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The Marine and Hydrokinetic ToolKit (MHKiT) for Data Quality Control and Analysis

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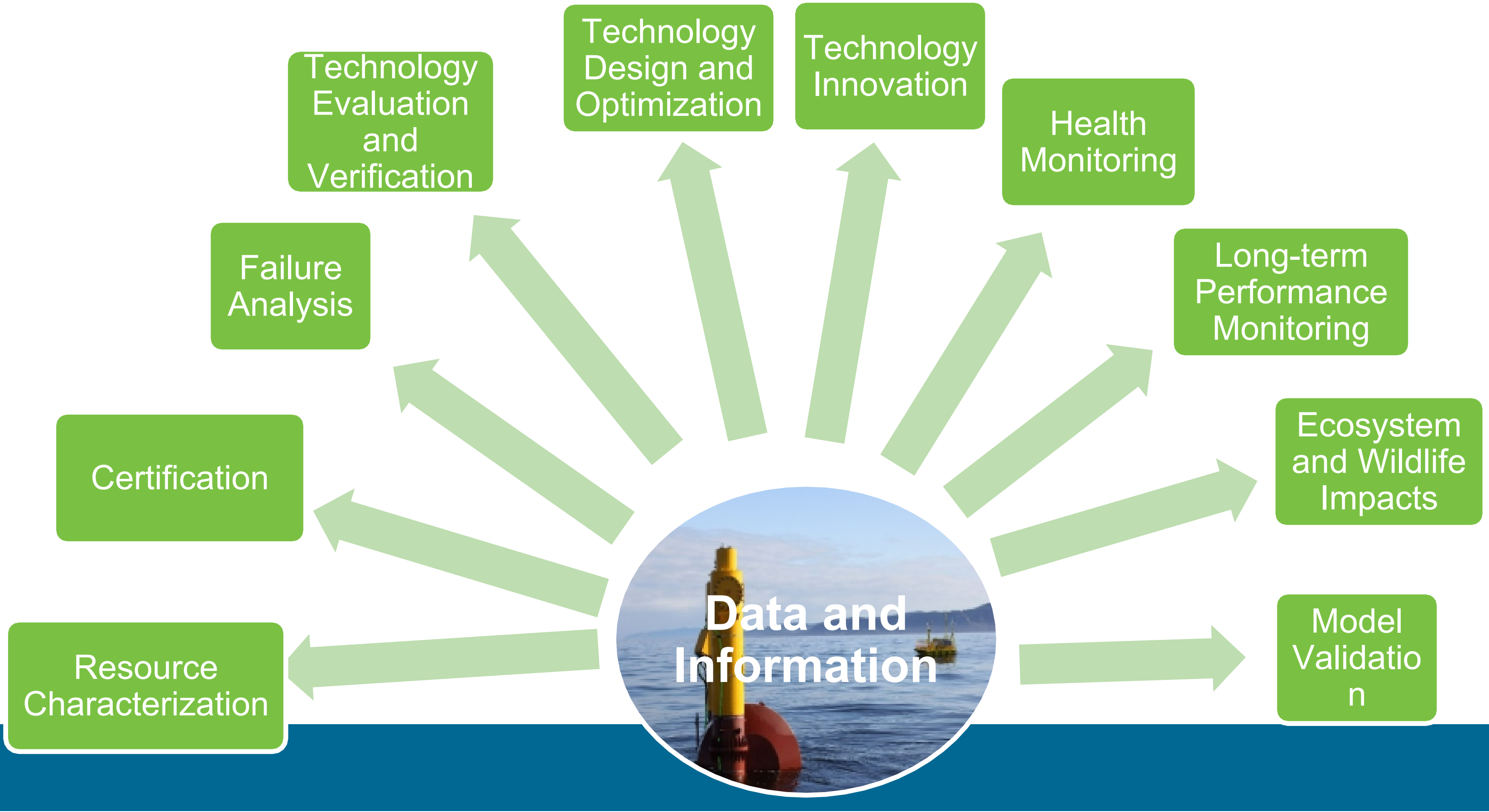
Overview

- Introduction to MHKiT
- MHKiT Documentation and Installation
- Application/ Demonstration
- Future Work
- Q&A

Importance of Data in Marine Renewable Energy

The ability to collect, ingest, condition, reduce, quality control, process, visualize, and store data in a standardized way is critical at all stages of Marine Energy (ME) research and technology/project development



MHKiT Solves Problems and Adds Value

A verified suite of ME data processing functions:

- Enables rapid data processing
- Eliminates the common code creation
- Standardized, referenceable, and readable code base
- Development platform where the can discuss issues and new features
- Creates reproducible data flow of quality control (QC), analysis, and visualization
- Assists developers in device certification for insurance, regulator bodies, and investors

What is MHKiT?

