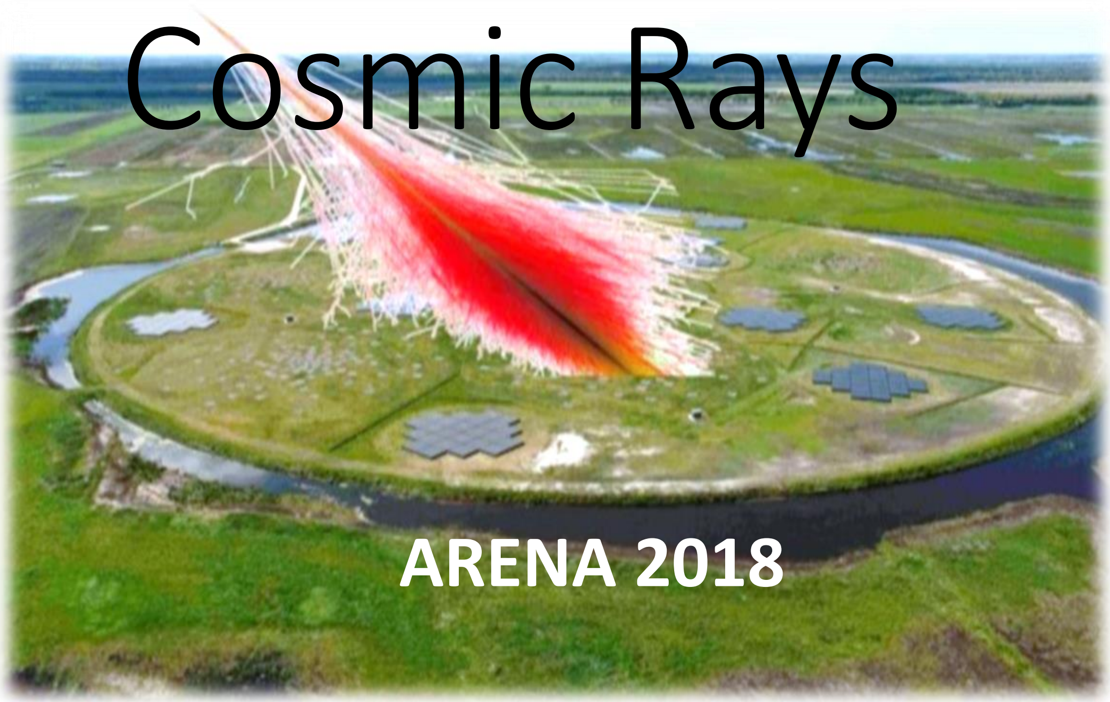
Atmospheric effects on Radio detection of Cosmic Rays



ARENA 2018

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VUB

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European Research Council

LOFAR

Effect of atmosphere on Xmax

- Monte Carlo simulation codes for air shower like CORSIKA/CoREAS based on US stdA.
- Major systematic uncertainty arises from the variation of refractive index in the atmosphere.
- Refractivity N=(n-1) 10^6 depends on pressure, temperature and relative humidity in radio frequencies -

$$N = 77.6890\frac{p_d}{T} + 71.2952\frac{p_w}{T} + 375463\frac{p_w}{T^2}$$

[after J.Rueger]

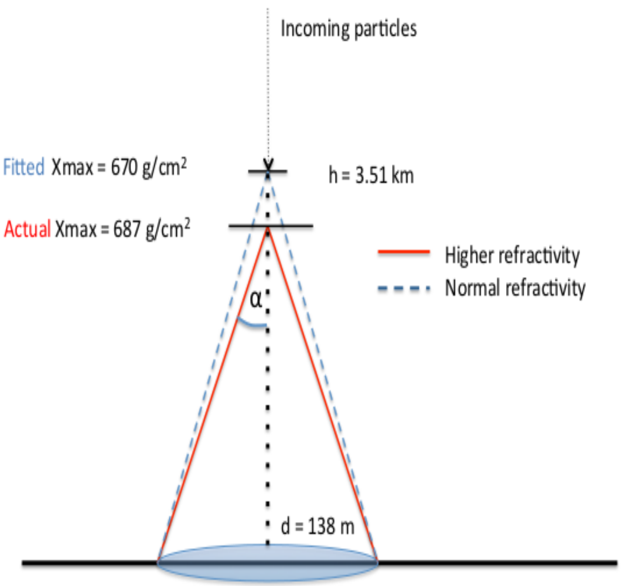
- Effect of humidity in N important in radio regime

Effect of RI on Radio Footprint

Toy Model

- Radio pulses compressed in time ~ Cherenkov like emission.
- Opening angle scales : $\mathbf{Cos\alpha = 1/\beta n}$
- 10% higher N underestimates Xmax 17 g-cm^2

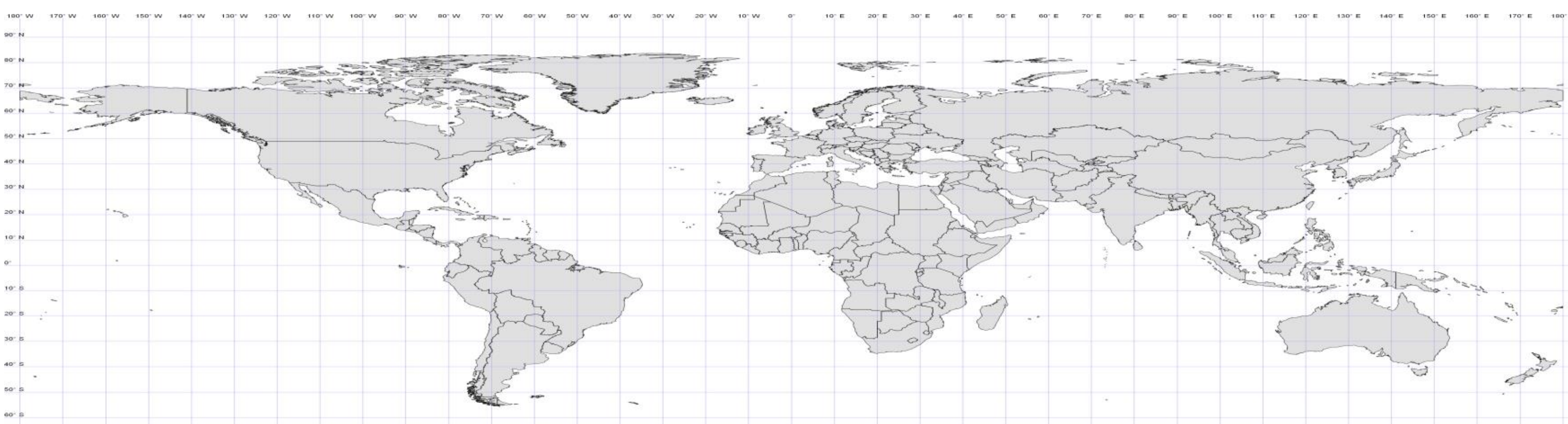
Limitations: considers only local RI.
Integrated RI important for propagation effects.



