Performative Benchmarking of Unidata MetPy with ASV

Jaye Norman 7/23/2025

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Why should we benchmark?

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C++ification

- Linfeng has created C++ to help MetPy run faster through bottlenecks like CAPE calculation
- We needed a way to quantify his and future changes

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Other Benefits

- Benchmarking also identifies bottlenecks and shows us when merges change the performance of the code

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Where can I see the results?

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unidata.github.io/MetPy-benchmark

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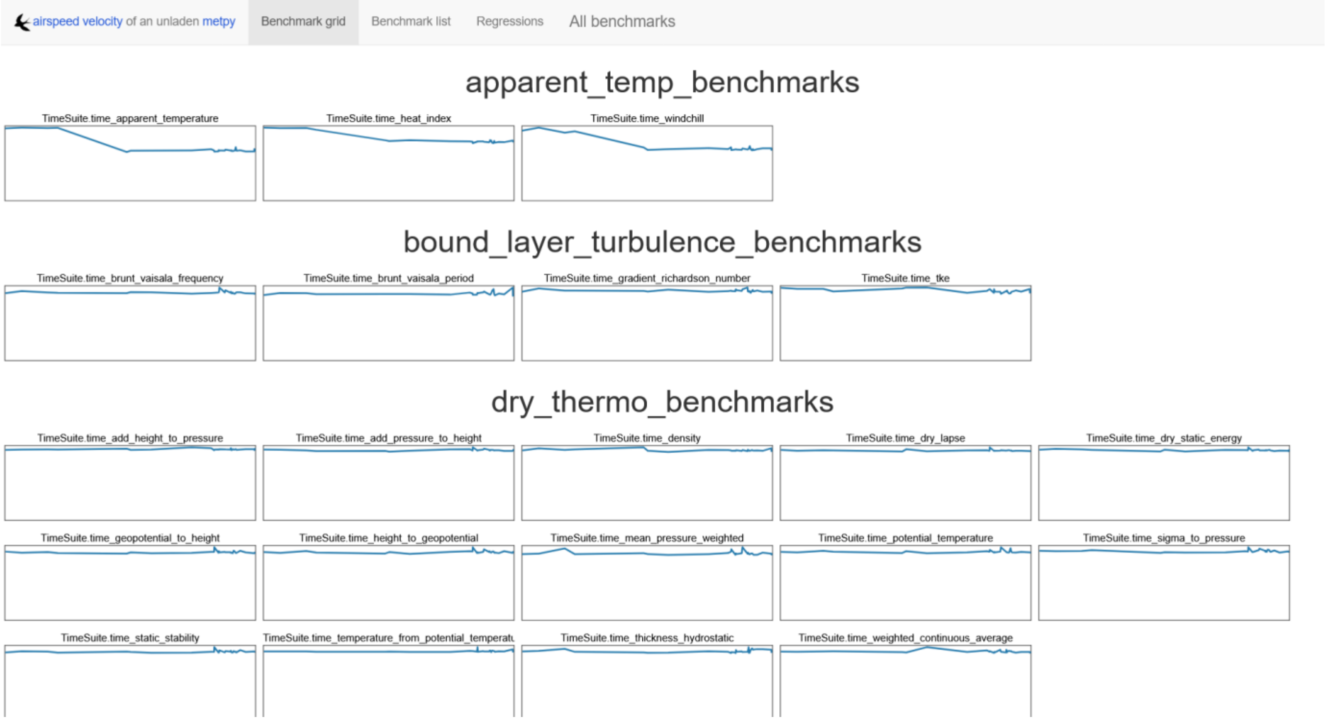
ASV Webpage



apparent_temp_benchmarks

TimeSuite.time_apparent_temperature
TimeSuite.time_heat_index
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bound_layer_turbulence_benchmarks

TimeSuite.time_brunt_vaisala_frequency
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What software did we use?

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GitHub

- Provides a home for the MetPy source code
- The MetPy repo holds the benchmarking functions and configs for CI/CD
- The MetPy-benchmark repo holds the results of the benchmark runs

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Airspeed Velocity

- ASV is an open-source python benchmarking package
- Creates environments based on historical states of a repo, runs the benchmark functions, and returns them in a pretty html format

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Jenkins

- Unidata’s Jenkins instance is used for CI/CD workflows
- Runs on a machine owned by UCAR and ensures that the machine specs are the same between each benchmark run

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Docker

- Within Jenkins, the benchmarks run in a Docker container from a Dockerfile
- Improves consistency between runs and is portable to many devices for local benchmarking

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GitHub Actions

- The MetPy-benchmark repo has a GHA that uses ASV to generate the html from the results
- Action also deploys files to a static page

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How does benchmarking with ASV work?

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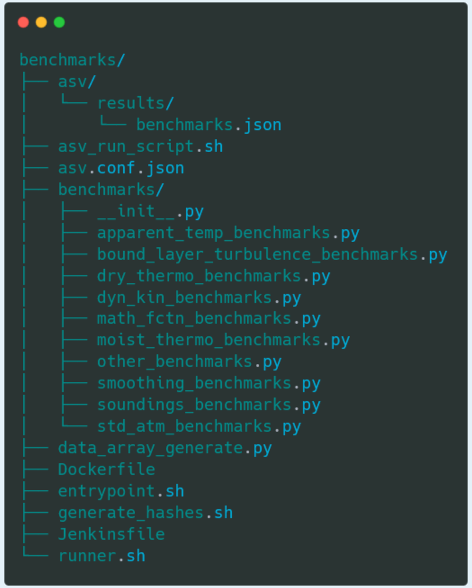
File Tree

- asv.conf.json: configuration file for ASV
- asv/results: where the results are stored
- benchmarks/.py files: benchmarking snippets



```
benchmarks/
├── asv/
│   └── results/
│       └── benchmarks.json
├── asv_run_script.sh
├── asv.conf.json
├── benchmarks/
│   ├── __init__.py
│   ├── apparent_temp_benchmarks.py
│   ├── bound_layer_turbulence_benchmarks.py
│   ├── dry_thermo_benchmarks.py
│   ├── dyn_kin_benchmarks.py
│   ├── math_fctn_benchmarks.py
│   ├── moist_thermo_benchmarks.py
│   ├── other_benchmarks.py
│   ├── smoothing_benchmarks.py
│   ├── soundings_benchmarks.py
│   └── std_atm_benchmarks.py
├── data_array_generate.py
├── Dockerfile
├── entrypoint.sh
├── generate_hashes.sh
├── Jenkinsfile
└── runner.sh
```

