Investigations into ionosphere-plasmasphere coupling during a severe magnetic storm over South Africa

PJ Cilliers [1], BDL Opperman[1,2], L-A McKinnell [1,2], CN Mitchell [3]

[1] Hermanus Magnetic Observatory, A Facility of the NRF, Hermanus, South Africa.

[2] Dept of Physics and Electronics, Rhodes University, South Africa.

[3] Dept of Electronic and Electrical Engineering, University of Bath, BA2 7AY, UK .

URSI General Assembly, 23 to 29 October 2005, New Delhi, India

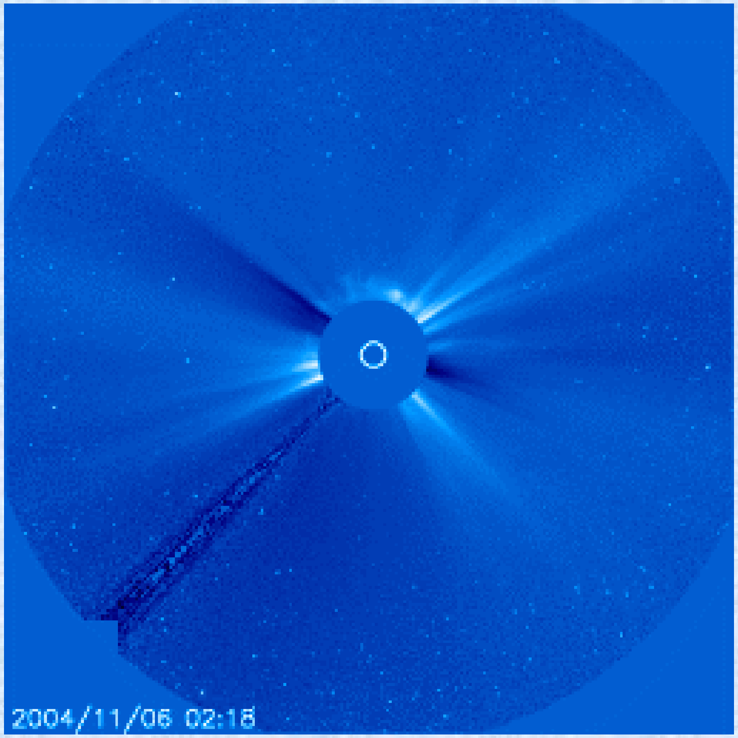
Paper GO4.2(01135)

http://www.hmo.ac.za

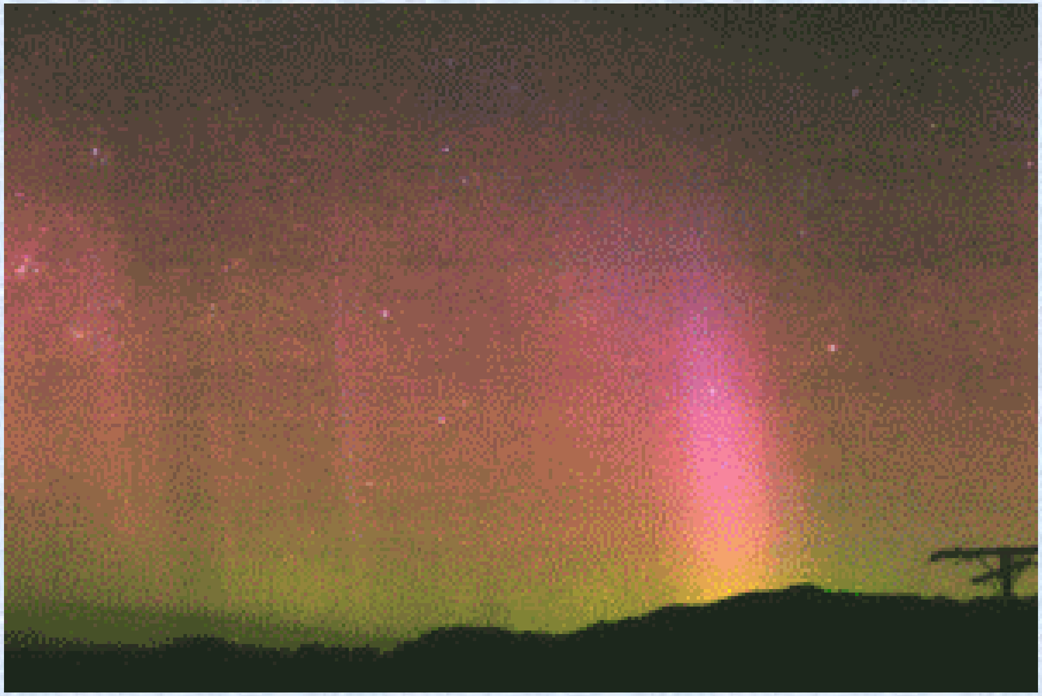
Outline

- Characteristics of the geomagnetic storm 7-10 Nov 2004
- Ionospheric parameters
- Mechanisms of ion-exchange during ionospheric storms
- Location of Ionosondes & GPS Receivers
- Approaches:
  - TEC interpolation using spherical harmonic model(SHM)
  - TEC & electron density profiles by ionospheric tomography using MIDAS
- Comparison of GPS & Ionosonde TEC
- TEC Maps & Electron density profiles
- Conclusions

6-8 Nov 2004 SOHO images & Aurora



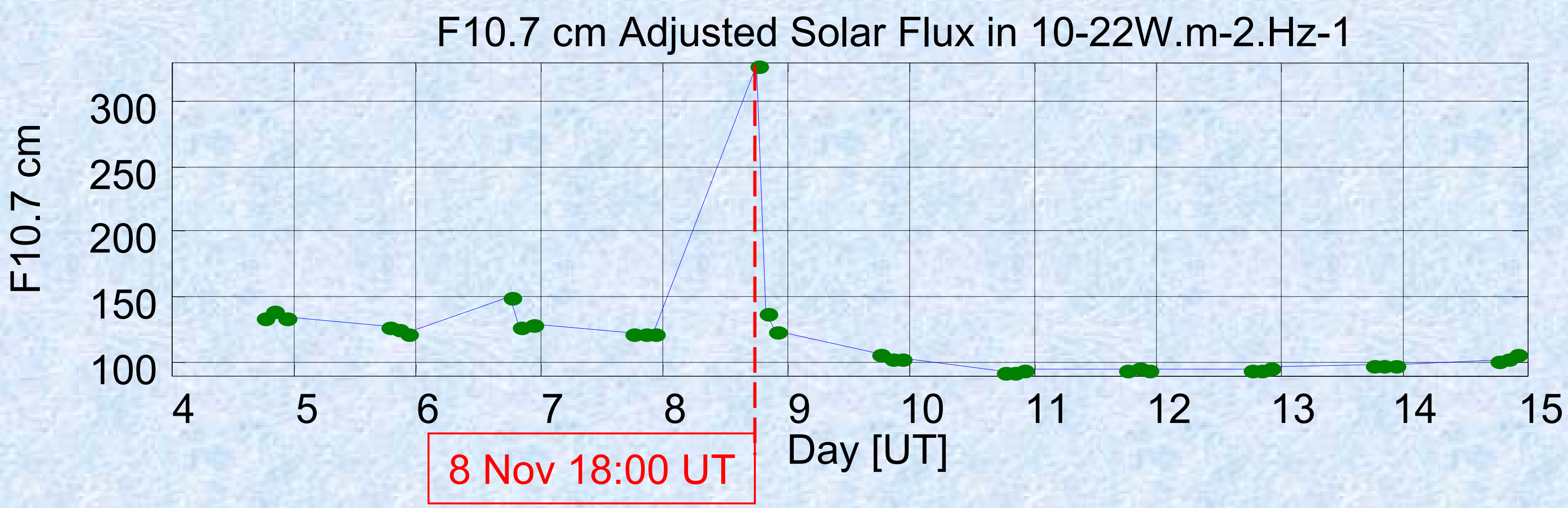
SOHO image of coronal mass ejection, which left the Sun on Nov. 6th, from coronal holes associated with sunspot 696, and reached Earth at about 10:00 UT (=12:00 LT) on Nov. 7th(doy 312), producing Aurora Borealis as far south as Oklahoma and California in the United States, and Aurora Australis as far north as North Island New Zeeland.



Mid-latitude Aurora Australasis observed on 8 Nov 2004 Wairarapa, North Island New Zeeland, (geographic 175.5294º E, 40.8903º S, magnetic latitude 101.6ºW, 46.8ºS); Such mid-latitude aurora is typically caused by electron precipitation from the radiation belt, rather than from the tail of the magnetosphere.

