Investigating Thunderstorm Electric Fields using Radio Emission from Cosmic-Ray Air Showers

T. N. G. Trinh, S. Buitink, U. Ebert, B.M. Hare, O. Scholten, H. Leijnse, A. Bonardi, A. Corstanje, H. Falcke, J.R. Hörandel, P. Mitra, K. Mulrey, A. Nelles, J. P. Rachen, L. Rossetto, C. Rutjes, P. Schellart, S. Thoudam, S. ter Veen, T. Winchen

LOFAR

-- The atmospheric electric field perpendicular to the Cosmic-ray shower axis determines the radio emission during thunderstorm conditions.
-- From the intensity and polarization data, as measured at LOFAR, the atmospheric electric fields can be inferred.

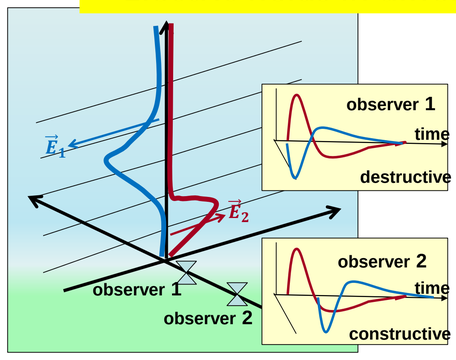
LOFAR

Six central stations in Exloo, Inverted V-shape dipole antennas 10 – 90 MHz

320 m diameter 'superterp' of LOFAR near Exloo, The Netherlands

Interference of emission from different heights

Electric fields in different layers are in opposite directions

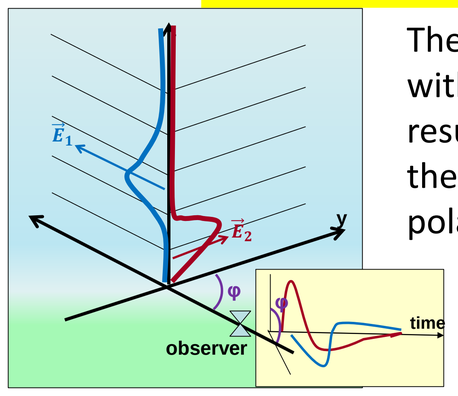


Destructive interference depends on relative arrival times, or distance to shower axis. Intensity pattern will have a ring-like structure.

Signal is linearly polarized along direction of atmospheric electric field

Circular polarization in thunderstorm events

Electric fields in different layers are at an angle



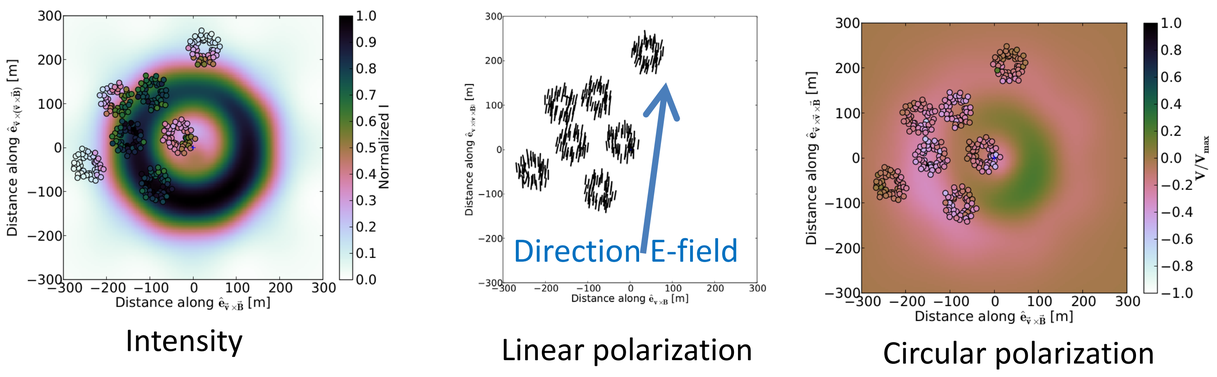
The pulses from the upper layer arrive with a delay with respect to the pulses from the lower layer resulting in a change of the polarization angle over the duration of the pulse, seen as circular polarization.

