SMB Wave Prediction Model

A collection of Python scripts for predicting wind-generated wave characteristics using the Sverdrup-Munk-Bretschneider (SMB) method. These tools calculate significant wave height (Hs), significant wave period (Ts), and the minimum required storm duration based on meteorological inputs.

Overview

This repository provides a practical implementation of the foundational SMB wave prediction model, a cornerstone of coastal and ocean engineering for decades. It is designed for engineers, scientists, and students who need to make preliminary estimates of wave conditions for design, planning, or research purposes.

The core model operates in two distinct modes, selectable by the user:

1. **Deep Water Mode:** For open-ocean or large lake scenarios where the water depth is sufficient to not influence wave generation.
2. **Depth-Limited Mode:** For coastal, nearshore, or shallow-water environments where the seabed interacts with and limits wave growth.

Methodology

The scripts are based on the semi-empirical Sverdrup-Munk-Bretschneider (SMB) method, which relates dimensionless wave parameters to wind conditions.

Deep Water Formulas

For deep water, the script uses the revised Bretschneider (1970) equations:

Dimensionless Fetch:

- $\hat{F} = \frac{gF}{U^2}$

Significant Wave Height (H_s):

- $\frac{gH_s}{U^2} = 0.283 \tanh\left[0.0125 (\hat{F})^{0.42}\right]$

Significant Wave Period (T_s):

- $\frac{gT_s}{U} = 7.54 \tanh\left[0.077 (\hat{F})^{0.25}\right]$

Minimum Duration (t_{min}):

- $t_{min} = \frac{U}{g} \cdot 6.5882 \cdot \exp\left(0.0161 \cdot (\ln \hat{F})^2 - 0.3692 \cdot \ln \hat{F} + 2.2024 + 0.8798 \cdot \ln \hat{F}\right)$

Depth-Limited Formulas

For shallower water, the script uses formulas from the Shore Protection Manual that incorporate a dimensionless depth parameter ($\hat{d} = gd/U^2$):

Significant Wave Height (H_s):

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$$H_s = \frac{U^2}{g} \cdot 0.283 \cdot \tanh\left(0.530 \hat{d}^{0.75}\right) \cdot \tanh\left[\frac{0.00565 \hat{F}^{0.5}}{\tanh\left(0.530 \hat{d}^{0.75}\right)}\right]$$

- **Significant Wave Period (** T_s **):**

$$T_s = \frac{U}{g} \cdot 7.54 \cdot \tanh\left(0.833 \hat{d}^{0.375}\right) \cdot \tanh\left[\frac{0.0379 \hat{F}^{0.333}}{\tanh\left(0.833 \hat{d}^{0.375}\right)}\right]$$

- **Minimum Duration (** t_{min} **):**

$$t_{min} = \frac{U}{g} \cdot 6.5882 \cdot \exp\left(0.0161 \cdot (\ln \hat{F})^2 - 0.3692 \cdot \ln \hat{F} + 2.2024 + 0.8798 \cdot \ln \hat{F}\right)$$

Features

- **Dual-Mode Calculation:** Accurately applies formulas for both deep and depth-limited water conditions.
- **Comprehensive Outputs:** Calculates Significant Wave Height (Hs), Significant Wave Period (Ts), and Minimum Storm Duration (t_min).
- **Interactive Interface:** A simple command-line interface guides the user through the input process.
- **Validated Formulas:** The implemented equations are based on authoritative sources, including the U.S. Army's Coastal Engineering Manual and Shore Protection Manual.
- **Data Visualization:** Generates contour charts for both deep and depth-limited conditions.
- **Nomogram Generation:** Creates printable nomograms for quick graphical estimations.
- **Tabular Output:** Generates a PDF table summarizing wave calculations for various parameters.

Scripts Description

This repository contains the following Python scripts:

`calculator.py`

This is the main interactive script for performing individual SMB wave calculations.

- **Functionality:**
  - Prompts the user for wind speed and fetch length.
  - Allows the user to choose between "Deep Water" and "Depth-Limited" calculation modes.
  - If "Depth-Limited" is selected, it prompts for water depth.
  - Calculates and displays Significant Wave Height (Hs), Significant Wave Period (Ts), and Minimum Storm Duration (t_min) based on the chosen mode and inputs.
- **Usage:** Run directly from the command line and follow the prompts.

  ```
  python calculator.py
  ```

`chart.py`

Generates a combined contour chart for SMB wave parameters in **deep water** conditions.

- **Functionality:**
  - Uses `matplotlib` to create a single plot showing contours of Hs, Ts, and t_min.

