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A Software Package Generating Long Term and Near Real Time Predictions of the Critical Frequencies of the F2 Layer over Europe and Its Applications

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Abstract

Long term prediction and near real time (nowcasting) maps of the critical frequency of the F2 layer (*fo*F2), over the geographic area extending in latitude from 34˚N to 60˚N and in longitude from −5˚W to 40˚E, have been provided since 2006 by the DIAS (European Digital Upper Atmosphere Server) system. This work describes the software package *PRODUCTION_DATABASE_foF2 & Extract_Real_Time_Grid_foF2* constituted by two original software packages called *PRODUCTION_DATABASE_foF2* and *Extract_Real_Time_Grid_foF2* which have been developed in the framework of the ESA SSA Programme P2-SWE-1, in order to provide numerical grids of *fo*F2 prediction on a mapping area more extended than that offered by the DIAS both in latitude (from 34˚N to 80˚N) and in longitude (from −10˚W to 40˚E). *PRODUCTION_DATABASE_foF2*, by means of the CCIR and SIRM models, provides a database of long term predictions of *fo*F2 for all the months and the solar activities characterized by the 12-month smoothed mean value of the monthly sunspots number (R_{12}) ranged between −50 and 150 with step = 1. On the basis of two effective sunspots numbers, $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$, which are calculated each hour using the *fo*F2 autoscaled values provided by some reference stations, *Extract_Real_Time_Grid_foF2* extracts from the database of long term predictions of *fo*F2 the numerical grids representing the near real time ionospheric conditions for the hour and month under consideration. Some applications of *PRODUCTION_DATABASE_foF2* and *Extract_Real_Time_Grid_foF2* in terms of long term forecast and nowcasting maps of *fo*F2 are shown and their usefulness is discussed.

Keywords

Ionosphere, Solar Activity, Nowcasting and Long Term Maps, DIAS System, SIRM Model

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1. Introduction

The European Digital Upper Atmosphere Server (DIAS) is a particular infrastructure platform operating since 2006 providing digital data collection on the state of the ionized part of the atmosphere which knowledge is relevant for space weather purposes. A detailed information about the products and services offered by the DIAS system can be found at the portal http://dias.space.noa.gr.

Among the many products distributed by the DIAS system there are the long term forecast maps of the critical frequency of the F2 layer (*foF*2), which are produced from the predictions obtained applying the simplified ionospheric regional model (SIRM) [1] [2], improved under the COST 251 action [3], and the maps of *foF*2 for near real time ionospheric conditions (nowcasting), based on the SIRMUP predictions [4] [5]. The mapping area extends in latitude from 34˚N to 60˚N and in longitude from −5˚W to 40˚E.

In the framework of the Space Situational Awareness (SSA) Programme P2-SWE-1 of the European Space Agency (ESA) (see the portal http://swe.ssa.esa.int/web/), supporting the development of the European Ionosonde Service (EIS) (see the portal http://ssa-be-vm-fe-09p.ssa.esa.int/web/guest/dias-federated), two original software tools were developed in order to provide numerical grids of *foF*2 on a mapping area more extended than that offered by the DIAS system both in latitude (from 34˚N to 80˚N) and longitude **(**from −10˚W to 40˚E), so including also the Scandinavian region.

The software package used for the achievement of this goal is *PRODUCTION_DATABASE_foF*2 *& Extract_Real_Time_Grid_foF*2 which is constituted by two software packages called *PRODUCTION_DATABASE_foF*2 and *Extract_Real_Time_Grid_foF*2. *PRODUCTION_DATABASE_foF*2 is the software that by means of the CCIR [6] and SIRM models generates a database of long term predictions of *foF*2 for all the months and the solar activities represented by the 12-month smoothed mean value of the monthly sunspots number (R_{12}) ranged between −50 and 150 with step = 1.

*Extract_Real_Time_Grid_foF*2 is the software tool which is used to extract from the database achieved by the *PRODUCTION_DATABASE_foF*2 procedure, the numerical grid of *foF*2 values representing the nowcasting ionospheric conditions relative to a given hour and month.

A general description of how the database of long term predictions of *foF*2 is produced is given in Section 2. An explanation of how the nowcasting numerical grids of *foF*2 are derived from the database of long term predictions of *foF*2 is presented in Section 3. A comprehensive description of how *PRODUCTION_DATABASE_foF*2*&Extract_Real_Time_Grid_foF*2 works is given in Section 4. Some applications of *PRODUCTION_DATABASE_foF*2*&Extract_Real_Time_Grid_foF*2 are shown and discussed in Section 5.

2. Description of the Long Term Predictions Database of *fo*F2 Produced by PRODUCTION_DATABASE_foF2

The achievement of a database of long term predictions of *foF*2 is fundamental because it constitutes the starting point from which numerical grids of *foF*2 related to nowcasting ionospheric conditions are then obtained. Long term predictions of numerical grids of *foF*2 have been obtained using simultaneously two different prediction models: 1) the CCIR global model developed by Comitè Consultatif International des Radio communications [6] was used to get predictions of *foF*2 in the northern part of Europe extending in latitude from 61˚N to 80˚N and in longitude from −10˚W to 40˚E, with a 1˚ × 1˚ resolution (high latitude grid); 2) As the performance of the simplified ionospheric regional model (SIRM) [1] [2] has been proven to be successful within the European area between 34˚N and 60˚N and −5˚W and 40˚E, the improved version of SIRM [3] was applied to generate *foF*2 forecasts in the southern part of Europe extending in latitude from 34˚N to 49˚N and in longitude from −10˚W to 40˚ E, with a 1˚ × 1˚ resolution (middle latitude grid).

A particular consideration was given in the latitude interval 50˚N - 60˚N to which we refer hereafter as *buffer zone*, where *foF*2 predictions have been obtained applying both CCIR and SIRM model and then performing a simple linear interpolation giving a suitable weight to the prediction according to the latitude under consideration (see **Table 1**).

The final grid of long term predictions of *foF*2, is then obtained combining three grids: the high latitude grid, the *buffer zone* grid and the middle latitude grid (see **Figure 1**).

The long term predictions of *foF*2 are obtained providing as input parameters to the CCIR and SIRM model, the 12-month smoothed mean value of the monthly sunspots number (R_{12}) representing the solar activity index, and the month *mm* of the year. Varying from time to time R_{12} from −50 to 150 (with step = 1) and *mm* from 1

Table 1. Weights given to the SIRM and CCIR predictions to calculate *foF*2 in the *buffer zone*.

Latitude	$Weight_{SIRM}$	$Weight_{CCIR}$	$foF2_{BUFFER\ ZONE}$
$\lambda = 50$	1.0	0.0	$foF2_{SIRM} \cdot 1.0 + foF2_{CCIR} \cdot 0.0$
$\lambda = 51$	0.9	0.1	$foF2_{SIRM} \cdot 0.9 + foF2_{CCIR} \cdot 0.1$
$\lambda = 52$	0.8	0.2	$foF2_{SIRM} \cdot 0.8 + foF2_{CCIR} \cdot 0.2$
$\lambda = 53$	0.7	0.3	$foF2_{SIRM} \cdot 0.7 + foF2_{CCIR} \cdot 0.3$
$\lambda = 54$	0.6	0.4	$foF2_{SIRM} \cdot 0.6 + foF2_{CCIR} \cdot 0.4$
$\lambda = 55$	0.5	0.5	$foF2_{SIRM} \cdot 0.5 + foF2_{CCIR} \cdot 0.5$
$\lambda = 56$	0.4	0.6	$foF2_{SIRM} \cdot 0.4 + foF2_{CCIR} \cdot 0.6$
$\lambda = 57$	0.3	0.7	$foF2_{SIRM} \cdot 0.3 + foF2_{CCIR} \cdot 0.7$
$\lambda = 58$	0.2	0.8	$foF2_{SIRM} \cdot 0.2 + foF2_{CCIR} \cdot 0.8$
$\lambda = 59$	0.1	0.9	$foF2_{SIRM} \cdot 0.1 + foF2_{CCIR} \cdot 0.9$
$\lambda = 60$	0.0	1.0	$foF2_{SIRM} \cdot 0.0 + foF2_{CCIR} \cdot 1.0$

