AC297r Fall 2019
Final Presentation
Optimal Real-time Scheduling for Black Hole Imaging

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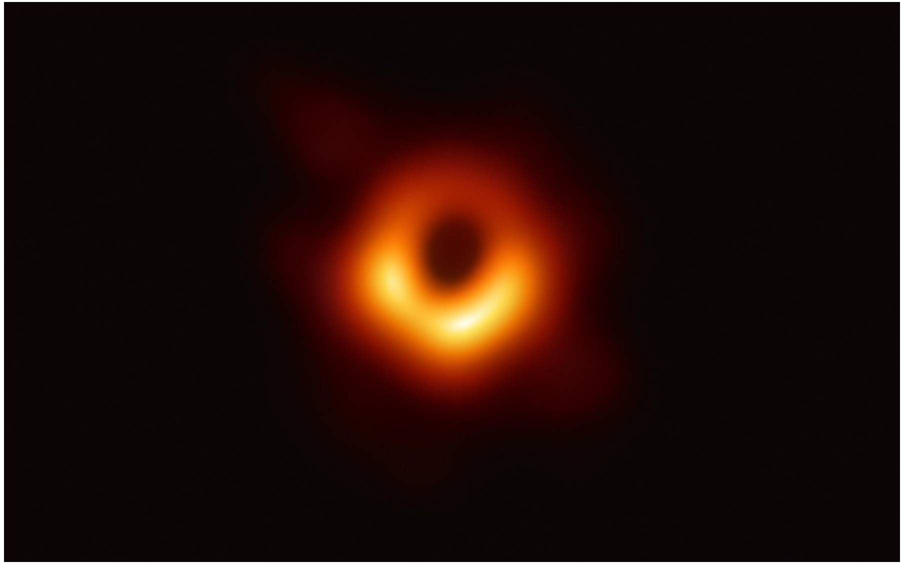
Outline

- Background
- Problem Statement
- Data
- Model Design
- Model Evaluation
- Software Demonstration
- Reflection

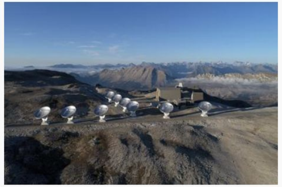
Background

The Event Horizon Telescope is an international collaboration capturing images of black holes using a virtual Earth-sized telescope.

Event Horizon Telescope



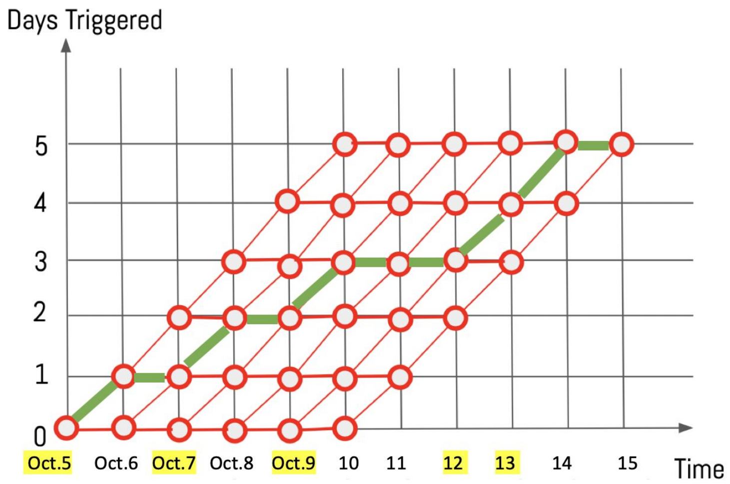
Background



Problem Statement

We are going to build a model that can:

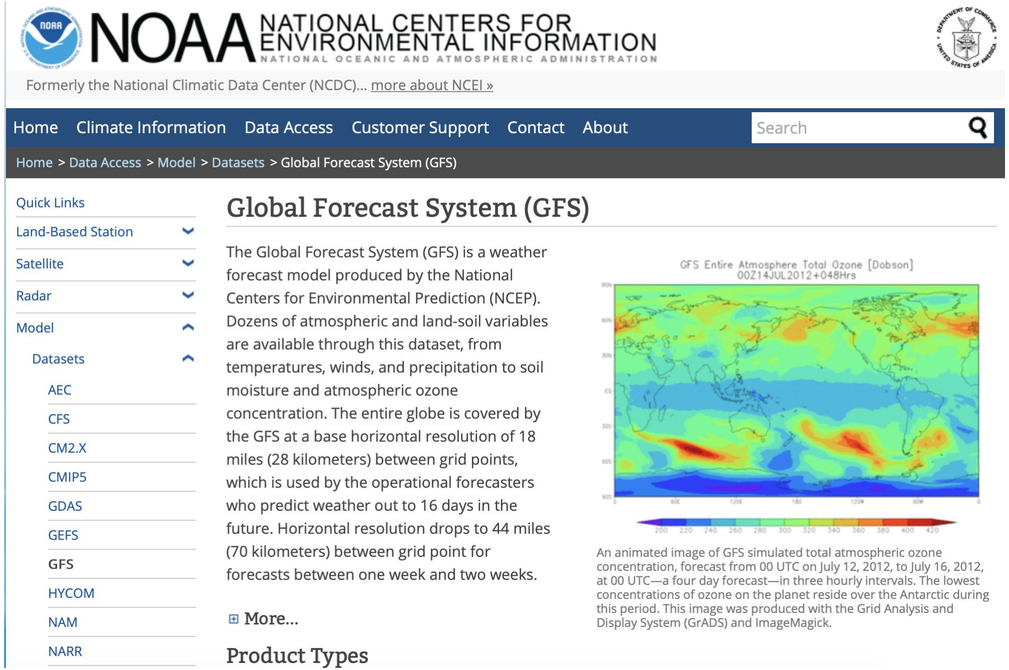
1. In total, choose 5 days from a 10-day window
2. On each day, determine the optimal strategy for future remaining days
3. If possible, provide a confidence level on its suggestion
4. Also provide the second optimal strategy



Motivations

1. Improve the decision making process
2. Increase the chance of capturing the black hole

Data Source


NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Formerly the National Climatic Data Center (NCDC)... more about NCEI »

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Global Forecast System (GFS)

The Global Forecast System (GFS) is a weather forecast model produced by the National Centers for Environmental Prediction (NCEP). Dozens of atmospheric and land-soil variables are available through this dataset, from temperatures, winds, and precipitation to soil moisture and atmospheric ozone concentration. The entire globe is covered by the GFS at a base horizontal resolution of 18 miles (28 kilometers) between grid points, which is used by the operational forecasters who predict weather out to 16 days in the future. Horizontal resolution drops to 44 miles (70 kilometers) between grid point for forecasts between one week and two weeks.

An animated image of GFS simulated total atmospheric ozone concentration, forecast from 00 UTC on July 12, 2012, to July 16, 2012, at 00 UTC—a four day forecast—in three hourly intervals. The lowest concentrations of ozone on the planet reside over the Antarctic during this period. This image was produced with the Grid Analysis and Display System (GrADS) and ImageMagick.

⊞ More...

Product Types

GFS provides:

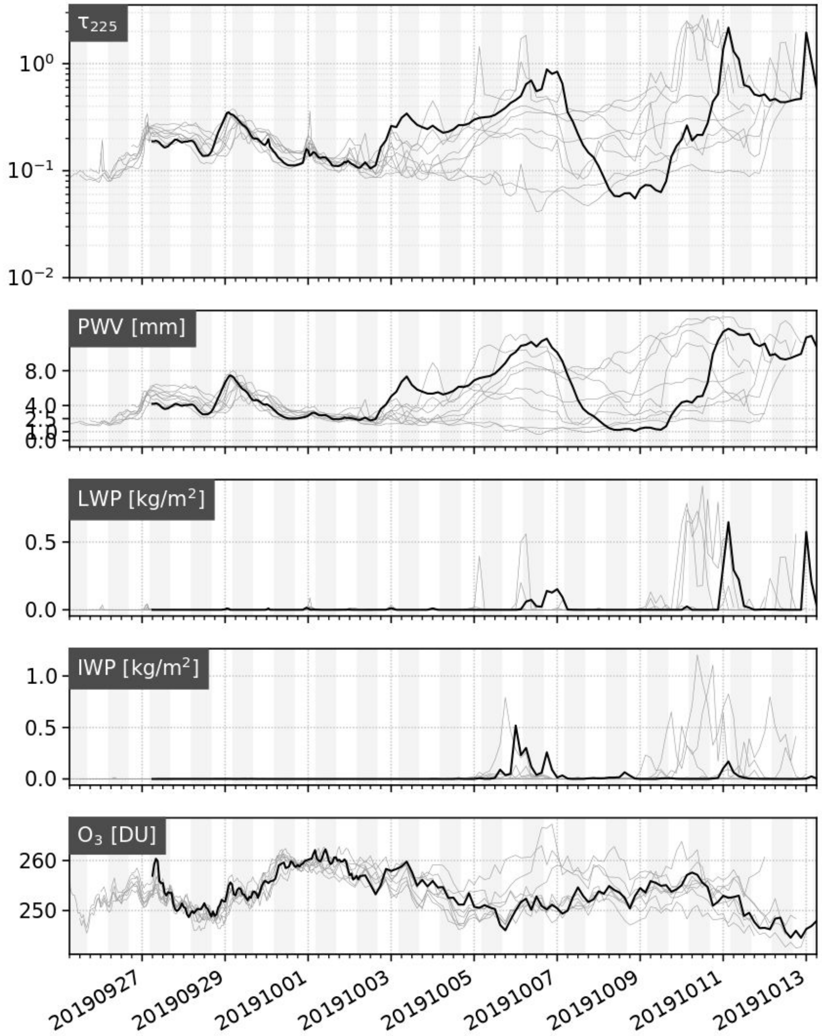
- ❖ Atmosphere's condition
- ❖ Layer-by-layer
- ❖ All over the globe

