

Discriminant Analysis Flare Forecasting System ("DAFFS")

Phase-II Prototype Development under
US/National Oceanic and Atmospheric Administration (NOAA)
Small Business Innovative Research (SBIR) Program

K D Leka, G Barnes, E L Wagner
North West Research Associates

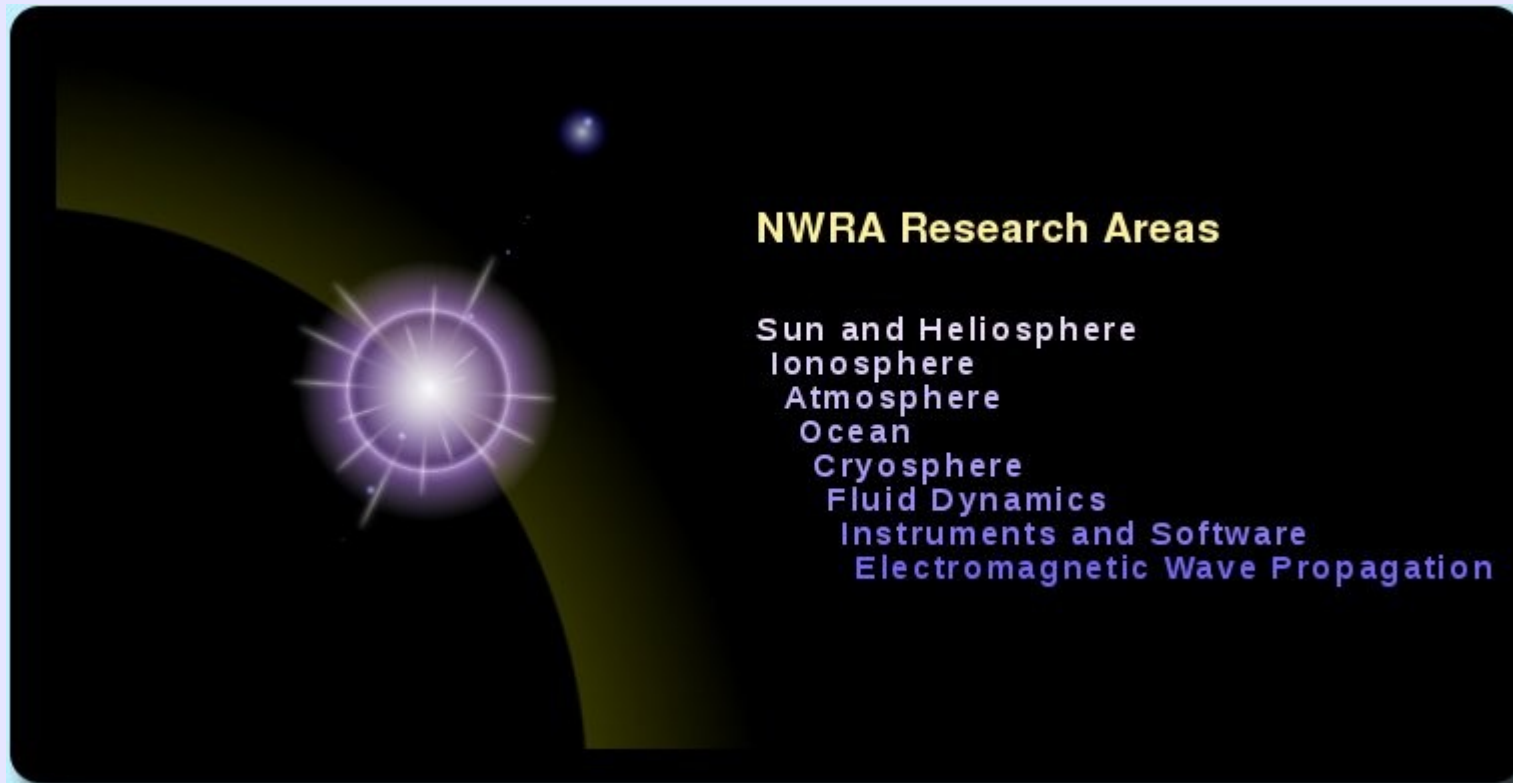
Frank Hill
National Solar Observatories

Funding for this work is acknowledged from NOAA/SBIR contracts WC-133R-13-CN-0079 and WC-133R-14-CN-0103, with additional support from NASA contracts NNH09CE72C, NNH12CG10C.

NWRA

NORTHWEST RESEARCH ASSOCIATES

"unencumbered science"



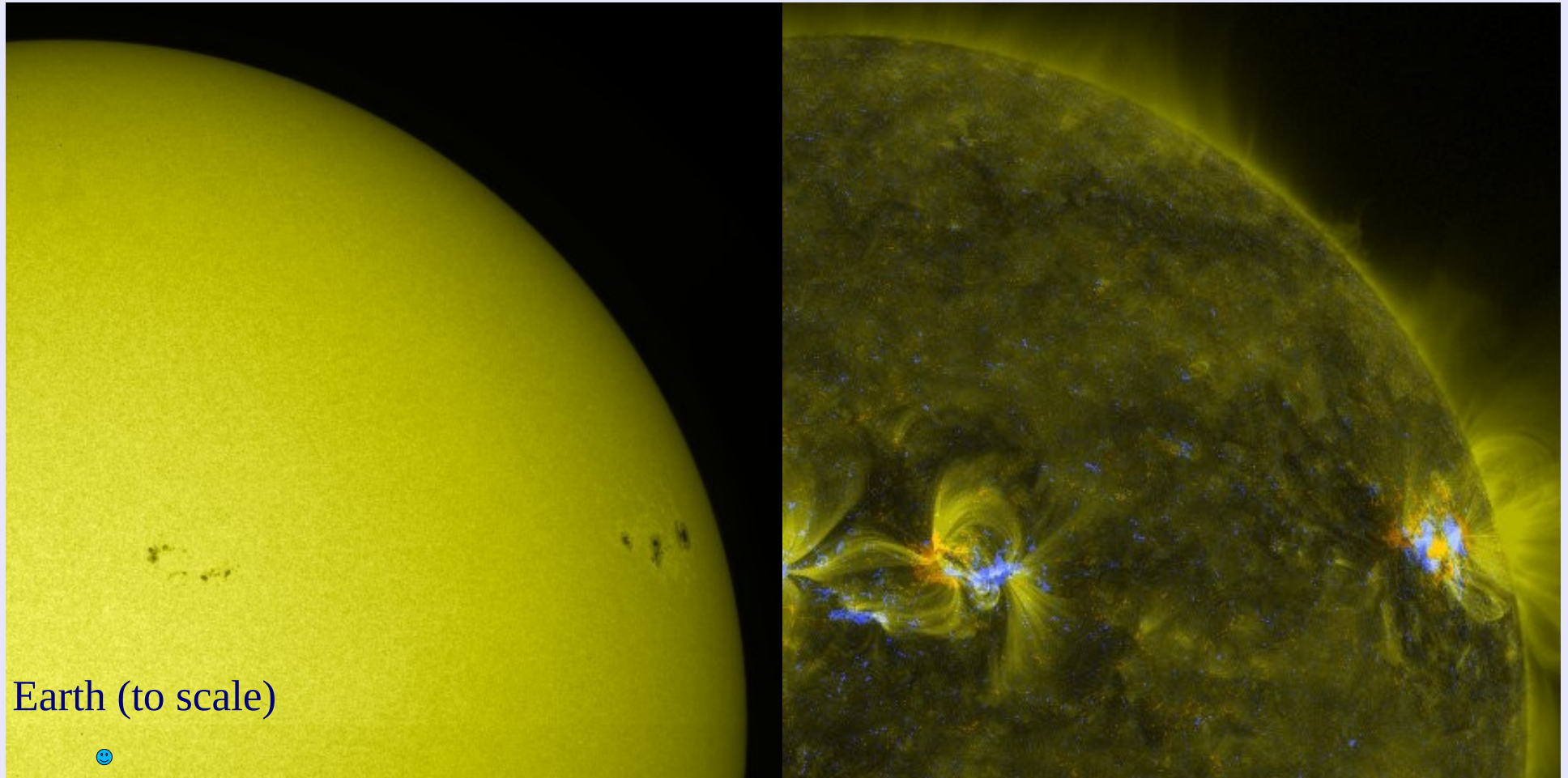
- Owned and managed by the Principal Investigators
- 75 Employees primarily in 4 US states (WA, CO, CA, NM)
- Good track record of SBIR Phase-II Commercialization.

NORTHWEST RESEARCH ASSOCIATES

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Q: What is a “solar flare”?

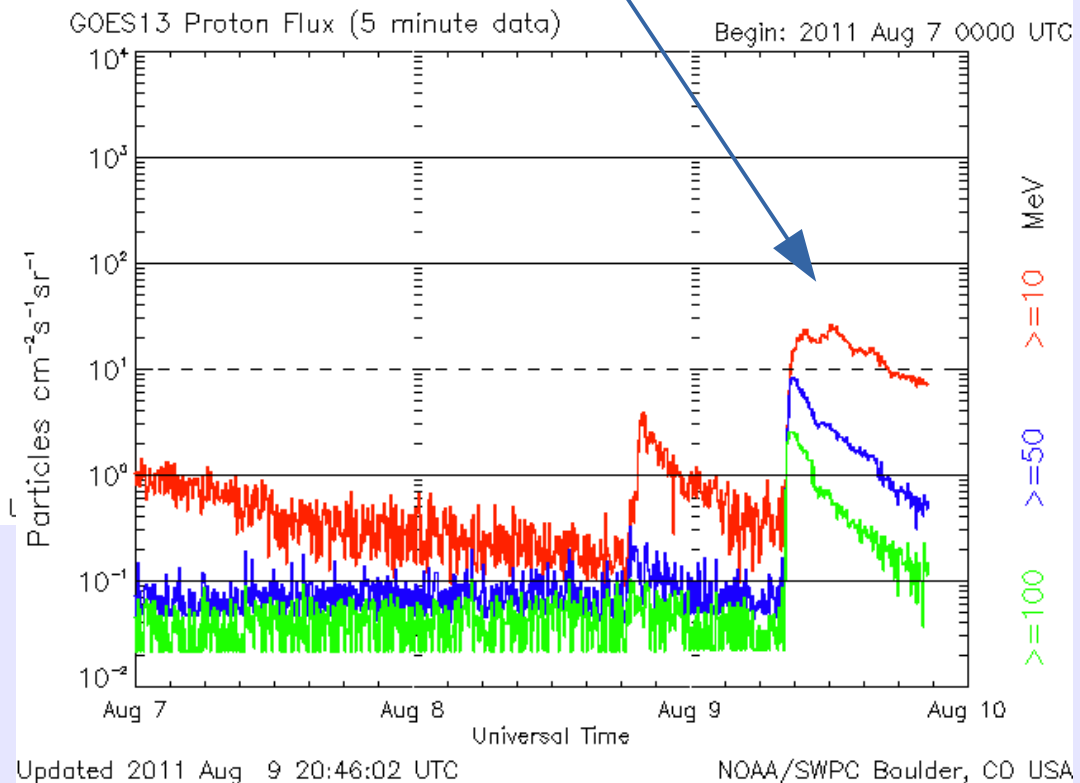
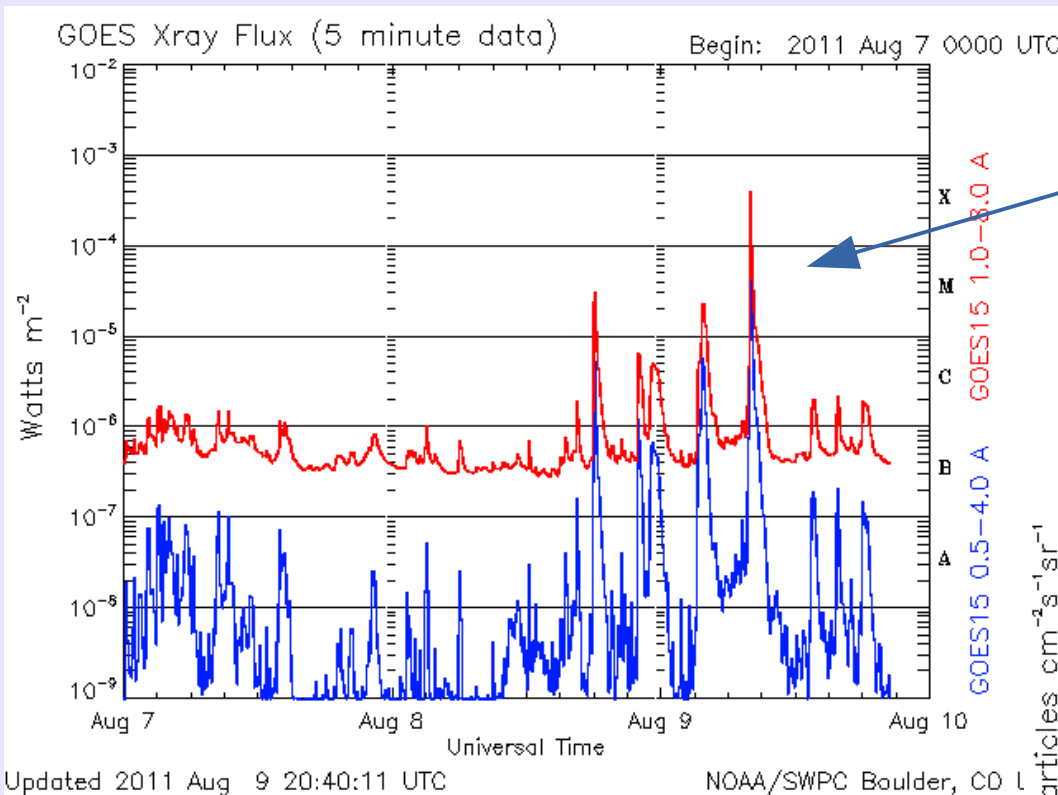
- A sudden, intense, release of magnetic energy from the Sun.



