A Parameter Constraint Algorithm for the Generation of "All Clear" Forecasts of Equatorial Scintillation using Radio Occultation Data

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Outline

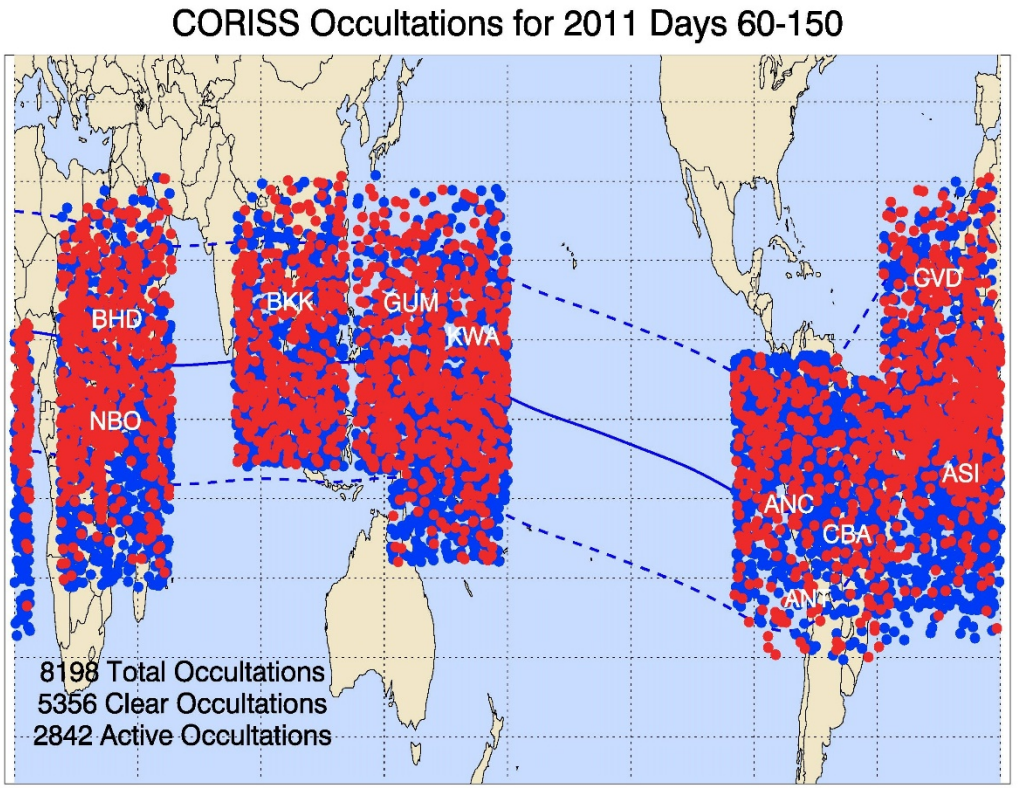
- Overview of Spread-*F* scintillation forecasting.
- Radio Occultation (RO) and ground data used in this study.
- Tangent Point Analysis (TPA) for “All Clear” predictions.
- What is Parameter Constraint Analysis (PCA)?
- Examples of PCA for active and quiet occultations.
- A visualization of PCA forecasting.
- A case study validation of PCA for “All Clear”
- Application of PCA to COSMIC-2 simulations.

Forecasting of Spread-*F* Scintillation

- Spread-*F* scintillation is an equatorial space weather phenomenon that impacts transionospheric communications and navigation.
- Forecasting models have been developed based on ground station monitoring but these are limited in geographic coverage.
- The measurement of scintillation during LEO satellite and GPS occultations has the potential for worldwide forecasting.
- The specification of Spread-*F* is complicated due to imprecise knowledge of the location of the irregularities in the RO FOV.
- The generation of an “All Clear” forecast is a simpler problem because a clear RO indicates the lack of scintillation in the FOV.
- In this study, we report on a Parameter Constraint Algorithm which allows us to model the clear region of non-scintillating RO’s based on simple empirical assumptions.

