HISTORY AND RECENT PROGRESS OF ASSIMILATIVE MAPPING OF IONOSPHERIC ELECTRODYNAMICS

All I know about AMIE I learned from Dr. Arthur D Richmond

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AMIE early days

1980’	NCAR/HAO’s CEDAR database was set up to store and distribute large amounts of data from many different instruments and models
1988	Richmond and Kamide [1988]
1989	CEDAR Prize Lecture, titled AMIE, by Art Richmond

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. A6, PAGES 5741-5759, JUNE 1, 1988

MAPPING ELECTRODYNAMIC FEATURES OF THE HIGH-LATITUDE IONOSPHERE FROM LOCALIZED OBSERVATIONS: TECHNIQUE

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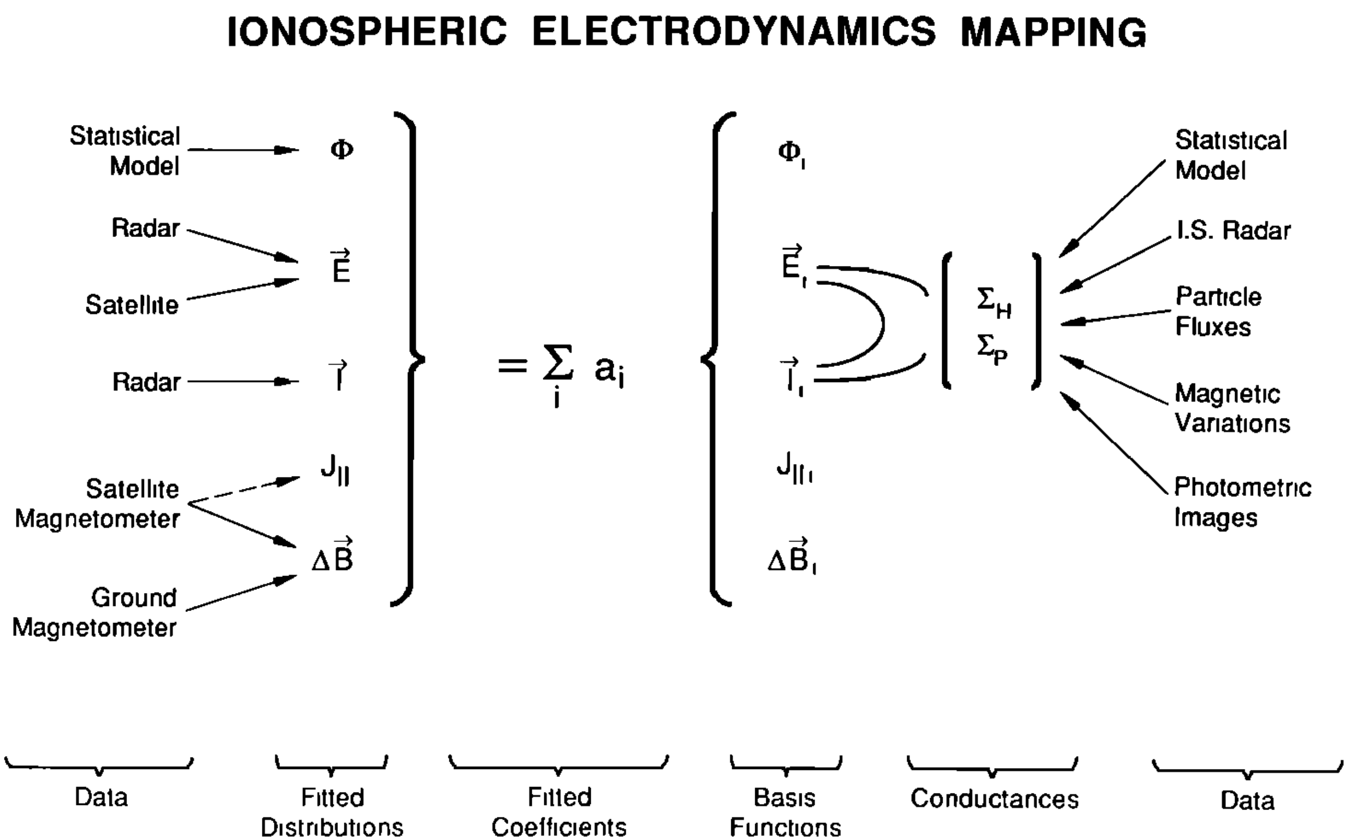
Y. Kamide

