SPACE WEATHER INTRODUCTORY COURSE

SWIC

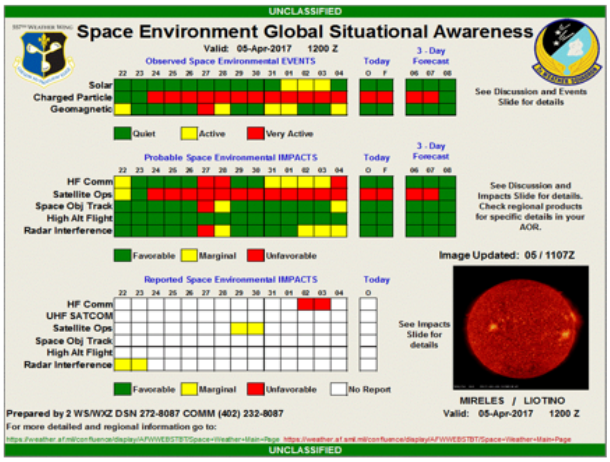
Collaboration of:

Solar-Terrestrial Centre of Excellence

Koninklijke Luchtmacht

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

May 2017



STOPLIGHT CHARTS

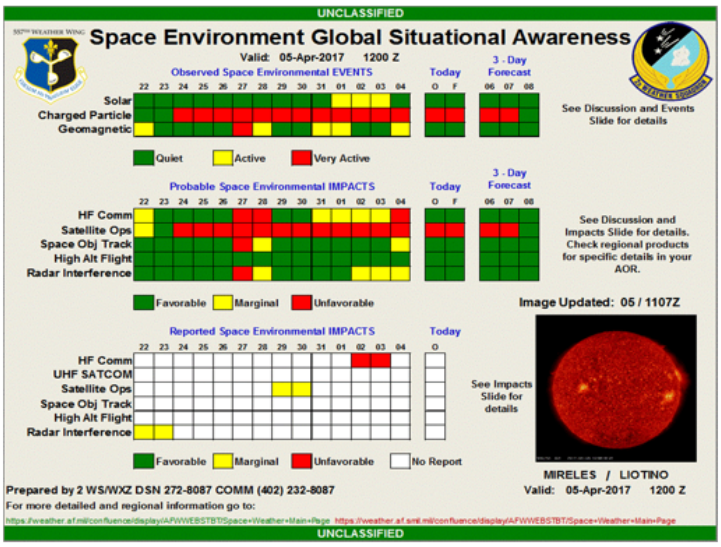
About the translation from EVENTS to IMPACTS

Willem-Pieter van der Laan

CREDITS & THANKS TO

- 557th Weather Wing US Air Force
- Dr. Mills
- Don Harper

INTRODUCTION



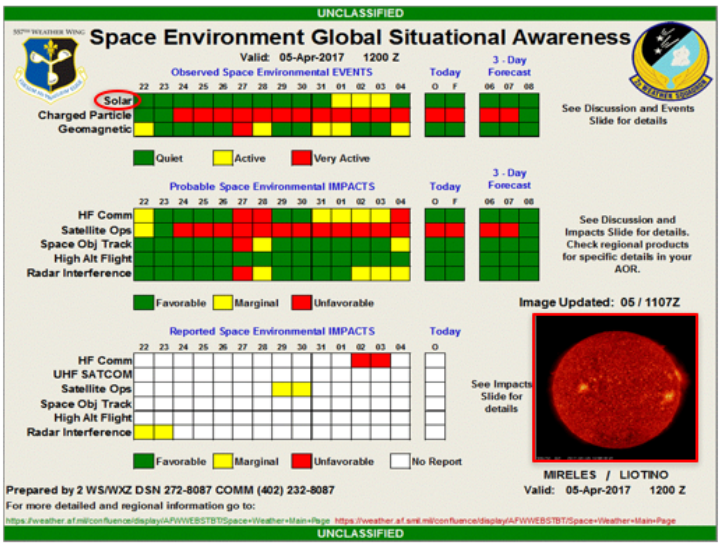
US Air Force 557th Weather Wing maintains a website with many operational products both on terrestrial as on space weather. The operational holy grail for the military are stoplight charts, indicating if the impact of the environment on assets or operations are favourable or unfavourable. Such charts exist for Space Weather too. We will use these charts to help you understand how EVENTS can be translated to IMPACTS.

Direct relationships between EVENTS and IMPACTS are hard to give. Nonetheless, physical reasoning, feedback and case studies are a good guidance. The coming hour we interpret these so called stoplight charts by AFWA to learn more about this relationship and get a feeling for it.

Each couple gets a chart with a few questions. Use the Ursigram of that day, the slides of the SWIC, internet (e.g. staff.oma.be) and answer the questions. Before we start, first a short introduction on the EVENTS. For a user's guide on solar and geophysical indicators, also visit:

http://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf

SOLAR



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The solar image in the lower right corner is an extreme ultraviolet (EUV) image of the sun that emphasizes the increased emissions associated with active regions.

Solar. This category shows the overall activity level of the sun and its likelihood to impact systems. Criteria analyzed to determine the state of this category are the occurrence of moderate or greater **x-ray flares** and significant **solar radio bursts**.

