Calibration and Validation of Weather Sensors for Rotary-Wing UAS

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Outline

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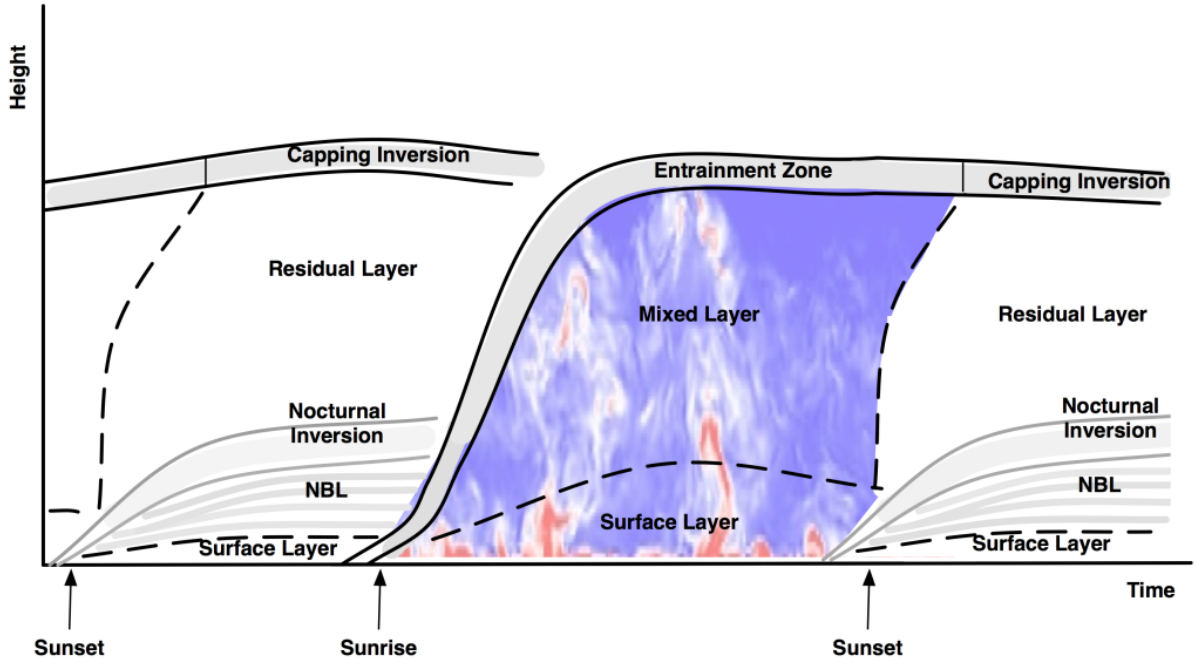
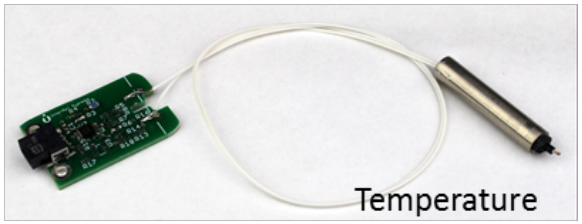
2. Sensor Packages and Platforms
3. Calibration
   a. Temperature and Relative Humidity Responses
   b. Sensor Placement
   c. Wind Retrievals
4. Validation
5. Conclusions

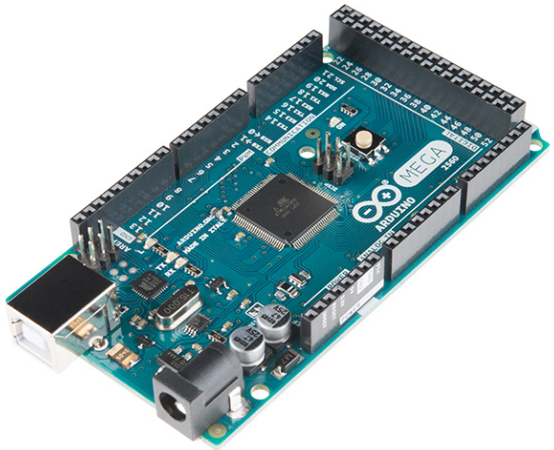
Background and Motivation



- Boundary Layer processes poorly sampled in space and time
- Rotary wing unmanned aircraft can help close this gap
- Need to understand strengths and limitations of placing sensors on UAS

Sensor Package





InterMet Systems Temperature and Relative Humidity sensors integrated onto an Arduino Mega

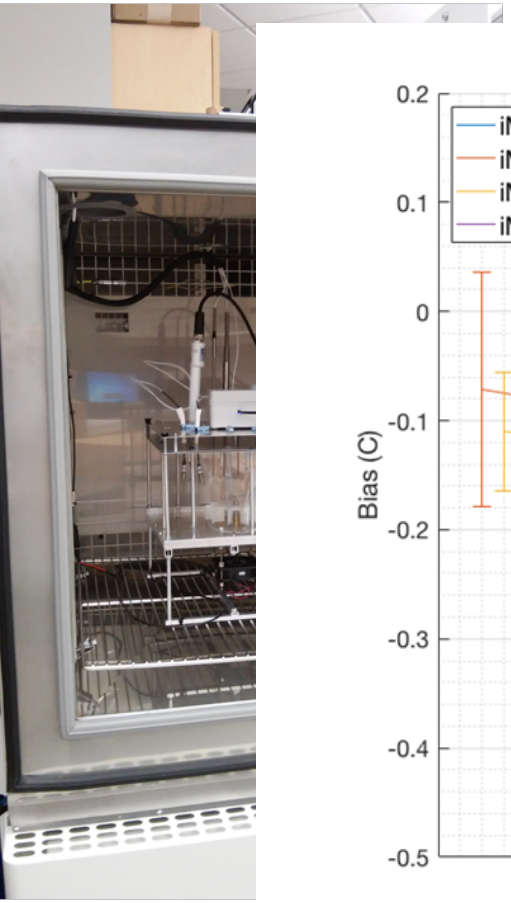
Allows for on board synchronization resulting in optimized data stream to ground station

