Living With a Star
Science Architecture Team
Review
(as presented to: Geospace Mission Definition Team Meeting; Paul Kintner, chair;
Greenbelt Marriott; Greenbelt, MD September 10, 2001)

Glenn Mason, former SAT chair

LWS MOWG Meeting
Holiday Inn Capitol, Washington, DC
September 20-21, 2007

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**SAT Guidance --**

- NASA HQ Charter

- SECAS Science Goals & Science Flowdown from March 2000 SECAS meeting

- Notional missions set aside per SECAS guidance Oct 2000

- Requirements organized to address priorities list from George Withbroe
Charter for the
Living With a Star (LWS) Science Architecture Team (SAT)
(9/15/00)

The goal of the LWS program is to develop the scientific understanding necessary to effectively address those aspects of the connected Sun–Earth system that directly affect life and society. The SAT will function as a top-level science working group for LWS and report to the Sun Earth Connection (SEC) Science Program Director and the Sun Earth Connection Advisory Subcommittee (SECAS). **The main role of the SAT is to examine the LWS program requirements and architecture from an overall systems point of view.**

The SAT is composed of solar-terrestrial scientists and representatives from the applications community. The members will be selected by the SEC Science Program Director at NASA HQ. It is expected that there will be a periodic rotation in the membership of the SAT as the LWS program evolves.
Table 1 -- LWS Goals and Objectives from SECAS

<table>
<thead>
<tr>
<th>LWS Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop the scientific understanding necessary to enable the US to effectively address those aspects of the Connected Sun-Earth system that directly affect life and society.</td>
</tr>
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</table>

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<thead>
<tr>
<th>LWS Objectives</th>
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<tbody>
<tr>
<td>• Identify and understand variable sources of mass and energy coming from our Star that cause changes in our environment with societal consequences, including the habitability of Earth, use of technology and the exploration of space.</td>
</tr>
<tr>
<td>• Identify and understand the reactions of Geospace regions whose variability has societal consequences (impacts).</td>
</tr>
<tr>
<td>• Quantitatively connect and model variations in the energy sources and reactions to enable an ultimate US forecasting capability on multiple time scales.</td>
</tr>
<tr>
<td>• Extend our knowledge and understanding gained in this program to explore extreme solar-terrestrial environments and implications for life and habitability beyond Earth.</td>
</tr>
</tbody>
</table>

March 2000 SECAS meeting
Priority

1. Solar Influences on Global Change.
2. Space Environmental “climate” data (e.g., specification models)
2. Nowcasting Space Environment
3. Prediction of:
   a) Solar Proton Events (astronaut safety, especially for deep space)
   b) Geomagnetic Storms for applications where effective mitigation is possible (e.g. electric power grid).
   c) Space Environment for operation and utilization of space systems.

George Withbroe 4/2001
Important Prior Studies--

- National Space Weather Program Reports
- NASA Workshop on Sun-Climate Connections
- DOD Space Weather Architecture Study
LWS Documents --

- LWS Pre-Formulation Study Vol. 1
- Notes from the LWS SAT Workshop
  Jan. 31, 2001
- Report to SECAS
  August 30, 2001
Other LWS SAT ground rules --

• LWS program must show clear progress in 5-10 year time scale to preserve robustness
  – higher risk, basic research for longer term improvements
  – SAT emphasis on near term activities

• Sparse data sampling -- ultimate product is physics-based models
  – observations to feed models
  – large scale linked model development required
    • well beyond scale of individual PI

• require a multi-year period of simultaneous observations of the whole system to understand the linkages
Practical considerations --

• SDO Mission Definition Team formed prior to SAT
  – cross membership of SAT members, LWS Project Scientist enables linkage with SAT
  – SAT effort emphasized other areas of LWS

• Initial mission sequencing (SDO followed by “Geospace”) determined by NASA HQ
  – SAT did not investigate alternate sequencing scenarios
"...to understand the nature and source of the solar variations that affect life and society."

