Weather-condition-regulated, heated 3-D sonic anemometers (CSAT3AH and CSAT3BH): Working rationale, operation algorithm, and performance assessment

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Introduction

Three-dimensional (3D) sonic anemometers are commonly used to measure 3D wind in eddy-covariance (EC) systems for the fluxes of momentum, sonic temperature, and when integrated with fast-response gas analyzers, the fluxes of CO_2/H_2O and trace gases. The anemometer has three pairs of sonic transducers spatially positioned with optimized geometry for 3D wind. The three pairs form three individual sonic paths, each of which is between paired transducers mutually emitting and receiving ultrasonic signals. The transmitting time of the signals in reference to coordinate geometry of the sonic paths is used to calculate wind velocities and sonic temperature at high frequencies. However, under unfavorable weather conditions, the dew, frost, snow, and/or ice often deposit on the transducer signal transmitting surface. The deposition interferes with the transmitting processes, bringing uncertainties to sonic measurements. These uncertainties degrade data quality and even interrupt data continuity, especially in the climate where this deposition is frequent. To minimize the uncertainties and optimize the data quality and continuity, Campbell Scientific Inc. (CSI) developed the weather-condition-regulated, heated 3D sonic anemometers: CSAT3AH and CSAT3BH for recent releases.

Applications in Sensor Configurations

- Configurations for stand-alone aerodynamic measurements, open-path EC, or closed-path EC
- CSAT3AHs can be paired with the CPEC300 series or EC150 (Fig. 1a, 1b, & 1c)
- CSAT3BHs can be paired with fine-wire thermocouples (Fig. 1d), used as a stand-alone, or be paired with other gas analyzer models for EC measurements

Fig. 1a (left) CSAT3AH and EC150 Open-Path EC Gas Analyzer; Fig. 1b (right) CSAT3AH in a CPEC310 Closed-Path EC System

Fig. 1c (left) CSAT3AH in a CPEC306 Closed-Path EC System; Fig. 1d (right) CSAT3BH with a fine-wire thermocouple

Specifications

Power Requirements	
Anemometer Voltage Requirement	9.5 to 32 Vdc
Current Required for 10 Hz Measurement Rate	110 mA (@ 12 Vdc) 65 mA (@ 24 Vdc)
Current Required for 100 Hz Measurement Rate	145 mA (@ 12 Vdc) 80 mA (@ 24 Vdc)

Arms and Strut	0.74 A nominal (@ 24 Vdc) 2.46 A at maximum heating (@ 24 Vdc)
Transducer Fingers	1.13 A nominal (@ 24 Vdc) 3.75 A at maximum heating (@ 24 Vdc)
Total System Power	1.86 A nominal (@ 24 Vdc) 6.2 A at maximum heating (@ 24 Vdc)
Controller Current Required	30 mA (heaters off [quiescent] @ 24 Vdc)

Theory of Operation

Both the CSAT3AH and CSAT3BH use the same technology for heating in hardware and software (Fig. 2a, 2b, & 2c). The CSAT3BH Heater Controller Box (Fig. 2b) receives diagnostic information from the CSAT3AH/BH and temperature/relative humidity (RH) information from the temp/RH probe (Fig. 2c) to determine the appropriate heating mode.

To avoid any additional aerodynamic effects on the anemometer structure from the heating hardware, the heating elements along with sensor temperature monitoring wires are built in. Heaters are located in the arms, strut, and each of the 6 transducer claws.

The heating elements are powered from the CSAT3H heater controller box (Fig. 2b). The power is programmatically regulated based on air temperature (*T*) and RH from a probe (Fig. 2c) and status diagnostics from the sonic anemometer.

When $T > 2$ °C, major heating starts only if the sonic working status has sustained diagnostic flags because of dew or rain. **When $T \le 2$ °C and no diagnostic flags**, the CSAT3H prevents frost from forming on the transducer surfaces by keeping the temperature the transducers several degrees above the dew point temperature. **When $T \le 2$ °C and diagnostic flags** are coming from the sonic anemometer all heating zones will be active due to the likelihood of snow, ice, frost, dew, or rain being present.

