Nowcasting the turbulence at the Paranal Observatory

Fuyan Bian on behalf of the team :

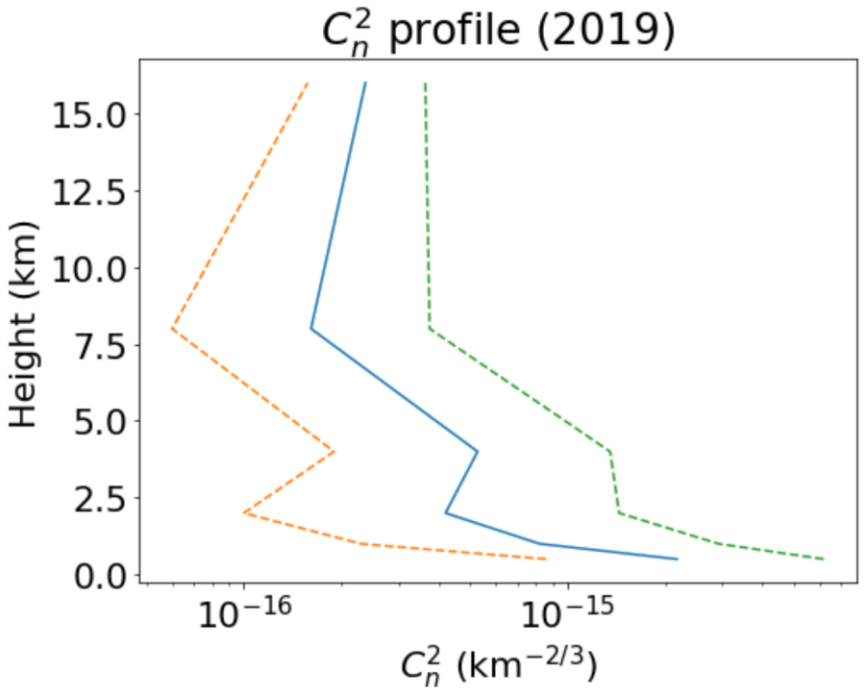
“Turbulence Nowcast Proof of Concept” in partnership with Microsoft Research/ EY Metric Arts

EIROForum Workshop Big Data 2020

What is Turbulence nowcasting?

- In meteorology, Nowcast = Now + Forecast weather forecasting in a near future (up to a few hours), using methods complementary to Numerical Weather Predictions.
  - New field for studies of optical turbulence

- First application to the optical turbulence:
  - Astronomical Seeing: amplitude of turbulence
  - Coherence time: characteristic time-scale of turbulence (millisecond)
  - Fraction of turbulence in the ground layer: location of turbulence

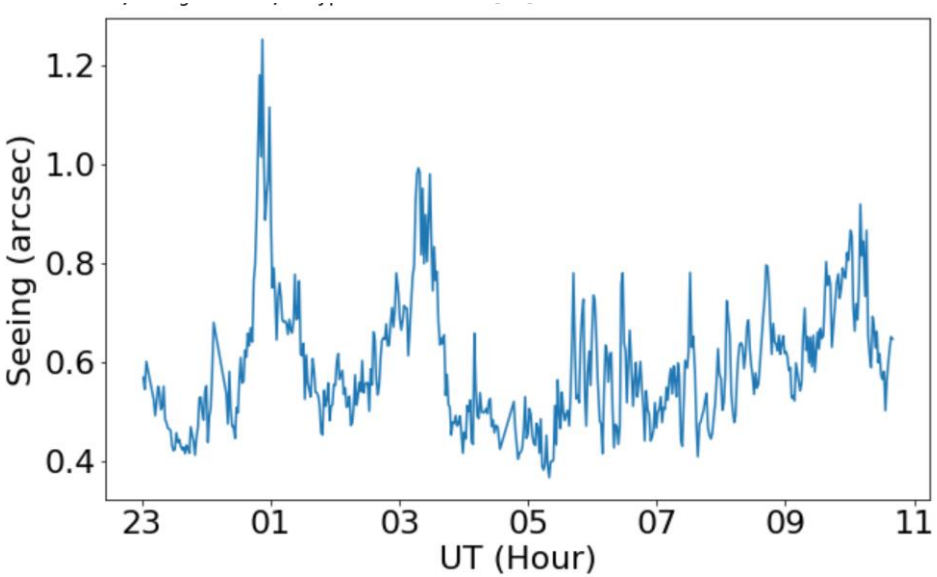


strength of atmospheric turbulence

What is Turbulence nowcasting?

