Quantitative comparison of high latitude ionospheric electric field models

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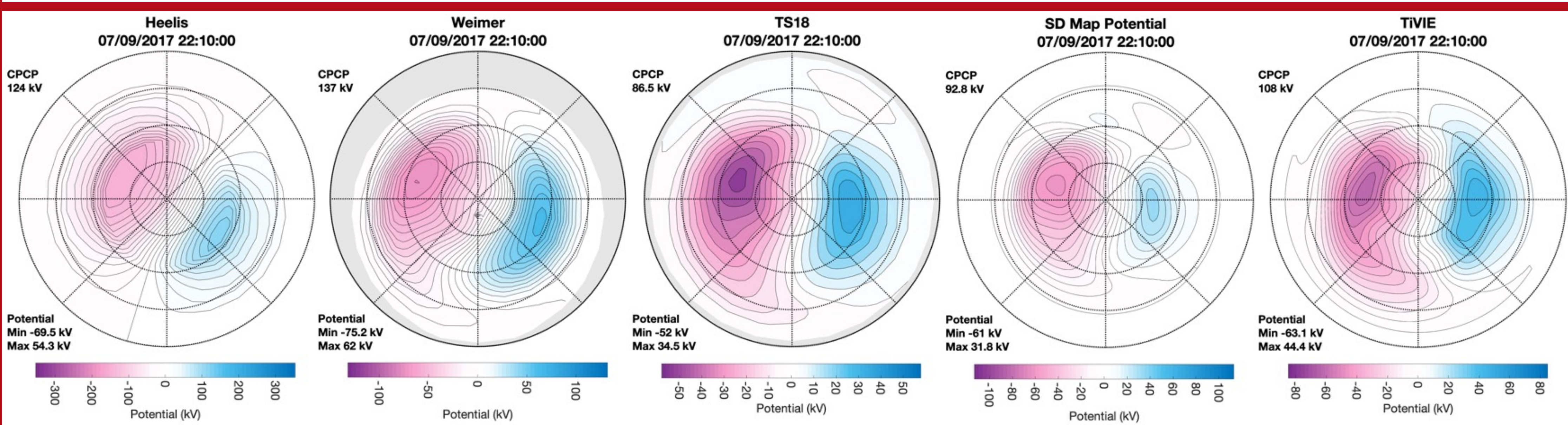
Abstract

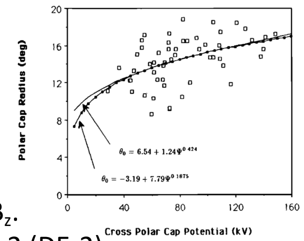
The Space Weather Instrumentation, Measurement, Modelling and Risk: Thermosphere (SWIMMR-T) programme aims to improve the UK's ability to specify and forecast the thermosphere. AENeAS (Advanced Ensemble electron density [Ne] Assimilation System) is a physics-based, thermosphere-ionosphere, coupled, assimilative model, which makes possible thermospheric forecasts. Currently AENeAS uses the Heelis[1] and Weimer[2] electric field spacecraft climatology models but it is possible a more recent electric field model will improve its functionality. The new models include three statistical models for ionospheric convection using line-of-sight velocity measurements from the Super Dual Auroral Radar Network (SuperDARN): Thomas and Shepherd (TS18)[3], the Time-Variable Ionospheric Electric Field model (TiVIE)[4] and the empirical orthogonal functions (BAS EOF)[5] model. Before implementation in AENeAS, we first compare the new SuperDARN-based models to the established spacecraft climatology models.

Here we present quantitative comparison of the electric-field models across a variety of geophysical conditions, including during storm times. To allow for fair comparison between models we explore methods of standardizing the input parameters using pre-existing equations. Once standardized, each model's ionospheric convection patterns can be compared for varying solar wind and interplanetary magnetic field (IMF) conditions. We explore the relationships between the IMF conditions and model output parameters such as the polar cap transpolar voltage and size. During storms we compare the parameterized model output time series from the different electric field models, including the commonly used SuperDARN Map Potential Model[6]. At peak storm times we find the calculated electric potential magnitude to be much greater from the spacecraft-based models. We will discuss the similarities and differences found using each method.

