Operational Space Weather Forecasting

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Dublin Institute for Advanced Studies

DIAS

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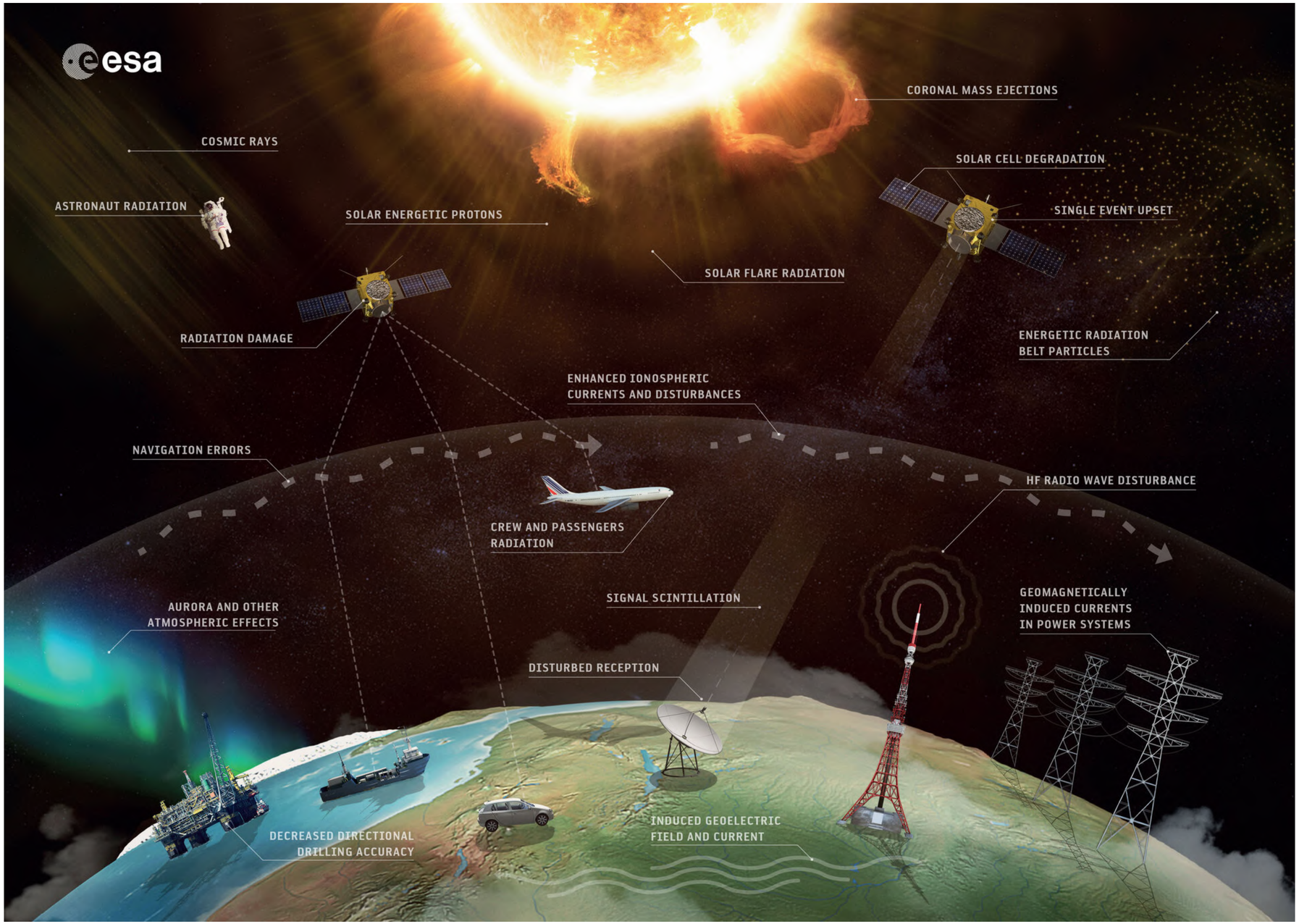
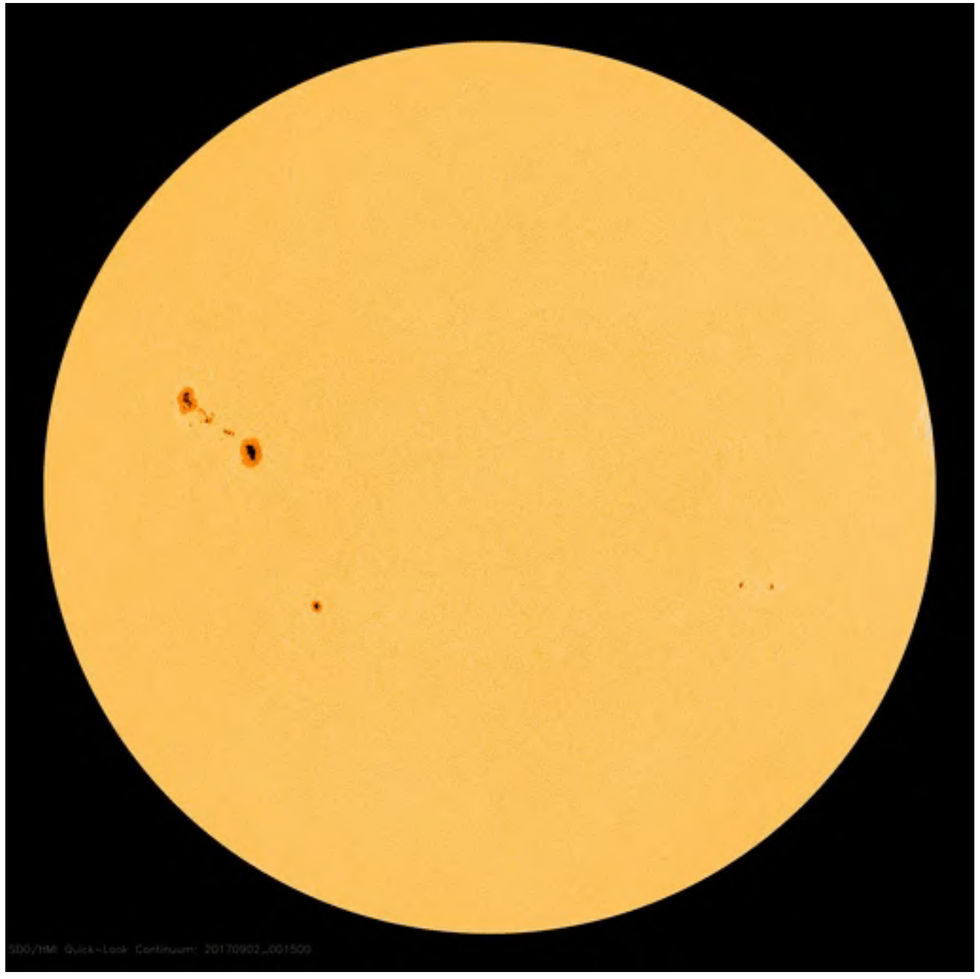
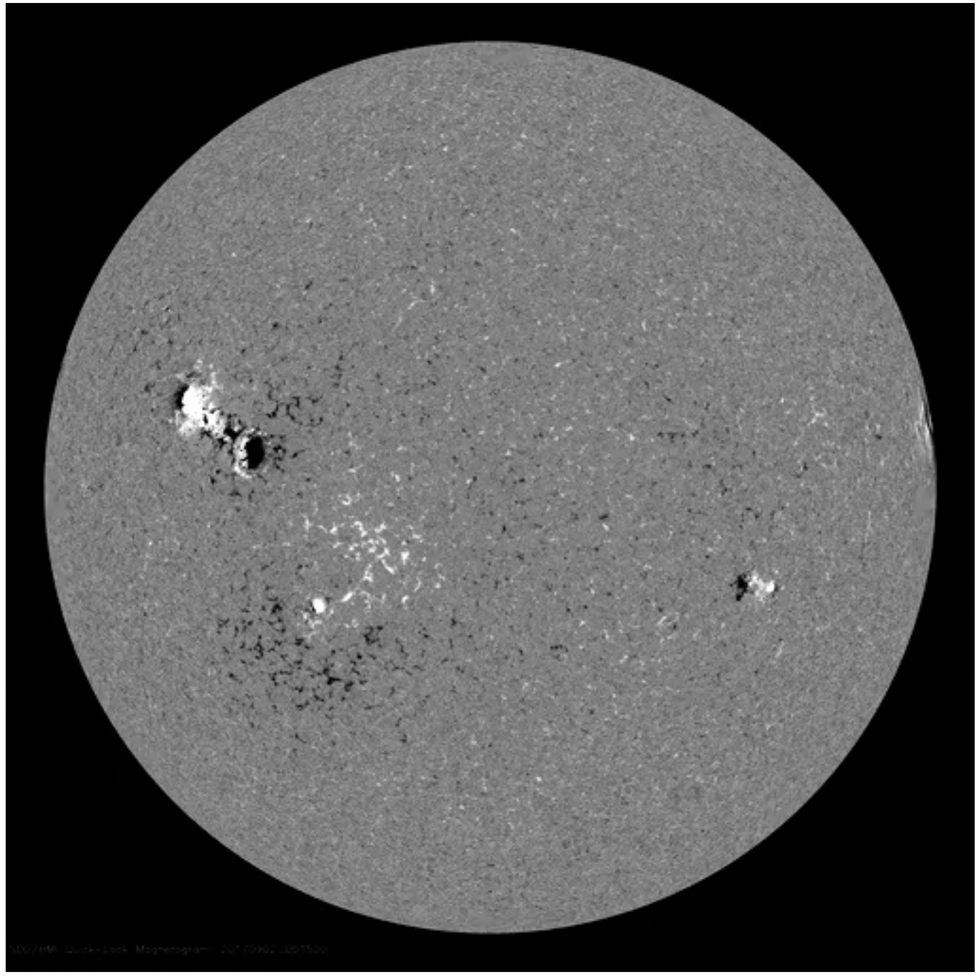
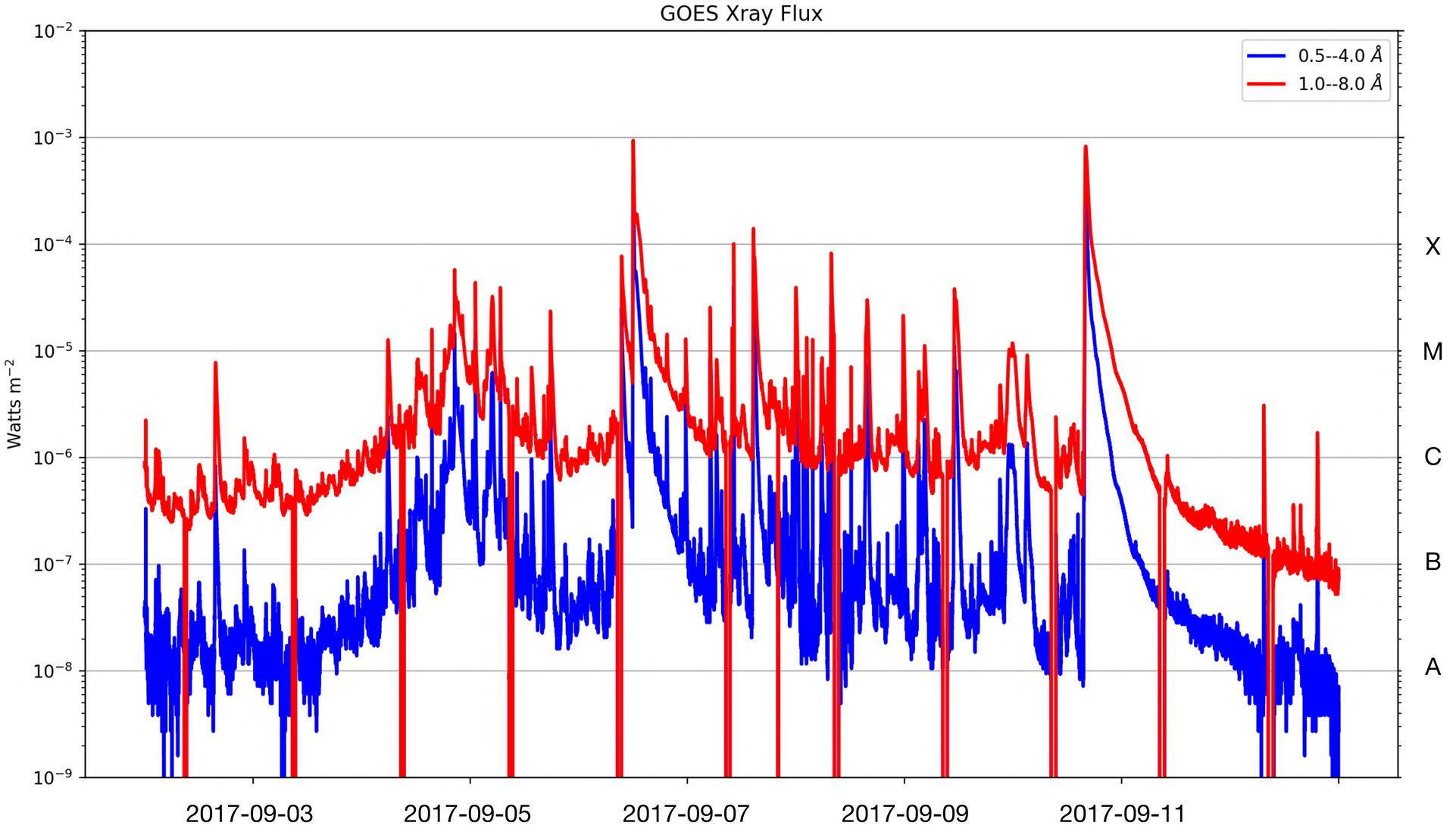
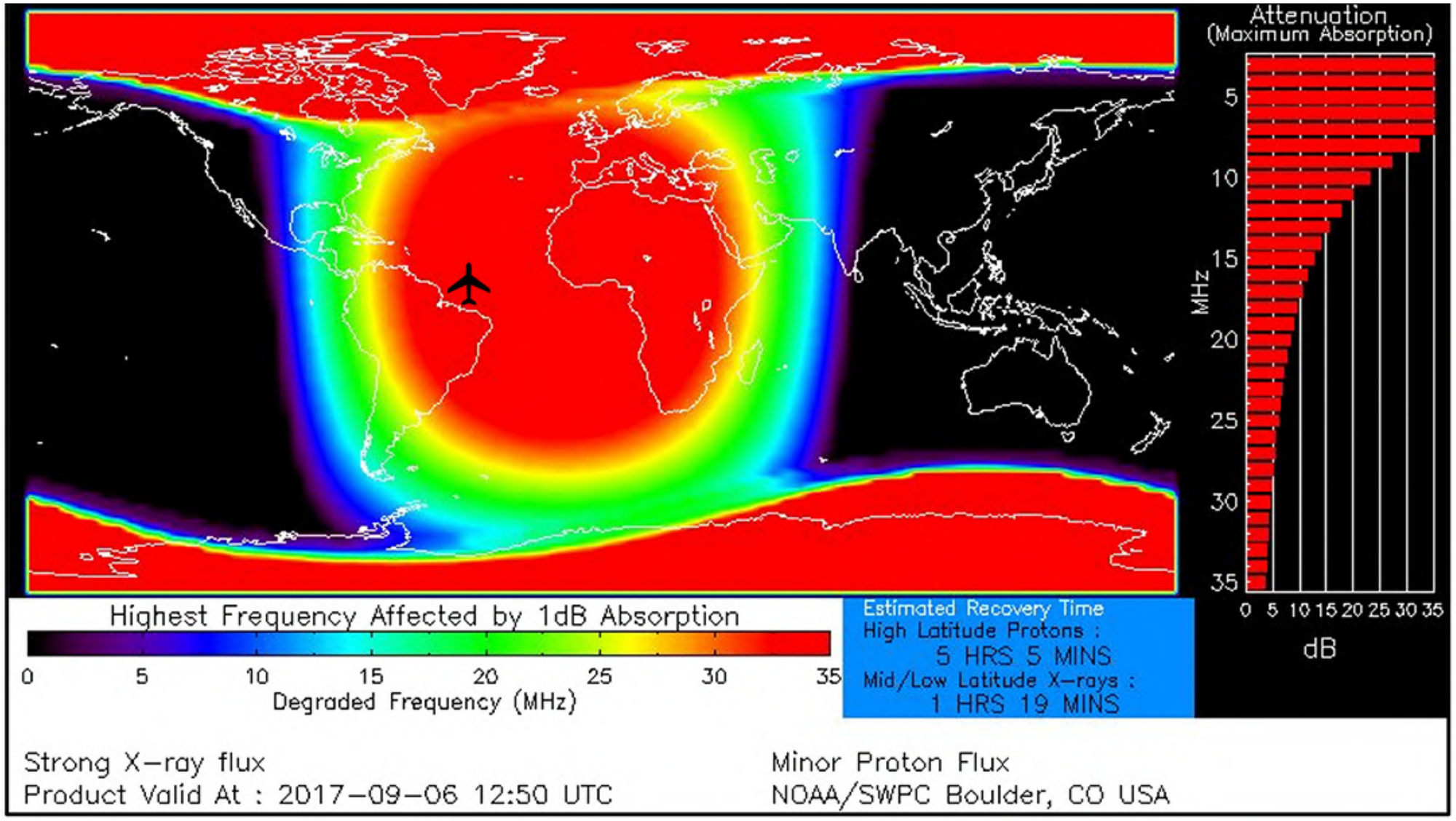

