PROGRESS Meeting 2018-08-02 – 03

# WP 3
# Forecast of the evolution of geomagnetic indices

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- ## Task 3.1 – Survey of existing operational models forecasting Kp, Dst, and AE
  Month 1-3 (IRF,USFD,SRI NASU-NSAU)
  Identify existing operational Kp, Dst, and AE forecast models. Analyse their respective requirements and benefits considering, e.g. inputs, latency, lead time, and resources. Detailed knowledge is available for the models available to the team.
- ## Task 3.2 - Identify and collect relevant data
  Month 4-6 (IRF)
  Collect historic real time ACE data, Science Level 2 ACE data, Kp, Dst, and AE. An SQL database shall be set up where the data are collected. Analyse data sets with respect to quality and coverage. Also include the coming DSCOVR spacecraft in the study.
- ## Task 3.3 - Evaluate and verify a set of selected existing models
  Month 7-9 (IRF, USFD, SRI NASU-NSAU)
  The models from Task 3.1 that are available to the team shall be verified using the datasets identified in Task 3.2. In this activity it is important to consider both science level data and real time data. This task also includes the identification and application of appropriate verification methodologies. As inputs methodologies from the meteorological domain [Jollife and Stephenson, 2012] and previous COST ES0803 Action [Wintoft et al., 2012] shall be used.
- ## Task 3.4 - Develop further existing Kp and Dst models
  Month 10-24 (IRF, USFD, SRI NASU-NSAU)
  The verification carried out in Task 3.3 will provide insights on how to improve existing Kp and Dst models. Classifications and categorisation methods will also be developed and applied with the purpose of improving existing models. The formulated verification strategy (Task 3.3) shall also be applied to the models.
- ## Task 3.5 - Develop new AE forecast models
  Month 16-30 (IRF, USFD, SRI NASU-NSAU)
  As a first step to provide a baseline the model in Gleisner and Lundstedt [2001] shall be implemented and verified (Task 3.3). The classifications and categorisation methods (Task 3.4) shall also be applied to provide insight to appropriate parametrisation of the high resolution (minute) solar wind and AE data. E.g., the approach in Gleisner and Lundstedt [2001] was to use 10 minute averages, however, averages are not always the most suitable way of reducing the complexity as important features may be missed. Again, the formulated verification strategy (Task 3.3) shall also be applied to the models.
- ## Task 3.6 - Implement models for real-time operation
  Month 28-36 (IRF, USFD, SRI NASU-NSAU)
  The improved and developed models shall be implemented for real time operation. The contributing institutes have long experience in this field. The data needed to drive the models shall be downloaded and stored in the database in real time. Various checks considering data quality and timeliness shall be implemented and mitigated. The output from the models shall be stored in the database and also provided over ftp/http. Simple web site with the forecasts shall be implemented tailored for this project.

# D3.7



## PRediction Of Geospace Radiation Environment and Solar wind parameterS

### Work Package 3
### Forecast of the evolution of geomagnetic indices

### Deliverable 3.7
### GMN and bi-linear *Dst* and *Kp* models: Development, testing and comparison of model outputs

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**R. Boynton, H.-L. Wei, S. Walker,**
**M. Balikhin, R. Erdelyi**
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**J. Krivickaya, S. Ivanov, I. Mulko, A. Bespalova**
**SRI**

**July 12, 2018**

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# D3.7 summary


## Summary

This deliverable is an extension of the PROGRESS project according to Amendment 23. It encapsulates the work originally proposed by the participant SRI as part of Tasks T3.4, T3.5, and T3.6 of Work Package 3. During the main period (2015-01-01 to 2017-12-31) of the project, SRI began to develop their forecast models for the geomagnetic indices *Kp*, *Dst*, and *AE*. Unfortunately, these models were never delivered. During the Project extension phase (2018-01-01 to 2018-07-31) the PROGRESS participants were given extra time to complete the development of these models and deliver the resulting products.

SRI originally promised to develop models for geomagnetic indices based on the following methodologies:

- a recursive, robust bilinear dynamical model
- a Guaranteed NARMAX Model

The Commission proposed that the Project reallocate some of the tasks allotted to SRI to other participants with the knowledge and skills to complete them. Following discussions with SRI and IRF it was agreed that

- SRI will continue to develop their models for *Kp*, *Dst*, and *AE* based on their Guaranteed NARMAX Model,
- USFD will develop models of the *Kp* and *Dst* indices based on the recursive, robust bilinear dynamical methodology.
- USFD will study the Lyapunov Exponents of the *Dst* data set in order to determine the forecast horizon
- IRF will investigate the performance of the models, perform an inter-comparison

These subtasks were incorporated into a new task, T3.7, within WP 3.

