ESA STUDY CONTRACT REPORT

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ABSTRACT:

This document constitutes Deliverable 4 of Task 2 of the abovementioned study It contains the description of the radiative transfer computations performed during Task–2 to generate databases of simulated spectra at the TOA.

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Global spectral Databases of simulated solar and thermal radiance fields at the TOA

Deliverable D4 (version 1)

March 11, 2010

Contents

1 Summary

In the context of Task 2 (Scene Classification Scheme Development), a large data base of both reflected solar and emitted thermal radiances has been built. To perform this task, radiative transfer simulations with LibRadtran 1.4 (Mayer & Kylling, 2005) have been performed. This data base aims to cover a wide range of physical situations and for this purpose, the scene definition has been done using ancillary models/data, such as, surface reflectances from the Aster Spectral Library data (Baldridge *et al.*, 2009) as regards to surface optical properties and OPAC Software (Hess *et al.*, 1998) for the computation of the aerosol optical properties. Moreover, and given that the Aster Spectral Library contains a large number of spectra, a k-means clustering of 12 clusters has been done for clear sky scenes, and an averaging of the spectra has been done for those scenes with presence of aerosols. The data base has a fine spectral resolution that covers both the Shortwave and Longwave range, and the simulations completely cover the EarthCARE illumination and observation geometries. This document constitutes version 1 of the deliverable 4 (D4) and the described databases are deliverable 3 (D3) of the study.

2 LibRadTran description

According to Task 1 report (Clerbaux *et al.*, 2009) and the requirements established for the study, LibRadtran 1.4 has been found to be a suitable code to be used to perform the radiative transfer simulations.

The model is a library of radiative transfer routines and programs, quite flexible, that allows the user to specify the properties of the atmosphere, including Rayleigh scattering, molecular absortion, aerosols, water and ice clouds and surface albedo. From the radiative transfer solvers available in the library we have chosen Version 2 of the standard plane-parallel DISORT algorithm, DISORT2 (Stamnes & Laszlo, 2000) with 24 streams for both shortwave and longwave. The molecular absorption parametrization used in the pseudo-spectral calculations is adopted from LOWTRAN/SBDART (Ricchiazzi *et al.*, 1998)

The standard profiles used for the simulations are Tropical, Midlatitude Summer, Midlatitude Winter, Subartic Summer and Subartic Winter (Anderson *et al.*, 1986), scaling the total column water vapor content in the LW simulations to take into account the latitudinal variability of the water vapor.

3 Generalities and Ancillary Data

3.1 Spectral definitions

Shortwave simulations have been done in the interval of 0.25 to 5 μm, for 833 wavelenghts, with the following spectral resolution:

- from 0.25 to 1.36 μm in steps of 0.002 μm
- from 1.36 to 2.5 μm in steps of 0.005 μm
- from 2.5 to 5 μm in steps of 0.05 μm

Due to the fact that ice and water cloud properties are defined only up to 100 μm, for both Yang and Mie parametrizations, longwave simulations have been done in the interval of 2.5 to 100 μm, for 762 wavelenghts, with the following spectral resolution:

- from 2.5 to 14 μm in steps of 0.05 μm
- from 14.1 to 50 μm in steps of 0.1 μm
- from 55 to 100 μm in steps of 0.5 μm

The results of the longwave simulations have been extrapolated up to 500 μm using the Black Body emission curve that would correspond to a body with the same brightness temperature as the retrieved from the last wavelength simulated in each scene, that is 100 μm.

3.2 Geometry definition

The Shortwave simulations are done for 9 Solar Zenith Angles, between 0 and 80 degrees in steps of 10 degrees, and outputs are provided at Viewing Zenith Angles between 0 and 85 degrees, every 5 degrees, and for Relative Azimuth Angles between 0 and 180 degrees, every 10 degrees.

3.3 Surface reflectance curves

The parametrization chosen for *Clear Sky Land* simulations includes spectral surface reflectance in the intervals 0.2 - 14 μm and 2.1 - 14 μm for soils and rocks, and 0.3 - 14 μm for vegetation and snow, obtained from the ASTER spectral library (Baldridge *et al.*, 2009). Spectral reflectances for lower or higher wavelenghts have been extrapolated.

