

Aurora Borealis

An introduction to the Northern Lights

Sherry Buttnor

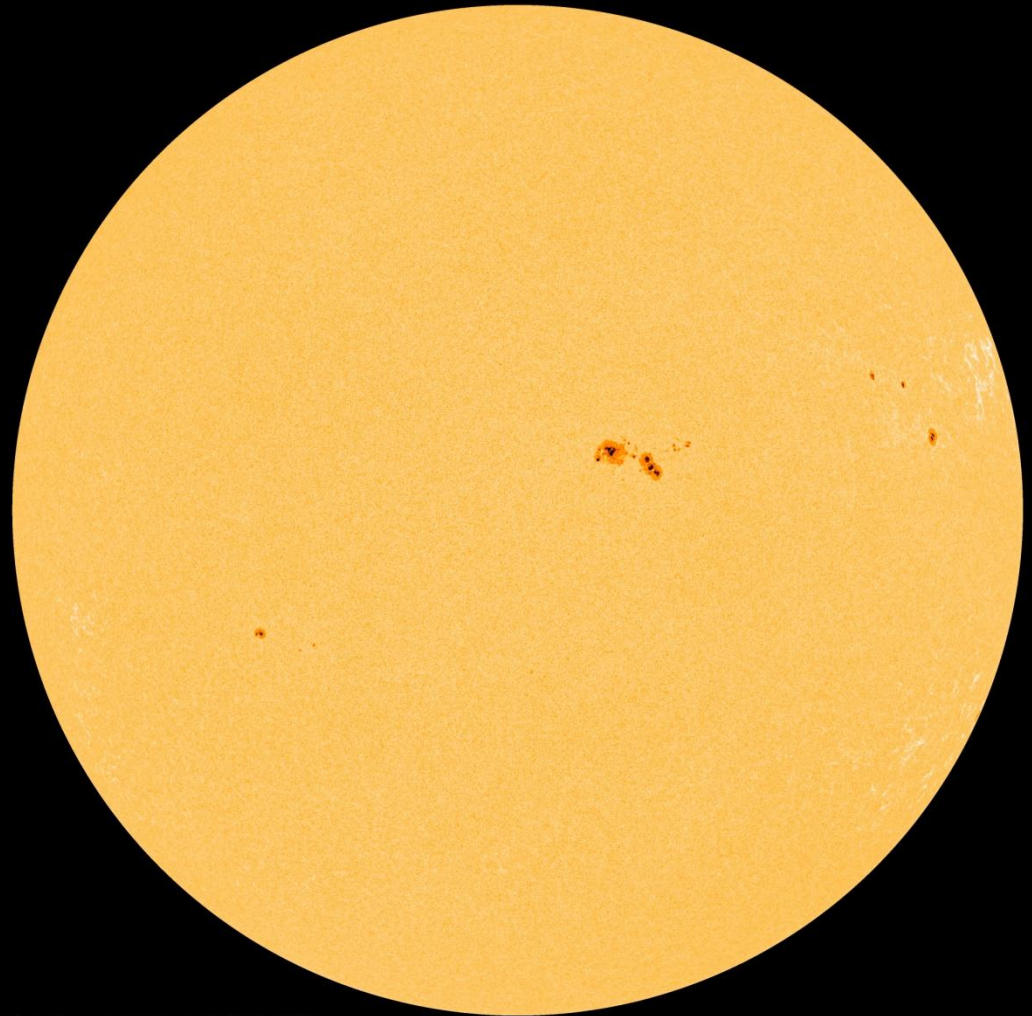
Royal Astronomical Society of Canada
Victoria Centre

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Solar cycles and sunspots

image: NASA/MSFC

- * the Sun goes through not one, but TWO “solar cycles”
- * the most commonly talked about is the 11-year sunspot cycle
- * the other is a 22-year magnetic solar cycle
- * alternate 11-year cycles have reversed magnetic polarity (N/S and S/N)
- * in fact, this is one method of knowing when one solar cycle ends and a new one begins
- * sunspots are magnetically-formed “storm” regions on the Sun’s surface; when the magnetic field of the sunspot can no longer resist the pressure within the spot, and flare is unleashed. If the flare is strong enough to escape the Sun’s gravity and magnetism, it becomes a Coronal Mass Ejection



SDO/HMI Quick-Look Continuum: 20121123_000000

Coronal holes

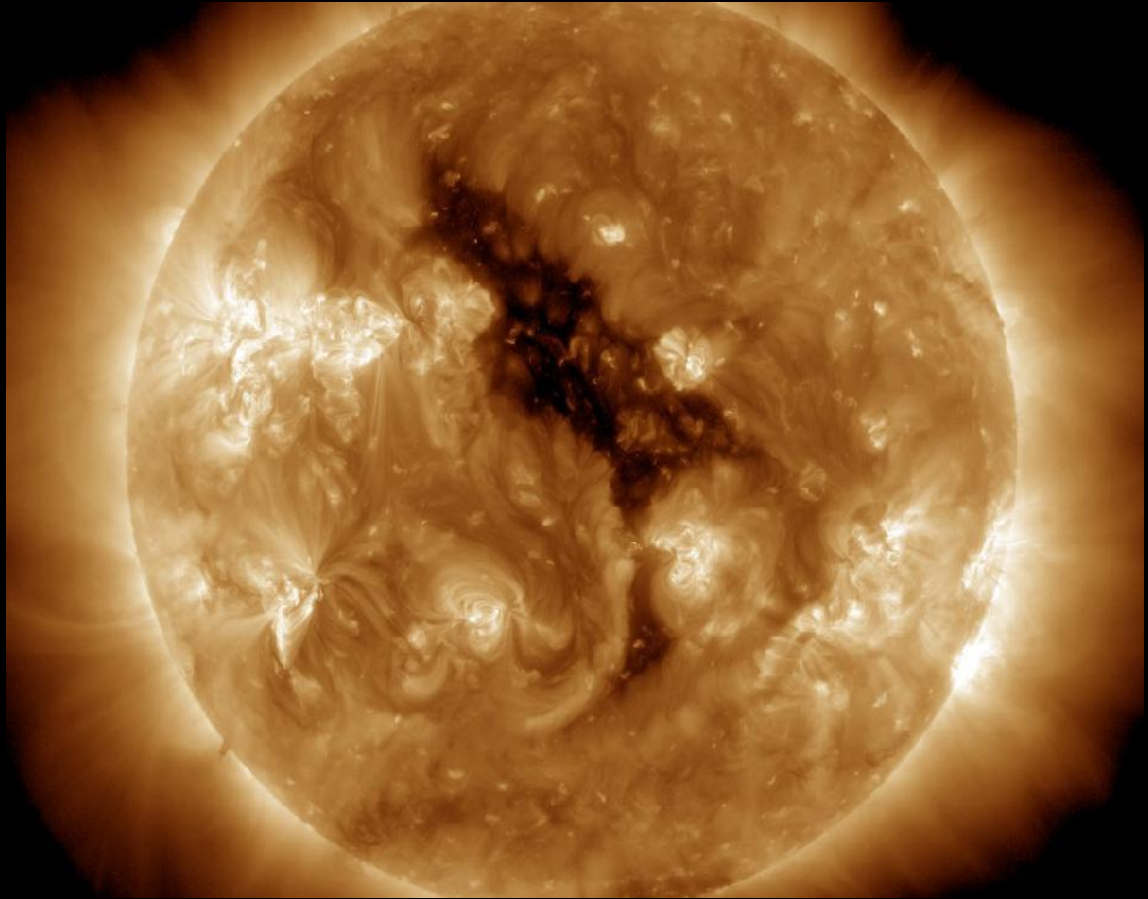
image: NASA/AIA

*coronal holes are weak regions, or 'rifts' in the Sun's coronal magnetic fields.

*these are regions where the magnetic field lines contain the normal solar wind, allowing higher than usual amounts to flow outward from the Sun.

