Uncharacteristically Slow Lightning Discharge Processes Observed Preceding Lightning Initiation

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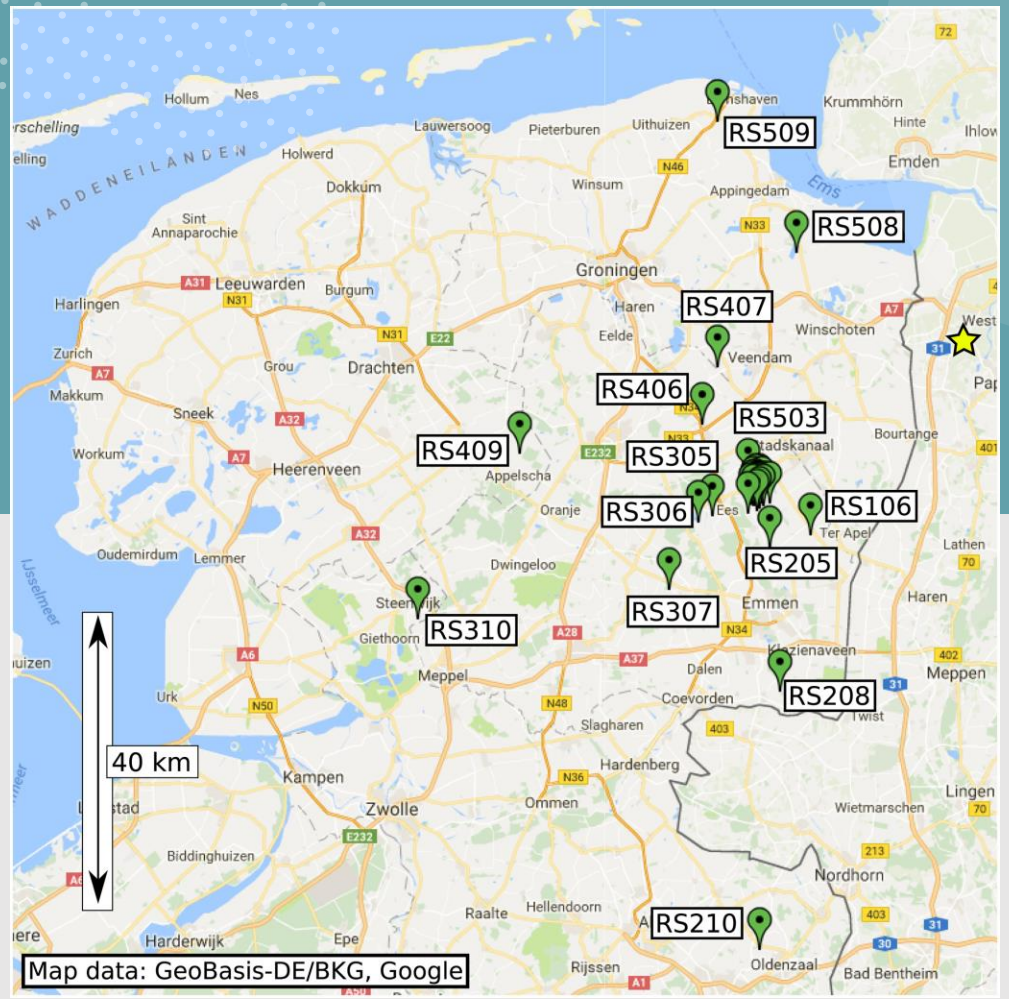
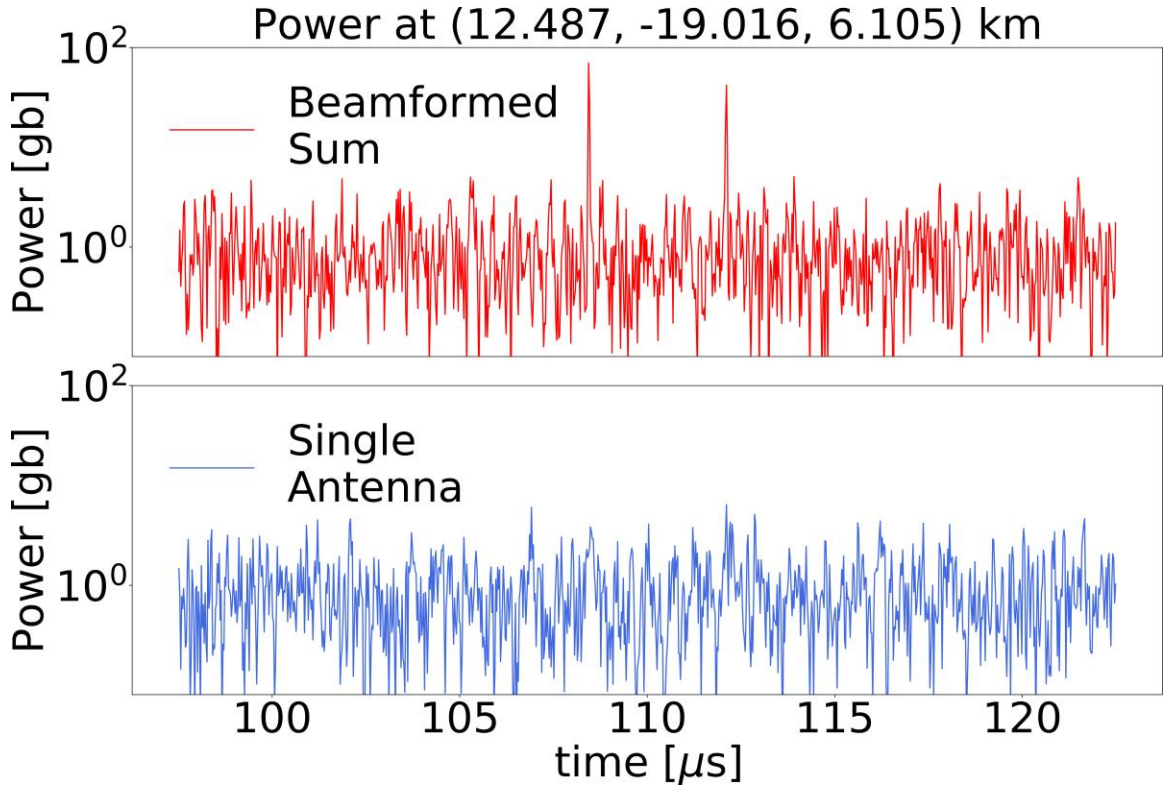
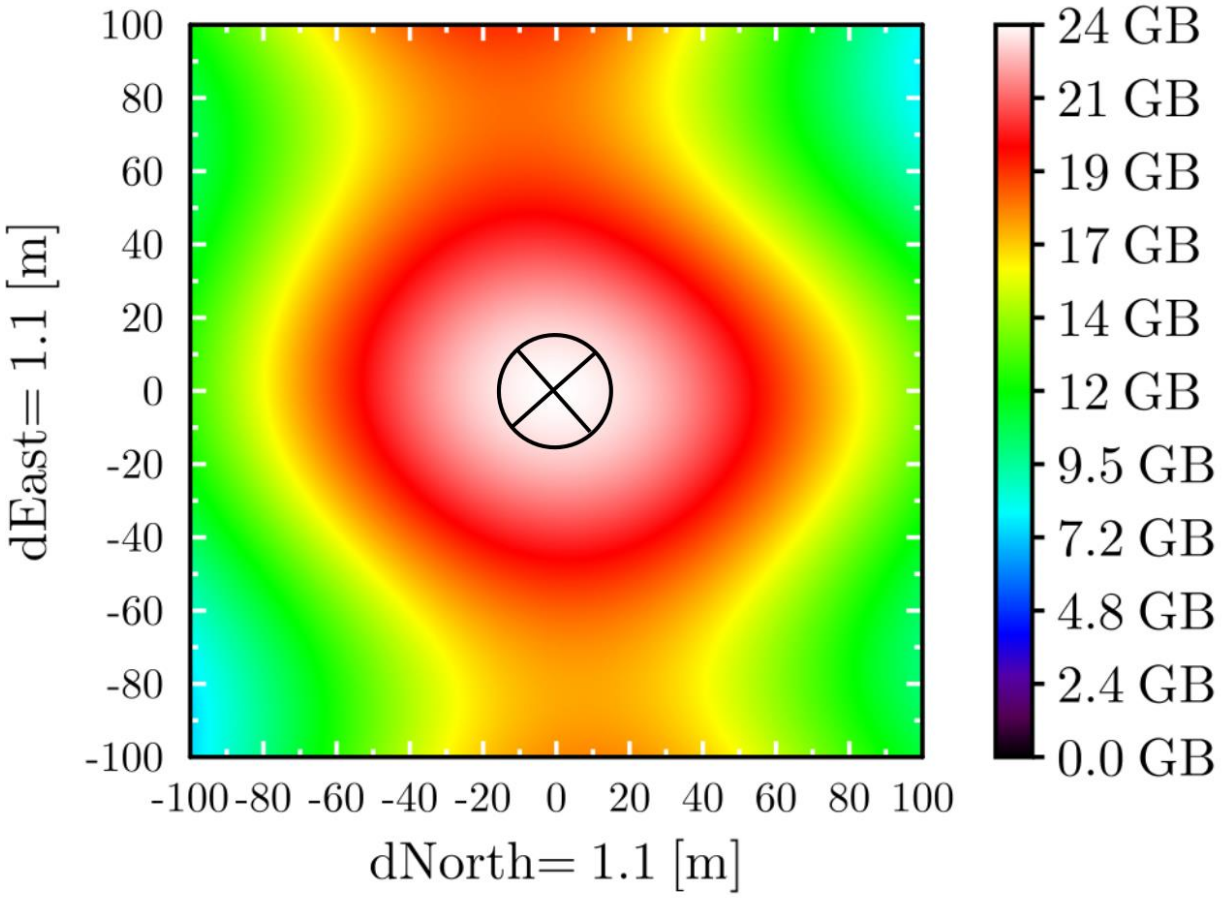


