Space Weather Strongly Affects Arctic Upper Atmosphere

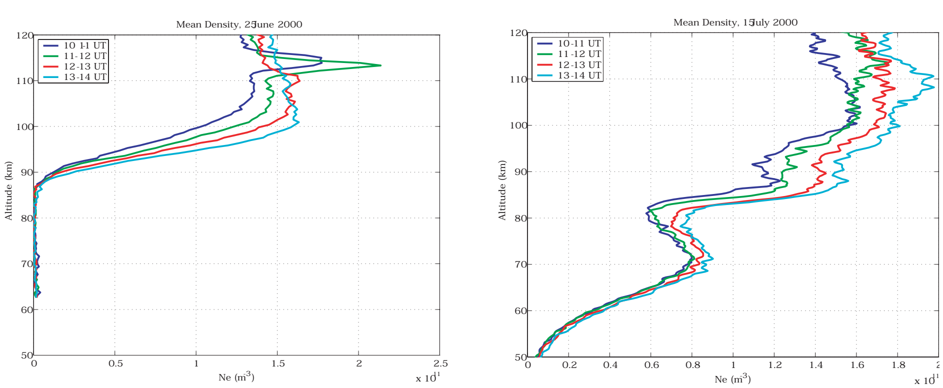
This article continues a series on current topics in arctic upper atmospheric research.

Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems. Modern society increasingly relies on space-based technologies for communications, environmental monitoring, mapping, navigation, and other applications, but detailed understanding of the processes and interactions involved in space weather is just emerging.

This is relevant to the Arctic because the magnetic polar regions can be strongly affected by solar plasma. While the upper atmosphere is largely protected from the Sun's energetic protons and electrons by the Earth's magnetic field, at high magnetic latitudes this shielding is much less effective at ionospheric and atmospheric altitudes. The aurora borealis and aurora australis manifest this incursion of solar plasma energy on the atmosphere (see Witness, Autumn 2001). Aurorae, which result primarily from accelerated electrons and ions impinging upon the upper atmosphere's neutral gasses, can carry significant amounts of energy and impact atmospheric chemistry and dynamics down to altitudes of roughly 90 kilometers.

Solar storms can impact the entirety of both polar regions. During solar storms the solar wind plasma can contain large fluxes of very energetic protons, in the range of tens to hundreds of million electron volts (MeV). When these protons reach the poles, they blanket the regions with significant ionization to quite low altitudes. Termed polar cap absorption (PCA) events because they absorb HF radio waves very efficiently (due to the large numbers of collisions between ionospheric electrons and neutral atoms at the lower altitudes at which they occur), these can cause communication blackouts in the HF bands and influence the chemistry of the polar atmosphere. The plasma in the polar cap can be very highly structured, especially during active conditions, resulting in communication difficulties between Earth-based and satellite-based transceivers.

Space-weathermen need to derive a predictive understanding of the various phenomena to help develop mitigation strategies, but our current knowledge can be likened to the tropospheric weather prediction capabilities of the 1950s. We know, in a broad sense, how the plasma ejected from the Sun affects the Earth's magnetosphere and, ultimately, the upper atmosphere, but not the details of that interaction. To address these problems with a coordinated effort, in 1996 several federal agencies initiated the National Space Weather Program (NSWP), a joint program involving NSF, NOAA, USAF, NASA, DOI, and DOE. Although the NSWP has made progress toward forecasting space weather, the present generation of models remain inadequate, measurements of critical parameters are scanty, and the scale of the problem is tremendous.



The dramatic increase of ionization from the 2000 Bastille Day storm. Left: quiet-time measurements of electron density as a function of altitude from the NSF Sondrestrom Incoherent Scatter Radar in Greenland. Solar illumination produces E-region ionization down to approximately 90 kilometers altitude. Two profiles also show thin sporadic E layers at just under 115 km; these layers consist of monatomic metal ions left behind by meteor ablation. Right: the impact of high energy protons, showing a distinct peak in ionization at 70 km lasting for many hours, and significant ionization enhancements to below 50 km. Figure by C. Heinselman.

Variability in space weather must be traced back to variability in the Sun, and upstream measurements are necessarily limited due to the enormous volume over which the physical interactions take place. Progress is being made largely through innovative active and passive remote sensing techniques as well as strategically placed in-situ measurements and increasingly sophisticated assimilative models. Starting at the Sun, spacecraft observations include those made by the Solar and Heliospheric Observatory (a joint NASA and ESA project), located 1.5 million km sunward of the Earth. Earth-orbiting spacecraft, such as the Wind and Polar spacecraft from the International Solar-Terrestrial Physics program at NASA, supply measurements of the solar wind and magnetospheric plasma. The Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) spacecraft provides views of the entire inner magnetosphere for the first time. The Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics (TIMED) satellite measures energy inputs and select ion and neutral species from ionospheric altitudes.

Several existing and planned ground-based observatories measure the ionospheric plasma variability. The incoherent scatter radars in Kangerlussuaq, Greenland (NSF's Sondrestrom Radar); in northern Scandinavia (European Incoherent SCATter radar); and in Svalbard, Norway (EISCAT Svalbard Radar) allow the diagnosis of most important plasma parameters. NSF's planned Advanced Modular Incoherent Scatter Radar (AMISR) should significantly extend and enhance this coverage from several locations in the Arctic, using a phased array antenna and distributed transmitter/receiver approach. Designed for remote and continuous operation, the AMISR will include three separate, relocatable phased-array radars. The proposed initial locations are near Fairbanks, Alaska, for auroral studies and Resolute Bay, Nunavut, Canada for studies of the central polar cap region.

For more information, see the NSWP web site (http://www.spacescience.org/SWOP/NSWP), or contact Craig Heinselman at SRI International in Menlo Park, CA (650/859-3777; fax 650/322-2318; craig.heinselman@sri.com).