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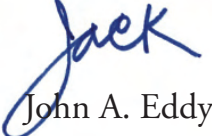
## ACKNOWLEDGMENT

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John A. Eddy





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# GLOSSARY OF TECHNICAL TERMS

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## A

### *absorption line*

a dark line in the spectrum of sunlight produced by the absorption of light of a specific wavelength by an identifiable chemical element, such as hydrogen or iron

### *active prominences*

a broad class of solar prominences of a dynamic nature, including eruptive prominences, radially-structured (as opposed to helical) prominences called sprays, and loop-shaped prominences, all of which are generally associated with flares

### *active region*

a complex area of concentrated magnetic field on the surface of the Sun where sunspots, faculae, plages (bright regions in the chromosphere) and filaments occur together

### *adaptive optics*

optical elements in a telescope that are designed to automatically compensate for the effects of atmospheric turbulence and other disturbances

### *aerosol*

a fine, solid or liquid particle suspended in air, such as a dust mote

### *alpha particle*

the nucleus of a helium atom, made up of two protons and two neutrons

### *anomalous cosmic ray; ACR*

a lower-energy cosmic ray created within the outer heliosphere when neutral atoms from the interstellar medium are ionized by solar short-wave radiation

### *anthropogenic*

of human origin

### *astronomical unit (A.U.)*

the average distance from the Earth to the Sun, about 93 million miles

*Technical or semi-technical words introduced in the text are printed in blue generally where they first appear in the text. They are then defined in alphabetical order in the Glossary.*

*atom*

the smallest unit of a chemical element (such as helium or carbon) that exhibits the properties characteristic of that element

*atomic weight*

the sum of the number of protons and neutrons in the nucleus of an atom

*aurora*

diffuse, glowing light emitted from atoms and molecules in the Earth's upper atmosphere when incoming high energy particles from the Sun or the Earth's magnetosphere collide with them

*aurora australis*

aurorae that appear in the Earth's southern hemisphere

*aurora borealis*

aurorae that appear in the Earth's northern hemisphere

*auroral oval*

a belt of latitude, several hundred miles wide and centered on the north or south magnetic pole, in which most aurorae occur

*auroral substorms*

particle-induced disturbances in the magnetosphere which are linked to the brightest and most dynamic aurorae

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**B**

*biosphere*

that part of the Earth's surface, atmosphere, and oceans where life can exist

*bow shock*

the shock wave formed in a plasma stream when it comes upon a barrier such as the Earth's magnetosphere, which deflects, slows and heats the incoming plasma. So-named because of its similarity to the curved "bow wave" which forms in the water ahead of the bow of a moving ship

*bulk speed; bulk motion*

the average speed of individual particles within a streaming cloud of plasma, such as a solar wind stream

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## C

### *carbon cycle*

the ongoing exchange of carbon among living things, the atmosphere, the oceans and the Earth's surface

### *Cêrenkov radiation*

electromagnetic radiation emitted by an atomic particle traveling through a medium at a speed that exceeds the speed of light in that medium

### *chromosphere*

a highly-structured layer in the Sun's atmosphere that lies between the cooler photosphere and the much hotter corona

### *chromospheric network*

the pattern of bright interconnected lines in the solar chromosphere that delineate the strong magnetic fields that exist at the boundaries of the closely-packed supergranulation cells

### *climate sensitivity*

the change in the Earth's mean surface temperature expected in response to a 1% change in the total solar radiation received at the top of the Earth's atmosphere

### *closed field line*

a magnetic line of force that connects regions of opposite magnetic polarity, as for example, in magnetically-active areas on the Sun, or between the two magnetic poles of the Earth

### *CME*

see coronal mass ejection

### *convection*

the upward transport of energy carried by the rising motion of hotter material, as in the atmosphere of the Earth or the Sun, or in a kettle heated from below

### *convection cell*

a closed cell of gas or liquid within which hotter material is borne upward by convection, at some point releases its thermal energy, and then sinks back downward to be reheated again

### *convection zone*

the deep, internal layer just beneath the solar surface in which convection is the dominant form of energy transport

***corona; solar corona***

the outermost atmosphere of the Sun, characterized by very low density and extremely high temperature

***coronagraph***

an especially-designed telescope employed in space or on the ground to allow observation of the Sun's corona at times other than during a total solar eclipse

***coronal hole***

a dark region in the inner corona where open magnetic field lines allow coronal electrons to escape the Sun, resulting in a region of partially-depleted density and hence reduced brightness

***coronal mass ejections; CMEs***

segments of the outer corona that have been expelled from the Sun into interplanetary space in the form of expanding clouds of solar plasma, some as large or larger than the Sun itself

***cosmic rays***

highly energetic atomic nuclei stripped of most or all of their electrons, that pass at all times and from all directions through intergalactic, interstellar and interplanetary space. The most energetic of these (called galactic cosmic rays) presumably originate in dynamic cosmic phenomena within or beyond the galaxy, such as supernova explosions

***cosmic ray shower; cascade***

the expanding sequence of secondary cosmic rays initiated by the collision of an incoming cosmic ray with an atom or molecule of air. This initial impact produces daughter particles that then collide, farther down in the atmosphere, to create a continuing series (or cascade) of similar events

***cosmogenic nuclide***

an isotope such as radiocarbon ( $^{14}\text{C}$ ) which is formed in the middle atmosphere of the Earth when an incoming cosmic ray collides with a neutral atom of air

***cosmos***

the universe, often taken to indicate all of space

***Cretaceous period***

a period of Earth history at the end of the Mesozoic era, extending from about 135 to 63 million years before the present