We pull data every 6 hours specifying:

- ❖ Longitude
- ❖ Latitude
- ❖ Altitude

EDA

- Every 6 hours, we get 16-day atmosphere forecast from GFS.
- First 5-day forecast is pretty accurate.
- Variables: **Tau_225**(absorption directly above head, the lower the better), **PWV, LWP, IWP** (amount of water in different forms), **O3**



Model Design: Baseline

Reward functions:

$$f(i) = -\mathbb{E}_{T_i}[\tau_{225}]$$

$$F(d) = \frac{1}{r_1^2 + \ldots + r_n^2}[r_1^2 f(1), \ldots, r_n^2 f(n)]^T \times \mathbf{D} \times \mathbb{1}$$

- Symbols
  - i: a telescope
  - T_i: observation window
  - r_i: radius of telescope i
  - D: baseline length matrix

Baseline Optimization Method

Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
19.03	13.93	16.24	16.38	18.80	12.99	17.02	19.03	18.81	14.06

Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
18.82	11.04	19.07	13.06	14.46	15.90	18.37	16.98	18.30

Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
10.21	17.67	14.48	11.21	19.31	16.50	11.41	12.22

Day4	Day5	Day6	Day7	Day8	Day9	Day10
18.97	17.30	17.83	17.42	14.64	16.43	12.25

Uncertainty I: Method 1

Uncertainty I only depends on how far in the future the GFS is predicting for.

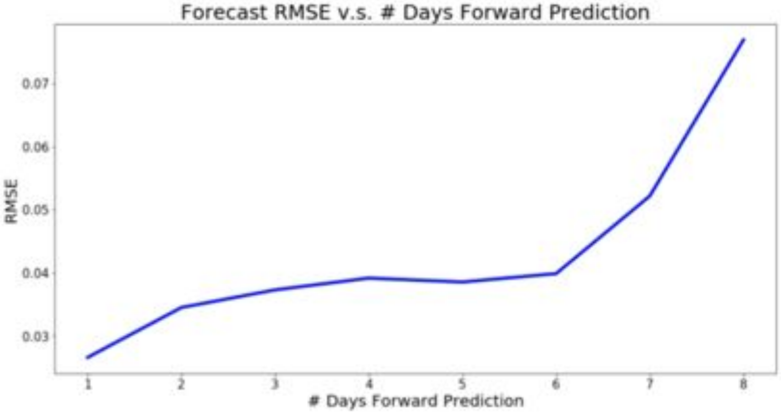
Method 1: discount factor

Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
-1.90	-1.39	-1.62	-1.64	-1.88	-1.29	-1.70	-1.90	-1.88	-1.41
x	$(1 + r)$	$(1+r)^2$	$(1+r)^3$	$(1+r)^4$	$(1+r)^5$	$(1+r)^6$	$(1+r)^7$	$(1+r)^8$	$(1+r)^9$

Uncertainty I: Method 2

Uncertainty I only depends on how far in the future the GFS is predicting for.

