Polar Clouds from Space Shuttle Exhaust

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Introduction: The Earth's mesosphere lies above the stratosphere in the region between 50 and 90 km altitude, far above where airplanes or balloons can fly. In the unique polar summer mesosphere, the temperature plummets below 150 K (–190 °F), making this region the coldest on Earth, so inaccessible that it is sometimes like studying the atmosphere of another planet. In this extremely rarefied and dry place, water ice particles are found in narrow layers near 82 km altitude called polar mesospheric clouds (PMCs). PMCs are not known in the published record until 1885.

The specific processes leading to the formation of PMCs are disputed. However, some evidence indicates that they became brighter and more frequent in the late 20th century, leading some scientists to argue that they are indicators of global climate change. One hypothesis reasons that increasing amounts of methane (CH_4) emitted at the Earth's surface by industrial and agricultural processes increase the humidity of the upper atmosphere as the methane is broken down by ultraviolet sunlight to form water vapor.

Recently, NRL's Space Science Division scientists have complicated this hypothesis by identifying a new source for PMCs, challenging long-held beliefs about the meteorology of the upper atmosphere. Using satellite observations from NRL's Middle Atmosphere High Resolution Spectrograph Investigation (MAHRSI), Stevens et al.[1] showed that the exhaust plume from the space shuttle can be transported all the way from the east coast of the United States to the Arctic summer mesosphere to form PMCs. Additional data from other experiments now reveal that this phenomenon has occurred over both poles. Here we present the initial observations leading to the discovery, and discuss its scientific impact.

The Discovery: MAHRSI was an experiment designed to measure hydroxyl (OH) in the Earth's mesosphere on a satellite deployed and retrieved by the crew of the space shuttle. It flew on two one-week missions in November 1994 (STS-66) and August 1997 (STS-85). MAHRSI observed near-ultraviolet light (~309 nm) from the atmosphere at high spectral resolution (0.02 nm), which allowed for the discrimination of OH solar fluorescence from the bright Rayleigh scattered background. PMCs were never considered as a science objective of MAHRSI, but were unexpectedly detected while analyzing data at the Kennedy Space Center during the late summer mission in 1997.[2]

OH is created when water vapor is destroyed by solar ultraviolet radiation and it is therefore sometimes used as a proxy for water vapor. Water vapor is the primary effluent of the shuttle's main engines and is copiously injected in a relatively narrow layer between 105 and 115 km altitude off the east coast of the United States as the shuttle accelerates to orbit.

As shown in Figs. 3(a) and 3(b), one to two days after the launch of STS-85, unexpectedly bright OH intensities were observed by MAHRSI in the upper mesosphere at Arctic latitudes (circled in red). Figure 3(c) shows that about a week after launch, PMCs were also observed over much of northern North America by MAHRSI, as indicated by the red crosses. Using observations from a German companion experiment called Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA), Stevens et al.[1] found that the water content of these clouds (~100 t) was consistent with the amount available in the shuttle plume (~300 t). This was the first evidence that a launch vehicle plume injected in the subtropics could create Arctic PMCs. To our knowledge, the global scale transport of this exhaust plume had never been considered before.

The Scientific Impact: We have since assembled more data from a variety of ground-based and satellite experiments. For example, we found that another shuttle exhaust plume (STS-107) created polar clouds, but this time they were in the Antarctic summer, contributing 10-20% to the total ice content of PMCs observed that season.[3] Proposed trends in cloud brightness since 1980 are not larger than this. This calls into question the interpretation of late 20th-century PMC trends solely in the context of global climate change.

The Upper Atmospheric Physics Branch at NRL's Space Science Division is poised to build on the success of MAHRSI with a new instrument called the Spatial Heterodyne IMager for MEsospheric Radicals (SHIMMER). This instrument uses innovative technology called spatial heterodyne spectroscopy that allows for higher spectral resolution and throughput while minimizing mass and volume. SHIMMER is scheduled to launch in 2007 on a much longer, one-year mission to measure OH in the middle atmosphere.

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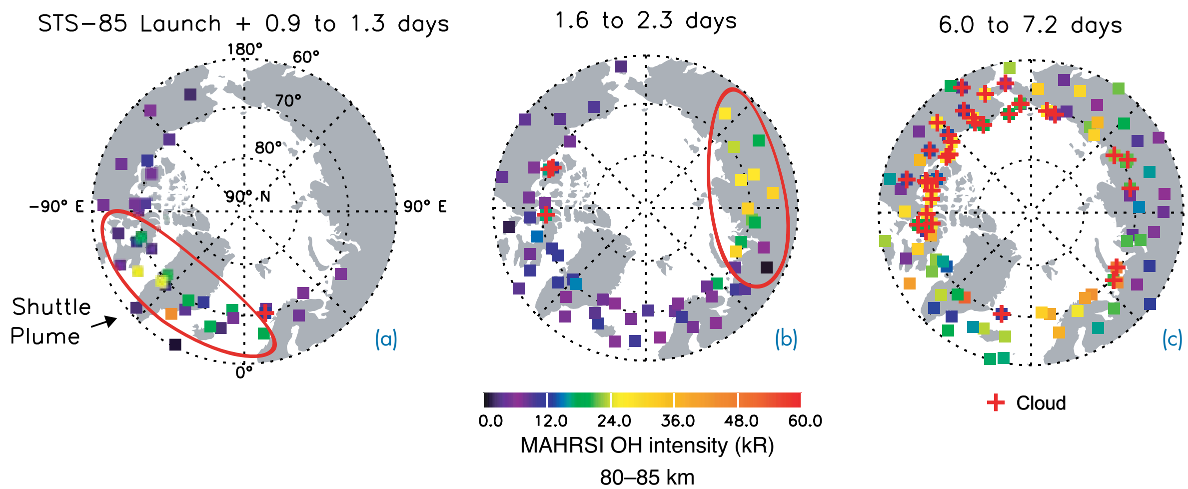

FIGURE 3
STS-85 carried the Middle Atmosphere High Resolution Spectrograph Investigation (MAHRSI) into orbit in August 1997. MAHRSI observed the shuttle's exhaust plume in the Arctic (circled in red) by measuring solar resonance fluorescence of OH, where 80–85 km radiances are referenced to the color bar. MAHRSI scans the limb of the Earth, so that OH observed viewing toward 80–85 km can originate at altitudes higher than this along the line of sight. A week after launch, MAHRSI observed polar mesospheric clouds over northern North America (red crosses, Fig. 3(c)). The amount of water in the observed PMCs is consistent with the amount injected by the shuttle.

References

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