Measured signal has strong circular polarization (Stokes V/I ≠ 0)

See: Trinh et. al. (2016) *Physical Rev. D* 95, 083004

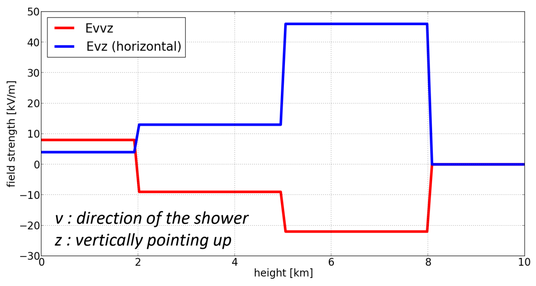
Radio footprint

Reconstructing Thunderstorm Electric Fields



Intensity — Linear polarization — Circular polarization

- Thunderstorm electric fields can be reconstructed by fitting the measured stokes parameters



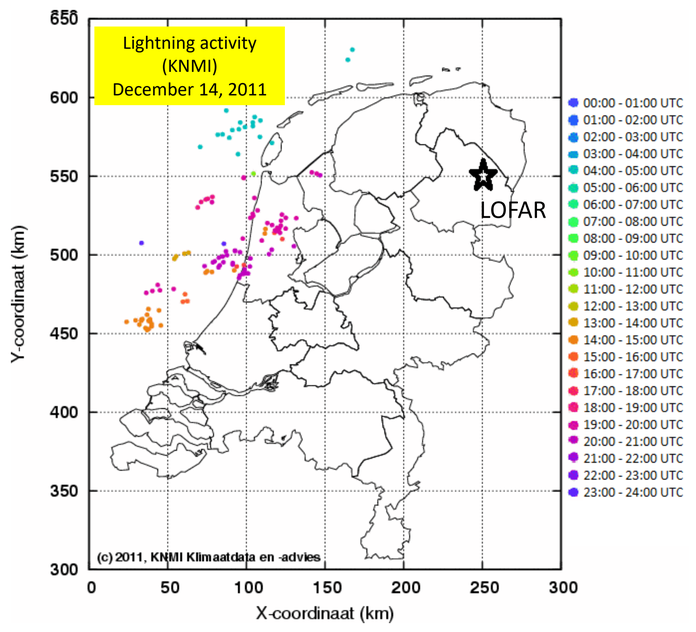
- A three-layered electric fields is needed in order to reconstruct main features in the intensity and polarization footprints.
- The atmospheric electric field has a sizable horizontal component.

Results

Event - ID	UTC Time	θ (°)	ϕ (°)	h_1 (km)	E_1 (kV/m)	α_1 (°)	h_2 (km)	E_2 (kV/m)	α_2 (°)	h_3 (km)	E_3 (kV/m)	α_3 (°)	h_0 (km)	h_{-10} (km)
1	14/12/2011, 21:02:27	39.4	144.8	7.6	17	-60	3.3	102	114	1.6	40	-93	0.7	2.3
2	14/12/2011, 21:10:01	14.1	134.0	9.2	34	-172	–	–	–	1.9	94	8	0.7	2.3
3	14/12/2011, 21:14:34	24.4	333.0	7.9	22	-92	5.0	92	-56	2.3	22	-35	0.7	2.3
4	26/04/2012, 15:22:33	22.2	129.0	10.1	65	68	7.4	102	68	3.0	33	-86	1.5	3.4
5	28/07/2012, 02:20:21	22.3	2.2	7.2	78	-39	5.6	85	-103	3.2	5	-168	3.6	5.6
6	26/08/2012, 13:52:23	22.8	143.8	7.8	95	-53	–	–	–	3.7	2	-6	2.5	4.2
7	26/08/2012, 14:02:56	17.6	309.5	7.3	16	-28	3.6	102	180	1.7	29	21	2.5	4.2
8	26/08/2012, 14:28:19	24.8	308.7	8.0	50	-78	6.9	20	-104	2.7	18	67	2.5	4.2
9	30/12/2012, 12:38:37	15.6	304.0	8.0	50	98	5.0	15	98	2.0	9	8	0.8	2.2
10	26/07/2013, 12:17:26	15.5	40.2	7.6	29	75	4.9	87	-105	3.6	37	-141	3.8	5.7
11	27/06/2014, 14:44:03	14.6	238.6	6.3	52	41	4.5	52	-20	3.3	5	-72	2.5	4.2

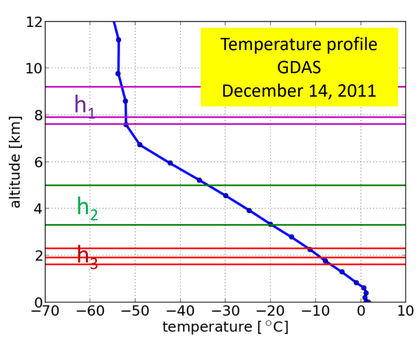
- Many of the events resemble the traditional tri-polar structure
- There are a few events that are close together in time, potentially allowing for a type of tomography

