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Relating magnetic field disturbances on ground and in space
Downward propagation of the AMPS model magnetic field

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Outline

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Introduction to The Average Magnetic field and Polar current System (AMPS) model

A statistical model of ionospheric magnetic field disturbances based on satellite magnetometers

Calculating AMPS model magnetic field on ground - the simplest approach

Comparing with data

Time-scale dependence of solar wind based regression models

Effects of induced currents

The AMPS model

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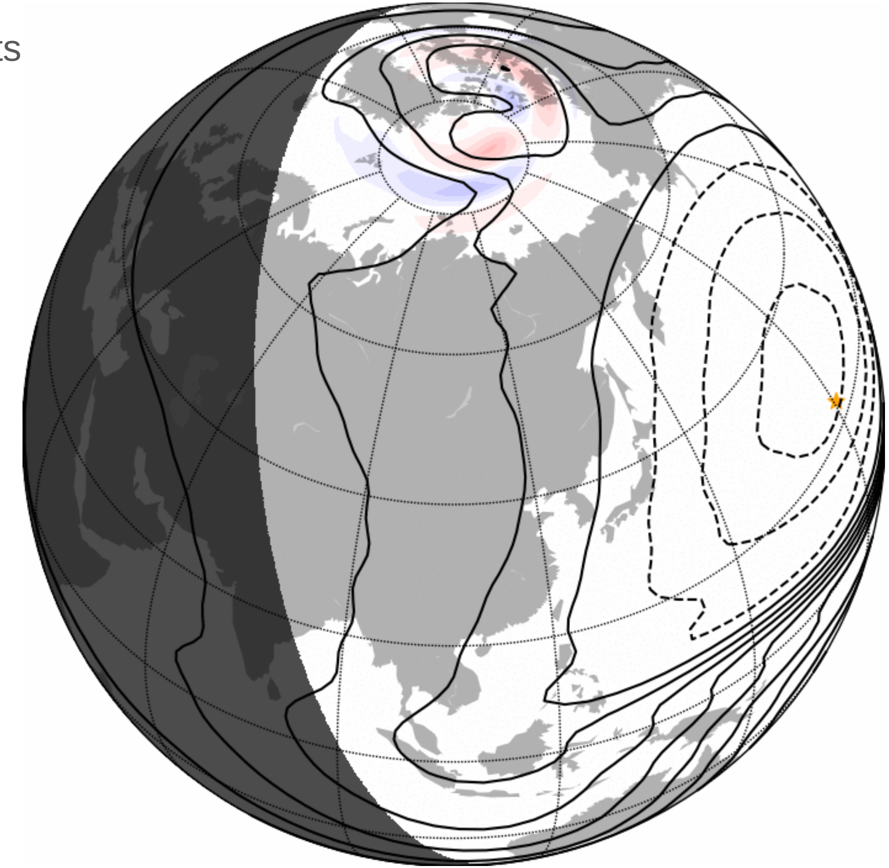
Empirical model based on magnetic field measurements from Swarm and CHAMP

Currents and fields continuous functions of
solar wind speed, IMF, dipole til, and F10.7

Global:
Gives both polar and low-latitude currents. No imposed symmetries between hemispheres

Available:
Published as *Swarm* data product, open-source Python forward code on GitHub, Web visualization at
https://birkeland.uib.no/data/amps



swarm SWARM DISC

Where to get it

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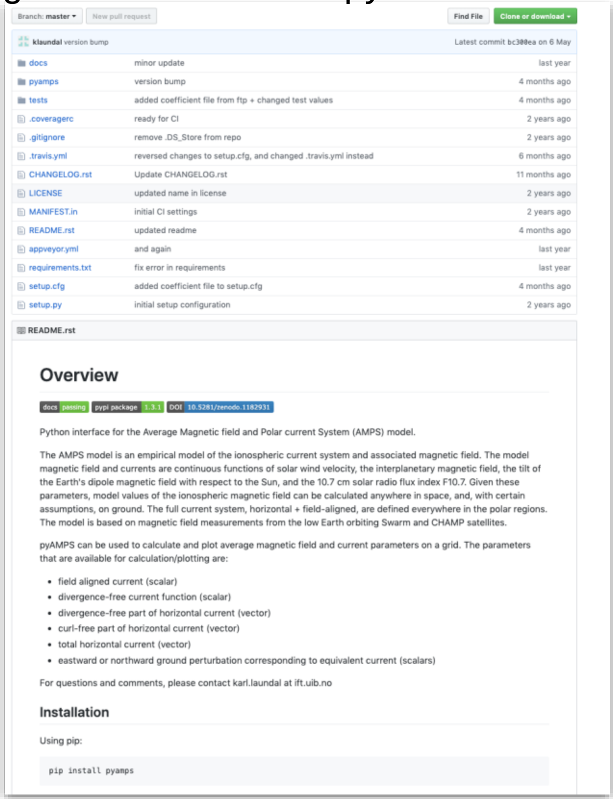
Extensive Python forward code on Github
github.com/klaundal/pyAMPS



Web visualization at
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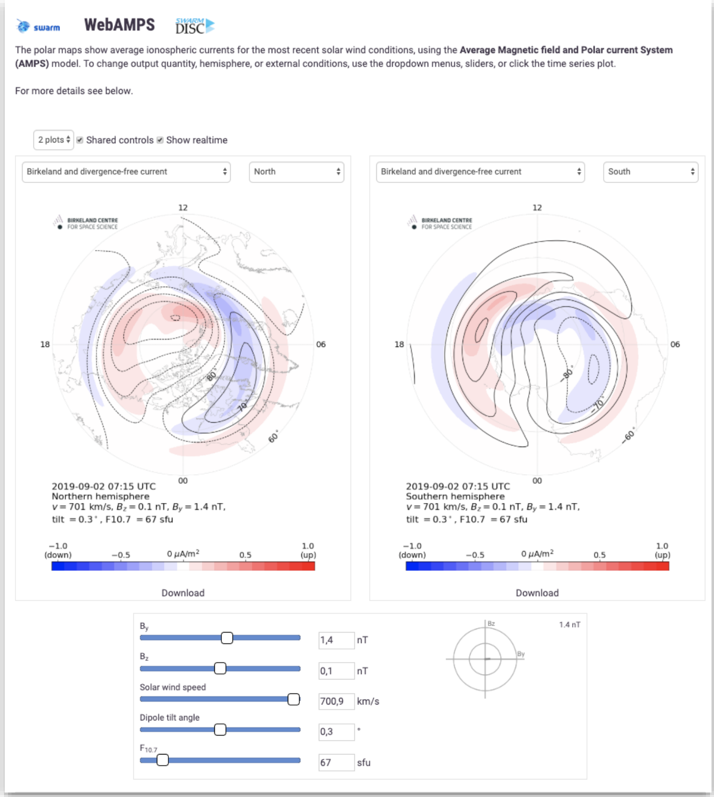