esa
CORONAL MASS EJECTIONS
COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SOLAR ENERGETIC PROTONS
SINGLE EVENT UPSET
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION
BELT PARTICLES
ENHANCED IONOSPHERIC
CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
CREW AND PASSENGERS
RADIATION
AURORA AND OTHER
ATMOSPHERIC EFFECTS
SIGNAL SCINTILLATION
GEOMAGNETICALLY
INDUCED CURRENTS
IN POWER SYSTEMS
DISTURBED RECEPTION
DECREASED DIRECTIONAL
DRILLING ACCURACY
INDUCED GEOELECTRIC
FIELD AND CURRENT

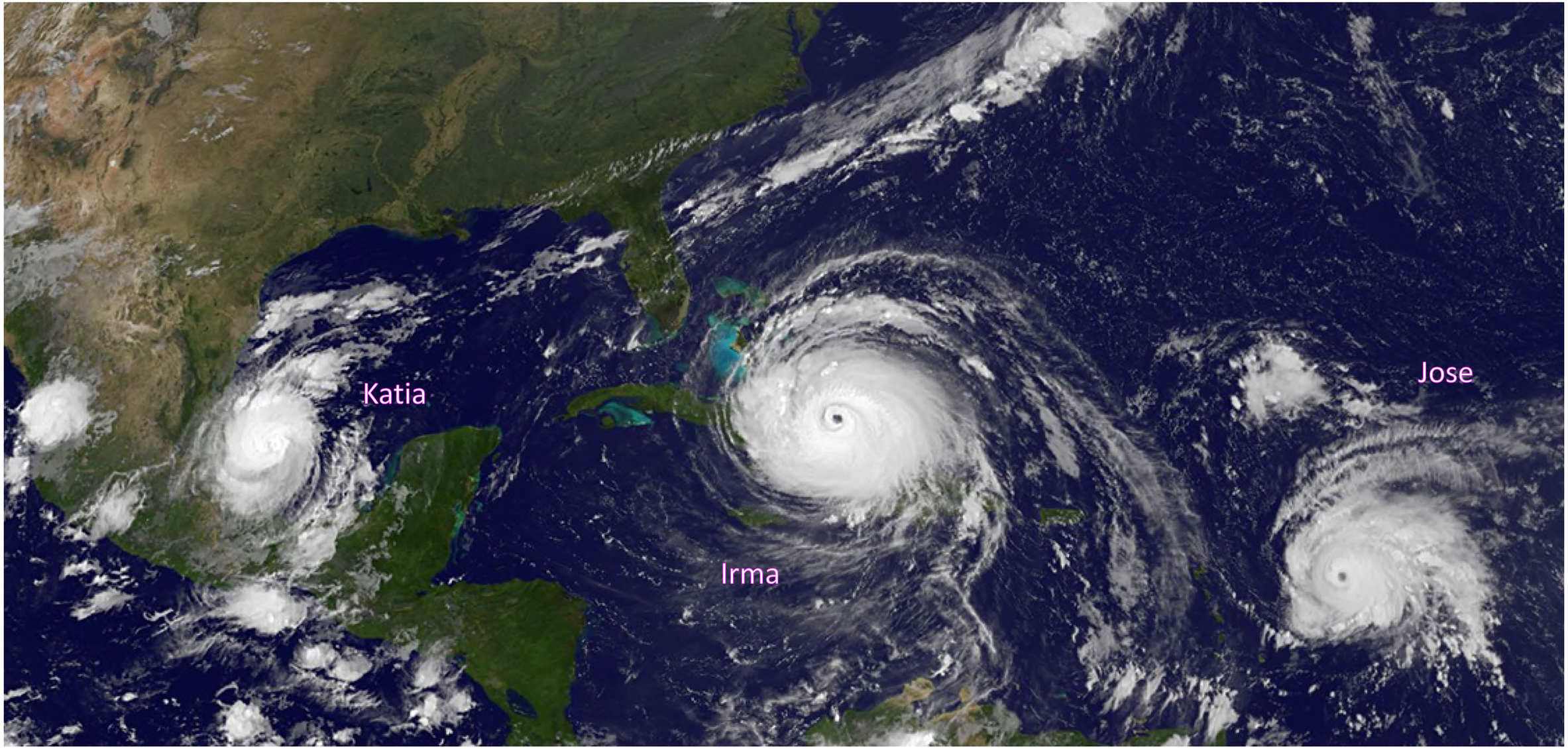

SDO/HMI Quick-Look Continuum: 20170902_001500




GOES Xray Flux
0.5--4.0 Å
1.0--8.0 Å
Watts m⁻²
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
X
M
C
B
A
2017-09-03
2017-09-05
2017-09-07
2017-09-09
2017-09-11

