EISCAT_3D Project

WP5 Report on Multidimensional Imaging Radar Data Visualization

University of Tromsø, Department of Physics

Vasyl Belyey, Cesar La Hoz, and Bjørn Gustavsson

February 2009

1. Abstract

In this report we consider the problem of visualizing the multi-dimensional brightness data produced by a radar imaging algorithm. In general the problem consists in displaying the multi-dimensional data (in the case of brightness three spatial coordinates, Doppler frequency, and time) on a 2D surface, usually on a computer monitor or a sheet of paper. In this case dimensionality reduction techniques are used to simplify the data representation. We suggest a combination of the dimensionality reduction with a multi-level approach providing unambiguous data visualization at different levels of displayed details.

2. Data insight levels

Presenting the multi-dimensional brightness data from imaging radar in a way that conveys its physical significance is a great challenge. The brightness computed by radar imaging software is a 5-dimensional function $B(t,\vec{r},f)$ describing the brightness distribution in space $\vec{r}=\{x,y,z\}$, frequency f, and varying in time t. To display the function unambiguously on a 2-dimensional surface dimensionality reduction techniques [1] have to be used.

A natural way of displaying a function developing in time is creating a sequence of consecutive image frames corresponding to separate times and playing them as a computer animation. Another natural step in the dimensionality reduction is using color pixels with the color reflecting the Doppler frequency and the intensity proportional to the brightness value at the given frequency. The result of the two dimensionality steps is a 3-dimensional function which can be plotted using the standard 3D plotting routines available in many programming languages and visualization software packages. An important advantage of the modern routines is the capability to interactively select the viewpoint enabling users to look at the image at different aspect angles. An example is the open source Vis5D package [2] designed for interactive visualization of large gridded data sets such as those produced by numerical weather models.

In order to make maximum possible use of the techniques described above we suggest dividing the brightness data visualization algorithm into three levels presenting the data with different degrees of the details distinguishable in the images.

2.1. Level 1. Static pictures displaying evolutions in time

The simplest and most traditional ways of plotting 1- and 2-dimensional time-dependent functions are producing line plots and grayscale or color map plots, respectively, with the horizontal axis indicating the time (called Range-Time-Intensity or RTI plots). At the same time the plots provide very effective and convenient tools for quick general insight into the particularities of the brightness developing in time.

In order to reduce the brightness data dimensionality we use integration along the axes that are not supposed to be shown in the pictures. First the integration is performed along all four axes excluding the time $B(t) = \iint B(t, \vec{r}, f)\, d\vec{r}\, df$. The resulting 1D function is the total brightness inside the volume illuminated by transmitting beam. Similarly, integrating along three axes other than the time, we obtain 2D plots presenting time developments of the brightness in range, two orthogonal planes determined by respective zenith angles, α and β, and azimuth angle φ, and frequency f or corresponding line-of sight velocity, V. An example of the plots is shown in figure 1.

2.2. Level 2. Animation displaying evolutions in time

At this level two dimensions, namely the time and the frequency, are reduced. The time dimension is reduced by plotting 2- and 3-dimensional figures corresponding to consecutive integration times and displaying them as frames of a computer animation file. The frequency dimension is reduced by using the color pixels comprising the image with the color combined from the particular colors assigned to each frequency component and having intensity proportional to the brightness at the particular frequency. Similar technique was used in paper [3] where authors divided entire frequency band into three spectral bins and generated images with the red- and blue-shifted Doppler bins assigned red and blue colors, and the remaining zero-shifted bin was assigned green. The intensity of the colors was proportional to the SNR on a logarithmic scale. By combining the colors in the images this way, the pixels come to represent the scattered power, Doppler shift, and spectral width in an intuitive way.

