Ionospheric effects in LOFAR observations

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1. Introduction

The free electrons in the top layer of the Earth's atmosphere, the ionosphere, affect radio waves passing through it by adding a direction and time dependent phase error. For high accuracy imaging at low radio frequencies with LOFAR we need to calibrate the ionospheric effects, but first we need to understand the ionospheric physics on the scales which affect LOFAR. The phase error is expressed in Total Electron Content (TEC), the electron column density along the path of the ray.

2. Observations

We have used LOFAR HBA (110 to 180 MHz) observations of 3C196 to isolate the ionospheric phase errors. The LOFAR standard imaging pipeline (BBS) was used to calibrate the data simultaneously towards 3C196 and the four next brightest sources in the field (Fig. 1). We used the ClockTEC separation method to separate the ionosphere from instrumental phase errors (van der Tol, in prep). The time resolution is 10 seconds.

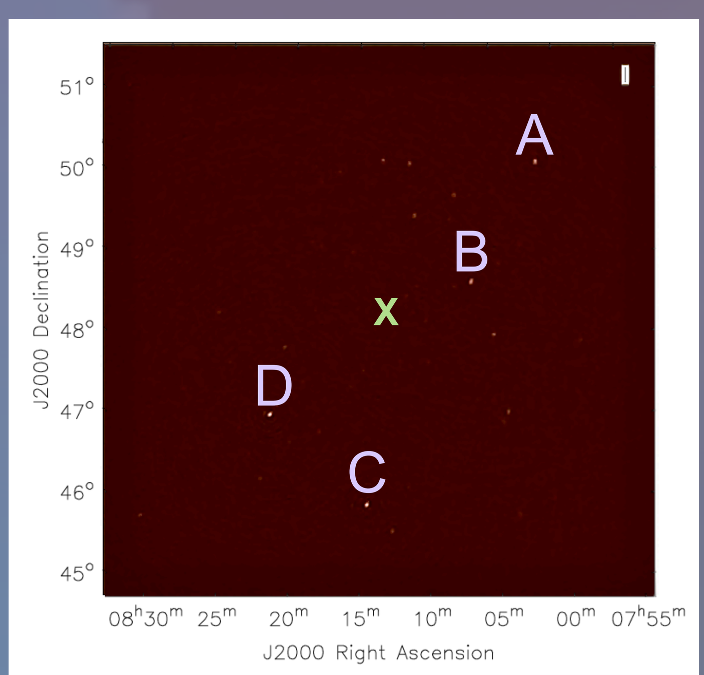

Fig. 1. Image of the field. 3C196 has been subtracted in this image, its position is marked by the green cross. The sources labeled A through D correspond to the sources shown in Fig. 3.

