Development of Aerosol Retrieval Algorithm Over Ocean Using FY-1C/1D Data

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Abstract: This study proposes a single-channel satellite remote sensing algorithm for retrieving aerosol optical thickness over global ocean using FY-1C/1D data. An efficient lookup table (LUT)method is adopted in this algorithm to generate apparent reflectance in channel 1 and channel 2 of FY-1C/1D over ocean. The algorithm scale the apparent reflectance in cloud-free conditions to aerosol optical thickness using a state-of-art radiative transfer model 6S with input of the relative spectral response of channel 1 and 2 of FY-1C/1D. Monthly mean composite maps of the aerosol optical thickness have been obtained from FY-1C/1D global area coverage data between 2001 and 2003. Aerosol optical thickness maps can show the major aerosol source which are located off the west coast of northern and southern Africa, Arabian Sea and India Ocean. These result is very similar to other satellite sensors such as AVHRR and MODIS in the location area of heavy aerosol optical thickness over global ocean. The algorithm have been used to FY-1D operational performance and it is the first operational aerosol remote sensing product in China.

Keywords: Aerosol optical depth, FY-1C/1D, 6S

1. Introduction

The impact of atmospheric aerosols on the radiative budget has been broadly demonstrated. One of the greatest source of uncertainties in climate modeling is due to aerosols. Radiative forcing by aerosol may explain the difference between the observed and modeled temperature trends. In fact, the interaction with solar and terrestrial radiation by aerosols perturbs the radiative budget via scattering and absorption of sunlight which is direct and indirect effect radiative forcing. By acting as CCN (Cloud Condensation Nuclei) or IN (Ice Nuclei), aerosol particles also modify the cloud microphysics. As a result, aerosol particles may change the cloud radiative properties. The direct effect of aerosol on radiation budget and the indirect effect on cloud albedo may cause a cooling effect that may counter balance the warming due to the increase in CO2 concentration. Present estimates of the aerosol forcing vary in a broad range from -0.6w/m^2 to -4.0w/m^2 if combining both the direct and indirect effects of sulfate aerosol and biomass burning aerosol(King et al, 1999). Dust originated from local area change is also suspected to be a major forcing. To fully understand these processes, the aerosol characteristics (composition, size distribution and total content) have to be determined on a global scale, and only satellite approach, combining information from remote sensing over land and ocean, can achieve this objective.

The AVHRR aerosol retrieval algorithm in NESDIS/NOAA have gone through three generation improvement (Ignatov et al, 2002). MODIS aerosol retrieval over ocean and land has been conducted operation since 2001 (Kaufman et al, 1997). FY-1C/1D Multi-channel Visible Infrared Scanning Radiometer (MVISR) is similar to the AVHRR/3 aboard the NOAA polar orbiting satellites. FY-1C/1D MVISR have more 3 channels for ocean color and 1 channel for NIR water vapor than AVHRR/3. They have Global Delayed Picture Transmission (GDPT) to acquire 4 channels global image data with 4 Km resolution whose center wavelengths are located in 0.63, 0.88, 11, 12µm. Channels 1 and 2, measuring reflected solar radiation, are useful for aerosol retrievals. In section 2, we describe the algorithm for derivation of aerosol optical depth(AOD) in channels 1 and 2. Section 3 and section 4 are about the data processing and result analysis.

2. Retrieval Algorithm

2.1 Theory

We are adopting the retrieval algorithm similar to the one used NOAA/NESDIS single–channel second- generation operational algorithm. A linearized single scattering radiative transfer equation is used to illustrate physical principles of algorithm and. The retrieval of aerosol optical depth is given by the following equation as

$$t_a = \frac{r^* - r_R - r_g T}{w P_a(\Theta)} 4m \cdot m_0 \qquad (1)$$

where r^* is an apparent reflectance of ocean –atmosphere system; r_R and r_a are Rayleigh and aerosol component; r_g is the ocean Lambertian component; T is atmosphere transmittance; $P_a(\Theta)$and ωΘw are the aerosol phase function and albedo of single scattering; μ_0=cos θs; µ=cos θv ;θs and θv are the solar and view zenith angles.

