WEATHERHIVE OVERVIEW: THE USE OF NANODRONES FOR HIGH RESOLUTION ENVIRONMENTAL SENSING

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1. INTRODUCTION

The global earth observing system is a key data source for near real-time monitoring of extreme weather events as well as input for numerical weather prediction (NWP). High spatial, temporal, and vertical sampling of critical meteorological information is imperative to improve forecasts and build a weather-ready nation. There are, however, significant gaps in the availability of observations, particularly in the planetary boundary layer (PBL) which is severely undersampled (Geerts et al. 2018). As noted in Teixeira et al. 2021: “A global PBL observing system is urgently needed to address fundamental PBL science questions and societal applications related to weather, climate and air quality”. These earth observing system data gaps reduce model prediction accuracy, limit the situational awareness for operational forecasters, and reduce our ability to monitor the climate completely.

Kull et al. 2021 found that improving the coverage of surface-based observations can deliver economic benefits of $5 billion/year. Furthermore, Bromann et al. 2019 found that conventional observations (radiosondes, in-situ, aircraft, etc.) and microwave radiances are the main drivers of increased skill in the ECMWF. Uncrewed Aircraft Systems (UAS) provide a unique opportunity to fill in the missing conventional observations over sparse-remote regions which will further improve the skill of global forecast systems. Indeed, Chilson et al. 2019 found the addition of UAS observations improves the short term forecast and can produce better convective forecasts through increased observations in the PBL.

2. OVERVIEW

WeatherHive (WxHive), shown in Figure 1, is an all in one platform developed by GreenSight (GS) consisting of a swarm of miniature drones that produce on-demand targeted meteorological monitoring at a high spatial, temporal, and vertical sampling rate throughout the PBL.. This novel technology makes use of nano drones (WISP - Weather Intelligence Sensing Platform) that work in AI coordinated swarms, providing more profiles than a single radiosonde without the material waste and expense of helium. Two sensors are mounted on each WISP providing in-situ observations of Temperature, Relative Humidity and Pressure while the flight controller measures wind speed and direction through a highly calibrated Kalman filter. WxHive can be used as a stationary observational platform or as a mobile platform, both of which gather meteorological data in remote locations providing critical information and filling in key observational gaps. They are specially designed to withstand severe weather conditions (including dense smoke), flying at high altitudes, covering long distances and flying at night. While the main suite of measurements include:barometric pressure, 2D wind speed and direction, ambient air temperature and relative humidity,, WxHive can be customized to the end user’s needs providing a wide range of measurements for routine monitoring or reconnaissance. Table 1 shows WxHive’s specs.

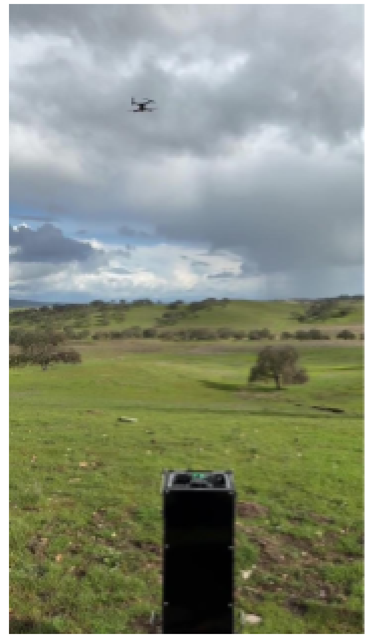

Figure 1: Deployed WxHive

2.1 WISP Design

Each WISP, shown in Figure 2, weighs less than 220g. While representing a minimal safety risk

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they are designed to withstand severe weather conditions. The WISPs are carried in a ‘Hive’ from which they autonomously launch, land, and charge.

Table 1: WxHive Specs

WISP	Body	GF ABS
	Diagonal	240mm
	Height	45 mm
	Weight	220 g
	Flight Controller	microBlue
Communications	Telemetry Frequency	900 MHz
	Transmission Distance	10 km
Propulsion System	Motors	3000kV BLDC
	Maximum Thrust	600 g
	Maximum Power	140 W
Power	Battery Type	2S 18650
	Capacity	3500 mAh
	Endurance	50 minutes
Hive	Dimensions	250 x 250 x 900 mm
	Weight	20 kg
	Battery	3x BB-2590
	Drone capacity	10 WISPs
Operation	Maximum Wind Resistance	22 m/s
	Maximum Operating Speed	16 m/s
	Maximum Flight Ceiling	5 km
	Recommended Operating Temperatures	-20 to 50 C
	Typical Ascent Rates	16 m/s
	Typical Descent Rates	10 m/s

Meteorological	In-Situ Variables	Air Temperature (T) Relative Humidity (RH) Barometric Pressure (P)
	Derived Variables	3D Wind Speed (WS) 3D Wind Direction (WD)
	Accuracy Goals*	T: within 0.5 Kelvin RH: within 2% P: within 1 hPa WS: within 1 m/s WD: within 2 degrees
	Logging Rate	10 Hz

The Hive weighs around 20 kg and can accommodate 10 WISPs. The low weight and cost provide convenience and portability, allowing WxHive to be deployed in remote and austere locations with relative ease.

