A New Prediction Capability for post-sunset Equatorial Plasma Bubbles

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Outline

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- **Equatorial Plasma Bubbles:**
  - Generalised Rayleigh-Taylor plasma instability
  - Typical characteristics and daily occurrence variability
- **Thermosphere-ionosphere modelling and observations**
  - TIEGCM
  - Daily variability of GPS scintillation observations from Vanimo
  - Global GPS scintillation observations from SCINDA
  - Migration of modelling to “predictive” capability using solar wind data
- **Summary and conclusions**

Equatorial Plasma Bubbles

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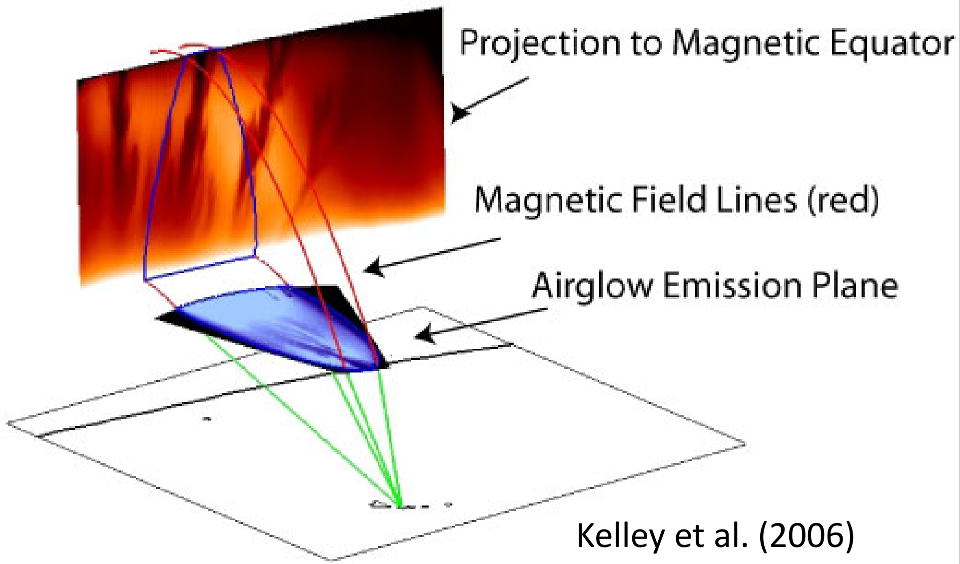
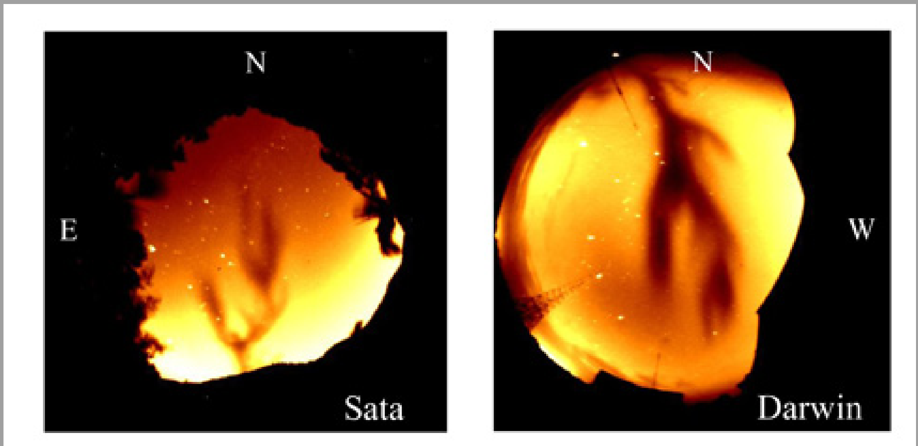
Ground-based radar measurements of EPBs

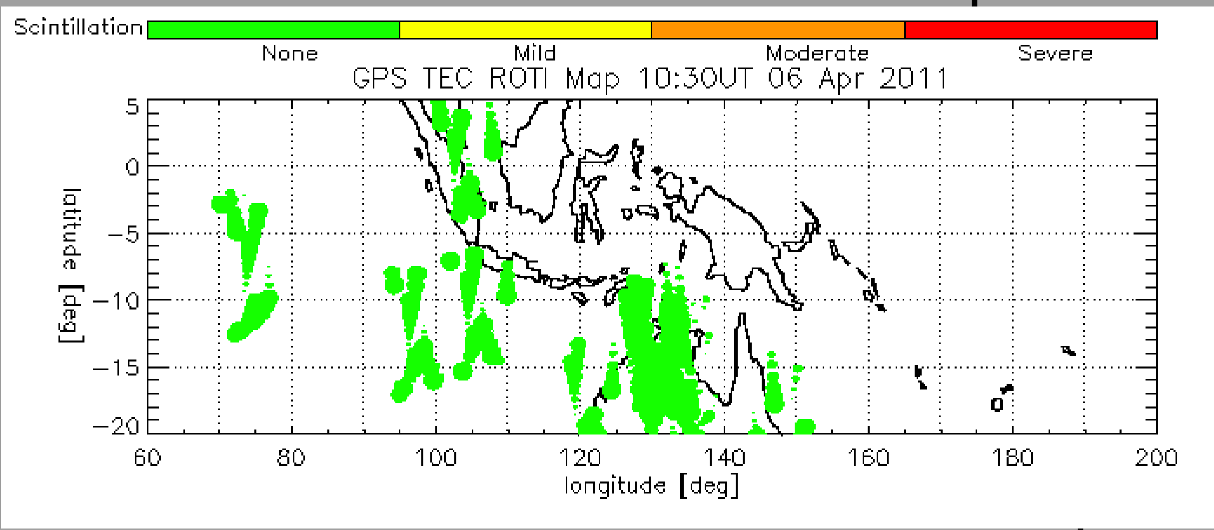


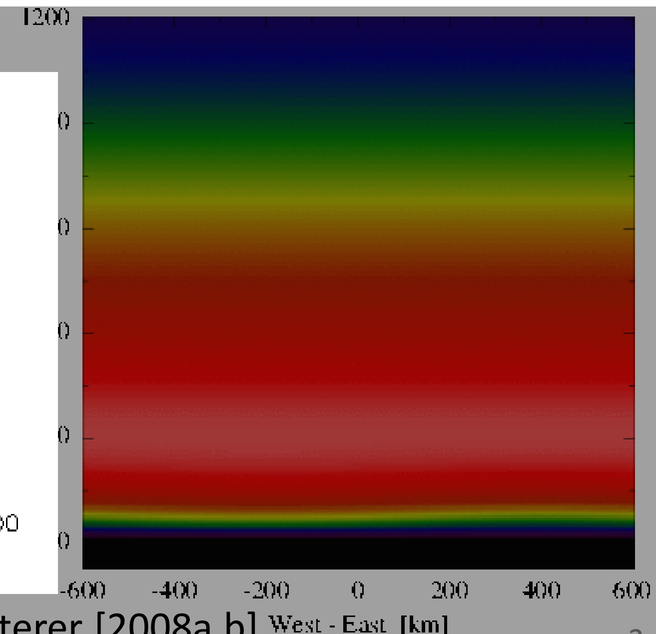
Kelley et al. (2006)