Aerosol retrievals are made in cloud free conditions on the antisolar(backscattering) side of orbit (φ>90°, φ is the relative azimuth), and outside of the sunglint area(γ> 40°, γ is the glint angle defined so that γ =0 when the satellite sensor is viewing precisely at the sun's reflected image on a flat ocean: φ=0°,θs=θv). The algorithm for two reflectance channels derives two pieces of aerosol information, τ1 and τ2, using two different single-channel lookup tables, LUT1 and LUT2, independently. The two LUTs are calculated for the same aerosol model, that is, a monomodal lognormal size distribution:

$$n(R) = \frac{dN}{dR} = \frac{1}{R \ln s \sqrt{2p}} \times \exp\left(-\frac{\ln^2(R/R_m)}{2\ln^2 s}\right) \qquad (2)$$

with R_m=0.10μm; and σ＝2.03; and complex index of refraction, $n＝1.40–0.0i$.

2.2 Construction of LUT

The two LUTs are constructed based on 6S(Vermote et al. 1997). The 6S code uses successive orders of scattering and Aerosol modeling in it is very flexible, allowing for a few choices from either user-specified micro-physical or standard composite models. The 6S offers a wide choice of surface bidirectional reflection models, including a rough ocean surface, for which wind speed and direction are two input parameters. Also, it automatically accounts for absorption by major atmospheric gases, and has the capability to easily integrate over the satellite spectral response functions.

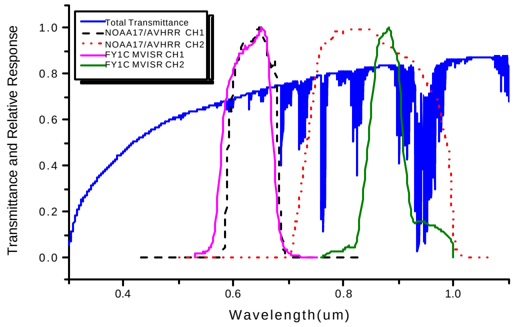

Figure1 FY-1C MVISR channel1,2 relatively spectral response

AOD τ_1 and τ_2 in channel 1, 2 is derived from FY-1C/1D MVISR channel 1, 2 using a four dimension LUT(14θs × 14θv × 19φ × 11AOD) of the apparent reflectance, precalculated using the 6S. 6S need a serial input parameters such as observation geometry condition, atmosphere model, diffuse oceanic reflectance and relative spectral response function(Figure1) as well as the above aerosol model parameter. Diffuse oceanic reflectance r_g is set as constant 0.2% in channel 1 whereas is 0.05% in channel 2(Stowe et al, 1997). The midlatitude summer atmosphere is as the input of atmosphere model. With one measurement, only τ is allowed to vary and all other oceanic and atmospheric parameters are prescribed.

3. Data processing and Result analysis

3.1 Processing procedure

The data used to retrieve aerosol optical depth over global ocean is FY-1C/1D GDPT data. The first step of data processing is data quality control and abandon the badly data. The badly data include the missing orbit, the loss of scanning line and abnormity data point whose Digital value is out of the dynamic range(0-1023). The next job is cloud masking. Cloud screening procedures are based on the fact that the cloud reflectance is high and relatively constant across much of visible and infrared spetrum. In contrast, aerosol backscattering is much stronger in visible than in near and far infrared. Pixels containing clouds are identify and removed by comparing the observed signal in the near-IR with the greatest signal while the AOD is 1.0. Consequently, value above 1.0 are deleted. The farther cloud masking will use spatial coherence tests. The 3X3-STD algorithm is the operational cloud mask used for MODIS aerosol retrievals over the ocean(Martins et al, 2002). Parameters are established determining the threshold value for the FY1C/1D aerosol cloud mask over the ocean. The 3X3-STD algorithm is also used to the operational cloud mask used for FY-1C/1D aerosol retrievals over the ocean.

