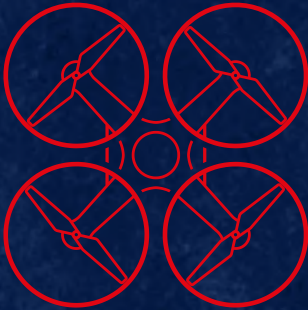August 2024

Weather Precision for BVLOS DFR Operations

**Response-ready weather solutions
for public safety resilience**

TruWeather Solutions

DRONERESPONDERS

WHITE PAPER

PREPAREDNESS. RESPONSE. RESILIENCE.

Introduction

DRONERESPONDERS' initiative aims to develop and share best practices, provide education and training, and advocate for the safe integration of unmanned aircraft systems (UAS) into emergency and public safety response frameworks. TruWeather Solutions has been working with DRONERESPONDERS for five years, including participation in the Drone as First Responder (DFR) Working Group, to bring weather education to the forefront of emergency and public safety services as part of their knowledge sharing platform.

The primary mission for responders is to protect lives and property, but agencies are often constrained by budgets and must justify expenditures to stakeholders, including taxpayers, government officials, and grant providers. Demonstrating a positive return of investment (ROI) helps these programs secure funding, optimize resource allocation, and improve operational efficiency. By integrating precision weather intelligence into operations, departments can enhance their preparedness, allowing them to conduct missions more safely and efficiently. This approach optimizes the use of high-demand assets, ultimately saving lives and protecting property. This paper will bring to light the components of precision weather needed to achieve measurable outcomes and support a quantifiable ROI for drone programs. By proving that these investments lead to better outcomes and cost savings, public safety programs can justify their budgets and continue to enhance their capabilities.

While preparedness and readiness may appear synonymous at first glance, there exists a subtle yet significant distinction between the two concepts. Preparedness refers to the state of being equipped or supplied for a task, often involving comprehensive training programs and the development of Tactics, Techniques, and Procedures (TTPs). This ensures that personnel are well-prepared, with ingrained "muscle memory," to perform at peak effectiveness when faced with a threat. On the other hand, readiness emphasizes the ability to act swiftly and decisively in real-time situations. Although

preparedness is a key component of readiness, being prepared does not always guarantee that one is ready to respond immediately to a given situation. The introduction of drones into the first responder system has significantly shifted procedures and reframed the requirements for operational readiness.

Strategies and protocols developed for adverse weather are instrumental in the efficiency and scalability of DFR programs. The weather aspect of TTPs requires novel approaches to ensure that all elements of readiness are addressed, particularly in the context of unpredictable and unseen weather conditions.

When coordinating responses to emergency situations, real-time data and data integrity are crucial for effective preparation, response, and recovery. Developing a DFR weather program begins with understanding the precision weather intelligence required for specific applications, workflows, and decisions that ensure mission success. This strategy necessitates a thorough knowledge of both well-known and lesser-known weather impacts, and the available innovative technology and infrastructure needed to reduce operational disruptions and manage situations with informed weather insights and discipline.

Shortfalls in Current Aviation Weather System and Infrastructure

Despite significant advancements in weather forecast models, the current weather observation network still lacks the necessary data to effectively detect and forecast weather in low-level airspace. The current aviation weather service framework was designed for large, weather-resilient human-crewed aircraft operating from well-instrumented airports. With ground-based weather stations predominantly located at airports, only three percent of the United States has sufficient cloud height and visibility data. Collecting data on winds above the ground and cloud icing presents an even greater challenge.

During Visual Line of Sight (VLOS) operations, pilots can directly observe and respond to weather conditions. However, UAS remote or Beyond Visual Line of Sight (BVLOS) operations introduce significant challenges because pilots cannot monitor the weather conditions throughout the entire route. Current weather products often rely on model estimates, which may not accurately reflect real-time conditions. This can lead to unexpected weather events, even during VLOS flights, such as sudden winds, wind shear, turbulence, reduced visibility, precipitation, and icing. These weather-related risks can drain battery power, delay arrivals, disrupt communications, and compromise flight stability. Traditional weather monitoring methods often fail to capture these risks in real-time, adding a layer of uncertainty to the decision-making process during flight operations.

One key aspect of weather intelligence involves obtaining data that captures winds at various altitudes (100, 200, 300, or 400 feet AGL) that can identify actual wind speeds at flight level, wind gust spreads, wind shear generated by inversions, updrafts, and downdrafts. This level of detail is not typically available through commercial weather apps or the National Weather Service. These sources often fail to account for microclimate wind events, particularly in hilly terrains or near land-water interfaces. Additionally, they do not address the predictability challenges associated with maintaining control of drones in urban environments. In city canyons, rapid changes in wind speed and direction from one street corner to the next can create dangerous eddies due to building-induced wake turbulence, making precise and reliable weather data

essential for safe and effective UAS operations.