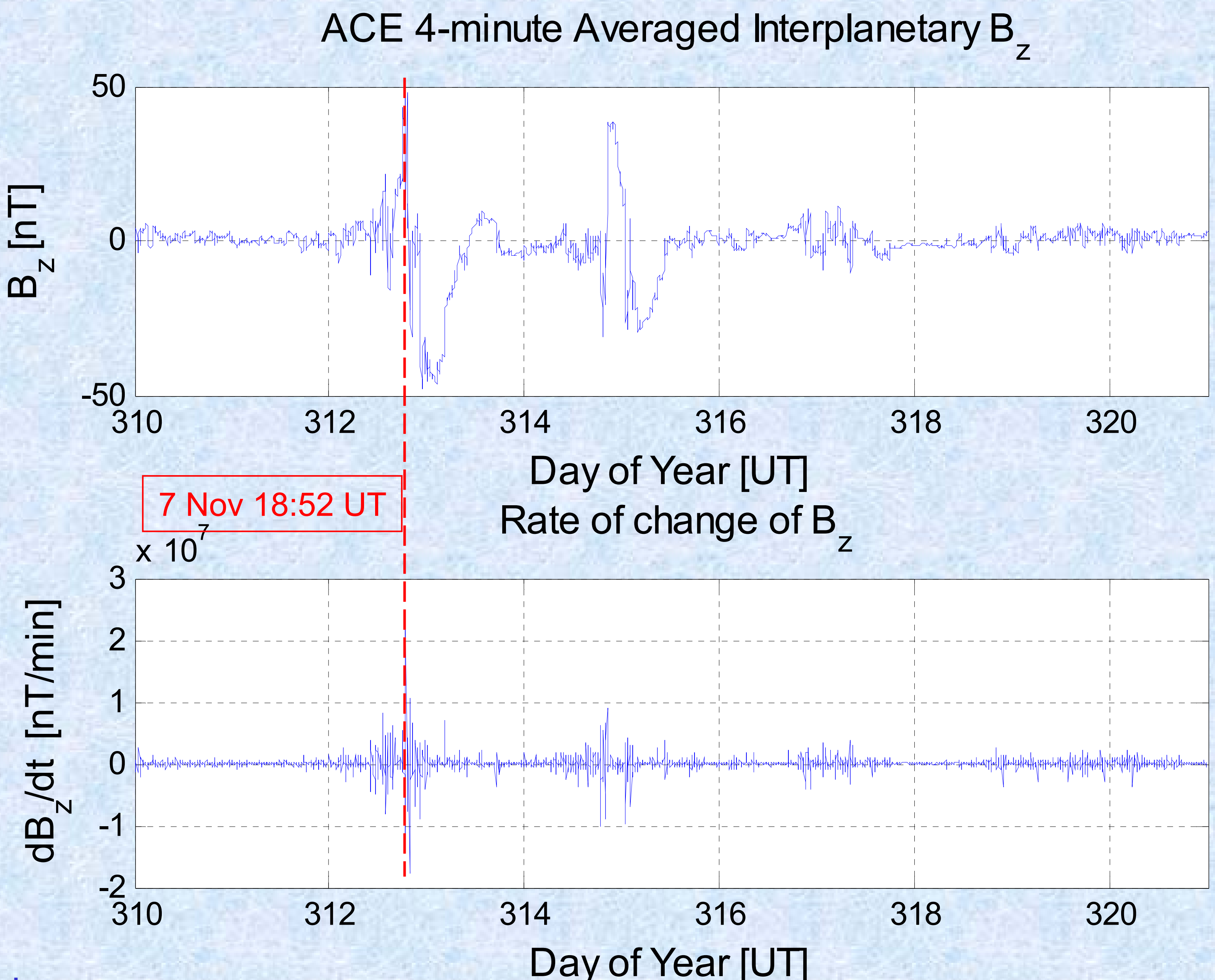
Image courtesy: Christopher Picking, chris@starrynightphotos.com

Solar flux



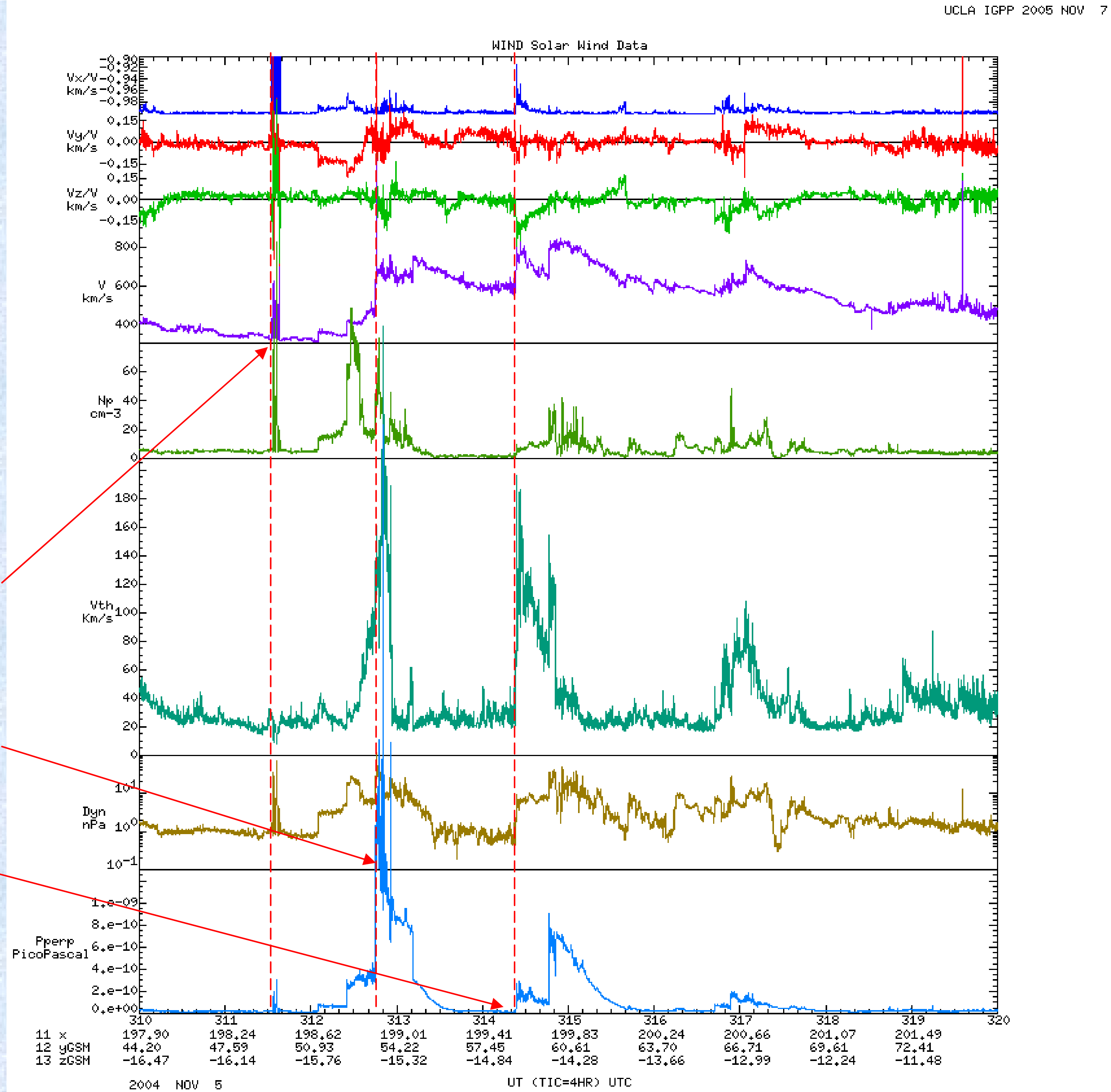
Data from: http://www.drao-ofr.hia-iha.nrc-cnrc.gc.ca/icarus/www/current.txt

Bz


ACE 4-minute Averaged Interplanetary B_z
B_z [nT]
50
0
-50
310
312
314
316
318
320
Day of Year [UT]
7 Nov 18:52 UT
Rate of change of B_z
x 10^7
3
2
1
0
-1
-2
dB_z/dt [nT/min]
310
312
314
316
318
320
Day of Year [UT]

Solar wind

WIND satellite data from:
http://www-ssc.igpp.ucla.edu/cgi-bin/solar_wind_master.v4



