

ENVIRONMENTAL DEFINITION OF THE EARTH'S NEUTRAL ATMOSPHERE

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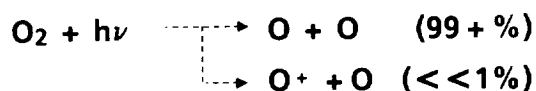
PRELIMINARY. DATA PLANS NOT FILMED

ENVIRONMENTAL DEFINITION OF THE EARTH'S NEUTRAL ATMOSPHERE

- ALTHOUGH NUMBER DENSITIES ARE LOW (10^6 - 10^9 PARTICLES/ cm^3) AT ALTITUDES WHERE SPACECRAFT TYPICALLY OPERATE, HIGH ORBITAL SPEEDS (8 km/S) RESULT IN INCIDENT FLUXES (10^{14} - 10^{15} atoms/S cm^2) AND COLLISIONAL ENERGIES (TRANSLATIONAL ENERGIES EQUIVALENT TO $\sim 60,000$ °K) LARGE ENOUGH TO INTERACT WITH AND DEGRADE MATERIAL SURFACES
- DURING PREVIOUS STS MISSIONS (STS-5, -8, AND -41G), SURFACE RECESSIONS AS HIGH AS 0.5 μm PER ORBIT HAVE OCCURRED FOR ORGANIC MATERIALS EXPOSED TO THE FLIGHT ENVIRONMENT
- SIMILAR EFFECTS HAVE BEEN OBSERVED FOR SOME METALS, MOST NOTABLY OSMIUM AND SILVER, WHICH BECOME HEAVILY OXIDIZED DURING LEO (LOW-EARTH ORBIT) EXPOSURE
- STS POST-FLIGHT RESULTS ARE CONSISTENT WITH AN ATOMIC OXYGEN-BASED MECHANISM

ATOMIC OXYGEN PRODUCTION MECHANISM

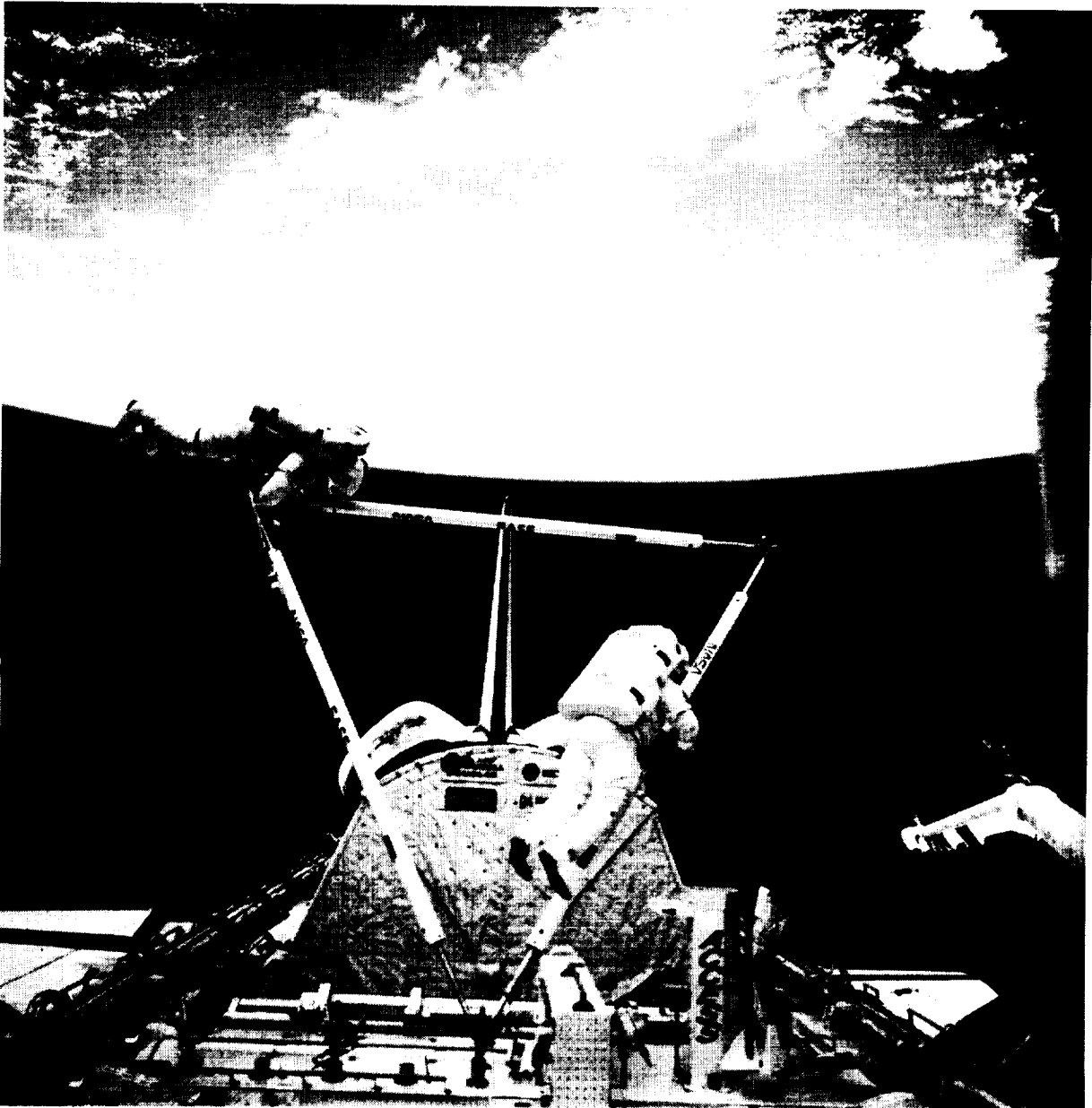
- EARLIER SATELLITE MEASUREMENTS HAVE SHOWN ATOMIC OXYGEN IS THE PREDOMINANT SPECIES IN THE UPPER ATMOSPHERE (200 TO 600 km) -- IT IS FORMED AT ORBITAL ALTITUDES THROUGH THE DISSOCIATION OF O_2 BY ULTRAVIOLET (100 TO 200 nm) RADIATION:



