PRIMER
on
IONOSPHERIC DRIFT ANALYSIS
USING THE DIGISONDE

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X International Training
Seminar for Digisonde Users
13 – 15 October 2004

OUTLINE

- Introduction - Basic Drift Concept
- Digisonde Drift Analysis
- Generalized Digisonde Drift Analysis
- Theory and Results

INTRODUCTION

The DIGISONDE measures the plasma drift in the local area of the sounder, typically in a region with a radius of 400 to 500 km (at F region altitudes) centered over the site. This area is determined by the radiation pattern of the Digisonde transmitting antenna which is frequency dependent.

Two analysis methods have been developed here at UMLCAR, each making certain assumptions about the drift motions within the field-of-view. These are:

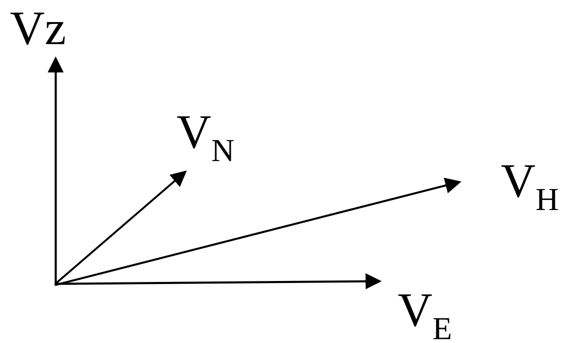
DDA (Digisonde Drift Analysis)
GDDA (Generalized Digisonde Drift Analysis)

DDA assumes that over the coverage area a unique drift velocity applies to the entire area, appropriate at mid-latitudes.

GDDA does away with this limitation and makes it possible to identify more than one velocity vector within the field-of-view, an assumption often appropriate at high latitudes. There are other advantages to the newer GDDA method that will be discussed later, but this increased generality comes at the expense of processing time.

INTRODUCTION – Drift Basics

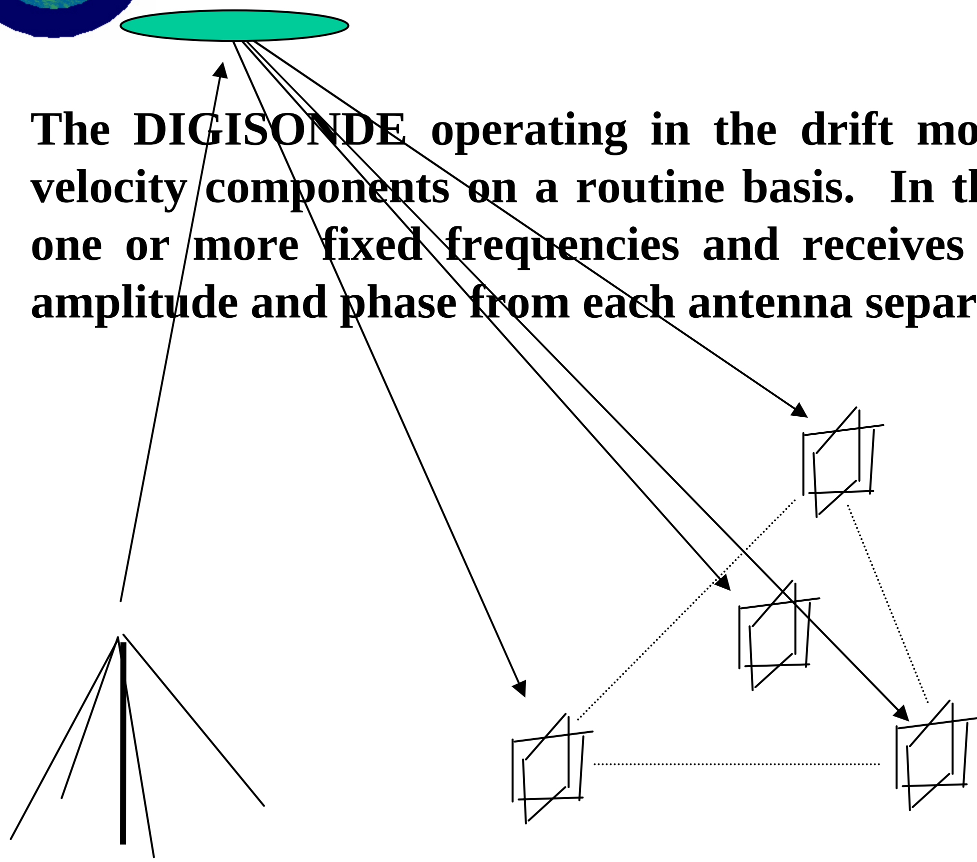
In general, ionospheric plasma is in motion, driven by electric fields and neutral winds. This plasma drift can obviously be described by a horizontal component V_H and a vertical component V_Z. Further, the horizontal drift can be resolved into a north-south component V_N and an east-west component V_E.



The character of the plasma drift changes dramatically with location, in particularly we often treat high latitude, mid-latitude and equatorial motions differently. These drift motions vary diurnally, with the season and with the level of solar and magnetic activity as well as with other factors.

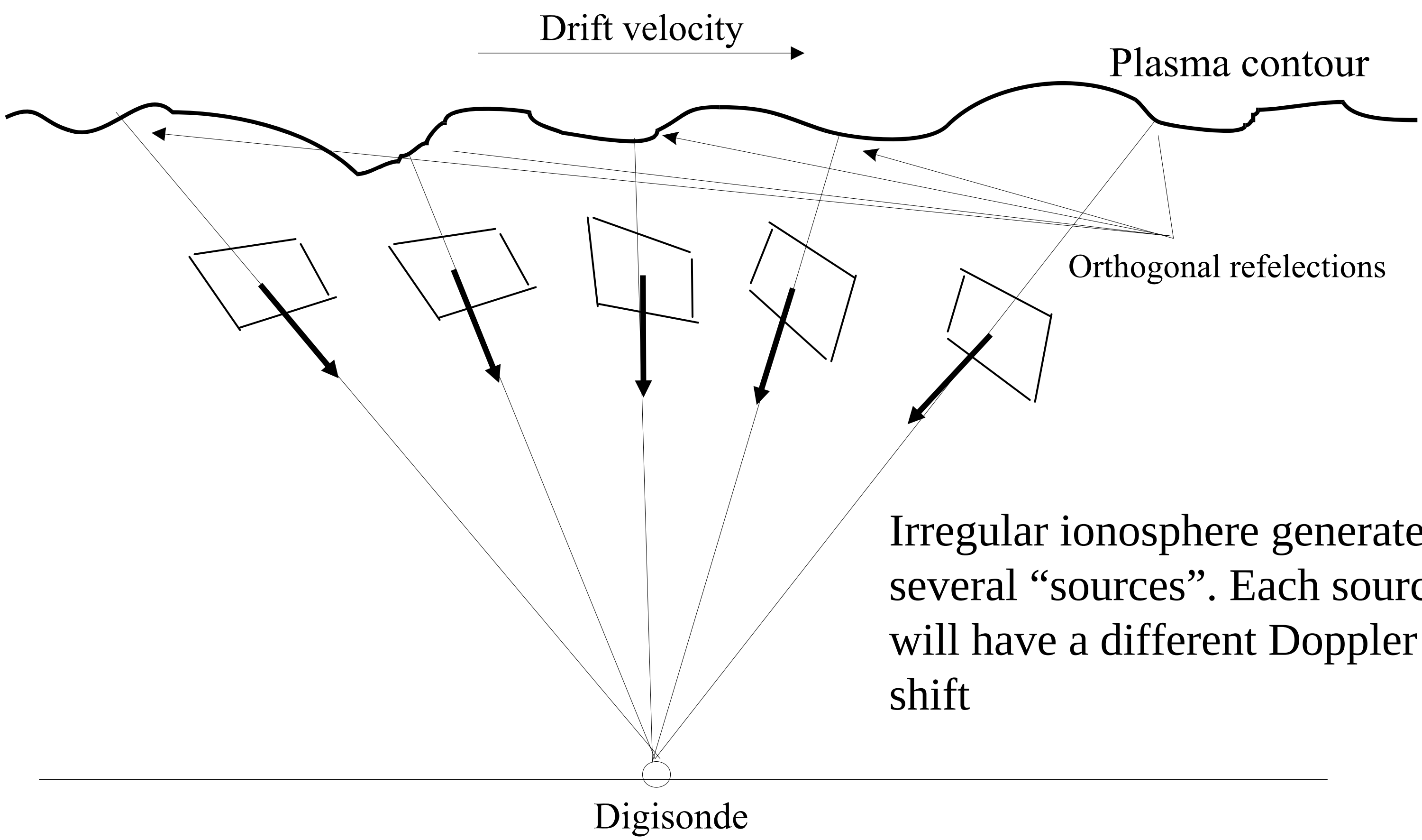
INTRODUCTION – Drift Basics

The DIGISONDE operating in the drift mode is designed to measure these velocity components on a routine basis. In this mode the Digisonde sounds at one or more fixed frequencies and receives and records the reflected signal amplitude and phase from each antenna separately.