Q: What is a “solar flare”?

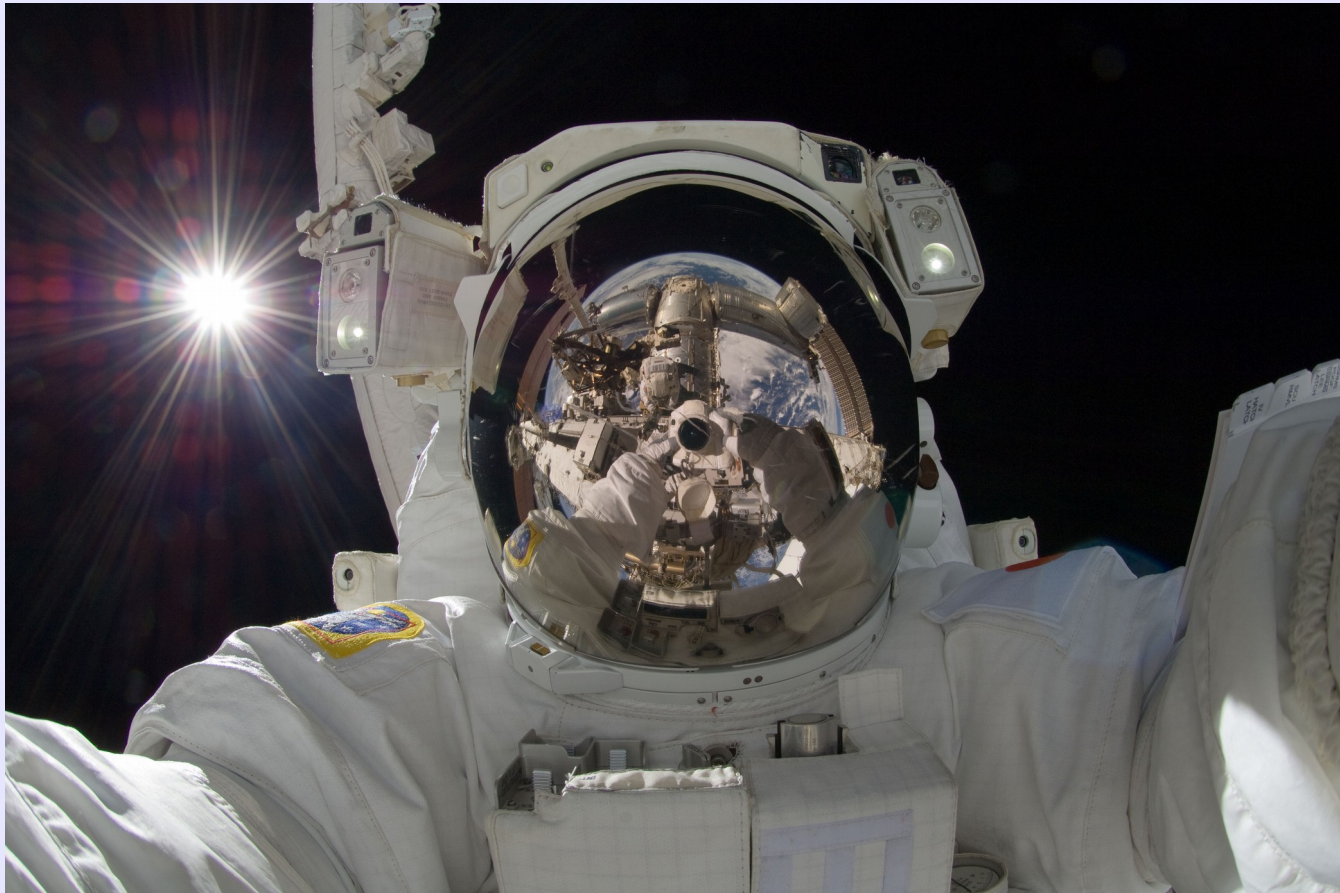
- A sudden, intense, release of magnetic energy from the Sun.
- An impulse of Ultraviolet, X-ray, and high-energy particles and radiation.

More than 2 orders of magnitude increase in soft X-rays and 2 in flux of high-energy particles.



Q: What is a “solar flare”?

- A sudden, intense, release of magnetic energy from the Sun.
- An impulse of Ultraviolet, X-ray, and high-energy particles and radiation.
- A reason to thank the Earth's magnetic field and atmosphere.



Radiation Storm

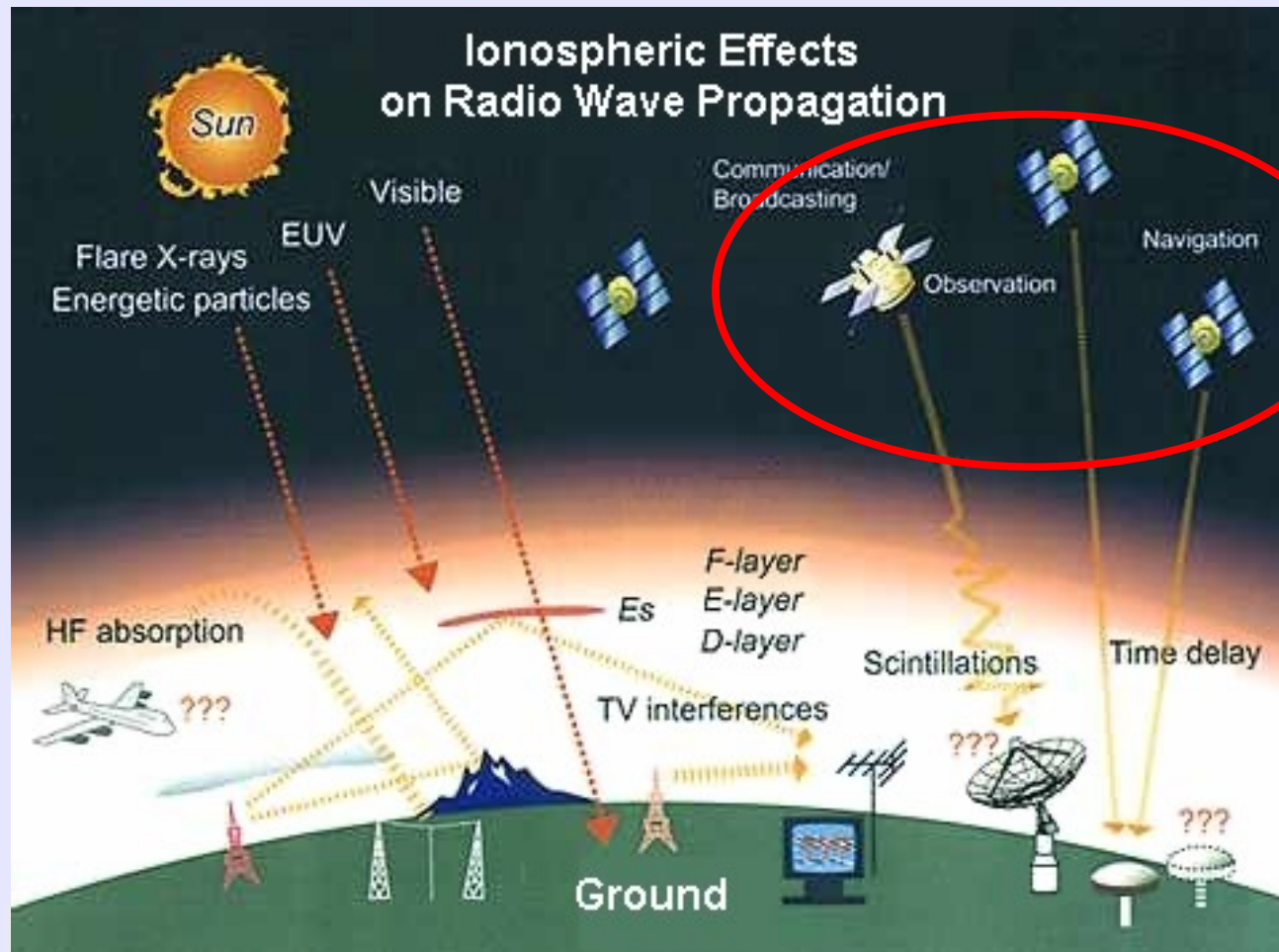
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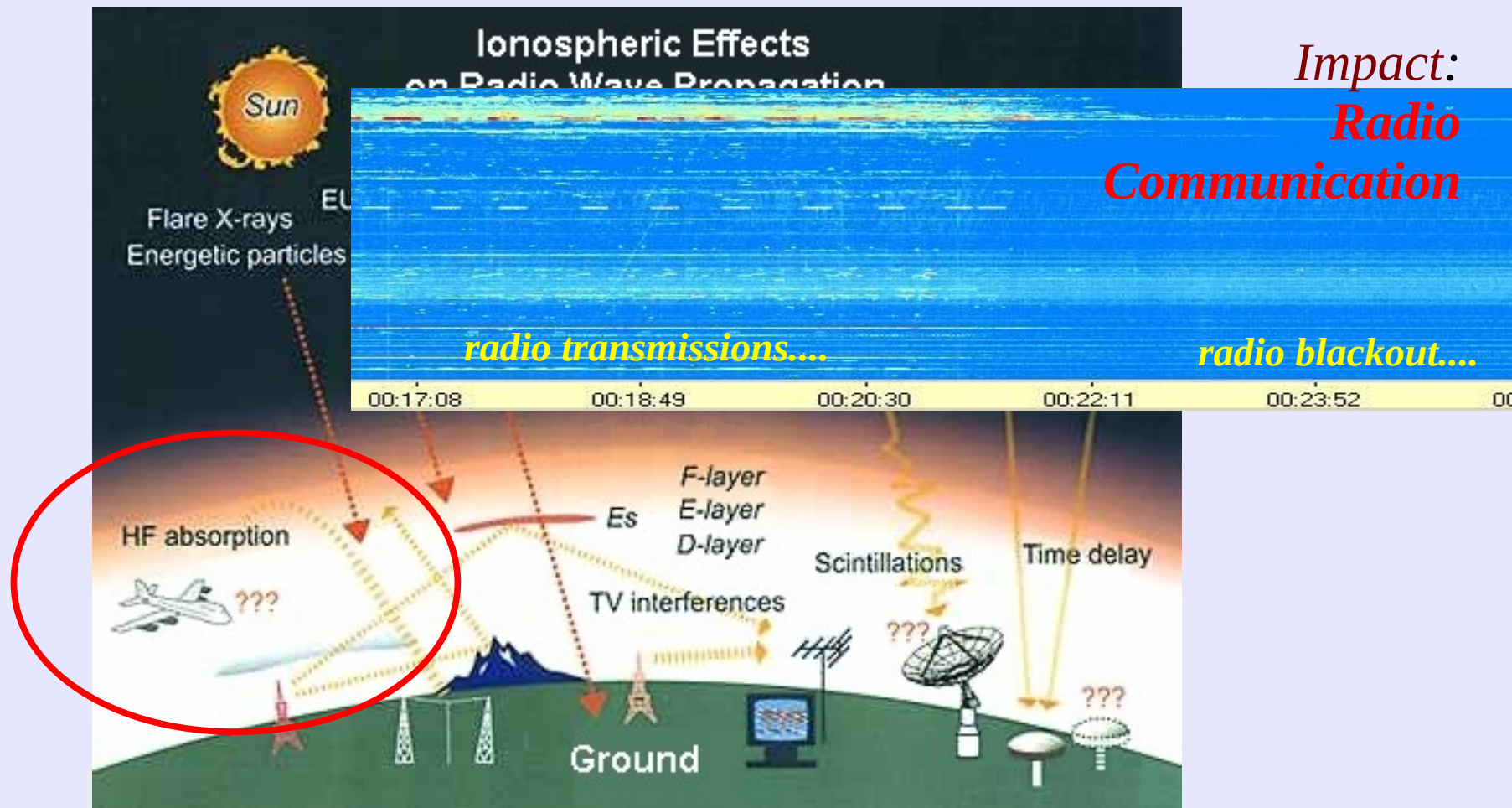
- A sudden, intense, release of magnetic energy from the Sun.
- An impulse of Ultraviolet, X-ray, and high-energy particles and radiation.
- A reason to thank the Earth's magnetic field and atmosphere.
- A reason to think about our technology infrastructure and dependence.



