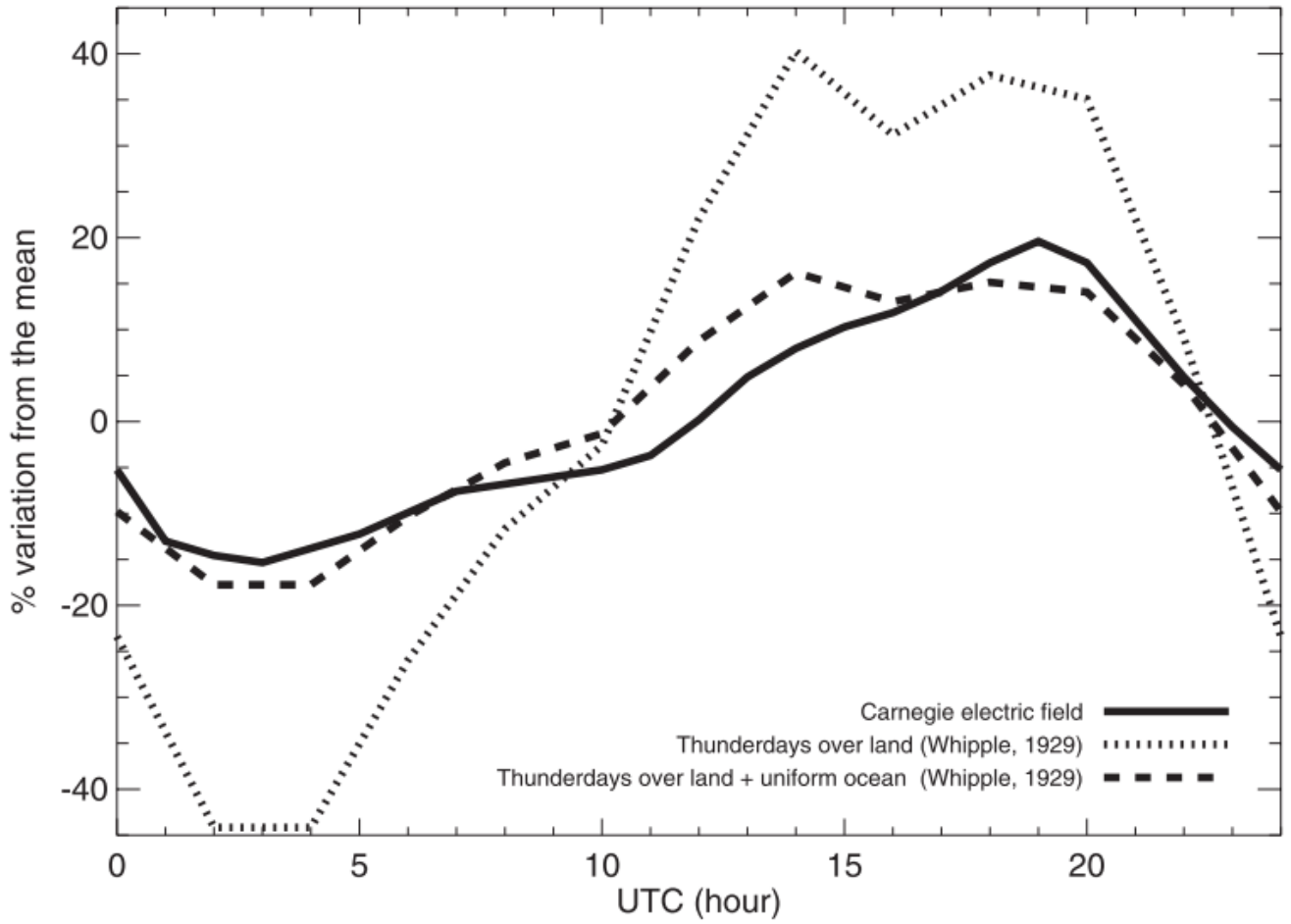
Contribution of Thunderstorms and Shower Clouds to the Global Electric Circuit

Review of “Diurnal Variations of Global Thunderstorms and Electrified Shower Clouds and Their Contribution to the Global Electrical Circuit” (Liu et. al. 2010)

Kyle Chudler
ATS 780

Thunder Days and Carnegie Curve



Whipple (1929)

- Two main discrepancies
  - Amplitude of thunder days is ~2 times that of Carnegie curve
  - Phases misaligned
    - Thunder Day curve max: Africa (14 – 15 UTC)
    - Carnegie curve max: South America (19 – 20 UTC)
- Possible explanations:
  - Ocean not accounted for
  - Non-lightning producing precipitation (electrified shower clouds)
- Try to use TRMM data to get a handle on both of these

Methods

- TRMM Precipitation Features
  - Groups contiguous raining pixels into one feature
  - Can get statistics of individual PF's (max echo height, precipitation volume, etc.)