A.Corstanje et al
arXiv:1701.07338v1

Towards realistic profile: GDAS

- Global Data Assimilation System: database of atmospheric data used for weather forecasting.
- 1°x1°, 3 hour grid.
- 23 constant pressure level data.
- Altitude profiles of temperature, pressure, humidity.
- Calculated the density and refractive index for use in the simulations.



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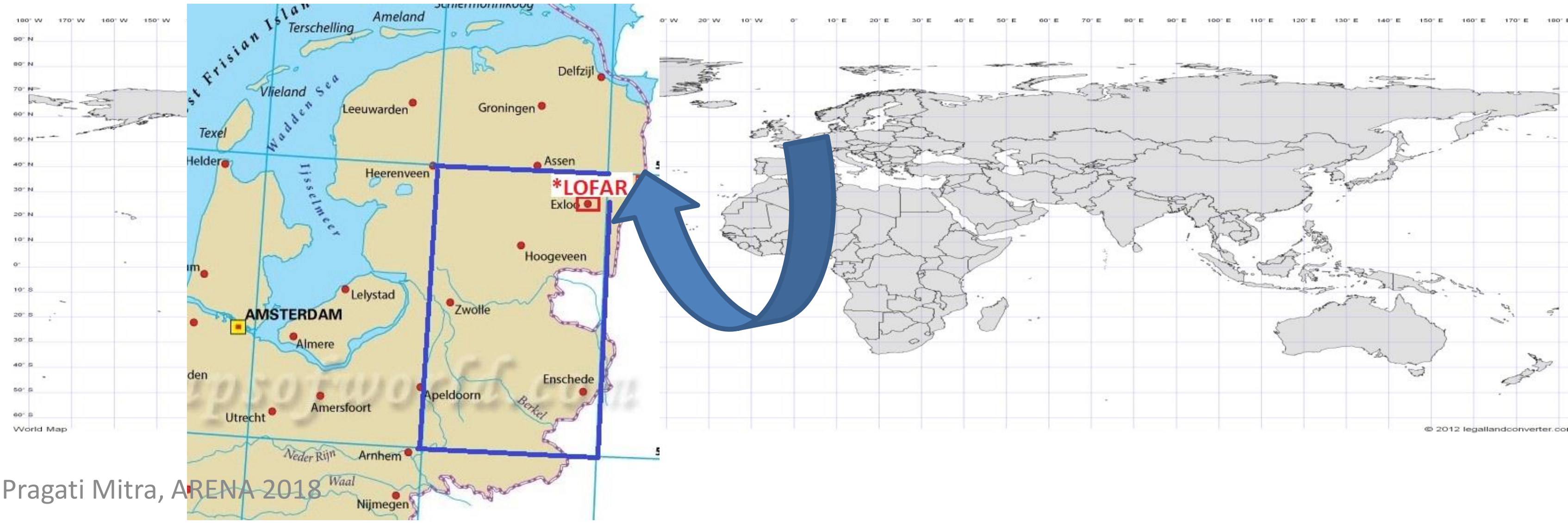
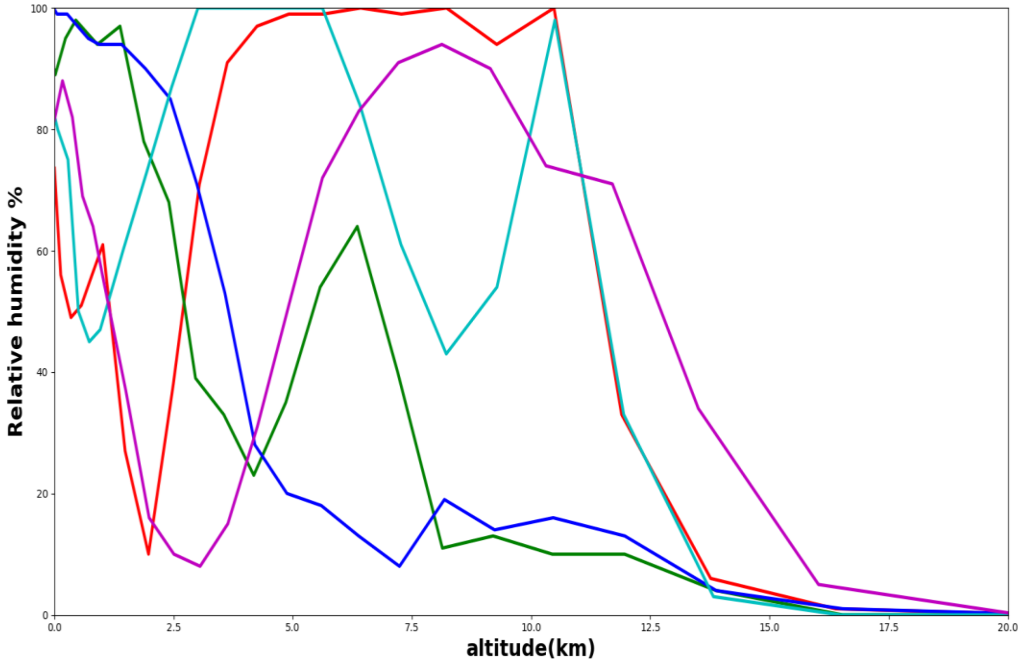
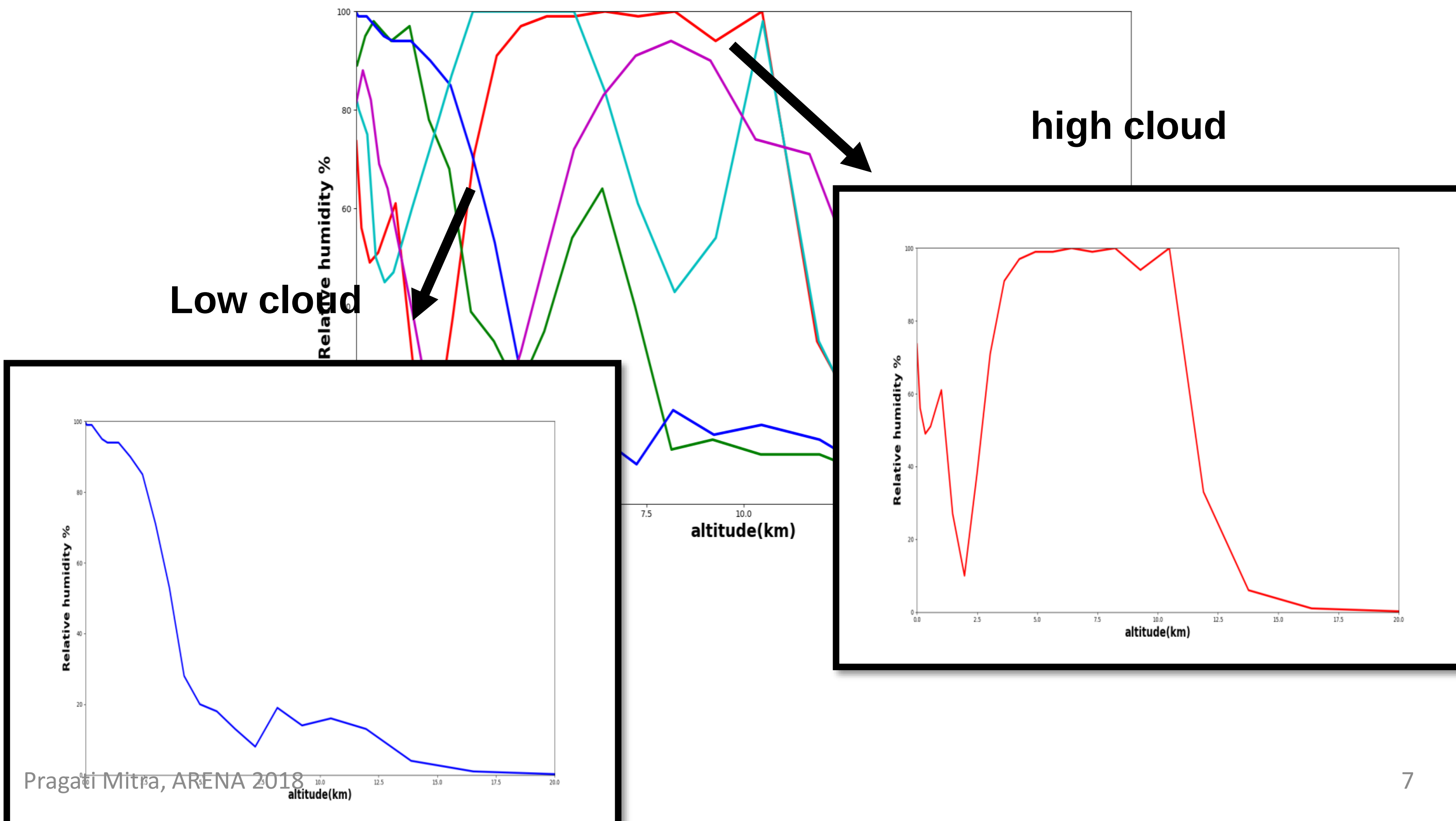


