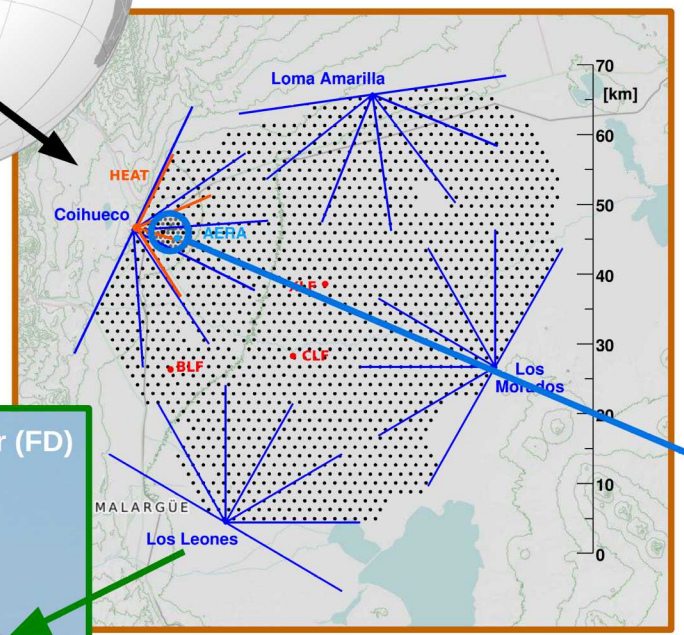
A New Network of Electric Field Mills at the Pierre Auger Observatory

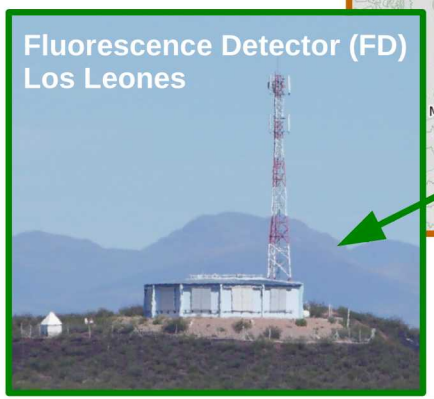
Max Büsken
for the Pierre Auger Collaboration

AtmoHEAD Workshop
13th July 2022

Radio Detection at the Pierre Auger Observatory



PIERRE AUGER OBSERVATORY



- Largest ground-based observatory for ultra-high energy cosmic rays (UHECRs)
  - Study their origin, mass composition, acceleration mechanisms,...
- Hybrid detection of extensive air showers:
  - Fluorescence Detectors
  - Water Cherenkov Detectors
  - Underground Muon Detectors
  - Scintillator Surface Detectors
  - Radio Detectors

→ Auger Engineering Radio Array (AERA):
>150 antenna stations, 30-80 MHz
17 km² array, >10 years operation

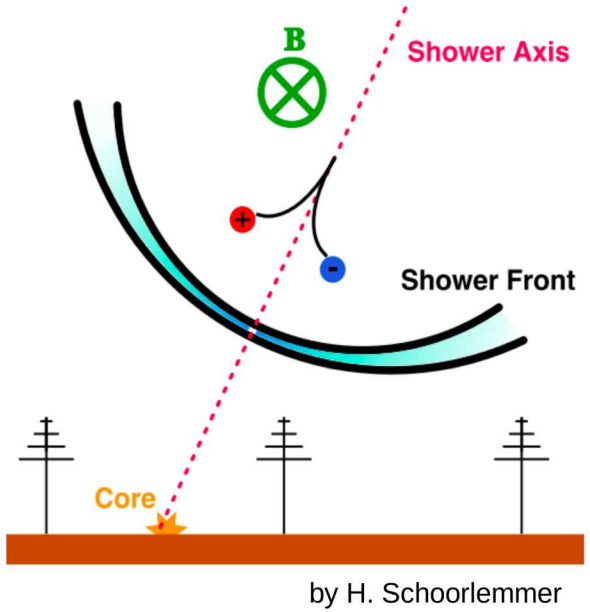
Radio Emission from Extensive Air Showers

Main mechanism:

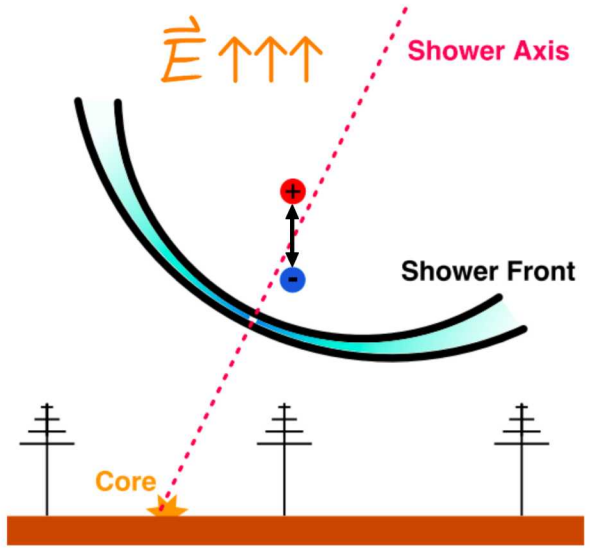
Deflection of charged shower particles in the Earth‘s magnetic field

analog

Deflection of charged shower particles in strong atmospheric electric fields (thunderstorms)



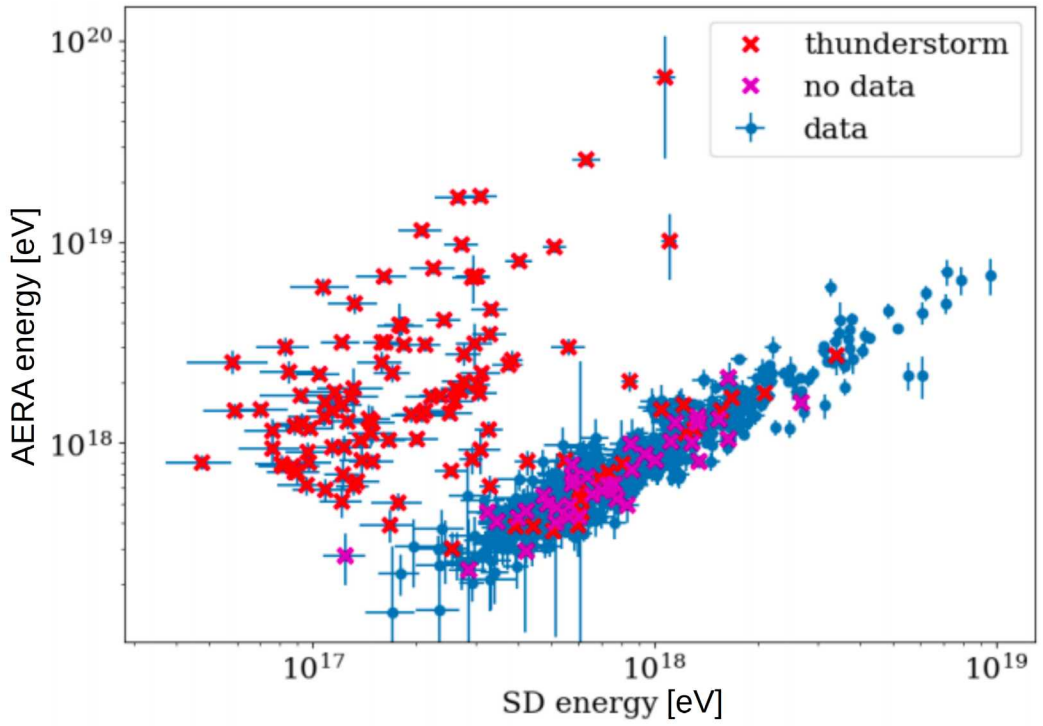
by H. Schoorlemmer



↳ details well-understood

↳ E-field structure in thunderstorms difficult to characterize

Radio Detection during Thunderstorms at AERA

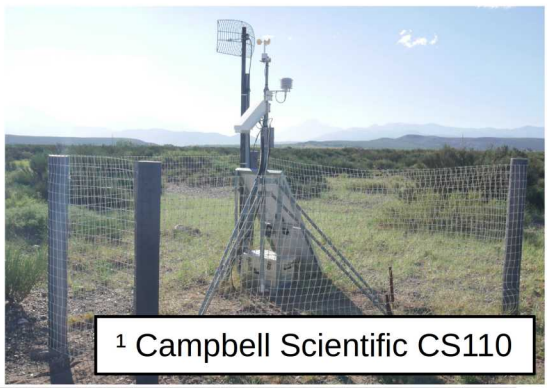


↳ Event-by-event energy estimators from the Radio Detector (AERA) vs. Surface Detector

- Atmospheric electric fields during thunderstorms heavily influence radio signals from air showers
- Affected events not interpretable

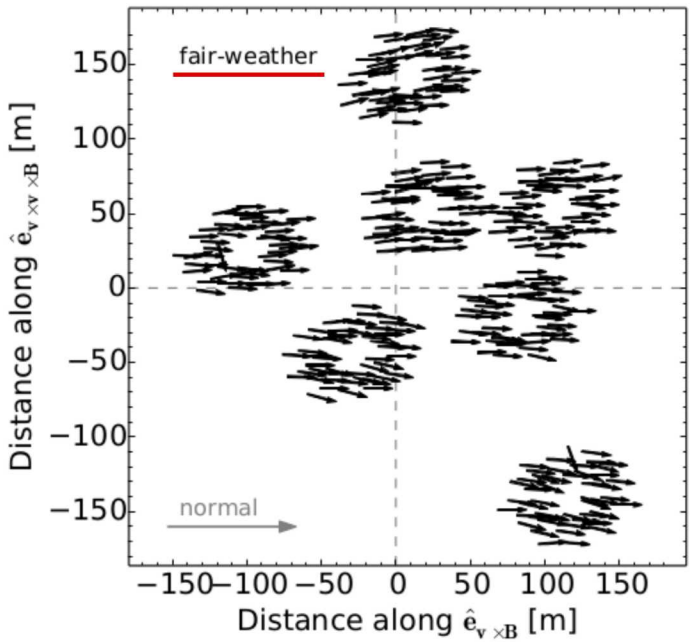
Solution:

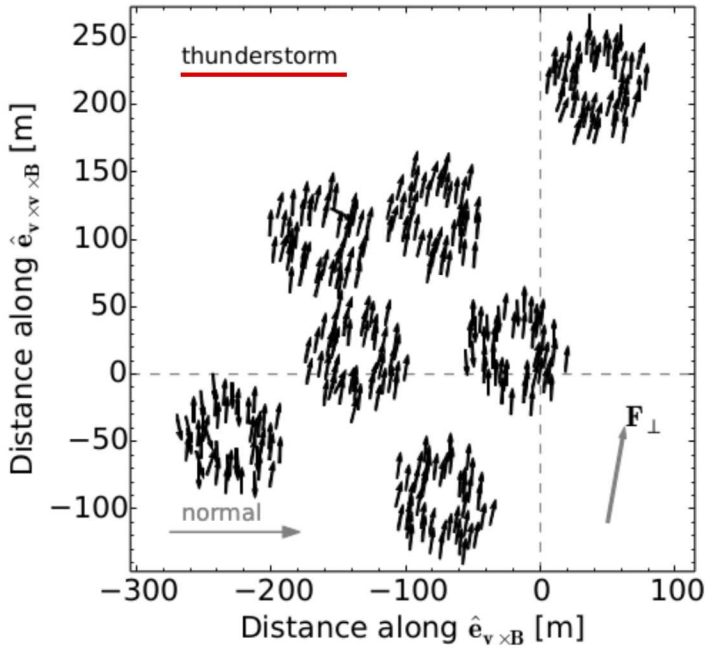
- Monitor the electric field and thunderstorms (TS) with Electric Field Mills (EFMs)
  → Flag TS periods
- Two EFMs[1] at AERA running stable & autonomously (10+ years)