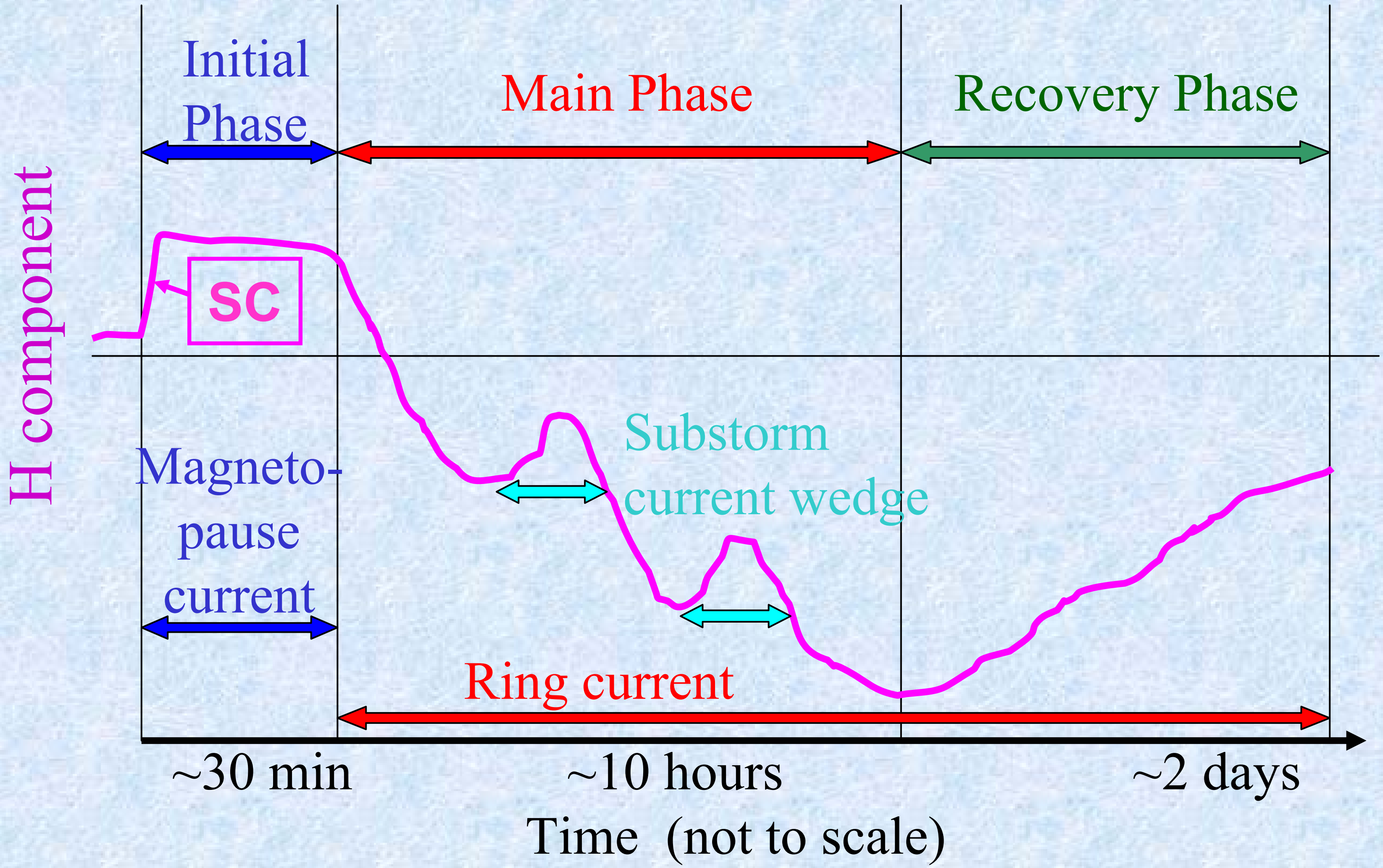
6 Nov 12:30 UT

7 Nov 16:30 UT

9 Nov 08:15 UT

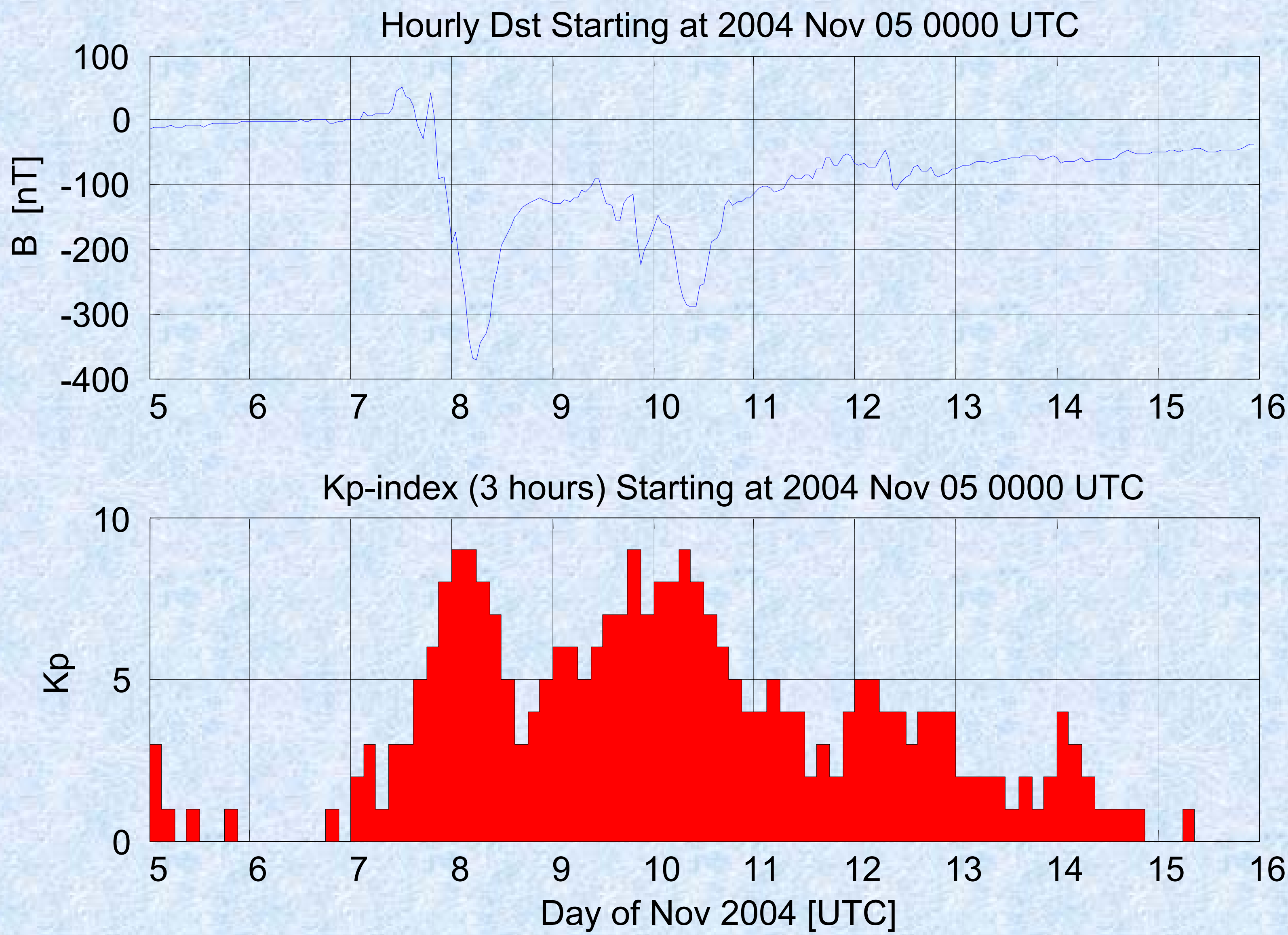
http://www.hmo.ac.za

Idealised geomagnetic storm



Schematic representation to illustrate the phases of a geomagnetic storm.

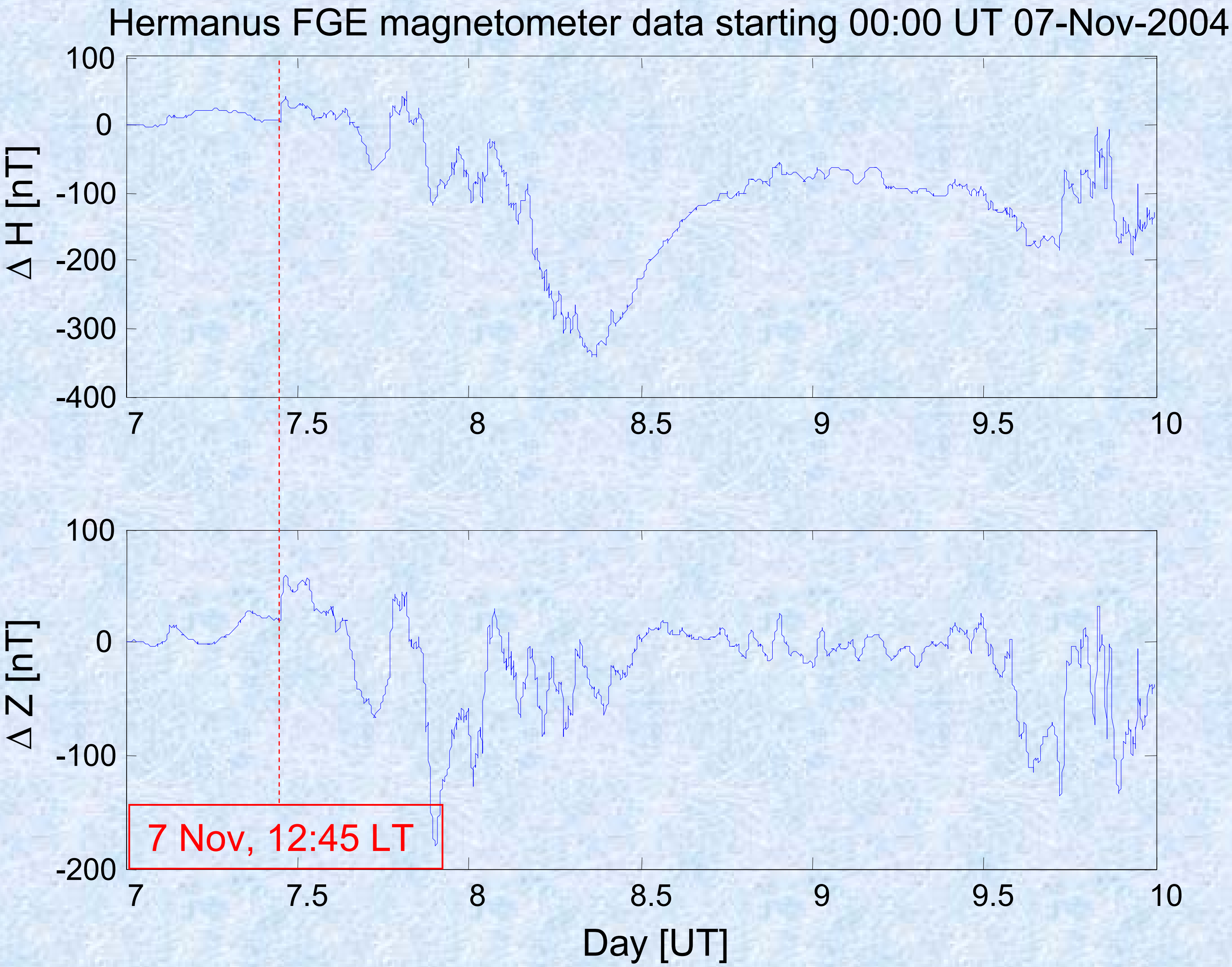
Dst & Kp



Hourly Dst Starting at 2004 Nov 05 0000 UTC
B [nT]
100
0
-100
-200
-300
-400
5 6 7 8 9 10 11 12 13 14 15 16
Kp-index (3 hours) Starting at 2004 Nov 05 0000 UTC
Kp
10
5
0
5 6 7 8 9 10 11 12 13 14 15 16
Day of Nov 2004 [UTC]

7-9 Nov 2004 Hermanus Magnetometer data

FGE 3-axis suspended fluxgate magnetomete. Data sampled at 5 sec and averaged over 1 min.



Both the H and Z-components show a sudden impulse followed by a large decrease in the magnetic field intensity, which is the defining signature of a magnetic storm. The large decrease in the H component is due to the storm time ring current.

