User guide for Python upgrade of Gemini Queue Planning Tool prototype

Matt Bonnyman
Gemini Observatory, La Serena, Chile
University of Victoria, British Columbia, Canada

Bryan Miller
Gemini Observatory, La Serena, Chile

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Software Summary

This software is a continuation of the Gemini Queue Planning Prototype Tool developed by Bryan Miller in 2004. From May-August 2018, the original IDL software was converted to Python and various new features were added.

Document Purpose

This document demonstrates the use of the Python Gemini Queue Planning Tool. It is intended as a guide for using the program's various features, as well as a resource for understanding the software data structures and input file formats. This document contains examples of how the software can be used to examine scheduling algorithms; examine observation weighting schemes; perform queue scheduling; simulate incoming targets of opportunity; simulate changing viewing conditions.

Intended Audience

This document is intended for use by Gemini's operations and software staff.

Contents

1 Introduction

1.1 Context

In 2005, Bryan Miller developed a *Gemini Queue Planning Tool Prototype* (GQPT). This software uses real or simulated weather conditions to generate nightly observing schedules consisting of the highest priority observable programs. For several years, Gemini's queue coordinators (QCs) used this software to prepare nightly observing plans.

1.2 Contribution

The original GQPT software has been converted from IDL to Python and several new features have been added. The new features aim to more accurately simulate observing at the Gemini telescopes. In addition, a small program for examining observation weighting functions was developed. This program is called the *Weight Function Plotting Tool* (WFPT). The upgrade process consisted of the following tasks...

1. Convert IDL prototype to Python.
2. Revamp work flow and data structures to accommodate new features.
3. Implement methods for evaluation of scheduling results.
4. Implement methods for evaluation of scheduling algorithms.
5. Develop a method for evaluating observation weighting schemes.
6. Implement a schedule of available instruments and instrument components.
7. Incorporate Gemini observation time constraints.
8. Develop a target of opportunity simulation.
9. Develop a changing sky condition simulation.

1.3 Installation

The python version of GQPT requires a Python 3.6+ installation with recent versions of astropy, numpy, and matplotlib. It is convenient to install these using the anaconda package manager. The following packages are also required: astroplan, astroquery, joblib, and pytest-mpl. These can be installed using conda or pip, e.g. "`pip install astroplan`". Finally, the GQPT code can be installed using git with

```
git clone https://github.com/bryanmiller/gem_adapt_queue.git
```

1.4 Software capabilities

The following is a list of the ways that the upgraded GQPT software and WFPT can be used - note that some of these features may be used simultaneously and have several customizable parameters. Most parameters can be defined using the command line or from within the program menu.

1. Generate observing plans over several nights.
2. Simulate targets of opportunity.
3. Simulate changing viewing conditions.
4. Examine steps made to assemble nightly plans.
5. Examine observation weighting functions.

GQPT currently reads observations from the ASCII catalog output of the OT Browser. As a result, it does not have information about the sequence steps and must make some simplifying assumptions.

1.5 Gemini Queue Planning Tool Prototype (gqpt.py)

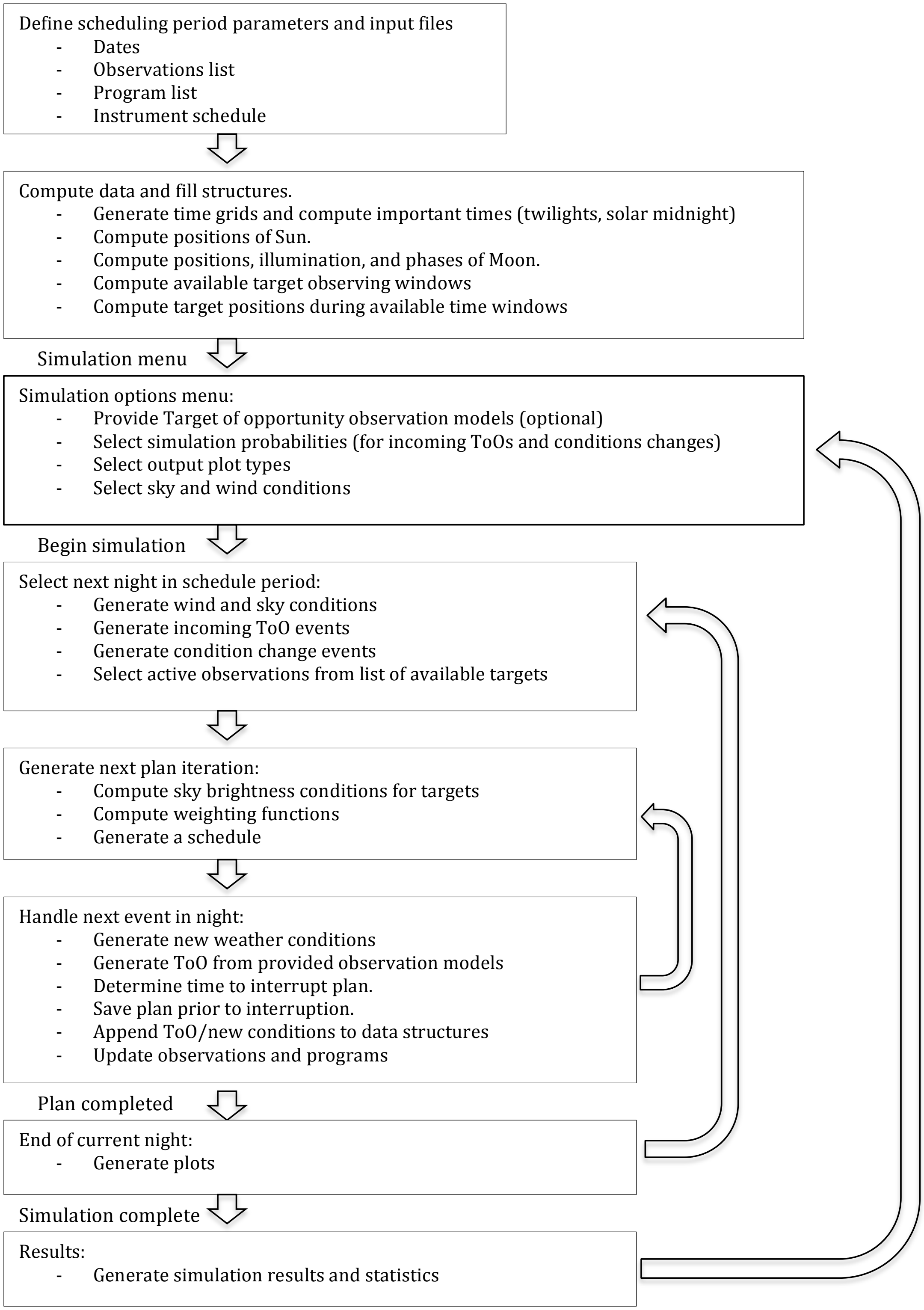

Figure 1: New software work flow

1.6 Weight Function Plotting Tool (wfpt.py)

The weight function plotting tool uses a simplified version of the GQPT workflow. In particular, it only needs to construct the necessary data for a single night of scheduling and does not include any simulation features (Section 3).

2 GQPT

This section will provide examples of the various ways that the program can be used. An observation file, program file, and instrument schedule file are always required to use the software. These files are summarized in Section 4.

