Daily Lightning Characterization at the Chimney Scale using Background and Transient Schumann Resonance Methods

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04/29/2026

Content

1.Background—Daily characterization

Afternoon thunderstorms and mesoscale convective systems are the primary sources of lightning, modulating its diurnal variation.

Lightning activity peaks:
LT14-18h over continent;
at night and in the early morning over ocean;
shift to nighttime in mid-latitude regions;
propagation feature towards either the sea or land in coastal areas:.

Local lightning activity shows significant variablity due to pronounced differences in underlying surface conditions, convective organization, and large-scale environmental background.

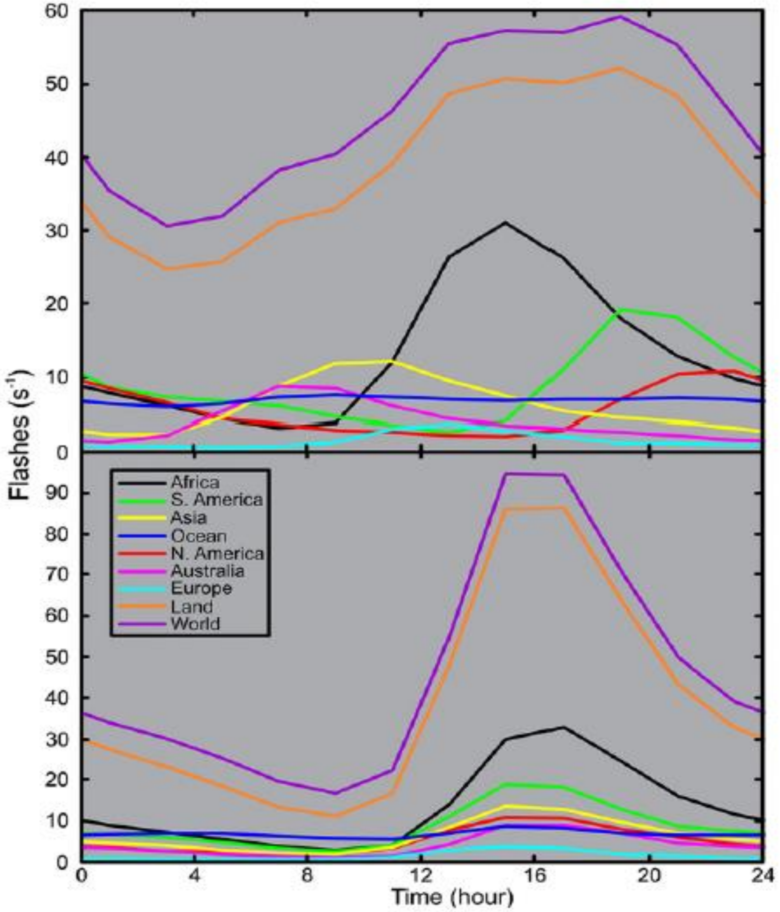
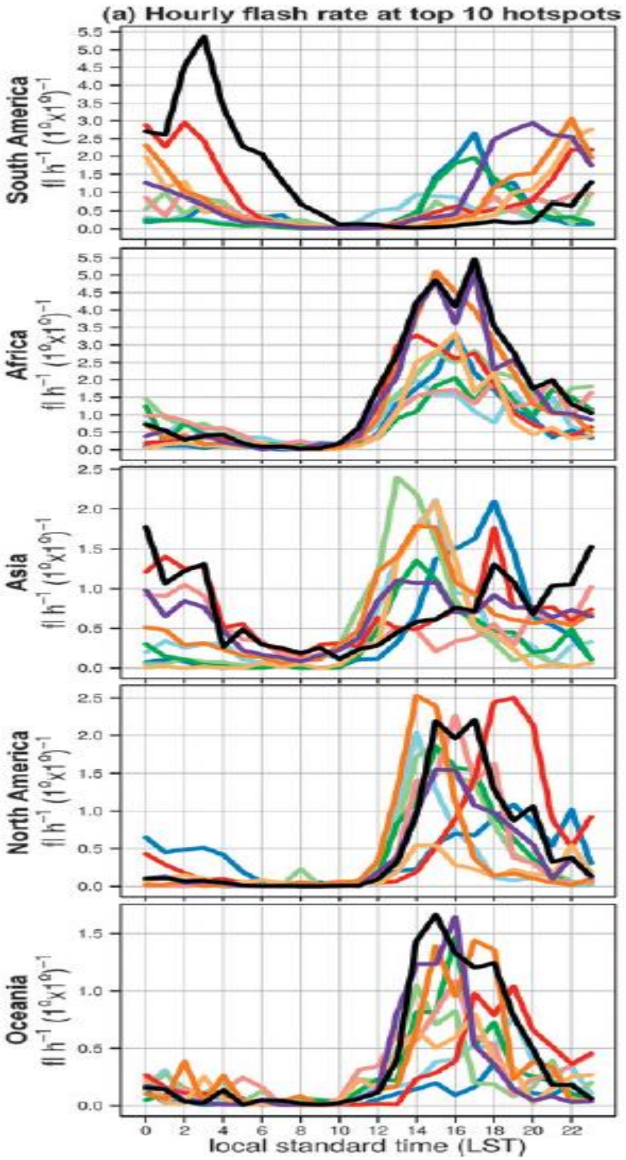


Fig. 3. Annual diurnal flash rate derived from the combined OTD/LIS data in UTC (top plot) and local time (bottom plot).

(Blakeslee et al., 2014)



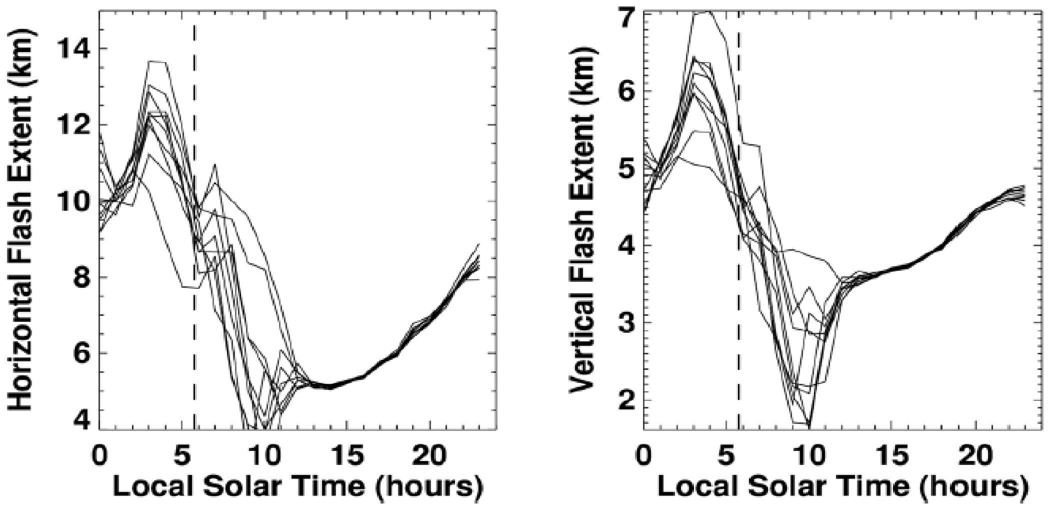
(Albrecht., 2016)

Why study on chimney scale?

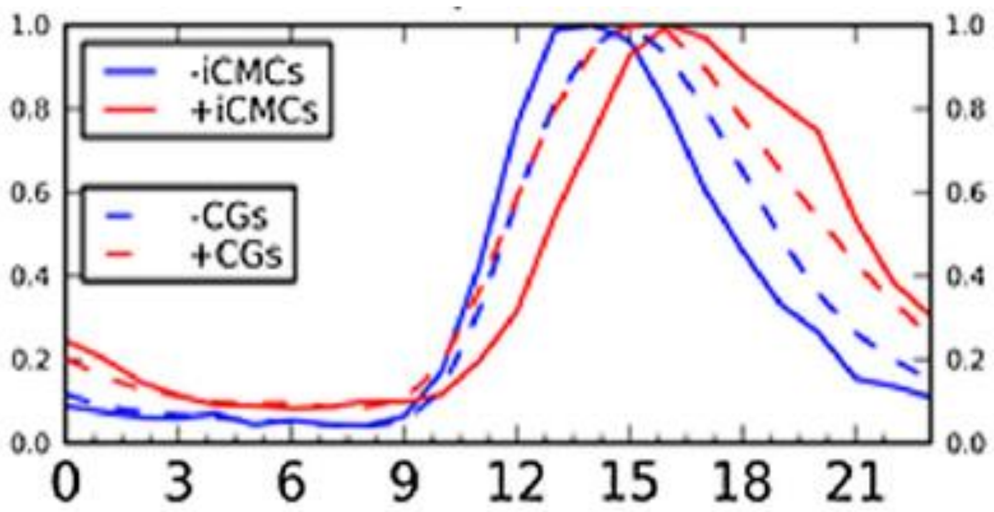
1.Background—Daily characterization

The diurnal variation of lightning activity also involves changes in flash extent and phase differences among different lightning types.

- Lightning flash extent tends to be larger at night (Chronis et al., 2015).
- Large negative iCMCs peak earlier in time than large positive iCMCs, which may be attributed to the growth of large stratiform charge reservoirs following initial convective (Beavis et al., 2014).



Chronis et al.,(2015)

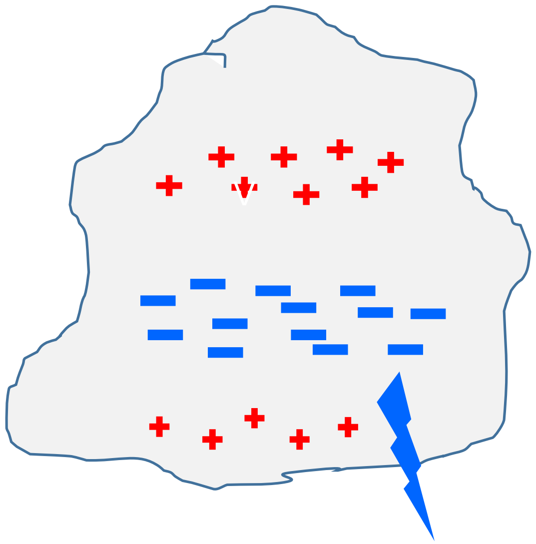


(Beavis et al., 2014)

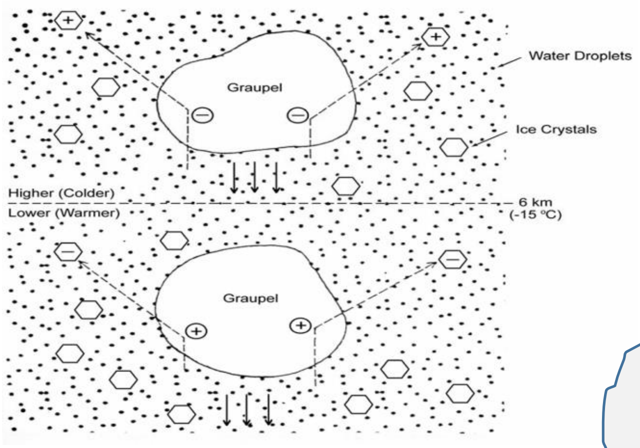
Are these diurnal characteristics still robust at the chimney scale?

