Challenges in modeling lightning in weather and climate models

Colin Price

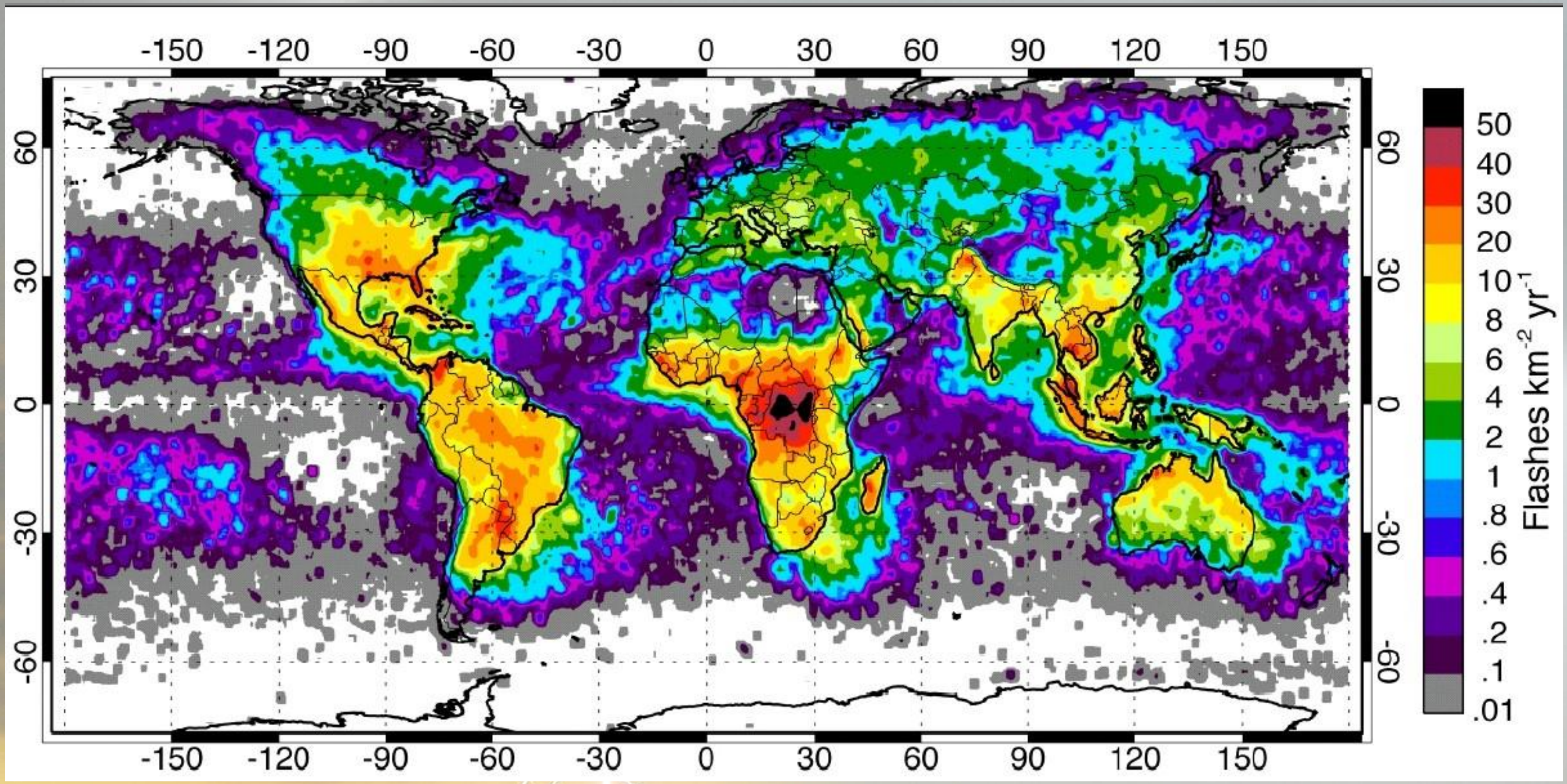
Porter School of the Environment and Earth Sciences
Tel Aviv University, Israel

cprice@flash.tau.ac.il

Who cares?

- ✓Thousands of deaths every year. Many more injured
- ✓Damage to sensitive infrastructures and equipment
- ✓Aviation hazard
- ✓Ignition of forest fires in boreal forests
- ✓Production of NO_x → production of O_3 (greenhouse gas)
- ✓Indicator of severe weather (tornadoes, hurricanes, flash floods)

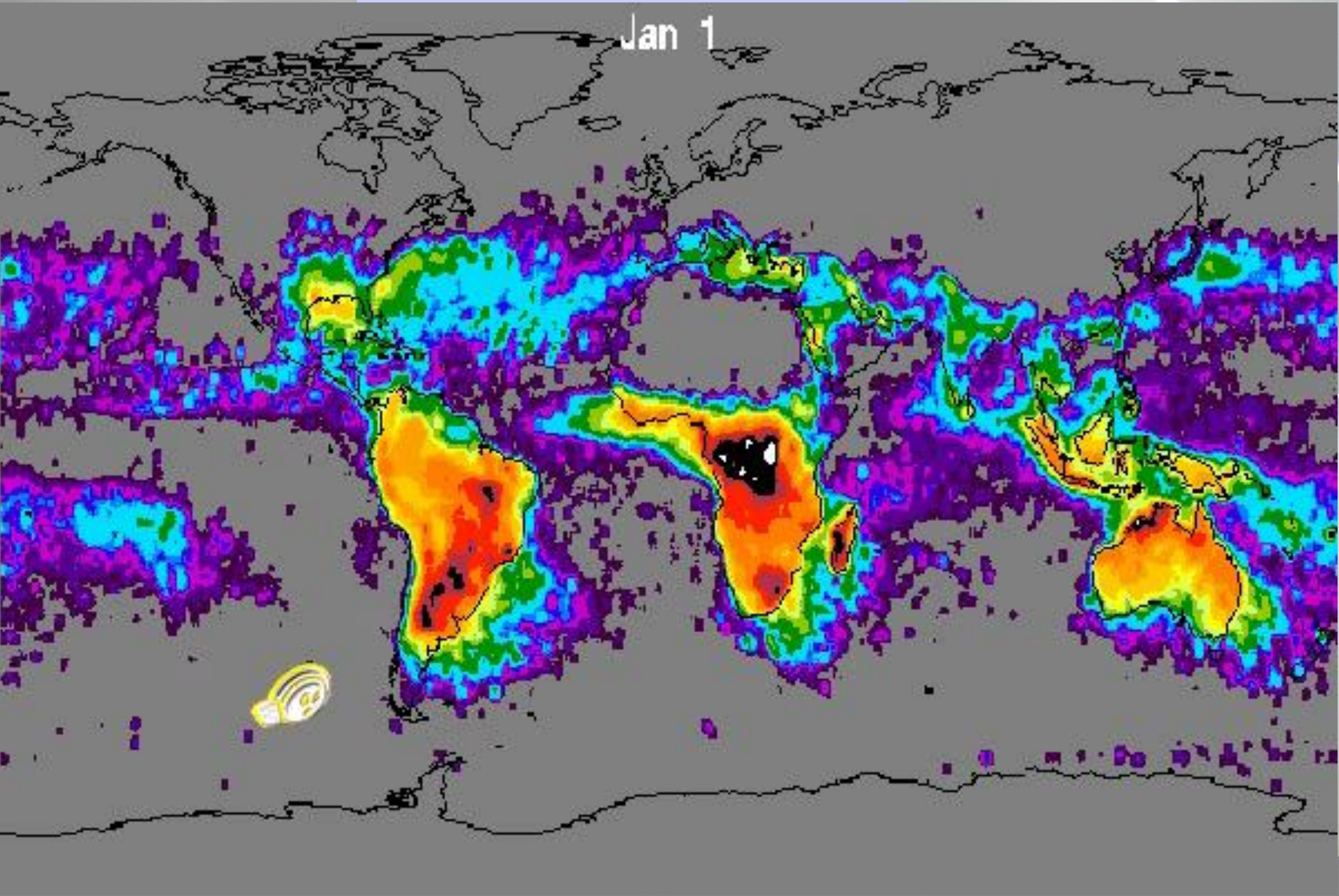
Where on Earth does lightning occur?



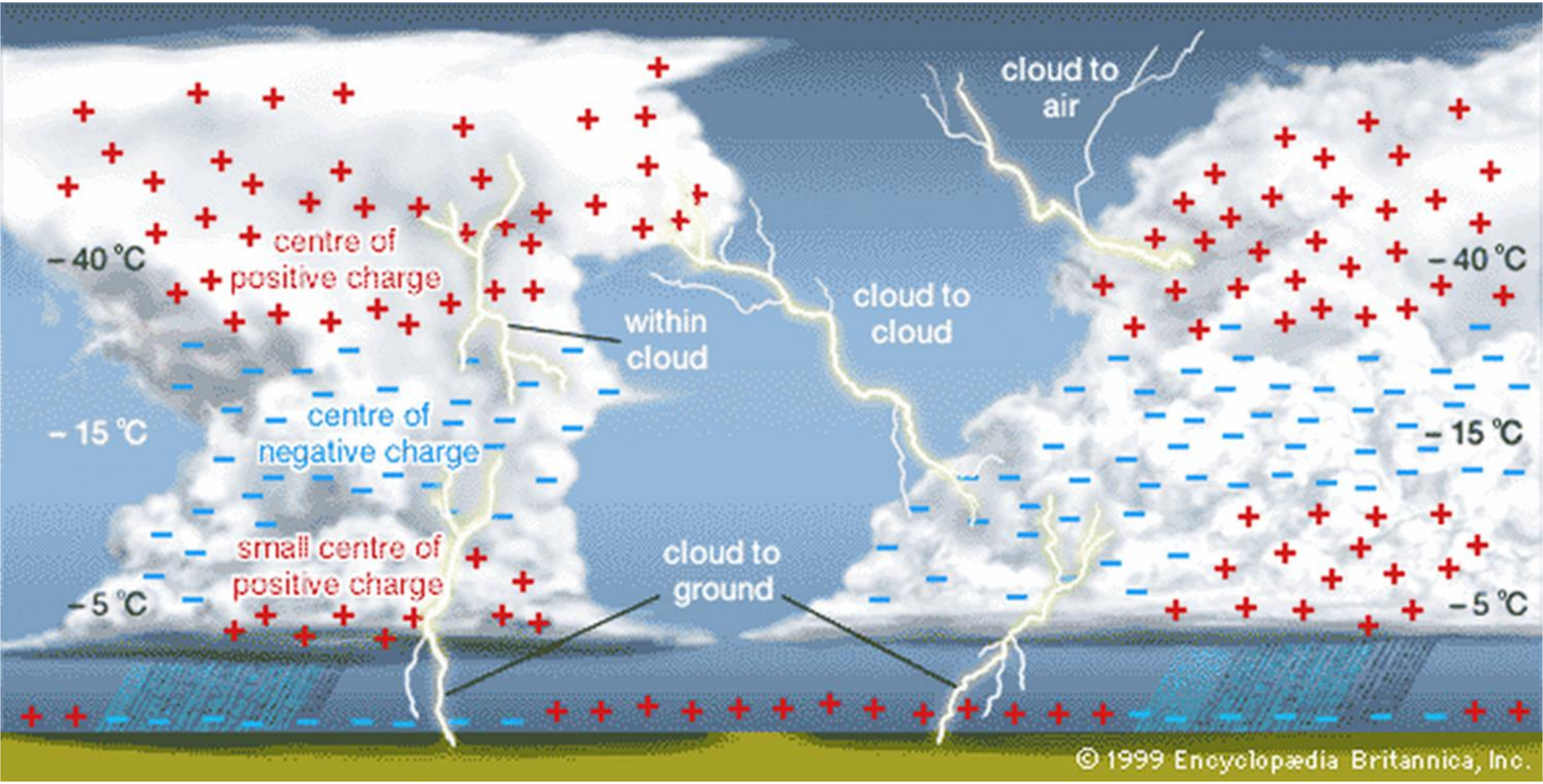
OTD/LIS 5-year climatology

(Christian et al., 2003)

Satellite tracking of lightning



Optical Sensors


cloud to
air
centre of
positive charge
– 40 °C
– 40 °C
within
cloud
cloud to
cloud
centre of
negative charge
– 15 °C
– 15 °C
small centre of
positive charge
cloud to
ground
– 5 °C
– 5 °C
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3.1 Cloud Electrification

The process of thundercloud electrification can be broken into 3 stages:

1. **Charge separation within cloud particles (droplets and ice)**
   1.1 Inductive processes (within an external electric field)
   1.2 Non-inductive processes (connected to melting, temperature gradients)

2. **Generation of charged cloud particles**
   2.1 Breakup of droplets and ice
   2.2 Collisions between particles (charge transfer between particles)
   2.3 Ion capture by cloud particles

3. **Charge Separation on the cloud scale** by updrafts and downdrafts within the cloud. Large particles fall towards the cloud base faster than small particles, while small particles can be transported aloft to the cloud top more easily than large particles. In order to explain the charge distribution in clouds, the larger particles need to get negative charges, and the smaller particles positive charges.

