Effective sunspot number: A tool for ionospheric mapping and modelling

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Introduction

Prediction of solar-induced effects relevant for ionospheric radio wave propagation is an important subject of the solar-terrestrial studies. Critical to the F region global and/or regional mapping and modelling processes is the well-documented fact that the critical frequencies of this ionospheric part and its MUF factors, depend in a systematic way on measurable quantities related to solar radiation.

Among other ionospheric indices, very often the effective sunspot number R12eff is used as efficient estimator of solar activity effects in the ionospheric F region, see Houminer et al. in J. of Electrical Engineering, 1993. By several statistical studies it has been shown that R12eff has considerable forecasting potential to specify both quiet and disturbed ionospheric conditions.

Outline

1. The role of R12eff as a filter mechanism to correct the results given by a long-term prediction models over Europe under the real-time conditions as indicated by Houminer et al.;

2. Its application on ionospheric mapping methods;

3. Behaviour of R12eff regional and R12eff local during different seasons in quiet as well geomagnetic disturbed conditions;

4. Application of the biharmonic interpolation (1 degree resolution) at two control stations : San Vito (40.0 N,17.0E) and Gibilmanna (38.0N,14.0E);

5. Concluding remarks and Future work.

The role of R12eff

One of the methods for determining R12eff was introduced by Houminer et al. in 1993. R12eff is chosen to give the best fit between model calculation and actual measurements obtained from a grid of ionosondes located in the mapping area, refer to hereafter as reference stations. The sunspot number, giving the minimum mean square error in the following expression:

$$\Delta = \frac{1}{n}\sum_{i=1}^{n}(\mathrm{foF2}_{obsi} - \mathrm{foF2}_{calci})^2$$

is called the effective sunspot number Reff. Here n is the number of reference stations, foF2obsi is the observed foF2 at the reference station i, foF2calci is the calculated value of foF2 at station i by a chosen ionospheric model.

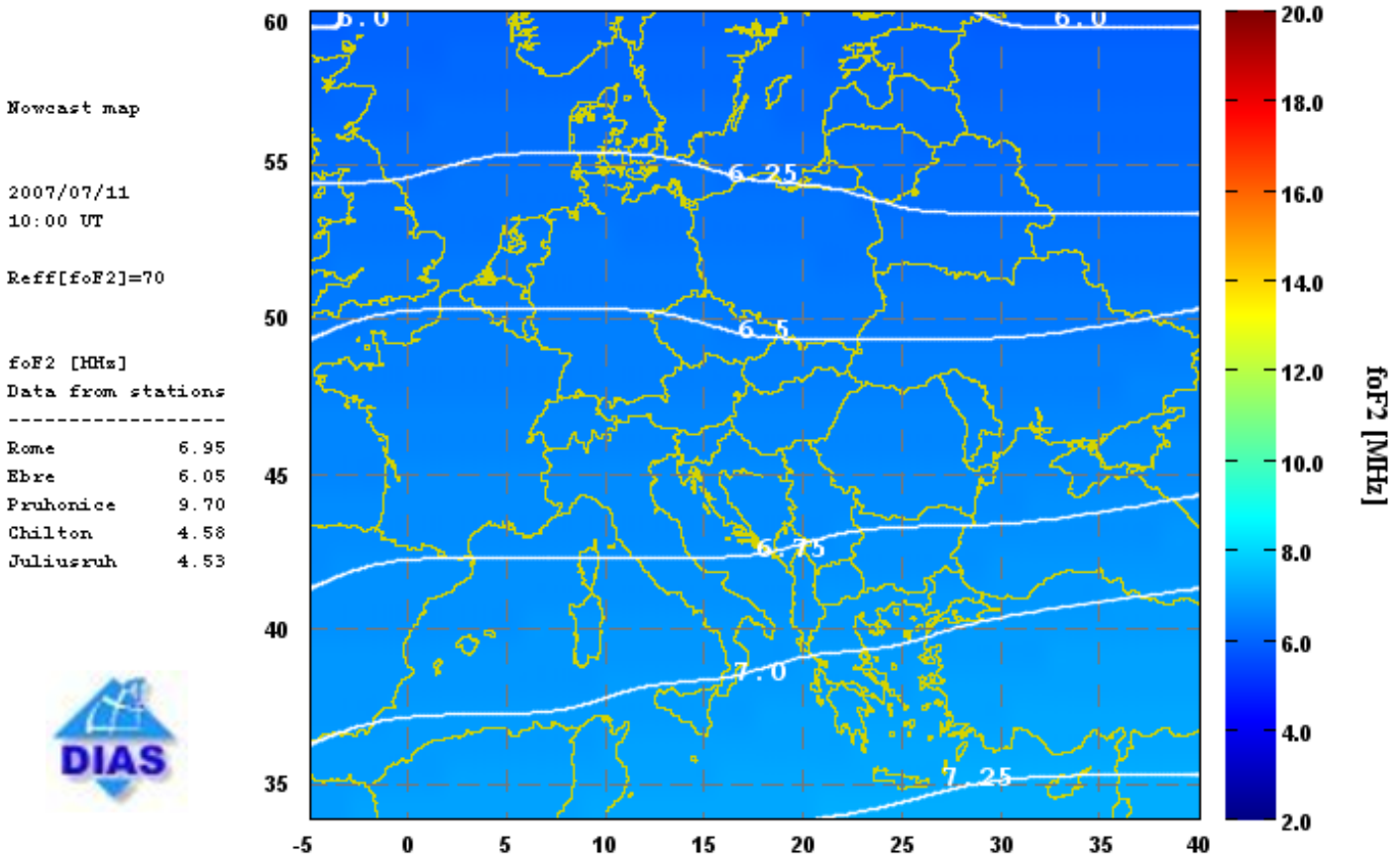
The R12eff : its application in the ionospheric mapping methods

The R12eff introduced by Houminer et. al. has been used in SIRMUP (Zolesi et. al., Radio Science, 39, 2, RS2011, 2004 and Tsagouri et. al., J. Atmos. Sol.-Terr. Phys., 67, 12, 1137-1146, 2005), a method for mapping of the ionospheric conditions over Europe suitable to be used in real-time for operational applications.

This method is based on the Simplified Ionospheric Regional Model (SIRM), a regional model of the standard vertical incidence monthly median ionospheric characteristics that is updated by a rapid conversion of real-time (automatic scaled) data from at least four European Digisondes Network (Digital Portable Sounders) to produce nowcasting maps over Europe.