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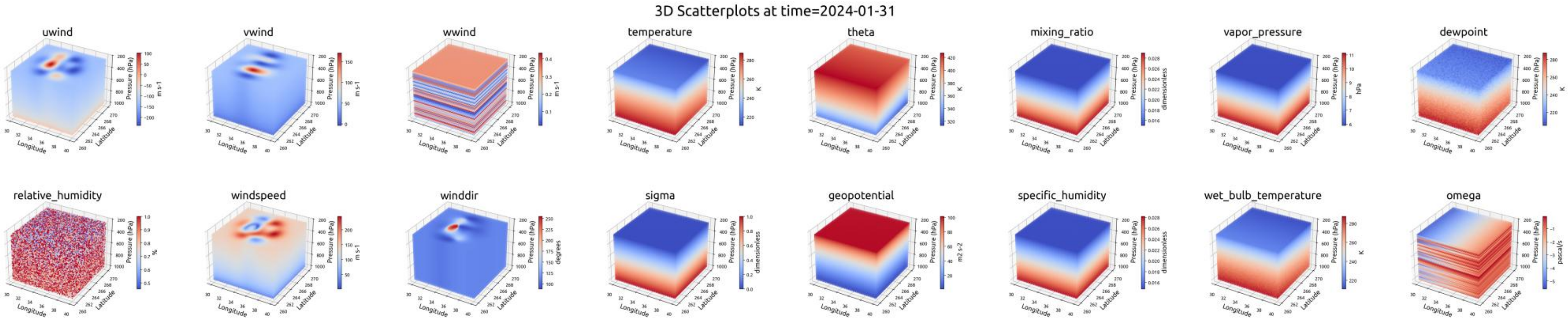
Benchmark Dataset


3D Scatterplots at time=2024-01-31

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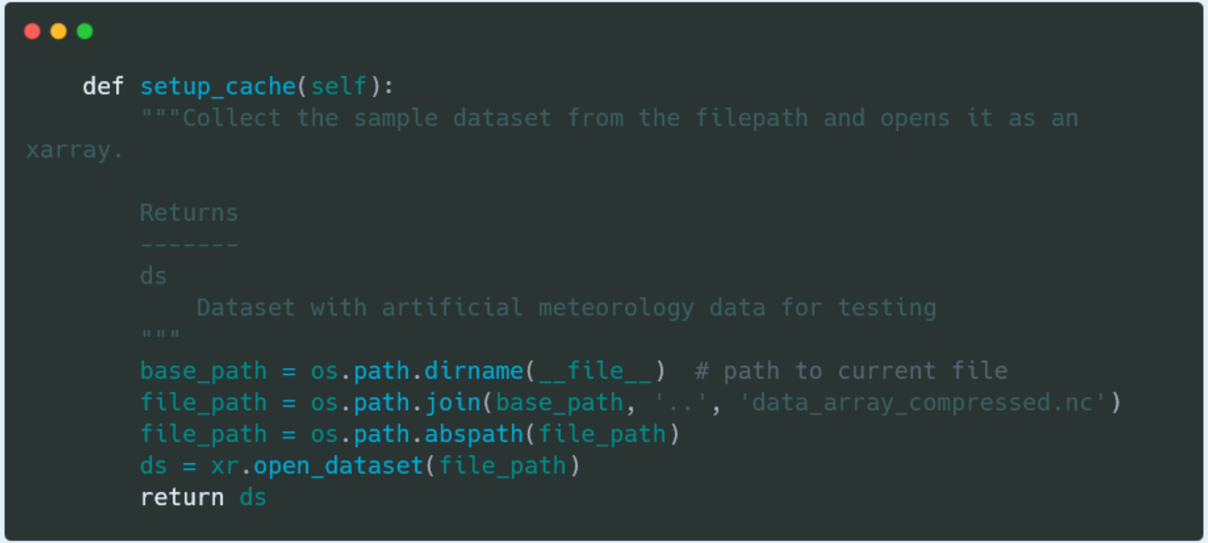
Benchmark setup_cache



```
    def setup_cache(self):
        """Collect the sample dataset from the filepath and opens it as an
xarray.

        Returns
        -------
        ds
            Dataset with artificial meteorology data for testing
        """
        base_path = os.path.dirname(__file__)  # path to current file
        file_path = os.path.join(base_path, '..', 'data_array_compressed.nc')
        file_path = os.path.abspath(file_path)
        ds = xr.open_dataset(file_path)
        return ds
```

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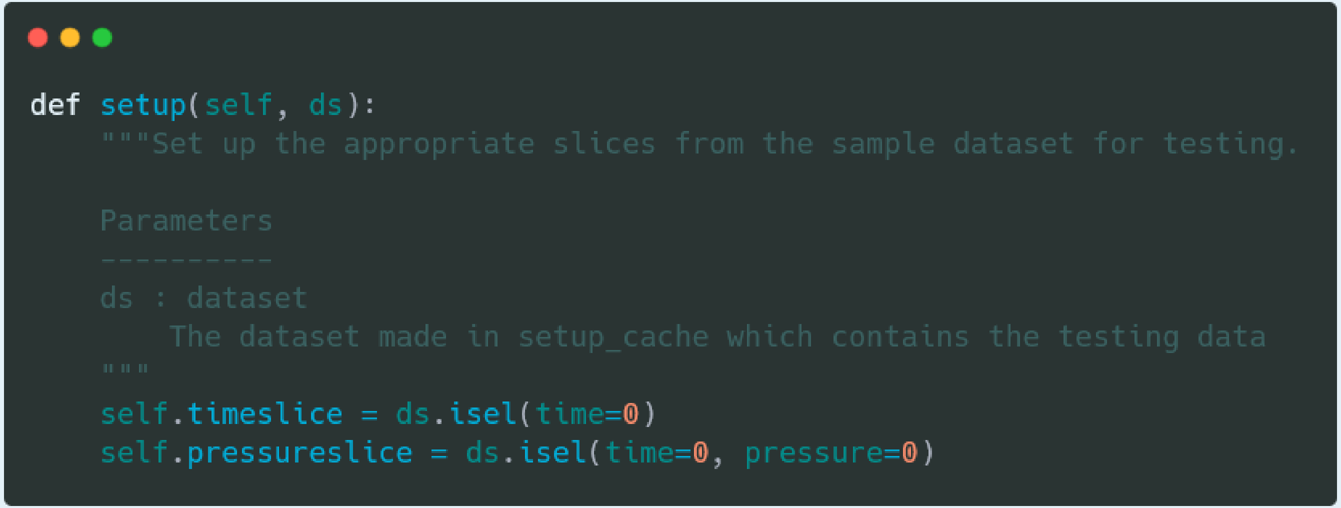
Benchmark setup



```python
def setup(self, ds):
    """Set up the appropriate slices from the sample dataset for testing.

    Parameters
    ----------
    ds : dataset
        The dataset made in setup_cache which contains the testing data
    """
    self.timeslice = ds.isel(time=0)
    self.pressureslice = ds.isel(time=0, pressure=0)
```