Report of the Science Definition Team

Available at:
SAT Approach --

• organize LWS program areas defined in terms of linked sequences of events in order to
  – follow physical processes from start to finish (e.g. sun to upper atmosphere)
  – ensure that *all* significant links in the chain are identified
  – enable a global theory & modeling effort to achieve predictive goals
solar dynamo

solar energy outputs

near UV VIS IR radiation

X-rays & EUV radiation

energetic particles (protons)

galactic cosmic rays

solar wind plasma

heliosphere & IMF

magnetosphere

energetic particles (electrons)

stratosphere & ozone

climate

courtesy of Judith Lean
GOES > 30 MeV protons, October 1989

3B X13 Flare
H-alpha onset 12:29 Oct 19
27°S 10°E

Shock passage at Earth

Day of 1989

Particles/cm² sec sr

second event  third event

0.01

0.1

1

10

100

1000

10⁴
<table>
<thead>
<tr>
<th>Priority</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar Influences on Global Change</td>
</tr>
<tr>
<td>2</td>
<td>Space Environmental “climate” data (e.g., specification models)</td>
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<td>Nowcasting Space Environment</td>
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|          | b) Geomagnetic Storms for applications where effective mitigation is possible (e.g., electric power grid).  
|          | c) Space Environment for operation and utilization of space systems. |
# LWS Science Architecture

<table>
<thead>
<tr>
<th>Implementation Group</th>
<th>LWS Science Architecture</th>
<th>Space Environment</th>
<th>Space Storms</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Pre) Science Definition Teams (SAT subgroups)</td>
<td></td>
<td>Specification modeling</td>
<td>Dynamic Models, Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irradiance</td>
<td>Flares CMEs SPEs</td>
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<tr>
<td></td>
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<td>Secular solar wind model</td>
<td>Solar/storm warning CME propagation</td>
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<tr>
<td></td>
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<td>Solar cycle radiation specification</td>
<td>Shocks Storm process</td>
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<td></td>
<td></td>
<td>Radiation tolerance (degradation)</td>
<td>Mitigation (SEUs, charging)</td>
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<table>
<thead>
<tr>
<th>Theory and Modeling /Data Analysis</th>
<th>Sun</th>
<th>Heliosphere</th>
<th>Geospace</th>
<th>Space Environment Testbeds</th>
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</table>

courtesy Larry Zanetti

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Space Storm Problem Areas

Solar Impacts on Communications, Navigation and Radar
  1) Forecast the effects of variations in the electron density distribution in the ionosphere
  2) Discover the cause of plasma density irregularities that cause radio scintillation

Tracking and Identification of Objects in Space
  3) Understand and predict solar influences on satellite drag

Geomagnetic Induced Currents
  4) Develop the capability to forecast induced currents due to ionospheric-geomagnetic current systems

Dynamics of the Near-Earth Radiation Environment
  5) Discover the processes that accelerate, transport, and distribute energetic particles during geomagnetic storms
  6) Understand and predict the intensity of outer-zone electrons due to high-speed solar wind streams

Particle Radiation Associated with Explosive Events on the Sun
  7) Develop the capability to forecast solar particles accelerated by flares and CMEs
  8) Predict the intensity of particles accelerated by traveling interplanetary shocks
  9) Understand how solar/interplanetary variability governs the entry of energetic particles into the magnetosphere
Space Environment Problem Areas

Solar Impacts on Communications, Navigation and Radar
1) Determine the effects of long and short term variability of the Sun on the global-scale behavior of the ionospheric density from 100 to 1000 km.
2) Discover the influence of solar variability on the intensity and location of plasma irregularities in the 100 km to 1000 km altitude region.

Tracking and Identification of Objects in Space
3) Determine the effects of long and short term variability of the Sun on the mass density of the atmosphere between 120 and 600 km altitude and describe them with accuracy better than 5%.

Dynamics of the Near-Earth Particle Radiation Environment
4) Understand the processes responsible for the acceleration, loss, and transport of radiation belt electrons and ions responsible for radiation dose and bulk charging effects.
5) Understand the geospace response to geomagnetic storms such as the development and trapping of the ring current, Joule heating of the ionosphere, ground induced currents, severe spacecraft surface charging environments, etc.
6) Reveal and characterize the effects of solar energetic particles at low Earth orbit and in the atmosphere/ionosphere

Climate variability due to solar variations
7) Identify and quantify the Earth’s near-surface temperature changes attributable to solar variability (from both direct and indirect solar energy forcings).
8) Identify and quantify the changes in ozone distribution attributable to solar variability (in the form of electromagnetic radiation and energetic particles).

Deep space probe / Astronaut safety on Mars mission
9) Develop the capability to specify and predict solar activity (on time scales of active regions to the solar cycle) and heliospheric modulation of energy inflow from the Sun and the galaxies to the Earth’s space environment.
Sample problem area treatment

Since observational sampling of the Sun, heliosphere, and geospace is extremely sparse, the SAT adopted the view that the **ultimate product of the program would be in physics-based models of the various regions of importance.** In this approach, the role of observations is to understand the physical processes so that theory and models can be developed, and, eventually, to drive the models so that nowcasting and predictions can be made. In the words of one attendee at the SAT workshop, “the observations should be made to feed the models.”
Implications --

1) The LWS program will need to develop large scale global models well beyond the scale undertaken by individual Principal Investigators, and involving interfaces among traditional SEC regimes that are not the focus of existing research.

