

# Cloud Atlas

## An LstmEncoder for UHECR AirShowers

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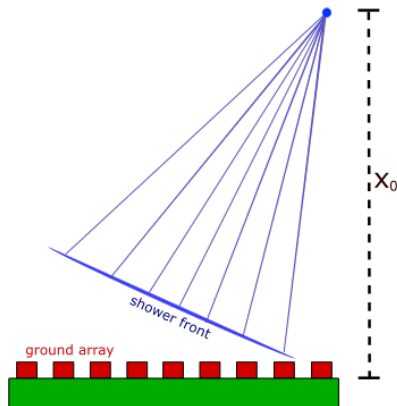
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# UHECR Airshower

When *Ultra High Energy Cosmic Rays* (UHECR) enters the atmosphere they produce a particle cascade.

**Detection:** grid of water-Cherenkov ground based detectors.

**Prediction:**  $X_0$  height at which the shower forms.



# Dataset, first glance

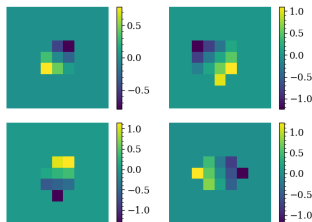
**Dataset:**  $10^5$  simulated events:

- 9x9 grid of detectors
- most intense at center
- 80 frames of time series (40MHz sampling rate)
- 1 frame of times of first arrival

Single record shape:  $(80 + 1, 81)$

pd4ml package splits by default in  
70% train 30% test

Times of arrival



Detector time series



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# Split the dataset

Dataset was already split in test and train.

We put it all back together, shuffled it and divided with the following percentage:

- 70% *train*
- 20% *test*
- 10% *validation*

For the design of the net it is convenient using `numpy` structured arrays



# Split the dataset: funky\_dtype

```
1 # custom numpy dtype
2 funky_dtype = np.dtype(
3     [
4         ("outcome", np.float64),
5         ("time_series", np.float32, (80, 81)),
6         ("toa", np.float32, (9, 9, 1)),
7     ])
8
```

All data relative to a single event is clustered in a single numpy object, transformation is:

$$(80 + 1, 81) \longrightarrow [(\text{"toa"}, (9, 9, 1)), (\text{"timeseries"}, (80, 9, 9))]$$

Data can be accessed "as a dictionary", depending on what is needed.



# DataFeeder class

Ensures an easy way to train the subnets separately Class DataFeeder main features:

- shuffles data randomly
- input fields can be specified
- can be extended to more complex training strategies
- returns a generator

Using a generator (`keras.utils.Sequence`)

- inherit multiprocessing features
- has default callbacks
- avoids memory overload

# Resolution

The reference article suggests using the resolution:

## Resolution

defined as the standard deviation of the distribution given by the difference between the predictions and the actual values of  $X_{max}$

We point out that

$$\sigma^2 = \frac{1}{N} \sum_i (\delta_i - \bar{\delta})^2$$

is a sensible estimator of the average error on predictions only if  $\bar{\delta} = 0$ , for which the adopted resolution is equal to the *RMSE* of the distribution

$$RMSE^2 = \frac{1}{N} \sum_i (x_i - \hat{x}_i)^2$$

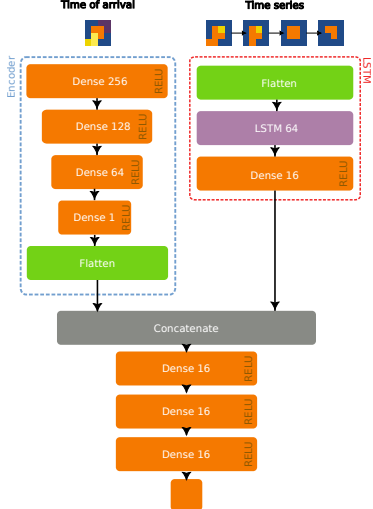
Since (on a typical trained model)  $\bar{\delta} \approx 10m$  we preferred the RMSE.