Lightning Potential Index
(Yair et al., 2010)

- Charge separation assumed to be by the non-inductive ice-graupel mechanism (Takahashi, 1978; Saunders and Peck, 1991)
- Electric field buildup proportional to the concentrations of the interacting particles and the velocity gradient between respective fall speeds (Keith and Saunders, 1991)
- LPI is the volume integral of the total mass flux of ice and liquid water within the charging zone (0 to -20C) of the cloud.
- Units of LPT are J/kg

$$LPI = 1/V \iiint \varepsilon\, w^2\, dx\, dy\, dz$$

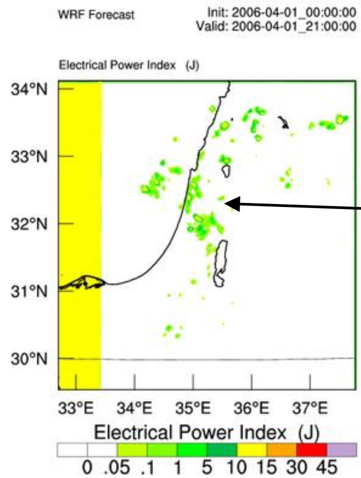
Where $\varepsilon = 2(Q_i\, Q_l)^{0.5} / (Q_i + Q_l)$

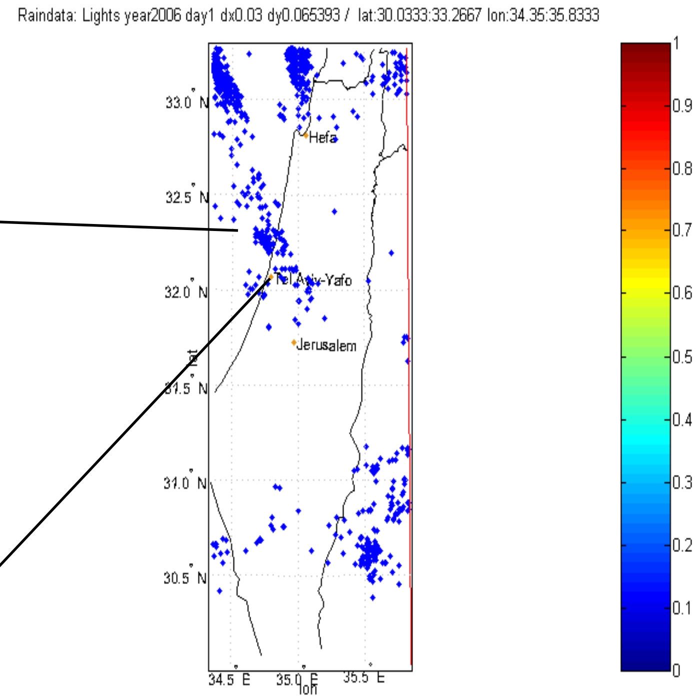
Q_l is total liquid water mass
Q_i is ice fractional content
W updraft velocity

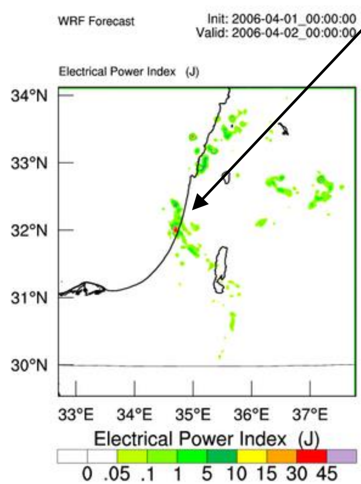
$$Q_i = 2\, q_g\, [((q_s\, q_g)^{0.5} / (q_s + q_g)) + ((q_i\, q_g)^{0.5} / (q_i + q_g))]$$

Where the mixing ratios of snow (q_s), cloud ice (q_i) and graupel (q_g) in [kg/kg]

Example: 1 April 2006 Northern Israel (WRF)







A good correlation exists between the locations of lightning as measured by LPATS and the places with the highest values of the Power Index

Flood event Israel 28/10/2006

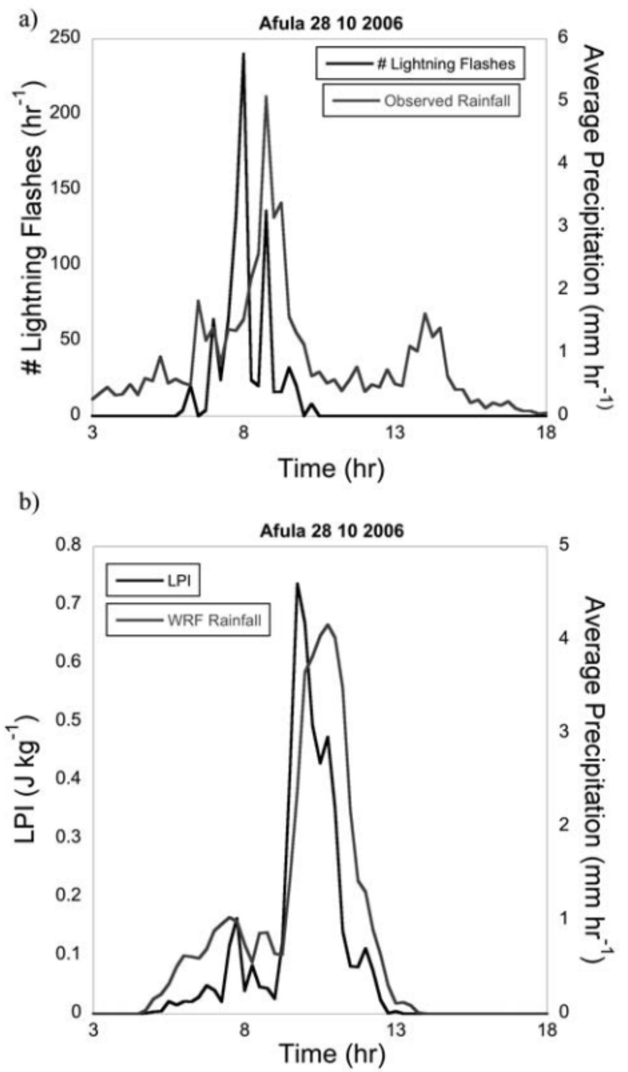
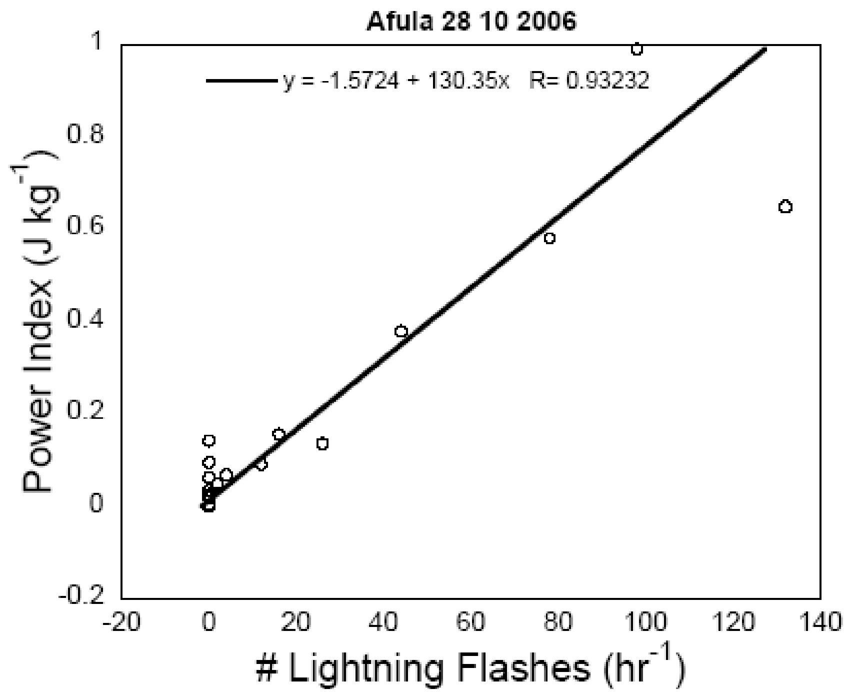
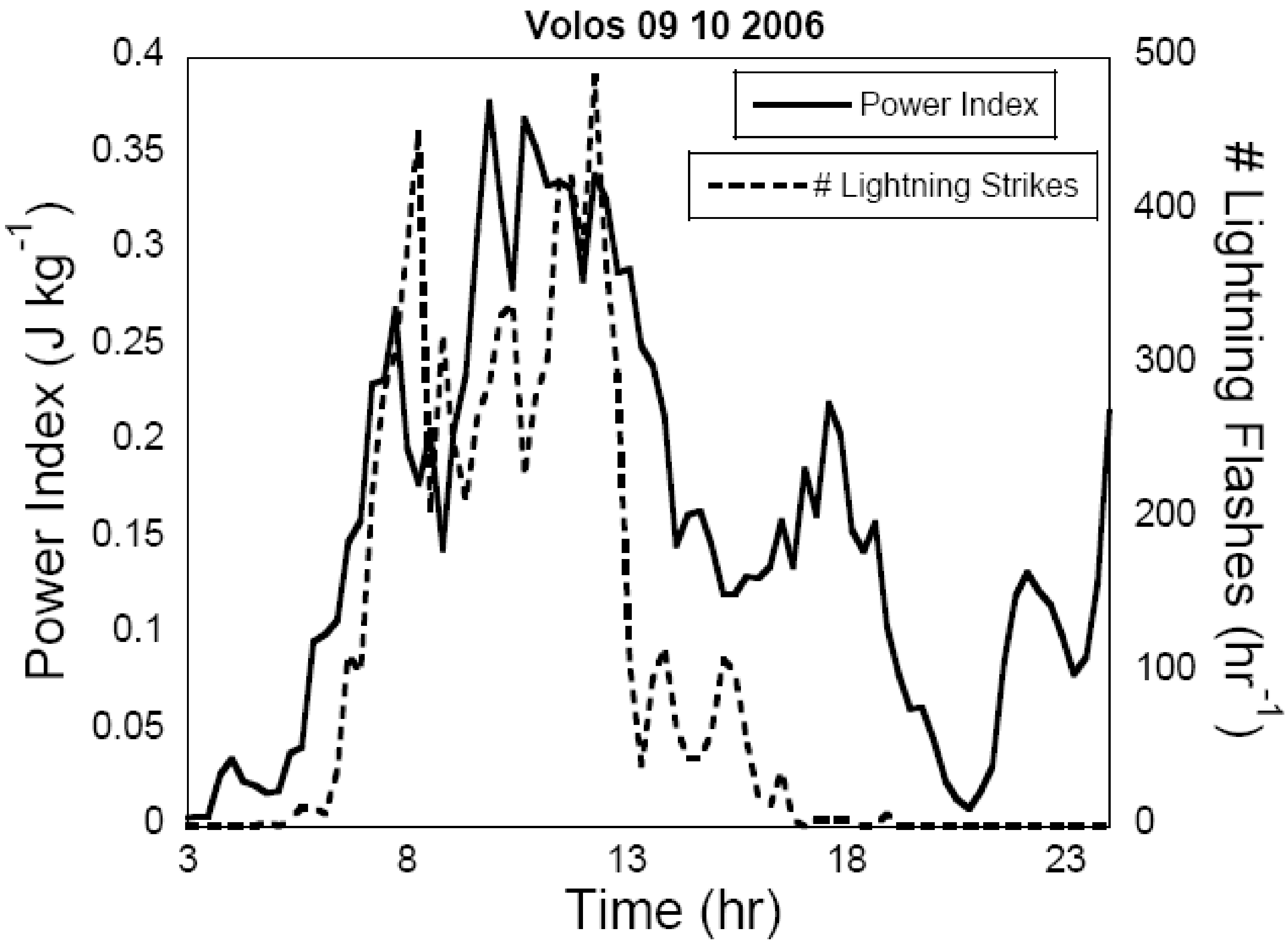


Figure 2. (a) The number of cloud-to-ground (CG) lightning flashes and the radar-derived precipitation as a function of time around the time of peak rainfall. (b) The lightning potential index (LPI) values and Weather Research and Forecasting (WRF)-derived average precipitation for the same time period.