MHKiT is an open-source, standardized suite of ME data processing functions that provides the ability to ingest, condition, reduce, quality control, process, visualize and store ME data.

MHKiT is developed in both Python and Matlab

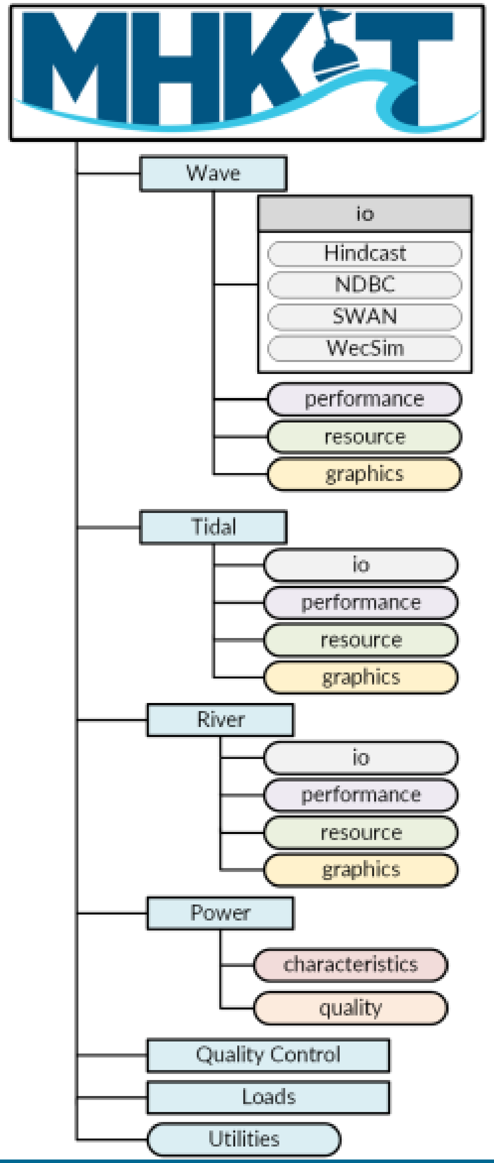
MHKiT software provides functionality for:

- Data processing (io)
- Data visualization (graphics)
- Data quality control (qc)
- Resource assessment (resource)
- Device performance (performance)
- Loads characterization (loads)
- Power quality characterization (power)

The software is developed for ME data, including measurements from field and laboratory environments, and datasets produced by numerical simulations.

v0.4.0 MHKiT Release – Jun 2021

MHKiT is hosted on GitHub for easy access and collaboration



Example Case: PACWAVE South

- Dunkel et. al performed a resource assessment of the PACWAVE site (North and South)
- Parts of the Dunkel et. al study were recreated using
  - MHKiT
  - NDBC buoy 46050
  - omni-directional wave data
- This results are available and can be run as an example notebook available on
- The following discussion will focus on how to apply MHKiT to perform parts of the Dunkel et. Al study using MHKiT.

NDBC 46050 shown in blue with PACWAVE north as a green four-square grid and PACWAVE south as a red nine-square grid

Dunkel et. al

- Dunkel et. al figures recreated in MHKiT example:
  - Annual histogram of sea state occurrences
  - H_{m0}, Te, J, Tp, Tz, descriptive statistics by month
  - 50 and 100 year contour
  - Wave Energy

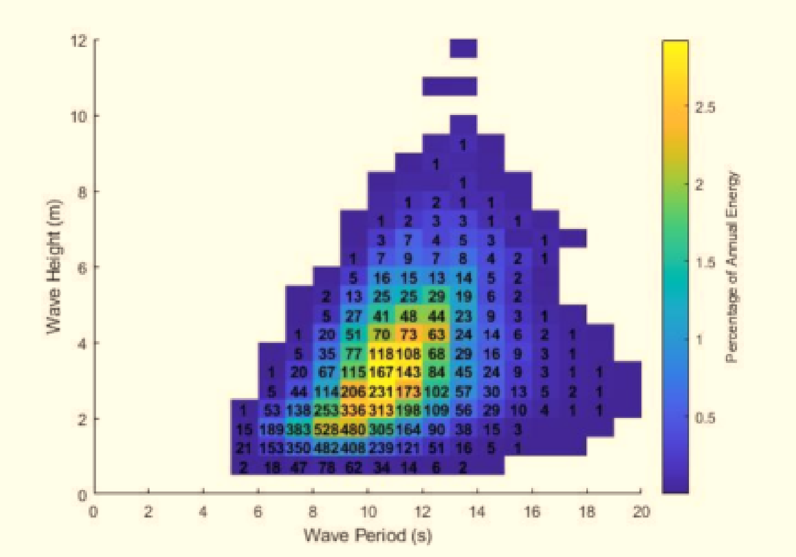


Figure 2: Omni-directional SWAN sea-state histogram from 1980-2010 at PacWave South (annual mean conditions,