2.1 Help guide

```
>>> python gqpt.py -h

                             Gemini Adaptive Queue Planning Tool
****************************************************************************************************

   REQUIRED
   --------
   otfile                OT catalog filename.

   prfile                Program status filename.

   instcal               Instrument calendar filename.

   OPTIONAL
   --------
   -s   --startdate      Start date 'YYYY-MM-DD' [DEFAULT=current].

   -e   --enddate        End date 'YYYY-MM-DD' [DEFAULT=startdate]. End date must be before
                         start date. If no end date is provided, the scheduling period will
                         default to a single night.

   -dst --daylightsavings Toggle daylight savings time [DEFAULT=False].

   -dt  --gridsize       Size of time-grid spacing [DEFAULT=0.1hr].

   -o   --observatory    Observatory site [DEFAULT='gemini_south']. Accepts the following:
                         1. 'gemini_north' (or 'MK' for Mauna Kea)
                         2. 'gemini_south' (or 'CP' for Cerro Pachon)

   -l   --logfile        Logfile name [DEFAULT='gaqptDDMMYY-hh:mm:ss.log'].

   -t  --toofile         Target of opportunity observation models filename [DEFAULT=None].

   -tp  --tooprob        Probability of incoming ToOs during the night [DEFAULT=0].

   -tm  --toomax         Maximum number of potential ToOs during the night [DEFAULT=4].

   -cp  --condprob       Probability of a sky conditions changing during the night [DEFAULT=0].

   -cm  --condmax        Maximum number of potential sky conditions changes during the night
                         [DEFAULT=4].

   -p   --plantype       Scheduling algorithm type [DEFAULT='Priority'].
```

```
                         Conditions (if distribution=False):
  -iq --iq               Image quality constraint [DEFAULT=70%].
  -cc --cc               Cloud cover constraint [DEFAULT=50%].
  -wv --wv               Water vapor constraint [DEFAULT=Any].

  -d  --distribution     Random viewing conditions from distribution [DEFAULT=False]. Accepts the
                          following:
                         1. 'random' (or 'r'). Generate conditions from uniform distribution.
                         2. 'variant' (or 'v'). Randomly select one of several variants.

                         Wind conditions:
  -dir --direction       Wind direction [DEFAULT=330deg].
  -vel --velocity        Wind velocity [DEFAULT=5m/s].

  -rw --randwind         Random wind conditions [DEFAULT=False].
                         Means and standard deviations at sites:
                            Cerro Pachon : dir=(330 +/- 20)deg, vel=(5 +/- 3)m/s
                            Mauna Kea    : dir=(330 +/- 20)deg, vel=(5 +/- 3)m/s

  -pp --planplots        Show airmass plot of nightly plan [DEFAULT=False].

  -ip --iterplots        Show airmass plot after each iteration of the plan (when simulating
                         incoming ToO and changing sky conditions) [DEFAULT=False].

  -bp --buildupplots     Show airmass plot after each time an observation is added
                         to the plan [DEFAULT=False].

  -sp --skyplots         Show sky conditions plot [DEFAULT=False].

  -wp --windplots        Show wind condition plot [DEFAULT=False].

  -u  --update           Download up-to-date IERS(International Earth Rotation and Reference
                          Systems) data.

  -rs --seed             Random seed number for random number generation [DEFAULT=1000].

  -v  --verbose          Print important variables [DEFAULT=False].

  -dg --debug            Print additional outputs (intended for trouble-shooting) [DEFAULT=False].

****************************************************************************************************

positional arguments:
  otfile
  prfile
  instcal

optional arguments:
  -h, --help           show this help message and exit
  -s STARTDATE, --startdate STARTDATE
  -e ENDDATE, --enddate ENDDATE
  -dst, --daylightsavings
  -dt GRIDSIZE, --gridsize GRIDSIZE
  -l LOGFILE, --logfile LOGFILE
  -o OBSERVATORY, --observatory OBSERVATORY
  -t TOOFILE, --toofile TOOFILE
  -tp TOOPROB, --tooprob TOOPROB
  -tm TOOMAX, --toomax TOOMAX
```

```
-cp CONDPROB, --condprob CONDPROB
-cm CONDMAX, --condmax CONDMAX
-p PLANTYPE, --plantype PLANTYPE
-iq IQ, --iq IQ
-cc CC, --cc CC
-wv WV, --wv WV
-d DISTRIBUTION, --distribution DISTRIBUTION
-dir DIRECTION, --direction DIRECTION
-vel VELOCITY, --velocity VELOCITY
-rw, --randwind
-pp, --planplots
-ip, --iterplots
-bp, --builduplots
-sp, --skyplots
-wp, --windplots
-u, --update
-rs SEED, --seed SEED
-v, --verbose
-dg, --debug
```

2.2 Launching from command line

Most of the simulation parameters can be defined in either the command line or the simulation menu. However, the observatory location, range of dates, daylight savings time, three required input files, and the time grid spacing cannot be changed once the program is launched.

The most basic way to launch the program is to provide only the three required input files. For example...

```
>>> python gqpt.py observations.txt exechours.txt instschedule.txt
```

The software uses a default one-night observing period on the current date at the Gemini South location and with a time-grid spacing of 0.1hr.

The user may prepare a one-night observing period for any date by providing only a start date.

```
>>> python gqpt.py observations.txt exechours.txt instschedule.txt --start 2018-01-01
```

An end date can be applied to prepare a scheduling period of any length. For example, the following would prepare a six-month scheduling period at Gemini North.

```
>>> python gqpt.py observations.txt exechours.txt instschedule.txt --start 2018-01-01 --end
    2018-06-01 --observatory MK
```

Once a scheduling period is prepared, simulations can be run any number of times from the program menu without re-launching the software. The menu will appear and prompt the user to continue once all time-grid data, Sun data, Moon data, observation information, instrument information, program information, and target data is prepared.

2.3 Scheduling

The user can define the remaining simulation parameters from the program menu. Here is an example of a simulation prepared using the default settings...

```
>>> python gqpt.py observations.txt exechours.txt instschedule.txt
...observatory site, time_zone, utc_to_local
...scheduling period dates
...time data and grids
...Sun data
```

```
...Moon data
...instrument calendar
...observations
...programs
...target calendar
...timing windows (convert time constraints)
...timing windows (twilights)
...timing windows (organize into nights)
...timing windows (instrument calendar)
...time window indices
...target data
...timing windows (elevation constraint)

  ---------------------------------------------------------------------
                Gemini Adaptive Queue Planning Tool
  ---------------------------------------------------------------------

  Dates: 2018-07-13 to 2018-07-13
  Number of nights: 1
  Daylight savings time: False

  Observatory:
    Site:         gemini_south
    Height:       2750.0000 m
    Longitude:    -70.7367 deg
    Latitude:     -30.2407 deg

  Options:
  --------
  1.        Log file                                  gqpt13Jul13-19:57:56.log
  2.        ToO file                                  None
  3.        ToO probability                           0.0
  4.        Max. number of ToOs per night             4
  5.        Conditions (iq,cc,wv)                     (70%, 50%, Any)
  6.        Conditions from distribution type         None
  7.        Wind conditions (dir, vel)                (330.0deg, 5.0m/s)
  8.        Generate random wind conditions           False
  9.        Probability of condition change           0.0
  10.       Max. number of condition changes per night   4
  11.       Show plan plots                           False
  12.       Show airmass plot of each plan iteration  False
  13.       Show airmass plots of plan building up    False
  14.       Show sky conditions plots                 False
  15.       Show wind condition plots                 False

  dir       Show files in current directory
  x,q       Exit

 Press enter to run or select an option:
```

