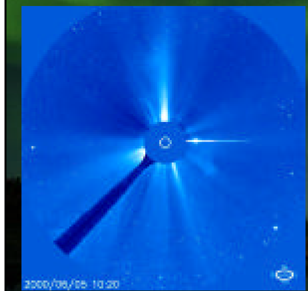
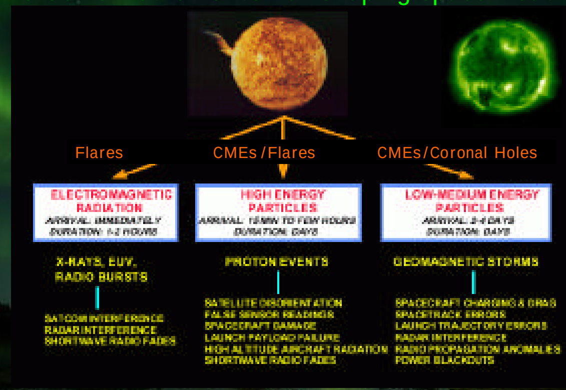
Improving prediction of space weather disturbances – what is needed?



ESA Space Weather Workshop:
Developing a European Space Weather Service Network
SWENET: Space Weather European Network
3-5 November 2003, ESTEC, Noordwijk

Rainer Schwenn
Max-Planck-Institut für Aeronomie
Lindau, Germany

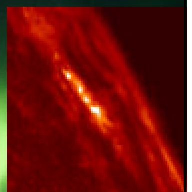
The Sun's instruments for shaping space weather



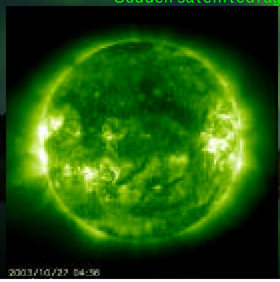
Let us inspect the the three branches
w.r.t. basic understanding, prediction reliability, needs for the future.

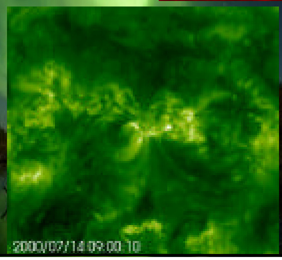
1. Electromagnetic radiation from flares

Visible light, EUV, X-rays, Gamma-rays



Physics: Unclear, but under intense study...
Arrival: Simultaneously
Duration: Minutes to hours
Effects: Sudden heating of the Earth's upper atmosphere
Impacts: * Radio communications disturbed
* Sudden satellite drag



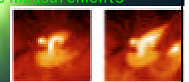


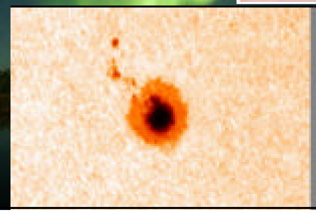
1. Electromagnetic radiation from flares

Prediction accurracy:

Timing	on time scales of days	poor
Location	often foreseeable	good
Magnitude	potential range, for experts	fairly good
Significance	wide range,	fairly good

Needed:
* Fundamental research for understanding basic release mechanism, source and amount of energy to be released,
* High time resolution optical observations of flare onset,
* Search for „dormant volcanos" by MDI type measurements and modelling.

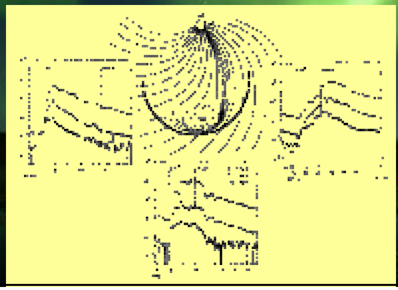




2. High energy particles from flares and CME shocks

Electrons, protons and other ions with energies
of few 100 MeV, at times several GeV

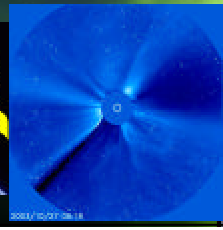
Physics:	Onset still unclear, particle acceleration under intense study...
Arrival:	Some 10 minutes to 1 hour after optical detection
Duration:	Hours to days



2. High energy particles from flares and CME shocks

Effects:
* Heating and ionization of the Earth's upper atmosphere
* Electrification of the upper stratosphere

Impacts:
* Radio communications disturbed,
* Damage to exterior satellite surfaces, causing degradation of solar cells, optical elements, etc.
* Damage to solid state devices, leading to malfunctions, single event upsets, latchups etc. in satellite electronics,
* Blinding of CCD cameras in Earth orbit,
* Enhanced radiation doses for astronauts, particularly dangerous during EVAs.