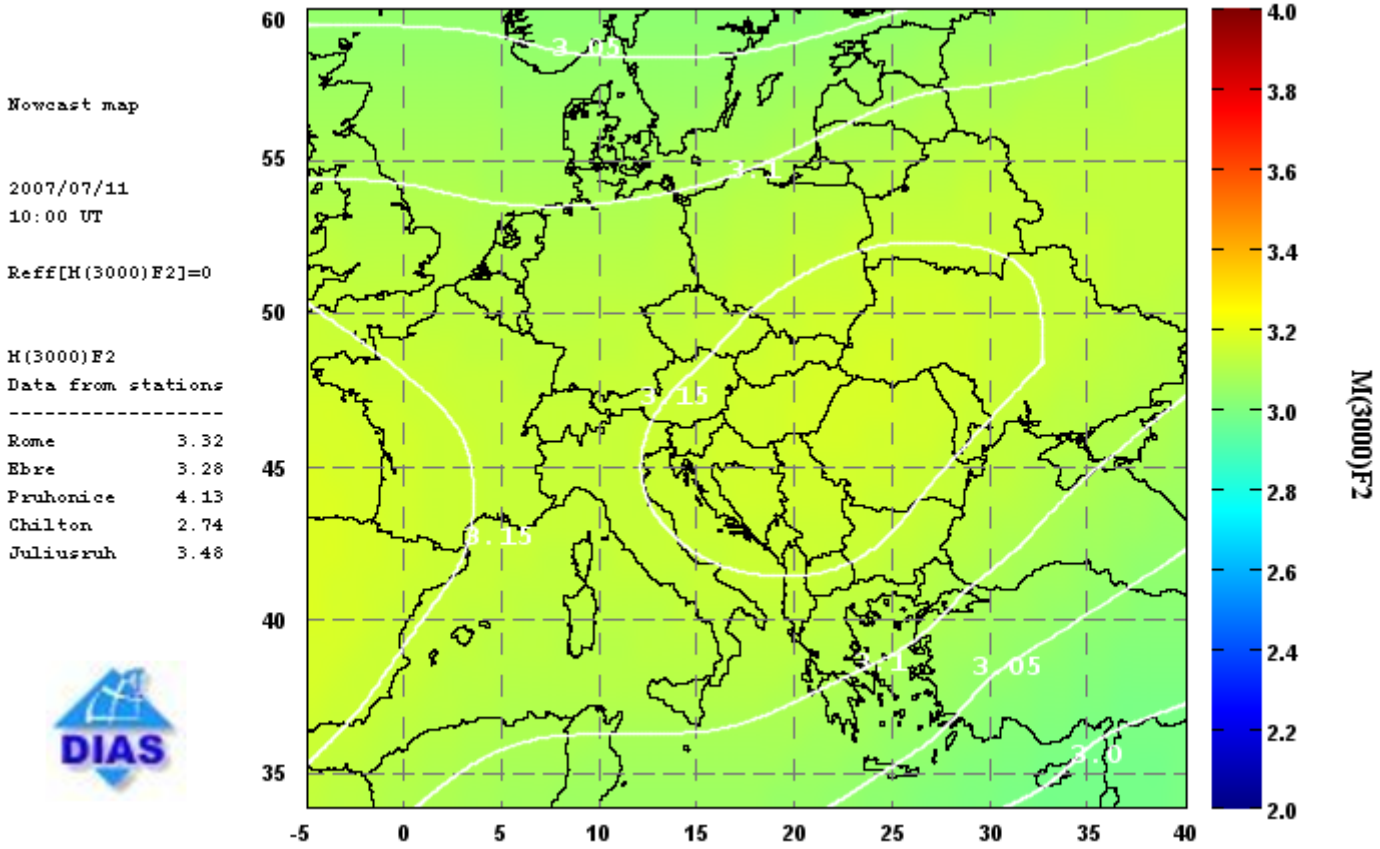
Nowcast Map of foF2 produced by SIRMUP at the DIAS system

