The impact of “quiet” space weather on technologies: Research progress on plasma bubbles and induced currents

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Outline

- **Introduction**
  - Extreme space weather events can be costly

- **What about "daily" space weather?**
  - Equatorial Plasma Bubbles (EPBs), which effects GPS and satellite communications
    - Our recent efforts to produce a day-to-day prediction capability
  - Geomagnetically Induced Currents (GICs) at equatorial latitudes
    - Our analysis of GICs caused by interplanetary shocks

- **Summary and conclusions**

The cost of extreme space weather

- Severe space weather event scenario, recovery 4-10 years, $US 1-2 trillion in first year alone[1]

- Tohoku Earthquake, estimated $US 210 billion[2]

- Hurricane Katrina, 2005, $US 81-125 billion[1]

- Potential Geostationary Satellite revenue loss, $US 25 billion per year[1]

- Late 2010-early 2011 Queensland floods, $AU 5-6 billion[3]

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[1] National Research Council. *Severe Space Weather Events--Understanding Societal and Economic Impacts: A Workshop Report*. Washington, DC: The National Academies Press, 2008 (and references therein).

[2] Brookings-Bern Project on Internal Displacement, *The Year that Shook the Rich: A Review of Natural Disasters in 2011*, March 2012, available at: http://www.refworld.org/docid/4f61a85a2.html [accessed 10 February 2014]

[3] http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/understanding-floods_full_colour.pdf

The cost of extreme space weather

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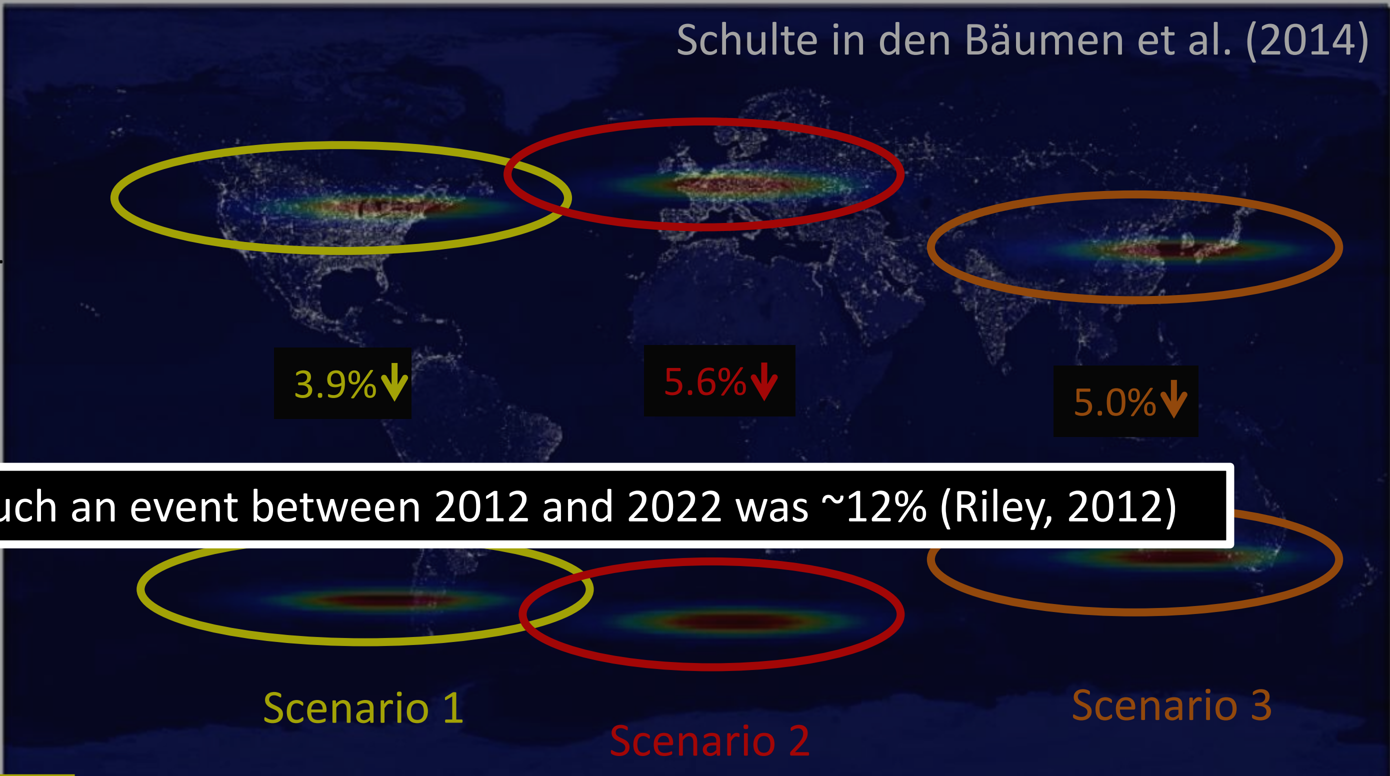
Max of 10% of electricity supply lost over 12 months

Global economic model

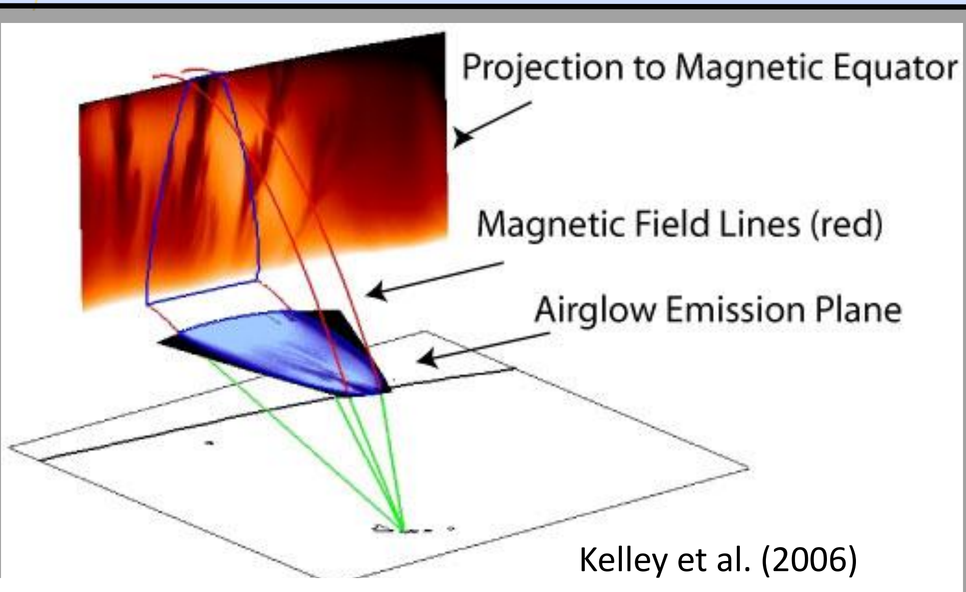
- 187 countries with 25-400 sectors per country
- captures ~99% of g activity



