The Technological Readiness of Functional Space Weather Predictive Capability

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Transition Needs for Environmental R2O [REF-1] :
- Reflects well-accepted management principles;
- Applicable for Space Weather also.

Research Program: should be strong, with clear opportunities for operational models improvement.

Infrastructure: should be healthy, with a strong exploratory program in advanced technologies and sensor development.

Interface with the User Community: should be strong, with attention to data archival needs of users of satellite data and products.

Observation and Data Access: ".. An efficient, robust data archiving system is at the core of effectively linking research to operations (R2O), the generation of advanced forecast products, and continual data utilization for the public good."

Evaluation Process: should include continuous examination of the impacts of various (new) sensors and forecasting techniques, parallel to operations. *

[NOTE: Now nearly a decade after this report, the capability for evaluation via metrics is not much improved.]

REF-1: NRC Board on Atmospheric Sciences & Climate, 2000, FROM RESEARCH TO OPERATIONS IN WEATHER SATELLITES AND NUMERICAL WEATHER PREDICTION: CROSSING THE VALLEY OF DEATH, ISBN 0-309-06941-6, 80 pages.

Global Space Weather Modeling Status [REF-2]

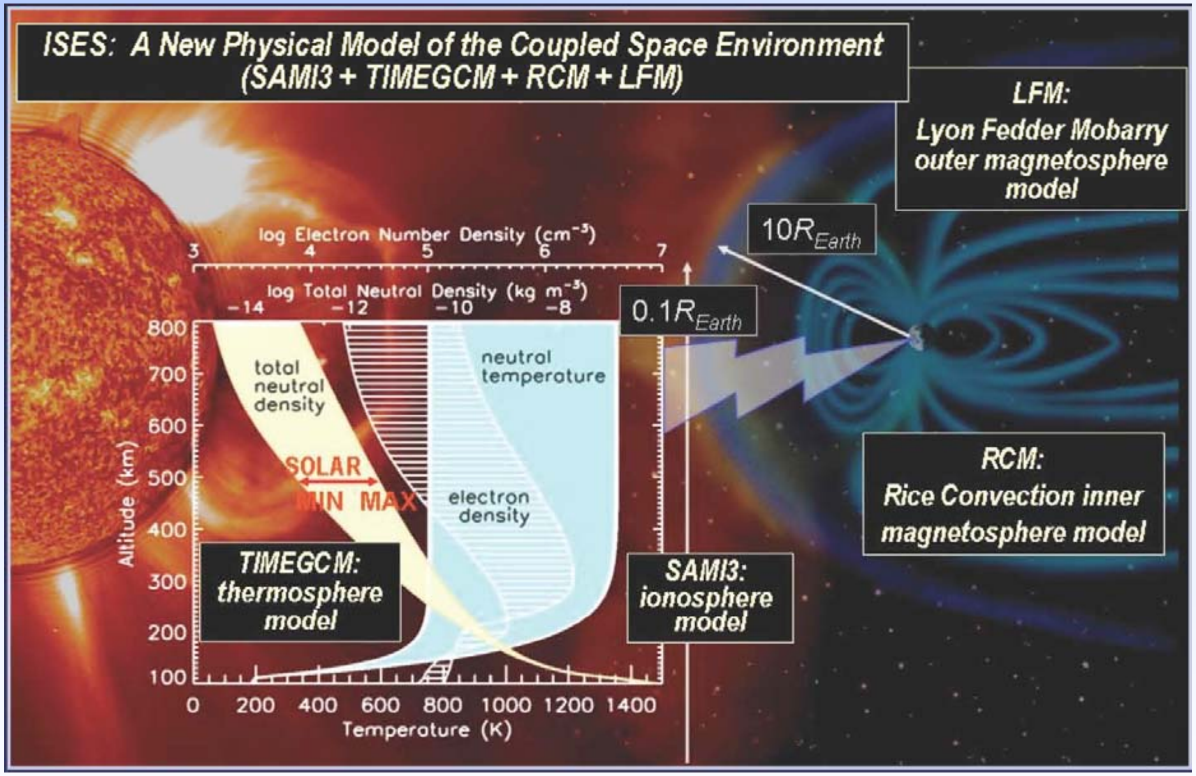
"As a threshold requirement for Space Situational Awareness ..