All-sky cameras and numerical modelling

http://center.stelab.nagoya-u.ac.jp/site1/info_e/kagoshima.html







Retterer [2008a,b]

GPS scintillation observations

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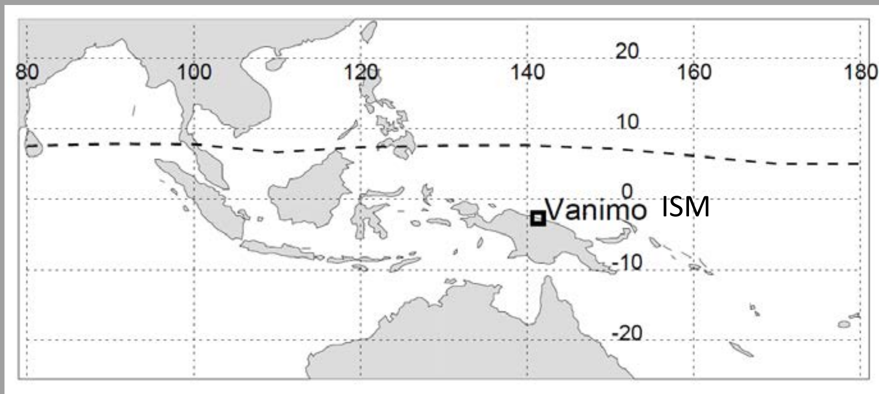

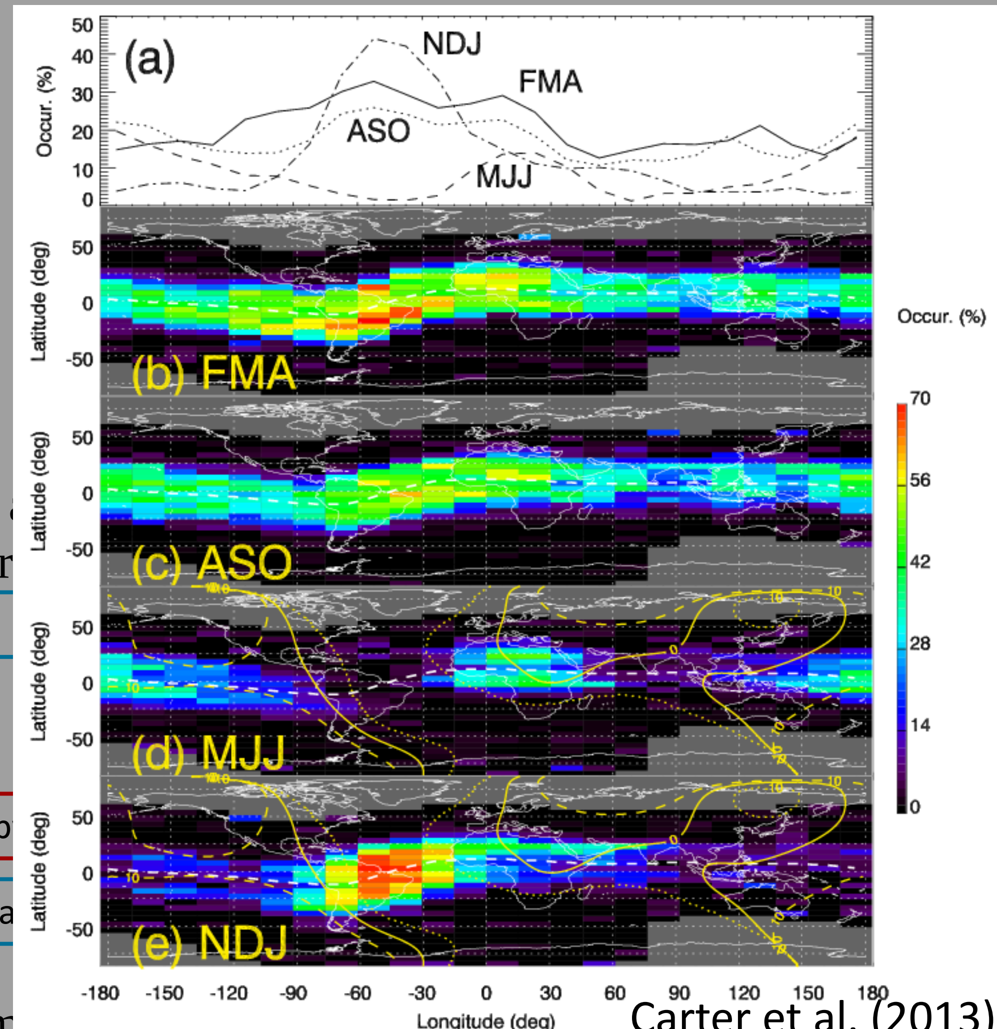

Carter et al. (2013)

- Ionosphere - thermosphere observations
  Rayleigh-Taylor linear instability growth r

(e.g. Gentile *et al.*, 2006)

$$\gamma = \frac{\Sigma_P^F}{\Sigma_P^E + \Sigma_P^F} \left(V_p \right.$$

Unknown

Pederson conductivities

Up

Upward plasma

Directly Measured/known

- Therefore, some form of ionosphere-therm

TIEGCM

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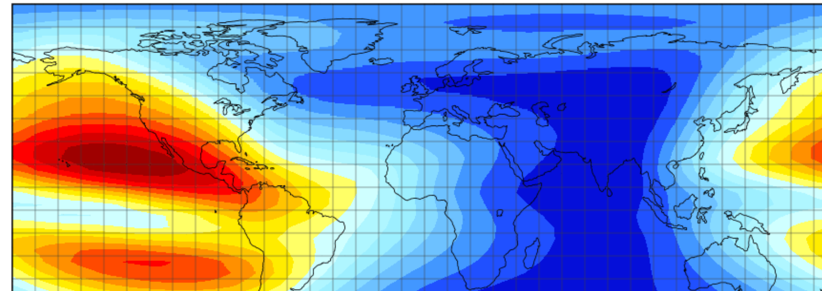
The Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) is a time-dependent 3D physics-based (i.e. not empirical) numerical simulation of the Earth's thermosphere and ionosphere.

