Sprites, Halos, and Jets, Oh My!
The Meteorology of Luminous Events in the Upper Atmosphere

Timothy Lang (M.S. 1997, Ph.D. 2001)

With contributions from Steve Rutledge, Tiffany Meyer, Walt Lyons, Steve Cummer, Jingbo Li, Gaopeng Lu, Bill McCaul

Department of Atmospheric Science 50th Anniversary Celebration
1. Introduction
2. Positive Sprites
3. Negative Sprites
4. Gigantic Jets
5. Conclusions

Pasko (2003)
Why even study these things?

Transient luminous events (TLEs) matter because they:

1. Could have impacts on space weather and/or pose hazards to high-altitude aircraft

2. Affect the global electric circuit, also high-altitude chemistry

3. Parent lightning could be more destructive to infrastructure than the average cloud-to-ground stroke (e.g., fires, utility damage)

4. Provide insight into storm electrification, microphysics, and dynamics
POSITIVE SPRITES

High-speed sprite video

Halo precedes actual sprite, total duration only a few ms

Phantom HSI, 5000 fps, 11 July 2011 (Tom Warner)
Wilson (1925): Transient electric field falls as $r^{-3}$ above storm, while breakdown field falls exponentially (air density).

At some point above a thunderstorm, $E$ will exceed the breakdown field.

Electric field magnitude controlled by the charge moment change of the lightning.

Pasko (2010)
Charge Moment Change:

\[
\text{CMC}(t) = Q(t) \times Z(t)
\]

Q is charge lowered
Z is height from which it is lowered

~100s of C km generally associated with sprite-parent cloud-to-ground strokes (CGs)

Positive sprites:
Impulse (1st 2 ms) + Continuing Current

Negative Sprites:
Impulse (iCMC) more important

Hu et al. (2002)
Typical Thunderstorm Charge Structure

Stolzenburg et al. (1998)
19 August 2009  Convective Initiated
19 August 2009

Convective Initiated
NegativeSprites

Continuing current not typical in -CGs, so need high impulse charge moment change (iCMC; 100s of C km)

Lu et al. (2012): Negative CGs with high iCMC almost exclusively associated with hybrid-IC/-CG or “bolt-from-the-blue” flashes that involve the upper positive charge in a normal-polarity thunderstorm tripole
Example of hybrid IC–NCG lightning

(a) North Alabama LMA

(b) Duke broadband

(c) View to the west

Lu et al. (2012)
94 Likely Negative Sprite Parents – Very Rare! (<6% of population for similar +CGs)
Typical example:
Intense, large multicellular convection
Have analyzed 40 potential negative sprite-producing events on 25 different days (2007-2011)

All but 3 events occurred within 15 km distance of a convective core that had 30 dBZ reaching to at least 10 km MSL on average (They frequently occur in or near intense convection)

34 of 40 events had >50% -CG lightning within 15 km of event for a 25-minute period surrounding the time of the event (They frequently occur in -CG dominated storms)

They frequently occur in large mesoscale systems

(Min. size of 30-dBZ echo observed was 616 km²)
26 March 2011, 1043 UTC, Northern Alabama
-974 C km, -145 kA
Gigantic Jets
Gigantic Jet Theory

Key Point: Relative depletion (via turbulent mixing, displacement, and/or lightning) of upper-level positive charge can energetically favor an upward discharge
Gigantic Jet Example – Oklahoma, 9 September 2010

Remains of Tropical Storm Hermine

Moist, tropical-like airmass

Tall convection with overshooting top
Oklahoma Gigantic Jets – 9 September 2010

NEXRAD reflectivity 30-dBZ
Time-height

VHF radio source density
Time-height

Other examples (Florida, Puerto Rico, North Carolina) often exhibit similar characteristics
Take Away Messages

• The meteorology of thunderstorms strongly affects their production of transient luminous events such as sprites and gigantic jets

• Direct link between tropospheric weather and electromagnetic activity within the upper atmosphere

• Mesoscale precipitation systems normally are responsible for sprites – positive CG/sprite in stratiform, negative in convection (Link between the two is upper positive charge)

• Tall, tropical or tropical-like convection undergoing surge may produce gigantic jets