1.Background—Daily characterization-mechanism

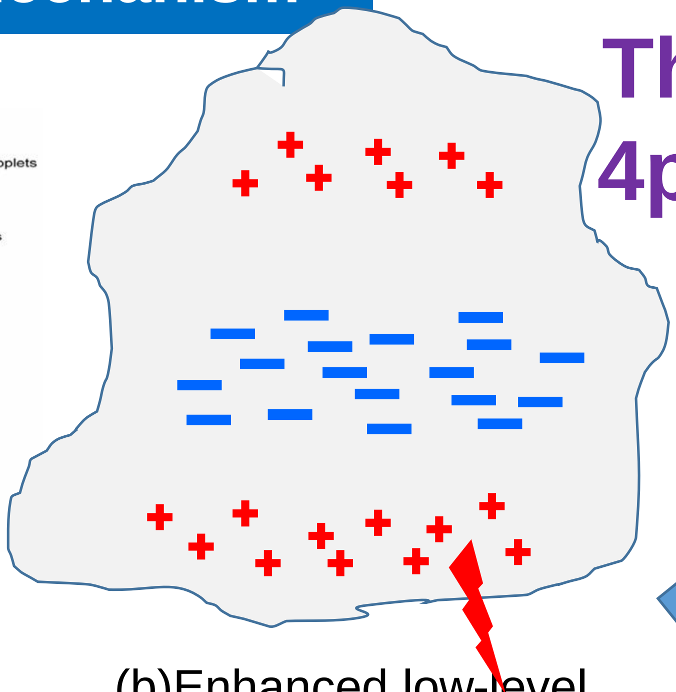
Thunderstorm 4pm aftermath



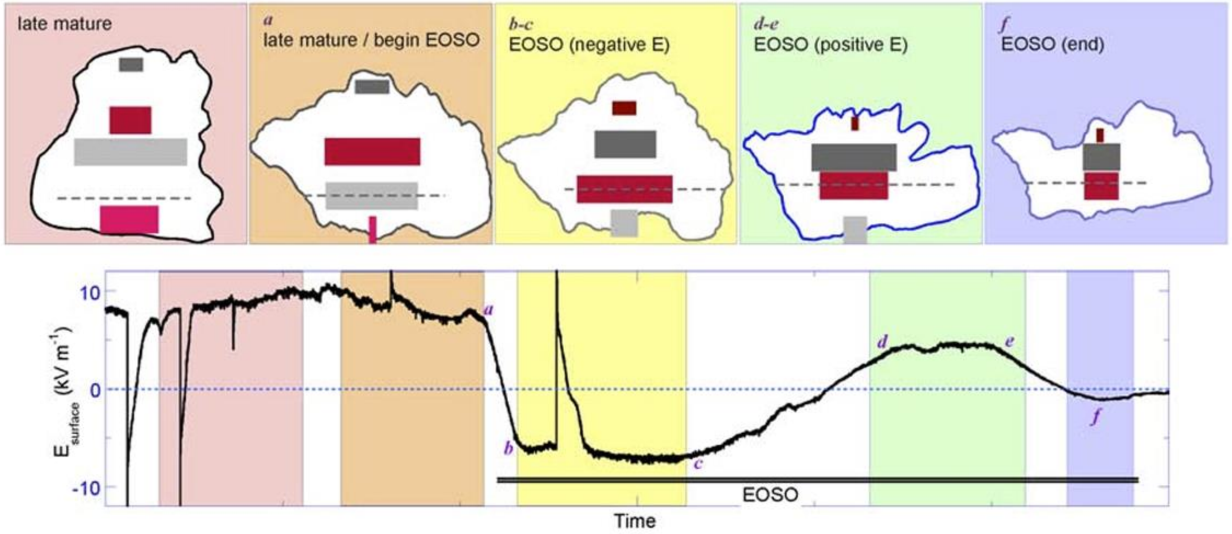
(a)Electric tripole



Reversed non-inductive charging



(b)Enhanced low-level positive charge region

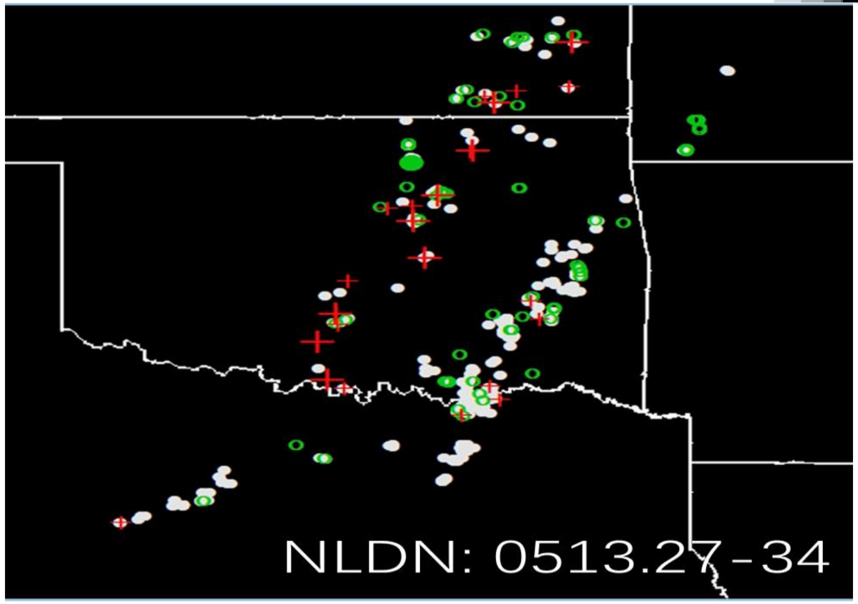


(c) Conceptual representation of the end-of-storm oscillation (EOSO, from Marshal et al., 2009)

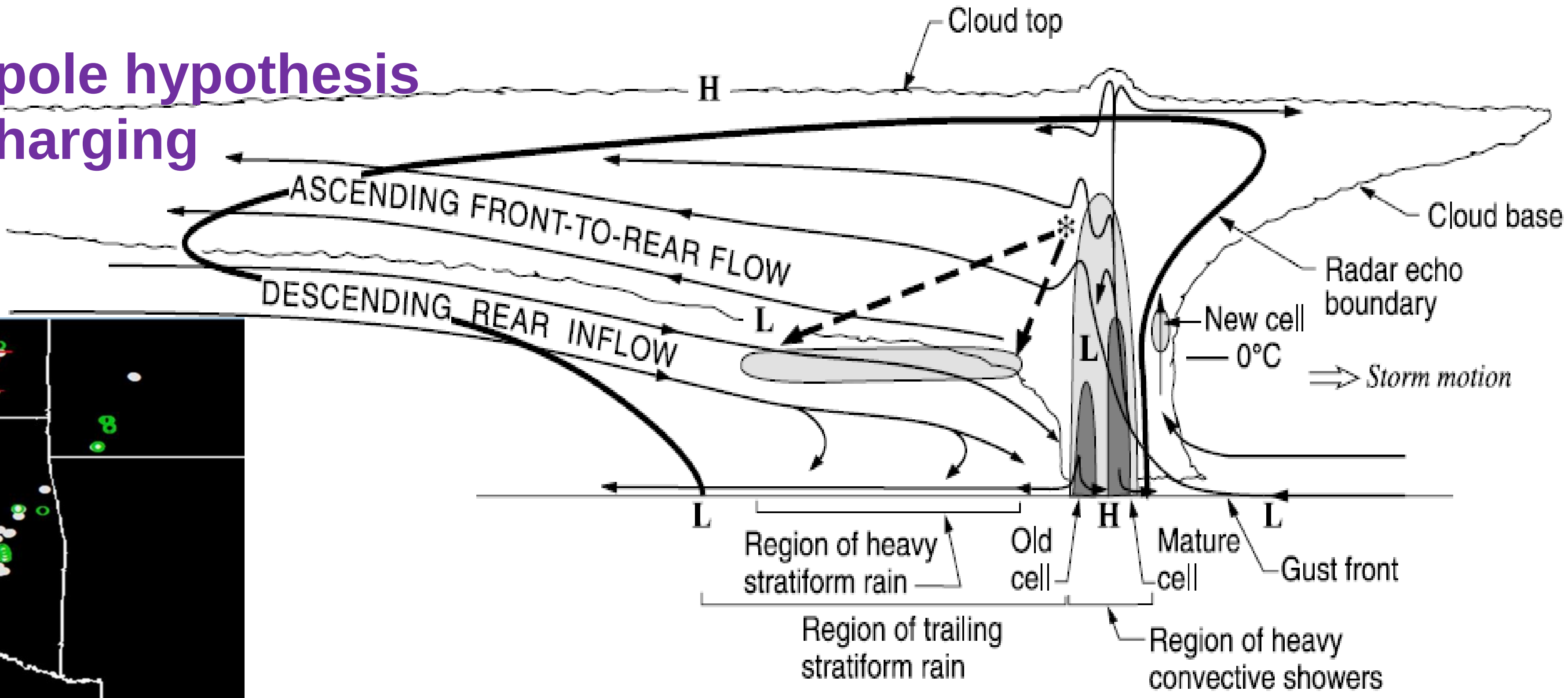
1.Background—Daily characterization-mechanism

MCS

1. Tilted dipole hypothesis
2. In-situ charging



+CG and –CG in a MCS, from Lyons et al., 2019)



Conceptual model of a convective line with trailing-stratiform

Are the charging conditions and mechanisms in 4pm aftermath and MCSs fundamentally the same?

2. Motivation

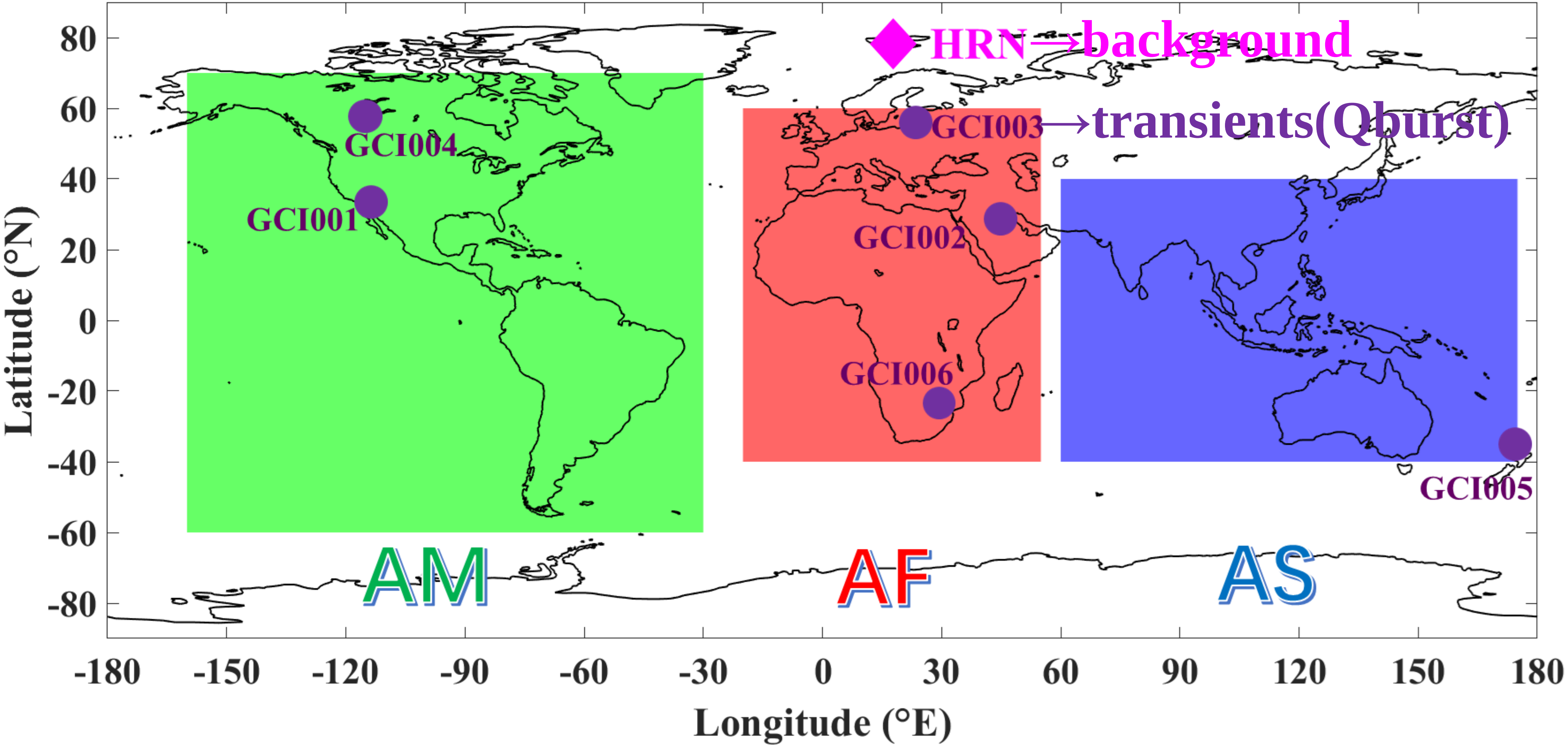
Is it possible to develop a method to achieve continuous, day-to-day monitoring and comparison of both ordinary lightning and high-energy lightning at the chimney scale?

Furthermore, do the diurnal characteristics of lightning activity and the phase differences between different lightning polarities remain robust at the chimney scale?

Are the charging conditions and mechanisms in afternoon thunderstorms and mesoscale convective systems fundamentally the same?

