Unseasonal equatorial F-region irregularities in Southeast Asian sector

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Outline

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- **Introduction**
  - Equatorial Plasma Bubbles (EPBs) and their impacts
- **Day-to-day variability**
  - Previous analyses using the Thermosphere-Ionosphere Electrodynamics Circulation Model (TIEGCM)
- **EPBs observed over Southeast Asia on July 28, 2014**
  - Ground-based GPS scintillation observations
  - Global GPS RO scintillation observations
  - Ionosonde observations
  - Geomagnetic activity examination
  - Forcing from below? TIMED/SABER data analysis
- **Summary and conclusions**

GPS disruptions

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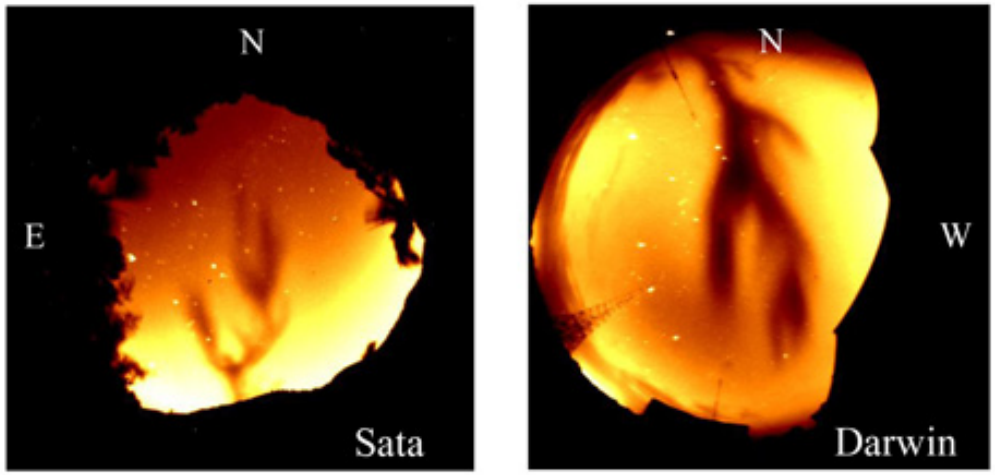
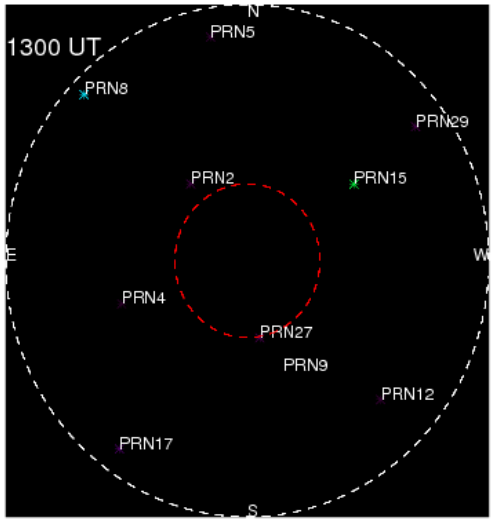
All-sky cameras (Otsuka et al., 2002)

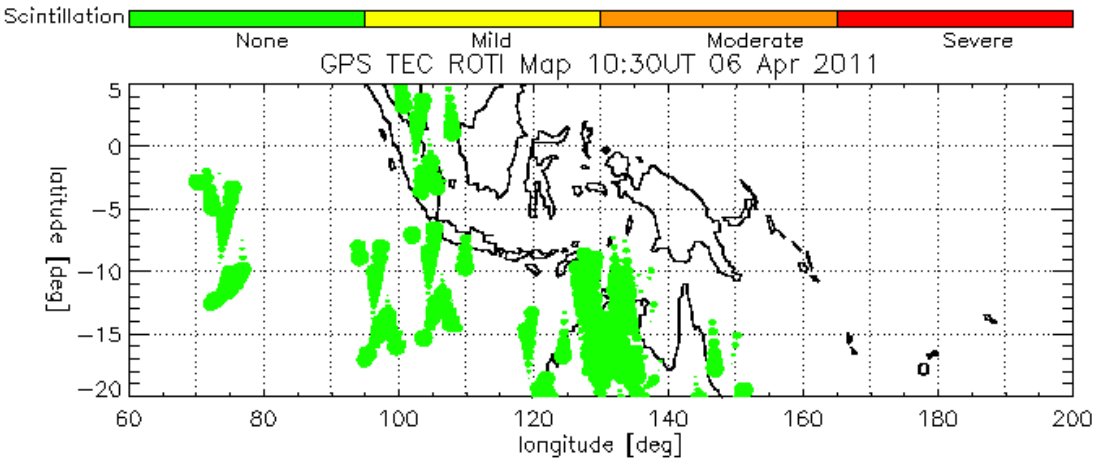


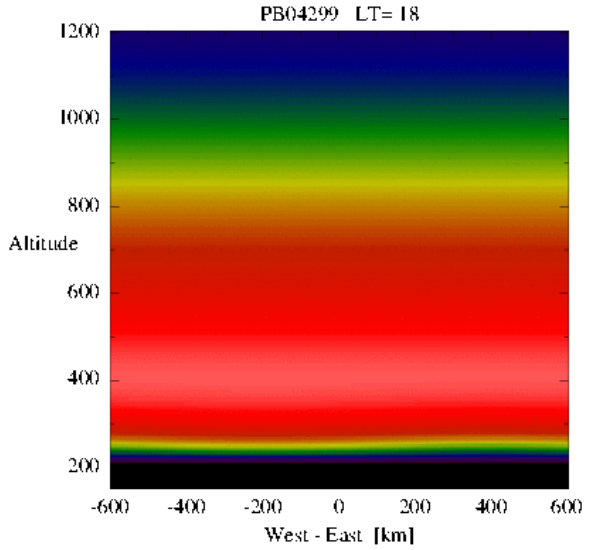
Darwin, Sept-21-2012

All-sky camera data provided by Kazuo



All GPS links affected: 1030 – 1300 UT





View from sky: BoM – Space Weather Services

Daily variability of EPBs

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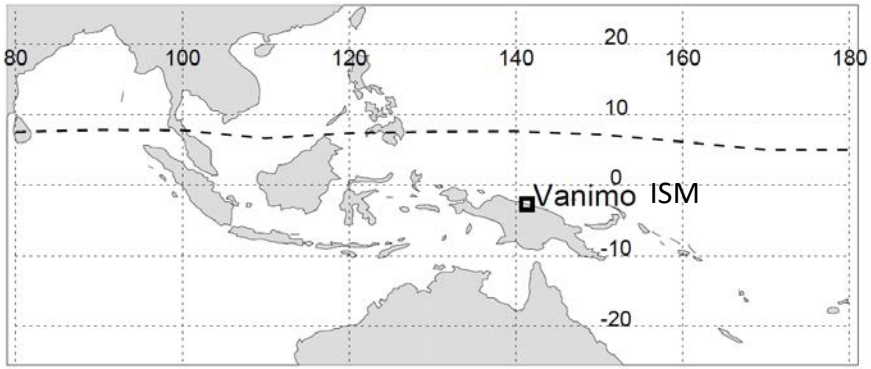
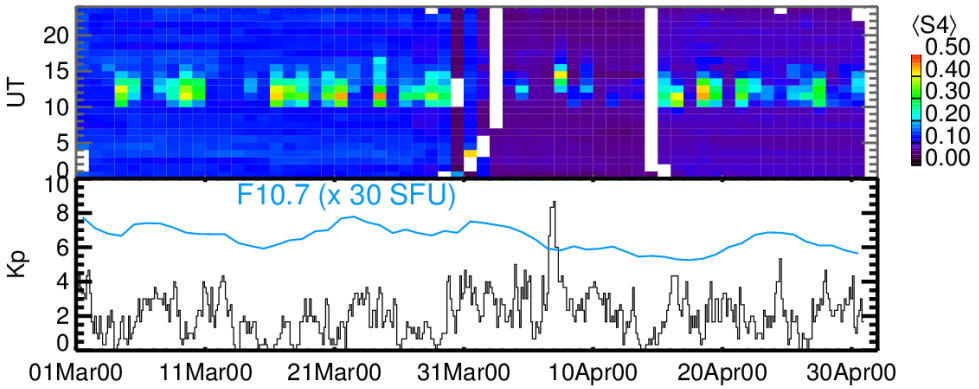




