Thunderstorm geometry & morphology suggested from Cassini/RPWS Saturn lightning flashrate data and comparative terrestrial meteorology

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Lightning on gas planets like Saturn can be understood in terms of lightning on Earth. Like terrestrial lightning, Saturn Electrostatic Discharges (SEDs) are most likely dependent on the change of the planet's season. In August 2009, Saturn's northern (southern) hemisphere entered spring (autumn), a 7-year-long season. Years before and after this (pre/post) equinox period, the Cassini/RPWS (Radio and Plasma Wave Science) instrument, since its orbital insertion in 2004 till now, has so far recorded several storms; few of them lasted for several months. In this contribution, we suggest underlying mechanisms based on Earth-analogues regarding how the lightning storms in Saturn's atmosphere could have sustained for long periods of time. By using 'rule-of-thumb' or single-parameter relationships derived from terrestrial lightning observations, we speculate the thunderstorm geometry and its evolution in time from distance-normalized SED flashrates; considering only the SED records taken from the same instrument mode during the Cassini equinox mission 2008-2010. Then by applying comparative terrestrial meteorology, we further speculate the most likely dominant thunderstorm morphology as lightning generator for each storm.

1. Preliminaries

Whenever the atmospheric structure and dynamics of a planet share common features with the Earth's atmosphere, comparative terrestrial meteorology can be applied. In this respect, SEDs (Saturn Electrostatic Discharges) on gas planets like Saturn can be understood in terms of lightning on Earth. In principle, if Saturnian flashrate data are available and terrestrial flashrate relationships are established; then we can extrapolate the thunderstorm geometry and morphology of each SED storm.

Among the common features shared by the two planets are (a) large tilts of rotation axes w.r.t. their orbital plane, causing the planet's season to change over time; and (b) water clouds in the troposphere, allowing a similar charge separation mechanism to produce lightning in the planet's atmosphere [1].

The large axial tilt of Saturn may trigger effects that can couple with the change of season; yet unexplained is the way the internal heat flux is transported at the water condensation layer [2], depositing a sufficient CAPE, bringing instability hence convective clouds. If distinct, lateral and localized updrafts and downdrafts co-exist, organized convective storms can be sustained for a long period of time, including episodic SEDs storms.

2. Cassini equinox mission 2008-2010

After having completed its prime mission to explore the Saturn system in 2008, the Cassini spacecraft continued its exploration until 2010 in the so-called equinox mission. Even before the equinox mission, one of the Cassini instruments, the RPWS (Radio and Plasma Wave Science) instrument has so far recorded several lightning storms [1,3]. Towards the spring (autumn) equinox in northern (southern) hemisphere, the duration and strength of these SED storms that raged at 35° South, dubbed as the 'storm alley', reached their peak, which is most probably modulated by seasonal effects [2].

Below, we use SED records from the end of the year 2007 to the middle of the year 2010. The same algorithm as in [4] was used to extract the SED from the dynamic spectra. For convenience, we consider only SED data measured from the same mode of the Cassini/RPWS instrument. This mode happens to be the most dominant mode of recording SEDs. In this mode, we assume that the number of flashes is absolute. The selected SED records are then normalized with respect to spacecraft distance to Saturn using half-orbit parameters. The details of the procedure used in normalizing the SED quantities are described elsewhere [5].

3. Thunderstorm geometry and morphology

A terrestrial thunderstorm is a cumulonimbus cloud vertically extending from the lower troposphere up to the tropopause. It has a complex charge distribution, but here we assume the thunderstorm to be dipolar, a parallel-plate capacitor with the cloud-top (cloud-base) having a positively (negatively) charged plate. The thunderstorm or the capacitor is charged as a result of collisions between upward moving ice-crystals and the falling riming-graupel, the so-called non-inductive graupel-ice mechanism. From this picture, the distance from the top to the bottom of the cloud is the height or the *ice-water path* and the space-charge region occupied by the capacitor at the plate separation defines the *graupel volume*.

From the normalized lightning flashrates, we can use a 'rule-of-thumb' relationship to deduce the thunderstorm geometry. They are single-parameter relationships deduced from terrestrial lightning observations, which state that flashrates increase linearly (1a) with the *horizontal area* of the charge region [6] and (1b) with *updraft surges* [7,8]; and further, correlate strongly (2a) to the *graupel volume* in vigorous updraft in upper cloud levels [9] and (2b) to the *ice-water path* [10]. As only the horizontal area of the thunderstorm geometry can be measured, we can find, as an illustration, the best-fit line on the relationship (1a) during the 14-day growth in area of the Great-White-Spot's head during its early phase in December 2011.

Based on the SED storm duration and intensity, we can speculate the most likely dominant thunderstorm morphology. Taking into consideration the thunderstorm geometry (relationships (1a-b) and (2a-b)) & its evolution described earlier, we can further speculate, i.e., whether the dominant convective mode [11] of the thunderstorm is (i) uni-cellular (single-cell), (ii) multi-cellular, or (iii) a supercell.

In Figure 1, a structure (ii), for example, is suggested for the SED storm F when flashrates show a large variability within one storm. Most likely in between the periods when flashrates decrease and then followed by an increase, a new cell may have been activated.

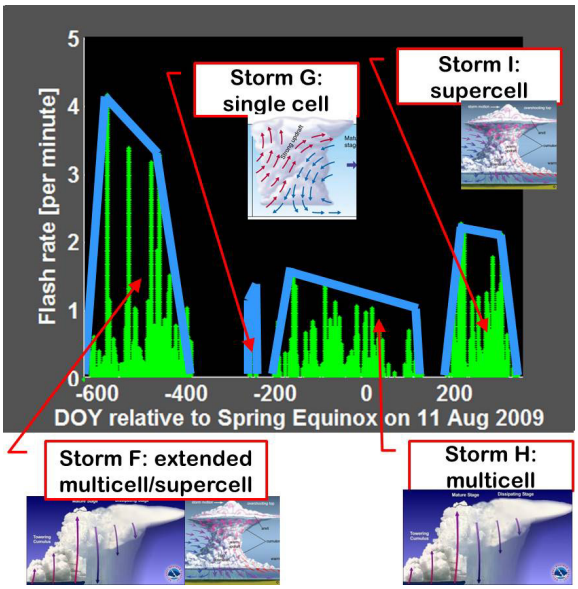

Figure 1: Normalized Saturn flashrates (green) during the time interval 600 days before and 400 days after spring equinox (11th of August 2009) their maxima envelope (blue) for each storm, and their most likely corresponding thunderstorm morphology as lightning generator; the latter dominant convective mode is suggested based on terrestrial comparative meteorology.

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4. References

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