SPACE WEATHER INTRODUCTORY COURSE

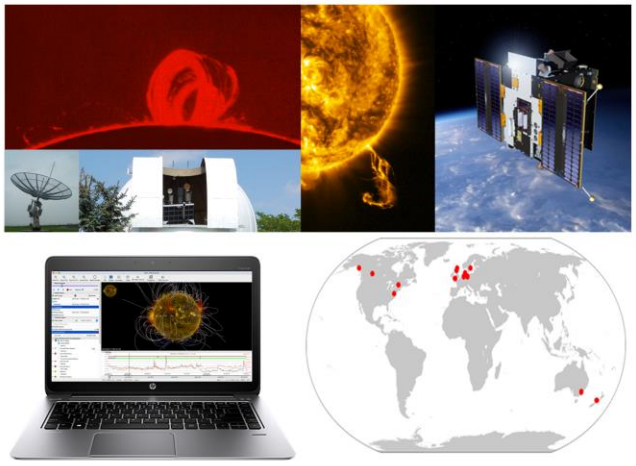
Collaboration of

Solar-Terrestrial Centre of Excellence

Koninklijke luchtmacht

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

June 2018



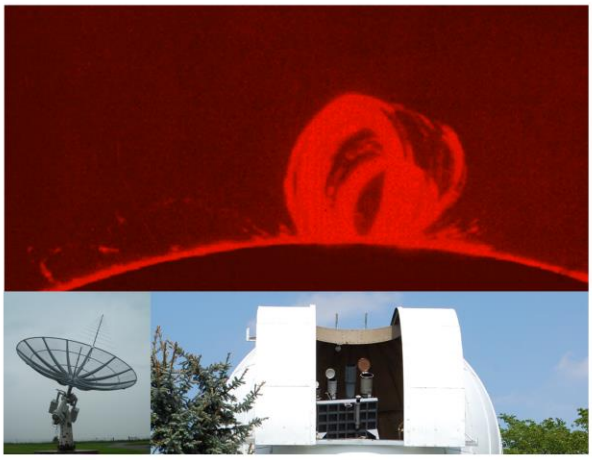
Sensors

Jan Janssens, Dr Christophe Marqué

H-alpha picture: https://www.windows2universe.org/spaceweather/ESF_loop.html (NSO/Sacramento Peak)

Contents

- **Groundbased sensors**
  - Visible light
  - Radio domain
  - Magnetosphere-Ionosphere
  - Geomagnetism
  - Dourbes
- **Spacebased sensors**
  - GOES
  - SDO
  - PROBA2
  - SOHO
  - ACE
  - DSCOVR
  - STEREO
- Tools
- Overviews



Groundbased sensors

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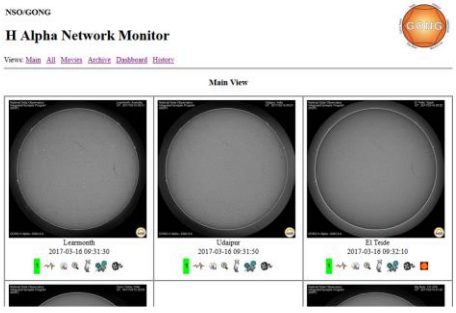
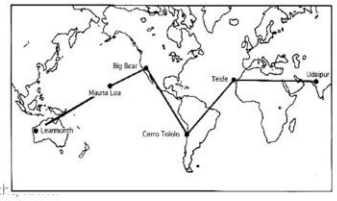
Visible light

- GONG Network
  - White Light
  - H-alpha
  - Magnetogram
- Sunspot number
  - SILSO
- USET
  - WL, Ha, CaIIK
  - 250 obs. days / yr
- Catania
- NOAA / (I)SOON
- K-Cor





GONG: **Global Oscillation Network Group (http://gong.nso.edu/)**
Originally developed to study solar oscillations
6 observing stations worldwide observing the Sun 24/7
The six sites comprising the GONG Network are:
The Big Bear Solar Observatory in California, USA.
The High Altitude Observatory at Mauna Loa in Hawaii, USA.
The Learmonth Solar Observatory in Western Australia.
The Udaipur Solar Observatory in India.
The Observatorio del Teide in the Canary Islands.
The Cerro Tololo Interamerican Observatory in Chile.
Links
H-alpha: http://halpha.nso.edu/index.html
White Light: https://gong2.nso.edu/products/mainView/table.php?configFile=configs/mainView.cfg
Magnetogram: https://gong2.nso.edu/products/mainView/table.php?configFile=configs/mainView.cfg

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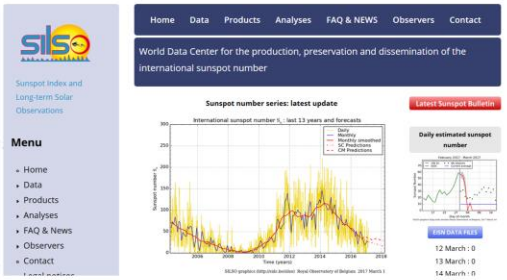

SWIC 2013 – Collaboration between STCE, Konin

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SILSO: http://sidc.oma.be/silso/ (Sunspot Index and Long-term Solar Observations)
USET: http://www.sidc.be/uset/ (Uccle Solar Equatorial Table)
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Catania and NOAA data are used as input for SIDC SWx forecasting

From the solar event listing at ftp://ftp.swpc.noaa.gov/pub/indices/events/README
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Events from GOES satellites data show the SWPC Primary or Secondary GOES spacecraft for the observatory, e.g. G12

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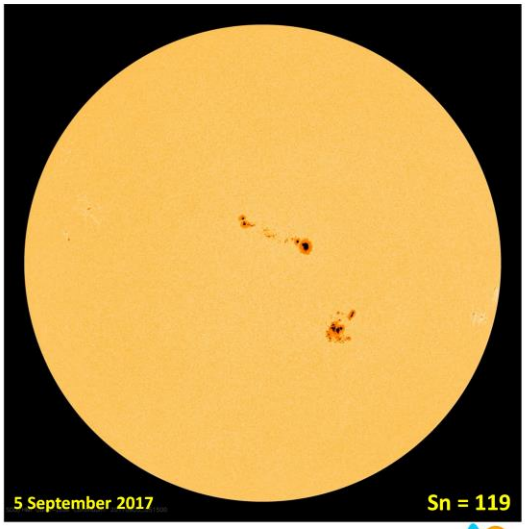
K-cor: http://download.hao.ucar.edu/d5/www/fullres/latest/latest.kcor.gif
Provides coronagraphic imagery. Large data gaps

Sunspot number & Solar cycle

- Sunspot number
  - Sn
    - Also called International Sunspot Number (ISN)
    - Network of observers
  - Sn = 10.g + s,
    - with g the number of groups, and s the number of spots
  - Determined by the SIDC/SILSO (Uccle)!
    - http://www.sidc.be/silso



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The International sunspot number is a quantity that measures the number of sunspots and groups of sunspots present on the surface of the sun.
It is computed from a number of international observers using the formula:

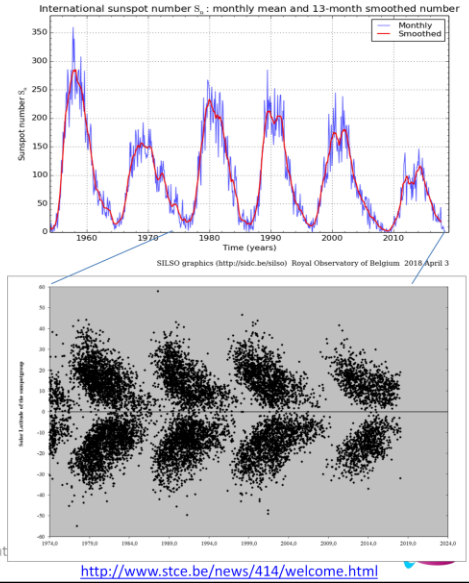
$$R = k (10 g + s)$$

where

s is the number of individual spots,
g is the number of sunspot groups, and
k is a factor that varies with location and instrumentation (also known as the observatory factor or the personal reduction coefficient). It is not to be computed or applied by the observer.

Sunspot number & Solar cycle

- Solar cycle
  - Avg. duration: +/- 11 years
    - Rise/Fall time: +/- 4 & 7 years
  - Avg. Sn_{max}: 184 (+/- 59)
    - SC24
      - Minimum: December 2008
      - Maximum: April 2014
      - Sn_{max} = 116.4
  - Butterfly diagram
    - Spots first appear at moderate latitudes (+/- 30°), then gradually move to equator
    - During SC minimum, groups of old and new SC exist



SWIC 2018 – Collaboration between STCE, Koninklijke Lucht

http://www.stce.be/news/414/welcome.html

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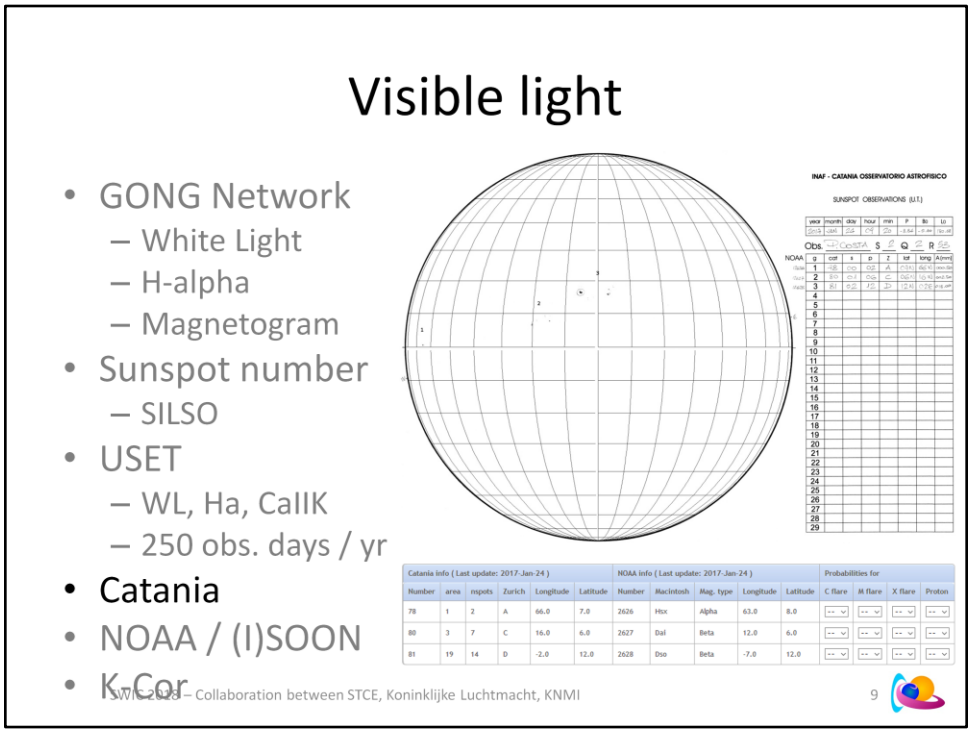

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:Issued: 2014 Apr 17 1325 UTC
:Product: documentation at http://www.sidc.be/products/tot
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DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
#---#
SIDC URSIGRAM 40417
SIDC SOLAR BULLETIN 17 Apr 2014, 1304UT

SIDC FORECAST (valid from 1230UT, 17 Apr 2014 until 19 Apr 2014)
SOLAR FLARES : Active (M-class flares expected, probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet

PREDICTIONS FOR 17 Apr 2014 10CM FLUX: 180 / AP: 013
PREDICTIONS FOR 18 Apr 2014 10CM FLUX: 184 / AP: 007
PREDICTIONS FOR 19 Apr 2014 10CM FLUX: 188 / AP: 005

Catania regions

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We expect quiet to unsettled (K index up to 3) geomagnetic conditions, with active geomagnetic conditions (K = 4) possible, but unlikely.