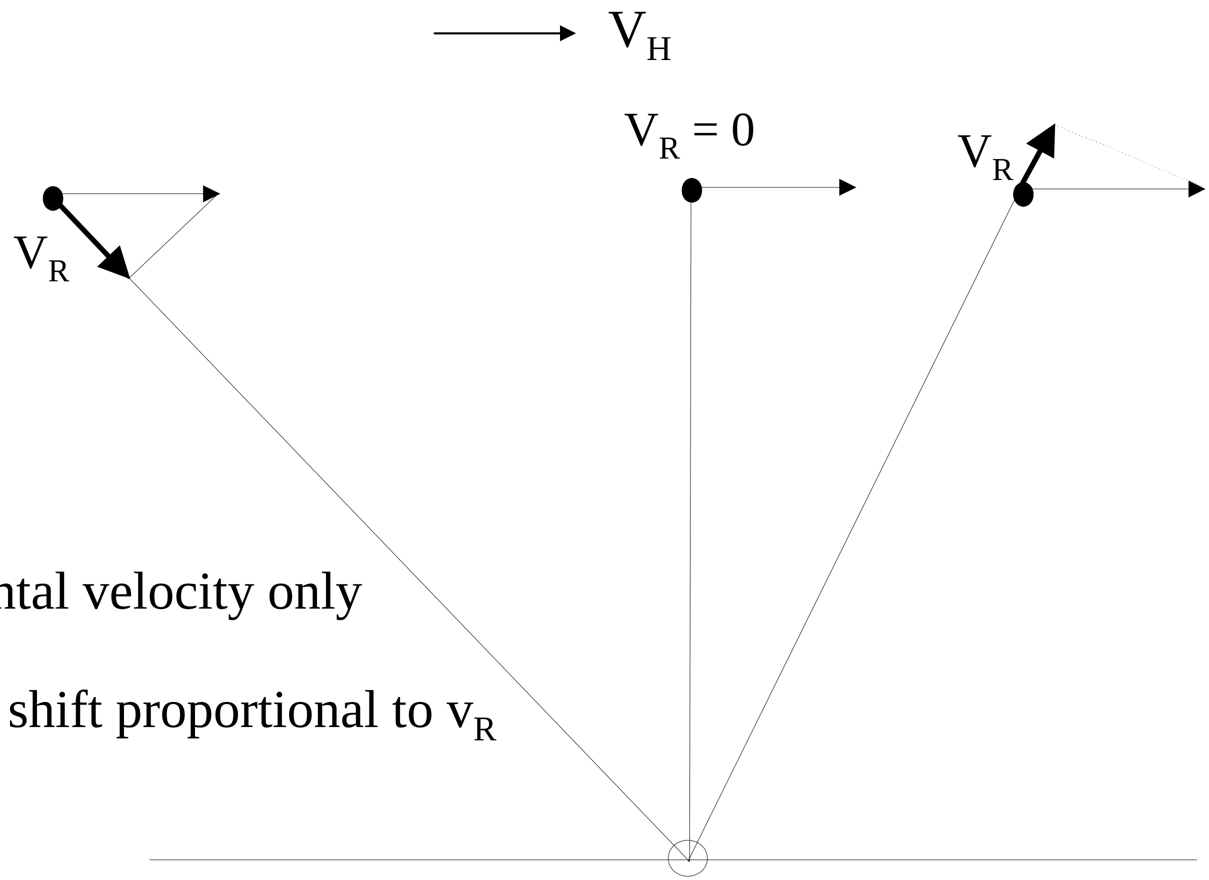


This technique depends on the presence of ionospheric irregularities that are embedded in the background plasma.

DRIFT BASICS



Irregular ionosphere generates several "sources". Each source will have a different Doppler shift



Horizontal velocity only

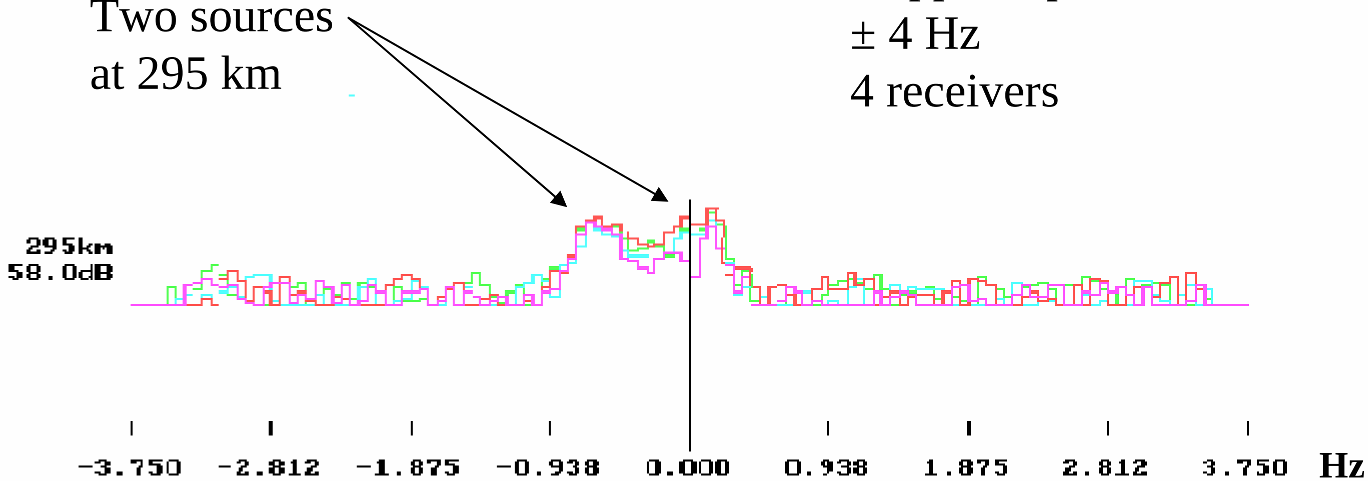
Doppler shift proportional to v_R

SPECTRUM ANALYSIS

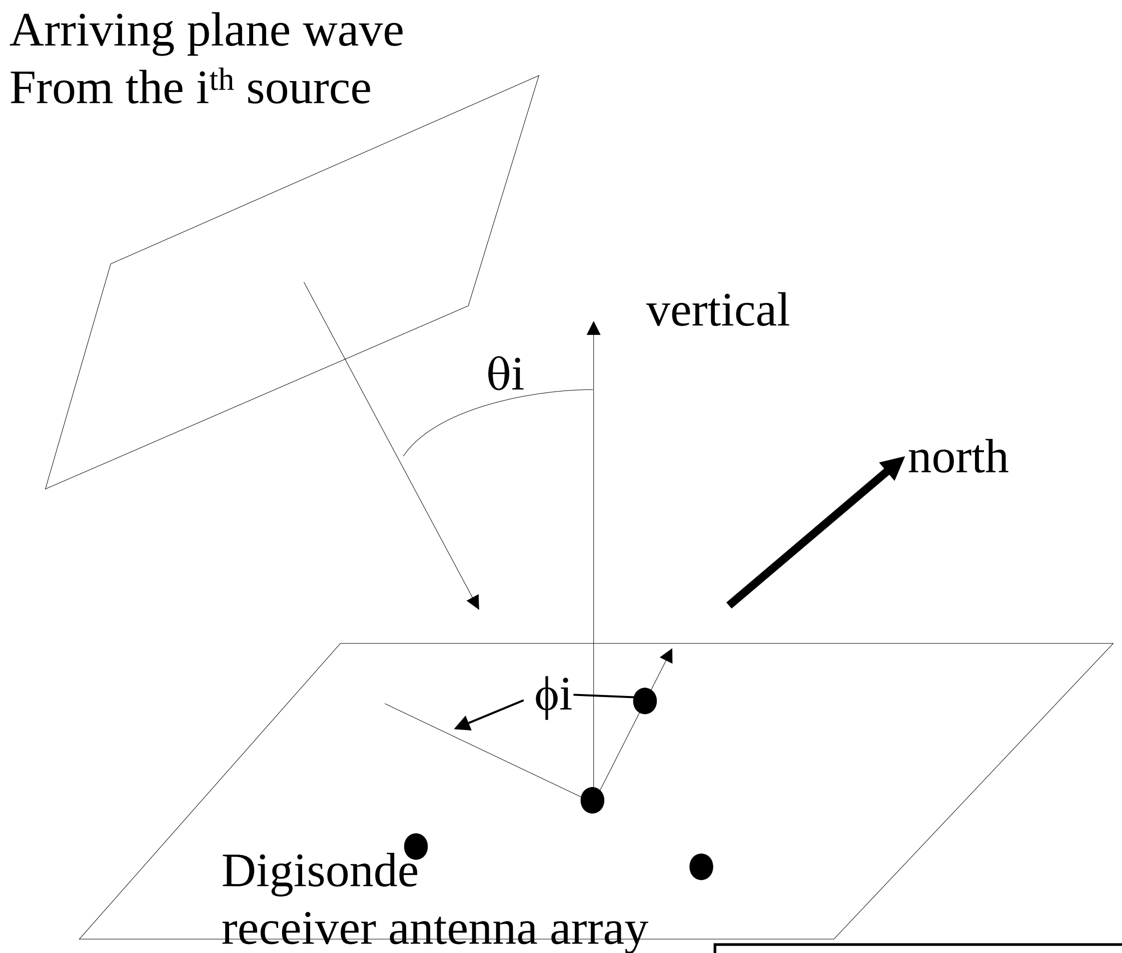
Individual sources are identified by performing spectrum analysis on the signals received on each antenna. With quadrature sampling of the receiver output we obtain both the phase and amplitude for each spectral line on each antenna.

