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Perturbations in F-region vertical drift associated with cloud-to-ground lightning strikes

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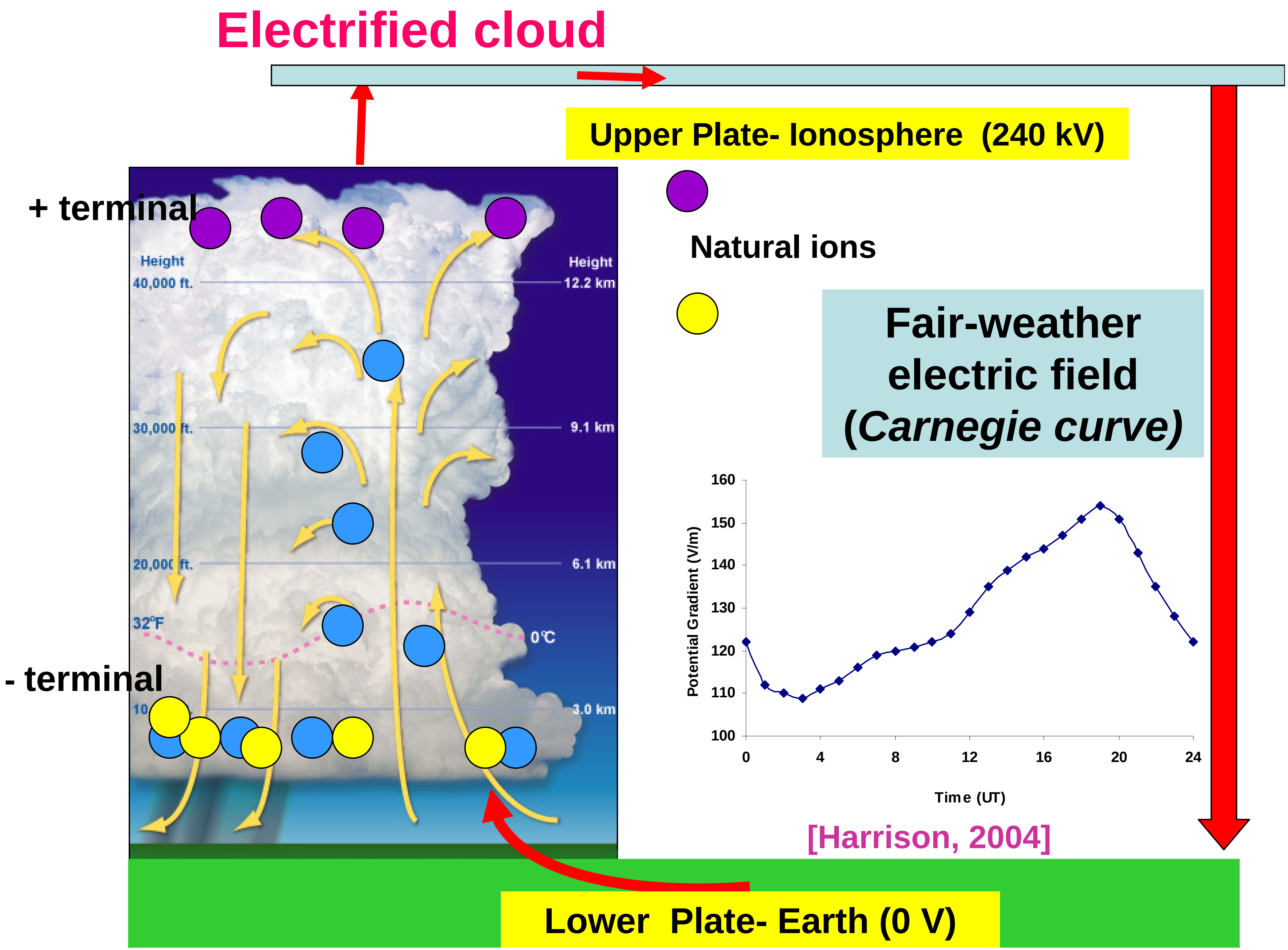
Presentation statement

Here we present statistically significant reproducible responses of a vertical descent of the F-region ionosphere associated with tropospheric thunderstorms located within the vicinity.

Bundoora, Melbourne (145.1°E, 37.7°S)

August 2003 – August 2004

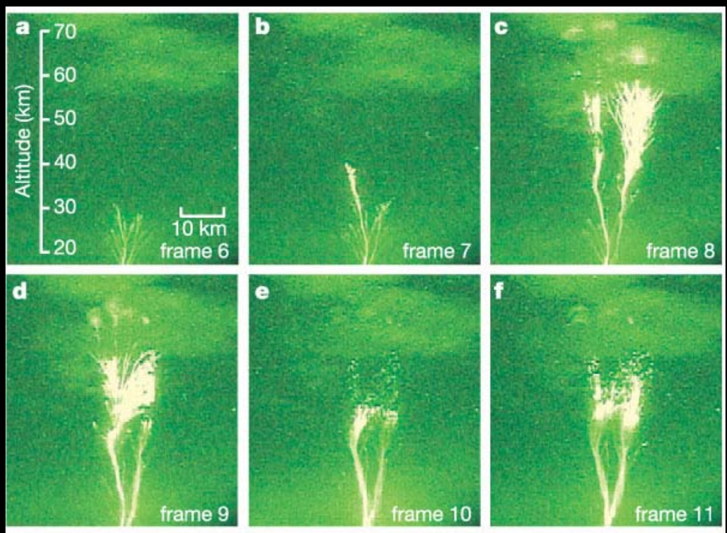
August 2007 – August 2008 (Work in progress)



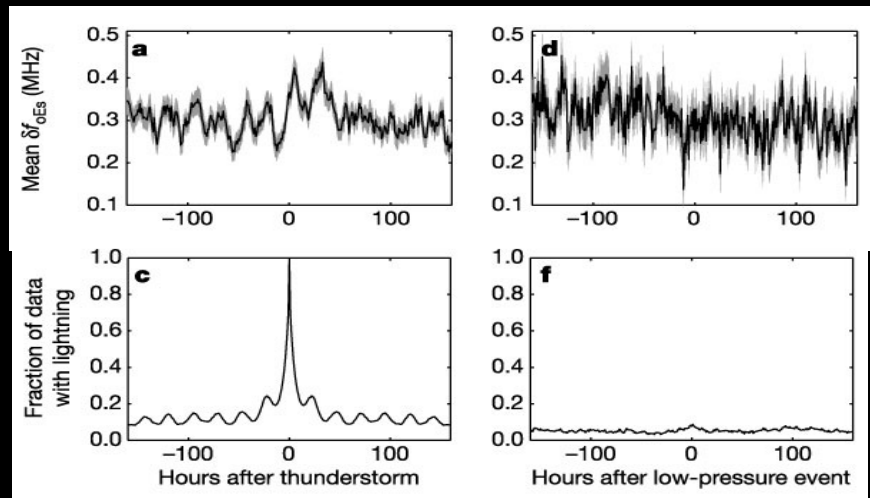
Electrified cloud
Upper Plate- Ionosphere (240 kV)
+ terminal
Height
40,000 ft.
30,000 ft.
20,000 ft.
32°F
- terminal
Height
12.2 km
9.1 km
6.1 km
0℃
3.0 km
Natural ions
Fair-weather electric field (*Carnegie curve*)
Potential Gradient (V/m)
160
150
140
130
120
110
100
0
4
8
12
16
20
24
Time (UT)
[Harrison, 2004]
Lower Plate- Earth (0 V)

Thunderstorms and F-region coupling

- **Several potential models and theories involving electrical discharges [Woodman and Kudeki, 1984; Pasko et al., 2002]; electrostatic heating [e.g. Pasko et al., 1995]; enhancements in ambient conductivity above thunderstorms [Rodger, 1999] and wave dynamics, e.g. acoustic gravity waves [Chimonas, 1971] explain the coupling between the thunderstorms and ionosphere, however the fundamental mechanism is still unclear.**