For Vegetation and Snow surfaces, there have been chosen 4 vegetation spectra (conifers, decidous, grass, dry grass) that have been scaled with factors of 0.8, 1.0 and 1.2 and 4 snow spectra (coarse, fine, frost, medium), that have been scaled with factors of 0.8, 0.9 and 1.0 in order to take into account surface reflectances more or less brighter than the ones from the library, making a total of 12 spectra for each surface. The resulting spectra are shown in figure 1 and figure 2.

In the plots it is also shown the average of the 12 spectra. These averaged spectra are used in simulations of *Clear Sky Land with aerosol presence*, and *Cloudy scenes*.

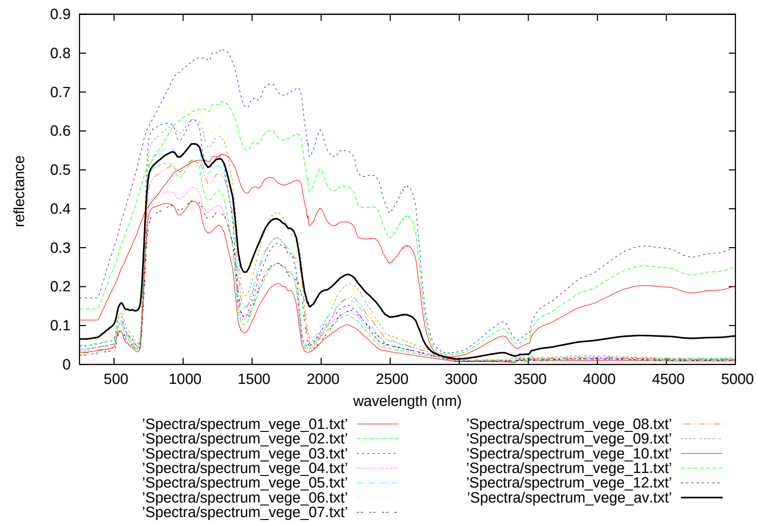

Figure 1: Scaled ASTER vegetation spectra

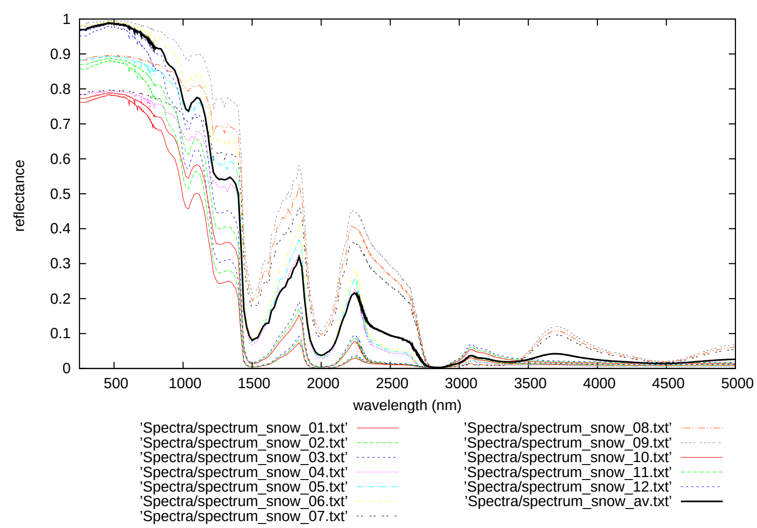

Figure 2: Scaled ASTER snow spectra

In the case of rock surfaces, from the 48 rock types present in the library, it has been done a clustering of 12 types of rocks using a k-means algorithm. As regards to soil surfaces, it has been followed the same procedure as for rocks, clustering the 40 soil types from the library in 12 classes. The k-means algorithm has been applied to a set of processed data in Task-1 (Clerbaux *et al.*, 2009), which contains BBR unfiltering factors and unfiltered radiances simulated with RTMOM (Govaerts *et al.*, 2008). The algorithm starts with a random position of the centroids of the cloud of data to be classified and it iteratively recomputes the centroids of the clusters minimizing the euclidean distance of the points to the centroids. The results of the clustering for rocks are shown in figure 3, and for soils in figure 5.

