Recent Advances in Dual Doppler Lidar Technique for the Measurement of 3D winds

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Introduction

- Weather data in the atmospheric boundary layer is a key to enabling safe and efficient advanced air mobility (AAM) operations.
- In this context, weather tolerance is identified as a critical need for aviation safety, environmental and community impact, and the global growth in air traffic.
- Undesirable microweather conditions are a barrier to ubiquitous urban air operations in many cities.
- Microweather conditions that make it difficult to fly in urban environments, especially local winds, are influenced by city planning and building designs.
- Recently, under the umbrella of NASA's Convergent Aeronautics Solutions (CAS) program, **Advanced Exploration of Reliable Operation at low Altitudes: meteorology, Simulation, and Technology (AEROcAST)** program was initiated.
- AEROcAST was a joint program between several NASA centers including Langley Research center, Armstrong Flight Research Center and AMES Research Center

Advanced Air Mobility (AAM)

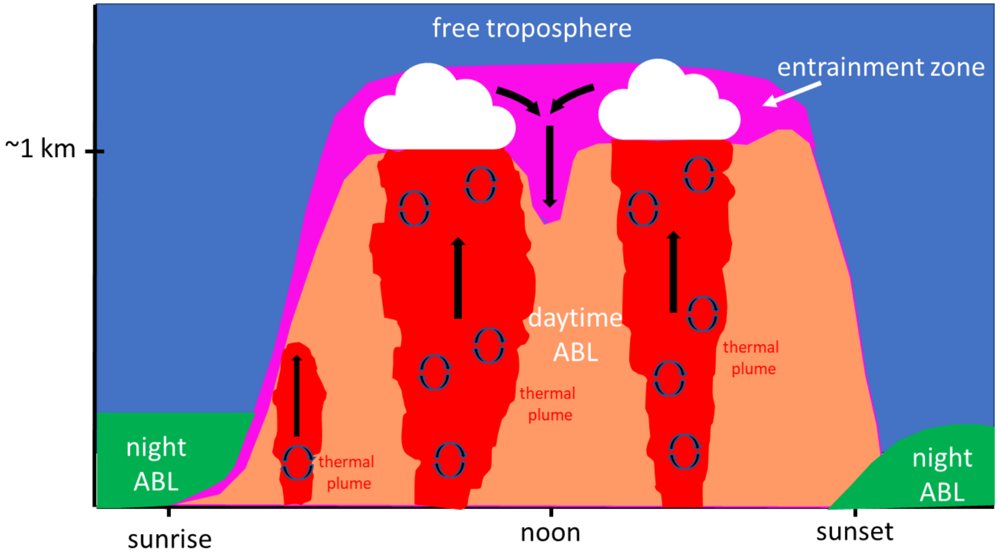
Advanced air mobility (AAM): https://www.nasa.gov/mission/aam/
AAM projects focus on air transportation system of the future will include low-altitude passenger transport, cargo delivery, and public service capabilities

- AAM concepts envision widespread use of aircraft in areas prone to hazardous wind conditions.
- Challenges include:
  - ➢ Measuring wind and turbulence in the atmospheric boundary layer.
  - ➢ Measuring wind and turbulence near the ground in complex terrain.

➢ AAM would benefit from new tools for measuring wind.

Wind in the Atmospheric Boundary Layer (it's complicated)