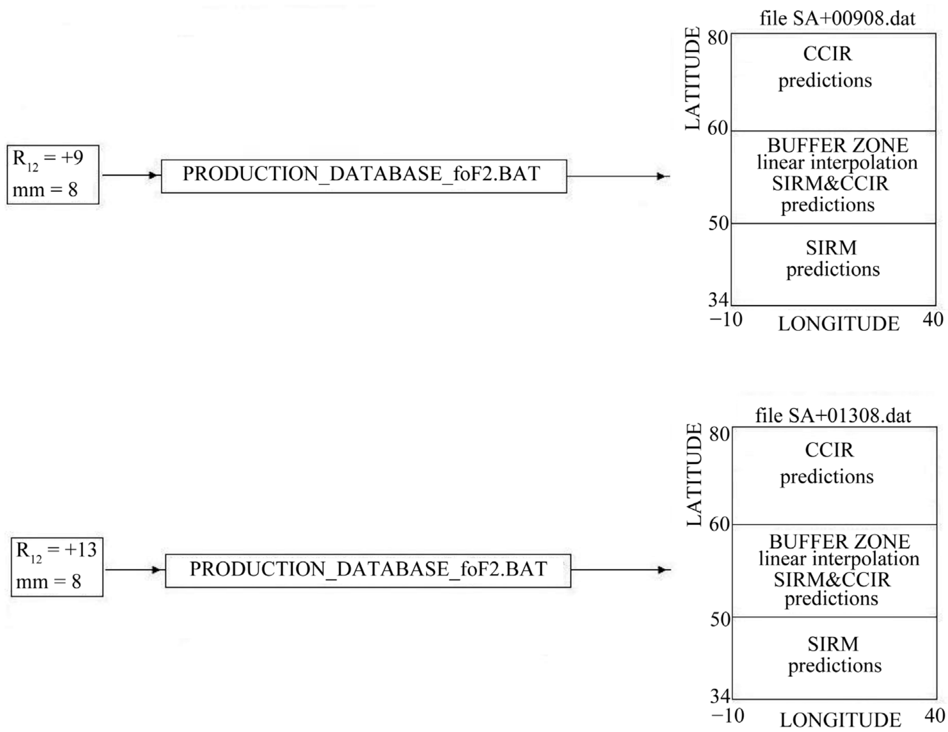


Figure 1. Scheme showing an example of how the two output files *SA*_+00908.*dat* and *SA*_+01308.*dat* are structured after applying the *PRODUCTION_DATABASE_foF*2 tool for $R_{12} = +9$ and $R_{12} = +13$, considering as month *mm* = 8 (August).

(January) to 12 (December), the whole database formed by 2412 (201 values of $R_{12} \times 12$ values of *mm*) output files named *SA_±rrrmm.dat* (where *±rrr* and *mm* indicate the sunspot number R_{12} and the month respectively) is generated. Each output file includes 24 numerical grids of *foF*2 relative to the different hour of the day. The reason for which negative values of R_{12} are also considered is explained in Section 3. **Figure 1** shows an example of how the two output files *SA*_+00908.*dat* and *SA*_+01308.*dat* are structured after applying the *PRODUCTION_DATABASE_foF*2 tool. Further details about the procedure followed by *PRODUCTION_DATABASE_foF*2 to generate the 2412 output files *SA_±rrrmm.dat* will be provided in Section 4.1.

3. Achievement of the Nowcasting Numerical Grids of *fo*F2 Produced by Extract_Real_Time_Grid_foF2

The attainment of nowcasting numerical grids of *foF*2 from the long term database of *foF*2 predictions, is based on the SIRMUP [4] [5] concept which is nothing but the SIRM model updated in real time when an effective sunspots number R_{12eff} is used as input parameter instead of R_{12}. The real time updating is made on the base of autoscaled values of *foF*2 in some reference stations.

In general, R_{12eff} is calculated from the autoscaled values of *foF*2 according to the method developed by Houminer *et al*. [7]. R_{12eff} gives the best fit between model predictions and real observations of *foF*2 obtained from the autoscaling performed by the ionosondes positioned within a given area. Therefore R_{12eff} can be considered as the real sunspots number at the time when *foF*2 observations are automatically scaled. This means that the application of SIRM by using R_{12eff} as input parameter (SIRMUP), constitutes a real time updating which generates nowcasting predictions of *foF*2.

In order to extract nowcasting numerical grids of *foF*2 from the database constituted by the 2412 files above mentioned, two effective sunspots numbers named $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ are calculated separately at high and middle latitudes respectively. $R_{12eff\_Northern}$ is the effective sunspots number that gives the best fit between model predictions and real observations of *foF*2 obtained from the autoscaling performed by the two digisondes located at Sodankyla (67˚4'N, 26˚6'E) and Tromso (69˚6'N, 19˚2'E), which are the new two stations considered to expand the DIAS prediction capabilities to high European latitudes.

Analogously, $R_{12eff\_Southern}$ is the sunspots number providing the best fit between background estimates and actual measurements of *foF*2 which are autoscaled in quasi real time from 8 European digisondes located at the ionospheric stations of Arenosillo (37˚1'N, 353˚3'E), Athens (38˚0'N, 23˚5'E), Ebre (40˚8'N, 0˚5'E), Rome (41˚9'N, 12˚5'E), Pruhonice (50˚0'N, 14˚6'E), Chilton (51˚5'N, 359˚4'E), Juliusruh (54˚6'N, 13˚4'E), and Moscow (55˚5'N, 37˚3'E) situated at middle latitudes and forming the standard Dias net.

It is worth noting that when the Houminer's procedure is applied for determining the effective sunspots number R_{12eff} on the basis of the autoscaled values of *foF*2, it emerges that also negative values of R_{12eff} are possible; this is the reason for which values of R_{12} ranged between −50 and −1 with step = 1 were also considered for the creation of the database.

$R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ represent the real solar activity in the northern ad southern part of Europe respectively to which we can refer to nowcast *foF*2.

Therefore, once $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ have been determined, the *Extract_Real_Time_Grid_foF*2 software tool, pulls out from the 2412 files *SA_±rrrmm.dat* an output file named *RN*± $R_{12eff\_Northern}$ *_RS*± $R_{12eff_Southern}$_m*mm*_h*hh.dat* providing a grid of nowcasting predictions of *foF*2 relative to a given month *mm* and hour *hh* that is formed by the union of 3 grids: the high latitude grid obtained for $R_{12eff\_Northern}$, the buffer zone grid calculated interpolating in the latitude interval 50˚N - 60˚N *foF*2 data derived from $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$, and the middle latitude grid obtained for $R_{12eff\_Southern}$ (see for example **Figure 2**). More details about the procedure followed by *Extract_Real_Time_Grid_foF*2*.exe* to generate the output files *RN*± $R_{12eff\_Northern}$*_RS*± $R_{12eff\_Southern}$ _m*mm*_h*hh.dat* will be provided in Section 4.2.

4. Description of PRODUCTION_DATABASE_*fo*F2&Extract_Real_Time_Grid_*fo*F2

The software package *PRODUCTION_DATABASE_foF*2*&Extract_Real_Time_Grid_foF*2 is constituted by two software tools. The first called *PRODUCTION_DATABASE_foF*2 is lunched to create the database of long term predictions of *foF*2. The second called *Extract_Real_Time_Grid_foF*2*.exe* is launched to extract from the database previously generated numerical grids representing the nowcasting predictions of *foF*2.

4.1. PRODUCTION_DATABASE_foF2 Software Tool

The procedure implemented by *PRODUCTION_DATABASE_foF*2 outputs for each value of R_{12} between −50 and 150 with step = 1 (hence 201 different values of R_{12}), and for each month *mm* ranged between 1 and 12, a file containing numerical grids of predicted values of *foF*2 for all the 24 hours in the area extending in latitude from 34˚N to 80˚N and in longitude from −10˚W to 40˚E with a 1˚ × 1˚ resolution. At the end of its execution a database of 201 × 12 = 2412 files named *SA_±rrrmm.dat* is provided.

