Lightning and Climate

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Outline

- Global perspective on thunderstorms and world views
- CAPE versus aerosol control of lightning in present climate
- Natural variations in global temperature and lightning
- Impact of urban areas on lightning
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- Puzzlements on 11 year solar cycle
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- Expectations for lightning in a warmer world
- Conclusions

Extreme Moist Convection: The Thunderstorm
World Views

Majority View
- Weather & Climate
- Electrification & Lightning
  - Thermodynamics
  - Aerosol

Minority View
- Electrification & Lightning
- Weather & Climate
  - Cloud microphysics
  - Atmospheric chemistry
  - Forest fire initiation

World Views on Variability of Lightning

1) Role for Thermodynamics
   - Temperature, CAPE, cloud base height are main causal variables
2) Role for aerosol
   - Cloud condensation nuclei are key components

Natural frameworks for monitoring global electrification

- DC Global Circuit
- AC Global Circuit
  - Schumann Resonances

Integrator of Electrified Weather
Integrator of Global Lightning
The contrast between lightning and rainfall (NASA TRMM)

Why should lightning activity follow surface air temperature?

- In all climates, water vapor increases with increasing temperature (Clausius-Clapeyron relationship)
  
  ![Temperature vs. Water Vapor](image)

  \[ \text{Temperature} \quad \text{Water Vapor} \]

- In the present climate, Convective Available Potential Energy (CAPE) increases with temperature

Convective Available Potential Energy (CAPE)

- Click to edit Master text styles
  
  - Second level
    
    - Third level
      
      - Fourth level
        
        - Fifth level

Moist Adiabat

Temperature Profile
CAPE - Lightning Relationships

Southeast Asia (Singh et al., 2012)  India (Pawar et al., 2011)

Global climatology of Convective Available Potential Energy (CAPE)
(from Riemann-Campe, 2010)

Global Climatology of CAPE NASA GISS GCM
(Dee Genio, 2012)

* One year of model results

Illustration of aerosol hypothesis for thunderstorm electrification

Model Support from:
- Khain et al. (2005)
- Li and Zhang (2008)
- Mansell and Ziegler (2012)

First global map of aerosol concentration (Shiratori, 1934)

Observations from Carnegie cruises

Global Aerosol Observations (Kinne, 2009)

AERONET / composite

Anderson (2003)
Role of aerosol in cloud buoyancy and land/ocean updraft contrast

CAPE debate: Saunders (1957)
Betts (1982)
Xu and Emanuel (1989)
Williams and Remno (1993)
Lucas and Zipser (1994)
Rosenfeld et al. (2008)
Riemann-Kampe (2010)

Should CAPE be calculated for land and ocean

- Reversible CAPE
  - Lift the condensate as droplets
  - Benefit from latent heat of freezing
  - Appropriate for polluted continents

- Irreversible CAPE
  - Condensate removed by warm rain
  - Superadiabatic loading of updraft
  - Appropriate for clean oceans

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Natural time scales with a global lightning response

- Diurnal
- Semiannual
- Annual
- ENSO
Thunderstorm Day

AMS Glossary definition for Thunderstorm Day:

An observational day during which thunder is heard at the station

Diurnal Variation of Global Lightning

Global Circuit Temperature Dependence-diurnal time scale (Markson, 2003)
Evidence for semiannual variation in lightning activity

Physical origin: 23° obliquity of Earth's orbit

Authors

- Williams (1994)
- Satori and Zieger (1996)
- Fülekugr and Fraser-Smith (1997)
- Nickolaenko et al. (1998)
- Manohar et al. (1999)
- Christian at al. (2003)
- Satori et. al. (2009)
- Hobara et al. (2011)

Observations

- Thunder days
- Schumann resonances
- ELF
- Schumann resonances
- Surface observations
- OTD satellite
- Schumann resonances
- Schumann resonances

Semiannual time scale: Seasonal variation of insolation and air temperature for the tropics

Evidence for semiannual variation in lightning from the Optical Transient Detector (Christian et al., 2003)
Semiannual signal in Congo River discharge

Annual variation of global temperature and global lightning (11% change/°C)

Global temperature variation (Williams et al., 1994)  Global lightning variation (Christian et al., 2003)

Seasonal variation of global lightning activity (Christian et al., 2003)
El Nino Southern Oscillation (ENSO)

Strong thunderstorm activity favored by synoptic scale subsidence

Best evidence: Pre-monsoon thunderstorms everywhere are more electrically active than monsoon thunderstorms

Tropical ‘chimney’ regions are in stronger subsidence in the warm El Nino phase (from Pacific Ocean upwelling)

Best evidence: The discharge of the Amazon and Congo rivers is reduced during this warm phase

Variations in lightning activity on the ENSO time scale

- Evidence for higher temperature in El Nino phase over tropical continental ‘chimneys’
  - Hansen and Lebedeff (1987)
- Evidence for greater lightning (and reduced rainfall) in the El Nino phase
  - Hamid, Kawasaki and Mardiana (2001)
  - Yoshida, Morimoto, Kawasaki and Ushio (2007)
  - Chronis, Goodman, Cecil, Buechler, Robertson, Pittman and Blakeslee (2008)
  - Pinto (2009)
  - Satori, Williams and Lemperger (2009)
  - Kumar and Kamra (2012)
- Evidence for increase in exceptional oceanic lightning and ELVES
  - Wu et al. (ISUAL Satellite Team) (2012)