Model definition

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$$\Delta \mathbf{B} = \Delta \mathbf{B}^{\text{pol}} + \Delta \mathbf{B}^{\text{tor}} = -\nabla V + \mathbf{r} \times \nabla T$$

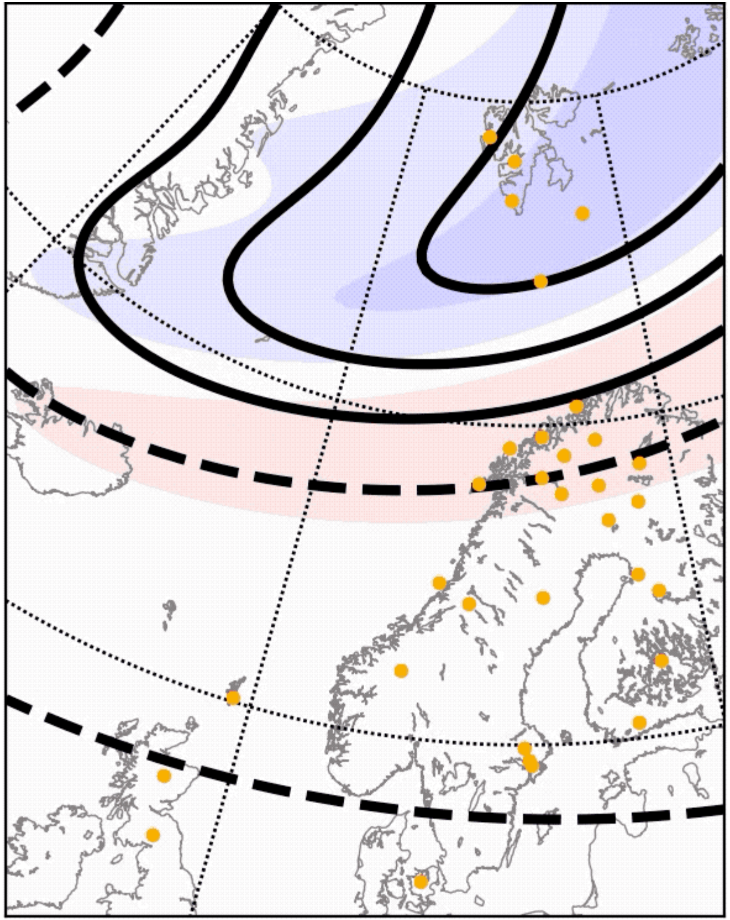
V and T are represented with spherical harmonics:

$$V(\lambda_q, \phi_{\text{mlt}}, h) = R_E \sum_{n,m} \left(\frac{R_E}{R_E + h} \right)^{n+1} P_n^m(\sin \lambda_q)[g_n^m \cos(m\phi_{\text{mlt}}) + h_n^m \sin(m\phi_{\text{mlt}})],$$

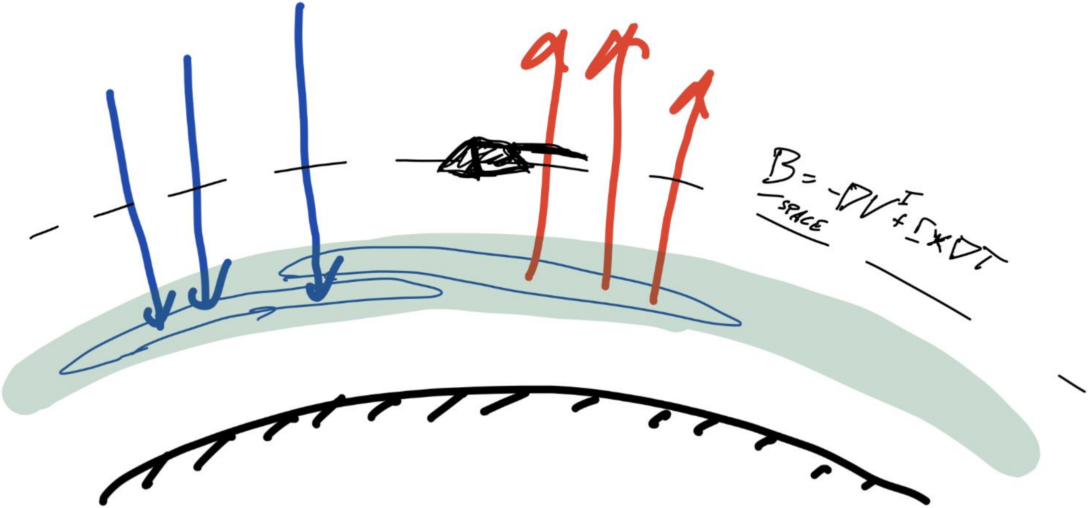
$$T(\lambda_m, \phi_{\text{mlt}}) = \sum_{n,m} P_n^m(\sin \lambda_m)[\psi_n^m \cos(m\phi_{\text{mlt}}) + \eta_n^m \sin(m\phi_{\text{mlt}})],$$

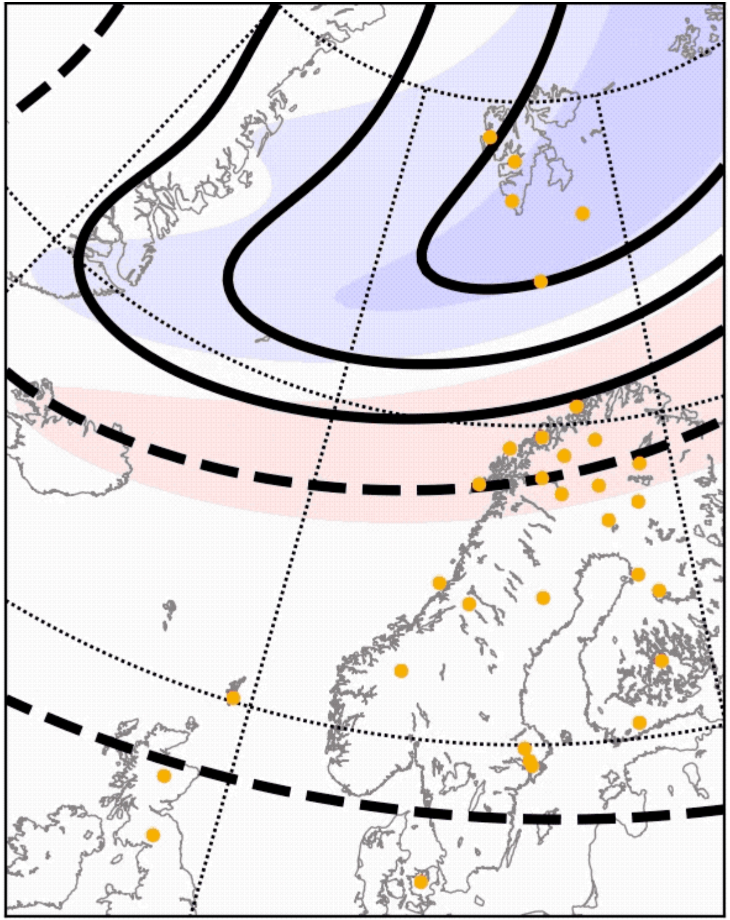
Each SH coefficient is function of external parameters:

$$\begin{aligned} g_n^m = & g_{n1}^m + g_{n2}^m \sin\theta_c + g_{n3}^m \cos\theta_c + g_{n4}^m \epsilon + g_{n5}^m \epsilon \sin\theta_c + g_{n6}^m \epsilon \cos\theta_c + \\ & g_{n7}^m \beta + g_{n8}^m \beta \sin\theta_c + g_{n9}^m \beta \cos\theta_c + g_{n10}^m \beta\epsilon + g_{n11}^m \beta\epsilon \sin\theta_c + g_{n12}^m \beta\epsilon \cos\theta_c + \\ & g_{n13}^m \tau + g_{n14}^m \tau \sin\theta_c + g_{n15}^m \tau \cos\theta_c + g_{n16}^m \beta\tau + g_{n17}^m \beta\tau \sin\theta_c + g_{n18}^m \beta\tau \cos\theta_c + \\ & g_{n19}^m \mathrm{F}_{10.7}. \end{aligned}$$



Relating magnetic field and currents





Relating magnetic field and currents

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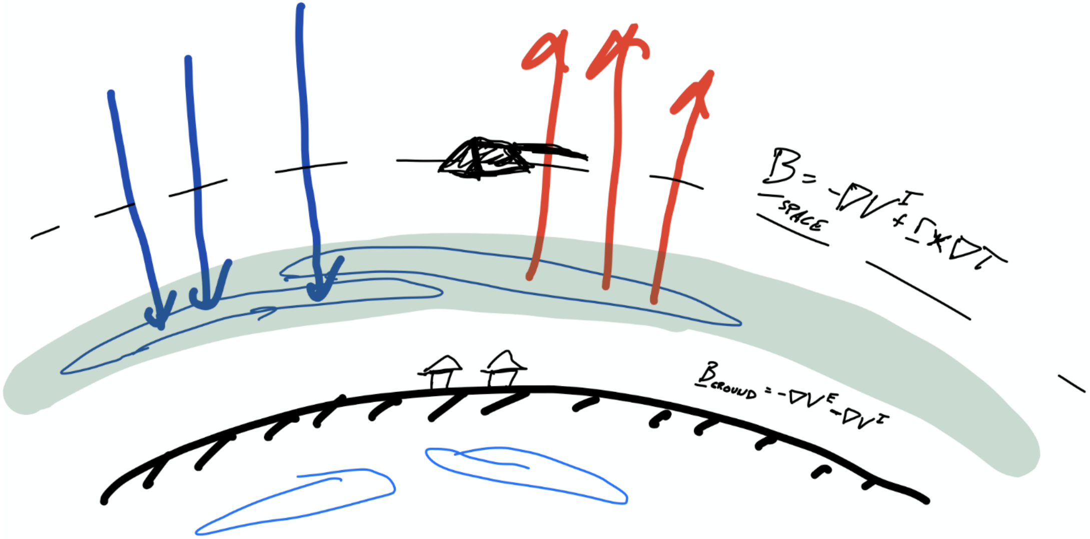