GDAS Atmospheric Profiles



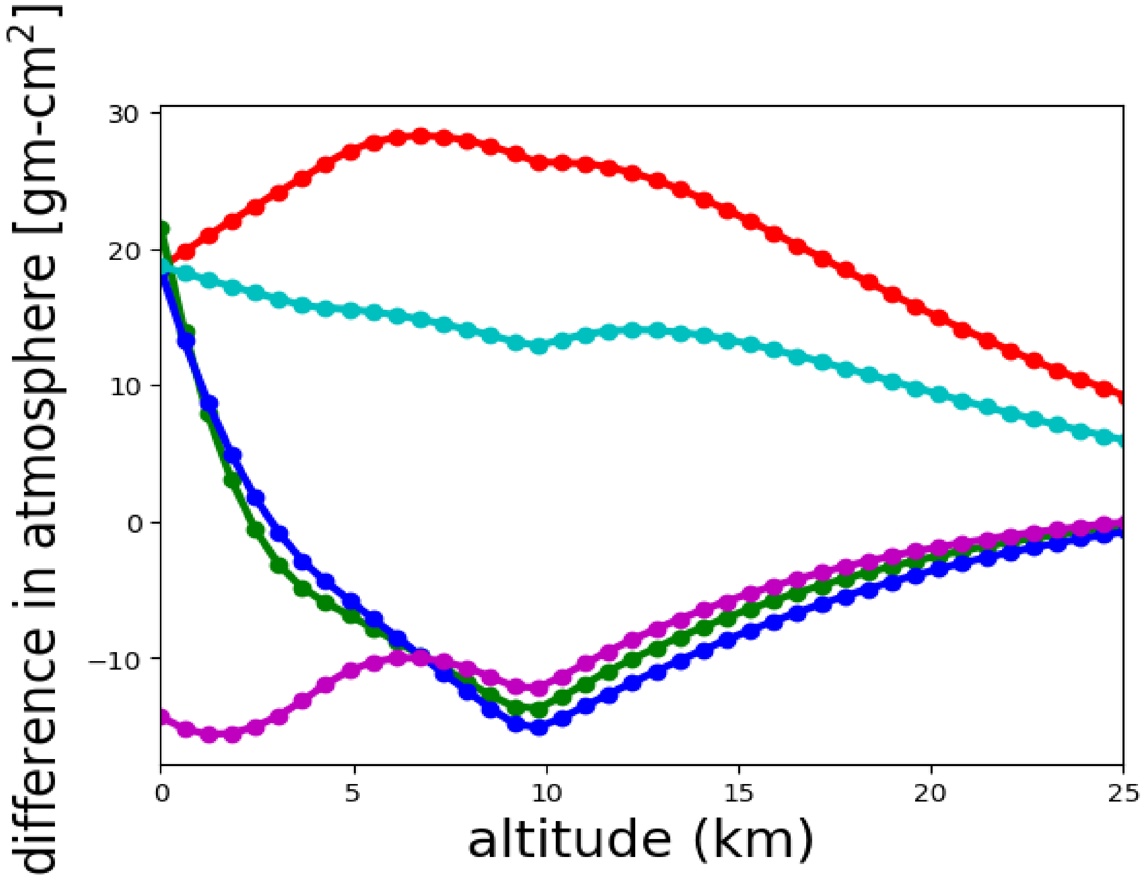
- Profile for 5 events.
- Huge variance at LOFAR site.

GDAS Atmospheric Profiles



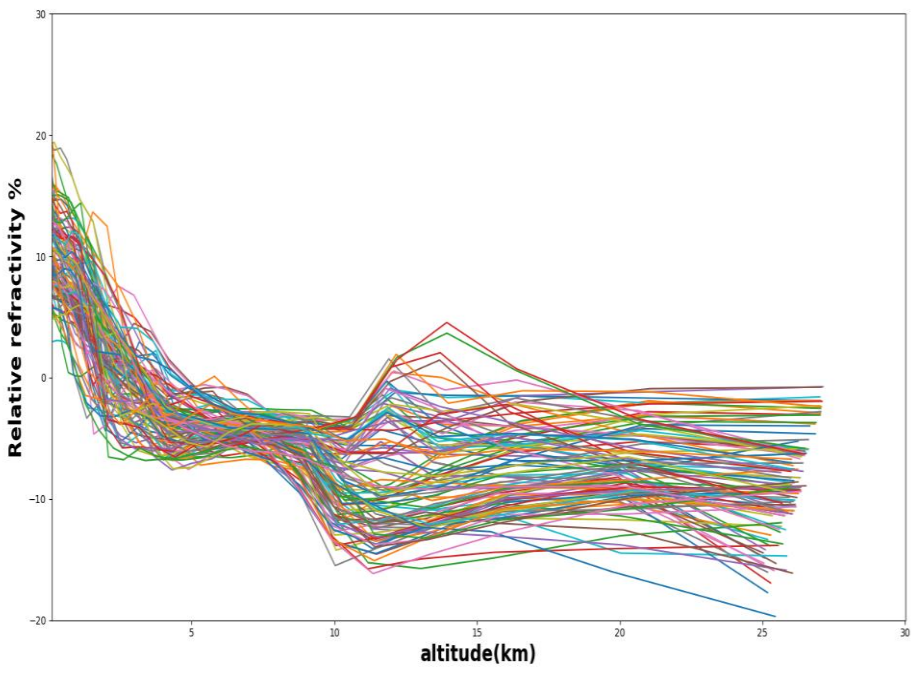
GDAS Profile: Atmosphere

GDAS- Us stdA atmosphere.



