8th CCMC Community Workshop
April 11-15, 2016 • Annapolis MD, USA

Session: *Working with CCMC in Preparation for Delivering LWS Strategic Capabilities*

Medium Range Thermosphere-Ionosphere Storm Forecasts

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Aaron Ridley, U Michigan
The Model Development Community

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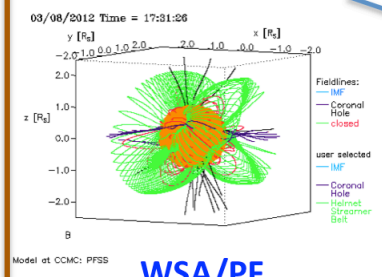
The Vision

- **Real-time forecasts of thermosphere-ionosphere conditions in response to conditions/events at the solar corona**
- **Accumulating statistics on forecast skill that improve over time**
- **Scientific insights that result from trying to improve forecasts**

- **Our effort is focused on the ionosphere (total electron content), but it could be generalized to other quantities characterizing the ionosphere and thermosphere**

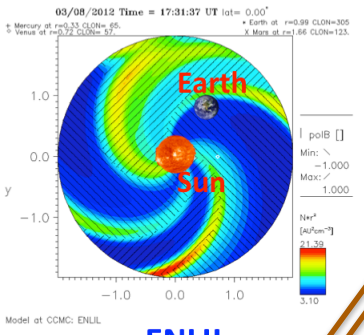
Modeling Chain: Sun to "Mud"

Solar Corona



WSA/PF

Heliosphere



ENLIL

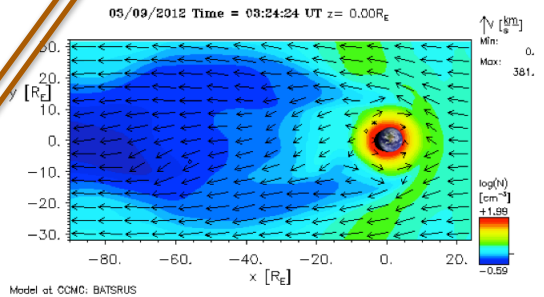
Operational

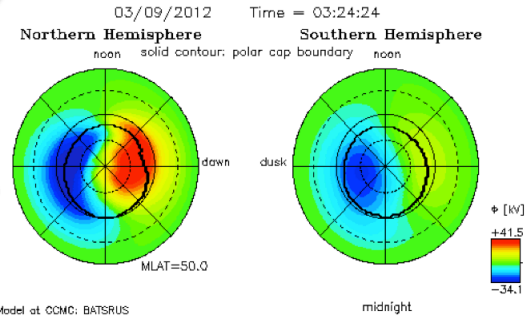
Current collaborators:
CSEM (U Michigan)
Antiochos, NRL

- Center for Integrated Space Weather Modeling (2000's), LWS TR&T, NSF, MURI, etc.
- NASA/NSF Partnership for Collaborative Space Weather Modeling (2013-)