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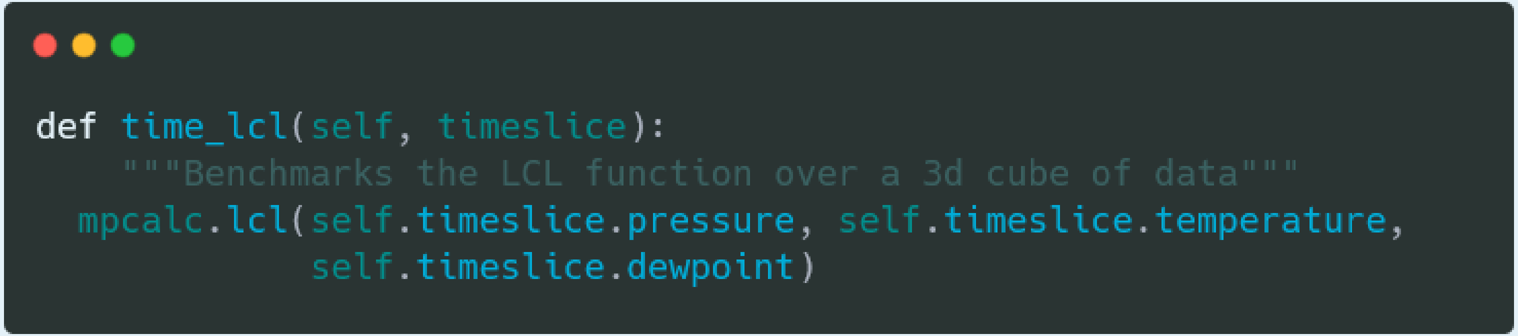
Example Benchmark



```
def time_lcl(self, timeslice):
    """Benchmarks the LCL function over a 3d cube of data"""
  mpcalc.lcl(self.timeslice.pressure, self.timeslice.temperature,
             self.timeslice.dewpoint)
```

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How does the workflow run?

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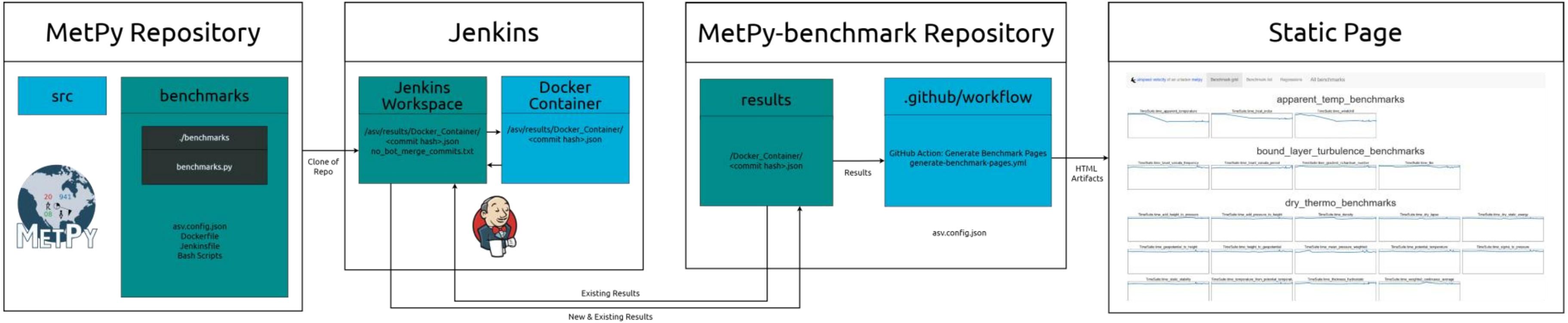
Jenkins Trigger

1) Jenkins is triggered Saturday morning



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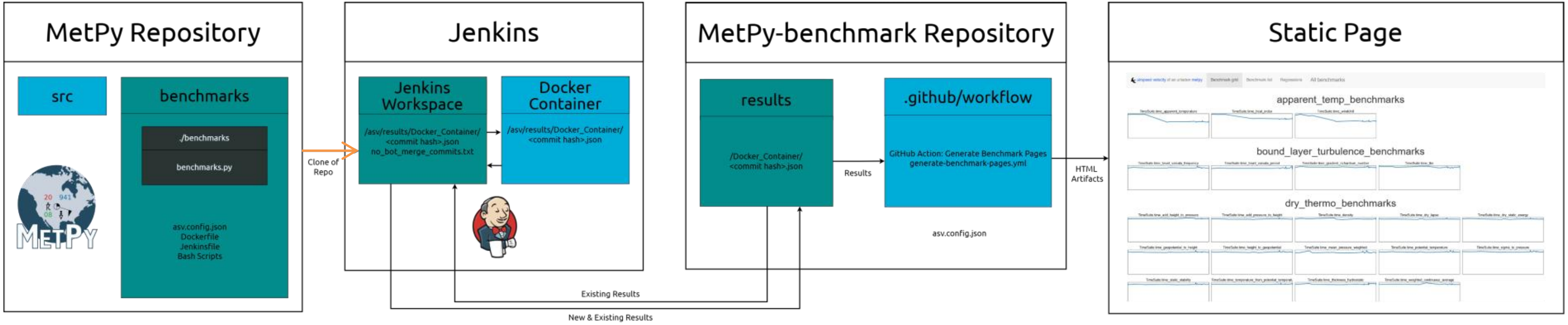
Jenkins Setup