2. High energy particles from flares and CME shocks

Prediction accurracy:

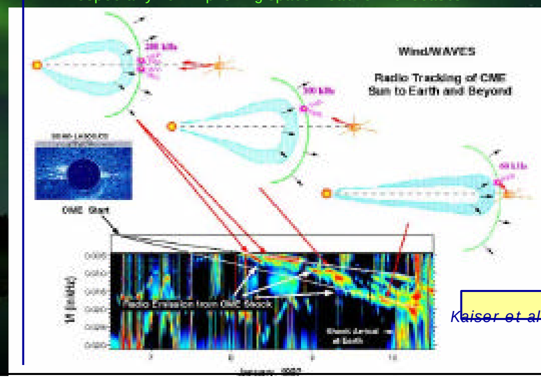
Timing	on time scales of days / years	poor / very poor
Location	often foreseeable	good
Magnitude	potential range, for experts	fairly good
Significance	wide range, with surprises	fair

Needed:
* Fundamental research for understanding basic mechanism, source and amount of energy to be released,
* ... for understanding shock formation and propagation
* ... for understanding particle acceleration
* ... for understanding particle propagation

2. High energy particles from flares and CME shocks

Propagation of shock waves from the Sun towards Earth

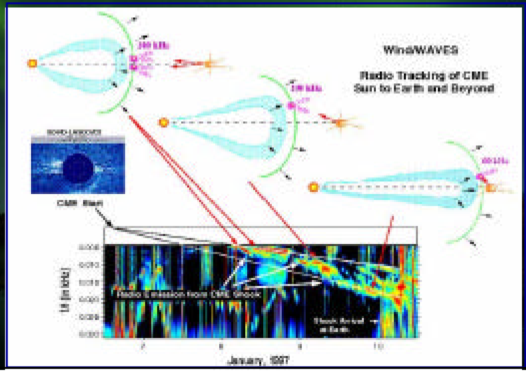
Where and how are they accelerated/decelerated?
Answers might come from radio wave observations,
especially for improving space weather forecasts.



Kaiser et al., 1998

2. High energy particles from flares and CME shocks

Needed: * High time-resolution optical observations of flare/CME onset,
* Radio observations, in frequency range from 100 MHz to 1 KHz.



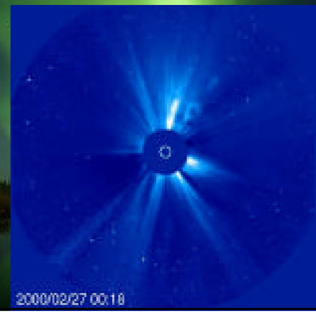
3. Low to medium-energy particles, plasma clouds

Interplanetary shocks, magnetic clouds, plasma turbulence as products of coronal mass ejections, all contributing to generate geomagnetic storms.

Physics: * Origin of CMEs unclear, but under intense study.
* Propagation is being modelled : empirical approaches under development.

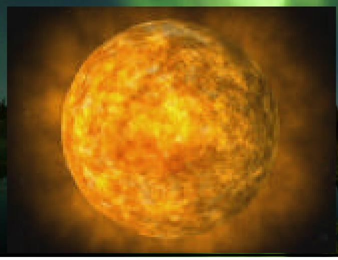
Arrival: after 1 to 5 days

Duration: hours to days



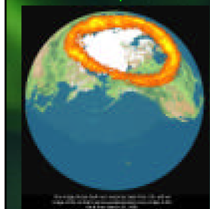
3. Low to medium-energy particles, plasma clouds

