Passive remote sensing of non-spherical dust particles and aerosol vertical profiles: preliminary studies and implications to the GEO-CAPE mission

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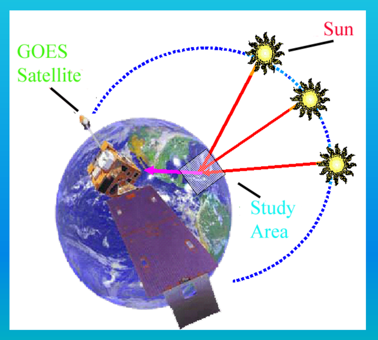


Motivation

Many progresses have been made in the last decade on the passive remote sensing of aerosols over both ocean and land; they include retrieval of fine vs. coarse-mode aerosols and non-absorbing vs. absorbing aerosol from multispectral and multiangle satellite observations. Future satellite missions on air quality should build upon this past success and continue to explore opportunity for advancement. To brainstorm ideas for preparing the GEO-CAPE mission, this poster shows two preliminary studies respectively on the retrievals of aerosol vertical profile and non-spherical aerosol particles, the two challenges in the today's passive remote sensing and thereby the opportunities for GEO-CAPE.

(1) **Aerosol vertical profile** is critical for mapping particulate matter air quality from space. While limited studies showed the potential of using reflectance at UV spectrum to retrieve the profile of absorbing aerosols, virtually all the passive remote sensing sensors today demonstrated zero capability to retrieve aerosol vertical profile and aerosol optical thickness simultaneously at the visible spectrum of the atmospheric window. Here, a preliminary study is presented of using polarization at O_2-A band (0.760-0.765μm) to retrieve vertical profile of both absorbing and non-absorbing aerosols.

(2) **Non-spherical aerosol particles** such as dust have very different phase function as of spherical particles, and hence make it difficult for satellite remote sensing to accurately characterize the air pollution and ocean color in the U.S. coastal regions that are frequently affected by the dust particles from Saharan desert and Gobi Desert. Here, a method is presented of using the geostationary satellite observation at multiple scattering angles to study the phase function of non-spherical particles.

Retrieval of Aerosol Vertical Profile (1)

Theory (First Principal) and Model Validation

The amount of upwelling radiation at the top of atmosphere at any gas absorption spectrum generally depends on the vertical profile of that absorbing gas and the radiative interaction of that gas absorption with the scattering of cloud, aerosol, and molecules in the atmosphere. This principal has been the basis for retrieval algorithms of various trace gases (such as O_3 and CO) that are highly variable in the troposphere; but the atmospheric scattering are generally assumed or specified in the algorithm. The method proposed here utilizes the same principle but from a different perspective; that is, to derive the vertical profile of aerosol scattering at the absorption spectrum where the gas absorption profile is well known (or shows little spatiotemporal variation). O_2-A absorption band fits this purpose nicely because: (a) the distribution of O_2 profile has little spatiotemporal variation and can be well characterized with high accuracy; (b) aerosol scattering at O_2-A band and its nearby spectrum belong to Mie scattering regime and this signal is strong; (c) molecular (Rayleigh) scattering at O_2-A band is virtually negligible.

A vector radiative transfer model was used in conjunction with the line-by-line radiative transfer model and the database of high-resolution transmission (HITRAN) molecular absorption to simulate the four Stokes parameters of upwelling and downwelling radiation, from which the degree of linear polarization (DOLP) of skylight is computed (Zeng et al., 2008).