2) A broad community of researchers will need to have ready access to data sets from many spacecraft covering broad areas of the Sun-Earth system.

3) It will be necessary to have a multi-year period of simultaneous observations of the whole system in order to understand, and convincingly demonstrate that we understand all the linkages.

4) The importance of observations in the program can be quantitatively linked to their role in improving models, and/or reducing the uncertainties in nowcasting or forecasting.
Implications --

The first three points above have a critical role in the management and organization of the LWS program.

The 4th point provides a clear mechanism for evaluating and prioritizing measurement objectives.
SAT Approach --

• for each problem area (e.g. S/C drag), identify
  – physical processes from start to finish (e.g. sun to upper atmosphere)
  – current state of theory and modeling, including accuracy
  – establish ~5-10 year goals for required improvements
    • model refinement; data assimilation; new models
    • observations required
      – existing missions that can provide needed data
      – missing observations required to meet LWS goals
Produce the capability to specify and predict the mass density of the atmosphere between 120 and 600 km altitude with accuracy better than 5%.

• Societal impact:
  Satellite orbits are perturbed by atmospheric drag.
  Atmospheric conductivity is critical parameter for determination of induced ground-currents, and ionospheric radio scintillation.

• Primary Current Limitations:
  Empirical model with 20% long term accuracy.
  Poor altitude specification below 350 km.
  Computational models driven by proxies for solar EUV radiation and electromagnetic drivers.
  Sensitive to poorly specified small scale motions at lower boundary.

• 5-10 yr LWS goal:
  Refine empirical model of winds and density with new data & inputs.
  Validation of physics-based models with variations in measured input drivers.
  Establish data assimilation processes to accommodate sparse data sets

• > 10 yr LWS goal:
  Validated physics-based assimilation model.
Atmosphere Ionosphere Magnetosphere Measurements Agenda

Solar Dynamo

Solar Outputs

IMF and Solar Wind

Magnetospheric Drivers

Ground-Based F10.7

IMP, ACE WIND

SuperDarn Radars Magnetometers DMSP

Ground and Sat Ionosondes DMSP

Ionosphere Model

Neutral Winds

Thermosphere Model

Waves from Below

Internal ExB Drifts

Ground Radar Ionosondes FPI Ground All-Sky

Low and Mid Inc Satellites. TIMED

SDO

L1 STEREO

L1 SENTINELS

SuperDarn Radars Magnetometers DMSP MMS

NPOESS GEC Low and Mid Inc Satellites

SuperDarn Radars Magnetometers NPOESS MagCon

DMSP COSMIC Low and Mid Inc Satellites

NPOESS L1

SENTINELS

Low and Mid Inc Satellites

Low and Mid Inc Satellites

SMEX

SMEX

Example
LWS SAT findings for --

1) new missions to fill the gaps in observational picture
2) system to make required data from non LWS missions easily available to LWS researchers
3) coordinated theory, modeling, and data analysis program

All 3 components are required for achieving LWS goals
## LWS SAT--
### recommended set of initial missions

<table>
<thead>
<tr>
<th>Name</th>
<th>Launch</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDO</td>
<td>2006</td>
<td>Solar seismology and magnetic field studies; EUV radiation; radiation belt studies</td>
</tr>
<tr>
<td>Geospace-Radiation Belt 1/2 &amp; 3/4</td>
<td>2008 &amp; ~2013</td>
<td>Radiation belts over a range of L shells; two launches in order to cover full solar cycle</td>
</tr>
<tr>
<td>Geospace-LEO</td>
<td>2009</td>
<td>\textit{in-situ} measurement of ionosphere and thermosphere dynamics and structure; solar energetic particles &amp; polar cap size; SAA</td>
</tr>
<tr>
<td>Geospace-EPO</td>
<td>2009</td>
<td>Global auroral imaging and O/N2 perturbations; energetic neutral atom imaging for ring current dynamics</td>
</tr>
<tr>
<td>Inner Heliosphere Mappers</td>
<td>2009</td>
<td>~4 identical spacecraft in inner heliosphere orbits; structure, dynamics, &amp; radial evolution of CMEs, solar particles, and geo-effective disturbances</td>
</tr>
</tbody>
</table>
Mission Concept: dedicated S/C & missions of opportunity