Effects: * Sudden compression of the Earth's magnetosphere,
* Distortion and depletion of the radiation belts, leading to release of large fluxes of energetic particles,
* Injection of plasma from magnetotail into polar magnetosphere/ ionosphere, thus causing aurorae,
* Severe disturbances of ring currents, i.e. geomagnetic storms,
* Heating of ionosphere and upper atmosphere



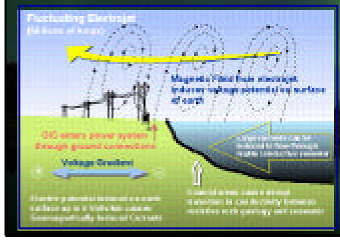
3. Low to medium-energy particles, plasma clouds

Impacts: * Bright aurorae, even at low latitudes,
* Strong fluctuations of geomagnetic field,
* Radio communications disturbed,
* Sudden satellite drag due to heating of the upper atmosphere,
* Charge-up of satellite surfaces due to high fluxes of energetic electrons,



3. Low to medium-energy particles, plasma clouds

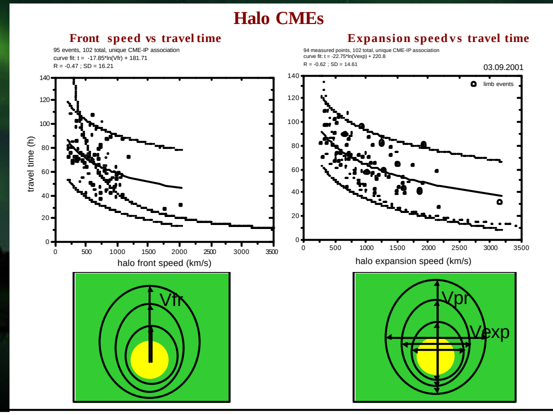
Impacts:
* Satellite damages from penetrating energetic particles,
* Satellite disorientation due to magnetic field distortion,
* GICs endangering power distribution nets, pipelines, telecommunication lines etc.
* Effects on biological systems



3. Low to medium-energy particles, plasma clouds

Prediction accurracy:

Timing	empirical models	good, t.b.i.s.



3. Low to medium-energy particles, plasma clouds

Conclusions from recent studies of CME/ICME correlations

- A good correlation between v_{exp} and the travel time to 1 AU was found from 102 events observed from 1997 to 2001.
- Measuring v_{exp} for halo CMEs allows to predict their travel time to 1 AU.

$$T_{tr} = 206.6 - 21.36 * \ln(v_{exp}) \quad [\text{hours}].$$

- There is still substantial uncertainty, indicating that processes occurring during the “trip” of the CMEs from the sun to 1 AU may play an important role.
- 7 out of 181 full front side halo CMEs never reach the earth –

  3.9% false alarms!
- 6 out of 145 transient shocks were not related to any CME –

  4.1 % shock predictions missed!
- 1 out of 30 intense storms and 4 out of 78 moderate storms were not related to any CME –

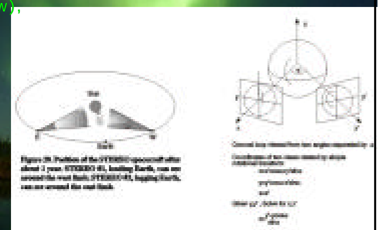
  6 % storm prediction missed!
- All very intense storms (D_{st} < -200 nT) were related to halo CMEs.

3. Low to medium-energy particles, plasma clouds

Prediction accurracy:

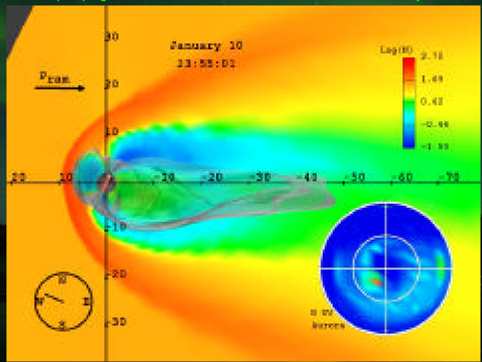
Location	orientation often dubious	fair
Magnitude	surprisingly low	fair
Significance	embarrasingly low	poor

Needed:
* Fundamental research for understanding basic mechanism of CME release.
* High time resolution optical observations of CME onset and propagation, simultaneously from different view points (stereo view).