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## D

### *D, E, and F regions*

horizontal strata in the middle and upper atmosphere of the Earth where free electrons are sufficiently abundant to affect the passage of radio and other electromagnetic radiation through these regions: D region @ 40-60 miles; E region 60-80, and F region about 100 to 1000 miles or more above the surface

### *daytime aurorae*

displays of the aurora borealis or australis which occur in the atmosphere above the daylit hemisphere of the Earth, and because of this go largely unseen

### *density*

the ratio of the mass of an object to its volume

### *differential rotation*

rotation of a fluid or non-rigid body like the Sun in which different depths rotate at different rates, with a resultant slippage between them

### *disk (of the Sun)*

the apparent circular shape of the Sun when seen in the sky, resulting from a two-dimensional projection of a spherical object

### *distant neutral line*

a quasi-permanent site in the far tail of the magnetosphere (at a distance of more than 300 thousand miles from the Earth's surface) where lines of magnetic force emanating from the magnetic northern and southern polar regions of the Earth are brought in contact with each other, creating a closed field line in the form of a long loop rooted at high latitudes in the two hemispheres

### *drag*

friction produced when the path of a spacecraft orbiting the Earth takes it through a denser (lower) part of the atmosphere, resulting in a reduction of speed and hence a further decrease in the altitude at which it operates

### *dynamo*

a device through which mechanical energy (e.g., in an electric generator, or the movement of a conductor through a magnetic field) is changed into electric energy. The solar dynamo works in a similar way by harnessing the mechanical energy of differential rotation to twist polar field magnetic lines within the Sun into toroidal fields (perpendicular to the Sun's axis of rotation.) These in turn give rise to sunspots when they are carried upward by convection to the solar surface

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## E

### *eccentricity (of an ellipse)*

a measure of the extent to which an orbit, such as that of the Earth around the Sun, departs from a perfect circle

### *ecliptic plane*

the plane defined by the path of the Earth's orbit around the Sun, fixed by the 23° tilt of the Earth's axis of rotation. As such, the ecliptic also defines the apparent path followed by the Sun across the celestial sphere in the course of one year: ascending higher in the sky in summer and lower in winter

### *electric field*

a region of space in which a detectable electric intensity is present at every point

### *effective temperature*

the temperature of a portion of the terrestrial or solar atmosphere defined by comparing the amount of energy it radiates with that emitted from an ideal radiator that is heated and cooled by radiation alone

### *electromagnetic radiation*

radiation consisting of oscillating electric and magnetic fields, including gamma rays, visible light, ultraviolet and infrared radiation, radio waves and microwaves

### *electromagnetic spectrum*

the entire range of electromagnetic radiation, from gamma rays to microwaves

### *electron*

a sub-atomic particle with a single negative charge and a mass of less than 1/1000 that of a proton, the corresponding positively-charged particle

### *electron volt; eV*

the energy required to raise an electron through a potential of one volt

### *electrostatic discharge; ESD*

the release of electric energy from a stationary (or static) charge, such as that built up when walking across a woolen rug or collected on the outer, metallic surface of a spacecraft

### *el Niño, la Niña*

opposite phases of a quasi-periodic worldwide climatic change, persisting for



three or more seasons, which is initiated by either a pronounced warming (or for la Niña, a pronounced cooling) of surface waters in the tropical eastern Pacific Ocean

***ENSO (El Niño Southern Oscillation)***

the combination of three related climatological phenomena: el Niño, la Niña, and the large-scale, seesaw exchange in sea-level air pressure between areas of the western and the southeastern Pacific known as the Southern Oscillation

***equatorial orbit***

a spacecraft orbit around the Earth that remains within north temperate, equatorial, and south temperate latitudes

***erg***

a metric unit of energy equal to the work done by a force of one dyne (the force required to accelerate one gram of mass by one centimeter per second<sup>2</sup>), or as the late George Abell once described it, about the energy exerted by a fly doing a pushup

***EVA (extra-vehicular activity)***

manned spaceflight ventures that take astronauts outside the protective structure of the spacecraft, including surface excursions on the Moon or other planets

***exosphere***

the region of relatively constant high temperature in the Earth's atmosphere above an altitude of about 600 miles. Here the few neutral atoms and molecules that remain are on their way out of the atmosphere, due to their high thermal velocities and the very low density of the region

***extreme-ultraviolet; EUV***

high-energy, short-wave electromagnetic radiation between wavelengths of 10 and 200 nanometers (100 to 2000 angstroms)

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**F**

***facula (plural, faculae)***

irregular patches in either the photosphere or chromosphere that appear brighter than their less disturbed surroundings as a result of the weak, vertical magnetic flux tubes that are concentrated there

***filament***

a chromospheric prominence seen on the disk of the Sun in the light of a hydrogen absorption line as a sinuous line, darker than its surroundings. The same feature observed at the limb would appear as a bright solar prominence

*firn*

glacial snow that has been partially compressed by thawing and freezing but not yet converted to glacial ice

*flare; solar flare*

a sudden and highly-localized increase in the brightness and the energy released from a restricted area on the solar surface which is most often located within a complex solar active region; thought to be provoked by instabilities in magnetic structures that cause opposite field lines to reconnect in a very small volume of material. in some ways like a short circuit between two electrical wires

*fossil fuel*

a carbon-based fuel (such as coal, oil or natural gas) that is formed in the Earth from plant or animal remains of a much earlier era

*frequency*

the number of electromagnetic waves that cross a given point per unit time, for example 60 per second for U.S. electric power, 97.3 million for an FM radio broadcast

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G

*galactic cosmic rays; GCRs*

see cosmic rays

*galaxy*

a large assemblage of stars, nebulae, and interstellar gas and dust, of which the Milky Way, the galaxy in which our Sun is located, is an example