Magnetosphere

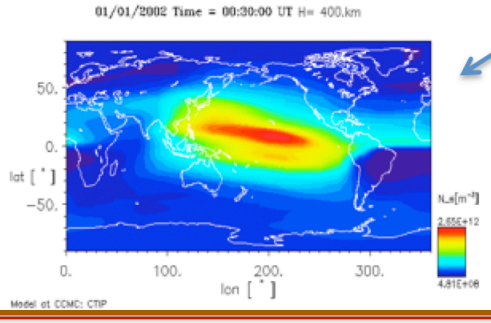
Our focus





High latitude convection pattern

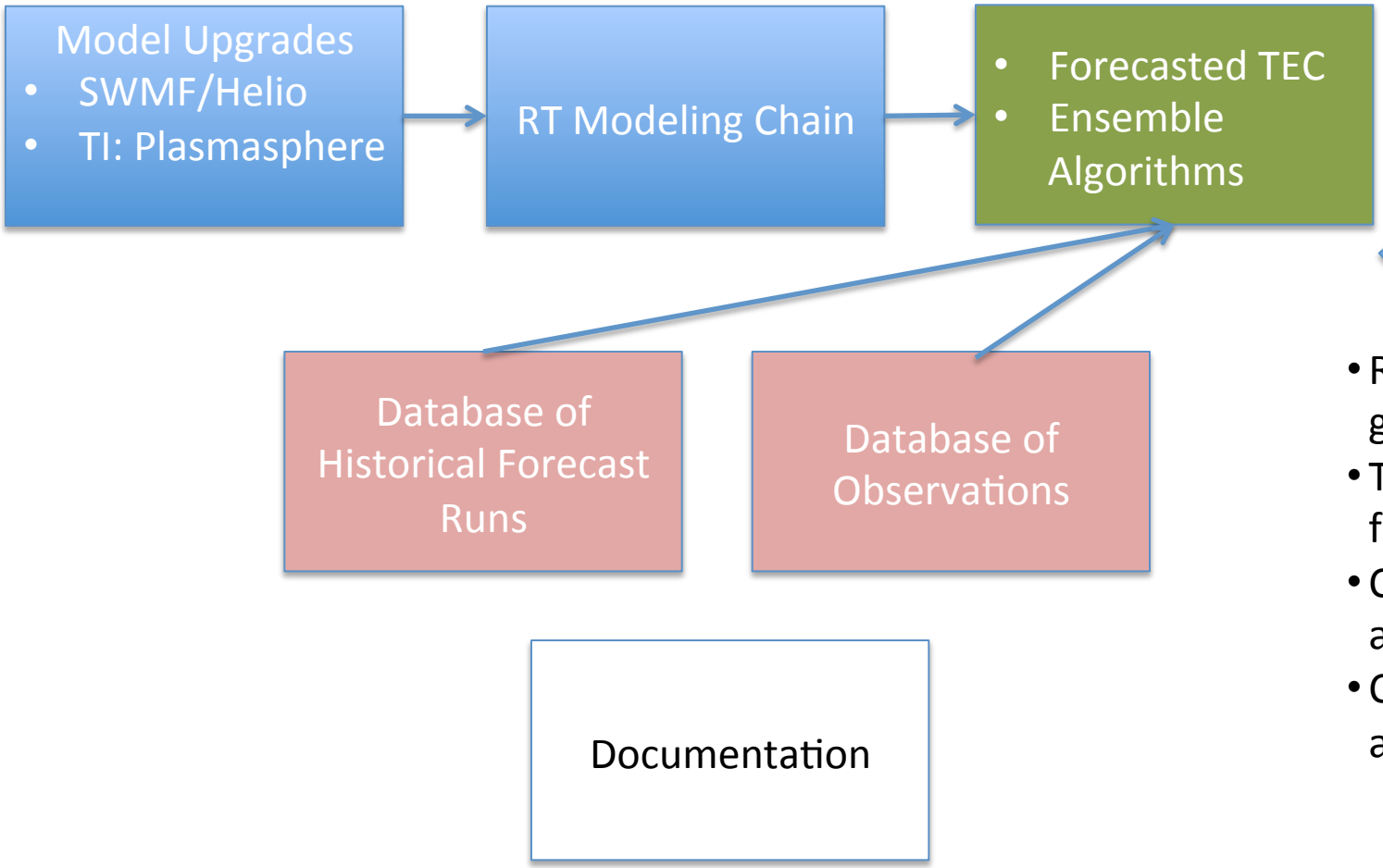
Global thermosphere-ionosphere storm



Non-MHD:

- Particle precipitation/ aurora (empirical model)
- Shielding currents (Rice Convection M)

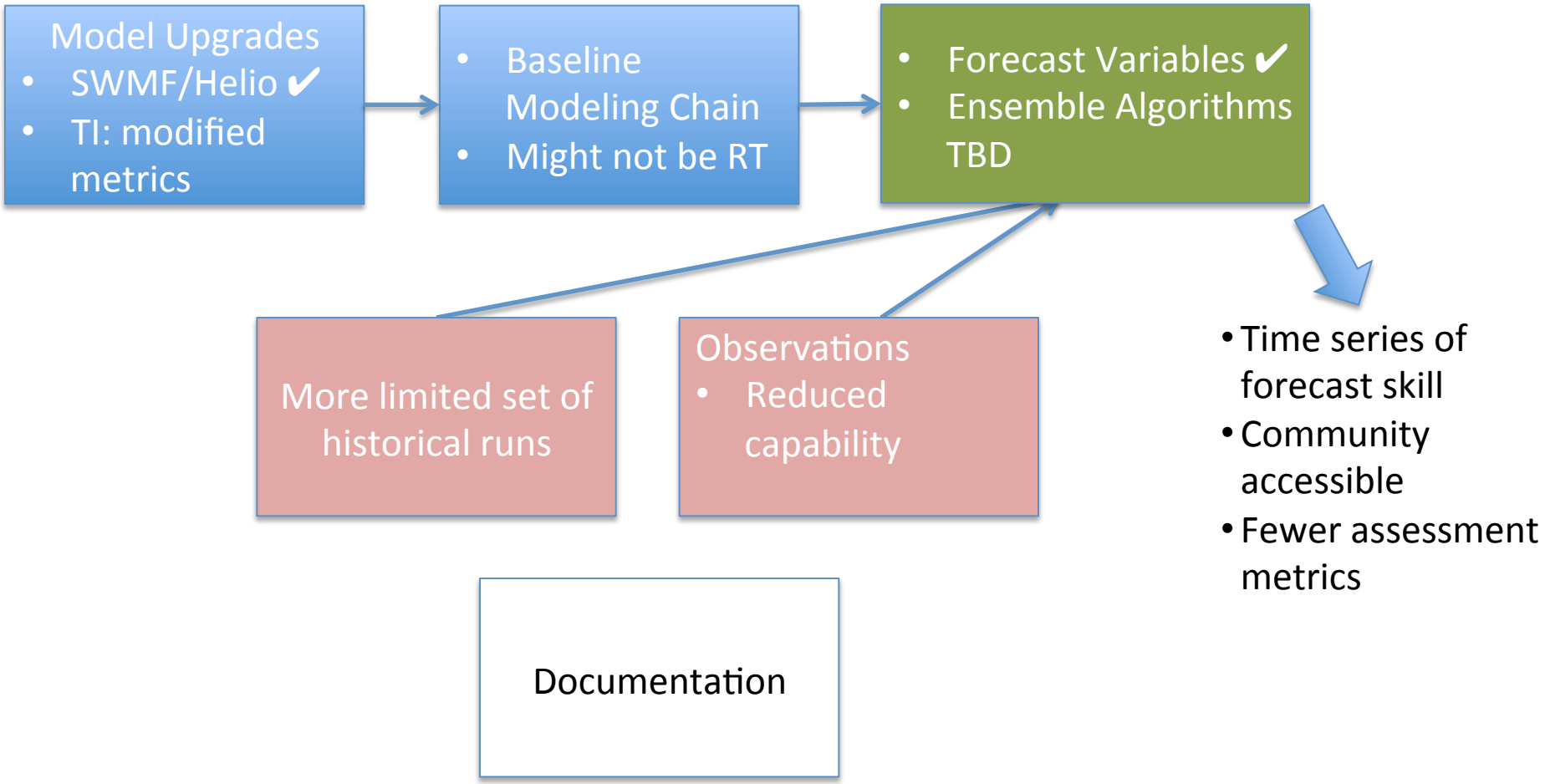
Original Deliverables*



- Real-time forecast generation
- Time series of forecast skill
- Comprehensive assessment
- Community accessible

