Deliverable 5.1

Online report "System Architecture Document for the Forecast System Ionosphere"

Project acronym: *AFFECTS*
Project title: *Advance Forecast For Ensuring Communications Through Space*
Grant Agreement number: *263506*
Coordinator: *Volker Bothmer*
Project co-funded by the European Commission,
Seventh Framework Programme
Funding Scheme: *FP7-SPACE-CALL-3*

Due date of deliverable:	December 31, 2011
Actual submission date:	December 23, 2011
Start date of the project:	March 1, 2011
Project duration:	3 years

Work package:	5. "Forecast System Ionosphere"
Deliverable:	5.1
Lead beneficiary for this deliverable:	DLR
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Project co-funded by the European Commission within the Seventh Framework Programme (2007)		
Dissemination level		
PU	**Public**	**PU**
PP	**Restricted to other programme participants (including the Commission Services)**	
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Issue record

Version	Date	Author(s)	Reason for modification	Status
1.0	26-05-2011	H. Barkmann et al.	NA	Submitted to AFFECTS PI
1.1	11-10-2011	V. Bothmer	General review	
1.2	28-03-2012, 17-04-2012	V. Bothmer, H. Barkmann et al.	Final review	Submitted to AFFECTS PI

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1. Introduction

Solar activity affects the entire Earth environment from the magnetosphere down to the ionosphere and even to the lower atmosphere climate system. The natural hazards of space weather do not only modify the atmosphere but also can catastrophically disrupt the operations of many technological systems, thus causing disruption to people's lives and jobs. The AFFECTS collaborative project uniquely addresses these key topics through state of the art analysis and modelling of the Sun-Earth Chain of Effects on the Earth's ionosphere and their subsequent impacts on communication systems. [Ref. 1]

The Forecast System Ionosphere (FSI) will be a major part of the AFFECTS system (shown in Figure 1) as described in the DoW. A preliminary and rough overview about the software modules and input interfaces to be used in the FSI is indicated in the yellow circle in Figure 1. The UV data set from the ISS provided by FHG has been added to the original DoW Figure for completeness.

A sophisticated description of the system architecture of the FSI which is developed in D5.1 follows in this document. It contains the input data management and the integrated modules as well as the way the quality control will be integrated and how the products and data will be archived.

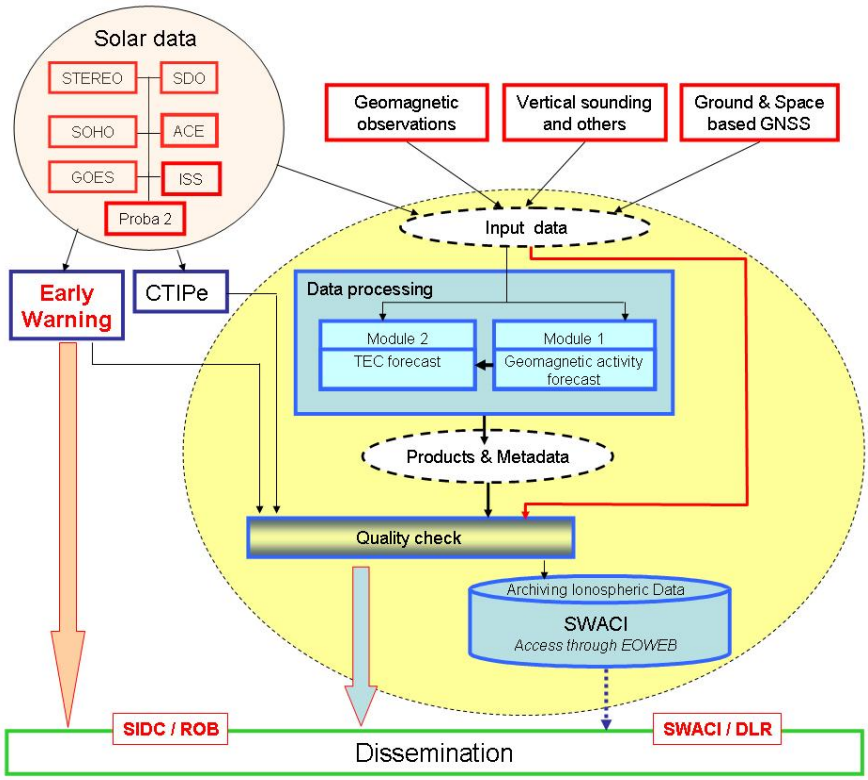

Figure 1 AFFECTS Overview [update of Ref. 6]

