Lightning and Climate

Earle Williams

MIT

Presented by Al Gasiewski

University of Colorado

Lighting Summit - Houston, TX – May 8, 2013

(As presented at the Franklin Lecture

AGU Fall Meeting - San Francisco, CA - December 5, 2012)

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
- Increases in lightning at high northern latitude
- Puzzlements on 11 year solar cycle
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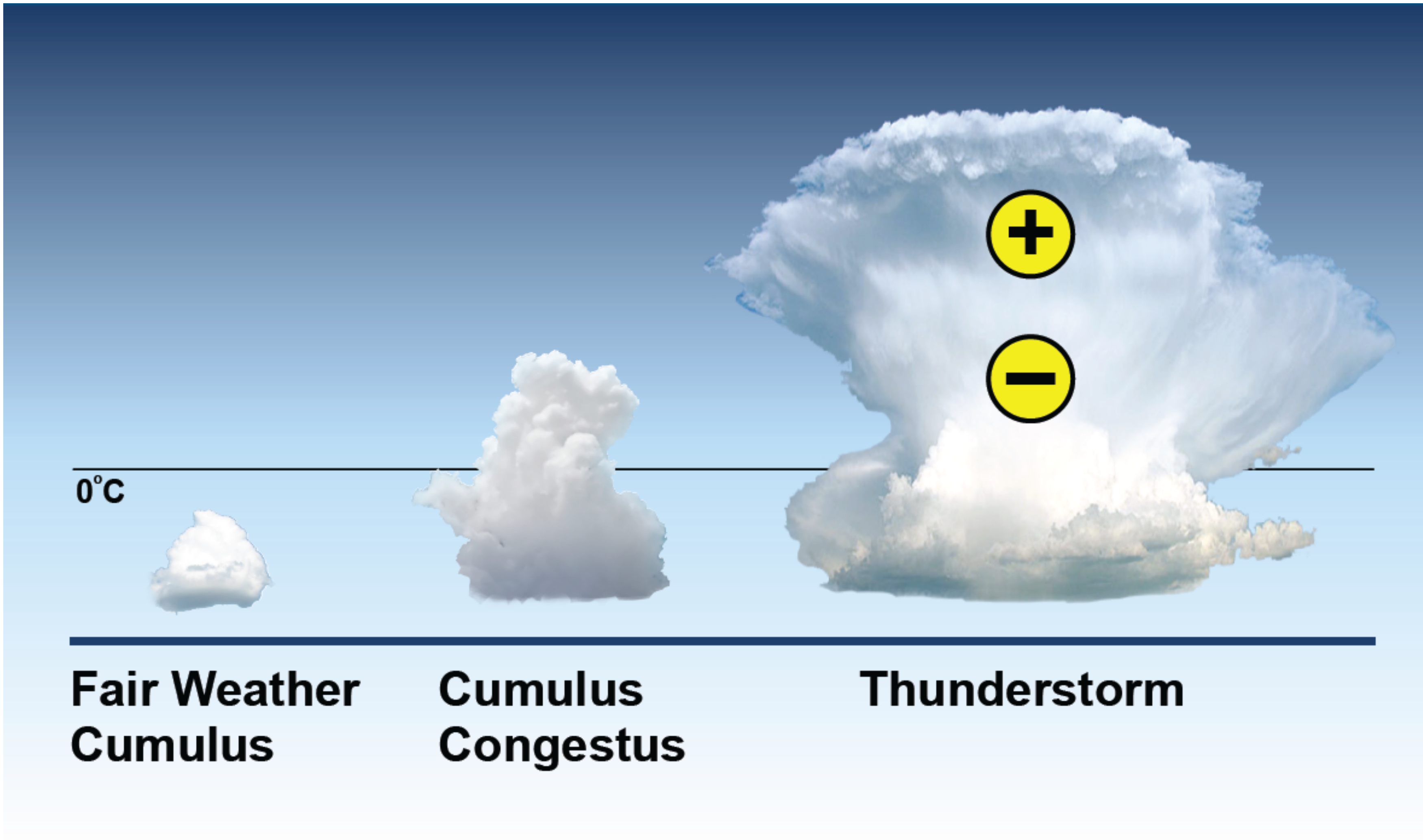
- Expectations for lightning in a warmer world
- Conclusions

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

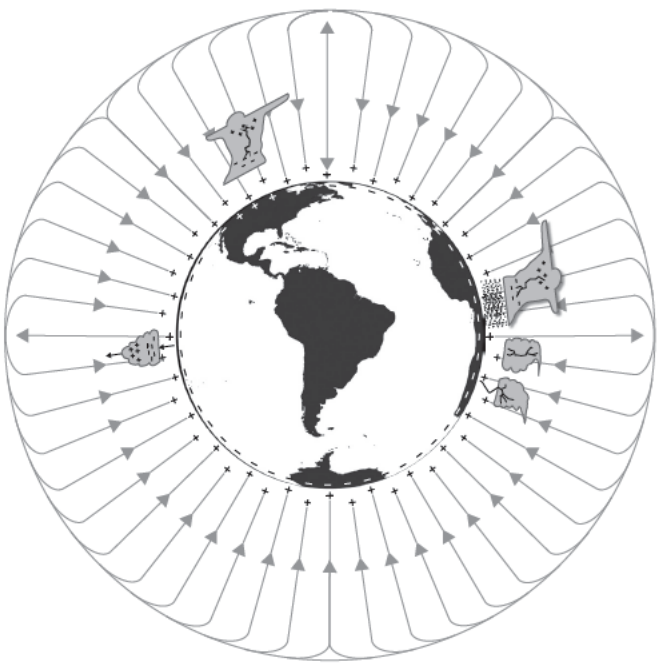
World Views on Variability of Lightning

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

Both aspects are crucial considerations for climate change

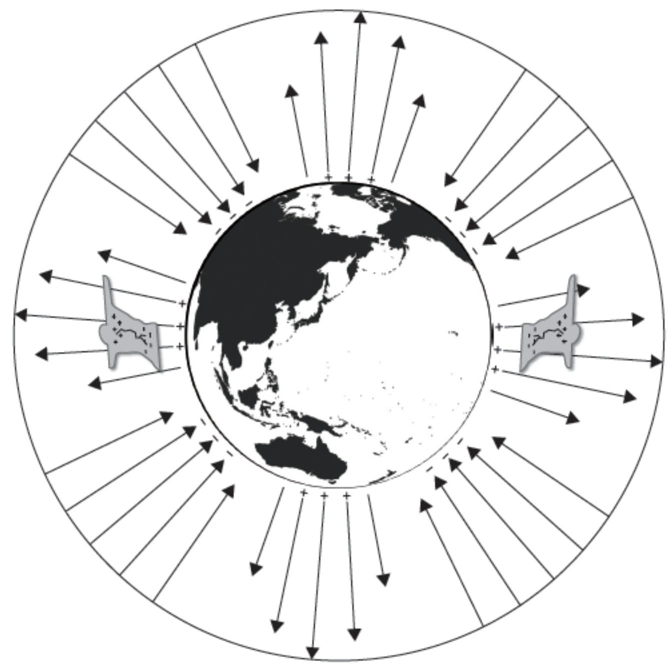
Natural frameworks for monitoring global electrification

DC Global Circuit



Integrator of Electrified Weather

AC Global Circuit
Schumann Resonances



Integrator of Global Lightning

The contrast between lightning and rainfall (NASA TRMM)

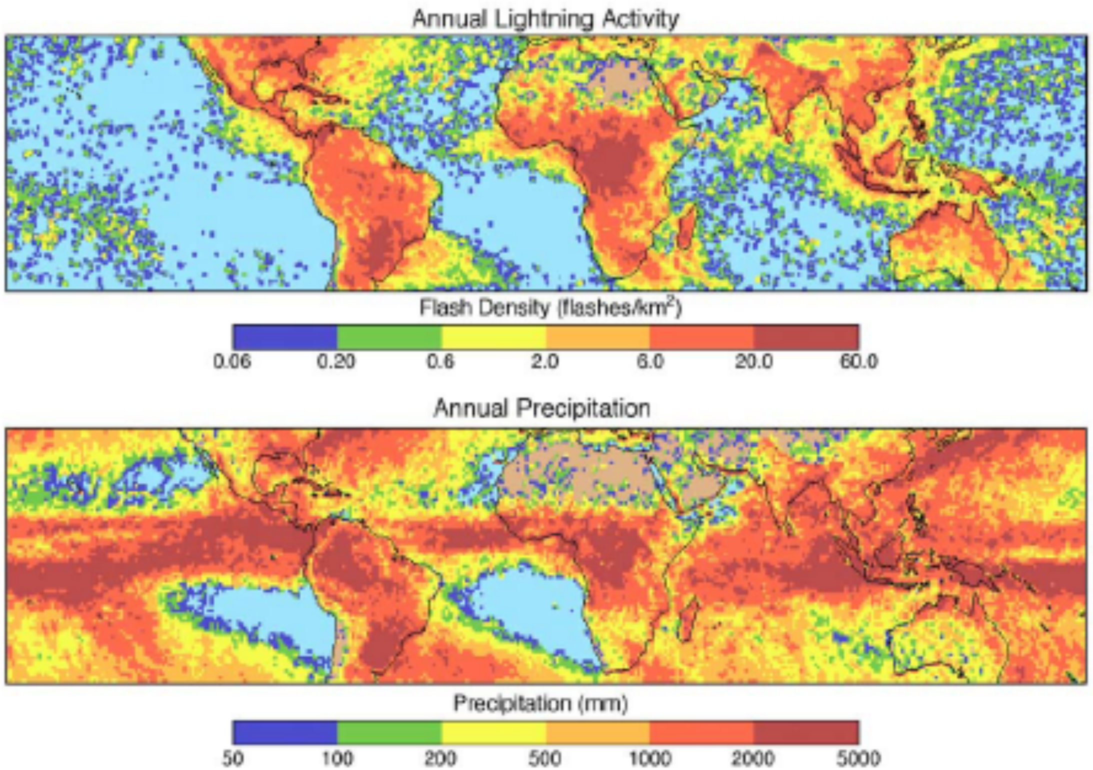
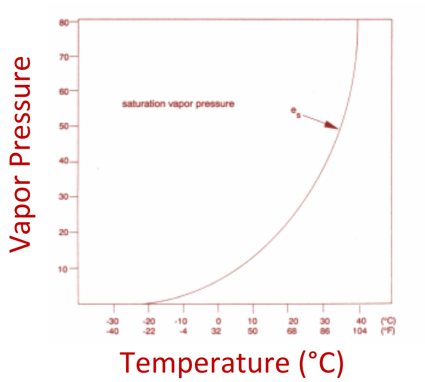


Fig. 1. Global lightning activity (top) based on observations with the Lightning Imaging Sensor and global rainfall (bottom) based on observations with the Special Sensor Microwave Imager (SSM/I) (courtesy of S. Goodman, NASA MSFC).

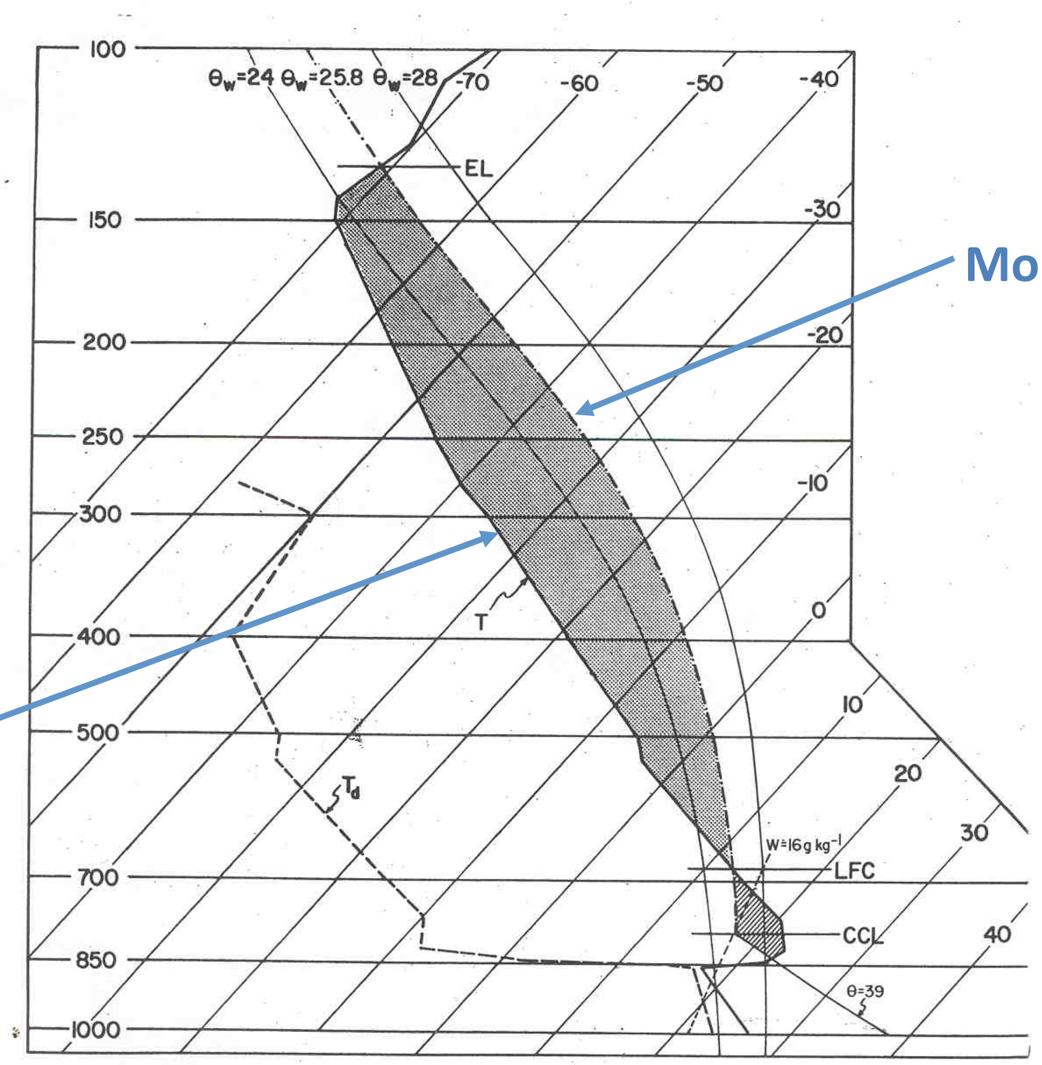
Why should lightning activity follow surface air temperature?

- **In all climates, water vapor increases with increasing temperature (Clausius-Clapeyron relationship)**
  - **+ 7% per degree C at 0°C**



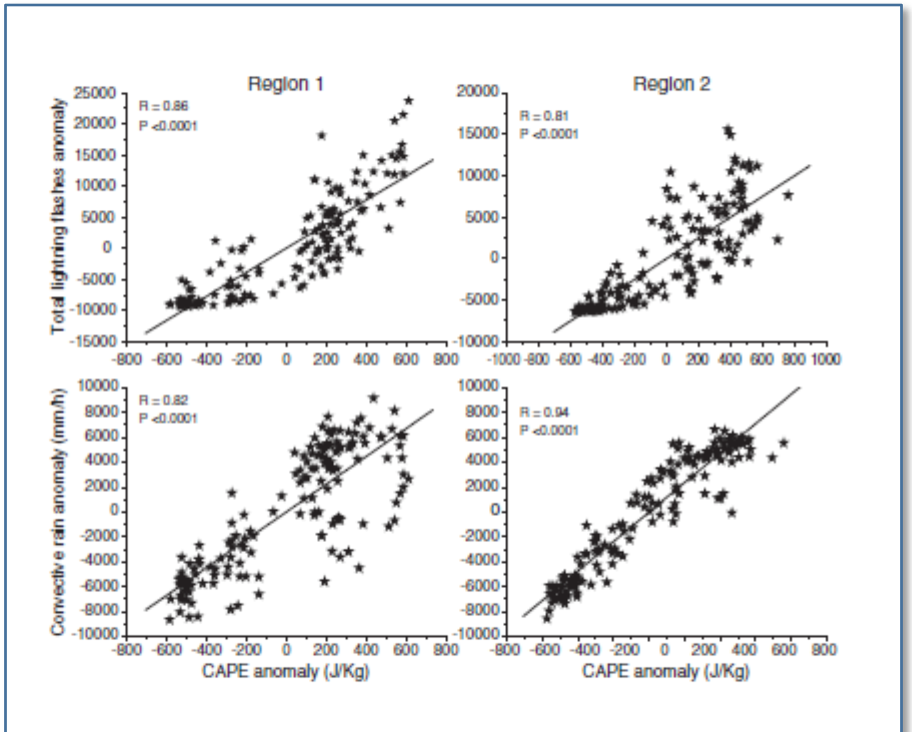
- **In the present climate, Convective Available Potential Energy (CAPE) increases with temperature**

Convective Available Potential Energy (CAPE)

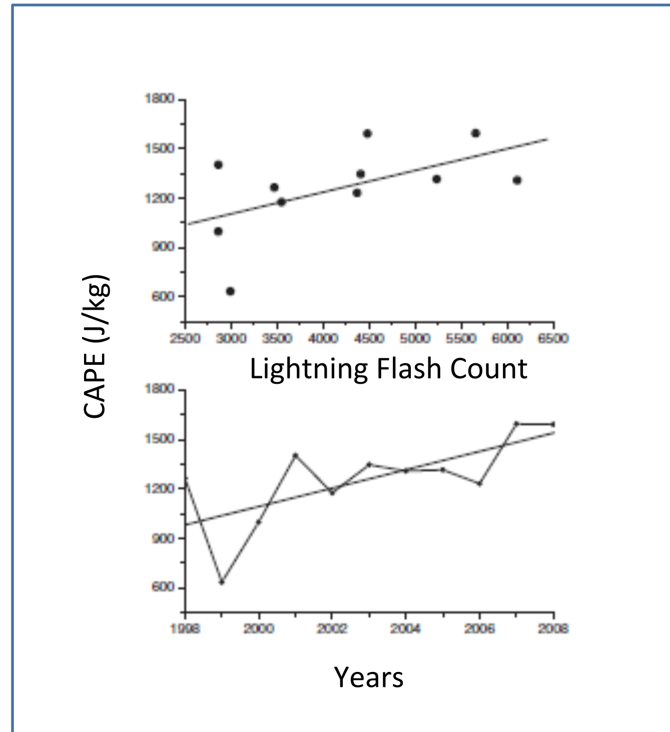


CAPE – Lightning Relationships

Southeast Asia (Siingh et al., 2012)

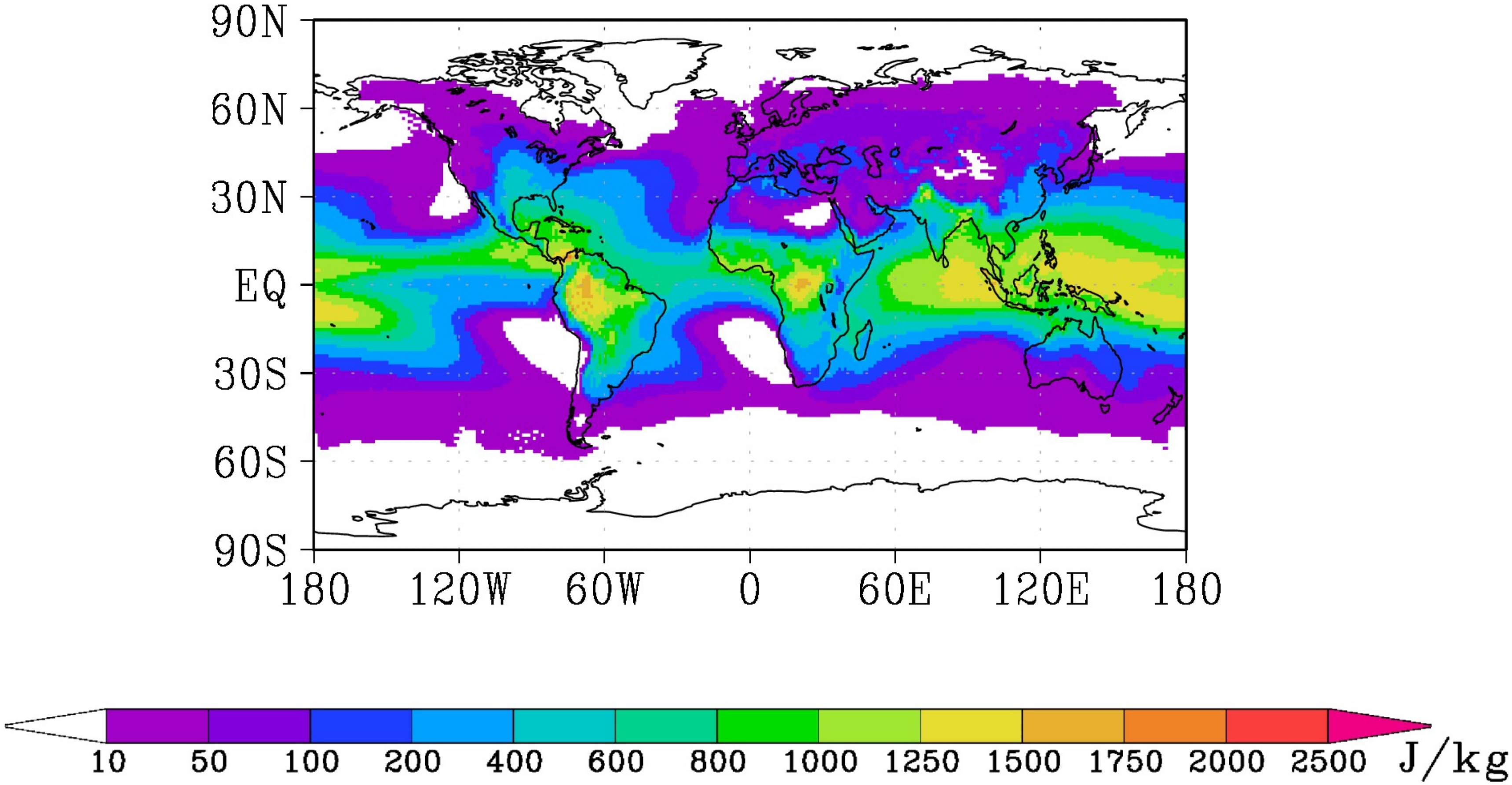


India (Pawar et al., 2011)