Diurnal variation of the atmospheric boundary layer



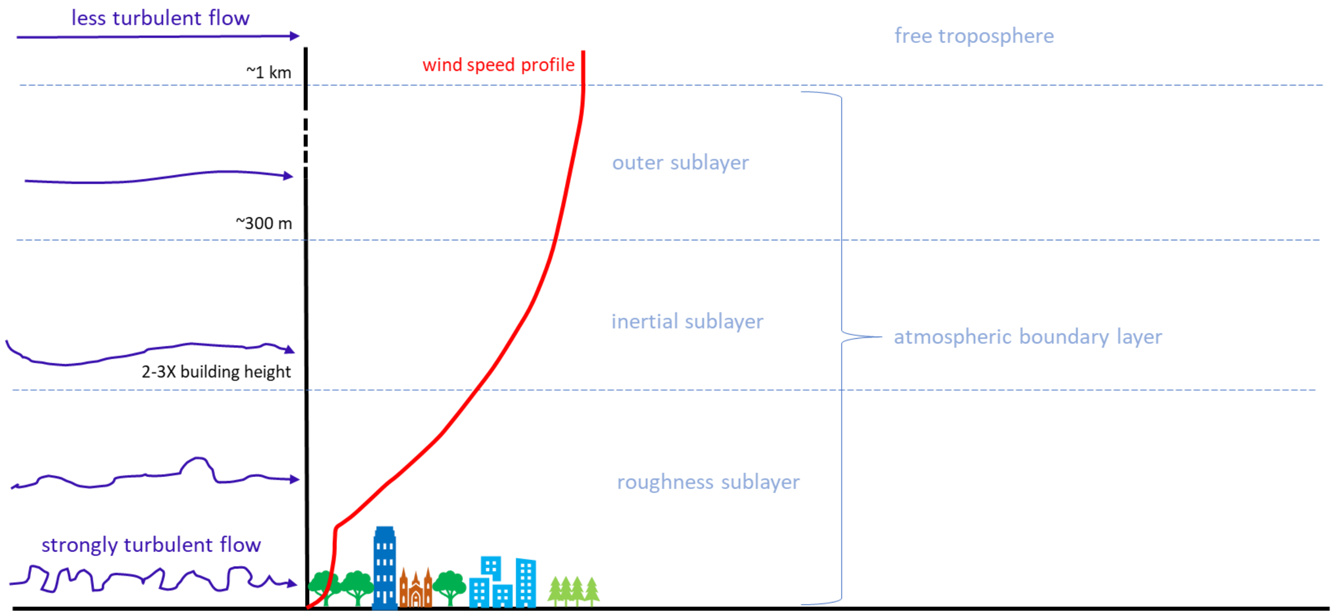
Complexity in temperature and humidity

Complexity in daily cycling

Effects on Advanced Air Mobility:

- safety
- operational efficiency
- ride quality
- passenger comfort
- vehicle wear and tear

Complexity in height layering

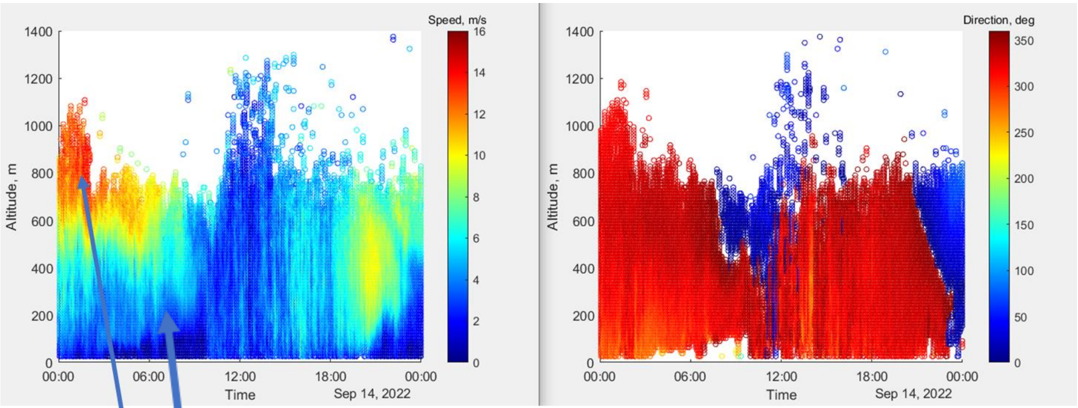


Background

- Wind and turbulence sensing will be critical for Advanced Air Mobility:
    - Monitoring winds at vertiports for landing/take-off
    - Monitoring winds aloft for aircraft navigation
    - Warning for oncoming hazardous wind events (gust fronts, wind shear, thunderstorms)
    - Understanding wake vortex and rotor downwash effects on vertiport operations

- Stakeholder interest:
    - RVLT: turbulence effects on ride quality
    - SWS: wind and wake effects on vehicle safety
    - Advanced Air Mobility: airspace operations
    - Winds aloft during Joby S4 flight tests
    - FAA: wind measurement standards, wake vortex effects

