VarSITI – Variability of the Sun and Its Terrestrial Impacts

the SCOSTEP 's scientific progra

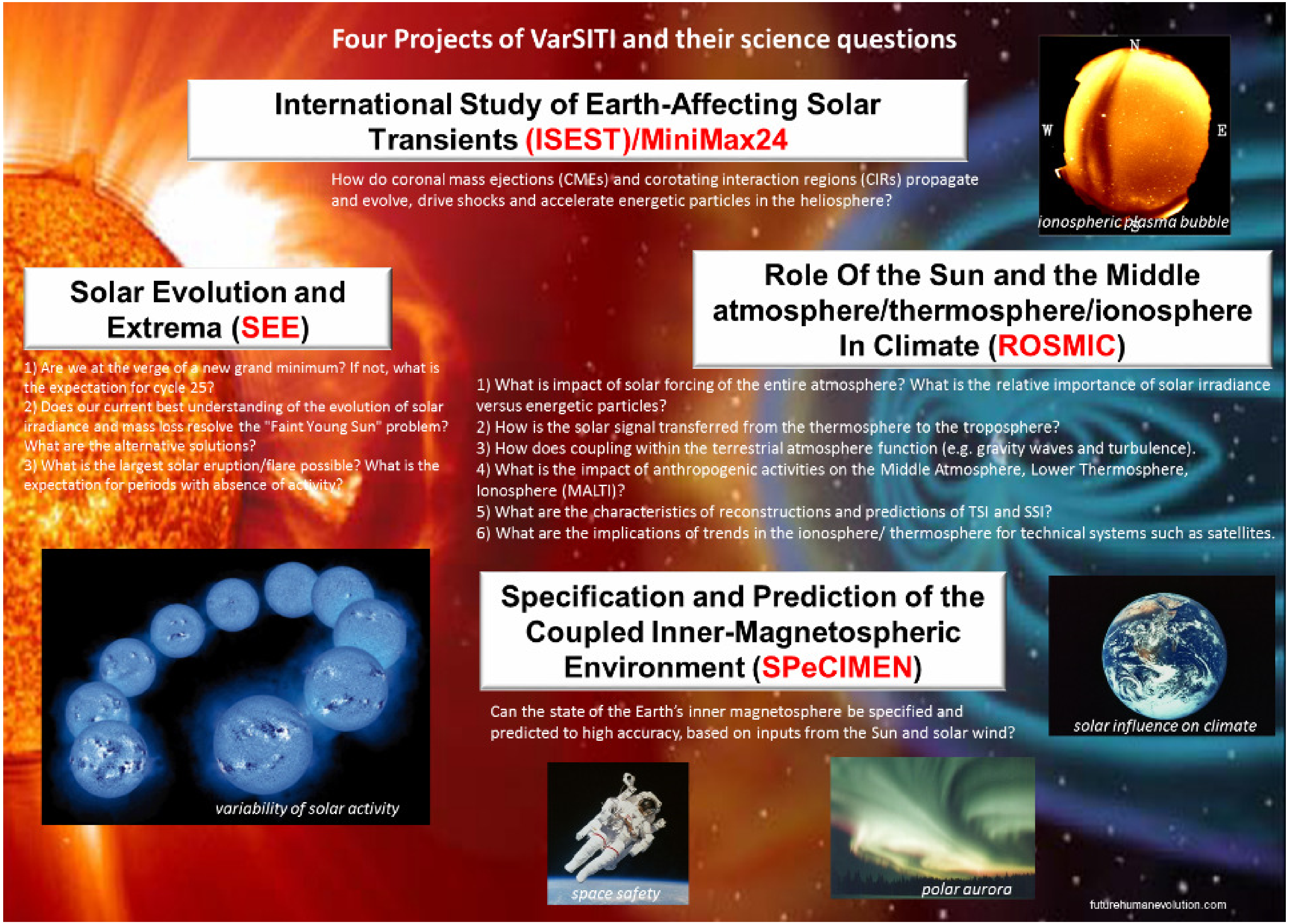
Scientific Committee on Solar-Terrestrial Physics

2014-2018

ISWI-related activities

Katya Georgieva and Kazuo Shiokawa – VarSITI co-chairs
Nat Gopalswamy – SCOSTEP president

VarSITI has 4 scientific projects

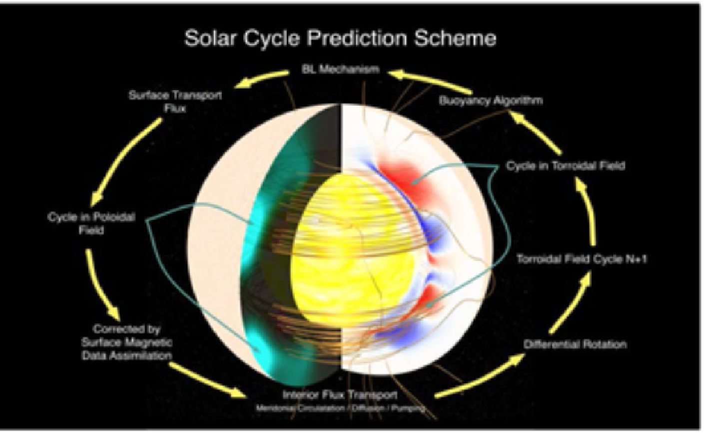


Solar Evolution and Extrema (SEE)

Dibyendu Nandy (India)
Piet Martens (USA)
Vladimir Obridko (Russia)

Members: 633
Countries: 63

Science Questions: the SUN



1) Are we at the verge of a **new grand minimum of solar activity**?

2) For the next few decades, what can we expect in terms of **extreme solar flares and storms**? What is the largest solar eruption/flare possible?

3) Does our current best understanding of the evolution of solar irradiance and mass loss resolve the "**Faint Young Sun**" problem? What are the alternative solutions?

What can we expect in terms of extreme solar flares and storms

CONFERENCE OF VarSITI SEE poject

«Superflares and Activity of the Sun in the Cycle Formation Epoch»