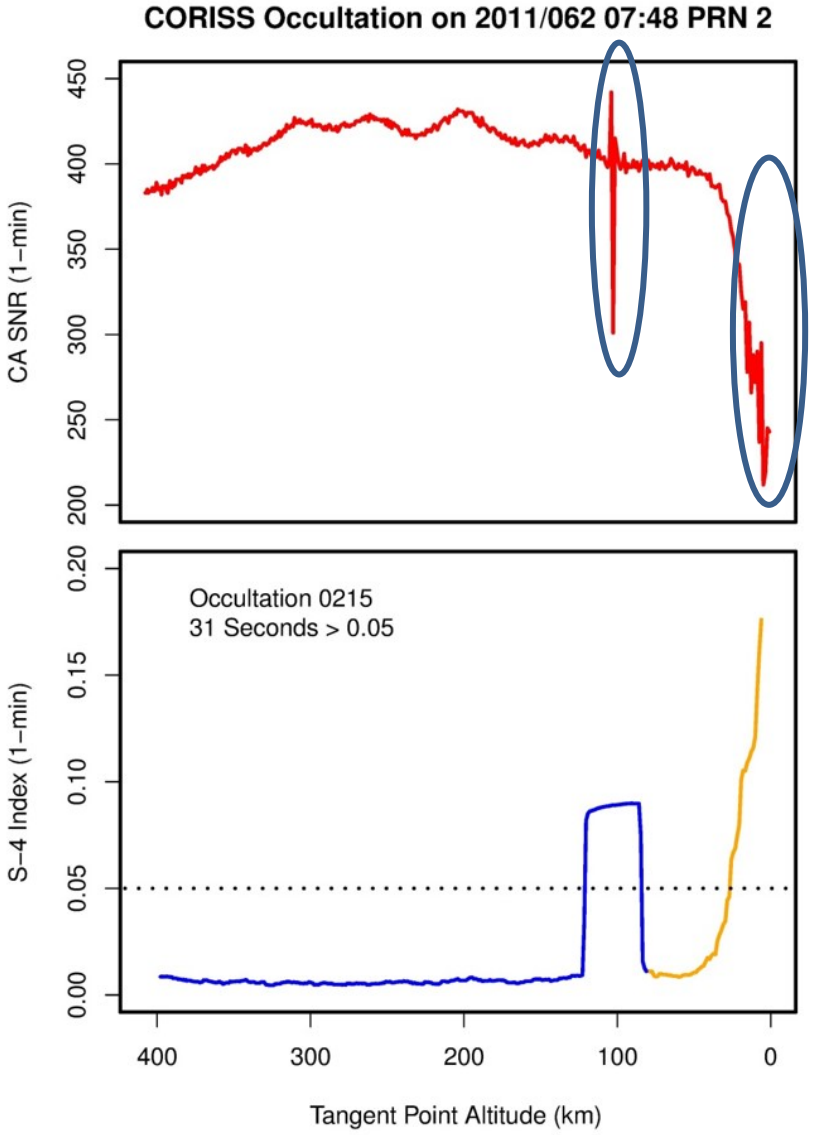
The RO Data Set for 2011

- RO data was obtained from Aerospace for two 90 day periods.
- The plot below shows the 350 km Tangent Point (TP) for all occultations from the March through May 2011 data set.
- The blue and red dots indicate quiet and active RO's based on an S_4 threshold of 0.05.
- So far, we have confined our PCA work to this data set for which the SWO SSN is 74 (solar moderate conditions).
- The 2009 data set is at solar minimum, which is less challenging for PCA.

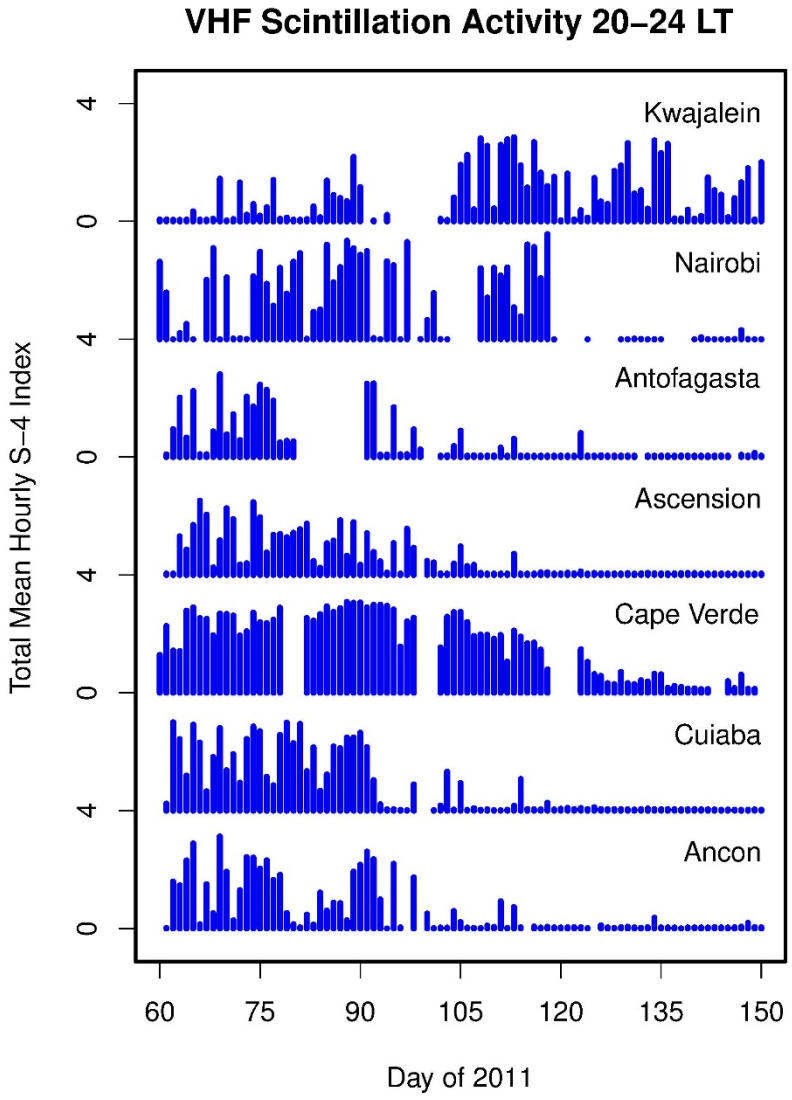


RO Data Considerations

- This plot shows the L1 signal strength (top) and the S_4 value (bottom) plotted as a function of the tangent point altitude.
- We filtered out the atmospheric effects shown in the rightmost oval by excluding data when the TP altitude was less than 80 km.
- The feature in the leftmost oval is apparently an *E*-Region effect as it occurs around 100 km.
- We excluded the perhaps 5% of occultations showing this feature.