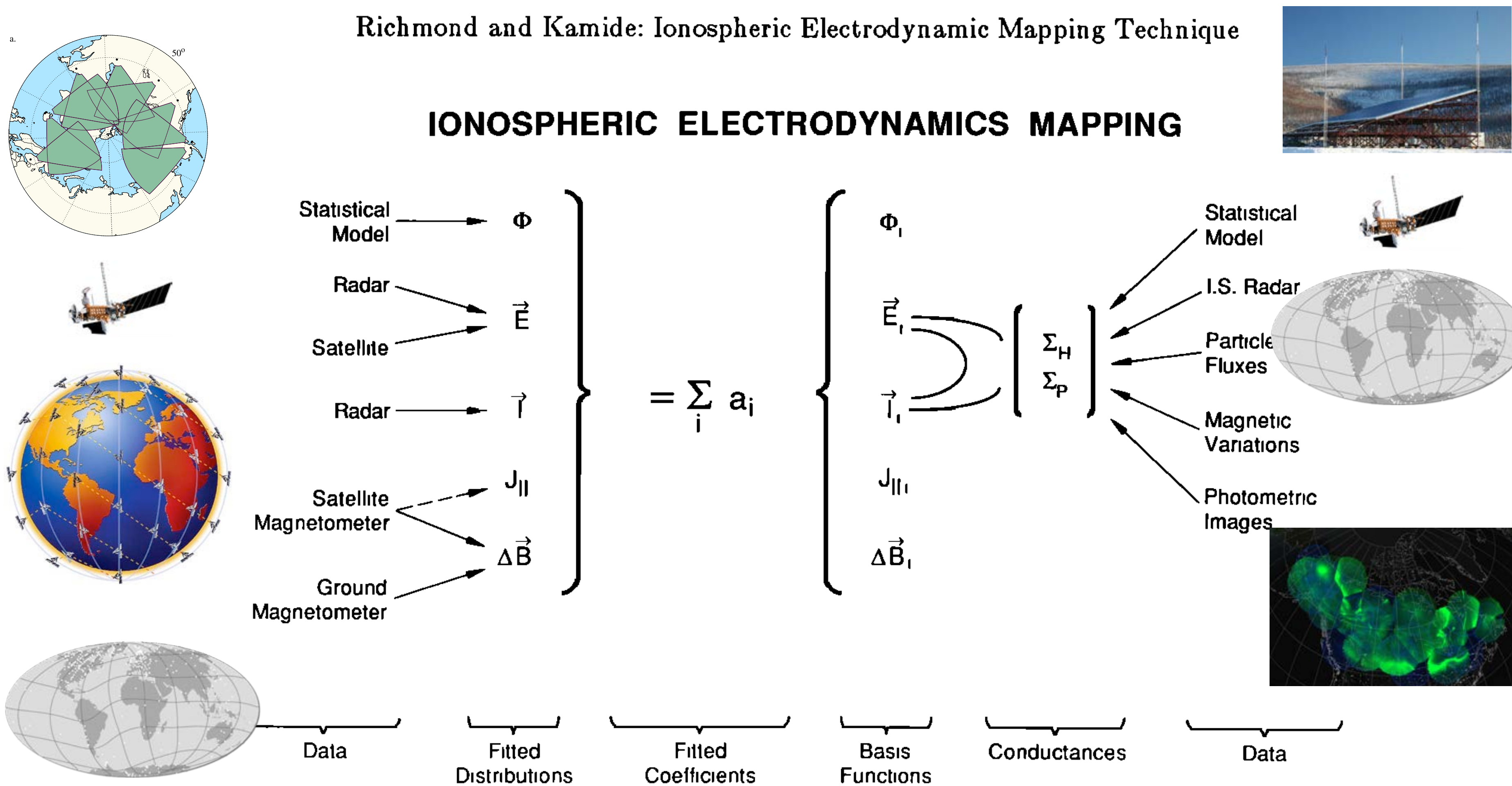
Kyoto Sangyo University, Japan

Vision for the future observing

Richmond and Kamide: Ionospheric Electrodynamic Mapping Technique

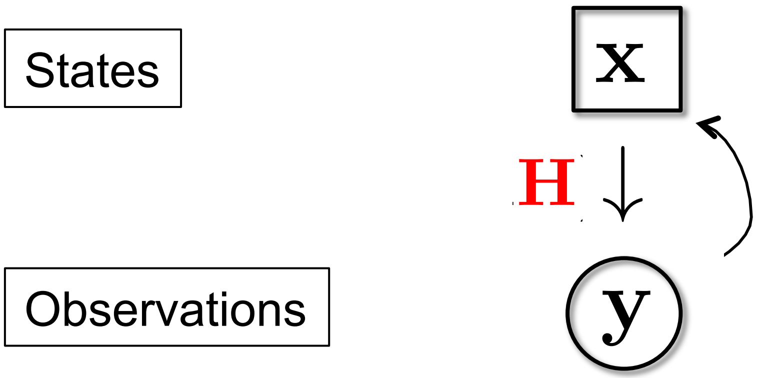


Vision for the future observing



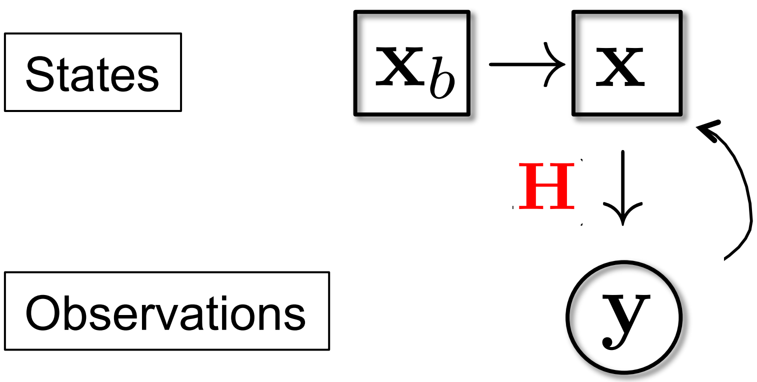
AMIE’s estimation problem

Inverse Problem



[Kamide, Richmond and Matsushita, 1981]

AMIE's estimation problem



Bayesian Inference (DA) Problem

Bayes' rule

$$[\mathbf{x}|\mathbf{y}] \propto [\mathbf{y}|\mathbf{x}][\mathbf{x}]$$

with assumptions of Gaussian errors for $[\mathbf{y}|\mathbf{x}]$ & $[\mathbf{x}]$, $[\mathbf{x}|\mathbf{y}]$ is Gaussian with

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

$$\mathbf{C}_a = (\mathbf{I} - \mathbf{K}\mathbf{H})\mathbf{C}_b$$

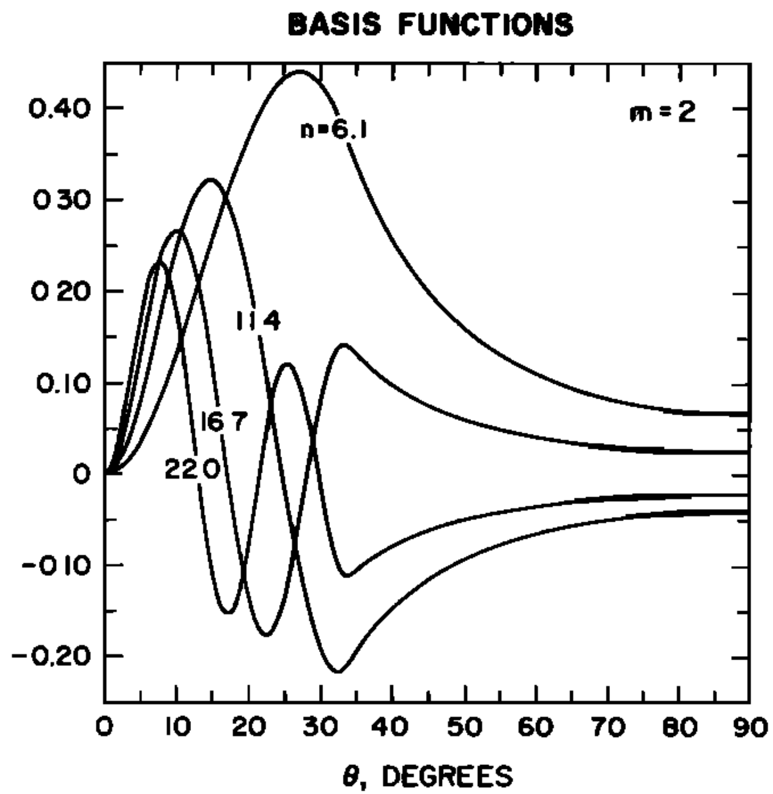
[Richmond and Kamide, 1988]

AMIE solves for coefficients of polar-cap vector spherical harmonic basis functions