This document is a new deliverable, D3.7, which reports on the modelling methodologies employed, the resulting forecasts, and compares the solar wind driven prediction models of the *Kp*, *Dst*, and *AE* indices developed by IRF, USFD, and SRI.

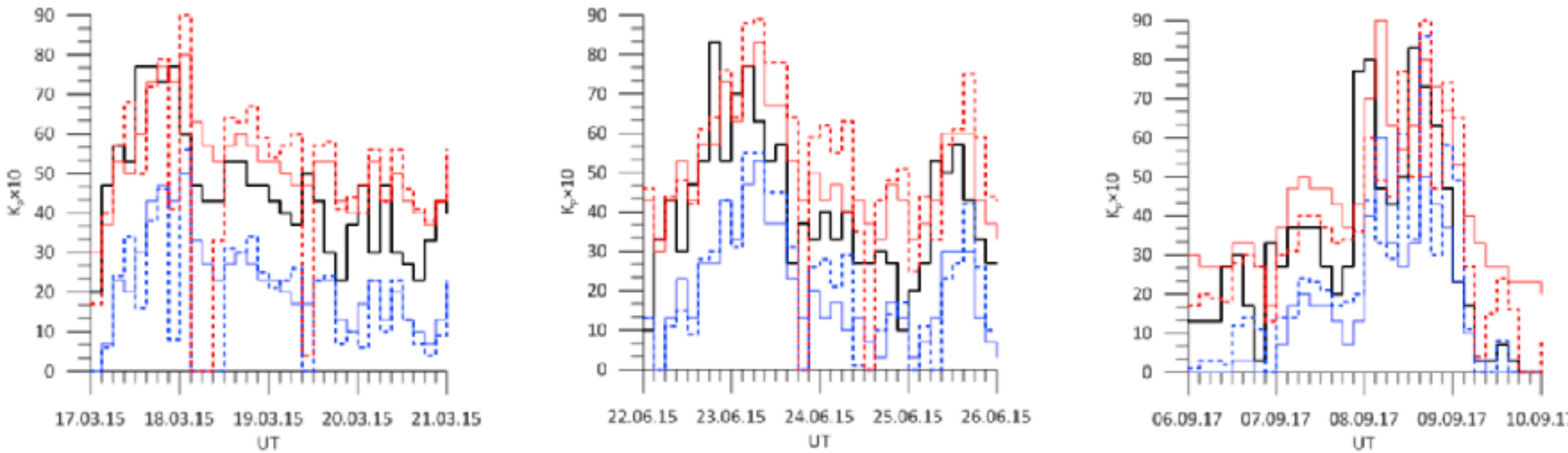

## Contents

# D3.7 models

| | Model | Horizon | Source | Data period |
|---|---|---|---|---|
| NN-X | IRF-Kp-2017 | 3h | ACE L2 | 1998 – 2015 except 2001 and 2011 |
| NARMAX | USFD-Kp | 3h | OMNI | 1998 – 2017 |
| G-NARMAX | SRI-Kp-GP | 3h | OMNI | 2006 |
| G-NARMAX | SRI-Kp-RM | 3h | OMNI | 1976 – 2008 |
| NN-X | IRF-Dst-2017 | 1h | OMNI | 1963 – 2015 except 1981, 1996, 2001, and 2008 |
| NARMAX | USFD-Dst | 1h | OMNI | 2001 – 2002 |
| NARMAX | USFD-Dst | 3h | OMNI | 2001 – 2002 |
| G-NARMAX | SRI-Dst-GP | 1h | OMNI | 2006 |
| G-NARMAX | SRI-Dst-RM | 1h | OMNI | 1976 – 2008 |
| G-NARMAX | SRI-Dst-RM | 3h | OMNI | 1976 – 2008 |
| NN-X | IRF-AE-2017 | | ACE L2 | 1998 – 2015 except 2001, 2005, and 2013 |
| G-NARMAX | SRI-AE | | OMNI | 2013-03-12 – 2013-06-03 |

# D3.7 sample result

## Guaranteed NARMAX (SRI-Kp-RM and SRI-Kp-GP)




(a) March 17-18, 2015 (b) June 22-23, 2015 (c) September 7-8, 2017

Figure 1: Retrospective GNM forecasts for the variation in the *Kp* index. Thin solid blue and red lines are low and high edges of the RM interval with 3h lead time, thick dotted red and blue lines are low and high edges of the GP interval with 3h lead time.