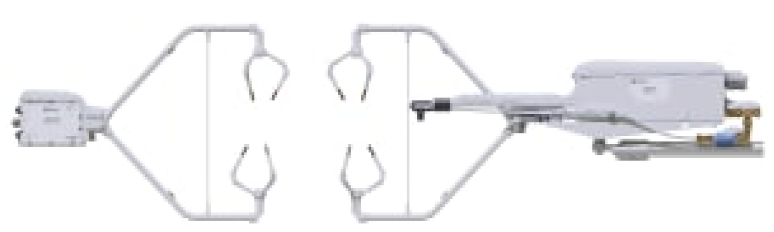


Fig. 2a CSAT3BH (left) and CSAT3AH (right) with EC155 closed-path gas analyzer

Fig. 2b CSAT3H Heater Controller Box

Fig. 2c Temp/RH for heater algorithm

Field and Laboratory Testing

The functionalities of weather-condition-regulation was tested in laboratory (Fig. 3d & 4a), in a snow field (Logan, UT, Fig. 3a), over forest canopy (Qingyuan, China, Fig. 3b), and in high altitude snow (Tibet, Fig. 3c), respectively.

Fig. 3a Heated sonic (right) compared to non-heated sonic (left) during icing conditions

Fig. 3b CSAT3BH (left) in Qingyuan, China testbed.

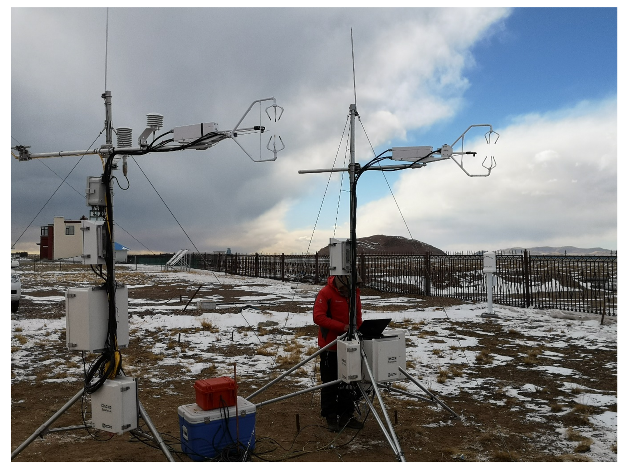


Fig. 3c Comparison heated closed-path EC system (left) to non-heated (right) in Tibet

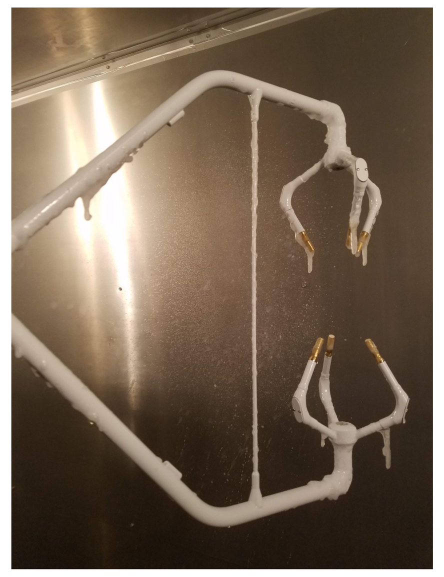


Fig. 3d Continuous icing application on a heated sonic associated with data from Fig. 4a

