Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 636–643

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Meteor-head echo observations using an antenna compression approach with the 450 MHz Poker Flat Incoherent Scatter Radar

Jorge L. Chau [a,*], Freddy R. Galindo [a], Craig J. Heinselman [b], Michael J. Nicolls [b]

[a] Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima, Peru
[b] Center for Geospace Studies, SRI International, Menlo Park, CA, USA

ARTICLE INFO

Article history:
Accepted 21 August 2008
Available online 6 September 2008

Keywords:
Meteors
Meteoroids
Ionosphere
Radar

ABSTRACT

In this work we present a novel use of the Poker Flat Incoherent Scatter Radar (PFISR) to study meteor-head echoes with wide (W) beams. Until now, most of the meteor-head echo studies have been performed with High-Power Large-Aperture Radars (HPLARs) using very narrow (N) beams. At PFISR we have implemented an antenna compression approach using a defocusing scheme, similar to Chirp (linear frequency modulation) in pulse compression. The resulting effective beam is $\sim$3 times wider than the narrowest PFISR beam. Using the signal-to-noise ratio (SNR) as a proxy measurement of cross-section, from the combined W and N beam experiments, our main results are: (1) observed meteors in the W beam are approximately half the number of meteors observed in the N beam, (2) we detected 10 times more large cross-section (strong) meteors (>15 dB if they were measured by the N mainlobe) than using only the N beam, and (3) more than 15% of the total N meteors were observed in the N sidelobes, therefore being at least 20 dB stronger if they were observed in the N mainlobe. Our results are summarized in a corrected distribution of relative meteor cross-sections as if all of them were observed with the N mainlobe, namely correcting their SNR values depending on where in the beam they were detected (sidelobes or mainlobe). In addition, we show a qualitative meteor cross-section distribution that one can obtain combining W and N beams. The resulting distribution is incomplete, since the W beam is not sensitive enough to detect the very small (weak) meteors, but could provide new information about the large cross-section events.

1. Introduction

Since mid 1990s extensive meteor-head echo observations have been performed with different High-Power Large-Aperture Radars (HPLARs) (e.g., Janches et al., 2000; Pellinen-Wannberg et al., 1998; Sato et al., 2000; Close et al., 2002; Chau and Woodman, 2004). Most of these observations are characterized by the use of very narrow beams (less than 2° half-power full beam widths). The results obtained from these observations have complemented more than 50 years of radar observations with much less-power smaller-antenna specular meteor radars (SMRs) (e.g., Jones and Brown, 1993). For example, Chau et al. (2007) have shown that the sporadic meteor population observed by typical HPLARs is in good agreement with the results obtained from SMRs, in both radiant sources and bimodal velocity distribution. The agreement improves when an altitude threshold is applied to the HPLAR results.

Besides knowing where meteors come from and how HPLAR results compare with SMR results, in recent years significant efforts have been devoted to the study of the meteor mass and sizes and what are the populations observed by the different HPLARs (e.g., Janches et al., 2008; Hunt et al., 2004; Close et al., 2004; Mathews et al., 2001; Bass et al., 2007). Details on the scattering mechanisms that might be behind meteor-head echoes are given by Close et al. (2004). Meteor mass estimates (and sizes) can be obtained from (a) deceleration, and (b) signal-to-noise ratio (SNR). Although there is a general consensus on the physics producing the meteor scattering, good estimates by both measurements required very precise measurements and a reasonable knowledge of the background atmosphere/ionosphere.

In the case of the deceleration method, it is well known now that meteor-head echoes are observed coming from different elevation angles, and not only down the beam. Therefore, measured decelerations are radial and have a component that is due to the geometry and one due to the true deceleration needed for mass estimation. To estimate the former (and later remove it), it is necessary to know the meteor trajectory (e.g., Chau and Woodman, 2004, Eq. (4)).

In the case of the mass estimation using SNR, a precise knowledge of where the meteor is coming from inside the illuminated volume is needed, so that the proper antenna gain is removed before the cross-section is obtained. Such corrections

* Corresponding author.
E-mail address: jchau@jro.igp.gob.pe (J.L. Chau).

1364-6826/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jastp.2008.08.007

could be as large as 20–40 dB. Nowadays, such measurements could be tried at the ALTAIR and Jicamarca radars, where interferometry can be applied. But even then, one has to be very careful in the interpretation, since meteors present a very large dynamic range of cross-sections can be observed with the antenna sidelobes.

In this work, instead of analyzing the results obtained with narrow beams, at the Poker Flat Incoherent Scatter Radar (PFISR) we have implemented a novel wide (W) beam and narrow (N) beam experiment. The main goal of this experiment is to observe meteor-head echoes with large cross-sections that are usually not observed with N beams or are observed in very small quantities. As is well known, larger meteors are expected to occur less frequently, so the probability of observing them with N beams is less than observing them with W beams. Using a W beam will make the interpretation of usual meteor parameters (radial velocity, initial range, radial deceleration, etc.) more complicated than when N beams are used. But as we see below, using the antenna pattern characteristics and the simultaneous W and N measurements, we are able to accomplish our initial goal. Moreover, we are able to identify meteors echoes with large cross-section, previously misinterpreted as small cross-section meteors in N beam observations.