2) Jenkins clones MetPy



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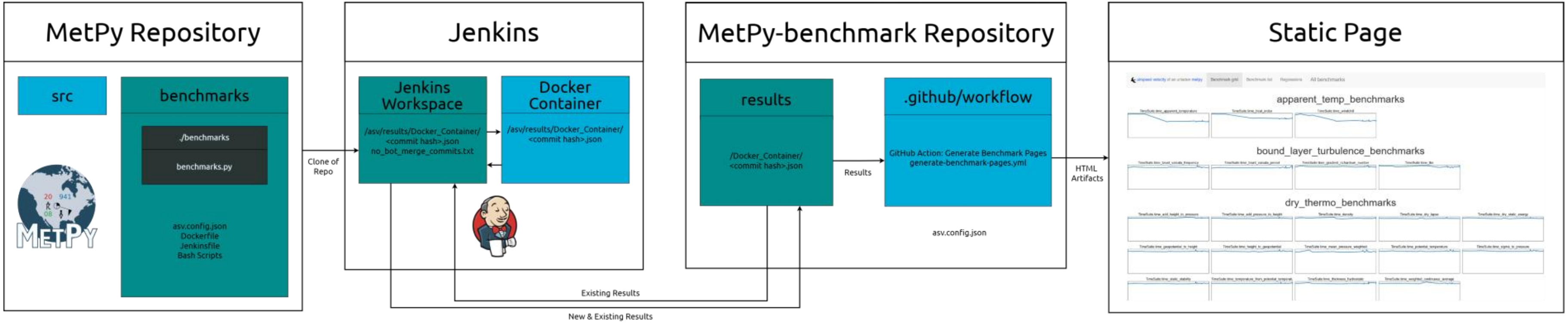
Jenkins Setup

3) Jenkins searches MetPy's history for minor version commits and recent merges



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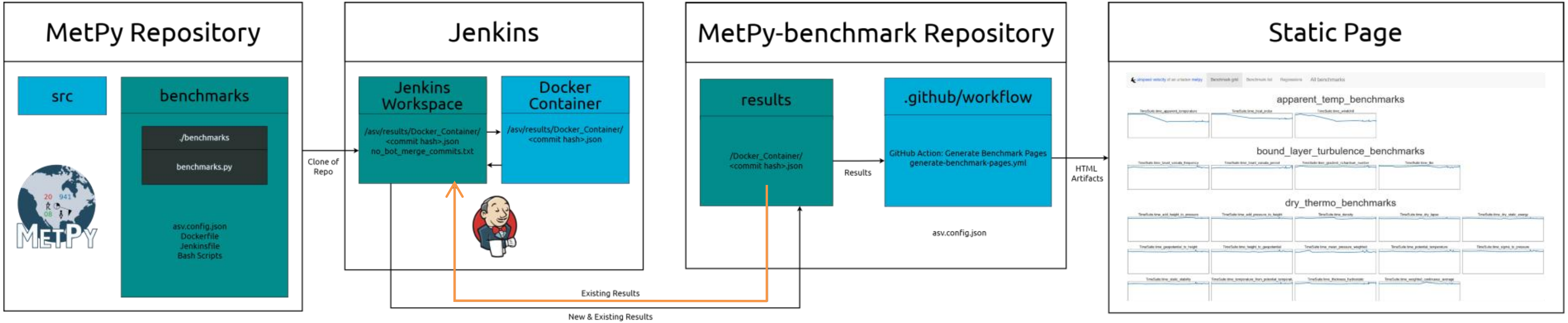
Jenkins Setup

4) From MetPy-benchmark, Jenkins copies the existing results



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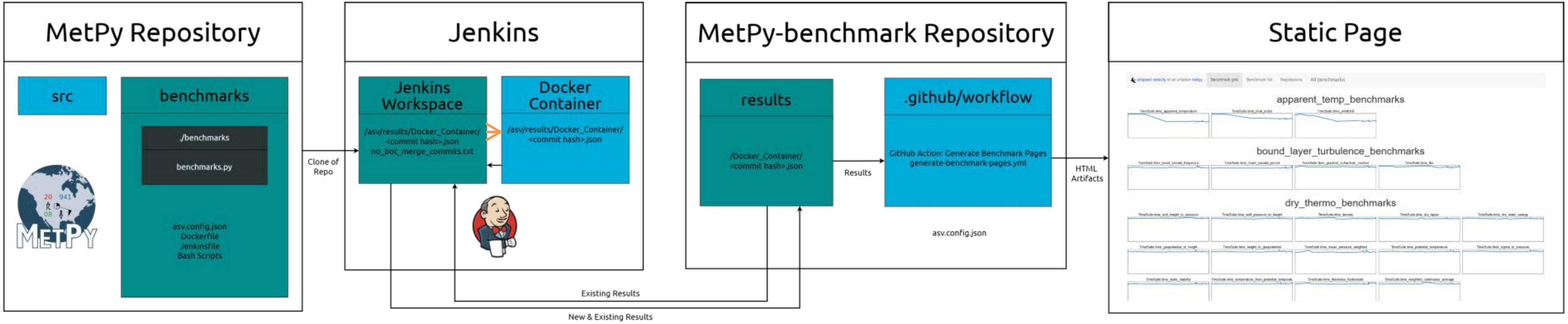
Jenkins Setup

5) Jenkins builds a docker container from the Dockerfile



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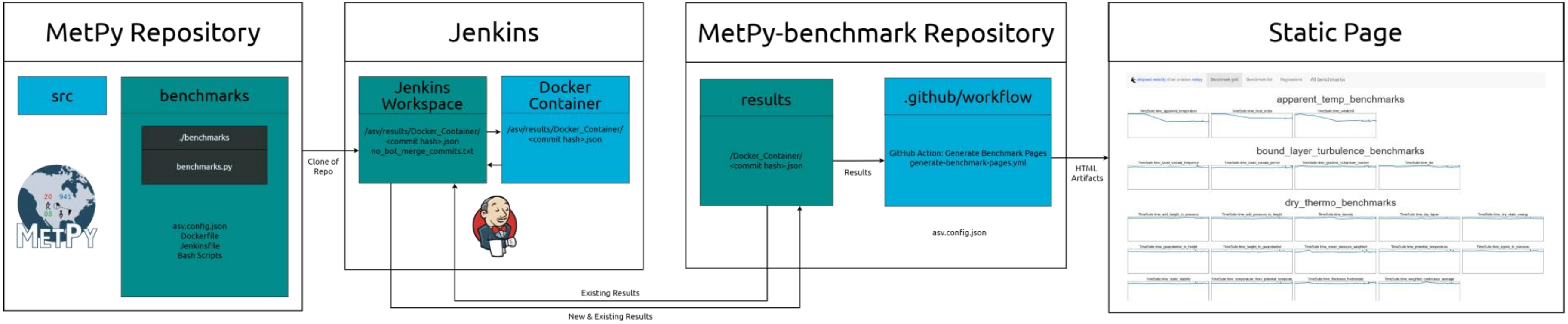
Docker runs Benchmarks

