LWS Heliophysics Science
Technical Interchange Meeting
May 30-June 2 2017

Medium Range Thermosphere-Ionosphere Storm Forecasts

Overview of Team Successes & Vision of Future Directions

Anthony Mannucci, Xing Meng, Olga Verkhoglyadova, Bruce Tsurutani, Xiaoqing Pi, Ryan McGranaghan (Jack Eddy Fellow), JPL/Caltech
Chunming Wang and Gary Rosen, University of Southern California
Surja Sharma, Erin Lynch, Eugenia Kalnay, Kayo Ide, U Maryland
Chip Manchester, Bart van der Holst, U Michigan [via Antiochos effort]

Active collaborations with:
CCMC/Goddard Space Flight Center – ensemble solar wind model runs
Yue Deng, U Texas at Arlington – guest editor, special issue SWSC, and GITM
Schunk/Gardner & MEPS team – data assimilation/validation using MEPS
Marty Mlynczak and Linda Hunt – SABER data from NASA TIMED mission
Barbara Emery, Gang Lu, NCAR HAO – high latitude validation data, AMIE runs
Cheryl Huang – AFRL
Aaron Ridley, U Michigan, GITM model

Collaborators:
Angelos Vourlidas, Peter MacNeice, William Bristow, Dave Hysell, William Lotko

Government sponsorship acknowledged: NASA/NSF Partnership for Collaborative Space Weather Modeling

Outline

- **Team successes**
- **Deliverable status (Chunming Wang)**
  - **Space Weather Forecast Testbed (SWFT)**
- **Vision of future directions**

A medium-range forecast is a forecast of about 3 days lead time

IT = Ionosphere-Thermosphere

Summary of Successes

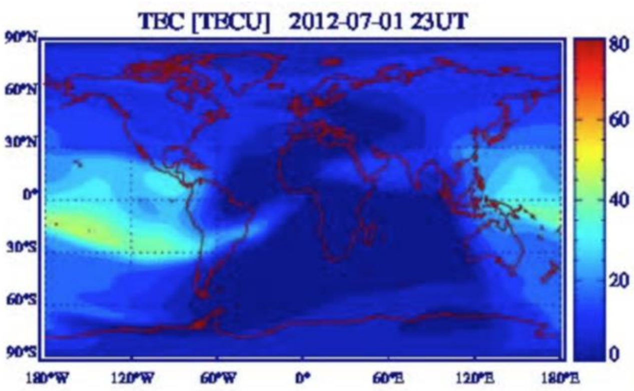
We view our effort as the beginning of a journey of forecasts that improve as knowledge is gained

- **Metrics that relate back to physical phenomena – *understanding* forecast errors**
- **Focus on energy flow and upstream coupling**
- **Broad definition of "space weather" that admits coupling above *and* below**
- **Focus on key solar driving and path towards improvement**
- **Fundamental discovery**
- **Community interaction**
  - **JPL TIM in 2014, AGU Sessions, CEDAR Sessions, SWSC and JGR Special Issues**

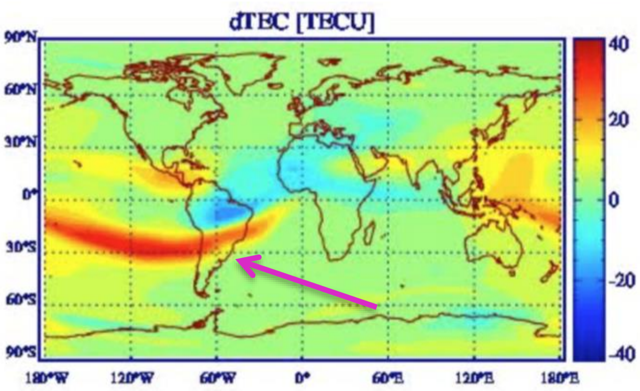
Understanding the Forecast

Example: Forecasting global ionospheric total electron content (TEC) – one of the simplest ionospheric quantities to forecast.