After preprocessing above, we can use the LUT1 and LUT2 to look up and interpolate the AOD1 and AOD2 based on observed apparent reflectance and geometry parameter. At last the AOD of every pixel are projected to geographic Latitude/longitude mapped grid. The AOD distribution results are presented as 0.072° × 0.072° composites of the data from 2×2 arrays of 4 km global area coverage pixels over the oceans. This is our daily aerosol product , which is a 0.072 degree resolution file, includes the area from -180 degrees to +180 degrees longitude and from -90 degrees to +90 degrees latitude. The aerosol monthly mean product is a gridded file of optical thicknesses. The optical thickness at each gridpoint is the average of the optical thicknesses calculated for each day within the month at that gridpoint.

3.2 Result

We have conducted the aerosol retrieval with FY-1C data since May, 2001 and FY-1D data since August, 2002. Now the aerosol product become our operational product since FY-1D began to be used operationally. By now, we have got the aerosol optical depth over global ocean for two years. The AOD distribution in Figure 2 clearly show that the most prominent areas of high value are associated with continent sources. In many regions the continents are fringed by areas of high AOD. In some regions the continents appear, in effect, to emit long “plumes” of increased AOD. The continental aerosol plumes are generally characterized by high values of AOD near the coasts, the values declining with distance from the coast. This pattern is consistent with the transport of aerosols from continent source by large-scale wind systems, followed by atmospheric dispersion and removal in the downwind direction. The tropical North Atlantic Ocean(NAO) aerosol plume from Sahara desert is very clearly showed in figure 2. it is the largest and most persistent area of high AOD values in global scale. The similar region include Arabian Sea and Red Sea. The India ocean and Bay of Bengal are also high aerosol areas which are from the industry pollution and biomass burning. Plume-like AOD features are clearly evident over middle Atlantic states of the United Sates and extends to the center NAO, consistent with the prevailing westerly winds in this region. The other plume extends from Asia across the center North Pacific Ocean(NPO), almost to the west coast of Alaska and Canada. But these results are not validated using the ground-based sunphotometer's measurement data. The global aerosol distribution over ocean from FY-1C/1D is basically consistent with the result retrieval from other satellite sensors such as AVHRR(Husar et al, 1997) and MODIS.

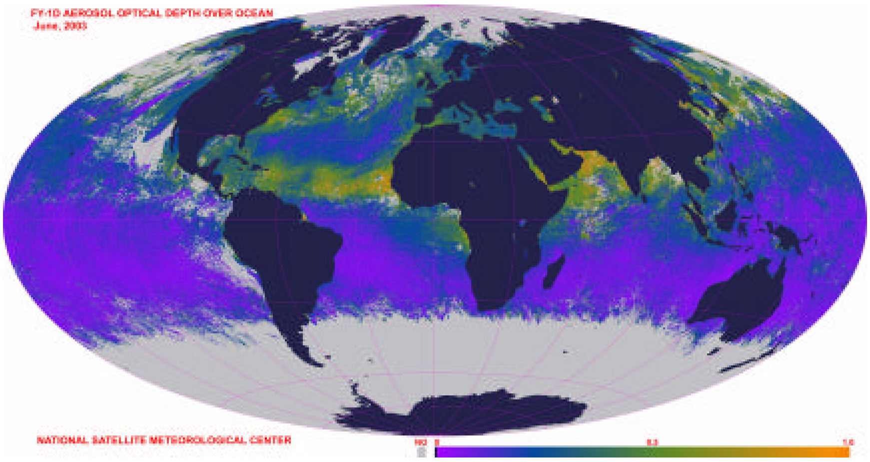

Figure 2 Aerosol Optical Depth Distribution over Global Ocean By FY-1D June, 2003

4. Conclusion

The single-channel algorithm for retrieving aerosol optical thickness over global ocean is firstly developed and applied to FY-1C/1D operational product. The results show good consistency with the one from other sensors such as AVHRR and MODIS. The accuracy of AOD value need to be validated using the ground-based data and the algorithm will be improved by an enhancements using the two channels simultaneous retrieval.

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