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DACCIWA

"Dynamics-aerosol-chemistry-cloud interactions in West Africa"

Deliverable

D 5.3
Multi-satellite dataset

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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2 Introduction

Satellites provide a valuable source of information on the physical properties of the atmosphere, particularly for regions such as southern West Africa where limited surface observations are available. For the DACCIWA project, satellite observations provide a broader spatial and temporal context to the extensive set of measurements undertaken as part of the DACCIWA field campaign in June-July 2016.

This report contains essential information about a number of cloud, aerosol and irradiance satellite products, which may be useful for DACCIWA research. Owing to issues with satellite data usage policies and data storage volumes it is not possible to make all this satellite data available as a single database. Instead, we provide instructions on how to obtain the individual satellite products alongside the product descriptions. We can also provide some of these datasets on request (as has been done for the model evaluation deliverables). DACCIWA project scientists can also contact Peter Hill (p.g.hill@reading.ac.uk) for further advice on using and obtaining these satellite products. A multi-satellite based climatology of the DACCIWA region is also available from Hill et al. [2016].

3 Satellite datasets

3.1 Cloud products

3.1.1 DARDAR

DARDAR combines observations from the CloudSat radar and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO. Both are part of the A-train satellite constellation. The combination of the cloud radar that can penetrate through thin clouds and detect lower cloud layers with the lidar that is sensitive to thin clouds provides detailed information on the vertical structure of cloud. Several other CloudSat and CALIPSO products exist. DARDAR has the advantage of consolidating a great deal of cloud data into two products. The DARDAR mask product provides an atmospheric feature mask and the DARDAR cloud product provides ice cloud properties.

CloudSat experienced a battery anomaly in April 2011, which caused it to stop collecting data and lose formation with the A-train. While the radar was turned back on in November 2011, it now only collects observations during the day and as it is no longer in the A-train formation, multi-satellite products such as DARDAR end in April 2011.

Variables	Atmospheric feature mask, including location of cloud, rain and aerosols. Ice cloud properties, including ice water content and effective radius.
Period	July 2007 - April 2011
Timestep	Twice per day, passing the DACCIWA region at approx. 13.30 and 01.30
Domain	Global coverage, but the swath is very narrow (1.4 km), so at any given time only a very small area is observed.
Resolution	Approx. 1.7 km along track, 1.4 km across track, 60 m vertical
Documentation	DARDAR mask: http://www.icare.univ-lille1.fr/projects/dardar/documentation_dardar_mask DARDAR cloud: http://www.icare.univ-lille1.fr/projects/dardar/documentation_dardar_cloud
Strengths	The complementary cloud radar and lidar provide what is probably the best estimate of cloud vertical properties from space.
Limitations	May miss some low clouds as Limited diurnal sampling. Limited spatial sampling.
Data Access	Requires registration http://www.icare.univ-lille1.fr/register ftp://ftp.icare.univ-lille1.fr/SPACEBORNE/MULTI_SENSOR/DARDAR_MASK ftp://ftp.icare.univ-lille1.fr/SPACEBORNE/MULTI_SENSOR/DARDAR_CLOUD
References	Delanoë, J., and R. J. Hogan, 2010: Combined CloudSat-CALIPSO-MODIS retrievals of the properties of ice clouds. J. Geophys. Res., 115, D00H29, doi:10.1029/2009JD012346. Delanoë, J., and R. J. Hogan, 2008: A variational scheme for retrieving ice cloud properties from combined radar, lidar, and infrared radiometer, J. Geophys. Res., 113, D07204, doi:10.1029/2007JD009000.

3.1.2 MODIS

The MODerate resolution Imaging Spectroradiometer (MODIS) instrument sits on two polar orbiting satellites: AQUA and TERRA. MODIS has 36 spectral channels, which facilitates the retrieval of a number of atmospheric properties including clouds. In addition to the instantaneous footprint products, the MODIS science team also provides aggregated products at lower temporal and spatial resolutions. Higher resolution files have geolocation data stored in a separate file.