TODAY'S ESTIMATED ISN : 145, BASED ON 17 STATIONS.
99999

SOLAR INDICES FOR 16 Apr 2014
WOLF NUMBER CATANIA : ///
10CM SOLAR FLUX : 184
AK CHAMBON LA FORET : 012
AK WINGST : 004
ESTIMATED AP : 004
ESTIMATED ISN : 139, BASED ON 29 STATIONS.

Sunspot numbers

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
16 1954 1959 2004 S14E09 M1.0 1N 24/2035 II/2
END

Visible light

- GONG Network
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  - Magnetogram
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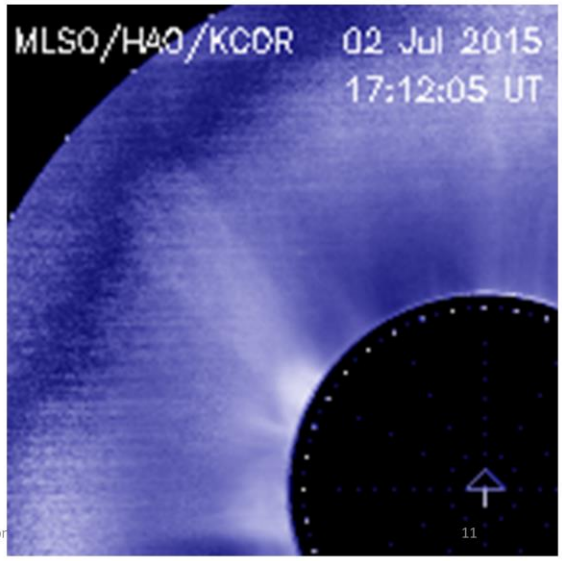

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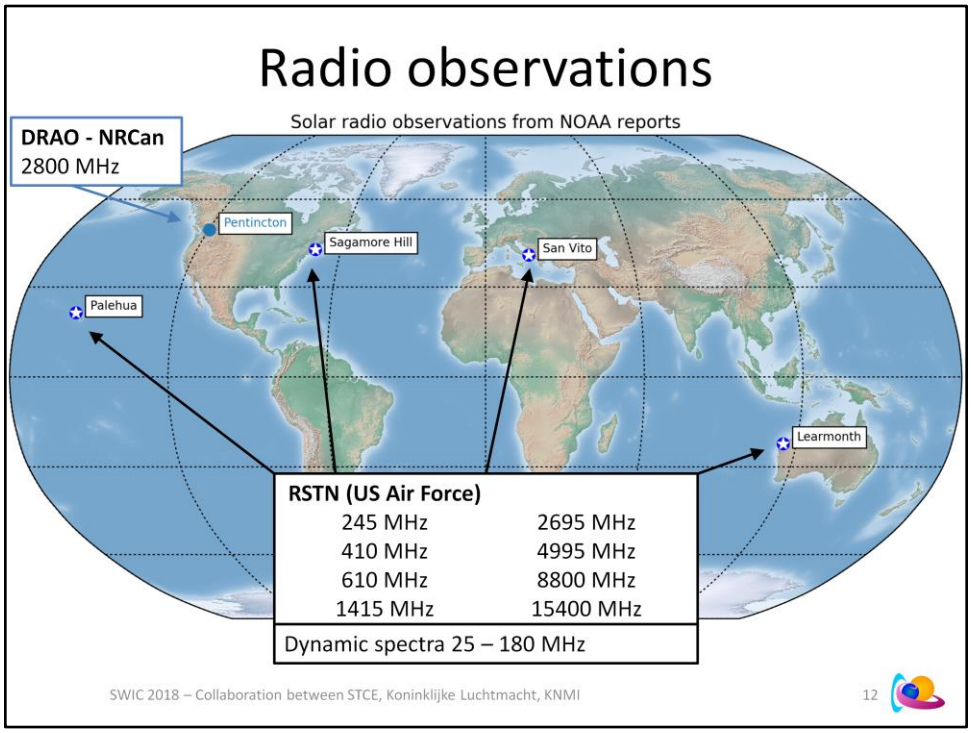
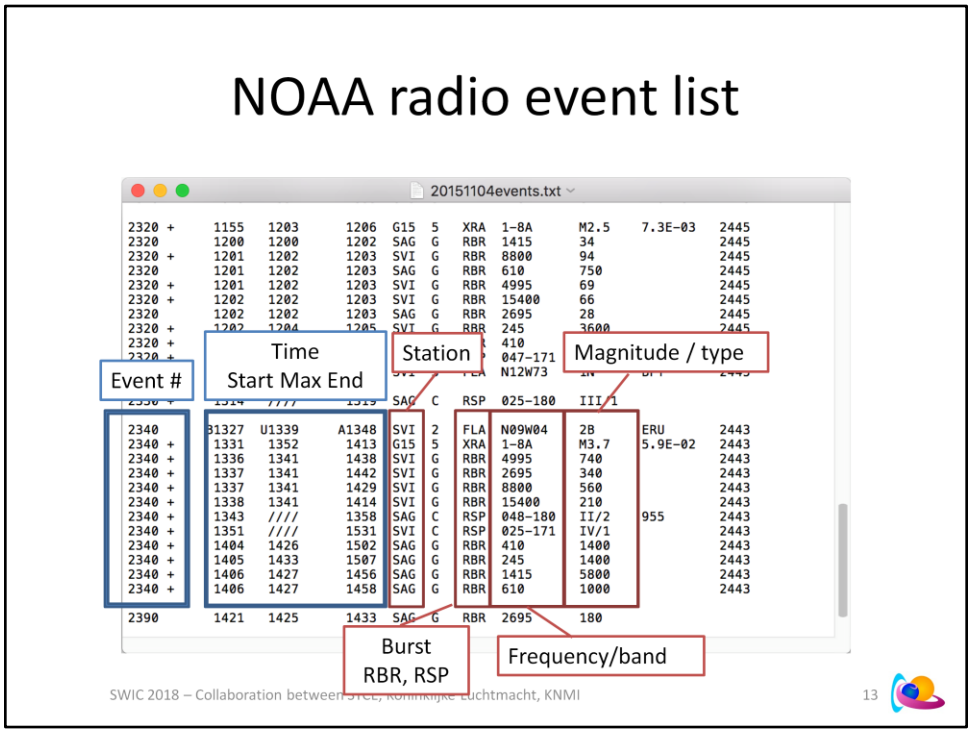
Also at https://www2.hao.ucar.edu/cosmo/k-cor
Provides coronagraphic imagery. Large data gaps, limited time coverage during the day.



The flux at 2800 MHz (10.7 cm) is measured since 1946-1947 in Canada. First in Ottawa, then in 1962 in Algonquin Radio observatory, 250 km away from Ottawa, and since 1990 in Penticton. This is the longest time series reflecting the solar activity besides the Sunspot Index (to which it highly correlates). More info in : K. F. Tapping, "The 10.7 cm solar radio flux (F10.7)", Space Weather, 11, 394, 2013

DRAO: Dominion Radio Astrophysical Observatory (https://www.nrc-cnrc.gc.ca/eng/solutions/facilities/drao.html)

The Radio Solar Telescope Network (RSTN) started its operation during the 1970s and is operated by the US Air Force. It consists of an ensemble of flux monitoring instruments and a set of radio spectrometers. Data are not available in real time, but reports of events are provided through NOAA. Data become available for scientists several months (or years!) afterwards.



NOAA radio event list available at http://www.swpc.noaa.gov/products/solar-and-geophysical-event-reports

Station Abbreviations:
SVI: San Vito
SAG: Sagamore Hill
PAL: Palehua
LEA: Learmonth
PEN: Pentincton

Type of Emission:
RBR: Radio Burst at fixed frequency
RSP: Radio Burst identified by its type in spectral data

Frequency:
Frequency of the burst (in MHz) or frequency range in which it is observed

Magnitude/type:
For bursts at fixed frequency: magnitude above quiet Sun in Solar Flux Unit
For bursts reported by type: type/magnitude (1-3: weak to strong). If type II a speed is given in km/s (here 955 km/s)

Radio burst magnitudes

Typ. Quiet Sun values [SFU]

Frequency	Solar min.	Solar max. (Z=200)
245 MHz	10	15
410 MHz	25	35
610 MHz	30	45
1415 MHz	50	100
2695 MHz	70	200
2800 MHz	70	200
4995 MHz	100	200
8800 MHz	220	290
15400 MHz	580	650

How frequently bursts of a certain magnitude occur? 1 event every X days

f < 2000 MHz

Magnitude	Solar min.	Solar max.
1000	5 days	0.7 day
10000	34 days	4 days
100000	212 days	17 days

f > 2000 MHz

Magnitude	Solar min.	Solar max.
1000	38 days	6 days
10000	247 days	39 days
100000	1594 days	255 days

The left table reports typical values observed for the quiet Sun during minimum and maximum conditions. There can be lower and higher values but this is just to give an idea.

Values from the tables to the Right are derived from the paper by Nita et al. 2002. This gives in how many days on average a burst of a certain magnitude happens in each band. If we take a finer frequency band definition, the numbers can be different (see next slide).

Nita et al., 2002
The Peak Flux Distribution of Solar Radio Bursts
http://adsabs.harvard.edu/abs/2002ApJ...570..423N

Radio burst magnitude

100 MHz < f < 900 MHz

Magnitude	Solar Min.	Solar Max.
1000	6 days	0.75 days
10000	36 days	4 days
100000	223 days	17 days

1000 MHz < f < 1700 MHz

Magnitude	Solar Min.	Solar Max.
1000	65 days	12 days
10000	385 days	75 days
100000	2266 days	450 days

The right table shows more interesting statistics for a frequency band that covers GNSS services and air traffic radar and surveillance bands

Penticton

- Flux measurement at 2800 MHz (10.7 cm), 100 MHz bandwidth
- 3 times per day
- "official" value for the day is the one of 20:00 UT (local noon)
- Accuracy:
  - < 100 sfu: 1 sfu
  - > 100 sfu: 1% of flux
- Uncorrected for solar flares

Information from: K. F. Tapping, "The 10.7 cm solar radio flux (F10.7)", Space Weather, 11, 394, 2013

Daily 10.7cm solar radio fluxes from Penticton at http://www.spaceweather.ca/solarflux/sx-4a-en.php

Daily radio fluxes (other wavelengths) at http://legacy-www.swpc.noaa.gov/ftpdir/lists/radio/rad.txt

Solar flux unit:
1 sfu = 10–22 W m–2 Hz–1

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10.7cm Radio flux

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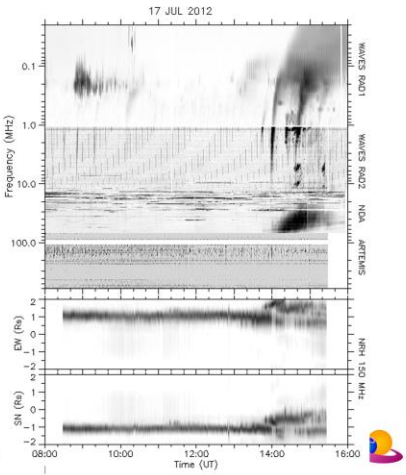
Nançay radio observations

- Nançay Radioheliograph
  - Imaging at several frequencies 150 – 450 MHz
- ORFEES spectrograph (130 – 1000 MHz)

https://realtime.obs-nancay.fr/orfees/

Archives: http://secchirh.obspm.fr

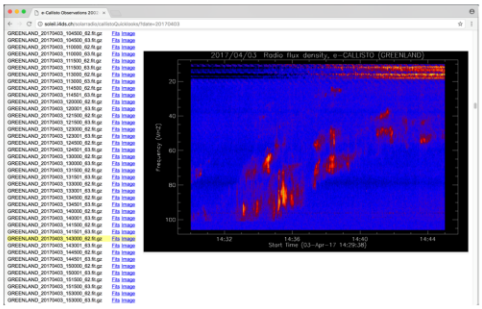


The Nançay Radioheliograph (NRH) provides 2d imaging of the solar corona between 150 and 450 MHz. It reveals radio emission associated with active regions (with sunspots) called noise storms. When an eruptive event occurs, imaging of different types of bursts (type II, type III, type IV etc…) is made. When solar activity is low, the quiescent corona becomes visible, showing the extent of large scale coronal structures (streamers, coronal holes etc…). The instrument is currently off for hardware upgrade.
The ORFEES spectrograph covers the band 130 – 1000 MHz and complements the imaging observations by providing the spectral type of the bursts. It's an instrument specifically built for space weather operations by a joint effort between the Paris Observatory and the French Air Force.