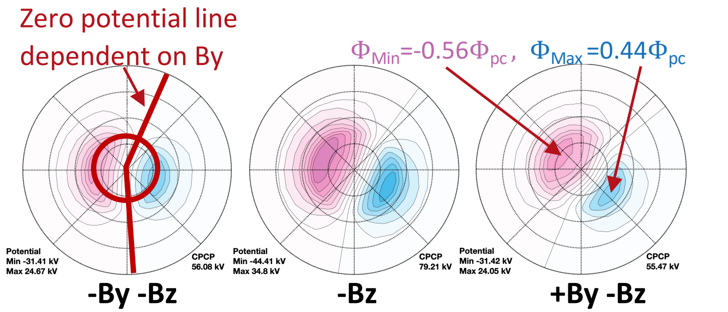


High latitude ionospheric electric field models

Heelis model[1]

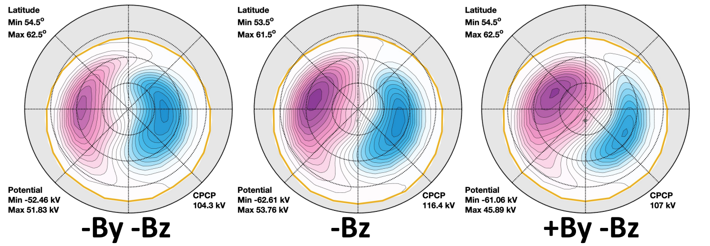


- Mathematical model of large-scale global convection pattern.
- Parameterized by IMF B_y & transpolar voltage, Φ_{pc} .
- Only valid for southward IMF, $-B_z$.
- Includes <100 Dynamic Explorer 2 (DE-2) passes.
- Model properties such as convection reversal radius, θ_0, are defined as relationships with Φ_{pc} and/or B_y.

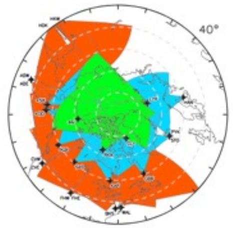


Weimer model[2]

- DE-2 satellite measurements to create empirical model of potential patterns.
- DE-2 operational Aug 1981- Mar 1983.
- 2604 valid passes.
- Parameterized by IMF B_y , B_z , SW velocity, SW density & dipole tilt.
- Calculates potential for geomagnetic grid.
- Lower boundary constructed from the ends of every polar pass where the electric field or magnetic perturbations go to zero.

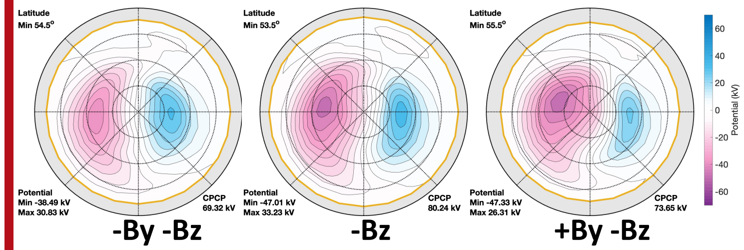


TS18 model[3]



- A statistical model using SuperDARN line-of-sight velocity measurements for 2010-2016.
- Complete network of mid, high & polar radars.
- 120 statistical climatology patterns parameterized by IMF, S W and tilt angle.
- Lower latitude boundary compressed on dayside.
- Velocity vectors are fitted to 8th order spherical harmonic functions.

$|B_{YZ}| = 7\text{nT}$ for all



TIVIE (Time-Variability of the Ionospheric Electric Field)[4]

- Statistical model from SuperDARN line-of-sight velocity measurements.
- Models EF as a spherical harmonic expansion of the ionospheric electric potential.
- Uses novel parameterisations that captures time-variability of the coupled SW-magnetosphere-ionosphere system.
- Accounts for storm variability by parameterizing by storm phase. Initial, main and recovery.
- Storm phases are decided using SYM-H.

BAS EOF (Empirical Orthogonal Functions) model[5]

BAS have recently developed new models based on Empirical Orthogonal Function (EOF) analyses of the surface external and induced magnetic field (SEIMF) (Shore et al., 2017, 2018) and the ionospheric electric field (Shore et al., 2021; under review). These models can be used to resolve the Joule heating in detail and understand its relationship to space weather drivers.

SuperDARN Map Potential[6]

- Derives large-scale convection maps using all available SuperDARN velocity data.
- Determines electrostatic potential from spherical harmonics.
- Data from a statistical model is used to fill in data gaps.
- 2 minute cadence.
- Date can be matched to OMNI parameters for comparison with other models during events.