A lesser-known weather challenge is understanding thermal crossover and its impact on the ability to detect trapped individuals or pets. In UAS search and rescue missions, the effectiveness of infrared (IR) sensors can be significantly influenced by absolute humidity, which differs from relative humidity. Common weather apps and data sources typically do not provide measurements or forecasts for absolute humidity. The human eye cannot discern whether IR sensor performance is being degraded by absolute humidity, which refers to the amount of invisible water vapor in the air. This lack of data can hinder the ability to detect heat signatures accurately, underscoring the need for specialized weather intelligence to ensure successful search and rescue operations.

To be clear, the aviation weather system that has enabled the safest aviation system in the world is important to reference. But it is only a baseline for what must come next for 21st century weather technology needed to ensure safe and effective ubiquitous flight of UAS.

Microclimate Impacts
on DFR Missions

Microweather Effects	Winds at Flight Level	Reduced Visibility and Ceilings	Extreme Temperatures	Precipitation
Flight Stability and Safety	Sudden gusts of winds can destabilize drones, especially smaller drones, leading to loss of control	Fog raises collision risk with other drones, buildings, trees and powerlines	Localized heating of the Earth's surface can cause thermal updrafts affecting drone altitude and flight path	Precipitation intensity reduces performance by increasing drag, reducing lift and compromises control
Battery Performance and Energy Efficiency	Flying against strong winds require more power, reduces battery life, reduces range and flight time	Fog, smoke and smog can hinder camera and sensor performance, leading to inaccurate obstacle detection	High temps reduce drone propeller lift and performance; cold temps decrease battery life, output & range	Rain can pose hazards to electronical components leading to short circuits, corrosion & component failure
Data Collection Accuracy	Strong wind can disrupt onboard sensors and communications, affecting data quality and video quality	Fog and mist can limit visibility, impacting the drone's ability to navigate and collect data	Extreme temps affect navigation & detection sensors; cold slowing them down and heat causing drift	Rain or snow can impact drone sensors and cameras, impacting data quality, especially in surveillance

Weather-related risks for drone operations vary depending on geographical climates (i.e., different areas of the country) and topography. Likewise, urban, suburban, and rural municipalities all have unique challenges, including weather instrument availability and location specific microweather challenges.

Source: Brookhaven PD

Urban Example: New York City

Weather can significantly affect drone flight in urban areas in several ways, whether it is wind, visibility, temperature, or a combination of all three. The presence of tall buildings and structures can also create canyon effects that produce unpredictable wind environments in urban centers.

Urban Microweather Risks in Drone Operations: Drone operations in urban areas face unique weather challenges. These include erratic wind patterns due to tall buildings, turbulence in narrow spaces, reduced visibility from pollution, and temperature variations caused by urban heat islands. For example, in New York City, southwest winds can create wind tunnels through urban structures,

significantly impacting drone stability and control. Additionally, urban heat islands can alter wind patterns, affecting lower atmosphere dynamics. Heat islands also affect density altitude, impacting drone lift response. Computational models are invaluable for visualizing these effects and understanding boundary layer phenomena, helping to mitigate these risks and improve operational safety.