Carter et al., 2014a [JGR]

- Ionosphere - thermosphere observations along the entire flux tube, as required by the Rayleigh-Taylor linear instability growth rate expression, are not possible/feasible

(Sultan, 1996)

$$\gamma = \frac{\Sigma_P^F}{\Sigma_P^E + \Sigma_P^F}\left(V_p - U_n^P - \frac{g_L}{\nu_{in}^{eff}}\right)\frac{1}{L_n} - R_T$$

Gravity

Ion-neutral collision frequency

Recombination rate

Pederson conductivities

Upward neutral wind

Gradient scale length

Upward plasma drift

Unknown

Directly measured/known

- Therefore, some form of ionosphere-thermosphere modelling is required…

TIEGCM

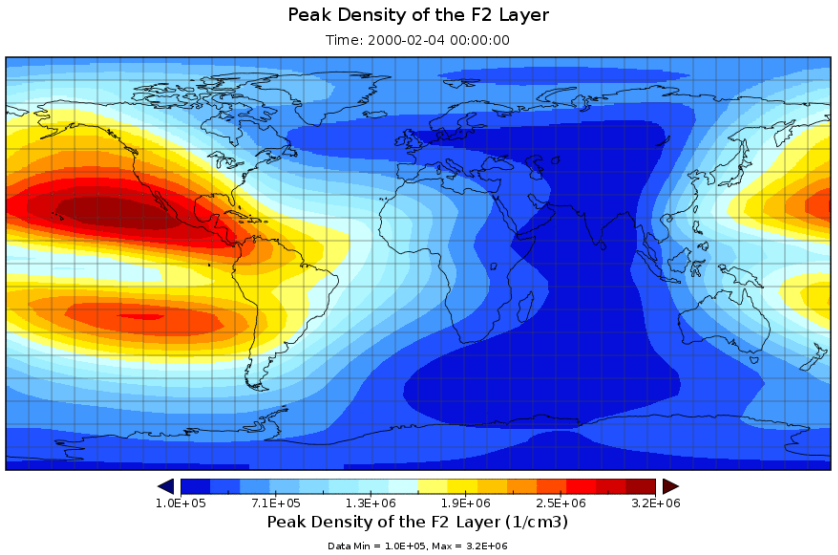
The Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) is a time-dependent 3D physics-based (i.e. not empirical) numerical simulation of the Earth's thermosphere and ionosphere.

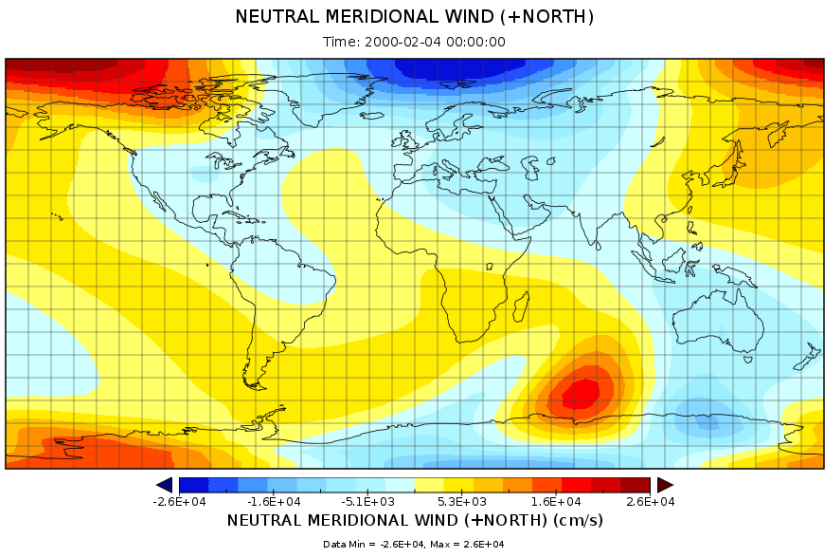
Inputs:

- Solar activity (F10.7 cm flux)
- Geomagnetic activity (Kp index)

Outputs:

- Electron density
- F layer height
- 3D plasma drift
- Thermospheric density
- 3D neutral winds…
- …
- Basically, everything that we need…





TIEGCM: EPB variability

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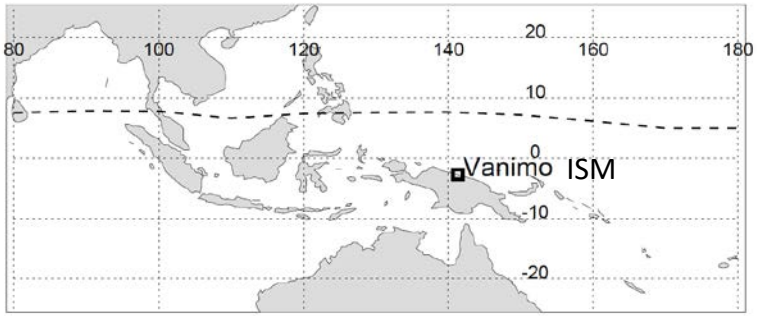
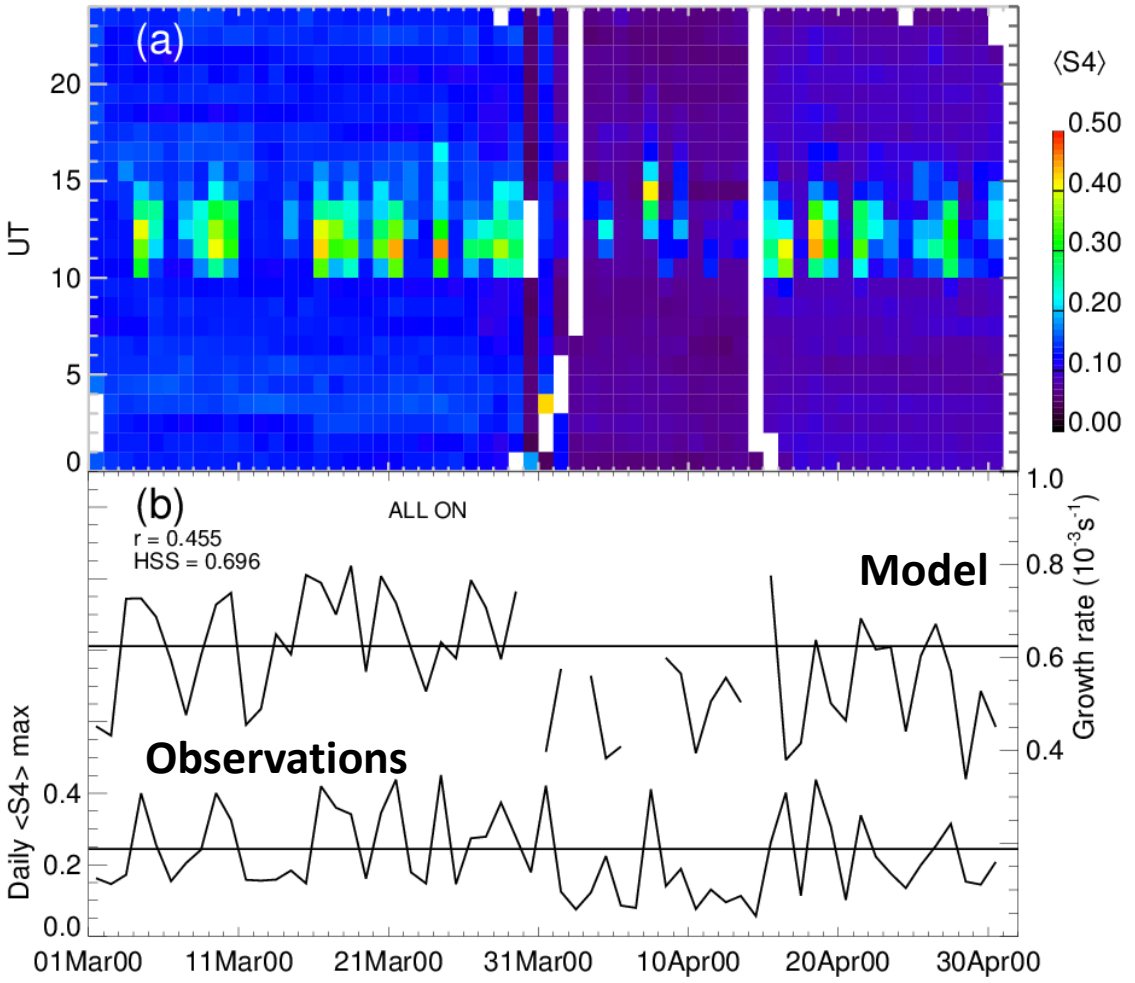