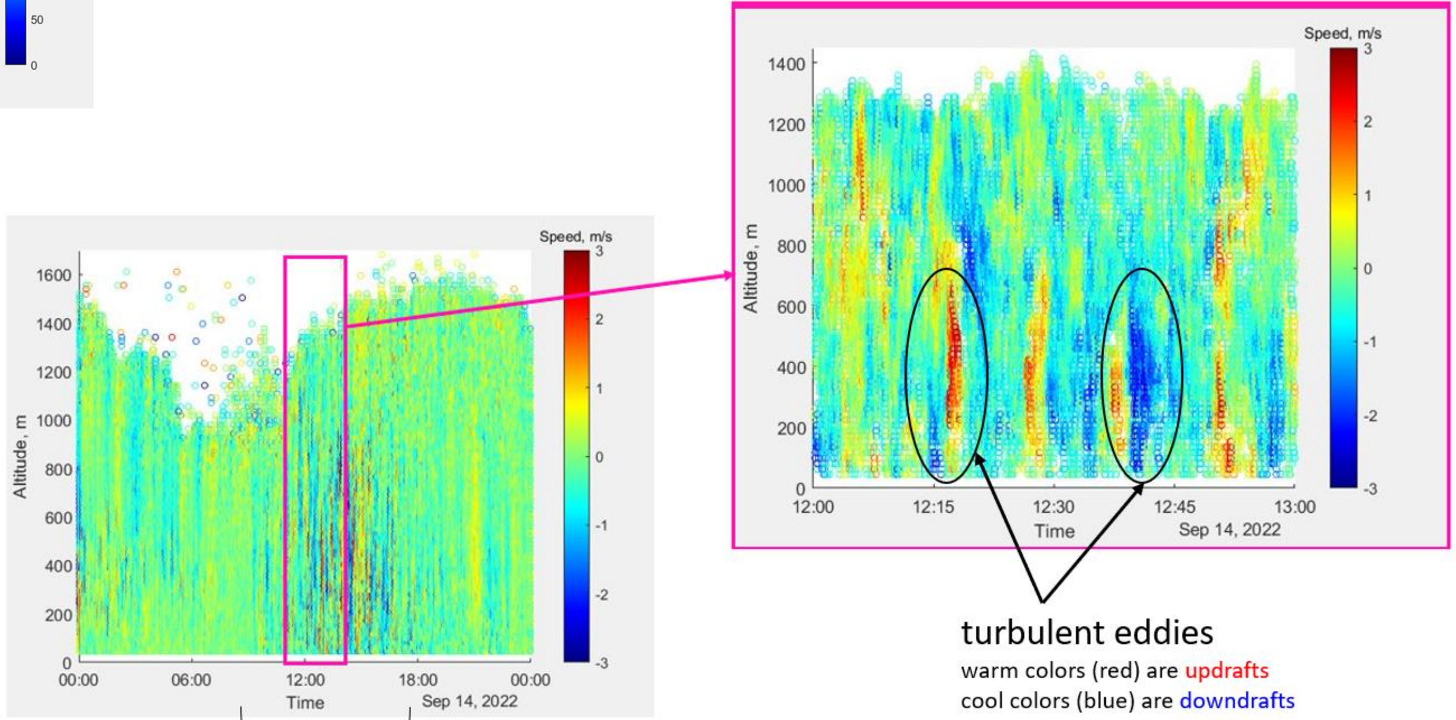
Lidar Horizontal & Vertical Wind Examples