Zonal variation of lightning enhancement in warm El Nino phase
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Lightning enhancement over Houston, Texas (Steiger et al., 2002)

Evolution of thunderstorm days and temperature in Sao Paulo, Brazil (Pinto, 2009)

Sensitivity: ~10% change in thunder days per °C

Slope ~3.6 °C/century
Evidence for a weekly cycle in lightning (Farias et al., 2009)

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Global warming most pronounced at high northern latitude (NASA GISS)

Thunderstorm Days versus Summer Temperature: Fairbanks, Alaska (65° N)

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Thunderstorm days on the 11-year solar cycle

Brooks (1934)
Global data
No phase behavior
No time series

Klimanov (1967)
Global data
Out-of-phase behavior
No time series

Görlieck and Epen (2008)
Global data
Out-of-phase behavior
Yes, time series

Singh et al. (2012)
Southwest USA
Out-of-phase behavior
Yes, time series

Pinto et al. (2012)
Remote stations
Out-of-phase behavior
Yes, time series

Richness of frequency information in Schumann resonances (Satori, 2012)

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Decade record from Lightning Imaging Sensor (NASA MSFC)

(Best record available of global lightning)

- Monthly lightning flash counts from the Lightning Imaging Sensor
- Annual global mean temperature

Four-decade record of ionospheric potential (Markson, 2007)

Positive trend +16% per century but not statistically significant

Trend in four-decade record of air-earth current at Kew (London)

Positive trend +25% per century and statistically significant
High and low water marks in Amazon basin at Manaus (1903-present)

Positive trends - statistically significant

1.4% change per century

Trend in discharge of Congo River (1905-1985)

Positive trend +15% per century and statistically significant

Period of Declining Global Temperature

Global record

US record
Consistent decline in thunderstorm days in the period of global and regional cooling

Chagnon (1985)
86 stations in US
+ 19% thunder day/°C

Gorbatenko and Dulzon (2001)
3 stations
Central Asia

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Molecules and Climate

Non-greenhouse gases

Primary greenhouse gases

Greenhouse compounds made by lightning
NOx delivered to upper troposphere by lightning source → Ozone Enhancement

Boundary Layer: Anthropogenic source for NOx

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CAPE response to warming scenarios
**CAPE changes in a warmer climate:**
two GCM predictions

(A. Del Genio, NASA GISS) (D. Randall, CSU)

**Higher flash rate in warmer climate?**

Integrated Flash Rate Histograms: Global Tropics

**Lightning in our future?**

**Thermodynamic view:** More lightning probable

** Aerosol view:** More difficult to say
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Conclusions

- Both thermodynamics and aerosol are influencing lightning activity; disentanglement is difficult task
- Lightning activity in cities and at high northern latitudes is on the rise
- 11-year thunder day antiphase condition most prevalent at low latitude
  - Possible role for galactic cosmic rays
- Long-term trends in tropical chimney regions are positive
- Expectation for more lightning in a warmer world
- Both global circuits deserve greater exploitation as inexpensive global monitors

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Global lightning at midnight (Orville and Henderson 1986)

Global oceanic maps of CCN concentration (Hogan, 1977)

Uses for the frequency variations of Schumann resonances are responsive to both the changes in properties of the Earth-ionosphere cavity and to variations in the lightning source-observer.

Solar cycle variation of SR frequencies is attributed to the variations in hard X-ray flux of more than two orders of magnitude influencing the upper boundary layer of the Earth-ionosphere cavity (Sátori et al. 2003). One would expect lower frequency values at the last solar minimum in 2008/2009 than in the previous one in 1996 if the frequency during the solar cycle is only...
Northward shift of the global lightning position indicated by SR frequency variations is attributed to the more intense global warming of the Northern Hemisphere starting at around 1996.

Contrasting the behavior between solar cycle minima

Frequency of the 1st Ez mode has maximum while the 1st horizontal magnetic mode exhibits minimum at NCK (Northern hemisphere) in summer. The summer peak frequencies of the 1st Ez mode (black segments) were higher in the 2008/2009 solar minimum than in the previous one in 1996. Even the frequency was much higher in summer, 2007 (red segment) than in 1996 in spite of the fact that the solar activity in 2007 already returned to the activity level of 1996. The opposite frequency response can be seen in case of the 1st horizontal magnetic mode when comparing summer frequency values at the two solar minima. The frequency minima are deeper in summer in 2008/2009 than in the previous solar minimum. The opposite frequency variation of the vertical electric and horizontal magnetic field components at the two consecutive solar minima hints that the centroid of the world lightning distribution is systematically shifted northward with increasing solar activity.

Smoke ingestion by thunderstorms and inversion of electrical polarity (Rudolfs and Fuelberg, 2011)
Variation of fair weather electric field at Kennedy Space Center (Harrison, 2006)