Observed

Modelled	EPBs	Yes	No
	Yes	17	3
	No	5	31

- Physics-based model was found to imitate the observed daily changes (correct ~86% of days)
- Kp is dominant source of TIEGCM variability during quiet period



Carter et al., 2014a [JGR]

Scintillation prediction trial: Mar-Jul 2014

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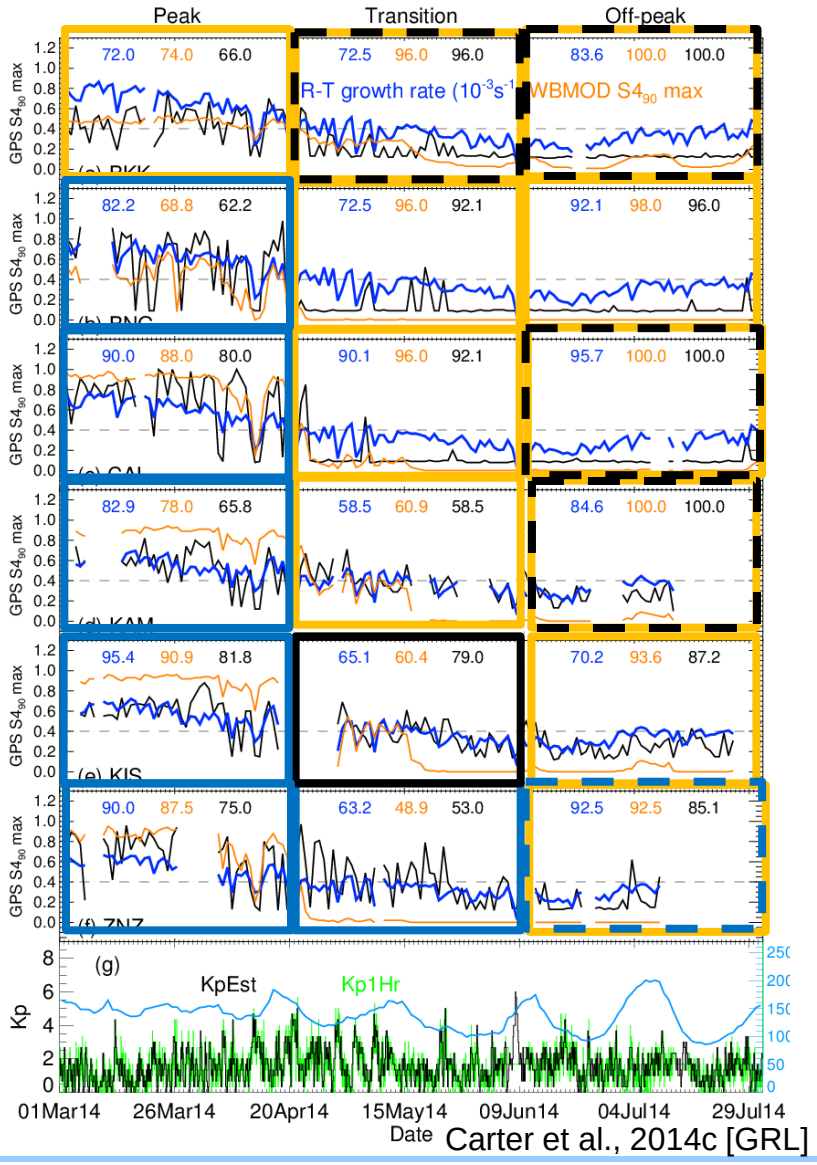
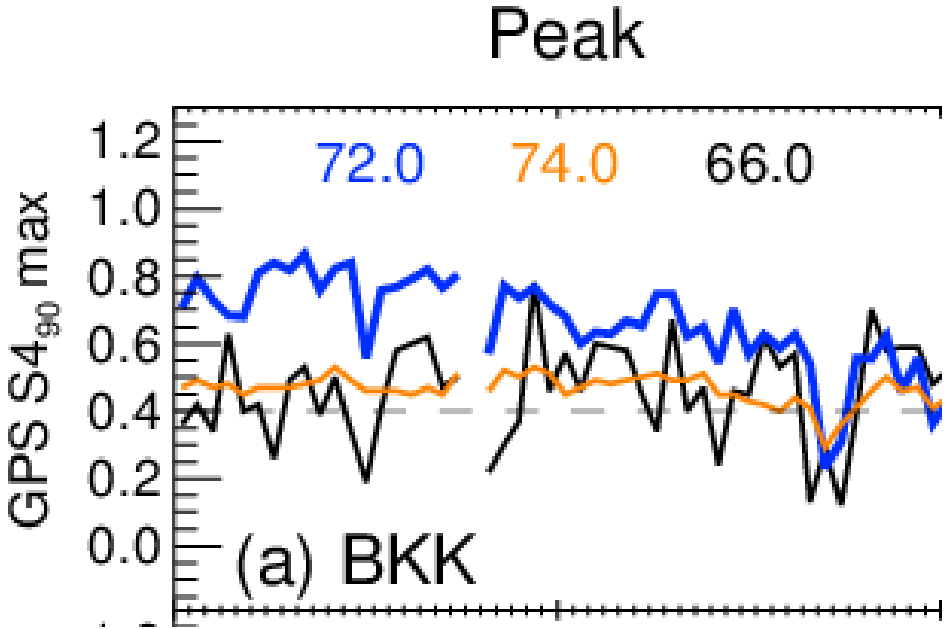


Carter et al., 2014c [GRL]

1-hour Wing Kp predictions:

Our technique generally performs best during peak EPB season, closely followed by AFRL's WBMOD (up to 95% for KIS)

During transition and off-peak seasons, either WBMOD or "persistence" forecast performs best