# D3.7 comparison

Table 5: Statistical measures for all data in 1998–2017 for the *Kp* prediction models. Tn indicates lead time with n in hours.

| | BIAS | RMSE | CORR | R2 |
|---|---|---|---|---|
| Pers | 0.00 | 0.85 | 0.81 | 0.62 |
| IRF-Kp-T0 | -0.04 | 0.53 | 0.92 | 0.85 |
| IRF-Kp-T1 | -0.03 | 0.53 | 0.92 | 0.85 |
| IRF-Kp-T2 | -0.02 | 0.61 | 0.90 | 0.80 |
| IRF-Kp-T3 | 0.01 | 0.72 | 0.85 | 0.73 |
| USFD-Kp-OSA-T1 | 0.10 | 0.71 | 0.86 | 0.73 |
| USFD-Kp-MPO-T1 | 0.20 | 0.78 | 0.84 | 0.68 |
| SRI-Kp-RM-T3 | -0.07 | 0.81 | 0.82 | 0.66 |
| SRI-Kp-GP-T3 | -0.04 | 1.17 | 0.62 | 0.29 |

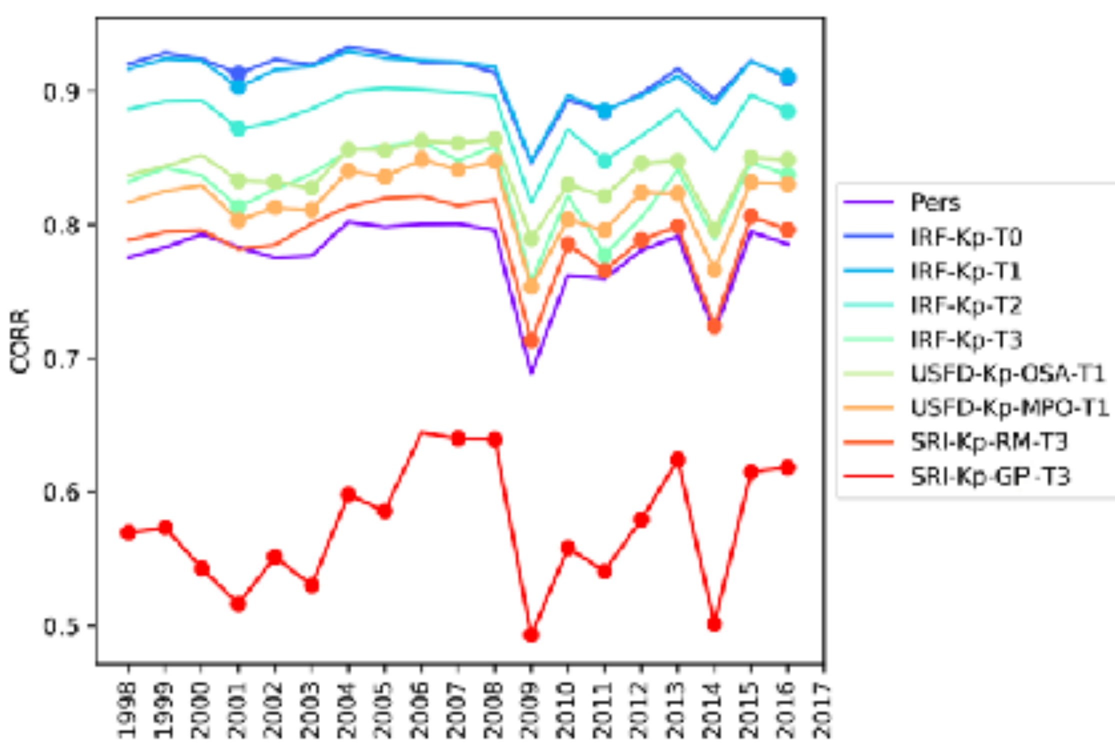



Figure 9: Linear correlation between predicted and observed *Kp* for the different models as function of year. Dots indicate that the year was not part of the training set.

