Local ionospheric empirical model based on Jicamarca incoherent scatter radar data

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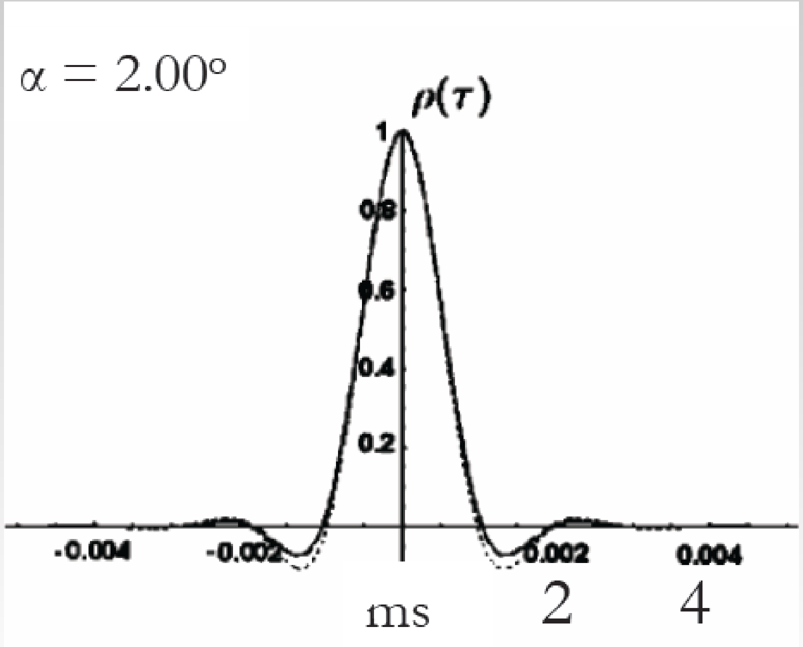


Measurements of:

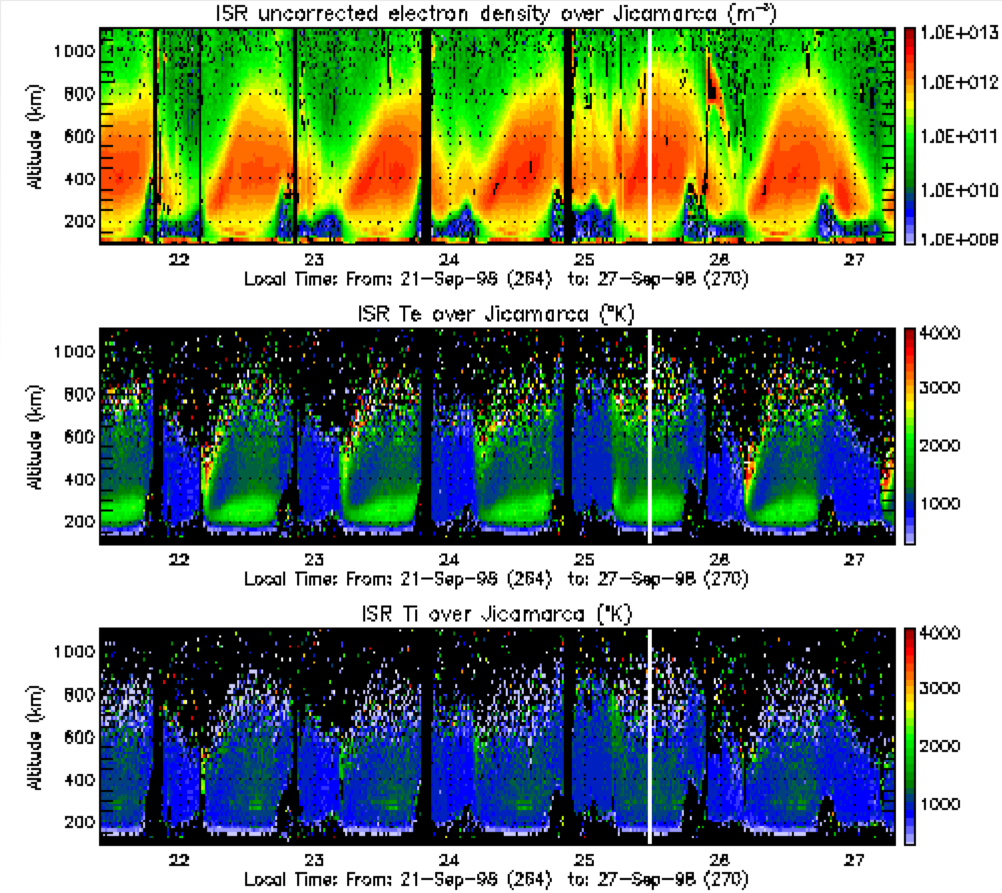
- Electron Density.
- Ionic Composition.
- Electron Temperature
- Ion Temperature
- Drifts (Electric Field)
- Magnetic Field

Statistical Characterization of the Signal

$$C_h(t) \propto \rho_h(\vec{k}_B, \tau; n_e, [n_i], Te, Ti, \vec{V}_{\text{¿}}, \vec{V}_{\parallel}, \vec{B})$$

Plasma Fluctuation of the Medium

Oblique ISR (1): Faraday Double Pulse (DP)



•This is the traditional mode (sinde 1960's) to get:

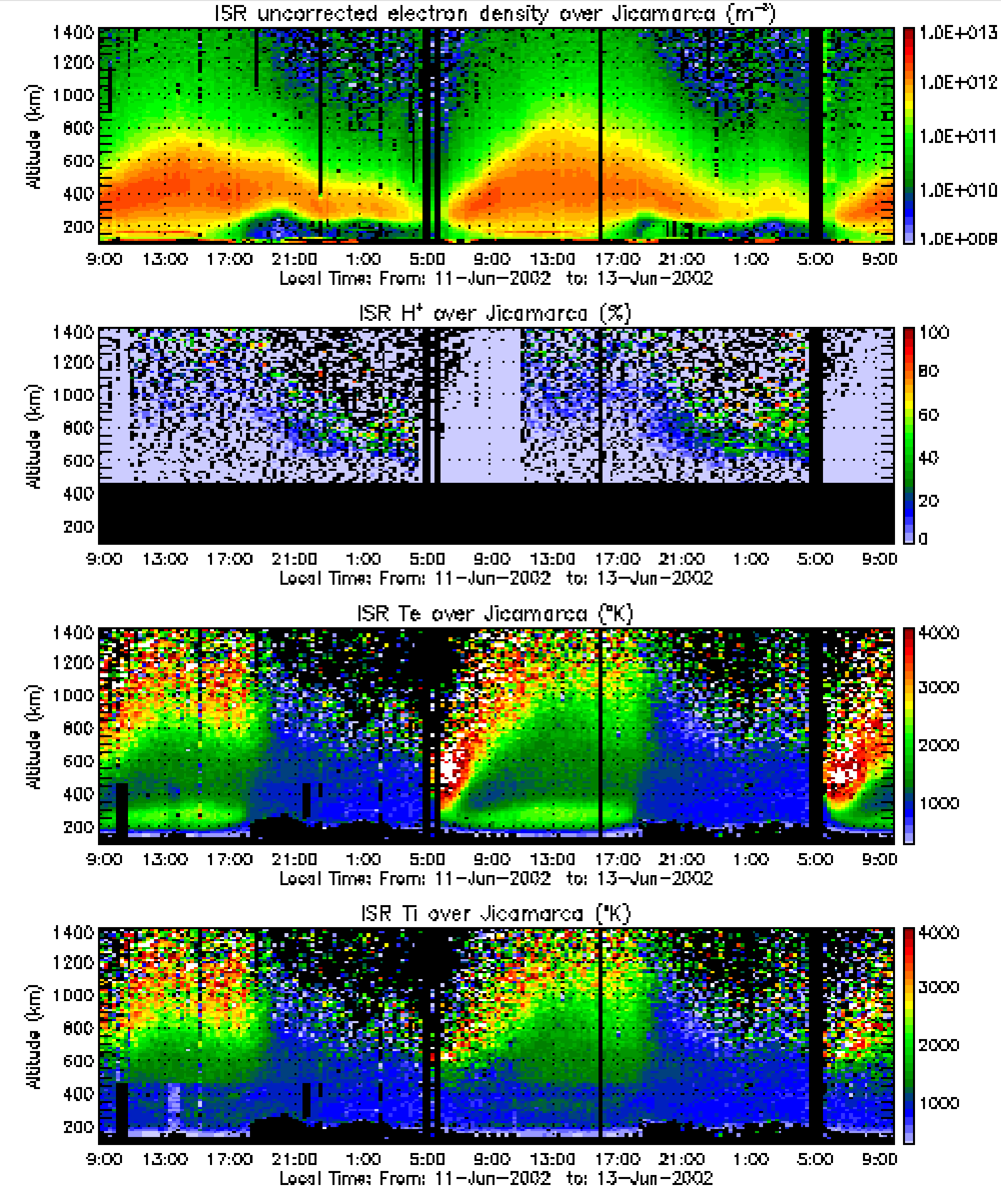
-Densities from Faraday rotation and power.