Once the clustering is done, it has been done an averaging of the spectra of each cluster (See figures 4 and 6). These averaged clusters have been used, in conjunction with the averaged snow and vegetation spectra, for the rest of simulations (that is all the cases but the *SW Clear Sky Land*).

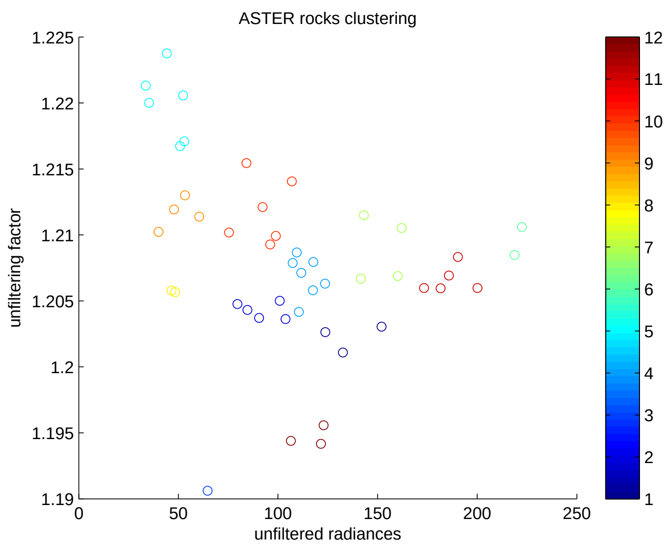

Figure 3: Rocks K-means clustering

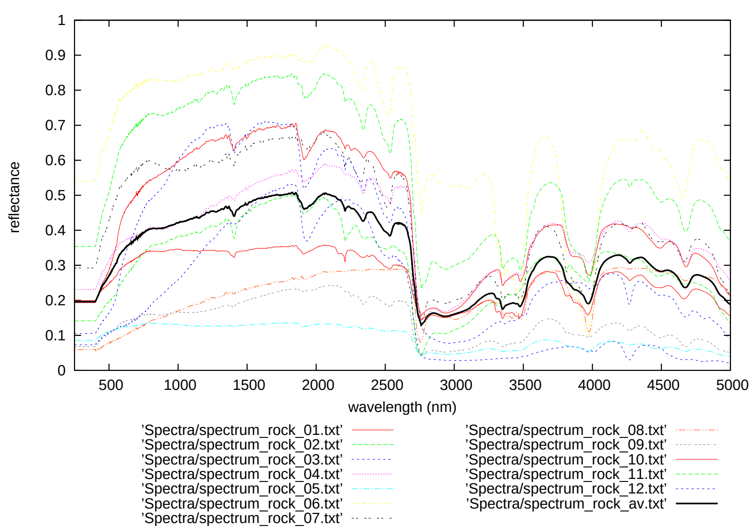

Figure 4: Clustered ASTER rock spectra

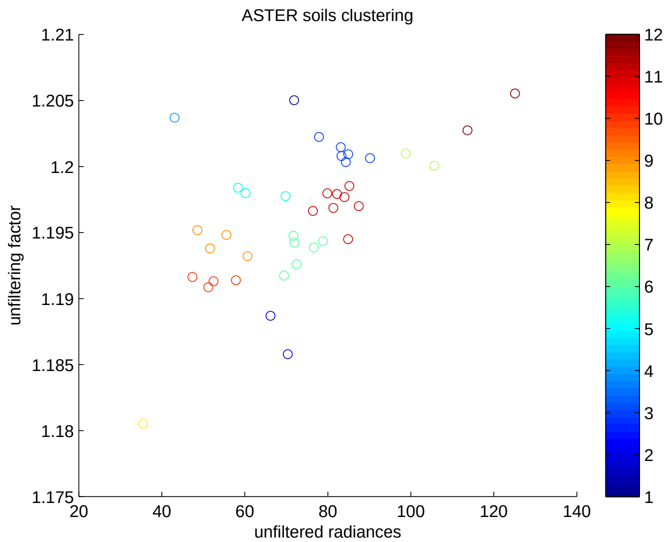

Figure 5: Soils K-means clustering

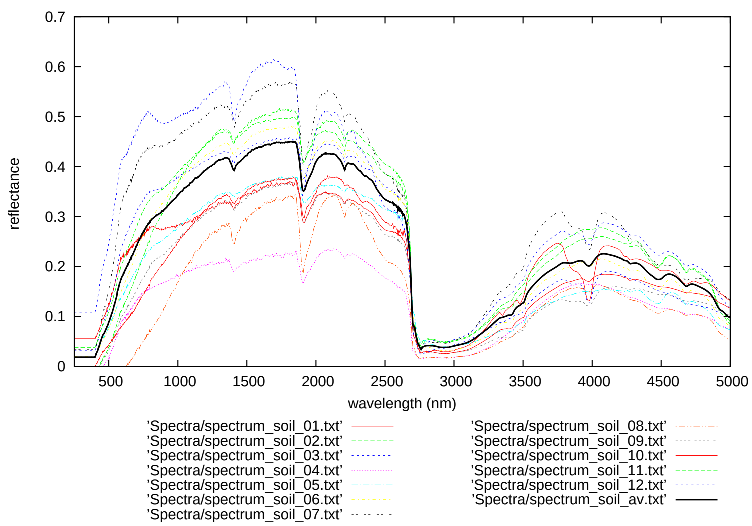

Figure 6: Clustered ASTER Soil spectra

3.4 Surface emissivity curves

Emissivity used in Longwave simulations has been calculated from the Aster Spectral Library data base (1-reflectance) for averaged rocks, soils, vegetation and snow spectra between 2.5 and 14 μm (figure 7. Reflectances for higher wavelengths have been extrapolated from 14 μm value.

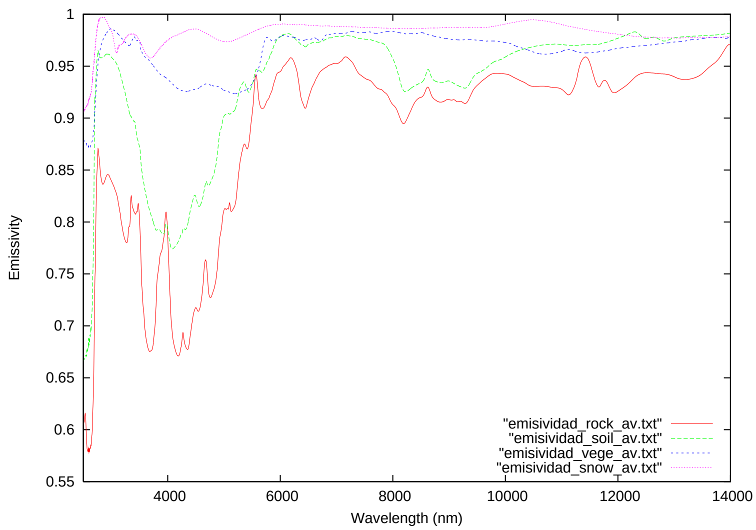

Figure 7: Spectral emissivity of averaged rock, soil, vegetation and snow spectra in the interval 2.5 - 14 μm

3.5 Aerosol definition

Aerosols types and loads are defined on base of OPAC (Hess *et al.*, 1998) definitions. The software package OPAC (Optical Properties of Aerosols and Clouds) provides optical properties in the solar and the terrestrial spectral range of atmospheric aerosols. The software computes aerosol properties for 61 wavelenghts between 0.25 and 40 μm and up to eight values of relative humidity. The software has been used to build the extintion coefficients, phase functions, single scattering albedo and vertical profiles of aerosol considered in the simulations.

The aerosol types used are the following:

- desert: aerosol over all deserts of the world, no distinction with respect to local properties made. It consists on the mineral aerosol components in combination that is representative for average turbidity, together with a certain part of the water-soluble component.
- continental average: represents anthropogenically influenced continental areas. It contains soot and an increased amount of the insoluble and water-soluble components.
- maritime clean: represent undisturbed remote maritime conditions with no soot, but with certain amount of water-soluble aerosol.
- maritime tropical: this type of aerosol has a low density of water-soluble substance and a lower number density of sea salt than the maritime polluted or maritime clean types.

