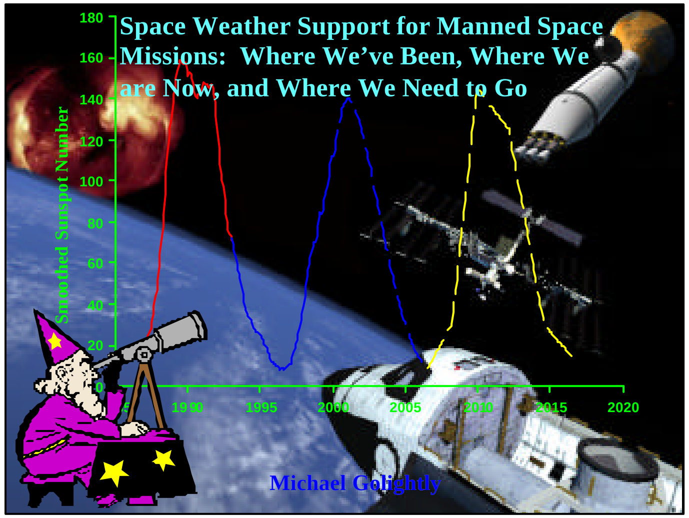

Disclaimer

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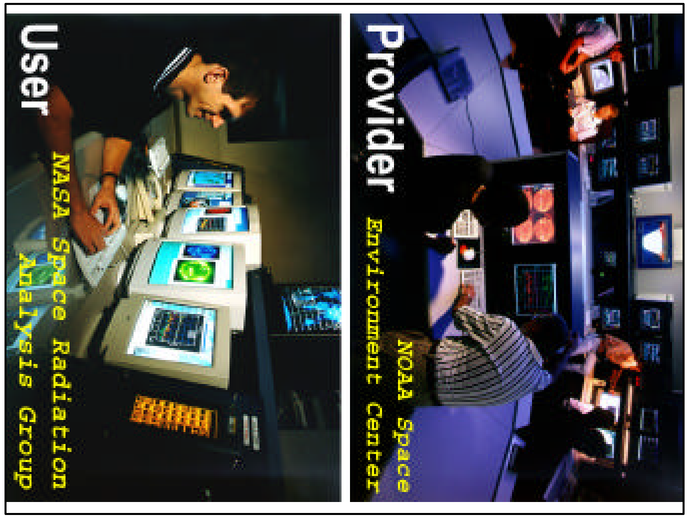
Although the facts speak for themselves, the spin placed on them and other opinions expressed here are those of the author and not necessarily the position or policy of NASA.



U.S. Manned Mission Scenarios . . .

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Past (Cycle 22 Max)	Present (Cycle 23 Max)	Future (Cycle 24 Max)
• Emphasis ➢ Space Shuttle Missions	• Emphasis ➢ International Space Station (ISS)	• Emphasis ➢ International Space Station (ISS)
• Development ➢ Space Station Freedom	• Development ➢ Mars robotic exploration and manned Mars mission technology development	• Development ➢ Manned Mars mission ➢ Lunar mission/base (?)
• Advanced Planning ➢ Manned Mars Mission	• Advanced Planning ➢ Manned Mars Mission ➢ Lunar return mission ➢ L2 Lagrangian point telescope servicing mission	• Advanced Planning ➢ ?
• Requires: ➢ ~ 860 on-orbit hours per year ➢ ~ 0 EVAs per year	• Requires: ➢ ~ 10600 on-orbit hours per year ➢ ~ 26 EVAs per year	• Requires: ➢ > 8760 on-orbit hours per year ➢ ~ 10-20 EVAs per year

. . . result in Concerns About Space Radiation Exposure . . .

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Past (Cycle 22 Max)

- Sources
  - Geomagnetically trapped p^+
  - GCR primaries
  - SPE p^+
  - Secondaries, including $^1n_0$, of minor importance
- Effects
  - Acute radiation effects from high exposure during a solar particle event
  - Increased risk of cancer
- Exposures
  - Average per crewman 1.6 mSv
  - Cumulative exposure 0.15 man-Sv/y

Present (Cycle 23 Max)

- Sources
  - Geomagnetically trapped p^+
  - Geomagnetically trapped e^-
  - GCR secondaries
  - SPE p^+
  - Secondaries, especially $^1n_0$, of significant importance
- Effects
  - Overall radiation risk greater than previously thought
    - BEIR V
  - Increased risk of cancer
  - High LET radiation unique effects
  - Importance of genomic instability
  - CNS effects (?)
- Exposures
  - Average per crewman 10.9 mSv
  - Cumulative exposure 0.43 man-Sv/y