Greek Flood


Volos 09 10 2006
Power Index
Lightning Strikes
Power Index (J kg^{-1})
Lightning Flashes (hr^{-1})
Time (hr)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
500
400
300
200
100
0
3
8
13
18
23

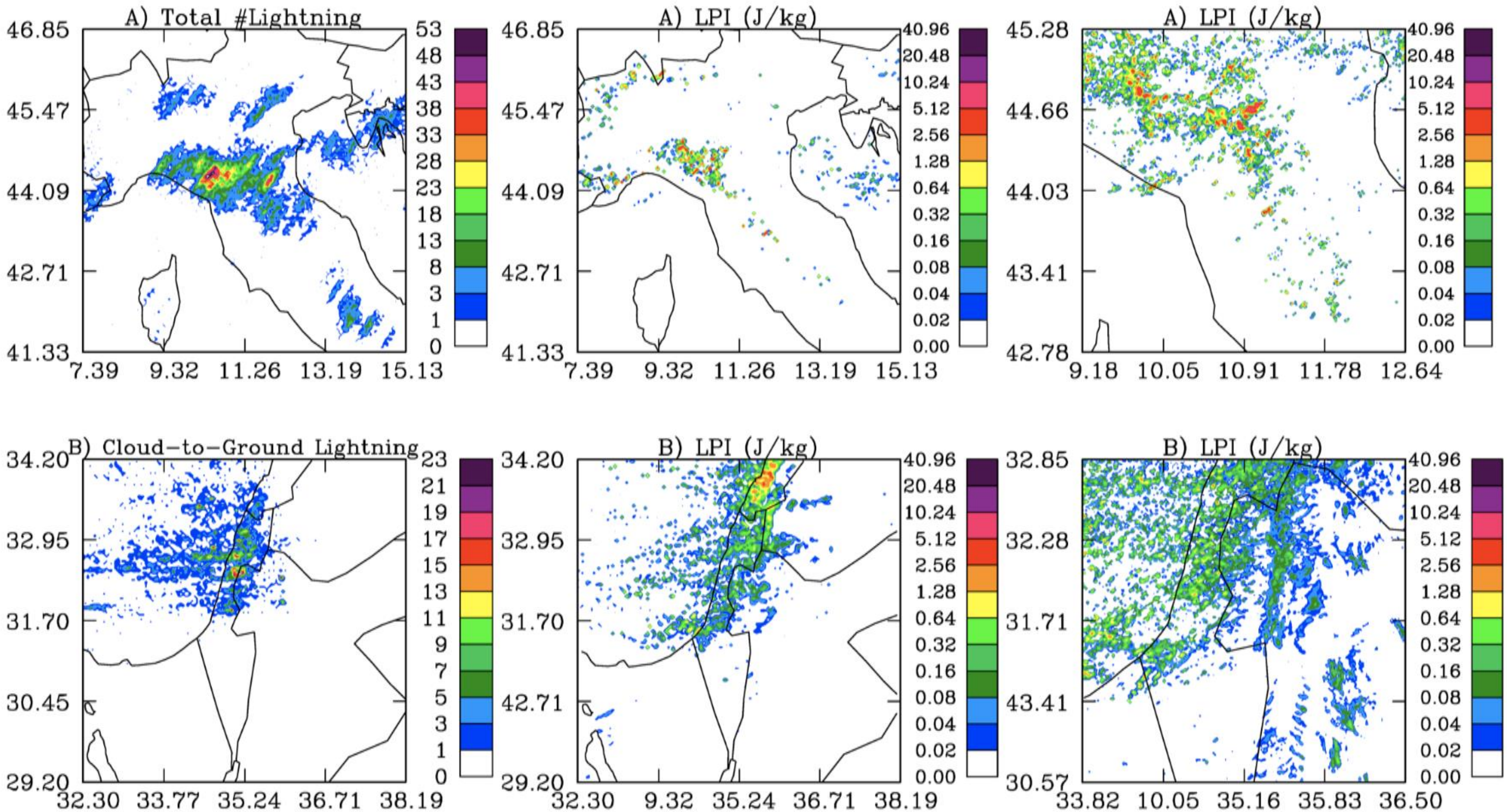
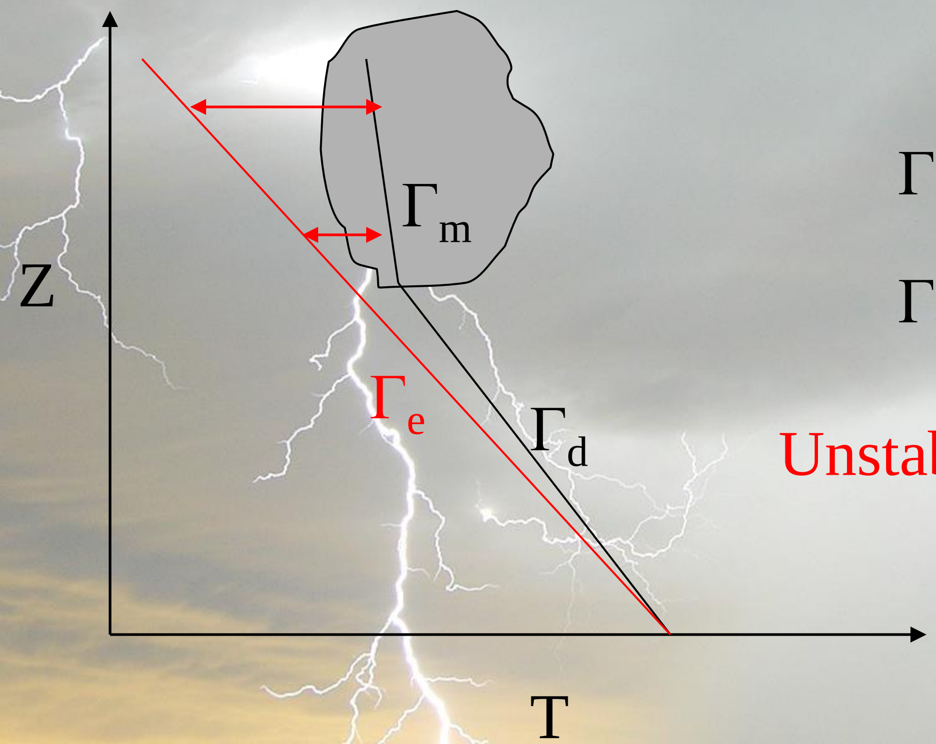


Fig. 1. Observed 24 h lightning is two case studies for Italy and Israel. The upper row is for case study **(A)** 9 September 2008 (ZEUS network), and the lower row for case study **(B)** 28 February 2009 (LPATS network), respectively. WRF model calculated, 24 h averaged, Lightning Potential Index (LPI) for both cases at 4 km (center) and 1.33 km (right) grid resolution for the same dates.

Thunderstorms need an unstable atmosphere to develop

Under adiabatic ascent, air cools at the Adiabatic Lapse Rate



$\Gamma_d \sim 10^o/km$

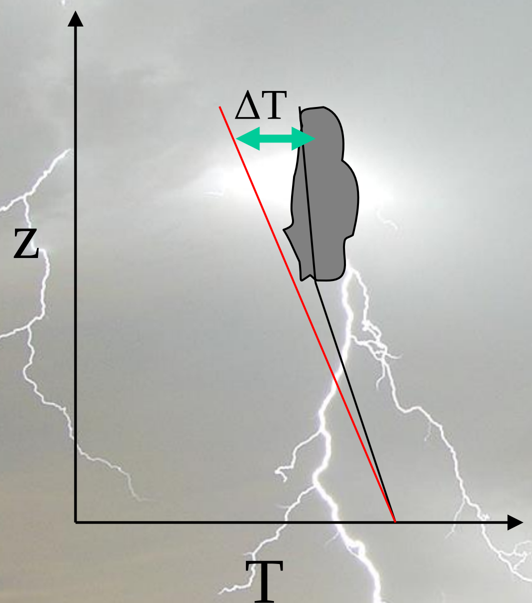
$\Gamma_m \sim 6^o/km$

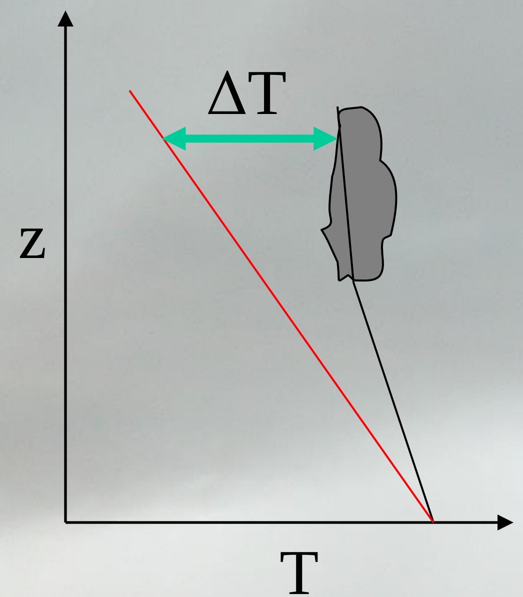
Unstable if $\Gamma_e > \Gamma_d$

Lightning influenced by both changes in Ts, but also lapse rate aloft

Atmospheric Instability is not enough for lightning

We need updrafts of at least 10 m/sec for significant electrification





Oceans (weak updrafts)

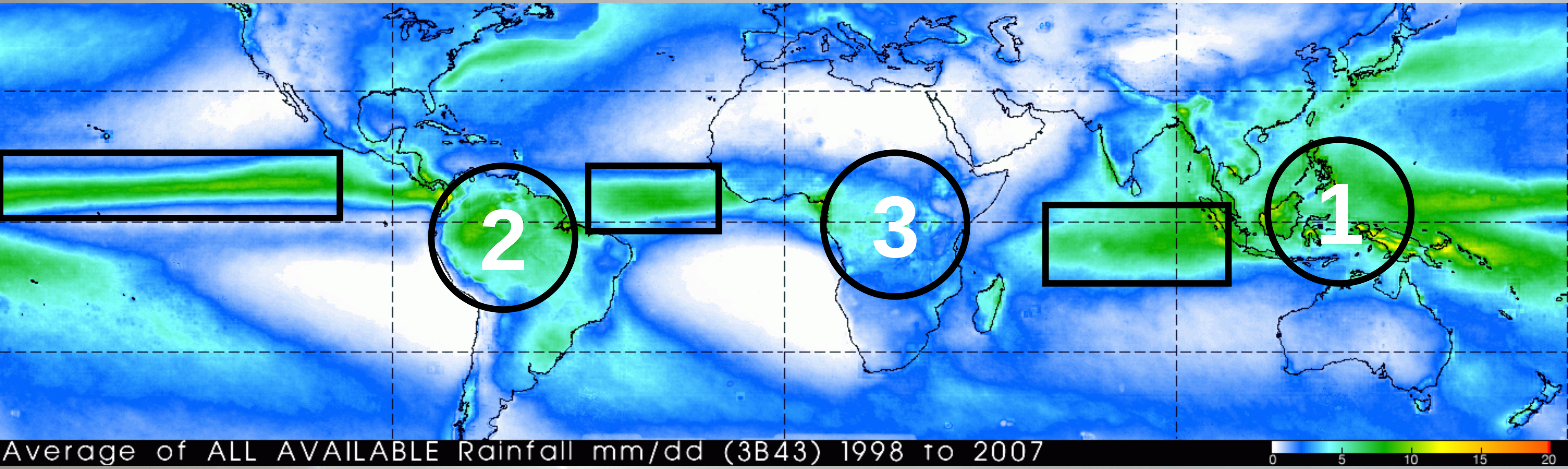
↓

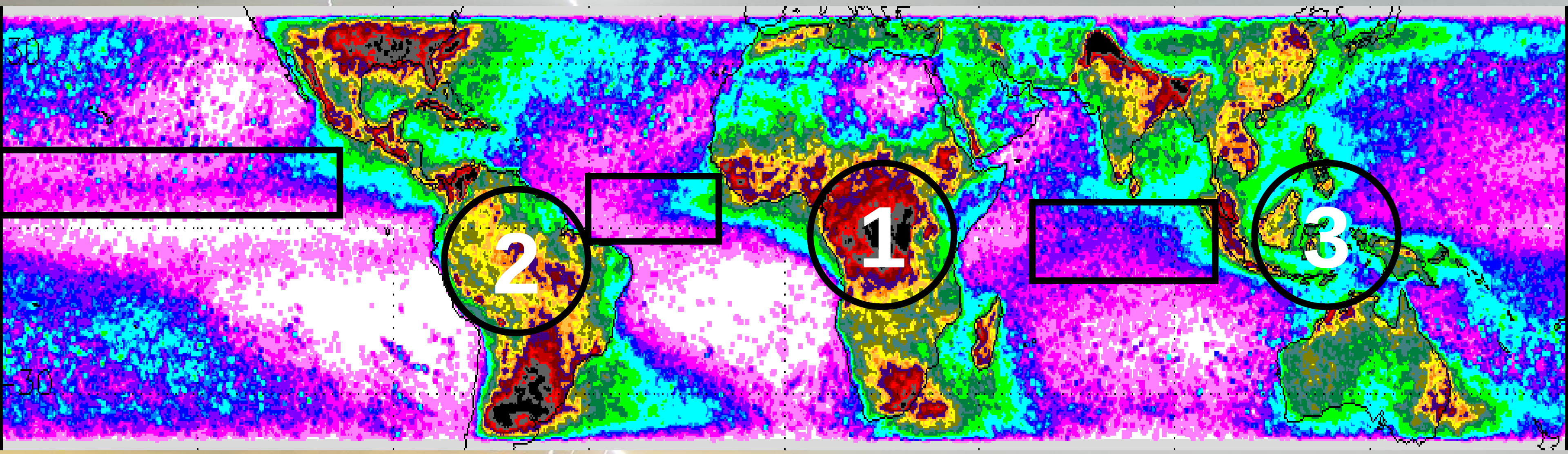
Rain with Little Lightning

Continents (strong updrafts)