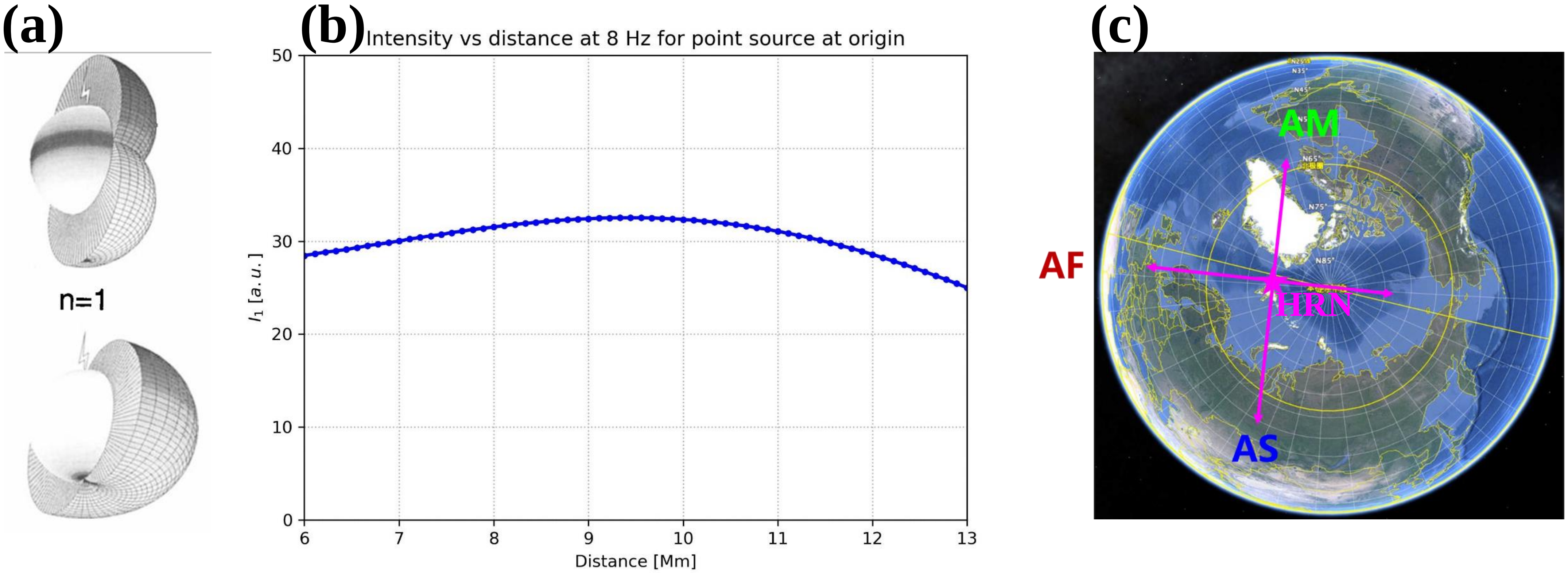
3.Methods—Dual SR methods (background+transients)

Three chimneys and Dual-Schumann Resonance methods



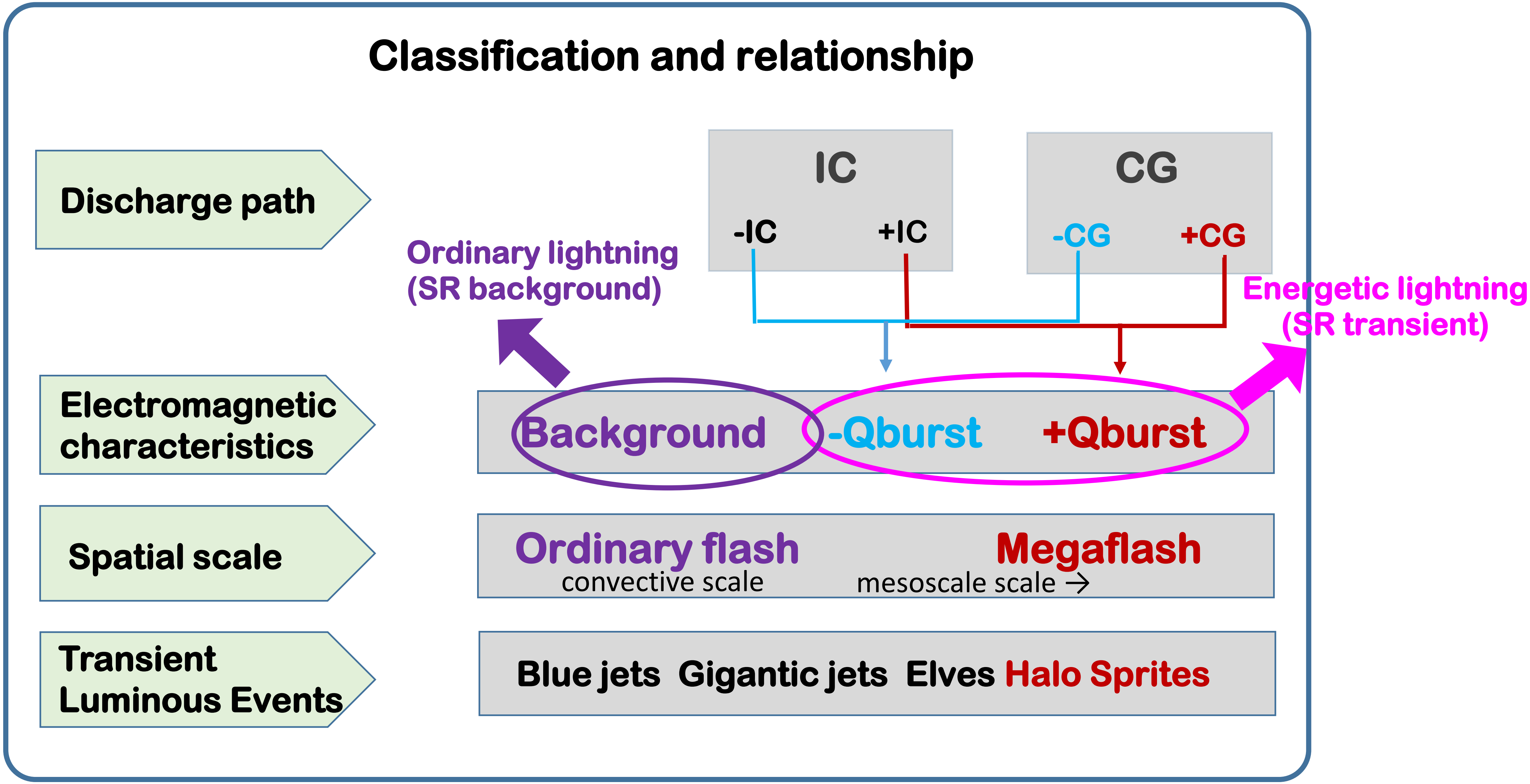
GCI001 California, USA GCI002 Hofuf, Saudi Arabia GCI003 Lithuania
GCI004 Alberta, Canada GCI005 Northland, New Zealand GCI006 Hluhluwe, South Africa

2.Methods—Dual SR methods (background)



(a) Idealized angular structure of the electric and magnetic field in the Earth-ionosphere cavity;
(b) Intensity vs distance at 8Hz; (c) Chimney separation in longitude is close to 90° each

Background lightning activities from 3 chimneys are separated by a high-latitude site (Hornsund,77°N)

