Weather Insights: Visualizing and Comparing Meteorological Data Across German Cities with Node-RED, InfluxDB, and Grafana

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ABSTRACT

Technology is evolving rapidly and data plays a crucial role in decision making. However, raw data alone is meaningless without proper analysis. This is why it is essential to implement visual tools that simplify data interpretation and comparison. The importance of effectively collecting, processing and visualizing data extends to various fields, such as finance, medicine, technology, agriculture and others.

This project integrates **Node-RED**, **InfluxDB** and **Grafana** to develop an effective visualization tool through a dynamic dashboard. Node-RED automates data collection, InfluxDB efficiently stores time series data and Grafana transforms it into interactive visualizations.

Our main objective is to create a Grafana dashboard to analyze live weather data. Focusing on five German cities: Freiburg, Kiel, Munich, Tübingen, and Zwickau, the system tracks key weather variables such as temperature, humidity, rain, snowfall, wind speed and wind direction over the period of 1 week from 10^{th} February 2025 up to and including 16^{th} February 2025. By transforming complex data sets into clear and actionable information, the project aims to provide a platform for identifying trends and facilitating real-time analysis and comparison of weather data. By emphasizing the importance of visualization tools, this project highlights how a well-organized and clearly presented dataset can make the decision-making process more intuitive and useful.

Key Words: Dashboard Design, Data Visualization, Node-RED, InfluxDB, Grafana, Real-time Data, Weather Comparison.

1 INTRODUCTION

In the age of data-driven decision-making, the ability to transform complex datasets into actionable insights is critical. This is especially true in meteorology, where variables such as temperature, precipitation, and wind patterns must be visualized effectively to uncover meaningful trends. This project addresses this challenge by developing a dynamic dashboard to analyze and compare weather data across five German cities: Freiburg (southwest, near the Black Forest), Kiel (north, by the Baltic Sea), Munich (southeast, near the Alps), Tübingen (south, in a river valley), and Zwickau (east, in a lowland region).

By integrating Node-RED for automated data collection, InfluxDB for efficient storage of time-series data, and Grafana for interactive visualization, the dashboard provides a platform for real-time weather analysis. It is designed to answer region-specific questions, such as:

- How do weather patterns differ between coastal (Kiel) and mountainous (Munich) regions?
- What are the temperature and precipitation trends in southern cities (Freiburg, Tübingen) compared to eastern (Zwickau) and northern (Kiel) cities?
- How do geographical features, such as proximity to the sea or mountains, influence wind patterns?

The design of the dashboard is central to its effectiveness. By employing visualization elements such as line charts, heatmaps, and windrose diagrams, the dashboard enables users to compare regional weather trends intuitively. This report details the design and implementation process, emphasizing the rationale behind the chosen visualizations and their role in facilitating data-driven insights.

Ultimately, this project highlights the importance of tailored visualization tools in transforming raw data into actionable knowledge. By combining advanced technologies with thoughtful design, the dashboard serves as a powerful tool for understanding regional weather variations and their implications.

2 OBJECTIVES

The primary objective of this project is to design and implement a Grafana dashboard for visualizing and comparing weather data across five German cities: Freiburg, Kiel, Munich, Tübingen, and Zwickau. These cities were selected to represent diverse geographical regions, including coastal areas, mountainous regions, river valleys, and lowland plains. By analyzing key weather parameters, the dashboard aims to provide insights into how geographical features influence local weather patterns.

The project focuses on the following key objectives:

- To collect, process, and store real-time weather data for the selected cities using Node-RED and InfluxDB.
- To create an interactive Grafana dashboard that enables users to compare weather variables such as temperature, precipitation, wind speed, wind direction and humidity across regions.
- To design visualization elements (e.g., line charts, heatmaps, windrose diagrams) that highlight regional differences and trends in weather data.
- To provide a platform for identifying patterns and anomalies in weather conditions, facilitating real-time analysis and decision-making.