Future (Cycle 24 Max)

- Sources
  - Geomagnetically trapped p^+
  - GCR secondaries
  - SPE p^+
- Effects
  - Fully quantify all medical risks (cancer, CNS effects, etc.)
  - Biomedical methods to arrest/ repair radiation damage
  - In-flight treatment methods (simple, low side-effects, etc)
- Exposures
  - Average per crewman 41.5 mSv
  - Cumulative exposure ≥ 1 man-Sv/y

. . . and Radiation Environment Enhance-ments from Space Weather Activity . . .

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Past (Cycle 22 Max)

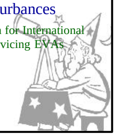
- Solar particle events
  - Only a concern for the less frequent high-inclination Shuttle missions
- Geomagnetic storms in conjunction with solar particle events
  - Reduced geomagnetic cutoffs
  - Concern for the less frequent mid- and high-inclination Shuttle missions
- Outer electron belt enhancements following geomagnetic disturbances
  - Not a concern
  - Not recognized as a concern

Present (Cycle 23 Max)

- Solar particle events
  - Concern for most missions
- Geomagnetic storms in conjunction with solar particle events
  - Reduced geomagnetic cutoffs
  - Concern for most missions
- Outer electron belt enhancements following geomagnetic disturbances
  - Concern for International Space Station construction and servicing EVAs

Future (Cycle 24 Max)

- Solar particle events
  - Concern for most NASA low-Earth orbit missions
  - Concern for any mission outside the magnetosphere
- Geomagnetic storms in conjunction with solar particle events
  - Concern for most NASA low-Earth orbit missions
- Outer electron belt enhancements following geomagnetic disturbances
  - Less of a concern for International Space Station servicing EVAs



. . . requiring Space Radiation Analysis Group (SRAG) Mission Support . . .

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Past (Cycle 22 Max)

- Concept
  - Continuous on-console support from launch through landing
  - Routine space weather monitoring is 0% automated, 100% human operator
- Requires
  - On-console ~ 870 hours per year
  - On-call ~ 0 hours per year
- Cost Savings
  - Baseline—requires 4 flight controllers

Present (Cycle 23 Max)

- Concept
  - Quiet space weather conditions—limited on-console support (4 hours per day); on-call during all off-console periods
  - Disturbed space weather conditions—on-console support during moderate to severe space weather disturbances
  - Continuous on-console support during EVAs
  - Routine space weather monitoring is 10% automated, 90% human operator
- Requires
  - On-console ~ 1640 hours per year
  - On-call ~ 7120 hours per year
- Cost Savings
  - Reduced number of flight controllers
  - $960,000 per year

Future (Cycle 24 Max)

- Concept
  - Routine space weather monitoring is 60% automated, 40% human operator
  - Human support adapted to mission parameters, position in solar cycle, communication capability with crew, etc.
  - Joint international support team (?)
- Requires
  - ?

. . . using Operational Space Weather Data . . .

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Past (Cycle 22 Max)

- Space-based
  - GOES
- Ground-based
  - H-α Patrol (SEON)
  - Transverse magnetic field images (SEON)
  - Magnetometer chains
  - Thule neutron monitor
  - Full-disk radio

Present (Cycle 23 Max)

- Space-based
  - GOES
  - TIROS/POESS
  - SOHO
  - ACE
  - Yohkoh
- Ground-based
  - H-α Patrol (SEON)
  - Transverse magnetic field images (SEON)
  - Magnetometer chains
  - Thule neutron monitor
  - Full-disk radio

Future (Cycle 24 Max)

- Space-based
  - GOES
  - NPOESS
  - "Living with a Star" Program
  - ISS
- Ground-based
  - H-α Patrol (automated)
  - Magnetometer chains
  - Thule neutron monitor (?)
  - SoRBL

. . . Accessed from the NOAA Space Environment Center . . .

Past
(Cycle 22 Max)

- Telnet via modem
  - SELDADS II
  - “capture” data scrolled to screen
- FTP via modem
- Teletype
- Fax
- Paper products
- Satellite broadcast
  - Not used for manned mission support

Present
(Cycle 23 Max)

- Direct data access via TCP/IP on a high-speed internet connection
- Web via high-speed internet connection
- Anonymous FTP

Future
(Cycle 24 Max)

- Direct data access via TCP/IP on a priority high-speed internet connection
- Wireless data access
- Two way communications from anywhere
- ?