*as the Sun rotates, the higher-than-normal solar wind sweeps across space (and the Earth) like a lighthouse beam

*coronal hole windstreams can trigger auroras via the same mechanisms as CME's



Aurora Borealis (Northern Lights) and Aurora Australis (Southern Lights)

- essentially, charged particles (electrons and protons) from the Sun colliding with molecules in Earth's upper atmosphere:
 - Green : oxygen, up to 150 miles
 - Red: oxygen, above 150 miles
 - Blue: nitrogen, up to 60 miles
 - Purple: nitrogen, above 60 miles
- Auroras result from emissions of photons in the Earth's upper atmosphere, from ionized nitrogen atoms regaining an electron, and oxygen and nitrogen atoms returning from an excited state to ground state. The atoms are excited by the collision of solar wind (CME) particles, which are funneled down and accelerated by Earth's magnetic field lines.
- Earth's Magnetic field lines are what gives auroras their shape and structure.

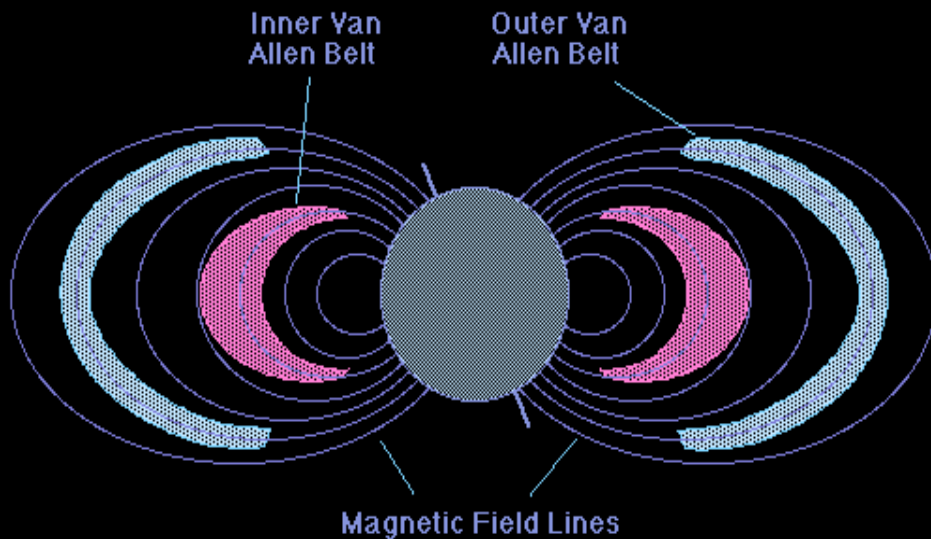


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Earth's magnetic field: charged particles are captured by the magnetic field lines and spiral down toward the north and south magnetic poles, creating the "auroral oval".

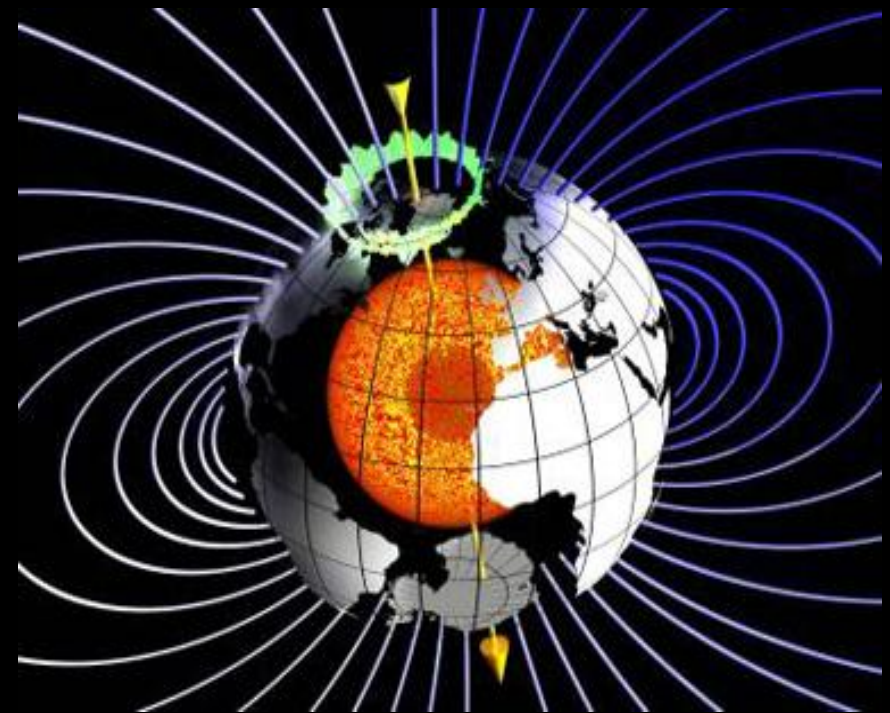
Earth's magnetic field

Image: University of Tennessee Knoxville



Earth's magnetic field and auroral oval

Image: DTU/NSI Denmark



Flare and Storm Categories

- Solar flares: A, B, C, M, X. Within each category, 0-9
- (linear scale e.g. X1 is twice as powerful as X0.)
- M- and X-class flares are the ones to watch
- Storm categories:
- Geomagnetic storms: G1 – G5 (G1 = Kp 5, G2 = Kp6, G3 = Kp7 etc)
- Solar Radiation storms: S1 – S5 (occur ~ 8 minutes after flare)
- Radio Blackout storms: R1 –R5
- Our Geomagnetic Latitude is ~N53
- Generally speaking, we need a G2 storm (Kp 6) to see auroras here (but it pays to watch any storm carefully!)

Why is the study of Solar-Terrestrial “spaceweather” important?

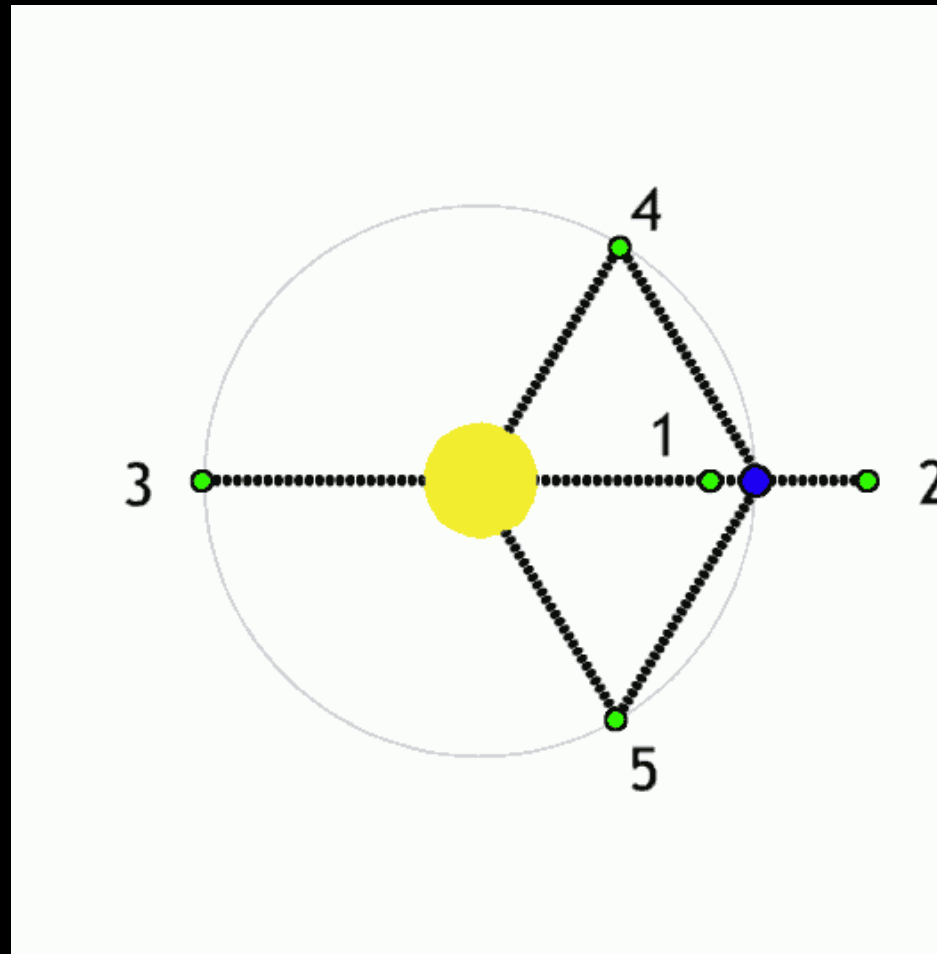
- * Incoming Coronal Mass Ejections (CME's) can heat Earth's upper atmosphere causing drag on satellites potentially causing unplanned de-orbit
- * Pressure from the CME can compress Earth's protective magnetic field, allowing highly-charged electrons and protons, and magnetism to fry satellite on-board electronics and instruments
- * Aircraft and pax, cellphones and other global comms, and astronauts are all negatively affected
- * Long power transmission lines (and even underground pipelines!) on Earth act as antennas and can transmit tremendous electrical energy from CME impacts to power substations, causing damage to the electrical grid, power outages, and damage to industrial and home electrical devices.
- * In March 1989, a massive solar flare/CME impact destroyed several power substations in Quebec, causing a cascade effect which blacked out most of eastern Canada and the northeast US!
- * It's good to know when auroras will occur for those of us nutty types who like to spend hours out in the dark and cold photographing them. =)