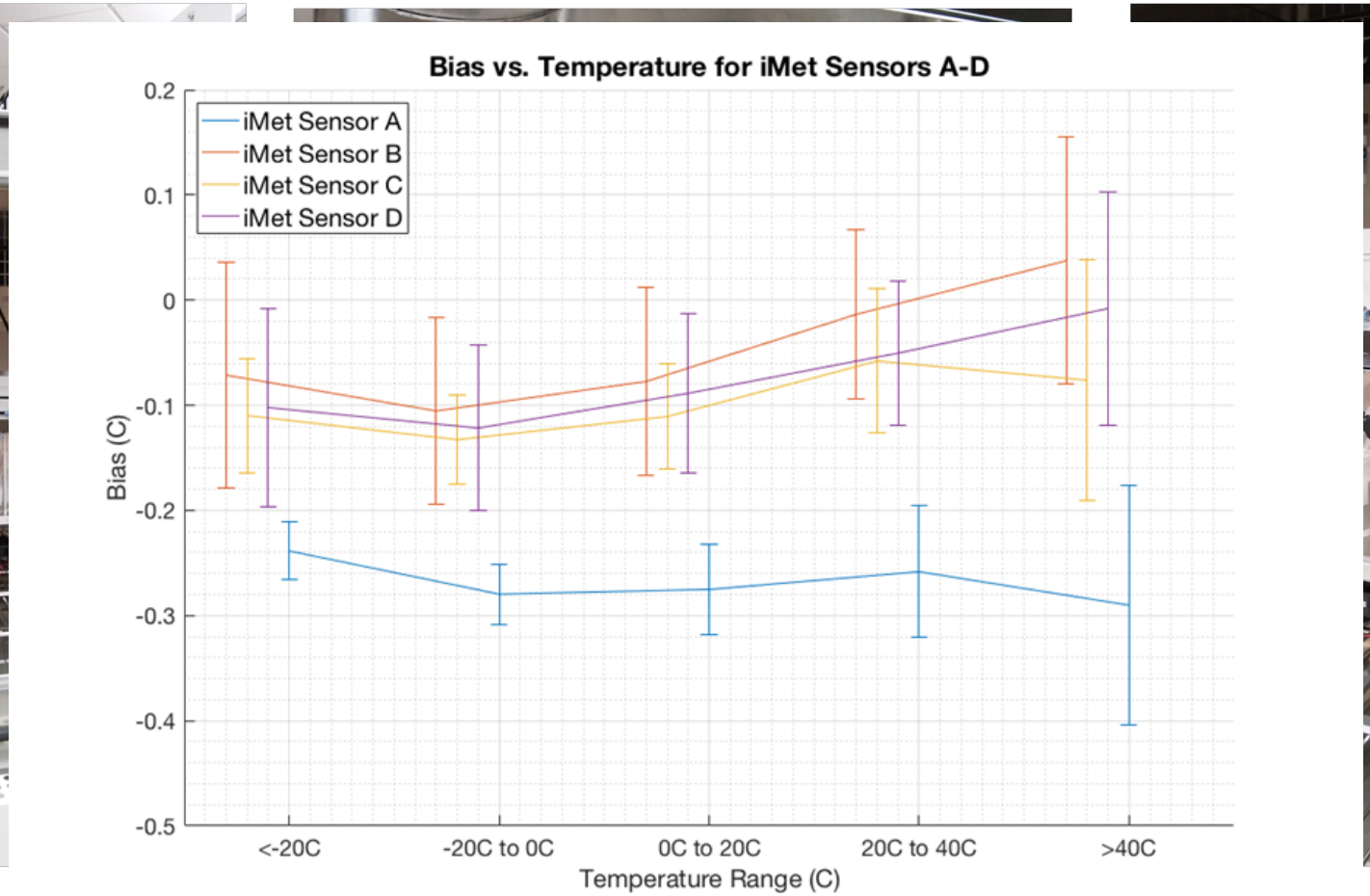
Coptersonde

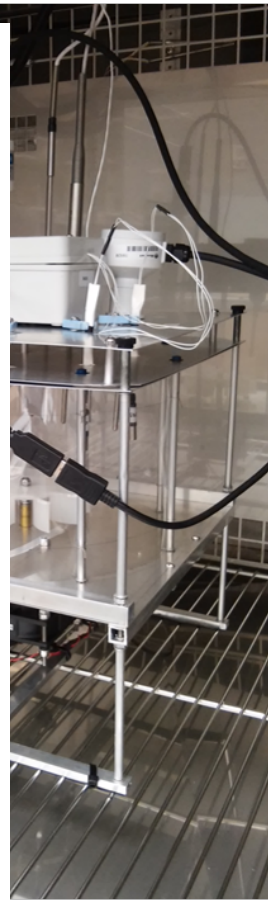
Parameter	Value
Length (ft)	2.25
Empty Weight (lbs)	12.7
Takeoff Weight (lbs)	12.7
Engine Type	Brushless electric
Engine Power	8 motors @ 500 W / motor
Battery Type	LiPo
Battery Capacity	22.2 V 6s 20,000 mAh
Parameter	**Value**
Max Cruise Speed (kts)	51
Min Cruise Speed (kts)	0
Max Range (nm)	6
Endurance (min)	25
Max Altitude (ft)	2500 for current mission
Min Altitude (ft)	0
Climb Rate (ft/min)	3,300
Descent Rate (ft/min)	1,500
Turn Rate (deg/sec)	180

The OU CopterSonde™ is an octo-rotor copter based on a hashtag frame design. The vehicle can be controlled manually or in autopilot mode. The on-board autopilot is the Pixhawk (PX4) running the APM Copter software. The inertial measurement unit (IMU) and GPS is built into the Pixhawk. Additionally, the system is equipped with differential GPS to improve accuracy of the positioning of the vehicle (2-8 cm) when in flight. The CopterSonde can maintain safe and stable flight even in the event of prop/motor failure. It is anticipated that the CopterSonde will be capable of operating in winds up to 50 knots.

Calibration – Mesonet Chamber







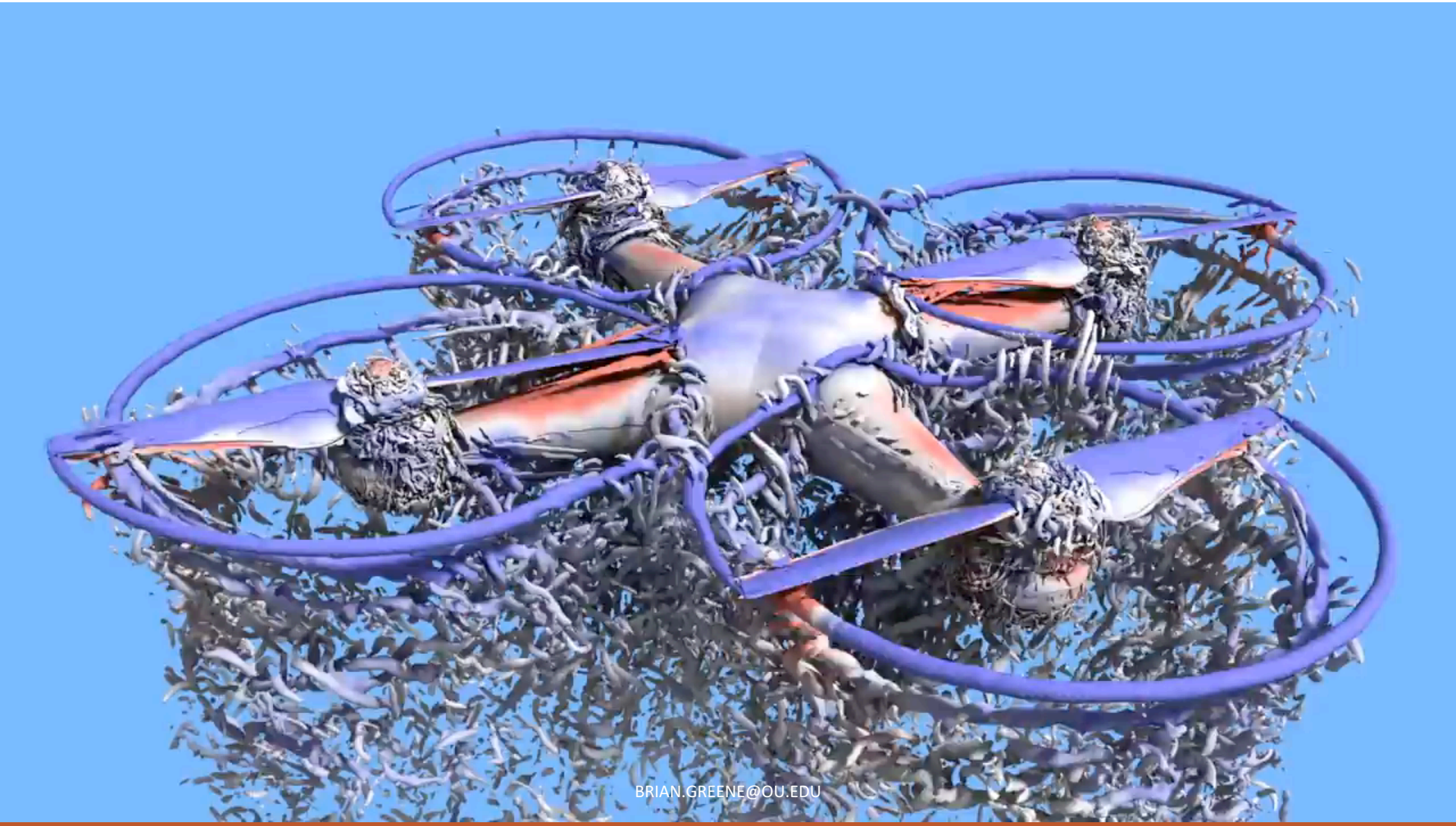
Calibration – NWC Mesonet Tower

National Weather Center Mesonet Tower

Aspirated and Non-Aspirated Chamber

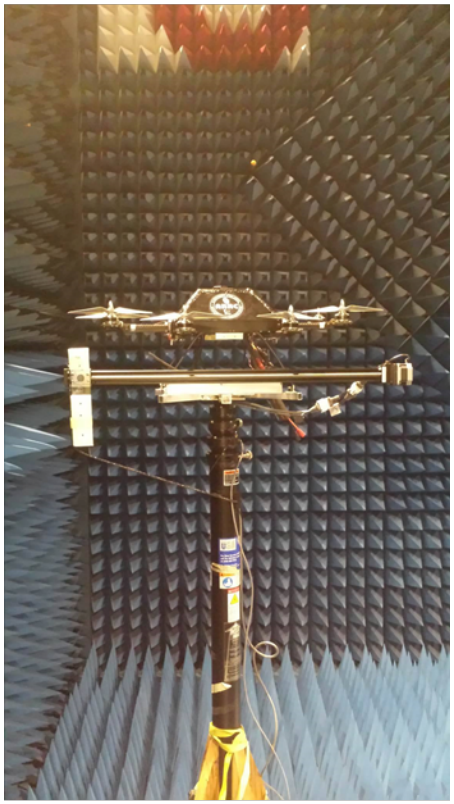
NASA Simulation of Air Flow From a DJI Phantom 3

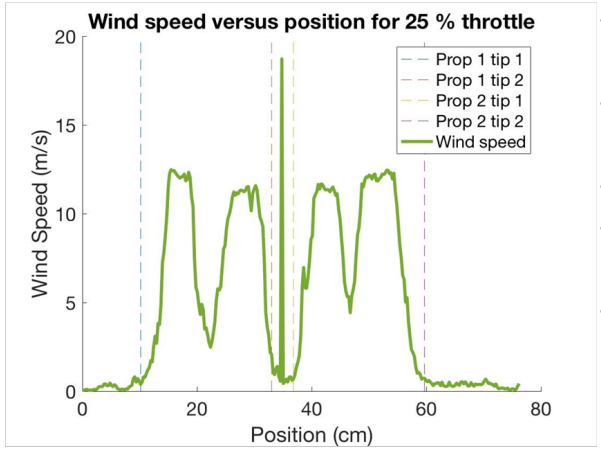
Airflow interactions are shown as undulating lines. Pressure changes are shown using color. Areas of high pressure are red; low are blue.