Schulte in den Bäumen et al. (2014)

The likelihood of such an event between 2012 and 2022 was ~12% (Riley, 2012)

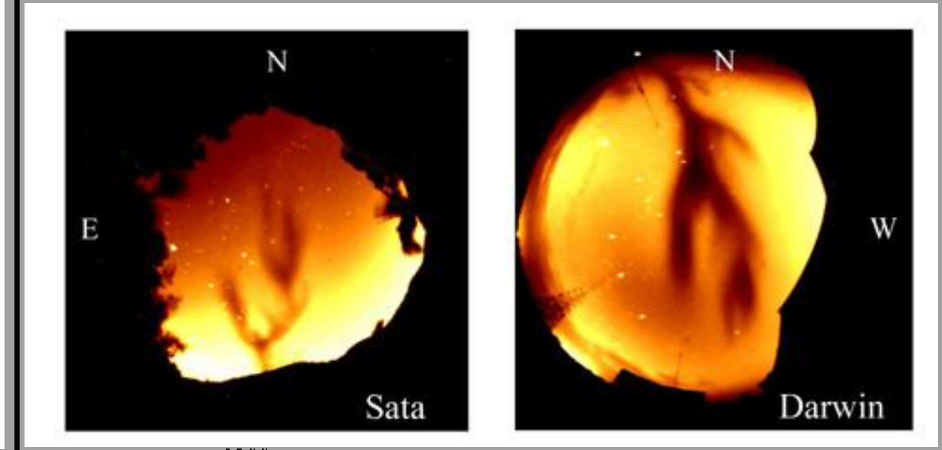
Equatorial Plasma Bubbles



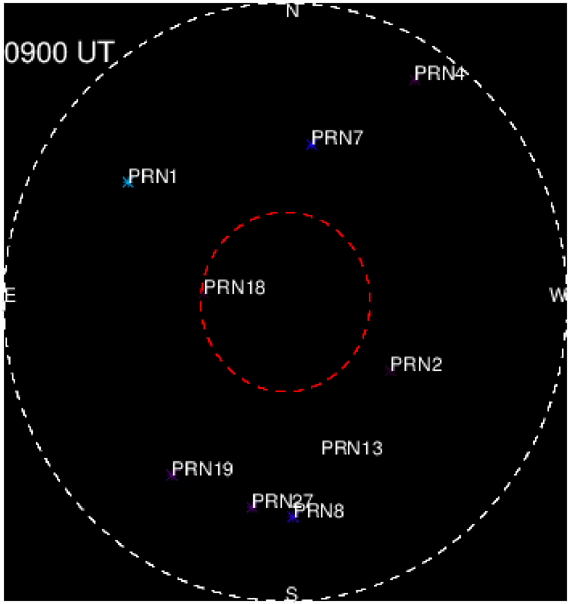
Kelley et al. (2006)

All-sky cameras and numerical modelling

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



Vanimo PNG, Mar-17-2000



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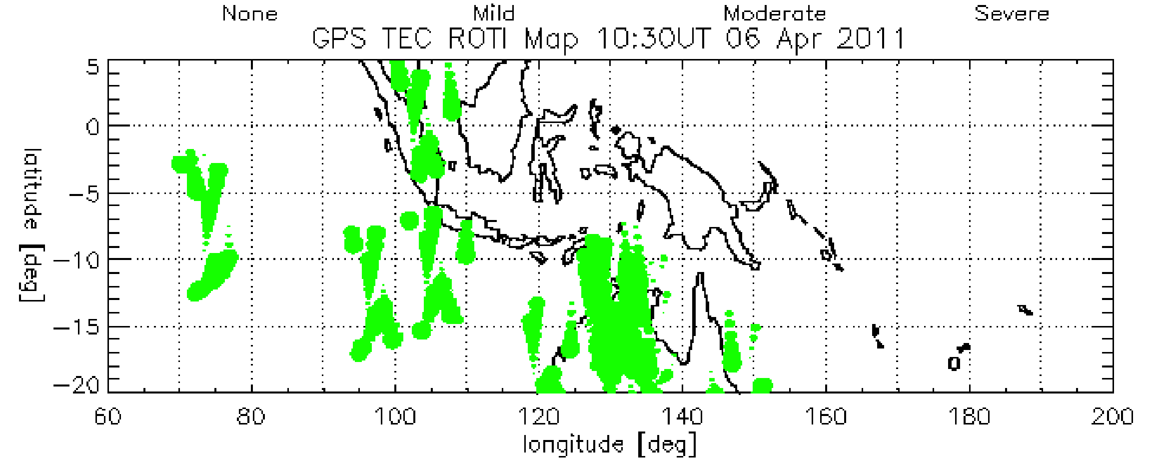

1200

-600 -400 -200 0 200 400 600

West - East [km]

Retterer [2008a,b]

