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Documentation

Release 0.1.0-beta

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Oct 08, 2020

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This package collects RASCIL scripts for various SKA-MID simulations: direction-dependent effects, high data rate observations, and observation sizing.

DIRECTION-DEPENDENT EFFECTS

These scripts simulate MID observations of multiple point sources and calculate the effect of direction dependent gain errors.

- The sky model is constructed from Oxford S3-SEX catalog. These are unpolarised point sources.
- The observation is by MID or MEERKAT+ over a range of hour angles.
- The visibility is calculated by Direct Fourier transform after application of the gaintable for each source.
- Dask is used to distribute the processing over a number of workers.
- Processing can be divided into chunks of time (default 1800s). This allows

See the following presentation for an overview of the results:

[Simulating MID direction dependent gain effects SPO-1057](#)

The core simulation functions reside in RASCIL. The RASCIL driver script in this repository is `direction_dependent/src/mid_simulation.py`. This can be run directly using the command line arguments listed below, or some typical bash scripts have been provided in `direction_dependent_src/scripts`. The bash scripts allow for looping over duration and declination. The scripts will need to be altered for location of the various files needed. We recommend use of the bash scripts at first.

Note that the simulation has two steps: first the visibilities are calculated and written to HDF files, using `mid_simulation.py` and then all the HDF files are combined into one MeasurementSet using `convert_to_ms.py`. In this conversion step, a number of diagnostic plots are written.

These simulations typically requiring a cluster to run. In Cambridge They work well on the P3 login node, which has 512GB and 64 threads/32 cores, using a large number of threads. For this approach `-use_slurm` should be False.

There are types of output: MeasurementSets and Images. Each are calculated for on, off, and difference. The time consumed in the calculation of the MeasurementSets is small compared to the time in writing the MeasurementSet and the time to make the images. The image calculation can be avoided by setting `-imaging_context None`

The fits images can be viewed using the `casaviewer` or `carta`. The MeasurementSets can be viewed using `casaviewer`.

1.1 Effects simulated

1.1.1 Heterogenous

- A set of point sources is simulated and the relevant voltage pattern for each end of interferometer is applied before Fourier transform.
- Simulates observations with all SKA and MEERKAT dishes (on state) and all SKA dishes (off state).
- stokesQUV, band B2

1.1.2 Heterogenous_meerkat+

- A set of point sources is simulated and the relevant voltage pattern for each end of interferometer is applied before Fourier transform.
- Simulates observations with MEERKAT+ configuration, all SKA and MEERKAT dishes (on state) and all SKA dishes (off state).
- stokesIQUV, band B2

1.1.3 Ionosphere

- A set of point sources is simulated and the phases calculated using a thin screen model for the ionosphere. The screen has units of meters of Total Electron Content. The phase is evaluated at places in the screen where the line of sight from source to a dish pierces the screen.
- Simulates observations with ionospheric screens on and off.
- This requires the screens to be calculated first or downloaded: see `../screens/README.md`
- stokesI, band B1LOW

1.1.4 Polarisation

- Simulates observations with SKA and EMSS calculated primary beam models with cross pol (on) and no cross pol set to zero (off)
- Polarisation stokesIQUV, linear, band B2

1.1.5 Surface sag

- Simulates observations with sagging dish (on) and nominal dish (off).
- Models of the voltage pattern are available at +15, +45, +90 deg elevation.
- We interpolate between those to 5 degrees.
- Stokes I, band B2

For more details see: <https://confluence.skatelescope.org/display/SE/Dish+deformation+simulations>

1.1.6 Troposphere

- Simulates observations with tropospheric screens on and off.
- This requires the screens to be calculated first or downloaded: see `../screens/README.md`
- stokesI, bands B2 and B5
- A set of point sources is simulated and the phases calculated using a thin screen model for the atmosphere. The phase is evaluated at places in the screen where the line of sight from source to dish pierces the screen. The screen has units of meters of delay.