2. References

Ref. 1	http://www.affects-fp7.eu/affects/ (2011-11-30)
Ref. 2	"Parnowski A.S. Regression modeling method of space weather prediction, Astrophysics & Space Science, 2009, 323(2), 169-180. doi:10.1007/s10509-009-0060-4 [arXiv:0906.3271]"
Ref. 3	AFFECTS, Annex I "Description of Work", Project full title: II Advanced Forecast For Ensuring Communications Through Space II, Grant agreement no: 263506, Date: 2011-01-25 Part A
Ref. 4	http://www.dlr.de/caf/en/desktopdefault.aspx/tabid-5396/10198_read-21918/ (2011-12-13)
Ref. 5	DIMS, Processing System Management, Integrator's Manual and ICD, Release 2.1.0, 16.12.2011, internal document
Ref. 6	AFFECTS, Annex I "Description of Work", Project full title: II Advanced Forecast For Ensuring Communications Through Space II, Grant agreement no: 263506, Date: 2011-01-25 Part B
Ref. 7	Online provision of L1 solar wind and geomagnetic indices data base, AFFECTS Deliverable 2.4
Ref. 8	Online Provision of GNSS based ionospheric data base, AFFECTS Deliverable 2.6

Table 1 References

3. Terms, Definitions and Abbreviations

CTIPe	Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model
DIMS	Data Information Management System
DLR	German Aerospace Center
DoW	Description of Work
FC	Forecast
FSI	Forecast System Ionosphere
GNSS	Global Navigation Satellite System
I/F	Interface
NC	Nowcast
PSM	Processing System Management
QC	Quality Check
REQ	Requirement

ROB	Royal Observatory of Belgium
SIDC	Solar Influences Data analysis Center
SWACI	Space Weather Application Center - Ionosphere
UGOE	Georg-August University of Göttingen
UoT	University of Tromsø
NOAA-SWPC	Space Weather Prediction Center of NOAA, USA
SRI NASU-NSAU	Space Research Institute, Ukraine

4. Requirements

The requirements that have to be fulfilled for the realization of the FSI follow the "Description of Work" [Ref. 3] and are listed in Table 2. These requirements are subdivided into 5 subsections and discussed in this document.

Requirement no.	Description	Source
General		
REQ1	Forecast System Ionosphere(FSI) should contain following core elements: • Input data management • Processing modules • Quality control of products • Archiving of data and products	[Ref. 3], p. 22
REQ2	FSI should contain and handle a module for Geomagnetic activity forecast (core from SRI NASU-NSAU)	[Ref. 3], p. 22
REQ3	FSI should contain and handle a module TEC and TEC maps over Europe	[Ref. 3], p. 22
REQ4	FSI should provide I/F for dissemination	[Ref. 3], p. 22
REQ5	FSI should provide I/F for archiving	[Ref. 3], p. 22
REQ6	FSI should provide Product descriptions for all (output) products	[Ref. 3], p. 22
Data		
REQ7	Input to FSI: solar, geomagnetic and ionospheric data	[Ref. 3], p. 22
REQ8	Output of FSI: Early warnings and forecasts of expected ionospheric perturbations	[Ref. 3], p. 22

Requirement no.	Description	Source
REQ9	FSI generates metadata	[Ref. 3], p. 22
Quality control of FSI		
REQ10	FSI handles quality control of the (output) products	[Ref. 3], p. 22
REQ11	Comparison of forecast results from physical modeling with ground and space based ionospheric data	[Ref. 3], p. 22
REQ12	Comparison of geomagnetic activity forecasts with geomagnetic data	[Ref. 3], p. 22
REQ13	Comparison of ionospheric perturbation forecasts with ground based TEC data	[Ref. 3], p. 22
REQ14	FSI operation on best-effort basis.	[Ref. 3], p. 22
Time constraints		
REQ15	Processing of observations in near realtime	[Ref. 3], p. 22
REQ16	Provision of ionospheric predictions up to 24 hours in advance	[Ref. 3], p. 22
I/Fs		
REQ17	Dissemination of ionospheric data products and forecasts via SWACI Webinterface	[Ref. 3], p. 23
REQ18	Development of interface to provide the overall space weather platform for dissemination at ROB-SIDC and at NOAA-SWPC based on generated space weather products, interface to UGOE, ROB, NOAA-SWPC for early warnings	[Ref. 3], p. 23