If run using the default settings, a nightly plan will be produced.

```
                        -- Generating plan for night of 2018-07-13 --

  Sky conditions (iq, cc, wv):    (70%, 50%, Any)
  Wind conditions (dir., vel.):   330.0 deg, 5.0 m / s

  Solar midnight (UTC):           2018-07-14 04:48
```

```
Solar midnight (local):       2018-07-14 00:48

Sun ra:                       113.2 deg
Sun dec:                      21.72 deg

Moon ra:                      129.04 deg
Moon dec:                     18.87 deg
Moon fraction:                0.02
Moon phase:                   2.87 rad


                              -- 2018-07-13 schedule --

Obs. ID         Target      RA    Dec.  Instr UTC   LST   Start End   Dur.  AM   HA    Complete
-------         ------      --    ---   ----- ---   ---   ----- ---   ---   --   --    --------
12 deg.twi.                                   22:54 13.65 18:54
S18A-FT-108[25] T2_ucd1     202.9 -41.9 GMOS- 23:06 13.85 19:06 19:30 0.4 h 1.02 0.32  True
S18A-FT-103[31] hip 67620 208.1 -24.4 GPI     23:42 14.45 19:42 20:30 0.8 h 1.01 0.58  True
S18A-FT-108[47] T7_ucd3     204.0 -43.0 GMOS- 00:30 15.25 20:30 20:54 0.4 h 1.09 1.65  True
S18A-FT-108[37] T2_ucd2     203.4 -41.2 GMOS- 00:54 15.66 20:54 21:18 0.4 h 1.13 2.10  True
S18A-FT-108[31] T2_ucd3     202.8 -40.9 GMOS- 01:18 16.06 21:18 21:48 0.5 h 1.18 2.53  True
S18A-FT-108[43] T1_ucd1     201.9 -43.6 GMOS- 01:48 16.56 21:48 22:18 0.5 h 1.28 3.09  True
S18A-FT-108[19] T6_ucd1     202.7 -45.5 GMOS- 02:18 17.06 22:18 22:42 0.4 h 1.38 3.54  True
S18A-LP-11[7]   133P        275.5 -21.4 GMOS- 03:18 18.06 23:18 23:42 0.4 h 1.01 -0.31 True
S18A-Q-106[25]  J2209-0055 332.5 -0.84 GMOS- 03:42 18.46 23:42 00:18 0.6 h 2.01 -3.70 True
S18A-Q-106[9]   J2217+0029 334.6 0.58  GMOS- 04:18 19.07 00:18 00:54 0.6 h 1.76 -3.25 True
S18A-Q-106[23]  J2159+0005 330.1 0.18  GMOS- 04:54 19.67 00:54 02:06 1.2 h 1.42 -2.34 True
S18A-Q-106[21]  J2141-0016 325.6 -0.19 GMOS- 06:06 20.87 02:06 03:18 1.2 h 1.18 -0.84 True
S18A-Q-106[15]  J2249+0047 342.5 0.9 d GMOS- 07:18 22.07 03:18 04:30 1.2 h 1.19 -0.77 True
S18A-Q-106[37]  J2343+0038 356.0 0.75  GMOS- 08:48 23.58 04:48 05:24 0.6 h 1.17 -0.16 True
S18A-LP-1[13]   SPT2106     316.8 -58.6 GMOS- 09:24 0.18  05:24 06:30 1.1 h 1.34 3.05  False
12 deg. twi.                                  10:36 1.38  06:36
```

The program will then return to the simulation menu. Each simulation will have the results saved to a time-stamped log file. These files contain the simulation parameters, initial and final program statuses, as well as the nightly plans and events (i.e. incoming targets of opportunity, viewing condition changes).

2.3.1 Plan plots

Without re-launching the program, the same one-night simulation can be re-run with plot outputs. Figure 2 shows an airmass and altitude-azimuth plot of the 2018-07-13 plan. This feature will generate plots for each nightly plan in the scheduling period. The plots will pop-up after each plan is generated and prompt the user to resume scheduling.

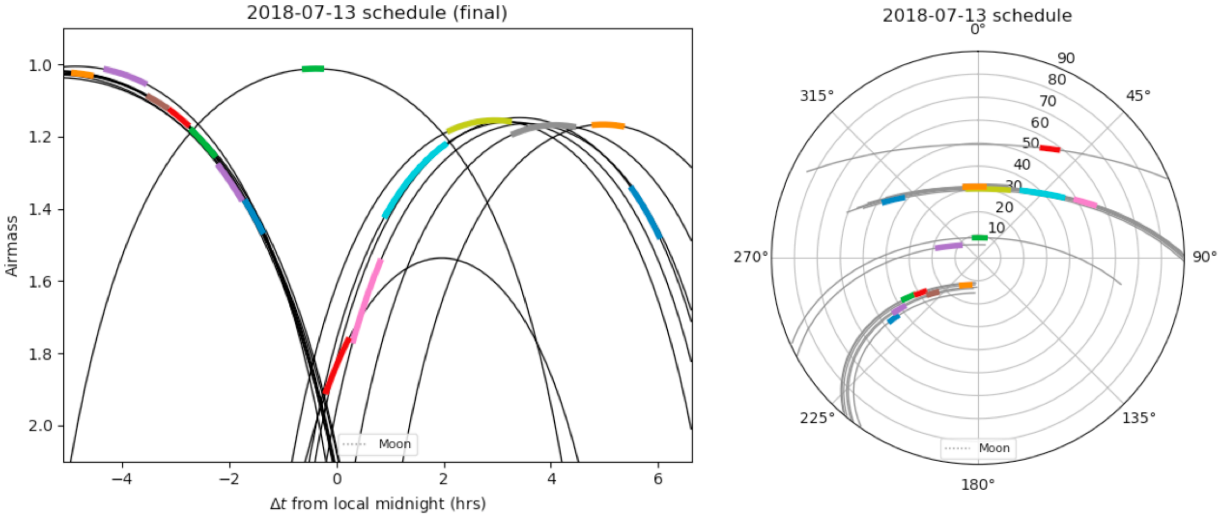

Figure 2: Airmass(left) and altitude-azimuth(right) of the 2018-07-13 plan

2.3.2 Plan build-up plots

The plan build-up feature is intended for use on very short scheduling periods. It is a tool for examining the program's scheduling algorithms. Figure 3 shows the 2018-07-13 plan building up using the *priority* scheduling algorithm. This algorithm selects the observation with the highest weight and schedules it at the most optimal time in the night(i.e. maximum of the weighting function integrated over the observation period).