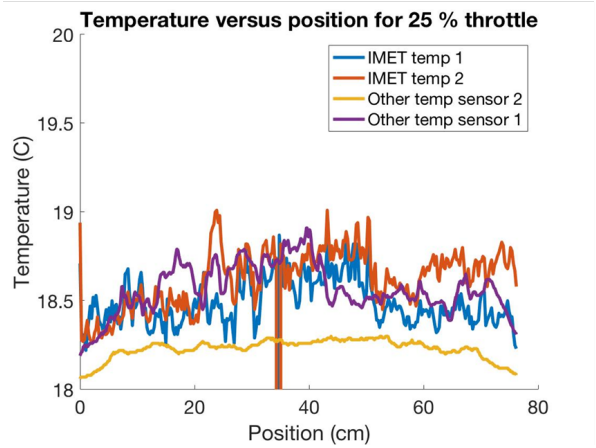


Calibration – Sensor Placement

Anechoic Chamber

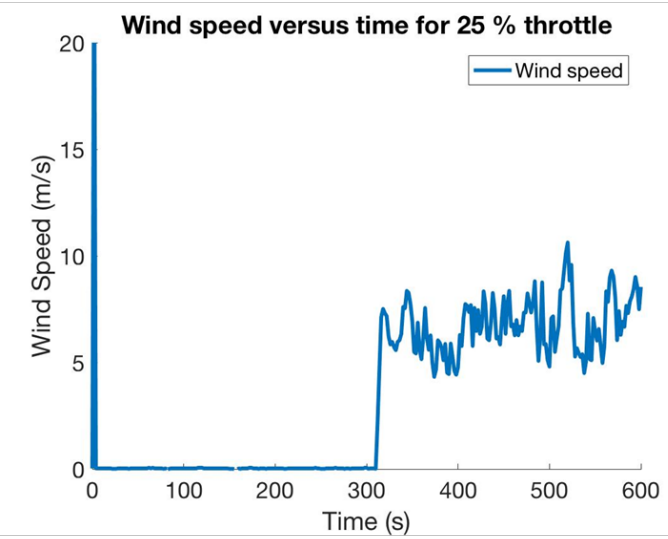


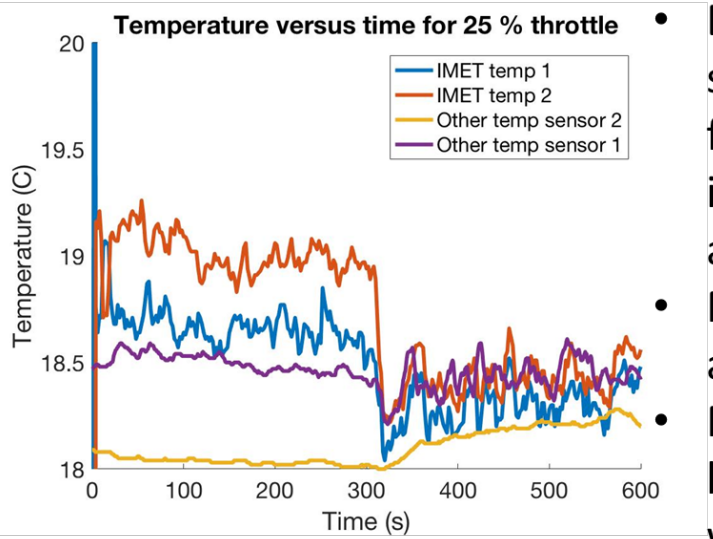




- Propellers are at 25% throttle for entire experiment
- "Other temp sensor" refers to those provided by NSSL
- Sensor 1 placed alongside iMets
- Sensor 2 placed a few feet away from setup as control
- Random spikes of larger than several degrees are random communication errors from, not representative changes
- Can visually identify correlation between wind speed and temperature
- Sources of error potentially due to propellers mixing warmer air downward from the top of the chamber downward across the sensors since chamber not perfectly climate controlled

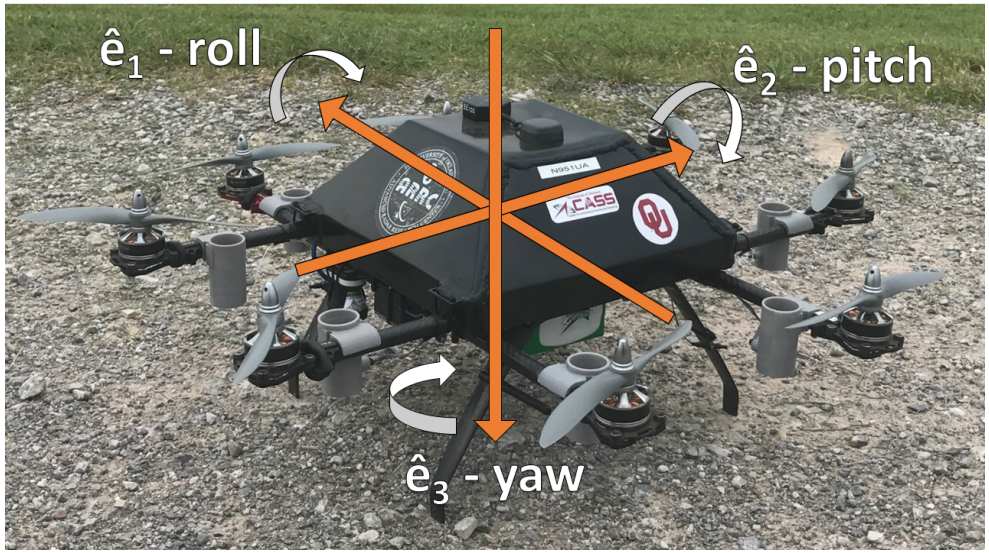
Anechoic Chamber





- Experiment #2: Sensors stationary with rotors off for 300 s, throttle increased to 25% afterward
- Noticeable difference in all sensors
- NSSL control increase likely due to mixing of warmer air downward

Wind Retrievals - Theory



$$Rx = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(roll) & \sin(roll) \\ 0 & -\sin(roll) & \cos(roll) \end{bmatrix}$$

$$Ry = \begin{bmatrix} \cos(pitch) & 0 & -\sin(pitch) \\ 0 & 1 & 0 \\ \sin(pitch) & 0 & \cos(pitch) \end{bmatrix}$$

$$Rz = \begin{bmatrix} \cos(yaw) & -\sin(yaw) & 0 \\ \sin(yaw) & \cos(yaw) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R = Rx * Ry * Rz = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix}$$

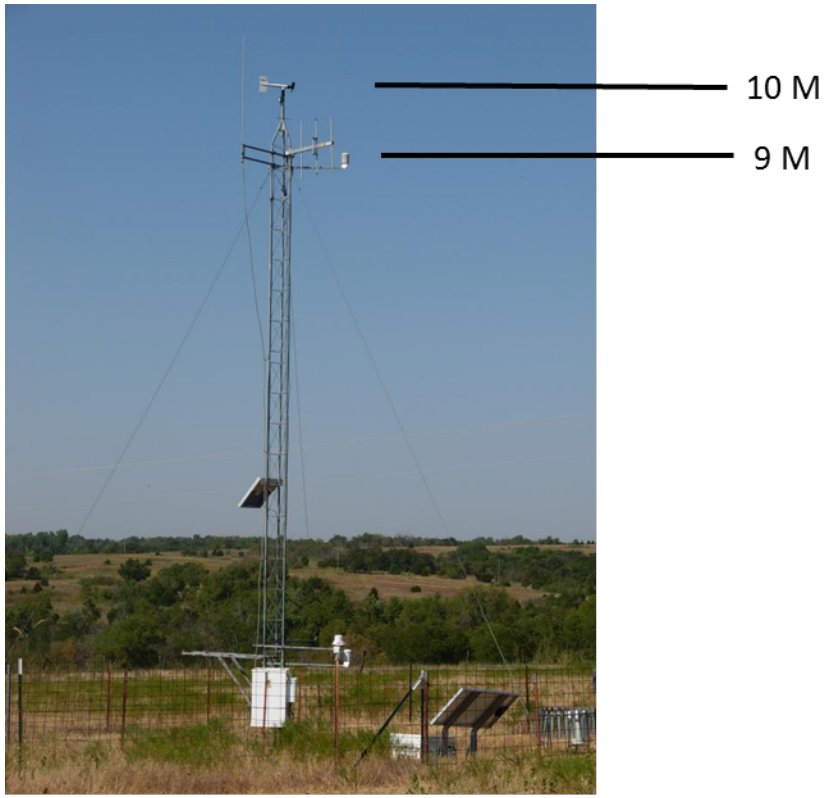
R_{ij} = projection of j in new coordinates onto i in original coordinates