Unresolved issues – Unseasonal EPB events

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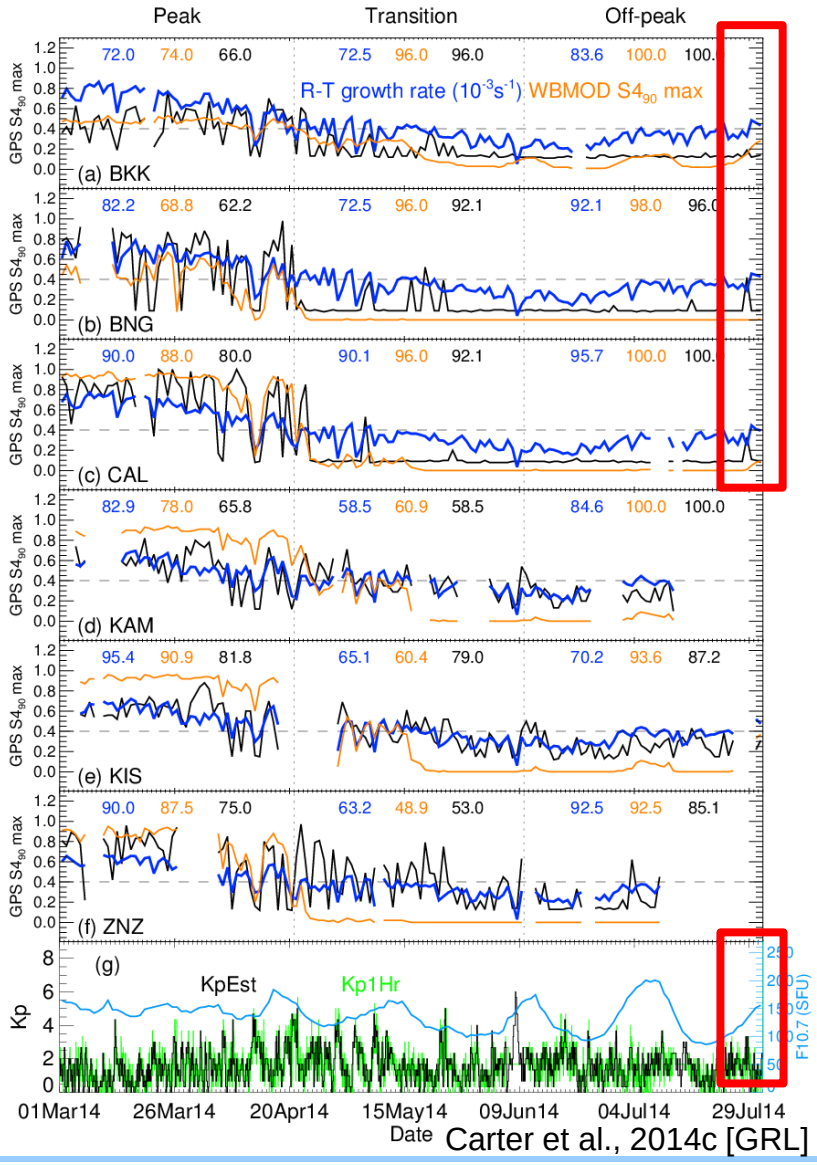
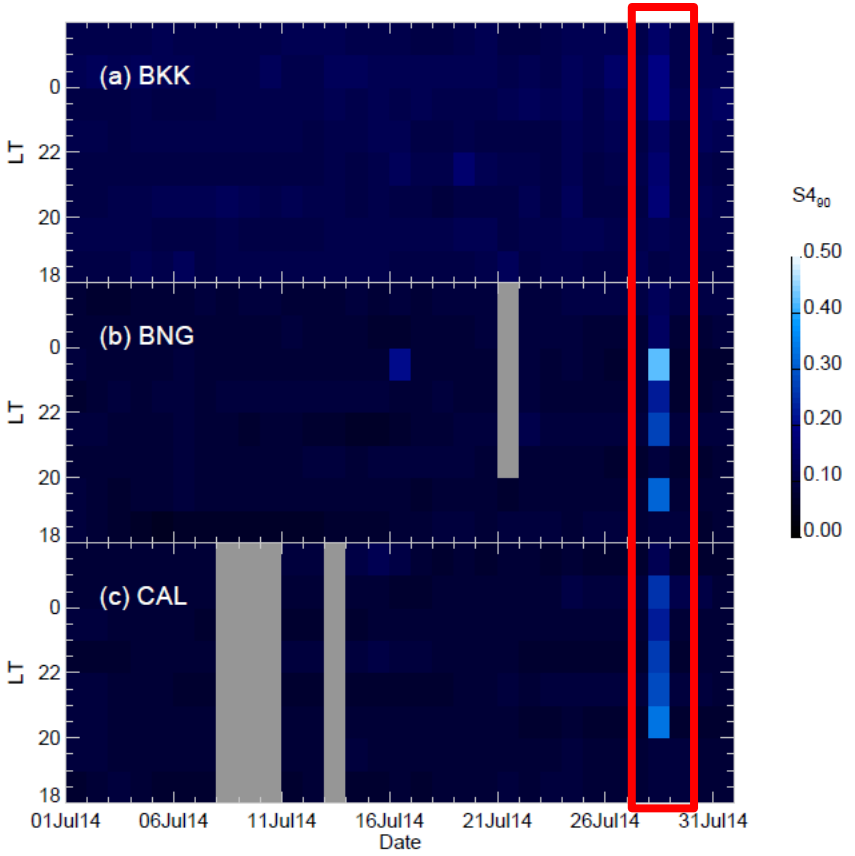


Carter et al., 2014c [GRL]

Neither model captured a scintillation event in Southeast Asia on July 28th

Carter et al. (in prep., 2017)



Low electron density at the magnetic equator (anomaly trough) is the reason S4 was low for BKK

GPS RO observations

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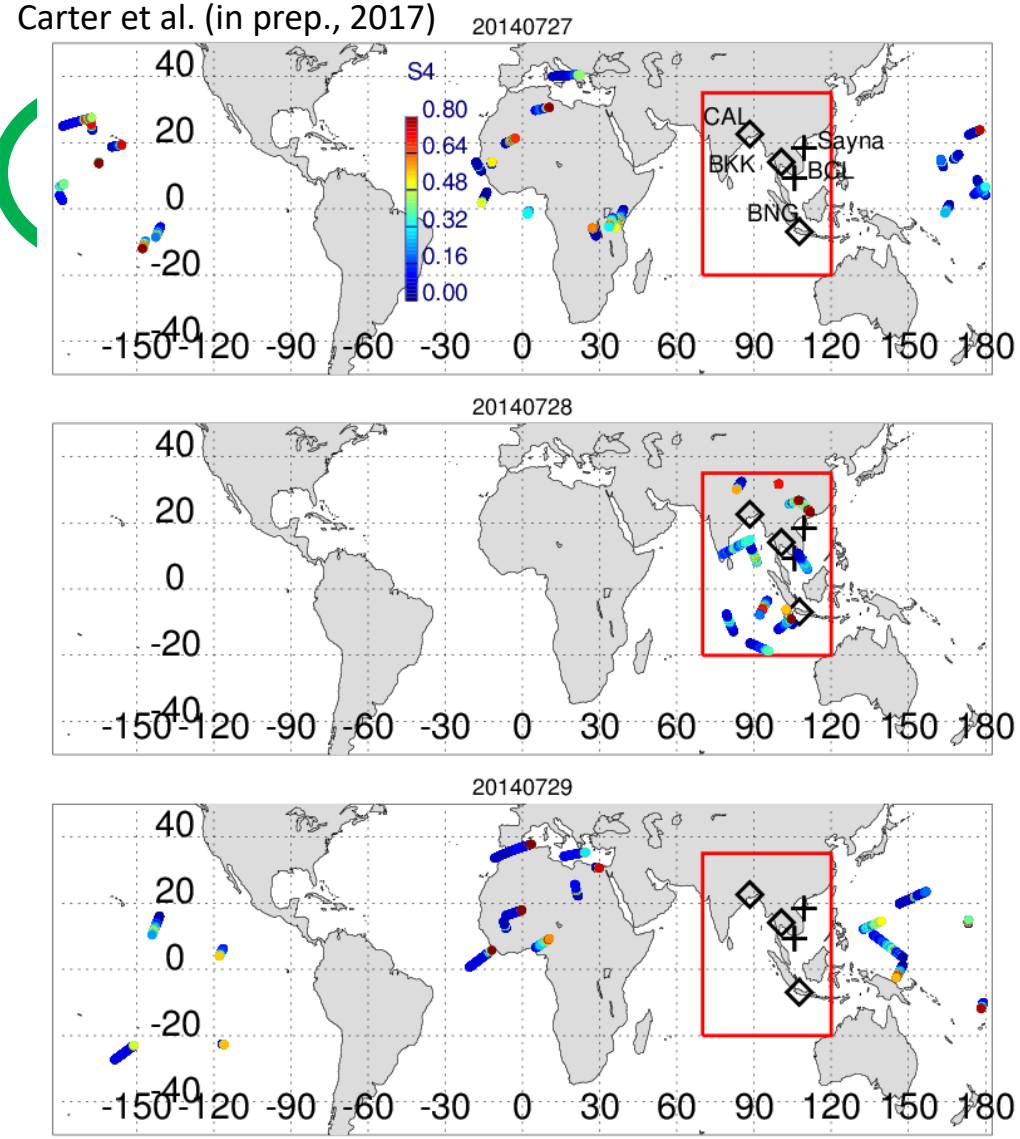
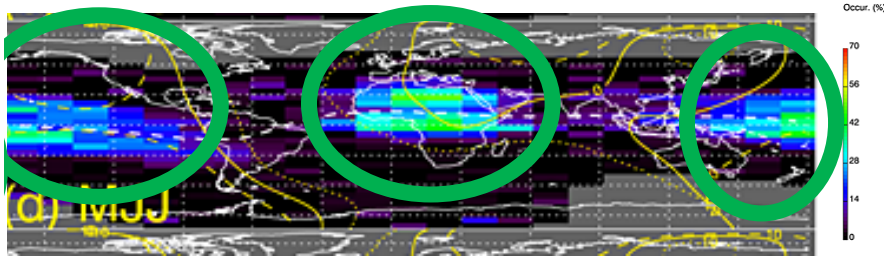
Carter et al. (in prep., 2017)