First we present the experimental details and how the wide beam pattern has been implemented using PFISR unique capabilities of changing beam positions from pulse to pulse and allowing phase changes at each antenna element. Basically the W beam is accomplished by defocusing the phase array using a Chirp-like phasing. Then we present the main results obtained with both W and N beams, including the SNR distributions for different groups, depending on which beam the meteor was observed. Finally, qualitative distributions of meteor cross-sections are estimated and discussed using the N SNR as proxy measurement of cross-section.

2. Experiment configuration and antenna compression

PFISR is located at the Poker Flat Research Range near Fairbanks, Alaska ($65.13^\circ, 147.47^\circ$). PFISR has the unique capability to steer the beam on a pulse-to-pulse basis. The radar is tilted so that its on-axis (or boresight) direction corresponds to elevation and azimuth angles of 74° and 15°, respectively. The beamwidth of PFISR is about $1^\circ \times 1.15^\circ$, with the larger dimension (x) in the plane perpendicular and north to the radar face. Typically, PFISR experiments employ multiple narrow beams almost simultaneously to avoid spatial and temporal ambiguities (e.g., Nicolls et al., 2007; Nicolls and Heinselman, 2007).

The beam positions are obtained by changing the phases of the different antenna element units (AEUS). As it is well known, the antenna pattern of an antenna array is given by the product of the element pattern and the array factor. For small zenith angles, the array factor of the PFISR antenna is given by

$$F_{\mathrm{array}}(\theta_x, \theta_y) = \sum_{i=1}^{M} g_i \exp[jk(x_i\theta_x + y_i\theta_y) + j\phi_i] \quad (1)$$

where $k = 2\pi/\lambda$, M the number of AEUs, x_i and y_i are the positions of the AEUS in meters, θ_x and θ_y are the zenith angles with respect to the on-axis position, and g_i and ϕ_i are the gain and phases (in radians), respectively, for each AEU. Although the PFISR system only allows phase changes, we have included the gain parameter to allow for gaps (i.e., $g_i = 0$ when some AEUs are not used for transmission and/or reception).

As mentioned in the Introduction, instead of sending multiple narrow beams, in this work we have used the unique capabilities of PFISR to transmit a narrow and a wide beam. In typical operations, PFISR transmits a narrow beam by changing the phase linearly with respect to the antenna positions. To transmit (and receive) a wide beam, we have defocused the array by changing the phase quadratically with respect to antenna position, as follows:

$$\phi_i = \phi_{0x} \times (x_i - \bar{x})^2 + \phi_{0y} \times (y_i - \bar{y})^2 \quad (2)$$

where $\phi_{0x} = 0.033$ and $\phi_{0y} = 0.029$ in rad/m^2. Since the antenna array is not square (y larger than x), in order to have a more symmetric beam, ϕ_{0x} is slightly larger than ϕ_{0y}.

This procedure is equivalent to using Chirp (linear frequency modulation) in pulse compression approaches, where wider pulses are transmitted to synthesize narrow pulses with the same average power. A synthetic wide beam approach was used by Woodman and Chau (2001) at the Jicamarca Incoherent Scatter radar, but using complementary binary phase codes in two dimensions. Following the analogy of pulse compression, our approach of transmitting wide beams with a large array is like an antenna compression, since the resulting antenna pattern is equivalent to the pattern of smaller sections of the array, but with the advantage that the total available power is transmitted. If we were to use only a small portion of the PFISR array, the transmitted power would be reduced since PFISR is a distributed transmitted phase array.

In Fig. 1 we show the two-way antenna patterns for a typical narrow beam and different wider beams, all of them pointing on-axis. Fig. 1b shows the theoretical wide beam that one obtains with a quadratic phase change as in Eq. (2) and an amplitude change to avoid the edge effects of a limited array (e.g., using a Hanning-type weighting). The remaining two contour plots show the wide beams using only quadratic phase changes for (c) using all AEUs for transmission and reception, and (d) using the actual AEUs units that were on during transmission and/or reception during the February 2008 experiments. The experiments were conducted on February 20 and 24, 2008 and out of the 4096 AEUs ~97.3% and ~79.5% were on during reception and transmission, respectively. The reason we have fewer transmitting modules is due to failures of a number of solid state power amplifiers (SSPA) and SSPA power supplies. The expected wide beam (Fig. 1c) is indeed wider than the narrow beam, but it has angular structure. Such structure is due to the edge effects, since changes are only done in phase and not in amplitude. The actual wide beam pattern is also wide and very similar to the expected pattern. The differences are due to the malfunctioning AEUs.

To have a closer look at the resulting patterns in Fig. 2 we show selected antenna pattern cuts. At the top normalized patterns are shown in lineal scale, while at the bottom, absolute cuts are shown in relative dB units. The pattern cuts shown are: (a) the narrow beam (N) (in black), (b) the theoretical wide beam using phase and amplitude changes, and (c) the wide beam (W) using only phase changes, for different planes. Usual definitions of antenna beam widths are with respect to the half power points. Since the resulting wide beam pattern presents power changes greater than 3 dB inside its "main" beam, for this work our full beam width is given by the −15 dB points (FBW15). Then the N beam FBW15 is ~1.8°, and for the new W beam FBW15 is ~6.2°.

The main characteristics of these patterns are:

- The maximum gain of N is more than 20 dB larger than the maximum gain of W.
- The sidelobe levels of N are in general similar to the gain of W at the same angles. However, the W beam does not present nulls.