Two sources
at 295 km

Doppler Spectrum
± 4 Hz
4 receivers



ARRIVAL ANGLE MEASUREMENT



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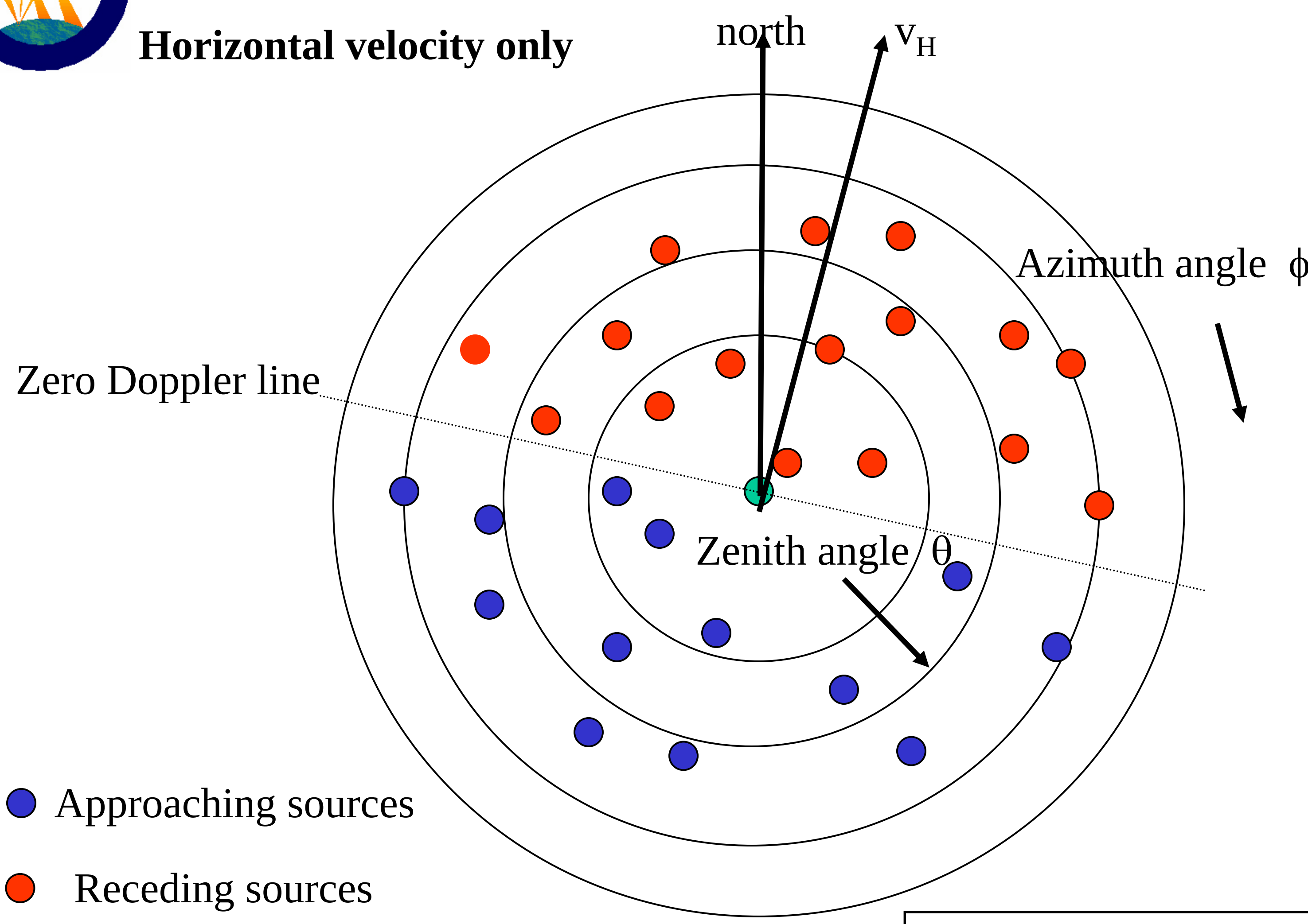
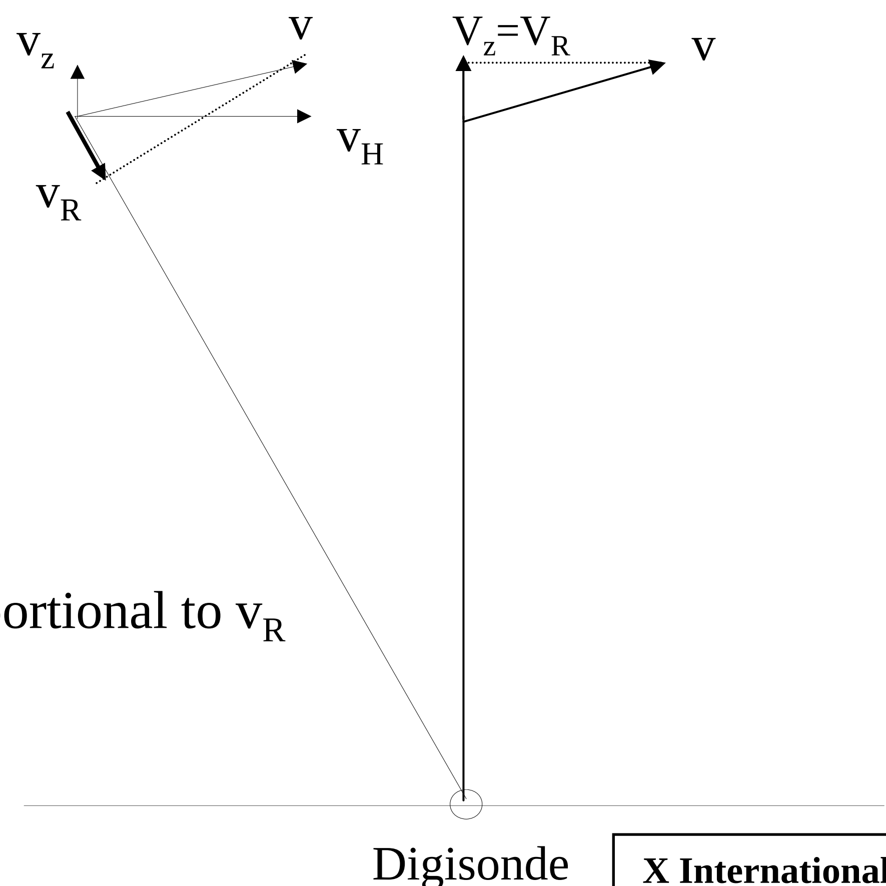
SKY MAP

