GAIM driven by different Empirical Models: A Comparisons with Data Assimilation

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Introduction/Motivation

The Ionosphere is a driven system with well defined climatological features that can show substantial day-to-day variability. Empirical models (EMs) are widely used to represent the significant drivers and they capture most large-scale variations. Data Assimilation (DA) methods have been leveraged in a variety of space weather studies and show promising applicability for capturing day-to-day variability, near-real time forecasting, and specific event studies [3].

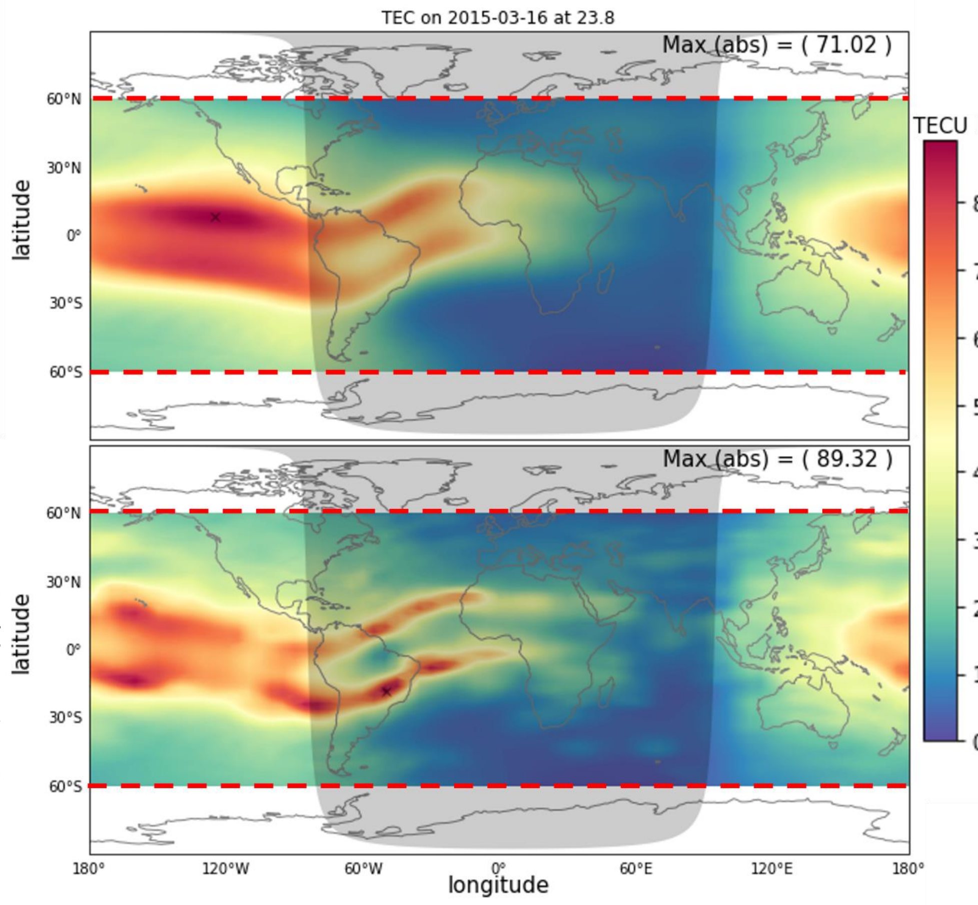

Fig 2. Example of physics-based model run (top) and DA run (bottom)

Why use DA for Ionospheric weather

- Physical processes governing ionospheric weather are not well understood (Forcing uncertainties).
- Advances in observational infrastructure allow for a variety of measurements to be assimilated.
- Operational/Scientific advantages such as driver estimation (variational methods)

The focus of this study is to use the Global Assimilation of Ionospheric Measurements (GAIM) for two purposes:

1. **Recommend empirical model options for the current development version of GAIM**
   How: Compare GAIM forward model outputs using a different combination of empirical model options (EMO) to quiet-time (QT) DA outputs for March 16th, 2015.
2. **Investigate differences in QT and ST KF state estimations**
   How: DA outputs are compared for Marth 16th and March 17th, 2015

