

# Space weather services for enhanced aviation

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# The Customer: ICAO

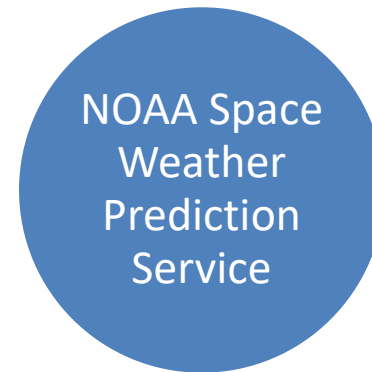
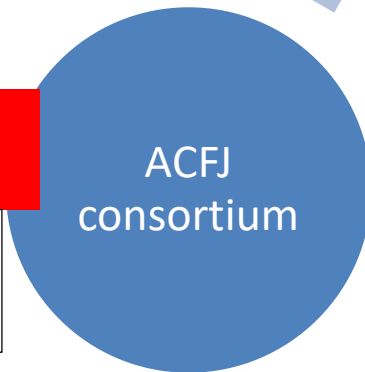
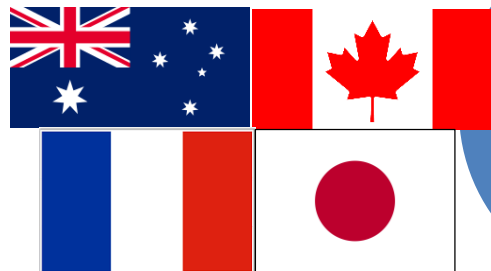
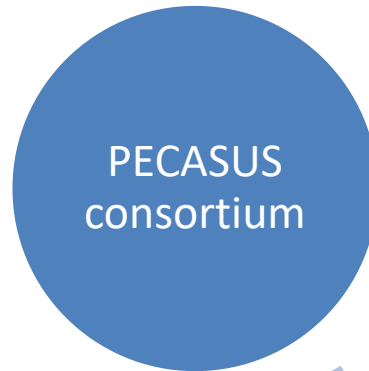


- International Civil Aviation Organization,
- Works under UN and was established in 1944
- Develops principles and techniques for enhanced safety in civil aviation
- Close collaboration with WMO
- Wishes to integrate Space Weather (SWx) services to its regulations



Figure: Wikipedia

## The three global space weather centers



- Two week shifts in the responsibility of advisory validation and dissemination
- All centers will monitor space weather continuously.

## SWx information will be given as strictly formulated advisories

Forecasts up to 24 HR; "Not available" is also OK

Location information in geographic coordinates

|                       |  |
|-----------------------|--|
| SWX ADVISORY          |  |
| DTG:                  | 20161108/0100Z   |
| SWXC:                 | DONLON*  |
| ADVISORY NR:          | 2016/2   |
| NR RPLC:              | 2016/1   |
| SWX EFFECT:           | HF COM MOD AND GNSS MOD  |
| OBS SWX:              | 08/0100Z HNH HSH E18000 – W18000   |
| FCST SWX +6 HR:       | 08/0700Z HNH HSH E18000 – W18000   |
| FCST SWX +12 HR:      | 08/1300Z HNH HSH E18000 – W18000   |
| FCST SWX +18 HR:      | 08/1900Z HNH HSH E18000 – W18000   |
| FCST SWX +24 HR:      | 09/0100Z NO SWX EXP  |
| RMK:                  | LOW LVL GEOMAGNETIC STORMING CAUSING INCREASED AURORAL ACT AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVBL IN THE AURORAL ZONE. THIS STORMING EXP TO SUBSIDE IN THE FCST PERIOD. SEE <a href="http://WWW.SPACEWEATHERPROVIDER.WE">WWW.SPACEWEATHERPROVIDER.WE</a> |
| NXT ADVISORY:         | NO FURTHER ADVISORIES  |
| * Fictitious location |  |

Updates can be provided

Additional info can be provided with a web-site

## Space weather impact areas of interest for civil aviation

- **Radiation at flight altitudes**
  - Flights across polar areas
  - Air crew: Accumulated doses
- **Problems in Global Navigation Satellite Systems (GNSS) SATCOM**
  - Errors in positioning
  - Scintillation in the signal amplitude and phase
- **Disturbances in HF communication**
  - Anomalous propagation paths
  - Variations in the usable frequencies
- **About SATCOM**
  - ICAO has not given yet the thresholds for advisories
  - Data and voice drop out at frequencies  $< 2$  GHz (L-band)
  - No big problems in S, C, Ku and Ka
  - SWX something to keep in mind when planning future automated ATM systems