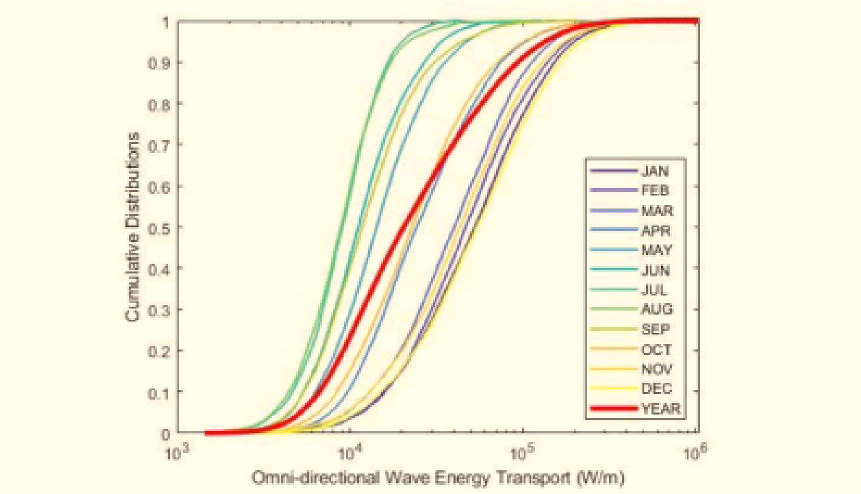
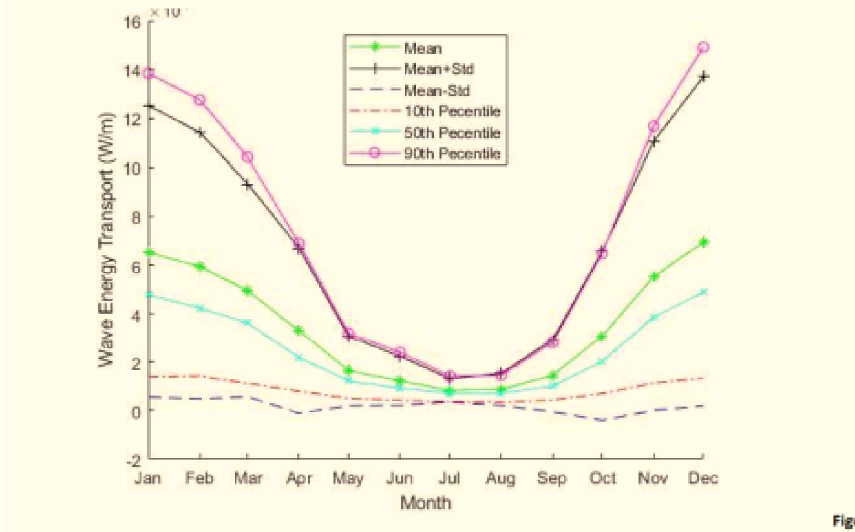


Figure 16: Monthly cumulative distributions of SWAN omni-directional wave energy transport from 1980-2010 at PacWave South. The x-axis is plotted on a logarithmic scale in order to better exhibit the cumulative distribution.



: 8: Monthly mean of maximum directionally resolved SWAN wave energy transport from 1980-2010 at PacWave South

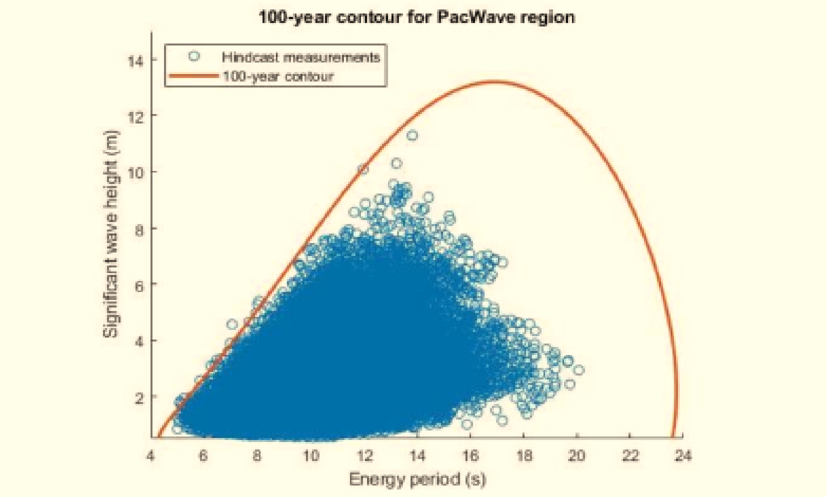


Figure 30: 100-year environmental contour for the PacWave region compared to hindcast measurements recorded for PacWave South from 1980-2010

