The Journal of Open Source Software

NLLJ Calculator: Automated Detection and Quantification of Nocturnal Low-Level Jets in South America

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DOI: 10.xxxxxx/draft

Software

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Editor:

Submitted: 11 October 2025
Published: unpublished

Summary

Nocturnal Low-Level Jets (NLLJs) are crucial atmospheric phenomena that transport moisture and influence precipitation patterns across South America. The NLLJ Calculator is a Python package that automates the detection, quantification, and visualization of NLLJs using ERA5 reanalysis data. The tool implements the methodology developed by Braz et al. (2021) and provides researchers with an efficient, reproducible workflow for NLLJ climatological studies.

Statement of Need

Low-level jets play a fundamental role in South American hydrometeorology, particularly in moisture transport from the Amazon Basin to the La Plata Basin (Marengo et al., 2004; Vera et al., 2006). Traditional identification of optimal atmospheric pressure levels for NLLJ detection requires extensive manual testing and subjective decision-making. This process is time-consuming, lacks reproducibility, and presents a barrier to researchers new to the field.

The NLLJ Calculator addresses these challenges by providing: (1) automated testing and optimization of pressure level combinations based on multiple statistical metrics, (2) a modular Python package that separates computation from visualization, allowing flexible integration into existing workflows, and (3) comprehensive documentation including data acquisition scripts and examples. This tool makes NLLJ analysis more accessible, reproducible, and efficient for the atmospheric science community.

Functionality

The NLLJ Calculator provides three main capabilities organized as a modular Python package:

Core Computation Module

The `calculator.py` module implements the NLLJ detection algorithm using NumPy arrays for computational efficiency. Key features include:

- **Automatic pressure level optimization**: Tests all viable combinations of lower (850-1000 hPa) and upper (500-700 hPa) atmospheric levels, evaluating each combination using multiple statistical metrics (mean intensity, maximum intensity, spatial coverage, and variability).

- **NLLJ index calculation**: Computes the index using wind shear differences between nighttime (00 LT from 00+06 UTC average) and daytime (12 LT from 12+18 UTC average) conditions, incorporating binary criteria for nocturnal acceleration and vertical wind maximum.
- **Seasonal climatology generation**: Processes monthly ERA5 data and aggregates results into austral seasons (DJF, MAM, JJA, SON).
- **Statistical analysis tools**: Calculates comprehensive statistics including frequency of NLLJ occurrence, percentiles, standard deviations, and identification of core jet regions based on intensity thresholds.
- **Anomaly detection**: Supports calculation of anomalies relative to reference climatologies and regional mean extraction for focused studies.

Visualization Module

The `plotting.py` module generates publication-ready figures:

- Four-panel seasonal climatology maps with customizable colormaps
- Analysis plots showing optimization results across pressure level combinations
- Support for custom shapefiles (e.g., political boundaries)

Data Acquisition

The package includes `download_era5.py`, a utility script that interfaces with the Copernicus Climate Data Store API to download properly configured ERA5 data for NLLJ analysis, eliminating common data preparation errors.

Mathematical Formulation

The NLLJ index follows the methodology of Braz et al. (2021), originally adapted from Rife et al. (2010). The index quantifies the intensity of nocturnal low-level jets through wind shear analysis:

$$\text{NLLJ} = \lambda \cdot \phi \cdot \sqrt{X^2 + Y^2}$$

The wind shear difference components are:

$$X = (u_{00}^L - u_{00}^U) - (u_{12}^L - u_{12}^U)$$

$$Y = (v_{00}^L - v_{00}^U) - (v_{12}^L - v_{12}^U)$$

Binary conditions ensure the presence of both nocturnal acceleration and a vertical wind maximum:

$$\lambda = \begin{cases} 1 & \text{if } W_{00}^L > W_{12}^L \\ 0 & \text{otherwise} \end{cases}$$

$$\phi = \begin{cases} 1 & \text{if } W_{00}^L > W_{00}^U \\ 0 & \text{otherwise} \end{cases}$$

Here u and v represent zonal and meridional wind components, W denotes wind speed magnitude, superscripts L and U indicate lower and upper pressure levels, and subscripts 00 and 12 refer to local times (midnight and noon).

The algorithm processes wind data at four UTC times (00, 06, 12, 18) to construct local time averages appropriate for South American longitudes, then applies the binary criteria at each grid point to identify regions where nocturnal jets are active (Fig 1).