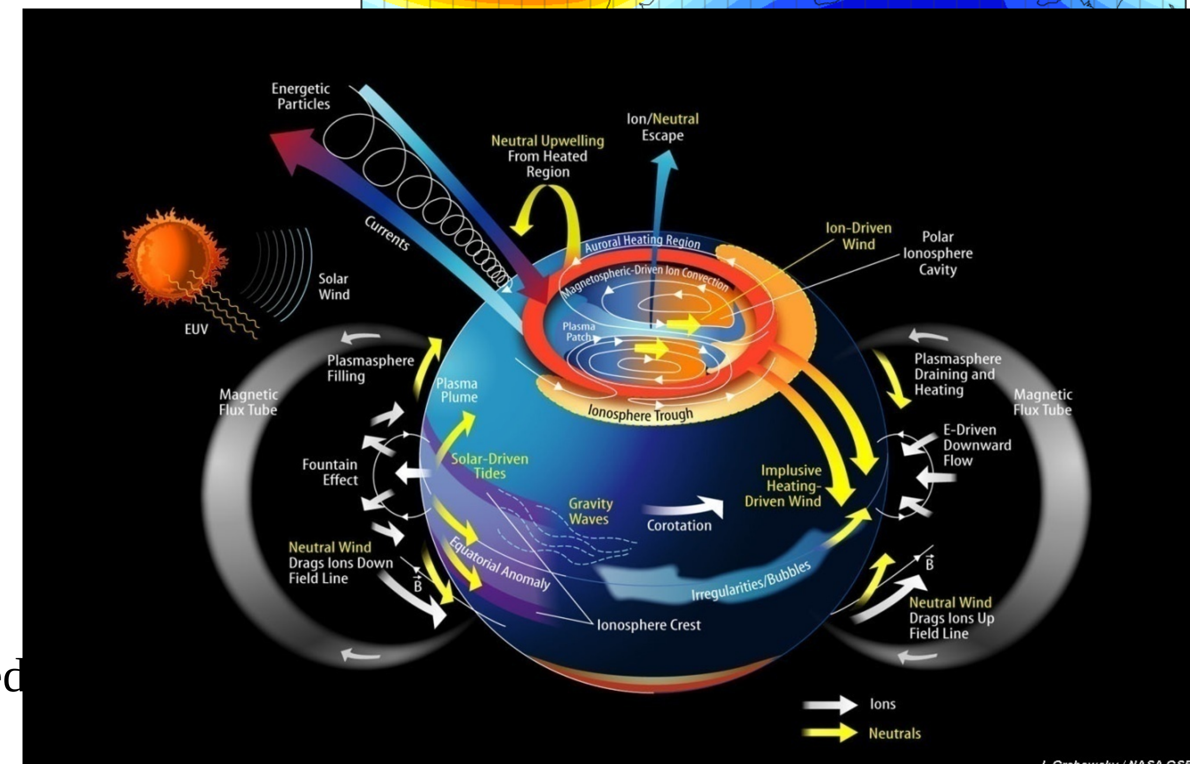


Inputs:

- 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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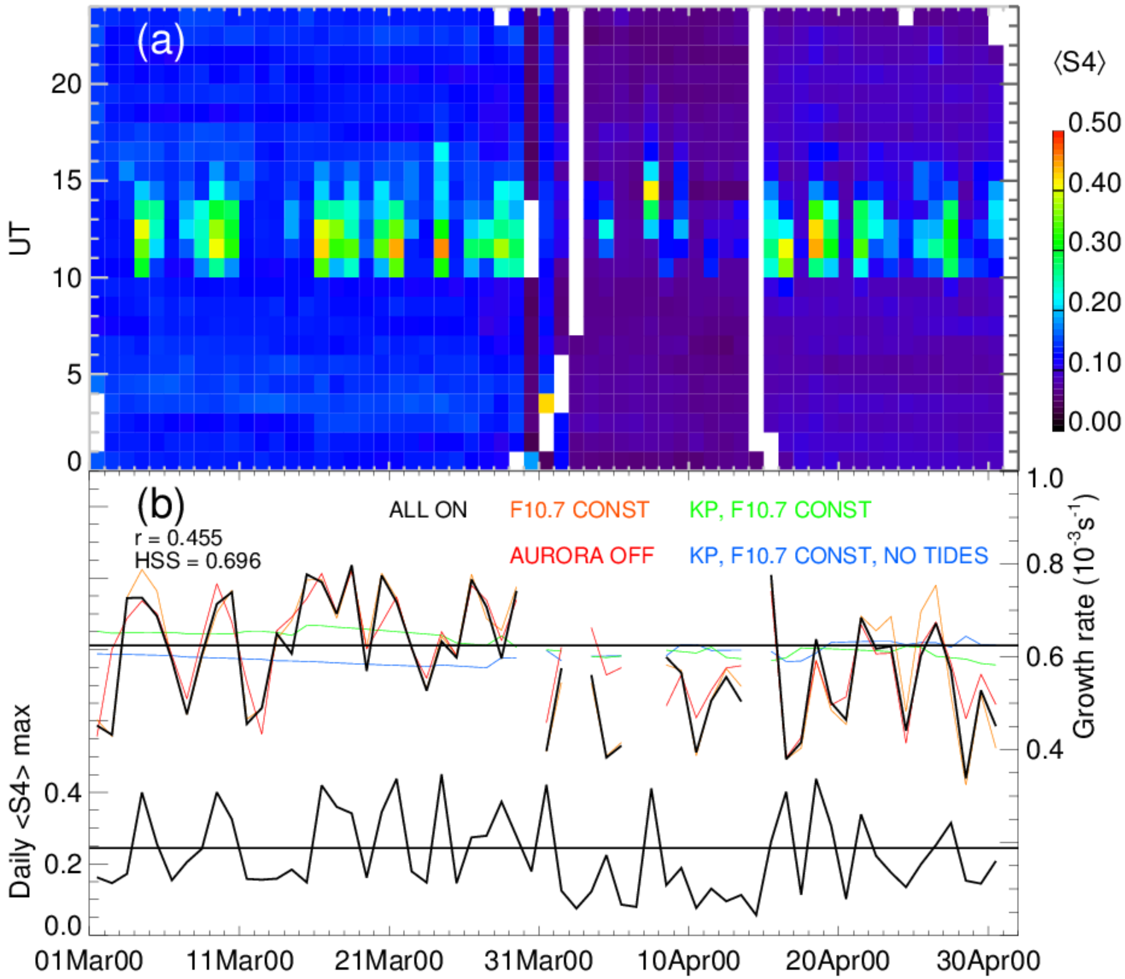
- Daily maximum average S4 shows good correlation with TIEGCM growth rate
- EPB modelling vs observations:

Observed / **Modelled**

EPBs	Yes	No
Yes	17	3
No	5	31

- Heidke skill score = 0.696
- Accuracy (17+31)/56 = 85.7%

- TIEGCM runs that varied Kp closely followed the observed daily variability
- Kp is dominant source of TIEGCM variability during quiet period



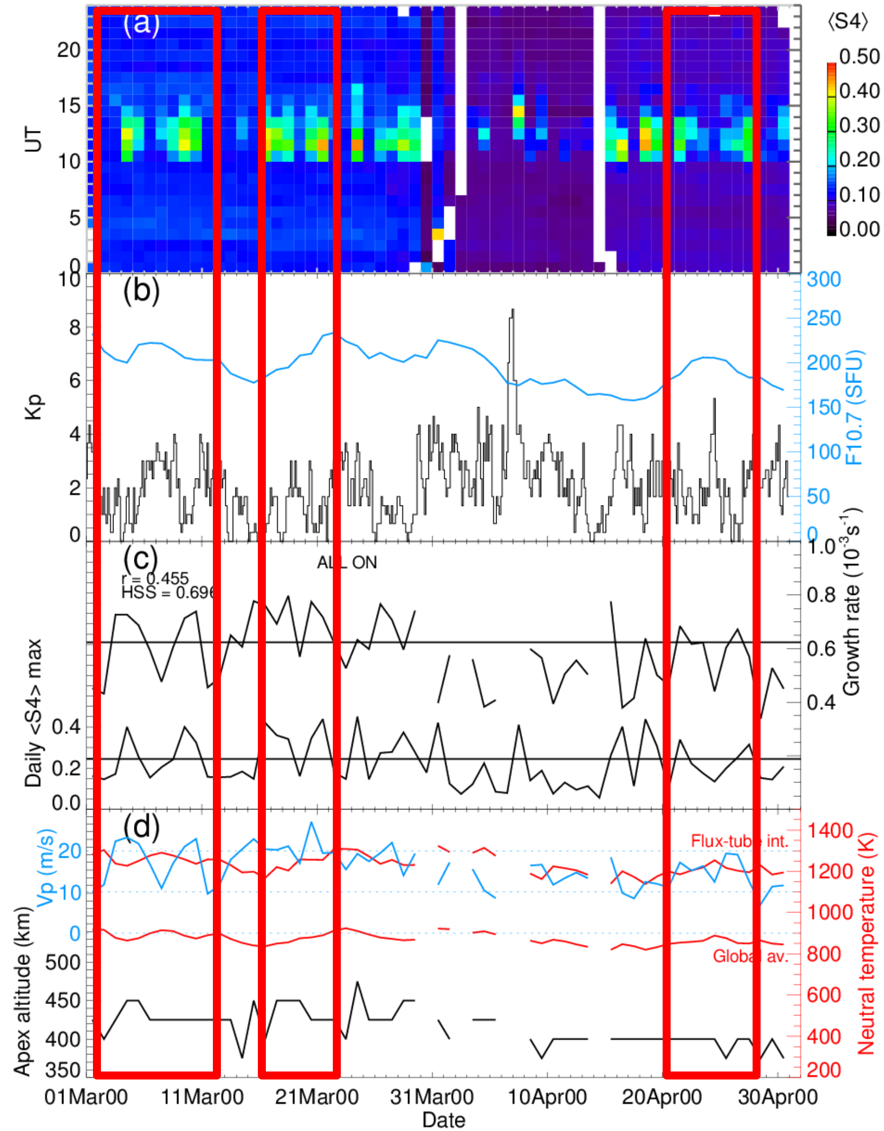
Carter et al., 2014 [JGR]

TIEGCM: EPB variability

Taking a closer look into the TIEGCM outputs:

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

(e.g. Gentile *et al.*, 2006)

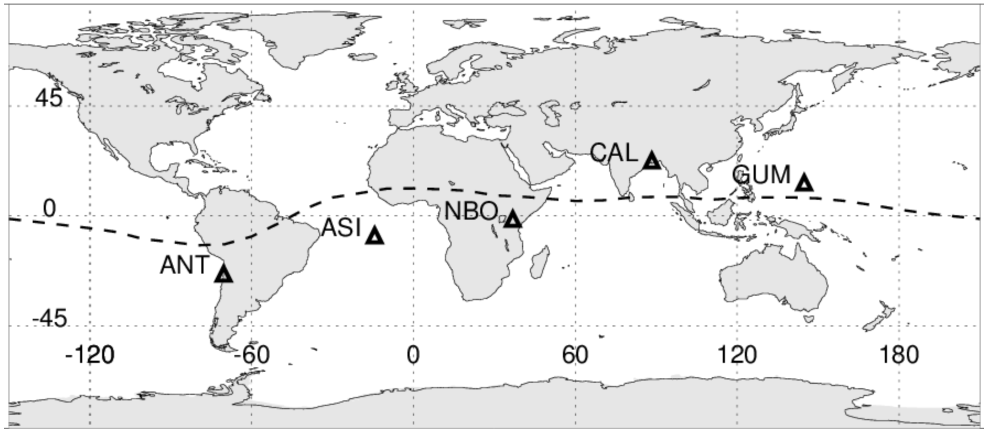


- Increases in Kp coincide with increases (decreases) in the thermospheric temperature (upward plasma drift)
- This implies that perturbations in the F-region dynamo are causing the quiet-time variability, and not storm-associated penetration electric fields