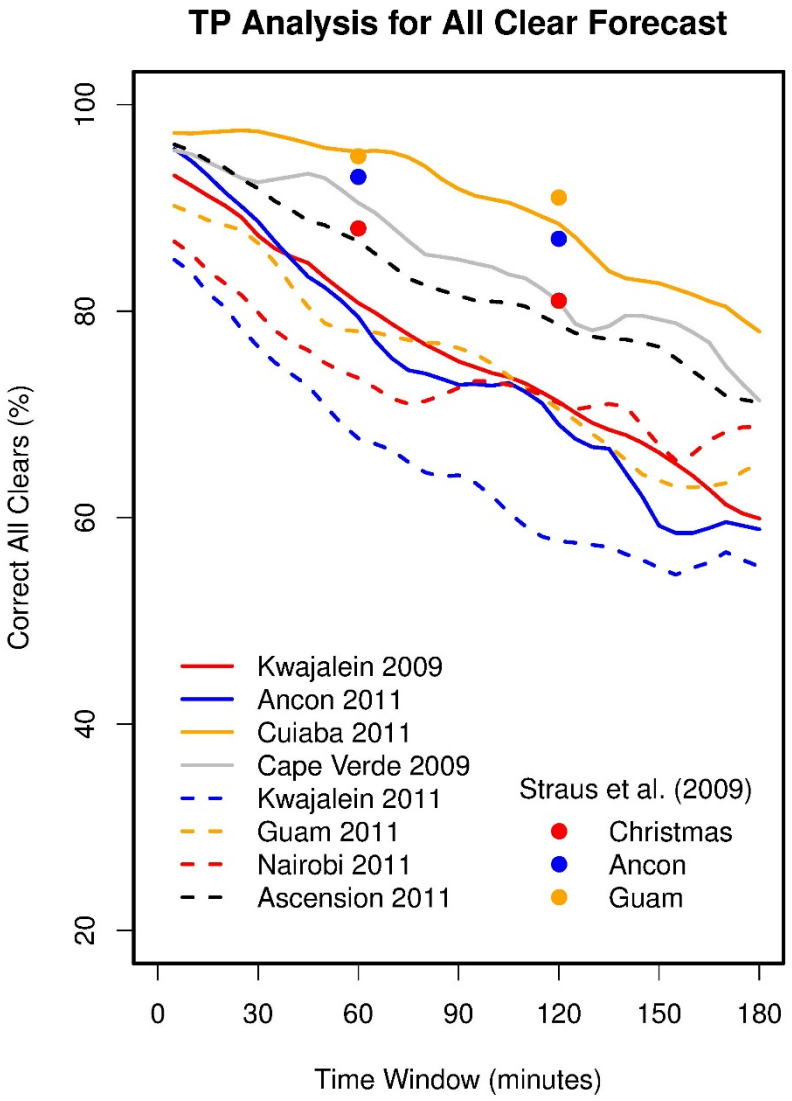
The VHF Ground Data



- This plot shows a measure of the scintillation as a function of day for seven stations.
- These are some stations for which we have corresponding RO's.
- We note here the seasonal behavior of scintillation, which is different at different longitudes.
- We limit our PCA validation here to the five stations on the bottom.
- Except for Cape Verde, which is anomalous, the bulk of the scintillation comes in March.
- This is important in what follows.

Tangent Point Analysis for “All Clear”

- One way to look at this problem is through TP Analysis.
- Here we take all clear RO’s within 5-deg of a station.
- We then ask whether the station detects scintillation within a certain time window.
- This gives us a fraction of correct “All Clear” predictions.
- We include here results of other workers on the C/NOFS RO’s.
- At 2 hours out, we see that the average correct ratio is 75%.