We extend the technique by avoiding the limitation of only three frequency bins. We suggest using the RGB model with the colors combined in a way covering the entire frequency band by introducing a frequency-to-color mapping scheme which can be expressed as

$$\begin{aligned} I_R &= \exp\left(-\frac{(f - f_{\min})^2}{2\sigma_F^2} \right) \\ I_G &= \exp\left(-\frac{(f - f_{med})^2}{2\sigma_F^2} \right) \\ I_B &= \exp\left(-\frac{(f - f_{\max})^2}{2\sigma_F^2} \right) \end{aligned} \qquad (1)$$

Here I_R, I_G, and I_B are the intensities of the red, green and blue color components, respectively, $f_{\min}$ and $f_{\max}$ are the minimum and maximum frequencies within the frequency band, respectively,

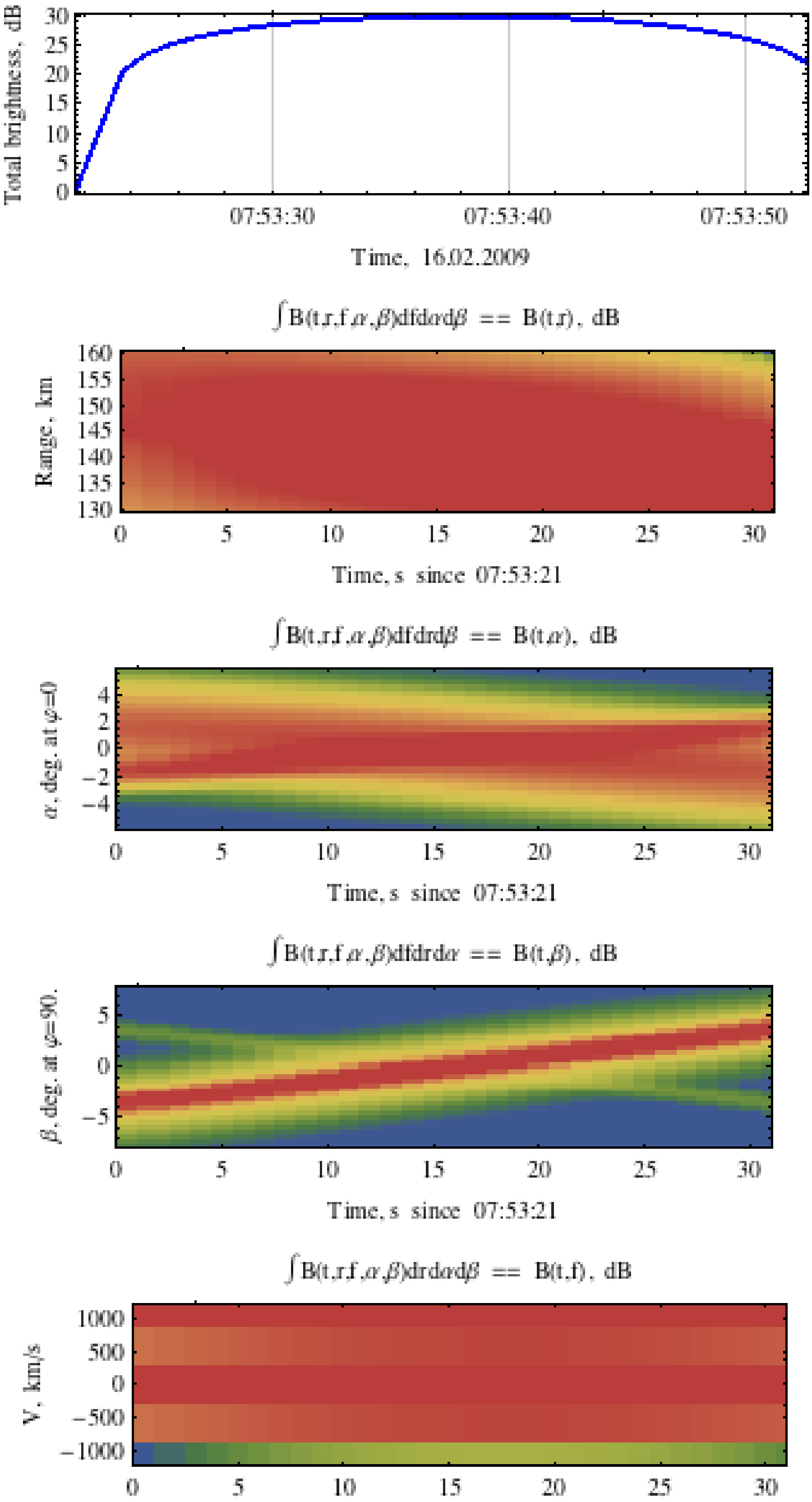


Figure 1. Example of Level 1 figures. The panels display time variations of total brightness (top) and the integrated brightness along the four remaining dimensions, r, α, β, and frequency f graduated in units of line-of-sight velocity V.

