Generation and use of a real-time estimated Dst-index at the Australian Space Forecast Centre.

R.A. Marshall[1] and J. Kennewell[2]

[1] *IPS Radio and Space Services, Sydney, NSW, Australia*
[2] *Australian Space Academy, Meckering, WA, Australia*

e-mail of author: ram@ips.gov.au

1. **Introduction**

The Dst-index was derived to quantify the decrease in the geomagnetic field H-component observed during the main phase of magnetic storms produced mainly by the equatorial current system in the magnetosphere referred to as the ring current (Figure 1).

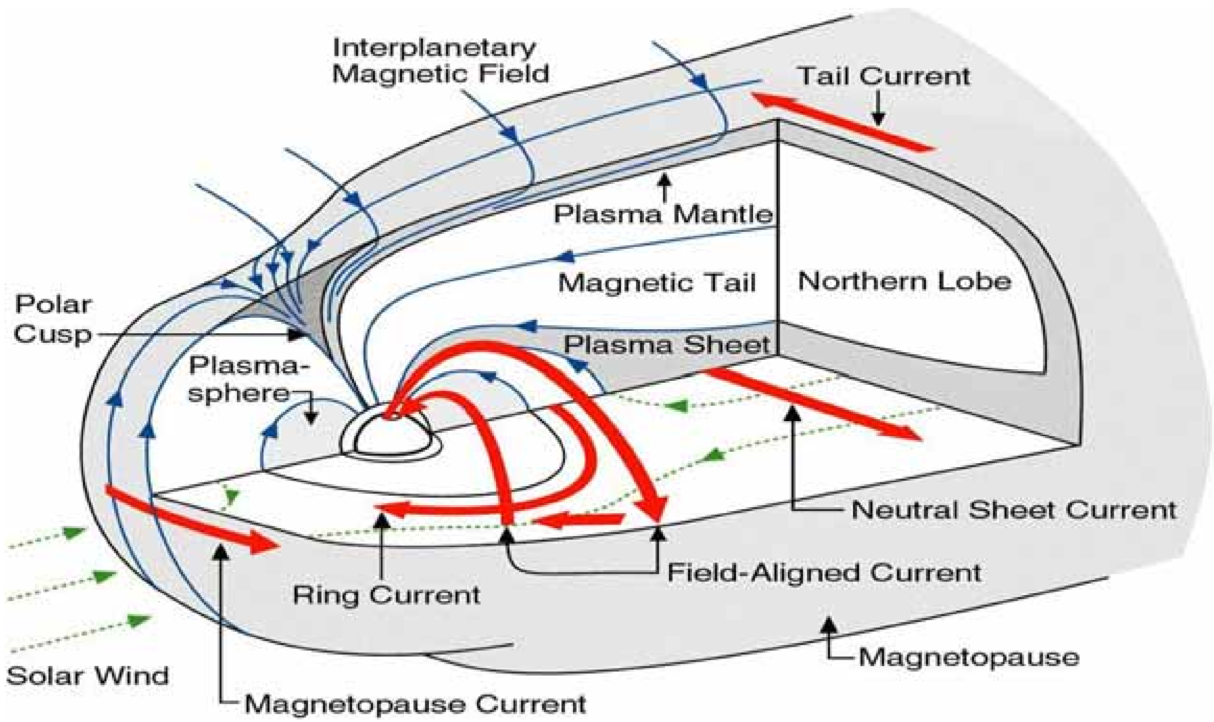


Figure 1: Schematic of major current systems within the Earth's magnetosphere. The Dst-index was originally designed to quantify the current system encircling the Earth and concentrated primarily in the equatorial plane referred to as the ring current.

Its derivation requires synthesis of the monthly Sq variations from Fourier coefficients determined using the international 5 quietest days of each month as well as removal of the baseline reference level (Mayaud, 1980). For each observatory, j, contributing to the global Dst-index, the disturbance field at time t is given by

$$D_j(t) = H_{obs,j}(t) - Sq_j(t) - H_{b,j}(t) \qquad (1)$$

where D is the disturbance field in nT, H_{obs} is the observed magnetic field in the north-south direction, Sq is the synthesised quiet-day field variation and H_b is the observatory baseline value. The disturbance field D(t) in equation (1) is scaled to give the equivalent storm time disturbance field due to the ring current, Dst, at the Earth's surface in the equatorial plane by

$$Dst(t) = (\Sigma_j D_j(t)/N)/(\Sigma_j \cos(\theta_j)/N) \quad (2)$$

where the sum is for j = 0, N observatories and θ_j is the observatory geomagnetic latitude.

