1. Product Requirements Document (PRD)

Project Title: Cloud-Native Weather & Air Quality Analytics Platform

1.1. Vision:

To create a near real-time and historical analytics platform that ingests, processes, and visualizes weather and air quality data for selected regions, enabling data-driven environmental insights.

1.2. Goals & Objectives:

- Data Ingestion: Automatically collect weather and AQI data from public APIs for multiple, configurable regions every hour.
- Data Processing: Cleanse, transform, and enrich the raw data to make it analysis-ready.
- Data Storage: Store raw data cost-effectively and processed data in an optimized format for analytical querying.
- Orchestration: Build a robust, automated, and scheduled pipeline.
- Data Analysis: Enable SQL-based analysis on historical data.
- Visualization: Provide an interactive dashboard for end-users to explore trends in temperature, humidity, AQI, and pollutant levels (PM2.5, PM10, O3, etc.).
- Cloud Focus: Utilize core AWS serverless technologies to demonstrate modern data engineering practices.

1.3. Scope:

- In-Scope:
  - Data from free-tier weather/air quality APIs (e.g., OpenWeatherMap, AirVisual API).
  - Configuring 5-10 major cities (e.g., London, New York, Tokyo, Delhi, Sydney).
  - Hourly data ingestion.
  - Historical data load for the past 30 days (if API allows).
  - Dashboard with basic time-series charts and metrics.
- Out-of-Scope:
  - Predictive modeling or ML.

    ○ Real-time (sub-minute) alerting.
    ○ User authentication and multi-tenancy for the dashboard.
    ○ Paid data sources or APIs.

1.4. Functional Requirements:

1. The system shall fetch current weather and AQI data for all configured cities every hour.
2. The system shall store a raw, immutable copy of each API response.
3. The system shall parse, flatten, and transform the nested JSON API responses into a structured tabular format.
4. The system shall load the transformed data into a data warehouse for analysis.
5. The system shall provide a dashboard with filters for date and city to visualize:
    - Time series of Temperature, Humidity, Pressure.
    - Time series of AQI and key pollutants (PM2.5, PM10).
    - Average AQI by city over a selected period.

1.5. Non-Functional Requirements:

- Reliability: The pipeline should have error handling and retry mechanisms.
- Cost-Efficiency: Use serverless and pay-per-use services to minimize cost, especially for a demo project.
- Maintainability: Code should be well-documented and infrastructure should be defined as code (IaC).
- Scalability: The design should be able to scale to ingest data for 100s of cities without a major re-architecture.

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2. High-Level Design (HLD)

Architecture Diagram:

```
[External Weather API] -> [AWS Lambda (Ingestion)] -> [Amazon S3 (Raw Layer)]
      ^
      |
[EventBridge Scheduler]

[Amazon S3 (Raw Layer)] -> [AWS Glue (Spark ETL Job)]
      |                      |
      |                      v
```

```
|                [Amazon S3 (Processed Layer - Parquet)]
|                        |
|                        v
|                [AWS Glue Data Catalog] <- (One-time setup for processed data)
|                        |
|                        v
+----------------->[Amazon Athena]
                 |
                 v
            [Amazon QuickSight]
```

Data Flow:

1. Orchestration: An Amazon EventBridge Scheduler triggers an AWS Lambda function every hour.
2. Ingestion (Lambda): The Lambda function reads the list of target cities from a config file (e.g., in S3). It then iterates through each city, calls the relevant APIs, and writes each JSON response as a separate file to an S3 bucket (`raw-layer/date=YYYY-MM-DD/hour=HH/api_name/city_id.json`).
3. Transformation (ETL): A scheduled AWS Glue Spark job:
   - Reads the raw data from the Glue Catalog tables.
   - Flattens the nested JSON, extracts relevant fields, handles data type conversions, and joins weather and AQI data where possible (using city, timestamp).
   - Writes the processed data into another S3 bucket in Apache Parquet format, partitioned by date (`processed-layer/date=YYYY-MM-DD/data.parquet`).
4. Cataloging (Processed): A Glue Crawler scans the `processed-layer` bucket and creates a table like `processed_weather_aqi`.
5. Querying: Amazon Athena is used to run SQL queries on the `processed_weather_aqi` table via the Glue Data Catalog.
6. Visualization: Amazon QuickSight connects to Athena as a data source and builds the analytical dashboard.

