Comparison of trans-ionospheric radio wave scintillation in the South–East Asian Region with WBMOD predictions

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Abstract

In this paper we evaluate the global scintillation modelling code WBMOD, developed at North West Research, in the Australia/South-East Asian region. The process used to evaluate WBMOD is detailed and results are presented for data collected during 1998 and 1999 from two sites in the region; one situated near the southern anomaly crest and the other near the geomagnetic equator. We generally found good agreement for low sunspot numbers at both sites. However, for higher levels of sunspot activity, we found that WBMOD does not perform as well at the magnetic equator.

1 Introduction

The trans-ionospheric radio-wave scintillation modelling code WBMOD, developed at North West Research using data collected by the DNA Wide Band satellite, provides a global description of scintillation occurrence [1]. However, the model has been calibrated with data from mainly the American/Atlantic longitude sector the main sites being Poker Flat (Alaska), Ancon (Peru), Huancayo (Peru) and Ascension Island. Data has also been obtained from Kwajalein Island in the Pacific sector. Only limited calibration has been carried out in the East Asian sector; data were obtained from only one site, that being Manila, Philippines, and at only one frequency in the VHF band. Thus, the performance of WBMOD in other localised regions such as Australia/South East Asia, and certainly at L-Band frequencies, needs to be validated. The Defence Science and Technology Organisation (DSTO), in conjunction with LAPAN, Indonesia; PSTP, Malaysia; Air Force Research Laboratory (AFRL), USA and the IPS Radio and Space Services of Australia, commissioned a network of GPS receivers in December 1997 to measure both scintillation and TEC from sites in the region, in order to carry out such a validation.

WBMOD is a climatological model which provides statistical predictions of scintillation activity as a function of radio frequency, day of year, time of day, ionospheric latitude and longitude, sunspot number, and magnetic activity. It predicts "average" behaviour (climatology), rather than instantaneous behaviour (weather); the detailed spatial and temporal structure of irregularity patches is not addressed. Its outputs include predictions of the amplitude scintillation index S_4, the phase scintillation index, the spectral power T and spectral slope p, together with statistics on the occurrence of these parameters. Parameters which describe the ionospheric irregularities generated by its internal irregularity models are also output.

This paper describes the network of GPS receivers used to record the scintillation data. The process used to validate WBMOD is detailed and results of the validation are presented for data collected during 1998 from two of the sites; one situated close to the southern anomaly and the other near the geomagnetic equator.

2 The Ionospheric Scintillation Monitor Network

Scintillation data are provided by Ionospheric Scintillation Monitors (ISM) on loan from AFRL. The ISMs are based on Novatel 951 GPS single frequency (L1) receivers which have been modified to process raw data sampled at 50 Hz and calculate various parameters which characterise the observed scintillation.

The receivers are stationed at 5 separate locations in the South–East Asian region: Marak Parak (Malaysia), Parepare (Indonesia), Pontianak (Indonesia), Vanimo (PNG) and Darwin (Australia). Details of the station location are shown in Table 1. Darwin, Marak Parak, and Parepare also have dual frequency Millenium Novatel GPS receivers for the purpose of measuring Total Electron Content. However, these will not be described here.

Station	Geog. lat.	Geog. long.	Geomag. lat.	Geomag dip.
Parepare	-3.98	119.65	-12.6	-26.2
Pontianak	0.00	109.37	-8.4	-18.8
Marak Parak	6.31	116.74	-1.3	-3.8
Darwin	-12.4	130.87	-21.9	-40.5
Vanimo	-2.4	141.2	-10.8	-21.6

Table 1: Station locations (in degrees). Geomagnetic data are from IGRF (1998).

The ISMs record processed data automatically at 1 minute intervals throughout the day. Quantities which are logged include the scintillation indices S_4 and σ_ϕ, and the spectral strength T and slope p. Raw 50 Hz data may also be recorded non-routinely if desired. Detailed descriptions of the ISMs may be found in [2] and [3].