The Instruments

- Solar and Heliospheric Observatory (SOHO), **Large Angle and Spectrometric Coronagraph Experiment**
- (LASCO), and **Extreme ultraviolet Imaging Telescope**
- (EIT):
- A collaboration between NASA and the ESA, launched in 1992.
- Parked at the L1 point for an uninterrupted view of the Sun
- Observes the Sun in many wavelengths
- Give us our preliminary data about flares and Coronal Mass Ejections (CME's)

Lagrangian Points

(L1 is 1.5million km from Earth)





SOHO image of a departing CME

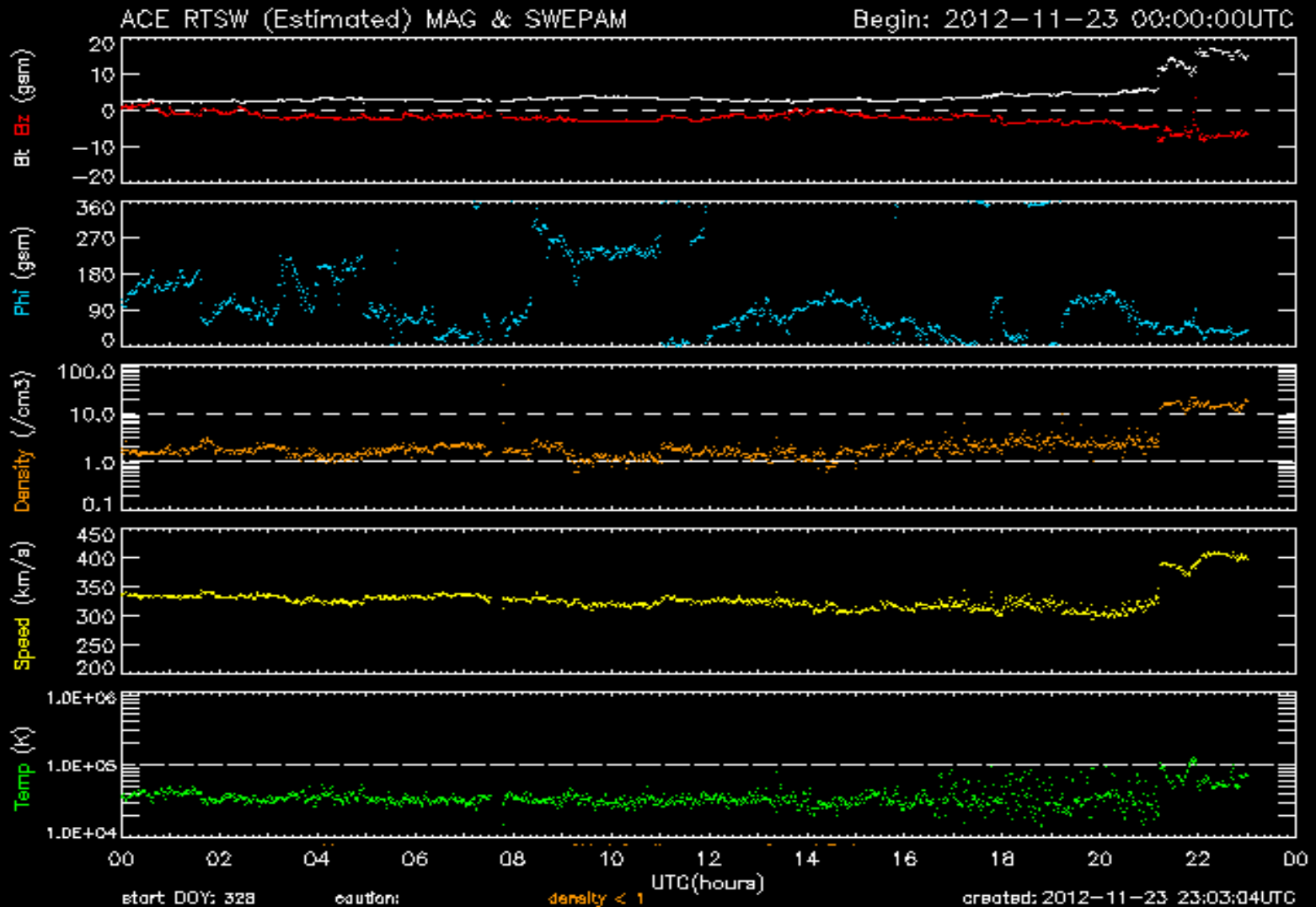
image credit: NASA/SOHO

Advanced Composition Explorer (ACE)

- Launched in 1997. NASA/CalTech
- Also parked at the L1 point
- Give us our detailed information about the flare and incoming CME:
- (solar wind speed, density, IMF strength and orientation N/S, temperature)
- (Also THEMIS and STEREO)

A typical ACE graph set (24hr)