- Events with same ground pressure could see different atmosphere over height.
- Full atmospheric description over correction to ground pressure.

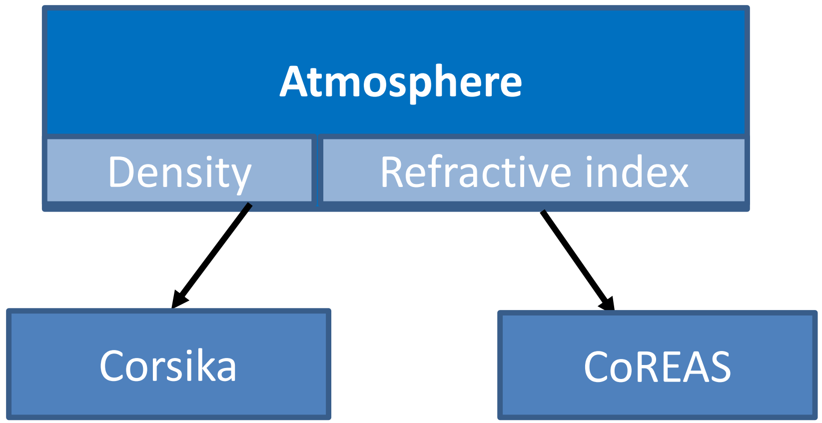
GDAS Profile: Refractivity



Relative refractivity: $(N_{gdas}-N_{us})/N_{us}$

- profile for 100 different CR events recorded at LOFAR.
- 3-5 % variation at 5-8 km ~ region of shower maximum.
- Integrated relative refractive index ~ 7-10 % between the same region.

Implementation of GDAS to CORSIKA/CoREAS



CORSIKA

- Fit layered atmosphere model to GDAS data.
- Feed fit parameters unto simulation.

Coreas

- Replace calculation of RI with look up table.
- Read RI data from file.

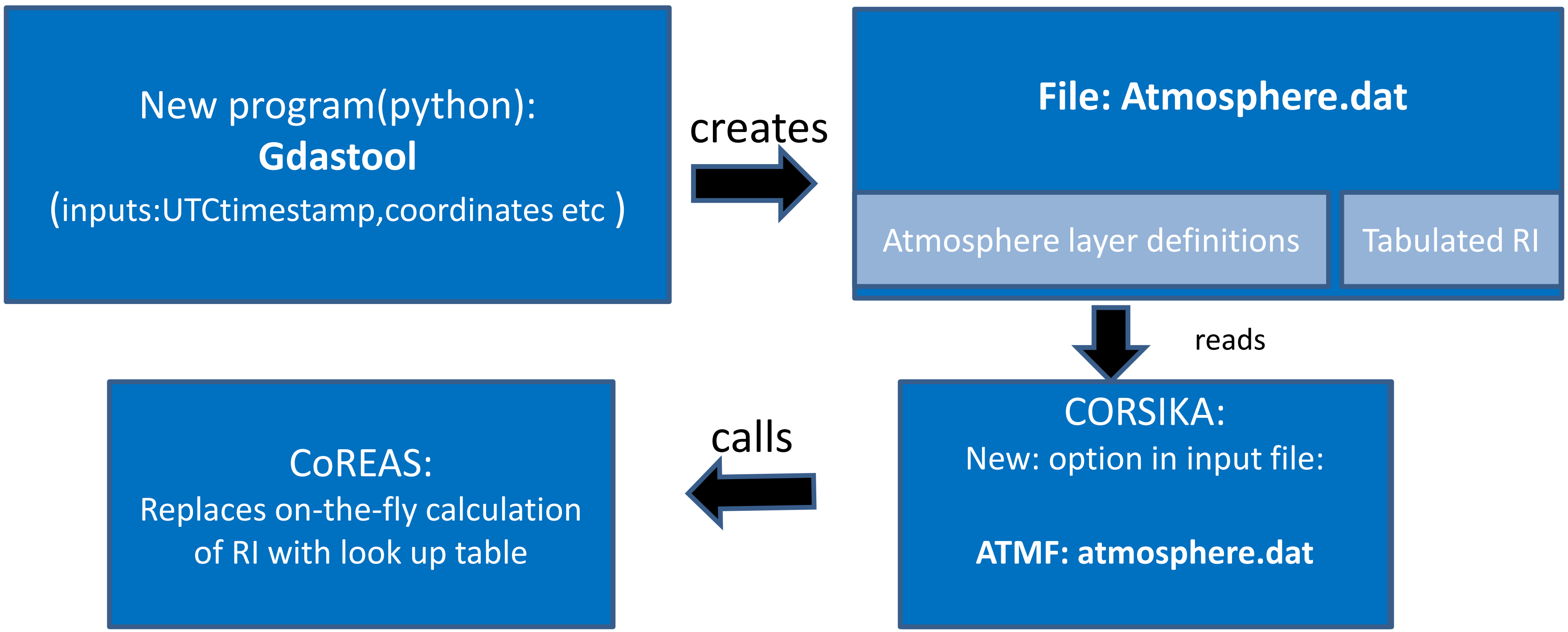
Fitting Procedure

- 5 layer atmospheric model:

$$X(h) = a + be^{-h/c}$$
$$\rho(h) = \frac{b}{c} e^{-h/c}$$

- Boundary condition: X(h) ,ρ(h) should be continuous at layer boundary
- Choosing boundary layers- 24 GDAS points divided into 3 layers-
- Fit density profile for **b,c**
- Analytically solve for **a**