*CCMC related

Modified Deliverables*



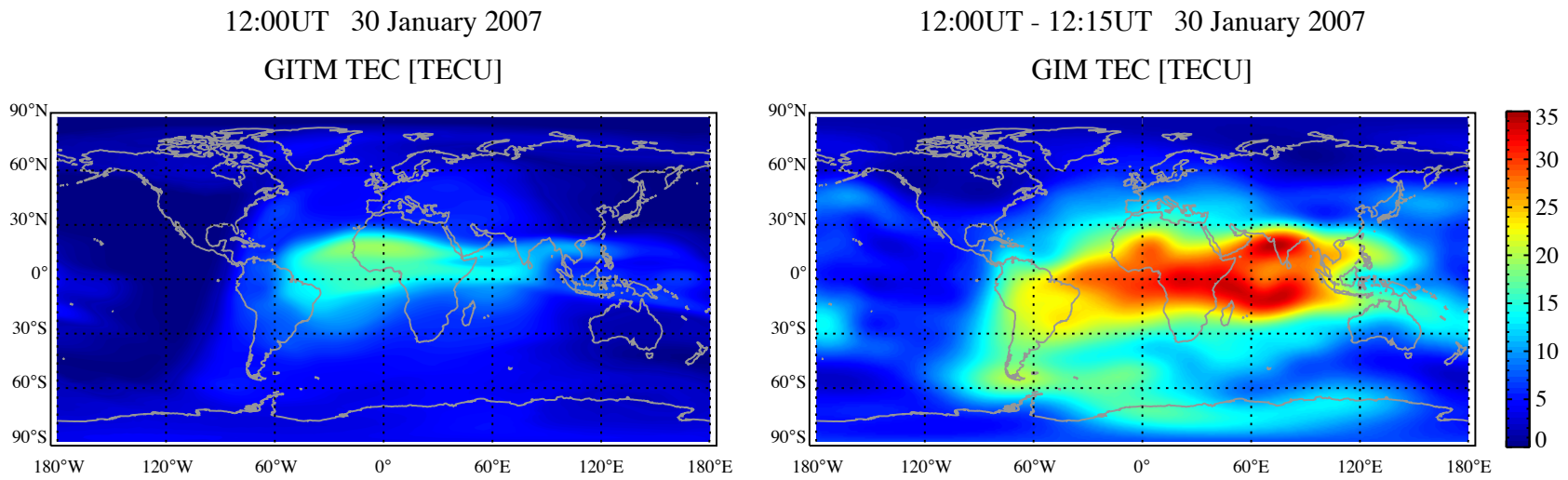
*CCMC related

Ionosphere "Storm" Forecasts

- **Based on Global Ionosphere-Thermosphere Model (GITM) [Ridley et al. 2006]**
- **"Forecast mode": inputs are F10.7, solar wind from OMNI data or ENLIL, CORHEL, SWMF predictions for the heliosphere, driving Weimer 2005 ionospheric electrodynamics**
- **Alternative high latitude driving: SWMF magnetosphere and ionospheric electrodynamics**
- **Data product: Global Ionospheric Maps (GIM) [Mannucci et al. 1998] based on GPS-derived TEC data.**

GITM: hourly TEC maps

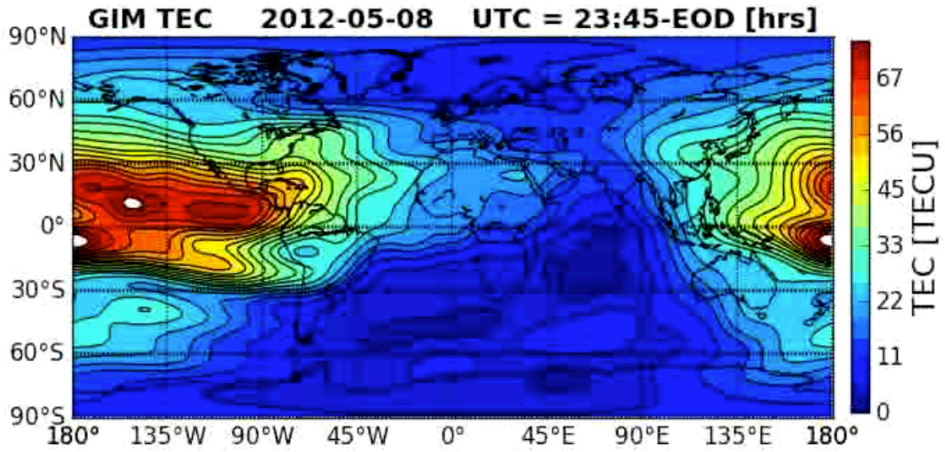
GIM: averaged TEC for the first 15 minutes of every hour

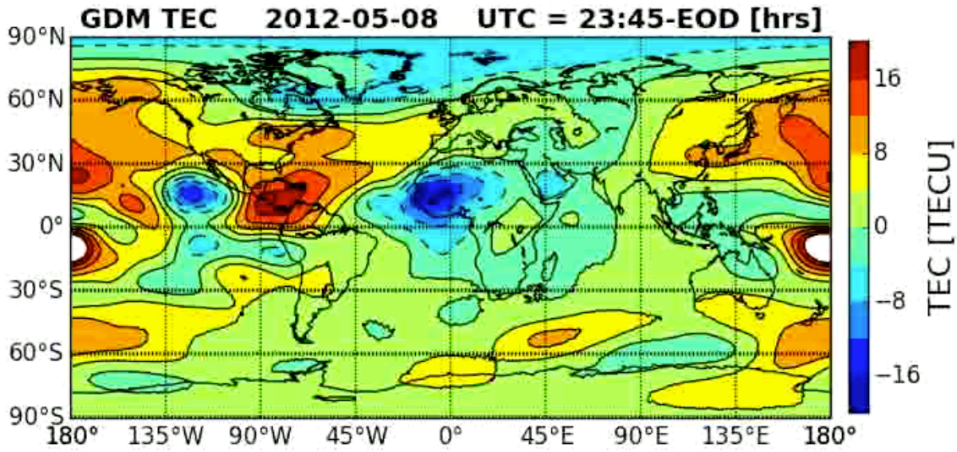


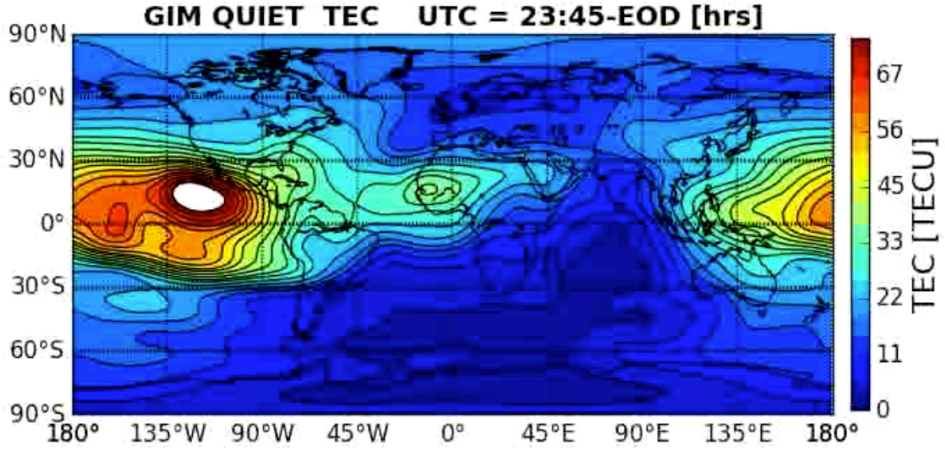
TEC maps from OMNI-driven **GITM** and **GIM** for the January High Speed Stream 2007 storm