Horizontal velocity only

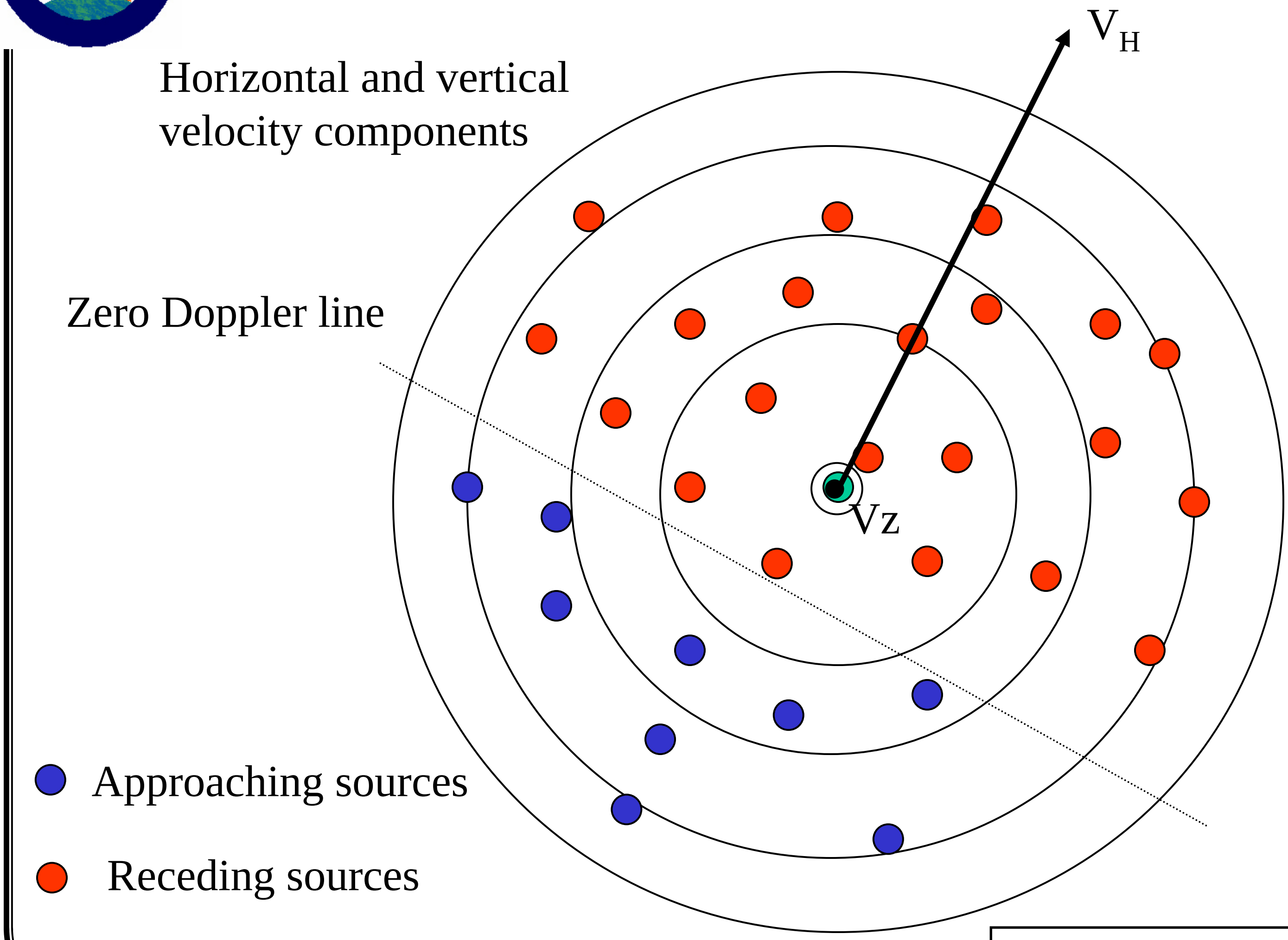


HORIZONTAL AND VERTICAL VELOCITY COMPONENTS



Doppler shift proportional to v_R

SKY MAP



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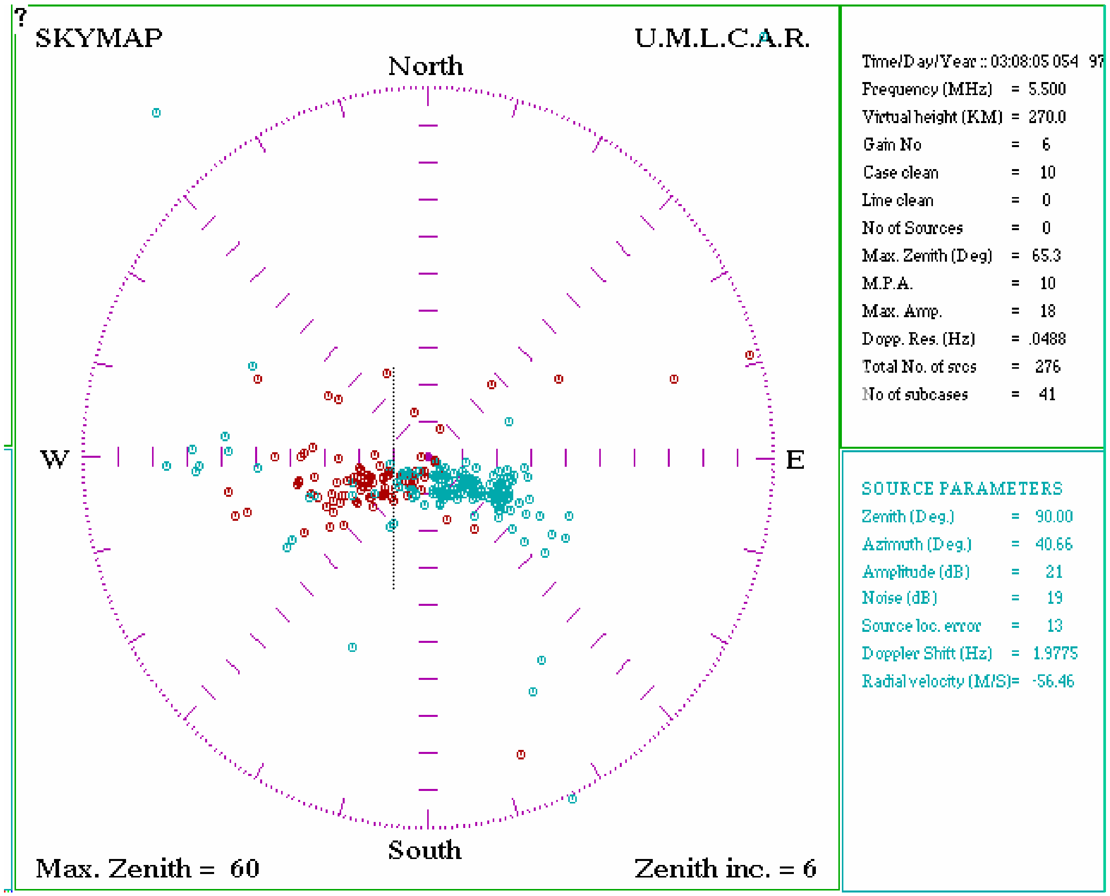
Sky Map (actual)



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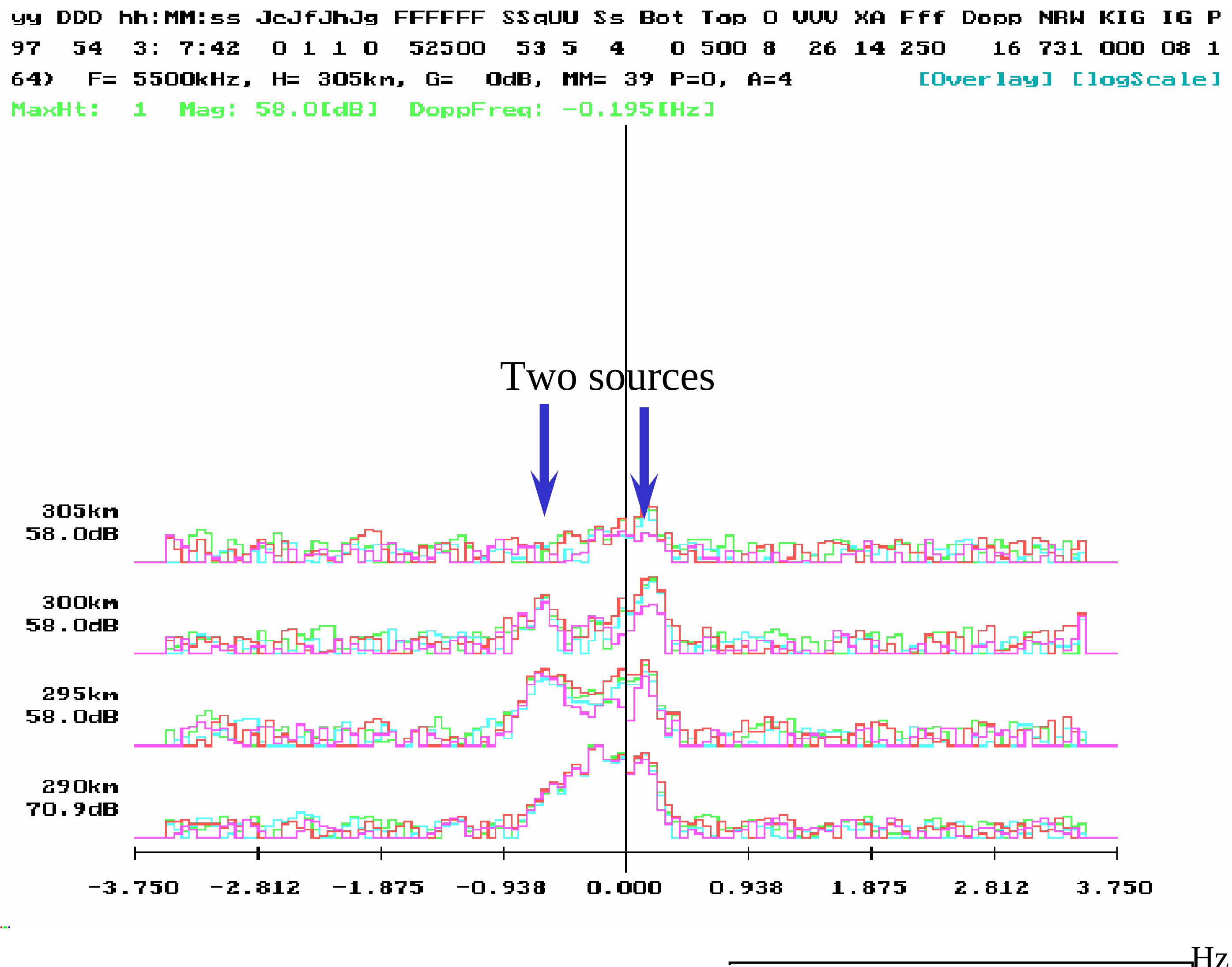


yy DDD hh:MM:ss JcJfJhJg FFFFFF SSqUU Ss Bot Top O VVV XA Fff Dopp NRW KIG IG P
97 54 3: 7:42 0 1 1 0 52500 53 5 4 0 500 8 26 14 250 16 731 000 08 1
64) F= 5500kHz, H= 305km, G= 0dB, MM= 39 P=0, A=4 [Overlay] [logScale]
MaxHt: 1 Mag: 58.0[dB] DoppFreq: -0.195[Hz]
Two sources
305km
58.0dB
300km
58.0dB
295km
58.0dB
290km
70.9dB
-3.750
-2.812
-1.875
-0.938
0.000
0.938
1.875
2.812
3.750
Hz