Due to the determination of Sq and H_b from the international 5 quietest days for each month of a given year, the "final" Dst-index values are not available until at least 12 months later. Customers with technologies affected by space weather often require timely notification of significant activity and this need has given rise to near real-time index estimates to drive alerts or nowcasts. For example, the World Data Centre for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/index.html), now provide the global Dst-index as "quick-look" values on an hourly basis, provisional values on a monthly basis and final values on a yearly basis. The increased timeliness of the indices usually comes at the expense of a decrease in accuracy and hence the indices are referred to here as "estimated indices". The method below describes the production of an estimated Dst-index used by the Australian Space Forecast Center (ASFC) at IPS Radio and Space Services.

2. Derivation of Real-time Dst-Index

Delivery of timely space weather products and indices requires a relatively robust automated procedure. One of the challenges that arise is dealing with the automated processing of spurious data and outages. A large data network provides redundancy and allows some filtering or processing of spurious data. The Australian region estimated Dst-index produced at the ASFC is generated from magnetometer data recorded by a large real-time network operated by IPS Radio and Space Services and referred to as IPSNET (Figure 2). Only low-mid latitude stations from the IPSNET network are used in the determination of the estimated Dst-index.

The method used by the ASFC to produce a near real-time estimated Dst-index effectively assumes that the average of the H-component data from station j for the M most recent "quiet days", QDC_j, is equivalent to the sum of the baseline H_b and the Sq values referred to in equation (1), ie.

$$QDC_j(t) = Sq_j(t) + H_{b,j}(t) \quad (3)$$

Using equation (3), equation (1) can be expressed as

$$D_j(t) = H_{obs,j}(t) - QDC_j(t) \quad (4)$$

and

$$Dst_j(t) = D_j(t)/\cos(\theta) \quad (5)$$

Hence the estimated Dst-index for each station Dst_j can be obtained by subtracting the pre-determined QDC_j values from corresponding real-time observed data, $H_{obs,j}$ for any given time. The Australian region estimated Dst-index, AusDst, is then obtained using an inter-station averaging process to remove any indices generated from spurious data. Each of the three stages of production of AusDst, ie, production of "Quiet Day Curves" for each station QDC_j; production of real-time station Dst-indices Dst_j; and production of the Australian region Dst-index are considered in more detail below.