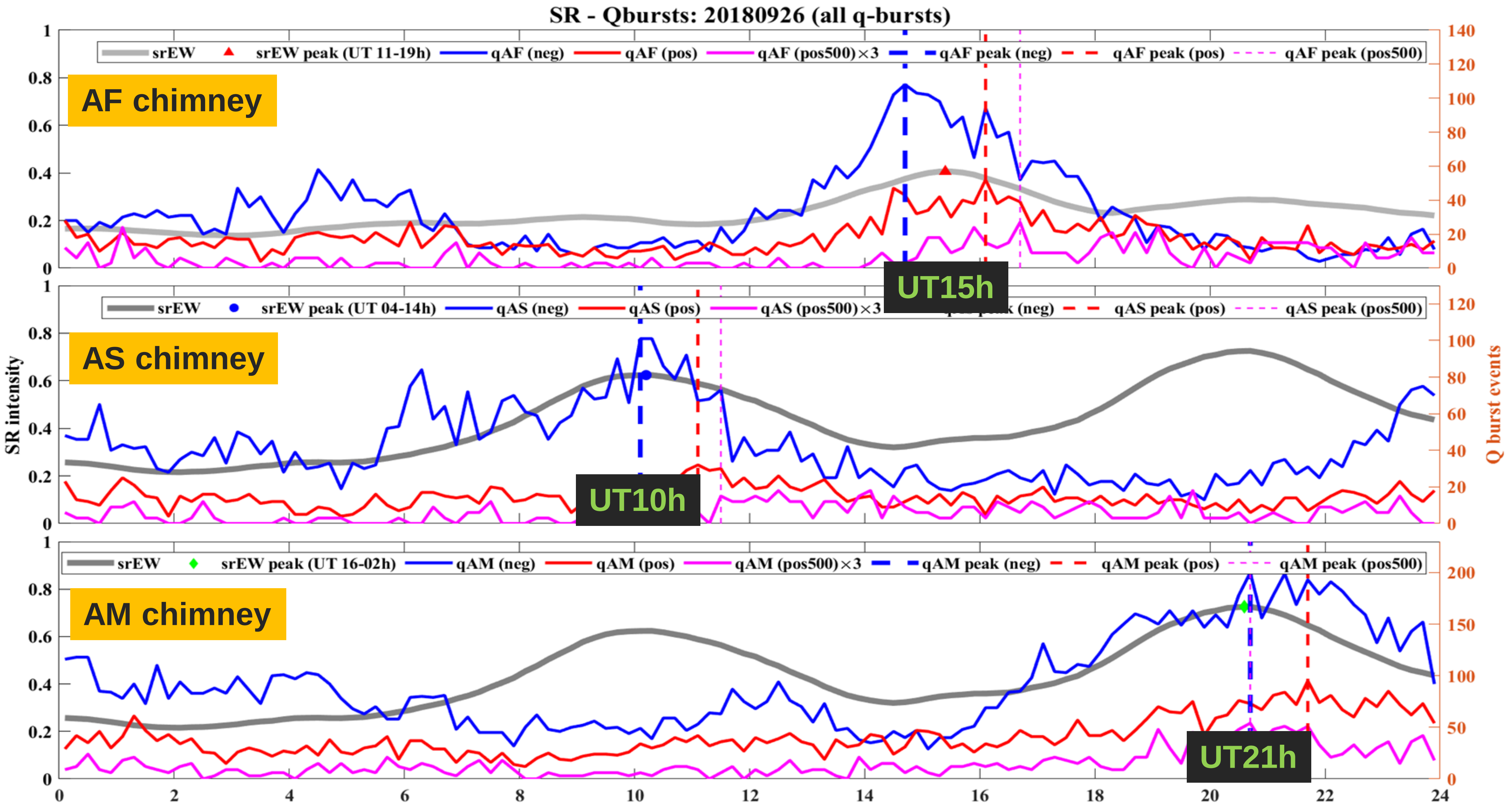


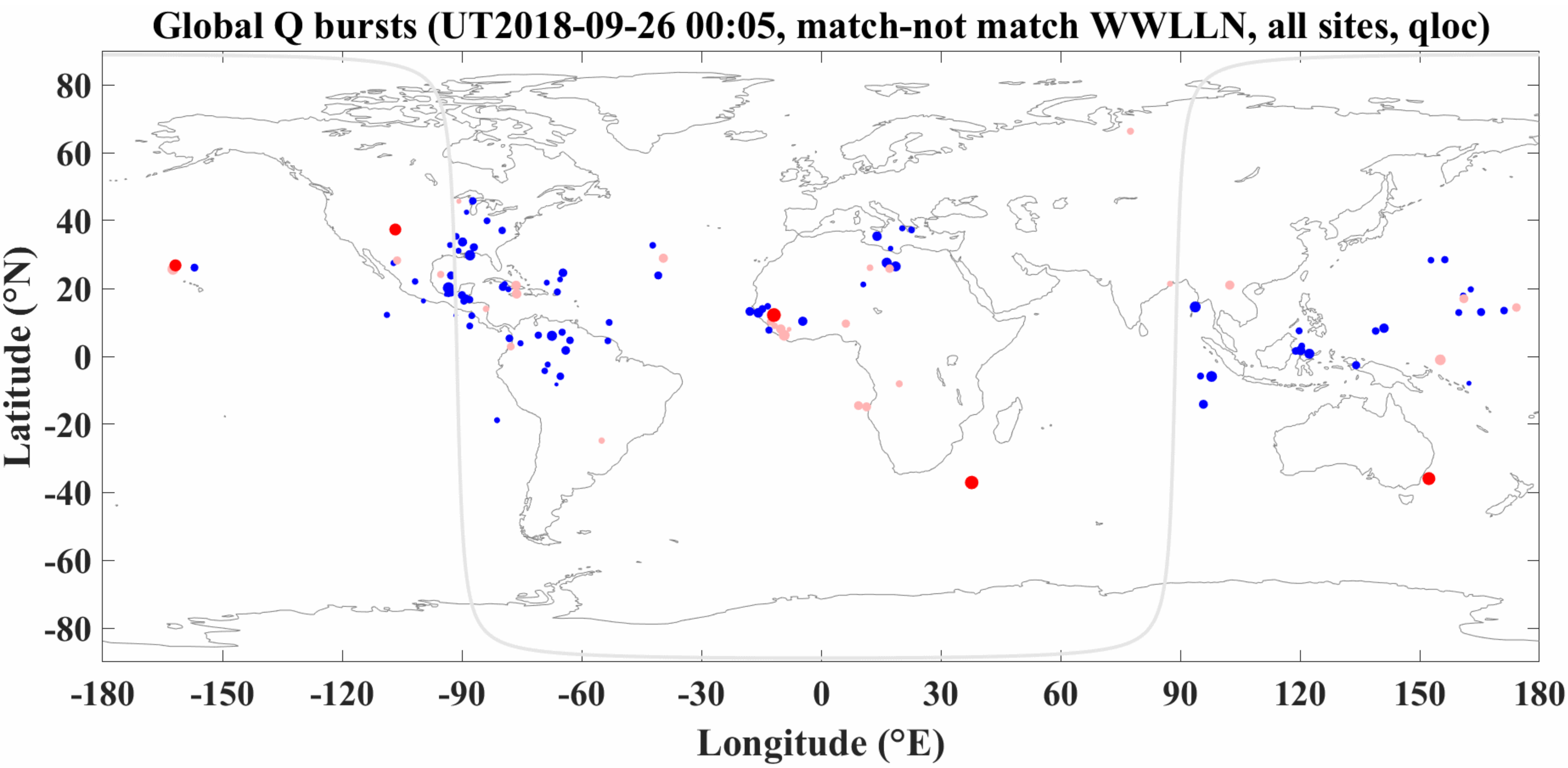
Classification and relationship
Discharge path
IC
-IC
+IC
CG
-CG
+CG
Ordinary lightning
(SR background)
Energetic lightning
(SR transient)
Electromagnetic characteristics
Background
-Qburst
+Qburst
Spatial scale
Ordinary flash
convective scale
Megaflash
mesoscale scale →
Transient Luminous Events
Blue jets
Gigantic jets
Elves
Halo Sprites

4. Diurnal variation of SR background and Q-bursts

(1) How to compare SR background and Q-burst activities day by day, on a chimney scale?

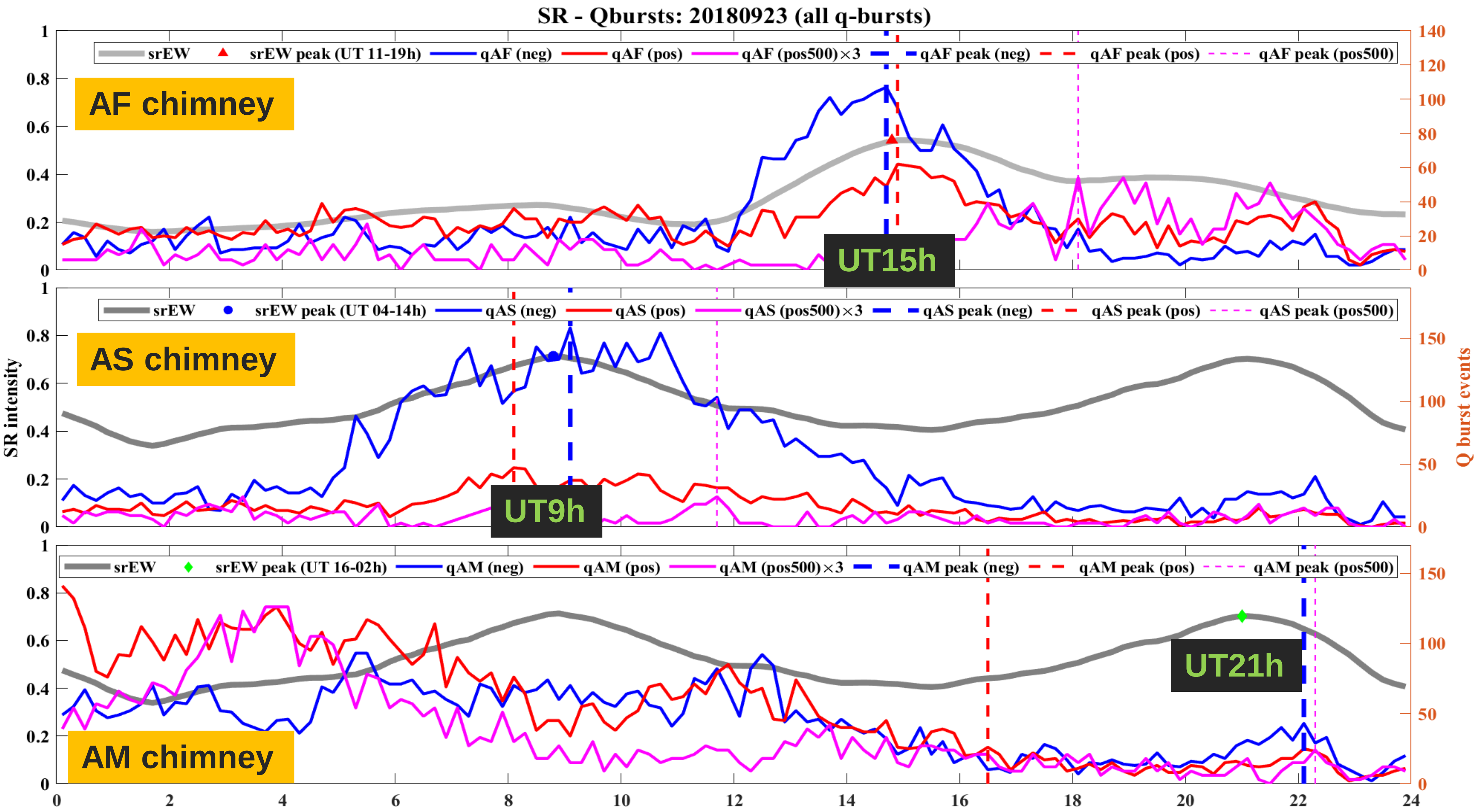
Daily comparison – thunderstorm (4pm aftermath) dominant

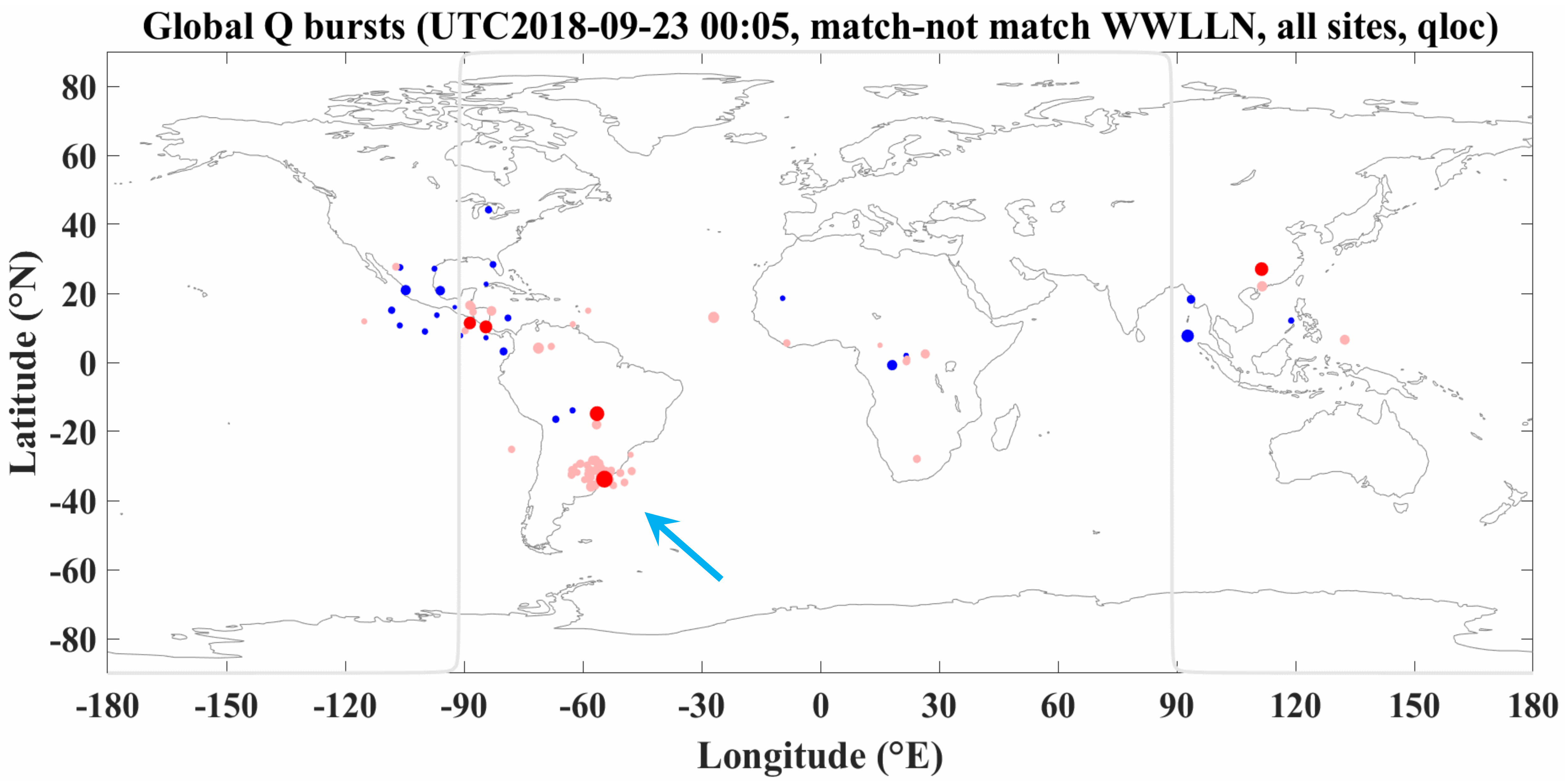




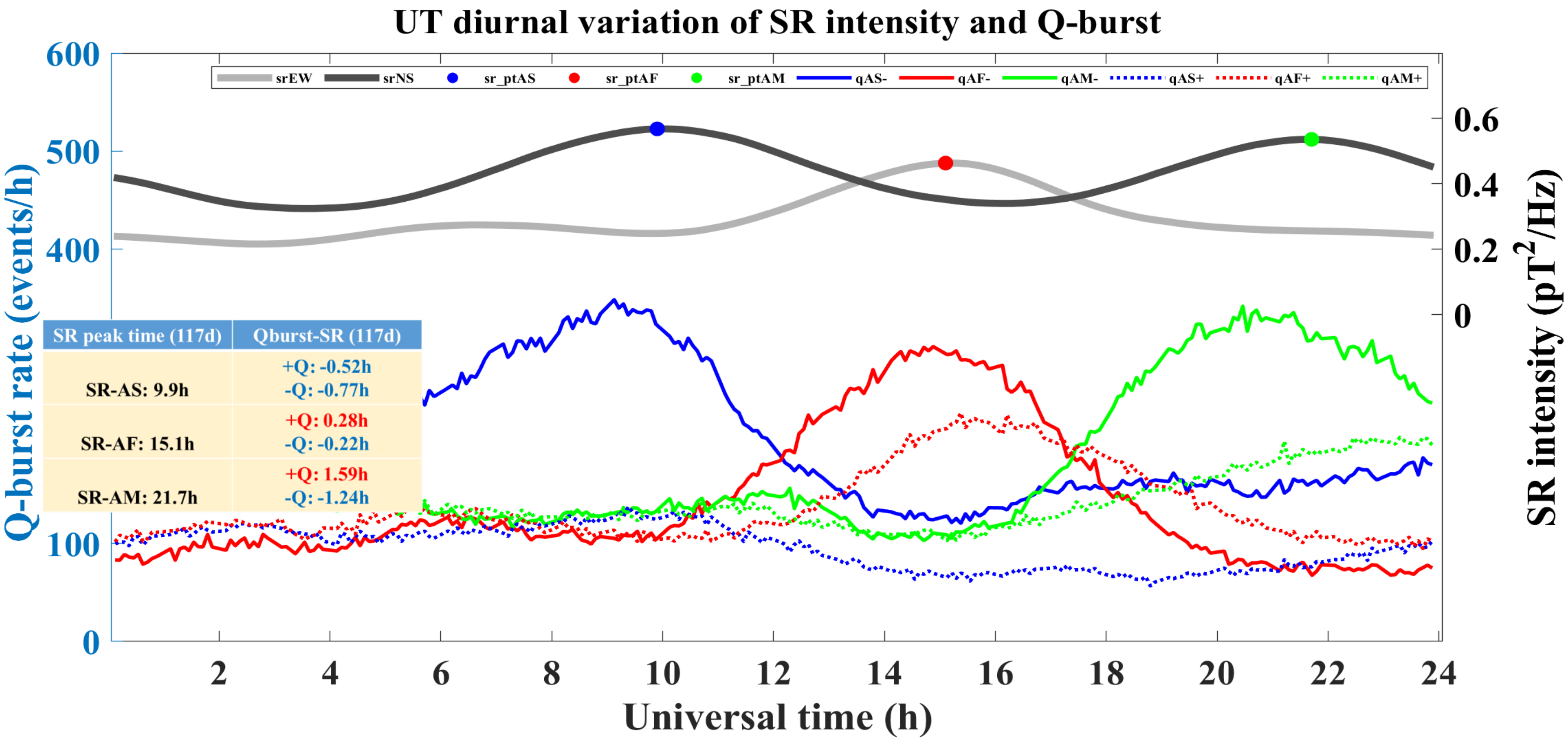
Global Q bursts (UT2018-09-26 00:05, match-not match WWLLN, all sites, qloc)
80
60
40
20
0
-20
-40
-60
-80
Latitude (°N)
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
Longitude (°E)