Carter et al. (2013)

- RO events with S4max9sec > 0.3 during 19-24 LT are shown
- On July 27 (and days prior, not shown), the appearance of scintillations is consistent with climatology during June solstice
- On July 28, scintillations **only** appear over Southeast Asia (red box)
- On July 29, scintillation event locations once again match climatology

Ionosonde observations

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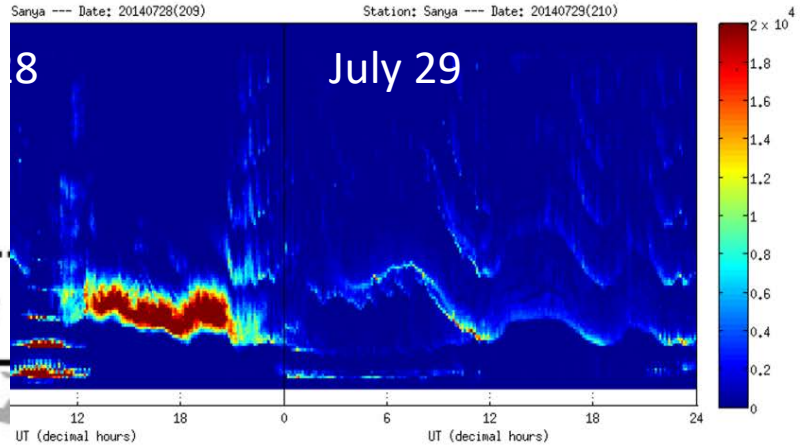
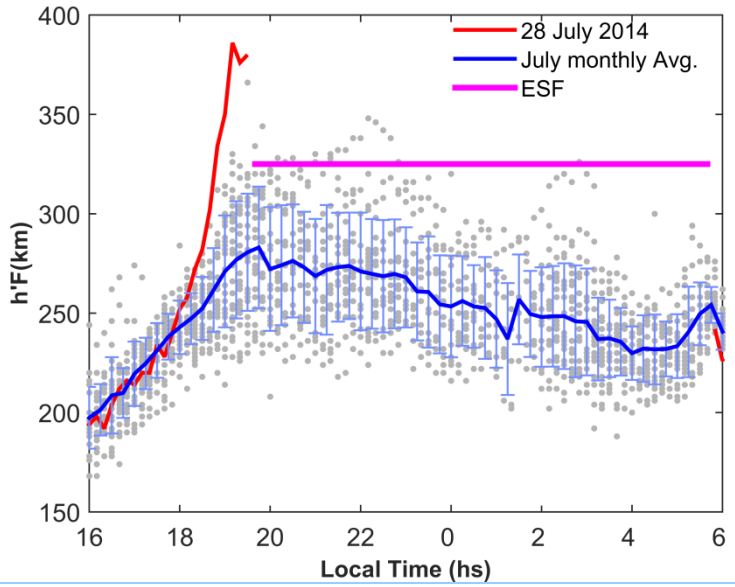
Sanya (off-equator)

Carter et al. (in prep., 2017)



EPBs confirmed by Spread F observed by Sanya on July 28

BCL (equatorial)



h'F data from BCL station reveals that upward plasma drift was significantly higher on July 28 compared to the rest of July (31.6 m/s vs. 6.4 m/s)

$$\gamma = \frac{\Sigma_P^F}{\Sigma_P^E + \Sigma_P^F}\left(V_p - U_n^P - \frac{g_L}{\nu_{in}^{eff}}\right)\frac{1}{L_n} - R_T$$

Question: Why?

Eastward "under-shielding" electric fields from geomagnetic activity?