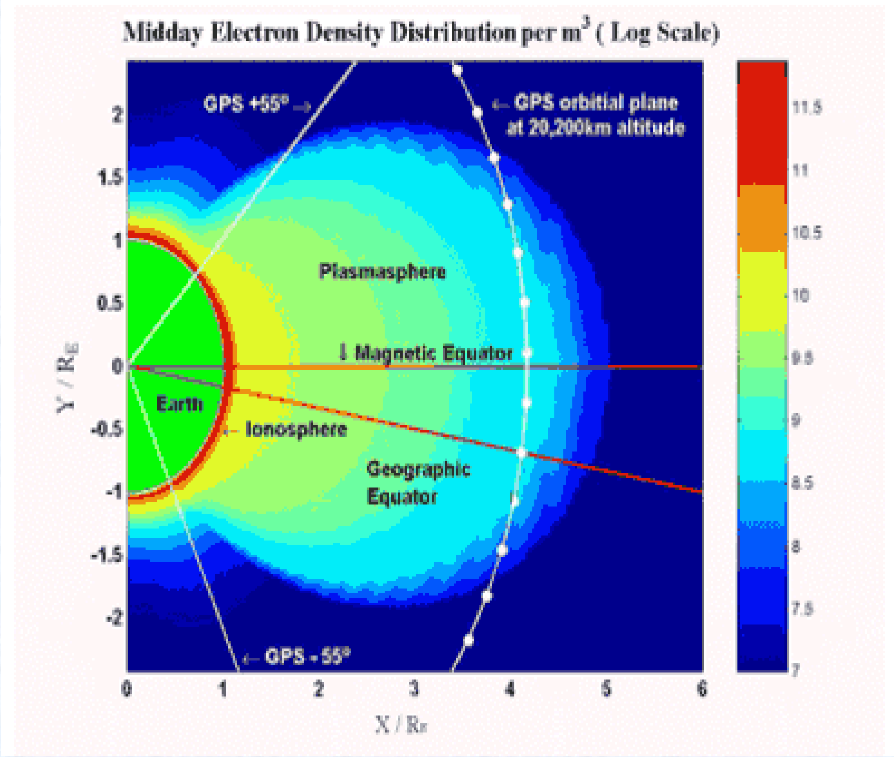
http://www.hmo.ac.za

Observations & ionospheric parameters

- Ionosonde data from 3 x DPS-4 ionosondes
  - Electron density profiles (ARTIST)
  - Total Electron Content (ITEC)
  - foF2, hmF2
- GPS data from 10 x 24/7 Ashtec Z12 GPS dual frequency receivers
  - TEC (SHM & MIDAS)
  - Electron Density profiles (MIDAS)

Mechanisms which affect mid-latitude ionosphere-plasmasphere ion exchange

- ExB drift
- Disturbance ring current
- Equatorward neutral winds
- Rapid heating: thermal expansion & change in ion production & loss rates
- Sudden ionospheric disturbances (SIDs)
- High latitude particle precipitation
- Storm enhanced density plumes
- Magnetospheric convection.

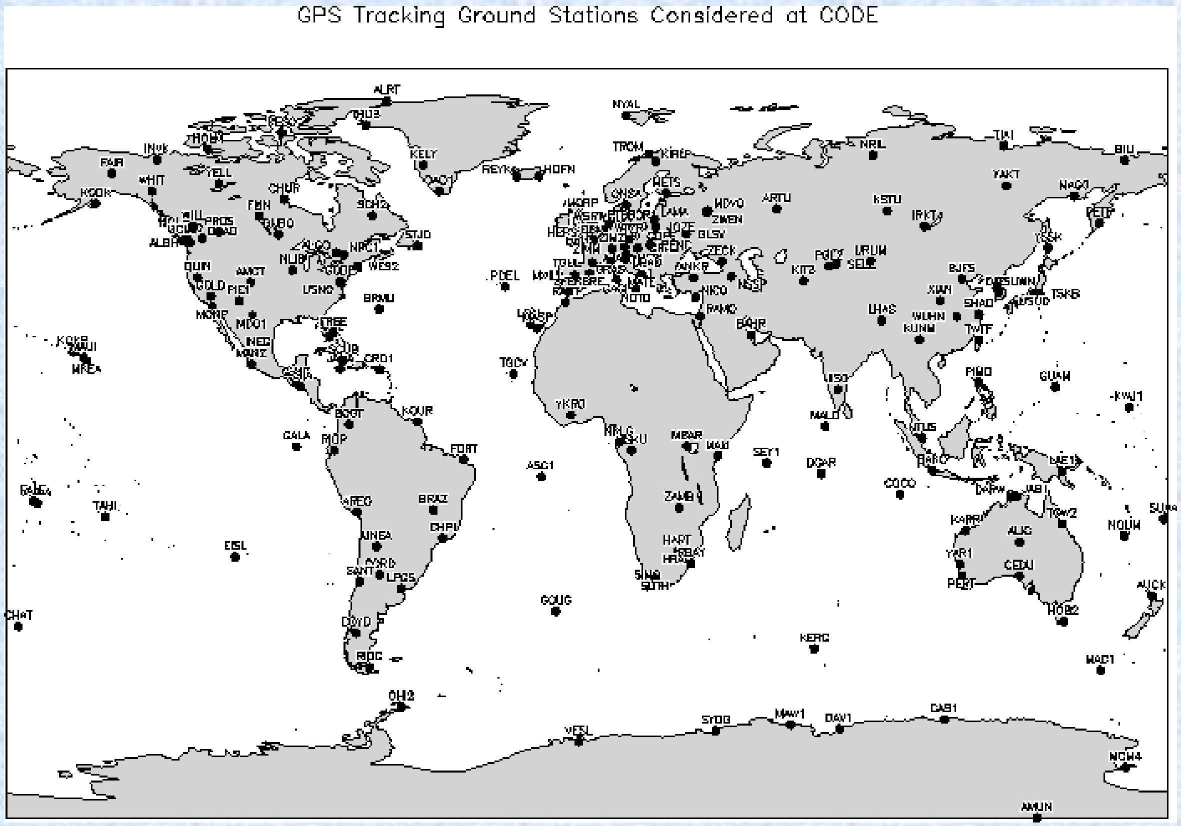


Plasmasphere range : 2 000 - 35 000 km

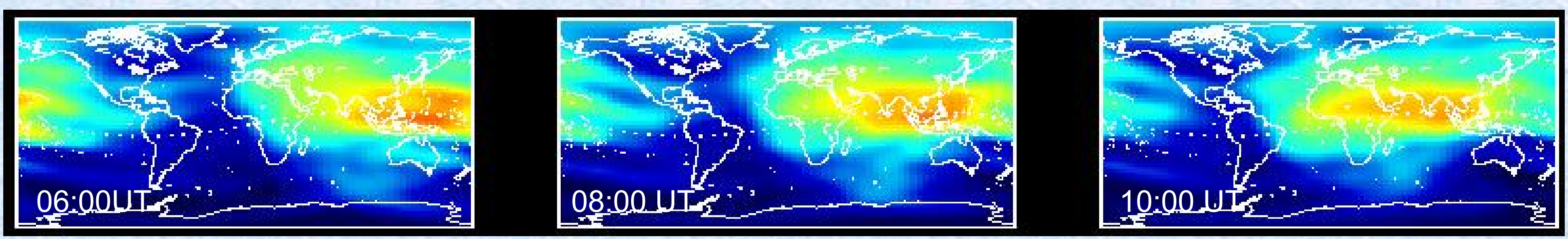
Plasmasphere contribution to TEC:

- Day time: 10%
- Night time: 50-60%

Global TEC maps

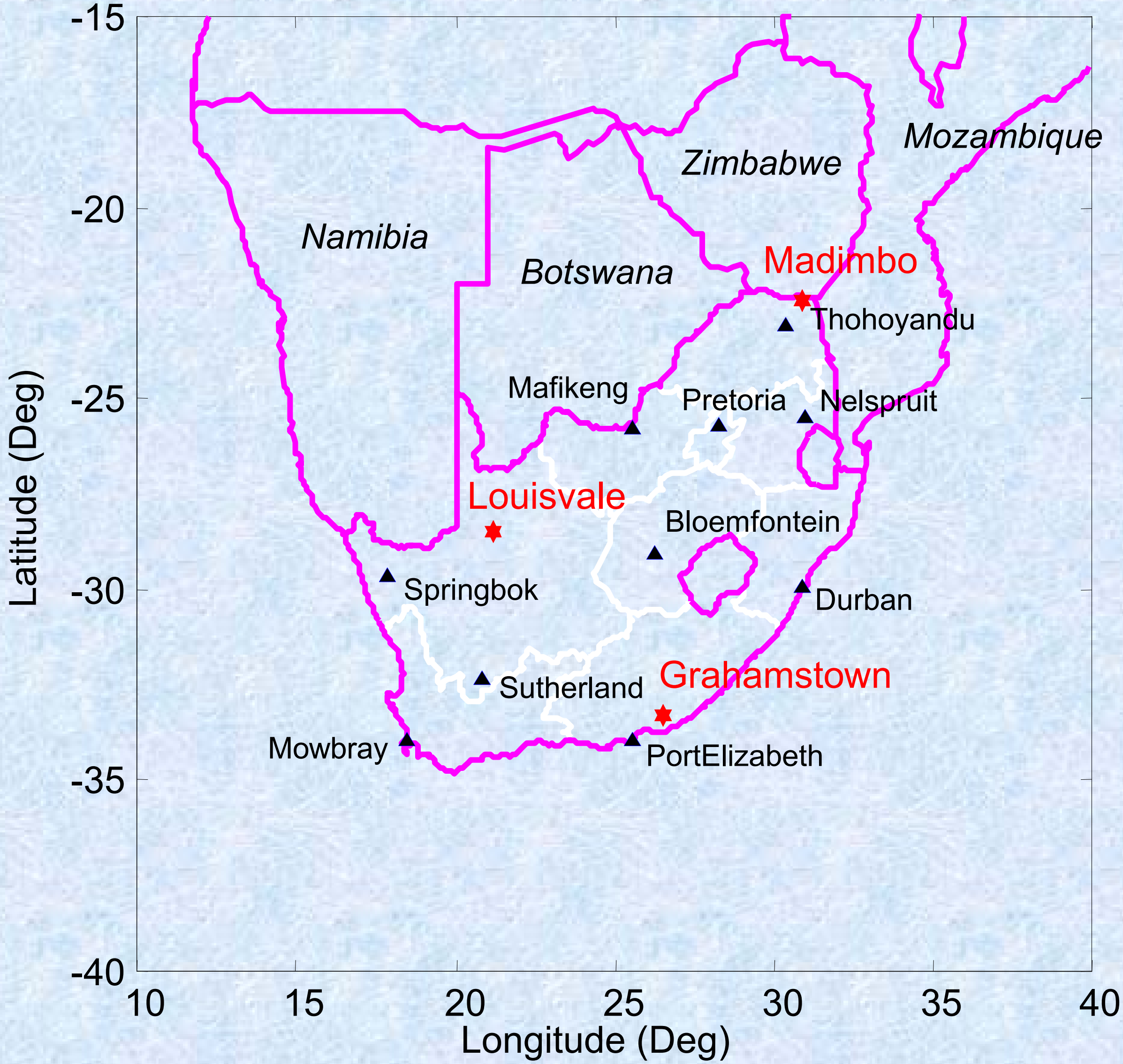


- Global Ionospheric Maps (GIMs) produced daily by Centre for Orbit Determination in Europe (CODE)
- 200 GPS receivers worldwide
- 5 RSA Receivers used:
  - 2 @ Sutherland,
  - 2@ HartRAO
  - Richardsbay
- 13 maps per day, 2h intervals
- Limited resolution