Table 2 Requirements

5. System architecture overview

The FSI uses existing and approved systems like the Data Information Management System (DIMS), the Processing System Management (PSM) and the DIMS Product Library (PL), which are already operating in SWACI. The assets of these systems are inter alia flexibility, controlling and extensibility.

The DIMS with the PSM is the data processing environment. PSMs will control the modules as well as the distribution of the output products to the AFFECTS website and to the data archive. For archiving of the AFFECTS products the PL is used.

In DIMS an "Emphasis is not only placed on controlling the processes of product generation (data processing), but also on the long-term archiving of all earth observation data in order to

preserve this valuable legacy for future generations. Efficient and uniform operation of several missions in parallel within one system and the continuous integration of new missions are additional important aspects […]" [Ref. 4]

Figure 2 provides an overview of the system architecture of the FSI. The different data inputs to the FSI are specified. This includes the solar, GNSS, vertical sounding data and geomagnetic observations. The solar Early Warning message is provided by UGOE, ROB (based on NOAA-SWPC) to the FSI for European distribution and forecast.

The data processing includes 6 modules which are described in detail in chapter 7. Each processing module incorporates a product specific Quality Check (QC). In addition the FSI contains an overall QC for the system. Details on the QC are given in chapter 9.

The data archiving part is realized by using the DIMS Product Library (PL) – see chapter 10.

The generated space weather products will be distributed via the SWACI-AFFECTS website. The Early Warning message for GNSS users, which is based on information provided at the main AFFECTS, the NOAA-SWPC and ROB websites jointly coordinated, will be additionally distributed to the user through specific mailing lists or other applications (c.f. Ref. 8).