1.1.7 Wind pointing

- Simulates observations with wind buffeting of dishes (on) and without (off)
- Stokes I, bands B2 and B5

For more details see: <https://confluence.skatelescope.org/display/SE/MID+pointing+error+simulations>

Simulate SKA-MID direction dependent errors

```
usage: mid_simulation.py [-h] [--rmax RMAX] [--configuration CONFIGURATION]
                        [--ra RA] [--declination DECLINATION] [--band BAND]
                        [--nchan NCHAN] [--channel_width CHANNEL_WIDTH]
                        [--integration_time INTEGRATION_TIME]
                        [--time_range TIME_RANGE TIME_RANGE]
                        [--image_pol IMAGE_POL] [--vis_pol VIS_POL]
                        [--imaging_context IMAGING_CONTEXT] [--npixel NPIXEL]
                        [--cellsize CELLSIZE] [--weighting WEIGHTING]
                        [--robustness ROBUSTNESS] [--pbradius PBRADIUS]
                        [--pctype PCTYPE] [--seed SEED]
                        [--flux_limit FLUX_LIMIT] [--results RESULTS]
                        [--elevation_sampling ELEVATION_SAMPLING] [--r0 R0]
                        [--height HEIGHT] [--screen SCREEN]
                        [--time_chunk TIME_CHUNK] [--mode MODE]
                        [--duration DURATION]
                        [--wind_conditions WIND_CONDITIONS]
                        [--global_pe GLOBAL_PE GLOBAL_PE]
                        [--static_pe STATIC_PE STATIC_PE]
                        [--dynamic_pe DYNAMIC_PE]
                        [--pointing_directory POINTING_DIRECTORY]
                        [--vp_directory VP_DIRECTORY] [--show SHOW]
                        [--nthreads NTHREADS] [--processes PROCESSES]
                        [--memory MEMORY] [--nworkers NWORKERS]
                        [--use_dask USE_DASK] [--use_slurm USE_SLURM]
                        [--cores CORES] [--slurm_project SLURM_PROJECT]
                        [--slurm_queue SLURM_QUEUE]
                        [--slurm_walltime SLURM_WALLTIME]
                        [--interface INTERFACE]
```

Named Arguments

| | |
|------------------------|---|
| --rmax | Maximum distance of dish from centre (m) Default: 200000.0 |
| --configuration | MID Configuration: MID MEERKAT+ Default: "MID" |
| --ra | Right ascension of phase centre (degrees) Default: 0.0 |
| --declination | Declination of phase centre (degrees) Default: -40.0 |
| --band | Band B1LOW B1 B2 Ku Default: "B2" |

| | |
|-----------------------------|--|
| --nchan | Number of frequency channels Default: 1 |
| --channel_width | Channel bandwidth (Hz) (default is to calculate from frequency) |
| --integration_time | Integration time (s) Default: 180 |
| --time_range | Time range in hour angle Default: [-4.0, 4.0] |
| --image_pol | RASCIL polarisation frame for image: stokesI stokes IQ stokesIQUV Default: “stokesIQUV” |
| --vis_pol | RASCIL polarisation frame for visibility: linear linearnp Default: “linear” |
| --imaging_context | Imaging context ‘2d’ ‘ng’ |
| --npixel | Number of pixels |
| --cellsize | Cellsize in radians |
| --weighting | Type of weighting Default: “robust” |
| --robustness | Robustness for robust weighting Default: 0.0 |
| --pbradius | Radius of sources to include (in HWHM) Default: 1.5 |
| --pbtype | Primary beam model: MID_B1 MID_B1LOW NID_B2 MID_Ku MEERKAT_B1 MEERKAT_B2 Default: “MID_B2” |
| --seed | Random number seed Default: 18051955 |
| --flux_limit | Flux limit (Jy) Default: 0.01 |
| --results | Directory for results Default: “.” |
| --elevation_sampling | Sampling in elevation for surface (deg) Default: 1.0 |
| --r0 | R0 (meters) Default: 5000.0 |
| --height | Height of layer (meters) |
| --screen | Location of atmospheric phase screen Default: <MagicMock name=’mock()’ id=’140486356967552’> |

