Application of Oxygen A-band Equivalent Width for Cloud Optical Depth Measurement

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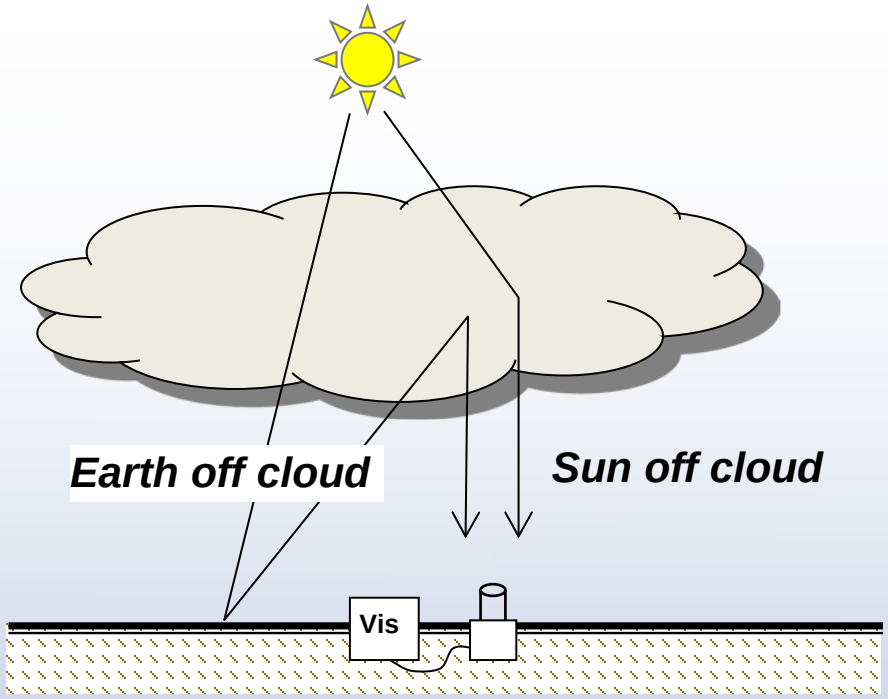
Overview

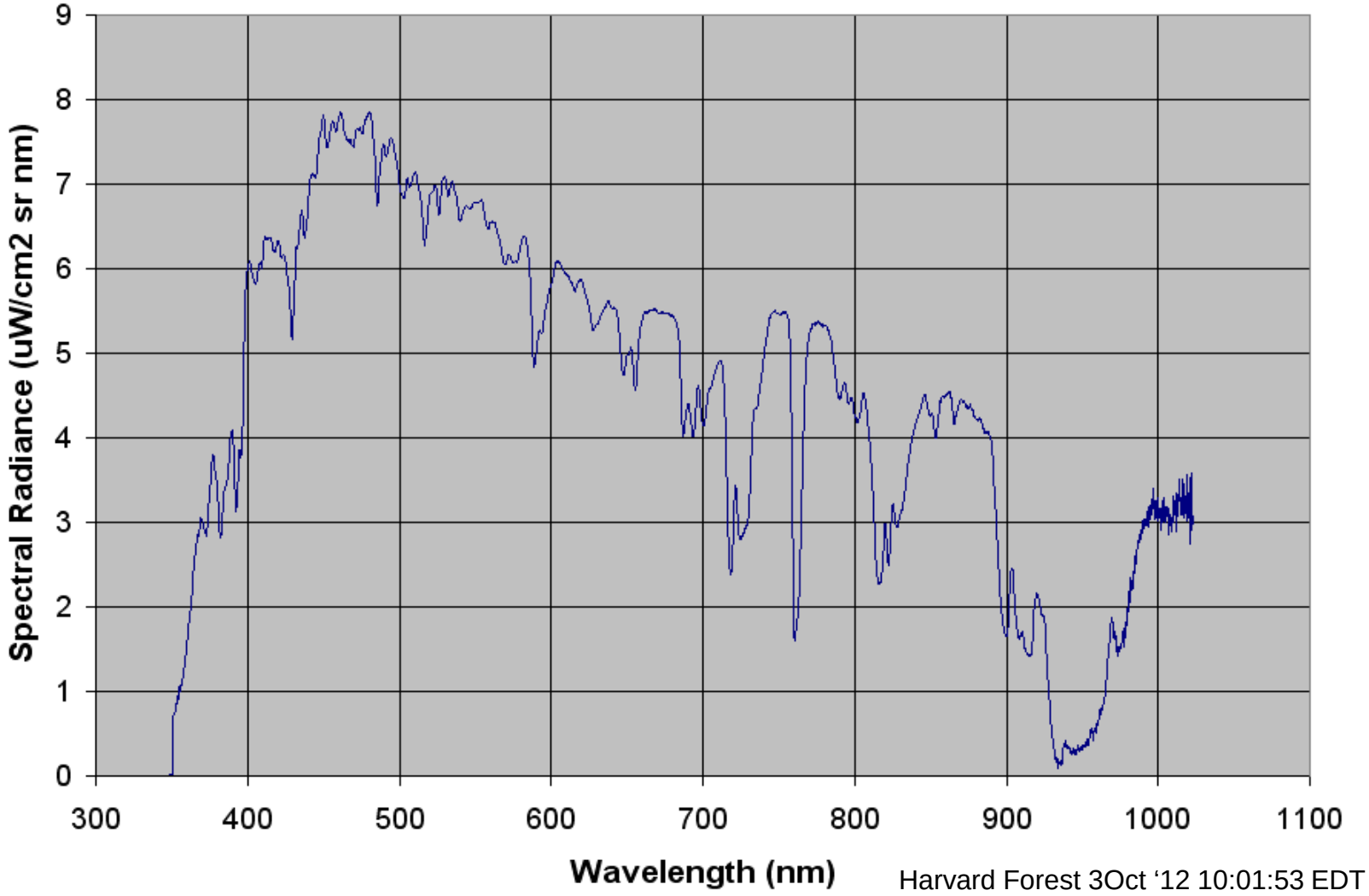
- Introduction
  - Relevant Phenomenology
  - EQuivalent Width (EQW), Cloud Optical Depth (COD)
  - Data Analysis Algorithm
- Results
  - Three-Waveband Spectrally-agile Technique (TWST) Sensor
  - Two Column Aerosol Project (TCAP)
    - AErosol RObotic NETwork (AERONET) - Cloud Mode
- Conclusions
- Acknowledgements