ORFEES (Observation Radio Fréquences pour l'Etude des Eruptions Solaires)
https://realtime.obs-nancay.fr/orfees/
https://www.obs-nancay.fr/-ORFEES-38-.html?lang=en

The 17 July 2012 event:
1260 + 1203 1715 1904 G15 5 XRA 1-8A M1.7 2.1E-01 1520
1330 1307 //// 1952 SAG C RSP 039-180 CTM/1
1260 + 1328 U1643 A1802 COM 3 FLA S28W65 1F 1520
1280 + 1328 1348 1356 SVI G RNS 245 260
1240 B1348 //// 1730 SOH 4 CME XUV,EUV,UV153-304/FS814 1520

Callisto Network



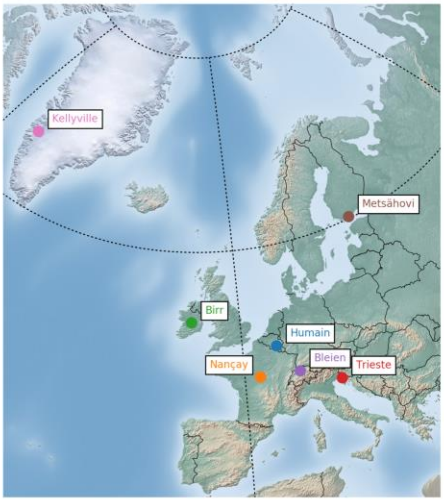
http://soleil.i4ds.ch/solarradio/callistoQuicklooks/

- Network of identical low cost analog receivers (~130 stations over the world)
- http://www.e-callisto.org/
- **Real time in Europe**
  - Birr Castle (Ireland): BIR
  - Humain (Belgium): HUMAIN
  - Bleien (Switzerland): BLEN5M, BLENSW
  - Trieste (Italy): TRIEST
  - Metsähovi (Finland): MRO
  - Kellyville (Greenland): GREENLAND

The e-Callisto network is a collection of individual Callisto receivers designed and set up by C. Monstein (ETH Zürich). Callisto receivers are based on an analog TV tuner (originally from Philips) that is controlled to scan the spectrum between 45 and 870 MHz. Up to 200 frequencies can be programmed in that range. Each station has its own set up (different antenna, front-end and frequency program). The stations mentioned here are the ones, in Europe, that are providing regular data to the network and are operated by institutional bodies.

Callisto stands for: Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory
e-callisto stands for the network of callisto observatories.

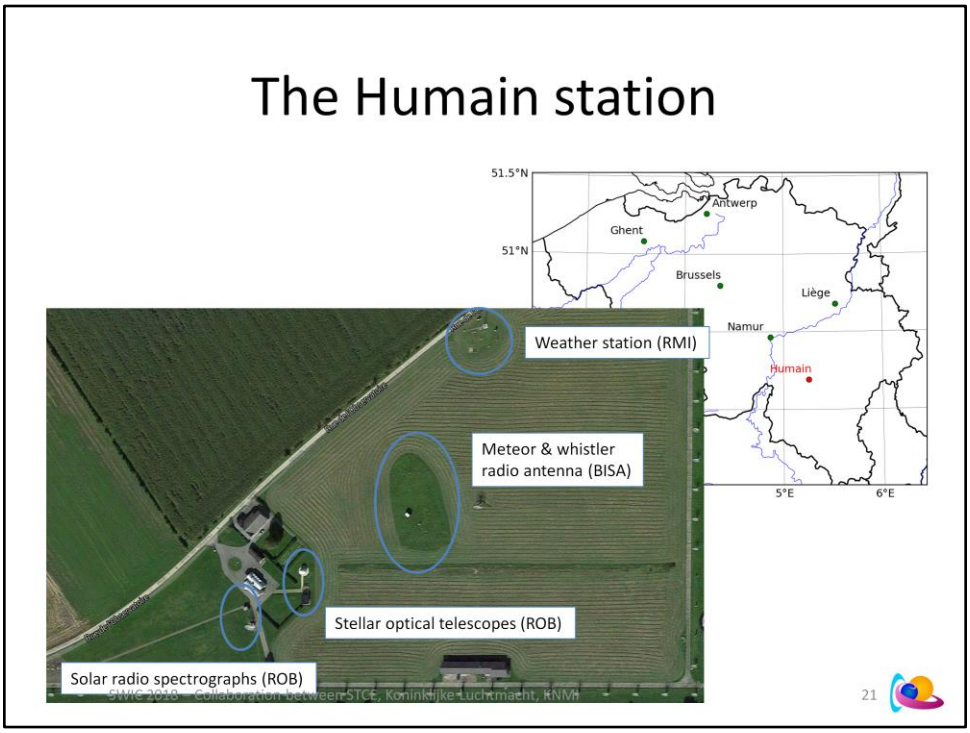
European solar radio observatories
with real-time access



SWIC 2018 – Collaboration between STCE, Koninklijke Luchtmacht, KNMI 20

This map shows the locations of solar radio instruments operated by professional bodies (institutes, observatories etc…). Their data (essentially dynamic spectra) are available in real time or near real time

Available at e-Callisto at http://soleil.i4ds.ch/solarradio/callistoQuicklooks/



About 120 km south–east of Brussels

Humain: Solar instruments

- 6-m dish
- Automated operations, Sun tracking ~7h30 – 16h00 UT
- VHF antenna (piggy back)
- UHF antenna at focus

- VHF antenna (45 – 450 MHz)
  - Callisto receiver
  - ARCAS receiver
- UHF antenna (275 – 1495 MHz)
  - HSRS receiver

The ARCAS and HSRS receivers are based on commercial Software Defined Radio receivers. The RF signal is digitized and all operations needed to create the dynamic spectrum is made by programming on a control PC. The development of ARCAS and HSRS was made at ROB.

Callisto stands for: Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory
ARCAS stands for Augmented Resolution Callisto Spectrometer - http://www.stce.be/news/369/welcome.html
HSRS stands for HUMAIN Solar Radio Spectrograph - http://www.stce.be/news/326/welcome.html

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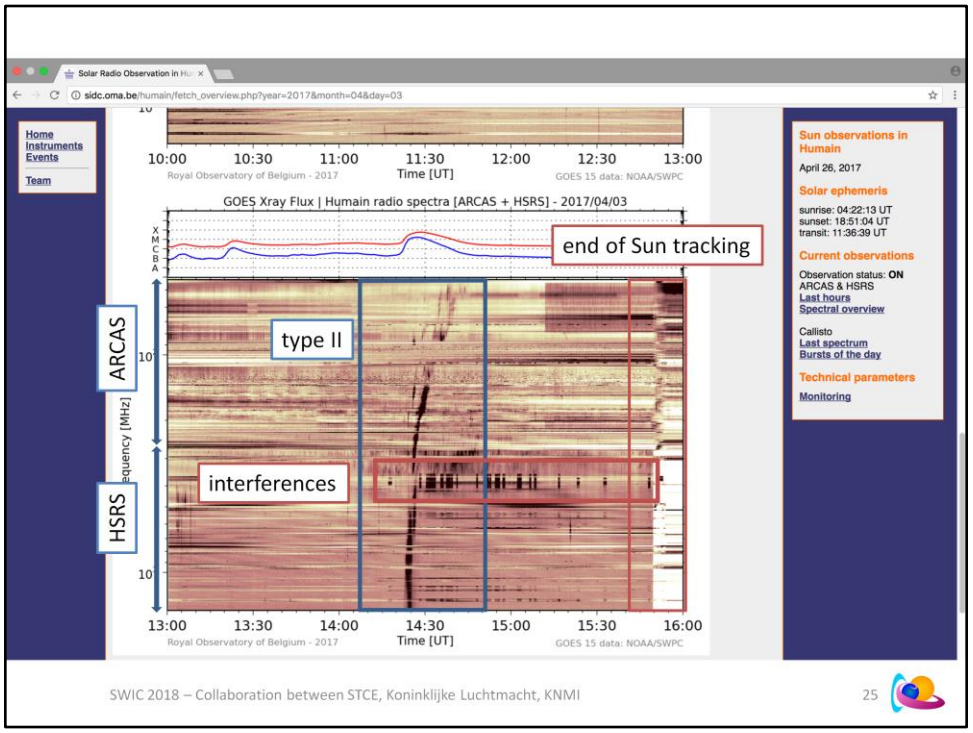
Humain: Solar instruments

	Callisto	ARCAS	HSRS
Type	Analog receiver	Digital	Digital
Frequency band	45 – 447 MHz	45 – 450 MHz	275 – 1495 MHz
Frequency resolution	63 kHz	98 kHz	98 kHz
Time resolution	250 ms	~ 84 ms	~ 250 ms
# of frequencies	200	~ 4.2 k	~ 12.5 k

Data available in near realtime
http://sidc.be/humain



See also the news item at http://www.stce.be/news/384/welcome.html for this event.

:Issued: 2014 Apr 17 1325 UTC
:Product: documentation at http://www.sidc.be/products/tot
#----------#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
#----------#
SIDC URSIGRAM 40417
SIDC SOLAR BULLETIN 17 Apr 2014, 1304UT

SIDC FORECAST (valid from 1230UT, 17 Apr 2014 until 19 Apr 2014)
SOLAR FLARES : Active (M-class flares expected, probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet

PREDICTIONS FOR 17 Apr 2014 10CM FLUX: 180 / AP: 013
PREDICTIONS FOR 18 Apr 2014 10CM FLUX: 184 / AP: 007
PREDICTIONS FOR 19 Apr 2014 10CM FLUX: 188 / AP: 005

COMMENT: Eleven sunspot groups were reported by NOAA today. NOAA ARs 2035,2036, and 2037 (Catania numbers 24, 25, and 26 respectively) maintain the beta-gamma configuration of the photospheric magnetic field. The strongest flare of the past 24 hours was the M1.0 flare peaking at 19:59 UT yesterday in the NOAA AR 2035 (Catania number 24). The flare was associated with an EIT wave and a weak coronal dimming, but the associated CME was narrow and is not expected to arrive at the Earth.
We expect further flaring activity on the C-level, especially in the NOAA ARs 2035 and 2037 (Catania numbers 24 and 26 respectively) as well as in the NOAA AR 2042 (no Catania number yet) that yesterday appeared from behind the east solar limb, with a good chance for an M-class event.

Since yesterday evening the Earth is situated inside a solar wind structure with an elevated interplanetary magnetic field magnitude (occasionally up to 10 nT). It may be a weak ICME or the compression region on the flank of an ICME that missed the Earth. The solar origin of this structure is not clear. The north-south magnetic field component Bz was not strong, so no significant geomagnetic disturbance resulted (K index stayed below 4). Currently the solar wind speed is around 380 km/s and the IMF magnitude is around 8 nT.
We expect quiet to unsettled (K index up to 3) geomagnetic conditions, with active geomagnetic conditions (K = 4) possible, but unlikely.

TODAY'S ESTIMATED ISN : 145, BASED ON 17 STATIONS.
99999

SOLAR INDICES FOR 16 Apr 2014
WOLF NUMBER CATANIA : ///
10CM SOLAR FLUX : 184
AK CHAMBON LA FORET : 012
AK WINGST : 004
ESTIMATED AP : 004
ESTIMATED ISN : 139, BASED ON 29 STATIONS.