MHKiT: Request NDBC Buoy Data 46050

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REQUEST DATA

```
from mhkit.wave.io import ndbc

ndbc_available_data = ndbc.available_data('swden', 46050’ )

filenames = ndbc_available_data['filename’]
ndbc_requested_data = ndbc.request_data('swden',  filenames)
```

	#YY	MM	DD	hh	mm	.0200	.0325	.0375	.0425	.0475	...	.3300	.3400
0	2020	1	1	0	40	0.0	0.0	0.00	2.28	2.99	...	0.19	0.22
1	2020	1	1	1	40	0.0	0.0	0.37	3.30	3.12	...	0.20	0.15
2	2020	1	1	2	40	0.0	0.0	0.00	4.80	5.16	...	0.07	0.18
3	2020	1	1	3	40	0.0	0.0	0.00	1.70	1.38	...	0.30	0.14
4	2020	1	1	4	40	0.0	0.0	0.24	5.72	7.90	...	0.12	0.18

CLEAN DATA

- Create DateTime Index

```
for year in ndbc_requested_data:
    year_data = ndbc_requested_data[year]
    ndbc_data[year] = ndbc.to_datetime_index(parameter, year_data)
```

date	0.0200	0.0325	0.0375	0.0425	0.0475	0.0525	0.0575	0.0625	0.0675	0.0725	...	0.3300	0.3400
2020-01-01 00:40:00	0.0	0.0	0.00	2.28	2.99	0.00	0.00	2.91	7.23	10.65	...	0.19	0.22
2020-01-01 01:40:00	0.0	0.0	0.37	3.30	3.12	0.94	1.49	3.13	8.58	12.09	...	0.20	0.15
2020-01-01 02:40:00	0.0	0.0	0.00	4.80	5.16	0.66	1.44	4.19	14.32	26.21	...	0.07	0.18
2020-01-01 03:40:00	0.0	0.0	0.00	1.70	1.38	0.00	0.47	2.91	15.89	32.12	...	0.30	0.14
2020-01-01 04:40:00	0.0	0.0	0.24	5.72	7.90	2.75	0.59	4.39	17.49	18.75	...	0.12	0.18

Calculate Quantities of Interest

Calculate Quantities of Interest

```
from mhkit.wave import resource

Hm0= resource.significant_wave_height(year_data.T)
Te = resource.energy_period(year_data.T)
J  = resource.energy_flux(year_data.T, h=399.)
Tp = resource.peak_period(year_data.T)
Tz = resource.average_zero_crossing_period(year_data.T)
```

Plot

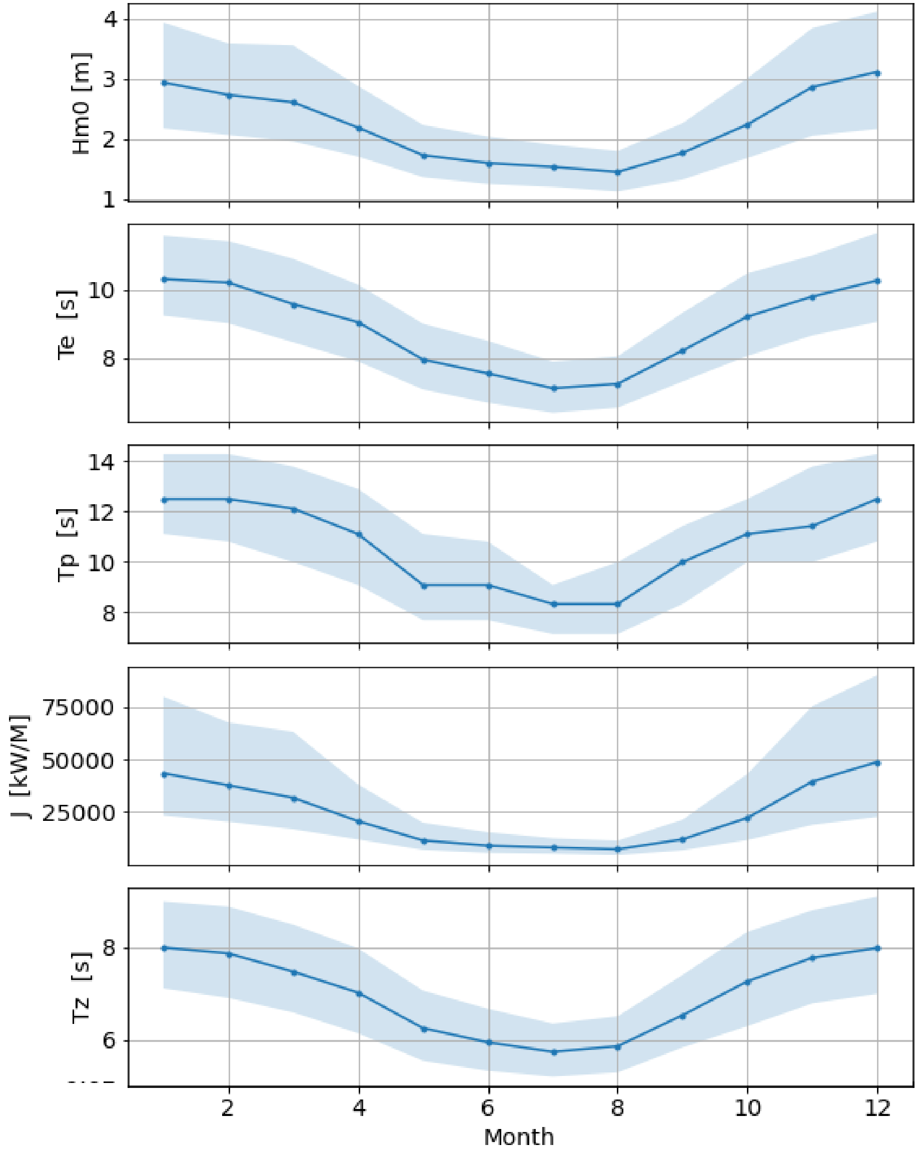
```
import matplotlib.pyplot as plt
import pandas as pd

ndbc_data = pd.concat([Hm0, Te, J, Tp, Tz],axis=1)

months=ndbc_data.index.month
data_group=ndbc_data.groupby(months)

QoIs = ndbc_data.keys()
for i in range(len(QoIs)):
    QoI = QoIs[i]
    axs[i].plot(data_group.median()[QoI], marker='.')

    axs[i].fill_between(months.unique(),
                        data_group.describe()[QoI,
                        '25%'],
                        data_group.describe()[QoI,
                        '75%'],
                        alpha=0.2)
```