By achieving these objectives, the project aims to demonstrate the value of effective data visualization in transforming complex datasets into actionable insights. The dashboard will serve as a tool for understanding regional weather variations and their underlying causes, contributing to a deeper understanding of local climate patterns.

3 METHODOLOGY

To perform our analysis, we fetch data from the **Open-Meteo API**, a free and open-source weather API [1] that provides historical and real-time weather data for a wide range of parameters, including temperature, precipitation, wind speed, wind direction and humidity. The data is collected for five German cities—Freiburg, Kiel, Munich, Tübingen, and Zwickau—representing diverse geographical regions such as coastal areas, mountainous terrain, and lowland plains.

The data is processed using Node-RED, where a workflow is designed to parse, format, and structure the data before sending it to InfluxDB for storage. InfluxDB, a time-series database, ensures efficient storage and retrieval of the time-stamped weather data.

Finally, the data is visualized in Grafana, where a dynamic dashboard is created to explore and compare weather patterns across the selected cities. The dashboard incorporates various visualization elements, such as line charts, heatmaps, and windrose diagrams, to highlight regional differences and trends.

In the following subsections, we provide a detailed explanation of each step in the process, from data collection and processing to visualization and analysis.

3.1 Data Collection and Processing

To retrieve weather data for five different cities in Germany, a workflow was initially designed for a single city using Node-RED (see Figure 1). This workflow was then replicated and customized for each of the five cities. The Node-RED workflow is designed to retrieve weather data from the Open Meteo API [1], process the data, and store it in an InfluxDB database. Below is a detailed explanation of the process and the workflow structure, which consists of the following nodes arranged in a sequential manner:

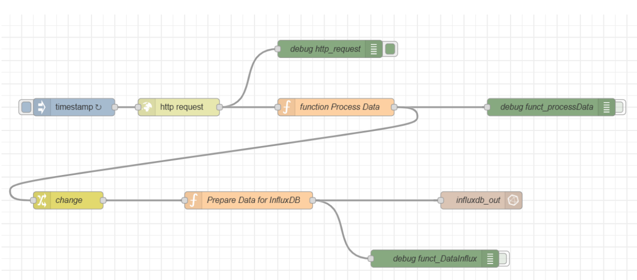

Figure 1: Node-RED Workflow - Fetch Live Weather Data of a City

- **Inject Node:** which is used to obtain data at 1-hour intervals.
- **Http Request Node:** To retrieve the data, a URL must be included in this node. The URL is structured as follows:

```
https://api.open-meteo.com/v1/forecast?latitude={LAT}&
     longitude={LON}&current={PARAMS}
```

where {LAT}, {LON}, {PARAMS}, should be replaced with the respective details of interests.

The geographical coordinates of the selected cities are presented in Table 1.

City	Latitude	Longitude	Key Characteristics
Freiburg	47.97891	7.774087	Warm, Rhine Valley
Kiel	54.30580	10.19531	Maritime, Baltic Sea
Munich	48.11951	11.5500	Continental, near Alps
Tübingen	48.54130	9.09091	Mild, Swabian Jura
Zwickau	50.72056	12.46892	Moderate, Ore Mountains

Table 1: Latitude, Longitude, and Key Characteristics of Selected Cities

- **Function Process Data Node:** Used to parse and format the API response (e.g., extracting temperature, humidity, etc.).
- **Change Node:** Maps the `msg.payload.timestamp` to `global.timestamp` with deep copying enabled, ensuring accurate and consistent timestamps for time-series storage in InfluxDB.
- **Function Prepare Data for Influx Node:** Formats the parsed and modified data into the specific structure required by InfluxDB.