2015, Qazrin – Tel-Aviv, Israel

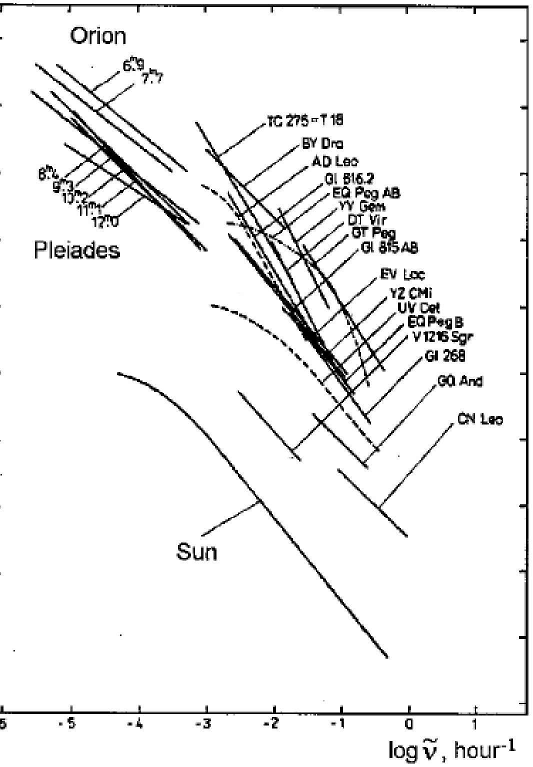
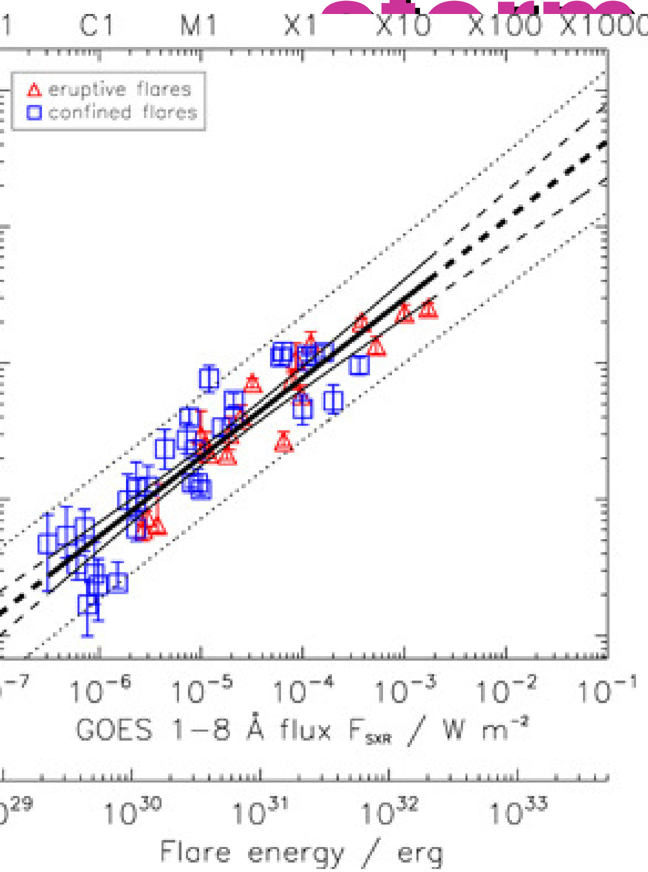


Fig. 2. Energy spectra of stellar flares in the solar vicinity, spectra of the Pleiades and Orion stellar clusters and solar flares (Gershberg et al., 1987)

Flares with energy > 10^{32} are not likely for the Sun

What can we expect in terms of extreme solar flares and storms

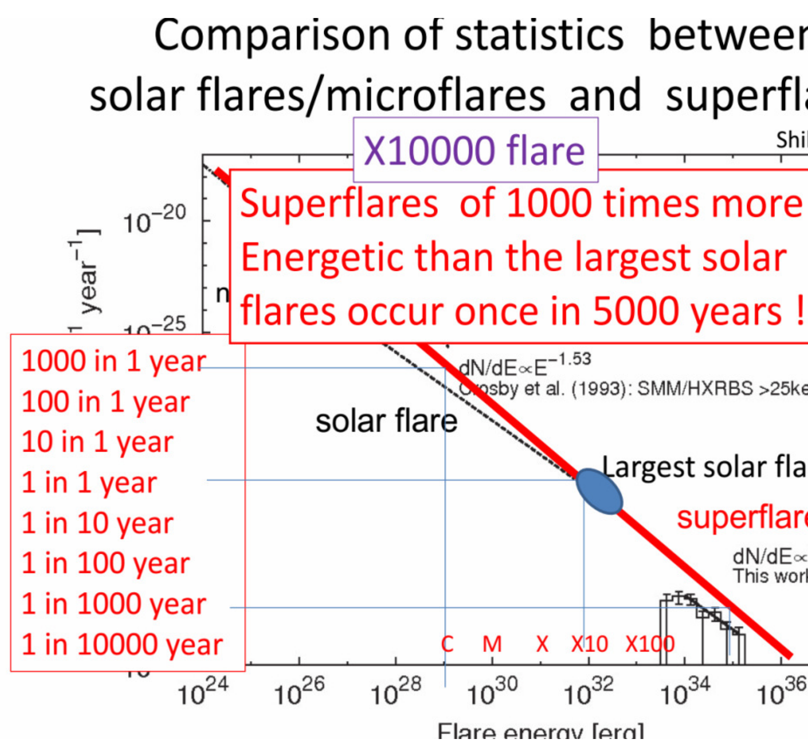


For the largest AR ever observed on the Sun (1947 April):

- magnetic flux ≈ 6 × 10^{23} Mx
- a flare of about class X500
- energy ≈ **3 × 10^{33}** erg

an order of magnitude larger than the largest flares reported during *GOES* era

No definite answer yet



Tschernitz et al., 2018

Project ISEST/MiniMax24

International Study of Earth-affecting Solar Transients

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[2]Institute of Physics, University of Graz, Styria, Austria
[3]NASA Goddard Space Flight Center, Greenbelt, MD, USA


Jie Zhang


Manuela Temmer


Nat Gopalswamy

Goal of ISEST

Understand the origin, propagation and evolution of solar transients through the space between the Sun and the Earth, and develop the prediction capability of space weather

ISEST WG1 Data Group

1. Identify all Earth-affecting solar transient events, CMEs and CIRs, during the STEREO era (2007 - 2017)

2. For selected events, fully measure, characteriz and quantify their evolutional properties from the Sun to the Earth

Provide a comprehensive event **database** which are valuable and necessary for a variety of scientific studies:

- Statistical studies of events and new findings
- Create empirical evolution models
- Create prediction models
- Improve theoretical understanding and models
- Constrain and validate numerical models

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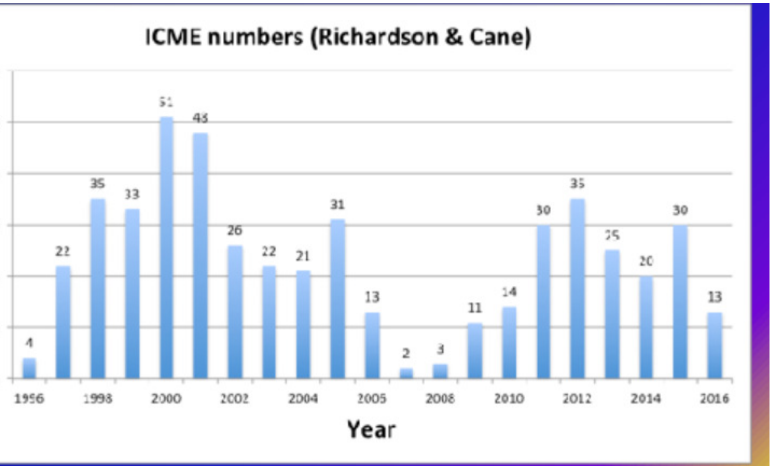
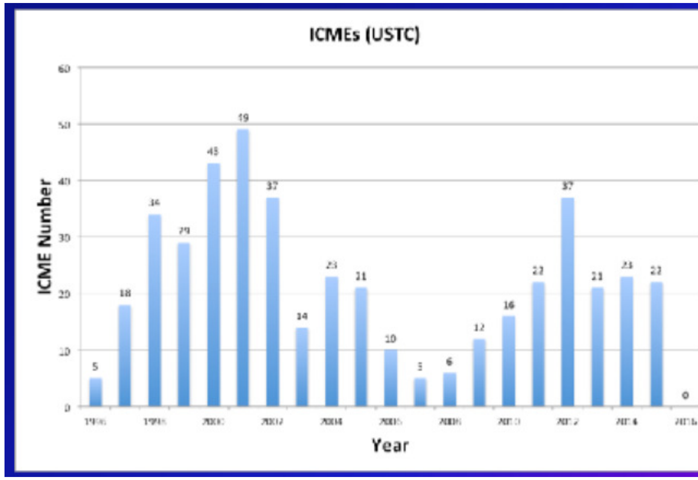
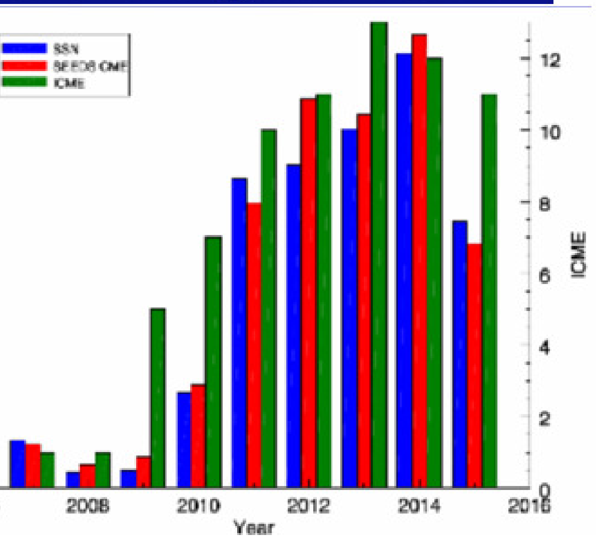