- In meteorology, Nowcast = Now + Forecast weather forecasting in a near future (up to a few hours), using methods complementary to Numerical Weather Predictions.
  - New field for studies of optical turbulence

- First application to the optical turbulence:
  - Astronomical Seeing: amplitude of turbulence
  - Coherence time: characteristic time-scale of turbulence (millisecond)
  - Fraction of turbulence in the ground layer: location of turbulence

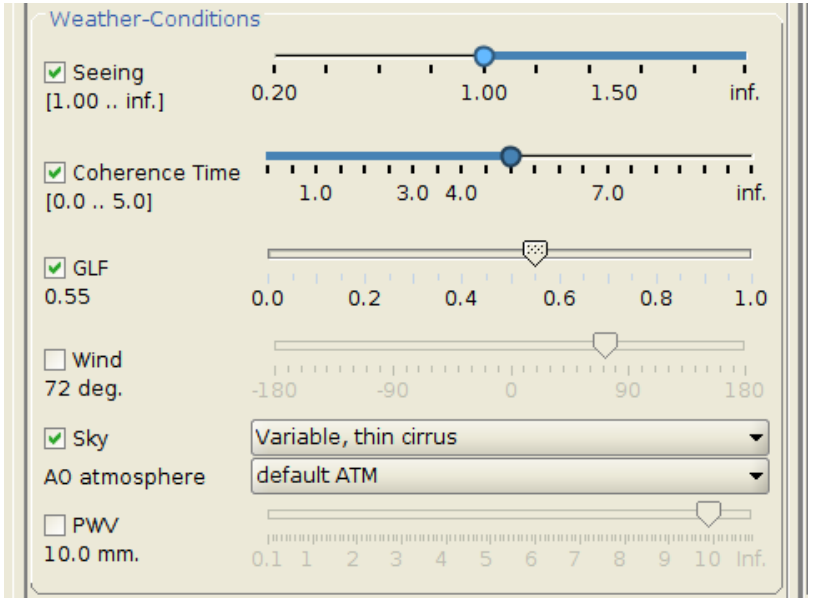


Why predicting the turbulence ?

- Support the night astronomer in decision making, in particular for AO instruments that have multi-parameter constraints

Why predicting the turbulence ?

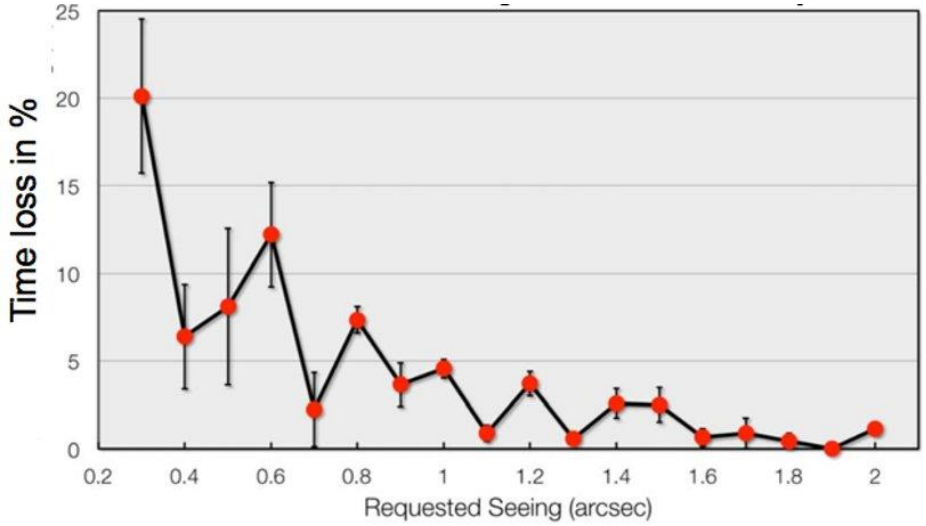
- Support the night astronomer in decision making, in particular for AO instruments that have multi-parameter constraints



GUI of the Paranal Observation RANking enGine (ORANG)

Why predicting the turbulence?

- Support the night astronomer in decision making.
  - In particular for adaptive optics instruments that impose multi-parameter constraints on the state of the atmosphere
- Enable more aggressive short-term scheduling with well-estimated risks.
  - Exploit to the maximum the unique atmospheric conditions at our sites.



Clear margin for improvement, especially for demanding programs (e.g. AO)

Why predicting the turbulence?

