CONTINUOUS WAVE INTERFEROMETER OBSERVATIONS OF MIDLATITUDE E REGION BACKSCATTER

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1. Introduction

Ionospheric radio interferometry was first introduced by *Woodman* [1971] in equatorial electrojet studies in order to determine the magnetic field inclination over Jicamarca, Peru. It was based on cross-correlation interferometry used in radio astronomy to determine the angular position and size of radio noise sources. Ionospheric interferometry was further developed by *Farley et al.* [1981] and applied to studies of equatorial electrojet and spread F irregularities. Since its development, backscatter interferometry has become a powerful tool for studying plasma turbulence and instabilities in the *E* region. First, this technique was applied in studies of the equatorial electrojet, using the capabilities of the large Jicamarca radar array (e.g., *Farley et al.,* 1981; *Kudeki et al*., 1982) and later in radio auroral studies. At midlatitude, where coherent backscatter of radio waves comes from unstable sporadic *E* layers, the technique was applied first by *Riggin et al.* [1986] using the Cornell University Portable Radar Interferometer (CUPRI). Recently multi-line interferometry and in-beam radar imaging techniques has been developed for studying fine structures inside large scale plasma waves in the nighttime equatorial spread *F* and electrojet echoes, and to investigate quasiperiodic (QP) echoes at midlatitude (e.g., see *Hysell et al.,* 2002, and more relevant references therein).

In the following, we first describe a midlatitude *E* region continuous wave (CW) radio interferometer experiment and then present examples of some first results. This work is continuation of research carried out the last decade in Greece, which led to a number of new findings, the most important being the detection at midlatitude of the Farley instability (*Schlegel and Haldoupis,* 1994) and the introduction of a new polarisation mechanism for its explanation (*Haldoupis et al.,* 1997).

2. SESCAT Interferometer

Here we describe in brief the upgrade of SESCAT, the 50 MHz CW *S*poradic *E SCAT*ter experiment located in the island of Crete, Greece, into a single-line azimuthal interferometer. Note that SESCAT is not a pulsed radar, but a continuous wave bistatic Doppler system that observes a fixed scattering volume with excellent temporal and Doppler spectrum resolution. The SESCAT experiment, which is described in detail by *Haldoupis and Schlegel* [1993], had its observing capacity considerably enhanced when operated as an interferometer. As such, it has become very useful for the study of microstructure and short scale dynamics in localised and strongly unstable scattering regions located within sporadic *E* layers.

To upgrade SESCAT into an interferometer a new receiver system was built that consisted of two identical superheterodyne receiver units. In order for the receivers to be phase-coherent, both were driven by a single ultra stable oven-controlled crystal oscillator operating at exactly 1 kHz below the transmitted frequency. This shift relative to the transmitted frequency is necessary for CW radars in order for both positive and negative Doppler shifts to be measured and, as such, for the full Doppler spectrum to be determined. The two antennas required for interferometry were simply provided by splitting the existing receiving array of four Yagis into two sub-arrays, each sub-array made up from two adjacent single Yagi antennas. In this way an approximately east-west antenna baseline of 16 m was formed that turned SESCAT into an azimuthal interferometer. In this configuration, the beamwidth for each receiving array now becomes about 12 degrees from the 8 degrees it was for the 4 Yagi array, which increased the 3-dB zonal extent of the scattering region to about 40 km at a range of 185 km. The output audio frequency signals of both receivers were digitised and processed on site by using two identical DSP (digital signal processor) units but run by the same clock, housed in a Pentium-class personal computer. Highly efficient software, partly written in assembly language and partly in C++, allowed for fast Fourier transformations and subsequent power spectrum and cross spectrum calculations to be performed in real time. The configuration, in block diagram form, of SESCAT interferometer is summarised in Figure 1.