Daily comparison – Nocturnal MCS dominant



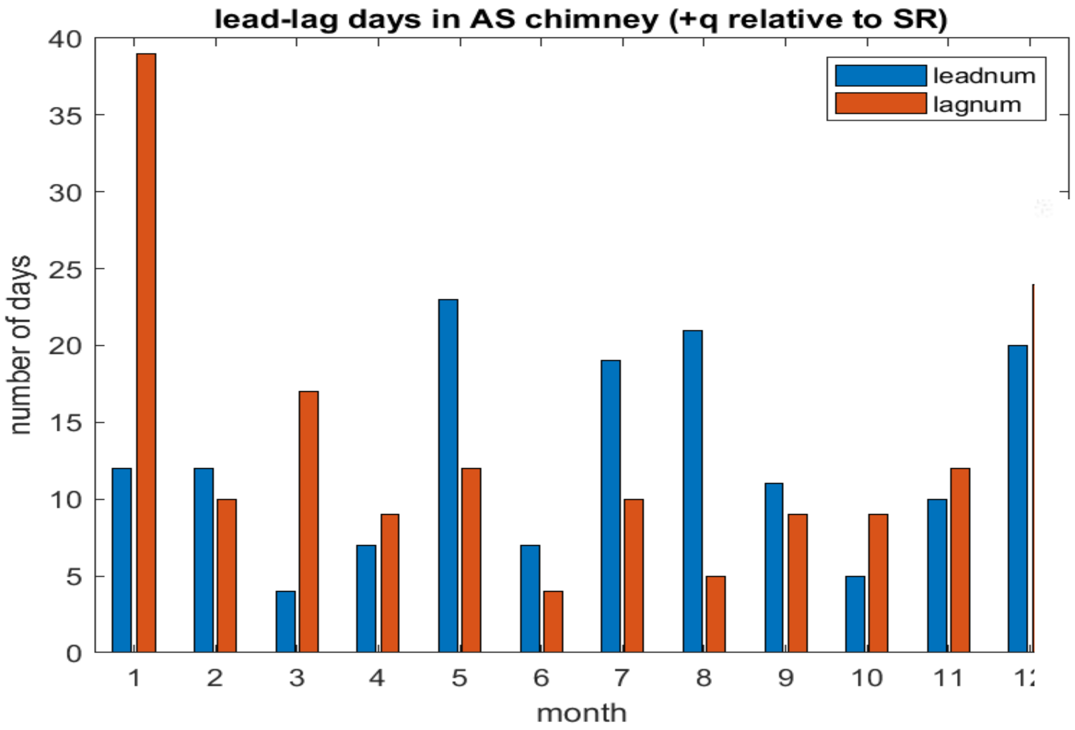

Global Q bursts (UTC2018-09-23 00:05, match-not match WWLLN, all sites, qloc)
Latitude (°N)
Longitude (°E)
80
60
40
20
0
-20
-40
-60
-80
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180

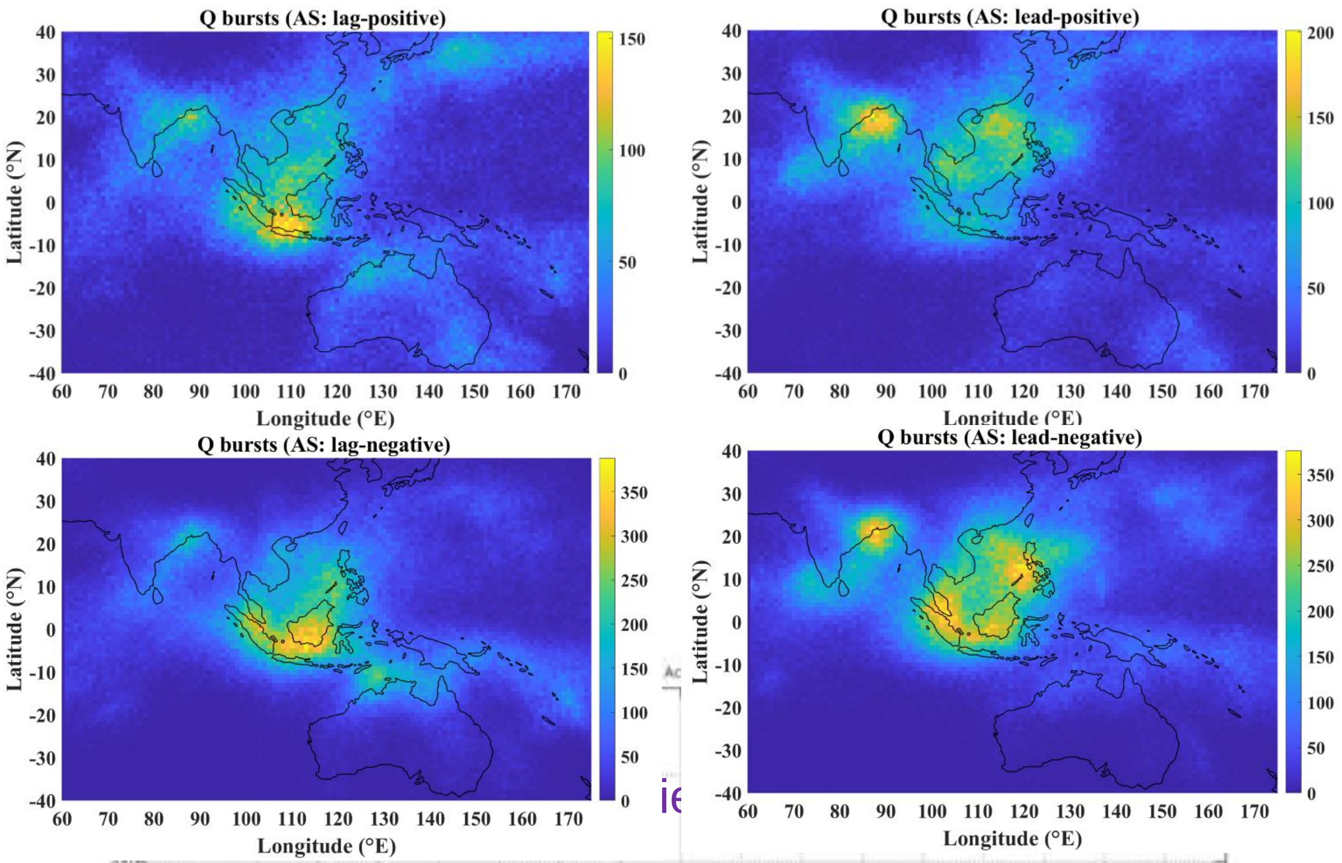
(2) Climatological comparison of diurnal variation

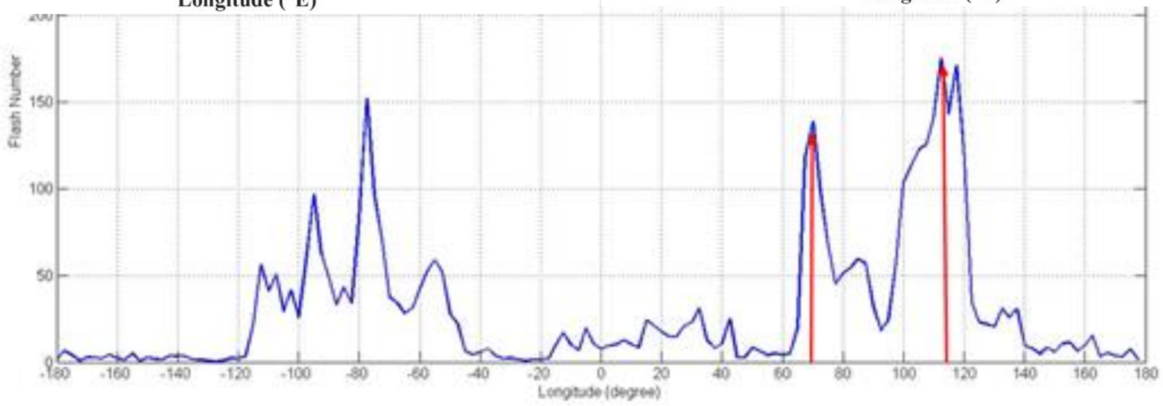


- SR background activity peaks at near 4 pm LT (roughly 10 UT, 15 UT, and 21 UT for AS, AF and AM chimneys).
- Lag (lead) behavior of positive (negative) Q-bursts relative to the SR background maxima are documented in AF and AM chimneys while both negative and positive Q-bursts show a leading behavior in AS chimney.

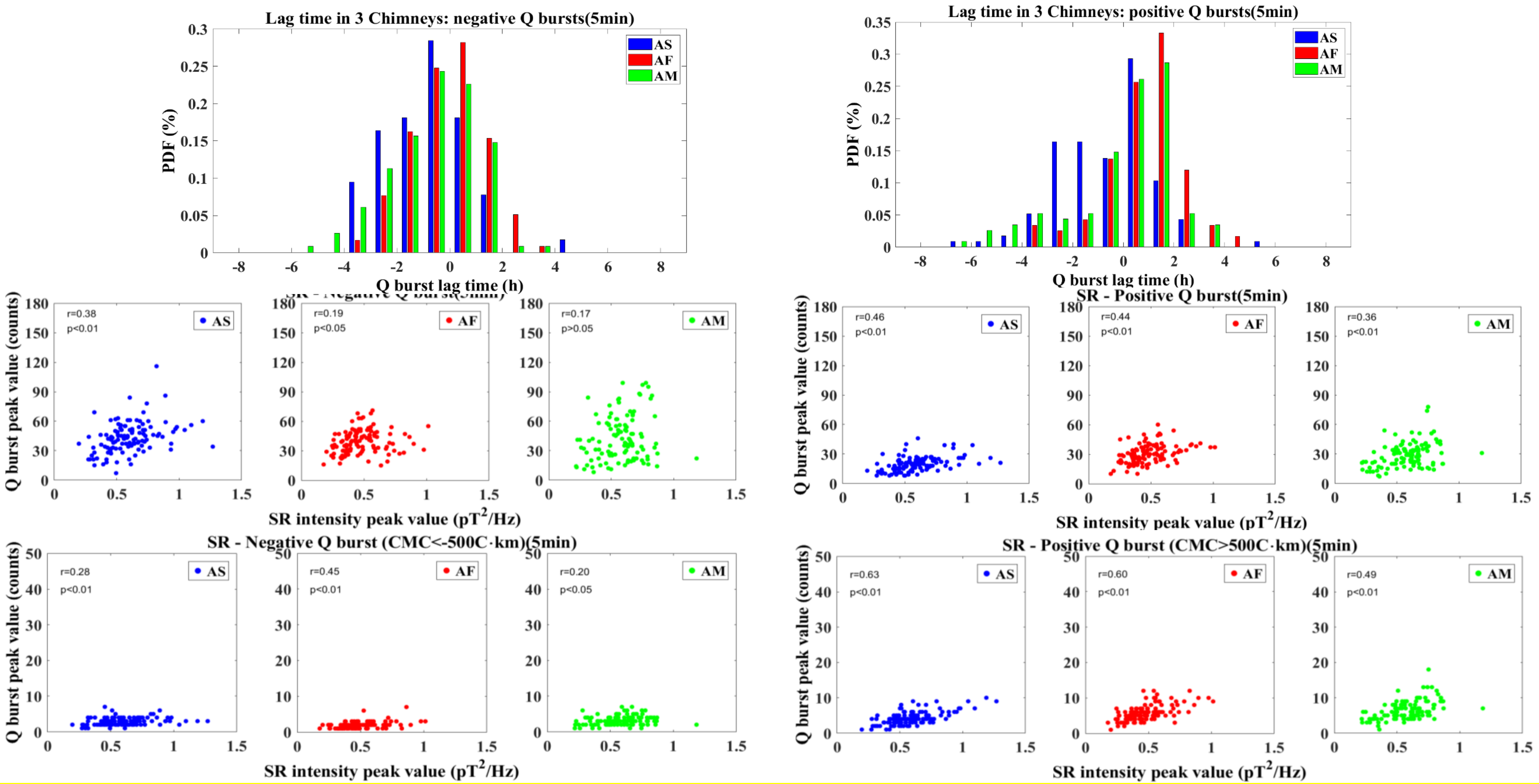
Leading behavior in AS chimney:
Two or three sub-chimneys in May-Sep.
The location of SR station.