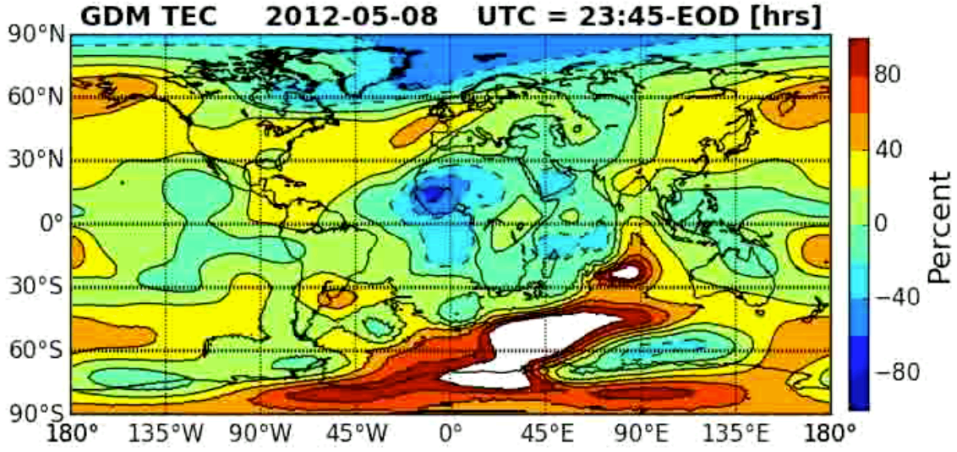
GITM "TEC" is integrated electron density between 100 km – 600 km altitudes.

Developing Forecast Variables









Forecast Variables Definition

- **Step 1: Divide the globe into grid boxes of size 30° (longitude) x 15° (latitude)**
- **Step 2: Compute the mean TEC within each grid**
- **Step 3: For each day, define and calculate the TEC perturbation as**

GIM TEC Metric

$$dTEC_{GIM}(UT, lon, lat) = \frac{TEC_{GIM}(UT, lon, lat) - TEC_{GIM,quiet}(UT, lon, lat)}{\sigma_{TEC,GIM,quiet}(UT, lon, lat)}$$

GITM TEC Metric

$$dTEC_{GITM}(UT, lon, lat) = \frac{TEC_{GITM}(UT, lon, lat) - TEC_{GITM,quiet}(UT, lon, lat)}{\sigma_{TEC,GIM,quiet}(UT, lon, lat)} * Scale(UT)$$

where $$Scale(UT) = \frac{median(TEC_{GIM,quiet}(UT, *, *))}{median(TEC_{GITM,quiet}(UT, *, *))}$$

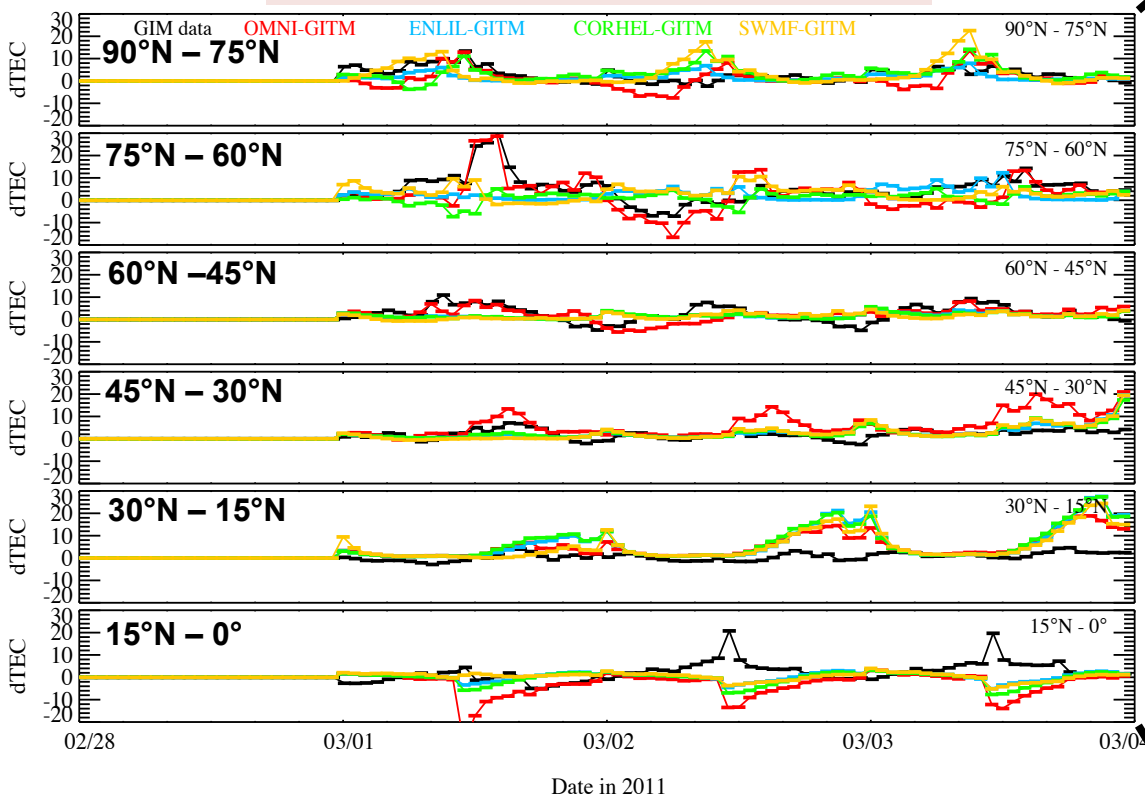
- **The quiet day is selected from the days before each storm event with daily Ap < 6**
- **Final output: hourly *dTEC* for every 30° x 15° grid box**
- **May require modification for CMEs (superstorms)**