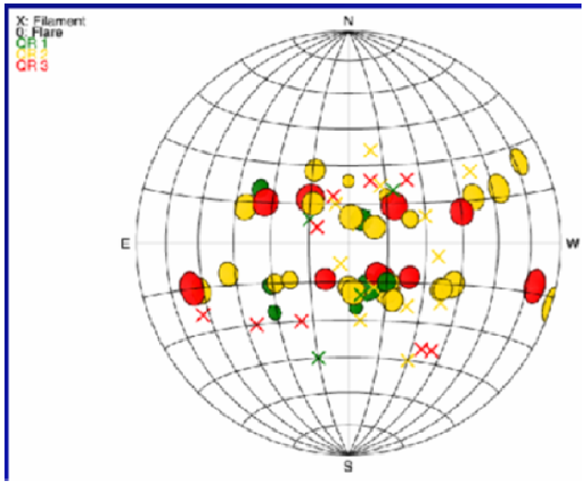
Richardson & Cane ICME Catalog



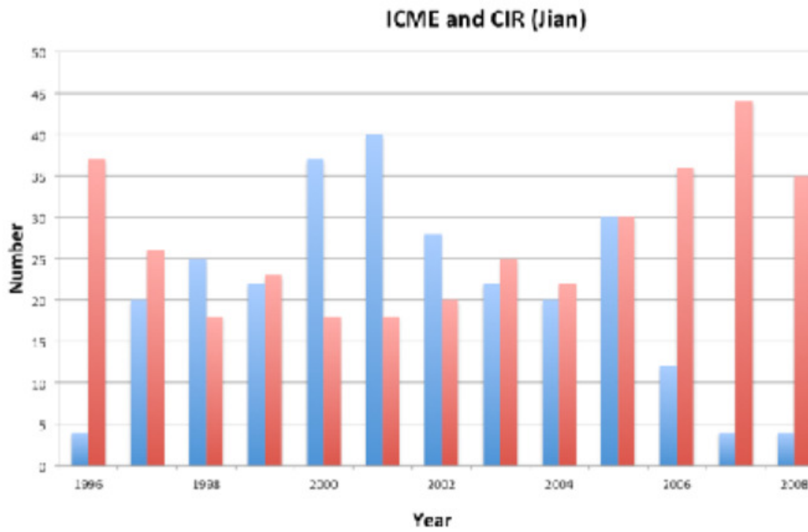
USTC ICME Catalog

ss & Zhang ICME-CME

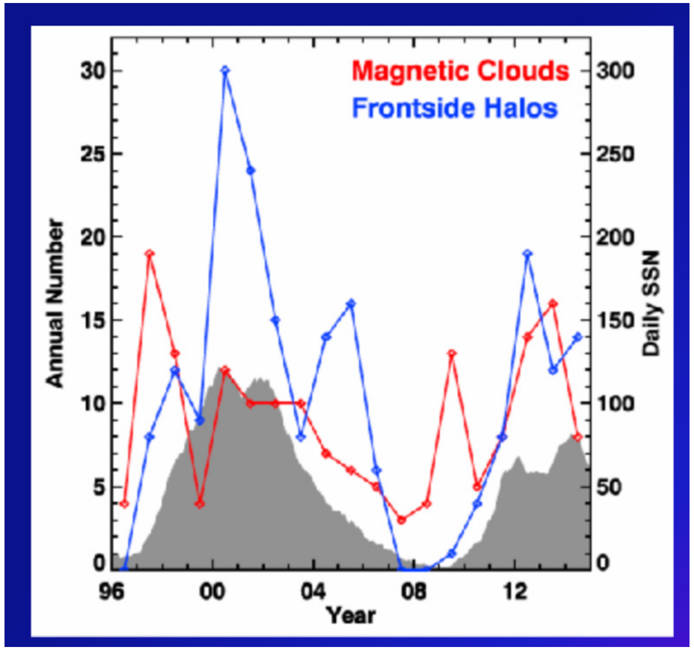




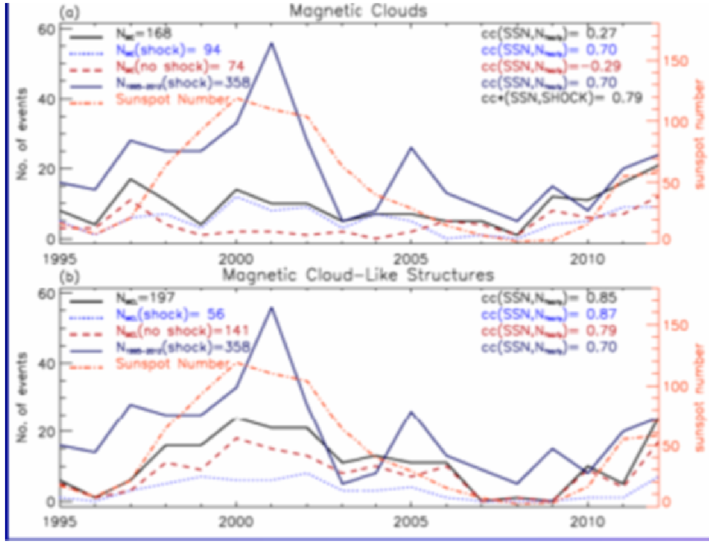
Jian's ICME and CIR Catalog



palswamy et al.