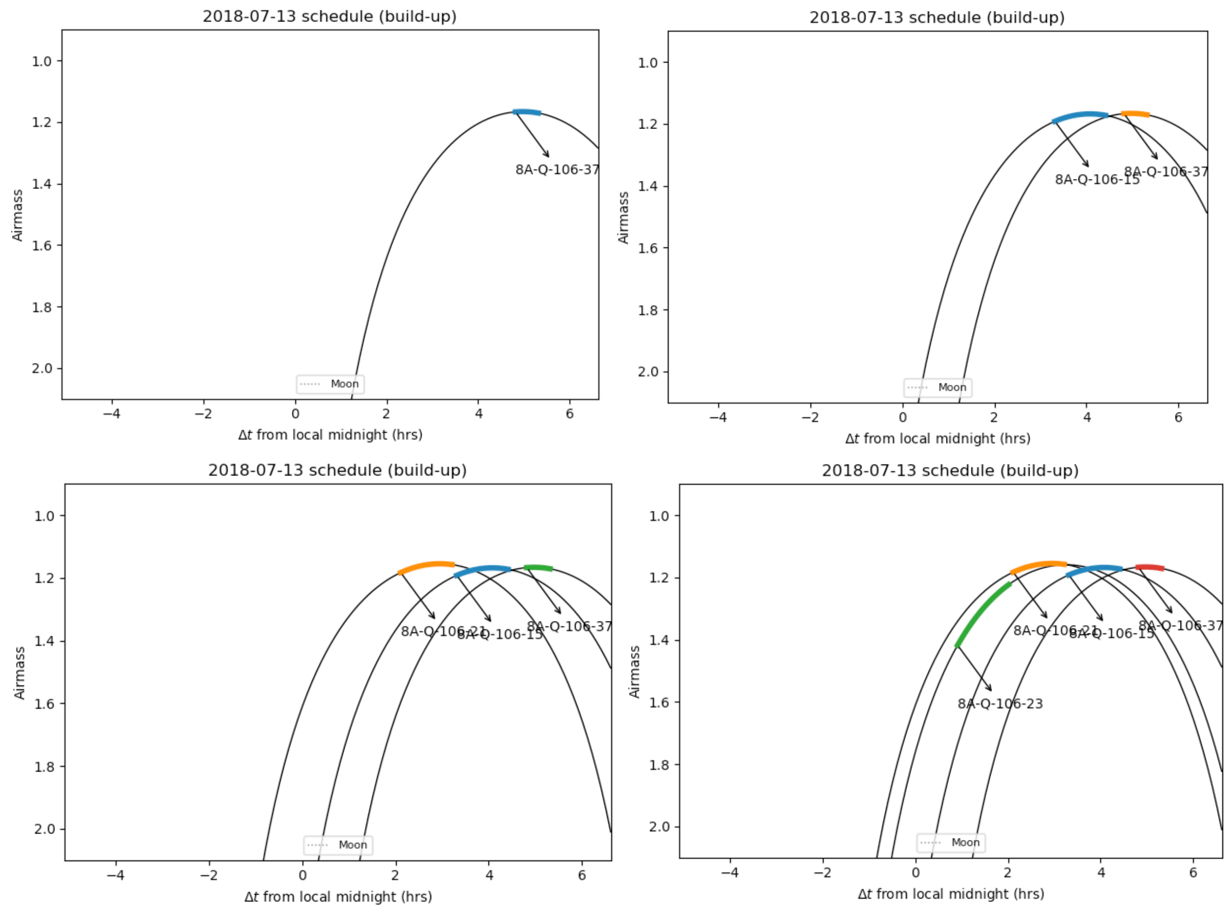

Figure 3: First four steps of 2018-07-13 plan assembly

2.3.3 Plan iteration plots

This feature is used when incoming targets of opportunity or changing viewing conditions are being simulated. When these events occur throughout the night, the plan may be interrupted and regenerated. These plots will display each iteration of the plan as the simulation progress through the night (Section 2.4.3).

2.3.4 Condition plots

The sky conditions plot feature will show decimal percentiles throughout the night for image quality, cloud condition, and water vapour (Figure 5). The sky background percentile is specific to each target and therefore is not displayed with this feature. Sky background conditions for individual targets can be viewed using the *Weight Function Plotting Tool* (Figure 8). Wind condition plots display the direction and velocity. Currently there is no simulation of changing wind conditions so these conditions remain constant throughout the night.

2.4 Simulations

Currently the GQPT has methods for simulating changing viewing conditions and incoming targets of opportunity (ToOs). Each of these simulators uses an event a probability and maximum event number. For example, if the ToO probability and event maximum are set to 0.2 and 4, up to 4 ToOs will arrive to the queue at random times throughout the night.

2.4.1 Viewing conditions simulation

The current conditions simulation uses random condition changes. This is by no means a realistic simulation method, but it has put the framework in place for more realistic simulations to be implemented. When a condition change event occurs, the simulation will determine whether or not the current observation can be continued. If so, the plan will remain unchanged. In the case that the conditions worsen, the plan may be interrupted and the remainder of the night rescheduled for the new conditions.

2.4.2 Target of opportunity simulation

The target of opportunity simulator requires a file of ToO observation types. This file is formatted exactly the same as the observation catalog file. However, the timing constraints for ToOs must have a value of -1 as the constraint start time. The software will set this start time as the time of arrival to the queue. Secondly, each ToO must have a program name but no observation name. The observation name must be set to 'null'. As ToO events are generated, each observation will be assigned a number. For example, if a ToO is from program GS-2018A-ToO-1 and is the 25^{th} ToO event in the simulation, it will have the observation identifier GS-2018A-ToO-1-25.

The simulator distinguishes between user priorities of *Interrupt Target of Opportunity* and all other target of opportunity types. *Standard Target of Opportunity* and *Rapid Target of Opportunity* types are handled in the same way but have different time constraints. When an *Interrupt* type ToO arrives to the queue, the simulator will attempt to schedule it immediately. If the conditions and observation constraints permit this, the plan changes to observe the ToO. Otherwise, it does not get scheduled at all(due to a very short time constraint). When *Rapid* and *Standard* type ToOs arrive, they are added to the queue without interrupting the current observation. Once the current observation is completed, the remainder of the night is rescheduled.

2.4.3 Example simulation

The following is an example of the simulator handling incoming ToOs and changing weather conditions throughout the night of 2018-05-01.

```
---------------------------------------------------------------------
                Gemini Adaptive Queue Planning Tool
---------------------------------------------------------------------

Dates: 2018-05-01 to 2018-05-01
Number of nights: 1
Daylight savings time: False

Observatory:
   Site:         gemini_south
   Height:       2750.0000 m
   Longitude:    -70.7367 deg
   Latitude:     -30.2407 deg

Options:
--------
1.       Log file                                  loggylog.log
2.       ToO file                                  tootypes.txt
3.       ToO probability                           0.3
4.       Max. number of ToOs per night             4
5.       Conditions (iq,cc,wv)                     (70%, 50%, Any)
6.       Conditions from distribution type         None
7.       Wind conditions (dir, vel)                (330.0deg, 5.0m/s)
8.       Generate random wind conditions           False
9.       Probability of condition change           0.3
```

10. Max. number of condition changes per night 4
11. Show plan plots False
12. Show airmass plot of each plan iteration False
13. Show airmass plots of plan building up False
14. Show sky conditions plots False
15. Show wind condition plots False

dir Show files in current directory

Press enter to run or select an option:

-- Generating plan for night of 2018-05-01 --

Sky conditions (iq, cc, wv):	(70%, 50%, Any)
Wind conditions (dir., vel.):	330.0 deg, 5.0 m / s
Solar midnight (UTC):	2018-05-02 04:40
Solar midnight (local):	2018-05-02 00:40
Sun ra:	39.05 deg
Sun dec:	15.28 deg
Moon ra:	246.0 deg
Moon dec:	-16.78 deg
Moon fraction:	0.95
Moon phase:	0.44 rad

-- 2018-05-01 schedule (iteration 1) --

Obs. ID	Target	RA	Dec.	Instr	UTC	LST	Start	End	Dur.	AM	HA	Completed
12 deg.twi.					23:00	8.95	19:00					
A-LP-12-26	hen 3-225	133.9	-43.5	GPI	23:00	8.95	19:00	20:18	1.3 h	1.03	0.02	False
A-LP-12-81	wray 15-53	154.0	-57.9	GPI	00:18	10.25	20:18	21:42	1.4 h	1.13	-0.01	False
-FT-103-29	hip 64150	197.4	5.11	GPI	02:18	12.26	22:18	23:06	0.8 h	1.26	-0.90	False
A-Q-109-16	HIP65426	201.4	-51.6	GPI	03:06	13.06	23:06	00:30	1.4 h	1.08	-0.37	False
-FT-103-33	hip67620	208.1	-24.4	GPI	04:30	14.46	00:30	01:18	0.8 h	1.01	0.59	False
A-Q-133-25	WISE J1623	246.2	-5.18	GMOS-	05:18	15.27	01:18	02:24	1.1 h	1.15	-1.15	False
A-Q-103-23	HR Del	310.8	19.23	GMOS-	09:54	19.88	05:54	06:24	0.5 h	1.58	-0.84	False
12 deg. twi.					10:18	20.28	06:18					

At 21:12 local time, Interrupt Target of Opportunity added to queue.

