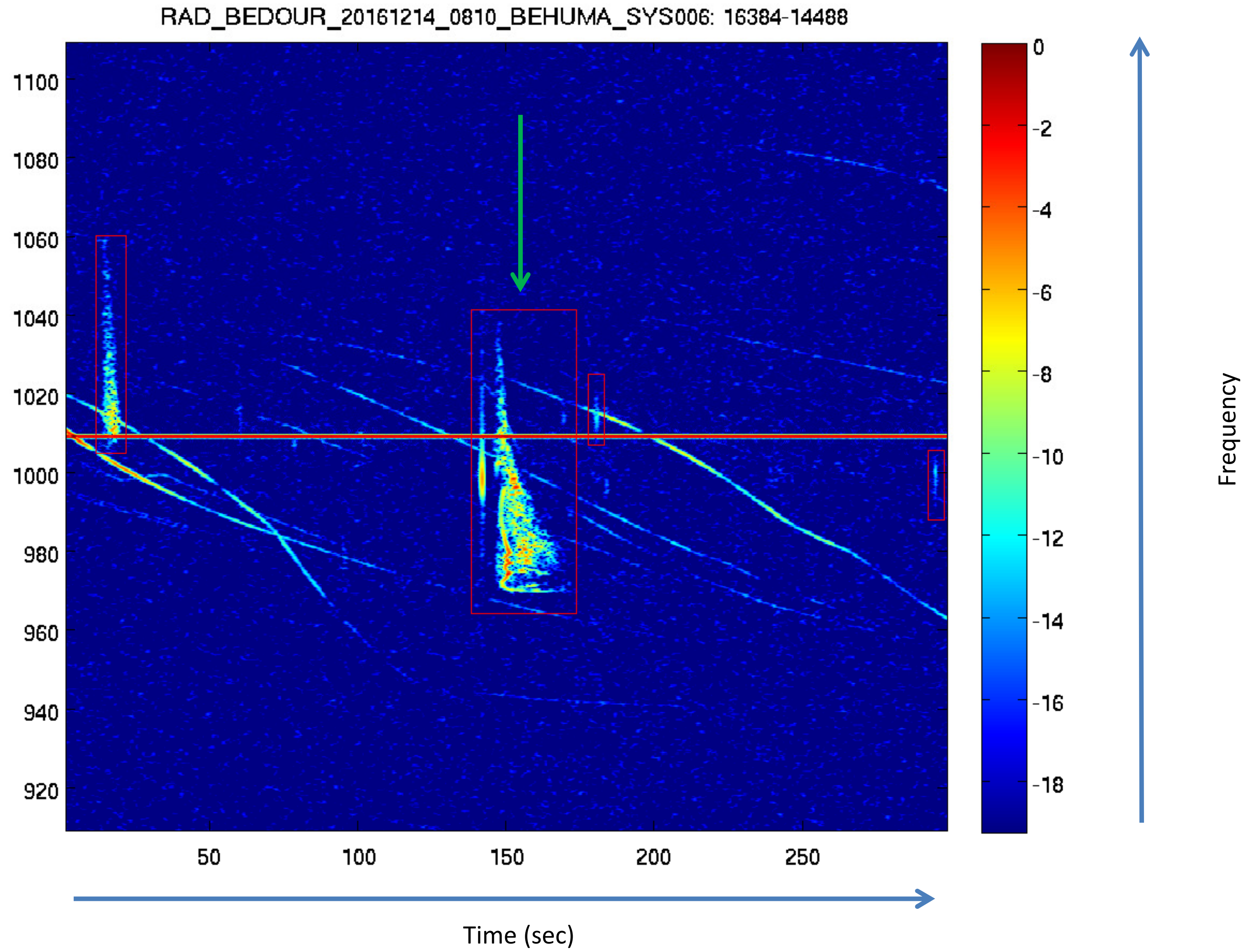


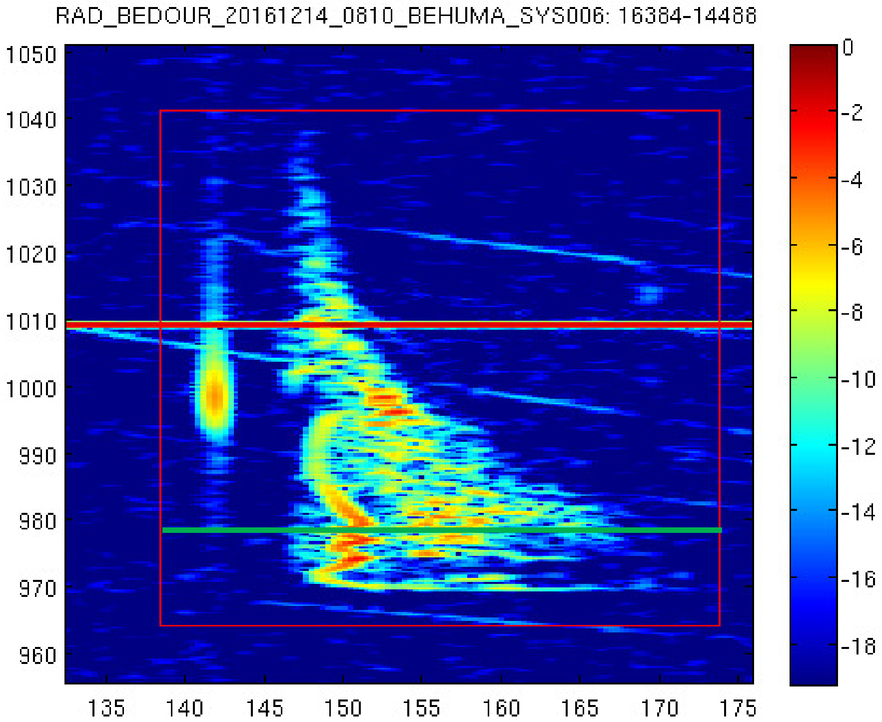
sum_NS
diff_NS
sum_EW
diff_EW
angle [°]
time [s]
200
100
0
-100
-200
200
205
210

