Aerosol Research Algorithm for TEMPO and TEMPO+GOES

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

K. Chance, X. Liu, Caroline Nowlan, Peter Zoogman
Harvard–Smithsonian

Jim Leitch & GEO-TASO team

Jay Al-Saadi & GEO-CAPE Aerosol Working group

TEMPO Science Team Meeting
Washington D. C.

Strategy for Retrieval Algorithm

- Algorithm development strategy
  - Forward thinking: the GOES+TEMPO synergy algorithm is for aerosol science 5-8 years from now.
  - Holistic thinking: aerosol will affect O3 and other gas retrieval in UV + Vis gas retrieval algorithm; likewise, gas affects aerosol retrieval.
  - Think about users:
    - satellite data are valuable but can not provide all information users needed.
    - Getting the data is not a key question; the key is the uncertainty associated with each retrieval and how does that help what users already have, in places where obs. data is not available.
    - A big community to use these data will modelers and data assimilation folks.
  - Think about validation: link retrieval to what can be measured.
  - Think about STM: climate or air pollution?
  - Start with theory, then real data

slide from 2014 GEO-CAPE meeting

The retrieval framework has been tested with AERONET multiple spectral and polarization data

AGU PUBLICATIONS

JGR

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 Xu[1] and Jun Wang[1]

RESEARCH ARTICLE

10.1002/2015JD023113

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

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

Xiaoguang Xu[1], Jun Wang[1], Jing Zeng[1], Robert Spurr[2], Xiong Liu[3], Oleg Dubovik[4], Li Li[5], Zhengqiang Li[5], Michael I. Mishchenko[6], Aliaksandr Siniuk[7], and Brent N. Holben[7]

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

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

Progress for TEMPO Retrieval Algorithm

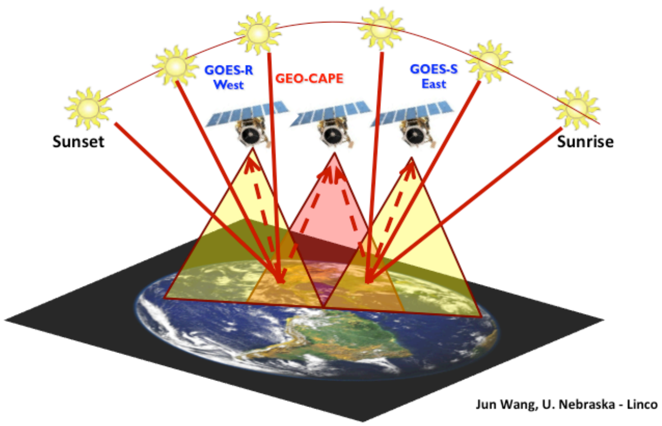
- What we have been developed so far:
  - A inversion/optimization framework that is consistent with what TEMPO's gas retrieval framework
  - Seek to provide uncertainty for each individual retrievals.
  - State-of-the-art treatment of gas absorption
  - Tested with AERONET sky radiance so far; Put physically-based constraints to ensure retrieval smoothness and reduce unphysical outliers.
  - Tested with synthetic data and GEO-TASO data

- Decision has not been made; some can not be answered without further studies:
  - Treatment of surface (there were multi-ways to do it, discuss later)
  - The role of priori knowledge for the retrieval: e.g., aerosol climatology from models, ground-based network, and existing satellite products.
  - What to retrieve and what not? Trying to pushing the limits, while still maintaining good accuracy. Fine-mode AOD, surface reflectance?

GOES+TEMPO

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



Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

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

ELSEVIER

JQSRT, 2014

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

TEMPO/GEO-TASO

Journal of Quantitative Spectroscopy & Radiative Transfer 178 (2016) 400–415

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

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

ELSEVIER

JQSRT, 2016

An algorithm for hyperspectral remote sensing of aerosols: 1. Development of theoretical framework

Weizhen Hou [a], Jun Wang [a,*], Xiaoguang Xu [a], Jeffrey S. Reid [b], Dong Han [a]

[a] Earth and Atmospheric Sciences, University of Nebraska–Lincoln, 303 Bessey Hall, Lincoln, NE 68588, USA
[b] Marine Meteorology Division, Naval Research Laboratory, 7 Grace Hopper Ave, Stop 2, Monterey, CA 93943, USA

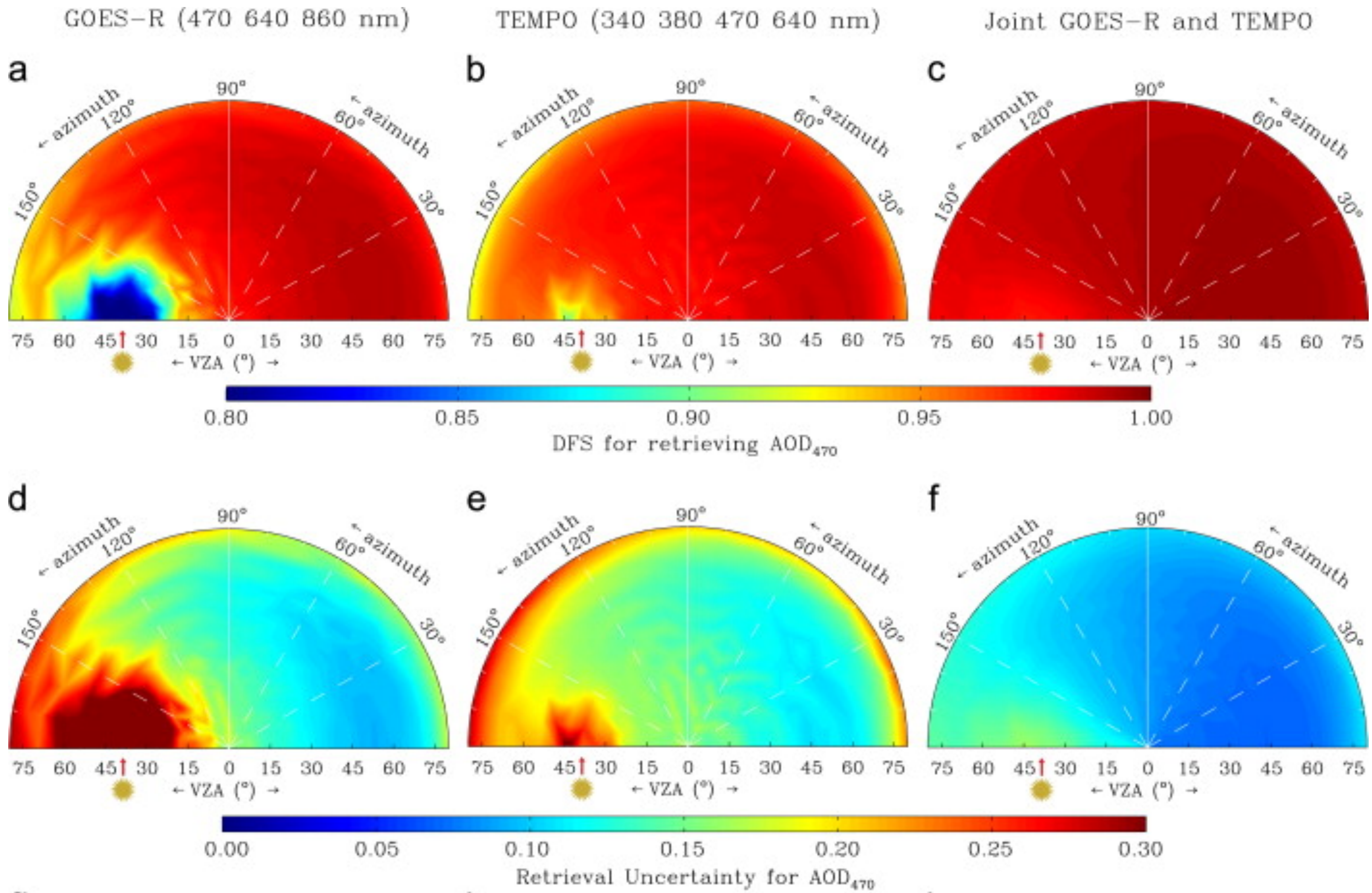
GOES-R
to be launched in 2016?

ABI: Advanced Baseline Imager

Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/ sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager

from Schmit et al., 2005.



Joint retrieval reduces AOD and fine-mode AOD uncertainties respectively from 30% to 10% and from 40% to 20%.

The improvement of AOD is especially evident for cases when either TEMPO or GOES-R (but not both) are located close to the direction of the Sun (solar azimuth).

Brief History of Geo. Weather Satellite

Better imager

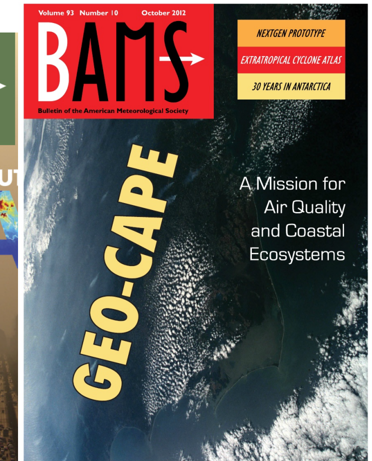
Advanced Himawari Imager (AHI)
16 bands
3 vis. , 1 km & .5 km
4 NIR, 2 km
9 TIR, 2 km.
10 minutes/full disk

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

Brief History of Geo. Aerosol/Air Pollution Satellite

Imager → Spectrometer

Launch 2018?



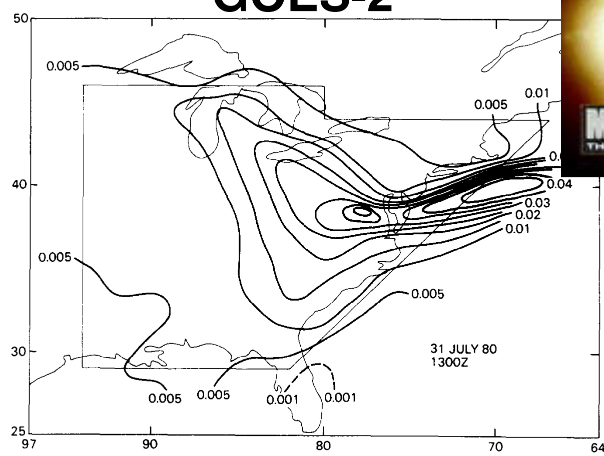
Lahoz et al., 2012
Fishman et al., 2012

Schmit et al., 2005

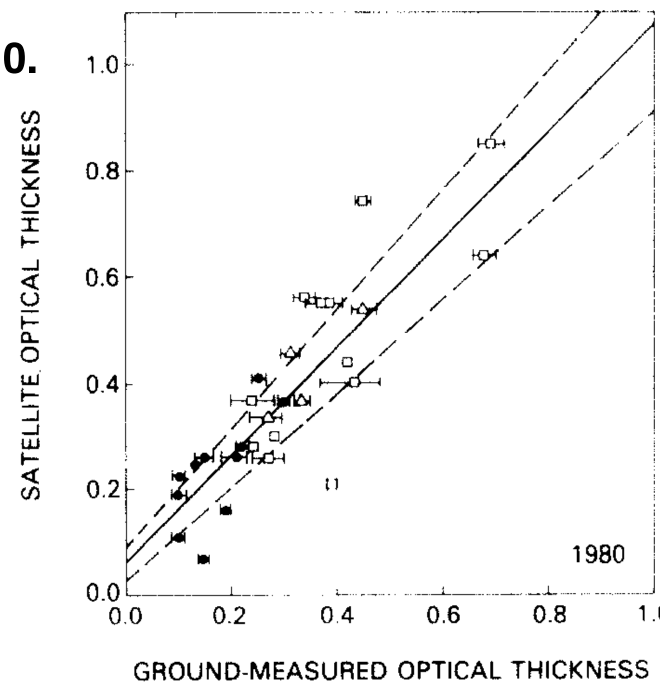
Lee et al., 2010. RSE
6 visible
2 NIR

MSG, 8/28/2002
12 channels
2 visible

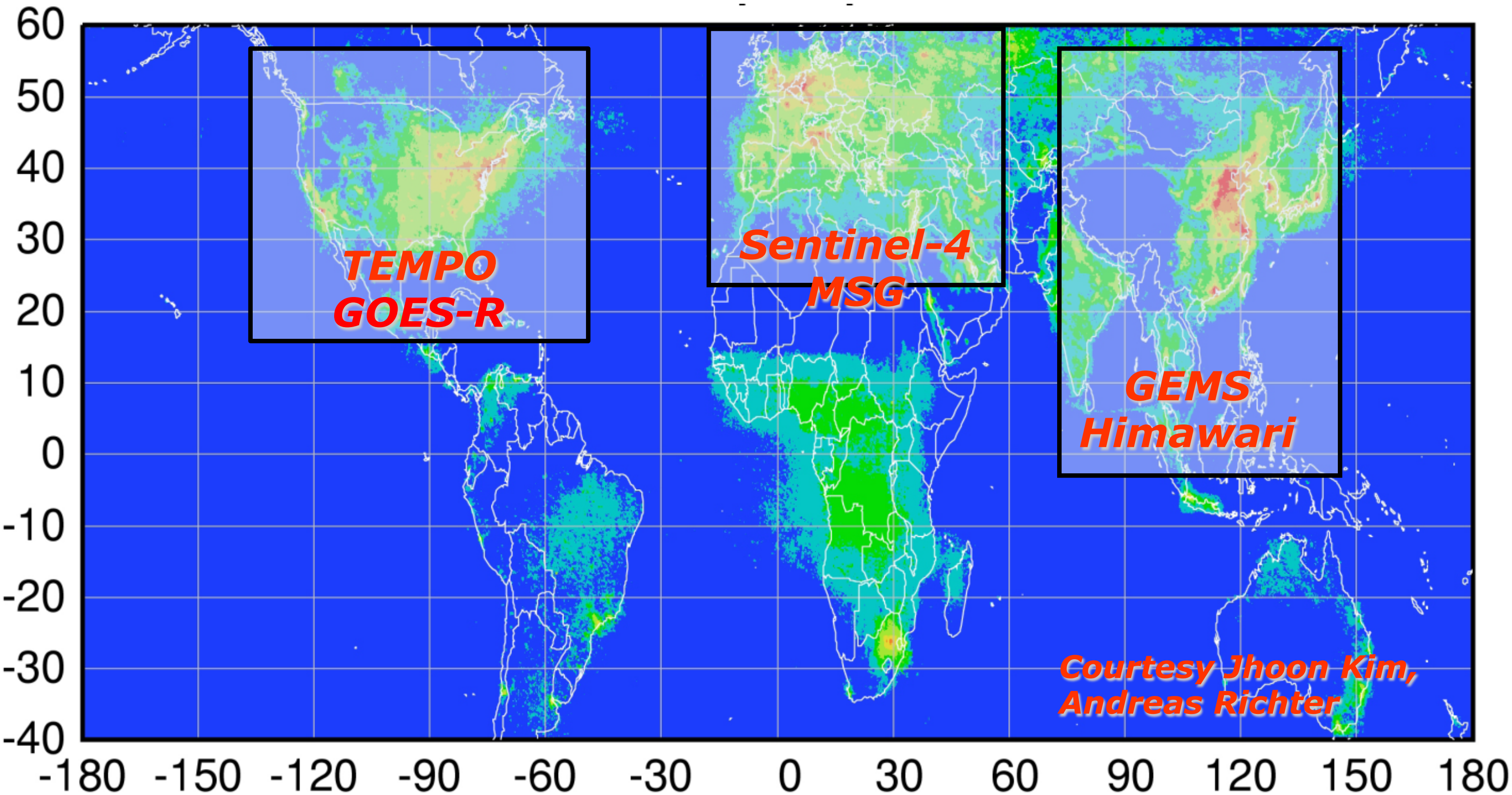
GOES-2



Fraser, Kaufman, Mahoney, 1984, AE



Hyperspectral GEO Era is coming!