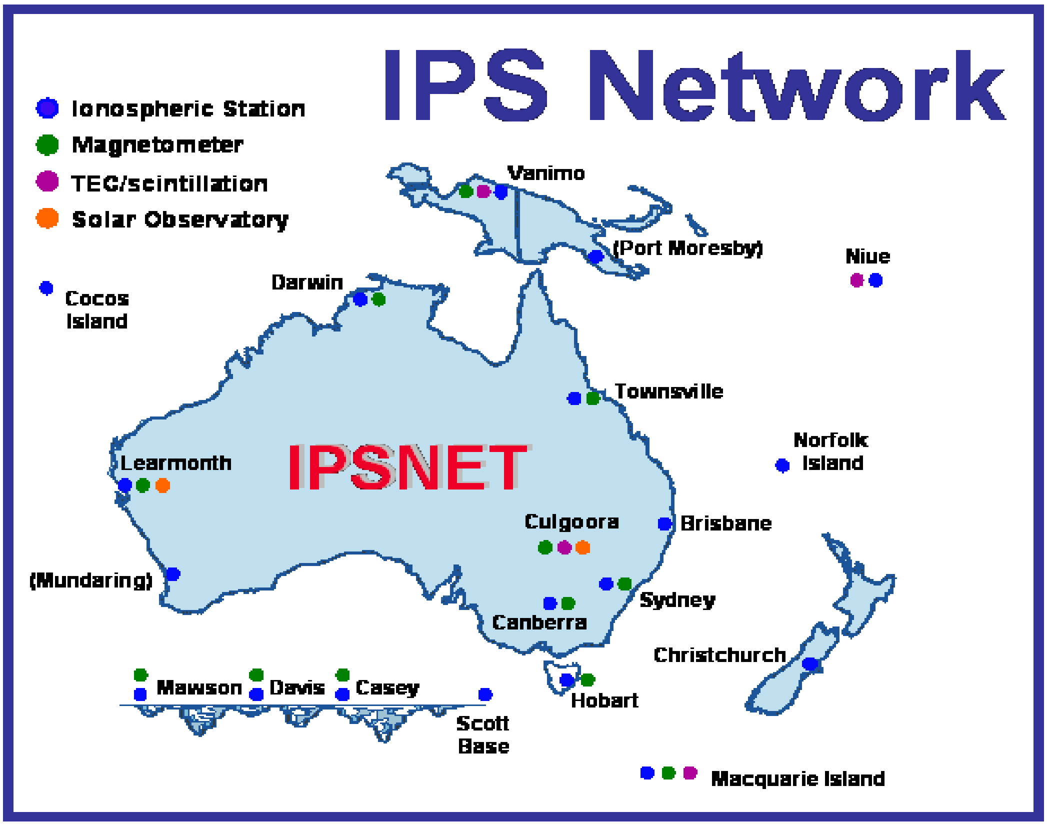


Figure 2: Map showing the locations of near real-time space weather monitoring stations across the Australian region operated by IPS Radio and Space Services.

a) Production of Station Quiet Day Curves, QDC_j

i. For each station, j, contributing to the AusDst-index a new data format of "standard hourly" data file is produced as part of the routine conversion process of magnetometer data. These files contain sub-hourly averages of the standard format data (raw data that has been cleaned to remove spikes etc) at *X*-minute intervals (presently this is set to 10 minutes).
ii. A search is performed backwards through the corresponding station K-index data to find the most recent "quiet day" defined as days with all K-indices less than a threshold (presently this threshold is set to a K-index<2).
iii. A search is performed for the stations' corresponding "standard hourly" data file produced in step (i) and the validity of the file checked (incomplete files are considered invalid and the search returns to the K-index data files to find the next "quiet day"). New valid files ($QDC_{new,j}$) are included into the average "Quiet Day Curve" ($QDC_{avg,j}$) of sub-hourly data by using an iterative method

$$QDC_{avg,j} = QDC_{avg,j} + (QDC_{new,j} - QDC_{avg,j})/M$$

where presently M is set to 3. This averaging method places more significance on the most recent data.
iv. The search continues through the station K-index and "standard hourly" data files until M is reached and the latest $QDC_{avg,j}$ of sub-hourly data has been determined.

v. This process is performed routinely each day to update the $QDC_{avg,j}$ for each station to include the most recent "quiet day" Sq and H_b information.

Figure 3 shows an example of Hobart H-component magnetometer data for the 3 most recent quiet days prior to 14th November, 2008 shown in red, yellow and orange, with the $QDC_{avg,j}$ generated from the averaging process of this data described above indicated by the green squares. It may be noted that $QDC_{avg,j}$ data shown in Figure 3 contains both baseline $H_{b,j}$ and Sq_j contributions.