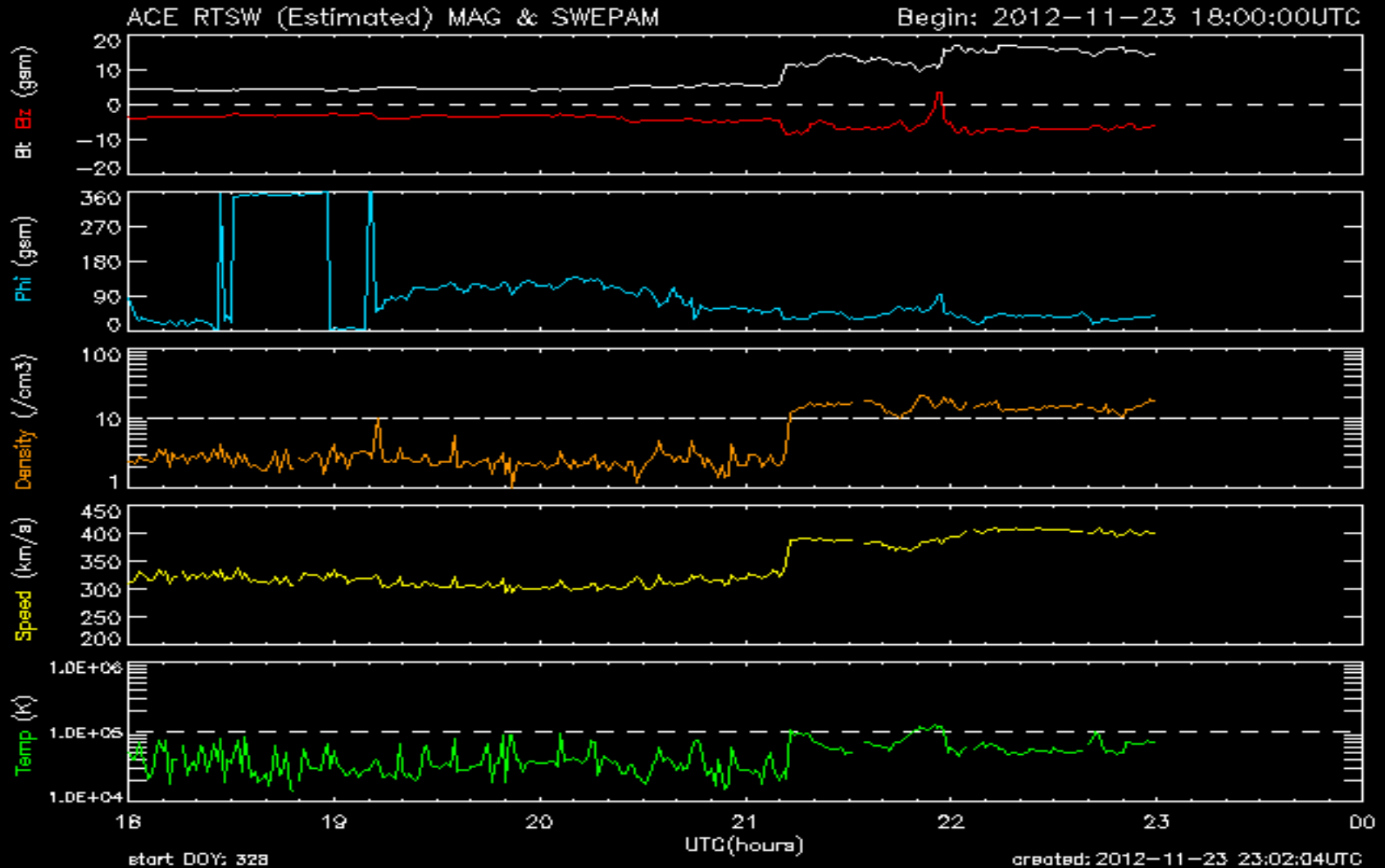
image: NASA/ACE



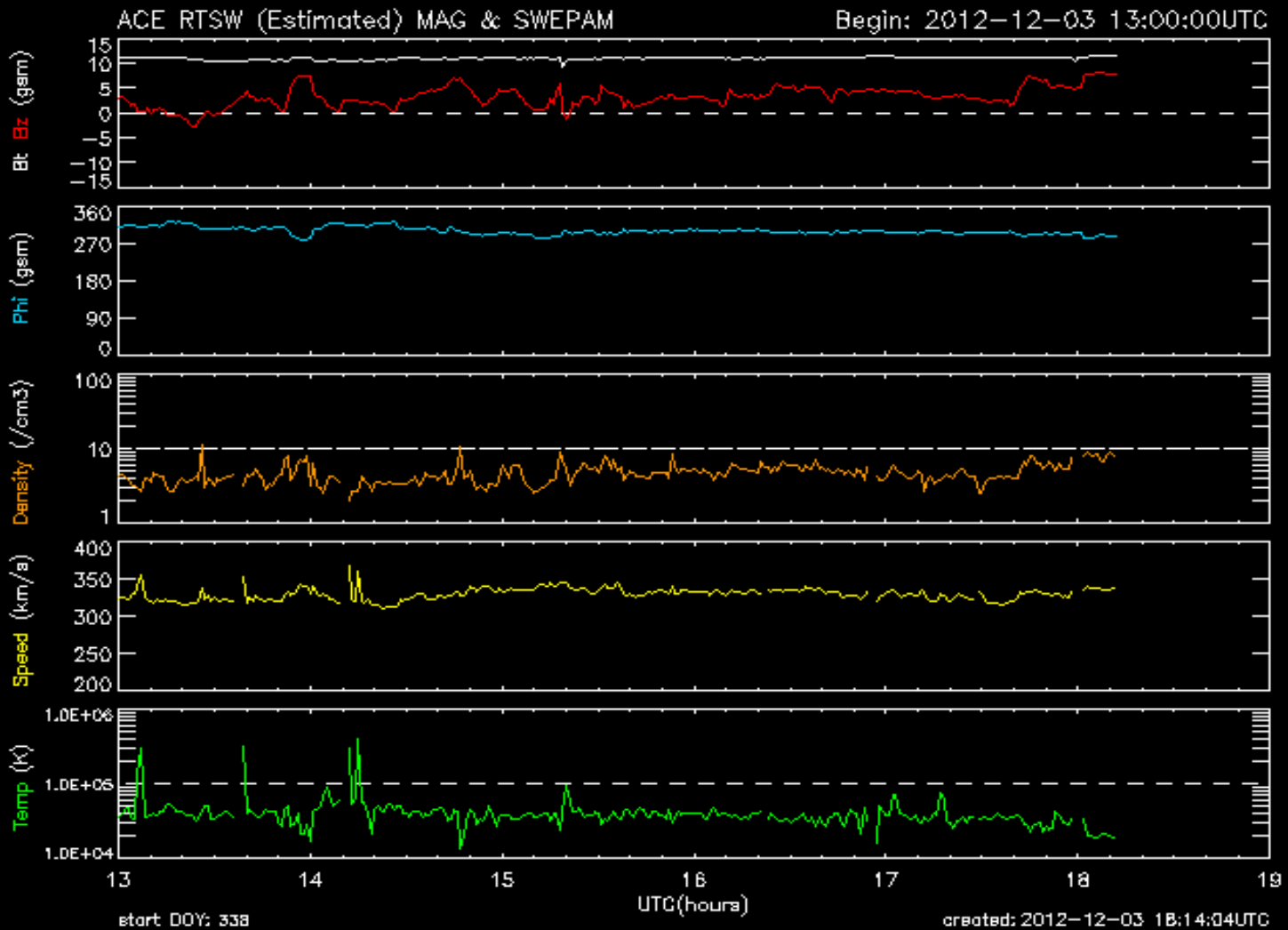
ACE Graph set (6hr)

This is Good

image: NASA/ACE



This is not-so-good



An incoming CME is a wild mix of charged particles embedded in a swirling magnetic field.

Bt: total Interplanetary Magnetic Field (IMF) strength

Bz: IMF orientation (North/South)