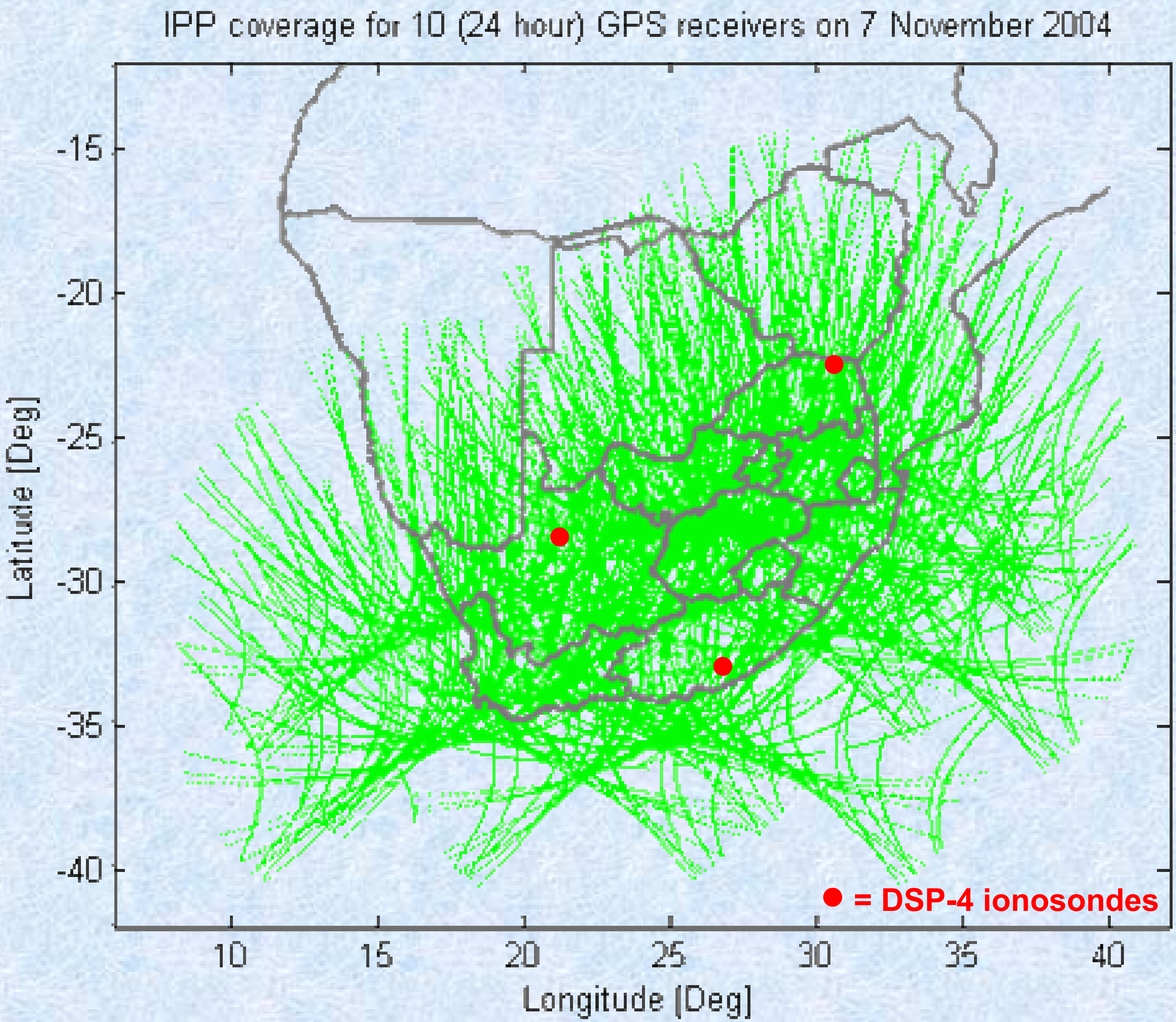
CODE GIMs for 1 July 2005 (http://www.cx.unibe.ch/aiub/ionosphere.html)

GPS receivers & ionosondes



Locations of the three ionosondes (*) and the ten real-time GPS dual frequency receivers (▲) used in this study.

24h IPP Coverage of all GPS receivers used (15 ° elevation mask)



Spherical Harmonic (SHM) TEC Model

Coefficients for vertical TEC interpolation, and interfrequency GPS biases estimated from 24 hours of vertical TEC at IPPs, decimated at 60 s, using Spherical Harmonic Model (SHM) of degree and order 12 solved by least squared method.

$$TEC(\lambda,\phi) = \sum_{n=0}^{N}\sum_{m=0}^{n} \overline{P}_{nm}[\sin(\phi)]\left\{a_{nm}\sin(m\lambda) + b_{nm}\cos(m\lambda)\right\}$$