must be able to describe space environmental conditions so decision-makers can distinguish whether the environment impacts a space mission:

- Most of the accuracy and resolution for the space weather parameters must be treated as 'objective' since that level of sensing requires a prohibitively extensive network of ground- and space-observing. Many of these requirements can only be met with space weather models.
- Much of the research to improve beyond today's modeling capability is yet to be done.
- The current suite of sensors, both space- and ground-based, does not meet the documented needs of customers, nor are they sufficient enough to adequately meet the needs for a relevant environmental capability for SSA."

REF-2: AFW Space Weather Implementation Plan: 2008-2015, Signed – Dr. Fred Lewis, March 2008.

Global Space Weather Modeling Status
Example - NRL Research Plan, ISES-OE REF-3

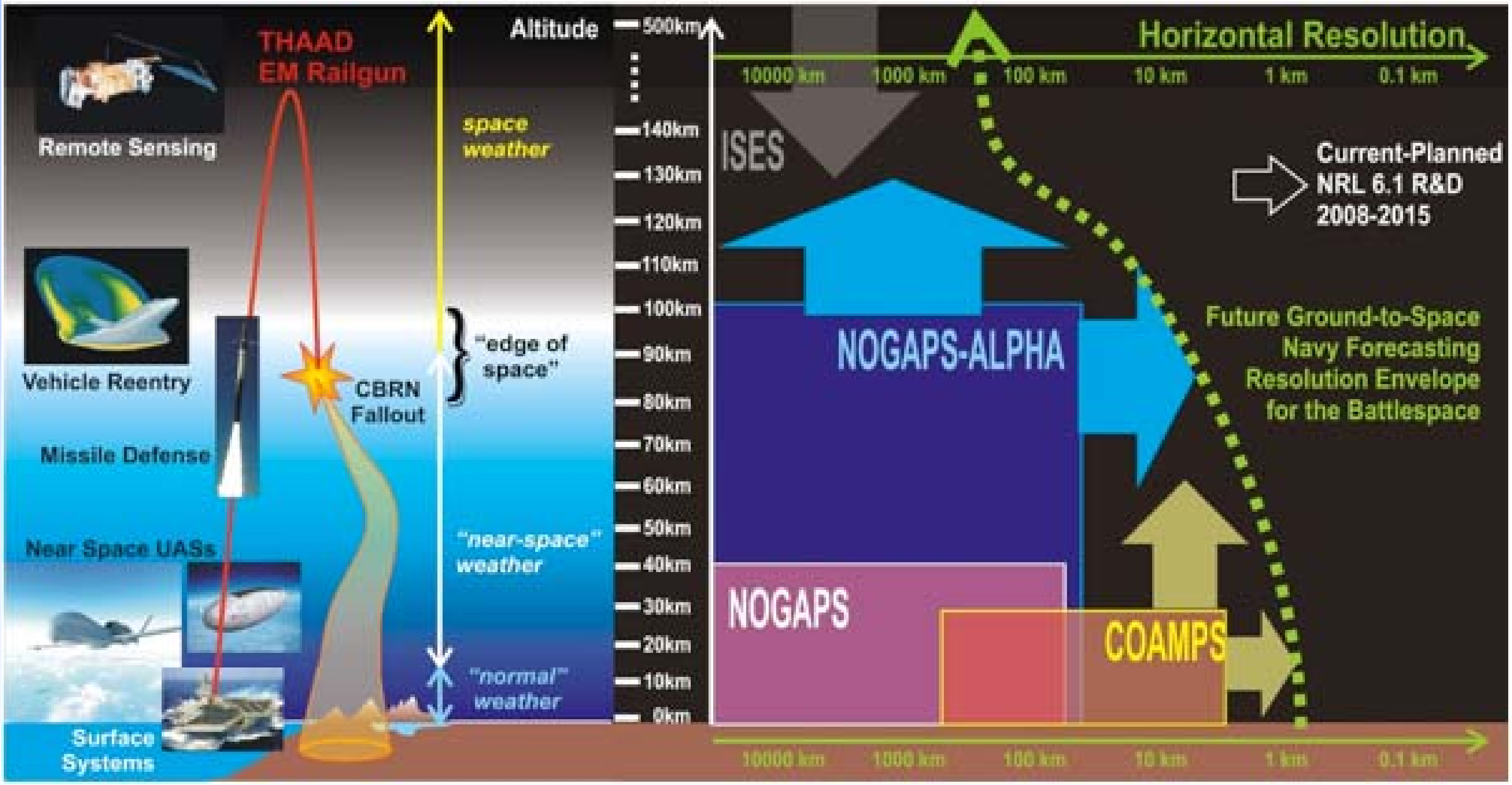


ISES-OE will characterize and simulate the multiple chains of physical processes that link the Sun Earth system, in order to advance space science and enable Naval operations to better account for, adapt to, and exploit operational impacts of the space environment due to electrons, ions, and neutrals.

This five-year NRL Initiative, Integrating the Sun-Earth System for the Operational Environment (ISES-OE), led by Dr. Judith Lean, will begin in October 2009.

Global Space Weather Modeling Status

Example - NRL Research Plan REF-4



NOGAPS: Navy Operational Global Atmospheric Prediction System

COAMPS: Coupled Ocean-Atmosphere Mesoscale Prediction System

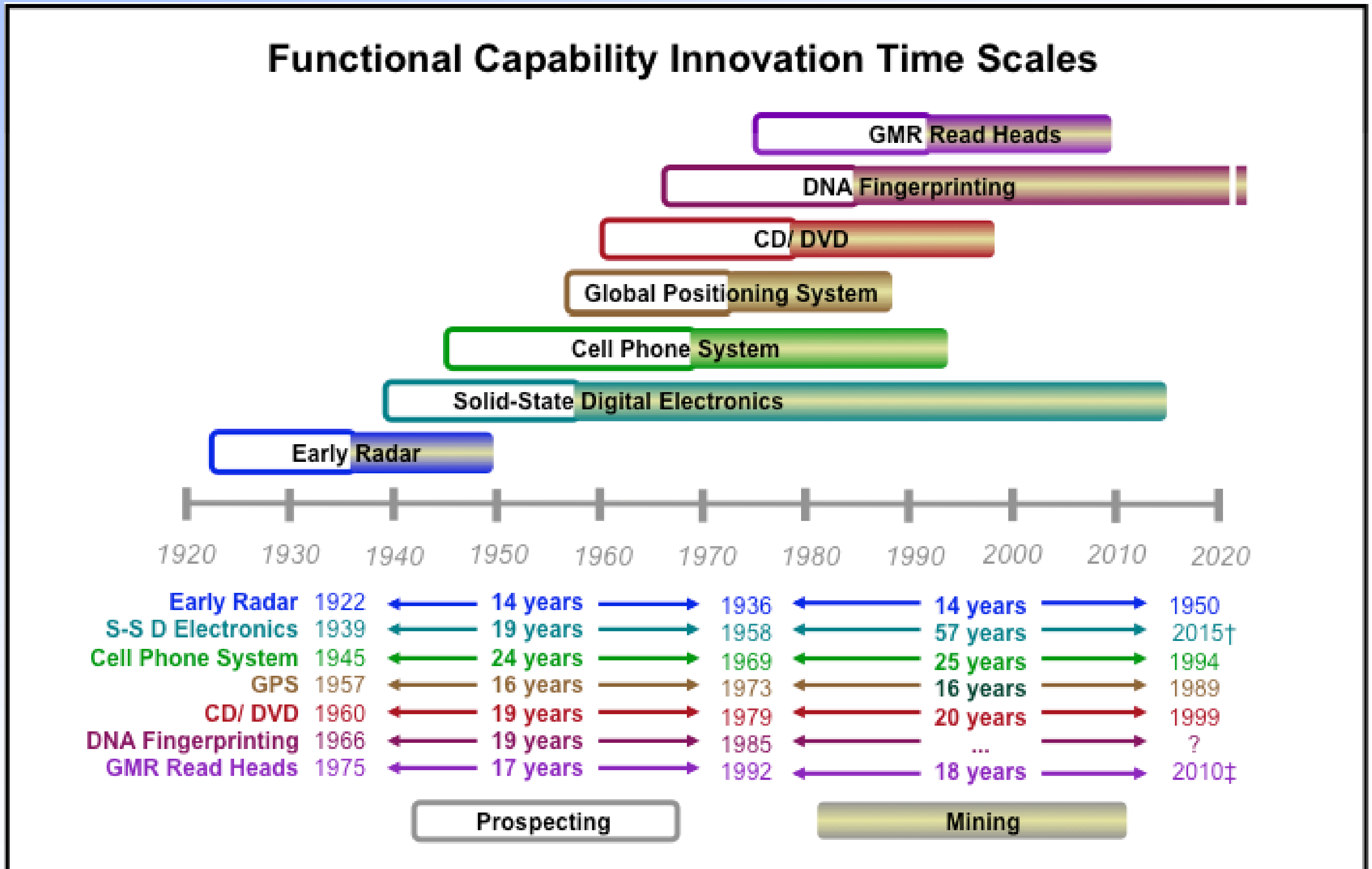
NOGAPS-ALPHA: NOGAPS with Advanced Level Physics and High Altitude