↓

Rain with Lots of Lightning





Rainfall and Lightning

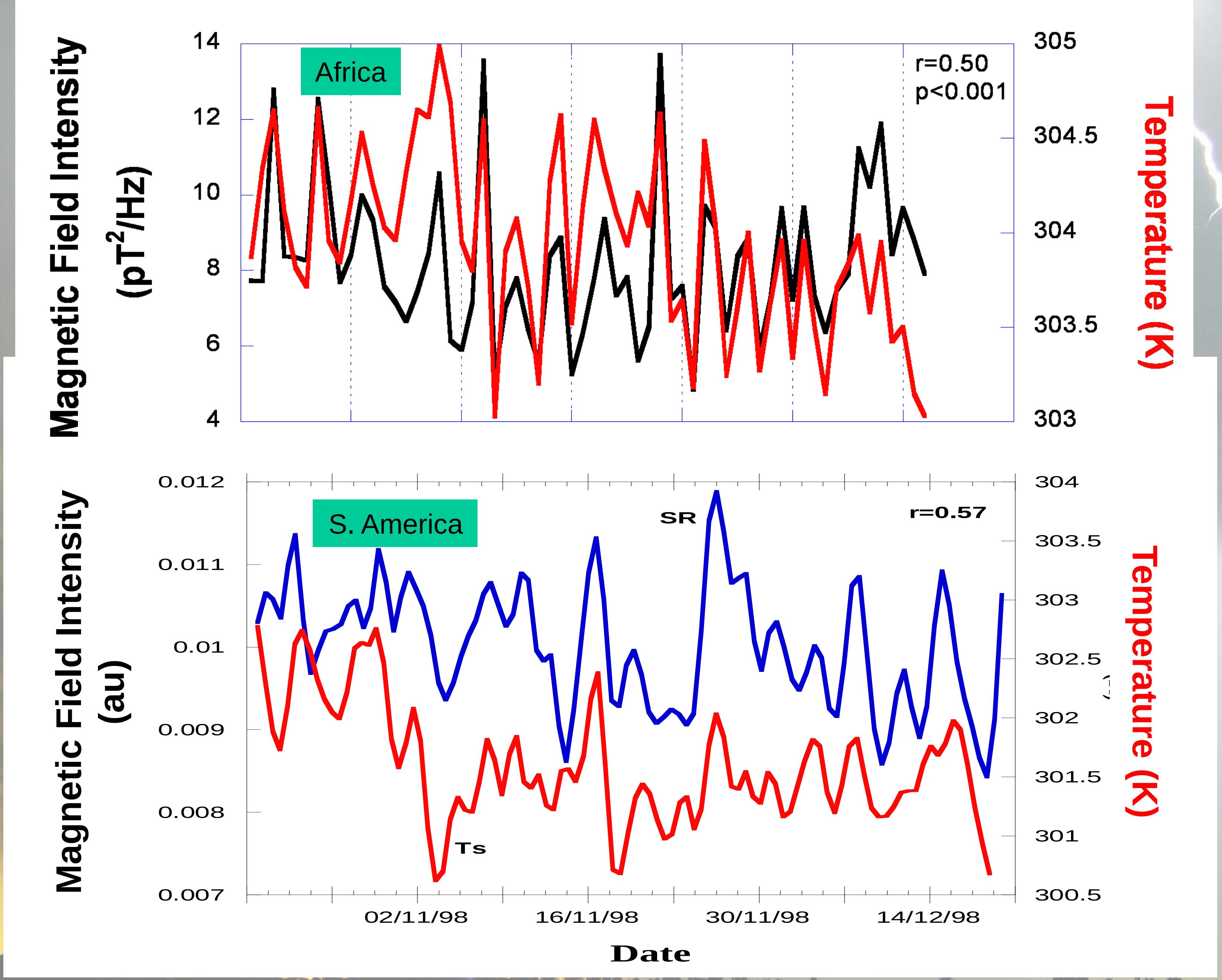
Williams and Satori (2004)
Price (2008)

Lightning prefers drier climates

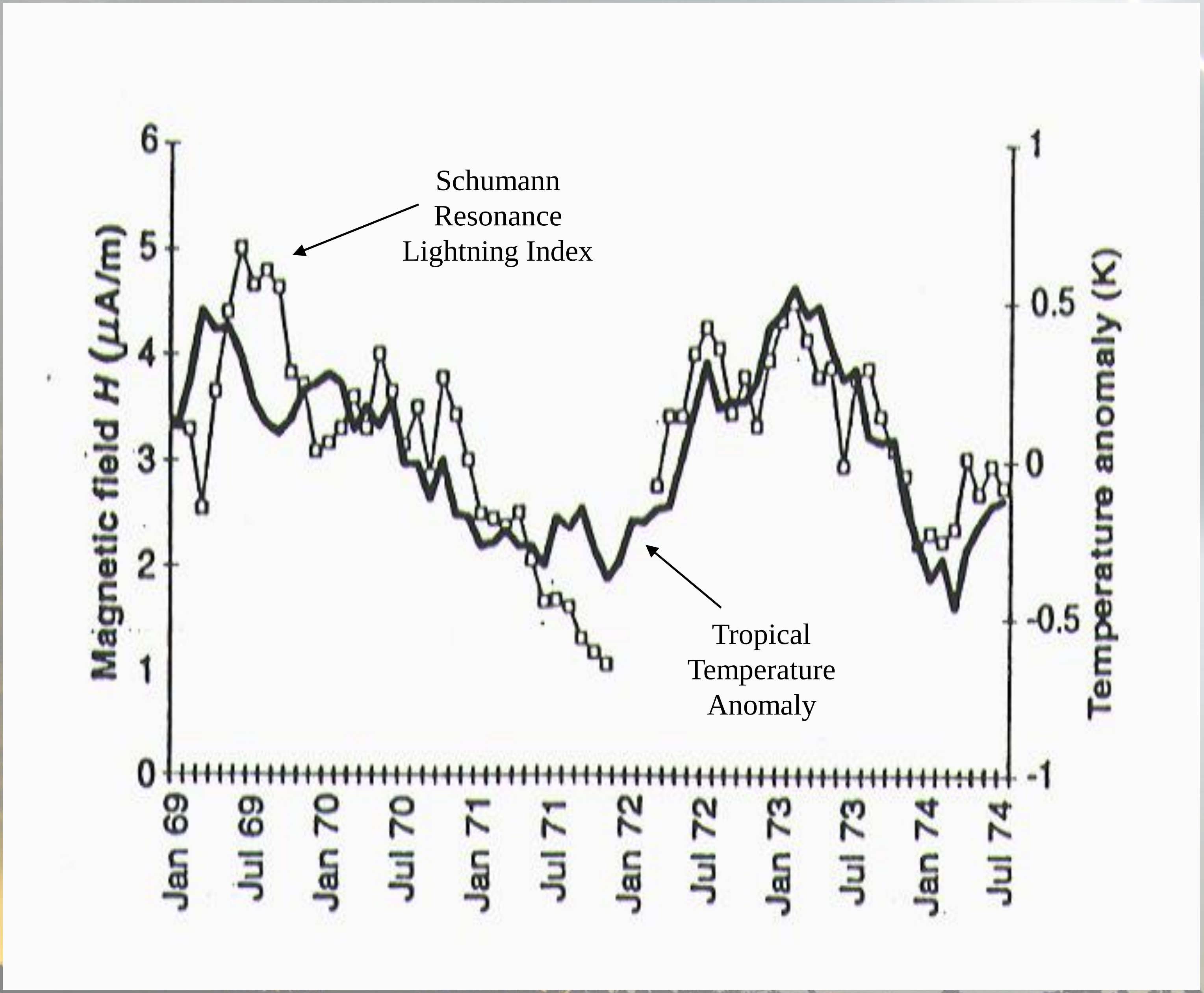
Surface Temperature and Lightning

Studies showing statistically significant positive correlations between **surface temperature** and lightning activity

- *Williams (1992)*
- *Price (1993)*
- *Williams (1994)*
- *Reeve and Toumi (1999)*
- *Markson and Price (1999)*
- *Price and Asfur (2006)*
- *Markson (2007)*

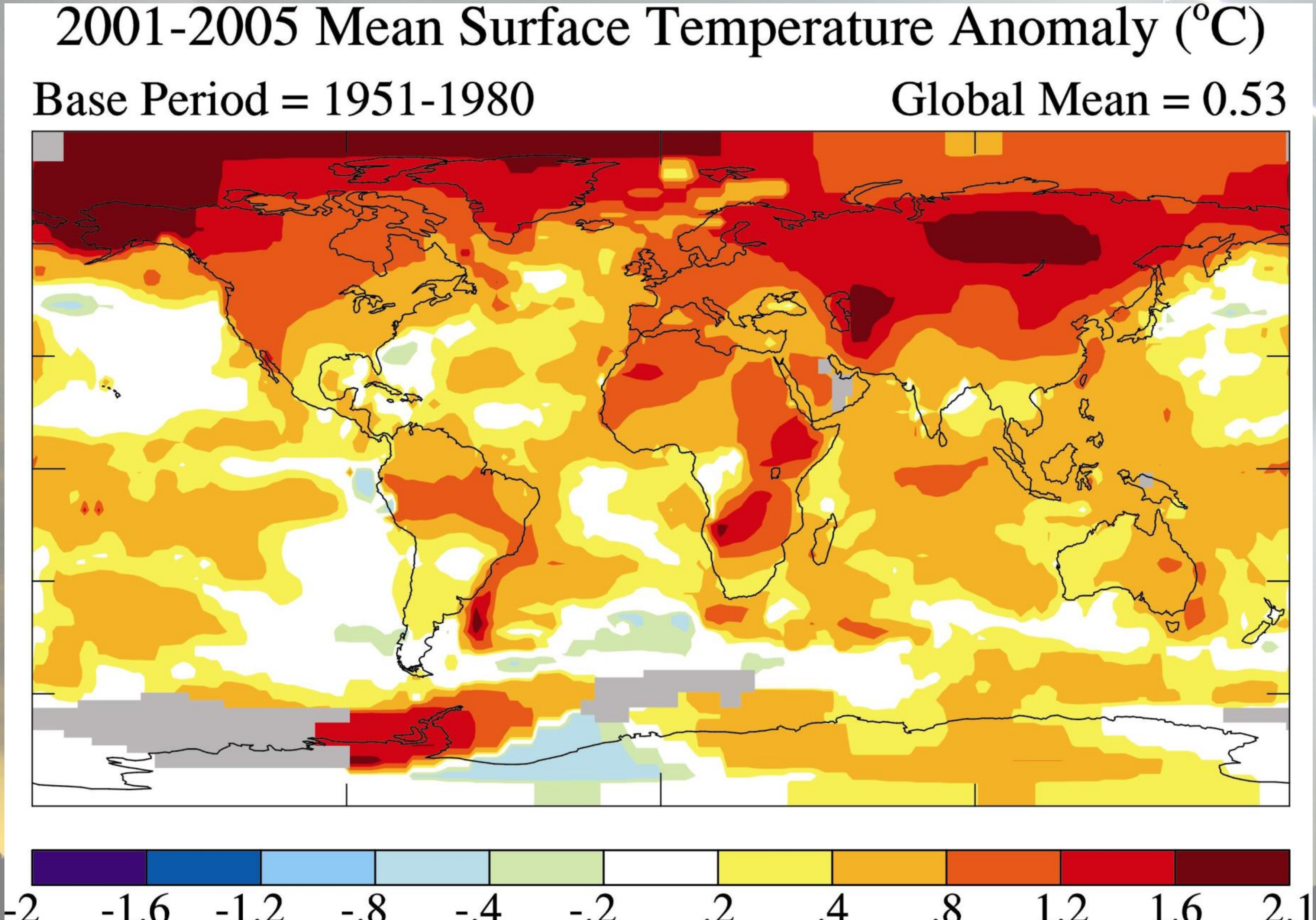


Price and Asfur (2006)