Phi: radial aspect of the IMF

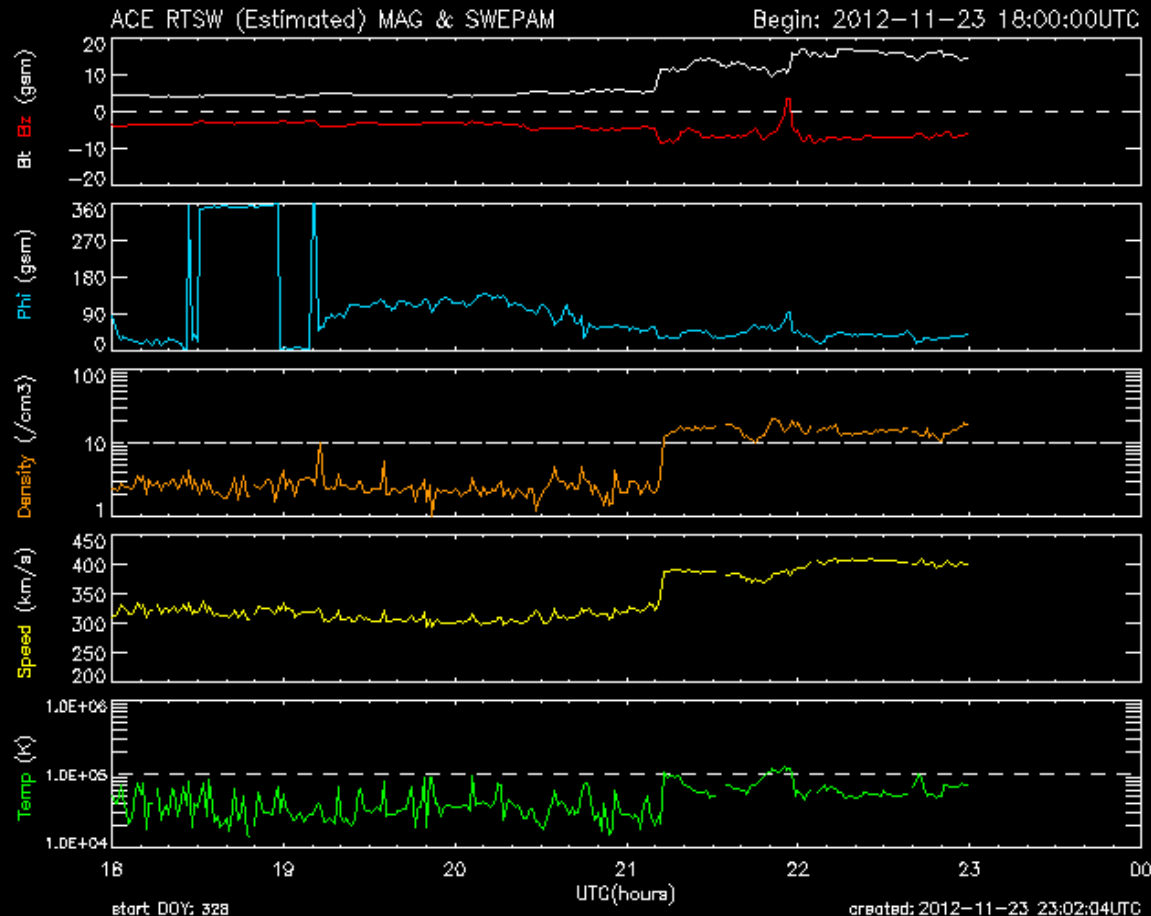
Density: protons per cm^3 (normal is $\sim 1\text{cm}^3$)

Speed: CME plasma wind speed (normal solar wind speed is $\sim 300\text{km/s}$)

Temp: proton temperature (K)

The BIG FOUR:

Bt, **Bz**, **Density**, and **Speed**. These are the ones to watch!



CANOPUS/CARISMA

image: Canadian Space Science Data Portal

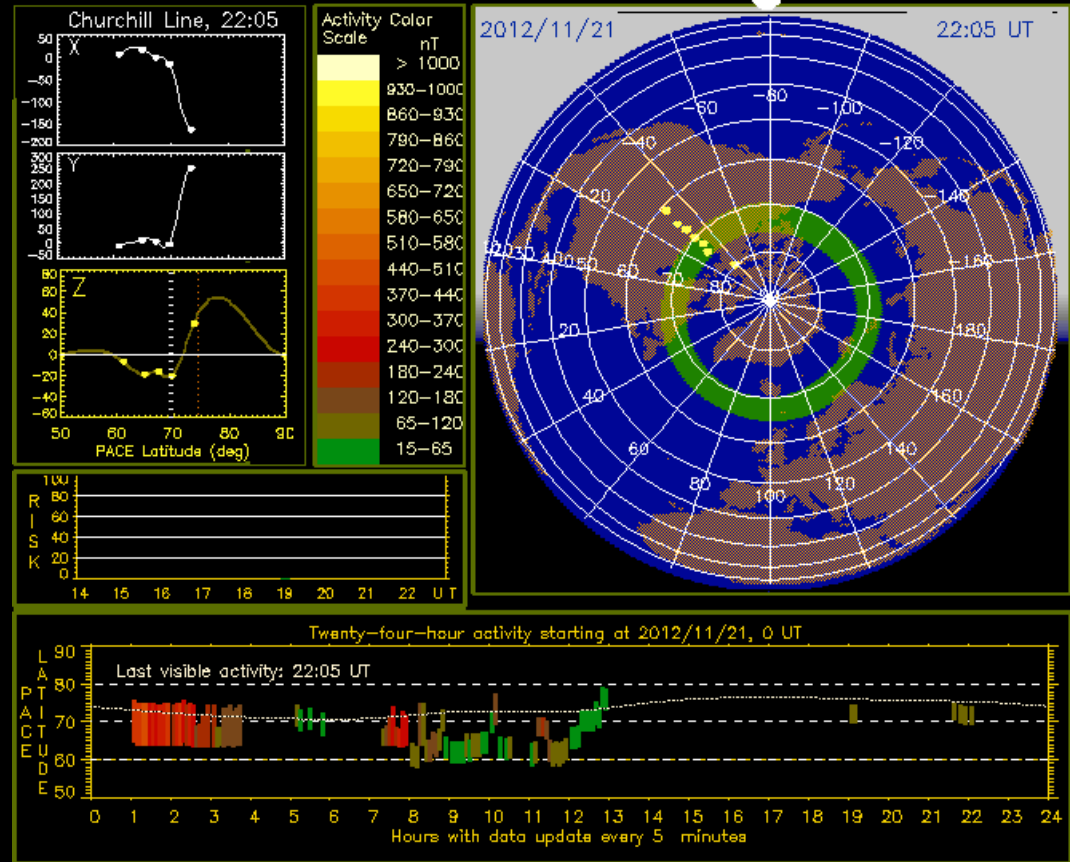
Canadian Array for Realtime Investigations of Magnetic Activity

