

Discussion Notes

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Scribes: Anthony Mannucci, Xing Meng, Anna Kelbert. Assistance from Delores Knipp

Note: To encourage free communication during and after the meeting comments are not attributed.

A “priorities” survey was provided mid-meeting. The number of responses was about 18, less than the number for the original pre-meeting survey (about 51).

This document reports on three major Discussion Topics on Day 3 of the Chapman Conference Scientific Challenges Pertaining to Space Weather Forecasting Including Extremes

- 1) **How Understanding Leads to Prediction**
- 2) **Users**
- 3) **Meeting Outcomes**

1. Discussion Topic: How understanding leads to prediction

This topic, formally offered as “Understanding how understanding leads to prediction, how it does and how it doesn’t”, had the largest standard deviation (lack of general agreement) than other questions, and not surprisingly averaged a relatively low 3.6 out of 5 score. (The score scale was: 1-5, with 5 having the highest priority and 1 the lowest). We deliberately sought discussion on the responses lacking consensus, for which there was no clear consensus. This was to maximize ideas and discussion (and possibly fits the “transformative” idea where not everyone believes the same thing. It’s about questioning assumptions).

Prediction requiring understanding:

- Prediction can be made even without understanding, like machine learning, etc.
- Many people need only prediction, but do not care about understanding.
- Machine learning doesn’t solve all questions, we still need understanding.

If we simply want to predict, can we invoke magic (e.g., machine learning) and get there? Would we be happy with this result as a community? As scientists, we might not be. But our customers would be, possibly.

Machine learning (ML) can offer insights.

I don’t understand why do we need to invoke machine learning to solve all the problems.

What does “understanding” really mean? Is there a new form of understanding, like in the phrase “understanding to the point of prediction”?

The notion of understanding is changing. Some years ago all we needed were equations on the blackboard. If the data has enough information to produce the results, machine learning can extract it.

One of the centerpieces in our field is Living with A Star, and the phrase guiding that program is "Understanding to the point of prediction".

Physics-based understanding is not the only type of understanding.

But if we have a new form of understanding, maybe this LWS phrase needs to be rephrased.

The community and agencies are asking for "new forms of understanding". In the past, understanding and theory were synonymous. These days, much more detailed understanding is required.

We need to focus on this fundamental "grand challenge" science question: what will improve our ability to predict space weather?

Data and observations:

Data and observations are most important, without which we cannot do machine learning, cannot do prediction, cannot understand anything.

There is understanding, and there's data. Without data there's no prediction. The user doesn't care about understanding, they care about prediction. What requires more improvement: data or understanding? Or better models? It depends on what you want to predict.

E.g., if you want to better predict solar eruptions, you need better data (improved magnetograms). Or predict the CME arrival times at the Earth, or Dst.

An observational network is needed to improve understanding.

No prediction is possible without data. Should we focus on improved data or improved understanding? Hodge podge of user needs, time scales, physics. Different roles for data and for understanding.

We need data!

Yes, observations!

Observations have enormous value/impact. They can tell us where the instabilities are. Models have lots of diffusion so they don't blow up, and are therefore limited. We cannot "understand" without observation.

Embrace different approaches, more or less physics, applications or not.

Extreme events:

Physical understanding is necessary for one to do extrapolation to extreme events.

It appears that big storms have big effects, small storms have small effects. Machine learning does a great job most of the time but might be lacking for extreme events, which is where we need physics-based understanding.

ML is limited in the case of extreme events. On the other hand, extreme cases are the easiest to identify, and do not require sophisticated methods.

We need to re-think what the definition of extremes is. It cannot be based too narrowly on a particular index, etc.

Machine learning (also numerical models) should focus on forecasting general conditions rather than rare extreme events.

How to define “extreme event”? According to their features/intensity in the CME etc., or their manifestation on Earth, e.g. GIC...?

There was a separate discussion on Tuesday about our definition of extremes. We should talk of the response of the Earth’s system. Need to be specific to an aspect of space weather program.

One of the reasons space weather is on the national register is extreme events. So they are really important from the users’ point of view.

Machine learning:

Machine learning is not a black box, it’s a mathematical tool, and an extension of human learning

Machine learning is really dumb in a way. If you can’t feed the machine a million examples of your problem and solution, it won’t work.

Coming back to the point that machine learning can’t do everything, I would challenge physics-based models to do that. People seem to think machine learning is black magic, but it is just math. In fact, it’s just an extension of human learning. Just like a forecaster uses experience to make a decision, the same is true for the computer. But there are other things that the computer cannot do as well yet.

I think we're talking of deep neural networks here when we say machine learning.

Agree that machine learning couldn't forecast extreme event or anything else that isn't in the training set. But why this emphasis on extreme events? Any human forecaster would immediately recognize a Carrington event if they see it. Machine learning is better used on an everyday basis.

