Investigation of the Gravitational Rayleigh Taylor Instability (GRTI) growth rate factors of equatorial plasma bubble irregularities with oblique HF Links

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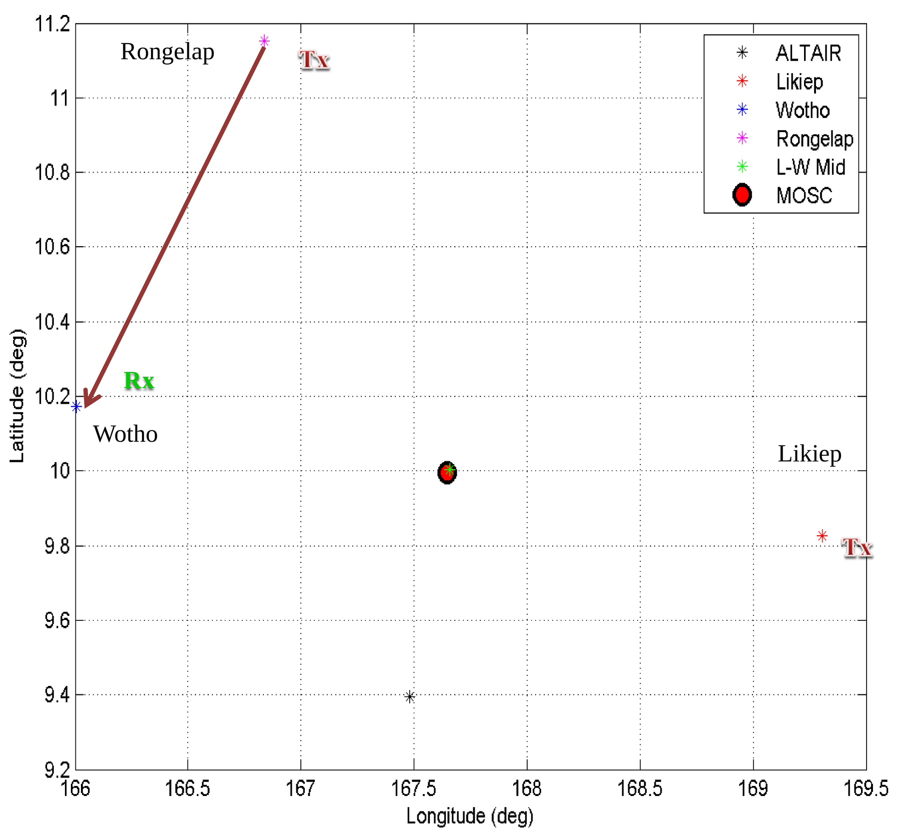
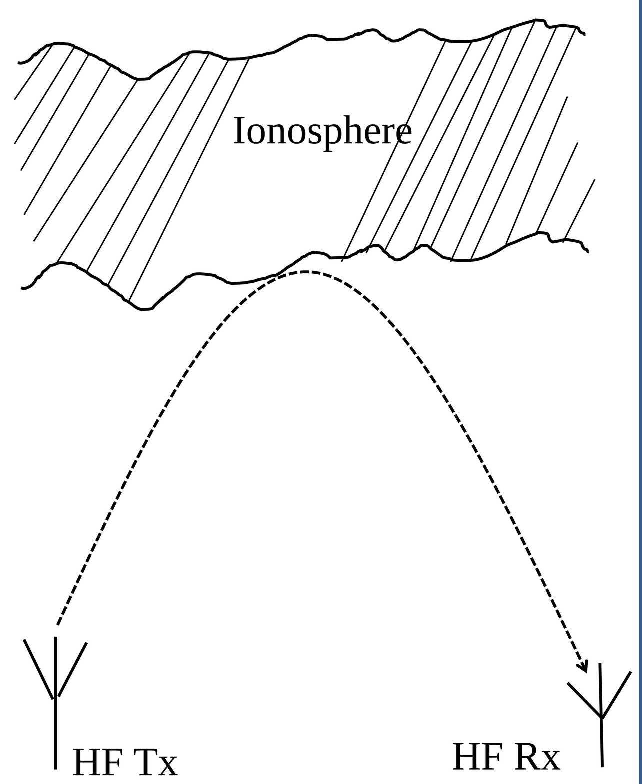
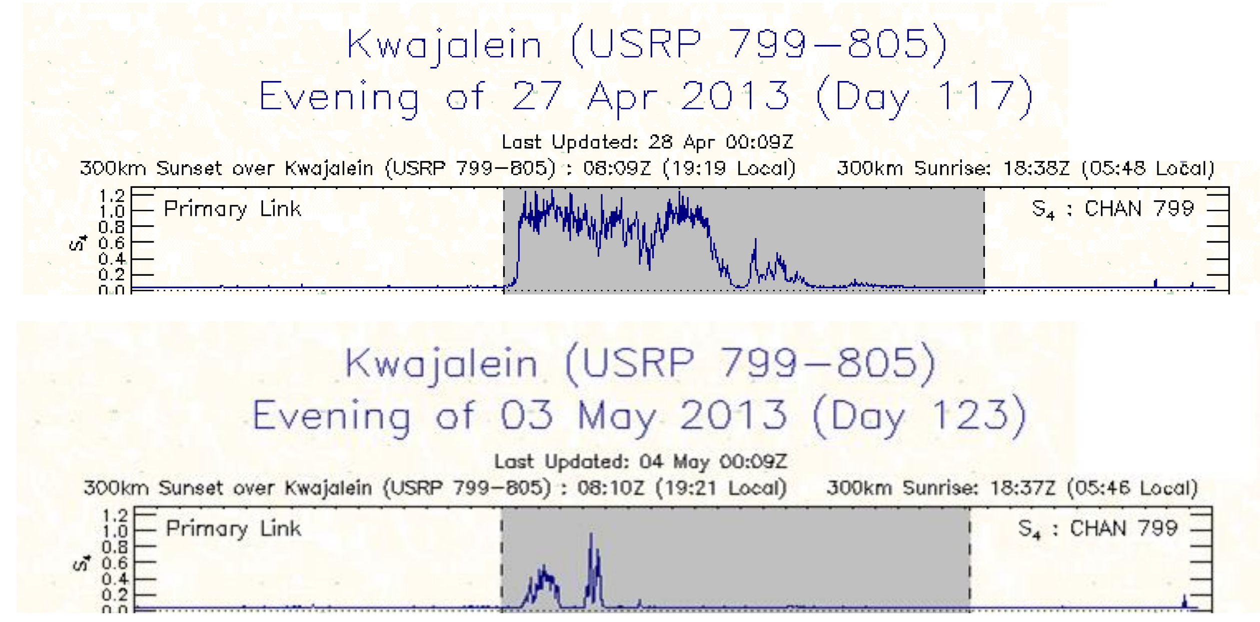
1. Introduction