GREEN indicates little chance of an event level flare and/or radio burst being observed or forecasted
YELLOW indicates good chance of an event level flare and/or radio burst being observed or forecasted
RED indicates very good chance of an event level flare and/or radio burst being observed or forecasted

<u>Solar Flare</u>

A solar flare is an explosive release of energy across a broad range of the electromagnetic spectrum. This energy is stored in intense magnetic fields near the solar surface, or photosphere (sunspots) or in coronal active regions. Significant emissions include x-rays, extreme ultraviolet waves, radio bursts (see below). Flares are classified according to the X-ray flux. The following is the classification breakdown.

<u>Class</u> <u>Flux (W/m^2)</u>

X – extreme	$> 10^{-4}$
M – major	$> 10^{-5}$
C – common	$> 10^{-6}$
B – comes before C	$> 10^{-7}$
A – comes before B	$> 10^{-8}$

A and B are "background" levels.

Data Input

Data are x-ray flux levels measured in units of Watts/m^2. These data are taken from GOES-12 (primary) and GOES-10 (secondary) space environment monitor (SEM) sensors.

Thresholds

Red	X level ($> 10^{-4}$ W/ m^2)
Yellow	M level ($> 10^{-5}$ W/m^2)
Green	Otherwise

Solar Radio Burst

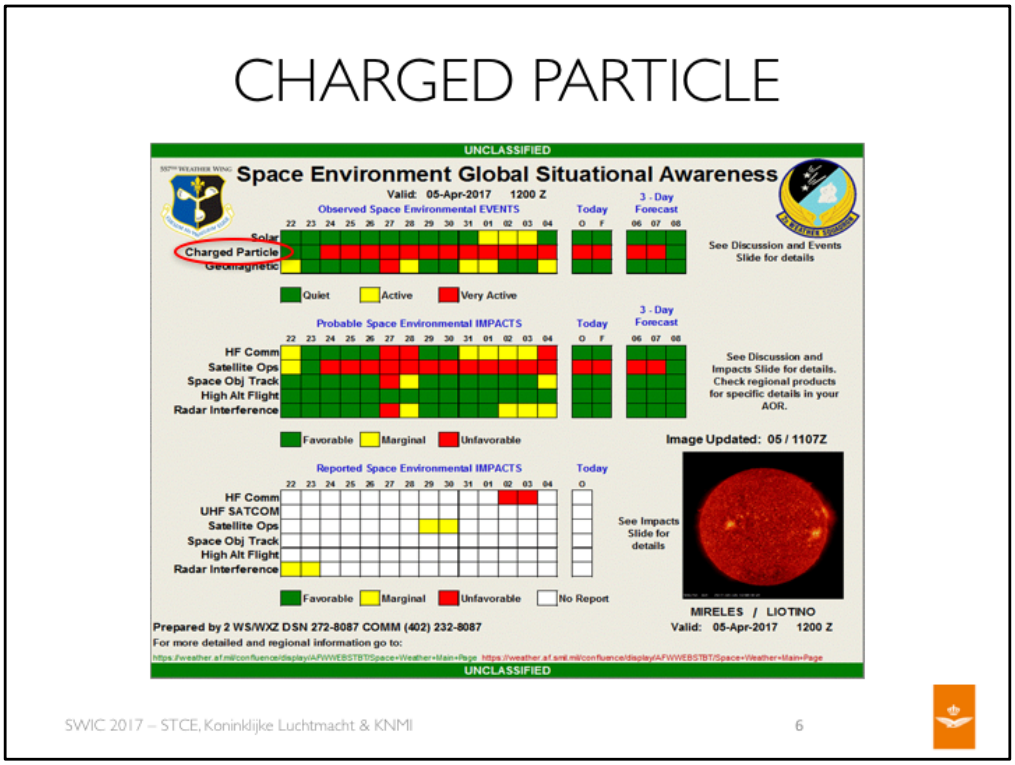
A solar radio burst is a short-lived solar radio emission usually associated with a solar flare linked with sunspots which reside in the solar photosphere. A sunspot is associated with a coronal active region. Active regions are relatively dense, hot, and bright areas in the corona.

Data Input

Data are solar flux levels measured in solar flux units (sfu), where 1 sfu = 10^{-22} W/m^2/Hz. These data are measured at discrete frequencies and are taken from US Air Force Radio Solar Telescope Network (RSTN) sites. Values are adjusted for 1 astronomical unit (AU), which is the average Sun-Earth distance (about 93 million miles).

Thresholds

Red	$> 10^4$ sfu
Yellow	> 5000 sfu
Green	Otherwise



Charged Particles – measured by GOES at geostationary orbits.
This category shows the observed or forecast potential for system impacts from charged particles significantly above normal background levels. Charged particle enhancements occur due to **solar events** or enhanced **geomagnetic activity.**

GREEN indicates that the amount charged particles is at or near normal background levels are being observed or forecasted
YELLOW indicates that moderate levels of charged particles are being observed or forecasted
RED indicates that severe levels of charged particles environment are being observed or forecasted

<u>Energetic Particle</u>
An electron volt (eV) is the amount of energy an electron gains as it passes through a potential difference of one volt. 1 MeV is 10^6 eV. (M is for mega, which means million.) Alternatively, this may apply to protons since they have the same amount of charge as electrons, but with a charge of opposite sign. Here, energetic particles are those protons with energies greater than 50MeV. However, protons with energies greater than 10 MeV are also considered under this heading since their detection contributes to discernment of a polar cap absorption (PCA) event. PCA events generally originate with solar flares, and they can cause ionospheric absorption of HF and VHF radiowaves or reflection of LF and VLF radiowaves at lower altitudes than normal in the polar regions.