3 Processing of the Data

Before any sensible comparisons can be made between the ISM data and the WBMOD predictions, suitable processing of the ISM data is necessary. The primary concern is that the ISM data are “weather” in nature (i.e. instantaneous observations) whereas the predictions produced by WBMOD give a climatological (average) picture. WBMOD is unable to reproduce the spatial, temporal and night-to-night variations in scintillation activity. For this reason the comparisons are performed on a monthly basis and are statistical in nature.

A 15 degree elevation mask was first applied to the ISM data to remove any multipath and other low elevation effects. During high levels of scintillation activity, the ISM tracking loops become severely stressed and the reliability of the output scintillation parameters decreases. Modeling of generic GPS receiver tracking loops suggests that this occurs at an S_4 level of about 0.8[4], but a more detailed analysis of the receiver's tracking loops is required to yield a more precise figure. We chose a conservative value for S_4 of 0.6 above which the data are flagged and this effectively sets a threshold for any subsequent processing, above which we can only say that scintillation occurs. We note here that prior to an ISM firmware upgrade performed on the receivers in August 1998, the S_4 data were unreliable above 0.3 with larger values being reported than in reality. Thus, a threshold of no greater than 0.3 must be used prior to the firmware upgrade.

For each day of the month for which the comparison was to be made, the path of each observed GPS satellite was split into segments of 3 hours duration based upon the geomagnetic activity index, Kp. WBMOD was then run for each of these satellite path segments of each satellite-receiver link using the appropriate Kp value. The orbital parameters of the GPS satellite were used to define the geometry of the satellite-receiver link at each point of the satellite's orbit (while in view) at a time resolution of 3 minutes. The resulting WBMOD predictions were later interpolated to produce one minute values so as to match the one minute ISM data. Figure 1 displays the geometry of the situation for a GPS satellite at various points in its orbit. For each WBMOD run the appropriate radio frequency, yearly smoothed sunspot number (SSN), and Kp index at local sunset (which is required in addition to the Kp index at the time of the run) were used. The one-way propagation mode was selected and the WBMOD internal models of the irregularity outer scale size, and drift velocity were used. Thus, for each GPS satellite pass observed which provided a time series of scintillation data, an equivalent WBMOD time series was produced and the geometry of the receivers and satellites that was input into WBMOD was identical to that observed.

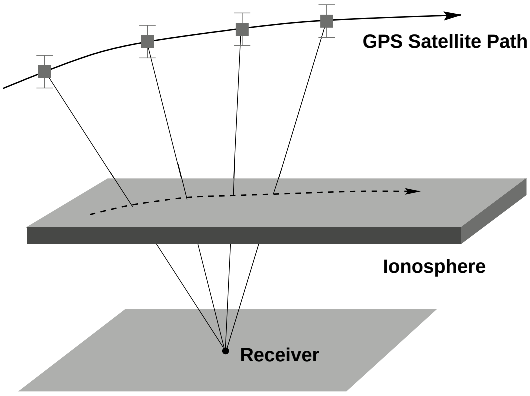

Figure 1: Geometry of a GPS satellite–receiver link at various points along its orbit. WBMOD is run for the satellite–receiver link at 1 minute intervals.

Typically about 25 satellite passes would be observed between local sunset and sunrise (the period of interest) with each pass lasting for about 5 hours on average. For a given site this equates to over 9000 WBMOD runs per year yielding a total of nearly one million WBMOD realizations for each threshold level or percentile.

Figure 2 displays examples of the ISM S_4 data and the corresponding WBMOD predictions at the 90^{th} percentile over 5 days in September 1999 at Parepare. These plots demonstrate the "patchy" nature of scintillation in contrast to WBMOD which produces smooth "average" predictions of scintillation. The night-to-night variability of scintillation activity which is unable to be predicted by the climatological WBMOD model is also illustrated with strong scintillation displayed on two nights and weak or no scintillation on the others.