Policy-relevant science and environmental services enabled by common observations

- Improved emissions, at common confidence levels, over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, *e.g.*, observations to support the United Nations Convention on Long Range Transboundary Air Pollution

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

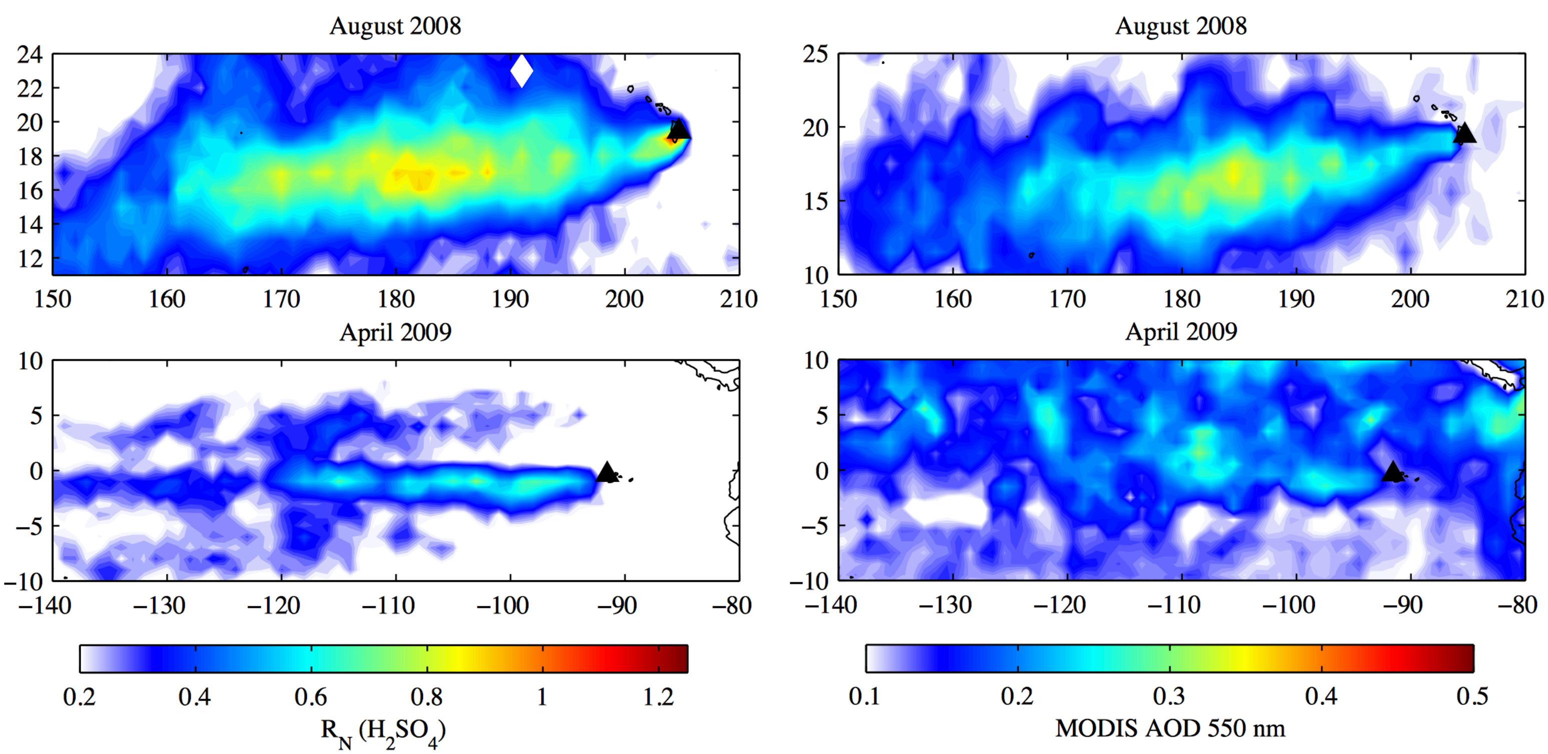
A unified approach to infrared aerosol remote sensing and type specification

ACP, 2013

(sulfate acid, ammonium sulfate, dust, smoke, volcanic ashes)

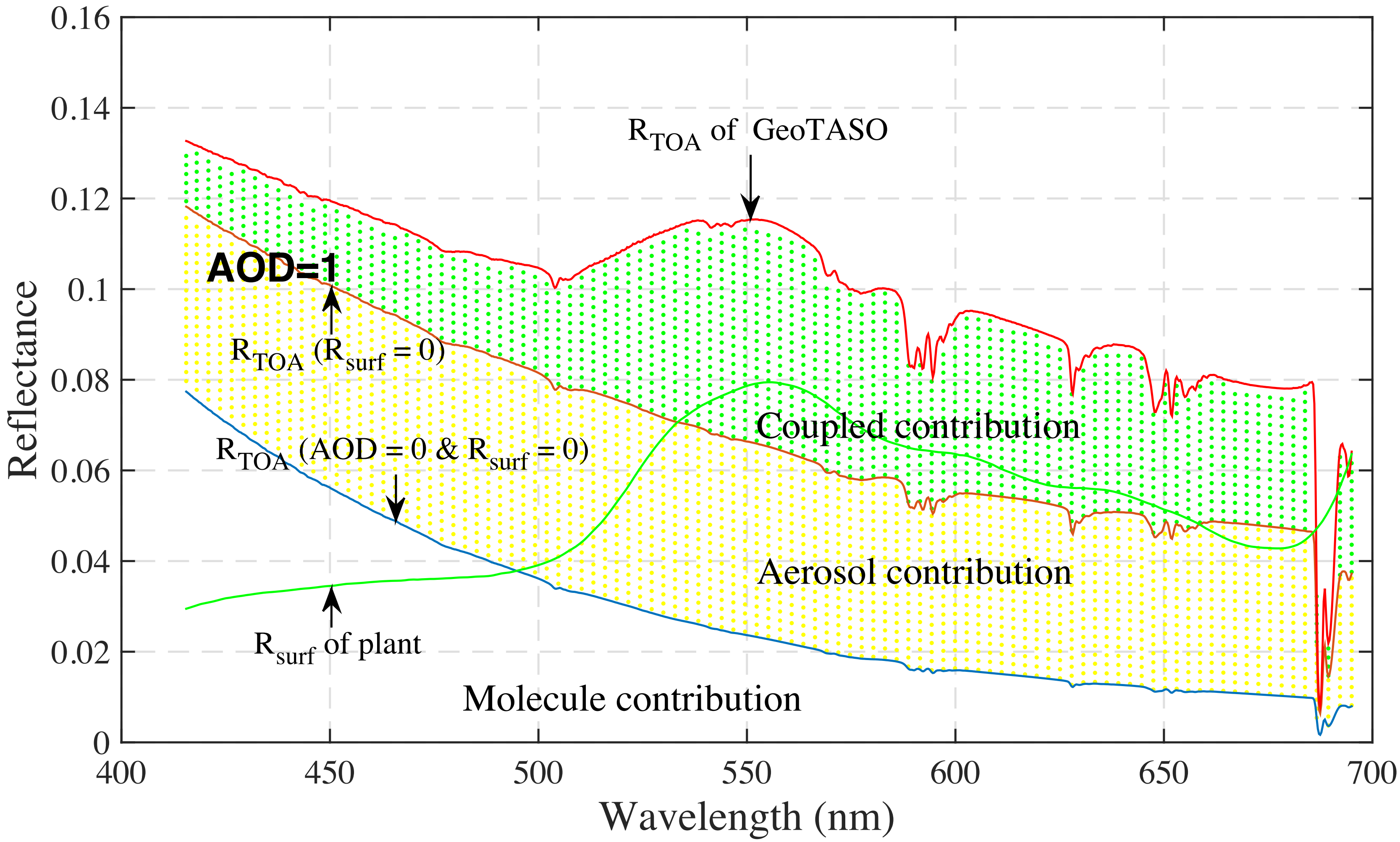
L. Clarisse[1], P.-F. Coheur[1], F. Prata[2], J. Hadji-Lazaro[3], D. Hurtmans[1], and C. Clerbaux[3,1]

[1]Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles, Brussels, Belgium
[2]Climate and Atmosphere Department, Norwegian Institute for Air Research (NILU) P.O. Box 100, Kjeller, 2027, Norway
[3]UPMC Univ. Paris 6; Université Versailles St.-Quentin, CNRS/INSU, LATMOS-IPSL, Paris, France

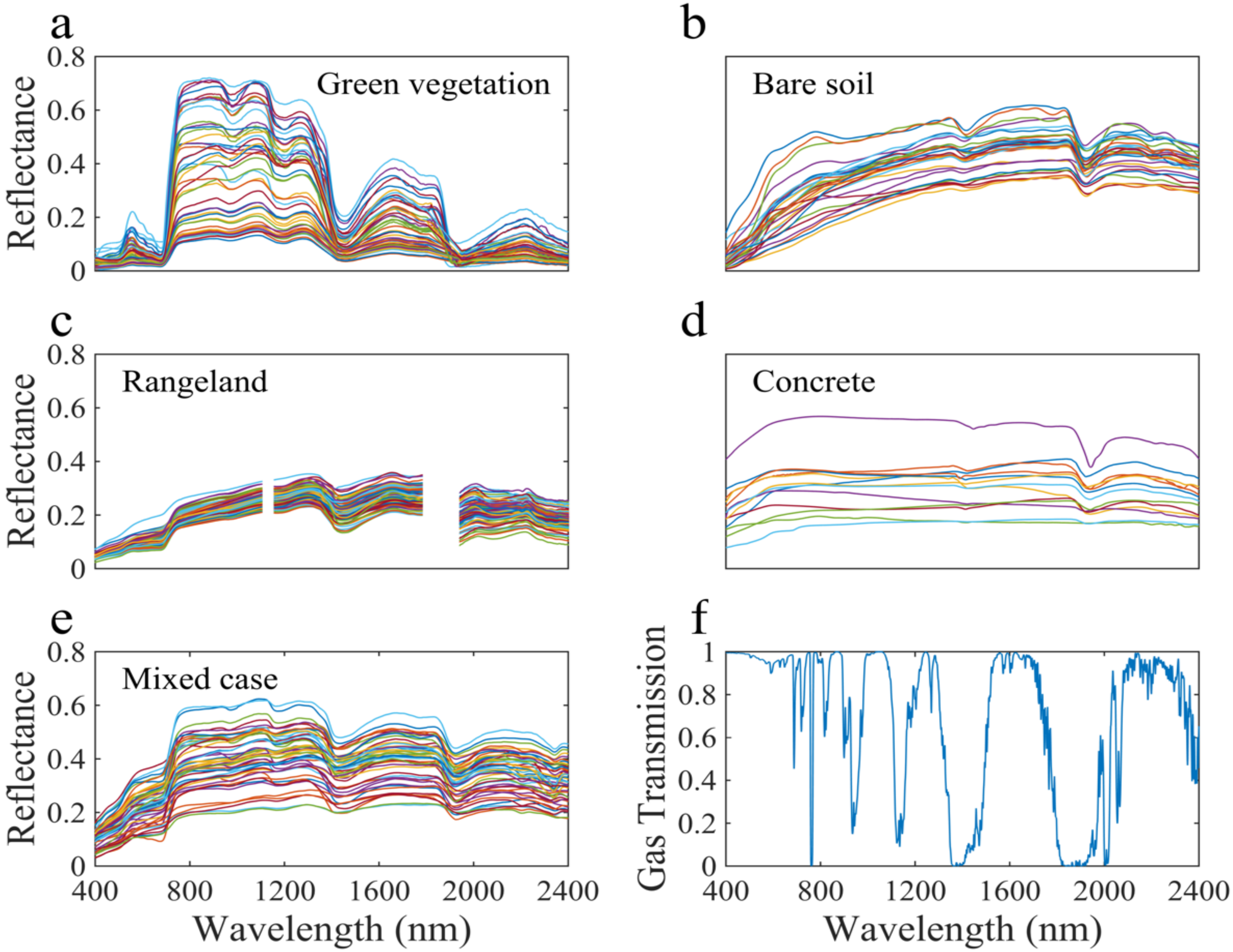


Hyperspectral remote sensing of aerosols in the shortwave spectrum?