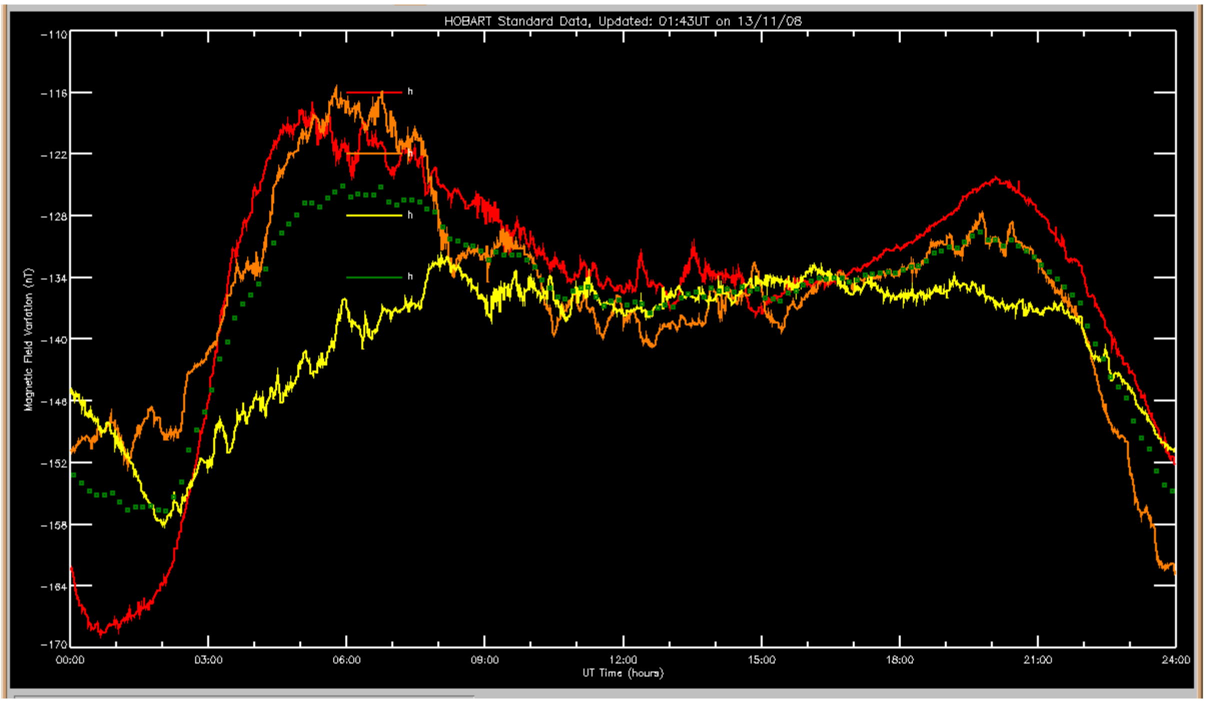


Figure 3: Time series plot showing Hobart magnetometer data for 3 most recent "quiet days" (defined as local station K-index<2) 11-13th November in red, yellow and orange respectively and the resultant $QDC_{avg,j}$ values for 14th November generated by the process described in (a) above shown as green squares.

b) Near Real-time Station Dst-index, Dst_j

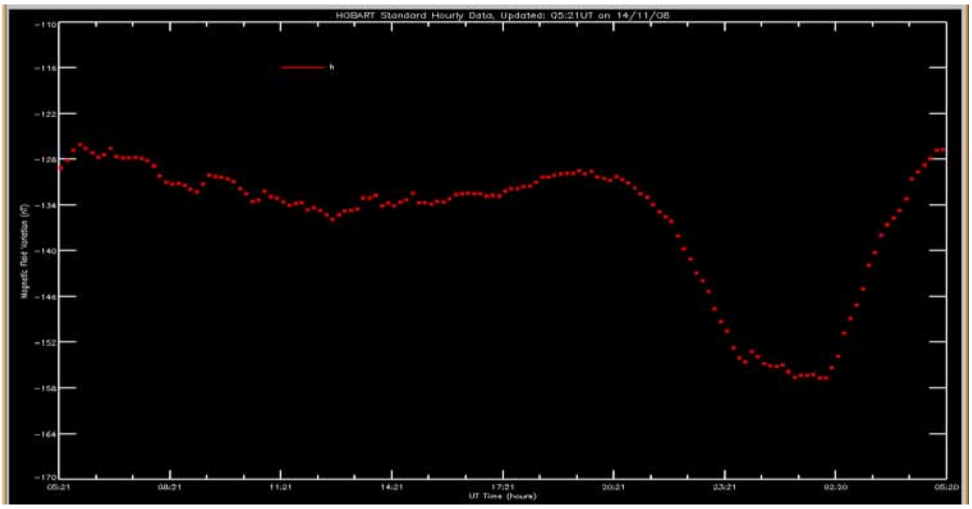
i. For each station, j, contributing to the AusDst-index, the $QDC_{avg,j}$ values are subtracted from the corresponding near real-time H-component "standard-hourly" data (as described in step (i) of (a) above) to give $D_j(t)$ as in Equation (4) (see Figures 4a & b).
ii. The station geomagnetic coordinates are read from a file that is updated routinely on a monthly basis and used to scale the resultant $D_j(t)$ values from (i) to give the equivalent equatorial disturbance field values for that station, Dst_j, as in equation (5) (see Figure 4c).

c) Australian Region Real-time Dst-Index, AusDst

For service implementation (see section 3) an Australian region Dst-index, AusDst, is produced by averaging the individual station Dst_j values. The method used by the ASFC is:

i. For each station, j, contributing to the AusDst-index the individual station Dst_j values are read into an N x (24 x 60/ *X*) array.
ii. For each station, j, unavailable Dst_j values are set to 9999.

(a)