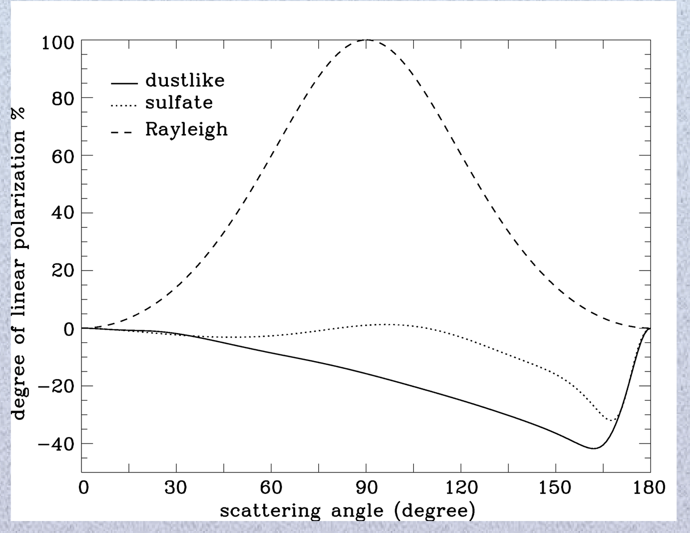


Figure 1: Degree of linear polarization (DOLP) as a function of scattering angle for light singly scattered respectively by dust-like aerosols (solid line), sulfate aerosols (dotted line), and molecular (Rayleigh scattering, dashed line). DOLP is calculated as P_{12}/P_{11} where P_{11} and P_{12} follow the traditional denotation of 44 scattering phase matrix.

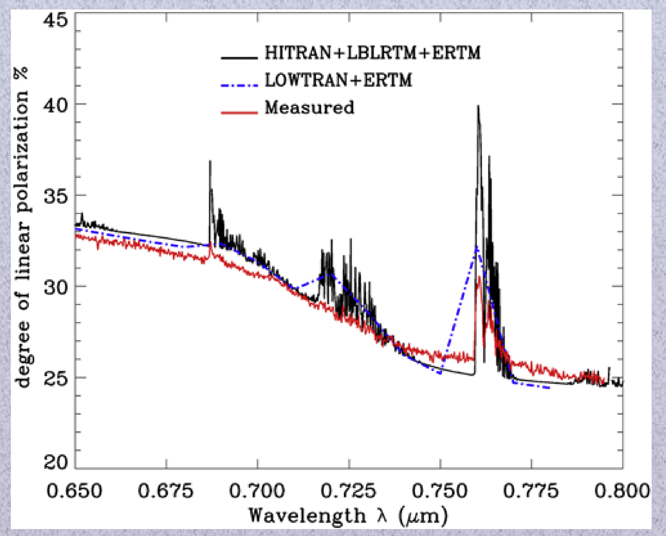


Figure 2. Comparison of the high-spectral resolution skylight zenith DOLP from the measurements (red line) and the simulations with gas absorption based upon LOWTRAN (blue line) and HITRAN (black line) respectively. ERTM denotes the vector radiative transfer model by Evans and Stephens [1991].

Retrieval of Aerosol Vertical Profile (2)

Results

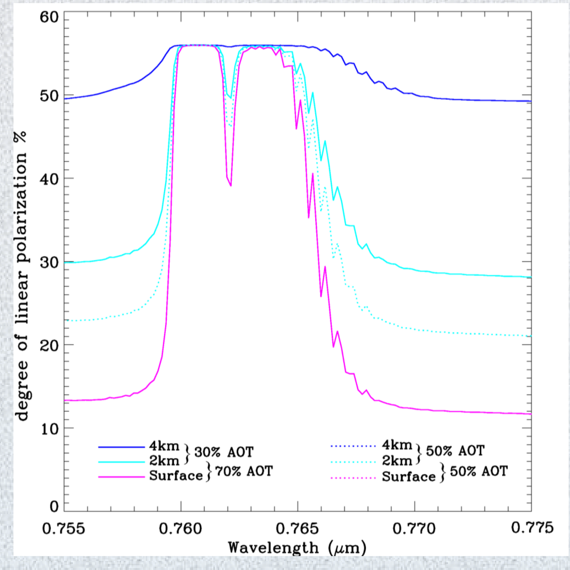


Figure 3. Skylight zenith DOLP near O_2-A band at the surface (pink lines), 2 km above the surface (green), and 4 km above surface (blue). Results at solar zenith angle of 58° are shown for two cases that assume the same (dustlike) aerosol properties for total AOT = 0.08 but with different vertical distributions: (1) 70% and 30% of total AOT distributed respectively in surface–2 km and 2–4 km (solid lines); (2) same (50% of total) AOT in surface–2 km and 2–4 km (dotted lines). Noted that the dot lines and solid lines are indistinguishable at surface and 4 km.