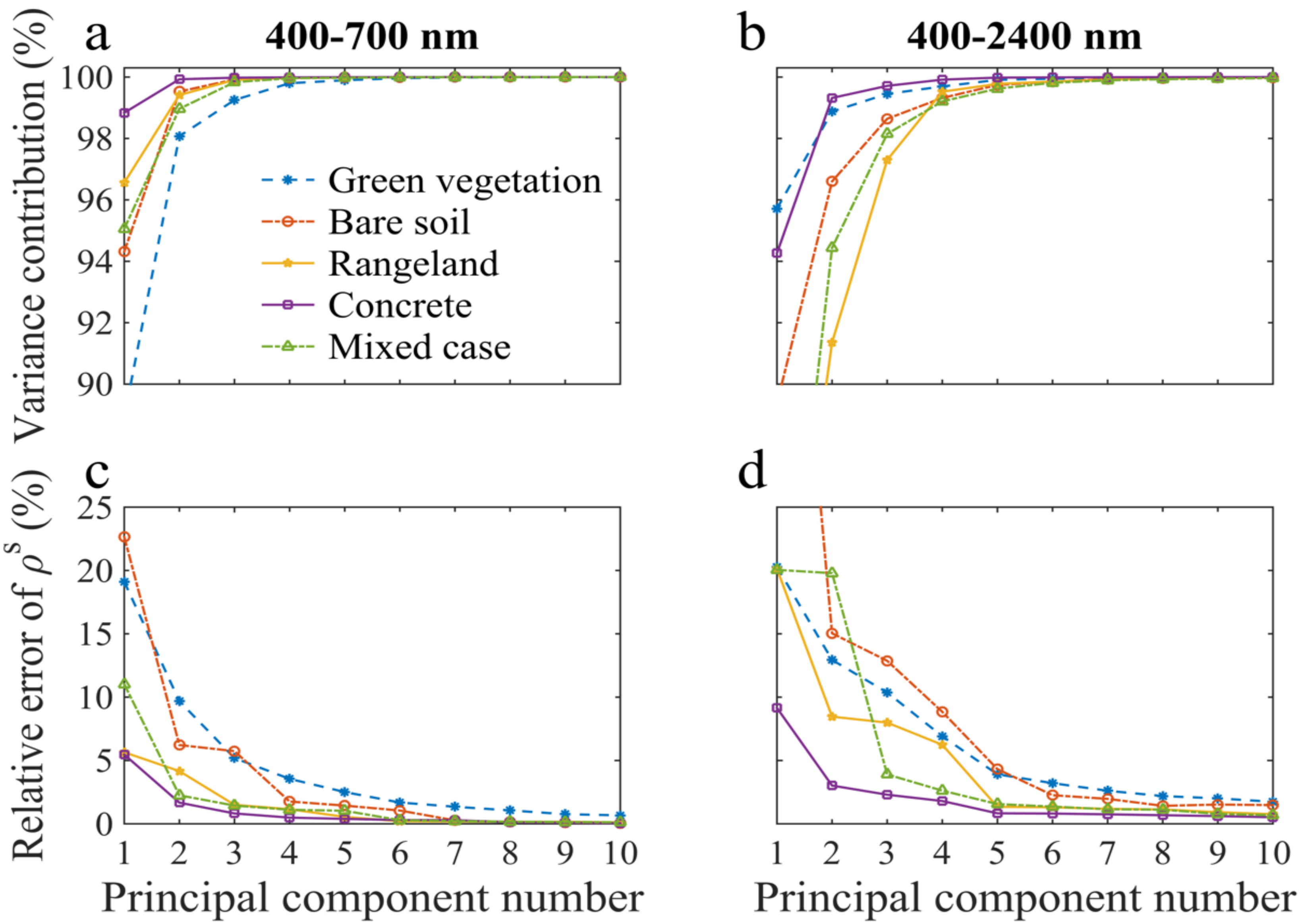
Need to characterize the surface spectra.



Spectral characteristics of different surface types

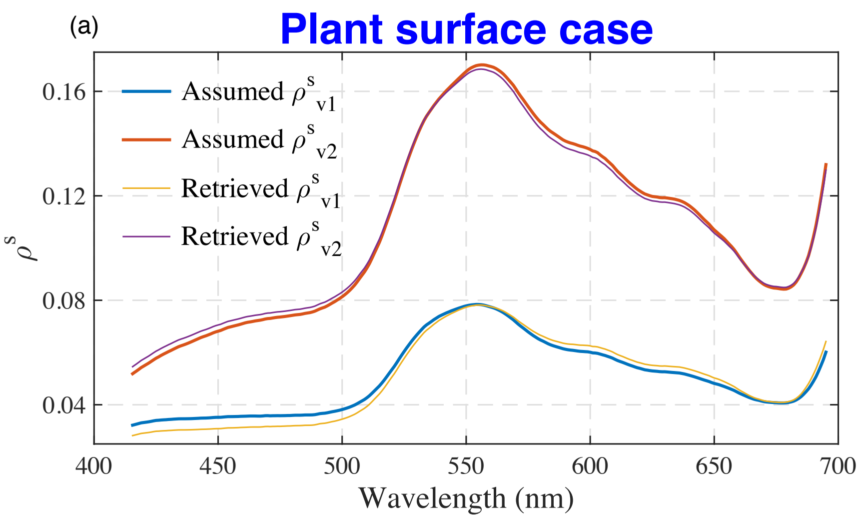


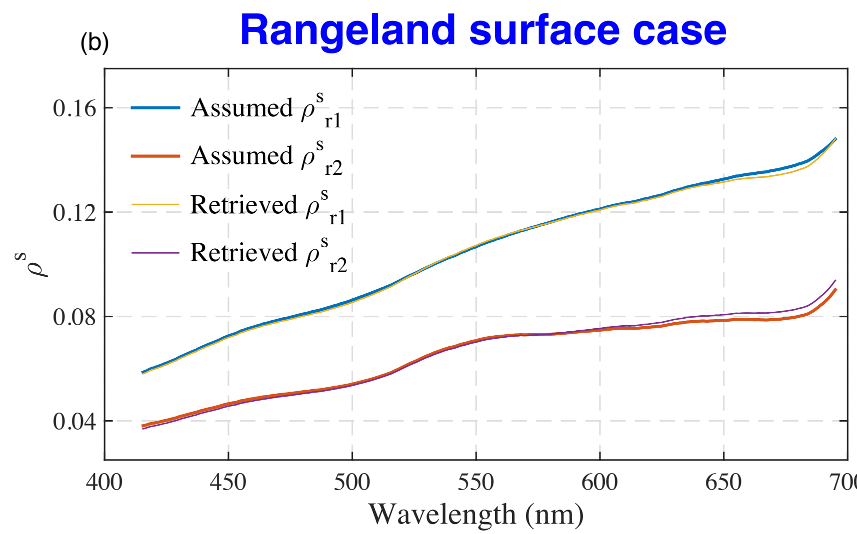
PCA analysis of surface reflectance



Self-consistent Check

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

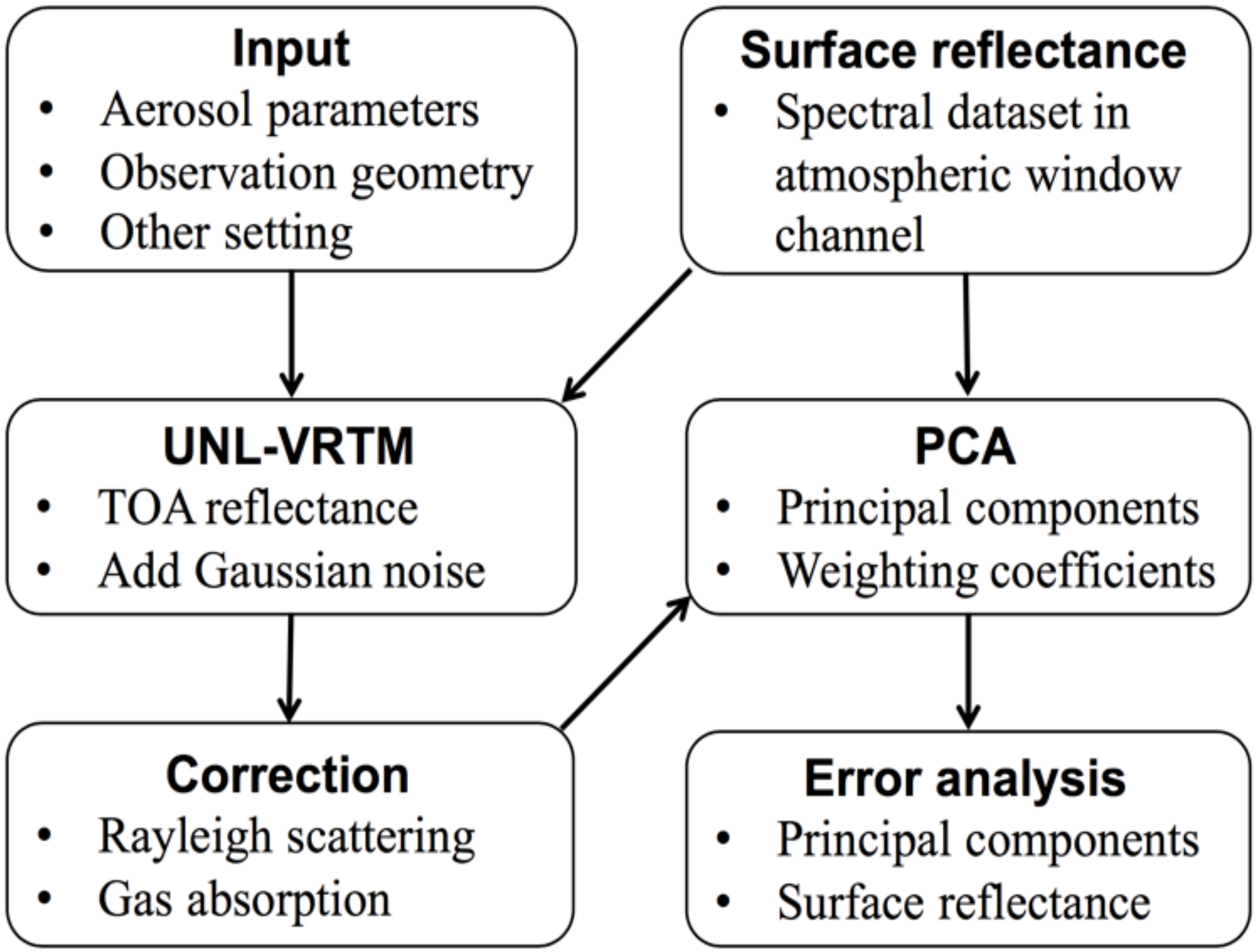




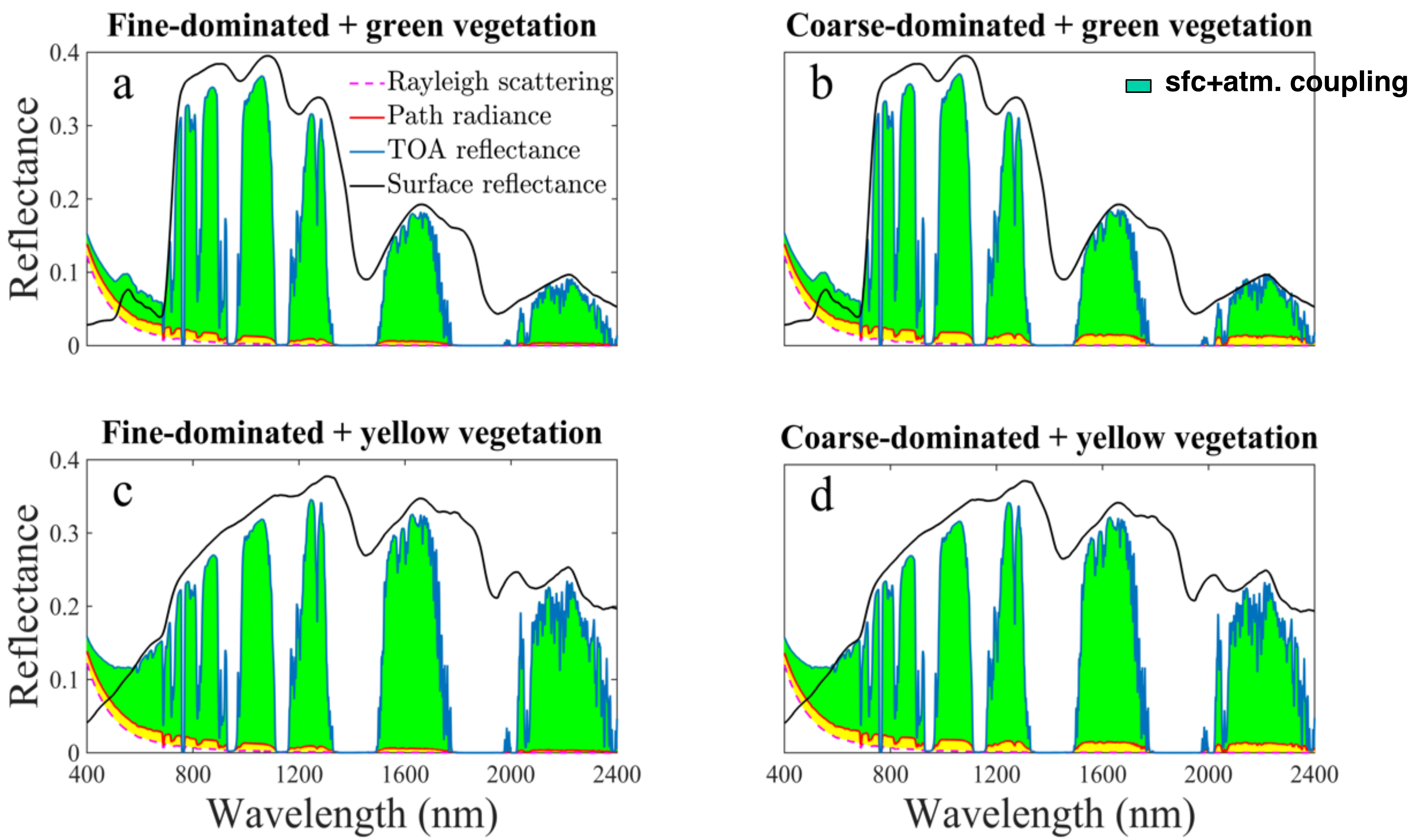
- ❖ **Only 6 weight factors of PCA are retrieved to reconstruct surface reflectance.**
- ❖ **Error in reconstruction in terms of rms is < 0.003.**

Hou et al., 2016, JQSRT

A numerical test: can we retrieve PCs from hyperspectral reflectance measured at TOA?