Data gathered from a line of magnetometers throughout central Canada

Provides near-real-time 3D

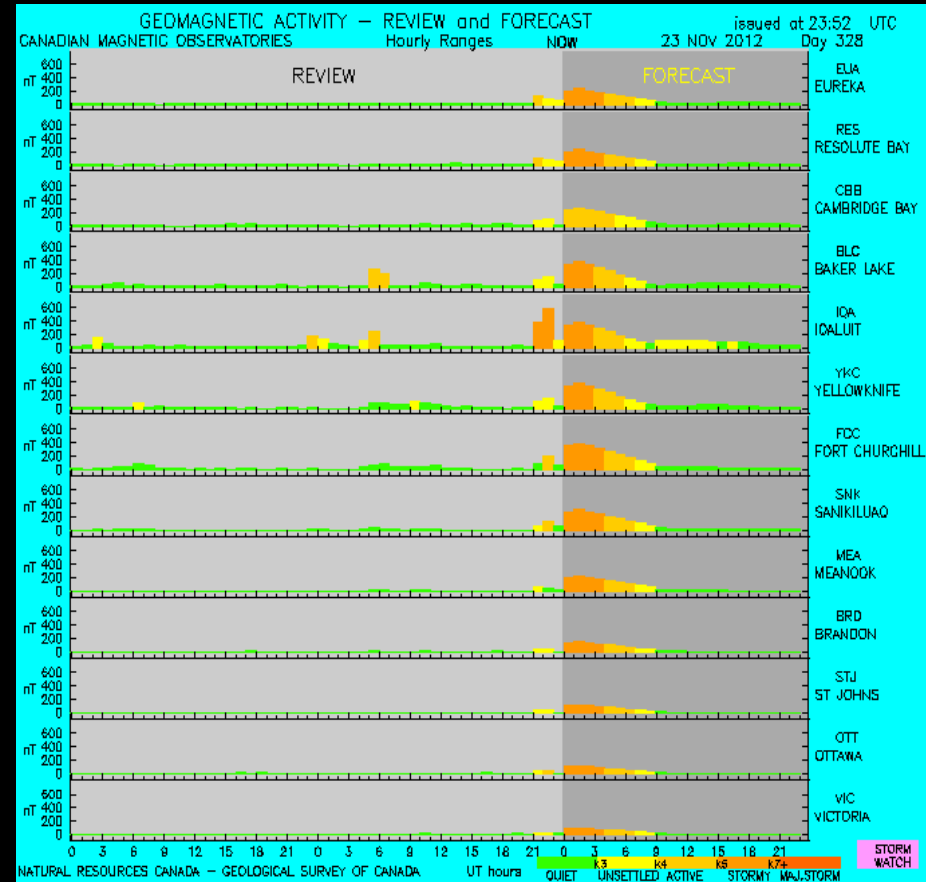
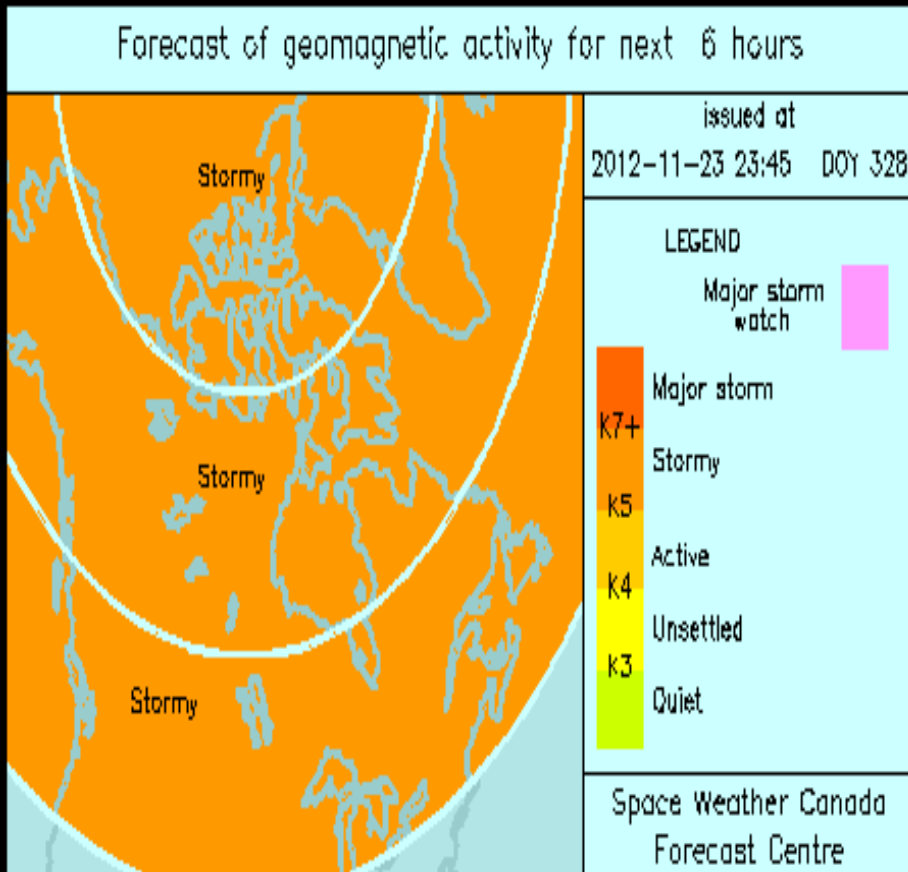
geomagnetic information (measuring the north-south component of the magnetic field (X), the east-west component (Y) and the vertical component (Z)).

Risk and Latitude : these are the ones to watch during a storm! The oval (R) and bars (bottom) will change colour and size based on current XYZ geomagnetic conditions.