Clearly, the nature of scintillation, displayed in Figure 2, indicates that a statistical approach is required to compare the WBMOD predictions with the observations. The approach that we have taken is to calculate the percentage of time that S_4 exceeds a certain threshold as a function of season and time of night. The ISM data were binned into half-hour bins over ten day intervals. The percentage of time that S_4 exceeded the threshold was then calculated in each of these 10-day half-hour blocks. WBMOD was run in a mode which yielded probabilities of S_4 exceeding the threshold level used for the

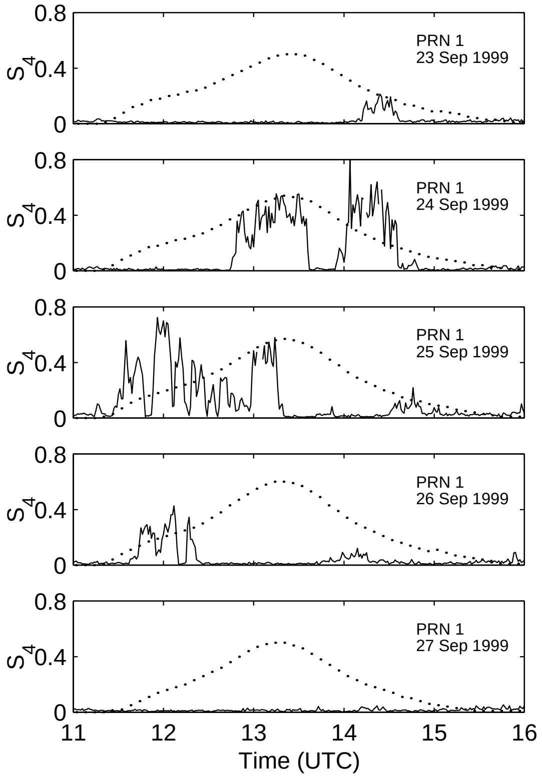

Figure 2: Comparisons between ISM S_4 (solid line) data and WBMOD predictions at 90th percentile (dotted line) on 5 separate days in September 1999 for GPS satellite PRN 1 observed at Parepare.

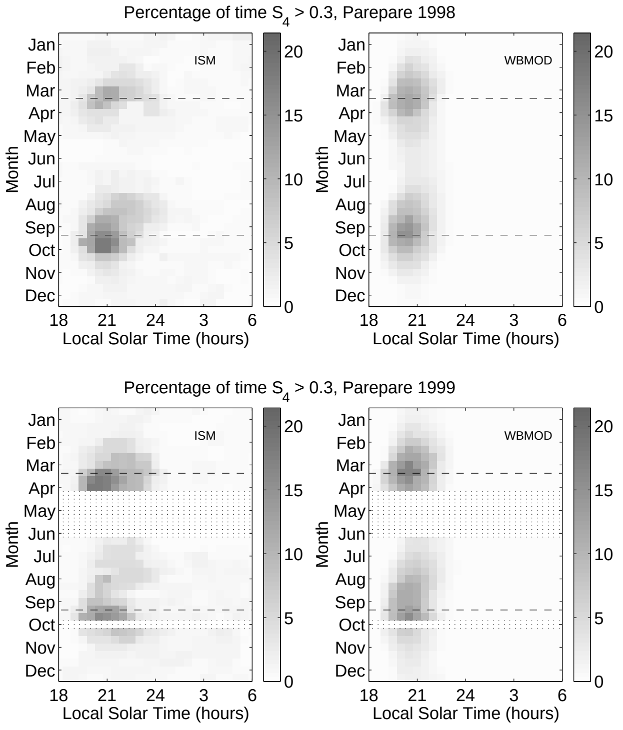

Figure 3: Percentage of time that S_4 exceeds 0.3 as a function of time and season at Parepare during 1998 (top) and 1999 (bottom). The left panels display the ISM data, the right panels the WBMOD predictions. The dashed lines indicate the equinoxes and the dotted regions are periods of no data.

treatment of the ISM data. The WBMOD data were then treated in a similar fashion to the ISM observations, yielding predicted values for the percentage of time that S_4 exceeded the threshold in the 10-day half-hour windows. The data and WBMOD may then be directly compared by producing contour diagrams or image plots. An example of this is displayed in Figure 3.