Initial forecasts will be for integrated density between 100-600 km

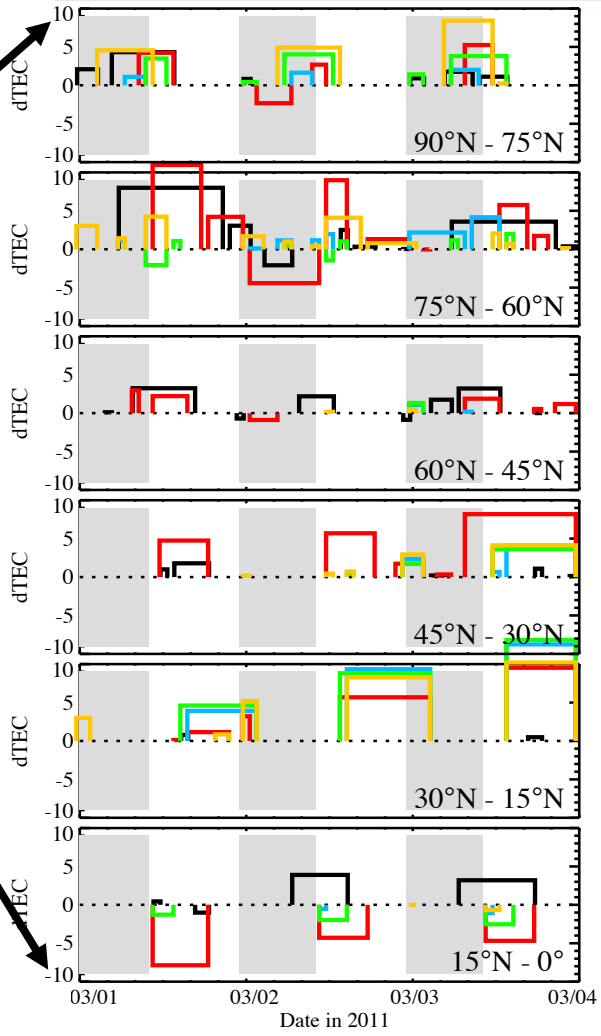
Forecast Variables Example

OMNI-GITM
ENLIL-GITM
CORHEL-GITM
SWMF-GITM

TEC Metric for the **Feb 2011** Event
Longitude **90°E - 120°E**



Average Metric for |dTEC| > 4
90°E - 120°E

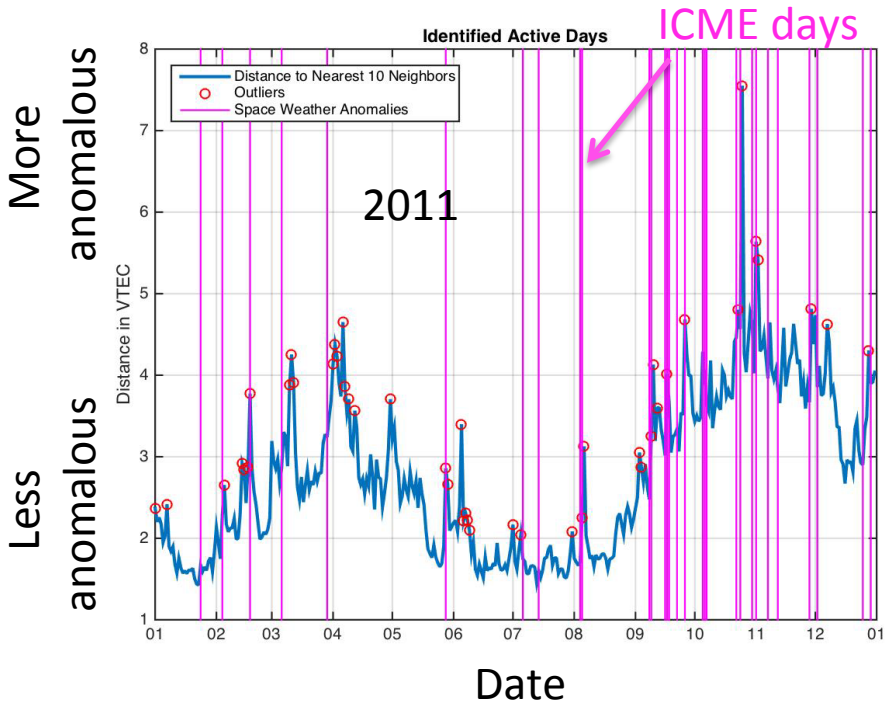


Average Metric: indicates for how long and by how much |dTEC| exceeds a certain level.

1800LT - 0600LT

Objective Analysis of "Ionospheric Anomalies"

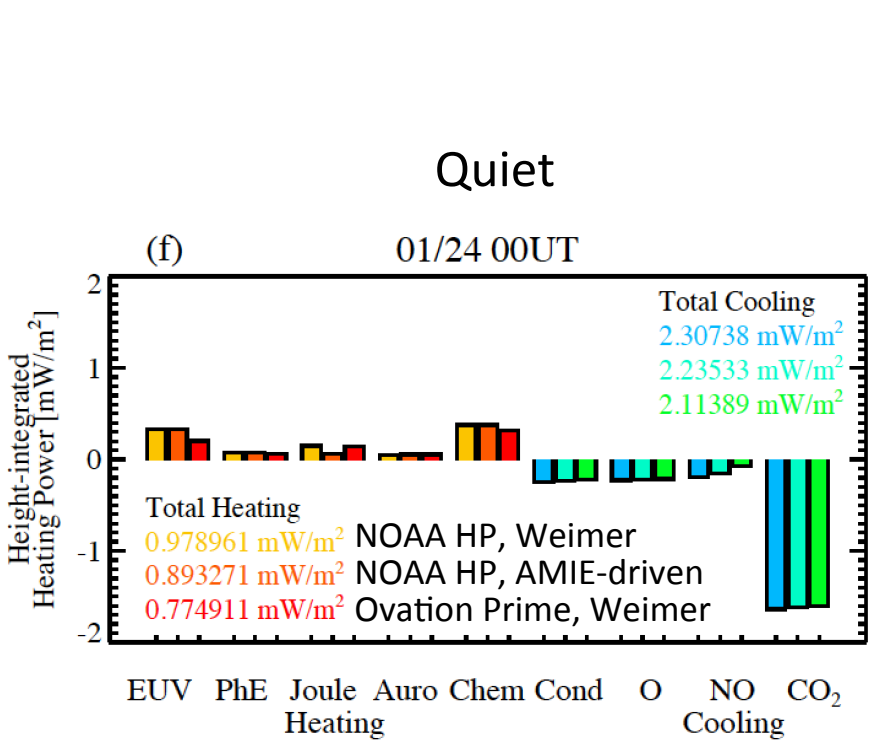
- **Cluster analysis of TEC maps identifies anomalies independently of geomagnetic conditions**
- **Bounds what can be achieved by solar wind driven forecasting**