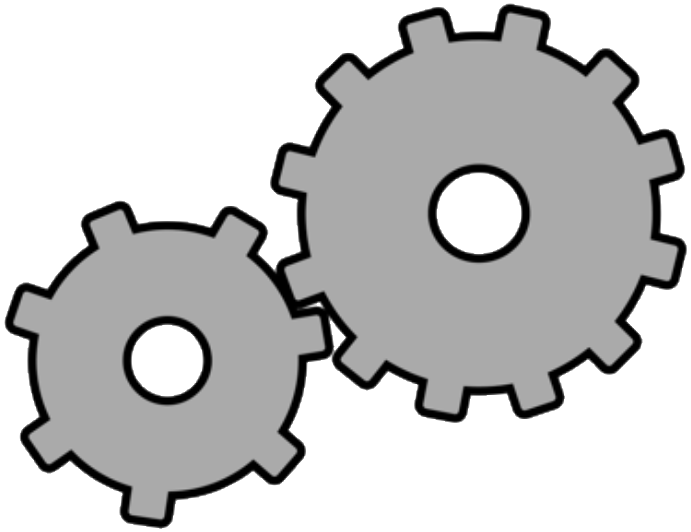
- Support the night astronomer in decision making.
  - In particular for adaptive optics instruments that impose multi-parameter constraints on the state of the atmosphere
- Enable more aggressive short-term scheduling with well-estimated risks.
  - Exploit to the maximum the unique atmospheric conditions at our sites
- Prepare the mode of operation of the future Extremely Large Telescope (ELT)
  - Much of the transformational science of the ELT requires very good atmospheric conditions. **Therefore, predicting the turbulence for up to 3 hours is one of the ELT's top operational requirements.**

Nowcast: the approach

Input

- DIMM seeing
- MASS-DIMM coherence time, ground layer fraction
- ASM data (pressure, wind, temperature, RH)
- Day of the year, hour the of day
- ECMWF 200mbar wind speed forecast
- Radiometer temperature profile

1 or 2h in the past



Three methods:

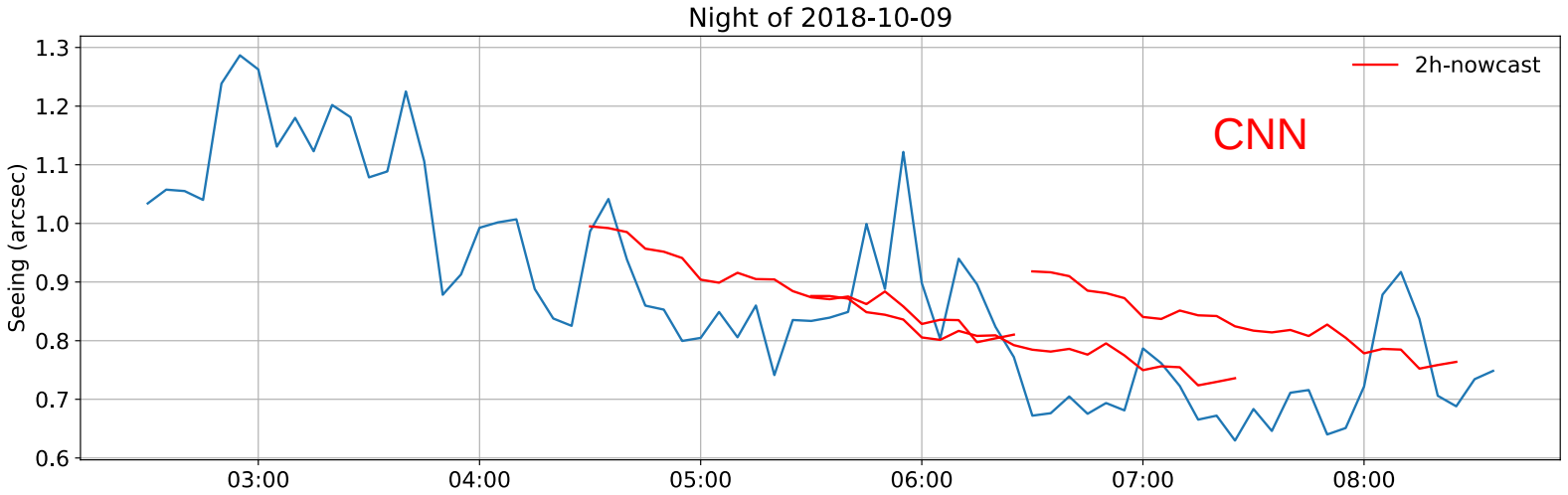
- Random Forests (RF)
- Convolutional Neural Network (CNN)
- Long Short-Term Memory (LSTM)

