“Chibis-M” observations of lightening radio-emission: capabilities and basic results

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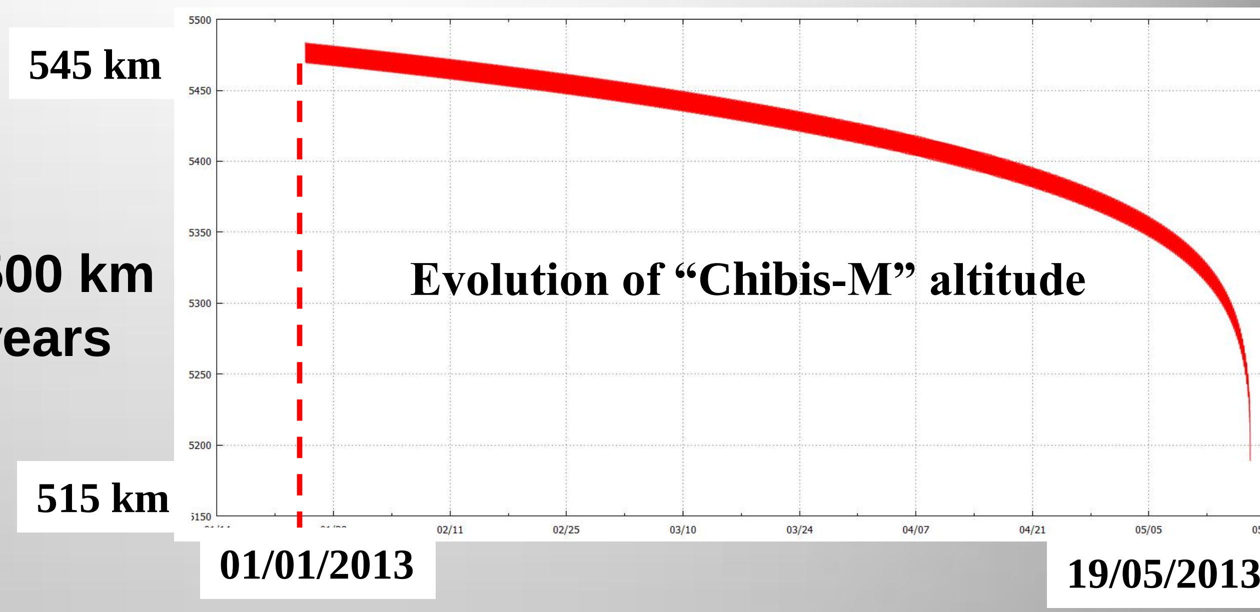
Basic characteristic of “CHIBIS-M”