References

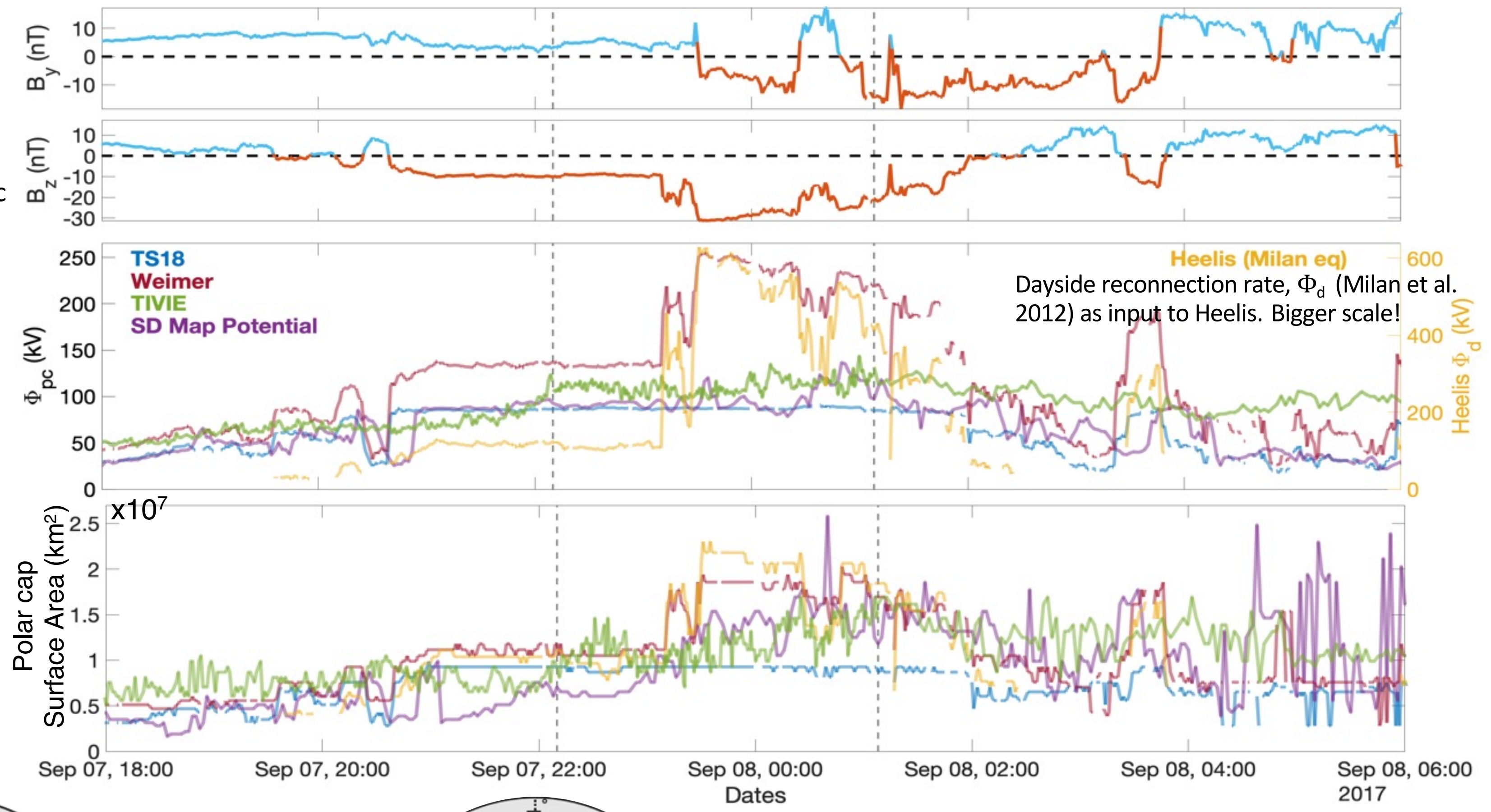
1 Hairston, M. and Heelis, R. (1990). JGR: Space Physics, 95(A3):2333–2343.
2 Weimer, D. (2005). JGR: Space Physics, 110(A5)
3 Thomas, E. G. and Shepherd, S. G. (2018). JGR: Space Physics, 123(4):3196–3216
4 Grocott, A and Walach, M.-T (in prep. 2021)
5 Shore, R.M, M.P. Freeman, and G. Chisham, (submitted 2021) JGR
6 Ruohoniemi, J. M., and K. B. Baker. (1998) JGR: Space Physics, 103(A9):20797-20811

