SPACE WEATHER INTRODUCTORY COURSE

Collaboration of:

Solar-Terrestrial Centre of Excellence

Koninklijke Luchtmacht

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

May 2017

WELCOME

- Introduction teachers


Jan


WP


Bert


Petra

- Introduction participants
  - What's your current function?
  - Please mention your expectations.

- Teachers [mention how you're related to SPWX];
- Students [current function, expectations and approximate level of physics];
- Distribute name badges.

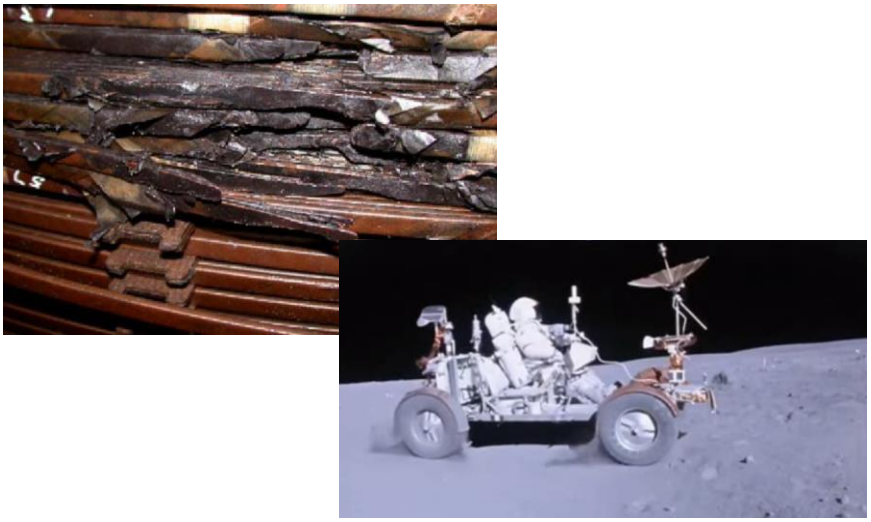
PRACTICALITIES

- Emergency
- Times and places
- Lunch & dinner
- WiFi & sharepoint
- Parking
- Telephone numbers
- List with acronyms
- Please make notes for evaluation!

INTRODUCTION

- Motivation
- Objectives
- History
- Before we start…

DANGEROUS & DEVASTATING



SWIC 2017 – STCE, Koninklijke Luchtmacht & KNMI 5

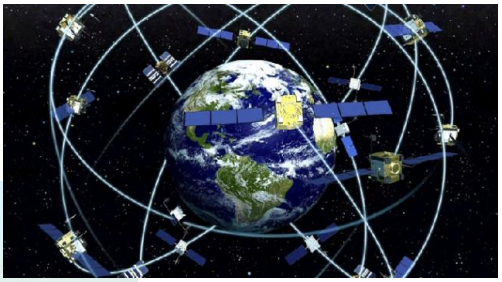
SPWX: dangerous & potential devastating

Dangerous: on August 7, 1972, between the Apollo 16 and Apollo 17 lunar missions, a large proton storm occurred. This would have been life threatening for the astronauts.

Devastating: failure in a large South African generator transformer three weeks after the Halloween storm of October 2003.

- http://www.stce.be/news/233/welcome.html
- https://www.researchgate.net/figure/222557718_fig4_Fig-4-Failure-in-a-large-South-African-generator-transformer-three-weeks-after-the

SOCIETAL DEPENDENCY



Society & military: more & more technology & space based.

Technology: electricity, radar and radio.

Space based: SATCOM, GPS and earth observation.

CUSTOMER PULL / POLITICAL PUSH

Solar-Terrestrial Centre of Excellence

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Koninklijke Luchtmacht

SWIC 2017 – STCE, Koninklijke Luchtmacht & KNMI 7

Space & weather organizations are expected to watch, forecast & warn for the impact of space weather on society/military operations.

Both customers ask & politicians demand (NL – Nota Ruimtevaartbeleid).

Also think of the founding of the MOSWOC (UK).