Implementation of GDAS to CORSIKA/CoREAS



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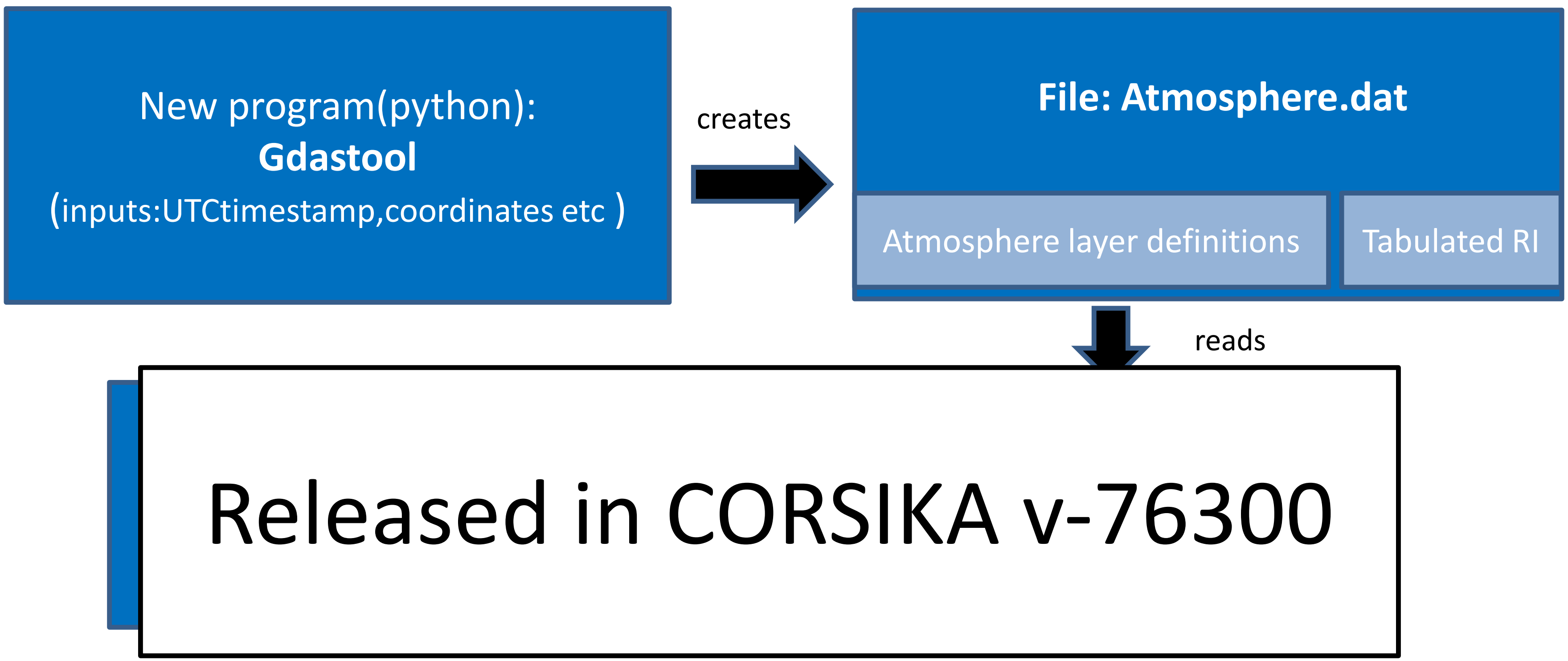

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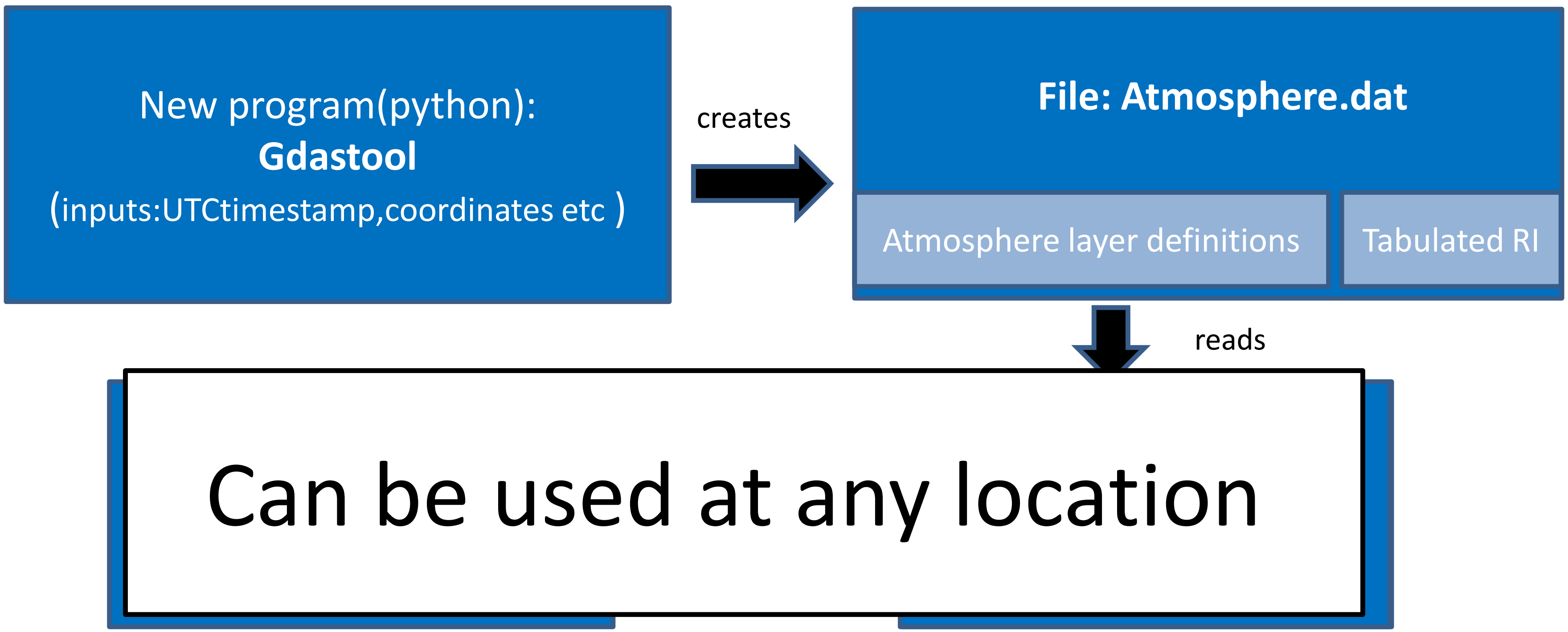