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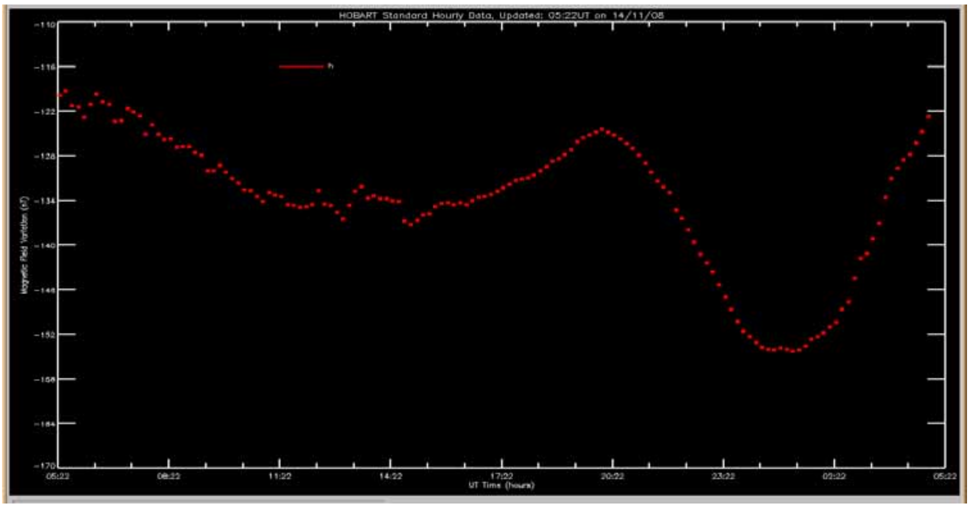


(c)

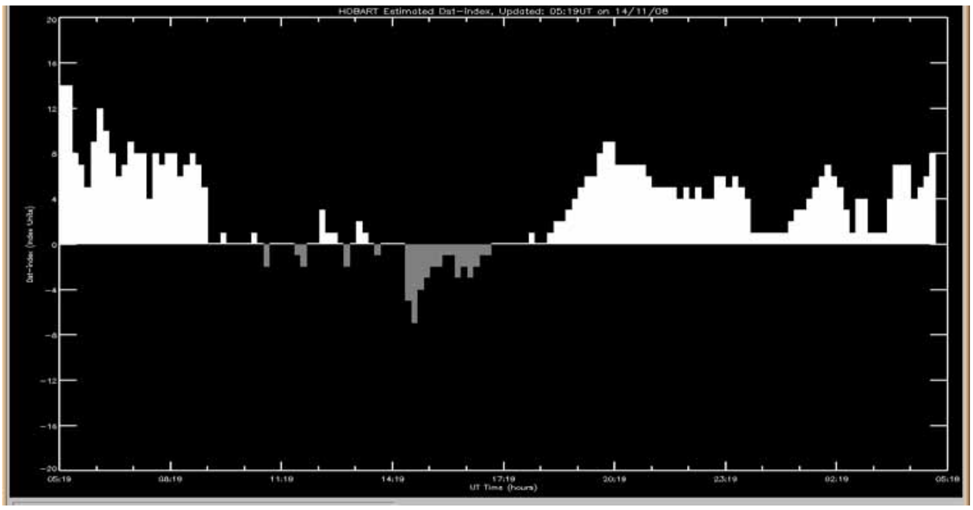
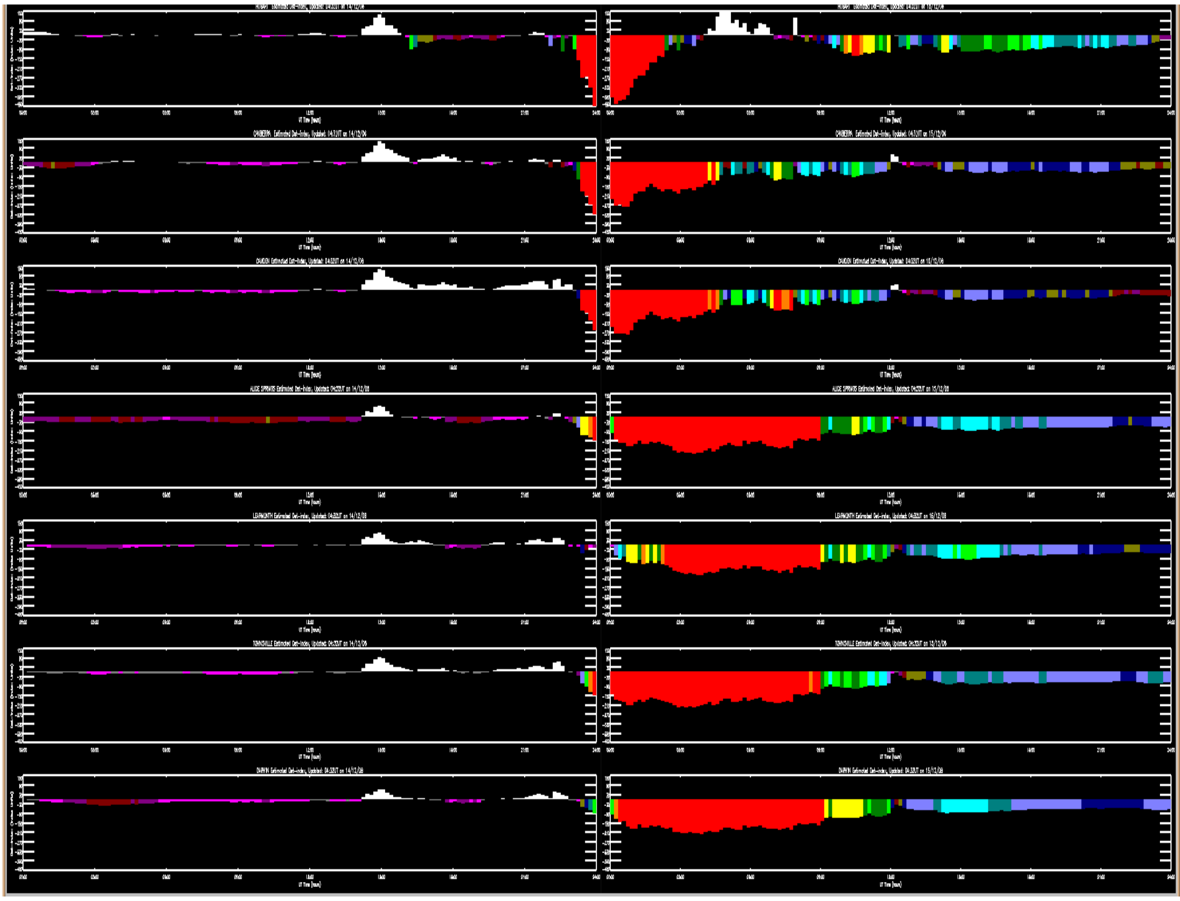