Lepping & Wu MC and MCL lis



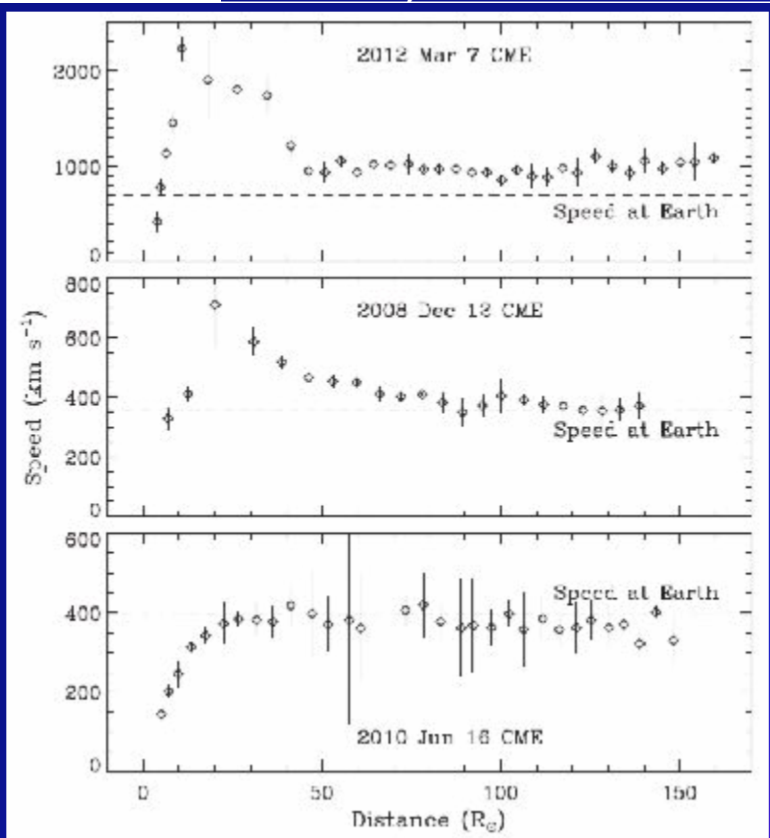
Yermolaev's large scale solar wind phenomena catalog

Type of event	Total number	Minimum number per year	Maximum number	Average number	Standard deviation
HCS	1449	17	219	57.96	46.12
CIR	884	21	55	35.4	9.04
SHEATH	740	10	51	29.6	13.9
EJECTA	1567	36	123	62.68	23.45
MC	136	0	15	5.44	4.19
RARE	18	0	8	0.72	1.8
IS	319	2	43	12.8	10.2
ISA	14	0	5	0.56	1.3

r selected events, fully measure, characterize
d quantify their evolutional properties from
Sun to the Earth

CME Sun-to-Earth Measurement

- Measure the evolution from the Sun to Earth in 3D for as many events as possible (but will be a small number)

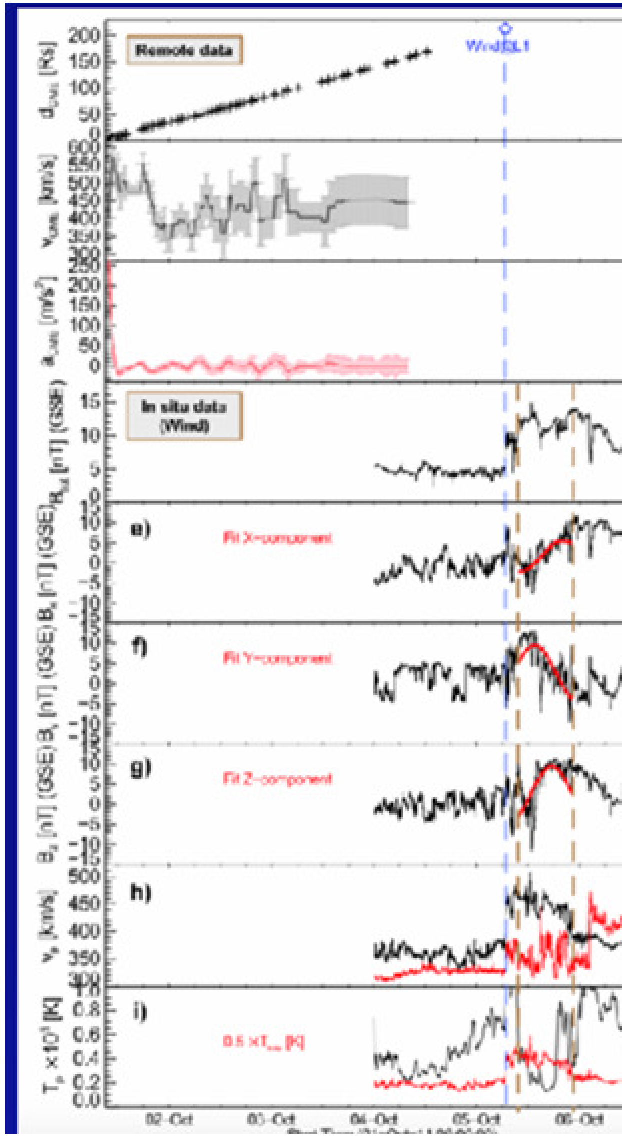


2012 Mar. 7 CME

2008 Dec.12 CME

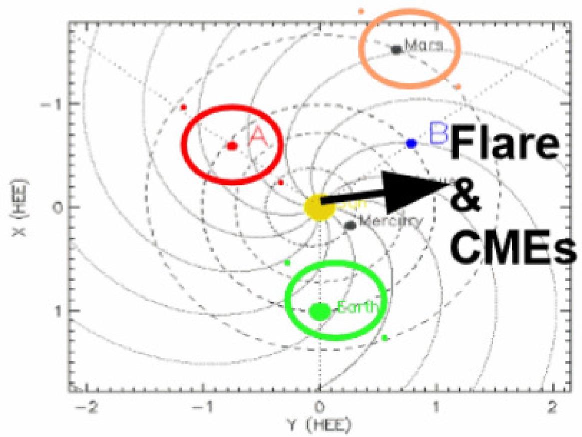
2010 Jun. 18 CME

Liu et al (2016)

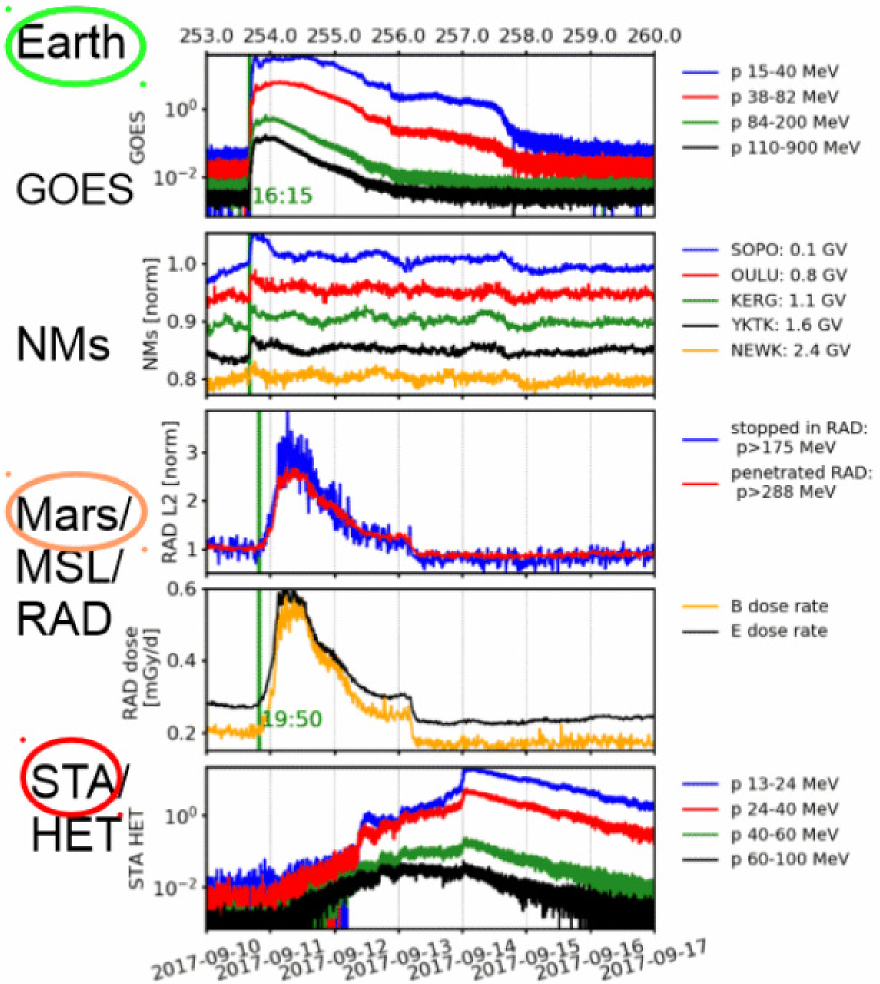


Temmer et al (2017)