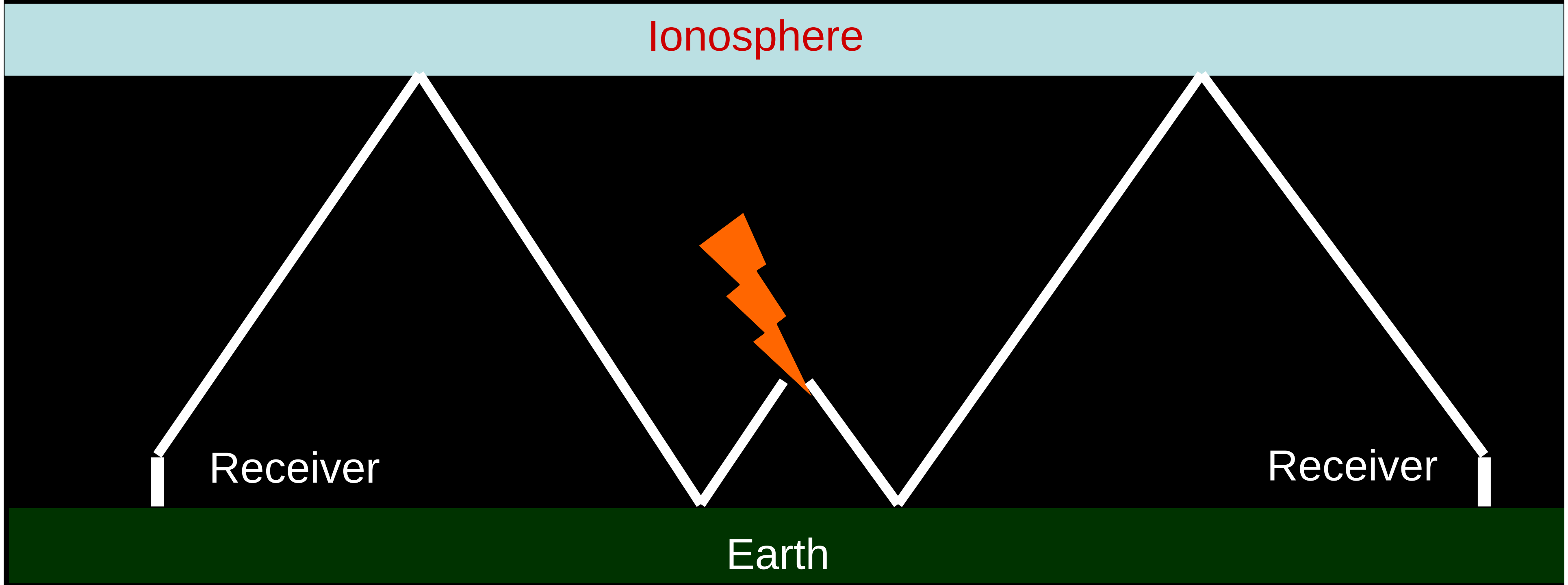


(Pasko et al., 2002)

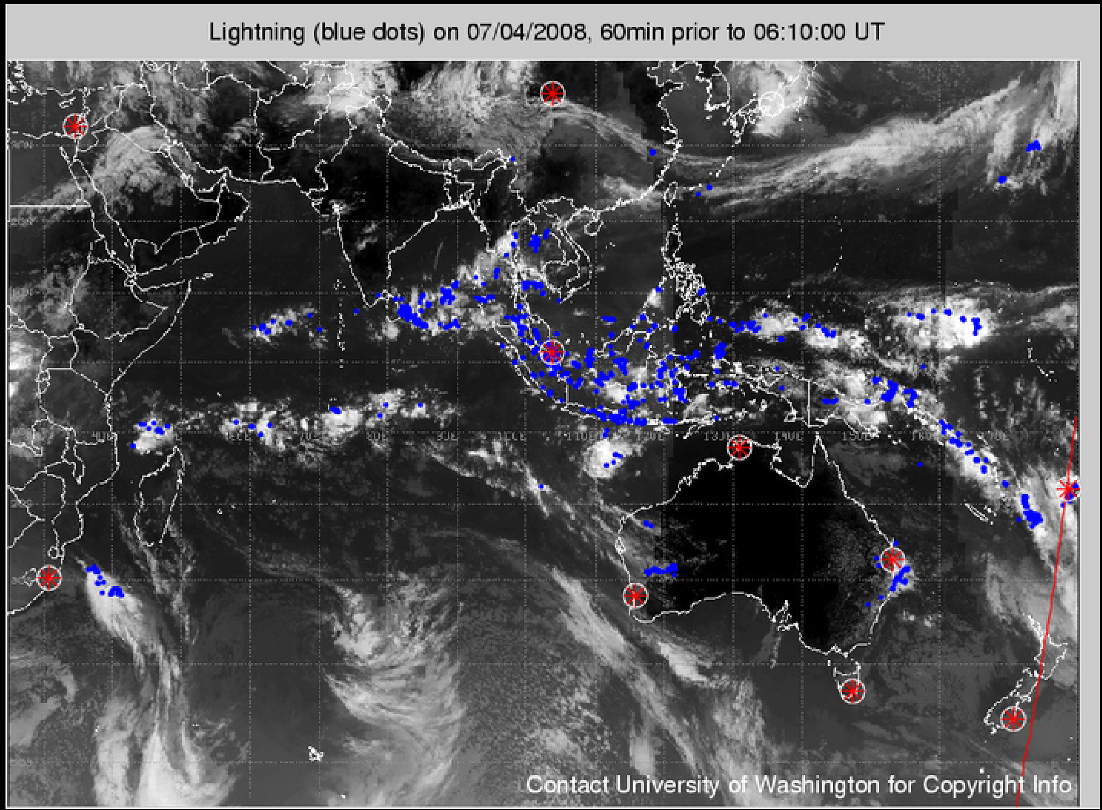


(Davis & Johnson, 2005)

Quantifying thunderstorm occurrence



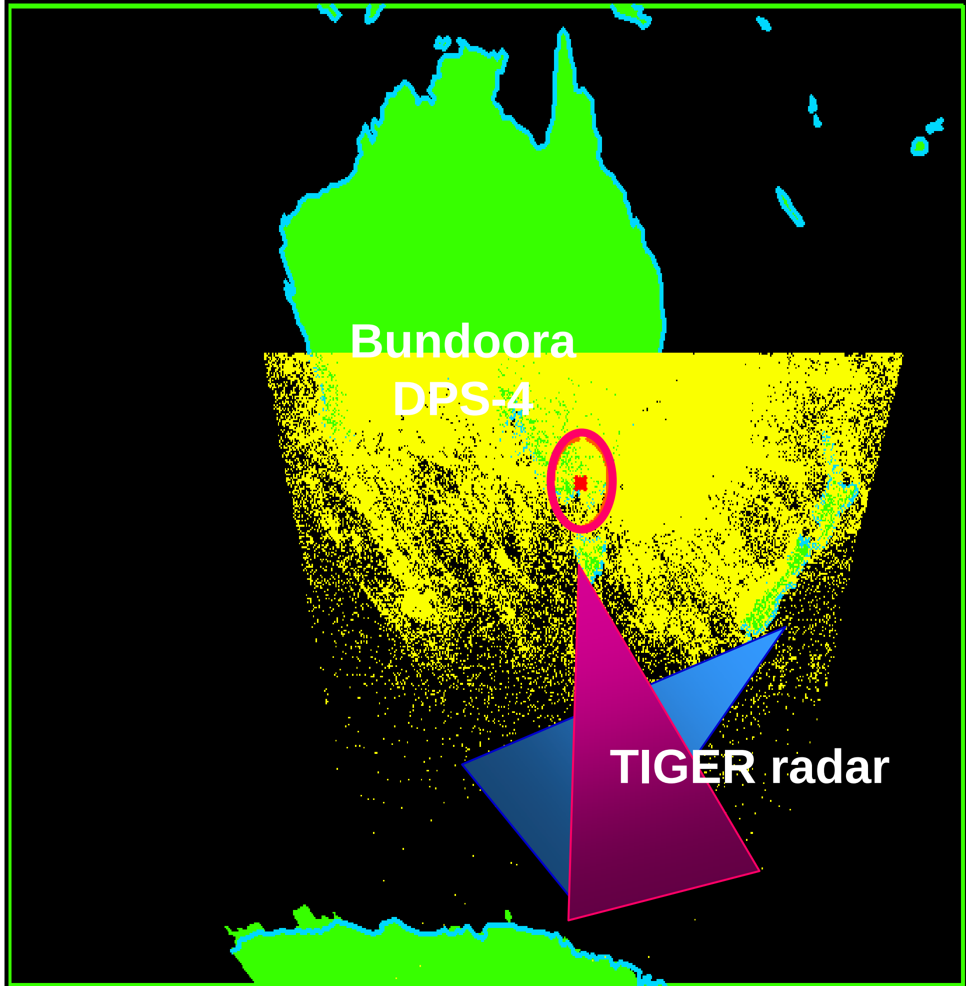
The CG lightning strokes emit very low frequency (VLF) radiowave pulses ‘sferics’ with the peak at ~10 kHz.