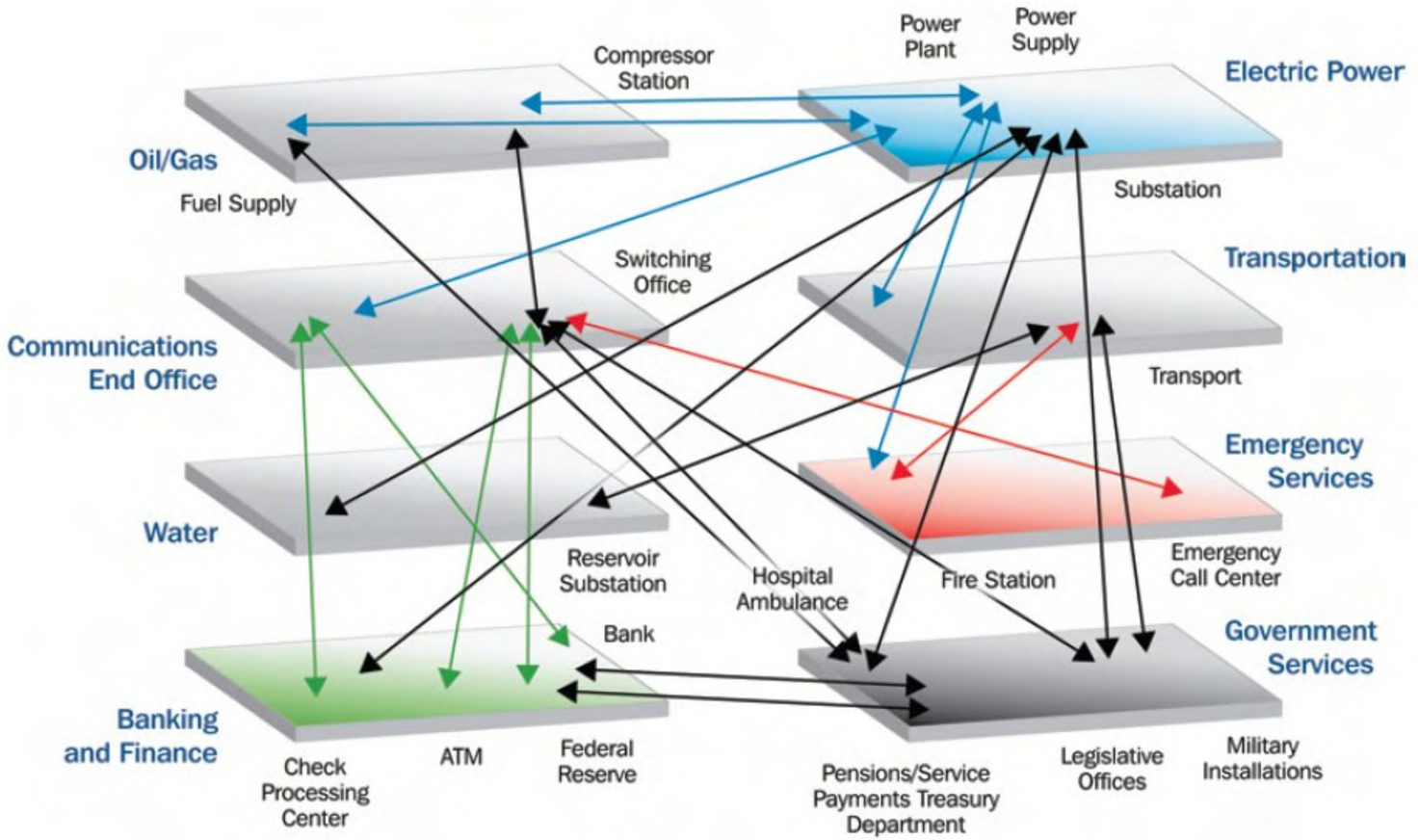


Redmon et al, 2018

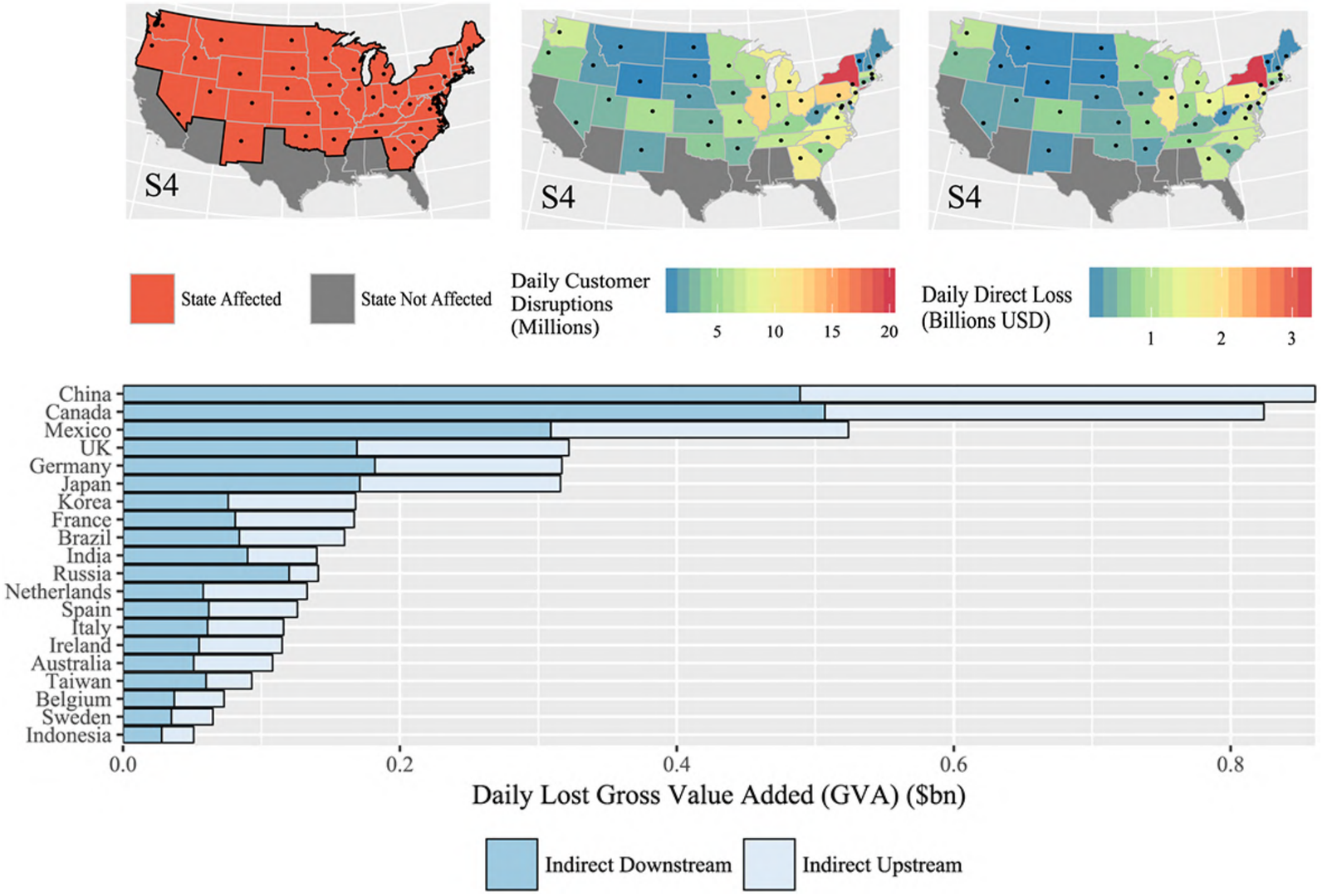


In the interval of 4–10 September 2017, the Sun presented multiple solar flares from active region AR 2673… the hurricane Katia category 2 in the Gulf of Mexico, and two major earthquakes… The conjunction of these natural phenomena were close to creating a worst-case scenario in terms of civil protection reaction.

Gonzalez-Esparza et al, 2018



US Department of Homeland Security



Oughten et al 2016

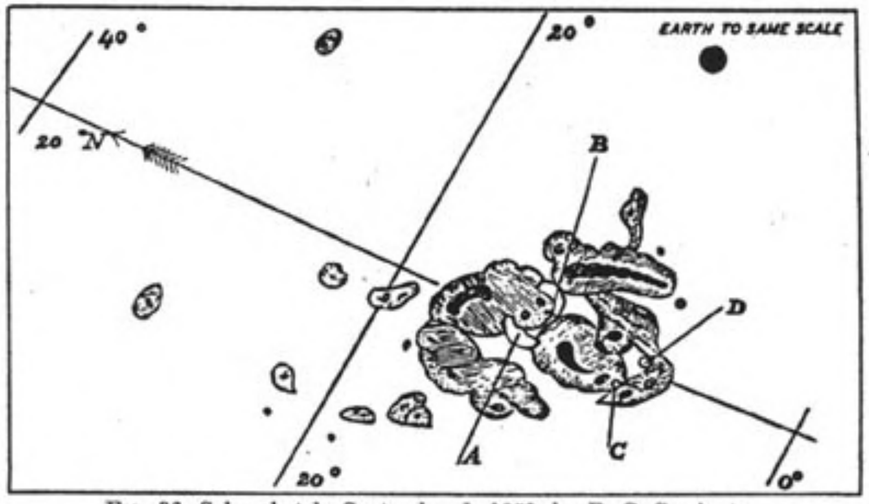
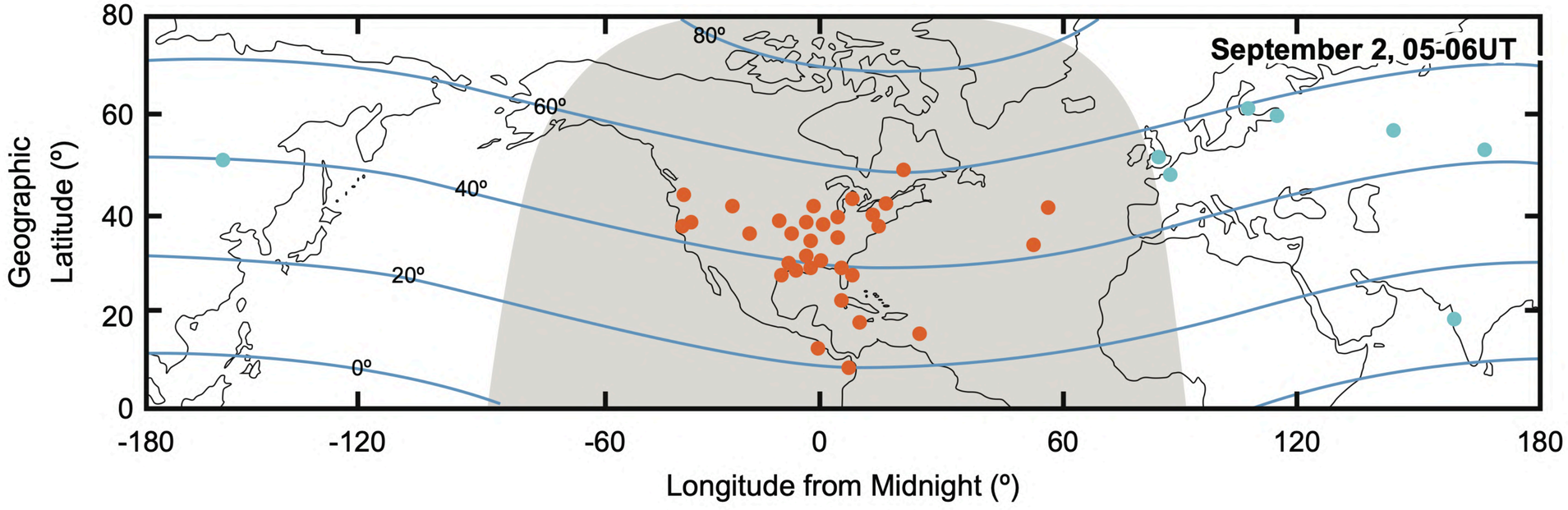