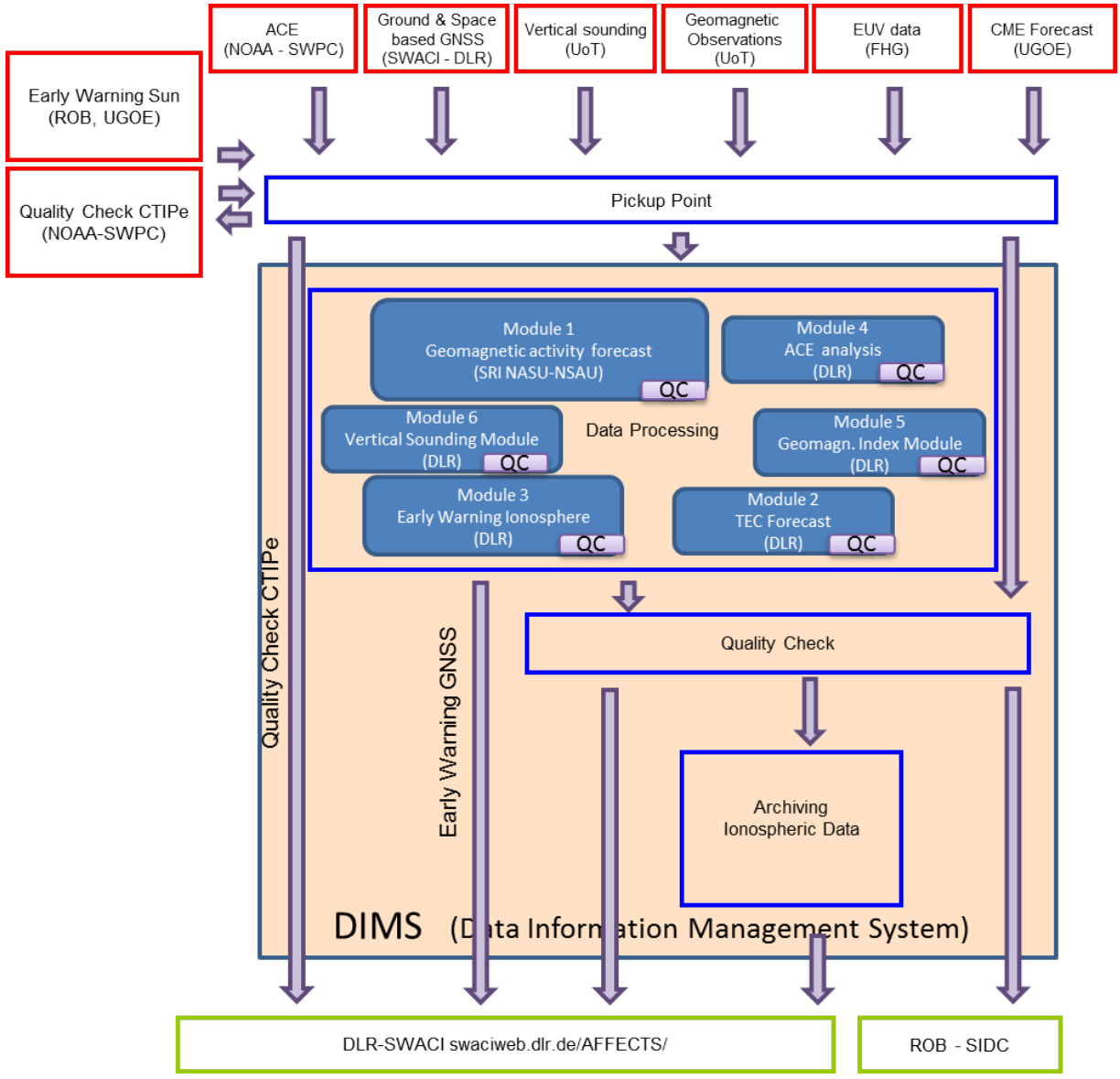

Figure 2 Layout of the Forecast System Ionosphere Architecture

6. Input data management

Table 3 lists the key input data provided to the FSI.

Input data	Description	Delivering Institution	Data Source
Solar Wind Data	ACE data description can be found in [Ref. 7]	NOAA-SWPC	ACE data details and resources are described in AFFECTS deliverable 2.4
Ground & Spaced based GNSS	TEC maps	DLR - SWACI	ftp://swaci@swaci-web.nz.dlr.de@swaciweb.dlr.de
Vertical Sounding	SAO Files	UoT	ftp://ionoftp2@swaci-web.nz.dlr.de@swaciweb.dlr.de ftp://ionoftp@swaci-web.nz.dlr.de@swaciweb.dlr.de
Geomagnetic Observations	List of indices can be found at http://swaciweb.dlr.de/affects/ => geomagnetic observations	UoT	ftp://ionoftp2@swaci-web.nz.dlr.de@swaciweb.dlr.de Indices can be found at http://swaciweb.dlr.de/affects/ => geomagnetic observation
Early Warning Sun	Individual Early Warning Message Sun based on NOAA-SWPC alerts and data	ROB, UGOE	Provision by Email or ftp to the Pickup Point
Quality Check CTIPe	Global CTIPe maps and quality maps.	NOAA-SWPC	ftp://noaaftp@swaci-web.nz.dlr.de@swaciweb.dlr.de
EUV	Provision of EUV data in project month 36 for future improvements of TEC maps.	FHG	tbd
CME Forecast	CME forecast for the improvement of TEC forecast and early warning GNSS. Provision in project month 36.	UGOE	tbd

Table 3 Summary of Input Data

7. Processing modules

The processing modules will be integrated at DLR by using the DIMS and PSM to incorporate them in to the SWACI System. Six modules will be established in the Forecast System Ionosphere.