− circular orbit height ~ 500 km
− active functioning – 2 years

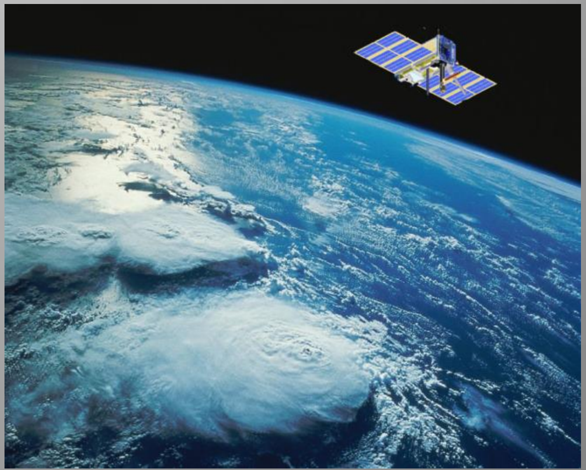
Parameters of Radio Frequency Analyzer

− VHF band $f \in [26; 48]$ MHz

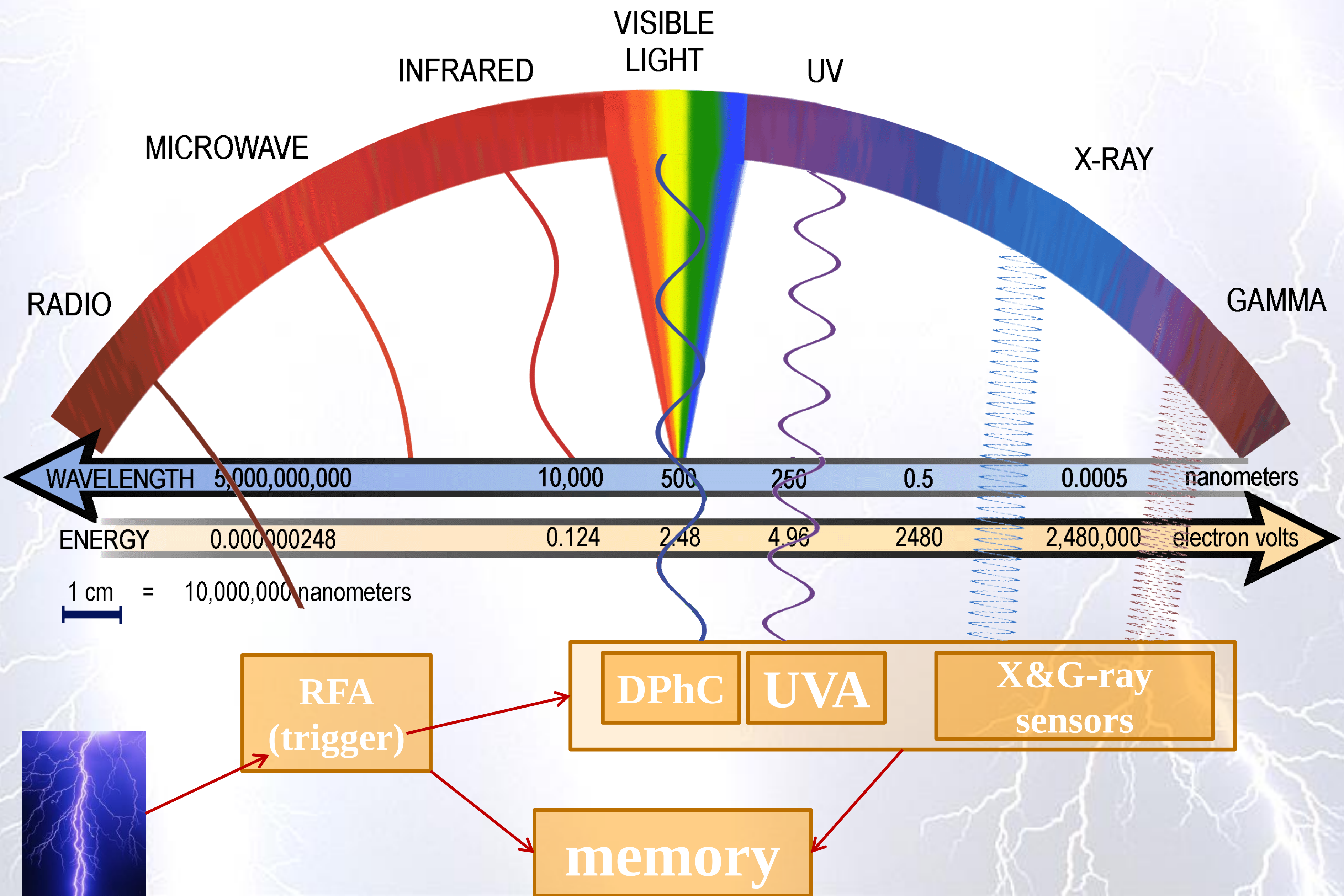
− sampling frequency 96 MHz

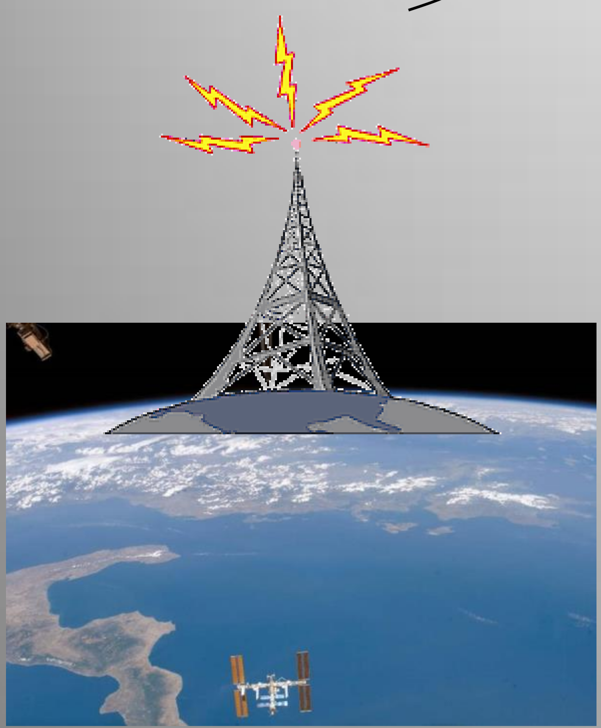
− sensitivity ~ 1 mV/m

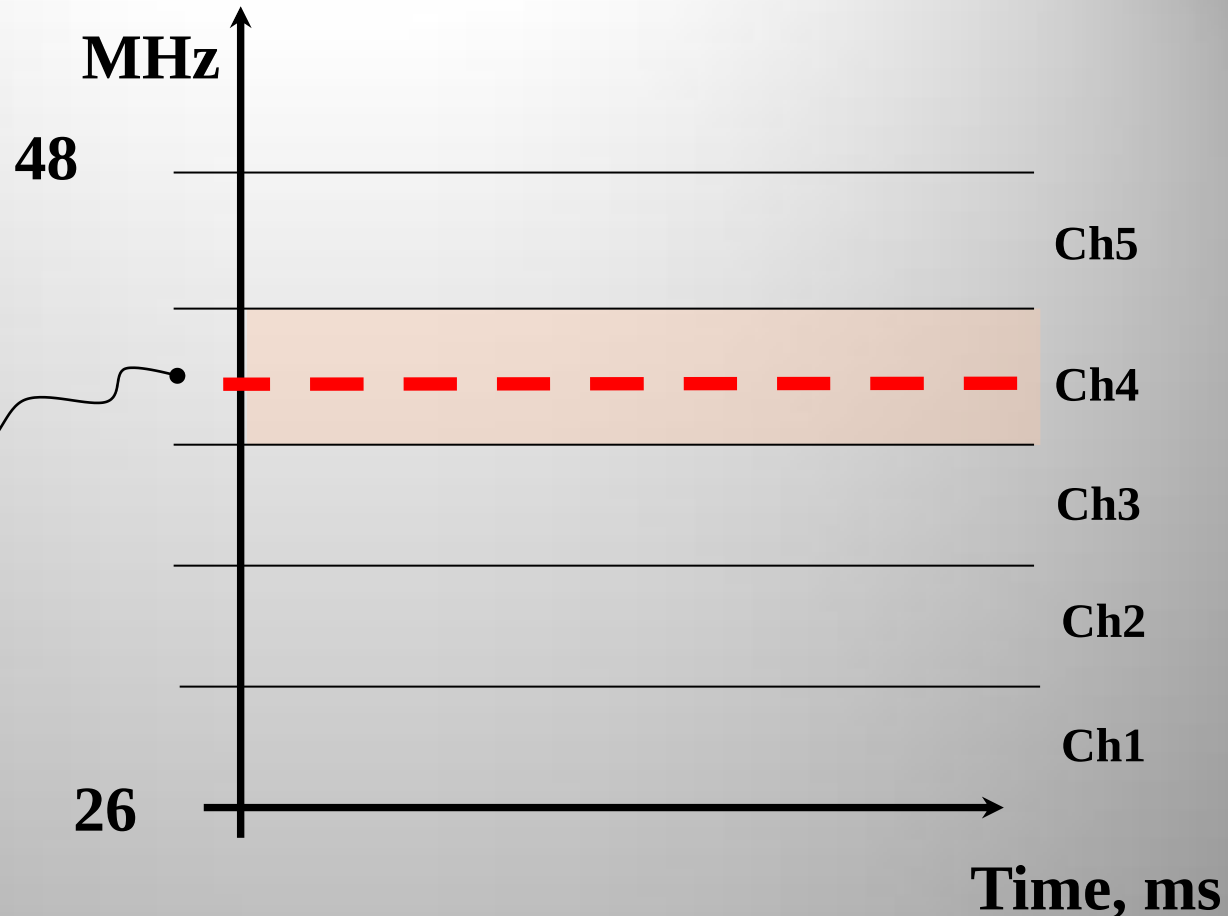
− antenna length 1.2 m



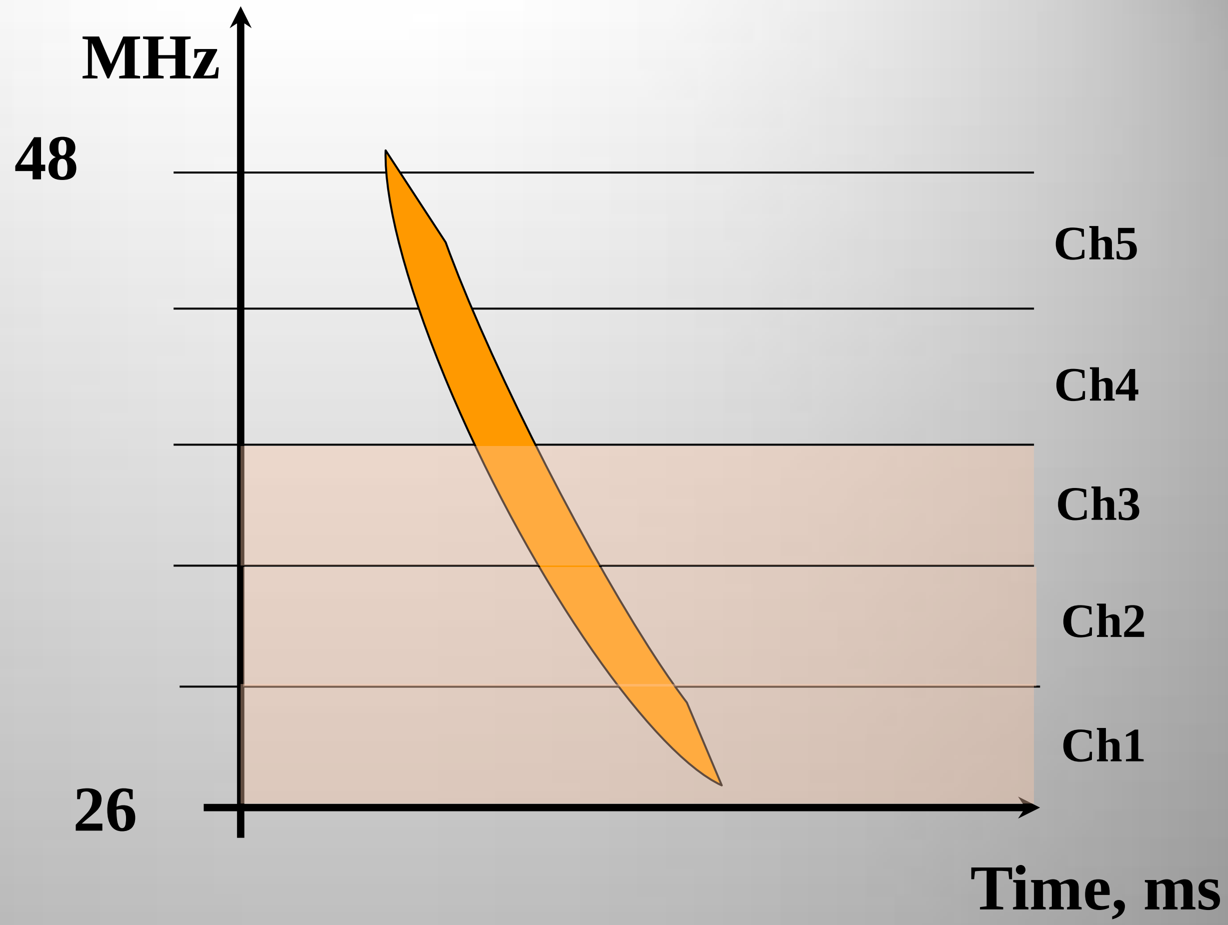
Scientific instrumentation onboard of “Chibis-M

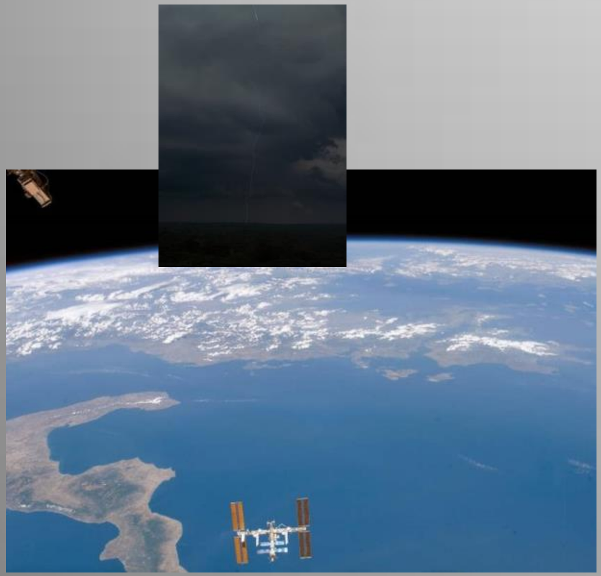






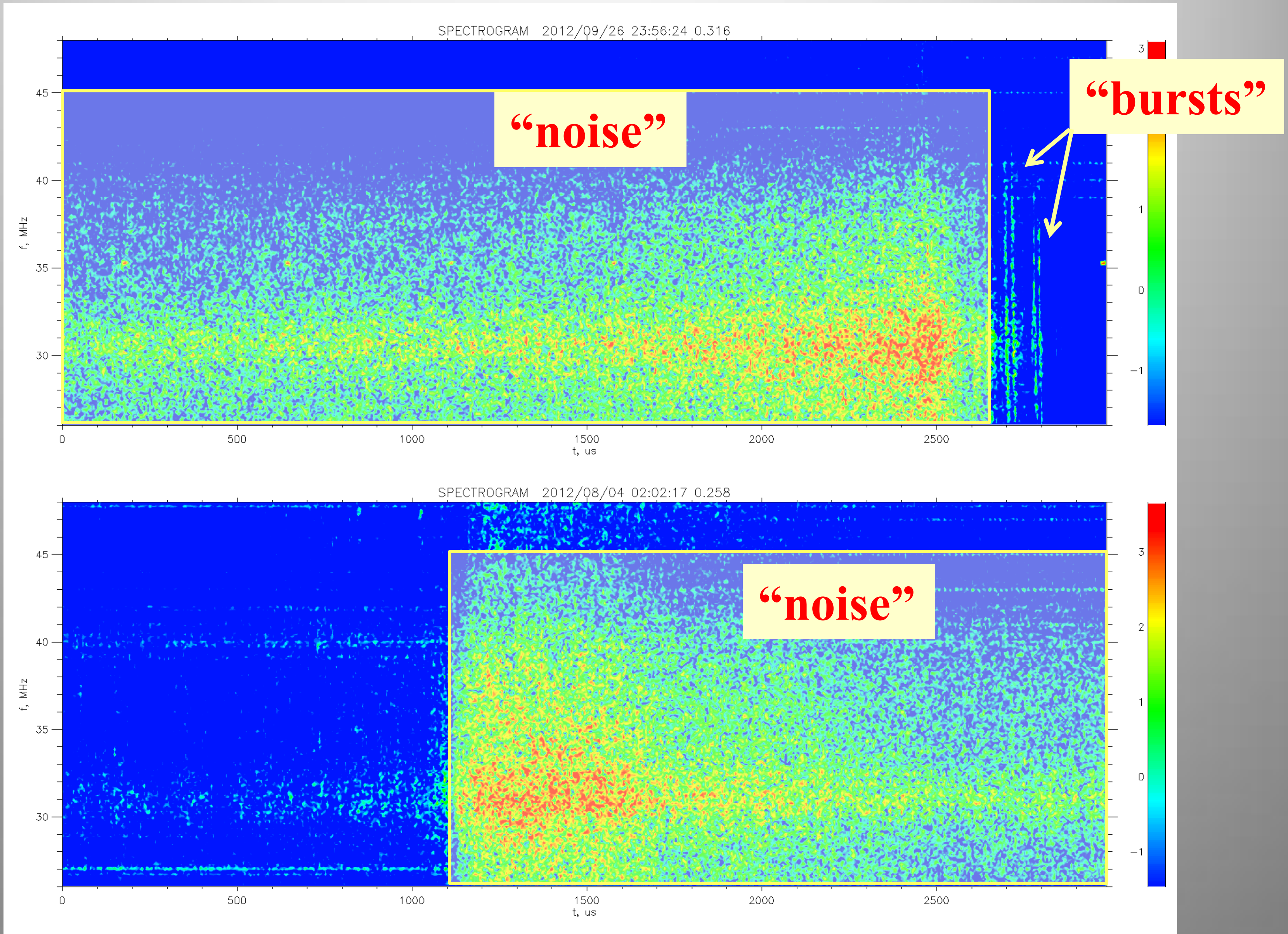
No trigger!



