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L5 operational science

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Many thanks for useful input from many others in
the Met Office space weather research & forecasting teams;
Masha Kuznetsova & CCMC colleagues; Matt Owens
& Reading U. colleagues; Claire Foullon & Exeter U. colleagues

Community Coordinated Modeling Center

Overview

- Description of Met Office forecasts and our need for L5 observations:
    - flare forecasts
    - solar wind statistical models
    - deterministic / probabilistic forecasting of solar wind & CMEs
- Potential for new science:
    - Data assimilation
    - Improved CME ensemble modelling
    - Substorm onset prediction using L5 measurements
- Instruments wishlist

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Flare forecasting

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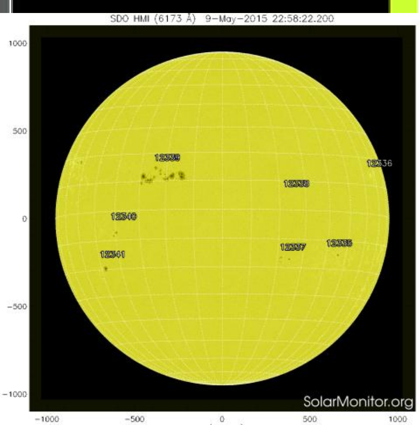
Statistical forecasting model

- Flare forecasting model relies on
  - McIntosh sunspot classification & 30 year climatology of flares → climatological probabilities
  - Size of the sunspot group and # of spots
  - History of the sunspot group
  - Forecaster experience
- Returns probabilities for M, X class flares

No.	Loc	Lo	Area	Z	LL	NN	Mag type	Growth	M	X	P
2339	N12 E34	129	1387	Fkc	19.	24	βγδ	Nil	66	18	6



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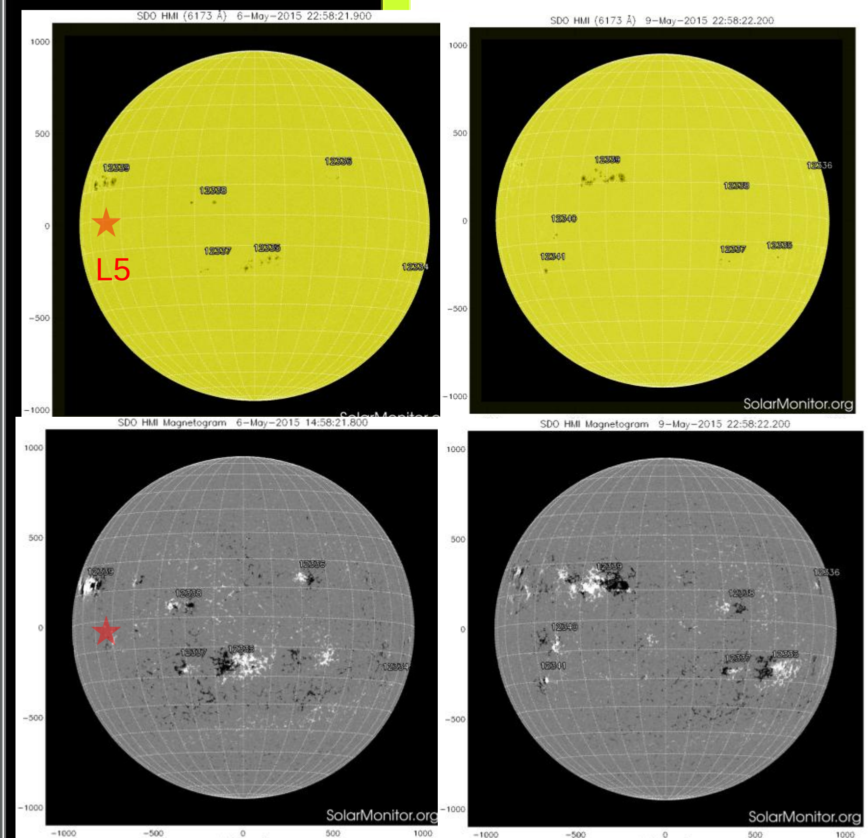
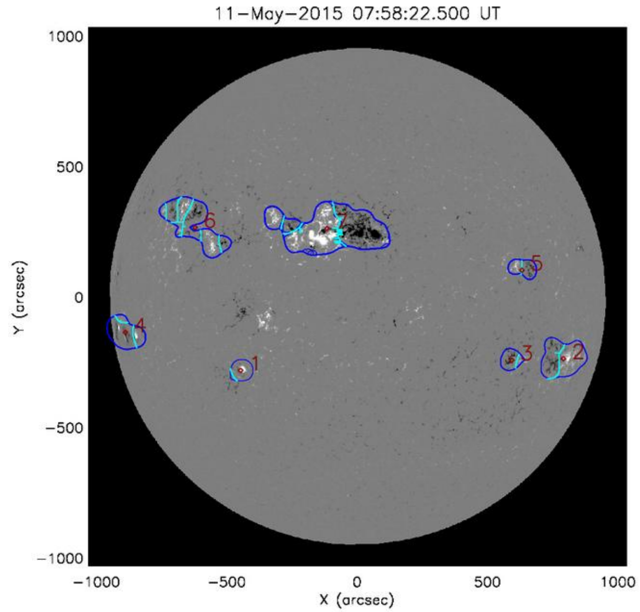
Improved flare forecasting with L5 magnetograms