Weather Sensor Analysis: There is an abundant supply of public sources for data in New York City. The main concern is the sensor height limitation and placement, which may affect wind data accuracy due to nearby buildings.
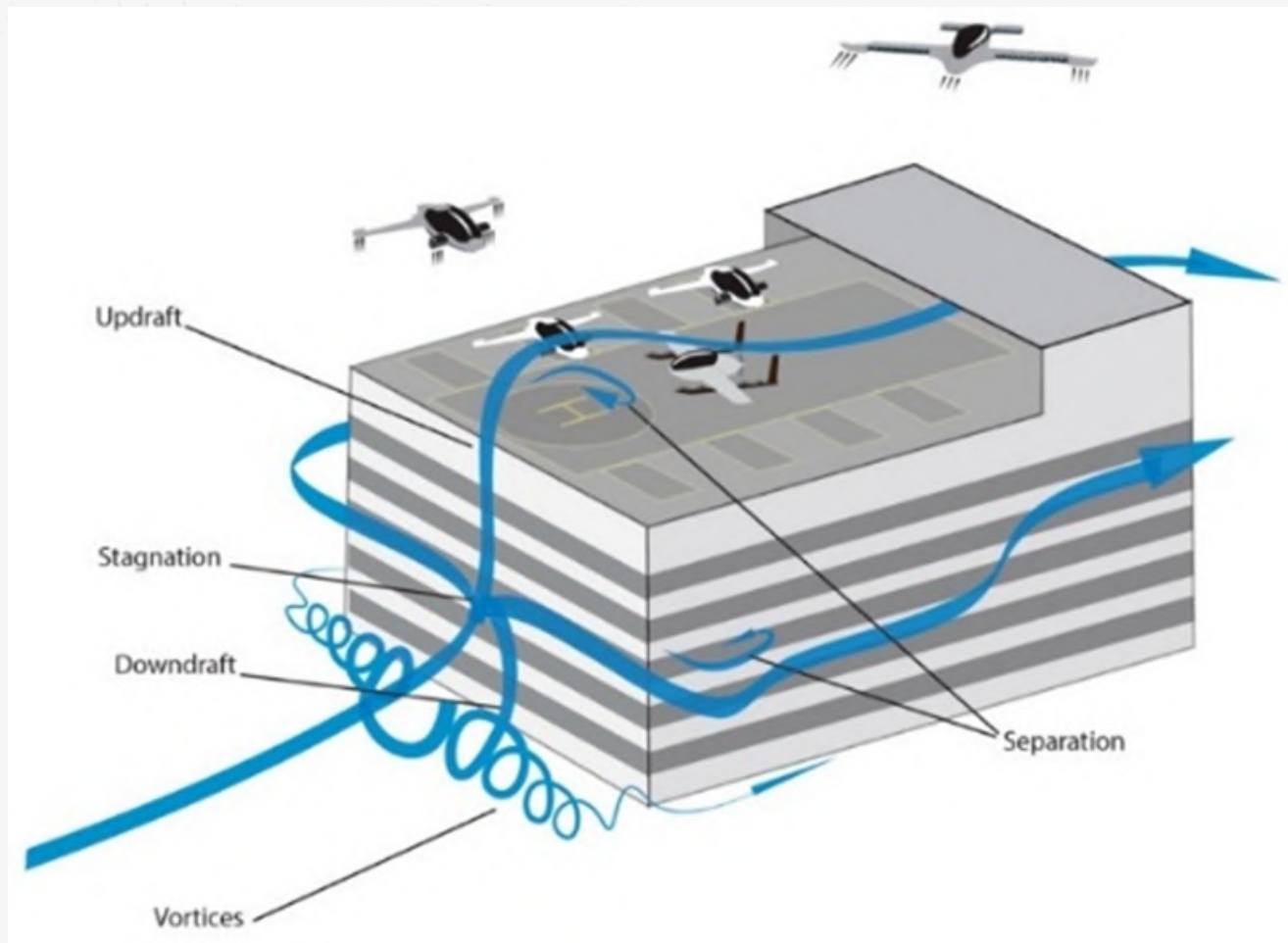

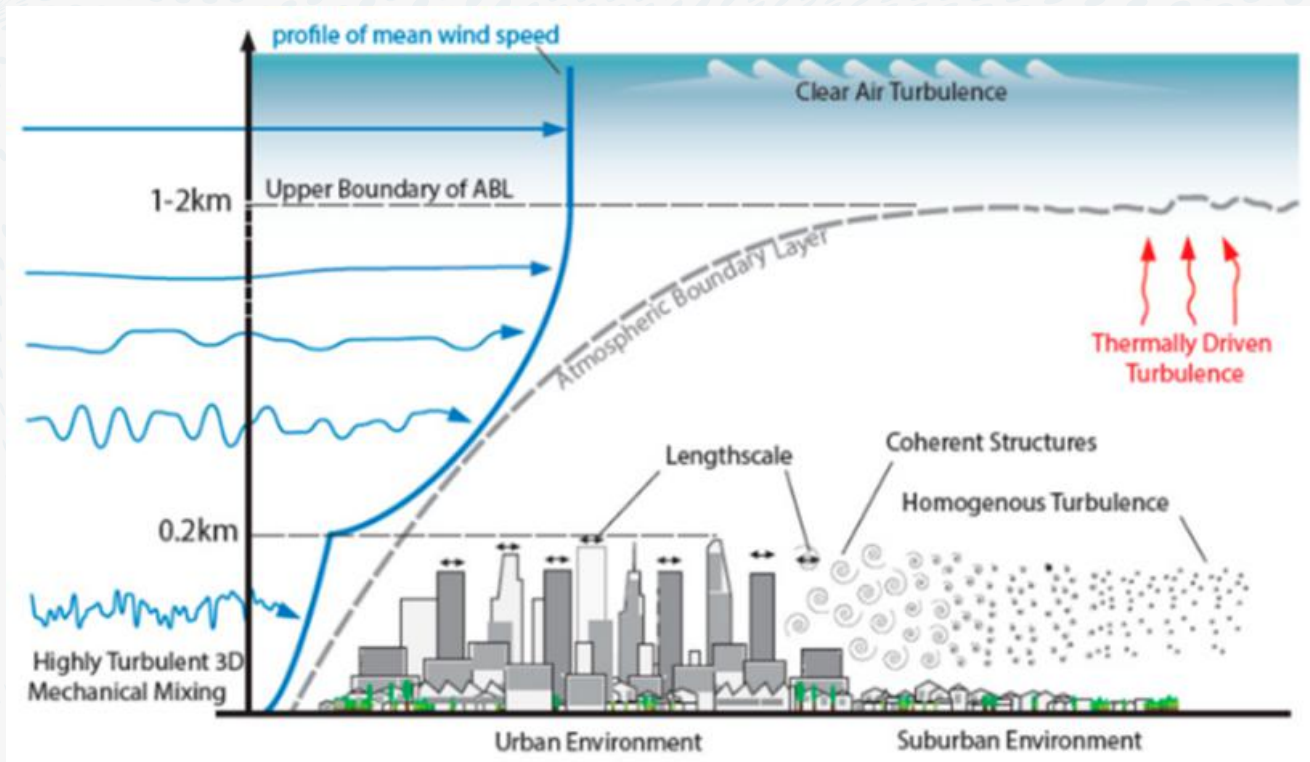Figure 1: Wind flow patterns around buildings