Principle of Operation

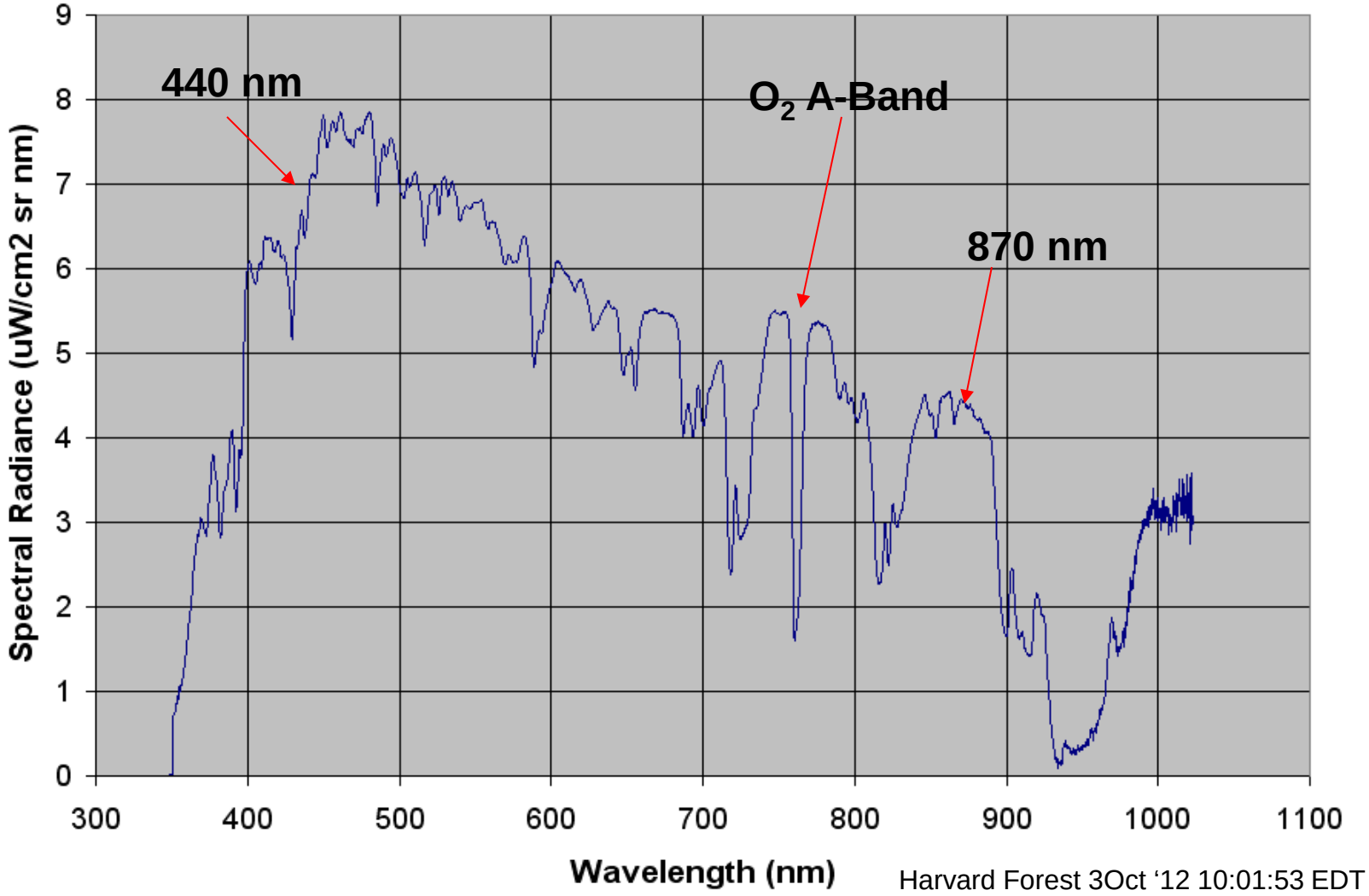


- Zenith Spectral Radiance
  - {Watts} / ({Solid Angle}{Wavelength}{Area})
  - Visible spectral band (339 to 1024 nm)

Sample Data

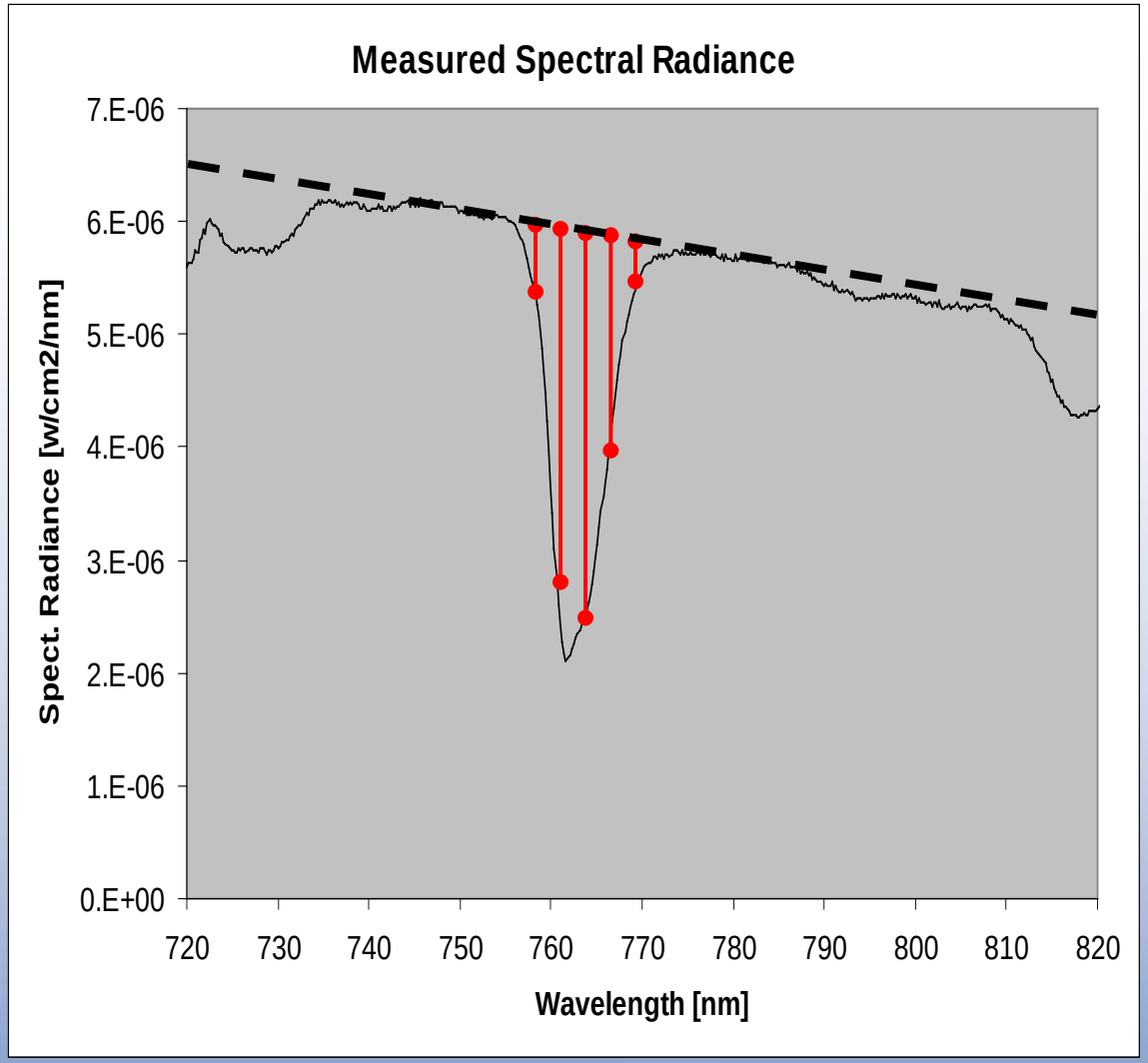

Spectral Radiance (uW/cm2 sr nm)
0
1
2
3
4
5
6
7
8
9
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)
Harvard Forest 3Oct '12 10:01:53 EDT

