NWS Science and Technology Roadmap

Space Weather Products

Team Composition

- Terry Onsager, Space Weather Prediction Center—Team Leader
- Tom Bogdan, Space Weather Prediction Center—Contributor
- Bill Murtagh, Space Weather Prediction Center—Contributor
- Mike Crumly, Space Weather Prediction Center—Contributor
- Rodney Viereck, Space Weather Prediction Center—Contributor
- Tim Fuller-Rowell, Univ. of Colorado/SWPC—Contributor
- Mihail Codrescu, Space Weather Prediction Center—Contributor
- Alysha Reinard, Univ. of Colorado/SWPC—Contributor
- Joshua Rigler, Univ. of Colorado/SWPC—Contributor

Vision/Benefits/Impacts

- **Focus Area Team Vision:**
  - To mitigate the impacts of space weather with actionable forecasts, warnings, and data
- **Benefits**
  - Safe and efficient National Airspace System through NextGen
  - Reduce human radiation risk and satellite failures
  - Ensure efficient electric power supply and mitigate blackouts
- **Impacts:**
  - Effective airspace management would safeguard life and property, also saving $200 million/year in polar route operations
  - Reliable navigation services would save $180 million/year
  - Preventing satellite launch failure would save $1 billion/launch
  - Power grid protection would save $1-2 trillion/extreme event

Goals/Targets:
Customer Needs

Goal	Outstanding Issues
1. Forecast adverse space weather for NextGen and 4-D Data Cube to ensure the efficiency and safety of our national and international airspace systems, GNSS-based navigation applications, communications, orbit tracking, and Space Situational Awareness	-Coupled Earth-Space system model required; -Enterprise solution required for data life cycle -International and interagency coordination required for data and model development - Integration with terrestrial weather products
2. Forecast adverse space weather for the electric power industry and other industries impacted by geomagnetic activity	-Coupled Earth-Space system model required; -Enterprise solution required for data life cycle -International and interagency coordination required for data and model development - Integration with terrestrial weather products
3. Forecast adverse space radiation to support our space infrastructure, including satellite reliability, human and robotic exploration missions, commercial space cargo services, and space tourism	-Solar eruption model development required; -Enterprise solution required for data life cycle -International and interagency coordination required for data and model development - Integration with terrestrial weather products

Goals/Targets:
Emerging Science & Technology

Goal/Target	Outstanding Issues
1. Earth-System Model – including coupled atmosphere-ionosphere-magnetosphere-sun	The ionosphere is driven by the atmosphere from below and the magnetosphere and the sun from above. Actionable space weather services require modeling the coupled system.
2. Data assimilation for Goal 1	Reliable data must be secured. Techniques are required to assimilate various ionospheric data into a coupled, physics-based model. Techniques are required to assimilate sparse magnetosphere and solar/solar wind data.
3. Prediction model of the background solar wind and intercalibrated measurements of the solar magnetic field to drive it	Measurements are available only from non-operational facilities, have large errors, and lack intercalibration among different sites. Continuous model improvement is required.
4. Model to initiate solar mass ejections to propagate in background model (Goal 3) and measurements to drive it.	Techniques to model solar mass ejection parameters are not mature and will require on-going improvement. Data today are available only from non-operational research facilities.

Goals/Targets:
Emerging Science & Technology

Goal/Target	Outstanding Issues
5. Data assimilation for Goal 3 and Goal 4	Reliable solar wind and solar data must be secured. New techniques are required to assimilate sparse data into a strongly externally driven model.
6. Model of solar active region stability – prediction of solar flares, energetic particles, and mass ejections	Models do not exist that can accurately predict the eruption of solar active regions. Considerable basic and applied research is required. Collaborations with NASA, NSF, DoD, and international partners are needed.