http://www.iono.noa.gr/Dias/



Nowcast Map of M(3000) F2 produced by SIRMUP at the DIAS system

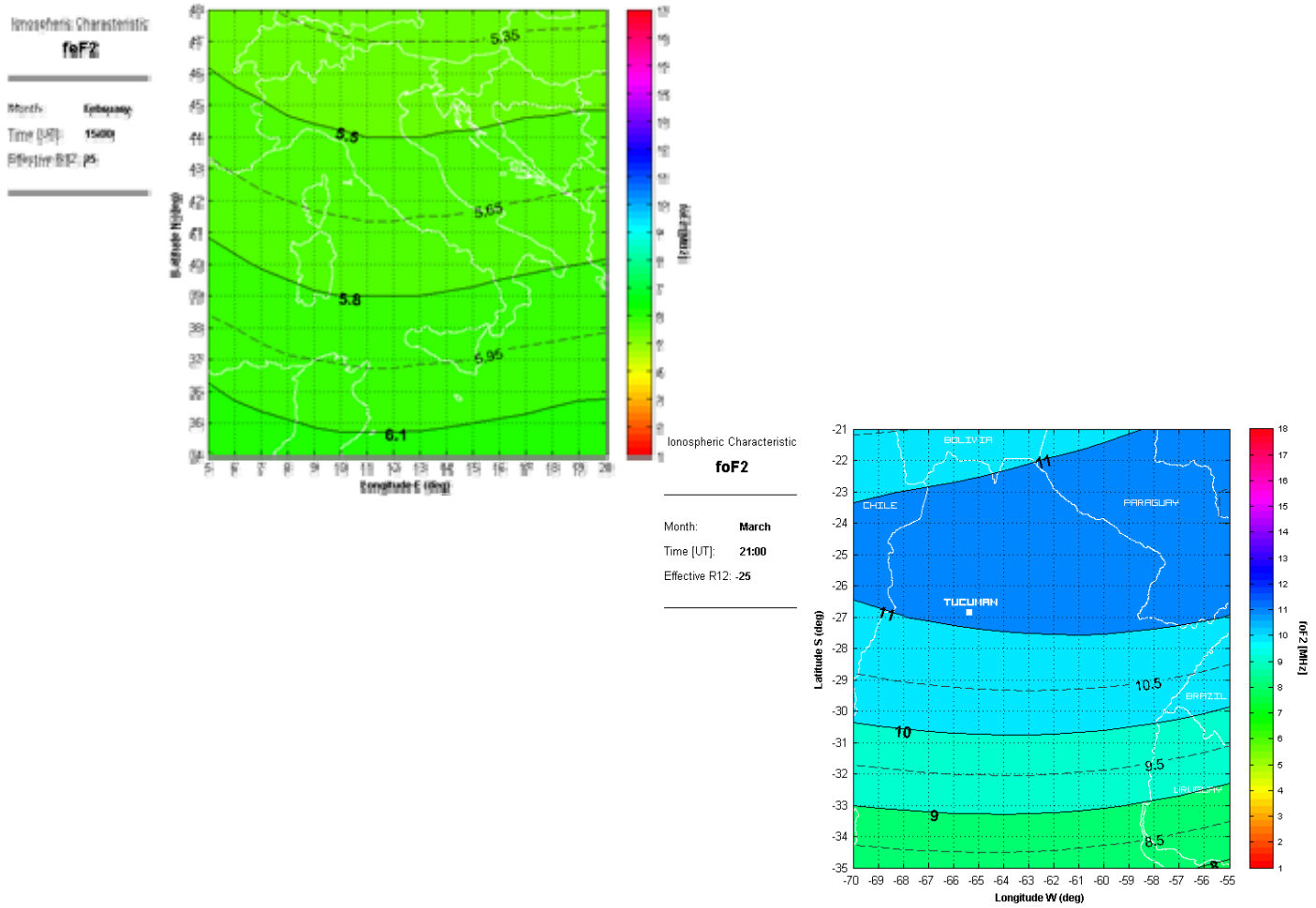
http://www.iono.noa.gr/Dias/



Nowcast Map of foF2 produced by SIRMUP at the GIFINT system

http://ionos.ingv.it/spaceweather/start.htm

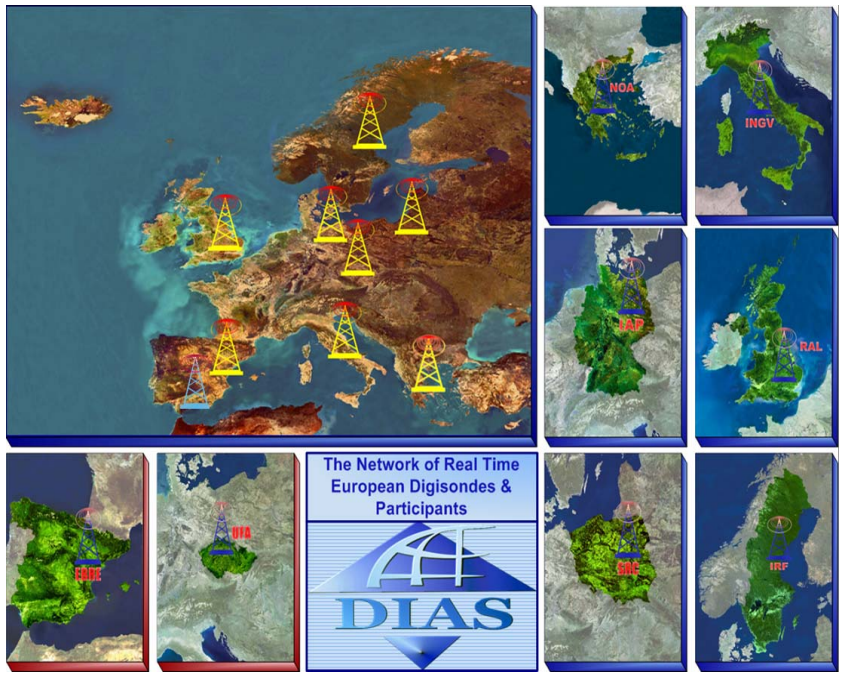
http://gifint.ifsi.rm.cnr.it



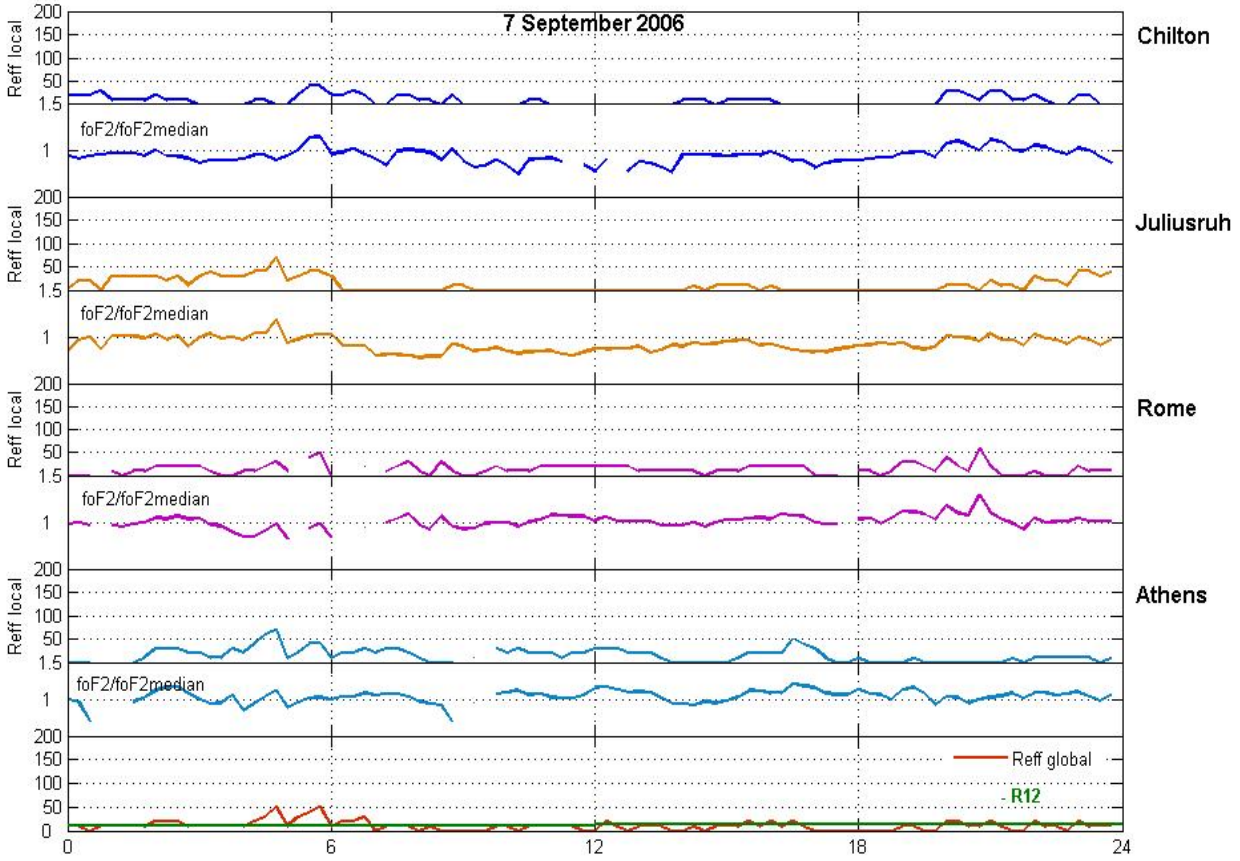
We have analyzed the behaviour of R12eff regional, as defined by Houminer et al. and the R12eff local, as it is in six European stations: Athens, Rome, Ebre, Chilton, Juliusruh and Pruhonice by using the DIAS network during three months: June, July and September 2006.

This period covers summer and equinox ionospheric conditions during solar minimum.

These months are in general characterized by low (Dst > -30 nT) or weak/moderate (Dst ~ 50 nT) geomagnetic activity according to the records of the Dst index.

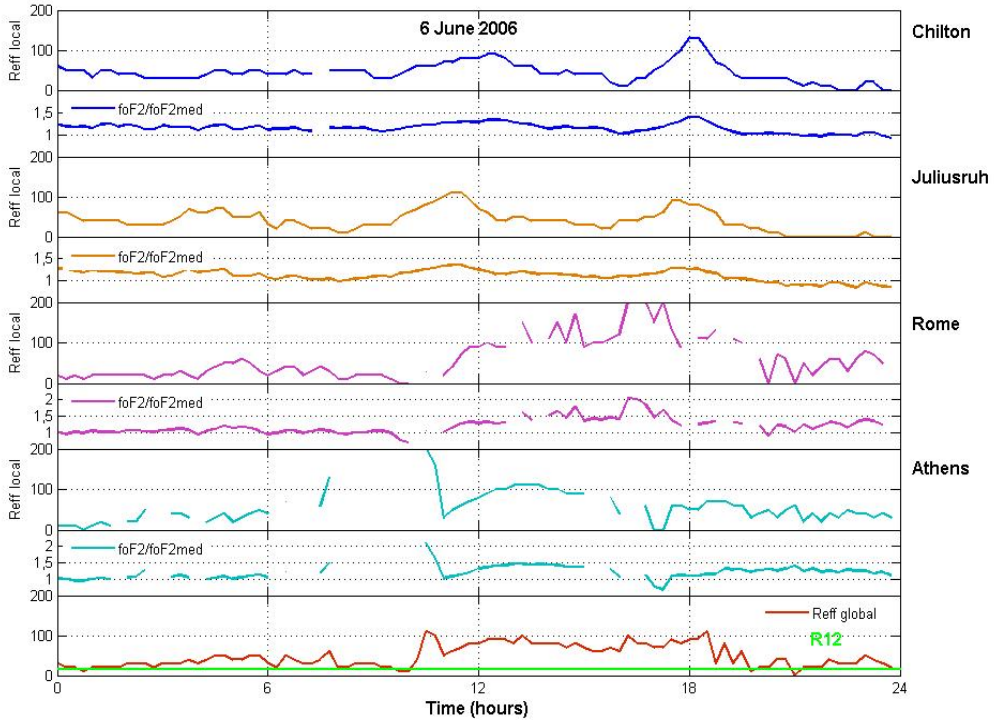


Quiet conditions



Even in quiet conditions, the R12eff regional reflects the average ionospheric activity over Europe, while the ionospheric activity over a single location is well correlated with R12eff local, as it is described by the ratio foF2obs/foF2median.

