Climatologies of ultra-low clouds over the southern West African monsoon region

Andreas H. Fink[1], R. Schuster[1], R. van der Linden *[1], J. M. Schrage[2], C. K. Akpanya[2], and C. Yorke[3]

[1]*Institute of Geophysics and Meteorology, University of Cologne, Germany*
[2]*Department of Atmospheric Sciences, Creighton University, Omaha, NE, USA*
[3]*Ghana Meteorological Agency, Accra-Legon, Ghana*

1 Motivation

Shallow, non-precipitating nocturnal stratus cloud decks are frequently observed in southern West Africa during the summer monsoon. Because of their late dissipation during daytime, these cloud decks have a large impact on the radiation balance.
Currently, global climate models show an insufficient representation in this field. They show a positive solar radiation bias over southern West Africa (Knippertz et al., 2011). That is why further insight into processes of genesis and lysis of these cloud decks is needed. Furthermore, more complete observations of the spatial extent and especially of the formation and dissipation of these clouds are desired to better understand the underlying processes. Satellite observations could serve the purpose, but the choice of an appropriate platform and the interpretation of the satellite imagery remains challenging.
It is assumed that the clouds result from vertical mixing caused by turbulence induced by the night-time low level jet (**NLLJ**; Schrage and Fink, 2012).
The objective of the present study is to investigate which combination of space-borne remote sensing platforms and derived satellite products is best suited to set up a multi-year climatology (2006 – 2011) of ultra-low clouds.

*e-mail: rvdlinde@uni-koeln.de

2 Preliminary results

We focus on satellite observations, because ground-based eye observations by observers of synoptic stations are subjective and problematic during darkness. In addition, the spatiotemporal coverage of synoptic observations is insufficient for obvious reasons. However, the availability of long-time series and non-existing problems with mid- and upper-level clouds is advantageous.
Depending on the satellite platform, satellites provide a high temporal resolution and a large spatial coverage. Moreover, information about the vertical structure of clouds can be obtained from some satellites. Disadvantages of satellite observations are mostly short observation periods, problems with the detection of low-level clouds if these are overlaid with mid- and upper-level clouds, and sampling problems for infrequently overpassing, polar-orbiting satellites.

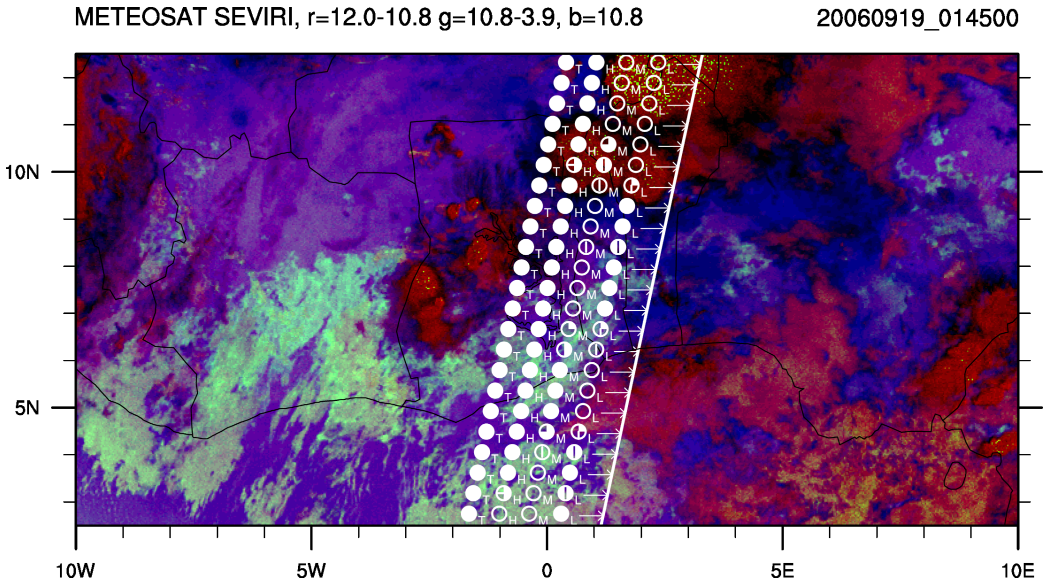
Hereafter, some preliminary results regarding the suitability of various satellite platforms to set up a low-level cloud climatology are shown. Results are shown for MSG SEVIRI red-green-blue (**RGB**) composites (section 2.1) as well as for a cloud classification product based on MSG SEVIRI data by the Satellite Application Facility on the support to Nowcasting and Very Short Range Forecasting (**SAFNWC**, section 2.2). In section 2.3 results for a merged product based on CloudSat and CALIPSO data are shown.

