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ON THE CONTROVERSY OF EXTREME SOLAR PARTICLE EVENT SIGNATURES IN ARCTIC ICE CORES: SUN TO ICE?

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On the morning of September 1, 1859, a particularly large and complex active region destabilized, launching an extremely fast Coronal Mass Ejection (CME) toward Earth. A large solar flare blazed; its optical brightness lasted 5 minutes and equaled that of the background Sun. A plausible yet perhaps partly controversial description of ensuing events is as follows. The ejecta propagated rapidly away from the Sun, generating a fast-mode wave ahead of it, which in turn steepened into a fast-mode forward shock. The shock, traveling in excess of 2000 km s1 accelerated suprathermal ions in the ambient solar wind to high energies. The first of these so-called Solar Energetic Particles (SEPs) arrived at the Earth within an hour. Energetic particles entered the Earth's magnetospheric environment directly through the polar cap region. Highly energetic particles penetrated to the stratosphere and produced nitrogen oxides (NOx) via impacts with molecular nitrogen and oxygen. The lower energy particles generated NOx and hydrogen oxides (HOx) in the mesosphere and thermosphere. Acting as a catalyst, NOx (HOx) rapidly destroyed stratospheric (mesospheric) ozone, substantially decreasing ozone concentrations immediately following the arrival of the energetic particles. Over a period of 4 months, vertical winds enhanced by the polar vortex transported the remaining NOx from the middle and upper atmosphere into the stratosphere, leading to a second depletion in the main ozone layer. Some ice core analyses further suggest rapid nitrate deposition (within weeks of production), requiring prompt downward transport to the surface through gravitational precipitation (i.e., snow), though more direct pathways of the nitrates to the ice may be possible.

Recent studies reveal a provocative and striking correlation between ice core nitrate spikes and Ground Level Enhancements (GLEs), a signature of large SEPs in Earth-based neutron monitors . Ice core nitrate spikes apparently occur within weeks of recorded GLEs. However, glaciochemists and the scientific community studying snow photochemistry cannot with traditional models describe a mechanism for maintaining such prompt nitrate enhancements in ice. A definitive association is thus incomplete until the chain of events linking rapid nitrate deposition and ice incorporation can be tested, measured and understood. In this paper, we articulate the controversies associated with the final link in the "Sun to Ice" chain: whether

nitrate spikes in the ice core record are associated with solar particle events.