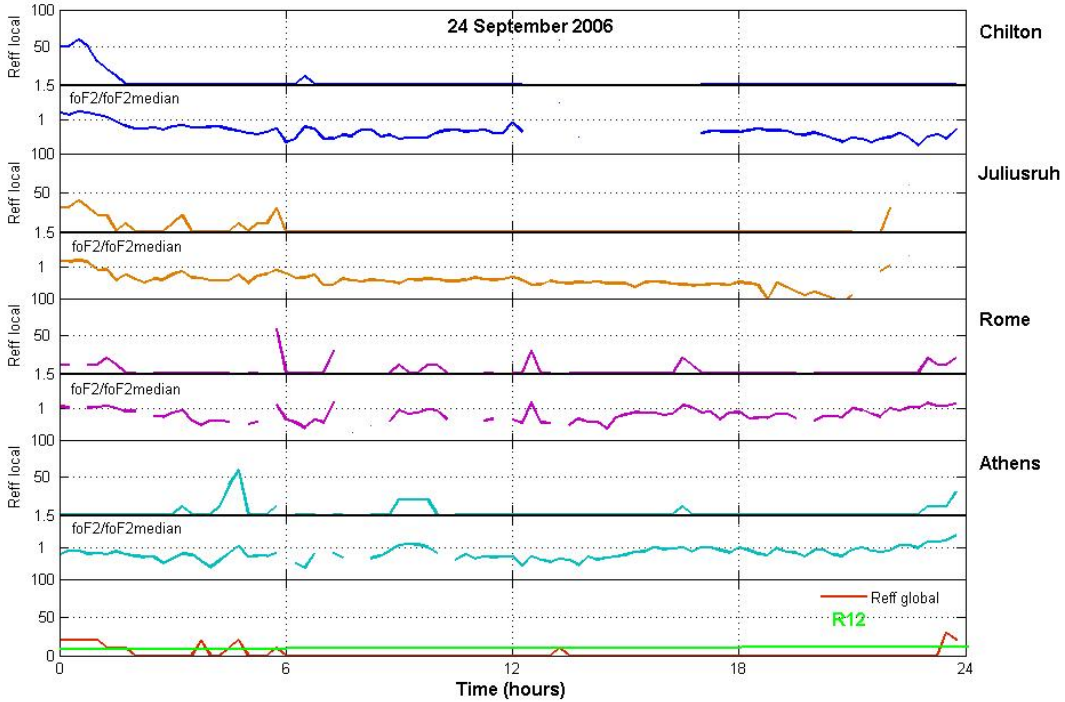
Disturbed conditions (positive effects)



The R12eff local is well correlated with the local ionospheric activity as it is described by the ratio foF2obs/foF2median.

The correlation is more obvious in the case of positive storm effects. In this case, the ionospheric response seems proportional to R12eff local.

Disturbed conditions (negative effects)



During negative storm effects, the scale of R12eff does not allow it to follow the level of the ionospheric activity. Both R12eff local and regional are always zero for negative deviations greater than 20%, independently on the disturbance intensity.

Large scale effects (either negative or positive) are also reflected in the R12eff regional estimates, while small scale effects are not captured by regional R12eff. In general, during disturbed conditions one single value of R12eff for the whole European region may only reflect the averaged ionospheric conditions over Europe.

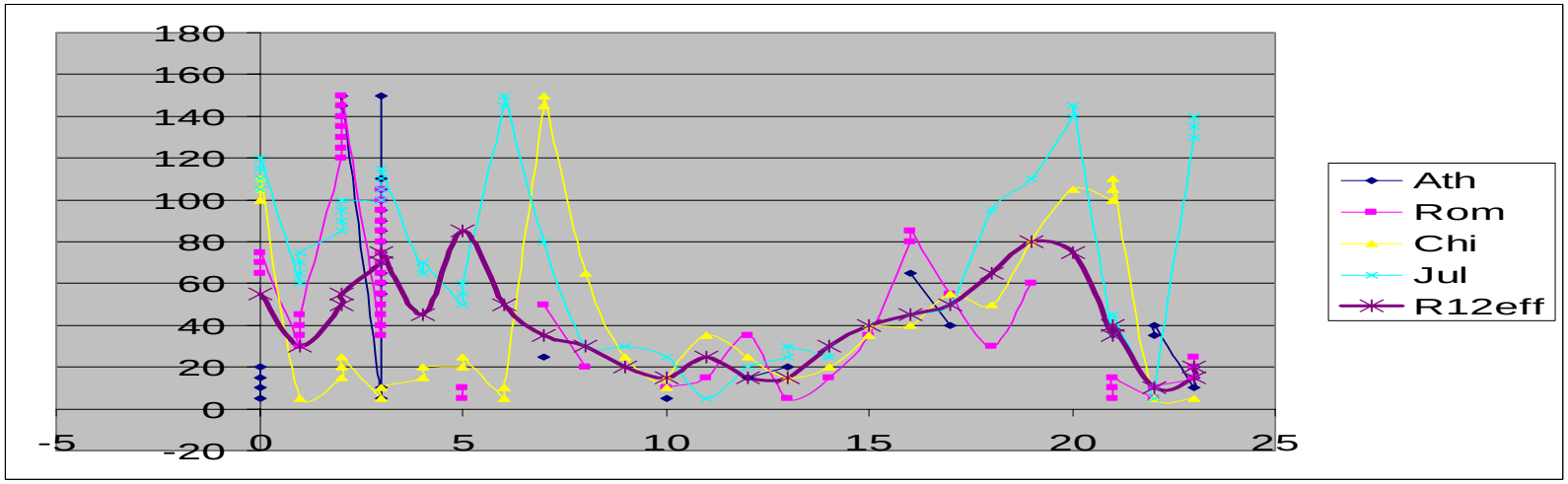
Only one R12eff cannot be enough as input parameter in a model describing ionospheric conditions over a continent or extended regions like Europe.

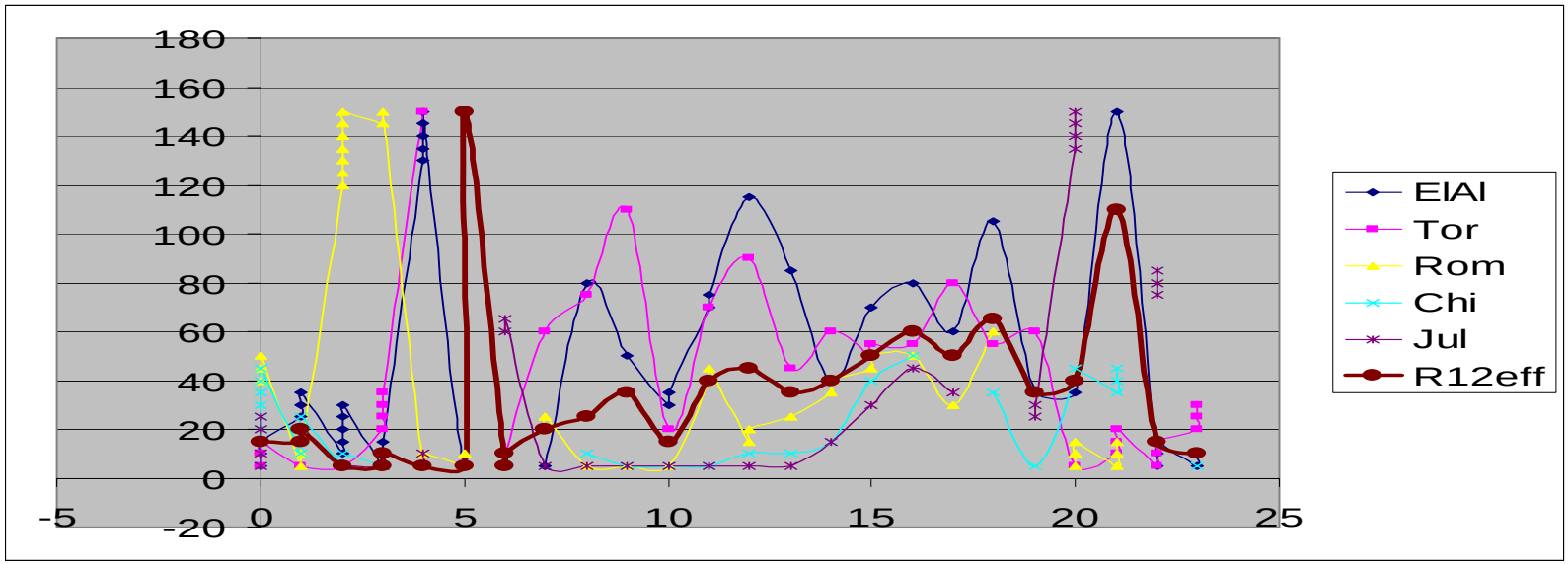
In particular, such R12eff cannot be sensitive to normal perturbation like dawn, sunset or the passage of the terminator and even more to geomagnetic or other storm perturbations.