and f_{med} is the median frequency defined as $f_{med} = (f_{\min} + f_{\max})/2$, and $\sigma_F = (f_{\max} - f_{\min})/6$. Thus the color corresponding to a given Doppler frequency is defined by a vector function $\vec{C}(f) = \{I_R(f), I_G(f), I_B(f)\}$ and each spectral component of the brightness $B(f)$ is represented by $\vec{C}(f) = \{I_R(f), I_G(f), I_B(f)\} \cdot B_N(f)$ where $B_N(f) = B(f)/B_{\max}$ is the brightness value normalized by absolute maximum of all the values. Finally, the color of a pixel is defined by combining the colors of all the spectral components of the brightness $\vec{C} = \sum_i \vec{C}(f_i)$. The frequency-to-color mapping scheme is shown in figure 2.

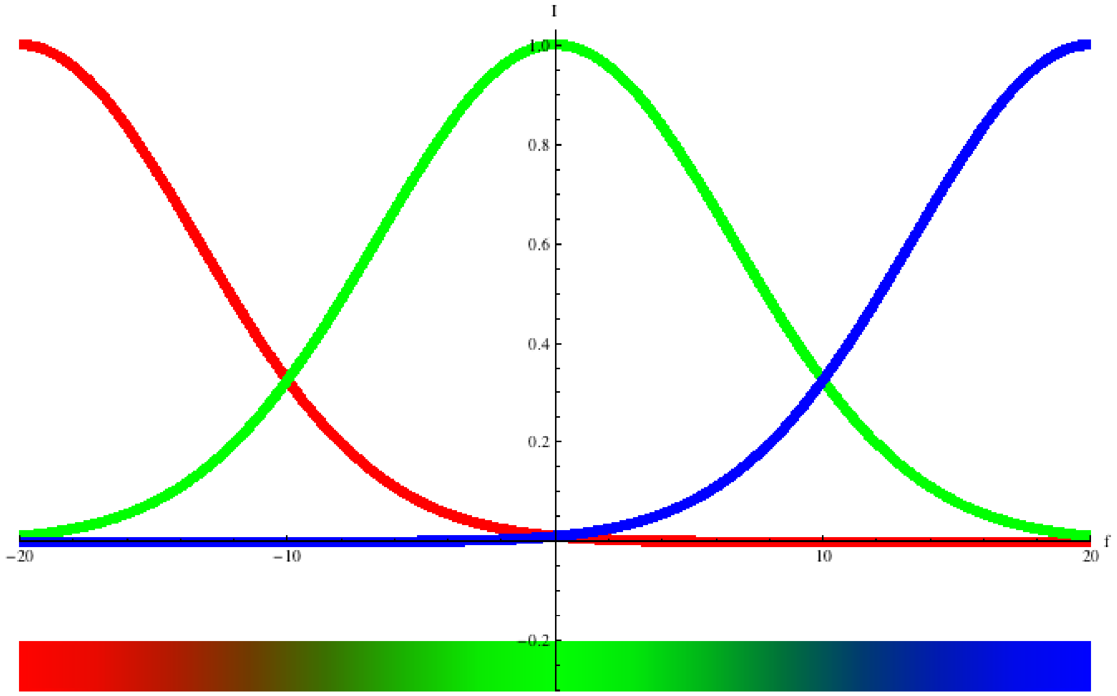
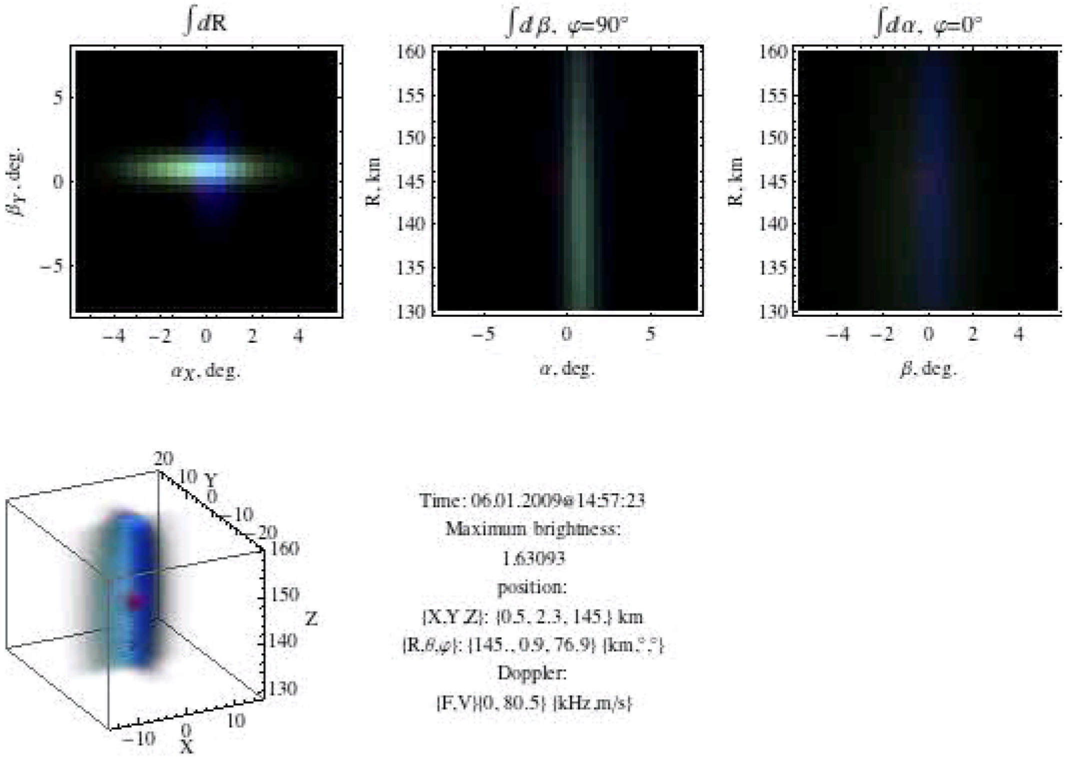