Data Input

Data are greater than 10 MeV proton and greater than 50 MeV proton particle flux units. A particle flux unit is one particle/cm^2/sec/sr (sr: steradian – see link below). These data are acquired from GOES-11 SEM sensors.

Thresholds

Red	greater than 50 MeV proton pfu > 10
Yellow	greater than 10 MeV proton pfu > 40
Green	Otherwise

Spacecraft Charging

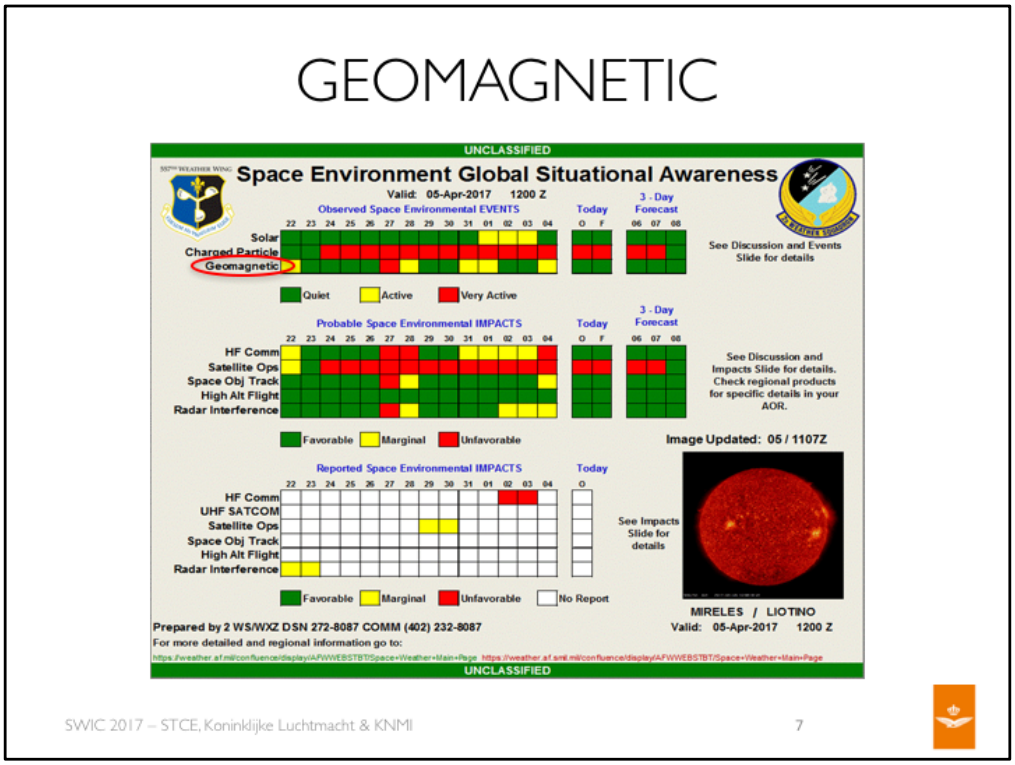
As represented here, the term "spacecraft charging" applies to internal charging, which refers to charging of internal components – e.g., dielectrics. Significant impacts associated with internal charging are deep-dielectric breakdown; damage to internal components; or single event upsets such as uncommanded switching (on or off, for example). Such breakdowns can damage instruments or render them inoperable, either temporarily or permanently. Here, charging conditions are characterized by calculating the 72-hour fluence of electrons with energies greater than 2 MeV. Whereas flux is calculated at a point in time, fluence is an accumulation of flux values over a period of time.

Data Input

Data are greater than 2 MeV electron fluxes reported at 5-minute intervals. Due to occasional data gaps, sometimes lasting over an hour, the data over the 72-hour period are averaged and multiplied by (60sec/min)(60min/hr)(72hr) to obtain the 72-hour value.

Thresholds

Red	greater than 2 MeV electron fluence exceeds 10^9/cm^2/sr/72hr
Yellow	greater than 2 MeV electron fluence exceeds 10^8/cm^2/sr/72hr
Green	Otherwise



Geomagnetic. This category shows the overall geomagnetic activity level of the Earth's magnetic field. A measured or forecast planetary geomagnetic activity index is used to determine the likelihood of system impacts.

GREEN indicates quiet geomagnetic conditions are being observed or forecasted
YELLOW indicates minor to major geomagnetic storming conditions are being observed or forecasted
RED indicates severe geomagnetic storming conditions are being observed or forecasted

<u>Geomagnetic</u>

Variations in the Earth's geomagnetic field are measured at locations throughout the world. AFWA/XOGX uses data from a subset of these stations to derive 3-hourly and 24-hourly Ap indices associated with these variations. These Ap indices are used to characterize the extent of the geomagnetic activity driving these variations.