- Divide PFs into thunderstorms, electrified shower clouds, and non-electrified
  - Thunderstorm: PF's with at least one lightning flash (LIS)
  - Electrified Shower Cloud: , T_{30dBZ} < -10 C over land and T_{30dBZ} < -17 C over ocean
  - Only look at PF's > 75 km^2
    - 75% of population, but <10% of rainfall and rain area

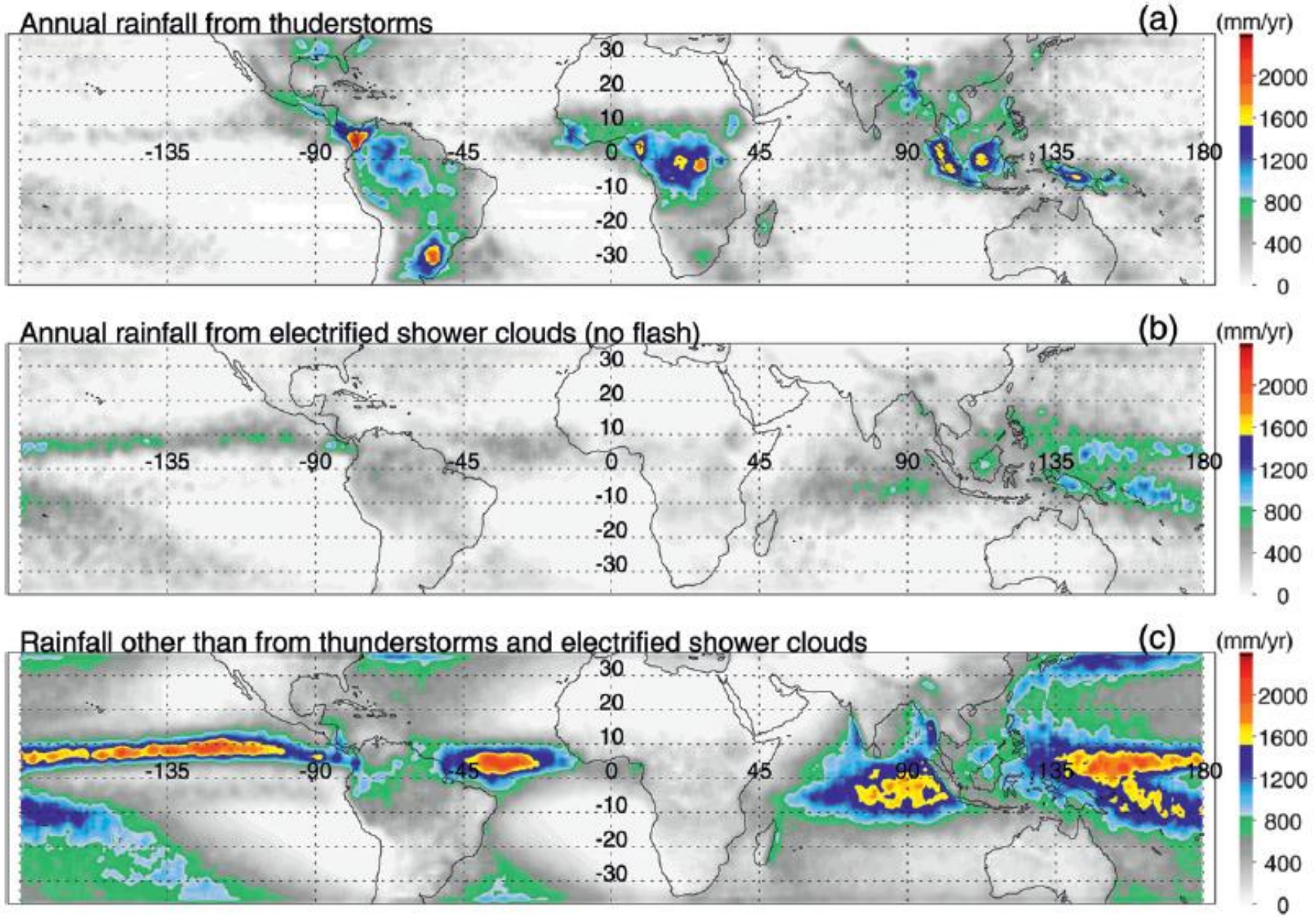
- Compare several diurnal cycles to Carnegie curve
  - Rainfall
    - Total, On/Off Land, Thunderstorm vs Electrified Shower
  - Total Lightning