-Temperatures and composition from ACFs.

•Composition is hardly obtained.

•15 km and 5 minutes of resolution.

Oblique ISR (2): Hybrid 1 (Faraday DP – Alternating Codes)



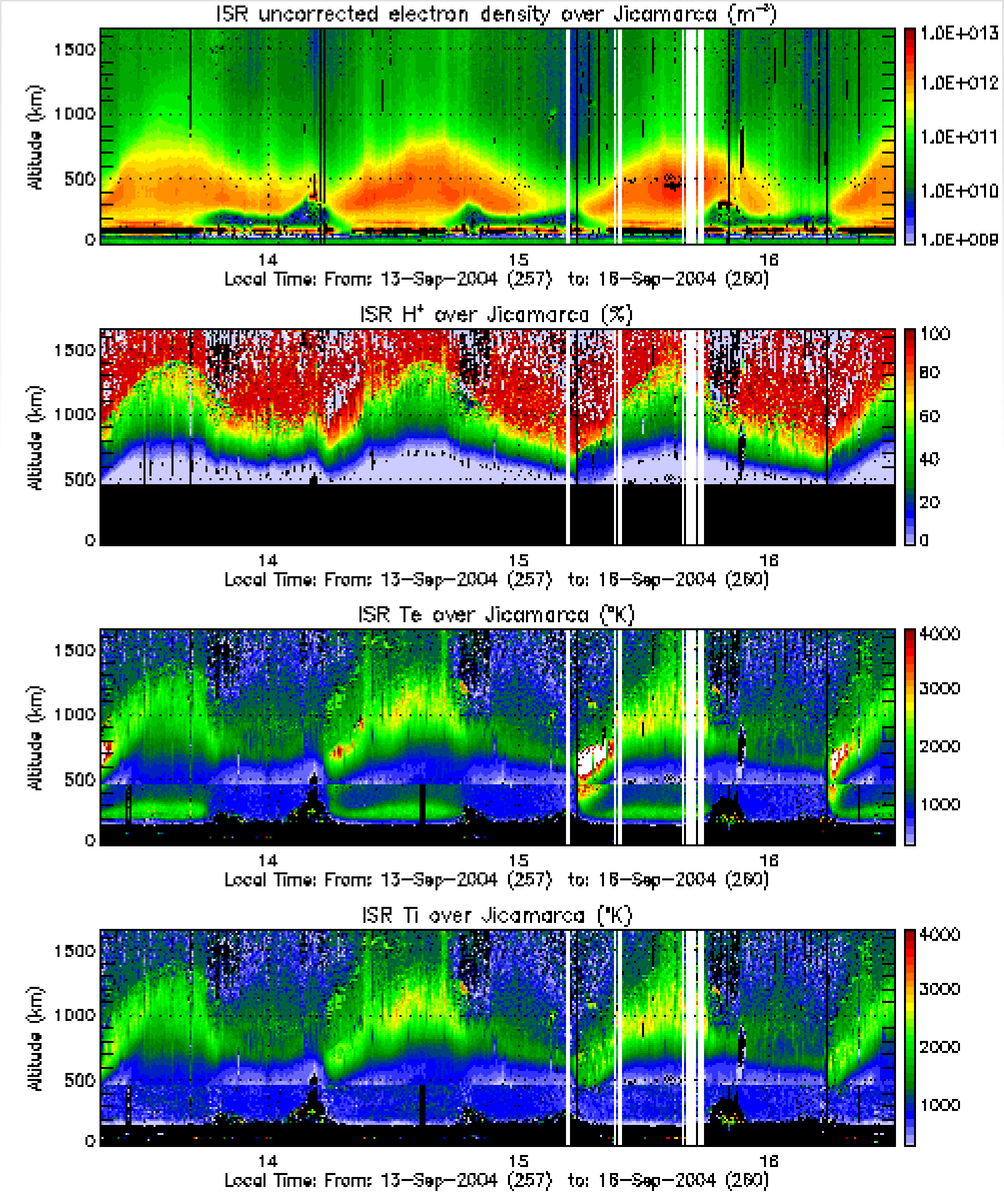
- This mode combines the Faraday DP mode with an alternating code mode [*Hysell*, 2000]. It provides:

-Density and temperatures below 500 km from Faraday DP.

-Density, temperatures and composition above 500 km.

- Altitudinal coverage it is better at the expense of bottom side temperature estimates with slightly less accuracy.
- 15 km and 5 minutes of resolution.

Oblique ISR (3): Hybrid 2 (Faraday DP – Long Pulse)



- This mode combines the Faraday DP mode with a long pulse mode.
- Altitudinal coverage it is better than previous two mode at the expense of less altitudinal resolution.
- Similarly, it provides:

-Density and temperatures below 500 km.

-Density, temperatures and composition above 500 km.

Existing Data

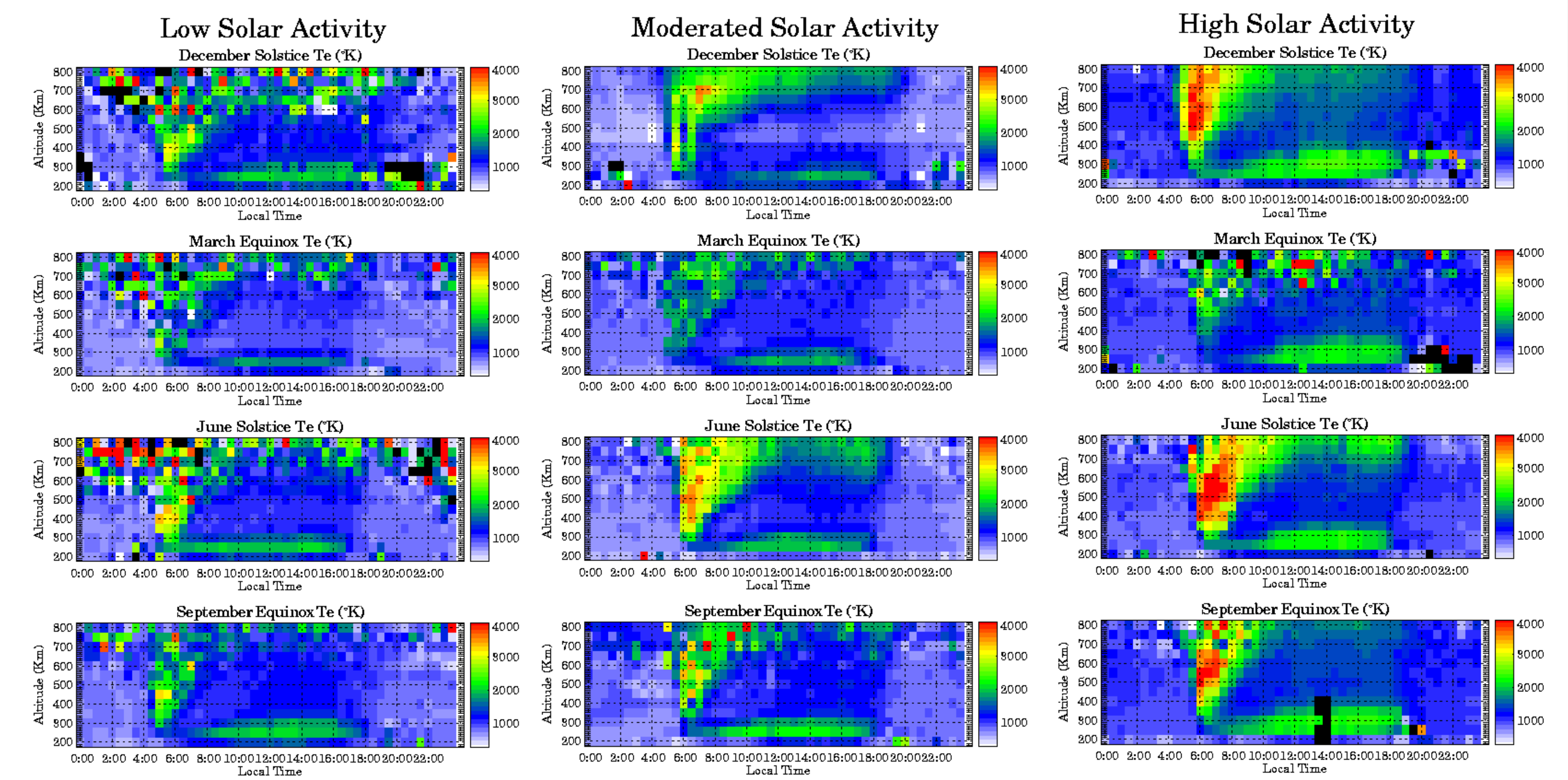
- 1960's
- 1980'
- and, since 1996
- Available in several archive format from MADRIGAL database