Three Spectral Factors

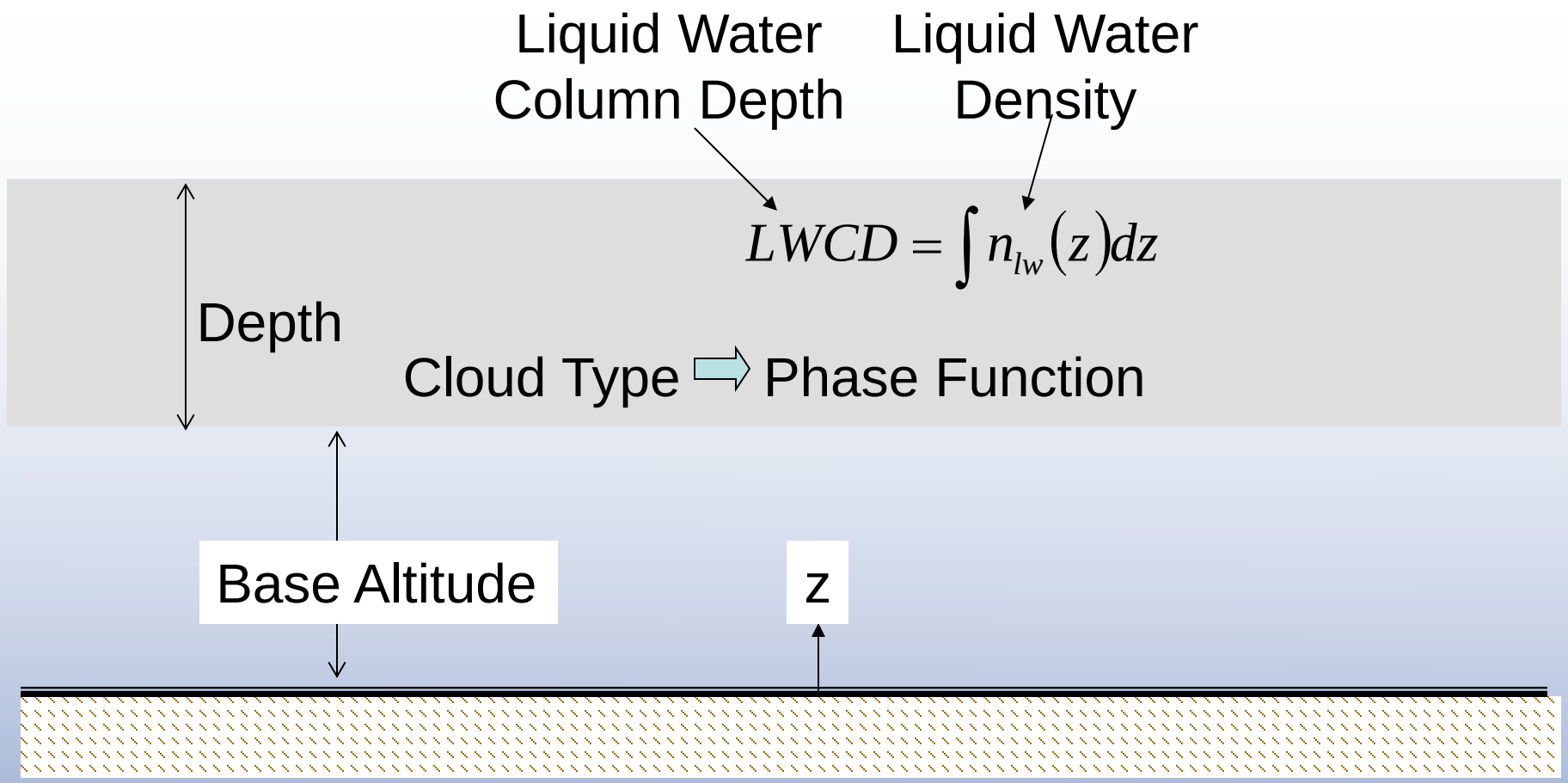


Equivalent Width

- **Divide each radiance by baseline to form transmittance**
- **Monotonic Function of Path Oxygen Amount**
- **Includes Photon Pathlength**
- **Units: nm**