1) With a docker run command, the docker file runs benchmarks on the commit file



MetPy Repository

src

benchmarks

./benchmarks

benchmarks.py

asv.config.json
Dockerfile
Jenkinsfile
Bash Scripts

Clone of Repo

Jenkins

Jenkins Workspace

/asv/results/Docker_Container/
<commit hash>.json
no_bot_merge_commits.txt

Docker Container

/asv/results/Docker_Container/
<commit hash>.json

MetPy-benchmark Repository

results

/Docker_Container/
<commit hash>.json

Results

.github/workflow

GitHub Action: Generate Benchmark Pages
generate-benchmark-pages.yml

asv.config.json

HTML Artifacts

Existing Results

New & Existing Results

Static Page

airspeed velocity of an unladen metpy
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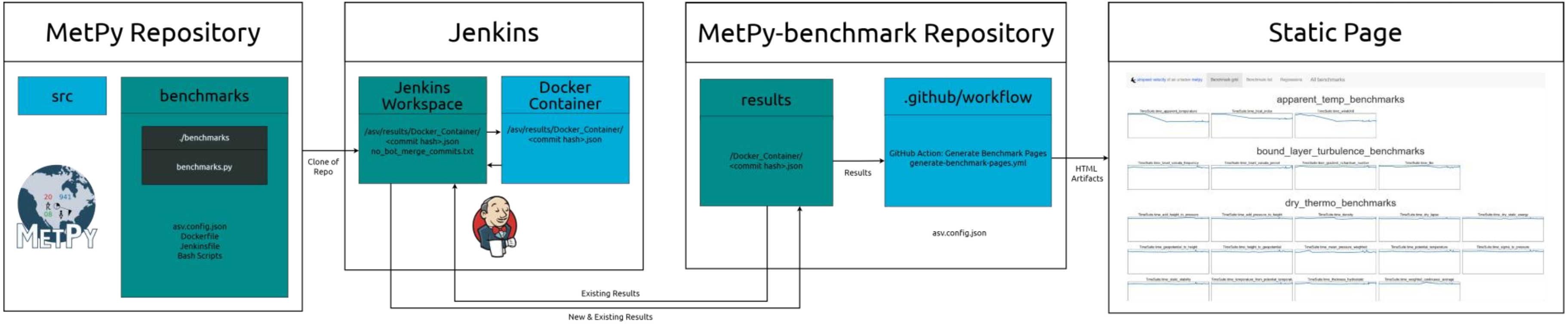
Docker runs Benchmarks

2) If there are already successful results for a certain commit, the benchmarks are skipped



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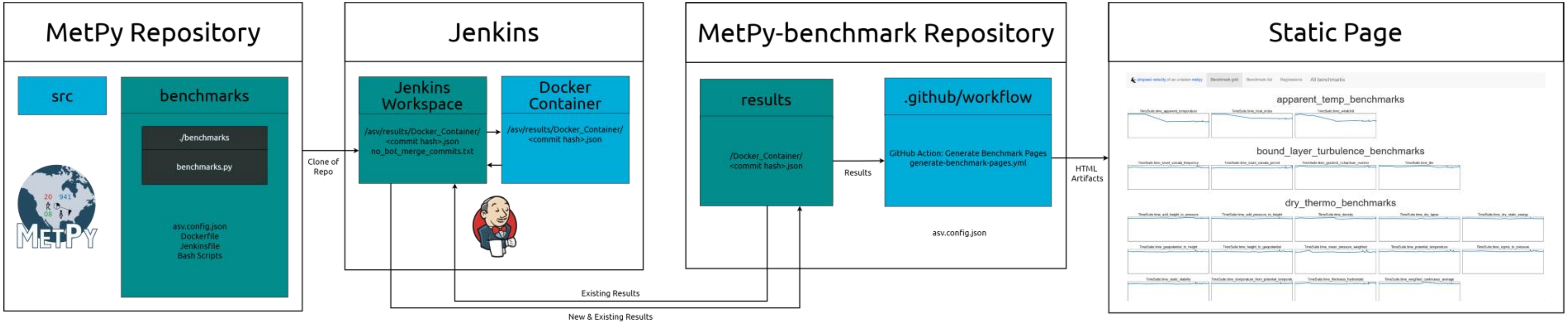
Docker runs Benchmarks

3) If there are not, like for a new commit, the benchmarks are run for this commit



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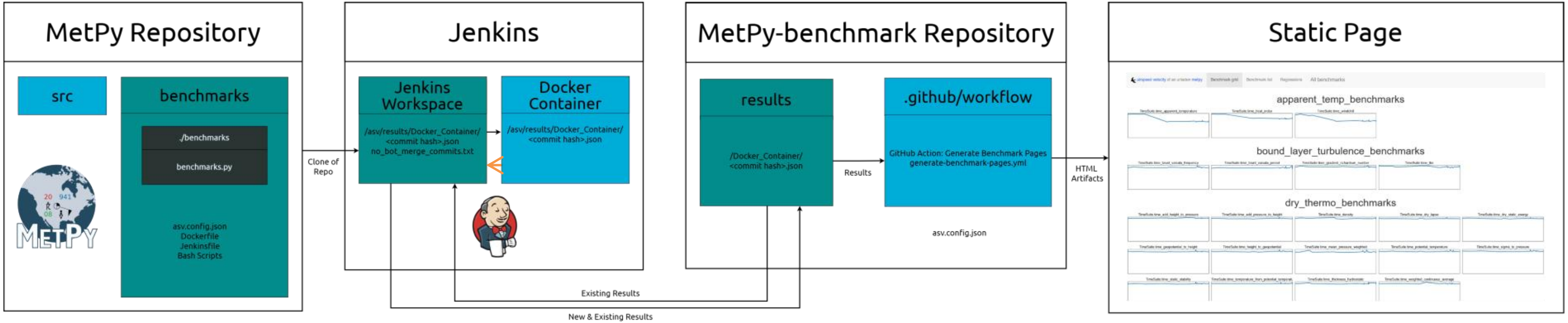
Jenkins saves results