Table 6: Statistical measures for all data in 1998–2017 for the *Dst* prediction models. Tn indicates lead time with n in hours. BIAS and RMSE are given in nT.

| | BIAS | RMSE | CORR | R2 |
|---|---|---|---|---|
| Pers | 0.01 | 4.40 | 0.98 | 0.95 |
| IRF-Dst-T0 | 0.69 | 8.70 | 0.91 | 0.82 |
| IRF-Dst-T1 | -0.15 | 8.80 | 0.90 | 0.82 |
| IRF-Dst-T2 | 0.07 | 9.31 | 0.89 | 0.80 |
| IRF-Dst-T3 | -1.19 | 10.04 | 0.88 | 0.76 |
| USFD-Dst-BL-T1 | 0.44 | 4.48 | 0.98 | 0.95 |
| USFD-Dst-BL-T3 | 0.13 | 8.10 | 0.92 | 0.85 |
| SRI-Dst-RM-T1 | -0.01 | 3.27 | 0.99 | 0.97 |
| SRI-Dst-RM-T3 | 0.07 | 7.24 | 0.94 | 0.88 |
| SRI-Dst-GP-T1 | -0.10 | 6.10 | 0.96 | 0.91 |

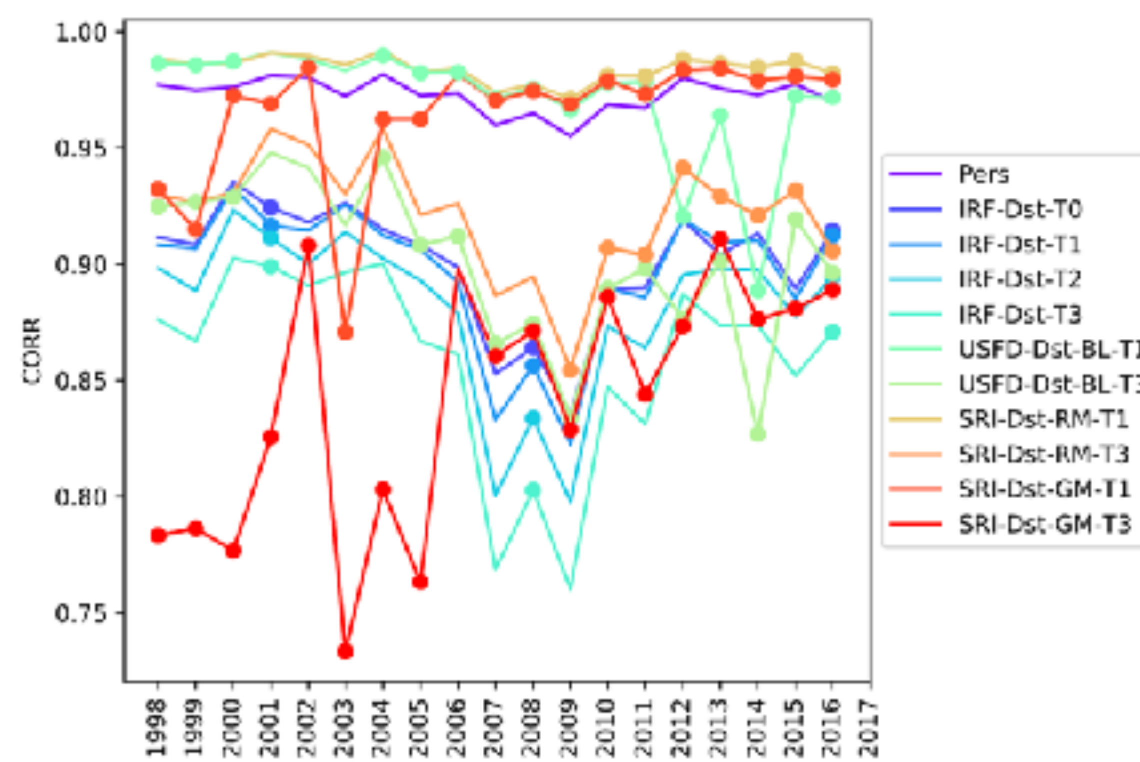
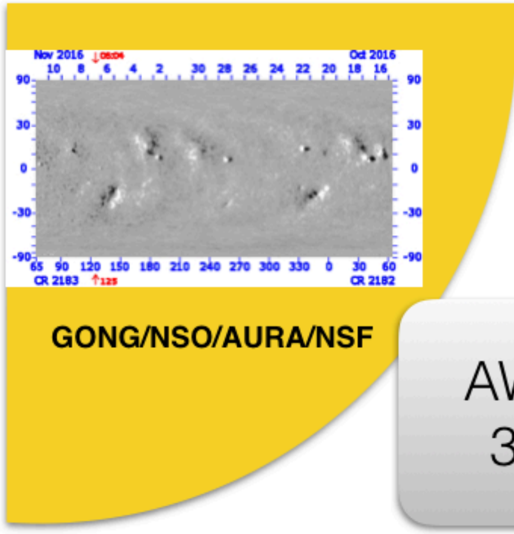