Figure 2: This further illustrates the decaying nature of turbulence in an urban scenario, whereby the coherent structures dissipate downstream of obstacles, and a well-mixed turbulent wake then develops (as can be seen downstream of the building in the figure). These flow features yield a velocity field with a broad spectral content that contains a wide range of length and time scales.
Source for Figure 1 and 2: Mohamed, A, et al, (2023), doi.org/10.3390/drones7010022

Suburban Example: Holly Springs, North Carolina

Suburban areas like Holly Springs present unique weather challenges for drone operations due to elevated winds, frequent thunderstorms, and localized wind patterns affecting stability during take-off and landing. Visibility is a key issue, from the increased likelihood of localized fog in the region.

Specific Microweather Risks Specific for Suburban Regions: In the suburban Southeast, dense areas of trees keep elevated winds above the tree line while the surface winds remain calm, especially during the early morning hours. Additionally, visibility challenges arise from localized fog based on land-use and water proximity, varying within the same town. Finally, frequent thunderstorms, especially during the spring and summer months can cause gusty winds, heavy precipitation, and lightning strikes, all of which pose threats to the drone. All these weather phenomena become more difficult for a remote pilot to "experience" and understand. The pilot is not operating within the same environment the drone is operating.

Weather Sensor Analysis: When conducting DFR missions in suburban areas like Holly Springs, North Carolina, weather sensors are spaced further apart due to the lack of nearby METAR data. This can cause challenges during rapidly changing weather conditions like morning fog and afternoon thunderstorms. Weather measurements require a higher density of coverage to compensate for the loss of the pilot eyes and weather services require a level of customization for collecting and updating real weather reports frequently and presenting the weather picture in a simple way through Command and Control Systems that should include local alerting and geo-fencing of wind and weather risk areas.
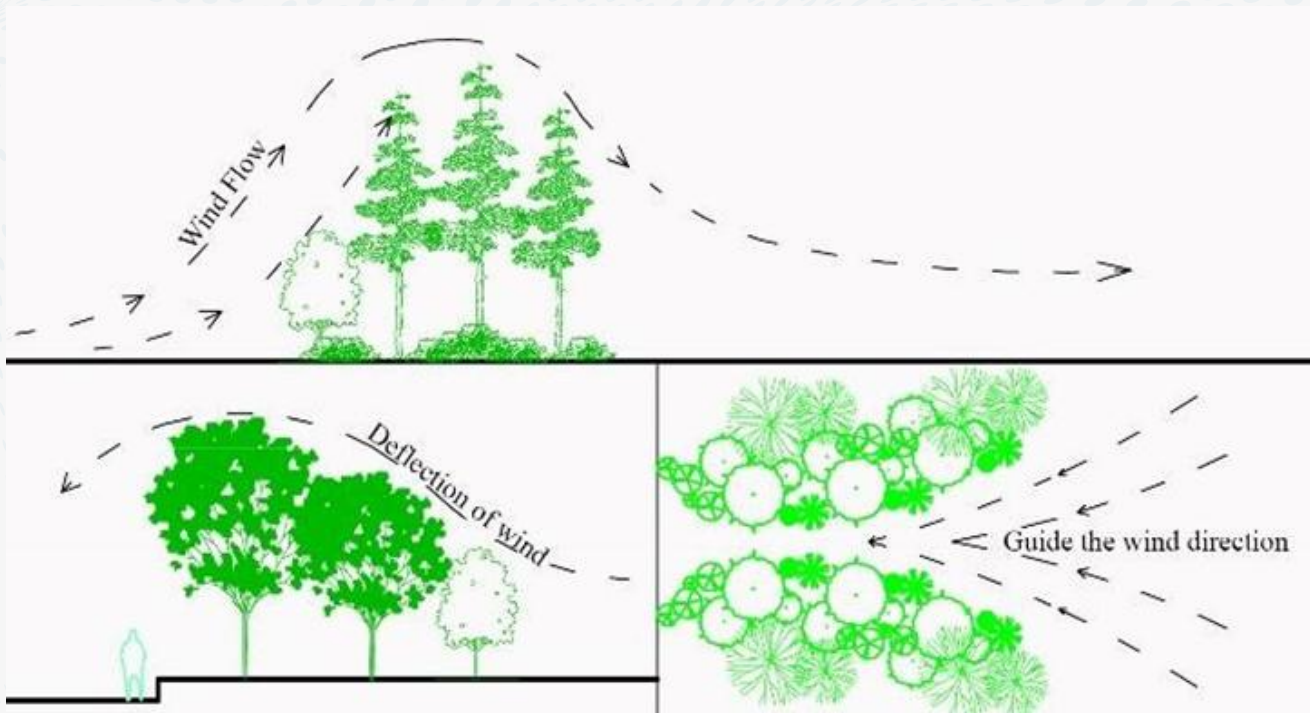
Figure 3: Le Minh, Tuan & Tran, Nguyen. (2019). Features of the formation of urban heat islands effects in tropical climates and their impact on the ecology of the city. E3S Web of Conferences. 91. 05005. 10.1051/e3sconf/20199105005.