EPB Climatology: GPS RO data

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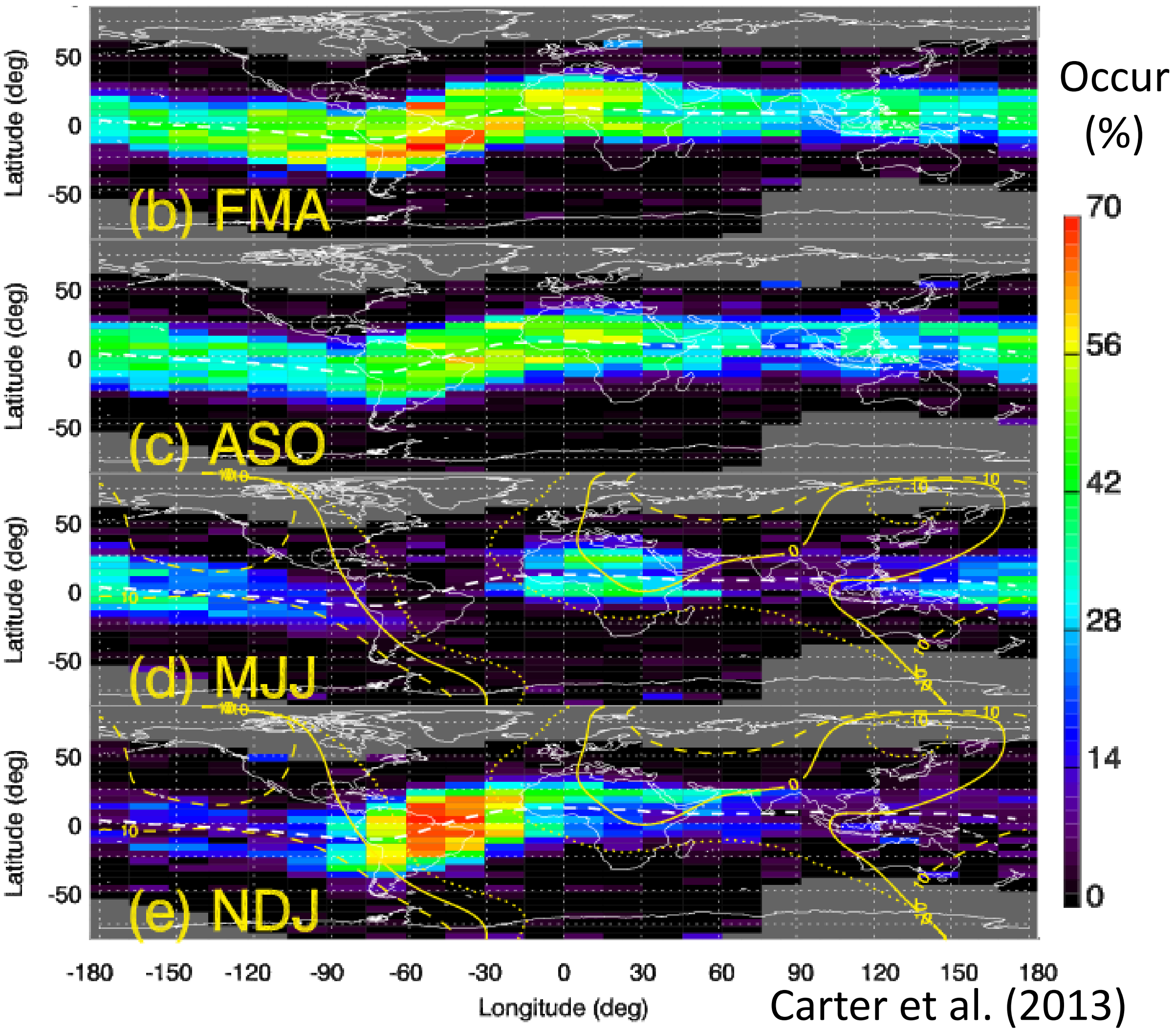
EPBs (and scintillation events on GPS and UHF systems) are most common during the equinoxes across all longitude sectors near the magnetic equator.

The June solstice months see elevated EPB activity in the Australian/Pacific longitude sector, and the December solstice shows increased EPB activity in South America and Africa.



Carter et al. (2013)

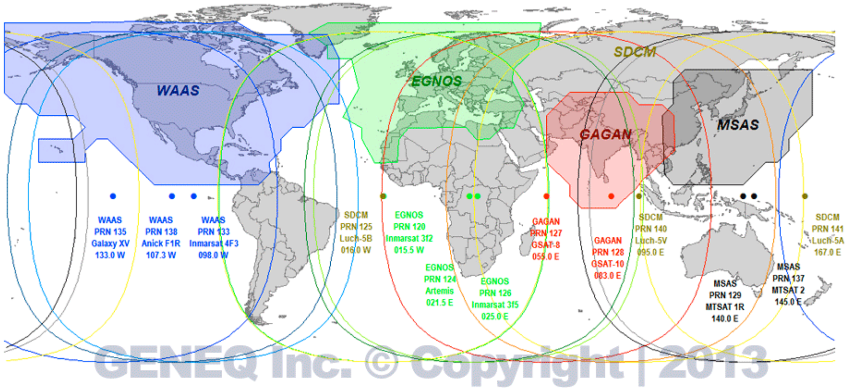
Potential economic vulnerabilities to day-to-day space weather: GNSS

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

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


GPSat Systems Australia


Credit: SSG Kyle Davis

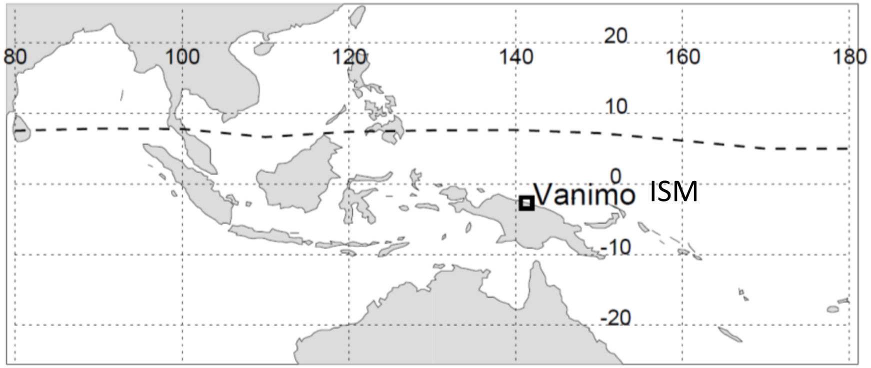


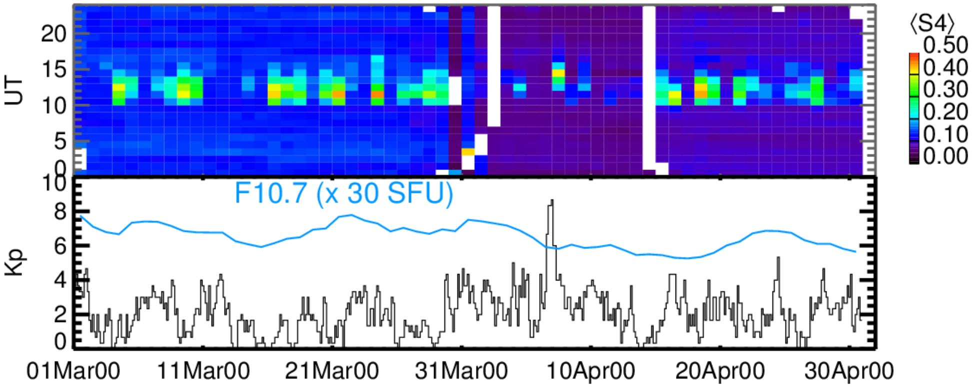
No study to date has investigated the impact of ionospheric scintillation events on operations in these sectors, and the flow-on impacts on the wider economy.