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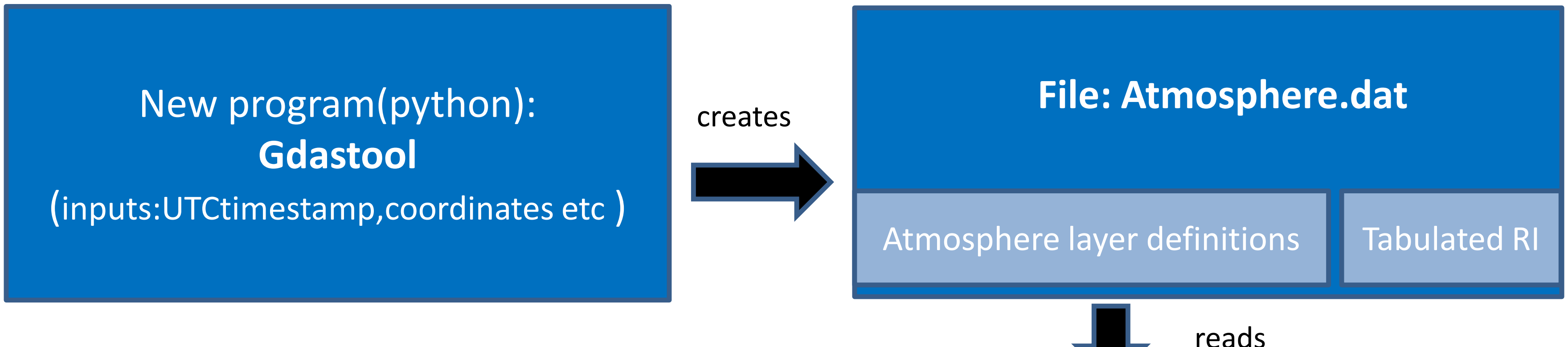
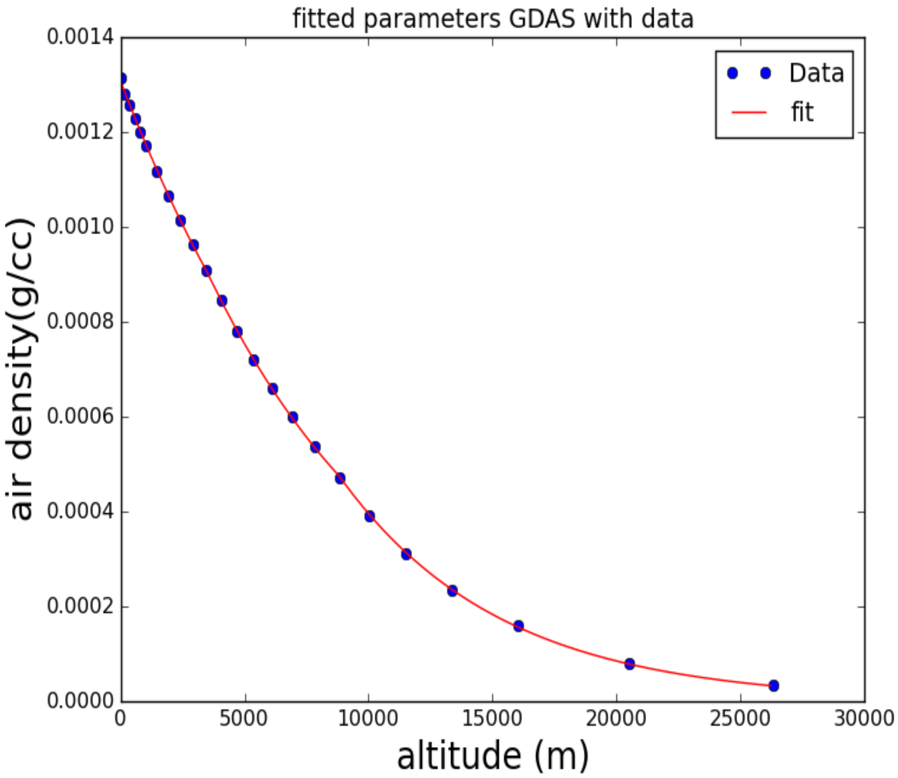
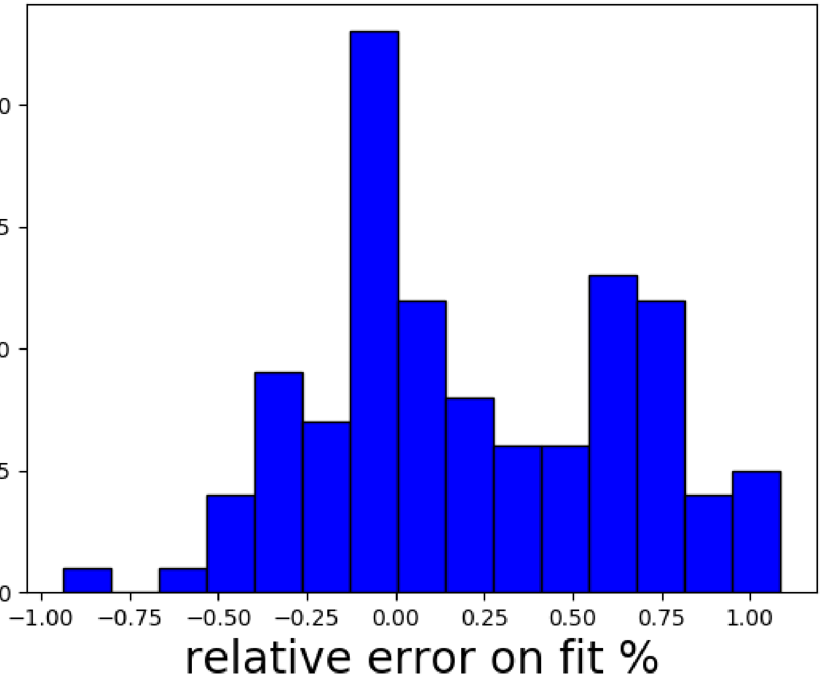


Execution: gdastool [-h] [-t UTCTIMESTAMP] [-o OUTPUT] (--observatory {lofar,aera} | -c COORDINATES COORDINATES)

gdastool : Output Example





Relative error:
Δdensity/density data

Simulation with LOFAR data

- New simulation with LOFAR events.
- 123 for this analysis
- New GDAS atmosphere .
- Xmax reconstruction with radio only fitting
- Compare between event sets:

Set- A

GDAS atm + CORSIKA-new

Set- B

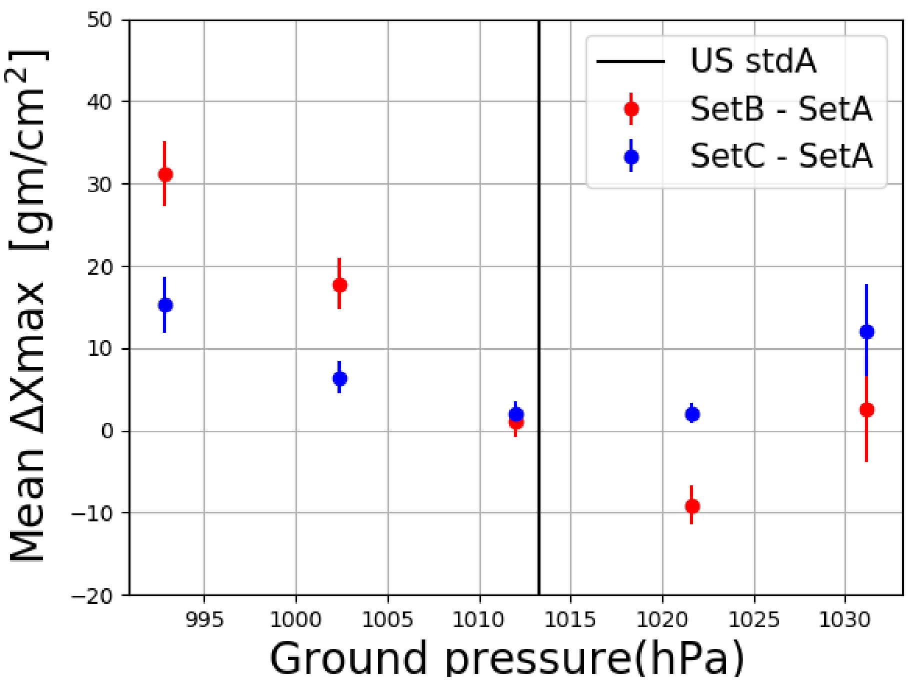
US stdA + CORSIKA-old

Set-C

US stdA +atm correction+ CORSIKA-old

CORSIKA-old: v 74385
CORSIKA-new: v 76300
Offset = 1.67 gm-cm^2

Mean Xmax vs ground pressure



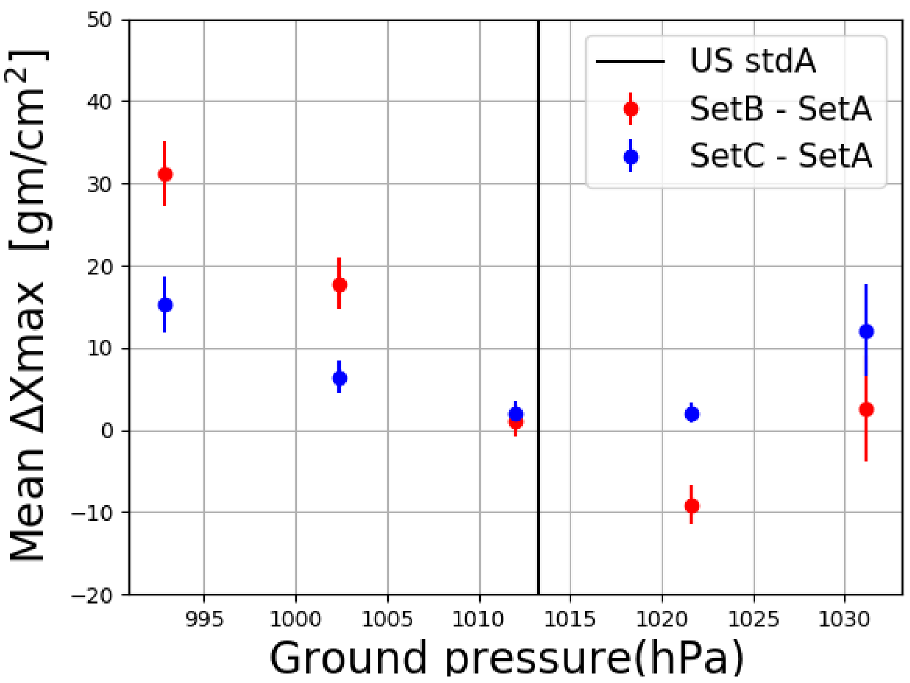
Difference in mean Xmax between

Set- A
GDAS atm + CORSIKA-new

Set- B
US stdA + CORSIKA-old

Set-C
US stdA +atm correction+ CORSIKA-old

Mean Xmax vs ground pressure



- Correction for pressure is important.
- Linear correction is not sufficient at lower pressure.
- full GDAS-based simulations required.

Humidity Effects: From MC studies

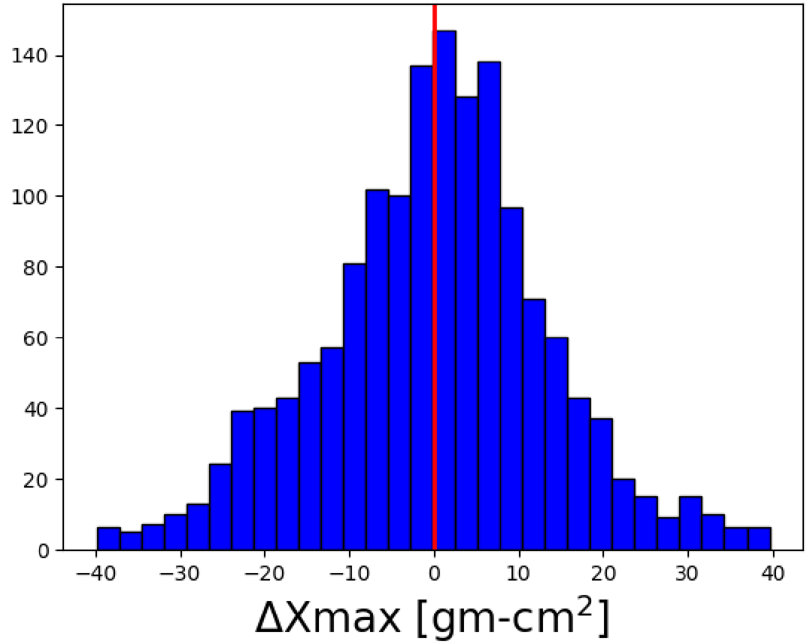
Set1

- New CORSIKA/CoREAS
- No humidity

Set2

- New CORSIKA/CoREAS
- With humidity

- Take one shower from **Set2** as "fake data"
- Fit showers from **Set1** to it.
- Difference $Xmax_{reco} – Xmax_{real}$: humidity effect.
- 50 event sets; each ~ 50-100 simulations.



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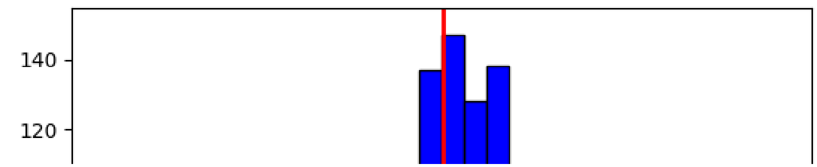
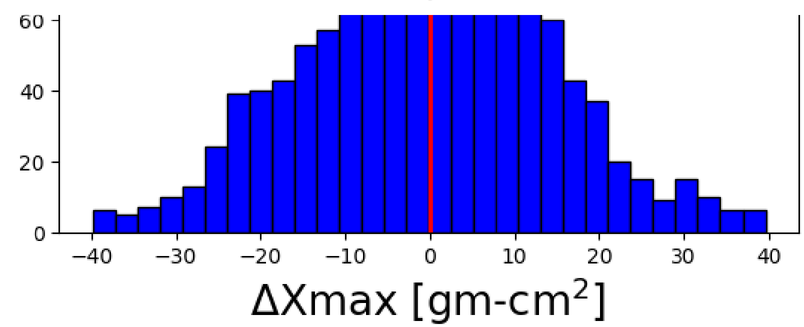


- no visible effect of humidity
- Further investigation



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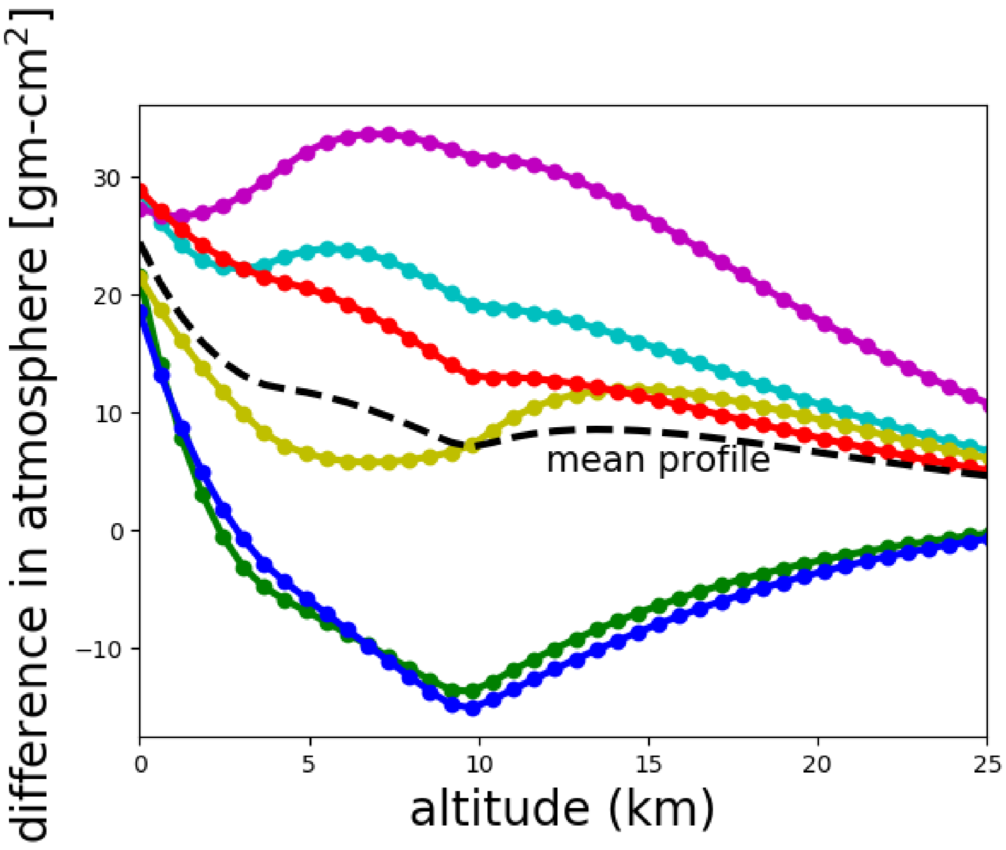
Conclusions