Seasonal variability of Te over Jicamarca

100 < F107cm

100 < F107cm < 150

150 < F107cm



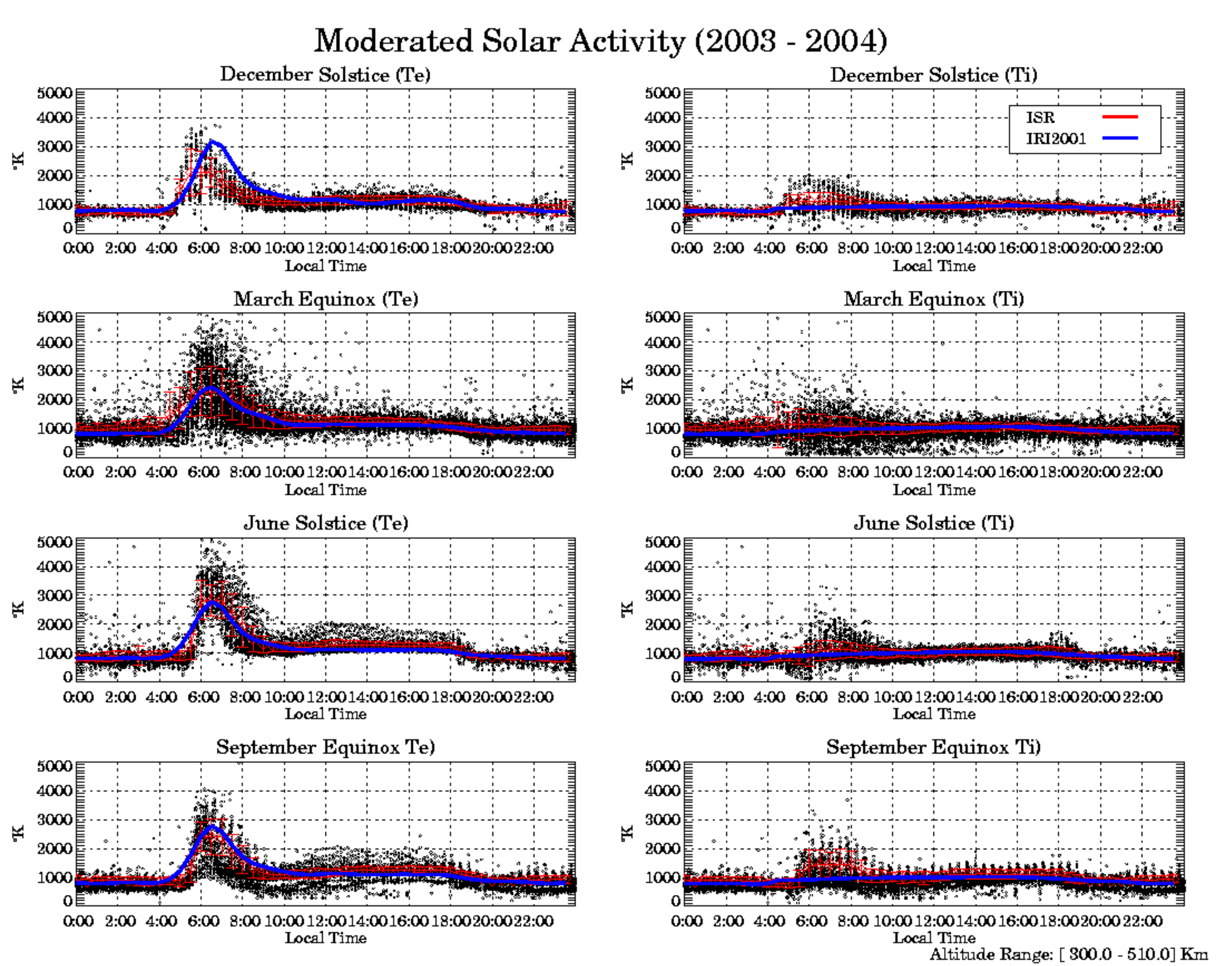
Te and Ti: Diurnal Variation

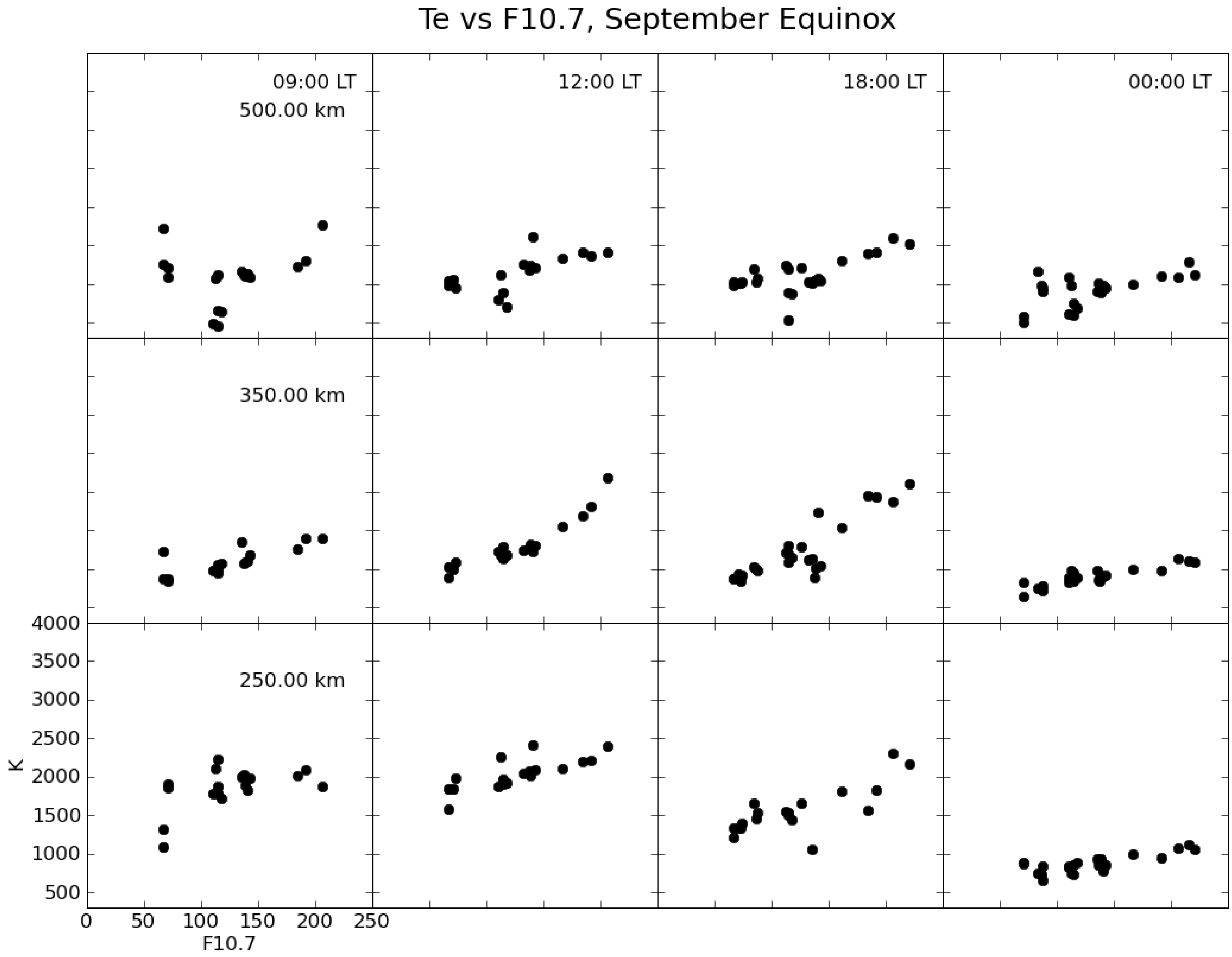
- Te data between

  [500 - 700 km]

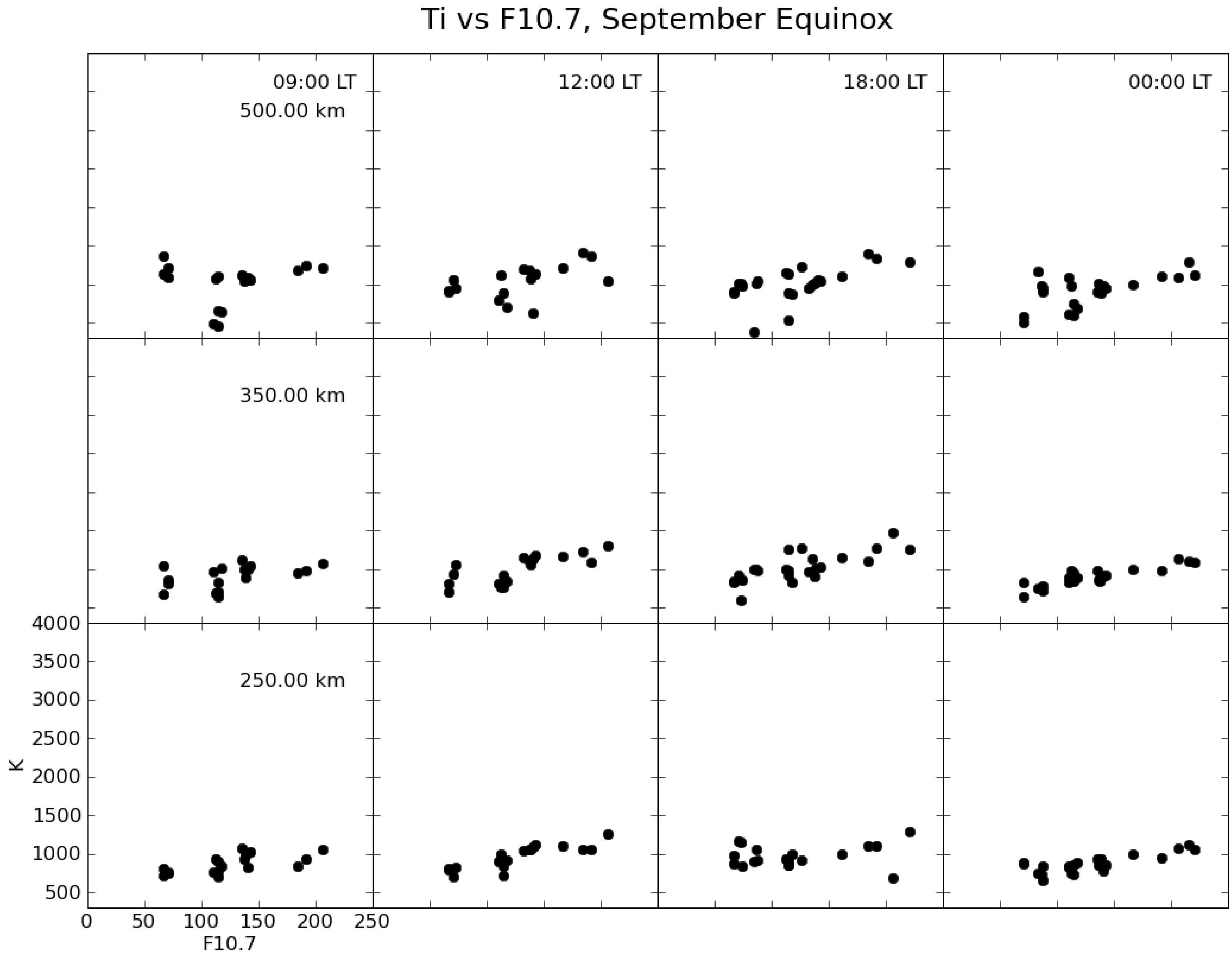
  100 < F107cm < 150

- IRI-95 option for Te





Te vs F10.7, September Equinox
09:00 LT
500.00 km
12:00 LT
18:00 LT
00:00 LT
350.00 km
250.00 km
4000
3500
3000
2500
2000
1500
1000
500
K
0
50
100
150
200
250
F10.7


Ti vs F10.7, September Equinox
09:00 LT
12:00 LT
18:00 LT
00:00 LT
500.00 km
350.00 km
250.00 km
4000
3500
3000
2500
2000
1500
1000
500
K
0
50
100
150
200
250
F10.7

Finding the least-squares solution

- The problem becomes

$$min\sum_{i=1}^{m}\frac{(d_i-(Gm)_i)^2}{\rho_i^2}$$

- As we have the data errors, these can be incorporated in the above system of equations as

$$W = diag(\frac{1}{\sigma_1},\frac{1}{\sigma_2},...,\frac{1}{\sigma_m})$$

- and

$$G_w = WG \qquad d_w = Wd$$

- The weighted system of equations is $G_w m = d_m$

Linear least-squares solution

- The system of equations may be

  Overdetermined: $m^{est} = (G^T G)^{-1} G^T d$

  Well and Underdetermined: $m^{est} = G^T (G G^T)^{-1} d$

- The linear algebra module of ”numpy” provides this function.