Geomagnetic activity

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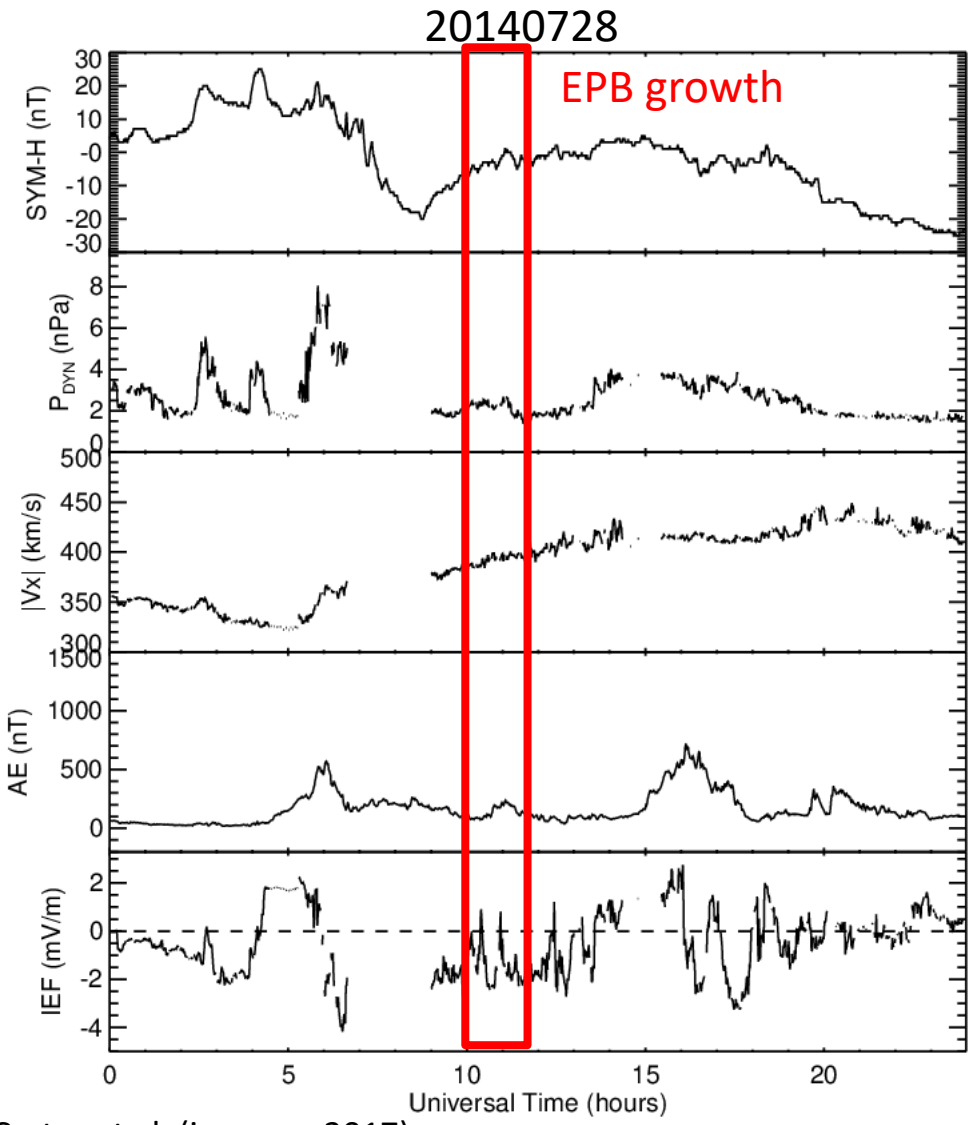
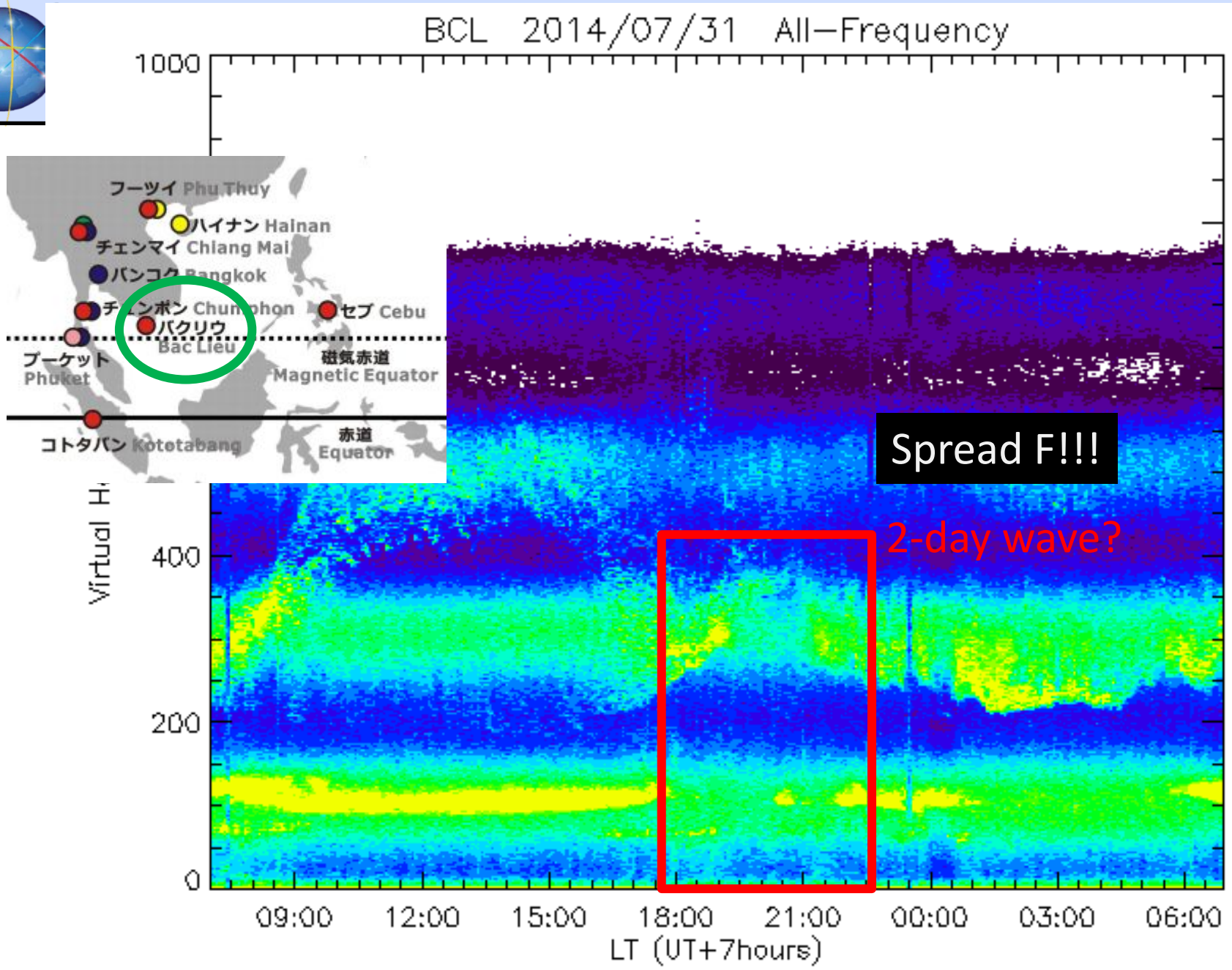


Carter et al. (in prep., 2017)

- Analysis of geomagnetic activity shows the presence of a co-rotating interaction region on July 28
- Negative IEF (northward IMF) during EPB growth period shows that an under-shielding electric field was not present
- When present, over-shielding and disturbance dynamo electric fields both suppress EPB growth, not encourage it (e.g., Abdu, 2012)
- **Conclusion:** Geomagnetic activity is not related to the enhanced upward plasma drift (and EPB activity) observed over Southeast Asia

So, forcing from below…?


BCL 2014/07/31 All-Frequency
1000
400
200
0
Virtual H
09:00
12:00
15:00
18:00
21:00
00:00
03:00
06:00
LT (UT+7hours)
フーツイ Phu Thuy
ハイナン Hainan
チェンマイ Chiang Mai
バンコク Bangkok
チュンポン Chumphon
セブ Cebu
バクリウ
Bac Lieu
プーケット
Phuket
磁気赤道
Magnetic Equator
コトタバン Kototabang
赤道
Equator
Spread F!!!
2-day wave?

Forcing from below?

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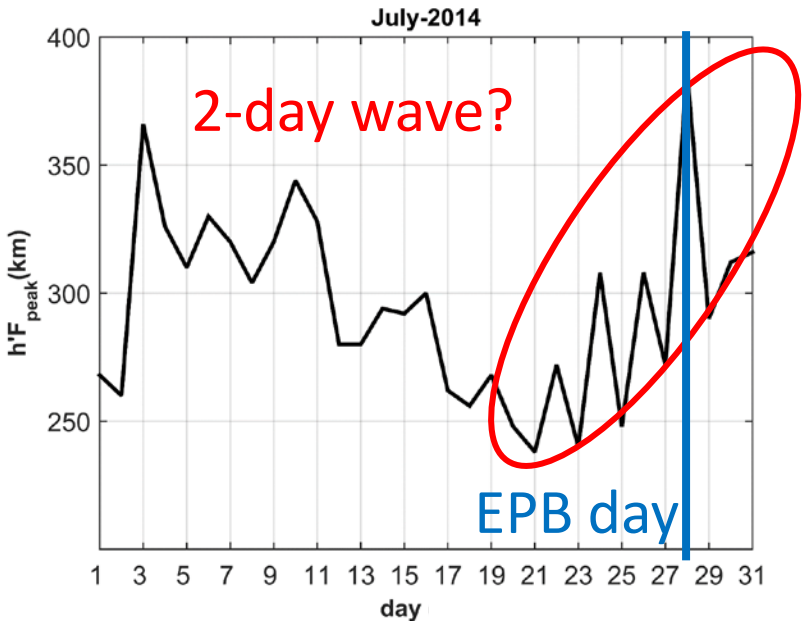
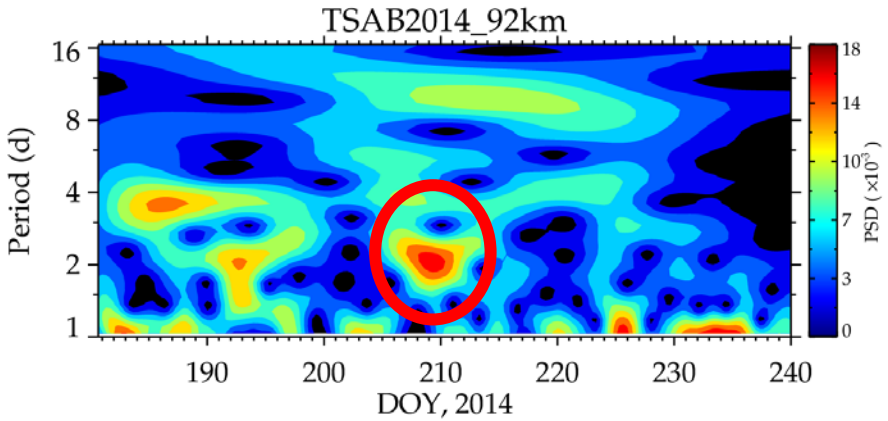