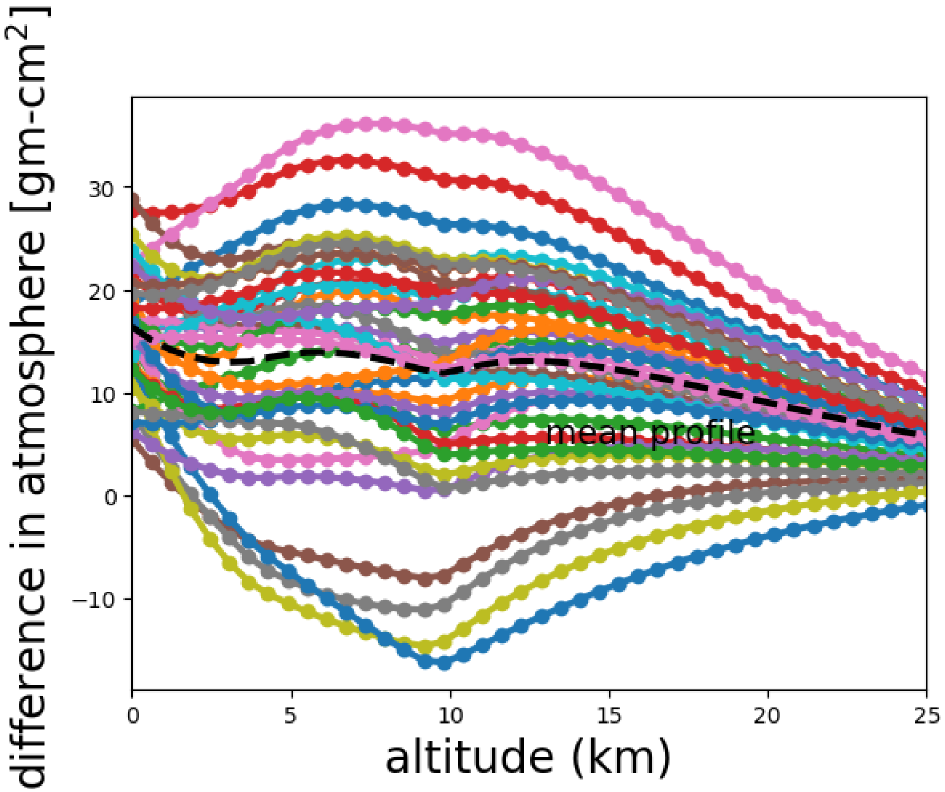
- GDAS atmosphere included in **CORSIKA-v76300**
- A Stand-alone script "**gdastool**" provides local real time atmospheric profiles (density + RI) for any location.
- LOFAR data simulated with GDAS atmosphere.
- Full GDAS atmospheric profile is required over Linear correction to US stdA.

Back ups

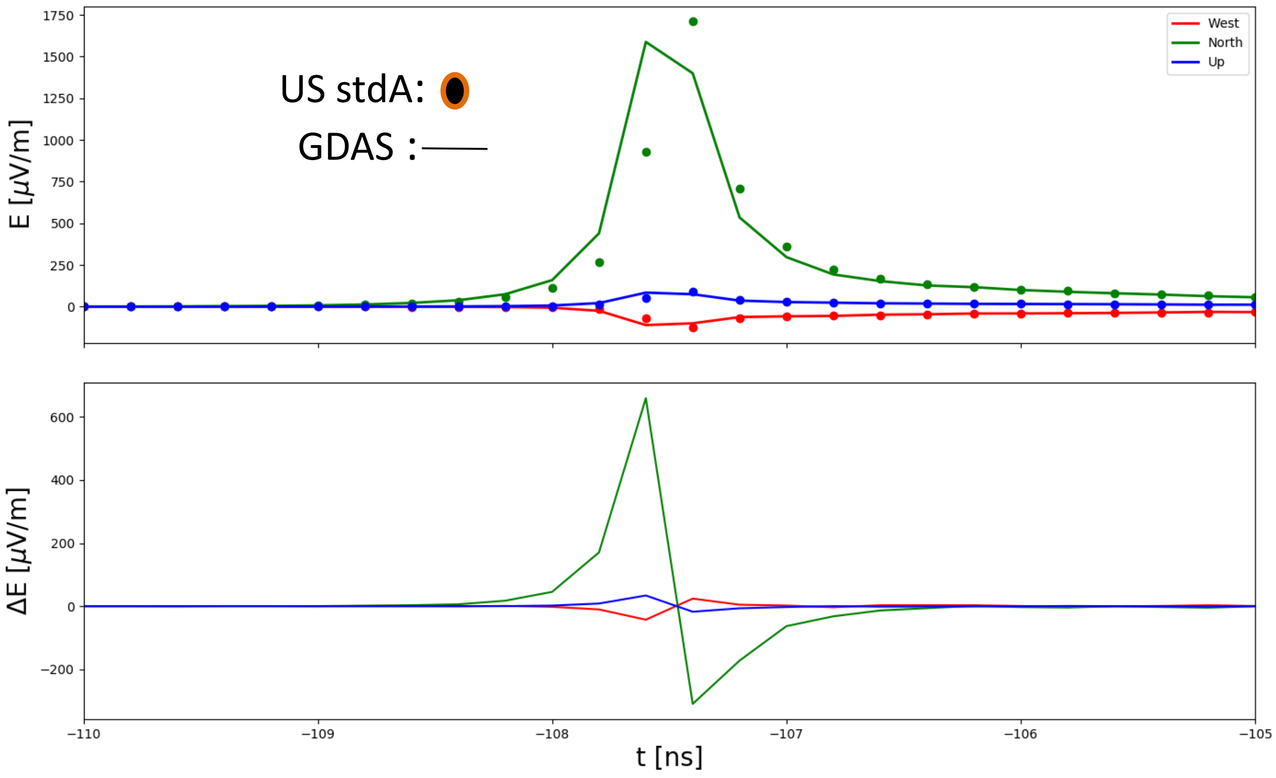
Atmosphere profile: last Pressure bin(high P)



Atmosphere profile: 2nd last Pressure bin



Effect of RI on E-field



10^8 GeV p shower, coming from 20 zenith measured at 100 m from core