Radio bursts

NOTICEABLE EVENTS SUMMARY

DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM	Catania/NOAA	RADIO_BURST_TYPES
16	1954	1959	2004	S14E09	M1.0	1N		24/2035	II/2

END

Magnetosphere - Ionosphere

Magnetosphere

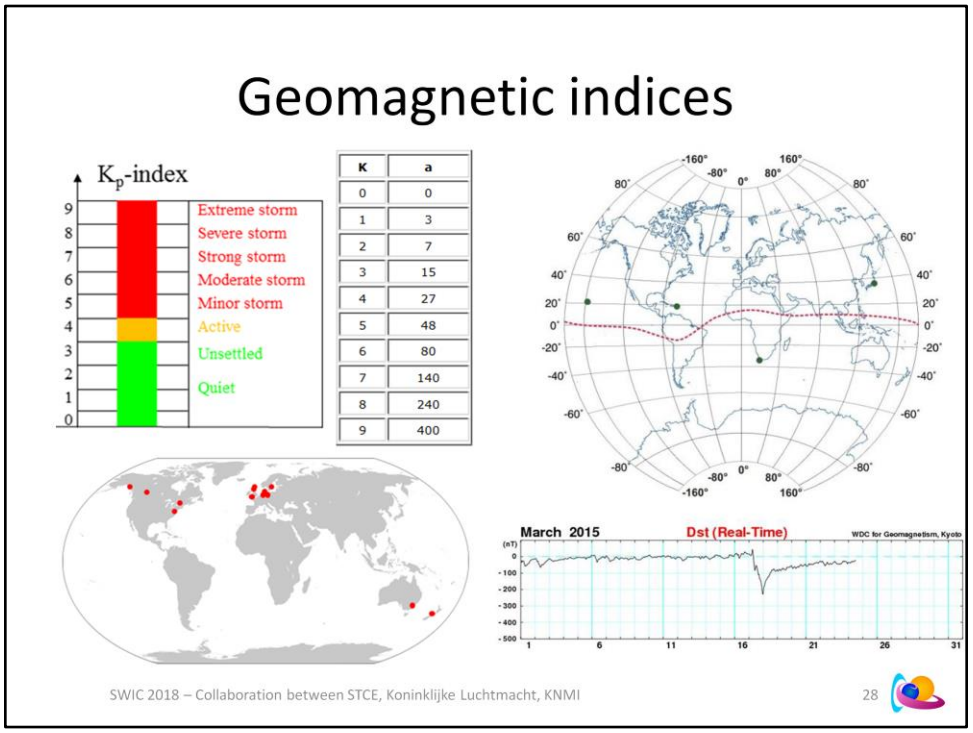
- Magnetometers
- Neutron monitors
- …

  – See **Earth Environment - Magnetosphere**

Ionosphere

- Ionospheric sounders
- GNSS
- …

  – See **Earth Environment – Ionosphere**



SWPC Kp index: http://www.swpc.noaa.gov/products/planetary-k-index
Dst index (Kyoto WDC): http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/presentmonth/index.html
GOES Hp: http://origin-www.swpc.noaa.gov/products/goes-magnetometer

http://www.swpc.noaa.gov/sites/default/files/images/u2/TheK-index.pdf

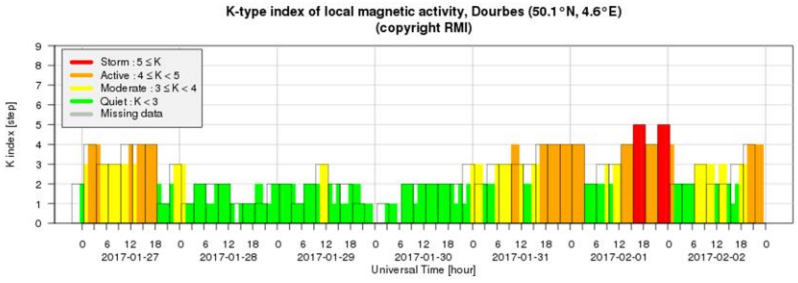
The A-index was invented because there was a need to derive some kind of daily average level for geomagnetic activity. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take averages of a set of K indices.

http://www.stce.be/news/243/welcome.html

http://www.stce.be/news/301/welcome.html

Cander et al. (1998): Forecasting ionospheric structure during the great geomagnetic storms
http://adsabs.harvard.edu/abs/1998JGR...103..391C
The size of a geomagnetic storm is classified as moderate (−50 nT > minimum of Dst > −100 nT), intense (−100 nT > minimum Dst > −250 nT) or super-storm (minimum of Dst < −250 nT).

Dourbes



Dourbes:
Geomagnetism: http://ionosphere.meteo.be/geomagnetism/ground_K_dourbes
Neutron monitor: http://www.nmdb.eu/
Ionosphere: http://digisonde.oma.be/

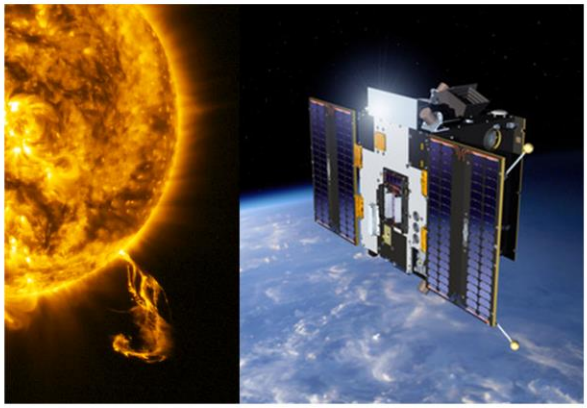
Exercise: 10.7cm Radio Flux

- It is 17 April 2014, and the solar cycle (SC24) is in its period of maximum solar activity. The 10.7cm radio flux for that day (at 20UT) is reported to be 600 sfu. This is:
  - ✘ A typical value for the radio flux during SC max
  - ✓ A radio flux value affected by a strong solar flare

Contents

- **Groundbased sensors**
  - Visible light
  - Radio domain
  - Magnetosphere-Ionosphere
  - Geomagnetism
  - Dourbes
- Tools
- Overviews

- **Spacebased sensors**
  - GOES
  - SDO
  - PROBA2
  - SOHO
  - ACE
  - DSCOVR
  - STEREO



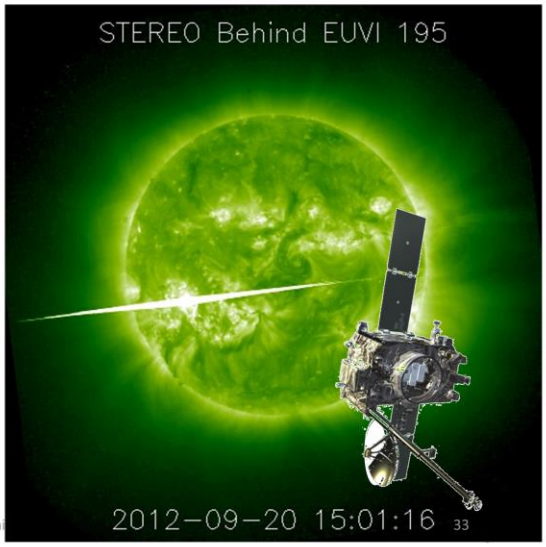
Spacebased sensors

Jan Janssens

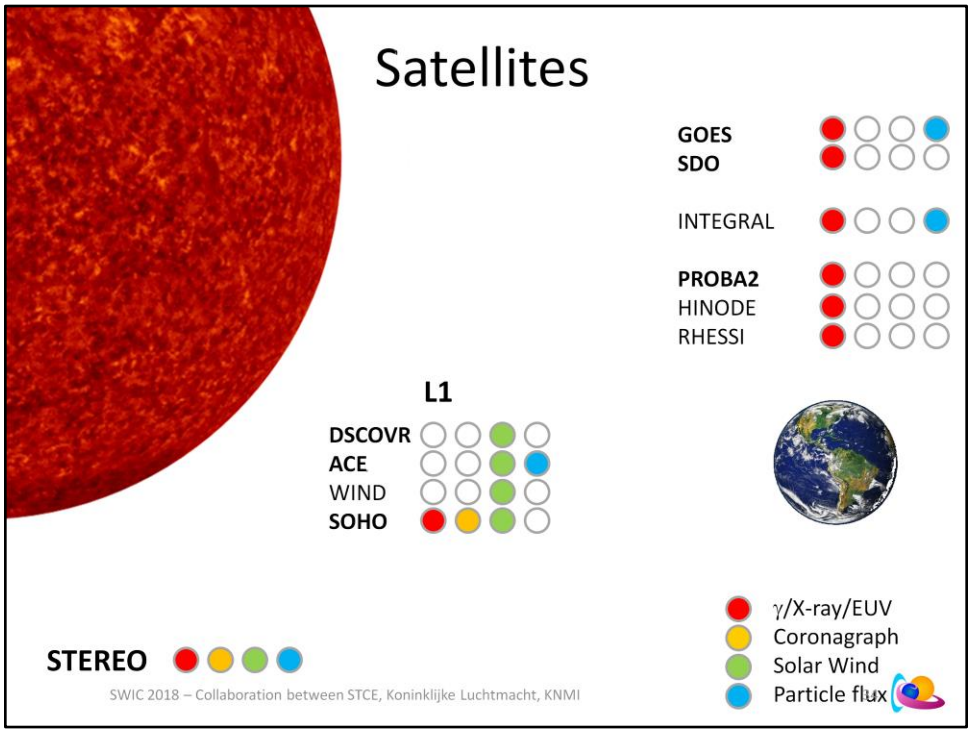
PROBA2 and picture of the Sun

Why do we need SWx satellites?

- EUV and X-ray (solar atmosphere)
  - Flares & Coronal holes
- Coronagraphs
- Solar wind (in-situ)
- Solar farside
  - 20 September 2012
  - 23 July 2012
  - …
- Radio
  - Triangulation
  - Low frequencies
- Science
- White light (24hrs)
-



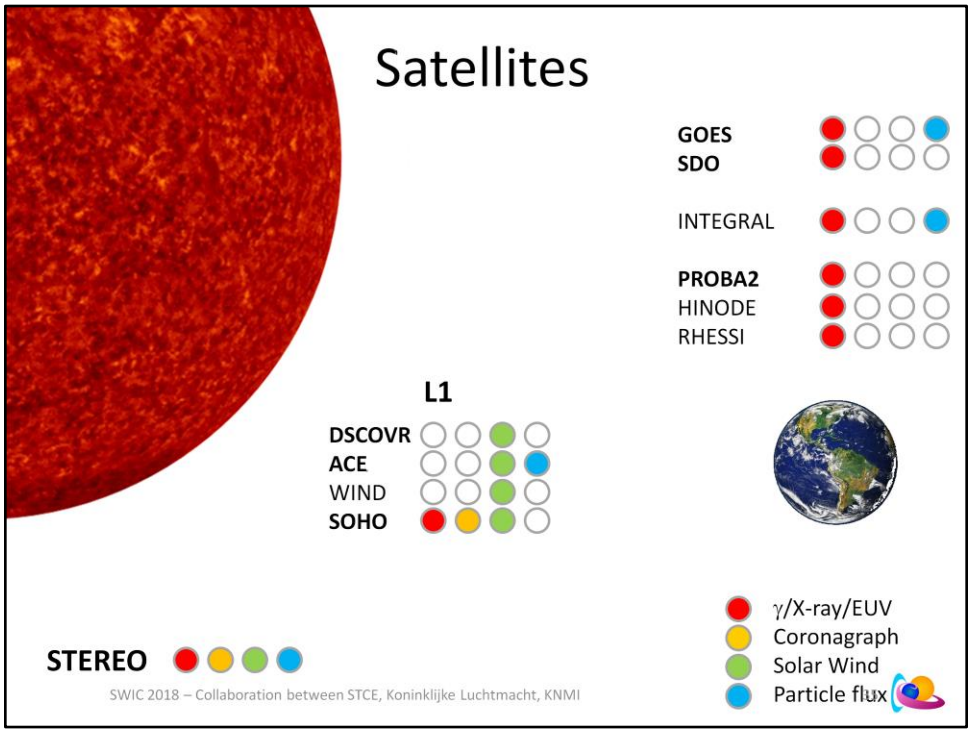
More on the 20 September 2012 flare at http://www.stce.be/news/263/welcome.html



Lagrangian points: https://en.wikipedia.org/wiki/Lagrangian_point

Earth orbits: https://en.wikipedia.org/wiki/List_of_orbits#Altitude_classifications_for_geocentric_orbits

* GEO: GOES, SDO (inclined)
Advantages and disadvantages of SDO in GEO at https://sdo.gsfc.nasa.gov/mission/project.php
Orbit
The rapid cadence and continuous coverage required for SDO observations led to placing the satellite into an inclined geosynchronous orbit. This allows for a nearly-continuous, high-data-rate, contact with a single, dedicated, ground station.
Nearly continuous observations of the Sun can be obtained from other orbits, such as low Earth orbit (LEO). If SDO were placed into an LEO it would be necessary to store large volumes of scientific data onboard until a downlink opportunity. The large data rate of SDO, along with the difficulties in managing a large on-board storage system, resulted in a requirement of continuous contact.
The disadvantages of this orbit include higher launch and orbit acquisition costs (relative to LEO) and eclipse (Earth shadow) seasons twice annually, During these 2-3 week eclipse periods, SDO will experience a daily interruption of solar observations. There will also be three lunar shadow events each year from this orbit.
This orbit is located on the outer reaches of the Earth's radiation belt where the radiation dose can be quite high. Additional shielding was added to the instruments and electronics to reduce the problems caused by exposure to radiation. Because this is a Space Weather effect, SDO is affected by the very processes it is designed to study!