low wind speed near ground level…

but, much stronger speed higher up

Horizontal



turbulence in daytime atmospheric boundary layer

turbulent eddies

warm colors (red) are updrafts

cool colors (blue) are downdrafts

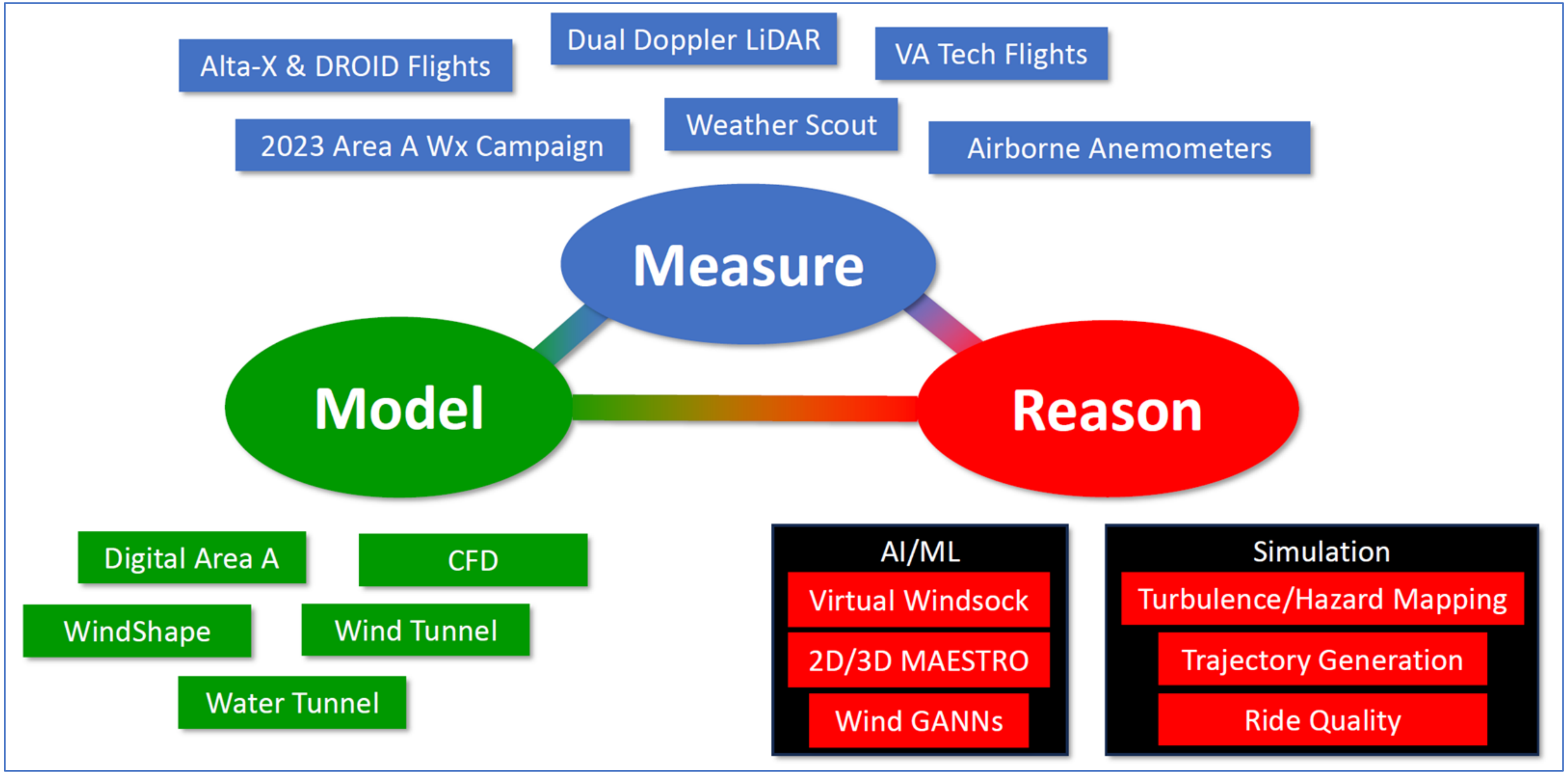
Vertical

AEROcAST: Low Altitude Research

- AEROCAST: **Advanced Exploration of Reliable Operation at Low Altitudes: Meteorology, Simulation, and Technology** program was initiated under NASA's Convergent Aeronautics Solutions (CAS) award.
- The AEROcAST research was carried out between 2022-2024.
- The overall goal was to investigate large gaps in weather data, especially wind, that exist in the atmospheric boundary layer and within the built environment.
- Furthermore, impacts of hyperlocal urban weather conditions on eVTOL aircraft and passenger comfort are mostly unknown.
- One of the techniques that were employed is the Dual Doppler technique for creating virtual towers to measure 3D wind characteristics.
- Dual-Doppler lidar emerged as a research tool, primarily in Europe, for measuring wind around turbines and wind farms. AEROcAST's adaptation of dual-Doppler is the first use of the technique for aviation or around buildings.