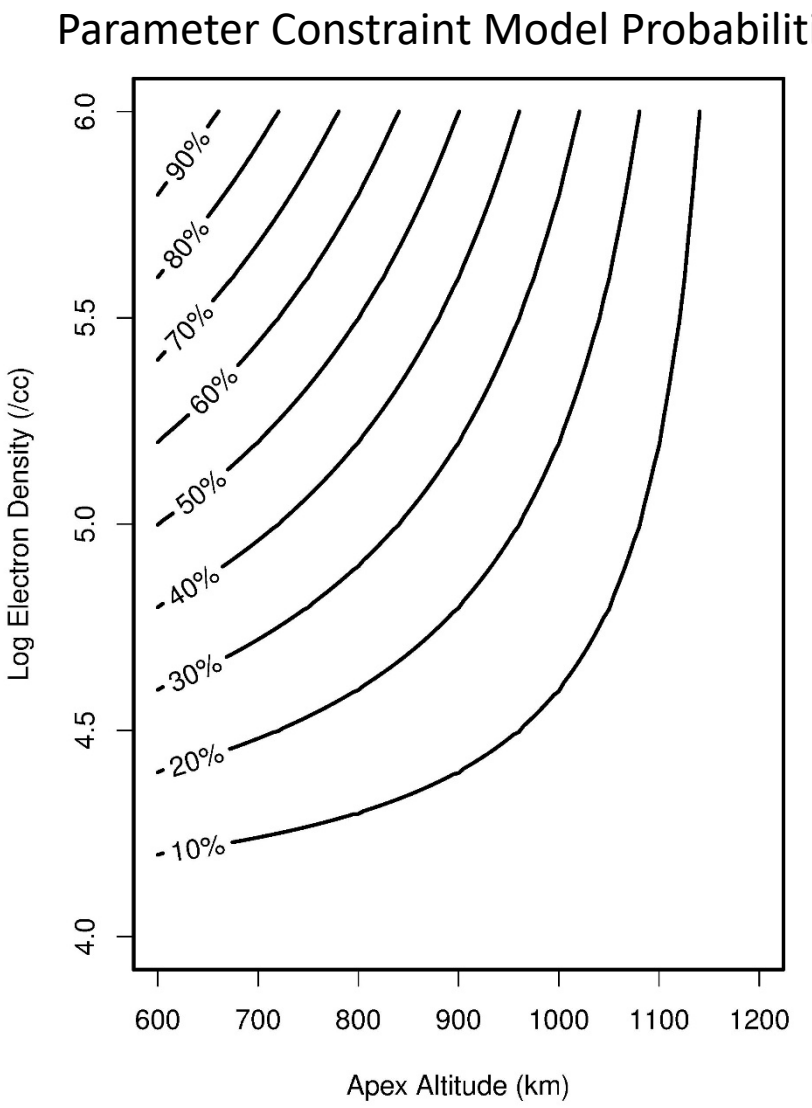
TPA and Season and Solar Activity

- This table shows the success rate averaged over several stations during various time periods two hours after the occultation.
- A two hour prediction goal seems reasonable in consideration of the fact that COSMIC-2 will have at least a 30 minute data latency.
- The numbers are highest at the solar minimum 2008-2009 (86%).
- They are lowest when we consider only in-season data (50%)

"All Clear" Success Rates from Tangent Point Analysis		
Time Period	Source	Success Rate
2008 to 2009	Straus et al. (2009)	86%
March - May 2011	This Work	73%
March 2011	This Work	50%

- This makes sense as it is easier to get an all clear condition when scintillation is infrequent.
- We want to challenge our TPA analysis, so we restrict our validation study to March 2011.

What is Parameter Constraint Analysis?