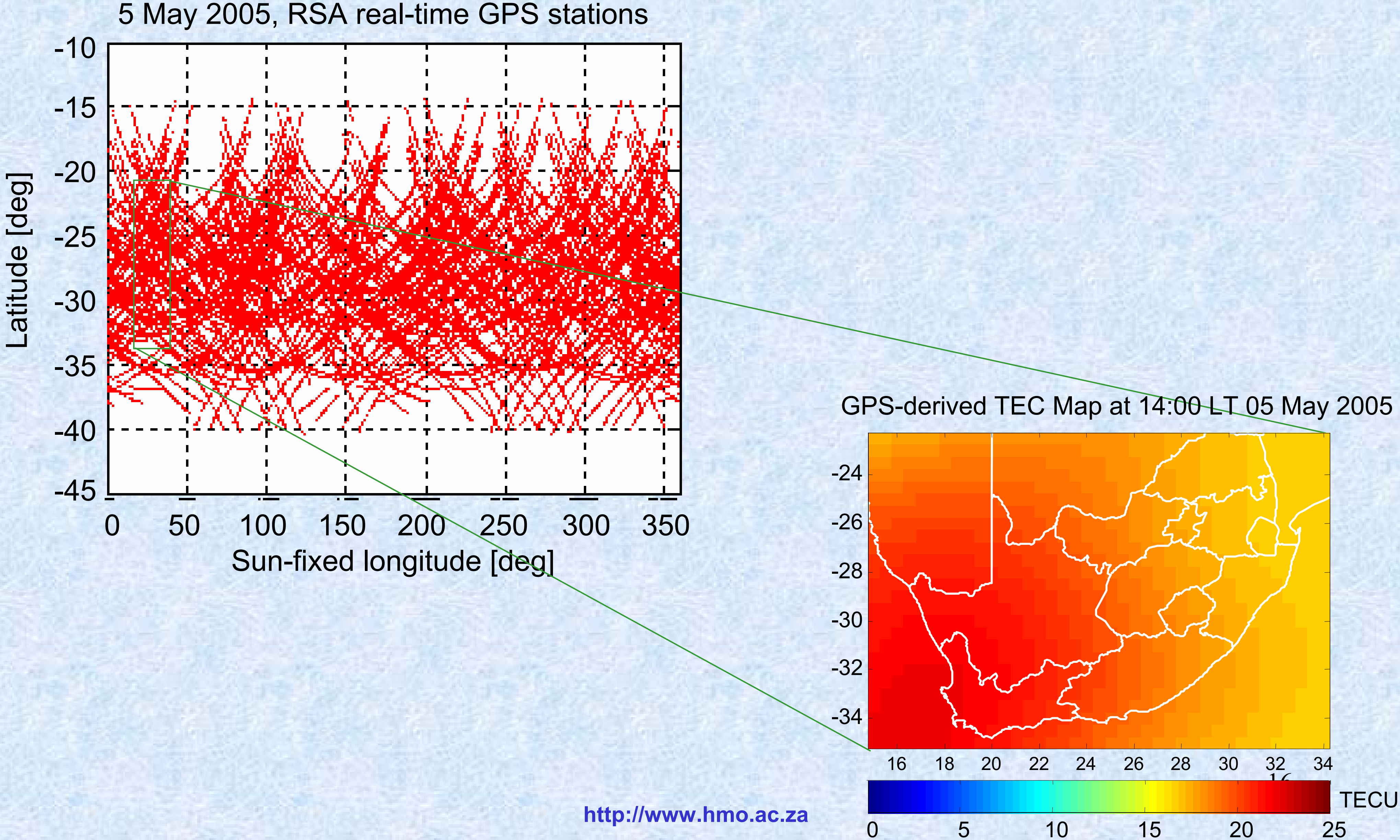
$\lambda = \text{Sun-fixed longitude}$

$\phi = \text{geographic latitude}$

$\overline{P}_{nm} = \text{Normalized associated Legendre functions}$

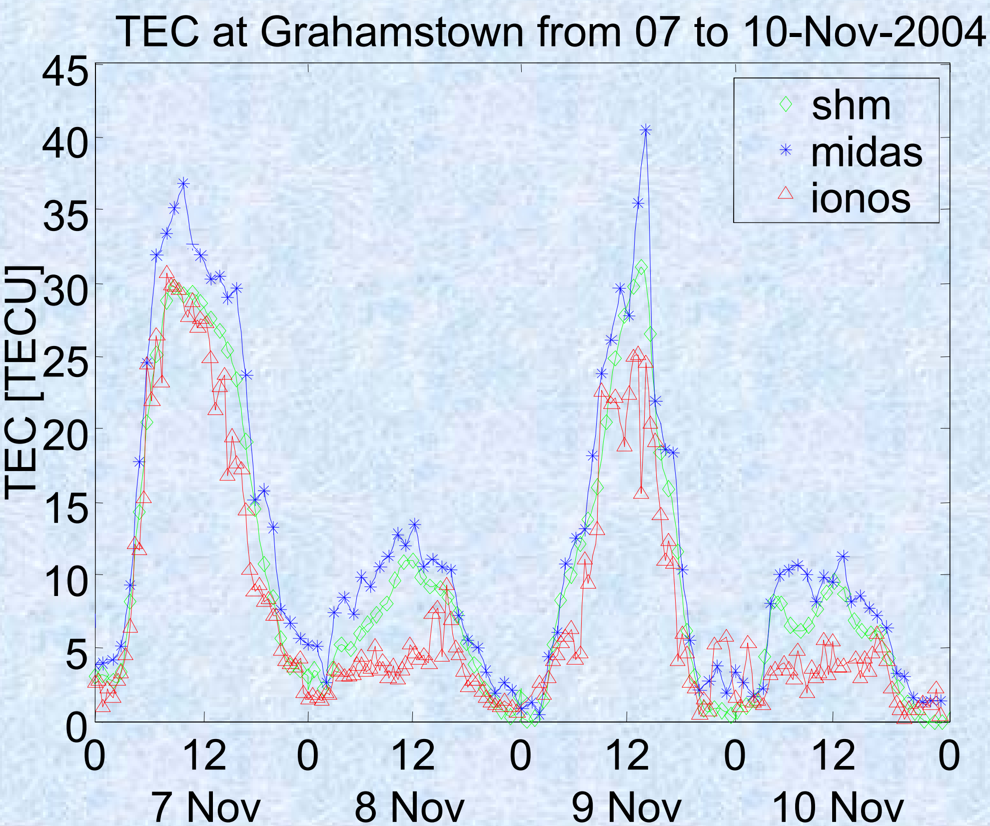
$a_{nm}, b_{nm} = \text{desired SHM coefficients}$