- DIURNAL AND SEASONAL VARIATIONS IN ATOMIC OXYGEN NUMBER DENSITY MAY BE PREDICTED USING GLOBAL MODELS OF THE EARTH'S UPPER ATMOSPHERE

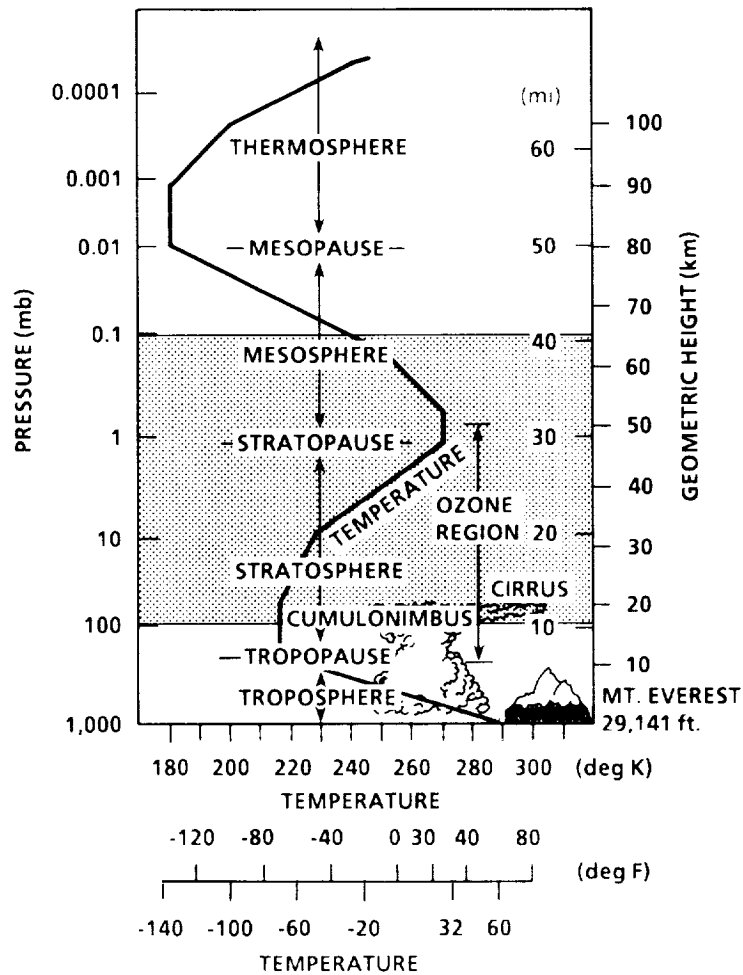
View of the Earth and Its Atmosphere as Observed from Space

The visible atmosphere shown in this photograph was obtained from Shuttle Mission 61-B during December 1985. In this photograph, Mission Specialists Jerry L. Ross and Woody Spring are shown assembling the EASE (Experimental Assembly of Structures in Extravehicular Activity) flight experiment. The lower atmosphere appears as a thin glow above the surface of the Earth. This glow results from emissions produced as excited oxygen molecules decay to their ground state, and extends upward to the edge of the mesosphere, or mesopause. The Earth's upper atmosphere begins above the region where the visible glow disappears, or about 85 km in altitude.



Vertical Temperature Distribution in Earth's Atmosphere from Surface to 100 km Altitude, Giving Nomenclature of Atmospheric Regions

The Earth's atmosphere is divided into specific regions. In the most commonly used system, these regions are differentiated by thermal stratification. The lowest region, extending from sea level to the first temperature minimum, is called the troposphere. The stratosphere, or second region, extends upward to the level of highest temperature. The upper atmosphere may be defined as the region above the mesopause, or upper temperature minimum, and extends from about 85 km to geostationary altitudes. Global thermospheric models are designed to operate within this region of the atmosphere. Their specific formulations give accurate estimates of temperature, density, and composition and are based on in situ measurements from the Atmospheric Explorer and Dynamics Explorer satellites. The upper atmosphere may be further divided into the thermosphere (85 to 500 km), and the exosphere (500 km and above). Spacecraft normally operate in the upper atmosphere at altitudes above 300 km to reduce drag effects, which are significant at lower altitudes, and minimize requirements for re-boost propulsion systems.



GLOBAL THERMOSPHERIC MODELS

- MOST RECENT GLOBAL MODELS INCLUDE J77 (JACCHIA, 1977), AND MSIS-86 (MASS SPECTROMETER AND INCOHERENT SCATTER, 1986)
- EARLIER JACCHIA MODELS (J70) WERE BASED SOLELY ON SATELLITE DRAG DATA AND DID NOT ACCURATELY REPRESENT CONSTITUENT DENSITY VARIATIONS ASSOCIATED WITH GEOMAGNETIC DISTURBANCES
 - THESE VARIATIONS WERE ASSUMED TO BE UNIFORM OVER THE GLOBE, WHILE MORE RECENT DATA HAVE SHOWN THEY HAVE VERY SIGNIFICANT GLOBAL STRUCTURE, MAINLY IN RELATION TO GEOMAGNETIC LATITUDE
 - J77 RESOLVED EARLIER DISCREPANCIES BY INCORPORATING SATELLITE MASS SPECTROMETER MEASUREMENTS AND INCLUDING A HIGH-RESOLUTION MODEL OF GEOMAGNETIC VARIATIONS IN THE THERMOSPHERE (85-500 km) AND OUTER ATMOSPHERE, OR EXOSPHERE (500 km AND ABOVE)
- IN FORMULATING MSIS-86, TERMS WERE ADDED TO MSIS-83 TO BETTER REPRESENT SEASONAL VARIATIONS IN THE POLAR REGIONS UNDER BOTH QUIET AND MAGNETICALLY DISTURBED CONDITIONS
- MSIS-86 AND J77 AVERAGE TEMPERATURE AND TOTAL DENSITY ESTIMATIONS AGREE TO WITHIN 10% OF ONE ANOTHER

