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Isolation of ionospheric events in GNSS phase scintillation observations

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Abstract

When providing space weather alerts or basing a scintillation model on actual data, the features of the data must be related to the effects of space weather. This can be difficult for scintillation indices where other events such as interference or oscillator issues can result in high phase scintillation values that are not space weather-related. For real-time space weather alerts to be valuable, taking precautions against high scintillation values caused by processes other than space weather is crucial before issuing alerts. In an alert set-up, a real-time event distinction could make the user aware of whether disturbances are space-weather-induced or not. Similarly, a distinction between the origin of extreme phase scintillation values in the database of a scintillation model could affect the integrity of the model. Both cases require a method for separating data according to whether or not it is space-weather induced. In this paper, two methods for evaluating the origin of high phase scintillation index values are examined and their use in tandem is discussed.

1. Introduction

In GNSS based space weather research, the phase scintillation index σ_ϕ is used as a measure of signal phase fluctuations [1]. These fluctuations can severely affect users of GNSS services, and users therefore must be aware of these impacts [2].

The σ_ϕ index follows a skewed distribution with few extreme values. This means that even large datasets will provide significantly less data for studies of extreme events, and these can therefore be underrepresented in statistical studies. Meanwhile, extreme values can also arise from non-space-weather-related sources, e.g. local interference and oscillator issues. Therefore, it is crucial in statistical studies of extreme events and input data for statistical models to ensure that extreme values are related to space weather. This paper presents algorithms to distinguish between interference, oscillator issues and ionospheric phase scintillation. The purpose of this work is to allow the correct distinction of genuine ionospheric events so that they can be used reliably in geophysical research studies.

2. Method

The study is performed with one year of GPS and Galileo scintillation data from 2022 collected at two GNSS stations in Greenland equipped with PolaRx5S scintillation receivers [6]. The stations are located in Kulusuk and Qaqortoq with geographic coordinates (65.5755, -37.1703) and (66.9956, -50.6202). These stations were chosen since the data from Kulusuk exhibited interference events during the year 2022, and both stations are within the auroral region suggesting that they will both experience increased σ_ϕ values related to space weather. Further, both stations are stationary and are installed as part of a space weather research project, ensuring that the station sites are selected to limit the probability of multipath.

The data from the stations is transmitted in ionospheric scintillation monitoring record (ismr) files which contain the phase scintillation index, σ_ϕ, used in the study. The main objective of the study is to determine methods for identifying different types of events that lead to increased σ_ϕ. The study will investigate two different methods for identifying phase scintillation events, Method 1 and Method 2. The two methods are intended to be used in tandem, Method 2 is faster and can perform categorisation based only on σ_ϕ from two frequencies, while Method 1 uses multiple data types to identify the origin of the increase in σ_ϕ. The two methods are presented below, starting with Method 1.

Method 1 utilizes simultaneous data from all visible satellites above 15 degrees and data from the preceding data files. The basis of the model is summarised in the following bullets:

- If there are N satellites in view and < N satellites exhibit scintillation on multiple frequencies, then it is probably due to space weather.
- If all N satellites have scintillation on one frequency, then it is probably interference.
- If all N satellites exhibit scintillation on all frequencies, then it might still be caused by

interference, since this can affect multiple frequencies. Other stations in the network can be investigated to determine whether it is a space weather event or a local event.

- For local events, the S4 correction can be examined. If the S4 correction is elevated, then it is likely due to interference.

- If there is no increase in the S4 correction, a preceding time interval can be searched for data gaps. If such data gaps are present, then the elevated σ_ϕ values are likely due to the oscillator.

In the ismr format, both the S4 index and the S4 correction are provided. In some receivers, one of the channels is assigned to measure the noise level, which is used to compute the S4 correction. Otherwise, the S4 level on the satellite signal, which experiences the least scintillation, can be used for the correction. In both cases, increases in the S4 correction could indicate local interference. Two examples of the use of this method are demonstrated in section 3.