Comparison of Electric Potential during Sept 2017 Storm

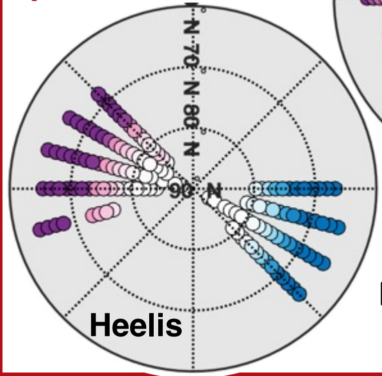
Lancaster University

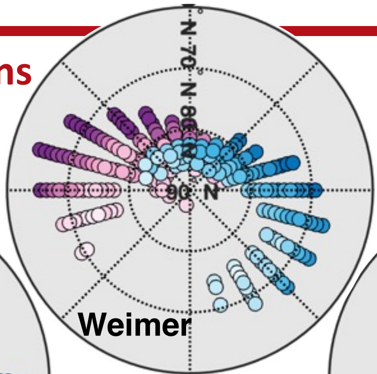
Parameter comparison

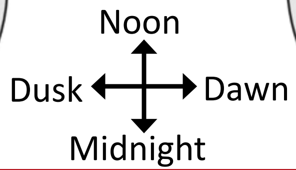
Quantitative comparison of convection pattern parameters produced by different models. Φ_{pc} is the transpolar voltage, the difference between the max & min electric potential per unit time. We use Φ_d as a proxy for Φ_{pc} , as an input parameter for the Heelis model (right axis). TS18 saturates at $\Phi_{pc} \approx 80$kV when $B_z \approx$-10nT. TIVIE and map potential increase steadily throughout the main phase. Weimer and Φ_d increase massively when B_z drops toward -30nT, with Φ_d reaching >600kV. Polar cap surface area is approximated by assuming the location of the max and min potentials form a circle containing the polar cap. Again TS18 saturates at moderate IMF conditions. Heelis and Weimer show expansion on similar scales to TIVIE and map potential through the main phase, despite having much larger Φ_{pc}.

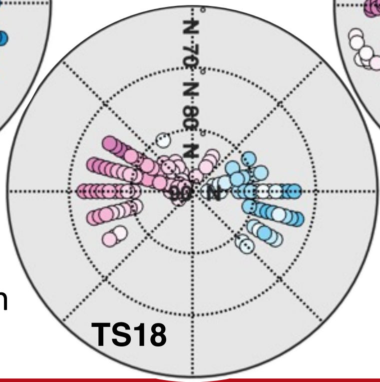


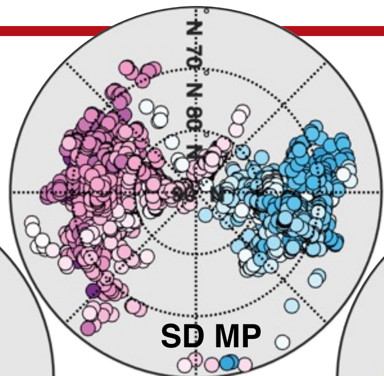
Compare locations of max and min potential