- X2.7 flare from AR12339 resulting in radio comms blackout in Pacific area
- Extremely limited info for forecasting for active region emerging on the limb (impossible to use classifications; no history;...)
- L5 viewpoint would have provided parameters for flare forecasting models plus flaring history for the active region
- Vector magnetograms could be used to drive codes to model evolution of the active region, yielding magnetic free energy, current density,...

SMART model



AR #	Lat + N	Lon + W	Flux_tot Mx	Area_tot m.s.h.	B_min G	B_max G	R value Mx	WL_sg G/Mm
1	-19.96	-29.98	3.75E+21	88.34	-523.93	1900.78	4.10E+03	4.04E+03
2	-16.02	59.75	2.77E+22	605.65	-826.69	1548.08	1.86E+04	1.91E+04
3	-17.18	40.52	3.01E+21	60.62	-692.47	516.44	3.28E+03	0.00E+00
4	-9.25	-71.42	3.08E+22	827.09	-1797.11	2269.22	7.92E+04	9.09E+04
5	3.80	41.57	3.35E+21	55.60	-642.87	629.03	3.96E+03	0.00E+00
6	13.87	-42.37	1.90E+22	405.01	-1497.13	1168.53	1.84E+04	2.28E+03
7	12.79	-7.22	5.60E+22	1594.62	-2110.36	1736.77	5.52E+04	9.60E+04

Property description: Heliographic latitude and longitude [degrees];
Total flux [Maxwell];
Total area [millionths of a solar hemisphere];
Minimum and maximum total field strength [Gauss];
Schrijver R value [Maxwell];
Falconer's WL_sg [G/Mm].

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Solar wind modelling

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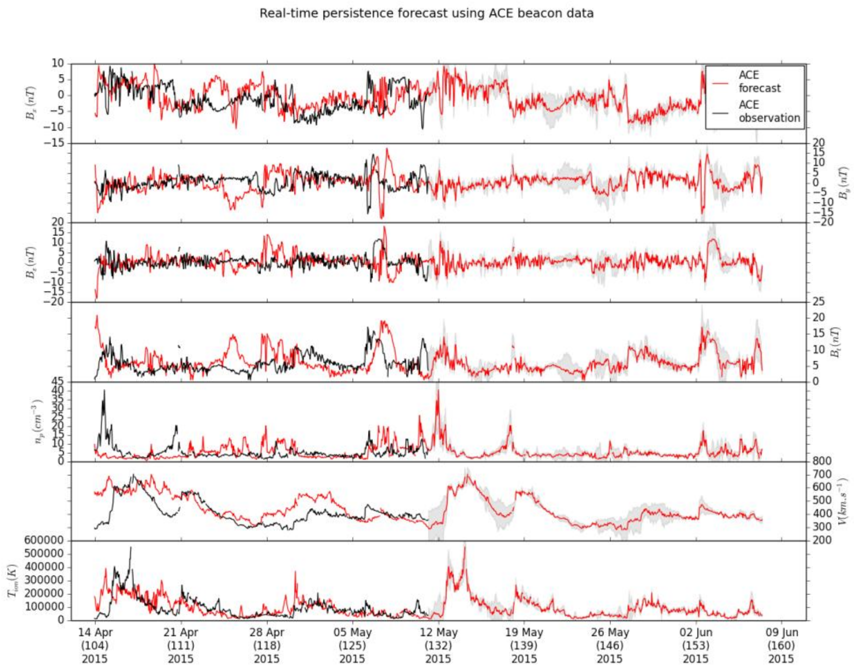
Persistence model of the solar wind