GTO-like: 2/3 satellites per launch in two launches phased for solar cycle coverage - core + opportunity; measure B, energetic particles, plasma incl. ion composition on first launch. Second launch spacecraft include above measurements plus waves and E

Geo mission of opportunity: measure B and energetic particles, plasma incl. ion composition, ENA, E

LEO: SEP and SAA measurements for ionospheric, atmospheric, climate, & human radiation exposure similar to SAMPEX or DMSP

Science Questions:

• What processes control the acceleration, loss, and transport of radiation belt electrons and ions?
• What is the geospace response to geomagnetic storms, e.g., development and trapping of ring current, Joule heating of the ionosphere, ground induced currents, and severe S/C charging?
• What are the effects of solar energetic particles at low Earth orbit and in the atmosphere/ionosphere?
• What is the radial and longitudinal distribution and dynamics of particles in CME and flare-associated solar particle events?

LWS Target Areas

• S/C radiation dose and bulk charging
• S/C drag
• Magnetospheric induced currents
• Communication, navigation, and radar
• Upper atmospheric chemistry / ozone
• Ground induced currents

Other contributing measurements:

L1: ACE, Wind, Triana

1. **LEO Orbits below the exobase**: inclination to maximize longitude and latitude coverage within seasonal variations (~70°); in-situ measurements of ionosphere and thermosphere dynamics and structure; solar energetic particles/polar cap access and size; SAA

2. **Elliptical Polar Orbit (EPO)**

Inclination and eccentricity to maximize efficiency of global auroral imaging and O/N2 perturbations and other pertinent parameters; energetic neutral atom imaging for ring current global view

Science Questions:

Global Specification and Prediction of Neutral Upper Atmospheric Density and Dynamics; Ionosphere Density, Structure and Irregularities

• Dynamics, latitude, longitude, and local time variations in: Thermospheric winds; Neutral mass composition and density E-field or ExB drift; Ionospheric mass composition and density; Scintillation and Density Irregularities

• Global Auroral Energy Deposition

• Global Neutral Density Perturbations

• Ring Current Dynamics

• LWS Target Areas

• Detection and tracking of space objects

• Communication, Navigation and Radar

• Geomagnetically Induced Currents

Other contributing measurements:

C/NOFS: equatorial ionosphere dynamics & structure

DMSP/NPOESS: latitude profiles of neutral density at fixed local times; energetic particle input

Ground Based Observations: Electric Fields, Conductivities, Magnetic Perturbations

L1: ACE, Wind, Triana: specification of IMF and Solar Wind; SDO: EUV spectral irradiance; Geoeffective disturbances
**Inner Heliospheric Mappers**

**Mission Concept:** Four identical spacecraft in elliptical heliocentric orbits (0.5 – 0.95 x 0.72 AU)

**Objective:** Continuous, in situ, inner-heliospheric observations to study the structure, dynamics, & radial evolution of CMEs, solar particles, and geo-effective disturbances

**Strategy:** Multi-point observations distributed in radius & longitude

**Instruments:** Magnetometer, Solar wind analyzer, Energetic particles, & Radio waves

**Launch Vehicle:** Single Delta-II launch

**Science Questions:**
- What is the ambient structure of the inner heliosphere?
- How do large-scale structures evolve during transit to Earth? (CMEs, shocks, fast streams)
- What dynamic processes in the corona can be determined from heliospheric observations?
- What is the radial and longitudinal distribution and dynamics of particles in CME and flare-associated solar particle events?

**LWS Target Areas**
- Solar impacts on communications, navigation, and radar
- Dynamics of the near-Earth radiation environment
- Magnetospheric induced currents
- Radiation from explosive solar events

**Other contributing measurements:**
- L1: ACE, Wind, Triana; STEREO:
  - Multi-pt imaging & in situ data on CMEs, SEPs
- Inside 1 AU: SOLO?, Messenger?, Beppi-Columbo?
- Also upstream: SOHO, IMP, Geostorm?, Magtail Con.; Outside 1 AU: Ulysses, Voyager
Solar Cycle & LWS Mission Observations

- Mean Sunspot Number
- Year
- Cycle 23
- Cycle 21/22 + 22 yrs
- Move beyond 122°
- Extended operations
- LWS SDO
- LWS Geospace LEO/EPO
- LWS Geospace RB 1/2
- LWS Heliospheric Mappers
- Simultaneous LWS observations
Table 8 -- LWS Supporting Missions