Global climatology of Convective Available Potential Energy (CAPE)

(from Riemann-Campe, 2010)



Global Climatology of CAPE NASA GISS GCM

(Del Genio, 2012)

- ***One year of model results***

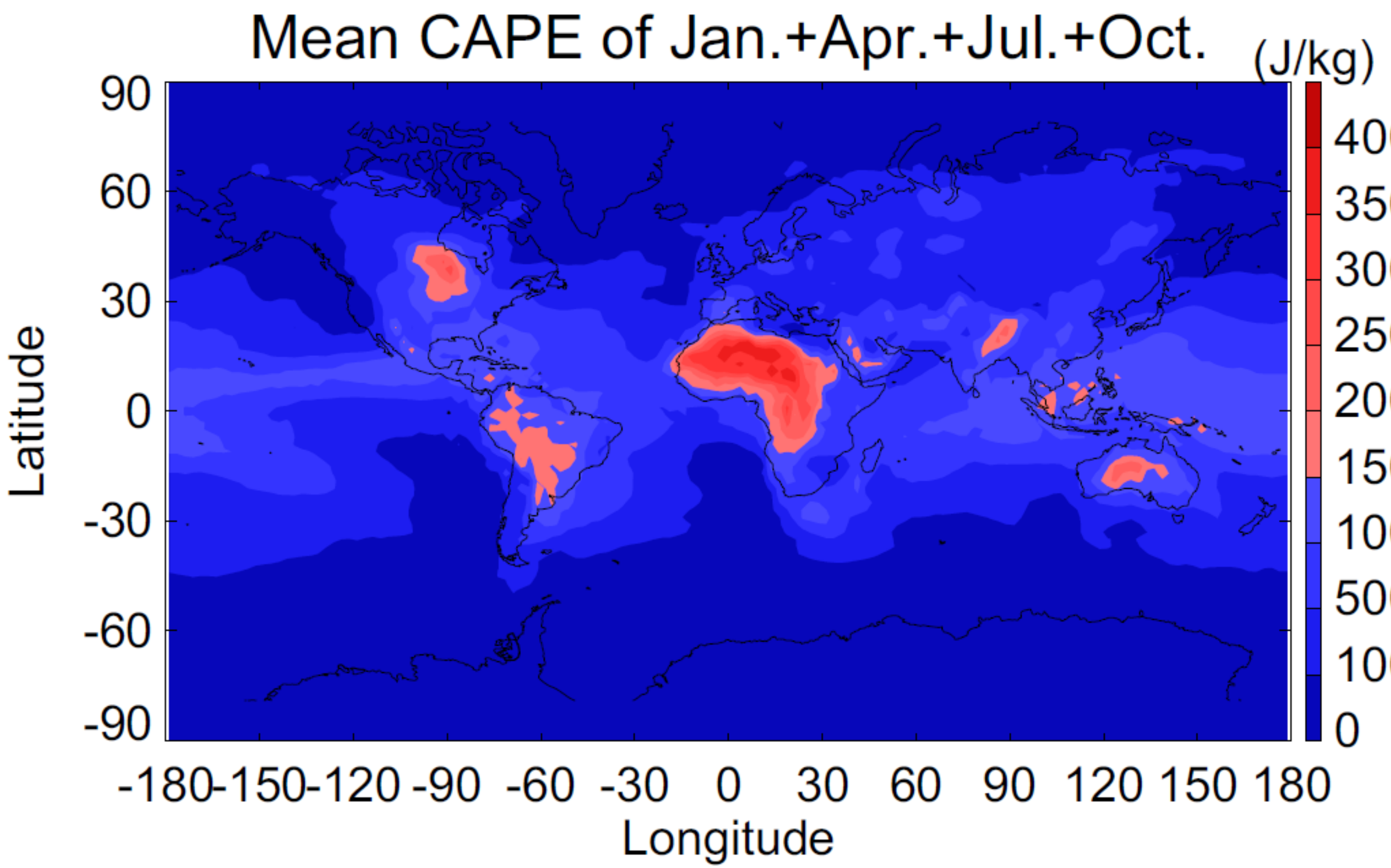
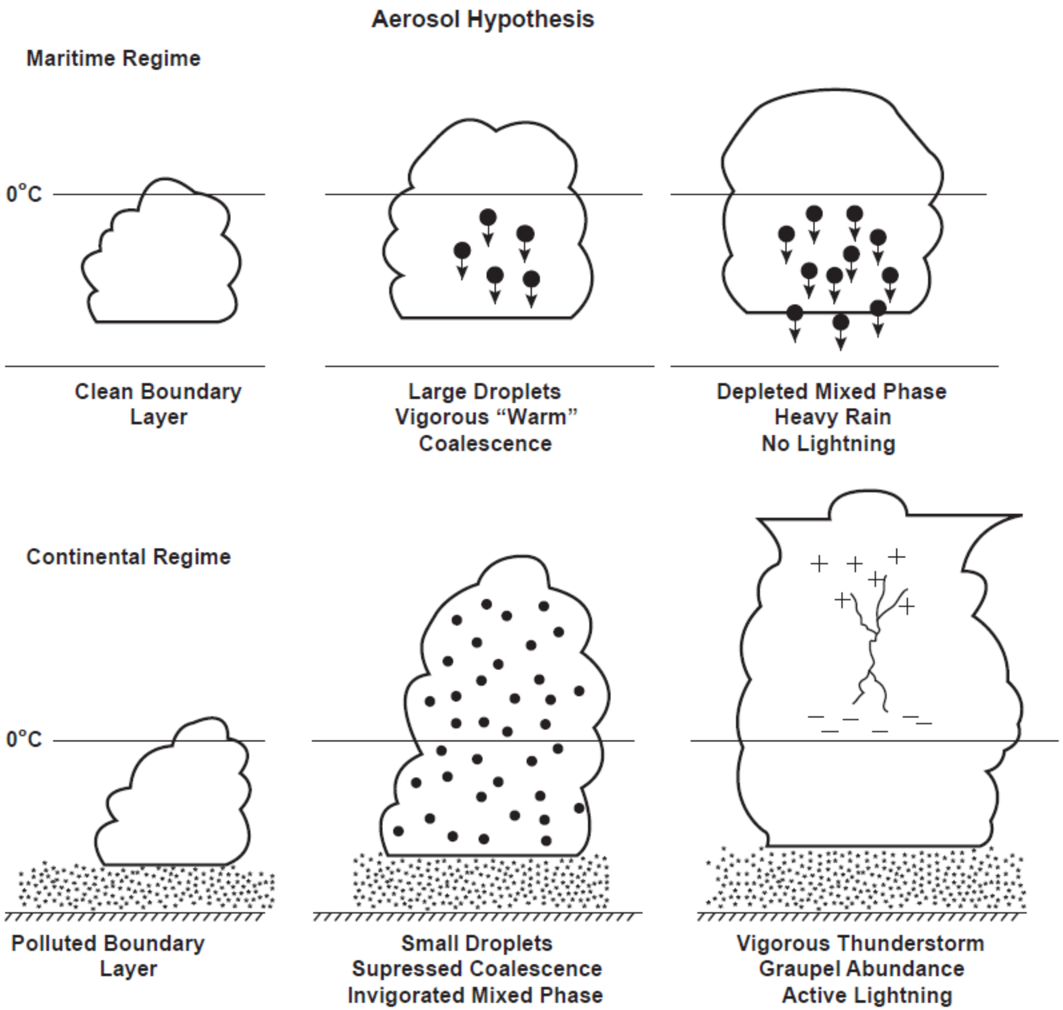


Illustration of aerosol hypothesis for thunderstorm electrification

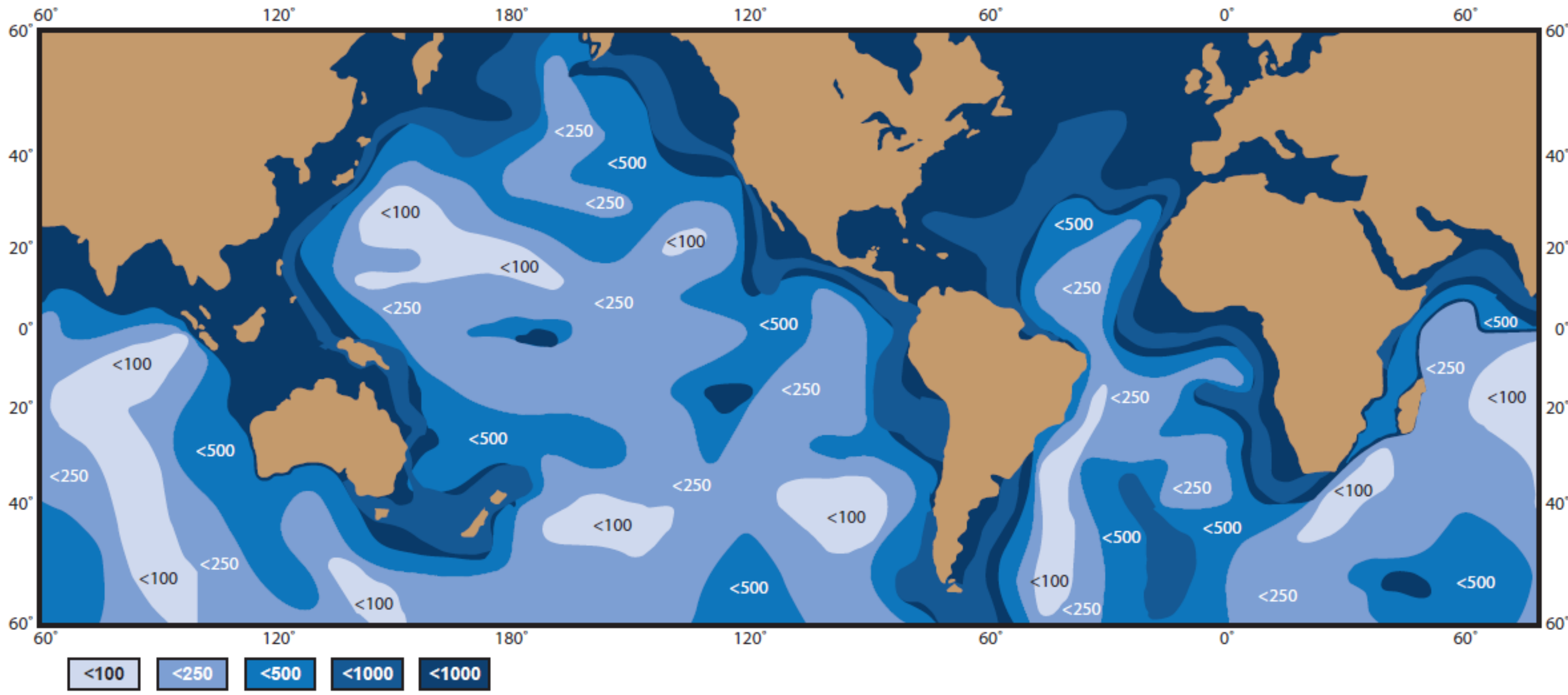


Model Support from:

Khain et al. (2005)
Li and Zhang (2008)
Mansell and Ziegler (2012)

First global map of aerosol concentration
(Shiratori, 1934)

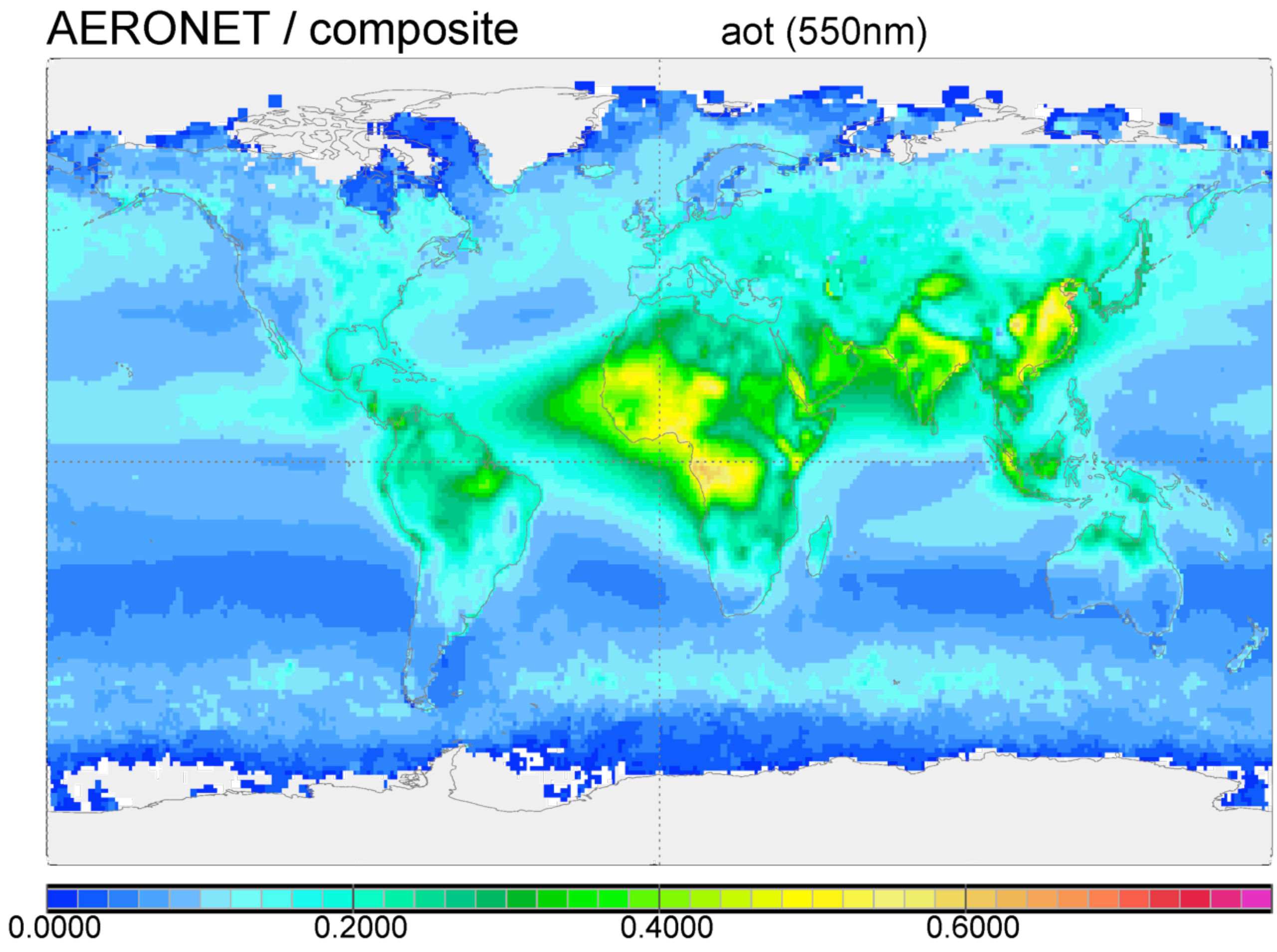
Observations from Carnegie cruises



Particles/cc

Aerosols are most prevalent near major land boundaries.
Recent pollution from populated areas only enhances this prevalence.

Global Aerosol Observations
(Kinne, 2009)

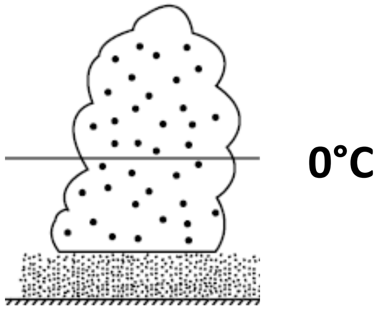


Role of aerosol in cloud buoyancy and land/ ocean updraft contrast

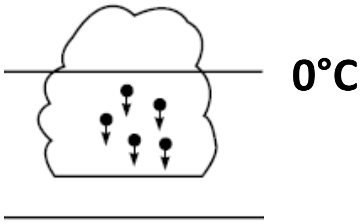
CAPE debate: Saunders (1957)
Betts (1982)
Xu and Emanuel (1989)
Williams and Renno (1993)
Lucas and Zipser (1994)
Rosenfeld et al. (2008)
Riemann-Kampe (2010)

How should CAPE be calculated for land and ocean?

- **Reversible CAPE (most common)**
  - 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

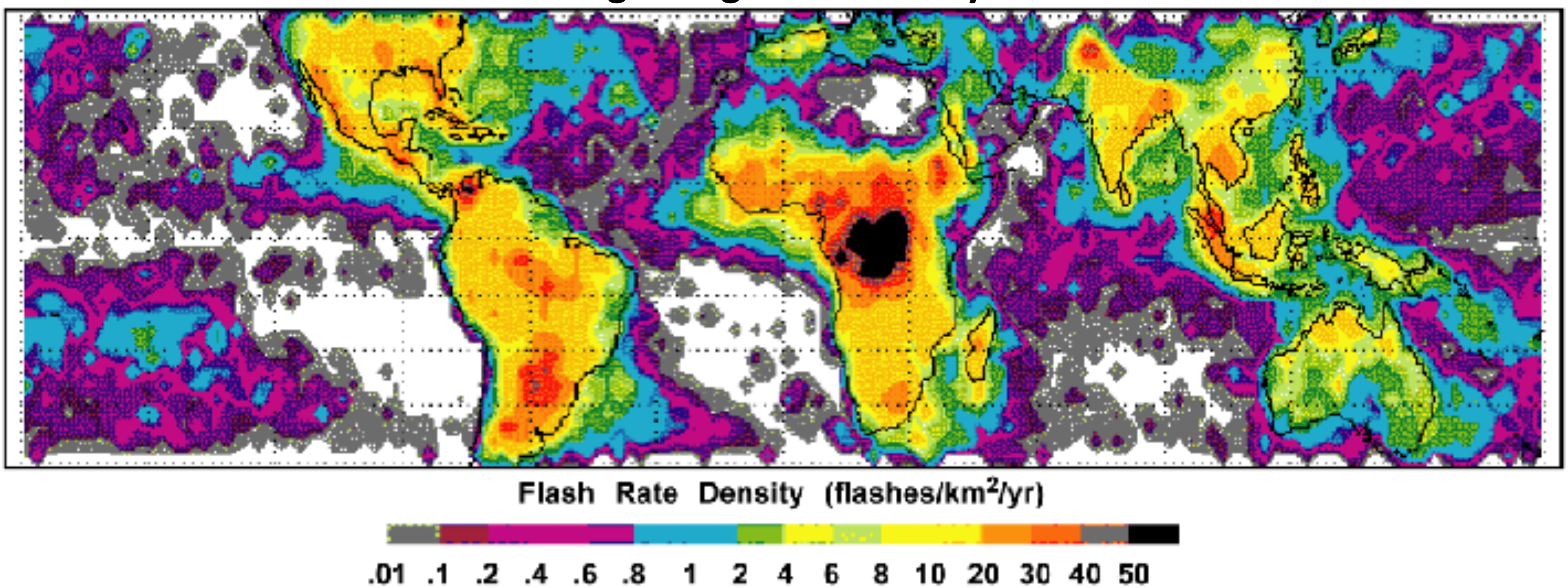
AMS Glossary definition for Thunderstorm Day:

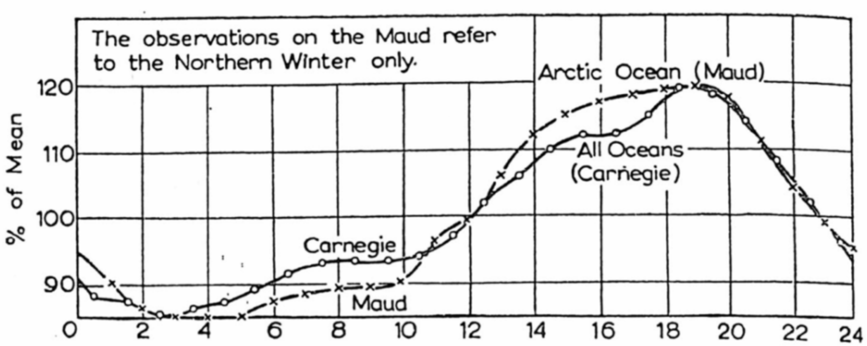
"An observational day during which thunder is heard at the station"

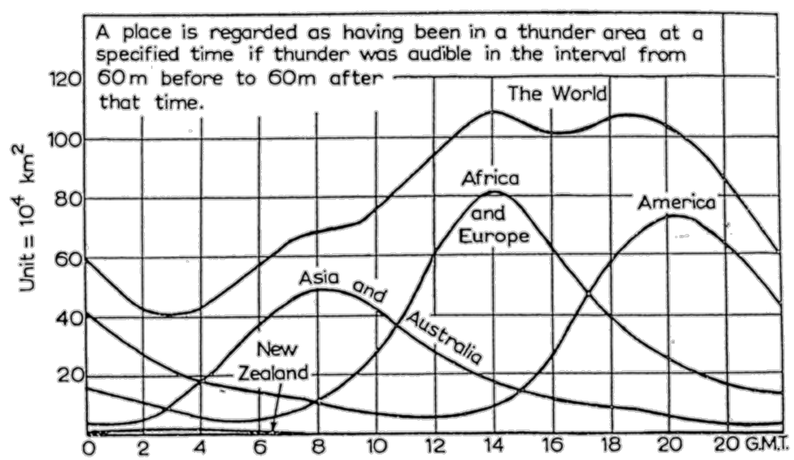
Still a reliable metric for lightning occurrence.