Digisonde Drift Analysis (DDA)

$$\delta f_i = -\frac{2}{c}(\hat{k}_i \bullet \vec{v}) f_o$$

and

$$\hat{k}_i \bullet \vec{v} = \sin\theta_i \cos\phi_i \, v_x + \sin\theta_i \sin\phi_i \, v_y + \cos\theta_i \, v_z$$

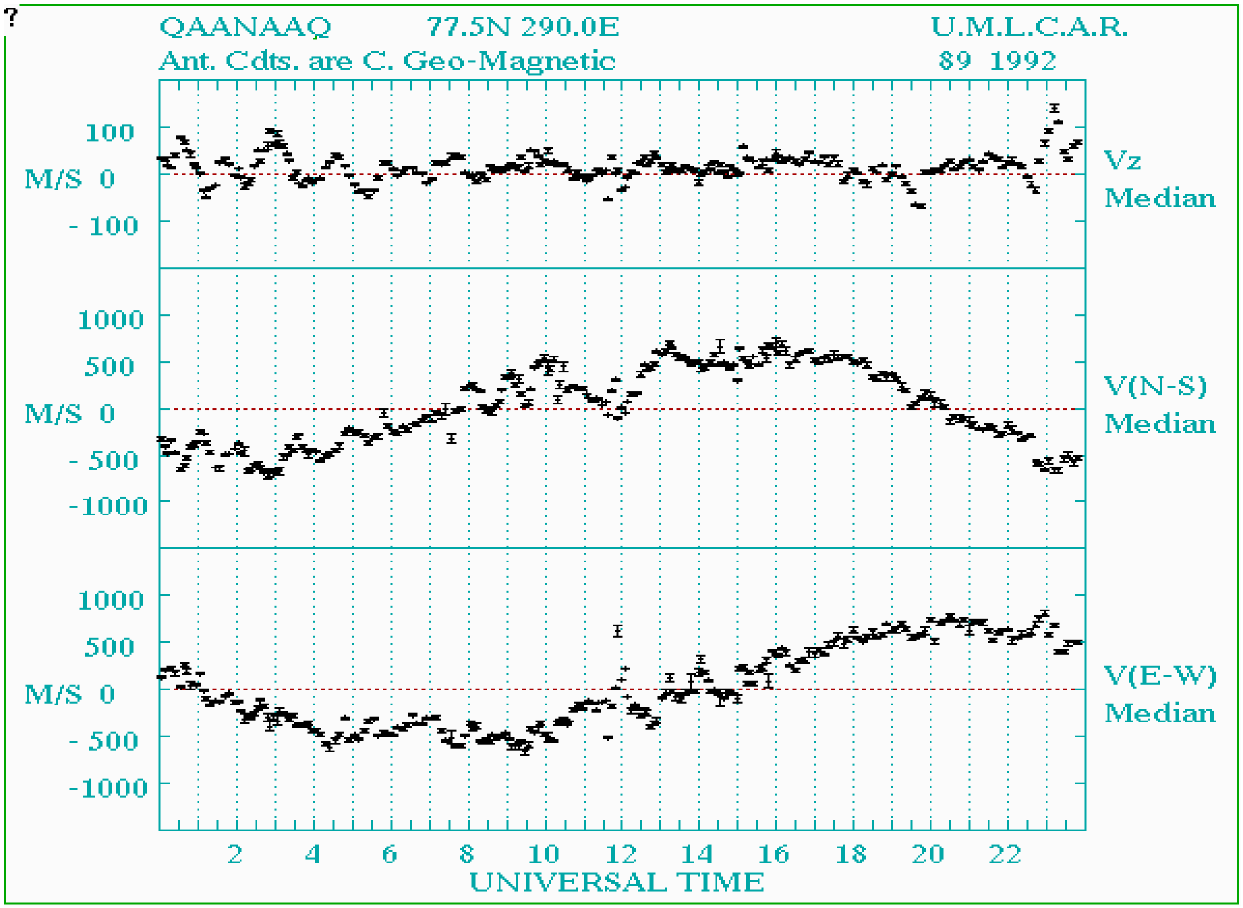
For each source we measure **δf, θ and ϕ**. We now have an equation with three unknowns; **v_x, v_y and v_z**. With just **three sources** we could solve uniquely for **v_x, v_y and v_z**. In general, we have many more than three sources and and the problem is over determined. We can then solve for the three velocity components that provides a "best fit", in a least square sense, to all the Doppler measurements.

Digisonde Drift Analysis (DDA)

$$\varepsilon^2 = \sum_i \left[\frac{2}{c} (\hat{k}_i \bullet \vec{v}) f_o + \delta f_i \right]^2$$

That is, we find a solution for $\mathbf{v_x}$, $\mathbf{v_y}$ **and** $\mathbf{v_z}$ that **minimizes** the above expression. This gives the best estimate of the drift velocity (both the horizontal and vertical components) at the time of the measurement. The **DDA** method uses all sources together, assuming a uniform drift velocity across the field of view. This calculation of the drift velocity can be performed every minute, five minutes, etc..

Digisonde Drift Analysis (DDA)