Tulasi Ram et al. (in prep., 2017)

- Increase in h'F from 21-28 July
- Apparent 2-day wave evident during increase



Contact: Takahashi-sensei <hisao.takahashi@inpe.br>

- Mesospheric temperature data from TIMED/SABER shows a strong 2-day wave centered on July 28 (day 209)

Conclusion: Unseasonal EPB event in Southeast Asia appears to be linked with a 2-day Planetary Wave (an "Ultrafast Kelvin wave") from the lower atmosphere

Clear example of an EPB event caused by the lower atmosphere

Summary and conclusions

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Unseasonal Equatorial Plasma Bubble event found over Southeast Asia

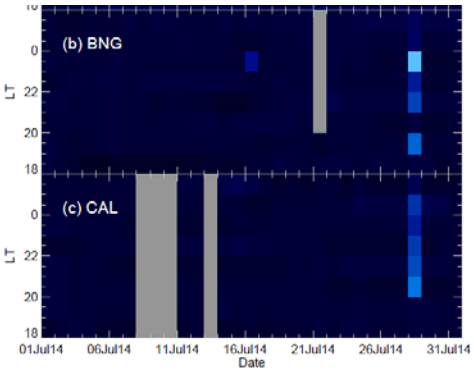
- Event occurred on July 28th 2014, during an "off-peak" EPB period
- Previous model analyses did not capture this event

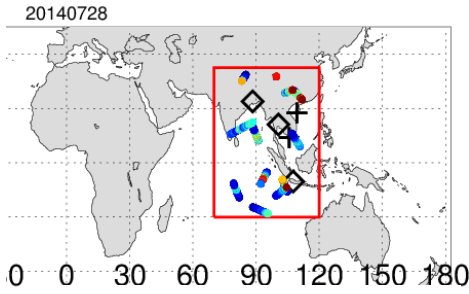
Observations of EPB event using space-based GPS receivers and ionosondes

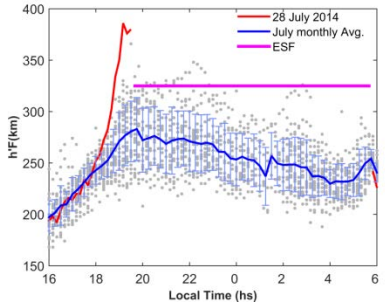
- GPS RO data showed that this EPB event coincided with an apparent suppression of EPBs in Africa and Pacific regions
- Ionosonde data confirms Equatorial Spread F associated with EPBs
- Abnormally strong upward plasma drift detected on July 28th, compared to monthly average (31.6 m/s vs. 6.4 m/s), which caused an enhancement in the R-T instability growth rate

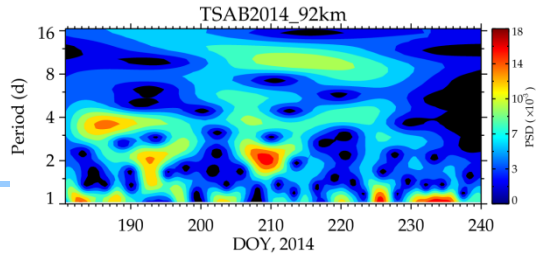
Origin of strong upward plasma drift (pre-reversal enhancement)

- Analysis of geomagnetic activity conditions did not reveal under-shielding (i.e., eastward) electric fields that could have caused this strong upward plasma drift
- 2-day wave is evident in h'F data collected by BCL ionsonde
- Analysis of TIMED/SABER data revealed a strong 2-day wave in the mesospheric temperature observations; i.e., "Ultrafast Kelvin wave" from lower atmosphere
- First strong evidence that lower atmospheric forcing is responsible for unseasonal EPB event