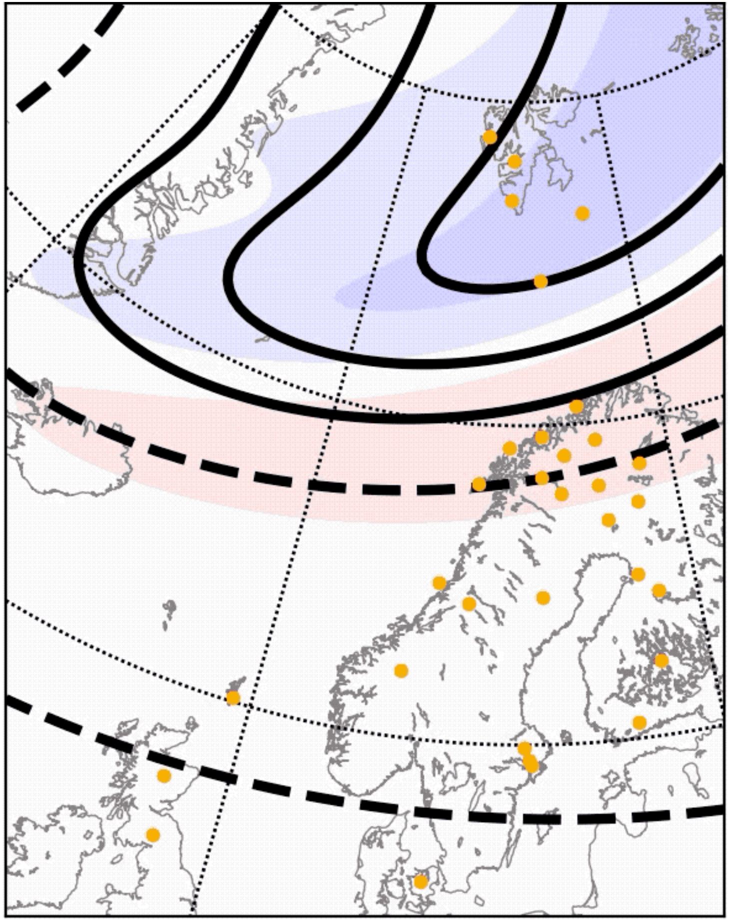

Relating field in space and ground

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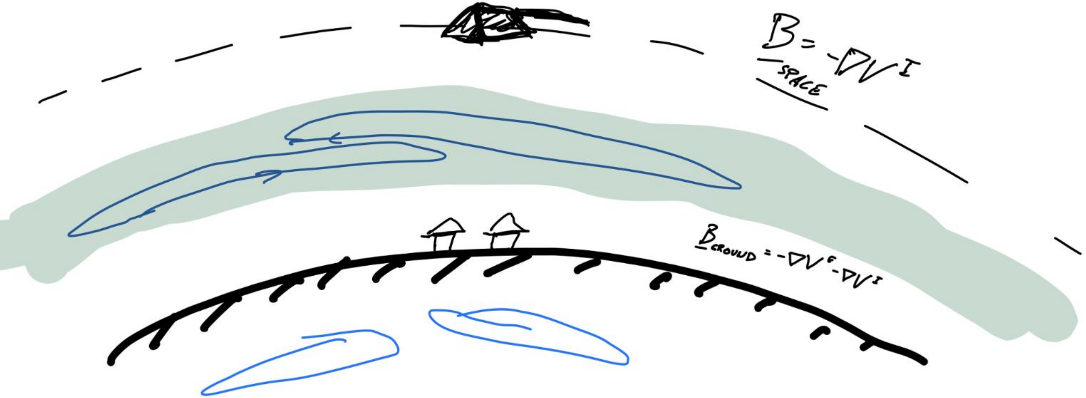