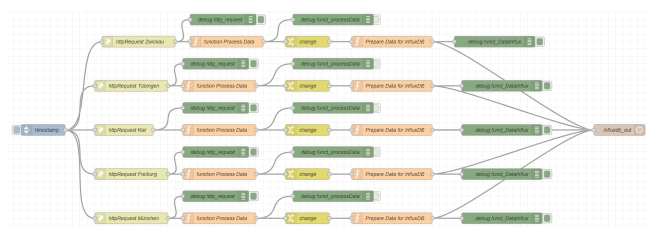

Figure 2: Node-RED Workflow - Fetch Data of 5 Cities

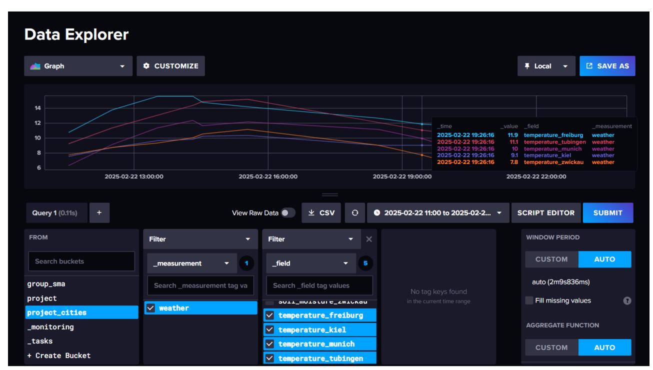

Figure 3: Storing Data in InfluxDB

Through the Influx Out node, we send the data to InfluxDB, where it is stored. As shown in the (Figure 3), the data is organized inside its respective bucket in InfluxDB. We have all the previous mentioned weather indicators stored for each city.

Finally, to achieve better visualization results on the dashboard, we decided to transfer the data to Grafana and proceed with the design phase. To connect InfluxDB with Grafana, Grafana was configured to use InfluxDB as a data source by specifying the InfluxDB URL, database name, and authentication details in the data source settings. Once the connection was established, dashboards and visualizations were created to display the data stored in InfluxDB.

4 DASHBOARD DESIGN

4.1 Introduction

This section provides an overview of designs used for elements of dashboards that address the purpose of selection of designs of the visualization of data. The objective of the dashboards is to present historical weather data of a certain time in an understandable manner allowing for easy interpretation and quick analysis. Another purpose of better dashboard design is to allow the user to derive results from the trends and patterns of data for whatever reason.

The design process includes the selection of appropriate layouts, charts, colors, shapes, etc. depending on the type of data presented. The dashboard contextualizes the weather factors with these designs. The continuation of this section will include the designs that we used in the context of the project and the reasoning behind it.

4.2 Dashboards

Below are a few examples of different types of visualization charts and maps used in our dashboard. Each element has a reason for selection based on readability and the type of data being presented.

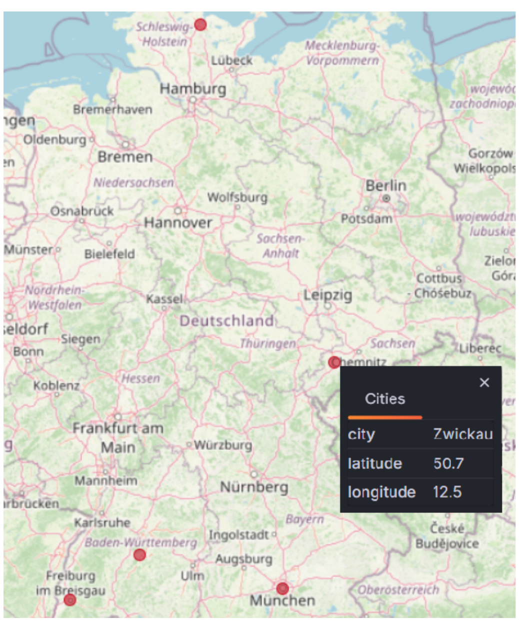

Figure 4: Geographical Map of Cities

Geographical Map of Cities. The map in Figure 4 provides a geographical overview of the cities included in the analysis. Each city is represented by a red dot, and clicking on it shows some important details of the city, such as its coordinates. It helps users understand the spatial distribution of the cities and their relative locations. This visualization is particularly useful for identifying regional weather patterns and comparing data across different geographical areas.