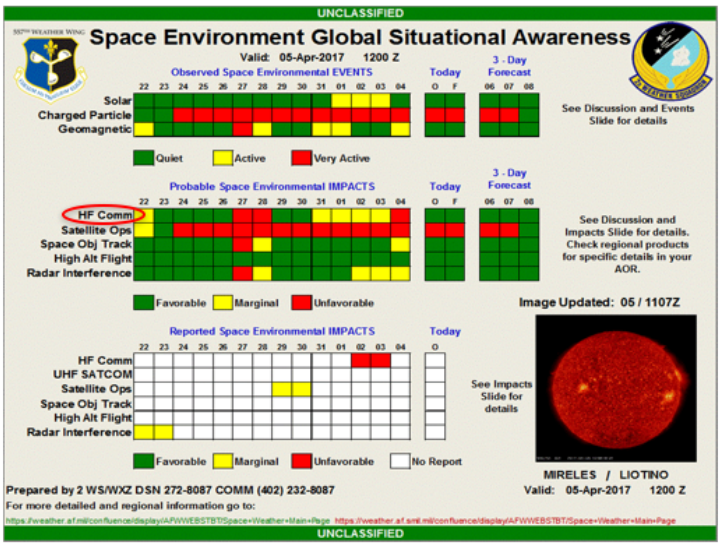
<u>Data Input</u>

Data are geomagnetic activity values from nine selected stations from the worldwide network of stations reporting variations in the Earth's magnetic field as recorded at these stations. Data are K values, from which A values are derived. The Ap is a planetary average of these station A values.

<u>Thresholds</u> Storm Category

Red	Ap greater than or equal to 100	Severe
Orange	Ap greater than or equal to 50	Major
Yellow	Ap greater than or equal to 30	Minor
Green	Otherwise	

HF COMM



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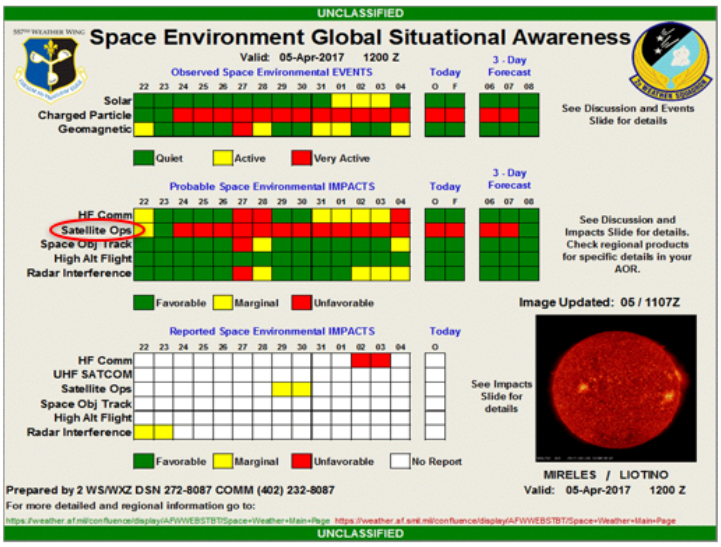
<u>HF Comm</u> is a function of **Solar** and **Geomagnetic**.

Solar is a function of *solar flares* and *solar radio bursts*.

Geomagnetic is a function of *geomagnetic activity.*

SATELLITE OPS

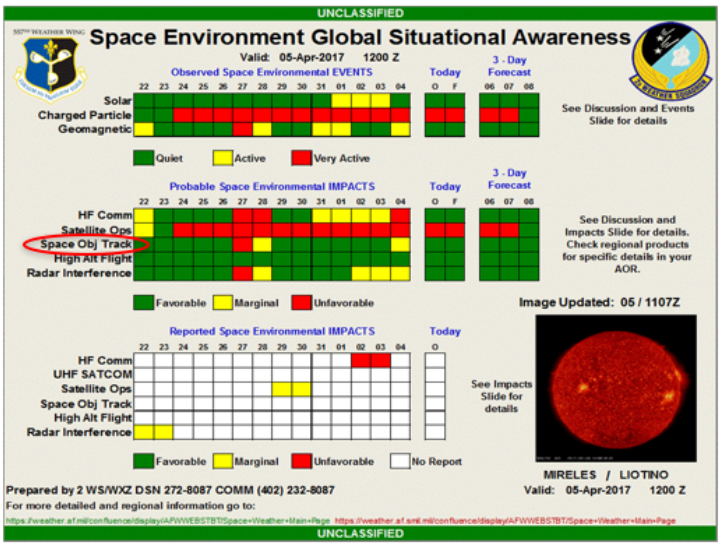


<u>Satellite Ops</u> is a function of **Charged Particle** and **Geomagnetic**.

Charged Particle is a function of *proton storms*, *solar wind* and *geomagnetic storms*.

Geomagnetic is a function of *geomagnetic activity*.

SPACE OBJECT TRACKING

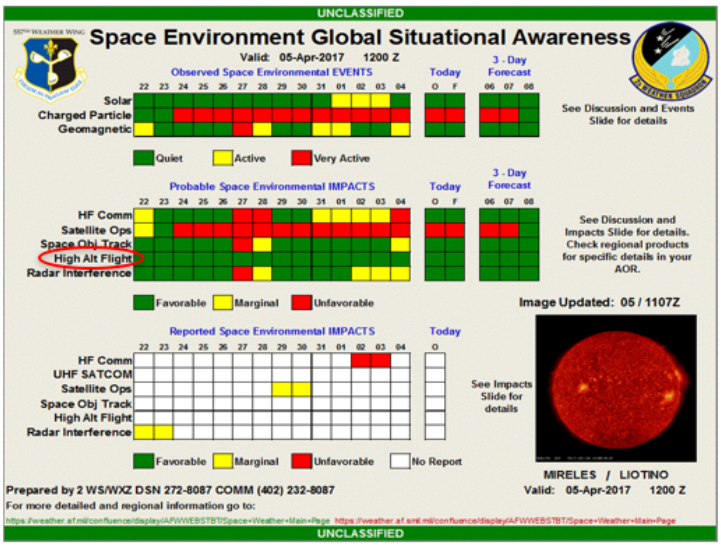


<u>Space Obj Track</u> is a function of **Solar** and **Geomagnetic**.