Ψ : Polar-cap SH

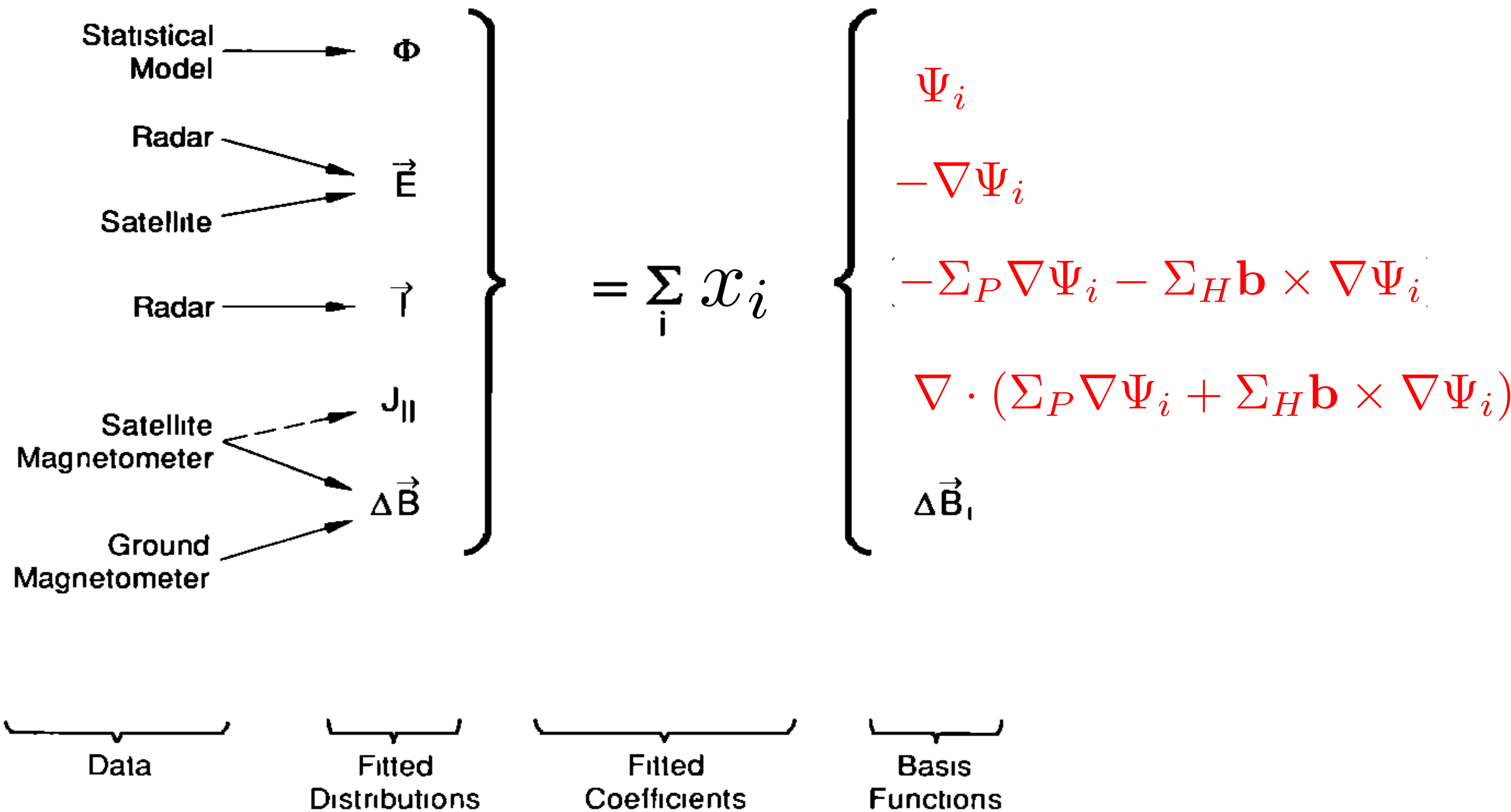
x : coefficients

$$\Phi = \sum_i x_i \Psi_i$$



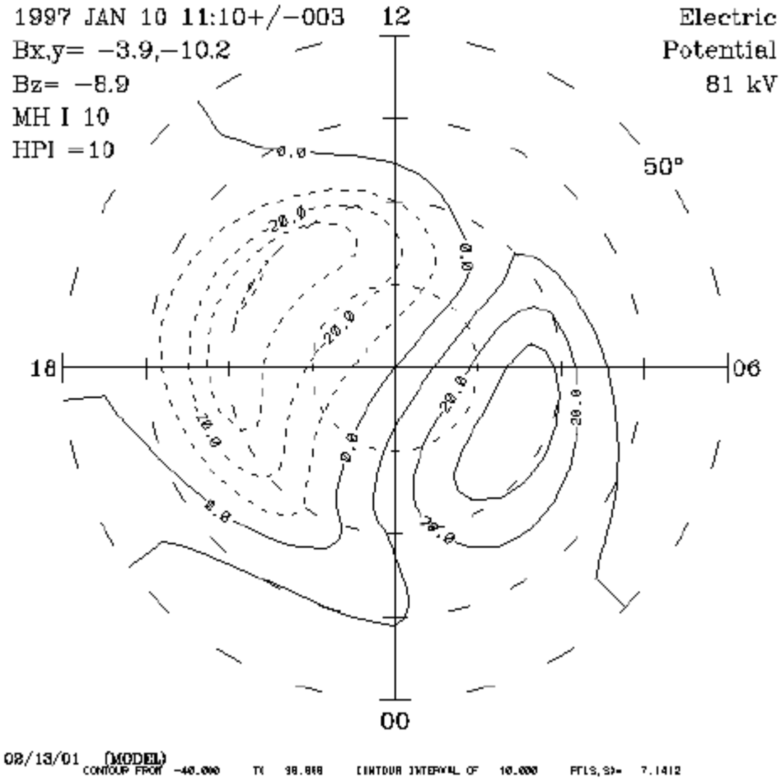
[Richmond and Kamide, 1988]

