Transitioning Models from Research to Operations at NOAA's Space Weather Prediction Center

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Center for Space Environment Modeling

Outline:

- **National Needs**
- **Observations**
- **Models**
- **Research**
- **Research to Operations**

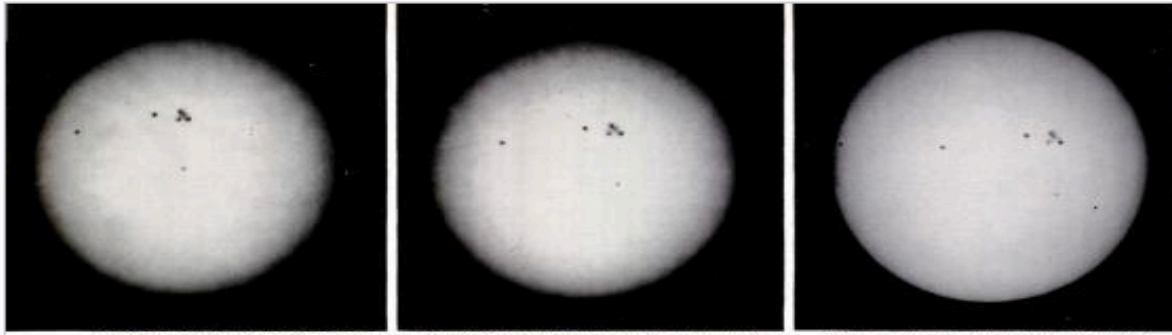
2016 SHIELDS Workshop
April 8, 2016
Santa Fe, NM

Acknowledgments: Berger, Biesecker, Evans, Murtagh, Onsager, Steenburgh, Viereck

Space Weather: Societal and Economic Impact

- March 25, 1940
- Large Geomagnetic Storm
- Western Union set up emergency circuits to re-route messages as regular lines went dead.
- Telegraph lines went haywire.
- Geospace models in operations will help to protect similar, but modern, vital services

Life Magazine, vol 8, no 15, page 38, April 8, 1940.



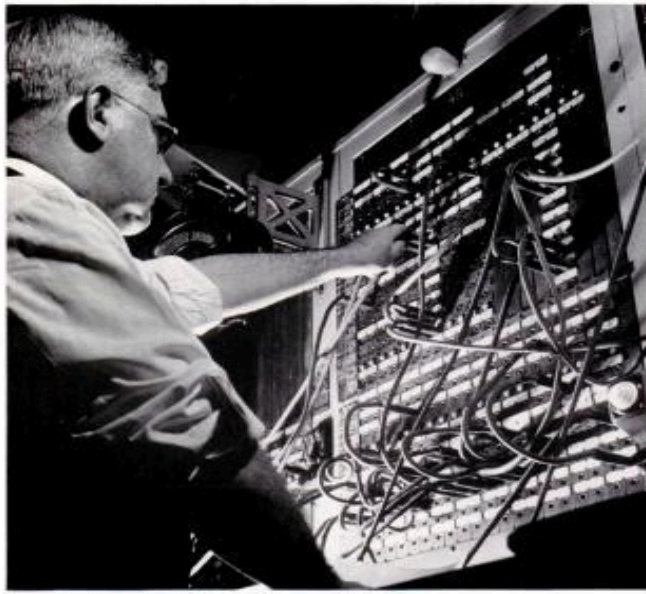
SUNSPOTS GREW TO THIS SIZE BY MARCH 25 — MARCH 26. SPOTS MOVE SLOWLY ACROSS THE SUN'S FACE — MARCH 27. BIGGEST GROUP IS 12,000 MILES ACROSS

SPOTS ON THE FACE OF THE SUN MESS UP EARTH'S COMMUNICATIONS

Last week the earth's magnetic field had a bad attack of spring fever. Well-behaved landlines of A. T. and T. turned taciturn. The ionosphere, the super-stratospheric layer of the earth's atmosphere, which radio companies use for a cushion to bounce their signals like billiard balls across the ocean, suddenly went porous. Wirephotos showed black streaks and teletype machines went to work on their own to click off analphabetic rhapsodies like the one below.

Moving across the face of the sun could be seen the villains of the piece—a series of sunspots, volcanic whirlwinds of gas which so upset the earth's magnetic field that forces as high as 700 volts were induced in power and communications lines. Counting up at the end of the week, the world found a debit that no one cared to estimate in disrupted communications and fused wires. On the credit side were several spectacular displays of northern lights.

MAP OF U. S. AREAS WHERE "EARTH CURRENTS" WERE STRONGEST



WESTERN UNION SET UP EMERGENCY CIRCUITS TO RE-ROUTE MESSAGES AS REGULAR LINES WENT DEAD

AT THE HEIGHT OF THE MAGNETIC STORM, TELETYPE AND OTHER AUTOMATIC TELEGRAPH MACHINES WENT HAYWIRE, PRINTED OUT MESSAGES LIKE THIS ON THEIR OWN HOOK