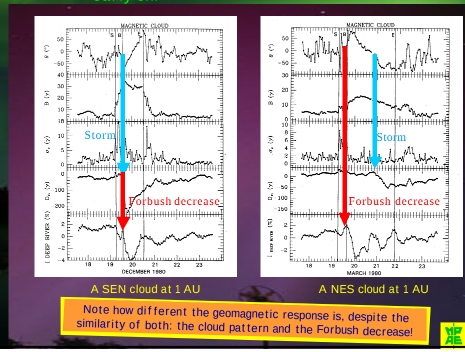
3. Low to medium-energy particles, plasma clouds

Needed: * On-line computer model of the heliosphere, continously updated, that allows to simulate CME ejections and propagation in realistic and near-real-time way.



3. Low to medium-energy particles, plasma clouds

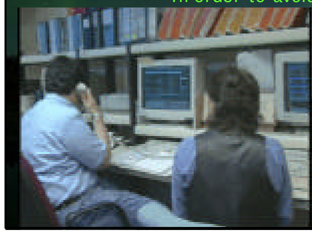
Needed: * Continuous survey (for CMEs propagating towards Earth) of the Earth-Sun line from distant spacecraft, e.g., STEREO,
* Continuous monitoring of filament helicities, in order to reveal potential magnetic cloud topologies (Bz south when?) early on.

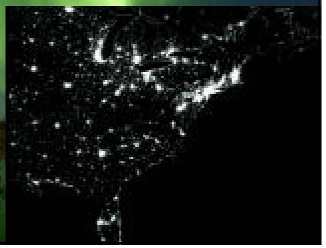


3. Low to medium-energy particles, plasma clouds

Needed: * A dedicated spacecraft at L1 (or closer to the Sun!), carrying:
an EUV/X-ray imager of the Sun,
a sensitive coronagraph, for quantifying halo CMEs,
a complete set of standard particle and field instruments,
a MDI type instrument to monitor the Sun's interor.
* A space weather warning center on the ground, equipped with real-time data links both to the spacecraft in orbit and to the modelling computers, to produce near-real-time reports through the Web

In order to avoid this:

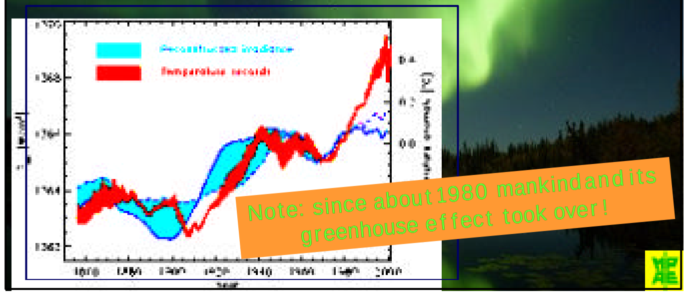




The Sun and global warming of the Earth?

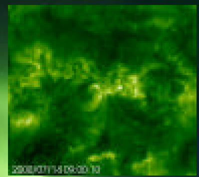
Potential causes:

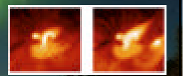
1. Long term variations in total irradiance ("total energy") is assumed to only explain part of the global warming.
2. Long term variation in UV/EUV radiation changes chemistry (ozone!), temperature etc. in the Earth's atmosphere.
3. Long term variation in the Sun's magnetic field modulates galactic cosmic rays and the solar wind.



Research topics for the future:

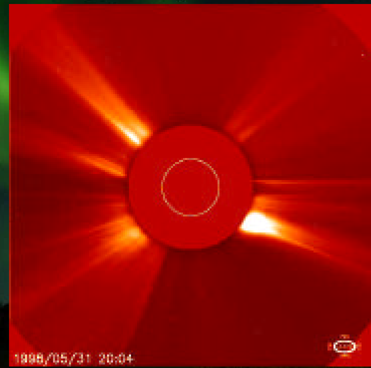
- How to predict CMEs/flares before they occur?