General considerations:

- How does space weather compare to meteorological weather?
- Which is of higher priority: data/observation or numerical models?
- All clear forecasts are also of great importance.

There aren't many forecasters here, or users. If we're trying to understand what would be useful, we should try to bring these people in. Perhaps they don't care as much for extreme events, but instead for fundamental understanding, also.

Understanding vs prediction without having understanding (such as machine learning).

What kind of users does space weather have? Geophysical surveys, radiation. Short-term forecasting. Might need to invest more in the model for that. For a three-day forecast, need to invest in the data, first.

This priorities survey is confusing, just like having a thousand dollars to distribute between everything.

Suggestion: instead of priorities, you are given \$1000. How would you spend it – on which topics and how much?

2. Discussion Topic: Users

This topic arose as an 'organic' discussion in post-presentation, comment-and-question intervals and during other facilitated discussion sessions.

General discussion:

Without hearing users' voice on what they need, we'd be shooting into the dark.

Interaction with users can help to deepen science understanding (e.g. the way on how to calculate the Kp index).

Scientists need users to do validation of their models.

Earth warning system is what many users need.



There aren't any users here. We should talk to users to discuss this.

This is incredibly important. We need to know who our user base is. We need to know that what we're providing to them is useful. That requires some back and forth and interaction.

R2O (research to operations) experience at SWPC to transition space weather modeling framework. After sitting down with SWPC and getting into the details, came back with much greater understanding. Welling indicated he enjoyed working with forecasters. Users don't like to talk with scientists.

It's important to understand who our users are. Michelle Cash's talk was very illuminating. She is talking to the users directly and is the user for the models.

Over the years we built a very good attendance at the European space weather week. I'd be nervous about losing contact with the users because then you're relying on SWPC or the Met Office for that interaction.

Understanding the value proposition is most important in any business relationship. We need to understand what businesses want from us. We need their validation. We were not making progress with science transfer to SWPC until people spent time and understood the requirements. In user interactions, the "value proposition" is paramount. We need to understand this, and have advocacy.

I enjoy studying space weather, but I also feel an obligation to be useful. It doesn't take that much more effort to be useful to the people who worry about space weather. But there's a communication problem. Sometimes we're not addressing the questions that are useful to the user side. We should focus research in these areas.

Scientists have a particular view of what "prediction" is, and it may be quite distinct with how users view it – a huge challenge.

We cannot lose contact with users. We need real [effective] interaction.

CSEM experience (Center for Space Environment Modeling): relatively less progress in transitioning to SWPC until people really focused on this specialized activity.

A coronal hole is coming. There is an earthquake analogy. Warning is useful and needed.

I feel an obligation to be useful. Communication problem. Need to connect with users 1-1. This helps to focus research.

Nowcasting also a key user need. Specification. Context for anomaly resolution. Understanding extreme variability and situational awareness. An archive of past measurements they can access.

Need benchmarks and [garbled] codes.

Users need tools for forecasting applications, packaging for forecasting, what are best operational practices?

We all have diverse ways to achieve understanding.

What do users want? A range of things. Not all users want predictions. Some want climatology (for design purposes). What are the major disconnects on user side?

Issues with scientist-user interaction:

Not every scientist needs to interact with users.

People should know and do what they are good at (science, predictions, ... should be done by different people)

Scientists should focus on identifying the big science challenges facing space weather (and how to solve them?)

Do scientists have to hold responsibility for their prediction?

Do scientists have to feel obliged to be useful to the society?

I think it's important to understand what the end users need, but I don't think that everybody in this room needs to interact with the users. That takes a lot of very special effort and creates distraction from good technical development.

Grand challenge in "prediction" vs. grand challenge in individual domains (sun, interplanetary space, terrestrial space, atmosphere)

Interaction with users is important, we all agree. Whether or not they want to interact with us, is different. But the grand challenge is a far better route to go here. Vastly different regimes of space physics that we're all coming from is a challenge to us. How do we tangibly and practically bring these different parts of space physics together to start addressing these problems.

Grand challenge related to prediction is different from that of fundamental understanding. Is there such a grand challenge? I believe, yes. Multiple. And they are all different, need different data and tools. Maybe that could be our next topic.

My plane is passing through Greenland, but the airline authority doesn't care that there's a coronal hole coming. What if a major space weather event happens? Are we responsible then? In Italy, seismologists were imprisoned for not providing a warning about an earthquake. If SWPC tells them that there's a KP6, my airline won't do anything different. The question of responsibility. Extreme is something that has bad consequences. Are we going to be pressed for not understanding an extreme event that's imminent?

Problems: lots of scientists do not need to interact with users. A user focus can detract from good work being done. The conclusions really depend on who is in the room.

Many users don't want to reveal their problems to scientists.

Companies don't disclose details. That makes it harder to understand what the users want.