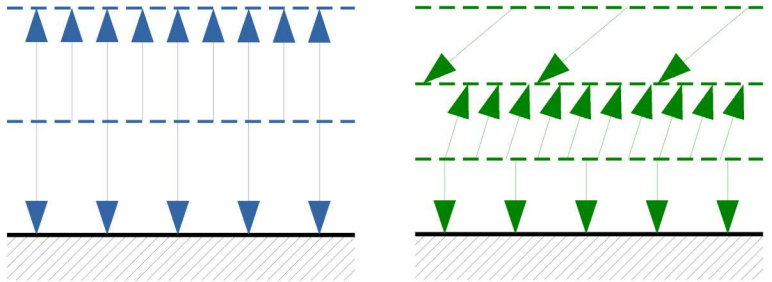
[1] Campbell Scientific CS110

Radio Signals during Thunderstorms (LOFAR)





Electric-field configurations:

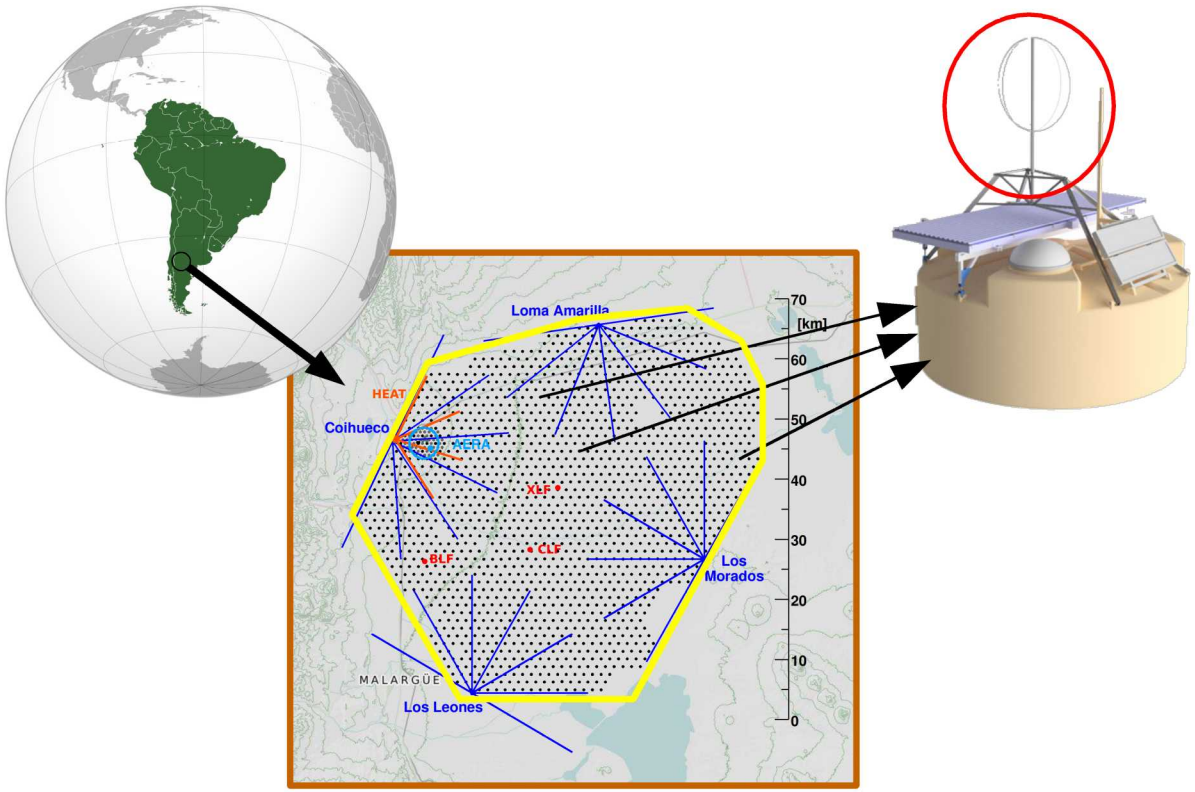


(Schellart et al., 2015) (Trinh, Scholten et al., 2022)

- Cosmic-ray radio signals have typical polarization patterns
- Strongly disturbed patterns during thunderstorm periods (seen in LOFAR measurements)
- Models of the atmospheric E-field configuration → Reconstruct layer heights & E-field strengths

  ↳ Improved results using analytic models for the radio emission (MGMR3D)

The New Auger Radio Detector (RD)



- Ongoing AugerPrime Upgrade: Radio Detector
- New radio antennas on each of the 1661 surface detector stations
- Expand studies to highly inclined air showers (>70°)
- > 3000 km² array

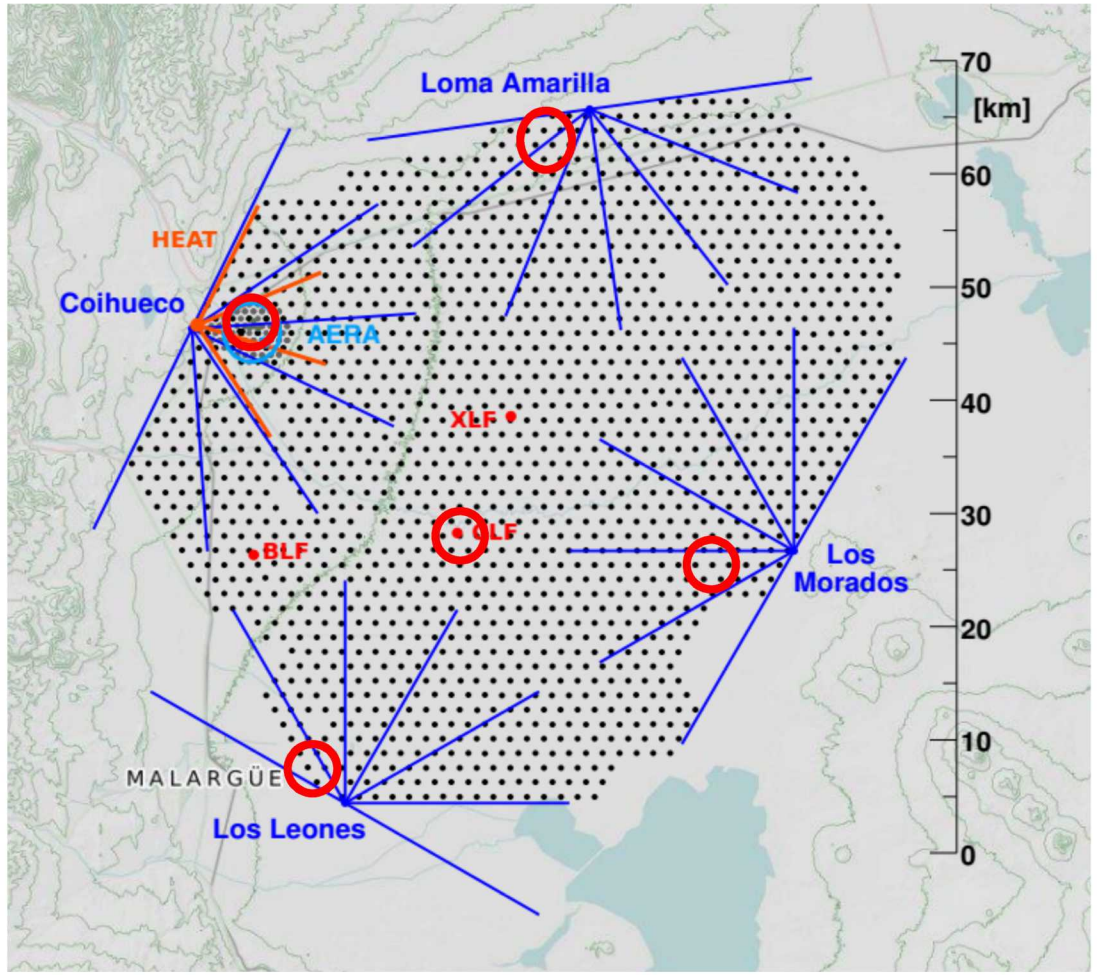
Thunderstorm flagging for RD:

- Need E-field monitoring on larger scale

Ideas:

- Track thunderstorms
- Smart flags based on shower direction and cloud movement

A New Network of Electric Field Mills



- 5 new EFMs spread over the array
  - 4 stations close to each FD site
  - 1 station at the Central Laser Facility (CLF)
- Autonomous, remote operation for 10+ years
- Aim for an absolute calibration of the EFMs
  → additional requirements to station design
  → profit for various analyses ?

EFM Station Design

E-Field Mill (CS110)
1 Hz sampling rate
2m above ground

Transmitter Comms
Ubiquiti Bullet + Antenna
(10 km range)

Receiver Comms
Ubiquiti Rocket + Antenna

5 GHz WiFi link

FD

DAQ

Clear Area
1) ~7m radius clear of larger vegetation
2) No tall objects nearby

Solar Panel
100W

Electronics Box:
Battery, charge controller, network adapter

~7m

Electronics Box

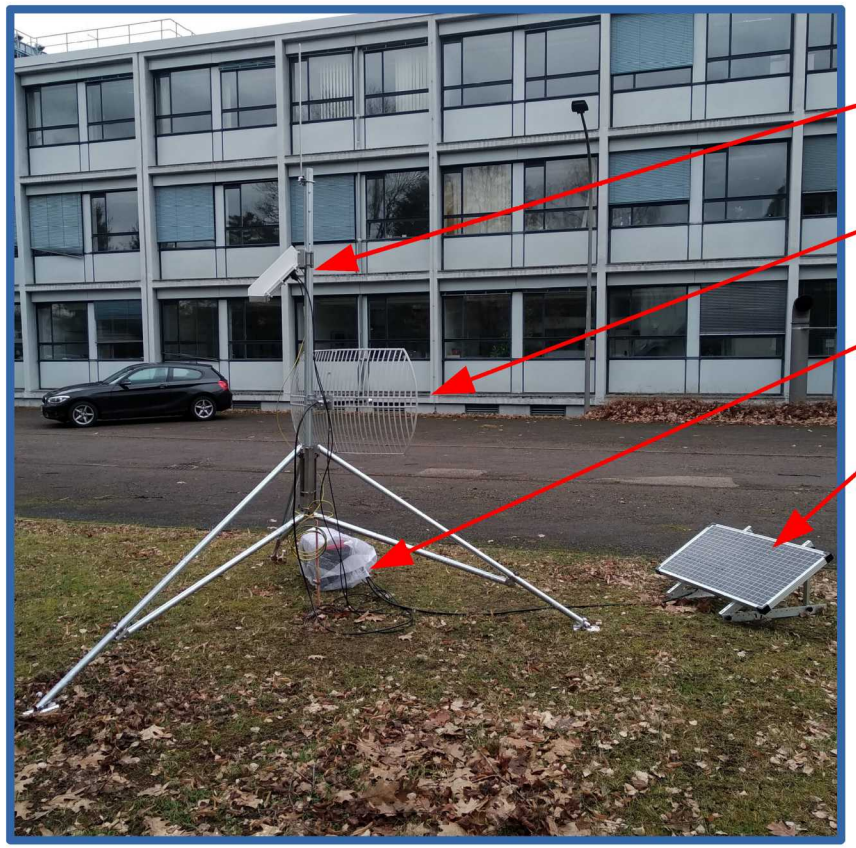
Fence
Metallic
Keep animals away

Tripod
~2.5m, steel, incl. grounding rod
+ concrete grounding

→ Unique station design already calibrated by the EFM manufacturer (within ±4%)