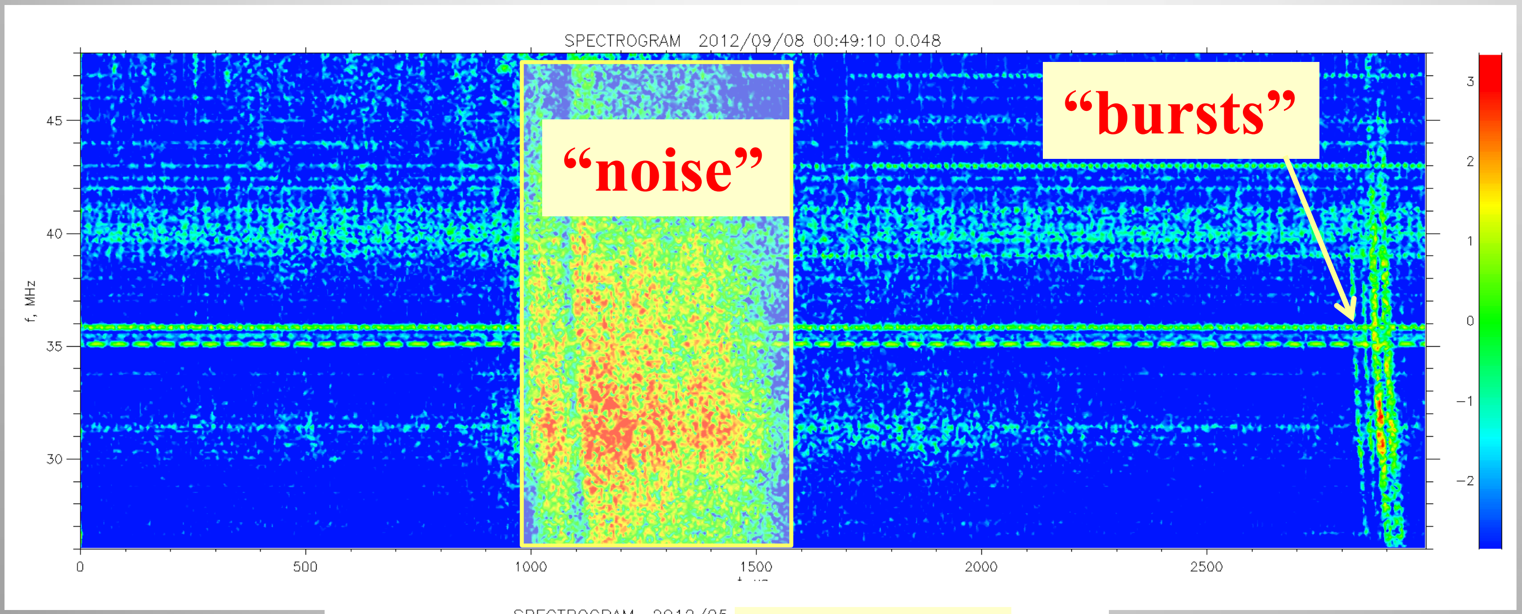


Trigger!

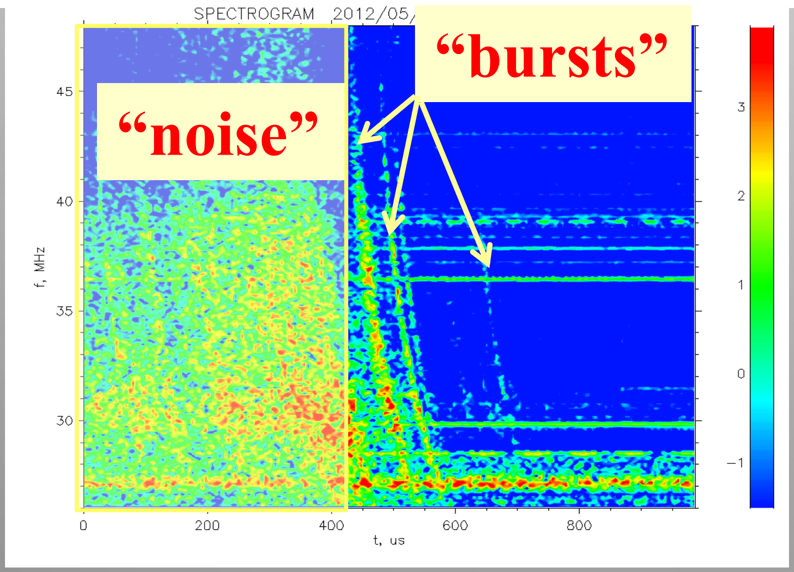
Some typical events (3 ms frame)



Some more events

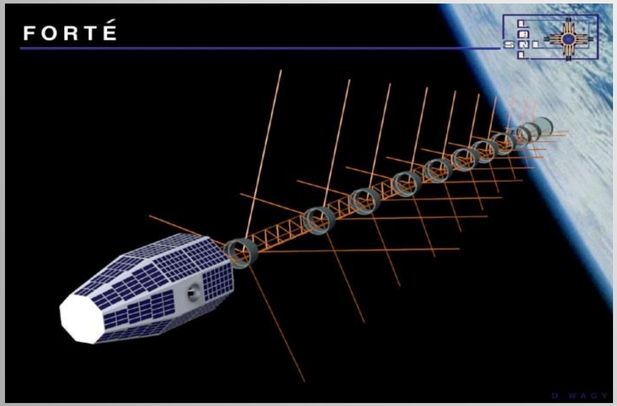


3 ms frame



1 ms frame

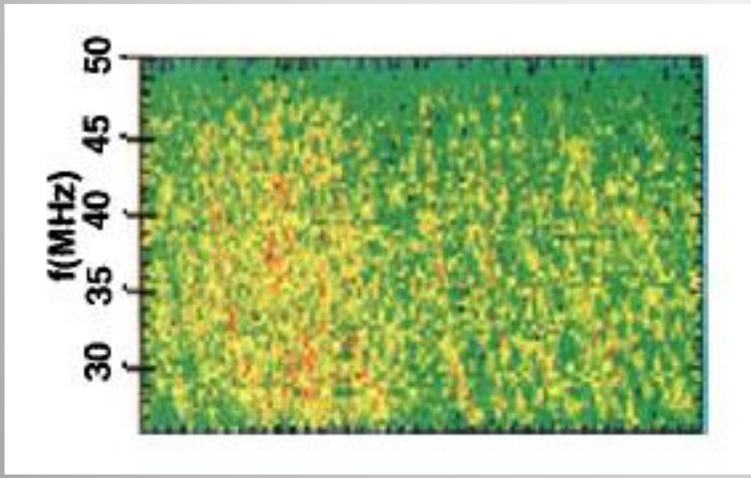
History. Observations from space.



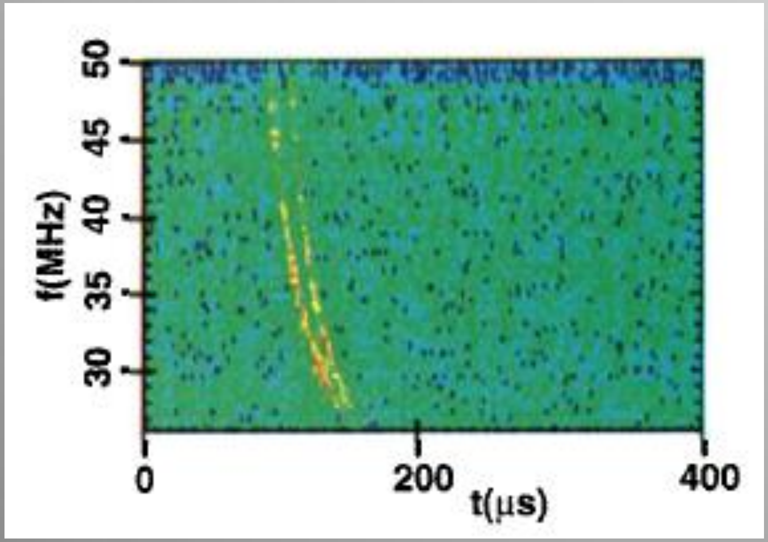
The **Fast On-orbit Rapid Recording of Transient Events** (**FORTE**) was launched on August 29, 1997 into a circular 800-kilometer which is inclined 70 degrees relative to the Earth's equator .

The data obtained by spacecraft are from the narrower band of the two RF receivers carried by FORTE. This narrower-band system contains two independently tunable passbands, tunable anywhere in the **range 20-300 MHz**. Each passband's signal is analog-filtered to a 22-MHz effective bandwidth and then digitized at 50 megasamples/sT. The **greatest advance of FORTE over ALEXIS/Blackbeard is its triggering scheme** for these narrowband receivers: Each receiver's passbandh as embedded within it eight independent triggering subbands spaced at 2.5-MHz separations, with each subband having 1 MHz of bandwidth. The two 22-MHz receivers are triggered together, so that both are digitized synchronously

History. Observations from space.