Solar is a function of *solar flares* and *solar radio bursts*.

Geomagnetic is a function of *geomagnetic activity*.

HIGH ALTITUDE FLIGHT



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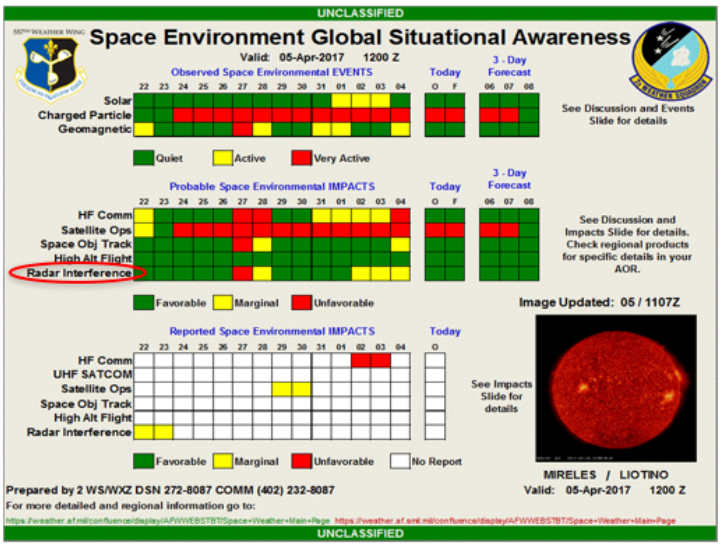
<u>High Alt Flight</u> is a function of **Charged Particle**.

Charged Particle is a function of *proton storms*, *solar wind* and *geomagnetic storms*.

RADAR INTERFERENCE



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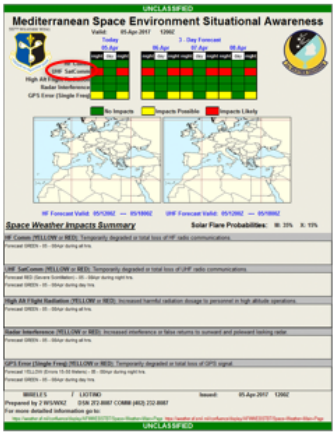
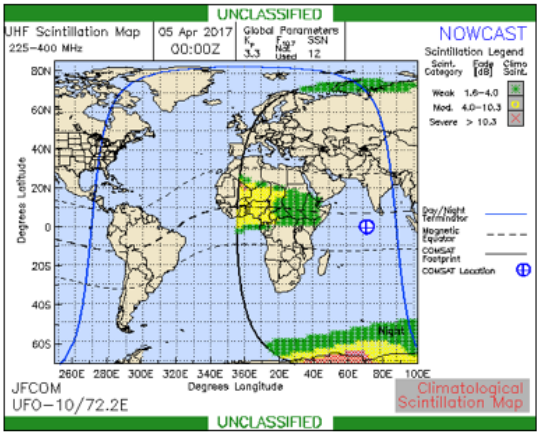
Radar Interference is a function of **Solar** and **Geomagnetic**.

Solar is a function of *solar flares* and *solar radio bursts*.

Geomagnetic is a function of *geomagnetic activity.*

UHF SATCOM





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PICTURE LEFT:

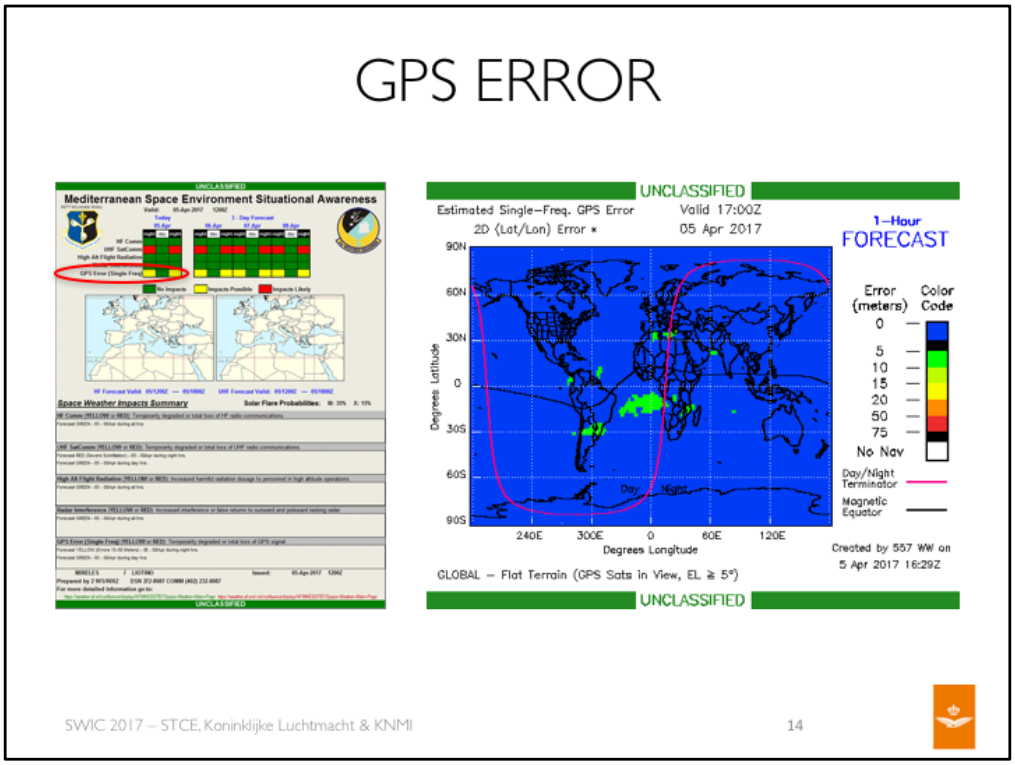
<u>UHF SATCOM</u> is a function of **Scintillation**.

