Deliverable 3.2

Provision of a layout of an early warning for GNSS users

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Editor:	C. Borries (DLR)
Authors:	C. Borries, N. Jakowski, H. Barkmann (DLR), V. Bothmer (UGOE), C. Verbeeck, R. Viereck (NOAA-SWPC)
Quality reviewer:	C. Verbeeck (ROB), V. Bothmer (UGOE)

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NOTICE

This report has been prepared under the scope of the AFFECTS project in collaboration of the following participants of Work Package 3 "Early Warning System" with lead of ROB (C. Verbeeck) and co-lead of UGOE (V. Bothmer):

Georg-August-Universität Göttingen, Stiftung Öffentlichen Rechts, Germany (UGOE)
Phone: +49 551 39 5044, Fax: -5043, http://www.astro.physik.uni-goettingen.de/
Volker Bothmer, e-mail: bothmer@astro.physik.uni-goettingen.de

Royal Observatory of Belgium, Belgium (ROB)
Phone: +32 2 890 98 19, http://www.observatory.be/
Cis Verbeeck, e-mail: cis.verbeeck@oma.be

Deutsches Zentrum für Luft- und Raumfahrt, Germany (DLR)
Phone: +49 3981 480 215, fax: -142, http://www.dlr.de/kn
Claudia Borries, e-mail: claudia.borries@dlr.de
Norbert Jakowski, e-mail: norbert.jakowski@dlr.de

Henrike Barkmann, e-mail: henrike.barkmann@dlr.de

Space Weather Prediction Center of NOAA, USA (NOAA-SWPC)

Phone: +1 303 497 7348, Fax: +1 303 497 3645, http://www.swpc.noaa.gov/

Rodney Viereck, e-mail: rodney.viereck@noaa.gov

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1 Introduction

This report defines the layout of an early warning message for customers and service operators of Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS or Galileo according to [REF6], WP 3.

The "early warning message for GNSS users" is especially directed to customers of space based radio systems used in telecommunication, navigation/positioning and remote sensing. In particular, as stated in the [REF6], WP 3, the warning shall inform customers and operators of GNSS on approaching space weather events. Thus, GNSS customers and service providers will be aware of potential performance degradation of their systems due to space weather impacts. Based on the early warning, customers shall become prepared to undertake efforts to help mitigate the space weather impacts on the operated systems. Safety of Life (SoL) applications may entirely stop the use of GNSS. The reliability of the early warning is of essential importance in this regards to avoid unnecessary and cost intensive actions. However, the customer himself has to estimate the risk of his decisions with respect to the concrete GNSS application or service he is involved in or is operating.

The "early warning message for GNSS users" precedes the forecast of the ionospheric behaviour over Europe based on GNSS measurements.

2 Potential user groups

As stated above, the primary user group of early warnings in the case of communication threats due to space weather impacts are customers and service providers of GNSS. E.g. in case of radio blackouts over the Earth's poles airlines may redirect or cancel flights with routes through the affected areas.

The terms used in the warning messages are closely related to the technical environment of GNSS users. Further on, the warning is also of importance for customers of other satellite based radio systems used in telecommunication and remote sensing.

Identified potential GNSS customer groups are:

Differential GNSS service providers

Individual GNSS users and users of transionospheric radio links, e.g.,operators and customers of ground based augmentation systems (GBAS) and operators and customers of space based augmentation systems (SBAS like EGNOS or WAAS)

Identified potential application fields outside GNSS are:

Radio communication at HF and lower frequencies

Remote sensing (e.g. radar systems using L- and P- band)

3 Specifications of the early warning message

The warning message shall contain the following general information:

- Onset time and peak flux of major (M, X) X-ray flares or "equivalent" EUV emission if possible
- Flux of solar energetic protons if possible
- Information on onset time, source region location, speed and direction of propagation of the coronal mass ejection (or solar wind stream), angular width and simulated magnetic field configuration, estimated arrival time and shock strength. If

possible information shall be supplied on error ranges for the estimated 1 AU geo-space arrival times and impact parameters (v, B, -Bz)