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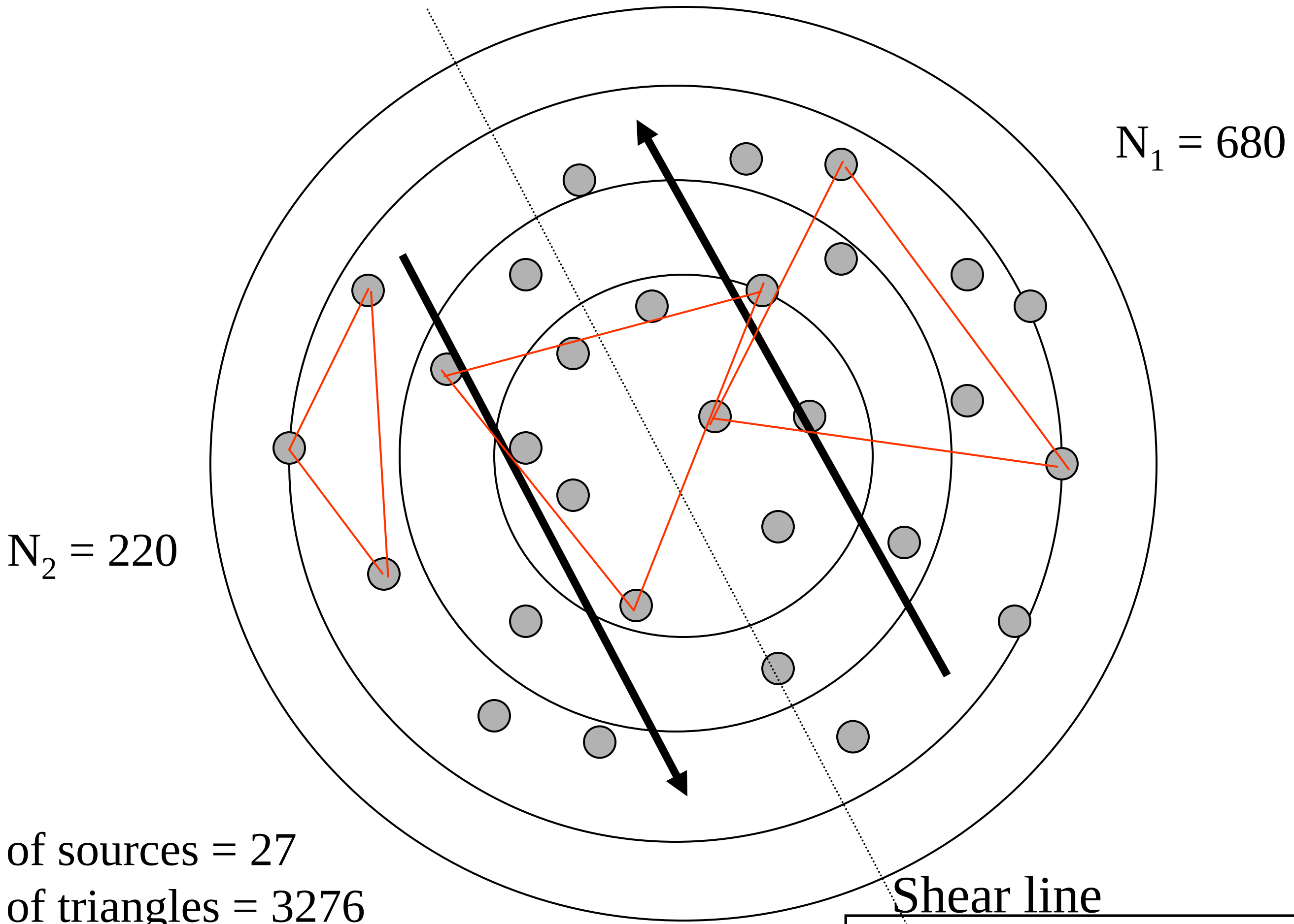
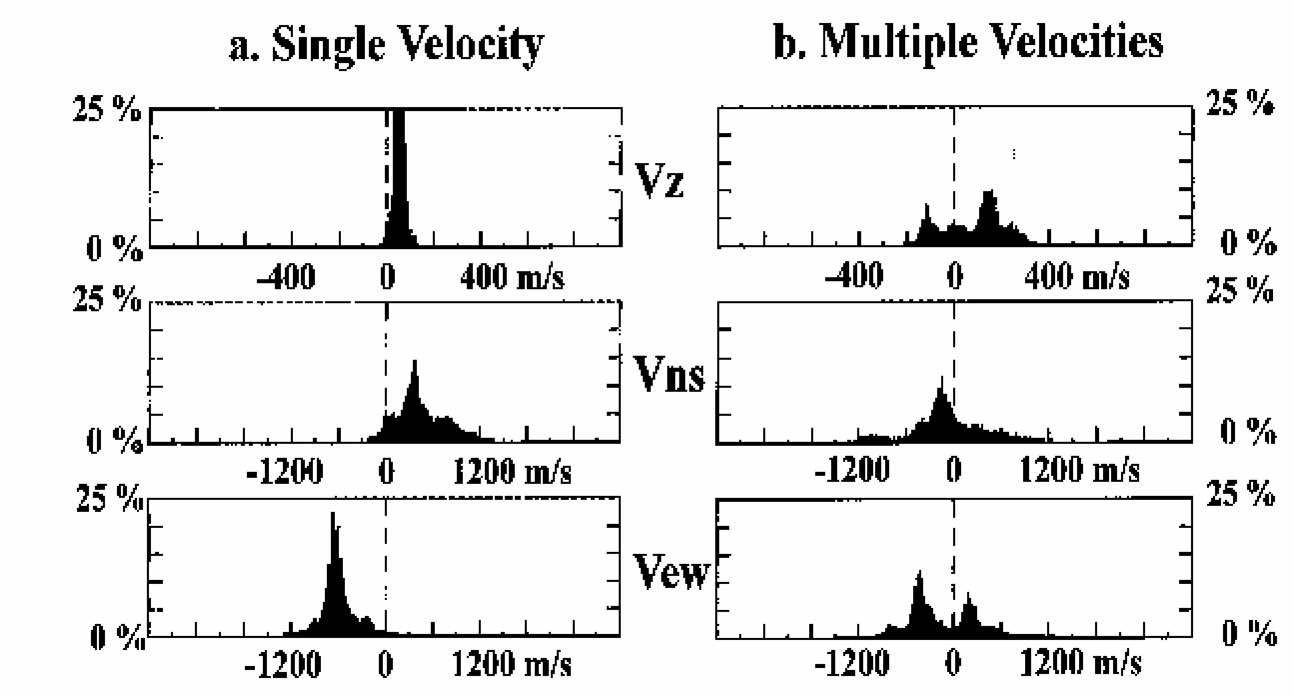
Generalized Digisonde Drift Analysis (GDDA)



Number of sources = 27
Number of triangles = 3276

Generalized Digisonde Drift Analysis (GDDA)

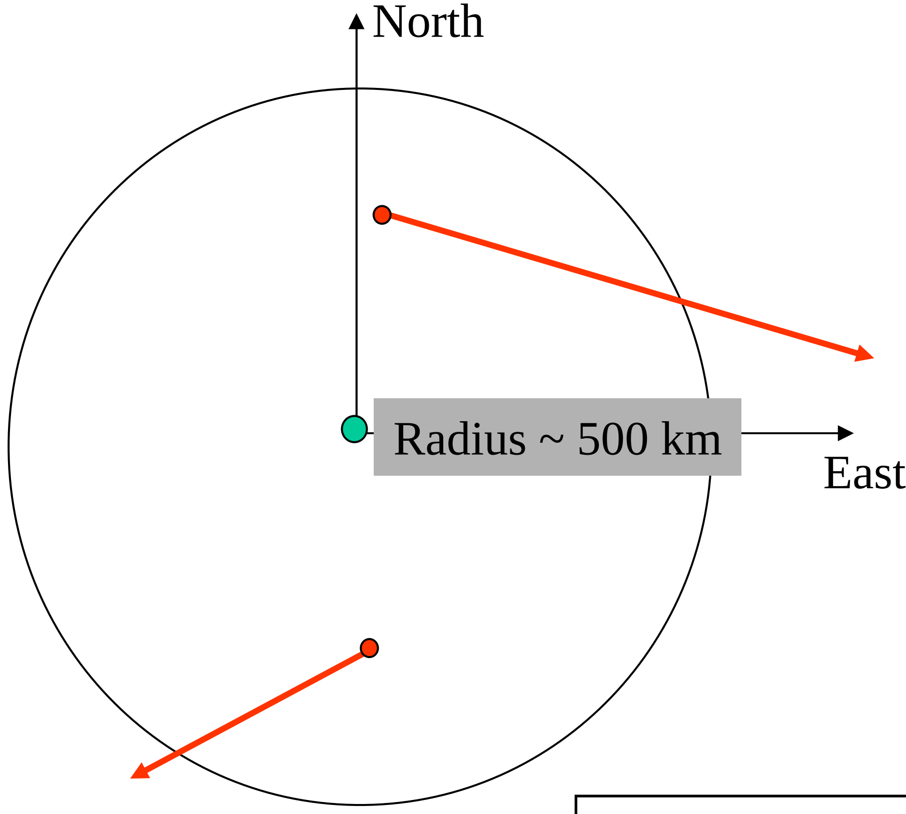
Sondrestrom, Greenland



8 Dec. 1991
1352 UT
N = 27173

8 Dec. 1991
0038 UT
N = 23751

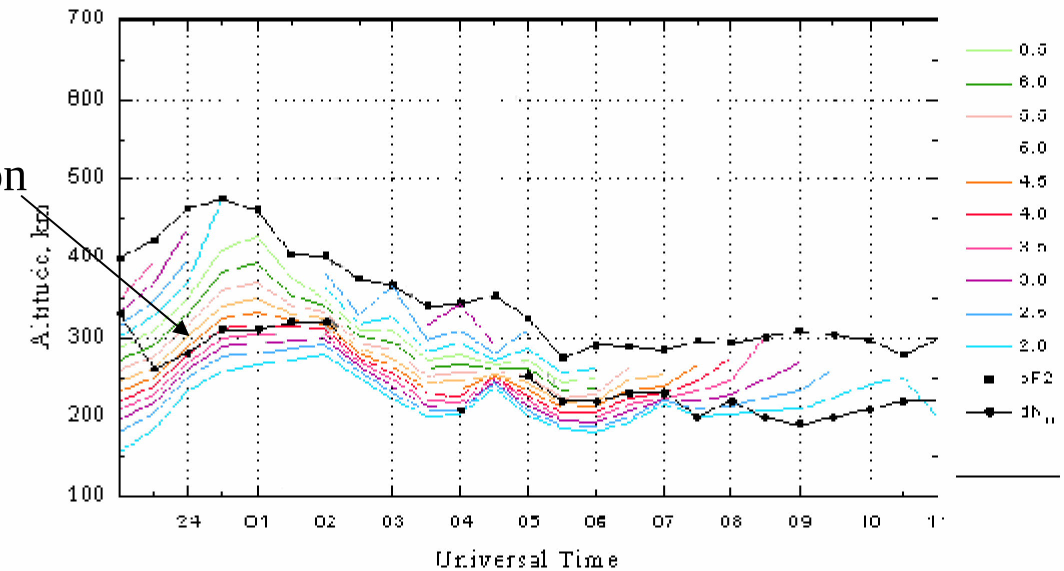
Generalized Digisonde Drift Analysis (GDDA)



CONTOUR VERTICAL VELOCITY ANALYSIS

It is often quick and convenient to estimate the vertical drift component from the plasma frequency isodensity contour plots that are a standard output from the SAO Explorer.

