Microsoft Azure Hybrid Cloud for Survivable Weather Forecasting

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Abstract

The Meteorological and Oceanographic (METOC) community relies heavily on advanced computational resources and data visualization tools to support mission-critical operations. With the existing Azure on-premises hardware, specifically the Stack Edge Pro R, and an Azure IL5 subscription, there is a significant opportunity to enhance the capabilities available to METOC professionals. This whitepaper outlines a plan to maximize current hardware resources to develop meaningful products that augment and supplement existing tools within the METOC community. This project presents a solution leveraging Azure Hybrid Cloud for the Meteorology, Oceanography, and Climatology (METOC) community. Addressing the challenges of existing Programs of Record that require iridium satellite uplink, this solution is able to provide climatological data for situational awareness and mission planning, while operating in Denied, Degraded, Intermittent, or Limited (DDIL) environments, this solution enhances METOC's capability to process weather sensor data on-site and share it with the Naval Research Laboratory (NRL) and other weather analytics communities of interest. The proposed system integrates Azure Stack Edge Pro-R for on-premise processing of SKU-T (Skew-T Log-P) data, enabling efficient management, processing, and distribution of weather data using a hybrid cloud infrastructure. The architecture utilizes Microsoft Azure's Secure Cloud Access Architecture (SACA) and Azure Kubernetes Service (AKS) to provide a modern microservice capable system for meteorological data processing.

Keywords: *JADC2, Azure, SKU-T, BUFR, FastAPI, MetPy Radiosonode Observation (RAOB), GFMPL (Graphical Forecaster's Meteorological Plotting Library),*

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1. Background and Motivation

The implementation of an on-premises Azure server with cloud tenant subscription addresses fundamental operational challenges faced by existing meteorological Programs of Record that rely on iridium satellite connectivity. This hybrid infrastructure solution enhances mission planning capabilities by enabling real-time processing and analysis of climatological data in Denied, Degraded, Intermittent, or Limited (DDIL) environments. The architecture strengthens METOC's ability to process weather sensor data locally while enhancing collaborative data sharing capabilities with the Naval Research Laboratory (NRL) and other weather analytics communities of interest when connectivity becomes available. Furthermore, this solution advances Joint All-Domain Command and Control (JADC2) initiatives by establishing a framework for sensor and data-centric information sharing, facilitating improved interoperability and decision-making across military domains.

2. Equipment and Existing Infrastructure

The project leverages a hybrid cloud architecture by combining Microsoft's Azure cloud services with on-premises hardware, specifically the Azure Stack Edge Pro R device and the Micro Weather Station (MWS®) from Intellisense Systems. This integration provides a powerful and flexible platform for Meteorological and Oceanographic (METOC) applications, enabling localized data processing and reducing dependency on external communication links.

2.1. Azure Stack Edge Pro R

Figure 1. Azure Stack Edge Pro R (ASE®)

The **Azure Stack Edge Pro R** is a high-performance edge computing device designed for data processing and machine learning workloads at the network's edge. Deploying this device on-premises offers several advantages:

- **Localized Weather Analysis**: By processing data locally, we can perform real-time or near-real-time weather analysis, which is critical for operational decision-making in METOC.
- **Reduced Dependency on Satellite Links**: Local processing minimizes reliance on the Iridium satellite link, conserving bandwidth and reducing costs associated with satellite communications.
- **Enhanced Security**: Keeping sensitive data within the local network mitigates risks associated with transmitting data over external networks.
- **Operational Resilience**: The system remains functional even in environments with limited or disrupted connectivity, ensuring continuous support for METOC operations.

2.2. Micro Weather Station (MWS®)

The **Micro Weather Station (MWS®)** from Intellisense Systems is a compact, ruggedized, and highly capable weather monitoring device designed for military applications. It provides a comprehensive suite of meteorological measurements essential for METOC operations.

Figure 2. Micro Weather Station (MWS®)

2.2.1. Overview

This guide serves as a comprehensive overview of the installation and operation of the Military Series of Micro Weather Stations (MWS®) from Intellisense Systems. The MWS Military Series includes two models: **M525** and **M625**. Both models are designed to provide critical environmental data in a compact form factor.

2.2.2. Features

- **Integrated Solar Panels**: Both models feature integrated solar panels for extended autonomous operation.
- **Integrated NiCd Battery Pack**: Provides reliable power storage for continuous functionality.
- **Supports Cloud-based Data Processing**: Enables seamless integration with cloud services for data analysis.