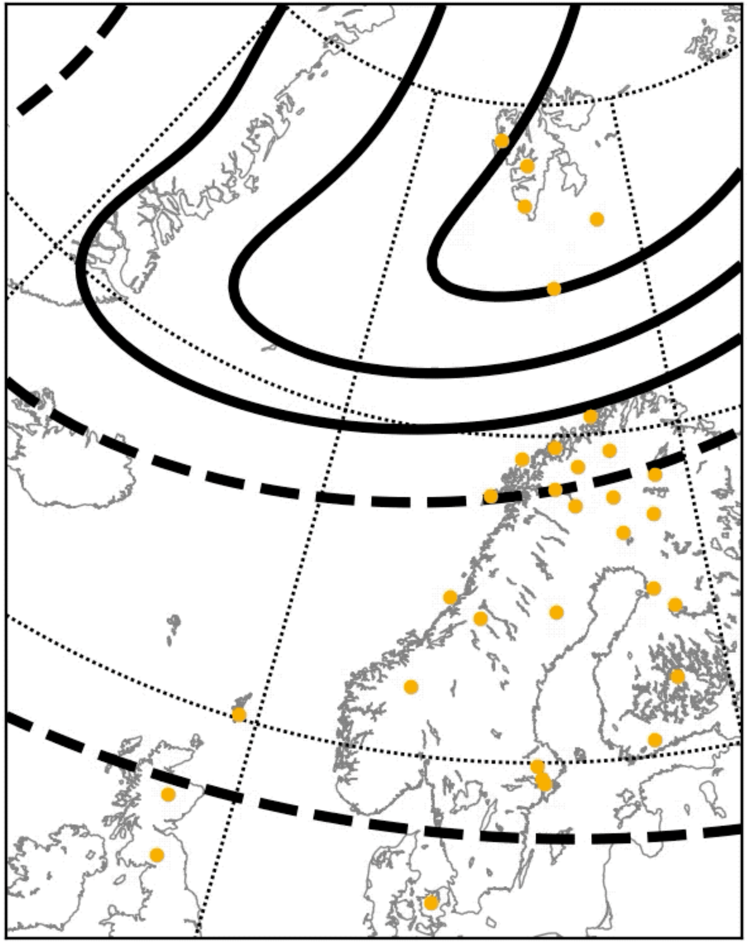

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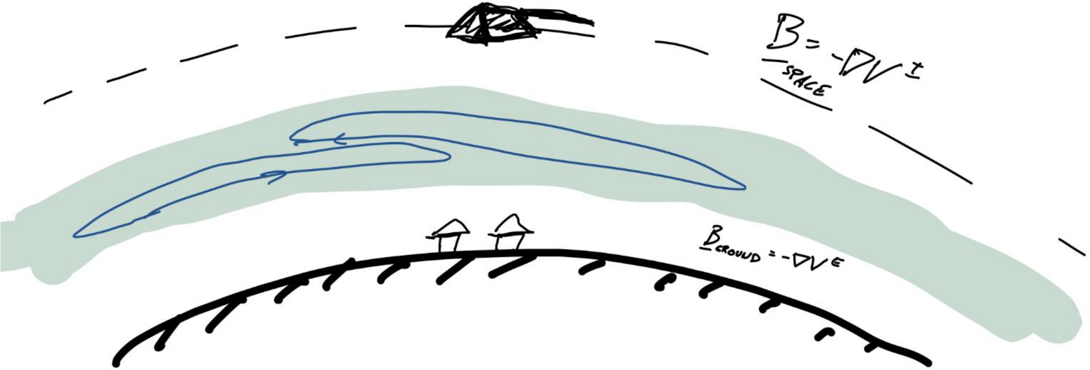
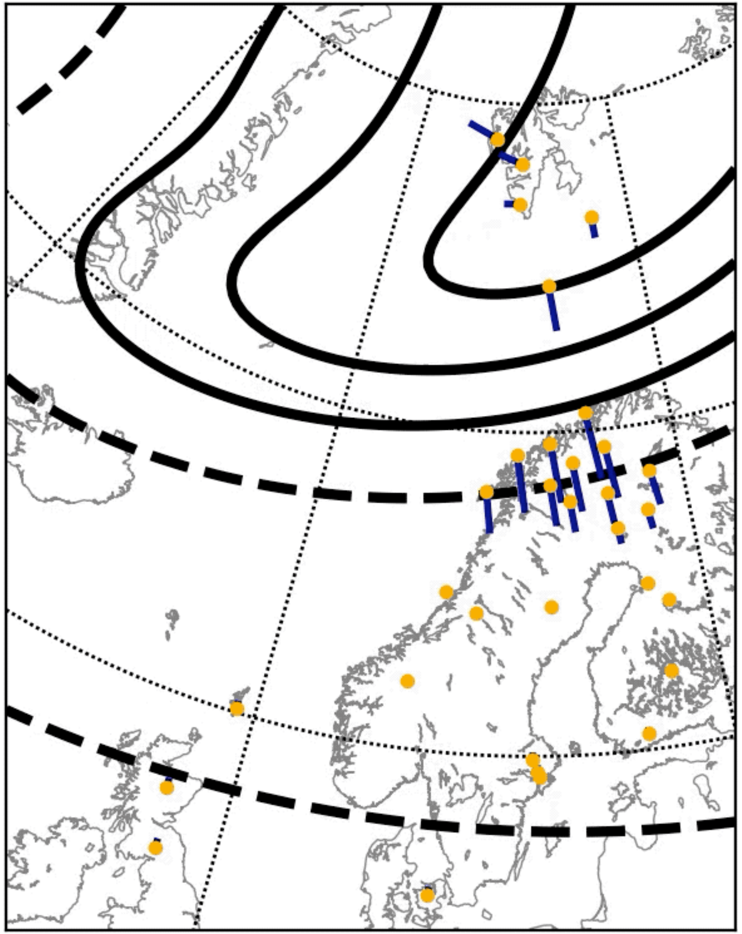
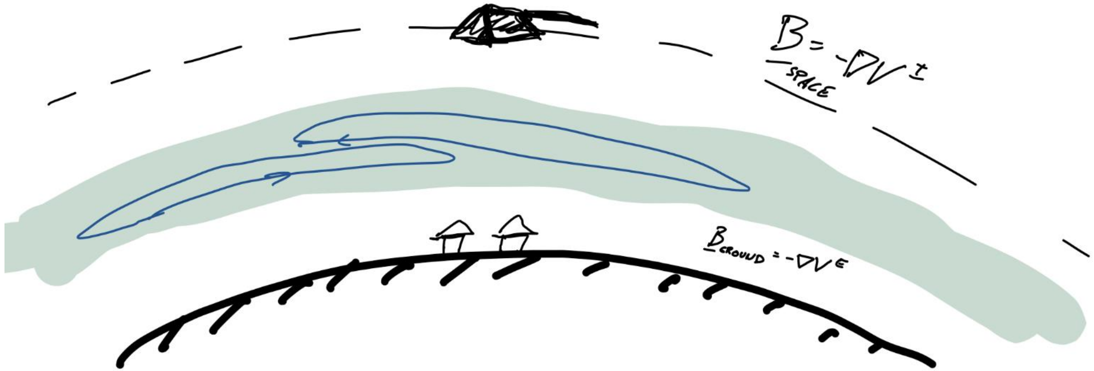
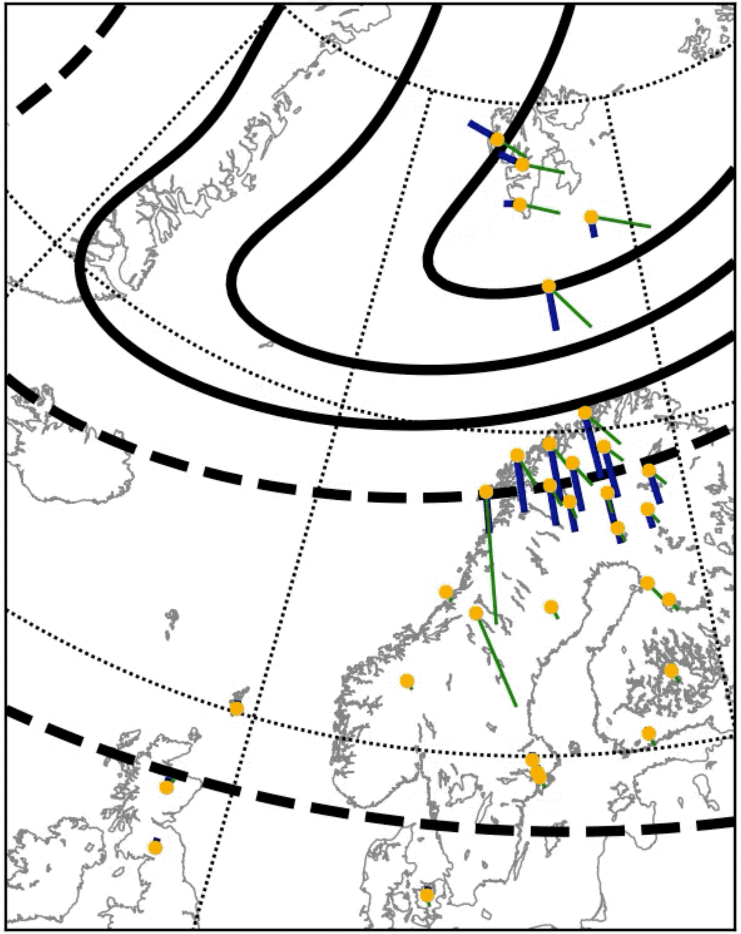




Relating field in space and ground





Dependence on current sheet height

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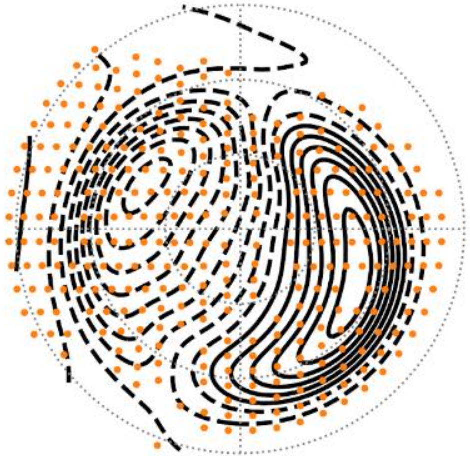
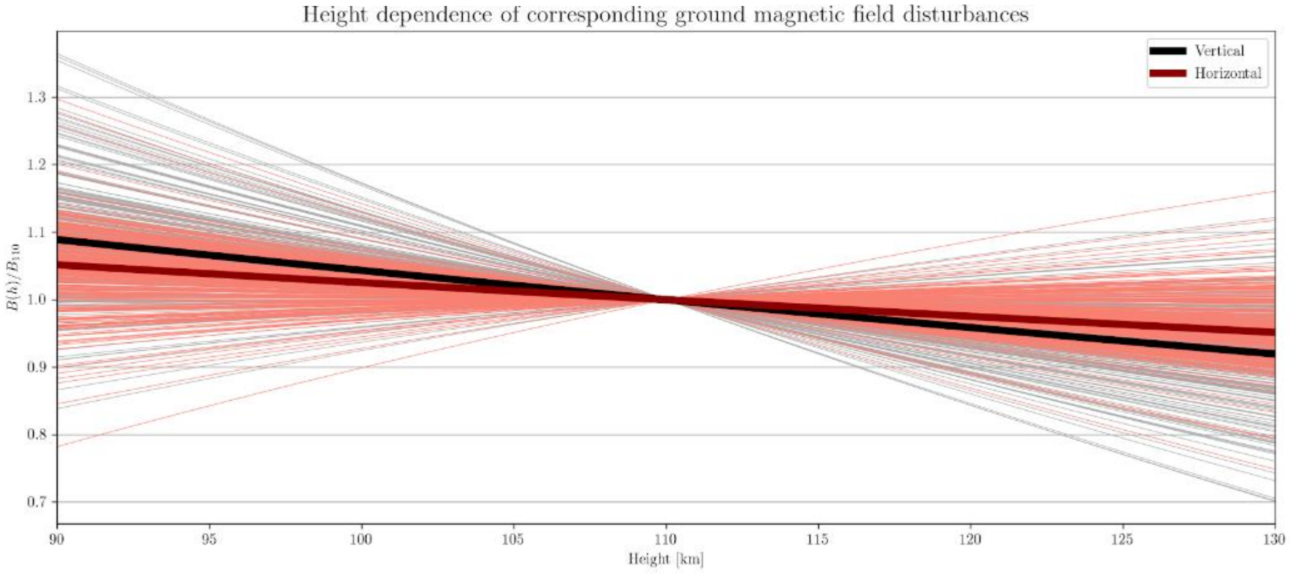
$$B_\phi = -\frac{1}{\cos\lambda}\sum_{n,m}\left(\frac{R_E}{R_E + h_R}\right)^{2n+1}\frac{n+1}{n}P_n^m(\sin\lambda_q)m[g_n^m\sin(m\phi_{\text{mlt}}) - h_n^m\cos(m\phi_{\text{mlt}})]$$