- Contrast amplitude and phases of cycles

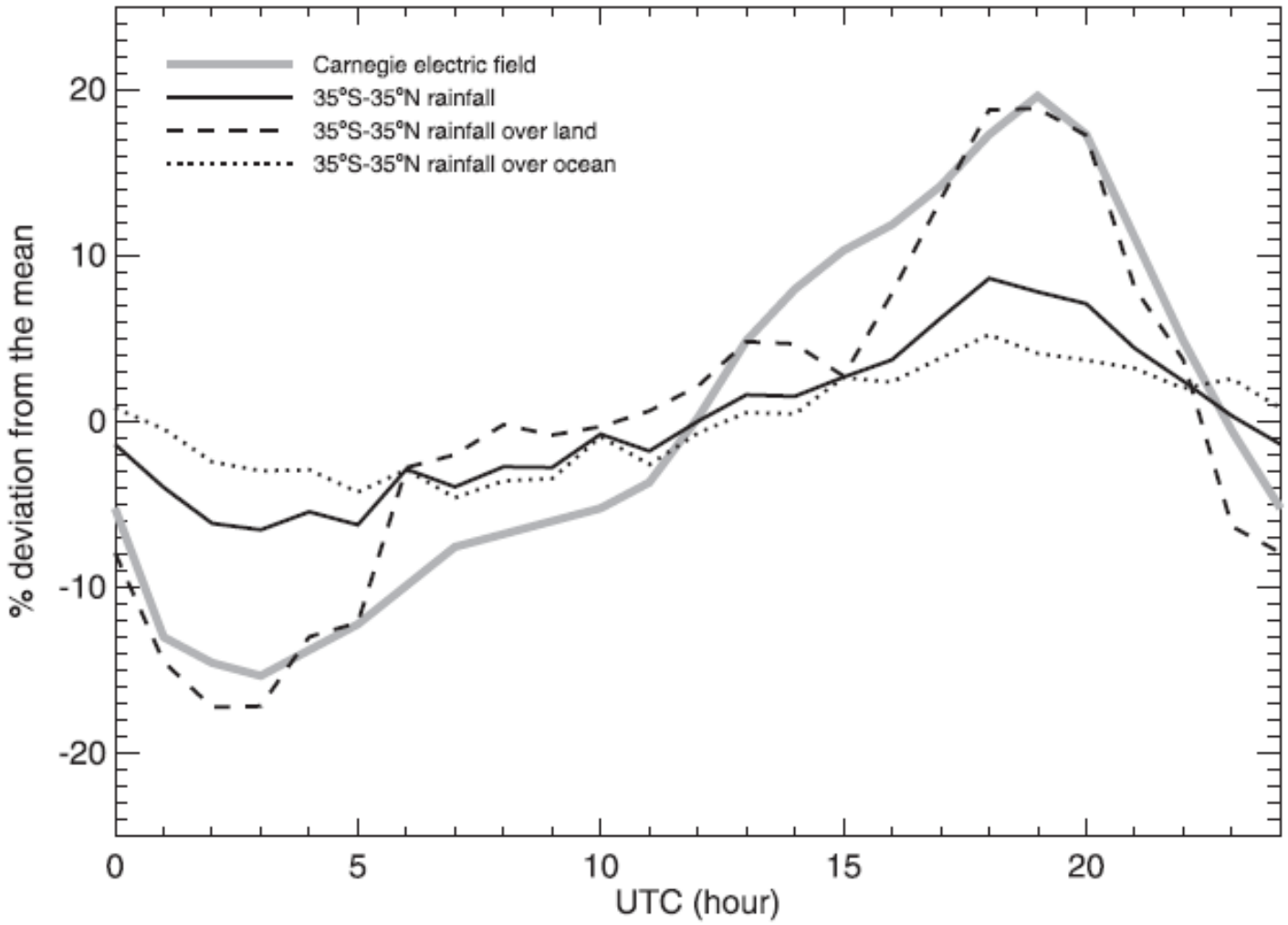
	35°S–35°N	Land	Ocean
Mean 35°S–35°N annual rainfall (mm/unit area/yr)	936	870	961
All PFs			
Population	100	19.13	80.87
Rain area	100	24.44	75.56
Rainfall	100	25.17	74.83
Thunderstorms (PFs with flashes)			
Population	0.61	0.45	0.16
Rain area	17.27	9.24	8.03
Rainfall	25.34	13.27	12.07
Electrified shower clouds $T_{30dBZ} < -10°C$ over land; $T_{30dBZ} < -17°C$ over ocean			
Population	0.53	0.34	0.19
Rain area	10.37	2.84	7.53
Rainfall	14.34	3.46	10.88
Nonelectrified PFs >75 km^2			
Population	24.47	4.23	20.23
Rain area	63.68	10.85	52.84
Rainfall	55.40	7.76	47.64
PFs < 75 km^2			
Population	74.39	14.11	60.28
Rain area	8.68	1.51	7.16
Rainfall	4.92	0.68	4.24

- More PFs over Ocean (81%) than land (19%)
- Thunderstorms
  - ~1/200 PFs
  - 25% of rainfall
- Electrified Shower Clouds
  - ~1/200 PFs
  - 15% of rainfall