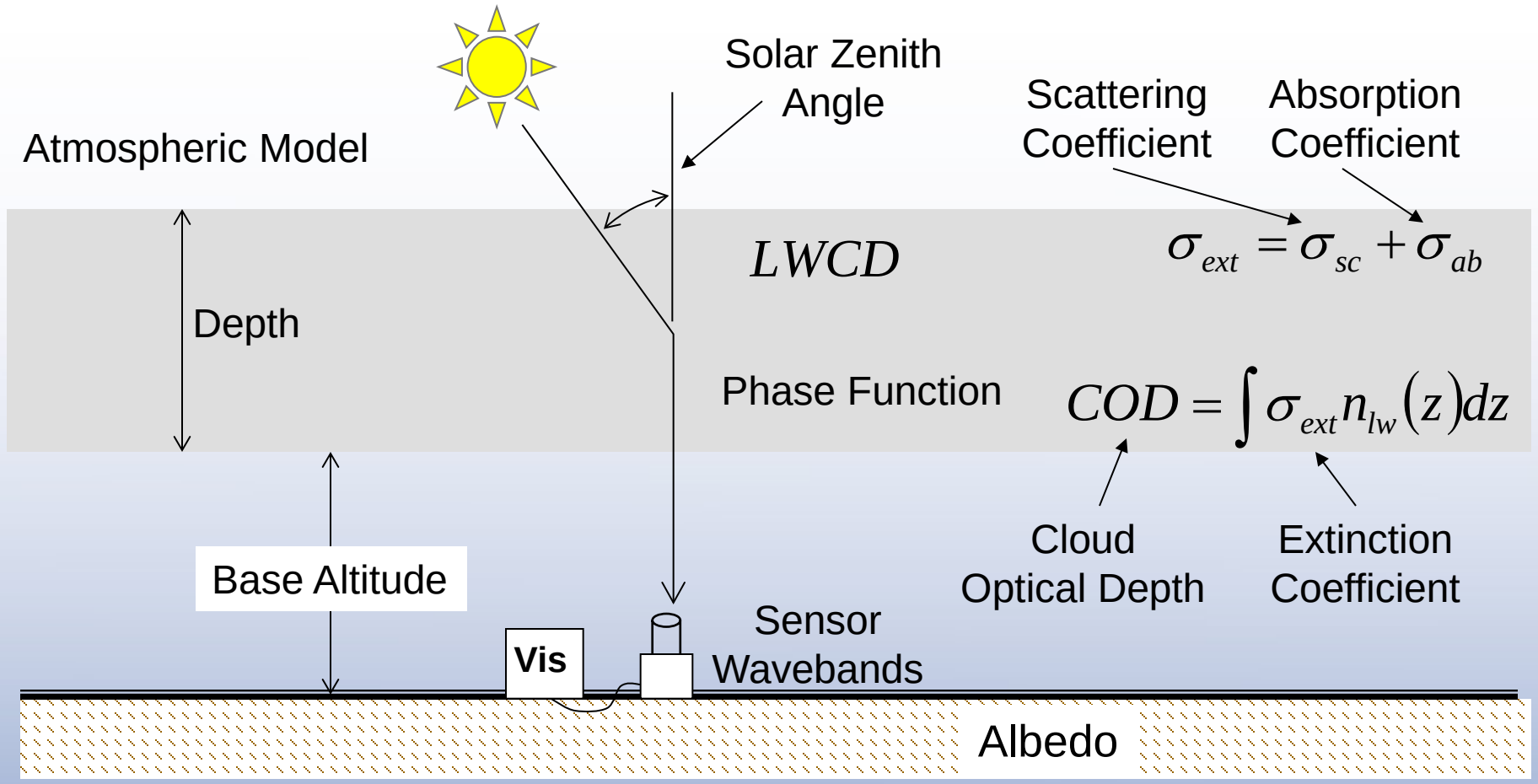


Cloud Physical Model



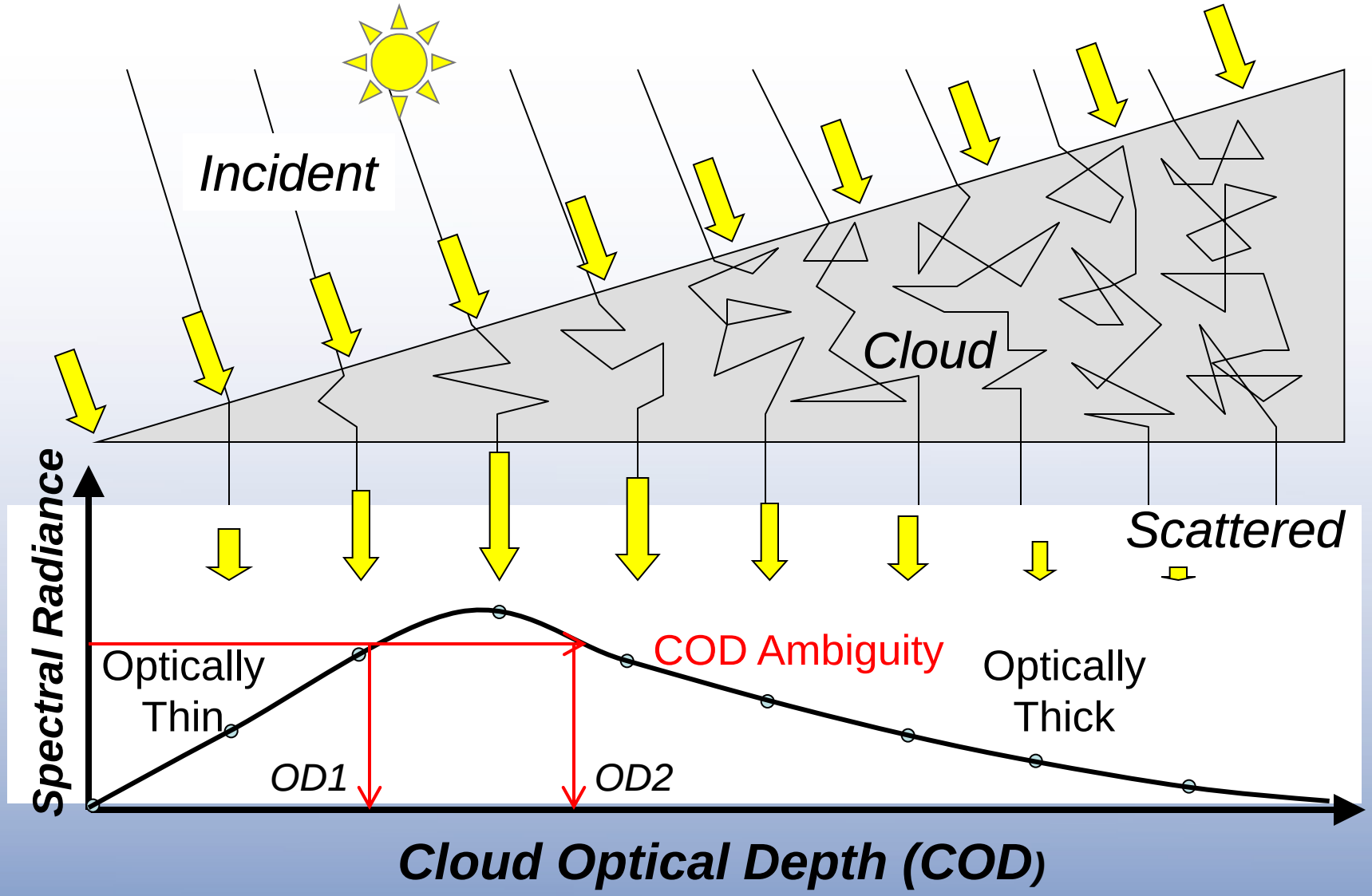
- 1D Cloud (Plane Parallel Cloud)