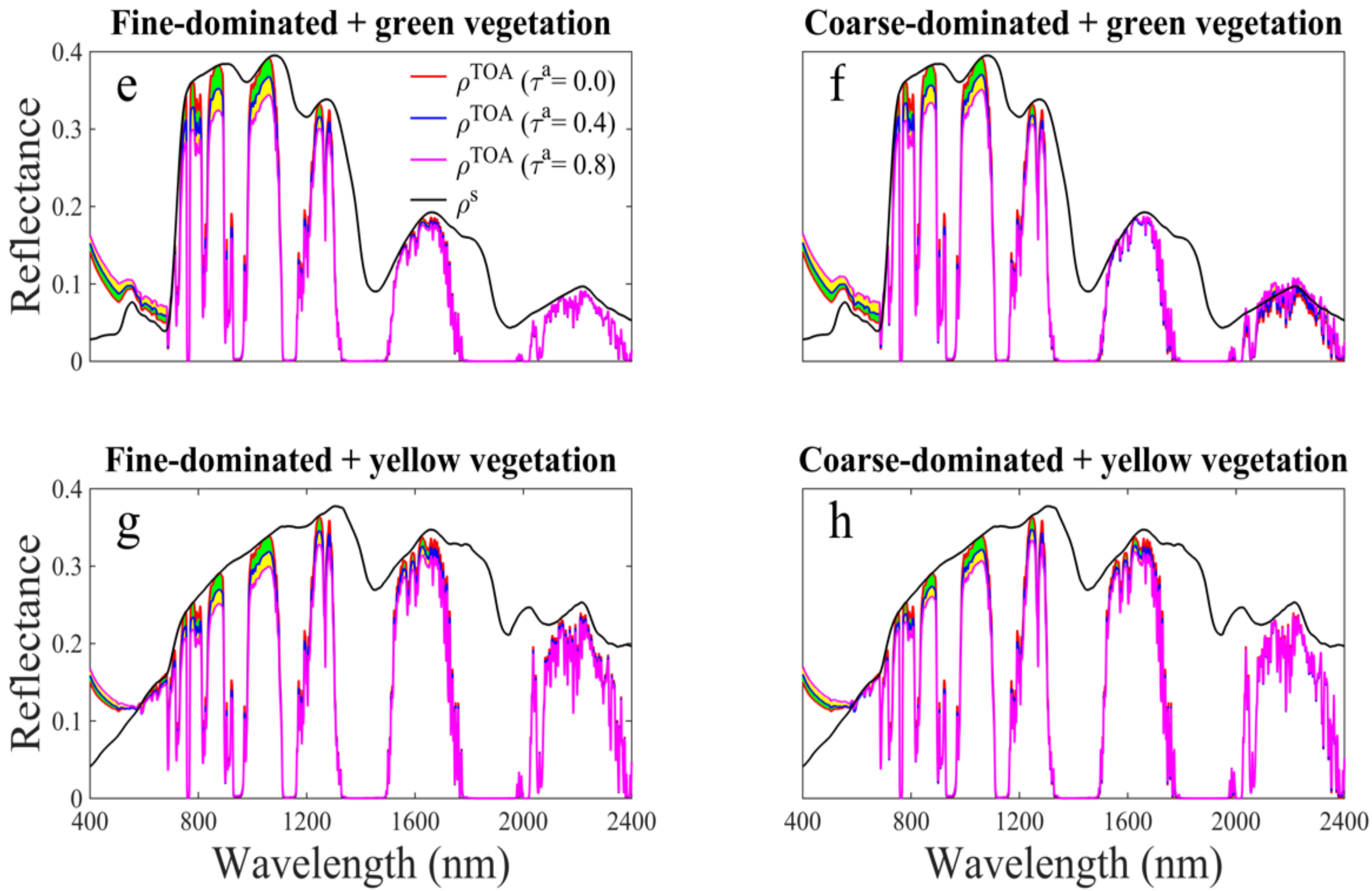


The challenge:
strong coupling between surface & atmosphere

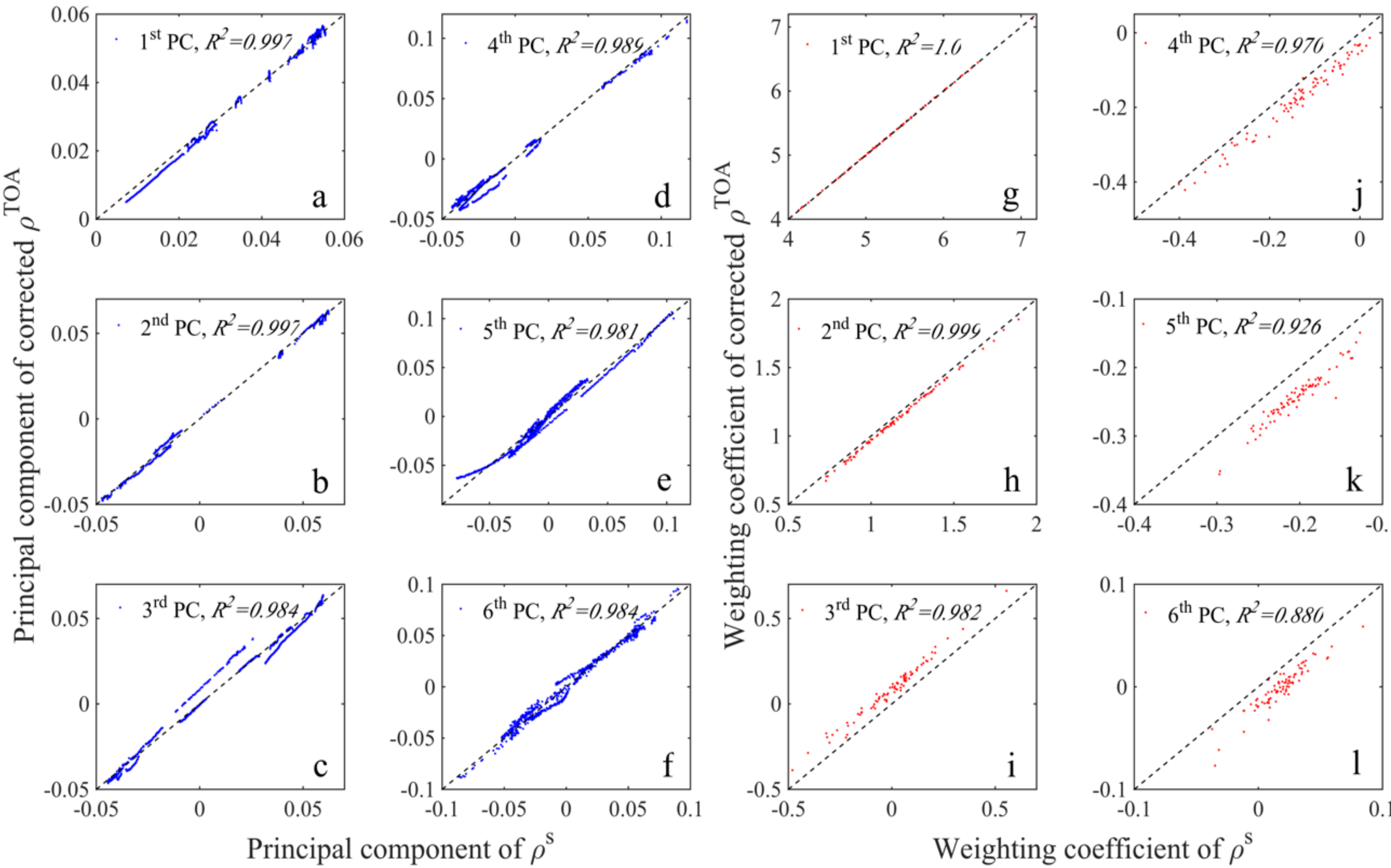


AOD = 0.2

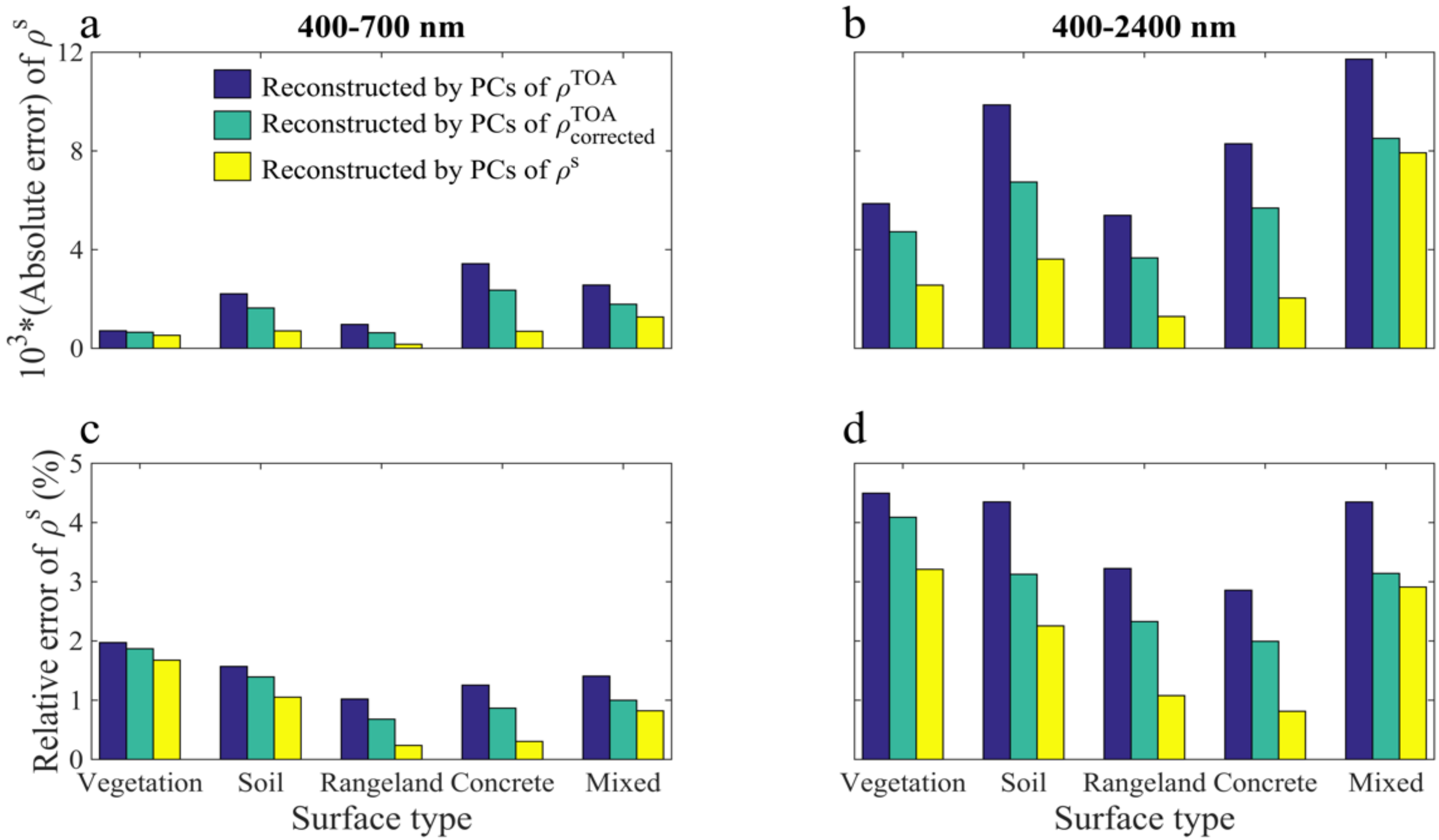
TOA spectra, at atmospheric window channels, resonates the characteristics of surface reflectance, regardless of AOD



Evaluation of PC and W derived from TOA spectra (after correction of Rayleigh scattering)