Figure 2. Frequency-to-color mapping scheme. Top panel shows relative intensities of the red, green and blue color components as functions of frequency. The values of $f_{\min}$ and $f_{\max}$ are set to -20 and 20 a.u., respectively. Bottom color stripe shows the color assigned to a single frequency component with unit brightness value within the frequency band.

Each time frame in the animation file contains five panels presenting the brightness data with the dimensionality reduced by 1. The reduction is performed by integrating the brightness along one coordinate chosen one at a time out of the three spatial coordinates: range r and two orthogonal zenith angles, α and β. In addition there are a 3D image and a text panel displaying characteristics of the maximum brightness point.

When plotting the 3-dimensional image we come to the problem of the points laying farther from the viewpoint being obscured by the closer ones, even though the latter may be of lower (and even zero) brightness. To solve the problem we assign the pixels opacity proportional to the brightness. In this case zero brightness points become invisible and the points with higher brightness are displayed very distinctly. The viewpoint of the 3D plot can be selected interactively.

An example of the panels is shown in figure 3. Simulated brightness data consisting of three blobs at different frequencies were used for plotting. The blobs are distinctly visible in the 3D plot.



Time: 06.01.2009@14:57:23
Maximum brightness:
1.63093
position:
{X,Y,Z}: {0.5, 2.3, 145.} km
{R,θ,φ}: {145., 0.9, 76.9} {km,°,°}
Doppler:
{F,V}{0, 80.5} {kHz,m/s}

Figure 3. Example of Level 2 time frame. Top panels show the brightness integrated along range r and the two zenith angles, β and α. Bottom panels present 3D brightness and text information on the maximum brightness point.

2.3. Level 3. Animated scans of 3D brightness

Level 3 is designed for displaying the brightness images with maximum details at a time of particular interest detected in levels 1 or 2. The brightness is shown by separate cross sections in three orthogonal planes which are combined and then played as animation files. The frequency dependence is color encoded as in level 2. Examples of single frames are shown in figures 4, 5 and 6. Each frame contains two panels, one displaying the cross section of the brightness and the other indicating the position and orientation of the cross section surface.