TEC Map From a GITM Run

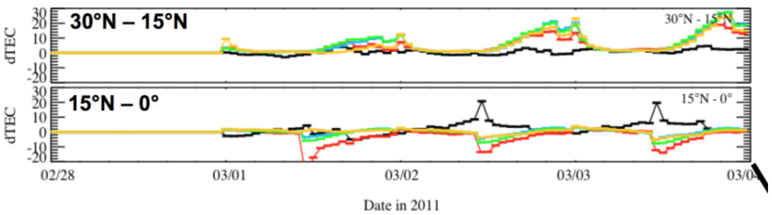


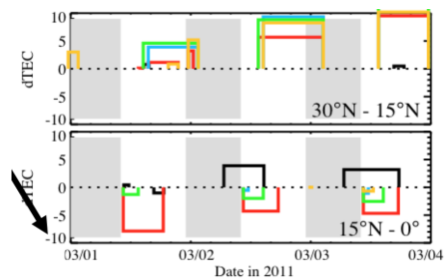
TEC "Difference" Map vs Quiet



Scientific understanding of ionospheric space weather tends to focus on the factors leading to TEC **increases** and **decreases** – latitude and local time dependences

Time series of regional TEC differences





Durations and locations of regional increases and decreases

Conclusion: Quality and utility of space weather forecasts depends on exactly what quantity is forecast – a critical research area

Energy Sources During Storms

A forecast cannot be successful if the energy input is mis-estimated during storms. This is a challenge even when the solar wind driver is perfectly known.

Finding for high-speed stream storms: Joule heating dominates over auroral heating, and is reasonably represented in a "forecastable" model run, but cooling is relatively worse.

Finding for CME-type storms: Joule heating is underestimated, but auroral heating is relatively well represented (again, "forecastable" mode). Cooling is relatively worse. There are fundamental differences in the literature on how Joule heating is defined.

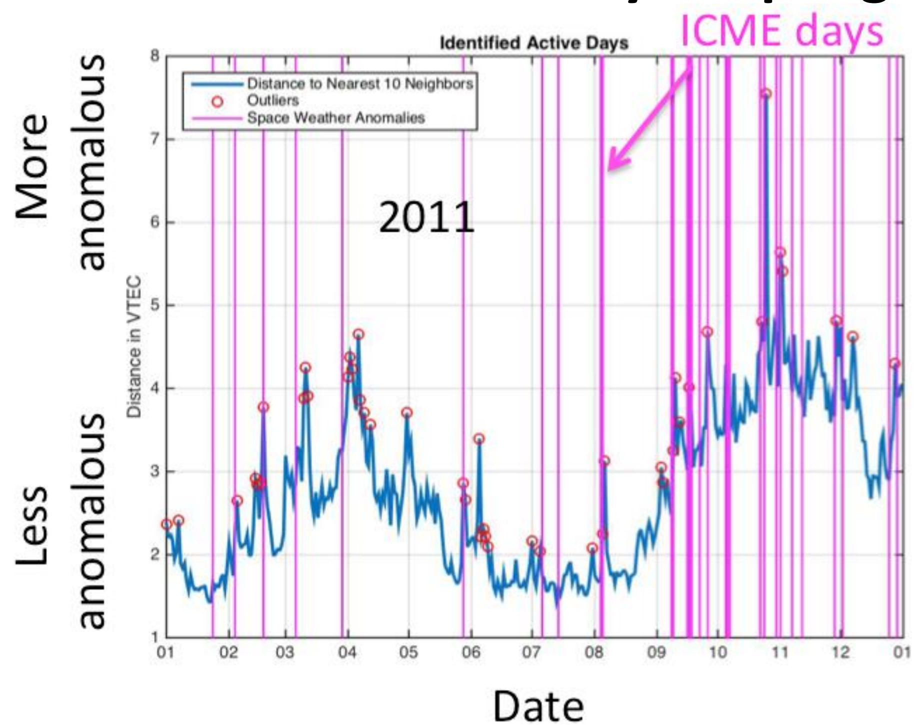
New observational methods: We developed new ways of using SABER measurements (NO emission) as a proxy for Joule heating and as a way to study energy input associated with increased E-region conductivity.