SPWX: HIGHLY ACADEMIC

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0.$$

$$\rho \left(\frac{\partial}{\partial t} + \mathbf{v} \cdot \nabla \right) \mathbf{v} = \mathbf{J} \times \mathbf{B} - \nabla p.$$

$$\mu_0 \mathbf{J} = \nabla \times \mathbf{B}.$$

$$\frac{\mathrm{d}}{\mathrm{d}t} \left(\frac{p}{\rho^\gamma} \right) = 0,$$

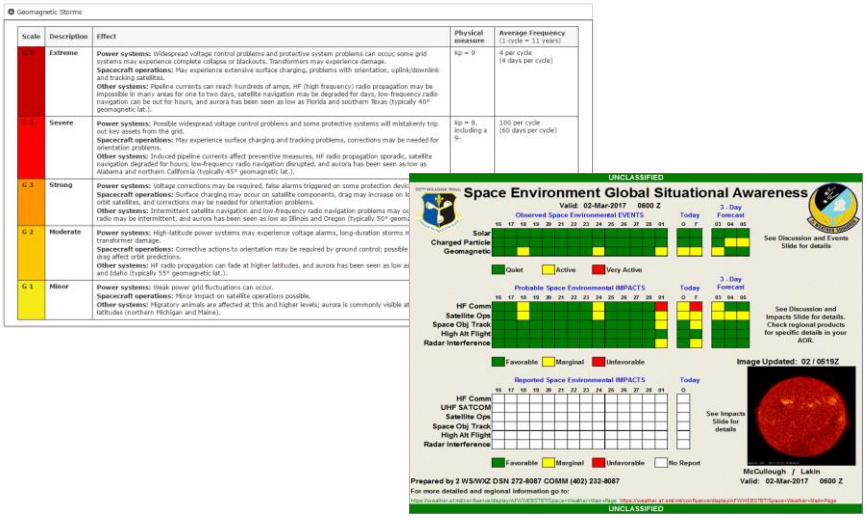
However… SPWX is highly academic, while many forecasters and metbriefers are not. And even if they are, magnetohydrodynamics (MHD) is another cup of tea.

Basis of SPWX is the sun, an MHD system that is not well understood.

Most SPWX knowledge is developed for/by space industry.

- https://en.wikipedia.org/wiki/Magnetohydrodynamics

TRANSLATION TO OPERATIONS



Geomagnetic Storms

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
G 5	Extreme	**Power systems:** Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** Pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** May experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** Induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** Voltage corrections may be required, false alarms triggered on some protection devic **Spacecraft operations:** Surface charging may occur on satellite components, drag may increase on k orbit satellites, and corrections may be needed for orientation problems. **Other systems:** Intermittent satellite navigation and low-frequency radio navigation problems may oc radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geom		
G 2	Moderate	**Power systems:** High-latitude power systems may experience voltage alarms, long-duration storms m transformer damage. **Spacecraft operations:** Corrective actions to orientation may be required by ground control; possible drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low a and Idaho (typically 55° geomagnetic lat.).		
G 1	Minor	**Power systems:** Weak power grid fluctuations can occur. **Spacecraft operations:** Minor impact on satellite operations possible. **Other systems:** Migratory animals are affected at this and higher levels; aurora is commonly visible at latitudes (northern Michigan and Maine).		

UNCLASSIFIED

Space Environment Global Situational Awareness

Valid: 02-Mar-2017 0600 Z

Observed Space Environmental EVENTS — Today — 3 - Day Forecast

Solar / Charged Particle / Geomagnetic

Quiet Active Very Active

See Discussion and Events Slide for details

Probable Space Environmental IMPACTS — Today — 3 - Day Forecast

HF Comm / Satellite Ops / Space Obj Track / High Alt Flight / Radar Interference

Favorable Marginal Unfavorable

See Discussion and Impacts Slide for details. Check regional products for specific details in your AOR.