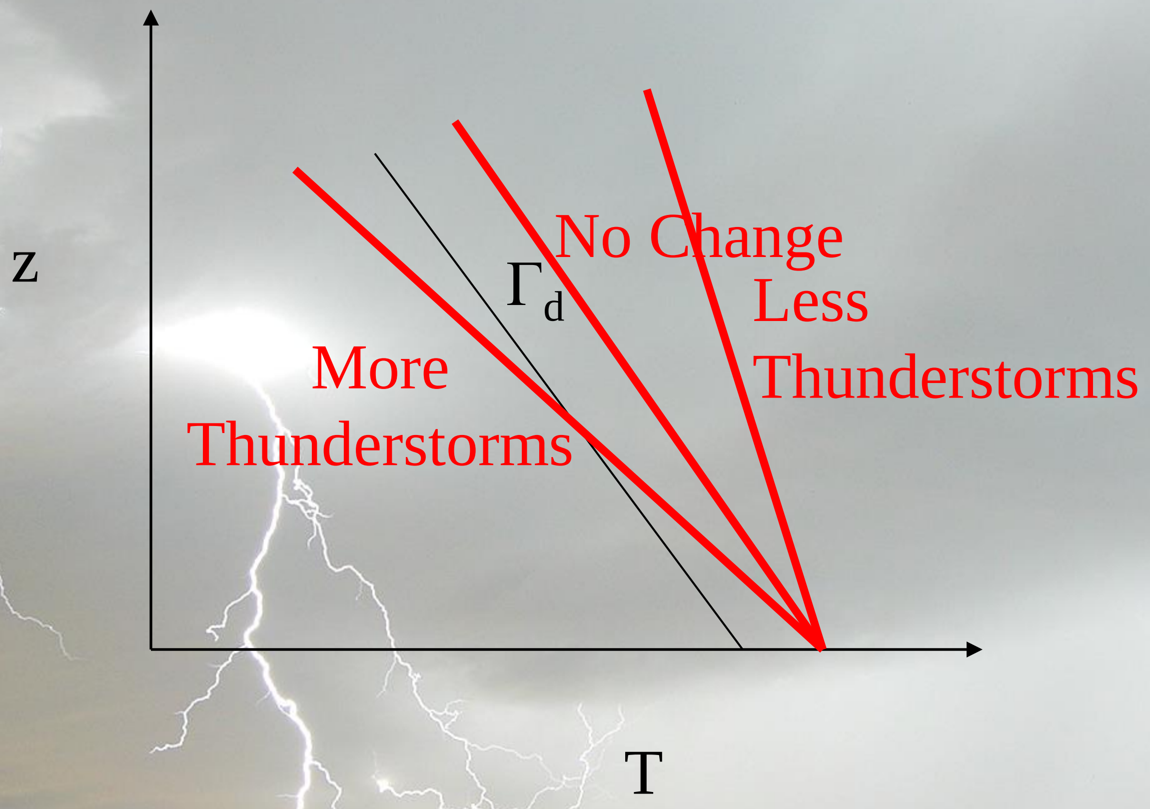


Williams (1992)

What about global warming?

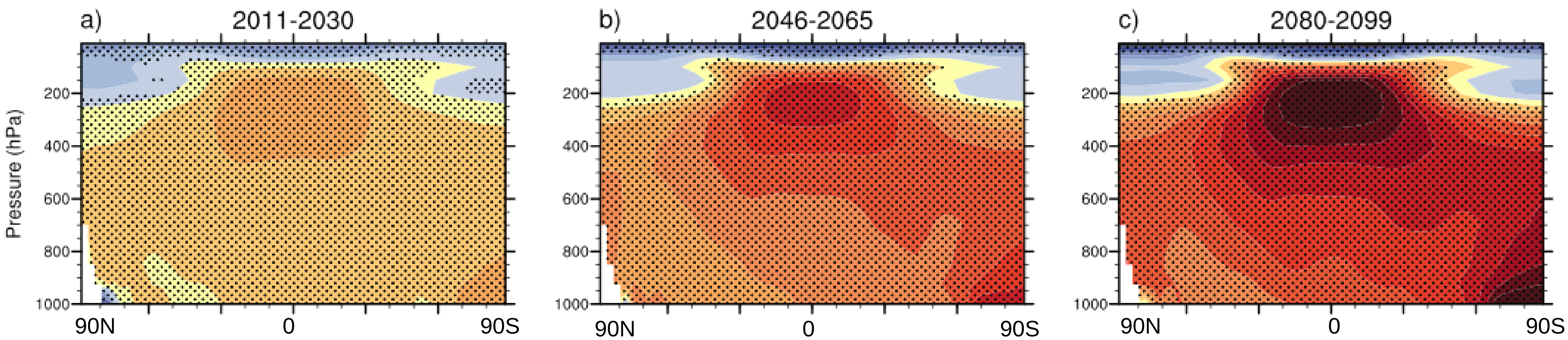


What about changes in Lapse Rate?



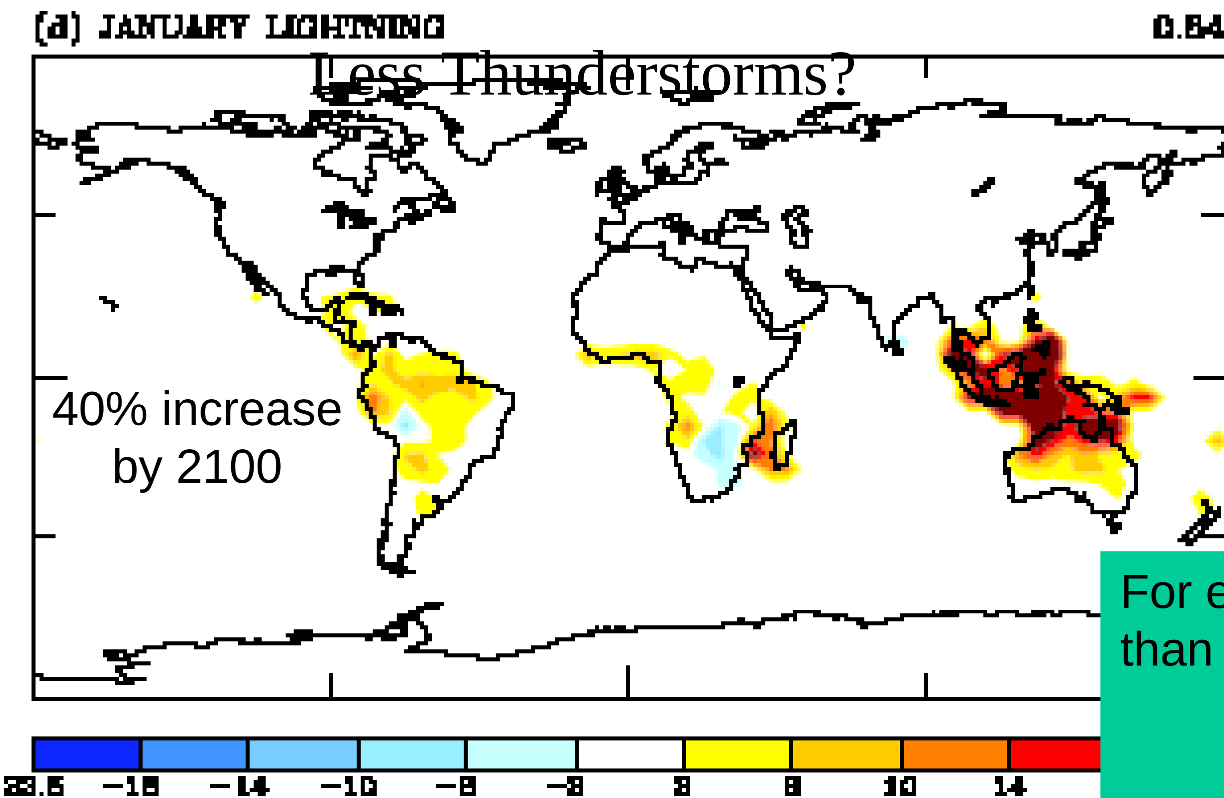
What is predicted for the future?

Maximum Warming Predicted in Tropical Upper Troposphere



Anomalies are relative to the average of the period 1980 to 1999.
(IPCC, 2007)

Less Thunderstorms?



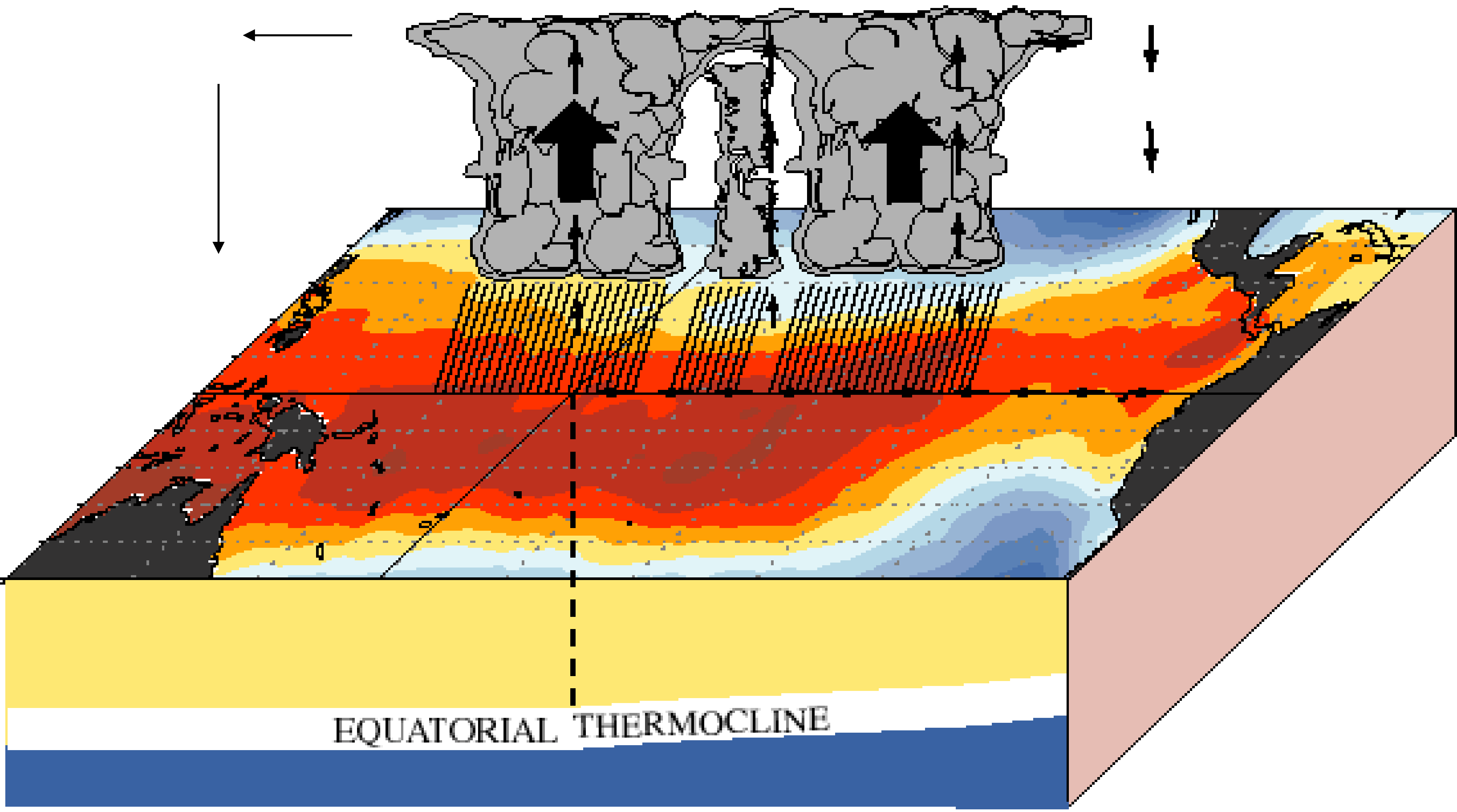
40% increase by 2100

Paradox?