Test Setup at KIT

- Made a test setup at KIT, Campus Nord: Remote operation, full readout chain incl. WiFi bridge

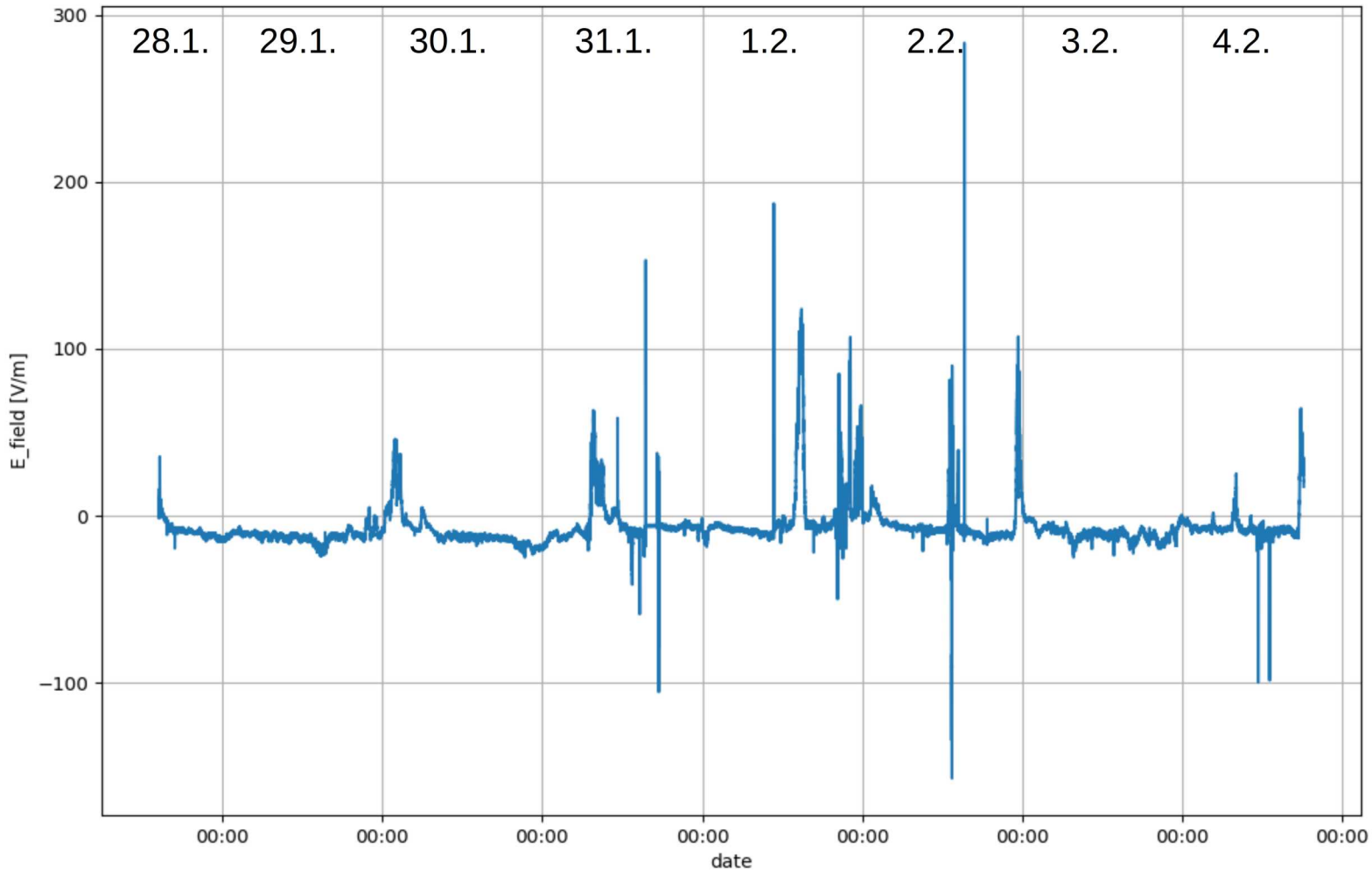


1) E-Field Mill
2) WiFi Antenna (5GHz)
3) Electronics
4) Solar Panel

Functionality of all components validated

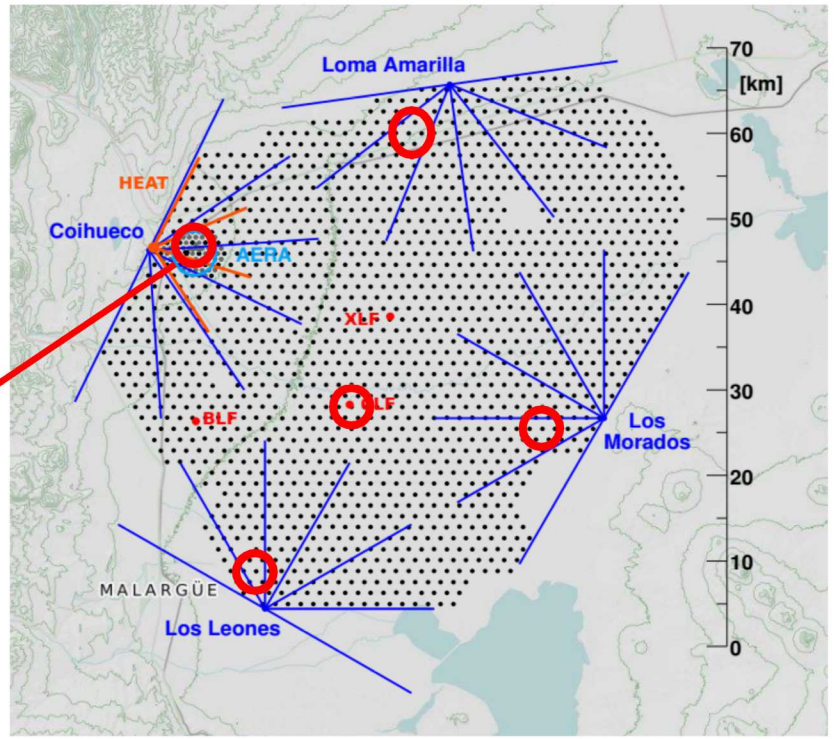
Test Setup at KIT

- No large E-fields measured
  - ! Thunderstorms can cause |E| of a few kV/m
- Spikes: people walking nearby
- Zero-offset
  is within expected range



Preparation for Deployment

- Shipped to Argentina ➔ arrived at Auger few weeks ago
- Found suitable spots for deployment
  ➔ flat, good soil, line of sight to comms tower, landowner situation, ...
- Initiated preparatory work (fences, comms installation)

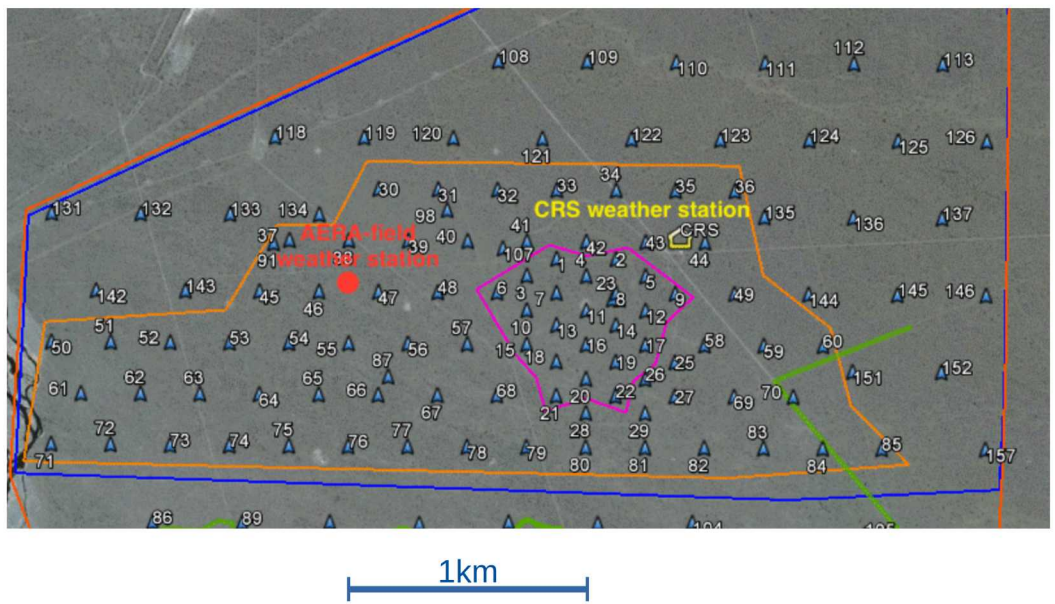


… work in progress ...

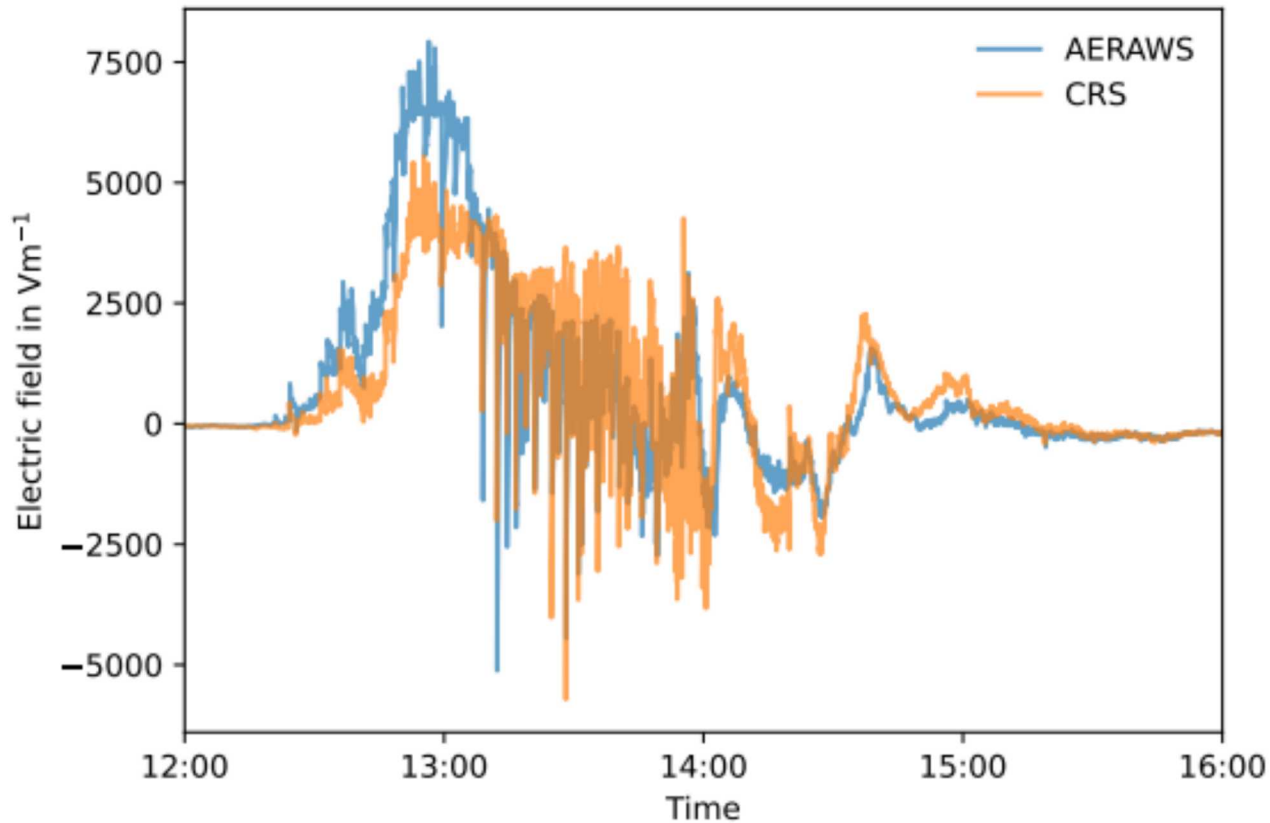
Analysis of AERA EFM Data

Work done by Asil Meidow

- Two EFMs with ~1.5km distance
- Taking data since 2011/2014



one „example“ thunderstorm (26.01.2022)