The *PRODUCTION_DATABASE_foF*2 software tool includes the file *PRODUCTION_DATABASE_foF*2*.exe*

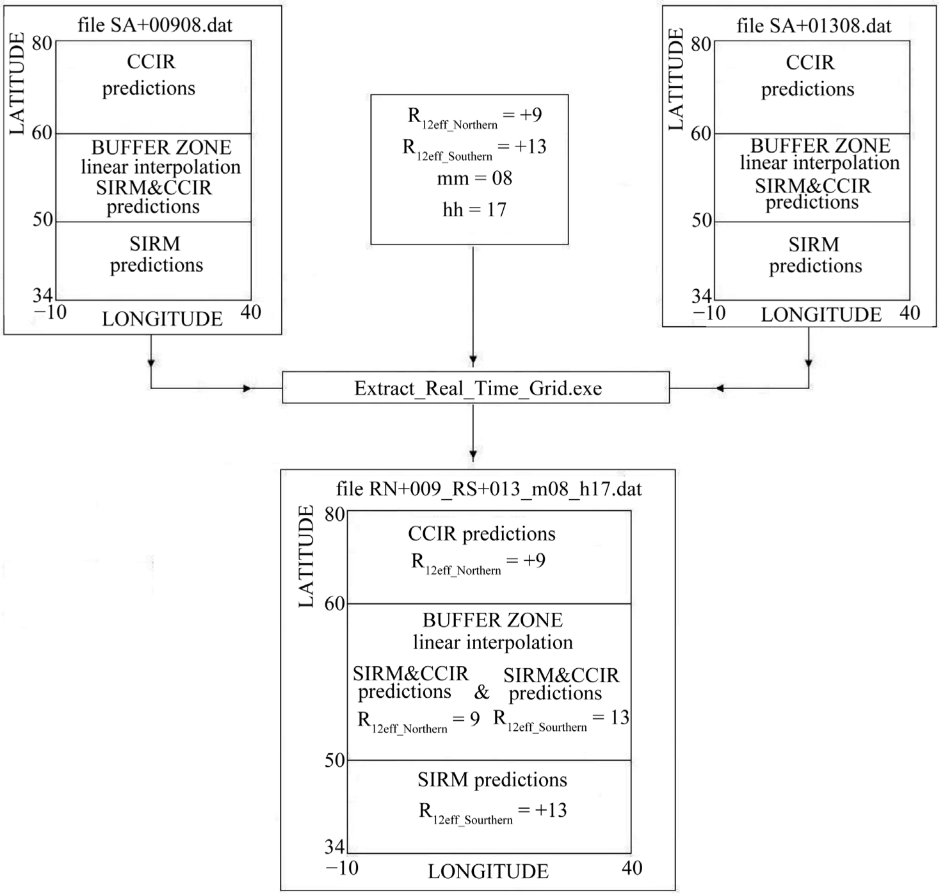


Figure 2. Scheme showing an example of how the output file RN+009_RS+013_m08_h17.dat is structured after applying the *Extract_Real_Time_Grid_foF*2*.exe* tool for $R_{12eff\ Northern}$ = +9, $R_{12eff\ Southern}$ = +13, *mm* = 08 (August), and *hh* = 17.

that runs a file batch named *PRODUCTION_GRD_foF*2*.bat* to produce the whole database.

As starting point the parameters of the input file SRIN must be initialized as follows: R_{12} = −50, month *mm* = 1. After this initialization, *PRODUCTION_DATABASE_foF*2*.exe* is run and the procedure *PRODUCTION_GRD_foF*2*.bat* is repeatedly executed for 2412 times. Each time an output file containing numerical grids of predicted values of *foF*2 for all the 24 hours is obtained for the value of R_{12} and the month *mm* written in file SRIN which is from time to time automatically updated. Therefore, just to better clarify the question, the first time *PRODUCTION_GRD_foF*2*.bat* is run, predicted values of *foF*2 for R_{12} = −50 for the month of January (*mm* = 1) are obtained for each hour and written in *SA_*-05001*.dat*, the second time *PRODUCTION_GRD_foF*2*.bat* is run, SRIN is properly updated and predictions of *foF*2 relative to R_{12} = −50 for February (*mm* = 2) are calculated again for each hour and written in *SA_*-05002*.dat*, the thirteenth time *PRODUCTION_GRD_foF*2*.bat* is run, SRIN is updated automatically with R_{12} = −49 and *mm* = 1 and *SA_*-04901*.dat* is generated. In this way the whole database is generated.

*PRODUCTION_GRD_foF*2*.bat* is constituted by the instructions *del SROUT*, *del CCIR_GRD.dat*, *del SRmapf*2, *del SRmapm*3, *del CCIR.DAT*, *del buffer_zone.dat*, which assure that any temporary file is deleted in order to avoid possible mistakes, and other seven instructions needed to run the executables which, for the sake of clarity, will be described in detail below.

4.1.1. Step 1: SIRM.exe

SIRM.exe (source code written in Fortran PowerStation version 4.0) reads from the input file SRIN the solar activity index R_{12} and the month *mm* under consideration and calculates *foF*2 and *M*3000*F*2 predictions writing them in the output file SROUT.

4.1.2. Step 2: TRASF2.exe

TRASF2.exe (source code written in Fortran PowerStation version 4.0) reads the input file SROUT providing two output files: SRmapf2 and SRmapm3. In files SRmapf2 and SRmapm3 are respectively written the predicted values of *foF*2 and *M*3000*F*2 for all the 24 hours by the SIRM model in the area extending in latitude from 34˚N to 60˚N and in longitude from −10˚W to 40˚E with a 1˚ × 1˚ resolution. SRmapm3 will not be taken into account because we are interested only in *foF*2. For this reason it does not appear in the flow diagram shown in **Figure 3**.

4.1.3. Step 3: CCIR.exe

CCIR.exe (source code written in Fortran PowerStation version 4.0) reads again from the input file SRIN providing the output file CCIR.DAT. CCIR.DAT contains the predicted values of *foF*2 by the CCIR model for all the 24 hours. The data are displayed according increasing values in latitude from 34˚N to 80˚N in the area extending in longitude from −10˚W to 40˚E with a 1˚ × 1˚ resolution.

4.1.4. Step 4: SIST_LAT.exe

SIST_LAT.exe (source code written in Visual Basic version 6.0) reads from CCIR.DAT the data and rearranges them in the output file named CCIR_GRD.dat. according decreasing values in latitude from 80˚N to 34˚N in the area extending in longitude from −10˚W to 40˚E with a 1˚ × 1˚ resolution.

4.1.5. Step 5: CALC_BUFFER_ZONE.exe

CALC_BUFFER_ZONE.exe (source code written in Visual Basic version 6.0) reads from files SRmapf2 and CCIR_GRD.dat the predicted values of *foF*2 by the SIRM model and CCIR model respectively and calculates in the range of latitude 50˚N - 60˚N new values of *foF*2 by means of the linear interpolation shown in **Table 1**. The output file named *buffer_zone.dat* contains the predicted values of *foF*2 in the buffer zone for all the 24 hours.

4.1.6. Step 6: JOIN_SIRM_BUFF_CCIR.exe

JOIN_SIRM_BUFF_CCIR.exe (source code written in Visual Basic version 6.0) reads from files SRmapf2, buffer_zone.dat, and CCIR_GRD.dat providing the output file JOIN_SIRM_BUFF_CCIR.DAT. JOIN_SIRM_BUFF_CCIR.DAT contains the *foF*2 predictions from SIRM model (in latitude interval 34˚N - 49˚N), buffer

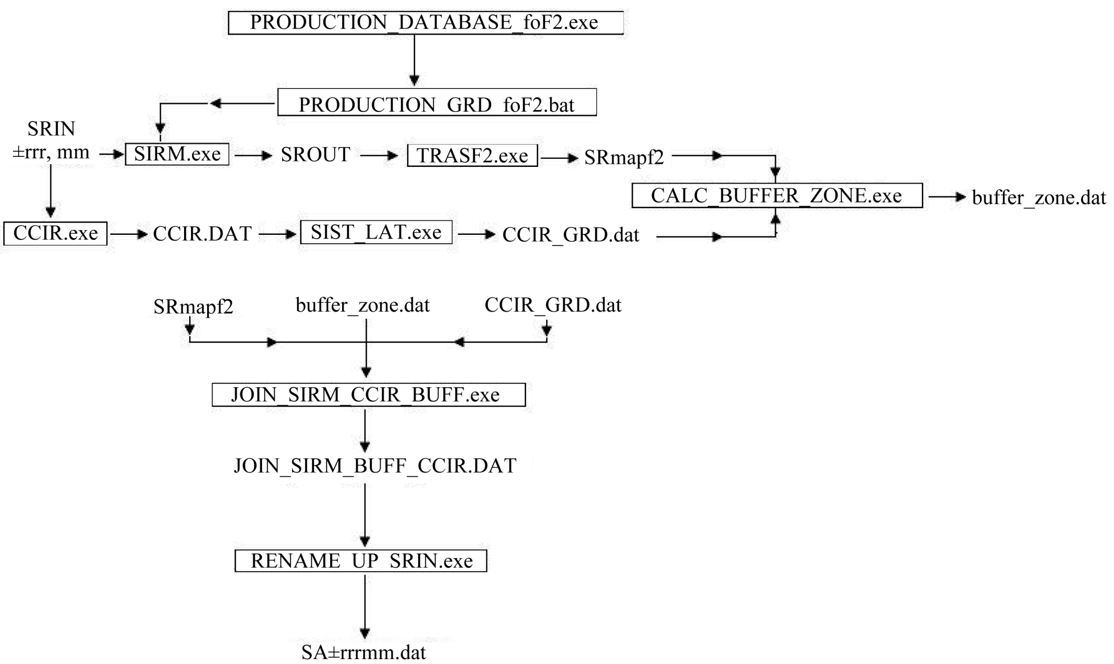


Figure 3. Flow diagram illustrating how the 2412 output files *SA_±rrrmm.dat* are derived starting from CCIR and SIRM predictions.