*gamma rays*

the most energetic form of electromagnetic radiation, of shorter wavelength and higher energy than x-rays, which is the next most energetic

*gap, or slot region*

a depleted zone that separates the Earth's inner and outer radiation belts—extending from about 12,000 to 16,000 miles above the surface of the Earth—in which protons but few if any electrons are found

*geosynchronous (geostationary) orbit*

an orbit at a distance from the Earth of about 22,200 miles, at which altitude an orbiting object revolves around the equator of the Earth in synchrony with the Earth's rate of rotation. Satellites that orbit the Earth in this way appear fixed in the sky, always remaining above a fixed geographical region on its surface

*geotail; geomagnetic tail; magnetotail*

the extension of the magnetosphere formed on the night-side of the Earth as its magnetic field is swept downstream by the pressure of the solar wind. The geotail acts as a giant energy reservoir for the magnetosphere and plays an important role in geomagnetic storms and other dynamic processes

*global electric circuit*

the cumulative effect of all the thunderstorms that charge the ionosphere to a potential of several hundred keV with respect to the Earth's surface. The difference in electric potential that thunderstorms create drives vertical electric currents downward from the ionosphere to the ground in regions where thunderstorms do not occur, completing the circuit

*granule*

the top of one of the close-packed, subsurface convective cells seen in the solar photosphere; their all-over pattern, called solar granulation, covers the entire photospheric surface

*great circle*

the intersection of a plane passing through the center of the Earth with its surface, which defines the shortest distance between two points on the surface of the spherical Earth. A great circle course—the path followed in long-distance air and ship travel—will appear as a curved line when plotted on a navigational chart

*ground-induced current; geomagnetically-induced current; GIC*

sudden surges of 10s to 100s of amperes of direct current that instantly flow through unintended conductors such as ground wires, railroad tracks, pipelines, or underground wires that happen to connect areas of different electric potential on the surface of the Earth. These differences in ground potential can arise immediately from large solar-driven changes in the magnetosphere and ionosphere

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## H

*half-life*

the time required for half of the radioactive nuclei or other unstable particles in a sample of material of any kind to disintegrate, which for radiocarbon (<sup>14</sup>C) is 5,730 years

*heavy elements*

chemical elements with atomic numbers greater than 2, which includes all

elements in the periodic table other than (and also heavier than) hydrogen and helium, the two most abundant in the Sun

***heliopause***

the outer boundary of the heliosphere, at which place the solar wind becomes indistinguishable from the local interstellar medium

***heliophysics***

the comprehensive study of the Sun and the region of space over which it wields influence, involving all scientific disciplines that study the Sun and the Earth, near-Earth space, the inner planets, and the processes that link these together

***helioseismology***

the study of the Sun's interior deduced from the observable oscillations of its surface

***heliosheath***

the region of subsonic flow that stands between the termination shock in the extended solar wind and the outer boundary of the heliosphere

***heliosphere***

the vast region surrounding the Sun dominated by atomic particles and magnetic fields that are carried away from the Sun by the solar wind

***high-speed solar wind; high-speed stream***

solar particles and imbedded magnetic fields (plasma) driven out from the outer atmosphere of the Sun at speeds of about 400 to more than 500 miles per second, originating from coronal holes and other open-field regions in the corona

***Holocene epoch***

the roughly 11,000 year period of time in Earth history between the end of the last Ice Age and the present day

***hydrologic cycle***

the continual, cyclic exchange of the Earth's supply of water among what is held in the atmosphere, the oceans, lakes, and rivers, and the solid Earth

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***infrared; infrared radiation***

electromagnetic radiation of wavelength longer than visible light (beyond the

darkest red we can see) but shorter than radio waves, and which produces the sensation of heat

***inner radiation belt***

the innermost of the two concentric Van Allen belts of trapped atomic particles that surround the Earth in the equatorial region. The inner belt contains more energetic electrons, protons and heavier ions and extends upward from the top of the atmosphere to a height of about 12,000 miles

***insolation***

electromagnetic radiation from the Sun that falls on the top of the Earth's atmosphere

***interplanetary magnetic field; IMF***

the extension of the magnetic field of the Sun throughout the heliosphere

***ion***

a neutral atom that has become electrically charged by the addition or loss of one or more electrons

***ionization; ionize***

any process by which an atom loses electrons

***ionizing radiation***

high-energy atomic particles (such as cosmic rays) that are capable of dislodging bound electrons from neutral atoms through the force of collisional impact, and thus ionize them. Not to be confused with electromagnetic radiation

***ionosphere***

the electrically-conducting region in the upper atmosphere made up of three horizontal layers extending from about 35 to more than 1000 miles above the surface, which are produced by the ionization of neutral atoms of air by short-wave solar radiation (see also D, E, and F regions)

***irradiance; solar irradiance***

electromagnetic radiation in all wavelengths received from the Sun at the top of the Earth's atmosphere in units of energy per square area

***isotope***

an atom (for example, oxygen-18) that has the same number of protons but a different number of neutrons in its nucleus, and hence a different mass than the common, non-isotopic form, (in this case, oxygen-16)

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## K

### *kinetic energy*

energy possessed by a body as a result of its motion, equal to half the product of its mass and the square of its speed

### *kinetic temperature*

a temperature directly related to the average speed of atoms or molecules in a substance such as air

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## L

### *Lagrangian point*

places in the combined gravitational fields of the Sun, Earth and Moon where a spacecraft or other object will not be pulled toward any of them

### *limb (of the Sun)*

the apparent, circular edge of the Sun as we see it in the sky

### *luminosity*

the rate at which electromagnetic energy is emitted from the Sun

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## M

### *magnetic declination; magnetic variation*

that part of the difference in degrees between the direction of true North and that indicated on a magnetic compass, due to the changing position of the Earth's magnetic pole, which changes with time and location on the Earth