Conclusion: Representing cooling accurately is perhaps the next focus for models. We need additional observations and observational proxies. NASA's SABER instrument is valuable.

Can we Forecast a Global "Ionospheric Anomaly"?

Unsupervised learning techniques were used for the first time to characterize the relation between solar wind conditions and the global ionosphere condition – influenced by coupling from above and below

One TEC day is a vector of dimension 180x360x96



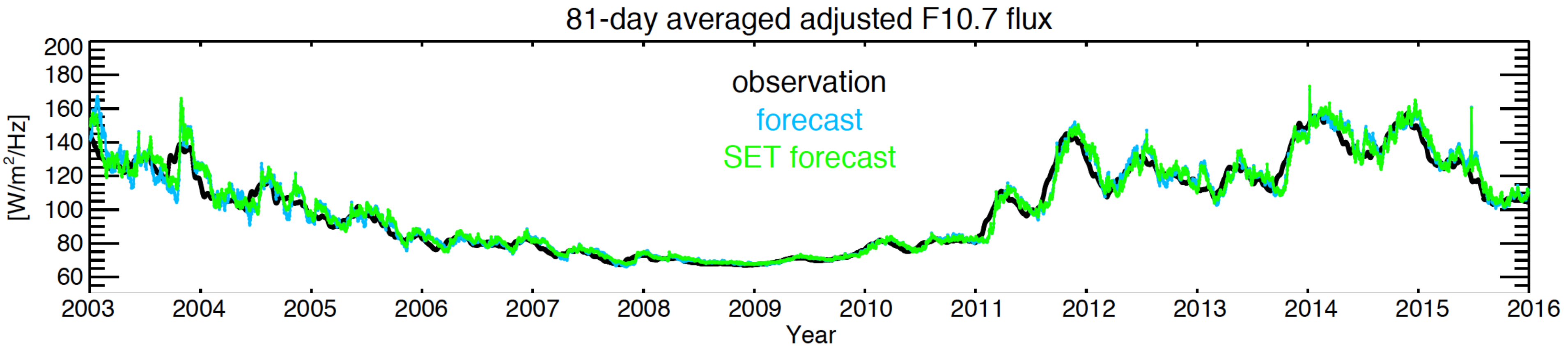
Wang, C., I. G. Rosen, B. T. Tsurutani, O. P. Verkhoglyadova, X. Meng, and A. J. Mannucci (2016), Statistical characterization of ionosphere anomalies and their relationship to space weather events, *J. Space Weather Space Clim.*, *6*, A5–16, doi:10.1051/swsc/2015046.

Conclusion: Machine learning methods can reveal new phenomena and new physics that needs to be understood – and that challenge first-principle based forecasts, leading to their improvement

Preparing for Solar Wind Forecasts

We developed “forecastable mode” IT model runs driven only by solar wind forecasts and forecasts of the solar EUV proxy

- Runs that use fully “forecastable” inputs submitted to CCMC via custom interface. Each of three models requires somewhat different inputs.
- 20 events currently run for GITM, CTIPe and TIEGCM
- 10 more events ready to go, more planned
- Ready to accept forecasts from e.g. EEGGL and ADAPT



Conclusion: “Forecast mode” model runs should continue at CCMC, combined with solar wind forecast runs using EEGGL, ADAPT, etc. Model output should be incorporated into the testbed (next talk)