Cloud Multiple Scatter Model

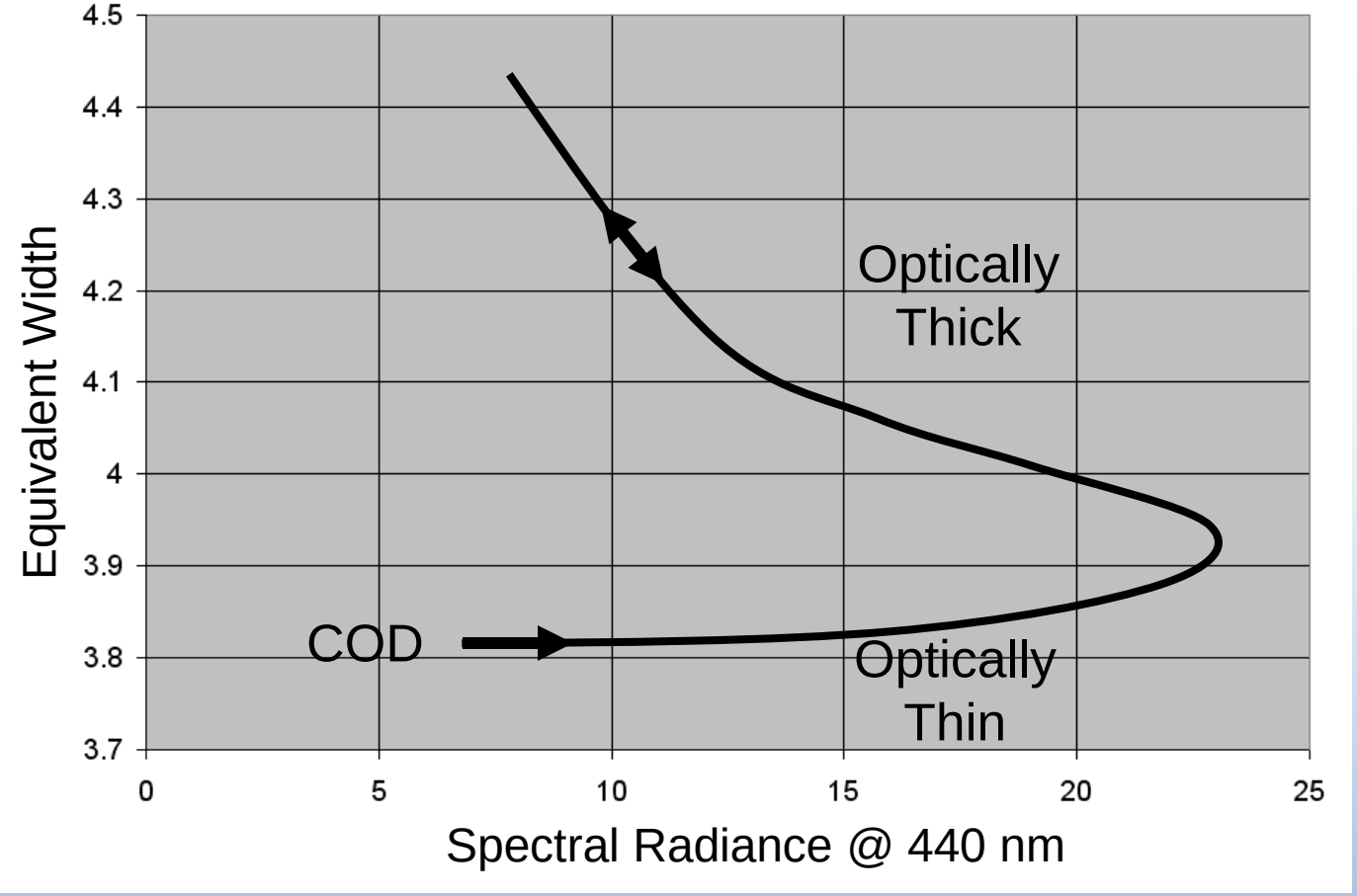


- DIScrete Ordinate Radiative Transport

Spectral Radiance vs COD



“Nose” Plot

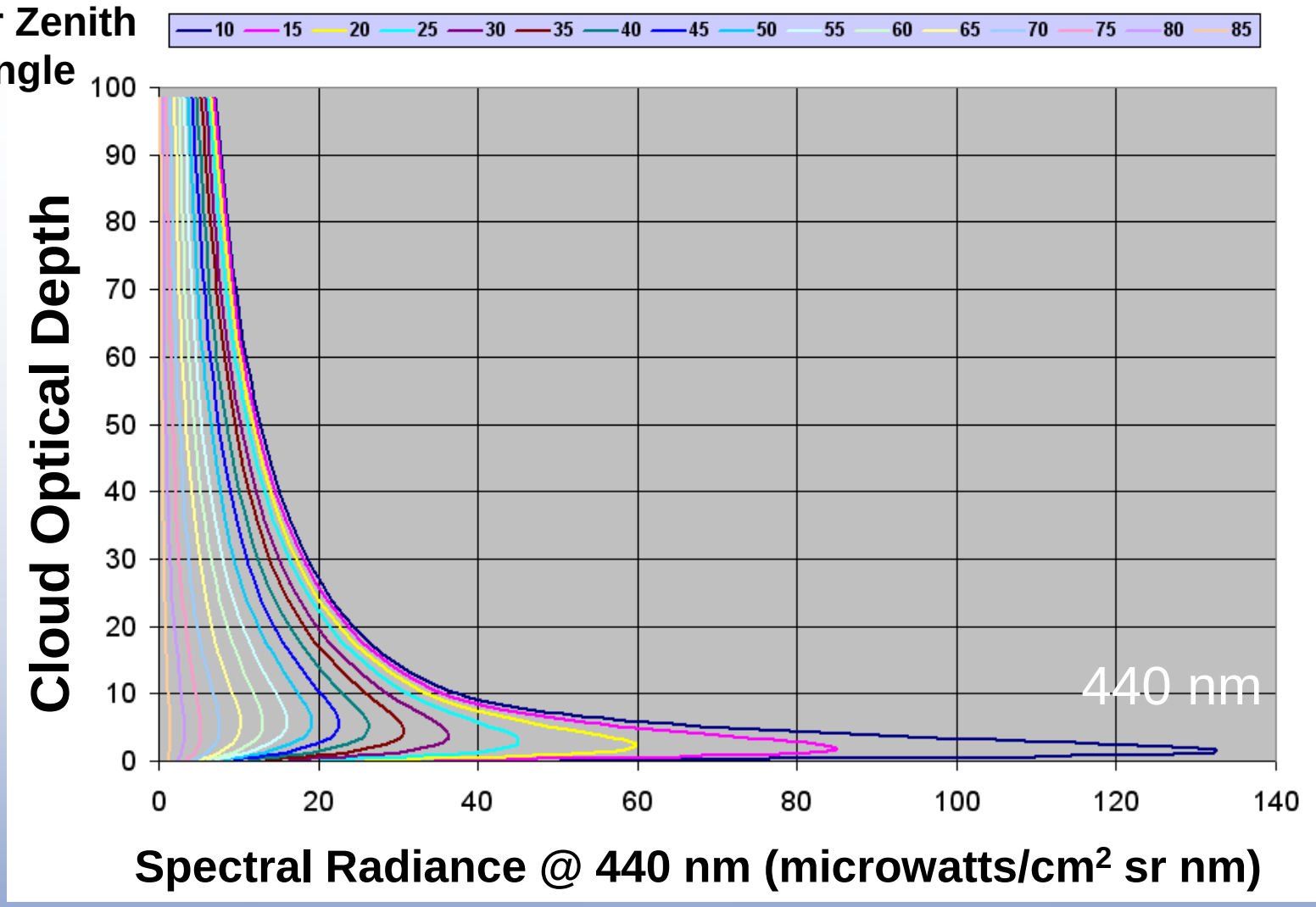


- **Random Fluctuations of COD**
- **Correlation of Equivalent Width and Spectral Radiance**

Data Processing Algorithm

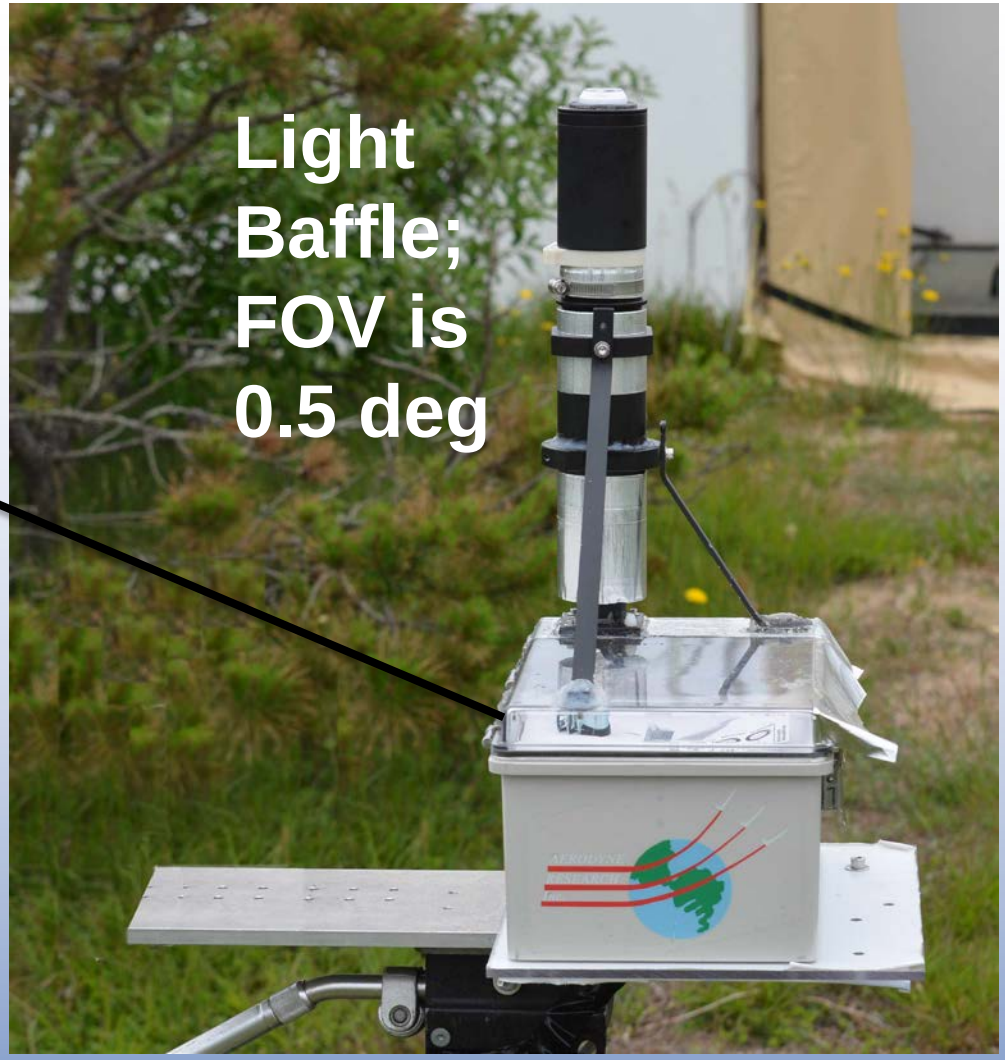
- Cloud State Determination (Thick/Thin)
  - "Blueness" Measure
    - Ratio of Spectral Radiances at 440 and 870 nm
  - Nonlinear Filter
    - Time History of "Nose" Plot Slope
    - Physics-based heuristics
- Spectral Radiance to COD Determination
  - MODTRAN5 Lookup Table
    - Atmospheric Radiative Transfer Model
    - See modtran5.com