World Wide Lightning Location Network (WWLLN) employs the Time of Group Arrival (TOGA) of the VLF radiations from these lightning sferics to locate the positions of the strokes.

WWLLN was fully operational from August 2003; thus our study interval was August 2003 – August 2004.

Southern HF radars



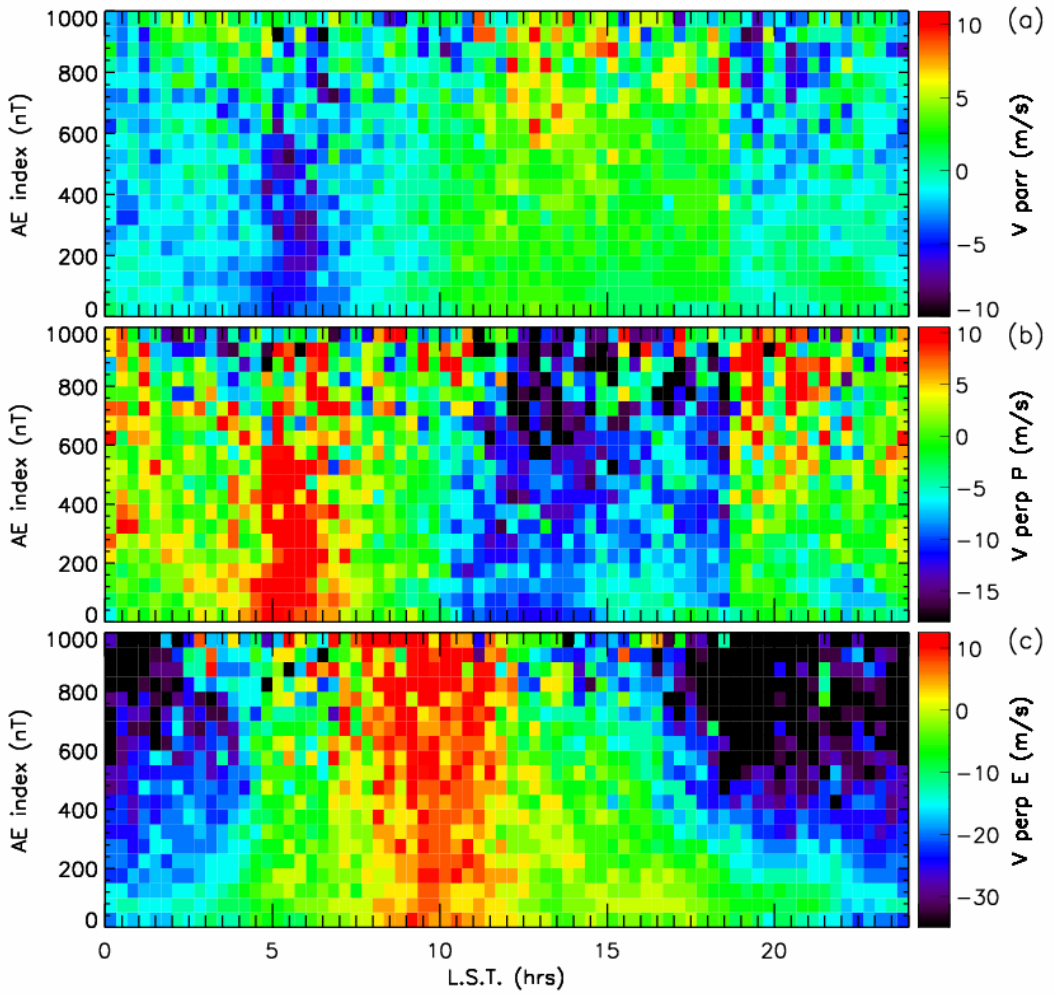
WWLLN Cloud-to-ground lightning strikes[110 to 180 E and 30- 90 S]

Bundoora Digisonde

Bundoora (DSP-4) database extends for almost 7 year

Ionograms (2 min) and drift measurements (8 min) at every 10 min interval

Summary of the F-region dynamics observed in a 5.5-year (1999-2004) Bundoora database



Characteristics of mid-latitudes F-region ionosphere

Distinct diurnal variations

E-region and F-region quiet-time dynamos

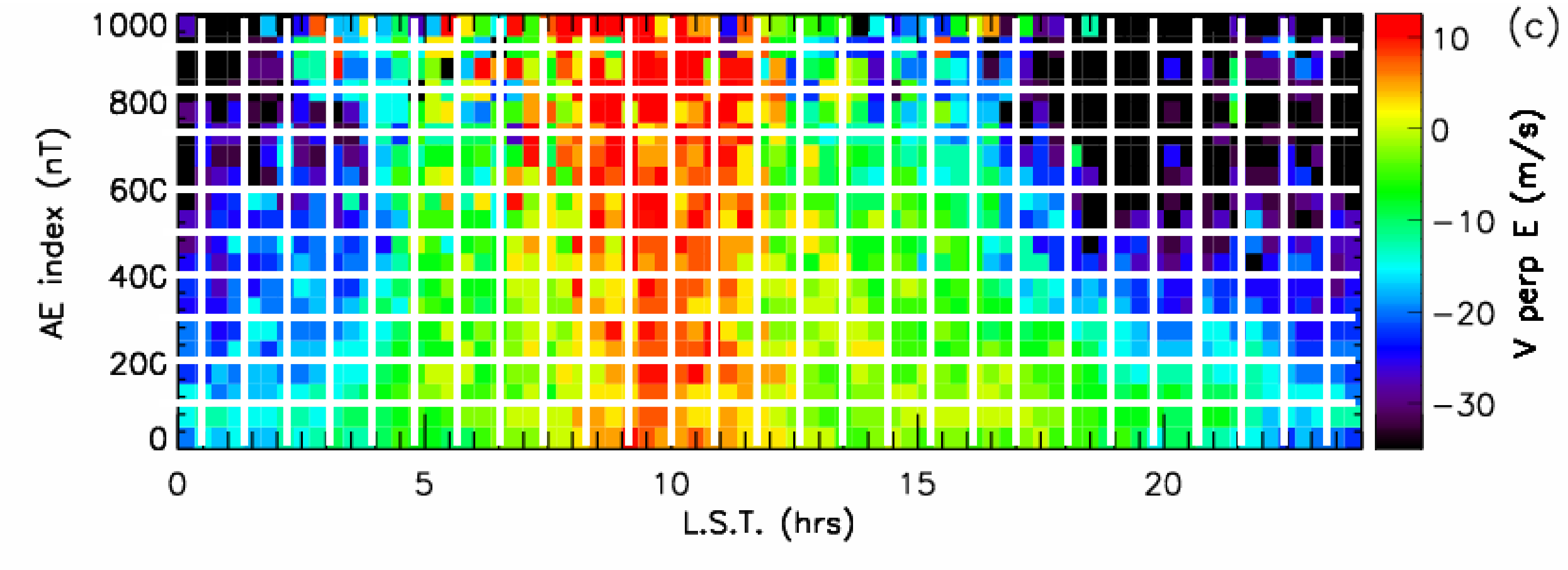
Good sensitivity to 1-min AE-index

There is a clear evidence of enhanced westward flows during the night time, consistent with sub-auroral polarization stream events.