$$\psi = \arccos(R_{33})$$

$$V = C * \tan(\psi)$$

$$Direction = \arctan\left(\frac{R_{23}}{R_{13}}\right)$$

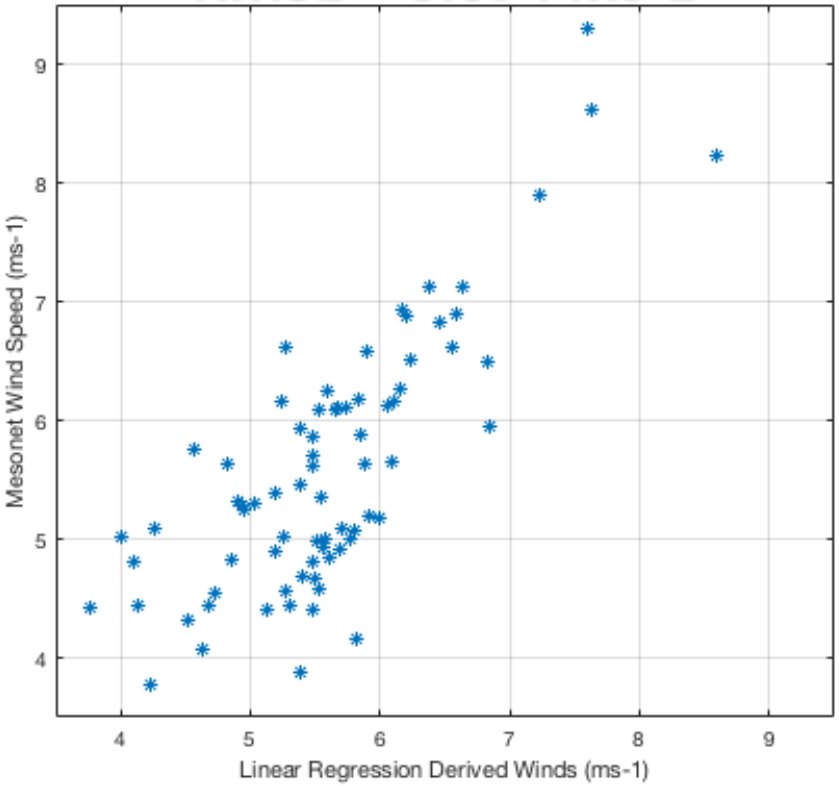
Wind Retrievals - Experiment



Wind Retrievals - Results

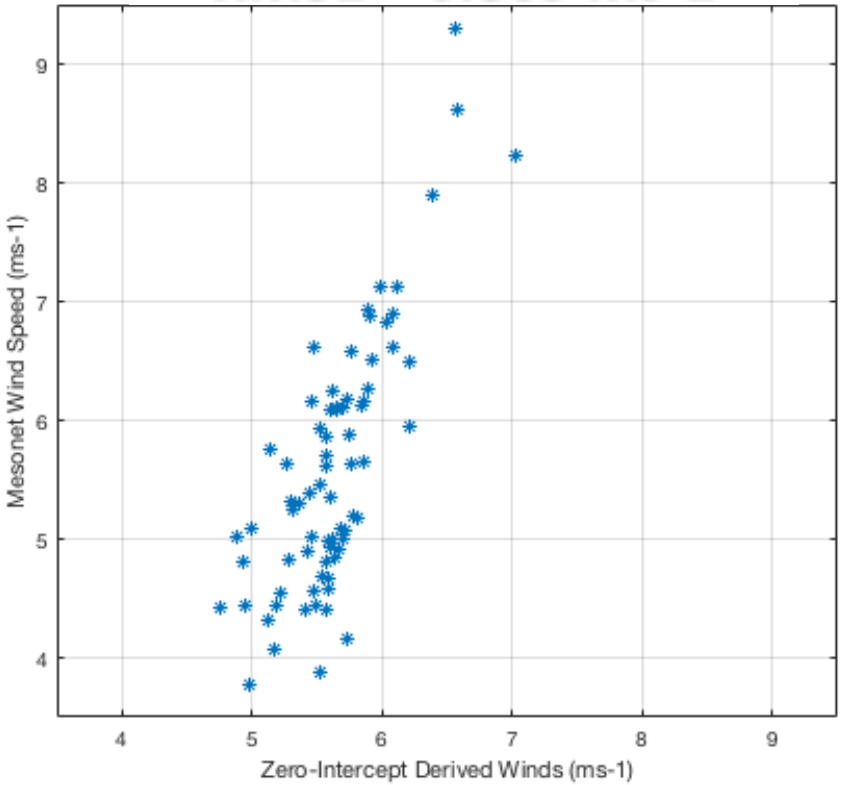
V = 34.494*sqrt(tan(psi)) – 6.337

RMSE = 0.674 ms-1

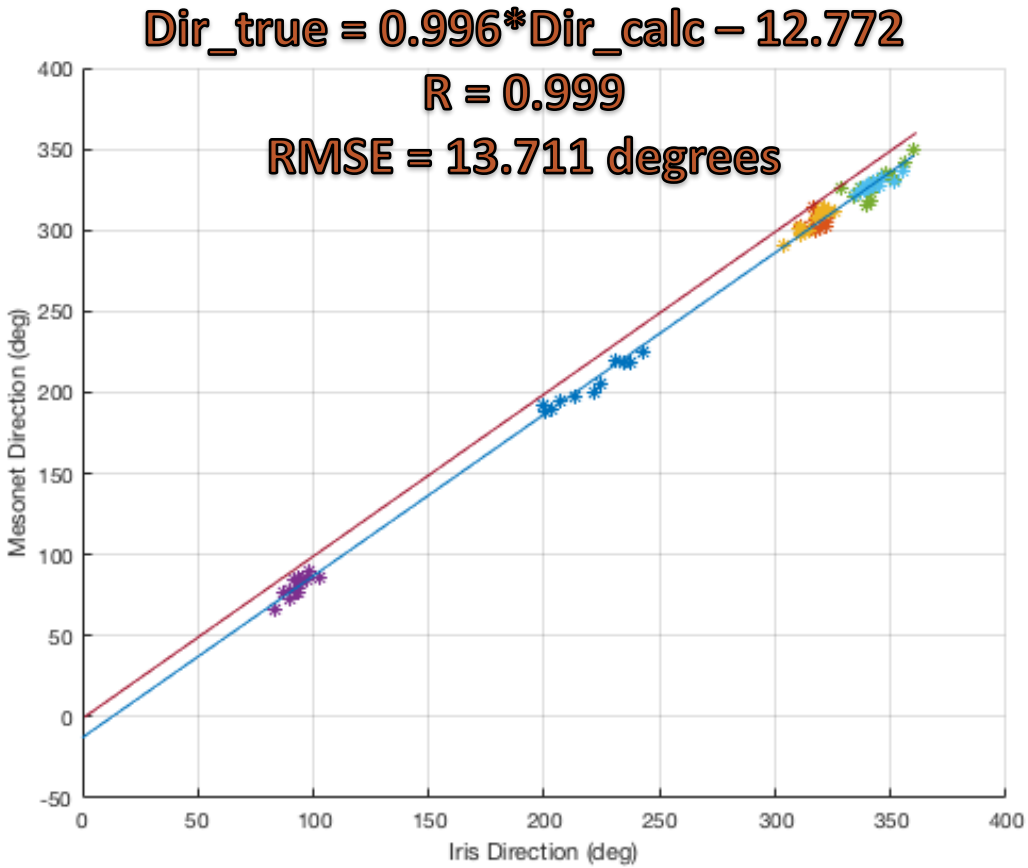


V = 16.208*sqrt(tan(psi))