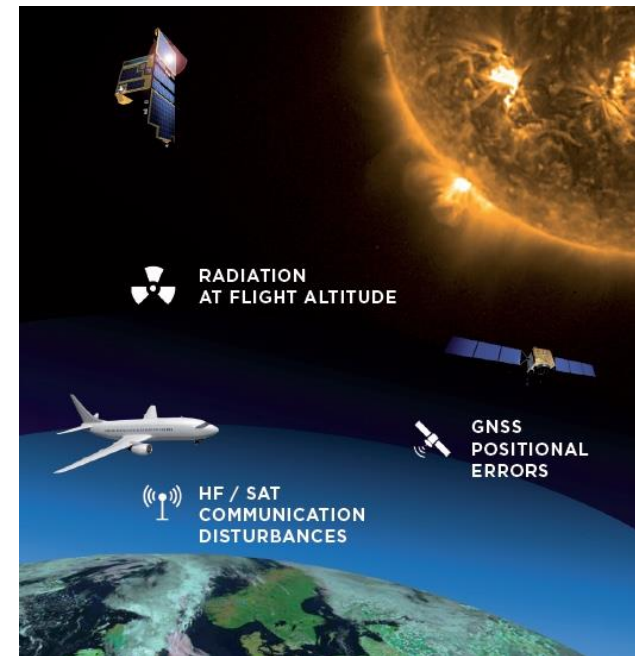
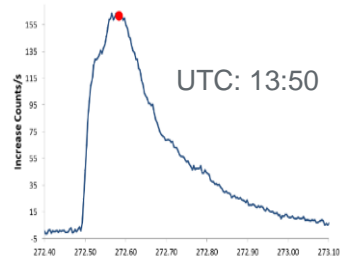
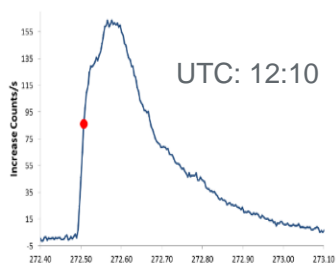


Figure: ESA/Proba-2, EUMETSAT, STCE

## AVIDOS Sample Maps for Historical GLE42, Sep. 28<sup>th</sup>, 1989

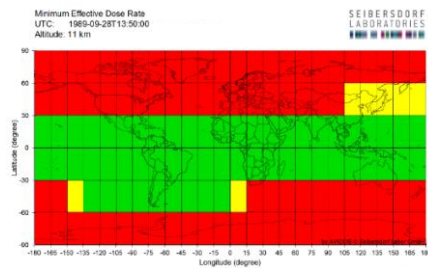
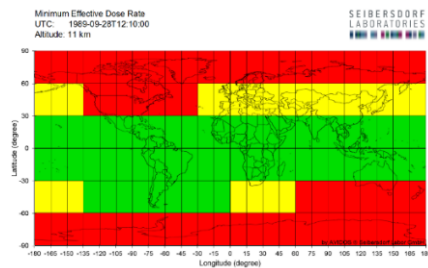
Minute INPUT-Data

Neutron Monitor (Oulu)



Global OUTPUT-Data - every 5 minutes

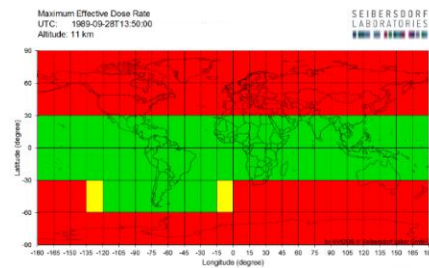
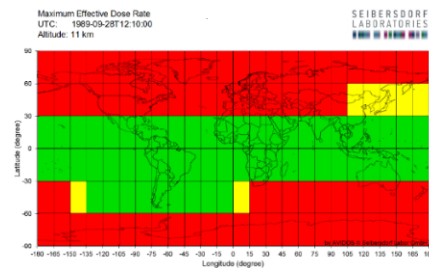
Minimum expected dose rate



Effective dose rate in µSv/h

AVIDoS  
AVIATION DOSIMETRY

Maximum expected dose rate



Effective dose rate in µSv/h

AVIDoS  
AVIATION DOSIMETRY

| RAD                                    | Moderate | Severe |
|--|----------|--------|
| Effective radiation dose (microS/hour) | 30       | 80     |