Test results

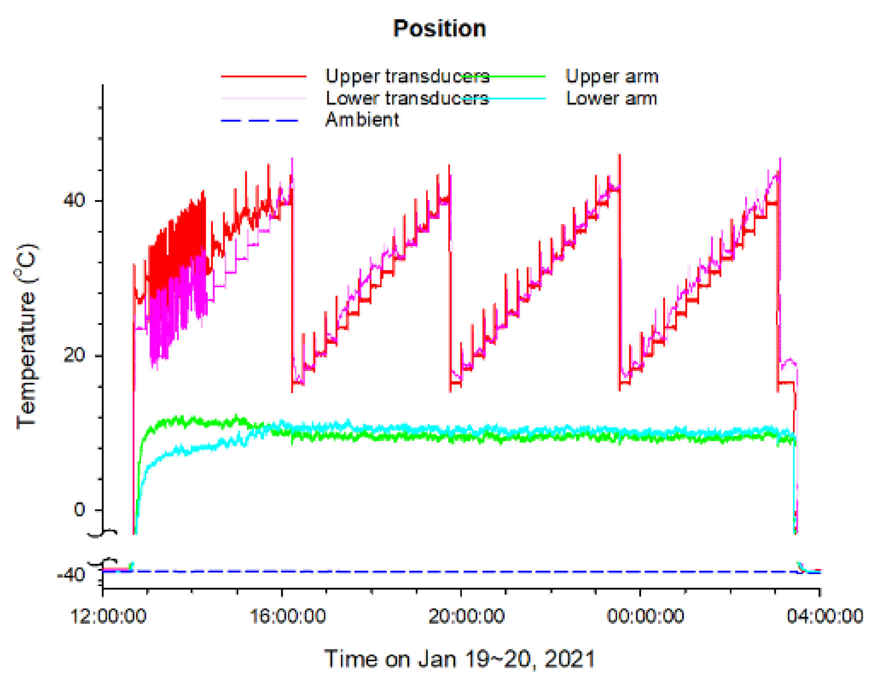
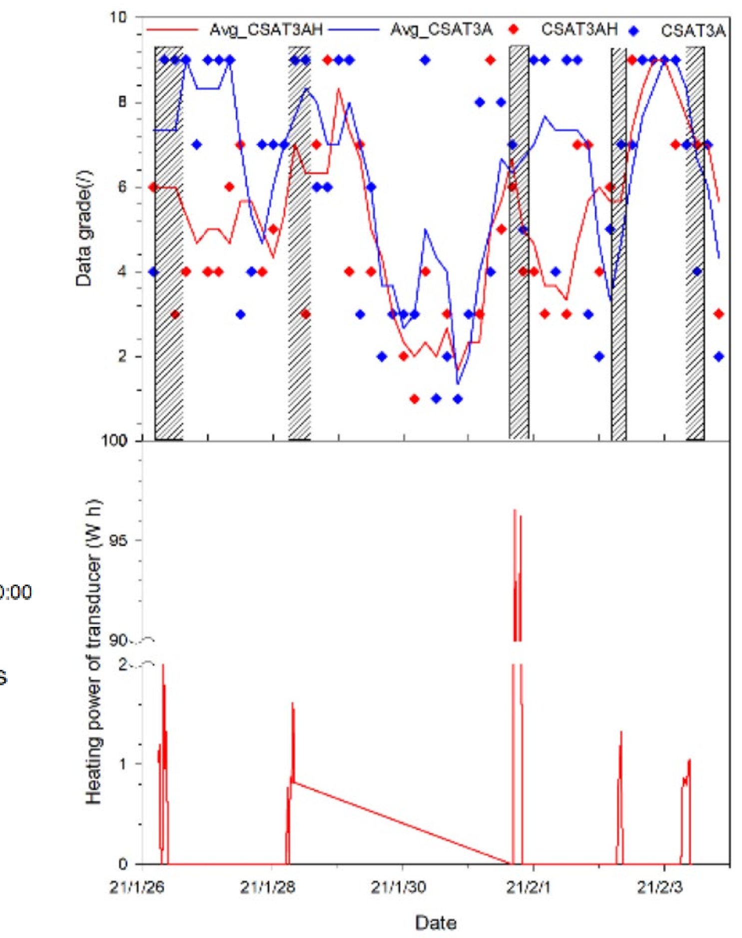


Fig. 4a Laboratory test for temperature dynamics of transducers and arms while heating power regulated by CSAT3H iteratively increases under continuous full ice cover on transducers.



- Fig. 4c Comparison of data quality between the heated and non-heated sonics (Fig. 3b). Under normal weather conditions without need of heating, the quality grade of momentum fluxes from both are very similar; however, the grade during harsh conditions is improved for the heated version compared to the non-heated.