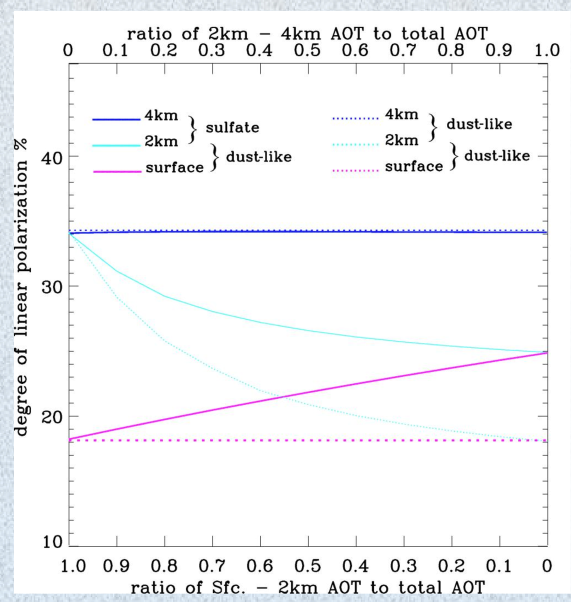


Figure 4. Skylight zenith DOLP near O_2-A band at the surface (pink lines), 2 km above the surface (green), and 4 km above surface (blue). Results at solar zenith angle of 58 are shown for two cases that assume the same (dustlike) aerosol properties for total AOT = 0.08 but with different vertical distributions: (1) 70% and 30% of total AOT distributed respectively in surface–2 km and 2–4 km (solid lines); (2) same (50% of total) AOT in surface–2 km and 2–4 km (dotted lines). Noted that the dot lines and solid lines are indistinguishable at surface and 4 km.

Other Results in the literature

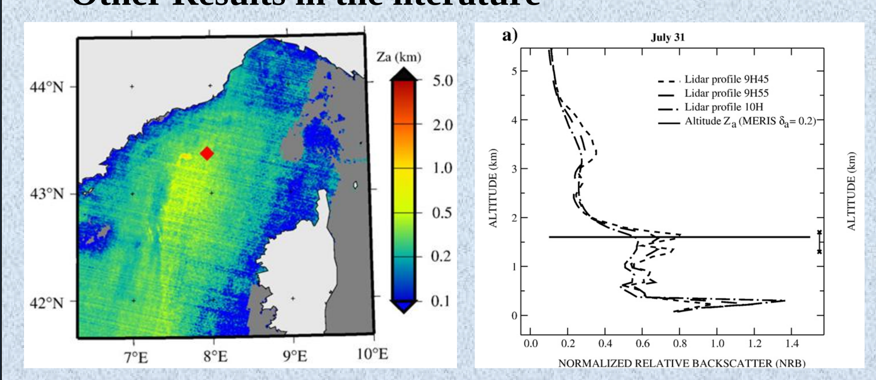


Figure 5. MERIS retrieved aerosol altitude Za (derived from the ratio of reflectance in O_2 and out of O_2 band, left column) and its comparison with lidar observations (at the side shown a red diamond in the left). Adopted from Dubuisson et al., 2009.

Study of Non-spherical Aerosol Phase Function with GOES

Concept

Geostationary satellite views the atmosphere with same viewing geometry as the solar angle changes from sun rise or sun set, offering unique observations at multiple scattering angles for the same region, and thus a unique opportunity to retrieve aerosol microphysics (such as the phase function, shape, and/or relative abudence of non-spherical dust particles).

An Example

Study the impact of non-spherical dust aerosol phase function on the retrieval of aerosol optical thickness form GOES satellite during the Puerto Rico Dust Experiment (Wang et al., 2003b).