Therefore, it is important to find an algorithm for an adaptive input value of solar activity that should act as a filter mechanism to correct the results given by a long term prediction mapping methods.

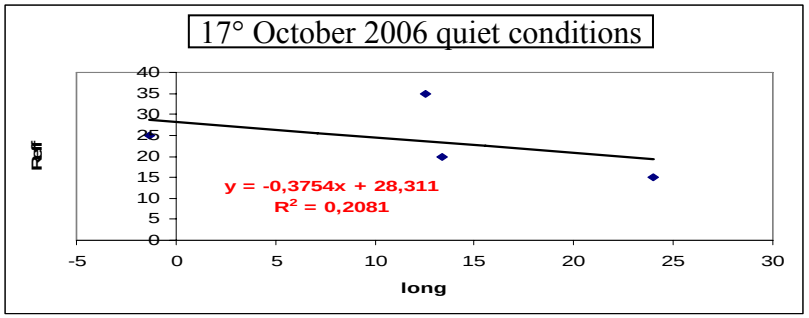
R12eff local versus the UT and superimposed the R12eff regional

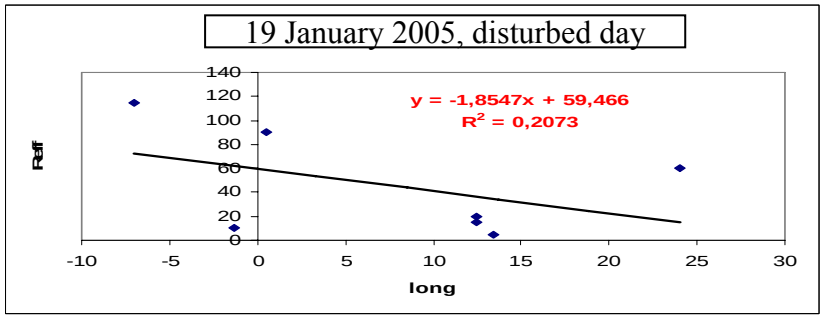
17October 2006 quiet conditions

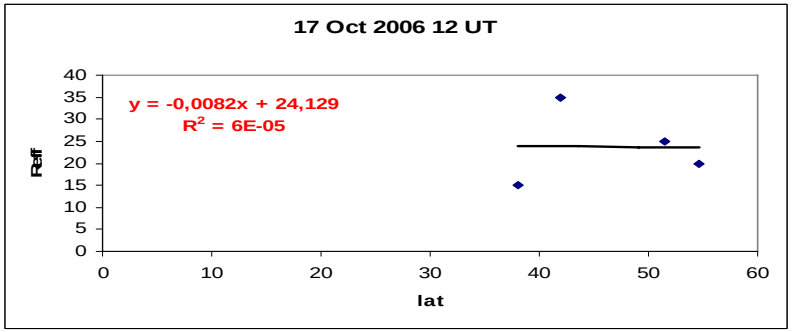


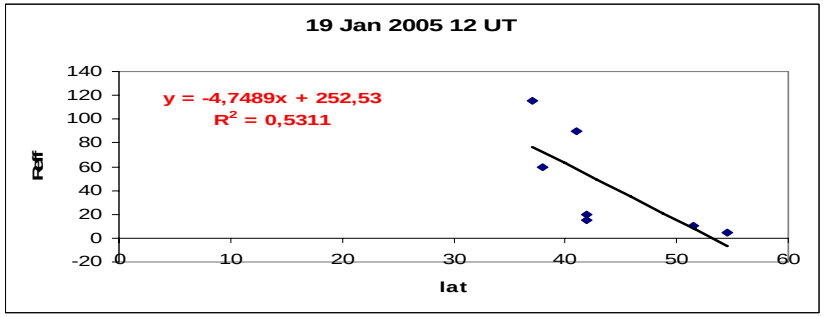


19 January 2005, disturbed day









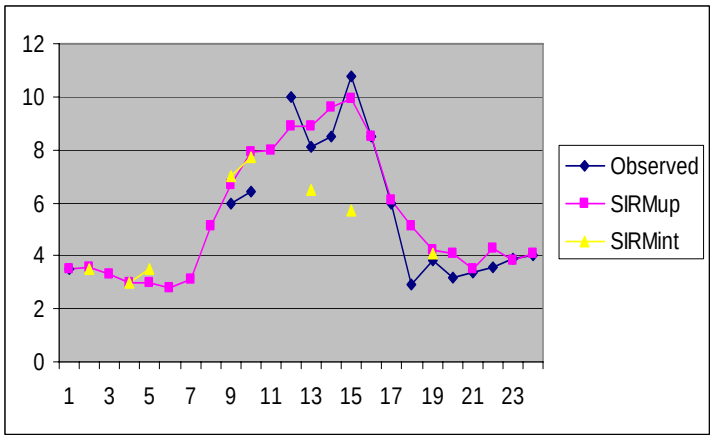
No simple linear trends vs longitude or latitude can be assessed in this first limited analysis over 3 disturbed days and 3 quiet days.

The large variability of R12eff local in the different points of observations demonstrates clearly that the R12eff regional, as introduced by Houminer et al., cannot be adequate even for a limited area as Europe.

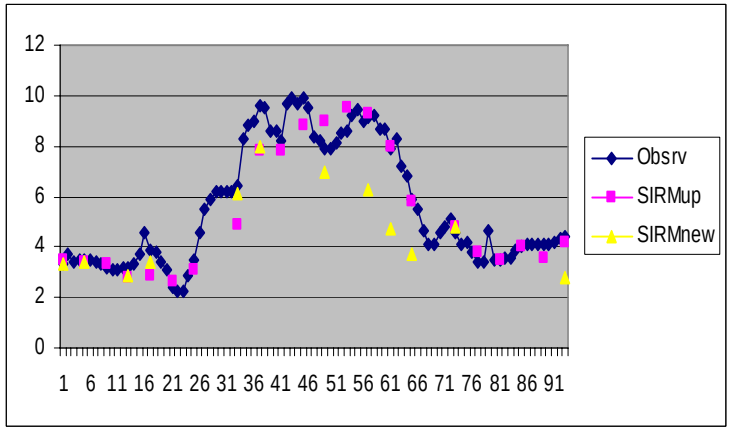
The present analysis has been done without cleaning the observed data of the eventual mistakes introduced by the auto scaling. The presence of any mistake may lead to large errors in drawing of a map.

Now we have to consider the crucial question for every mapping description: what happens in a place where there are no measurements? How to use or to interpolate the available measurements in other locations?