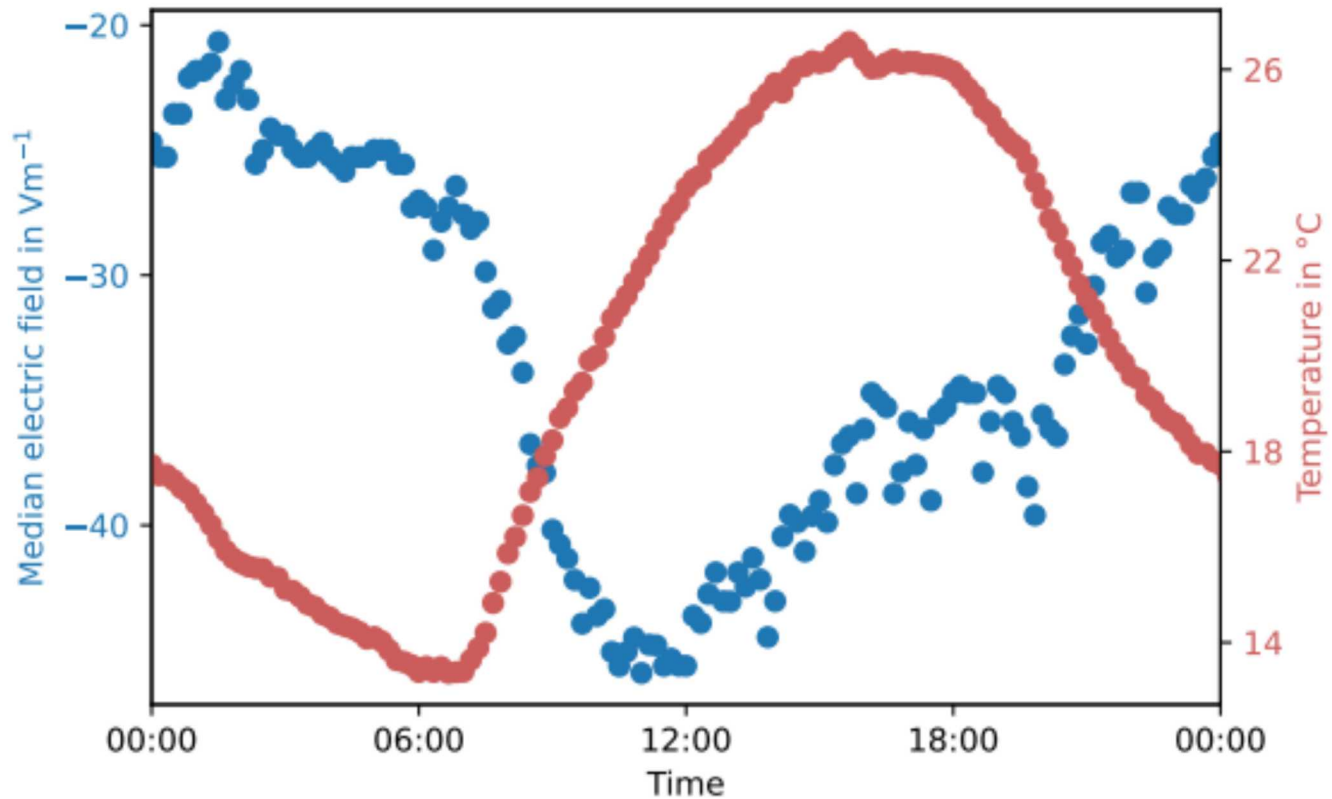


Analysis of AERA EFM Data

Work done by Asil Meidow

- Try to better understand the typical “fair-weather electric field“
- Look for correlations with other weather observables
- Median electric field
  (less sensitive to thunderstorm outliers than mean)
  vs. air temperature
- Spurious correlation?
  Electric field more closely connected to the ionosphere?
  Solar irradiance?

data from January 2022



Summary and Outlook

New EFM Stations for the AugerPrime Radio Detector:

- 5 calibrated stations over the whole array ➔ tested and shipped to Argentina
- Installation of fences and comms infrastructure to be done first ➔ takes time
- Possible deployment of the first station in August ➔ remaining ones in the months after

Analysis of electric-field data:

- 10 years of data to investigate correlations between EFMs ➔ potential for thunderstorm tracking?
- Correlation between electric field and air temperature ➔ other weather observables?

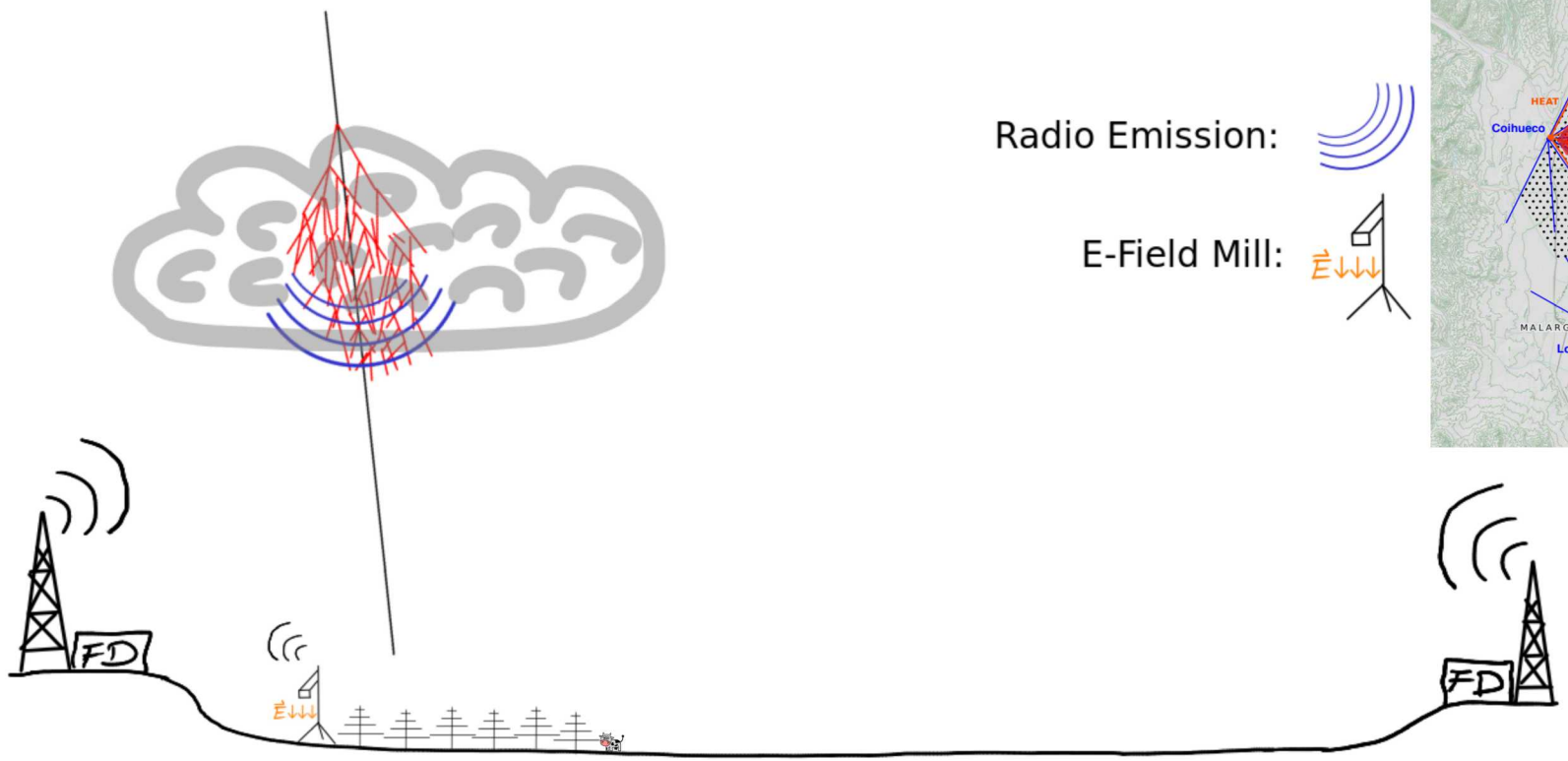
Outlook:

- Possible applications of calibrated E-field data? TGFs, TS & Radio, lightning studies…?

Backup

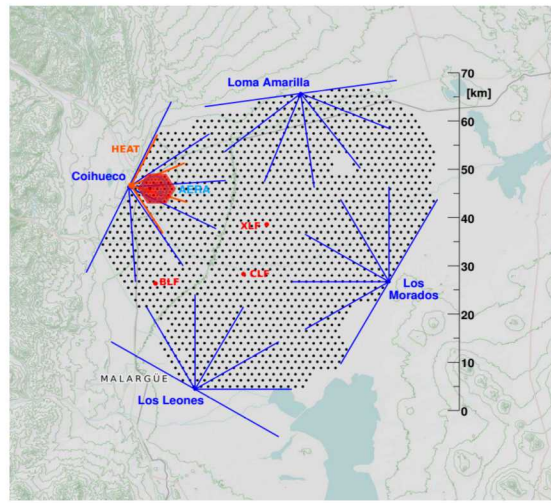
CR Air Showers & Thunderstorms

Vertical air showers: Thundercloud influencing the shower core is overhead
→ directly detect with an E-Field mill + simple algorithm (done at AERA)



Radio Emission:

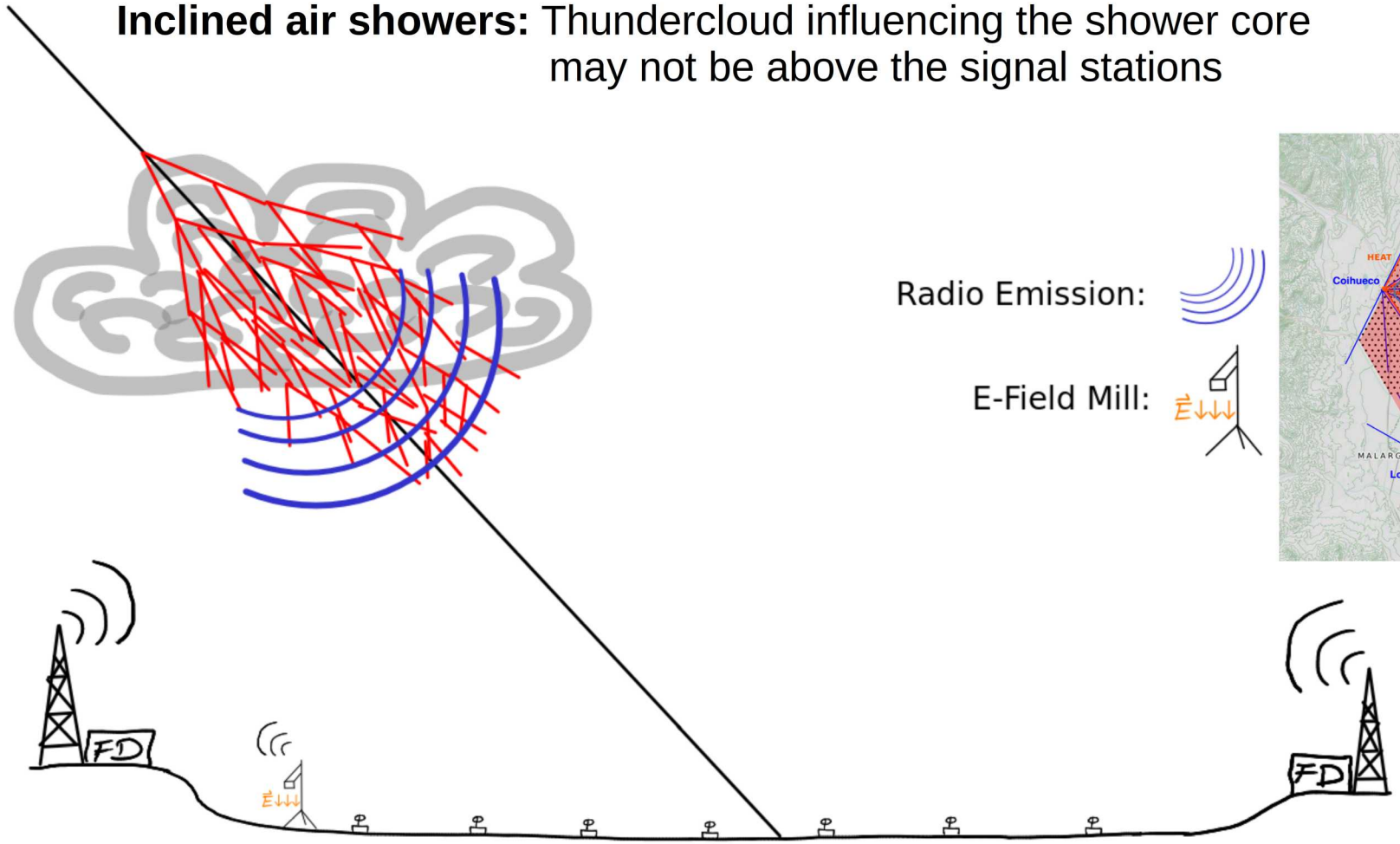
E-Field Mill:



17 km²

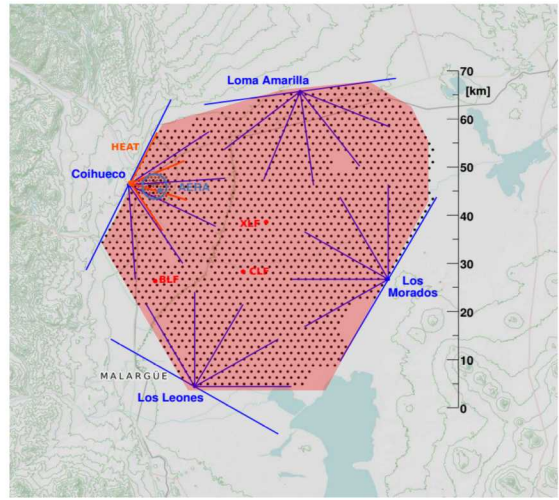
CR Air Showers & Thunderstorms

Inclined air showers: Thundercloud influencing the shower core may not be above the signal stations



Radio Emission:

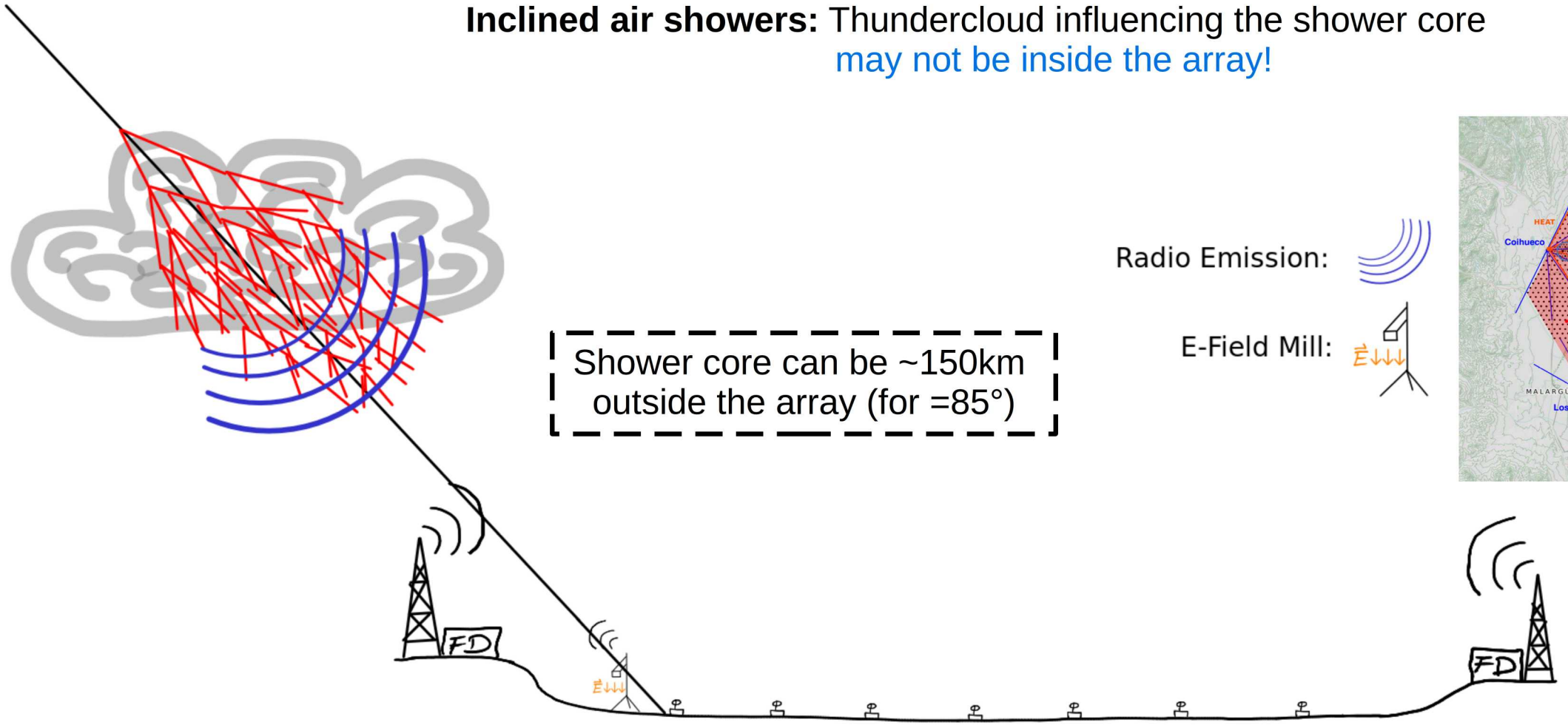
E-Field Mill:



3000 km²

CR Air Showers & Thunderstorms

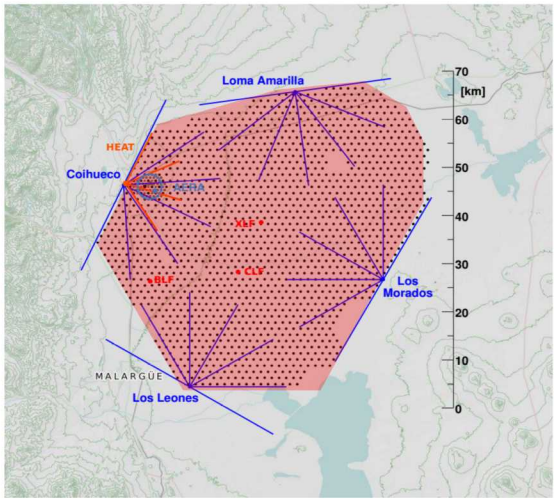
Inclined air showers: Thundercloud influencing the shower core
may not be inside the array!



Shower core can be ~150km outside the array (for =85°)

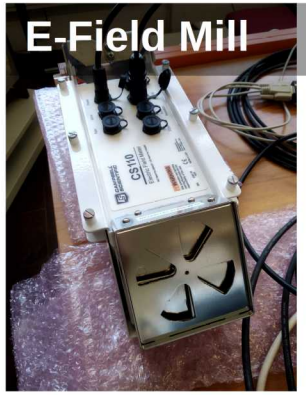
Radio Emission:

E-Field Mill:

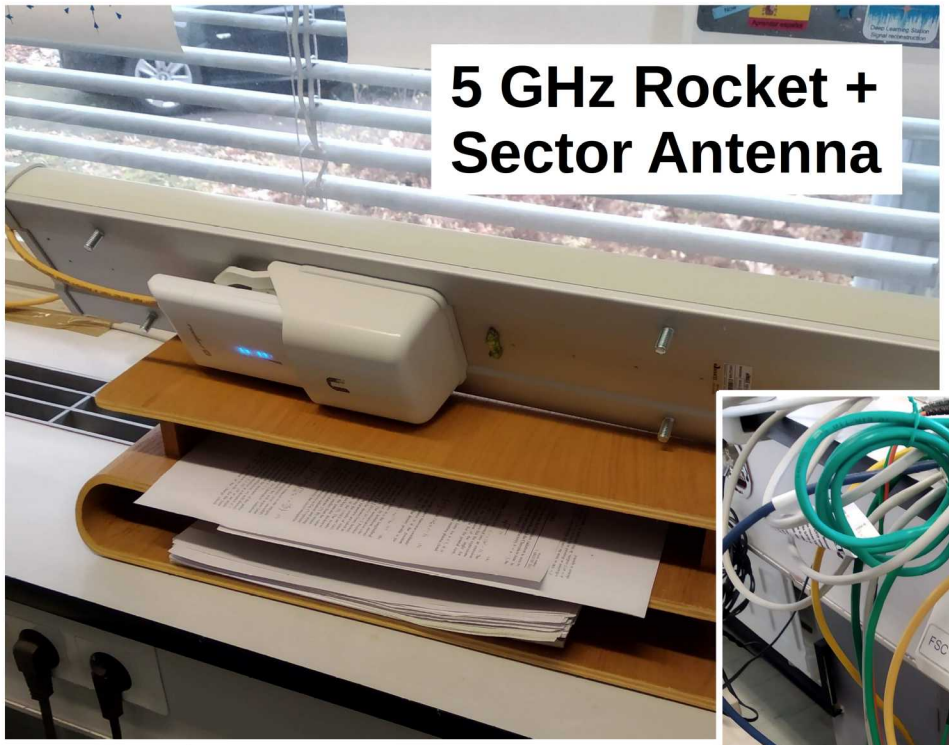


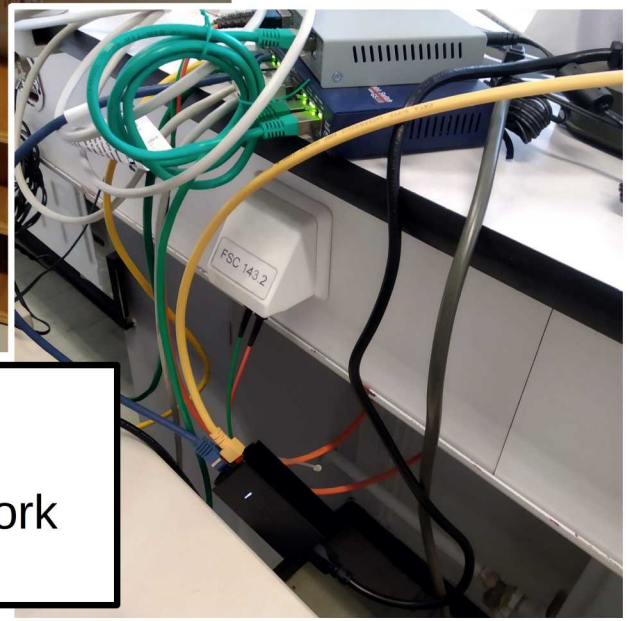
3000 km²

Acquisition of Components



2.1) Test Setup at KIT

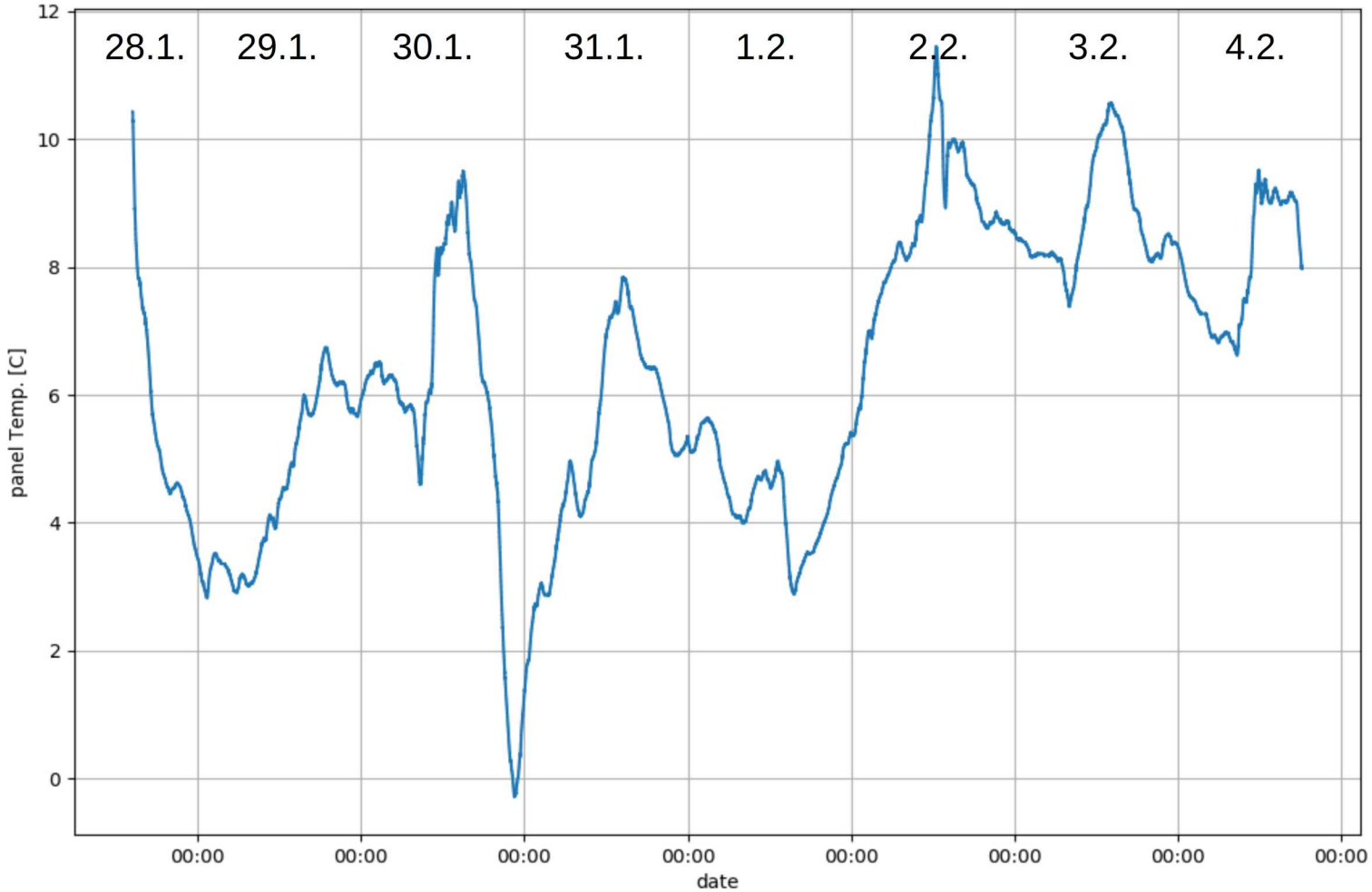




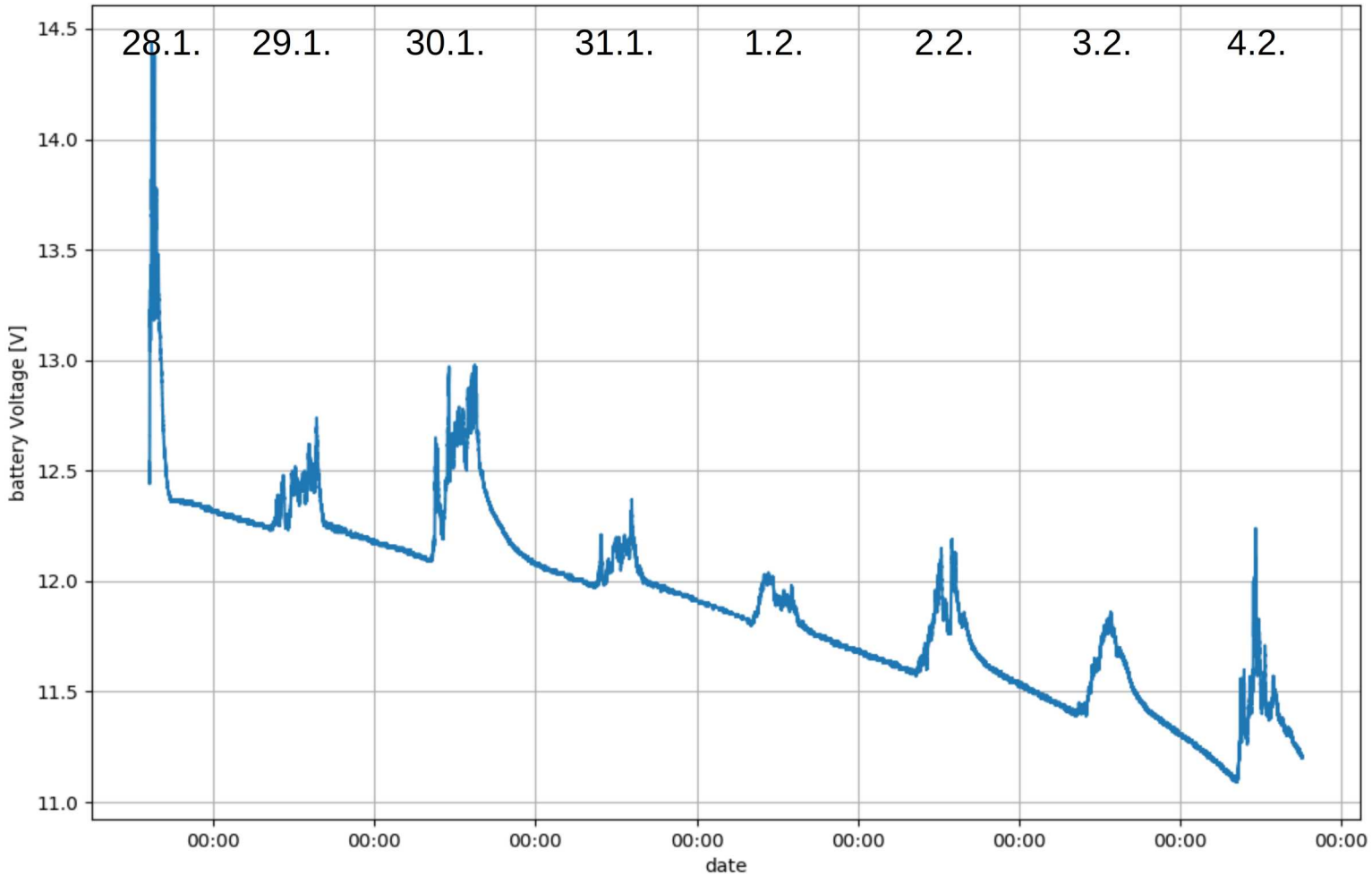
Rocket powered over ethernet
Connected to KIT network
→ Remotely reachable