2.1 MSG SEVIRI

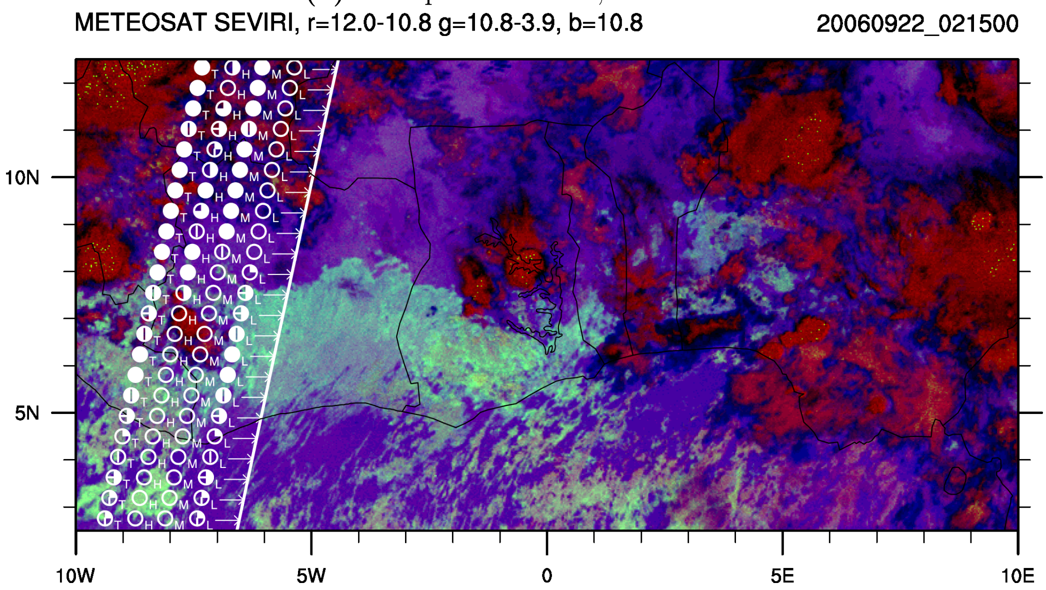
The Meteosat Second Generation Spinning Enhanced Visible and Infrared Imager (**MSG SEVIRI**) is a geostationary (nominal position at 0° longitude) and passive remote sensing instrument (Schmetz et al., 2002). The imaging-repeat cycle of its 12 spectral channels is 15 minutes for a full-disk image including Europe and Africa. The spatial resolution is 3 km at nadir except the high resolution visible (**HRV**) channel with 1 km.
We make use of red-green-blue (**RGB**) composites, namely the "night microphysical" colour scheme for the manual classification of clouds at night (Lensky and Rosenfeld, 2008). Therefore, the brightness temperatures or rather the brightness temperature differences calculated from the 3.9 μm (IR3.9), 10.8 μm (IR10.8), and 12.0 μm (IR12.0) infrared channel radiances are plotted as a RGB composite (red: brightness temperature difference between IR12.0 and IR10.8 channels ($BTD_{12.0-10.8}$); green: $BTD_{10.8-3.9}$; blue: brightness temperature of the IR10.8 channel ($BT_{10.8}$)).
To gain good contrasts for the interpretation, specific thresholds for the brightness temperature differences and the brightness temperature are chosen (Lensky and Rosenfeld, 2008). Red is giving information about the cloud depth, green about the cloud phase and the droplet

size, and blue about the temperatures of cloud tops and of the surface. The $BTD_{10.8-3.9}$ is of great importance for the detection of low-level clouds. The 3.9 μm emissivity is clearly smaller for small droplets than for large droplets whereas it's almost the same for small and large droplets at 10.8 μm. That's why the $BTD_{10.8-3.9}$ is larger for clouds with small droplets (Lensky and Rosenfeld, 2008) and low-level clouds appear in greenish colours.

In Figure 1 RGB composites for (a) 19 September 2006 at 0145 UTC and (b) 22 September 2006 at 0215 UTC are shown. Additional information is given by cloud cover fractions in octas from a merged product based on CloudSat and CALIPSO data for the closest overflight of CloudSat and CALIPSO satellites (for details see section 2.3).