Rural Example: Fauquier County, Virginia

In rural areas, diverse terrain features like mountains and valleys create localized weather effects such as strong small-scale wind flow that is not detectable with the current observation systems, and downdrafts and turbulence that impact drone stability and control. Valleys near water bodies can lead to fog and low clouds in rural areas. In some regions, such as the Great Lakes states or areas with mountainous terrain like the Appalachians, the National Weather Service's radar may not detect precipitation accurately due to the beam height being above the level where the precipitation forms. This issue is particularly pronounced for low-level precipitation like drizzle or freezing drizzle, which is difficult for radar systems to detect, especially in rural areas where the existing weather reporting network may have limitations.

Specific Microweather Risks Specific for Rural Areas: In rural areas, open landscapes and complex terrain make drones susceptible to high winds, turbulence, gusts, and wind shear. Morning fog in rural valleys also adds to navigational challenges.

Weather Sensor Analysis: Rural communities, like Fauquier County, Virginia have less access to weather instrumentation with distant METARs. This leads to potential inaccuracies in weather data, especially in areas without sensors displaying crucial information like wind speed and visibility.

LOGISTICS AND RESOURCE MANAGEMENT

The Value of Weather Intelligence

Drones quickly deployed to a target site provides real-time aerial views and situational awareness that can be critical in the early stages of a response.

Weather intelligence plays a vital role to enhance response times and maximize flight duration. Without adequate low-altitude data, drones may face inefficient routing, leading to longer flight times and higher energy consumption. This not only reduces the number of missions that can be completed on a single charge but also increases response time.

Prevailing Tailwind During Response Flight: In aviation and drone operations, the term "tailwind" denotes a wind that blows in the direction of travel, influencing speed and performance. Tailwinds boost flight efficiency, leading to decreased energy usage. By digitally analyzing prevailing winds, drone missions can be optimized for efficiency. Drone routes and infrastructure planned with the prevailing winds accounted for can reduce responsetimes for delivering essential equipment such as AEDs and EpiPens.

Optimal Microweather Routing: Accurate weather data

enables the optimization of flight paths to avoid adverse weather conditions, thus ensuring quicker and safer routes. This efficiency can be crucial in emergencies where time is of the essence. Anticipating (which is an aspect of readiness) and knowing precise weather conditions before launching allows for better resource allocation, ensuring that the most suitable drones and equipment are deployed for specific weather scenarios.

Increased Uptime: With reliable weather forecasting, DFR operations can minimize downtime caused by unexpected weather conditions, ensuring that drones are available for missions whenever needed. This confidence in the continuity of operations is a direct result of accurate weather data, which allows for the extension of operational windows, enabling DFR missions to be conducted during times when they would otherwise be grounded due to uncertain weather.
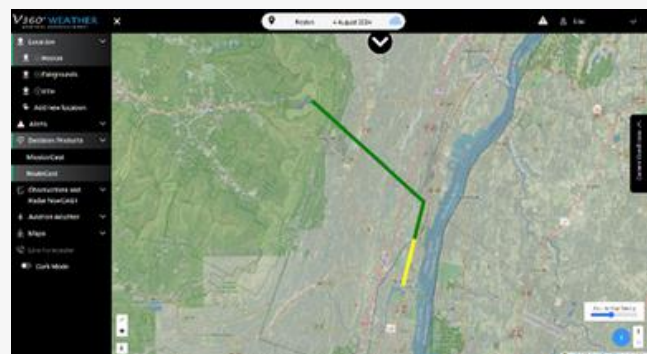

Figure 4 and 5: Side by side comparison of wind thresholds (V360 Weather, RouteCAST Decision Tool). By changing the flight path, the drone can reach its destination in a shorter amount of time and with more battery life.