. . . and viewed on Space Weather Data Displays . . .

Past
(Cycle 22 Max)

- SELDADS II via modem
  - Mostly text displays—data “captured” to local hard disk for further use
  - Simple static line plots
  - Simple real-time line plots
  - Only 1 plot available at a time
  - Space weather data had to be re-entered or imported into other applications for viewing
- Solar images viewed offline with FTS viewer application
  - Only 1 image viewable at a time
- Rely on displays built by others
- Cost Savings
  - Baseline—0 programmers

Present
(Cycle 23 Max)

- Direct access and viewing of space weather data from custom developed applications
  - SRAG Space Weather Monitor and Alarm + SPE--Real-Time
  - SEC_Display
- Populating databases/data objects with data obtained by anonymous FTP
  - Solar Active Region Display
- Multiple datasets, historical and real-time data plots via Web
- Multiple image viewing via Web
- Build unique, customized displays and applications
- Cost Savings
  - Increased number of programmers
  - -$360,000 per year

Future
(Cycle 24 Max)

- Improved direct access and viewing of space weather data and images from custom developed applications
  - NOAA IDS
  - Integrate space weather data into other radiation environment displays
- Extracting data from XML-based Web pages and displaying or using in customized applications
  - Require current space weather Web sites to convert HTML-based products to XML
  - Need for a community set of tag/attribute standards
- WAP compatible data sources
- High fidelity simulated space weather data
  - NOAA DSS

. . . as well as Space Weather Nowcasts and Forecasts . . .

Past
(Cycle 22 Max)

- Solar Particle Event
  - 3-day event probability forecast — subjective
  - Prediction of SPE based on “big-flare” occurrence
  - Some warning of shock formation from radio bursts
  - Model prediction of on-set time, peak flux, time of peak flux
  - Subjective prediction of shock arrival and magnitude
  - Detection and tracking of event progression from GOES particle detectors
  - Indication of very-high energy particles from ground-level events

Present
(Cycle 23 Max)

- Solar Particle Event
  - 3-day event probability forecast — subjective
  - Prediction of SPE based on “big-flare” occurrence and/or CME observation
  - Some warning of shock formation from radio bursts
  - Model prediction of on-set time, peak flux, time of peak flux
  - Subjective prediction of shock arrival and magnitude
  - Upstream detection of shock arrival from ACE particle and solar wind monitors
  - Detection and tracking of event progression from GOES and ACE particle detectors
  - Indication of very-high energy particles from ground-level events

Future
(Cycle 24 Max)

- Solar Particle Event
  - Improved 3-day event probability forecast
  - Improved prediction of interplanetary shock propagation (e.g., shock arrival)
  - Improved prediction of SPE based following “big-flare” occurrence
  - Detection and tracking of event progression from GOES particle detectors
  - ?—additional observation, monitoring, and forecast improvements will depend on availability of follow-on spacecraft to SOHO, TRACE, ACE, etc.

. . . as well as Space Weather Nowcasts and Forecasts (cont) . . .

Past
(Cycle 22 Max)

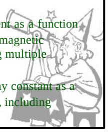
- Geomagnetic Disturbances
  - 3-day event probability forecast from recurrence—subjective
  - No real capability to predict very large events
  - General indication of ejected solar plasma from observation of disappearing filaments
  - Monitor progression of event from magnetometers
- Outer Electron Belt Enhancements
  - No forecast capability
  - Monitor relativistic electron flux at geosynchronous orbit with GOES particle detectors

Present
(Cycle 23 Max)

- Geomagnetic Disturbances
  - Observation of potentially geo-effective coronal holes
  - Indication of ejected material from “halo CMEs”
  - 3-day event probability forecast from recurrence, “halo CMEs,” and coronal holes observations
  - Prediction of very large events—subjective
- Outer Electron Belt Enhancements
  - General forecast capability based on predicted geomagnetic disturbances--subjective
  - Monitor relativistic electron flux at geosynchronous orbit with GOES particle detectors
  - Ineffective monitoring of electron belt enhancements in low-Earth orbit

Future
(Cycle 24 Max)

- Geomagnetic Disturbances
  - Improved prediction of magnetic storm on-set time from improvements in interplanetary shock propagation models
  - Improved prediction of magnetic storm intensity from improved knowledge of CME properties
  - Prediction of very large events—will depend on availability of CME monitoring
- Outer Electron Belt Enhancements
  - Predict magnitude of enhancement as a function of electron energy, including multiple events
  - Predict enhancement as a function of geographic/geomagnetic position, including multiple events
  - Enhancement decay constant as a function of energy, including multiple events



. . . while Radiation Conditions are Monitored at the Vehicle . . .