Taking into account that there is no clear trend of R12eff local VS latitude or VS the longitude a tentative was done by using the the biharmonic interpolation (1 degree resolution, see Sandwell, David T., Geophysical Research Letters, 1987) given by mathlab procedure. This method has been used to calculate the values R12eff local in two control stations, Gibilmanna (38.0 N, 14.0 E) and San Vito (40.7 N, 17.0E)

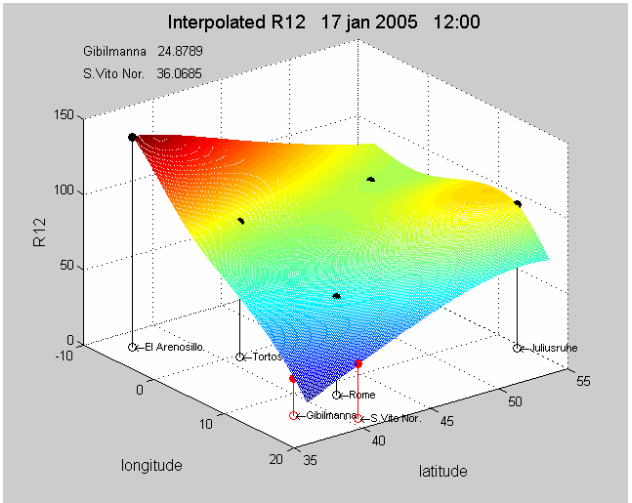


Gibilmanna 38.0 N; 14.0 E

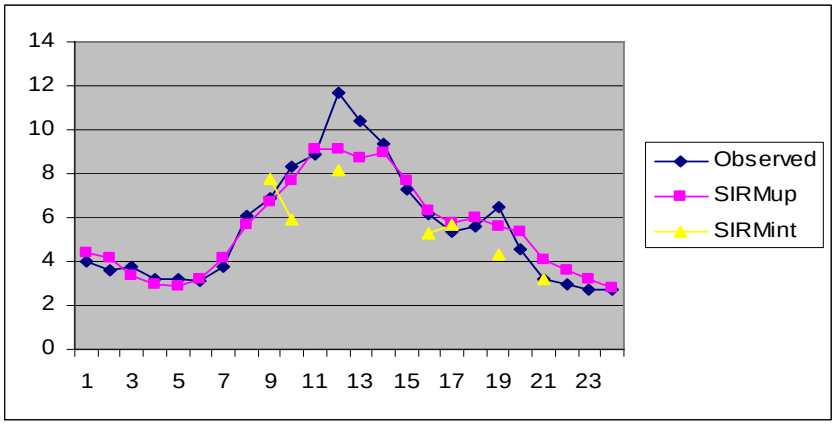


San Vito 40.0N 17.0 E

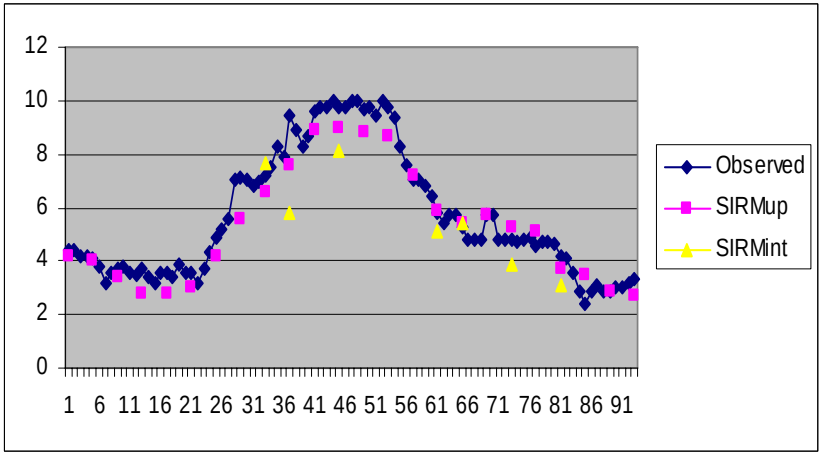
These interpolated values have been used to nowcast, with SIRMUP, the hourly behaviour of foF2 in the two control stations comparing these results with the real observed values and those obtained by the same SIRMUP method that used the R12eff regional .



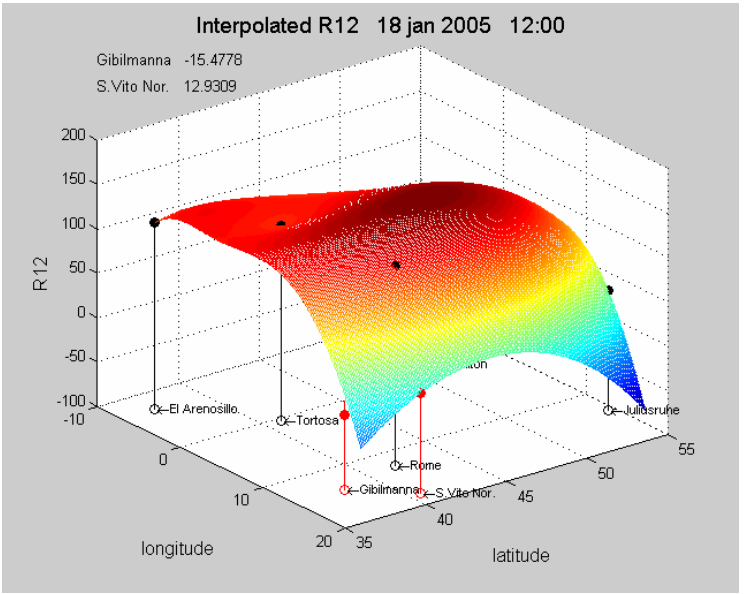
17th Jan. 2005



Gibilmanna 38.0 N; 14.0 E

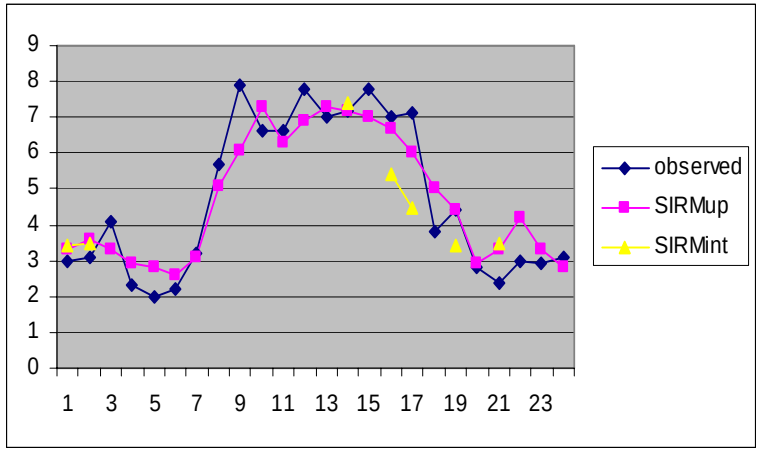


San Vito 40.0N 17.0 E

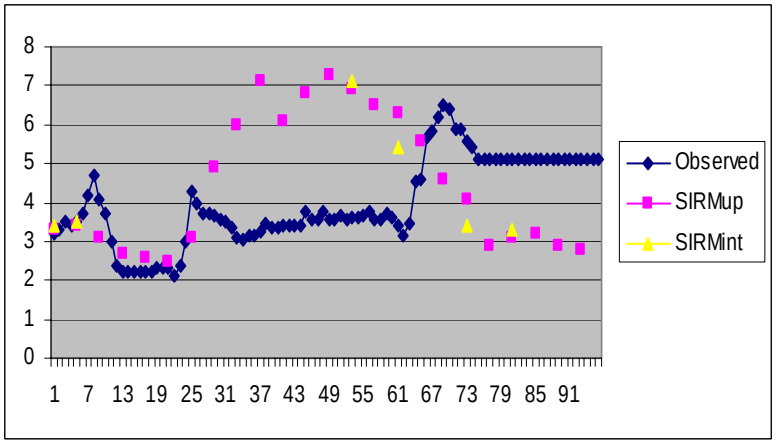


18th Jan 2005

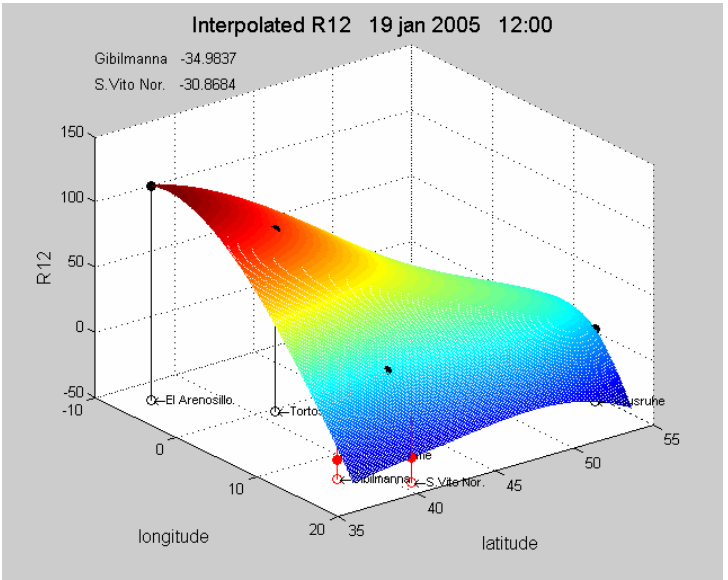
19th Jan 2005



Gibilmanna 38.0 N; 14.0 E



San Vito 40.0N 17.0 E



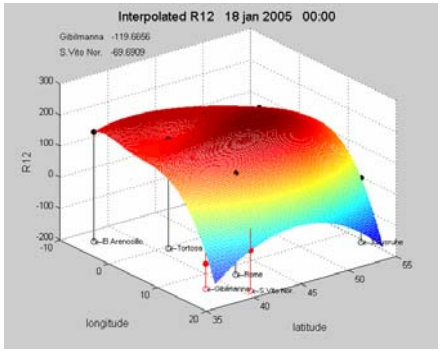
Critical Points :