AMIE solves for coefficients of polar-cap vector spherical harmonic basis

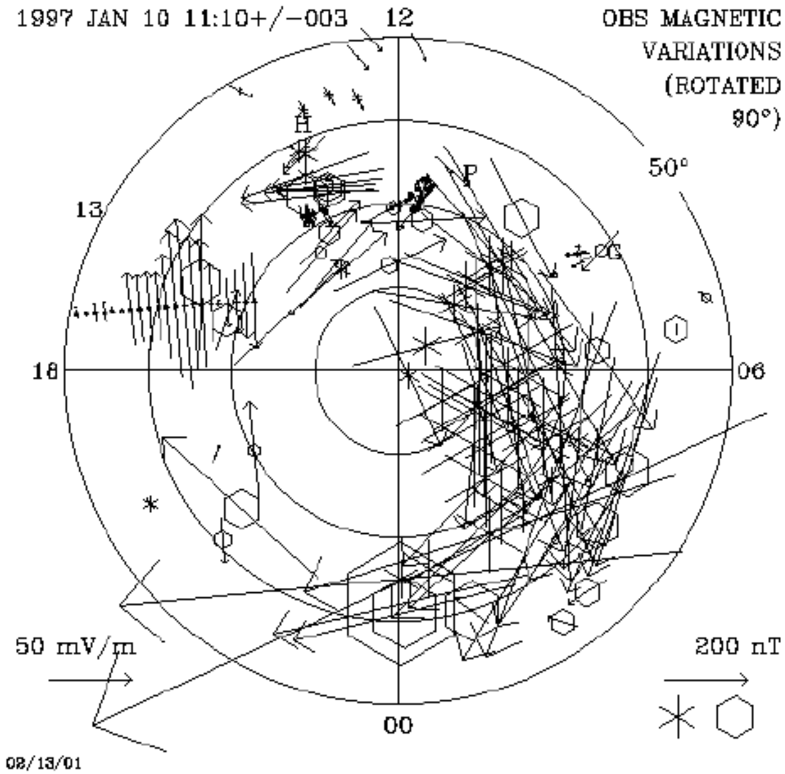


AMIE example for January

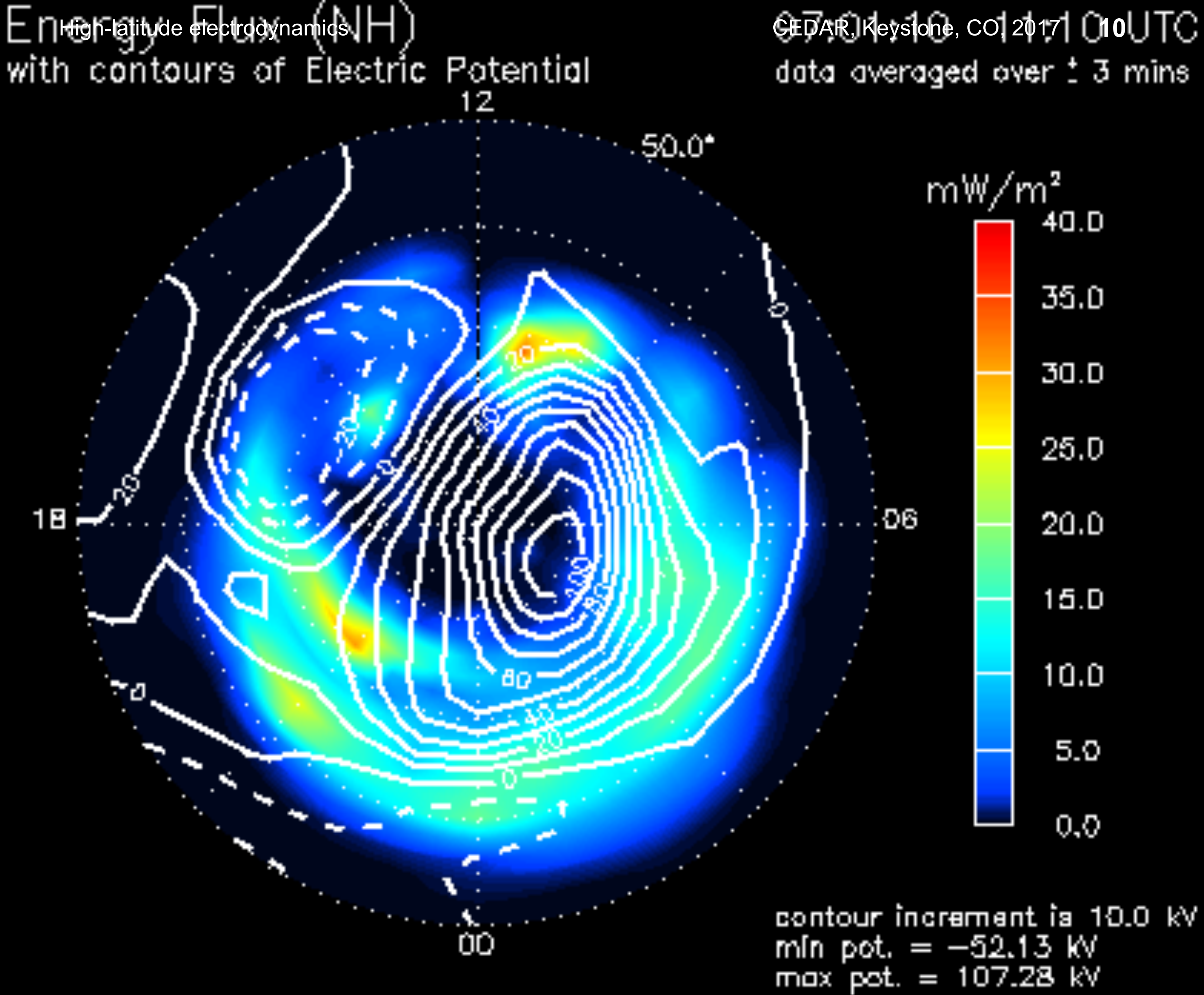
Background



Observations



Foster empirical model


with contours of Electric Potential
data averaged over ± 3 mins
12
50.0°
18
06
00
mW/m²
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
contour increment is 10.0 kV
min pot. = −52.13 kV
max pot. = 107.28 kV

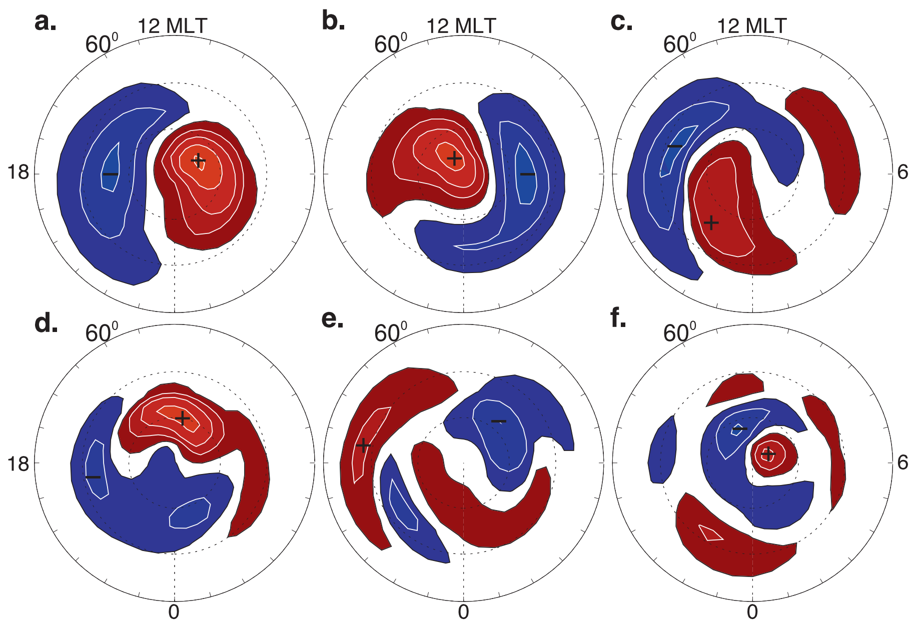
Recent AMIE progress – background error covariance

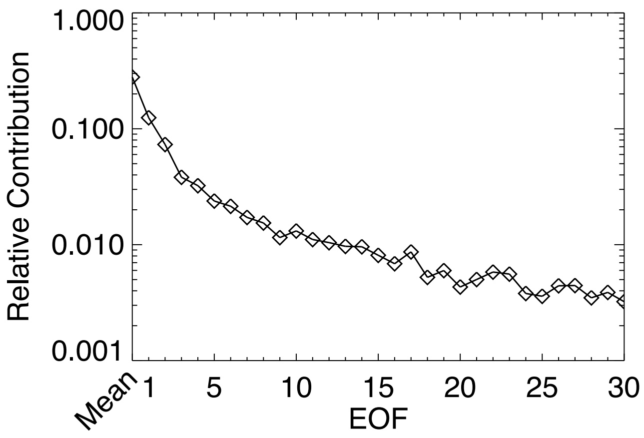
Covariance model with Empirical Orthogonal Functions (EOFs)

$$\mathbf{C}_b \approx \mathbf{Q}\Gamma\mathbf{Q}^T$$

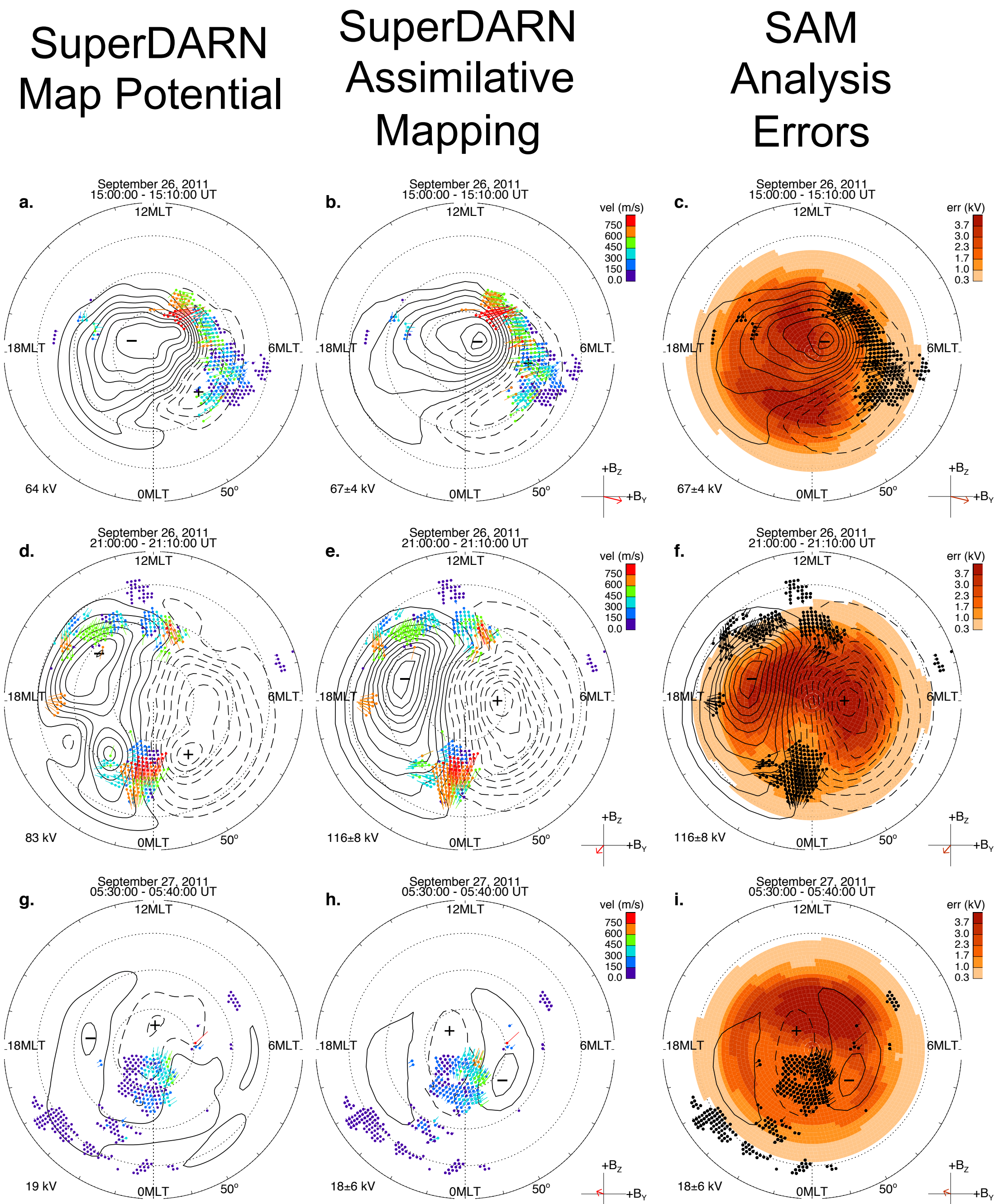
[Matsuo et al., 2002, 2005]