## HF service

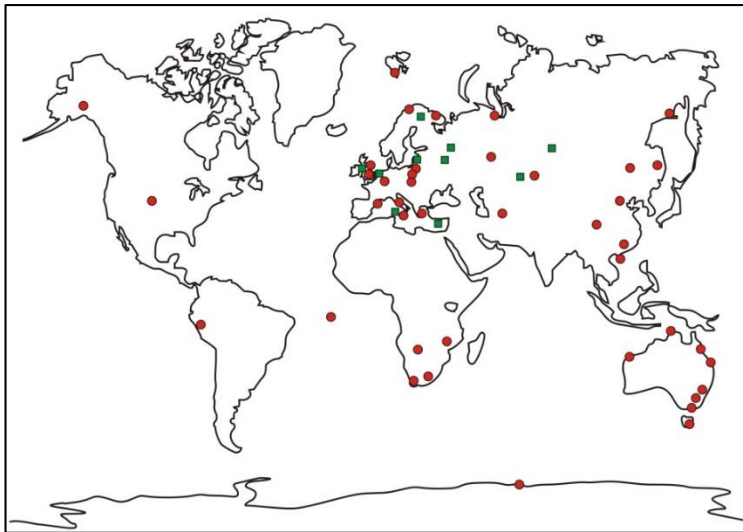
| HF  | Moderate                | Severe                   |
|---|-------------------------|--------------------------|
| Kp-index                                    | 8                       | 9                        |
| dB from 30 MHz riometer data                | 2                       | 5                        |
| X-ray flux (0.1-0.8 nm) (W/m <sup>2</sup> ) | 1x10 <sup>-4</sup> (X1) | 1x10 <sup>-3</sup> (X10) |
| MUF depression                              | 30%                     | 50%                      |