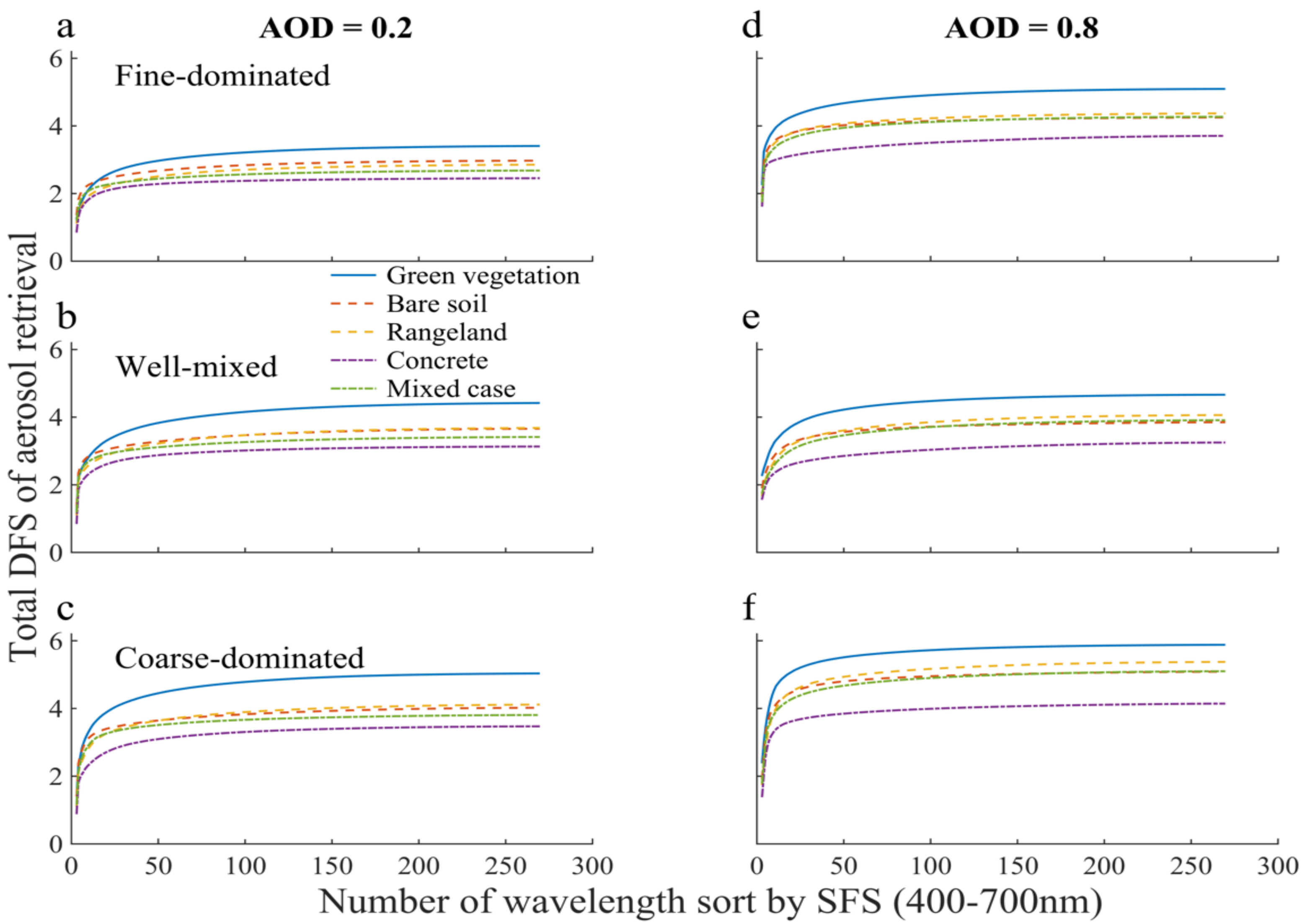


Errors in reconstructed surface spectra from different methods



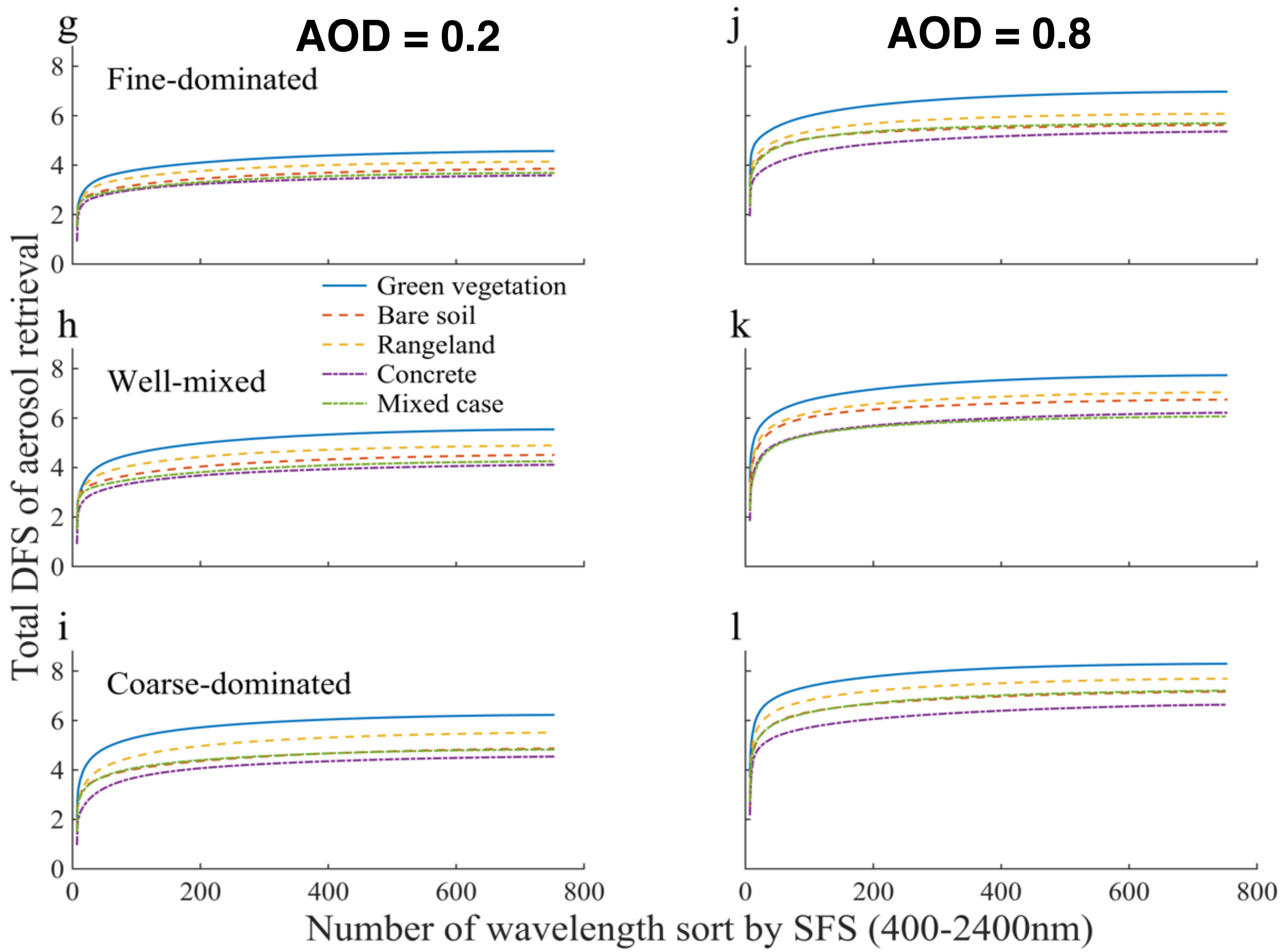
Total DFS Analysis (TEMPO spectral range)

assuming surface spectra is known with uncertainties

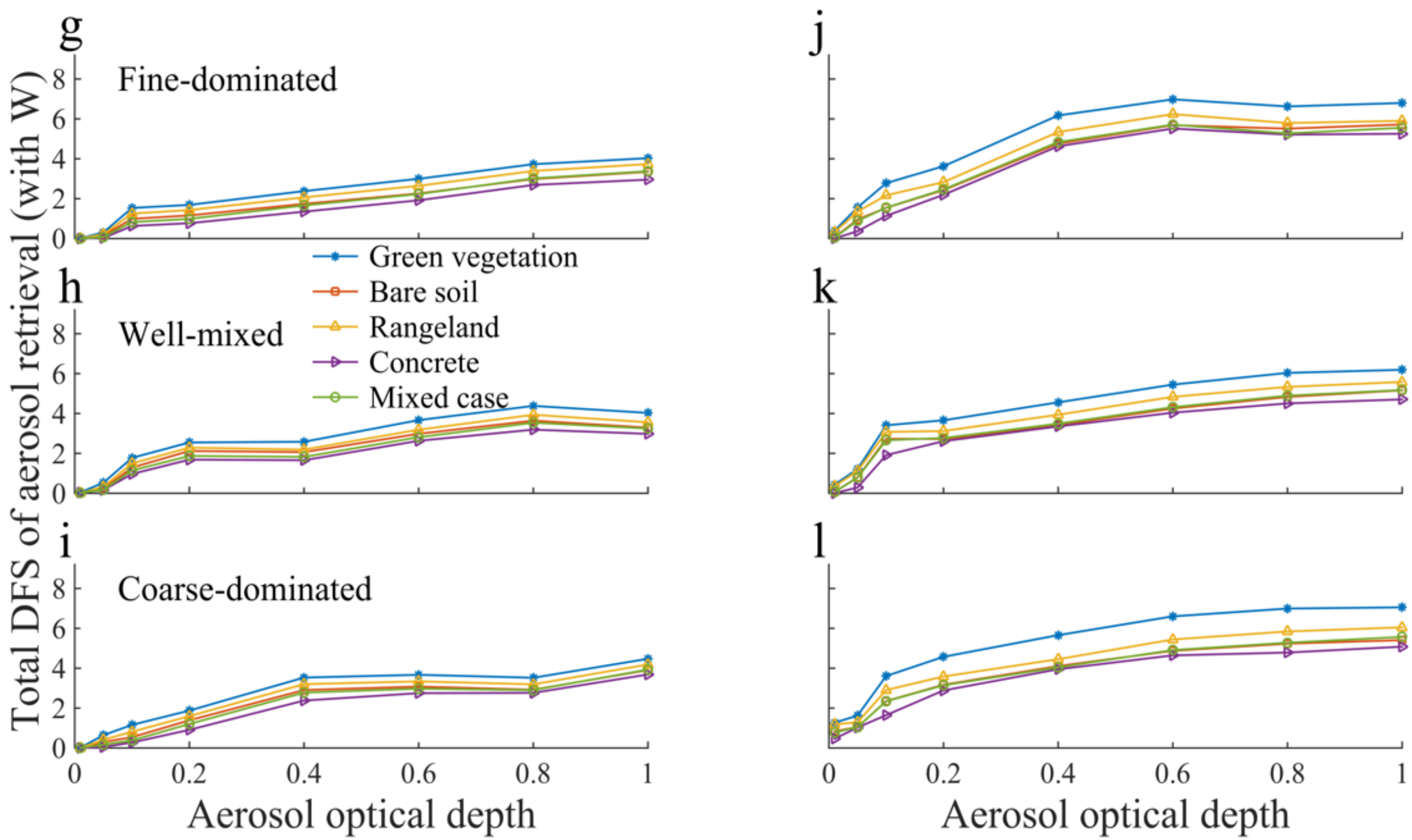


Total DFS Analysis (400-2400 nm)

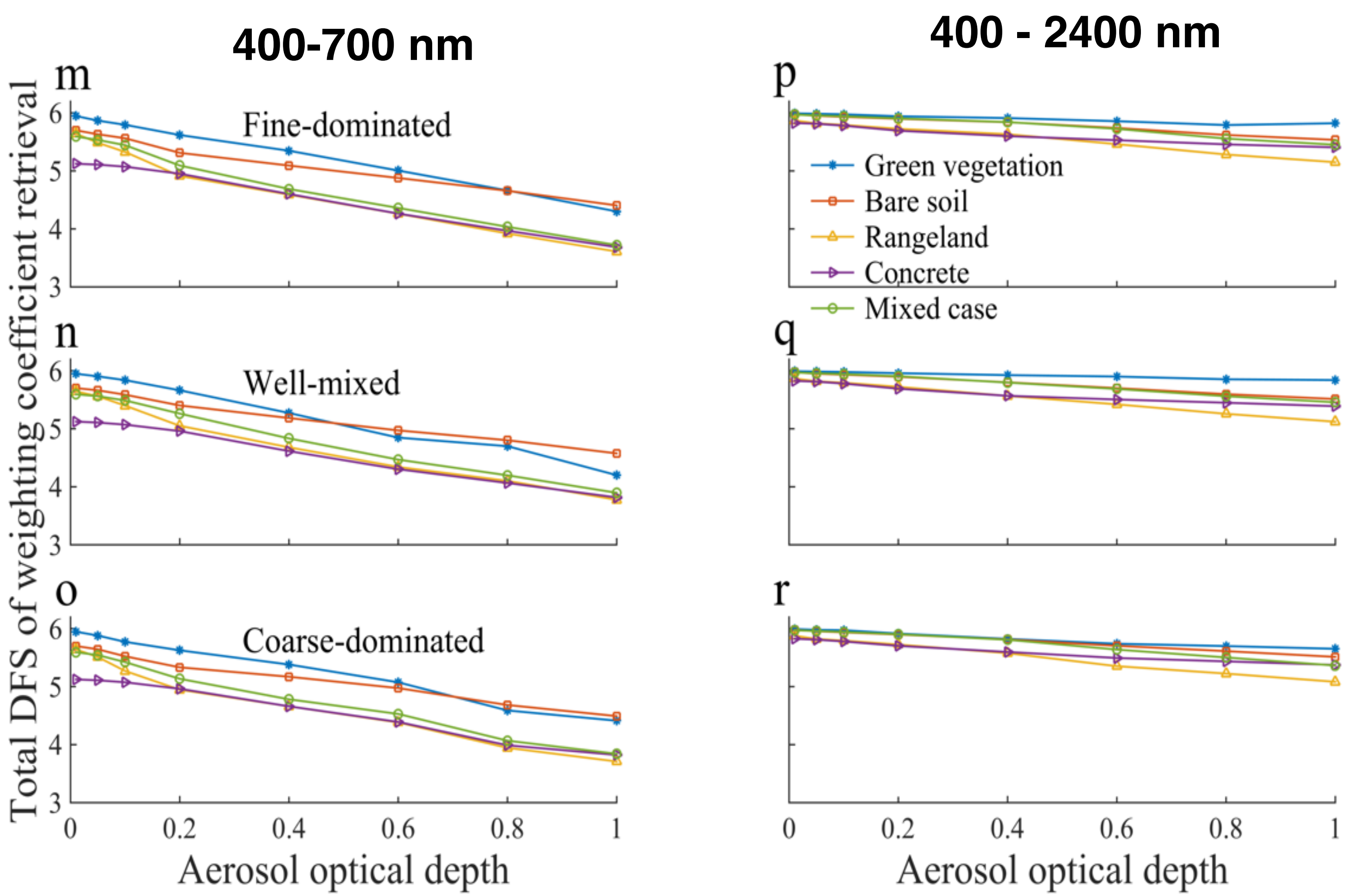
assuming surface spectra is known with uncertainties