- maritime polluted: it describes a maritime environment under anthropogenic influence with highly variable amounts of soot and also anthropogenic water soluble particles.

All these aerosol types are assumed to be well mixed and defined in the mixing layer, between 0 and 6 km for desert aerosols and between 0 and 2 km for continental and maritime aerosols.

Aerosol properties computed with OPAC software are only available up to 40 μm and since only larger aerosols (dust, sea-salt, volcanic ash etc.) have a discernable impact on TOA LW fluxes, and since these will mainly affect regions where the atmosphere is fairly transparent (so in the window region between 8-12 microns), aerosol properties for wavelenghts higher than 40 μm are assumed to be the same than in 40 μm.

It has been necessary to compute and normalize the moments of the Legendre Polynomials from OPAC phase function to use the built aerosol properties of the mixed species in LibRadtran radiative transfer simulations.

3.6 Output format

The output files are ASCII files with the same number of lines than wavelenghts simulated and the columns correspond to:

- Wavelength (nm): λ
- direct downwelling irradiance: F_{down}
- diffuse upwelling irradiance: F_{up}
- upwelling radiances as a function: L($\mu_i \phi_j$) of the viewing zenith angle and the relative azimuth angle (18 VZA * 19 RAA columns for the SW, and 18 VZA columns for the LW)

The irradiances are given in mW m^{-2} μm and the radiances in mW m^{-2} sr^{-1} μm.

The structure of the output file is the following:

λ, F_{down}, F_{up}, L(θ_1, ϕ_1), ... , L(θ_1, ϕ_{19}), ... , L(θ_{18}, ϕ_1), ... , L(θ_{18}, ϕ_{19})

4 SW Geotype data base

In each subsection it is briefly described the definition of the Shortwave scenes that have been simulated.

4.1 Clear sky land

For this set of simulations, clustered rocks and soils and scaled vegetation and snow surface reflectance explained before have been used.

The atmospheric profiles used for Clear Sky Land Simulations are Tropical, Midlatitude Winter and Subartic Winter, due to the fact that it is believed that the inclusion of summer profiles in the simulations will not produce any significance difference in the shortwave domain.

With the configuration proposed for Clear Sky Land there are 144 scenes defined, with solar geometry included it means 1296 simulations.

The output files have the following format:

sits_SW_SURF_xx_PROF_0.0_SZA.txt

in which SURF stands for: rock, soil, vege, snow; xx: 01 to 12, stands for number of scaled spectra (vegetation or snow) or cluster (rocks and soils); PROF, stands for atmospheric profile: *afglt* (Tropical), *afglmw* (Midlatitude Winter) or *afglsw* (Subartic Winter); 0.0 is aerosol optical thickness 0 for Clear Sky Land and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

4.2 Clear sky land with aerosol load

For these set of simulations it has been used the averaged surface spectra for rocks, soils, vegetation and snow (See figures 1 and 2, 4, 6).

Aerosol properties come from the Aerosol definition set up before and there have been used two types and profiles of aerosols: desert and continental. Optical thickness has been scaled setting the aerosol optical thickness at 550 nm to 0.2, 0.5, 1 and 3 (only for desert simulations), being the other wavelengths scaled accordingly. Only one atmospheric profile, Midlatitude Winter, has been considered.

For Clear Sky Land in presence of aerosol, 32 scenes are defined, that implies 252 simulations.

The output files have the following format:

sits_SW_SURF_av_afglmw_AOT_SZA.txt

in which SURF stands for: rock, soil, vege, snow; av means averaged spectra; AOT stands for aerosol optical thickness: 0.2, 0.5, 1 and 3; and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

4.3 Clear sky ocean

Cox and Munk (Cox & Munk, 1955) reflectance model is used to simulate Ocean BRDF. Due to the fact that the Cox and Munk option involves a huge memory space, A. Ipe has introduce modifications to the code to cope with this problem. The model has been run with 4 different wind speeds: 1, 5, 10 and 15 m/s, 1 pigment concentration of 0.01 mg/m3 and 1 salinity content of 34.3 ‰.