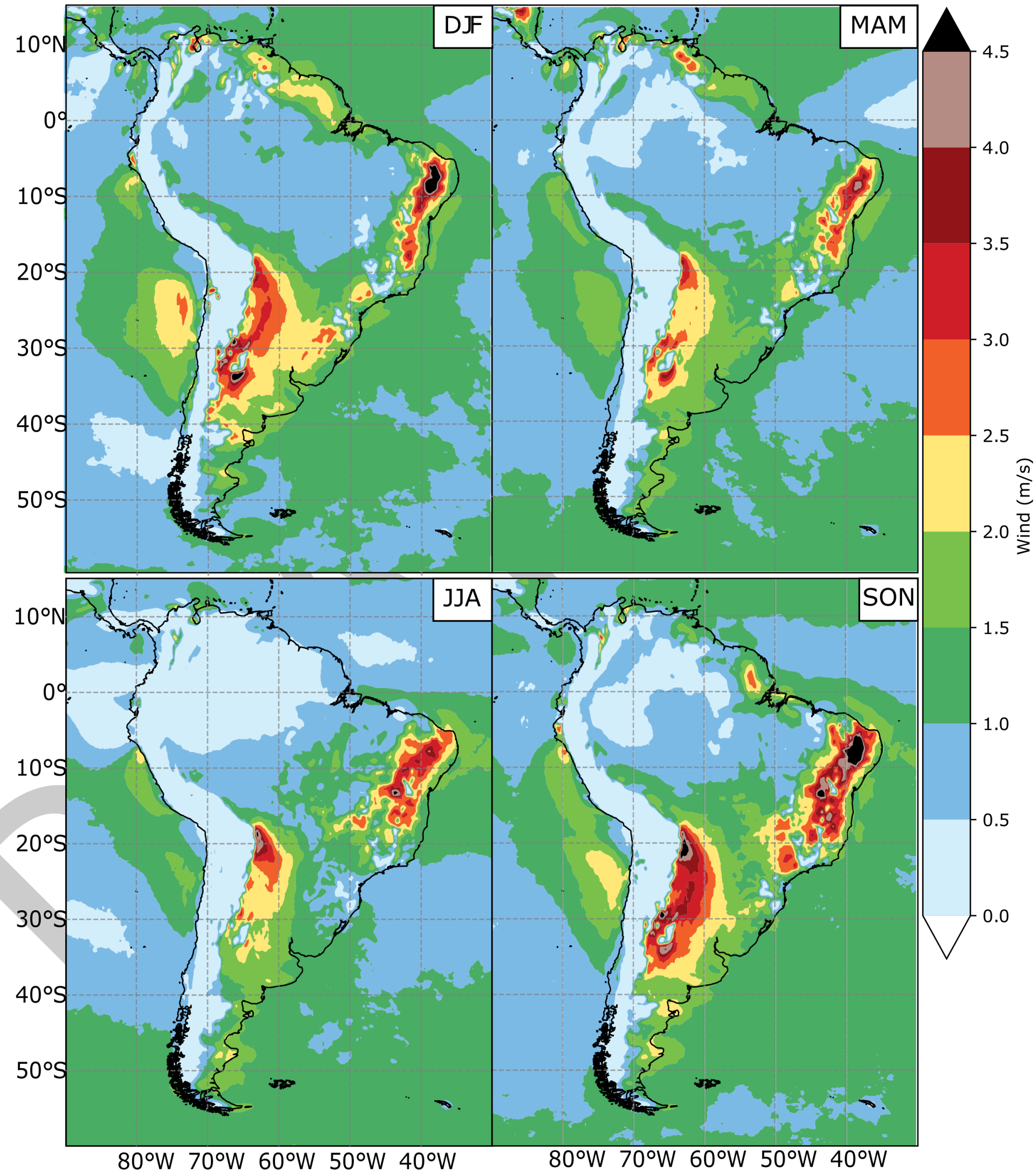

Figure 1: Seasonal NLLJ Climatology

Figure 1 Seasonal climatology (1980–2016) of the nocturnal low-level jet (NLLJ) index

Example Usage

```
from nllj_calculator import NLLJCalculator, plot_seasonal_maps
```

```python
# Initialize calculator
calc = NLLJCalculator(data_dir='/path/to/era5/data')

# Automatically find optimal pressure levels
results = calc.analyze_all_level_combinations(year=1980, month=1)

# Calculate seasonal climatology
seasonal_clim = calc.calculate_climatology(year=1980)

# Generate publication-ready maps
plot_seasonal_maps(seasonal_clim, year=1980,
                   level_lower=calc.level_lower,
                   level_upper=calc.level_upper)
```

Software Architecture

The package follows modern Python best practices with clear separation of concerns:

- **calculator.py** : Core computation and data processing
- **plotting.py** : Visualization functions
- **download_era5.py** : Data acquisition utility
- **run_analysis.py**: Complete workflow example

This modular design allows users to import only needed components, facilitates testing, and enables easy extension for related research questions.

Impact and Applications

This tool has been applied to climatological studies of moisture transport in South America (Braz et al., 2021) and provides a foundation for:

- Long-term trend analysis of NLLJ characteristics under climate change
- Evaluation of climate model representations of low-level jets
- Operational monitoring of moisture transport conditions
- Teaching and training in atmospheric dynamics

The automated optimization feature has revealed that the 900-650 hPa level combination consistently produces the strongest and most spatially coherent NLLJ signals across South America, validating and extending previous manual analyses.

Acknowledgements

We acknowledge the Copernicus Climate Change Service for providing ERA5 reanalysis data. We thank the atmospheric science community for valuable feedback during development.

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