Kumar et al., 2008 (submitted)

The possible effects of thunderstorms may be disguised by these strong mid-latitude ionospheric processes.

An LT-AE model generated using the 5.5 year Bundoora database was used to compensate for the background ionospheric process.

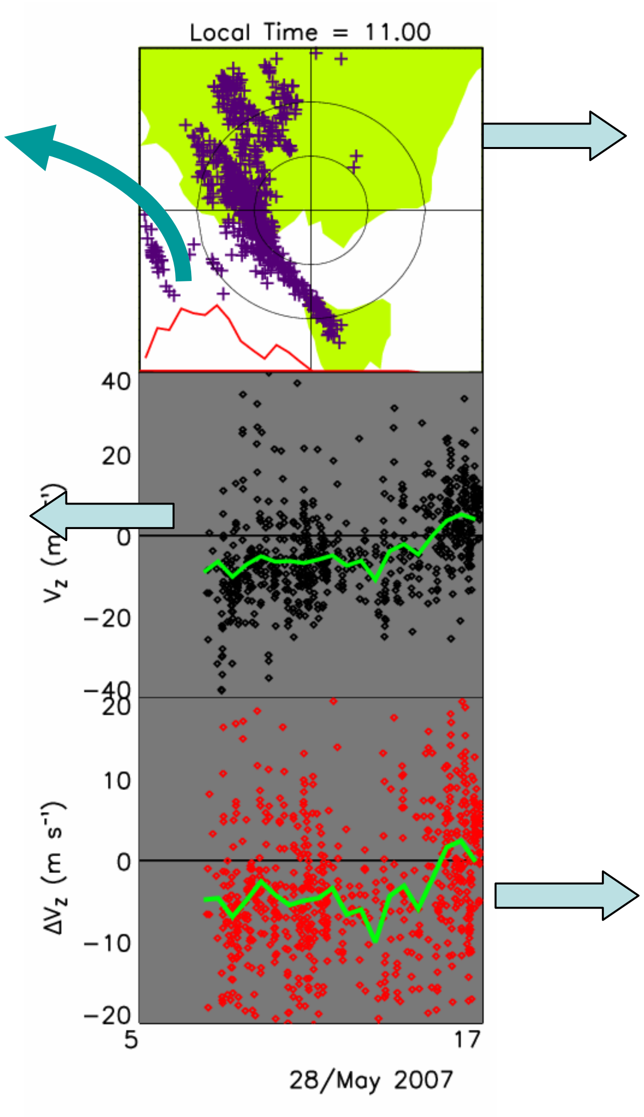


Perturbation (Δ) **= (Measured values) – (LT-AE model value)**

The perturbations showed no diurnal and magnetic dependance.

Typical responses in the overhead ionosphere during thunderstorm days

The drift velocity in the vertical direction is usually the most accurate component because the echoes tend to be concentrated toward zenith; hence the fit errors are larger for the horizontal components.

