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Field Validation of Cloud Properties Sensor Field Campaign Report

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Acronyms and Abbreviations

AERI	atmospheric emitted radiance interferometer
AERIoe	AERI Optimal Estimation value-added product
AERONET	Aerosol Robotic Network
ARM	Atmospheric Radiation Measurement
CLDTYPE	Cloud Type Classification value-added product
COD	cloud optical depth
CSPHOT	Cimel sunphotometer
FOV	field of view
GOES	Geostationary Operational Environmental Satellite
GOES-ABI	GOES–Advanced Baseline Imager
KAZR	Ka-Band ARM Zenith Radar
LWIR	longwave infrared
LWP	liquid water path
MFRSR	multifilter rotating shadowband radiometer
MWR	microwave radiometer
MWR3C	microwave radiometer–3-channel
PVC	polyvinyl chloride
Reff	frequency distribution of cloud droplet effective radius
SASZe	shortwave array spectroradiometer–zenith
SBIR	Small Business Innovative Research
SGP	Southern Great Plains
TWST	cloud optical properties sensor
TWST-EN	extended wavelength cloud optical properties sensor
URL	uniform resource locator
USB	universal serial bus
VAP	value-added product
VIS/NIR	visible/near-infrared

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1.0 Summary

The purpose of this campaign is to deploy Aerodyne Research Inc.'s extended wavelength cloud optical properties sensor (TWST-EN) in an operationally relevant environment with co-located, validated sensors. The Atmospheric Radiation Measurement (ARM) user facility's Southern Great Plains (SGP) observatory is ideal for this deployment because of the variety of operational sensors that can measure some of the same cloud properties using different modalities. While cloud property sensors have long existed, they tend to be costly to produce and maintain. Our sensor measures absolute spectral radiance in the two bands and will retrieve cloud optical depth (COD), droplet effective radius, and thermodynamic phase. Our prototype is built predominantly from off-the-shelf components and uses uncooled spectrometers. A lower-cost, easy-to-use sensor such as this could allow deployment at many more sites for greater spatial coverage. Analysis and retrieval algorithm development using the data from this deployment has been a central technical objective of our U.S. Department of Energy Small Business Innovative Research (SBIR) Phase 2 contract (DE-SC0020473: Low-Cost Shortwave Spectroradiometer for Retrieval of Cloud Properties).

TWST was deployed at SGP from 3 April 2020 until 2 June 2024. We have performed data and retrieval comparisons with several baseline sensors and value-added products. We were able to produce good COD retrieval agreement under most conditions with the microwave radiometer (MWR), microwave radiometer–3-channel (MWR3C), multifilter rotating shadowband radiometer (MFRSR), Cimel sunphotometer (CSPHOT), Atmospheric Emitted Radiance Interferometer Optimal Estimation value-added product (AERIoe), and Geostationary Operational Environmental Satellite (GOES). Effective radius and phase retrieval comparisons were good under favorable circumstances.

Figure 1 shows TWST early prototype originally deployed at SGP in the optical cluster region, just outside the optical trailer. TWST consists of the top box along with its PVC mounting post and flange. The other boxes are part of the permanent SGP installation. The instrument software runs on a laptop computer located in the optical trailer. Communication to the instrument is via a USB extender.

Figure 1. TWST (early prototype) deployed at SGP.

2.0 Results

TWST was deployed at SGP from 3 April 2020 until 2 June 2024. On 1 April 2023, the newest version replaced the earlier prototype version that was originally deployed. All data have been uploaded to the ARM Data Center and are available for download. See Section 3.1.2 for access URLs for all TWST data.

Table 1 compares the instruments that yield data products similar to TWST. The shortwave array spectroradiometer–zenith (SASZe) is very similar to TWST in the sense that it uses two small shortwave spectrometers to measure zenith radiance. The difference in that SASZe exposes only the collection optics to the environment. The spectrometers are in a temperature-controlled enclosure located inside a building. TWST is entirely contained in the fieldable enclosure. An Ethernet cable connects TWST to a computer that is typically inside a building. CSPHOT (i.e., Aerosol Robotic Network (AERONET)/Cimel) uses narrowband filters that are sequenced with a filter wheel. The data rate of CSPHOT is much slower than TWST. We typically have used the CSPHOT data to cross-check our radiometric calibration. Stray light issues were discovered with this check and dirty window conditions can be detected as well. MFRSR views the hemisphere. COD/liquid water path (LWP) are calculated only when there is sufficiently high cloud fraction. Our comparisons with MFRSR COD have been good but the hemispherical field of view (FOV) is not ideal for comparison purposes. Most of our comparisons have been with MWR LWP (e.g., sgpmwrlosC1.b1), mostly because of the regular availability of the data and the different modality (i.e., passive microwave versus passive shortwave). Comparisons have been generally good, and examples are shown below. Differences tend to arise when there is some fraction of ice cloud present.