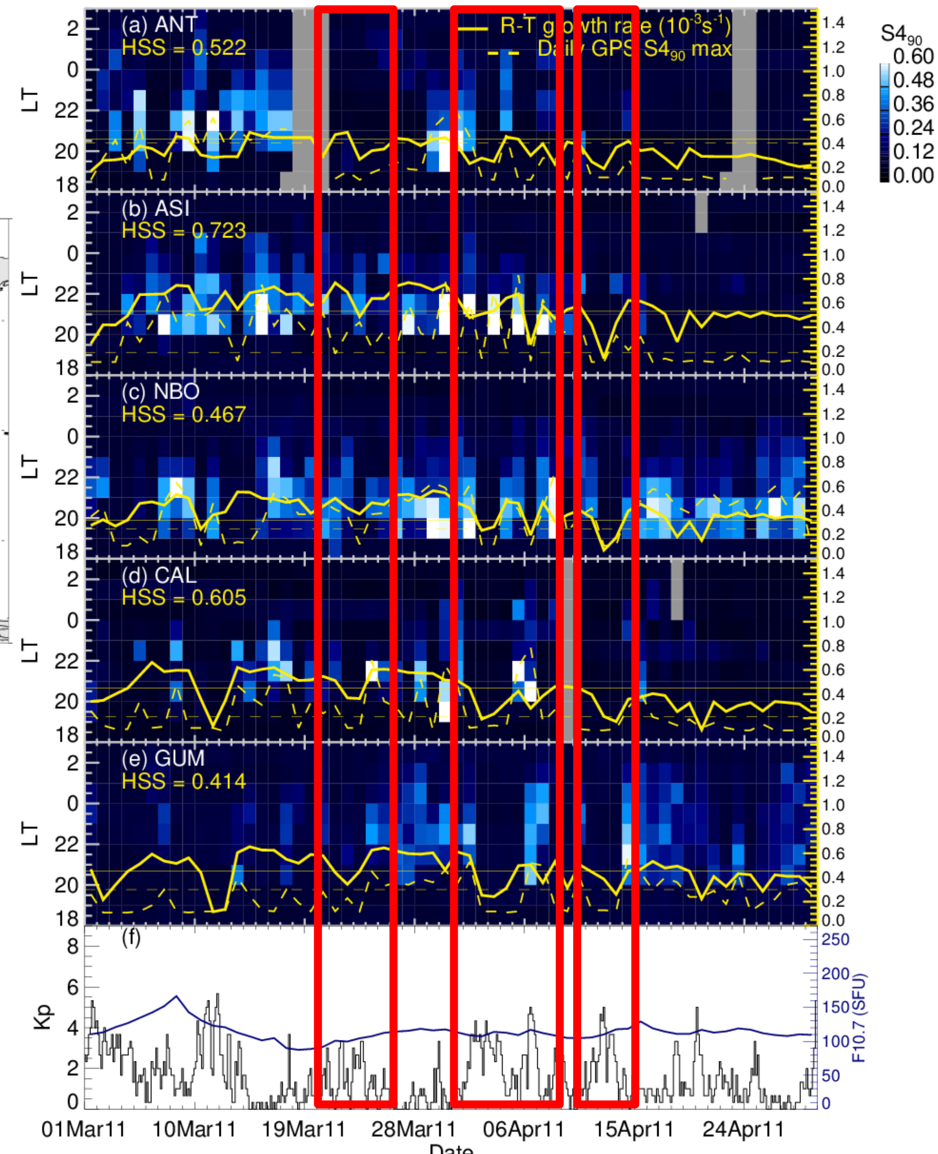
Carter et al., 2014 [JGR]

TIEGCM: EPB variability

The analysis was repeated for stations in the SCINDA network located different longitude sectors in 2011

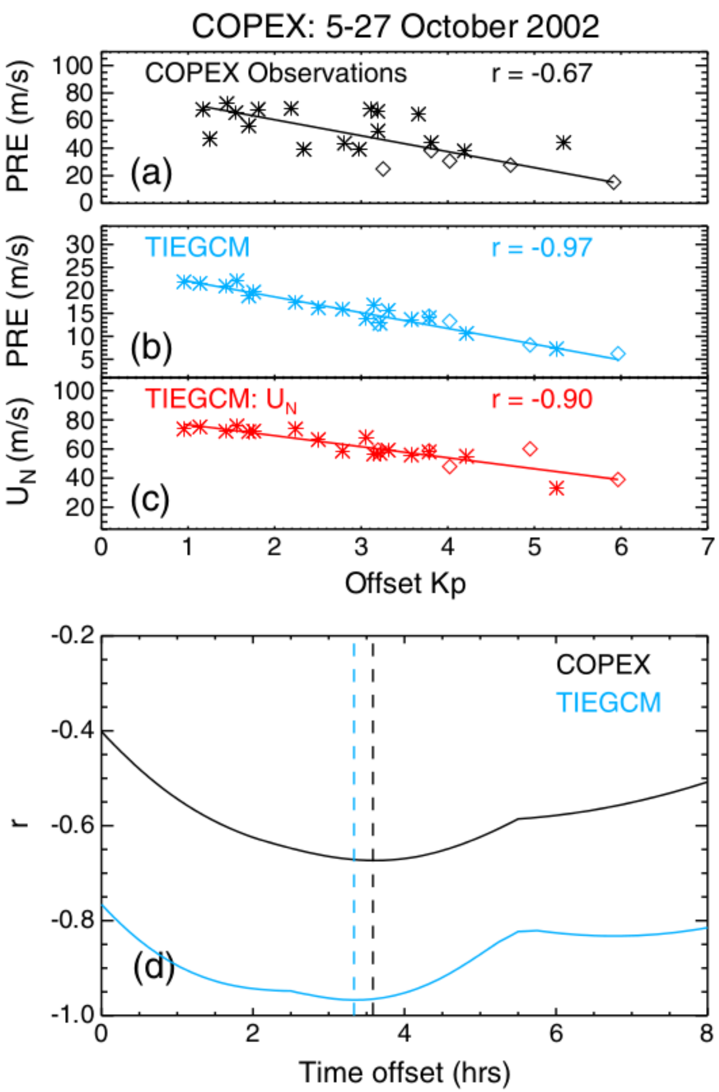


- Days that exhibited a drop in the TIEGCM R-T growth rate corresponded well to a lack of scintillation observations; e.g. early April for Nairobi, Calcutta and Guam
- Once again, it is clear that periods of increased (and not necessarily high) Kp corresponded to a lack of scintillation