EOFs estimated from SuperDARN data





[Cousins et al., 2013a]



SAM available at http://vt.superdarn.org/

[Cousins et al., 2013b]

Recent AMIE progress – solve for magnetic potentials in addition to electrostatic potential

Toroidal and poloidal decomposition

$$\Delta\vec{B} = \nabla \times \mathbf{r}A^t + \nabla \times \nabla \times \mathbf{r}A^p$$

Analysis of toroidal fields observed by satellite magnetometer

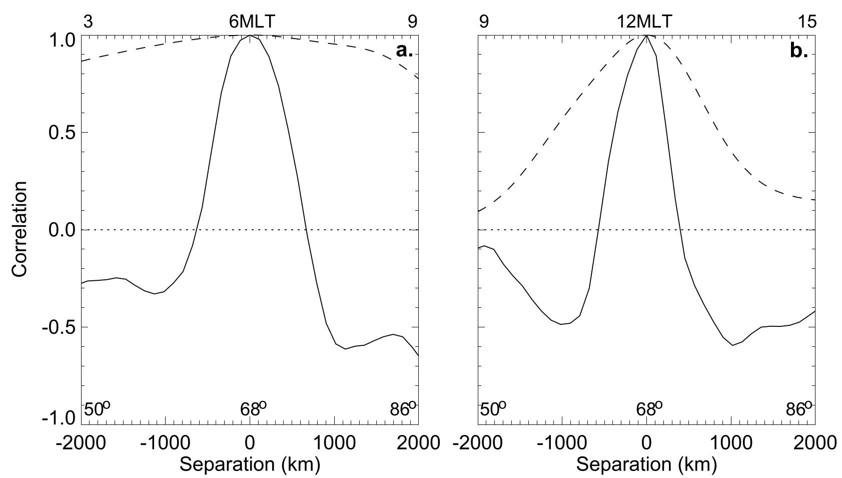
$$\Delta\vec{B} = \sum_i x_i \nabla \times \mathbf{r}\Psi_i$$

$$J_{||} = \frac{1}{\mu_o}\sum_i x_i \nabla^2 \Psi_i$$

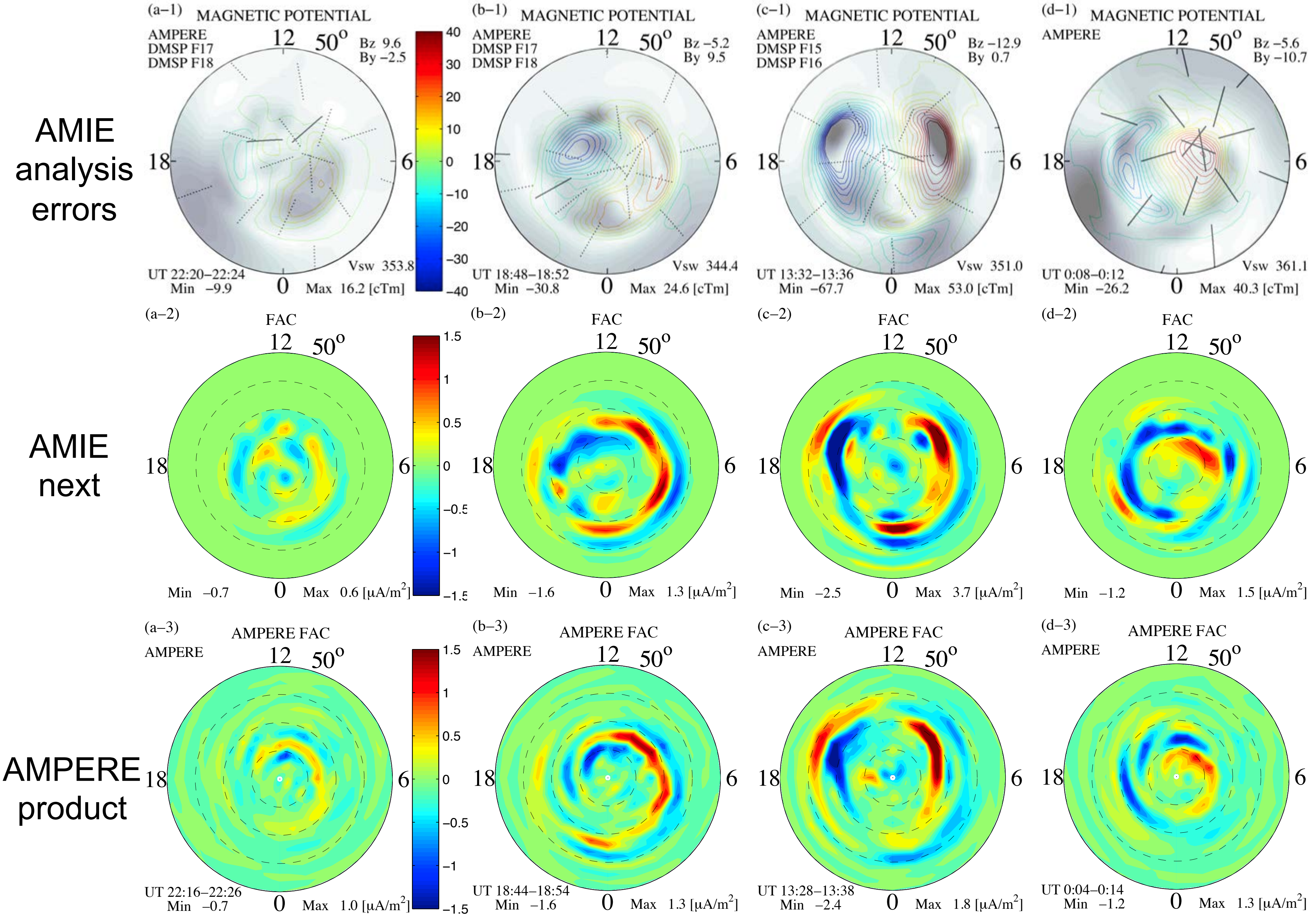
[Matsuo et al., 2015]