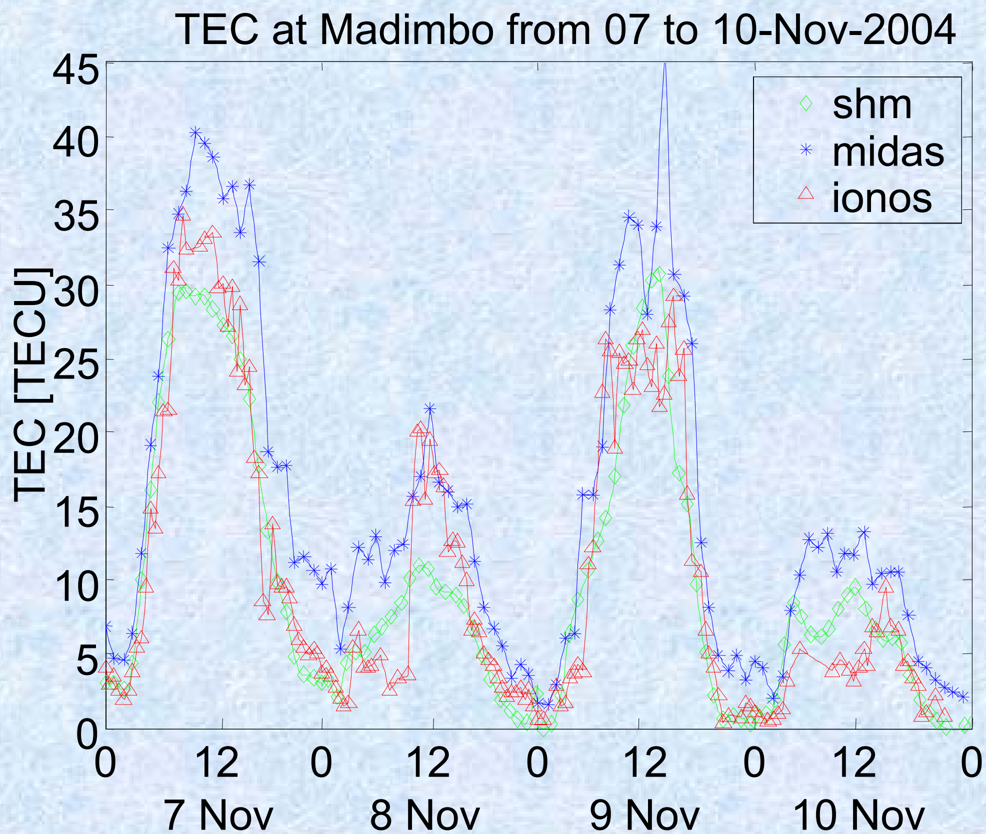
2D GPS TEC map using SHM

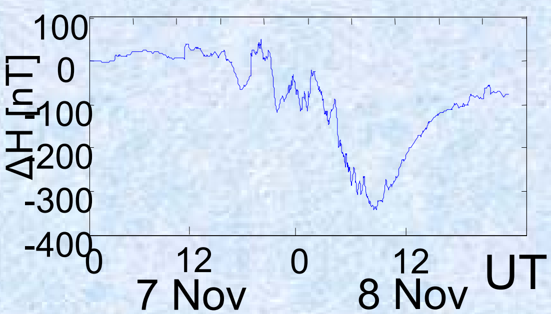


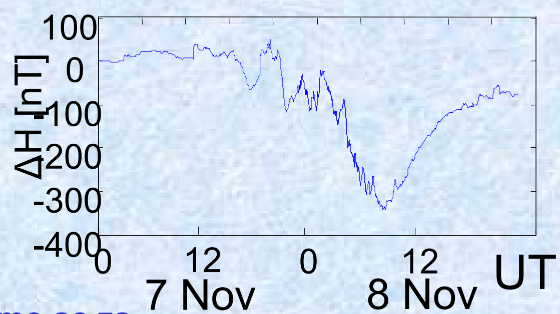
http://www.hmo.ac.za

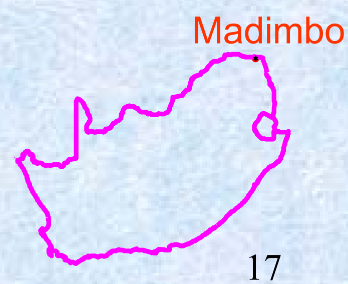
Total Electron Content



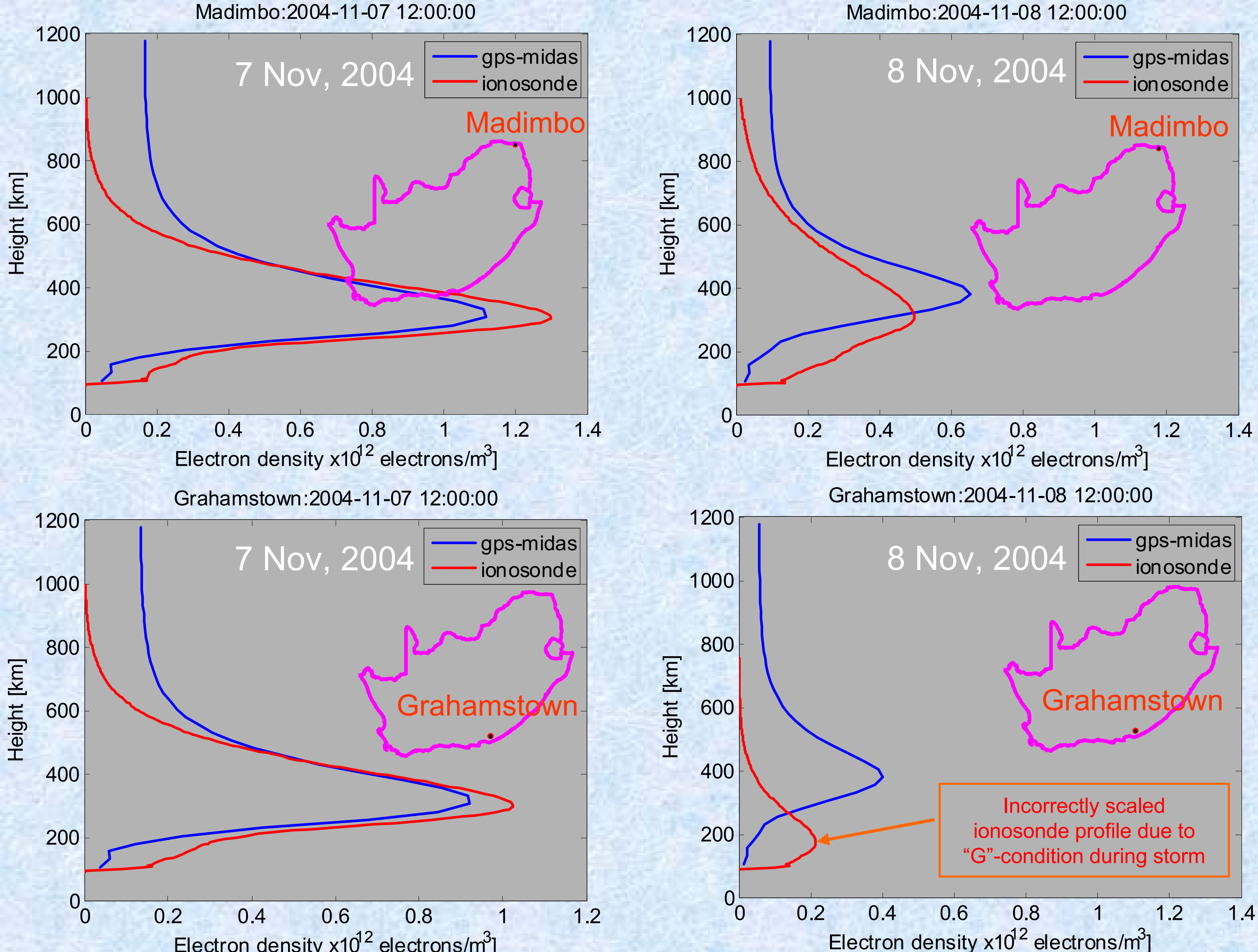




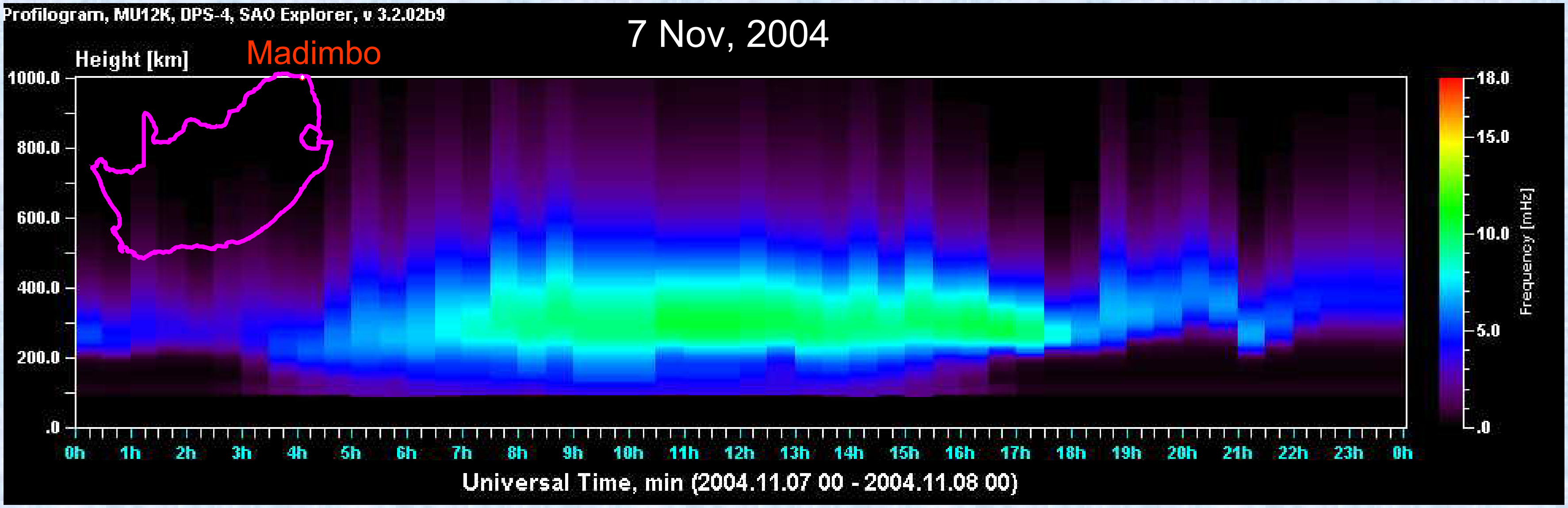


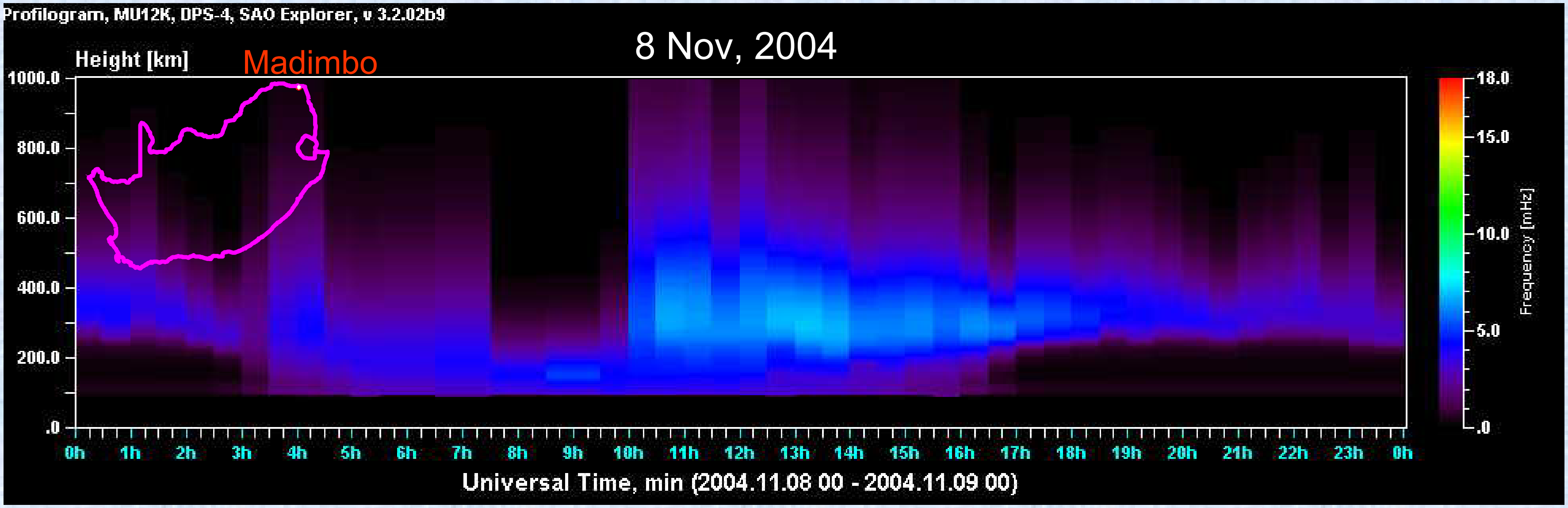


MIDAS Electron density @ 12h00 UT



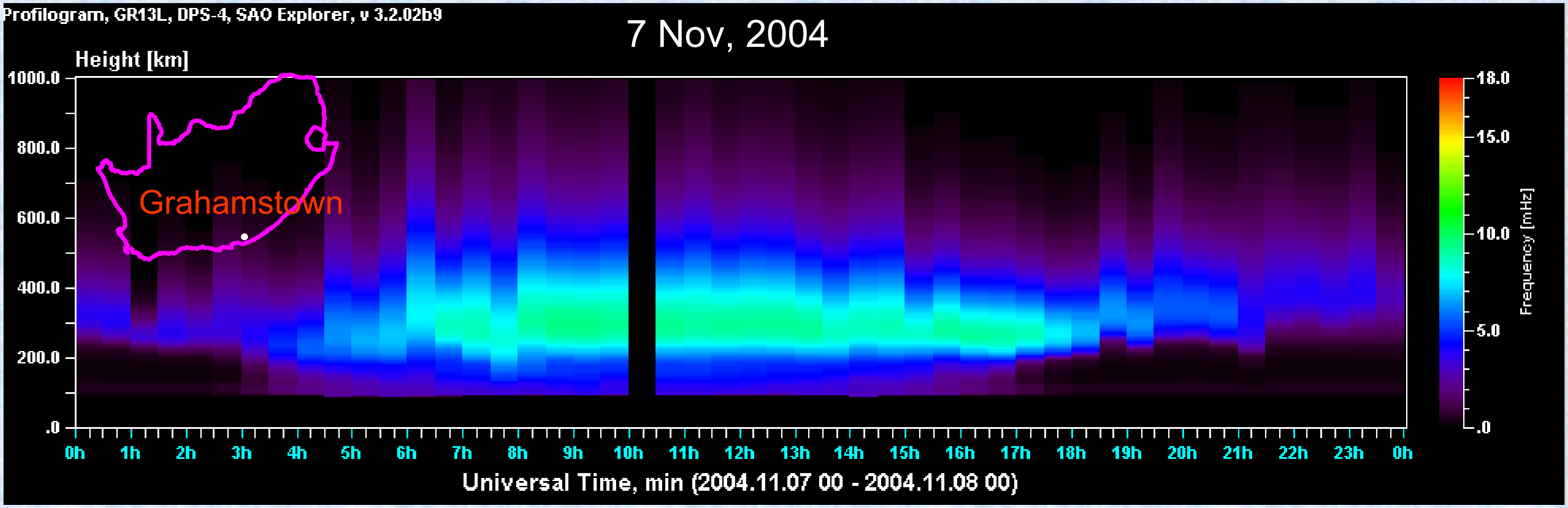
Ionosonde profilograms 7&8 Nov 2004, Madimbo