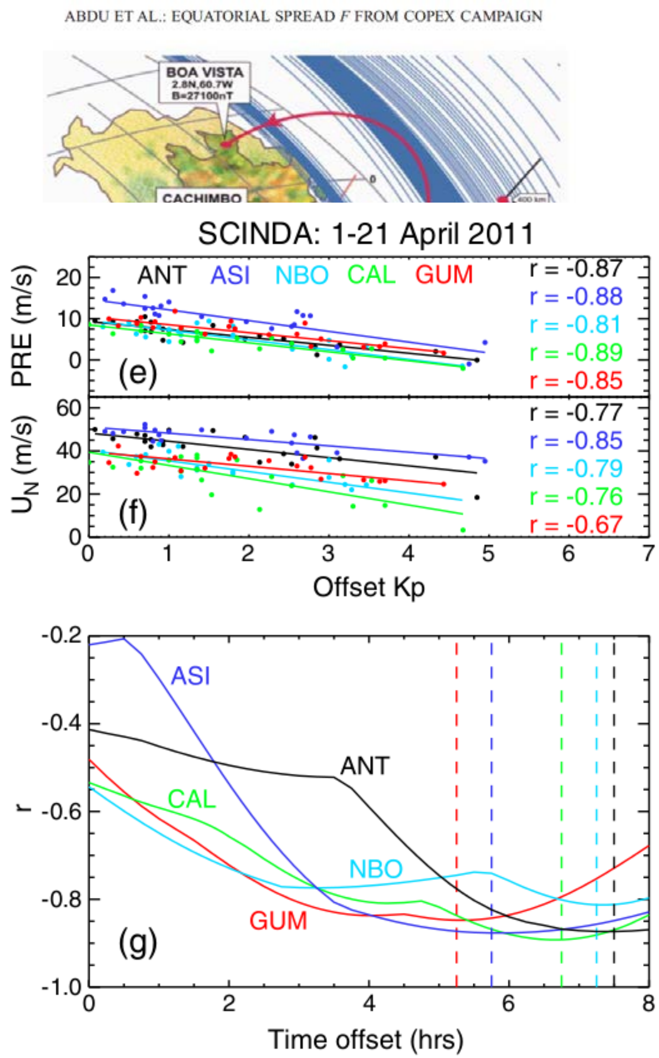


Carter et al., 2014b [GRL]

COPEX data: high and low latitude coupling



Carter et al., 2014b [GRL]



- COPEX observations were used to investigate timing of high-latitude and low-latitude coupling
- Best anti-correlation observed between PRE and Kp from ~3.5 hours prior
- TIEGCM modelling independently reproduces this result
- Zonal neutral wind also shows strong anti-correlation with offset Kp
- Results hold for 2011 SCINDA data

Physical processes: Cause and effect

Increased Kp

↓

Intensified plasma convection at high latitudes

↓

Increased Joule heating

↓

Thermospheric wind perturbations propagate towards equator

↓

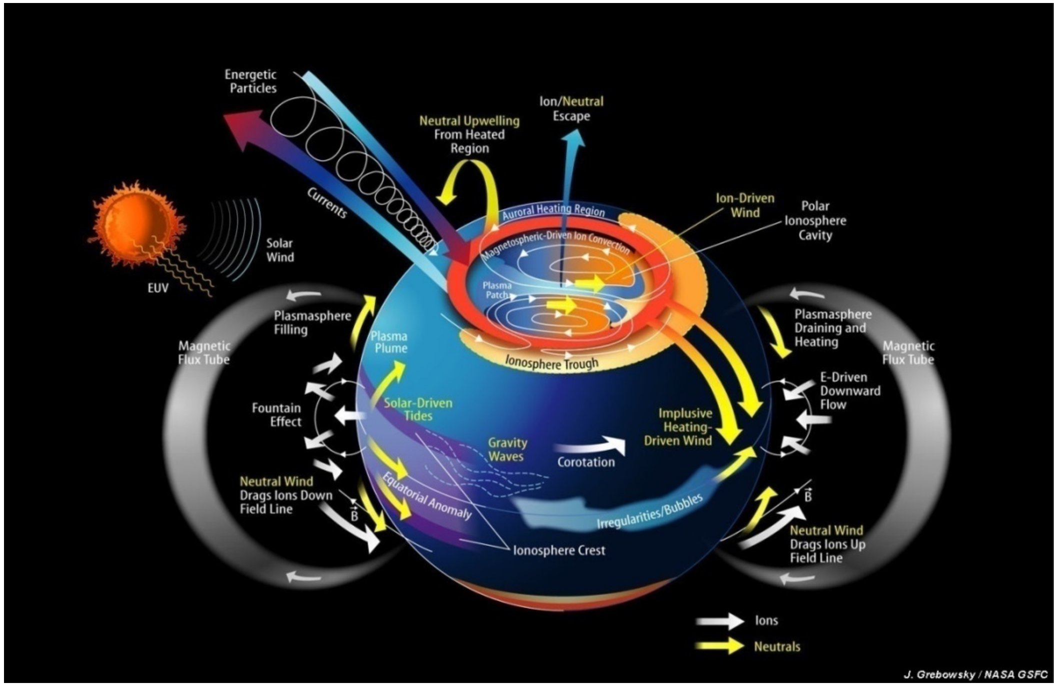
Decrease in zonal wind at equator

↓

Decrease in upward plasma drift (Vp)

→

Decreased R-T growth rate (no EPBs or scintillation)