TECHNOLOGY TRANSFORMATION

Data Integrity and Optimization
Across the Value Chain

This is where precision comes into play. Weather 4.0 is an evolving concept that aligns with the principles of Industry 4.0, focusing on integrating advanced technologies to enhance weather monitoring and forecasting. It leverages IoT (Internet of Things) sensors, edge computing, advanced analytics, and machine learning algorithms to provide precise, real-time weather data and insights.

This approach transforms traditional weather systems by incorporating numerous data sources, including previously inaccessible data from existing and supplementary sensors, to deliver rapid refresh rates and high accuracy.

Key aspects of Weather 4.o include

1. IoT Integration: Utilizing IoT sensors to gather comprehensive weather data from diverse locations, not limited to traditional weather stations for real-time monitoring and fusion

2. Weather Data Integrity: Emphasizes the importance of validating and verifying weather data. It includes protocols for checking the accuracy of data, identifying and correcting errors, and ensuring that data is representative of the actual conditions - see ASTM F38 (23-06)

Weather 4.0 is a fusion of advanced information and communication technology – *An end-to-end information stream on multiple levels across the value chain that will enable new services and transform business models.*

The goal is to empower autonomous decision-making processes, monitor assets and processes in real-time, and enable real-time connected value creation networks with data integrity and compliance.

The result is to be more agile, innovative, streamlined and efficient for better service-driven results and revenue.

The ASTM F38 (23-06) Weather Standard, published in January 2024, serves as a foundational framework that the FAA is utilizing to develop an Advisory Circular expected to be released in 2025. This forthcoming Advisory Circular will specify the means and methods of compliance for certifying third-party weather providers and IoT weather reporting devices that must meet FAA regulations for Beyond Visual Line of Sight (BVLOS) operations.

As part of these new regulations, existing weather sources outside traditional government channels and newly deployed weather stations will need to comply with the requirements set forth in the Advisory Circular, with potential exceptions. Consequently, it's crucial for drone program managers to ensure that the sensors and weather services they purchase have a clear path to approval under the impending guidelines.

The ASTM F38 (23-06) Weather Standard is specifically designed to uphold data integrity by setting comprehensive guidelines and best practices for the collection, processing, and utilization of weather data in Unmanned Aircraft System (UAS) operations. By adhering to these standards, operators can ensure that their weather data is reliable, accurate, and compliant with future FAA regulations

3. Cybersecurity Assurance: Protection of critical information

4. Edge Computing: Processing data closer to where it is collected to ensure rapid and efficient data analysis and decision-making

5. Advanced Analytics and Machine Learning: Employing sophisticated algorithms to analyze vast amounts of data, improving the accuracy and timeliness of weather forecasts

6. Automation: Reduce human error, increase reliability and efficiency

7. Digitalization: CFD (Computational Fluid Dynamics) Digital Twin Technology

The goal of Weather 4.0 is to provide the detailed, real-time weather intelligence required for modern, risk-based performance standards, data-driven architectures, and technology-driven applications, ensuring compliance and efficiency in various fields, especially in low-level airspace where traditional weather monitoring systems fall short.

Sensors Enable
Real-time Intelligence

The deployment of strategically placed weather sensors into drone operations is a game-changer. Real-time weather data empowers DFR teams to make informed, data-driven decisions, enhancing the overall effectiveness and reliability of their missions. Various IoT sensors contribute different types of critical information. For instance, a low-cost surface weather station can provide real-time data from any specific location, which can then be analyzed using machine learning or analytic systems. Additionally, leveraging data from existing road weather sensors offers

municipalities a cost-effective way to achieve situational awareness for both ground and air operations.

More advanced, dual-use mobile or fixed weather stations can provide additional capabilities such as ceiling heights, visibility along flight routes, 360-degree camera views, and lightning detection. These stations, often 10-20 times less expensive than traditional airport-deployed sensors, deliver highly accurate data on temperature, pressure, humidity, ceiling, visibility, wind speed and direction, peak gusts, and precipitation amounts. Deploying one or two of these sensors along a flight route or near a vertiport can strengthen BVLOS waiver packages submitted to the FAA. And it allows operators to more accurately determine ceiling height and visibility at terminal locations or along routes, ensuring compliance with the FAA's regulatory requirement to maintain a 500-foot clearance from clouds. Simply adding a low-cost wind sensor on a tower provides actual measurements of winds above treetops eliminating the guessing that may occur today and what the winds are doing at flight level before launching.