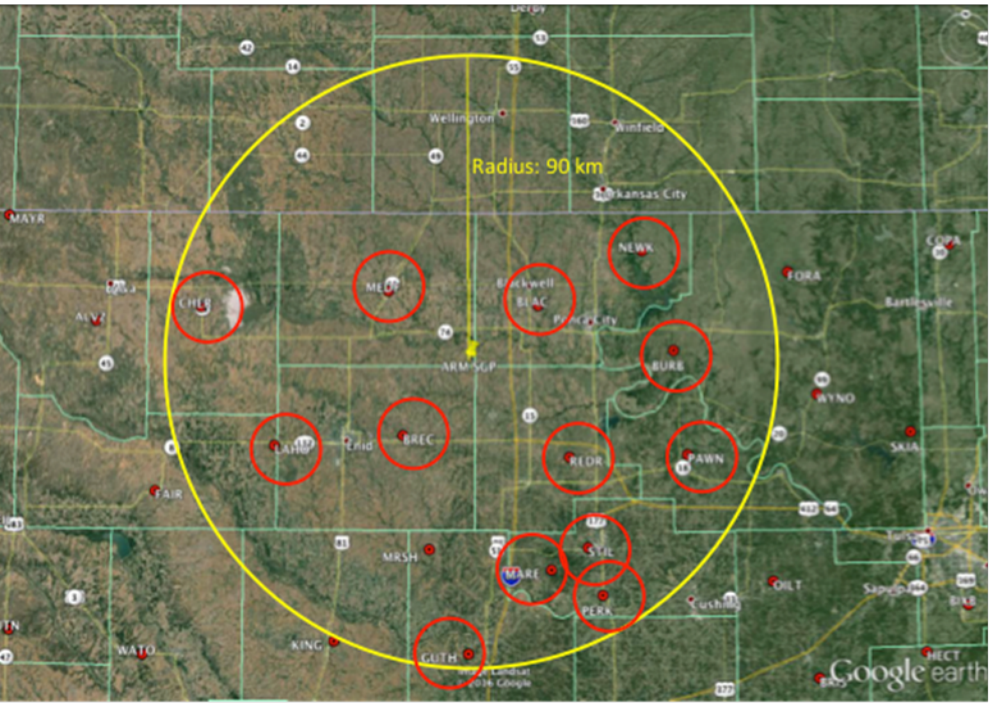
RMSE = 0.809 ms-1

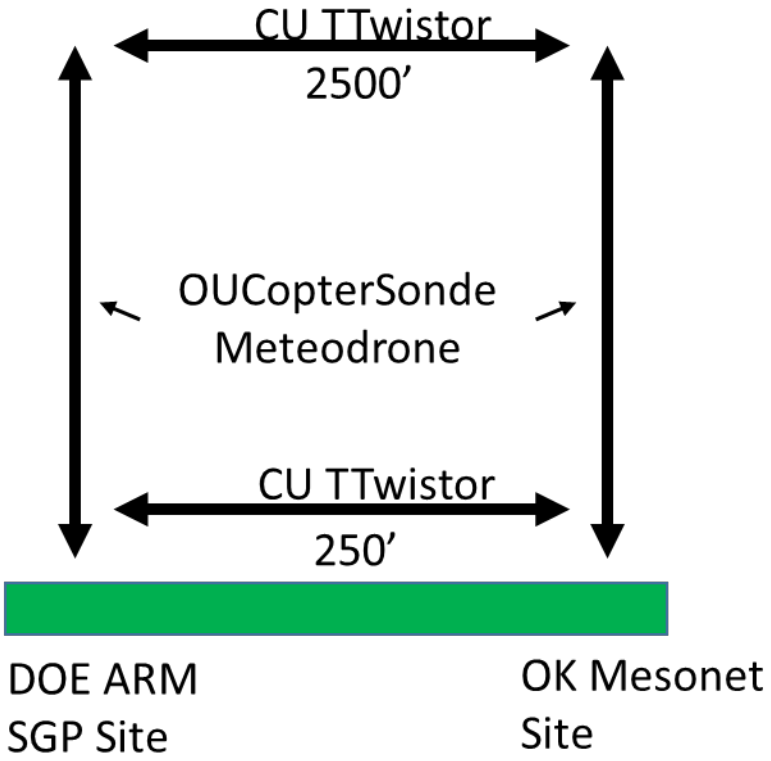


Wind Direction Results



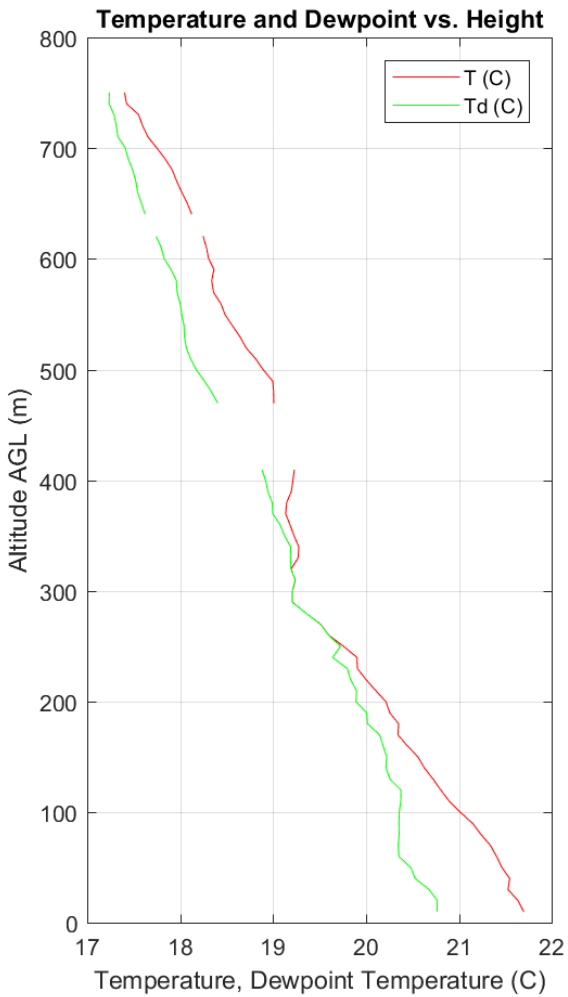
Environmental Profiling and Initiation of Convection (EPIC)