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


CRC for Spatial Information

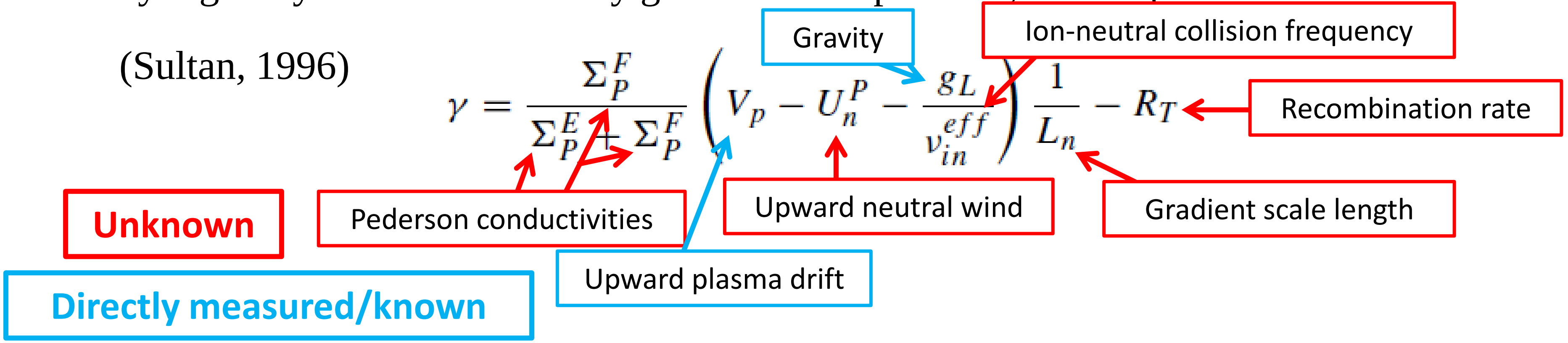
GPS scintillation observations





Carter et al., 2014 [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

Gradient scale length

Upward neutral wind

Pederson conductivities

Upward plasma drift

Unknown

Directly measured/known

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

TIEGCM

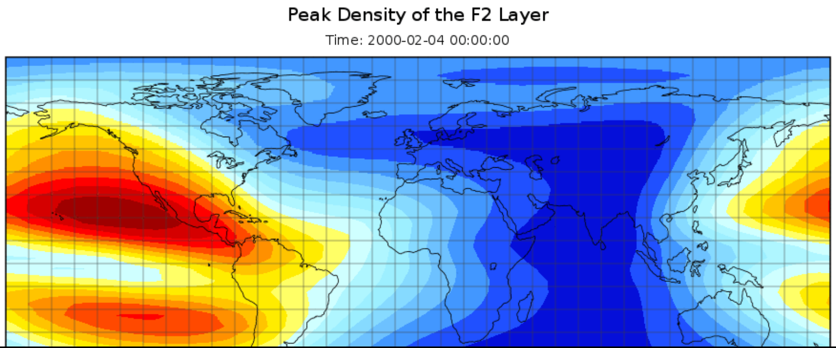
The Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) is a time-dependent 3D physics-based (i.e. not empirical) numerical simulation of the Earth's thermosphere and ionosphere.

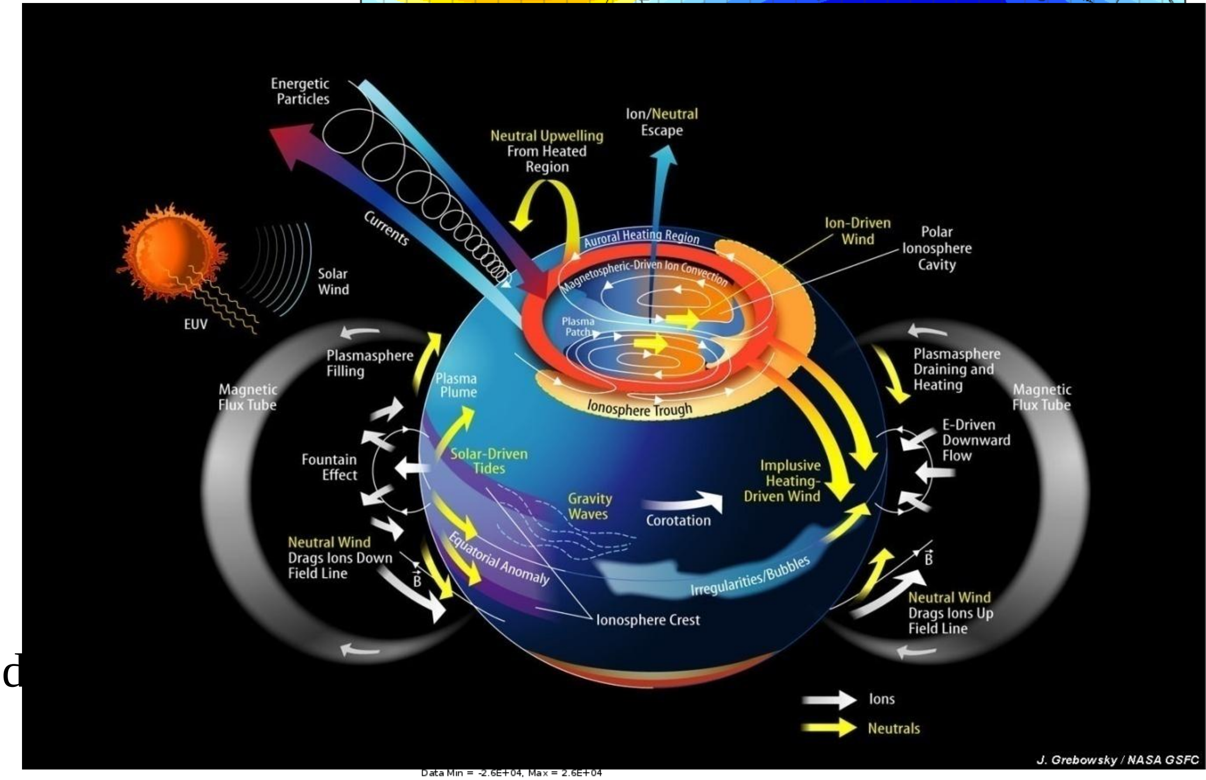
Inputs:

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

Outputs:

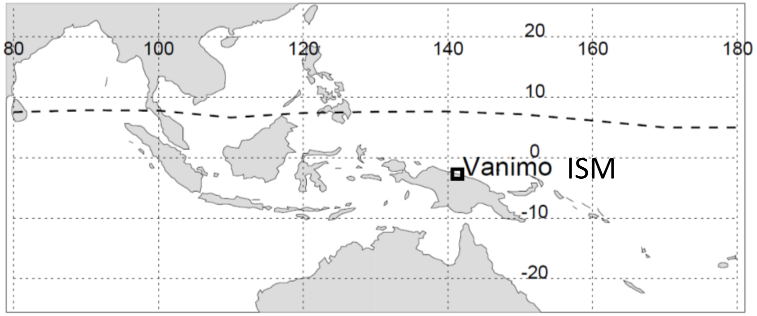
- Electron density
- F layer height
- 3D plasma drift
- Thermospheric density
- 3D neutral winds…
- …
- Basically, everything that we need





Data Min = -2.6E+04, Max = 2.6E+04

TIEGCM: EPB variability

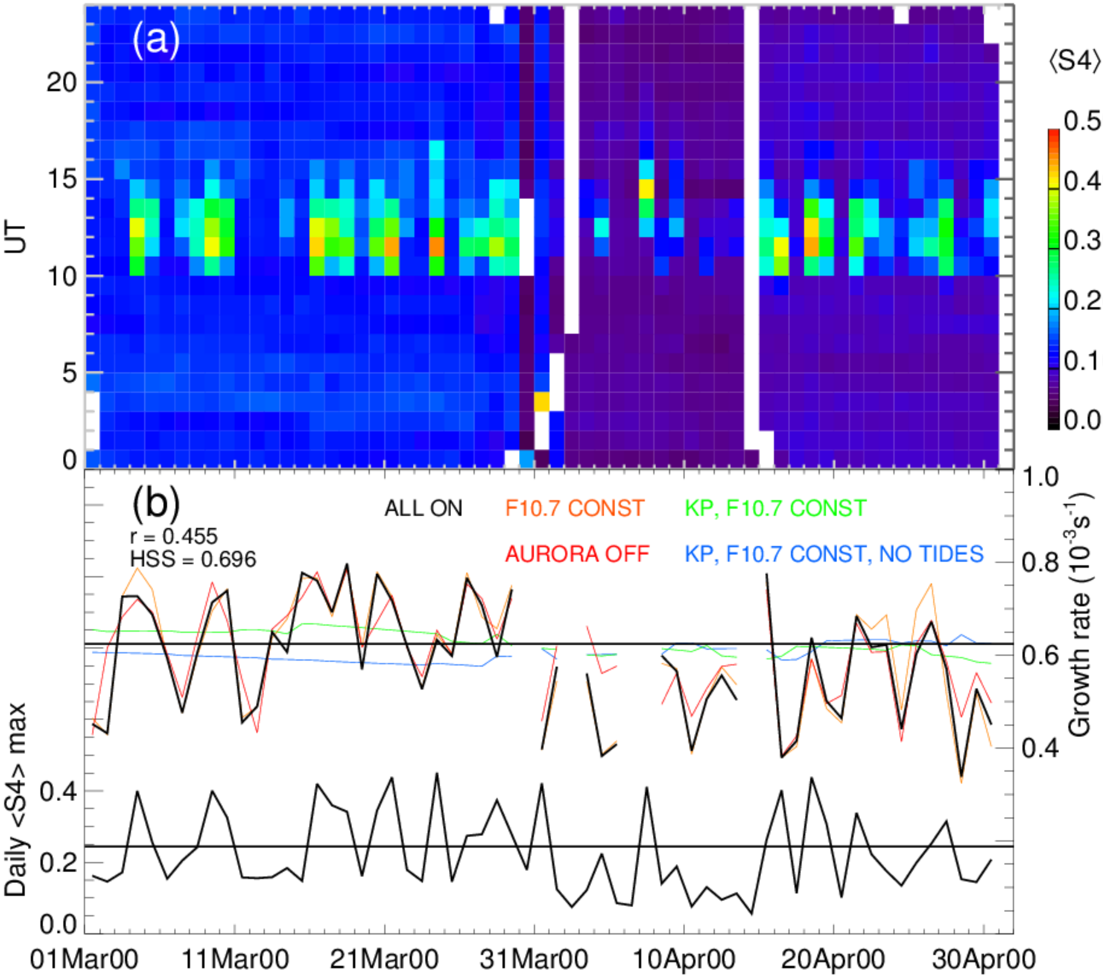


Observed

Modelled

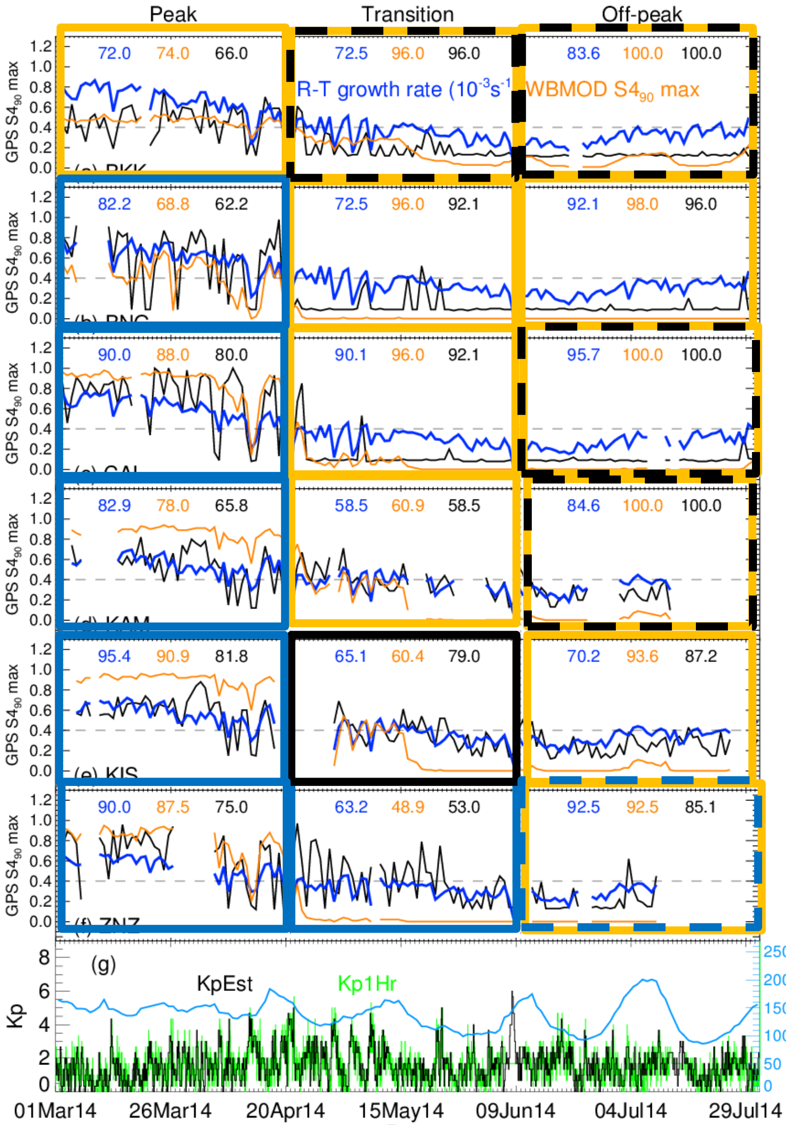
EPBs	Yes	No
Yes	17	3
No	5	31

- Physics-based model was found to imitate the observed daily changes