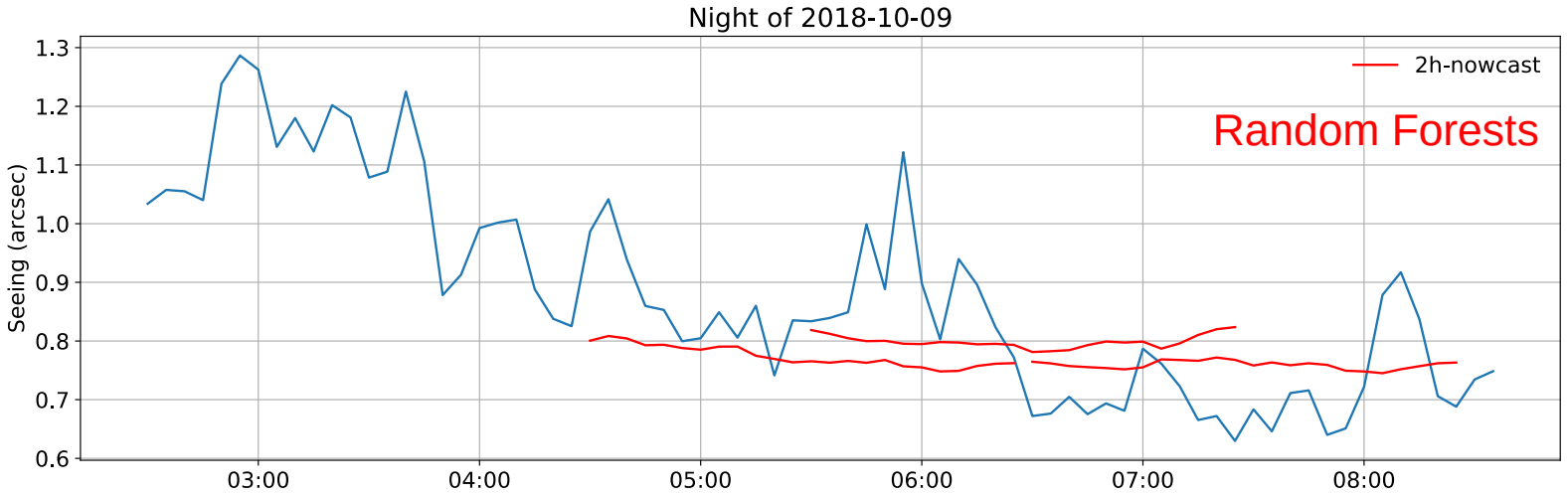
Output:

- Seeing
- Coherence time
- Ground layer fraction

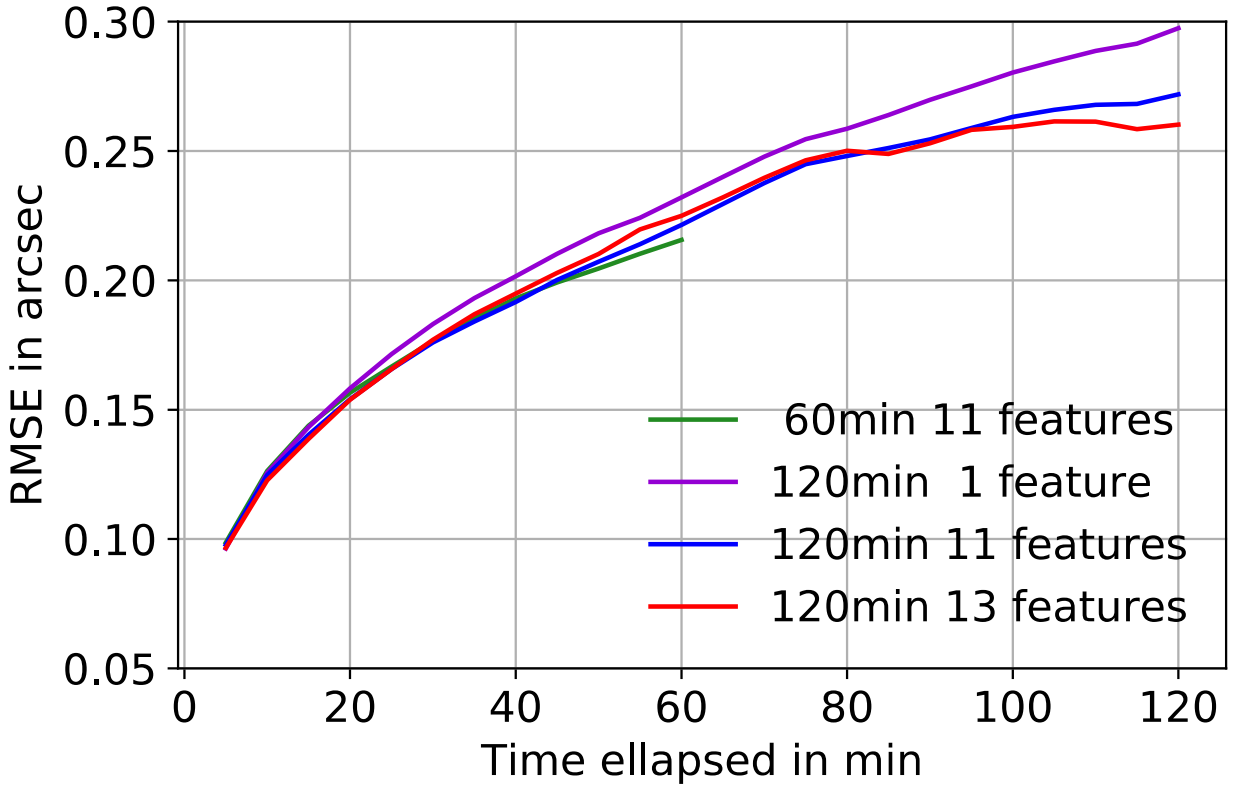
1 to 2h in the future

Results: examples