Image Credit: Hare et al 2018

LOFAR 3D Beamforming

Interferometric beamforming enables imaging sources below the noise level on individual antennas!





Scholten et al 2021a; Scholten et al 2021b

Study Background

Events found as a result of the LOFAR lightning **initiation studies**[1].

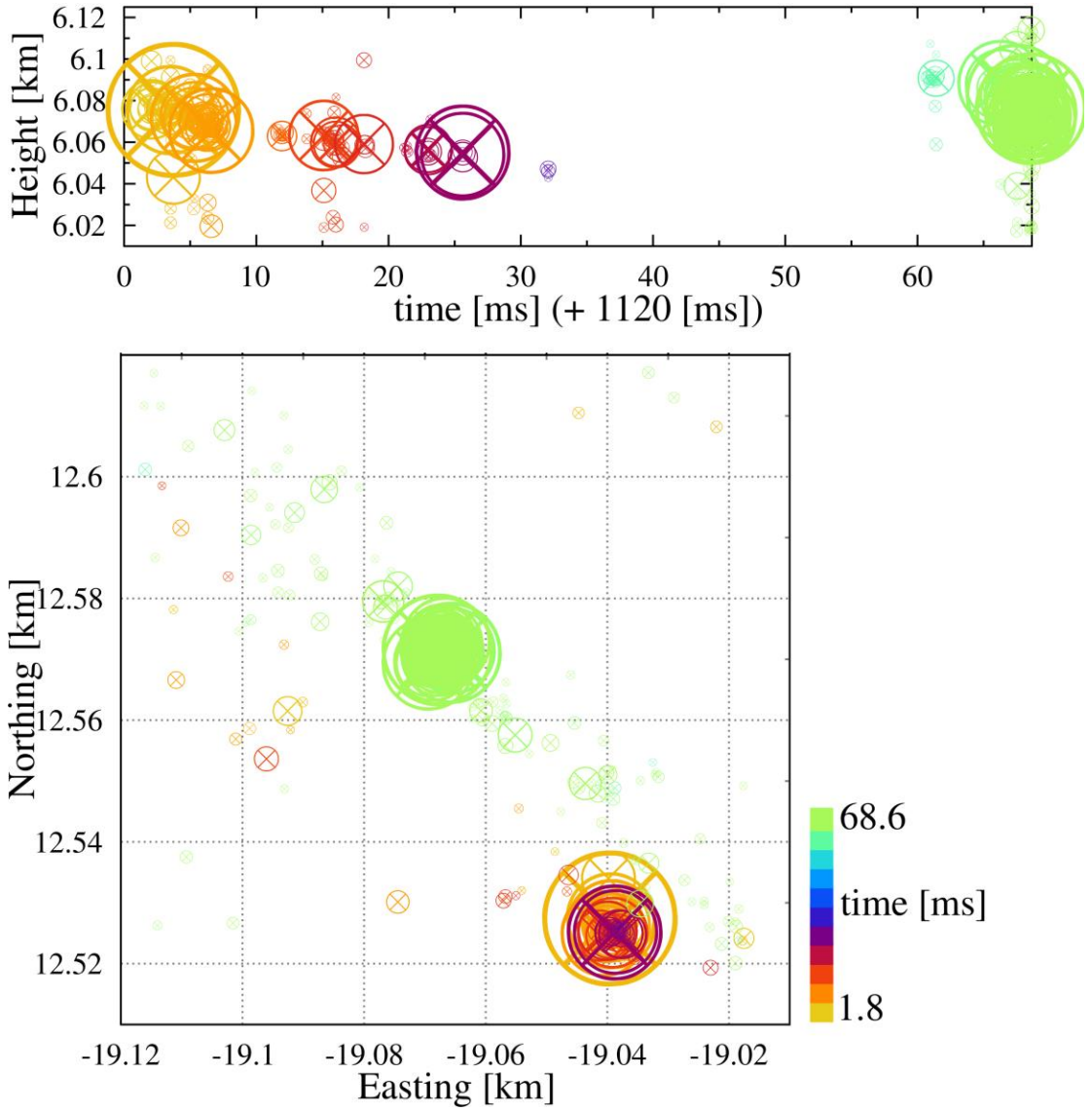
Discovered what first appeared **to be a failed initiation before the onset of leader.**

Events comprised of bursts which collectively propagate along a single trajectory.