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3. Low-Level Design (LLD)

3.1. Data Sources & Ingestion (Lambda Function):

- API: OpenWeatherMap (Current Weather Data) & AirVisual (Air Quality). You might need to create free accounts.
- Lambda Runtime: Python 3.10
- Lambda Code Logic:

```
import boto3, requests, json, datetime
s3 = boto3.client('s3')
config = get_config_from_s3() # List of dicts: [{'city': 'London', 'country': 'GB', 'lat': 51.50, 'lon': -0.11, 'city_id': 123}]

for city in config:
    # Fetch Weather Data
    weather_url = f"https://api.openweathermap.org/data/2.5/weather?lat={city['lat']}&lon={city['lon']}&appid={API_KEY}&units=metric"
    weather_resp = requests.get(weather_url)
    weather_data = weather_resp.json()

    # Fetch AQI Data (example for AirVisual)
    aqi_url = f"http://api.airvisual.com/v2/nearest_city?lat={city['lat']}&lon={city['lon']}&key={AQI_API_KEY}"
    aqi_resp = requests.get(aqi_url)
    aqi_data = aqi_resp.json()

    # Generate S3 Paths with Partitioning
    current_dt = datetime.datetime.utcnow()
    date_str = current_dt.strftime("%Y-%m-%d")
    hour_str = current_dt.strftime("%H")

    weather_key = f"raw-layer/date={date_str}/hour={hour_str}/openweathermap/{city['city_id']}.json"
    aqi_key = f"raw-layer/date={date_str}/hour={hour_str}/airvisual/{city['city_id']}.json"

    # Write to S3
    s3.put_object(Bucket='weather-project-raw', Key=weather_key, Body=json.dumps(weather_data))
    s3.put_object(Bucket='weather-project-raw', Key=aqi_key, Body=json.dumps(aqi_data))
```

3.2. Data Storage:

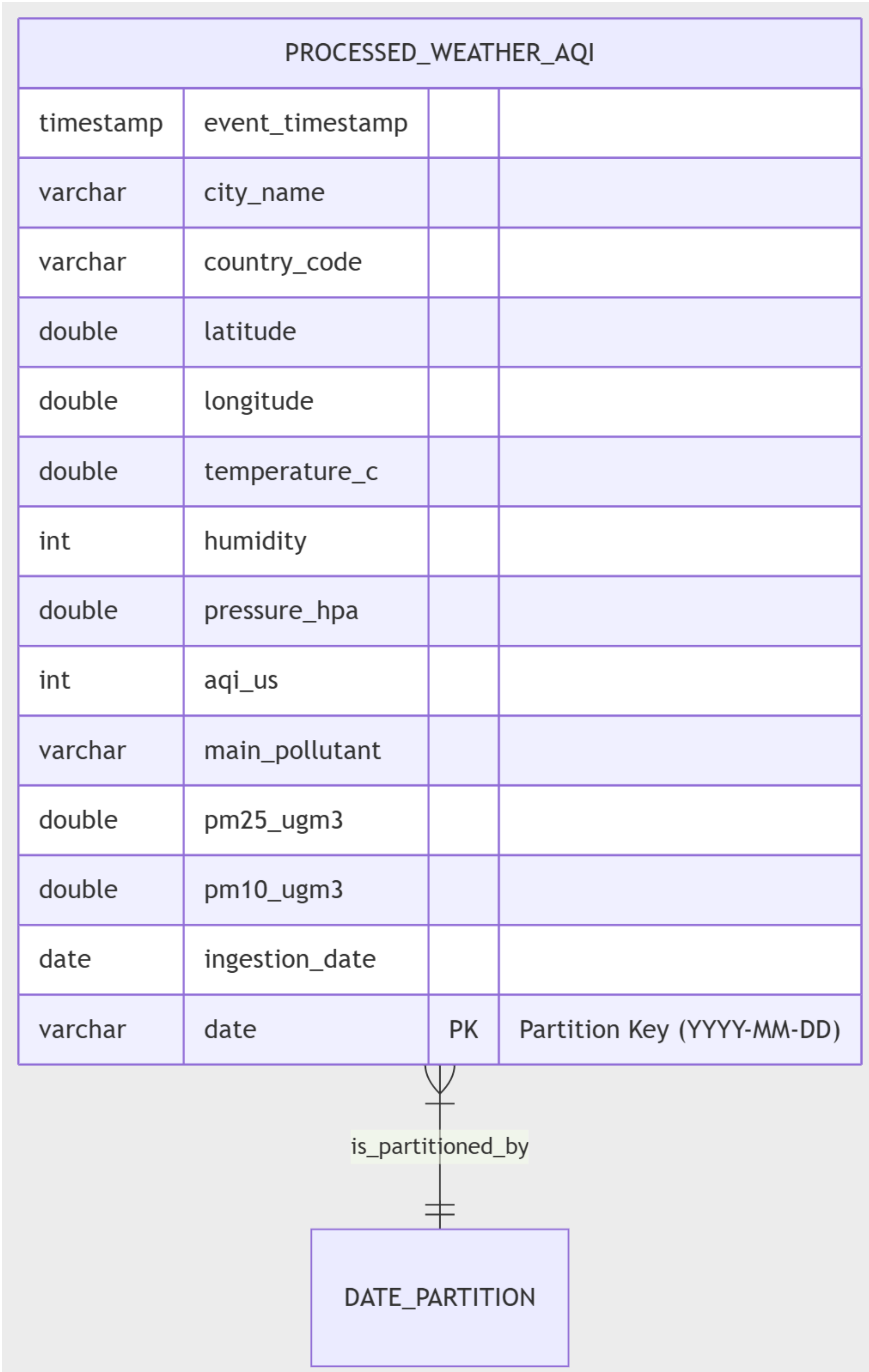
- Amazon S3 Buckets:
  - `weather-project-raw`: Storage for raw JSON API responses.
    - Partitioning: `date=YYYY-MM-DD/hour=HH/api_name/`
  - `weather-project-processed`: Storage for processed data in Parquet format.
    - Partitioning: `date=YYYY-MM-DD/`
- Data Format: Apache Parquet for the processed layer. It's columnar, compressed, and efficient for Athena queries.