MODTRAN5 Database



TWST Deployed at TCAP with ARM Mobile Facility Sensors

TWST Deployed at TCAP



TWST Performance Specifications:

- Power – 5Vdc via single USB cable from computer
- Data Rate – 1Hz typical; variable integ 0.1 to 120 sec
- Spectral range – 350 – 1000 nm
- Spectral resolution - ~2 nm
- Operating range - Blue sky to Cloud OD 100

DOE ARM TCAP Campaign

- Two-Column Aerosol Project (TCAP)
  - "Quantify aerosol properties, radiation and cloud characteristics"
  - Collect database to assist climate modeling studies
  - Department of Energy (see www.arm.gov/tcap)

- Ground-based Campaign
  - Atmospheric Radiation Measurement (ARM) Mobile Facility
    - Sun Photometers (**AERONET – Cloud Mode sensor**, SAS), Cloud Radars, Total Sky Imager, Microwave Radiometers, Meteorological Data, Wind Profilers, Doppler Lidar, Ceilometer, Atmospheric Emission Radiometers, Aerosol Mass Spectrometer
  - ARM Highlands, Cape Cod, Massachusetts
  - July 2012 – June 2013

- Aerial Campaign
  - Mobile Aerosol Observing System (MAOS)
    - Two Aircraft with Remote and In Situ Sensors
  - 6 July – 30 July 2012, 4 February – 28 February 2012

AERONET

- AEosol RObotic NETwork (AERONET)
  - Established by NASA and LOA-PHOTONS (CNRS)
  - Extended by Many Collaborators
  - Holben, B. N. et. al (1998). "AERONET-a federated instrument network and data archive for aerosol characterization." *Remote Sensing of the Environment 66*: 1-16.

- AERONET Cimel Sun Photometer
  - Eight Spectral Filters, Two Detectors
  - Solar Power, Robotic Pointing, Satellite Data Transmitter

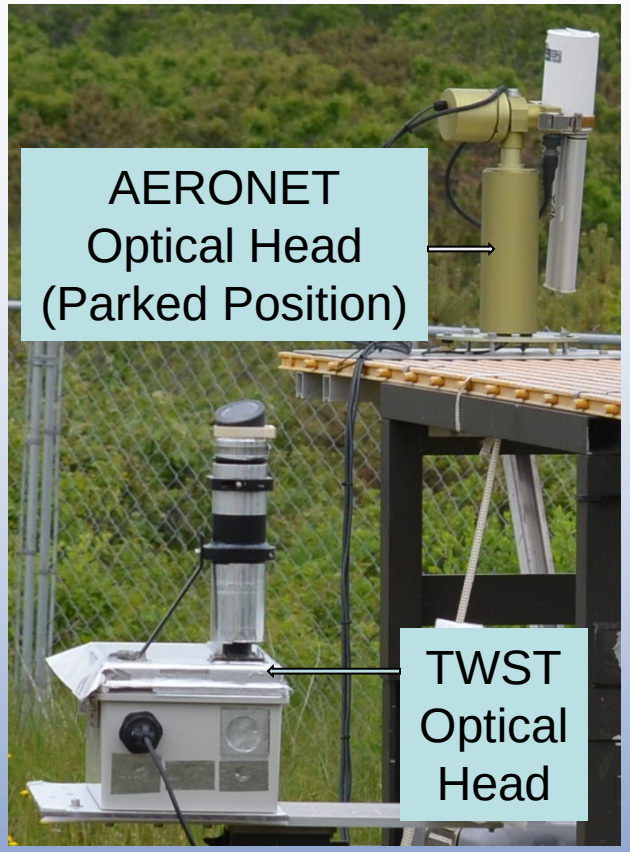
- AERONET Cloud Mode
  - Subset of AERONET
  - Uses 440 and 870 nm Zenith Spectral Radiances for COD Determination
  - 15 Minute Update When Solar Disk Not Visible and Not Raining
  - Chiu, J. Christine; Chiung-Huei Huang, Alexander Marshak, Ilya Slutsker, David M. Giles, Brent N. Holben, Yuri Knyazikhin, 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.

AERONET & TWST
Cloud OD Sensors at TCAP

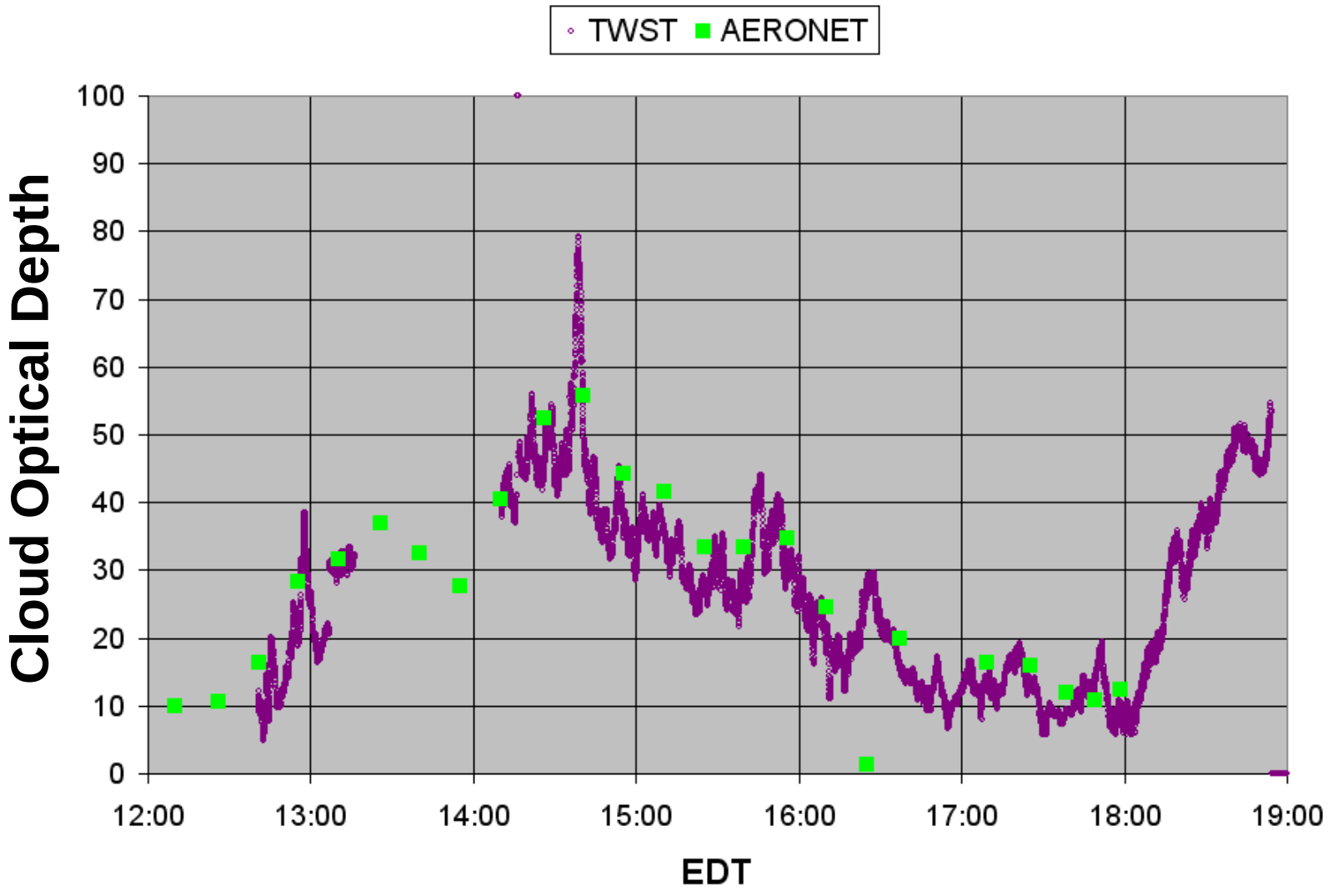
- Both Use Zenith Spectral Radiance at 440 nm