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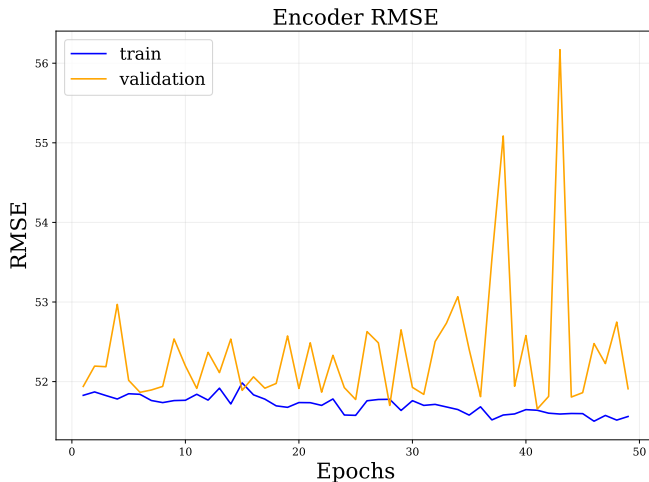


# Overview on the network

The assumption that lead to this design is that from the time of arrival matrix it is possible to infer some kind of “homogeneous” shower parameters (incidence angle, spread, etc.) while the time series can be processed by a recurrent network.

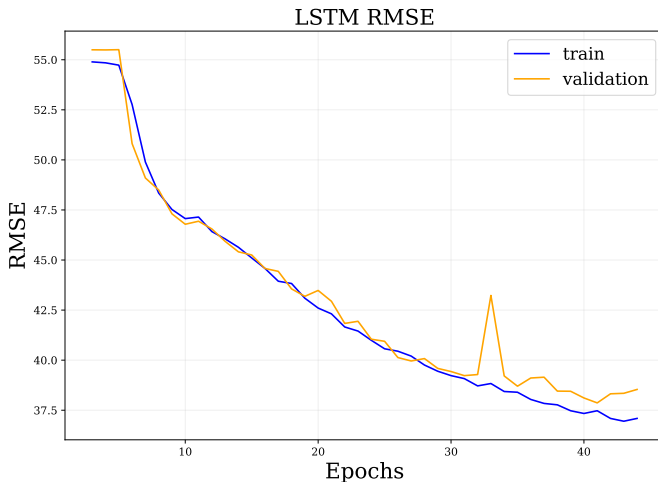
# Encoder for the time of arrival

We tried to train just the Encoder with input time of arrival matrices.



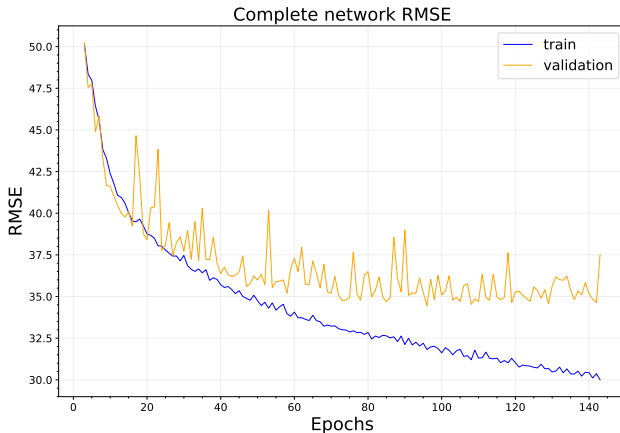
# LSTM for the time series

We did the same thing with the LSTM network with the time series.



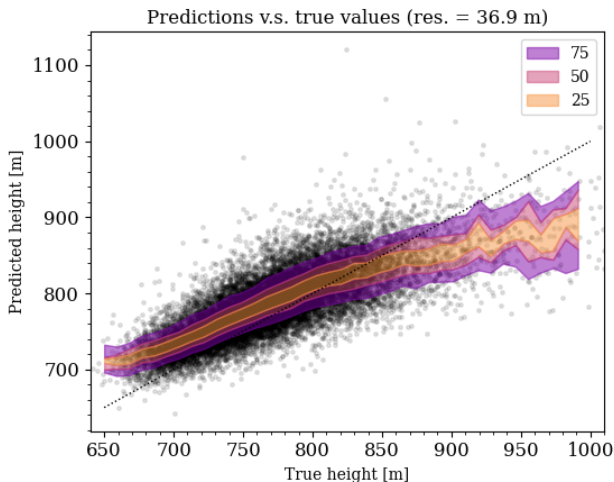
# Complete Network performance

This is a training of the whole network on 144 epochs.