DFR WEATHER INFRASTRUCTURE GUIDANCE
Guidance is tailored to each operational environment

Rural DFR Operations
(Low-Altitude Weather Monitoring System)

- Ceilometer to capture cloud deck, ceiling and visibility data (only required if operations are distant from nearest ASOS)
- Mounted anemometer(s) to capture winds above ground level
- Strategically placed low-cost ground-based microweather station(s)

Suburban DFR Operations
(Enhanced Microscale Wind Detection)

- Ceilometer to capture cloud deck, ceiling and visibility data (only required if operations are distant from nearest ASOS)
- Mounted anemometer(s) to capture winds above ground level
- Fixed microweather stations and streaming cameras positioned at various locations (rooftops, streetlights, etc)
- Mobile sensors for placement along routes

Urban DFR Operations
(Hyper-Resolution Weather Observations)

- Fixed weather stations, ceilometer, streaming cameras, mounted anemometer(s)
- Additional mounted high resolution wind sensors to capture wind flow between buildings and structures
- Vertical wind profiler depicting 3D wind fields
- Flight corridor planning service based on real-time data and hyper-local analysis

Closing the Gap

In aviation, a weather gap analysis highlights areas where low-level atmospheric data is insufficient to ensure preparedness, readiness and a sufficient risk assessment of wind and weather conditions that are undetectable in the current aviation weather system. In such cases, the analysis could suggest the deployment of additional sensors, improvement in data-sharing protocols, or the introduction of higher precision weather models.

OPTIMIZING DRONE-IN-A-BOX ECOSYSTEMS

The Power of Integrated Systems

Integrating weather stations with other ground sensor systems for Drone-in-a-Box ecosystems can significantly enhance operational efficiency and effectiveness by centralizing the data management into one platform, enhancing pre-flight planning, real-time operational adjustments, and providing comprehensive post-flight analysis.

Centralized Data Management: A unified platform that integrates data from all sensors—such as weather, docking, optical, communications, detect-and-avoid, and payload sensors—provides operators with a comprehensive, real-time overview of all critical information. These sensors work together to enable the drone to function autonomously, safely, and efficiently, supporting continuous operations across diverse environments and applications.

Enhanced Pre-Flight Planning: Incorporating weather into the pre-flight checklist and risk assessment is crucial in identifying and mitigating potential hazards and adverse conditions along the intended mission route, thereby ensuring safe and successful missions.

Dynamic Mission Adjustment: Weather sensors and analytics can be integrated into automated systems, allowing for real-time decisions improving responsiveness to changing weather conditions.

Comprehensive Post-Flight Analysis: Weather data can be analyzed alongside flight data to show how environmental conditions affected the mission. This helps refine operational strategy and improve future performance.

CAPTURE THE OPPORTUNITY

Pathway
to Optimal Outcomes

Initiative 1 - Time
When incidents occur, fragmented systems, incompatible tools, and insecure workarounds can impede response times when every second counts. Adopting a change mindset can help anticipate challenges and streamline support services, ensuring a more effective and timely response.

Initiative 2 - Technology
Outdated, incompatible, or fragmented data systems can compromise response efforts. Modern technology accelerates decision-making, enabling immediate resource mobilization. Adapting to and leveraging rapidly evolving technology can significantly enhance service delivery and improve overall efficiency in emergency situations.

Initiative 3 - Data Integrity
The best outcomes depend on reliable, secure and validated information with a known chain of custody. Stakeholders must have confidence that shared data and communication is accurate and secure. To gain full value of weather intelligence you should apply the right data, at the right time, for the right location, with the right application.

Initiative 4 - Compliance
A modern weather management system allows an auditable trail for complete compliance of regulations. The FAA and ASTM have developed a clear strategy for rapidly identifying and publishing an Advisory Circular that outlines the approved data sets necessary for safe and routine UAS operations within civil airspace. This rule is expected to include requirements for an auditable trail and chain of custody for weather data used in Go/No Go decisions and for monitoring weather conditions during flight.

*To ensure compliance with future FAA weather data regulations, it is essential to collaborate with weather providers who are well-versed in the ASTM Weather Standard and have a proven track

record in the aviation industry. This approach will help ensure that the weather data used in UAS operations meets the forthcoming standards and remains in full compliance with FAA requirements.

Initiative 5 - Infrastructure Ecosystem
Purpose built for real-time data integration to mobilize resources immediately based on accurate, rapid refresh data. By leveraging previously inaccessible data sources from existing sensors and expanding the network through the deployment of gap-filling sensors, departments can enrich the data pool.