Diurnal Variation of Global Lightning

Lightning Flash Density



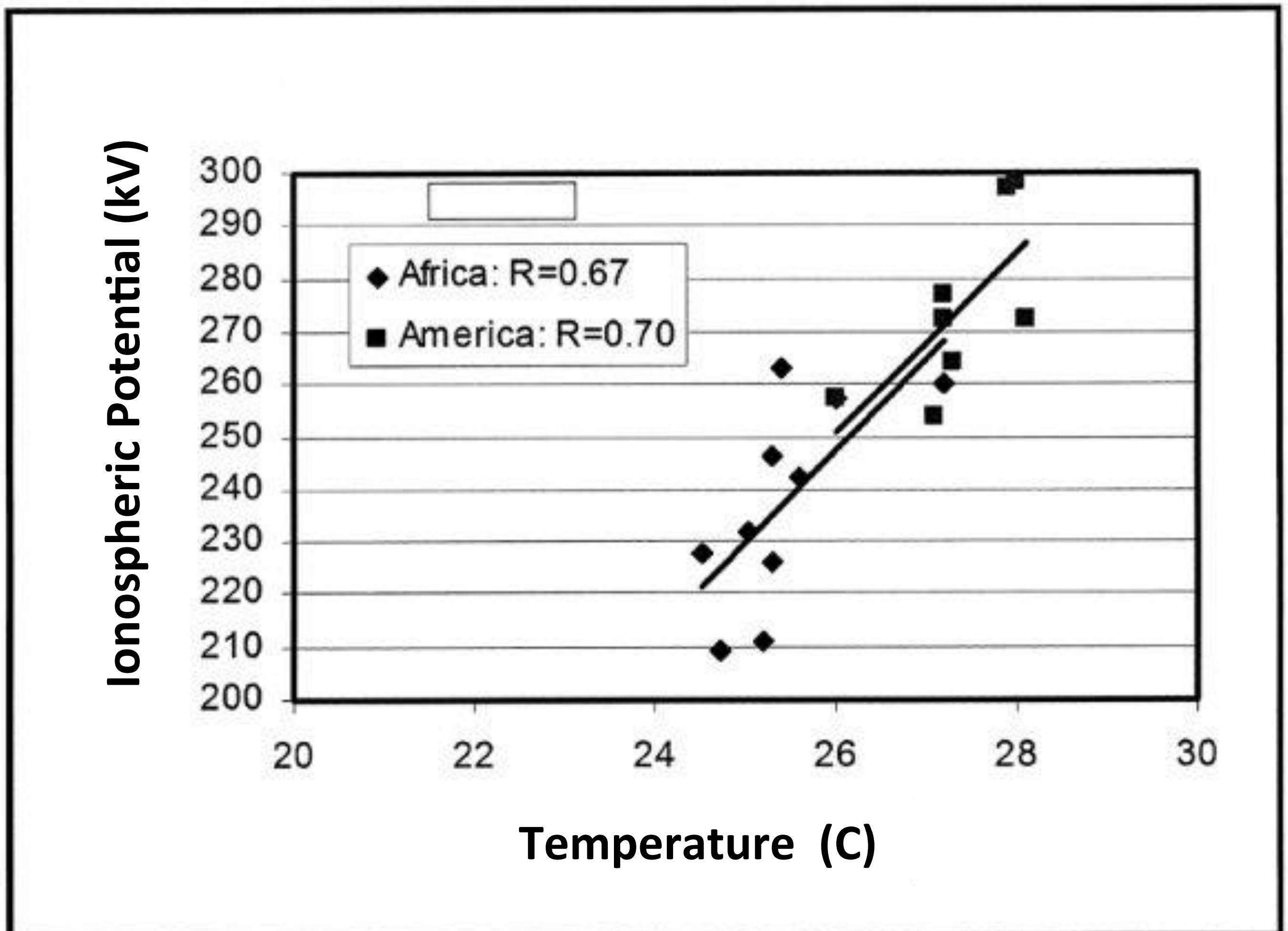




Carnegie Curve

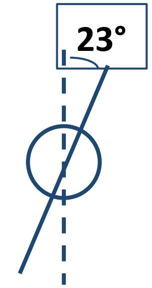
Thunder Area

Global circuit temperature dependence-diurnal time scale (Markson, 2003)



Slope
~7% change Vi
per °C

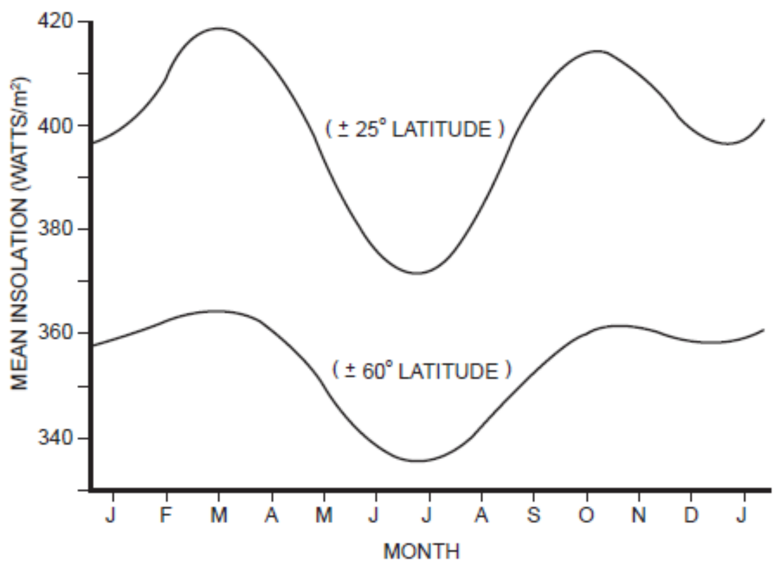
Evidence for Semiannual variation in lightning activity

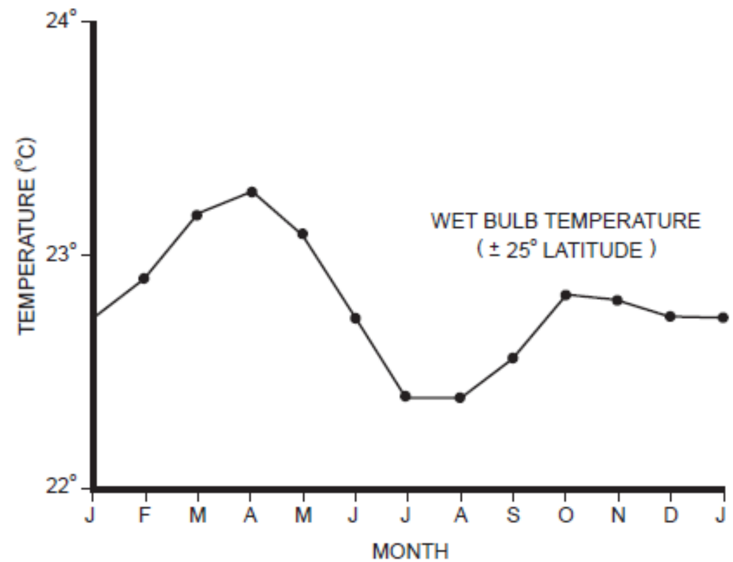


Physical origin : 23° obliquity of Earth's orbit

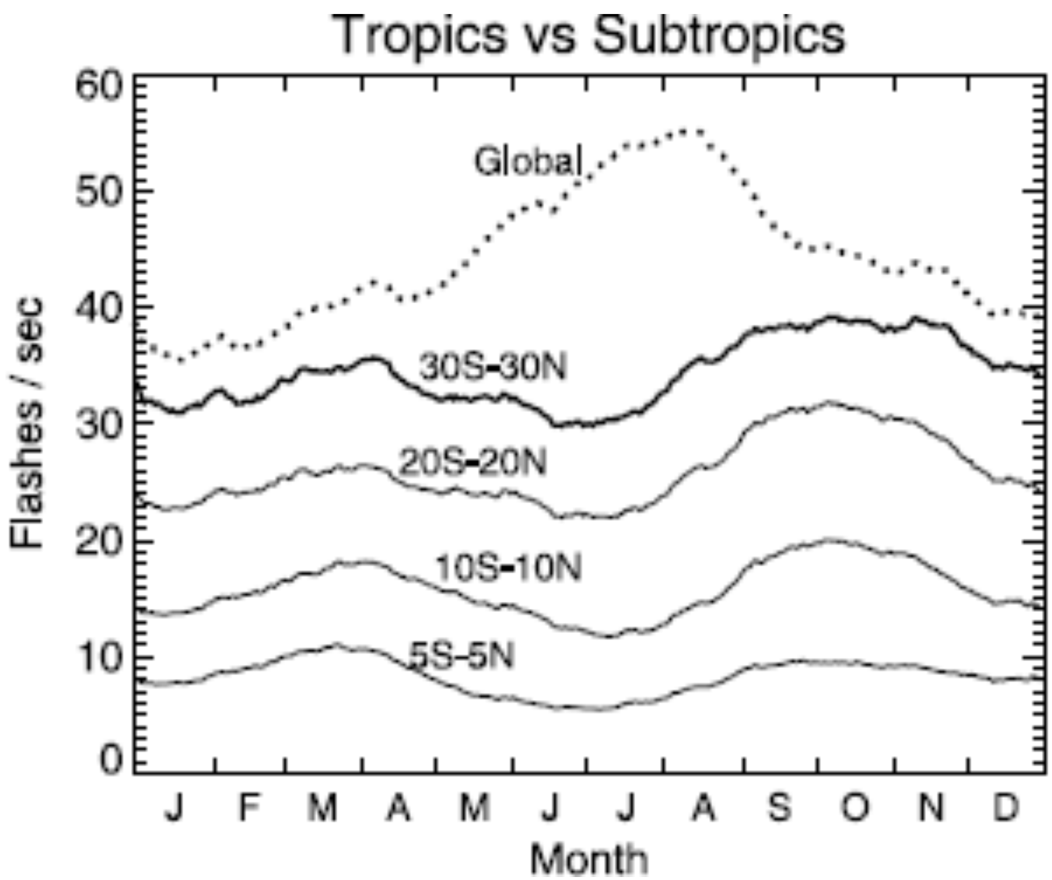
<u>Authors</u>	<u>Observations</u>
Williams (1994)	Thunder days
Satori and Zieger (1996)	Schumann resonances
Füllekrug and Fraser-Smith (1997)	ELF
Nickolaenko et al. (1998)	Schumann resonances
Manohar et al. (1999)	Surface observations
Christian at al (2003)	OTD satellite
Satori et. al. (2009)	Schumann resonances
Hobara et al. (2011)	Schumann resonances

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



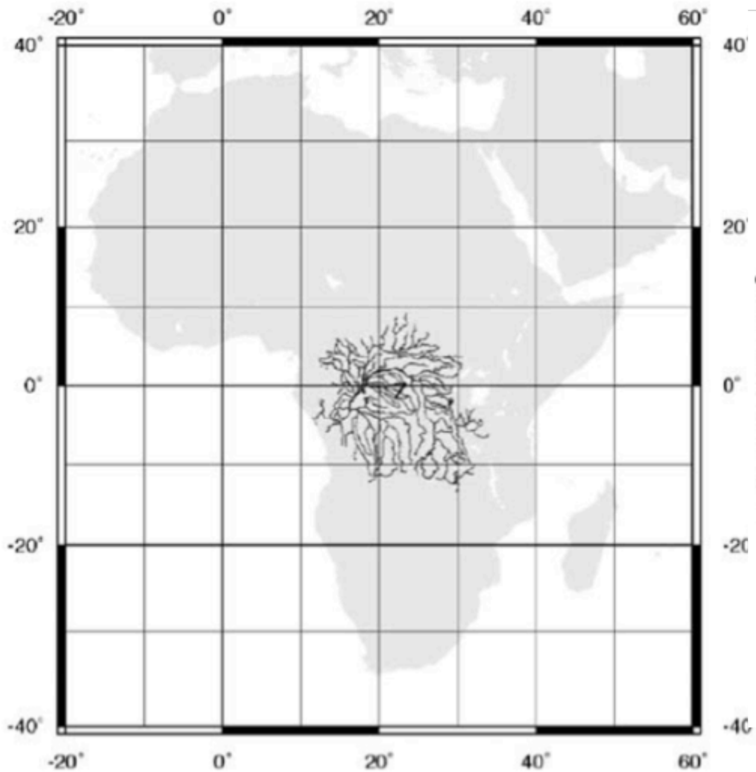


Evidence for semiannual variation in lightning from the Optical Transient Detector (Christian et al., 2003)

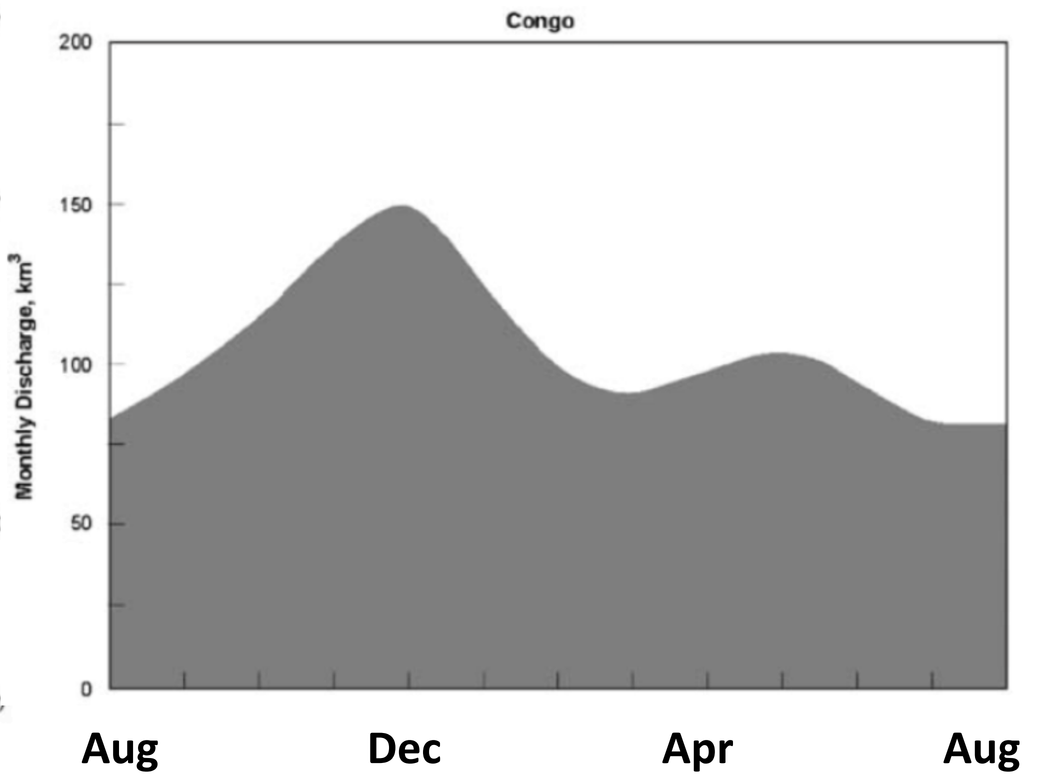


Semiannual signal in Congo River discharge

Drainage area

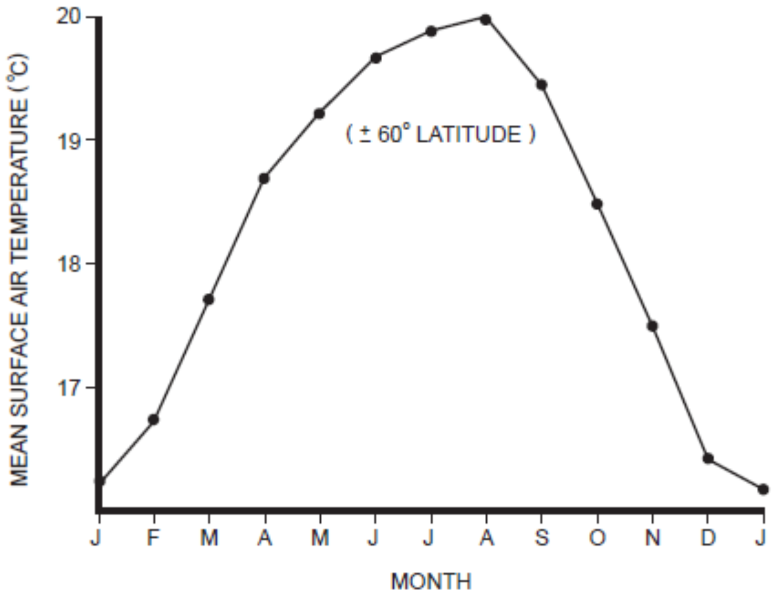


Annual discharge record

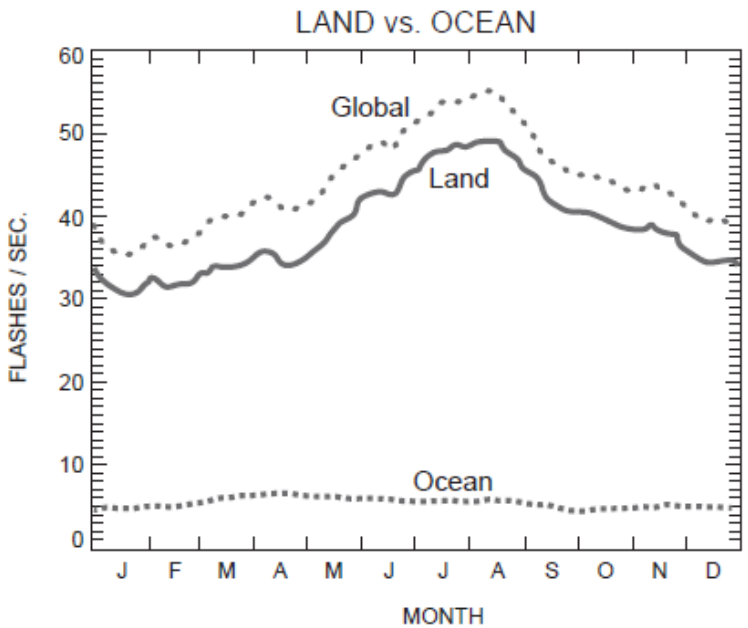


Annual variation of global temperature and global lightning (11% change/°C)