1) The docker container terminates when it’s finished



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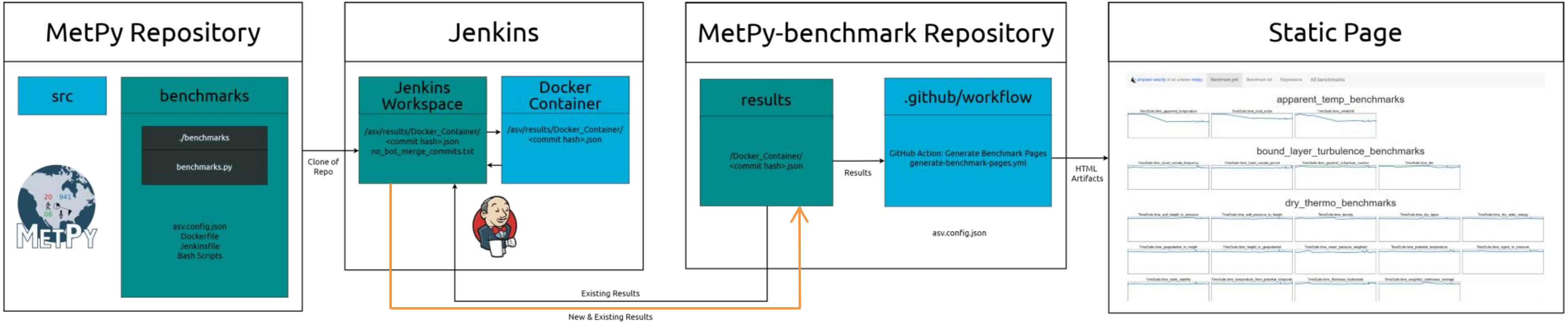
Jenkins saves results

2) Jenkins pushes the results, old and new, to the Metpy-benchmark repository



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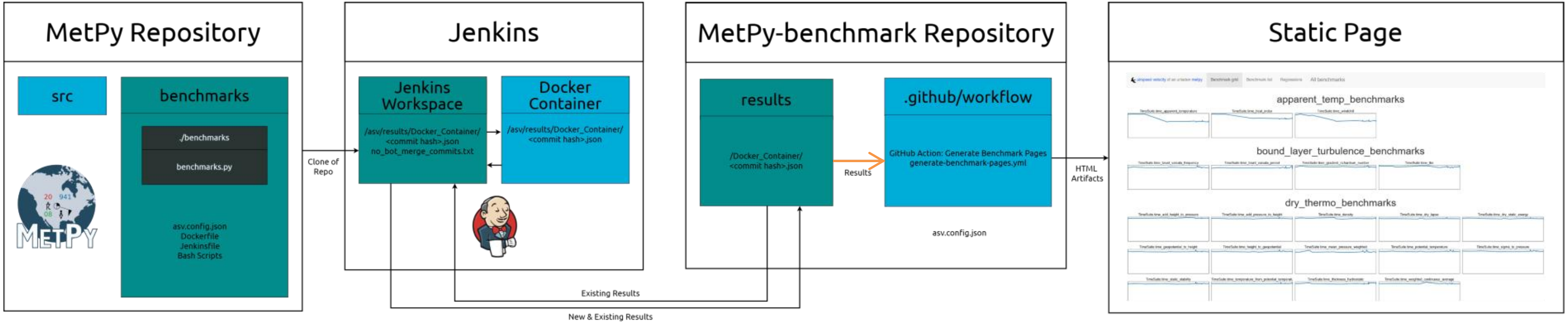
Metpy-benchmark Deployment

1) Upon push to Metpy-benchmark, a GitHub Action creates the html for the static page



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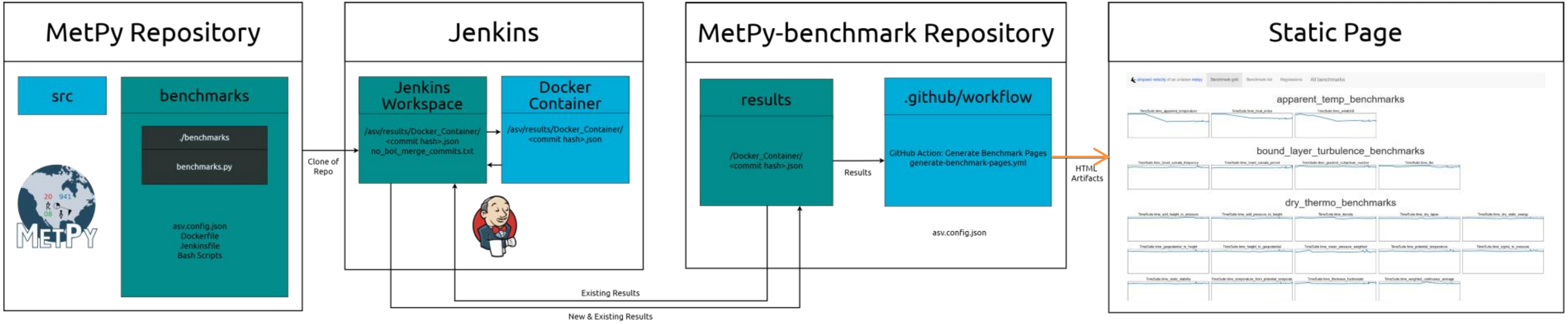
Metpy-benchmark Deployment

2) The GitHub action deploys the html to the static page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Can we see performance changes before we merge commits?

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Comparative Benchmarking

- Comparative benchmarking is when you compare the performance of two branches
- ASV has a built-in function for this, and when combined with GHA, can do it automatically on pull requests

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Comparative GitHub Action

- We can compare the current main branch to the pull request branch using their commit hashes if the PR is labelled.
- Currently a failure occurs when a benchmark is 10% slower, but this is customizable