Non-electrified Rainfall Dominates Ocean

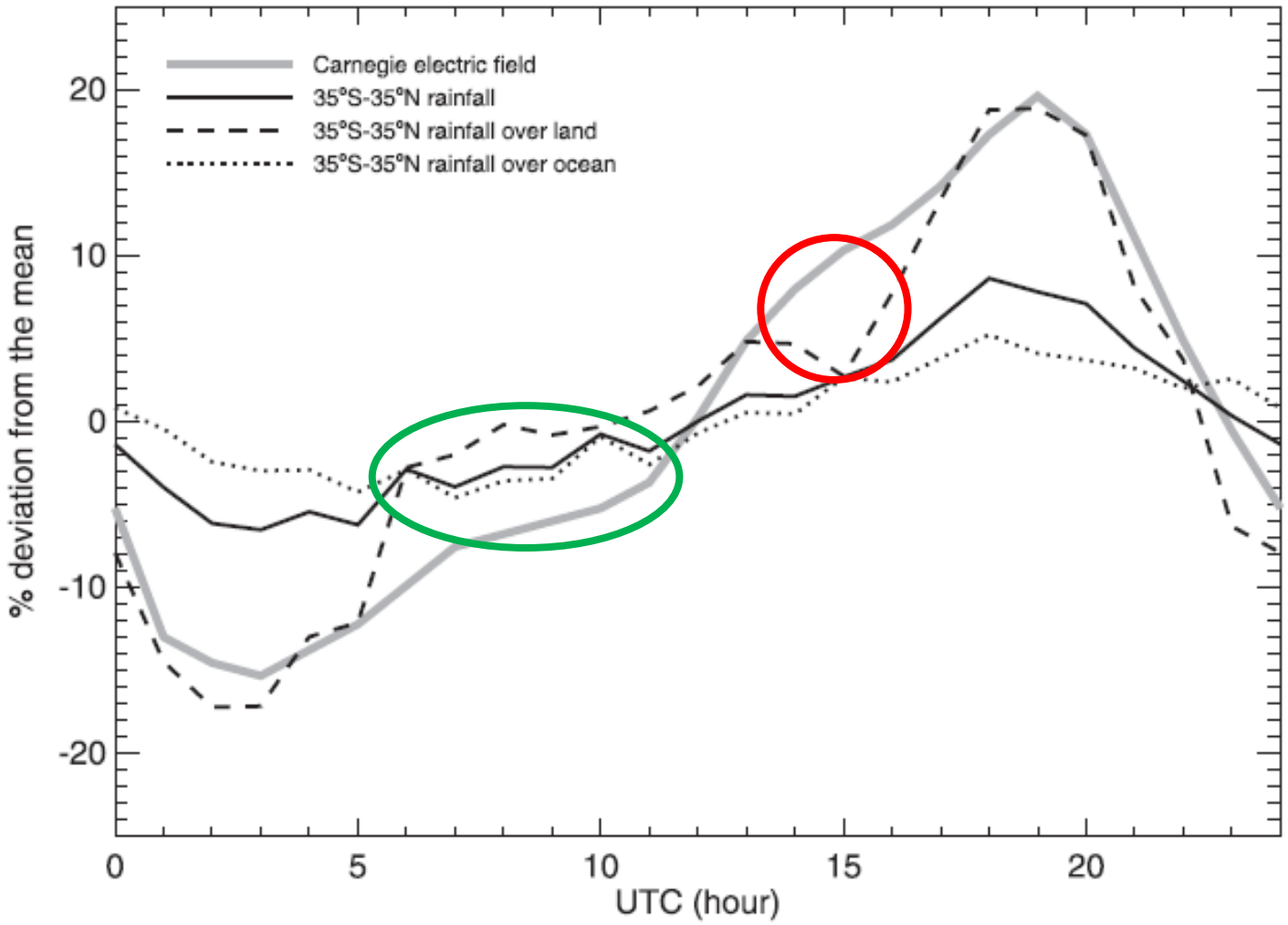


Diurnal Rainfall vs. Carnegie Curve



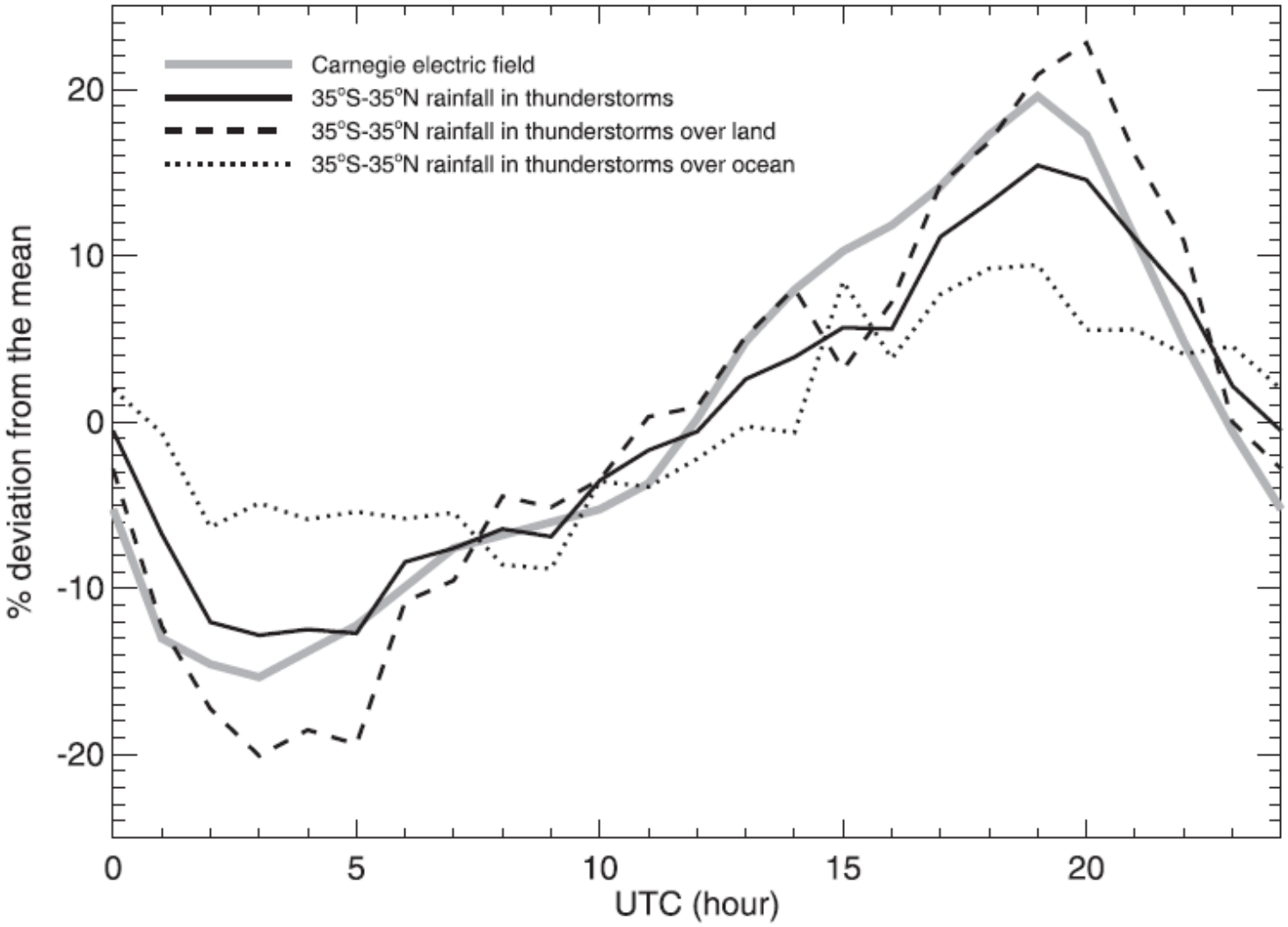
- Total rainfall (black line) has similar phase, smaller amplitude
  - Includes ocean, which has weaker diurnal signal
- Best match is land rainfall
  - 60% of land rainfall is from electrified storms/showers