- Kp is dominant source of TIEGCM variability during quiet period



Carter et al., 2014a [JGR]

Scintillation prediction trial: Mar-Jul 2014

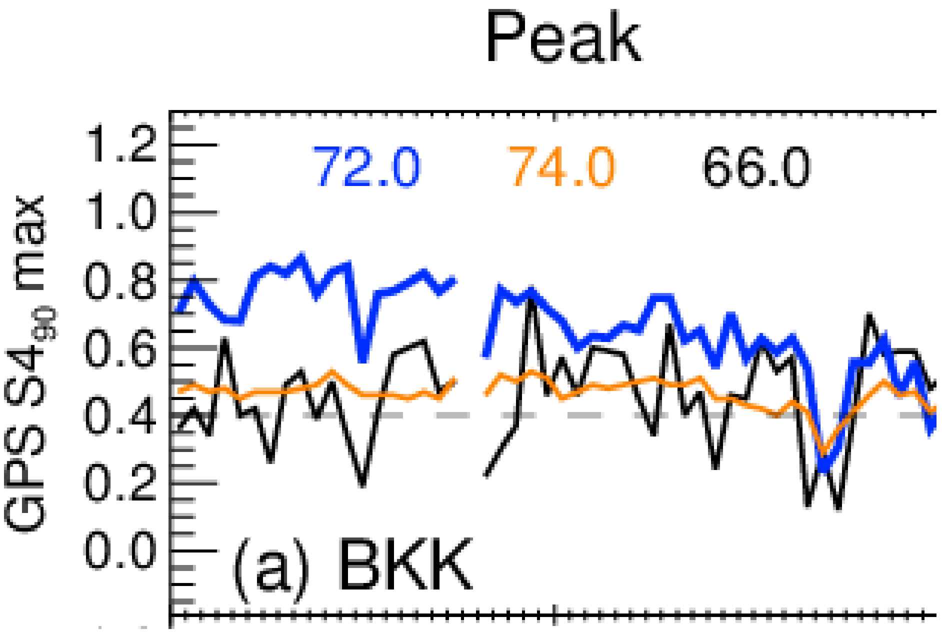


Carter et al., 2014c [GRL]

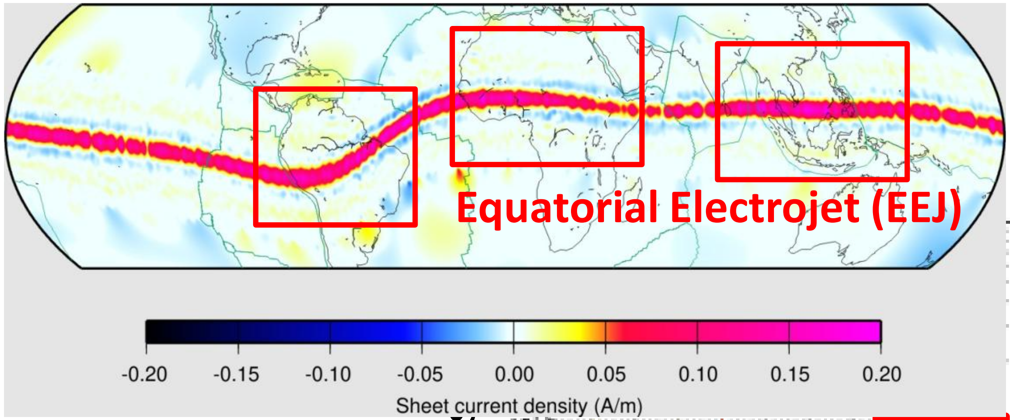
1-hour Wing Kp predictions:

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

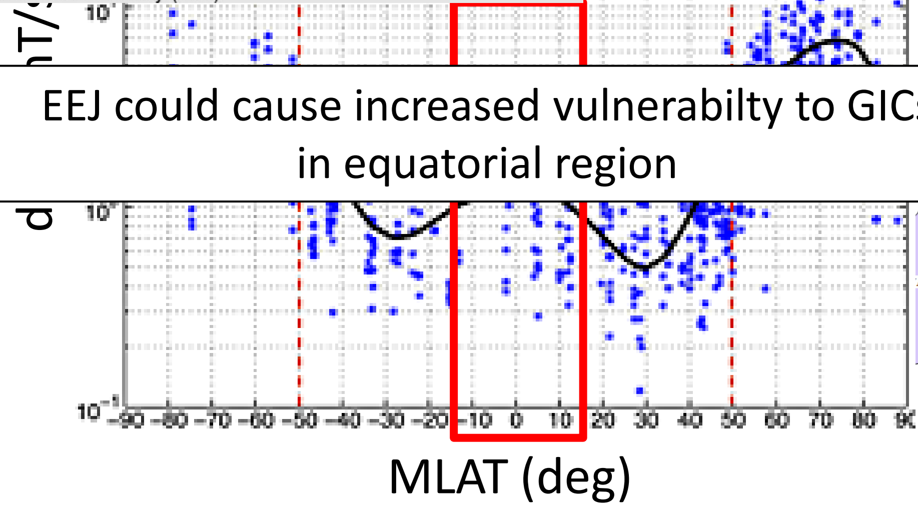
During transition and off-peak seasons, either WBMOD or "persistence" forecast performs best