MSIS 86 THERMOSPHERIC MODEL

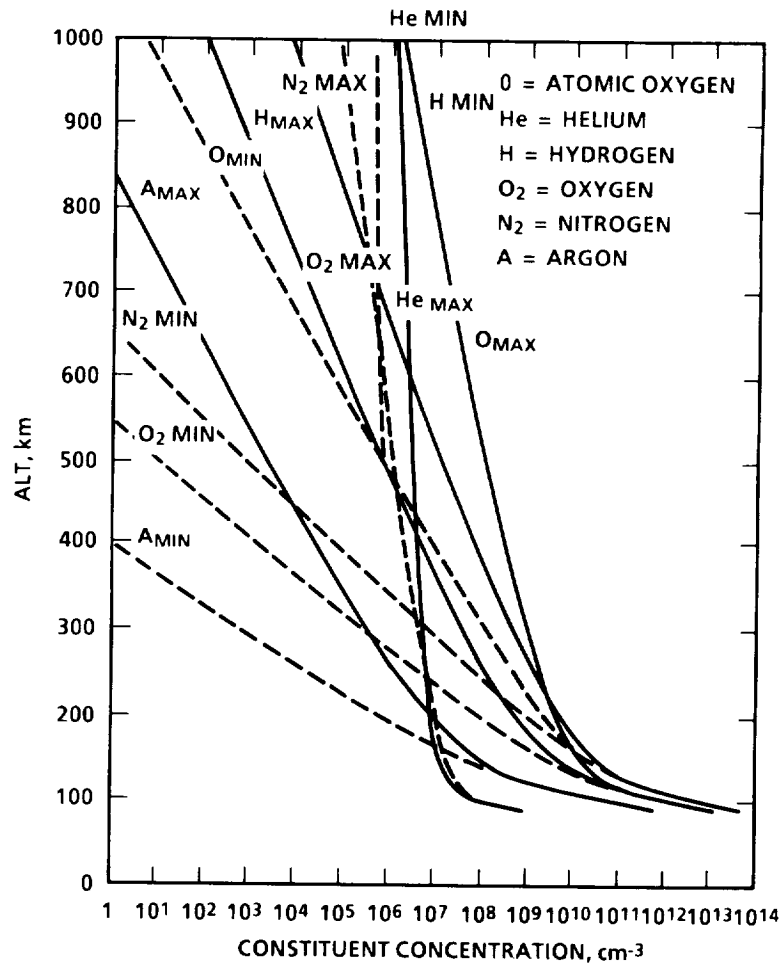
- THE MSIS 86 MODEL, DEVELOPED BY GSFC, IS FREQUENTLY USED TO PREDICT CONSTITUENT NUMBER DENSITIES FOR SHUTTLE AND SPACE STATION ATOMIC OXYGEN INTERACTION STUDIES
- MODEL IS BASED ON IN-SITU DATA FROM SATELLITES, SUCH AS ATMOSPHERIC EXPLORER AND DYNAMICS EXPLORER, AND GROUND-BASED INCOHERENT SCATTER STATIONS:
 - OUTPUT DATA INCLUDE BOTH TEMPERATURE PROFILES AND CONSTITUENT (N_2 , N, O_2 , O, He, H, Ar) NUMBER DENSITIES WITHIN A 85-750 km ALTITUDE RANGE
 - MODEL ASSUMES TURBULENT MIXING OCCURS BELOW THE TURBOPAUSE (NOMINALLY 105 km), AND DIFFUSIVE EQUILIBRIUM EXISTS AT HIGHER ALTITUDES:
 - MESOSPHERE - 50-85 km
 - THERMOSPHERE - 85-500 km
 - EXOSPHERE - 500-∞ km
- HEAVIER GASES (N_2 , O_2 , Ar) HAVE SMALLER SCALE HEIGHTS AND DECREASE MORE RAPIDLY WITH INCREASING ALTITUDE -- LIGHTER GASES (H, He, O) HAVE LARGER SCALE HEIGHTS AND DECREASE MORE SLOWLY WITH ALTITUDE
- CONSTITUENT CONCENTRATIONS ARE STRONGLY INFLUENCED BY SOLAR ACTIVITY CONDITIONS AND GEOMAGNETIC DISTURBANCES WHICH VARY WITH THE 11-YEAR SOLAR CYCLE

SOLAR ACTIVITY VARIATIONS IN CONSTITUENT NUMBER DENSITIES

- **EXOSPHERIC TEMPERATURE AND NUMBER DENSITY OF ALL CONSTITUENTS, EXCEPT HYDROGEN AND MOLECULAR OXYGEN, INCREASE WITH SOLAR ACTIVITY**
- **AS SOLAR ACTIVITY INCREASES, ATMOSPHERE EXPANDS AND REGIONS OF HIGH DENSITY RISE TOWARD HIGHER ALTITUDES TO REPLACE REGIONS OF LOWER DENSITY**
- **GEOMAGNETIC STORMS OCCUR WHEN CLOUDS OF CHARGED PARTICLES INTERACT WITH THE EARTH'S MAGNETOSPHERE -- DENSITY INCREASES PRIMARILY IN THE POLAR REGIONS, BUT EFFECTS ARE ALSO SEEN AT LOWER LATITUDES**
- **UNDER MAGNETICALLY QUIET CONDITIONS, N₂, O₂, AND Ar DENSITIES INCREASE TOWARD THE POLES WHILE O, N, He, and H DECREASE IN DENSITY**

Plot of Constituent Number Density in Earth's Atmosphere
from
100 to 1,000 km Altitude

At altitudes where LEO (low-Earth orbital) spacecraft typically operate (300 to 500 km), constituent number densities vary in direct proportion to solar activity. Higher atomic oxygen number densities result in higher fluxes incident on spacecraft surfaces and, consequently, in higher surface recession rates for reactive materials. During conditions of high solar activity (Curve O_{MAX} shown in the figure below), the O-atom number density varies from 10^9 to 10^8 atoms/cm³ over an altitude range of 300 to 500 km. During conditions of low solar activity, variations over these altitudes are reduced to 10^8 to 10^6 atoms/cm³. Consequently, spacecraft launched during times of minimum solar activity experience less exposure to the neutral O-atom environment than spacecraft launched during times of high activity. Typically, a Space Shuttle mission is flown at an altitude near 300 km. For these missions, the atomic oxygen number density varies between 10^8 and 10^9 atoms/cm³ during the 11-year solar cycle. Spacecraft flown at a higher altitude of 500 km would encounter much lower number densities (10^6 to 10^8 atoms/cm³) during the same exposure period.