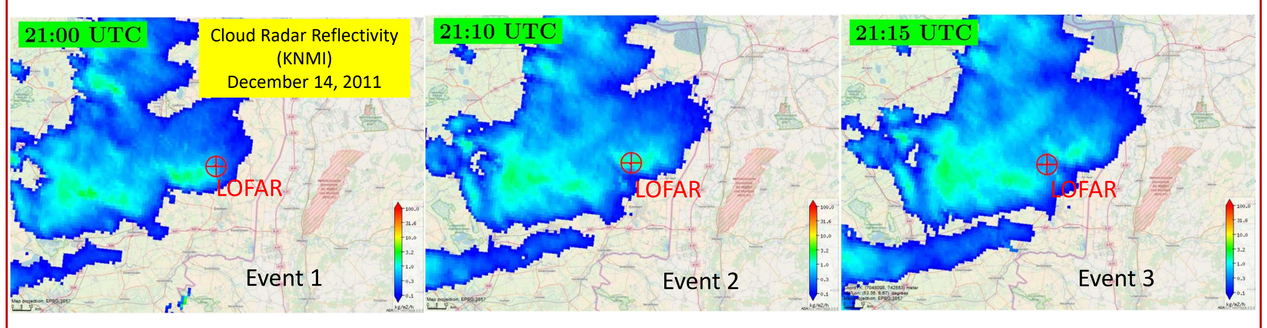
Cloud tomography; events 1, 2 & 3



Events 1, 2, and 3 detected within 15 minutes:
UTC 21:02, 21:10, 21:15

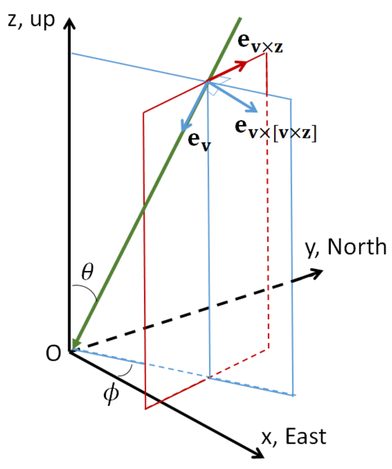
Test the fields in the same cloud



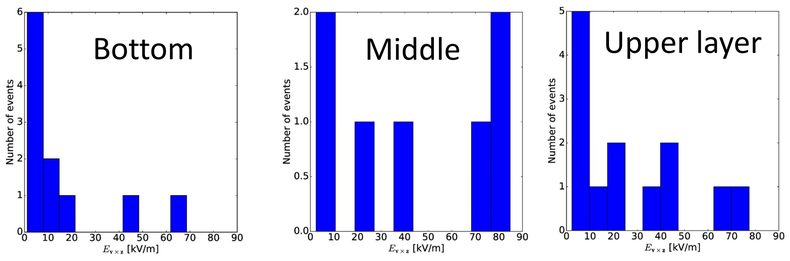


Electric fields are very different for the three events, in all layers.

Horizontal components



Event	h_1 (km)	$E_{\mathbf{v}\times\mathbf{z}}$ (kV/m)	$E_{\mathbf{v}\times(\mathbf{v}\times\mathbf{z})}$ (kV/m)	h_2 (km)	$E_{\mathbf{v}\times\mathbf{z}}$ (kV/m)	$E_{\mathbf{v}\times(\mathbf{v}\times\mathbf{z})}$ (kV/m)	h_3 (km)	$E_{\mathbf{v}\times\mathbf{z}}$ (kV/m)	$E_{\mathbf{v}\times(\mathbf{v}\times\mathbf{z})}$ (kV/m)
1	7.6	-2	17	3.3	85	-60	1.6	-2	40
2	9.2	25	-23	–	–	–	1.9	69	64
3	7.9	22	4	5.0	38	84	2.3	4	22
4	10.1	8	-65	7.4	7	-102	3.0	-5	33
5	7.2	3	78	5.6	73	33	3.2	1	-5
6	7.8	-77	56	–	–	–	3.7	1	-2
7	7.3	7	14	3.6	2	-102	1.7	-11	27
8	8.0	40	30	6.9	20	1	2.7	-17	-6
9	8.0	50	4	5.0	-15	-2	2.0	1	9
10	7.6	-14	-25	4.9	70	51	3.6	34	15
11	6.3	46	-24	4.5	3	-52	3.3	-3	-4



- The horizontal electric fields between the bottom charge region and the ground is small. They become large inside thunderclouds.

Contact: Scholten@kvi.nl and www.kvi.nl/~scholten/

Work to be submitted soon

We have an open PhD position, see www.kvi.nl/~scholten/PhD-PositionAdvertizementt.pdf for details