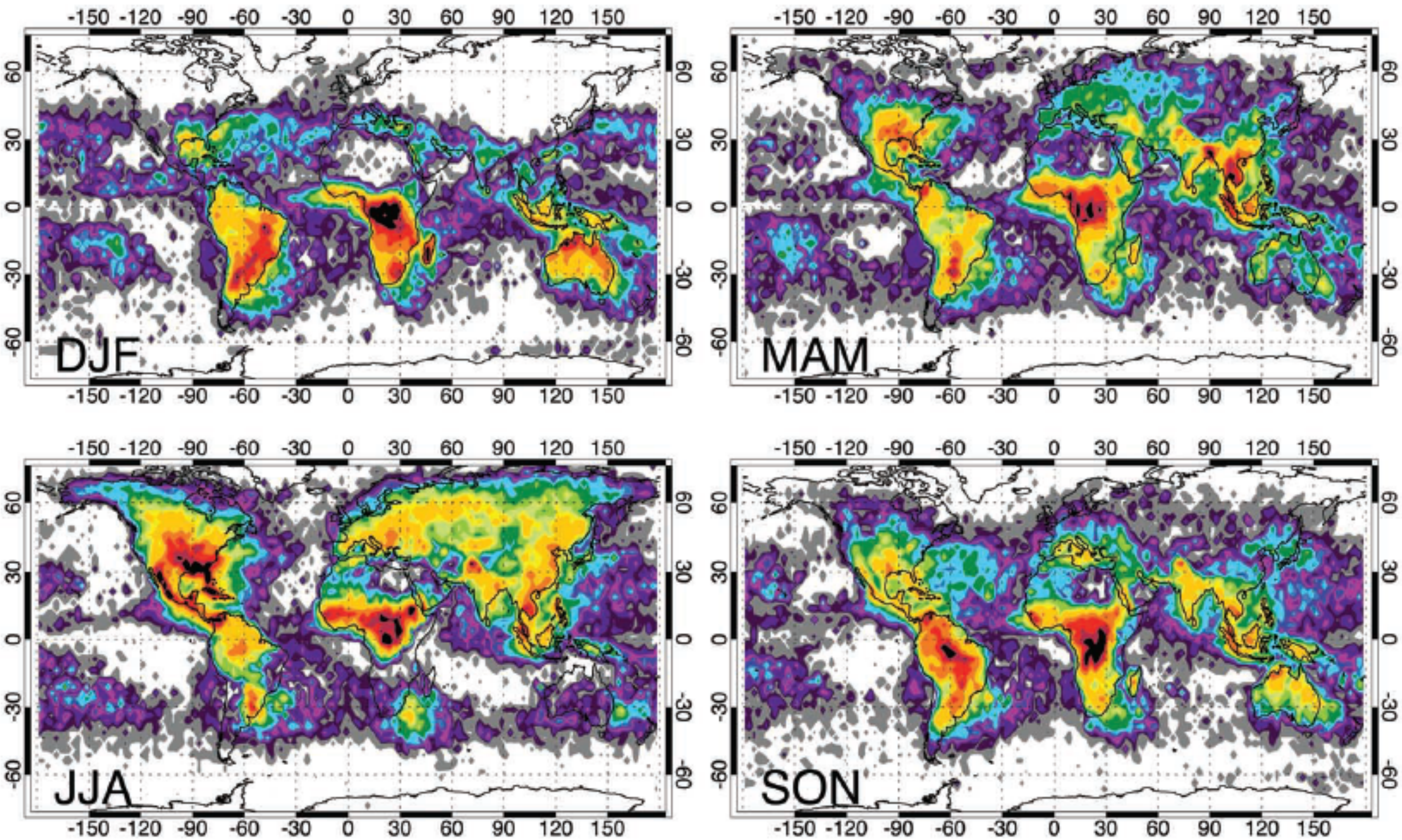
Global temperature variation (Williams et al., 1994)



Global lightning variation (Christian et al., 2003)



Seasonal variation of global lightning activity (Christian et al., 2003)



Global Maximum

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

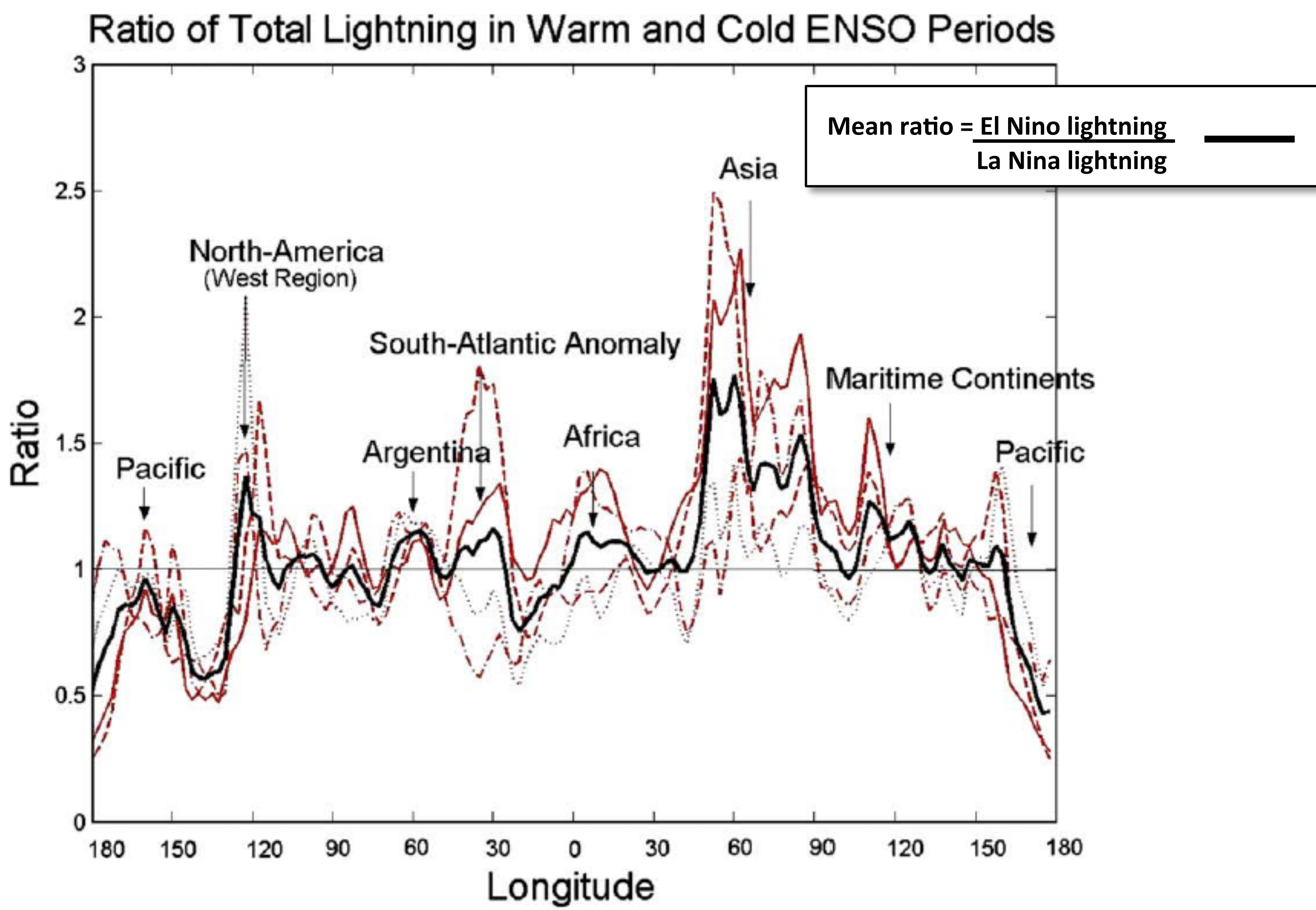
Tropical 'chimney' regions are in stronger subsidence in the warm El Nino phase (from Pacific Ocean upwelling)

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



"from Satori et al. (2009)"

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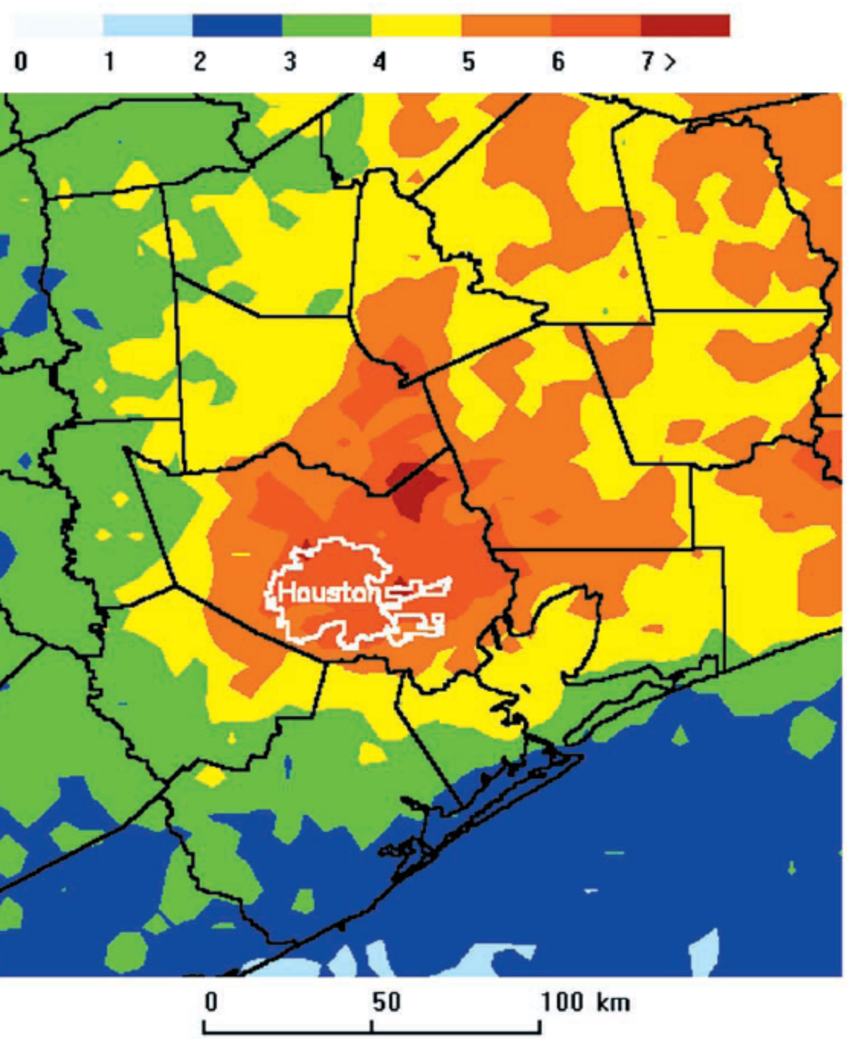
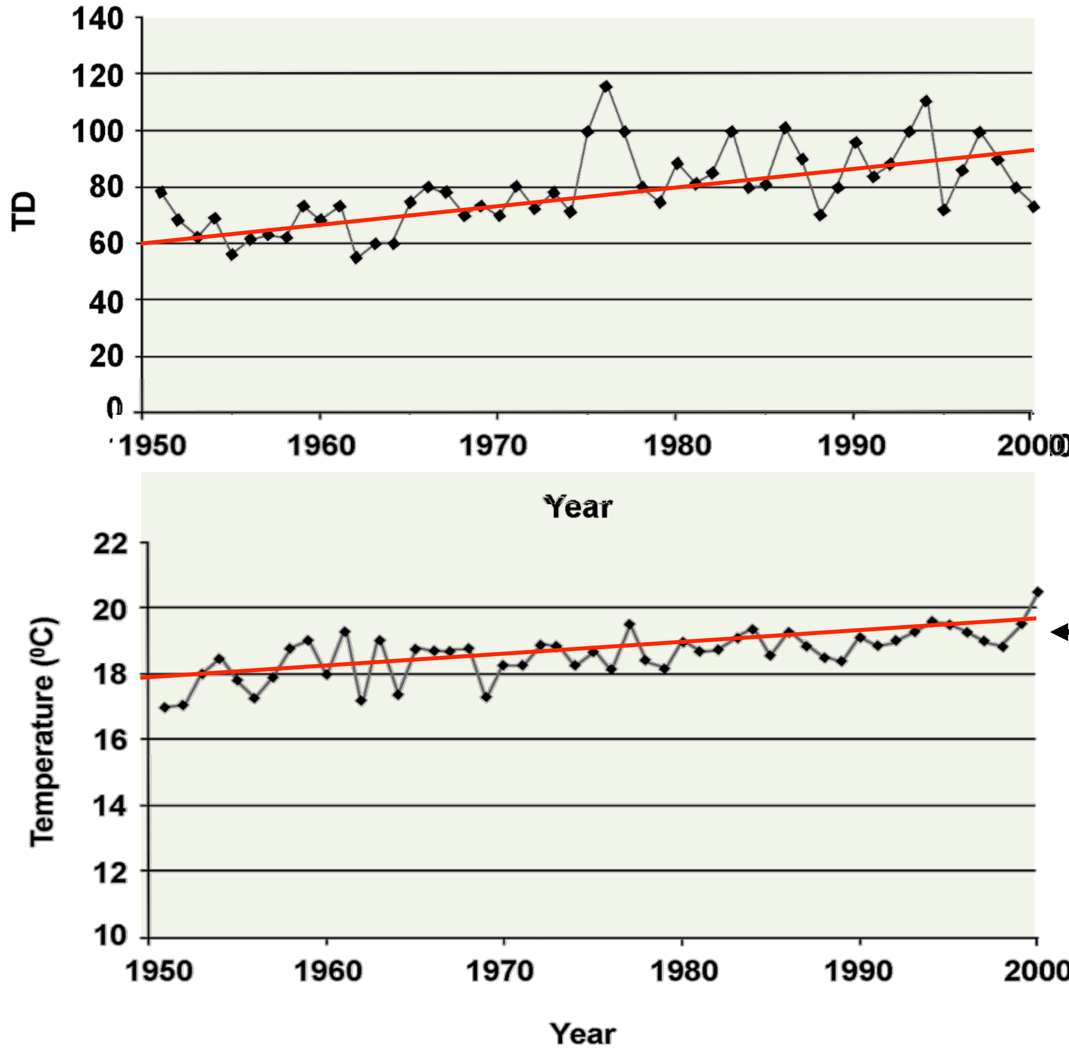
Lightning enhancement over Houston, Texas (Steiger et al., 2002)



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



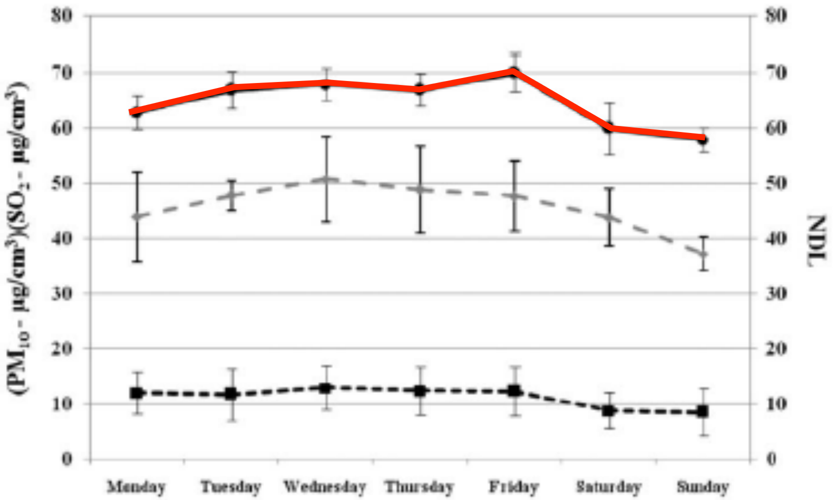
Sensitivity:
~10% change in thunder days per °C

Slope
~3.6 °C/century

Evidence for a weekly cycle in lightning

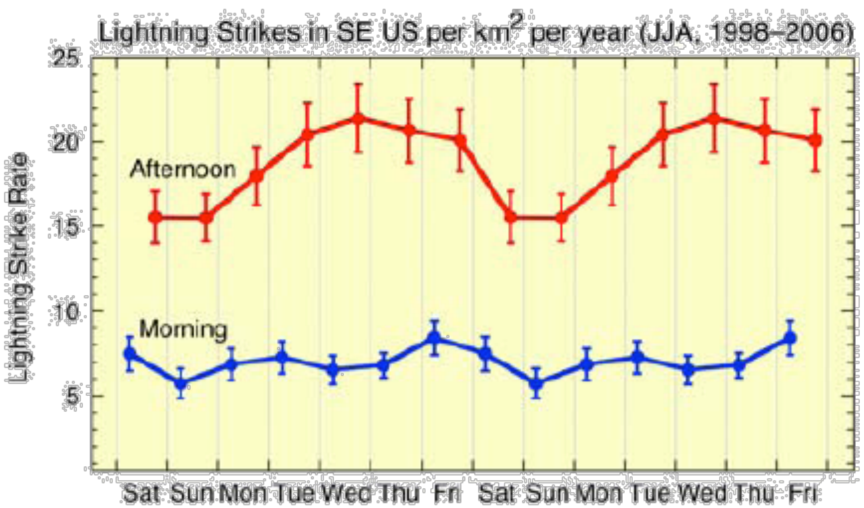
Sao Paulo, Brazil (Farias et al.,2009)

Number of Lightning Days



Southeastern United States (Bell et al., 2009)

Flash Rate



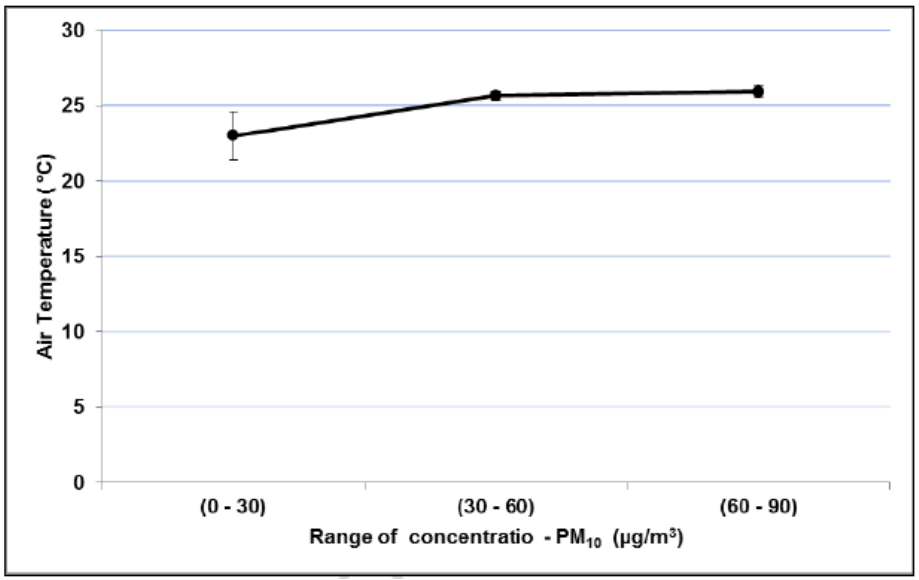
Weekend

Weekend

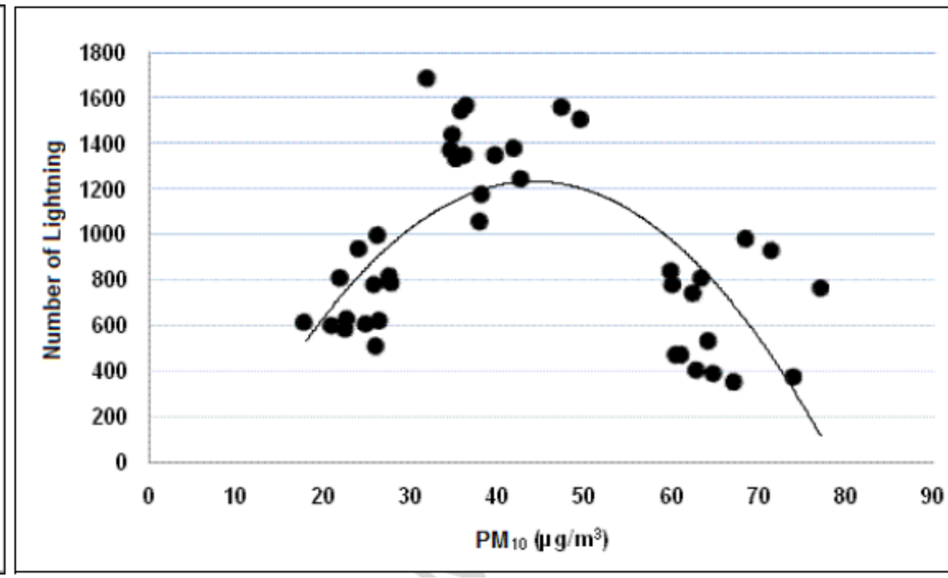
Weekend

Evidence for role of aerosol in lightning activity (Farias et al., 2009)

"Control" of temperature



Lightning dependence on aerosol concentration



See also model results by Mansell and Ziegler (2012)

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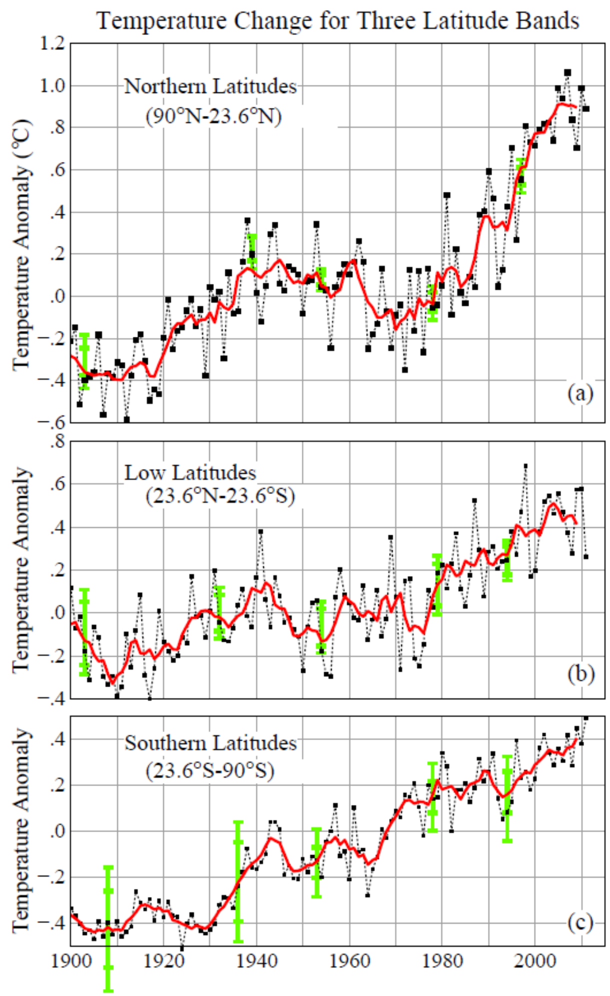
Global warming most pronounced at high northern latitude (NASA GISS)