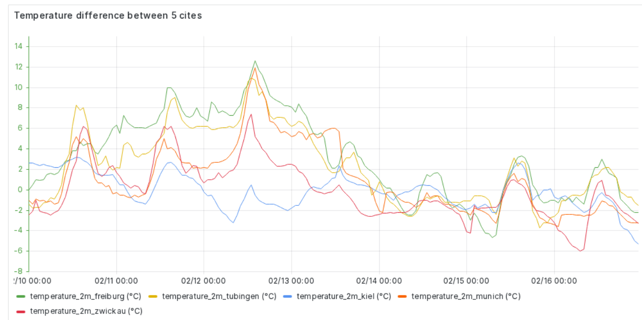

Figure 5: Temperature Difference Graph

Hourly Temperature Difference Between the 5 Cities (Freiburg, Tübingen, Kiel, Munich, Zwickau). The chosen design in Figure 5 effectively visualizes the temperature differences across five cities over a week using a simple line graph. Each city is represented by a different color, and the gray background columns are divided into the 7 days of the week, helping users quickly identify daily variations. The line graph answers questions such as the highest and lowest temperatures for each city. Colors are used to distinguish cities rather than extreme weather values, as the y-axis clearly represents the temperature range, avoiding unnecessary over-coloring.

Max. and Min. Temperature of the Week

Field	Max	Min	Mean
Freiburg	12.6 °C	-4.70 °C	3.15 °C
Kiel	3.20 °C	-5.30 °C	-0.123 °C
Munich	11.9 °C	-3.60 °C	0.995 °C
Tübingen	10.9 °C	-3.70 °C	2.32 °C
Zwickau	7.40 °C	-6 °C	-0.0399 °C

Figure 6: Max., Min., and Mean Temperature of the Week

Max., Min., and Mean Temperature of the Week. The table in Figure 6 summarizes the maximum, minimum, and mean temperatures for five cities over a week. Freiburg had the highest maximum temperature (12.6°C) and warmest mean (3.15°C), while Kiel recorded the lowest minimum (-5.30°C) and coldest mean (-0.123°C). Munich and Tübingen showed moderate ranges, with means of 0.995°C and 2.32°C, respectively. Zwickau had a narrower range, with a mean of -0.0399°C. This data highlights regional climate variations, with Freiburg being the warmest and Kiel the coldest, aiding in quick comparisons of temperature extremes and averages.

Figure 7: Temperature vs Apparent Temperature in Zwickau

Temperature vs Apparent Temperature in Zwickau. The line graph in Figure 7 compares the actual temperature with the apparent temperature (how it feels) in Zwickau over a week. This visualization helps users understand the difference between the two metrics and how factors like humidity and wind might affect the perceived temperature. The mean humidity in Zwickau was 76.9%, which likely contributed to the differences between actual and apparent temperatures. The graph shows that the apparent temperature often deviated from the actual temperature, with noticeable drops, indicating that conditions felt colder than the recorded temperatures.

Zwickau Hourly Heatmap. This design in Figure 8 visualizes the temperature across Zwickau over a week using cell color to indicate the temperature level for each hour of the day. The y-axis represents the time of day (00:00–24:00), and the x-axis spans the days of the week. The color-coded intensity allows users to quickly identify patterns, such as the warmest or coldest hours.

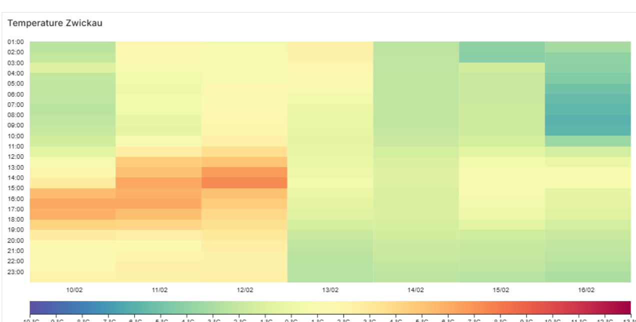

Figure 8: Zwickau Hourly Heatmap

Key insights from this visualization include:

- **Warmest Hours:** The warmest temperatures were reached on February 10th, 11th, and 12th hours after midday, peaking on February 12th between 13:00 and 14:00, with temperatures around 7°.