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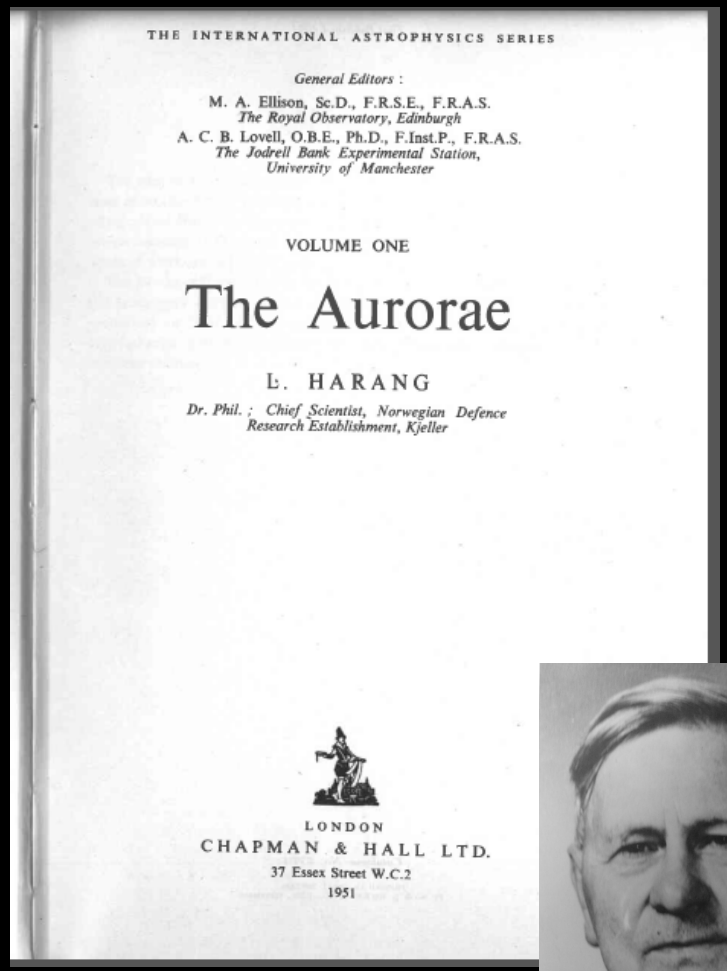
Space Weather:
Societal and Economic Impact

"On the lines to Syltefjord and Makkaur all fuses (4 amp.) burnt through. Sparks and permanent arcs were formed in the coupling racks and watch had to be kept during the night to prevent fire from breaking out"

Log of the Vardø Station
Norwegian Telegraph Service
24 March, 1940


THE INTERNATIONAL ASTROPHYSICS SERIES

General Editors :

M. A. Ellison, Sc.D., F.R.S.E., F.R.A.S.
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The Jodrell Bank Experimental Station, University of Manchester

VOLUME ONE

The Aurorae

L. HARANG

Dr. Phil. ; Chief Scientist, Norwegian Defence Research Establishment, Kjeller

LONDON
CHAPMAN & HALL LTD.
37 Essex Street W.C.2
1951

The Aurorae, Leiv Harang, 1951.

Brought to my attention by D. Evans

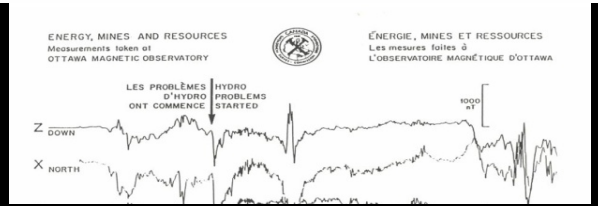
Significant grid problems have occurred…

HYDRO-QUEBEC PRESS RELEASE

Direction Relations Publiques
HYDRO-QUEBEC
MONTREAL, CANADA

MARCH 13 BLACKOUT CAUSED BY AN EXCEPTIONALLY STRONG MAGNETIC STORM

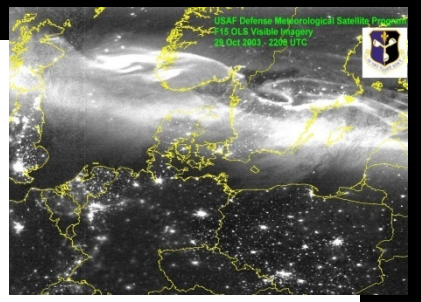
Montreal, March 15, 1989 - Hydro-Quebec confirms that the March 13 blackout was caused by the strongest magnetic storm ever recorded since the 735-kv power system was commissioned. At 2:45 AM the storm, which resulted from a solar flare, tripped five lines from James Bay and caused a generation loss of 9,450 MW. With a load of some 21,350 MW at that moment, the system was unable to withstand this sudden loss and collapsed within seconds, thereby causing the further loss of generation from Churchill Falls and Manio-Outardes.



Information Notice No. 90-42:
FAILURE OF ELECTRICAL POWER EQUIPMENT DUE TO SOLAR MAGNETIC DISTURBANCES

Specific events occurred at the Three Mile Island Unit 1, Hope Creek Unit 1, and Salem Unit 1 nuclear power plants. …inspection of the generator step-up transformer… severe overheating, melted low-voltage service connections in phases A and C, and insulation discoloration in phase B. On September 19, at Salem Unit 2 nuclear power plant, a second solar storm damaged the generator step-up transformer. *Sep 1990*

Department of Homeland Security
Information Analysis and Infrastructure Protection
Daily Open Source Infrastructure Report for 03 November 2003



Energy Sector

Current Electricity Sector Threat Alert Levels: Physical: Elevated, Cyber: Elevated
Scale: LOW, GUARDED, ELEVATED, HIGH, SEVERE [Source: ISAC for the Electricity Sector (ES-ISAC) – http://esisac.com]

October 31 ***- Sun storm causes problems for Swedish power system. The solar storm has caused technical glitches in Sweden's power system in the past few days and may be to blame for a blackout that affected 50,000 people on Thursday, October 30****.*

Transformer exit-lead overheating

Strategic National Risk Assessment

Executed in support of Presidential Policy Directive 8 (PPD-8): Identifies incidents that pose greatest threat to the Nation's security