Part1 : GAIM Empirical Model Study

Comparison of Fwd model Outputs w/EMOs and QT DA outputs

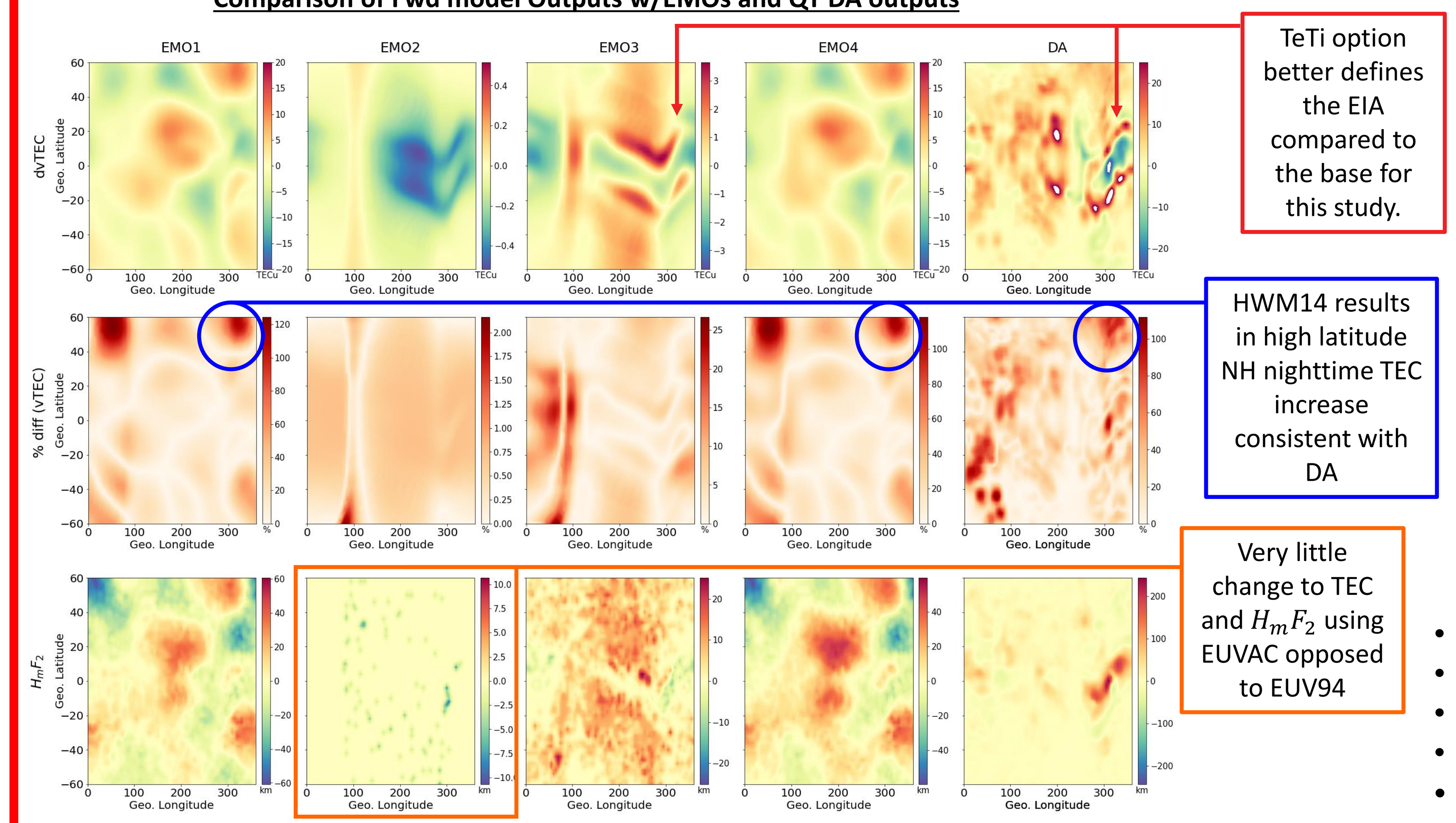

Fig 4. EMO comparison to QT DA

- HWM results in the largest TEC changes.
- TeTi option results in consistent increases in TEC on dayside high latitude boundary.
- HWM14 option creates high latitude % diff compared to base, more so in the NH.
- TEC more sensitive to Neutral wind then ion/electron Temp? (TeTi affects higher altitudes)
- All EMOs underestimate the magnitude changes associated with this QT day.

