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# Tethered Balloon Systems

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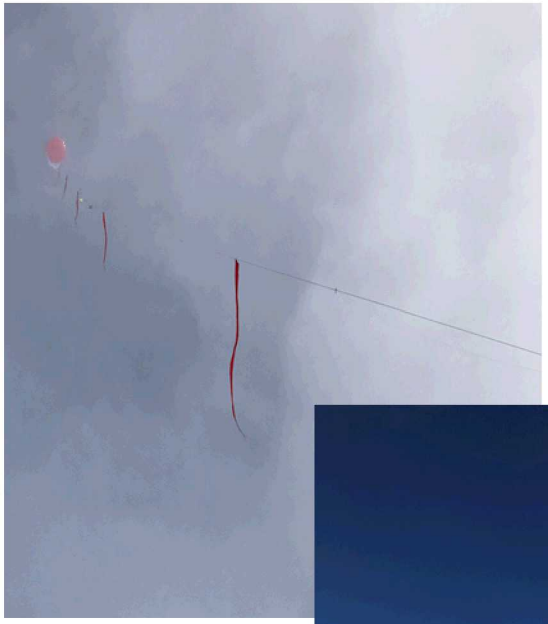
# Tethered Balloon System (TBS)

- Tethered balloon systems (TBSs) are developed by SNL
  - Flown on behalf of DOE's Atmospheric Radiation Measurement (ARM) Climate Research Facility
  - to collect in-situ atmospheric measurements to provide data products that advance climate models
  - Fly regularly to over 1.5 km at 3 ARM sites in Oklahoma and 2 ARM sites in Alaska
  - Operating and developing TBS anemometers and met instrumentation that could benefit AWAKEN science goals



# Instrument Trading Card: Tethered Balloon System (TBS) Cup Anemometer Booms

## Brief Description

TBS cup anemometers use airborne boom-mounted NRG 40C anemometers suspended from a tethered balloon system.

## Quantity Measured

- Horizontal velocity
- 3D GPS, pressure, temperature, relative humidity

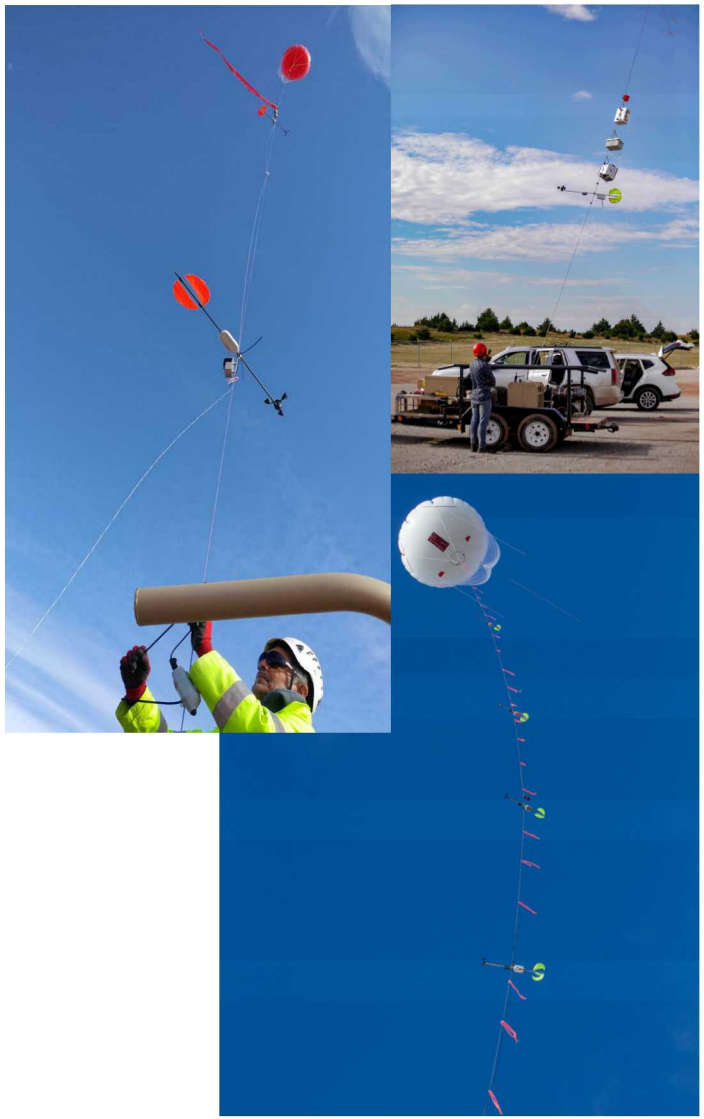
| Spatial Scale | Temporal Scale |
|---|---|
| ▪ 2.5 m distance constant | ▪ Rate: ~1 Hz |