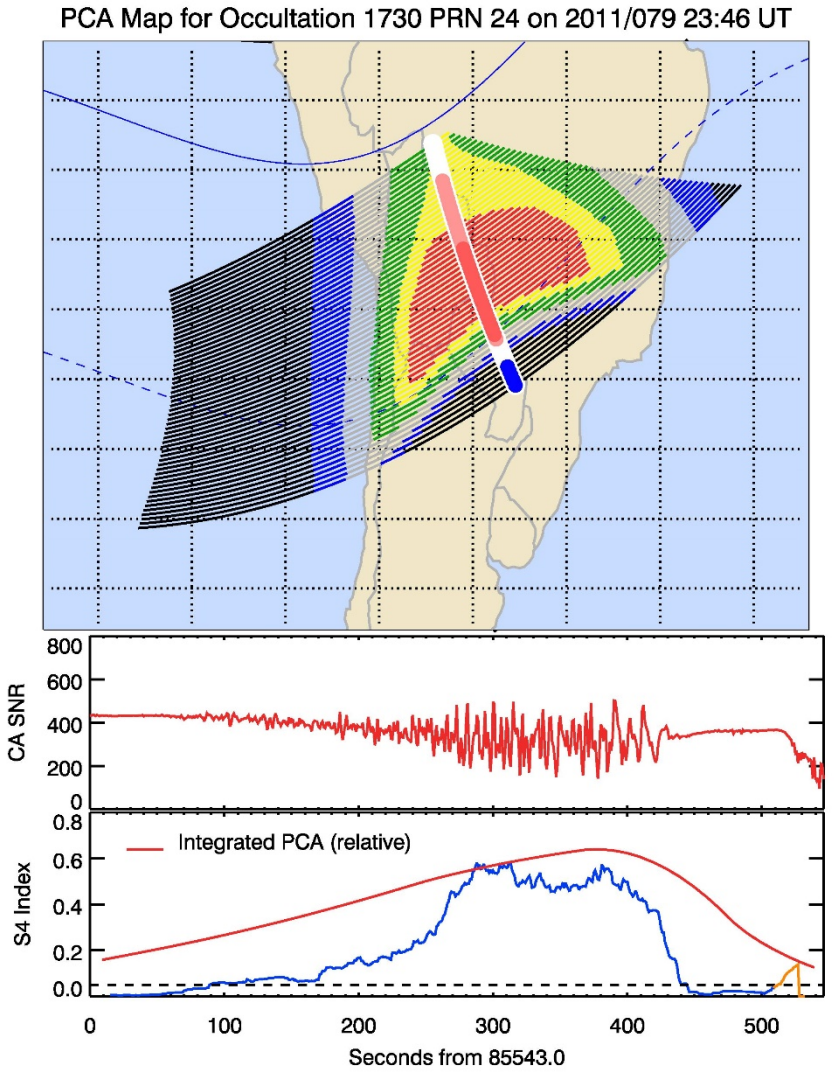


PCA is essentially an attempt to define within an RO FOV where we would detect scintillation *if it were present.*

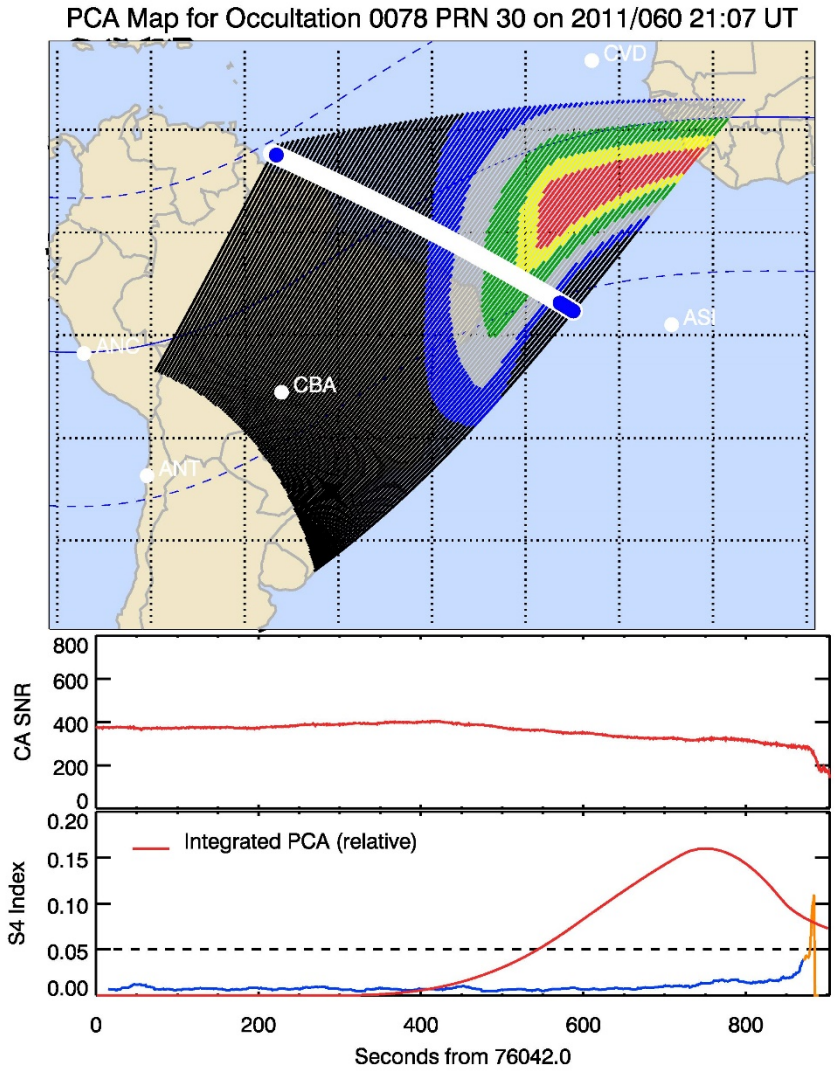
- We do this by combining empirical functions depending on plasma density and on apex altitude.
- This results in a "percentage" which delineate regions where scintillation can be detected by an RO and where detection is unlikely.
- This allows us to define a region which ought to be "all clear" when the RO is quiet.

PCA for a Scintillating Occultation

- This plot shows the PCA levels for an active RO which are colored according to the PCA probability.
- The thick line is the tangent point like, which is colored red to indicate the ray paths where scintillation is measured.
- We can see that PCA is effective in defining the location in space where the detection of scintillation is likely.
- We see this because the scintillation is within the “red” and “yellow” regions.