Fundamental Discovery

Bruce Tsurutani is our science lead

- **The occurrence of supersubstorms (substorms with intensities with SML or AL < -2500 nT) has been studied. It was a surprise to find that supersubstorms are often triggered by high density plasma parcels in the solar wind. It was found that supersubstorms occur during geomagnetic quiet and low intensity storms as well as super intense magnetic storms.**
- **Coherent magnetospheric plasma waves is a relatively new discovery. It has been shown that for wave-particle interactions the scattering rate is 3 orders of magnitude faster than Kennel-Petschek (JGR 1966) rate (which assumes incoherent waves). This high rate of scattering has been confirmed by several theoretical studies and is an explanation for ionospheric microbursts.**
- **It has been shown that heliospheric plasma sheet impingements onto the magnetosphere cause the dropout of relativistic magnetospheric electrons.**
- **A review of interplanetary turbulence in high speed solar wind streams has been written and submitted to a journal. The paper indicates that interplanetary Alfven waves may dissipate by kinetic processes relatively fast. A theoretical idea on the replacement of this energy by an in situ instability has been proposed.**
- **The interplanetary causes, solar cycle and seasonal dependences of HILDCAAs were determined for the first time. It was found that HILDCAAs statistically occur in the declining phase of the solar cycle and are almost all (93%) associated with high speed solar wind streams emanating from coronal holes.**
- **In a series of papers, it was found that for every HILDCAA event occurring during SC23, acceleration of E > 0.6, > 2.0 and >4.0 MeV magnetospheric "killer" electrons occurred.**

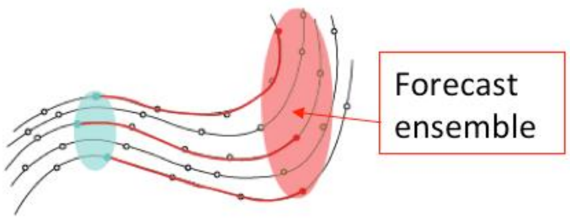
HILDCAA = High Intensity Long-Duration Continuous Auroral Activity

Data-Driven Modeling

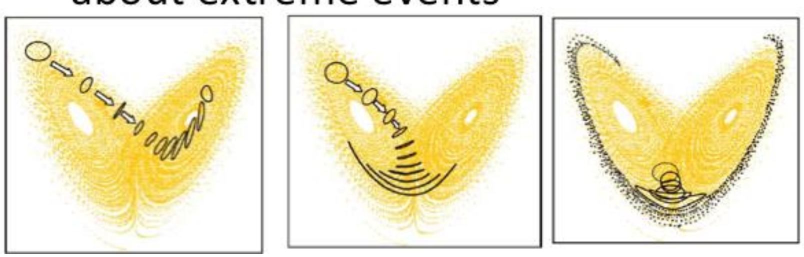
U Maryland team: Erin Lynch, Surja Sharma, Eugenia Kalnay and Kayo Ide

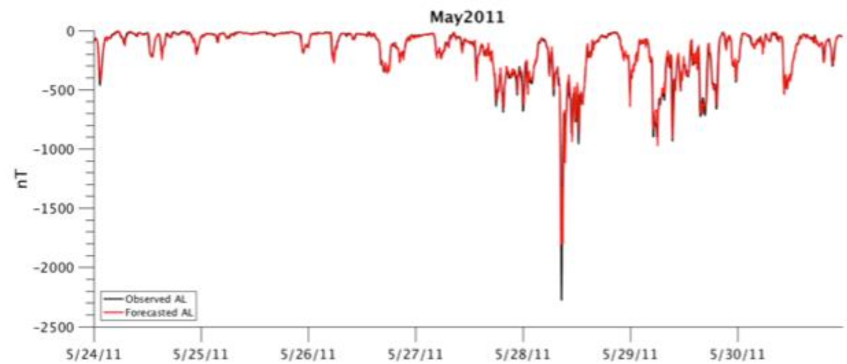
Ensemble forecasts from data-derived models