Impact:
GPS

Q: What is a “solar flare”?

- A sudden, intense, release of magnetic energy from the Sun.
- An impulse of Ultraviolet, X-ray, and high-energy particles and radiation.
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- A reason to think about our technology infrastructure and dependence.



Substantial even when not extreme:

- Mitchell & Schrijver conducted a study using public information that revealed a general correlation between large *but not extreme* solar flares and disturbances in the U.S. electric grid; these disturbances may have an impact of \$5-8 billion a year on the US GDP.

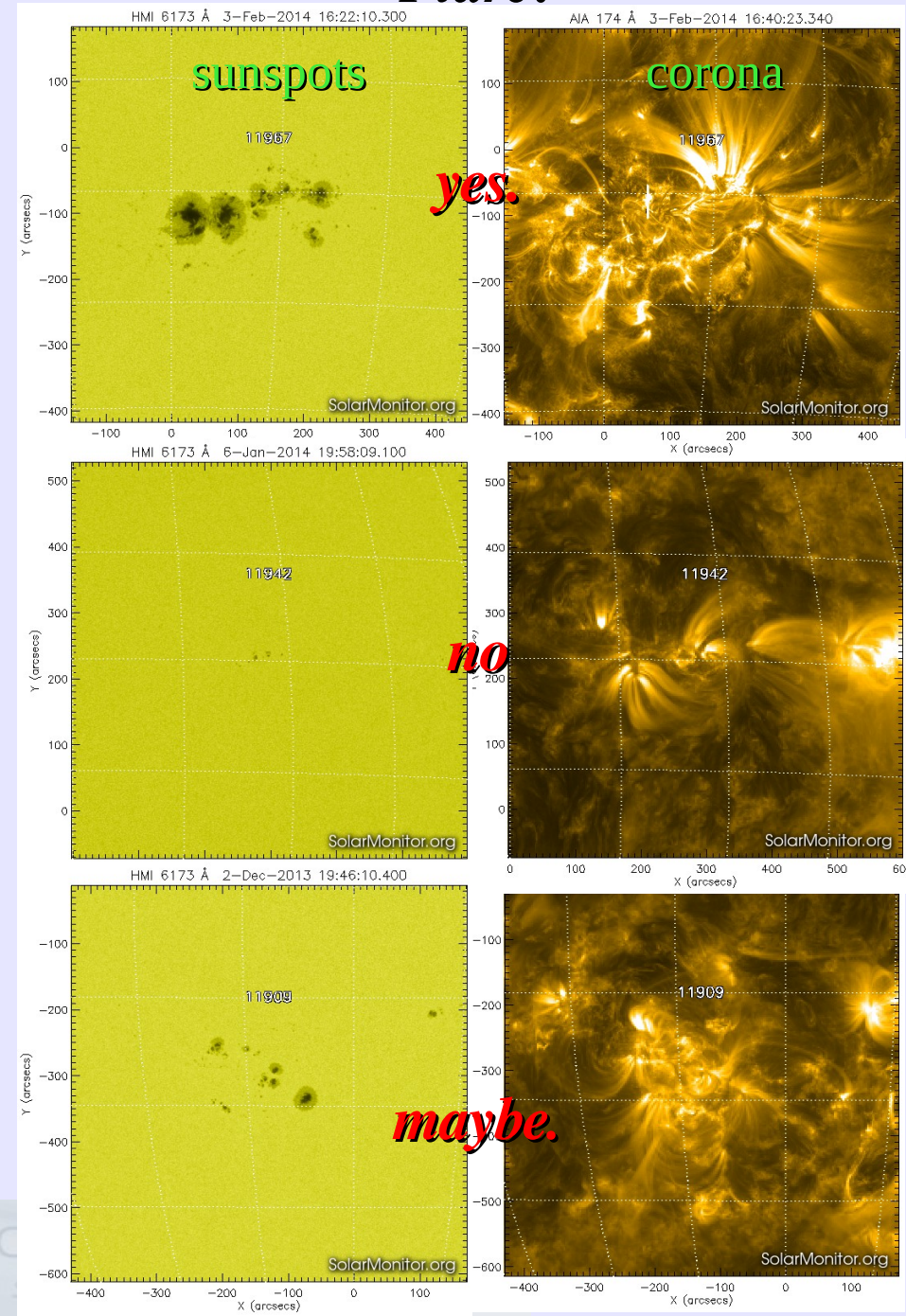


from Mitchell & Schrijver, 2013 Space Weather Week.

Present NOAA/Space Weather Prediction Center Forecasts:

- Daily forecasts for a few standard “event definitions”.
- Many factors/inputs used in forecasts.
 - Lots of data examined.
 - Generally *qualitative* evaluation.
 - Morphology-associated past flaring probability is primary component.

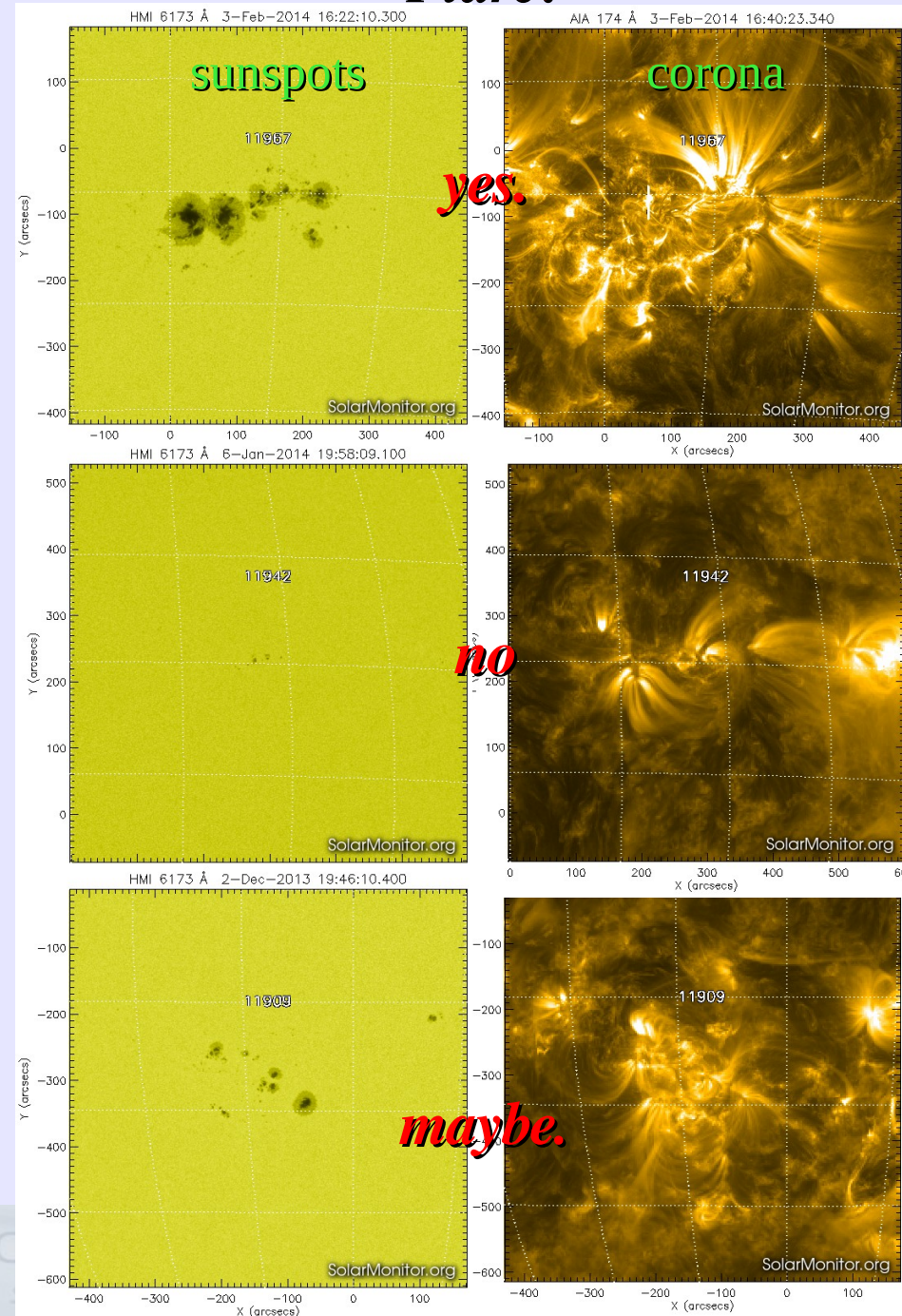
Flare?



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- Decades of experience.
 - Huge “training set”
- Forecasts used by many Centers.
- Report Skill statistics in many forms.

Flare?



“Truth Table”:

Observed

yes

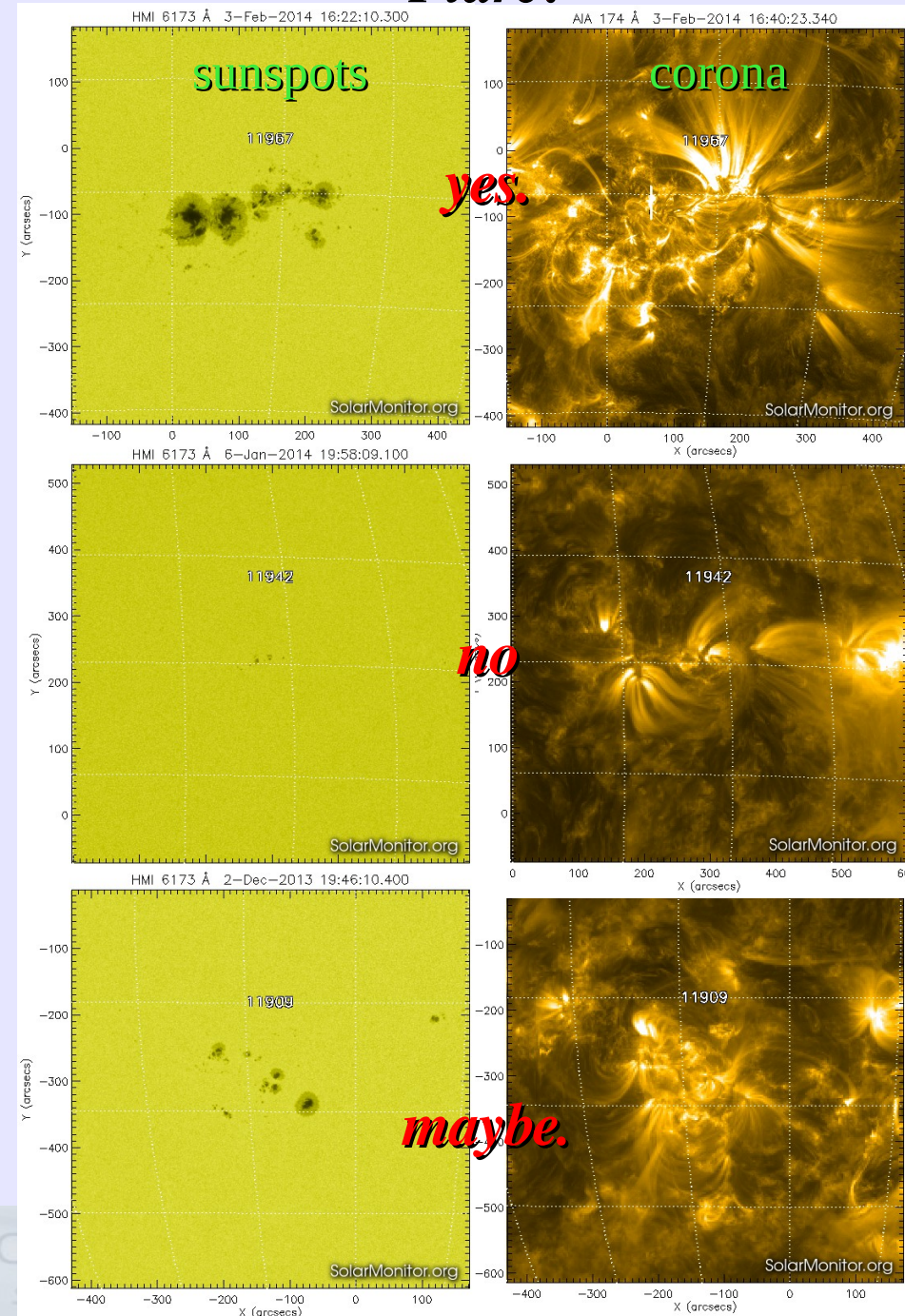
no

Predicted	<i>yes</i>	True Positive	False Positive
	<i>no</i>	False Negative	True Negative

Present NOAA/Space Weather Prediction Center Forecasts:

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Flare?