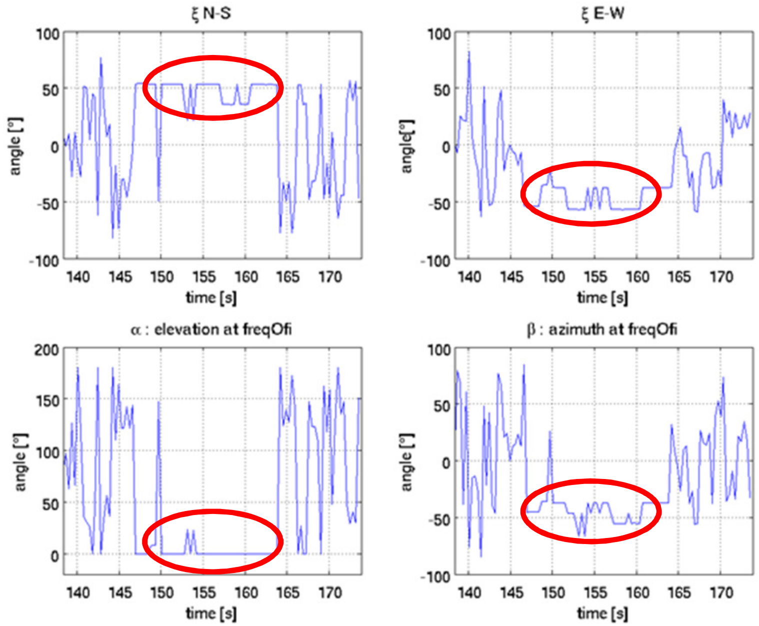


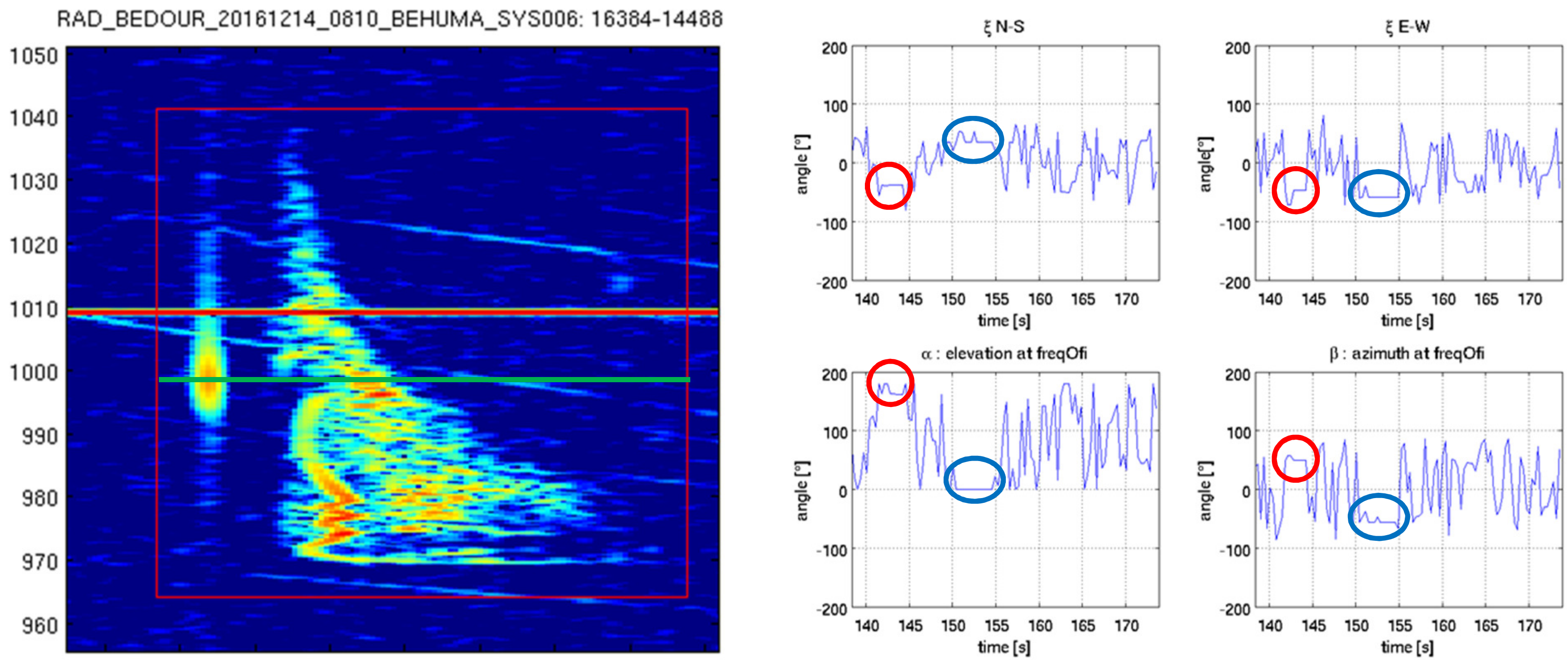
ξ N-S
ξ E-W
α : elevation at freqOfi
β : azimuth at freqOfi
angle [°]
time [s]
100
50
0
-50
-100
200
150
200
205
210

A long overdense meteor echo




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]



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

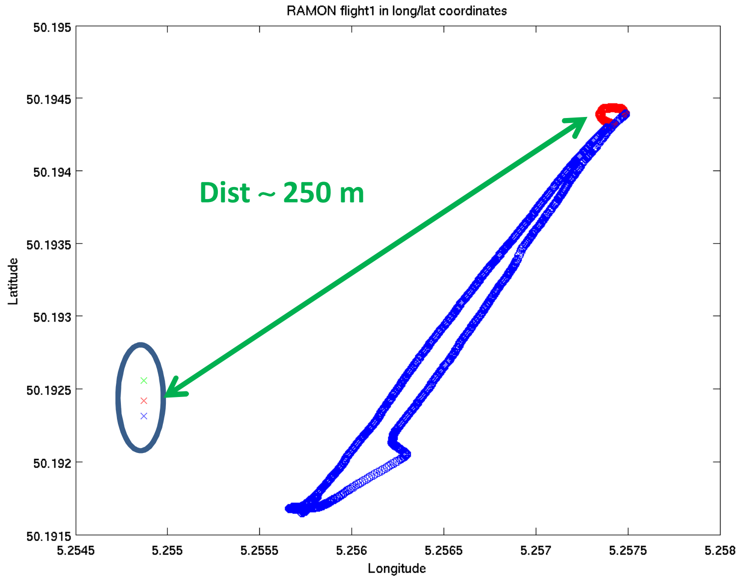
- Phases become coherent as soon as a meteor echo occurs. The higher the S/N ratio, the more stable the results for the angles of arrival
- For the fainter meteor echoes, it might be interesting to sum up the contributions of individual frequencies present in the meteor echo to increase the S/N ratio. 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, e.g. the difference in length of the cables going from the antenna to the receiver