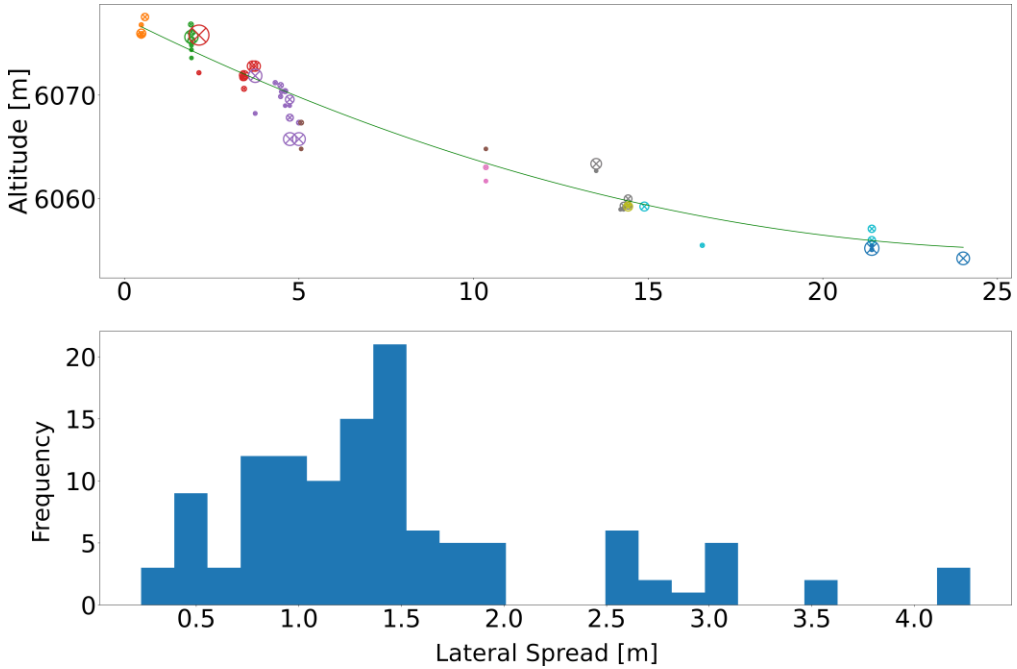
Observed events last for tens of milliseconds.

Events show signs of acceleration or deceleration and are fit **with** a **quadratic.**