Image Updated: 02 / 0519Z

Reported Space Environmental IMPACTS — Today

HF Comm / UHF SATCOM / Satellite Ops / Space Obj Track / High Alt Flight / Radar Interference

Favorable Marginal Unfavorable No Report

See Impacts Slide for details

McCullough / Lakin

Valid: 02-Mar-2017 0600 Z

Prepared by 2 WS/WXZ DSN 272-8087 COMM (402) 232-8087

For more detailed and regional information go to:

UNCLASSIFIED

This means that we cannot just link a military end-user or a governmental official to a solar physicist.

A translation of SPWX events to impact on operations and society is needed. In the USA they are miles ahead on this. The Space Weather Prediction Center (NOAA/SWPC) and USAF Space Weather Operations Center (SPWOC) translates events to potential impacts and warn their customers.

See e.g. the stoplight chart of the US Air Force & the NOAA scales.

TRAINING IS NEEDED

To enable weather forecasters, metbriefers and space operations personnel to advise their customers, training is need on:

- The basics of the sun & earth environment;
- The basics of different technologies;
- The basics of the impact of the sun on technologies.

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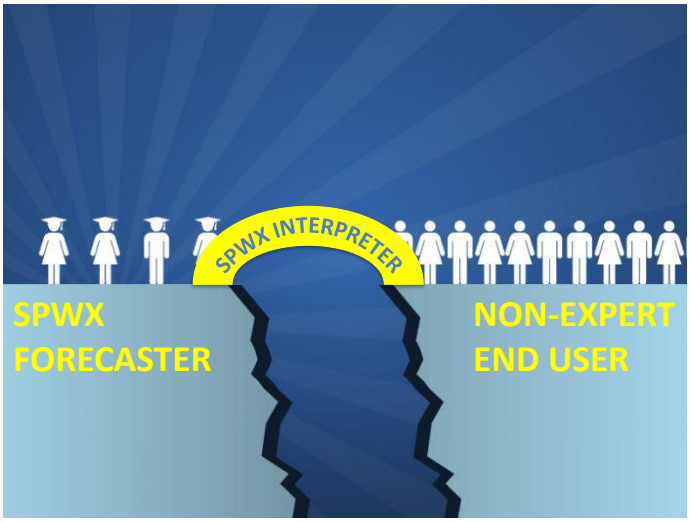
BRIDGING THE GAP



The intention of the SWIC is to help [weather forecasters and metbriefers] to bridge the gap between [solar physicists and SPWX forecasters] & [both civilian as well as military non-expert end users].

After the course the students should be abe to interpret SPWX forecasts & discussions (made by scientists) and understand how these are translated to potential impact on technology (used by their customers).

We call this bridging function the interpreter. Starting from this point of view we define our main objectives.

OBJECTIVES

After the course you:

- are able to read & understand SPWX guidance;
- feel confident while briefing elementary products;
- know whom to direct expert questions.

- After the course the student is able to read & understand the space weather guidance: the ursigram.
- After the course the student feels confident while briefing elementary products (solar synopsis, main events, stoplight chart, applied products).
- After the course the student knows whom to refer to when questions or requests are on the expert level.