- Scaling of the event shall follow the NOAA-SWPC classification as geomagnetic storms (G1-G5), solar radiation storms (S1-S5), radio blackouts [REF5]
- Information on the reliability of the warning
- Time stamp and version number of message

Technical requirements for the warning service shall be:

- Capability to distribute the warnings through different media (Internet, public weather services, mobile phone services, RSS feeds, etc.)
- Subscribe/unsubscribe services
- Contact address to enable feedback

4 Concept of early warning provision to GNSS users

4.1 Data base

The early warning message for GNSS users takes benefit of the relevant space weather data sets summarized in WP2 of the AFFECTS project and the space weather products and services that will be specifically developed in the course of the project. Key elements of the warning system are the existing data bases and services provided by the SIDC (the Solar Physics department of the Royal Observatory of Belgium, ROB), by DLR's SWACI system and by NOAA-SWPC.

The most important ionospheric parameter for GNSS users is the integral of the vertical electron density distribution, the Total Electron Content (TEC) because TEC is proportional to the first-order range error in positioning and navigation.

The prime space weather drivers caused by solar activity are short-term bursts of electromagnetic radiation (flares), bursts of energetic charged particles, especially energetic protons and co-rotating and transient solar wind streams, especially coronal mass ejections (CMEs). Radiation enhancements can produce sudden ionospheric disturbances in TEC, whereas solar wind driven perturbations often cause a mid- to large scale horizontal ionisation structure.

Unique measurements of these space weather phenomena are provided through direct participation in state-of-the-art projects (see Figure 3.2 of DoW):

- SOHO and STEREO provide simultaneous multipoint space observations of CMEs and on coronal structure and dynamics
- Proba2 provides measurements of solar irradiance with unique spectral resolution and coronal observations
- SDO provides unprecedented high resolution solar observations
- SolACES on the ISS provides unique UV measurements
- GOES provides X-ray and solar energetic particle (SEP) data
- ACE provides solar wind and energetic particle data from L1 measurements

Dedicated geomagnetic and ionospheric data and forecasts provided by the Geophysical Institute of the University of Tromsø and Space Research Institute Ukraine complement the satellite data.

4.2 Data analysis, modelling and forecast

The solar data have to be evaluated and analysed in near real time to extract the following crucial information about the space weather event to be alerted.

Flares:

The flare as measured by the GOES and Proba2 instruments will be provided and translated into a corresponding TEC enhancement. The estimated probability of flare occurrences for the next days is inferred from the SIDC ursigram [REF3]. Flare location is derived from Proba2, SDO, SOHO and STEREO observations.

SIDC will provide a spectrum in the L-band as part of the extension of its radio observatory in Humain (expected by 2013). At the time when it is available the strength of radio emission in the L-band will be provided to the GNSS customer for interference risk estimations.

CMEs:

The CME parameters such as direction, speed and time of arrival derived from analysis of SOHO and STEREO data will be translated into worst case estimates for the 1 AU geospace impact parameters with respect to the occurrence of spatial gradients and the rate of change in TEC. Modelling of expected solar wind conditions is under development through collaborative work on improvement and calibration of the ENLIL code with its developer at NOAA-SWPC and at NASA/GSFC. It shall be noted, that due to the complex coupling processes of the magnetosphere - thermosphere - ionosphere system TEC variations are strongly dependent on local time and location to be taken into account in the warning message. For flares and CMEs the degree of ionospheric perturbation is estimated for two latitude ranges above Europe, the mid-latitude band 30 to 60°N and the high latitude band 60 to 90°N. The transformation algorithms will be developed in WP 5 within AFFECTS.

4.3 Definition of Warning Levels

As stated already earlier, as baseline for defining warning levels the NOAA space weather scales [REF5] are used. Additions might be applied if necessary.

4.4 Risk classification

Due to broad variations of specific GNSS applications along with different requirements on sensitivity, a risk estimation and classification is only possible at user level and cannot be provided by the warning message. Therefore, no plan for classifying risk categories in AFFECTS is provided.