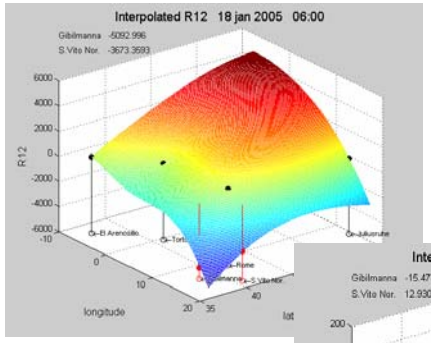
1. The most important critical point is that the number stations that could provide real time measurements at the same time are, in many cases, not enough for the interpolation. In the Houminer et al. method this number should be at least 4 stations.

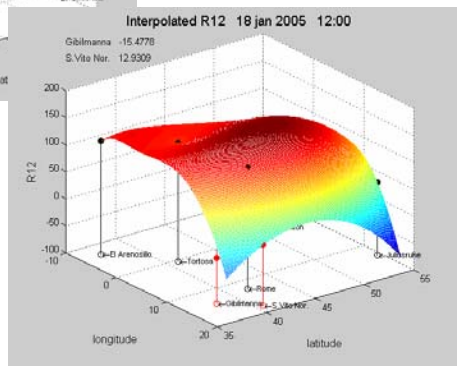
   In any case, in the Houminer el al. method even with less than 4 stations a result may be given, of course with a reduced performance. Instead by using the biharmonic interpolation few stations or even more than 4 but located near a line may give extremely wrong results.

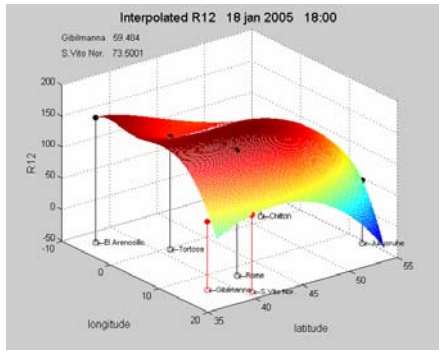
Critical Points :

2. The second critical point is the location of the control stations that are in the a peripherical zone of the region considered. This is clear looking at the graphs of the surface of interpolation: in many cases this surface is instable and gives very high or very low numbers especially and obviously near the borders or in the buffer zone .





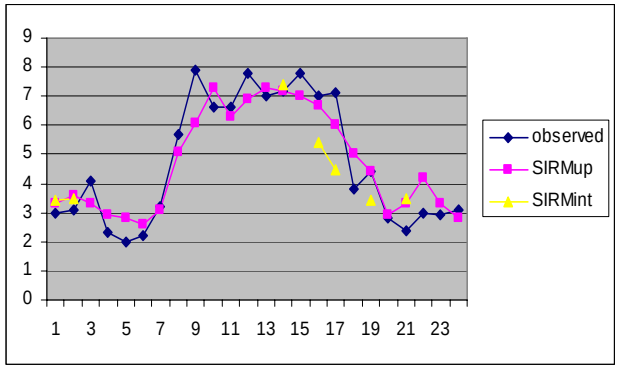


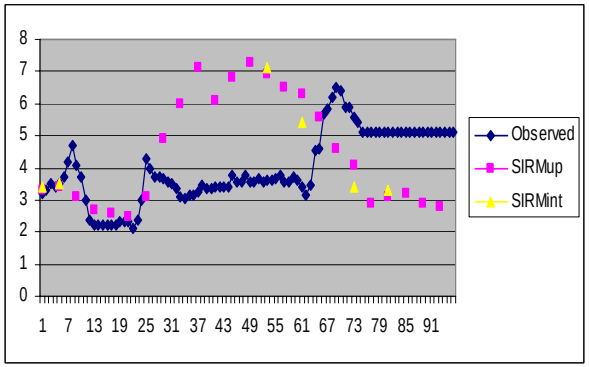


Critical Points:

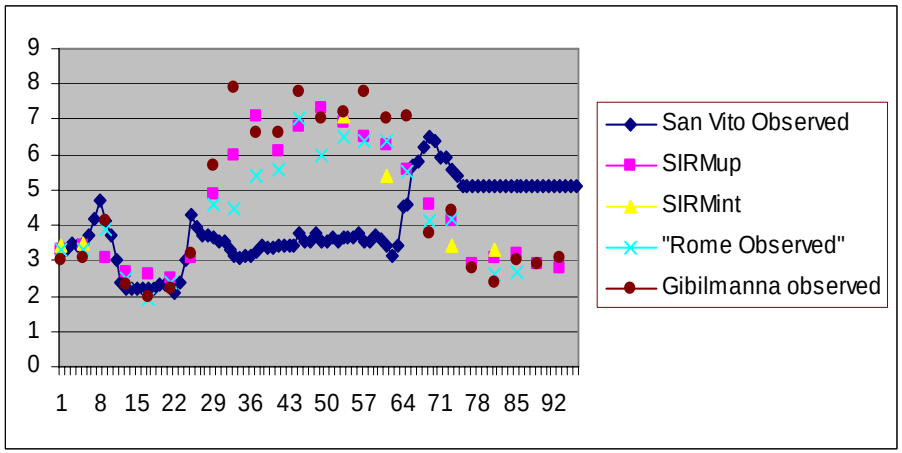
3. The present analysis has been done without cleaning the observed data of the eventual mistakes introduced by the auto scaling. The presence of any mistake or false interpretation may lead to large errors in drawing of a map.

Gibilmanna
38.0 N; 14.0 E





San Vito
40.0N 17.0 E



19th Jan 2005

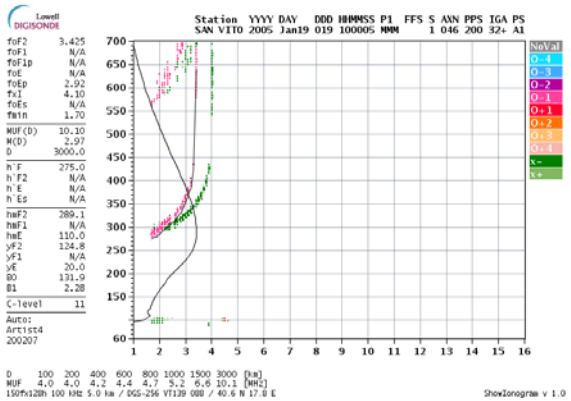
Critical Points:

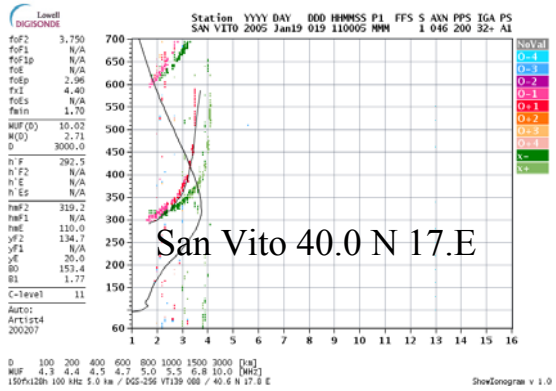
4. During 19° January 2005, a geomagnetic disturbed day, a normal hourly behaviour of the foF2 is observed in 3 close ionospheric stations : Athens (38.0 N, 24.0 E); Gibilmanna (38.0 N,14.0 E) and Rome(41.8N,12.5 E).