Key Information Gaps

Gap	Solution Alternative	Impact
3. Improved lead time from 1 hour to 1-3 days for large geomagnetic storms	3.1 Solar wind background model and operational data 3.2 Status quo	3.1 Up to 3-day forecasts of globally averaged geomagnetic storm intensity, enabling effective airspace management, reliable navigation services, electric power grid protection. Supports Customer Need Goals 1, 2, and 3 3.2 No long lead-time warnings
4. Accurate model for the initiation of solar disturbances	4.1 Solar wind disturbance initiation model and data 4.2 Status quo	4.1 Accurate 3-day forecasts of globally averaged geomagnetic storm intensity. Supports Customer Need Goals 1, 2, and 3 4.2 Reduced storm forecast accuracy
5. Improved model accuracy through data assimilation	5.1 Solar and solar wind data assimilation 5.2 Status quo	5.1 Improved accuracy of 3-day forecasts of globally averaged geomagnetic storm intensity. Supports Customer Need Goals 1, 2, and 3 5.2 Reduced accuracy

Key Information Gaps

Gap	Solution Alternative	Impact
6. Accurate 1-day forecasts of solar flares and solar energetic particles	6.1 Model of solar eruptions causing x-ray flares and energetic particle radiation 6.2 Status quo	6.1 Effective airspace management, reduced human radiation risks and satellite failures. Supports Customer Need Goals 1 and 3 6.2 Low-accuracy, short lead-time forecasts
7. Coordination of space weather data and models to improve global specifications and forecasts	7.1 International coordination of space weather data and models 7.2 Status quo	7.1 Overall improvement of nearly all products and services. Supports Customer Need Goals 1, 2, and 3 7.2 Ineffective use of global resources