4.5 Distribution of early warning message

An early warning message for GNSS users will be generated by DLR based on information derived from analysis of solar observations provided by UGOE, ROB and NOAA-SWPC, including the NOAA-SWPC, SIDC PRESTO and UGOE AFFECTS space weather warnings (http://www.affects-fp7.eu/weather/). DLR will incorporate ursigram information along with CME and geomagnetic predictions.

The warnings for GNSS users will be made public via the SWACI AFFECTS and SIDC websites (Figure 1). Active distribution processes via e-mail, SMS and mobile phone applications will be established in the course of the project in dialogue with the potential users.

The service of the early warning message is supposed to be free within the frame of this project. Each interested person/ company/ institute will get the opportunity to request this service by signing in on the SWACI AFFECTS website. Each registered user shall be able to unsubscribe from the user list at any time. This option can be implemented via a hyperlink attached to each message or due to a service provided on the SWACI AFFECTS website.

To attract the attention of potential user, the service shall be advertised on topic related platforms e.g. boards of SWWT, COST, SBAS, ICTSW and others. A restricted user community testing the early warning message service is supposed to be established during the commissioning phase of WPs 5 and 6.

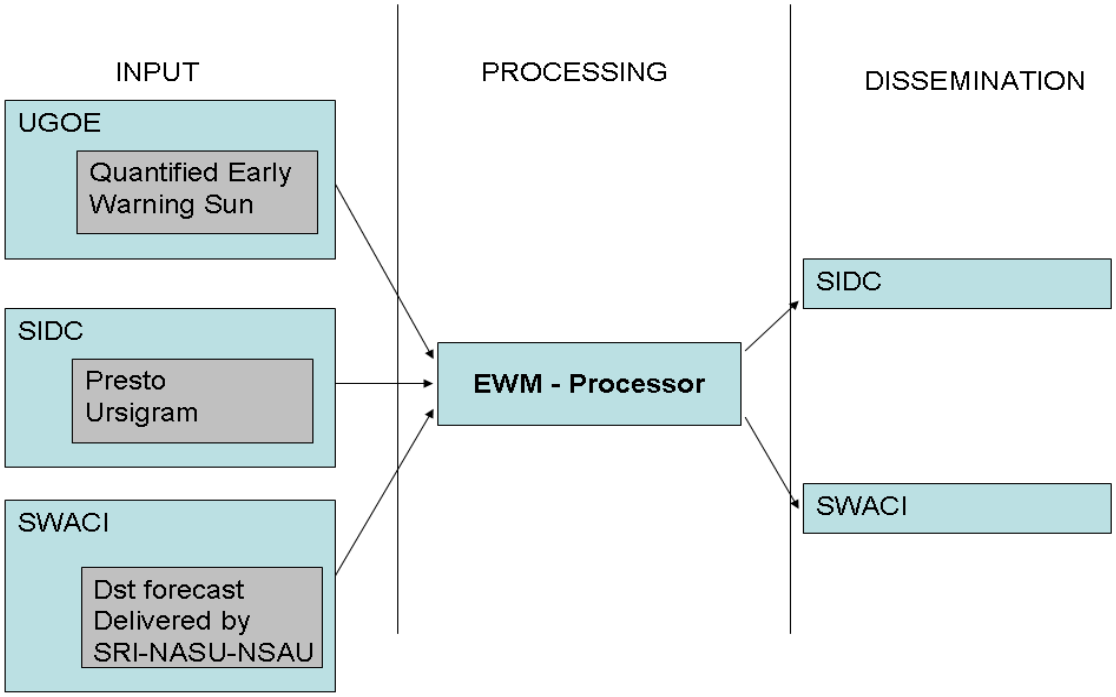

Figure 1 Workflow of the Early Warning Message (EWM) processor and subsequent dissemination.

4.6 Commissioning phase

Before officially releasing the early warning message service, there will be a commissioning phase first. During the commissioning phase the early warning messages will only be distributed internally and to a small group of pilot users. The commissioning phase will start after the dissemination of the final early warning system (AFFECTS deliverable 3.3) and will cover about six month.