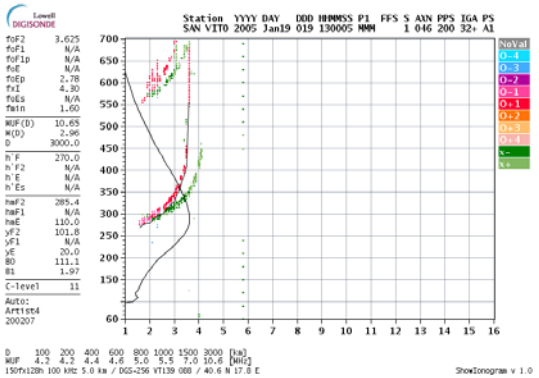
A large depletion of electron density during dayly hours is instead observed in the ionospheric station of San Vito (south east of Italy and close to Greece), 40.0 N,17.0 E.

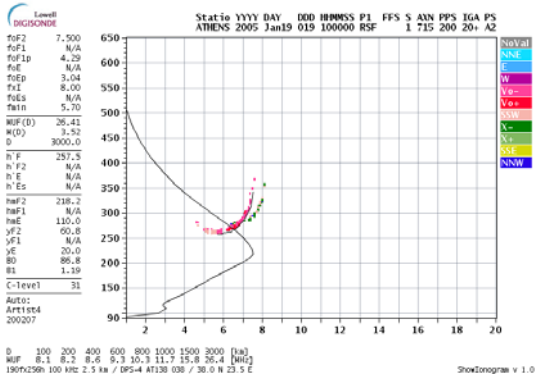
The direct analysis of the ionograms shows the correct autoscaling procedures, ARTIST for Rome ,Athens and San Vito and AUTOSCALA for Gibilmanna obtained thanks to SPIDR, DIAS, Digisonde DIDbase and ESWA data bases.

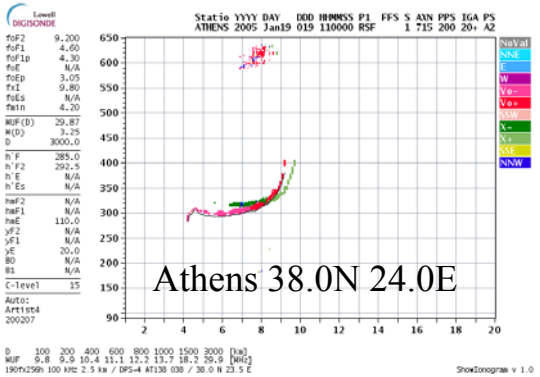
Some ionograms , as example, are shown in the following figure.

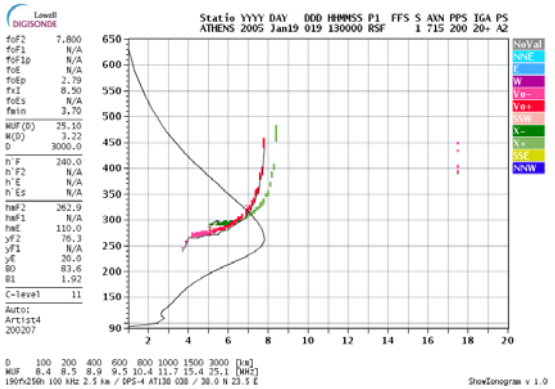

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
SAN VITO 2005 Jan19 019 100005 MMM 1 046 200 32+ A1

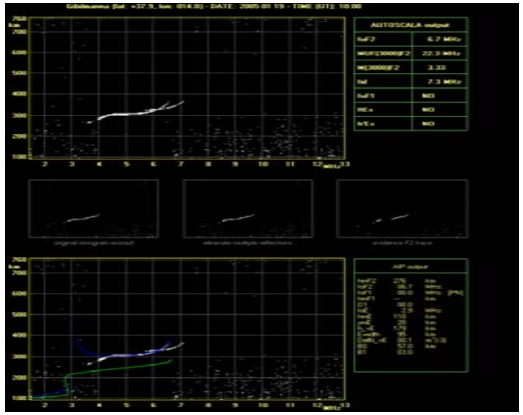

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
SAN VITO 2005 Jan19 019 110005 MMM 1 046 200 32+ A1
San Vito 40.0 N 17.E

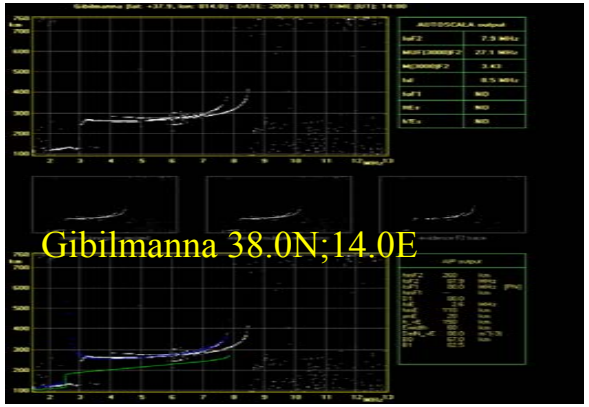

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
SAN VITO 2005 Jan19 019 130005 MMM 1 046 200 32+ A1

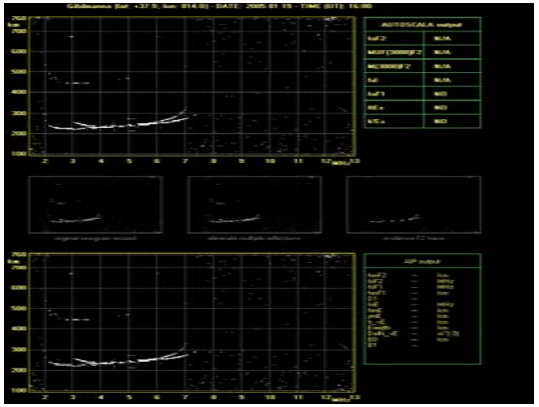

Statio YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
ATHENS 2005 Jan19 019 100000 RSF 1 715 200 20+ A2


Statio YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
ATHENS 2005 Jan19 019 110000 RSF 1 715 200 20+ A2
Athens 38.0N 24.0E


Statio YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
ATHENS 2005 Jan19 019 130000 RSF 1 715 200 20+ A2




Gibilmanna 38.0N;14.0E



Concluding remarks:

1. Real time Ionospheric mapping of the major ionospheric characteristics or in general the 3 D dimensional description of the ionospheric plasma is a problem that cannot be separated by the geographical area considered, the places and number of the real time points of observations and of course by the kind of application.

Concluding remarks:

2. In general, this first analysis still confirms the good performances and applicability of the R12eff regional as an efficient estimator of solar activity effects in the ionospheric F region.

3. Concerning the hourly behaviour of foF2 we note a good performance of SIRMUP joint to the R12eff regional in both the control stations in January 2005, excluding 19th January for San Vito as noted in the critical points. Lower performances have been noted in October, even if the geomagnetic activity was much more quiet than in January

Future work:

1. In this partial analysis the biharmonic interpolation gives always lower performances in comparison with the R12eff regional. Nevertheless, the future activity is oriented to look for a stable interpolation algorithm for an adaptive solar effective index in function of the geographic coordinates.

2. Kriging method, or introducing weighting function or virtual stations to maintain stable the surface of interpolation could be a solution