-- 2018-05-01 schedule (iteration 2) --

Obs. ID	Target	RA	Dec.	Instr	UTC	LST	Start	End	Dur.	AM	HA	Completed
12 deg.twi.					23:00	8.95	19:00					
A-LP-12-26	hen 3-225	133.9	-43.5	GPI	23:00	8.95	19:00	20:18	1.3 h	1.03	0.02	True
A-LP-12-81	wray 15-53	154.0	-57.9	GPI	00:18	10.25	20:18	21:18	1.0 h	1.13	-0.01	False
018A-T-1-1	SN-4	200.2	-40.1	GMOS-	01:18	11.26	21:18	23:18	2.0 h	1.13	-2.10	False
A-Q-133-25	WISE J1623	246.2	-5.18	GMOS-	03:18	13.26	23:18	00:24	1.1 h	1.59	-3.15	False
-FT-103-33	hip67620	208.1	-24.4	GPI	04:24	14.36	00:24	01:12	0.8 h	1.01	0.49	False
-FT-103-23	hip 67620	208.1	-24.4	GPI	05:12	15.17	01:12	02:00	0.8 h	1.05	1.29	False
A-Q-103-23	HR Del	310.8	19.23	GMOS-	09:54	19.88	05:54	06:24	0.5 h	1.58	-0.84	False
12 deg. twi.					10:18	20.28	06:18					

```
At 23:36 local time, Standard Target of Opportunity added to queue.


                -- 2018-05-01 schedule (iteration 3) --

Obs. ID     Target     RA    Dec.  Instr UTC   LST   Start End   Dur.  AM   HA    Completed
-------     ------     --    ---   ----- ---   ---   ----- ---   ---   --   --    ---------
12 deg.twi.                              23:00 8.95  19:00
A-LP-12-26  hen 3-225  133.9 -43.5 GPI   23:00 8.95  19:00 20:18 1.3 h 1.03 0.02  True
A-LP-12-81  wray 15-53 154.0 -57.9 GPI   00:18 10.25 20:18 21:18 1.0 h 1.13 -0.01 False
018A-T-1-1  SN-4       200.2 -40.1 GMOS- 01:18 11.26 21:18 23:18 2.0 h 1.13 -2.10 True
A-Q-133-25  WISE J1623 246.2 -5.18 GMOS- 03:18 13.26 23:18 00:24 1.1 h 1.59 -3.15 True
018A-T-1-2  SN-6       180.2 -41.1 GMOS- 04:24 14.36 00:24 02:00 1.6 h 1.16 2.35  False
A-Q-103-23  HR Del     310.8 19.23 GMOS- 09:54 19.88 05:54 06:24 0.5 h 1.58 -0.84 False
12 deg. twi.                             10:18 20.28 06:18

At 03:36 local time, sky conditions change to iq=70%, cc=50%, wv=20%.


                          -- 2018-05-01 schedule --

Obs. ID     Target     RA    Dec.  Instr UTC   LST   Start End   Dur.  AM   HA    Completed
-------     ------     --    ---   ----- ---   ---   ----- ---   ---   --   --    ---------
12 deg.twi.                              23:00 8.95  19:00
A-LP-12-26  hen 3-225  133.9 -43.5 GPI   23:00 8.95  19:00 20:18 1.3 h 1.03 0.02  True
A-LP-12-81  wray 15-53 154.0 -57.9 GPI   00:18 10.25 20:18 21:18 1.0 h 1.13 -0.01 False
018A-T-1-1  SN-4       200.2 -40.1 GMOS- 01:18 11.26 21:18 23:18 2.0 h 1.13 -2.10 True
A-Q-133-25  WISE J1623 246.2 -5.18 GMOS- 03:18 13.26 23:18 00:24 1.1 h 1.59 -3.15 True
018A-T-1-2  SN-6       180.2 -41.1 GMOS- 04:24 14.36 00:24 02:00 1.6 h 1.16 2.35  True
A-Q-103-23  HR Del     310.8 19.23 GMOS- 09:54 19.88 05:54 06:24 0.5 h 1.58 -0.84 True
12 deg. twi.                             10:18 20.28 06:18

Simulation complete!
```

The various iterations of the plan are provided, and plots of each plan may be viewed. As seen above, an *Interrupt* type ToO caused an immediate interruption of the plan at 12:12, whereas the *Standard* type ToO was added to the queue at 23:36 and was scheduled later in the night at 00:24. At 03:36, the viewing conditions improved so the plan was not interrupted. Figure 4 shows plan iteration plots for this example.

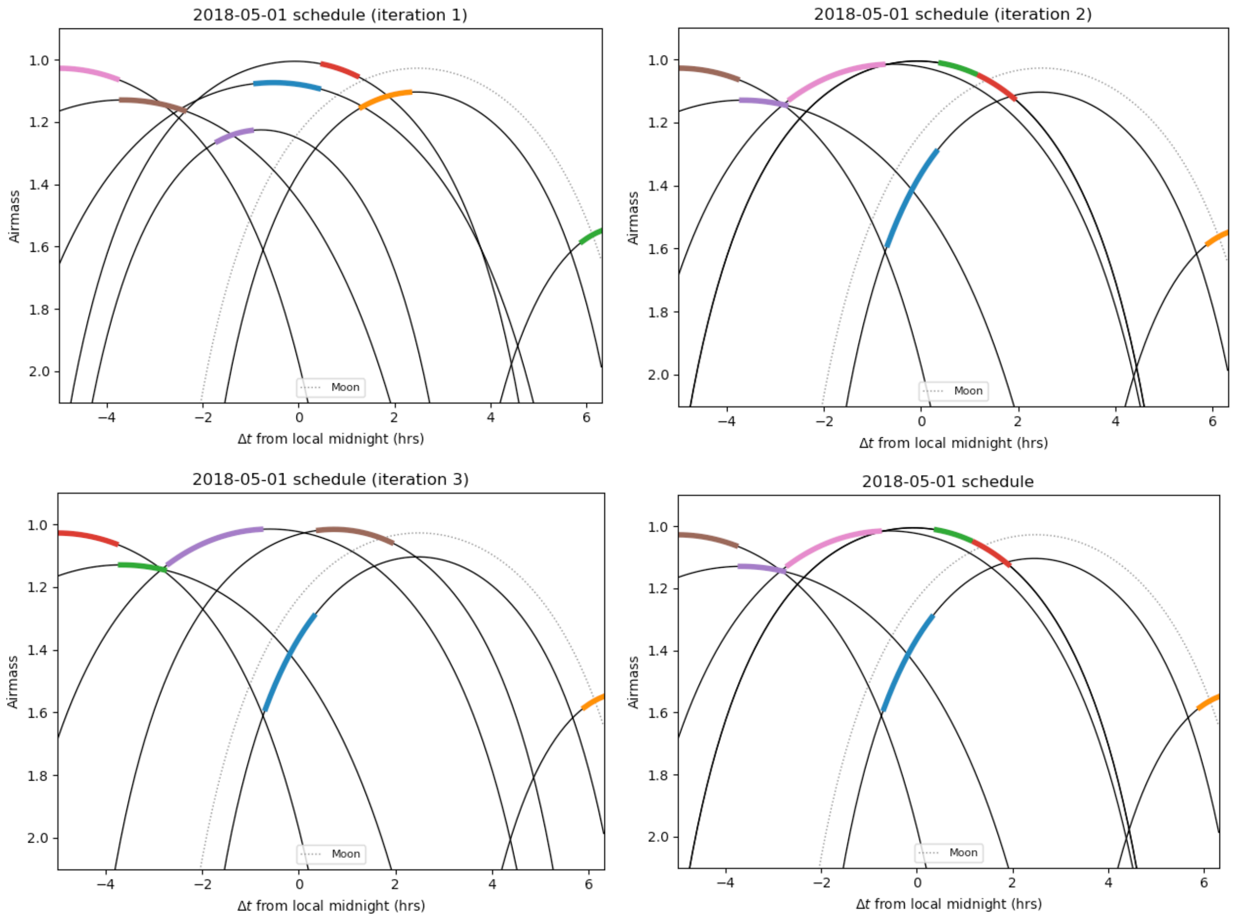

Figure 4: Iterations of nightly plan with ToOs and changing conditions

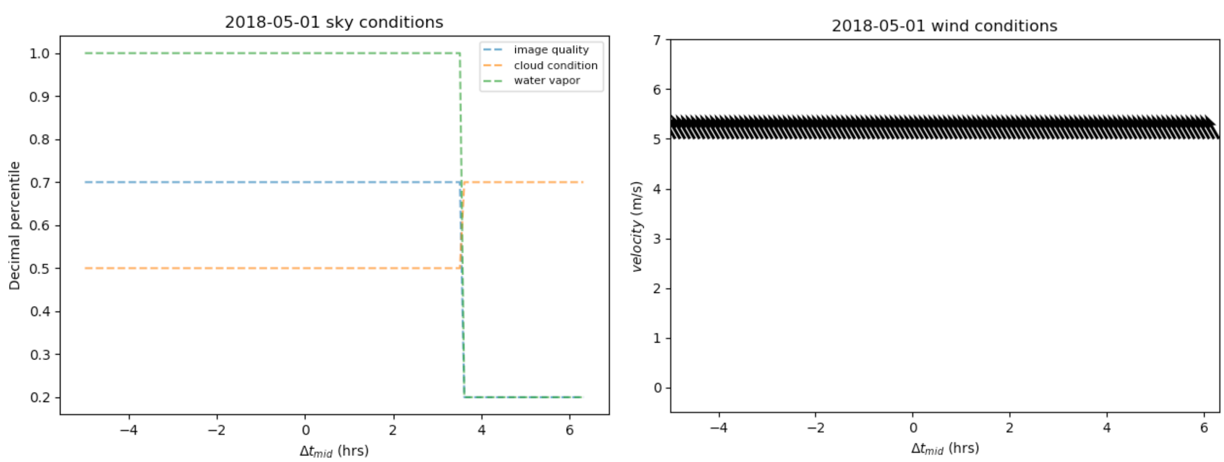

Figure 5: Sky conditions(left) and wind conditions(right) for the 2018-05-01 example

3 Weight Function Plotting Tool

The Weight Function Plotting Tool functions as an independent program. It requires only an observation file, program file, and instrument schedule file. However, similar to the GQPT, the user must define the date and observatory in the command line if non-default parameters are desired.