“Truth Table”:

		Observed	
		yes	no
Predicted	yes	“hits”	“false alarms”
	no	“misses”	“clears”

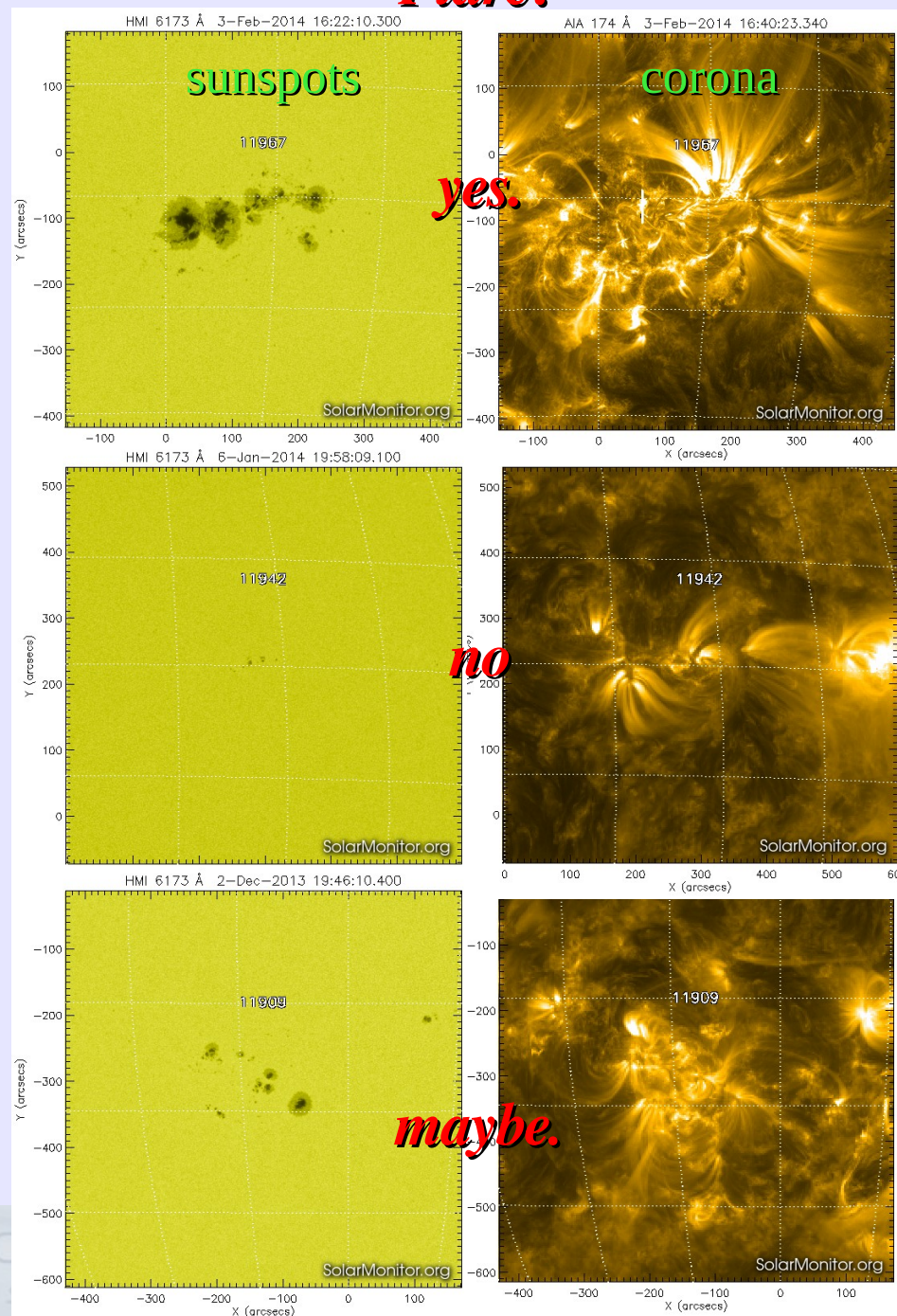
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- Report Skill statistics in many forms.
 - *Generally fair skill reported.*

“Truth Table”:

		Observed	
		yes	no
Predicted	yes	63	27
	no	14	4,367

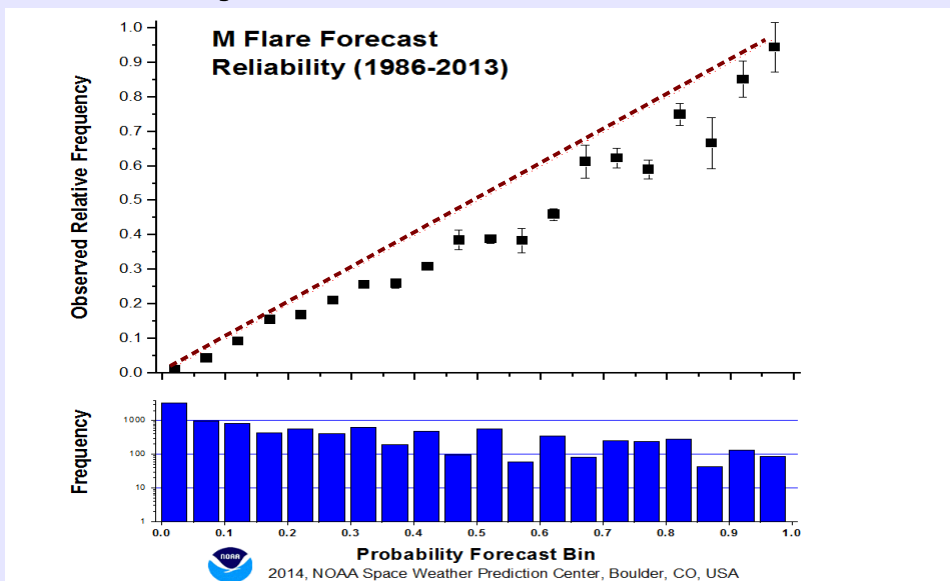
Flare?



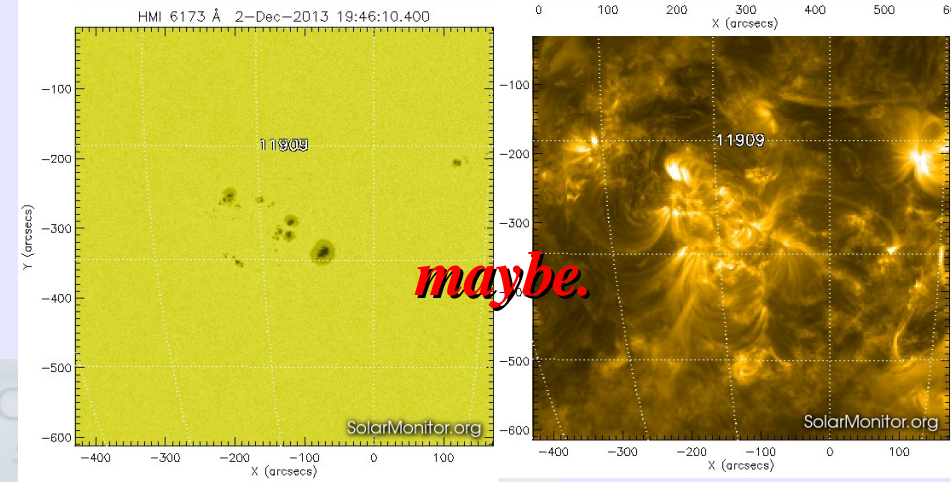
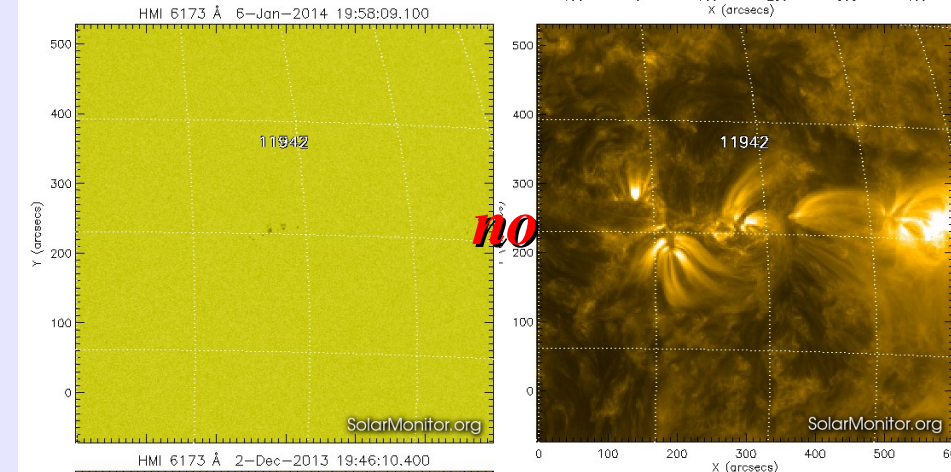
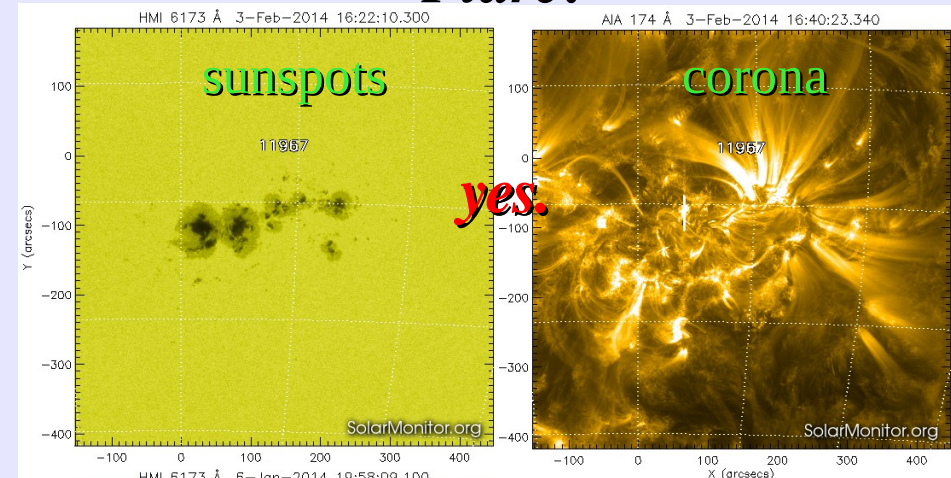
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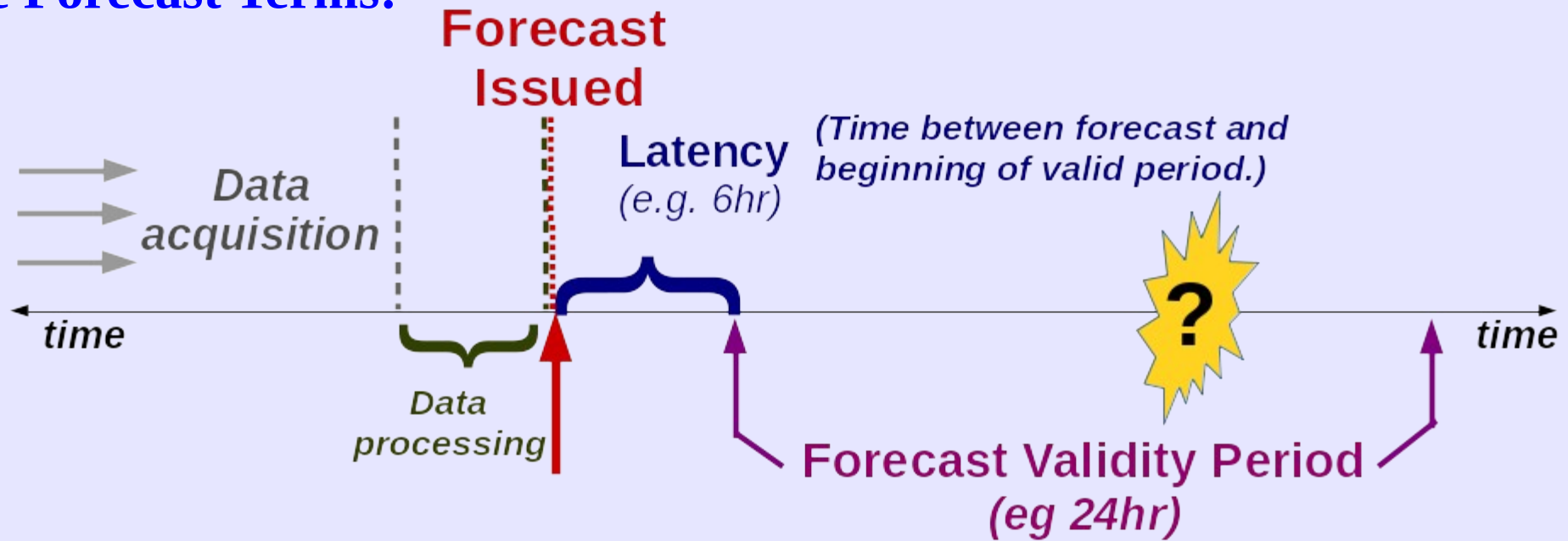
“Reliability Plot”:



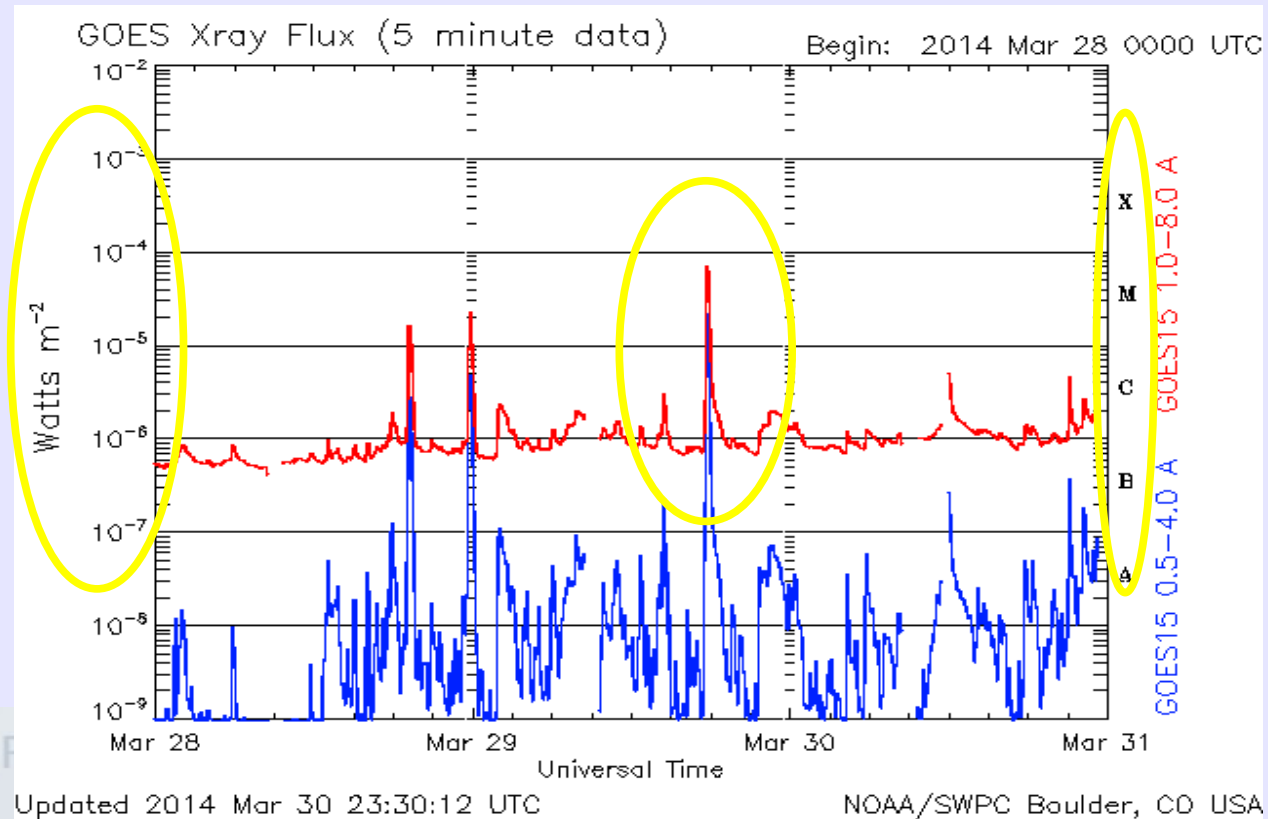
Flare?



Flare Forecast Terms:



Event Definition:



Discriminant Analysis Flare Forecasting System ("DAFFS")

Prototype: Flare forecasting tool development by NWRA for NOAA, under US/Small Business Innovative Research (SBIR) program.

- Phase-I results generally met requirements to *improve* on NOAA solar flare forecasts by 25%.
- Phase-II awarded for prototype development August 2014.

Targets: NOAA/Space Weather Prediction Center published forecasts :

- 1-day probability forecasts for visible active regions.
- 1-, 2-, and 3- day full-disk probability forecasts (for larger flares).

Deliverable: Real-time DAFFS Prototype release in 2016.

- Initial real-time tests running now.
- See Dr. KD Leka for demonstration here at ESWW12

Discriminant Analysis Flare Forecasting System (“DAFFS”)

Parametric Analysis Quantifies:

- solar magnetic field morphology: “complexity” and “energy storage”
- coronal topology: “available energy” and “readiness to flare”
- recent active region evolution, and
- prior flare history.

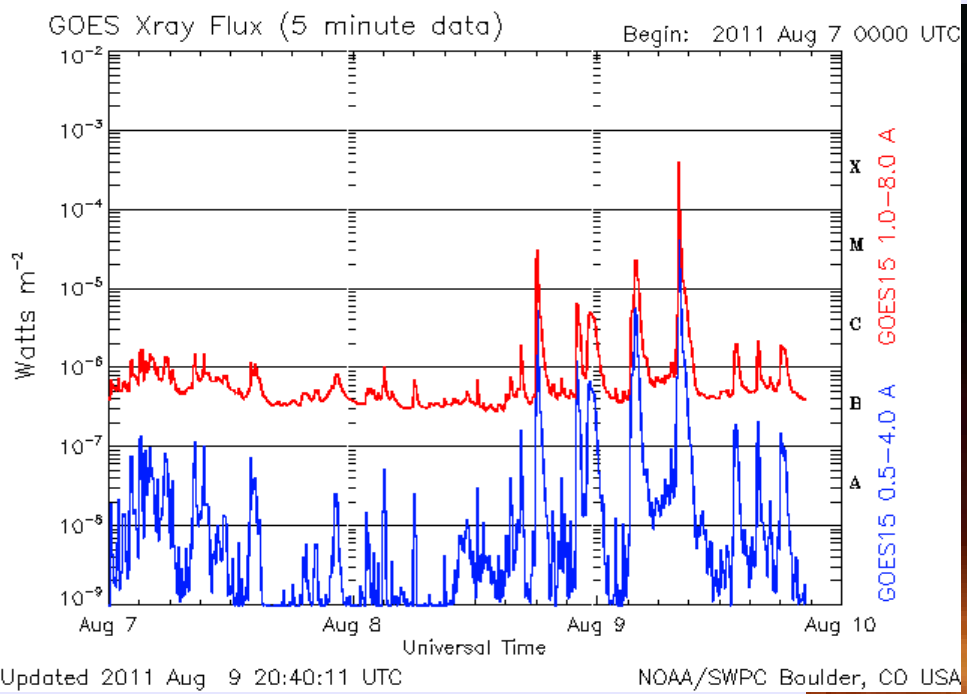
Discriminant Analysis:

- computes parameter-space separation between “flaring” and “flare quiet” active regions, and
- makes the forecasts (Categorical or Probabilistic)

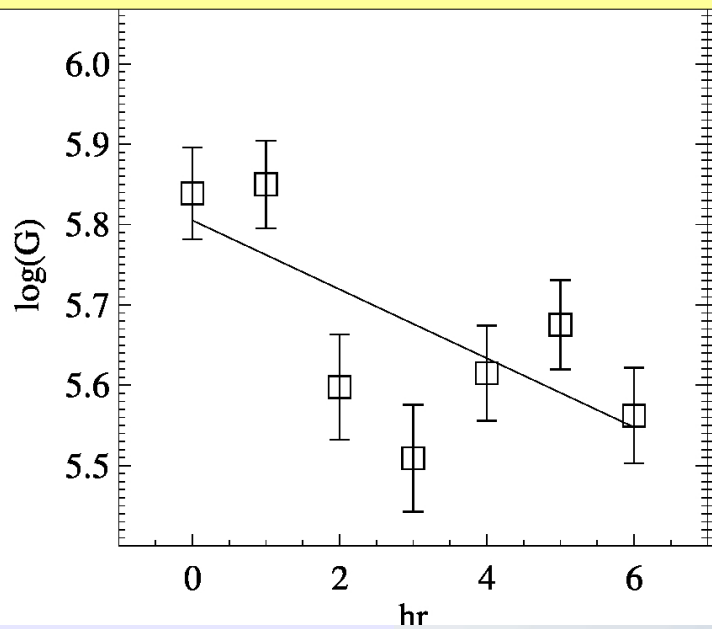
Performance Evaluation Metrics:

- Brier Skill Scores and Reliability plots automatically generated and provided.
- Cross-validation and Bootstrap included.

Leka & Barnes 2003a, b
Barnes & Leka 2006
Leka & Barnes 2007
Barnes et al 2007
Barnes & Leka 2008
Barnes et al 2015 (“The All-Clear Workshop”, *in preparation*.
Leka & Barnes 2015, “DAFFS”,
in preparation.