# Complete network performance

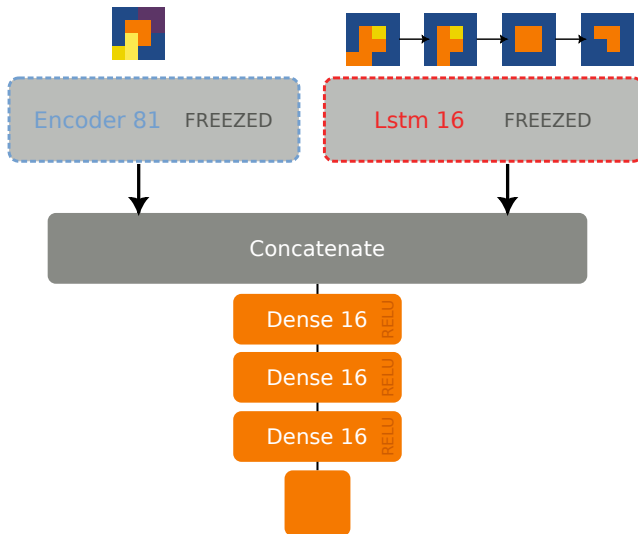


# Strategies for Performance Improving

We tried 3 strategies to improve network's performance:

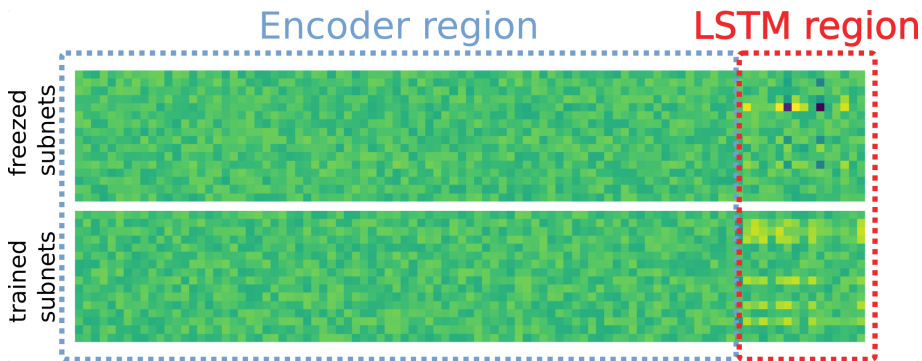
- 1 **Transfer Learning**
- 2 **Data Augmentation**
- 3 **Curriculum Learning**

# Transfer Learning Strategy



# Weights at concatenation layer

Is the encoder really useful?



# Data Augmentation Strategy

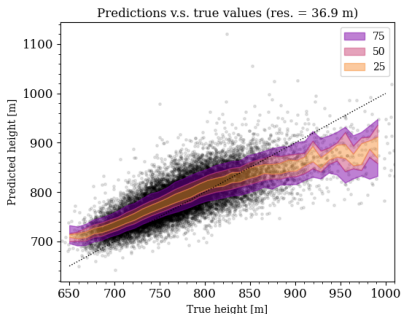
Dataset has a lack of high events ( $X > 850\text{m}$ ) so a first network training showed a worse resolution for samples corresponding to this range

## Strategy

Increase the number of samples that overcome a certain height threshold using the symmetries of the problem

Data is augmented using

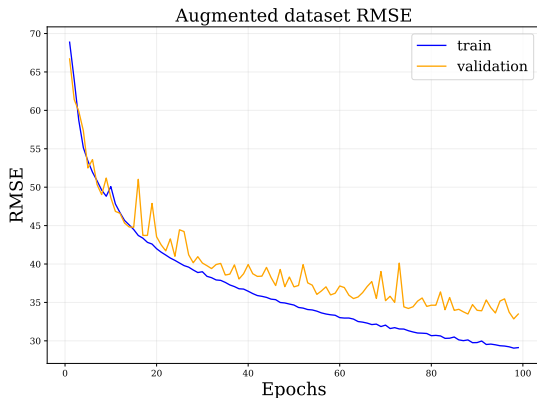
- flip up-down
- flip left-right
- diagonal flip
- rotation of  $90^\circ$



# Augmented dataset performance

The network trained with an augmented dataset gave the following performance on test dataset (not augmented):