3.1 Help guide

```
                                    Weight function plotting tool
****************************************************************************************************

   otfile               OT catalog file name.

   prfile               Gemini exechours program status file name.

   instcal              Instrument calendar filename.

   -o   --observatory    Observatory site [DEFAULT='gemini_south']. Accepts the following:
                         1. 'gemini_north' (or 'MK' for Mauna Kea)
                         2. 'gemini_south' (or 'CP' for Cerro Pachon)

   -d   --date           Date 'YYYY-MM-DD' [DEFAULT=current].

   -dst --daylightsavings Toggle daylight savings time [DEFAULT=False].

   -dt  --gridsize       Size of time-grid spacing [DEFAULT=0.1hr].

                         Sky conditions:
   -i   --iq             Image quality constraint [DEFAULT=70].
   -c   --cc             Cloud cover constraint [DEFAULT=50].
   -w   --wv             Water vapor constraint [DEFAULT=Any].

                         Wind conditions:
   -dir --direction      Wind direction [DEFAULT=270deg].
   -vel --velocity       Wind velocity [DEFAULT=10deg].

   -rw  --randwind       Random wind conditions (use mean and standard deviation of site):
                            Cerro Pachon : dir=(330 +/- 20)deg, vel=(5 +/- 3)m/s
                            Mauna Kea    : dir=(330 +/- 20)deg, vel=(5 +/- 3)m/s

   -u   --update         Download up-to-date IERS(International Earth Rotation and Reference
                         Systems).

****************************************************************************************************

positional arguments:
  otfile
  prfile
  instfile

optional arguments:
  -h, --help          show this help message and exit
  -o OBSERVATORY, --observatory OBSERVATORY
  -d DATE, --date DATE
  -dst, --daylightsavings
  -dt GRIDSIZE, --gridsize GRIDSIZE
  -iq IQ, --iq IQ
  -cc CC, --cc CC
```

```
-wv WV, --wv WV
-dir DIRECTION, --direction DIRECTION
-vel VELOCITY, --velocity VELOCITY
-rw, --randwind
-u, --update
```

3.2 Plotting

The WFPT, just like the GQPT, defaults to the current night if not specified otherwise. Here is an example of how it would be used...

```
>>> python wfpt.py observations.txt execHours.txt instschedule.txt
```

The program will generate the necessary data structures before displaying the options menu and prompting the user.

```
---------- Weight function plotting mode ----------

Plan date:        2018-04-01

Options:
--------
1.  See list of available observations  -
2.  Conditions (iq,cc,wv)               (0.7, 0.5, 1.0)
3.  Wind conditions (dir, vel)          (330 deg, 5 m / s)

Select option or provide an observation identifier:
```

If option '1' is selected, the list of available observations is displayed.

```
Observation          Program           Target            Group
-----------          -------           ------            -----
GS-2018A-A-12-2      GS-2018A-A-12     OGLE-TR-7         OGLE-TR-7 - [1] Visitor IGRINS
GS-2018A-A-10-13     GS-2018A-A-10     HIP65426          HIP65426 - [3] GPI Prism Coronograph
GS-2018A-A-10-16     GS-2018A-A-10     HIP65426          HIP65426 - [1] GPI Prism Coronograph
GS-2018A-B-10-18     GS-2018A-B-10     HIP65426          HIP65426 - [4] GPI Prism Coronograph
GS-2018A-B-10-20     GS-2018A-B-10     HIP65426          HIP65426 - [5] GPI Prism Coronograph
GS-2018A-B-10-23     GS-2018A-B-10     HIP65426          HIP65426 - [2] GPI Prism Coronograph
GS-2018A-B-13-37     GS-2018A-B-13     Alpha Centauri    Alpha Centauri A - [visit 1] GPI
GS-2018A-C-15-41     GS-2018A-C-15     Alpha Centauri    Alpha Centauri A - [visit 2] GPI
GS-2018A-C-15-47     GS-2018A-C-15     alpha centauri    Alpha Centauri B - [visit 3] GPI
GS-2018A-C-15-49     GS-2018A-C-15     alpha centauri    Alpha Centauri B - [visit 4] GPI
...                  ...               ...               ...
```

The user may then select an observation by providing the full observation identifier. The software will display the observation weighting function, variables. Constants are printed to the terminal and time dependent variables are plotted (Figures 6, 7). Additionally, the sky brightness condition can be examined for the provided viewing conditions (Figure 8).

```
>>> Select option or provide an observation identifier: GS-2018A-Q-109-13

GS-2018A-Q-109-13 weights
-------------------------
Total cond:           12.915451895 (iq=0.7, cc=0.5, bg=1.0, wv=1.0)
RA:                   7.757871808036047
Band:                 3000.0 (Band 1)
User priority:        1.0 (Medium priority)
Status:               1.0 (Partially complete: prog=False, obs=False)
```