2.2.3. Measurements and Capabilities

The MWS® provides a wide range of meteorological measurements:

- Temperature
- Pressure (Barometric)
- Humidity
- Altimeter
- Wind Speed and Direction
- Angular Tilt
- Dust Accumulation
- Lightning Count and Distance
- GPS Positioning
- Compass Heading
- Precipitation Amount
- Present Weather Conditions
- Visibility
- 360° Panoramic Camera

Additionally, the M625 model includes:

- **Ceilometer**: For measuring cloud base height.

2.2.4. Communication Options

- **Cabled Communication (RS-232 to USB)**: Allows direct connection to computing devices for data transfer.
- **Iridium Short Burst Data (SBD)**: Enables satellite communication for remote data transmission.

2.2.5. Benefits for METOC Applications

Incorporating the MWS® into our equipment lineup offers several advantages:

- **Comprehensive Data Collection**: Provides essential meteorological data required for accurate weather analysis and forecasting.
- **Autonomous Operation**: Integrated power solutions allow for deployment in remote or austere environments without external power sources.
- **Durable and Rugged Design**: Built to military specifications to withstand harsh environmental conditions.
- **Reduced Dependency on Satellite Communications**: While capable of Iridium SBD, local data processing minimizes reliance on satellite links, preserving bandwidth.

2.2.6. Integration with Azure Stack Edge Pro R

By connecting the MWS® directly to the Azure Stack Edge Pro R via cabled communication, we can:

- **Process Data Locally**: Perform on-site data analysis without the need for continuous satellite communication.
- **Enhance Data Security**: Keep sensitive meteorological data within the secure local network.
- **Improve Response Times**: Immediate access to processed data aids in rapid decision-making.

2.3. Benefits of Hybrid Cloud and Edge Computing

Implementing a hybrid cloud architecture with edge computing offers several key advantages for METOC applications:

- **Reduced Latency**: Processing data locally on the edge device minimizes latency, enabling timely analysis and response.
- **Bandwidth Optimization**: Local data processing reduces the need for high-bandwidth connections to the cloud, preserving bandwidth for other critical communications.
- **Reliability**: The system's functionality is less dependent on external network conditions, enhancing reliability in challenging environments.
- **Flexibility**: A hybrid approach allows for workload distribution between local and cloud resources based on operational requirements.

By combining the capabilities of the Azure Stack Edge Pro R and the Micro Weather Station with the Azure IL5 Subscription, we establish a robust and efficient platform. This setup enhances METOC operations by providing localized processing power and comprehensive weather data while maintaining the flexibility and scalability of cloud services. It addresses the limitations of relying solely on satellite communication links like Iridium, which can be bandwidth-constrained and less reliable in certain operational contexts.

3. Goals and Objectives

- **Maximize Hardware Utilization**: Leverage the capabilities of the Azure Stack Edge Pro R to enhance METOC operations.
- **Develop User-Centric Tools**: Create applications that directly address the needs of METOC professionals, improving efficiency and data accessibility.
- **Enhance Data Ingestion and Visualization**: Streamline the process of data acquisition and present data in an accessible, graphical format.

4. Project Thrusts

4.1. Upper Air Visualization

Objective: Ingest Radiosonde Observation (RAOB) text-formatted data and display it graphically to improve upper-air analysis.
Approach:

- **Prototype Development**: Create a web application similar to GFMPL using FastAPI and MetPy for deployment via a web interface.
- **Data Access**:
  - Utilize non-PKI methods to demonstrate capability.
  - Download data to blob storage within the tenant and synchronize it to the edge device.
- **NEXTGEN Integration**:
  - Incorporate the capability to ingest sounding information directly from NEXTGEN systems.
  - Synchronize ingested data back to the tenant blob storage for centralized access.

4.2. Electromagnetic (EM) Propagation

Objective: Deploy EM propagation modeling tools to support scenario planning and operational decision-making.
Approach:

- **Interactive Scenario Builder Deployment**:
  - Install a lightweight version of the "Builder" on the edge device.
- **Data Integration**:

    - Use sounding data from Upper Air Visualization (especially direct ingest from NEXTGEN) to drive small scenarios.
- **Advanced Modeling**:
    - If feasible, download 3D atmospheric model data from FNMOC to the tenant's blob storage and sync it to the edge device for enhanced scenario modeling.