For every 1K global warming, more than 10% increase in global lightning

Price and Rind (1994)
Grenfell et al. (ACP, 2003),
Shindell et al. (ACP, 2006)

December - February El Niño Conditions



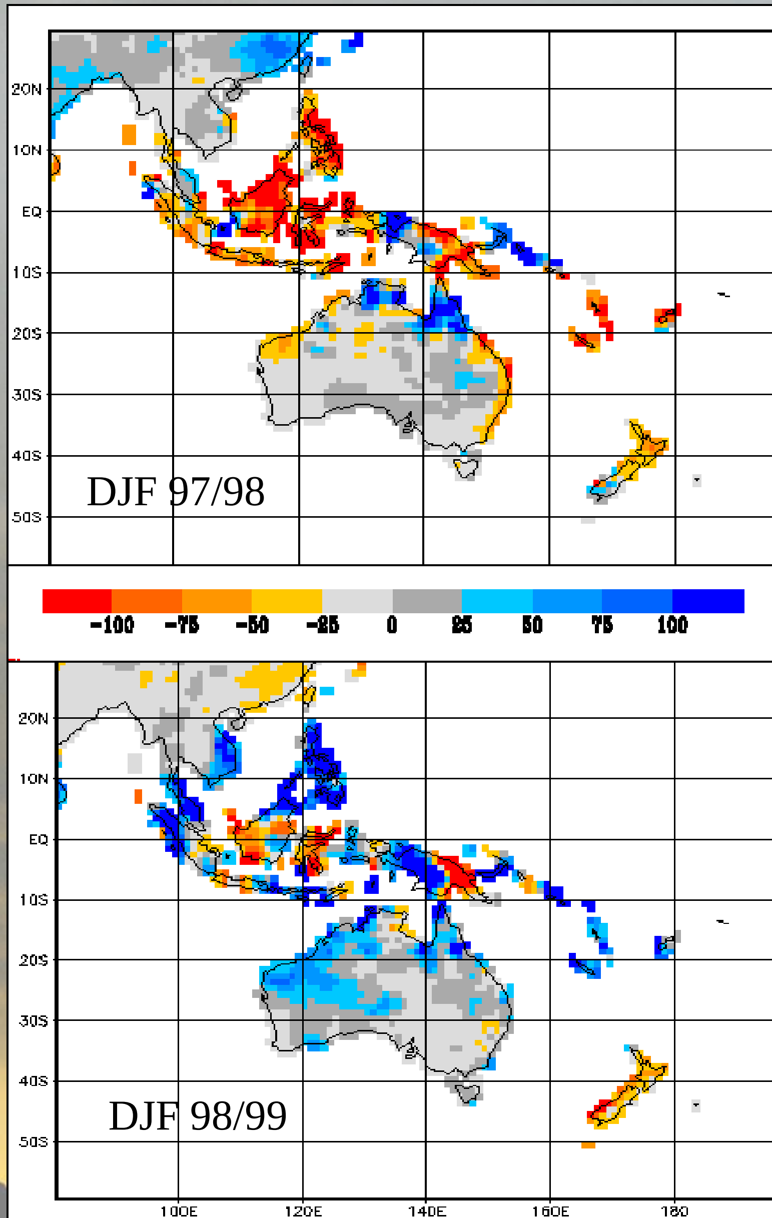
The El Nino-Southern Oscillation (ENSO)

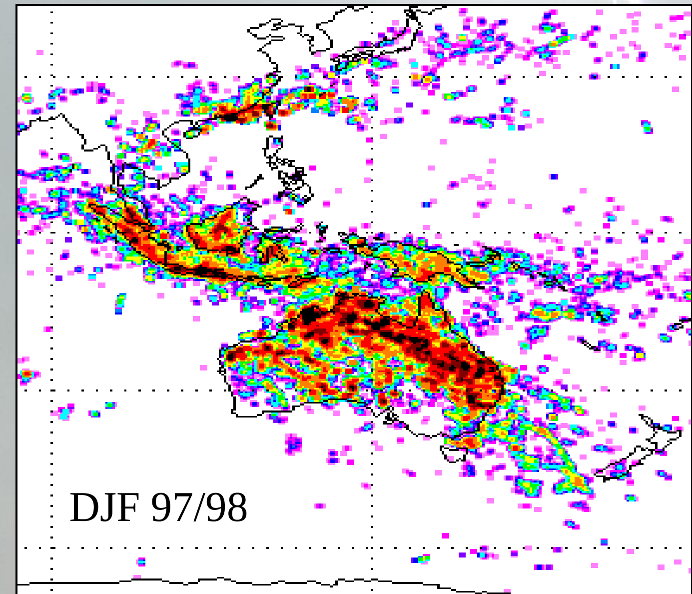
Precipitation Anomaly

OTD Lightning

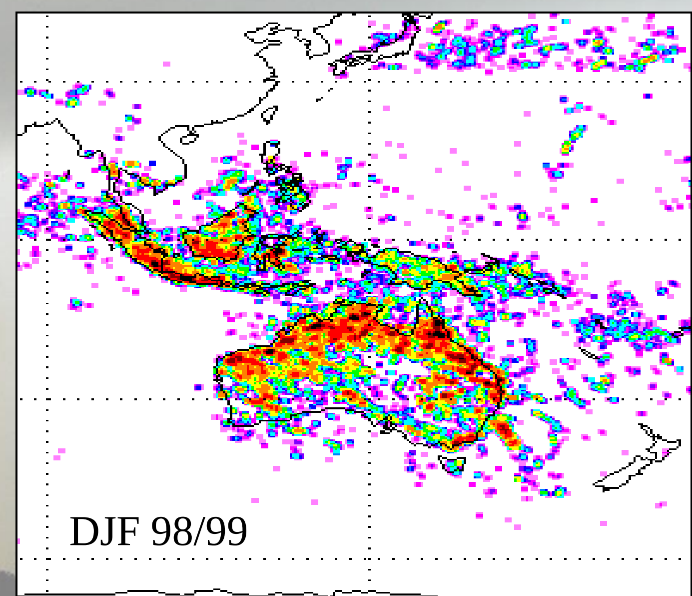
El Nino

La Nina



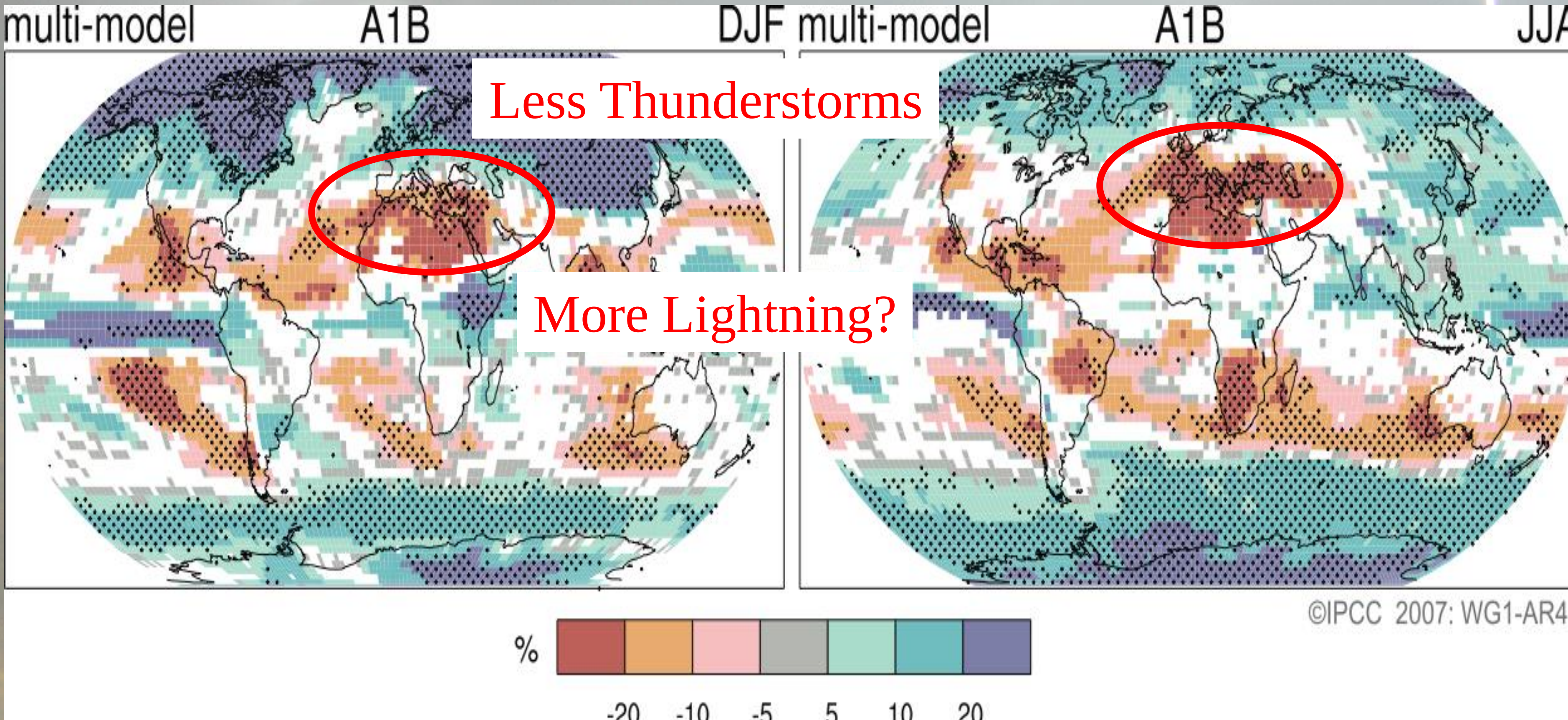


+57%



Hamid et al., (2001)

What is predicted for rainfall in the future?

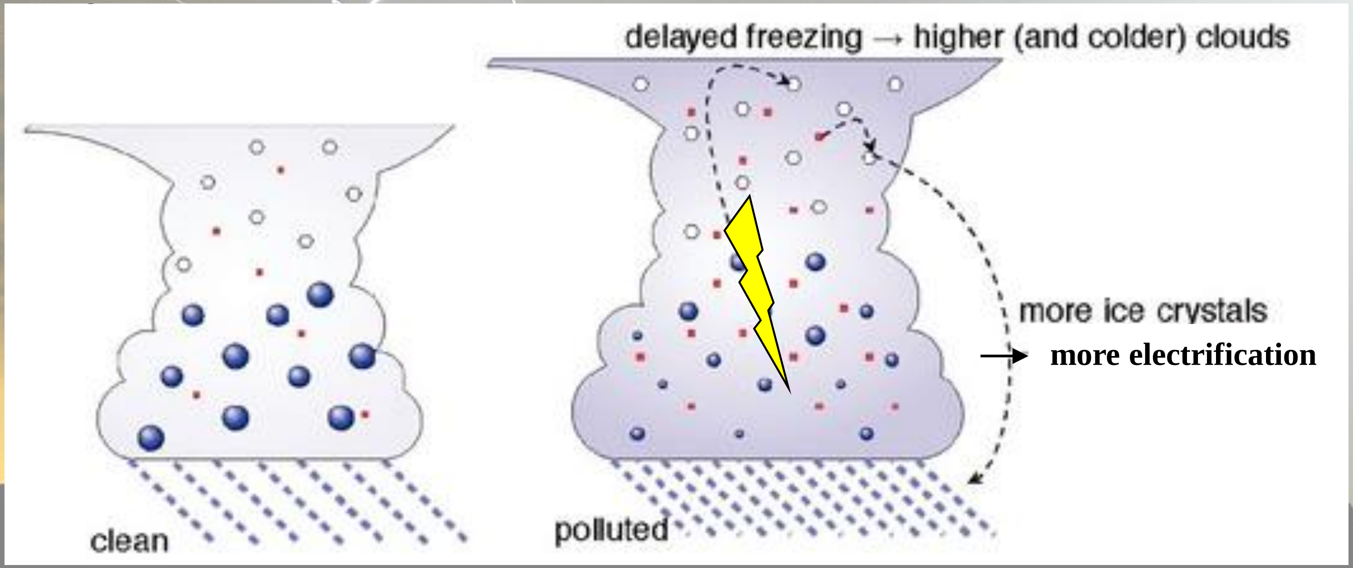


Changes in Precipitation (%) by 2099

Price (2008)