Method 2: forecast penalty



For a single telescope i on day d:

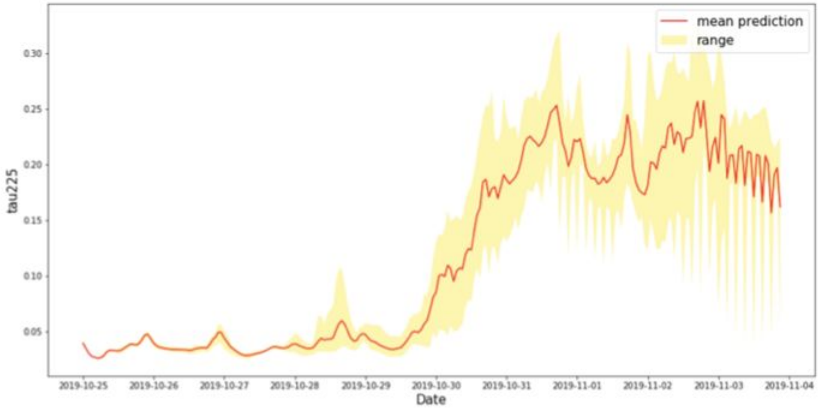
$$f_{i,d} * \underbrace{\boxed{e^{\text{penalty\_level}*\text{RMSE}_{[i][t]}}}}_{\text{penalty term}}$$

t: how far is day d from the current

Uncertainty II: Method 3

Uncertainty II only depends on the date for which the forecast is being made.

Method 3: prediction difficulty of specific time



For a single telescope i on day d:

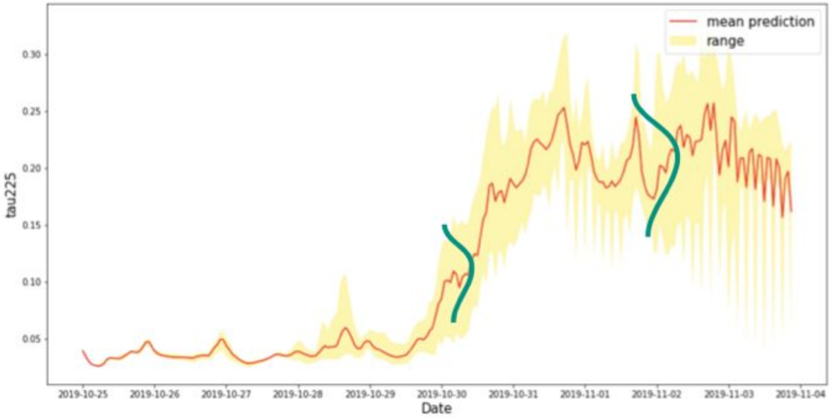
$$\mathrm{latest}(f_{i,d}) \times \boxed{e^{\mathrm{penalty\_term} * RMSE_{i,d}}}$$

penalty term

Uncertainty II: Method 4

Uncertainty II only depends on the date for which the forecast is being made.

Method 4: sampling from normal distribution



For a single telescope i on day d:

$$\text{reward} \sim \mathbb{N}(latest(f_{i,d}), \text{RMSE}_{i,d})$$

Parameters Tuning and Models Evaluation

Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
19.03	13.93	16.24	16.38	18.80	12.99	17.02	19.03	18.81	14.06

Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
18.82	11.04	19.07	13.06	14.46	15.90	18.37	16.98	18.30

Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10
10.21	17.67	14.48	11.21	19.31	16.50	11.41	12.22

Day4	Day5	Day6	Day7	Day8	Day9	Day10
18.97	17.30	17.83	17.42	14.64	16.43	12.25

New weather forecast

	Oct 25	Oct 26	Oct 27	Oct 28	Oct 29	Oct 30	Oct 31	Nov 1	Nov 2	Nov 3	Average tau225
Model n, Penalty m											0.13
Ground-Truth Best											0.12