Figure 11: Linear correlation between predicted and observed *Dst* for the different models as function of year. Dots indicate that the year was not part of the training set.

# D3.7 conclusions

- Guaranteed NARMAX Models for *Dst*, *Kp* and *AE* indices were constructed using two different algorithms by SRI.
- All the developed forecasts with the exception of the GP-based Kp forecast, which has a too wide prediction interval, provide useful information and are ready for transition to near-real time operations.
- Bi-linear models for the *Kp* and *Dst* indices were constructed by USFD.
- The performance of each of the models generated within PROGRESS were assessed for common periods of data.
- For *Kp* predictions the IRF-Kp-T0 and T1 models performs best, using past *Kp* seems to have minor effect.
- For *Dst* predictions the SRI-Dst-RM-T1 model performs best, past *Dst* values have significant effect.
- Lead-times beyond 1 hour is generally not possible.
- For real-time implementation, if past indices are used as inputs it will reduce the lead time.

# The PROGRESS project





AWSoM
30 Rs

SWIFT
L1

Neural Network
NARMAX

Kp
Dst
AU, AL, AE

Statistical
wave
models

VERB
IMPTAM

**Predicting the radiation belts from observed solar magnetic data.**

- Ayala Solares, J. R., Wei, H.-L., Boynton, R. J., Walker, S. N. & Billings, S. A., ‘Modelling and prediction of global magnetic disturbance in near-earth space: A case study for Kp index using narx models’, *Space Weather, 2016*.
- Wintoft, P., M. Wik, J. Matzka and Y. Shprits, Forecasting Kp from solar wind data: input parameter study using 3-hour averages and 3-hour range values, J. Space Weather Space Clim. Volume 7, A29, 2017

European Union’s Horizon 2020 grant agreement No 637302 (PROGRESS)