## Enables Beyond Existing Technology

- Capable of airborne in-situ met and horizontal velocity measurements without met tower

## Region of Application

| | | | | |
|---|---|---|---|---|
| **Single Turbine:** | **Inflow X** | Turbine Response | **Near Wake X** | Far Wake **X** |
| **Wind Plant:** | Inflow | Turbine Response | Wake Mixing | Plant Wake |
| **Other:** | Describe: | | | |



# Instrument Trading Card: Tethered Balloon System (TBS) Cup Anemometer Booms

## Helps Validate or Calibrate These Models

| LES X | RANS | DWM | WRF X | Turbine | Other - Describe |
|---|---|---|---|---|---|

## Helps Answer AWAKEN Science Questions

1. Wind direction, shear and veer
2. Wind plant wake
3. Terrain impacts
4. Wind plant upstream blockage

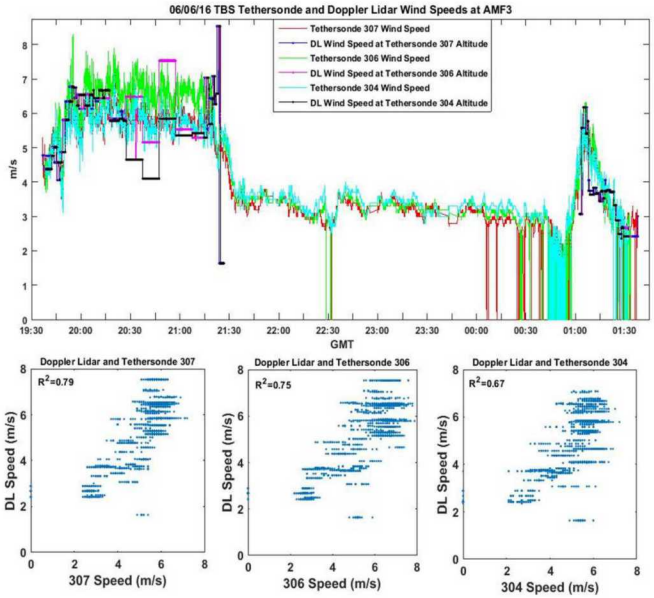
## Current State of Technology

- Operated for over 600 hours from DOE TBSs

## Developmental Challenges and Requirements

- Off-axis flow correction, particularly overestimation of wind speed during negative vertical velocities

| | |
|---|---|
| **Hours:** | 600+ operating hours |
| **Technology:** | Climate modeling and weather forecasting under DOE ARM program |



# Instrument: Tethered Balloon System (TBS) Sonic Anemometer Next-Gen Booms

## Brief Description

Airborne boom-mounted miniaturized 3D sonic anemometer with met data, IMU, and GNSS heading

## Quantity Measured

- Horizontal and vertical velocity to ±0.1 m/s (<11 m/s) or ±1% (11 – 30 m/s)
- 3D GPS, pressure, temperature, relative humidity
- Motion tracking, and accurate heading and orientation data
- 3D position to ± 1.2 m, heading (wind direction) to ± 0.08°, pitch/roll to ± 0.5°

| Spatial Scale | Temporal Scale |
|---|---|
| ▪ 35 mm measurement path | ▪ Rate: 10 Hz |

## Enables Beyond Existing Technology

- Capable of airborne in-situ met, 3D velocity, and wind direction measurements without met tower
- Capable of highly accurate (sub-degree) wind direction measurements
- Capable of turbulence kinetic energy measurements