Binning and Fitting technique

- Te and Ti are binned according to local time, height and season.
- Solar activity dependence is determined by a least-squares fit to a linear function to F10.7cm index.
- Median filter, 3 (hours) time and height bins, is applied to the fitting coefficients
- The bin size is 1 hour for local time
- 10 altitude bins centered at: 200, 225, 250, 300, 350, 400, 500, 600, 800, 1000 km

Dependence between Te (Ti) with solar activity

- It can be quantified with the following expression:

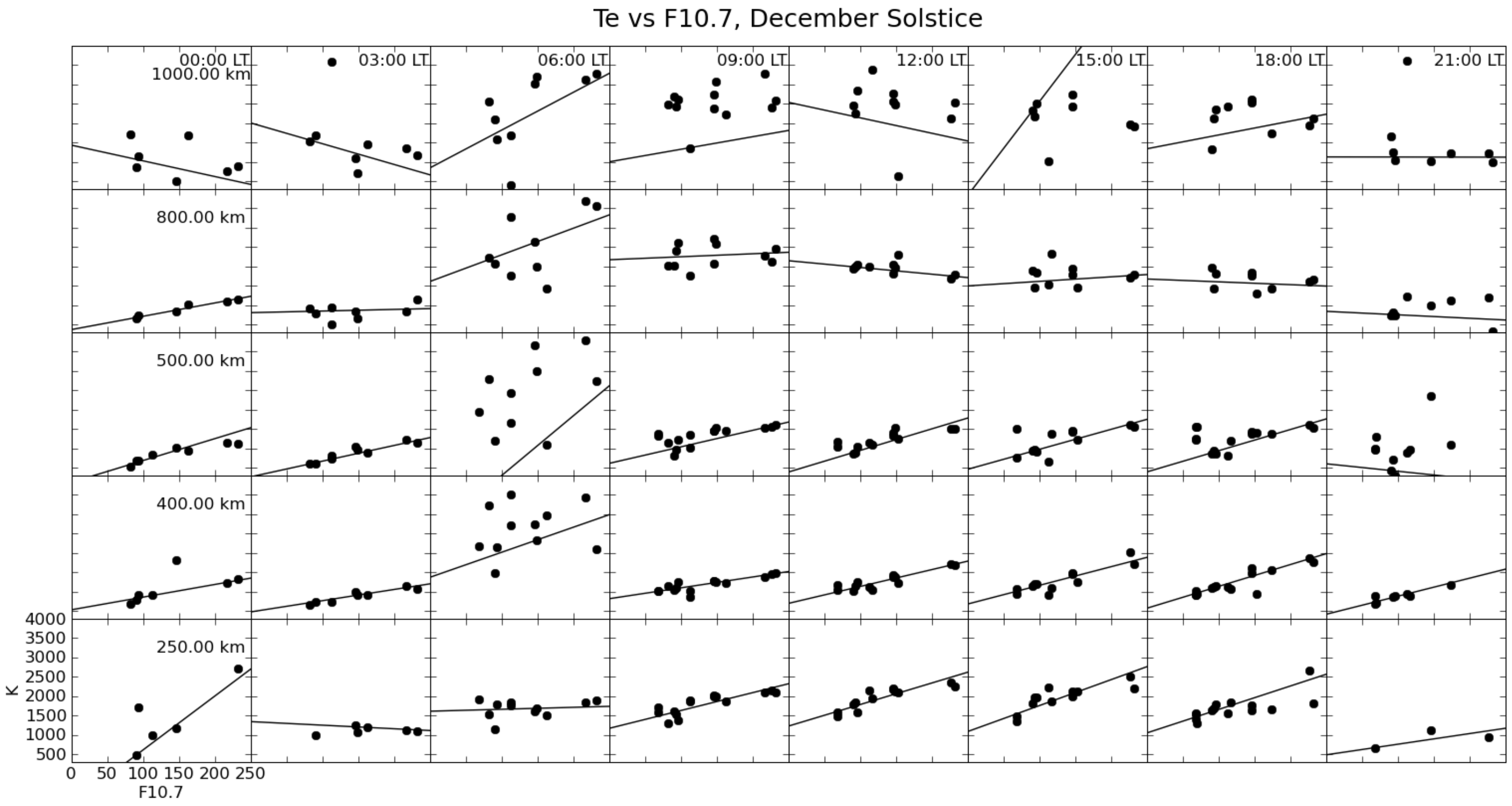
$$P = C_0 + C_1 f$$

- Where f is the normalized F10.7 index

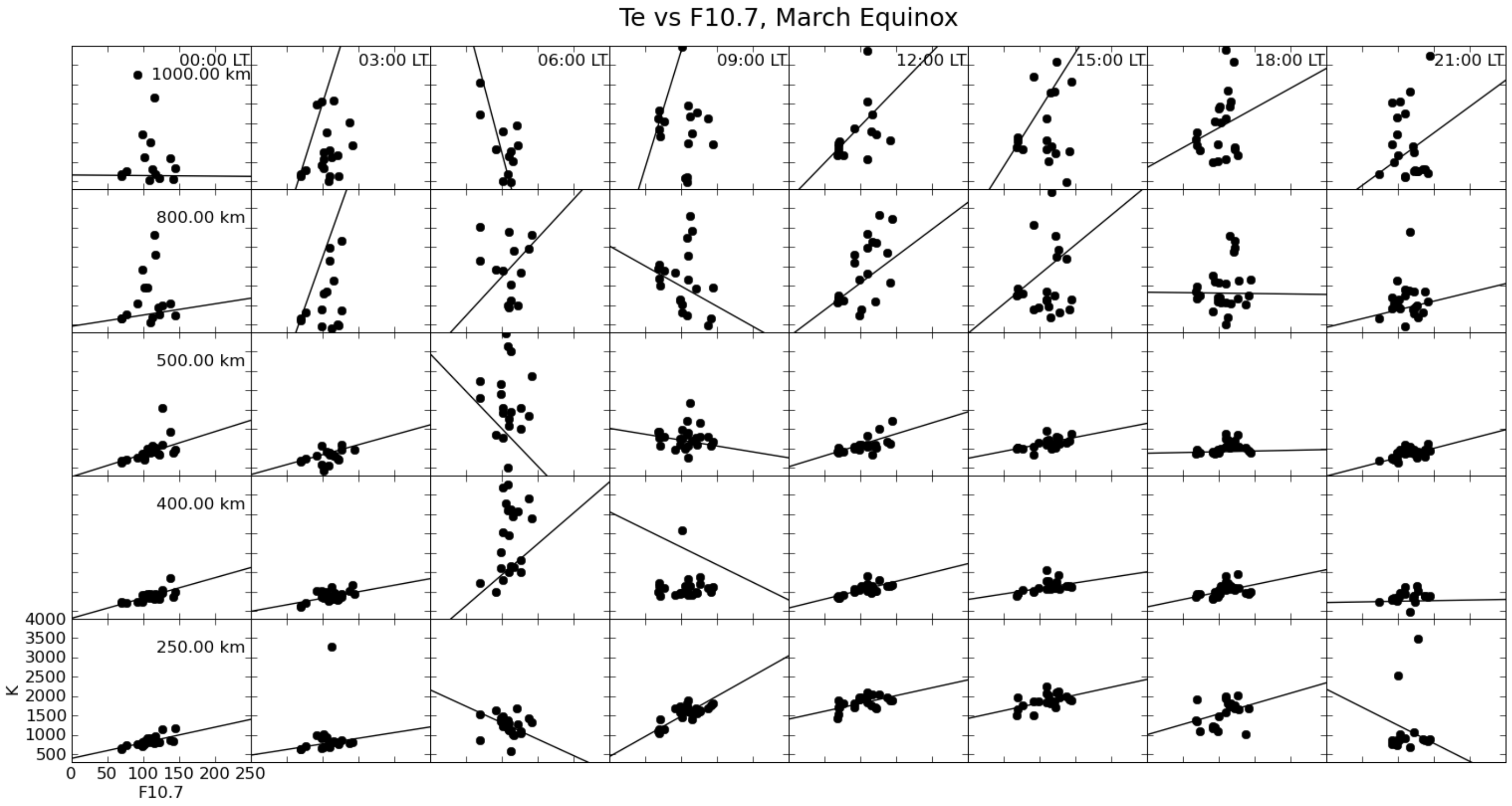
$$f = \frac{F10.7 - 135}{100}$$

- P can be Te or Ti
- C_0 is the background plasma temperature independent of solar activity
- C_1 is the slope of the temperature change with respect to f change