MIN SOLAR CONDITIONS: 0400 hr USING $\bar{F}_{10.7} = 70$ & $\bar{A}_p = 0$

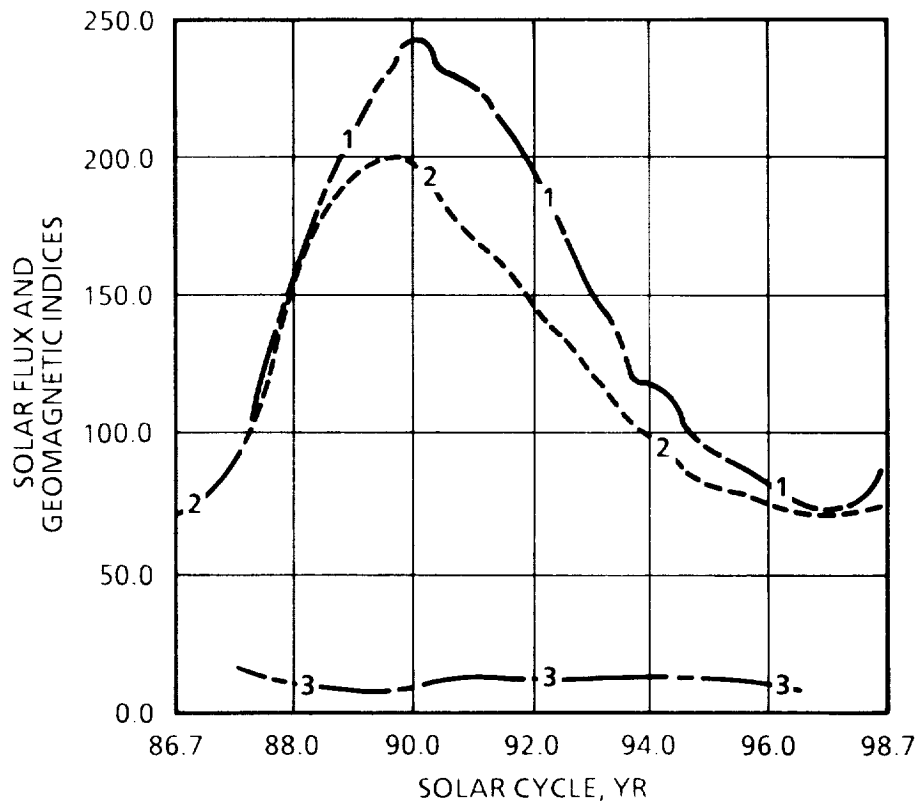
MAX SOLAR CONDITIONS: 1400 hr USING $\bar{F}_{10.7} = 230$ & $\bar{A}_p = 35$

Solar Activity Predictions for Cycle 22

In the thermosphere, the density is strongly influenced by changing levels in solar activity. Both radiant energy and charged particles are emitted by the Sun's surface. It is largely the ultraviolet (UV) and extreme ultraviolet (EUV) radiation emitted by the Sun that heats the upper atmosphere and produces changes in the constituent number density. One component of this radiation relates to the active regions on the solar disk and varies from day-to-day in direct proportion to the ebb and flow of sunspot activity. The other component relates to the solar disk itself and moves more slowly with the 11-year solar cycle. The intensity of this component is measured directly by the $F_{10.7}$ number, which is shown in the figure below. This number represents the radio flux density (in units of 10^4 Jansky, or 10^{-22} watts/m²/S/bandwidth) at 10.7 cm wavelength, and is used as a measure of solar activity because it correlates well with radiation absorbed by the upper atmosphere. The A_p number, also shown in this figure, is a measure of variations in the Earth's magnetic field intensity. Charged particles emitted by the Sun spiral along the Earth's magnetic field lines and also contribute to heating of the atmosphere, but to a much lesser extent than the Sun's radiant energy. Increases in the A_p number (geomagnetic index) result in higher number densities at any given altitude.

LEGEND

- 1 = SOLAR FLUX $F_{10.7}$ + 2 SIGMA, (10E4 JANSKY)
- 2 = SOLAR FLUX $F_{10.7}$ (10E4 JANSKY) PREDICTED
- 3 = GEOMAGNETIC INDEX MEAN