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million

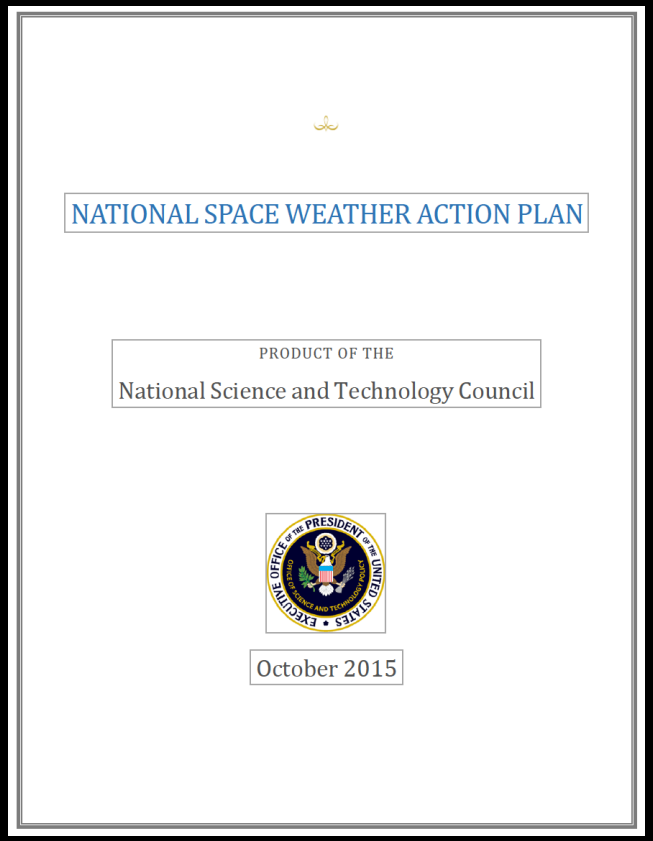
Obama Does Space Weather

Press Conference on Cyber Security

13 Jan 2015

National Space Weather Strategy and Action Plan
(Released October 2015)
Identifies Needs for R20 and O2R

- Ensuring that this Nation is prepared to respond to and recover from severe space weather storms
- Evaluate potential impact space weather may have on key infrastructures and technologies including the electric power grid, GPS applications, aviation and satellite operations
- Goal 5.6 Improve Effectiveness and Timeliness of the Process that Transitions Research to Operations


NATIONAL SPACE WEATHER ACTION PLAN

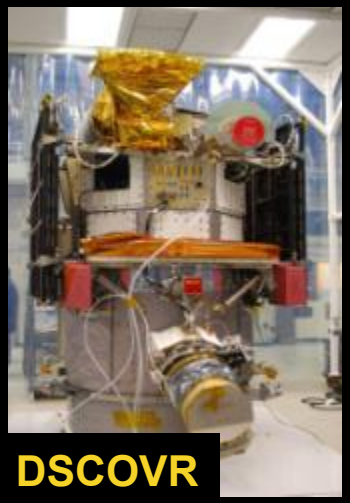
PRODUCT OF THE
National Science and Technology Council

October 2015

NOAA Satellite Programs (and Partnerships) in Support of Space Weather Services

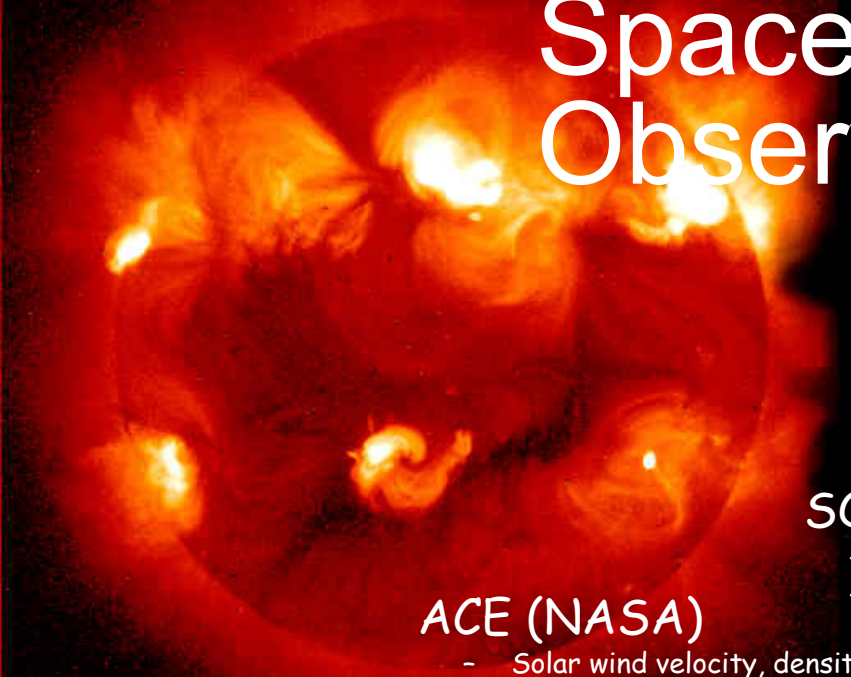
(foundations in the research community)

- **GOES-R** (planned Oct 2016 launch): Solar imaging, in-situ plasma, energetic particles, and magnetic field
- **Deep Space Climate Observatory (DSCOVR)** (launch Jan 2015): Solar wind plasma and magnetic field – Warnings of imminent solar storms (NOAA, NASA, AF)
- **Future L1:** Warnings of imminent solar storms; 2014 RFI to update commercial data buy prices; studies APL, GSFC, AMES/Langley; planned ~2022 with CCOR
- **Compact Coronagraph (CCOR):** Sensor development planning – Long lead-time forecasts of solar storms (NRL studies)
- **COSMIC-2** (planned 2016 launch): GNSS radio occultation for space weather and meteorology (Taiwan, AF, NOAA, NSF)



Data used for situational awareness and in models (input conditions, assimilation, validation)

Space Weather Observations



STEREO (Ahead)

Ground Sites
- –Magnetometers (USGS)
- –Thule Riometer and Neutron monitor (USAF)
- –SOON Sites (USAF)
- –RSTN (USAF)
- –Telescopes and Magnetographs
- –Ionosondes (AF, ISES, …)
- –GPS (NOAA CORS)

SOHO (NASA/ESA)
- Solar EUV Images
- Solar Corona (CMEs)

ACE (NASA)
- Solar wind velocity, density, energetic ions and electrons
- Magnetic field strength and direction

GOES (NOAA)
- Energetic Particles
- Magnetic Field
- Solar X-ray Flux
- Solar X-Ray Images
- Solar EUV Flux

COSMIC II (Taiwan/NOAA/DOD/NSF)
- Ionospheric Electron Density Profiles
- Ionospheric Scintillation

SOHO
ACE
DSCOVR
L1

GOES
SDO

POES
METOP
COSMIC II

DSCOVR (NOAA/NASA/DOD)
- Solar wind velocity and density
- Magnetic field strength and direction