### *magnetic deviation*

that part of the difference in degrees between the direction of true North and that indicated on a magnetic compass at a specific location, which is due to the local presence of iron

### *magnetic field*

the portion of space near a magnetic body (such as the Sun) or a current-carrying body (such as an electric power line) in which there is a detectable magnetic force at every point in the region

### *magnetic field lines; magnetic lines of force*

imaginary lines (like the arrows used to show wind flow direction on a meteorological chart) that indicate the direction of the magnetic force at any

point in a magnetic field. A compass needle aligns itself along these local lines of force of the Earth's field

***magnetic reconnection; magnetic merging***

a process through which oppositely-directed, closed magnetic field lines come into contact, sever, and join to form new magnetic field structures. In the process part of the magnetic energy contained in the magnetic field is converted into thermal or kinetic energy

***magnetic pole***

either of two non-fixed points on the Earth, close to but not coincident with the north and south rotational poles, where the Earth's magnetic field is most intense and where magnetic field lines are most nearly perpendicular to the Earth's surface

***magnetic storm; (geomagnetic storm)***

a severe but transitory fluctuation in the Earth's magnetic field, evident initially as a sharp decrease in the strength of the horizontal component of the Earth's magnetic field, felt around the world and lasting a few hours, followed by a recovery phase lasting a day to several days. Geomagnetic storms are most often initiated when regions of enhanced solar wind flow compress the steady-state form of the magnetosphere on its Sun-facing side

***magnetometer***

a classical instrument employed since the 1820s to measure the intensity of the Earth's magnetic field at a given point on the surface of the planet, and in modern form, to record minute-to-minute variations as a function of time

***magnetopause***

the outer boundary of the Earth's magnetosphere, where the strength of the solar wind magnetic field surpasses that of the Earth. Though highly variable, it is typically 40,000 to 60,000 miles away from the Earth on the Sun-facing side, and much farther away on the down-wind side

***magnetosheath***

the region of slowed, heated and turbulent solar wind that lies between the bow shock in the incoming solar wind and the Earth's magnetopause

***magnetosphere***

the region around the Earth occupied by its magnetic field

***Maunder Minimum***

a distinctive period between about AD 1645 and 1715 when sunspots and solar activity were very much depressed

*mesopause*

the upper boundary of the mesosphere and lower boundary of the thermosphere, which lies just above it

*mesosphere*

the upper part of the middle atmosphere of the Earth, extending from about 30 to 53 miles above the surface, in which air temperature falls monotonically from about plus 200 to minus 135° F

*Milankovitch effect*

the combined effects of three subtle changes in the orbit of the Earth and its axis of rotation, acting over periods of tens of thousands of years, which work together to reappportion in time and reallocate in space the continuous flow of energy that the Sun delivers to the Earth

*molecule*

atomic nuclei and electrons from one or more different elements that are bound together, such as water (H<sub>2</sub>O) or molecular oxygen, O<sub>2</sub>

*muon*

an unstable sub-atomic particle with a lifetime of about 10<sup>-6</sup> seconds, a mass about 200 times greater than an electron, and a negative electrical charge. Muons are among the “secondary particles” released when cosmic rays impact atoms or molecules of air in the upper and middle atmosphere

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N

*near-Earth neutral line*

a region within the Earth's geomagnetic tail, at a distance of about 96,000 miles from the surface at which, during magnetic storms, magnetic field lines of opposite polarity rooted in the two magnetic poles of the Earth come together and reconnect. This results in a closed field line along which solar and other charged particles in the geotail are redirected back toward the Earth

*near-infrared*

the portion of the infrared spectrum of solar electromagnetic radiation that lies just beyond the limit of the visible portion, extending between wavelengths of about 700 and 7000 nanometers [7000 angstroms to 7 microns]

*near-ultraviolet*

the portion of the ultraviolet spectrum of solar electromagnetic radiation that adjoins the visible spectrum, extending between wavelengths of about 200 and 400 nanometers [2000 to 4000 angstroms]



***neutral line***

one of two regions in the magnetotail where stretched-out open magnetic field lines of opposite polarity, attached at the Earth's north and south magnetic poles, are brought in contact, allowing a return path for captive particles in the magnetotail to be channeled back toward the planet

***neutron***

a subatomic particle with no charge and of mass approximately equal to that of a proton (which is the other principal constituent of the nucleus of any atom)

***neutron monitor***

a device installed at high-altitude stations to detect the passage of neutrons resulting from collisions between cosmic rays and atoms or molecules in the Earth's atmosphere, as a measure of the flux of cosmic rays that produce these collisions

***North Atlantic Oscillation; NAO***

a quasi-regular, back-and-forth oscillation in sea-level air pressure between large-scale regions in the North Atlantic Ocean, which in terms of climatic function resembles the oscillatory ENSO phenomenon of the equatorial Pacific Ocean

***northern lights***

aurorae seen in the Northern hemisphere

***nucleus (of an atom)***

the heavy part of an atom, composed mostly of protons and neutrons, about which electrons revolve

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**O**

***open field line; open magnetic field line***

a magnetic line of force in the magnetic field of either the Sun or the Earth, one end of which is rooted in the photosphere or at the surface of the Earth, and the other drawn away and detached by dynamic forces

***outer radiation belt***

the outer of the two concentric Van Allen belts of trapped atomic particles that surround the Earth in the equatorial region. The outer belt is separated from the inner belt by a 4000 mile gap, and extends above the surface of the planet from about 16,000 to 24,000 (and at times as far as 36,000) miles. Within it are the lighter and less energetic trapped particles: primarily weaker electrons with energies in the range of 10,000 to about one million electron volts