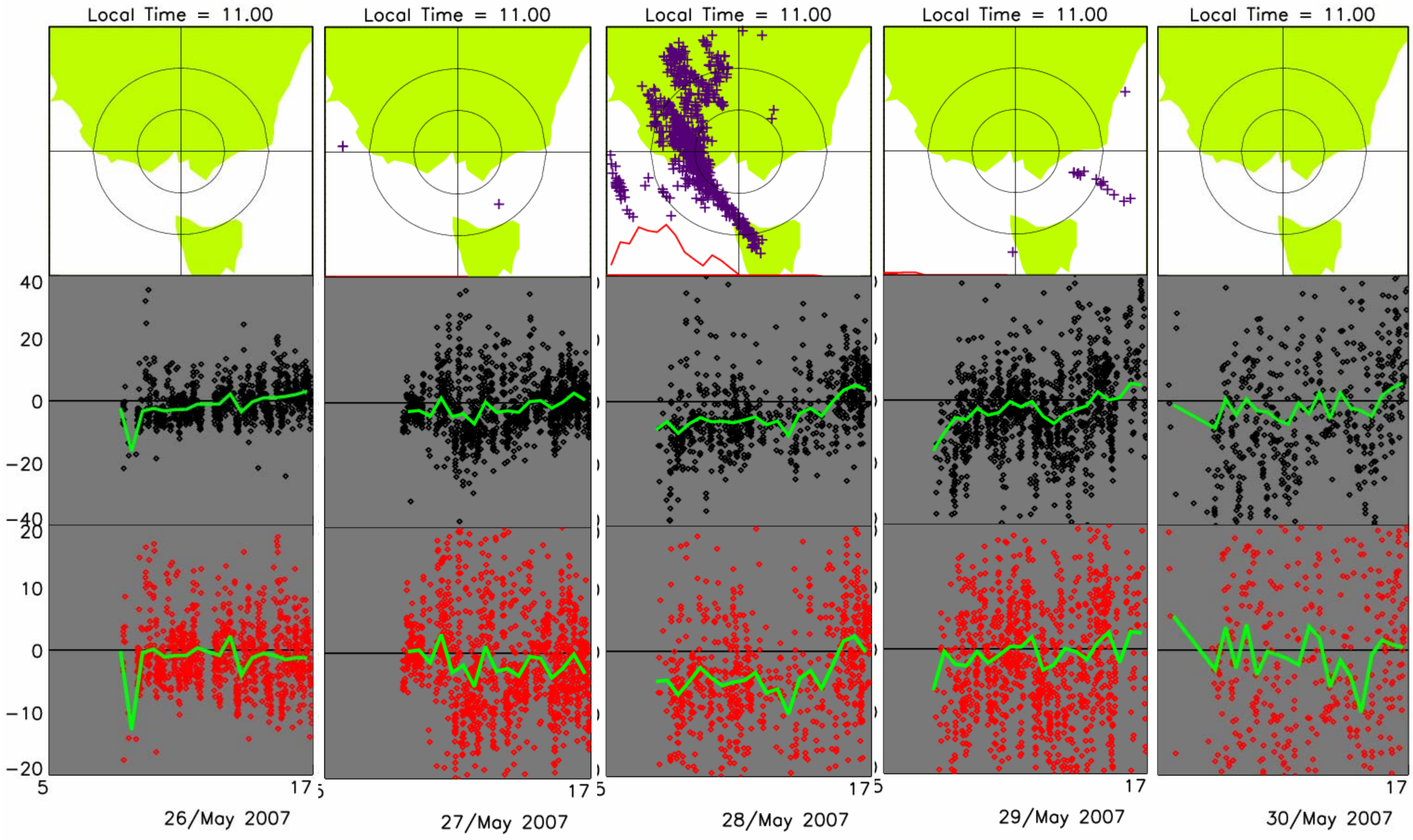


Lightning location within 600 km of Bundoora

Solid green curves are 30 min running average

Perturbation in V_z calculated using LT-AE model

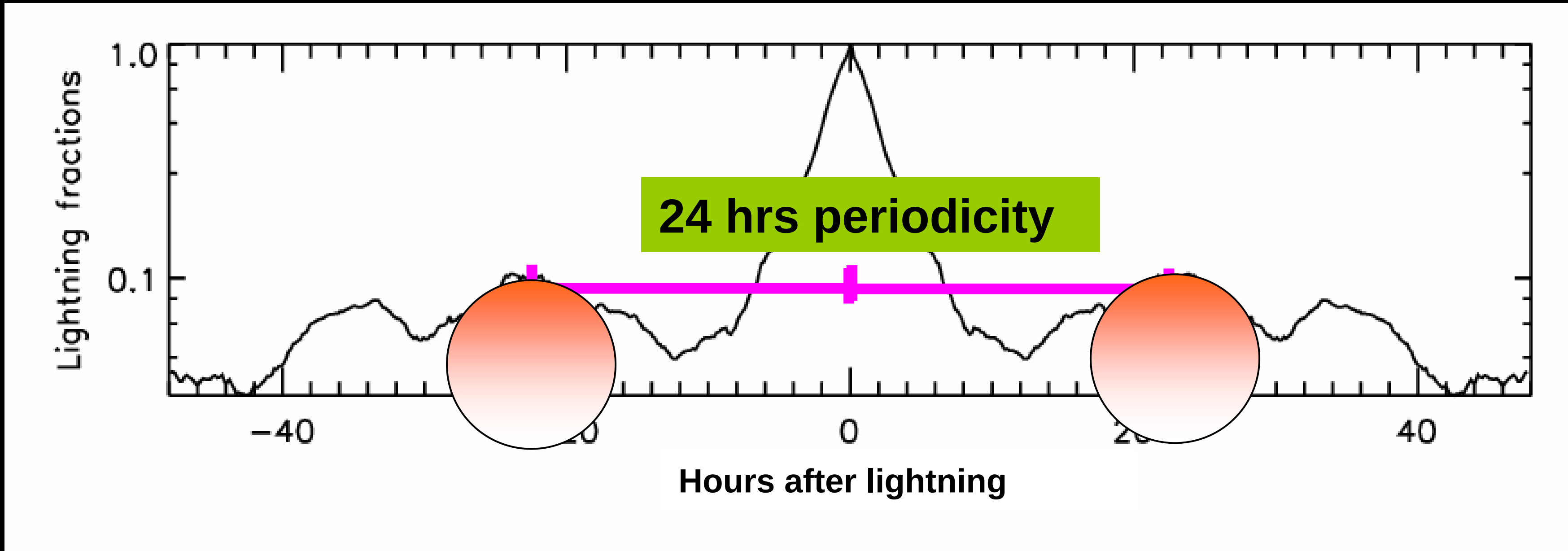
Typical responses in the overhead ionosphere during thunderstorm days



Superposed epoch analysis (SEA)

- **The changes in F-region ionosphere in response to CG lightning strokes were studied for 48 hours on either side of each lightning stroke using SEA.**

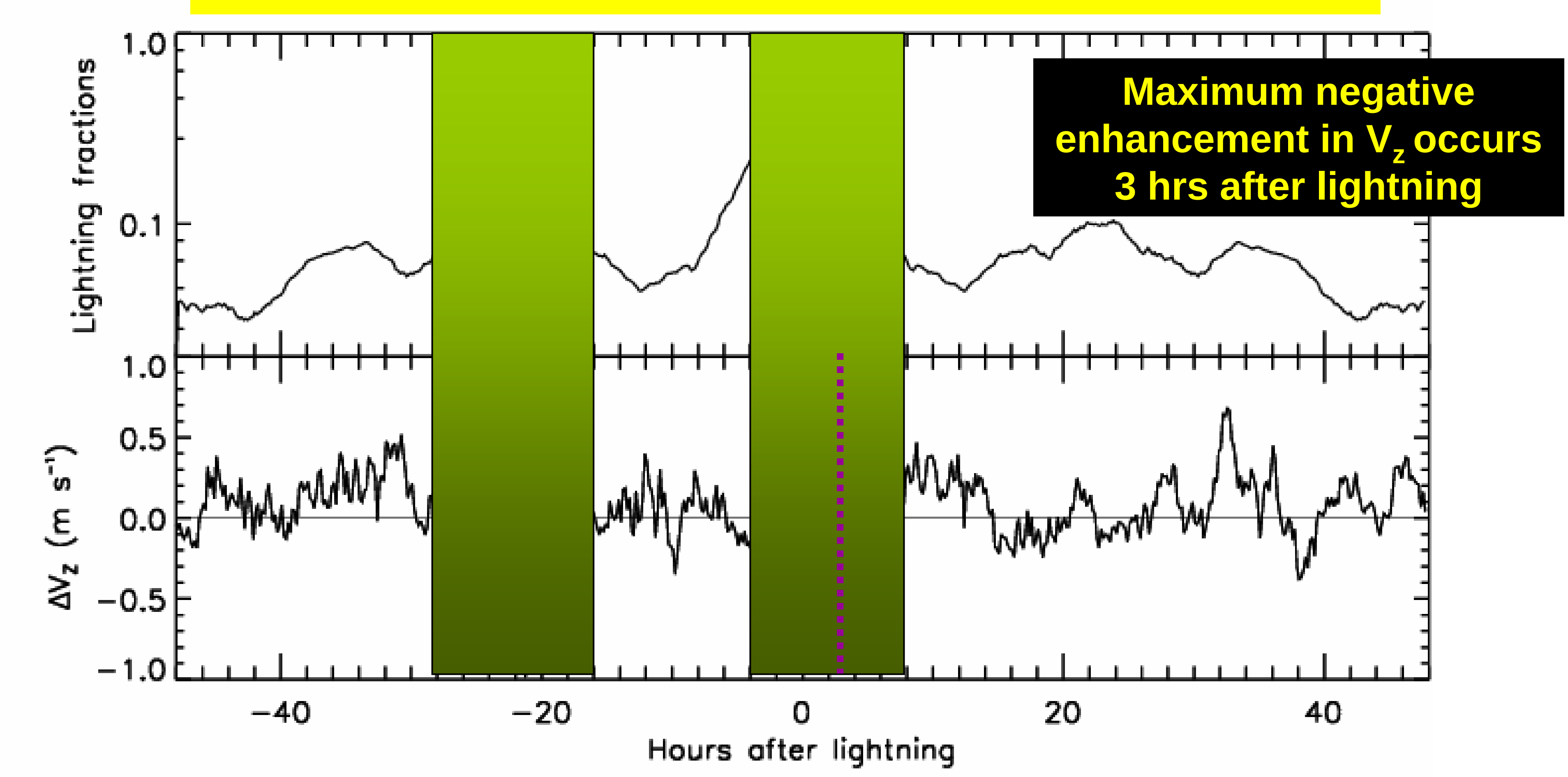
SEA of lightning strikes



All lightning times within 600 km of Bundoora were set a control time of zero hours. There were in total 24202 strikes from August 2003- August 2004. As expected, the lightning SEA is symmetrical about *t*=0

Lightning is more common to certain local time sector of the day (afternoon) and is likely to occur of consecutive days