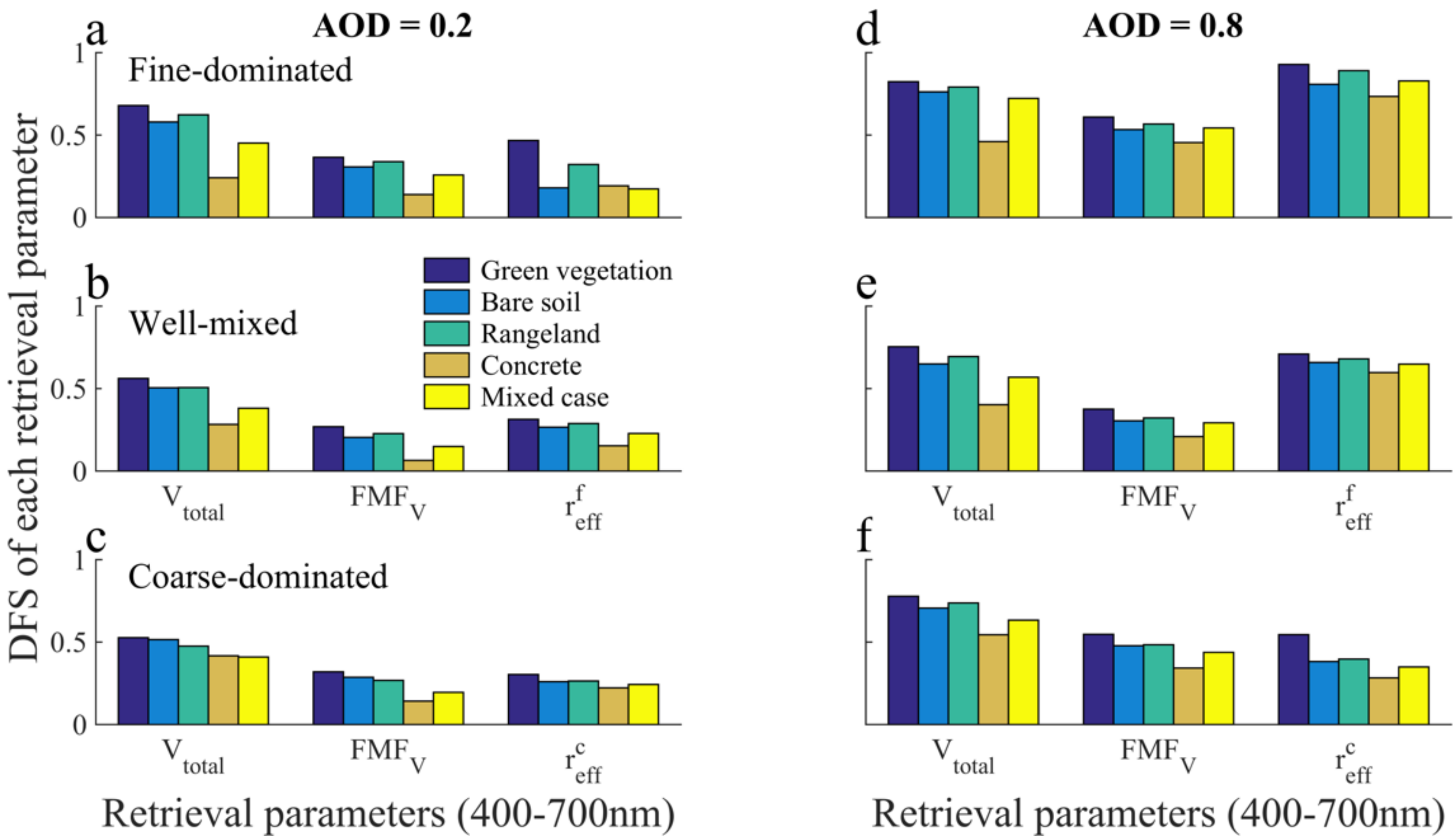
DFS for aerosol parameters as a function of AOD