- **Weekly Trend:** Temperatures gradually decreased during the week, with the second half of the week staying below 2°C and the coldest temperature reaching -6°C on the morning of February 16th.

This heatmap effectively captures daily and weekly temperature trends, providing clear insights into Zwickau's weather patterns. From the complete dashboard (Figure 14), we can see that Tübingen, Munich, and Freiburg have the highest temperatures (indicated by red and orange cells), while Kiel only shows lower temperatures (represented by green, blue, and light yellow cells). Zwickau has temperatures higher than those in Kiel but lower than those in Freiburg, Munich, and Tübingen.

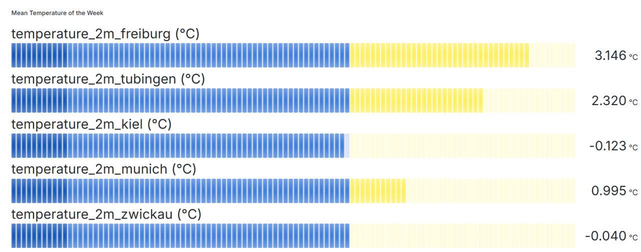

Figure 9: Mean Temperature Bar

Mean Temperature Bar. This style, as seen in Figure 9, represents the average temperature for five cities using a bar-style heatmap. Each row corresponds to a city, with colored segments indicating temperature variations. The horizontal layout ensures readability, and the blue-to-red gradient highlights temperature trends.

Freiburg had the highest mean temperature at 3.146°C, followed by Tübingen (2.320°C) and Munich (0.995°C). Zwickau and Kiel recorded slightly negative temperatures (-0.040°C and -0.123°C), showing a gradient from warmer southern to cooler northern cities.

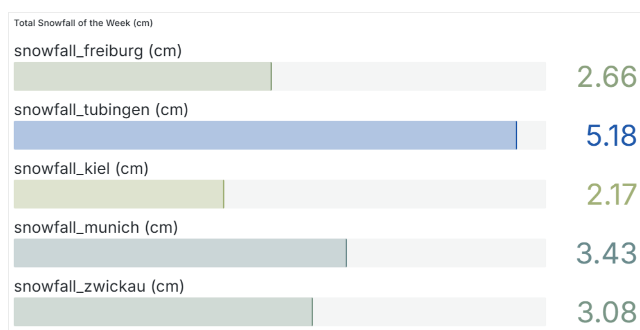

Figure 10: Total Snowfall of the Week

Total Snowfall of the Week. The bar chart in Figure 10 displays the total snowfall in centimeters for each of the five cities over the week. This visualization allows users to quickly compare snowfall amounts across cities and identify trends. The use of a bar chart makes it easy to interpret the data at a glance.

From Figure 10 we can see that Tübingen received the highest snowfall with 5.18 cm in this week, followed by Munich with 3.43 cm, Zwickau with 3.08 cm, Freiburg with 2.66 cm, and Kiel with the least snowfall at 2.17 cm.

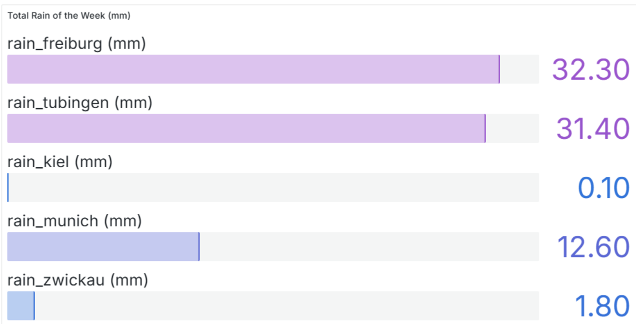

Figure 11: Total Rainfall of the Week

Total Rainfall of the Week. Similar to the snowfall chart, the bar chart in Figure 11 shows the total rainfall in millimeters for each city over the week. This visualization helps users compare rainfall amounts and identify patterns or anomalies in precipitation data.

