Broadband VHF Interferometer Observations of an Energetic In-cloud Pulse (EIP)

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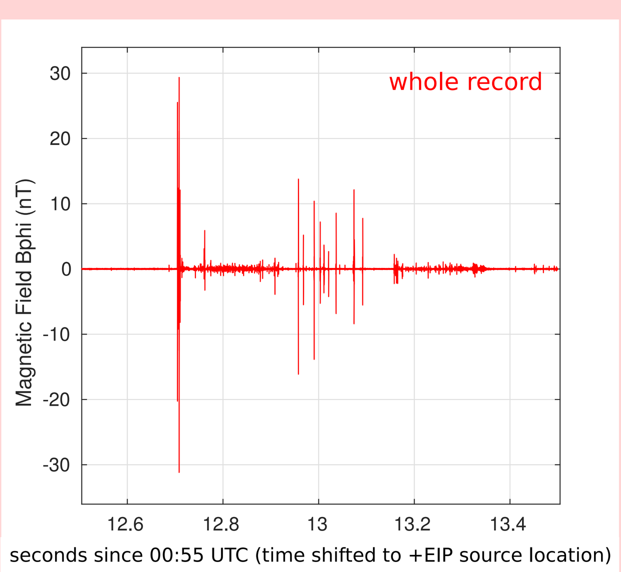
ABSTRACT: Energetic in-cloud pulses (EIPs) are a little-known in-cloud subprocess of lightning. While they may be best identified by their large peak current (>200 kA) [Lyu et al., Geophys. Res. Lett., 42, 2015], they differ from narrow bipolar events (NBEs) -- another type of in-cloud, high peak-current process -- in that the sferic of an EIP lasts an order of magnitude longer (~100 us) than that of a typical NBE (~10 us). To further differentiate them from NBEs, EIPs are generally embedded within other electrical activity, whereas NBEs are known to primarily occur in isolation or as a lightning-initiating event [Smith et al., J. Geophys. Res., 104, D4, 4189-4212, 1999; Rison et al., Nat. Commun., 7, 10721, 2016]. Moreover, EIPs may have an intrinsic connection with the production of terrestrial gamma ray flashes (TGFs) [Cummer et al., Geophys. Res. Lett., 41, 8586-8593, 2014].

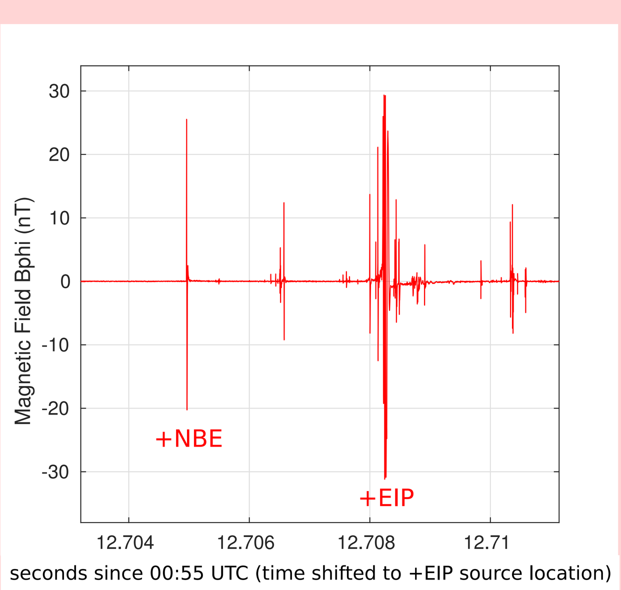
Here we present coincident broadband VHF interferometer (INTF) observations and electric and magnetic field waveforms of an EIP with an associated NLDN peak current of 247 kA. The EIP occurs nearly 4 ms into a normal-polarity intracloud flash as part of the upward extension of the negative-polarity lightning leader. For this reason, we suspect that EIPs are a more energetic version of initial breakdown pulses (IBPs), which accompany the development of negative stepped leaders [e.g. Marshall et al., J. Geophys. Res. Atmos., 119, 445-460, 2014]. In addition, we show similarities with NBE-producing fast breakdown [Rison et al., 2016; Tilles et al., AE12A-03, AGU Fall Meeting, 2016], in that the breakdown accompanying the EIP propagates over a similar vertical extent (~0.5-1 km) and with similar propagation speed (~3x10^7 m/s).