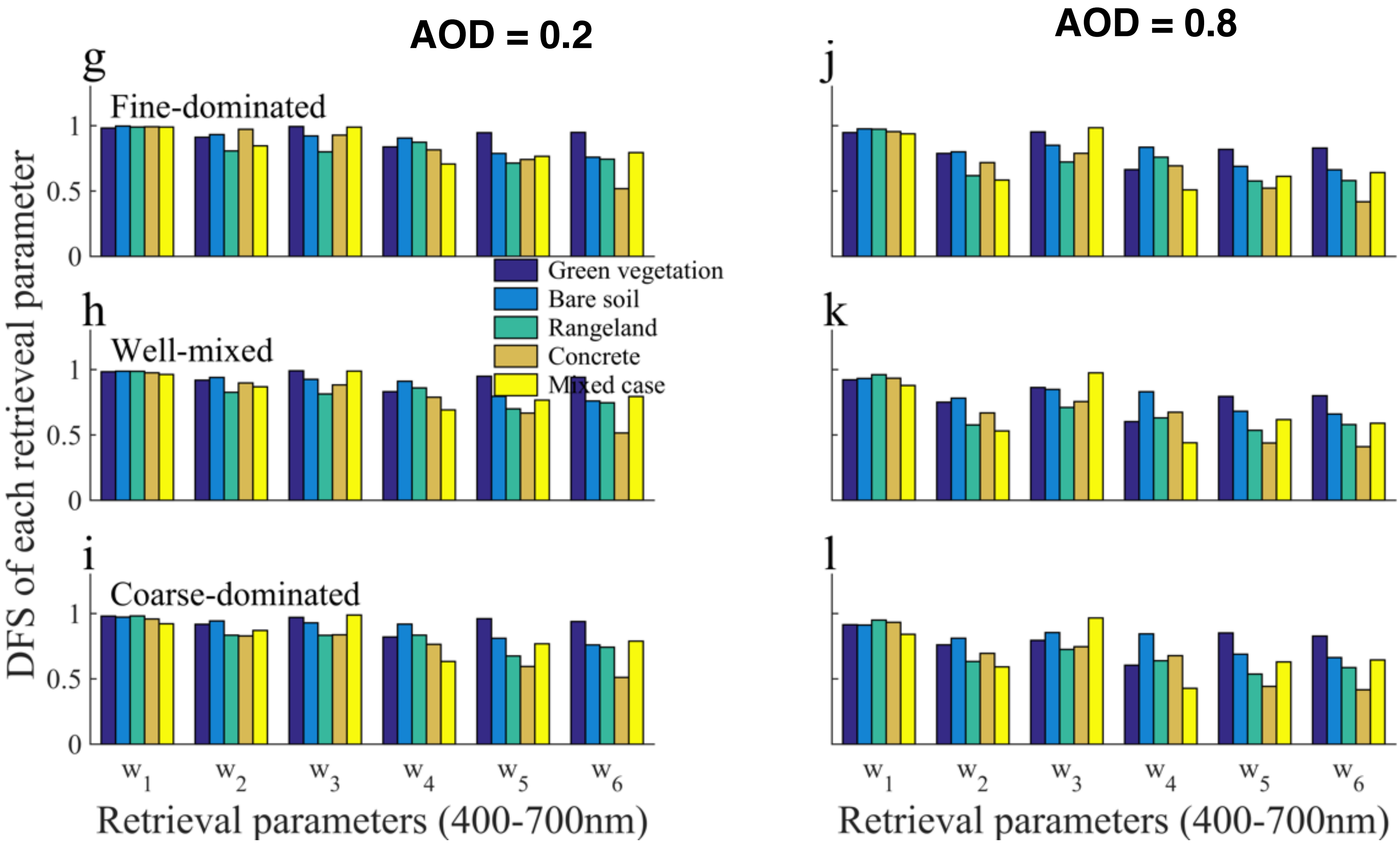
DFS for retrieving W



DFS for aerosol retrieval parameters

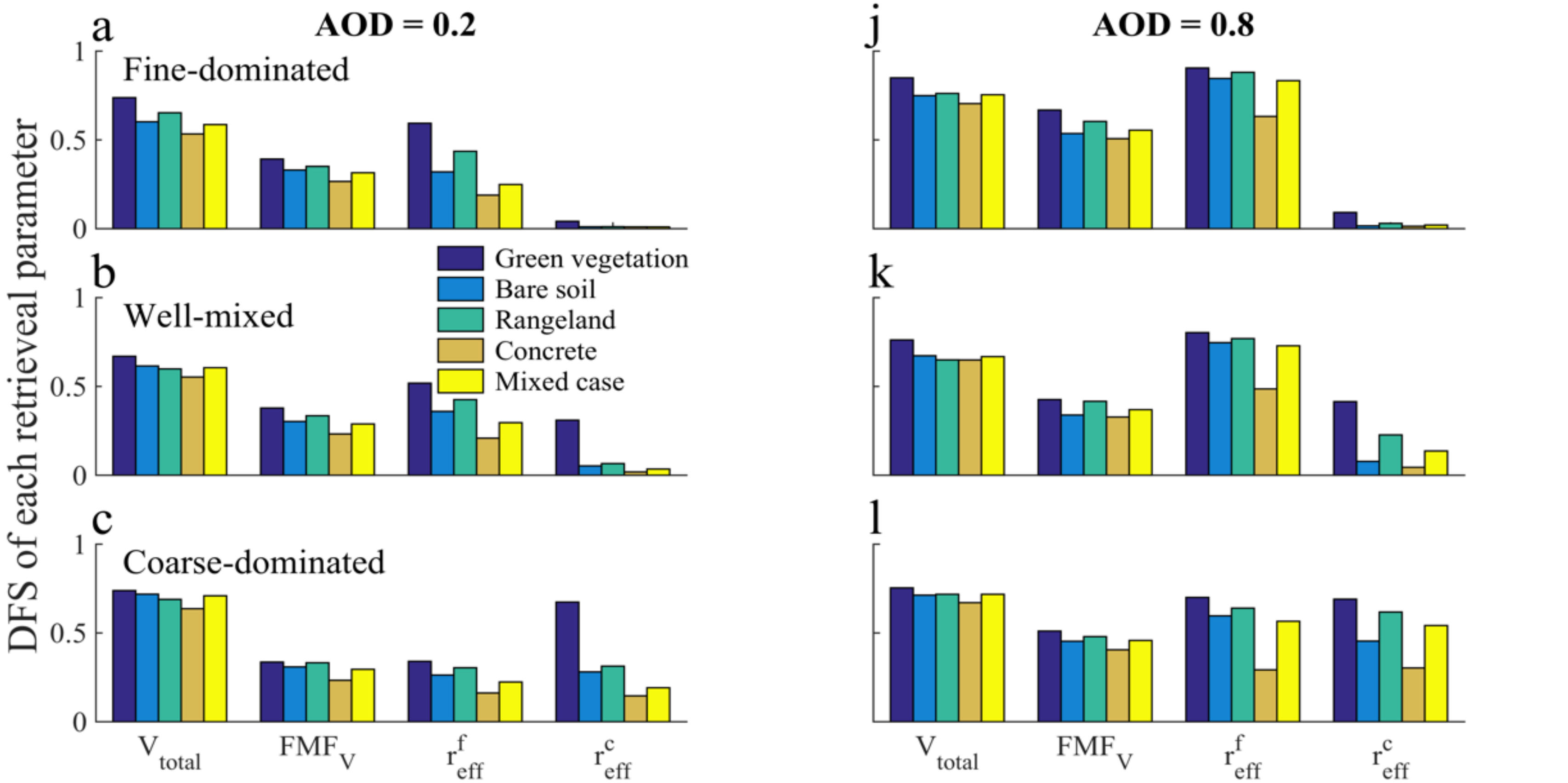


DFS for retrieving W for PCs

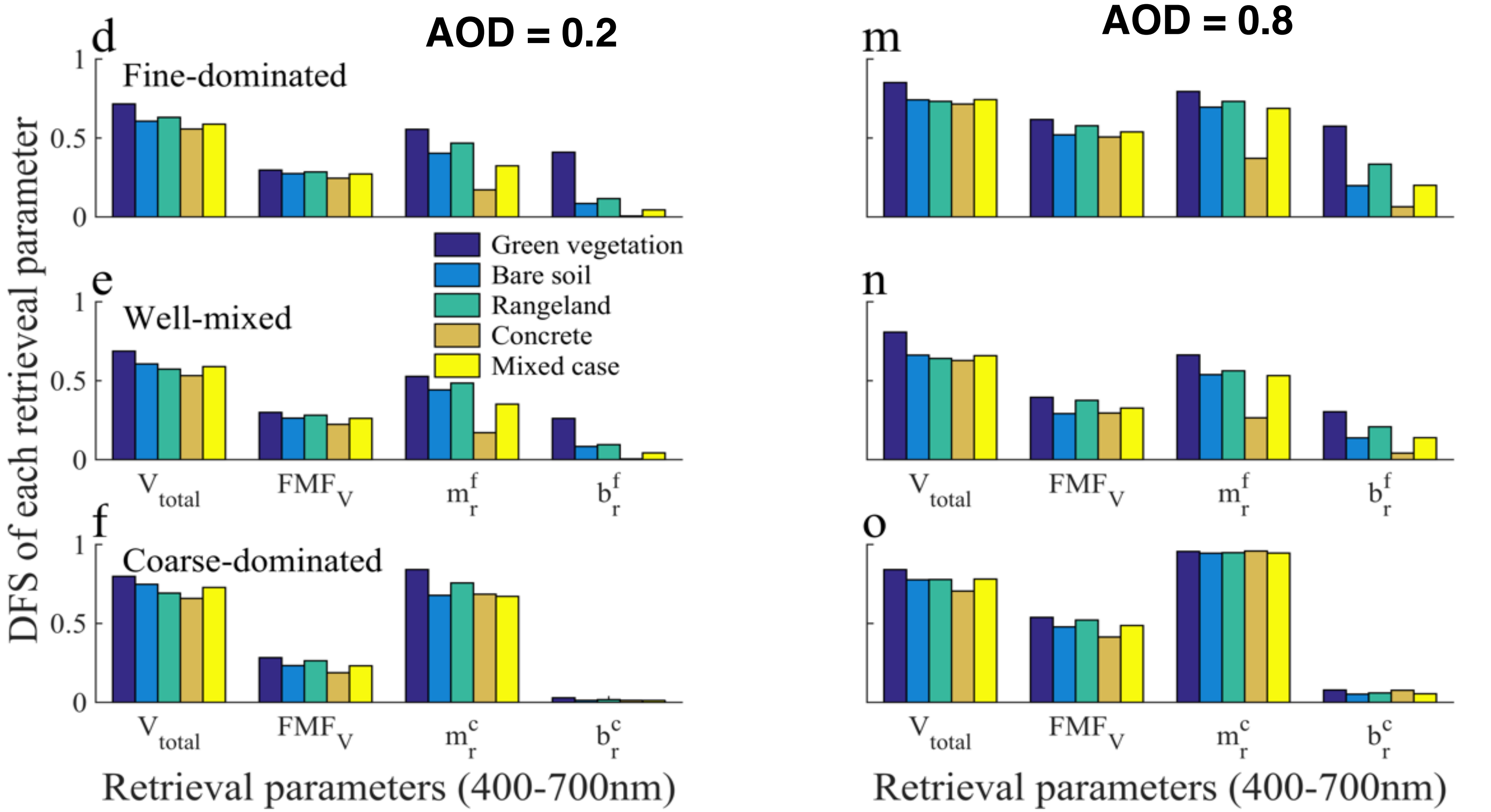


If we reconstruct the surface spectra using TOA spectra in low-AOD conditions

DFS for aerosol size parameters

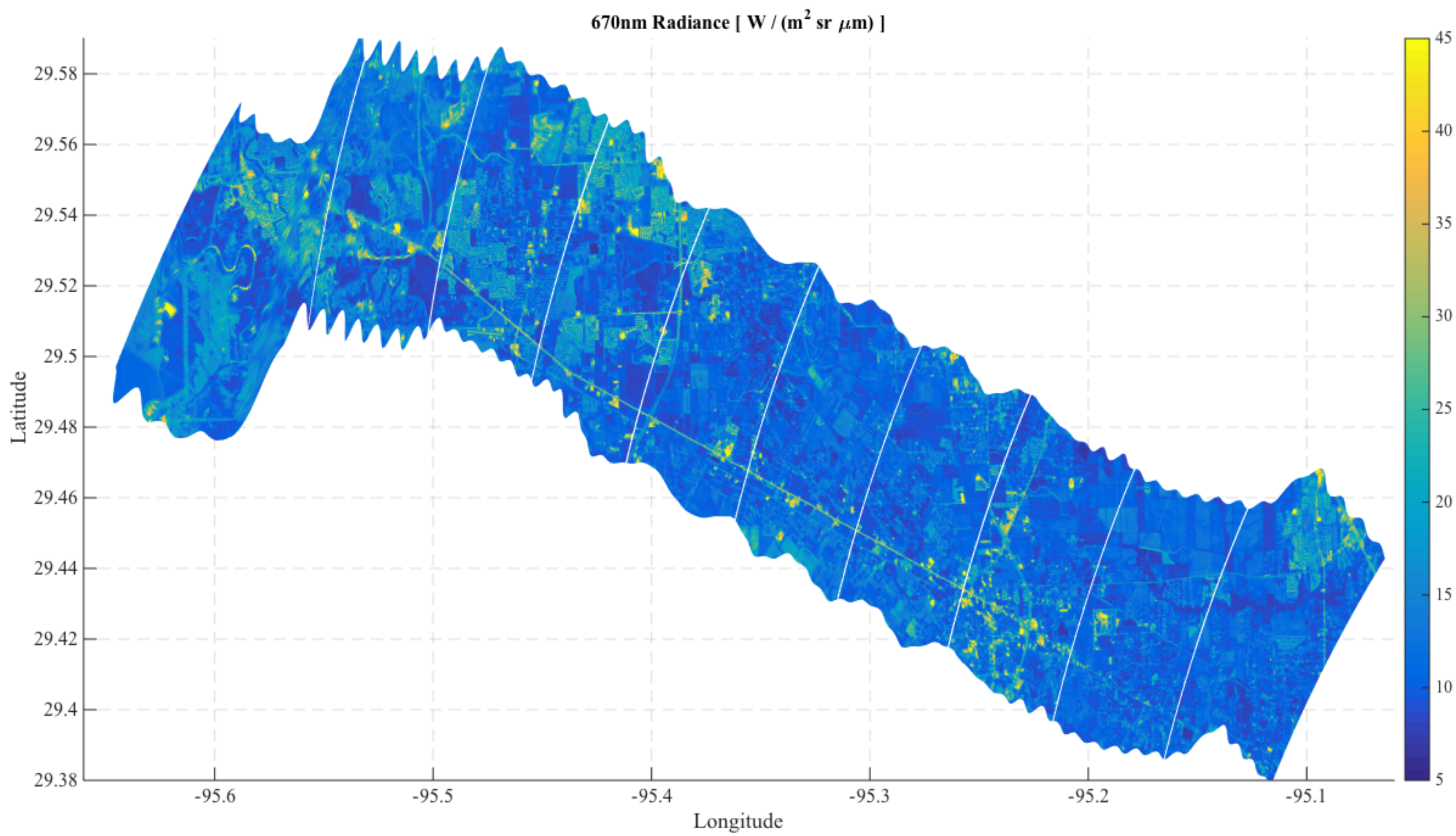


DFS for aerosol refractive index



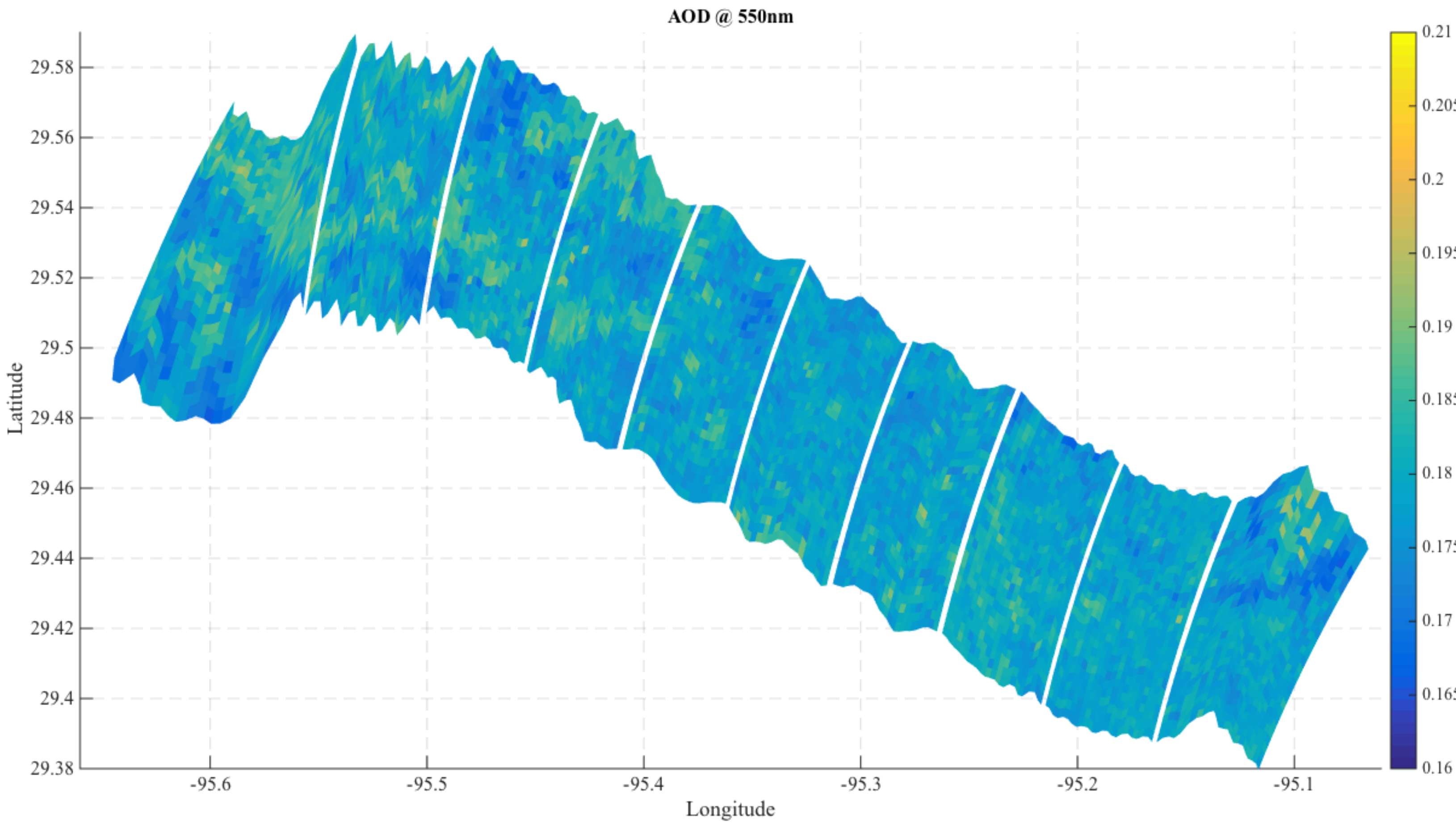
➢ Segment of picture at each band

Real Data Analysis

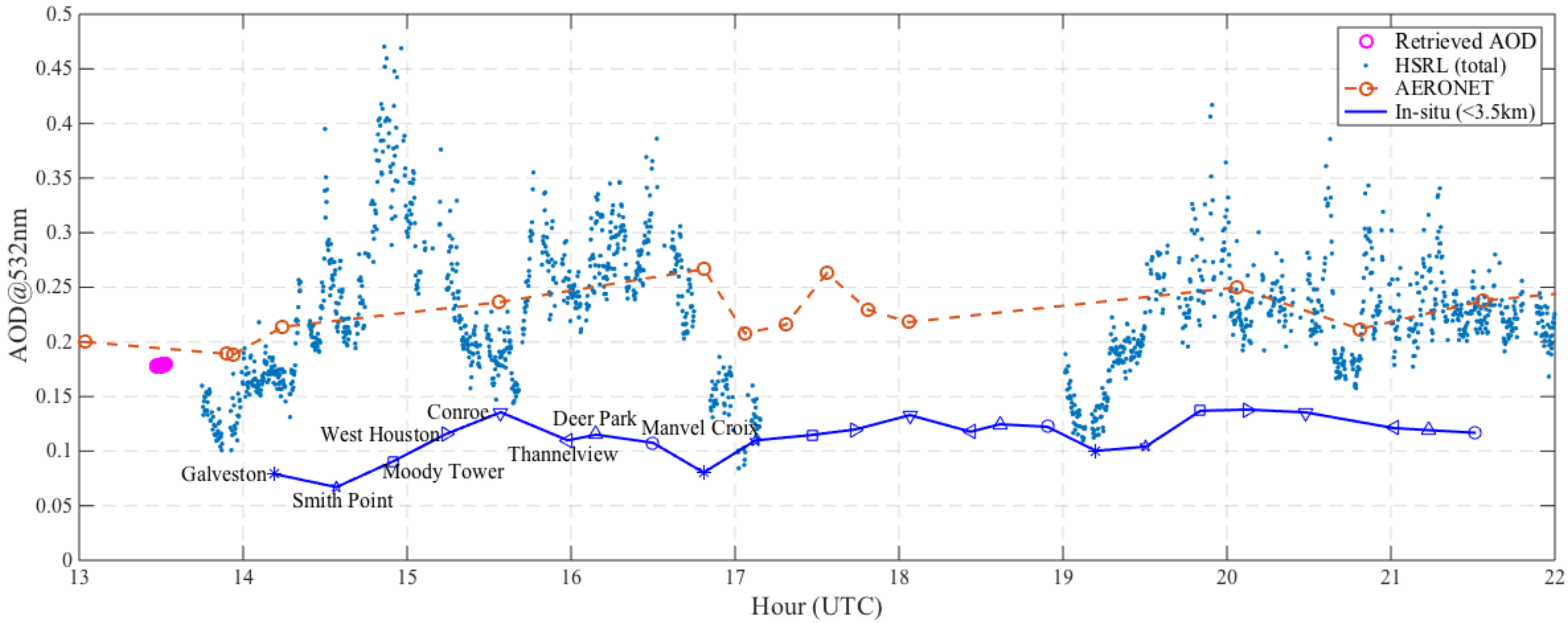


The aircraft GEO-TASO data in Houston, Sep. 13, 2013

➢ AOD retrieved from GEO-TASO



➢ AOD validation



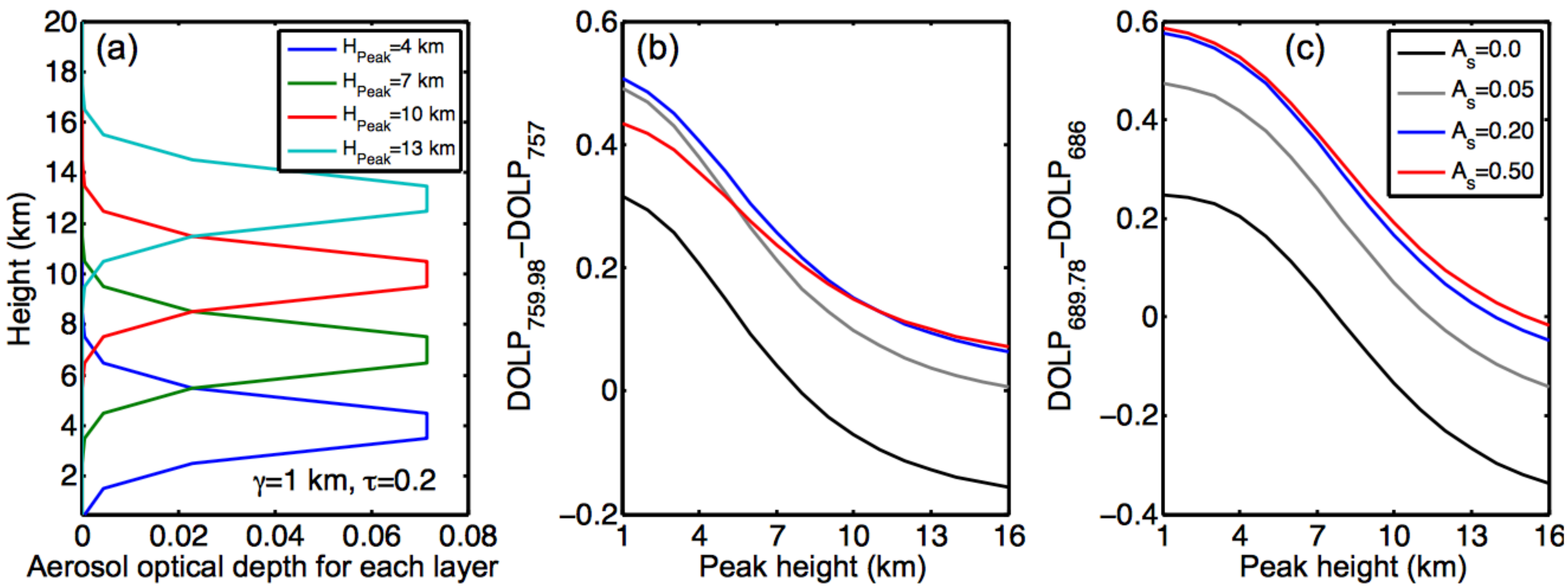
Atmos. Meas. Tech., 9, 2077–2092, 2016
www.atmos-meas-tech.net/9/2077/2016/
doi:10.5194/amt-9-2077-2016