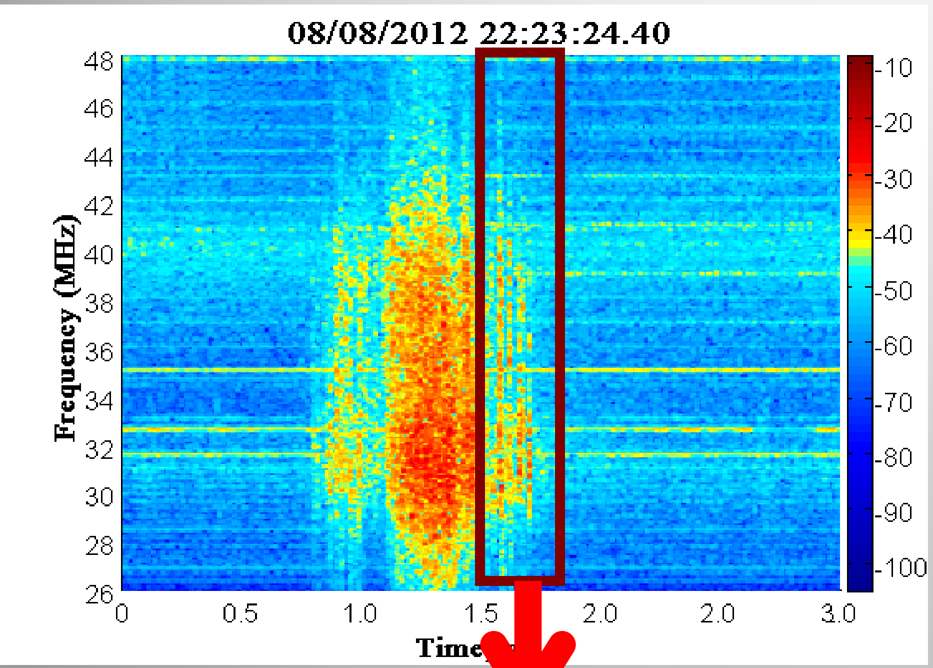


Jacobson, A. R. et al. (**1999**). FORTE observations of lightning radio-frequency signatures: Capabilities and basic results. *Radio Science*, *34*(2), 337. doi:10.1029/1998RS900043



Jacobson, A. R., & **Light**, T. E. L. (**2012**). Revisiting "Narrow Bipolar Event" intracloud lightning using the FORTE satellite. *Annales Geophysicae*, *30*(2), 389–404. doi:10.5194/angeo-30-389-2012

Preliminary data processing…

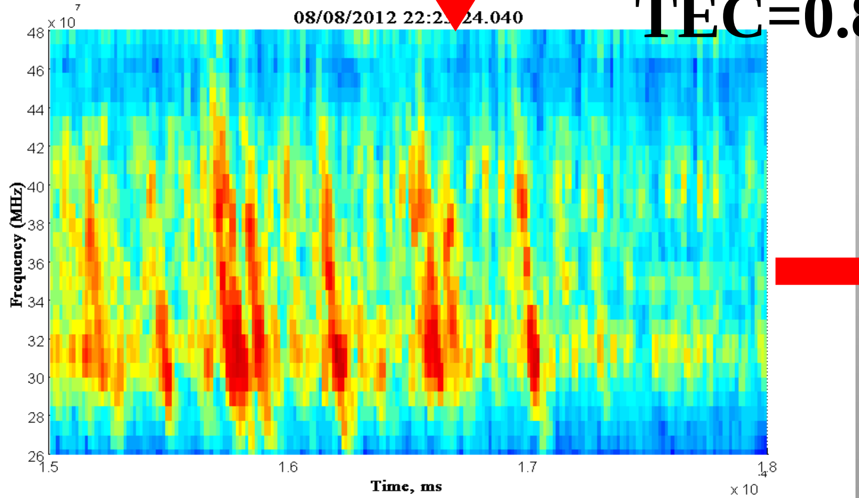


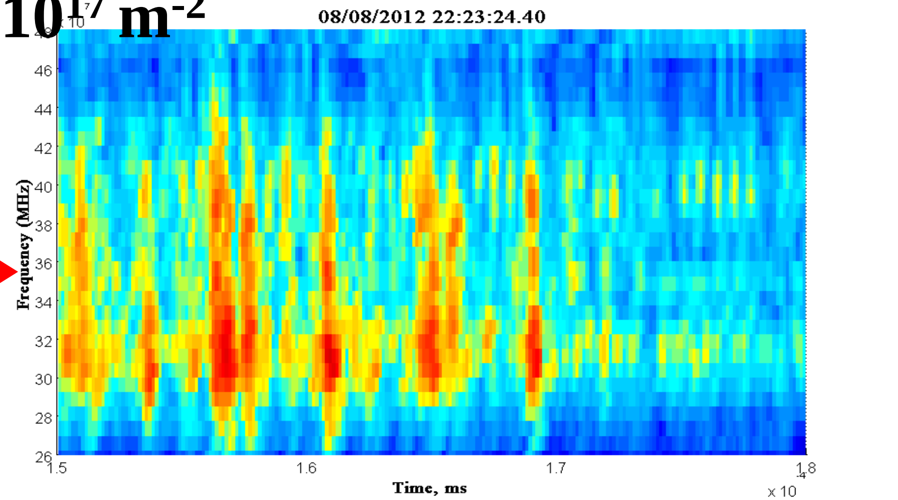
Each event shows the distinctive $\mathbf{f^{-2}}$ ionospheric dispersion ("chirp") approximately described by a group delay, versus frequency **f** as follows:

$$\tau(\mu s) = 1.34 \times \left(N \big/ 10^{17} m^{-2} \right) \times \left(f \big/ 100 MHz \right)^{-2}$$

where **f** is the radio frequency and **N** is the line-of-sight-integrated **T**otal **E**lectron **C**ontent (slant **TEC**).

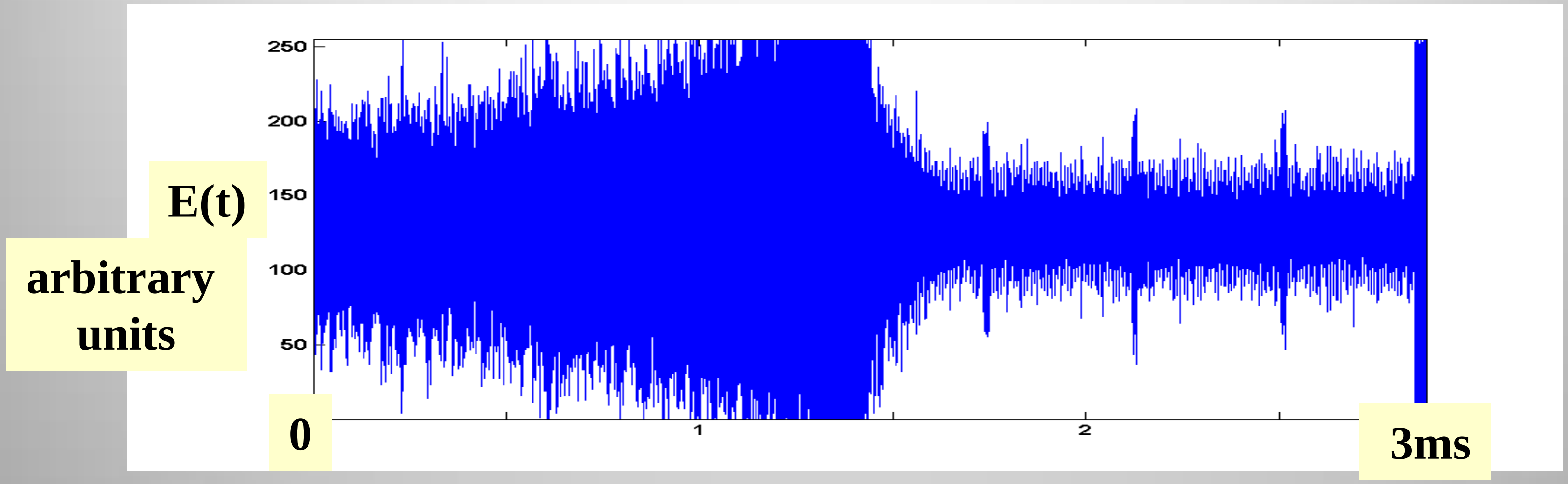
TEC=0.8 × 10^{17} m^{-2}





“Noise”

R/S analysis of "noise" detected by "Chibis-M"



$E(t_k) = E_k$-discrete data set with $k \in [1; N]$

$$R_N = E_{max} - E_{min}$$

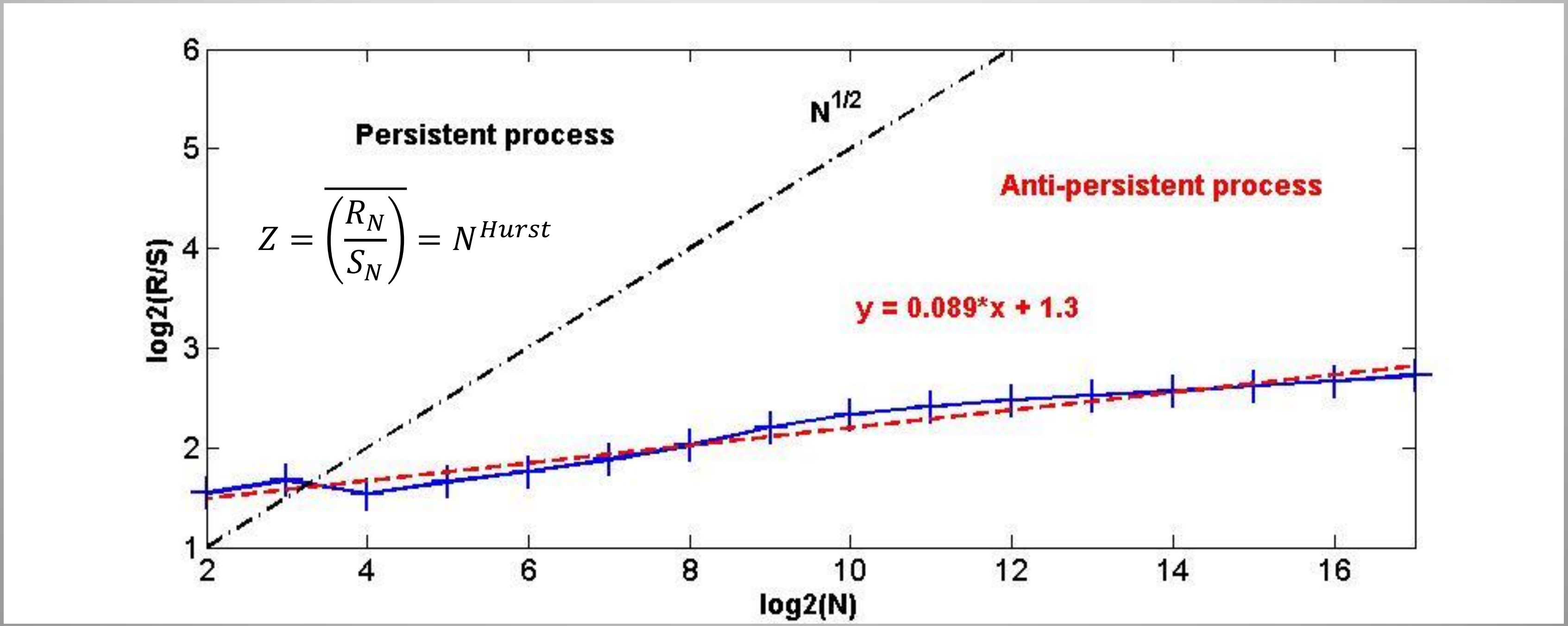
$$\overline{E} = \frac{1}{N}\sum_{k=1}^{N} E_k$$ mean value