Contour Motion



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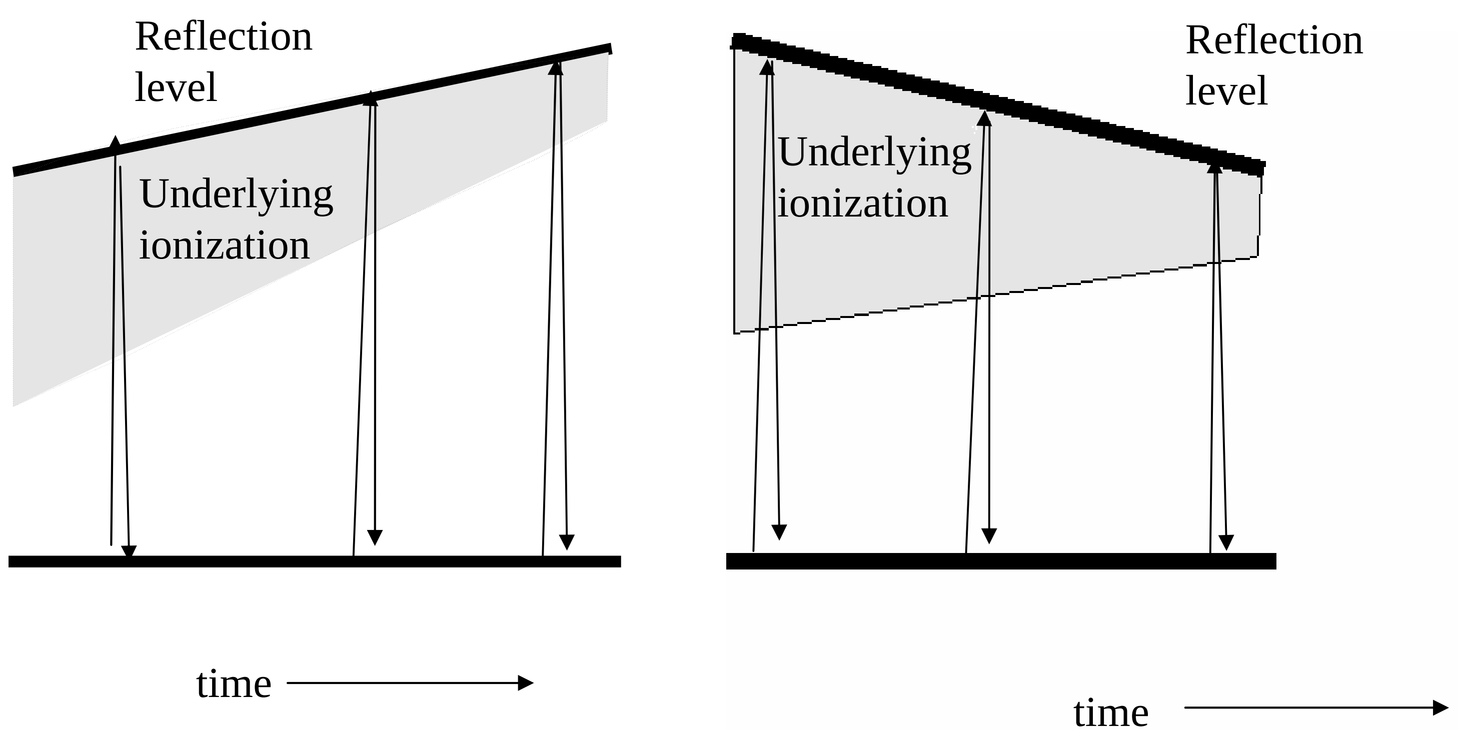
Contour Vertical Velocity Analysis



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The phase path is defined as: $P = \int_0^{zr} \mu \, dz$

where $\mu^2 = 1 - \frac{80.6 \, N_e}{f_o^2}$ is the phase refractive index

The Doppler frequency shift is proportional to the time derivative of the phase path.

$$\delta f = -\frac{1}{\lambda}\frac{\partial P}{\partial t}$$

As the underlying ionization disappears with time (N_e becomes smaller), the refractive index, μ, increases, approaching unity and the time derivative is positive and the Doppler is negative (effectively receding away from the sounder). This loss of ionization is effectively a velocity away from the sounder.

The exact analysis involves the continuity equation.

$$\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e \mathbf{v}) = Q - L .$$

Equation of Continuity

$$\frac{\partial v_z}{\partial z} + \left(\frac{1}{n_e} \frac{\partial n_e}{\partial z} \right) v_z = \frac{1}{n_e} \left[\frac{\partial n_e}{\partial t} - (Q - L) \right]$$

or

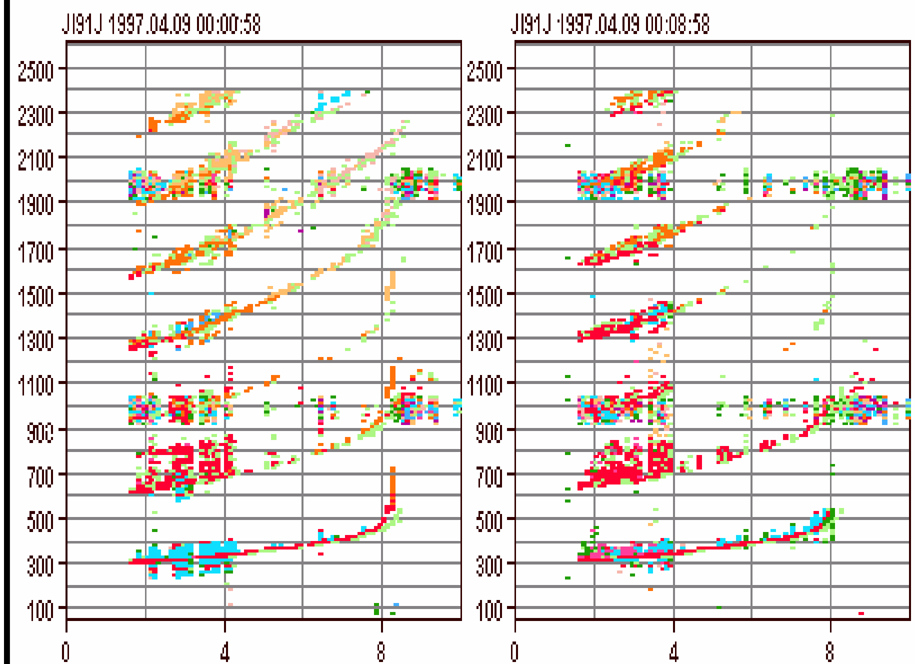
$$\frac{\partial v_z}{\partial z} + S(z) v_z = T(z)$$

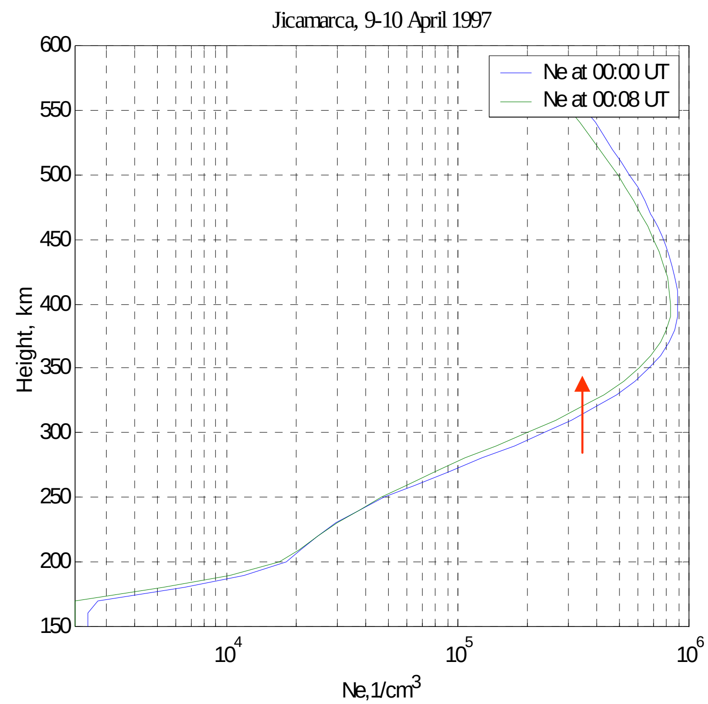
where $S(z) = \frac{1}{n_e} \frac{\partial n_e}{\partial z}$ and $T(z) = \frac{1}{n_e} \left[\frac{\partial n_e}{\partial t} - (Q - L) \right]$

$$v_z(z) = -\frac{1}{n_e(z)} \frac{\partial}{\partial t} \left[TEC(z) \right] + \frac{1}{n_e(z)} \int_0^z \left[Q(\zeta) - L(\zeta) \right] d\zeta .$$