Variables	Cloud fraction, cloud top temperature & pressure, effective radius, cloud optical thickness, cloud water path
Period	TERRA: February 2000 – date AQUA: July 2002 - date
Timestep	Four times per day, passing the DACCIWA region at approx. 01.30, 10.30, 13.30 and 22.30.
Domain	Global coverage, though instantaneous swath width is 2,330 km
Resolution	Up to 1 & 5 km at nadir, depending on variable.
Documentation	Cloud product: https://modis-atmos.gsfc.nasa.gov/sites/default/files/ModAtmo/C6MOD06OPUserGuide.pdf Gridded product: https://modis-atmos.gsfc.nasa.gov/sites/default/files/ModAtmo/L3_ATBD_C6_0.pdf
Strengths	Cloud-top pressure estimates for high clouds are more robust than imagers that have only infrared window measurements. MODIS products are mature, widely used and well validated.
Limitations	Only identifies uppermost cloud layer. Limited diurnal sampling.
Data Access	https://ladsweb.modaps.eosdis.nasa.gov/search/ We have created netCDF datasets merging TERRA and AQUA observations for the region bound by 8°W, 8°E, 5°N and 10°N on regular latitude-longitude grids with resolution of 0.2° for June-July 2016 and 1° for June-September, 2006-2015 for the purpose of model evaluation. These datasets include cloud fraction, cloud top temperature, cloud water path and precipitable water and can be provided to other DACCIWA scientists.
References	Platnick, Steven, et al. "The MODIS cloud products: Algorithms and examples from Terra." IEEE Transactions on Geoscience and Remote Sensing 41.2 (2003): 459-473. Platnick, Steven, et al. "The MODIS cloud optical and microphysical products: Collection 6 updates and examples from Terra and Aqua." IEEE Transactions on Geoscience and Remote Sensing 55.1 (2017): 502-525.

3.1.3 SEVIRI CMSAF CLAAS

The Spinning Enhanced Visible and Infrared Imager (SEVIRI) sits on a series of geostationary Meteosat satellites. There are a number of SEVIRI-based cloud products. The satellite application facility on climate monitoring (CMSAF) CLoud property dAtAset using SEVIRI (CLAAS) product provides a long-term cloud record. Intercalibration between the different SEVIRI instruments and MODIS is used to ensure a homogeneous record. Both instantaneous and monthly mean data is available.

Variables	cloud mask/type, cloud top temperature/pressure/height, cloud phase, cloud optical thickness, effective droplet radius and cloud water path
Period	2004 -2011 (CLAAS v1), 2004-2015 (CLAAS v2).
Timestep	15 minutes
Domain	81S-81N, 81W-81E
Resolution	Approx. 3km (nadir) and 11 km (edge of field of view).
Documentation	https://wui.cmsaf.eu/safira/action/viewDoiDetails?acronym=CLAAS_V002
Strengths	Excellent diurnal sampling
Limitations	Only identifies uppermost cloud layer. Some issues in version 1 with identifying low cloud, particularly at night [Hill et al., 2016]
Data Access	https://wui.cmsaf.eu/safira/action/viewProduktSearch requires registration here: https://wui.cmsaf.eu/safira/action/viewCreateNewAccount
References	Benas, N., Finkensieper, S., Stengel, M., van Zadelhoff, G.-J., Hanschmann, T., Hollmann, R., and Meirink, J. F.: The MSG-SEVIRI-based cloud property data record CLAAS-2, Earth Syst. Sci. Data, 9, 415-434, https://doi.org/10.5194/essd-9-415-2017, 2017 Stengel, M., Kniffka, A., Meirink, J. F., Lockhoff, M., Tan, J., and Hollmann, R.: CLAAS: the CM SAF cloud property data set using SEVIRI, Atmos. Chem. Phys., 14, 4297-4311, https://doi.org/10.5194/acp-14-4297-2014, 2014 Meirink, J. F., Roebeling, R. A., and Stammes, P.: Inter-calibration of polar imager solar channels using SEVIRI, Atmos. Meas. Tech., 6, 2495-2508, https://doi.org/10.5194/amt-6-2495-2013, 2013

3.1.4 SEVIRI OCA

The SEVIRI Optimal Cloud Analysis (OCA) product uses an optimal estimation method and all SEVIRI channels simultaneously to retrieve cloud parameters for up to two cloud layers.