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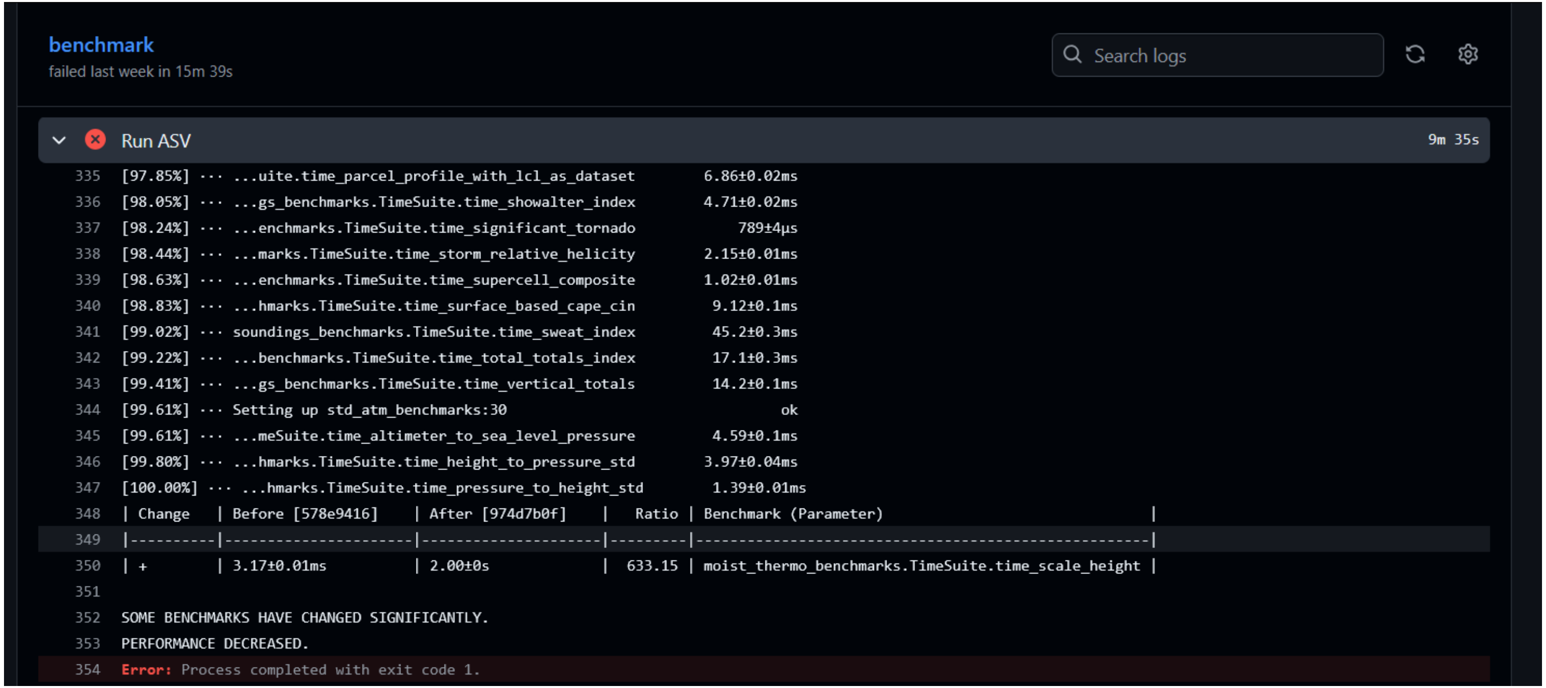
Example GitHub Action



```
[97.85%] ··· ...uite.time_parcel_profile_with_lcl_as_dataset        6.86±0.02ms
[98.05%] ··· ...gs_benchmarks.TimeSuite.time_showalter_index        4.71±0.02ms
[98.24%] ··· ...enchmarks.TimeSuite.time_significant_tornado            789±4μs
[98.44%] ··· ...marks.TimeSuite.time_storm_relative_helicity        2.15±0.01ms
[98.63%] ··· ...enchmarks.TimeSuite.time_supercell_composite        1.02±0.01ms
[98.83%] ··· ...hmarks.TimeSuite.time_surface_based_cape_cin         9.12±0.1ms
[99.02%] ··· soundings_benchmarks.TimeSuite.time_sweat_index         45.2±0.3ms
[99.22%] ··· ...benchmarks.TimeSuite.time_total_totals_index         17.1±0.3ms
[99.41%] ··· ...gs_benchmarks.TimeSuite.time_vertical_totals         14.2±0.1ms
[99.61%] ··· Setting up std_atm_benchmarks:30                                ok
[99.61%] ··· ...meSuite.time_altimeter_to_sea_level_pressure         4.59±0.1ms
[99.80%] ··· ...hmarks.TimeSuite.time_height_to_pressure_std        3.97±0.04ms
[100.00%] ··· ...hmarks.TimeSuite.time_pressure_to_height_std        1.39±0.01ms
| Change   | Before [578e9416]    | After [974d7b0f]    |   Ratio | Benchmark (Parameter)                                 |
|----------|----------------------|---------------------|---------|-------------------------------------------------------|
| +        | 3.17±0.01ms          | 2.00±0s             |  633.15 | moist_thermo_benchmarks.TimeSuite.time_scale_height |

SOME BENCHMARKS HAVE CHANGED SIGNIFICANTLY.
PERFORMANCE DECREASED.
Error: Process completed with exit code 1.
```

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Local Comparisons

- You can also locally run a comparison assuming you have an untouched local main branch and have ASV installed
- This allows you to see if your changes are working as you anticipate

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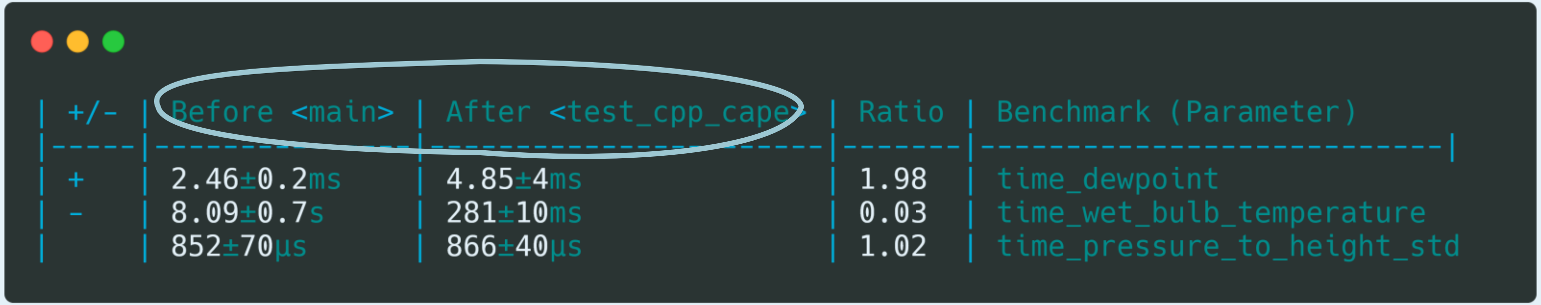
Example Local Comparison

- This compares main and test_cpp_cape



```
| +/- | Before <main> | After <test_cpp_cape> | Ratio | Benchmark (Parameter)
|-----|---------------|-----------------------|-------|---------------------------|
| +   | 2.46±0.2ms    | 4.85±4ms              | 1.98  | time_dewpoint
| -   | 8.09±0.7s     | 281±10ms              | 0.03  | time_wet_bulb_temperature
|     | 852±70µs      | 866±40µs              | 1.02  | time_pressure_to_height_std
```