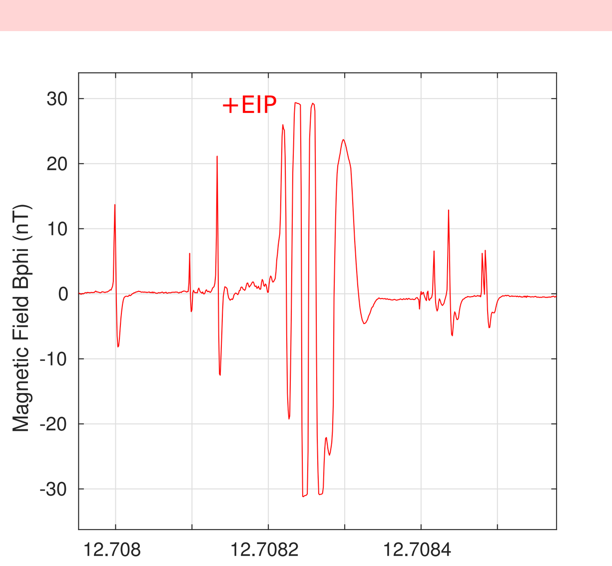
The INTF was developed by New Mexico Tech and has been deployed at Kennedy Space Center since July 2016. It employed three 100-m baselines in 2016, has a bandwidth of 14-88 MHz and samples at 180 MS/s with 16-bit resolution. A synchronously digitized fast antenna (FA), with 100-us decay time constant, samples the electric field, and the whole INTF+FA system is automatically triggered on strong VHF radiation. Coincident VLF/ LF (1-300 kHz, sampled at 1 MS/s) observations are made with Duke University's magnetic sensor network.

EIP detection

A +EIP was identified by large NLDN peak current (>200 kA) with NLDN location (28.3033°, -80.4739°), making it less than 40 km away from Duke's low-frequency (LF) sensor located at Florida Institute of Technoldy (FIT). The LF sensor confirmed the large