4.3. Data Science and Exploration

Objective: Provide tools for data scientists to explore and analyze METOC data effectively.

Approach:

- **JupyterHub Deployment**:
    - Install JupyterHub on the edge device to enable collaborative data analysis.
- **Data Accessibility**:
    - Configure storage solutions to allow access to sounding data from NEXTGEN or other sources within JupyterHub.
- **Enhanced Analytics**:
    - Facilitate the development of custom scripts and models for data interpretation.

5. Gaps and Challenges

1. **Data Acquisition**:
    - Obtaining URLs for the USMC to test data downloads into their subscription.
    - Identifying non-PKI data sources for upper-air soundings outside of AFWEBS/FNMOC.
    - Provisioning all required personnel (to include non-DoD) access to USMC IL5 Tenant
2. **Software Deployment**:
    - Getting the Builder-Lite application running with profiles on the edge device.
    - Deploying Azure Kubernetes Service (AKS) on the edge device and the landing zone.
3. **Data Integration**:
    - Integrating profiler data onto the edge device.
    - Establishing PKI solutions to access AFWEBS securely.

6. Unknowns

1. **FNMOC Data Access**:
    - Determining whether the USMC can download data from FNMOC into their tenant environment.
2. **AKS Deployment**:
    - Clarifying the process for deploying AKS on the edge device.
3. **NEXTGEN Connectivity**:
    - Understanding how to connect NEXTGEN systems directly to the edge device for data ingestion.

Integration Challenges with Program Offices

Currently, there is no charter for comprehensive integration between these efforts and the program offices. This gap results in insufficient programmatic funding and engineering support, which hinders the progress and effectiveness of these initiatives. Establishing a holistic integration strategy is crucial to ensure that resources are allocated efficiently, communication is streamlined, and all stakeholders are aligned with the project goals. By improving collaboration, we can secure the necessary funding and engineering support to advance these efforts successfully.

7. MWS Data Format and Skew-T Visualization

The Micro Weather Station (MWS®) data output requires specific processing to generate Skew-T visualizations for atmospheric analysis. This section details the relationship between raw MWS output and its corresponding representation in Skew-T format.

7.1. Skew-T Visualization Example

Figure 3 shows a typical Skew-T diagram generated from atmospheric data.

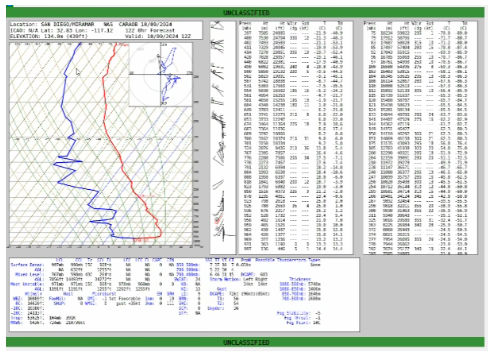

Figure 3. Example Skew-T diagram showing temperature (red) and dew point (blue) profiles with wind barbs (right).

7.2. MWS Raw Data Format

The MWS transmits data through RS-232 in the following format:

```
@I:356726109932152      # Station Identification
T:20/04/29,23:27:13     # Timestamp
LA:34.99414             # Latitude
LO:-108.33632           # Longitude
EL:68:D                 # Elevation
TA:22.4                 # Temperature (°C)
BA:1006.50:2995         # Pressure (mb)
RH:73                   # Humidity (%)
WI:4:357                # Wind (kt:deg)
```

7.3. Data Correlation

The relationship between MWS output and Skew-T elements is as follows:

- **Temperature Profile (Red Line)**
    - MWS Tag: `TA:22.4`
    - Skew-T: Surface temperature anchor point
- **Pressure Levels**
    - MWS Tag: `BA:1006.50:2995`
    - Skew-T: Surface pressure baseline
- **Wind Barbs**
    - MWS Tag: `WI:4:357`
    - Skew-T: Surface wind indicator

7.4. Data Processing Requirements

To generate Skew-T visualizations from MWS data:

1. Surface observations from MWS establish the diagram's base point
2. Temperature and dew point profiles require vertical interpolation
3. Wind barbs at altitude require additional data sources
4. Pressure levels must be calculated using standard atmospheric models

7.5. Implementation Considerations

When integrating MWS data with Skew-T visualization:

- Surface data provides initialization points
- Vertical profiles require supplemental upper-air data
- Time synchronization between measurements is critical
- Data validation must precede visualization

This integration enables comprehensive meteorological analysis by combining surface observations with upper-air profiles in a standardized visual format.