GFZ Potsdam & UKMO

Riometers in Finland and Sweden

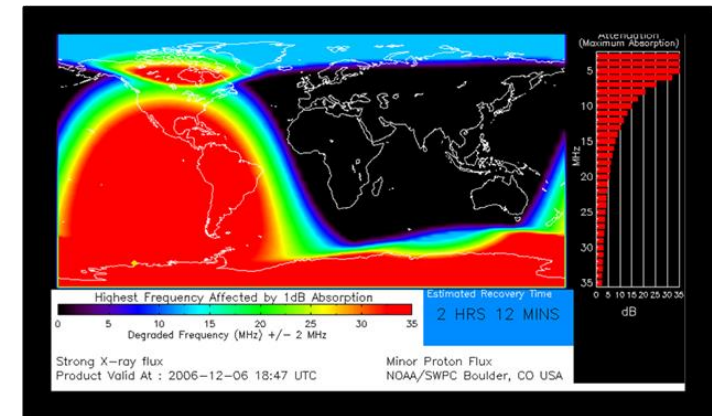
GOES from NOAA

## D-RAP model



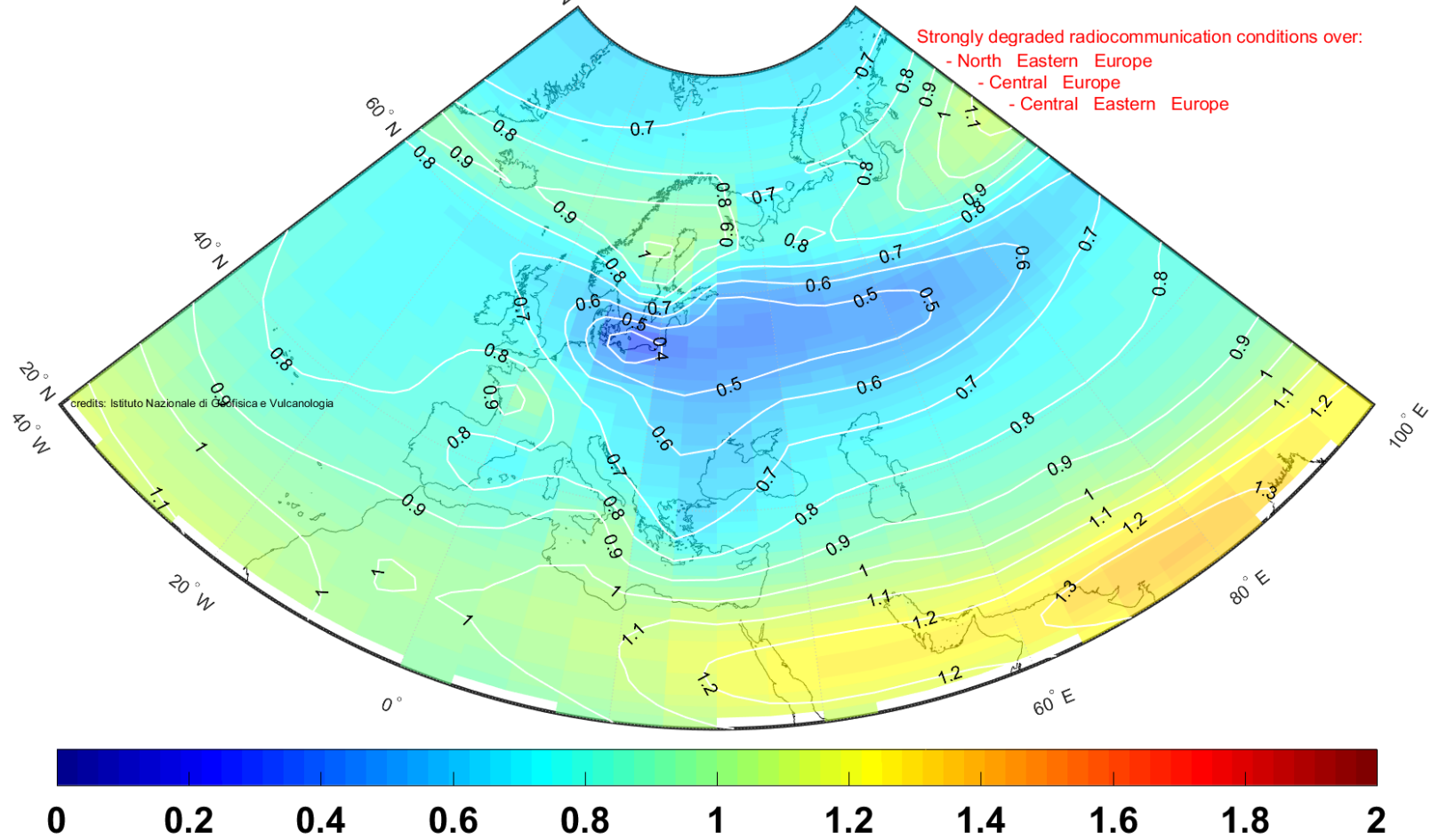
Network of ionosonde stations will be used to create the MUF depression maps