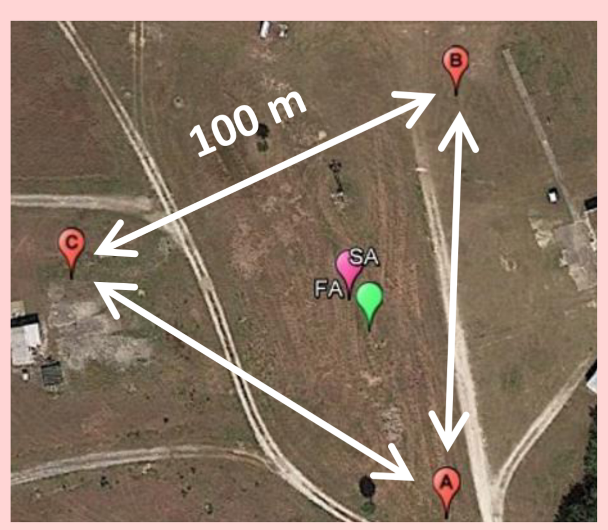




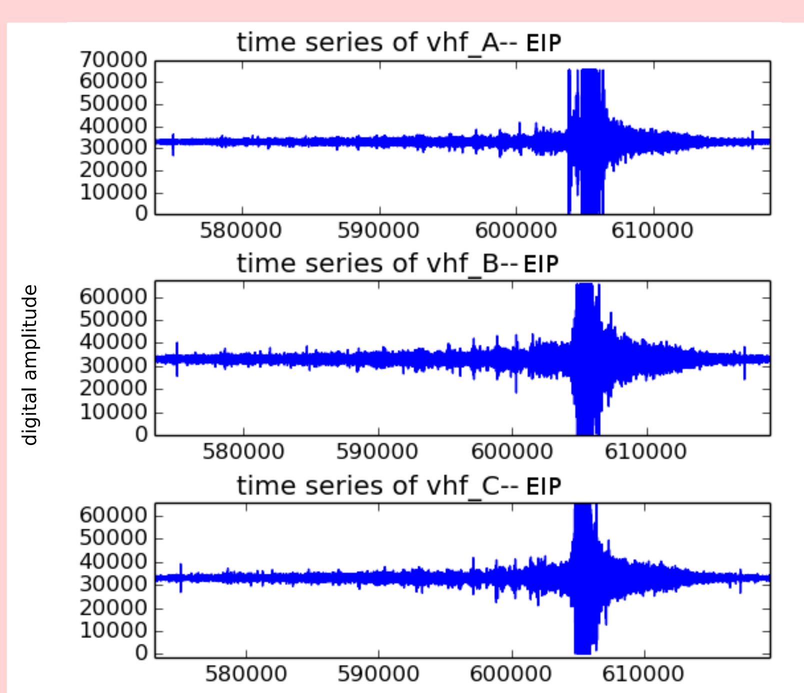


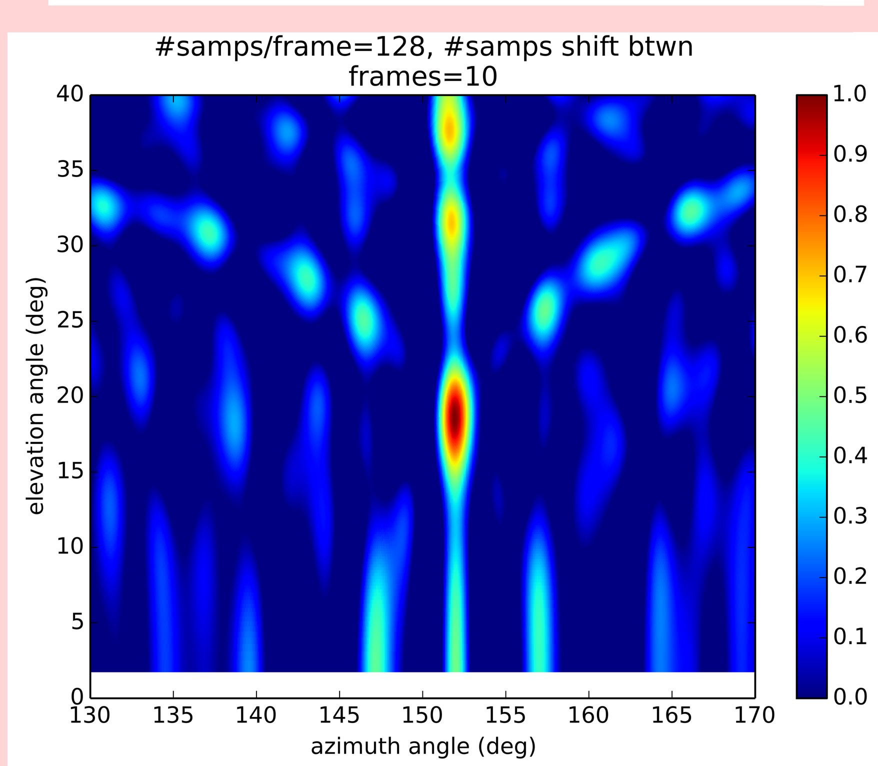
Broadband VHF interferometer (INTF) imaging/ mapping

Fourier synthesis imaging [c.f. Stock et al., J. Geophys. Res. Atmos., 119, 3134–3165, 2014] is employed to make 0.7-us exposure images of lightning sources.



The location of the brightest pixel in the image is designated as the source centroid.





By locating the centroids of sequential frames, we map the evolution of the source over time.