ISES: Integrated Space Environment System

This research plan underpins a developing space weather predictive capability that is intended to further reliable operational forecasting.

For this Panel Forum, suggest considering space weather prediction as a 'functional capability' development, to further shed light on next steps.

Many studies have been performed on functional innovation, e.g. Ref-5.



† Estimated, e.g., Borsuk & Coffey, 2003, "Moore's Law: A Department of Defense Perspective," *Defense Horizons*, 30, http://www.ndu.edu/inss/DefHor/DH30/Dh30.pdf
‡ Estimated, e.g., Prinz, 1995, "Spin-Polarized Transport," Physics Today (April, 1995)

[Figure modified from: Coffey, Dahlburg & Zimet, 2005, "The S&T Innovation Conundrum," Defense & Technology Papers, 17, http://www.ndu.edu/ctnsp/Defense_Tech_Papers.htm]

REF-5: Timothy Coffey, Jill Dahlburg, Eli Zimet, 2005, THE S&T INNOVATION CONUNDRUM, Center for *Technology & National Security Policy* Defense & Technology Paper No. **17**, 60 pages.

The two phases of innovation identified on the previous chart *REF-5* :

Prospecting: is characterized by a few discrete but high impact events, and culminates with one or a few technical groups pulling together the requisite disparate developments with, as available, commercial capabilities. A working innovation prototype is produced that has all of the essential attributes of the final capability and is recognized by individuals with the ability to significantly advance the innovation that it is ready for production.

Mining: is a later, more predictable phase that is is characterized by a larger number of lower-impact innovations than occurred in the early phase, each having smaller impact than those in the previous phase but nevertheless with cumulative impact that can be huge. During the mining phase, the time scales for progress are much faster than in prospecting, and the functional capability produced can usually be related to the funding applied and to the inherent potential of the technology being exploited. Developments in this phase thus are underwritten with near-term return on investment strategies in mind.

O2R (Operations to Research) is important to both Prospecting and Mining phases of innovation. For space weather forecasting, O2R touches on a number of things not generally considered in operations, such as: data stewardship; and, statistical metrics and assessments of performance.

Note: The ‘valley of death’ (i.e., funding gap that must be crossed in order to move from the prospecting phase to the mining phase) and the prospecting phases overlap. Both are characterized by a small number of discrete events that have a very large impact, and are generally closely linked to an individual scientist, engineer, or entrepreneur. A successful prospecting phase culminates with a working innovation prototype that is recognized to be ready for operations. Throughout the prospecting phase (and the valley of death) it is difficult to find the resources necessary to bring innovations to the point that predictable development programs can be launched.