2011 Oct. 01 CME



The first GLE observed on two planets: 2017-09-10 event with SEPs (>100 MeV) arriving at Earth, Mars and STEREO-A



Earth

- The onset of protons > 100 MeV seen by GOES at Earth is at about **16:15** on 2017-09-10.
- SEPs were also registered as a ground level enhancement (GLE) seen by multiple neutron monitors with cutoff rigidities of about 3 GV (~2 GeV protons)

Mars

- Mars magnetic foot point is ~150 degrees from the flare.
- The earliest onset at Mars is about **19:50** and this has been the biggest GLE at Mars seen by the Radiation Assessment Detector (RAD) since the landing of the Curiosity rover.
- Considering the atmospheric cutoff and the RAD detector response function, particles with > ~300 MeV arrived at Mars.
- *We are working on retrieving the SEP spectra at Mars on top of the atmosphere from surface measurement.*

STEREO-A

- STA foot point is >~200 degrees away from flare and still detected particles ~ 100 MeV.
- The SEPs arriving at STA are likely transported there across Interplanetary Magnetic Field (IMF) lines via diffusion and scattering as STA was at the back side of the flare and CME shock.

WG-4
CAMPAIGN EVENTS

WG-4 Goals

- **Integrate observations, theory and simulations to understand chain of cause-effect dynamics from Sun to Earth/1 AU for carefully selected events.**
- **Develop/improve the prediction capability for these transients' arrival and their potential impacts at Earth.**
- **Textbook cases are provided for the community, but a focus is on less well understood events, such as stealth & problem CMEs.**
  - WG 4 wiki: ***http://solar.gmu.edu/heliophysics/index.php/Working_Group_4***

• Textbook cases: Complete chain of a well-observed event from solar source, through IP propagation, to geoeffects.

• Not Textbook but Understood cases: Something is missing in the chain of a well-observed event but, *in retrospect,* we understand why.

• Problem cases: The chain is not complete and we still do *not* understand why.

Improving Forecasts *(after Webb & Nitta, SP, 2017)*

- "Textbook" Event: 12-14 July 2012 *Mostly successful*
  - Complete chain of well-observed Sun-to-Earth event → from solar source, through IP propagation, to its geoeffects.

- Problem Event: 17-18 March 2015 *Under-predicted*
  - Strength of this first "super storm" under-predicted, but we now understand why.
  - 2 flares/CMEs occurred at Sun but somewhat offset. CMEs may have interacted.
  - During transport there was interaction with a CIR & deflection toward Earth.

- Possibly a textbook event: 21-24 June 2015 *Mostly successful*
  - Forecast of a severe storm was accurate but probably not to superstorm levels.
  - Multiple shocks & sheaths, strong B_S MC axial fields, HSS: compound event

- Problem Event: 10-12 September 2014 *Over-predicted*
  - But we think we now understand why.
  - Major storm was predicted → strong long-duration MC shock hit Earth.
  - However storm was minor → sheath and MC B field were northward

    (Source FR orientation is hard to predict at Sun)

- Problem Event: 4-9 October 2012 *Under-predicted*
  - Source apparently a CME and resulting ICME that drove a small geostorm.
  - But there were only weak and multiple surface signatures.

- Problem Event: 27 May – 1 June 2013 *Failed prediction*
  - An unforecasted brief, but strong storm.
  - Possible slow CME but surface features unclear
  - Interaction with CIR/HSS and embedded ICME at Earth.

The Bs challenge: Statement of the WG

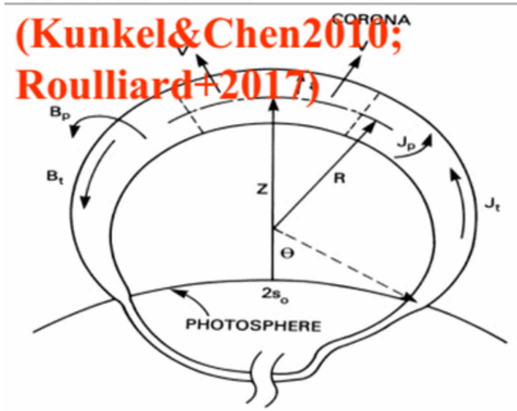
(from ISEST description)

The presence of **southward** magnetic fields in ICMEs are the most important factor in producing **geomagnetic storms**.

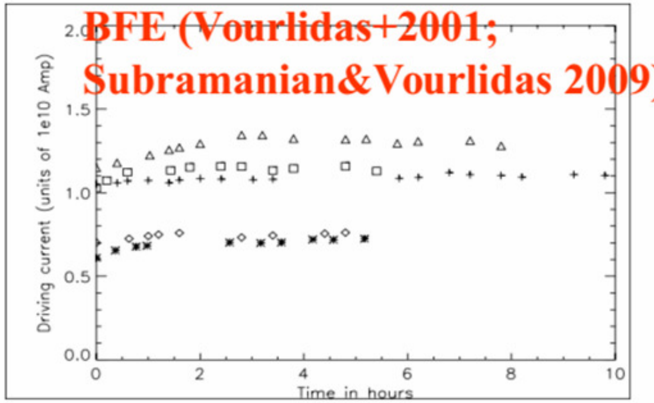
WG5 aims to understand and reconstruct the possible flux rope **magnetic structure** of CMEs/ICMEs from observations and models. It also aims to **predict** the **intensity** and the duration of the **Bs** in ICMEs **upon arriving at the Earth**.

Many Models of CME Magnetic Field Infererence

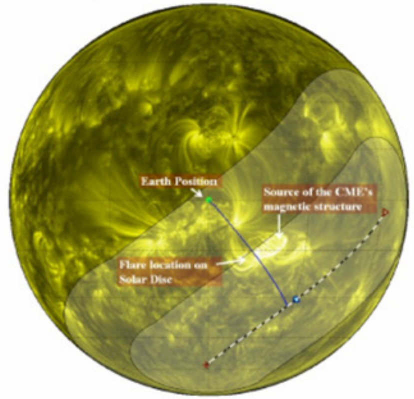
HELIO-XM (Kunkel&Chen2010; Roulliard+2017)



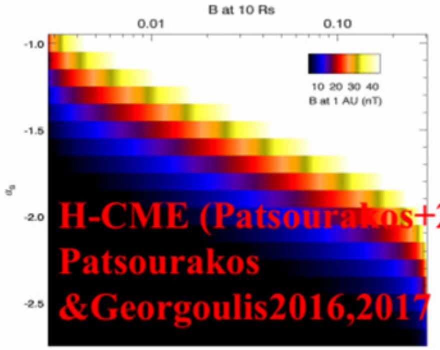
BFE (Vourlidas+2001; Subramanian&Vourlidas 2009)