## Region of Application

| | | | | |
|---|---|---|---|---|
| **Single Turbine:** | **Inflow X** | Turbine Response | **Near Wake X** | Far Wake **X** |
| **Wind Plant:** | Inflow | Turbine Response | Wake Mixing | Plant Wake |
| **Other:** | Describe: | | | |

# Instrument: Tethered Balloon System (TBS) Sonic Anemometer Next-Gen Booms

## Helps Validate or Calibrate These Models

| | | | | | |
|---|---|---|---|---|---|
| **LES X** | **RANS** | DWM | WRF **X** | Turbine | Other - Describe |

## Helps Answer AWAKEN Science Questions

1. Wake interaction, merging, meandering
2. Momentum transport within, around, above and below the farm
3. Wind direction, shear and veer
4. Wind plant wake
5. Wind plant upstream blockage

## Current State of Technology

- In development for DOE TBSs. First airborne deployment in February 2020.

## Developmental Challenges and Requirements

- Integration of GNSS for extremely accurate heading
- Validation of miniaturized 3D velocity measurements and sensitivity to pitch, roll, and off-axis flow

| | |
|---|---|
| **Hours:** | ▪ 80+ development hours |
| **Technology:** | ▪ Climate modeling and weather forecasting under DOE ARM program |

# Instrument: Tethered Balloon System (TBS) Distributed Temperature Sensing (DTS)

## Brief Description

Finely-resolved airborne fiber optic-based Distributed Temperature Sensing (DTS) measurements from TBS

## Quantity Measured

- Atmospheric temperature

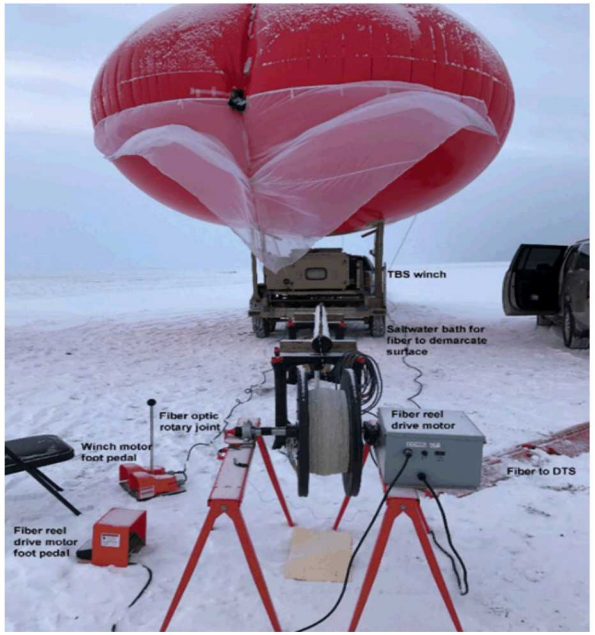
| Spatial Scale | Temporal Scale |
|---|---|
| ▪ 0.25 m spatial resolution | ▪ Rate: 0.2 Hz |

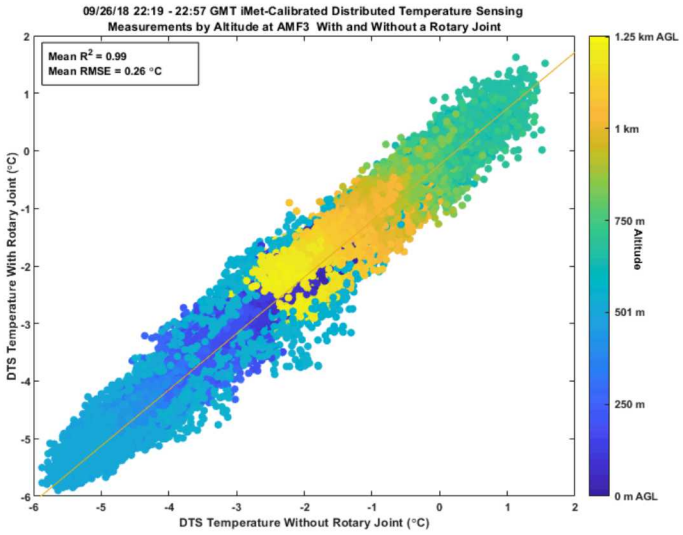
## Enables Beyond Existing Technology

- Capable of airborne in-situ atmospheric temperature measurements at fine spatial and temporal resolution to ± 0.08 °C.