Modules	Description	
Module 1: geomagnetic activity forecast **Delivery by SRI NASU-NSAU**	The geomagnetic forecast module predicts the geomagnetic index Dst 3 hours in advance. The lead time may be increased in the future. The forecast is based upon the regression modeling method [Ref. 2]. Kp or ap forecast can also be provided if necessary.	
	Input	ACE data for last 24 hours. Previous Dst values for last 28 days.
	output	Dst forecast (3h lead time, 1 h cadence)
	Other parameter	
Module 2: TEC forecast **DLR [Ref. 8]**	The TEC forecast module is designed to predict TEC over Europe 6, 12 & 24 hours in advance. The advantage of this TEC forecast module is that it implements a new TEC perturbation model, which predicts TEC during disturbances. Therefore it uses geomagnetic forecast, ACE solar wind measurements and CME forecasts. EUV-Measurements will be delivered to this module (D2.3, due in month 36) for future improvements of TEC forecast.	
	Input	EU TEC map nowcast Dst forecast ACE measurements EU TEC model EU TEC perturbation model CME forecast (STEREO, SOHO) EUV (SDO, Proba2, ISS, available after month 36)
	Output	EU TEC forecast map

Modules	Description	
		EU TEC quality map
	Other parameter	F10.7cm radioflux index
Module 3: Early Warning Message DLR [Ref. 8]	This module generates an early warning message which is primarily directed to users of GNSS systems. It uses solar alerts disseminated by UGOE and ROB (based on NOAA-SWPC alerts) and translates it to the special needs of GNSS users.	
	Input	Solar wind alert (UGOE, ROB) ACE measurements Dst forecast
	Output	Early warning message to GNSS users Reliability statistics
	Other parameter	
Module 4: ACE Analysis DLR [Ref. 8]	The ACE analysis module applies preanalysis and correlations studies on ACE measurements in preparation for the TEC forecast module.	
	Input	ACE measurements EU TEC map nowcast
	Output	ACE measurements
	Other parameter	
Module 5: Geomagn. Index Module DLR [Ref. 8]	Magnetometer measurements which are provided for the AFFECTS consortium by UoT are analyzed and processed as input for TEC forecast.	
	Input	Magnetometer measurements
	Output	Geomagnetic data
	Other parameter	
Module 6: Vertical Sounding Module DLR [Ref. 8]	The slab thickness is calculated on the basis of vertical sounding data delivered by UoT and TEC measurements.	
	Input	Vertical sounding EU TEC maps
	Output	Slab thickness
	Other parameter	

Table 4 Module Descriptions

Modules 1 to 5 handle a job-order-file which is generated by DIMS. It contains specific information for data processing such as input and output paths and other parameters. An example of a Job-Order-File is given in ANNEX I.

All modules generate metadata (for details on format and content of this metadata files see ANNEX II).

8. Product Generation Flow

Figure 3 shows the general product generation flow of the FSI. The input data will be processed within the DIMS environment by the above specified modules. All input data and generated products have to pass dedicated quality controls (the detailed description of the quality control follows in chapter 9). Qualified data will be archived at DIMS and send to the dissemination facilities SIDC and SWACI-AFFECTS portal.