Several events have been observed



Slow Discharge Observations

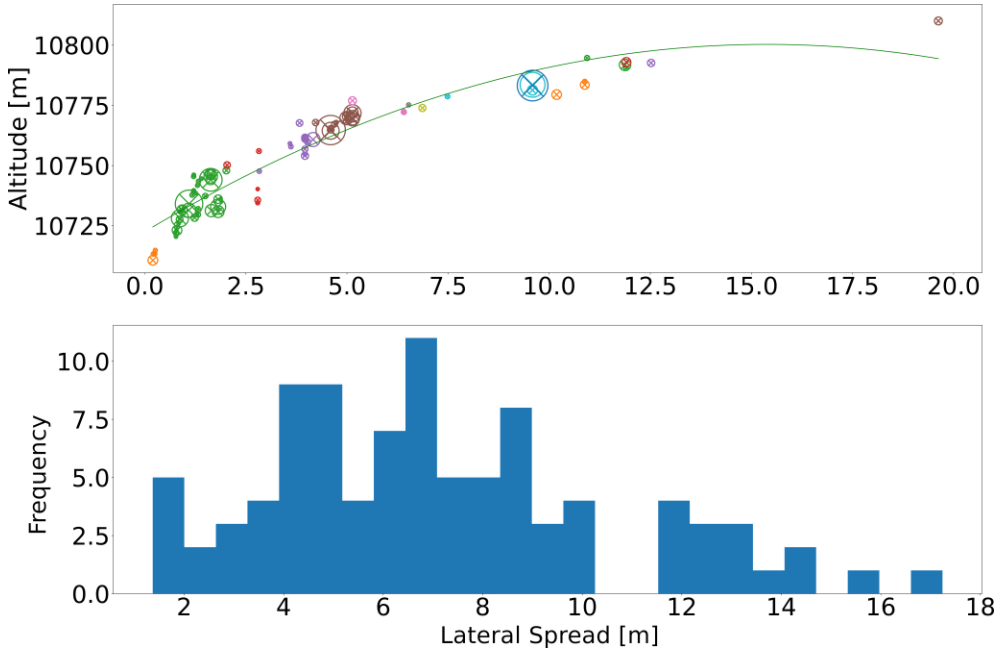


1.7 km/s starting speed that slows to 400 m/s! RMS: 1.4 m

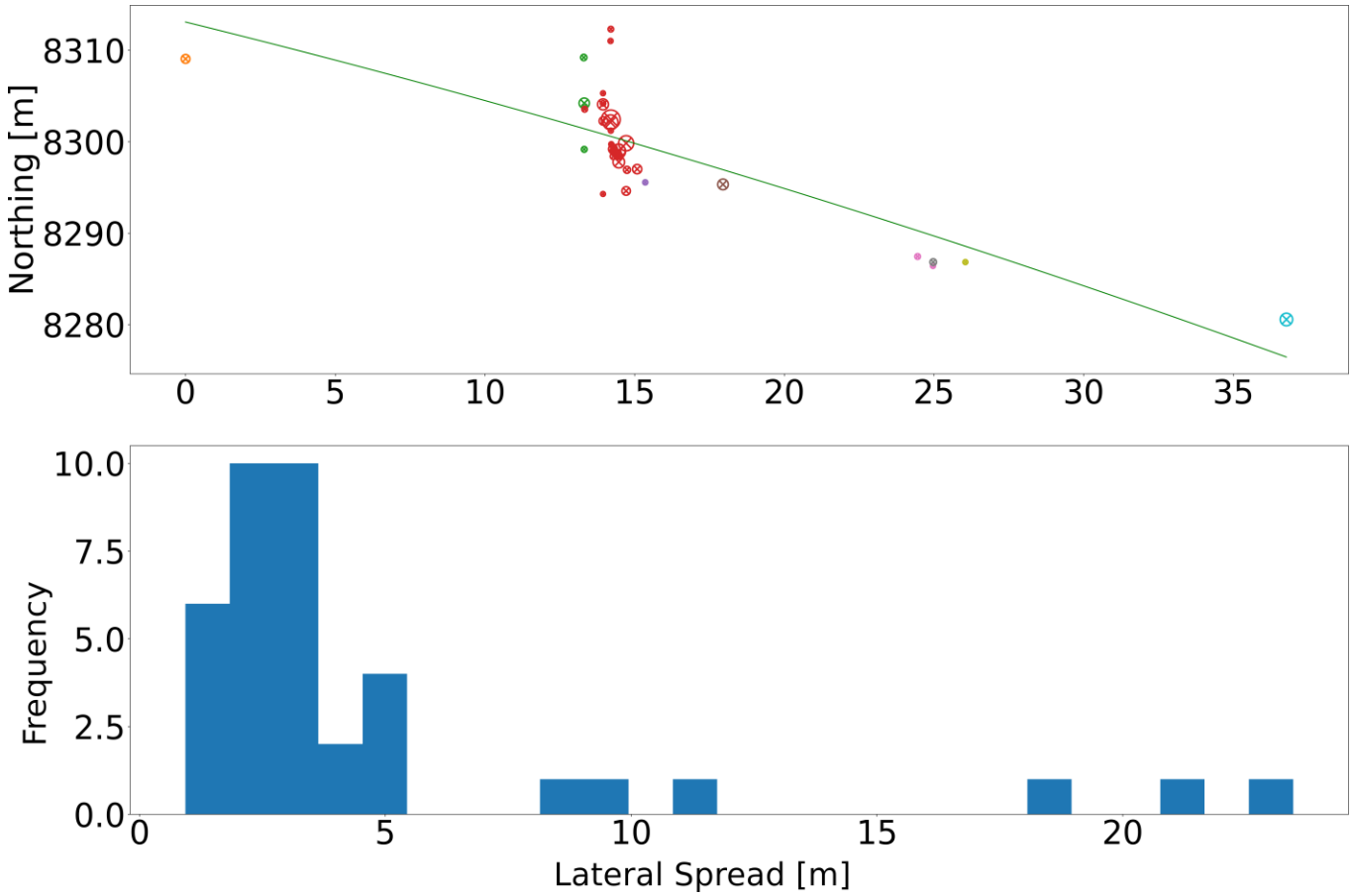
- Total distance traveled: 22 m.
- Possibly failed initiation.

Starting speed of 10 km/s ends with a speed of 2 km/s. RMS: 6.1 m

- Total distance traveled: 84 m.
- **Lightning initiation, nearly 1 second later, ≈100 m from slow discharge!**



Slow Discharge Observations (Continued)



Isolated event, no visible activity in this region within at least ±700 ms

- Starts with speed of 850 m/s ends with speed of 1.2 km/s
- Total distance traveled: 38 m