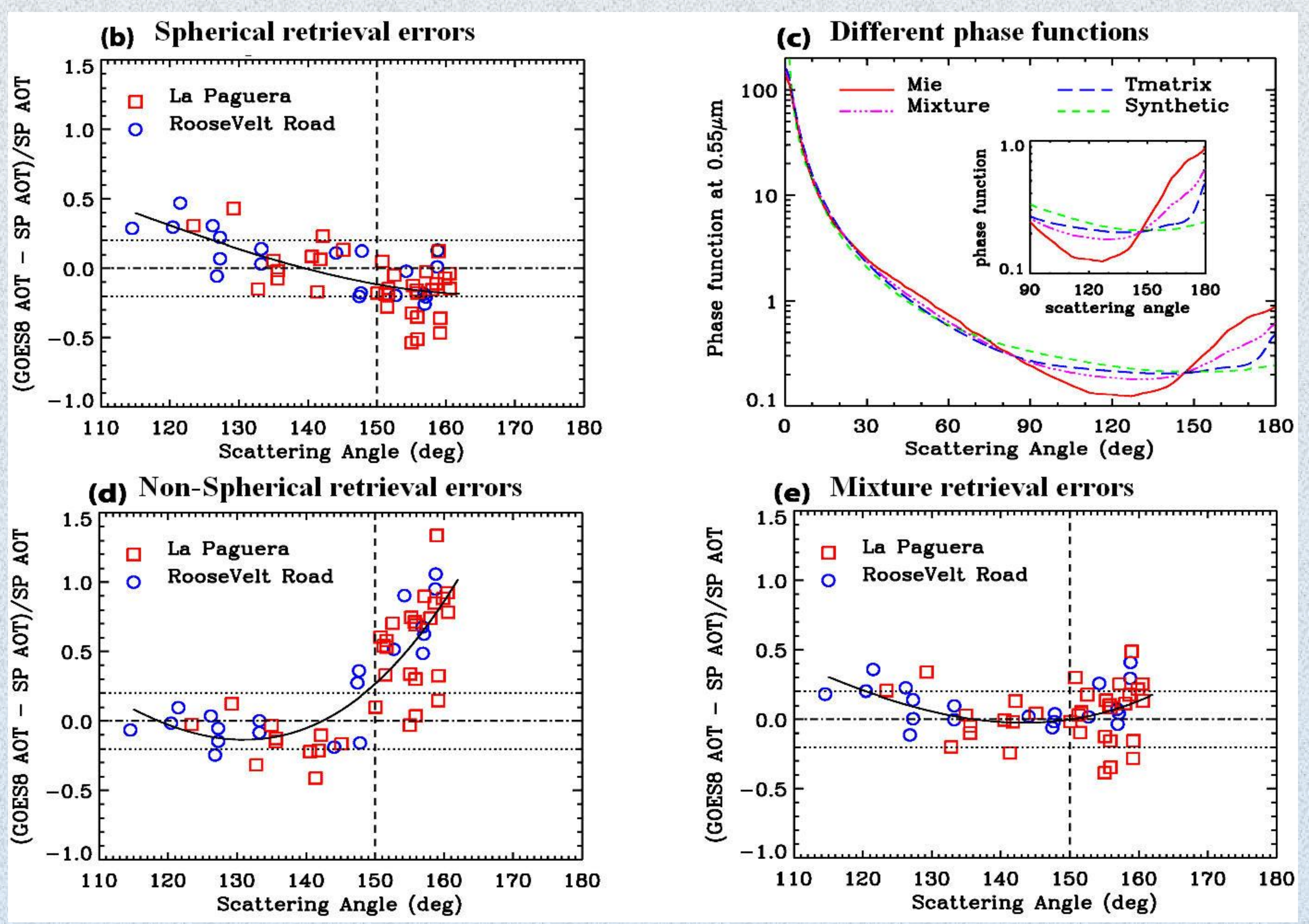


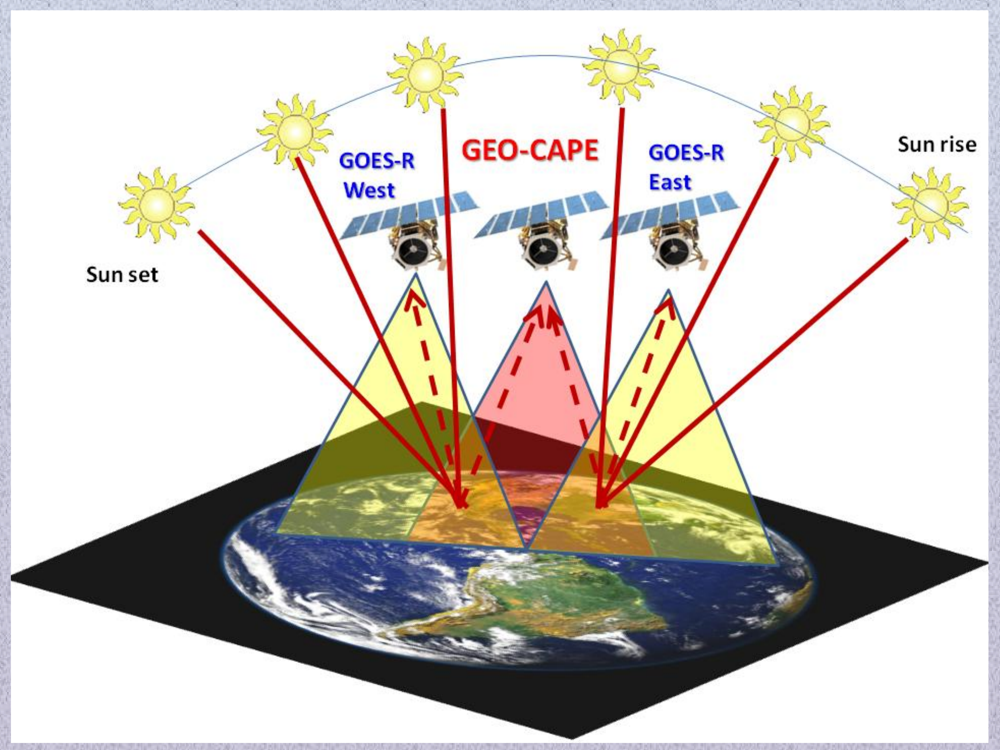
Figure 6. Retrieval errors as a function of scattering angles for using (b) spherical phase functions [Wang et al., 2003a], (d) non-spherical phase function, and (e) a composite phase function for the mixture of spherical and non-spherical particles. (c) shows the comparison of these three phase functions. The synthetic phase function by Liu et al [2003] is also shown in b for reference purposes. The inset in (c) shows the average of measured aerosol volume size distribution in dusty conditions (AOT > 0.2). The dotted lines in (a), (c) and (d) show the possibly maximum relative errors (±20%) from the uncertainties other than phase function. The different symbols in (b), (d) (e) denote two AERONET sites at Roosevelt Road (18.20N, 65.60W) and La Paguera (17.97N, 67.05W).

Implications to GEO-CAPE

GEO-CAPE and GOES-R synergy offers observations uniquely collected from dual viewing angles and multiple scattering angles to

(1) characterize non-spherical dust particles that have that have important impacts on air quality, ocean color, and costal ecosystems in the west and east coasts of U.S.

(2) to derive the wind speed (and possibly stereo height) of pollution plume.



Recommendations & Nest Steps:

- At currently early stage of GEO-CAPE mission concept development, it is necessary to conduct the feasibility analysis of some new and promising retrieval techniques in the literature to maximize the potential advancement of GEO-CAPE for a better achievement of its mission goal.
- GEO-CAPE should take the advantage of its observations at multiple scattering angles to better retrieve the temporal evolution of the long-range transport non-spherical dust particles as well as to better characterize the phase function of spherical particles from space. This potential can be further maximized by its synergy with GOES-R to obtain dual viewing angles for the same scene (figure on the left) for deriving wind speed (and possibly stereo height) of the pollution plume at the east and west cost of U.S.
- To characterize the vertical distribution of aerosols, GEO-CAPE should consider (under its budget constraints) an option to measure the reflectance and polarization at the O_2-A absorption band. The estimate cost for adding this capability to GEO-CAPE should be relatively low, if we consider that POLDER/PARASOL having similar capability is a micro-satellite mission and MERIS already has channels of measuring the reflectance at the O_2-A band.
- The modeling infrastructure showed in this poster is now integrated with the GEOS-Chem to conduct the OSSE of aerosol vertical profile and non-spherical dust retrieval for GEO-CAPE.

References & Acknowledgement

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