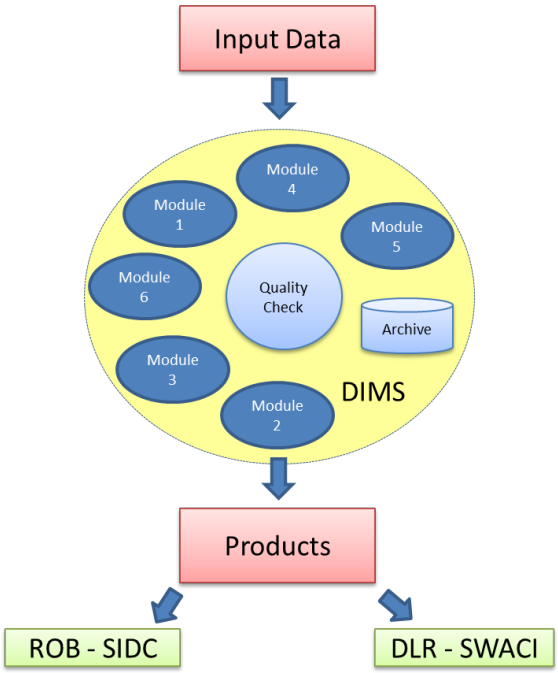

Figure 3 Product Generation Flow

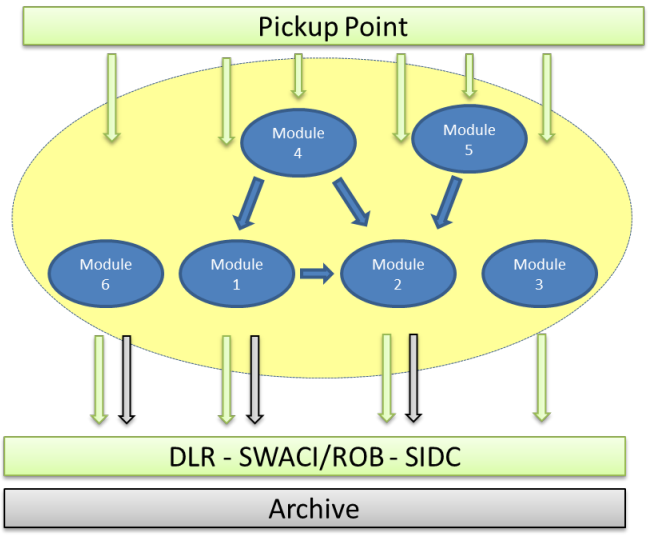

Figure 4 Relationship Modules

Attention has to be paid that there also exist data dependencies between the processing modules. Products generated in one module are used as input data in another. Figure 4 illustrates the product flow between the modules. Modules 1, 4 and 5 create output products that are used by module 2. After their generation the products processed by modules 1, 2 and 6 are archived and uploaded to the website. Modules 4 and 5 only operate as preprocessors for module 2. There products are not published.

Module 3 operates independently of other FSI modules. While modules 1, 2, 4, 5 and 6 are running continously, module 3 is triggered by events (early warning messages generated from solar data reported by UGOE and ROB). The products of module 3 are distributed by the dissimination facilities but are not archived.

9. Quality check of products

The Quality Check (QC) is organized in 3 layers.

The first QC is directly performed within the modules themselves (see Figure 5). The product quality will be defined in two flag parameters given in the meta data. The first flag indicates the completeness and quality of the input data. The second flag indicates the quality of the data output based on the results of difference plots, BIAS, RMS and/ or standard deviation methods.

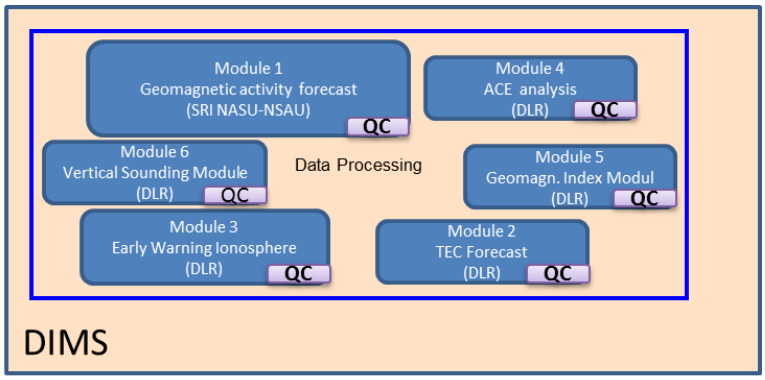

Figure 5 Quality Check Modules

The second layer is part of the infrastructure and data management layer. It controls the products' completeness levels and the activity states of the modules and processors. Based on this information the current status of each processing module (e.g. time of the last run) is written into an overview chart. Furthermore the requirements for archiving and dissemination of the products via the websites will be quality checked. This check includes verification of the metadata (see Figure 6 and chapter 10, 11). The results and charts will be published on the SWACI-AFFECTS website (http://swaciweb.dlr.de/affects/).

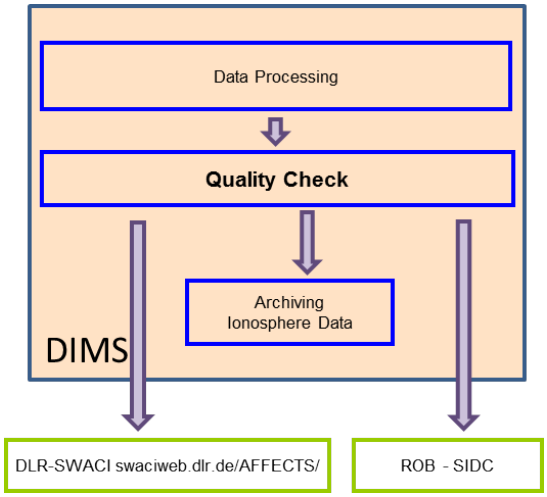

Figure 6 Quality Check Data Management

The third QC is executed externally by NOAA-SWPC. CTIPe maps are checked with the help of SWACI global TEC-maps (nowcast, NC) using common methods, such as calculation of standard deviations, difference plots, BIAS and RMS. SWACI TEC maps are provided on the Pickup Point. The QC results are send back by NOAA-SWPC to the same Pickup Point (see Figure 7) and disseminated on the SWACI-AFFECTS website.