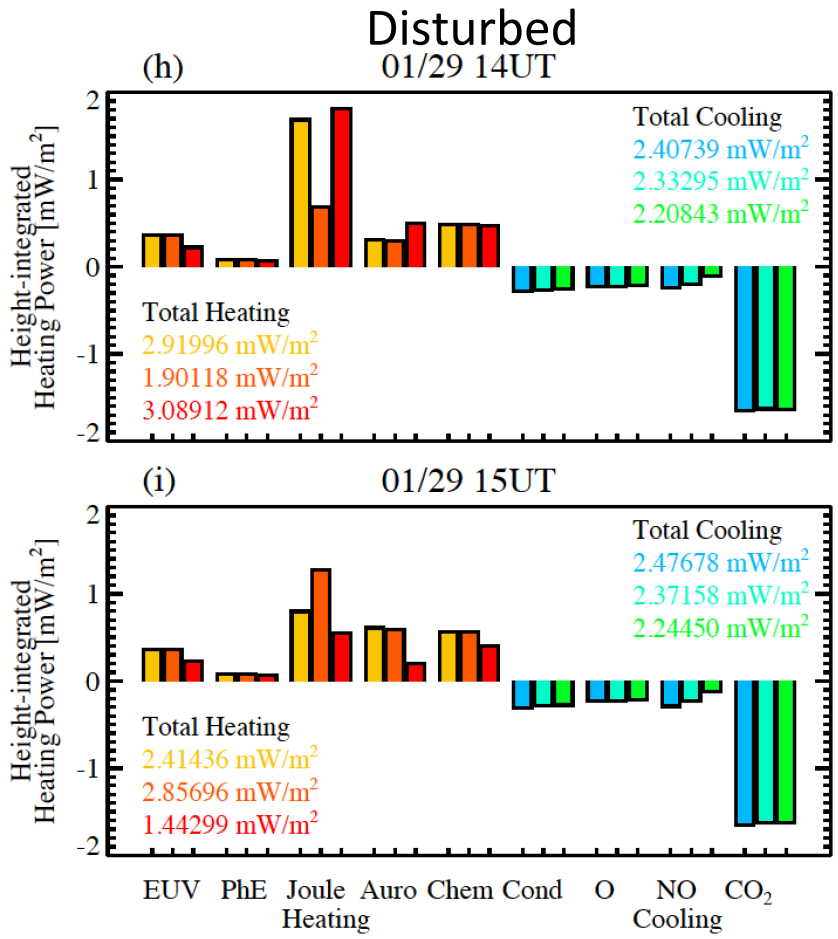


Wang, C., I. G. Rosen, B. T. Tsurutani, O. P. Verkhoglyadova, X. Meng, and A. J. Mannucci (2016), Statistical characterization of ionosphere anomalies and their relationship to space weather events, *J. Space Weather Space Clim.*, *6*, A5–16, doi:10.1051/swsc/2015046.

