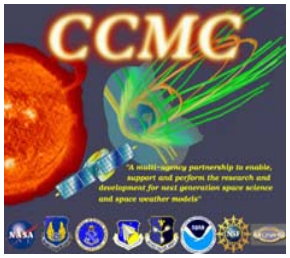


Polar-Cap-Size Metrics Study at CCMC

Lutz Rastaetter, M. Kuznetsova, M. Hesse, CCMC, NASA GSFC
T. Gombosi, U. Michigan, J. Raeder, U. New Hampshire, D. Weimer, Mission Research Corp.

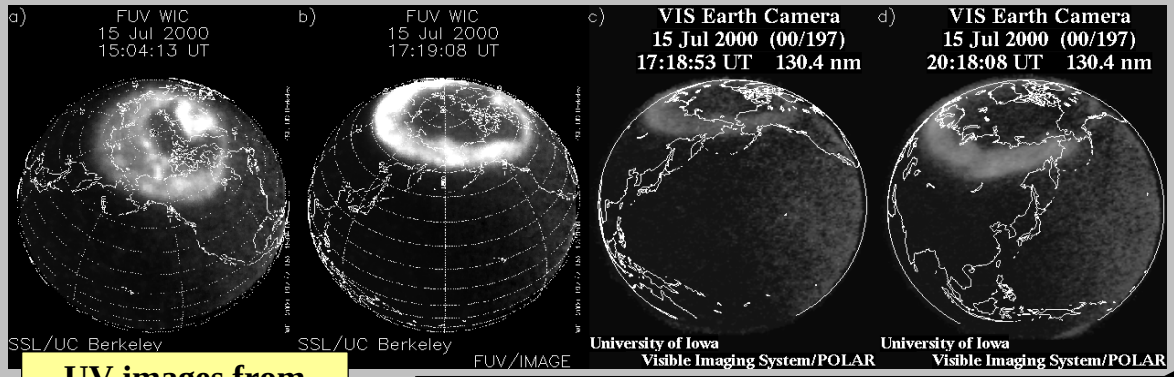
Polar cap size and location determine the area exposed to energetic particles from the heliosphere.
Studies use images from POLAR to estimate polar cap size and position in northern hemisphere.
Skill scores track the performance of models over time if models are compared to the same standard.

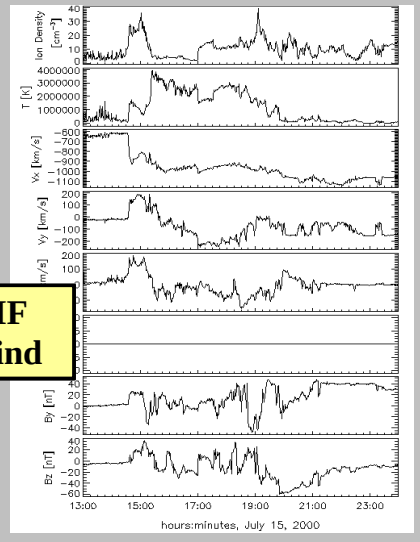
The Community-Coordinated Modeling Center (CCMC) is an independent evaluating entity for models of the Solar Corona, Heliosphere, Magnetosphere and Ionosphere.
Applicable standards and metrics are being developed and applied to model outputs in collaboration with the Space Physics modeling community.

Initial study: Bastille Day event (Rastaetter et al. 2005) – compared polar cap sizes obtained from IMAGE and POLAR satellite observations with modeling results from BATSRUS and OpenGGCM (UCLA-GGCM) magnetohydrodynamic (MHD) models of the magnetosphere.

This work: Add more events: Feb. 18, 1999,
Introduce Weimer field aligned current (FAC) models (Weimer-2K, Weimer-2005),
Estimate polar cap position from FAC patterns in addition to field line tracings through the magnetosphere in the global MHD models.