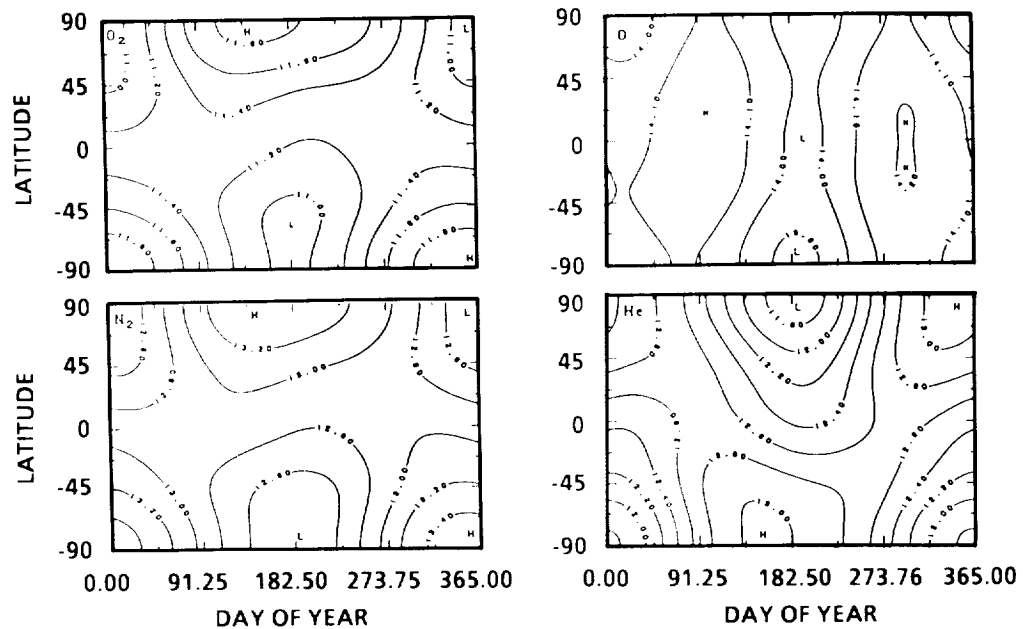
0-3

SEASONAL VARIATIONS IN CONSTITUENT NUMBER DENSITY

- ALL CONSTITUENTS HAVE A SIGNIFICANT (5-10%) SEMIANNUAL VARIATION IN NUMBER DENSITY DUE TO SUN BEING ABOVE THE EQUATOR DURING SUMMER MONTHS, AND BELOW THE EQUATOR DURING MONTHS OF WINTER
- ATOMIC OXYGEN HAS A SUMMER MAXIMUM AT HIGHER ALTITUDES, AND A WINTER MAXIMUM AT LOWER ALTITUDES
- BOTH ATOMIC OXYGEN AND ATOMIC NITROGEN UNDERGO A SEMIANNUAL VARIATION IN NUMBER DENSITY
- AND AT HIGHER ALTITUDES, THEIR MAXIMUM DENSITIES OCCUR NEAR THE EQUINOXES
- HEAVIER SPECIES (O_2 , N_2 , Ar) EXPERIENCE LOWEST DENSITIES DURING WINTER MONTHS, AND HIGHEST DENSITIES DURING SUMMER MONTHS
- CONVERSELY, HIGHEST DENSITIES FOR THE LIGHTER SPECIES (H, He) OCCUR DURING WINTER MONTHS

Contour Plots of Diurnally Averaged Number Densities of O₂, N₂, O and He at 400 km Altitude during Nominal Solar Activity Conditions

All constituents in the upper atmosphere have a significant (5 to 10 percent) semiannual variation in number density, which results from the Sun being above the equator during summer months and below the equator during the months of winter. Atomic oxygen behaves differently than the other species in that it experiences a winter maximum at lower altitudes and a summer maximum at higher altitudes. During months of summer, O (as well as N) exhibits maximum density near the equinoxes. In the northern hemisphere, O₂ and N₂ have highest densities during summer months and lowest densities during winter months. Conversely, He, which is a lighter species, has its highest density during winter months. These results from the MSIS-86 model are consistent with data obtained from the Explorer Satellites, which have demonstrated helium experiences a winter density bulge in the exosphere. The formation of this bulge near the polar region may be attributed to seasonal winds in the thermosphere. The mechanism of this bulge and its variation with latitude are, however, still under investigation.



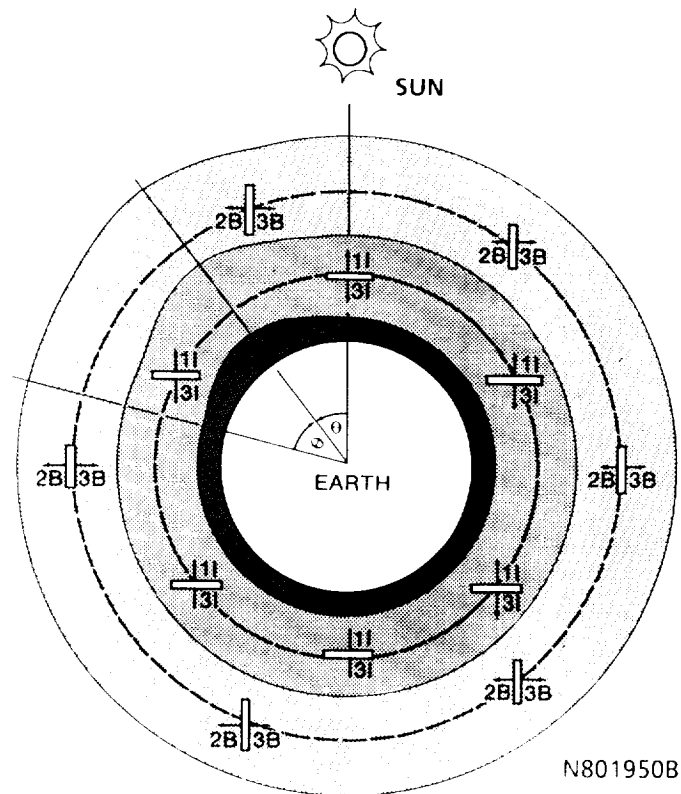
(LOGARITHM TO BASE 10) OF O₂, N₂, O AND He AT 400 km ALTITUDE DURING NOMINAL SOLAR CONDITIONS. NOTE O (AS WELL AS N) EXHIBITS MAXIMUM DENSITY NEAR THE EQUINOXES. IN NORTHERN HEMISPHERE, O₂ AND N₂ HAVE HIGHEST DENSITIES DURING SUMMER MONTHS; He, WHICH IS A LIGHTER SPECIES, HAS ITS HIGHEST DENSITY DURING WINTER MONTHS (SOURCE: NASA/GSFC: H. HEDIN, 1987)

DINURAL VARIATIONS IN CONSTITUENT NUMBER DENSITIES

- **NEAR EQUATORIAL LATITUDES, A DENSITY BULGE DURING DAYLIGHT HOURS IS PRODUCED BY SOLAR HEATING OF THE ATMOSPHERE**
- **DIURNAL WINDS IN THE THERMOSPHERE CAUSE TOTAL DENSITY INCREASES TO LAG SUB-SOLAR POINT - BULGE OCCURS ABOUT 30° EAST OF SOLAR NOON AND MIGRATES NORTH AND SOUTH AS SUN'S DECLINATION ANGLE CHANGES**
- **CONSTITUENT NUMBER DENSITIES DO NOT EACH MAXIMIZE AT SAME LOCAL TIME**
 - **HELIUM EXPERIENCES A MORNING MAXIMUM IN NUMBER DENSITY**
 - **ATOMIC OXYGEN (AO) REACHES MAXIMUM DENSITY APPROXIMATELY 40° EAST OF SOLAR NOON**
- **AT ANY GIVEN HEIGHT ABOVE 120 km, MAXIMUM DENSITY OCCURS WITHIN THE CENTER OF DENSITY BULGE - SATELLITES MOVING THROUGH THIS REGION PERIODICALLY EXPERIENCE ENHANCED AO EFFECTS**