Variables	Cloud top pressure and optical thickness for up to two layers. Cloud effective radius and phase for upper layer.
Period	June 2013 - date
Timestep	15 minutes
Domain	81S-81N, 81W-81E
Resolution	Approx. 3km (nadir) and 11 km (edge of field of view).
Documentation	http://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=PDF_DMT_770106&RevisionSelectionMethod=LatestReleased&Rendition=Web
Strengths	Excellent diurnal sampling. Up to two cloud layers.
Limitations	As a relatively new product, there is little existing validation and performance is less well understood than the other satellite cloud products
Data Access	http://archive.eumetsat.int/usc/ require registration here: https://eoportal.eumetsat.int/userMgmt/register.faces We can provide netCDF files for 0-30N and 20W -20E for the SEVIRI OCA product, but data volumes are very large (approx. 1.5 GB per day at 15 min temporal resolution).
References	Watts, P. D., R. Bennartz, and F. Fell (2011), Retrieval of two-layer cloud properties from multispectral observations using optimal estimation, J. Geophys. Res., 116, D16203, doi:10.1029/2011JD015883.

3.2 Aerosol products

Most satellite aerosol retrievals require clear-sky, which is rare in the DACCIWA region. As a result, most satellite aerosol products are based on infrequent retrievals and therefore vulnerable to large sampling errors.

3.2.1 VIIRS

The Visible Infrared Imaging Radiometer Suite (VIIRS) is a scanning radiometer on board the Suomi National Polar-orbiting Partnership (NPP) satellite. While Suomi-NPP is not part of the A-train it is in a similar polar orbit and passes the DACCIWA region at approx. 13.30 and 01.30. The current version of the VIIRS algorithm does not retrieve aerosol properties over bright surfaces (highly reflective desert surfaces, snow and ice cover, and fire spots), in cloud-affected pixels, over inland water, or at night. The EDR (Environmental Data Record) product is preferred.

Variables	Aerosol optical depth at 11 wavelengths. Angstrom exponent, small mode fraction.
Period	March 2012 - date
Timestep	Up to twice a day at approx. 13.30 and 01.30 (currently no nighttime aerosol properties)
Domain	Global, but swath width is 300 km
Resolution	Approx 6 km at nadir for EDR
Documentation	https://www.star.nesdis.noaa.gov/JPSS/documents/AMM_All/Aerosol_AOT-APSP/Validated/Aerosol_Product_Users_Guide_V3.pdf
Strengths	Larger swath (than MODIS) ensures global coverage every day.
Limitations	Newer product is less well validated than others. Missing retrievals over bright surfaces and inland water that are available from other products (e.g. MODIS). Missing aerosol properties for cloudy pixels.
Data Access	https://www.class.ncdc.noaa.gov/saa/products/catSearch Requires registration at https://www.class.ncdc.noaa.gov/saa/products/user_profile
References	Jackson, J. M., H. Liu, I. Laszlo, S. Kondragunta, L. A. Remer, J. Huang, and H.-C. Huang (2013), Suomi-NPP VIIRS aerosol algorithms and data products, J. Geophys. Res. Atmos., 118, 12,673–12,689, doi:10.1002/2013JD020449. Liu, H., L. A. Remer, J. Huang, H.-C. Huang, S. Kondragunta, I. Laszlo, M. Oo, and J. M. Jackson (2014), Preliminary evaluation of S-NPP VIIRS aerosol optical thickness, J. Geophys. Res. Atmos., 119, 3942–3962, doi:10.1002/2013JD020360.