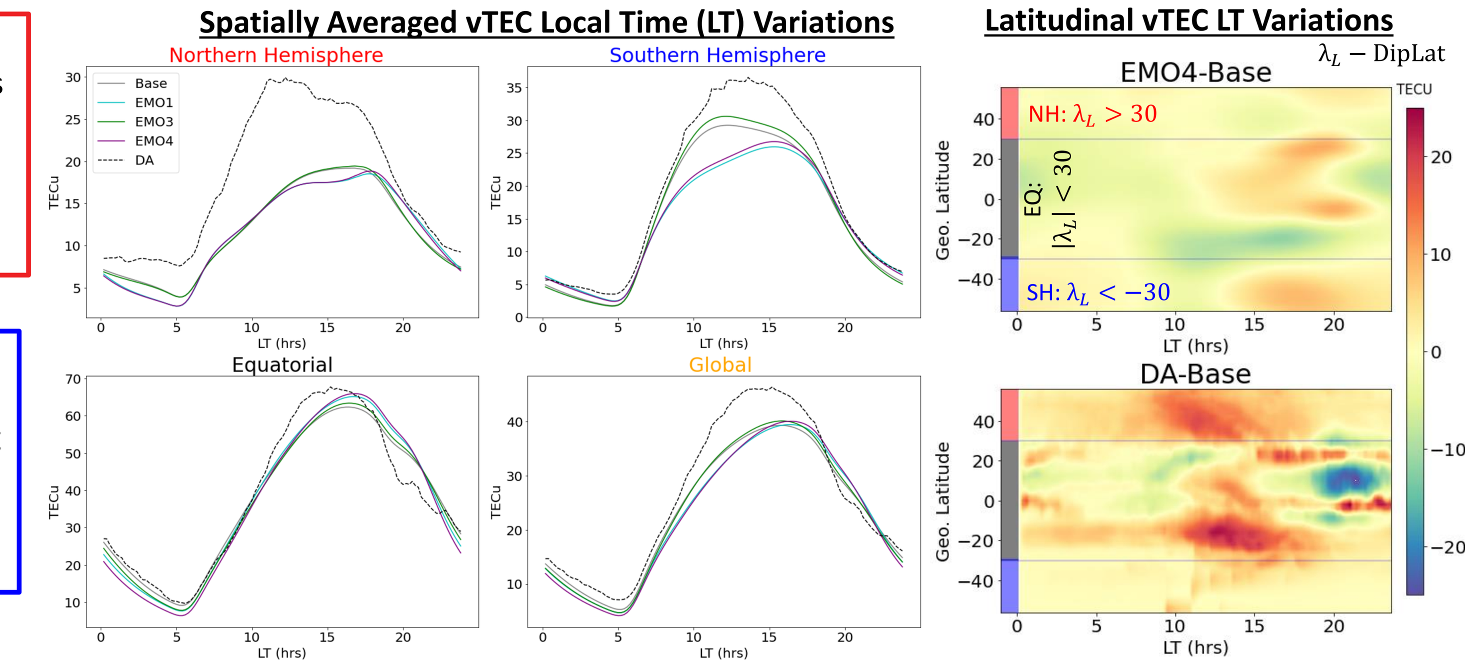

Fig 5. Local Time (Lon = 0) vTEC Variation for different latitude sectors

- Comparisons for all EMOs are worse in the NH and best in the EQ region.
- Similarity to SH could be due to lack of data compared to NH
- EMO1 slightly improves EQ DA comparison and slightly worsens comparison in NH/SH.
- EMO3 slightly improves upon the base in all comparisons.
- EQ region between 0°-20° show some similarities in Lat/LT variations potentially due to non-migrating tidal structure included in HWM14.

