CE669 Term Paper Report

METEOROLOGICAL ASSESSMENT FOR INDUSTRIAL PLANNING USING WRF MODEL

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Part - A

1.Introduction

As the city administration works to expand its industrial infrastructure, it is placing a strong emphasis on understanding local weather patterns—particularly wind speed and direction—since these elements significantly influence how pollutants disperse through the atmosphere. To gain a comprehensive and accurate picture, the Weather Research and Forecasting (WRF) model is being employed to simulate real-world wind conditions across the region. The aim is not only to determine suitable locations for industrial development but to do so in a way that responsibly reduces pollution exposure for residential areas, promoting cleaner and healthier air for the community.

WRF Model Description

The Weather Research and Forecasting (WRF) model is a robust system designed for both meteorological research and operational forecasting. It accurately simulates atmospheric conditions such as wind speed, temperature, and pressure over defined geographic areas. Due to its high precision, the WRF model is commonly used in environmental assessments to track the movement of pollutants and to guide strategic, sustainable infrastructure planning.

1.1 Objective of the Study

To utilize the WRF (Weather Research and Forecasting) model for simulating wind characteristics (speed and direction) in the study region and analyze its results to support decision-making for optimal industrial site selection with minimal impact on city residents.

2. Methodology

2.1 Working Principle

WRF works by simulating the atmosphere through physics-based equations that capture how wind moves, how temperatures shift, and how pressure changes over time. It relies on actual meteorological data as input to generate detailed, high-resolution forecasts or simulations for a chosen area.

2.2 Installation Process

WRF is set up on Linux systems along with essential dependencies like NetCDF, MPICH, and the required compilers. The model has two main components: WPS, which handles the preparation of input data, and WRF-ARW, which carries out the actual weather simulation.

2.3 Domain and Parameter Setup

A domain refers to the specific geographical area chosen for the simulation. Users set the size of this region, the resolution (like 9 km grid spacing), and the number of vertical levels in the atmosphere. They also choose physical parameterization schemes that represent key processes such as boundary layer dynamics, cloud formation, and interactions with the land surface.

2.4 Model Execution

The process begins with input data (e.g., from GFS). The WPS prepares this data using:

- geogrid.exe (creates domain grid)
- ungrib.exe (reads data)

- metgrid.exe (prepares final input)

Then, real.exe initializes the model and wrf.exe runs the simulation.

The model was run for the month of **October 2023**. It produced hourly data showing:

- Wind Speed at 10 meters height (WS10m)
- Wind Direction at 10 meters (WD10m)

2.5 Data Post-Processing

Post-processing was performed using Python and exported to Excel. Wind speed was calculated from U10 and V10 using:

$$\mathbf{WS10m = \sqrt{U10^2+V10^2}}$$

Both simulated and observed wind data were imported into Excel for validation. In Excel, the WRF wind speeds were compared to observed wind speeds (WSo) using basic formulas to calculate:

- **Slope**
- **Intercept**
- **FB** (Fractional Bias): Shows the relative bias between model and observed values
- **d** (Index of Agreement): Measures how closely the WRF model predictions match the observed values, with 1 indicating perfect agreement
- **r** (Correlation Coefficient): Shows how strongly the predicted and observed wind speeds follow the same trend, with values close to 1 indicating a strong linear relationship.
- **NMSE** (Normalized Mean Squared Error): Indicates the average squared difference between predicted and observed values, normalized by their product, where lower values mean better model performance.

The wind speed and direction data were also used to generate a wind rose diagram using **WRPLOT View software**. This diagram illustrates the frequency and intensity of winds from various directions, providing valuable insight into optimal industrial placement to minimize pollution impact on city. Additionally, a scatter plot was created with observed wind speeds on x-axis and WRF-simulated wind speeds on y-axis. A reference line (y = x) was included to visually assess the accuracy of the model by comparing it directly with real-world observations.

Part - B

i) Validation of WRF data

3.Methodology

In this study, the validation of the WRF model's wind speed predictions was carried out by comparing the model-generated data (Cp) with observed wind speed data (Co). First, the data was extracted, ensuring that both datasets corresponded to the same time period and location. Validation metrics were calculated using the following statistical parameters:

- **Slope**: Measures trend similarity
- **Intercept**: Indicates systematic bias
- **FB** (Fractional Bias): Shows the relative bias between model and observed values
- **Normalized Mean Square Error (NMSE)**: Represents overall prediction error
- **Index of Agreement (d)**: Reflects model agreement with observations
- **Pearson correlation coefficient (r)**: Measures linear correlation

Excel Procedure:

1. Input WRF (Cp) and Observed (Co) wind speed in two columns.
2. **Use formulas:**

- =AVERAGE(Co), =AVERAGE(Cp)
- =SLOPE(Co_range, Cp_range),
- = INTERCEPT(Co_range, Cp_range)
- =CORREL(Co_range, Cp_range) for r
- Custom formula for d and NMSE using cell-based calculations.