3.2.2 MODIS

As for the MODIS cloud products, the MODIS science team provides aggregated products at lower temporal and spatial resolutions in addition to the instantaneous footprint products. Moreover, the MODIS aerosol products are mature, widely used and well validated. Two different algorithms are applied to retrieve aerosol properties from MODIS observations. The dark target algorithm cannot be applied over bright surfaces. The deep blue algorithm can be applied over bright surfaces. Most MODIS products include separate aerosol properties retrieved from each of these algorithms, but also since collection 6, a merged aerosol properties dataset that is based on the dark target retrieval with the deep blue retrieval used to fill in missing data.

Variables	Aerosol optical depth at 550 nm. Angstrom exponent over the ocean.
Period	TERRA: February 2000 – date AQUA: July 2002 - date
Timestep	Up to four times a day at approx. 01.30, 10.30, 13.30 and 22.30 (but currently no nighttime aerosol properties)
Domain	Global, but swath width is 2,330 km.
Resolution	Up to 3 km at nadir
Documentation	http://modis-atmos.gsfc.nasa.gov/_docs/ATBD_MOD04_C005_rev2.pdf
Strengths	Results from two distinct algorithms, maximises the area over which aerosol is retrieved.
Limitations	No nighttime aerosol Unable to retrieve aerosol when cloud is present.
Data Access	https://ladsweb.modaps.eosdis.nasa.gov/search/order/2/MOD04_L2--6,MYD04_L2--6,MOD04_3K--6,MYD04_3K--6
References	Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F., and Hsu, N. C., 2013: The Collection 6 MODIS aerosol products over land and ocean, Atmos. Meas. Tech., 6, 2989-3034, doi:10.5194/amt-6-2989-2013.

3.2.3 MISR

The Multi-angle Imaging Space Radiometer (MISR) is an instrument on the Terra satellite. It consists of 9 cameras with an overlapping swath that is 360 km wide with a resolution of 1.1 km. Aerosol retrievals are performed at a lower resolution of 17.6 km and aggregated data (i.e. lower temporal and spatial resolution) is available.

Variables	Aerosol optical depth, angstrom exponenet and aerosol type
Period	February 2000 – date
Timestep	Up to twice a day at approx. 10.30 and 22.30 (but currently no nighttime aerosol properties)
Domain	Global, but swath width is 380 km.
Resolution	17.6 km
Documentation	https://eosweb.larc.nasa.gov/sites/default/files/project/misr/quality_summaries/ L2_AS_Products.pdf https://eosweb.larc.nasa.gov/sites/default/files/project/misr/DPS_v50_RevS.pdf
Strengths	Additional information provided by multiple viewing angles means that aerosol type can be identified.
Limitations	Unable to retrieve aerosol when cloud is present. No retrieval at night. Very limited sampling of diurnal cycle.
Data Access	https://l0dup05.larc.nasa.gov/MISR/cgi-bin/MISR/main.cgi
References	Diner, David J., et al. "Multi-angle Imaging SpectroRadiometer (MISR) instrument description and experiment overview." IEEE Transactions on Geoscience and Remote Sensing 36.4 (1998): 1072-1087. Kahn, R.A., B.J. Gaitley, M.J. Garay, D.J. Diner, T. Eck, A. Smirnov, and B.N. Holben, 2010. MISR aerosol product assessment by comparison with AERONET. J. Geophys. Res., doi: 10.1029/2010JD014601.

3.3 Irradiance products

3.3.1 GERB

The Geostationary Earth Radiation Budget (GERB) product is based on a series of instruments on Meteosat geostationary satellites. GERB measures radiances, which are converted to irradiances using angular distribution models using scene type from the SEVIRI imager.