## Region of Application

| | | | | |
|---|---|---|---|---|
| **Single Turbine:** | **Inflow X** | Turbine Response | **Near Wake X** | Far Wake **X** |
| **Wind Plant:** | Inflow | Turbine Response | Wake Mixing | Plant Wake |
| **Other:** | Describe: | | | |



# Instrument: Tethered Balloon System (TBS) Distributed Temperature Sensing (DTS)

## Helps Validate or Calibrate These Models

| LES X | RANS | DWM | WRF X | Turbine | Other - Describe |
|---|---|---|---|---|---|

## Helps Answer AWAKEN Science Questions

1. Wake recovery and dissipation
2. Deep array effects/internal boundary layer
3. Atmospheric stability and surface heat flux
4. Momentum transport within, around, above and below the farm
5. Air-sea interaction (DTS can also be used for subsea or surface measurements to 10 km)

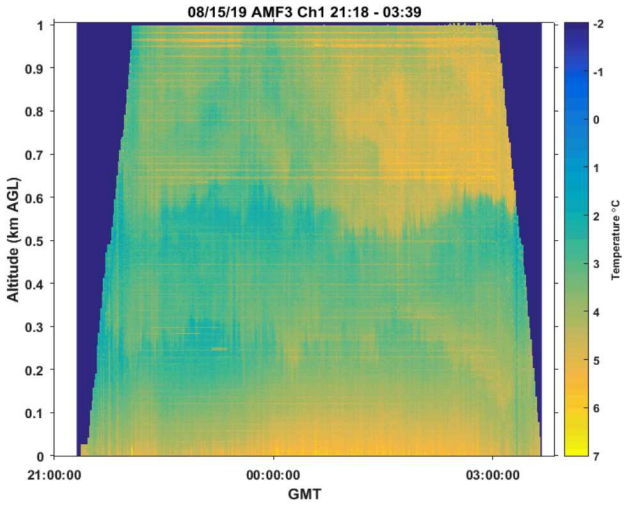
## Current State of Technology

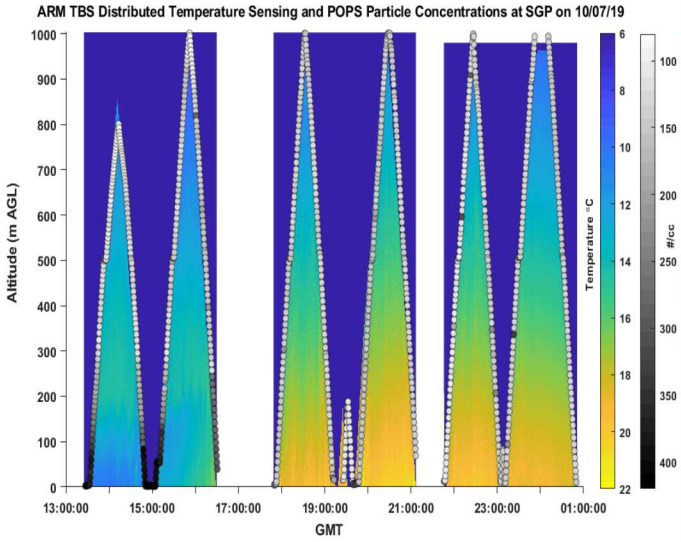
- Operated on DOE TBSs for over 300 hours.