Method 2 is based on an investigation of the effects on different GNSS frequencies. If the quotient between two frequencies is termed q, as shown in equation 1, then the phase scintillation index, σ_ϕ, on two frequencies scales with q [3,5].

$$q = \frac{f_1}{f_2} \quad (1).$$

For GPS L1 and L2 this gives $q = 1.2833$, for Galileo E1 and E5a it gives $q = 1.3391$. The effects of oscillator issues on σ_ϕ are expected to scale with the inverse of q. For GPS L1 and L2 this gives $q^{-1} = 0.7792$ and for Galileo E1 and E5a it is $q^{-1} = 0.7468$.

Method 2 was used to categorise the data in the study as originating from space weather, oscillator issues, interference, or as being uncategorised. This was done by first elevation cutting the data, filtering out satellites below 15 degrees elevation. Then, times with σ_ϕ values above 0.4 radians on the highest of the two frequencies were identified. This subset of data was further filtered to only include times with σ_ϕ data on both frequencies since the method can not be applied if only one frequency is available.

After the initial processing of the data from the ismr files, the categorisation of the data was performed. This was done by identifying the times with σ_ϕ values on f_1 and f_2 lying within 10 percent of the expected relation for space weather and oscillator events respectively. The interference events were identified as times where q from equation 1 exceeded 4. All times which passed the initial processing but did not fit in the other categories was termed "Uncategorised".

3. Results and discussion

Method 1 was tested on two scenarios with elevated σ_ϕ values. The first scenario is from Kulusuk on the 22nd of April 2022. The increased σ_ϕ values were only experienced on one frequency. Further, the number of affected satellites was examined. Since interference is a local phenomena, it would affect signals from all satellites received at the location simultaneously. Coinciding increases in σ_ϕ on all satellites were found, which indicates that the values are not related to space weather events, except perhaps in very extreme space weather cases, however other stations in the network were not affected. Increases in S4 were also occurring simultaneously, indicating that the scenario resulted from local interference.

Another incident of substantially increased σ_ϕ values was identified in data from Qaqortoq on the 4th of January 2022. Investigations revealed that the increased values were observed for most satellites. Therefore, interference was initially assumed to be the cause. However, the amplitude index S4 was unaffected. Further investigations placed the increased σ_ϕ values at the beginning of a data file where the two previous files were missing. Indicating that the increased σ_ϕ index was not due to interference, but rather a restart of the receiver, causing the oscillator to be unstable while warming up. This incident suggests that σ_ϕ values attained shortly after a data gap should be cautiously evaluated.

While Method 1 successfully identified the source of two events with elevated σ_ϕ, it would be advantageous if the times of high scintillation could be categorised in fewer steps and be dependent on less input data. This is the strength of Method 2, the method can quickly categorise large datasets and the categorisation of data can potentially be used to perform a real-time distinction between event types and identification of the data points that need to be examined further. Figures 1 and 2 illustrate the GPS event categorisation at Qaqortoq and Kulusuk respectively.

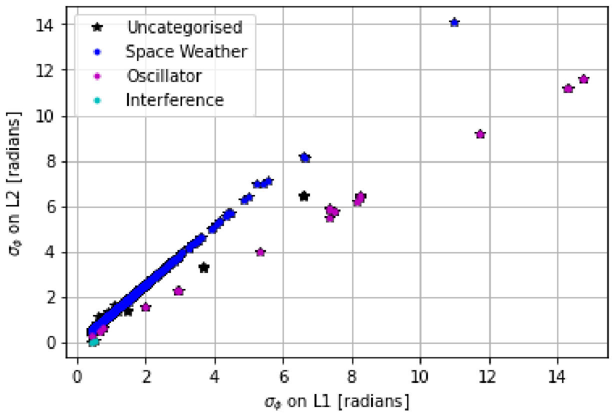

Figure 1: Categorisation of GPS data from 2022 collected at Qaqortoq. All data with σ_ϕ above 0.4

radians on L1 is illustrated as black stars, with the category colours overlaying the corresponding data points.