Variables	Outgoing top of atmosphere solar irradiance Outgoing top of atmosphere thermal irradiance
Period	GERB2: February 2004 – April 2007 GERB1: May 2007 – February 2013 GERB3: October 2012 - date
Timestep	15 minutes
Domain	81S-81N, 81W-81E
Resolution	9x9km at nadir (for HR product)
Documentation	ftp://gerb.oma.be/Documents/userguide.pdf
Strengths	Excellent diurnal sampling High horizontal resolution
Limitations	Some data missing due to sunglint No observations at high solar zenith angles (> 80°) No data around the equinoxes.
Data Access	ftp from ftp://gerb.oma.be (Requires registration at https://gerb.oma.be/mailman/listinfo/rolss) We have created netCDF datasets for the region bound by 8°W, 8°E, 5°N and 10°N on regular latitude-longitude grids with resolution of 0.2° for June-July 2016 and 1° for June-September, 2006-2015 for the purpose of model evaluation. These datasets include top of atmosphere outgoing SW and LW irradiances and can be provided to other DACCIWA scientists.
References	Harries, J. E., et al. (2005), The Geostationary Earth Radiation Budget Project, Bull. Am. Meteorol. Soc., 86(7), 945–960. Dewitte, S., L. Gonzalez, N. Clerbaux, A. Ipe, C. Bertrand, and B. D. Paepe (2008), The Geostationary Earth Radiation Budget Edition 1 data processing algorithms, Adv. Space Res., 41(11), 1906–1913.

3.3.2 CERES

The Clouds and the Earth's Radiant Energy System (CERES) instrument sits on the same two polar orbiting satellites as MODIS, i.e. Aqua and Terra. CERES measure top of atmosphere irradiances. Surface irradiances are also available and are computed using a radiative transfer model with input from reanalysis and cloud and aerosol properties derived from MODIS observations. There are a number of CERES products. The Single Scanner Footprint (SSF) product include irradiances at the CERES footprint scale. The synoptic (SYN) product includes irradiances at one degree resolution with geostationary observations used to fill gaps in the diurnal cycle that are not covered by CERES. The energy balanced and filled (EBAF) product includes monthly mean irradiances that are constrained to the ocean heat storage. Like GERB, CERES uses angular distribution models to convert the measured radiances to irradiances. Scene type is based on the MODIS imager.

Variables	Solar and thermal irradiances at both the top of atmosphere and surface.
Period	Terra: March 2000 – date Aqua: March 2002 - date
Timestep	CERES equator overpass times are at approx. 01.30, 10.30, 13.30 and 22.30. The SYN product extends the observation frequency to hourly.
Domain	Global, but instantaneous swath width is
Resolution	Approx. 20 km at nadir
Documentation	https://ceres.larc.nasa.gov/docs.php
Strengths	CERES products are mature, widely used and well validated.
Limitations	Limited temporal sampling of the actual measurements. Surface irradiances are computed and will be affected by imperfect input.
Data Access	https://ceres.larc.nasa.gov/order_data.php We have created netCDF datasets using CERES-SYN for the region bound by 8°W, 8°E, 5°N and 10°N on regular latitude-longitude grids with resolution of 1° for June-September, 2006-2015 for the purpose of model evaluation. These datasets include top of atmosphere outgoing SW and LW irradiances and can be provided to other DACCIWA scientists.
References	Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee, G. L. Smith, and J. E. Cooper (1996), Clouds and the Earth's Radiant Energy System (CERES): An Earth Observing System experiment, Bull. Am. Meteorol. Soc., 77(5), 853–868. N.G. Loeb, J.M. Lyman, G.C. Johnson, R.P. Allan, D.R. Doelling, T. Wong, B.J. Soden, and G.L. Stephens, 2012: Observed changes in top-of-the-atmosphere radiation and upper-ocean heating consistent within uncertainty. Nature Geosciences, DOI 10.1038/NGE Doelling, D. R., N. G. Loeb, D. F. Keyes, M. L. Nordeen, D. Morstad, C. Nguyen, B. A. Wielicki, D. F. Young, and M. Sun (2013), Geostationary enhanced temporal interpolation for CERES flux products, J. Atmos. Oceanic Technol., 30(6), 1072–1090.

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Peter G. Hill, R. P. A. J. C. C. T. H. M. S., 2016. A multi-satellite climatology of clouds, radiation and precipitation in southern West Africa and comparison to climate models. *Journal of Geophysical Research: Atmospheres.*