Future implications

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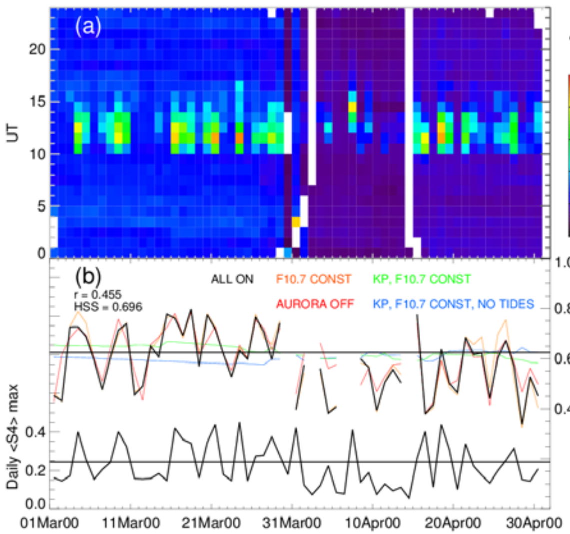
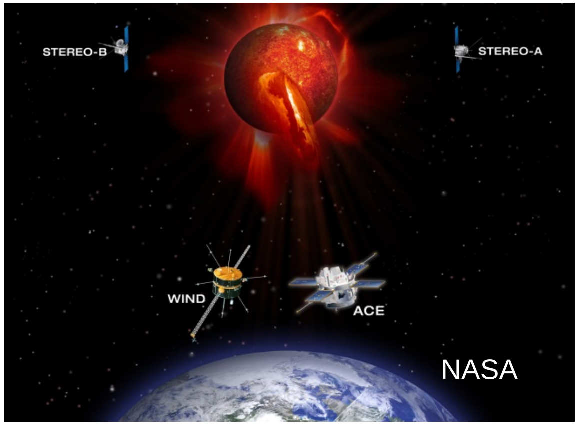
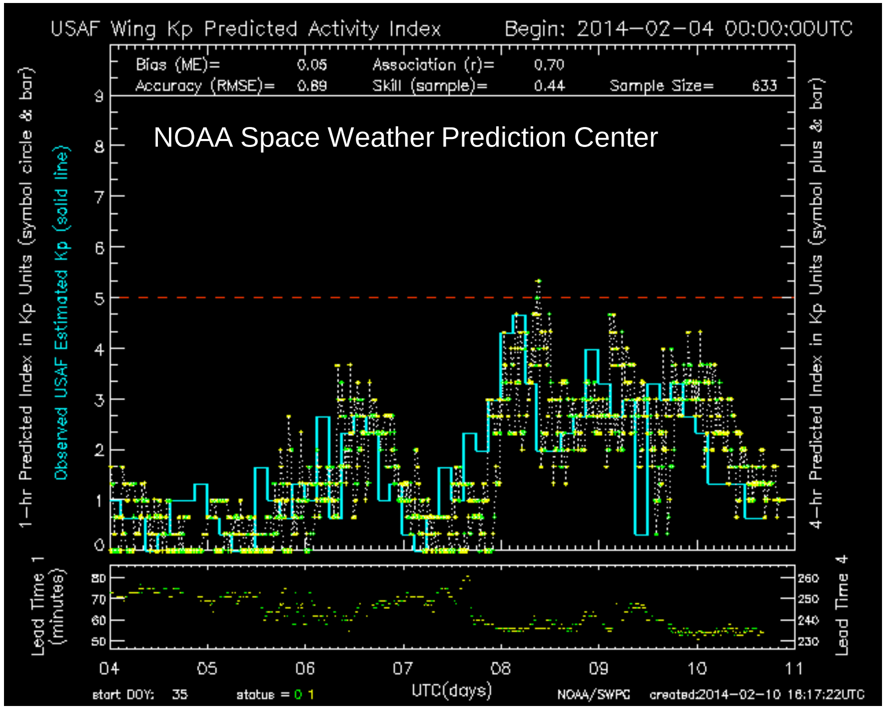
Analysis has shown that the most important source of variability in the TIEGCM originates from the Kp index (geomagnetic activity)





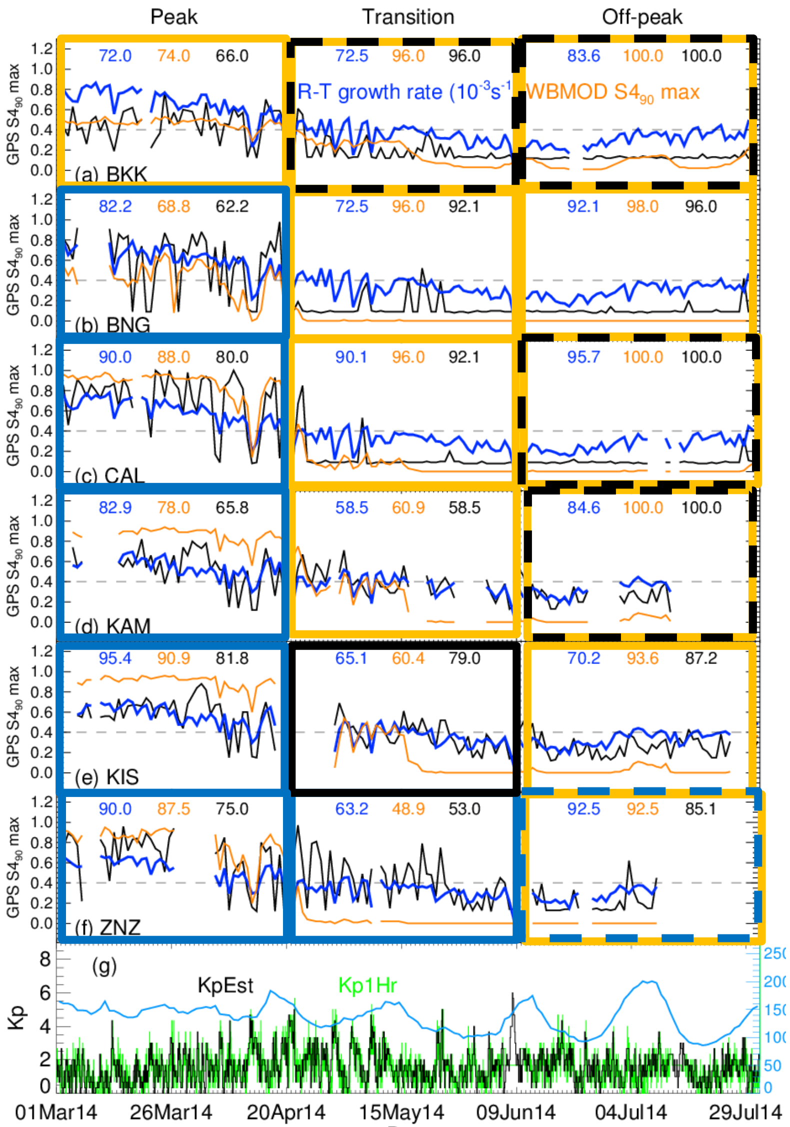
Can we predict Kp?

Yes, the ACE and WIND spacecraft are routinely used by the USAF to predict Kp with rather good accuracy.



Are these predictions good enough?