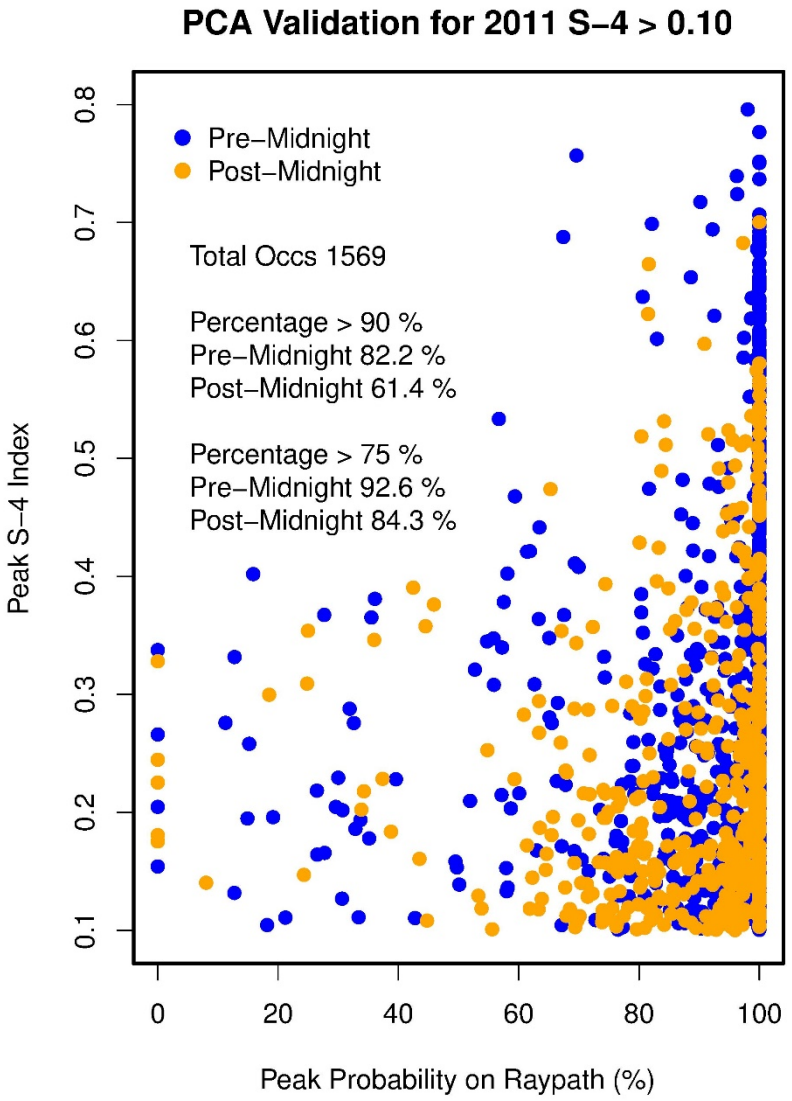
PCA for a Quiet Occultation



- It follows that, for an RO where we do not detect scintillation, the region defined by some PCA level will likely be free from scintillation.
- In the quiet RO illustrated here, if we pick “yellow” as our PCA threshold, we would predict that scintillation should be absent over the Atlantic.
- So, this is the simple idea of PCA.
- We ask in what region scintillation would be detected and, if none is in fact detected, we declare this region “all clear”.

A PCA Threshold

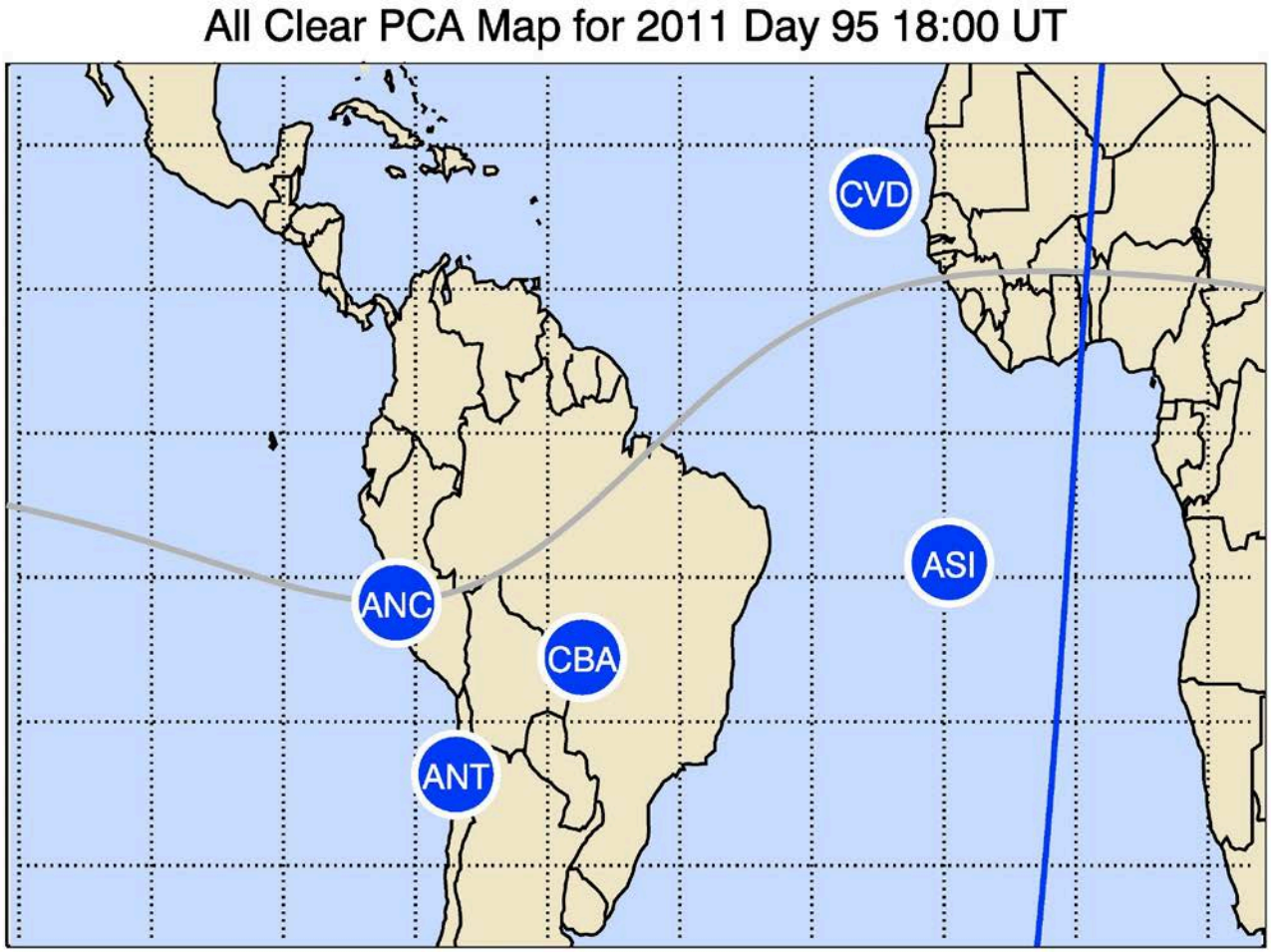
- We have puzzled over what PCA threshold to pick for defining an “all clear” area.
- To investigate this, we have made a scatter plot of the S_4 measured in the RO against the peak PCA calculated along the ray path corresponding to the S_4.
- Our results show that about 90% of the scintillating ray paths have PCA levels above 0.75.
- So, we have tentatively selected the 0.75 PCA level as “all clear”.
- As we examine more validations, this number may be adjusted.