In this case we can see that Freiburg had the highest rainfall with 32.30 mm, closely followed by Tübingen with 31.40 mm. Munich experienced moderate rainfall with 12.60 mm, while Zwickau had significantly less at 1.80 mm. Kiel recorded the least rainfall with only 0.10 mm.

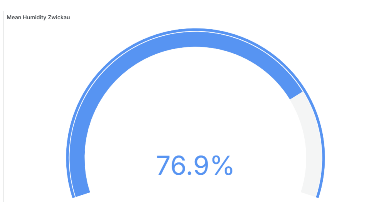

Figure 12: Mean Humidity in Zwickau

Mean Humidity in Zwickau. The visualization in Figure 12 displays the average humidity level in Zwickau over the week. This metric is crucial for understanding the perceived temperature and comfort level, as humidity significantly affects how temperatures are experienced. The simplicity of the design allows users to quickly grasp the humidity trends. The weekly mean humidity in Zwickau was 76.9%. From Figure 14, a quick comparison can be made between the humidity of the 5 cities, with Tübingen 86.5% having the highest mean humidity and Kiel the lowest 76.5%. However, it can be seen that the difference between these values is not very large.

Windrose. This design, as seen in Figure 13, is a powerful tool for assessing wind direction and speed. The circular area imitates a compass with cardinal directions, and the length of the radius

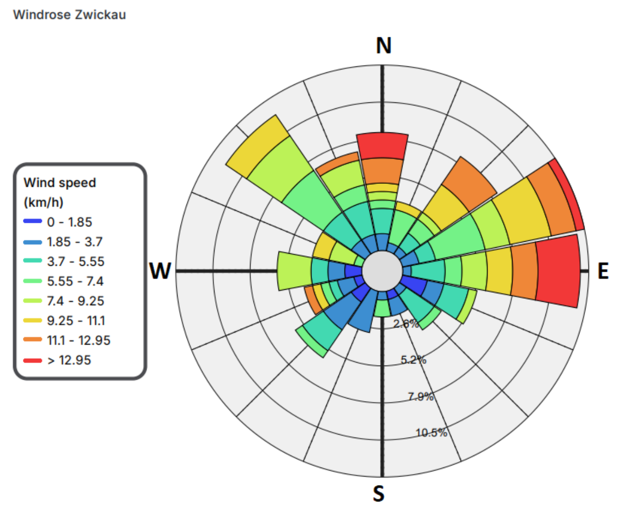

Figure 13: Windrose

represents wind speed. The color of the fill indicates wind intensity, with blue to red denoting low to high winds, respectively. This visualization is intuitive and allows for multi-variable representation in a single visual.

The chart highlights a range of wind speeds in Zwickau from 0 to over 12.95 km/h, with moderate speeds (5.55 - 7.4 km/h) being the most common at 10.6%. The most frequent winds come from the east (E), with 7.9% of winds in the 3.7 - 5.55 km/h range. The strongest winds (indicated by the red color) are experienced from the east and north, exceeding 12.95 km/h. The second most frequent wind direction is from the northwest (NW), with 5.2% of winds in the 1.85 - 3.7 km/h range. This distribution suggests a prevailing easterly wind pattern with occasional strong gusts from the north.

Complete Dashboard. The final dashboard, as seen in Figure 14, is a comprehensive and well-structured dashboard which essentially displays weekly weather data for five cities, combining multiple visualization options to provide different insights. The selection of a variety of graphs, heatmaps, and gauges makes it easy to identify patterns, compare cities, and track trends over time.