Recommendations for Part 1:

- EMO2 is more flexible and only results in small changes (use).
- EMO3 appears to enhance DA comparison (use).
- EMO1 makes large changes in TEC but it is unclear if it will improve upon the base (inconclusive).

Methodology

Global Assimilation of Ionospheric Measurements (GAIM)[4]

- Time-dependent physics-based model of ionosphere-plasmasphere (IPM).
- Band-limited Kalman filter is used for DA of ion & electron densities
- Computational grid follows magnetic flux tubes
- Outputs: global N_e, h_mF_2, N_mF_2

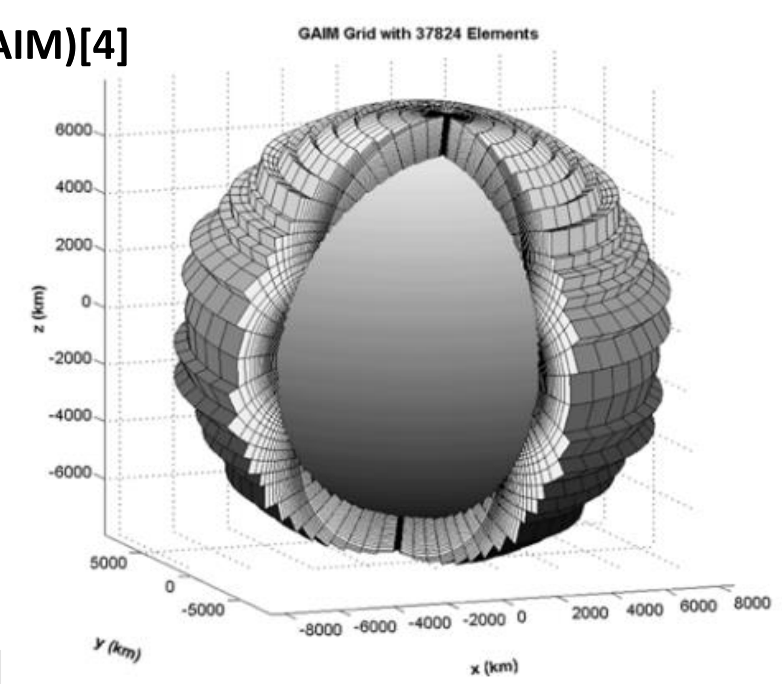

Fig 2. Example of GAIM fwd. model computation domain [4]

Simulation Set up

- Single Ion
- Std output grid has resolution (2° x 5°) (lat x lon)
- 110-1100 km altitude ($\Delta z = 10$ km)

