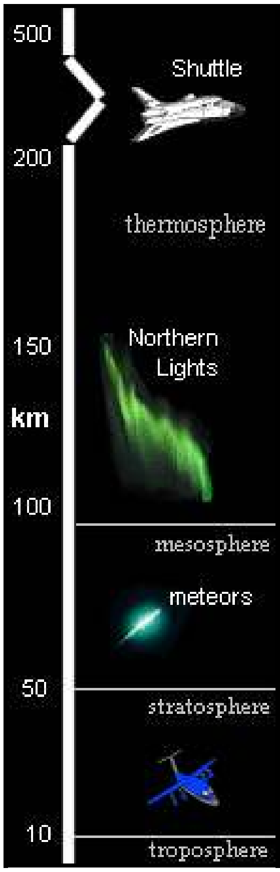
Solar S'Mores

May 30, 2000 -- As most Boy and Girl Scouts can testify, if you hold a marshmallow close to a roaring camp fire it puffs up. A well-roasted marshmallow can grow to nearly twice its normal size, doubling its allure to a voracious sweet tooth.

Something similar happens to Earth's atmosphere every 11 years when the sunspot cycle nears maximum. As solar activity increases, extreme ultraviolet radiation (EUV) heats our planet's gaseous envelope, causing it to swell and reach farther into space than normal. While puffed-up marshmallows can lead to tooth decay, our puffed-up atmosphere vexes satellite operators with a different kind of problem -- orbit decay.

Above: The space shuttle orbits in the thermosphere, a tenuous layer of our atmosphere that gets hotter and expands during solar maximum. The puffed-up thermosphere increases drag on Low Earth Orbit (LEO) satellites.

"There are layers of our atmosphere that extend hundreds of kilometers above Earth's surface," explains Dr. David Hathaway, a solar physicist at the Marshall Space Flight Center. "The space shuttle and the ISS both orbit within the thermosphere. The thermosphere is about a million times less dense than the atmosphere at sea level, but that's enough to affect the orbits of these satellites."



"Orbit decay" happens as these *L*ow-*E*arth *O*rbit (*LEO*) satellites move through the thermosphere. Each time a *LEO* satellite circles the globe, its perigee (closest approach to Earth) becomes a bit lower as aerodynamic drag robs the satellite of orbital energy. The most famous example of this effect was Skylab, which burned up in the atmosphere on July 11, 1979 after its orbit deteriorated for 5 years.

Left: Layers of the Earth's atmosphere. The troposphere is the first layer above the surface and contains half of the Earth's atmosphere. Weather occurs in this layer. Many jet aircraft fly in the stratosphere because it is very stable. The stratosphere contains the ozone layer. Meteors burn up in the mesosphere. Aurorae occur in the lower thermosphere. The thermosphere is also where the space shuttle orbits. [more information from the University of Michigan]

Some satellites, like the Compton Gamma Ray Observatory, have onboard jets to compensate for orbit decay. When perigee gets too low, they can nudge themselves back to a higher altitude.

Other *LEO* satellites need a little help. The Hubble Space Telescope (HST) has no jets or engines of any kind for propulsion, so the only way to restore the altitude is to grab it and move it. This can and has been done by the space shuttle during HST servicing missions.

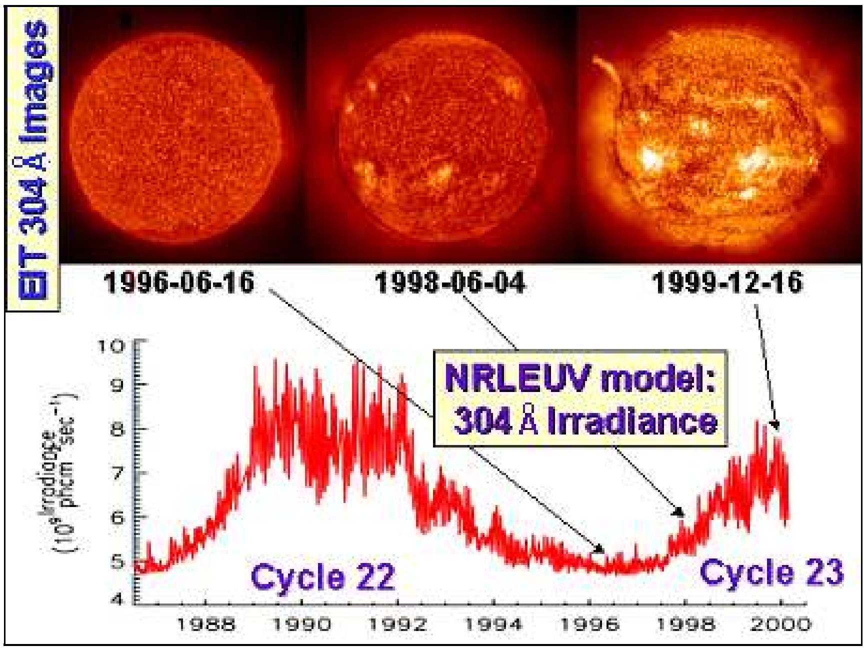
Just last week, astronauts flying the space shuttle Atlantis used the orbiter's jets to raise the altitude of the 35-ton International Space Station by 27 statute miles.