Lagrangian points: https://en.wikipedia.org/wiki/Lagrangian_point

Earth orbits: https://en.wikipedia.org/wiki/List_of_orbits#Altitude_classifications_for_geocentric_orbits

* M/HEO: **INTEGRAL** (INTErnational Gamma-Ray Astrophysics Laboratory)
http://space-env.esa.int/index.php/SREM_Plots.html
SREM: Standard Radiation Environment Monitor
http://srem.web.psi.ch/html/srem_home.shtml
Integral is the last remaining operational radiation monitor.

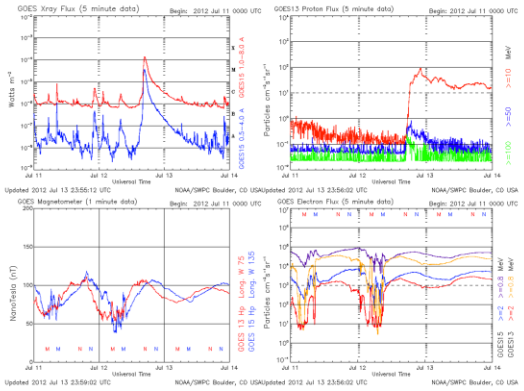
* LEO: PROBA2, HINODE, RHESSI, FERMI
Hinode: http://hinode.nao.ac.jp/gallery/latest/
XRT: X-Ray Telescope ; Also at https://www.solarmonitor.org/
RHESSI: Reuven Ramaty High Energy Solar Spectroscopic Imager
https://hesperia.gsfc.nasa.gov/rhessi3/
PROBA2: PRoject for Onboard Autonomy
http://proba2.oma.be/ssa
FERMI: Fermi Gamma-ray Space Telescope
http://www.astronomerstelegram.org/?read=10720 (detections of solar gamma ray bursts)

* L1: First Lagrangian point
DSCOVR, ACE, SOHO
Wind: https://pwg.gsfc.nasa.gov/windnrt/

* Solar orbit
STEREO

GOES

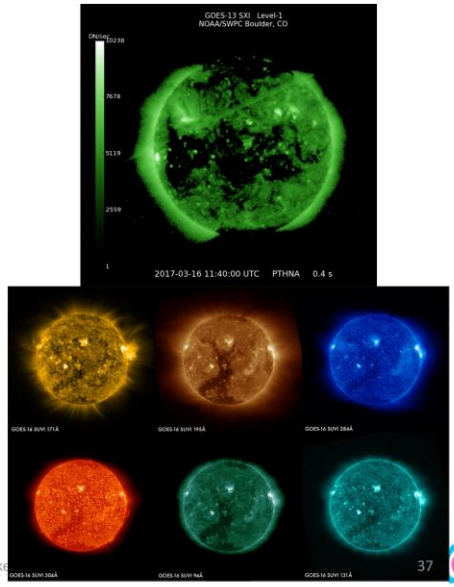
- X-ray flux
- Proton flux
- Magnetic field
- Electron flux
- Imagery
  - GOES-12-15
    - X-ray: SXI
  - GOES-16
    - EUV: SUVI



X-ray flux: http://www.swpc.noaa.gov/products/goes-x-ray-flux
More info at https://www.ngdc.noaa.gov/stp/satellite/goes/doc/GOES_XRS_readme.pdf
Proton flux: http://www.swpc.noaa.gov/products/goes-proton-flux
Magnetic field: http://www.swpc.noaa.gov/products/goes-magnetometer
Electron flux: http://www.swpc.noaa.gov/products/goes-electron-flux
Imagery (X-ray): http://www.swpc.noaa.gov/products/goes-solar-x-ray-imager-sxi

GOES

- X-ray flux
- Proton flux
- Magnetic field
- Electron flux
- Imagery
  - GOES-12-15
    - X-ray: SXI
  - GOES-16
    - EUV: SUVI
      - Safe mode



Imagery (X-ray): http://www.swpc.noaa.gov/products/goes-solar-x-ray-imager-sxi
Solar X-ray Imager

GOES-16/SUVI has been operationally checked out.
SUVI and 4 other instruments onboard GOES-16 have been put in safe mode as of 20 December 2017.
They will enter into operations as required.
https://www.nesdis.noaa.gov/GOES-R-Series-Satellites

Imagery (SUVI): http://www.goes-r.gov/spacesegment/suvi.html
Solar UltraViolet Imager

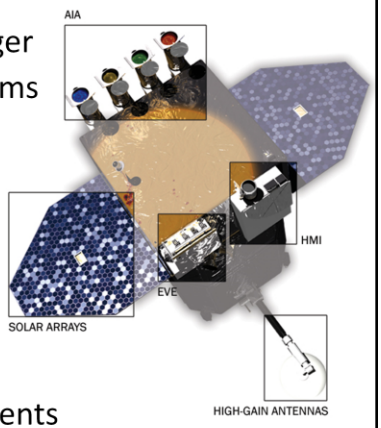
SUVI

Wavelength Log (Te)	94 Å 6.8	131 Å 7.0,7.2	171 Å 5.8	195 Å 6.1,7.3	284 Å 6.3	304 Å 4.7
Filaments						■
Coronal Holes					■	
Active Region Complexity		▒	■	■		
CMEs (e.g. dimming)			■	■		
Flare Location and Morphology	■	■				
Quiet Regions		▒	■	■		■

Table from https://www.goes-r.gov/spacesegment/suvi.html

SDO

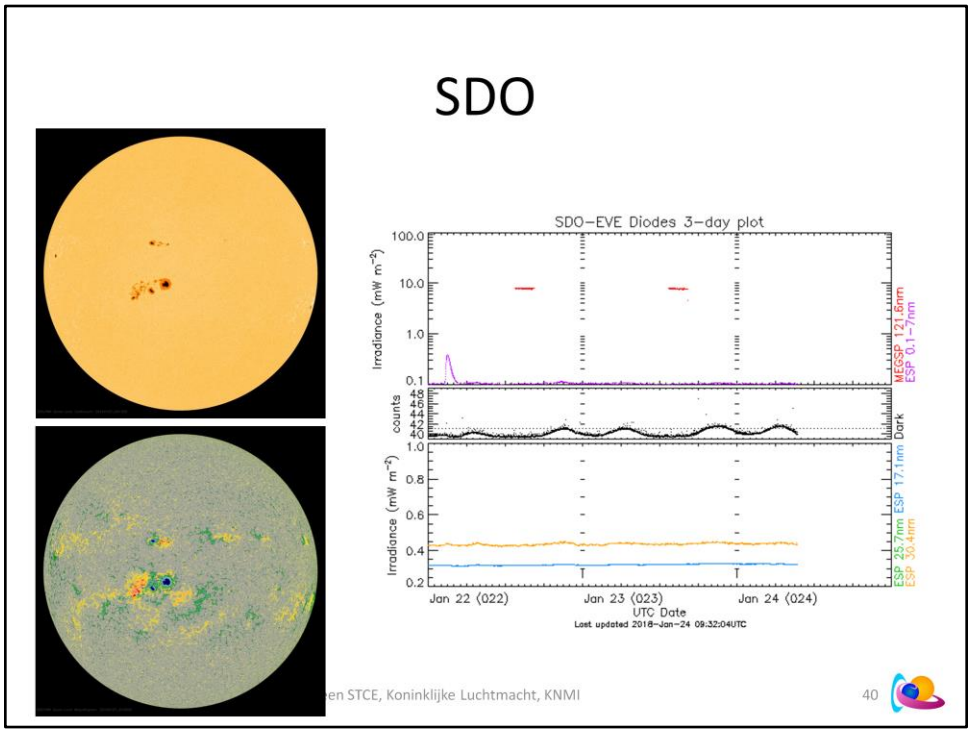
- HMI
  - Helioseismic and Magnetic Imager
  - « White light » and Magnetograms
- AIA
  - Atmospheric Imaging Assembly
  - EUV imagery in 10 filters
- EVE
  - Extreme ultraviolet Variability Experiment
  - Scaled to GOES x-ray measurements



Imagery and data at https://sdo.gsfc.nasa.gov/data/

AIA: Instument description and characteristics of filters:
Boerner et al., 2012: http://adsabs.harvard.edu/abs/2012SoPh..275...41B
http://jsoc.stanford.edu/HMI/docs/AIA_calibration.pdf

https://www.nasa.gov/pdf/417176main_SDO_Guide_CMR.pdf



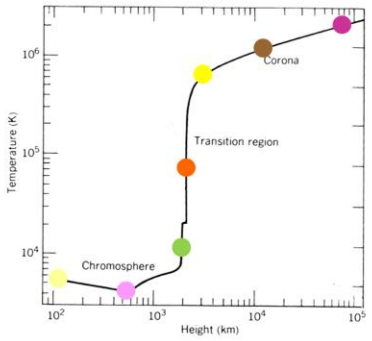
ESP: EUV SpectroPhotometer
MEGS: multiple EUV grating spectrograph (-A no longer operational)
SAM: Solar Aspect Monitor (no longer operational)

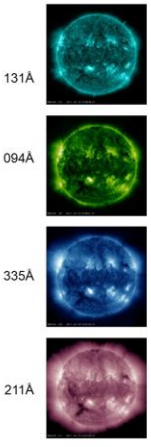
The EVE proxy for x-ray flux is at
http://lasp.colorado.edu/eve/data_access/sdo_xray_proxy/eve_goes_xray_proxy
B9.5 flare on 22 January 2018

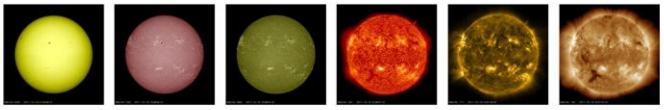
Crotser et al. (2004): SDO-EVE multiple EUV grating spectrograph (MEGS) optical design
http://adsabs.harvard.edu/abs/2004SPIE.5563..182C
The NASA Solar Dynamics Observatory (SDO), scheduled for launch in 2008, incorporates a suite of instruments including the EUV Variability Experiment (EVE). The EVE instrument package contains grating spectrographs used to measure the solar extreme ultraviolet (EUV) irradiance from 0.1 to 105 nm. The Multiple EUV Grating Spectrograph (MEGS) channels use concave reflection gratings to image solar spectra onto CCDs that are operated at -100°C. MEGS provides 0.1nm spectral resolution between 5-105nm every 10 seconds with an absolute accuracy of better than 25% over the SDO 5-year mission. MEGS-A utilizes a unique grazing-incidence, off-Rowland circle (RC) design to minimize angle of incidence at the detector while meeting high resolution requirements. MEGS-B utilizes a double-pass, cross-dispersed double-Rowland circle design. MEGS-P, a Ly-α monitor, will provide a proxy model calibration in the 60-105 nm range. Finally, the Solar Aspect Monitor (SAM) channel will provide continual pointing information for EVE as well as low-resolution X-ray images of the sun. In-flight calibrations for MEGS will be provided by the on-board EUV Spectrophotometer (ESP) in the 0.1-7nm and 17-37nm ranges, as well as from annual under-flight rocket experiments. We present the methodology used to develop the MEGS optical design.