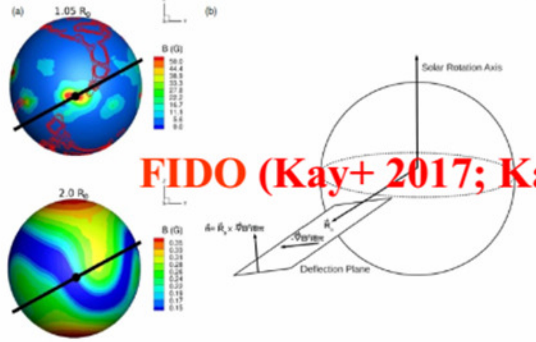
BZ4CAST (Savani+ 2015, 2016)



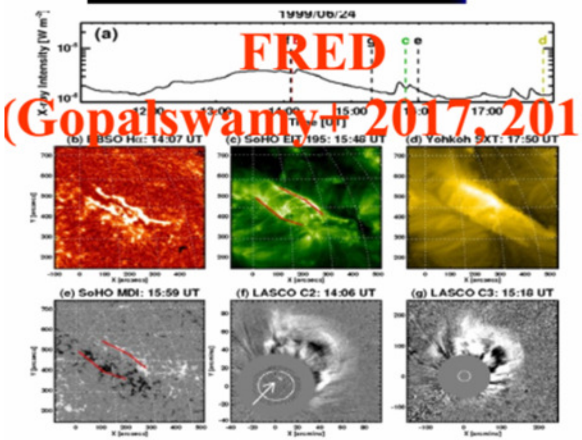
H-CME (Patsourakos+2016; Patsourakos &Georgoulis2016,2017



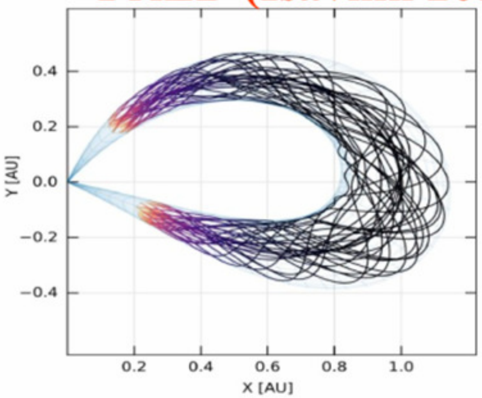
FIDO (Kay+ 2017; Kay&Gopal 2017b)



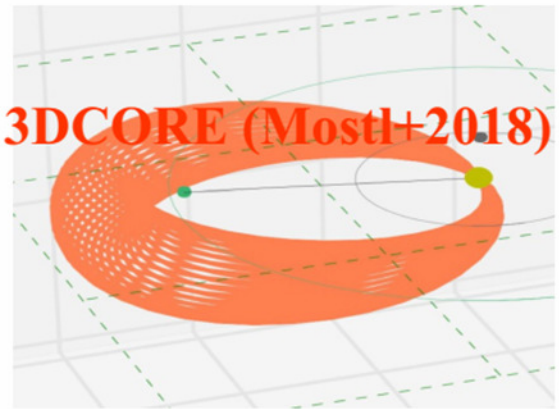
FRED (Gopalswamy+ 2017,2018)



FriED (Isavnin 2016)



3DCORE (Mostl+2018)



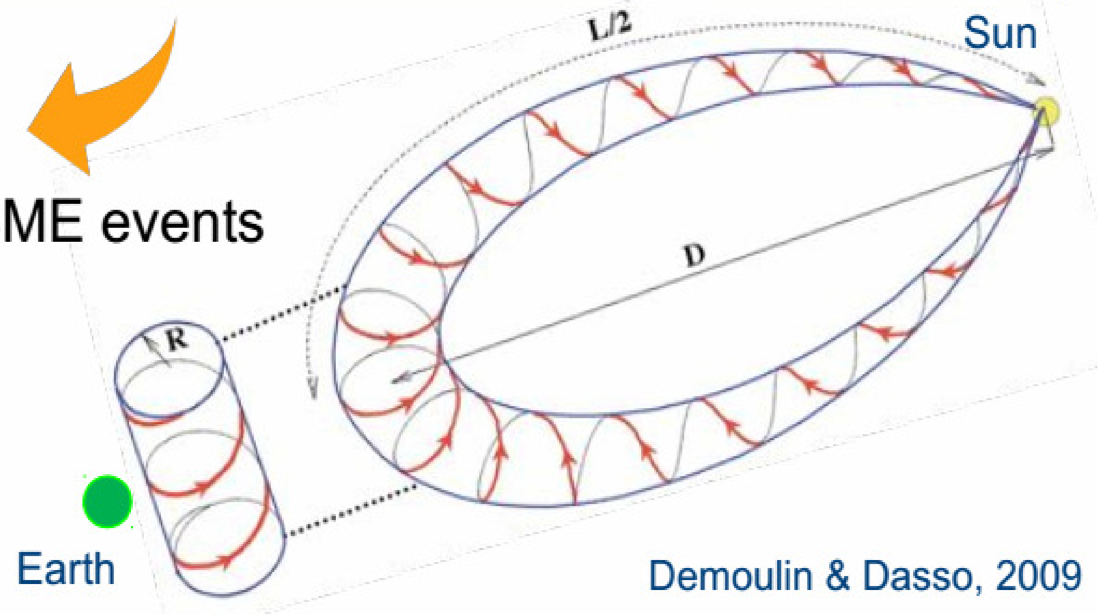
1) **EUHFORIA**: newly developed solar wind and CME propagation model designed for space weather purposes (Pomoell & Poedts 2018)

- **Flux-rope CME models** (spheromak and Gibson-Low) recently implemented (Verbeke et al 2018, in prep)

→ Goal of **this study:** assessing the predictive capability of the new flux-rope models at Earth (ICME and ICME geoeffectiveness), based on CME observations at the Sun

2) **ISEST WG4 campaign events**:
textbook (T) and problematic (P) CME events

- July 12, 2012 (T)
- March 15, 2013 (T?)
- September 9-10, 2014 (P)

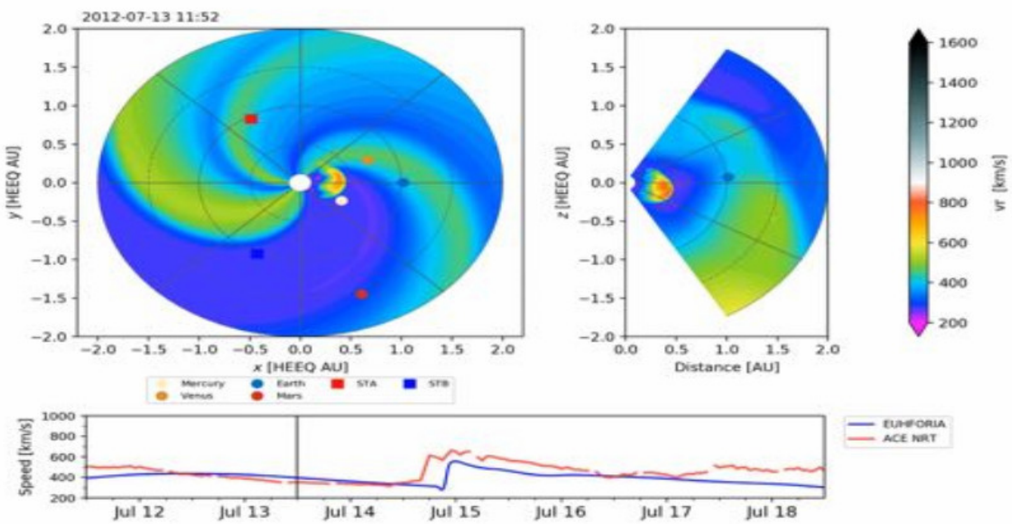


Demoulin & Dasso, 2009

Pomoell & Poedts (2018, JSWSC)