Surface Orientations Relative to Atomic Oxygen Density at Solar Noon

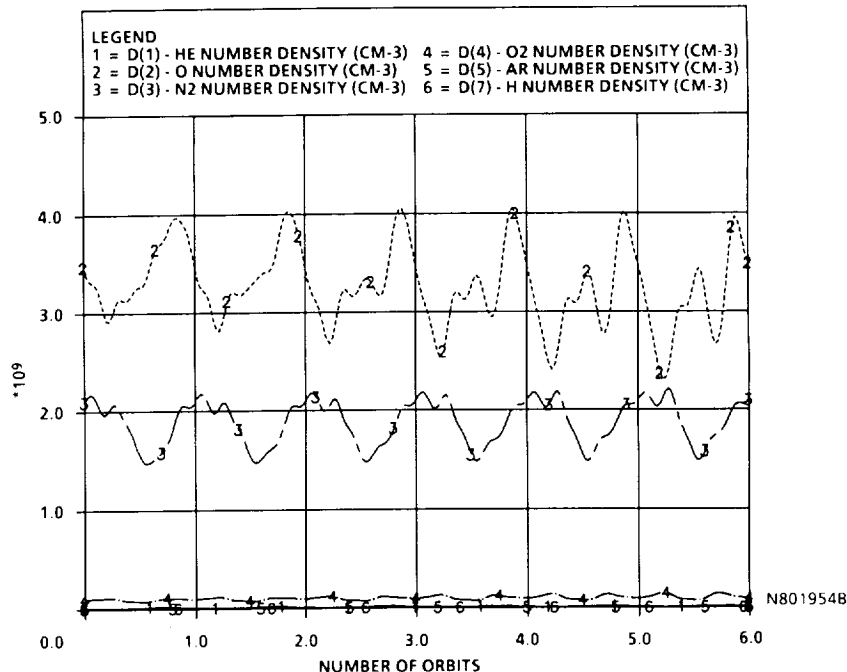
Diurnal (24 hr.) variations of density occur in the upper atmosphere and result from the Earth's rotation about its axis. During rotation, regions of the atmosphere illuminated by the Sun are warmed by its rays, and regions in darkness are cooled by radiative heat loss to space. These variations become more pronounced at higher altitudes. At an altitude of 200 km, the nightside and dayside densities are about the same. At 600 km altitude, the dayside density may become a factor of eight higher than the nightside density during conditions of high solar activity. The total density has a maximum around 1400 hrs. local solar time (30° east of solar noon) at a latitude equal to that of the sub-solar point, and a minimum around 0300 hrs. at about the same latitude in the opposite hemisphere. These effects are attributed to absorption of EUV radiation by the neutral atmosphere, followed by heat conduction downward toward lower altitudes. Diurnal winds in the thermosphere cause the densities of individual constituents to maximize at different local times. Helium maximizes during the mid-morning hours, about 30° west of solar noon. Atomic oxygen reaches its maximum density about 40° east of solar noon. Note from the figure shown below, spacecraft surfaces, such as Surfaces 3I and 2B, which fly through this bulge in atomic oxygen density will experience higher fluxes than surfaces protected from it because of wake effects.



SIMULATED SURFACES
1I: SOLAR-VIEWING
3I: ANTISOLAR
2B: SPACE-VIEWING, RAM
3B: SPACE-VIEWING, WAKE

SDIO DELTA STAR FLUENCE PREDICTIONS

ALT = 120NMI, INCL = 50 DEG, EXPOSURE: 6 ORBITS



ATOMIC OXYGEN SURFACE INTERACTION STUDIES

- PREVIOUS STS EXPERIMENTS HAVE SHOWN SURFACE RESSION OF TYPICAL SPACECRAFT MATERIALS IS DIRECTLY RELATED TO FLUENCE, OR TOTAL INTEGRATED FLUX, DETERMINED OVER THE EXPOSURE PERIOD:
 - FLUX = NUMBER DENSITY TIMES ORBITAL VELOCITY
 - FLUENCE = FLUX TIMES EXPOSURE PERIOD
- ATOMIC OXYGEN NUMBER DENSITY MAY BE DETERMINED FOR EACH ORBITAL PASS USING GLOBAL THERMOSPHERIC MODELS
- SPACECRAFT VELOCITY IS DERIVED USING ORBITAL MECHANICS EQUATIONS
- FLUENCE PER ORBIT IS OBTAINED BY MULTIPLYING PRODUCT OF VELOCITY AND DENSITY TIMES THE ORBITAL PERIOD (NOMINALLY, 90 MINUTES) EXPRESSED IN SECONDS
- TOTAL FLUENCE IS THEN DETERMINED BY SUMMING FLUENCE OBTAINED DURING EACH ORBITAL PASS OVER THE TOTAL NUMBER OF ORBITS MADE DURING THE MISSION -- CALCULATIONS ARE STRAIGHTFORWARD FOR RAM-ORIENTED EXPOSURES
- DIFFICULTIES ARISE, HOWEVER, WHEN THE INCIDENT FLUX IS NOT ALWAYS NORMAL TO THE SURFACE, SUCH AS FOR SOLAR INERTIAL OR SUN-SYNCHRONOUS SATELLITES