Look back

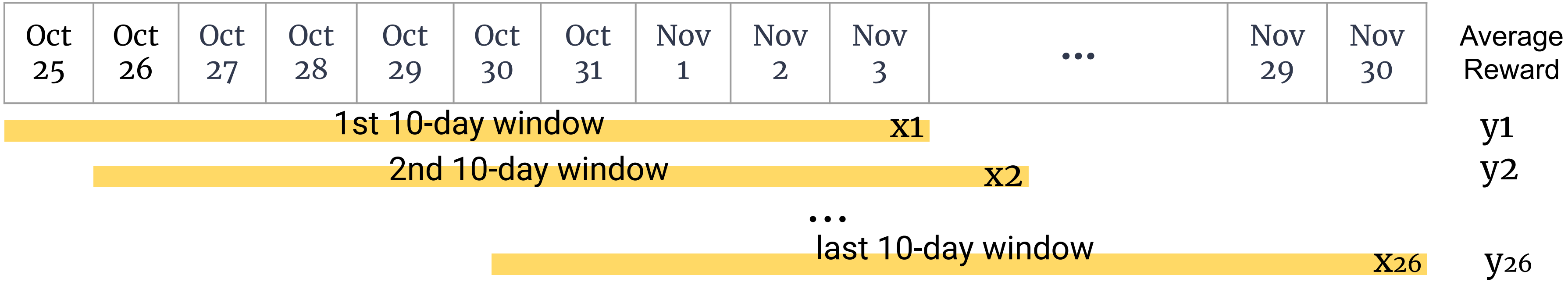
Calculate squared error

Model Evaluation

Choose 5 days From Nov.09 - Nov.18, 2019

	Model	Nov 09	Nov 10	Nov 11	Nov 12	Nov 13	Nov 14	Nov 15	Nov 16	Nov 17	Nov 18	Average Reward
	Ground-Truth Best											-0.124
	Random Pick	-	-	-	-	-	-	-	-	-	-	-0.176
	Baseline											-0.137
I	Discount Factor											-0.124
I	Forecast Penalty											-0.124
II	Prediction Difficulty of Specific Time											-0.124
II	Sampling from Normal											-0.137

Model Evaluation



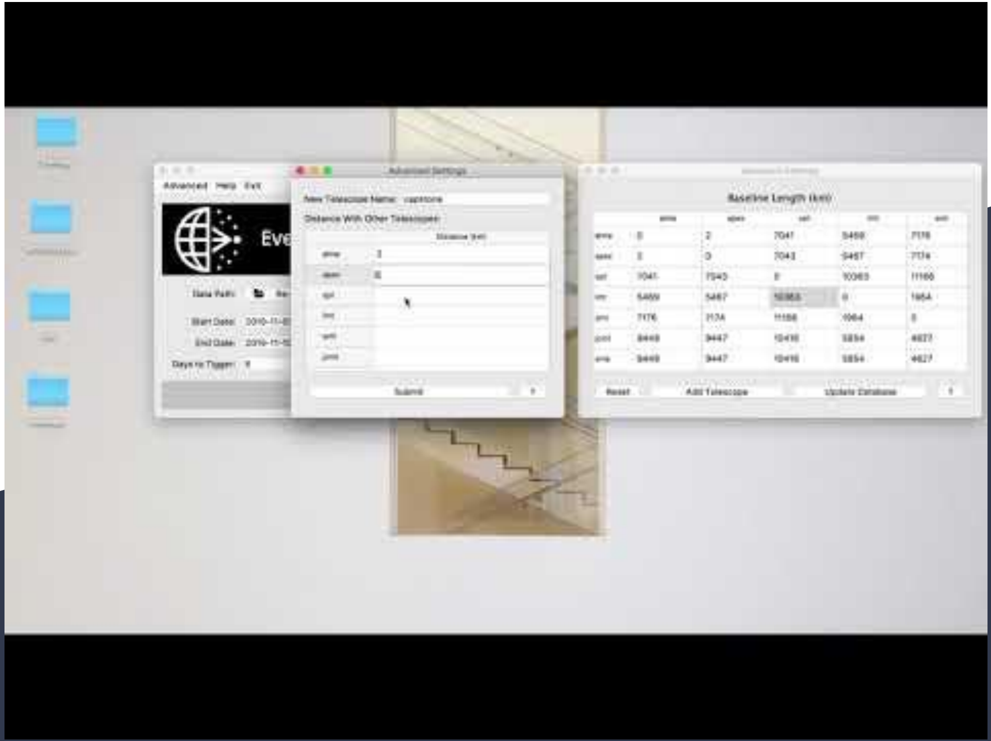
Metrics

- MSE of average reward compared with best path
- Relative score computed from average reward:
  (model - random)/(best - random), which ranges from 0 to 1

Results

	MSE	Relative Score (0-1)
Method 3 (prediction difficulty of specific time) with penalty = 1	0.000015	0.957
Method 2 (forecast penalty) with penalty = 0.6	0.000016	0.955
Method 1 (discount factor) with penalty = 0.03	0.000017	0.952
Method 4 (sampling from distribution)	0.000028	0.951
Baseline Method	0.000028	0.951
Random Pick	0.003107	0.0

Software Demonstration



Phase I

No data. Fancy model designs in mind. Had lots of questions about the problem itself.

Phase II

Meet the EHT Team for the first time. Slowly gathering data. Fancy models won't work. Redesigning simple models that best solve the issue.

Phase III

Gathered second thoughts from the EHT. Learned to build GUI and functional software. Cannot truly tune hyperparameter due to lack of data.

REFLECTION

Thank you!

Any questions?