Scintillation prediction trial: Mar-Jul 2014

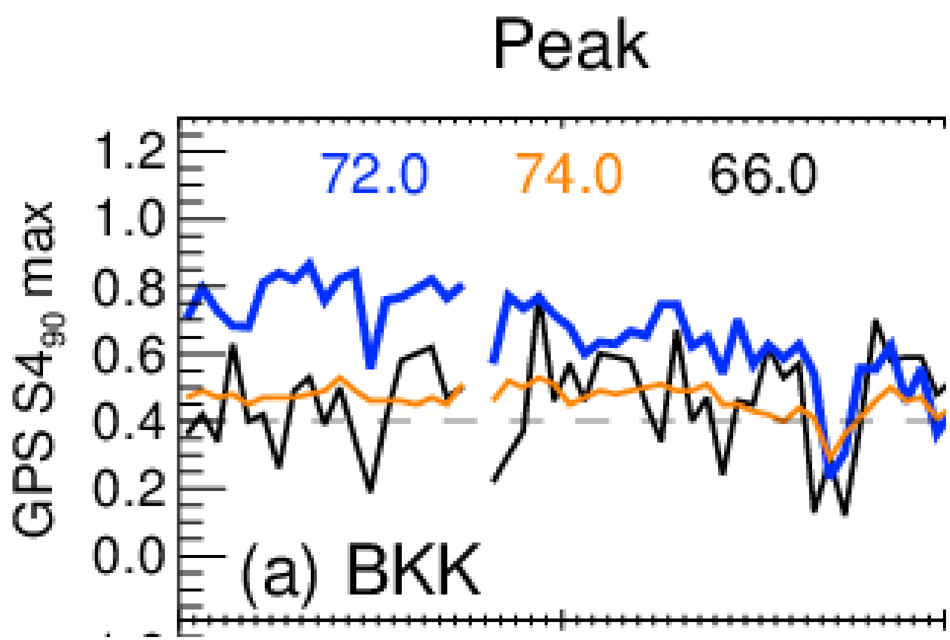


Carter et al., 2014c [GRL]

1-hour Wing Kp predictions:

TIEGCM generally performs best during peak EPB season, closely followed by WBMOD (up to 95% for KIS)

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



Scintillation prediction trial: Mar-Jul 2014

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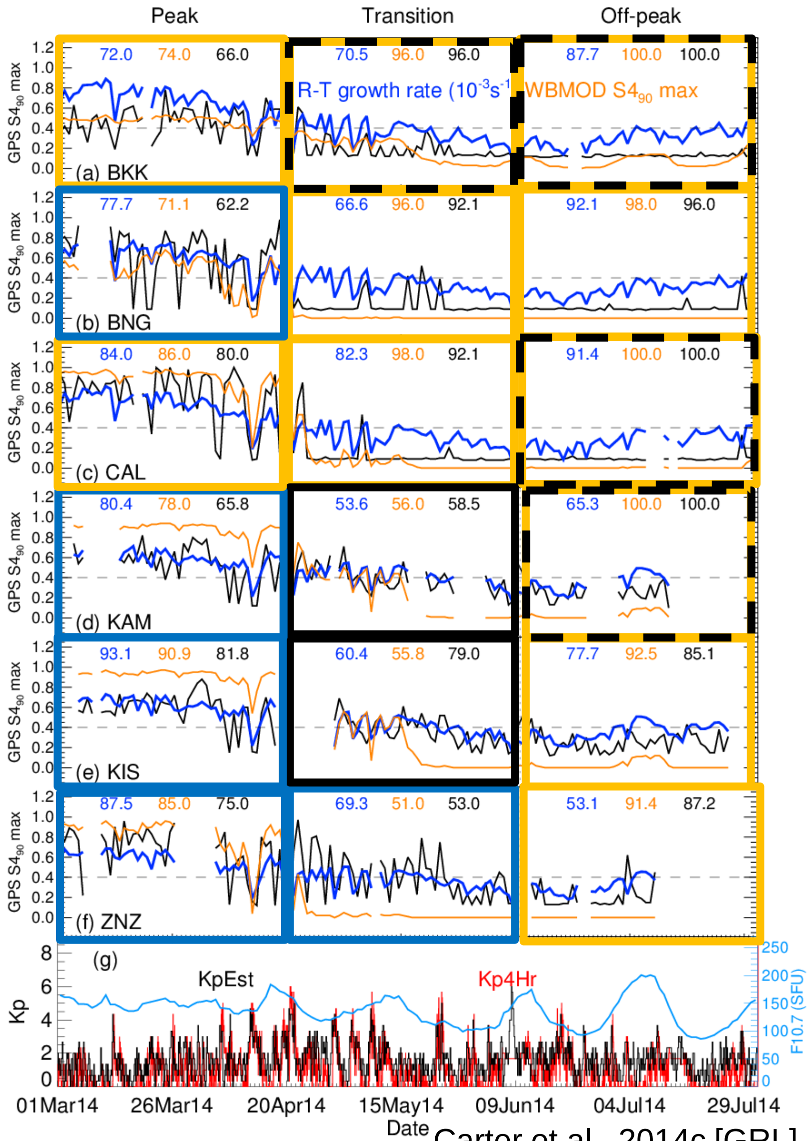


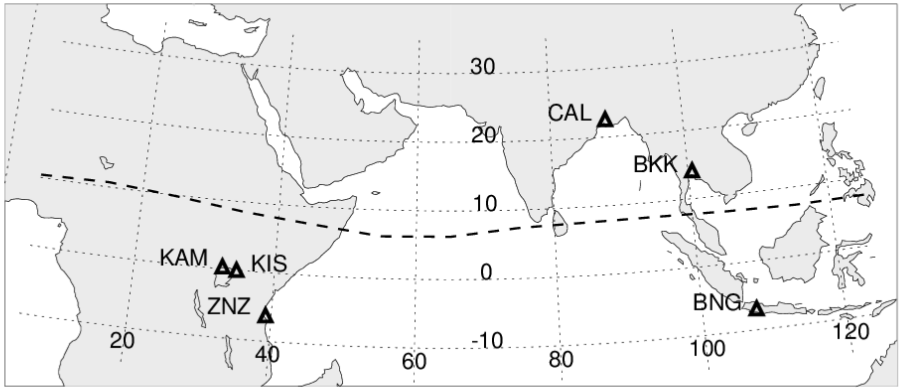
Carter et al., 2014c [GRL]

4-hour Wing Kp predictions:

Ranking of models is only slightly unchanged

Using 4-hour predictions doesn't result in significant decrease in accuracy

This is due to several hours delay between high-latitude changes (by Kp) and their effects at the equator via thermosphere wind perturbations



Summary and conclusions

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Day-to-day variability in Equatorial Plasma Bubbles in Southeast Asia:

- Complicated daily variability in EPB/scintillation occurrence observed using ground-based GPS receiver at Vanimo
- Not correlated with (predictable) solar and geomagnetic activity indices, so advanced ionosphere-thermosphere modelling was required

TIEGCM results agreed well with the GPS data for locations experiencing peak scintillation activity (Africa and Asia):

- Increased, but not necessarily high, Kp was found to control the likelihood of EPBs on any given day during peak EPB season
- Control of geomagnetic activity level on the strength of the thermospheric zonal wind at the equator is found to be a primary influence on the PRE

A scintillation prediction trial using geomagnetic activity forecasts in combination with TIEGCM and WBMOD was successful:

- Both models were capable of predicting EPB suppression days due to increased geomagnetic activity during peak season
- Neither model was capable of predicting scintillation events during off-peak season – this needs further research…