## Developmental Challenges and Requirements

- Completed validation studies regarding solar radiation and fiber optic rotary joint impacts on measurement accuracy

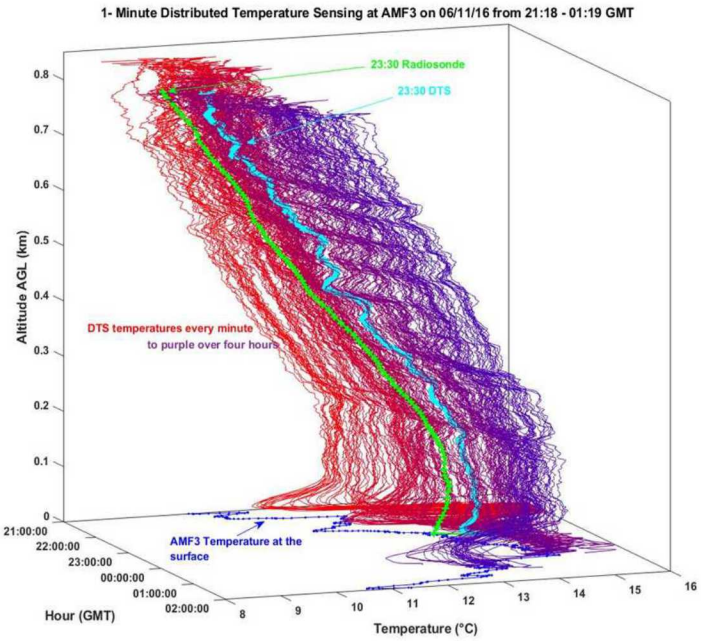
| | |
|---|---|
| **Hours:** | 300+ operating hours |
| **Technology:** | Climate modeling and weather forecasting under DOE ARM program |



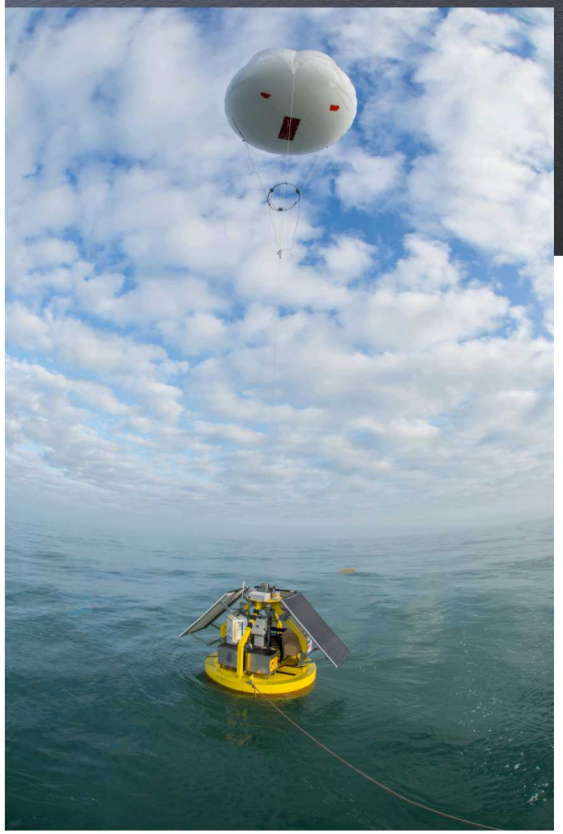



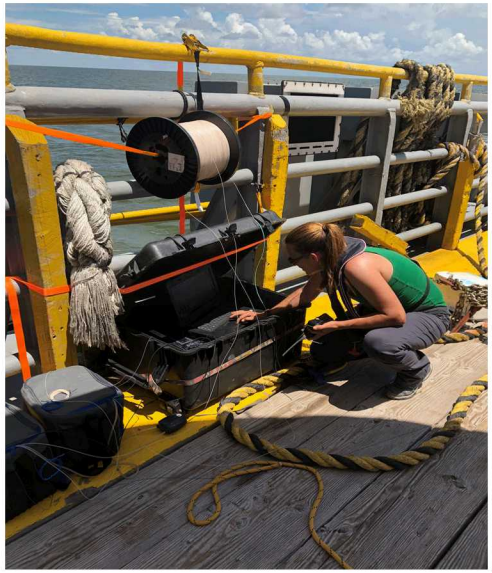
# DTS from UAV

- DTS was operated from a rotorcraft under a 2017 SNL study
- 'Jack in the box' concept as potential radiosonde replacement at remote or unmanned locations



# DTS from marine platform





- Underwater DTS profiles have also been collected under two ship-based SNL studies
- DTS could be operated from TBS and underwater simultaneously to couple ocean and atmosphere models using in situ measurements from both domains

Thank you!

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