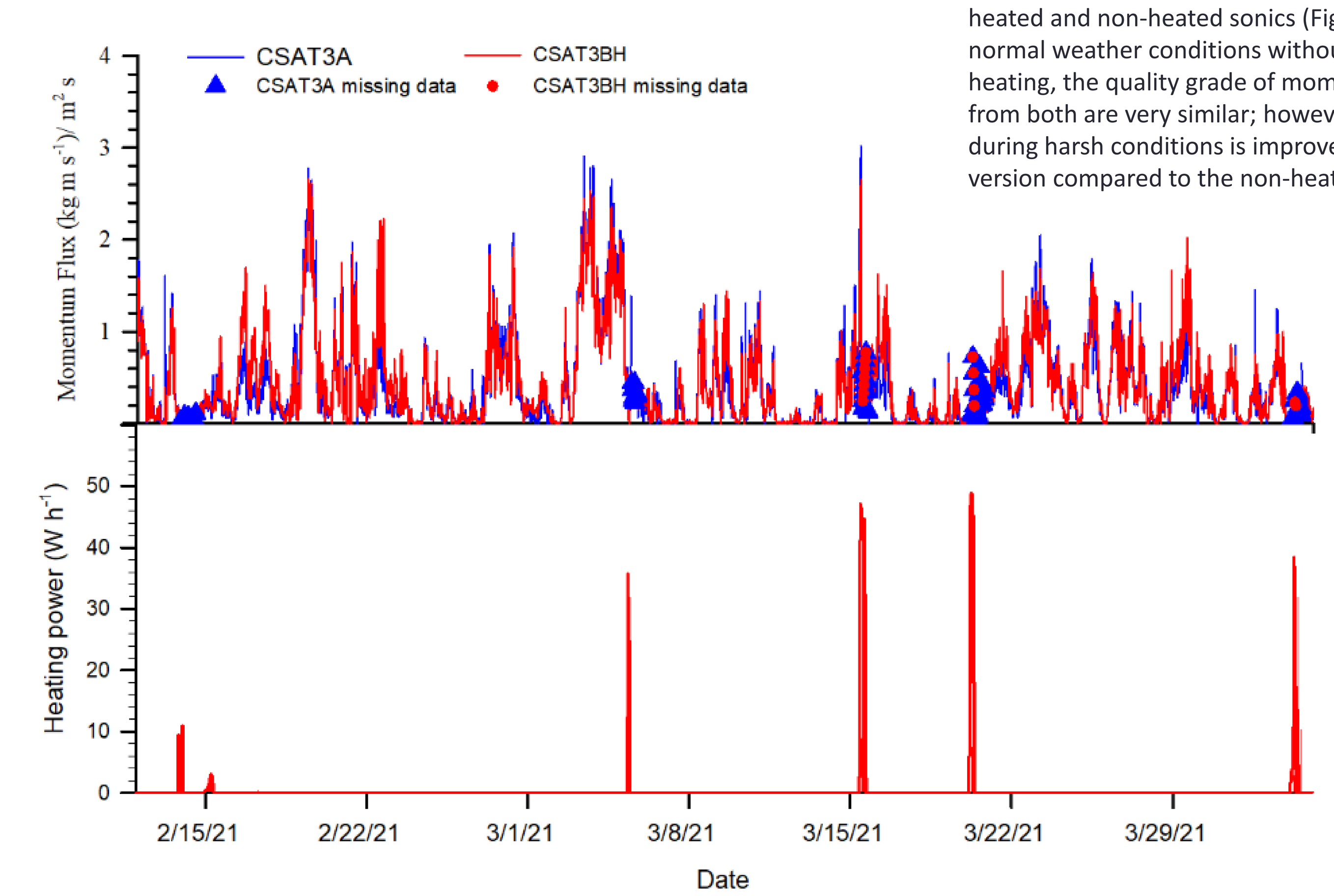


Fig. 4b Continuity of momentum flux data in snow, ice, and/or frost events

- Fig. 4b shows the performance of a CSAT3BH in comparison with a non-heated sonic (data from Fig. 3b). Between Feb 12 to Apr 04, 2021 both sonics collected 2449 half-hour data at the same tower. Among the 2449 data points, the CSAT3BH missed 14 data points and the non-heated sonics missed 109 data points. All 14 data points missed by the CSAT3BH were also missed by the non-heated sonic. The heated sonic was able to salvage almost 8x the amount of data compared to the non-heated.

Overall Benefits of Heated Sonics

- Increased Data Continuity
- Improved data quality grade of EC fluxes
- Two-Zone Heating
- Automated Smart-Heating Algorithm
- Real-Time Heater Diagnostics
- Power Efficient
- Ice & Dew Prevention
- Research Grade
- Stand-Alone Wind Applications
- Eddy-Covariance Applications