8. Pseudocode for GFMPL-like Web Application

- We define sample weather sounding data. In a real application, this would be fetched from an API or loaded from a file.
- The SoundingChart component renders a Card containing the chart.
- We use the ChartContainer from shadcn/ui to set up the chart configuration.
- Inside the ChartContainer, we use recharts' ResponsiveContainer and LineChart to create the actual chart.
- We set up the X and Y axes. The X-axis represents temperature, while the Y-axis represents pressure. Note that the Y-axis is reversed to match standard meteorological convention (lower pressures at the top).
- We add two Line components to represent temperature and dewpoint.
  To make this a full GFMPL-like application, you would need to add more features such as:
- 1. Data loading from real weather sources
- 2. Additional chart types (e.g., wind barbs, humidity)

```
"use client"

import { Line, LineChart, XAxis, YAxis, CartesianGrid, Tooltip, Legend, ResponsiveContainer } from "recharts"
import { Card, CardContent, CardDescription, CardHeader, CardTitle } from "@/components/ui/card"
import { ChartContainer, ChartTooltip, ChartTooltipContent } from "@/components/ui/chart"

// Sample weather sounding data
const soundingData = [
  { pressure: 1000, temperature: 25, dewpoint: 20, height: 0 },
  { pressure: 925, temperature: 20, dewpoint: 15, height: 762 },
  { pressure: 850, temperature: 15, dewpoint: 10, height: 1524 },
  { pressure: 700, temperature: 5, dewpoint: 0, height: 3048 },
  { pressure: 500, temperature: -15, dewpoint: -20, height: 5572 },
  { pressure: 300, temperature: -40, dewpoint: -45, height: 9144 },
  { pressure: 200, temperature: -60, dewpoint: -65, height: 11887 },
  { pressure: 100, temperature: -70, dewpoint: -75, height: 16154 },
]

export default function SoundingChart() {
  return (
    <Card className="w-full max-w-4xl">
      <CardHeader>
        <CardTitle>Weather Sounding Visualization</CardTitle>
        <CardDescription>Temperature and Dewpoint vs Pressure</CardDescription>
      </CardHeader>
      <CardContent>
        <ChartContainer
          config={{
            temperature: {
              label: "Temperature",
              color: "hsl(var(--chart-1))",
            },
            dewpoint: {
              label: "Dewpoint",
              color: "hsl(var(--chart-2))",
            },
          }}
          className="h-[500px]"
        >
          <ResponsiveContainer width="100%" height="100%">
            <LineChart data={soundingData} margin={{ top: 5, right: 30, left: 20, bottom: 5 }}>
              <CartesianGrid strokeDasharray="3 3" />
              <XAxis
                dataKey="temperature"
                type="number"
                label={{ value: 'Temperature (C)', position: 'bottom', offset: 0 }}
                domain={[-80, 40]}
                ticks={[-80, -60, -40, -20, 0, 20, 40]}
              />
              <YAxis
                dataKey="pressure"
                type="number"
                domain={[100, 1000]}
                reversed={true}
                label={{ value: 'Pressure (hPa)', angle: -90, position: 'insideLeft' }}
              />
              <ChartTooltip content={<ChartTooltipContent />} />
              <Legend />
              <Line
                type="monotone"
                dataKey="temperature"
                stroke="var(--color-temperature)"
                name="Temperature"
                dot={false}
              />
              <Line
                type="monotone"
                dataKey="dewpoint"
                stroke="var(--color-dewpoint)"
                name="Dewpoint"
                dot={false}
              />
            </LineChart>
          </ResponsiveContainer>
        </ChartContainer>
      </CardContent>
    </Card>
  )
}
```

Code 1. Example of matlab code.

```
\addbibresource{rho.bib}
```

9. Terminology

9.1. Terminology

This section provides definitions and explanations of key terms and technologies referenced throughout this document. Understanding these concepts is essential for comprehending the project's objectives and methodologies.