FLUENCE COMPUTATIONAL MODEL

- COMPUTATIONAL PROGRAMS ARE AVAILABLE TO COMPUTE FLUENCES INCIDENT ON SPACECRAFT SURFACES IN LOW-EARTH ORBIT FOR A VARIETY OF EXPOSURE ATTITUDES
- MODEL IS GENERALIZED AND INCLUDES CONDITIONS OF EITHER NORMAL OR OBLIQUE (SWEEPING) IMPINGEMENT -- SURFACE ORIENTATIONS AND INITIAL ORBITAL CONDITIONS DEFINED PRIOR TO PROGRAM EXECUTION:
 - SURFACES ARE SPECIFIED BY: (1) SPACECRAFT ALTITUDE, (2) ORBIT INCLINATION, (3) EARTH LONGITUDE AND LATITUDE OF FIRST NODAL CROSSING, (4) LOCAL SOLAR TIME, (5) YEAR, MONTH, AND DAY SIMULATION WILL BEGIN, AND (6) MISSION DURATION
 - SPACECRAFT IS PERMITTED TO ADVANCE THROUGH ITS ORBIT IN DISCRETE STEPS -- AVERAGE AO DENSITY MIDWAY THROUGH PATH DISTANCE TRAVELED IS OBTAINED USING MSIS-86 THERMOSPHERIC MODEL
 - EQUATIONS ARE USED TO DETERMINE ORBITAL VELOCITY NORMAL TO EACH SURFACE UNDER STUDY
 - AO FLUENCE IS DETERMINED USING VALUES OF AVERAGE DENSITY, RELATIVE VELOCITY, AND EXPOSURE DURATION ALONG EACH PATH-LENGTH TRAVELED
 - INCREMENTAL EXPOSURES OBTAINED DURING PROGRAM OPERATION ARE THEN SUMMED OVER DURATION OF SIMULATION TO OBTAIN TOTAL FLUENCE INCIDENT ON EACH SPACECRAFT SURFACE UNDER STUDY

SPACECRAFT FLUENCE PREDICTIONS

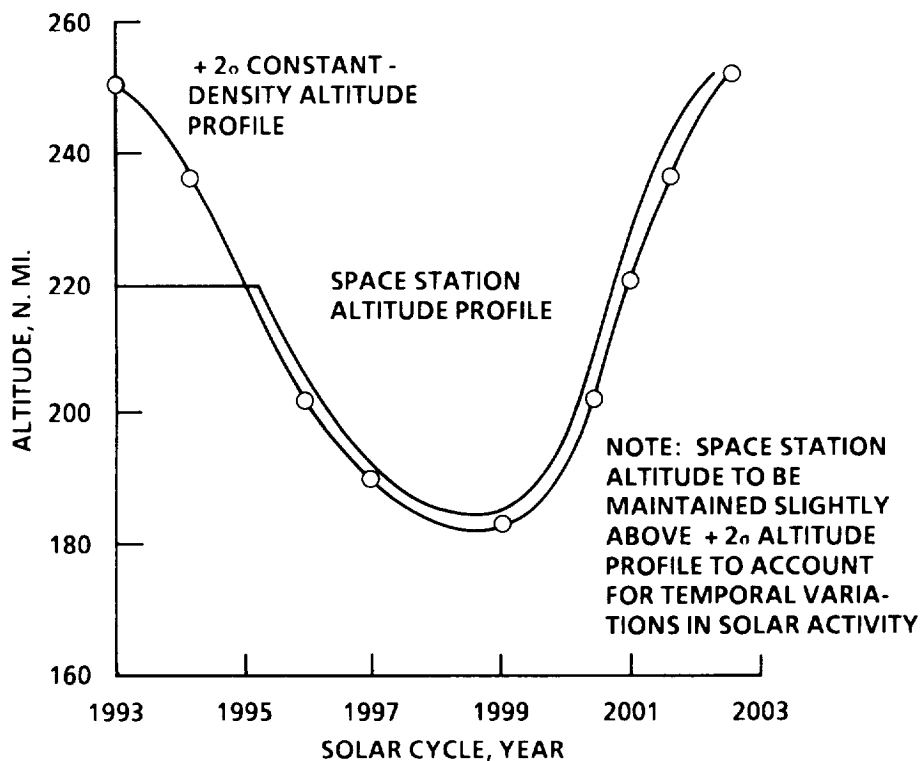
SPACECRAFT PROGRAM	EXPOSURE ALTITUDE, NMI	ORBIT INCLINATION	MISSION DURATION	ATOMIC OXYGEN FLUENCE, ATOMS/cm ²	ESTIMATED SURFACE RECESSON, MILS (KAPTON)*
DELTA STAR	120	50°	7 DAYS	1.5 X 10 ²¹ (RAM)	1.8
DELTA STAR	176	50°	3 MONTHS	9.0 X 10 ²⁰ (SI)	1.1
DELTA STAR	176	50°	1 YEAR	3.5 X 10 ²¹ (SI)	4.1
SPACE TELESCOPE	320-260	28.5°	5 YEARS	4.0 x 10 ²¹ (RAM)	4.7
SPACE TELESCOPE	320-260	28.5°	5 YEARS	1.4 x 10 ²¹ (SI)	1.7
SPACE STATION	250-180	28.5°	30 YEARS	1.5 X 10 ²³ (RAM)	177
SPACE STATION	250-180	28.5°	20 YEARS	5.5 X 10 ²² (SI)	65