A PCA Visualization

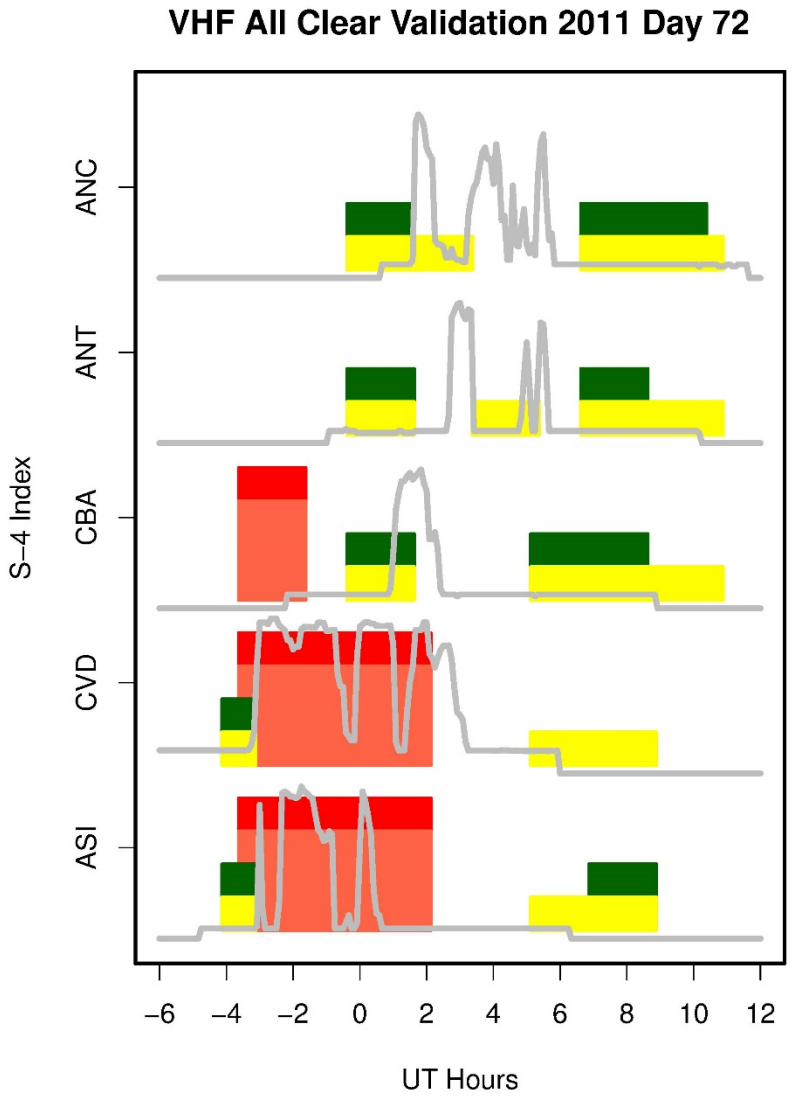
- The following is a animation of the PCA “patches” for an evening over the South American and Atlantic sector.
- In these slides, we have colored the quiet occultations “green” when the PCA exceeded 0.75 and “yellow” for PCA over 0.50.
- For scintillating occultations, we use dark and light red.
- We have allowed the patches to remain for two hours.
- The ground stations light up in “red” when scintillation is present.
- We should remember that the “red” patches do not necessarily represent scintillation at the stations due to geolocation uncertainty.
- We should also mentally follow the patches all along the field lines (perpendicular to the equator) to the conjugate points.