5 Draft Message layout

Early warning messages based on solar observations are already distributed by ROB as PRESTO alerts via the SIDC and taken here as a baseline sample that will be modified according to the AFFECTS specifications.

```
:Issued: 2011 Dec 09 1606 UTC
:Product: documentation at http://www.sidc.be/products/presto
#-----------------------------------------------------------------#
# FAST WARNING 'PRESTO' MESSAGE from the SIDC (RWC-Belgium)        #
#-----------------------------------------------------------------#
Solar activity was low and is expected to remain low over the next 24
hours. Thereafter, on day +2 and +3, the activity may increase due to
the arrival at the East limb of new active regions that spawned several
recent active events behind the limb in SDO coronal images. The Earth
magnetic field is still very quiet. A sector boundary crossing is
expected over the next 24 to 48 hours, followed by a faster solar wind.
The geomagnetic field may thus become unsettled on days 2 and 3 of the
forecast period (Dec. 10 &11).


#-----------------------------------------------------------------#
# Solar Influences Data analysis Center - RWC Belgium             #
# Royal Observatory of Belgium                                    #
# Fax : 32 (0) 2 373 0 224                                        #
# Tel.: 32 (0) 2 373 0 491                                        #
#                                                                 #
# For more information, see http://www.sidc.be.  Please do not reply #
# directly to this message, but send comments and suggestions to  #
# 'sidctech@oma.be'. If you are unable to use that address, use   #
# 'rvdlinden@spd.aas.org' instead.                                #
# To unsubscribe, visit http://sidc.be/registration/unsub.php     #
#-----------------------------------------------------------------#
```

The layout of the Early Warning Message for GNSS users according to the baseline alert could be as follows:

```
:Issued: 2012 12 09 06:30 UTC
:Product: documentation at http://www.swaciweb.dlr.de/products/EWAG
#-----------------------------------------------------------------#
# EARLY WARNING MESSAGE for GNSS users from DLR                   #
#                                                                  #
# Solar data are provided by PRESTO warning from SIDC (RWC-Belgium)  #
#-----------------------------------------------------------------#
Message is valid for European longitude sector (-10 to 40°E) and
latitude sectors specified as HLAT: 60 to 90°N and MLAT: 30 to 60 °N

#--- Solar Flare Event ------------------------------------------#

Solar flare of class X may cause TEC jumps/TEC rate of change
of up to 20/10 and 5/3 TECU/TECU/min at MLAT and HLAT, respectively
Time interval estimation: 09 12 2012, 10 to 16 UT
Duration: 15 min
Probability of Occurrence: 50%

Flare may be accompanied by radio emission in the L-band reaching a
power of up to 10000 sfu

#--- CME Event --------------------------------------------------#

A severe CME is approaching with a speed of 1000 km/s, expected to
reach the Earth on 10 12 2012, at around 23:00 UT
GNSS users might expect spatial TEC gradients of up to 50 mm/km
at HLAT and up to 20 mm/km at MLAT.
Time rate of change may reach values of up to 6 TECU/min at MLAT
```

```
and 9 TECU/min at HLAT.
Enhanced scintillation activity expected at HLAT up to S4=0.8

Time interval estimation: 10 12 2012, 15 UT until 11 12 2012, 10 UT
Probability of Occurrence: 50%

#--- Geomagnetic field activity ------------------------------------#

The Earth magnetic field is still quiet. A sector boundary
crossing is expected over the next 12 to 48 hours
Geomagnetic Ap values may reach values of up to 150 on days 2 and 3
of the forecast period (Dec. 10 &11) indicating a severe storm.
Dst value is estimated to reach -200 nT within the next 12 hours.
Storm onset
Time interval estimation: 10 12 2012, 10...16 UT
Probability of occurrence: 60%
According to NOAA space weather scales a G4 storm is expected.

#--------------------------------------------------------------------#
# German Aerospace Center (DLR), Institute for Communications and    #
# Navigation                                                         #
# Fax : 49 (0) 3981 480 ???                                          #
# Tel.: 32 (0) 3981 480 ???                                          #
# Email: ???@dlr.de                                                  #
#                                                                    #
# For more information, see http://www...                            #
# For more information on PRESTO see http://www.sidc.be.             #
# Please do not reply                                                #
# directly to this message, but send comments and suggestions to     #
# ???@dlr.de.                                                        #
#                                                                    #
# To unsubscribe, please visit http://www....                        #
#--------------------------------------------------------------------#
```