Panel Temperature

- Includes heating-up of the housing

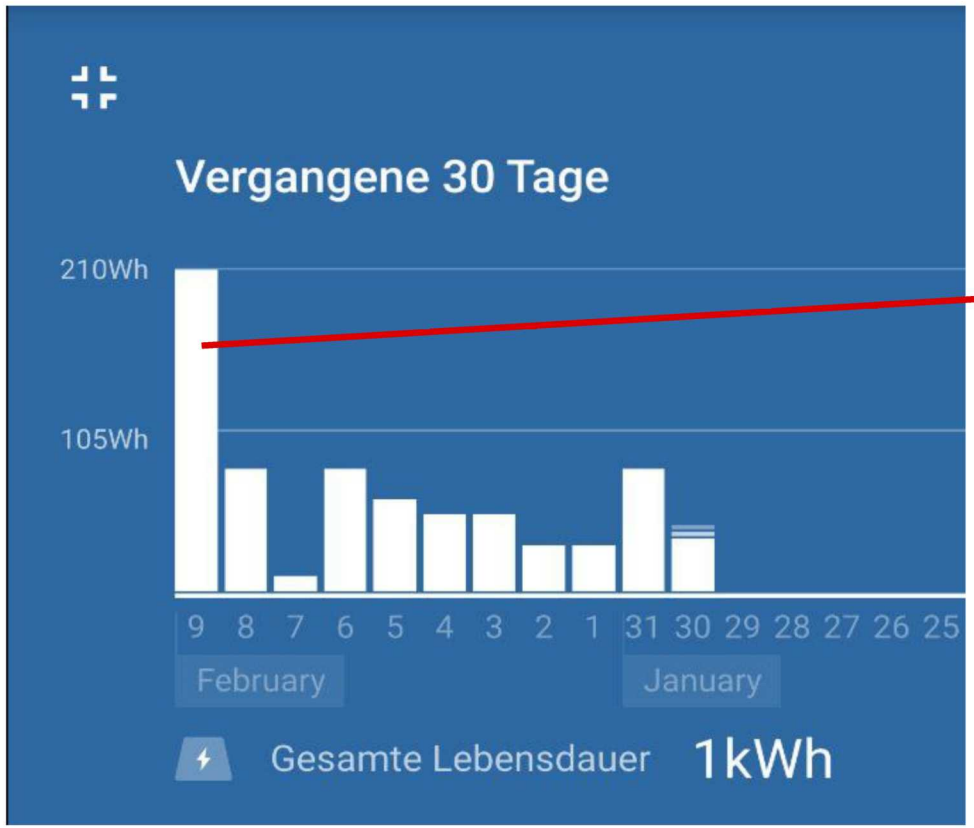


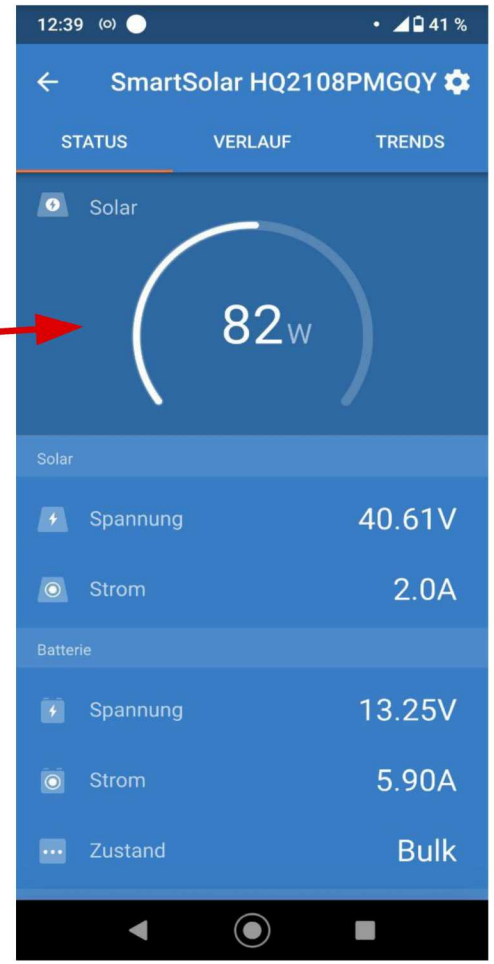
Battery Voltage From Test Setup



2.2) Solar Panels in Full Sunlight

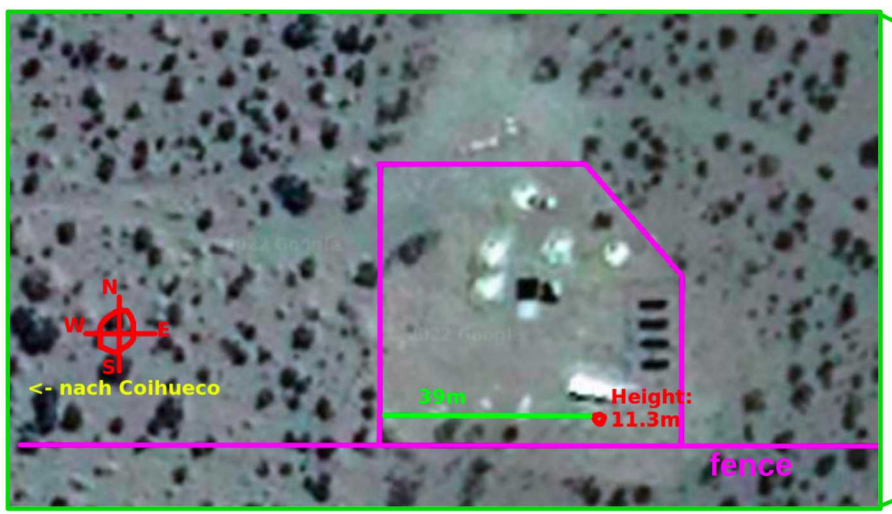
- Solar panels and charge controllers tested on a sunny winter day
  → consistently at ~82W (100Wp panel)
- System should be sufficiently dimensioned
  (average consumption ~130Wh/day)
- Small shadows reduce yield significantly
- Whole column of cells blocked (vertical) → yield drops to 0W

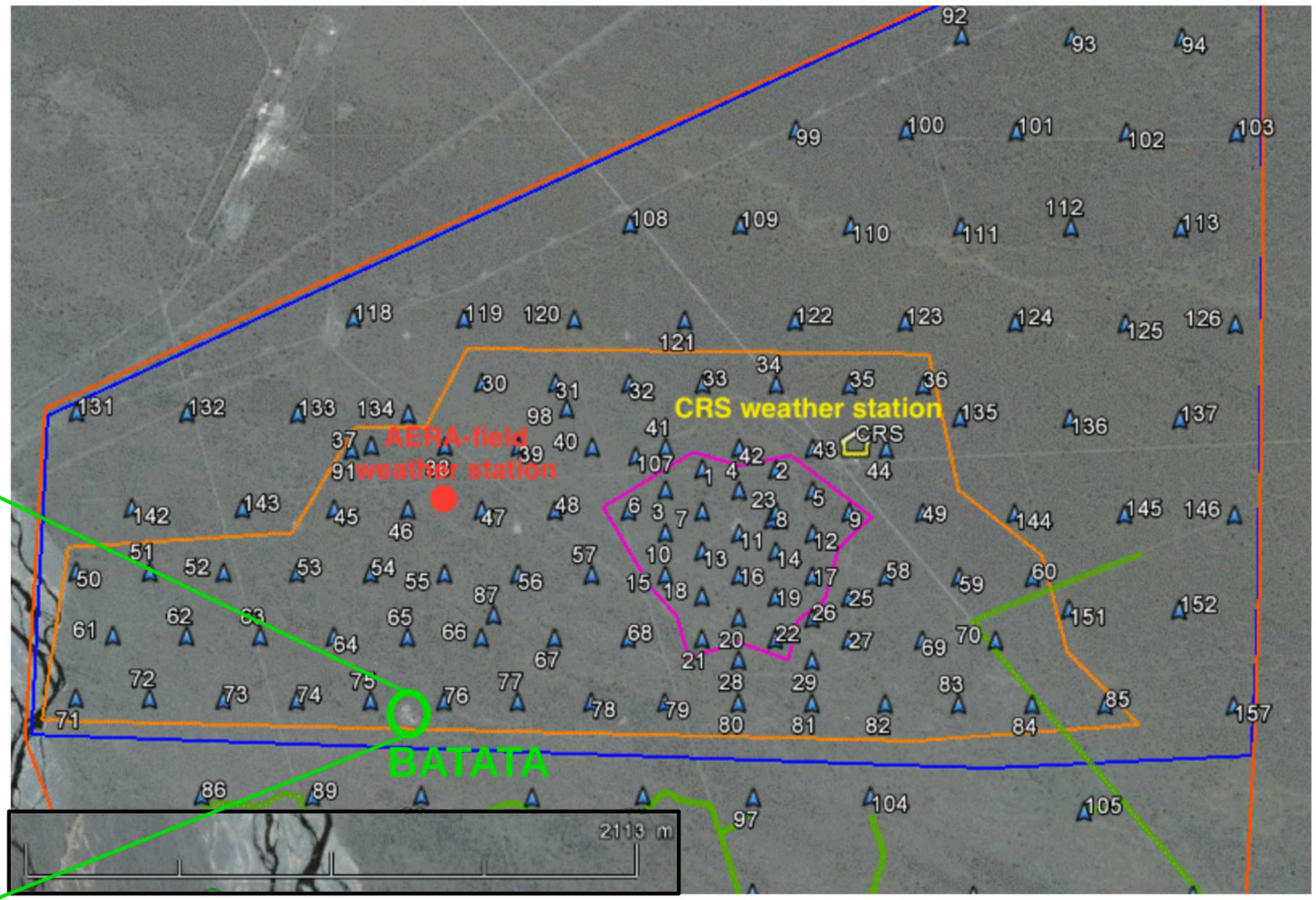




Deployment (Coihueco)

- Old test site is already fenced and not used anymore
- Opportunity for correlation studies with the two AERA EFMs

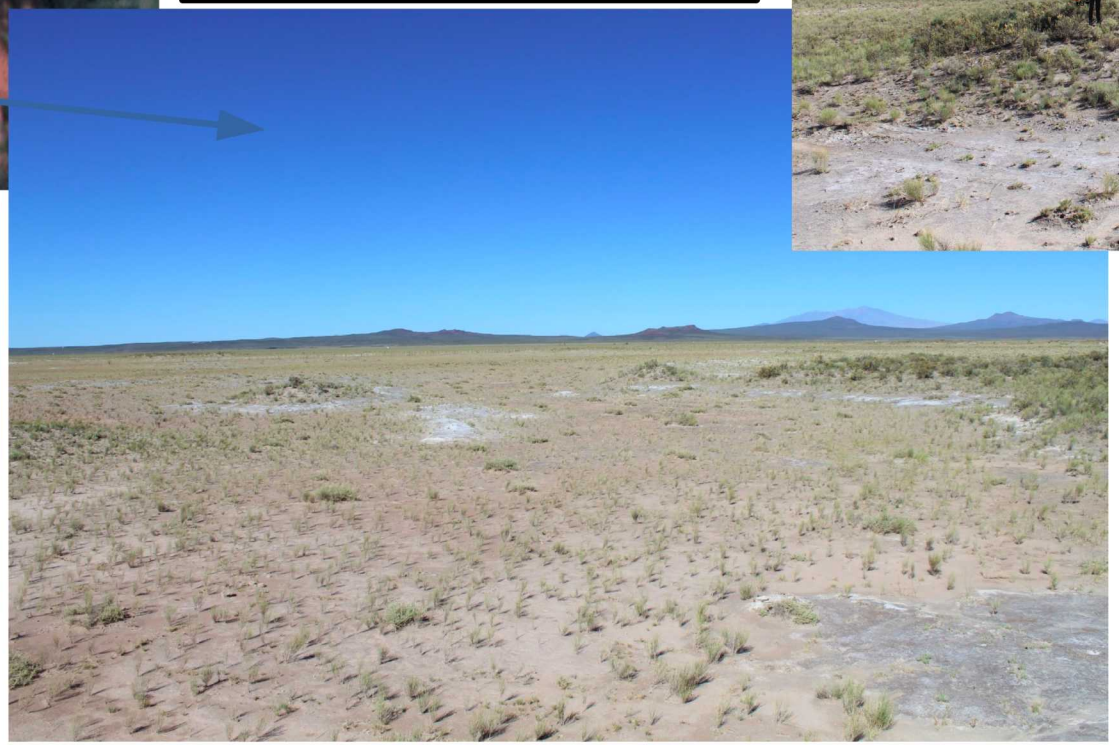




Deployment (Los Morados)

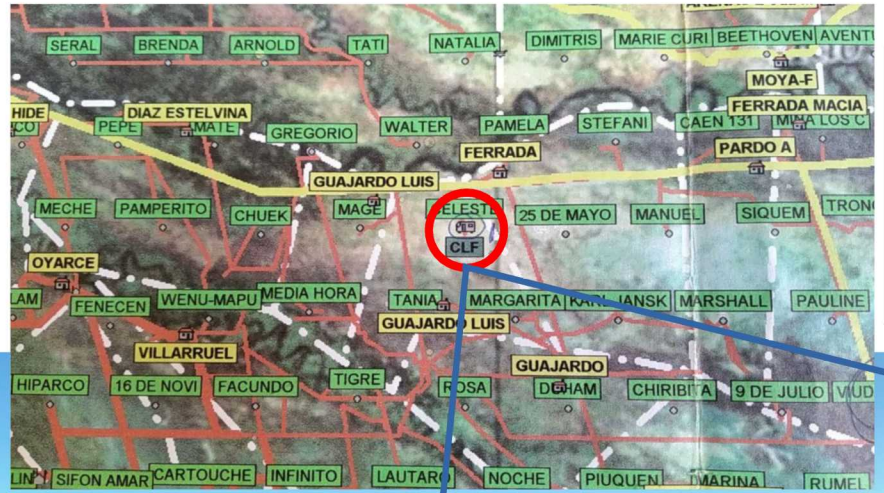
- Flat land (elevated?)
- Good line of sight