Atmospheric Measurement Techniques
Open Access

Polarimetric remote sensing in oxygen A and B bands: sensitivity study and information content analysis for vertical profile of aerosols

Shouguo Ding[1,a], **Jun Wang**[1], **and Xiaoguang Xu**[1]

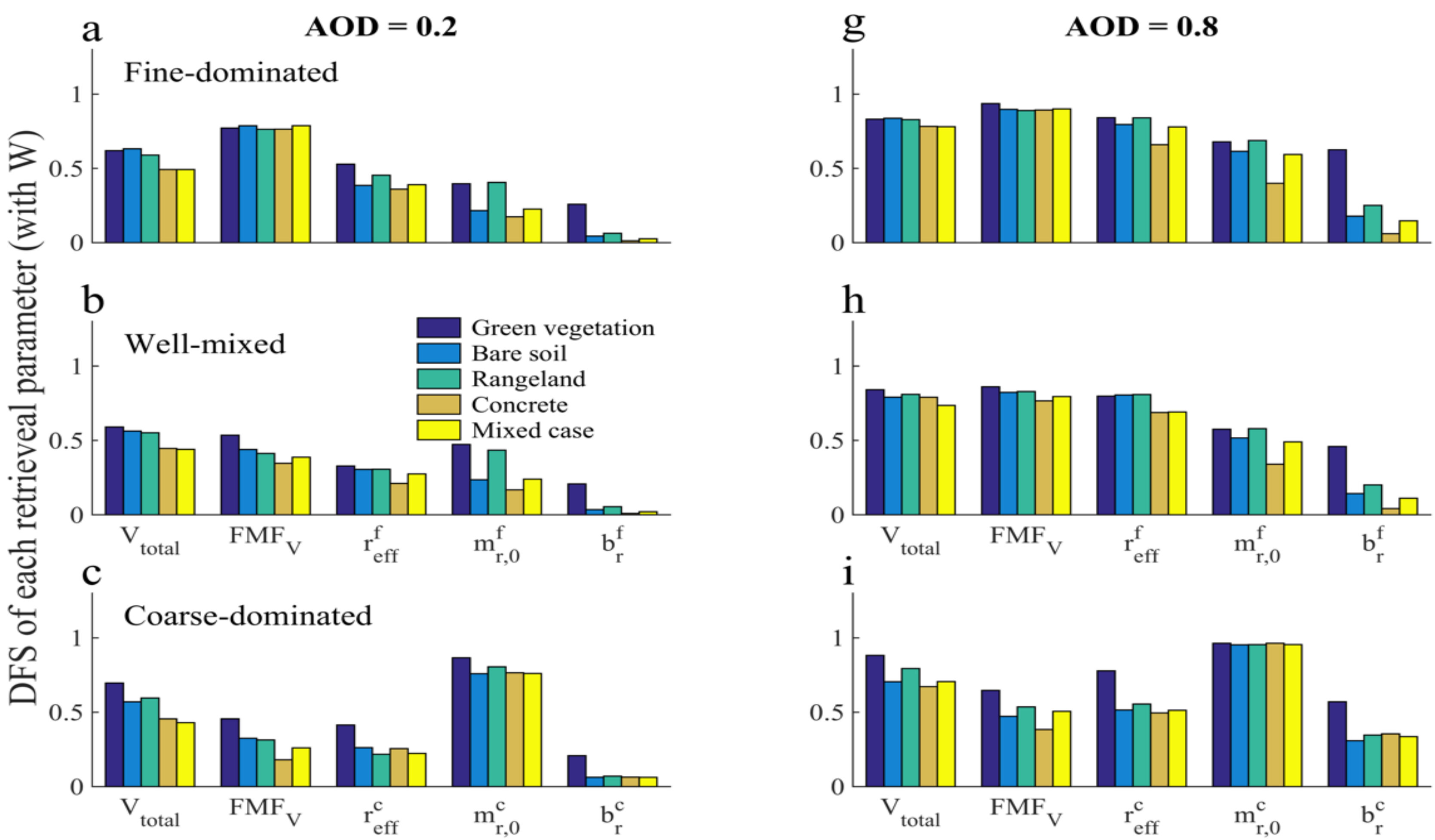
[1]Department of Earth and Atmospheric Sciences, University of Nebraska Lincoln, Lincoln, NE 68588, USA
[a]now at: Earth Resources Technological Inc., Laurel, MD 20707, USA



Summary

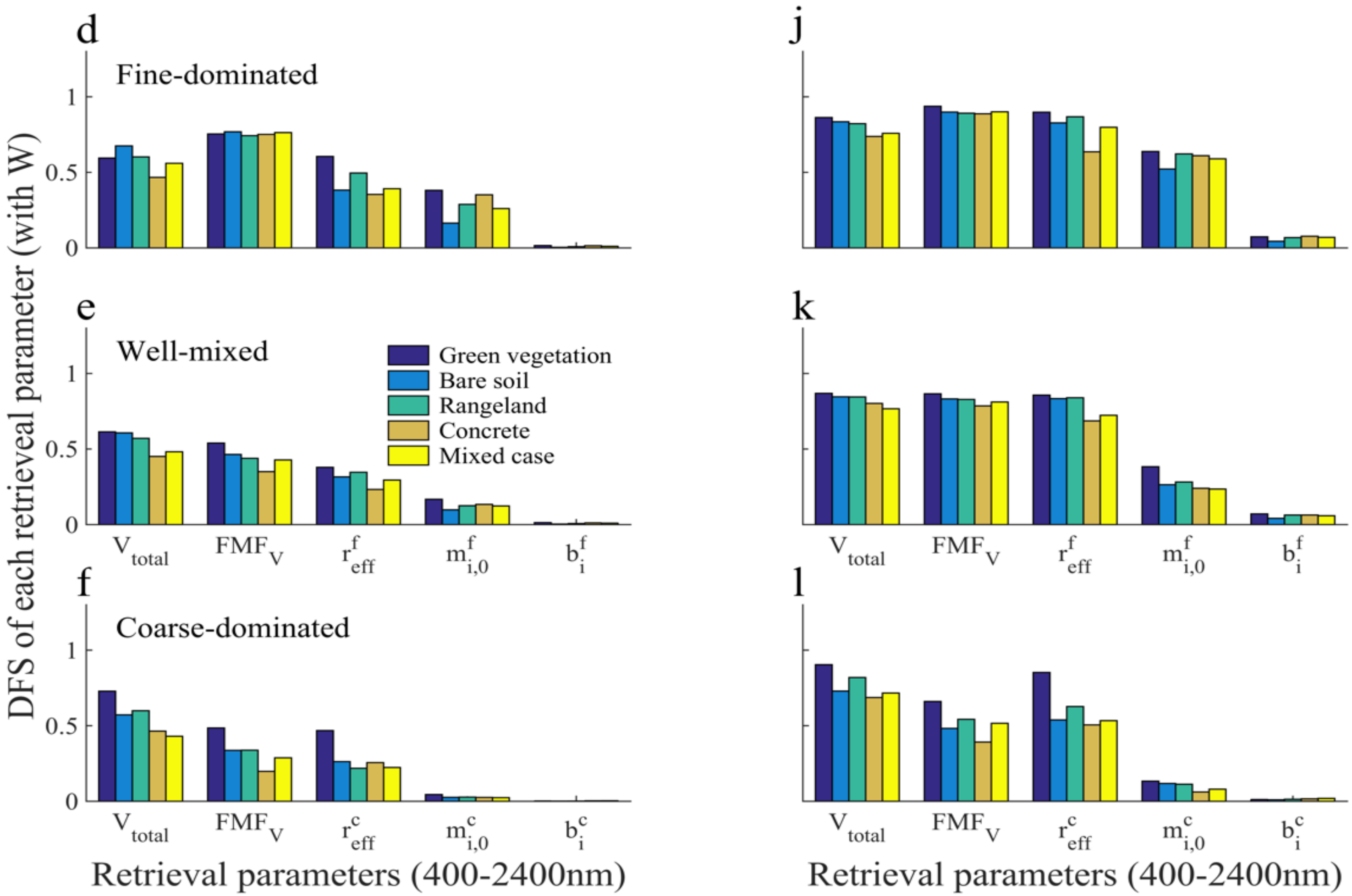
- TEMPO has strong synergy with GOES-R
- TEMPO's unique offer
  - Hourly, high spatial resolution (4km),measurements of UV for aerosol retrieval - 1st time of its kind
  - Hourly Vis spectra contains more information for characterizing aerosols, especially fine-mode particles (r_{eff} and real-part of refractive index)
  - In line with trop. O3 retrievals that will have a surface spectra database, it likely we will had at least two pieces of information for aerosols in addition to AOD.
- Making good progress with GEO-TASO data
- No heritage algorithm, so it takes time to develop…

400 – 2400 nm



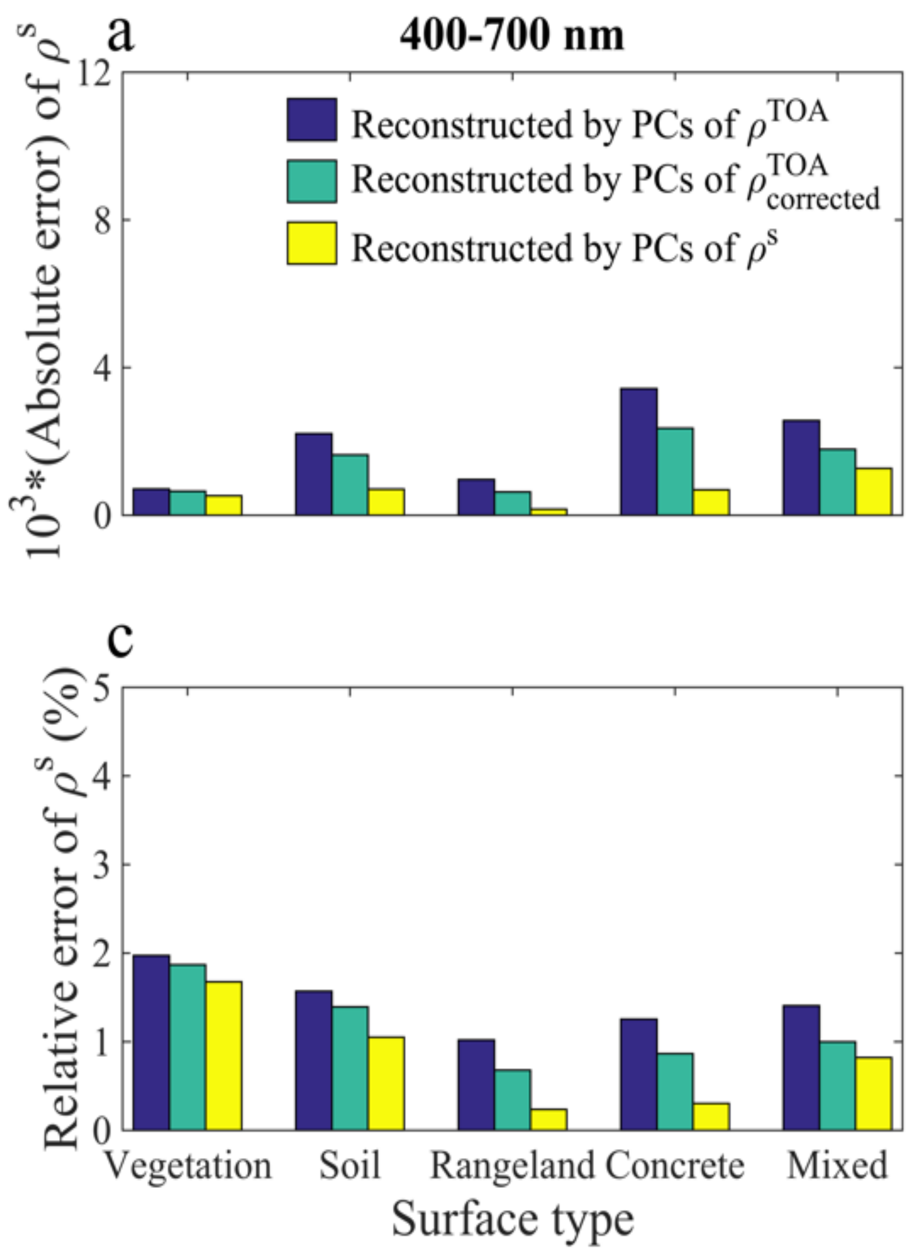
a
AOD = 0.2
g
AOD = 0.8
Fine-dominated
b
Well-mixed
h
c
Coarse-dominated
i
DFS of each retrieveal parameter (with W)
Green vegetation
Bare soil
Rangeland
Concrete
Mixed case
0
0.5
1
V total
FMF V
r f eff
m f r,0
b f r
r c eff
m c r,0
b c r

400 – 2400 nm



d
Fine-dominated
j
e
Well-mixed
k
f
Coarse-dominated
l
Green vegetation
Bare soil
Rangeland
Concrete
Mixed case
DFS of each retrieval parameter (with W)
1
0.5
0
V_{total}
FMF_V
r^f_{eff}
$m^f_{i,0}$
b^f_i
r^c_{eff}
$m^c_{i,0}$
b^c_i
Retrieval parameters (400-2400nm)

Error in reconstructed surface reflectance



Thank you.

ABI Capability

	ABI	Current GOES Imager
Spectral Coverage	16 bands	5 bands
Spatial Resolution		
0.64 μm Visible	0.5 km	~ 1 km
Other visible/near-IR	1.0 km	n/a
Bands (>2 μm)	2 km	~ 4 km
Spatial Coverage		
Full Disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	Every 30 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

http://www.goes-r.gov/