SDO (NASA)
- Solar EUV Images
- Solar Magnetograms
- Solar EUV spectra

STEREO (NASA)
- CME Direction and Shape
- Solar wind velocity and density
- Magnetic field strength and direction

POES (NOAA) METOP (EUMETSAT)
High Energy Particles
Total Energy Deposition
Solar UV Flux

STEREO (Behind)

Red: Future Missions

Magnetosphere: A strongly Driven System

Solar Wind:

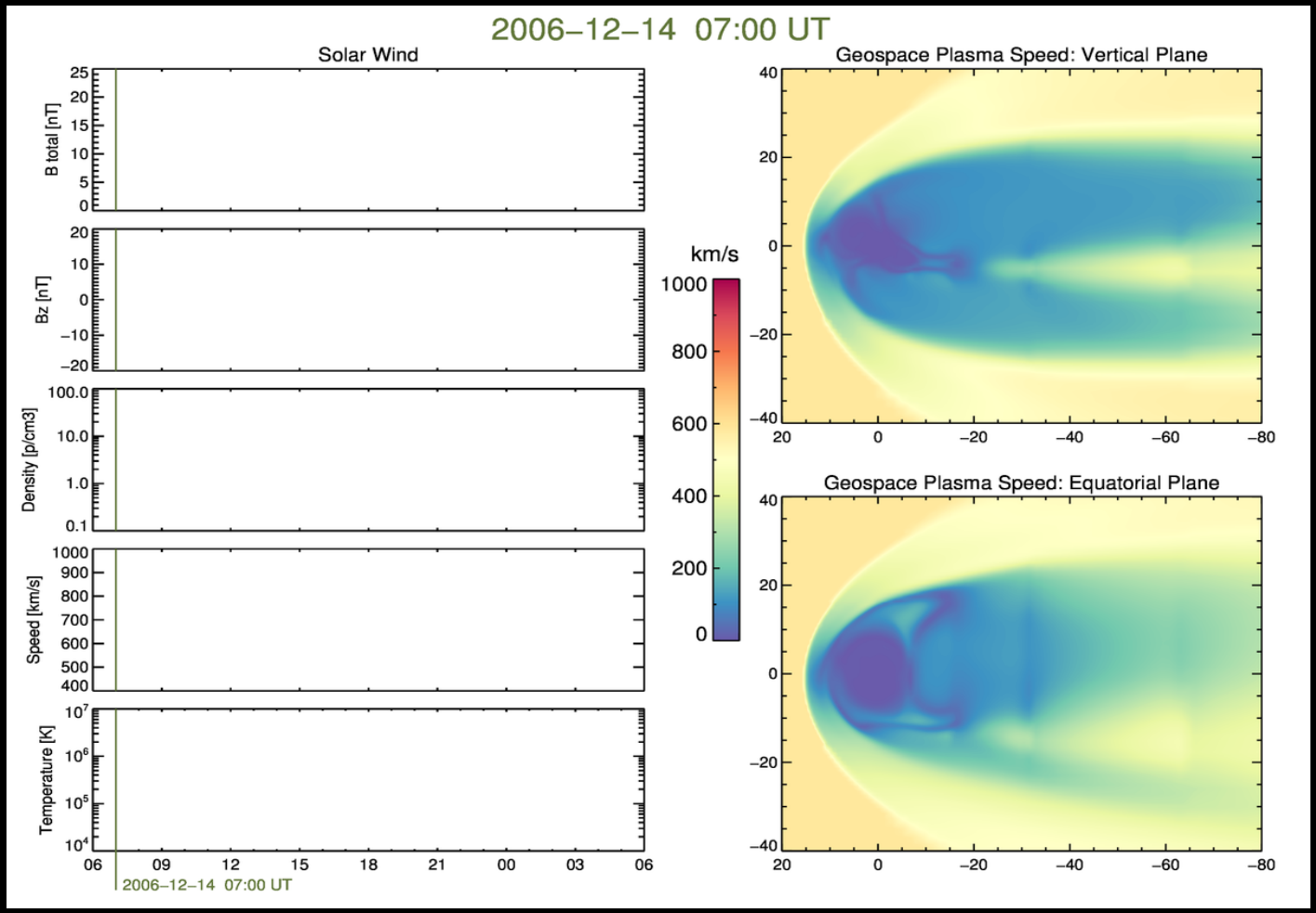
B Total

Bz

Density

Speed

Temperature



Michigan SWMF

Consequently, real-time or near-real time data are needed to capture the response without delay