* SURFACE RECESSON = **MATERIAL REACTION EFFICIENCY (cm³/atom) X AO FLUENCE (atoms/cm²), WHERE

** REACTION EFFICIENCY = VOLUME OF MATERIAL LOSS PER INCIDENT OXYGEN ATOM (3.0 X 10⁻²⁴cm³/atom FOR KAPTON)

Space Station Freedom Altitude Strategy for Surface Interaction Studies

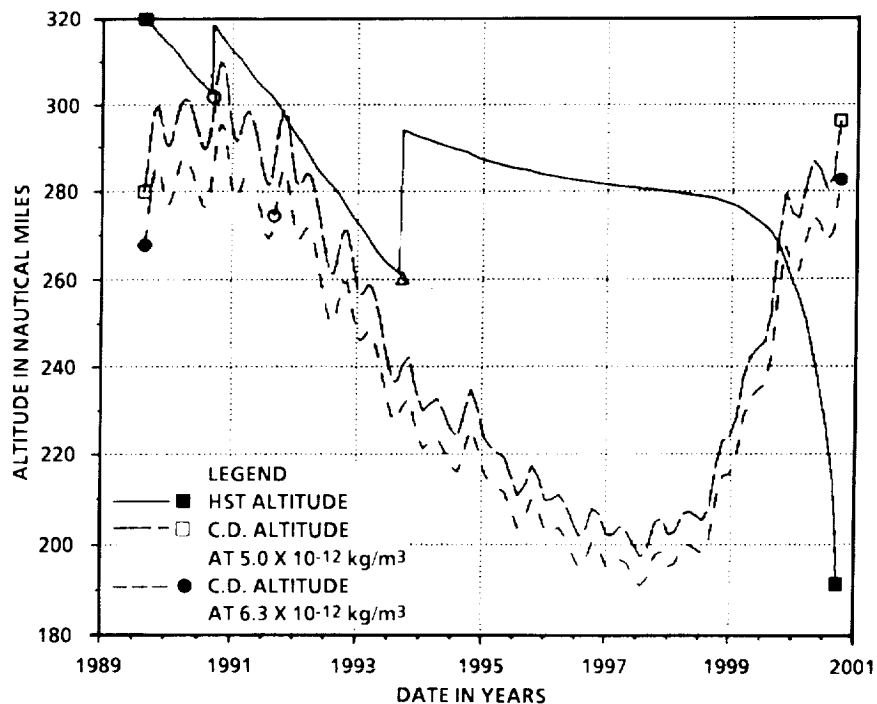
During conditions of high solar activity, the atmosphere expands and the drag on spacecraft surfaces increases substantially. Spacecraft flying at low altitudes during solar maximum experience higher deceleration forces and must be re-boosted to higher altitudes to remain in stable orbit about the Earth. Not only does drag often dictate requirements for re-boost capability, but it usually restricts use of sensitive microgravity experiments. As is illustrated in this figure, a variable altitude strategy has been baselined for Space Station Freedom which reduces the amount of atmospheric drag it will experience during the next solar cycle. During periods of high solar activity, Space Station Freedom will be operated at high altitudes (220 to 250 nmi) to minimize deceleration forces on its sensitive microgravity experiments. As solar activity decreases, the altitude of Space Station Freedom will be reduced to maintain number density constant. Since variations in orbital velocity over this altitude range are very small, constant density will result in constant aerodynamic drag. At Solar minimum, Space Station Freedom will have attained its lowest (180 nmi) altitude. As solar activity increases to its maximum level, aerodynamic drag will once again be controlled by boosting Freedom to higher altitudes at rates which maintain the number density constant. This strategy will result in significant savings in STS operations costs -- it will reduce the number of Shuttle resupply flights for Space Station Freedom because the Orbiter can deliver more payload weight to lower altitudes than it can to higher altitudes. However, when compared to a constant altitude strategy, the constant density strategy will increase the atomic oxygen fluence on Space Station surfaces by about a factor of four. Thus, when compared to a constant altitude strategy, the need for protective coatings to limit AO surface interactions becomes even more significant.



Hubble Space Telescope Predicted and Constrained Orbital Altitudes

The Hubble Space Telescope (HST) is a Shuttle-launched and serviced satellite designed to have an operational life over many years. To meet these lifetime requirements, on-orbit maintenance is planned, with major refurbishment accomplished by retrieval and return to Earth. The HST is designed to operate in a 28.5° inclined circular orbit at altitudes from 320 to 215 nmi (593 to 398 km). The satellite will be deployed at an altitude just high enough so that "worst case" aerodynamic drag will not cause it to decay below 215 nmi at the end of a 5-year period. Lifetime predictions are strongly dependent on assumptions made about the degree of solar activity, as high activity increases the atmospheric density at a given altitude, thereby increasing the drag force and shortening vehicle life. Given current solar activity predictions (see constant density curves shown below), the HST must be reboosted twice by the Space Shuttle during its 5- to 7-year lifetime. The first reboost will occur approximately 1 year after launch, and is required to maintain the satellite above the 6.3×10^{-12} kg/m³ density curve encountered early-on during its mission. Assuming a reboost flight is delayed by several months, reaction wheels aboard the HST will have to spin at higher speeds to maintain attitude control within the high aerodynamic drag environment, and excessively long times will occur between target acquisitions. Even longer delays would saturate the reaction wheels, and attitude control would then be lost altogether. To avoid these problems, NASA will dedicate a Shuttle flight to reboost the HST early in its mission. Also note from this figure, a second reboost flight will occur approximately 4 years after the HST is delivered to orbit, during which time its batteries and solar arrays will be changed out to extend its lifetime.

STS LAUNCH DATE OF 8/31/89, $F_{10.7}(\text{PEAK}) = 245$
 ALTITUDE VARIATIONS FOR DENSITIES OF 5.0×10^{-12} AND 6.3×10^{-12} kg/m³ (+ 2σ DENSITY CURVES)



SOURCE: NASA/MSFC; V. BUCKELEW

CONCLUSIONS

- **ATOMIC OXYGEN IS THE MOST ABUNDANT CONSTITUENT IN THE LOW-EARTH ORBIT ENVIRONMENT:**
 - **AT ORBITAL ALTITUDES, NEUTRAL ATMOSPHERE CONSISTS PRIMARILY OF 80% ATOMIC OXYGEN AND 20% MOLECULAR NITROGEN**
 - **INCREASES IN SOLAR ACTIVITY LEAD TO HIGHER ATOMIC OXYGEN NUMBER DENSITIES**
 - **OXYGEN DENSITY DECREASES EXPONENTIALLY WITH INCREASING ALTITUDE**
- **GLOBAL THERMOSPHERIC MODELS, WHEN COMBINED WITH ORBITAL MECHANICS MODELS, MAY BE USED TO PREDICT ATOMIC OXYGEN FLUENCE, OR TOTAL INTEGRATED FLUX, INCIDENT ON SPACECRAFT SURFACES:**
 - **RAM-ORIENTED SURFACES RECEIVE MORE FLUENCE THAN SOLAR INERTIAL SURFACES**
 - **MISSIONS OF LONG DURATION MORE SEVERELY AFFECTED THAN MISSIONS OF SHORT DURATION**
 - **MISSIONS CONDUCTED DURING PERIODS OF LOW SOLAR ACTIVITY LESS SEVERELY AFFECTED THAN MISSIONS DURING HIGH ACTIVITY**
- **FLUENCE PREDICTIONS, WHEN USED WITH STS MATERIAL REACTIVITY MEASUREMENTS, PROVIDE RELIABLE ESTIMATES OF THE OXIDATIVE EFFECTS ON SPACECRAFT SURFACES**