Assimilated Data

- GPS TEC
- Cosmic

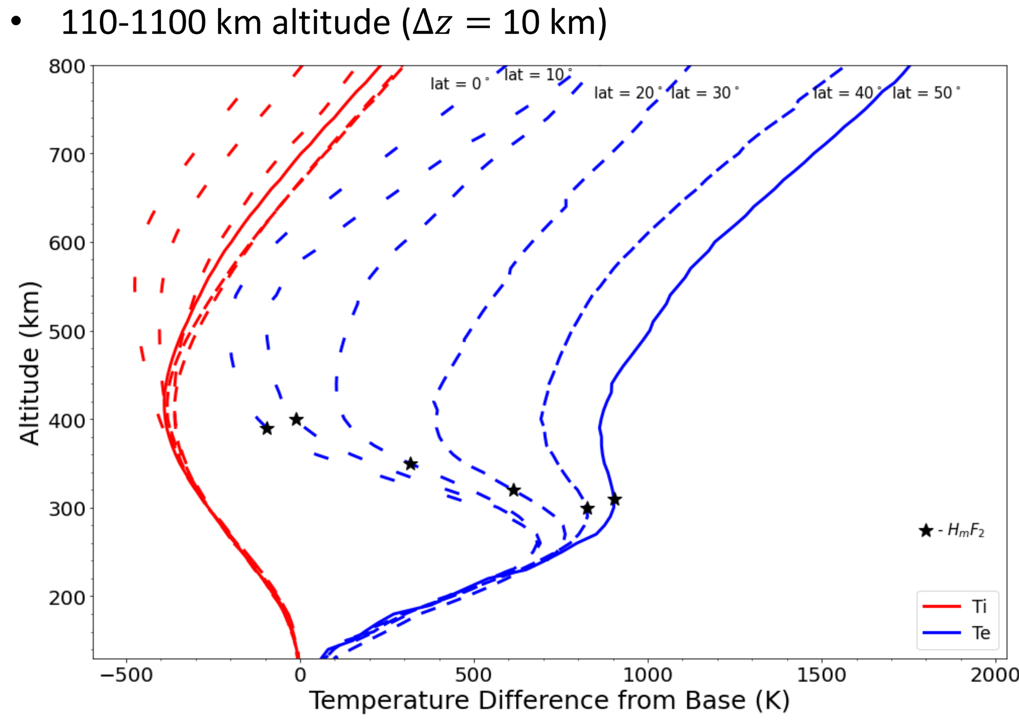

Fig 3. Example of Forcing difference for Ion and Electron Temperature

Empirical Model Options (EMOs)

Run	HWM	EUV	TeTi
Base	93	94	SLR
EMO1	14	94	SLR
EMO2	93	VAC	SLR
EMO3	93	94	EM
EMO4	14	VAC	EM

Basic Difference between Ems at H_mF_2

TeTi		HWM		EUV	
SLR	EM	93	14	94	AC
Simple Linear Relation	TBT-2012 (Te) TBKST-2021 (Ti) (ISR data)	Simple f10.7 dependence	Increased data usage (dusk/dawn) Non-migrating tides	Uses data files for specific years	Proxy F10.7 as only input
Forcing Difference (F2): Large		Forcing Difference (F2): Large		Forcing Difference (F2): Small	