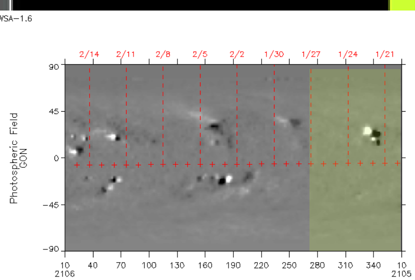


Skill	Bx	By	Bz	B	Np	Vp	Tp
ACE	0.3	0.2	0.04	0.17	0.54	0.56	0.44
STEREO	0.4	0.3	0.2	0.25	0.23	0.65	0.29

- Reading work showed strong 27 day autocorrelation in solar wind parameters allows use of persistence models
- Similar forecast can be produced using "fresher" data from L5 instead
  - 4.5-day-old data, not 27-day-old
- Test done when STEREO-B was near L5 showed improvements to skill scores
- Instrument requirements:
  - magnetic field and plasma
  - heavy ions (identify CME-contaminated periods & replace with older "clean" data)

Solar wind and CME operational prediction system

Updated GONG line-of-sight magnetograms

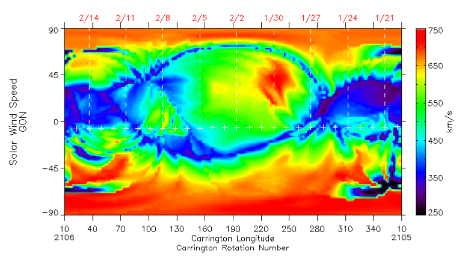


WSA model (PFSS) :

Br, Bφ at 21.5 Rs

SW speed determined from empirical formula

Vr at 21.5Rs



New: assimilate L5 data to update model fields in this zone?

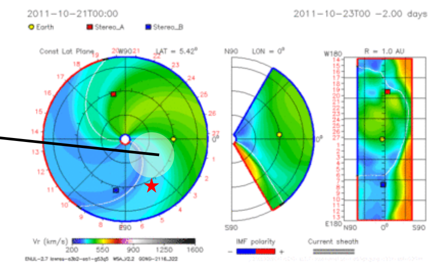
ENLIL
(3D MHD model)

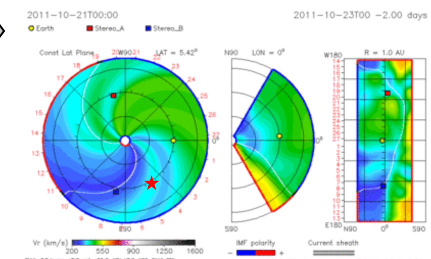
D, T, **v**, **B**

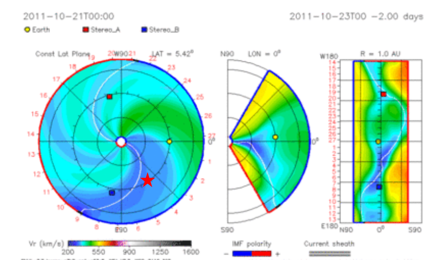
CME Analysis Tool

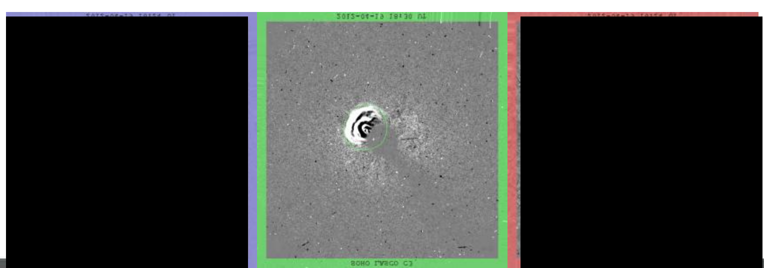
LASCO, STEREO-A & B coronagraph data

Fits a geometrical shape to the CME









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Current limitations for ambient & transient solar wind predictions

Ambient

- relies on accurate magnetograms used to derive solar wind speed (semi-empirically) at model inner boundary
- errors are often of the order of 20% of the solar wind speed
- issue with exact timing of CIR arrivals
- Could be corrected using data assimilation of in-situ data