EUHFORIA

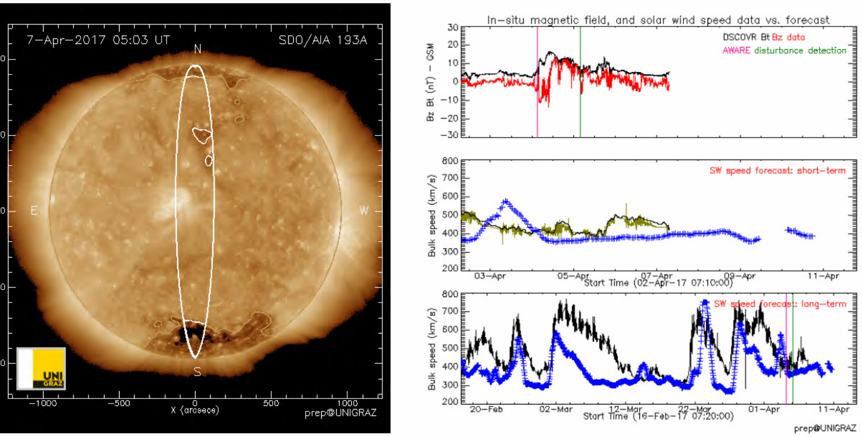
- 3D coronal and heliospheric model
  - Corona (up to 0.1 AU): magnetogram + semi-empirical WSA model
  - Heliosphere (0.1 AU to 2.0 AU): time-dependent 3D MHD model
  - CME models: cone CMEs or **flux-rope CMEs**



How much do we improve using a flux-rope CME model?

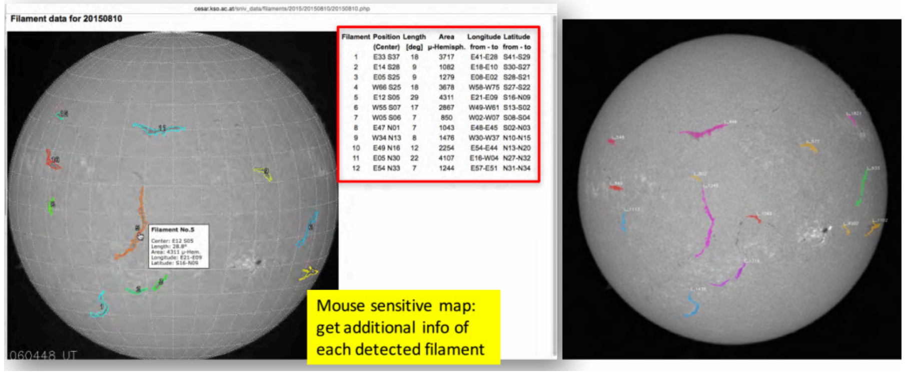
- Up to +40%(min Bz)/+80%(min Dst) compared to cone model (2012-07-12)
- Modelling geoeffective sheaths beyond tested capabilities (2014-09-10)
- Flux-rope results vary significantly moving around Earth by just few degrees (2013-03-15)

SWF and AWARE – CME/HSS etection in real-time :: testing phase

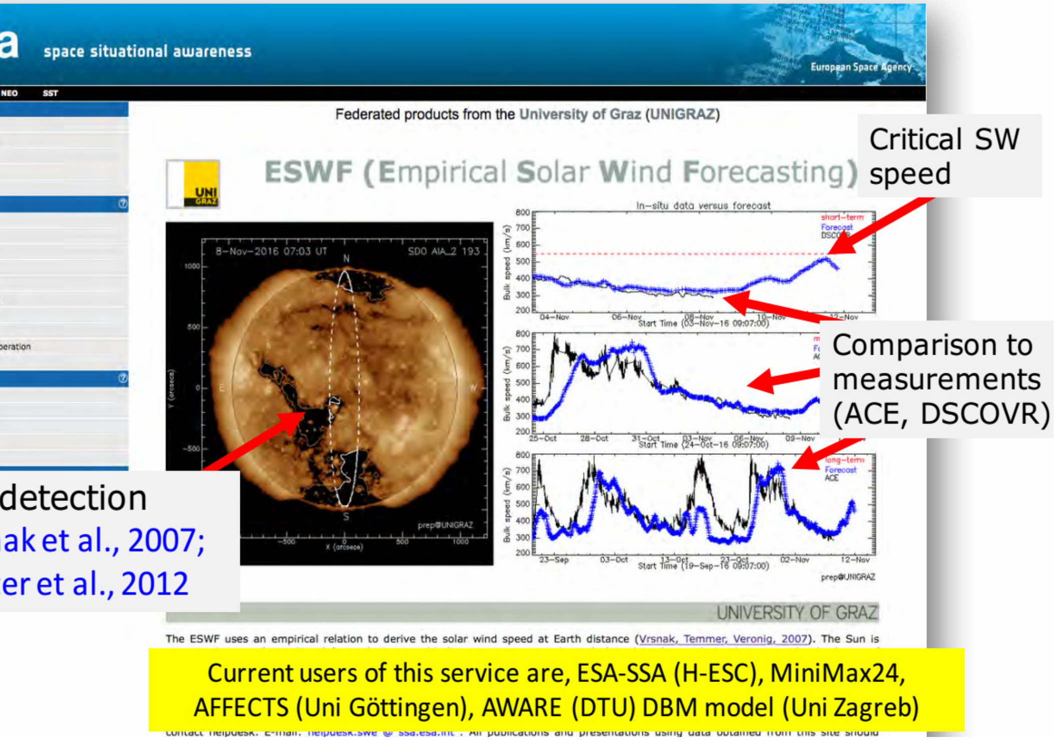


Automatic filament detection at KSO: in operation for MiniMax24 since summer 2015

The filament detection algorithm established at Kanzelhöhe Observatory (Pötzi et al., 2015) automatically gives the position and size of filaments that is used for the MiniMax24 forecasting.

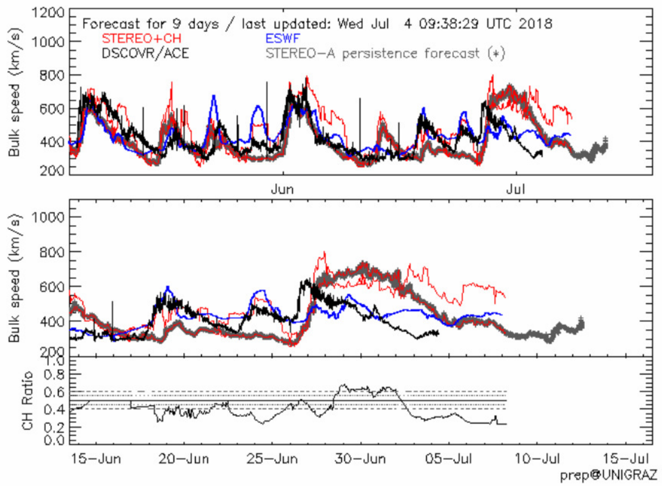


wind forecasting using surface mation from CH areas

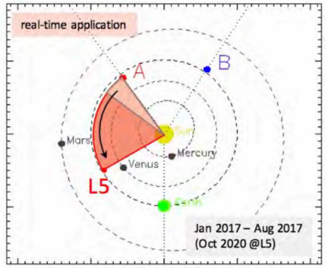


Current users of this service are, ESA-SSA (H-ESC), MiniMax24, AFFECTS (Uni Göttingen), AWARE (DTU) DBM model (Uni Zagreb)