RMS value $$S_N = \left[\frac{1}{N-1}\sum_{k=1}^{N}\left(E_k - \overline{E}\right)^2\right]^{1/2}$$

$$Z = \overline{\left(\frac{R_N}{S_N}\right)} = N^{Hurst}$$

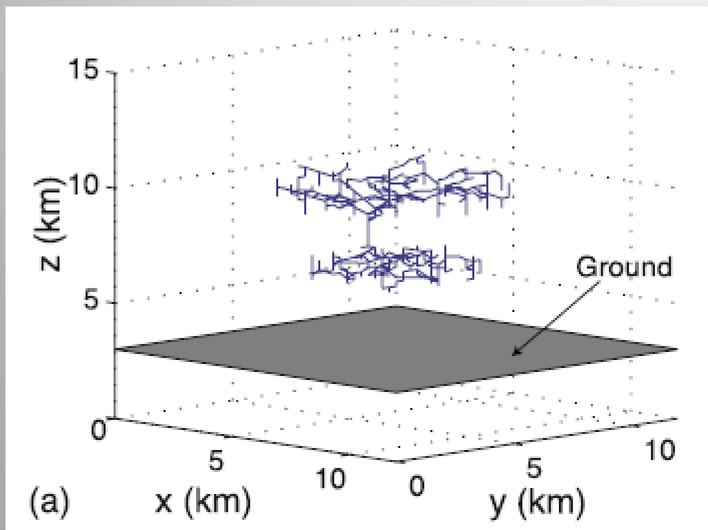
Sampling $N = 2^n$, $n \in [1,18]$ for 3 ms frame

The Hurst exponent describes the randomness of the statistical data set. When H $\in$[0.5; 1.0), the process contains persistence (its current amplitude depends on the pre-history), while H$\in$[0; 0.5) implies anti-persistence.



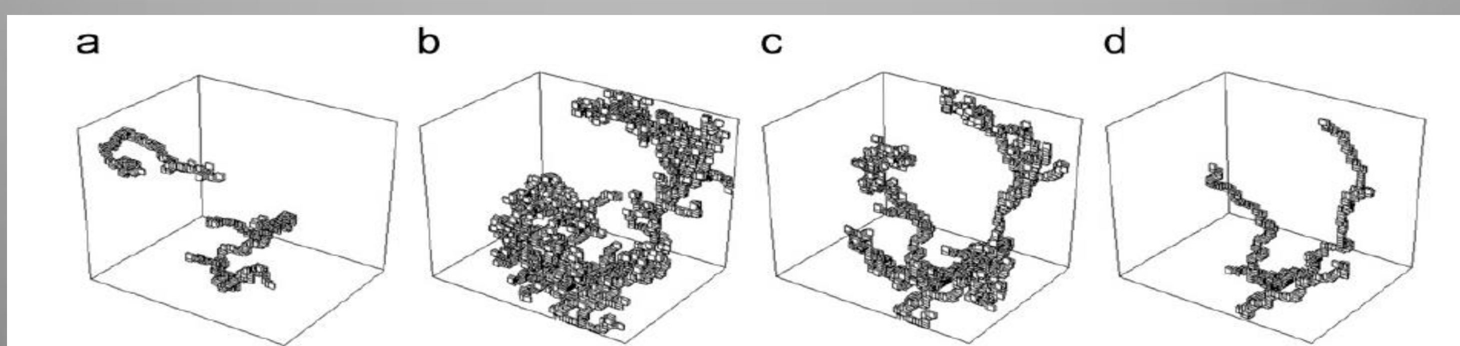
"Hurst"~0.08 indicates that VHF signal from lightning represents anti-persistent noise. It means that individual discharges are independent!

Riousset et al., (2007), Three-dimensional fractal modeling of intracloud lightning discharge in a New Mexico thunderstorm and comparison with lightning mapping observations, *JGR*, *112*(D15), D15203, doi:10.1029/2006JD007621.



adopted from google.com

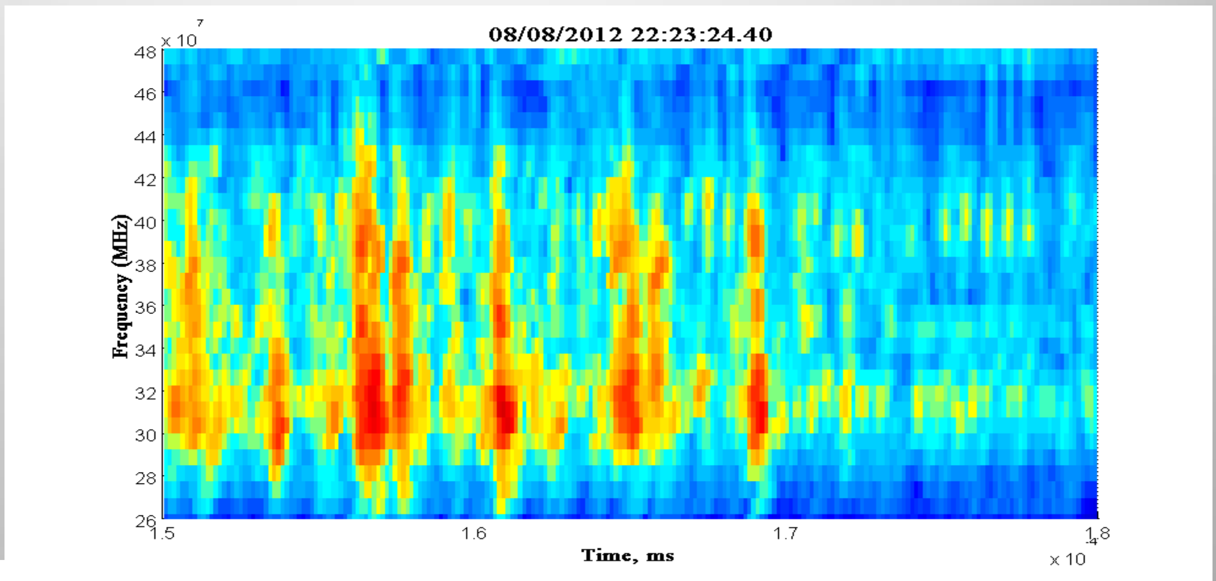
Hayakawa et al., (2008), Modeling of thundercloud VHF/UHF radiation on the lightning preliminary breakdown stage, *JASTP*, *70*(13), 1660–1668, doi:10.1016/j.jastp.2008.06.011.



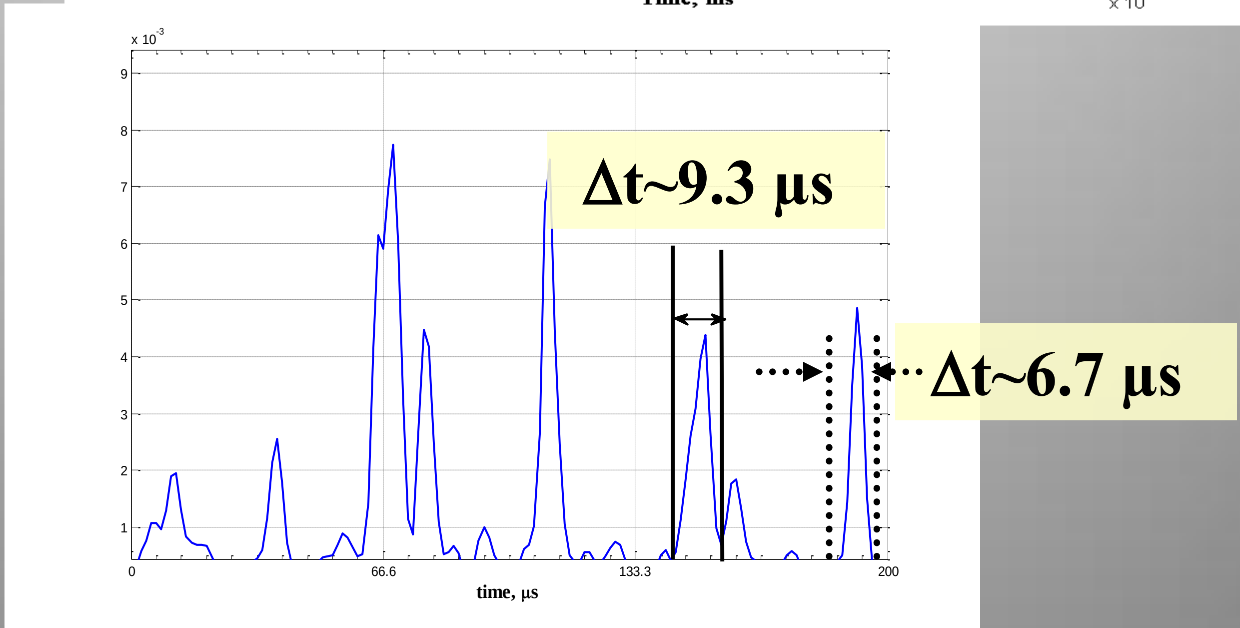
“Bursts”