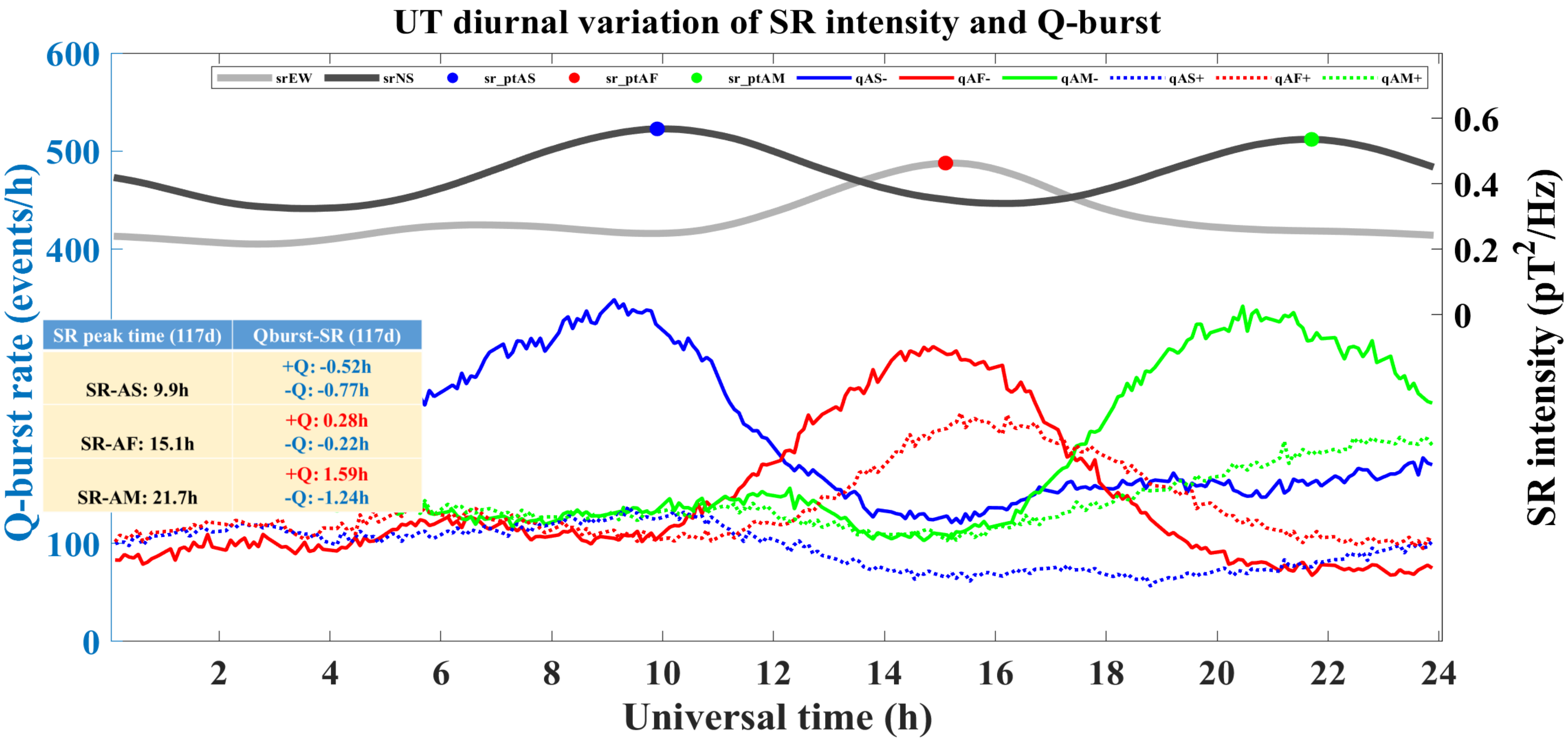


(3) Lead/lag behavior



- High correlations between positive Q-burst (with CMC>500C·km) counts and background peak intensity;
- Chimneys with stronger ordinary lightning activity are prone to generating more energetic positive Q-bursts.

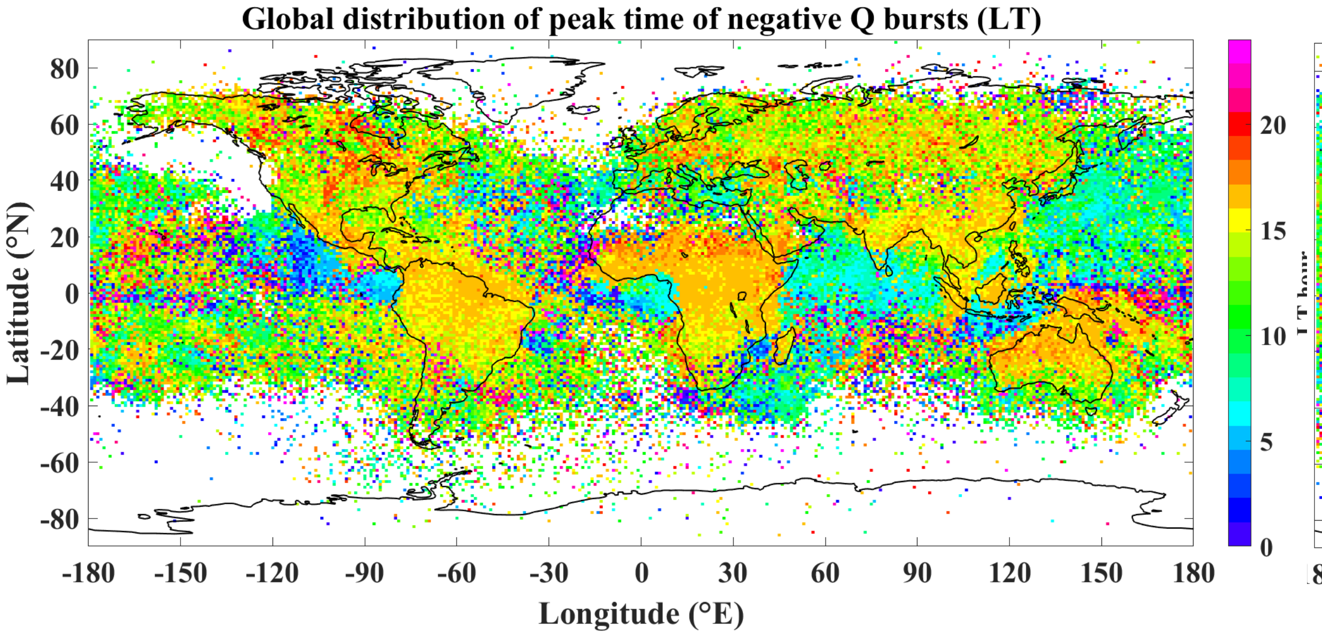
(2) Climatological comparison of diurnal variation

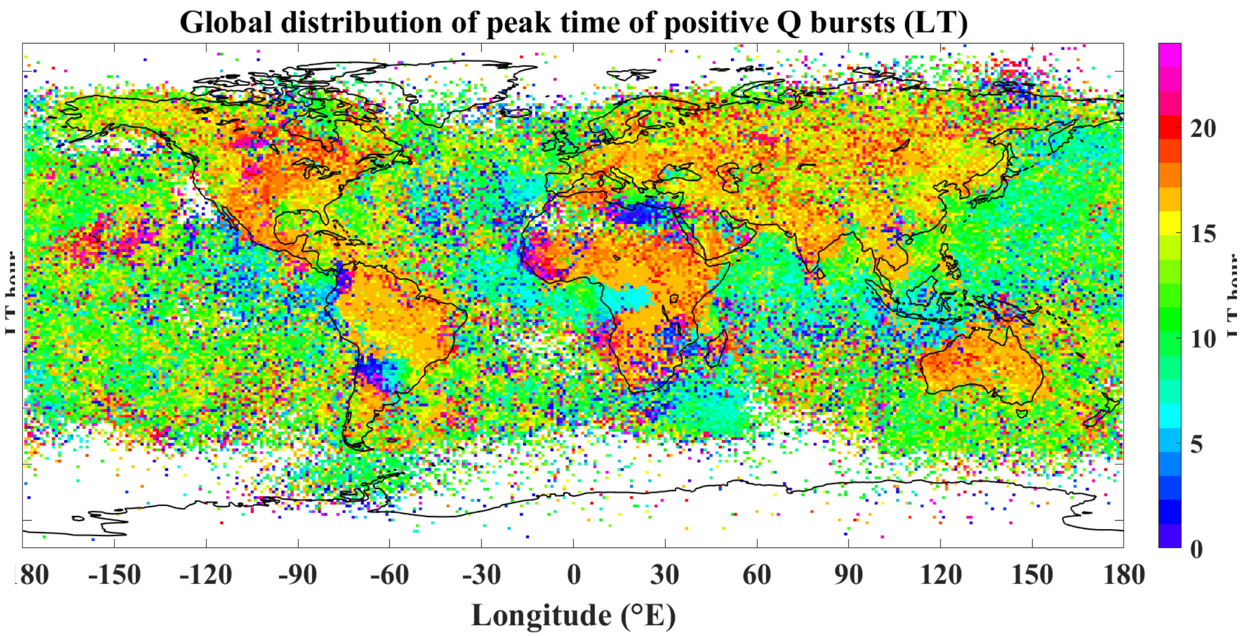


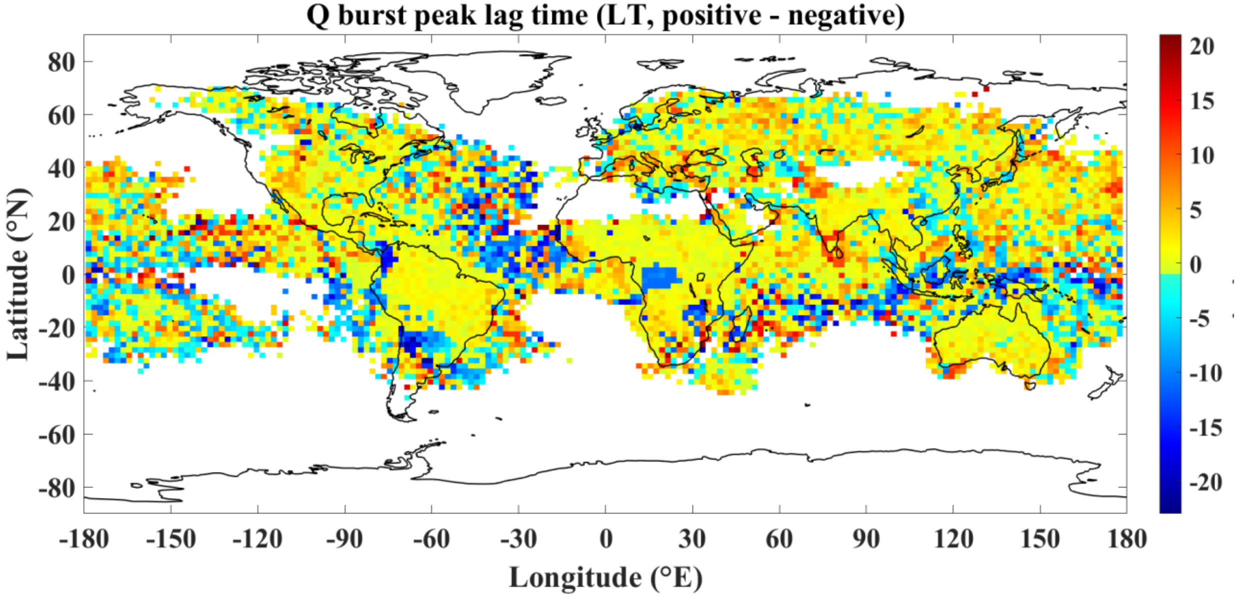
SR peak time (117d)	Qburst-SR (117d)
SR-AS: 9.9h	+Q: -0.52h -Q: -0.77h
SR-AF: 15.1h	+Q: 0.28h -Q: -0.22h
SR-AM: 21.7h	+Q: 1.59h -Q: -1.24h

- Lag behavior of +Q-bursts relative to the –Q-burst is robust in three chimneys.