SDO

- AIA
  - Some filters peak at multiple temperatures
  - AIA 4500 no longer in use







More info at http://aia.lmsal.com/public/instrument.htm
And at https://www.nasa.gov/content/goddard/how-sdo-sees-the-sun

SDO/AIA: Filters & Features

Filter/Wavelength (Å) **Temperature* (K)**	1700 6K	1600 10K	304 80K	171 700K	193 1.25M	211 2M	335 2.8M	94 6M	131 10M
Coronal holes				\	X	X	\		
CMEs: Coronal wave/dimming				\	X	X			
CMEs: ejections			X	X	X	\			\
Coronal loops			\	X	\				\
Flare ribbons		X	\	\	\	\			
Flare locations		\					\	X	X
Flares				\	\	\	\	X	X
Jets			X	\			\	\	X
Filament channels				\	X	X			
Filaments/Prominences			X	\	X	X			\
Sunspots		X							

X : Optimal line to see feature; \ : Reasonably visible ; "blanc" denotes barely or not visible

* : Most filters peak at more than 1 temperature, have a broad bandpass, and see many of the features mentioned. The 1700Å filter is contaminated by continuum and C IV.

More info at http://aia.lmsal.com/public/instrument.htm
And at https://www.nasa.gov/content/goddard/how-sdo-sees-the-sun

Table in collaboration with Dr Matt West (ROB/SIDC).

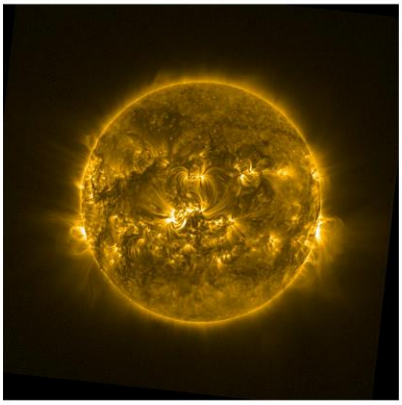
SDO

Credits: NASA / Goddard Space Flight Centre

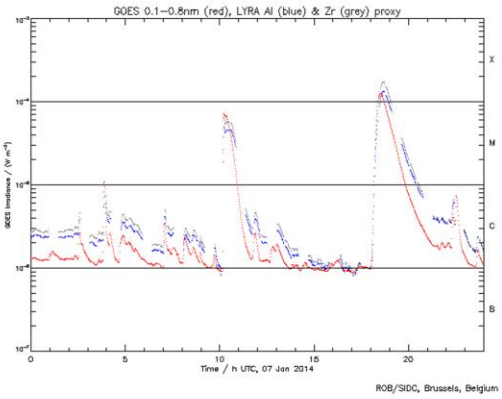
Credits: NASA/GSFC
https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11385

PROBA2

SWAP



LYRA



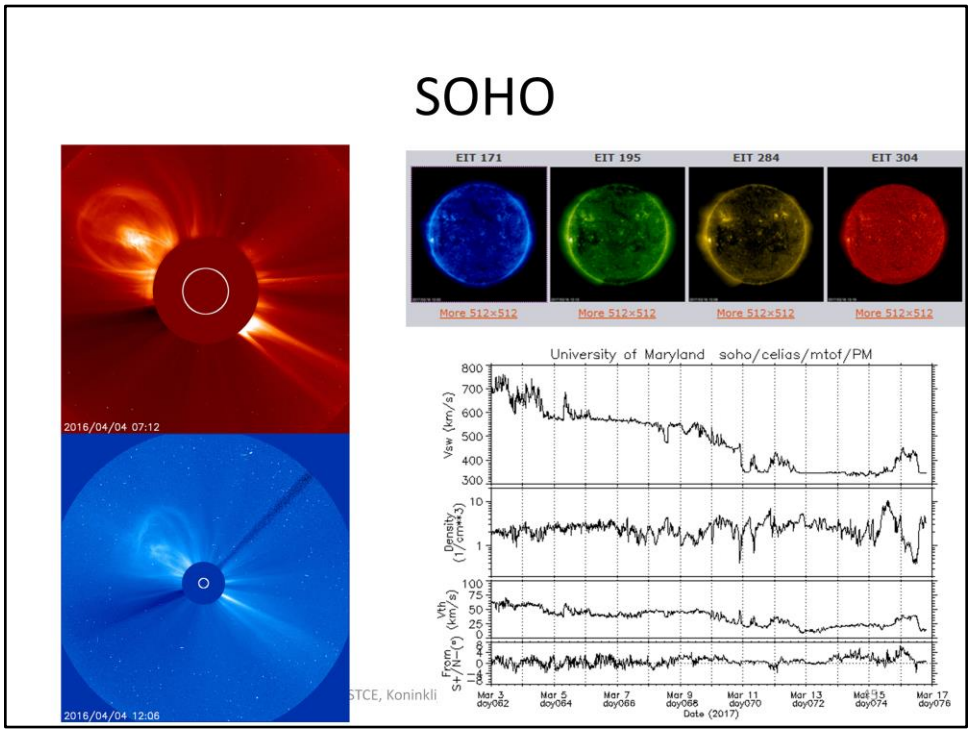
SWIC 2018 – Collaboration between STCE, Koninklijke Luchtmacht, KNMI 44

Data and imagery at http://proba2.oma.be/ssa

From P2SC: http://p2web.oma.be/about/sciencePayload

LYRA (**L**arge **Y**ield **RA**diometer, formerly **LY**man alpha **RA**diometer) is an ultraviolet irradiance radiometer that observes the Sun in four passbands, chosen for their relevance to solar physics, aeronomy and space weather. This instrument can also detect flares and analyze the atmospheric composition of the Earth.

SWAP (**S**un **W**atcher using **A**ctive Pixel System detector and Image **P**rocessing) is a small EUV telescope that images the solar corona with a bandpass around 17.4 nm, corresponding to a temperature of 1 million degrees. SWAP continues the systematic CME watch program of EIT at an improved cadence and monitors events in the lower solar corona that might be relevant for space weather.



SOHO: Solar and Heliospheric Observatory
Launched on 2 December 1995 and still observing from the L1 point!

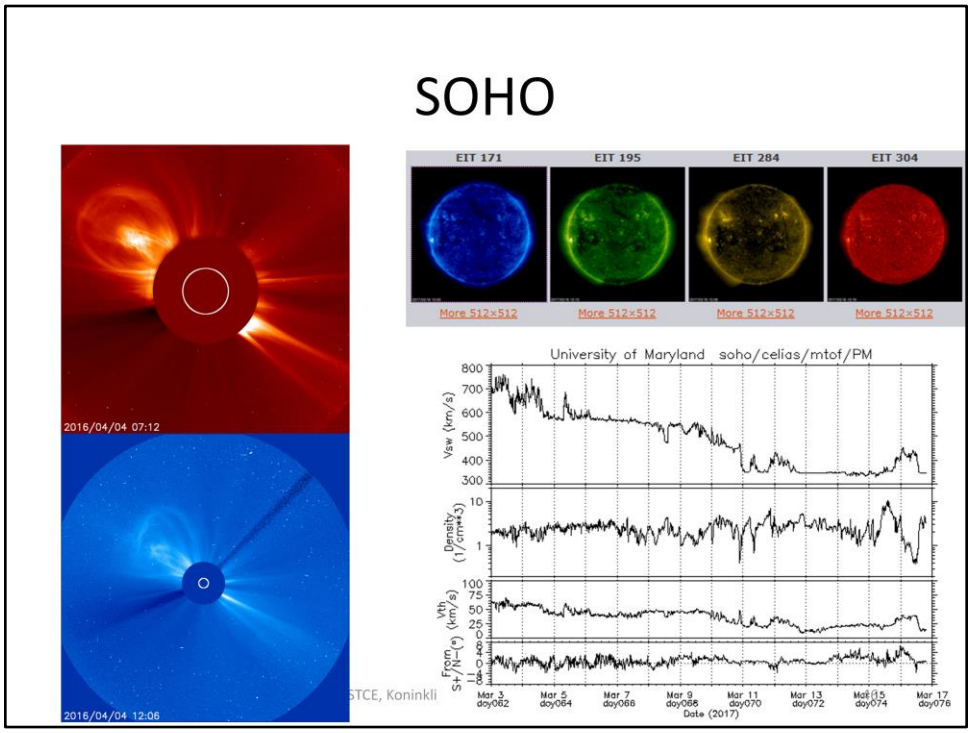
EIT and coronagraphic imagery at https://sohowww.nascom.nasa.gov/data/realtime-images.html
The passbands and related temperatures are similar to SDO/AIA, with the 28.4 nm filter corresponding to 2 million degrees.

Solar wind data (and shocks) at http://umtof.umd.edu/pm/

EIT: Extreme ultraviolet Imaging Telescope
CELIAS: Charge, Element, and Isotope Analysis System
MTOF: Mass Tome-of-Flight sensor
LASCO: Large Angle and Spectrometric Coronagraph
http://star.mpae.gwdg.de/

- C2 (1.5-6 solar radii)
- C3 (outer: 3-32 solar radii)

The C1 (inner: 1.1-3 solar radii) is no longer operational following SOHO's summer holidays in 1998:
https://lasco-www.nrl.navy.mil/index.php?p=content/intro
LASCO comprises of three telescopes (C1, C2 and C3), each of which looks at an increasingly large area surrounding the Sun. For the first year-and-a-half of the SOHO mission, all three instruments worked perfectly. However, in 1998 SOHO was accidentally "lost" in space after it received a bad command. The entire spacecraft lost power and essentially froze solid for several weeks. Eventually -- miraculously! -- the SOHO team were able to relocate the spacecraft, regain control and slowly power-up and thaw out the instruments. Sadly, the LASCO C1 camera was lost as a result of this but the rest of spacecraft came through almost completely unscathed! Eighteen years later -- and over twenty years since launch -- LASCO C2 and C3 (and most of the rest of SOHO!) continue to work extremely well, sending back images and data on a daily basis.



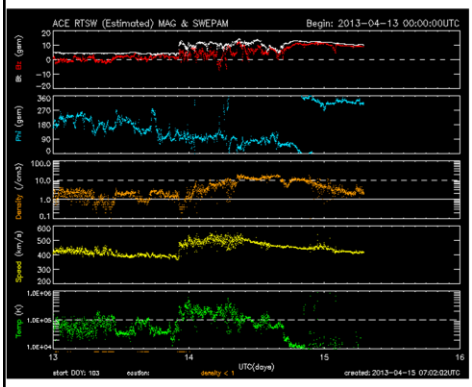
The weak CMEs/structures become better visible in difference imagery (one image subtracted from the other). Movies for the last 4 days can be found at https://sohowww.nascom.nasa.gov/data/realtime/mpeg/ (resp. LASCO C2 combo and LASCO C3 combo).