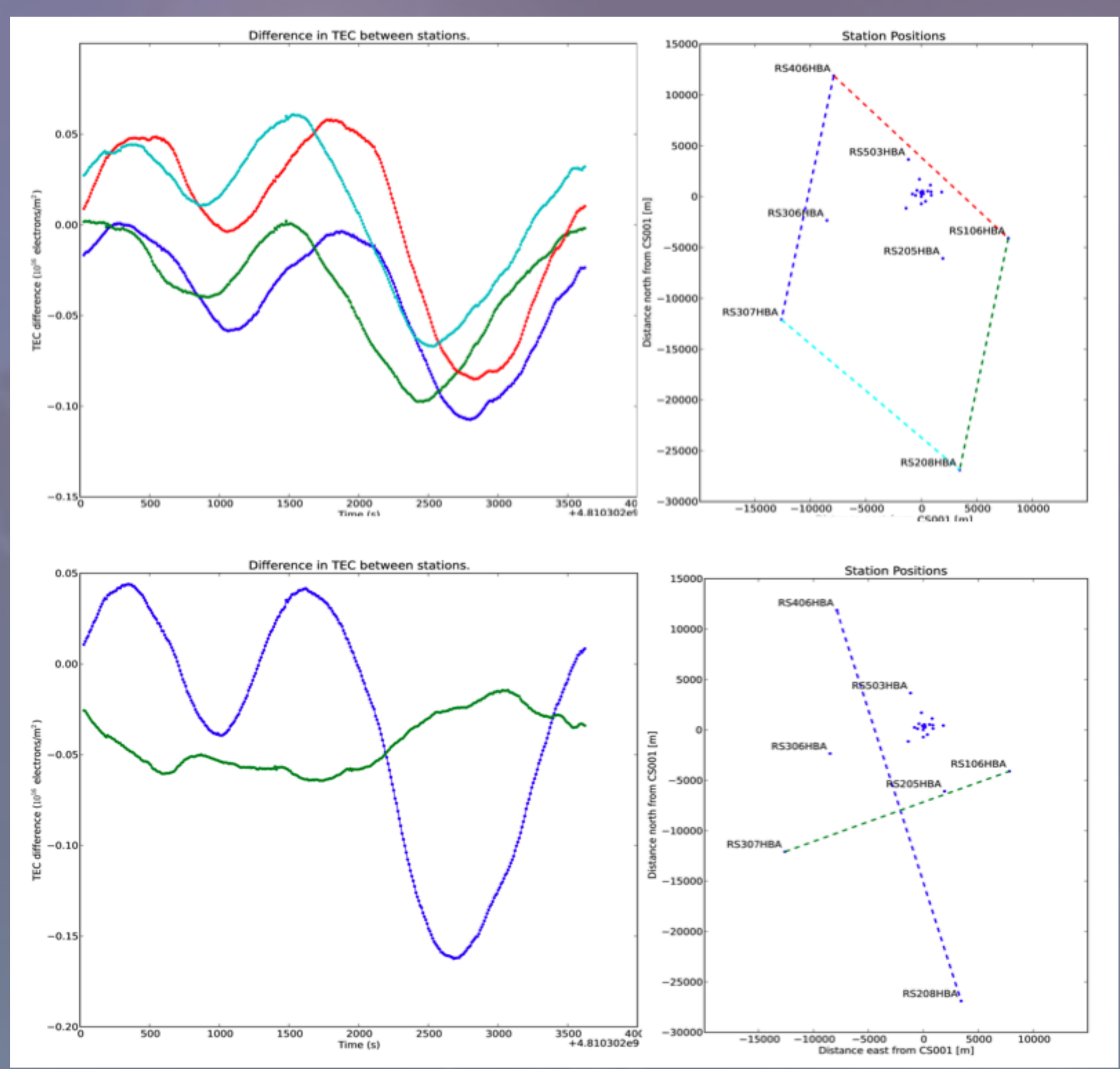

Fig. 2. Ionospheric TEC difference for different baselines. **Top**: the peak of the wave is de-tected first by the cyan and green baselines, before it reaches the blue and red ones. **Bottom**: a wave is clearly detected on the long diagonal baseline, but only marginally on the orthogonal baseline, confirming the wave direction.

3. Results on 3C196

Isolating one hour of data, and using the longest baselines, we clearly detect a wave-like TEC feature which travels roughly from South to North (Fig. 2). From the delay between the southern and northern pair of baselines we derive a speed of ~250 km/s. This gives a wavelength of ~120 km, similar to previous detections of ionospheric waves.

4. Secondary effects

After calibration and subtraction of 3C196, BBS was used to calibrate the four next brightest sources. After averaging over all frequencies, the differential phases still display significant small scale variability (Fig. 3). This can be attributed to ionospheric turbulence, but not all of the alternative explanations have been excluded yet, e.g. instrumental effects or errors arising in BBS.

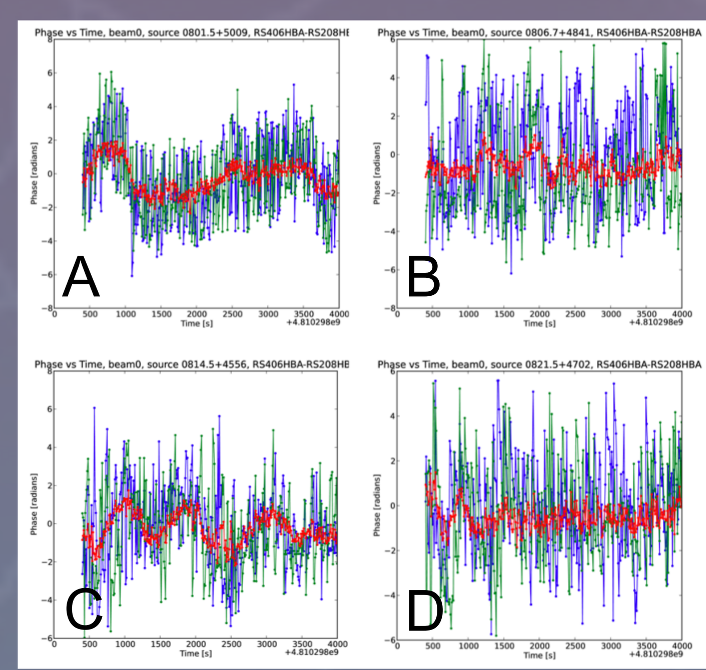

Fig. 3. Differential phase solutions for four bright sources in the field (Fig 1.), on the longest baseline (Fig. 2, bottom right). Red: average over all frequencies. Blue and green : solutions for a single subband at 115 and 132 MHz respectively.

5. Conclusions

An ionospheric wave is detected over LOFAR, and its properties are similar to previously detected waves. Inspection of the differential phase solutions after correcting for 3C196 reveal more small scale variation, potentially due to ionospheric turbulence. Due to its high sensitivity and large field of view LOFAR is ideally suited to study ionospheric effects on radio waves, as well as ionospheric physics on kilometer scales.

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