  - Best amplitude match of all cycles

Diurnal Rainfall vs. Carnegie Curve



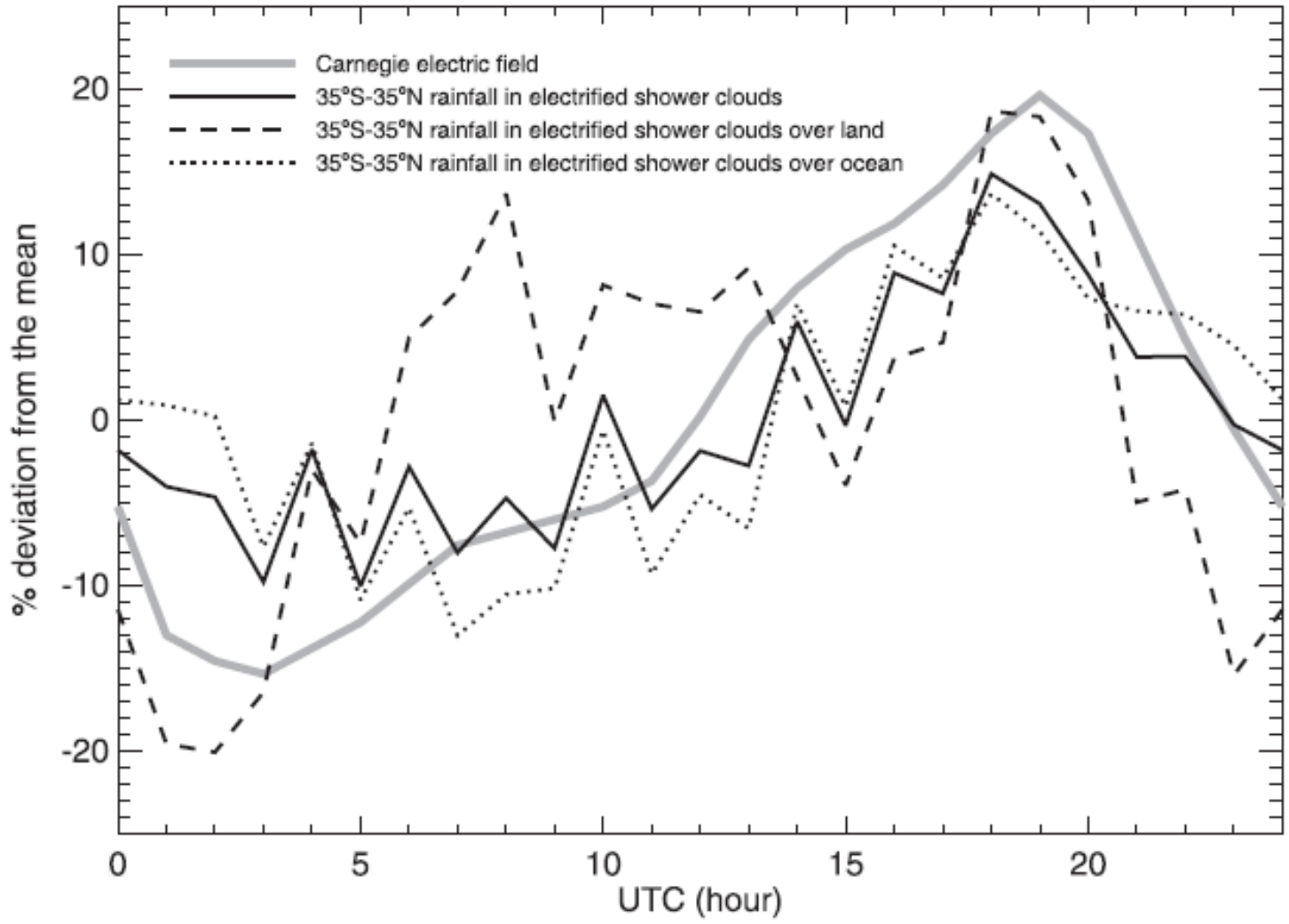
- Positive amplitude departure in most maritime (Maritime Continent) region and negative departure in most continental (Africa) region
- Suggests electrical contribution from rainfall inaccurately represented in these regions

