A Real-Time Cloud Optical Depth Sensor

Three-Waveband Spectrally-agile Technique (TWST)

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Introduction

A unique, real-time Cloud Optical Depth (COD) sensor, dubbed the Three-Waveband Spectrally-agile Technique (TWST), has been developed and successfully deployed to serve as a ground-based, portable and reliable means for remote cloud monitoring. It uses the spectral radiance of scattered sunshine from a small area of overhead cloud and the MODTRAN5 model of atmospheric radiation transport to determine Cloud Optical Depths. A real-time output assists with monitoring dynamic situations, and continuous data logging permits detailed post processing. The underlying phenomenology of TWST is similar to that employed in AERONET sensors running in cloud-mode [1,2,3,4] which provided direct validation of TWST during simultaneous TWST-AERONET data collections at the AERONET site in Harvard Forest, Petersham MA.

Akin to, but Differentiated from AERONET Cloud Mode

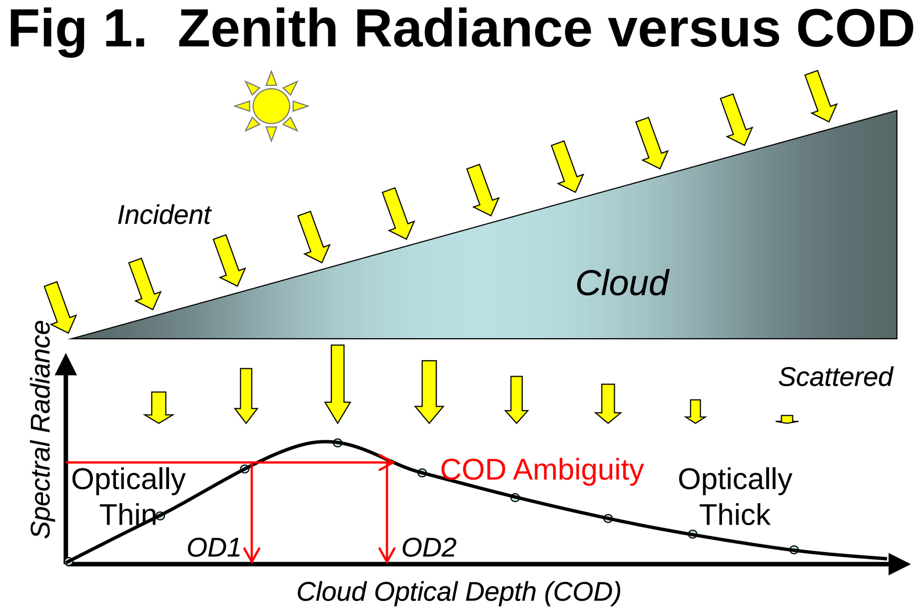
Unlike AERONET, TWST is a dedicated, continuous cloud sensor with the ability to work in vegetated and non-vegetated terrains, in addition to being portable rather than a fixed installation like AERONET. Although the TWST concept is strongly grounded in the NASA AERONET Cloud Mode approach [2,3], the requirements driving the TWST sensor design demanded a substantial extension beyond the capabilities provided by the basic AERONET Cloud Mode. These requirements included:

-Need for a continuously-updated, real-time COD output;
-Fast, providing updates of COD at rates up to 1 per sec;
-Field-worthy – reliable, rugged and accurate;
-Portable - easy to set up and operate under field conditions;
-Spectrally-agile in response to the changing earth albedo by location and by season.

Equivalent Width Distinguishes Thin vs Thick Clouds

An underlying problem in inferring optical depth from solar-scattered radiance measurements is that the down-welling cloud radiance is a two-valued function of the COD [Fig 1]. TWST uses the O_2 A-band Equivalent Width as the means to overcome this ambiguity. This band, centered at 761 nm, is not badly overlapped by other absorbers such as H_2O, and unlike water vapor, O_2 concentrations in the atmosphere are quite stable. The Equivalent Width of the O_2 band depends on the total photon path length and increases with more scattering events thereby distinguishing thin from thick clouds.