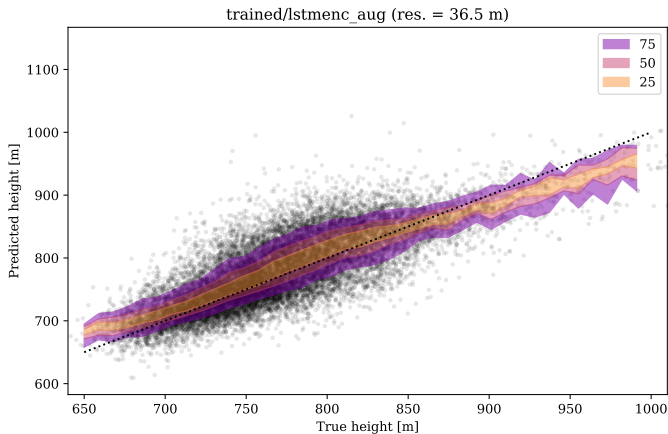
- **loss**= 1744.27
- **rmse**= 36.48



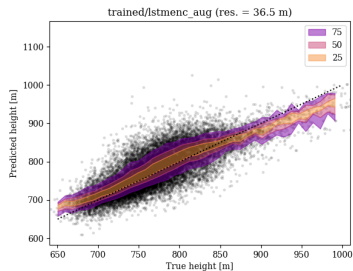
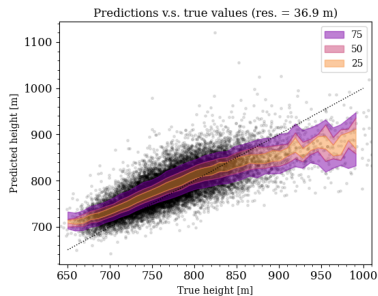
# Augmented dataset performance

The augmented-dataset-train gave a Pearson correlation coefficient of:

$$\rho_{X,Y} = 0.80 \pm 0.02$$



# Comparison with vanilla network





# Curriculum Learning Strategy

- Normal training
- Use the trained NN to score the difficulty of samples
- Schedule a training for another NN

We also tried to generalize Augment class to augment more difficult data.

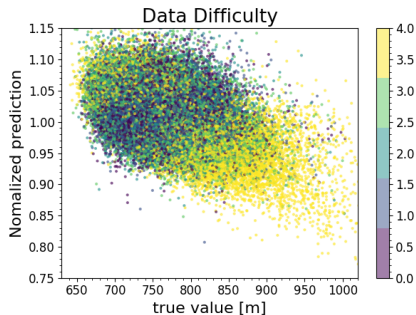
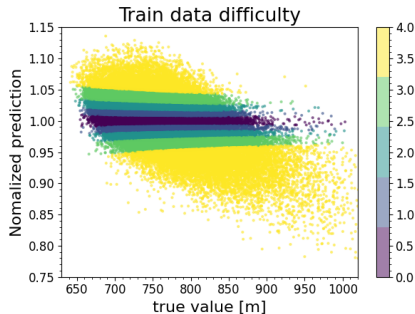
Maybe useful on classification tasks, but for regressions..

# Curriculum learning

Training over “difficult” data makes the net forget the easier samples

Sort in ascending error and divide in equal-length groups that the “prof” feeds to the next network

The “student” network is trained increasing in difficulty but spends more time on hard samples



# Test setup on CircleCI

We covered  $\sim 60\%$  of the whole project, main test ideas are for training classes and functions with a fictitious smaller dataset.

Main tests:

- **Net building**: checks if networks are correctly built
- **DataFeeders**: builds a fictitious dataset and checks whether DataFeeders work fine
- **Augmentation**: tests if an augmented matrix is effectively “rotated”, “flipped”, etc.

Some tests required a trained model so they were not executed in CI.

# Code coverage



## cloudatlas

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## Generated code description

Code description generated automatically from docstrings.

### Models

Module for nets generation.

The three proposed designs are a small encoder (ToaEncoder) a time series LSTM (TimeSeriesLSTM) and a concatenation of the two (LstmEncoder).

```
class cloudatlas.nets.LstmEncoder(optimizer='adam',  
encoder=None, lstm=None, train_encoder=True, train_lstm=True,  
**net_kwargs)
```

The net to analyze the AirShower dataset.

It is composed by a *time of arrival* branch and a *time series* branch.

The latter is designed as an encoder of dense layers. The hypothesis that brought to this design is the information redundancy of the time of arrival matrix. The more a paricle shower is homogeneous the less number of parameters are needed to describe it, such as an incidence angle, spread angle and height of first collision. The encoder aims to extract those "homogeneous beam" parameters.

The time series branch is composed of a layer of lstm units and a relu-activated dense layer. It processes the time evolution of the detectors activity.

 v: latest ▾

Finally the output of the two branches are concatenated and porcessed with a small

Danke Schon