Thunderstorm Rainfall vs Carnegie Curve



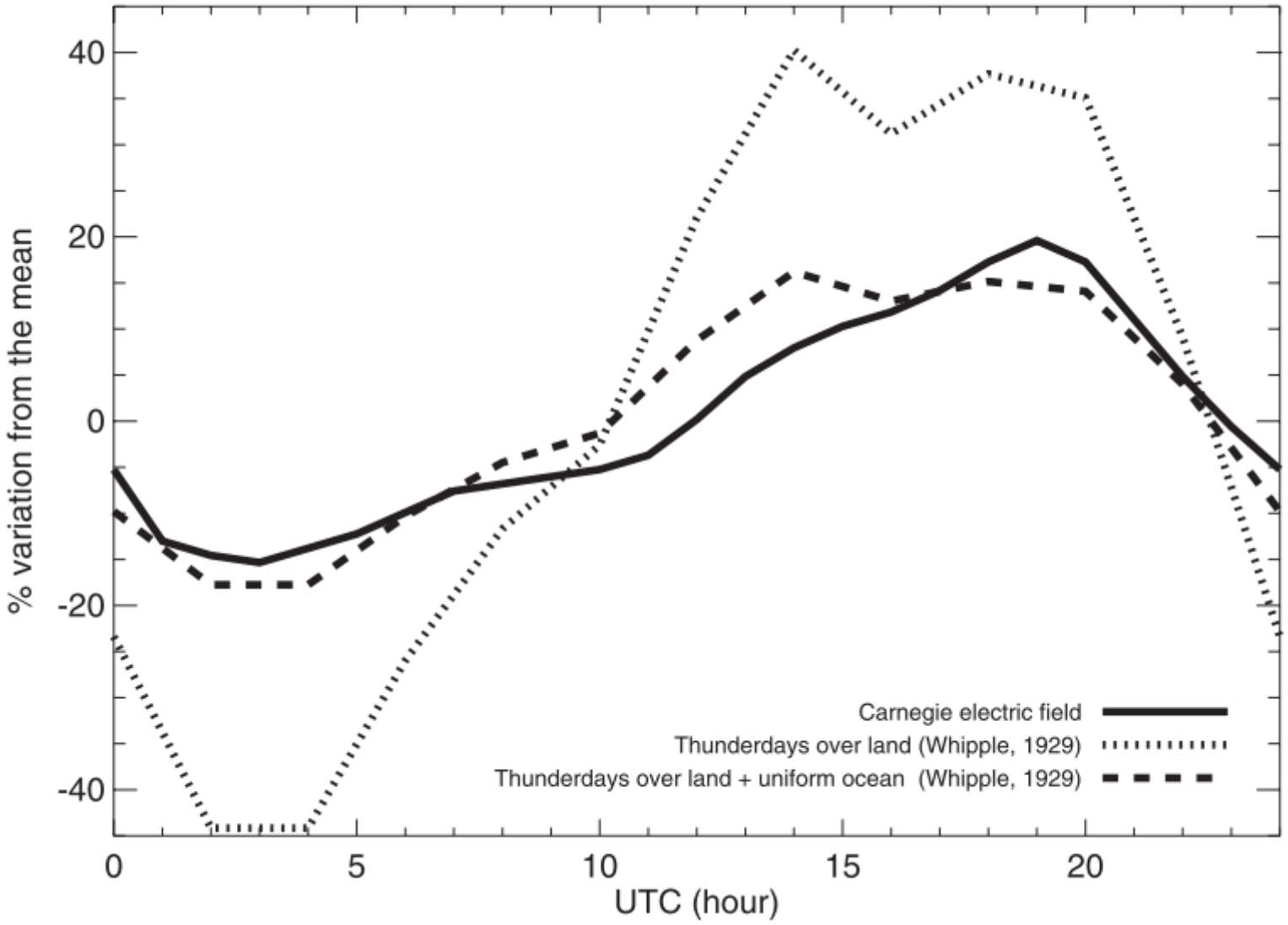
- Best phase match to Carnegie curve
- Over-land thunderstorms overshoot amplitude at peaks
- Rainfall from electrified shower clouds could dilute this
  - No way of weighting shower cloud contribution relative to thunderstorms