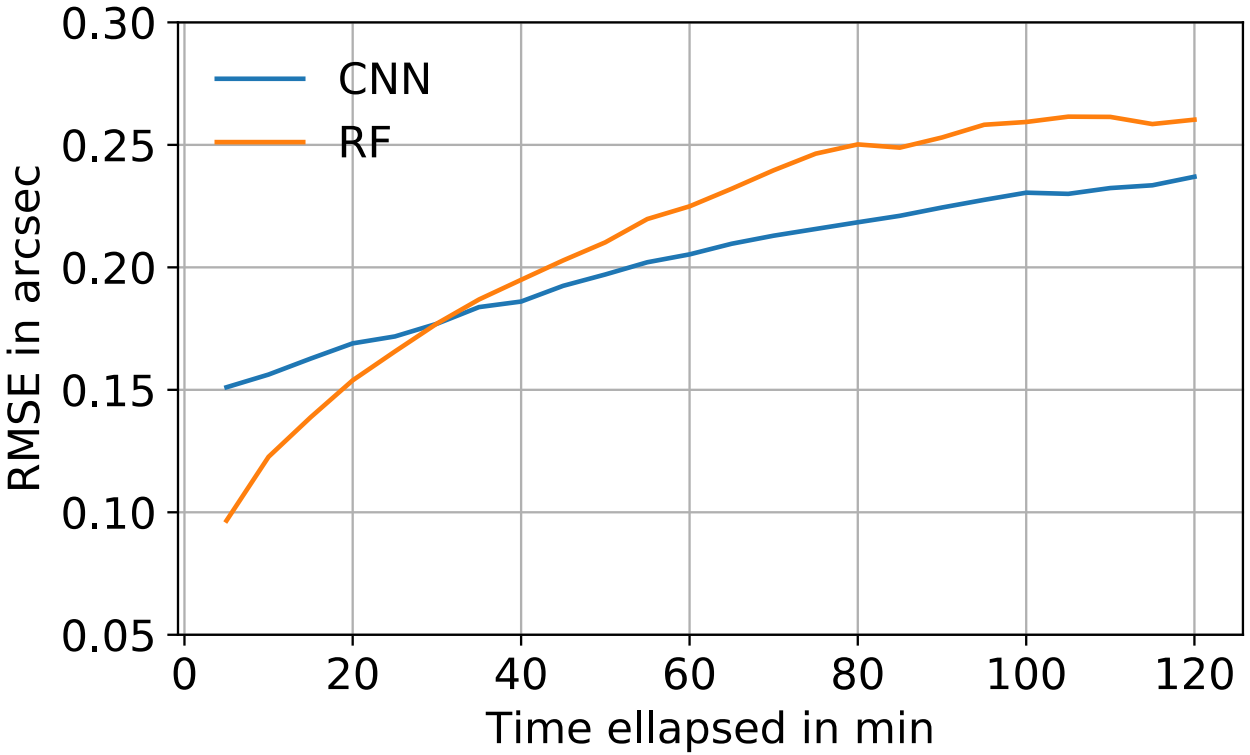




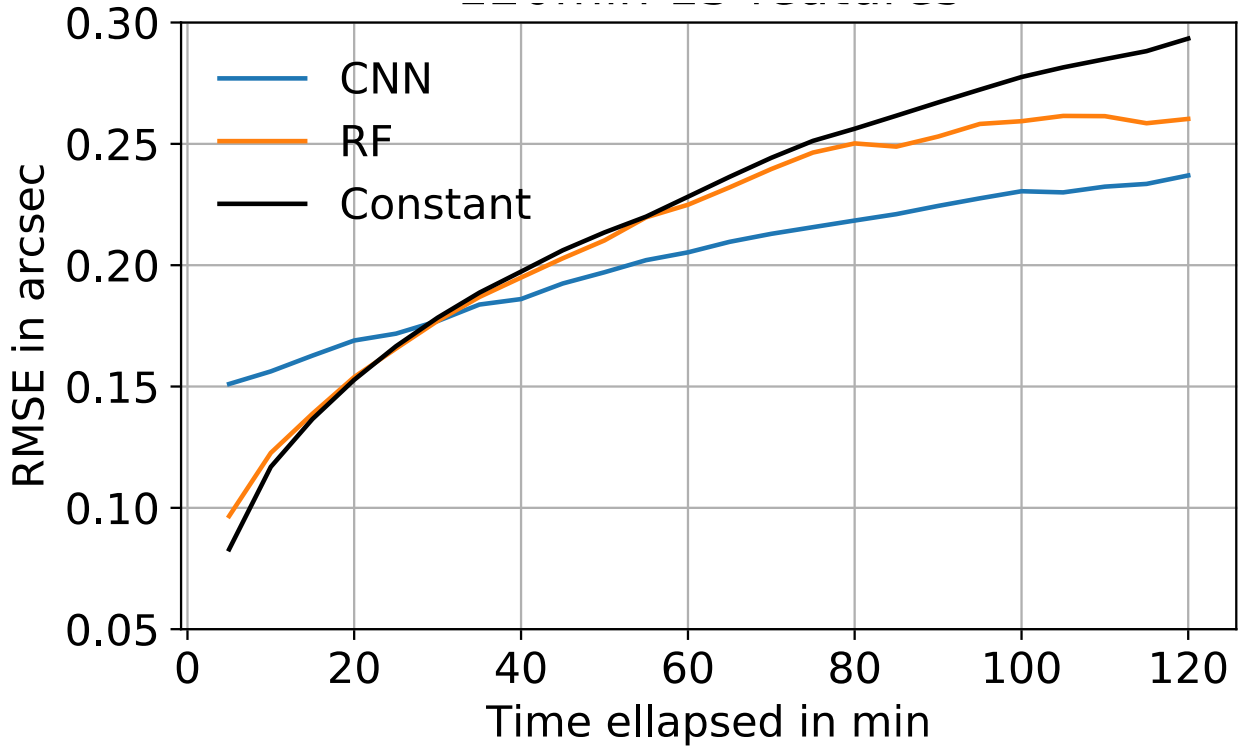
Accuracy for Random Forests



Comparison Random Forests vs CNN