Northern Latitudes

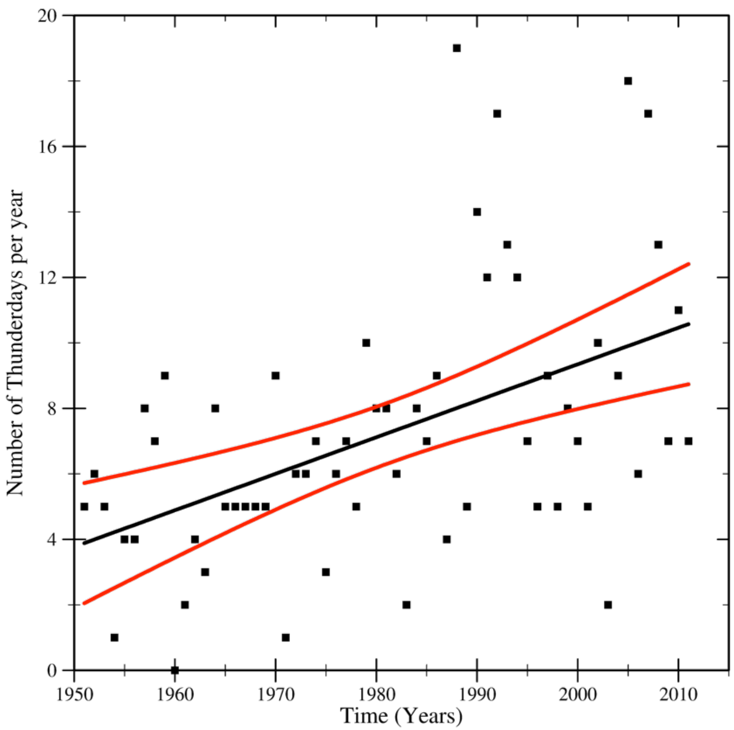
Tropics only

Southern Latitudes

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

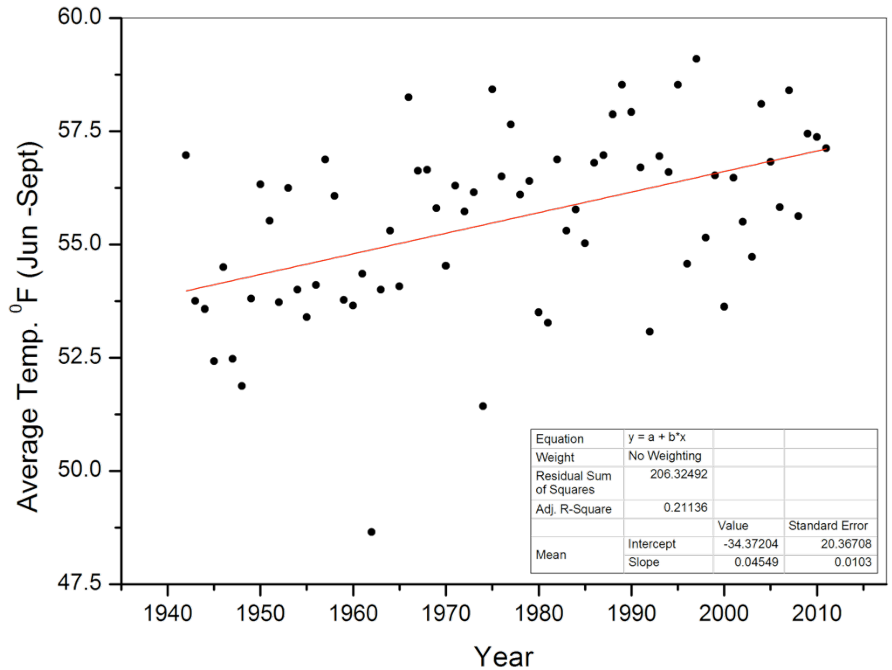
Thunderstorm Day Trend

300% change/century



Summertime Temperature Trend

3.2 °C/century



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Thunderstorm days on the 11-year solar cycle

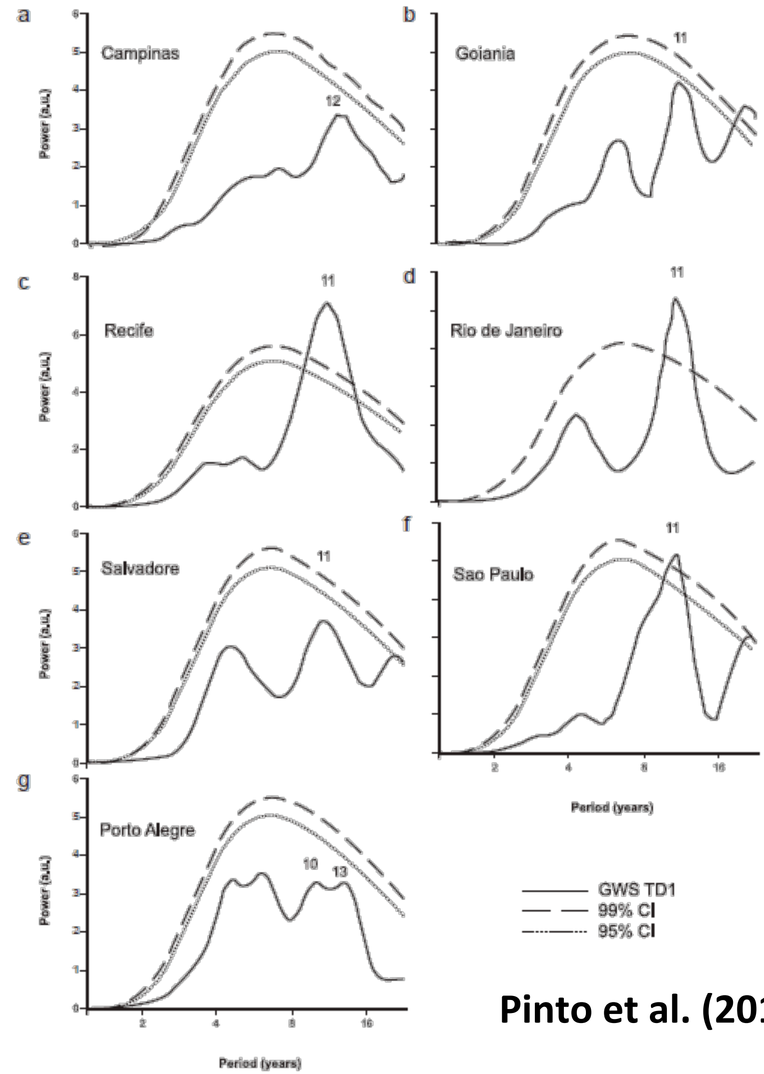
Brooks (1934)
- Global sites
- In phase behavior
- No time series

Klejmenova (1967)
- Global sites
- Out-of-phase behavior
- No time series

Girish and Eapen (2008)
- India (tropics)
- Out-of-phase behavior
- Yes, time series

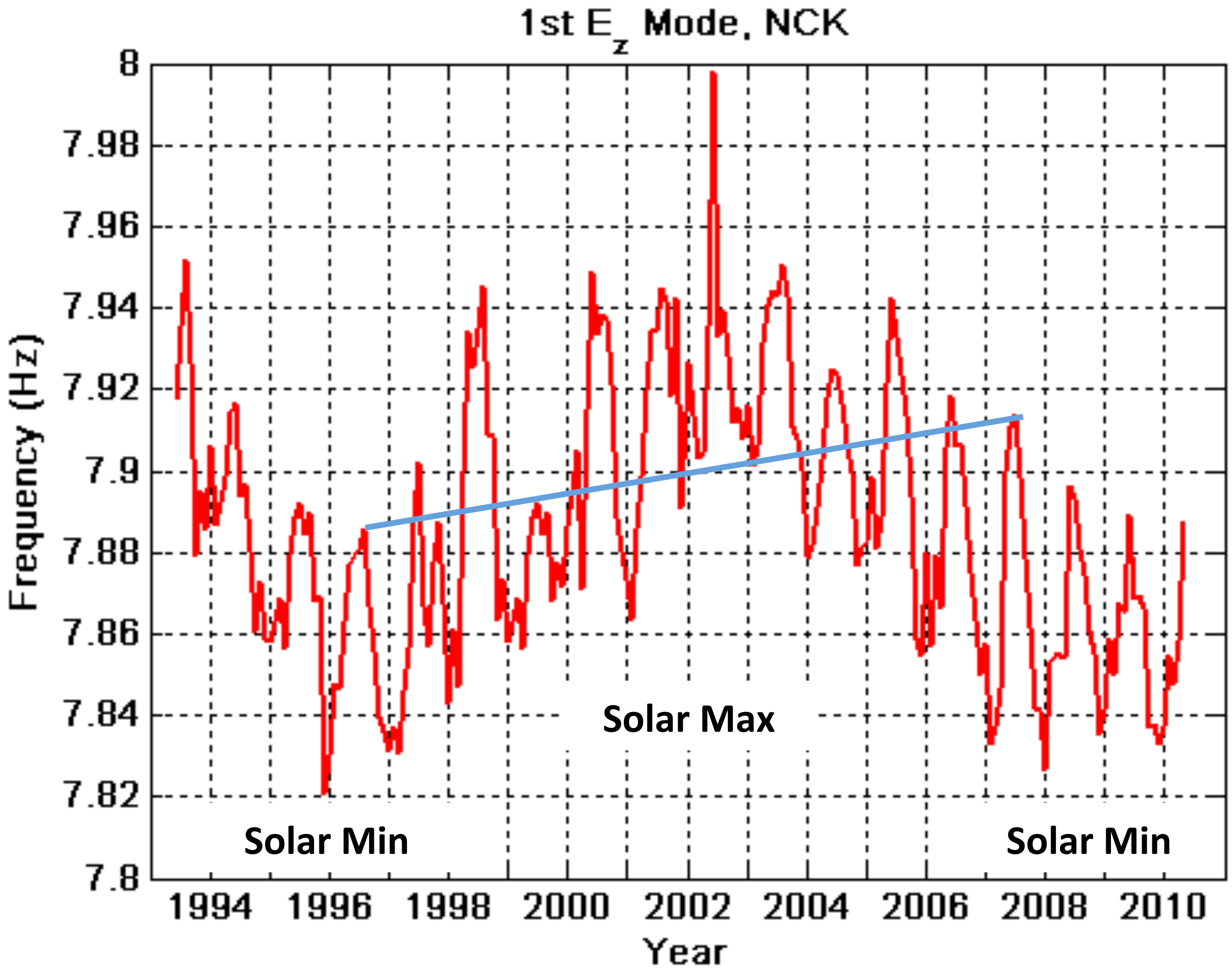
Siingh et al. (2012)
- Southeast Asia
- Out-of-phase behavior
- Yes, time series

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



Pinto et al. (2012)

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



On display:

1) 11-year cycle
2) Annual thunderstorm migration
3) Northward migration due to warming

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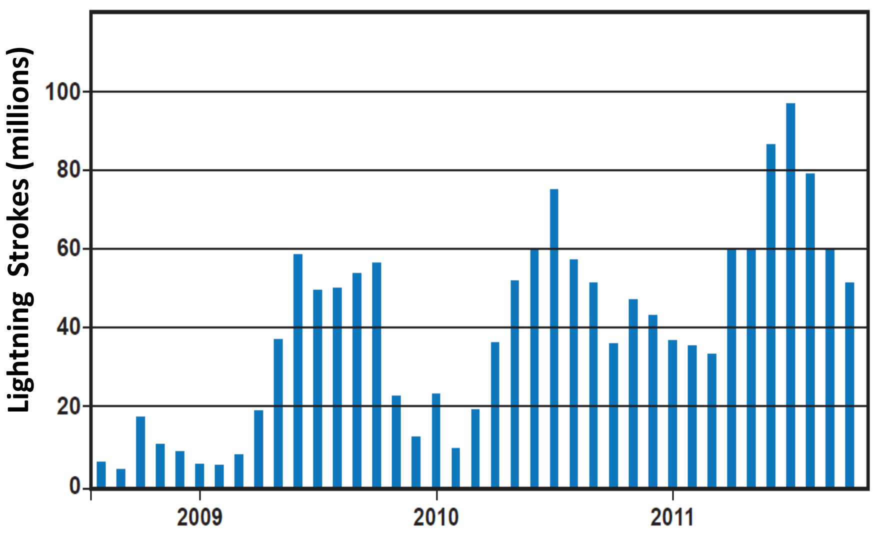
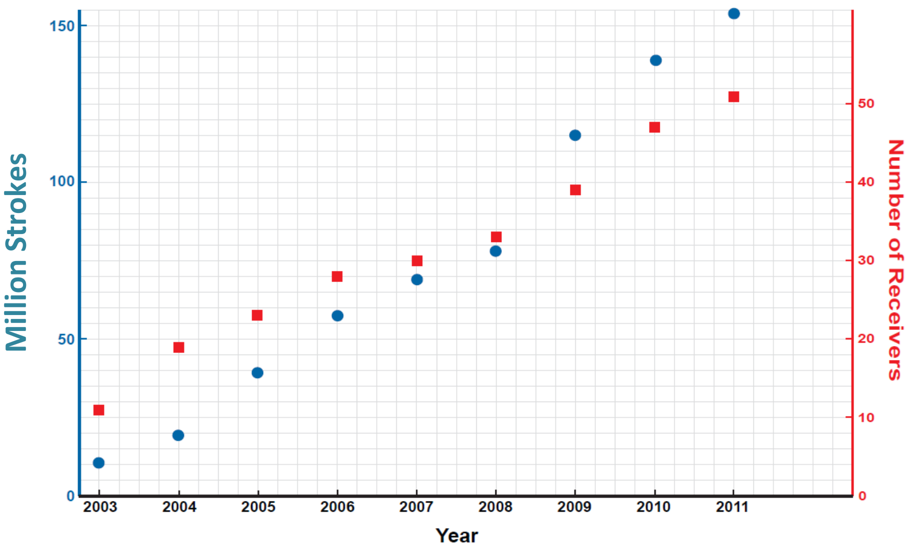
Time-dependent lightning detection by global networks

Vaisala GLD360 (R.Said)

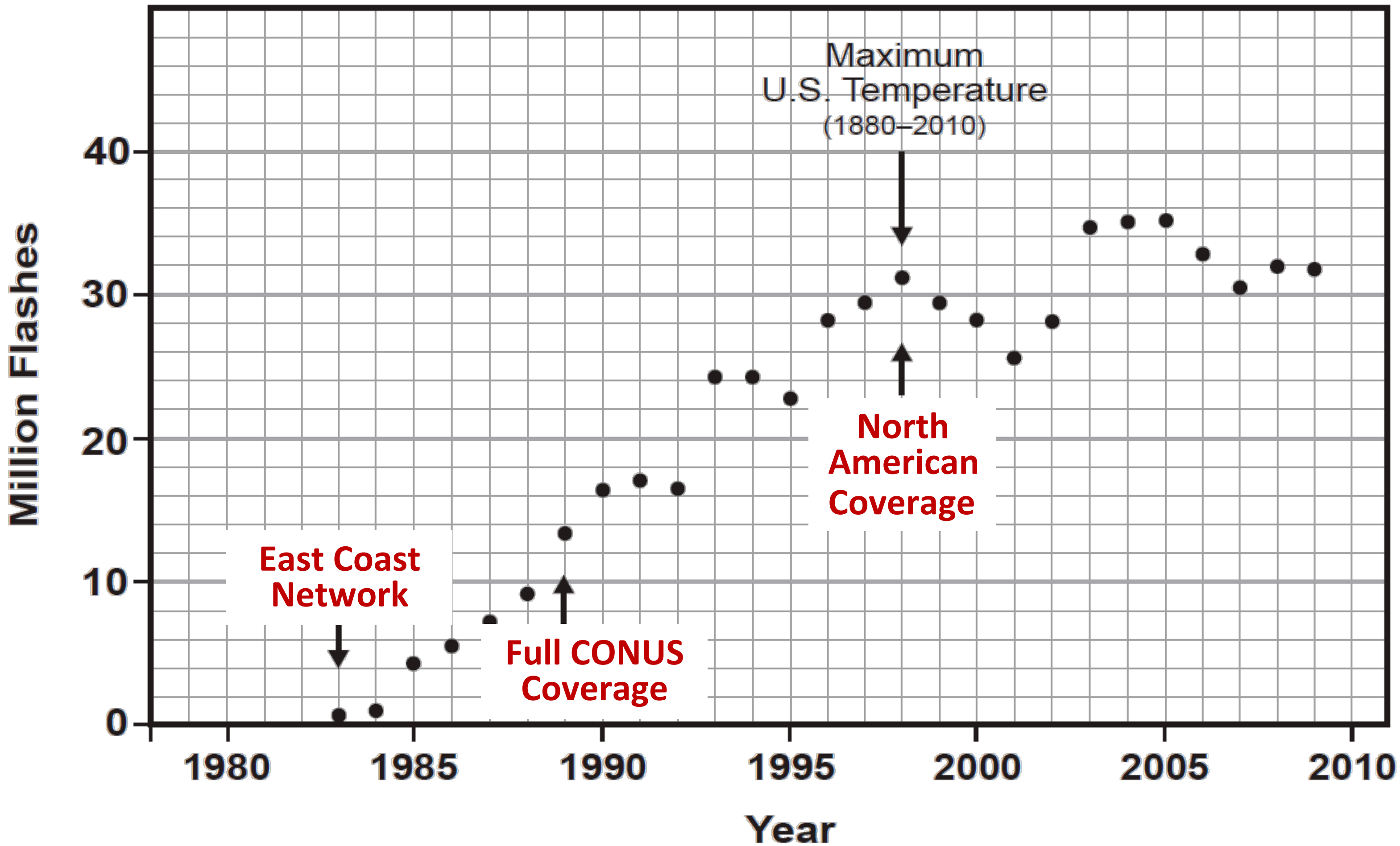


World wide Lightning Location Network (WWLLN) (C. Rodger)



National Lightning Detection Network
Annual totals: Ground Flashes

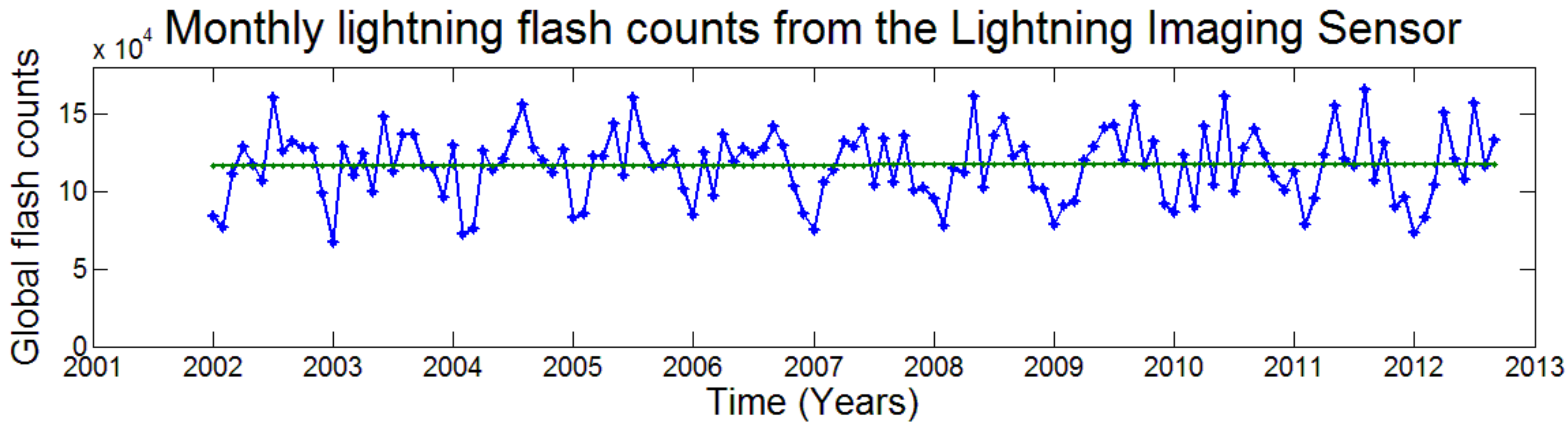
(numerous Orville papers)