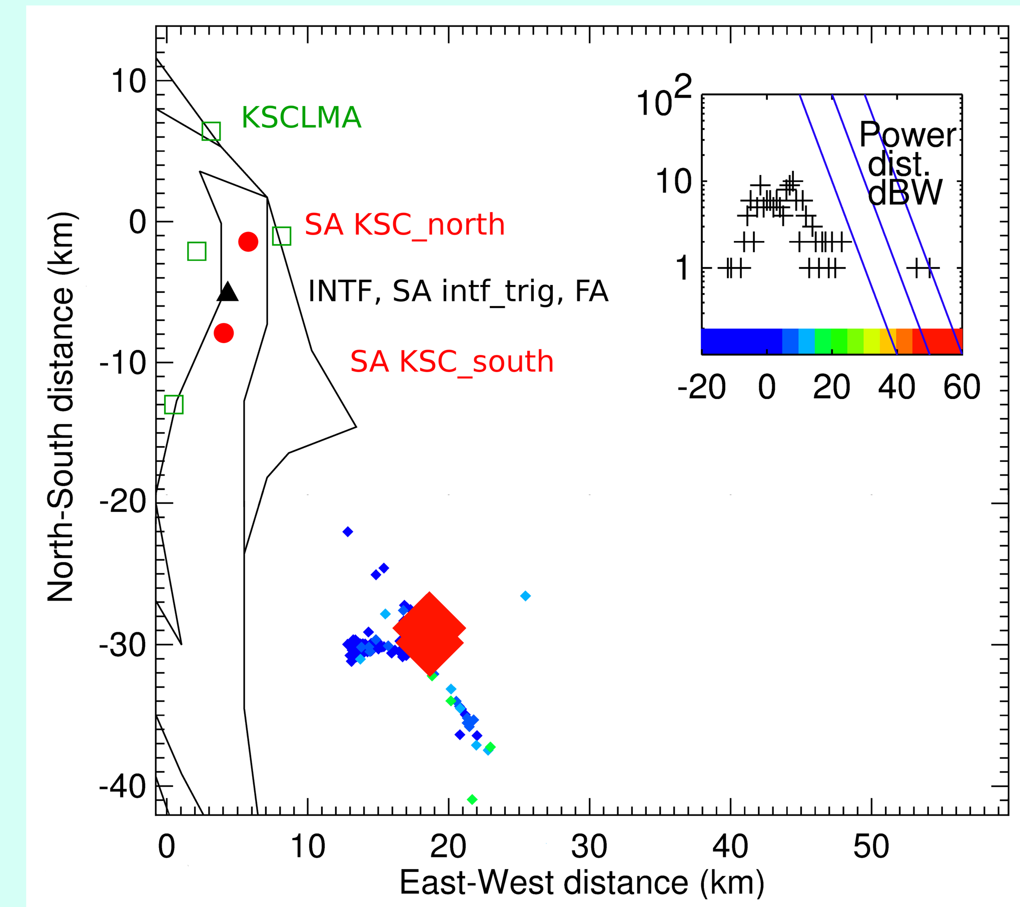
Event overview

The +EIP took place during a normal-polarity intracloud lightning flash, approximately 27 km away from the interferometer (INTF).