- Displays wave parameters as functions of wind speed and fetch length for deep water.
    - Utilizes different black line styles (solid for Hs, dashed for Ts, dotted for t_min) for clarity.
    - The chart is generated in A3 landscape format for better readability.
- **Usage:** Run directly to generate and display the chart.

```
python chart.py
```

`chart_10m.py`

Generates a combined contour chart for SMB wave parameters in **depth-limited water** conditions, specifically for a fixed water depth of 10 meters.

- **Functionality:**
    - Similar to `chart.py`, but tailored for depth-limited scenarios.
    - Calculates and plots contours of Hs, Ts, and t_min for a constant water depth (defaulting to 10m).
    - Provides a visual representation of how wave parameters change with wind speed and fetch in shallow water.
    - The chart is generated in A3 landscape format.
- **Usage:** Run directly to generate and display the chart. The `FIXED_DEPTH` variable can be modified within the script.

```
python chart_10m.py
```

`smb-nomogram-deep.py`

Generates a multi-page PDF containing three nomograms for **deep water** wave prediction.

- **Functionality:**
    - Creates separate nomograms for Significant Wave Height (Hs), Significant Wave Period (Ts), and Minimum required wind duration (t_min).
    - Outputs a single PDF file named `smb-nomogram-deep.pdf`.
    - Requires `pynomo` and `nomogen` libraries for nomogram generation.
- **Usage:** Run directly to generate the PDF.

```
python smb-nomogram-deep.py
```

`smb-nomogram-shallow.py`

Generates a multi-page PDF containing three nomograms for **depth-limited (shallow water)** wave prediction, configured for a fixed water depth of 10 meters.

- **Functionality:**
    - Similar to `smb-nomogram-deep.py`, but specifically for shallow water conditions.
    - Generates nomograms for Hs, Ts, and t_min at a constant water depth (defaulting to 10m).

- Outputs a single PDF file named `smb-nomogram-shallow.pdf`.
- Requires `pynomo` and `nomogen` libraries.

- **Usage:** Run directly to generate the PDF. The `WATER_DEPTH` variable can be modified within the script.

```
python smb-nomogram-shallow.py
```

`tables.py`

Generates a comprehensive PDF table summarizing SMB wave calculations for various combinations of wind speed, fetch, and depth.

- **Functionality:**
  - Calculates Hs, Ts, and t_min for predefined ranges of wind speeds (5-35 m/s), fetches (0-50 km), and depths (Deep Water, 100m, 50m, 25m, 10m, 5m, 1m).
  - Organizes the results into a well-formatted table within a PDF document.
  - Uses `reportlab` for PDF generation, ensuring a professional and readable output.
- **Usage:** Run directly to generate the PDF file `comprehensive_wave_calculations.pdf`.

```
python tables.py
```

How to Use

1. **Prerequisites:** Ensure you have Python 3 installed. You will also need to install the following libraries:
   - `numpy`
   - `scipy` (for `smb-nomogram-deep.py` and `smb-nomogram-shallow.py`, specifically for `scipy.arange` compatibility fix)
   - `matplotlib` (for `chart.py` and `chart_10m.py`)
   - `reportlab` (for `tables.py`)
   - `pynomo` (for `smb-nomogram-deep.py` and `smb-nomogram-shallow.py`)
   - `PyPDF2` (for `smb-nomogram-deep.py` and `smb-nomogram-shallow.py` to merge PDFs)
   - `PyX` (for `smb-nomogram-deep.py` and `smb-nomogram-shallow.py` for LaTeX rendering)

   You can install most of them using pip:

   ```
   pip install numpy matplotlib reportlab PyPDF2 PyX
   ```pynomo` might require manual installation or specific setup; refer to its
   documentation if `pip install pynomo` fails. `nomogen.py` is expected to be in a
   discoverable path (e.g., parent directory or same directory).
   ```

2. **Running Scripts:**
   - For interactive calculations, run `python calculator.py`.
   ```

- For deep water charts, run `python chart.py`.
- For 10m depth-limited charts, run `python chart_10m.py`.
- For deep water nomograms, run `python smb-nomogram-deep.py`.
- For shallow water nomograms, run `python smb-nomogram-shallow.py`.
- For the comprehensive table, run `python tables.py`.

Assumptions and Limitations

- **Steady-State Wind:** The model assumes that the wind speed and direction are uniform and constant across the entire fetch for the specified duration. This is an idealization not always met in nature.
- **Input Data Quality:** The accuracy of the results is highly dependent on the quality of the inputs. For best results:
  - **Wind Speed:** Should be the standard 10-meter overwater wind speed, adjusted for atmospheric stability if possible.
  - **Fetch Length:** Should be the "effective fetch," which accounts for the geometry of the water body, not just a straight-line distance.
- **Fetch-Limited Focus:** The scripts primarily calculate wave parameters assuming the condition is fetch-limited and provide the minimum duration for this to be valid. They do not explicitly handle duration-limited scenarios by calculating an equivalent fetch.

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