There are times when Near-Real Time doesn't work

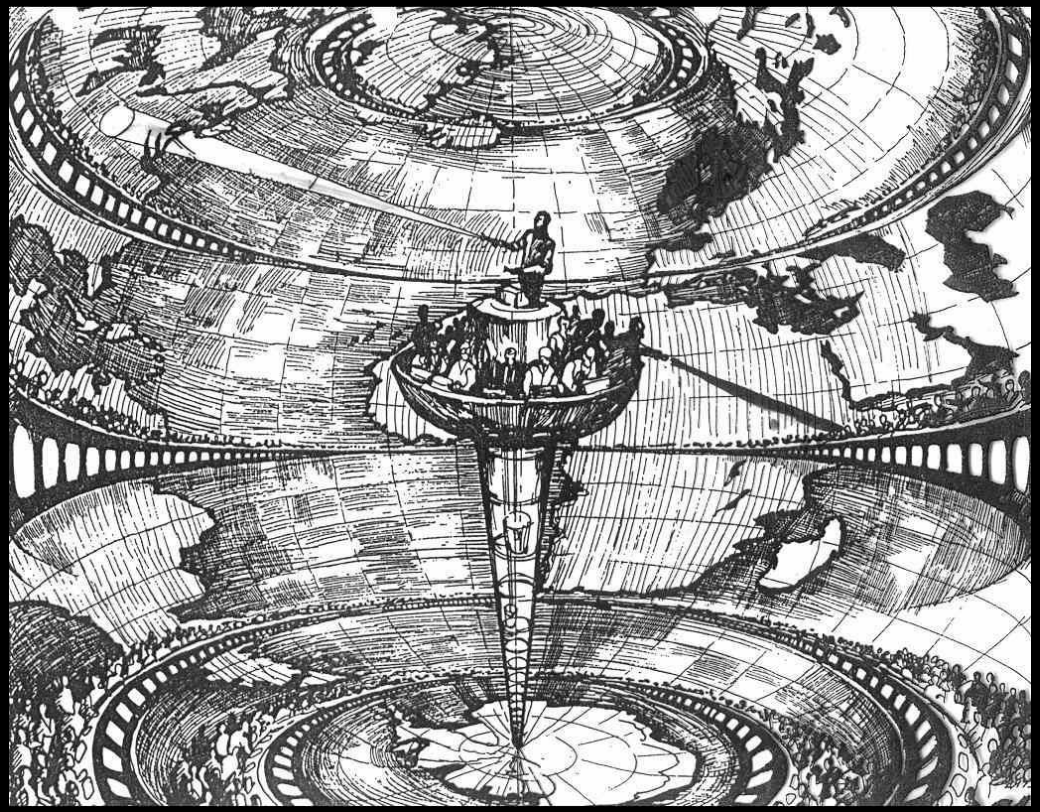
Speedometer reading delayed by 1 minute

Too late to take action!

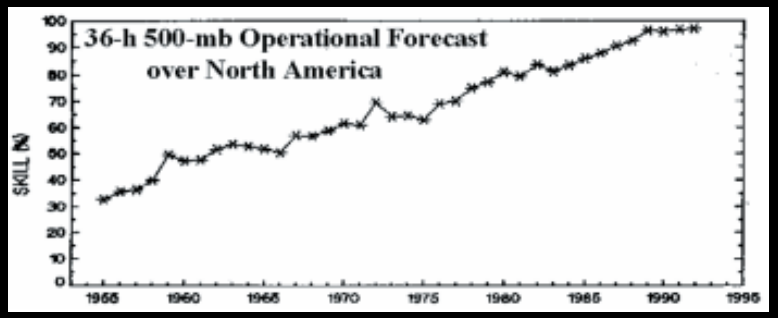
There are times when even Real-Time doesn't work, and we need Predictions

Weather Prediction By Numerical Process

L.F. Richardson (1922) Cambridge U. Press



Dagens Nyheter, Stockholm



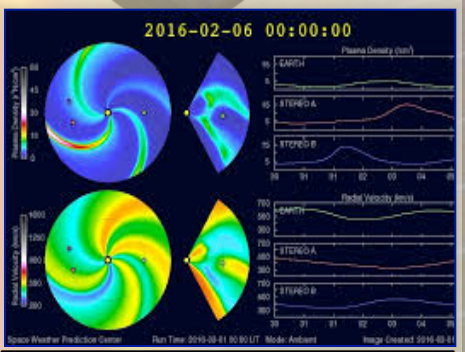
Stephen Conlin

- Forecast Center “fantasy”
- Solve problem of atmospheric flow, use cells with dynamic variables; a finite difference scheme
- Similarities with massively parallel processor (MPP)

Rob Steenburgh introduced me to this topic

SWPC Operational Model Suite

Tracking solar storms from "Sun to Mud"



GMU/AFRL WSA/Enlil

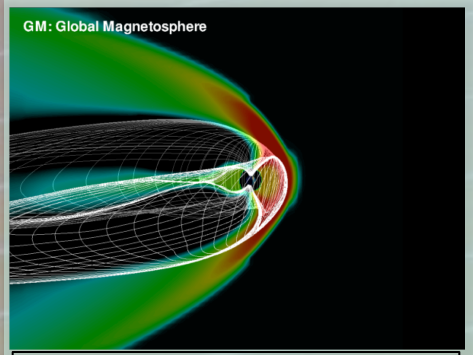
Inputs:

1. GONG solar magnetic field data
2. SOHO/LASCO coronagraph CME images from L1

Validation:

1. DSCOVR solar wind character at L1
2. GOES magnetometer shock arrival

Operational



U. Michigan Geospace

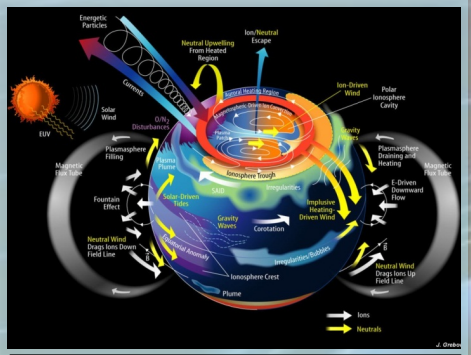
Inputs:

1. DSCOVR solar wind density, temp, speed, mag field at L1
2. Solar F10.7 radio flux measurements

Validation:

1. GOES vector magnetic field
2. USGS magnetometer network

Operational FY16



NOAA/CIRES WAM-IPE

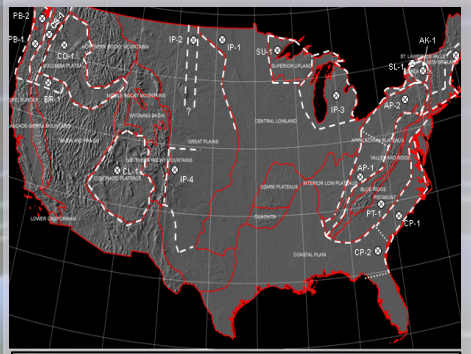
Inputs:

1. GFS Tropospheric weather model inputs
2. GOES Solar EUV flux
3. COSMIC-2 RO electron density
4. Geomagnetic storm data from Geospace

Validation:

1. GPS receiver network TEC measurements

Operational FY17-19



USGS/NOAA E-field

Inputs:

1. USGS lithospheric conductivity model
2. USGS magnetometer network

Validation:

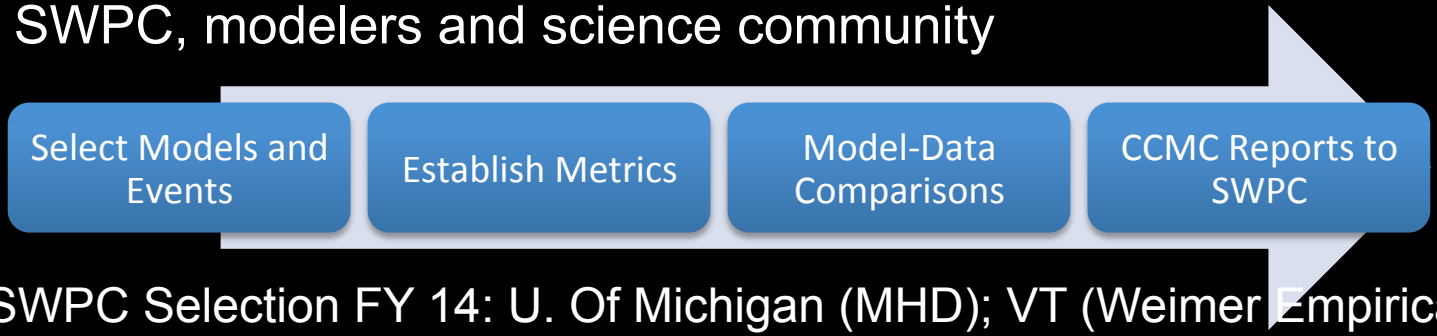
1. USGS geoelectric field measurements.

Operational FY16-17

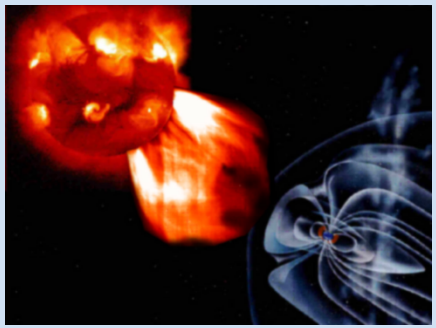
Note: all models developed with NASA and/or NSF funding at some level.

Geospace Models: Transition to Operations

- **Goal:** Evaluate Geospace models (MHD and empirical) to determine which model(s) are ready for transition to operations
- **Focus:** Regional K and dB/dt (important to electric utilities)
- **Partnership:** Evaluation at NASA/Goddard CCMC working with SWPC, modelers and science community



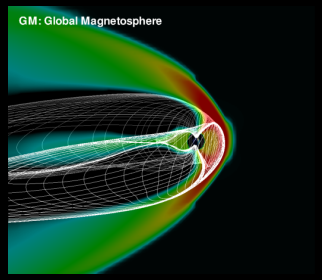
SWPC Selection FY 14: U. Of Michigan (MHD); VT (Weimer Empirical) based on CCMC reports, internal and external advice, and following considerations:

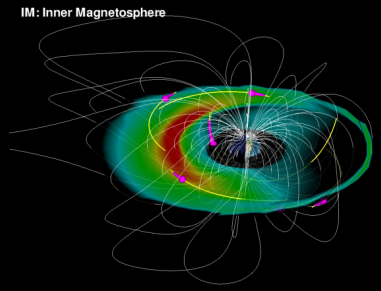


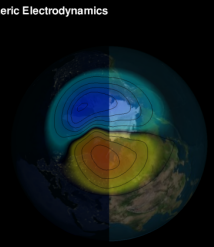
Solar Influences on Geospace Predicted with Geospace Models using Solar Wind Input

- Strategic Importance
- Operational Significance
- Implementation Readiness
- Cost to Operate, Maintain, and Improve