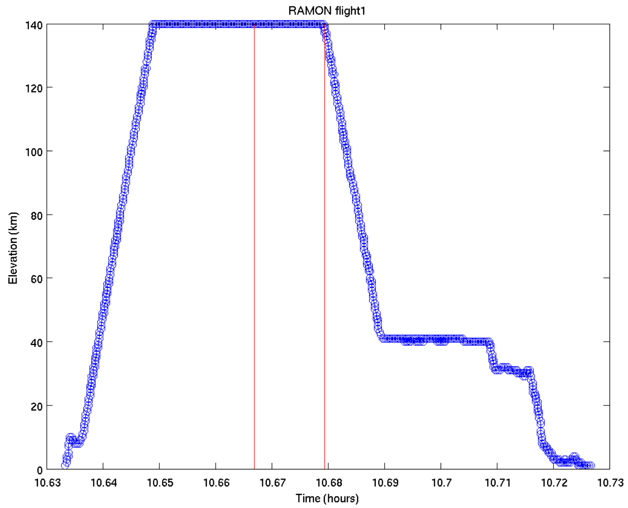
Calibration

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

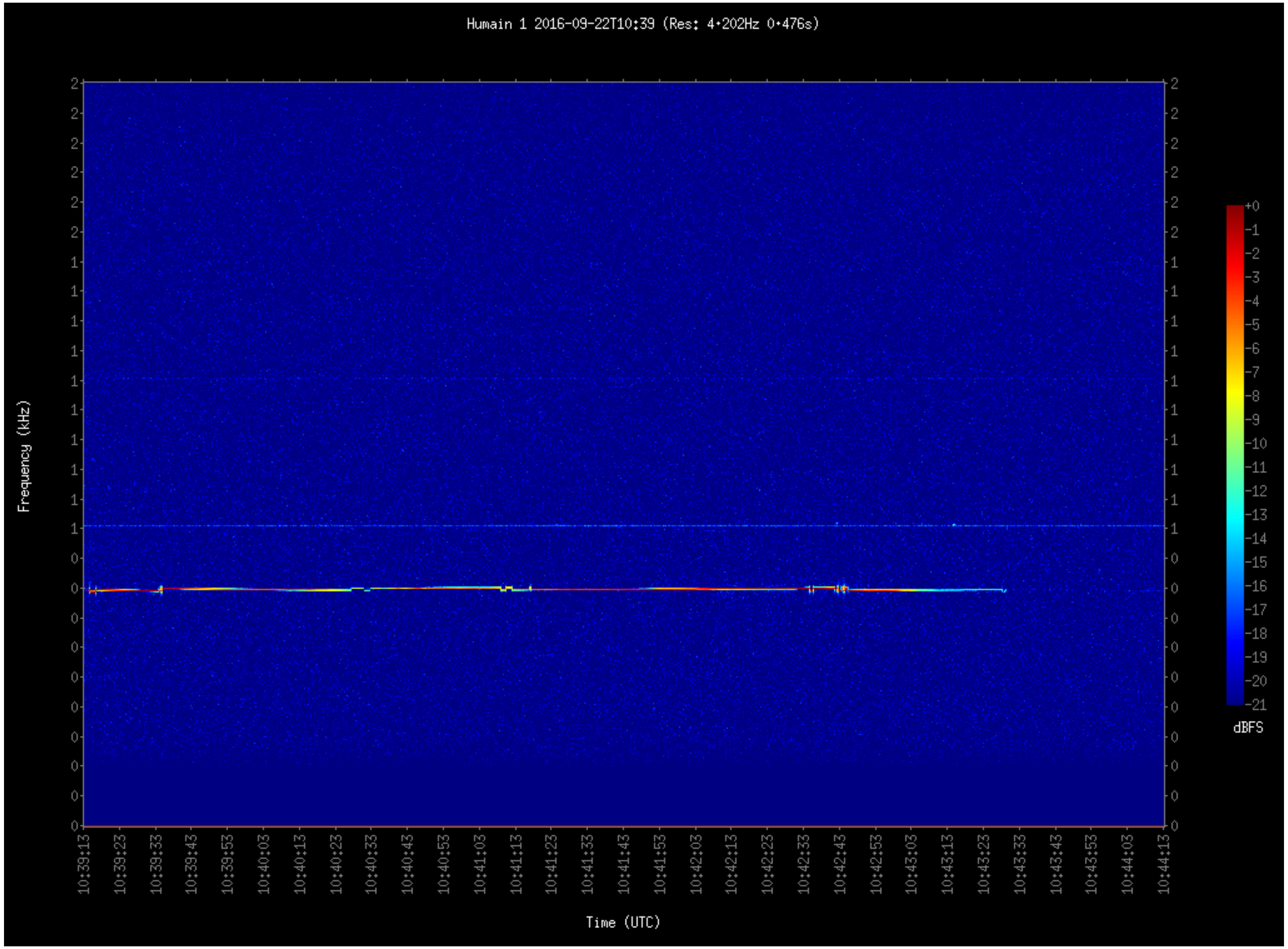
Calibration with a drone