Aerosol types considered are desert, maritime polluted, maritime clean and maritime tropical. Aerosol thickness has been scaled as in Clear sky land with aerosol load case, to values of 0.0, 0.1, 0.3, 1 and 3 (only for desert-type aerosols). Midlatitude Winter atmospheric profile has been considered.

The output files have the following format:

sits_SW_ocean_afglmw_WIND_SZA.txt (no aerosols)

sits_SW_ocean_afglmw_WIND_AEROTYPE_AOT_SZA.txt

in which WIND varies between 1 and 15 m/s in steps of 5 m/s, AEROTYPE can be *des* (desert), *m_tro* (maritime tropical), *m_pol* (maritime polluted) and *m_cle* (maritime clean); AOT stands for aerosol optical thickness: 0.1, 0.3, 1 and 3 (only desert); and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

The total amount of scenes is 56, that is, 504 simulations.

4.4 Thin and Moderate clouds

In this case, 5 surfaces are studied: ocean, rock averaged, soil averaged, vegetation averaged and snow averaged. For ocean, Cox and Munk model has been used, with wind speed of 5 m/s, pigment concentration of 0.01 mg/m3 and salinity content of 34.3 ‰.

Ice and Water cloud phases have been simulated. Parametrizations for clouds are the following:

- Effective radius: 6, 12 and 18 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization for plate ice cloud habit have been used.
- Cloud optical thickness of 0.3, 1 (thin clouds), 3 and 10 (moderate clouds) for both water and ice clouds.
- Cloud altitude: 1km layered clouds have been assumed, being water clouds placed at 1 and 6 km and ice clouds at 6 and 12 km.

The output files have the following format:

sits_SW_semi_SURF_afglmw.dat_CPH_REFF_TAUC_ALT_SZA.txt

in which SURF is either rock_av or ocean; CPH is cloud phase: water or ice; REFF is the effective radius of the ice water droplet or the ice crystal. TAUC is the Cloud Optical Thickness; ALT is the altitude in which the cloud is placed and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

The resulting number of scenes is 240, that is, 2160 simulations.

4.5 Thick clouds

In this case, only 2 surfaces are considered: ocean and rock averaged. For ocean, Cox and Munk model has been used, with wind speed of 5 m/s, pigment concentration of 0.01 mg/m3 and salinity content of 34.3 ‰.

Ice and Water cloud phases have been simulated. Parametrizations for clouds are the following:

- Effective radius: 6, 12 and 18 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization for plate ice cloud habit have been used.
- Cloud optical thickness of 30, 100 and 300 for both water and ice clouds.
- Cloud altitude: clouds of physical thickness of 1 km have been assumed, being water clouds with bottom placed at 1 and 6 km and ice clouds at 6 and 12 km.

The output files have the following format:

sits_SW_SURF_afglmw_CPH_REFF_TAUC_ALT_SZA.txt

in which SURF is either rock_av or ocean; CPH is cloud phase: *wat* (water) or *ice*; REFF is the effective radius of the ice water droplet or the ice crystal. TAUC is the Cloud Optical Thickness; ALT is the altitude in which the cloud is placed and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

The resulting number of scenes is 72, that is, 648 simulations.

4.6 Multilayer clouds

In this case, 2 surfaces are studied: ocean and rock averaged. For ocean, Cox and Munk model has been used, with wind speed of 5 m/s, pigment concentration of 0.01 mg/m3 and salinity content of 34.3 ‰.

We assume a thin ice cloud over a thick water cloud, the parametrizations chosen are the following:

- Effective radius: 8 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization for plate ice cloud habit have been used.
- Cloud optical thickness of ice layer: 0.3, 1, 3 and 10.
- Cloud optical thickness of water layer: 10, 30 and 100.
- Cloud altitude: clouds of physical thickness of 1 km have been assumed, being water clouds which bottom placed at 1km and ice clouds at 12 km.

The output files have the following format:

sits_SW_multi_SURF_afglmw_CPH_REFF_TAUC_ALT_SZA.txt

in which SURF is either rock_av or ocean; CPH is cloud phase: water or ice; REFF is the effective radius of the ice water droplet or the ice crystal. TAUC is the Cloud Optical Thickness; ALT is the altitude in which the cloud is placed and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees).