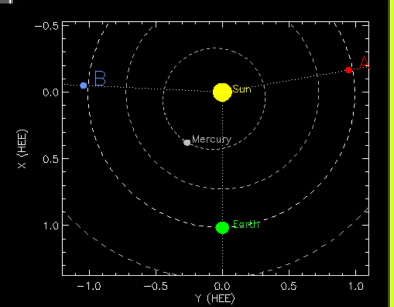
Transient

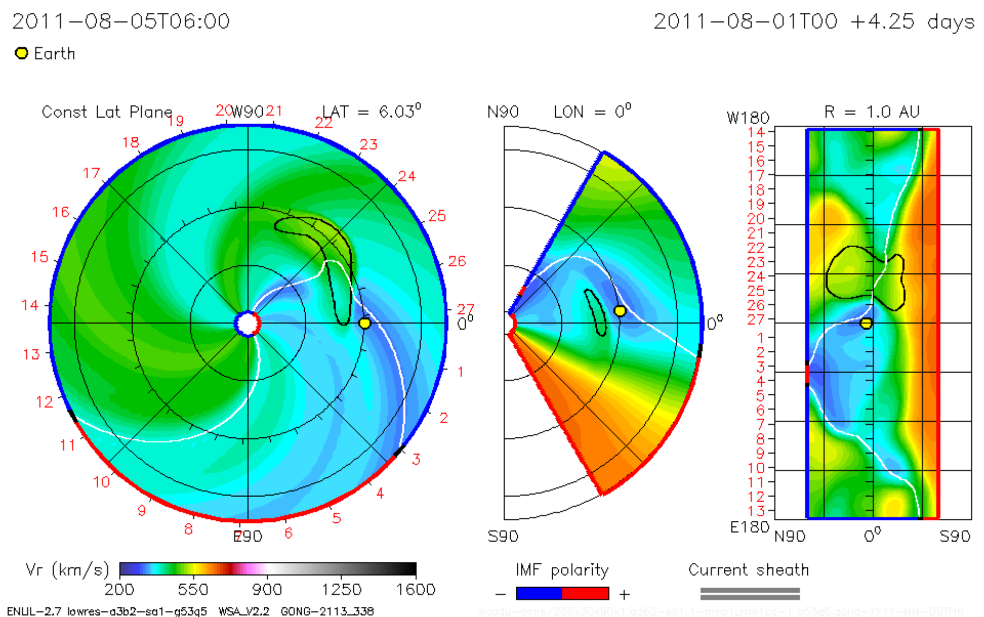
- CME parameters (speed, location, cone angle) are usually determined using a combination of LASCO and STEREO coronagraph imagery
- Possible to get CME arrival time error to within 6 hours
- now limited to LASCO only – degrades forecast accuracy

Using L5 data to improve ENLIL predictions

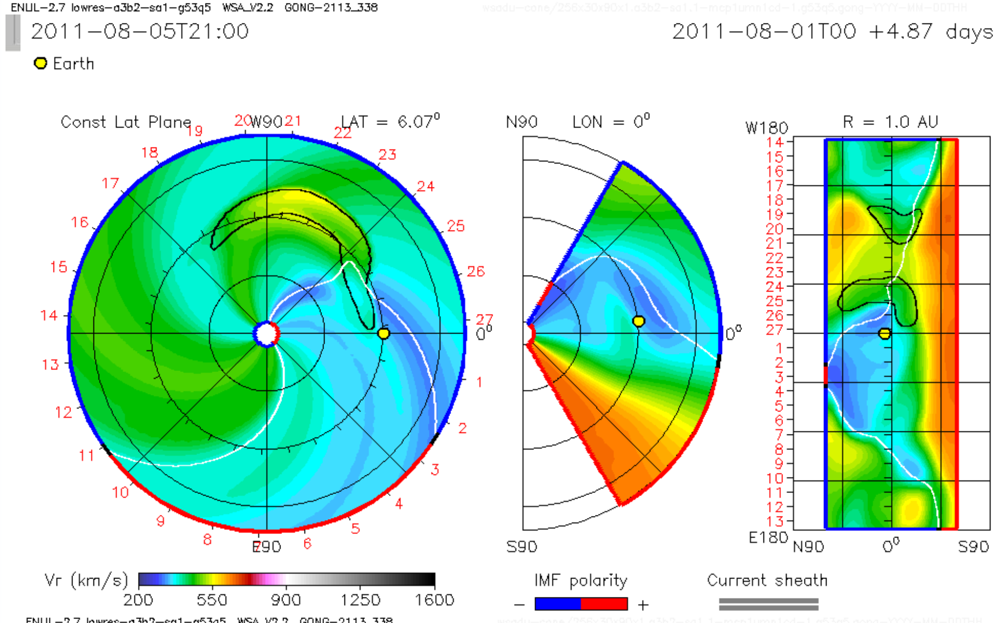
- L5 in-situ data to drive data assimilation (merging data and model) enhancing ENLIL's background solar wind and CME prediction
- L5 coronagraph to improve CME initial conditions
- L5 magnetograms to provide more up-to-date boundary conditions to ENLIL
    - ADAPT maps infer active regions on the far side but detail is limited
    - Current synoptic map uses data from the last 27 days, but could be updated with L5 magnetograms
    - Need to investigate creating synoptic map using L5 and Earth-based / SDO magnetograms