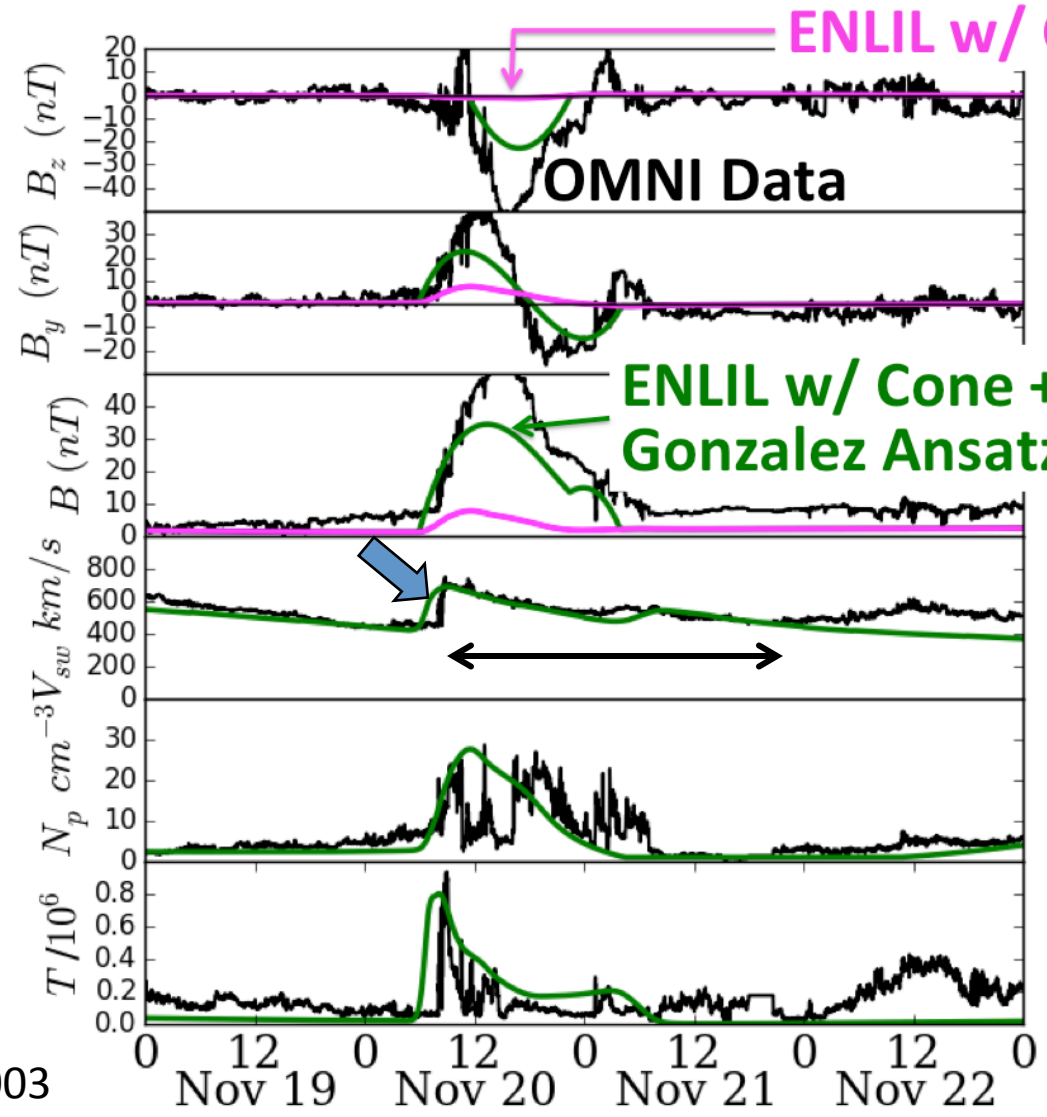
Energy Analysis

- **Energy input (Joule heating and auroral) is a potential major uncertainty driving T-I models**



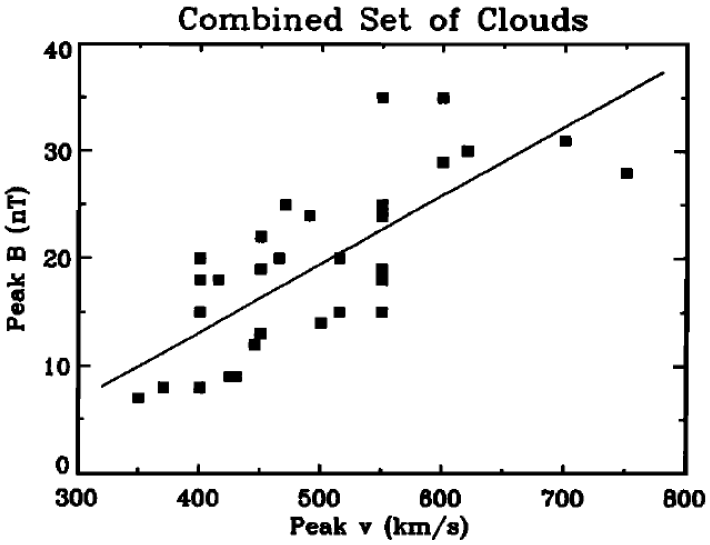


Semi-Empirical CME Driving



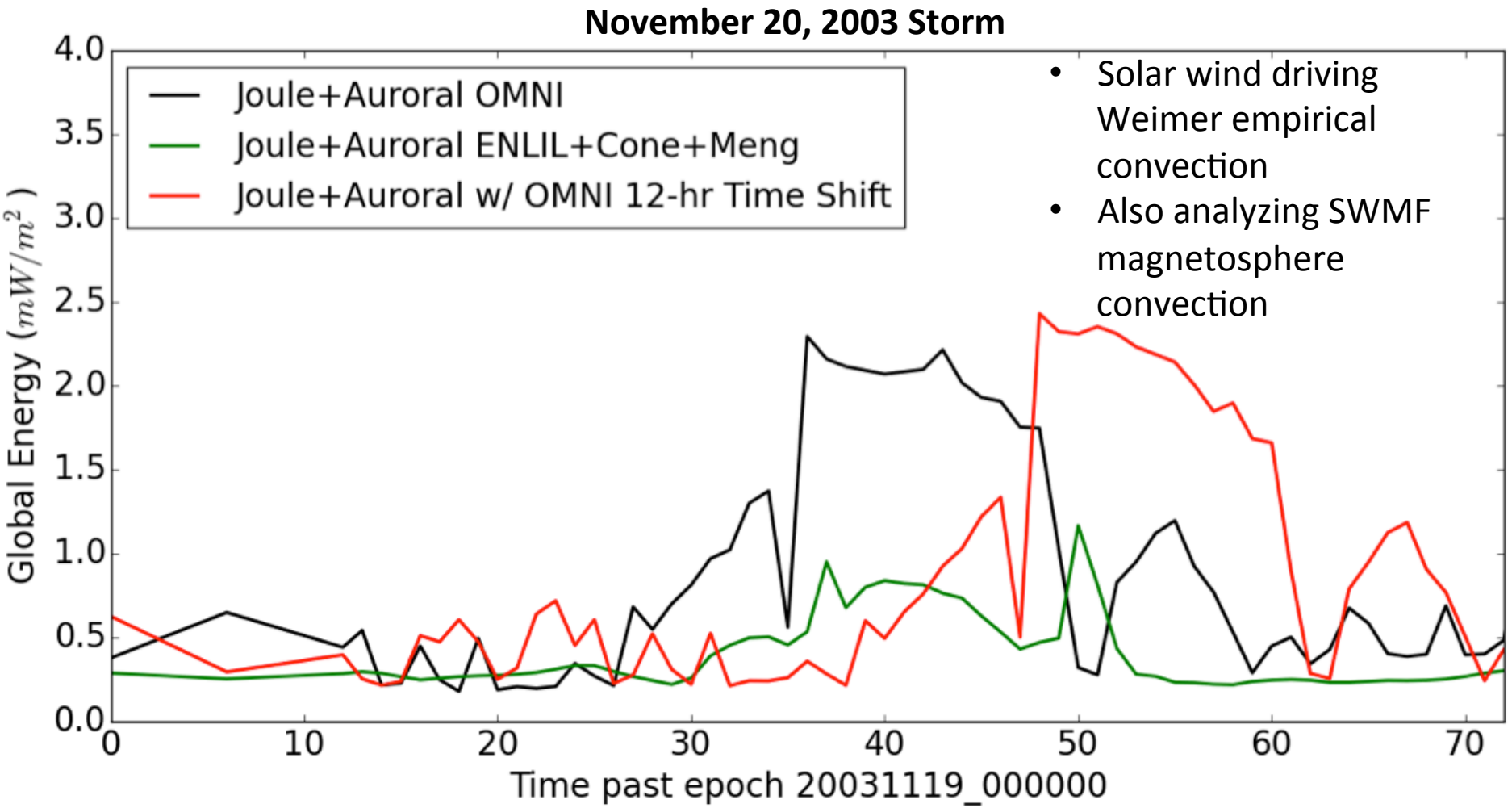
2003

- CONE hydrodynamics provides time of arrival
- Ansatz provides B field components based on velocity profile and Gonzalez et al., 1998



Gonzalez, W. D., et al. (1998), Magnetic cloud field intensities and solar wind velocities, Geophysical Research Letters, 25(7), 963–966, doi: 10.1029/98GL00703.