9.2. Radiosonde Observation (RAOB)

A **Radiosonde** is a battery-powered telemetry instrument carried into the atmosphere typically by a weather balloon. It measures various atmospheric parameters and transmits them by radio to a ground receiver. **Radiosonde Observation (RAOB)** refers to the collected data, which includes:

- **Temperature**
- **Humidity**
- **Pressure**
- **Wind Speed and Direction**

This data provides a vertical profile of the atmosphere and is crucial for weather forecasting and atmospheric research.

9.3. Skew-T Log-P Diagram (Skew-T)

A **Skew-T Log-P Diagram**, commonly known as **Skew-T**, is a thermodynamic chart used to plot vertical profiles of atmospheric temperature and dew point data obtained from radiosondes. The diagram is called "Skew-T" because the temperature lines are skewed at a 45-degree angle to the vertical. Features of a Skew-T diagram include:

- **Isobars**: Horizontal lines representing constant pressure levels.
- **Isotherms**: Skewed lines representing constant temperatures.
- **Dew Point and Temperature Profiles**: Plotted to assess moisture content and temperature changes with height.
- **Wind Barbs**: Indicate wind speed and direction at various altitudes.
- **Adiabatic Lapse Rates**: Lines indicating temperature changes in rising or sinking air parcels.

Skew-T diagrams are essential tools for meteorologists to assess atmospheric stability, predict weather phenomena like thunderstorms, and understand vertical atmospheric structure.

9.4. Joint All-Domain Command and Control (JADC2)

JADC2 is a Department of Defense (DoD) initiative aimed at connecting sensors from all military services—Air Force, Army, Marine Corps, Navy, and Space Force—into a single network. The goal is to enable faster decision-making by sharing data seamlessly across domains and services.

9.5. Azure

Microsoft Azure is a cloud computing service created by Microsoft for building, testing, deploying, and managing applications and services through Microsoft-managed data centers. Key features include:

- **Computing Power**: Virtual machines, containers, and serverless computing.
- **Storage Solutions**: Scalable storage options for data.
- **Networking**: Virtual networks, load balancers, and gateways.
- **Analytics**: Data processing and analysis tools.

Azure plays a significant role in this project by providing cloud services and on-premises hardware integration.

9.6. BUFR (Binary Universal Form for the Representation of meteorological data)

BUFR is a binary data format maintained by the World Meteorological Organization (WMO) for the efficient exchange and storage of meteorological data. It is designed to be platform-independent and supports a wide range of data types, including:

- **Surface Observations**
- **Upper-Air Observations**
- **Satellite Data**
- **Radar Data**

BUFR is highly flexible and can be expanded to include new data types as needed.

9.7. FastAPI

FastAPI is a modern, high-performance web framework for building APIs with Python 3.6+ based on standard Python type hints. It offers:

- **High Performance**: Comparable to Node.js and Go.
- **Easy to Use**: Intuitive design that promotes rapid development.
- **Standards-Based**: Built on OpenAPI (formerly Swagger) and JSON Schema.
- **Asynchronous Support**: Allows for efficient handling of concurrent requests.

FastAPI is used in this project to develop web applications for data ingestion, processing, and visualization.

9.8. MetPy

MetPy is an open-source Python library for meteorological data processing and visualization. It provides tools for:

- **Reading Meteorological Data**: Supports formats like RAOB, BUFR, and more.
- **Calculations**: Thermodynamic calculations, wind computations, and other meteorological functions.
- **Visualization**: Plotting routines for Skew-T diagrams, maps, and other meteorological charts.

MetPy is instrumental in processing and visualizing atmospheric data within the project's applications.

9.9. Radiosonde

A **Radiosonde** is an instrument package carried by a weather balloon to collect atmospheric data. It measures temperature, humidity, pressure, and wind data as it ascends through the atmosphere. The data is transmitted back to ground stations for analysis.

9.10. GFMPL (Graphical Forecaster's Meteorological Plotting Library)

GFMPL stands for **Graphical Forecaster's Meteorological Plotting Library**. It is a conceptual tool designed to visualize meteorological data, particularly upper-air observations. In this project, GFMPL represents an application that leverages FastAPI and MetPy to create web-based visualizations like Skew-T diagrams.

9.11. Conclusion

Understanding these terms is fundamental to grasping the project's scope and technical details. These technologies and concepts collectively contribute to enhancing the capabilities of the METOC community in data processing, analysis, and visualization.

10. Contact

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