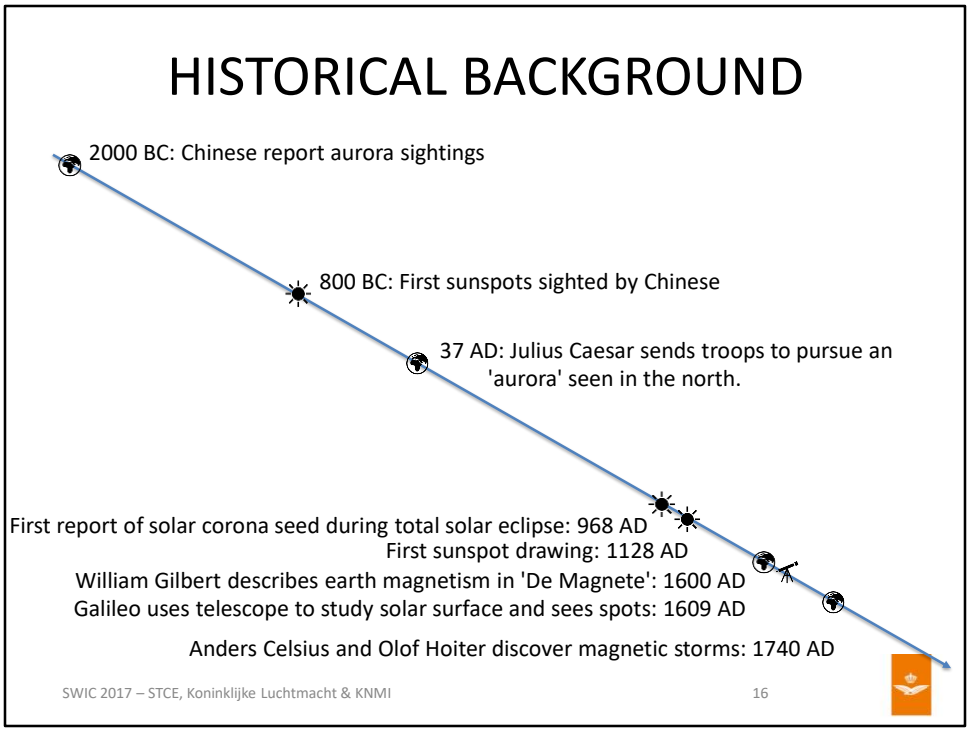
This leads to the outline of the SWIC.

OUTLINE SWIC

- Introduction
- The Sun: Driver of Space Weather
- The Earth: Impact on its Environment
- Technology: Basics and Impact
- SPWX Sources: Institutes & Sensors
- SPWX Practice: Forecasting & Products
- Quizes
- Visits

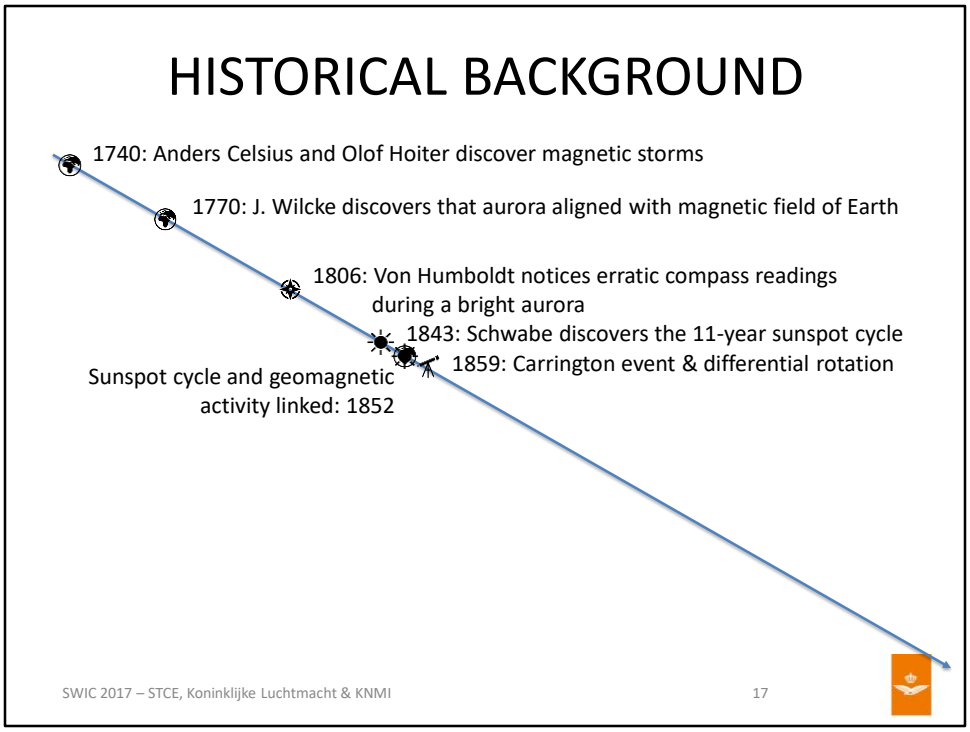
Mainly in this order. Visits in between.

INTRODUCTION



Space Weather: as old as the sun, though got attention after society became technological.