zone (in latitude interval 50˚N - 60˚N) and CCIR model (in latitude interval 61˚N - 80˚N) for all the 24 hours.

4.1.7. Step 7: SIRM.exe

RENAME_UP_SRIN.exe (source code written in Fortran PowerStation version 4.0) renames the output file JOIN_SIRM_BUFF_CCIR.DAT as *SA_±rrrmm.dat* where *rrr* and *mm* indicate respectively the value of the solar activity index and month under consideration read in SRIN, and updates from time to time R_{12} and *mm* in file SRIN to produce the next *SA_±rrrmm.dat* files.

Figure 3 shows the procedure implemented by *PRODUCTION_DATABASE_foF*2.

4.2. ExtractReal_Time_Grid_foF2 Software Tool

*Extract_Real_Time_Grid_foF*2 provides nowcasting grids of *foF*2 for a given hour *hh* taking as input from the 2412 output files produced by *PRODUCTION_DATABASE_foF*2 two appropriate files on the basis of two solar activity indexes $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$, which are calculated taking into account the *foF*2 measurements autoscaled at the hour *hh* in the stations located at high and middle latitudes mentioned in Section 3. Once $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ have been calculated, they are written in the input file SRIN in which is also written the month *mm* and the hour *hh* under consideration. At each hour *hh*, when new autoscaled data of *foF*2 are available, new values of $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ are calculated and written in SRIN. Therefore SRIN is updated each hour so that, from time to time, new nowcasting numerical grids of *foF*2 are provided by *Extract_Real_Time_Grid_foF*2 for the hour *hh* under consideration.

For the sake of clarity, the main subroutines making up the *Extract_Real_Time_Grid_foF*2 software tool are described more in detail below.

4.2.1. Step 1: Subroutine North

The subroutine *North* is the first subroutine to be launched from the procedure implemented by *Extract_Real_Time_Grid_foF*2*.exe*. When *North* works, it calls two secondary subroutines: 1) the subroutine *chiama_settings* reads from the input file settings.dat and returns the name of the path where the database formed by 2412 files is placed (path_inp) and the name of the path where the user wants to put the output files (path_out) generated by *Extract_Real_Time_Grid_foF*2*.exe*; 2) the subroutine *chiama_R_month_North* which, after reading from the input file SRIN the values of $R_{12eff\_Northern}$, $R_{12eff\_Southern}$, the month and hour under consideration, returns the value of $R_{12eff\_Northern}$ and the month *mm*. $R_{12eff\_Northern}$ and *mm* are then used to "build" a file name (nomefile_built); for example if $R_{12eff\_Northern}$ = +009 and *mm* = 08, nomefile_built = *SA*_+00908.*dat*, while path_inp is used "to fish" the appropriate input file (nomefile_inp) from the database. The value *hh* also returned after the call of *North* will be used afterwards.

At this point a check is made: if nomefile_built = nomefile_inp, nomefile_inp = *SA*_+00908.*dat* is opened as input file and a new file named N_nomefile_built = *N_SA*+00908.*dat* is built and opened as output file. As last step, *foF*2 predictions read from nomefile_inp = *SA*_+00908.*dat* in the latitude intervals 80˚N - 61˚N (northern part, CCIR *foF*2 predictions for R_{12} = +009), and 60˚N - 50˚N (buffer zone, SIRM&CCIR *foF*2 predictions for R_{12} = +009) are written for the 24 hours in the output file *N_SA*+00908.*dat*. To further clarify how *North* works, an example of the procedure implemented by *North* is sketched in **Figure 4**.

4.2.2. Step 2: Subroutine South

The subroutine South is the second subroutine to be run from the procedure implemented by Extract_Real_Time_Grid_foF2.exe. When South works, it calls two secondary subroutines: 1) the subroutine chiama_settings which reads from the input file settings.dat and returns the name of the path where the database formed by 2412 files is placed (path_inp) and the name of the path where the user wants to put the output files (path_out) generated by Extract_Real_Time_Grid_foF2.exe; 2) the subroutine chiama_R_month_South which, after reading from the input file SRIN the values of $R_{12eff\_Northern}$, $R_{12eff\_Southern}$, the month and hour under consideration, returns the value of $R_{12eff\_Southern}$ and the month *mm*. $R_{12eff\_Southern}$ and *mm* are then used to "build" a file name (nomefile_built); for example if $R_{12eff\_Southern}$ = +013 and *mm* = 08, nomefile_built = SA_+01308.dat, while path_inp is used "to fish" the appropriate input file (nomefile_inp) from the database.

At this point a check is made: if nomefile_built = nomefile_inp, nomefile_inp = SA_+01308.dat is opened as input file and a new file named S_nomefile_built = S_SA+01308.dat is built and opened as output file. As last