It shall be noted that the full information as described above is not yet guaranteed for each event since the estimated numbers of ionospheric perturbation parameters remain uncertain. Short traffic light information has eventually more practical value for GNSS users in the field. This has still to be discussed in close dialogue with GNSS users.

6 Perspectives and Recommendations

Update of the Early Warning Messages is aimed to be in close collaboration with UGOE, SIDC NOAA-SWPC and the AFFECTS consortium as a whole to provide users with state of the art information.

7 Summary and Conclusions

Provision of specific ionospheric information on expected disturbance levels caused by space weather events is the main goal of the Early Warning Message to GNSS users. To provide state-of – the-art warnings, comprehensive research activities will be undertaken within the AFFECTS project (e.g., CME detection and analysis, ENLIL stream code, TEC analysis, CTIPe) to help translate the predicted space weather impacts on geospace into temporal and spatial estimations of ionospheric perturbation levels. Considering the complexity of this task, we are aware of the fact that such research will continue beyond the AFFECTS project.

8 References

[REF1] Halo CME detection alert: http://www.sidc.be/products/cactus/

[REF2] PRESTO: http://www.sidc.be/products/presto/

[REF3] SIDC ursigram: http://www.sidc.be/products/meu/)

[REF4] SWACI home: http://swaciweb.dlr.de

[REF5] NOAA Space Weather Scales: http://www.swpc.noaa.gov/NOAAscales/

[REF6] AFFECTS Grant Agreement, Annex I, DoW Part A

9 Appendix

List of Acronyms

ACE	**A**dvanced **C**omposition **E**xplorer
AFFECTS	**A**dvance **F**orecast **F**or **E**nsuring **C**ommunications **T**hrough **S**pace
CME	**C**oronal **M**ass **E**jection
COST	**C**ooperation **o**n **S**cience and **T**echnology
DLR	**D**eutsches Zentrum für **L**uft- und **R**aumfahrt
DoW	**D**escription **o**f **W**ork
EGNOS	**E**uropean **G**eostationary **N**avigation **O**verlay **S**ervice
EWM	**E**arly **W**arning **M**essage
GBAS	**G**round **B**ased **A**ugmentation **S**ystem
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
HF	**H**igh **F**requency radio waves (3-30 MHz)
ICTSW	**I**nter-programme **C**oordination **T**eam on **S**pace **W**eather
IMF	**I**nterplanetary **M**agnetic **F**ield
NOAA	**N**ational **O**ceanic and **A**tmospheric **A**dministration
NRT	**N**ear **R**eal **T**ime
ROB	**R**oyal **O**bservatory of **B**elgium
RWC	**R**egional **W**arning **C**enter
SBAS	**S**pace **B**ased **A**ugmentation **S**ystem
SIDC	**S**olar **I**nfluences **D**ata analysis **C**enter
SoL	**S**afety **o**f **L**ife
SWACI	**S**pace **W**eather **A**pplication **C**enter – **I**onosphere
SWPC	**S**pace **W**eather **P**rediction **C**enter Boulder
SWWT	**S**pace **W**eather **W**orking **T**eam

TEC	**T**otal **E**lectron **C**ontent
UGOE	Georg-August-**U**niversity **Goe**ttingen
UoT	**U**niversity **o**f **T**romsø
UT	**U**niversal **T**ime
WAAS	**W**ide **A**rea **A**ugmentation **S**ystem
WP	**W**ork **P**ackage