Introduction: We analyze data from the Metal Oxide Space Cloud (MOSC) experiment conducted in April-May 2013 by the Air Force Research Laboratory with support from the NASA sounding rocket team to understand the factors influencing the growth rate of the Gravitational Rayleigh Taylor Instability (GRTI) believed to be the main cause of equatorial plasma irregularities generally known as spread F. Data from oblique HF radio links and VHF radar are analyzed to examine the parameters influencing the GRTI growth rate such as the plasma drift velocity, the vertical density gradient and the ion-neutral collision frequency correlating to scintillation activity in the equatorial ionosphere. We apply numerical ray-tracing to optimize the ionospheric profile to match the delay observations so that the actual height of the reflection of radio waves can be deduced to calculate the parameters in the GRTI linear growth rate equation. It was found that the linear growth rate calculated in this manner showed a strong correlation with the integrated scintillation activity as defined by the Total Hourly Mean S4 (THMS4) index. The results suggest that oblique HF links may be exploited for short-term forecasts of low-latitude scintillation activity.





3. VHF : Scintillation



The growth rate of the linearized generalized Rayleigh Taylor Instability (GRT) instability is given by :

$$\Upsilon = \frac{\Sigma_P^F}{\Sigma_P^E + \Sigma_P^F} \left(V_p - U_n^P + \frac{g_L}{\upsilon_{in}^{eff}} \right) \frac{1}{L_n} - R_T \qquad \text{(Gentile } et\ al.\text{, 2006)}$$

where, Σ_P^F is the F-region integrated Pederson conductivity, Σ_P^E is the E region integrated Pederson conductivity, V_p is the integrated plasma drift , U_n^P is the integrated neutral wind , g_L is the effective gravity , υ_{in}^{eff} is the effective collision frequency., L_n is gradient scale length and R_T is the effective recombination rate.

From the F-region layer contours , we can derive :

i) Upward Plasma Drift (V_p)

ii) Gradient Scale Length

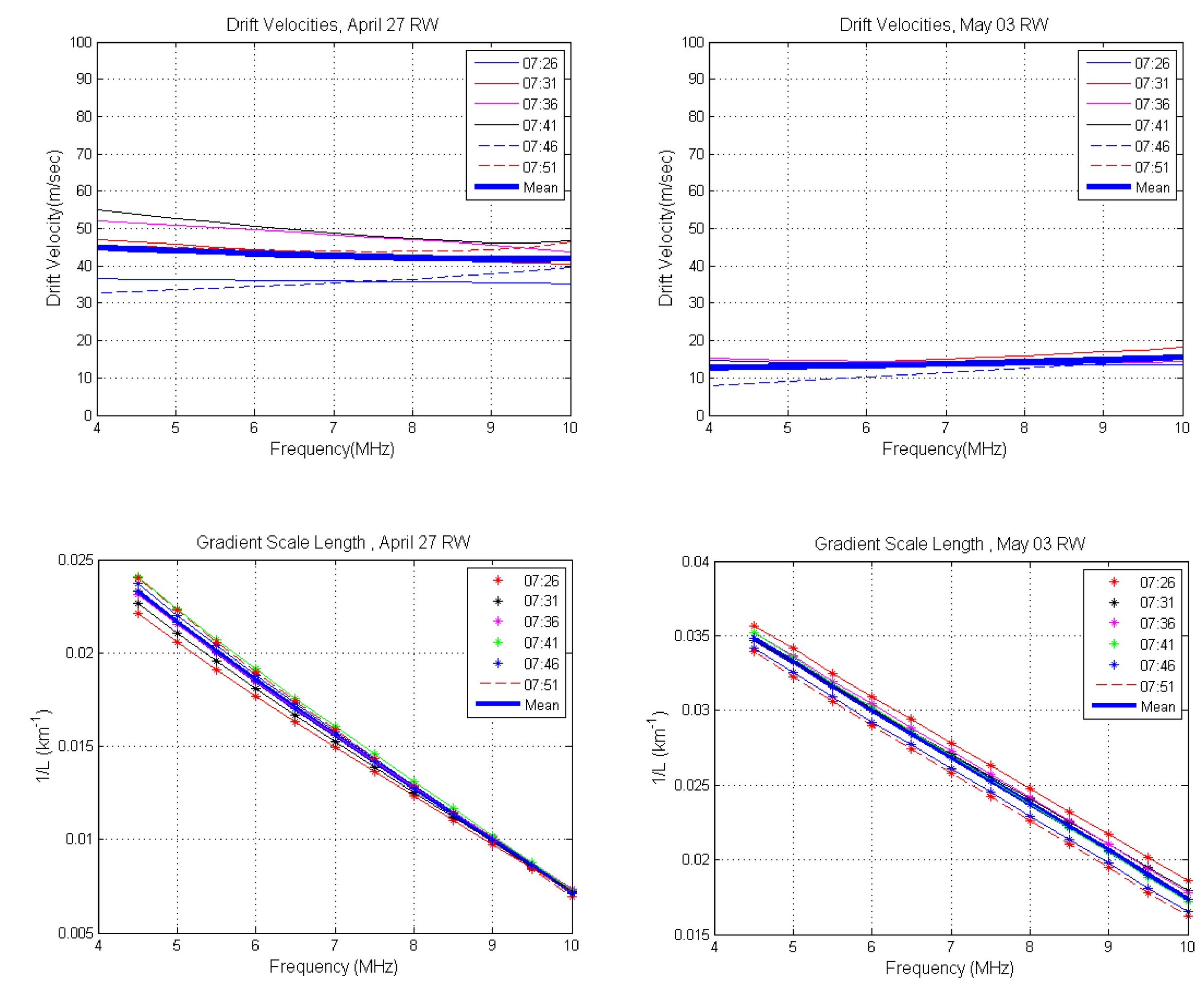
$$\frac{1}{L} = \frac{1}{N_e}\frac{dN_e}{dh}$$; N_e is the electron density, h is height