I used to attend the space weather meeting. Now it's mostly users and few scientists, and most users don't want to talk to scientists, because all details are proprietary. Companies want to provide space weather services and make money. There is a need for intermediary. E.g., satellite operators don't want to tell anyone what their problems are, and for a good reason, to avoid competition. All this isn't appropriate for a Chapman conference.

This meeting is not the venue for this discussion. Grand challenge science questions can be discussed here. Space weather workshop is all about the uses of these results.

3. Discussion Topic: Meeting Outcomes

The final topic of discussion was meeting outcomes: what can and should be accomplished. Although Friday afternoon was planned to be devoted to outcomes, there was a recognition that the meeting would start thinning out by then, so it was felt that introducing the topic on Thursday afternoon would provide valuable inputs.

Importance of observations:

Emphasize the importance of data and observation, which are needed to drive everything, including the assessment of model performance.

It's the first AGU Chapman meeting I ever attended. Been in this field for 30 yrs. There are only 2 companies here. Ok, 3. I think a consensus in this community, and a consensus between the users, is that the data, observations are critically needed. What kind of data sets would move forward the modeling, both for physics-based and machine learning, is a key discussion to have.

What kind of observations are the most impactful? We should approach this problem systematically. There are committees that do just that. What we need to observe are the dynamic areas, sources of error and instability. Operational centers don't like these areas, they want everything to be stable, and they are therefore not observed.

We should also think about nowcasting, characterizing the storm as it's going on.

Observations are necessary not only for prediction, but also for understanding. You have to prepare the initial state of your model properly before you can understand what is happening in the real world.

A new paper would be: are historical indices (not invented with users in mind) the right measures? We need ties to a new data infrastructure.

Numerical modeling:

Numerical models alone are not sufficient for us to understand the physics.

Need to document the availability of models, codes, and know-how on how to transition physics models to operational use.

For outcomes, we should document the current state-of-the-art in the modeling, what are they capable of and what is operational at the moment. Document all the space physics packages that are available (paper published) to describe the landscape for the open-source or open-to-use codes and their status. Another summary was metrics for space weather. Getting a landscape of what models are out there, how to get them and what they're trying to get at. R2O lessons learned best practices would also be useful.

Extremes and Engineering:

Someone should write a paper on the definition of extreme. Broadening the definition of what "extreme" means is an outcome of this meeting.

Understanding the extreme variability that we're going to experience, e.g., during engineering a spacecraft, would be valuable. So not only space weather but space climate.

Also, situational awareness is important. It's all about what the user needs. Not just about prediction.

Forecasting is a lot more than predicting the next Carrington event. We need to characterize the space weather environment, and not doing so would be a loss, and disservice to the community. Whether it's GICs or radiation, we need to understand whether our measurements are adequate. When we talk about predictions in SWPC, when it comes to understanding extreme events we have different needs from predictions. Can we trust their predictions for the kind of things that are going to happen? Not necessarily to get the timing or the details right.

Paper needed: definition of extremes. Wide range of meanings. Broader definition needed. G1-G3 is actually really hard to forecast. G3 are impactful also!

Don't just focus on Earth-bound CMEs. There is more data out there, e.g. STEREO.



Predictions at SWPC: someone will use them. Can we trust them for extreme events? SWPC does not have a picture for extremes. Extremes for user very different than for SWPC.

G1-G3 level events are actually more difficult to forecast than dramatic events

Prediction is not everything. Possibilities are: prediction/forecasting/nowcasting/anomalies.

Space weather vs. space climate.

Forecasting should be able to forecast a whole spectrum of events, not just Carrington-like extreme events.

Recommendations/Agencies:

In terms of outcomes, I've been most impressed listening to these talks. The beauty is that there are so many different facets to it, and everyone should work in their own comfort area. There's space for all of us to participate in our own way.

Yes, but here's my concern. NASA as an agency will pay for scientific knowledge and understanding. They will not pay for a heuristic tool. There are a lot of different passions in this room, but how do we all fit this into a paradigm?

The science community should learn how to push back agency's policies.

Publications:

"Methods and challenges in space weather forecasting" is suggested topic for the special issue. G1-G3 storms are hard to forecast accurately.

On the outcomes. The only thing we do as scientists is write stuff. The outcomes would be useful if they have new, tangible ideas. Let's for the last few minutes focus on that.

To obtain outcomes from this meeting, could use domain expertise in the room, to address one of the topics that were voted as important. A candidate would be the time and spatial scales for different processes and whether or not they are currently adequately characterized, thereby documenting the state-of-the-art in the space weather forecasting. That would require a focused discussion on such a topic.

A new paper will emerge by tapping into domain expertise across domains. This is new.

A paper like: "Methods and Challenges of Space Weather Forecasting"

Provide open access documentation of the meeting.