- AERONET (Cloud Mode)
  - 8 (**2**) Spectral Filters
    - 340, 380, **440**, 500, 675, **870**, 940, 1020 nm
    - 10 nm Resolution
  - Robotic Pointing
  - Radiance Update: 4 sec
  - COD Update: 15 minutes
  - SNR (peak): 3,000:1
  - FOV: 1.2 deg

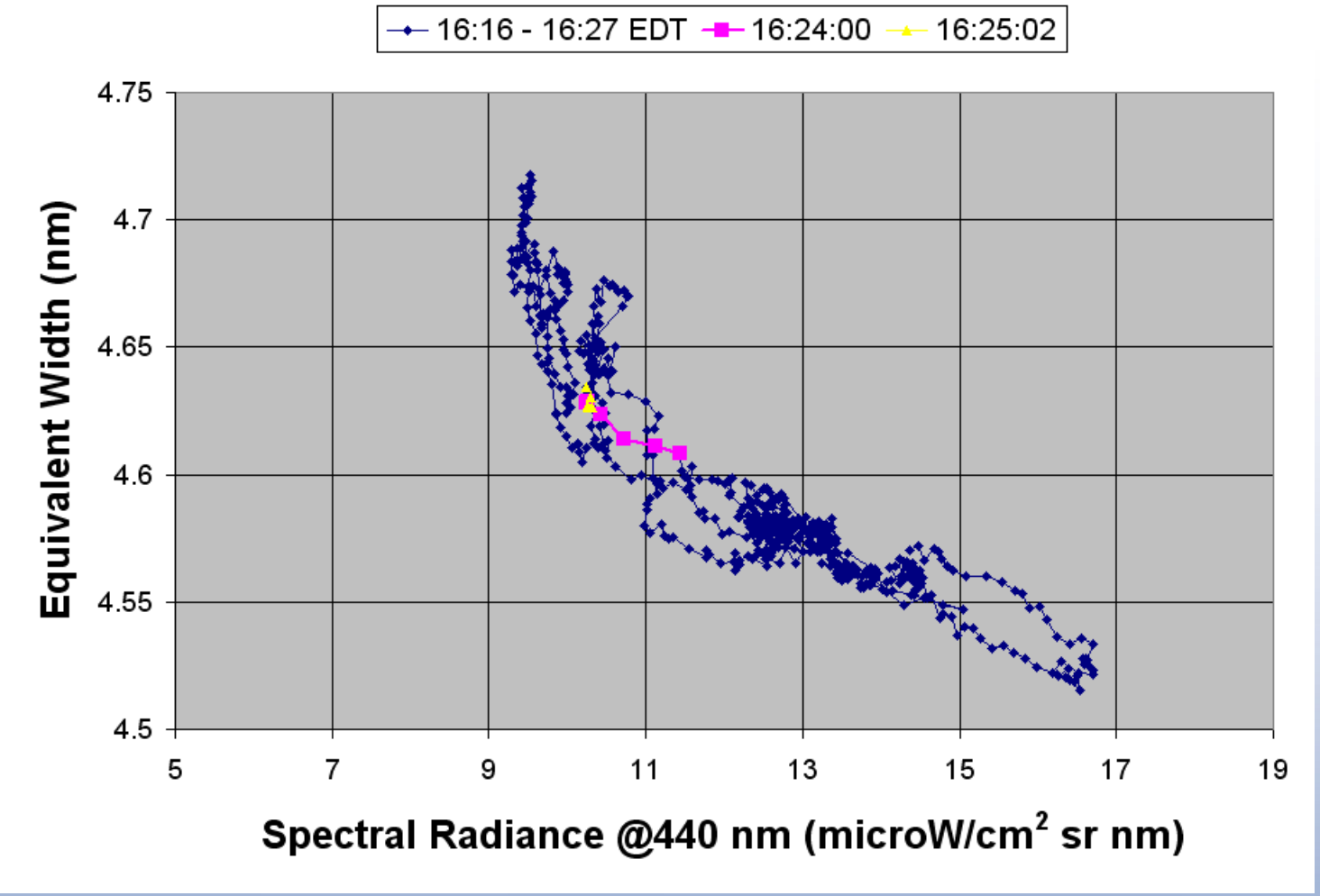
- TWST
  - 300 Unique Spectral Channels
    - 339 – 1024 nm
    - 2 nm Resolution
  - Zenith Staring
  - Radiance/COD Update: 1 Second
  - SNR (peak): 14,000:1
  - FOV: 0.5 deg