A PCA Visualization



A Validation Case Study

- We have carried out a validation of PCA on 10 in-season nights.
- Here we trace field lines from the boundaries of the PCA regions to the equator and compare these to the station apex longitude.
- If the station apex is within the “green” PCA region, we issue an “all clear” for this station and this time.
- This plot shows the results of the RO predictions compared to the ground data for one day.
- Only the “green” blocks shown here are “all clear” predictions.



Validation Results for Our 10 Nights

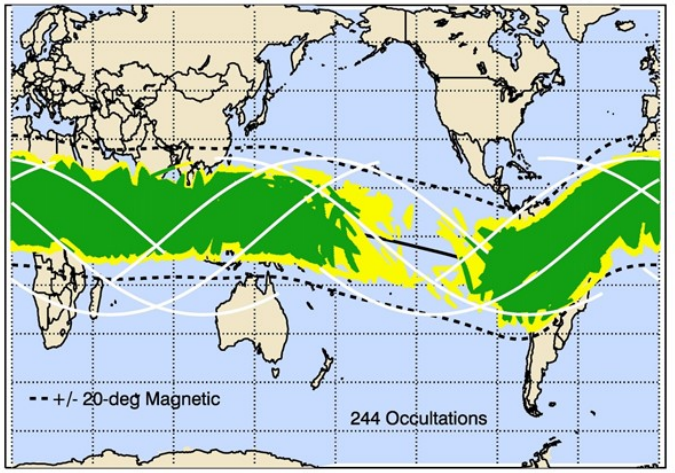
- This table shows the results of our “all clear” predictions for the 10 nights considered.
- As indicated earlier, these nights were selected from the in-season data for the South American and Atlantic sectors.
- We can see that we correctly predicted “all clear” conditions in excess of 90% of the time.
- This compares favorably with the 50% or at most 75% correct using the simple tangent point analysis.

2011 Statistics on “All Clear” Predictions				
Case	Night	Total	Correct	Percent
1	60/61	192	180	93.8%
2	63/64	48	39	81.2%
3	65/66	68	58	85.3%
4	96/97	224	224	100.0%
5	72/73	42	40	95.2%
6	71/72	104	100	96.2%
7	92/93	152	128	84.2%
8	93/94	132	118	89.4%
9	66/67	106	96	90.6%
10	95/96	144	127	88.2%
Combined		1212	1110	91.6%

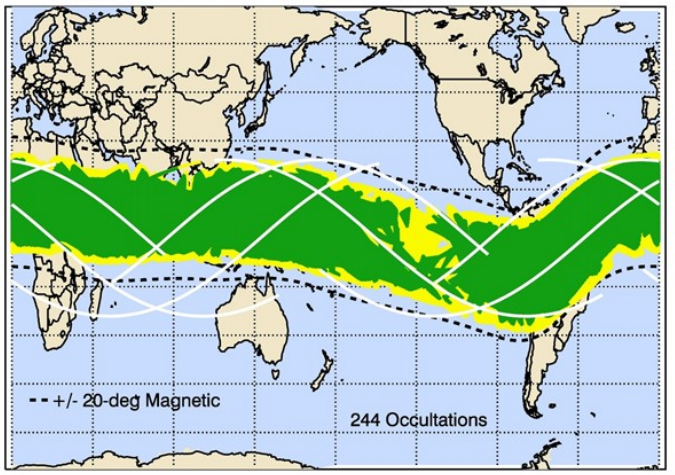
COSMIC-2 Simulation Results

- We have carried out PCA calculations using simulated COSMIC-2 occultations.
- These plots show results for solar minimum (top) and solar moderate (bottom) conditions.
- We see that there is a “hole” in the PCA coverage at solar min.
- We find that this will limit the PCA coverage after about 0200 LT.
- This is not too limiting as this local time has less scintillation.
- We should have no problem predicting all night at solar max.

PCA Map 13-14 UT but for March 2009 (GPS Only)



PCA Map 13-14 UT but for November 2011 (GPS Only)



Summary

- We have developed an algorithm with which we can predict regions of a radio occultation where we would not expect Spread-*F* scintillation to be present.
- This method uses empirical constraints that show us the regions where scintillation would be detected if it is present.
- If this particular RO is quiet, then we can predict that this region is “all clear”.
- We tested this method on 10 days of data in a solar moderate period an obtained a success rate of around 90%.
- This compares favorably to using Tangent Point analysis.
- Our next goal is to expand the validation using more data and different regions.
- This effort will allow us to refine the PCA “all clear” model.

Thanks for your attention.

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