# IRF REST server

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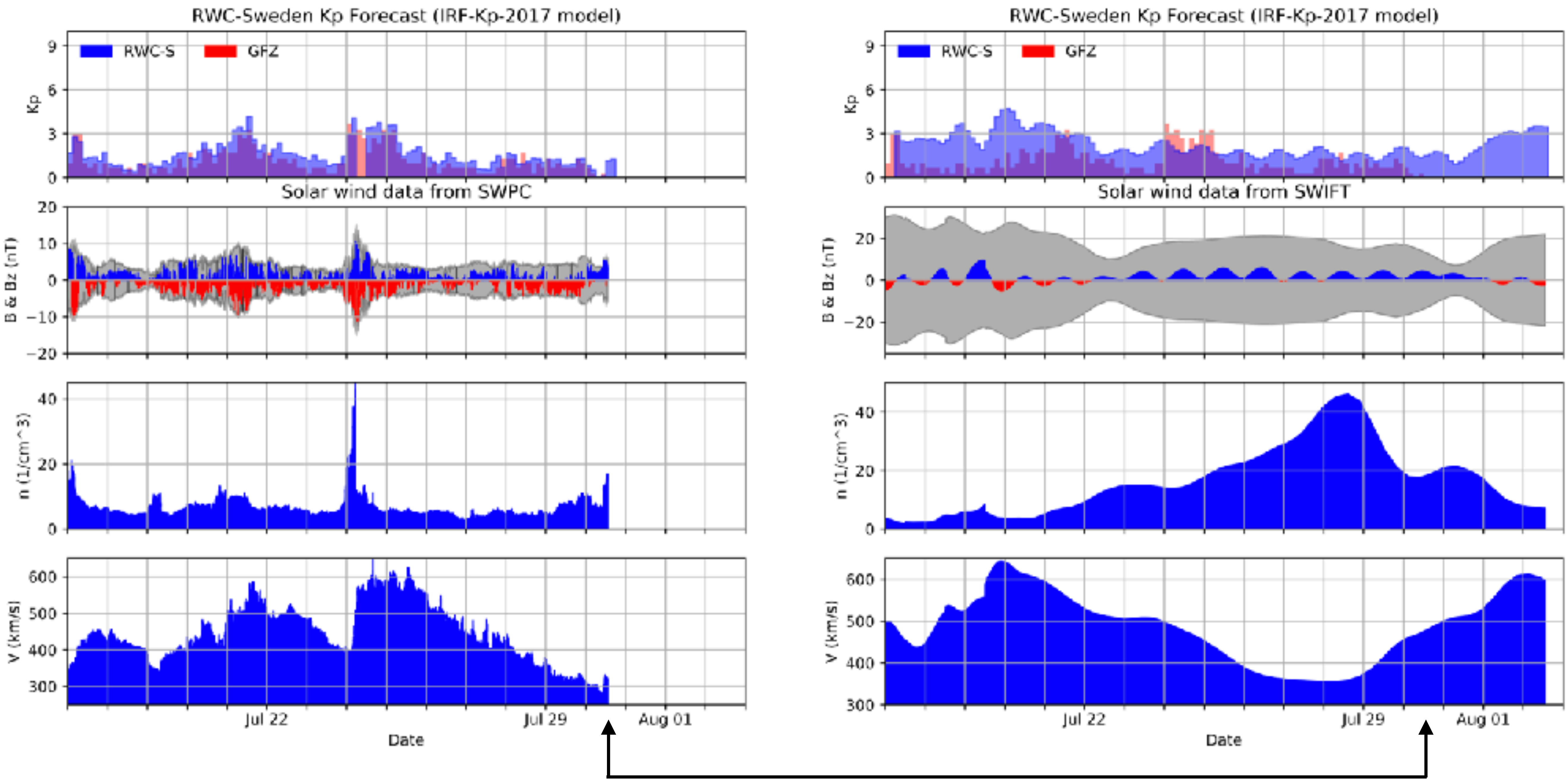
# SWIFT input (WP 7)




2018-07-30 13:00 UT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ISES currently includes 16 Regional Warning Centers, four Associate Warning Centers, and one Collaborative Expert Center. ISES is a Network Member of the International Council for Science World Data System (ICSU-WDS) and collaborates with the World Meteorological Organization (WMO) and other international organizations.