- RMS of about 4.1 m

Propagation is mainly along the North-South axis

Discussion

Velocities of 1-10 km/s are not indicative of normal lightning processes:

1. Not ion-diffusion, at least an order of magnitude too fast.
2. Not a typical streamer or leader process, far too slow!
3. Can be associated with an initiation event, but also can be hundreds of milliseconds after a discharge or even unconnected with observed discharges.
4. So what causes it?

Publication in preparation

References

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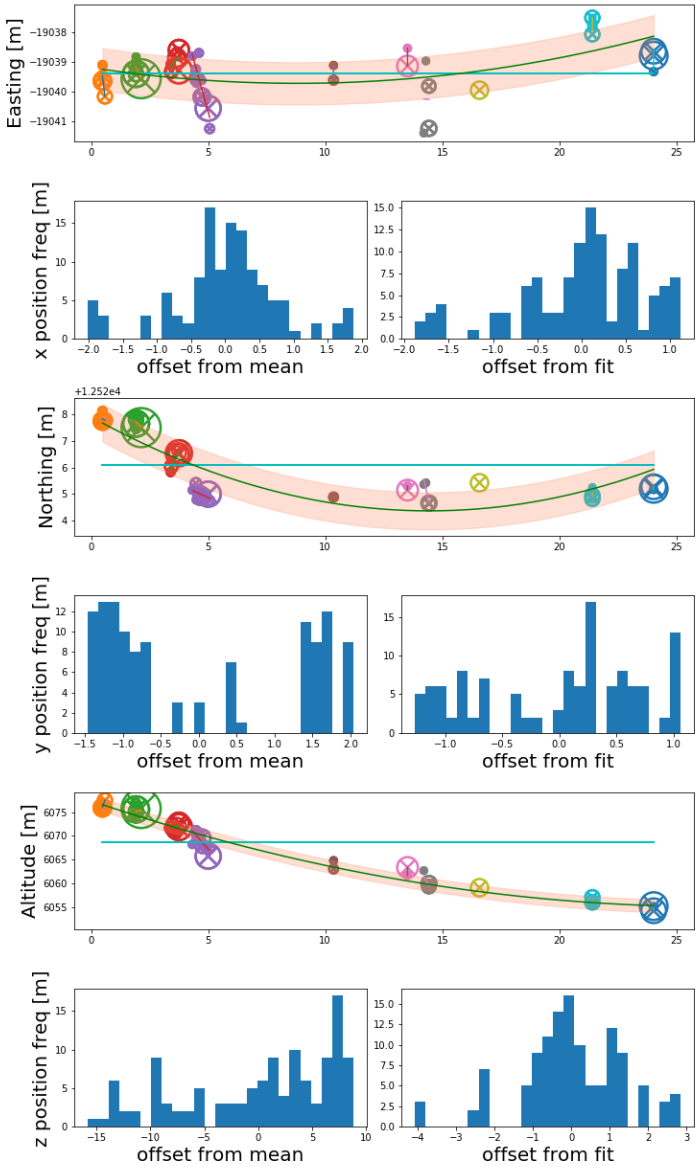
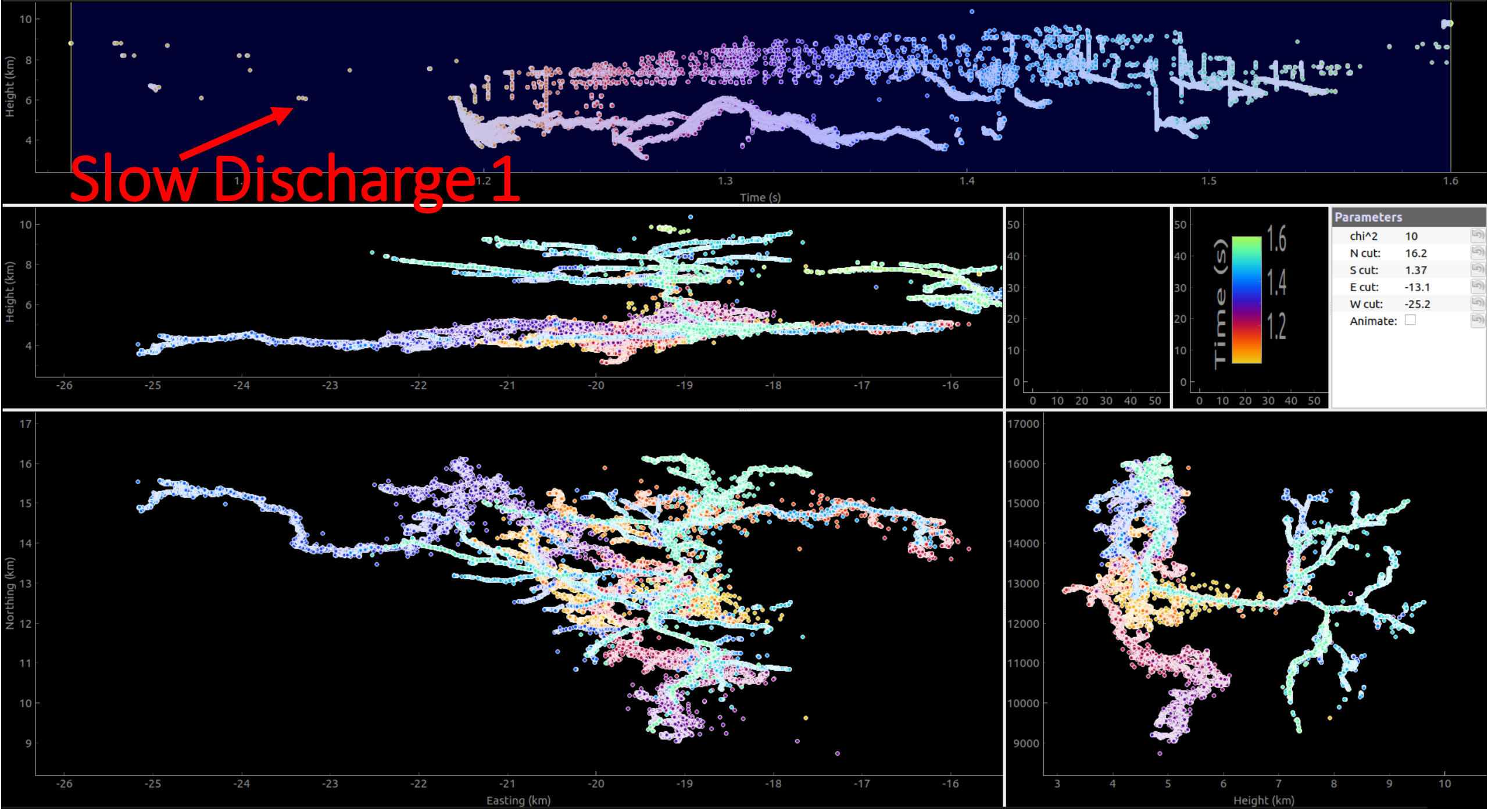
Supporting Slides