Dependency on coronagraphs





CME fit using LASCO C3 + STEREO B

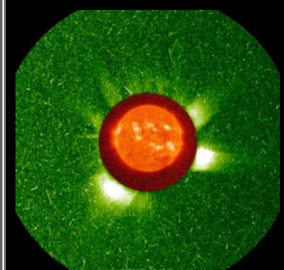


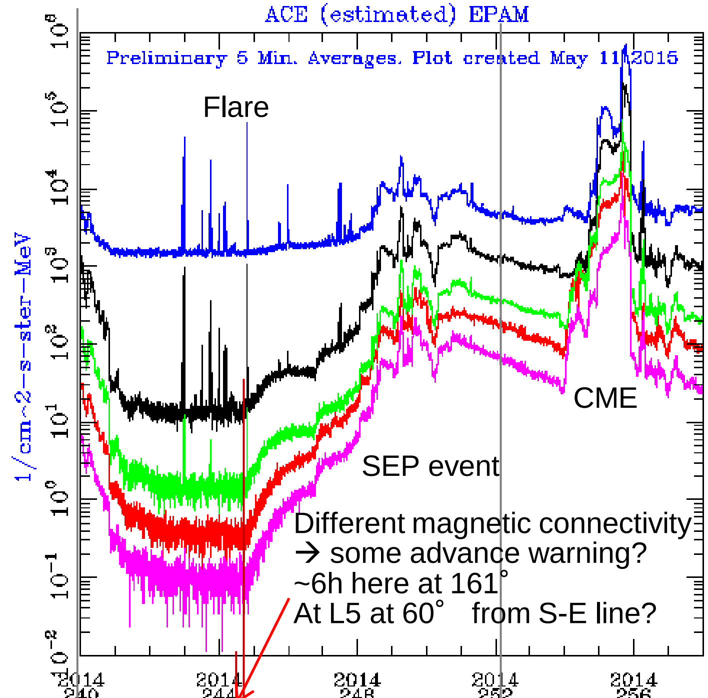
CME fit using LASCO C3 only

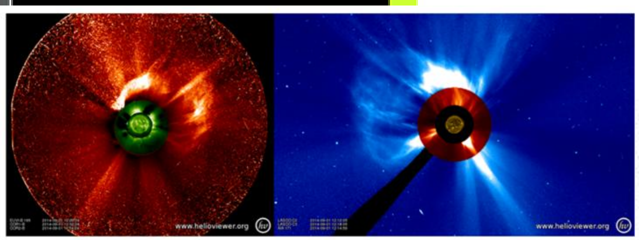
SEPs

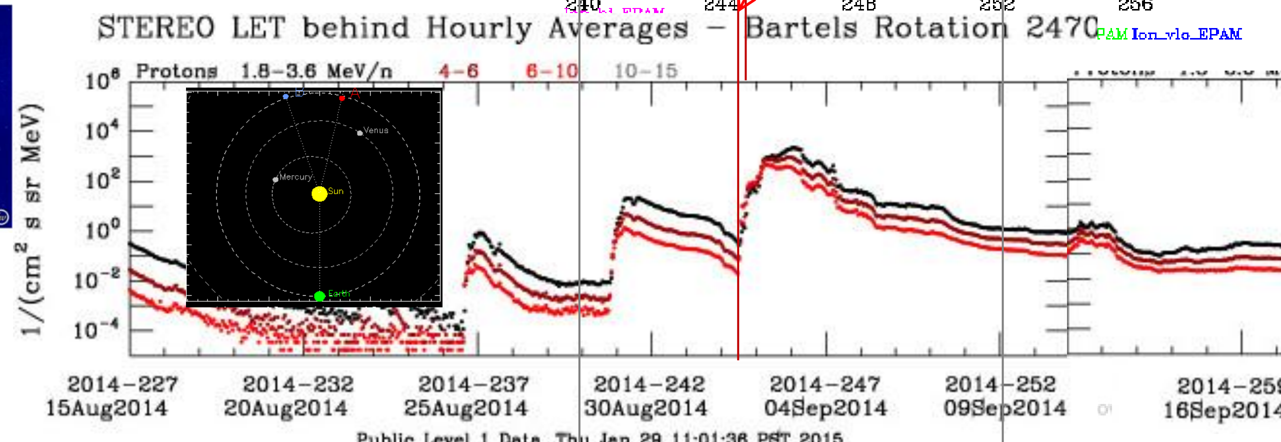
In situ instrumentation and SEPs

- Backside ~X flare seen by STEREO B on Sep 1 2014 1105Z
- Ensuing proton storm confuses STEREO star trackers
  → STEREO B rolls
  (e.g. of SEP impact!)
- Proton storm seen ~6h earlier on STEREO B c.f. ACE
- Similar SEP instruments useful at L5 for early warning, resilience