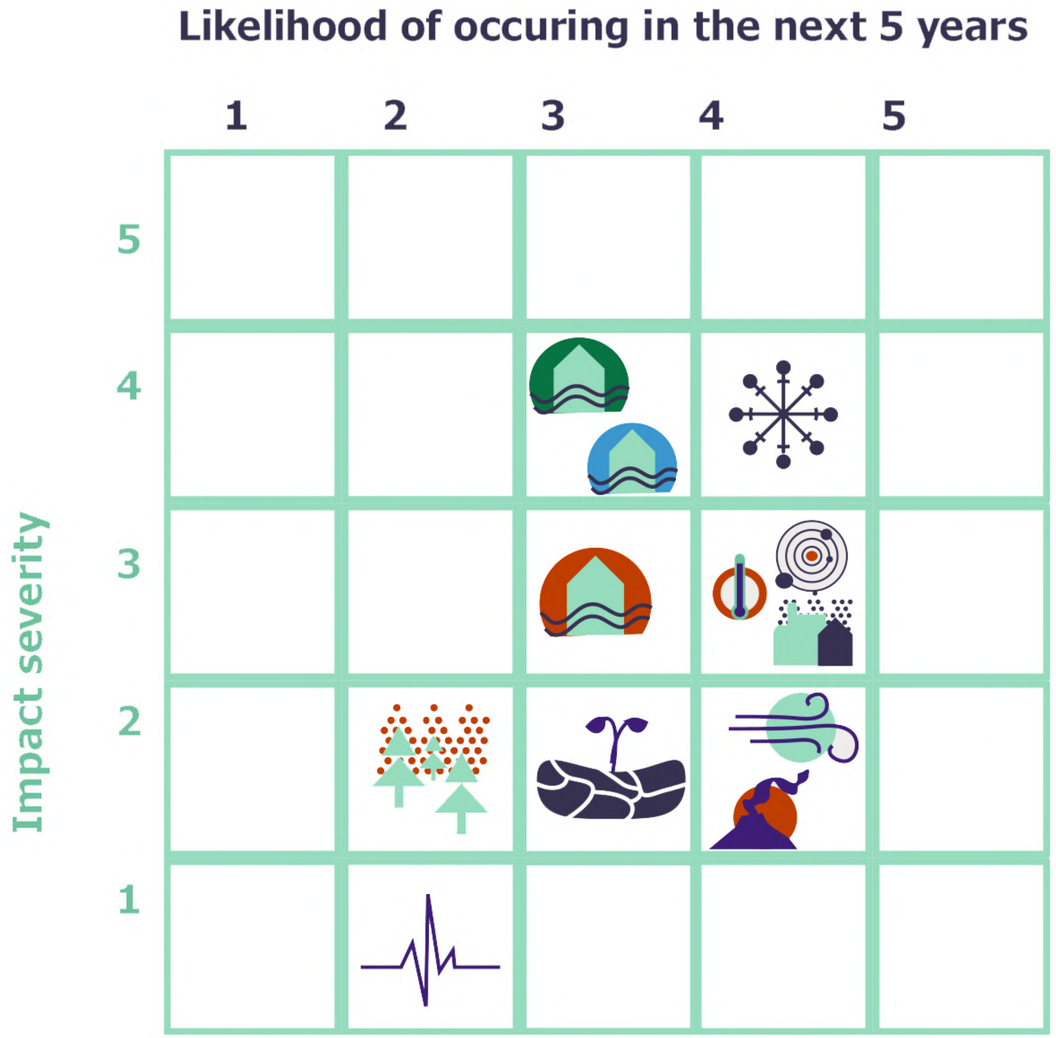
FIG. 36. Solar sketch, September 1, 1859, by R. C. Carrington

Auroral Display.

BOSTON, September 2.—The auroral display of last night was so brilliant after midnight that ordinary print could be read by its light. It considerably impeded the working of the telegraph lines, and its effects were continued up to noon of to-day. The auroral current from East to West was so regular that the operators on the eastern lines could send messages to this city without the usual batteries being applied; the same extraordinary effect was apparent on the National telegraph wires between Philadelphia and Pittsburg.



Cliver et al 2013



*Symbol Index

River flooding

Coastal flooding

Surface water flooding

Poor air quality

Volcanic eruptions

Storms and gales

Earthquakes

Drought

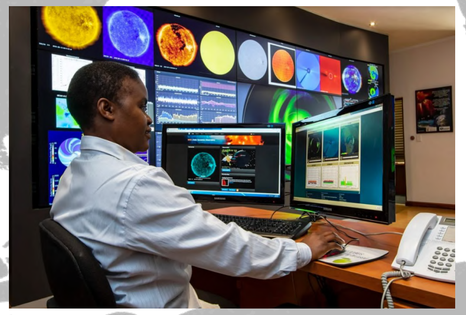
Wildfires

Heatwaves

Space weather

Cold and snow

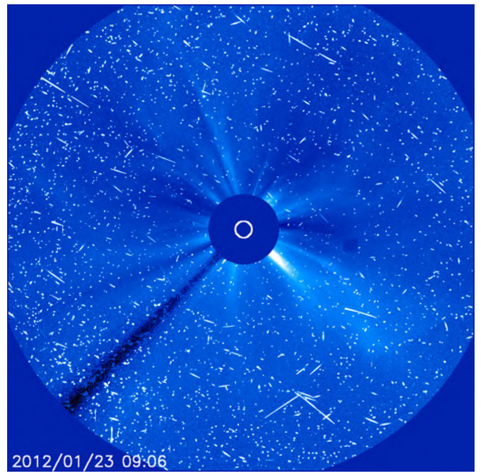
UK Natural Hazard National Risk Assessment 2019



spaceweather.org

Solar eruption prediction

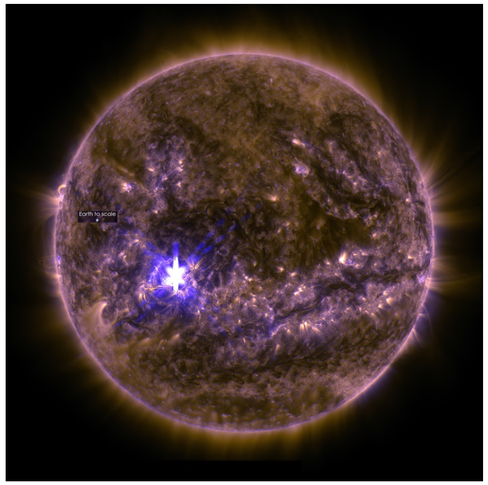
Solar radiation storms
(SEPs)



Latest Observed

R	S	G
none	none	none

Radio blackouts
(solar flares)

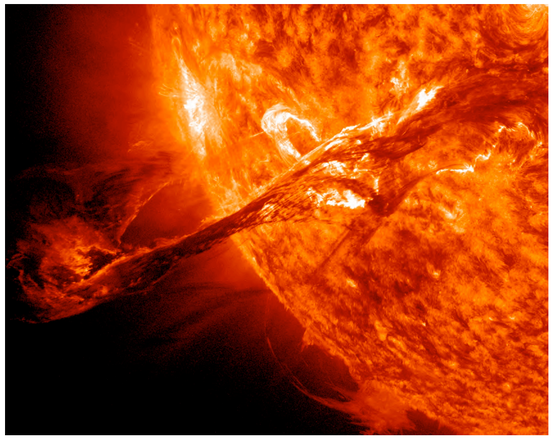


Predicted 2020-07-18 UTC

R1-R2	1%	S1 or greater	1%	G: none
R3-R5	1%			

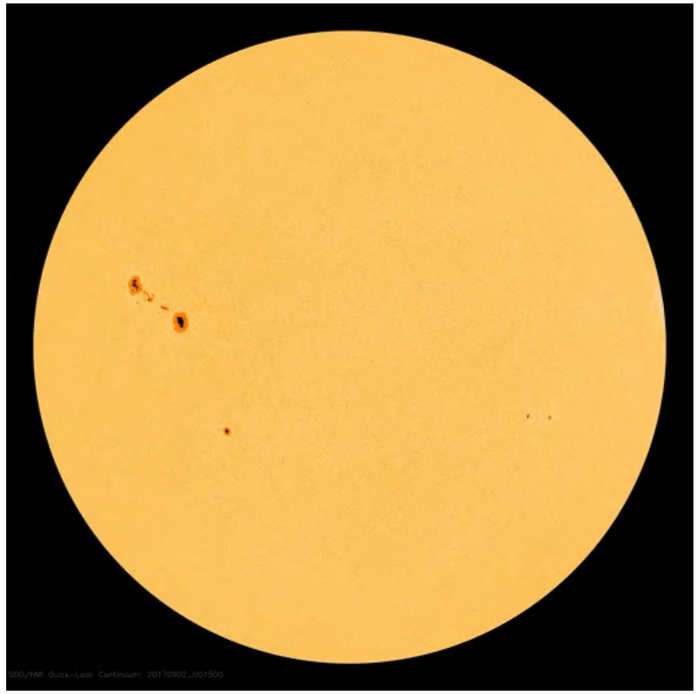
NOAA/SWPC

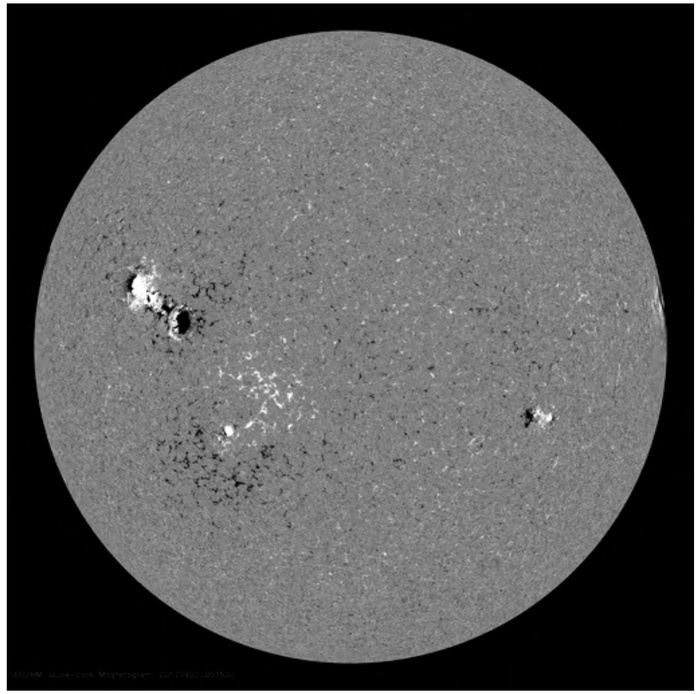
Geomagnetic storms
(CMEs, solar wind)



Making a forecast

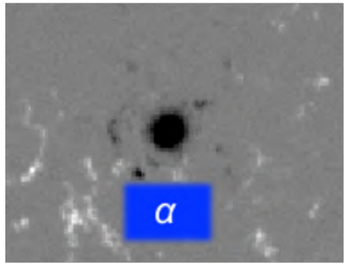
- Identify property related to flaring



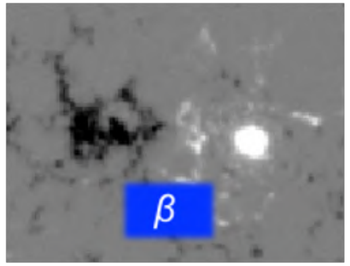


Making a forecast

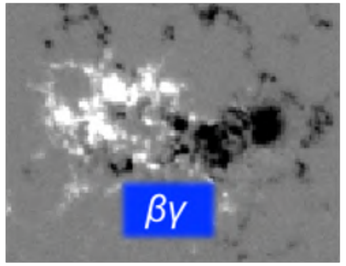
- Identify property related to flaring
- Parameters to characterise this property



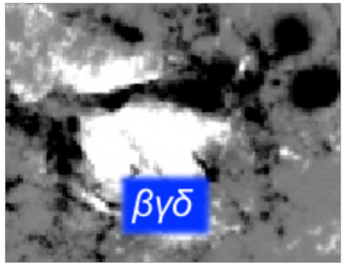
unipolar



bipolar



mixing of polarities



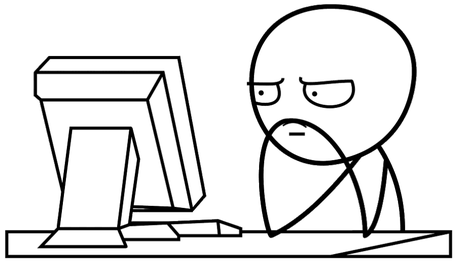
opposite polarity umbrae within one penumbra

Making a forecast

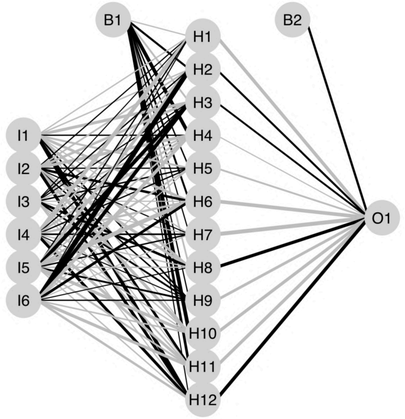
- Identify property related to flaring
- Parameters to characterise this property
- Method to convert parameter values to a forecast

X Ray Flares Probability	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	Yes	80	80	80	80
Very Active	R3 to R5 X Class	No	35	35	35	35