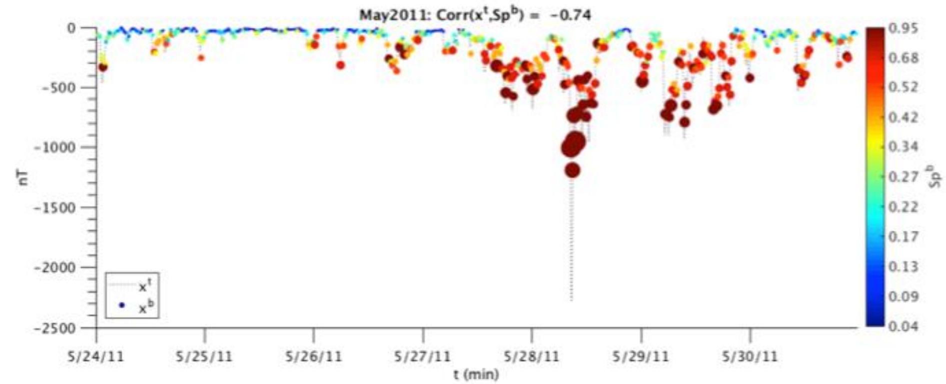
- Data driven models without governing equations
- Forecasts using Ensemble Transform Kalman Filter (ETKF)



- Ensemble spread gives information about extreme events





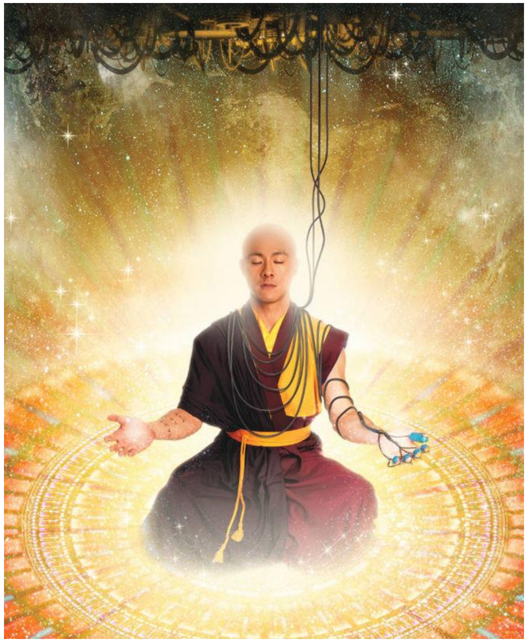


Thanks to the Team!

- **A truly multi-disciplinary team with expertise across ionosphere, magnetosphere, heliosphere and solar wind, solar corona (UM), terrestrial weather, dynamical systems theory, plasma physics, shock physics, wave-particle interactions, data analysis, modeling, applied mathematics**
- **Who put up with *many* telecons and many, many discussions (always with interesting perspectives)**
- **And who showed great interest, made significant intellectual contributions, and were productive**
- **Xing Meng was hired by JPL in 2016**
- **Erin Lynch (UMD) has been actively involved with space weather summer schools**

37 publications as of the mid-term review (April 2016)

VISION OF FUTURE DIRECTIONS



Google "zen of space weather"

The Nature of a Forecast

"Understanding to the point of prediction"

What is the relationship between understanding and prediction?

Physical law is often expressed as a set of mathematical relationships between rates of change

A forecast requires a unique trajectory be calculated ("equations are solved")

Hence the need for observations relevant to the forecast

What is the Role of LWS?

Should LWS fund uncertainty quantification (UQ)?

Or is UQ strictly the purview of the operational agencies?

Uncertainty quantification is not *per se* related to scientific discovery

Or is it?

Orientation

Modeling tends to have a success orientation: we want our models to reproduce actual observations

"Models are doomed to succeed" – Paul Kintner

What about a success orientation applied to space weather forecasts?

Future Directions

Ack. Ryan McGranaghan

"Understanding to the point of prediction" requires fundamental understanding, modeling *and* data-based resources to determine a unique system trajectory consistent with physical law

Fusing models and observations requires a success orientation – do what works

The LWS program should accept a broad spectrum of what is required to make a successful forecast

Include extreme events in the research program