Past (Cycle 22 Max)

- Telemetered—real time
  - None
- Telemetered—non-real time
  - None
- Non-Telemetered
  - Pocket ion chambers
  - Fixed area monitors (TLDs)
  - Crew exposure monitors (TLDs & CR-39)
  - Point LET spectrum

Present (Cycle 23 Max)

- Telemetered—real time
  - ISS TEPC
    - Dose rate, Q_{avg}
  - EV/IV-CPDS
    - Count rate (proportional to dose rate)
  - R-16 (Russian)
    - Accumulated skin/depth dose
- Telemetered—non-real time
  - Time-resolved ISS TEPC LET spectra
  - EV/IV-CPDS full particle detection information
  - Bonner Ball Neutron Dosimeter count-rate
- Non-Telemetered
  - High rate dosimeters
  - Fixed area monitors (TLDs)
  - Crew exposure monitors (TLDs)

Future (Cycle 24 Max)

- Telemetered—real-time
  - Second generation of ISS monitoring instruments
    - Common set supporting all member groups?
  - External omni-directional electron flux monitor?
  - EVA crew-worn dosimeter
  - ?
- Telemetered—non-real time
  - Crew dosimeter
  - Radiation area monitors
  - High-energy neutron spectrometer
  - ?
- Non-Telemetered
  - ?

. . . and viewed on Flight Controller Radiation Monitor Displays.

Past (Cycle 22 Max)

- None

Present (Cycle 23 Max)

- ISS real-time dose/dose equivalent rate displays
  - TEPC
  - IV-, EV-CPDS (dose rate only)
  - Line and "tiger" plots
  - Single-point vehicle locations only
  - Limited to low-rate "cyclic" data
- ISS and Space Shuttle non-real-time displays
  - Bulk of ISS measurement data available only through batch dumps
  - No telemetry available from Space Shuttle
  - Some ISS data will require too much processing to be available in real-time
  - Information used for periodic crew risk updates, model validations, and research/ development

Future (Cycle 24 Max)

- Real-Time displays of dose/dose equivalent rate throughout vehicle
  - Use point external and internal measurements to extrapolate throughout vehicle
- Real-time displays of dose/dose equivalent from inside EVA suit
- On-board crew dosimeter evaluation/data downlink
- Cumulative medical risks using all operational radiation monitoring data
  - Displays tailored to individual crewmen
- Integrate radiation measurement data into existing space environment applications
  - AF-Geospace

NOAA SEC's Operational Space Weather Models . . .

Past (Cycle 22 Max)

- One simple model
  - PROTONS

Present (Cycle 23 Max)

- Seven models
  - PROTONS
  - THERMAL PROTONS
  - COSTELLO
  - Magnetospheric Specification
  - Killer electron prediction
  - Solar Wind ion vs. shock model
  - Wang-Sheely Solar Wind Model

Future (Cycle 24 Max)

- Undetermined
  - CME Initiation
  - CME Propagation
  - New PROTON models
  - Plus current models

. . . are an important component of Space Weather Forecast & Prediction Accuracy . . .

Past (Cycle 22 Max)

- Solar Flares
  - **Poor**
- Solar Particle Events
  - **Poor**
  - **Forecast of event occurrence—80 %**
  - **SPE False alarm rate—>40%**
  - **Magnitude forecast—three orders of magnitude**
- Geomagnetic storms and interplanetary shock waves
  - **Poor**

Present (Cycle 23 Max)

- Solar Flares
  - Moderate
- Solar Particle Events—poor but increasing with use of new observations.
  - **Forecast of event occurrence—estimated 85%**
  - SPE False alarm rate—30-40%
  - **Magnitude forecast—two orders of magnitude**
- Geomagnetic storms and interplanetary shock waves
  - **Significantly improving with use of new data**

Future (Cycle 24 Max)

- Solar Flares
  - **Moderate to good**
  - Experience remains a major factor in forecasting
- Solar Particle Events—Objectives:
  - **Forecast of event occurrence—90%**
  - **False alarm rate—5 %**
  - **Magnitude forecast—one order of magnitude**
- Geomagnetic storms and interplanetary shock waves
  - Depends on maintaining current experience and solar/interplanetary observation platforms

. . . along with the NOAA SEC Solar Forecasters' Levels of Experience.