- http://www.solarstorms.org/SWtimeline.pdf
- Sten Odenwald: "The 23rd Cycle", chapter 3.
- https://www2.hao.ucar.edu/Education/solar-physics-historical-timeline-1223-BC-250-BC
- http://www.spaceacademy.net.au/env/spwx/spwxforhist.htm



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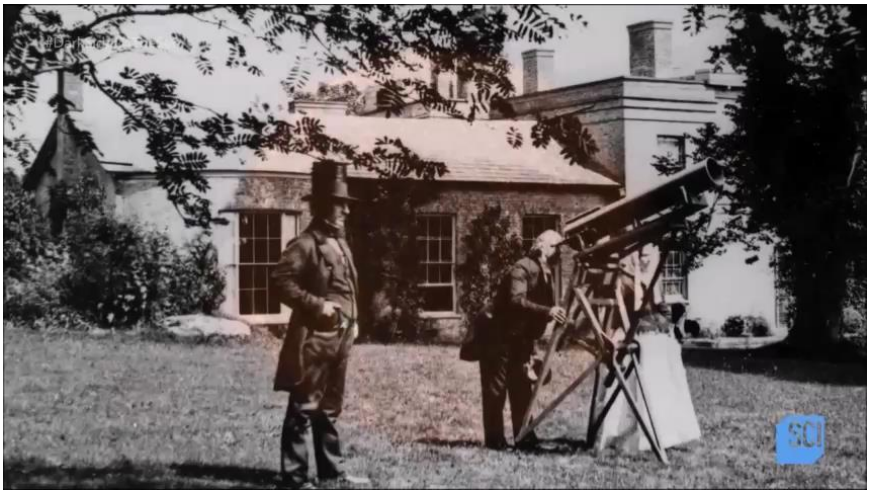
CARRINGTON EVENT (1859)



- http://www.solarstorms.org/SRefPeople.html
- https://en.wikipedia.org/wiki/Solar_storm_of_1859
- https://en.wikipedia.org/wiki/Balfour_Stewart
- https://en.wikipedia.org/wiki/Richard_Christopher_Carrington