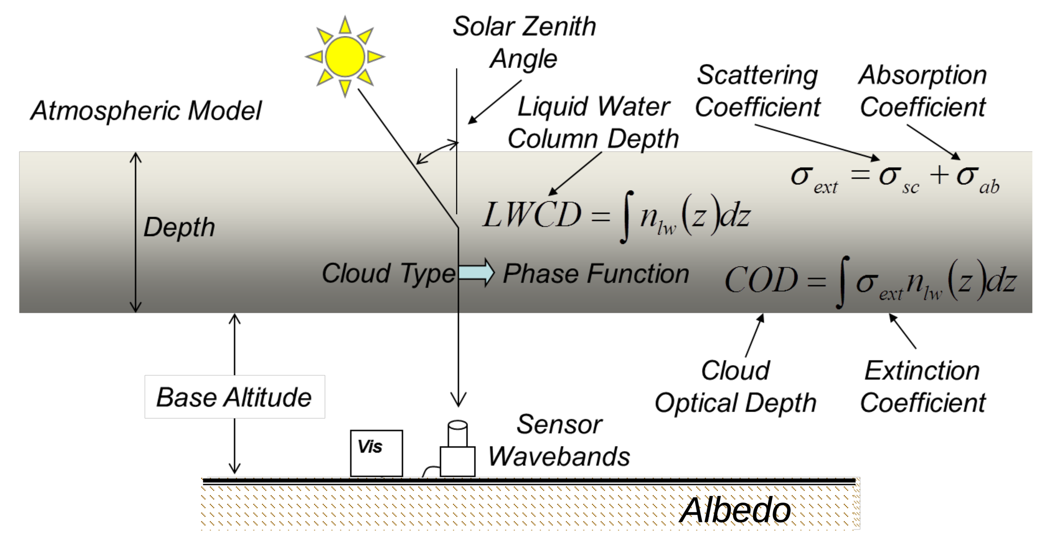
Fig 1. Zenith Radiance versus COD



Methods

TWST uses the brightness of visible and Near Infra-Red (NIR) sunlight scattered off a small region of cloud directly overhead to determine the COD. MODTRAN is used to pre-compute a table of COD versus spectral radiances as a function of solar zenith angle.