> "The ISS will sink a couple of kilometers per year in the future because of atmospheric drag - in its current configuration," says Larry Kos, a NASA/Marshall Space Flight Center engineer with experience in computer modeling of the space station's orbit decay. "These kinds of 'reboosts' are entirely normal. Eventually the station will have its own propulsion system to compensate for orbital decay, but until the facility has a propulsion module, it's going to need occasional lifts from the shuttle."

"When we did our original orbit analysis for the space station in 1993, we had to take many variables into account," continued Kos. "The size, shape, and orientation of the space station is critical. When the solar panels are added, for example, it can dramatically increase the frontal area of the ISS and its aerodynamic drag. Solar activity is important, too. Orbital decay is much greater when the sunspot number is high."

The solar cycle has a big effect on the thermosphere where satellite drag takes place, agreed David Hathaway. "During solar minimum, the gas temperature in the thermosphere is around 700 °C. That's high, but not nearly as high as the temperature during Solar Max. When the Sun is active, high levels of solar EUV raise the temperature of the thermosphere all the way to 1,500 °C."

Increased solar heating makes the thermosphere puff out as denser layers from lower altitudes expand upward. The density of the thermosphere can soar by a factor of 50 during solar maximum, with a commensurate increase in atmospheric drag on satellites.



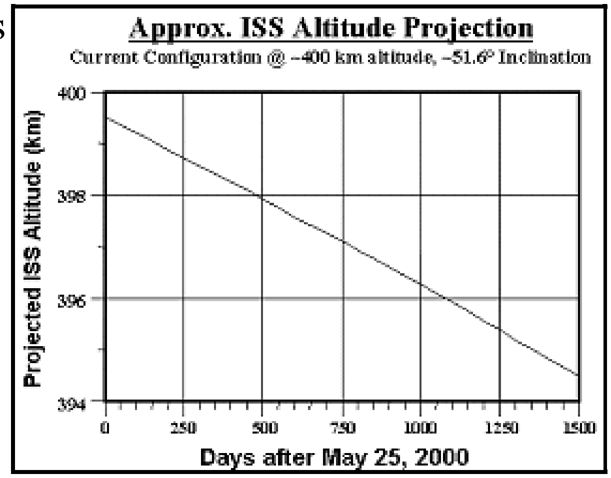
Above: This image, courtesy of Dr. Judith Lean at the US Naval Research Laboratory, shows three extreme ultraviolet (EUV) pictures of the Sun captured by the ESA/NASA Solar and Heliospheric Observatory at different times during the current solar cycle. In 1996, near solar minimum, the EUV Sun was nearly featureless. Now, near the peak of the cycle, the Sun is dotted by fiery regions of hot gas trapped in magnetic fields above sunspots and plages. These active regions produce copious numbers of EUV and X-ray photons that are absorbed in outer layers of our atmosphere before they reach Earth's surface. The red curve in the image is a computer model of the solar EUV flux at 304 Angstroms derived from ground-based Ca K images made at the Big Bear Solar Observatory.

"The extreme ultraviolet photons that heat the thermosphere aren't the same as the UV rays that give you sunburns," says Dr. Judith Lean, a physicist at the US Naval Research Labs. "They are much worse. Sunburns come from the UV-A and UV-B bands around 3000 Angstroms. The photons that heat the thermosphere are at least 10 times more energetic and they vary 100 times more [between solar minimum and solar maximum]. It's good thing they're all absorbed by nitrogen and oxygen at high altitudes

-- otherwise a day at the beach would be no fun."