*ozone layer; stratospheric ozone layer*

the region in the Earth's middle atmosphere, between altitudes of about 25 and 65 miles above the surface, where almost all atmospheric ozone is found. The remainder is created in the form of air pollution at ground level in the photosphere

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**P**

*penumbra (of a sunspot)*

a less-dark, roughly annular region surrounding the dark, cooler central portion of a sunspot, made up of a radial fine structure of dark and bright filaments

*photic zone*

that region of the upper ocean into which sunlight penetrates, extending (depending upon the clarity of water and the wavelength of light) to about 650 feet below the surface: greatest in the blue and least in the ultraviolet and infrared

*photon*

a discrete packet of electromagnetic radiation whose energy is directly proportional to the frequency of radiation and is thus much greater for an ultraviolet photon than one in the infrared

*photosphere*

the region of the solar atmosphere from which all visible light and heat are radiated into space. The intangible surface we see when we look at the Sun in visible light

*photosynthesis*

the process by which plant cells containing chlorophyll convert incident sunlight into chemical energy, and thereby synthesize needed cellulose for plant growth from carbon dioxide and water, with the release of oxygen

*pion*

an unstable sub-atomic particle with a lifetime of about  $10^{-8}$  seconds, a mass about 260 times greater than an electron, and either a neutral or negative charge

*plage*

a bright region seen in the Sun's photosphere or chromosphere

*plasma*

an often very hot, electrically-neutral gas composed of an approximately equal number of electrons and protons, capable of carrying an imbedded magnetic field

*plasmopause*

the outer boundary of the Earth's plasmasphere and inner boundary of the magnetosphere

*plasma sheet*

the central and densest part of the Earth's magnetotail, consisting of a compressed sheet that extends downwind of the Sun for at least 950,000 miles from the Earth, separating the northern and southern lobes of the tail, which have opposite magnetic polarity. The plasma sheet is a major storage region for ionized particles in the geomagnetic tail

*plasmasphere*

the upward extension of the Earth's ionosphere into the exosphere, within and co-existing with the magnetosphere, which reaches on its Sun-facing side from about 1000 miles to as much as a million miles above the surface. It consists of a relatively low-energy plasma and takes its form as charged particles from the ionosphere flow upward to fill the relative vacuum of space surrounding the Earth

*plate tectonics*

the movement of segments, or plates, of the encrusted, outer layers of the solid Earth over the hotter and more fluid underlying mantle

*Pleistocene epoch*

the earlier of the two epochs of the Quaternary period of Earth history, extending from about a million years until 11,000 years before the present and characterized by the alternate appearance and recession of northern glaciation

*polar cap*

in auroral nomenclature, the area around either the north or south magnetic pole of the Earth bounded by the inner boundary of the auroral oval. Here, poleward of the auroral oval, auroras are more frequent but weaker, more diffuse and less variable than in the auroral oval itself

*polar cap aurora*

aurorae, seen throughout the solar cycle, that occur outside the bounded region of the auroral oval, in the space that separates it from the magnetic pole

*polar cusps*

the singular regions over the Earth's magnetic poles where magnetic field lines are nearly perpendicular to the Earth's surface, creating an "opening" in the magnetosphere that allows charged particles paths of easier entry into the upper atmosphere

***polar orbit (around the Earth)***

a spacecraft orbit that passes over the polar (as opposed to restricted to middle and equatorial) latitudes of the Earth. For spaceborne instruments that observe the Sun, a polar orbit offers the opportunity for continuous 24-hour monitoring. The present polar orbit of the Ulysses spacecraft around the Sun was chosen to allow the first observations of much of the solar poles and to explore conditions in the solar wind above them

***polar plumes***

coronal rays extending like a crown outward from the two magnetic poles of the Sun, that outline the open magnetic field lines which emanate there

***positive ion***

an ion formed by the loss of one or more of the electrons from a neutral atom, resulting in an atomic particle of net positive charge

***primary cosmic ray***

a high-energy atomic particle that arrives at the Earth from beyond the planet, as opposed to the secondary cosmic rays that are formed as a result of a collision of a primary with an atom or molecule of air in the Earth's atmosphere

***prominence; solar prominence***

a shapely extension of chromospheric material into the corona, formed and suspended there by magnetic fields, which is visible at the limb of the Sun or on the disk (where it is called a solar filament)

***proton***

heavy subatomic particle of unit positive charge which is one of the two principal constituents (the other, neutrons) of the nuclei of atoms

***proxy record***

data regarding past solar behavior that is obtained indirectly, derived from what is known of the Sun's impacts on other physical phenomena such as aurorae or records of tree-ring radiocarbon or ice-core beryllium-10

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**Q**

***quiescent prominence***

a long-lived and relatively stationary solar prominence, in contrast to those that are more active or eruptive

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## R

### *radiant energy*

electromagnetic energy emitted from the Sun

### *radiation*

here used to mean electromagnetic energy, as defined above. When qualified as “particle radiation” it is often conventionally used to refer to the kinetic energy of high energy particles

### *radiation belts; Van Allen belts*

two concentric areas of trapped electrons, protons and ions held within the closed part of the Earth’s magnetic field, from about 600 miles to 25,000 miles above the surface

### *radiative zone*

a voluminous region in the solar interior, between the innermost core and the outer convective zone, where radiation is the dominant mode of outward energy transport

### *radio frequency spectrum*

the lowest frequency, lowest energy portion of the total spectrum of electromagnetic radiation from the Sun, which includes radio waves of all wavelengths

### *radio telescope*

an antenna or set of antennas designed to make observations of the Sun or other astronomical objects based on their emission of radio waves