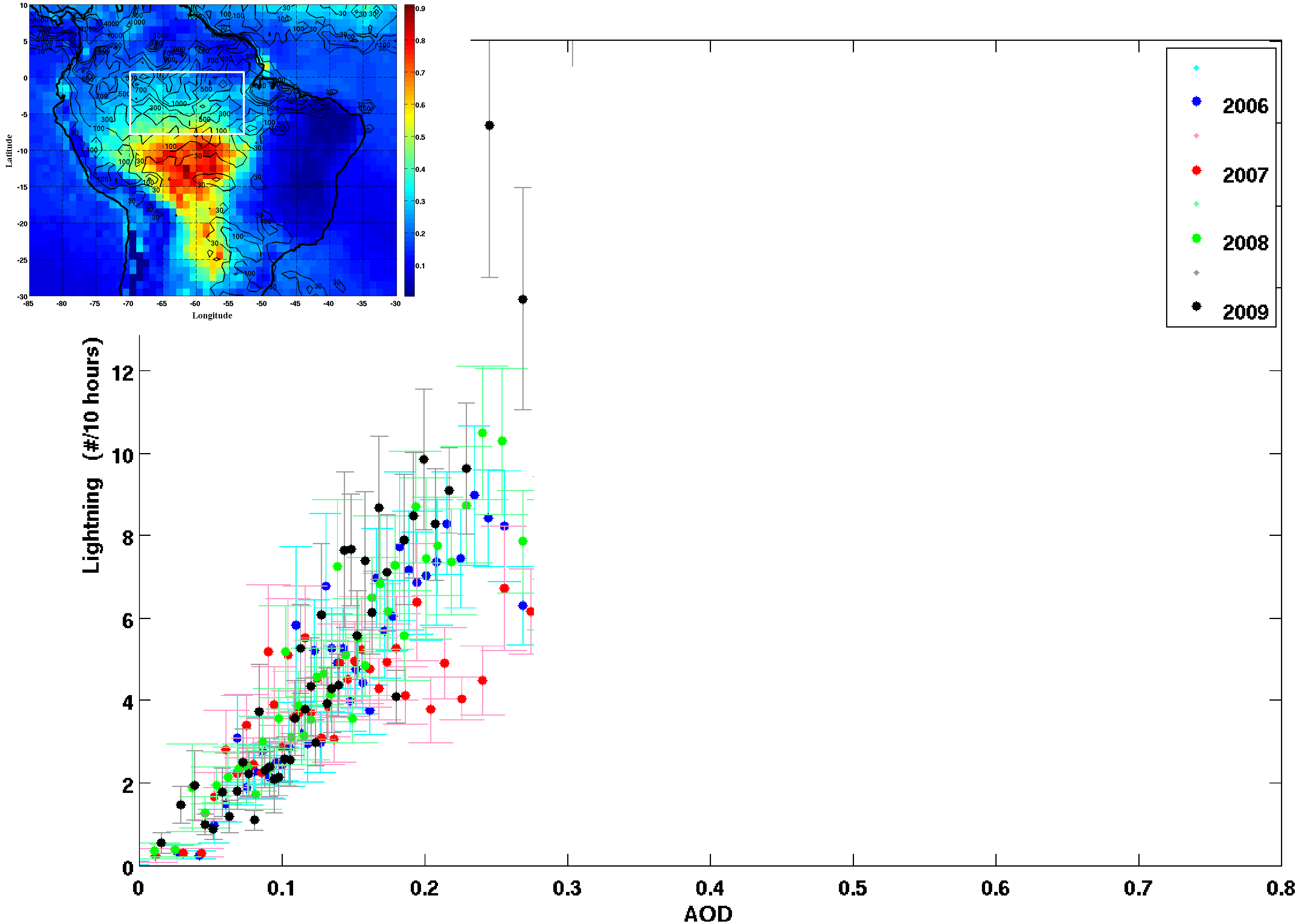
What about aerosols?

- ✓All cloud drops form on cloud condensation nuclei (CCN)
- ✓Ice crystals form on ice nuclei (IN)
- ✓Low levels of CCN support warm rain processes
- ✓High levels of CCN support cold rain processes (ice)
- ✓For cloud electrification we need supercooled drops, ice, and hail interacting in the mixed phase region of clouds (0 to -40C)

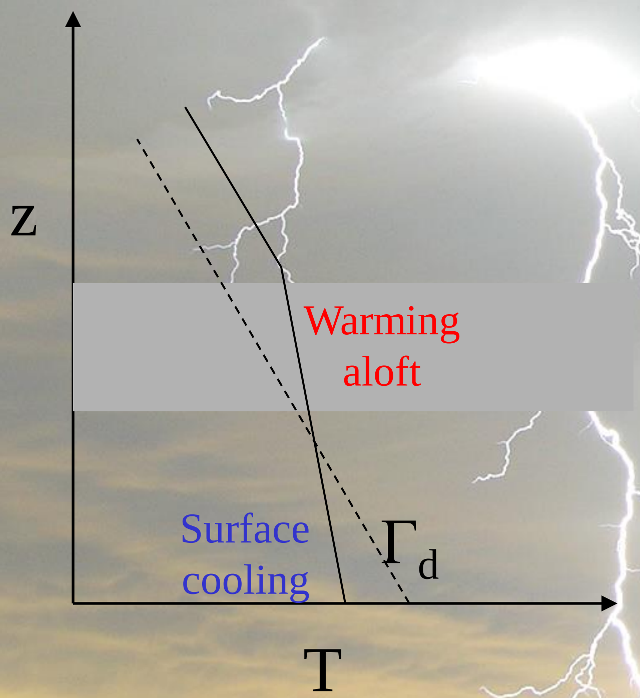


How does increasing aerosol loading impact lightning?

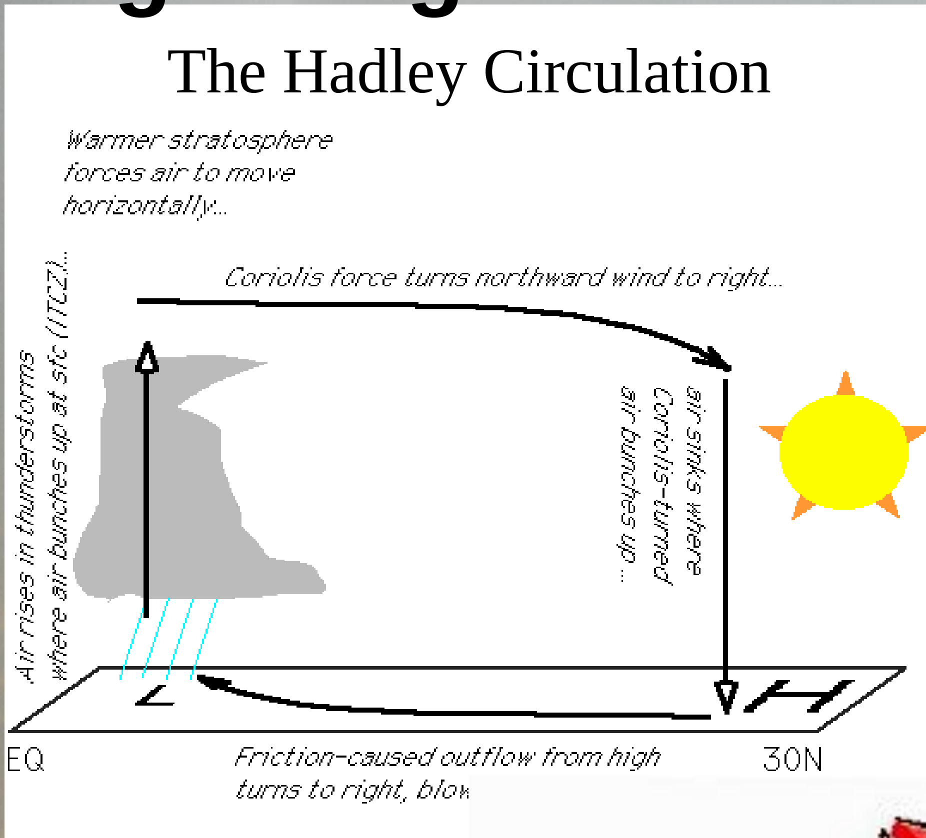
Altaratz et al (2010, GRL)

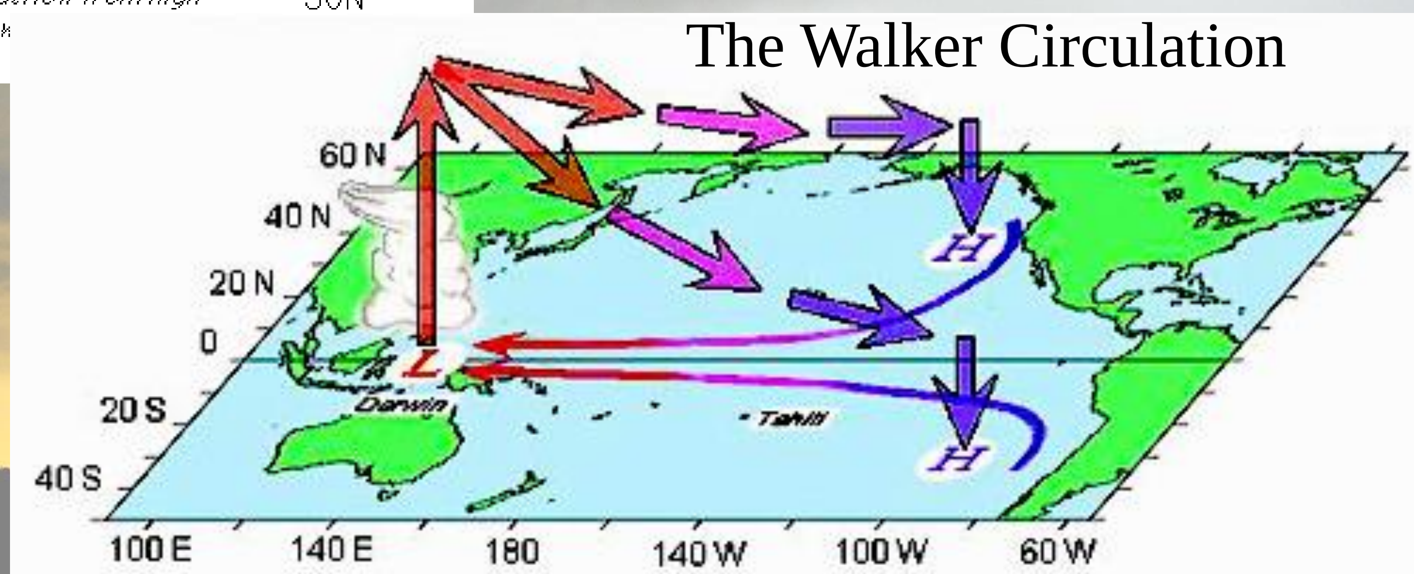


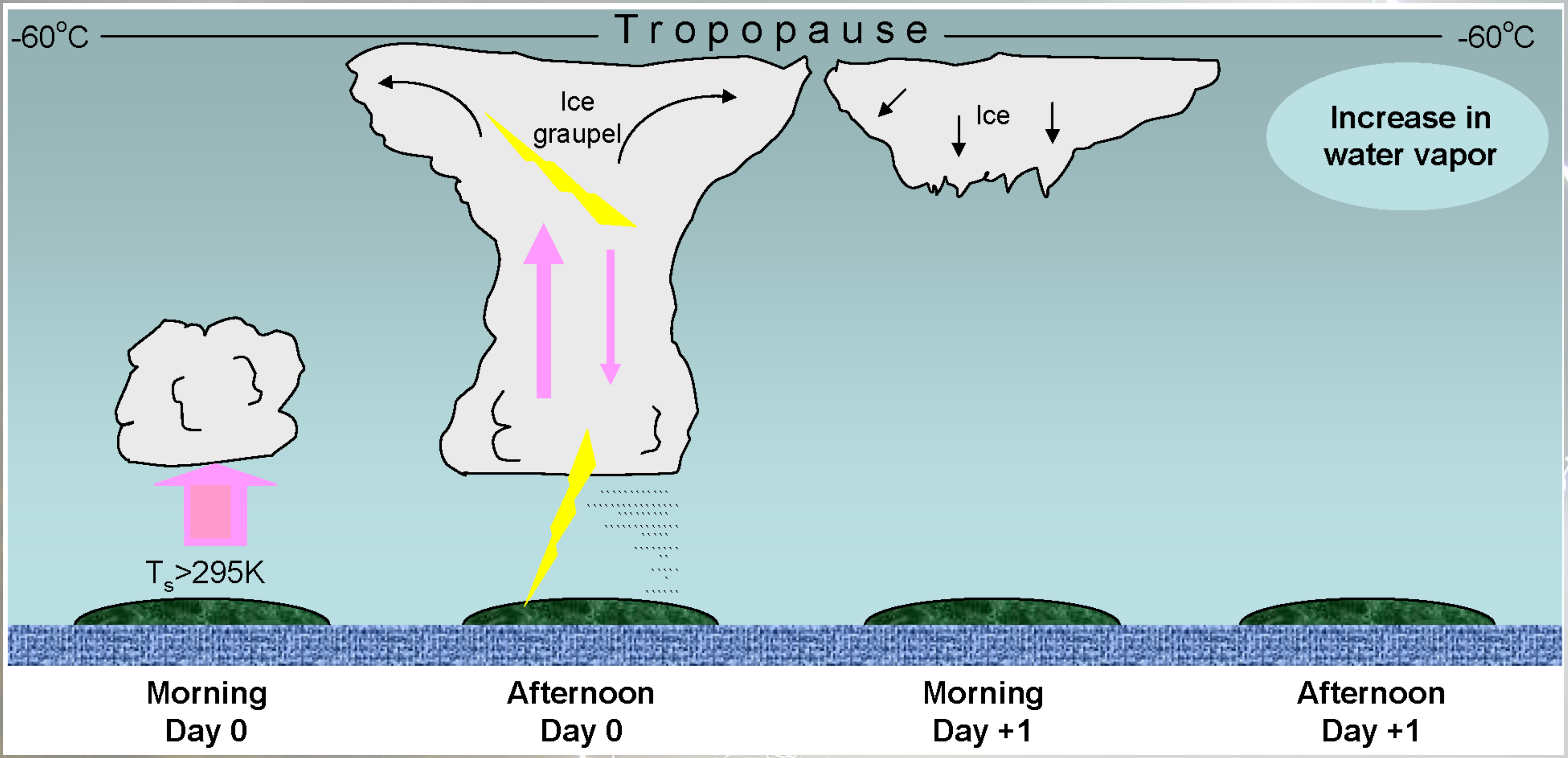
Too many aerosols stabilize the atmosphere