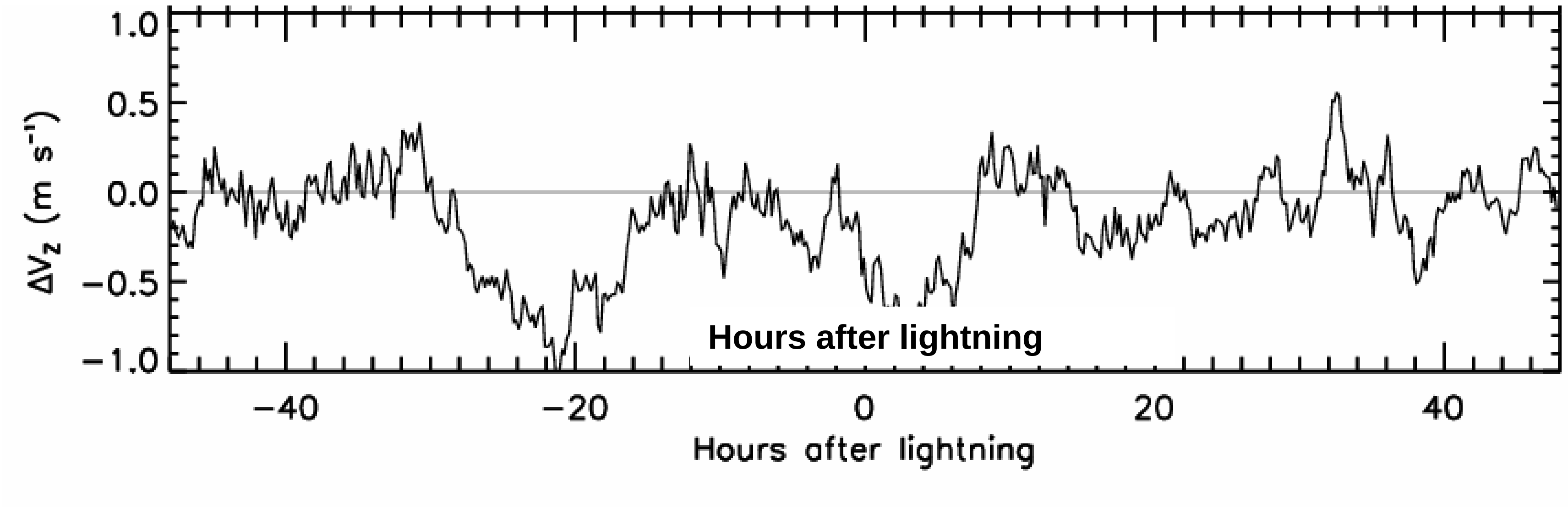
SEA of ΔV_Z with respect to lightning times



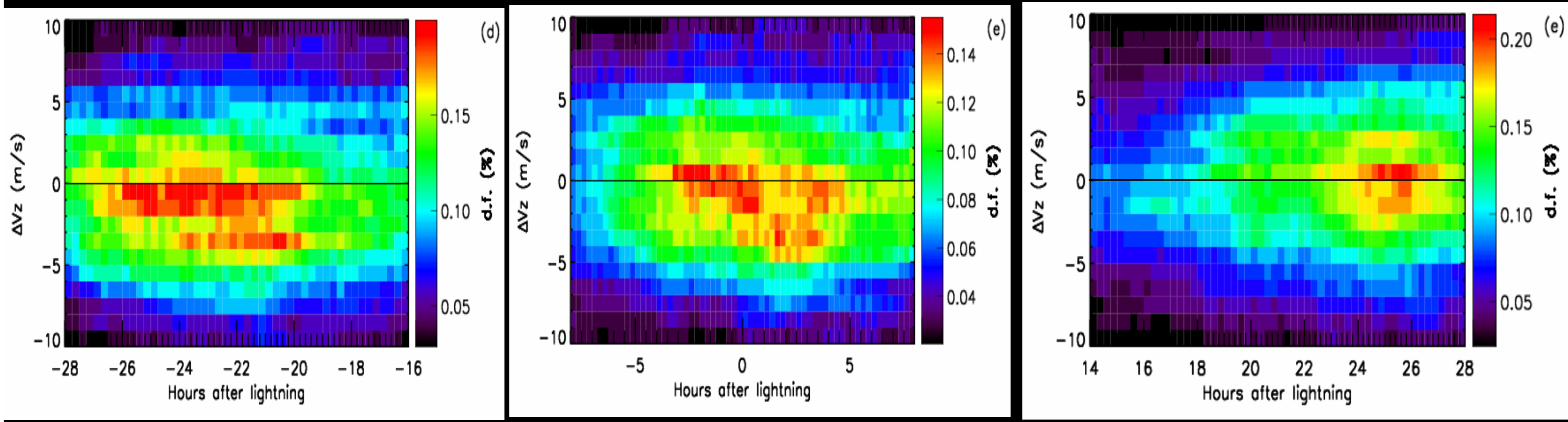
Distinct downward enhancements in V*z* are noticed between (- 28 to - 16) hrs and (- 4 to 8) hrs. These times are in reasonable correlation with the peaks in lightning fraction.

Test of statistical significance I

Probability Distribution test



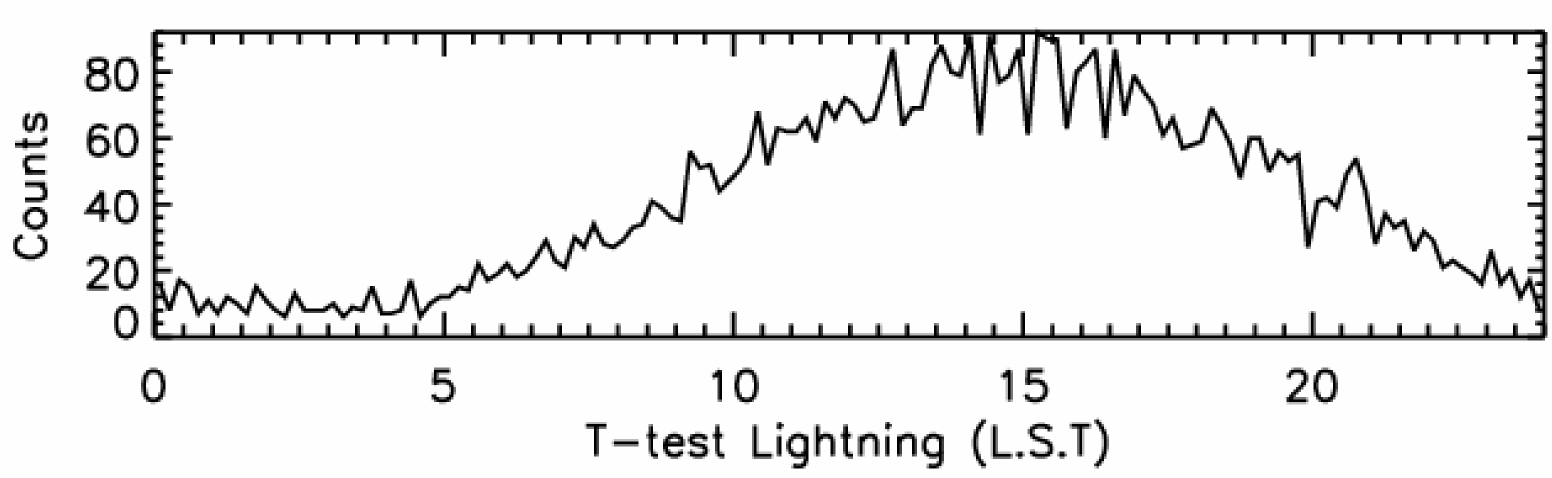
Prior to averaging the data into 10 mins bins, all ΔV_Z values beyond the range ± 10 m s^{-1} (<4.2% of samples) were rejected.



These result indicates that the responses in Vz is generated by a large number of small and consistent patterns.