| | |
|-----------------------------|---|
| --time_chunk | Time for a chunk (s) Default: 3600.0 |
| --mode | Mode of simulation: wind_pointing random_pointing polarisation ionosphere troposphere heterogeneous Default: "wind_pointing" |
| --duration | Type of duration: long or medium or short Default: "long" |
| --wind_conditions | SKA definition of wind conditions: precision standard degraded Default: "precision" |
| --global_pe | Global pointing error Default: [0.0, 0.0] |
| --static_pe | Multipliers for static errors Default: [0.0, 0.0] |
| --dynamic_pe | Multiplier for dynamic errors Default: 1.0 |
| --pointing_directory | Location of wind PSD pointing files Default: <MagicMock name='mock()' id='140486356967552'> |
| --vp_directory | Location of voltage pattern files Default: <MagicMock name='mock()' id='140486356967552'> |
| --show | Show details of simulation? Default: "False" |
| --nthreads | Number of threads per worker Default: 1 |
| --processes | Number of processes per worker Default: 1 |
| --memory | Memory per worker (GB) |
| --nworkers | Number of workers Default: 4 |
| --use_dask | Use dask processing? Default: "True" |
| --use_slurm | Use SLURM? Default: "False" |
| --cores | Number of cores for a SLURM job Default: 4 |
| --slurm_project | SLURM project for accounting Default: "SKA-SDP" |

| | |
|-------------------------|---------------------|
| --slurm_queue | SLURM queue |
| | Default: "compute" |
| --slurm_walltime | SLURM time limit |
| | Default: "01:00:00" |
| --interface | Network interface |
| | Default: "eth0" |

PSI SIMULATIONS

These are simulated visibility data sets in Measurement Set format, as needed to test the operation of the CBF-SDP interface and the real-time signal displays.

These simulations generate fully time-sampled, high number of spectral channel observations using the simulated Prototype System Integration (PSI) test arrays: a small number of antennas or stations (between 4 and 8), with a large number of frequency channels (of order 10000).

The beam models and sky models used for these simulations should not be too complicated. We anticipate that a sky model of order 1 to 10 components, and primary beams modelled as a Gaussian will be sufficient here.

Simulate time and frequency dense PSI observations

```
usage: mid_write_psi.py [-h] [--rmax RMAX] [--configuration CONFIGURATION]
                        [--ra RA] [--declination DECLINATION] [--band BAND]
                        [--nchan NCHAN] [--nspw NSPW]
                        [--channel_width CHANNEL_WIDTH]
                        [--integration_time INTEGRATION_TIME]
                        [--time_range TIME_RANGE TIME_RANGE]
                        [--image_pol IMAGE_POL] [--vis_pol VIS_POL]
                        [--duration DURATION] [--results RESULTS]
                        [--split SPLIT] [--nthreads NTHREADS]
                        [--processes PROCESSES] [--memory MEMORY]
                        [--nworkers NWORKERS] [--use_dask USE_DASK]
                        [--use_slurm USE_SLURM] [--cores CORES]
                        [--slurm_project SLURM_PROJECT]
                        [--slurm_queue SLURM_QUEUE]
                        [--slurm_walltime SLURM_WALLTIME]
                        [--interface INTERFACE]
```