<table>
<thead>
<tr>
<th>Spatial Region</th>
<th>LWS Supporting Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Heliosphere</td>
<td>Voyager, Ulysses</td>
</tr>
<tr>
<td>Solar (remote)</td>
<td>SOHO, HESSI, TRACE, Solar-B</td>
</tr>
<tr>
<td>Inner Heliosphere</td>
<td>SOLO, Messenger, Beppi-Columbo, Solar Probe</td>
</tr>
<tr>
<td>Heliosphere at 1 AU</td>
<td>STEREO, IMP, Geostorm, Solar Probe</td>
</tr>
<tr>
<td>L1</td>
<td>ACE, Wind, Triana</td>
</tr>
<tr>
<td>Magnetosphere</td>
<td>MagCon, GEC, TWINS, Polar, Cluster, GOES, LANL-GEO, GPS, IMP-8</td>
</tr>
<tr>
<td>Low Earth Orbit</td>
<td>SORCE, TIMED, DMSP, TIROS, NPOESS, SAMPEX, C/NOFS</td>
</tr>
</tbody>
</table>

Missions shown in red are to be terminated prior to LWS new missions, per August 2001 SEC Senior Review Final Report
LWS Data System finding--

• **new LWS missions to fill the gaps in observational picture**
  – recommended missions take account of other assets

• **critical that NASA LWS management ensure that these other data are taken, and are easily available**
  – NASA operated non-LWS S/C: a factor in mission extensions, etc.
  – non NASA S/C: seek to obtain required data through partnering, etc.
  – require a data system (possibly a virtual system) that will serve an archive that individual researchers and coordinated large-scale modeling teams can access to achieve required LWS theory & modeling goals.
**LWS Data System --**

- **LWS SAT finding:**
  - Data Systems Team (DST) should be formed to examine issues and make specific recommendations to LWS program management
    - need to examine cost/benefit of adding any particular data set to the system
    - should include archival data that can form the basis for many early studies and payoffs from the LWS program (e.g. radiation belt model updates) well before the first LWS mission is launched.
    - report activities of the DST to the Science Architecture Team
LWS Theory & Modeling Program finding --

• LWS will be a success if and only if there are substantial improvements in theoretical understanding and modeling of each component of the Sun-heliosphere-geospace system
• Theory and modeling will embody the knowledge acquired by the LWS program
• It would be unwise to assume that the required theory and modeling program will arise through the natural instincts of the community
• The SAT believes that a comprehensive theory and modeling program needs to be embarked upon immediately --
LWS Theory & Modeling Program finding --

• A Theory, Modeling, and Data Analysis Definition Team (TMDADT) needs to be formed with the same status as a mission definition team. Its charge should include:
  – definition of goals and objectives, including metrics
  – recommendations on management structure that will be in place through the LWS program and will ensure coordinated and unified development
  – recommendations on procedures to ensure that the program encourage and promotes new concepts, and provides for their speedy inclusion in the developing models
  – preliminary assessment of the data that will be needed for success that can provide useful guidance to the SDTs
  – as assessment of the utility and necessity of data for theory and model development that can be provided from existing and planned NASA and non-NASA sources
LWS Theory, Modeling, and Data Analysis Program finding (con’t) --

- Selected members of the TMDADT should also be appointed to the mission SDTs to ensure coordination.
  - the converse should also occur: members of the SDTs should have joint appointments on the TMDADT.

- The TMDADT should disband and replaced by a permanent management structure that will ensure success of the theory and modeling effort
LWS Theory & Modeling Program finding (con’t) --

The LWS program has accepted a daunting challenge -- to deliver comprehensive knowledge and improved predictability of how our changing Sun impacts our society. There are multiple spacecraft, coordinated measurements, and intertwining theories and models. The challenge is one of science and also one of management, and nowhere is the success in meeting the management challenge more crucial for the ultimate success of LWS that it is for theory and modeling.
**LWS SAT picture**

**Observations:**
- Existing
- Archival
- new LWS missions

**Comprehensive Data System** ➔ **Theory, Modeling, and Data Analysis** ➔ **Critical management challenges**
Conclusion: How to coordinate Mission Definition Teams with SAT approach?

• Identify the LWS problem areas best addressed by a mission or missions,

• Determine significant model improvements achievable in the 5-10 year time frame,

• Enumerate existing or planned missions whose measurements can be employed to support the model development and theory improvements, and identify critical missing measurements,

• Identify targeted new measurements (partnerships or individual S/C) required to fill in the missing pieces,

• Iterate the process to achieve closure with resources, the level of science understanding, and societal impact.