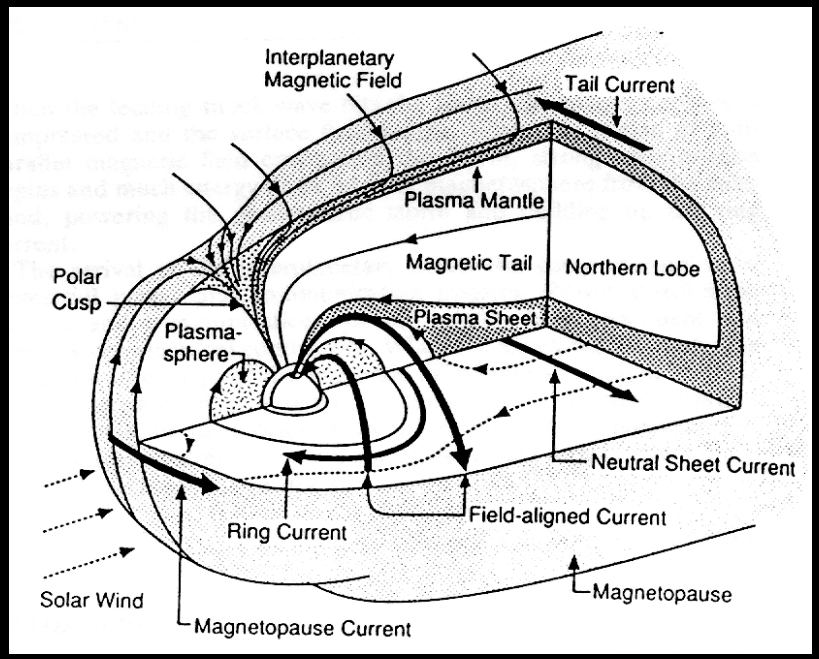
Michigan Geospace Model





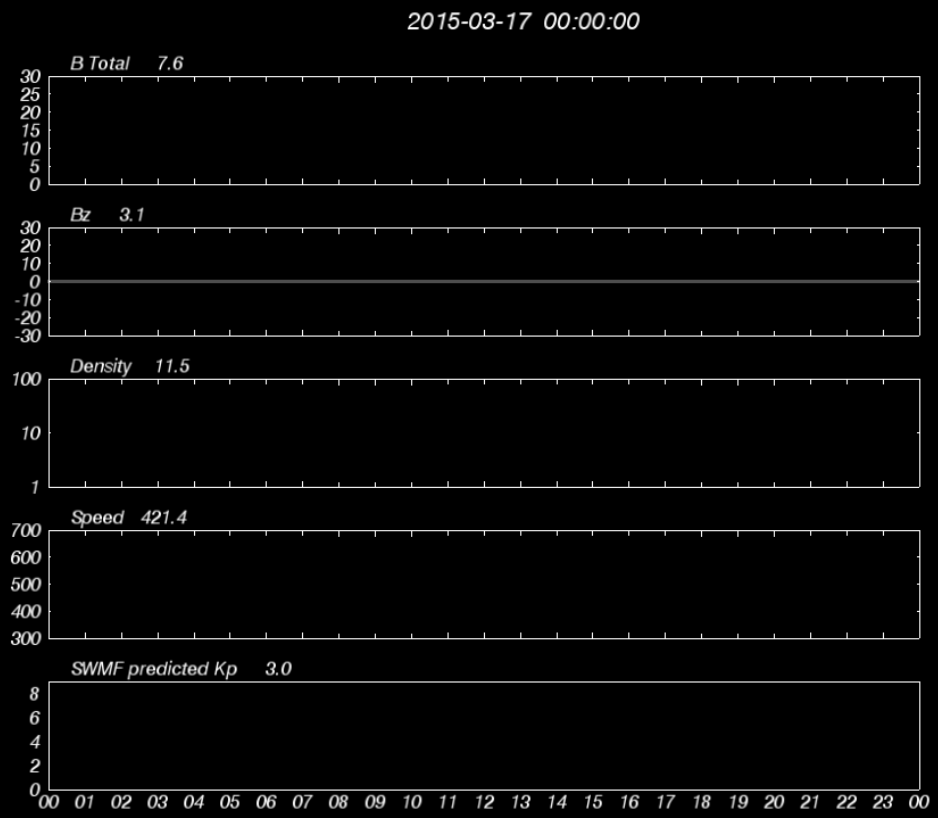


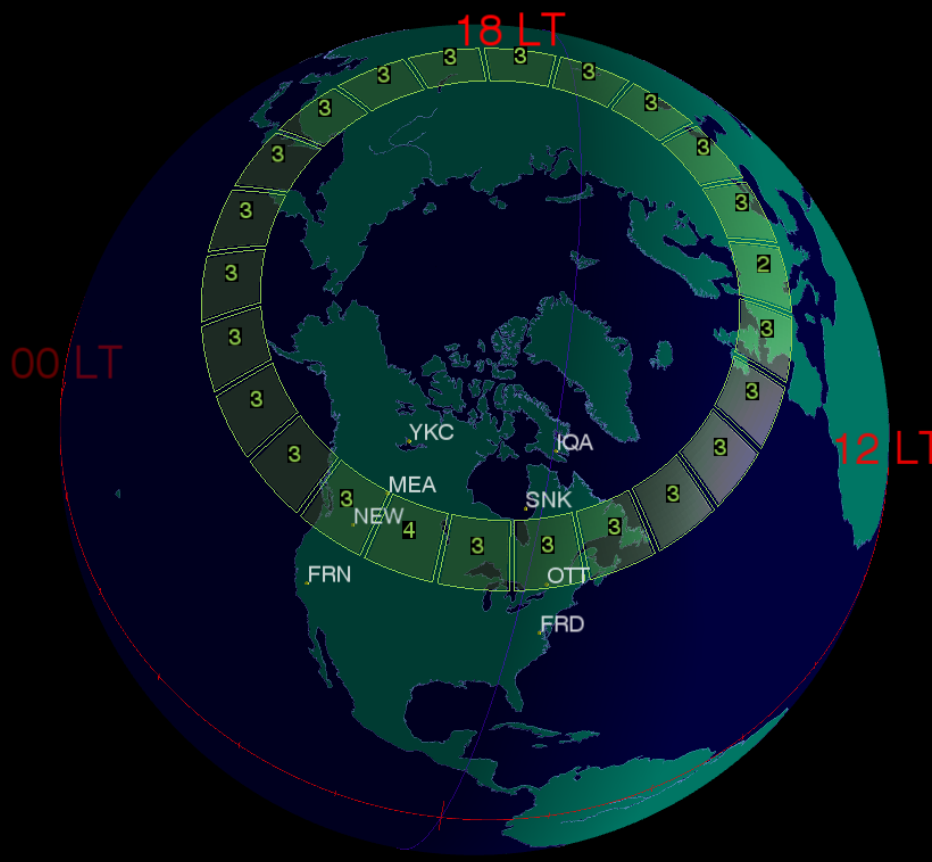
Contributing current systems: Magnetopause, Field-aligned, Ring Current, Ionospheric Currents



Ground, spatial, time-varying dB, calculated via Biot-Savart integration

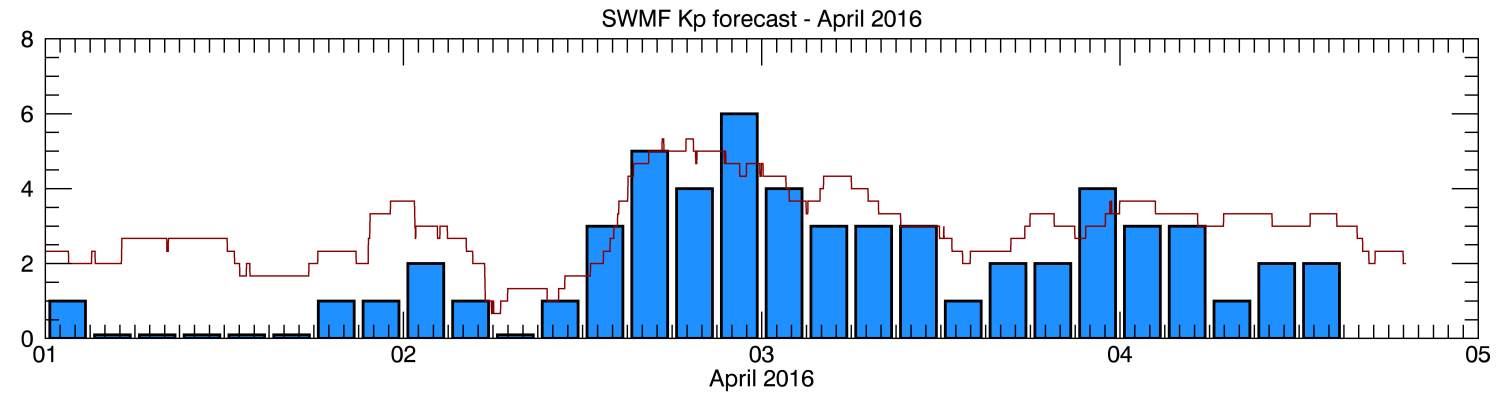
Initial Test: Real-time operations on NWS supercomputer in 2016.
Working with U. Mich, NCEP/NCO, and NASA/CCMC.
Accurate "re-Forecast" of St. Patrick's Day G4 storm!
Product : Local Time regional K prediction