Solution for the vertical velocity

SEQUENTIAL DIGISONDE IONOGRAMS and ELECTON DENSITY PROFILES





Time separation = 8 minutes

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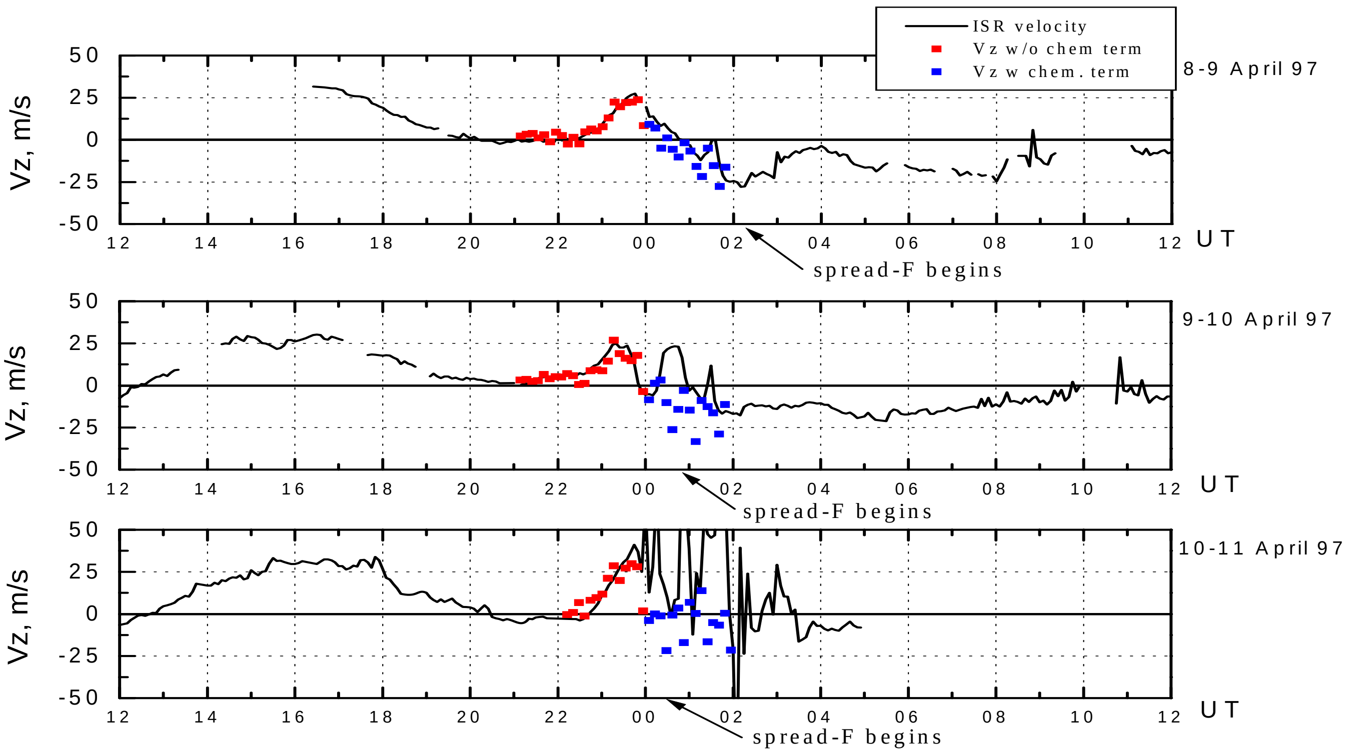
Contour Drift compared to ISR (Jicamarca)

300 km



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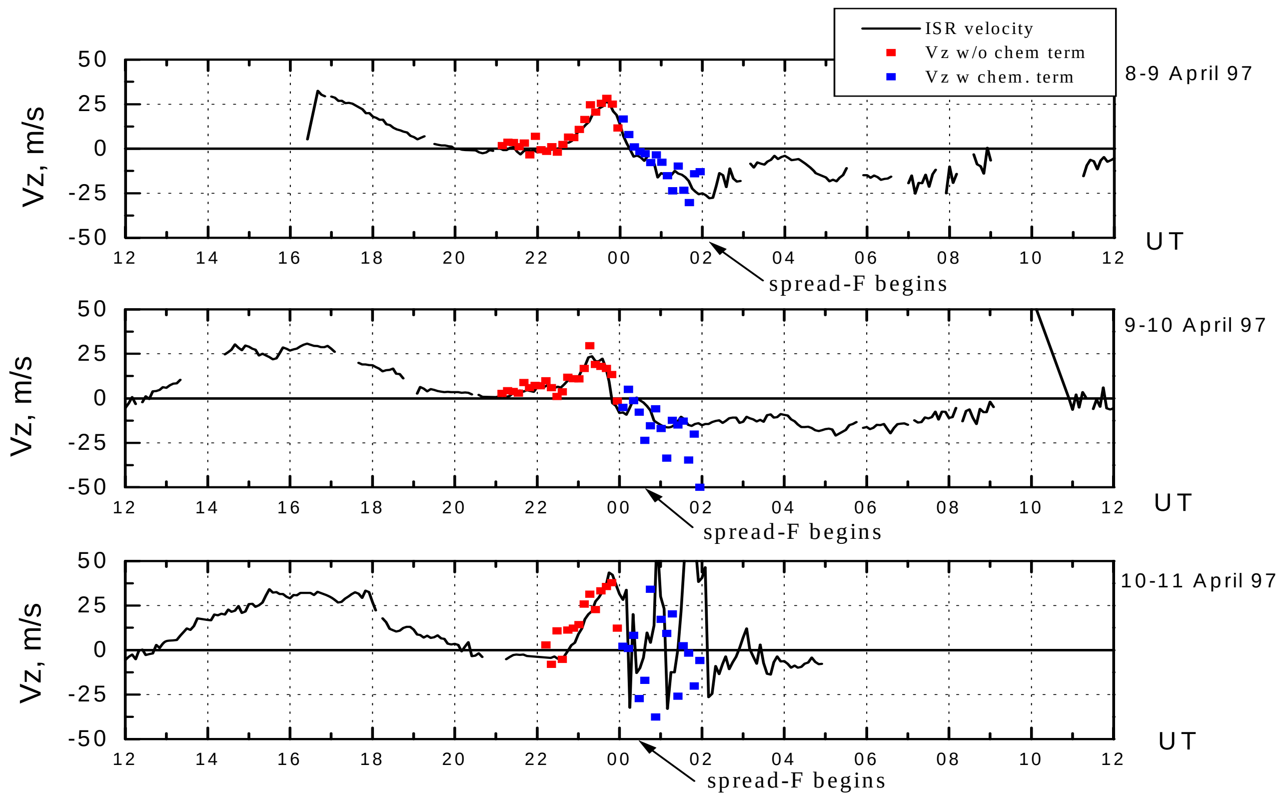
Contour Drift compared to ISR (Jicamarca)

350 km



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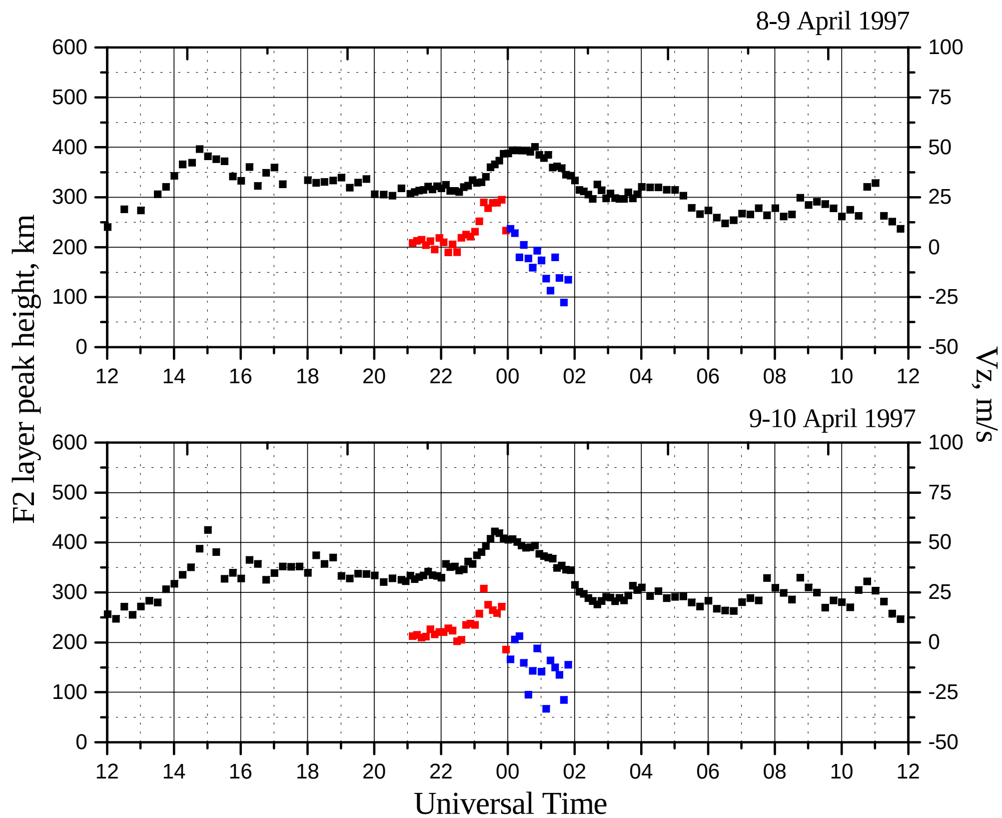
Vertical motion and vertical drift



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