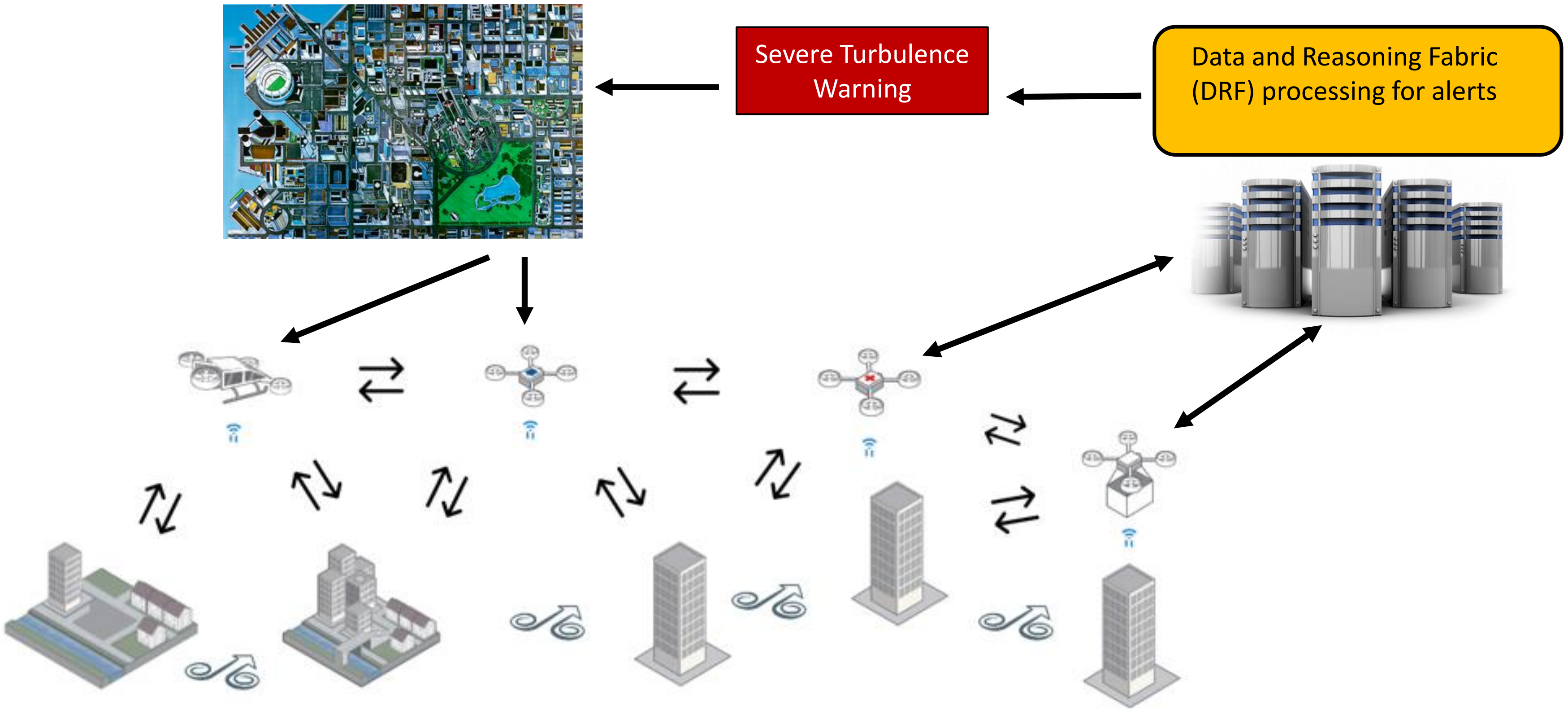
AEROcAST Programmatic Approach

Several interrelated activities were carried out simultaneously



This presentation focuses on the field campaign carried out at AFRC to demonstrate Dual Doppler Lidar methodology

Use Case for Virtual Tower Measurements



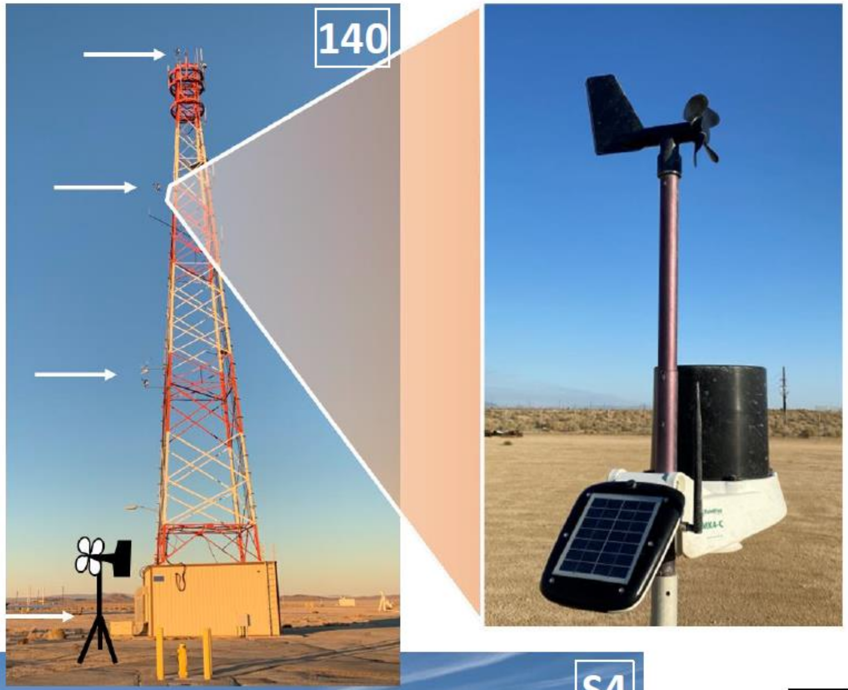
Weather Data Collection
- On every vehicle
- Some ground locations

Weather Data Transmission
- Distributed through ground networks and the airborne vehicle network

Weather Data Processing
- Data is processed through ground stations and alerts are generated and distributed to the airborne network

Smart Routing
- UAMs will respond to real-time weather alerts to safely reroute around threats

Sensors Used in the Field Campaign at AFRC



LL	LiDAR - LaRC
LA	LiDAR - AFRC
S2	SoDAR 2000
S4	SoDAR 4000
BA	Balloon/Aerostat
140	Tower - 140ft
50	Tower - 50ft
TC	Tower - Campbell
TV	Tower - Vaisala
LVT	LiDAR Virtual Tower
● (blue)	Building Temperature
● (yellow)	Ground Temperature