Mean overall accellerations x, y, z: [13745.8 ± 1.43] [34227.78 ± 1.42] [62850.0 ± 2.7
v0-vf speeds x, y, z: [-120.9 -> 202.63] [-494.09 -> 311.51] [-1675.78 -> -196.52]



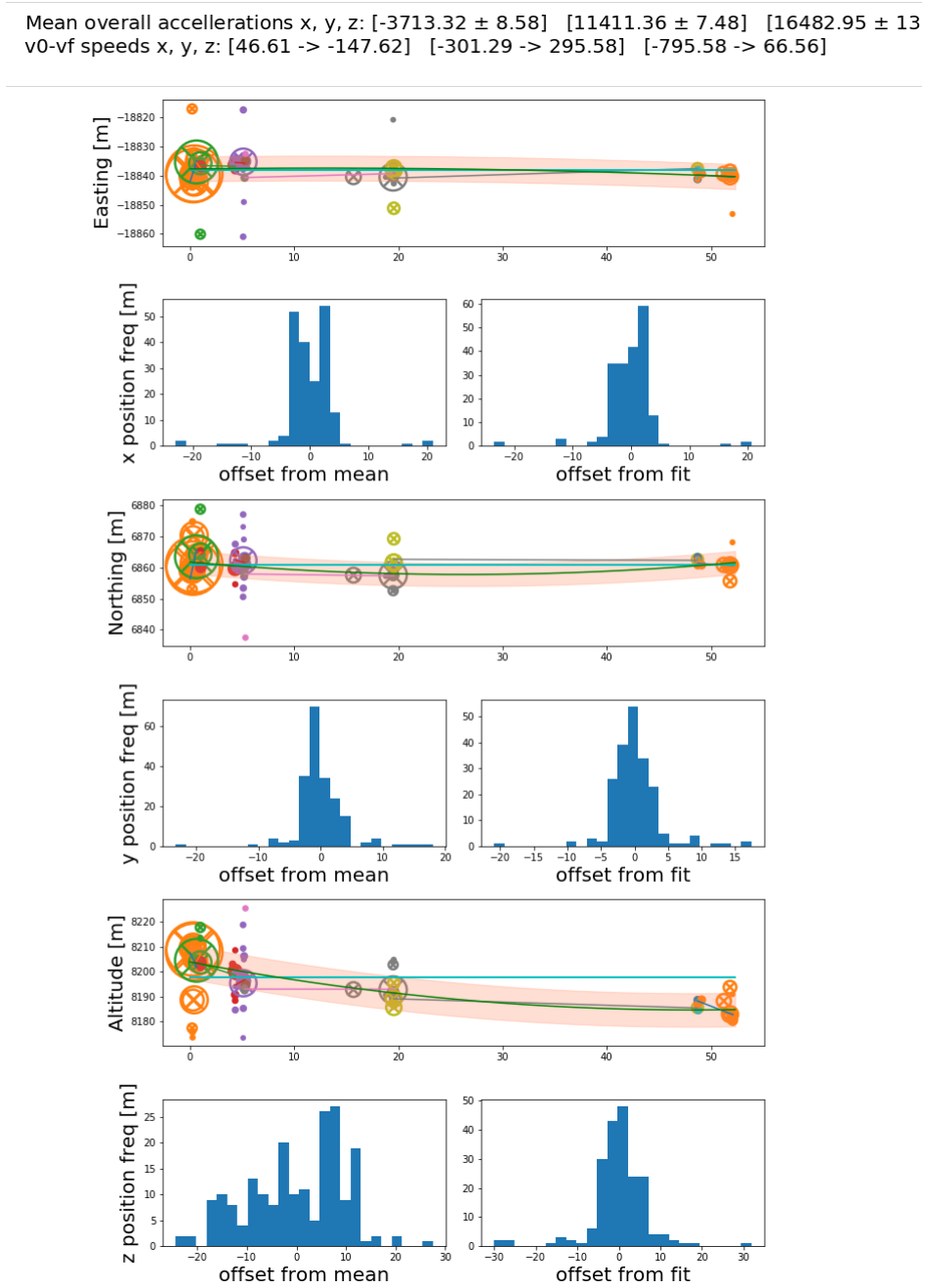
Slow Discharge 1

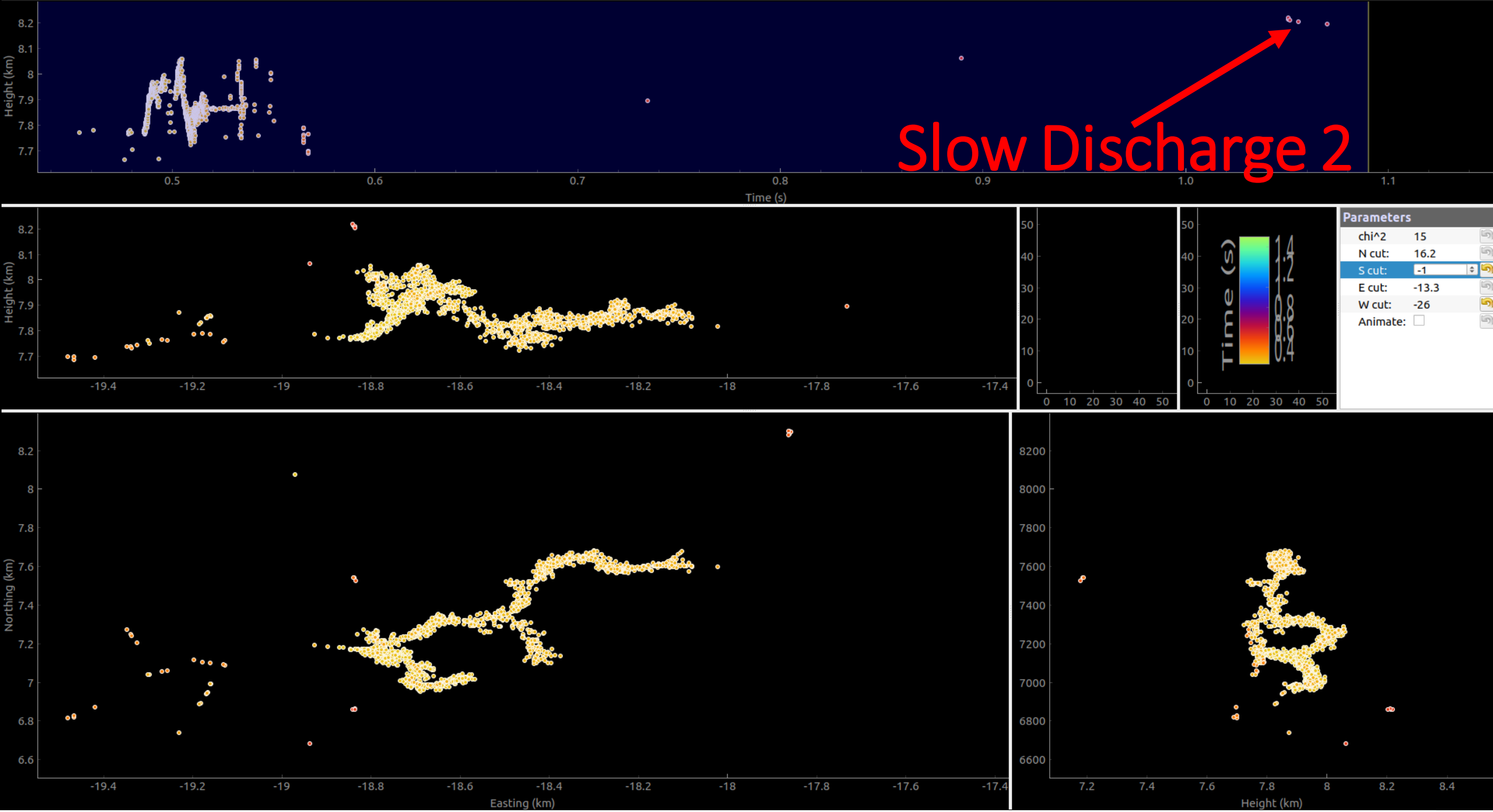
- Possibly failed initiation, begins with speed of 1700 m/s then ends with 400 m/s.
  - This is the first activity visible in this region.
  - Leader forms 30 ms after activity ceases and within 50 m of the slow propagation.
  - RMS of quadratic fit is about 1.4 m


Slow Discharge 1
Height (km)
Time (s)
Parameters
chi^2 10
N cut: 16.2
S cut: 1.37
E cut: -13.1
W cut: -25.2
Animate:
Time (s)
Northing (km)
Easting (km)
Height (km)