EOF-based background error covariance estimated from Iridium/AMPERE data

$$\mathbf{C}_b \approx \mathbf{Q}\Gamma\mathbf{Q}^T$$

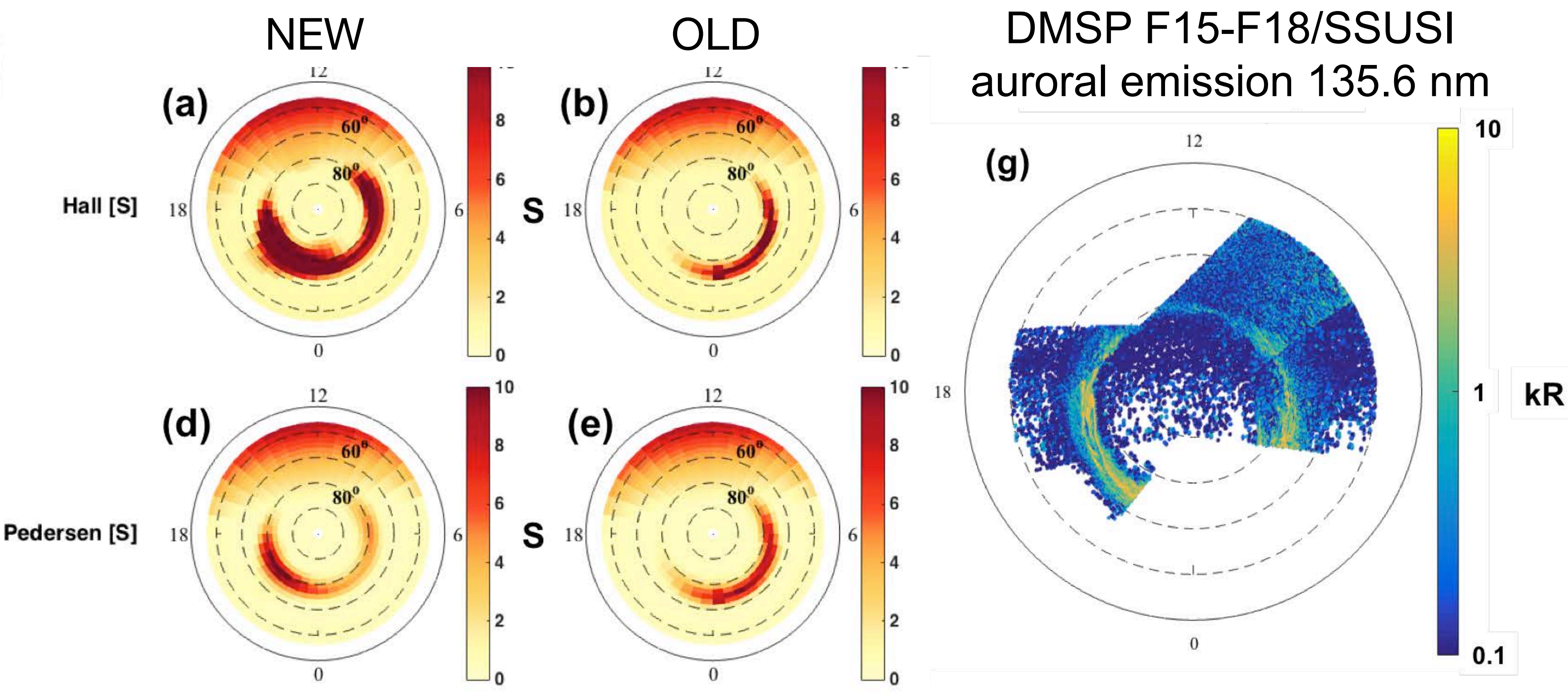


[Cousins et al., 2015a]



[Matsuo et al., 2015]

Recent AMIE progress – Assimilative mapping of conductance update



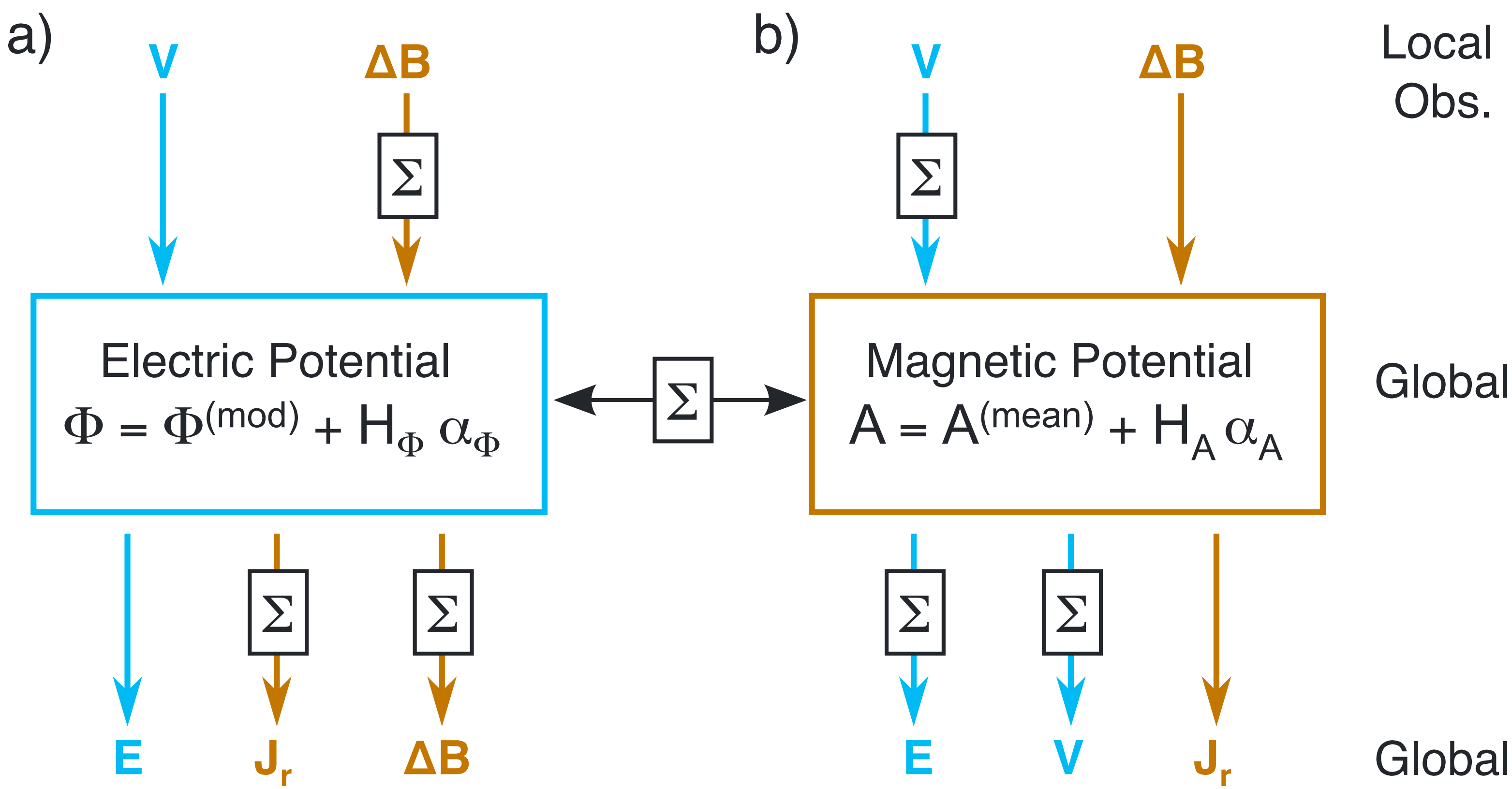
1205 – 1215 UT

1135 – 1225 UT

[Mcgranaghan et al., JGR, 2016a]