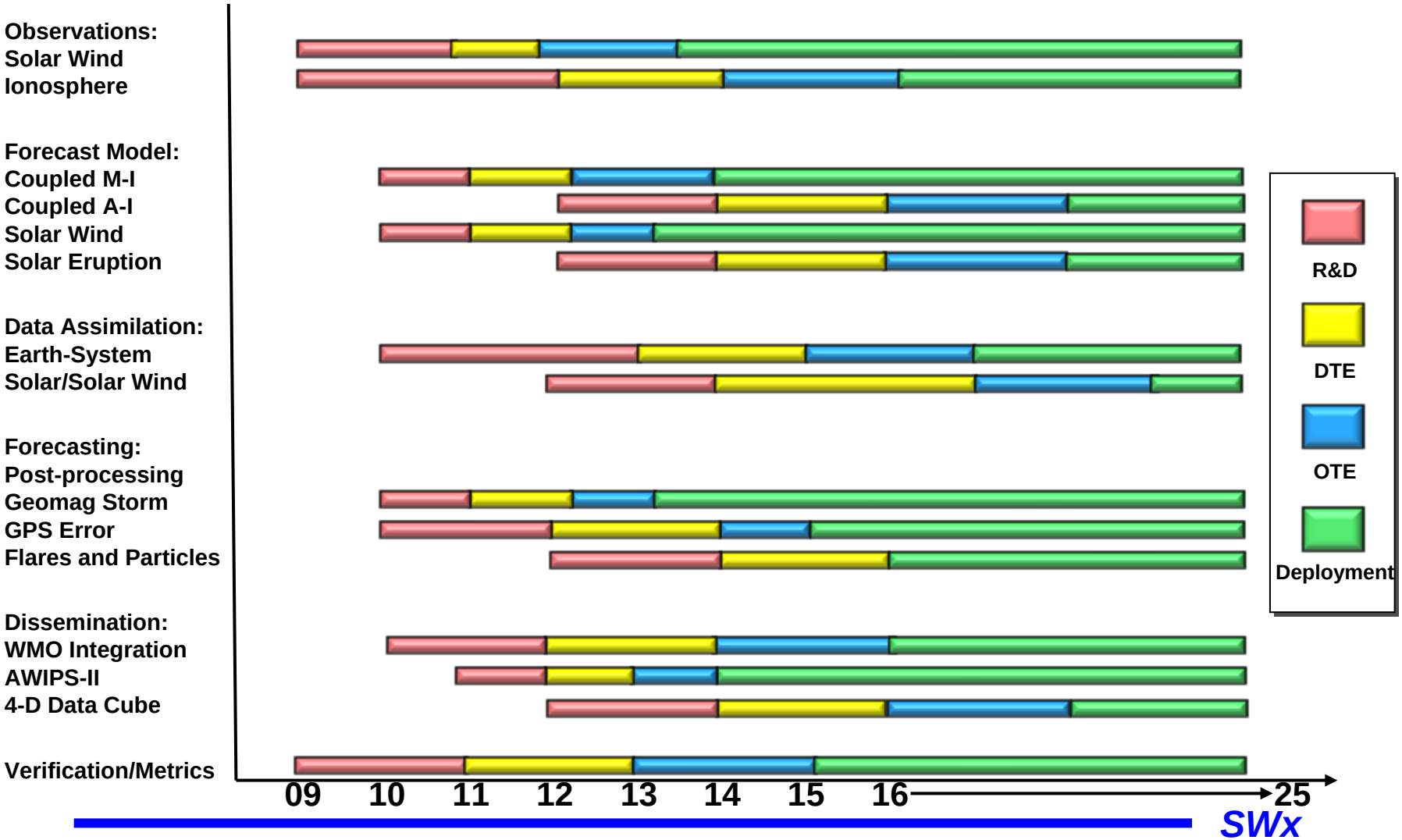
Key Information Gaps

Gap	Solution Alternative	Impact
1. Accurate, spatially resolved services for GPS errors, power grid stress, and energetic particle radiation hazard	1.1 Coupled Earth-Space system model 1.2 Empirical global ionosphere model with data assimilation 1.3 Status quo	1.1 Effective airspace management, reliable navigation services, electric power grid protection. Supports Customer Need Goals 1, 2, and 3 1.2 Global near-real-time specification of ionospheric conditions. Little or no warning lead time. 1.3 Little or no warning lead time, global average of geomagnetic activity rather than spatial resolution, large uncertainty
2. Improved lead-time, from near real-time to 6-12 hours, for spatially resolved ionospheric and geomagnetic services	2.1 Data assimilation for Earth-Space system model 2.2 Status quo	2.1 Effective airspace management, reliable navigation services, electric power grid protection. Supports Customer Need Goals 1, 2, 3 2.2 Large uncertainty, little lead time