The atmospheric emitted radiance interferometer (AERI; in particular, AERIoe) retrieves LWP and Reff using a passive longwave modality. Agreement with AERIoe is generally good but the data product was not frequently available during the project. The Ka-Band ARM Zenith Radar (KAZR) and other instruments are inputs to the Cloud Type Classification value-added product (CLDTYPE VAP), which we frequently used to assess our phase retrievals in addition to the GOES-ABI product. As mentioned above, we also used CLDTYPE to train a neural network phase classifier. Finally, we used GOES–Advanced Baseline Imager (GOES-ABI) data products largely because COD, frequency distribution of cloud droplet effective radius (Reff), and phase was always available. Agreement was usually good, but the large footprint and greater sensitivity to the cloud tops are the cause of some differences.

Table 1. Comparison of other instruments with TWST.

Instrument	Long Name	Field of View	Modality
TWST-CPS	TWST Cloud Properties Sensor	0.5°	VIS/NIR grating spectrometers
SASZe	Shortwave Array Spectroradiometer -- Zenith	1°	VIS/NIR grating spectrometers
CSPHOT	Multifilter Sun/Sky Photometer (AERONET/Cimel)	1.2°	VIS/NIR narrowband filters
MFRSR	Multifilter Rotating Shadowband Radiometer	Hemisphere	VIS/NIR narrowband filters
MWR	Microwave Radiometer	5.9°, 4.5°	23.8, 31.4 GHz
AERI	Atmospheric Emitted Radiance Interferometer	1.3°	3-19.2 mm
KAZR	Ka-Band ARM Zenith Radar	0.2°	35 GHz
GOES-ABI	Geostationary Operational Environmental Satellite – Advanced Baseline Imager	2-3 km footprint	VIS-LWIR filters

Figure 2 shows retrieval results for TWST and several other instruments at SGP on a day when there was both liquid and ice cloud present. For COD, the TWST retrievals with suffix RET_V3.1 are joint retrievals of COD and Reff after a preliminary phase retrieval as discussed above. If the joint retrieval does not converge, the COD result is used. The results are generally good. The best agreement seems to be when there is unambiguously (as gauged by GOES imagery) a 100% liquid path. Currently, the joint retrieval performs best at COD greater than approximately 5-10.

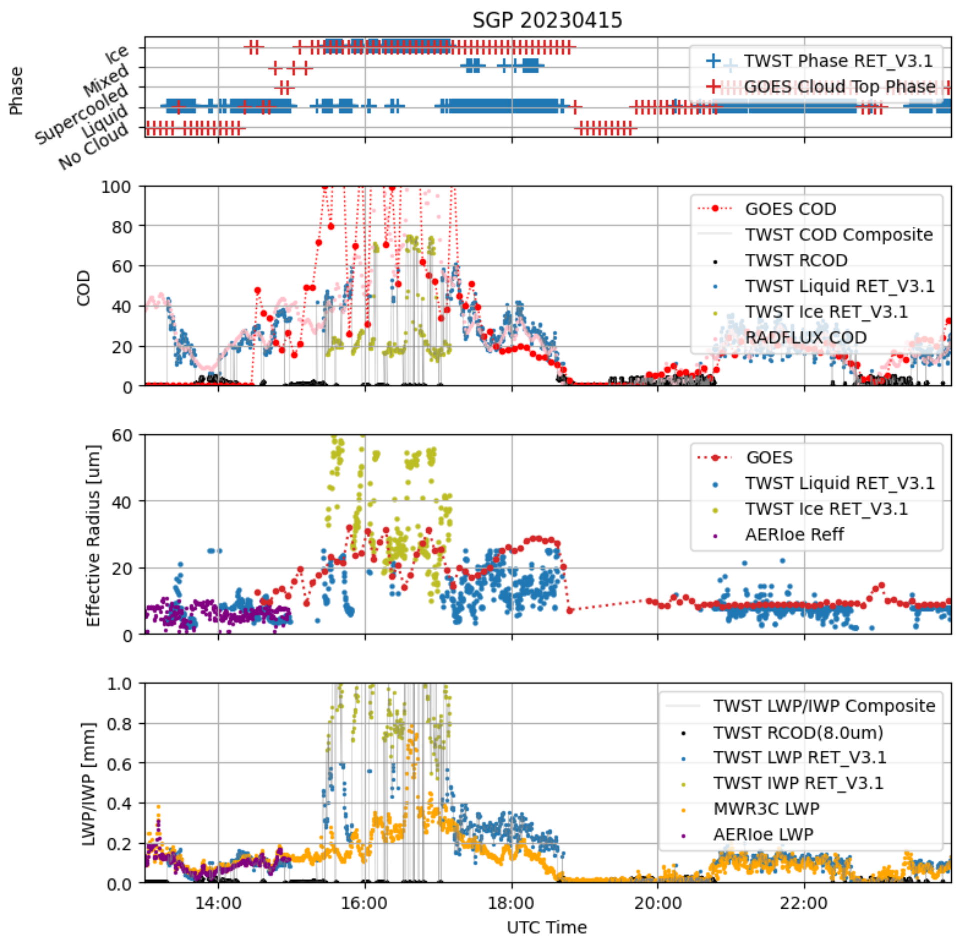

Figure 2. Retrievals from SGP data. There were relatively few days when TWST data coincided with AERIoe.