Conclusion

Weather is a complex field that extends beyond standard weather apps and government sources. These services are not designed, tuned, nor focused on low altitude wind and weather hazards at the levels of certainty required to scale reliable drone operations. Leveraging higher-density observations, detailed models, analytics, and customized decision-making tools can significantly reduce the impact of weather on DFR operations. More importantly, appreciating the details required to have a high-performing drone program that is tuned to fully leverage advanced weather technology in training, TTP development and operations will achieve higher mission completion rates, faster response times, better use of a low density, high demand asset, and achieve higher levels of mission preparedness and readiness. The drone program will become an even better steward of taxpayer money by delivering a higher drone program return on investment for a small upfront investment in building weather resiliency into the budget and program.

Advances in atmospheric science and technology, particularly in sensor equipment and weather prediction modeling, are rapidly enhancing the precision and accuracy of weather data. NASA and private companies like TruWeather are focused on closing the gaps in flight-level wind data, particularly within challenging urban environments.

For DFR teams, understanding the effects of microweather specific to their operational area is critical during missions. However, the most effective approach is to incorporate expert strategies during the initial planning and setup stages to anticipate and mitigate adverse weather impacts before they happen.

Implementing a "microweather playbook" tailored to the specific needs of a municipality— considering factors such as climate, terrain, flight frequency, location, timing, payload, and weather impacts — can unlock the full potential of DFR missions.

The integration of real-time weather data into the DFR ecosystem not only optimizes mission effectiveness but also facilitates scaling and expansion across a county and a state.

As DFR programs grow and evolve, continuous learning will refine how best to meet their needs. This White Paper aims to motivate the DFR community to become operationally prepared for low-altitude weather and demonstrate how compliant real-time weather data can enhance and optimize DFR missions.

About DRONERESPONDERS

DRONERESPONDERS, a nonprofit program, was established to support the advancement of drone use in public safety by providing essential resources, driving regulatory changes, fostering innovation, and recognizing achievements. The program also aims to build a collaborative public safety drone community, promoting the sharing of knowledge and experiences to enhance operational effectiveness and improve real-time situational awareness. "We are happy to partner with TruWeather," says Charles Werner, Director/Founder, DRONERESPONDERS. "As drone programs scale and operate over longer distances autonomously, precision digital weather services are essential for modernizing and optimizing public safety and DFR operations." https://www.droneresponders.org/

About TruWeather Solutions

Since 2017, TruWeather Solutions has collaborated with operators using a sandbox approach to study and understand weather anomalies in drone operations. This experience led to the development of V360, a purpose-built platform for weather precision in autonomous low-level atmospheric operations. "In DFR operations, weather challenges are less pronounced in VLOS scenarios, but once you move to BVLOS, the uncertainty of conditions above ground level and beyond visual sight increases, leading to greater reliance on ground operations. This can slow response times and raise costs within departments," says Don Berchoff, Founder and CEO of TruWeather Solutions. TruWeather is addressing these challenges by driving the evolution of high-quality low altitude weather intelligence into meaningful information and actionable insights.
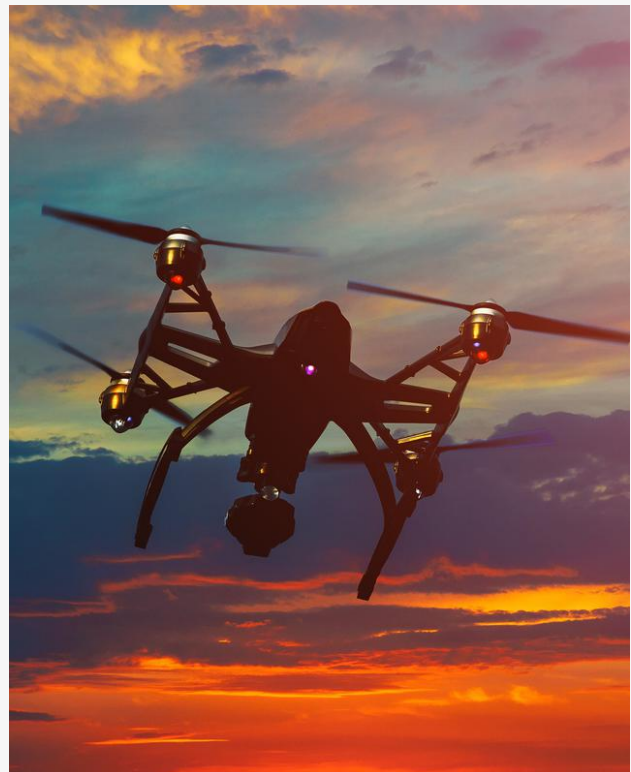
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