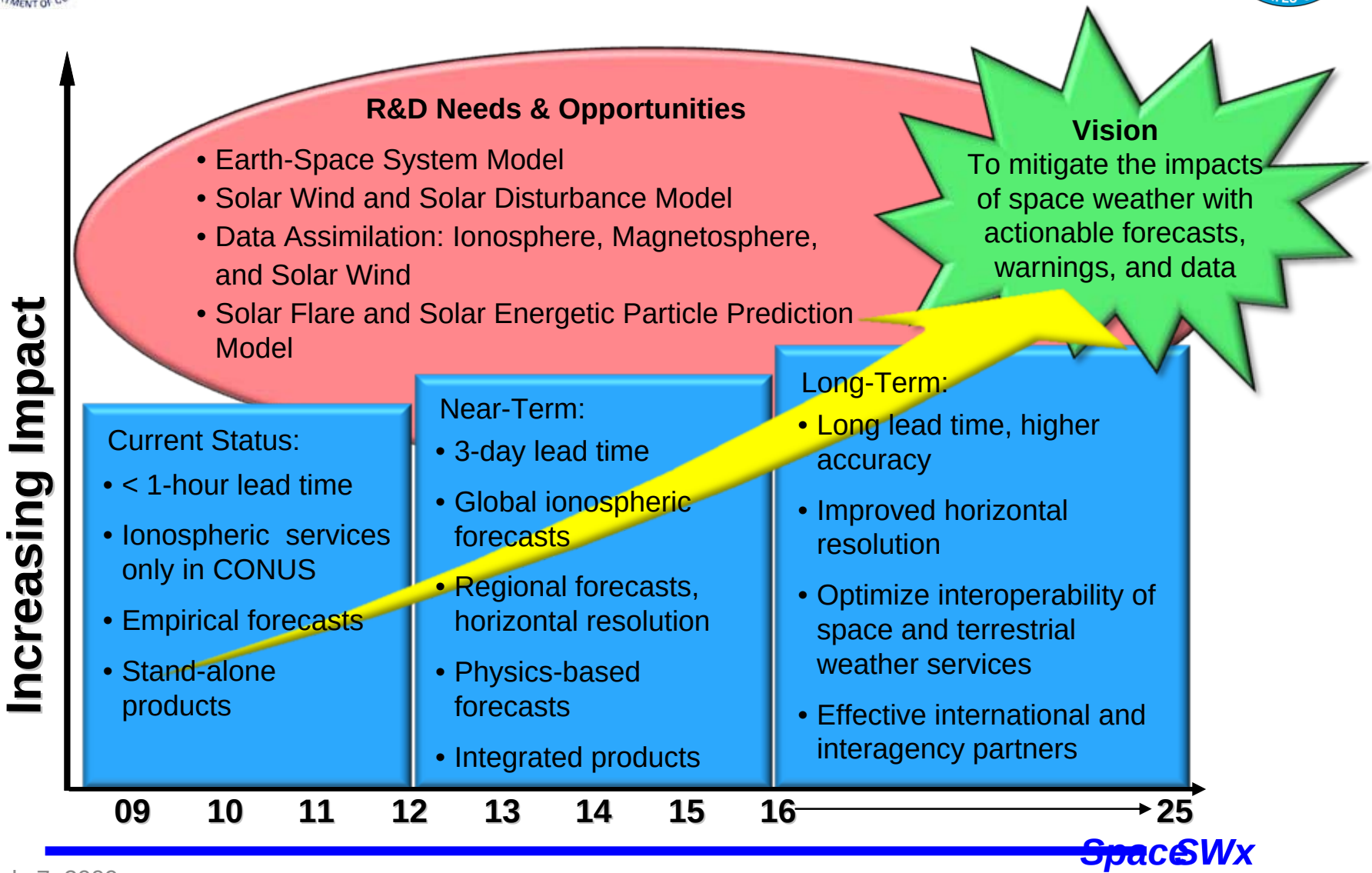
Research Needs and Opportunities

- **Short-term**
  - Develop initial global data-assimilation model to predict conditions that impact GPS accuracy and radio communication
  - Develop the ionospheric extension of the Whole Atmosphere Model
  - Develop model of solar mass eruption parameters
  - Develop data assimilation for solar and solar wind model
  - Social science analysis of product effectiveness
- **Long-term**
  - Develop the Earth-system model – coupled Atmosphere-Ionosphere-Magnetosphere
  - Develop data assimilation for the Earth-system model
  - Improve solar wind magnetic field prediction
  - Develop full coupling of solar/solar wind driving to Earth-system model
  - Develop prediction model of solar flares and energetic particles

SWx Alternative Solutions



Focus Area Team Summary: Space Weather



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SWx Team Additional Information

Target Performance Measures: Space Weather

Proposed	Current (2009)	FY 2016 Target Example	FY 2025 Target Example
Geomagnetic Storm extended warning (day 1-3) accuracy	Under development	70% based on onset time and intensity	90% based on onset time and intensity
Spatially resolved geomagnetic storm intensity	None	1000 km resolution	500 km resolution
Forecasts of global ionospheric variability	None	6-hour lead time	2-day lead time
Spatially resolved forecasts of global ionospheric variability	None	1000 km resolution	500 km resolution
1-day forecasts for solar proton events	Under development	60% accuracy	90% accuracy
Spatially resolved 30-min warnings of proton intensity	None	1000 km resolution	500 km resolution
1-day forecasts for X-ray flare events	Under development	60% accuracy	90% accuracy