Figure 3 shows a radiometric comparison with CSPHOT. This is typical performance. Due to the spatiotemporal characteristics of clouds, the narrow fields of view, and the slight difference in pointing between the instruments, there will be differences when clouds are present as they are in this plot. CSPHOT is less sensitive to contamination of the optical window than TWST because the collimator tube is parked in a downward pointing direction while idle and during inclement weather. Snow, and to a lesser extent, rain and condensation cause significant errors in the TWST radiance measurements. Furthermore, contamination on the window (e.g., dust, pollen, bird droppings) also causes errors. The instrument routine maintenance instructions include periodic cleaning of the window. However, this does not always occur in a timely manner. More extensive CSPHOT comparisons have indicated significant periods when the window was likely contaminated enough to cause the observed large deviations (>10%). Our top-priority development goal is to devise a means to protect the TWST window from snow, rain, and contamination.

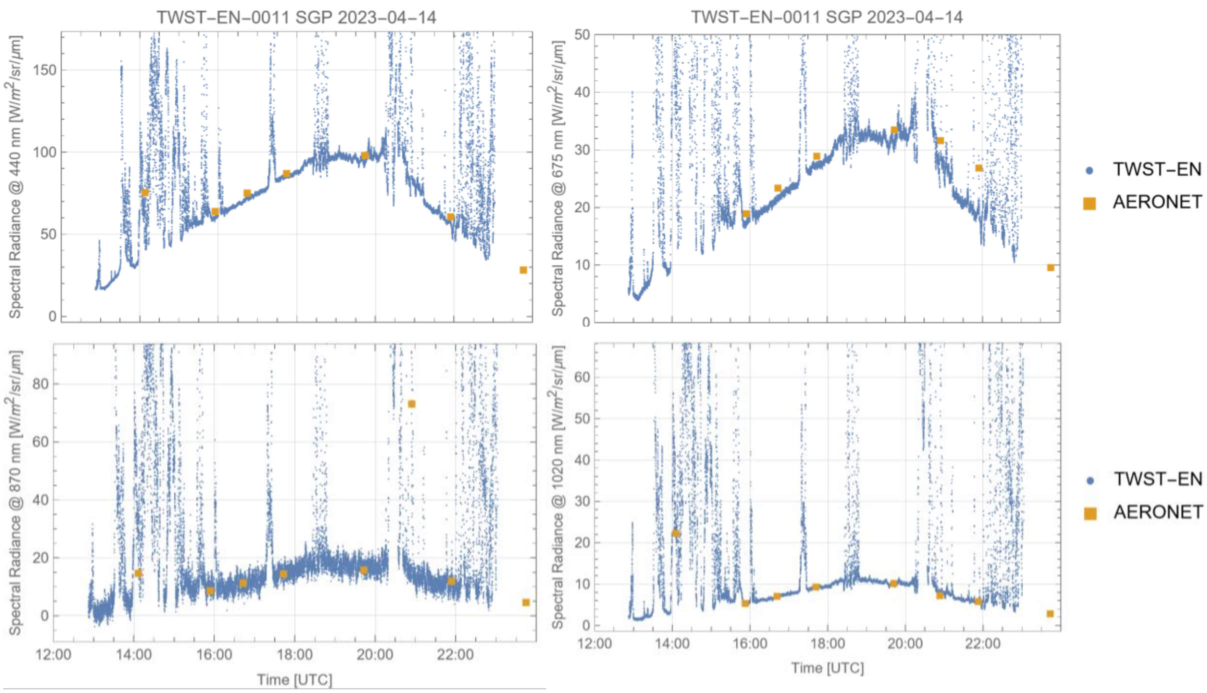

Figure 3. Radiometric comparison between TWST and AERONET (CSPHOT, Cimel).

3.0 Publications and References

3.1 Conference Papers and Presentations

Jones, SH, F Iannarilli, S Cartagena, B Moul, and T Onasch. 2023. "Cloud Properties from Shortwave Spectroradiometer Retrievals." Poster presented at the ARM/ASR Joint User Facility and PI Meeting.

3.2 Data

SGP data from 2021 were uploaded to the ARM Data Center on 17 February 2022 and are available here:

https://iop.archive.arm.gov/arm-iop/2020/sgp/visvalidation/jones-twst/v2/

Data from the 2020 and 2022 SGP deployments on Phase 1 of this project can be accessed here:

https://iop.archive.arm.gov/arm-iop/2020/sgp/visvalidation/jones-twst/

As of 9 January 2023, SGP data is available at the ARM Data Center as datastream: sgptwstC1.00

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