2.1 Named Arguments

| | |
|------------------------|---|
| --rmax | Maximum distance of dish from centre (m) Default: 200000.0 |
| --configuration | MID Configuration: MID MEERKAT+ Default: "MID" |
| --ra | Right ascension of phase centre (degrees) Default: 0.0 |
| --declination | Declination of phase centre (degrees) |

| | |
|---------------------------|--|
| | Default: -40.0 |
| --band | Band B1LOW B1 B2 Ku Default: "B2" |
| --nchan | Number of frequency channels Default: 1024 |
| --nspw | Number of spectral windows Default: 8 |
| --channel_width | Channel bandwidth (Hz) (default is to calculate from frequency) |
| --integration_time | Integration time (s) Default: 600 |
| --time_range | Time range in hour angle Default: [-1.0, 1.0] |
| --image_pol | RASCIL polarisation frame for image: stokesI stokes IQ stokesIQUV Default: "stokesIQUV" |
| --vis_pol | RASCIL polarisation frame for visibility: linear linearnp Default: "linear" |
| --duration | Type of duration: long or medium or short Default: "long" |
| --results | Directory for results Default: "./" |
| --split | In concat, type of tree e.g. 2->binary Default: 2 |
| --nthreads | Number of threads per worker Default: 1 |
| --processes | Number of processes per worker Default: 1 |
| --memory | Memory per worker (GB) |
| --nworkers | Number of workers Default: 4 |
| --use_dask | Use dask processing? Default: "True" |
| --use_slurm | Use SLURM? Default: "False" |
| --cores | Number of cores for a SLURM job Default: 4 |

| | |
|-------------------------|--|
| --slurm_project | SLURM project for accounting Default: "SKA-SDP" |
| --slurm_queue | SLURM queue Default: "compute" |
| --slurm_walltime | SLURM time limit Default: "01:00:00" |
| --interface | Network interface Default: "eth0" |

Todo:

- Insert todo's here
-

SIZING OBSERVATIONS

This script estimates the size of CASA MeasurementSets for various MID observations. it does this by constructing a scaled down BlockVisibility and writing it to a MeasurementSet.

The maximum size of the array (maximum distance from the array centre) can be set. This determines the angular resolution. See parameter rmax.

The field of view to be imaged is set to a multiple of the primary beam. See parameter guardband.

The time and frequency sampling is adjusted to match the SKA specification of 2% decorrelation at the half-power point of the primary beam. See parameter dela.

Calculate MeasurementSets sizes for MID observations

```
usage: mid_size.py [-h] [--output_msname OUTPUT_MSNAME] [--context CONTEXT]
                  [--ra RA] [--declination DECLINATION] [--rmax RMAX]
                  [--band BAND] [--integration_time INTEGRATION_TIME]
                  [--time_range TIME_RANGE TIME_RANGE]
                  [--fractional_bandwidth FRACTIONAL_BANDWIDTH]
                  [--guardband GUARDBAND] [--dela DELA] [--verbose VERBOSE]
```

3.1 Named Arguments

| | |
|------------------------|--|
| --output_msname | MeasurementSet to be written Default: "mid_simulation.ms" |
| --context | s3sky or singlesource or null Default: "s3sky" |
| --ra | Right ascension (degrees) Default: 15.0 |
| --declination | Declination (degrees) Default: -45.0 |
| --rmax | Maximum distance of station from centre (m) Default: 1000.0 |
| --band | Band Default: "B2" |

| | |
|-------------------------------|--|
| --integration_time | Integration time (s) Default: 80.0 |
| --time_range | Time range in hours Default: [-4.0, 4.0] |
| --fractional_bandwidth | Fractional bandwidth Default: 0.1 |
| --guardband | Size of field of view relative to primary beam Default: 2.0 |
| --dela | Allowable degradation of point source at half power point of primary beam Default: 0.02 |
| --verbose | Verbose output? Default: "False" |

