FAC validation in global MHD

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This is an old exercise

Fedder et al. [1997]
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“The agreement between the curves is remarkable”

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“The agreement between the curves is remarkable”

“It is satisfying that the simple method chosen worked so well”
Limited FAC data sources

FAC patterns compared with AMIE

Quiet time

Growth phase

Expansion phase

Recovery phase

Raeder et al. [2001]
Limited FAC data sources

FAC patterns compared with AMIE

Quiet time  Growth phase  Expansion phase  Recovery phase

Raeder et al. [2001]

+ ground mags and DMSP magnetometers, e.g., [Ridley et al. 2001]
Iridium patterns

Steady southward IMF conditions

23 November 1999

ACE: MAG, SWEPAM

no (cm⁻³)

V₀ (km/s)

BX (nT)

BY (nT)

BZ (nT)

B (nT)

Clock (°)

UT

11/23/1999 14:00 -- 11/23/1999 17:00

(a) Iridium

(b) LFM (lores, 3 Re)

(c) LFM (lores, 2 Re)

(d) LFM ( hires, 2 Re)

Average FAC Density [µA/m²]

-1.0 -0.5 0.0 0.5 1.0

Figure 1.

Solar wind conditions on 23 November 1999 as observed by ACE. The interval of stable IMF conditions is marked by vertical dashed lines, and the period chosen for the comparison is indicated by dotted lines.

Figure 3.

Distribution of the (a) Iridium and (b)–(d) LFM field-aligned current density averaged from 1400 to 1700 UT on 23 November 1999 with downward and upward FACs represented by the colors blue and red, respectively. See text for explanation.

Korth et al. [2004]
Iridium patterns

Steady southward IMF conditions

Discrepancy due to strong nightside Hall current in the simulation

Korth et al. [2004]
Iridium patterns and DMSP cross-validation

Steady northward IMF conditions

Merkin et al. [2007]
Iridium patterns and DMSP cross-validation

Steady northward IMF conditions

- Iridium allowed global comparisons.
- Revealed close agreement with simulation.
- In-situ validation still important. Model under-resolved.

Merkin et al. [2007]
from THEMIS C (THC) spacecraft (Figure 1b), which was to conditions actually impacting Earth, we ran two simulations in projecting measured IMF and solar wind parameters. The time series were shifted \( \tau = 30 \pm 15 \) minutes later and proceeds in a much more gradual fashion. By \( 17:50 \) UT, both magnetic field observations converge to a major deviation of ACE, THB, and THC from the actual IMF (and, by extension, solar wind) conditions. We expect both simulated and observed FAC patterns to be presented below to respond to the solar wind incident on the magnetosphere.

The different solar wind density values could be due to differences in the THC and Wind spacecraft locations and/or instruments. Whereas the Wind plasma instrument is tailored to accurate solar wind characterization, the THEMIS instrument is tailored to accurate magnetic field characterization. The THEMIS spacecraft indicate a weak predominantly negative transition, with density sharply decreasing after the shock arrival (in THC, the magnetic field measurements by both spacecraft indicate the sharp transition). The different solar wind density values could be due to differences in the THC and Wind spacecraft locations and/or instruments. Whereas the Wind plasma instrument is tailored to accurate solar wind characterization, the THEMIS instrument is tailored to accurate magnetic field characterization.

**Event Description**

**References**

Lepping et al., 1995

Sibeck et al., 1998

McFadden et al., 2008

Smith et al., 1995

Lepping et al., 2008

Merkin et al. [2013]
AMPERE: Global and nearly simultaneous coverage

10-min global FAC patterns vs high-res LFM

- What is the actual solar wind driver?

Merkin et al. [2013]
• Steady state prior to shock arrival
• Good agreement of FAC morphology

Merkin et al. [2013]
Merkin et al. [2013]
• After shock arrival
• Only dayside currents updated in AMPERE
• Nightside: stale data

Merkin et al. [2013]
Merkin et al. [2013]
- After shock passage
- All currents updated in AMPERE
- Good agreement of morphology, including R2

Merkin et al. [2013]
• After northward IMF rotation
• Good agreement of morphology, including R2
• Convection throat orientation not fully captured in AMPERE because it falls between Iridium tracks

Merkin et al. [2013]
• Model FAC change rapidly in response to shock. AMPERE pattern does not resolve the time evolution.

• Time-dependence is a major challenge.

• But if you are careful and patient, significant information can be extracted from individual spacecraft tracks.
Finally, in a situation during any given time, the region of maximum perturbations of Maximum Magnetic Perturbations 5.4. Quantitative Comparison and Time Evolution (Figure 10l).

As in the previous comparisons in this section, the rest of the netic perturbations do not reproduce the observed signature. The simulation does produce a downward current around the duskside near the pole, and thus the positive magnetic potential cell is centered on the pole as well. The corresponding observed signature created a distribution of magnetic vectors, which is in close agreement with the simulation. Particularly, the green satellite equatorward of 10° colatitude is reproduced well indicating the presence of a substantial Region-2 current there. The eastward perturbation vectors measured by the red satellite equatorward of 10° colatitude suggest a strong NBZ current system, which is consistent with the AMPERE FAC sheet currents.

The eastward perturbation vectors measured by the red satellite equatorward of 10° colatitude suggest a strong NBZ current system, which is consistent with the AMPERE FAC sheet currents. Since the AMPERE current densities are derived through a spherical cap fitting procedure, high current densities considerably exceed those inferred from the AMPERE inversions. This is particularly interesting in view of our earlier finding that the peak simulated FAC densities could significantly exceed those inferred from the AMPERE inversions. The simulation does produce a downward current around the duskside near the pole, and thus the positive magnetic potential cell is centered on the pole as well. The corresponding observed signature created a distribution of magnetic vectors, which is in close agreement with the simulation. Particularly, the green satellite equatorward of 10° colatitude is reproduced well indicating the presence of a substantial Region-2 current there. The eastward perturbation vectors measured by the red satellite equatorward of 10° colatitude suggest a strong NBZ current system, which is consistent with the AMPERE FAC sheet currents.

- AMPERE FAC density lower than LFM.
- Is it true for dB magnitude?
- dB magnitudes agree very well in regions where sheet currents are a good approximation.

Merkin et al. [2013]
Feature-based model validation

Same event as Merkin et al. [2013]

FAC

Feature detection

Agglomerative clustering

LFM

AMPERE

Kleiber et al. [2015]

Wiltberger et al. [2016]
Feature-based model validation

Same event as Merkin et al. [2013]

FAC

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Kleiber et al. [2015]

Wiltberger et al. [2016]

• New types of validation enabled by global data sets
Global ionosphere datasets: Going beyond a single parameter

- AMPERE, SuperMAG and SuperDARN (together with SUSSI, etc.) can now be used to provide global simultaneous maps of key ionospheric electrodynamic parameters.

- Proof of principle: current-voltage relationship compared with Weimer model.
Summary

• Global observational FAC patterns became available only recently.

• Together with other global ionospheric data sets they provide a new type of a validation tool for global codes.

• Validation exercise gets more complicated: “global” usually means temporal and spatial dimensions are intermingled. Time-dependent comparisons are a challenge on fast scales, but possible if care is taken.

• New types of comparison algorithms need to be developed, e.g., pattern recognition. Efforts are already underway.

• Combined analysis of available ionospheric datasets with models provides insight into the physics of the system previously impossible to glean.