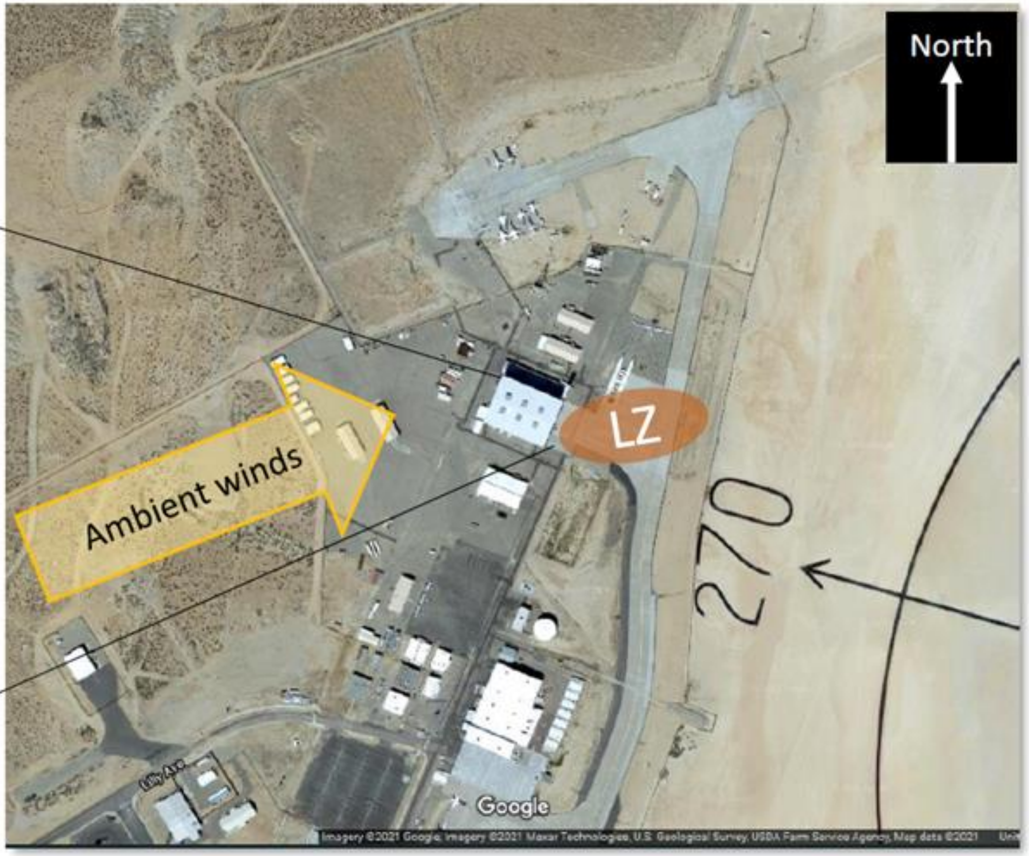
AEROcAST: Dual Doppler Lidar Measurements for AAM applications

- **Operational principle:** Use of Doppler lidar to provide ground-based sensing of wind. Combining two wind lidars so that a “virtual tower” is created where the lidar beams intersect.
  - ✓ A specific need is for remote measurement, based on the ground with a capability to measure upwards, that can resolve wind features on the order of 1 meter in size to meet AAM applications
  - ✓ Dual-Doppler lidar emerged as a research tool, primarily in Europe, for measuring wind around turbines and wind farms. AEROcAST’s adaptation of dual-Doppler is the first use of the technique for aviation or around buildings.

- **Measurement Goal:** The goal was to measure high-resolution (<1 m spatial, <1 minute temporal, <1 m/s speed) wind flow measurements around buildings or structures.
- **Advantages:** The virtual tower can be instantaneously be relocated by steering the lidar beams to a different intersection point.
- **Field Campaign:** Carried out at AFRC for 2 months during Summer 2023 to measure wind effects in the vicinity of Shuttle Hangar building structure.

Field Site in AFRC

Shuttle Hangar: 80’ at peak, 180’ x 140’ floor



North end of AFRC campus

- Field Campaign Goal: Collect a comprehensive set of high-density real-world weather measurements around a large isolated building in coordination with a plethora of ground based and airborne sensors.

Why Shuttle Hangar?

- This Shuttle Hangar building was selected for being a large isolated structure, presenting a complex interaction with the ambient wind.
- The concrete area in front of the Shuttle Hangar was used in the past for the National Campaign project as a vertiport simulator.
- A helicopter served as a proxy AAM vehicle, whose pilots noted complex wind effects during flight operations.
- As the wind flows over the roof and around the sides of the building, the wind forms eddy patterns.
- Measurements show that the vorticity (the diameter and strength of the eddy) varied with height with a smaller, tighter eddy at low altitudes.
- These eddies will change with time, though, as the wind continues to swirl over and around the building.

Virtual Tower Generation

- To achieve Dual Doppler Operation, two Halo Doppler wind lidars were utilized.
- These two lidars were positioned using GPS devices and range/distances were measured using a laser range finder
- The two horizontal axes represent the North and East direction in meters, and the vertical axis represents the altitude in meters.
- The maximum altitude and spacing between vectors are adjustable
- Spatial intersection of lidar beams at discrete altitudes is ensured
- Synchronizing both lidar units to sample the volume at those altitudes yields spatial-temporally resolved wind vector measurements from near-ground level to several hundreds of meter meeting AAM wind sensing requirements.