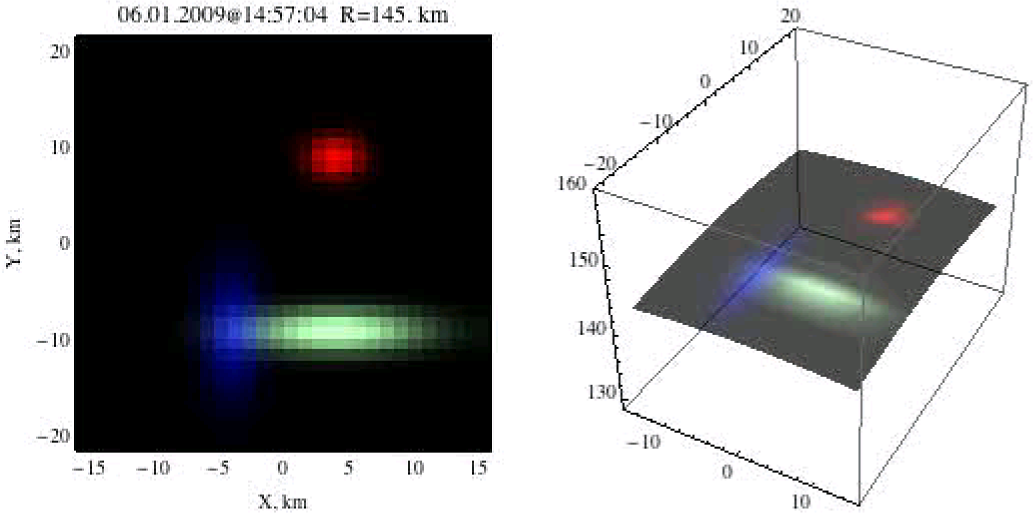


Figure 4. Cross section of the simulated brightness data a at given range ($R = 145$ km).

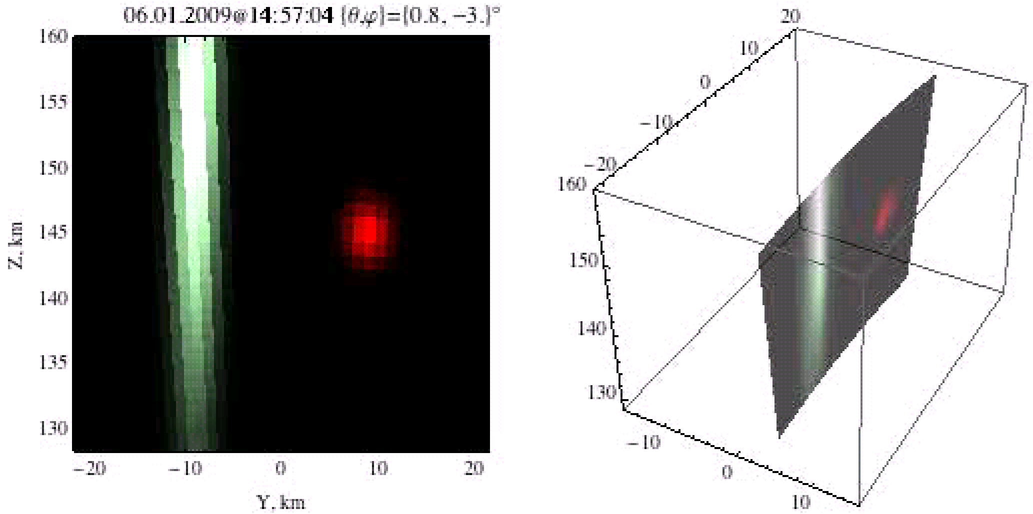


Figure 5. Cross section of the simulated brightness data at a given zenith angle in YZ plane.