Data Flow – From Observations to Models' Skill Scores





UV images from IMAGE or POLAR

measured IMF and Solar Wind

Data Analysis

Modeling

BATSRUS | **OpenGGCM** | **Weimer FAC**

Get emission boundaries: Polar cap is region poleward of aurora

Trace magnetic field lines and determine topology (array of 61x61 positions in polar area)

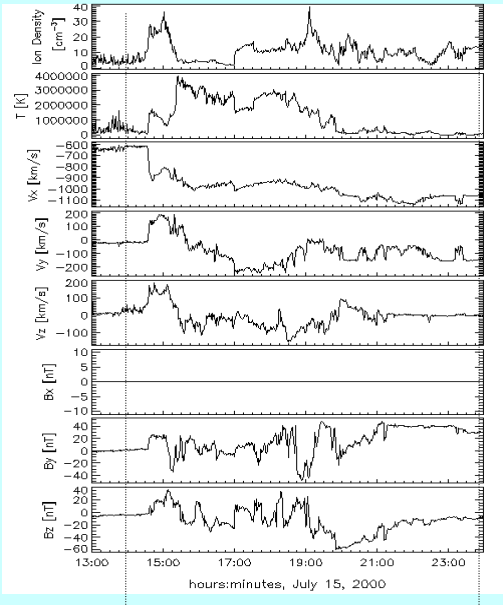
Get maximum currents in 16 sectors in local time. FAC maxima form polar cap boundary.

Polar cap size and location

Standard model:
Average of observed polar cap size over time period analyzed

Skill Score S:
S=1: perfect
S=0: model performs like standard model
-infinity<S<0: model performance worse than standard
Apply exponentiation to convert the range to:
0%<[50%*(2^S)]<100% or to **-1<[2^S-1]<1** with
standard model performance at 50% or 0, respectively.

July 15, 2000 – Bastille Day Storm:



Time period: 14:00 – 24:00 UT

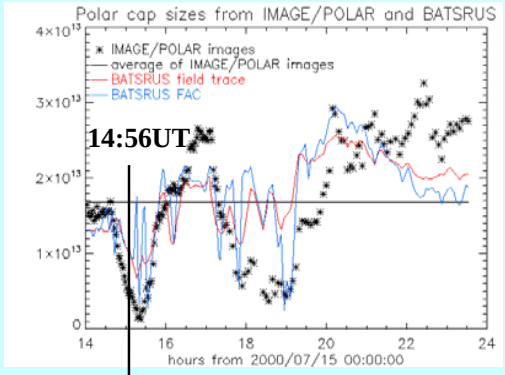
BATSRUS - field line tracings and FAC better than standard model

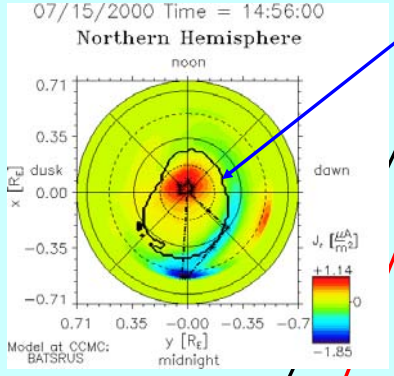
Weimer-2K – polar cap sizes differ in northward IMF less variable in 2005 model; estimates too large

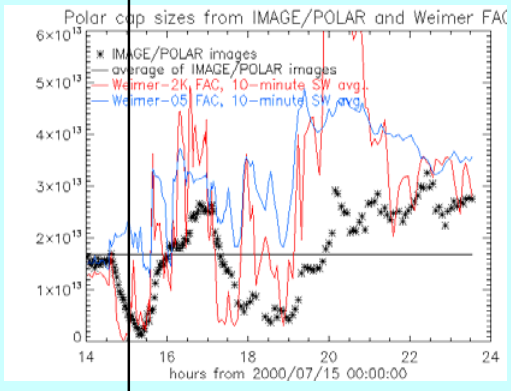
OpenGGCM – slightly worse than standard

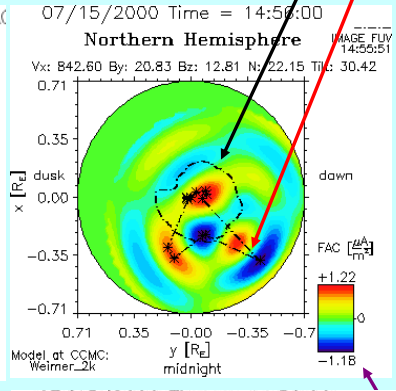
Skill Scores

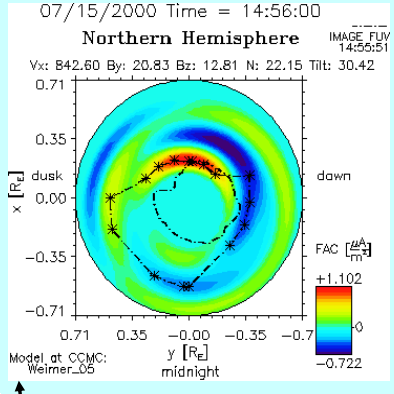
BATSRUS FL:	0.303
BATSRUS FAC:	0.223
Weimer-2K FAC:	- 1.160
Weimer-2005 FAC:	- 0.882
OpenGGCM FL:	- 0.057
OpenGGCM FAC:	- 0.025