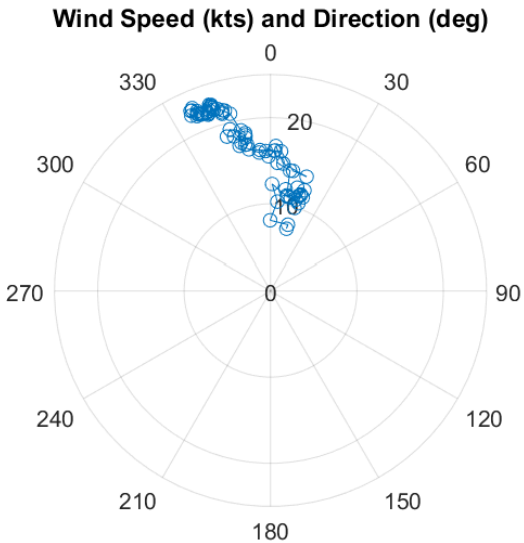




EPIC First Trials – 10 May 2017

Coptersonde-1 MRSH 20170510-211528 UTC





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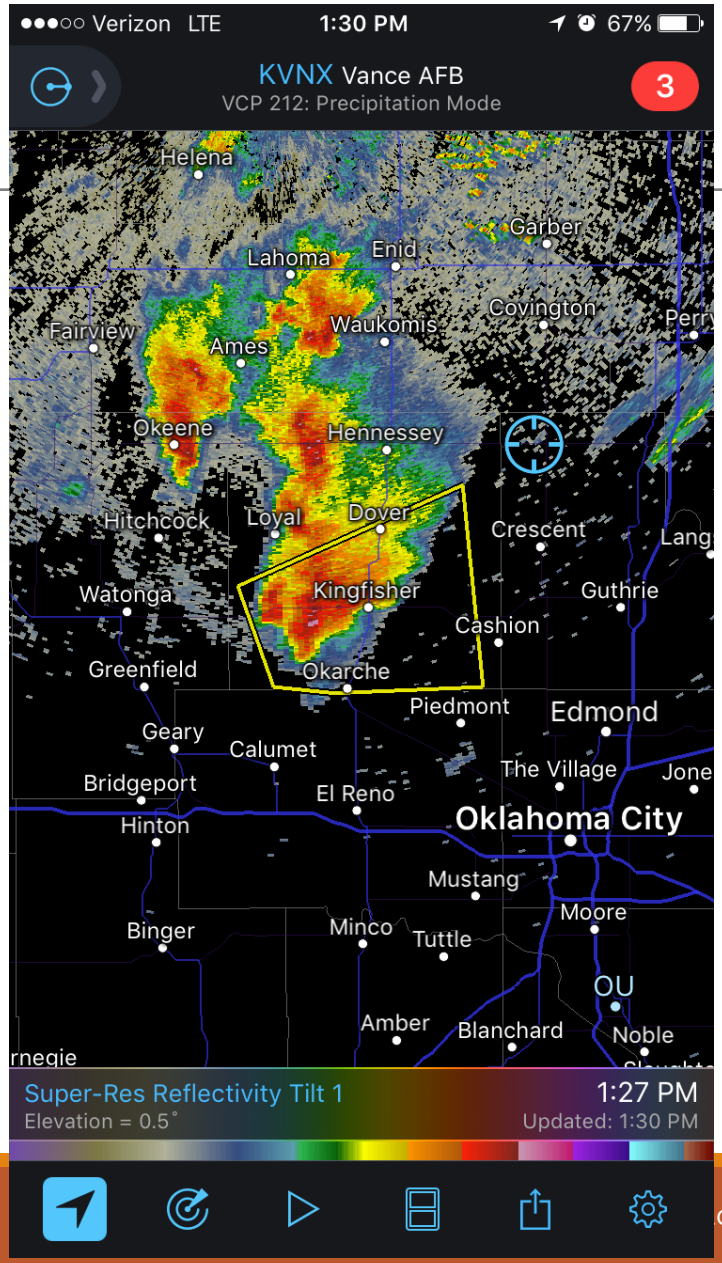
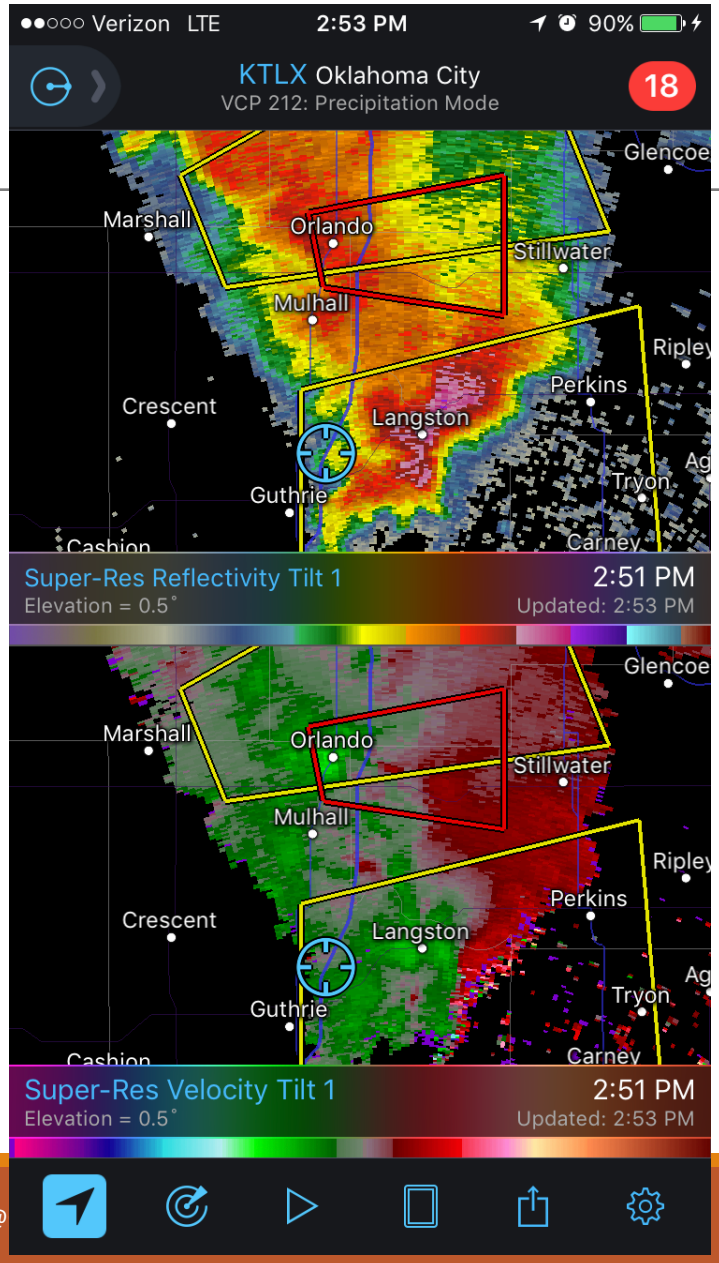
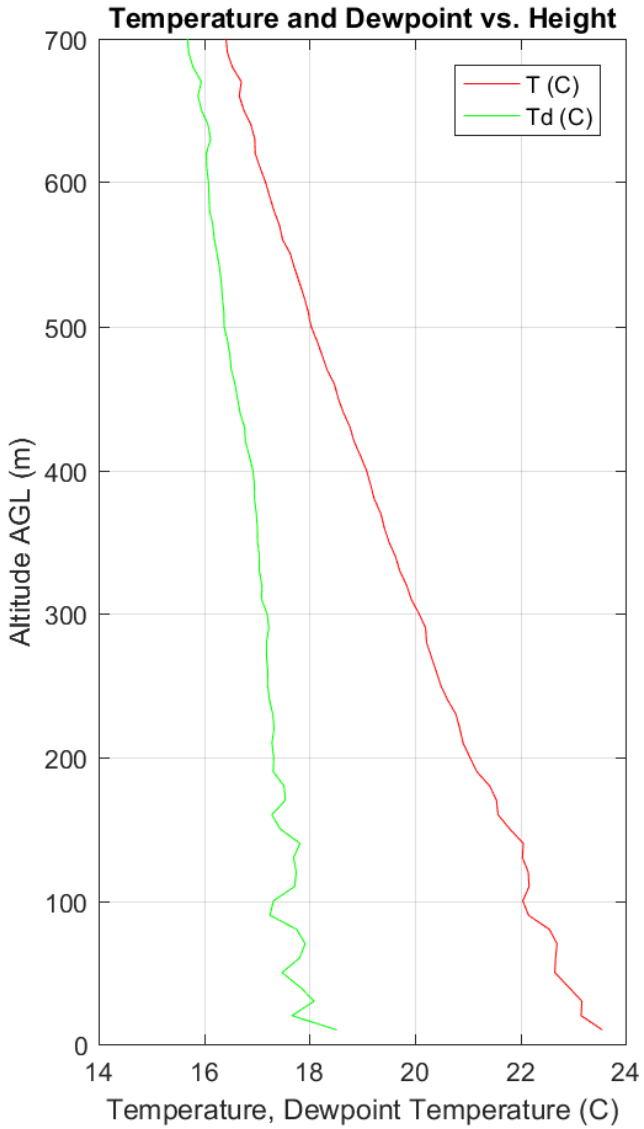
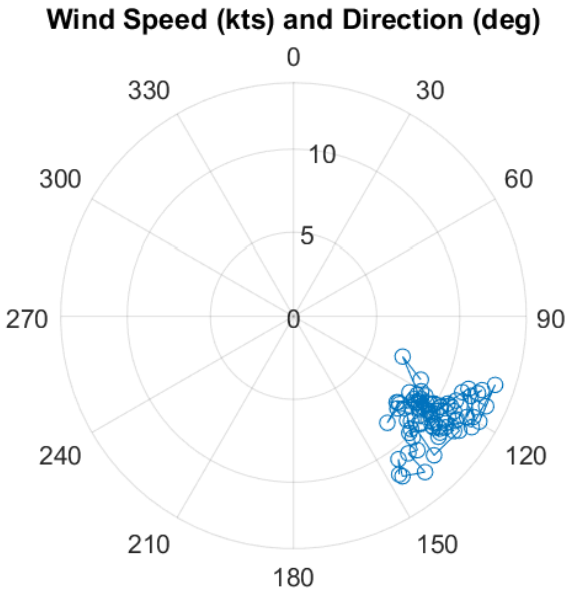
Convective Case – 11 May 2017





Coptersonde-1 MRSH 20170511-164930 UTC





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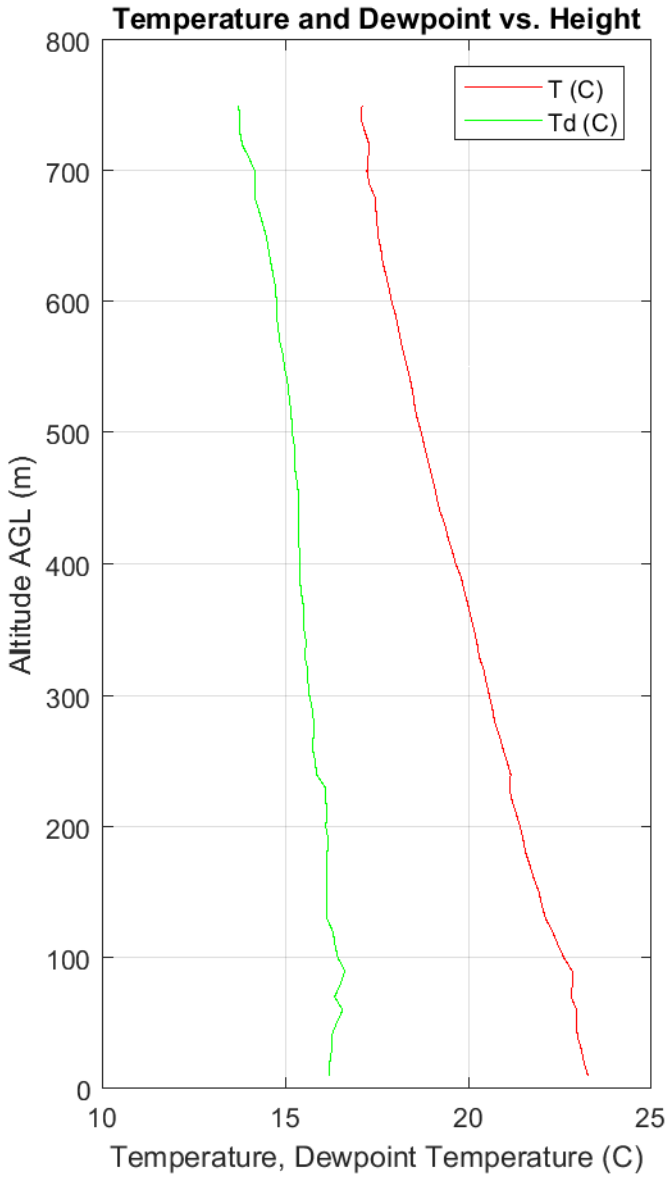
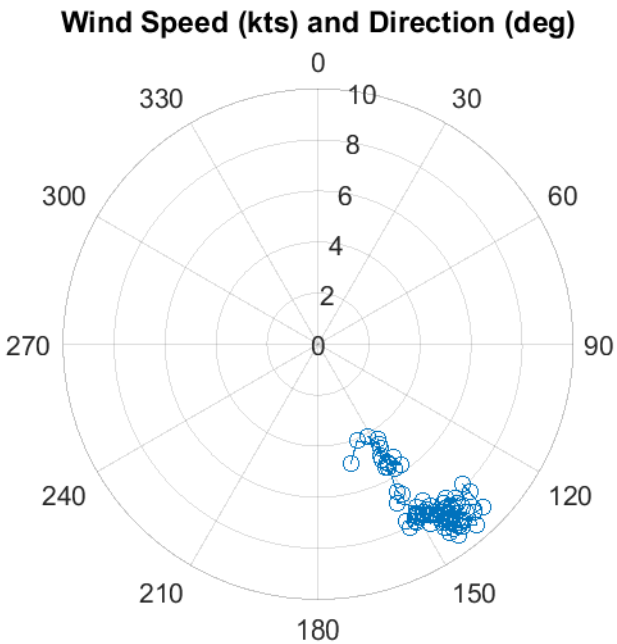
Coptersonde-2 MRSH 20170511-171857 UTC