Q-burst peak time

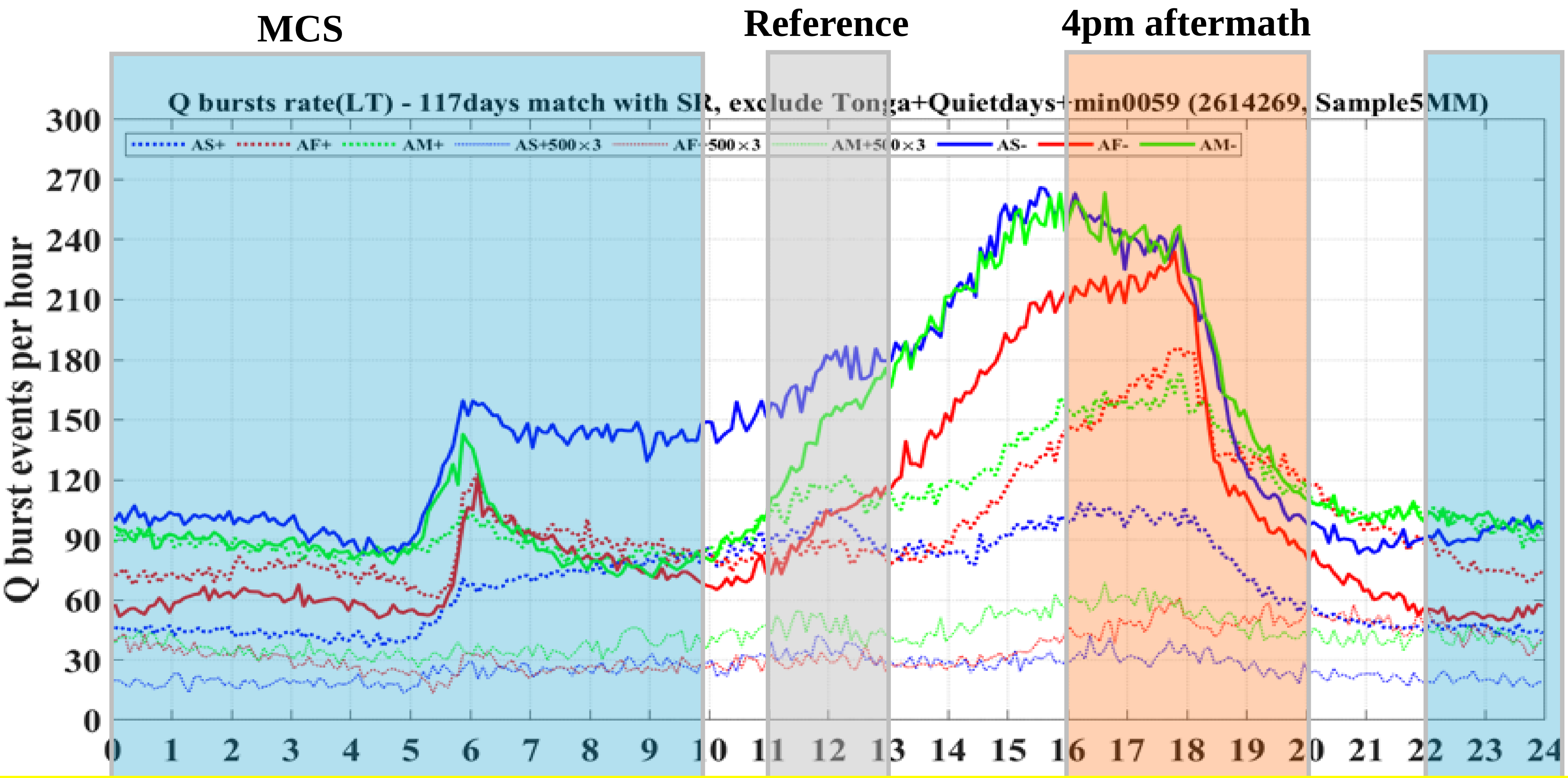






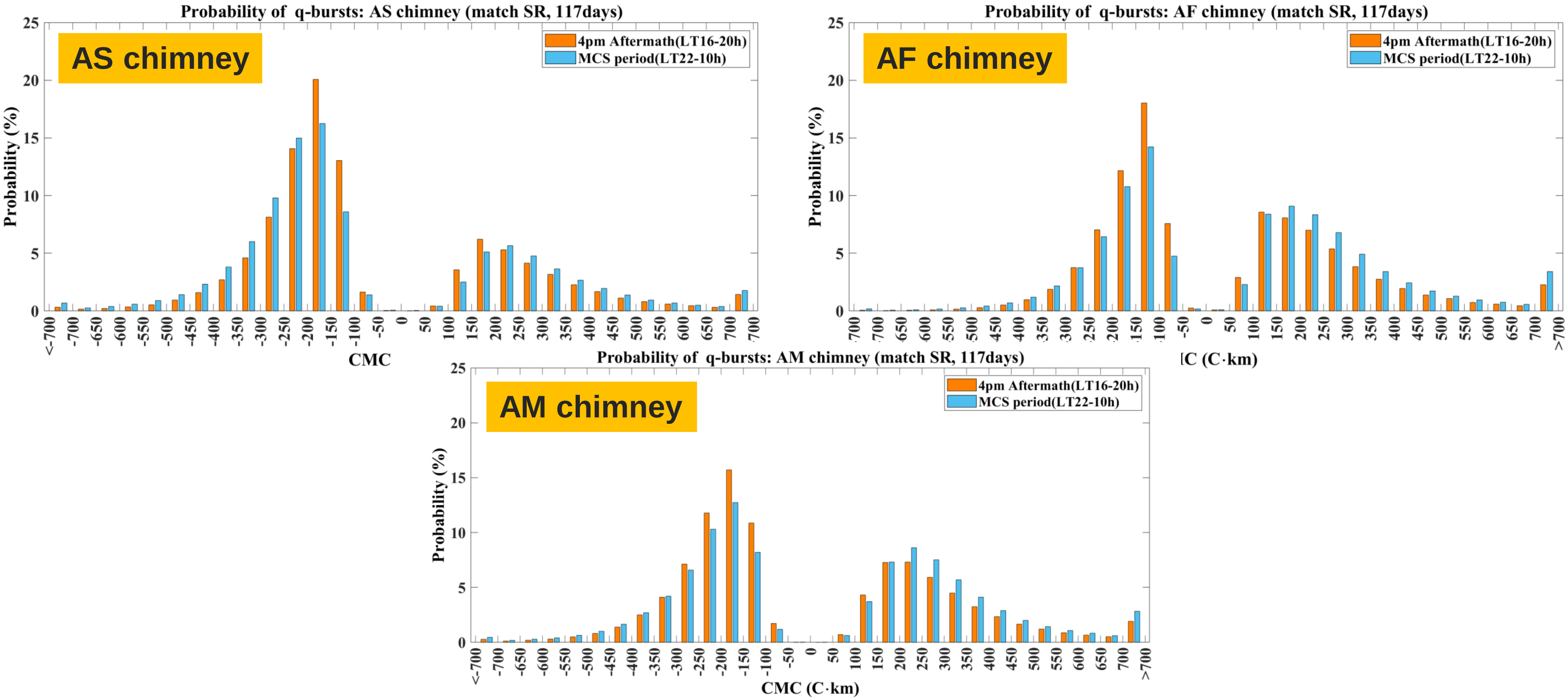
5. Meteorological mechanism

3 regimes



- Robust and consistent lag behavior of positive Q-bursts relative to negative Qbursts in 3 chimneys.

PDF of Charge Moment Change (CMC)

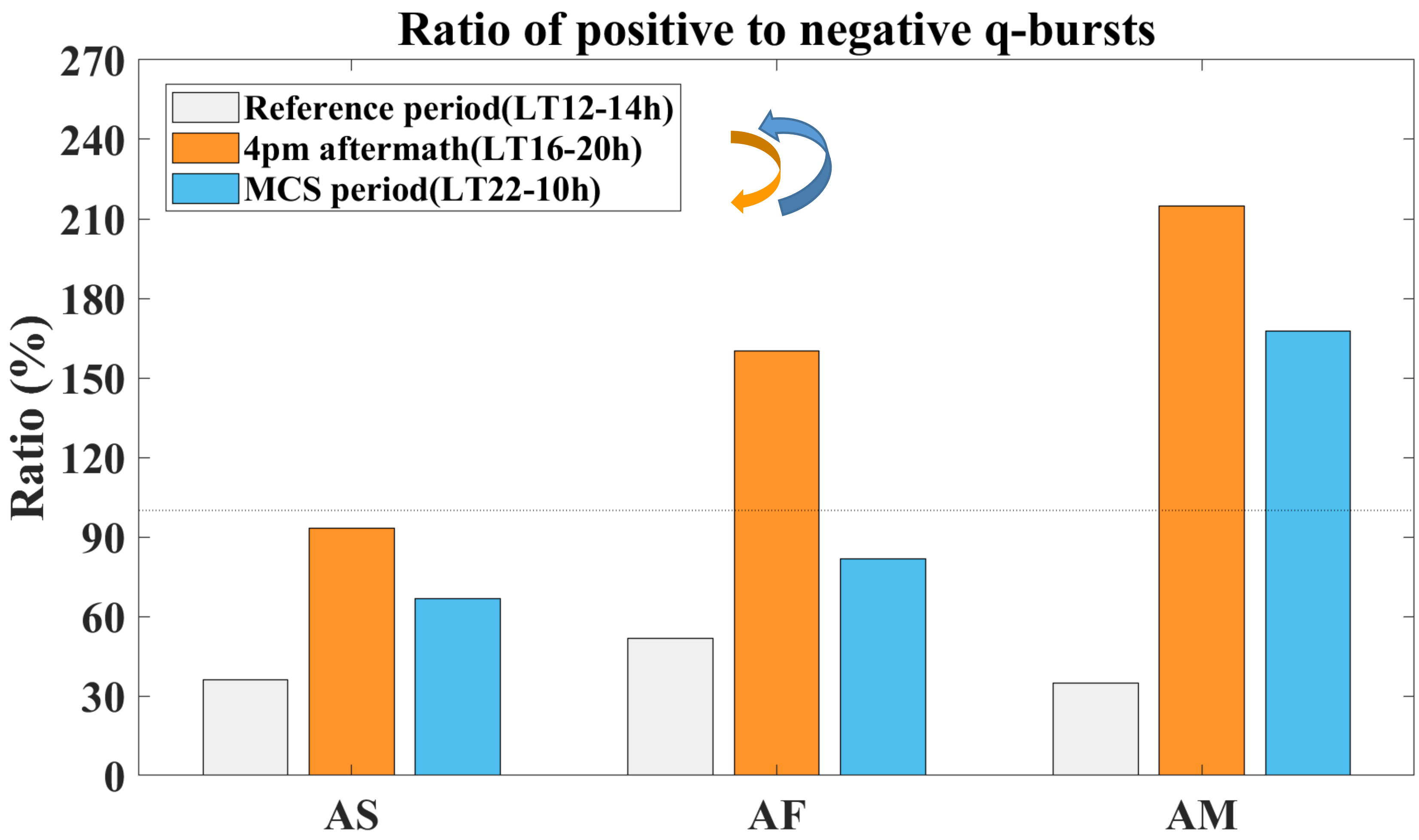


- Similar PDFs of CMC during thunderstorms and MCS periods in 3 chimneys;
- The positive Q-burst has a broader and flatter PDF relative to negative Q-burst;
- Q-bursts have larger CMC in MCS period (when |CMC|>200C·km,especially for +Q-bursts).