Preliminary ST/QT DA output comparisons

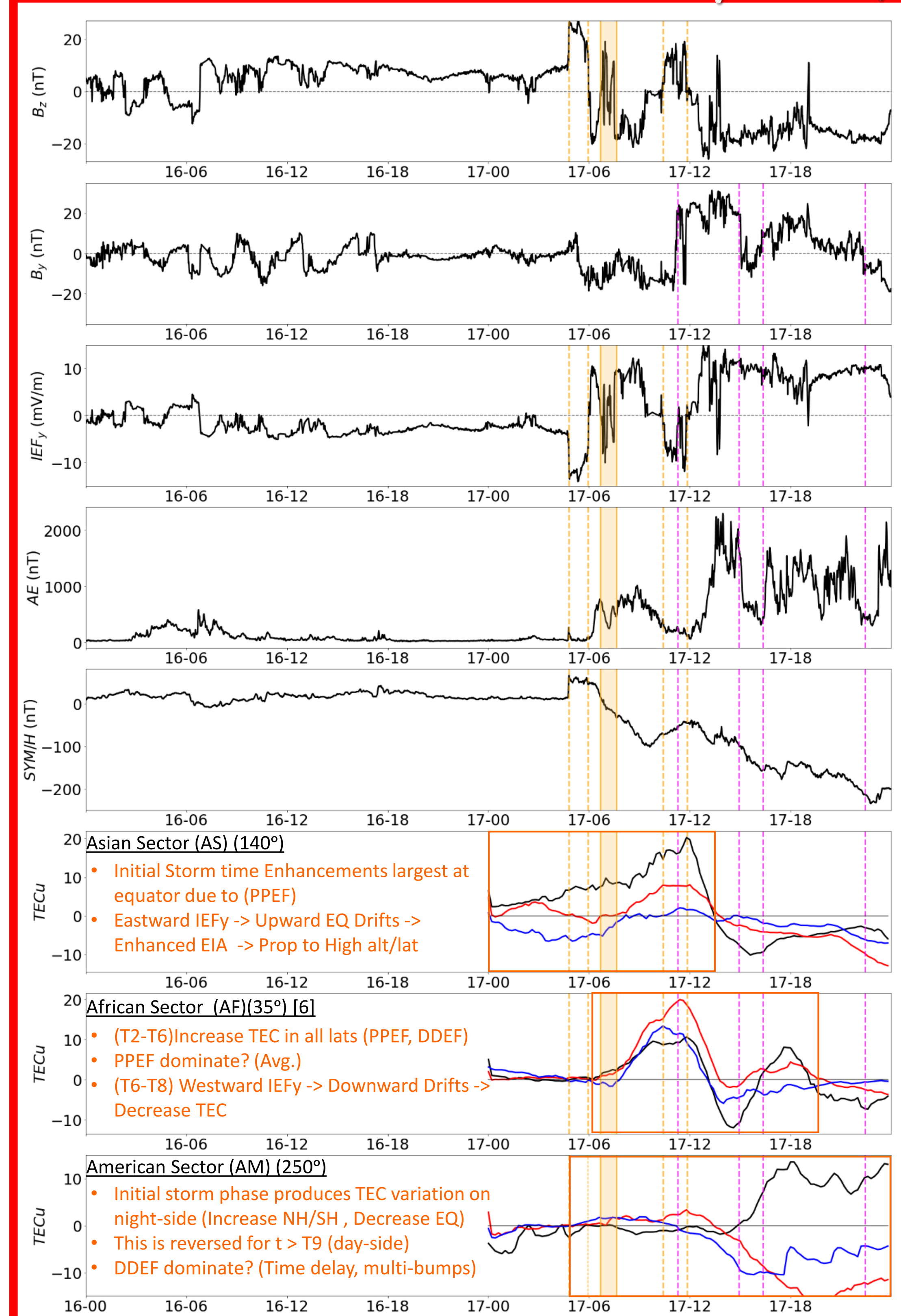

Fig 7. Comparison of QT/ST chronology and Averaged TEC difference field in differ latitude sectors