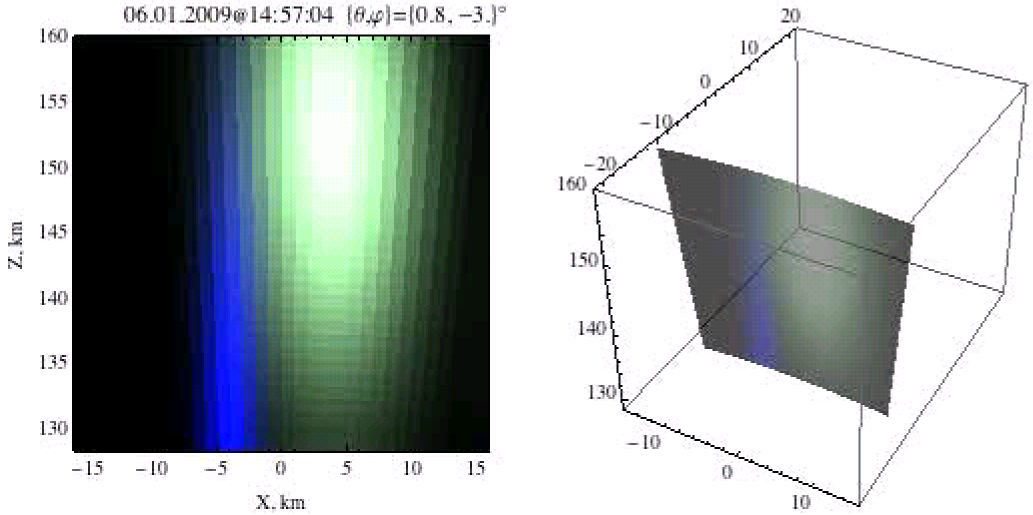


Figure 6. Cross section of the simulated brightness data at a given zenith angle in XZ plane.

3. Prototype visualization software

Prototype brightness visualization software was developed as a Mathematica package E3Dvisualize.m. The package contains two basic functions for simulating (SimulateBrightnessData) and plotting the brightness data (PlotImagingData). To generate multi-blob brightness data we use a Gaussian model of brightness distribution for each blob:

$$B(t,\vec{r},f)=\sum_i \exp\left[-\frac{1}{2}\left|\left(\vec{r}-\vec{r}_i(t)\right)\cdot\vec{\kappa}_i\right|^2+\frac{(f-f_i)^2}{2\sigma_{f_i}^2}\right] \qquad (2),$$

where $\vec{r}_i(t)$ defines the center of the i-th blob, $\vec{\kappa}_i=\left\{\frac{1}{\sigma_X},\frac{1}{\sigma_Y},\frac{1}{\sigma_Z}\right\}_i$ is the vector of inverse variances defining the spatial widths of the i-th blob along the three coordinate axes, f_i is the central frequency of the i-th blob, and σ_{f_i} defines the width of the i-th blob in frequency. Variability in time of the blob centers is simulated so that the centers move symmetrically with respect to the median point of the coordinate grid defined as one of input parameters during a given number of time frames.

A short test program for simulating and plotting brightness data (VisuTest.nb) as well as necessary packages (DataTypes.m, E3Dimaging.m, E3Dvisualize.m) can be downloaded from the EISCAT_3D site: http://e7.eiscat.se/Members/Vasyl_Belyey/WP5/WP5imaging/folder_contents. Examples of visualization animations produced using both simulated data and the data obtained at Jicamarca Radio Observatory and described in [4] can be found at the site as folders.

References

1. Illuminating the Path: The Research and Development Agenda for Visual Analytics. Edited by James J. Thomas and Kristin A. Cook. National Visualization and Analytics Center (NVAC™). Available online http://nvac.pnl.gov/docs/RD_Agenda_VisualAnalytics.pdf
2. Hibbard, B., Kellum, J., and Paul, B. Vis5D Visualization Project. Space Science and Engineering Center (SSEC), University of Wisconsin-Madison. Available online http://www.ssec.wisc.edu/~billh/vis5d.html
3. Hysell, D.L. and Chau, J.L. (2006), Optimal aperture synthesis radar imaging, *Radio Science*, *41*, RS2003, doi:10.1029/2005RS003383.
4. Belyey, V., La Hoz, C.. Chau, J., and Pinedo, H. (2008), First 3-dimensional radar interferometry observations of equatorial E region irregularities at Jicamarca, *The 12-th International Symposium on Equatorial Aeronomy*, Poster S5-P2-01, Greece, 18-24 May 2008.