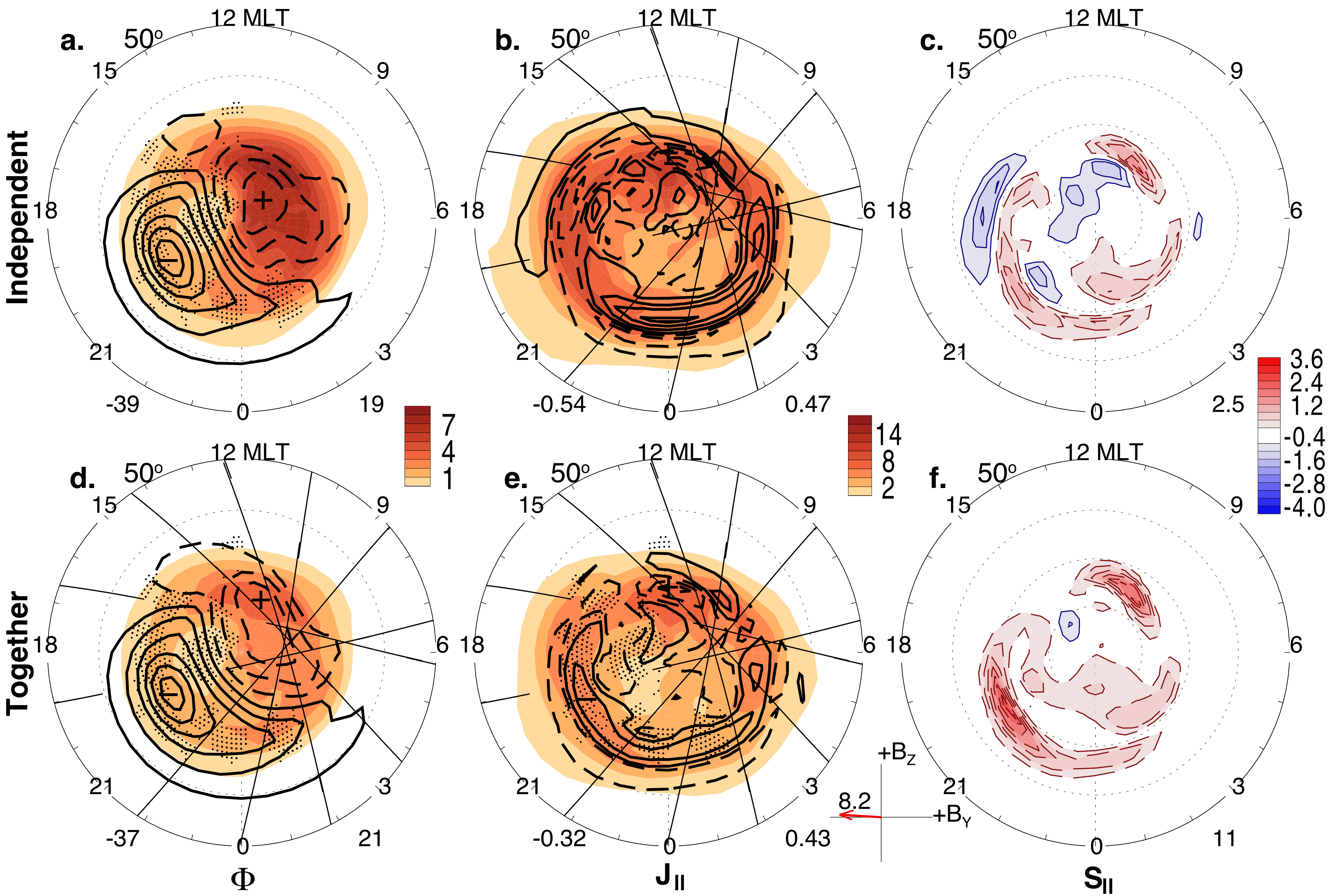
Recent AMIE progress – Dual optimization of electrostatic and troidal magnetic potential

current continuity $$\mathbf{J}_{\|} = \nabla \cdot (\Sigma_p \mathbf{E} + \Sigma_h \mathbf{b} \times \mathbf{E})$$



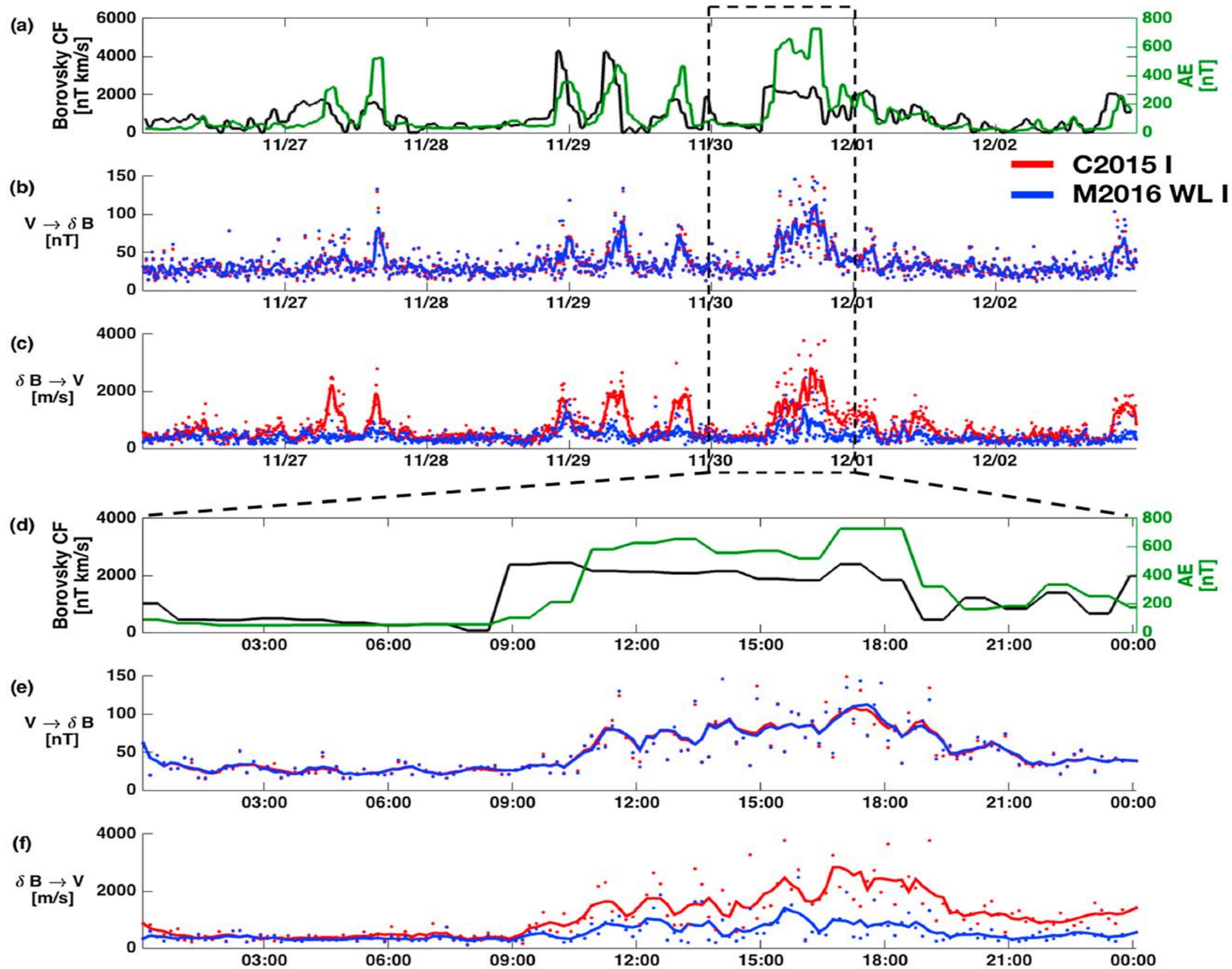
[Cousins el at., 2015b]