The Dashboard elements are divided and coupled in a modular way, where similar visualizations are grouped in or around a single location so as to not scatter similar amount of data elsewhere keeping the 'Law of proximity' in mind according to the Gestalt laws[2]. The size of numerics on the dashboard have been meticulously selected to present appropriate weight of information when needed. The balance of color, numbers, text and graphs is also carefully selected based on the information we wish to provide the user.

This structured approach improves the dashboard's usability by allowing users to quickly identify related data without unnecessary cognitive load. High-demand numerical values, such as temperature extremes, are displayed with colors, for immediate recognition. The use of colors further helps in identifying warm and cool areas and temperature variations. Additionally, time-series graphs and heatmaps are positioned very logically on the top, so its easier to compare between cities and trends over time. By maintaining a balance between textual information and graphical representation, the dashboard offers an overview of the weather indicators for the five selected cities, enabling a deeper understanding of the details for each one.

4.3 Provisions Of The Journey

Several additional dashboards were created during the project, each designed to explore different aspects of the weather data with unique visualization techniques within the cities and intra-cities. These dashboards provided insights into specific trends, such as daily variations, rainy weather occurrences, and weather code occurrences across different time frames. While not all of them were included in the report, they played a valuable role in refining our approach, testing different visualization styles, and ensuring that the final dashboard effectively captured the most relevant weather patterns.

5 RESULTS

The final implementation of the dashboard successfully achieves the project's objective of providing an intuitive and informative visualization of weather data for five German cities. By integrating Node-RED, InfluxDB, and Grafana, the system processes and presents time-series weather data over a week. The results demonstrate how a well-structured and balanced dashboard can simplify complex data analysis, enabling users to compare regional weather patterns and derive actionable insights. The use of diverse visualization techniques, such as line charts, heatmaps, and windrose diagrams, effectively highlights trends and variations in temperature, precipitation, and wind speed across the selected cities.

5.1 Geographical Influences on Weather Patterns

The data reveals distinct weather patterns influenced by geography, addressing key questions raised in the introduction:

• **Coastal vs. Mountainous Regions:** Coastal Kiel exhibits milder temperatures and minimal snowfall (0.10 mm rainfall, 2.17 cm snow), while mountainous Munich has colder temperatures and higher snowfall (3.43 cm), as seen in Figures 11 and 10.

• **Southern vs. Eastern/Northern Cities:** Southern cities (Freiburg, Tübingen) experience higher rainfall (32.30 mm, 31.40 mm) due to proximity to the Black Forest, compared to eastern (Zwickau) and northern (Kiel) cities, which show lower precipitation (1.80 mm, 0.10 mm), as shown in Figure 11.

• **Wind Patterns:** Coastal Kiel has stronger, consistent winds (Figure 14), with higher wind speeds due to its proximity to the sea. while mountainous Tübingen, Munich, Zwickau and Freiburg exhibit variable wind patterns with moderate speeds due to terrain influences.

These findings highlight how geographical features—such as proximity to the sea or mountains—shape local weather patterns, providing valuable insights for regional climate analysis. The dashboard effectively answers the questions posed in the introduction, demonstrating its utility in understanding and comparing weather data across diverse regions.

6 CONCLUSION

This project highlights the successful integration of Node-RED, InfluxDB, and Grafana to create a dynamic dashboard for visualizing and comparing weather data. The system efficiently collects, stores, and presents time-series data, making it accessible for real-time analysis. The dashboard's design, incorporating advanced visualization techniques, effectively communicates regional weather trends and differences, supporting data-driven decision-making.

Future work could expand the scope to include additional cities or weather parameters, further enhancing the dashboard's utility. Overall, this project underscores the importance of combining modern technologies with thoughtful design to transform raw data into meaningful insights, providing a foundation for further exploration in meteorology and related fields.