HISTORICAL BACKGROUND

e location for auroral currents

'ionosphere' layer

VW I

tt detect the ionosphere layer

vers SRB by radar

ann discovers solar wind

t Van Allen belts discovered

1962: Warwick discovers PCA

1962/1967 SPWX during the Cold War

by opp… …tic fields: 1953

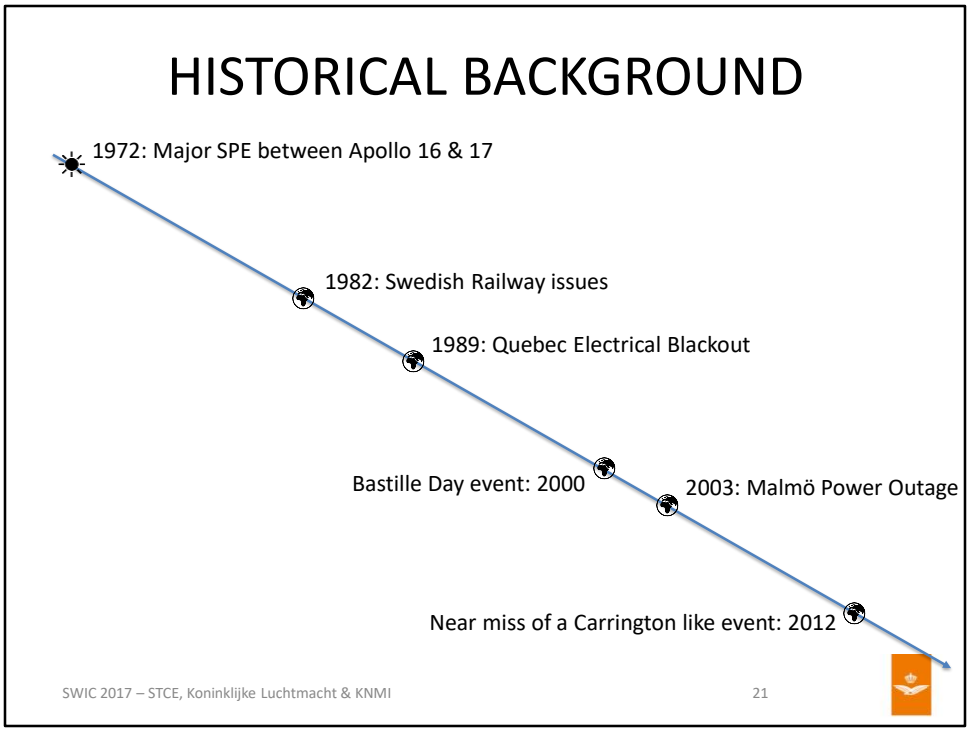
W… …ler discovers coronal holes &

Alfvén proposes that t… …nd is magnetized: 1957

…r SPE between Apollo 16 & 17 1972

Storms after Carrington: WWII (German subs, UK radars), Apollo missions (sixties), Quebec (1989), Malmo (2003), Swedish ATC (2015)

- http://www.spaceacademy.net.au/library/notes/firstsolburst.htm
- https://eos.org/features/the-geomagnetic-blitz-of-september-1941
- http://www.solarstorms.org/SS1938.html
- https://www.britannica.com/technology/radio-technology#toc25125
- https://www2.hao.ucar.edu/Education/solar-physics-historical-timeline-1223-BC-250-BC
- http://www.solarstorms.org/SWtimeline.pdf
- http://www.spaceacademy.net.au/env/spwx/spwxforhist.htm



- https://books.google.nl/books/about/Sentinels_of_the_Sun.html?id=WMh4REf3iZQC&printsec=frontcover&source=kp_read_button&redir_esc=y#v=onepage&q&f=false
- http://www.sws.bom.gov.au/Educational/1/3/16
- http://ann-geophys.net/27/1775/2009/angeo-27-1775-2009.pdf
- http://www.spaceacademy.net.au/library/notes/firstsolburst.htm
- https://eos.org/features/the-geomagnetic-blitz-of-september-1941
- http://www.solarstorms.org/SS1938.html
- https://www.britannica.com/technology/radio-technology#toc25125
- https://www2.hao.ucar.edu/Education/solar-physics-historical-timeline-1223-BC-250-BC
- http://www.solarstorms.org/SWtimeline.pdf
- http://www.spaceacademy.net.au/env/spwx/spwxforhist.htm

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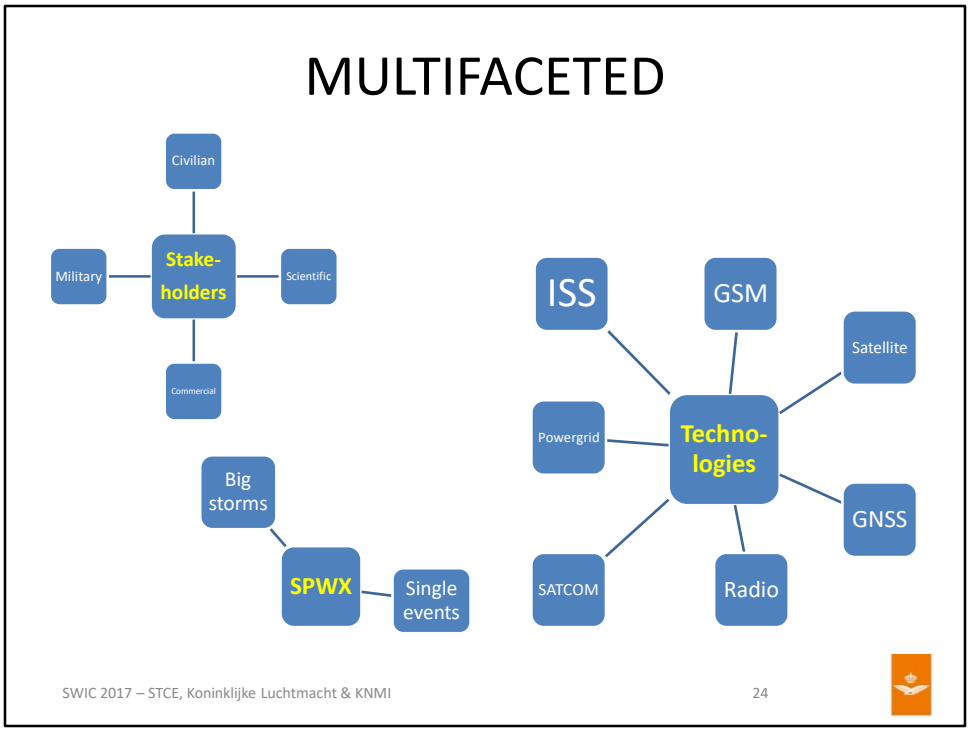
ABBREVIATIONS