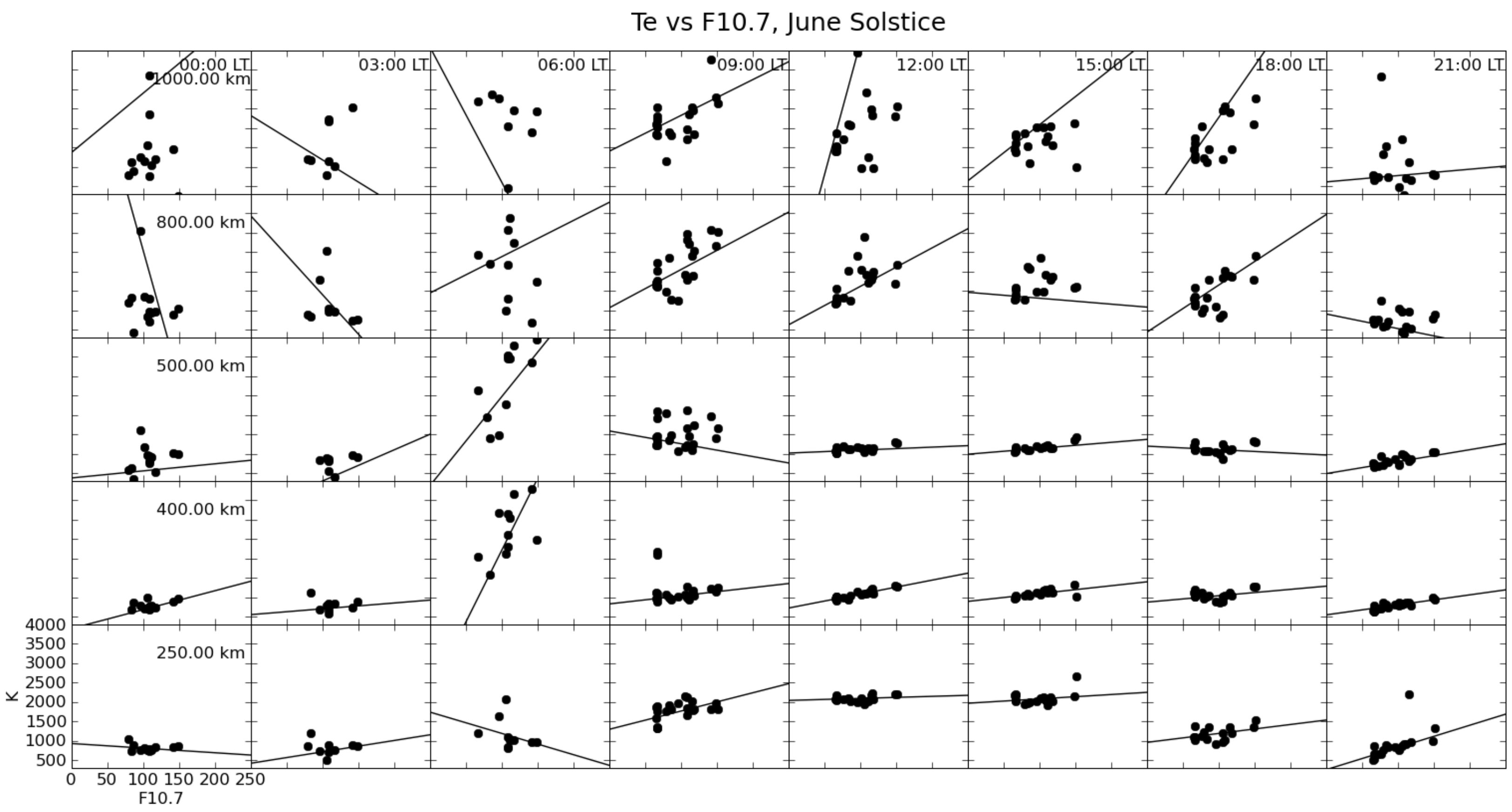
Solar Activity Dependence (1): December Solstice



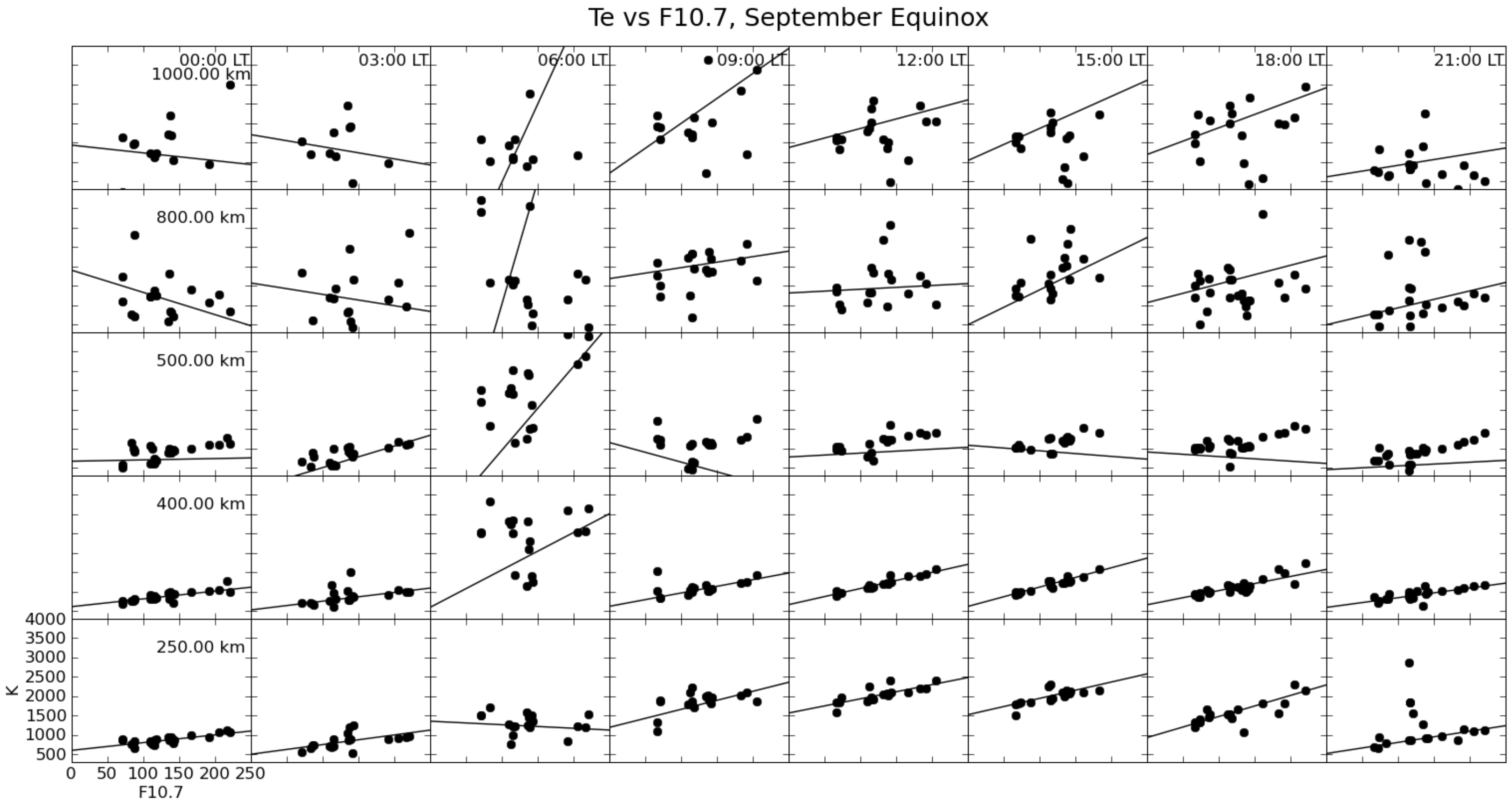
Solar Activity Dependence (2): March Equinox