Statistical parameters

Parameter	Formula
Slope	$\text{Slope} = \frac{\sum(Cp-\overline{Cp})(Co-\overline{Co})}{\sum(Cp-\overline{Cp})^2}$
Intercept	$\text{Intercept} = \overline{Co} - slope*\overline{Cp}$
FB	$FB = 2*\frac{(\overline{Co}-\overline{Cp})}{(\overline{Co}+\overline{Cp})}$
NMSE	$NMSE = \frac{\overline{(Co-Cp)^2}}{\overline{Co}*\overline{Cp}}$
r	$r = \frac{\overline{(Co-\overline{Co})(Cp-\overline{Cp})}}{\sigma_{Cp}*\sigma_{Co}}$
d	$d = 1 - \frac{[(\sum((Co-Cp)^2)]}{\sum((abs(Cp-\overline{Co})+abs(Co-\overline{Co})))^2}$

3. Metrics were computed for October 2023 (713 hourly values).

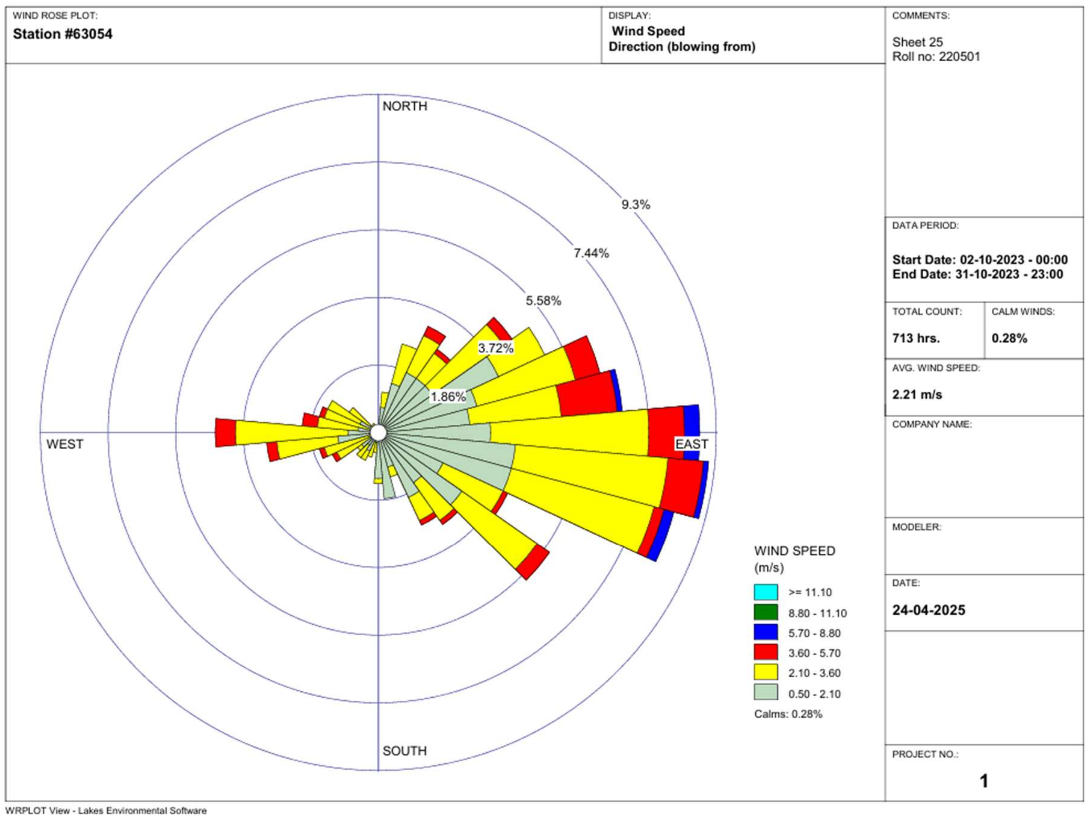
4. Results

Parameter	Value
slope	0.233800824
intercept	0.268306
FB	-0.952148
NMSE	1.713684
d	0.428701
r	Values are given in excel sheet

The calculations of the parameters are done in the excel sheet consisting of the data given to me and is attached in a zip file.

ii) Wind Rose Analysis

With the **WRPLOT View software**, the **wind rose diagram** has been created.



iii) Wind Rose Interpretation

A wind rose diagram was generated using WRPLOT View based on WRF-generated wind direction and speed for October 2023.

Findings:

- **Predominant wind directions**: **Northwest (NW) and West-Northwest (WNW)**
- Winds mainly blow from **NW** towards **SE**
- Average wind speed: **2.21 m/s**
- Calm conditions: **0.28%**

5.Industrial Location Recommendation

Given the wind predominantly flows from **NW/ WNW directions**, it is recommended to locate the industrial infrastructure towards the **Southeast (SE)** of the city center. This siting minimizes the transport of air pollutants towards densely populated areas and helps maintain better air quality in the city.