An algorithm for simultaneous inversion of aerosol properties and surface reflectance from hyperspectral remote sensing data

> Jun Wang, Weizhen Hou, Xiaoguang Xu, University of Nebraska-Lincoln

2015 HyspIRI Science Workshop 13-15 October 2015 JPL/Caltech, Pasadena, CA

Most aerosol algorithms use data from radiometers

Table 1

List of current satellite sensors with measurement specifications relevant for operational retrieval of aerosol properties.

Acronyms	Full names	Wavelengths (nm)	Measurements characteristics
MERIS	Medium Resolution Imaging Spectrometer	15^{a} bands in 390 nm to 1040 nm including one O ₂ A band	Radiance at single view angle
MISR	Multi-angle Imaging SpectroRadiometer	446, 558, 672, and 867 for both land and ocean algorithm	Radiance at view angles \pm 26.1° ^b , \pm 45.6°, \pm 60.0°, and \pm 70.5°, and 0°
MODIS	Moderate Resolution Imaging Spectroradiometer	470, 678, 2130 for land 550, 678, 870, 1240, 1640, and 2130 for ocean	Radiance at single view angle ^c
OMI	Ozone Monitoring Instrument	354, 388 for Aerosol index 19 channels ^d in 332–500 for multi-channel algorithm	Radiance at single view angle
POLDER	POLarization and Directionality of the Earth's Reflectances	670, 865	Radiance and polarization at 14–16 viewing angles ^e
VIIRS	Visible Infrared Imaging Radiometer Suite	410, 440, 488, 672, 2250 nm for land 672, 746, 865, 1610, 1240, 2250 nm for ocean	Radiance at single view angle ^f
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization	532, 1064	Layer backscattering radiance and depolarization ratio ^g

^a 412, 442, 490, 510, 560, 620, 665, 681, 705, 753, 760, 775, 865, 890, 900 nm.

^b Positive and negative signs respectively denote the view angles in the forward and backward plane of the local vertical (e.g., nadi

^c Radiances are measured at 36 channels from 405 nm to 14395 nm.

^d 332, 340, 343, 354, 367, 377, 388, 340, 406, 416, 426, 437, 442, 452, 463, 477, 484, 495, and 500 nm.

^e The exact number of view angles depends on the geographical location. Radiances and linear polarization at 490 nm, 670 nm a radiance-only at 440 nm, 565 nm, and 1020 nm.

^f 22 channels with centers from 412 nm to 1201 nm.

^g Depolarizaiton ratio is only measured at 532 nm.

Wang et al., 2014, JQSRT

Past work done using spectral fitting, primarily in the infrared spectrum

A unified approach to infrared aerosol remote sensing and ACP, 2013 type specification (sulfate acid, ammonium sulfate, dust, smoke, volcanic ashes)

L. Clarisse¹, P.-F. Coheur¹, F. Prata², J. Hadji-Lazaro³, D. Hurtmans¹, and C. Clerbaux^{3,1}

¹Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles, Brussels, Belgium

²Climate and Atmosphere Department, Norwegian Institute for Air Research (NILU) P.O. Box 100, Kjeller, 2027, Norway ³UPMC Univ. Paris 6; Université Versailles St.-Quentin, CNRS/INSU, LATMOS-IPSL, Paris, France



The tool we use Unified and Linearized Vector Radiative Transfer (UNL-VRTM)



Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

A numerical testbed for remote sensing of aerosols, and its demonstration for evaluating retrieval synergy from a geostationary satellite constellation of GEO-CAPE and GOES-R

Jun Wang^{a,*}, Xiaoguang Xu^a, Shouguo Ding^a, Jing Zeng^a, Robert Spurr^b, Xiong Liu^c, Kelly Chance^c, Michael Mishchenko^d

^a Department of Earth and Atmospheric Sciences, University of Nebraska – Lincoln, 303 Bessey Hall, Lincoln, NE 68588, USA ^b RT Solutions, Inc., Cambridge, MA 02138, USA

^c Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

^d NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA

- Linearly and coupled scattering and radiative transfer codes, optimization code included
- Joint retrieval reduces AOD and fine-mode AOD uncertainties respectively from 30% to 10% and from 40% to 20%
- Polarization in O₂ A band is sensitive to aerosol height over visibly bright surface.

Geo-CAPE literature GEO-CAPE and GOES-R/S synergy

Joint retrieval from observations collected from dual viewing angles and multiple scattering angles to characterize particle shape and derive aerosol plume speed and stereo height



Geo-CAPE meeting, Maryland, 2009

Components of the testbed



Jacobians validation (UNL-VRTM) $x\partial S / \partial x$



Finite Difference Derived Jacobian

(Wang et al, JQSRT, 2014)

The theory and algorithm now are tested with AERONET multiple spectral and polarization data

AGU PUBLICATIONS



Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2015JD023108

This article is a companion to *Xu et al.* [2015] doi:10.1002/2015JD023113.

Retrieval of aerosol microphysical properties from AERONET photopolarimetric measurements:

1. Information content analysis

Xiaoguang Xu¹ and Jun Wang¹

RESEARCH ARTICLE 10.1002/2015JD023113

This article is a companion to *Xu and Wang* [2015] doi:10.1002/2015JD23108.