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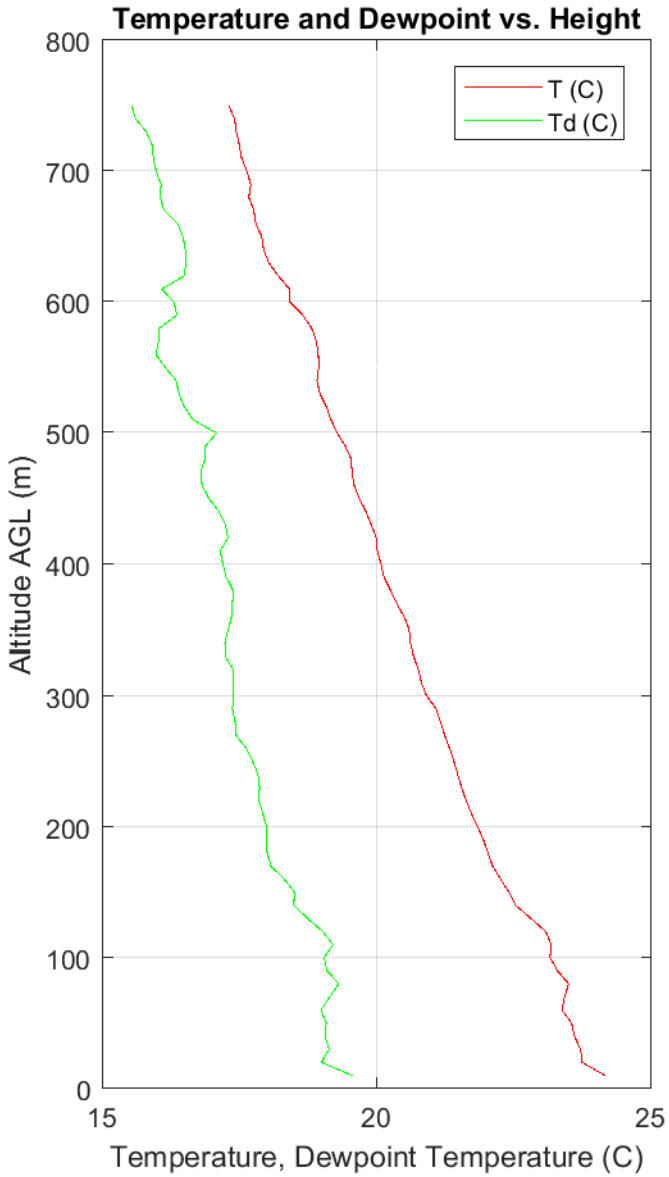
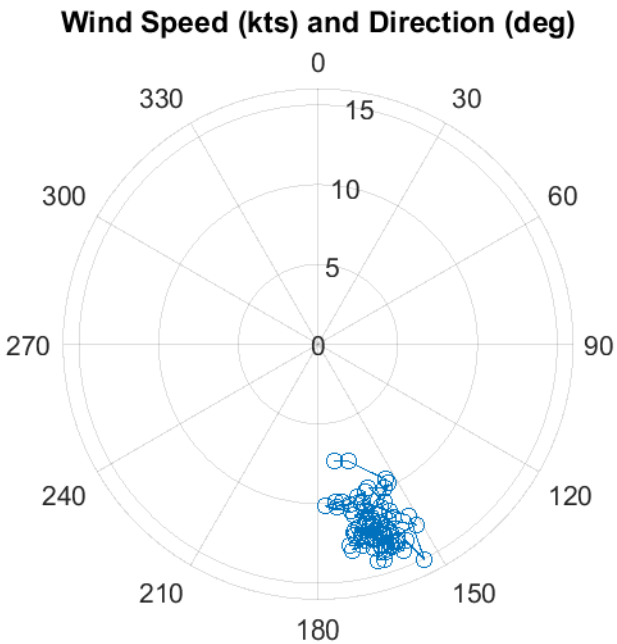
Coptersonde-1 MRSH 20170511-175124 UTC





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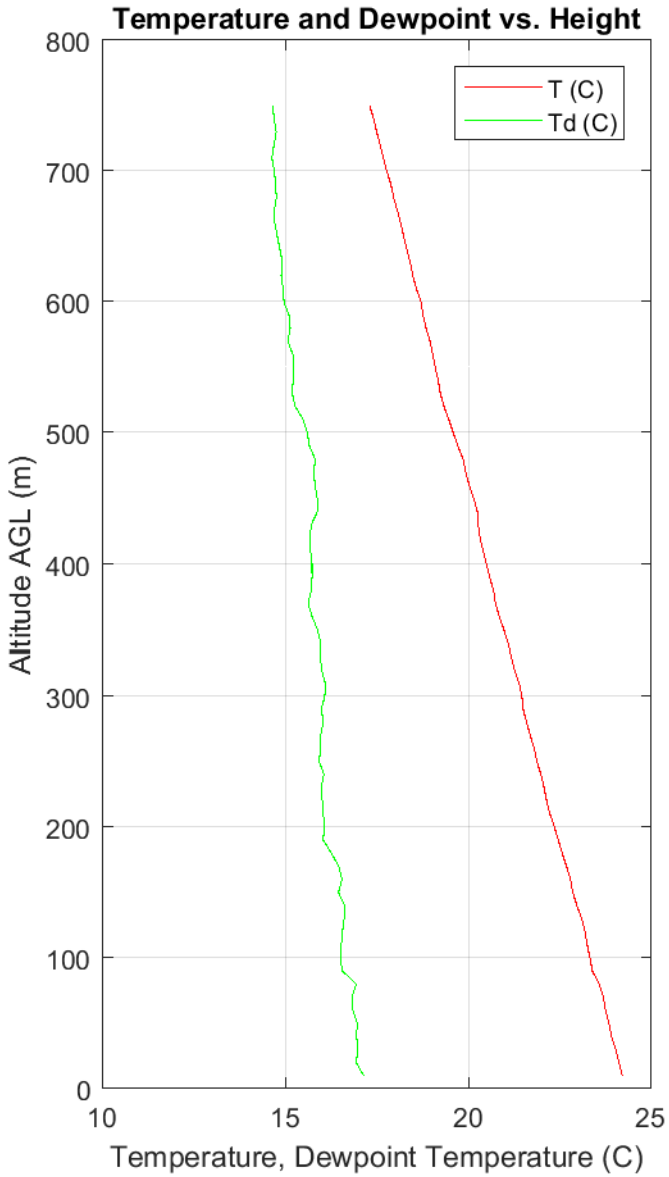
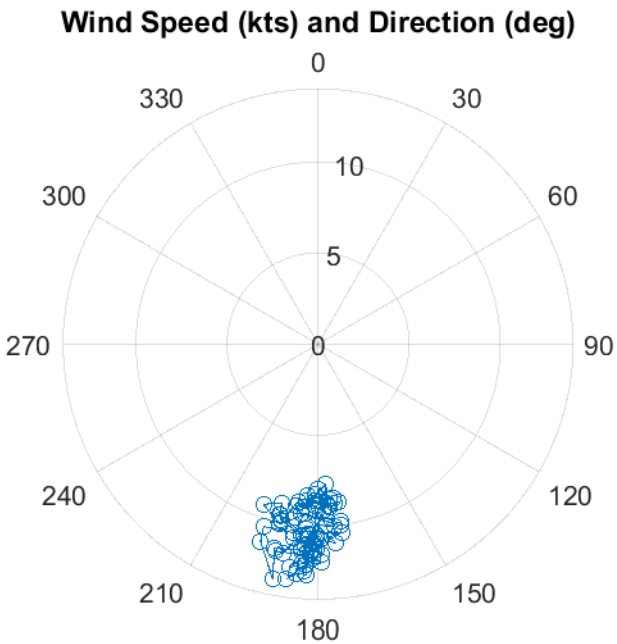
Coptersonde-2 MRSH 20170511-182843 UTC