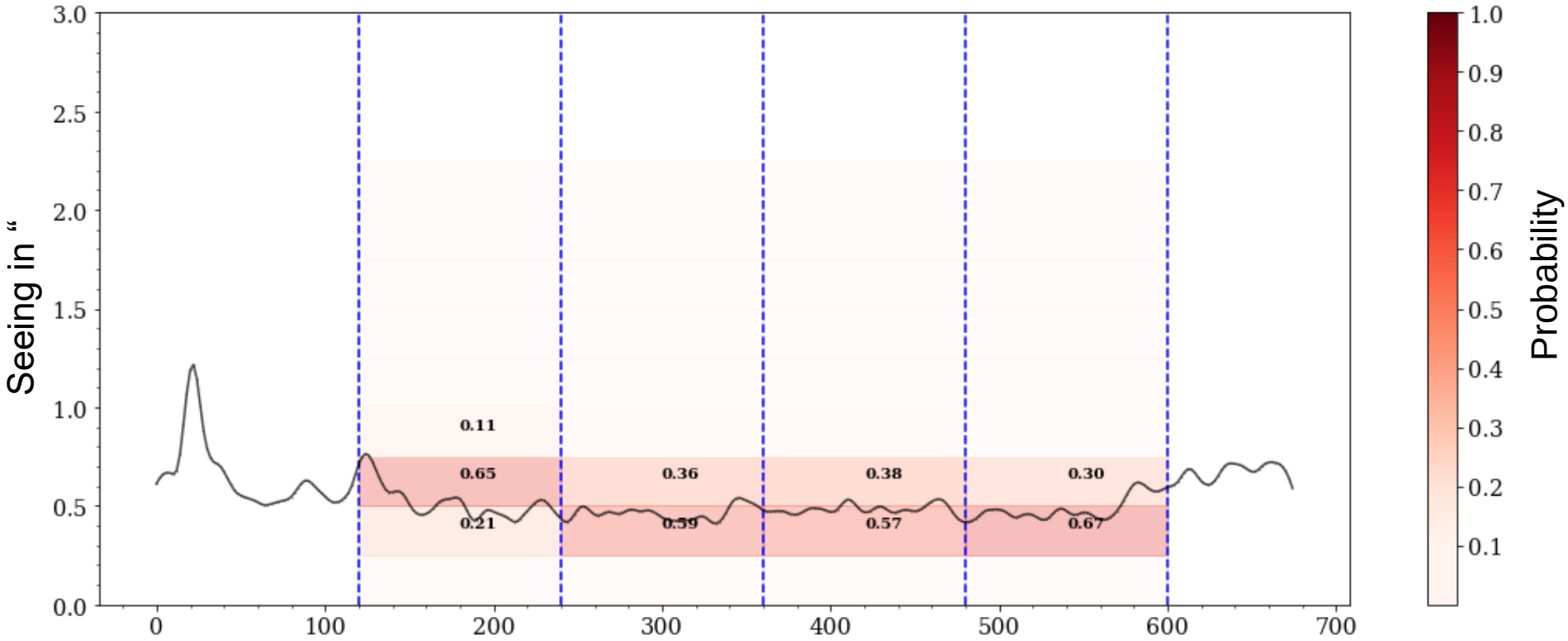
But…



Constant = scenario in which the seeing is constant in the next 2h and equal to the average of the past 15min