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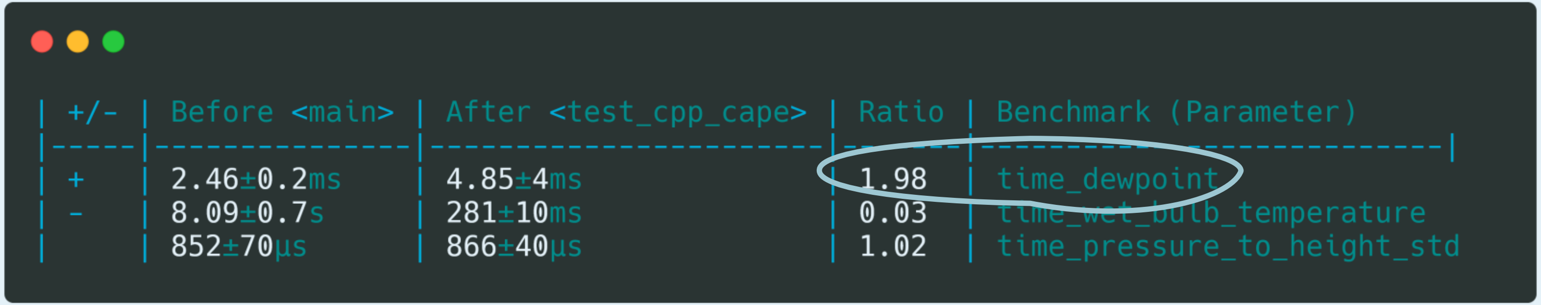
Example Local Comparison

- The dewpoint function is 98% slower



```
| +/- | Before <main> | After <test_cpp_cape> | Ratio | Benchmark (Parameter)
|-----|---------------|-----------------------|-------|-----------------------------|
|  +  | 2.46±0.2ms    | 4.85±4ms              | 1.98  | time_dewpoint
|  -  | 8.09±0.7s     | 281±10ms              | 0.03  | time_wet_bulb_temperature
|     | 852±70µs      | 866±40µs              | 1.02  | time_pressure_to_height_std
```

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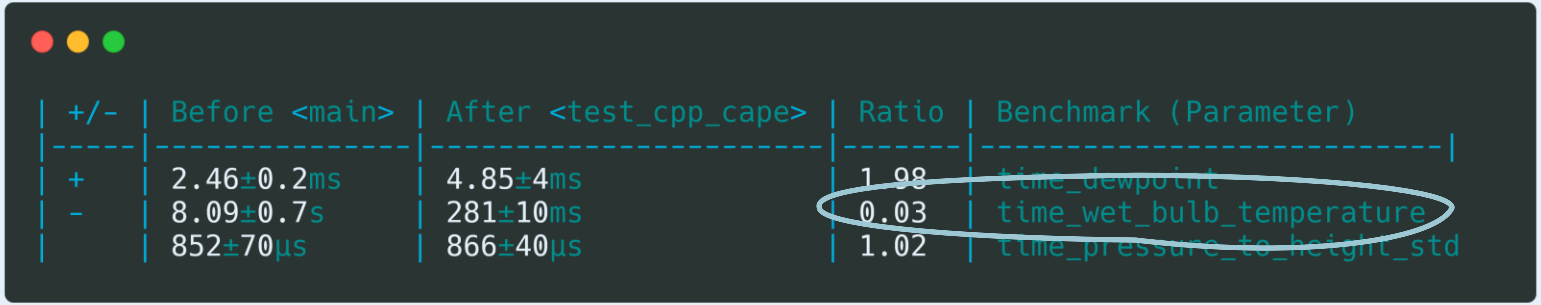
Example Local Comparison

- The wet_bulb function is 97% faster



```
| +/- | Before <main> | After <test_cpp_cape> | Ratio | Benchmark (Parameter)
|-----|---------------|-----------------------|-------|---------------------------|
| +   | 2.46±0.2ms    | 4.85±4ms              | 1.98  | time_dewpoint
| -   | 8.09±0.7s     | 281±10ms              | 0.03  | time_wet_bulb_temperature
|     | 852±70µs      | 866±40µs              | 1.02  | time_pressure_to_height_std
```

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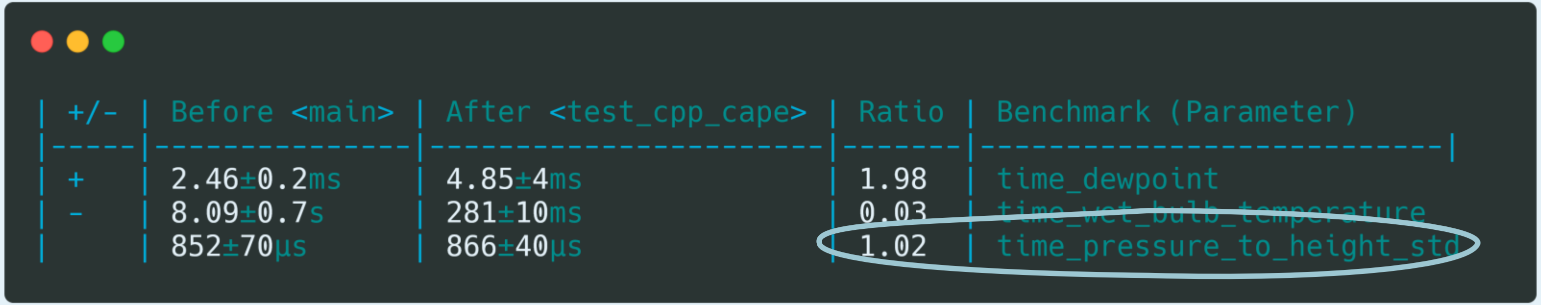
Example Local Comparison

- The p_to_h function hasn't changed much



```
| +/- | Before <main> | After <test_cpp_cape> | Ratio | Benchmark (Parameter)
|-----|---------------|-----------------------|-------|---------------------------|
|  +  | 2.46±0.2ms    | 4.85±4ms              | 1.98  | time_dewpoint
|  -  | 8.09±0.7s     | 281±10ms              | 0.03  | time_wet_bulb_temperature
|     | 852±70μs      | 866±40μs              | 1.02  | time_pressure_to_height_std
```

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