DAFFS uses numerous
“pieces” of the puzzle:



“unencumbered science”

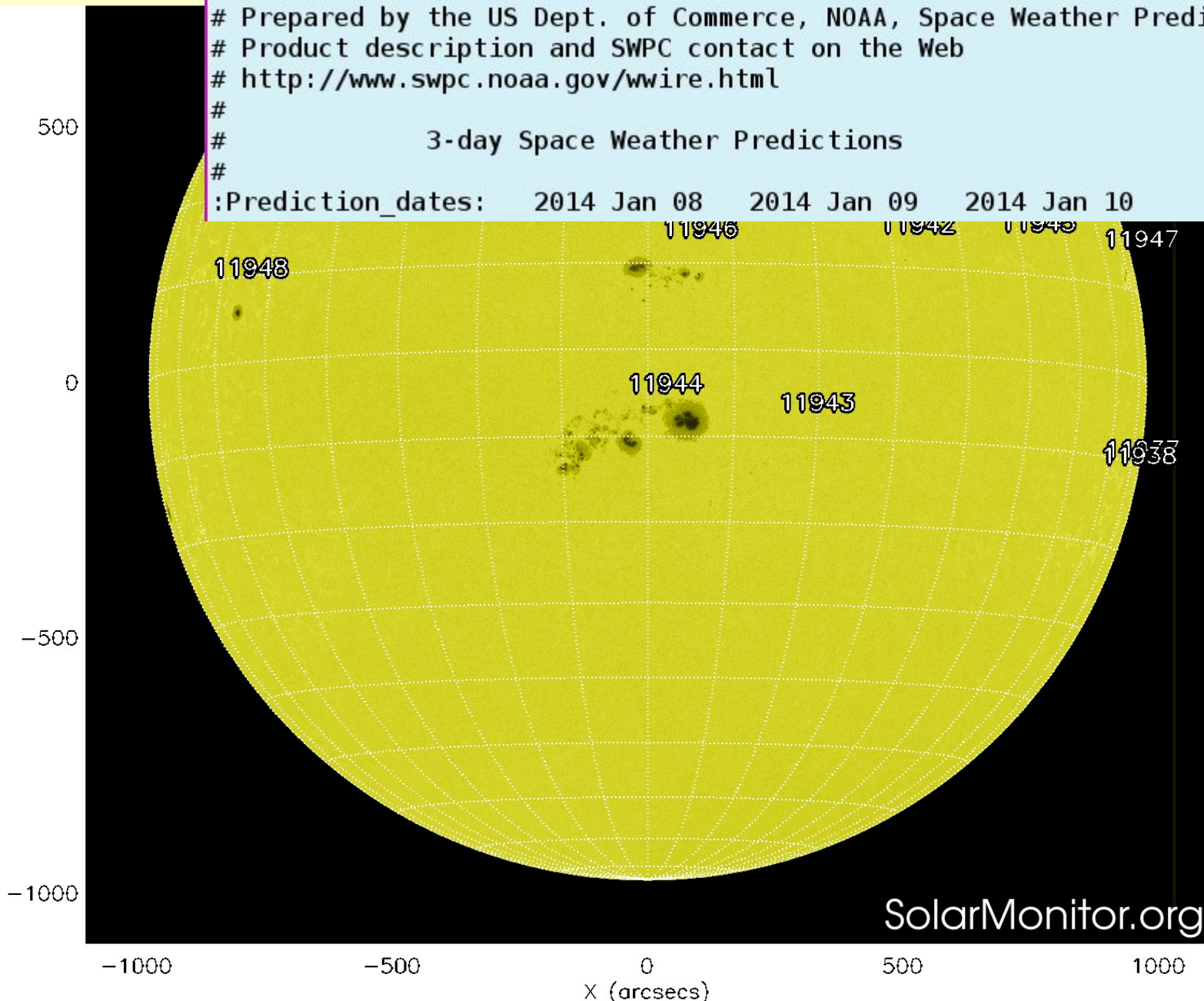
Performance Evaluation

- Match NOAA published forecasts.

```

:Product: 3-day Space Weather Predictions daypre.txt
:Issued: 2014 Jan 07 2200 UTC
# Prepared by the US Dept. of Commerce, NOAA, Space Weather Predictions
# Product description and SWPC contact on the Web
# http://www.swpc.noaa.gov/wire.html
#
#           3-day Space Weather Predictions
#
:Prediction_dates: 2014 Jan 08 2014 Jan 09 2014 Jan 10

```



Performance Evaluation

- Match NOAA published forecasts.
- Two “flavors”:

• Full-disk

- M1.0+, X1.0+;
- 24hr validity;
- 0hr, 24hr, 48hr latencies.

```

:Product: 3-day Space Weather Predictions daypre.txt
:Issued: 2014 Jan 07 2200 UTC
# Prepared by the US Dept. of Commerce, NOAA, Space Weather Predictions
# Product description and SWPC contact on the Web
# http://www.swpc.noaa.gov/wwire.html
#
#           3-day Space Weather Predictions
#
:Prediction_dates:   2014 Jan 08   2014 Jan 09   2014 Jan 10
#
:Whole_Disk_Flare_Prob:
Class_M             80             80             80
Class_X             50             50             50
Proton              99             99             99
#
    
```

500

-500

-1000

-1000 -500 0 500 1000

X (arcsecs)

11038

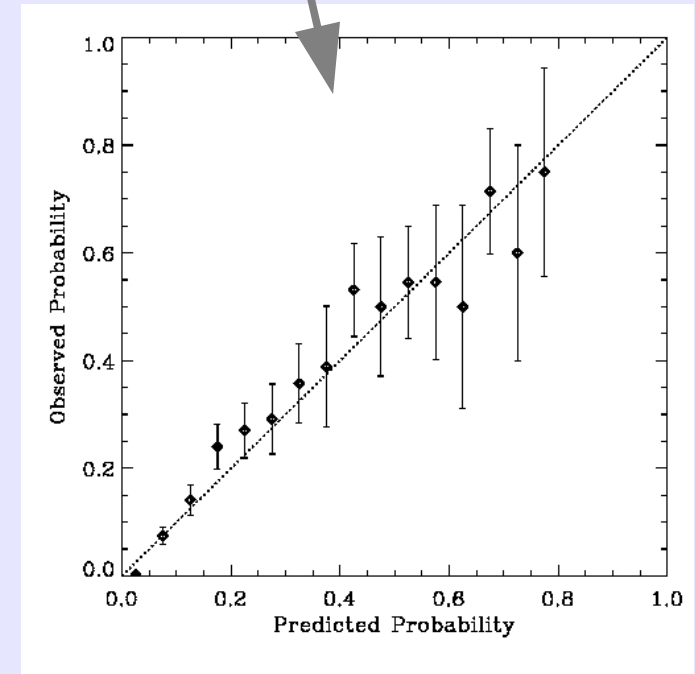
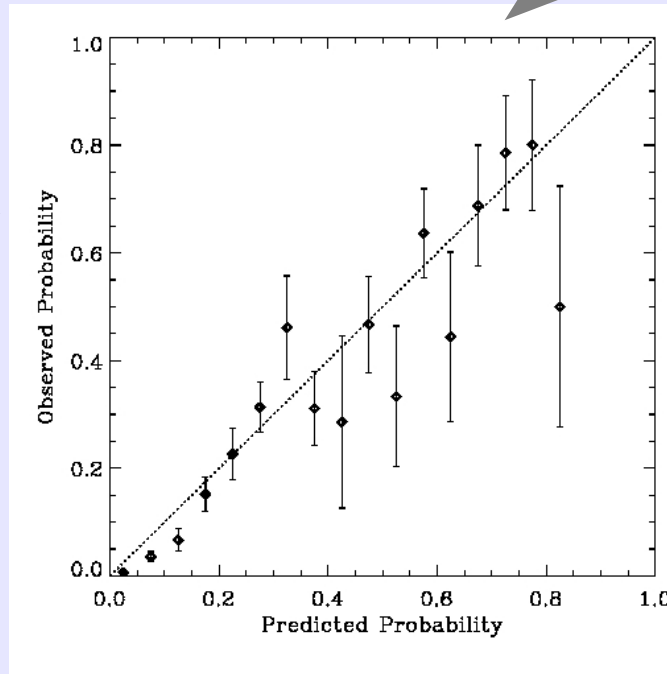
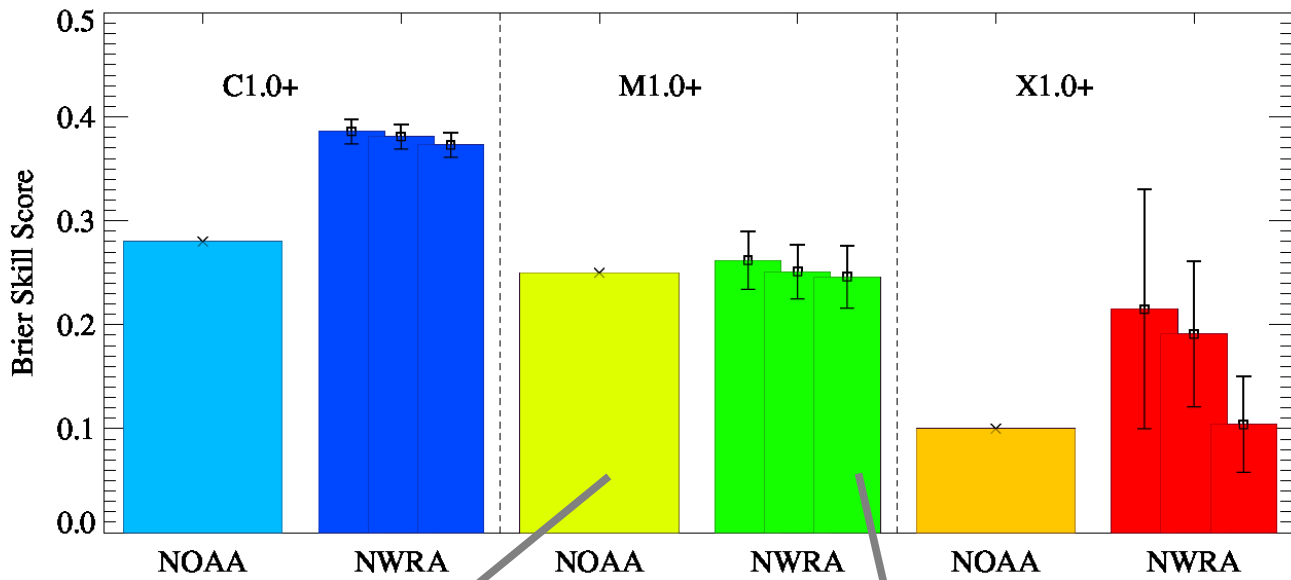
• *Region-by-Region*

- C1.0+, M1.0+, X1.0+
- 24hr validity,
- 0hr latency

DAFFS generally demonstrates higher Brier Skill Scores.

➤ smaller error bars with higher sample sizes.

➤ Where BSS are similar, reliability plots show Improvement (NOAA consistently over-predicts, while **DAFFS** typically does not).