iii) Ion Collision frequency

$\upsilon_{in}^{eff} = (2.6 \times 10^{-9})(n_n + n_i) A^{-1/2}\ s^{-1}$; n_n is neutral density and n_i is the ion concentration in reciprocal cubic centimeters, and A is the mean molecular weight of the neutrals and ions.

We derive the local values of the above mentioned quantities to compare the relative change in the growth rate in nights with high scintillation – April 27, 2013 (top) and with low scintillation – May 3 , 2013 (below).

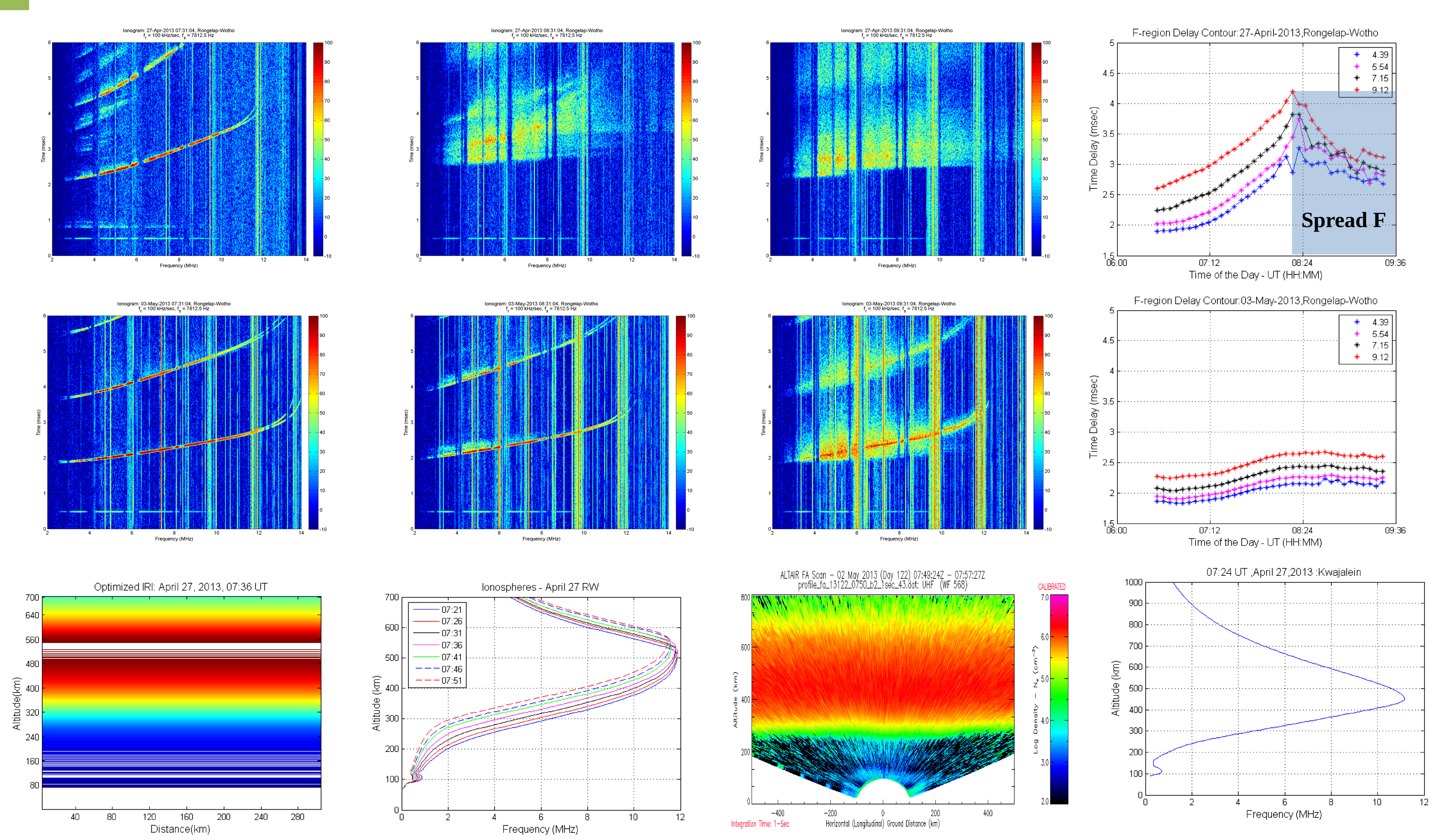
4. Drift Velocity and Gradient Scale Length:



Upper Row - Plasma drifts calculated from the optimized profiles on April 27 and May 3

Lower Row - Gradient Scale Lengths on April 27 and May 3

2. Observations: Oblique HF Ionograms and ALTAIR Radar



Upper Row: The upper row shows hourly ionograms beginning at 07:31 UT on the night of 27th April , 2013 showing the growth of the spread F . The right-most image shows the time-delay contours of the frequency specific F-region layers.

Middle Row: Same as above for the evening of 3 May, 2013 , which shows considerably less spread than 27 April. The right-most image depicts the time-delay contours of frequency specific F-region layers which show weak upward drifts.

Lower Row : Numerical ray-tracing through a 2-D plane of ionosphere (left-most) is used to optimize the IRI profiles (second from left) to match the observed oblique ionosonde delays . The Nelder-Mead Downhill Simplex method was applied to optimize the IRI profiles to be used in lieu of the true profiles to calculate the quantities in the growth rate of the linearized Gravitational Rayleigh Taylor Instability (GRTI) equation. The optimized profiles shall be validated with the true profiles from the ALTAIR incoherent scatter radar scan (second from the right) and the vertical digisonde profile (right-most).

5. Results

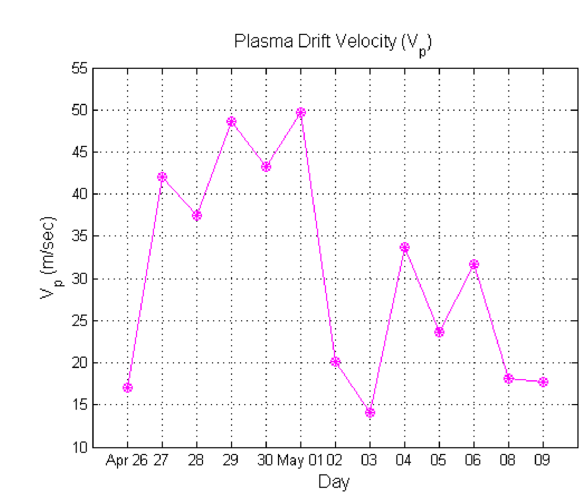
Growth rate parameters plotted during the pre-reversal enhancement period (07:26 – 07:51 UT) prior to the occurrence of spread F.