Impulse duration

1.6 ms frame



E(t)
arbitrary units



Probability of CID as a function of local time

85 events **(Alexis)**

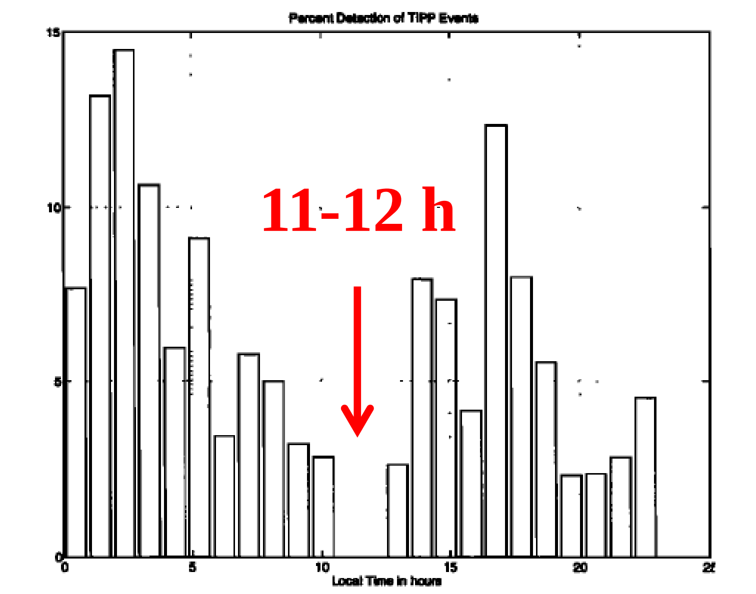
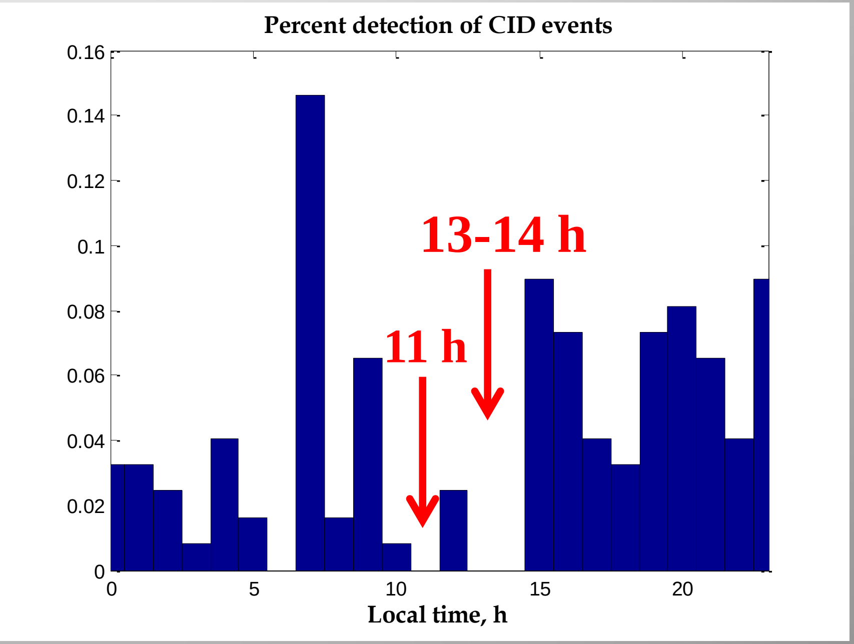


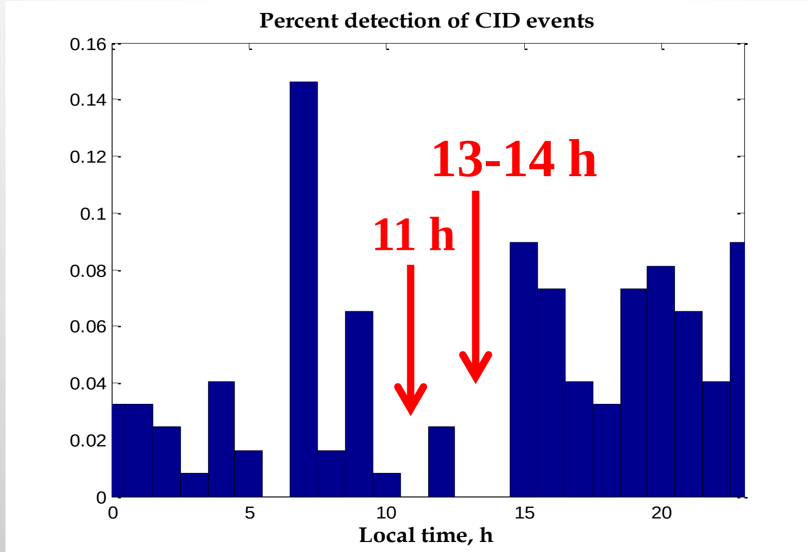
Figure 4. Probability (expressed as a percentage) of collecting a TIPP event in one minute as a function of local time at the sub-satellite point, for latitudes within 8° of the equator.

158 events **("Chibis-M")**



Latitudes |λ|<25°

Holden et al., (1995), Satellite observations of transionospheric pulse pairs, *GRL*, *22*(8), 889–892, doi:10.1029/95GL00432.