- SW
- SpW
- SPWX

SW/SpW: civilian

SPWX: military



The multifaceted character of SPWX leads to many definitions. They have one thing in common: the sun disrupting human technology.

WMO

"Space Weather" designates the physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments. The associated discipline aims at observing, understanding and predicting the state of the Sun, of the planetary and interplanetary environments and their disturbances, with particular attention to the potential impacts of these disturbances on biological and technological systems.

WMO: World Meteorological Organization

US NATIONAL SPWX PROGRAM

"Space weather" refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health.

National Space Weather Program (USA).

NSWP: a.o. NOAA/SWPC, AFWA, NASA, USGS.

http://www.spaceweathercenter.org/swop/NSWP/1.html

ESA

Space weather refers to the environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health.

Space weather deals with phenomena involving ambient plasma, magnetic fields, radiation, particle flows and other physical happenings in space. At ESA, the scientific properties of space weather are studied by a number of teams and offices, and it is also a key element of our SSA Space Weather Segment.

European Space Agency

http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness/Space_Weather_-_SWE_Segment

NATO

Space Weather is a branch of space physics and aeronomy concerned with the time varying conditions within the Solar System, including the solar wind, emphasizing the space surrounding the Earth, including conditions in the magnetosphere, ionosphere and thermo-sphere.

Periodically, the sun produces bursts of energy and radiation that stream out across the solar system and interplanetary space. When these enhanced emissions interact with near-Earth space, they can affect many aspects of human activities that depend on modern technology. These technologies form the backbone of the economic vitality and national security in modern

Poppe, Barbara B.; Jorden, Kristen P. (2006). Sentinels of the Sun: Forecasting Space Weather. Johnson Books, Boulder, Colorado.

From: Report on Space Weather by NATO, 21 March 2016.

NATO

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Poppe, Barbara B.; Jorden, Kristen P. (2006). Sentinels of the Sun: Forecasting Space Weather. Johnson Books, Boulder, Colorado.

From: Report on Space Weather by NATO, 21 March 2016.

EUROPEAN SCIENTISTS

Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems.

COST: European Cooperation in Science & Technology

http://www.cost.eu/COST_Actions/essem/724

JAN

“De invloed van de zon en de zonneactiviteit op ons en onze technologie”.

RELATED SUBJECTS

- Space climate
- Hazardous sources inside & outside our solar system
- Weather
- Space

Several subjects are directly or indirectly associated with SPWX, though not discussed in the SWIC:
@ climate: interesting for s/c developers etc.
@ hazards inside: debris and near earth objects (comets, asteroids)
@ hazards outside: cosmic rays, gamma bursts (NATO SCI-285)
@ weather: similarities/differences
@ space: spacecraft relate to SPWX as aircraft relate to WX

http://www.swpc.noaa.gov/sites/default/files/images/u33/SpaceEnvironmentSupport_MauroMesserotti_NATO.pdf

LAST BUT NOT LEAST

1. Limited knowledge of the physics.
2. Impact is strongly dependent on the technology itself.
3. Big flares & storms can occur any moment.

We don’t want to lower your expectations or lessen your attention, but we do remind you that our knowledge about SPWX is just beginning.

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2. Impact is strongly dependent on the technology itself.
3. Big flares & storms can occur any moment.

Credit slide: Mauro Messerotti.