Slow Discharge 2

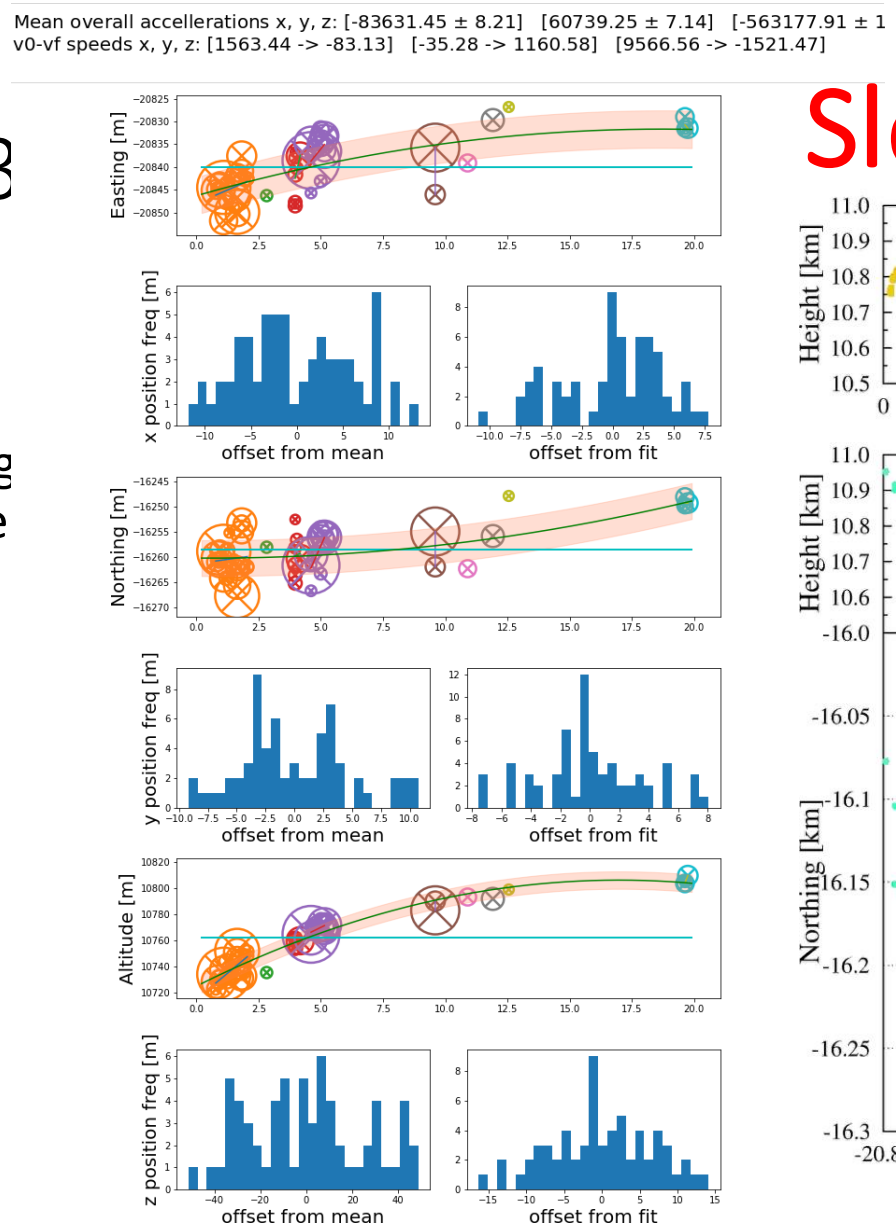
- Event follows a flash 400 ms after activity has ceased.
  - Roughly 200 m from main lightning activity.
  - RMSE of 7.4 m
  - Velocity decreases from about 900 m/s to 300 m/s



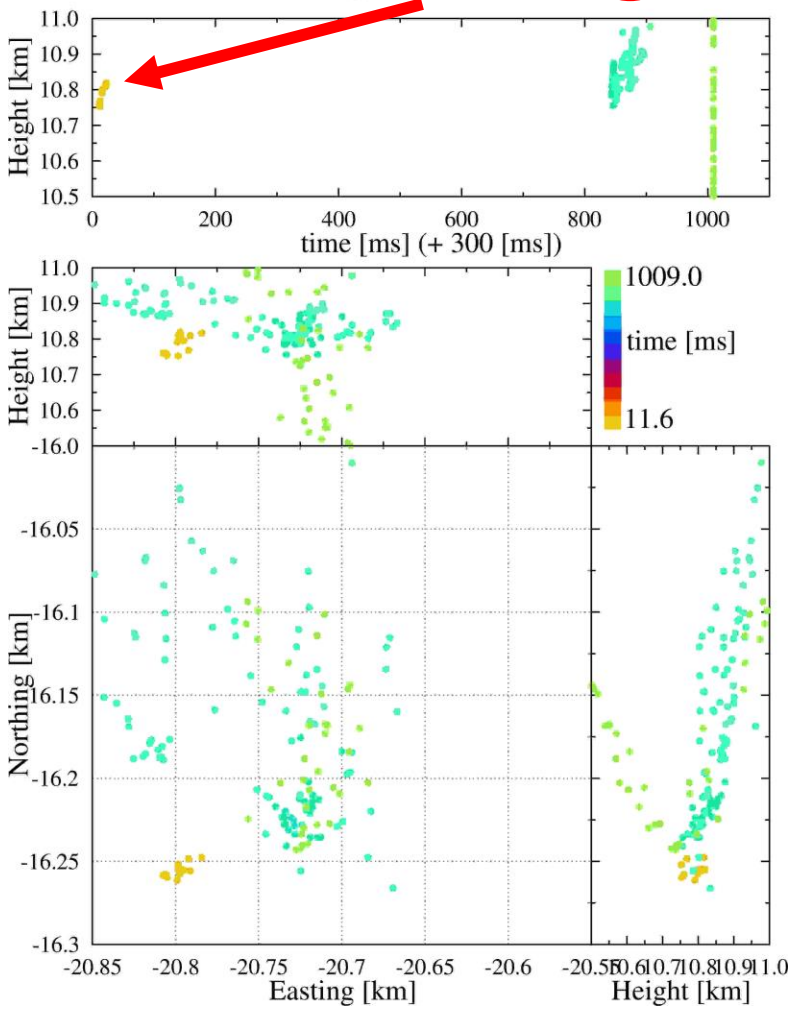

Slow Discharge 2
Height (km)
Time (s)
Parameters
chi^2 15
N cut: 16.2
S cut: -1
E cut: -13.3
W cut: -26
Animate:
Time (s)
Northing (km)
Easting (km)
Height (km)

Observed Discharge 3

- Lightning initiation, nearly 1 second later, <100 m from same location!
  - Likely same high field, accounting for wind speed at source altitude for 1 s
  - Starts with velocity of 10 km/s ends with velocity 2 km/s
  - RMSE of 6.1 m
  - Interference from flash 100 km away contributes to noise and resulting in lower quality of fit.