Figure 2: GS’s WISP

The weather sensor board consists of two sensors: BME280 (humidity, pressure, temperature) and TMP117 (temperature) which weigh only 1g. The board is located under the arm, ensuring the sensors are exposed to fresh air, allowing adequate airflow to pass the sensors while shielding them under the top shell away from direct sunlight. Spacers are used to ensure the sensors have air passing above and below, while holding it away from heat generated electronics.

2.2 Swarm Control System

WxHive has an automated swarm controller which will program the aircraft, launch and manage the WISPs in flight, and ingest their data during operation. This limits the end-user workload as well as reduces the training requirement to operate. The swarm can be launched in an array of settings allowing the end-user to decide the best sampling technique for their goal. Options can include continuous vertical sampling where the drones continuously ascend and descend in a fixed location of interest or customized spatiotemporal-resolution where a user selects a region to be sampled and the WISPs optimally fill this 2-dimensional region, building columns of measured data providing a 3D grid of weather information.

Figure 3: Adaptive Swarm Control. The WISPs adaptively refine the mission to cover areas of interest with higher gradients of measured data.

Adaptive swarming is also available, shown in Figure 3. This would be customized to the end-user application. In this option, an initial region and goal is defined. The swarm is launched and begins sampling the region. When the goal is met, the swarm adjusts to a new sampling technique. For example, the swarm could be set to a region to look for micro changes in the wind speed. When the vertical plane of max wind is observed, the swarm could be sent to that plane to map a perimeter of the high wind.

2.3 Safety Features

Safety of other crewed and uncrewed aircraft in the region is of the utmost importance. Given the extreme operating conditions WxHive may operate in, we will ensure that WxHive can detect other aircraft and be detected. An accurate surveillance interface between aircraft and Air Traffic Controller (ATC) is made possible by the modern transponder technology known as Automatic Dependent Surveillance-Broadcast (ADS-B). We can integrate lightweight ADS-B receivers into the WxHive design which will increase safety, maneuverability, and performance of the system in multiple ways. If there is a chance of air traffic collision, the drones will automatically end their mission or land immediately.

Aircraft endurance changes both over the course of its life and over the course of the flight, depending on the environmental conditions. During flight, the aircraft continuously checks their 'power to home' to ensure they have the flight performance to return to the hive. If this goes below a safe threshold they either return home or reduce altitude to find a better operating environment. Additional functions may be added to update the missions to return to home in the case of unexpected events.

2.4 End User Applications

WxHive has the potential to be used for a number of end-user applications. GS is actively collaborating with multiple end users including, NWP modelers and general researchers, to integrate WxHive into daily operations. Near-real time data dissemination will allow for nowcasting while the flexible autonomous swarming capability will create customizable measurements to answer specific research questions. WxHive can work in austere and remote environments making it an ideal candidate for integration into wildfire monitoring, deployment for field campaign experiments, and more.

GS is actively collaborating with NOAA and NWS Weather Forecast Offices (WFOs) to deploy WxHive for real-time targeted surveillance for locally specific weather phenomena, filling in a critical observational gap in the lower atmosphere during periods of rapid change that impedes operational forecaster's ability to forecast certain phenomena and warn the public (Houston et al. 2021, Pinto et al. 2021, Walther et al. 2020). WxHive will also be deployed for targeted field campaigns to address critical earth science process questions providing a low-cost solution to traditionally logistically complex and high cost projects (Avallone and Baeuerle 2017, Zhang and Moore 2023). As the frequency, size, and intensity of wildfires grows, GS is working closely with the wildland firefighting community to deploy WxHive for 24/7 wildfire weather monitoring, filling a significant nighttime observational gap (Figure 4 shows the required lights for nighttime operation) and improving the situational awareness, reducing the time from ignition to detection and response (Thompson et al. 2022a; Thompson et al. 2022b; On Fire, 2023; Dabiri et al. 2023).