Scintillation is a function of *solar activity (SSN), geomagnetic activity (Kp)* and *climatology*.

PICTURE RIGHT:

<u>UHF SATCOM Scintillation Nowcast and Forecast:</u>
This product is a graphic map depicting the estimated potential amount of performance degradation (signal fading) of UHF SATCOM as a result of ionospheric scintillation. Although DoD SATCOM uses the entire UHF radio band, these UHF Scintillation maps apply only to UHF SATCOM between 225 MHZ and 400 MHZ (the lower portion of the UHF spectrum is impacted more than the higher end). Regions of light or weak degradation (1-4 dB) are in green, regions of moderate degradation (4-10 dB) are in yellow and regions of severe degradation (greater that 10 decibels) are in red.

<u>Operational Impacts/Uses</u>
Customers can use this product for situational awareness and to develop planning guidance for operations using UHF and SATCOM systems.



PICTURE LEFT:

<u>GPS Error (Single Freq)</u> is a function of **Solar** and **Scintillation**.

Solar is a function of *solar flares* and *solar radio bursts*.

Scintillation is a function of *solar activity (SSN), geomagnetic activity (Kp)* and *climatology*.

PICTURE RIGHT:

<u>Estimated Global Positioning Satellite (GPS) Single Frequency Error Maps – 1-Hour Nowcast and Forecast:</u>
A graphical product that estimates near real-time positioning errors that result from inaccurate ionospheric correction for single-frequency GPS users. The product displays errors in total position (latitude, longitude, and height), horizontal position (latitude only), and altitude position (height only). Product assumes a greater GPS error for hilly terrain than flat terrain. Geometric data from 4 visible GPS satellites are used to create the product. GPS errors are color-coded and are displayed in meters.

<u>Operational Impacts/Uses</u>

Customers can use this product for situational awareness and to develop planning guidance for operations using single-frequency GPS systems. It is important to note that the effects shown in this product do not apply to dual-frequency GPS systems.

DISCUSSION SLIDE

UNCLASSIFIED

SPACE ENVIRONMENT DISCUSSION

VT: 05/12Z

Space Weather Events/Impacts Summary

Solar Activity: Observed GREEN. Forecast GREEN 05 – 08 Apr.
Flare Probabilities: M: 35% X: 15%

Charged Particle Environment: Observed RED for Spacecraft Internal Charging. Forecast RED 05 – 07 Apr for Spacecraft Internal Charging. Forecast GREEN 08 Apr.

Geomagnetic: Observed GREEN. Forecast GREEN 05 – 08 Apr.

HF Comm: Observed GREEN. Forecast GREEN 05 – 08 Apr.

Satellite Operations/Health: Observed RED for Spacecraft Internal Charging. Forecast RED 05 – 07 Apr for Spacecraft Internal Charging. Forecast GREEN 08 Apr.

Space Object Tracking/Satellite Drag: Observed GREEN. Forecast GREEN 05 – 08 Apr.

High Altitude Flight: Observed GREEN. Forecast GREEN 05 – 08 Apr.

Radar Interference/False Returns: Observed GREEN. Forecast GREEN 05 – 08 Apr.

Potential Impacts to DoD Operations

HF Comm (when YELLOW or RED): temporary degraded or total loss of HF radio communications.

UHF SATCOM (when YELLOW or RED): temporary degraded or total loss of UHF radio communications.

Satellite Operations/Health (when YELLOW or RED): increased likelihood of spacecraft anomalies; degradation of spacecraft components due to radiation interference to communication satellite circuits.

Space Object Tracking/Satellite Drag (when YELLOW or RED): increased likelihood for space object tracking loss; increased drag on low earth orbiting spacecraft.

High Altitude Flight (when YELLOW or RED): increase in harmful radiation dosage to personnel in high altitude operations.

Radar Interference/False Returns: (when YELLOW or RED): increased interference or false returns to sunward and/or pole ward looking radars.

This slide provides a generalized situation awareness of past and future space environment impacts to war-fighters and weapon systems. The severity of the impacts due to the space environment may be more or less than indicated by the color coded assessment in a particular area. The impact variability is dependent on a variety of factors including, but not limited to, system location, geometry, and operating frequency. Please contact the 2 WS Space Weather Forecaster at DSN 272-8087 or 272-4317 (Commercial 402-232-8087 or 402-232-4317) to arrange mission-specific support or to report conditions experienced by your system that may be related to space weather disturbances.