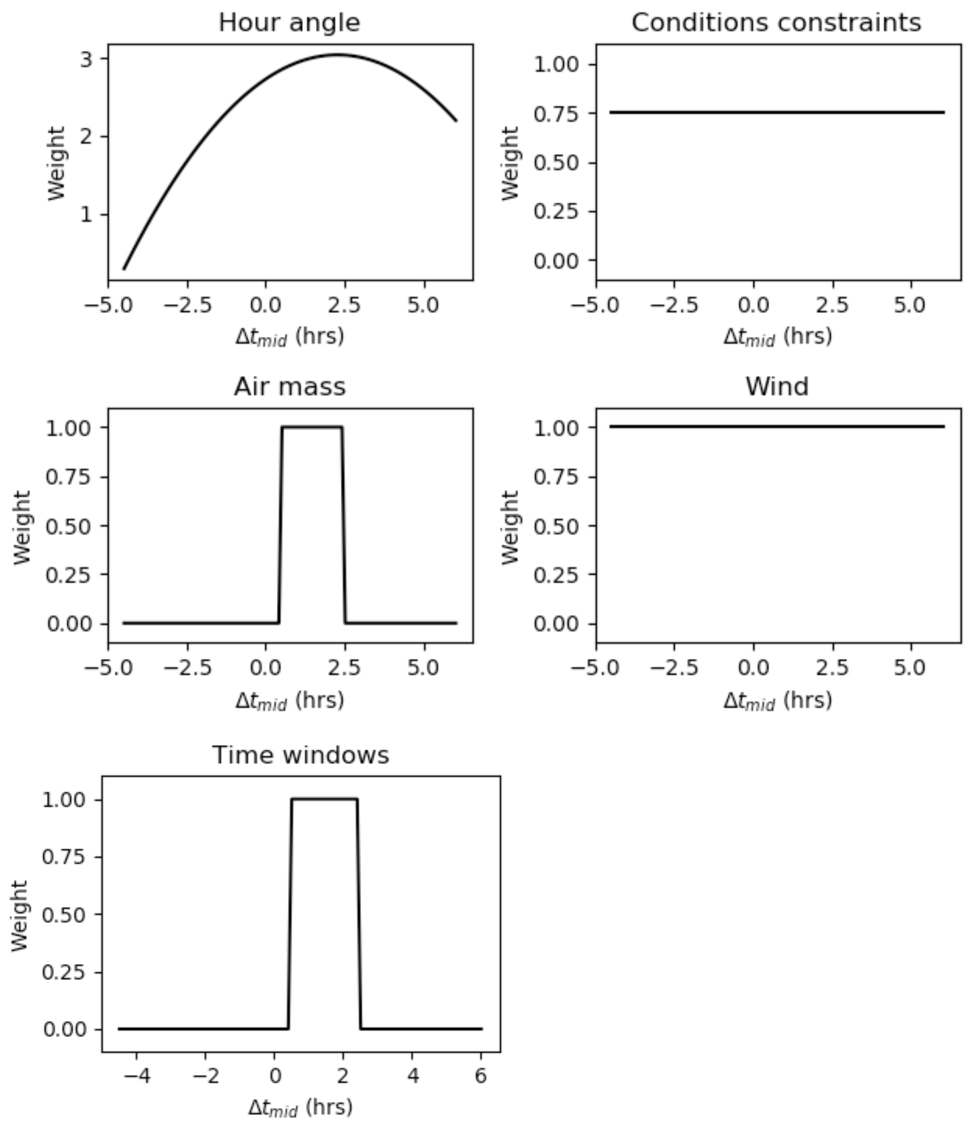

Figure 6: Time dependent weighting factors for GS-2018A-Q-109-13 on 2018-04-01

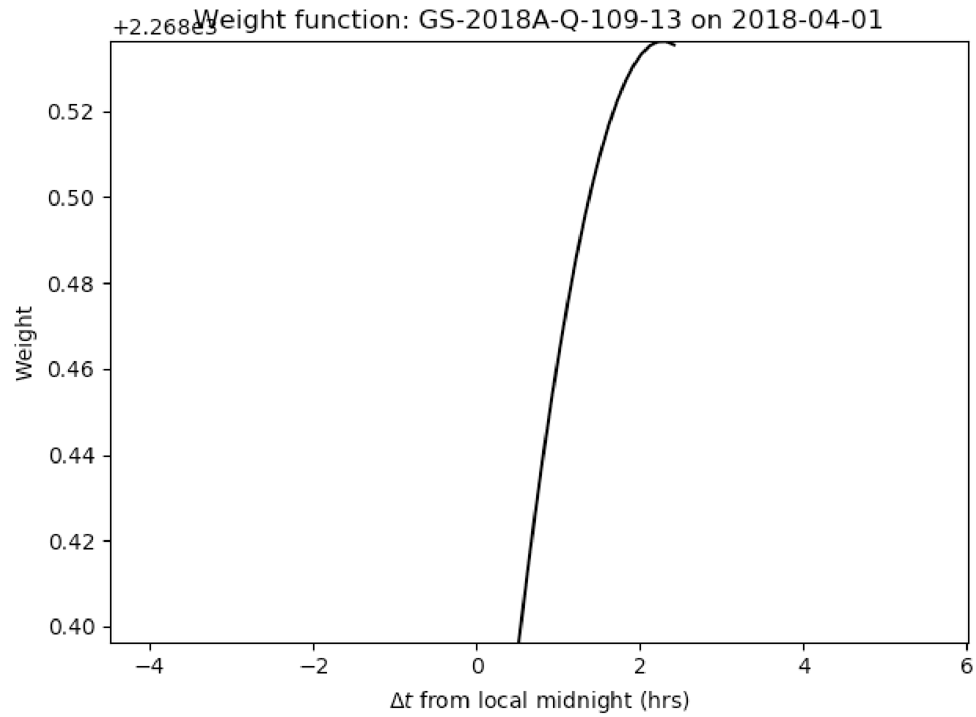

Figure 7: GS-2018A-Q-109-13 weighting function

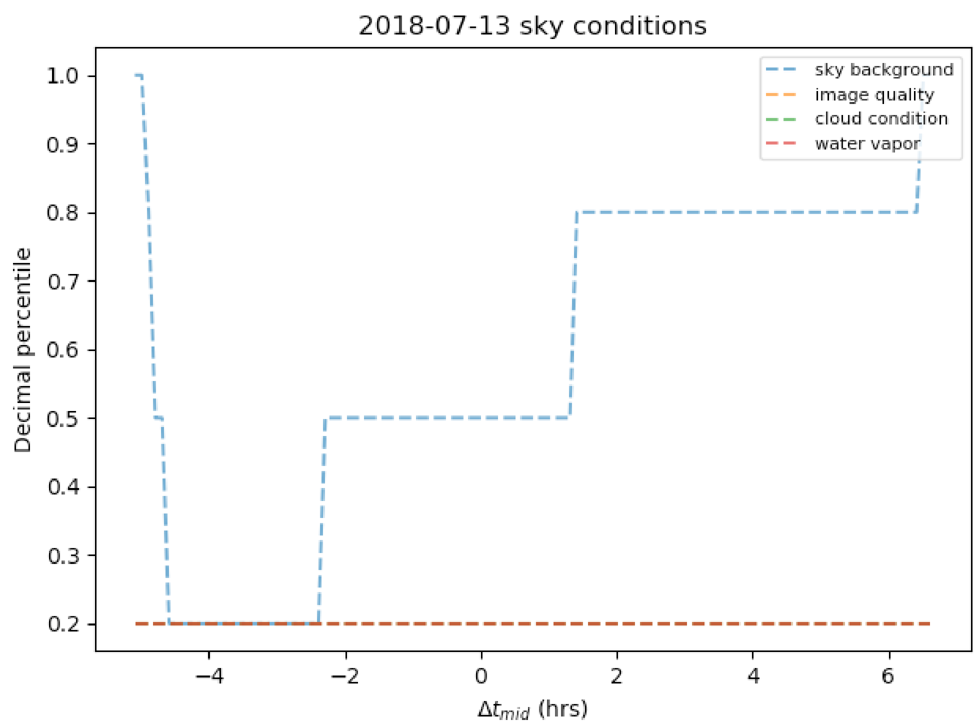

Figure 8: GS-2018A-Q-109-13 sky conditions (including sky background)

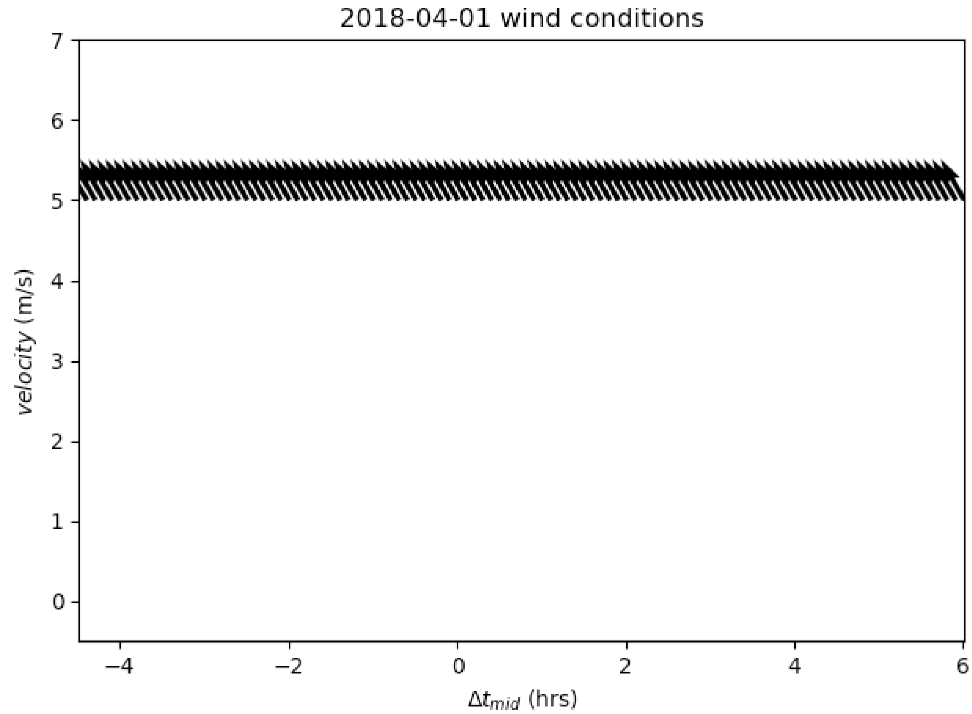

Figure 9: GS-2018A-Q-109-13 wind conditions

4 Input files

The following file formats are currently required by the GQPT and WFPT. These formats may change in the future as new methods become available for querying observation, program, ToO, and instrument information.