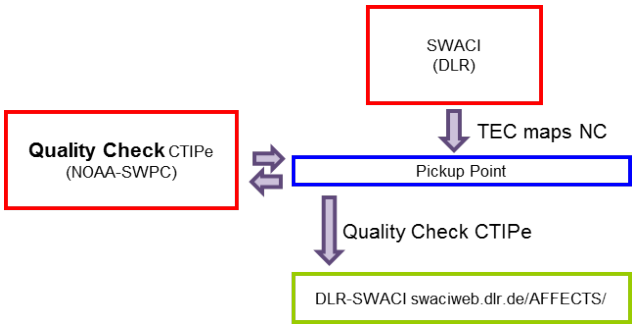

Figure 7 Quality Check CTIPe

Altogether all data and products pass a quality control check before they will be provided to the users.

10. Archiving of data and products

The archiving of the data and space weather output products is realized through use of the DIMS-PSM and –PL. The corresponding data and products are listed in Table 5.

An important precondition for the archiving process is the completeness level of the products and data files for which also metadata are needed. Each product meta file is generated as output result by the corresponding module. Metadata information can be found in ANNEX II. The data and generated products will be archived as daily files (each product separately).

Product/Data	Description
Geomagnetic activity forecast	Dst index forecast
TEC Forecast	EU TEC forecast map

	EU TEC quality map
Slab thickness	foF2 hmF2
Geomagnetic indices	Geomagnetic data
ACE measurements	ACE data

Table 5 Products and Data to be archived

11. Output data management

In Table 6 all output data generated by the data processing modules are summarized, including user access informations (e.g., website access, through archive, by ftp, through e-mail).

Output product name	**Module**	**Destination**			**User access**
		Website	**Archive**	**Others**	
Geomagnetic activity forecast	1	x	x	Module 2	http://swaciweb.dlr.de/affects/
TEC EU Forecast	2	x	x		http://swaciweb.dlr.de/affects/
Early Warning for GNSS Users	3	x		SIDC	http://swaciweb.dlr.de/affects/ Email ftp Others e.g. cell phone application
ACE Measurements	4			Modules 1 and 2	
Geomagnetic indices	5	x		Module 2	
Slab Thickness	6	x	x		http://swaciweb.dlr.de/affects/

Table 6 Output Data Management

12. Summary

The document describes the layout of the Forecast Ionosphere System architecture, including information on input and output data and interfaces. It shall be noted that modifications may take place during the implementation phase of the system to enable quality enhancements. All changes

will be discussed and distributed to all involved AFFECTS members. The modifications shall be approved by the AFFECTS AB.

Table 7 shows the requirements traceability matrix. It provides an overview on the requirement-chapter interconnection within this document.

Requirement no.	Chapter 5	Chapter 6	Chapter 7	Chapter 8	Chapter 9	Chapter 10	Chapter 11
REQ1		X	x	x	x	x	
REQ2			x	x			
REQ3		X	x	x			
REQ4	x			x		x	x
REQ5	x			x		x	x
REQ6						x	x
REQ7		X		x			
REQ8			x	x			x
REQ9			x			x	x
REQ10					x		
REQ11			x		x		
REQ12			x		x		
REQ13			x		x		
REQ14	x						
REQ15	x		x				
REQ16			x				
REQ17				x			x
REQ18							x