Space weather effects on technologies – GICs

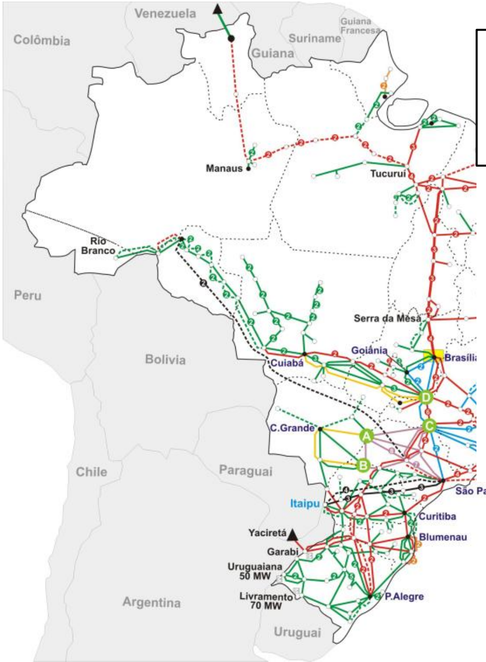


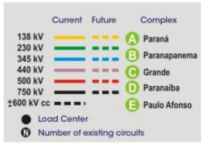
(2013)



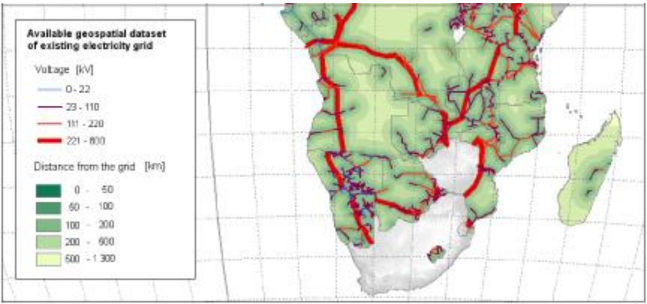
MLAT (deg)

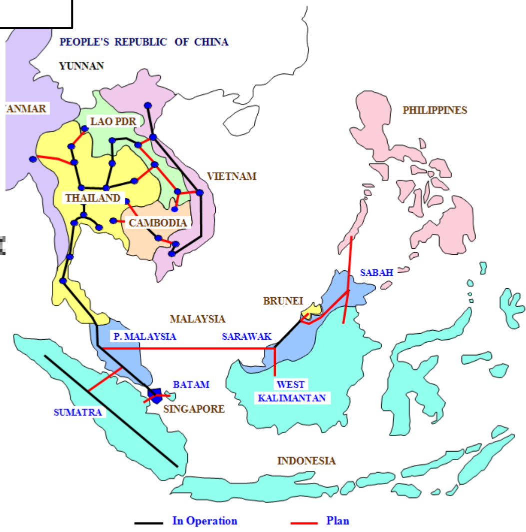
EEJ could cause increased vulnerabilty to GICs in equatorial region





Moldwin et al., AGU Monograph (2016)