Methods



e.g., Murray et al 2017



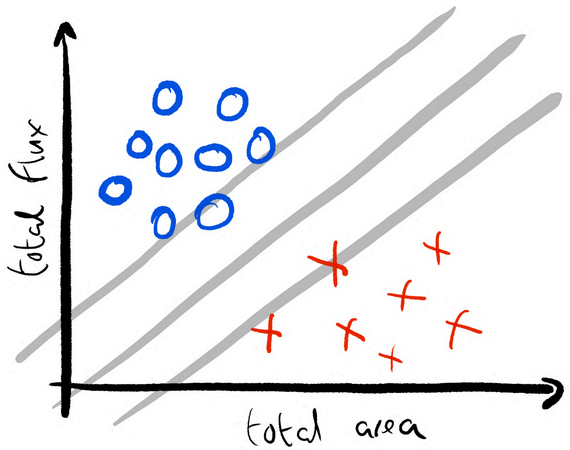


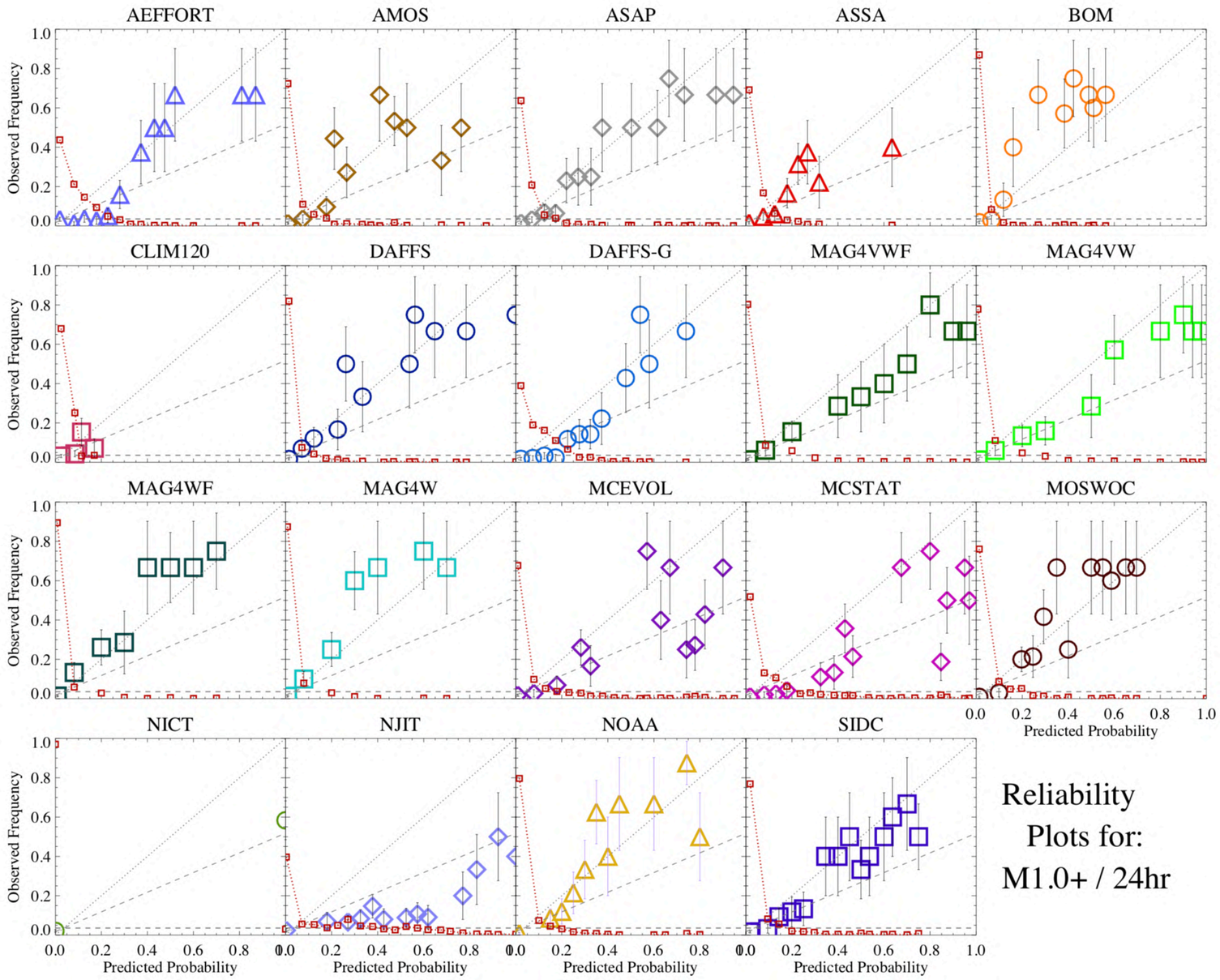
Table 2
McIntosh Classification Flare Statistics

McIntosh	SWPC (1988–1996)				Kildahl (1969–1976)[b]				Combined Flare Rate (24 hr^{-1})				Poisson Flare Probability (%)				
Region	Region	Total Flares			Region	Total Flares			In *GOES* Class				In *GOES* Class			Above *GOES*[d]	
Classes[a]	Count	C	M	X	Count	C[c]	M	X	C	M	X	$\pm\sigma$	C	M	X	M1.0	C1.0
AXX	2748	82	10	0	2517	75.1	31	3	0.03	0.01	0.00	0.01	3	1	0	1	4
BXO	3342	217	18	1	1906	123.8	41	2	0.06	0.01	0.00	0.01	6	1	0	1	7
BXI	0	0	0	0	334	0.0	20	0	0.00	0.06	0.00	0.05	0	6	0	6	6
HRX	336	21	1	0	211	13.2	7	1	0.06	0.01	0.00	0.04	6	1	0	2	8
HSX	1968	94	21	0	1963	93.8	99	6	0.05	0.03	0.00	0.02	5	3	0	3	8
HAX	598	49	13	0	222	18.2	14	0	0.08	0.03	0.00	0.03	8	3	0	3	11
HHX	53	3	1	0	150	8.5	16	2	0.06	0.08	0.01	0.07	6	8	1	9	14
HKX	49	11	2	0	38	8.5	7	0	0.22	0.10	0.00	0.11	20	10	0	10	28
CRO	745	102	3	0	368	50.4	20	2	0.14	0.02	0.00	0.03	13	2	0	2	15
CRI	6	2	0	0	152	50.7	7	0	0.33	0.04	0.00	0.08	28	4	0	4	31
CSO	1504	284	27	0	1020	192.6	40	1	0.19	0.03	0.00	0.02	17	3	0	3	19
CSI	14	8	2	0	211	120.6	16	2	0.57	0.08	0.01	0.07	44	8	1	9	48
CAO	1455	361	38	2	232	57.6	18	1	0.25	0.03	0.00	0.02	22	3	0	3	25
CAI	27	14	6	0	166	86.1	19	0	0.52	0.13	0.00	0.07	40	12	0	12	48
CHO	88	21	2	1	112	26.7	8	1	0.24	0.05	0.01	0.07	21	5	1	6	26
CHI	2	1	0	0	29	14.5	6	0	0.50	0.19	0.00	0.18	39	18	0	18	50
CKO	135	59	11	0	52	22.7	13	2	0.44	0.13	0.01	0.07	35	12	1	13	44
CKI	17	14	6	0	28	23.1	6	2	0.82	0.27	0.04	0.15	56	23	4	27	68
DRO	63	12	3	0	75	14.3	6	0	0.19	0.07	0.00	0.09	17	6	0	6	23
DRI	2	7	0	0	54	189.0	7	1	3.50	0.12	0.02	0.13	97	12	2	13	97
DSO	546	198	26	1	553	200.5	51	6	0.36	0.07	0.01	0.03	30	7	1	7	36
DSI	39	34	6	0	246	214.5	31	1	0.87	0.13	0.00	0.06	58	12	0	12	63
DSC	0	0	0	0	20	0.0	5	2	0.00	0.25	0.10	0.22	0	22	10	30	30
DAO	1775	784	124	4	288	127.2	28	2	0.44	0.07	0.00	0.02	36	7	0	7	40
DAI	391	419	70	6	324	347.2	58	7	1.07	0.18	0.02	0.04	66	16	2	18	72
DAC	8	5	3	0	46	28.8	12	1	0.62	0.28	0.02	0.14	46	24	2	26	60
DHO	46	26	1	1	43	24.3	11	0	0.57	0.13	0.01	0.11	43	13	1	14	51
DHI	11	14	1	0	41	52.2	3	0	1.27	0.08	0.00	0.14	72	7	0	7	74
DHC	0	0	0	0	6	0.0	2	0	0.00	0.33	0.00	0.41	0	28	0	28	28
DKO	217	178	55	5	43	35.3	14	2	0.82	0.27	0.03	0.06	56	23	3	25	67
DKI	223	288	69	6	88	113.7	42	6	1.29	0.36	0.04	0.06	73	30	4	33	81
DKC	57	93	35	5	100	163.2	72	10	1.63	0.68	0.10	0.08	80	49	9	54	91
ESO	95	37	6	0	82	31.9	14	0	0.39	0.11	0.00	0.08	32	11	0	11	39
ESI	18	33	1	0	78	143.0	22	2	1.83	0.24	0.02	0.10	84	21	2	23	88
EAO	459	267	61	0	47	27.3	10	4	0.58	0.14	0.01	0.04	44	13	1	14	52
EAI	295	370	83	2	82	102.8	48	1	1.25	0.35	0.01	0.05	71	29	1	30	80
EAC	3	5	1	0	17	28.3	6	3	1.67	0.35	0.15	0.22	81	30	14	39	89
EHO	42	31	6	0	39	28.8	6	0	0.74	0.15	0.00	0.11	52	14	0	14	59
EHI	15	24	6	0	45	72.0	28	4	1.60	0.57	0.07	0.13	80	43	6	47	89
EHC	2	9	0	0	4	18.0	8	0	4.50	1.33	0.00	0.41	99	74	0	74	100
EKO	185	173	35	3	52	48.6	20	1	0.94	0.23	0.02	0.06	61	21	2	22	69
EKI	423	703	173	23	81	134.6	103	11	1.66	0.55	0.07	0.04	81	42	7	46	90
EKC	103	278	132	17	63	170.0	149	21	2.70	1.69	0.23	0.08	93	82	20	85	99
FRI	0	0	0	0	2	0.0	1	0	0.00	0.50	0.00	0.71	0	39	0	39	39
FSO	14	9	3	0	13	8.4	6	1	0.64	0.33	0.04	0.19	47	28	4	31	64
FSI	6	12	0	0	8	16.0	15	0	2.00	1.07	0.00	0.27	86	66	0	66	95
FAO	73	63	16	0	3	2.6	0	0	0.86	0.21	0.00	0.11	58	19	0	19	66
FAI	91	106	35	3	12	14.0	8	0	1.16	0.42	0.03	0.10	69	34	3	36	80
FHO	9	5	1	0	10	5.6	0	0	0.56	0.05	0.00	0.23	43	5	0	5	46
FHI	10	17	9	0	18	30.6	15	0	1.70	0.86	0.00	0.19	82	58	0	58	92
FHC	0	0	0	0	5	0.0	4	0	0.00	0.80	0.00	0.45	0	55	0	55	55
FKO	97	165	29	1	19	32.3	6	0	1.70	0.30	0.01	0.09	82	26	1	27	87
FKI	235	517	161	17	47	103.4	106	17	2.20	0.95	0.12	0.06	89	61	11	66	96
FKC	93	233	146	24	27	67.6	39	13	2.51	1.54	0.31	0.09	92	79	27	84	99

e.g., Bloomfield et al 2012

e.g., Li et al 2020, Florios et al 2018, Bobra & Couvidat 2015, Colak & Qahaji 2009….