$$B_{\lambda_q} = \sum_{n,m}\left(\frac{R_E}{R_E + h_R}\right)^{2n+1}\frac{n+1}{n}\frac{dP_n^m(\sin\lambda_q)}{d\lambda_q}[g_n^m\cos(m\phi_{\text{mlt}}) + h_n^m\sin(m\phi_{\text{mlt}})]$$

$$B_r = \sum_{n,m}\left(\frac{R_E}{R_E + h_R}\right)^{2n+1}(n+1)P_n^m(\sin\lambda_q)[g_n^m\cos(m\phi_{\text{mlt}}) + h_n^m\sin(m\phi_{\text{mlt}})]$$





Summary so far:

The AMPS model describes the magnetic field in space as function of dipole tilt and solar wind parameters

Downward propagation to the ground can be performed by “reflection” across a spherical current sheet

Varying the current sheet height within realistic values changes the ground field by about 10%

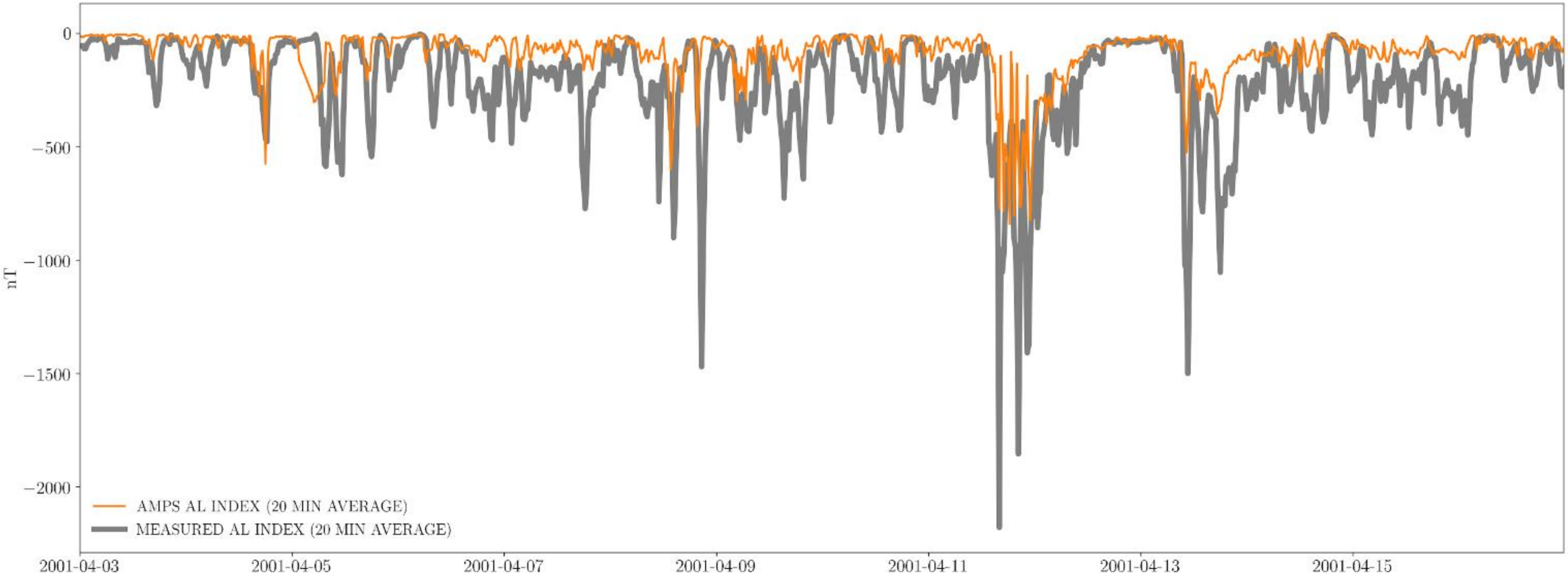
Next:

Quantitative comparison between model and measured AL index

AL model comparison

We calculate AMPS model magnetic field at all AL station locations, and derive synthetic AL index.

Here is an example of a time series:



AL model comparison

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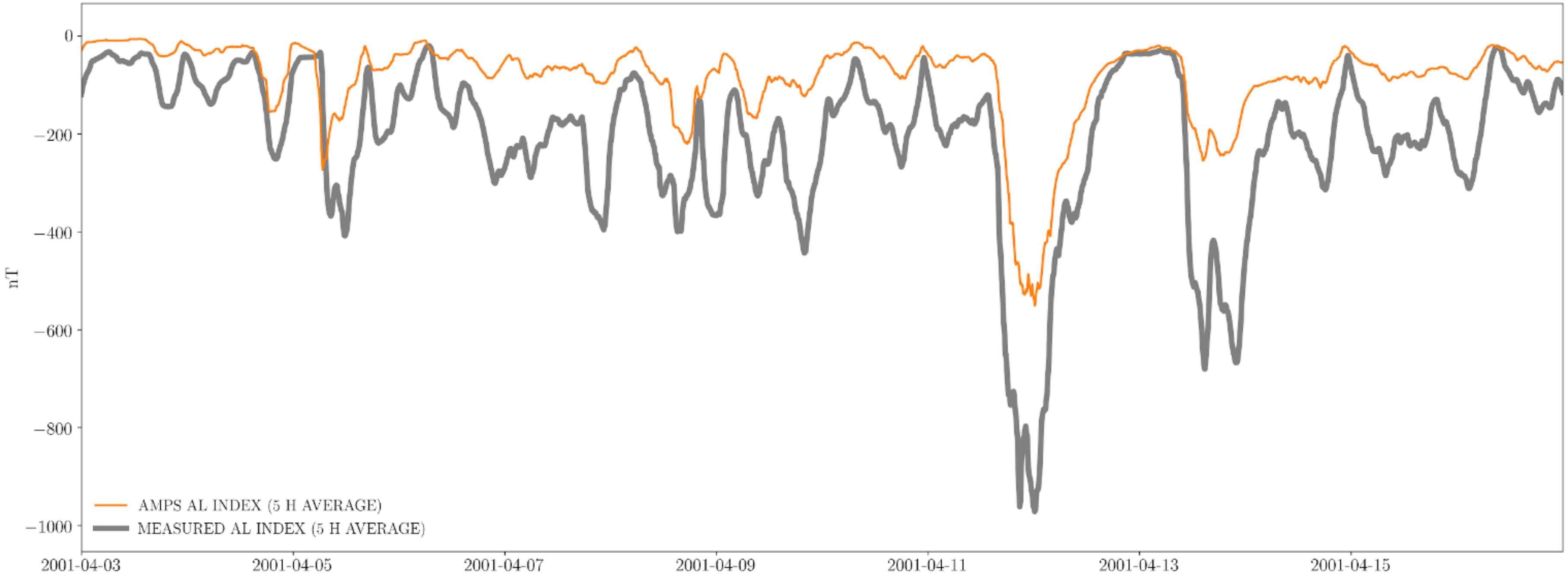