Annual Histogram of Sea State Occurrence

NREL Sandia National Laboratories Pacific Northwest National Laboratory

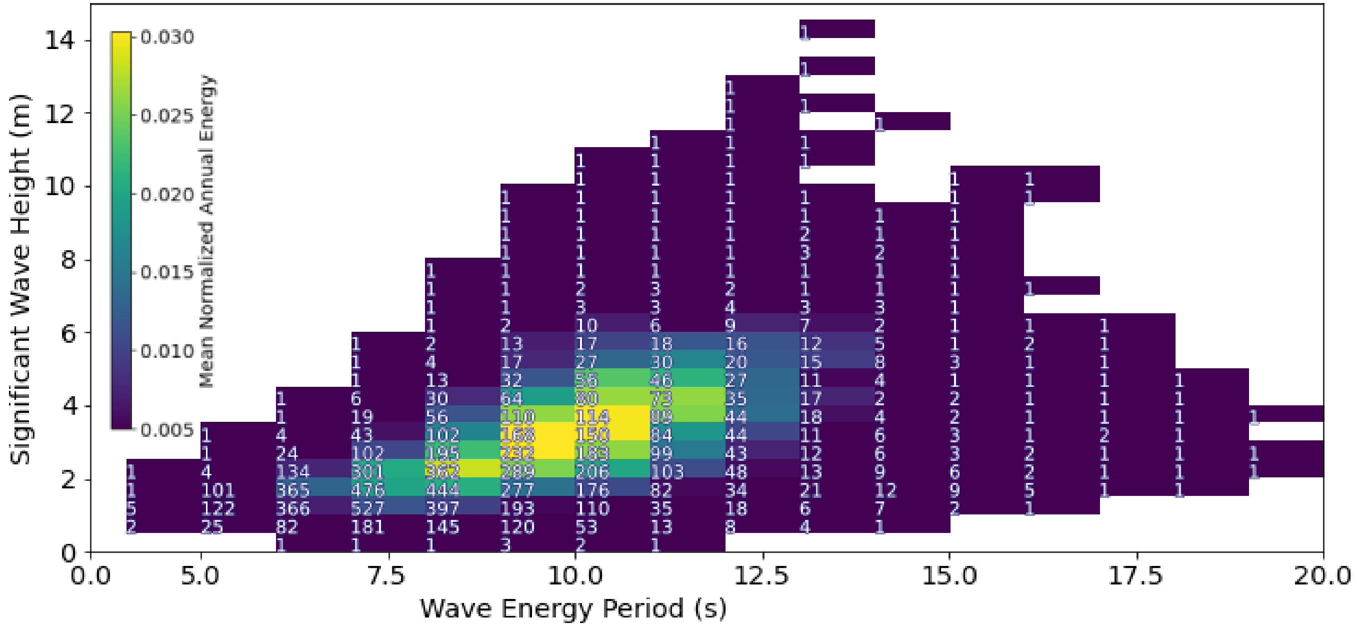
Plot Energy Flux Mean Annual Histogram

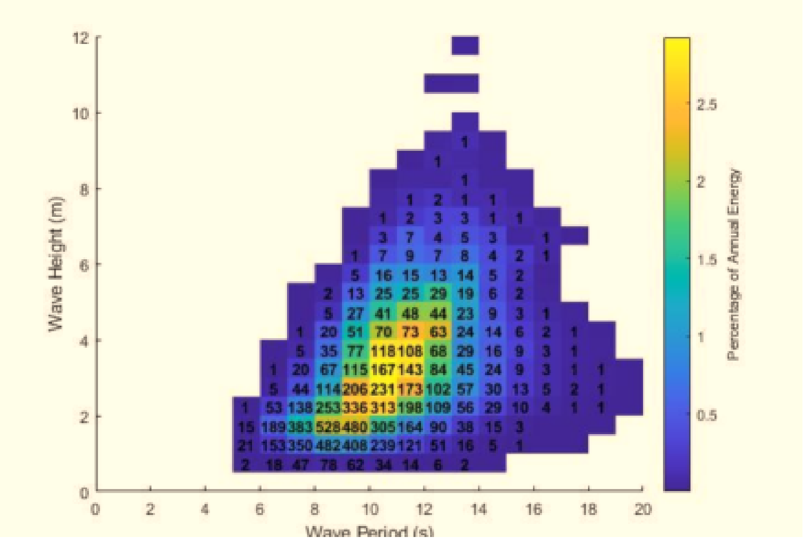
```
from mhkit.wave import graphics

Hm0_bin_size = 0.5
Hm0_edges = np.arange(0,15+Hm0_bin_size,Hm0_bin_size)

Te_bin_size = 1