Fig 2. Cloud Multiple Scatter Model

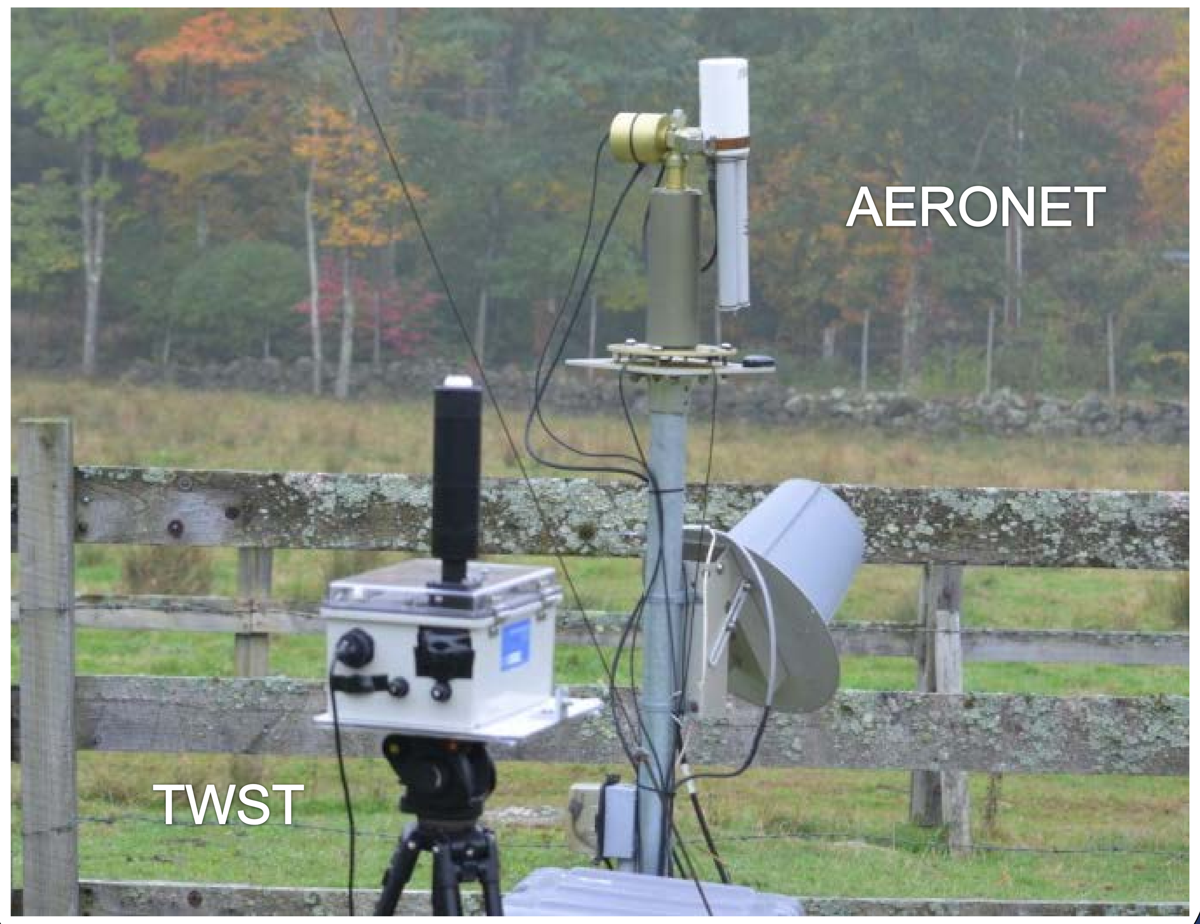


- 1D Plane Parallel Cloud
  - DIScrete Ordinate Radiative Transport

Table 1. TWST COD Sensor Specifications

Weight	20 lbs
Power	5 hour battery life, or continuous with AC power source for control computer
Size	11" x 8" x 8" plus 8" external sun baffle; or 11" x 11" x 8" with internal sun baffle
Operating COD Range	Blue Sky to Cloud OD 100
Cloud OD Precision	1% (typical, depends on update rate)
Cloud OD Accuracy	5 % (typical)
Electrical Power + Data	One USB connection to computer
Container	NEMA 4 sealed enclosure
Data Logging Rate	1 Hz (typical), variable sampling interval from 0.1 to 120 seconds
Spectral Range	350 – 1000 nm
Spectral Bands used in Cloud OD retrieval	440, 761, and 870 nm (typical)

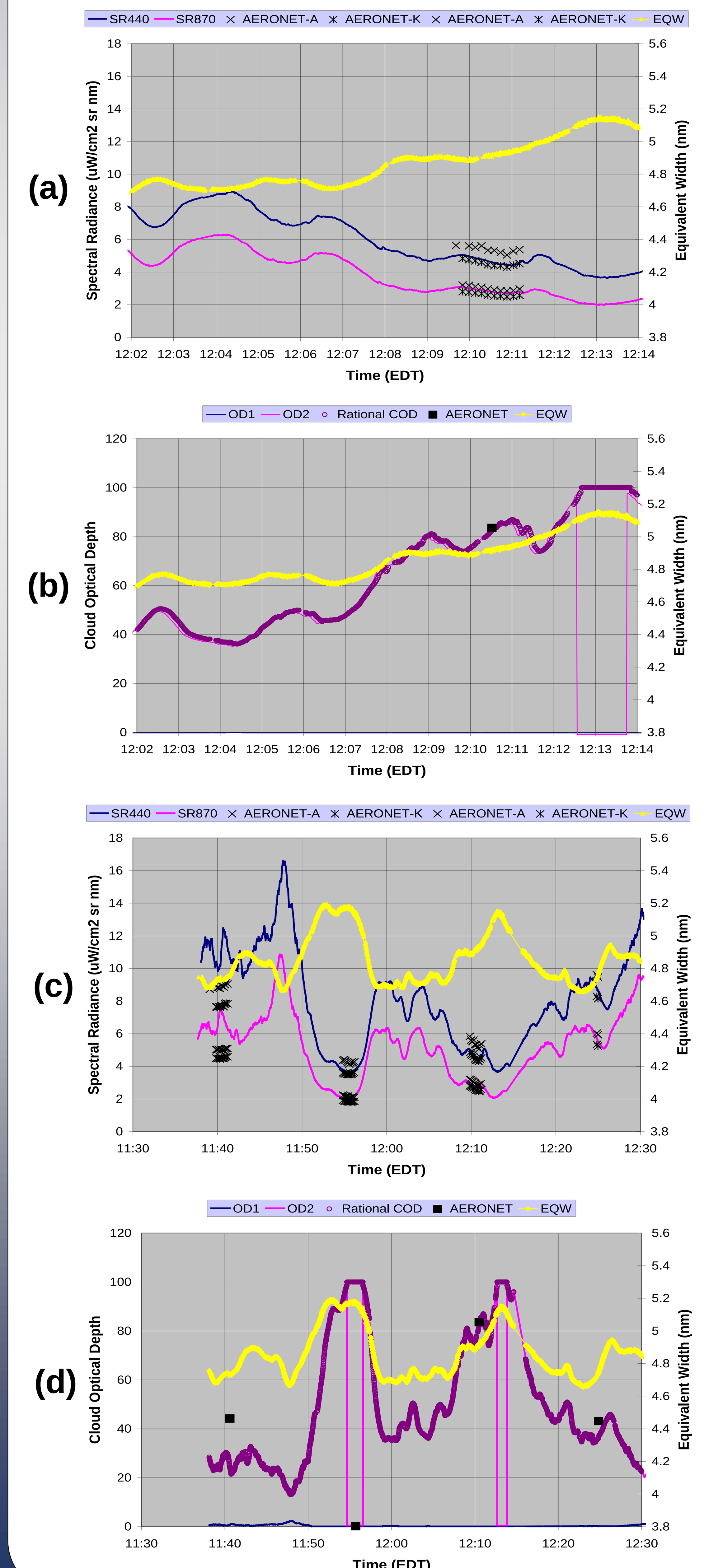
Fig 3. Harvard Forest AERONET Site with TWST Collecting Data Simultaneously



Comparing to AERONET

Data were collected at the Harvard Forest AERONET Site on Oct 3, 2012. AERONET and TWST data analyses were performed independently.