STEREO-A persistence modeling + CH information



swe.uni-graz.at



Temmer, Hinterreiter, Reiss 2018 (SWSC)

A persistence model based on STEREO-A data is used to forecast the solar wind at L1. The uncertainties in the speed forecast are estimated from observed changes in the CH areas (expansion/decay) causing an under-/overestimation of the persistence result. The STEREO+CH forecast has a lead time of 4 days. (upcoming ESA service)

Diversity of VARSITI

- The MiniMax24 email list reaches more than 600 participants from more than 60 countries.
- Huge platform of experts in different fields of solar and heliospheric physics – we communicate daily!
- Daily emails (around 10UT) are sent by the MiniMax team
- Increases visibility of young researchers

Daily email from MiniMax24

- 1. Non-flare Target – selected by the MiniMax24 campaign team (large coronal holes close to central meridian, large filaments within +/- 30° of central meridian likely to erupt)
- 2. Information on current flare activity (MaxMillenium)

VarSITI Closing Symposium

June 10÷14, 2019, Sofia, Bulgaria

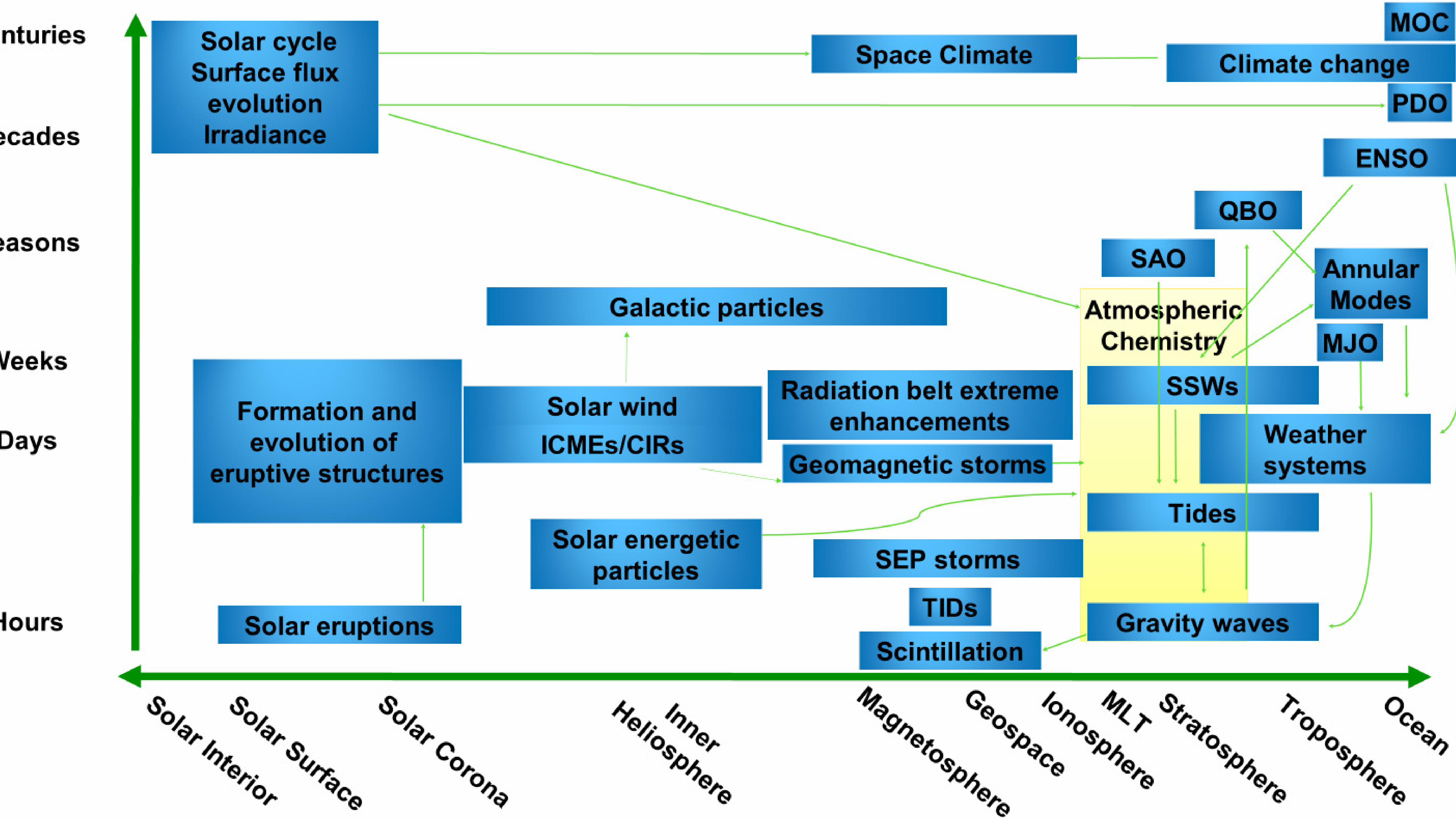
http://newserver.stil.bas.bg/VarSITI2019/

1. Mechanisms of solar variability and its Earth-affecting manifestations
2. Long-term solar variability and its impacts on the heliosphere and the terrestrial system inclu solar wind, geomagnetic field, and Earth's climate (Space climate)
3. Short-term solar variability and Earth-affecting events, and the reaction of the terrestrial syst to solar/heliospheric drivers (Space weather)
4. Coupling between the Earth's atmosphere and space under quiet or active Sun
5. Sun to Earth event case studies
6. Sun-Earth related data: definition, maintenance, archiving
7. Predictability of the Variable Solar-Terrestrial Coupling (PreSTo): The science behind

SCOSTEP new scientific program 2019-2022

- ***PreSTo***: **Pre**dictability of the variable **S**olar-**T**errestrial C**o**upling

- **A major motivation is the desire to conduct fundamental research that has the promise to advance predictive capability with societal implications.**
- **1. Sun, interplanetary space and geospace**
- 1.1. Occurrence and properties of flares and CMEs/CIRs and the propagation of CMEs/CIRs from the Sun to the Earth
- 1.2. Predictability of interplanetary shocks (ISs) and energetic particle flux enhancements
- 1.3. Predictability of substorms and storms
- 1.4 Solar wind-magnetosphere coupling and internal magnetospheric
- **2. Space weather and Earth System**
- 2.1 Multiscale vertical and horizontal coupling between atmospheric regions and its effects on space weather
- 2.2. Effect of atmospheric waves on the global circulation in the middle and upper atmosphere
- **3. Solar activity and its influence on climate**
- 3.1. Understanding and predicting solar activity
- 3.2 Sub-seasonal to decadal variability of the terrestrial system
- 3.3 Centennial variability of the terrestrial system



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Atmospheric
Chemistry
Galactic particles
Formation and
evolution of
eruptive structures
Solar wind
ICMEs/CIRs
Radiation belt extreme
enhancements
Geomagnetic storms
SSWs
Weather
systems
Tides
Solar energetic
particles
SEP storms
TIDs
Gravity waves
Scintillation
Solar eruptions
Solar Interior
Solar Surface
Solar Corona
Inner
Heliosphere
Magnetosphere
Geospace
Ionosphere
MLT
Stratosphere
Troposphere
Ocean