Probabilistic approach with LSTM

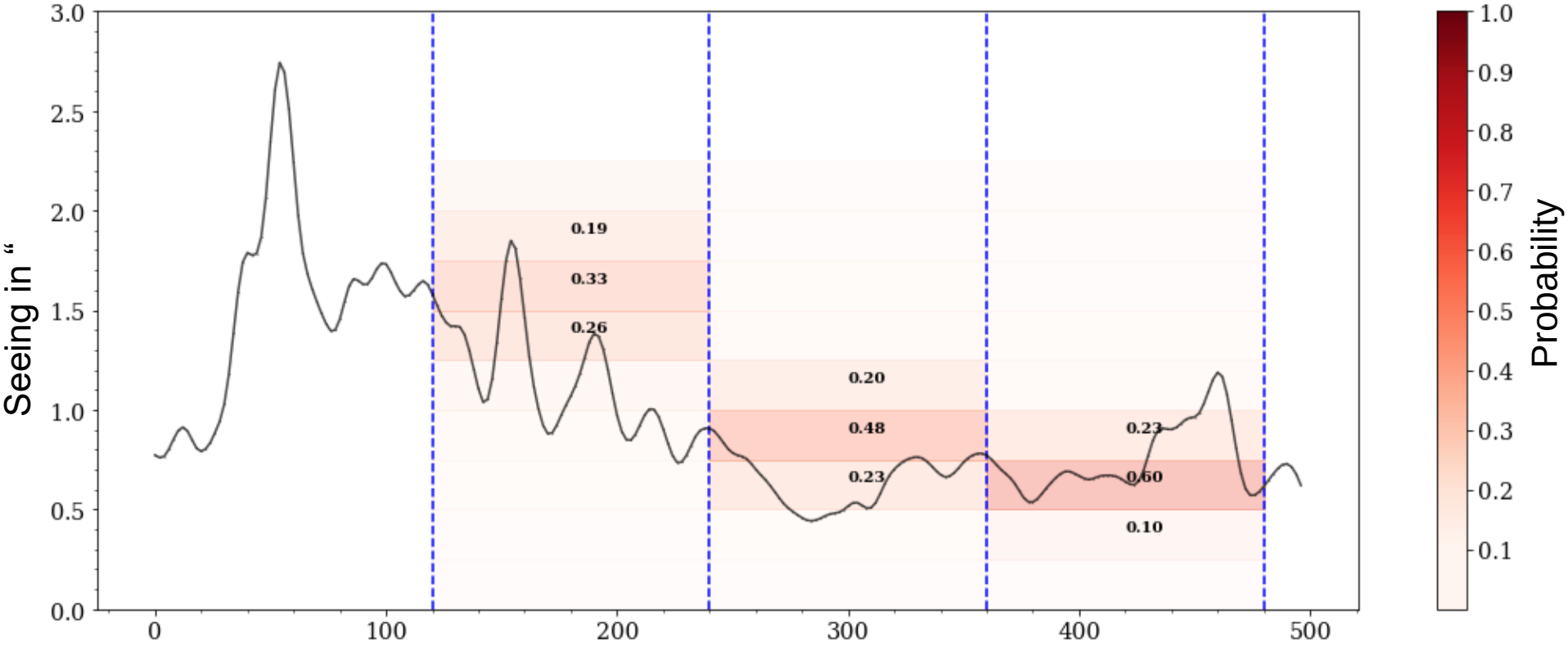
An example of a quiet night



Time elapsed in minutes

Probabilistic approach with LSTM

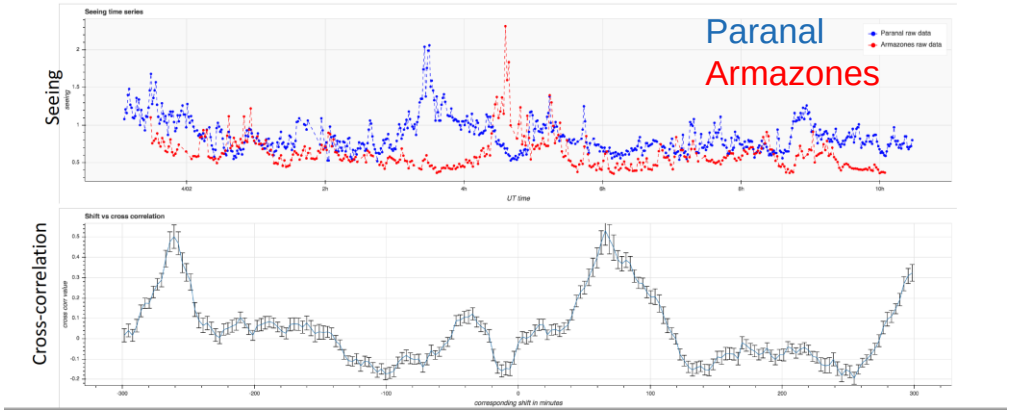
An example of a chaotic night



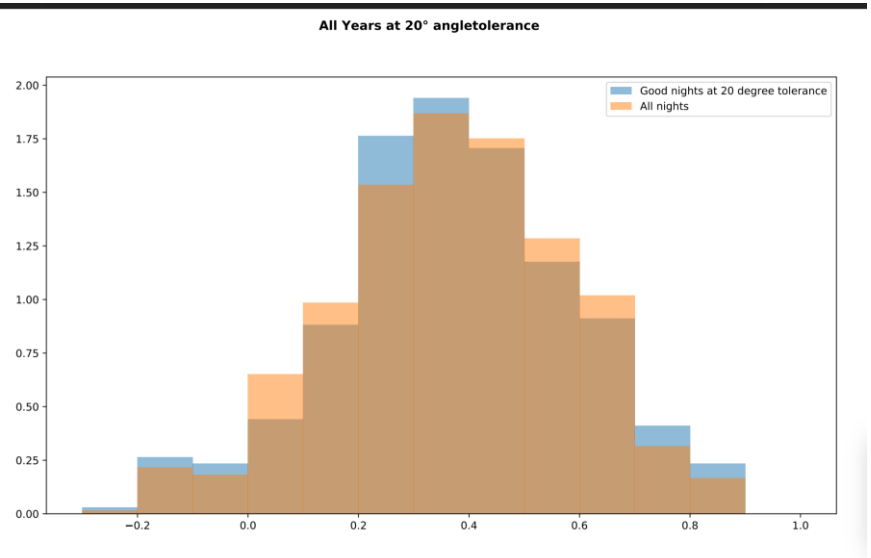
Triangulation Analysis

by intern students Tomas Rojas and Hendrik Tackenberg

- Example of night with a seeing correlation



Time (hours)



- Investigate the relation between time lag vs. wind speed and direction in different height layers from ECMWF.

- The traditional method
cannot find statistically significant correlation betwe en the seeing time delay and the wind speed and wind direction

NOWCAST POC2.0 and Beyond

- Maximum exploitation of ML techniques with maximized available sensor data:
  - Explore new methods and algorithm
  - Triangulation: 1. Armazones 2004-2009 2. Ventarrones 2008-2010
  - Extend the analysis to old DIMM data at Paranal (1998 -2016)
  - Focusing on good seeing data or put higher weight on good seeing data
  - The seeing instability in the next few hours?

- Optimize monitoring station site selection using ML
  - Use the ML method and the atmospheric turbulence simulations.
  - Check whether adding such data will improve the nowcast predictions.
  - Decide which site(s) will let us make the largest improvements.