Ionospheric hole caused by rocket engine

from Michael J. Rycroft

AMONG the most interesting of the wide variety of active experiments[1] that can be carried out to study the tenuous upper atmosphere and ionosphere are those that are 'accidental'. One such experiment, perhaps better termed an 'experiment of opportunity', is the operation of a rocket engine at heights above 200 km. The Saturn V launching of Skylab on 14 May 1973, which halved the total electron content of the ionosphere for three hours[2,3], created considerable interest in the effects of rocket exhaust gases on the ionosphere. Further measurements of an artificially induced 'ionospheric hole' were made during the Atlas-Centaur launch on 20 September 1979 of HEAO-C[3,4]. Michael Mendillo and Jeffrey Baumgardner, of Boston University, report[5] the first results of the latest experiment of this type, that for the Atlas-F launch of the NOAA-C weather satellite on 23 June 1981. Launched from Vandenburg Air Force Base, California, at around 03.00 local time, the rocket engine burned to an altitude of 434 km, well into the topside F-region of the ionosphere.

Because the rocket exhaust gases contain highly reactive molecules such as H_2, H_2O and CO_2, reactions with atomic oxygen ions (which are dominant in the F-region) produce molecular ions such as H_2O^+ and H_3O^+. The rates of the reactions are between a hundred and a thousand times faster than those which normally occur with ambient atmospheric nitrogen and oxygen molecules. Thus the atomic ion plasma is rapidly converted to a molecular ion plasma which then recombines quickly with ionospheric electrons, removing ionization and creating the local ionospheric hole. As the rocket proceeds and the plume of exhaust gases diffuses through the atmosphere, the electron content of a column through the F-region, both bottomside and topside, is depleted. The dissociative recombination reactions of the molecular ion plasma, which create the hole, produce oxygen atoms in the singlet D excited state. As these fall into triplet P states, red airglow is emitted, primarily at a wavelength of 630 nm. The position where the airglow is emitted is determined by the time scale of the diffusion of rocket exhaust species through the atmosphere.

The two important quantities to be observed in such experiments are the airglow and the total electron content (TEC) of the ionosphere. In the June 1981 experiment, the TEC was found by measuring the Faraday rotation of the plane of polarization of 136 MHz radio beacon signals from the ATS-1 geostationary satellite over the Pacific Ocean, the groundsite for such observations being chosen such that the ray path passed through the rocket's exhaust plume at 350 km altitude. Four minutes after launch, the TEC decreased rapidly, and reached a steady value some three minutes later; the TEC was found to decrease by 1.7×10^{17} electrons per m^2. From the same site narrow-band optical observations were made using a low-light level image-intensified photographic system with a 60° field of view. As the TEC decreased, an expanding shell of airglow with an intensity of several kiloRayleighs was observed; in the horizontal plane, this appeared rather like a 'smoke ring' with a radius of up to about 1,200 km. As the shell expanded more, its intensity decreased on a time scale of several minutes.

What can be deduced from such observations of the expanding shell of rocket exhaust molecules? First, the diffusion coefficient can be estimated to be $3 \times 10^7 m^2 s^{-1}$. This is consistent with the lightest species of exhaust gases (H_2) diffusing through an ambient atomic oxygen atmosphere, with a temperature of 1,000K at 350 km altitude. Second, knowing that the Atlas-F rocket ejects 10^{27} H_2O molecules per s (about 50 kg s^{-1}), the observation that the airglow emission was maximal two minutes after the initiation of the hole can be interpreted. It is found that 14 per cent of the plasma recombinations yield oxygen atoms excited in the singlet D state. Also, it is shown that, to first order, quenching of the excited oxygen atoms by molecular species is not important.

Further analysis of this and similar experiments can be expected in the future, and other chemical release experiments are planned, for example from the Space Shuttle. Even the operation of the Shuttle's engines or the dumping of water produced by its fuel cells could lead to interesting results. Such active space plasma experiments conducted in the ionosphere are not only of scientific interest, but also have practical significance for various aspects of radio communications. □

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Coastal plants take to the road

from Peter D. Moore

IT has long been recognized that the spreading of salt on roads in Britain during the winter is having a progressive influence on the vegetation of our roadside verges[1]. A similar problem has been described from the United States back in 1969, when it was estimated that 6×10^6 tons of salt were applied annually to roads in the northern states[2]. Up to 10^6 tons are used annually in Britain[3], and locally this often means that salt is being added to the soil of these verges at a rate of 3–4 kg m^{-2} yr^{-1} (in the United States, values of up to 6 kg m^{-2} yr^{-1} have been recorded[2]).

If we compare these figures with those obtained from studies of natural salt spray on coastal vegetation, such as maritime cliff grasslands, then the ecological impact of the salt input can be appreciated more fully. In his studies of the Lizard peninsula, Cornwall, Malloch[1] determined the annual 'salt' (Na, K, Mg, Ca, Cl) deposition in rain gauges to be approximately 0.07 kg m^{-2} yr^{-1}. In only one location did he record a value as high as 0.86 kg m^{-2} yr^{-1} of sodium, which is approximately equivalent to 2.6 kg m^{-2} yr^{-1} of total salt. The results are in keeping with those from sites in western Ireland 15 km from the sea[5] (0.04 kg m^{-2} yr^{-1}), in Lancashire 2 km from the sea[6] (0.01 kg m^{-2} yr^{-1}) and in Cheshire 40 km from the sea[6] (0.004 kg m^{-2} yr^{-1}). It is evident, therefore, that our roadside verges are receiving a considerably greater (often by a factor of 50) input of salt than our most exposed cliff grasslands, and it is not surprising that the effects of such treatment are being increasingly felt.

The application of salt to soil has a strong influence on its structure, and leads to clay flocculation and consequent loss of aeration. It also, naturally, raises the osmotic potential of the soil water, making it difficult for plants which lack physiological adaptation to absorb water. There are two main consequences for the vegetation: first, there will be a strong selective pressure against those individuals within populations that lack the requisite adaptations; and second, halophytic, maritime plant species will be able to invade these inland habitats.

Relatively little data are available on the effects of salt application upon the general

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