### *radio waves*

electromagnetic radiation emitted in the radio frequency spectrum

### *red giant*

a star that is larger and cooler than the Sun

### *resolution*

spatial resolution: the degree to which a telescope can distinguish, or resolve, fine details in the image it produces, expressed in terms of an angle in the sky, such as 1 arc second; temporal resolution: the shortest interval of time for which information can be distinguished

### *ring current*

an electrical current produced in the equatorial plane within the closed part of the Earth’s magnetic field where properties of the magnetic field cause ions and electrons to drift in opposite directions

***rotation***

the turning of the Earth (one turn in 24 hours) or the Sun (in about 27 days) about an axis that passes through it

---

**S**

***scattering***

the dispersal of a beam of light into a spread of directions as a result of physical interactions: in the daytime sky, the redirection of incoming sunlight across the dome of the sky by its interaction with molecules of air; in the white-light corona, the redirection of photospheric radiation by free electrons

***scintillation***

a flickering of electromagnetic radiation caused by its passage through turbulent media: examples are the twinkling of stars caused by the passage of starlight through turbulence and inhomogeneities in the air; and irregular deflections in the passage of radio waves through layers of electrons in the ionosphere

***secondary cosmic ray***

a secondary or “daughter” particle produced by collisions between primary cosmic rays from space and the atomic nuclei of atoms and molecules in the Earth’s atmosphere

***sectors***

discrete, wedge-shaped segments, centered on the Sun, in the expanding solar wind in which the magnetic polarity of the source region on the Sun is carried outward in the plasma and preserved. They are sensed at the Earth (as they sweep by with solar rotation) as distinct changes in the prevailing polarity of the solar wind

***seismology***

the study of earthquakes and the internal structure of the solid Earth deduced from the analysis of reflected sound waves

***shock wave***

an abrupt change in temperature, speed, density and pressure in a moving plasma, produced by the movement of an object traveling through the medium at a speed greater than the local speed of sound, that can accelerate energetic particles and trigger geomagnetic phenomena. A similar phenomenon occurs in the Earth’s atmosphere when an aircraft reaches supersonic speed

***short-wave radiation***

electromagnetic radiation from the Sun in the ultraviolet, x-ray and gamma ray region of the spectrum

*single event effect; SEE*

a malfunction or failure of a piece of electronic equipment in a spacecraft that is traceable to the impact of a single high-energy particle such as a solar energetic proton or cosmic ray particle

*single event upset; SEU*

the malfunction or failure in a micro-circuit most often traced to the action of a single incoming heavy ion, from the Sun or the cosmos that deposits sufficient electrical charge on a sensitive circuit element to cause it to change state

*slow-speed solar wind; slow speed stream*

solar particles and imbedded magnetic fields (plasma) driven outward from the outer atmosphere of the Sun at an average speed of about 200 miles per second, most often from coronal streamers

*solar activity*

phenomena on the Sun such as sunspots, plages, flares, and CMEs whose frequency of occurrence is related to the 11-year sunspot cycle

*solar atmosphere*

the photosphere, chromosphere, and corona of the Sun

*solar constant*

the total amount of radiant energy received from the Sun per unit time per unit area at the top of the Earth's atmosphere, at mean Sun-Earth distance. Once thought, erroneously, to be constant, the term has now been supplanted by the more precise term, total solar irradiance

*solar cycle; sunspot cycle*

the roughly 11-year cyclic variation in the state of activity on the Sun, most apparent in annual averages of the number of sunspots seen on its white-light surface

*solar dynamo*

the internal mechanism that generates sunspots and magnetically active regions on the surface of the Sun through the interaction of convection, differential rotation, and magnetic fields within the solar interior

*solar energetic proton; SEP*

a proton ejected from the Sun with an energy in the 1 to 500 meV range, which is potentially damaging due to its heavy mass and high speed

*solar equator*

a great circle on the Sun, midway between its rotational poles

*solar granulation*

the pattern of closely-packed convective cells that covers the photospheric surface of the Sun

*solar interior*

the bulk of the Sun that lies beneath the photosphere, consisting of its nuclear core and overlying radiation and convective zones

*solar irradiance*

radiant energy received from the Sun per unit time and unit area at the top of the Earth's atmosphere

*solar magnetic cycle*

the 22-year combination of two eleven-year cycles of solar activity needed for the surface magnetic field of the Sun to switch from one polarity to the other and back again

*solar system*

the Sun together with the planets and all other objects that revolve about it

*solar wind*

the continual release of atomic particles and imbedded magnetic fields (plasma) from the Sun resulting from the thermal expansion of the corona

*South Atlantic Anomaly; SAA*

a region located over southern South America and the South Atlantic Ocean where the strength of the Earth's magnetic field is considerably reduced. Because of this, energetic particles in the Earth's inner radiation belt are able to penetrate here more deeply into the thermosphere, to altitudes where spacecraft operate

*space weather*

the variable state of the magnetosphere, ionosphere and near-Earth space as perturbed by solar activity and the solar wind: the counterpart of meteorological weather

*space climate*

long-term or average conditions in the magnetosphere, ionosphere and near-Earth space: the counterpart of terrestrial climate

*spectral irradiance; solar spectral irradiance*

electromagnetic radiation in specific wavelengths received from the Sun at the top of the Earth's atmosphere

*spectrum*

the distribution of electromagnetic energy emitted by a radiant source such as



the Sun, arranged in order of wavelength, from gamma rays and x-rays to long-wave radio emission

*spicule*

one of many spike-like jets of rising gas in the chromosphere, about 600 miles wide and about ten times as high, with a lifetime of about 15 minutes

*Spörer Minimum*

a distinctive period between about AD 1450 and 1540. evident in the record of tree-ring radiocarbon, when the level of solar activity was much reduced