Fig 4 (a), (c). Compare Spectral Radiance; then (b), (d) Compare Cloud Optical Depth



More Results

Fig 5. Spectral Radiance Comparisons of TWST versus AERONET in Two Bands

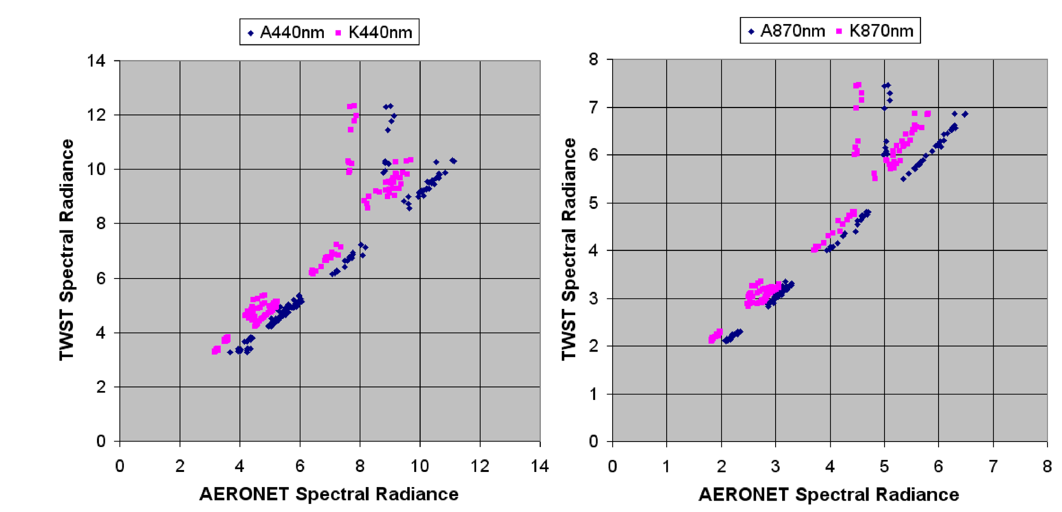
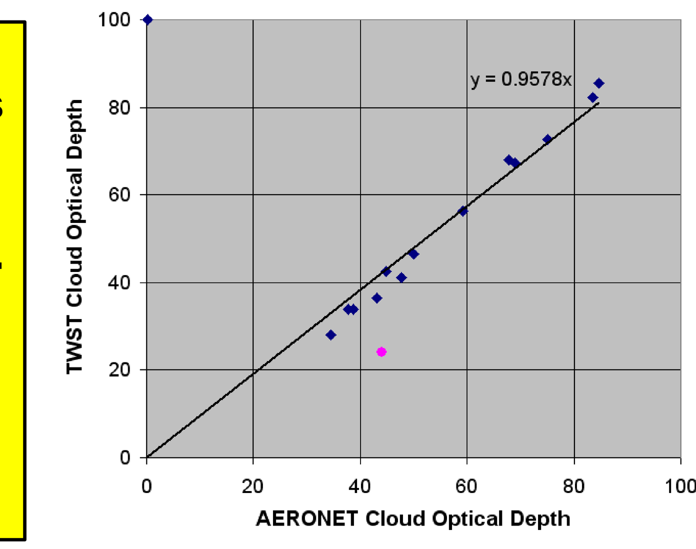


Fig 6. Cloud Optical Depth Comparison

TWST consistently returns COD values within 5% of AERONET results for CODs up to 100. Compared equally well against MW Radiometer and a Ka band Cloud Profiling Radar.



Conclusions

- Validation with AERONET – Simultaneous Data Collections and Independent Analysis Techniques have shown the TWST Real-Time Cloud Optical Depth Sensor returns COD results in excellent agreement with the AERONET Cloud Mode Sensor
- The Added Benefits of TWST are:
  - Use of O_2 A-band (761 nm) Equivalent Width overcomes the thin versus thick cloud ambiguity
  - Portable, real-time (1 sec updates), easy set-up, robust, and accurate (radiometric calibration)
- A unique combination of features make TWST well suited for ground truth Cloud OD measurements in support of airborne and space-based atmos sensors

References

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2. Chiu, J. Christine; Chiung-Huei Huang, Alexander Marshak, Ilya Slutsker, David M. Giles, Brent N. Holben, Yuri Knyazikhin, and Warren J. Wiscombe. (2010), "Cloud Optical Depth Retrievals from the Aerosol Robotic Network (AERONET) Cloud Mode Observations." *J. Geophys. Res., 115,* D14202, doi:10.1029 /2009JD013121.
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4. http://aeronet.gsfc.nasa.gov/new_web/index.html