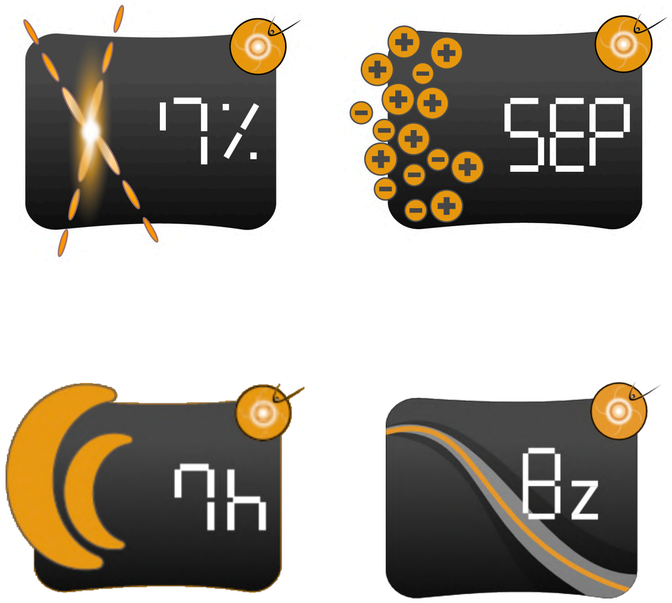
Community evaluation



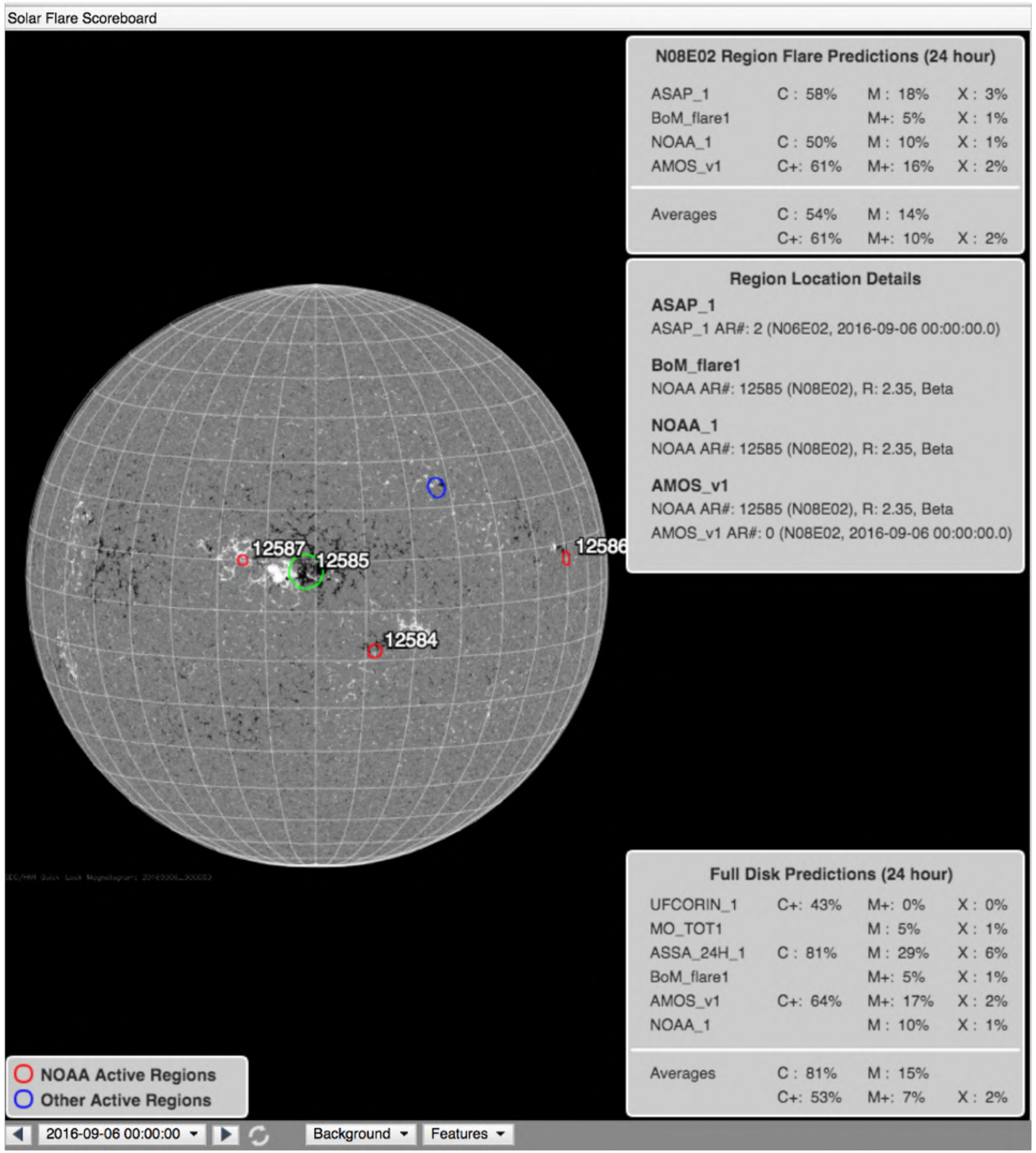
Reliability Plots for: M1.0+ / 24hr

Leka et al 2019

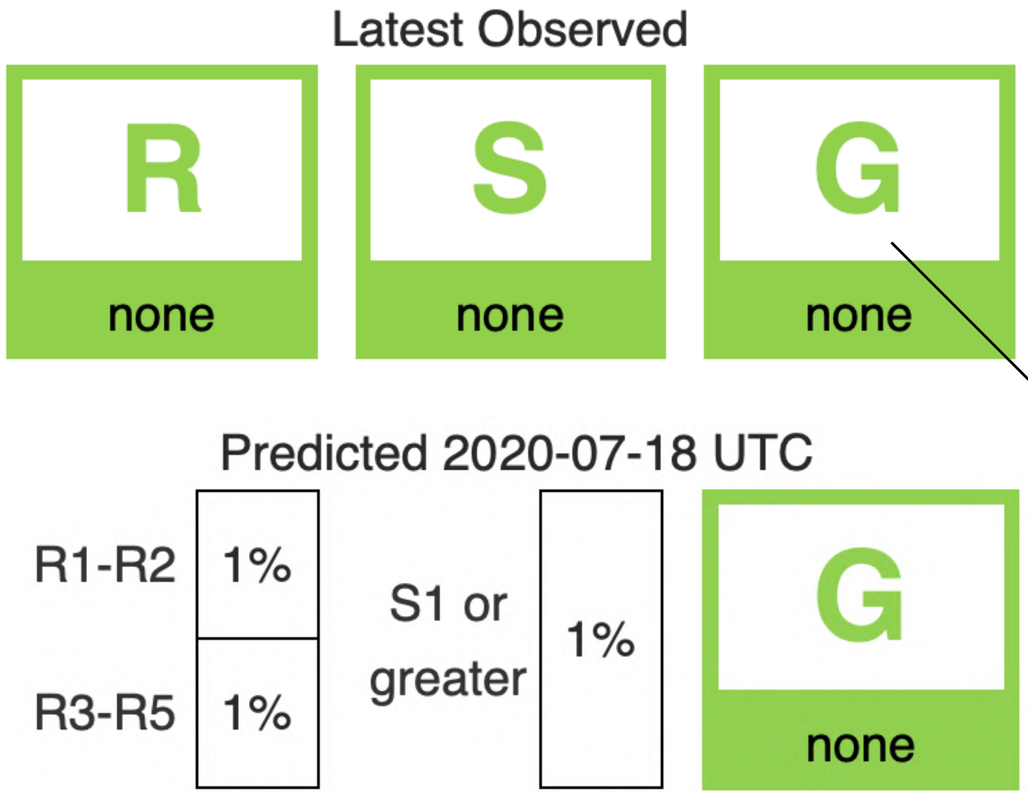
Scoreboards



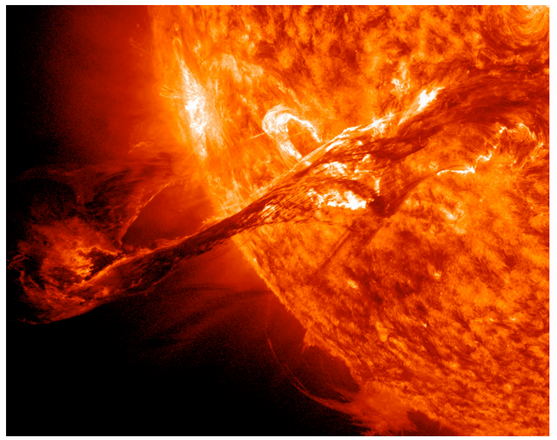
ccmc.gsfc.nasa.gov/challenges

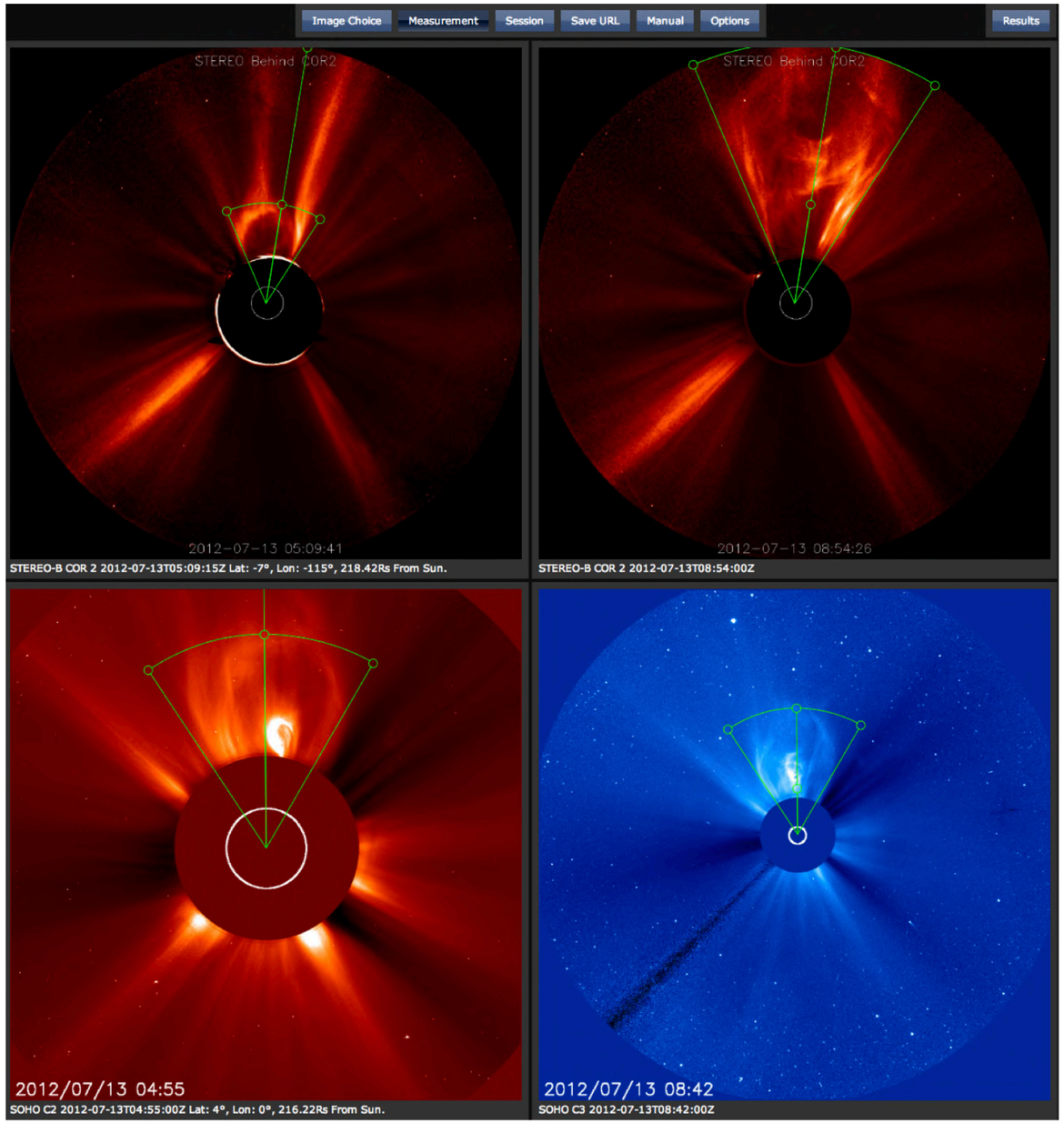


Solar eruption prediction