*stratopause*

the upper limit of the Earth's stratosphere and lower limit of the mesosphere

*stratosphere*

the atmosphere extending above the troposphere to an altitude of about 30 miles that exhibits warming with height, the result of the absorption of solar radiant energy by stratospheric ozone

*streamer; coronal streamer*

a major structure in the outer corona consisting of a magnetically-formed bulbous base near the Sun that is reduced in diameter and swept outward by the solar wind into an extended tapered shape

*sunspot*

a distinctive, activity-related region in the photosphere, the embodiment of a very strong magnetic field that is cooler and hence darker than the surrounding photosphere

*sunspot cycle; solar cycle*

the roughly 11-year cycle of variation in the number of sunspots visible on the solar disk: a manifestation of a more fundamental cyclic variation in the number of solar magnetic fields that are brought to the surface from the interior of the Sun

*sunspot number*

an historical index of solar activity defined in the 1860s as the number of spots that are visible on the Sun at any time plus ten times the number of groups of sunspots, multiplied by a factor intended to correct for differences in telescopes, observing sites, and observers

*sunspot maximum or minimum; solar maximum or minimum*

the years when the 11-year sunspot cycle reaches its maximum or minimum level

*supergiant*

a very large, extremely luminous star

*super-granulation*

convective cells—each of which is up to 200 times larger than those found in the photosphere—which covers the entire surface of the chromosphere in an all-over closely-packed pattern. Like the granules seen immediately below them in the photosphere, they are a consequence of the tumultuous release of energy from the interior convective zone of the Sun, and the organizing of large numbers of photospheric cells into a far larger pattern

*suprathermal particles*

highly accelerated atomic particles with energies of up to a million or more electron volts, corresponding to temperatures of billions of degrees

---

T

*tachocline*

the shear layer in the solar interior between the inner radiation zone and the convective zone that lies above it, thought to be the site of origin of the solar dynamo

*termination shock*

a shock wave that forms at the place in the outer heliosphere where the solar wind first begins to feel the competing force of stellar winds. In passing through it, the solar wind slows from supersonic (about a million miles per hour) to subsonic speeds

*terrestrial*

pertaining to the Earth and its inhabitants

*Tertiary period*

the period of Earth history following the Cretaceous and preceding the Quaternary, extending from about 63 million years until about 2 million years before the present

*thermal electrons*

electrons with energies per particle in the range from a few electron volts (eV) to 100, representing temperatures of 10,000 to 10<sup>6</sup>° F, typical of particles found in the chromosphere, transition zone, and corona of the Sun

*thermal energy*

energy associated with the temperature-driven movements of atoms or molecules in a substance

*thermal inertia*

a property of matter expressing its capacity to retain heat

*thermohaline circulation*

vertical ocean circulation driven by differences in the temperature and salinity of seawater

*thermosphere*

the uppermost layer of the Earth's atmosphere, extending from an altitude of about 50 to more than 1000 miles, where absorption of short-wave solar radiation heats the gas to very high temperatures

*toroidal; toroid*

a surface generated by the rotation of a closed curve, such as a circle, about an axis lying in its own plane, creating a three-dimensional object like a doughnut

*total solar eclipse; total eclipse*

an eclipse of the Sun in which the photosphere is entirely covered by the lunar disk, darkening the sky and allowing observers within the moving shadow of the Moon to see the dim solar corona

*total solar irradiance*

electromagnetic energy in all wavelengths received from the Sun at the top of the Earth's atmosphere

*transition zone*

the thin shell between the Sun's chromosphere and corona, where the temperature climbs from about 10,000 to more than a million° F

*Trojan asteroid*

one of a group of asteroids (minor planets) that share Jupiter's orbit about the Sun

*tropopause*

the upper limit of the troposphere and lower limit of the stratosphere, at an altitude of about seven miles above sea-level, though somewhat higher in the tropics

*troposphere*

the lowest region of the Earth's atmosphere, extending from the surface to the tropopause (about 7 miles high) and characterized by decreasing temperature with increasing altitude; the locus of all weather and climate

---

## U

### *ultraviolet radiation*

invisible, electromagnetic radiation of shorter wavelength and greater energy per photon than that of visible light, spanning wavelengths between about 100 to 4000 angstroms (10 to 400 nanometers)

### *ultraviolet spectrum*

that portion of the spectrum of electromagnetic radiation that extends from about 100 to 4000 angstroms

### *umbra (of a sunspot)*

the dark central region of a sunspot that is often circumscribed by a slightly more luminous penumbra. Sunspot umbrae define intrusions in the photosphere of highly-concentrated, local magnetic fields that inhibit the flow of energy from below and are hence cooler and less bright than the surrounding photosphere

### *universe*

all space, including the totality of all matter and radiation

### *UV-A and UV-B*

two adjoining bands of potentially-damaging incoming solar ultraviolet radiation that can reach the surface of the Earth, as opposed to the shorter wavelength and more energetic UV-C which is entirely blocked by atmospheric oxygen high in the atmosphere. Direct exposure to either UV-A (3150 to 4000 angstroms wavelength) or UV-B (2800 to 3150 angstroms) radiation can damage the skin and eyes and human immune system, although the more energetic UV-B is the greater threat in terms of potential skin cancer

---

## V

### *visible spectrum*

the portion of the spectrum of electromagnetic radiation that can be sensed by the human eye, including all colors of the rainbow from the barely visible violet (about 3900 angstroms wavelength) to the dark and barely visible red (about 6600 angstroms)

---

## W

### *wavelength*

a metric used to distinguish different parts of the spectrum of electromagnetic

radiation, equal to the distance separating two successive crests in a wave of radiation