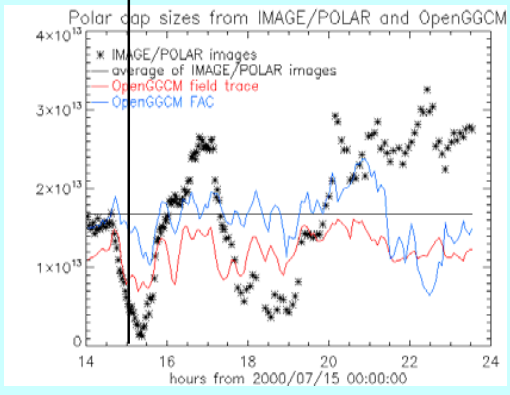


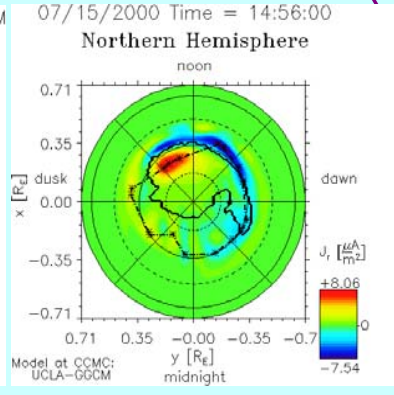












Polarcap boundary

Solid lines: **fieldline tracing**

Dash-dotted (in Weimer plots): **Image FUV observations**

Dashed+Asterisks: **FAC**

14:56 UT:

MHD models agree with observations in terms of polar cap size, but ...

BATSRUS: strong NBZ current at pole

Weimer-2K: inputs off-range (|B|>10, N>20)

Weimer-2005: FAC valid, no currents near pole are output

OpenGGCM: Dayside FAC similar to Weimer-2005

Skill Score (S): a single number resulting from a comparative analysis of modeling outputs to a reference model and to measurements. Data can be entered as sums of squares of linear differences or of logarithms of ratios (if all data values > 0).

A **reference or standard model** is needed to establish a baseline to compere model performance.

S > 0: model performs better than reference model.

A **perfect fit with measurements** is indicated by **S =1**.

Example standard models:

a) **constant**, e.g. the average of a measurement over a time period

b) **persistence**, i.e. prediction is equal to most recent measurement

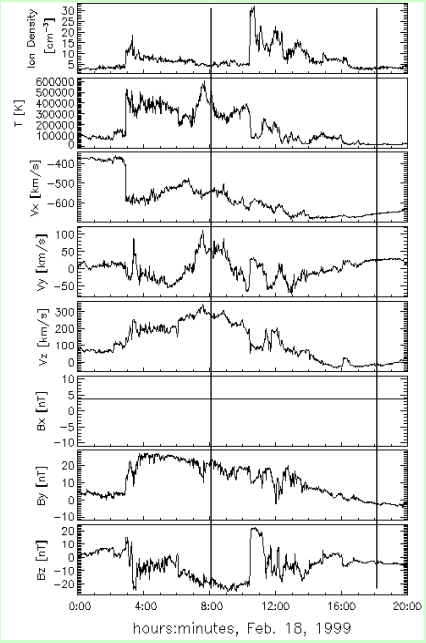
c) **some other model**, e.g. a simple estimate or statistical model.

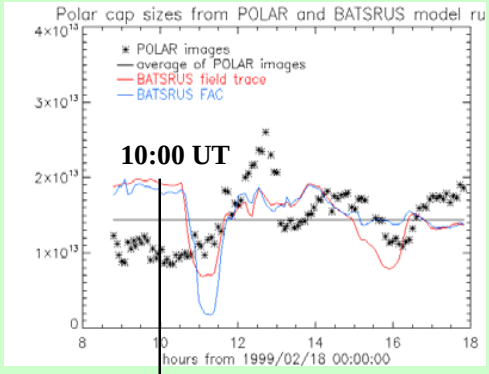
Skill scores are normalized by comparing with the standard model.