Te_edges = np.arange(0, 20+Te_bin_size,Te_bin_size)

graphics.plot_avg_annual_energy_matrix(Hm0, Te, J,
Hm0_edges=Hm0_edges, Te_edges=Te_edges)
```





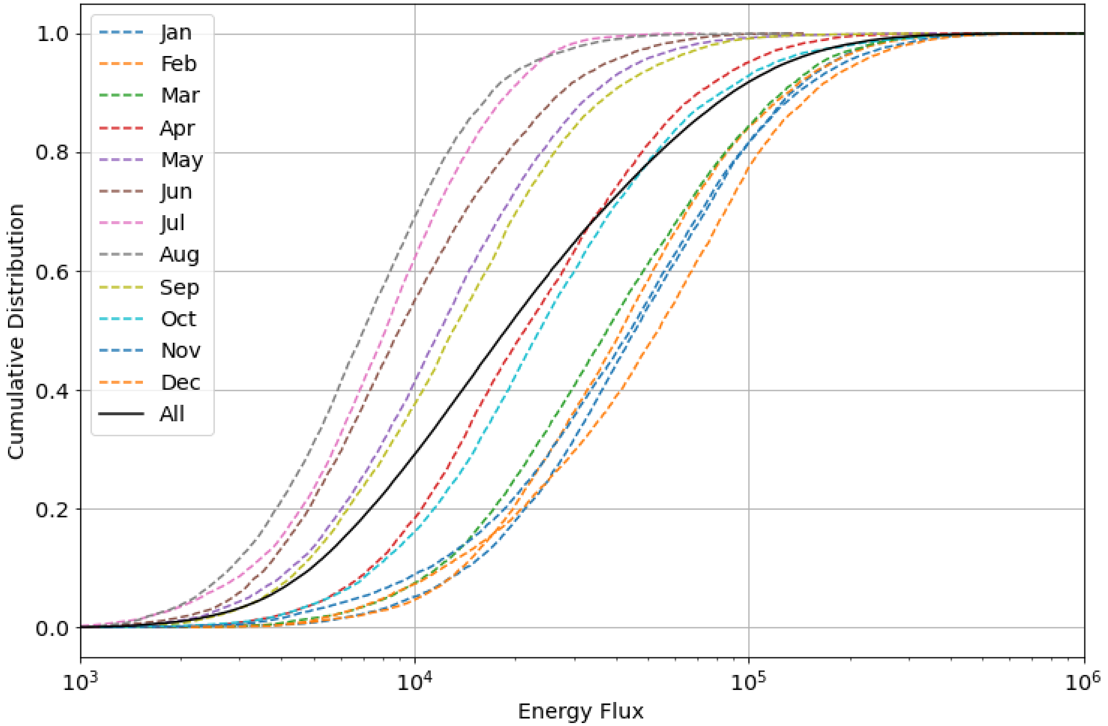
Dunkel et. al 2020

NDBC 46050 energy flux (J) mean annual histogram for years 1996 to 2019 for each month. Bins are numbered by number of hours each year a sea state occurs