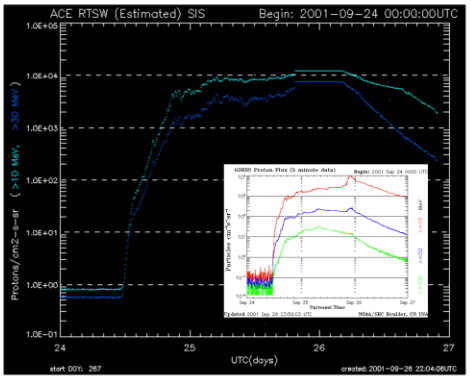
SOHO/LASCO is also a notorious comet chaser, discovering its 3000th comet on 14 September 2015.

SOHO has/had many other instruments, amongst which was the famous MDI (Michelson Doppler Imager) which made images of the Sun in “white light” as well as magnetograms. This program was terminated in 2011 as it was superseded by SDO/HMI. It was exceptionally switched on again for the Mercury transit 2016 (https://soho.nascom.nasa.gov/pickoftheweek/). The MDI archives are at http://soi.stanford.edu/

Descriptions of the other instruments can be found at https://sohowww.nascom.nasa.gov/about/instruments.html

ACE





ACE: Advanced Composition Explorer
http://www.srl.caltech.edu/ACE/

All data at NOAA/SWPC: http://www.swpc.noaa.gov/products/ace-real-time-solar-wind

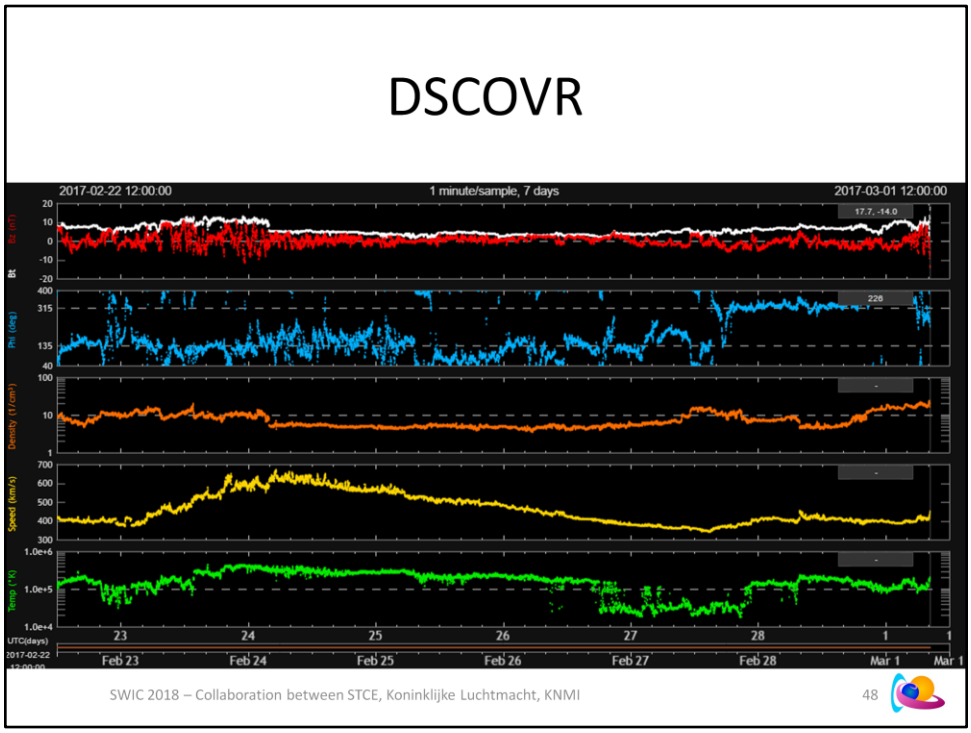
EPAM: Electron Proton Alpha Monitor
- measurements of low-energy electrons and protons

SWEPAM: Solar Wind Electron Proton Alpha Monitor
- measurements of solar wind density, speed and temperature

MAG: Magnetometer instrument
- Measurements of solar wind magnetic field

SIS: Solar Isotope Spectrometer
- Measurements of high-energy protons (>10 MeV, > 30 MeV)

ACE measurements of e.g. solar wind speed are sometimes unreliable in case of strong proton events, which is annoying when a CME arrives.
As of 27 July 2016, ACE is superseded by the DSCOVR satellite, and as such there's no longer a 24hr data coverage anymore.



DSCOVR: Deep Space Climate Observatory
https://www.nesdis.noaa.gov/content/dscovr-deep-space-climate-observatory

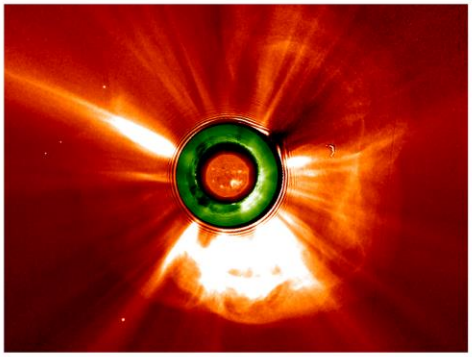
Solar wind data are available at http://www.swpc.noaa.gov/products/real-time-solar-wind

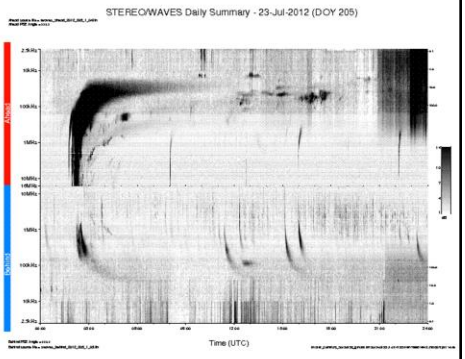
From NOAA/SWPC: Real-Time Solar Wind (RTSW) data refers to data from any spacecraft located upwind of Earth, typically orbiting the L1 Lagrange point, that is being tracked by the Real-Time Solar Wind Network of tracking stations. The NOAA DSCOVR satellite became the operational RTSW spacecraft on July 27, 2016 at 1600UT (noon EDT, 10am MDT).
SWPC maintains the ability to instantaneously switch the spacecraft that provides the RTSW data. During times of outages in DSCOVR data or problems with the data, this page may instead display the data from the NASA/ACE spacecraft.

The two DSCOVR instruments for which data are available:
Faraday Cup (FC) of the Harvard Smithsonian Astrophysical Observatory(link is external)
Magnetometer (MAG) of the University of NASA Goddard Space Flight Center (link is external)

Note that DSCOVR is vulnerable to GCR, which introduces spurious measurement readings from time to time. The correctness of the values can be checked against the ACE data.
More on this issue at http://www.nature.com/news/cosmic-rays-may-threaten-space-weather-satellite-1.20880

STEREO





SWIC 2018 – Collaboration between STCE, Koninklijke Luchtmacht, KNMI 49

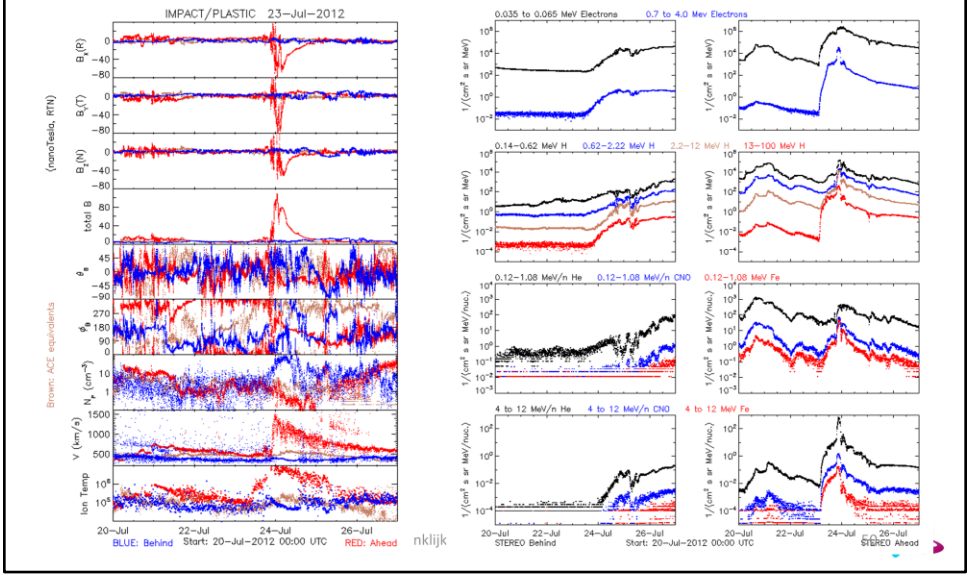
STEREO: Solar-Terrestrial Relations Observatory - SSC: STEREO Science Centre
All data and info are at https://stereo-ssc.nascom.nasa.gov/beacon/beacon_secchi.shtml

Twin spacecraft in sun orbit, one ahead (ST-A) of Earth in its orbit, the other trailing behind (ST-B). They were launched on 25 October 2006.
Contact with ST-B was lost on 1 October 2014 during a test. Re-establishing contact will be tried again in June 2017.
Both spacecraft have passed the anti-solar point in 2015, heading back to earth, but now ST-A is trailing the earth (not re-labelled).
Spacecraft will be close to earth again somewhere in 2023.

The main SWx advantages of the STEREO mission are
- A stereoscopic view of the Sun and CMEs, allowing e.g. a much better determination of the speed and direction of a CME.
- A direct view on the Sun's farside and its solar activity.
- Knowing 1-2 weeks in advance on the strength of CH HSS or active sunspot groups that may rotate over the east limb as seen from earth.

There are 4 main instrument packages:
- SECCHI: Sun Earth Connection Coronal and Heliospheric Investigation
    - EUVI: extreme ultraviolet imager (4 passbands: 171, 195, 284, 304 Angstrom or 17.1, 19.5, 28.4, 30.4 nm)
    - COR1/2: white-light coronagraphs (inner: 1.3 to 4 solar radii/outer: 2-15 solar radii)
    - HI1/2: heliospheric imagers
- PLASTIC: PLAsma and SupraThermal Ion Composition
    - Specifically interesting for proton and SEP events
- IMPACT: In-situ Measurements of Particles and CME Transients
    - Solar wind measurements
- SWAVES: STEREO Waves instrument
    - Track radiobursts from the Sun

STEREO



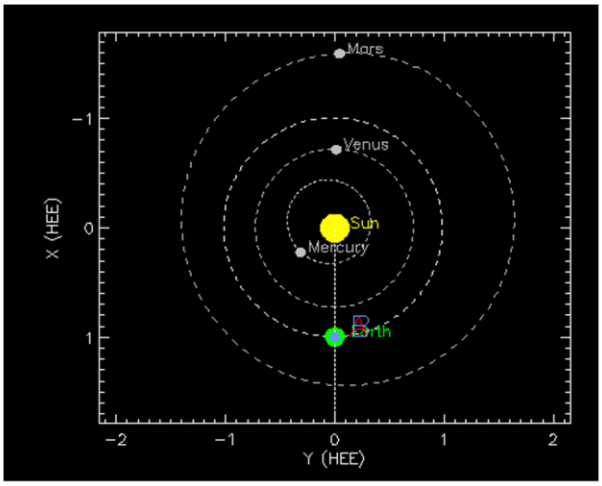
The example is from the Carrington-like event from 23 July 2012 (Sun's farside), showing:
Previous slide

- The EUVI304, COR1 and COR2 shortly after the maximum of the flare (but before the start of the proton event);
- The Type II and III radiobursts associated to the event (SWAVES)

This slide:

- The solar wind data from from PLASTIC/IMPACT for 7 days centered on 23 July 2012. Notice the strength of the event as observed by ST-A, and the lack of impact as observed by ST-B which was at the other side of the Sun
- The SEP data from the IMPACT instrument for 7 days centered on 23 July 2012. Notice the obvious differences between a well-connected (ST-A) and a poorly connected (ST-B) observer (much later, gradual and weaker with ST-B).