Electrified Shower Rainfall vs Carnegie Curve

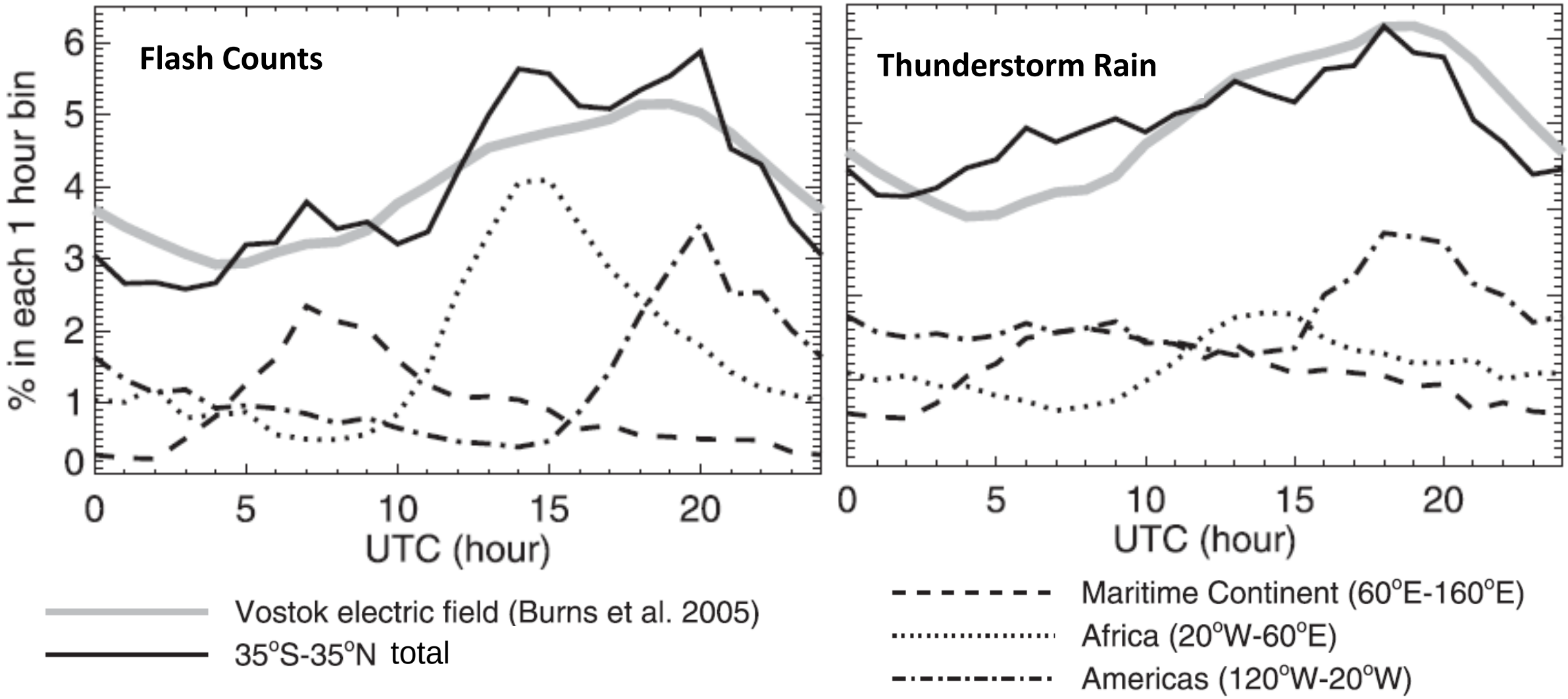


- Not as smooth as thunderstorm curves
  - Sampling noise should be the same
- Two effects flatten diurnal cycle
  - Predominance of MC (5-9 UTC)
  - Substantial population over ocean
- Serves to dampen contribution from thunderclouds and lightning alone

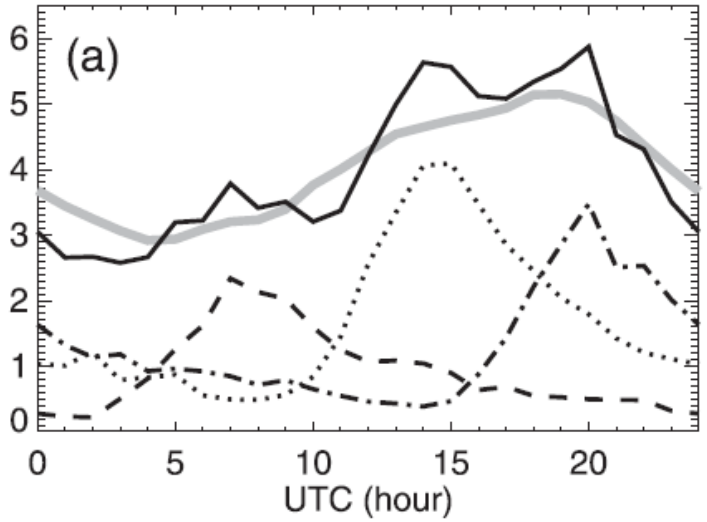
Recall: Maximum in Carnegie curve out of phase with thunder days