Lidar Placement for Virtual Tower Measurements

Wind Lidar Unit (~3 ft. Tall) from Lumibird
Laser beams are eyesafe
(operates 1550-nm wavelength)

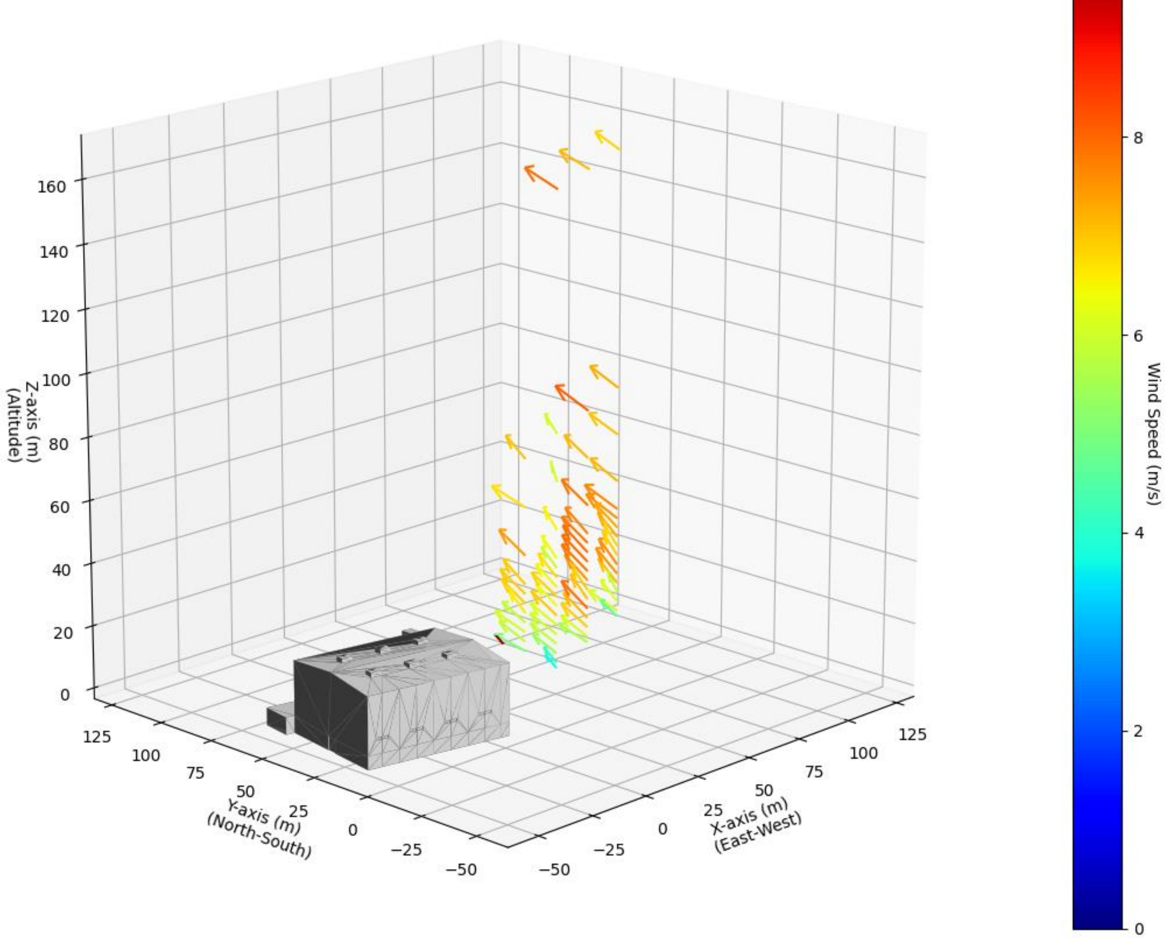
2023 lidar installation at AFRC
Lidars were set for 24/7 automated operation