The resulting number of scenes is 72, that is, 648 simulations.

5 LW Geotype data base

5.1 Clear sky land and ocean

Table 1 summarizes the atmospheric profiles and surface temperatures used in the longwave simulations. Surface temperature corresponds to the lowest level of the selected profile and it is increased or decreased as shown in the table.

Integrated water vapor of the atmospheric profiles is scaled with the following factors 0.6, 0.8, 1.0, 1.2 and 1.4.

Aerosol optical thickness at 550 nm is set to 0, 0.3 and 1.

The output files have the following format:

sits_LW_SURF_PROF_sc_delta_T_AOT.txt

in which SURF can be ocean, rock averaged, soil averaged, vegetation averaged and snow averaged; PROF, stands for atmospheric profile: *afglt*(Tropical, TRO), *afglms* (Midlatitude Summer, MLS), *afglmw* (Midlatitude Winter, MLW), *afglss* (Subartic Summer, SAS) or *afglsw* (Subartic Winter, SAW); sc is the scaling factor applied to the water vapor; delta_T is the amount the first level of the profile is increased or decreased to be used as surface temperature and AOT is the Aerosol Optical Thickness.

The resulting number of scenes is 540.

surface description	Standard atmosphere model	Surface Temperature
Desert/Land	MLS, MLW	$T_{std}, T_{std} + 15, T_{std} + 30$
Vegetation	TRO, MLS, MLW, SAS, SAW	$T_{std}, T_{std} + 5, T_{std} + 10$
Snow	SAS, SAW	$T_{std}, T_{std} - 5, T_{std} - 10$
Ocean	TRO, MLS, MLW	$T_{std}, T_{std} - 3, T_{std} + 3$

Table 1: Clear sky longwave

5.2 Thin Clouds and Moderate Clouds

Table 2 summarizes the atmospheric profiles and surface temperatures used in the longwave simulations for thin clouds. Table 3 summarizes the atmospheric profiles and surface temperatures used in the longwave simulations for moderate clouds. Surface temperature corresponds to the lowest level of the selected profile and it is increase or decreased as shown in the tables (2,3) .

Integrated water vapor of the atmospheric profiles is scaled with the following factors 0.7, 1.0 and 1.3.

Both Ice and Water cloud phases have been simulated. Parametrizations for clouds are the following:

- Cloud altitude (high, medium, low)

  High Clouds: Base over 6 km. It is assumed to be an ice cloud, and it has been placed at 8, 10 and 12 km.

  Medium Clouds: Base between 2 km and 6 km. It is assumed to be a water cloud, and it has been placed at 4 and 6 km.

  Low Clouds: Base below 2. It is assumed to be a water cloud, and it has been placed at 0.5, 1 and 2 km.

- Effective radius: 6, 12 and 18 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization for plate ice cloud habit have been used.

- Cloud optical thickness of 0.5 and 1 for thin clouds and 3, 6 and 10 for moderate clouds, for both water and ice clouds.

The output files have the following format:

sits_LW_semi_SURF_PROF_sc_delta_T_CPH_REFF_TAUC_ALT.txt

in which SURF can be ocean, rock averaged, soil averaged, vegetation averaged and snow averaged; PROF, stands for atmospheric profile: *afglt* (Tropical), *afglms* (Midlatitude Summer), *afglmw* (Midlatitude Winter), *afglss* (Subartic Summer) or *afglsw* (Subartic Winter); sc is the scaling factor applied to the water vapor; delta_T is the amount the first level of the profile is increased or decreased to be used as surface temperature; CPH is cloud phase: water or ice; REFF is the effective radius of the ice water droplet or the ice crystal. TAUC is the Cloud Optical Thickness and ALT is the altitude in which the cloud is placed.