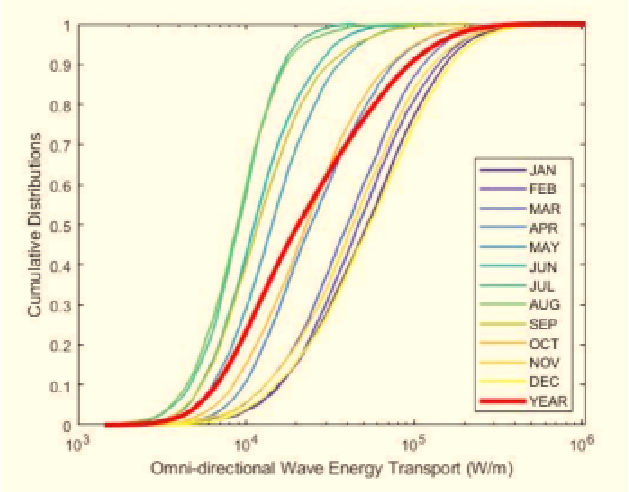
Example Case: PACWAVE South

Plot Energy Flux Cumulative Distribution.

```
graphics.monthly_cumulative_distribution(noaa_data.J)
```



NDBC 46050 energy flux (J) cumulative distribution for years 1996 to 2020 for each month. All months are shown as a solid black line.



Dunkel et. al 2020

- IEC TS 62600-101
- The summer months
  - have a lower maximum energy flux f
  - found left of the black data line representing the cumulative distribution of all collected data.
- April and October most closely follow the overall energy flux distribution
- winter months show less variation than the summer months in their distribution.

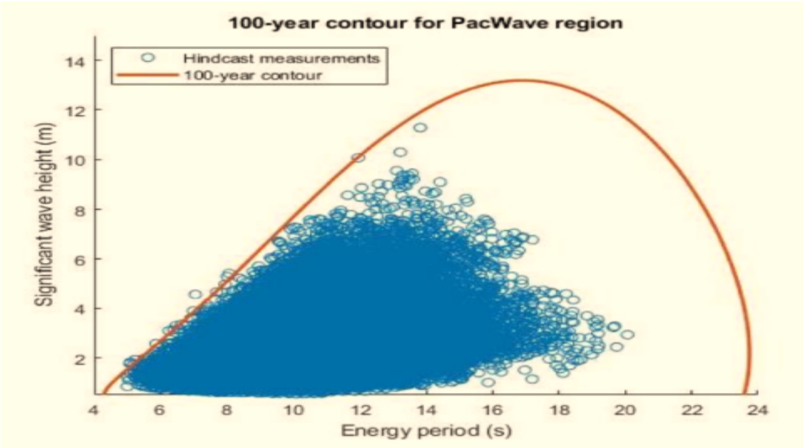
Example Case: PACWAVE South

Plot Energy Flux Mean Annual Histogram

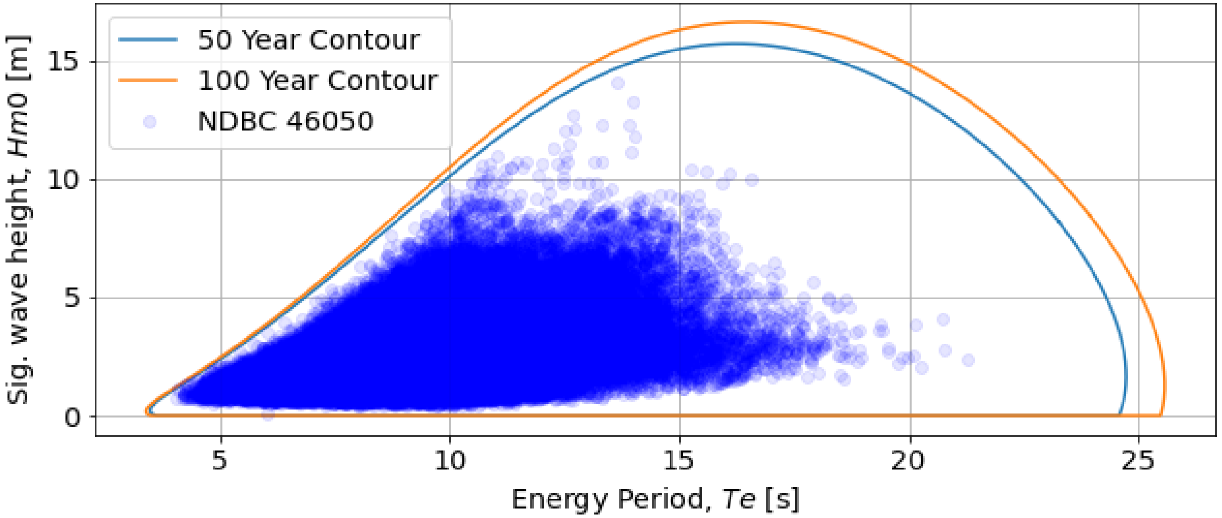
```
period = 50
Hm0_50, Te_50 = resource.environmental_contour(Hm0, Te,
                                               dt, period,
                                               PCA=PCA)

period = 100
Hm0_100, Te_100, PCA = resource.environmental_contour(Hm0, Te,
                                                      dt, period,
                                                      return_PCA=True)

graphics.plot_environmental_contour(Te, Hm0,
                                    [Te_contour_50, Te_contour_100],
                                    [Hm0_contour_50,Hm0_contour_100] )
```



