The Aurora Borealis as a Space Hazard

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KEY POINTS

- **The production of the Aurora Borealis via solar storms creates many problems: disruptions to electrical grids, interference with satellite and communication signals including GPS and rail networks, aviation, space exploration and much more.**
- **To avoid these issues, it is useful to use models to forecast the presence of solar storms and the aurora to manage situations accordingly and reduce the risk of major impacts.**
- **But we set out to discover; how well do the models we currently use actually work? Do they effectively predict where and when solar storms and the aurora will take place?**

1. HOW AND WHY DO WE MODEL AURORAL FORECASTS?

$$\frac{d\Phi}{dt} = v^{\frac{4}{3}} B_T^{\frac{2}{3}} \left(\sin\frac{\theta}{2}\right)^{\frac{8}{3}}$$

THE COUPLING FUNCTION

There are a number of models which can be used to forecast the aurora - the one we used is called the OVATION-Prime 2013 model and is parameterised by estimated levels of solar wind coming towards the earth. In essence, this means it used solar wind data to predict when the aurora may appear in the atmosphere. It's aim is similar to that of our normal weather forecasting systems on earth; it predicts when certain weather conditions, like solar storms may occur so that we can act accordingly. The Dungey Cycle and atom excitation are what cause the production of the aurora, so there is a clear correlation between the amount of solar wind coming in towards earth compared to the appearance of the aurora - a pretty sight if you're in the right place on earth, but a process which can cause also significant problems, as described in the key points section.

The model works by measuring particles entering the atmosphere over the course of about 20 years and averaging the measurements over different solar storm periods. It also uses the *coupling function* shown above which combines a number of variables observed in the solar wind used to predict the effect that solar wind will have/has had on the magnetosphere and environment. This allows us to predict the impact that solar wind may have (given a number of variables recorded by satellites) so that we can mitigate risks of potential damage accordingly.

2. FORECAST VERIFICATION: HOW WELL DOES THE MODEL WORK?

TRUTH TABLES:

- A truth table is used to assess the combinations of two outcomes from a set of input data. In this case, we are comparing whether auroral forecasts match with actual observations to see if the model we are using provides **accurate** and **reliable** results.
- If the aurora is forecast and observed, it's a ***hit***, if it was forecast but was not observed, we call is a ***false alarm*** etc.

		Was the aurora observed?	
		YES	NO
Was the aurora forecast?	YES	A = Hit	B = False Alarm
	NO	C = Miss	D = True Negative

SOME EXAMPLE TEST STATISTICS (SKILLS SCORES):