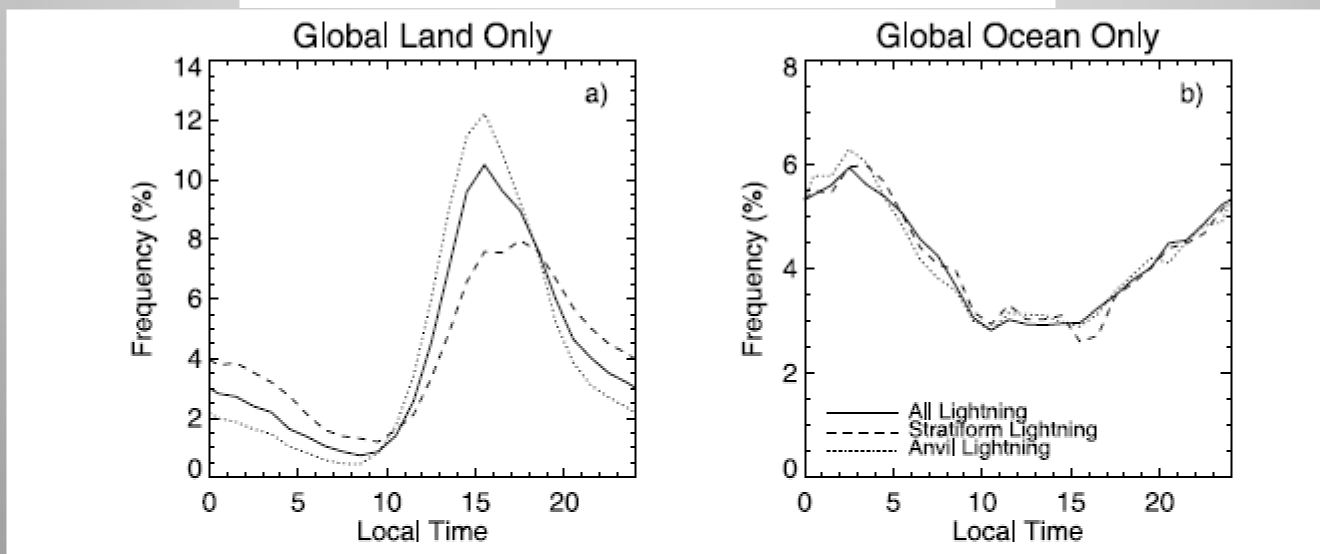
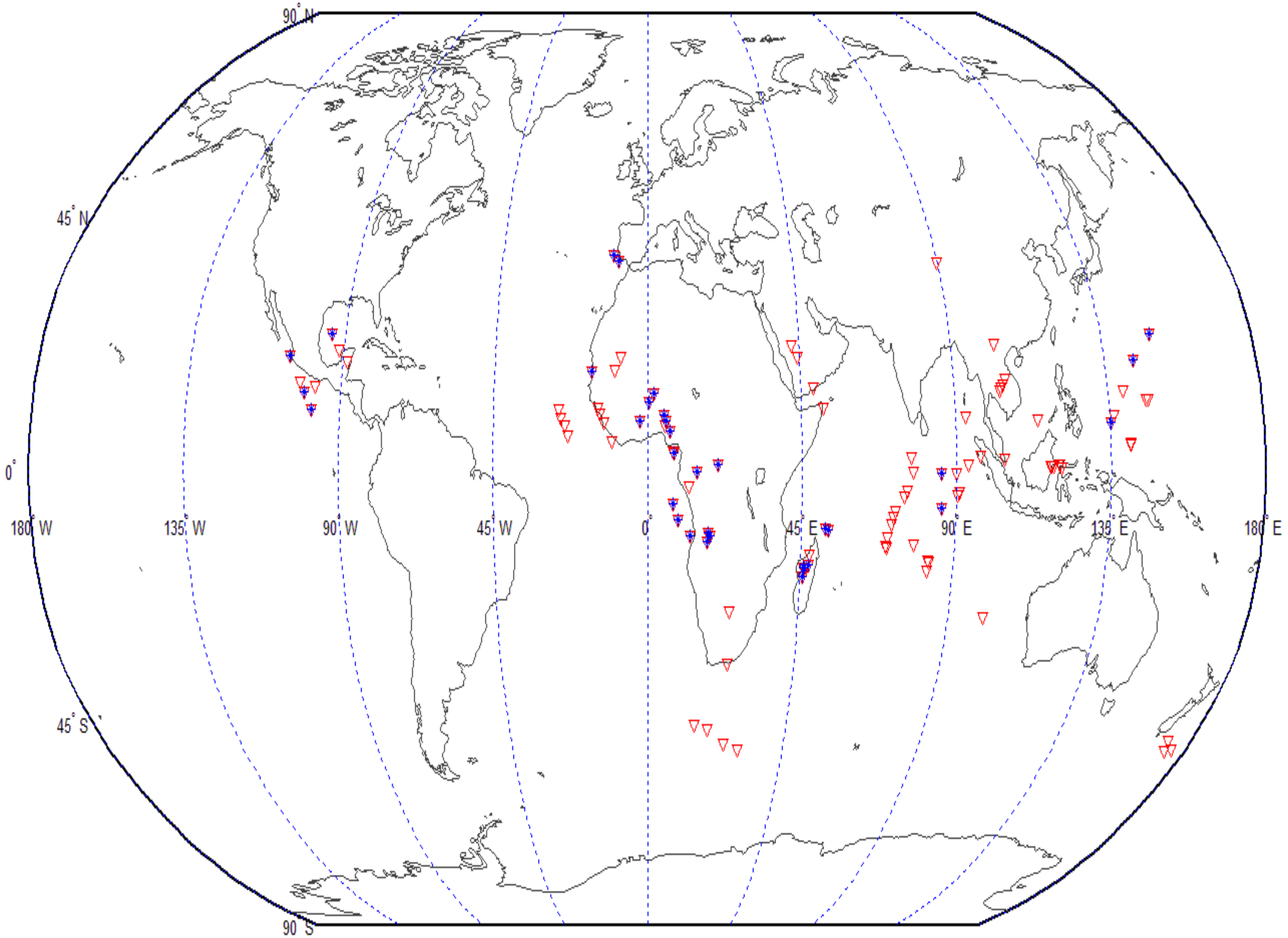
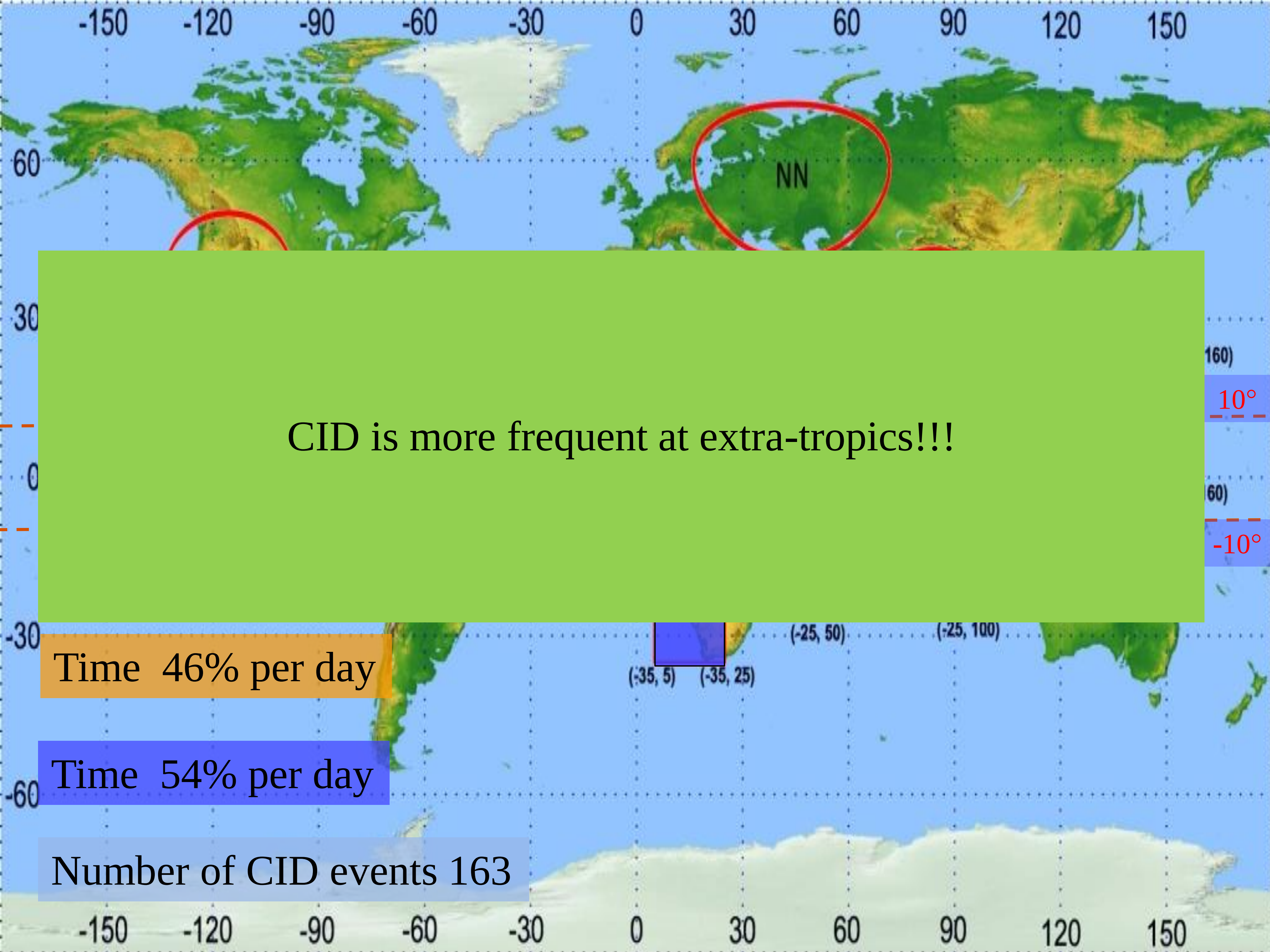


Figure 4. Diurnal cycles of all lightning, stratiform flashes, and anvil flashes over (a) land and (b) oceans.

Peterson, M., and C. Liu (2011), Global statistics of lightning in anvil and stratiform regions over the tropics and subtropics observed by the Tropical Rainfall Measuring Mission, *JGR*, *116*(D23), D23201, doi:10.1029/2011JD015908.

Map of detected events





CID is more frequent at extra-tropics!!!

Time 46% per day

Time 54% per day

Number of CID events 163

Global statistics of lightning over the tropics and subtropics observed by TRMM

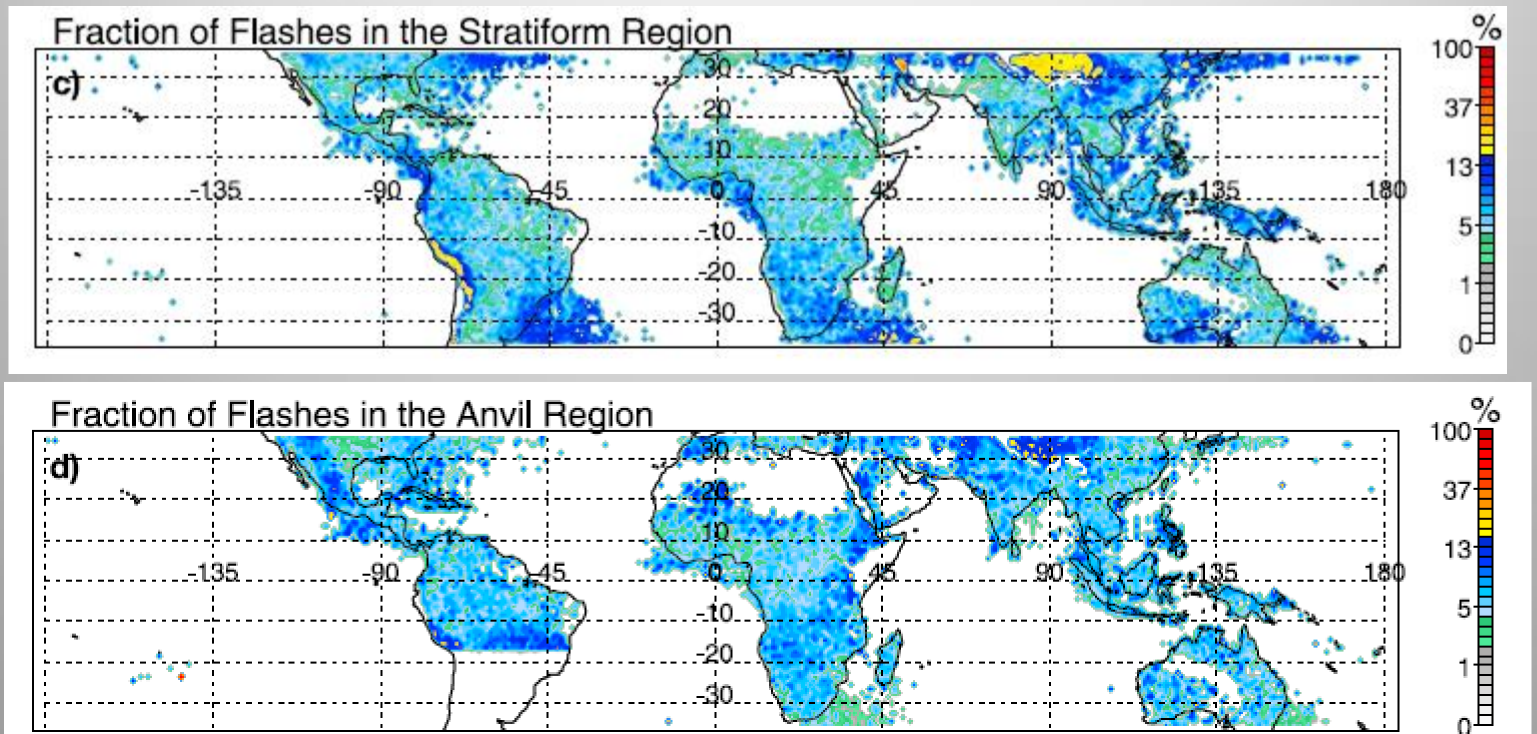
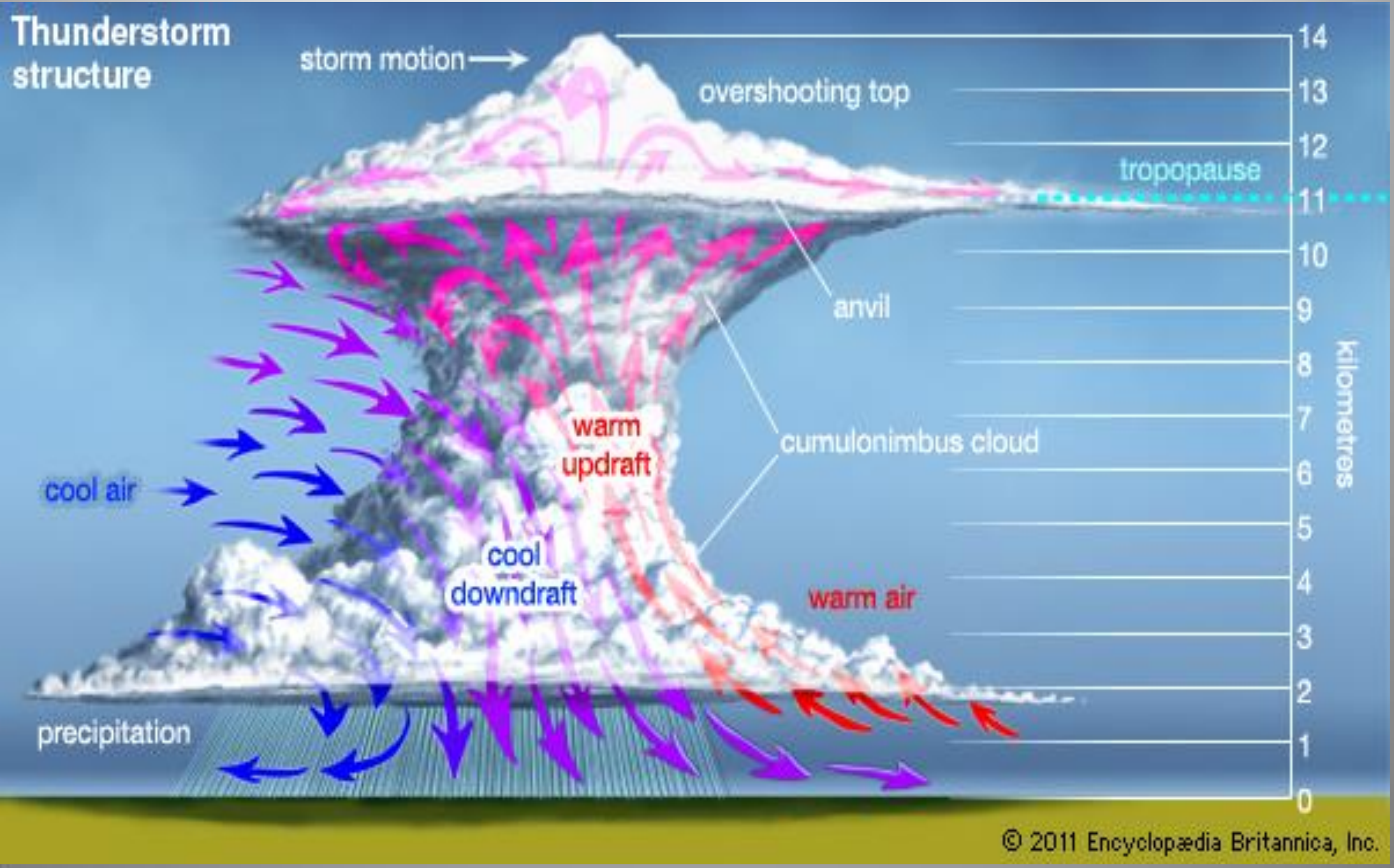