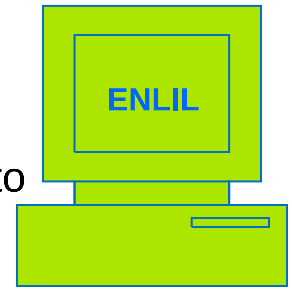


New developments

Data assimilation primer

→"**analysis**":
Model solar wind state brought closer to **observations**

Put **analysis** into **forecast** model



Ability to provide a more accurate running forecast to end users

DA cycle

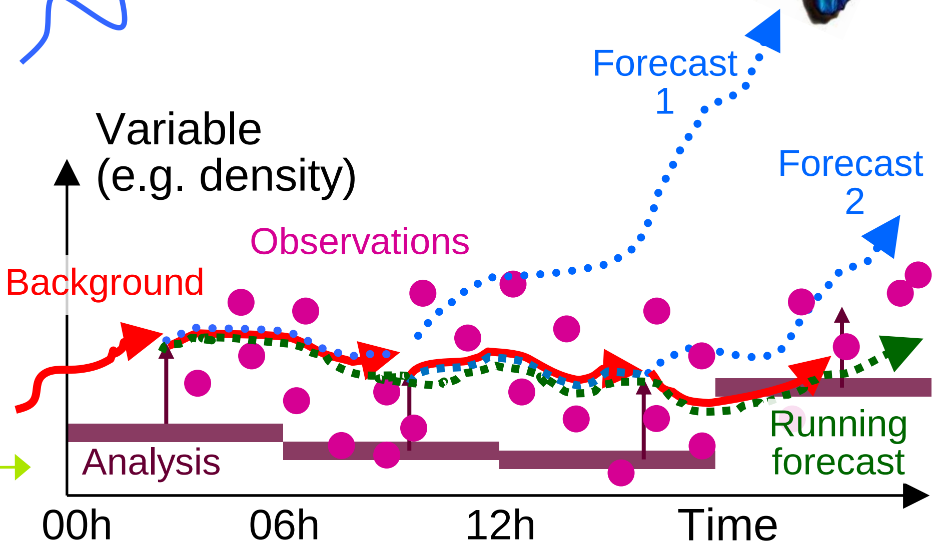
Do data assimilation on innovations (differences)

→ better **forecast**

Compare **observations** with improved model "**background**" (previous **forecast**)

START!

L5 mission
Carrington?



DA timeline

Context

Assimilation plans

Improving ENLIL solar wind via data assimilation, for better forecasts of solar wind at earth & more accurate predictions of CME arrival times

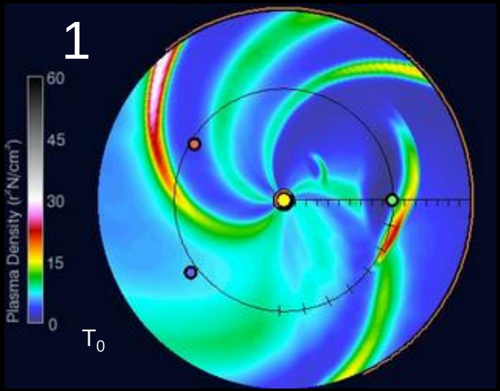
Developing in conjunction with University of Reading

Starting with in situ data (plasma, magnetic field)

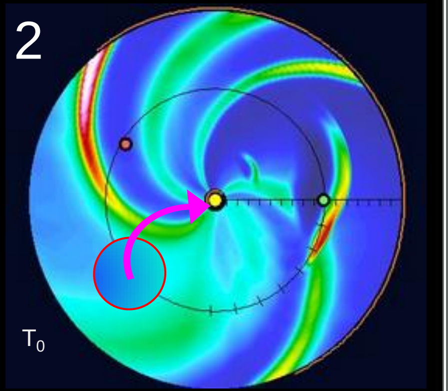
Other observations may be useful later

- e.g. HI data – increments more complex – 3D from 2D – yet coverage better – less of a point measurement

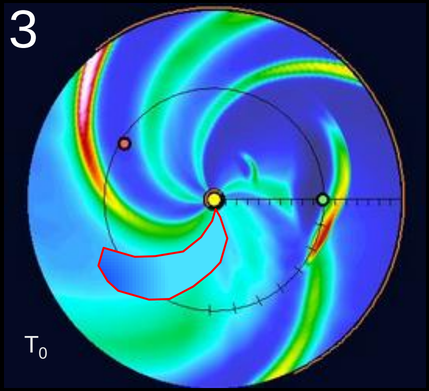
Will be doing this with STEREO data; proof of concept for L5