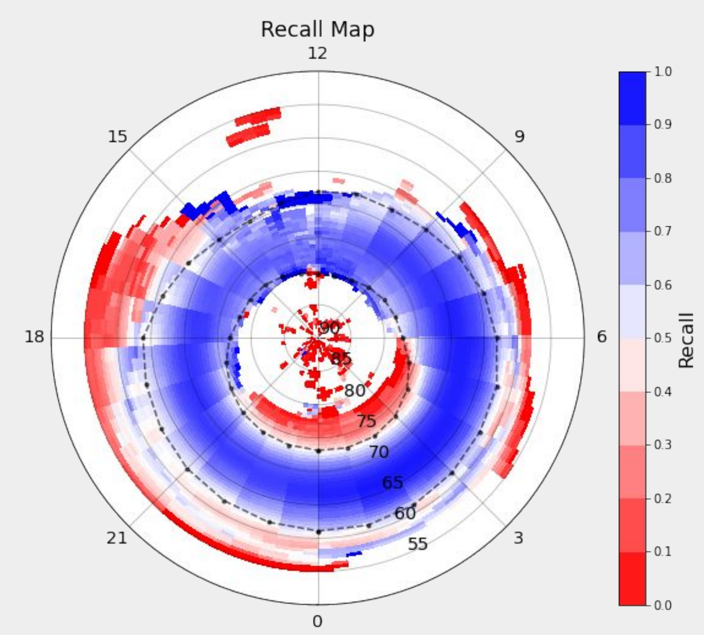
$$Hit\ Rate = \frac{A}{A+C}$$

$$Accuracy = \frac{A+D}{A+B+C+D}$$

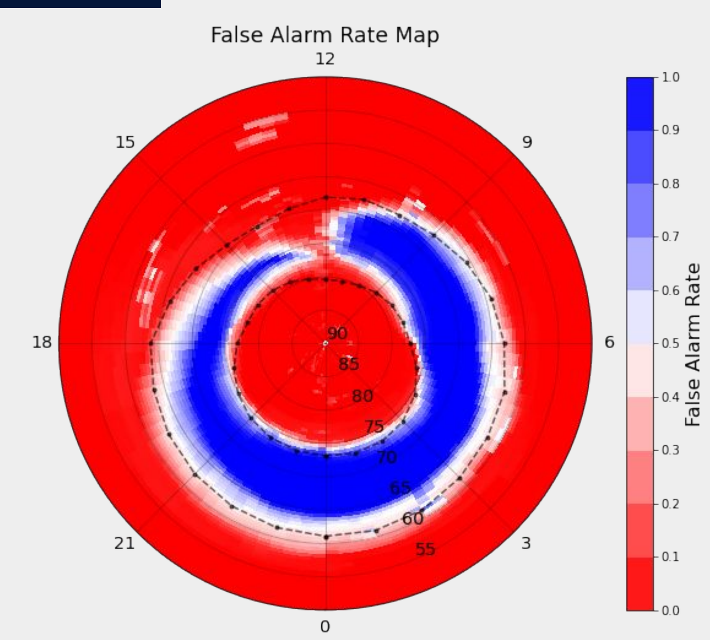
$$False\ Alarm\ Rate = \frac{B}{B+D}$$

- By using the 'skills scores' formulae above, among many others, we began to evaluate the accuracy of our model by calculating how often it correctly predicted whether or not the aurora would appear (A and D) and also the number of incorrect forecasts (B and C), where the forecasts and observations did not correctly match.