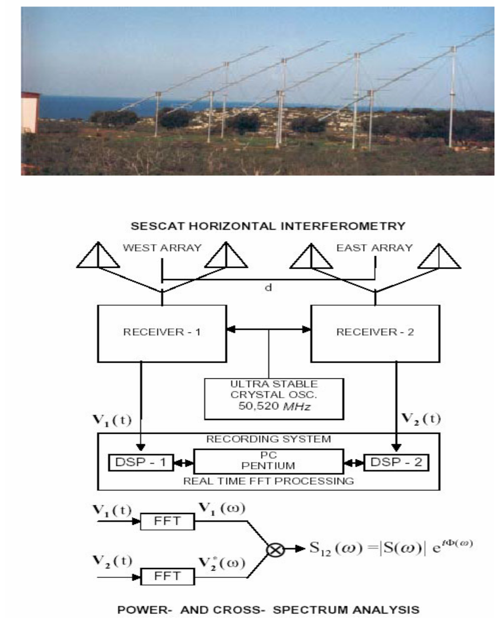

Figure 1. The SESCAT Interferometer

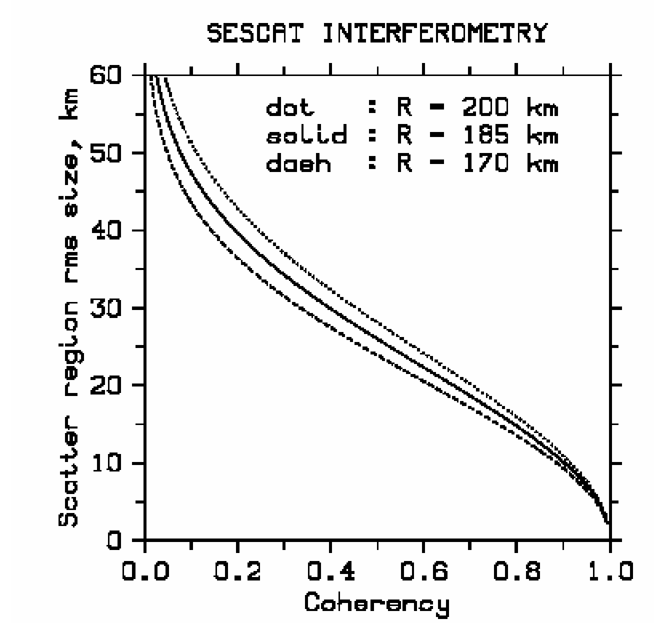

Figure 2. Region mean size for different radar ranges

Figure 2 (above left) shows the scattering source mean sizes as a function of the measured cross spectrum coherencies, in line with the interferometer theory of *Farley et al.* [1981]. The scatter source mean size is computed in Figure 2 for three radar ranges in order to also estimate the anticipated errors due to range uncertainties, which are inherent in a CW bistatic radar. The solid line curve is for the most likely range of 185 km that corresponds to exact perpendicularity at *E* region altitudes near 105 km, the altitude usually assumed to be optimal for plasma instability excitation. In addition, also shown in Figure 2 are the corresponding curves for the ranges of 170 km (dashed curve) and 210 km (dotted curve), which represent the lower and upper range limit, respectively. As seen, the maximum errors anticipated in source mean size because of uncertainties in SESCAT range are not larger 10 %.

3. Examples of Observations

Here we present only a couple of interferometric observations which, although they tend to exemplify somewhat our data base, they are by no means exhaustive. The interferometry records are characterised by a great variety of “signatures” reflecting the complexity of instability mechanisms and dynamics in the scattering medium, and provide information which goes undetected in the Doppler spectrum alone.

Figure 3 shows a rather typical example of SESCAT interferometric observations. The Doppler spectrogram in the upper panel starts with a burst of strong scatter having broad spectra which identify with type 2 echoes. This is followed by some weaker bursts with narrow spectra near zero Doppler shift accompanied by a narrow spectral band of a faint scatter at large negative velocities, presumably of type 1. The latter is depicted much more clearly in the coherency plot which shows the weak type 1 echoes to originate from localised regions at different azimuths relative to the low velocity echoes. The cross phase changes with time, dΦ/dt, show that all regions undergo a bulk motion to the west. A detailed analysis reveals the following: 1) What we identify as type 2 echoes are often structured in Doppler velocity, with positive and negative Doppler bands coming from zonally adjacent echoing regions separated by a few km. Both Doppler bands move as an entity, however across the radar beam with a speed near 50 m/s which means they associate with one and the same scattering region. This picture seems to be in contradiction with the notion of isotropic (Sudan-like) turbulence applying for type 2 echoes. 2) The type 1 echoes, due to Farley's instability, show no structure across their Doppler band and come from the same region, which in this event has a zonal extent of ~10 km and traverses across the radar beam to the west with a speed nearing 120 m/s.