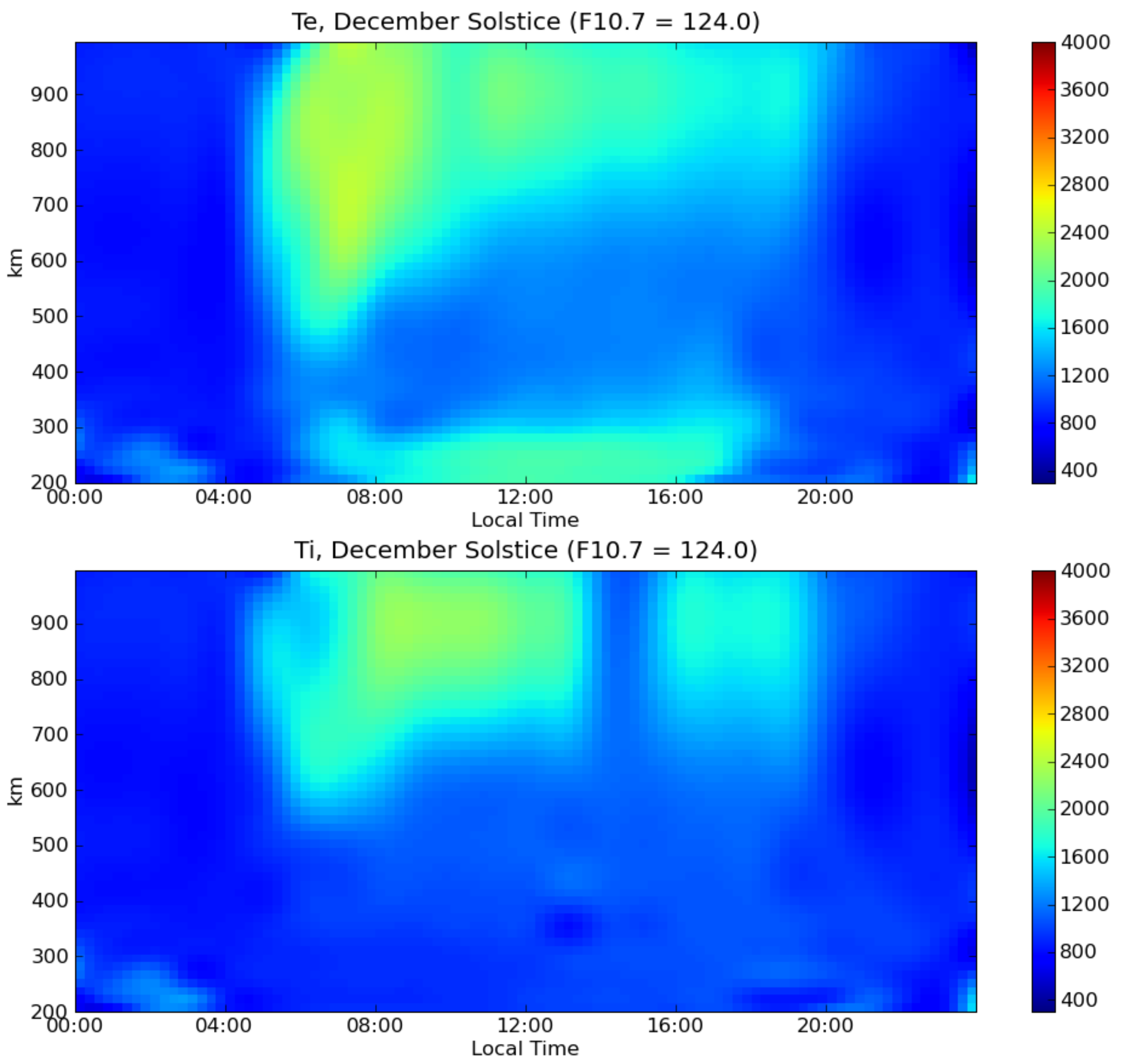
Solar Activity Dependence (3): June Solstice



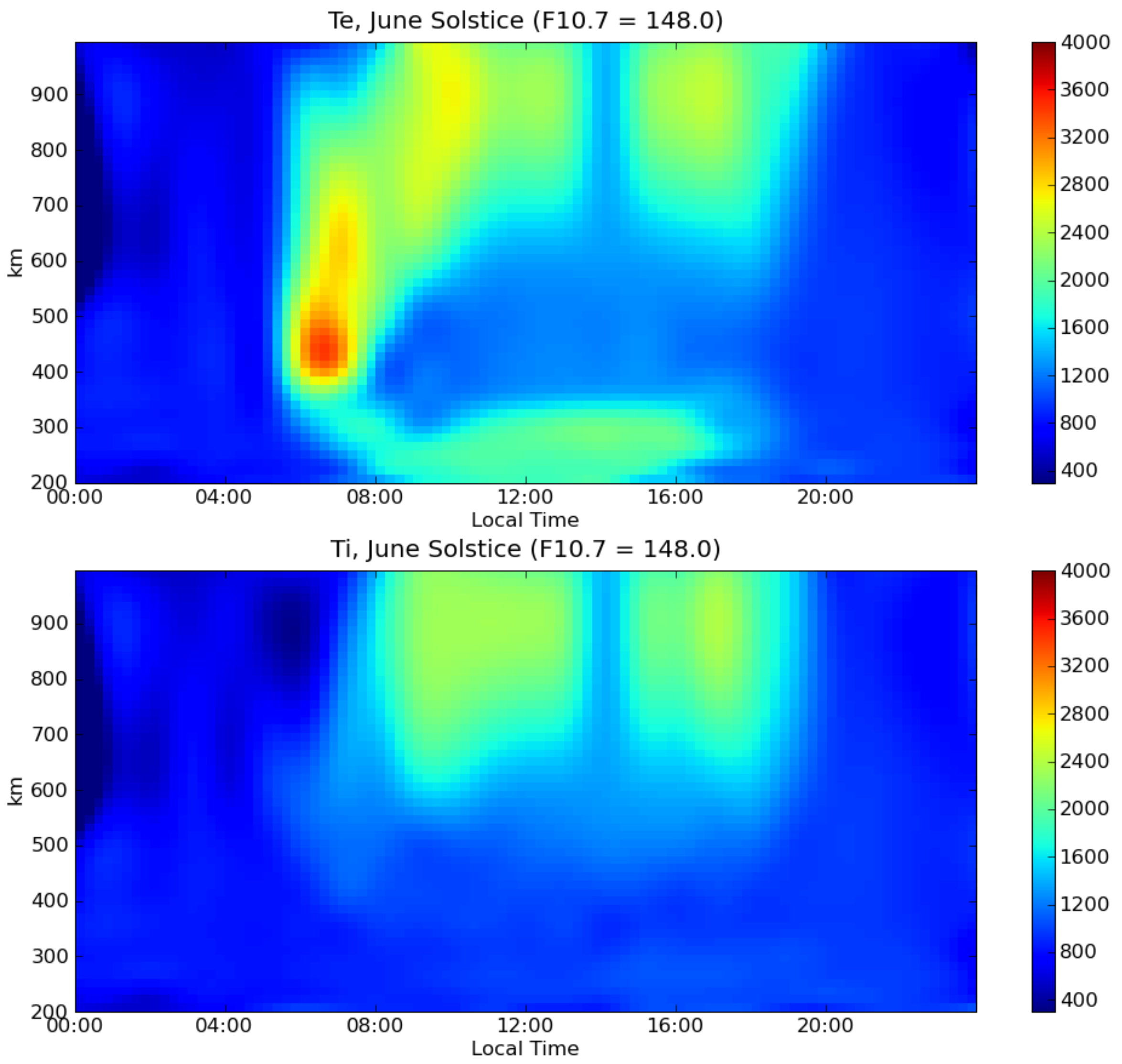
Solar Activity Dependence (4): Sep Equinox



Te and Ti, F10.7 = 124, December Solstice



Te and Ti, F10.7 = 148, June Solstice



Concluding Remarks

- More than 5000 simultaneous Ne, Te, Ti profiles available from 1997.
- In general, ISR measurements are reliable over 200 km.
- These new equatorial ionospheric profiles are available at MADRIGAL database (www.openmadrigal.org).

Future Work

- Get statistical characteristics of ISR densities, temperatures and composition using improved database since 1996, e.g.
- To derive a *F* region empirical model for this new density profiles
- Include additional profiles model in our comparisons (e.g. vary-Chap, NeQuick).

Electron density estimates from the absolute ISR power at Jicamarca: Preliminary results

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Introduction

Until recently, ISR measurements at Jicamarca provided either drifts or electron densities, depending on the radar mode selected. Kudeki et al. [2003] showed that absolute density measurements can be also obtained when a drift mode is used if two linear polarizations were received. Such measurements are based on the phase difference between the normal transverse modes of propagation when the radar points perpendicular to B. Although preliminary density estimates are very good, this mode is still under development and not for operational purposes, since manual intervention is still needed, for example, during events of equatorial spread F irregularities.