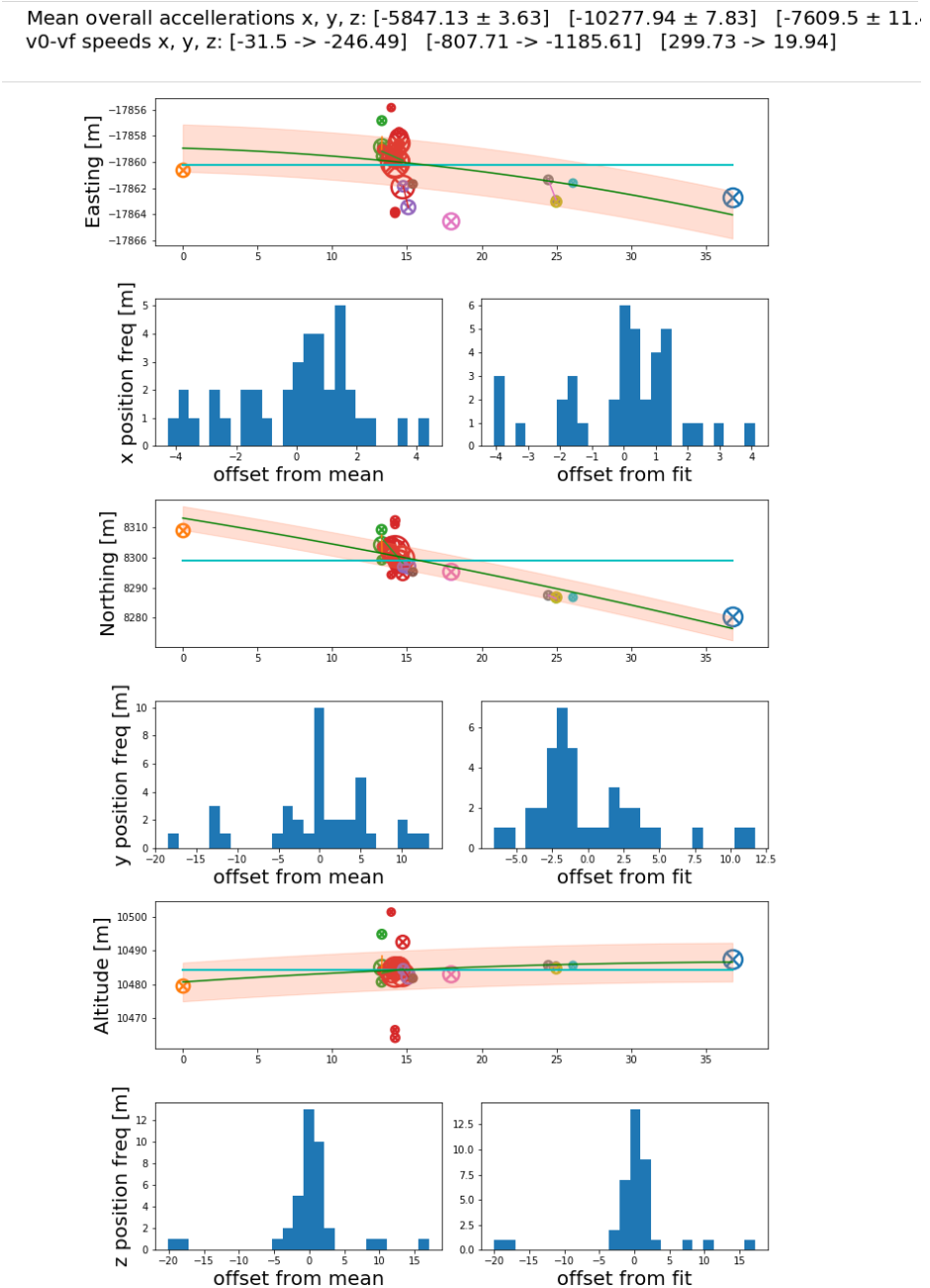


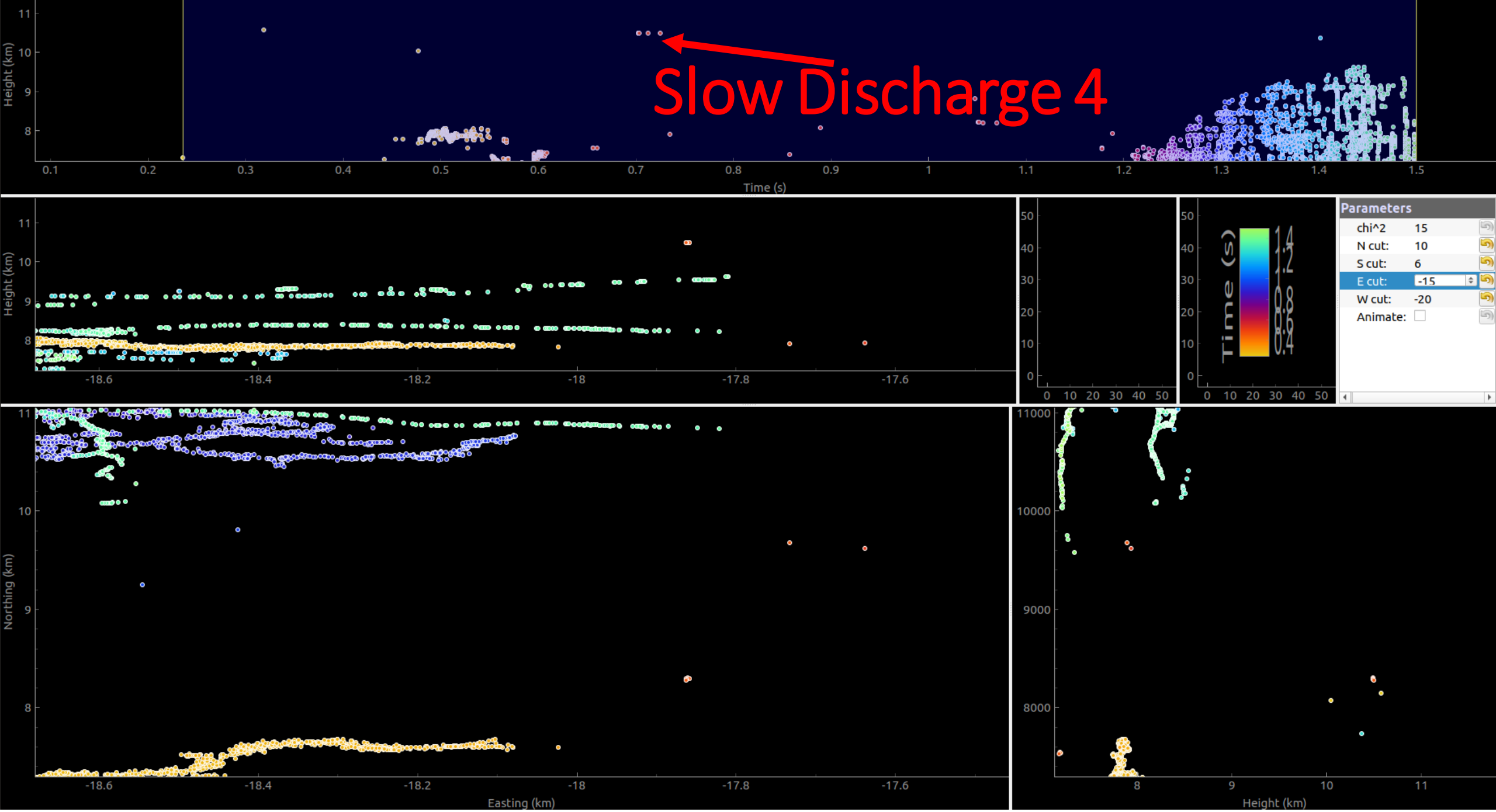
Slow Discharge 3



Observed Discharge 4

- Isolated event, no observed flash within at least +/-700 ms
  - Starts with velocity of 100 m/s ends with velocity of 1.1 km/s
  - RMSE of about 4.1
  - Propagation is mainly along the North-South axis!




Slow Discharge 4
Height (km)
Time (s)
Parameters
chi^2 15
N cut: 10
S cut: 6
E cut: -15
W cut: -20
Animate:
Time (s)
Northing (km)
Easting (km)
Height (km)