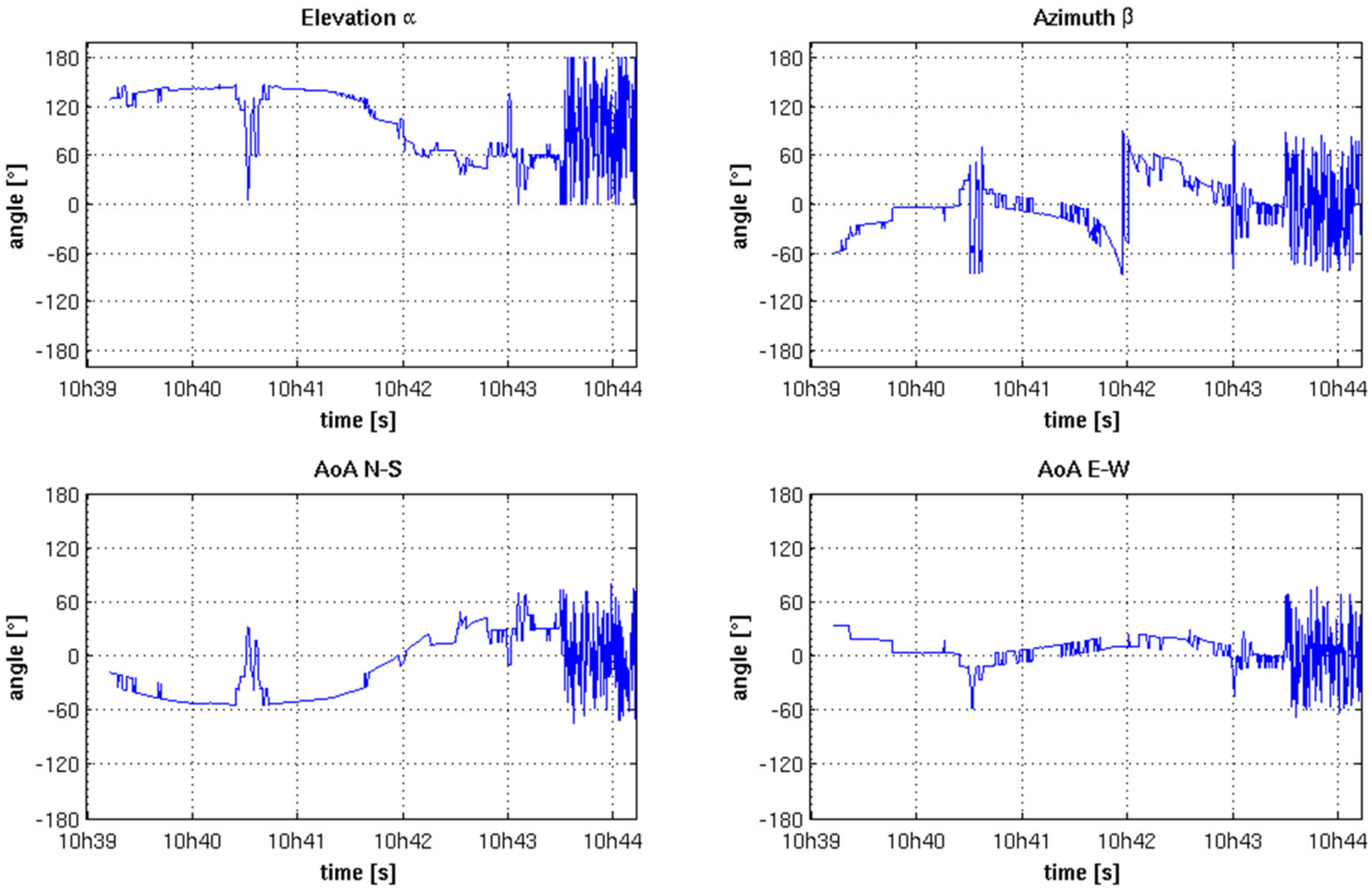




Tx = BRAMS calibrator (see Lamy et al 2015)

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

Thank you