Reference level median of previous 30 days





**Maximum Usable Frequency (MUF) ratio forecasting**  
**08-09-2017 19:00 UT**



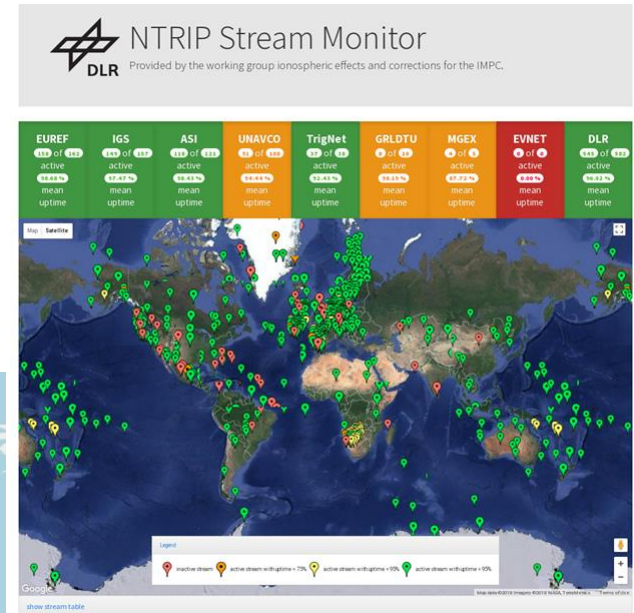
*Plot: INGV, Italy*



## GNSS service

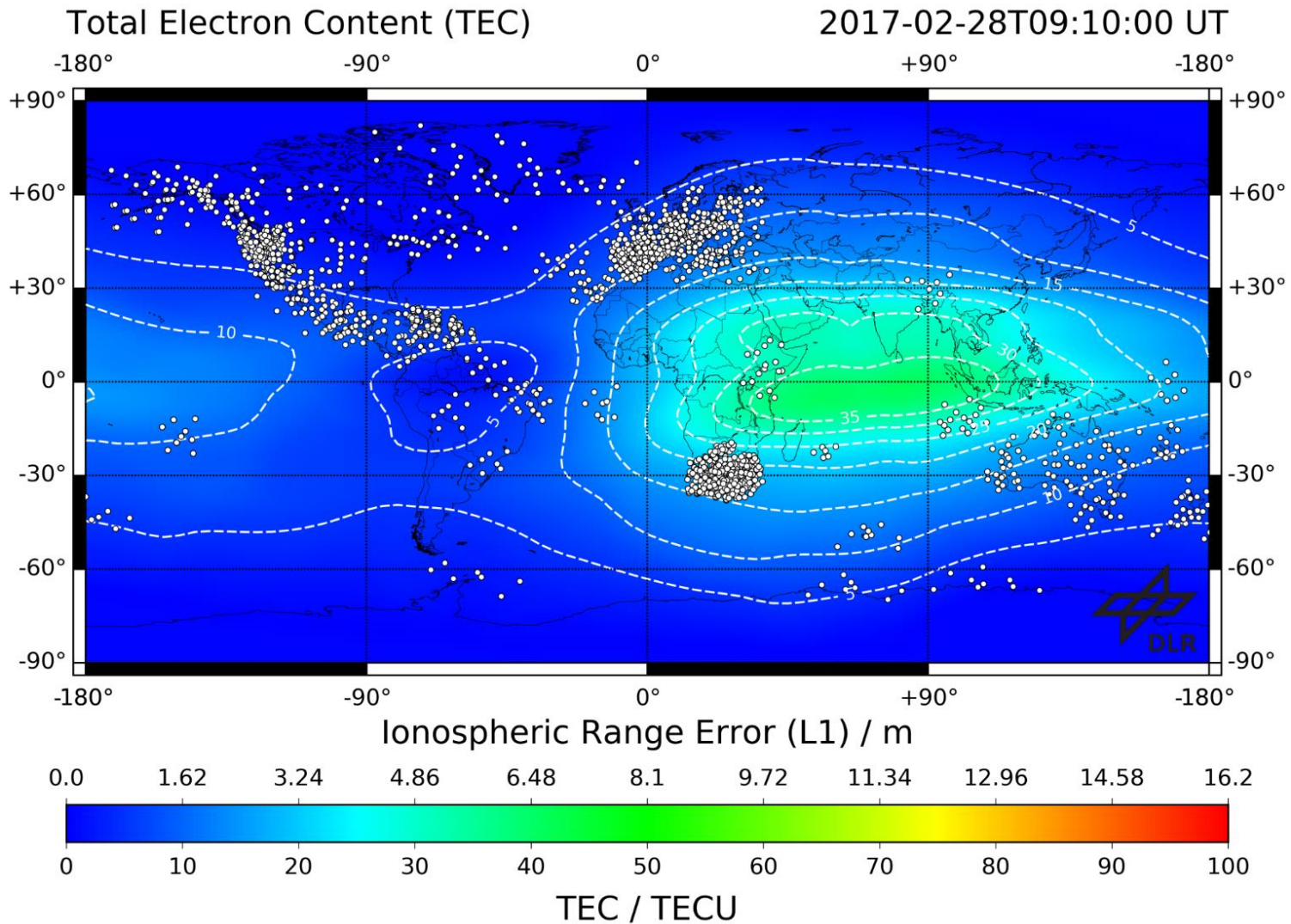
| GNSS   | Moderate | Severe |
|--|----------|--------|
| Amplitude Scintillation (S4) (dimensionless) | 0.5      | 0.8    |
| Phase Scintillation (Sigma-Phi) (radian)     | 0.4      | 0.7    |
| Total Electron Content (TEC) (TEC Units)     | 125      | 175    |

## Scintillation measurement stations



## GNSS receivers (1Hz)

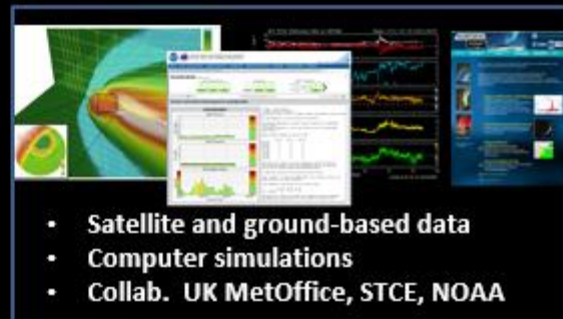




*Plot: DLR, Germany*

# Space Weather service 24/7

## Hazards



- Satellite and ground-based data
- Computer simulations
- Collab. UK MetOffice, STCE, NOAA