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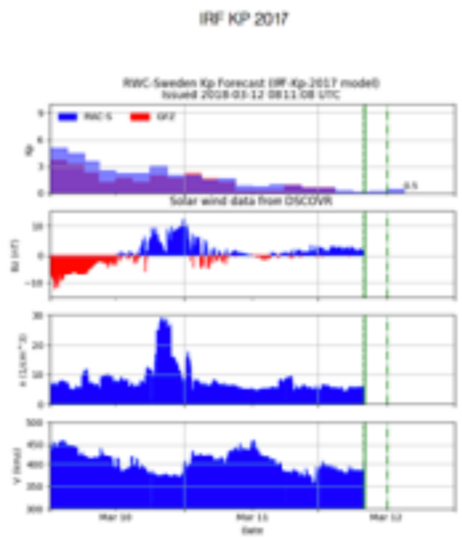
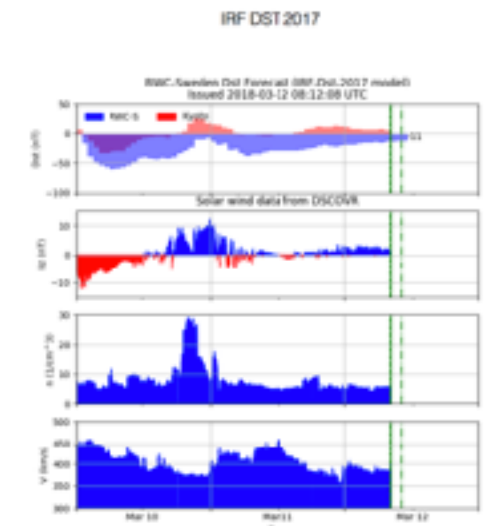
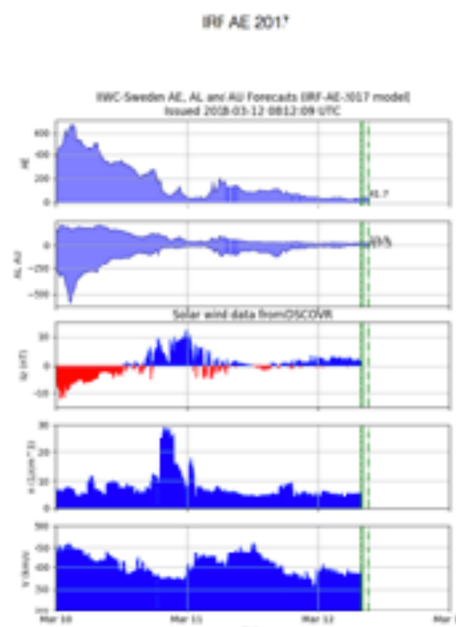
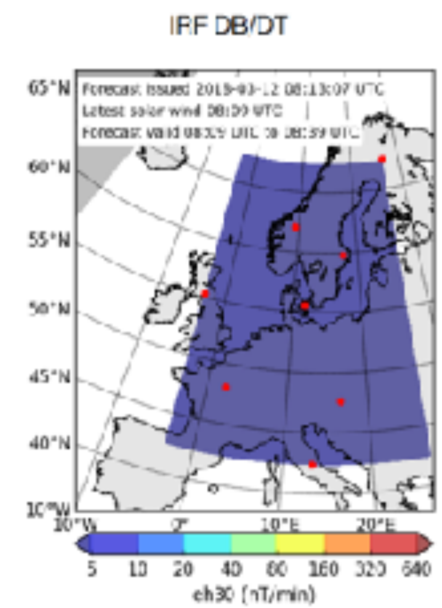
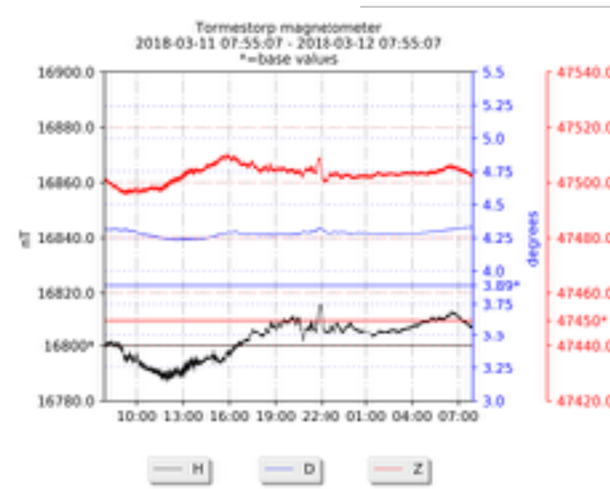