Figure 4: Time series plots showing (a) $QDC_{avg,j}$ values shown in Figure 3 as green squares re-plotted to align with (b) "real-time" observed H-component "standard-hourly" values $H_{obs,j}(t)$ of Equation (4). The plot of (a) is subtracted from the plot (b) to produce the station $D_j(t)$ values and then scaled using the station geomagnetic latitude and Equation (5) to produce the associated near real-time station Dst_j values plotted in (c). Vertical scale are -170 to -110 nT for (a) and (b) and -20 to +20 Index units for (c), horizontal is 24 hrs.

iii. For each row of the array, the median is determined using only valid Dst_j values (non 9999 values).
iv. The estimated AusDst-index for each array row (ie time interval of *X* minutes) is defined as the average of those non-9999 Dst_j values whose values are within the range *d* of the median determined in step (iii), presently *d* is set to 20.

Figure 5a presents example plots of the individual station Dst_j values contributing to the AusDst-index for the geomagnetic storm of 14-15 December, 2006. Figure 5b shows the resultant AusDst-index derived from the individual station Dst_j values using the averaging method above.

(a)



(b)

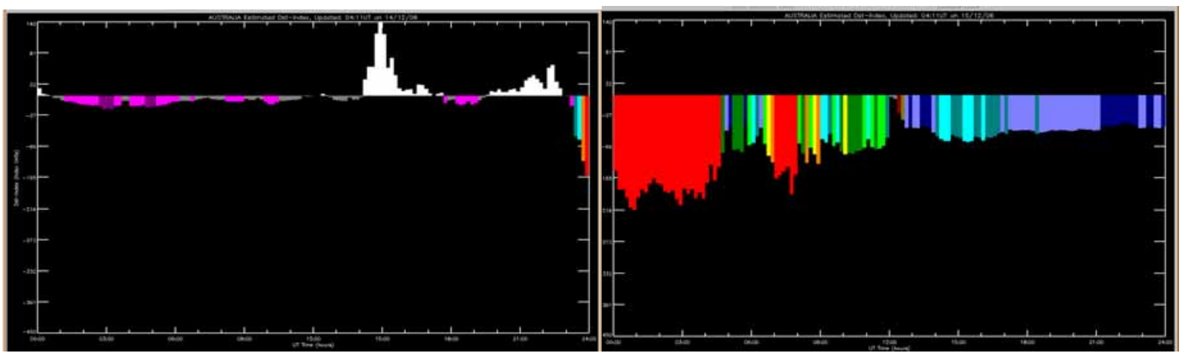


Figure 5: Time series plots of (a) individual station Dst_j values and (b) AusDst-index for geomagnetic storm of 14-15 December, 2006. Figure (a) shows a stack plot of Dst_j values for seven stations contributing the AusDst-index ranging from highest latitude at the top (~ -43ºS) to lowest latitude at the bottom (~ -13ºS). For each time interval *X*, the median of the seven associated Dst_j values is used to remove data gaps and outliers from the averaging to produce the corresponding AusDst-index plot in (b). Vertical scale: -450 to +140 index units for all plots, horizontal is 48 hrs.