### UNITS OF WAVELENGTH

| UNIT                      | IN METERS         | EQUIVALENT      | REGION OF ELECTROMAGNETIC SPECTRUM             |
|---------------------------|-------------------|-----------------|--|
| meter (m)                 |                   | 100 cm          | radio waves                                    |
| centimeter (cm)           | $10^{-2}$ meters  | 10 mm           | radio waves                                    |
| millimeter (mm)           | $10^{-3}$ meters  | 1000 $\mu$      | microwaves                                     |
| micron ( $\mu$ )          | $10^{-6}$ meters  | 1000 nm         | infrared waves                                 |
| nanometer (nm)            | $10^{-9}$ meters  | 10 $\text{\AA}$ | visible and ultraviolet waves                  |
| angstrom ( $\text{\AA}$ ) | $10^{-10}$ meters |                 | visible, ultraviolet, x-ray and $\gamma$ -rays |

#### *wave-particle interaction*

an interaction between a charged atomic particle and ambient electromagnetic radiation that can alter the energy of the particle or disturb its path and manner of movement. This can occur in the presence of electromagnetic radiation of a frequency that happens to resonate with the particle's own motion

#### *white-light*

the combination of light of all colors in the visible spectrum of electromagnetic radiation. The disk of the Sun, which appears white to us, is an example, as is the white color of clouds or the solar corona, both of which represent scattered light from the white photosphere

## X

#### *x-rays*

extremely high energy, short-wave electromagnetic radiation in the wavelength range from 1 to 100 angstroms





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## SOURCES FOR ADDITIONAL INFORMATION

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### Books

*Nearest Star: The Surprising Science of our Sun*

by L. Golub and J. Pasachoff; Harvard University Press, Cambridge, MA, 2001, 267 pp. A popular-level book about the Sun written by two renowned solar scientists.

*The Cambridge Encyclopedia of the Sun*

by K.R. Lang; Cambridge University Press, Cambridge, England, 2001, 256 pp. A complete, modern guide to our nearest star, well-illustrated and explained, in a handsome, over-sized book.

*Storms from the Sun: the Emerging Science of Space Weather*

by M. Carlowicz and R. Lopez; Joseph Henry Press, Washington, D.C., 2002, 234 pp. A description of the active Sun and space weather and their effects on the Earth, written at a popular level with emphasis on specific effects of dynamic solar events on the Earth and society.

*Space Weather*

edited by P.L. Song, H.J. Singer, and G. L. Siscoe; American Geophysical Union, Washington, D.C., 440 pp, 2001 A collection of technical articles dealing with many aspects of space weather.

*Effects of Space Weather on Technology Infrastructure*

edited by I. A. Daglis; Kluwer Academic Publications, Dordrecht, the Netherlands. 334 pp. 2004. Review articles dealing with various aspects of the impact of space weather on human activities, from commercial aircraft to electric power systems, from a NATO workshop on this subject.

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## Articles

### *The Sun: Living with a Stormy Star*

by Curt Suplee; in National Geographic, July 2004, pp. 2-33. A current portrayal of the Sun, solar activity and space weather, illustrated as only the Geographic can with an awesome collection of diagrams and breath-taking pictures from space.

### *Living with a Variable Sun*

by Judith Lean; in Physics Today, June, 2005, pp. 32-38. An easily-read and up-to-date review of solar variability and its effects on the Earth, told by an acknowledged expert in the field.

### *Shielding Space Travelers*

by Eugene Parker; in Scientific American, March, 2006, pp. 40-47. A popular-level review of the problem of galactic cosmic rays in space travel, by the scientist who accurately foretold the existence and characteristics of the solar wind before it was first discovered.

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## Some Recommended Web Sites

### <http://heliophysics.nasa.gov/>

A general description of NASA's program that keeps a round-the-clock watch on the Sun and its impacts on the Earth and its near environment, including a summary of current Sun-Earth spacecraft, planned or underway, with access to specific information about each of them.

### <http://www.swpc.noaa.gov/>

Up-to-the-minute information from NOAA's 24-hour Space Weather Prediction Center, including current information on solar activity and conditions in near-Earth space, space weather alerts and warnings that are disseminated worldwide, and current and predicted sunspot numbers for 11-year solar cycle #23, now ending, and #24, soon to be underway.

### <http://srag-nt.jsc.nasa.gov/>

Information regarding the monitoring of space-weather at the NASA Space Radiation Analysis Group at the Johnson Space Center, tailored to the specific needs of individual manned space flight missions, including a trove of summarized information on space shuttle missions currently planned or in progress and the current status of the International Space Station.



[\*http://umbra.nascom.nasa.gov/images/latest.html\*](http://umbra.nascom.nasa.gov/images/latest.html)

Current, daily images of the solar disk, in color and enlargeable to full screen-size portraying today's photosphere, chromosphere, transition region, corona, magnetic fields and vertical motions derived from Doppler images.

[\*http://climate.gi.alaska.edu/Curtis/aurora.html\*](http://climate.gi.alaska.edu/Curtis/aurora.html)

A beautiful and enlightening collection of photographs of the aurora borealis taken in Alaska by a renowned expert, Jan Curtis.

[\*http://www.scostep.ucar.edu\*](http://www.scostep.ucar.edu)

A series of delightfully drawn, up-to-date and expertly written introductory explanations of different features of the Sun-Earth system, presented in comic book form, each about 12 pages long. Ingeniously produced in Japan, in English and other languages, and sponsored by SCOSTEP, the International Scientific Committee on Solar-Terrestrial Physics. The most recent issue treats the subject of solar variability and climate. Try them; you'll like them. size;





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*The Index is intended as a guide for locating the initial or principal reference for specific technical words or phrases.*