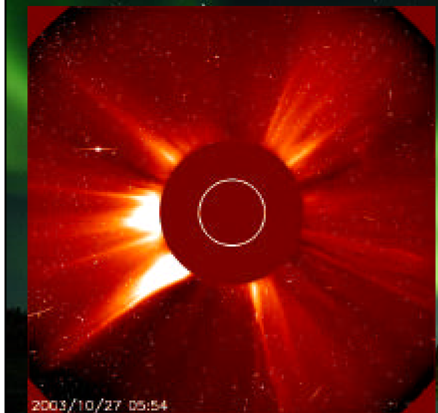
Sigmoids?

Triggering CMEs?



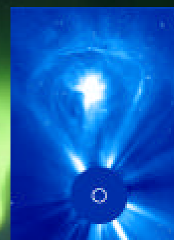
Two small comets were evaporating near the Sun.
A few hours later a huge ejection occurred. Coincidence?
No, says Dan Baker!

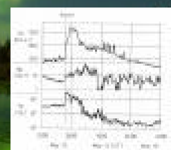
Triggering CMEs?



Research topics for the future:

- How to predict CMEs/flares before they occur?
- Topology evolution: from CMEs to interplanetary clouds?





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Research topics for the future:

- How to predict CMEs/flares before they occur?
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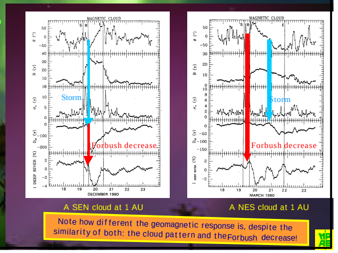
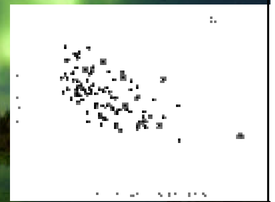
- How to predict geoeffectiveness?



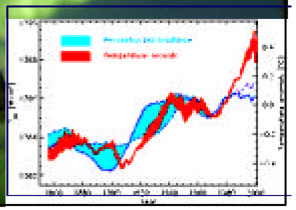
Research topics for the future:

- How to predict CMEs/flares before they occur?
- Topology evolution: from CMEs to interplanetary clouds?
- How to predict geoeffectiveness?
- Better models/observations of CME propagation towards Earth.



Research topics for the future:

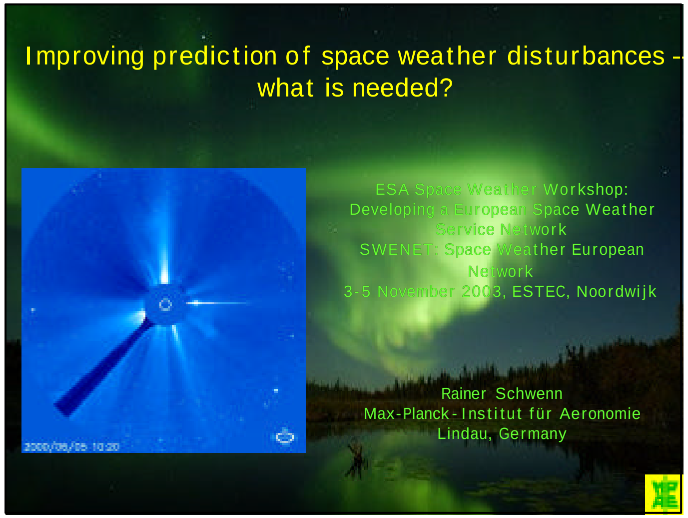
- How to predict CMEs/flares before they occur?
- Topology evolution: from CMEs to interplanetary clouds?
- How to predict geoeffectiveness?
- Better models/observations of CME propagation towards Earth.
- Separate solar effects on terrestrial weather and climate from reveal human impacts and sell that well to the public!



Space weather experts: remember the fundamental law for data evaluation in science:

- **There are lies...**
  - **damned lies...**
    - **and statistics!**

Let us continue searching for the physical links between causes and effects of the long chain connecting the Sun to the Earth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