(a) 19 September 2006, 0145 UTC



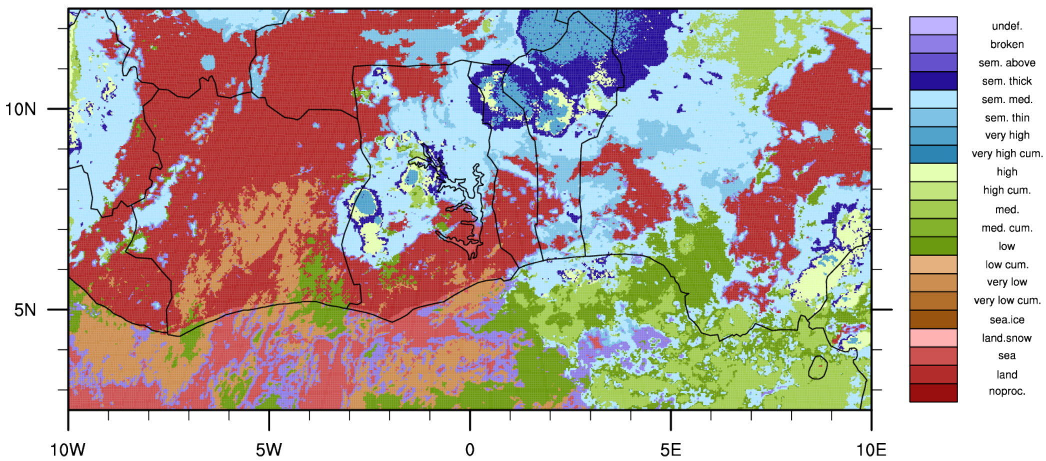
(b) 22 September 2006, 0215 UTC

Figure 1: Low-level clouds at the Guinea Coast: MSG SEVIRI RGB composites for (a) 19 Sept. 2006 0145 UTC and (b) 22 Sept. 2006 0215 UTC with total (T), high (H), middle (M), and low (L) cloud cover from the merged CloudSat/CALIPSO product (2B-GEOPROF-LIDAR) in octas.

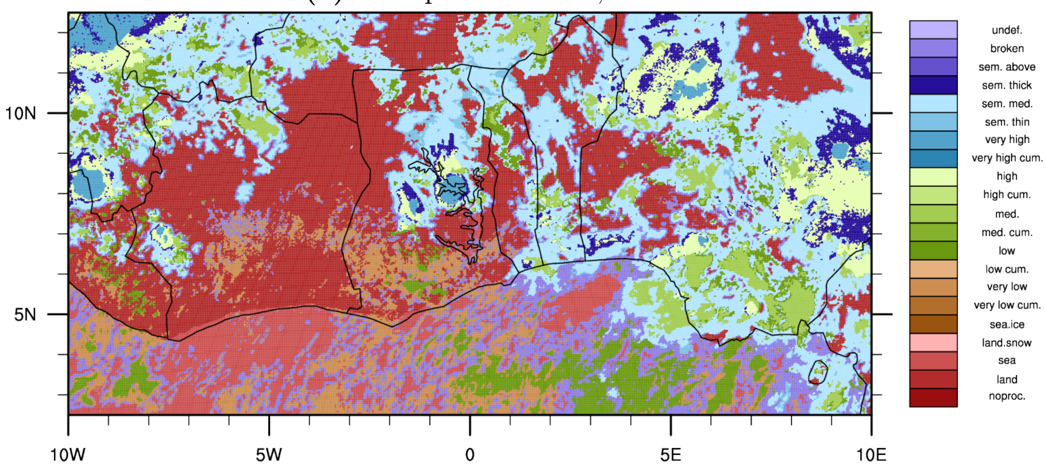
Figure 1 shows low-level clouds with a large extent over Ivory Coast and Ghana on both days. The main difference is that on 19 September 2006 (Fig. 1 (a)) low-level clouds at Benin are overlaid with mid- and upper-level clouds (see cloud cover from the merged CloudSat/CALIPSO product and cloud cover fractions in Figure 4 (a)). That means that this day would not be suitable to be included in a low-level cloud climatology. On 22 September 2006 low-level clouds at the Ivory Coast are not overlaid by higher-level clouds. Thus, for this day the MSG SEVIRI RGB composite describes the actual low-level cloud cover in the field of view of the CALIPSO CALIOP instrument correctly. Summing up, to set up a low-level cloud climatology, enough nights are needed that meet the requirements in such a way that the low-level clouds are not overlaid with higher level clouds at least most of the time.