COD for 22 May 2013

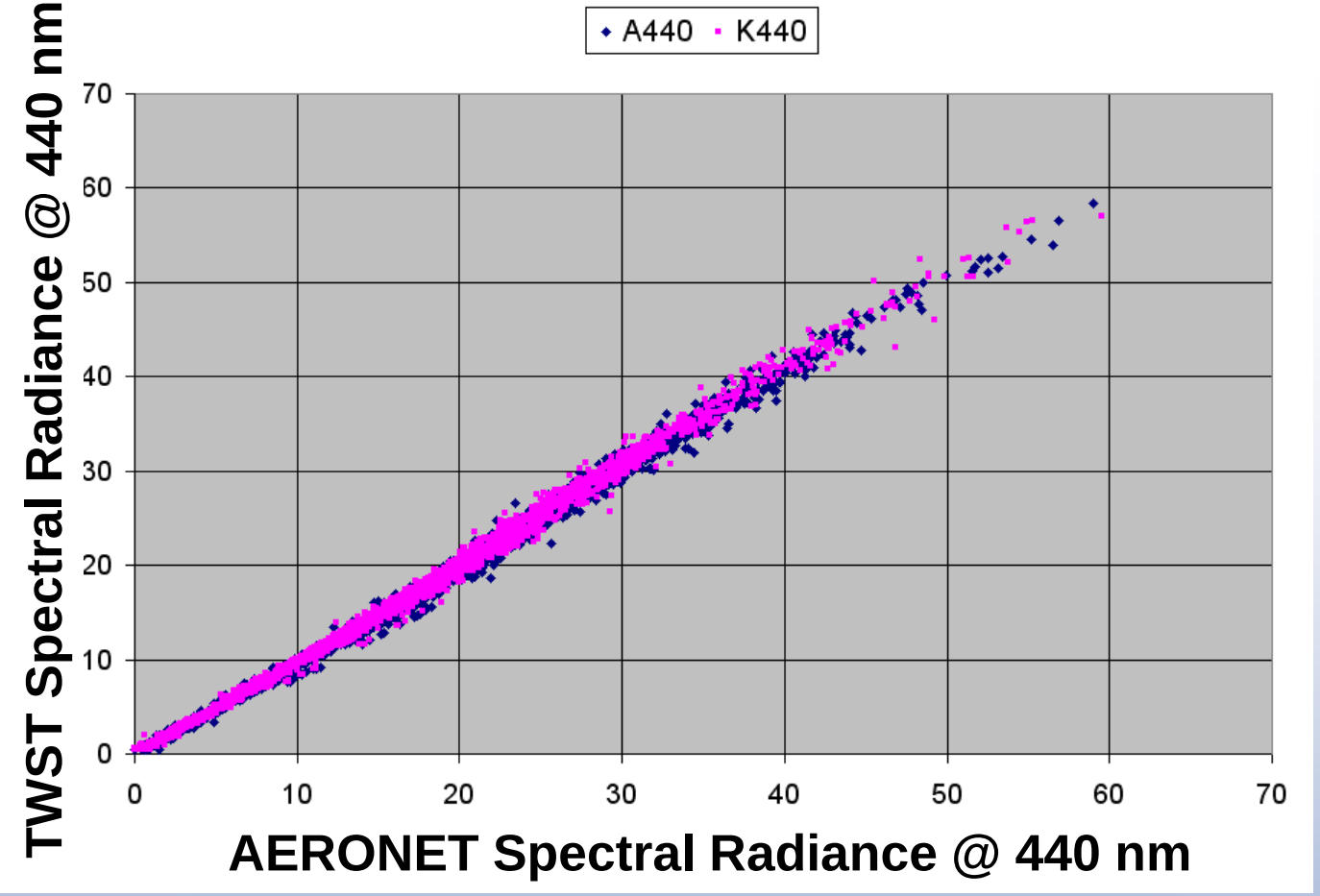


“Nose” Plot for 16:25 EDT



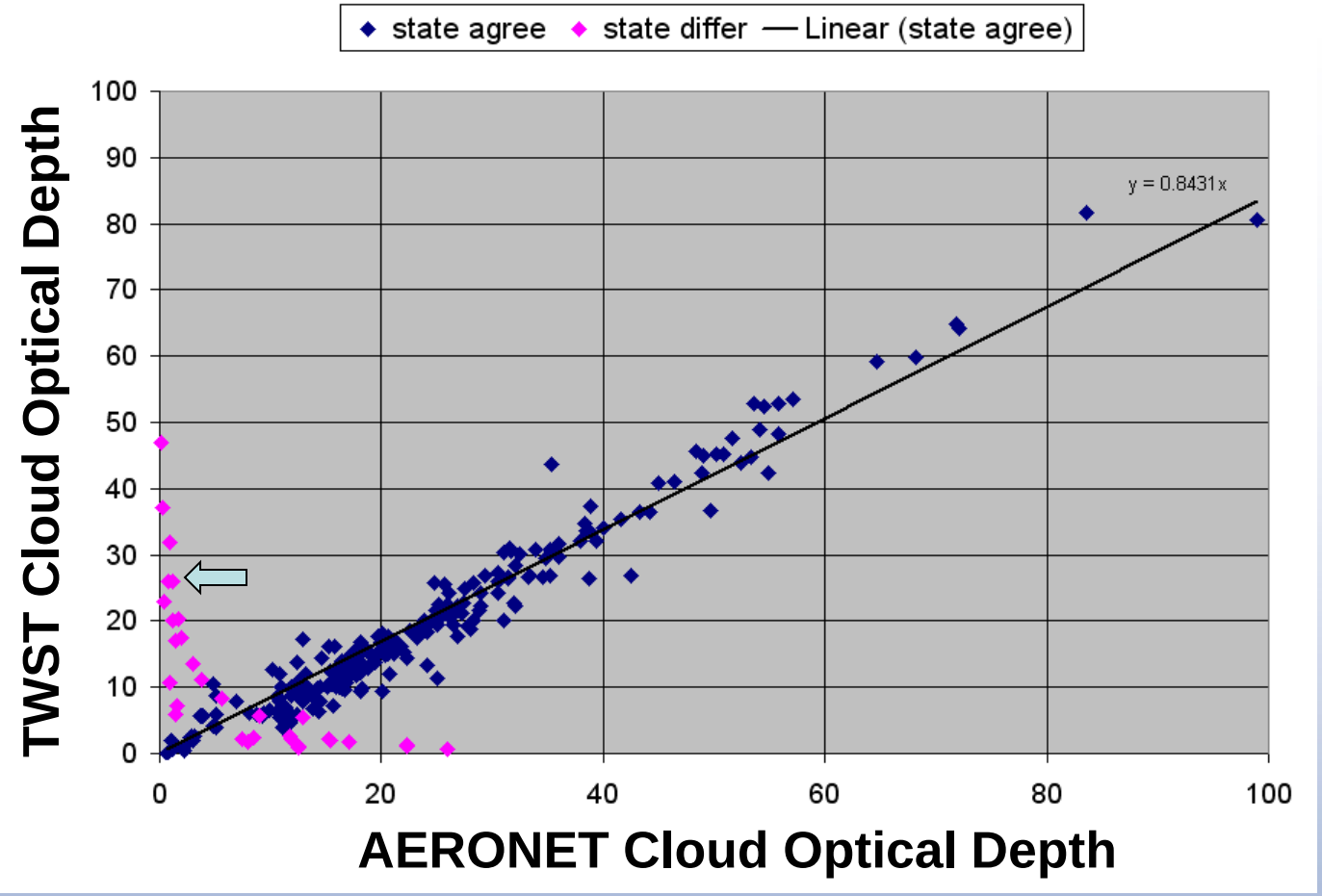
- **Negative slope indicates COD is optically thick**

AERONET vs TWST Radiance



- **Very Good Agreement (Time Synchronization Required)**
  - **8,609 points, May-June 2013, rms difference: 0.63 (uW/cm^2 sr nm)**

AERONET vs TWST COD



- **Good Agreement (Careful Averaging of TWST Required)**
  - **235 of 266 points, rms difference: OD 3.2 (using scale: 0.843)**

Conclusions and Future Plans

- Oxygen A-band EQuivalent Width (EQW) Improves Cloud Optical Depth (COD) Retrievals from Radiance Measurements
  - Compares favorably with AERONET - Cloud Mode
  - Not Sensitive to Ground Albedo Effects
- Sufficient SNR for 1 Second Update
  - High Temporal/Spatial Resolution useful for Cloud Edges
- Improved EQW Modeling will lead to Better COD
  - Extend Current Slope-only Algorithm
- EQW Key to other Cloud Parameter Measurements and Improved Retrievals
  - Cloud Base Altitude, Multiple Cloud Layers, Cloud Depth

Acknowledgements

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