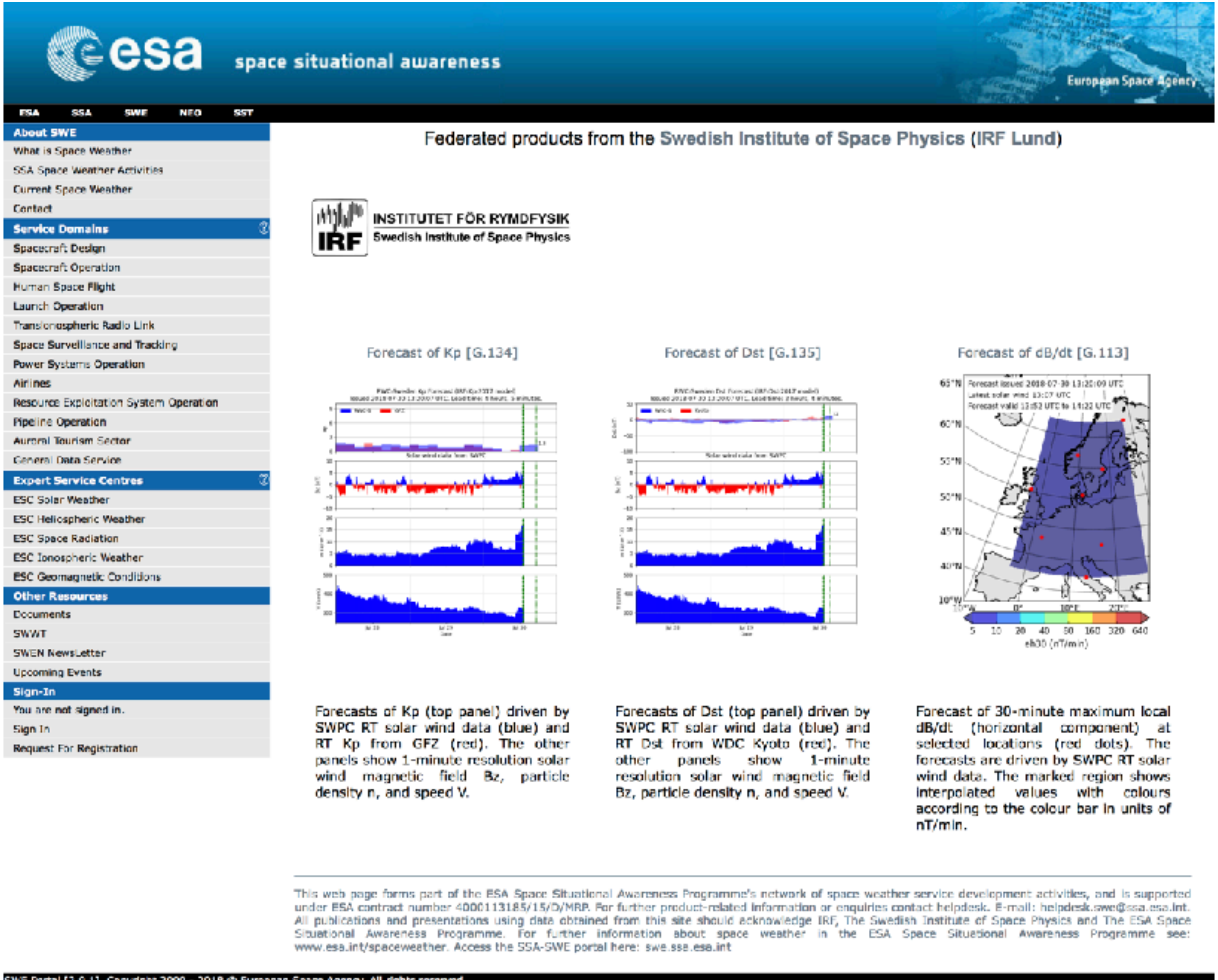



# ESA SSA http://swe.ssa.esa.int



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| Forecast of Kp [G.134] | Forecast of Dst [G.135] | Forecast of dB/dt [G.113] |
|---|---|---|
| Forecasts of Kp (top panel) driven by SWPC RT solar wind data (blue) and RT Kp from GFZ (red). The other panels show 1-minute resolution solar wind magnetic field Bz, particle density n, and speed V. | Forecasts of Dst (top panel) driven by SWPC RT solar wind data (blue) and RT Dst from WDC Kyoto (red). The other panels show 1-minute resolution solar wind magnetic field Bz, particle density n, and speed V. | Forecast of 30-minute maximum local dB/dt (horizontal component) at selected locations (red dots). The forecasts are driven by SWPC RT solar wind data. The marked region shows interpolated values with colours according to the colour bar in units of nT/min. |

This web page forms part of the ESA Space Situational Awareness Programme's network of space weather service development activities, and is supported under ESA contract number 4000113185/15/D/MRP. For further product-related information or enquiries contact helpdesk. E-mail: helpdesk.swe@ssa.esa.int. All publications and presentations using data obtained from this site should acknowledge IRF, The Swedish Institute of Space Physics and The ESA Space Situational Awareness Programme. For further information about space weather in the ESA Space Situational Awareness Programme see: www.esa.int/spaceweather. Access the SSA-SWE portal here: swe.ssa.esa.int

# Dissemination

- Presentations at ESWW 2016 and 2017.
- Posters at ESWW 2016 and 2017, Space Weather workshop in Leiden 2017, SRS meeting in Kiruna 2018.
- Published paper “Forecasting Kp from solar wind data: input parameter study using 3-hour averages and 3-hour range values”, Peter Wintoft, Magnus Wik, Jurgen Matzka och Yuri Shprits, J. Space Weather Space Clim. https://www.swsc-journal.org/articles/swsc/abs/2017/01/swsc160051/swsc160051.html.
- Submitted paper “Evaluation of Kp and Dst predictions using ACE and DSCOVR solar wind data”, Peter Wintoft and Magnus Wik, Space Weather Journal, June 2018.
- Draft manuscript “Forecasting the AE indices using model and parameter studies with neural networks”, Magnus Wik and Peter Wintoft, J. Space Weather Space Clim.

- Submitted to SWJ. Higher cost for open access. Covered by PROGRESS? Will occur after project ends.