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Past (Cycle 22 Max)	Present (Cycle 23 Max)	Future (Cycle 24 Max)
≥ 4 cycles = 0	≥ 4 cycles = 0	≥ 4 cycles = 0
≥ 3 cycles = 0	≥ 3 cycles = 3	≥ 3 cycles = 0
≥ 2 cycles = 4	≥ 2 cycles = 1	≥ 2 cycles = 3
≥ 1 cycle = 2	≥ 1 cycle = 4	≥ 1 cycle = 0
< 1 cycle = 7	< 1 cycle = 4	< 1 cycle = 7 (?)
Total = 13	Total = 12	Total = 10
Total Experience: 14.6 cycles	Total Experience: 18.9 cycles	Total Experience: 8.6 cycles

NASA's Involvement in Operational Space Weather Support . . .

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Past (Cycle 22 Max)

- User only

Present (Cycle 23 Max)

- User
  - SRAG
  - Goddard space flight operations
- Collaborator
  - Data processing hardware
  - Data dissemination system development
  - Unique, customized data displays
- Data supplier
  - SOHO
  - ACE
  - WIND
  - IMAGE
  - POLAR

Future (Cycle 24 Max)

- User
  - SRAG
  - Goddard space flight operations
  - ?
- Collaborator
- Data supplier (?)
  - Depends to large extent on the success of the "Living With a Star" proposal
- Partner with NOAA in joint space weather operations center (?)
- Independent operational space weather office (?)

Top 10 Space Weather Needs—NOAA SEC Provider

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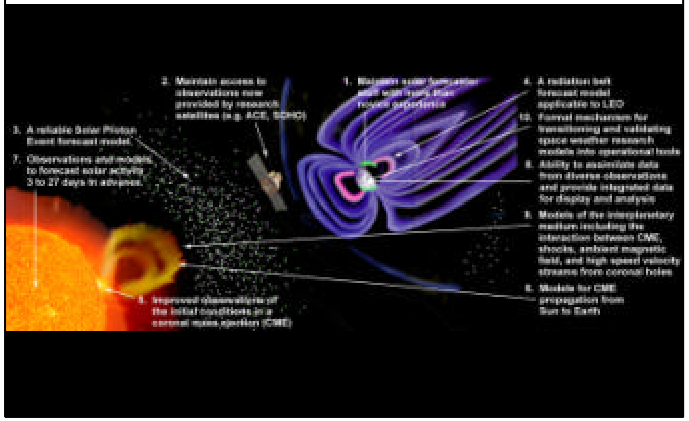

Summary

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- The general understanding of space weather phenomena has improved over the past solar cycle
- The character of U.S. manned missions has changed significantly from the last solar maximum
- Our understanding of space weather concerns for manned missions has changed over the past solar cycle
- The medical risks from space radiation exposure, including that from space weather events, is greater than thought a solar cycle ago
- Space weather during this solar cycle has been monitored with the most capable fleet of spacecraft to date, but *without new programs the level of monitoring will decrease by the next maximum*
- The availability of new data streams and models has out paced the current capability to ingest, reduce, and display the information--more work is needed to develop intelligent displays to help space weather forecasters and users to not only monitor space weather, but accurately predict its behavior in the near future

Summary (cont)

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- Automation—to the extent possible —of space weather monitoring is critical to meet the expected needs of future manned missions within the constraints of tight budgets
  - Automation allows reduced on-console support (e.g., more on-call) with an expected cost savings over 10 years of $6 million
- Space weather monitoring and forecasting over the past three solar cycles has resulted in a small group of highly-experienced space weather forecasters—*the experience level of the space weather forecasters is expected to dramatically diminish by the next solar maximum*
- Obtaining real-time data from future research spacecraft (i.e., “Living With a operational space weather will likely require the operational community to provide the necessary communication infrastructure. Given the cost of providing continuous tracking coverage, this will probably require a multinational effort by space weather groups
  - Current tracking coverage of the ACE spacecraft for real-time solar wind data involves 7 different groups
- Although science has produced significant improvements in the understanding of space weather phenomena and its effects on technical systems, from the NASA user perspective the biggest impact over the past decade are the technological advances (internet capabilities, more powerful computers) which have improved the access to and real-time analysis of critical space weather data.