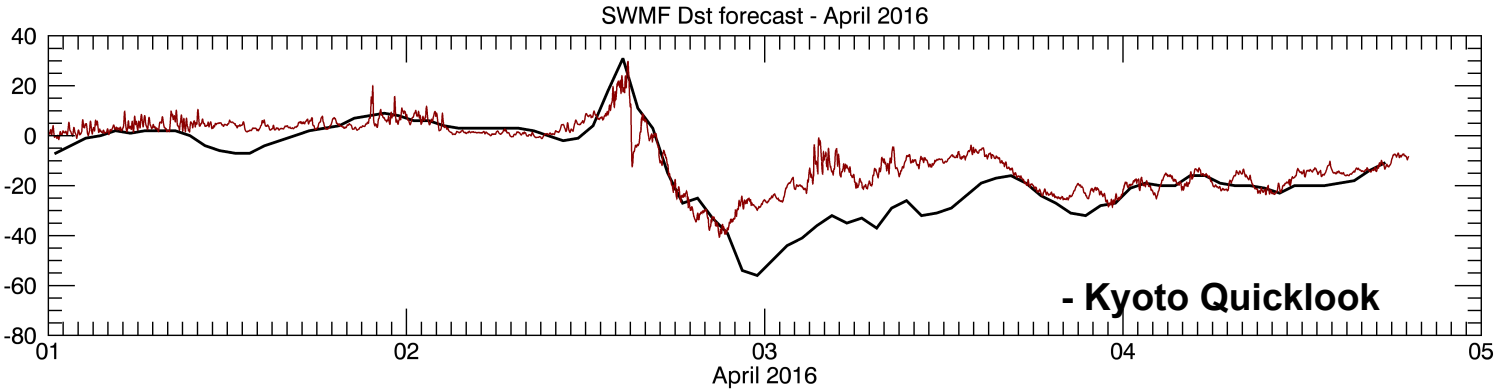




Space Weather Prediction Center

Michigan SWMF - Geospace Model
Kp and Dst Compared to Observation





- Top: “Kp” (SWMF model red, forecast center Kp blue)
- Bottom: Dst (SWMF model red, observed black)

Research to Operations: Some Lessons Re-Learned

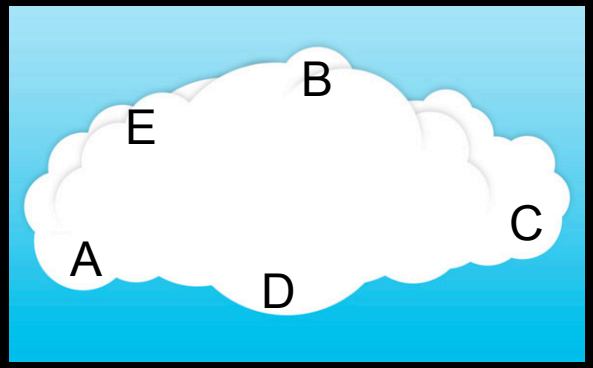
- Work with the experts: model developer, CCMC, other gov't agencies, commercial service partners
- Be prepared to iterate, otherwise you get what you asked for but not what you wanted - example of how a model running in real-time means different things for science vs. operations
- Science continues to advance: stay informed, participate and continue communications with community after model selection
- Encourage research agencies to continue to support model development
- Provide opportunities for comparing results of operational models and research models
- O2R results contribute to improved scientific models
- While models have been developed over decades, for R2O it is important to bring together all the pieces: operational needs and metrics, community partnerships, modeler participation, …

The Intersection of Research and Operations

- At SWPC, the co-location of scientists and forecasters provides the opportunity, and challenge, to explain and forecast space weather activity as it unfolds in real-time.
- This experience can be used to develop requirements for observations and models, to validate models, and to seek new understanding, improved products and forecasts.

Matching Research Model Capabilities to User Requirements

Multitude of Space Weather Research Models



Model's A, B, C … at CCMC or modeler institution or commercial service provider...

Time →

SWPC Operations

Focused Customer Requirements
- Power Grids
 -Airlines
- GPS…

Need to select from the menu of models those that can demonstrate satisfying a customer need

Research to Operations: A Grand Challenge

- Space physics isn't alone in its effort to determine an effective way to **transition new knowledge into practical applications that benefit society.**
- In 2011, National Institutes of Health (NIH) Director Francis Collins established the **National Center for Advancing Translational Sciences (NCATS) that's supposed to better connect fundamental science advances to progress in the clinical setting** so that new treatments and cures for disease can be delivered to patients faster.
- **Translational research** is engineering research that aims to make findings from basic science useful for practical applications that enhance human health and well-being. --Wikipedia
- The Space Weather community is examining the **best practices for facilitating the transition of research to operations.**

Conclusions

- Observations, models and scientific understanding are essential for the space weather enterprise.
- For operations, research models must be able to produce outputs and products that are relevant to decision makers.

George Siscoe reminded us of a quote from Lord Kelvin, “There cannot be a greater mistake than that of looking superciliously upon practical applications of science. The life and sole of science is its practical applications.”