100-year contour from Dunkel et. al



MHKiT Contours of 50-year and 100-year extreme sea-state contours for NDBC 46050 for 24 years of hourly spectral data from 1996 to 2020.

Future Plans

Module	Description
I/O	• Swan data ingestion • Water Power Technologies Office hindcast data ingestion • ADCP and acoustic Doppler profiler data ingestion ported from DOLfYN • Standardized data formats for upload to the Marine and Hydrokinetic Data Repository (MHKDR) • Data ingestion from the standardized MHKDR data formats
Mooring	• Assessing mooring design and loads • Functions for ingesting and processing data from mooring models as well as assessing strains on mooring lines
Met-Ocean	• Focus on identifying existing packages that could be leveraged by the ME community • Quantities of interest will include wind, water temperature, and water salinity
Uncertainty	• Calculating the uncertainty in measurements and derived quantities following the IEC technical specifications where applicable • Uncertainty in sensor calibrations, instruments, and data acquisition systems
Noise	• Filtering noise out of signals • Functionality for excluding data following the requirements prescribed in each technical specification will be developed and included within each relevant module

Module	Description
OTEC	• Resource characterization • Graphics

Acoustic	• The acoustic characterization module will include:
	  o I/O functions for ingesting acoustic measurement data
	  o Sound pressure calculations
	  o Geo-referencing
	• Statistics
	• Graphics

Environmental Impacts	• New module with functionality for assessing the environmental impacts around deploying Marine Energy Converters

Powering the Blue Economy	• New functionality specifically geared toward Powering the Blue Economy applications. Current planned area of focus will be:
	  o Water desalination
	  o Aquaculture
	  o Battery charging
	  o Distributed/integrated applications

General/ Misc.	• Flicker characterization • Data transformation • QC graphics • Additional tidal and wave graphics

Thank you!

Contact us:

– Sterling Olson (ssolson@sandia.gov)
– Rebecca Fao (Rebecca.fao@nrel.gov)

MHKiT Resources:

- Documentation: https://mhkit-software.github.io/MHKiT/index.html
- Provide Input/Feedback:
  https://github.com/MHKiT-Software/MHKiT-Python/issues

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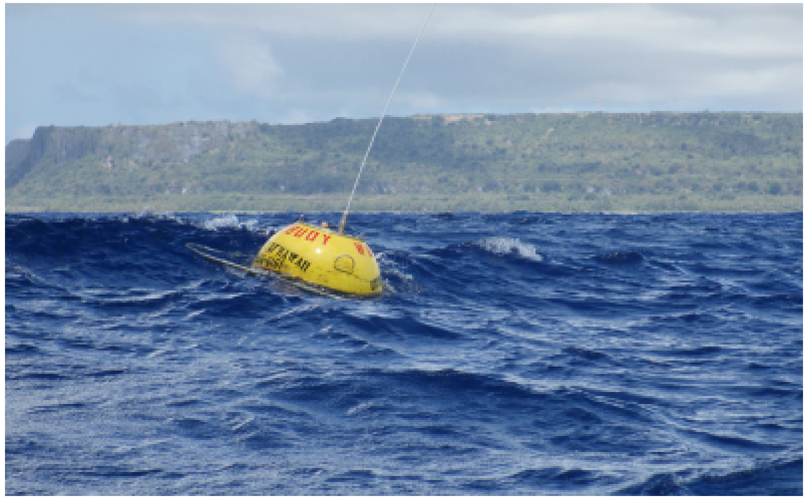
Wave Resource Module

- Spectrum: Elevation, Pierson Moskowitz, Bretschneider, Jonswap
- Significant Wave Height
- Energy Period
- Surface Elevation
- Frequency Moments
- Periods: zero crossing, average crest, average wave, peak, energy,
- Spectral Bandwidth
- Spectral Width
- Energy Flux
- Wave Celerity
- Wave Number



PacIOOS Wave Buoy 196: Ritidian Point, Guam

Wave Performance

- Capture Length
- Matrices: Capture Length and Power
- Mean Annual Energy Production