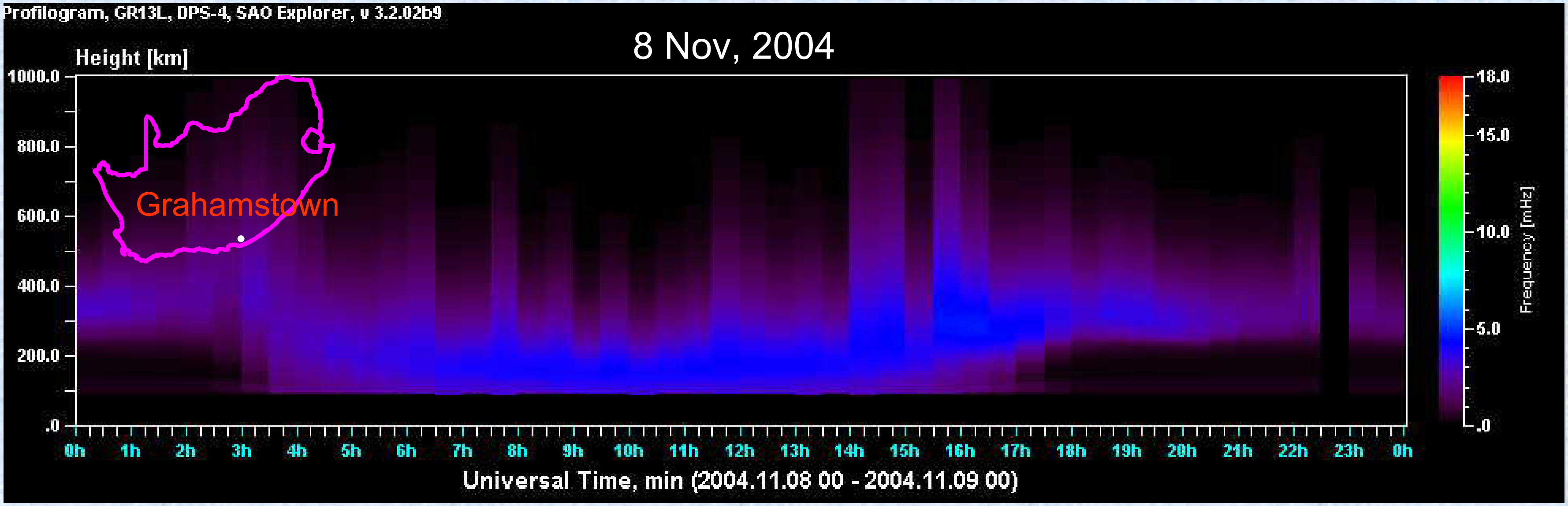




http://www.hmo.ac.za

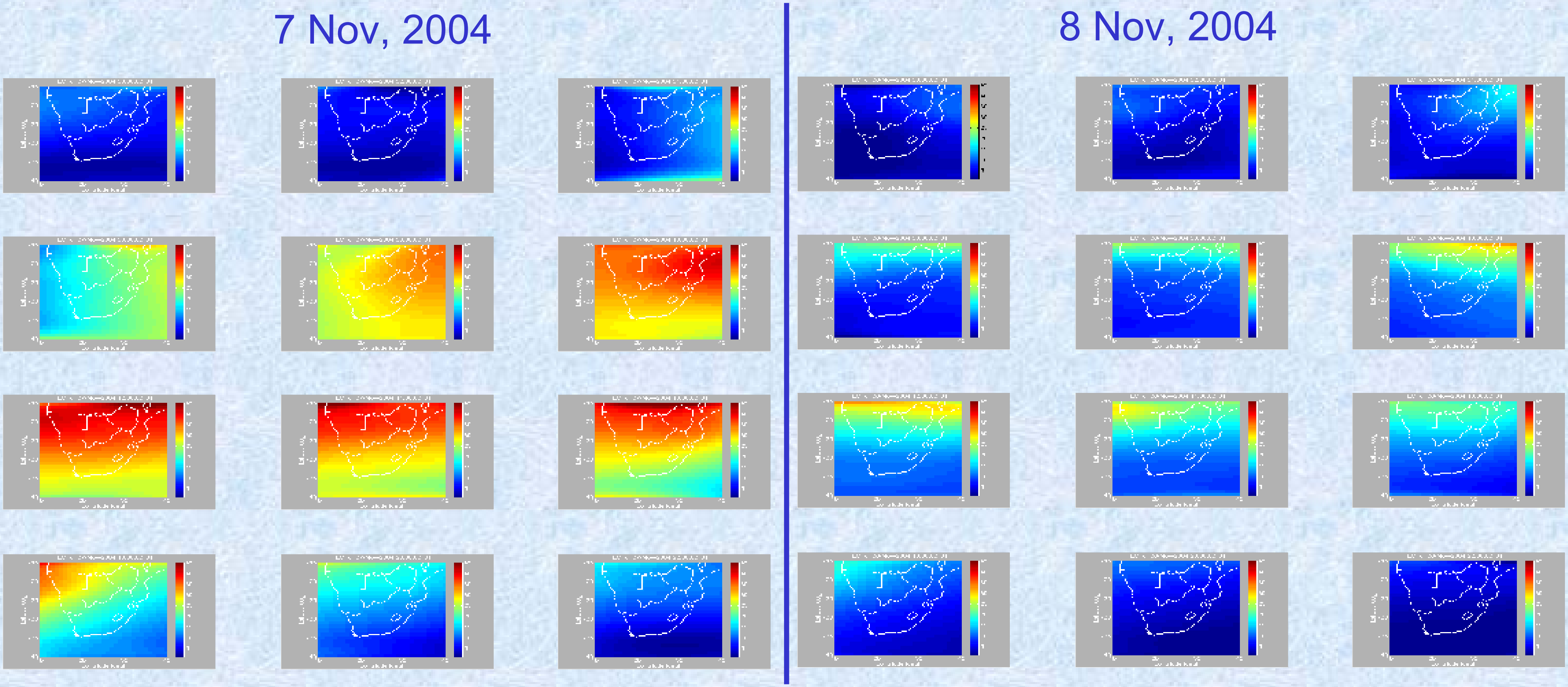
Ionosonde profilograms 7&8 Nov 2004, Grahamstown





GPS TEC maps in 2 hour increments

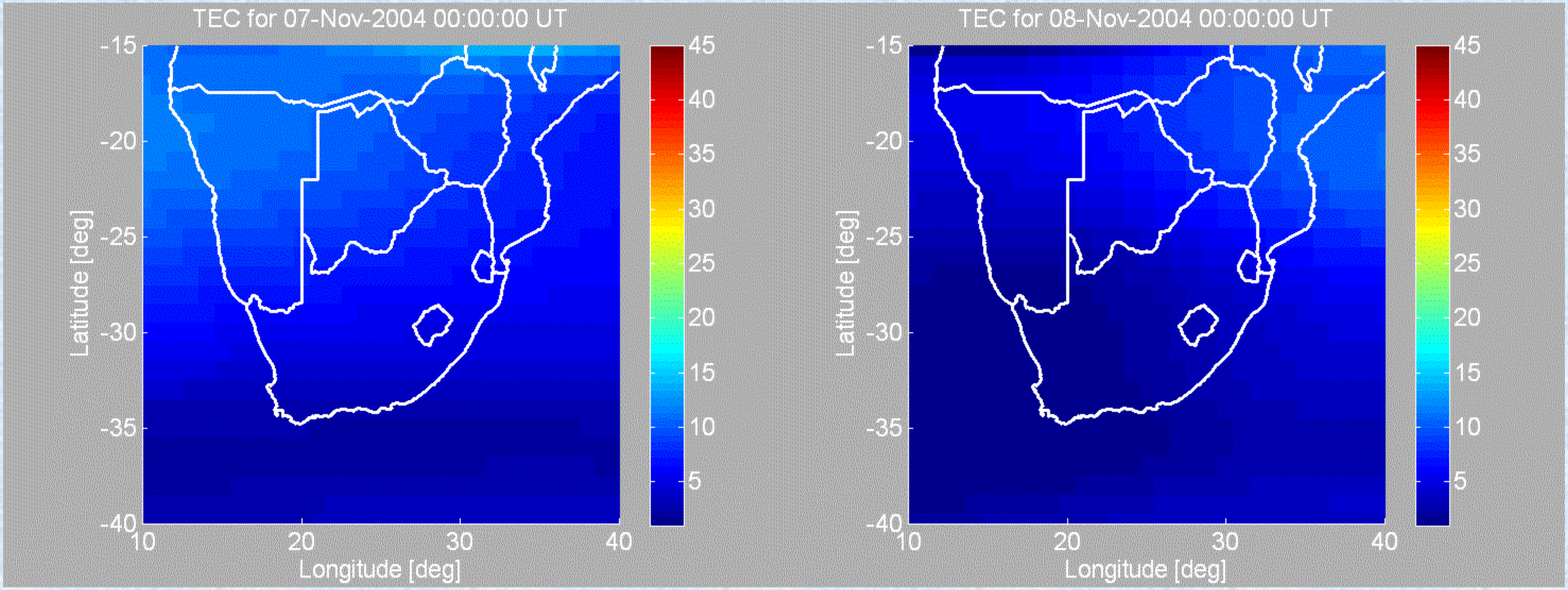
7 Nov, 2004 | 8 Nov, 2004



TEC maps determined from 24 hours of GPS data decimated to 60 s, and interpolated using a 12th order Spherical Harmonic Model. Maps shows snapshots at 2 hour intervals.

GPS TEC movies in 15 min increments

7 Nov, 2004 | 8 Nov, 2004



TEC movies determined from 24 hours of GPS data decimated to 60 s, and interpolated using a 12th order Spherical Harmonic Model. Movie shows snapshots at 15 minute intervals.

http://www.hmo.ac.za

Comparisons of GPS-MIDAS, Ionosonde & LAM NN model

- During the quiet days (7 Nov & 9 Nov) GPS, Ionosonde and LAM Neural Network model agree fairly well with almost the same values for hmF2 and slightly different values for the peak electron density (Ne(max)).
- GPS-MIDAS seems to underestimate Ne(max) by about 10% compared to ARTIST and the LAM model overestimates Ne(max) by about 20% compared to ARTIST.
- On storm days (8 Nov & 10 Nov) it is not obvious which of the three methods gives the “correct” electron density profile. Because of the reasons given above, the ARTIST is least likely to be correct. The LAM derived Ne(max) seems to be close to that of GPS-MIDAS, but the hmF2 values differ significantly.

Conclusions

- RSA GPS receiver infrastructure is sufficient for giving 24/7 ionospheric dynamic mapping with better resolution than from IGS stations alone.
- TEC significantly reduced on storm days 8 Nov & 10 Nov.
- Dynamic ionospheric TEC-maps may be valuable to investigate ionospheric dynamics during geomagnetic storms.
- Some evidence of decrease in TEC directly after SC phase of storm.

Acknowledgements

- The Chief Directorate Surveys & Mapping (CDSM) of South Africa for making available the GPS data.
- Grintek Ewation for the ionosonde data.
- Dst indeces from WDC for Geomagnetism, Kyoto Dst index service, as derived by M. Sugiura and T. Kamei.

Thank you