3. Service Implementation

a) Web Services

The estimated Australian region Dst-indices have been incorporated into IPS web services (Figure 6a). Clicking on the AusDst-index icon (updated in near real-time) takes the customer to a page displaying the AusDst-index time series plot which is updated in near real-time (Figure 6b).

(a)

(b)

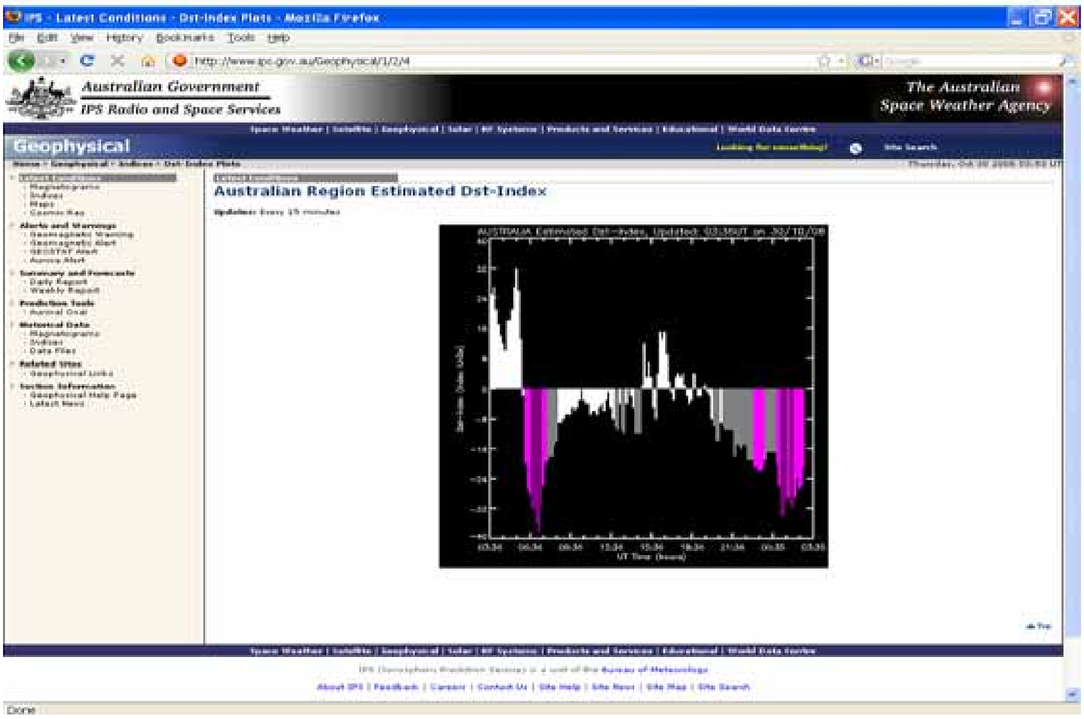


Figure 6: (a) IPS Space Weather Status Panel web page showing recently incorporated AusDst-index. (b) AusDst-index time series plot web page updated in near real-time.

b) Dst-index Based Storm Duration Forecast

An automated "storm duration forecast" service is being developed at the ASFC based on the analogy between the Dst-index time series and lognormal distributions (Campbell, 1996, 1997, 2004). Lognormal distributions arise when there are many simultaneous elementary processes to a measurement or when the measurement is the result of a sequential series of elementary processes as illustrated in Figure 7. Campbell suggests that the Dst-index is not a measure of a simple single equatorial ring current, and that the stations used in the production of the Dst-index are receiving significant contributions from a variety of field sources during storm-time (eg, field-aligned currents, partial ring currents, tail currents and ionospheric currents).