- Risk of ponding water during rain times



Photos by Jannis Pawlowsky

Deployment (CLF)

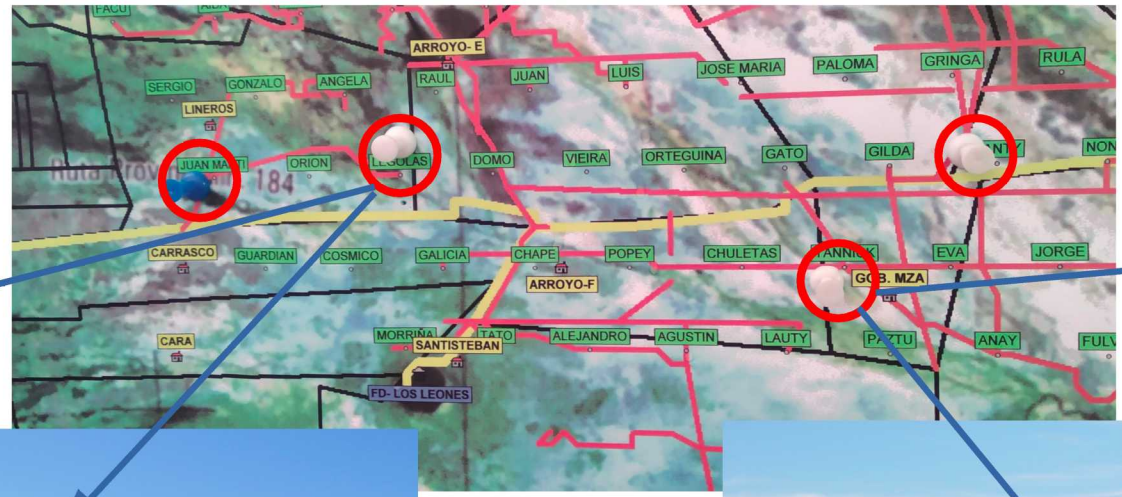


- Flat land
- Some vegetation

- Risk of ponding water during rain times?
- Careful installation to not interfere with the laser

Photos by Felix Schlüter

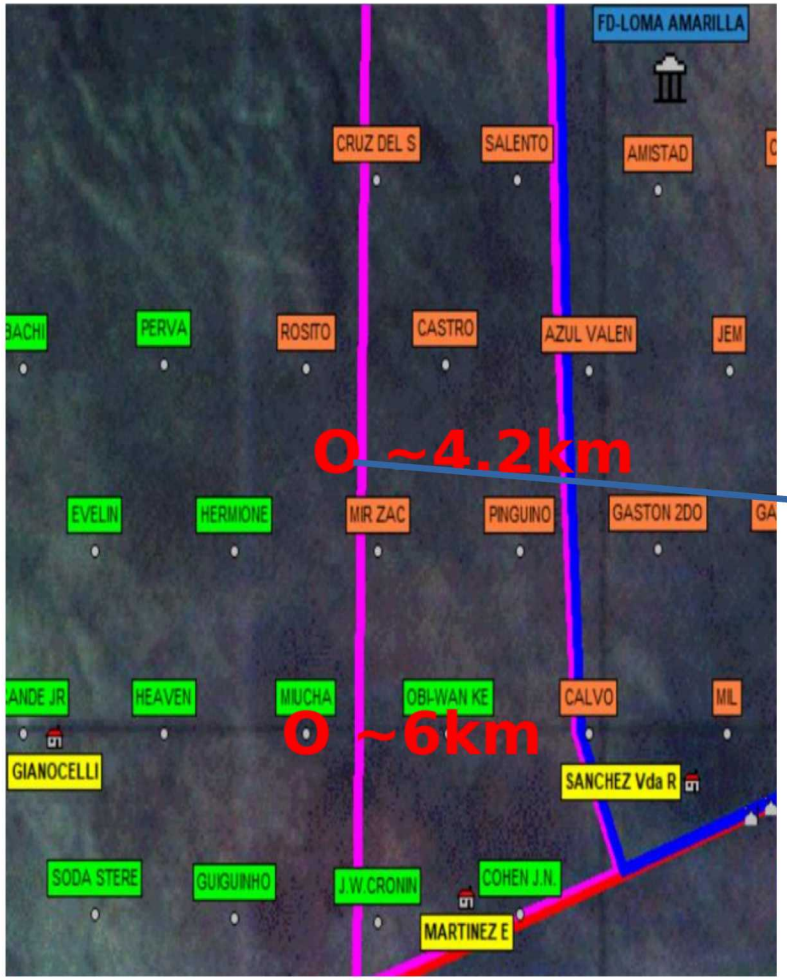
Deployment (Los Leones)



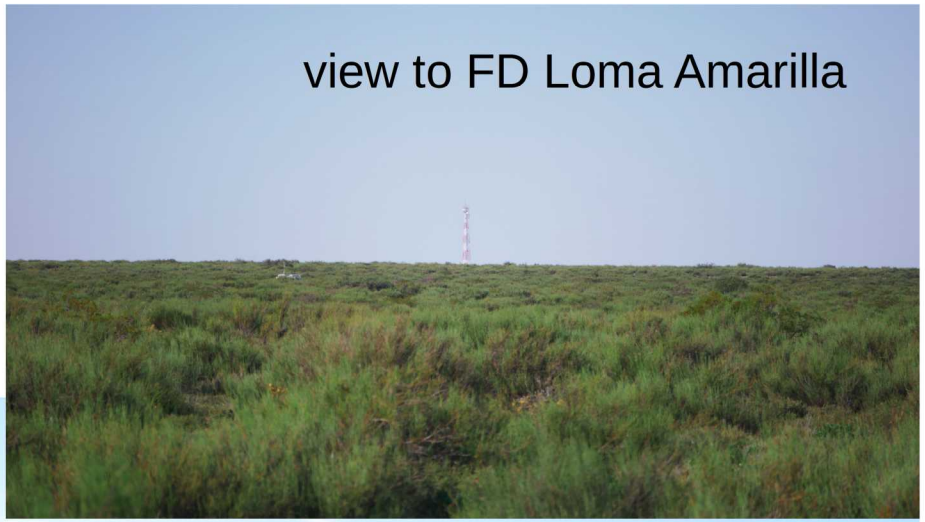
- Flat land
- Good line of sight

- Risk of ponding water during rain times + erosion
  (suggestions made by local staff)

4) Deployment (Loma Amarilla)

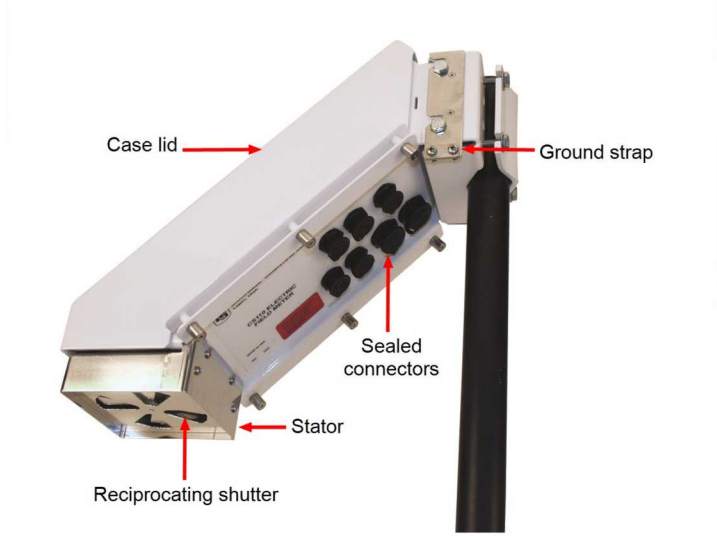


- Mostly flat
- Some larger bushes
- Decent line of sight
- No risk of ponding water

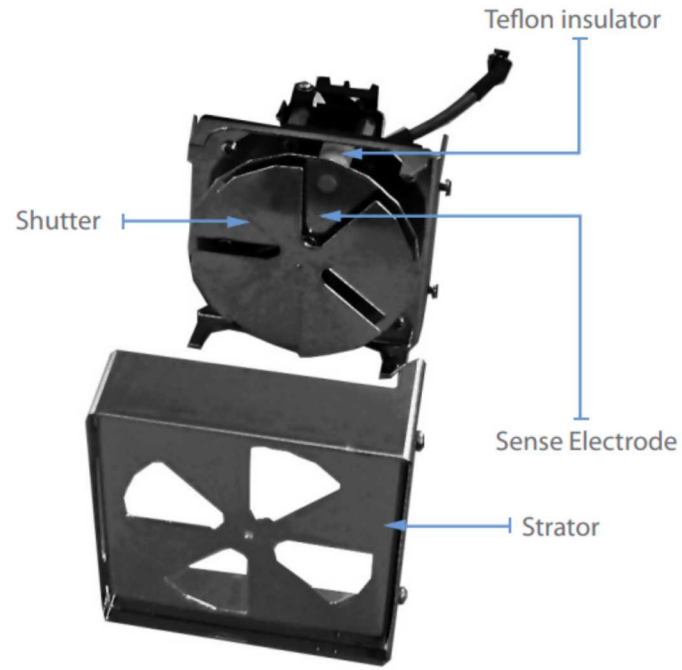


The CS110 E-field mill

Campbell Scientific CS110



- Sense electrode periodically covered and exposed to the atmospheric E-Field by reciprocating shutter
- modulation of the induced electrical charge
  → amplified & converted into AC voltage
  → translated into electric field
  $E = M_{\text{Field Mill}} \cdot V$ ($M_{\text{Field Mill}}$ from factory calibration)
- Sample rate up to 5 Hz → will use 1 Hz
- Internal Datalogger (Can store ~1 day of data at 1 Hz)
- Good Technical Support available



The CS110 E-field mill

Karlsruhe Institute of Technology

Campbell Scientific CS110

- Site correction factor
  $C_{Site} = 0.105 \pm 4\%$
- Accuracy for our setups might be a little worse since we won't fulfill calibration requirements 100%
  → still a lot better than E-Field mill stations at AERA

Price:

- CS110: ~4500€ (incl. data logger)
- Additional parts: ~2000€

Table 5-1: Electric Field Measurement Performance

Configuration	Accuracy[1]	Measurement range[2] (V/m)	Resolution (V/m)	Sensitivity (µV/m)	Noise V/m RMS)
Parallel Plate	±1% of reading + 60 V/m offset	±(0 to 21,000)	3	12	4.0
		±(21,000 to 212,000)	30	118	18.0
2-meter Tripod[3]	±5% of reading + 8 V/m offset	±(0 to 2,200)	0.32	1.2	0.42
		±(2,200 to 22,300)	3.2	13	1.9

[1]Typical offset for clean electrodes is ≤ |30 V/m| for the parallel-plate configuration, which is reduced by the field enhancement factor for typical inverted and elevated mounting configurations.

[2]The CS110 incorporates automatic gain ranging between two input ranges. The measurement is first tried on the lowest input range. If the signal is too large for the lowest range, the larger range is used.

[3]Field enhancement due to typical inverted and elevated mounting requires additional site correction, estimated at ±5% accuracy when done in appropriate high field conditions. Practical outdoor CS110 electric field measurement accuracy is estimated at ±5% of reading + 8 V/m for the CS110 2-meter Tripod Site.

Electric Field Mill