STEREO orbit (2006-2022)



https://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif

Exercise: Space-based instruments

- You want to have a clear view of any coronal holes that are visible on the Sun. Which instrument(s) would you use?
  - ✘ SOHO / LASCO C2
  - ✘ STEREO / Waves
  - ✓ SDO / AIA 193
  - ✘ GOES / XRS

:Issued: 2014 Apr 17 1325 UTC
:Product: documentation at http://www.sidc.be/products/tot
#----------#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
#----------#
SIDC URSIGRAM 40417
SIDC SOLAR BULLETIN 17 Apr 2014, 1304UT

SIDC FORECAST (valid from 1230UT, 17 Apr 2014 until 19 Apr 2014)
SOLAR FLARES : Active (M-class flares expected, probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet

PREDICTIONS FOR 17 Apr 2014 10CM FLUX: 180 / AP: 013
PREDICTIONS FOR 18 Apr 2014 10CM FLUX: 184 / AP: 007
PREDICTIONS FOR 19 Apr 2014 10CM FLUX: 188 / AP: 005

COMMENT: Eleven sunspot groups were reported by NOAA today. NOAA ARs 2035,2036, and 2037 (Catania numbers 24, 25, and 26 respectively) maintain the beta-gamma configuration of the photospheric magnetic field. The strongest flare of the past 24 hours was the M1.0 flare peaking at 19:59 UT yesterday in the NOAA AR 2035 (Catania number 24). The flare was associated with an EIT wave and a weak coronal dimming, but the associated CME was narrow and is not expected to arrive at the Earth.
We expect further flaring activity on the C-level, especially in the NOAA ARs 2035 and 2037 (Catania numbers 24 and 26 respectively) as well as in the NOAA AR 2042 (no Catania number yet) that yesterday appeared from behind the east solar limb, with a good chance for an M-class event.

Since yesterday evening the Earth is situated inside a solar wind structure with an elevated interplanetary magnetic field magnitude (occasionally up to 10 nT). It may be a weak ICME or the compression region on the flank of an ICME that missed the Earth. The solar origin of this structure is not clear. The north-south magnetic field component Bz was not strong, so no significant geomagnetic disturbance resulted (K index stayed below 4). Currently the solar wind speed is around 380 km/s and the IMF magnitude is around 8 nT.
We expect quiet to unsettled (K index up to 3) geomagnetic conditions, with active geomagnetic conditions (K = 4) possible, but unlikely.

TODAY'S ESTIMATED ISN : 145, BASED ON 17 STATIONS.
99999

SOLAR INDICES FOR 16 Apr 2014
WOLF NUMBER CATANIA : ///
10CM SOLAR FLUX : 184
AK CHAMBON LA FORET : 012
AK WINGST : 004
ESTIMATED AP : 004
ESTIMATED ISN : 139, BASED ON 29 STATIONS.

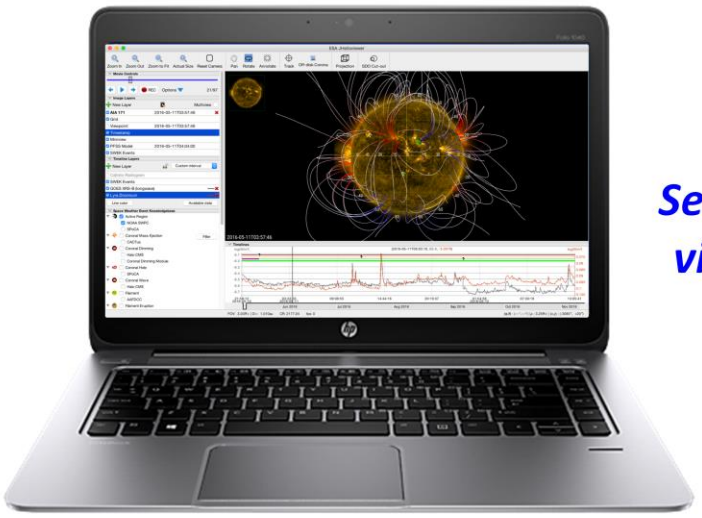
Satellites and instruments

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
16 1954 1959 2004 S14E09 M1.0 1N 24/2035 II/2
END

Contents

- **Groundbased sensors**
  - Visible light
  - Radio domain
  - Magnetosphere-Ionosphere
  - Geomagnetism
  - Dourbes
- **Spacebased sensors**
  - GOES
  - SDO
  - PROBA2
  - SOHO
  - ACE
  - DSCOVR
  - STEREO

- Tools
- Overviews



See the visits!

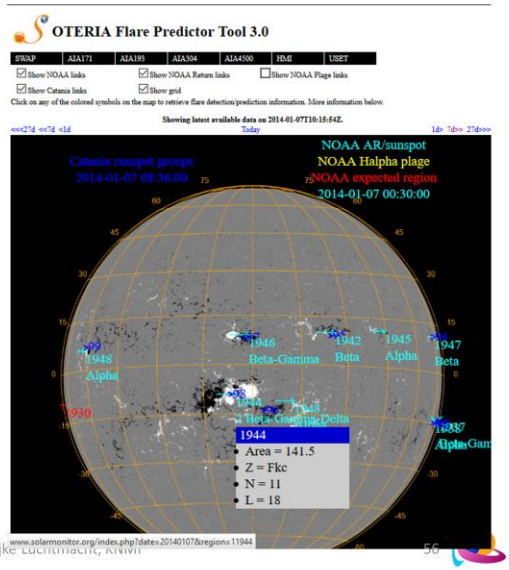
Space weather tools

Jan Janssens

ESA Jhelioviewer: http://swhv.oma.be/user_manual/

Tools

- Various
  - Soteria
  - Solar Demon
  - CACTus
  - Drag model
  - JHV (SWHV)
  - STAFF
  - COR2 J-plots
  - COMESEP
  - *EUHFORIA*
  - *10.7cm radioflux*



Soteria: http://www.sidc.be/soteria/soteria.php
Solar Demon: http://solardemon.oma.be/flares.php
CACTus: http://www.sidc.oma.be/cactus/out/latestCMEs.html
Drag model: http://oh.geof.unizg.hr/DBM/dbm.php
JHV (SWHV): http://www.jhelioviewer.org/
STAFF: http://www.staff.oma.be/
COR2 J-plots: http://www.sidc.be/rwc/cor2speed/cor2speed.html#canvas_position
COMESEP: http://www.comesep.eu/alert/
EUHFORIA: operational testing/development phase
10.7cm radioflux: operational testing/development phase

Other:
Solar Monitor: http://www.solarmonitor.org/index.php
SWPC synoptic diagram: http://www.swpc.noaa.gov/products/solar-synoptic-map
Spacecast: http://fp7-spacecast.eu/
EURISGIC: http://eurisgic.org/

Overviews

Forecast Weekly Presto Cactus All quiet CME arrival Monthly bulletin Quarterly Links

UTC time: 16:07:39

General | Regions | Flares | Energetic Particles | Radio | CME | Solar Wind | Geomagnetism | Forecast Centres | Custom Campaigns

General

- STAFF viewer (backup)
- Helioviewer (backup)
- Internal Documents (webserver version)
- cloud-as (access to internal documents should be under SWOP_InternalOperation
- password storage server (in case forecaster needs passwords to IT infrastructure t

Back to top

Regions

- Soteria
- Solar Monitor Regions
- Latest NOAA synoptic map
- Raben Maps
- STEREO Stonyhurst heliographic maps
- PROBA2 LYRA data and SWAP images
- SDO movies
- SDO movies (ROB page)
- SOHO movies
- STEREO movies
- Realtime GONG H-alpha movies (backup)

Back to top

SWx Dashboards in the SIDC SWx Forecast room

http://sidc.be/previweb/links

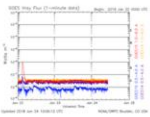
Overviews

Space Weather Now!

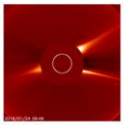
Latest Reports	Proton, SEP & Radiation	Solar Wind
X-ray flares	Radio Observations	Geomagnetic
X-ray/EUV imagery	CME	Aurora
White Light	Coronal Holes	Radio Comma & TEC
Magnetograms	Farside	Electrons
H-alpha & Ca II K	Tools & Data	GIC
Movie Centre	Products	Satellites

Current Space Weather Conditions

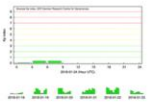
SDO/HMII



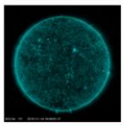
GOES x-ray flux

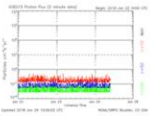


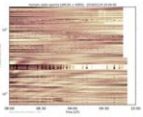
SOHO/LASCO C2

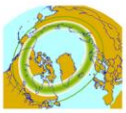


Potsdam Kp



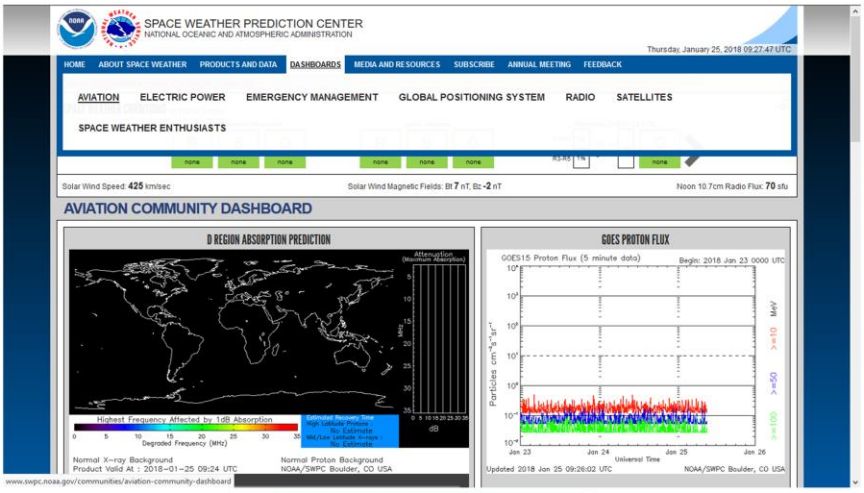






http://users.telenet.be/j.janssens/Spaceweather.html

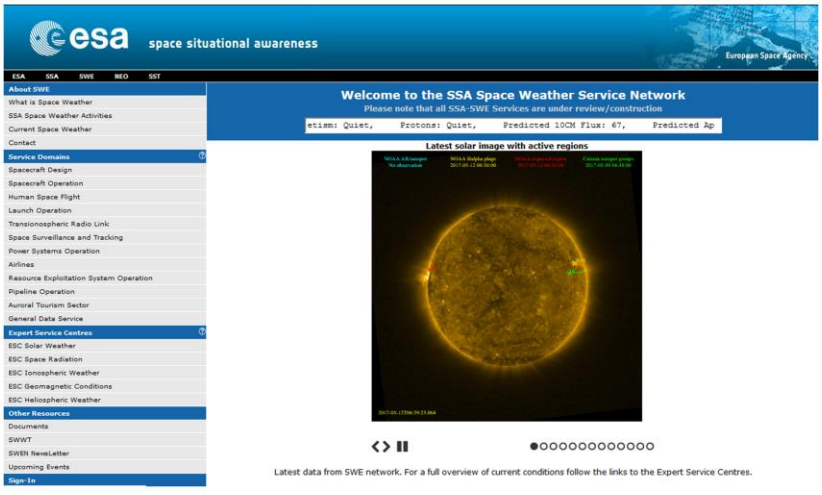
Overviews



http://www.swpc.noaa.gov/

NOAA/SWPC has developed SWx dashboards for specific SWx user communities such aviation or satellites.
http://www.swpc.noaa.gov/

Overviews



http://swe.ssa.esa.int/

Other websites:
WMO/ICTSW: https://www.wmo-sat.info/product-access-guide/theme/space-weather

Summary

- Both ground- and space-based data and imagery are used in SWx
  - Depends on the SWx user community and the purpose
- Multiple stations are a must
  - Back-up, cross-check & continuous monitoring
- Tools for analysis and forecasting are available
- Dashboards are available online