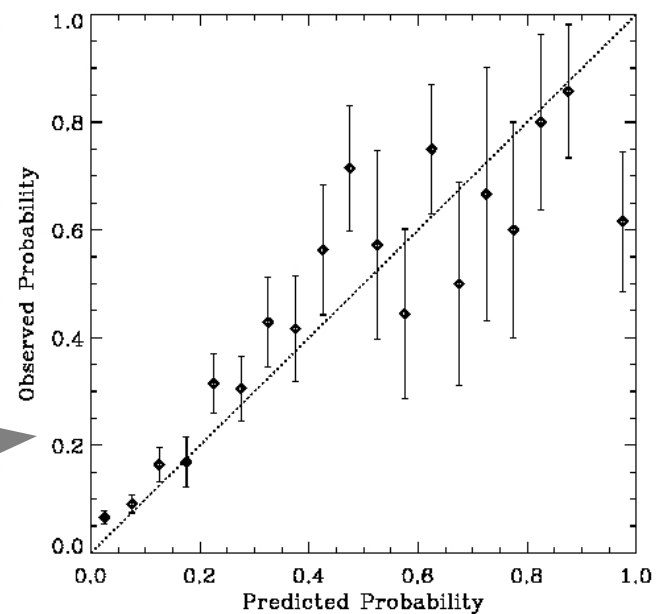
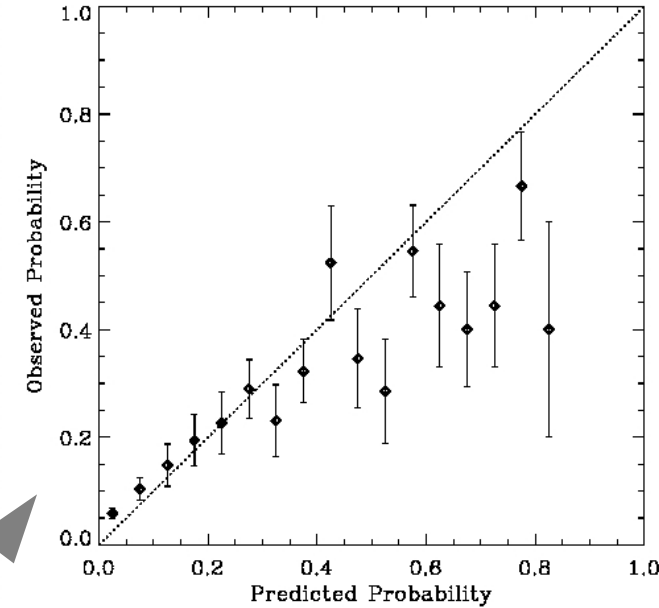
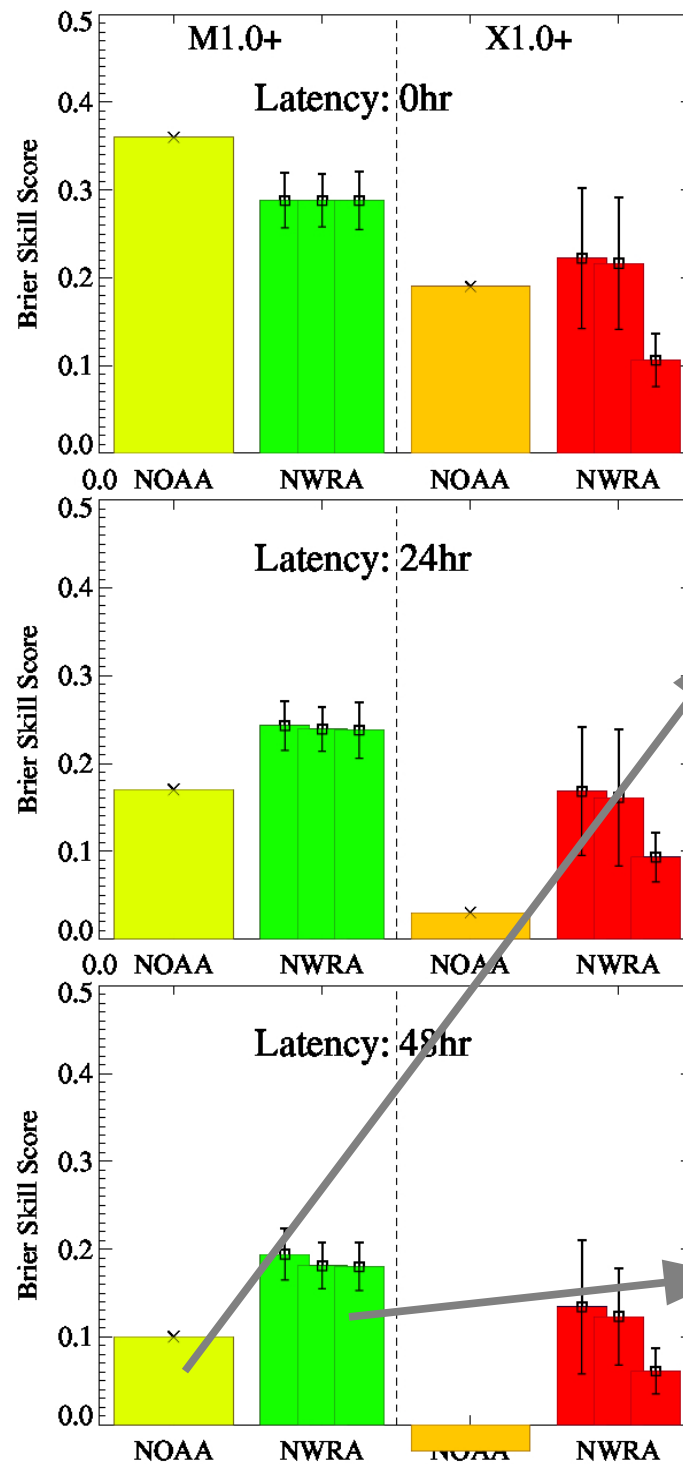


• Full-disk

- M1.0+, X1.0+;
- 24hr validity;
- 0hr, 24hr, 48hr latencies.

DAFFS generally demonstrates higher Brier Skill Scores.

➤ Especially for larger events @ longer latencies (2- and 3-day forecasts).



DAFFS Prototype Development Tasks (Phase-II)

- Automate.
- Create tool with NOAA/SWPC-forecaster-guided “look & feel”.
- Establish secondary system with backup data source.
- Outreach.



Automate

- Most **DAFFS** autonomy is now complete.
- Implementing “best practices” and standards (such that they exist).
- Prototype runs on NWRA servers.

Create NOAA/SWPC-forecaster-guided “look & feel”

- Graphical/text output, including region-forecast “context”.
- “Ensemble-forecast” information provided.
- Facilitates later “look & feel” development for other customers.

Establish **DAFFS** secondary system with backup data source.

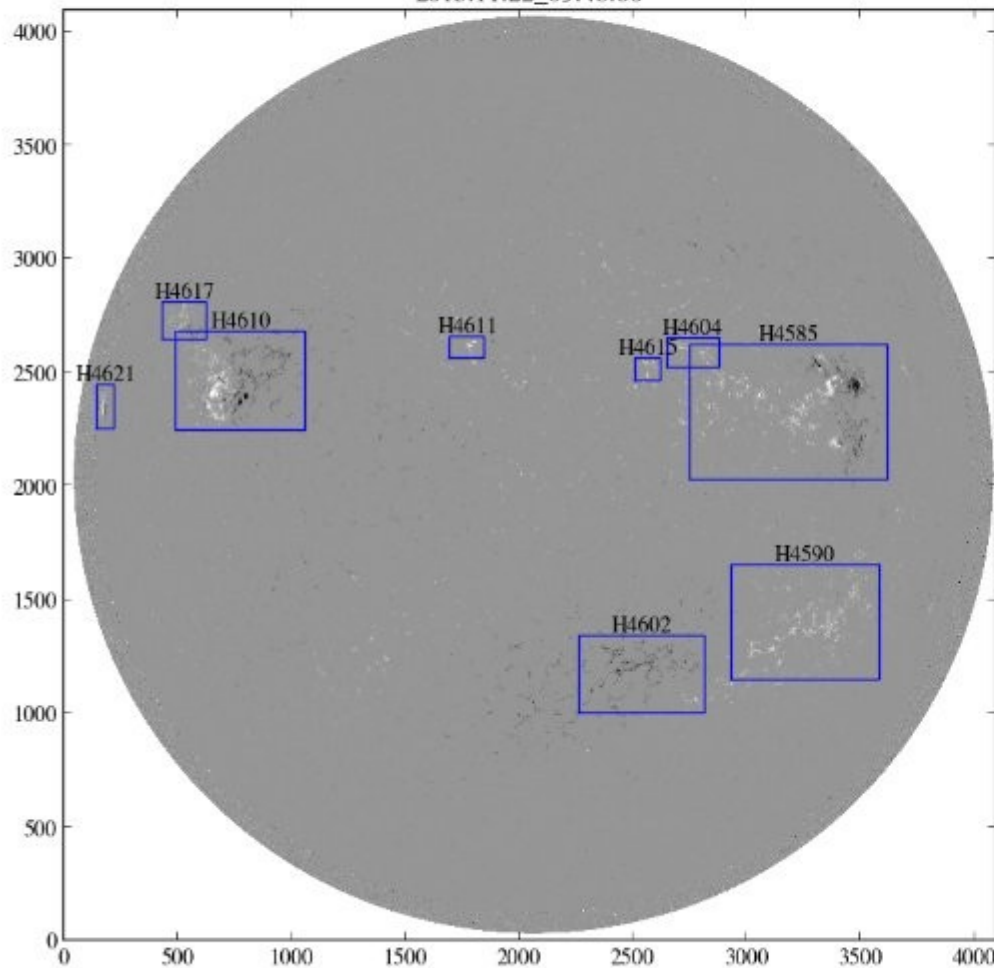
- Primary data stream: Solar Dynamics Observatory + GOES X-ray event detection.
 - GOES: NOAA operational design & run.
 - SDO: Limited lifetime.
 - SDO: Not designed for operations.
 - SDO: No “hot spare” or follow-on scheduled.
- Secondary data stream: Global Oscillations Network Group magnetic field data + GOES X-ray event detection.
 - GONG: science project of the NSF/National Solar Observatories.
 - GONG: ground-based network of solar observatories.
 - GONG: , no design-limited lifetime, but not funded for long-term operations and threatened for shut-down.
 - GONG: Less information available for DAFFS, but preliminary testing shows still out-performs present NOAA/SWPC forecasting.
- Secondary system runs automatically according to data availability; no “switch-over” time lag.

Relevant Customer Highlights:

- **DAFFS is fast.**
 - Real-time data needs are generally small.
 - Real-time calculation needs are small (off-the-shelf desktop).
- **DAFFS is highly customizable.**
 - Many industries/customers have highly specialized needs.

NWRA/DAFFS Flare Forecasting System: 2015-11-22 @11:54:00UTC

2015.11.22_09:48:00



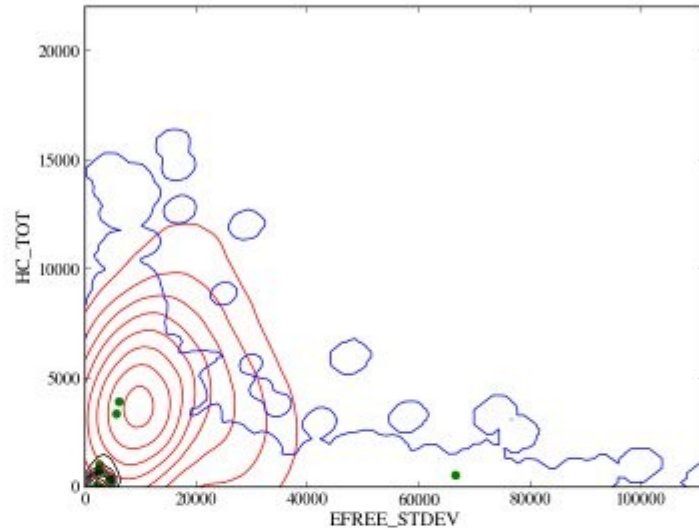
Full-Disk Forecasts:

Event Definition	Forecast
1 Day:	C1+ 0.79
2015-11-22_12:00:00 to	M1+ 0.06
2015-11-23_12:00:00	X1+ <.01
2 Day:	C1+ 0.75
2015-11-23_12:00:00 to	M1+ 0.13
2015-11-24_12:00:00	X1+ <.01
3 Day:	C1+ 0.61
2015-11-24_12:00:00 to	M1+ 0.18
2015-11-25_12:00:00	X1+ 0.02

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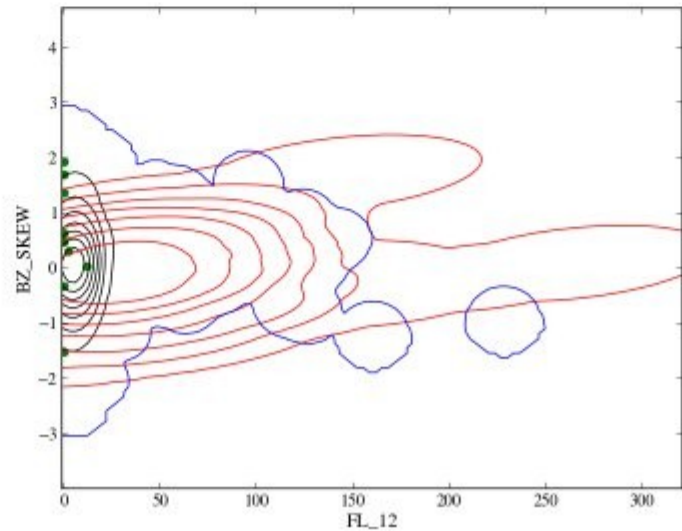
M1+ 2015-11-22 12:00:00 to 2015-11-23 12:00:00

HARP	NOAA	Forecast	Status
H4585	12454	0.03	0 (good data)
H4590	??	<.01	0 (good data)
H4602	??	<.01	0 (good data)
H4604	??	<.01	0 (good data)
H4610	12457	0.02	0 (good data)
H4611	??	<.01	0 (good data)
H4615	??	<.01	0 (good data)
H4617	??	<.01	0 (good data)
H4621	??	<.01	0 (good data)
FULL DISK		0.08	



X1+ 2015-11-22 12:00:00 to 2015-11-23 12:00:00

HARP	NOAA	Forecast	Status
H4585	12454	<.01	0 (good data)
H4590	??	<.01	1 (null-good)
H4602	??	<.01	1 (null-good)
H4604	??	<.01	1 (null-good)
H4610	12457	<.01	0 (good data)
H4611	??	<.01	1 (null-good)
H4615	??	<.01	1 (null-good)
H4617	??	<.01	1 (null-good)
H4621	??	<.01	1 (null-good)
FULL DISK		<.01	