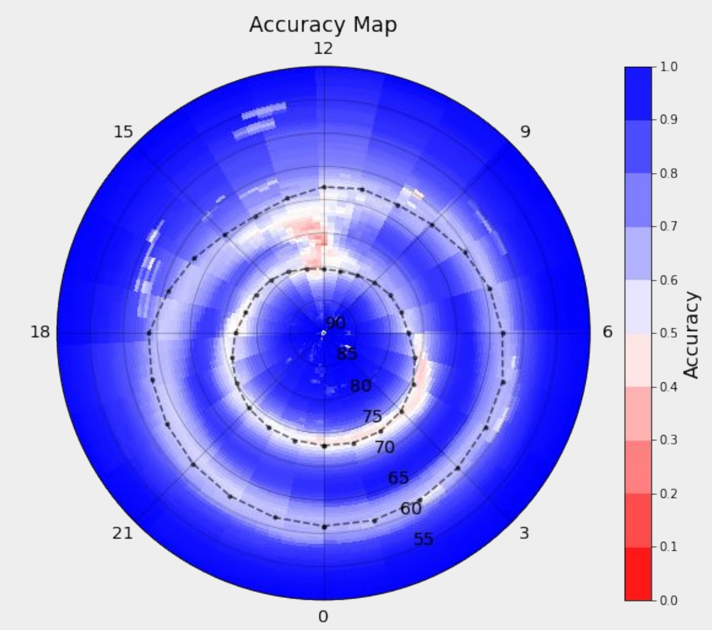
3. REPRESENTING OUR DATA



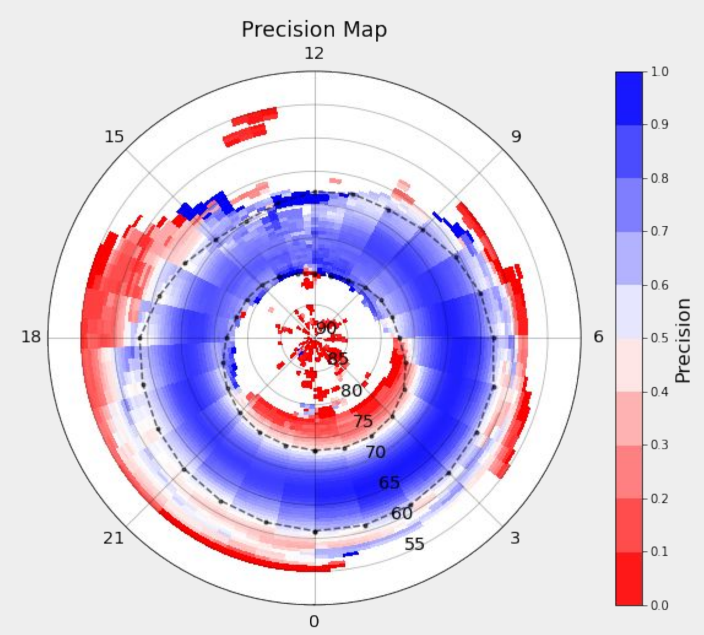
HIT RATE



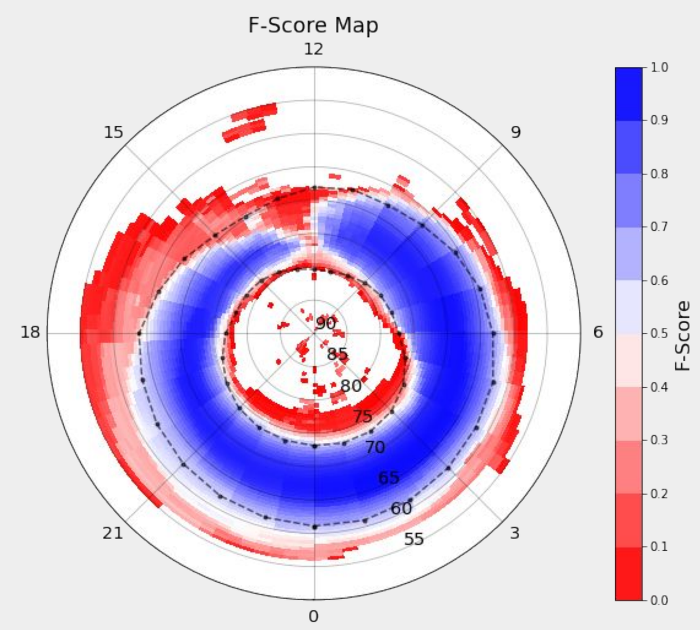
FALSE ALARM RATE



ACCURACY



PRECISION RATE



F-SCORES

*If you compare our *accuracy* and *false alarm* map you may notice a contradiction. The accuracy map seems to imply that the model is correctly predicting the outcomes, but the false alarm rate map seems to display a high false alarm occurrence (which implies it is consistently forecasting the aurora and not getting it right). On paper this would indicate that our model isn't reliable, however once you compare these maps against the other visualised data from the truth table we can see that the problem actually lies with the way the false alarm rate is calculated. In the areas where the aurora always occurs, true negatives don't occur and since the false alarm rate is a ratio between that of false alarms and true negatives(value of zero), this effectively makes it a 1/1 ratio, even when minimal false alarms occur, and so "improving our model" would have minimal impact on the misleading data

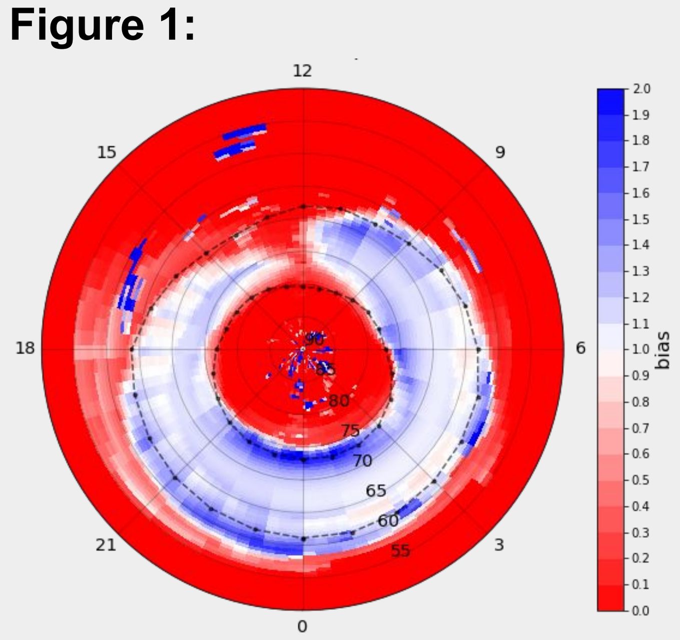
4. LOOKING IN DEPTH AT THE BIAS SCORE

A skills score measures the accuracy of a forecasting model. More particularly, the *bias score* measures the ratio of the *frequency* of forecasted events to the *frequency* of observed events.

- If the value of BIAS > 1, there is an over forecast; the aurora happens **less often** than predicted.
- If the value of BIAS = 1, observations **perfectly** match the number predicted
- If the value of BIAS < 1, there is an under forecast; the aurora happens **more often** than predicted.

Figure 1 depicts the bias score of our model. The **red** areas show an underforecast and the **blue** areas indicate an over forecast. The **white** areas show where the number of forecast events predicted by the model closely match those observed.

Figure 1:



$$Bias = \frac{A+B}{A+C}$$

5. CONCLUSIONS

After gathering data about predicted auroral forecasts and cross referencing it with observed events, we were able to evaluate how well the OVATION-Prime 2013 model works. Observing the data collected within our 'donut-shaped' area of activity enclosed by the black dotted lines on all of our maps, allows us to conclude that, on the whole, the model **does work effectively,** and can be used to help reduce the risk of major events on earth linked to solar storms and the aurora. Our conclusion is based on the following:

- The *hit rate* and the *precision rate* are both high showing an encouraging number of correct forecasts
- The *accuracy* was also high in our areas of interest so the auroral predictions matched the observations
- *False alarms* were also low, meaning there where few predicted events which did not actually occur*
- The *bias* score has a pretty perfect result showing that the predicted hits often matched observations

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