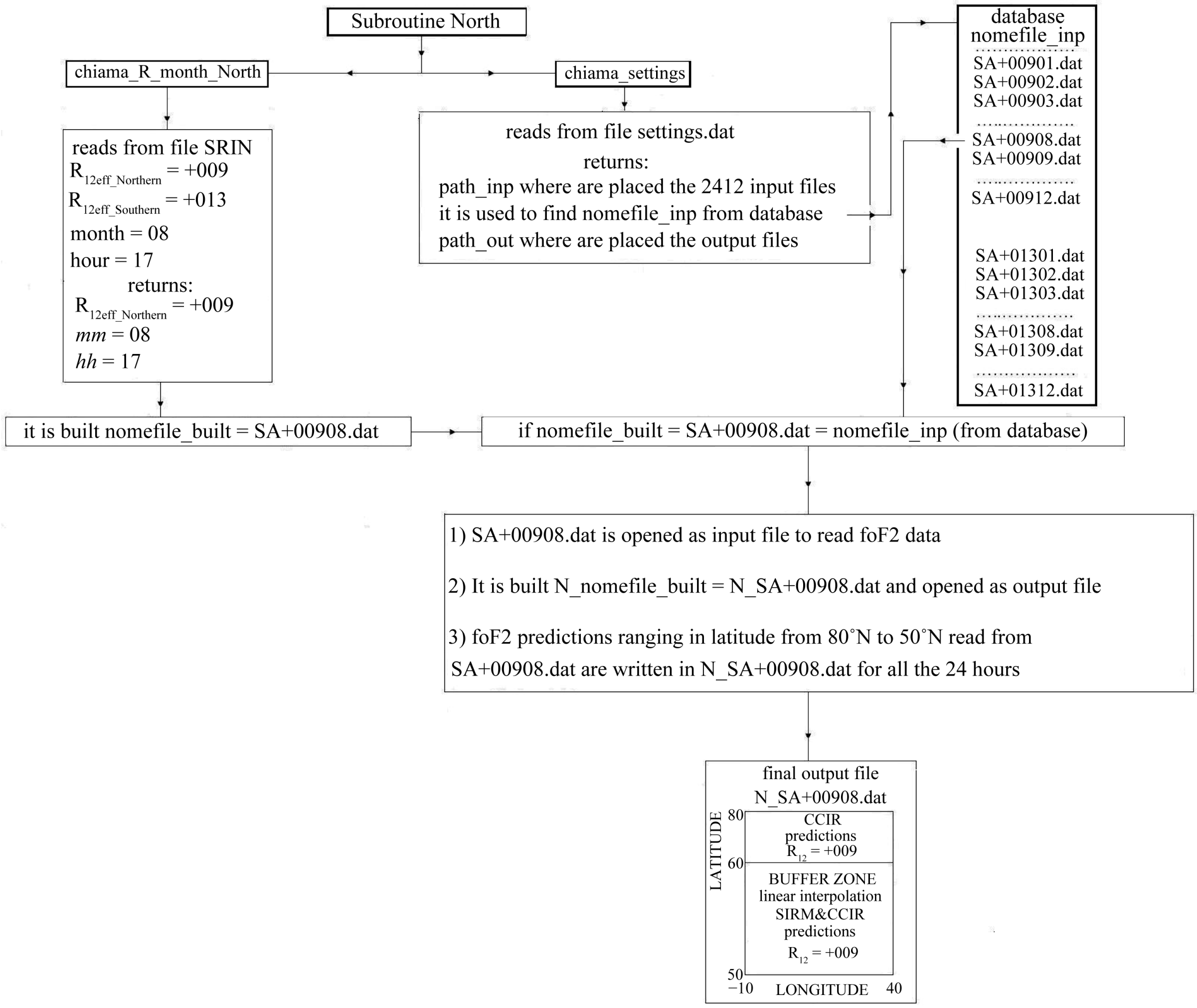


Figure 4. Example of the flow diagram performed by the subroutine North for a case study characterized by $R_{12eff\ Northern}$ = +009 and *mm* = 08 (August). The output file N_SA+00908.dat is returned.

step, foF2 predictions read from nomefile_inp = SA_+01308.dat in the latitude intervals 34˚N - 49˚N (southern part, SIRM foF2 predictions for R_{12} = +013), and 50˚N - 60˚N (buffer zone, SIRM&CCIR foF2 predictions for R_{12} = +013) are written for the 24 hours in the output file S_SA+01308.dat. To further clarify how South works, an example of the procedure implemented by South is sketched in Figure 5.

4.2.3. Step 3: Subroutines Calc_Buff_Zone_h00-Calc_Buff_Zone_h23

In general, the 24 subroutines calc_buff_zone_h00, calc_buff_zone_h01, calc_buff_zone_h02… calc_buff_zone_h21, calc_buff_zone_h22, and calc_buff_zone_h23 take as input foF2 predictions from the file N_SA±$R_{12eff_Northern}$mm.dat (for example N_SA+00908.dat) and S_SA± $R_{12eff_Southern}$mm.dat (for example S_SA+01308.dat) calculated in the buffer zone, and after executing a linear interpolation between foF2 predictions obtained with $R_{12eff\_Northern}$ and $R_{12eff\_Southern}$ according the weights shown in Table 2, output the file buffer_zone.dat where are written the foF2 values for all the 24 hours. Figure 6 shows the procedure that outputs buffer_zone.dat when the 24 subroutines work all together.

4.2.4. Step 4: Subroutines Unione_h00-Unione_h23

The subroutines unione_h00, unione_h01, unione_h02… unione_h21, unione_h22, and unione_h23 take as input CCIR foF2 predictions from N_SA±$R_{12eff_Northern}$mm.dat (for example N_SA+00908.dat) in the latitude interval 80˚N - 61˚N, foF2 data from buffer_zone.dat in the latitude interval 60˚N -50˚N, and SIRM foF2 predic-

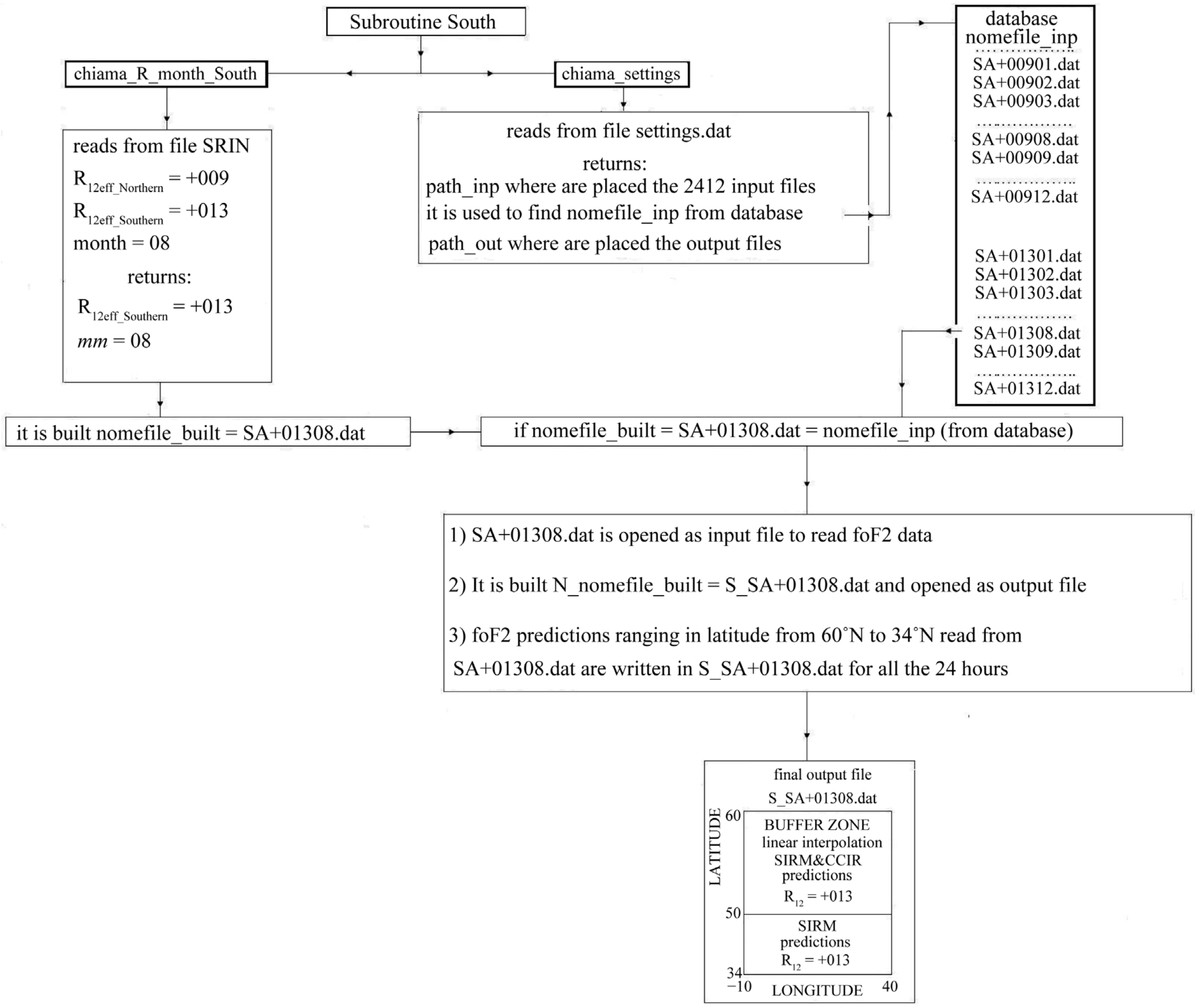


Figure 5. Example of the flow diagram performed by the subroutine *South* for a case study characterized by $R_{12eff\ Southern}$ = +013 and *mm* = 08 (August). The output file *S_SA+01308.dat* is returned.

Table 2. Weights given to the SIRM&CCIR foF2 predictions calculated for $R_{12} = R_{12eff\ Northern}$ (see for example **Figure 4**) and $R_{12} = R_{12eff\_Southern}$ (see for example **Figure 5**) to determine foF2 data in the buffer zone.