4 Results and Discussion

Figure 3 displays the percentage of time that S_4 observed by the ISM (left panel) and predicted by WBMOD (right panel) exceeds 0.3 as a function of time and season at Parepare during 1998 (top) and 1999 (bottom). The geomagnetic latitude of Parepare is $-12.6°$ which places it close to the southern anomaly region. The yearly smoothed sunspot number varied from 44 to 78 during 1998 and from 82 to 111 during 1999. This figure shows in general that the WBMOD predictions agree with the ISM observations. There are however, some differences. The shape of the equinoctial maxima differ to a small degree; the observations tend to to be constrained more seasonally but extend further into the night. Also, WBMOD cuts off $\sim$ 1.5 hours before midnight whereas scintillation is observed until and occasionally past midnight. This may be an indicator of a significant problem with WBMOD, particularly at lower frequencies. The amplitude scintillation index, S_4, scales as $f^{-1.5}$[5] so that at lower frequencies scintillation is both stronger and also extends later into the night[1]. Thus, at lower frequencies, the consequences of WBMOD significantly underestimating scintillation activity post-midnight are potentially greater.

Figure 4 displays a similar plot for Marak Parak (geomagnetic lat. −1.3°). The first point to note is that the maximum activity level is about a factor of 2 lower than at Parepare. This is expected as scintillation maximises in the anomaly regions and decreases at the equator[6, 7]. As with the Parepare comparison there are differences between the ISM data and WBMOD at Marak Parak; again it may be observed that the ISM data are constrained more to the equinoxes but extend later into the night than the WBMOD predictions. It is interesting to note that at the equator it would appear that scintillation activity lasts $\sim$ 1 hour longer than at the anomaly, albeit at a lower level.

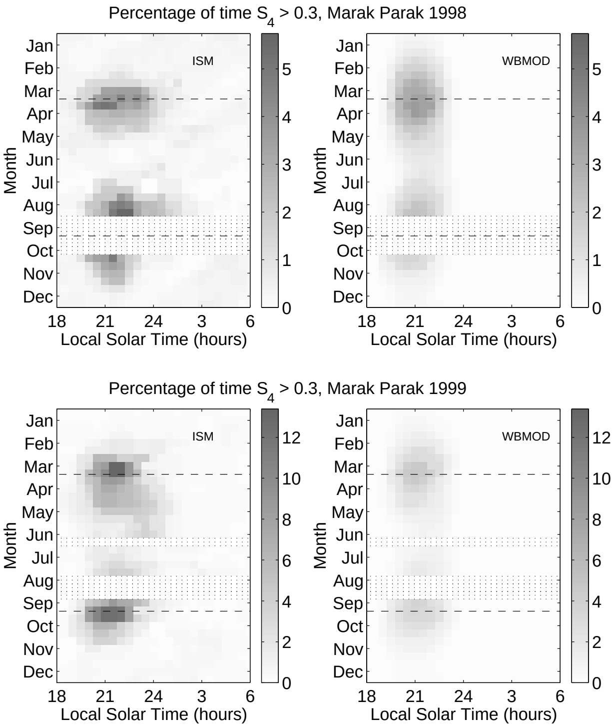

Figure 4: Percentage of time that S_4 exceeds 0.3 as a function of time and season at Marak Parak during 1998 (top) and 1999 (bottom).