3.3. Data Transformation (AWS Glue Job - Spark):

- Job Type: Spark ETL Job (Python)
- Script Logic:
  1. Create DynamicFrames from the Glue Catalog tables for `raw_weather` and `raw_aqi`.
  2. Use `Relationalize` or `Spark SQL` functions to flatten the nested structures.
  3. Select and rename relevant columns.
     - *From Weather:* `dt (timestamp)`, `name (city name)`, `main.temp`, `main.humidity`, `main.pressure`, `coord.lat`, `coord.lon`
     - *From AQI:* `data.current.pollution.ts (timestamp)`, `data.city`, `data.current.pollution.aqius`, `data.current.pollution.mainus`, `data.current.weather.hu` (humidity, for validation)
  4. Join the two datasets on city name and timestamp (might need tolerance for slightly different timestamps).
  5. Write the final DataFrame to S3 in Parquet format, partitioned by `date`.

3.4. Data Model (Processed Layer Schema):

Table Name: `processed_weather_aqi`


PROCESSED_WEATHER_AQI
timestamp event_timestamp
varchar city_name
varchar country_code
double latitude
double longitude
double temperature_c
int humidity
double pressure_hpa
int aqi_us
varchar main_pollutant
double pm25_ugm3
double pm10_ugm3
date ingestion_date
varchar date PK Partition Key (YYYY-MM-DD)
is_partitioned_by
DATE_PARTITION

4. Tools & Technologies

- Ingestion & Compute: AWS Lambda (Serverless), Python (`requests`, `boto3`)
- Orchestration: AWS EventBridge Scheduler (Simple, serverless cron)
- Storage: Amazon S3 (Durable, cheap object storage)
- Data Catalog: AWS Glue Data Catalog (Central metadata repository)
- ETL: AWS Glue (Serverless Spark)
- Data Warehouse & Querying: Amazon Athena (Serverless SQL querying on S3)
- Visualization: Amazon QuickSight (Cloud-native BI tool)
- Infrastructure as Code (IaC): AWS CDK (Python/TypeScript) or Terraform (Highly Recommended for the project). This allows you to script the creation of all resources (S3 buckets, Lambda, Glue Jobs, etc.).

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5. Implementation Plan & Milestones

1. Milestone 1: Setup & Configuration
    - Create AWS accounts (use Free Tier).
    - Sign up for API keys from OpenWeatherMap and AirVisual.
    - Write IaC script to create S3 buckets, IAM roles, and policies.
2. Milestone 2: Ingestion Pipeline
    - Write and deploy the Lambda function.
    - Configure EventBridge Scheduler to trigger it hourly.
    - Validate that raw JSON files are landing correctly in S3.
3. Milestone 3: Data Cataloging
    - Configure Glue Crawlers for the raw S3 data.
    - Verify that tables (`raw_weather`, `raw_aqi`) are created in the Glue Data Catalog.
4. Milestone 4: ETL Pipeline
    - Develop the AWS Glue ETL script (in Python).
    - Schedule the job to run after the hourly ingestion.
    - Verify that processed Parquet files are created in the `processed-layer` bucket.
    - Run a Glue Crawler on the processed data to create the `processed_weather_aqi` table.
5. Milestone 5: Analytics & Visualization
    - Run test SQL queries in Athena (e.g., `SELECT * FROM processed_weather_aqi WHERE date = '2023-10-27' LIMIT 10;`).

    - Connect QuickSight to Athena.
    - Build a dashboard with time series charts for temperature, AQI, and pollutant levels.
6. Milestone 6: Documentation & Cleanup
    - Document the project in a README (include architecture diagram, how to run, etc.).
    - Write a project summary/blog post.
    - (Optional) Create a GitHub repository with IaC code and Lambda/Glue scripts.
    - Important: Schedule a cleanup script to delete resources to avoid ongoing costs.