**Security Duty Officer**



**Space Weather Officer**



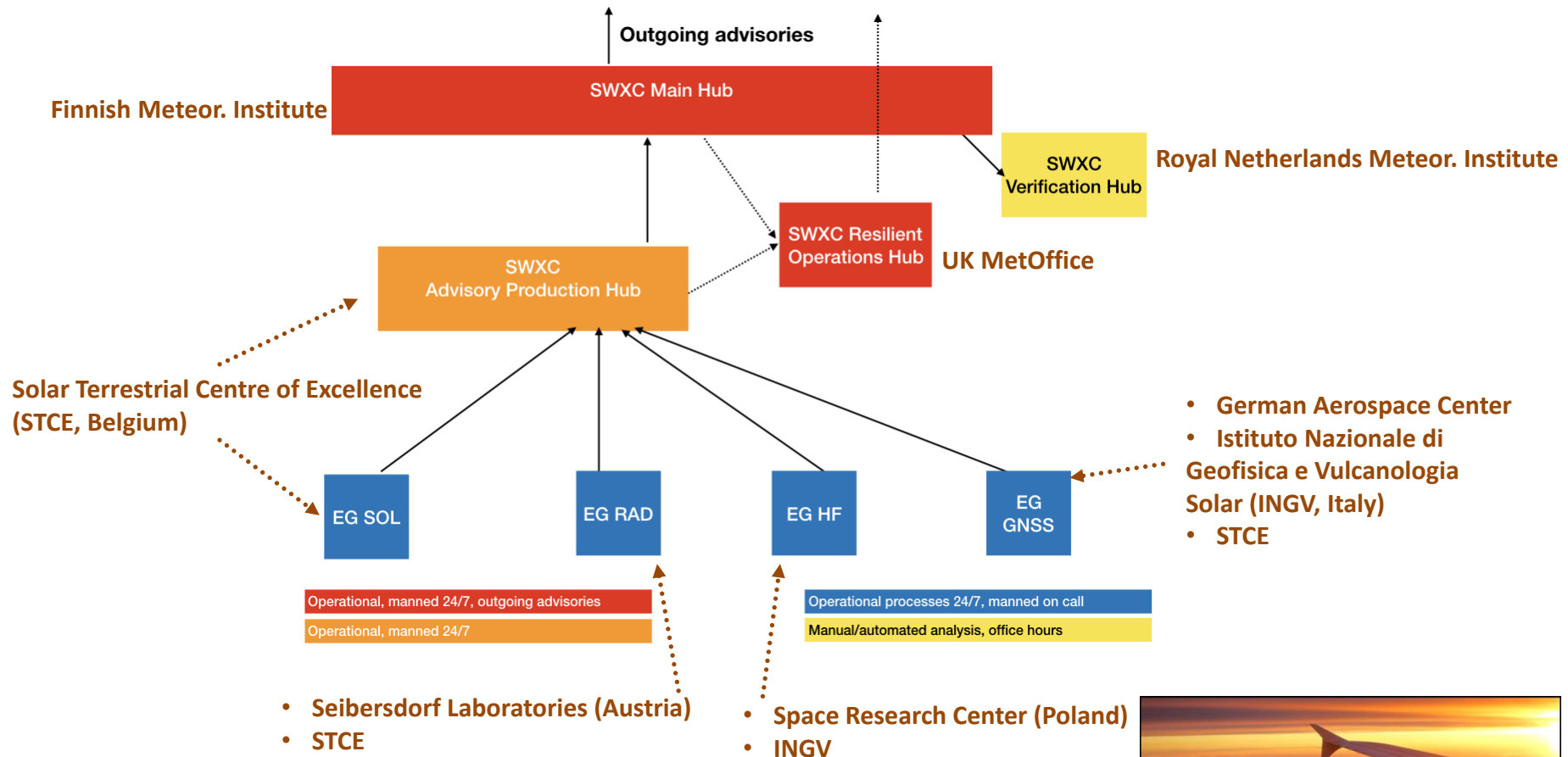
**Alerts and Warnings**

**Tailored guidance**

## Auroras



# The concept for operations



# Future steps

- Official operations will start on Nov 7 2019
- Pilot phase (operations by own cost) → 2022 after that the cost of the services will be included to the aviation cost base.
- Regional SWXCs will be integrated at latest 2022
- ICAO will re-evaluate the number of centers in 2027
- Plans in Finland:
  - Collaboration between FMI and Defence Forces for dual-usage of the services
  - The routines and procedures developed for PECASUS will be used as the starting point for a national Space Situational Awareness system





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# Thanks for your attention!

18.10.2019