AL model comparison

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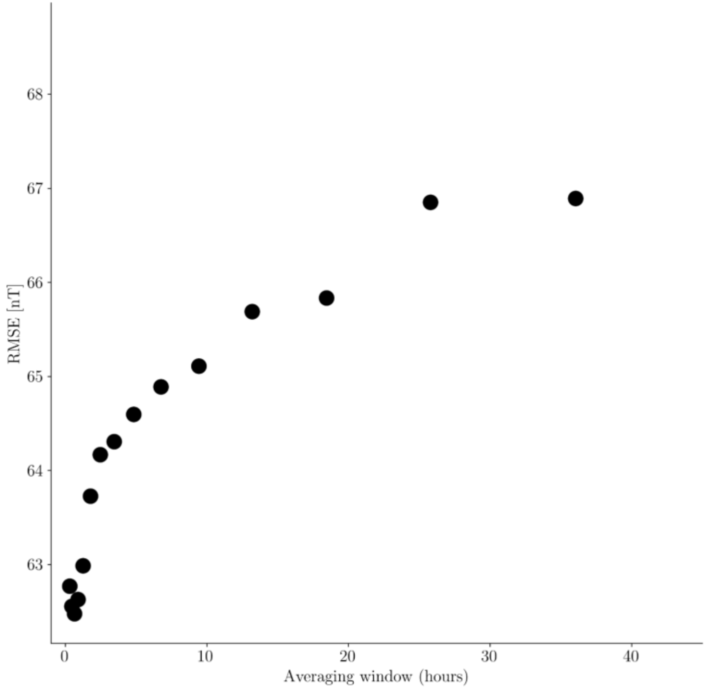
The misfit increases with time scale:



Solar wind based regression models are time scale dependent

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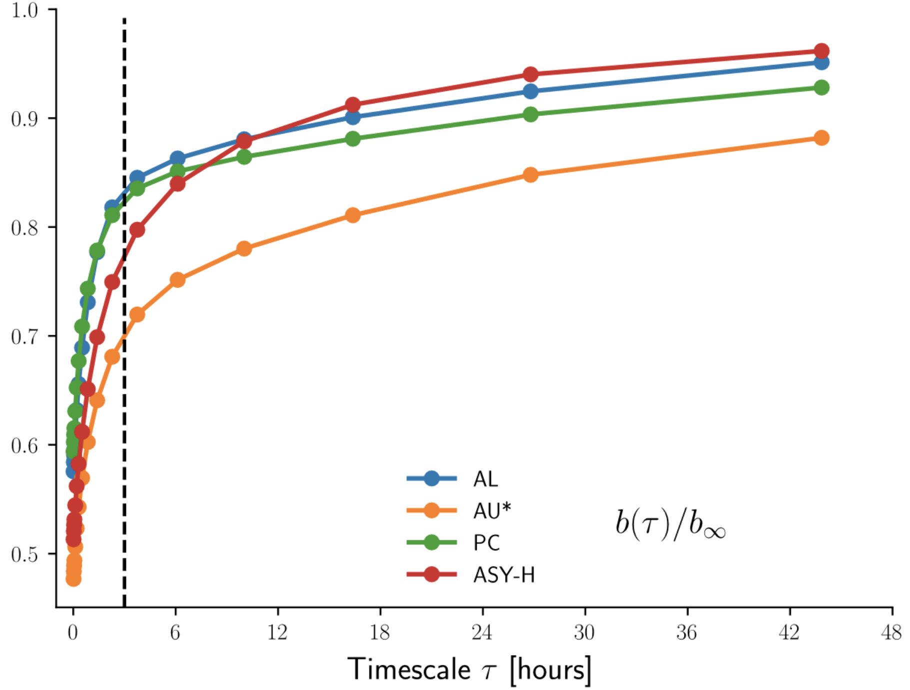
Consider a model on the form **Y = a + b * E (Newell's coupling function)**