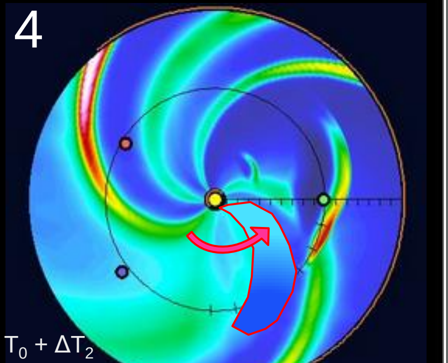
Compare ENLIL background solar wind & in situ data at T_0 (here data lower density)



Get local increment, & via e.g. variational technique the source increment at 25 R_s at $T_0 - \Delta T_1$



Apply source increment, run ENLIL forward to T_0 → good analysis – model solar wind is balanced, yet closer to observations – more realistic

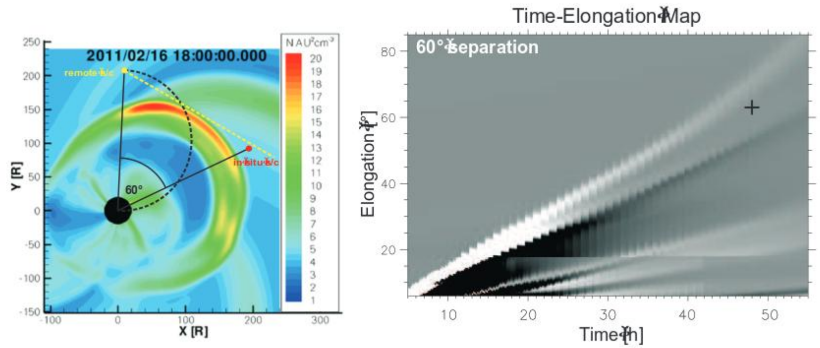


(background SW rotation is not shown)

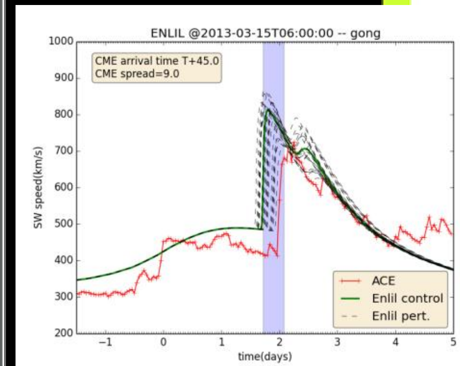
Persist source increment to $T_0 + \Delta T_2$ → better solar wind forecasts at earth; better also between sun & earth → more accurate CME arrival times

Heliospheric imagers

- Can be used to prune down a CME ensemble forecast
  - Generate synthetic Jmaps for each ensemble member



Lugaz 2009,
Rollett 2013



  - Forecaster / computer compares actual HI Jmaps to model Jmaps, rejecting (model) ensemble members disagreeing most with observations
    → more realistic ensemble spread

- Can also highlight discrepancies between modelled CME and observed CME front → potential for forecasters to correct forecast, or at least estimate the sign of the bias

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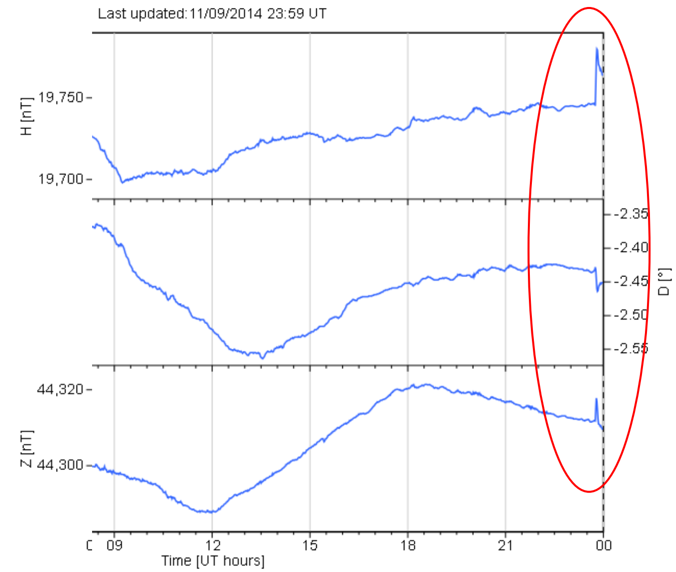
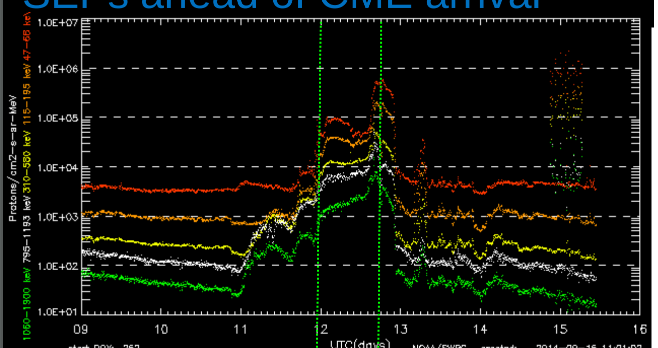
Sudden impulses and Sudden Storm Commencements