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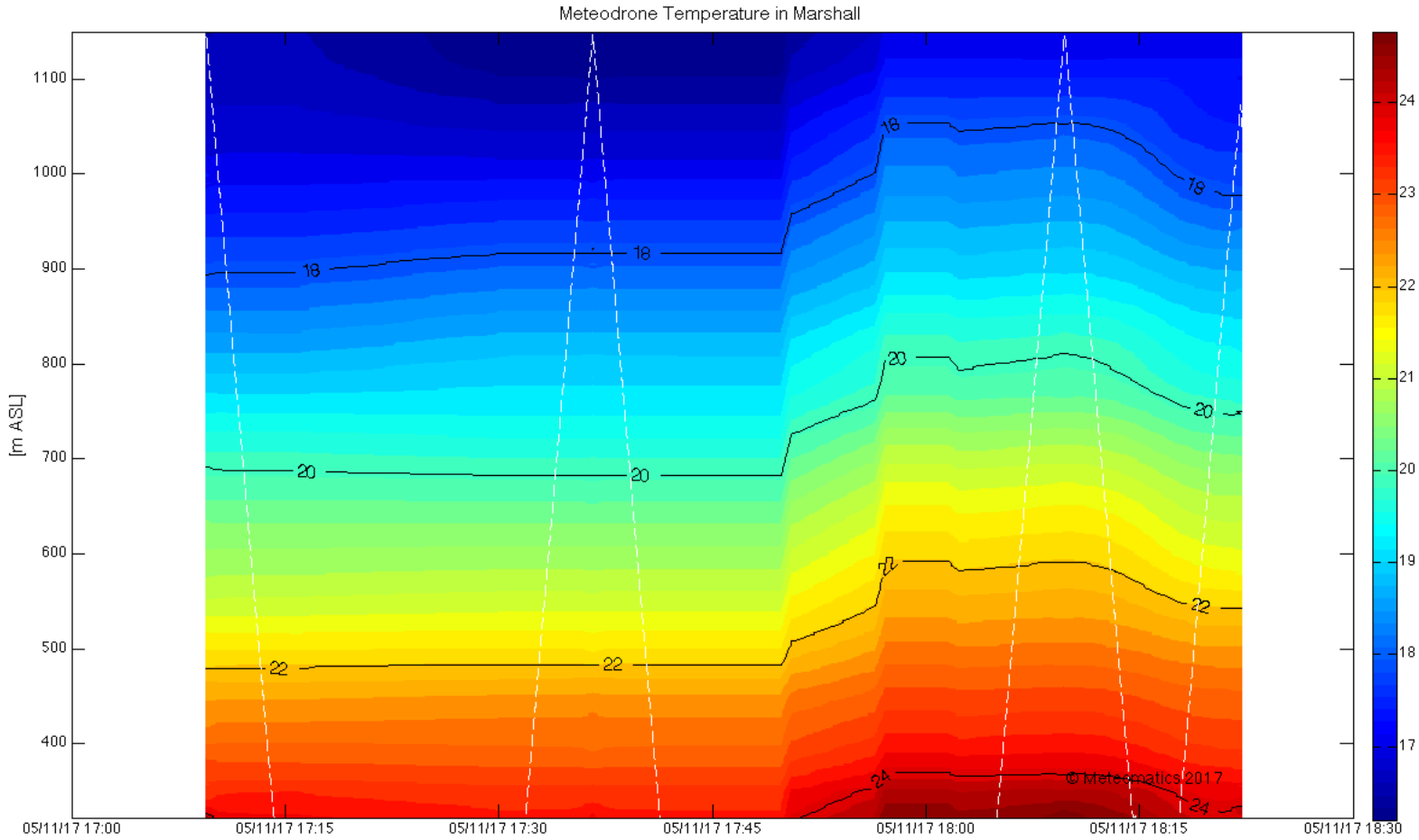
Meteodrone Temperature in Marshall
[m ASL]
1100
1000
900
800
700
600
500
400
05/11/17 17:00
05/11/17 17:15
05/11/17 17:30
05/11/17 17:45
05/11/17 18:00
05/11/17 18:15
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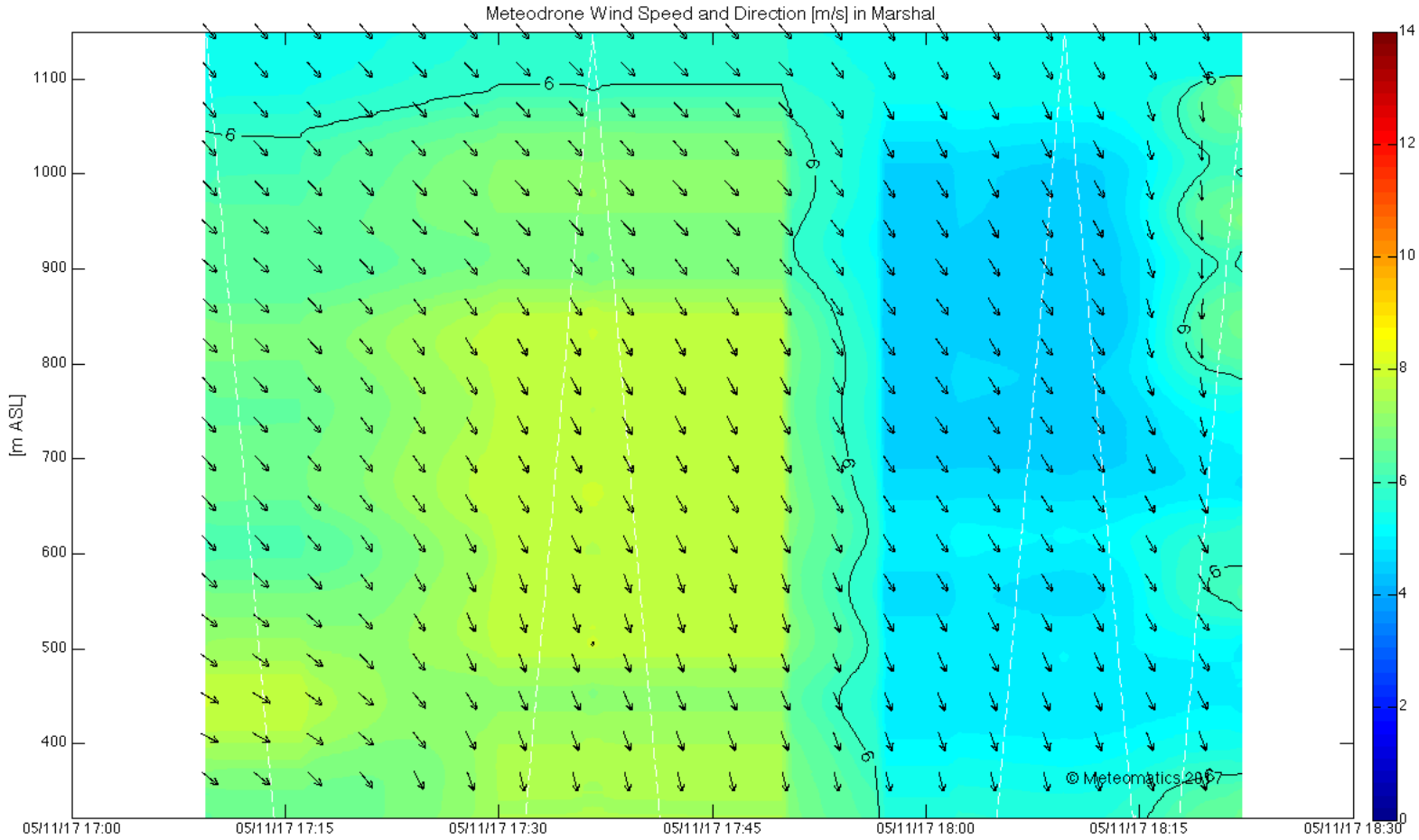
Meteodrone Wind Speed and Direction [m/s] in Marshal
[m ASL]
1100
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400
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05/11/17 17:15
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05/11/17 17:45
05/11/17 18:00
05/11/17 18:15
05/11/17 18:30
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Conclusions and Future Work

It is imperative to properly aspirate sensors in order to collect meaningful data

- In general, best results when sensors placed underneath rotors close to tip

Wind derivations using Euler angles show encouraging results, leave lingering questions

- New technique also being explored involving control theory and explicit calculations of drag coefficients

Several meaningful case studies from EPIC

Will continue wind calibration with sonic anemometers to get higher resolution readings

CLOUD-MAP in June 2017 will develop and refine sampling techniques

Citations

Neumann, P. P., and M. Bartholmai, 2015: Real-time wind estimation on a micro unmanned aerial vehicle using its internal measurement unit. *Sensors and Actuators A: Physical*, 235, 300–310, doi:10.1016/j.sna.2015.09.036.

Palomaki, R. T., N.T. Rose, M. van den Bossche, T.J. Sherman, and S.F.J. De Wekker, 2017: Wind estimation in the lower atmosphere using multi-rotor aircraft. *Journal of Atmospheric and Oceanic Technology*, early online release, *http://dx.doi.org/10.1175/JTECH-D-16-0177.1*.