Table 7 Requirements Traceability Matrix

13. ANNEX I

Input for most processing modules of the FSI is a Job-Order-File. The DIMS generates an individual Job-Order-File for each processing module containing necessary information e.g. the path information for input and output and other required processing parameters. Table 8 shows a sample of such a Job-Order-File.

```
<?xml version="1.0" encoding="UTF-8"?><Ipf_Job_Order>
  <Ipf_Conf>
    <Processor_Name>Scintillation</Processor_Name>
    <Version>prototype</Version>
    <Logging_Level/>
    <Stdout_Log_Level/>
    <Stderr_Log_Level/>
    <Control_Folder/>
```

```
    <Test>false</Test>
    <Troubleshooting>false</Troubleshooting>
    <Breakpoint_Enable>false</Breakpoint_Enable>
    <Acquisition_Station/>
    <Processing_Station/>
    <Phase/>
    <Config_Files/>
    <Sensing_Time>
      <Start/>
      <Stop/>
    </Sensing_Time>
  </Ipf_Conf>
  <Processing_Parameters count="0">
    <Processing_Parameter>
      <Name>filename</Name>
      <Value>lcte100701.sct</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>Station</Name>
      <Value>tene</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>date</Name>
      <Value>100701</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>lastmodificationtime</Name>
      <Value>2010-07-01T08:27:49</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>lastmodificationtimeLong</Name>
      <Value>1277972869000</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>matlabExe</Name>
      <Value>/home/swaci/MatLab/bin/matlab</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>matlabMFile</Name>
      <Value>LinuxScintillationMainDFDJOB</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>matlabMFilePfad</Name>
      <Value>/home/swaci/vDOmatlab/Scint2010DFD</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>jobOrderStyleSheet</Name>
      <Value>/home/swaci/inst/psm-scintillation-2/etc/JobOrder.xsl</Value>
    </Processing_Parameter>
    <Processing_Parameter>
      <Name>ConfigFile</Name>
      <Value>/home/swaci/vDOmatlab/Scint2010DFD/ScintillationConfigLinuxDFD.cfg</Value>
    </Processing_Parameter>
  </Processing_Parameters>
  <List_of_Ipf_Procs count="1">
    <Ipf_Proc>
      <Task_Name/>
      <Task_Version/>
      <Breakpoint>
        <Enable>OFF</Enable>
        <List_of_Brk_Files count="0"/>
      </Breakpoint>
      <List_of_Inputs count="1">
        <Input>
          <File_Type>ScintillationSct</File_Type>
          <File_Name_Type>Directory</File_Name_Type>
          <File_Name>/home/swaci/inst/psm-scintillation-2/cache/SCINT-
329661134</File_Name>
        </Input>
```

```
      </List_of_Inputs>
      <List_of_Outputs count="1">
        <Output>
          <File_Type>ScintillationPng</File_Type>
          <File_Name_Type>Directory</File_Name_Type>
          <File_Name>/home/swaci/inst/psm-scintillation-2/cache/SCINT-
329661134</File_Name>
        </Output>
      </List_of_Outputs>
    </Ipf_Proc>
  </List_of_Ipf_Procs>
</Ipf_Job_Order>
```

Table 8 Sample of a Job Order File

14. ANNEX II

The metadata file requires xml format and the following basic information:

- mission
- productname
- sensor
- stationName
- code
- project
- product_creation_time
- revision
- description
- contact_person
- input_quality_flag
- startTime
- stopTime
- location
- Latitude_Start
- Latitude_End
- Longitude_Start
- Longitude_End
- format
- data_type
- Preprocessing_software_version
- output_quality_flag

Note, that it is possible to expand the list for every module individually with additional information. Table 9 shows a sample metadata file.

```
       <mission>mission name</mission>
       <productname>Product name</productname>
       <sensor>Groundbased</sensor>
       <stationName>diverse EU</stationName>
       <code>L2</code>
       <project>swaci</project>
       <product_creation_time>2011-11-20T23:57:28</product_creation_time>
       <revision>1.0</revision>
       <startTime>2011-11-20T00:00:00</startTime>
       <stopTime>2011-11-20T23:57:28</stopTime>
       <location>Neustrelitz</location>
       <Latitude_Start>35</Latitude_Start>
       <Latitude_End>65</Latitude_End>
       <Longitude_Start>-15</Longitude_Start>
```

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<Longitude_End>30</Longitude_End>
<format>NetCDF</format>
<data_type>nc</data_type>
<description>The Product xy is a measure  of ionospheric ...</description>
<contact_person>Dr. N. Jakowski: norbert.jakowski@dlr.de</contact_person>
<Processing_software_version>1.0</Processing_software_version>
```

Table 9 Sample of a Metadata File