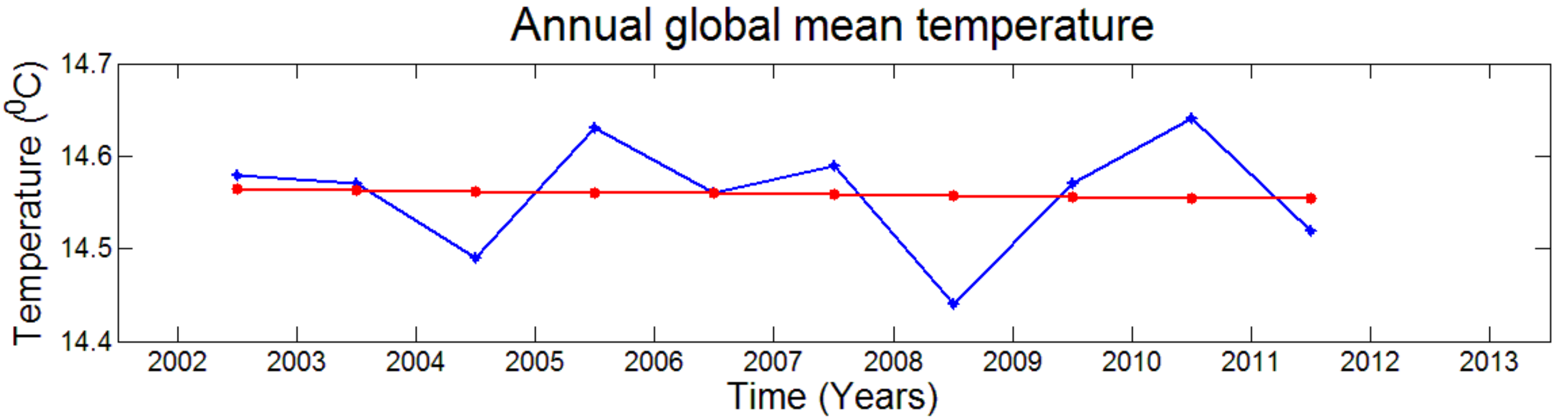


Decade record from Lightning Imaging Sensor

(NASA MSFC)

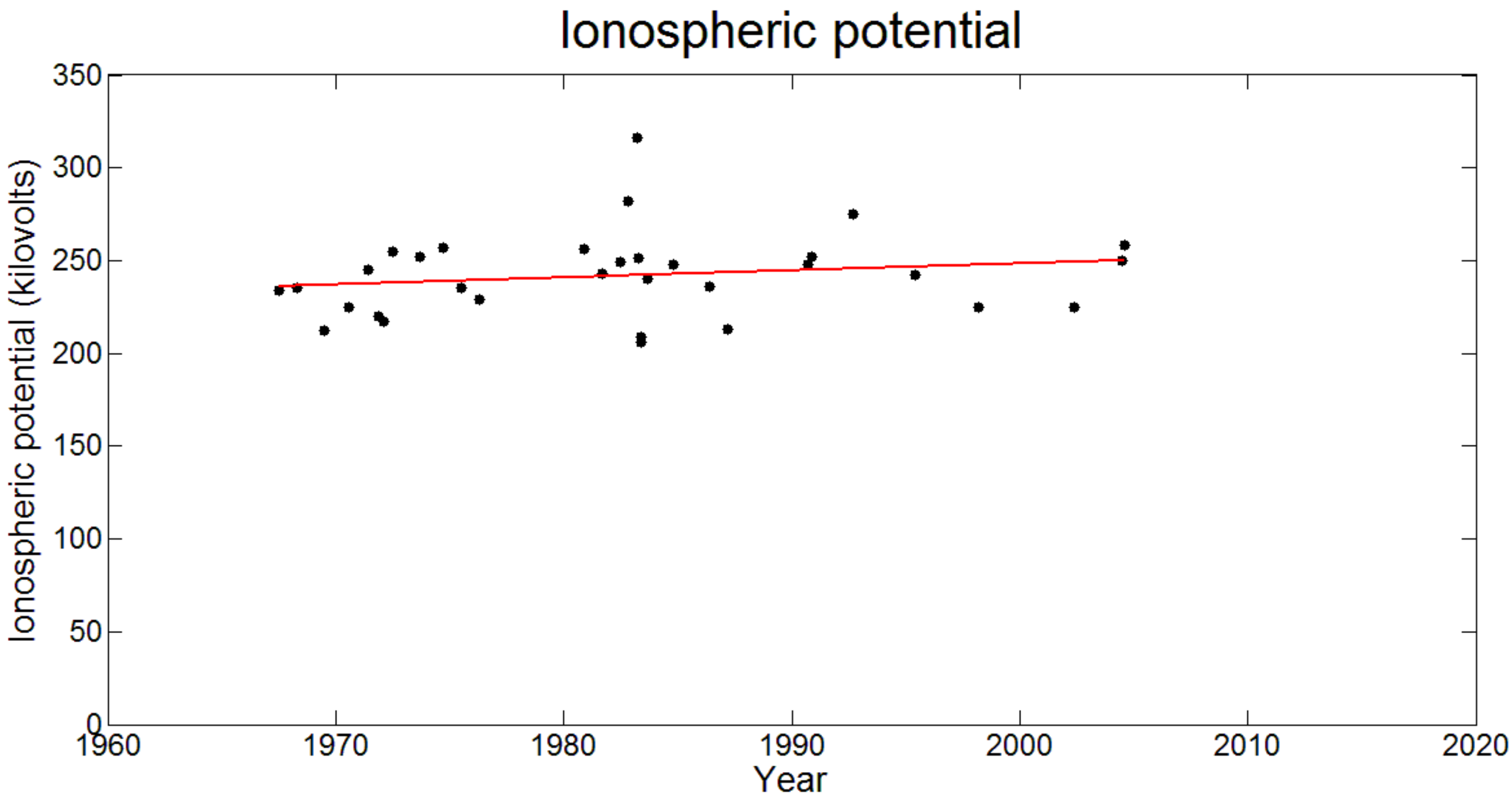
(Best record available of global lightning)





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

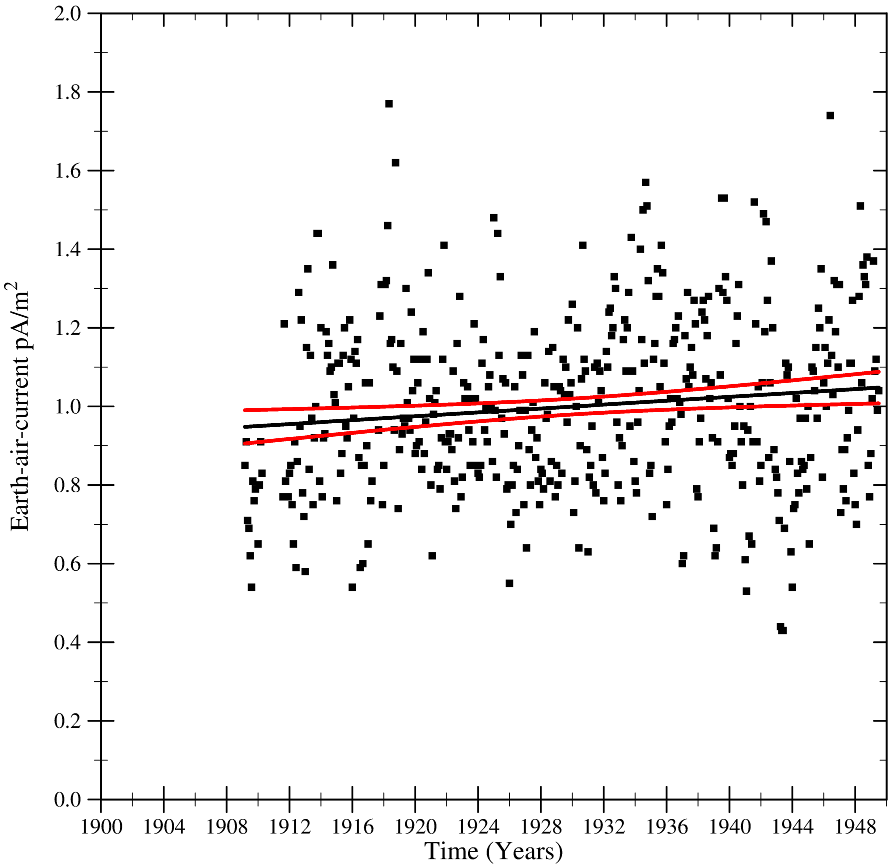
Positive trend +16% per century but not statistically significant



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

Positive trend +25% per century and statistically significant

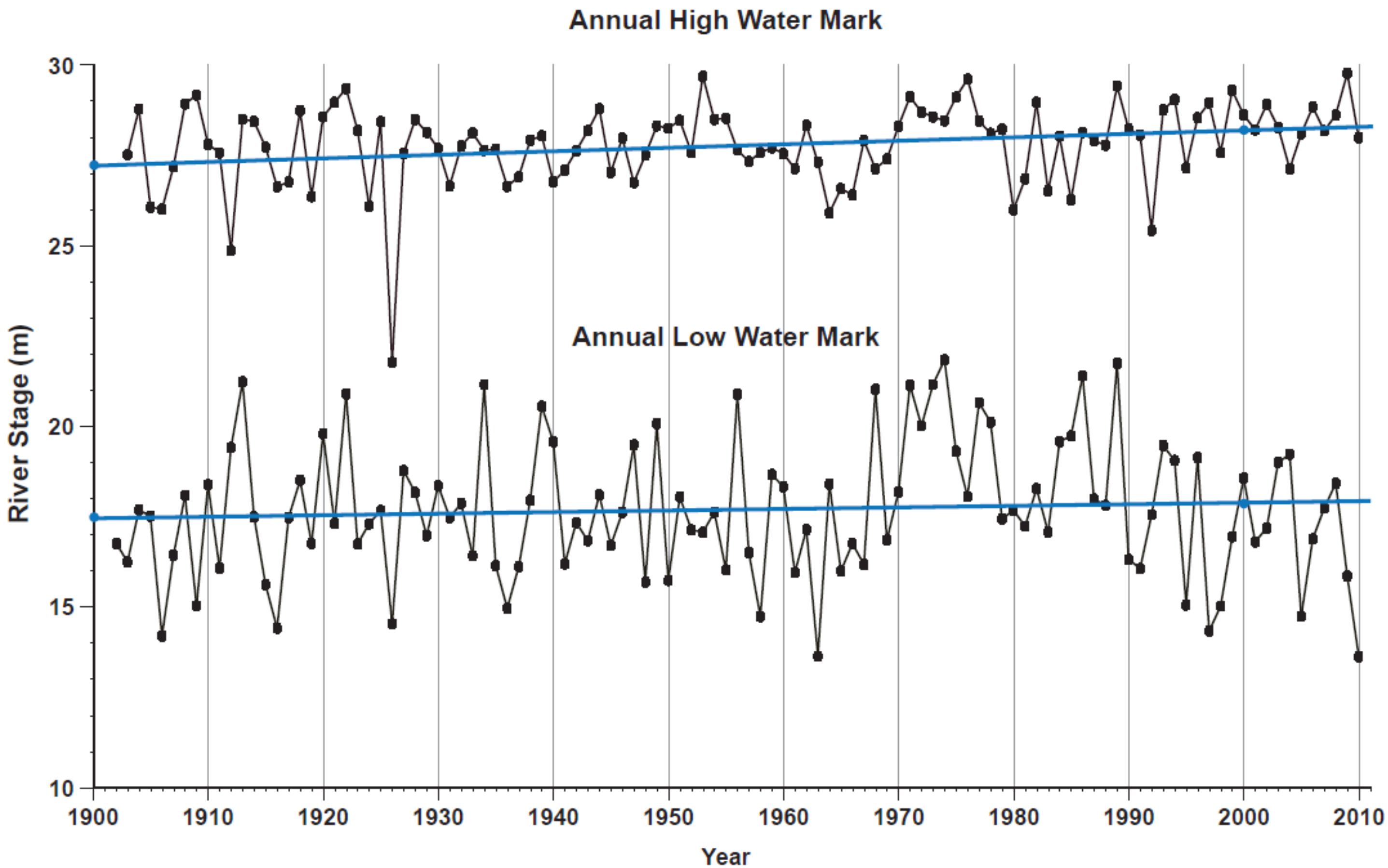
Earth-air-current vs time



Harrison and Ingram (2005)

High and low water marks in Amazon basin at Manaus (1903-present)

Positive trends - statistically significant

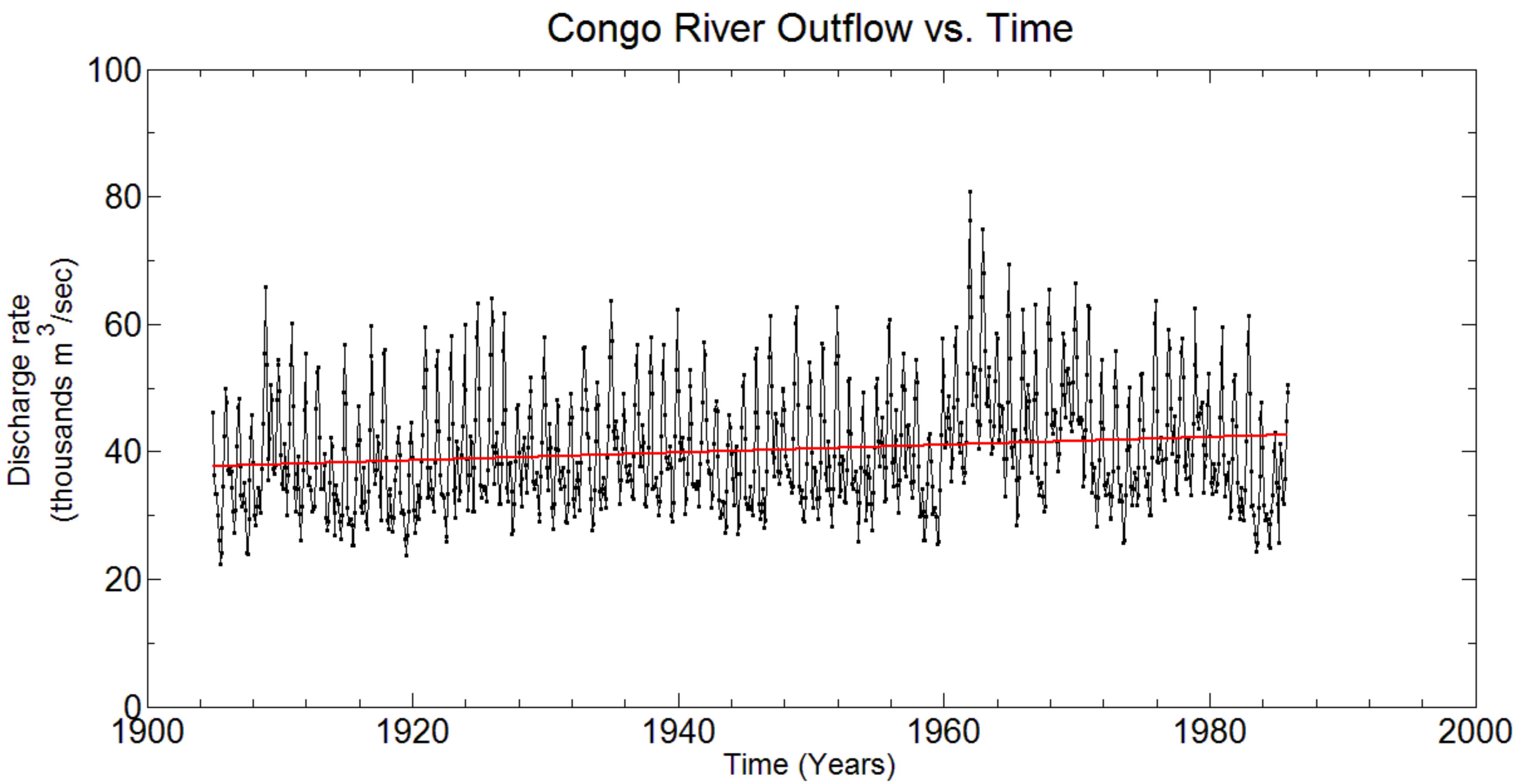


+4 % change per century

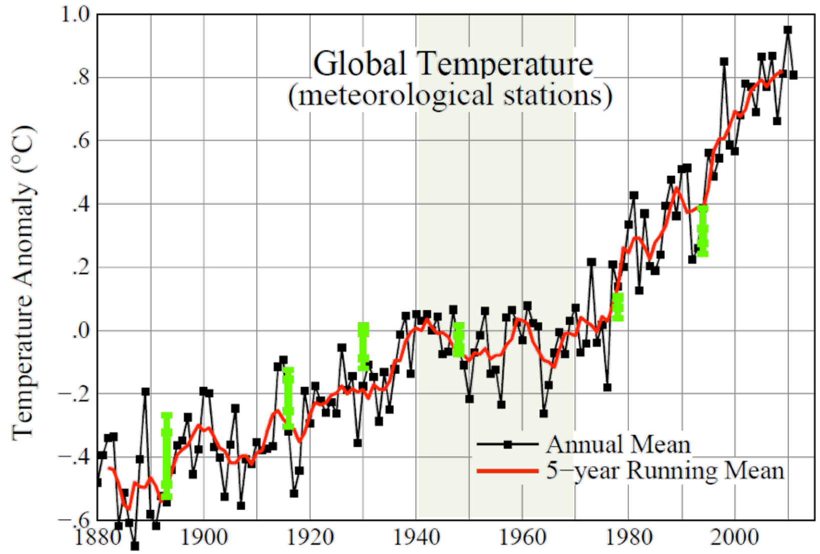
+1 % change per century

Trend in discharge of Congo River (1905-1985)

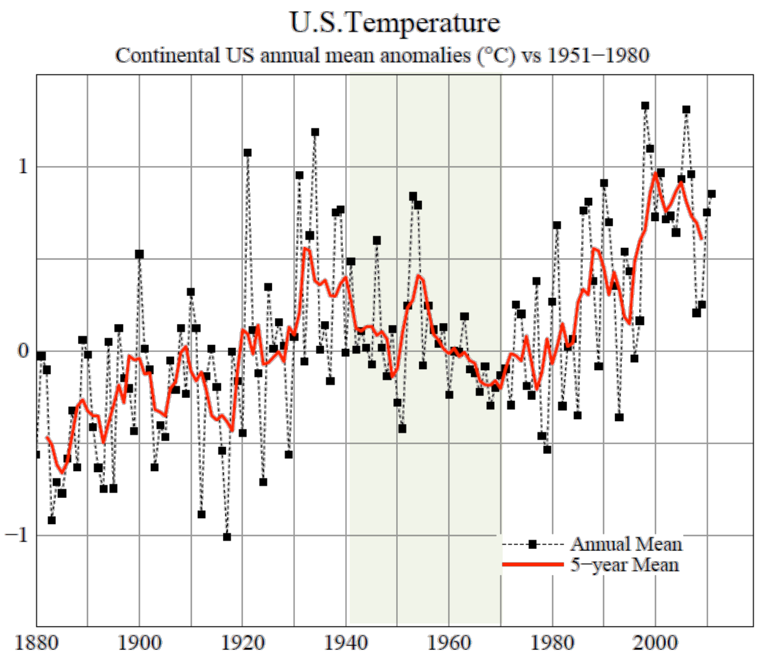
Positive trend +15% per century and statistically significant



