Quantifying the Scientific Skill of High-Resolution Models with *pyhanami*

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The Package: *pyhanami*

An open-source Python package for evaluating the **scientific skill** and **replicability** of Earth System Models (ESMs) through visualization tools, objective scalar-based metrics, and statistical testing.

pyhanami

Check our repo:

Easy input handling

SimulationData class

1. Load climate simulation ensembles from a **NetCDF file** or an **xarray.Dataset** object.
2. Automatically verify the integrity and consistency of the input datasets.

Intuitive syntax:

```
import pyhanami
sim_data = pyhanami.SimulationData('sim_data_path', name='sim name')
```

Model evaluation

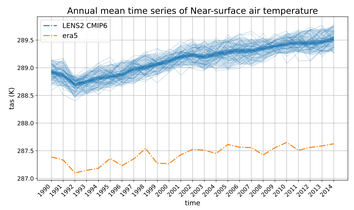
DataDiagnostics class

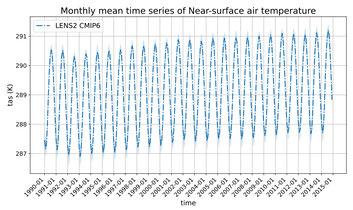
Diagnostics of **ensemble** simulations for a given variable:

1. **Time series**: multiple simulations + observations
2. **Spatial plots**: absolute difference + effect size (Cohen's d)

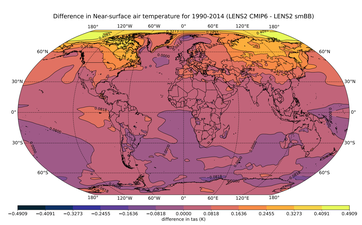
Usage examples employing CESM2 LENS2 data:

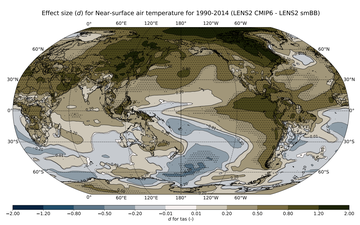
```
diags = pyhanami.DataDiagnostics(lens2_cmip6)
diags.time_series_plot('tas', start_year=1990, end_year=2014, obs=True, plot_ens=True)
diags.time_series_plot('tas', start_year=1990, end_year=2014, time_freq='monthly')
```






```
diags.add_dataset(lens2_smbb)
diags.abs_diff_plot('tas', start_year=1990, end_year=2014)
diags.eff_size_plot('tas', start_year=1990, end_year=2014, clon=180)
```





ScientificEvaluation class

Plots and **scalar scores** for evaluating scientific model skill. Examples using IFS-NEMO simulations at different resolutions:

```
sciskill = pyhanami.ScientificEvaluation([ifs_nemo_5km, ifs_nemo_10km, ifs_nemo_25km])
x_analysis = sciskill.compute_x_scores('IFS-NEMO 10km', start_year=1990, end_year=2014)
```

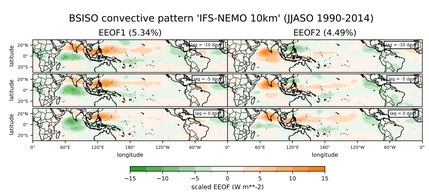
1. Tropical Intraseasonal Oscillation (ISO)

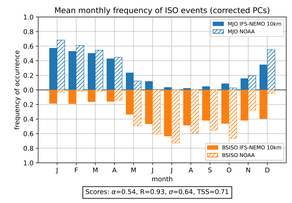
Predominant phenomenon in the tropics throughout the year:

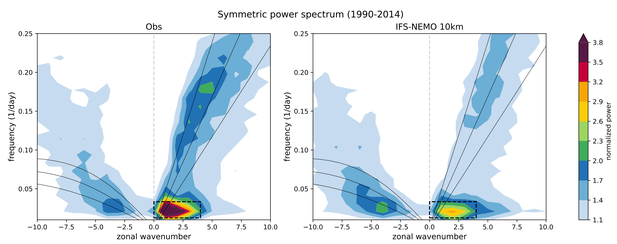
i. In boreal winter: **Madden-Julian Oscillation (MJO)**

ii. In boreal summer: **Boreal Summer ISO (BSISO)**

Evaluation: Empirical Orthogonal Function (EOF) analyses + Wavenumber-frequency power spectra







2. Tropical Cyclones (TCs)

Warm-core, rapidly rotating storm systems characterized by strong winds and heavy precipitation that begin over the tropical oceans. Evaluation:

Track TC trajectories ⇒ Compute TC metrics (duration, intensity, latitude) ⇒ Compute TC scores (bias, correlations)

Examples of usage employing several reanalyses and NICAM16-7S data (with $\sim$ 56 km horizontal resolution):

Global climatological mean bias (1990-2010)

5° x 5°	$\overline{b}_{clim,count}$ (#)	$\overline{b}_{clim,tcd}$ (days)	$\overline{b}_{clim,ace}$ (10^{-4} kn^2)	$\overline{b}_{clim,pace}$ (10^{-4} kn^2)	$\overline{b}_{clim,lmi}$ (° lat.)
IBTrACS	107.7	851.9	772.3	743.7	18.6
ERA5	-26.9	-329.0	-499.7	-347.1	5.0
JRA-55	-36.5	-377.3	-543.9	-458.8	4.9
NICAM16-7S	-32.3	-282.8	-408.1	-219.2	3.3

Negative bias — No bias — Positive bias

Extra and Future Features

- ✓ Spatial bias plots (simulations - observations)
- ✓ General scalar scores (bias, RMSE, correlation)
- ✓ Replicability test (following (K.Keller et al., 2025))
- ✓ Comprehensive documentation in ReadTheDocs
- ✍ Additional climate phenomena (e.g., precipitation)
- ✍ Intake data catalogue (standardized data interface)

Documentation:

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