Energy Input to T-I



- Solar wind driving Weimer empirical convection
- Also analyzing SWMF magnetosphere convection

Energy analysis paper:

Verkhoglyadova et al. (2016) Estimation of Energy Budget of Ionosphere-Thermosphere System During Two CIR-HSS Events: Observations and Modeling, J. Space Weather Space Climate, under review, Topical Issue "Scientific Challenges in Thermosphere-Ionosphere Forecasting"

CCMC Implementation

- **Establish baseline modeling chain**
  - **Path towards real-time implementation**
  - **Variants to baseline could be implemented to produce multiple forecasts per event**
- **Historical forecast runs**
  - **EEGGL+AWSOM, Ansatz+ENLIL and OMNI (data) for CMEs**
  - **ENLIL, CORHEL, SWMF and OMNI (data) for HSS**
- **Community accessible TEC forecast variables and assessment data**
- **Updated as new events occur**

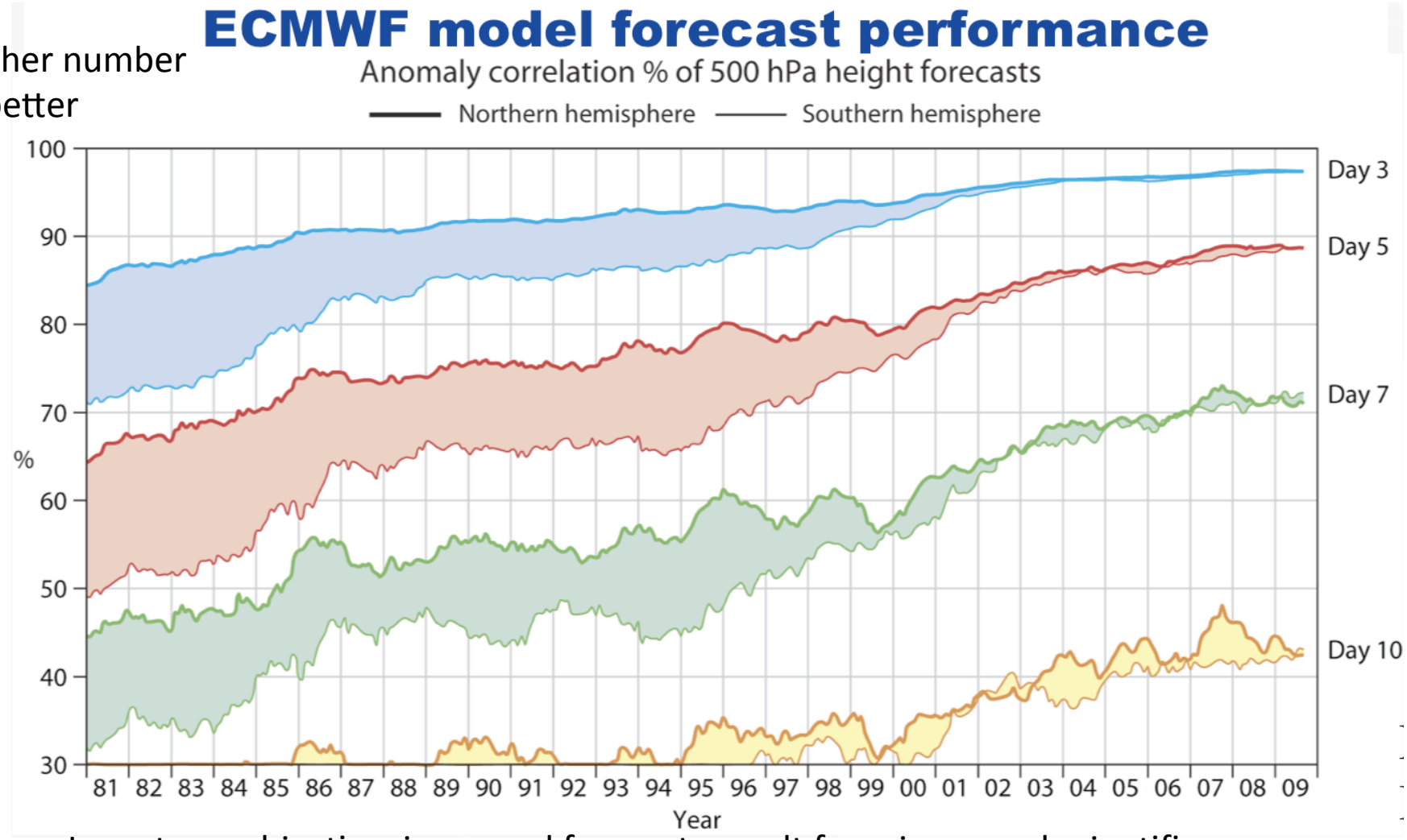
We will deliver forecast variables and related algorithms to facilitate such a capability at CCMC

Acknowledgement: CCMC provided solar wind model runs (ENLIL, CORHEL, SWMF, ENLIL+Cone) and TIEGCM runs

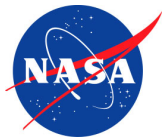
See http://ccmc.gsfc.nasa.gov/community/LWS/lws_medrangestorms.php

Weather Forecasting

Higher number is better



Long-term objective: improved forecasts result from improved scientific understanding and new observations



BACKUP

Data-Driven Methods