Latitude	$Weight_{R12eff\_Southern}$	$Weight_{R12eff\_Northern}$	$foF2_{BUFFER\ ZONE}$
$\lambda = 50$	1.0	0.0	$foF2_{R12eff\_Southern} \cdot 1.0 + foF2_{R12eff\_Northern} \cdot 0.0$
$\lambda = 51$	0.9	0.1	$foF2_{R12eff\_Southern} \cdot 0.9 + foF2_{R12eff\_Northern} \cdot 0.1$
$\lambda = 52$	0.8	0.2	$foF2_{R12eff\_Southern} \cdot 0.8 + foF2_{R12eff\_Northern} \cdot 0.2$
$\lambda = 53$	0.7	0.3	$foF2_{R12eff\_Southern} \cdot 0.7 + foF2_{R12eff\_Northern} \cdot 0.3$
$\lambda = 54$	0.6	0.4	$foF2_{R12eff\_Southern} \cdot 0.6 + foF2_{R12eff\_Northern} \cdot 0.4$
$\lambda = 55$	0.5	0.5	$foF2_{R12eff\_Southern} \cdot 0.5 + foF2_{R12eff\_Northern} \cdot 0.5$
$\lambda = 56$	0.4	0.6	$foF2_{R12eff\_Southern} \cdot 0.4 + foF2_{R12eff\_Northern} \cdot 0.6$
$\lambda = 57$	0.3	0.7	$foF2_{R12eff\_Southern} \cdot 0.3 + foF2_{R12eff\_Northern} \cdot 0.7$
$\lambda = 58$	0.2	0.8	$foF2_{R12eff\_Southern} \cdot 0.2 + foF2_{R12eff\_Northern} \cdot 0.8$
$\lambda = 59$	0.1	0.9	$foF2_{R12eff\_Southern} \cdot 0.1 + foF2_{R12eff\_Northern} \cdot 0.9$
$\lambda = 60$	0.0	1.0	$foF2_{R12eff\_Southern} \cdot 0.0 + foF2_{R12eff\_Northern} \cdot 1.0$

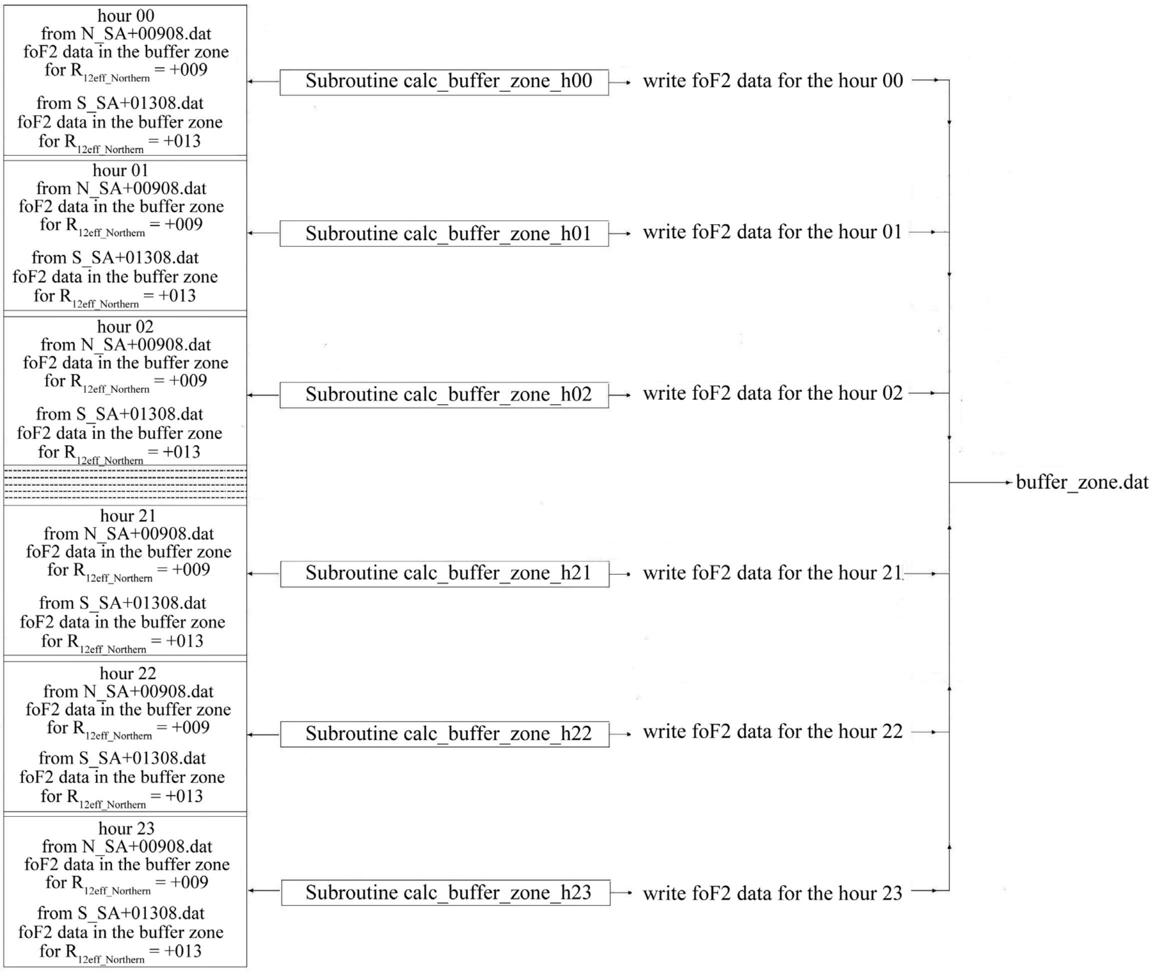


Figure 6. Example of the flow diagram performed by the 24 subroutines *calc_buff_zone_h*00… *calc_buff_zone_h*23 for a case study characterized by $R_{12eff\ Southern}$ = +013, $R_{12eff\ Northern}$ = +009 and *mm* = 08 (August). The output file *buffer_zone.dat* is returned.

tions from S_SA±$R_{12eff_Southern}$mm.dat (for example S_SA+01308.dat) in the latitude interval 49˚N - 34˚N, which are calculated respectively for the hours 00,01,02 … 22, and 23, and join them together outputting the files called respectively RN±$R_{12eff_Northern}$_RS±$R_{12eff_Southern}$m08_h00.dat, when the value of *hh* is equal to 00
RN±$R_{12eff_Northern}$_RS±$R_{12eff_Southern}$m08_h01.dat, when the value of *hh* is equal to 01
RN±$R_{12eff_Northern}$_RS±$R_{12eff_Southern}$m08_h02.dat, when the value of *hh* is equal to 02
……………………………………………………………………………………………
……………………………………………………………………………………………
RN±$R_{12eff_Northern}$_RS±$R_{12eff_Southern}$m08_h22.dat, when the value of *hh* is equal to 22
RN±$R_{12eff_Northern}$_RS±$R_{12eff_Southern}$m08_h23.dat, when the value of *hh* is equal to 23.

The procedure providing the outputs files when each subroutine is launched is sketched in **Figure 7** for a case study characterized by $R_{12eff\_Northern}$ = + 009, $R_{12eff\_Southern}$ = + 013 and *mm* = 08 (August).

Figure 8 synthesizes the procedure implemented by *Extract_Real_Time_Grid_foF*2 described above for a case study characterized by $R_{12eff\_Northern}$ = + 009, $R_{12eff\_Southern}$ = + 013 and *mm* = 08 (August), when the value *hh* returned after the call of *North* is *hh* = 17.

5. Application of PRODUCTION_DATABASE_*fo*F2&Extract_Real_Time_Grid_*fo*F2: Some Results and Discussion

As already mentioned above, long term and nowcasting maps of *foF*2 released routinely by the DIAS system

Figure 7. Example of the flow diagram performed by the 24 subroutines *unione_h*00… *unione_h*23 for a case study characterized by $R_{12eff\_Northern}$ = + 009, $R_{12eff\_Southern}$ = + 013 and *mm* = 08 (August).

represent the final outputs which are generated when the SIRM and SIRMUP methods are respectively applied. **Figure 9** shows an example of long term forecast map of *foF*2 (on the left) and nowcasting map of foF2 (on the right) over the European area extracted from the DIAS system.