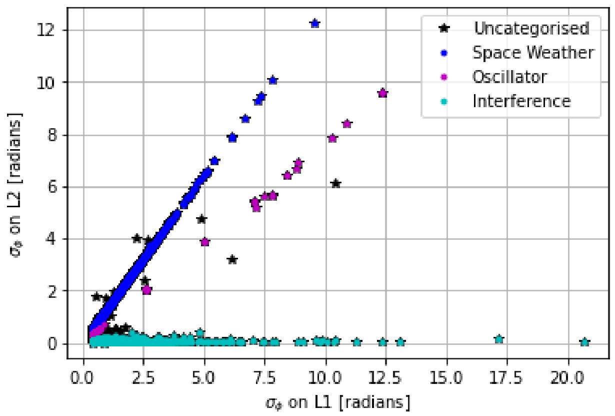

Figure 2: Categorisation of GPS data from 2022 collected at Kulusuk. All data with σ_ϕ above 0.4 radians on L1 is illustrated as black stars, with the category colours overlaying the corresponding data points.

The analysis of one year of GPS data from two stations in Greenland, shown in Figures 1 and 2, is supported by the fact that the events identified by Method 1 were classified correctly by Method 2. Only 16 out of 5,323 events are uncategorised by Method 2 at Qaqortoq, at Kulusuk it is 290 out of 15,119 events. This considerably brings down the number of data points which should be examined more closely by Method 1.

Method 2 was also tested for Galileo at Qaqortoq and Kulusuk with similar results. The results from Kulusuk are shown in Figure 3.

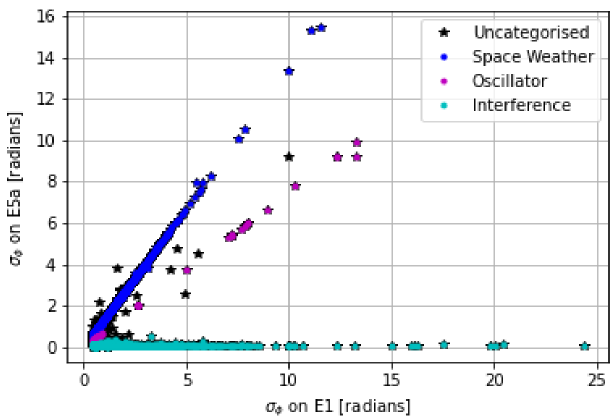

Figure 3: Categorisation of Galileo data from 2022 collected at Kulusuk. All data with σ_ϕ above 0.4 radians on E1 is illustrated as black stars, with the category colours overlaying the corresponding data points.

The results seen in Figures 1, 2, and 3 are likely a result of refractive scintillation being the dominant type in the Arctic. Including equatorial data could provide more diffractive scintillation events.

4. Further work

The analysis will be extended with L5 and E5b. Further, the analysis will include the quotient of the S4 index on dual frequencies, which scales with $q^{1.5}$ [3,5]. While σ_ϕ is sensitive to both refractive and diffractive events, S4 is mainly sensitive to signal diffraction. The dataset used in this study is from Greenland, where most of the identified phase scintillation events relate to refraction [4]. It would be advisable to include equatorial data to investigate diffractive events, as these are more common in this region. This will be done in the next phase of the project, which will also include an extension to other constellations and signals.

6. Conclusion

The two methods show promise in the Arctic region, where Method 2 categorised over 99 % of the events identified in the preprocessing at both Qaqortoq and Kulusuk. Method 1 provided a framework of how to identify specific events based on the extent of the impact. It also verified Method 2 by providing the same conclusion as Method 2 in two specific cases. In conclusion, these methods could be used as the basis of real-time distinction of causes for increased σ_ϕ values in the Arctic, both for GPS and Galileo.

7. Acknowledgements

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