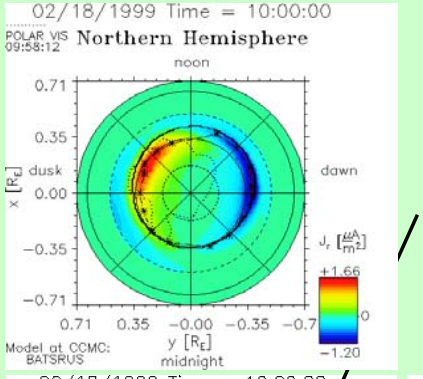
Methods of polar cap determinations:

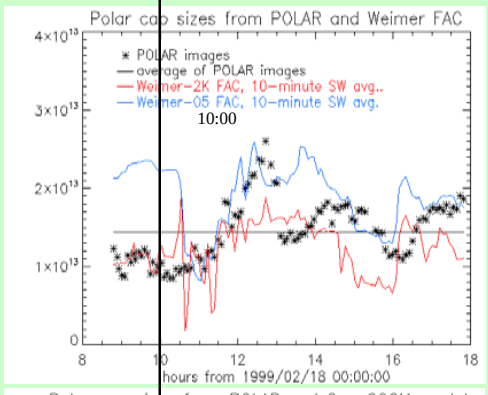
- **Field line tracing:** Polar cap boundary is between open and closed field lines as traced through the magnetosphere. Field lines start in the high-latitude region at the near-Earth boundary.
  Models: **BATSRUS**, **OpenGGCM**
- **Polar cap from field-aligned current (FAC) pattern:** Positions of the maximum or minimum of the field-aligned current in each of the 16 sectors of local time form the cap:
  Models: **BATSRUS**, **OpenGGCM**, **Weimer FAC (2K, 2005)**

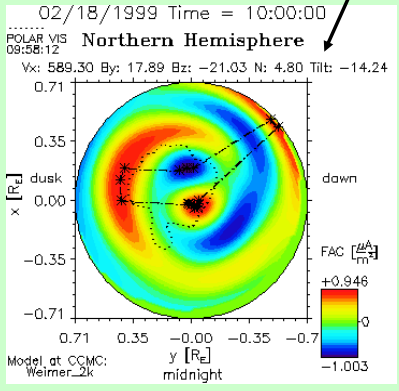
Storm of February 18, 1999

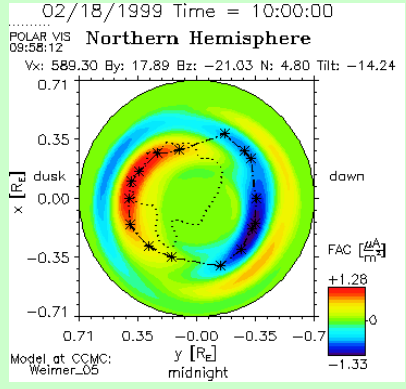


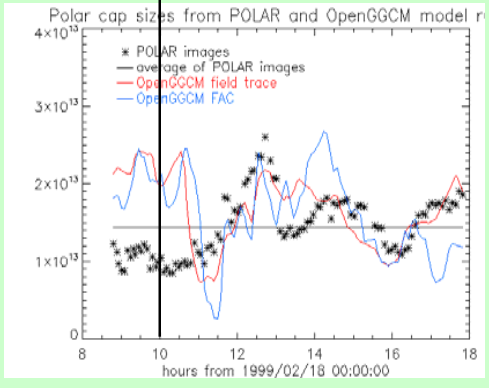


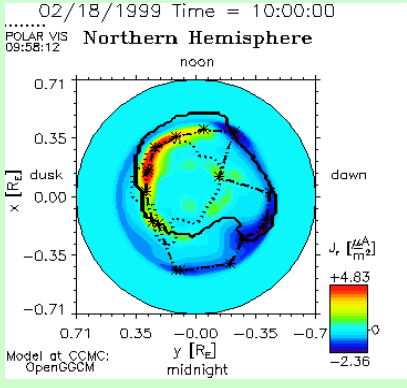












10:00 UT:
Low-latitude **Weimer FAC** patterns are very similar to the MHD results.
Weimer-2K shows currents in high latitudes which yield vastly different polar cap determination.