a) Drift Velocity

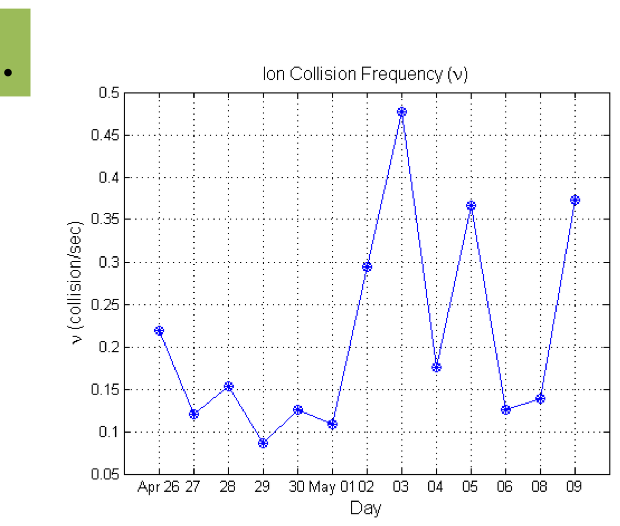
b) Ion Collision Frequency

c) Gradient Scale Length

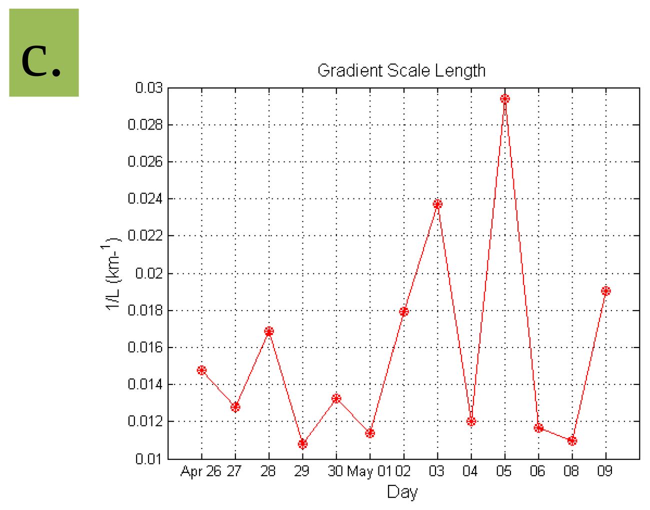
a.



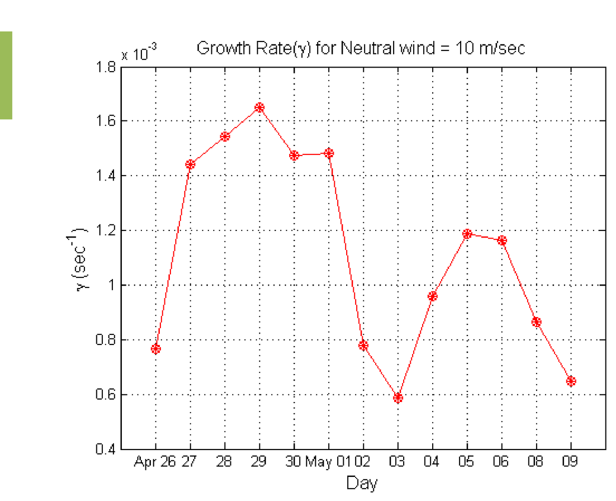
b.



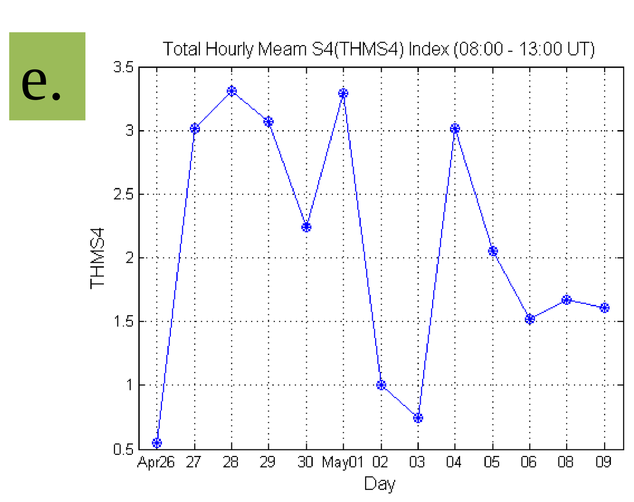
c.



d.



e.



Results for growth rate are shown in panel d above where the neutral wind component (U_n^P) = 10 m/sec for each day is assumed. The corresponding scintillation activity represented by total hourly mean S4 (hourly mean S4 integrated from 08:00 to 13:00 UT) is shown in panel e, highly correlated with the calculated linear growth rate.

6. Conclusions:

- Plasma drift velocity is approximately 100% higher on days with Spread F compared to days with low/no spread F
- For the small number of days investigated here the GRTI linear growth appears to provide a surprisingly accurate prediction for instability development
- HF Oblique Ionosonde and numerical ray-tracing can be used to determine the factors influencing the growth rate of the GRTI

Future Work:

- Validate the technique with truth data from ALTAIR incoherent scatter radar
- Predict spread F growth using only oblique HF ionograms
- Understand the seed mechanism of the plasma bubbles on perpendicular and quasi-parallel (to **B**) paths

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