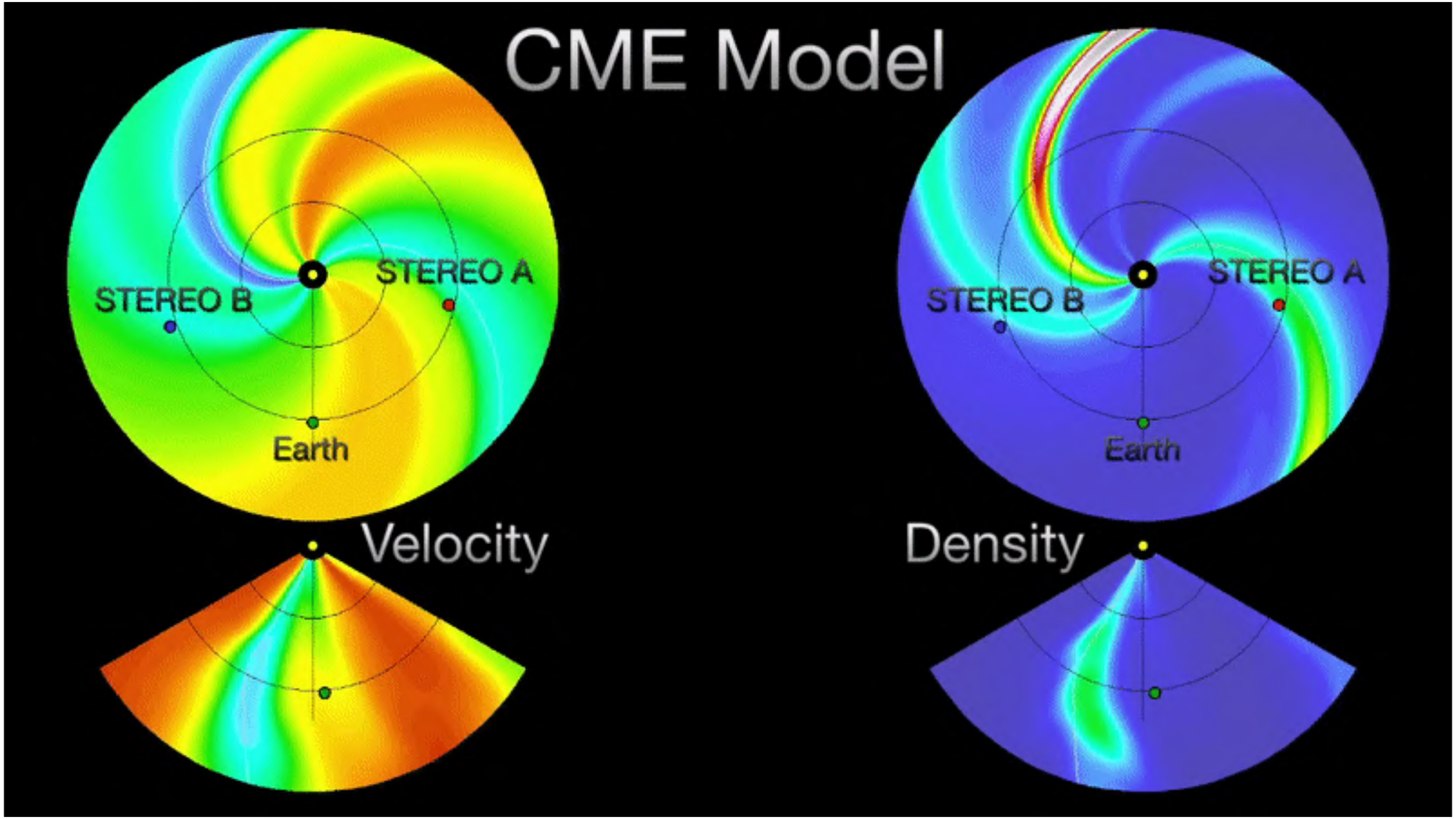


Geomagnetic storms
(CMEs, solar wind)

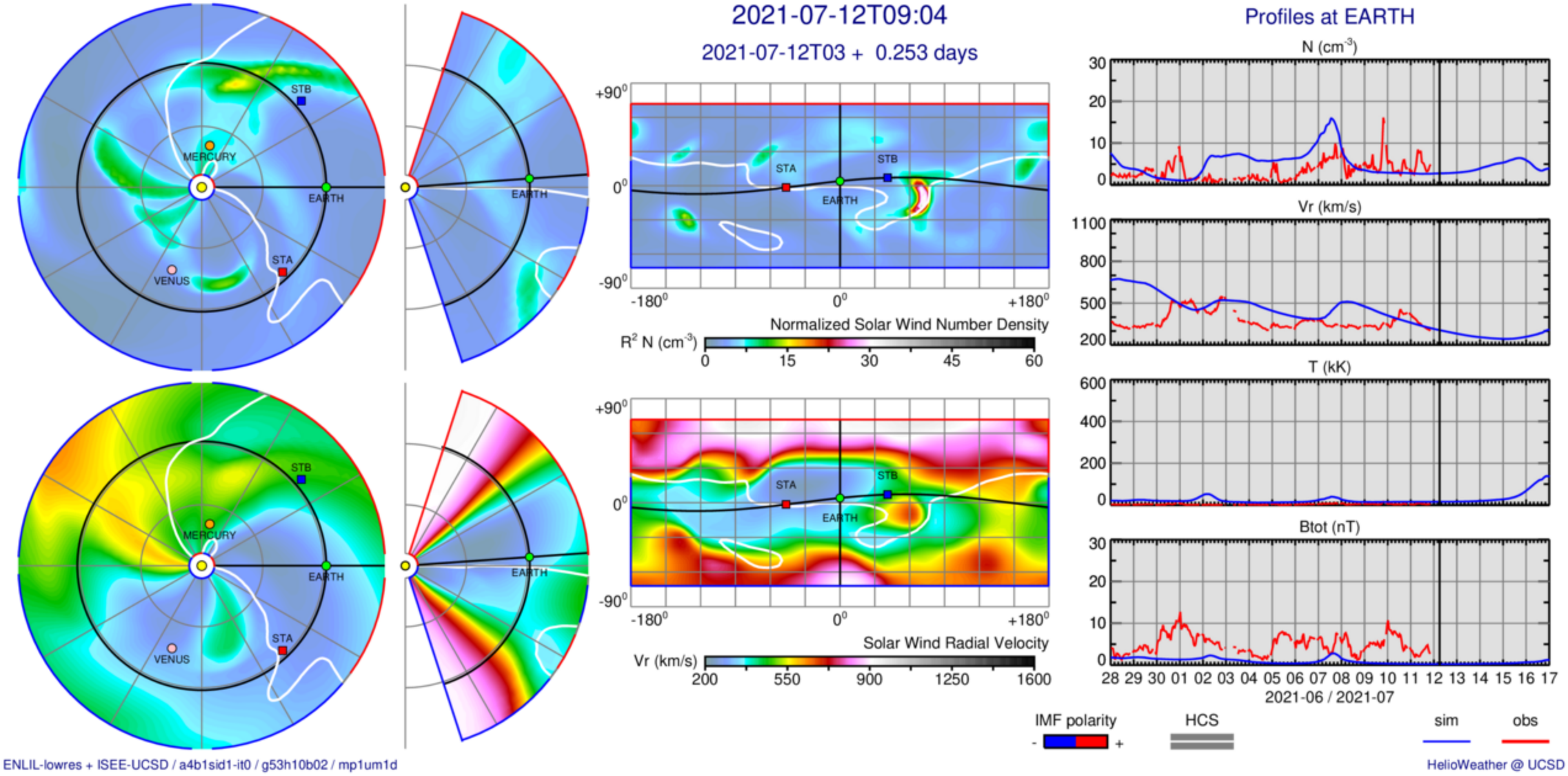




https://ccmc.gsfc.nasa.gov/analysis/stereo/



https://www.swpc.noaa.gov/products/wsa-enlil-solar-wind-prediction



https://ips.ucsd.edu/ENLIL_predictions

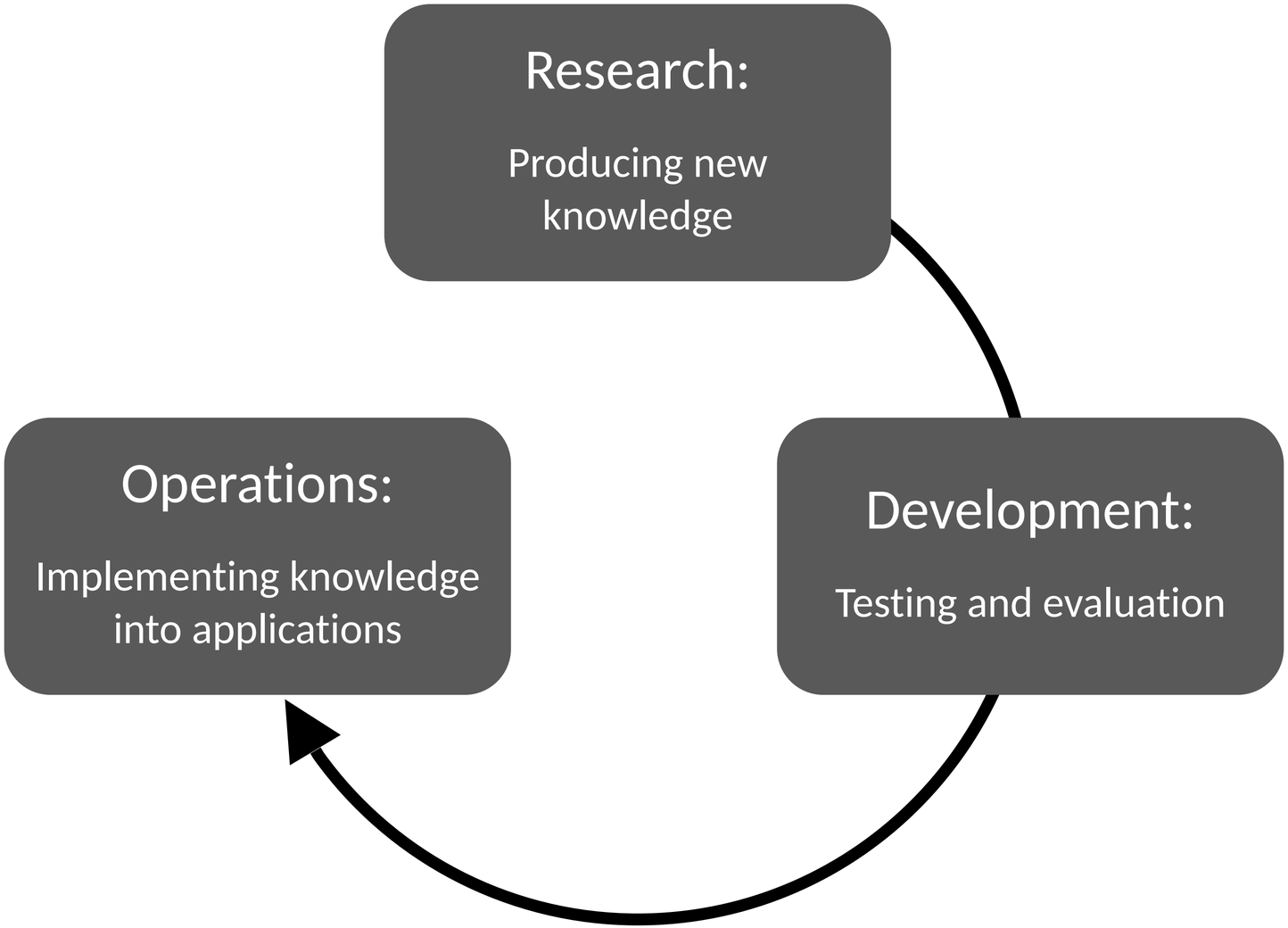
Operational Requirements

‘Operational’ means end-to-end system with:

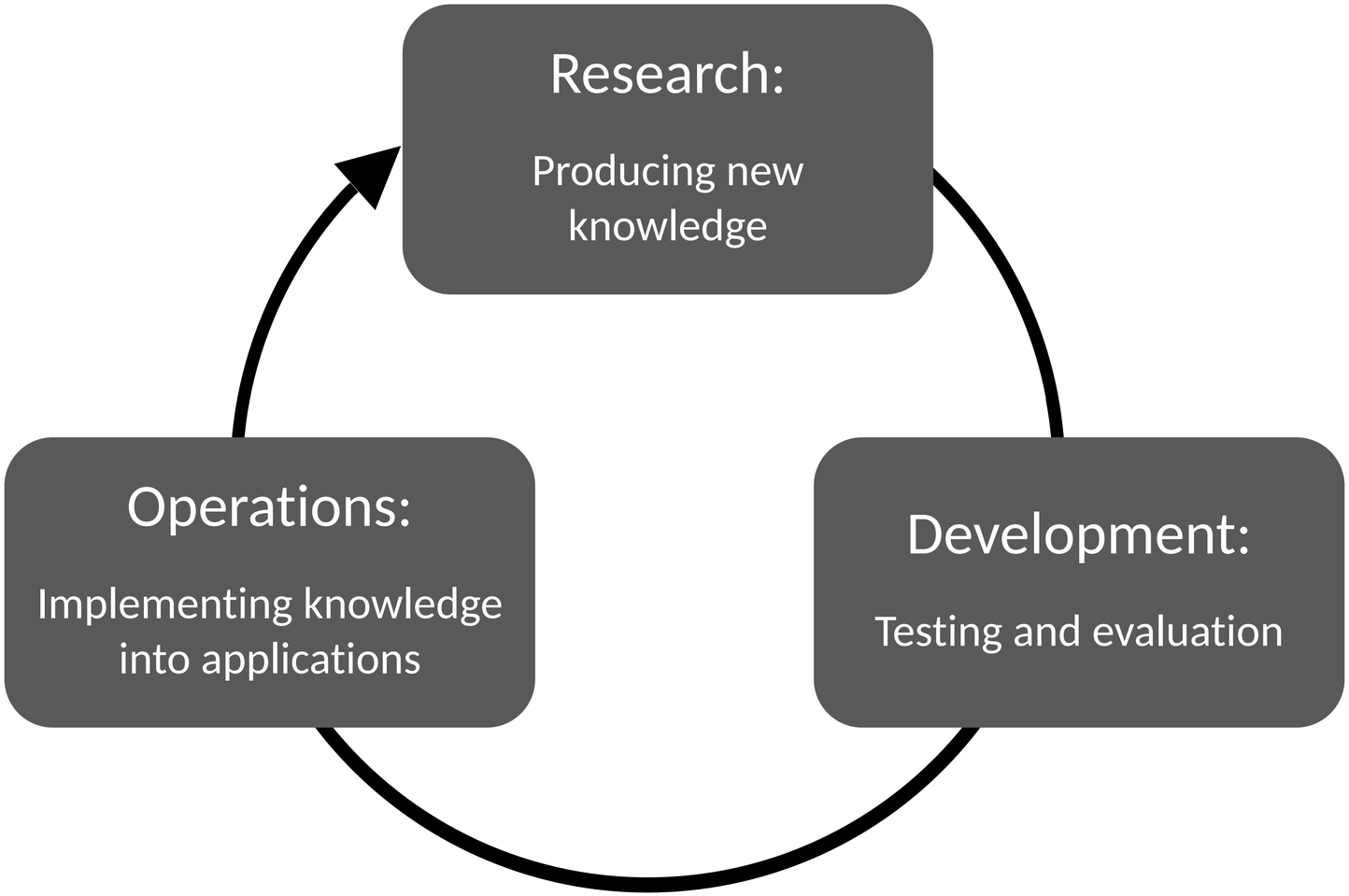
- Real-time observations stream
- Model predictions
  - Rigorously tested
  - Imbedded in robust infrastructure
  - Supported 24/7/365
- Product dissemination
- Quality control

This is to provide unfailing, timely, reliable (99+%) output to forecasters.

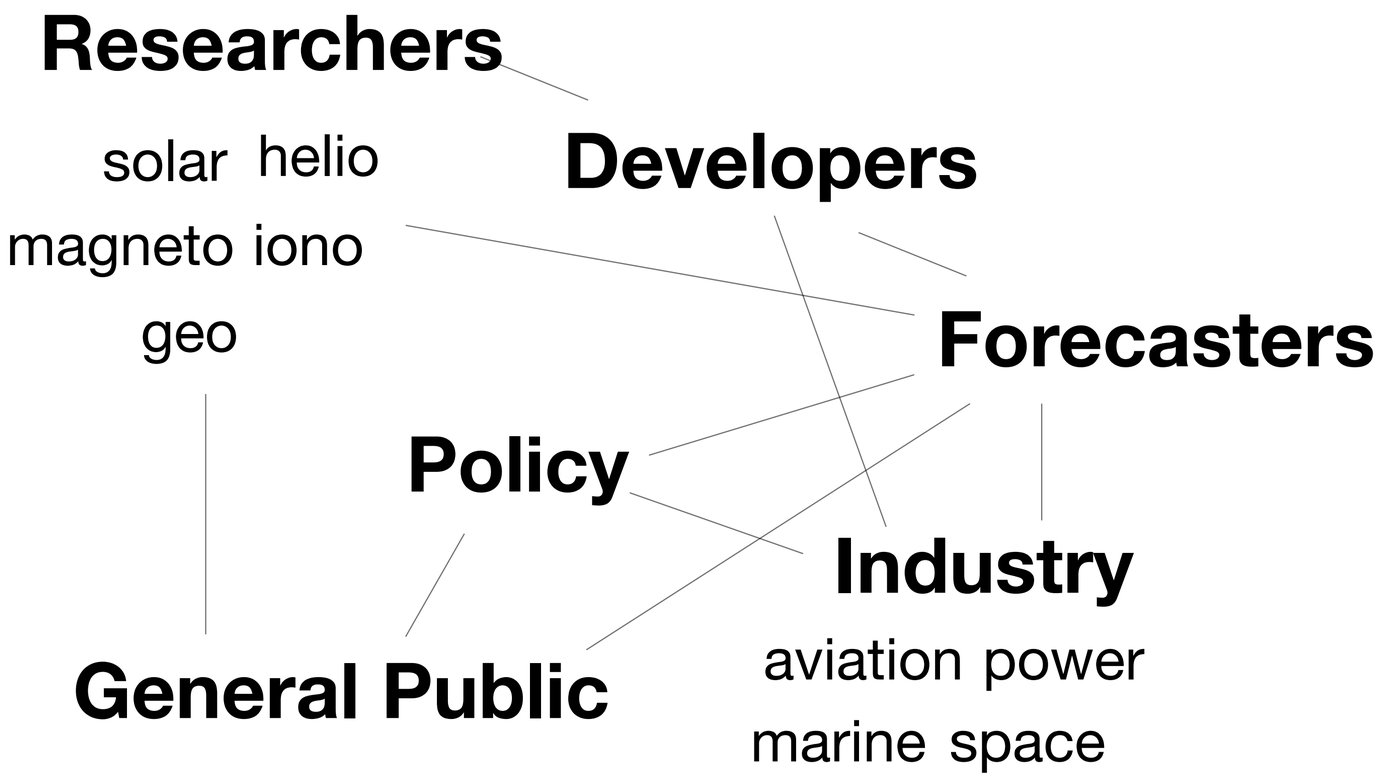
Research to Operations

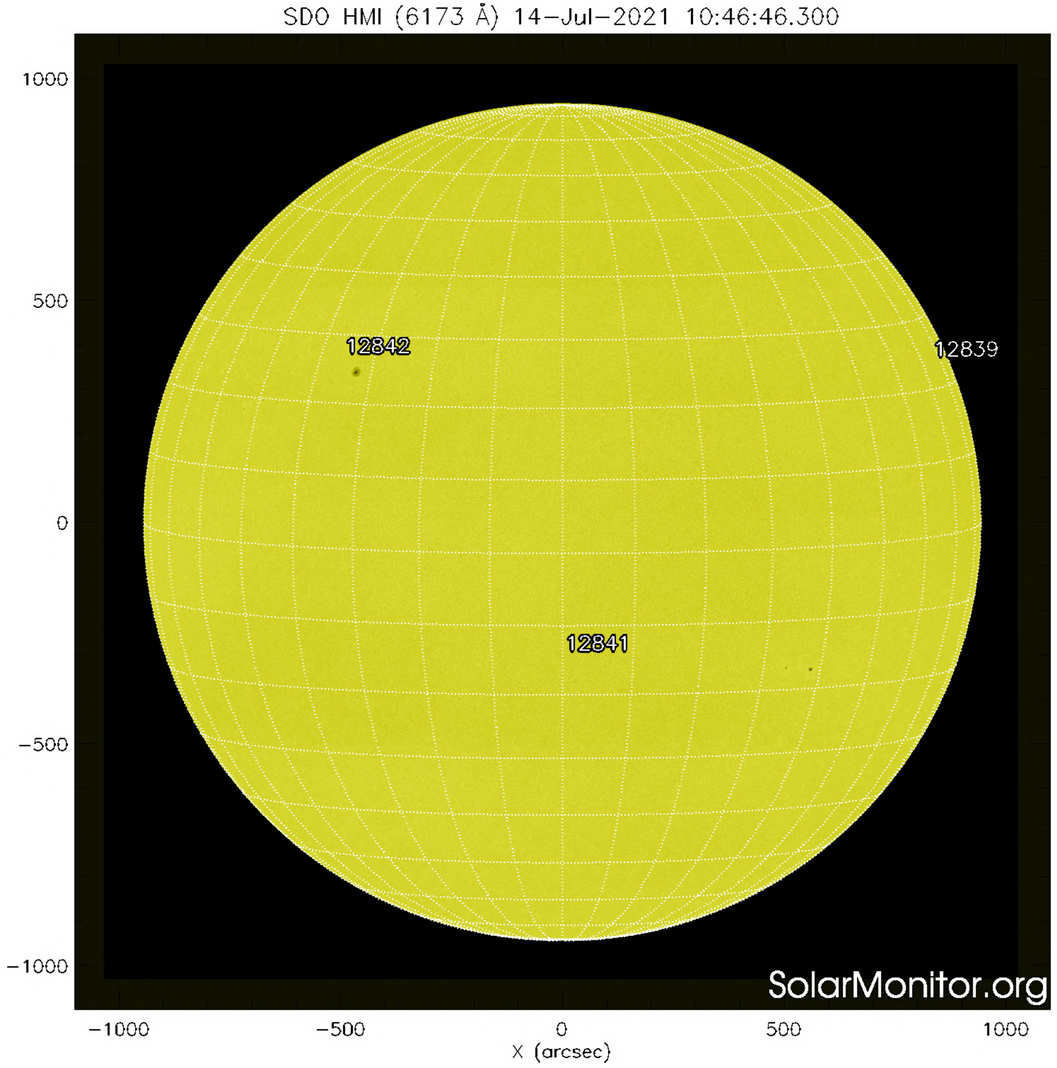


Operations to Research



Who are you users?





24-Hour Observed Maximums

R	S	G
none	none	none

Latest Observed

R	S	G
none	none	none

Predicted 2021-07-16 UTC

R1-R2	1%	S1 or greater	1%
R3-R5	1%		

G: none

NOAA SWPC

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