APPENDIX: FULL DASHBOARD

See Figure 14 on the next page

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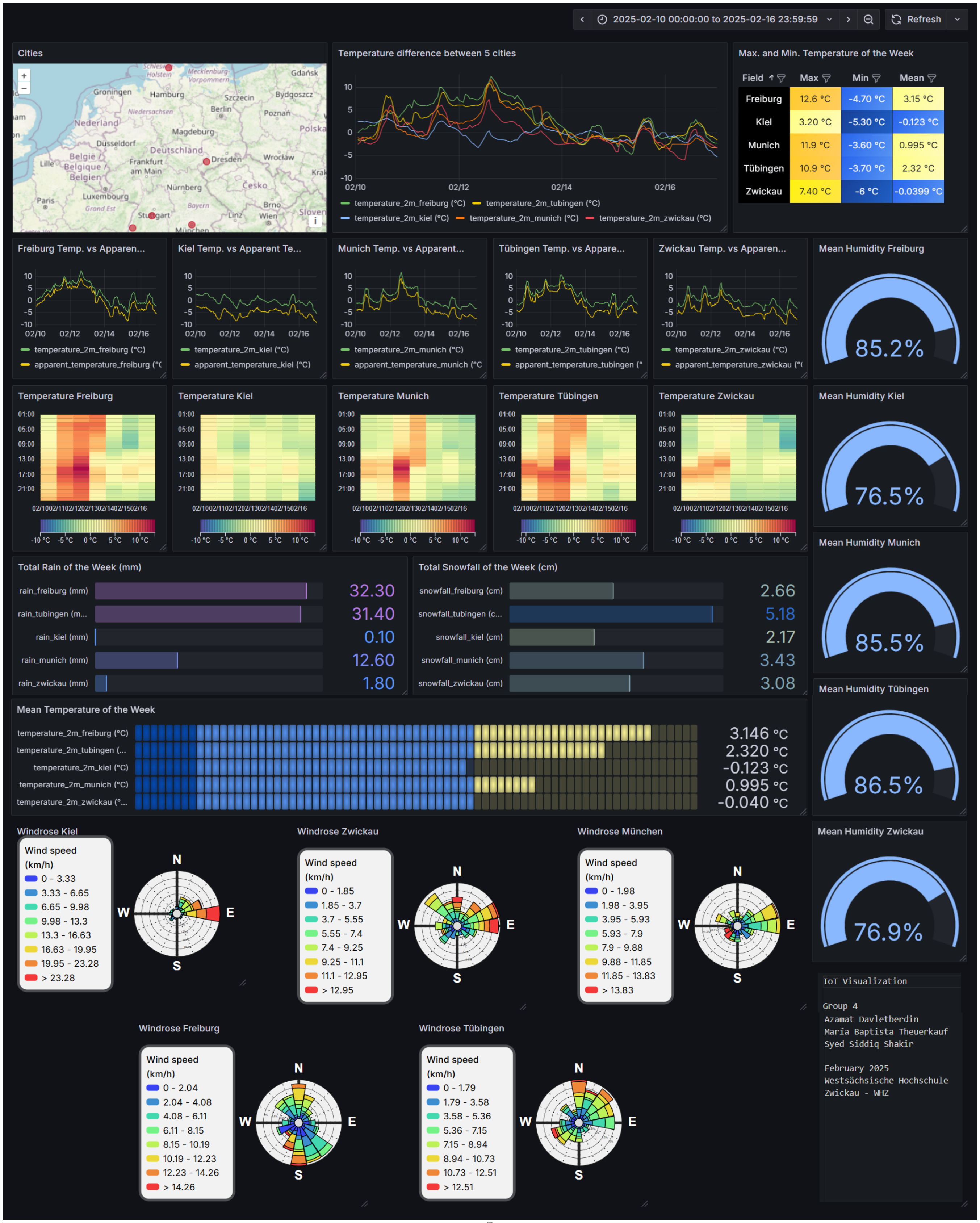

Figure 14: Complete Dashboard