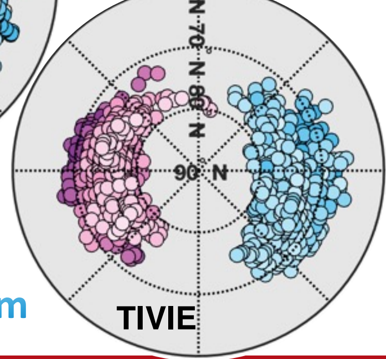






Minimum

Maximum

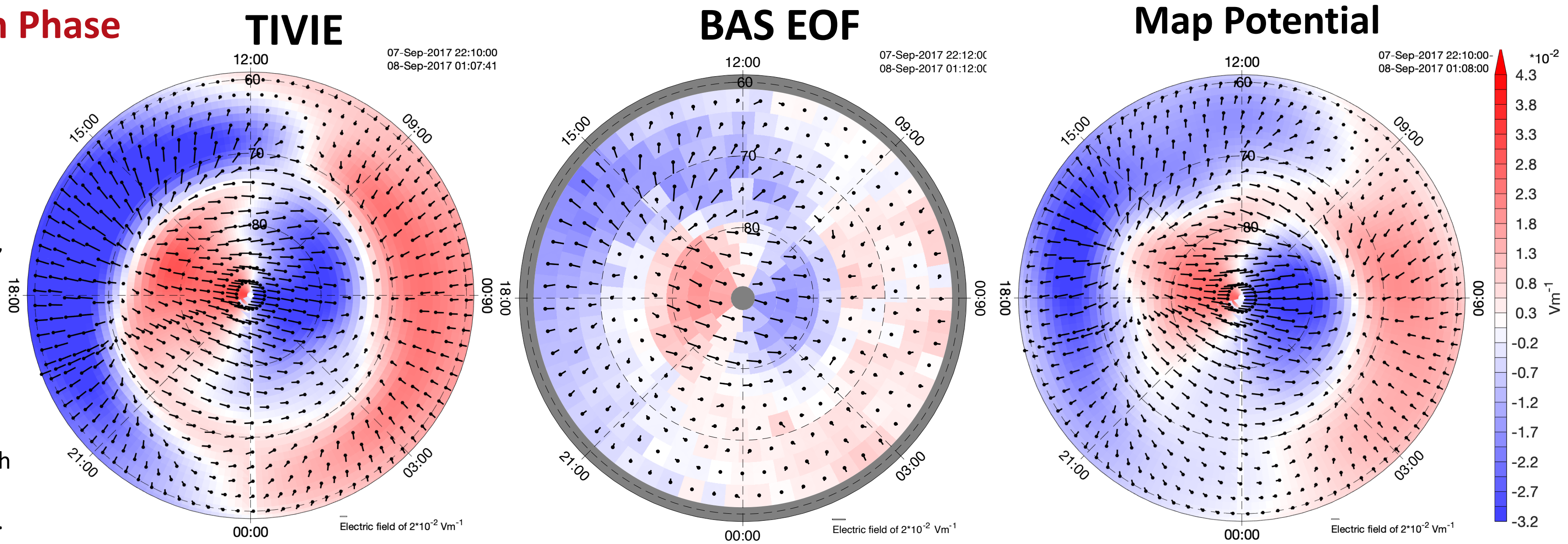


Heelis has a tight wedge for max and min locations due to the dependance of zero potential line on By. Weimer explores a broader range of local times but has significant overlap in the noon sector that isn't seen in any other models output. TS18 does not extend to latitudes lower than 70°. Map potential uses superDARN output of the event showing max/min potentials down to ≈60° with most max/min contained within the dawn/dusk sectors. TIVIE is mostly confined to 70-80° and the dawn/dusk sectors.

Electric Field Vectors comparison

Average during Main Phase Sept 2017 Storm

The BAS EOF model is calculated for a grid with even area with vectors in the centre of each bin. TIVIE and Map Potential are plotted on a 1 degree lat long grid, but fewer vectors are shown for clarity. The colour represents the north-south orientation and the vectors also include the east-west component. Similar patterns are seen from all three models. TIVIE has the lowest latitude north-south direction change at ≈ 70°. For the BAS model this boundary is ≈ 78°.



Summary

- Six ionospheric electric field models are compared: Heelis & Weimer- older models based on DE-2 satellite passes, SuperDARN based models TS18, TIVIE and EOF. Map potential uses actual SuperDARN measurements of the event.
- Thomas and Shepherd consistently has the lowest electric potential output and doesn't expand to low latitudes during Sept 2017 storm.
- The Milan dayside reconnection rate is too high during peak storm times but the shape of the Heelis convection pattern is reasonable.
- TIVIE is parameterized by storm phase timings, not IMF and SW conditions- it's output compares well to the other models.
- There are many differences and similarities between the model output, but without a baseline it is hard to decide what model is best

What's next

- Compare quantitatively the electric field vectors BAS EOF model.
- Compare models during non-storm times.
- See how the difference affects the thermspheric predictions made by AENeAS (Advanced Ensemble electron density [Ne] Assimilation System).

Thank you for your attention. Any questions email l.orr1@lancaster.ac.uk