Period of Declining Global Temperature

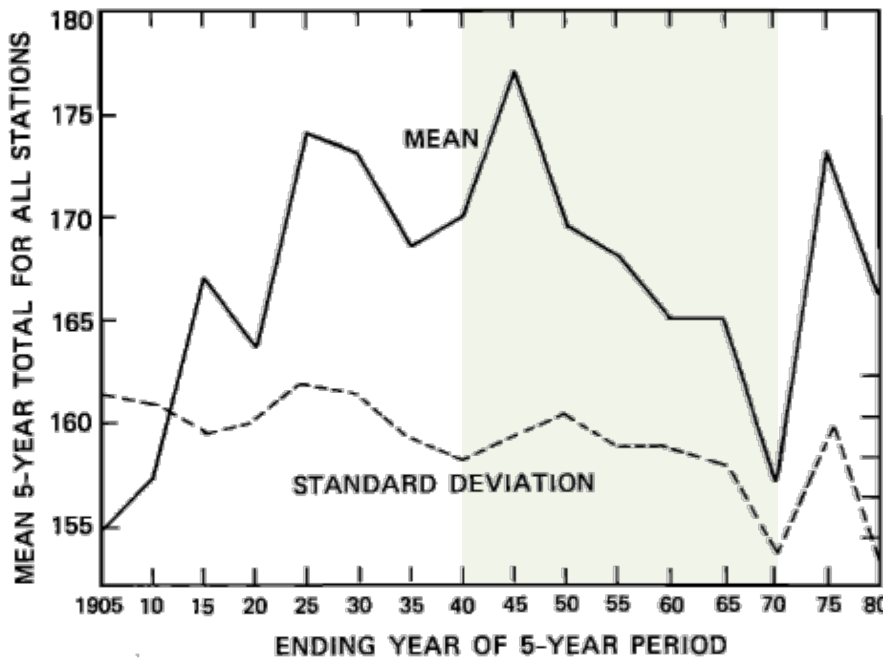


Global record

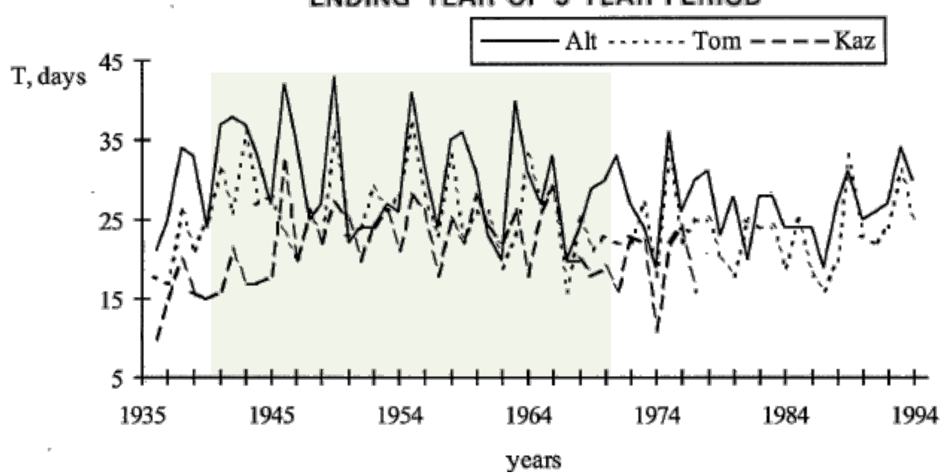


US record

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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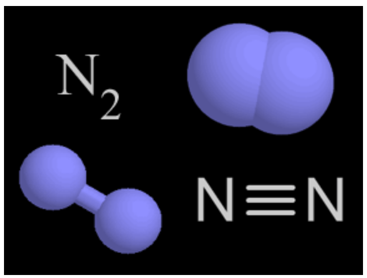
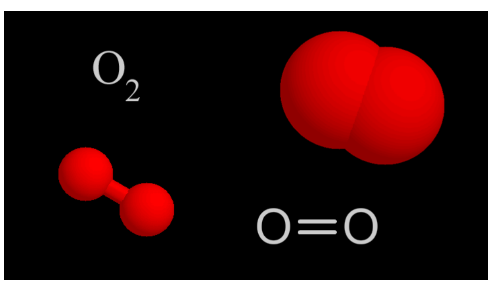
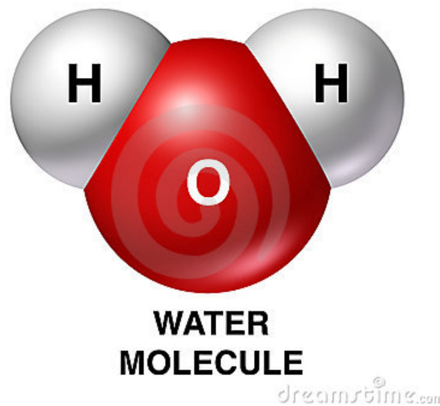
Molecules and Climate

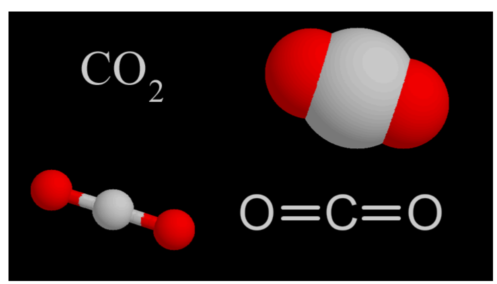
Non-greenhouse gases



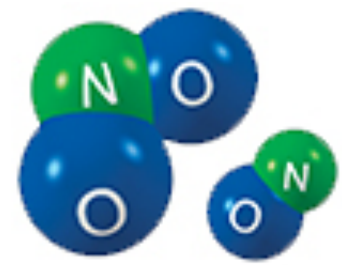


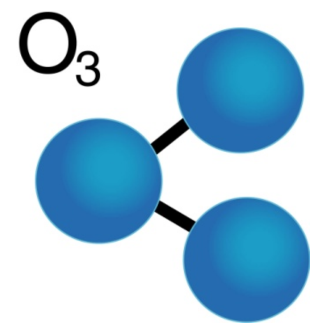
Primary greenhouse gases



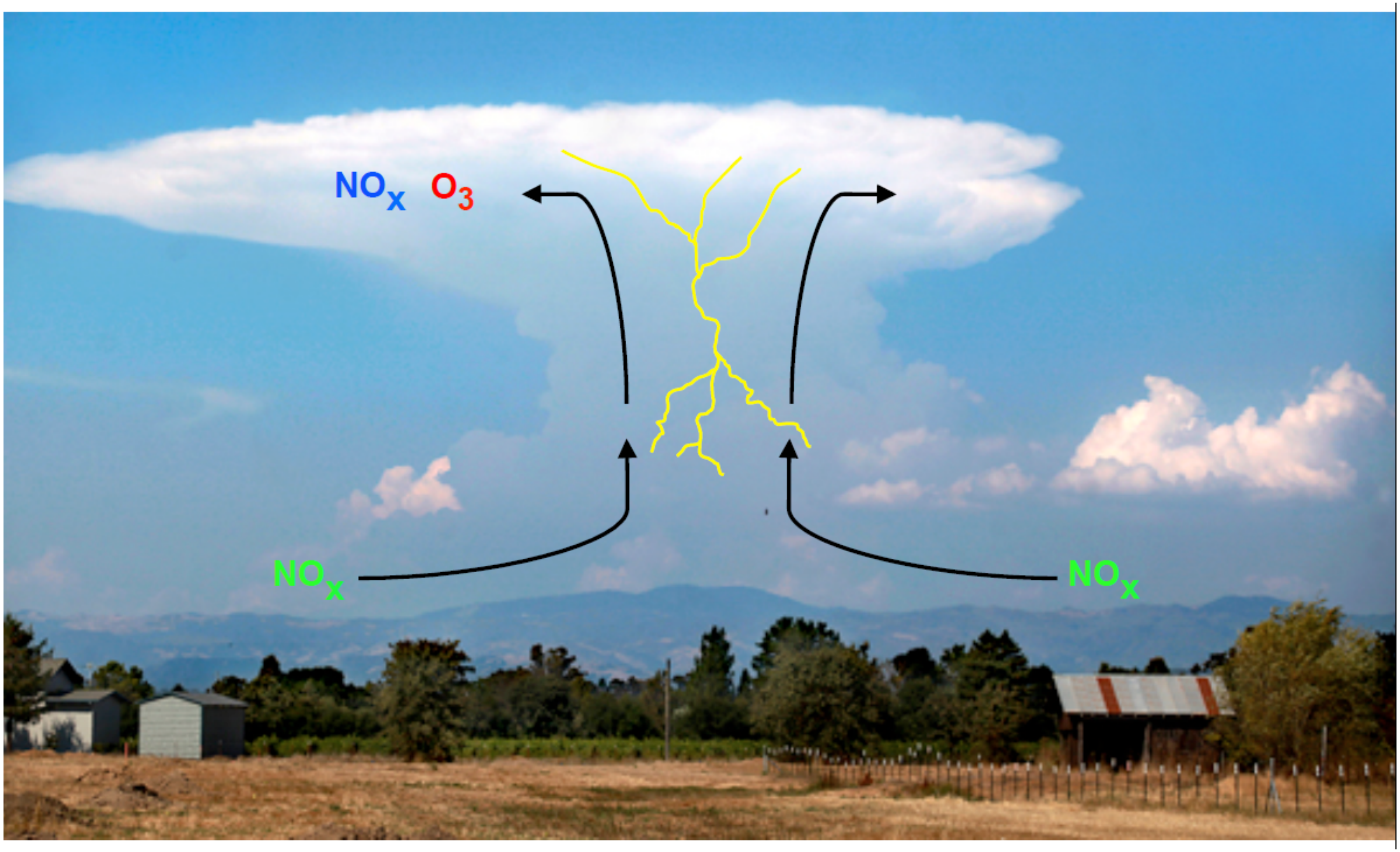


Greenhouse compounds made by lightning





NOx delivered to upper troposphere by lightning source → Ozone Enhancement



Boundary Layer: Anthropogenic source for NOx

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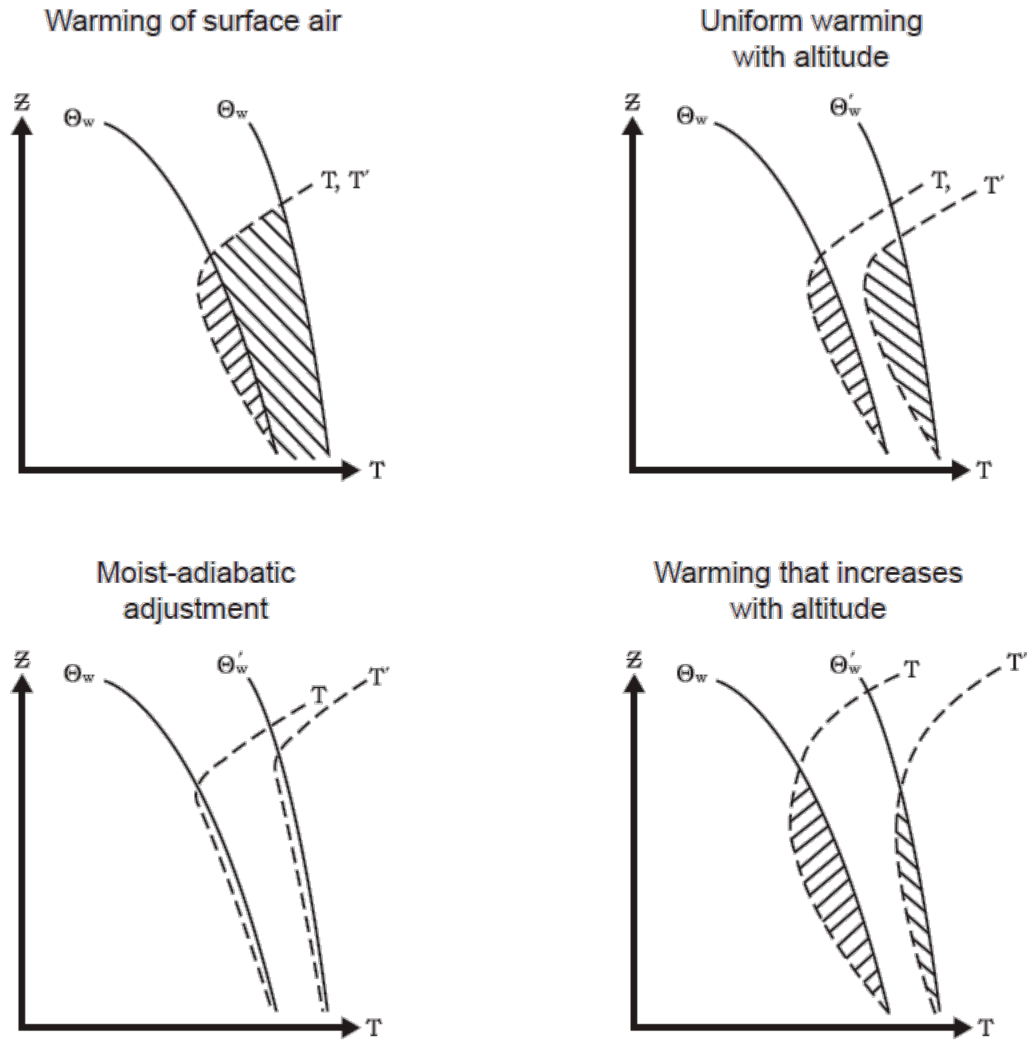
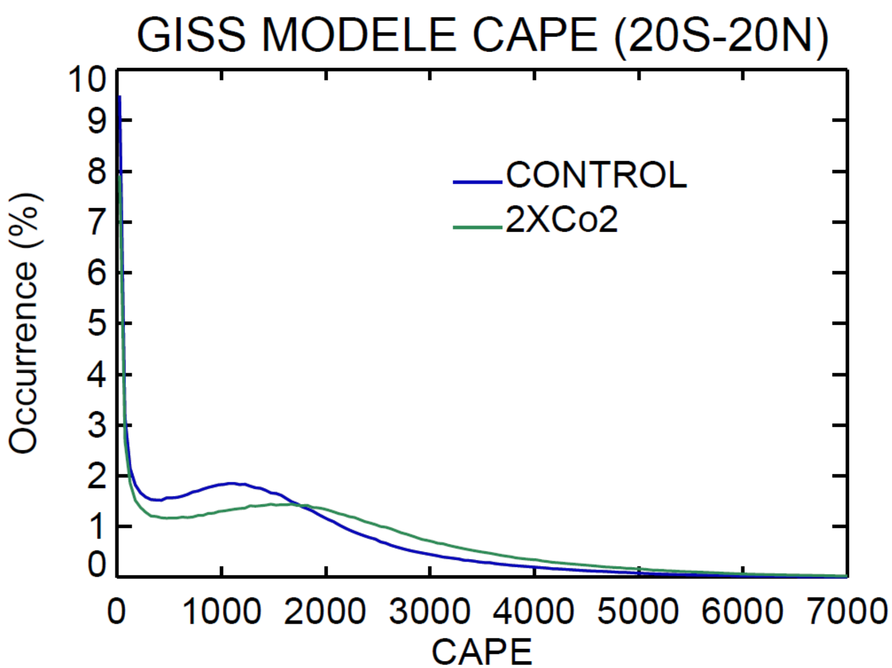
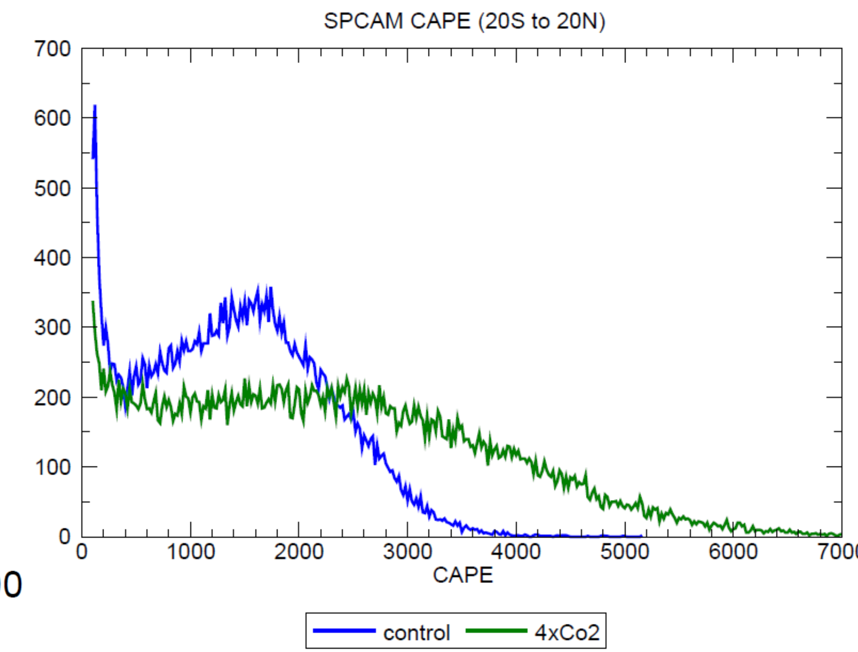
CAPE response to warming scenarios



CAPE changes in a warmer climate: two GCM predictions

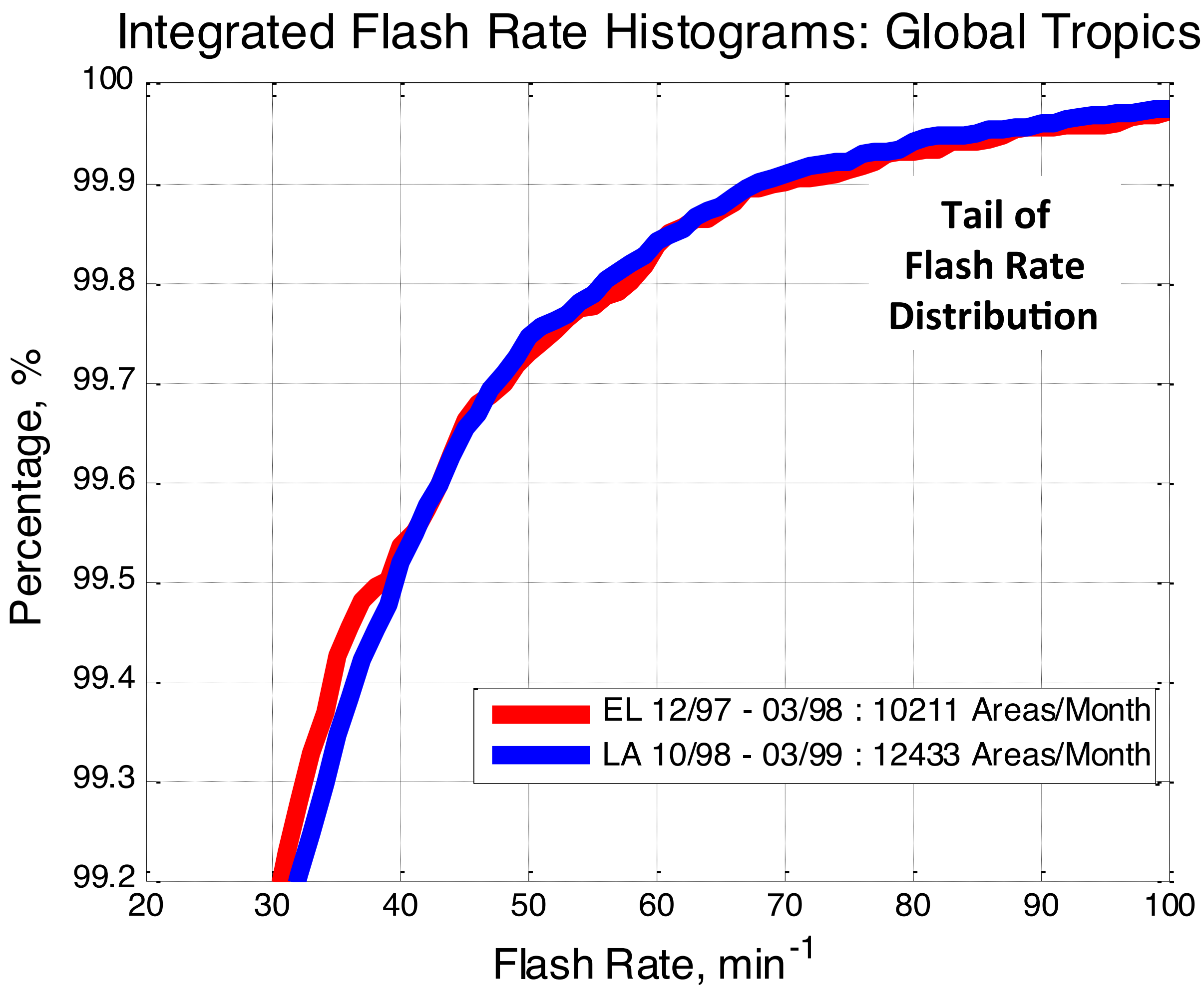


(A. Del Genio, NASA GISS)



(D. Randall, CSU)

Higher flash rate in warmer climate?



Lightning in our future?