Covective coditions with weaker updraft

Stratiform clouds

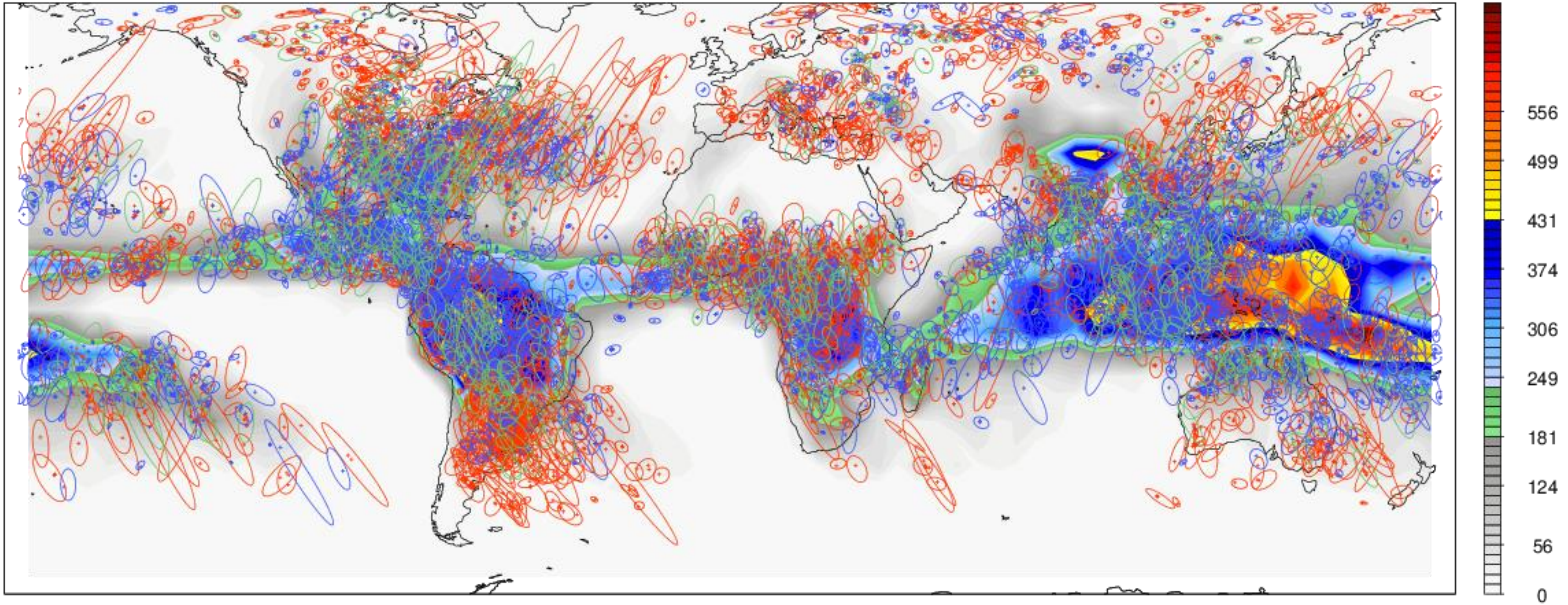
Stratiform clouds with large extent



- Reference period:The ratio of +Q-burst/-Q-burst is small in three chimneys; -Q-bursts are dominant in small-scale convections, AS and AM chimneys have smaller ratios relative to AF ;
- 4pm aftermath: The ratio of +Q-burst/-Q-burst increases relative to reference period;
- MCS period: The ratio of +Q-burst/-Q-burst reaches its maximum among three time regimes, with larger CMC (from previous slide).

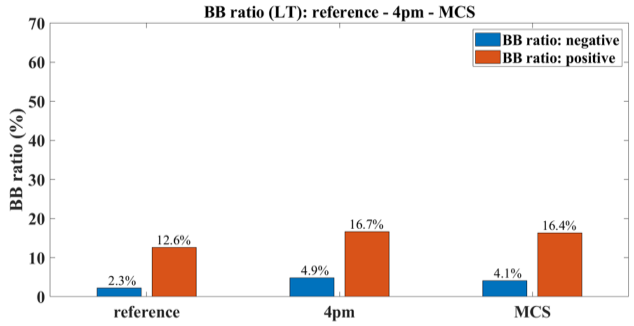
(10 min collocation, from Chuntao Liu)

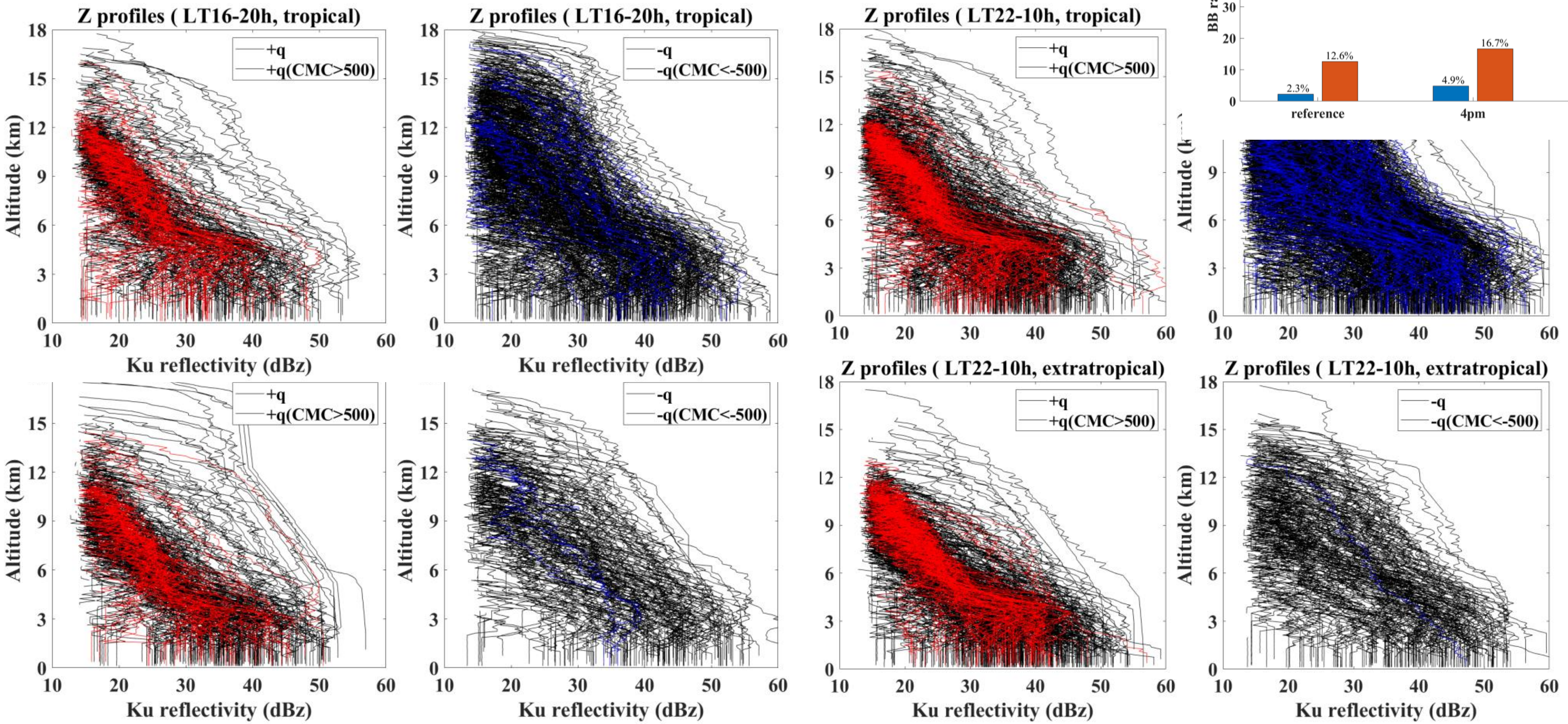
GPM PM samples (color fill) in 5°X5° on Q-burst observation days and PFs collocated with Q-bursts



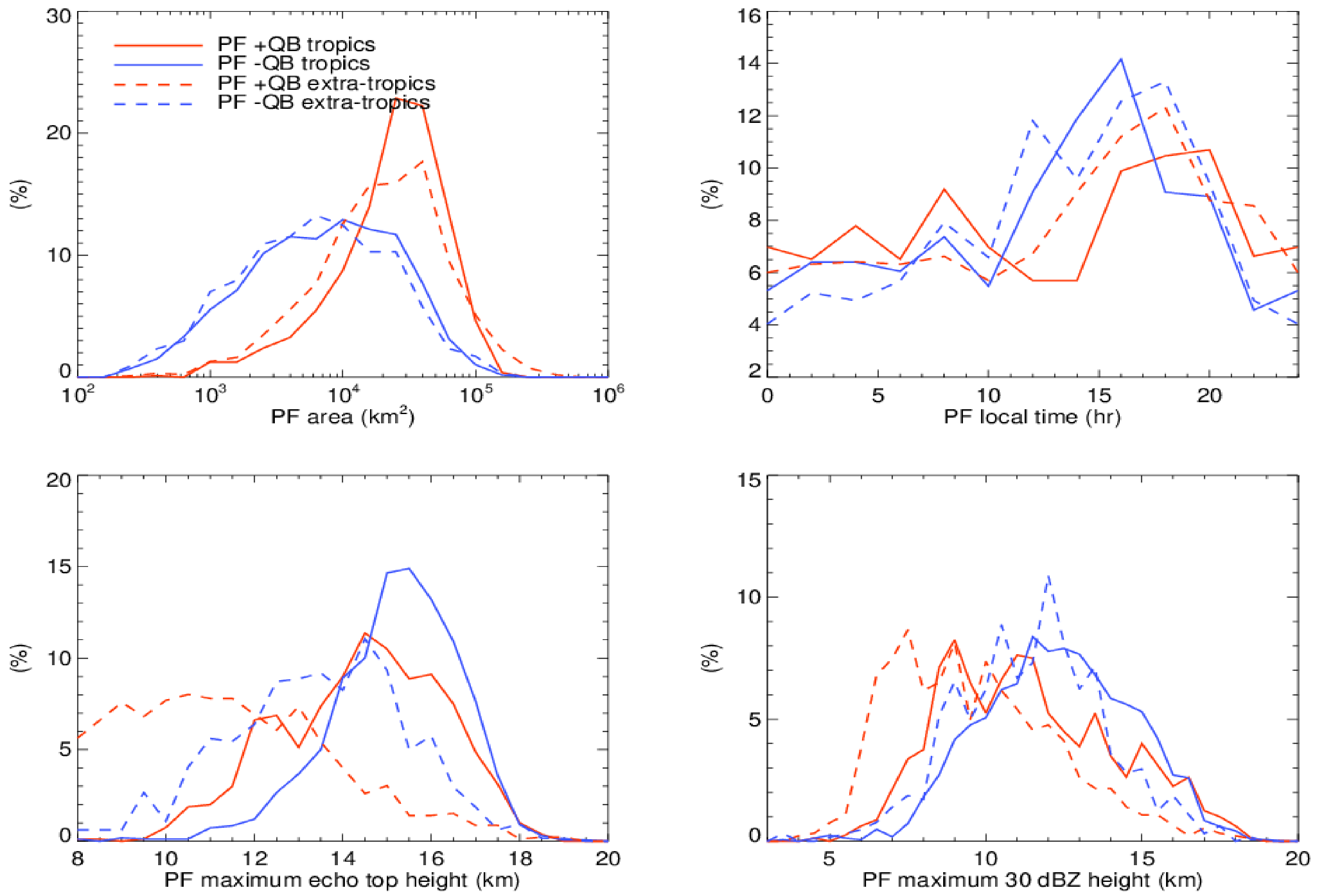
Ellipse are fitted on PFs, small crosses are location of Q-bursts, color fill are PF samples in those 440 days
With + QB in red, with –QB in blue, with both in green.

Radar reflectivity profiles and bright band





- The positive Q-bursts are frequently coincident with radar bright band signatures in both 4pm aftermath and MCS periods, while negative Q-bursts are not.
- BB ratios at positive Q-burst locations were similar for 3 regimes.



- Positive Q-bursts are linked with large PF area, later PF peak time, lower maximum echo top height and maximum 30 dBZ height.
- Negative Q-bursts are more often associated with convective meteorology than with stratiform.

6. Conclusions

- Daily diurnal variation on chimney scale is dominated by the local 4 pm aftermath but adjusted by strong nocturnal/early morning MCSs. Due to the randomness in the occurrence of MCSs, their modulation of the diurnal cycle is not reflected in the statistical results.
- An individual MCS can produce a large number of high-energy lightning discharges with very large CMC, but its total flash rate cannot compete with total flash rate in any active chimney; which is insufficient to make significant background signals.
- Chimneys with stronger ordinary lightning activity are prone to generate more energetic positive Q-bursts later in the chimney cycle.
- -Q-bursts are more often associated with convective meteorology, while +Q-bursts are associated with stratiform meteorology.
- The demise of both the 4 pm aftermath and the MCSs provide similar microphysical conditions favorable for polarity reversal, thereby promoting the production of +Q-burst, while MCS tends to create more energetic Q-bursts with larger CMC.

This is the first study to conduct a comparative analysis of electrical behavior at the chimney scale using a dual Schumann resonance approach, revealing the chimney-scale lagged behavior of Q-bursts relative to ordinary lightning, as well as that of +Q-bursts relative to −Q-bursts.

Thanks for your attention!
Comments welcome!

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