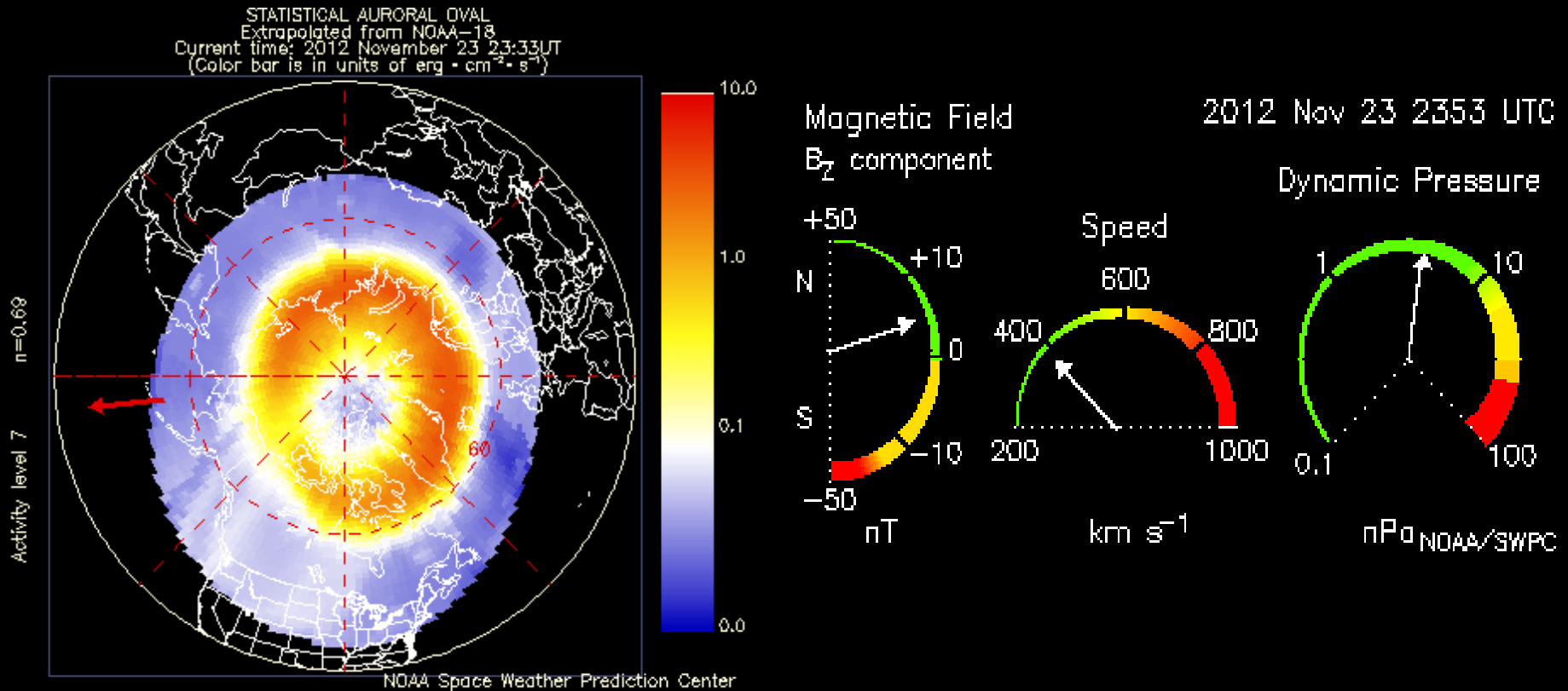
Spaceweather Canada

images: Spaceweather Canada



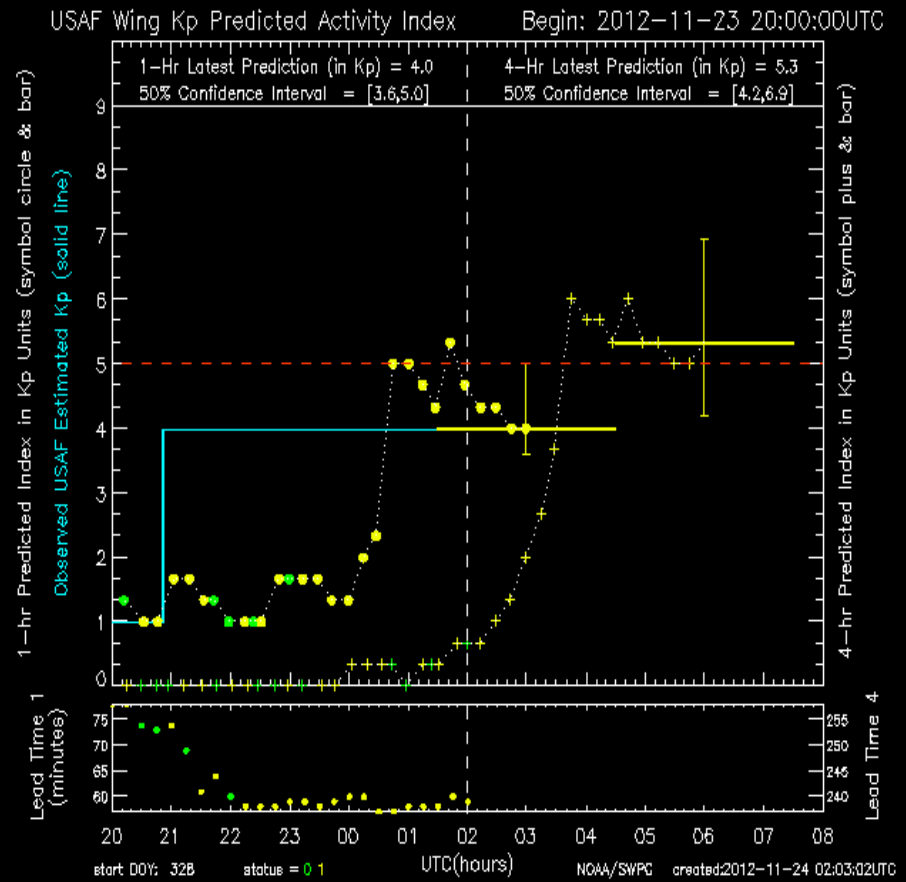
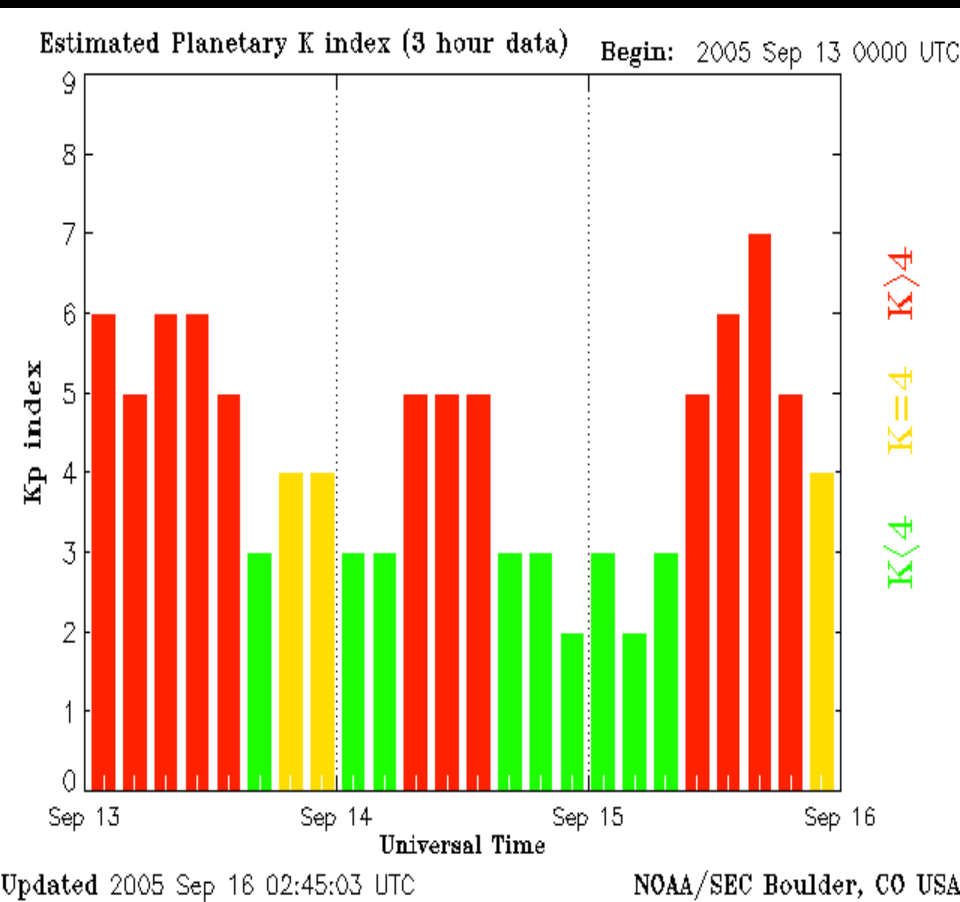
Other online resources

images: NOAA /Space Weather Now



Planetary Kp index. Another measurement of geomagnetic strength, usually measured over a 3-hour period.

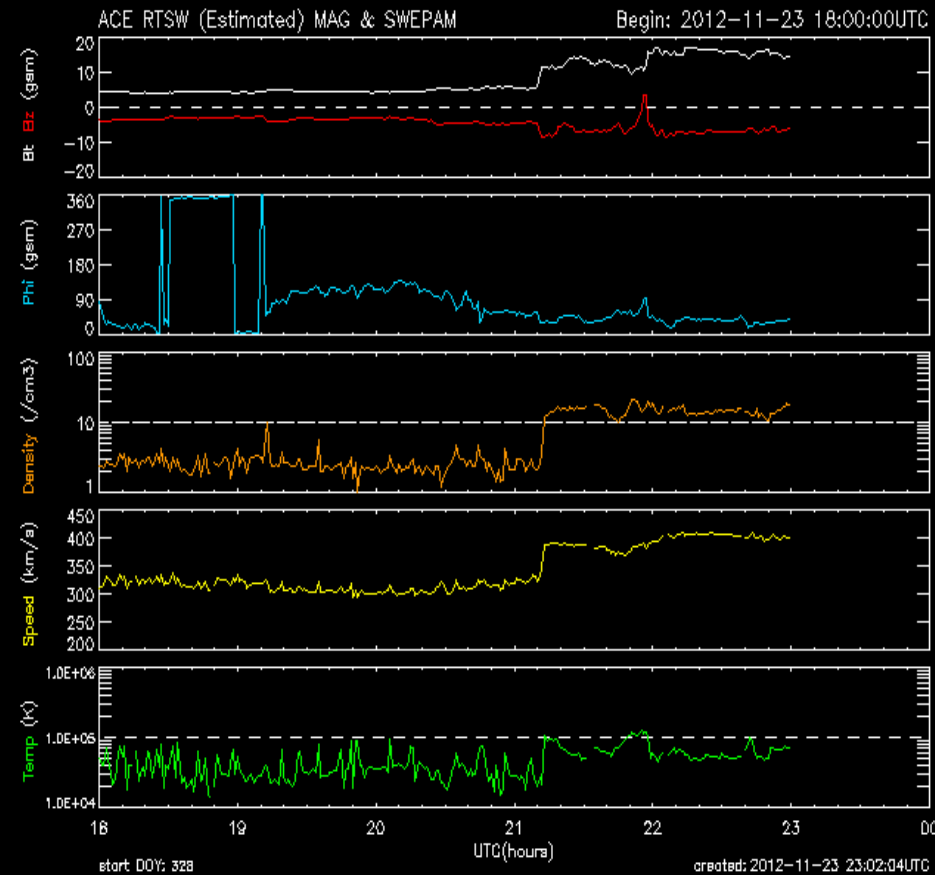
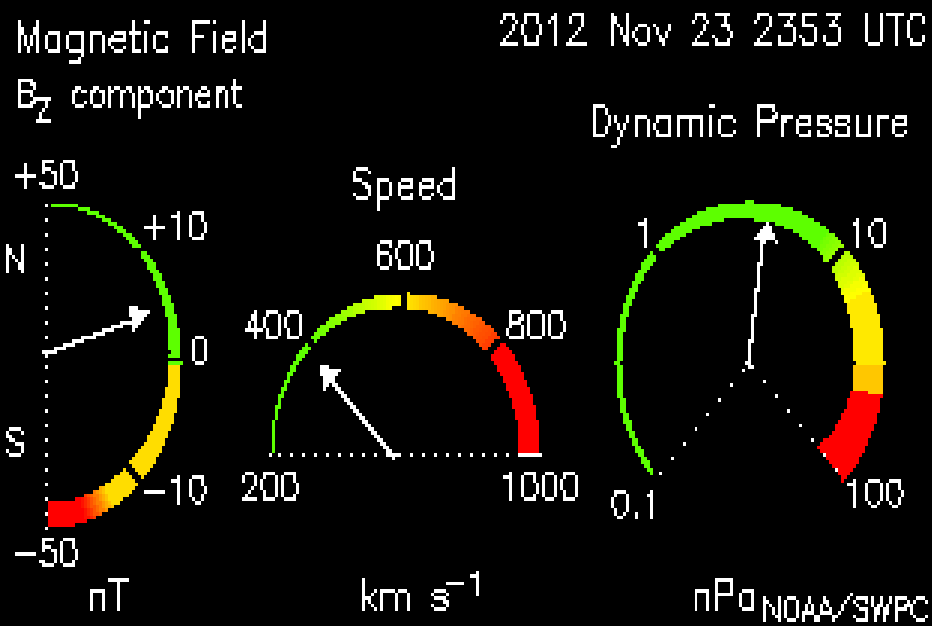
Images: NOAA/SWPC