Key Points:

- A new aerosol retrieval algorithm for AERONET polarimetric measurements
- Retrieve size and refractive index for both fine- and coarse-mode aerosols
- Promising results with real data, limitations, and next research steps discussed

Retrieval of aerosol microphysical properties from AERONET photopolarimetric measurements: 2. A new research algorithm and case demonstration

Xiaoguang Xu¹, Jun Wang¹, Jing Zeng¹, Robert Spurr², Xiong Liu³, Oleg Dubovik⁴, Li Li⁵, Zhengqiang Li⁵, Michael I. Mishchenko⁶, Aliaksandr Siniuk⁷, and Brent N. Holben⁷

¹Earth and Atmospheric Sciences, University of Nebraska–Lincoln, Lincoln, Nebraska, USA, ²RT Solutions Inc., Cambridge, Massachusetts, USA, ³Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, USA, ⁴Laboratoire d'Optique Atmosphérique, CNRS–Université de Lille 1, Villeneuve d'Ascq, France, ⁵State Environmental Protection Key Laboratory of Satellites Remote Sensing, Institute of Remote Sensing and Digital Earth of Chinese Academy of Sciences, Beijing, China, ⁶NASA Goddard Institute for Space Studies, New York, New York, USA, ⁷NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Hyperspectral remote sensing of aerosols in the shortwave spectrum?

Need to characterize the surface spectra.



Characterize surface reflectance with PCA



Assumptions & Derivation/validation of Jacobians

$$\frac{\partial I}{\partial W} = \frac{\partial I}{\partial R} [P_{i,1}, P_{i,2}, \cdots, P_{i,6}]^T, (i = 1, \cdots, d)$$



Assumptions & Derivation/validation of Jacobians

$R(\lambda, \mu_0, \mu_v, \varphi) = f_{\rm iso}(\lambda) + k_1(\lambda) f_{\rm geom}(\mu_0, \mu_v, \varphi) + k_2(\lambda) f_{\rm vol}(\mu_0, \mu_v, \varphi)$ $\frac{\partial I}{\partial R} = \left(f_{\rm iso} \frac{\partial I}{\partial f_{\rm iso}} + k_1 \frac{\partial I}{\partial k_1} + k_2 \frac{\partial I}{\partial k_2} \right) / R$



Assumptions & Derivation/validation of Jacobians

Wavelength-dependence of refractive index (similar as AERONET algorithm):



Optimization framework

Forward model and Jacobians matrix

$$\mathbf{y} = \mathbf{F}(\mathbf{x}) + \boldsymbol{\varepsilon}$$



$$J = \frac{1}{2} [\mathbf{y} - \mathbf{F}(\mathbf{x})]^T \mathbf{S}_{\varepsilon}^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x})] + \frac{1}{2} [\mathbf{x} - \mathbf{x}_a]^T \mathbf{S}_a^{-1} [\mathbf{x} - \mathbf{x}_a]$$

- Gradient vector: $\nabla_{x}J = -\mathbf{K}^{T}\mathbf{S}_{\varepsilon}^{-1}[\mathbf{y} - \mathbf{F}(\mathbf{x})] + \mathbf{S}_{a}^{-1}[\mathbf{X} - \mathbf{X}_{a}], \quad \mathbf{K} = \frac{\partial \mathbf{y}}{\partial \mathbf{x}}$ $\nabla_{x}J = [\frac{\partial I}{\partial V_{total}}, \frac{\partial I}{\partial r_{g}^{f}}, \frac{\partial I}{\partial \sigma_{g}^{f}}, \frac{\partial I}{\partial r_{g}^{c}}, \frac{\partial I}{\partial \sigma_{g}^{c}}, \frac{\partial I}{\partial \sigma_{g}^{c}}, \frac{\partial I}{\partial \sigma_{g}^{c}}, \frac{\partial I}{\partial \sigma_{g}^{f}}, \frac{\partial I}{\partial \sigma$
 - Surface reflectance: $\mathbf{R} = \mathbf{A}^T \mathbf{W}$

Self-consistent Check

assuming aerosol properties are well known (such as in field campaigns to derive surface reflectance); 1% measurement error.



- **Only 6 weight factors of PCA are retrieved to reconstruct surface reflectance.**
- **\therefore** Error in reconstruction in terms of rms is < 0.003.

Geo-TASO Data 415-695 nm spectrometer, 0.2 nm resolution



Google earth



Geo-TASO RGB



Preliminary Results - data used for the retrieval



Spectral fitting



Preliminary Results AOD & size distribution retrievals



Preliminary Results AOD & surface reflectance retrievals



967 bands

HSRL extinction profile (B200 aircraft) in Sep. 13, 2013





AOD validation



Summary & next step

- A framework for hyperspectral remote sensing of aerosol over green canopy is established.
- We like to apply this algorithm to HyspIRI-type data that measure the radiances at from UV to NIR (2.1 um).

Thank you!

Brief History of Geo. Weather Satellite

Himawari-8 Latest geo weather, JAXA Launched 10/7/2014





GOES-A/1

Advanced Himawari Imager (AHI) 16 bands 3 vis. , 1 km & .5 km 4 NIR, 2 km 9 TIR, 2 km. 10 minutes/full disk

Spin Scan Radiometer (VISSR) 0.55-0.75 μm, 1 km 10.5-12.6 μm, 9 km

1st geo., launched in 02/14/1963, a communication sat., NASA



Geostationary

NASA

Smithsonian

100



• Improved assessment, *e.g.*, observations to support the United Nations Convention on Long $_{9/18/13}$ Range Transboundary Air Pollution