Time period: 8:00 – 18:00 UT

BATSRUS Field line tracings and FAC worse than standard model

OpenGGCM – slightly worse than BATSRUS

Weimer – polar cap sizes very variable

Skill Scores:

BATSRUS FL tracing:	- 0.410
BATSRUS FAC:	- 0.400
Weimer-2K FAC:	- 0.142
Weimer-2005 FAC:	- 0.840
OpenGGCM FL tracing:	- 0.705
OpenGGCM FAC:	- 0.821

Computational methods and parameters

Computation of skill scores:

OBS: observational values

MOD: modeled values

STD: standard model (here: average of OBS over N samples)

Linear comparison (used in this work):

$$norm = \sqrt{\sum_{i=1}^{N}[(OBS(i) - STD(i)]^2}$$

$$S = 1 - \frac{1}{norm}\sqrt{\sum_{i=1}^{N}[MOD(i) - OBS(i)]^2}$$

Logarithmic comparison (positive values only):

$$norm\_\log = \sqrt{\sum_{i=1}^{N}\left[\ln\left(\frac{OBS(i)}{STD(i)}\right)\right]^2}$$

$$S\_LOG = 1 - \frac{1}{norm\_\log}\sqrt{\sum_{i=1}^{N}\left[\ln\left(\frac{MOD(i)}{OBS(i)}\right)\right]^2}$$

Model inputs and parameters:

Weimer FAC models:
use solar wind parameters (B_y, B_z, V_x, N)
propagated to the Earth and
averaged with a 10-minute memory time.

BATSRUS and **OpenGGCM**:
use solar wind (**V**, N, T) and IMF (B_y,B_z) at 33 R_E upstream,
model the magnetosphere within 48 R_E in Y, Z and from
-250 to 33 R_E in X.
The inner radius is 3 R_E around Earth.

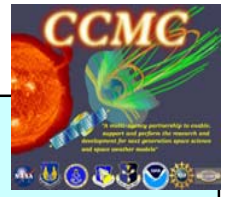
FAC to Polarcap:

Use 16 local time sectors.

Take position of max(|FAC|) in each sector.

Connect positions to form polar cap.

Summary



Polar cap sizes derived from field line tracings in the MHD models yields comparable results compared to the use of maximum FAC in 16 local time sectors.

Weimer FAC model results differ considerably from MHD modeled results.

Especially the 2005 version of the Weimer model excludes FAC from high-latitudes and thus tends to overestimate polar cap sizes for northward IMF conditions where Weimer-2K FAC can give smaller cap sizes.

Current patterns can be too irregular to apply the maximum-current method.

The "standard model" (averaged polar cap size over the time period analyzed) used to calculate skill scores is hard to beat (because it is derived from the measurements).

Statistical Weimer model not applicable for strong IMF or high-density solar wind.

Weimer 2005 does better for large IMF and solar wind densities than Weimer-2K.

FAC from MHD models limited to latitudes > 55deg. due to MHD inner boundary of 3 R_E.

References

Polar cap study: Rastaetter, L, et al. (2005), Polar cap size during July 14-16 2000 (Bastille Day) solar CME event. MHD modeling and satellite imager observations, *JGR Space Physics* **110 (A7)**.

BATSRUS: Powell, K. G., et al., (1999), A solution-adaptive upwind scheme for ideal magnetohydrodynamics, *J.Comp.Phys*. **154(2)**, 284.

OpenGGCM: Raeder, J., Wang, Y., and Fuller-Rowell, T. (2001), Geomagnetic storm simulation with a coupled magnetosphere-ionosphere-thermosphere model, in Song, P., Siscoe, G., and Singer, H.~J. (eds.), *Space Weather*, AGU Geophys. Mongr. Ser.

Weimer-2K FAC: Weimer, D.R. (2001), Maps of Field-aligned currents as a function of the interplanetary magnetic field derived from Dynamic Explorer 2 data, *JGR Space Physics*, **106 (A7)**, 12,889.

Weimer-2005 FAC: Weimer, D.R. (2005), Improved ionospheric electrodynamic model and application to calculating Joule heating rates, *JGR Space Physics* **110 (A5)**.