Test of statistical significance II

Null hypothesis Test (Worst case scenario)



RANDOMN function

Gaussian Distribution

Mean = 15 hrs

SD = 4 hrs

+

RANDOMU function

0 - 365 day numbers

→

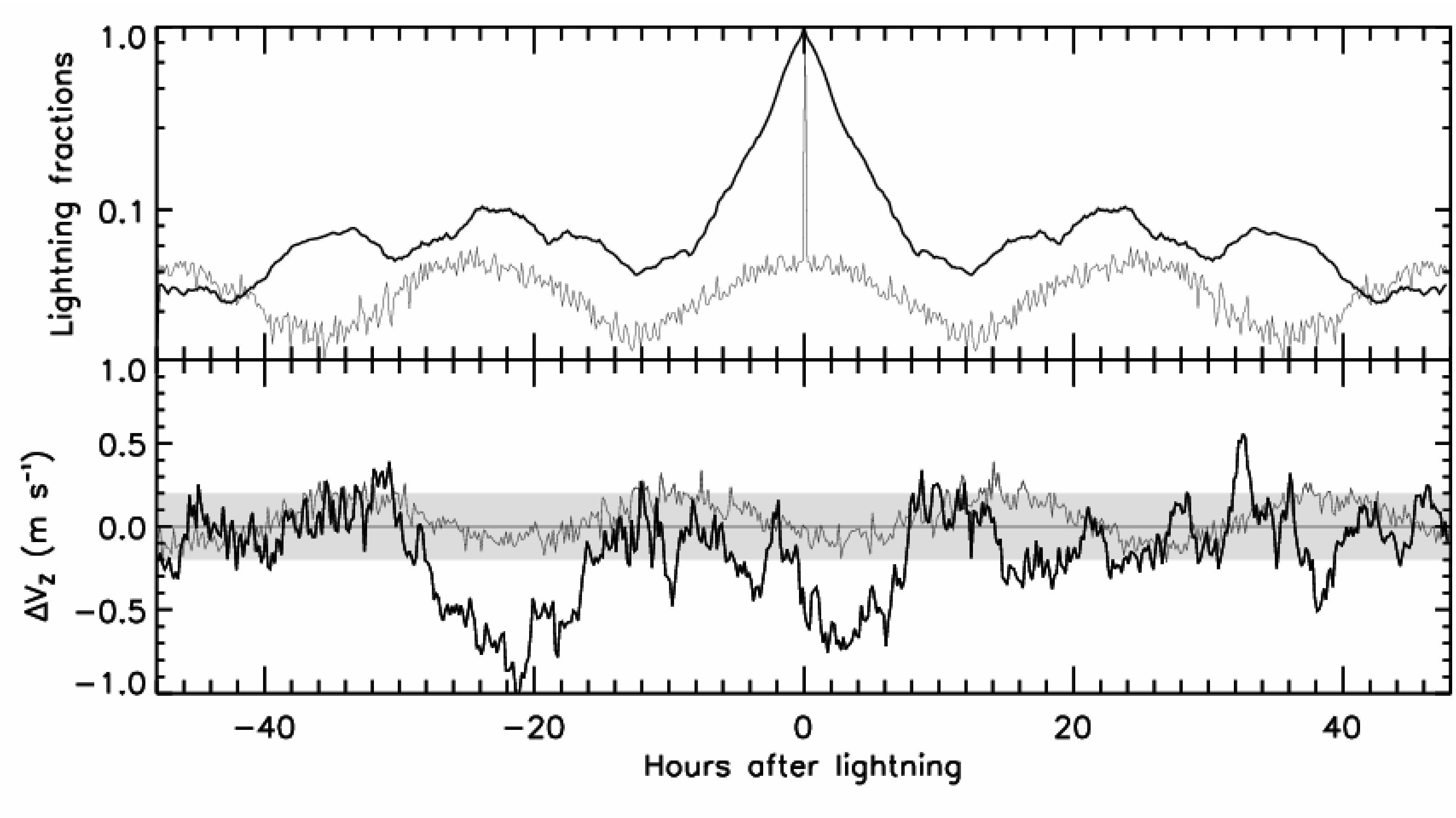
T-test

8000 lightning times generated

Preference to local lightning time

Only non-lightning days (N < 10 with 200 km) were selected

Results of T-test lightning samples

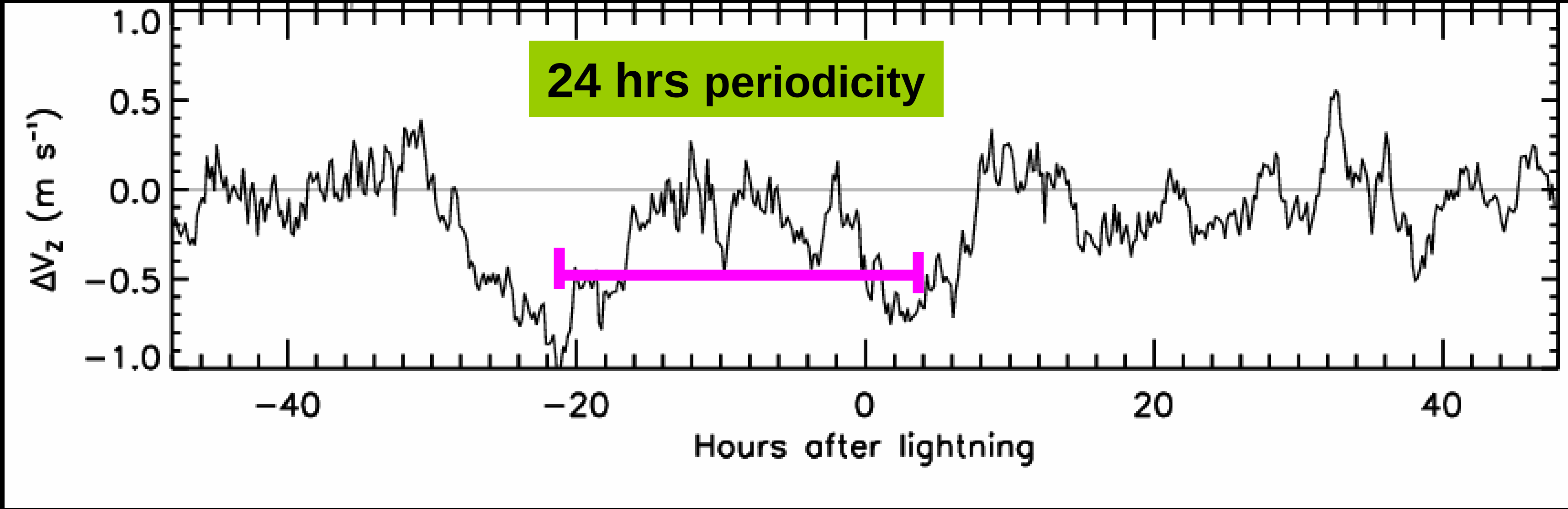


Gray curve - results obtained using t-test

Dark Black curve – results obtained using the real lightning times

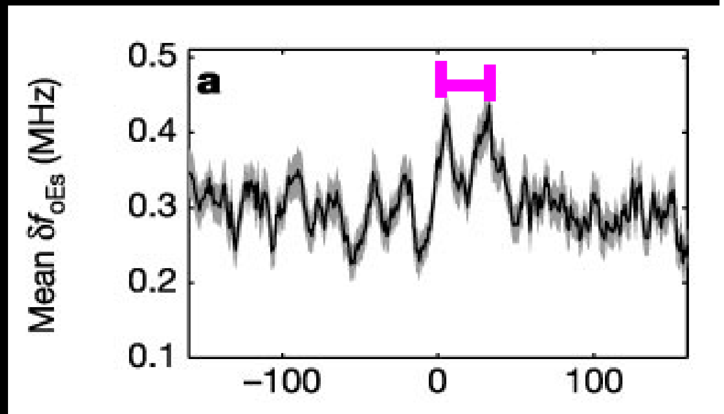
This null hypothesis test proves that the response in V*z* component associated with electrified cloud is significant