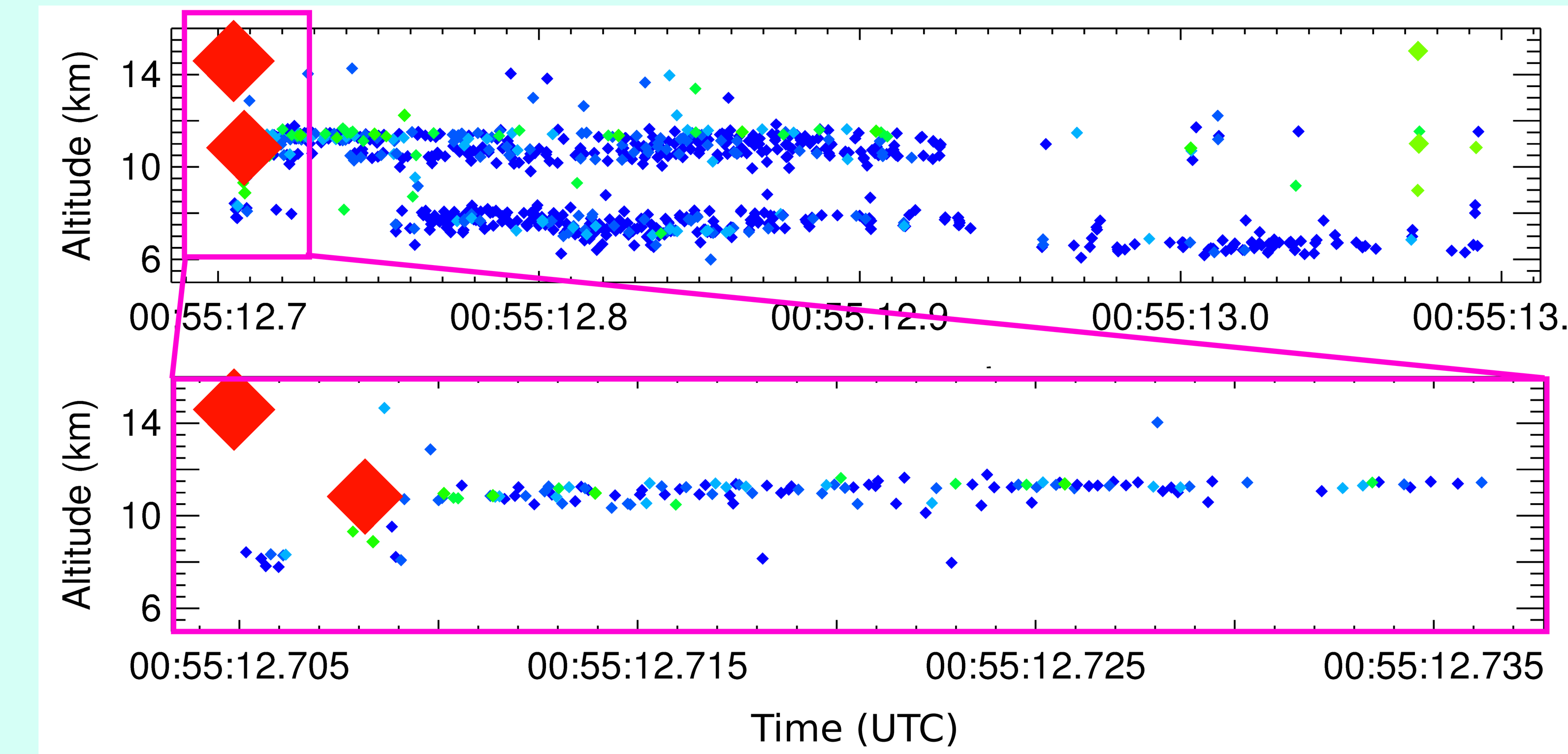
LMA and INTF sources are coloured/ sized by emitted and received VHF power, respectively.

The 1st large, red diamond in the KSCLMA data depicts a flash-initiating +NBE, followed 3 ms later by a 2nd large, red diamond, which depicts the EIP.