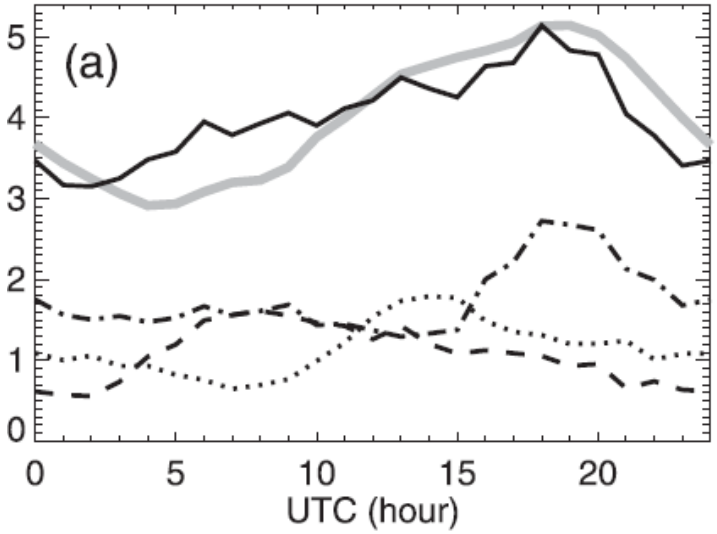
Africa dominates in lightning, but Americas dominate in rainfall



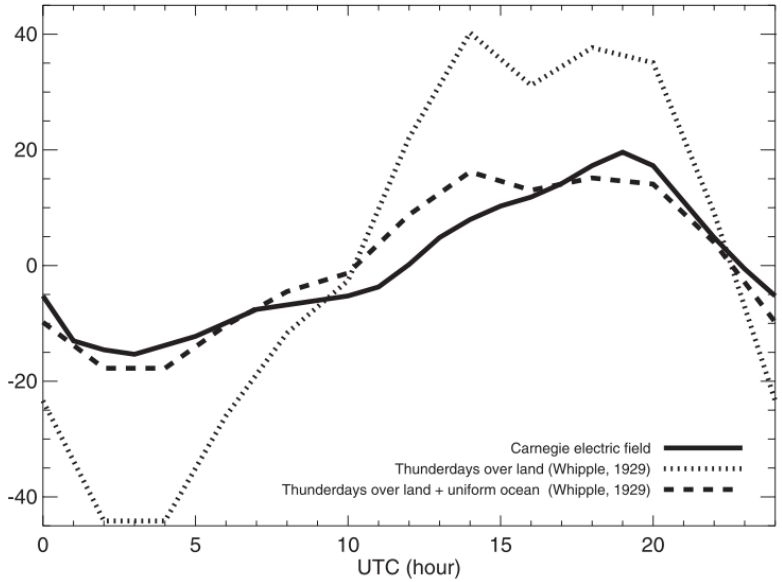
Flash Counts



Thunderstorm Rain



Thunder Days



- Original 1929 study looked at thunder days, which is analogous to lightning flashes
- Carnegie curve max coincides with rainfall maximum in Americas, rather than lightning max in Africa
- Suggests lightning is not the main source for global circuit
- Reinforces importance of electrified shower clouds

Classification method has some caveats

- Unexpectedly, roughly the same number of thunderstorms and electrified shower clouds were found.
  - “In a hierarchical global population of convective clouds, one expects more cumulus clouds than warm rain shower clouds, more warm rain shower clouds than electrified shower clouds, more electrified shower clouds, than thunderclouds, and more thunderclouds than giant supercells with strongly overshooting tops”
- Any PF with a single lightning flash is classified as a thunderstorm
  - May contain smaller embedded cells that are electrified shower clouds
- Method developed to examine substructure of PFs
- Initial examination of 90 PFs show embedded shower clouds outnumber embedded thunderstorms by 2-to-4 times over

Classification method has some caveats

- Rough approximation:
  - -Electrified shower clouds outnumber thunderstorms 3 to 1
  - -Cloud top conduction of electrified shower clouds is 25% that of a thunderstorm
  - →Integrated global current of electrified shower clouds would be 75% that of thunderstorms
- Regardless of exact numbers, appears as if electrified shower clouds play some important role in maintaining the global electric circuit

Conclusions

- Diurnal variation in rainfall matches that of the Carnegie curve
  - Supports original hypothesis by Wilson (1903) that negative charge carried down by precipitation maintains circuit
- Ocean precipitation, which typically has a weaker diurnal variation, serves to dampen the overall global cycle
  - Resolves the amplitude discrepancy between thunder days and Carnegie curve
- Lightning maximum over Africa preludes the rainfall maximum over Americas, which matches the Carnegie curve better
  - Resolves the phase discrepancy between thunder days and Carnegie curve
- Better method of determining the electrical current contribution of individual storms would greatly increase the value of using radar to do studies such as this