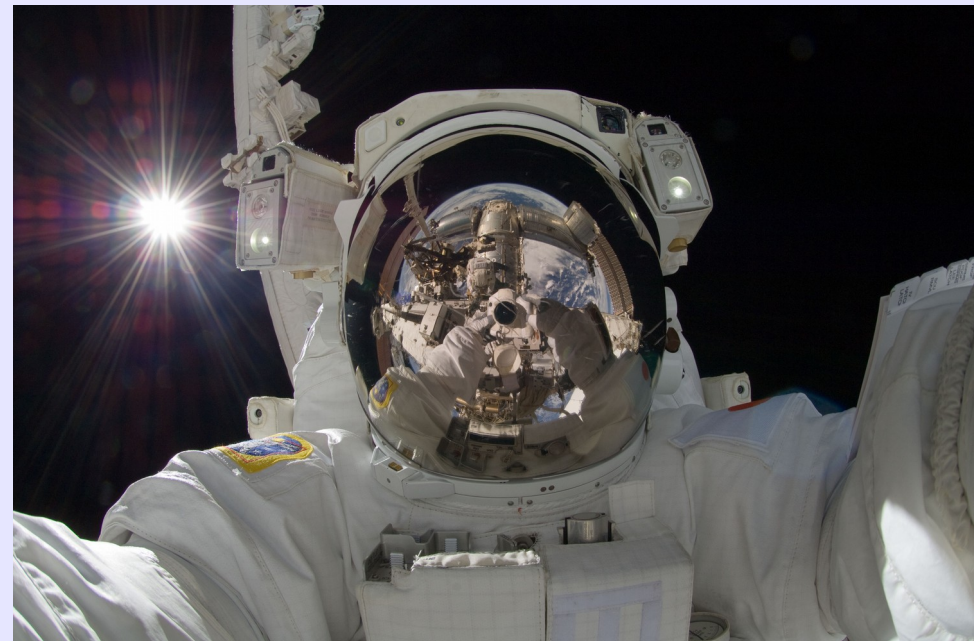
Customer #1 wants:

- Basic situational awareness for 1—2 days out.
- Is very sensitive to *any* GPS disturbances.
- Simply implements “heightened awareness”: false alarms are not a problem, but missed events are a big problem.



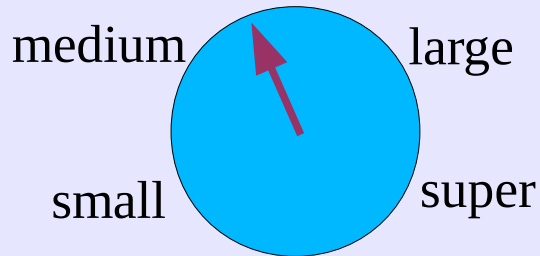
Customer #2 wants:

- “All-Clear” forecast for 12hr, starting in 6hr from forecast issuance for particular periods.
- Only large/powerful events are critical.
- False alarms are expensive, but missed events are catastrophic.

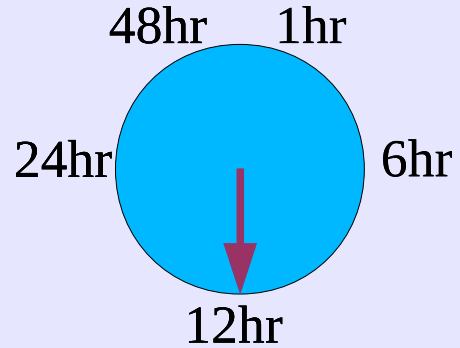


DAFFS Customizable Features

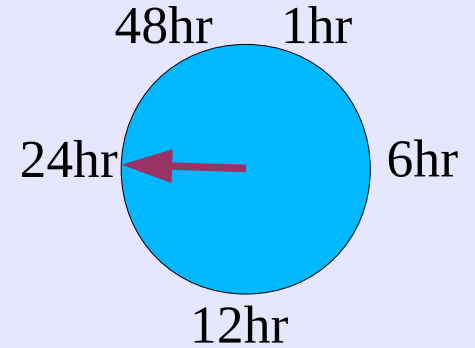
Event Size/Type



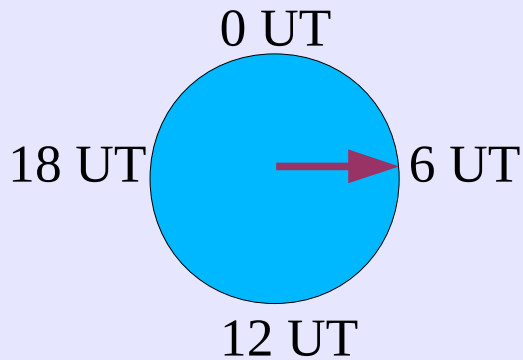
Validity Period



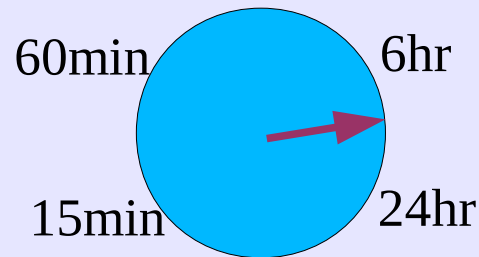
Latency



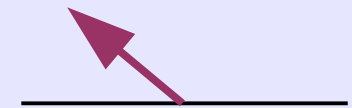
Issuance Time



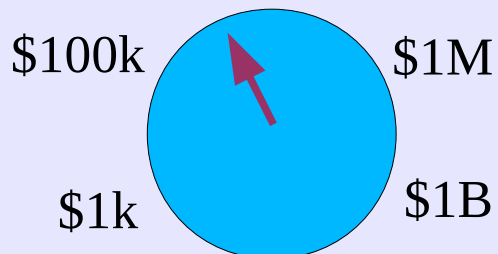
Forecast Frequency



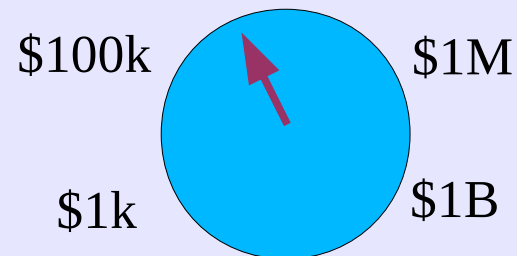
Full Disk Active Region



False Alarms

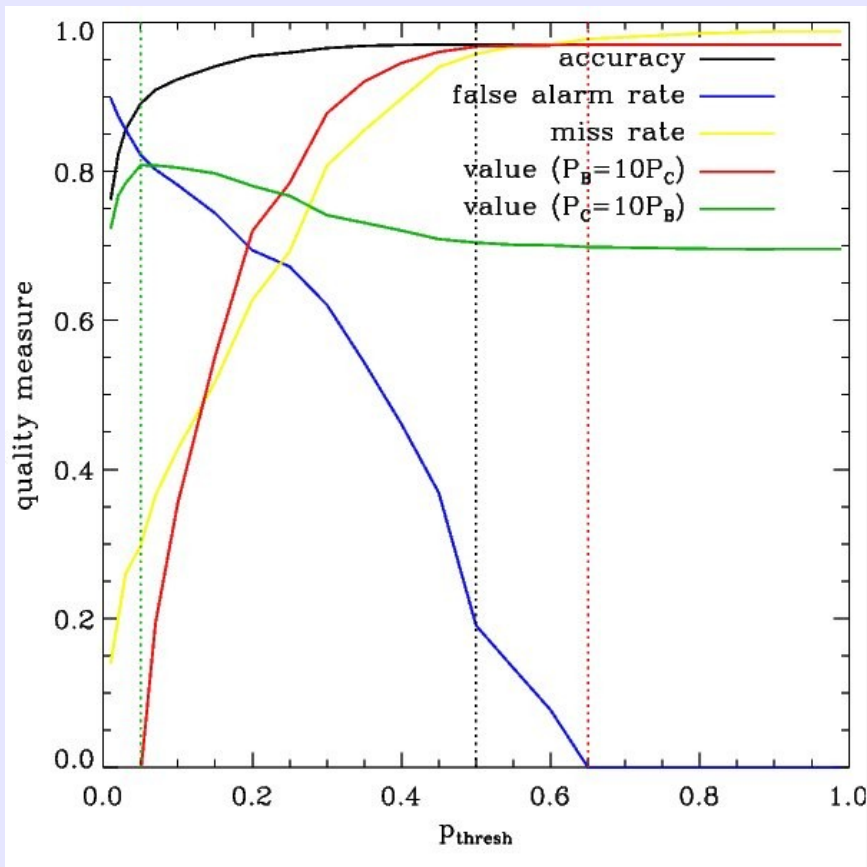


Missed Events



Customizing “Costs”

Trends in value (skill score) for different optimization options as a function of the probability level.



The “cost” of a particular *type* of forecast error, supplied by the customer can be incorporated into a “go/no-go” recommendation; *customized forecast optimization.*

		Observed	
		yes	no
Predicted	yes	“hits”	“false alarms”
	no	“misses”	“clears”

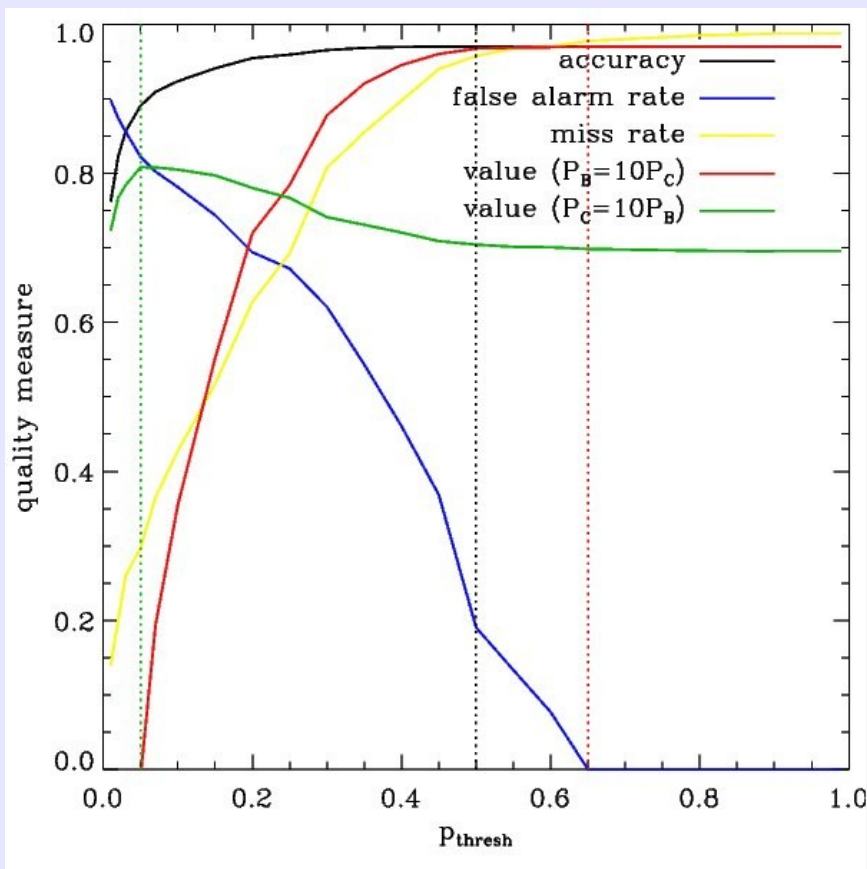
	$P_B = 0.1P_C$		$P_B = P_C$		$P_B = 10P_C$			
	observed		observed		observed			
predicted	event	no event	predicted	event	no event	predicted	event	no event
event	281	1298	event	17	4	event	9	0
no event	119	11267	no event	383	12561	no event	391	12565

Optimized for equal cost between false alarms and misses.

Customizing “Costs”

The “cost” of a particular *type* of forecast error, supplied by the customer can be incorporated into a “go/no-go” recommendation; *customized forecast optimization.*

Trends in value (skill score) for different optimization options as a function of the probability level.



		Observed	
		yes	no
Predicted	yes	“hits”	“false alarms”
	no	“misses”	“clears”

	$P_B = 0.1P_C$		$P_B = P_C$		$P_B = 10P_C$			
	observed		observed		observed			
predicted	event	no event	predicted	event	no event	predicted	event	no event
event	281	1298	event	17	4	event	9	0
no event	119	11267	no event	383	12561	no event	391	12565

Thank you.
Any questions?