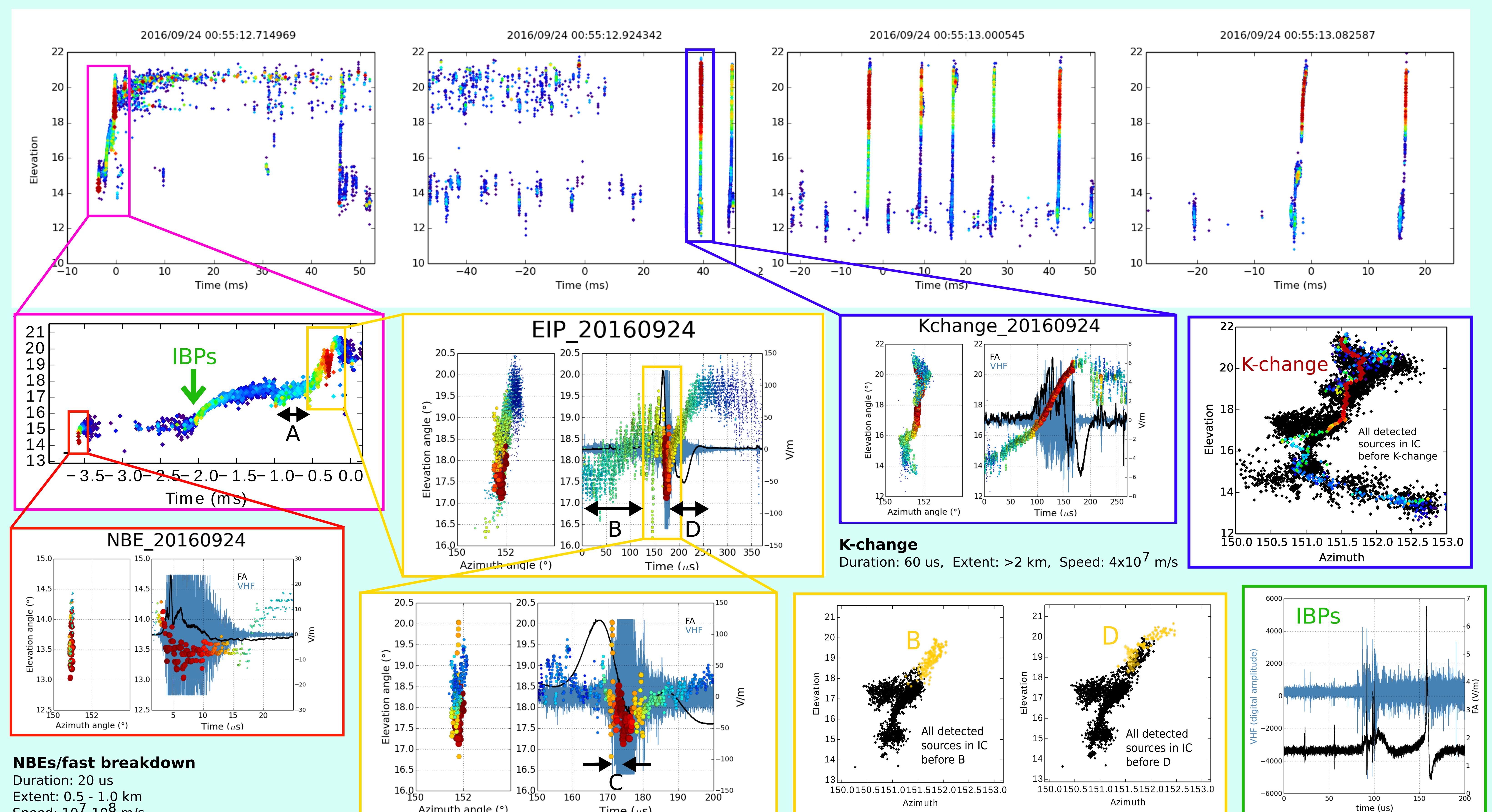
Other example of fast/ impulsive processes are shown in the INTF data below for comparison with the EIP.



Kennedy Space Center Lightning Mapping Array (KSCLMA)



Interferometer (INTF) record



K-change
Duration: 60 us, Extent: >2 km, Speed: 4x10^7 m/s

NBEs/fast breakdown
Duration: 20 us
Extent: 0.5 - 1.0 km
Speed: 10^7-10^8 m/s
Current: 50-100 kA (typical)

Stepped Leaders (not shown)
Step duration: 1-2 us
Step extent: 50 meters
Step speed: 5x10^7 m/s
Current: >1 kA
[Rakov and Uman, p.7-8, Lightning: Physics and Effects, 2003]

Energetic In-cloud Pulse (EIP)
Duration: >100 us
Extent: ~1 km
A speed: 5x10^5 m/s --> typical (-) leader speed
B speed: 6x10^6 m/s
C speed: >3x10^8 m/s --> non-physical; possible branching/ multiple sources
D speed: 2x10^7 m/s --> into preconditioned channel
Current: 247 kA (NLDN peak current)

Conclusions

The sequence of events surrounding the EIP are as follows:

* A fast leader (6x10^6 m/s) travels upward over 1 km distance for 150 us into virgin air (event **B**).
* Subsequently, a large surge in current (FA signal) initiates, but is not accompanied by surge in VHF amplitude.
* 10 us later, a large surge in VHF amplitude initiates (event **C**), but the associated process is unclear.
* A recoil-like leader (2x10^7 m/s) traverses the previously-ionized channel (event **D**).

One unique feature in the event is that there is a significant delay between the rise in current and VHF amplitude, which is different from NBEs, stepped leaders, IBPs, and K-changes.

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