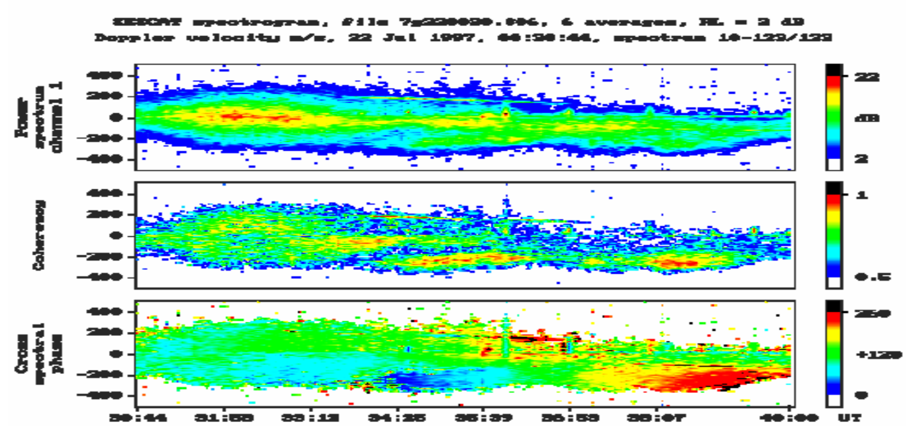

Figure 3. SESCAT Interferometric observations of type 1 and type 2 echoes

Figure 4 shows Doppler spectra and cross-spectral spectrograms for a typical example of quasiperiodic (QP) echoes having on the average a period of about 8 minutes. As seen QP are basically coming from a sequence of unstable plasma patches (or clouds) that move across the radar beam. The systematic phase change for each drifting plasma patch shown in the lower panel, corresponds to a westward near 110 to 120 m/s for the sequential scatter regions traversing across the field of view, apparently, with the neutral wind.

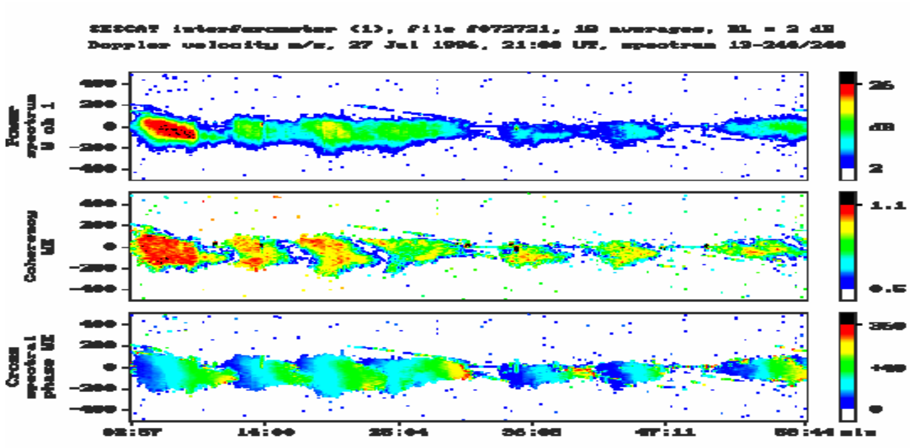

Figure 4. SESCAT interferometer observations of quasiperiodic echoes

4. Summary

Here we describe a radio interferometric experiment and present examples of midlatitude E region backscatter observations. These were obtained with SESCAT (Sporadic E SCATter experiment), a bistatic 50 MHz continuous wave (CW) Doppler radar located on the island of Crete, Greece, which was operated as a single (east-west) baseline interferometer. The interferometric observations reveal that the aspect sensitive area viewed by the radar often contains a few zonally located backscatter regions, presumably blobs or patches of unstable plasma, which drift across the radar field-of-view with the neutral wind. On average, these echoing regions have mean zonal scales ranging from a few kilometers to a few tens of kilometers and drift with westward speeds mostly between 20 and 100 m/s, and occasionally up to 150 m/s. The cross-spectral analysis shows that midlatitude type 1 echoes (Farley waves) occur much more frequently than has been previously assumed and they originate in single and localized areas of elevated electric fields. On the other hand, typical bursts of type 2 echoes are often found to result from two adjacent regions in azimuth undergoing the same bulk motion westwards but producing scatter of opposite Doppler polarity, a fact that contradicts the notion of isotropic turbulence to which type 2 echoes are attributed. Finally, quasiperiodic (QP) echoes are observed simply to be due to sequential unstable plasma patches or blobs which traverse across the radar field-of-view, sometimes in a wave-like fashion. For more on the SESCAT interferometer and its results see recent paper by *Haldoupis et al.* [2003] (*Ann. Geophys.,* 21, 1589, 2003)

5. Acknowledgements

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