Lightning as a tool to study the Climate

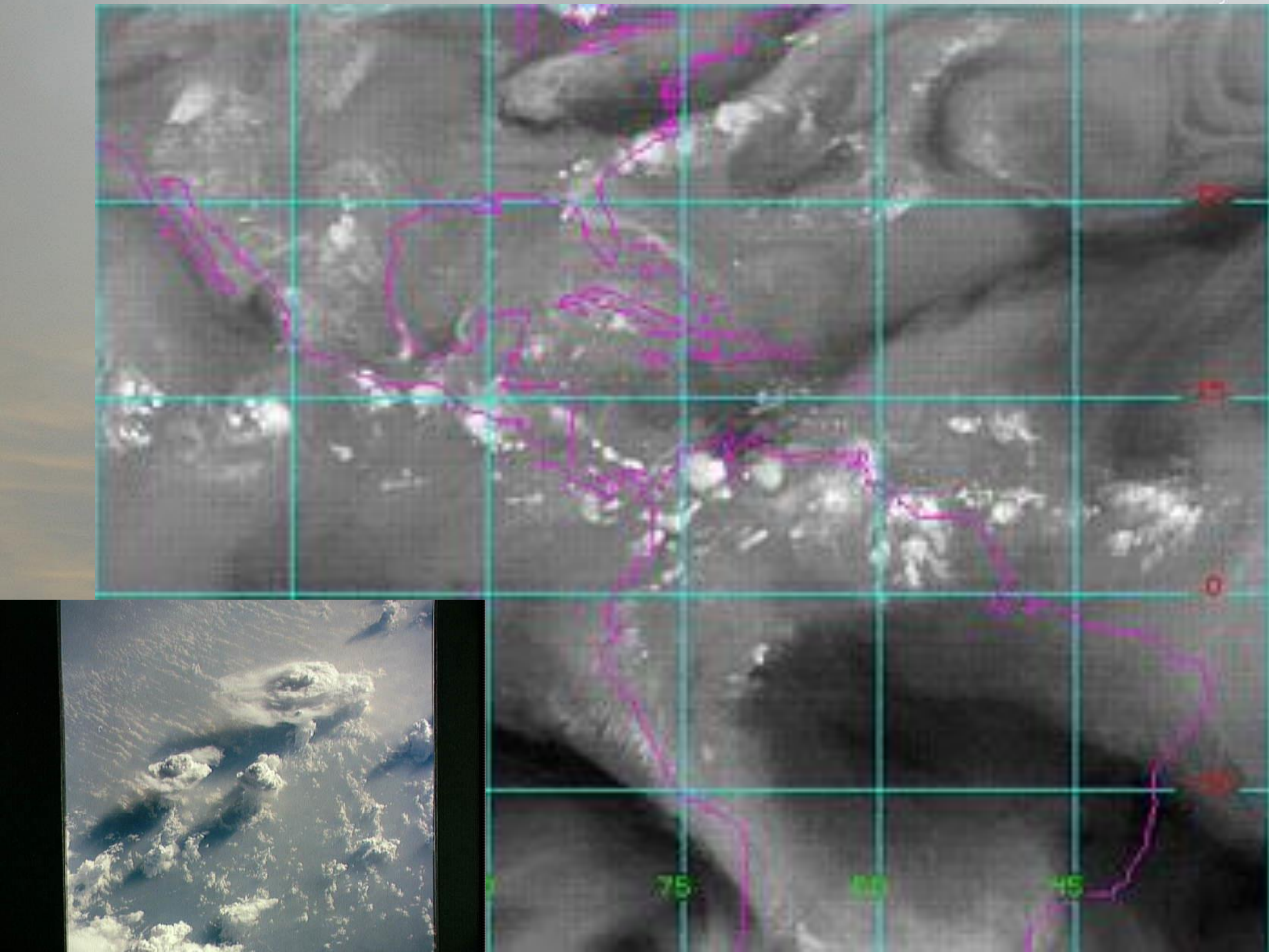






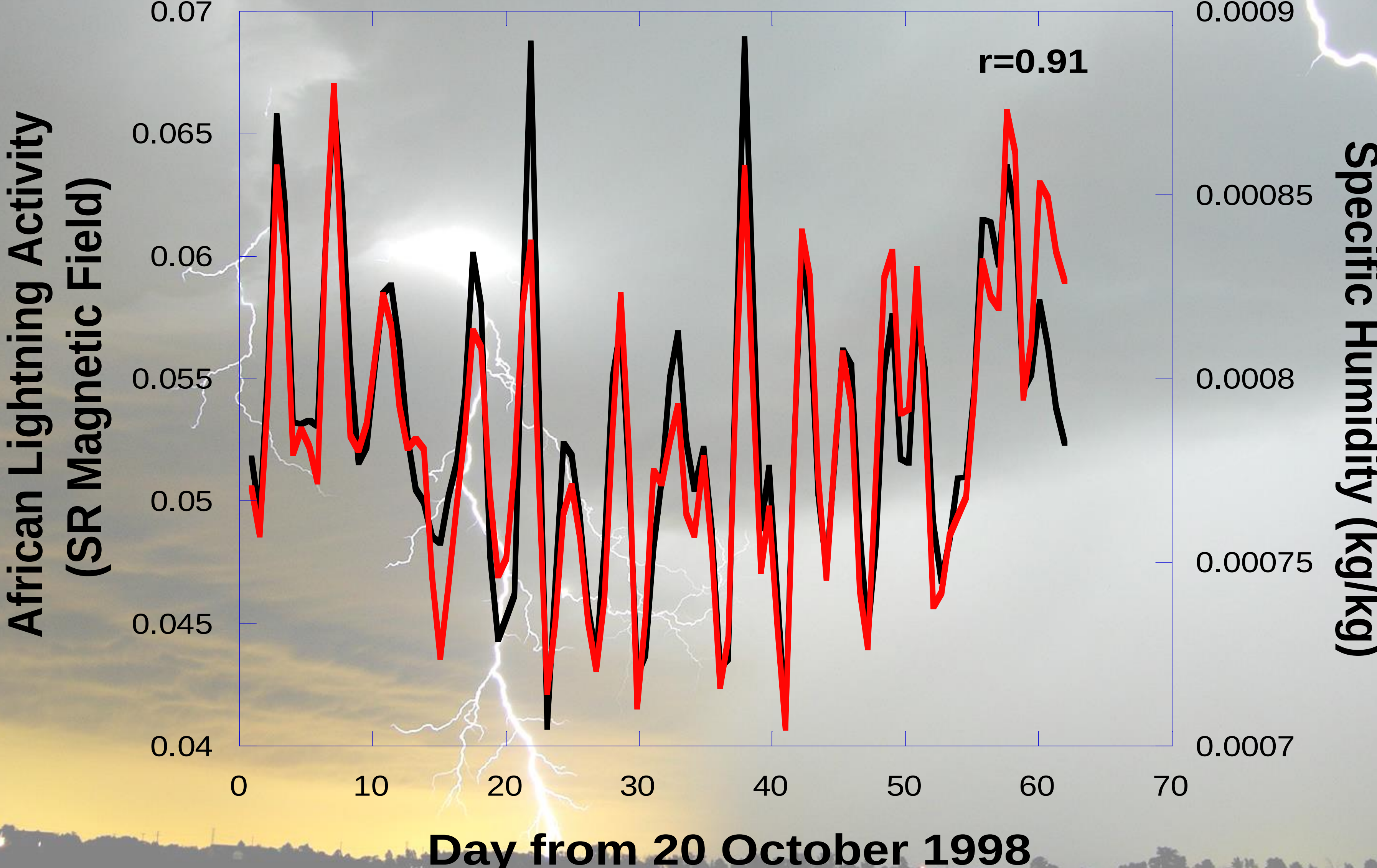
Lightning – UTWV (Price and Asfur, BAMS 2006)
Lightning – Clouds (Sato and Fukunishi, GRL 2005)
Lightning – Ice Crystal size (Sherwood et al., GRL 2006)
Lightning – Ice Water Path (Petersen et al., GRL 2005)

Upper Tropospheric Water Vapour



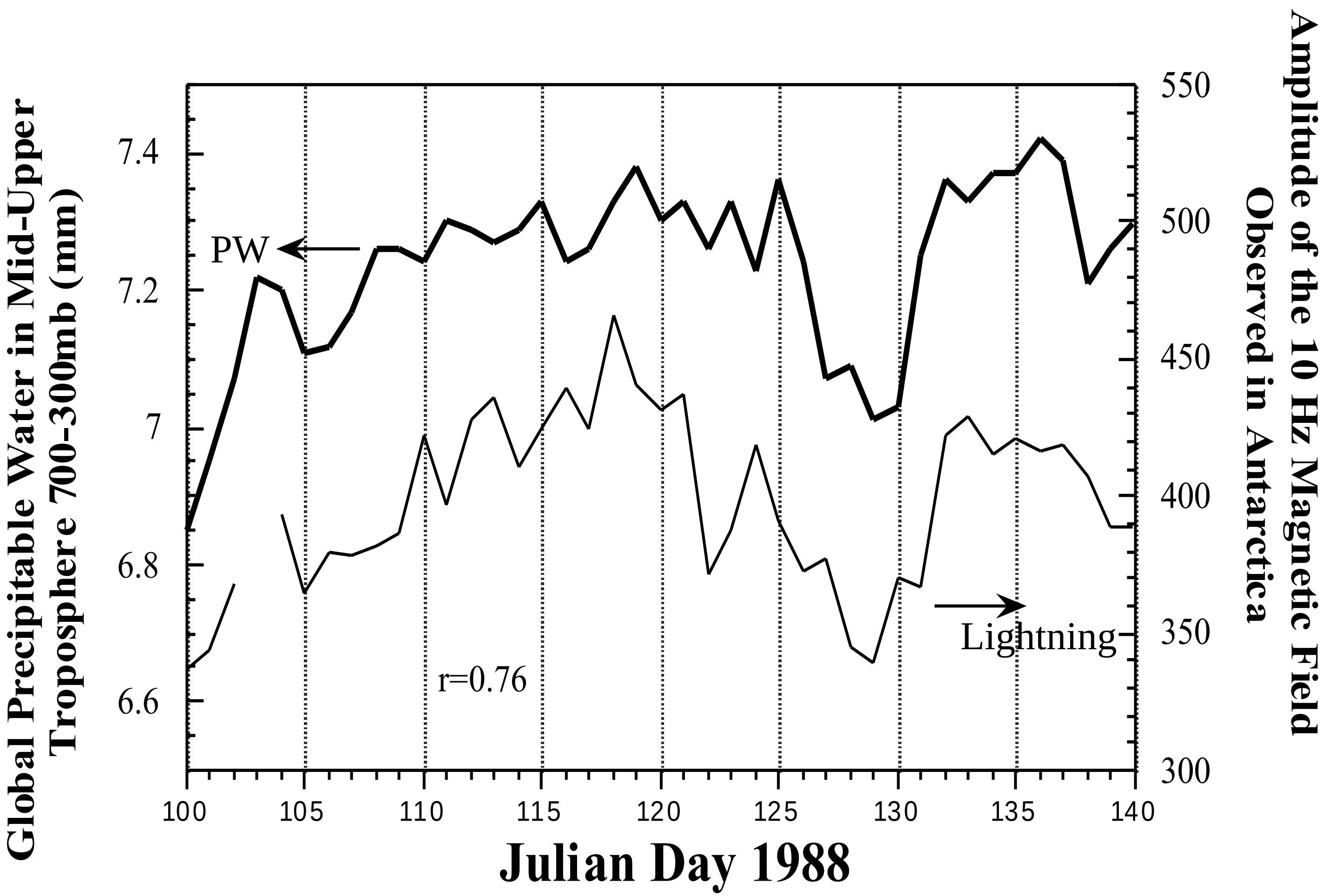
Lightning Activity vs. Specific Humidity (300mb) +24hours

26% SR change => 0.1 g/kg change



Price and Asfur (2006)

Global Precipitable Water in the Mid-upper Troposphere Together with Global ELF (lightning) activity



Summary and Conclusions