The web site of the DIAS system (http://dias.space.noa.gr), has a link (see the arrow in **Figure 10**) through which it is possible to have access, after you have registered, to the European Ionosonde Service (EIS) (see

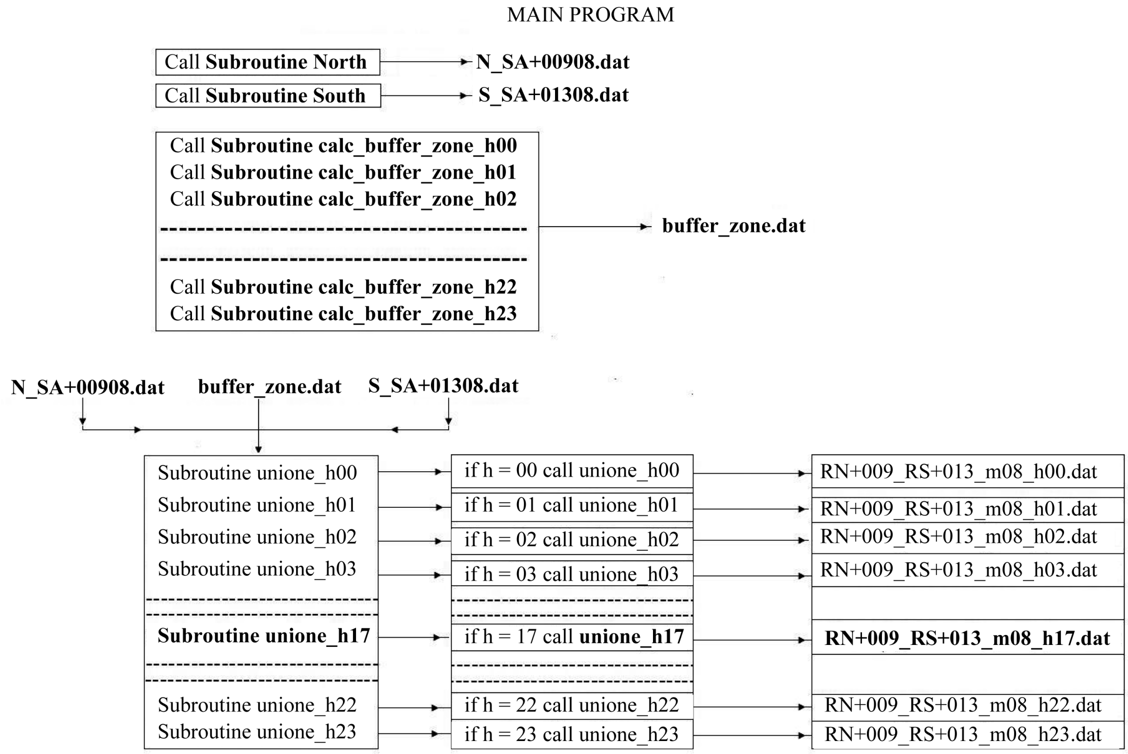
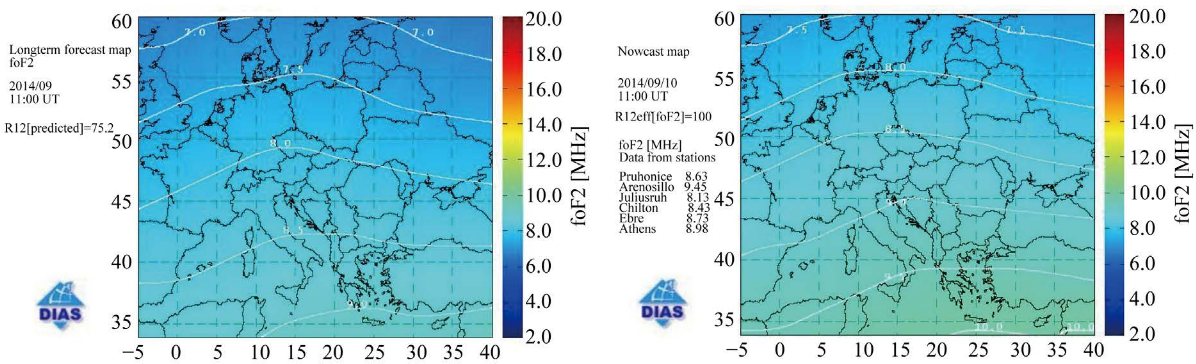


Figure 8. In bold the flow diagram of the main program is summarized for the case study characterized by $R_{12eff\ Northern}$ = +009, $R_{12eff\ Southern}$ = +013, *mm* = 08 (August), and *hh* = 17. The output file labelled *RN*+009_*RS*+013_*m*08_*h*17.*dat* is returned.



(a) (b)

Figure 9. (a) Example of long term forecast map of *foF*2 released by the Dias system for the epoch September 2014 at 11:00 UT over the European area extending in latitude from 34˚N to 60˚N and in longitude from −5˚W to 40˚E after applying SIRM method for R_{12} = 75.2; (b) Example of nowcasting map of *foF*2 released by the Dias system for the epoch 10 September 2014 at 11:00 UT over the European area extending in latitude from 34˚N to 60˚N and in longitude from −5˚W to 40˚E after applying SIRMUP method. On the left are shown the value of R_{12eff} taken as input by SIRMUP and the autoscaled *foF*2 data from which R_{12eff} is calculated.

Figure 11), which is part of the Ionospheric Weather Services provided by the ESA SSA SWE (Space WEather) Portal.

Long term forecast and nowcasting maps of *foF*2, covering a more extended area than that provided by the DIAS system both in latitude (from 34˚N to 80˚N), and in longitude (from −10˚W to 40˚E) are routinely released from the EIS system, and represent the final outputs which are produced when the software packages *PRODUCTION_DATABASE_foF*2 and *Extract_Real_Time_Grid_foF*2 are respectively applied. **Figure 12** shows an

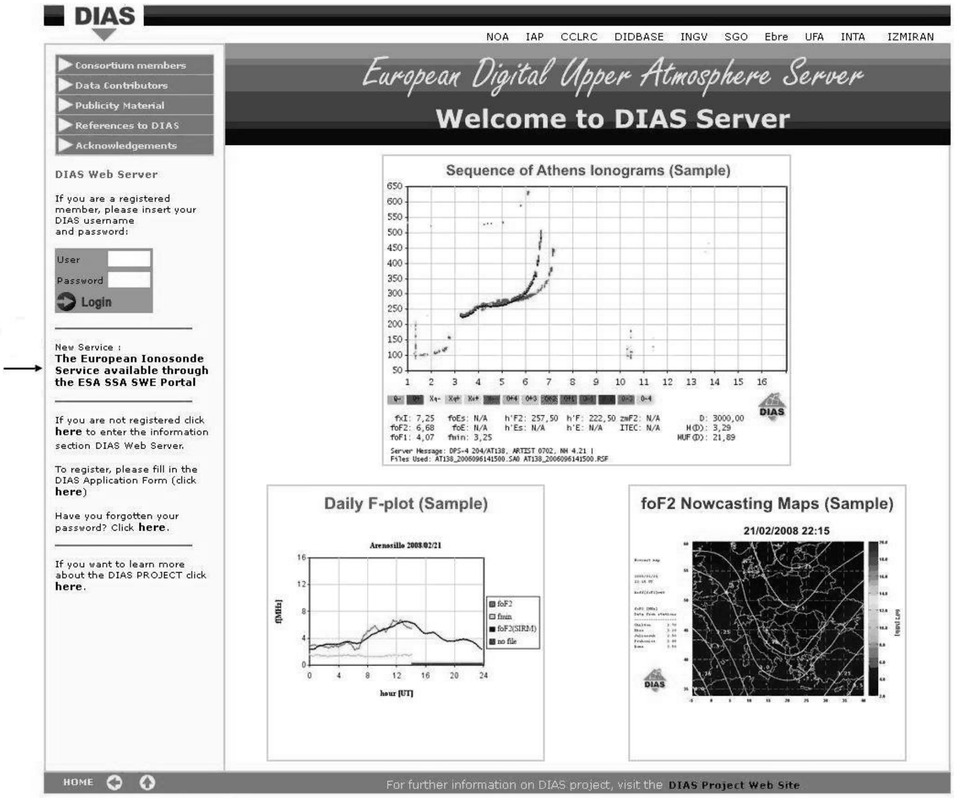


Figure 10. Login page of the DIAS system. The black arrow on the left shows the link by means of which the user can access to the EIS system (**Figure 11**).