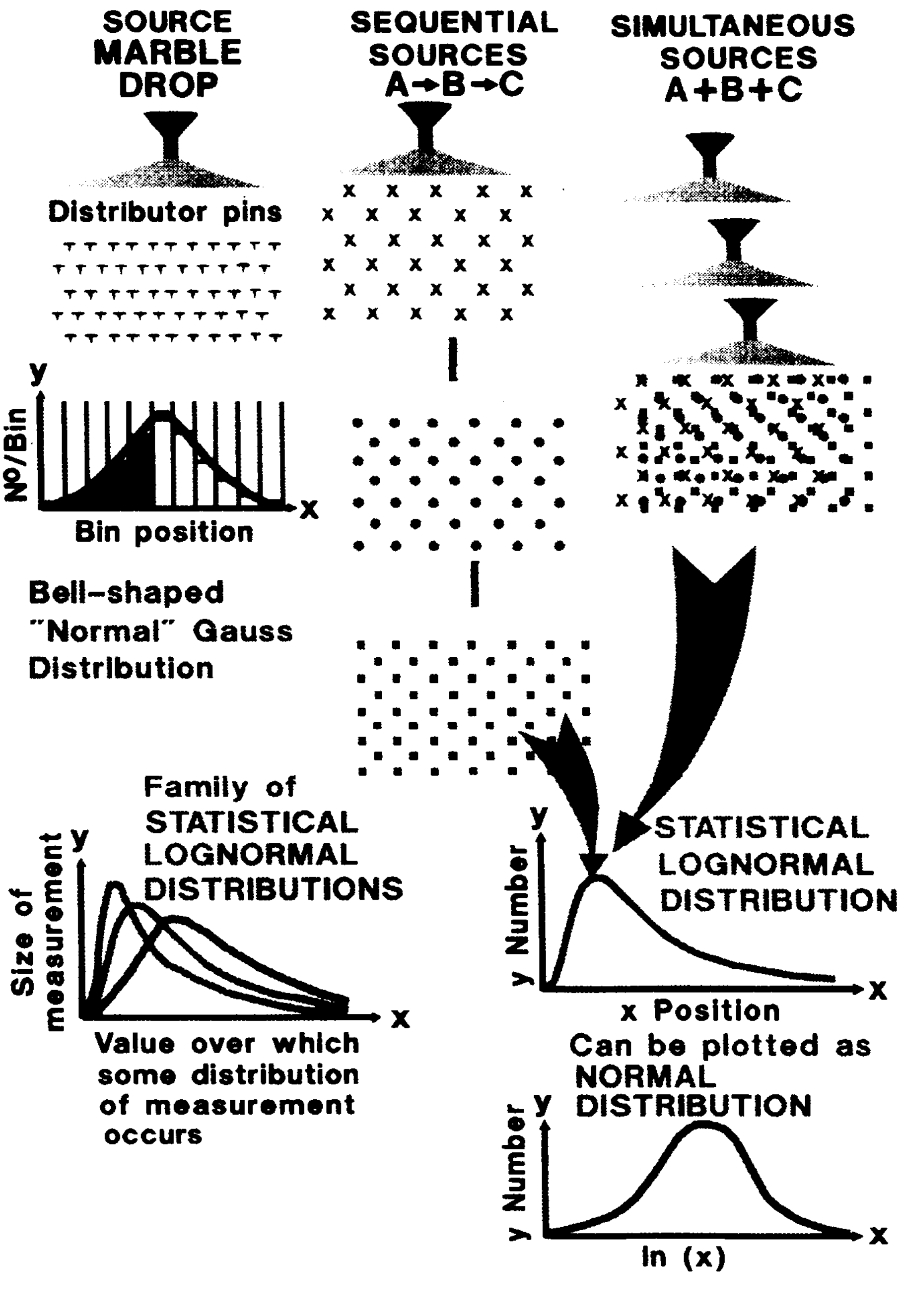


Figure 7: Illustration showing formation of lognormal distributions from sequential and simultaneous sources (Campbell, 1997). The analogy is made between the ensemble of processes observed by low-mid latitude stations and the resultant Dst-index storm-time lognormal shape.

Campbell (1996) demonstrates the lognormal shape of the Dst-index time series and suggests the Dst-index storm-time shapes are the result of the ensemble of magnetospheric and ionospheric processes observed by the middle- and low-latitude observatories contributing to the Dst-index. Campbell further suggests that the Dst-index plotted in the log-time domain will produce a normal distribution shape (Figure 7) from which storm end-time can be obtained from the mirror of log-time to storm absolute maximum. The method used by the ASFC for calculating the storm end-time is based on this idea as described below:

i. A search is preformed using the previous two days of AusDst-index data for storm level values (presently set at -100).
ii. If storm threshold exceeded then test for storm level minimum turning value and time when it is reached is determined.
iii. If storm level value minimum turning has been detected then the pre-storm level values and associated storm start time (most recent AusDst-index > -10) are determined.
iv. The storm end time is calculated using the storm start time, peak time, and the symmetry of a normal distribution when the AusDst-index is plotted on a log-time scale (Campbell, 1996, 1997).

It is envisaged that this “storm recovery time” will be incorporated into IPS services in the near future.

3. References

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