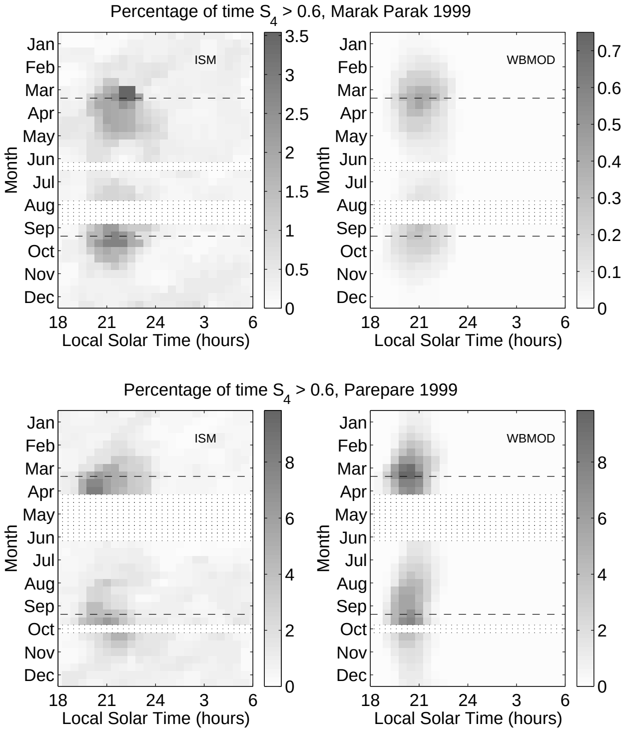

Figure 5: Percentage of time that S_4 exceeds 0.6 as a function of time and season at Marak Parak (top) and Parepare (bottom) during 1999. Note, different intensity scales have been used for the Marak Parak ISM and WBMOD plots.

However, the main point to note is that during 1999 the WBMOD predictions for Marak Parak underestimate the observations by a factor of about $\sim$ 2.5. Clearly, in the South–East Asian region, and for sunspot numbers above $\sim$ 80, WBMOD underestimates the scintillation activity level at the equator, i.e., WBMOD localizes the scintillation activity to the anomaly regions to a greater extent than is observed. Upon a closer examination of the data near the September 1998 equinox, there is evidence that WBMOD is starting to underestimate the observations during this period. However, due to the lack of data from this equinox we cannot conclude anything further. We are limited to concluding that WBMOD performs well at the equator in the South–East Asian region only for sunspot levels lower than $\sim$ 55.

We now examine the performance of WBMOD at moderate to strong scintillation levels by applying an S_4 threshold level of 0.6. Figure 5 displays the percentage probability of S_4 exceeding the 0.6 threshold at Marak Parak (top) and Parepare (bottom) during 1999. Again the left panels are the ISM data and the right panels the WBMOD predictions.

Turning first to the comparison at Marak Parak, we see that at an S_4 threshold of 0.6 the underestimation of the scintillation levels by WBMOD is much worse than the comparison at a threshold of 0.3. Now the ISM data are greater than the WBMOD predictions by a factor of ~ 9. Clearly under moderate to high scintillation conditions the performance of WBMOD at the geomagnetic equator is poor. At Parepare, however, we observe that the comparision is quite good. These comparisons indicate that the empirical models used to characterise the latitudinal variation of the strength of the ionospheric irregularities do not accurately reflect the environment, at least at L Band frequencies and in the SE Asian region. WBMOD confines the irregularities too narrowly to the anomaly regions.

5 Conclusion

We have found that at both the equatorial and anomaly site WBMOD agreed well with the data during low sunspot activity, although minor differences were noted. However, as sunspot activity increased and for moderate to high scintillation levels we found that WBMOD confined the scintillation activity too narrowly to the anomaly regions. This aspect of WBMOD will need to be improved to better characterise the latitudinal dependence of scintillation in the equatorial region.

A further area of concern is that WBMOD cuts off too early in the night. At GPS frequencies this is not a great issue because the observed scintillation levels at these times are low. However, at lower frequencies this behaviour is of great concern because at these frequencies strong scintillation extends later into the night and the potential exists for WBMOD to underestimate the scintillation activity at these times. Observations at VHF and extensive comparisons with WBMOD will be required to investigate this further and to quantify the effect.

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