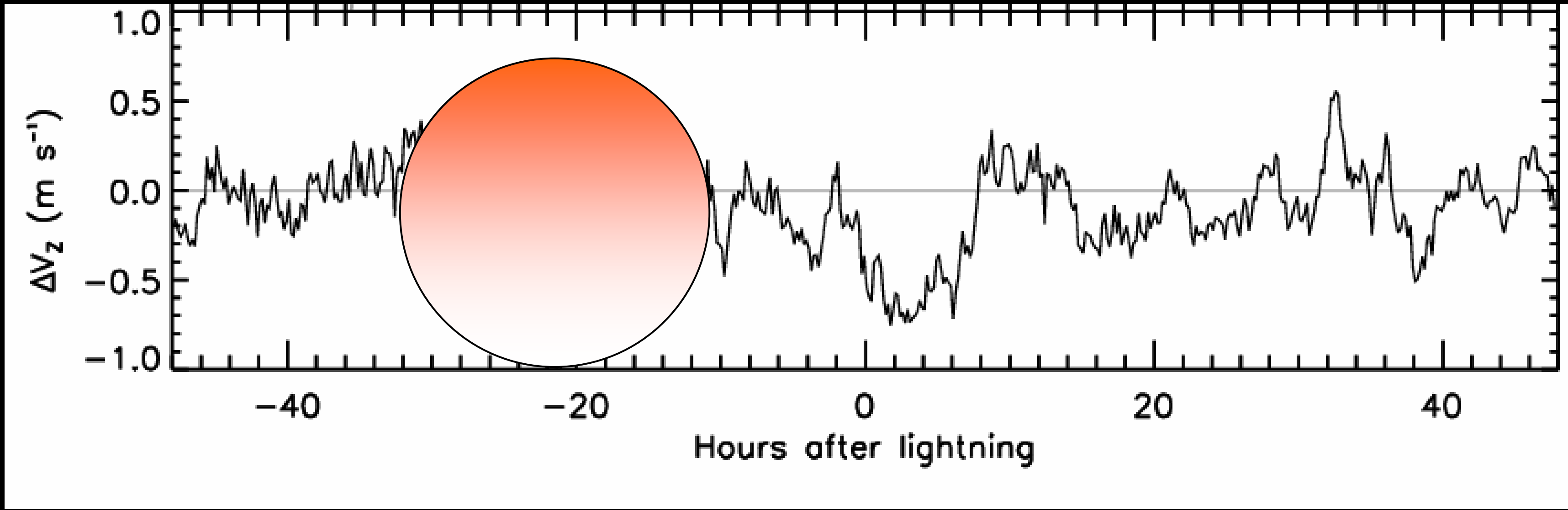
Interpretation of these results



[Davis & Johnson, 2005]

They found that lightning induced enhancements in F_{oEs} were seen at 6 hours after lightning and again after 30 hrs (the exact time of the ionospheric response may be masked by the residual diurnal variation in the data).





The gradual descent and asymmetrical pattern about time zero hours in ΔV_Z when compared to the lightning fractions suggest that these effects are less likely to be due to electric discharge, lightning is merely a proxy for this activity.

Larger downward velocities on the day before could be related to the tendency for Bundoora thunderstorms to occur in runs of 3-4 days. Thunderstorms are electrically strongest on the first day, decaying to the least on the last day.

Three plausible explanations for a negative perturbation in V_Z

Strong electric field above positive cloud-head

Theoretical models [Raymond and Tzur, 1986] and experimental [Kelley et al., 1981] evidences have demonstrated that electric field of thunderstorm origin are capable of penetrating into the E-region and plausibly in the F-region. Thus this external electric field coupling *via* Dougherty ion drag theory, could explain slow response of the ionosphere.

Atmospheric gravity wave (AGW) mechanism

AGWs are known to affect the Doppler shifts measured by HF radar [Belehaki et al., 2005].

An AGW with phase speed 55 m s^{-1} can, in principle, travel ~600 km in 3 hrs. However, upward propagating gravity waves transport momentum to the lower thermosphere where they break and enhance the mean neutral flow [Medeiros, et al., 2004]. The modified winds and dynamo action will generate electric fields which perturb the entire ionosphere.

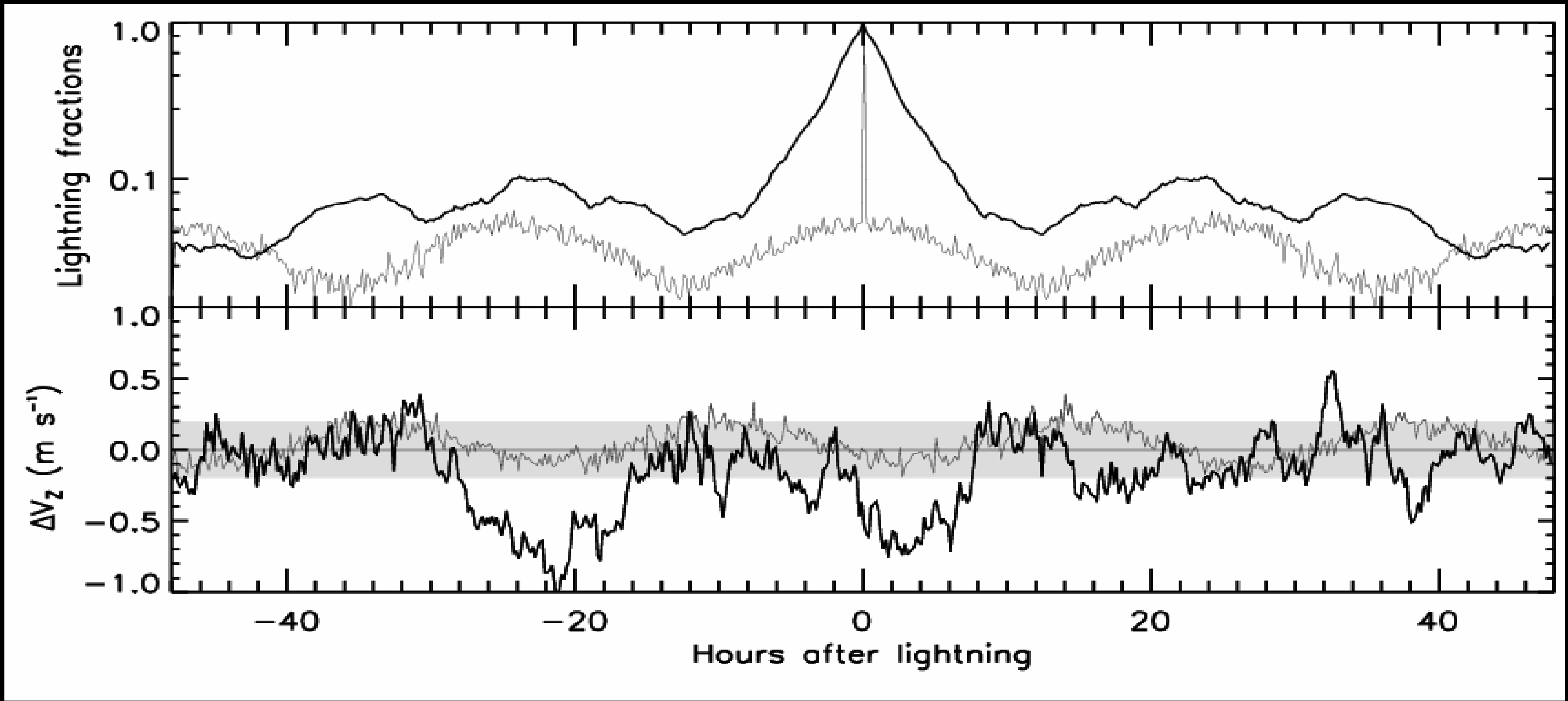
LIE mechanism

Lightning induced ionization enhancements at the base of the ionosphere is equivalent to a descending ionosphere from the point of view of Doppler shift [Taranenko et al., 1993; Davis and Lo, 2008;]

However, the peak responses in Vz were delayed by ~3 hours, longer than expected for the immediate effects of lightning and the subsequent decay of ionisation via recombination.

Main result

Statistically significant reproducible responses of a vertical descent of the F-region ionosphere associated with tropospheric thunderstorms located within the vicinity.



Thank You

Acknowledgements

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Details;

PhD Project; Effects of thunderstorms on Geopace

Date of Commencement ;

12th March, 2007

Project Supervisors;

Dr. Murray Parkinson

Prof. Peter L Dyson

Institution; La Trobe University, Bundoora Campus, Melbourne, Vic

Principal Researcher; Vickal Kumar

Conference; SuperDARN 2008

Date; Thursday, 26 June 2008

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