Typical output:

```
mid_size: Starting MID simulation sizing

{'band': 'B2',
 'context': 's3sky',
 'declination': -45.0,
 'dela': 0.02,
 'fractional_bandwidth': 0.1,
 'guardband': 2.0,
 'integration_time': 80.0,
 'output_msname': 'mid_simulation.ms',
 'ra': 15.0,
 'rmax': 1000.0,
 'time_range': [-4.0, 4.0],
 'verbose': 'False'}
mid_size: Using only dishes within 1000.0m of the array centre requires 12 channels,
↳ of 1.13e+07Hz and integration time 683.8s, the MS size is 0.338GB
mid_size: The time and frequency sampling is to provide no more than 2% smearing at,
↳ the half power point of the primary beam.
mid_size: Image has shape 768 by 768, 4 polarisations, and size 0.018GB
mid_size: W processing requires 49 w planes of step 238.8 wavelengths and maximum,
↳ support 0 pixels
mid_size: Allowing fractional bandwidth 0.100 to fill in the uv sampling.
nmid_size: Starting MID simulation sizing

{'band': 'B2',
 'context': 's3sky',
 'declination': -45.0,
 'dela': 0.02,
 'fractional_bandwidth': 0.1,
 'guardband': 2.0,
 'integration_time': 80.0,
 'output_msname': 'mid_simulation.ms',
 'ra': 15.0,
 'rmax': 10000.0,
 'time_range': [-4.0, 4.0],
 'verbose': 'False'}
```

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```
mid_size: Using only dishes within 10000.0m of the array centre requires 107 channels_
↳of 1.27e+06Hz and integration time 80.4s, the MS size is 50.382GB
mid_size: The time and frequency sampling is to provide no more than 2% smearing at_
↳the half power point of the primary beam.
mid_size: Image has shape 8192 by 8192, 4 polarisations, and size 2.000GB
mid_size: W processing requires 428 w planes of step 238.8 wavelengths and maximum_
↳support 12 pixels
mid_size: Allowing fractional bandwidth 0.100 to fill in the uv sampling.
nmid_size: Starting MID simulation sizing

{'band': 'B2',
 'context': 's3sky',
 'declination': -45.0,
 'dela': 0.02,
 'fractional_bandwidth': 0.1,
 'guardband': 2.0,
 'integration_time': 80.0,
 'output_msname': 'mid_simulation.ms',
 'ra': 15.0,
 'rmax': 200000.0,
 'time_range': [-4.0, 4.0],
 'verbose': 'False'}
mid_size: Using only dishes within 200000.0m of the array centre requires 1161_
↳channels of 1.17e+05Hz and integration time 7.4s, the MS size is 8512.629GB
mid_size: The time and frequency sampling is to provide no more than 2% smearing at_
↳the half power point of the primary beam.
mid_size: Image has shape 98304 by 98304, 4 polarisations, and size 288.000GB
mid_size: W processing requires 4065 w planes of step 238.8 wavelengths and maximum_
↳support 132 pixels
mid_size: Allowing fractional bandwidth 0.100 to fill in the uv sampling.
```


INSTRUCTIONS

To install these scripts, use git:

```
git clone https://gitlab.com/ska-telescope/ska-mid-simulations.git
```

Or download the source code from <https://gitlab.com/ska-telescope/ska-mid-simulations>

None of these simulations need to be installed into the python path. Instead please set the environment variable SMSROOT to the location of code:

```
export SMSROOT=/path/to/code
```

RASCIL must be installed - the options are via pip, git clone, or docker. The simplest approach is to use pip. In the ska-mid-simulations directory, do:

```
pip3 install -r requirements.txt
```

A script can be run as:

```
export SMSROOT=`pwd`  
cd sizing/scripts  
sh make_sizes.sh
```

The resource files for the SKA direction-dependent MID simulations are 80GB in size and are kept on the Google Cloud Platform. The python command line tool gsutil allows for interacting with the Google Cloud Platform:

```
https://cloud.google.com/storage/docs/gsutil
```

After installing gsutil, you may download the resources as follows:

```
cd resources  
gsutil -m rsync -r gs://skal-simulation-data/skal-mid/beam_models/ beam_models  
gsutil -m rsync -r gs://skal-simulation-data/skal-mid/screens screens
```