Visualization of Virtual Wind Towers

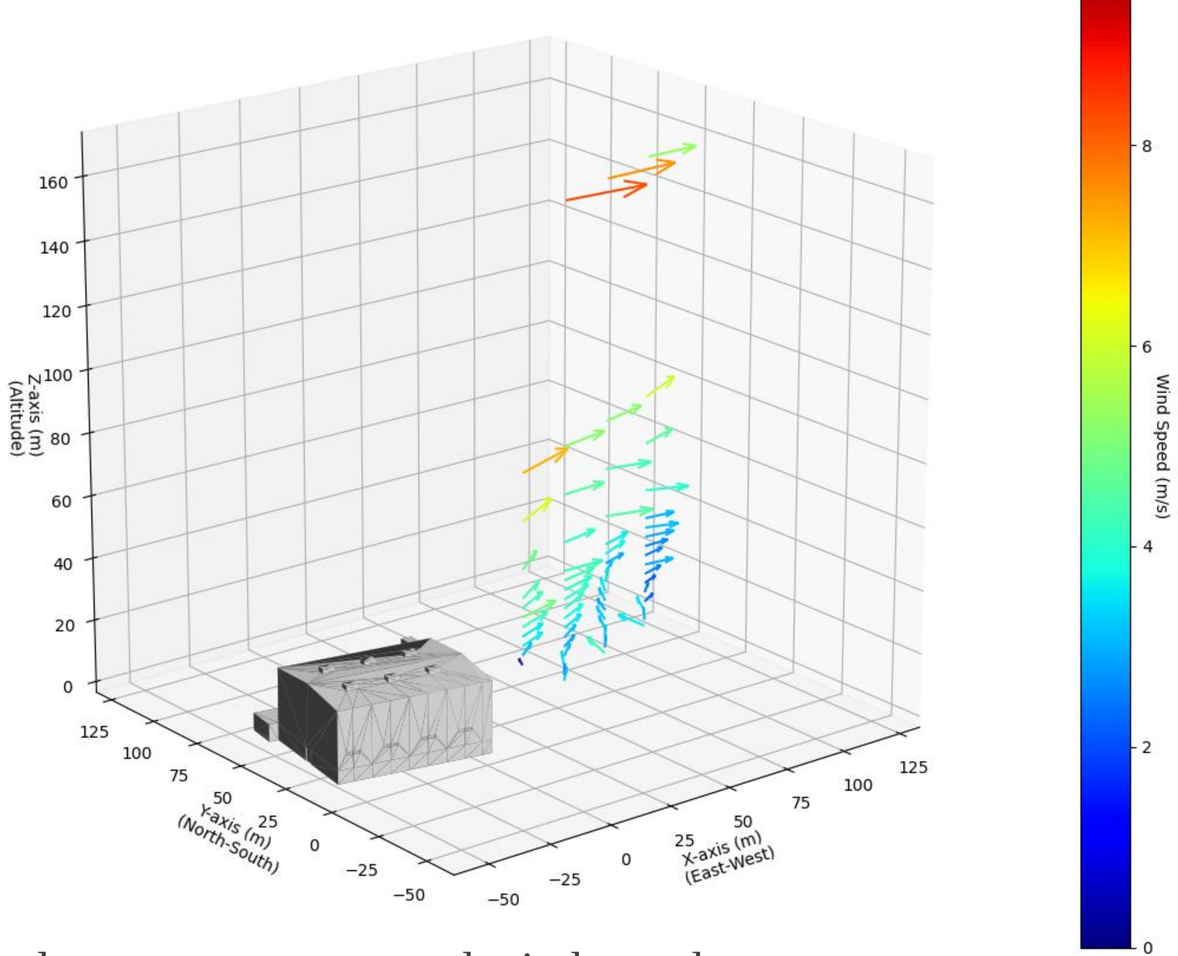
(sub-meter resolution using dual-Doppler lidar)

Dual-Doppler Virtual Tower Results: Parallel vs Perpendicular In-Flow

8/1/23 16:46 UTC (in-flow ~parallel to hangar wall)



8/1/23 23:18 UTC (in-flow ~perpendicular to hangar wall)



Arrows point in the direction of wind, and their length and color represent measured wind speed. Together, the color and direction of the arrows display the wind vectors along the virtual tower.

Summary of Results

- A field deployment of automated Dual Doppler Lidar technique using commercial-off-the shelf lidars provided encouraging results.
- The field campaign was carried out for about 2 months
- Wind vector measurements from lidars were compared with data from other instruments, including a ground-based sonic anemometer, sodar and sUAS. One such test was to intersect a dual-Doppler measurement at the same location as two *in situ* sensors, including a ground-based sonic anemometer and multi-rotor sUAS's capable of measuring winds.
- All three sensors agreed in measurements to be within 1 to 2 m/s of wind speed and 20 to 30 deg of wind direction.

Conclusions

- Advanced Air Mobility (AAM) will largely take place in the complex weather environment of the atmospheric boundary layer.
  - Wind and turbulence are especially problematic.
- There is currently a gap in atmospheric boundary layer measurement and modeling.
  - NASA has started projects to fill this gap.
- Two wind-measuring technologies are promising for operational use:
  - Ground-based Doppler lidar
  - Wind from airborne vehicles
- A specific need is for remote measurement, based on the ground with a capability to measure upwards, that can resolve wind features on the order of 1 meter in size.
- Dual Doppler technique was successfully demonstrated use two lidars at AFRC.
- Dual Doppler Lidar technique could help in validating simulated urban wind flows to the real atmosphere.
- AAM would thus benefit from new tools for measuring wind.

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2. AEROcAST Team, "AEROcAST Advanced Exploration of Reliable Operation at low Altitudes: Meteorology, Simulation, and Technology," Convergent Aeronautics Solutions Expo, Cleveland, OH, April 2024.
3. AEROcAST Team, "Advanced Exploration of Reliable Operation at low Altitudes: meteorology, Simulation, and Technology (AEROcAST): Improving Weather Tolerant Operations for AAM," 4th Annual ImaginAviation Conference, February 2024.
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5. AEROcAST Team, "Micro-Weather Moderation," 3rd Annual ImaginAviation Conference, February 2023.
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