Figure 2. Global distribution of (a) lightning flashes and (b) the fractions of flashes in regions that do not meet the 30 dbZ at 6 km Larsen area definition, (c) flashes in the stratiform region, and (d) anvil lightning flashes in 1° by 1° bins. Bins with insignificant numbers of flashes are set to 0 in Figures 2b, 2c, and 2d. Note that, owing to a lack of PR observations over central-west Australia, no flashes are shown in this region.

Peterson, M., and C. Liu (2011), Global statistics of lightning in anvil and stratiform regions over the tropics and subtropics observed by the Tropical Rainfall Measuring Mission, *JGR*, *116*(D23), D23201, doi:10.1029/2011JD015908.

Thunderstorm structure



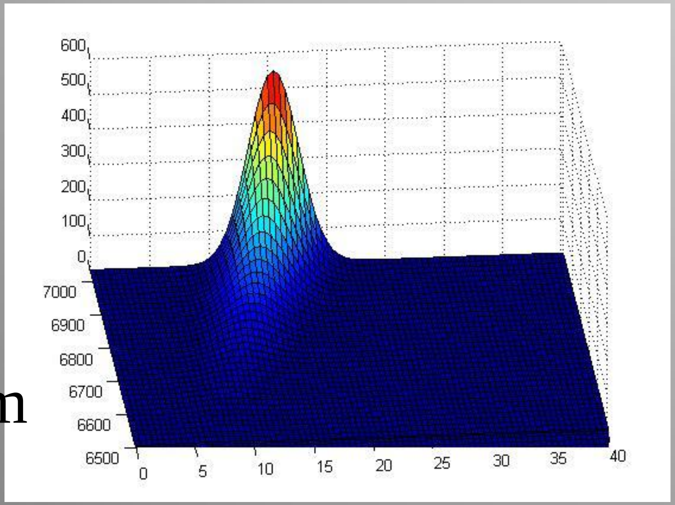
Estimation of “burst” parameters

If we assume that

$$i(z,t) = A\, e^{(z-H_1)/\gamma} \cdot e^{-\left(\alpha\left(t-t_1-\frac{z-H_1}{v}\right)/k\right)^2}$$

This model represents thermal electrons moving upward with exponential increase of the current along the channel . This model is motivated by the exponential increase in charge carriers associated with the runaway breakdown mechanism (*Thottappillil et al., 1997, Watson, S. S., T. C. Marshall 2007, Nag and Rakov, 2009-2010*).

H, m

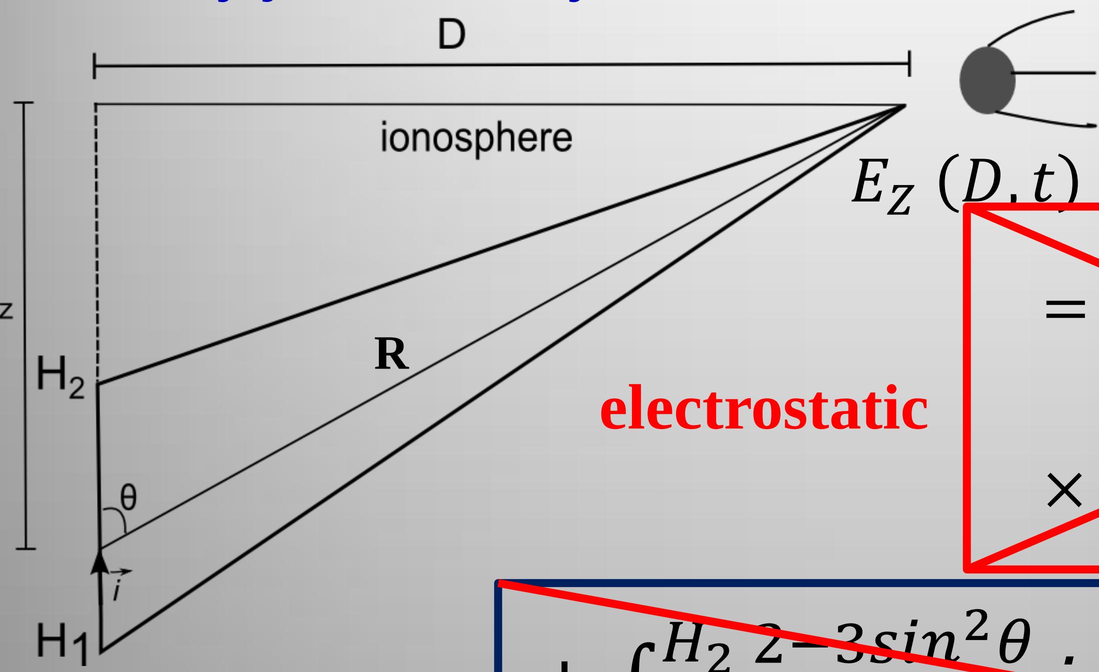


μs

γ=100 m, total duration t_2=30 μs,
α=10/t_2, zero-to-peak risetime t_2=5 μs
pulse velocity $v = 6 * 10^7$ m/s

⇒ Current peak ~ 50 kA

The radiated electric field, deduced from Maxwell's equations resulting from a discharge current density j and seen by a remote observer at time t is given,



$$E_Z(D,t) = \frac{1}{2\pi\varepsilon_0}\left[\int_{H_1}^{H_2}\frac{2-3sin^2\theta}{R^3} \times \int_0^t i\left(z,\tau-\frac{R}{c}\right)d\tau dz + \cdots\right.$$

electrostatic

$$+\int_{H_1}^{H_2}\frac{2-3sin^2\theta}{cR^2}\,i\left(z,\tau-\frac{R}{c}\right)dz + \cdots$$

induction

$$\left. + \int_{H_1}^{H_2}\frac{2sin^2\theta}{cR}\,\frac{\partial i(z,\tau-\frac{R}{c})}{\partial t}dz\right]$$

radiation term

Conclusions

In the data of Radio Frequency Analyzer onboard of "Chibis-M" two classes of phenomena could be clearly revealed:

1. **VHF "noise"** with duration from hundreds of microseconds up several milliseconds. Small value of Hurst exponent (~ 0.08) obtained from R/S analysis of the data set indicates that data represents anti-persistent noise. It means that individual discharges are independent.
2. **Wideband bursts** (Compact Intercloud Discharges) with duration ~ several μs. Typical current in CID might be estimated as ~ tens of kA.
3. Global diurnal probability of this bursts have gaps at 11 AM and 1-2 PM of the local time.
4. In extra-tropical regions ($10° < \lambda < 25°$, both hemispheres) CID are more frequent.

Շնորհակալություն ուշադրության համար !