BGS Hartland magnetometer



SEPs ahead of CME arrival



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- SI and SSCs can be linked to solar wind dynamic pressure enhancements associated with shocks

- Response depends on Bz – some predictability from persistence models

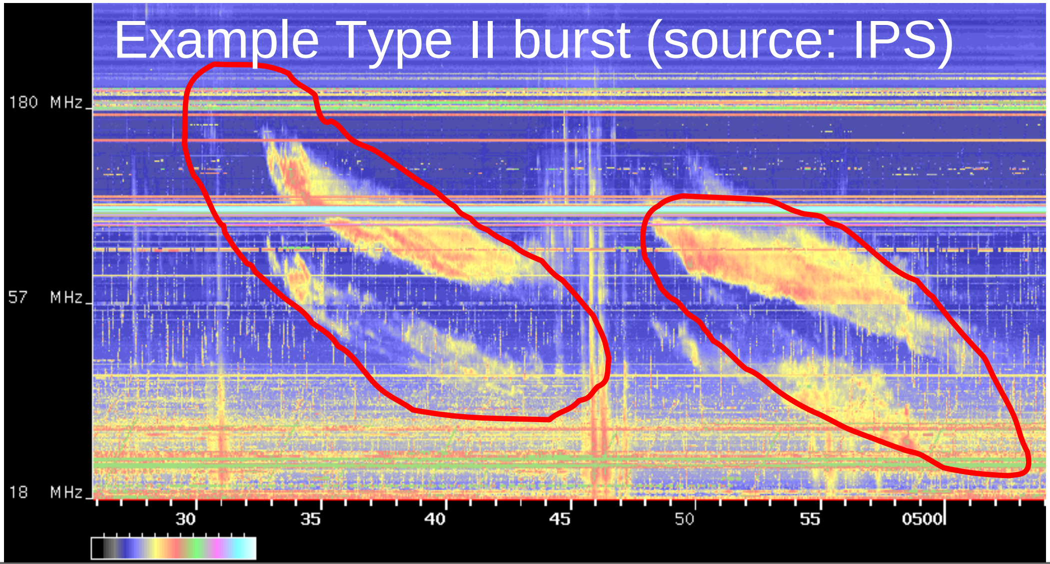
- Upstream measurements of dynamical pressure and Bz at L5 could increase predictability of these events – either with statistical models or feeding in the pressure pulse into a magnetospheric model

- Likely to help most with CIR-linked effects, maybe some help for CME-linked too?

- SEP measurements may help here too

Real-time space-based type II / IV radio burst signatures

- Space-based measurements of type II / IV radio bursts may help determine CME initial speeds, back up imagery
  - Accuracy of CME speed estimates unclear, but worth pursuing
- Needs to be near-real-time – early signature of CMEs
  - Current space-based observations (WIND) not near-real-time
  - Current ground-based observations near-real-time, but limited by cut-off



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L5 instruments wishlist

L5 instruments wishlist

- Plasma and magnetic in-situ observations:
  - Persistence models (incl. heavy ions O^7/O^6, Q_{Fe})
  - Data assimilation into ENLIL → knock-on effect on CME arrival times
  - Substorm prediction due to SW pressure enhancements
  - Improved advance warning for SEPs
- Coronagraphs and heliospheric imagers:
  - Coronagraphs: crucial for CME fits and hence arrival times; redundancy for LASCO
  - HI for pruning ensembles; idea of error in ENLIL prediction; data assimilation
- Magnetograms (line-of-sight and vector):
  - Flare forecasting
  - SW modelling (improved boundary condition to ENLIL)
- Radio measurements (type II / IV signatures)
  - Improved CME arrival times, backup for imagery

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Discussion