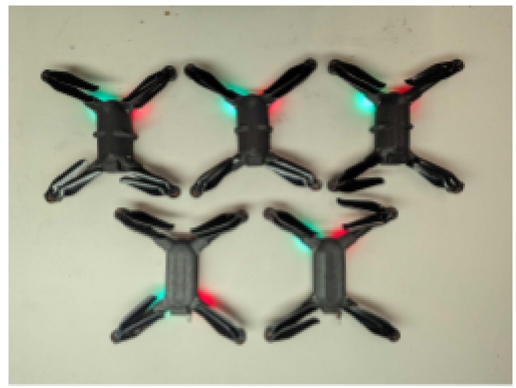

Figure 4: GS's WISPs are equipped with lights allowing for nighttime operation.

2.5 Current Status

We are currently validating the accuracy and precision of our measurements. In tandem, we are working on the estimation of 3D wind speeds and direction. Wind estimation will be done using a novel aerodynamic model based technique that fits high fidelity drag and lift models, incorporating both positional and altitude impact on the vehicle, for a full 3D wind estimation. WxHive is available for demonstration campaigns and pilot programs.

3. FLYABILITY

The flyability of a UAS is an important characteristic. Indeed, understanding weather constraints on global drone flyability is necessary for development and deployment. Similar to other studies performed by academia (Gao et al. 2021), GS performed a flyability analysis on the WxHive system based on the current operating requirements. Using hourly output for one year from the ERA5, we assessed the percentage of time a WISP can operate up to 2 km AGL. Figure 5 shows the results by season. On average, GS's WISP can operate over 87% of the time over CONUS (70% on average during winter and 95% during summer) There are spatial and seasonal differences but this flyability analysis will help us work with end-users to strategically select operating locations and time periods.

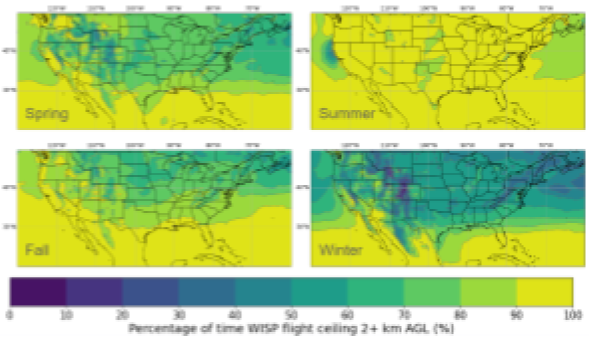

Figure 5: WxHive flyability, the % of time the WISP can fly above 2 km AGL, by season using ERA5.

4. INITIAL TESTING

Multiple test flights have been performed under various environmental conditions. Data has been collected and examined. Figure 6 shows an example test flight on January 4th, 2024 when a WISP was flown up to 8200 ft (~2.5 km). During this test flight, one of the temperature sensors (TMP117) experienced anomalous values.

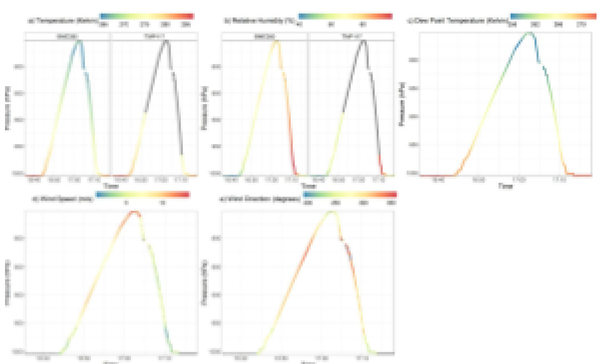

Figure 6: WxHive data during a test flight on January 4th, 2024

However, since the WISP is built with redundancy (e.g. two sensors), the system was able to continuously monitor and provide data. Although not shown, initial comparisons to reanalysis and remotely sensed observations show promising results. GS will be participating in a validation campaign during Fall of 2024 and will be releasing an open peer-reviewed paper with the results.

5. NEXT STEPS

WxHive will be evaluated in greater detail over the next few months with validation campaigns planned April - November of 2024. In tandem with the validation, WxHive samples will be made available for several Observing System Simulation Experiments (OSSEs) to assess the value of our data and sampling techniques for Numerical Weather Prediction. As we perform more test flights and expand our end-user base, we will integrate WxHive into operational forecasting and deploy WxHive to answer critical earth system process questions. WxHive will continually be modified and improved to meet end-user requirements. The low cost, lightweight nature, and customizability makes WxHive ideal for a wide range of applications.

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