In this work we present results of absolute densities from power measurements. This procedure is common practice at other ISR facilities, where usually ionosonde values are used for calibration. In our case, we also use the ionosonde values, but just at the beginning of the experiment, the other parameters changing with time are being recorded, e.g., transmitter power and receiver gain.

Experiment Setup

Parameters	
IPP	1000 km
Number of IPPs	144 (128 of Data + 16 of Noise)
Transmitted Pulse Width	45 km
Code	Barker 3 (110,001)
Sampling Window	
• First Height	0 km
• Resolution	5 km
• Samples	186
Number of channels	4
Duty Cycle	4%

Table 1. Typical parameters for Differential Vertical Drift (DVD) experiment.

Description

As mentioned on the introduction we usually use ionosonde values for calibration to get absolute densities, but now we are measuring other parameters changing with time to obtain absolute densities from absolute power measurements.

From the radar equation for ISR we have that:

$$P_r = \frac{P_t(t) K K_{rx}(t)}{R^2} N \sigma_e$$

Equation 1. Radar Equation for ISR

Therefore, keeping track of the transmitter power and the receiver gain (variables in time), we can get density measurements from power.

Transmitter Power - $P_t(t)$

The transmitter power is acquired from a directional coupler at the end of the transmitters. In addition, the line voltage delivered to the transmitters is measured, resulting in a good proxy measurement for the actual transmitted power. Both measurements have a high correlation, as shown in Figure 1.

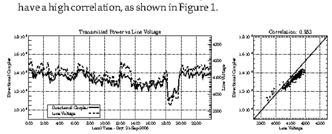

Figure 1. Comparison between Tx Power and Line Voltage

Receiver Gain - $K_{rx}(t)$

Normally one would have used a stable noise source for calibrating the receiver gain as indicated in Figure 2. In our case, given that the receiver noise is dominated by the skynoise, we have decided to use the skynoise as a our external noise source.

The measured skynoise is a function of the antenna position, so a good skynoise measurement for the same antenna position used in the experiment is needed.

Figure 3 shows the skynoise for the antenna poisition used in the observations reported here. To compare the received noise with the skynoise we had to put them on sideral time, obtain the relation and then put it on local time again. An example of this comparison is shown on Figure 4.

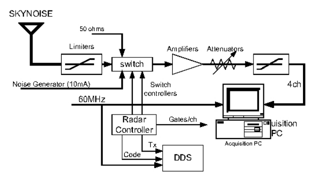

Figure 2. System Configuration. The noise generator and a load of 50Ω were employed to normalized the skynoise used to obtain the receiver gain values.

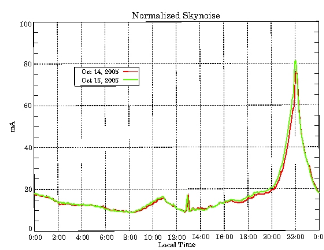

Figure 3. The galaxy noise is so strong that is enough to use the skynoise to estimate the receiver gain.

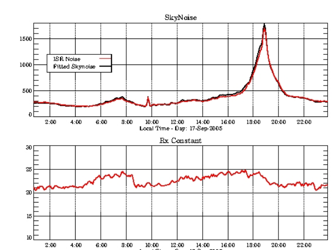

Figure 4. Calculation of the receiver gain for Sept 17th, 2005, comparing the Normalized with the received skynoise.

System constant, invariant on time

Because the Krx(t) and Ptx(t) are in different scales, we need another constant (K) that is not going to change on time (e.g., antenna gain). This constant is obtained by dividing the ionosonde calibration constant with the Pt and Krx for a specific time as described in Equation 1.

Once a system constant is found, relative power measurements are scaled in electron density units following Equation 1. Note that absolute power measurements are obtained after proper combination of the powers obtained with the two linear polarizations. Proper noise estimation is a critical component of this task.

Results

We present preliminary results of such procedure for the World Month campaigns (September 2005 and March 2006). For each campaign the transmitter power and the skynoise have been acquired. Special discussion will be given to the possibility of using this procedure in on-line runs.

September 2005

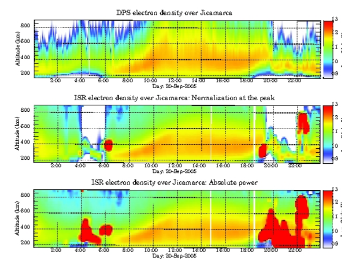

Figure 5. Electron density measured simultaneously by the Digisonde (upper panel), ISR (fitted at the F-region peaks values, centre panel) and ISR densities from absolute power measurements (lower panel). The iso-contours keep the same scale (in units of $\log_{10}$[Ne], Ne in units of m^{3}).

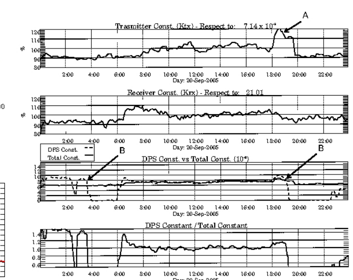

Figure 5b. The arrow A in the upper panel indicates a drop on the line voltage which affects the acquire data.
The arrows B indicate that an Spread-F event occured (see figure 5a), hence the calculation of the digisonde constant is mistaken.

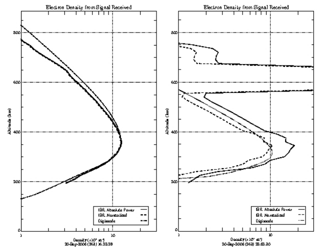

Figure 7. Comparison between electron densitiy profiles measured at daytime (left panel) and nighttime (right panel) by the Digisonde (dot line) and ISR: fitted at the peak (dash line) and absolute values (solid line). It is almost impossible to recover reliable density information from ionosonde when Spread-F events occurs. A manual scaling ionograms is a hard work for operators.

March 2006

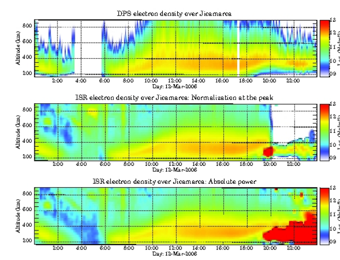

Figure 6a. The same as Figure 5a, but on March 12th, 2006. Between 3:30 and 5:40 LT, strong absortion of radiowaves from D-region do not allow to observe echoes from F-region by means of ionosonde technique as it is evident in the upper figure. On the contrary, our new procedure has made it possible.

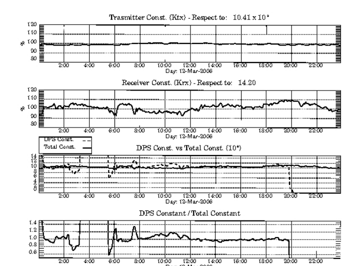

Figure 6b. The transmitted power is more stable during this campaign. Here we can see again how Spread-F events made digisonde constant inappropiated to estimate the electron density.

Conclusions

1. We have shown that the proposed procedure works very well.
2. Discrepancies against calibrating with the ionsonde all the time are due to:
   - Presence of Equatorial spread F or other coherent echoes around the F peak, where the radar power is not representative of the ISR power.
   - Poor estimation of noise due to external interferences.
   - There are no ionosonde echoes either due to very low densities or due to D-region absoprtion.
3. Our methodology show that density measurements are possible during spread F events and could be used in standard vertical drift modes.
4. During the day, our estimated desnities need to be corrected by the Te/Ti ratio below the F peak.

References

K. L. Bowles, G .R. Ochs and J. L. Green , On the Absolute Intensity of Incoherent Scatter Echoes from the Ionosphere :Journal of Research 1962.

Presented at the 2006 CEDAR Workshop, Santa Fe, New Mexico, USA, Jun 19 - Jun 23, 2006