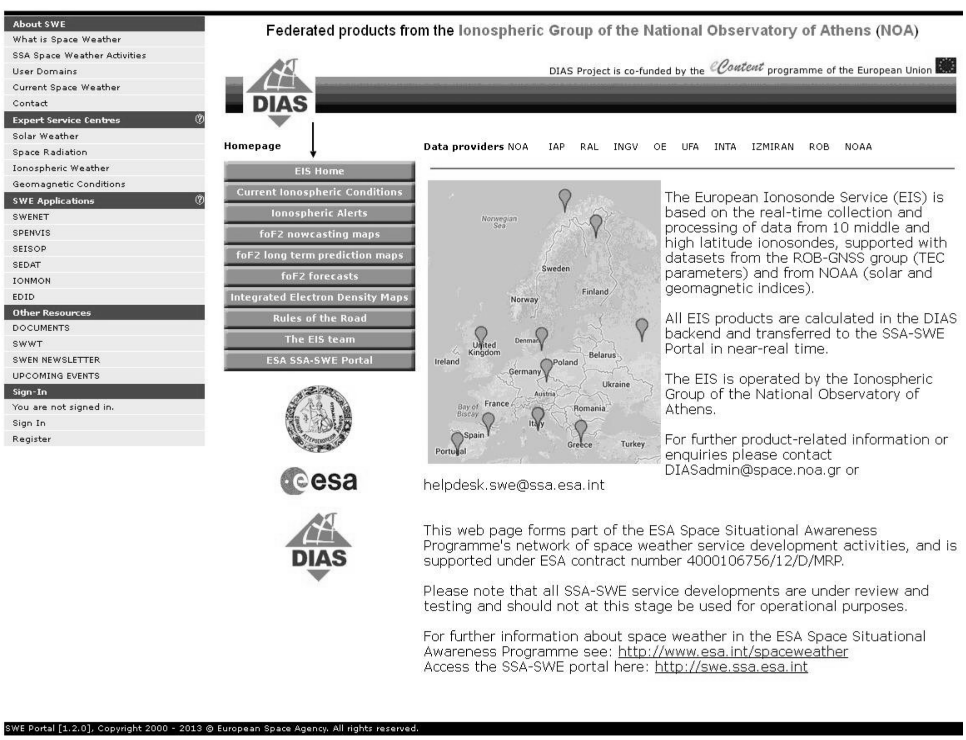


Figure 11. Home page of the EIS portal: the black arrow at the top on the left panel indicates the products provided by the EIS system.

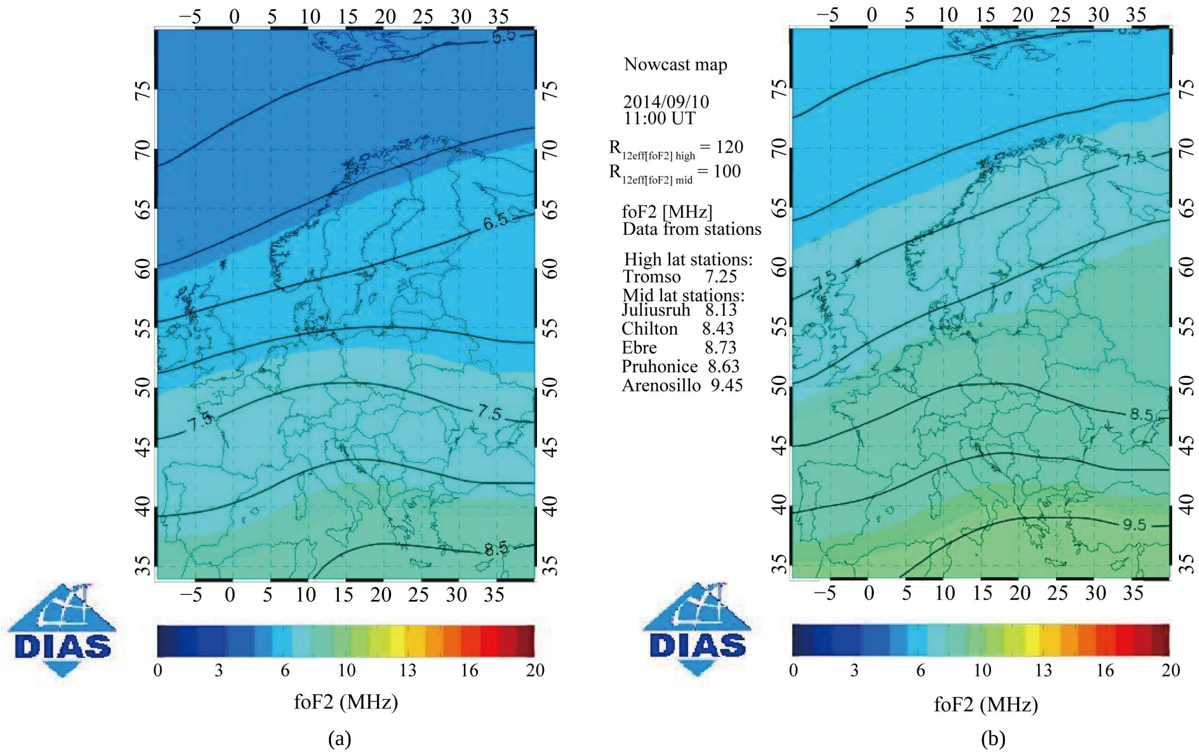


Figure 12. (a) Example of long term forecast map of *foF*2 released by the EIS system for the epoch September 2014 at 11:00 UT over the European area extending in latitude from 34˚N to 80˚N and in longitude from −10˚W to 40˚E produced by the *PRODUCTION_DATABASE_foF*2 software tool. (b) Example of nowcasting map of *foF*2 released by the EIS system on 10 September 2014 at 11:00 UT over the European area extending in latitude from 34˚N to 80˚N and in longitude from −10˚W to 40˚E after applying the *Extract_Real_Time_Grid_foF*2 procedure. The values of $R_{12eff\ Northern}$ and $R_{12eff\ Southern}$, indicated in figure respectively as $R_{12eff\ high}$ and $R_{12eff\ mid}$, and the autoscaled *foF*2 data from which $R_{12eff\ high}$ and $R_{12eff\ mid}$ are calculated are shown on the left.

example of long term forecast (on the left) and nowcasting map (on the right) of *foF*2 extracted from the EIS system.

The availability of long term forecast and near real time maps of *foF*2 is very important because *foF*2 is the main parameter describing the ionospheric conditions at a particular location, it also corresponds to the maximum radio frequency that can be reflected by the ionospheric *F*2 region at vertical incidence. This means that the contour plot of *foF*2 refers to the transmitted signals that are vertically incident on the ionosphere. Frequencies higher than those indicated on the contours pass through the ionosphere and get lost in space. Therefore *foF*2 prediction maps can be helpful to establish which are the frequencies that will always be returned to the Earth when a radio signal is transmitted vertically or in Near Vertical Incidence Skywave conditions (NVIS). More precisely, under quiet ionospheric conditions, long term predictions maps of *foF*2 provide good guidelines for the choice of frequencies to be used for all short distance communications on HF, i.e. in case of a station operating in NVIS mode; under disturbed ionospheric conditions, such as those often occurring after a geomagnetic storm event, nowcasting maps of *foF*2 can be exploited by the user as a guide to NVIS ionospheric frequency support.

Moreover, long term forecast and nowcasting maps of *foF*2 can also be used to get information about the frequencies to be used for all long-distance radio communications. Contours plot of lower/higher *foF*2 values indicate regions of the ionosphere capable of reflecting signals describing an oblique path over shorter/longer distances.

Finally, another important application which derives from the maps of *foF*2, is the possibility to estimate the Maximum Usable Frequencies (*MUFs*) which assure a radio link between the transmitter (*Tx*) to the receiver (*Rx*): knowing *foF*2 (from the *foF*2 maps) and the maximum height of reflection of the *F*2 layer, *hmF*2, (from the *hmF*2 maps) in the mid point of a given radio link *Tx*-*Rx* which distance is *D*, the secant of the optimum angle at which to broadcast the signal that has to be received at the distance *D*, (*M*(*D*)*F*2), can be easily calculated, so that *MUF*(*D*) can be determined by the user applying the approximate formula *MUF*(*D*)= *foF*2·*M*(*D*)*F*2 for any oblique circuit that can be of interest inside the mapping area under consideration.

6. Conclusions

The foF2 mapping over Europe provided by the DIAS and EIS system allows the users to know the maximum radio frequency that can be reflected by the ionospheric *F*2 region at vertical incidence, and it offers a guide both for the NVIS ionospheric frequency support and the estimate of the maximum usable frequencies for a given radio link on relatively long distances, under quiet and disturbed ionospheric conditions.

In particular, nowcasting maps are capable to provide a near real time description of the ionosphere under very disturbed geomagnetic conditions, thus offering an interesting approach to Space Weather forecast in the ionospheric domain.

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