The least squares estimate of b depends on the averaging window used on Y and E



The two-step response to changes in the solar wind

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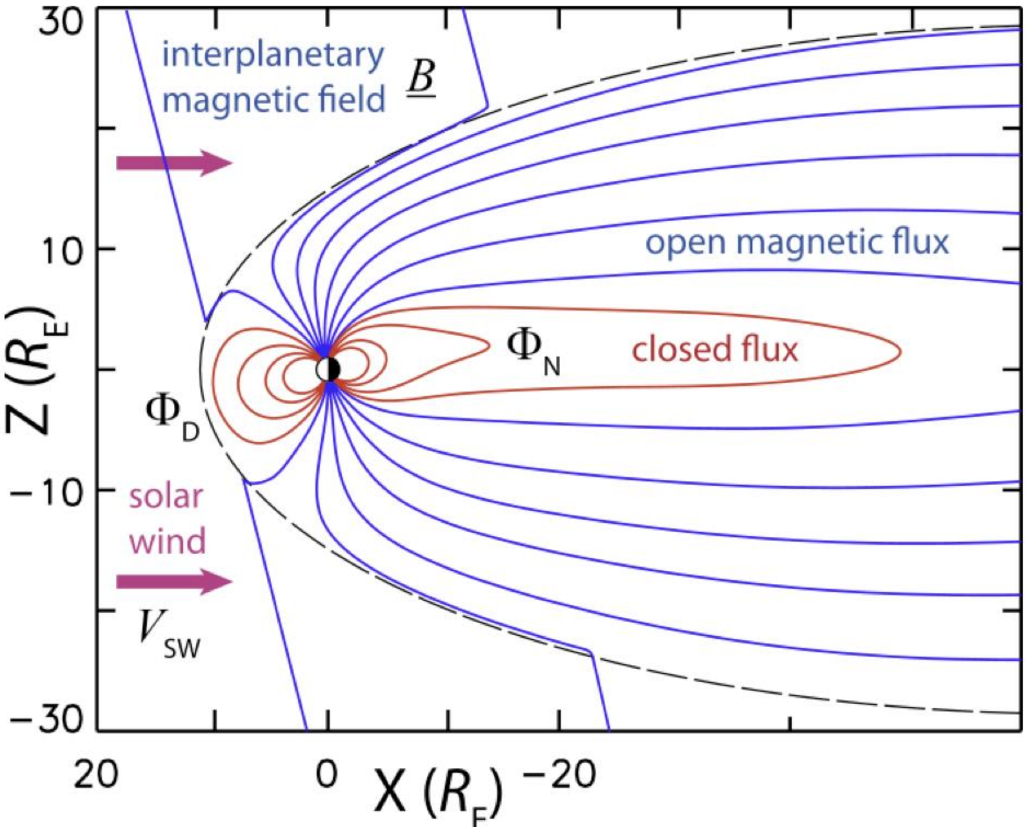

Φ_D(~ E) and Φ_N are

≅ Uncorrelated on short time scales

≡ Identical on long time scales

With high time resolution Φ_N signal with be noise and the model scaled only to Φ_D

With time averaging the model will be scaled to both Φ_D and Φ_D

AL model comparison

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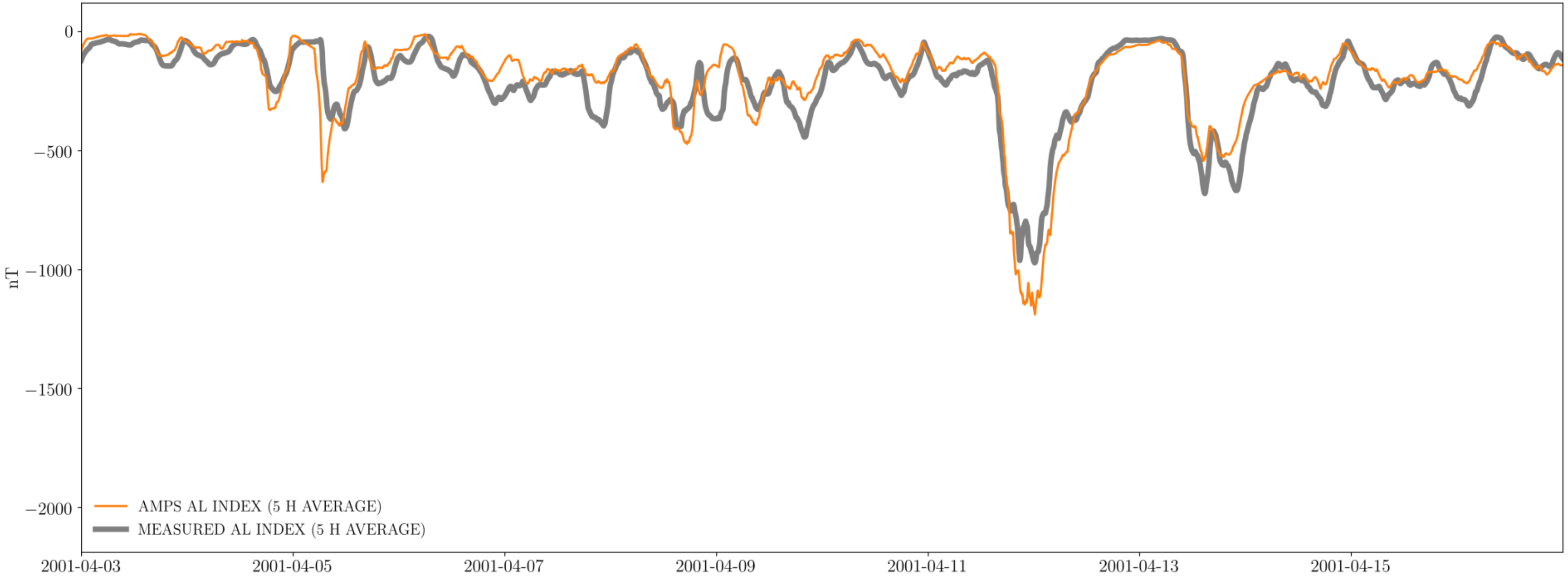
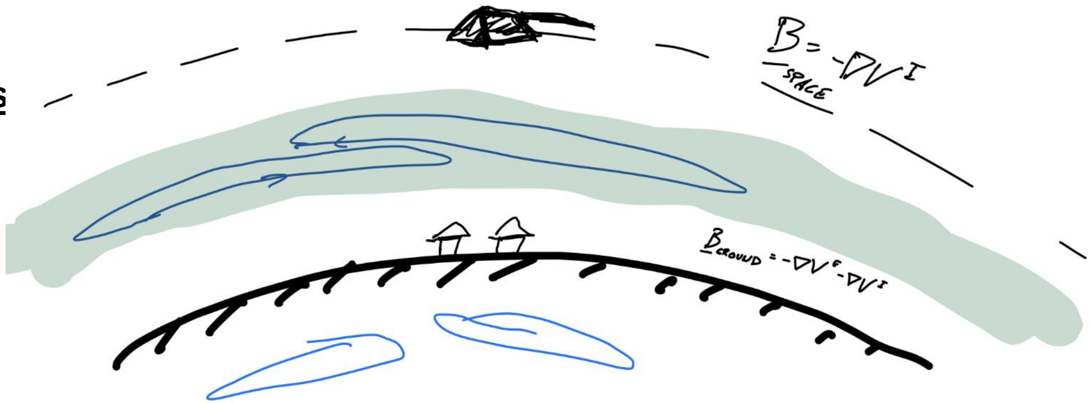
Data model comparison with time-scale dependent scale factor



Summary - AMPS model description of ground disturbances

The AMPS model can be used to describe directly driven variations in magnetic field disturbances on ground.



<u>Two important potential improvements</u>

1) <u>Include substorm parameter(s)</u>,
   Which one? How?

2) <u>Account for induced currents</u>
   How? Include ground mags?

How to measure the horizontal current