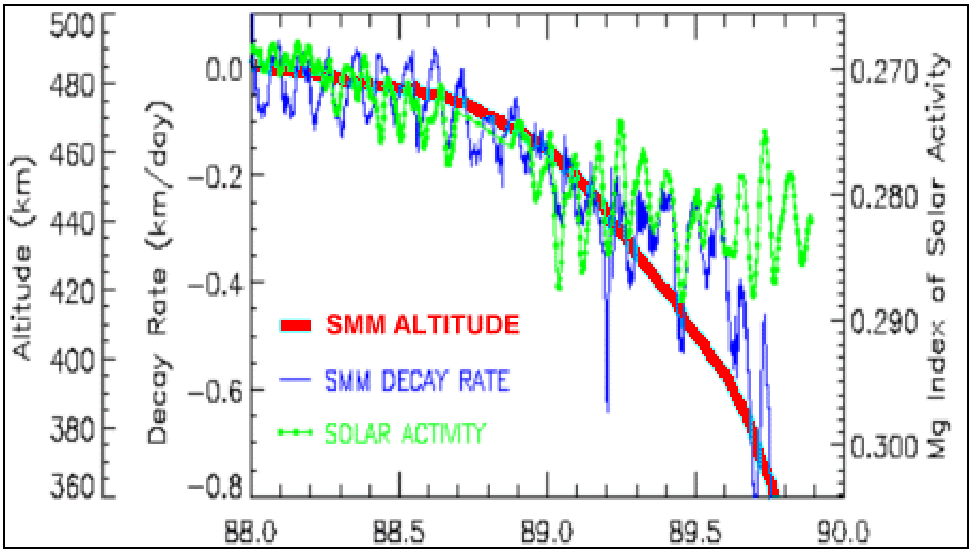
If the thermosphere is so hot, wouldn't astronauts feel uncomfortably warm during space walks?

No, says Hathaway. The air up there is so tenuous that you can't really feel the heat. In fact, it's so thin that scientists can't even measure the temperature directly. Instead, they put orbital decay to good use by monitoring the drag on satellites to estimate the density of the rarefied air. Then they can use the density to calculate the temperature -- proof that every cloud has a silver lining!



Right: NASA/Marshall's Larry Kos used a computer model of the ISS orbit to project its orbital decay resulting from atmospheric drag. Left uncorrected, the space station would decline in altitude by less than 6 km over the next 1500 days. The software that produced this approximate prediction is called LTIME (*i.e.*, Lifetime). It has been developed and improved, most recently by Mr. Jim McCarter, over the last 30+ years at the Marshall Space Flight Center. Input parameters include the assembly stage of the space station (solar panels, *e.g.*, would increase drag) and the response of the atmosphere to the solar cycle.

Another positive result of orbit decay involves space debris. According to the Orbital Information Group at NASA's Goddard Space Flight Center, in April 2000 there were 6133 bits of unwanted debris in Earth orbit, far outnumbering useful satellites. Astronauts on the space shuttle occasionally have to make course corrections to avoid these derelict pieces of space junk. Atmospheric drag on these objects can be good because it helps clear out the littered neighborhood of low Earth orbit. On the other hand, the changing orbits of these objects as they slowly reenter the bloated atmosphere make them more difficult to track for collision avoidance.



Above: The decay rate of the Solar Maximum Mission, which deorbited in December 1989, varied with the Sun's 27--day rotation and the solar cycle. This image, which originally appeared in *The Sun's Variable Radiation and its Relevance for Earth* (Annual Reviews of Astronomy & Astrophysics, 1997) is courtesy of Dr. Judith Lean, NRL.

For more news and updates about space weather and solar activity, please visit SpaceWeather.com. Also: Do you have a favorite satellite, or would you like to know where the International Space Station is tonight? Visit NASA Liftoff's J-Track for a 3D view of more than 600 Earth-orbiting objects.

SOHO is a cooperative project between the European Space Agency (ESA) and NASA. The spacecraft was built in Europe for ESA and equipped with instruments by teams of scientists in Europe and the USA.

Web Links

SOHO home page -real-time images of the Sun, screen savers, and more

International Space Station -- home page

The Thermosphere -- from the University of Michigan

Boosting Compton -- June 6, 1997, GSFC Astronomy Picture of the Day

Orbits in Space -- from the NASA/Goddard Space Flight Center

Orbit Decay of the Hubble Space Telescope

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