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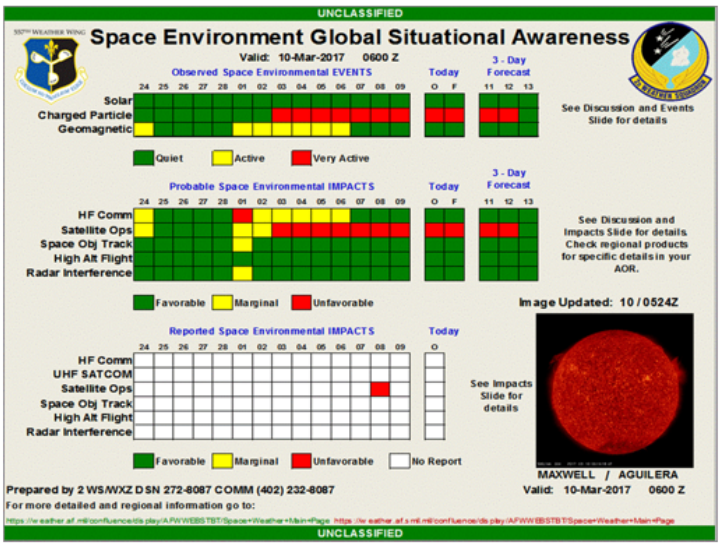
The discussion slide should be used in conjunction with the stoplight chart.

INSTRUCTION

- Have a look at your chart & the questions.
- Use the Ursigram and STAFF to mentally rebuild the SPWX-situation of that day.
  - http://sidc.oma.be/archive
  - http://www.staff.oma.be/
- Make use of the SWIC-slides and other sources if necessary.
- Formulate your answers and motivate them.
- Present your case.

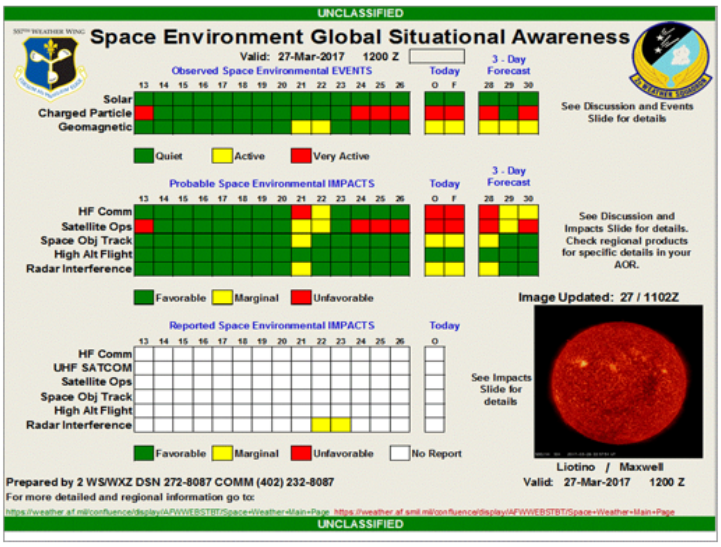
EXERCISE 1



Questions:

1a. Why is the forecast of 'Charged Particle' unfavorable while 'Geomagnetic' is favorable?
1b. Why is only 'Satellite Ops' affected during these days while the other stay green?
1c. Which satellites at are affected most?
1d. What kind of impact on 'Satellite Ops' could have been reported on the 8th of March 2017?

EXERCISE 2



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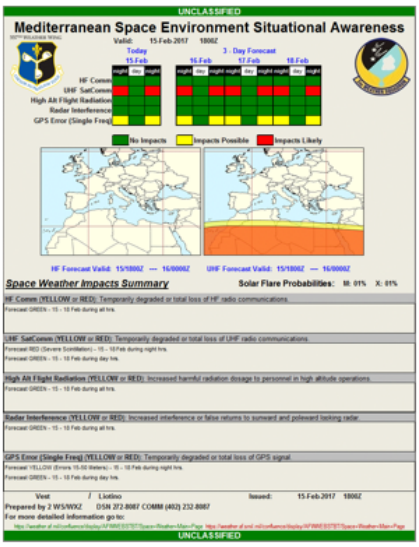
Questions:

2a. What SPWX event makes the forecasted impact on HF Comm unfavorable?
2b. Are the charged particles around 27-Mar-2017 dominated by electrons or protons?
2c. Which kind of radars do you expect to be impacted around 27-Mar-2017?

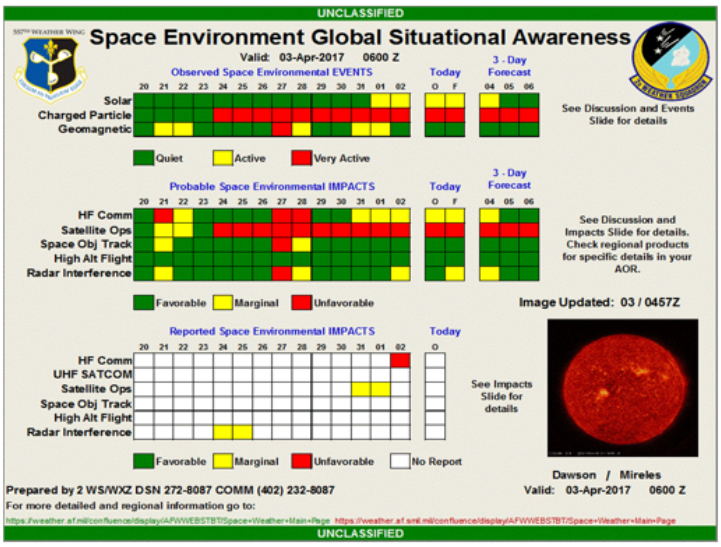
EXERCISE 3



Questions:

3a. Where is impact on UHF SatCom likely during the mentioned time period?
3b. Why is impact on UHF SatCom likely during nighttime?
3c. Why is impact on GPS (Error on Single Freq) possible during nighttime?
3d. Explain the difference between red for UHF & yellow for GPS.

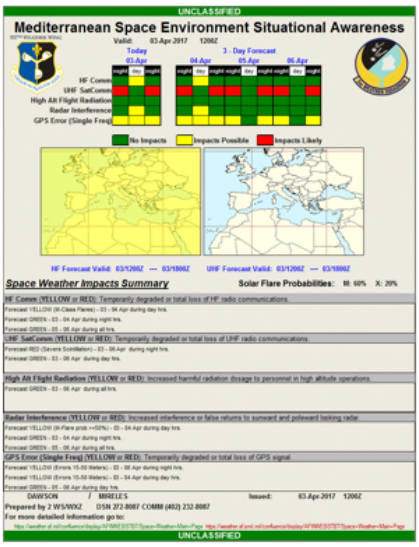
EXERCISE 4



Questions:

4a. What are the approximate thresholds for ‘Active’ Solar EVENTS?
4b. Why is the Probable IMPACT for Radar Interference set to ‘Marginal’?
4c. Which radars might be disrupted: poleward looking or sunward looking?

EXERCISE 5



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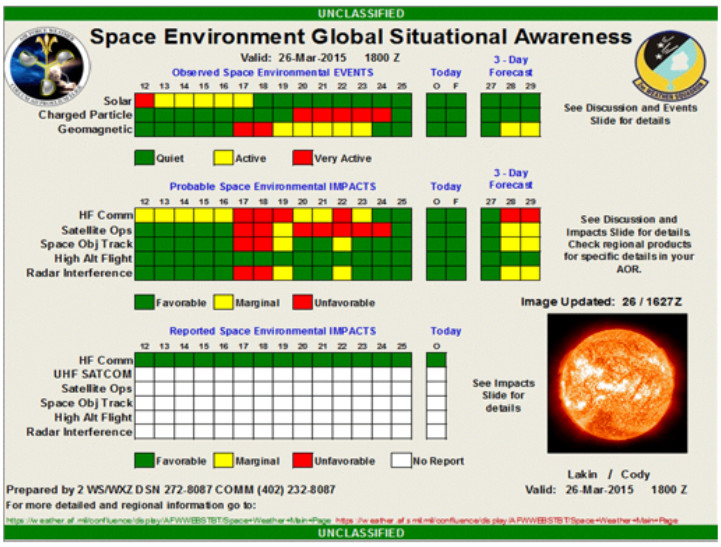
Questions:

5a. Are the possible impacts on HF Comm, Radar Interference and GPS Error (Single Freq) correlated? If so, how?
5b. GPS and SATCOM are both trans-ionospheric radio links. Why is impact on GPS possible during day time while at the same time no impact is expected on SATCOM?
5c. Why is the map for the HF Forecast all yellow?

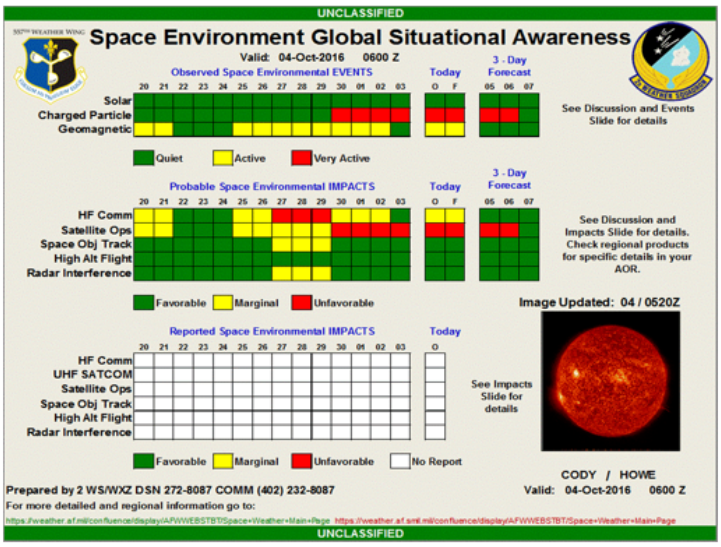
EXERCISE 6



Questions:

6a. What happened on the 17th of March 2015?
6b. In Mali an Apache helicopter unfortunately crashed during the event. Could these be correlated or causally related?

EXERCISE 7



Questions:

7a. What caused the Geomagnetic activity from 25SEP16 to 02OCT16?
7b. Apparently the activity was stronger from 27SEP16 tot 29SEP16. Why?

CONCLUDING REMARKS

- Translation and simple presentation are a prerequisite for operational relevance.
- Be aware of the physics behind and the shortcomings of the relationships.