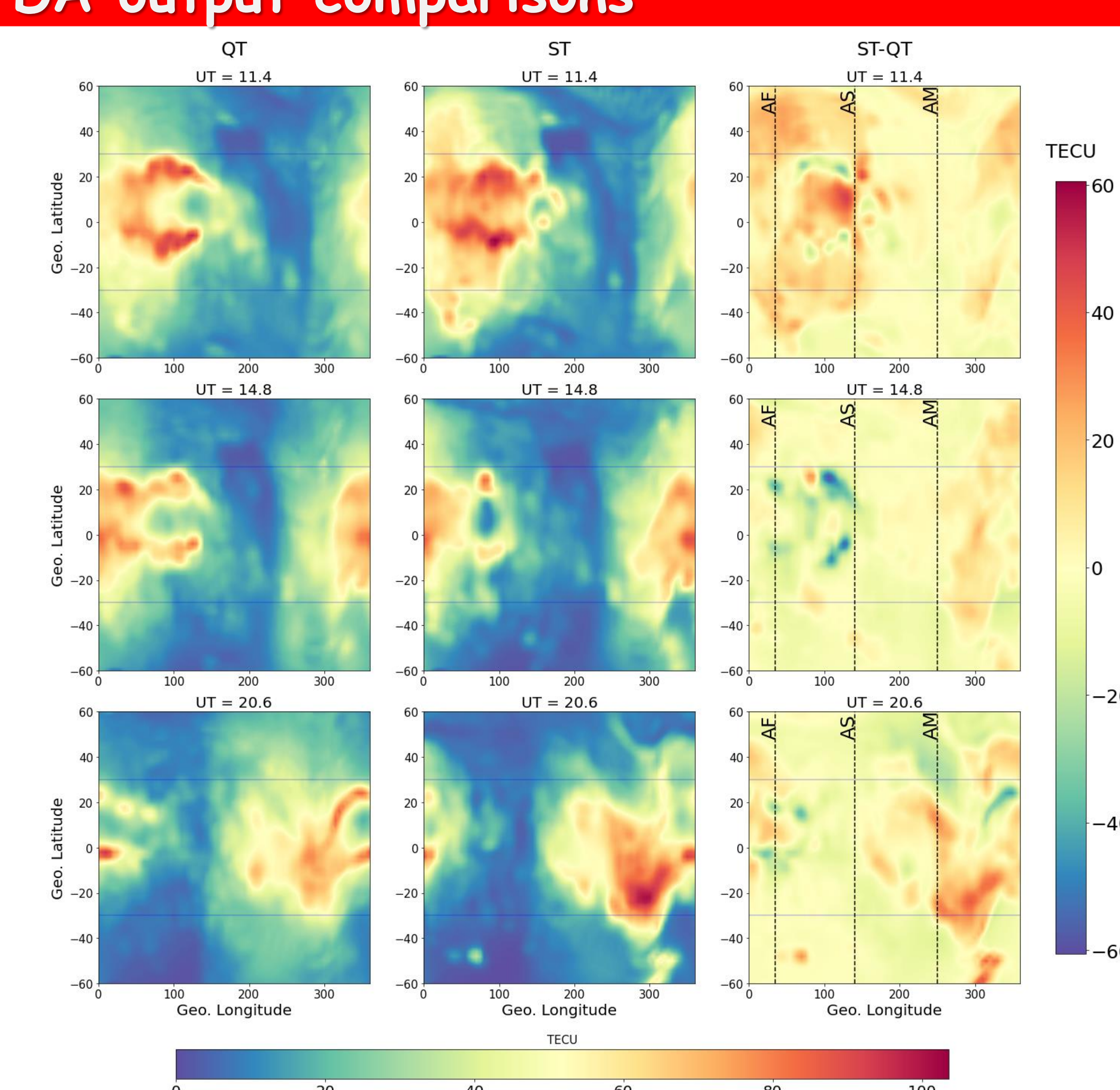

Fig 7. Snapshot of global GAIM outputs for QT/ST days at T6 (top), T8 (mid), and T9-T10 (bottom). Bottom color bar corresponds to abs TEC for QT/ST. Right color bar corresponds to diff. TEC

- Instantaneous increases suggest Penetration Electric Field (PPEF) plays role
  - More efficient PPEF when [5]:
    1. $\frac{dIEF_y}{dt}$ – "gentle" slope (T4-T8)
    2. $IEF_{y,0} > 0$ ($B_{z,0} < 0$) (T6)
- One increase in AS, Two (or more) in AM/AF [7]
- Negative ST effect (Decrease TEC) at Higher latitudes in all Sectors post ~14 UT [7]
- AM TEC increases most in EQ for t > T8 (westward Drift?) .
- Disturbance Dynamo Electric Field (DDEF) plays role in rel. long term Diurnal oscillations.
- Short term DDEF from poleward propagating TIDs (AM)

Summary/Future Work

Part 1

- HWM option resulted in the largest deviations
- TeTi option appears to improve DA comp. and consistently increases TEC at high lats.
- KF DA approaches may help improve studies where ionospheric day-to-day variability is high.
- The Following recommendations were made:
  - Use EMO2 & EMO3 in dev. GAIM.
  - EMO1 currently inconclusive.

Part 2

- GAIM averaged DA runs diff runs reproduce observed trends in other publications
- Identified times of potential PPEF dominance to TEC changes for AS/AF and DDEF dominance to TEC changes for AM.
- Demonstrated the Potential for GAIM to infer physics-based understanding of storm-time event impact on IT.

Future Work

- Comparisons to data (DMSP) and IRI2020
- GAIM with 4DVAR estimation of E field and Neutral wind.

References

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