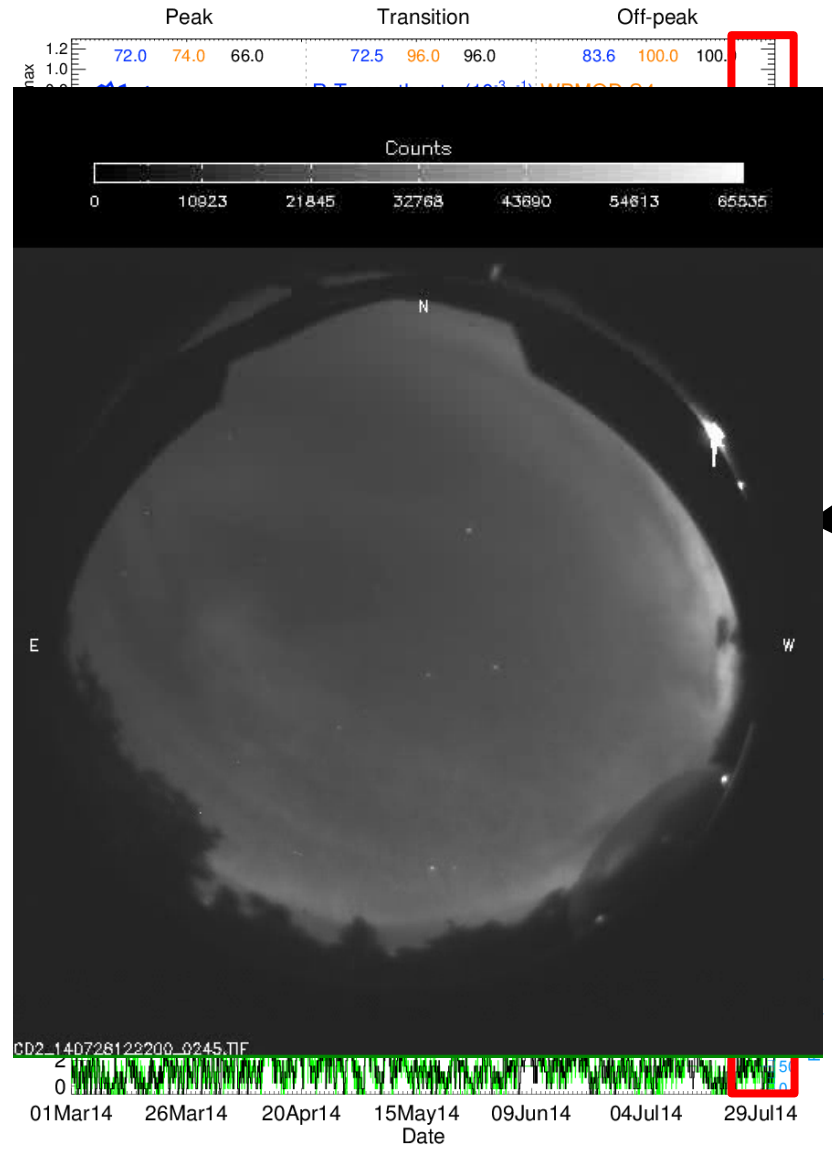


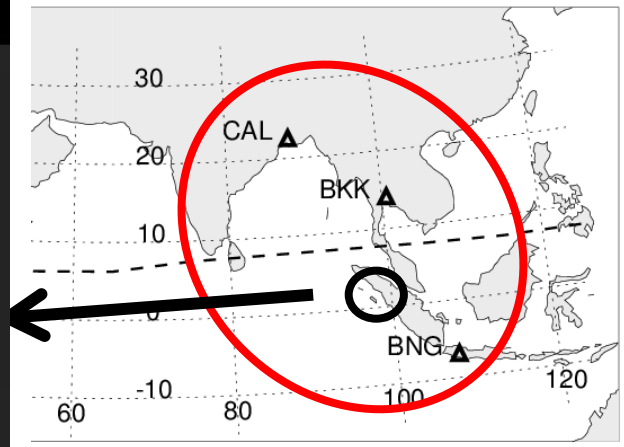






Unresolved issues – Unseasonal EPB events





- This DRUIDAE event (28 July, 2014) was observed across Asia
- TIEGCM/WBMOD did not pick up increase in R-T growth conditions
- No geomagnetic storms (no prompt penetration electric fields)
- Coupling with lower altitudes? Tides? AGWs?...

TIMED/SABER analysis (90-120º E)

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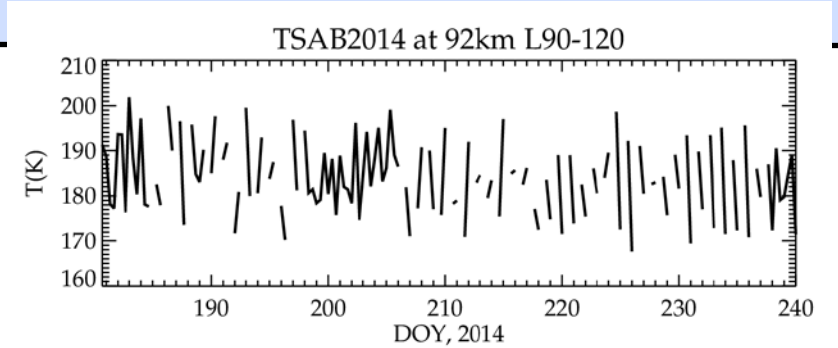
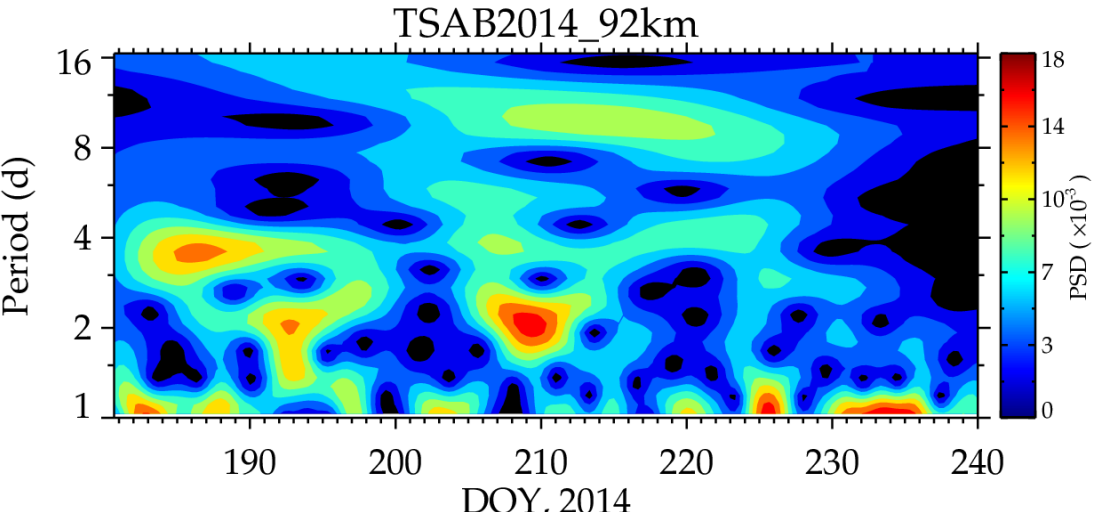
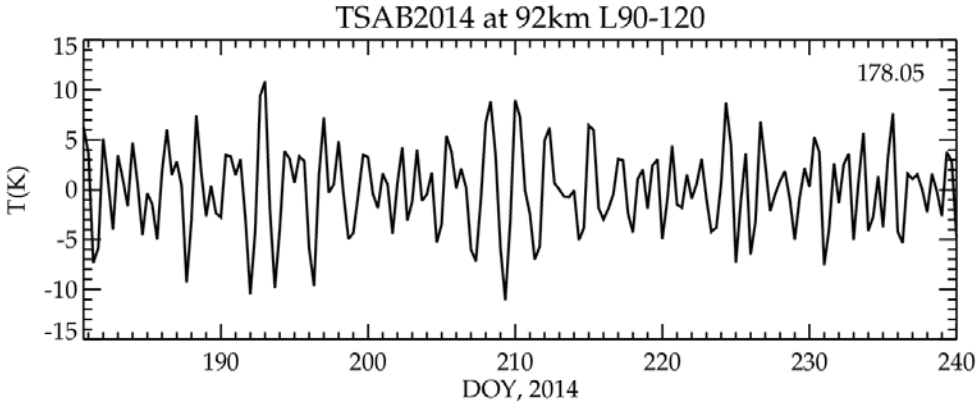


TIMED/SABER Raw data plot: 3 plots/day (a mean of 8 hours time interval, in the area of +/- 20 deg of latitude and 30 degree of longitude), from Day number 180 to 240 in 2014)



Wavelet power density spectrum: 2-day oscillation at DOY 207 to 211 (principal), and DOY 192-194. There is ~4 day oscillation also.



Reconstruction of spectrum with a filter of 1-3 day period. Amplitude of oscillation of temperature at 92 km altitude: +/- 10K (significant!)

Contact: <hisao.takahashi@inpe.br>

Potential economic vulnerabilities to day-to-day space weather: GNSS

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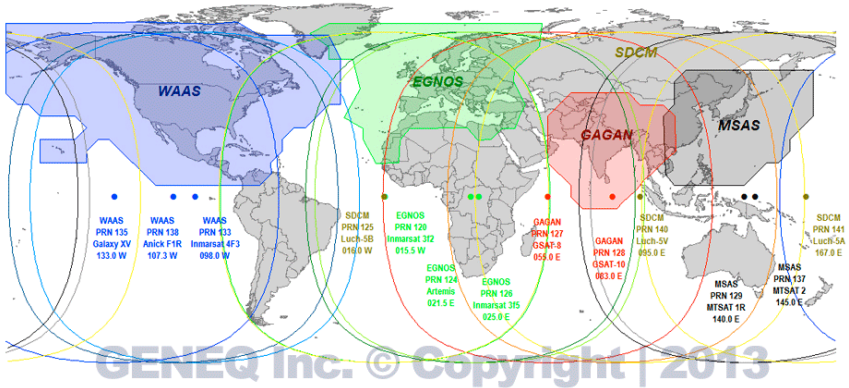
GNSS (Global Navigation Satellite Systems) and satellite communications are being increasingly utilised by various industry sectors. For example;

- Mining
- Aviation
- Agriculture
- Construction
- Military/Defence



No study to date has investigated the impact of ionospheric scintillation events on operations in these sectors, and the flow-on impacts on the wider economy.

In the meantime, reliable daily scintillation forecasts are needed around the world…