4.1 Observation file

The observation catalog file uses the same format as the ODB browser ascii output.

4.2 Target of opportunity file

This file uses the same format as the observation file. However, the start times of the observation time constraints must be assigned the value -1. This is necessary in order for the software to start the ToO time constraint at the time that is it generated. Additionally, the observation identifiers are set to 'null'. ToOs are assigned an observation number when they are generated.

4.3 Program file

The GQPT and WFPT require any version of an *execHour* program status file. Here is an example of the file format...

```
# Executed Hours Report for Gemini South 2018A
# Generated at 01 Apr 2018 00:00:00 GMT.
# Columns: Program ID,Allocated,Elapsed,Non-charged,Partner,Program
GS-2018A-A-1,20.00,0.00,0.00,0.00,0.00
GS-2018A-B-11,8.00,0.00,0.00,0.00,0.00
```

```
GS-2018A-B-12,2.00,0.00,0.00,0.00,0.00
GS-2018A-C-1,8.70,0.00,0.00,0.00,0.00
GS-2018A-C-19,10.00,0.00,0.00,0.00,0.00
GS-2018A-D-25,11.20,0.00,0.00,0.00,0.00
GS-2018A-D-26,0.30,0.00,0.00,0.00,0.00
...
```

4.4 Instrument schedule

Currently, the instrument schedule must be manually written. This file contains the installed instruments, as well as the GMOS disperser, GMOS focal plane unit, and Flamingos2 focal plane unit installed on each night. If instrument information is missing for any dates in the scheduling period, the software will allow any instrument and configuration to be scheduled. The following is an example of the instrument file format - note that columns must be separated by tab '\t' characters.

```
UT Instrument GMOS FPU GMOS Disperser F2 FPU
---- ----- -------- ------------- ------
2018-04-01 GPI,cal,GMOS-S,INGRINS,Flamingos2,Visitor Instrument null null null
2018-04-02 GPI,cal,GMOS-S,INGRINS,Flamingos2,Visitor Instrument null null null
2018-04-03 GPI,cal,GMOS-S,INGRINS,Flamingos2,Visitor Instrument null null null
2018-04-04 GPI,cal,GMOS-S,INGRINS,Flamingos2,Visitor Instrument null null null
2018-04-05 GPI,cal,GMOS-S,INGRINS,Flamingos2,Visitor Instrument null null null
...
```

5 Data structures

The GQPT and WFPT use *astropy.table.Table* objects as the main data structure. Tables or list of tables store important times, time grids, Sun data, Moon data, observation information, instrument information, program information, and target data for the entire scheduling period.

Table 1: Main data structures used in GQPT, WFPT

Variable	Data type	Description
obs	astropy.table.Table	All observations catalog file
progs	astropy.table.Table	All Gemini programs in execHours file
timetable	astropy.table.Table	Important times and time-grids for scheduling period
sun	astropy.table.Table	Location of Sun at solar midnights throughout scheduling period
moon	astropy.table.Table	Location of Moon at at all times throughout scheduling period
targetcal	list of astropy.table.Table	Locations and important quantities for throughout nights in scheduling period

5.1 Observation table

A single observation table stores the entire queue (Table 2). When ToOs are generated they are appended to the bottom of this table.

5.2 Time, Sun, and Moon tables

The time, instrument, Sun, and Moon variables are each a single astropy table (Tables 3, 4, 5, 6). The rows in these tables corresponding to single nights in the scheduling period.

5.3 Target tables

Target data is stored as a list of astropy tables. Each table in the list corresponds to a night in the scheduling period. The rows in each of these tables corresponds to the available targets for that night. Table 7 shows the structure of each of these tables. It should be noted that not all columns constructed simultaneously. The columns i, id, ZD, HA, AZ, AM, and mdist are computed when the table is first constructed. Once the scheduling simulation begins, the software will add the columns vsb, bg, and weight, as these columns are dependent on the current conditions and status of the queue.

Table 2: Observation table (variable name: *obs*)

Key	Data type	Description
prog_ref	str	unique program reference
obs_id	str	unique observation identifier
pi	str	principle investigator
inst	str	instrument
target	str	source name
ra	astropy.coordinates	right ascension
dec	astropy.coordinates	declination
band	int	ranking band (1,2,3,4)
partner	str	Gemini partner name
obs_status	str	'ready' status
obs_time	astropy.units hours	hours observed
charged˙time	astropy.units hours	hours charged
obs_comp	float	completion fraction
obs_class	str	observation class
iq	float	image quality percentile
cc	float	cloud condition percentile
bg	float	sky background percentile
wv	float	water vapour percentile
user_prior	str	user priority ('Low', 'Med', 'High', 'Interrupt Target of Opportunity', 'Rapid Target of Opportunity', 'Standard Target of Opportunity')
group	str	observation group name
elev_const	dict	elevation constraint ('type min max')
time_const	dict	time constraint ('[{start duration repeats period}]')
ready	bool	'ready' status
disperser	str	disperser
fpu	str	focal plane unit
grcwlen	str	grating control wavelength
crwlen	str	central wavelength
filter	str	filter
mask	str	mask
xbin	str	bin number
ybin	str	bun number

Table 3: Time table (variable name: *timetable*)

Key	Data type	Description
date	string	date of night in schedule
utc	astropy.time.core.Time array	UTC time grid
local	astropy.time.core.Time array	local time grid
lst	astropy.units hourangle array	local sidereal time grid
evening_twilight	astropy.time.core.Time	nautical twilight time
morning_twilight	astropy.time.core.Time	nautical twilight time
solar˙midnight	astropy.time.core.Time	solar midnight time

Table 4: Sun table (variable name: *sun*)

Key	Data type	Description
ra	astropy.units degrees	right ascension at solar midnight
dec	astropy.units degrees	declination at solar midnight
ZD	astropy.units degrees	zenith distance angles
HA	astropy.units hourangle	hour angles
AZ	astropy.units radians	azimuth angles

Table 5: Moon table (variable name: *moon*)

Key	Data type	Description
fraction	float	fraction illuminated at solar midnight
phase	astropy.units radians	phase angle at solar midnight
ra_mid	astropy.units degrees	right ascension at solar midnight
dec_mid	astropy.units degrees	declination at solar midnight
ra	astropy.units degrees array	right ascension throughout night
dec	astropy.units degrees array	declination throughout night
ZD	astropy.units degrees array	zenith distance angles
HA	astropy.units hourangle array	hour angles
AZ	astropy.units radians array	azimuth angles
AM	float array	airmass throughout night

Table 6: Instrument calendar table (variable name: *instcal*)

Key	Data type	Description
date	string	date of night in schedule
insts	string	list of available instruments
gmos˙fpu	string	available GMOS focal plane unit
gmos˙disp	string	available GMOS disperser
f2˙fpu	string	available Flamingos-2 focal plane unit

Table 7: Target table (variable name: *targets*) - each of these tables is an element from a list of tables: *targetcal*.

Attribute	Data type	Description
i	integer	observation table row index
id	string	observation identifier
ZD	astropy.units degrees array	zenith distance angles
HA	astropy.units hourangle array	hour angles
AZ	astropy.units radians array	azimuth angles
AM	float array	airmass throughout night
mdist	astropy.units radians	angular distances from moon
vsb	float array	visible sky brightnesses
bg	float array	sky background condition percentiles
weight	float array	weighting factors