0050-0100 UT, November 29, 2011



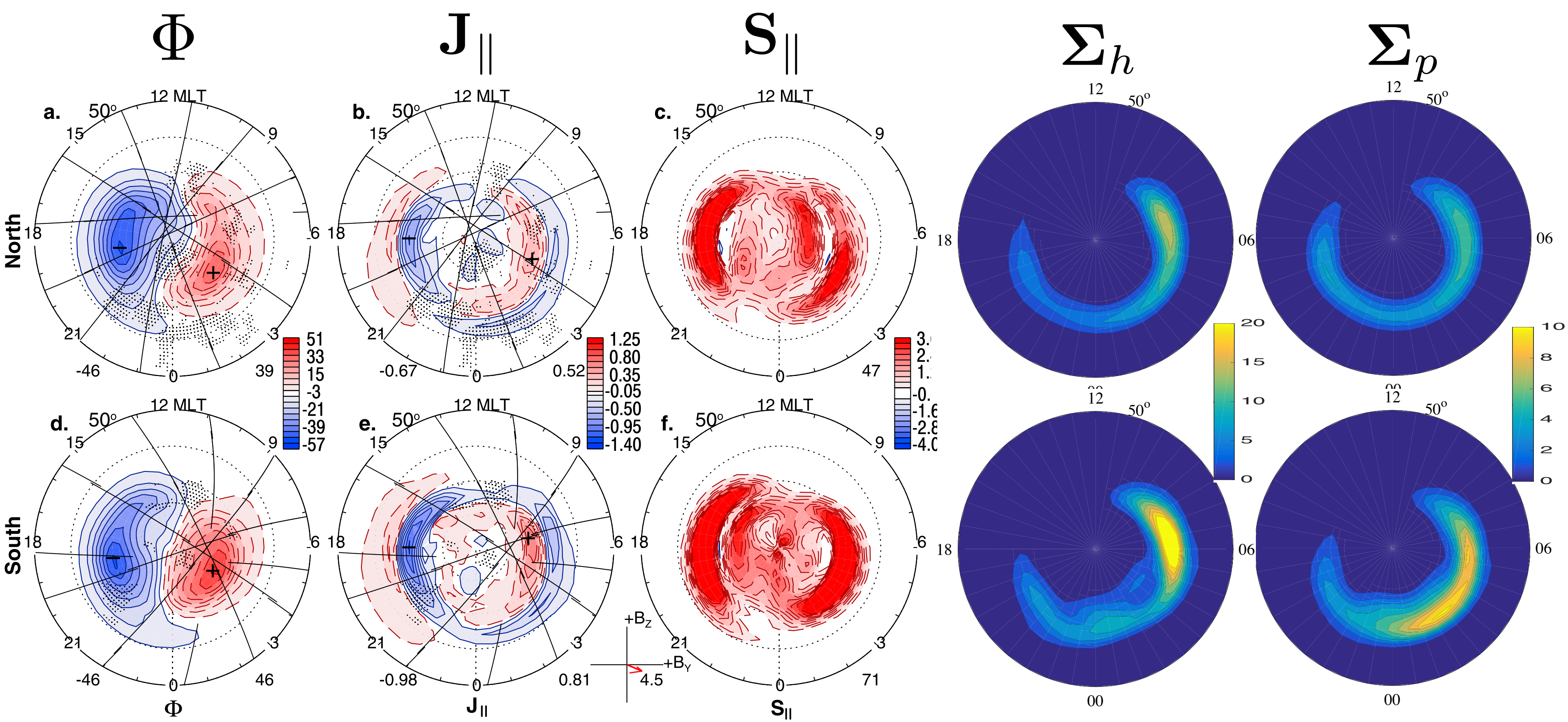
[Cousins et al., JGR, 2015b]

Recent AMIE progress – New assimilative mapping of conductance improves agreement of AMPERE and SuperDARN observations



[Mcgranaghan et al., 2016]

Recent AMIE progress as AMIE NextGen



[Cousins et al., 2013b, 2015b; Matsuo et al., 2015; Mcgranaghan et al., 2016a]

AMIE NextGen and beyond - extending capabilities for the assimilative mapping of ionospheric electrodynamics *to exploit new geospace instrumentation capacity*

① New prior covariance models derived from SuperDARN and AMPERE data to better account for the prior model uncertainty.

② Optimization problem now solved in terms of both magnetic potential and electrostatic potential to take advantage of the global monitoring of multiple electrodynamics variables (e.g, SuperDARN, AMPERE, and SuperMag).

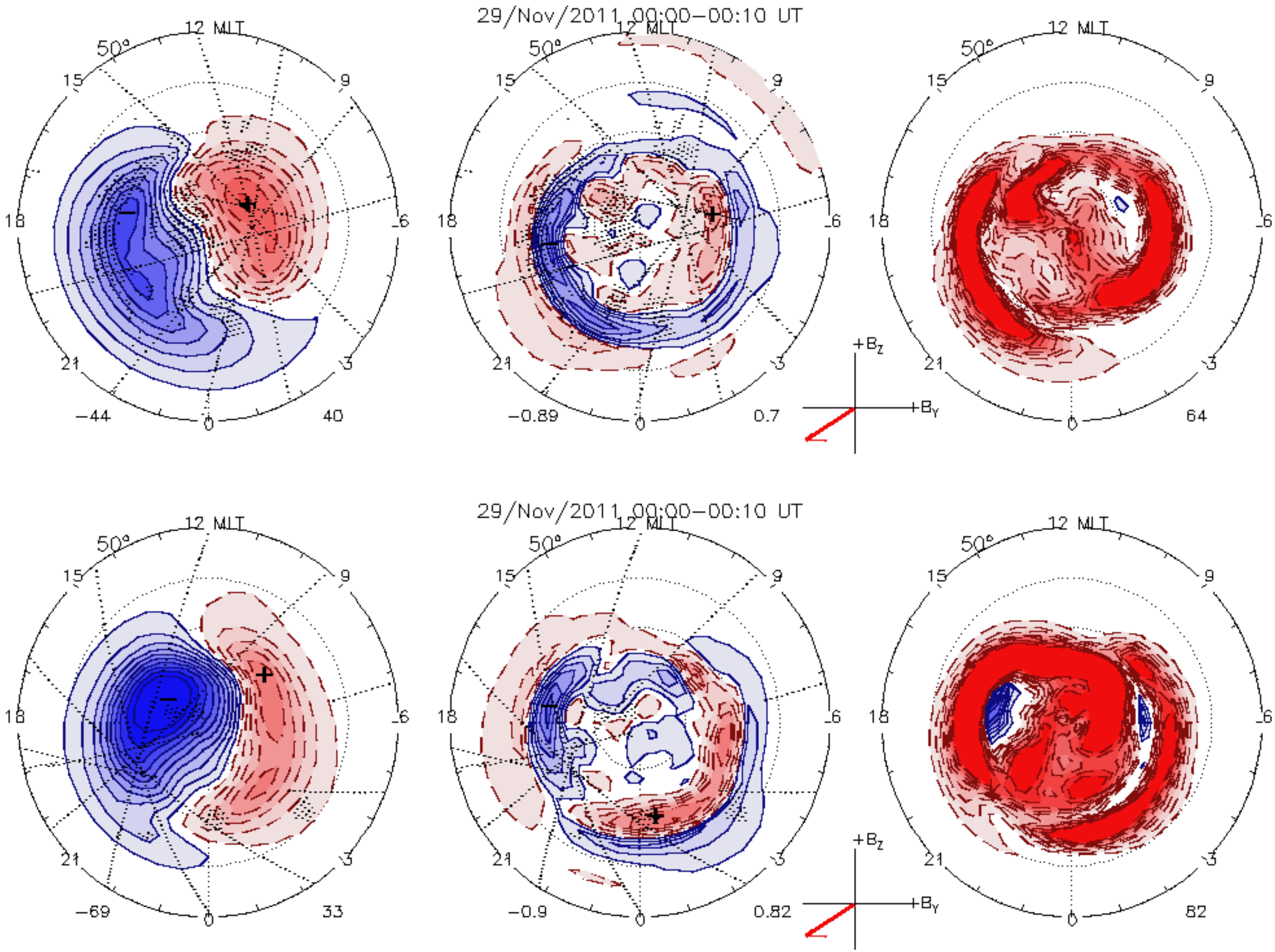
③ Improved conductance specification from DMSP data to facilitate a self-consistent inference of electrodynamics variables.

④ Towards 3D mapping enabled by 3D conductivity mapping.

⑤ Towards non-Gaussian stochastic parameterization of subgrid scale high-latitude ionospheric electrodynamics processes.

⑥ Open shared source Python version of AMIE and AMIE Nextgen - AMIEPy

References: *Richmond and Kamide, JGR,1988; Richmond, JGG, 1995; Matsuo et al., GRL., 2002; Matsuo et al., JGR, 2005; Cousins et al., JGR 2013a, 2013b, 2015a, 2015b; Matsuo et al., JGR, 2015; Mcgranaghan et al., JGR, 2015, 2016; Mcgranaghan et al., GRL, 2016; Fan et al., JASA, 2017, AAS, 2017.*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15
9
18
6
21
3
0
−44
40
−0.89
0.7
64
+B$_Z$
+B$_Y$
29/Nov/2011 00:00–00:10 UT
−69
33
−0.9
0.82
82