If I had to watch just one index, it would be these two:

Space Weather Now

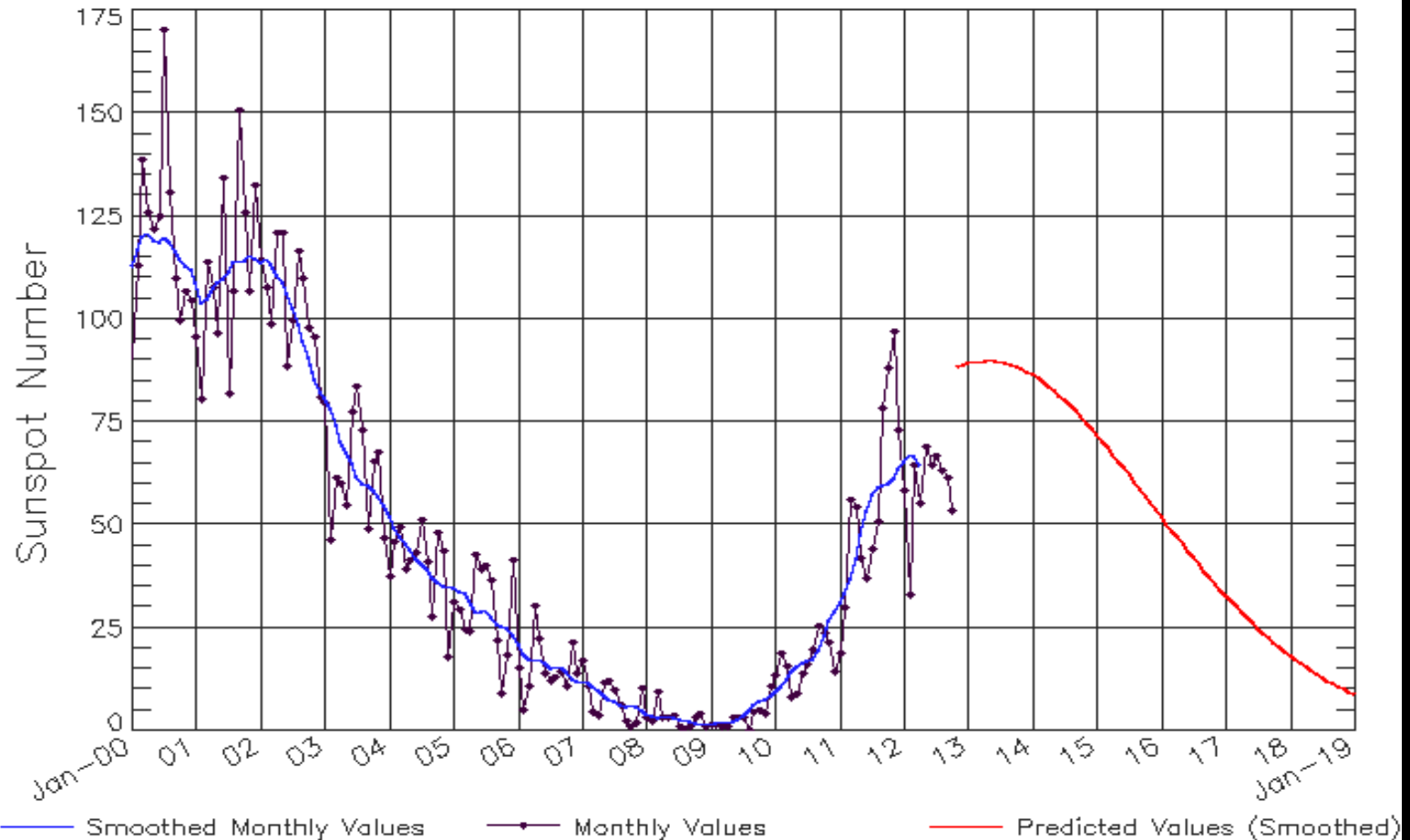
ACE 6hr



Current Solar Cycle (24)

image: NASA/SWPC

ISES Solar Cycle Sunspot Number Progression
Observed data through Oct 2012



To Summarize:

- Watch the alerts for M and X class flares, and significant coronal hole conditions
- Monitor ACE: Bt, Bz, speed, and density
- Monitor Kp/Kr (5-6 and above)
- Monitor CANOPUS/CARISMA and Spaceweather Canada indices

pray to the weather gods, that –all else being favourable- there are clear skies! =))

Acknowledgements

information and data provided by:

- Solar Terrestrial Dispatch: Cary Oler, et al
- Observer's Handbook, Royal Astronomical Society of Canada: Ken Tapping ppg 189-193
- NASA: JPL,/MSFC/SDO
- NOAA: Space Weather Prediction Centre, Space Weather Now
- Spaceweather Canada
- Canadian Space Science Data Portal
- 24 years of head-banging, teeth-gnashing (but ultimately satisfying!) study and pursuit of the ethereal *Lights*.

Links

- Spaceweather.com. Lots of new and at-a-glance info: <http://www.spaceweather.com/>
- Today's Spaceweather: <http://www.swpc.noaa.gov/today.html>
- Space Weather Now: <http://www.swpc.noaa.gov/SWN/>
- Solar Terrestrial Dispatch: <http://www.spacew.com/>
- ACE 24hr: http://www.swpc.noaa.gov/ace/MAG_SWEPAM_24h.html
- ACE 6hr: http://www.swpc.noaa.gov/ace/MAG_SWEPAM_6h.html
- Kp (current and predicted Kp values): <http://www.swpc.noaa.gov/wingkp/index.html>
- Spaceweather Canada stations (reviews and forecast): <http://www.spaceweather.gc.ca/sfst-4-eng.php>
- Spaceweather Canada (zone forecast map): <http://www.spaceweather.gc.ca/current-actuelle/short-court/sfst-2-eng.php>
- CANOPUS/CARISMA oval and graphs: https://cssdp.ca/ssdp/app/static/related_projects/rt_oval.html
- Space Weather Prediction Center (email alerts): <https://pss.swpc.noaa.gov/LoginWebForm.aspx?ReturnUrl=%2fproductsubscriptionservice%2f>



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