A classic and important innovation example is Early Radar

Table. Radar Technology Readiness. REF-5

 Radar on U.S.S. New York, 1939	MAXWELL	HERTZ	MARCONI	HUELSMEYER	TAYLOR	YOUNG	PAGE	PAGE
DATE	**1873**	**1887**	**1901**	**1904**	**1922**	**1930**	**1934**	**1936**
Electromagnetic Waves (Theory)	YES	YES	YES	YES	YES	YES	YES	YES
Electromagnetic Waves (Experiment)	NO	YES	YES	YES	YES	YES	YES	YES
Reflected Signals	NO	YES	YES	YES	YES	YES	YES	YES
Power Supplies	NO	NO	NO	NO	YES	YES	YES	YES
Transmitters	NO	NO	NO	NO	YES	YES	YES	YES
Antennas	NO	NO	NO	NO	YES	YES	YES	YES
Receivers	NO	NO	NO	NO	NO	NO	NO	YES
Synchronizers	NO	NO	NO	NO	NO	NO	YES	YES
Displays	NO	NO	NO	NO	NO	NO	YES	YES

REF-5: Coffey, T., Dahlburg, J., Zimet, E, 2005, THE S&T INNOVATION CONUNDRUM, CTNSP Defense & Technology Paper No. 17, 60 p; [www.ndu.edu/ctnsp/Def_Tech/DTP%2017%20S&T%20Innovation%20Conundrum.pdf].

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Recommendation: an analogous Technological Readiness Table for space weather prediction of

- RADIATION DOSAGE @ real time, 3 hr, 8 hr, 3-5 day
- ELECTRON DENSITY @ real time, 3 hr, 8 hr, 3-5 day
- NEUTRAL DENSITY @ real time, 3 hr, 8 hr, 3-5 day

YEAR	1960	1970	1980	1990	2000	2010	2020	2030
SENSORS								
Research								
Solar								
Interplanetary Space								
Magnetosphere								
Ionosphere								
Upper Atmosphere								
Terrestrial								
Operational								
Solar								
Interplanetary Space								
Magnetosphere								
Ionosphere								
Upper Atmosphere								
Terrestrial								
DATA AVAILABILITY, STEWARDSHIP								
Relative to Real Time								
Coverage								
MODELS								
Individual								
Solar								
Interplanetary Space								
Magnetosphere								
Ionosphere								
Upper Atmosphere								
Terrestrial								
Man Made								
Coupled								
COMPUTING RESOURCES								
Research								
Operational								
ASSESSMENTS								
Verification & Validation								
Metrics								

Where are we at, with populating this Table

- FOR RADIATION DOSAGE @ real time? 3 hr? 8 hr? 3-5 day?
- FOR ELECTRON DENSITY @ real time? 3 hr? 8 hr? 3-5 day?
- FOR NEUTRAL DENSITY @ real time? 3 hr? 8 hr? 3-5 day?

YEAR	1960	1970	1980	1990	2000	2010	2020	2030
SENSORS								
Research								
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Upper Atmosphere								
Terrestrial								
DATA AVAILABILITY, STEWARDSHIP								
Relative to Real Time								
Coverage								
MODELS								
Individual								
Solar								
Interplanetary Space								
Magnetosphere								
Ionosphere								
Upper Atmosphere								
Terrestrial								
Man Made								
Coupled								
COMPUTING RESOURCES								
Research								
Operational								
ASSESSMENTS								
Verification & Validation								
Metrics								

Other Thoughts

1. The 2009 Space Weather Enterprise Forum provides a comprehensive view of where we are today, towards achieving broadly accurate space weather forecasting.

2. Building from today's readiness checklist, suggest next step: develop a Functional Space Weather Predictive Capability Technological Readiness Table, as a TRL planning tool for Research-to-Operations transitions.

   (… at a one-day community gathering, this summer?)

REFERENCES

REF-1: NRC Board on Atmospheric Sciences & Climate, 2000, FROM RESEARCH TO OPERATIONS IN WEATHER SATELLITES AND NUMERICAL WEATHER PREDICTION: CROSSING THE VALLEY OF DEATH, *ISBN 0-309-06941-6*, 80 pages.

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REF-3: Judith Lean *et al.,* 2007, ISES-OE; presentation to the Naval Research Laboratory Research Advisory Committee.

REF-4: Stephen D. Eckermann *et al.,* 2009, HIGH-ALTITUDE DATA ASSIMILATION SYSTEM EXPERIMENTS FOR THE NORTHERN SUMMER MESOSPHERE SEASON OF 2007*, J.Atmos.Chem.&Phys.* **71,** 531-551.

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