The resulting number of scenes is 3024 for thin clouds and 2592 for moderate clouds, that makes a total of 5616 scenes.

surface description	Standard atmosphere model	Surface Temperature
Desert/Land	MLS, MLW	$T_{std}, T_{std}+15$
Vegetation	TRO, MLS, MLW, SAS, SAW	$T_{std}, T_{std}+5$
Snow	SAS, SAW	$T_{std}, T_{std}-5$
Ocean	TRO, MLS, MLW	T_{std}

Table 2: Thin Clouds

5.3 Thick Clouds

For thick clouds, the surface emissivity is equal to 1, as it is not going to contribute to the radiance field at the TOA. All the atmospheric profiles are used, that is, Tropical,

surface description	Standard atmosphere model	Surface Temperature
Desert/Land	MLS, MLW	T_{std}
Vegetation	TRO, MLS, MLW, SAS, SAW	T_{std}
Snow	SAS, SAW	T_{std}
Ocean	TRO, MLS, MLW	T_{std}

Table 3: Moderate Clouds

Midlatitude Summer, Midlatitude Winter, Subartic Summer and Subartic Winter, and surface temperature is taken as the first level temperature from the profiles.

Integrated water vapor of the atmospheric profiles is scaled with the following factors 0.7, 1.0 and 1.3.

Both Ice and Water cloud phases have been simulated. Parametrizations for clouds are the following:

- Cloud altitude (low, medium, high)

  High Clouds: Base over 6 km. It is assumed to be an ice cloud, and it has been placed at 8, 10 and 12 km.

  Medium Clouds: Base between 2 km and 6 km. It is assumed to be an water cloud, and it has been placed at 4 and 6 km.

  Low Clouds: Base below 2. It is assumed to be an water cloud, and it has been placed at 0.5, 1 and 2 km.

- Effective radius: 6, 12 and 18 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization and plate ice cloud habit have been used.
- Cloud optical thickness of 20, 50 and 100 for both water and ice clouds.

The output files have the following format:

sits_LW_thick_PROF_sc_CPH_REFF_TAUC_ALT_SZA.txt

in which PROF, stands for atmospheric profile: *afglt* (Tropical), *afglms* (Midlatitude Summer), *afglmw* (Midlatitude Winter), *afglss* (Subartic Summer) or *afglsw* (Subartic Winter); sc is the scaling factor applied to the water vapor; C_PH is cloud phase: water or ice; R_EFF is the effective radius of the ice water droplet or the ice crystal. TAUC is the Cloud Optical Thickness; ALT is the altitude in which the cloud is placed and SZA stands for Solar Zenith Angle (between 0 and 80 in intervals of 10 degrees)

The resulting number of scenes is 1080.

5.4 Overlapping Clouds

For overlapping clouds all the atmospheric profiles are used, that is, Tropical, Midlatitude Summer, Midlatitude Winter, Subartic Summer and Subartic Winter, emissivity is set to one as in Thick Clouds and surface temperature is taken as the first level temperature from the profiles.

Integrated water vapor of the atmospheric profiles is scaled with the following factors 0.7, 1.0 and 1.3.

We assume a thin ice cloud over a moderate or thick water cloud, the parametrizations chosen are the following:

- Effective radius: 2, 8 and 16 μm for water clouds and 10, 30 and 48 μm for ice clouds, in which Yang *et al.* (2000) parametrization for plate ice cloud habit have been used.
- Cloud optical thickness of ice layer: 0.5 and 1 (thin cloud)
- Cloud optical thickness of water layer: 10 (moderate) and 50 (thick cloud).
- Cloud altitude: water cloud is placed at 2, 4 and 6 km and ice cloud is placed at 8, 10 and 12 km.

The output files have the following format:

sits_LW_multi_PROF_sc_CPH_REFF_TAUC_ALT1_CPH2_REFF2_TAUC2_ALT2.txt

in which PROF, stands for atmospheric profile: *afglt* (Tropical), *afglsw* (Midlatitude Summer), *afglmw* (Midlatitude Winter), *afglss* (Subartic Summer) or *afglsw* (Subartic Winter); sc is the scaling factor applied to the water vapor; CPH is the cloud phase for the bottom cloud: water; REFF is the effective radius of the ice water droplet; TAUC is the Bottom Cloud Optical Thickness; ALT1 is the altitude in which the ice cloud is placed; CPH2 is the cloud phase for the top cloud: ice; REFF2 is the effective radious of the ice crystal; TAUC2 is the Top Cloud Optical Thickness; and ALT2 is the altitude in which the top cloud is placed.

The resulting number of scenes is 4860.

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