Thermodynamic view: **More lightning probable**

Aerosol view: **More difficult to say**

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Conclusions

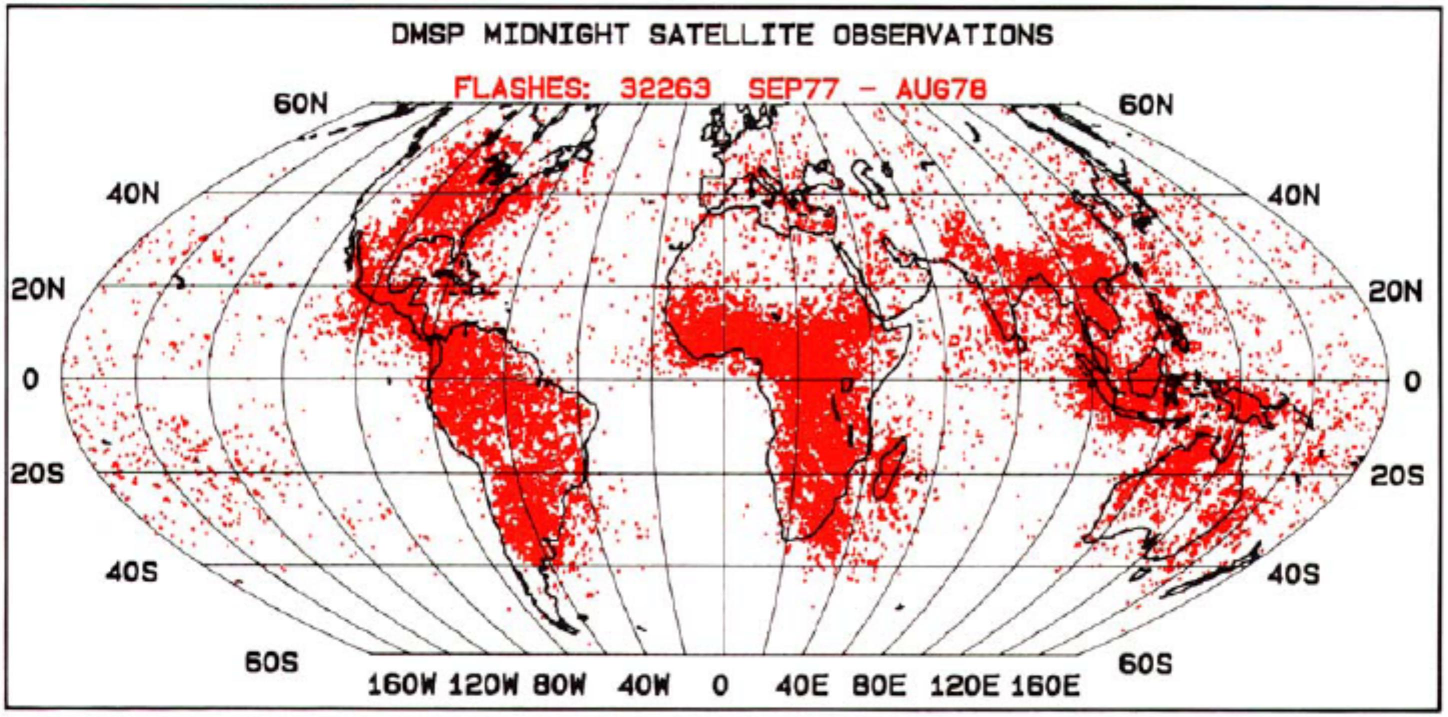
- **Both thermodynamics and aerosol are influencing lightning activity; disentanglement is difficult task**
- **Lightning activity in cities and at high northern latitudes is on the rise**
- **11-year thunder day antiphase condition most prevalent at low latitude**
  - **Possible role for galactic cosmic 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**

Acknowledgements

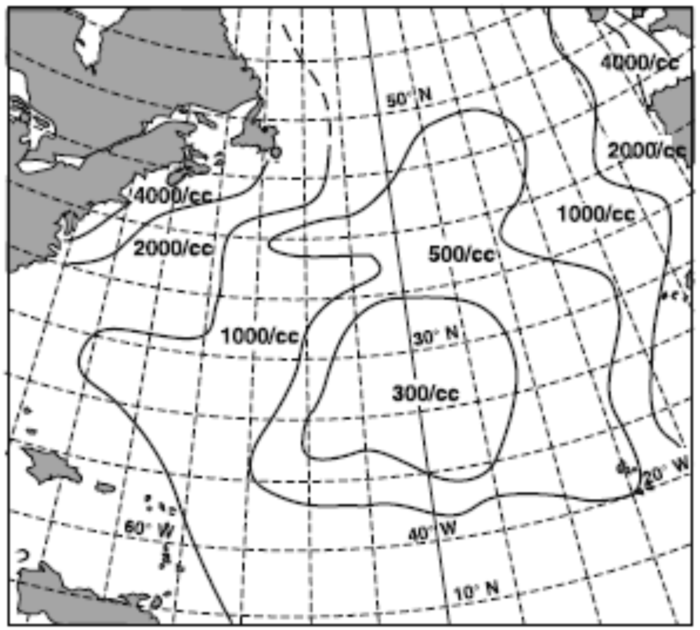
Thank you, Ben Franklin

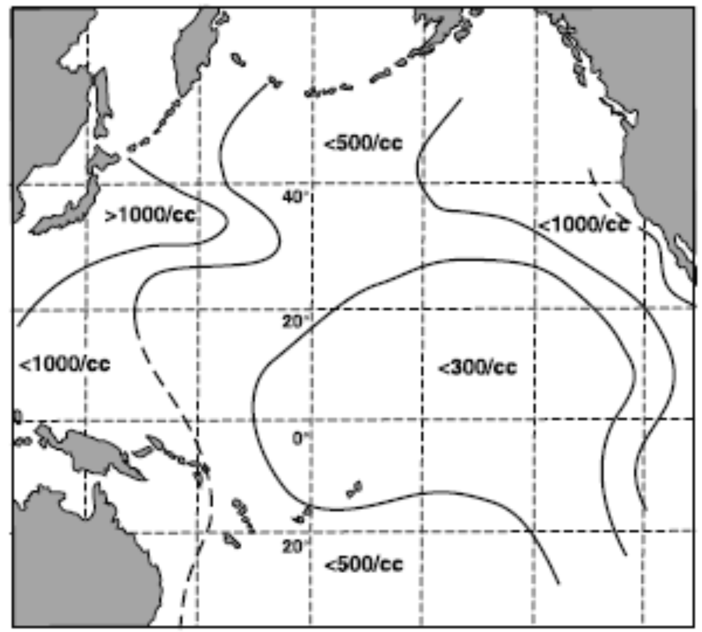
R. Albrecht
M. Andreae
M. Baker
M. Barth
T. Bell
R. Blakeslee
R. Boldi
H. Christian
T. Chronis
S. Cummer
A. Del Genio
R. Dickinson
E. Eltahir
M. Fullekrug
S. Goodman
A. Guha
R. Hallowell
J. Hansen
S. Hardy
G. Harrison
S. Heckman
Y. Hobara
A. Hogan
K. Hood
E. Huang
H. Iskenderian
S. Kandalgaonkar
S. Kinne
W. Lyons
D. MacGorman
A. Malhado
T. Mansell
R. Markson
V. Mushtak
R. Orville
W. Petersen
K. Pickering
N. Renno
K. Riemann-Campe
M. Riley
C. Rodger
D. Rosenfeld
S. Rutledge
X. Qie
R. Said
G. Satori
H. Schiffer
D. Sentman
E. Simons
D. Smalley
N. Taylor
B. Tinsley
H. Viswanatha
J. Wu
R. Zhang
E. Zipser

Global lightning at midnight (Orville and Henderson 1986)



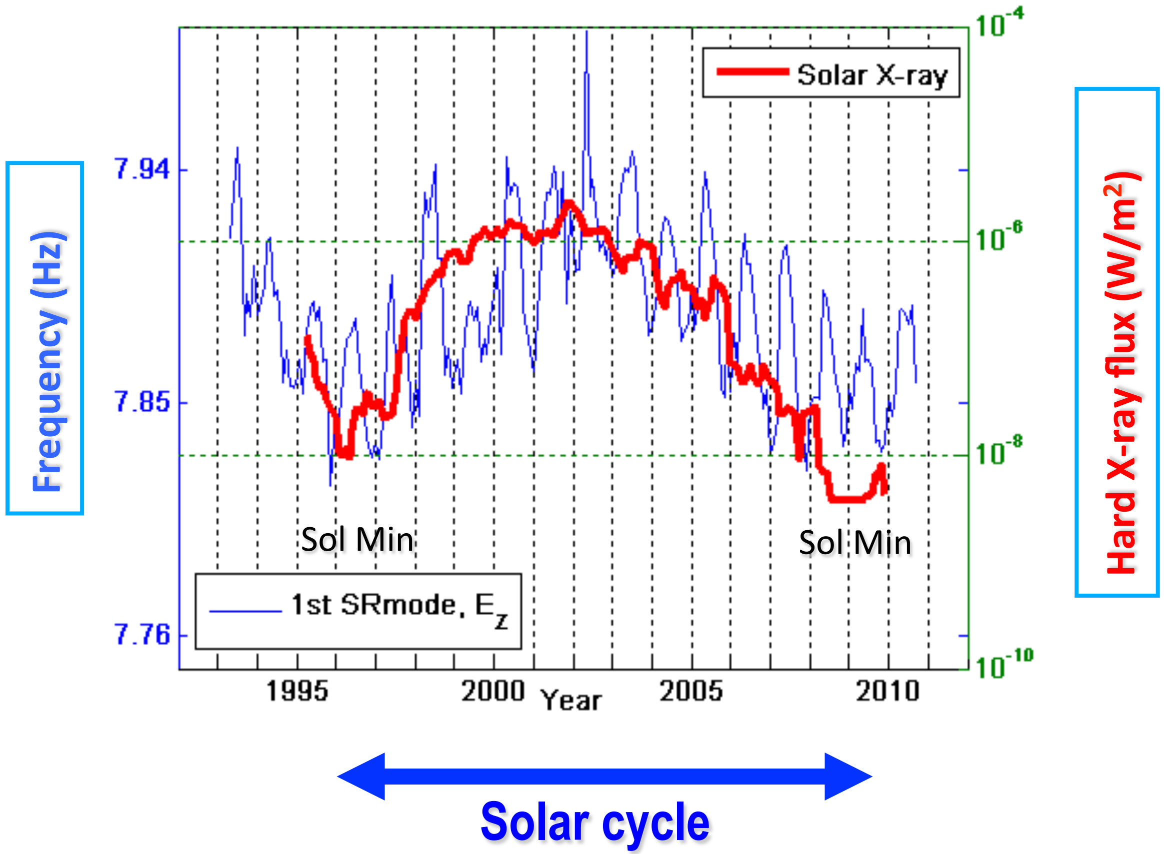
Global oceanic maps of CCN concentration (Hogan, 1977)



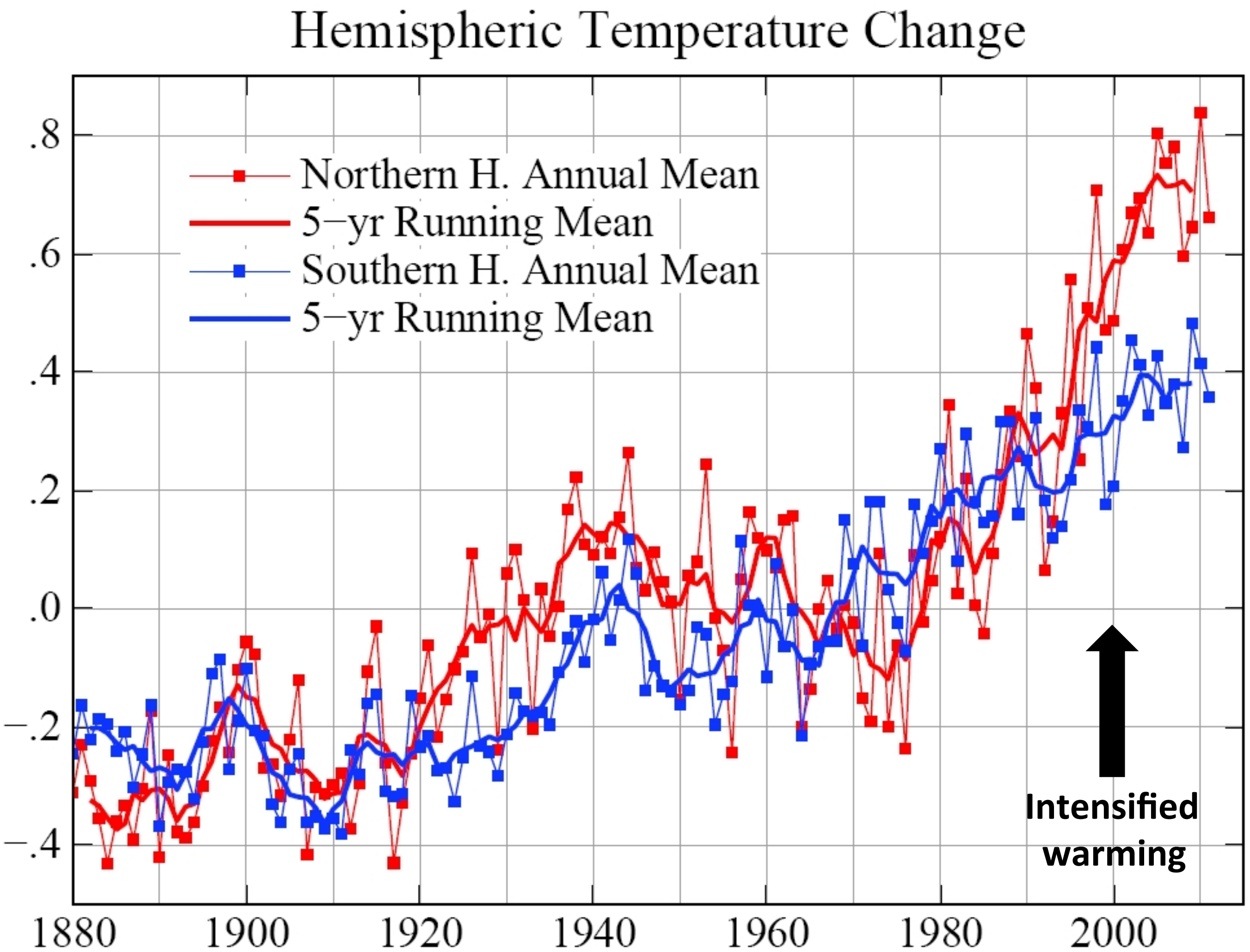


Physical causes for the frequency variations of Schumann resonances (SR)

SR frequencies are responsive to both the changes in properties of the Earth-ionosphere cavity and to variations in the lightning source-observer distance.



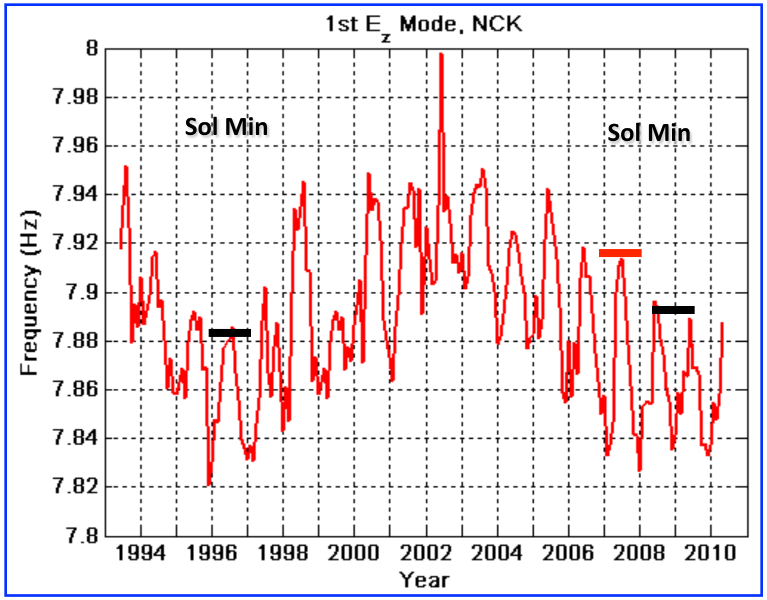
Solar cycle variation of SR frequencies is attributed to the variations in hard x-ray flux of more than two orders of magnitude influencing the upper boundary layer of the Earth-ionopshere cavity (Sátori et al. 2003). One would expect lower frequency values at the last solar minimum in 2008/2009 than in the previous one in 1996 if the frequency during the solar cycle is only responsive to the changes of ionospheric propagation conditions due to hard X-ray flux variations. Frequency observations at Nagycenk, Hungary above don't support this expectation.

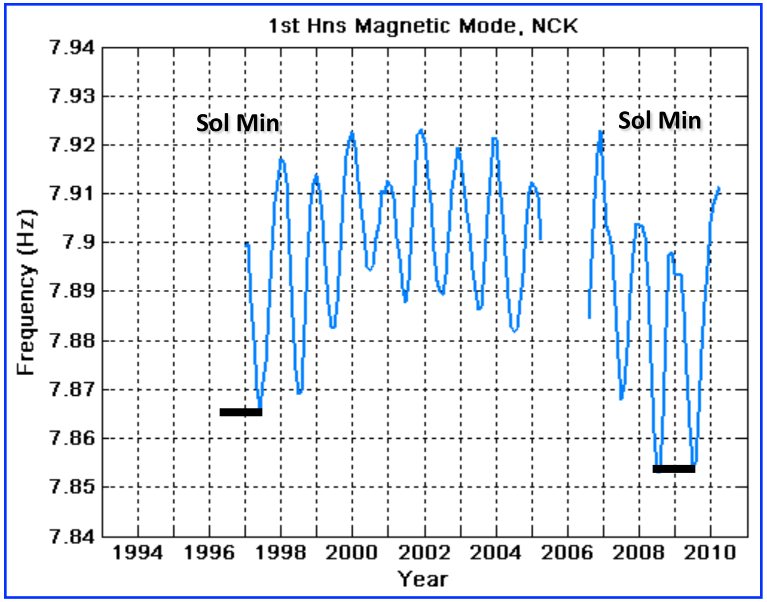


(Source: J.E. Hansen, R. Ruedy, M. Sato, and K. Lo; NASA Goddard Institute for Space Studies)

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 1995 (Sátori et al., 2011).

Contrasting the behavior between solar cycle minima

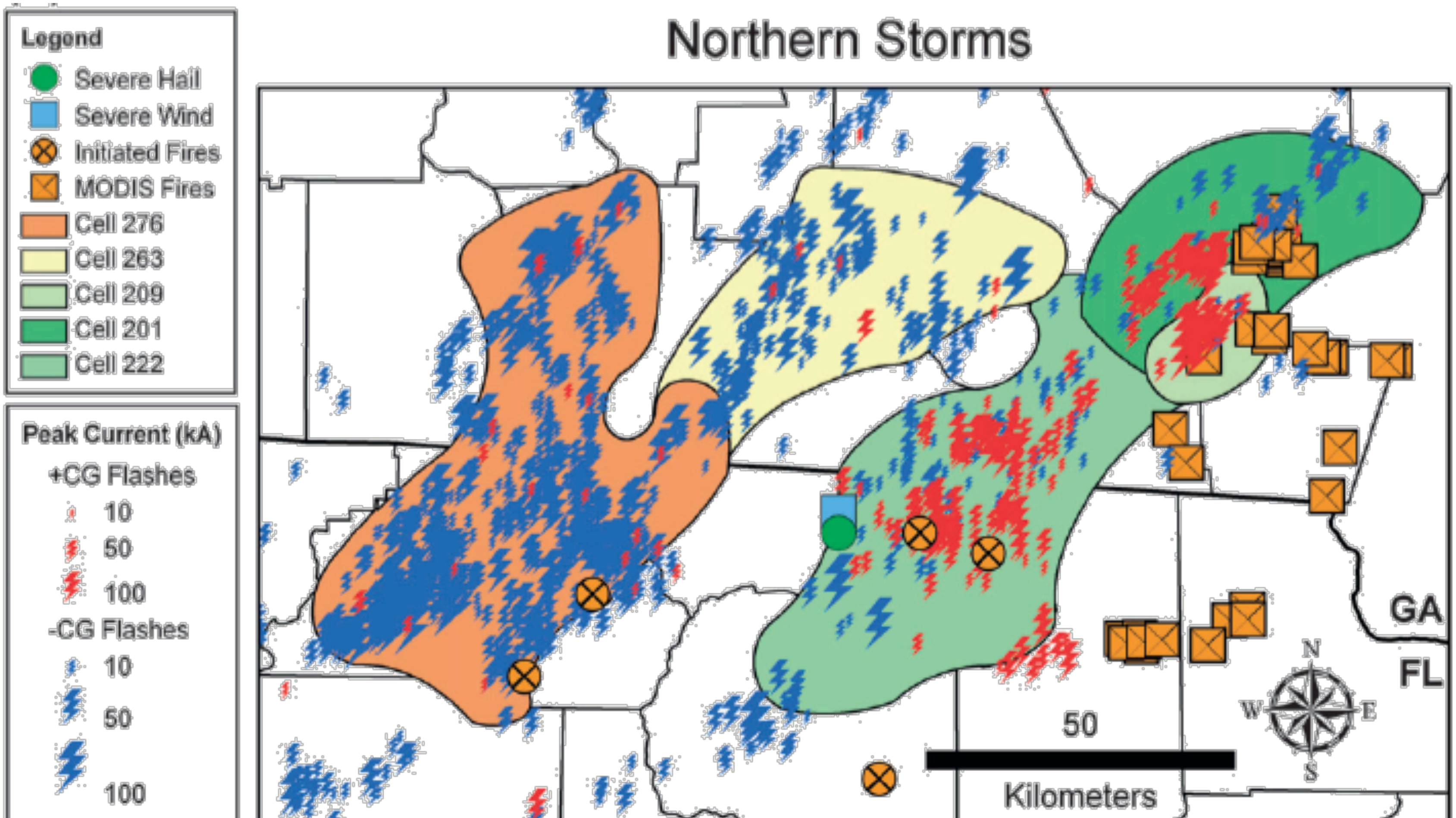




Solar cycle

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 fequencies 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 4°- 6° in latitude in the Northern hemisphere summers during the last elongated solar cycle (12-13 years) (Sátori et al., 2011).

Smoke ingestion by thunderstorms and inversion of electrical polarity (Rudlosky and Fuelberg, 2011)



Variation of fair weather electric field at Kennedy Space Center (Harrison, 2006)