Interplanetary Shocks and GICs

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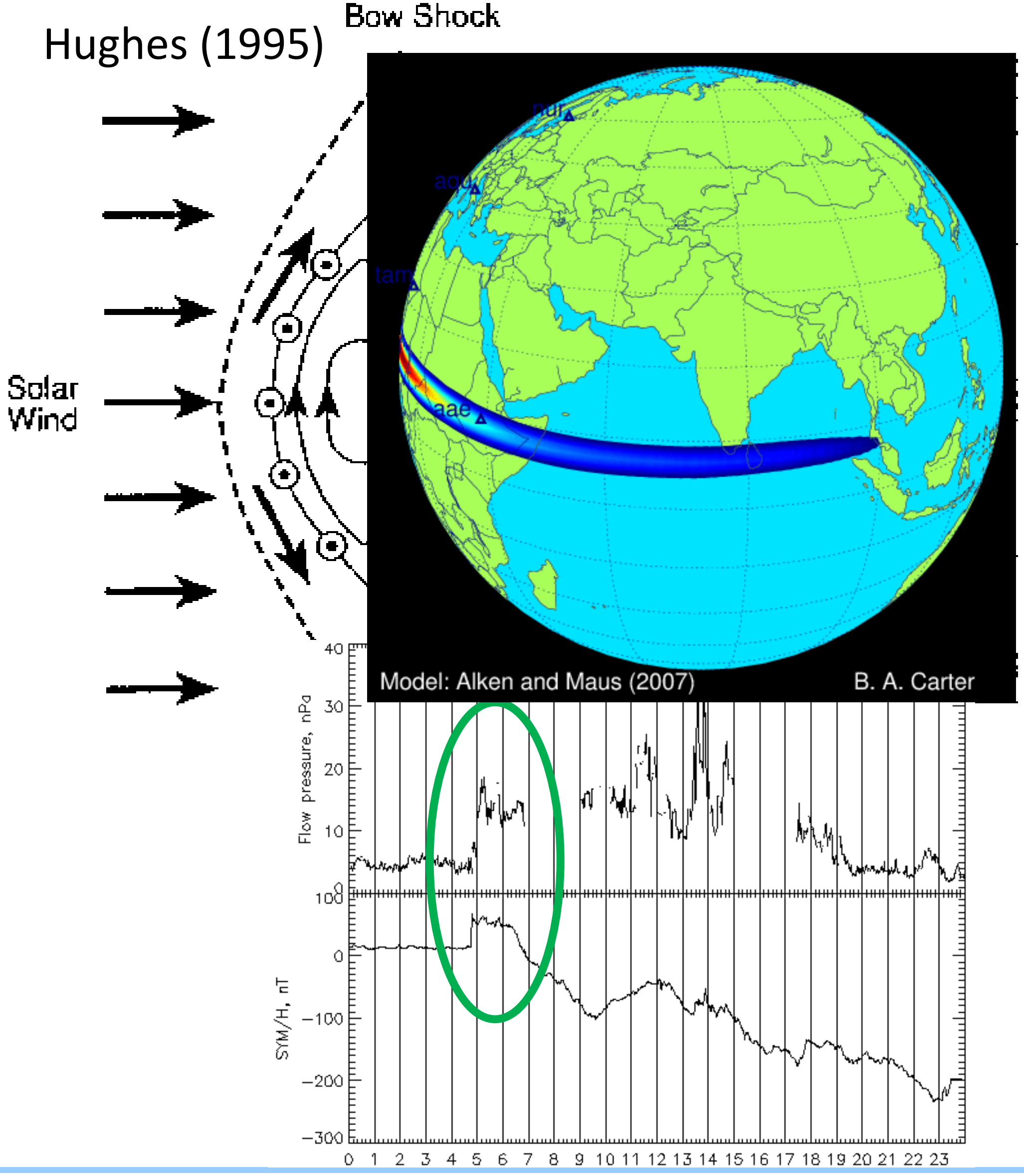
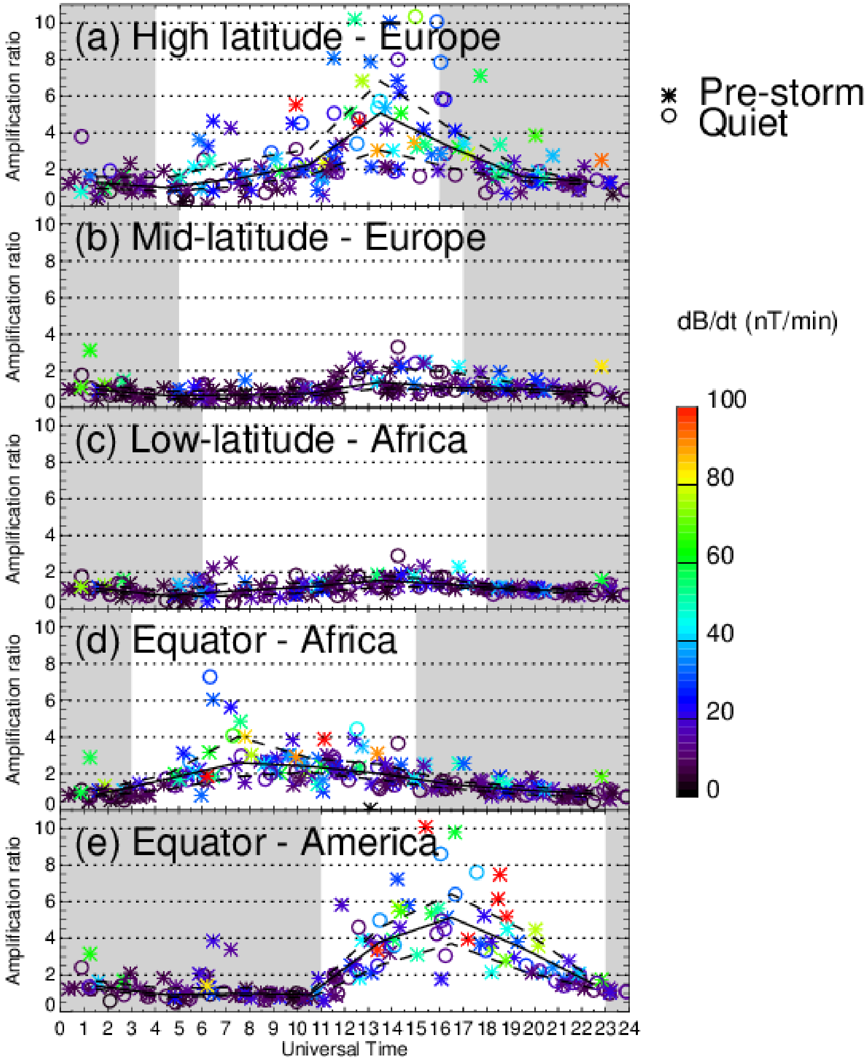
Hughes (1995)



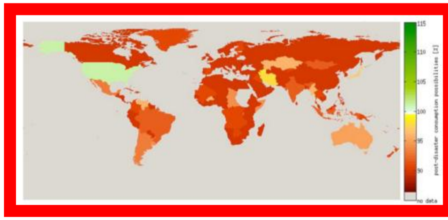


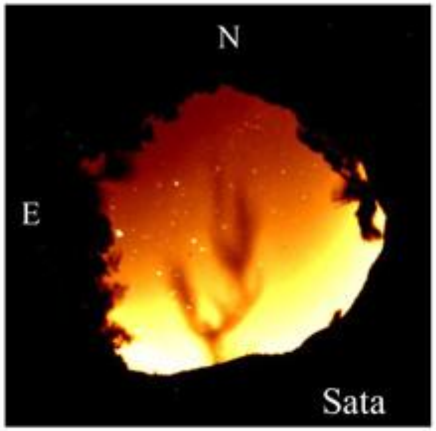
Carter et al., 2015 (GRL)

Summary and conclusions

Severe space weather events can be very costly

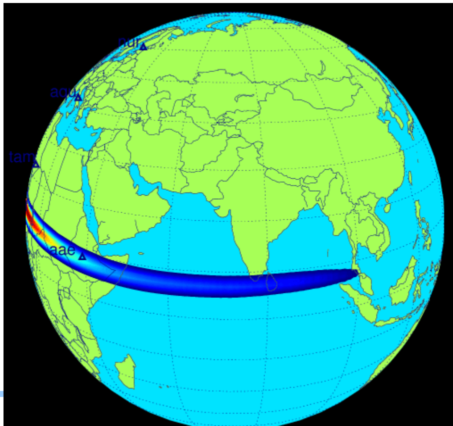
- Investigating the impacts of “Carrington-scale” events is very important because of society’s heavy reliance on modern technologies
- Such an event has been estimated to affect the global economy on the same level as major wars and global financial crises





However, everyday “quiet-time” features of the near-Earth space environment have a measurable impact on some important technologies:

- The equatorial region has been found to be vulnerable even during quiet times, but the implications in terms of economic impact(s) have yet to be explored/understood
- Equatorial Plasma Bubbles cause scintillations on GPS and UHF systems, which are heavily relied upon by an increasing number of applications
- Recent results have shown that interplanetary shocks, which are not always associated with geomagnetic storms, can cause significant GICs at equatorial latitudes



Model: Alken and Maus (2007)

Shifting focus towards understanding how the “quiet-time” space environment affects us (and our pockets) will keep our research area relevant throughout the technology age