2.2 SAFNWC Cloud Type

The cloud type algorithm by the Satellite Application Facility on the Support to Nowcasting and Very Short Range Forecasting (**SAFNWC**; Derrien and Le Gléau, 2005) is based on a multi-spectral threshold technique. It makes use of various MSG SEVIRI channels. A cloud type classification is performed for MSG SEVIRI pixels that are flagged as cloudy by a cloud mask algorithm. Figure 2 shows the results for the same examples as in Fig. 1, namely 19 September 2006 0145 UTC and 22 September 2006 0215 UTC. Low-level clouds appear in light brown and dark green colours.



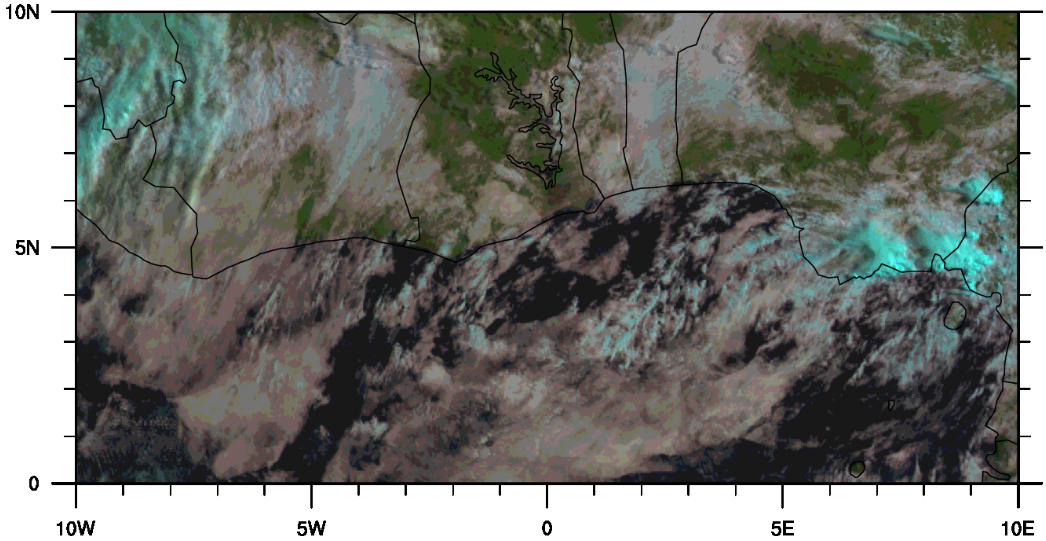
(a) 19 September 2006, 0145 UTC



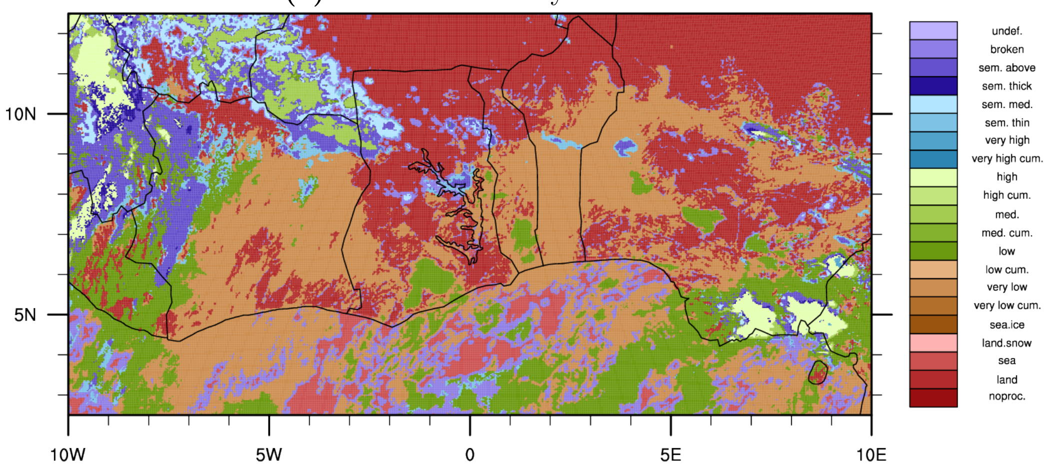
(b) 22 September 2006, 0215 UTC

Figure 2: The same examples as in Fig. 1 for the SAFNWC cloud type algorithm (source: AMMA database).

Evidently, the cloud type algorithm has deficiencies in detecting the full extent of low-level clouds at night if compared to the RGB composites in Fig. 1. This applies at least to this version of the algorithm used for the processing of MSG SEVIRI data. The classification of low-level clouds during daytime seems to be trustworthier if compared to the "day natural colours" RGB scheme (Fig. 3). In addition, the transition from nighttime detection to daytime detection works smoothly; there are few problems at twilight conditions (not shown).



(a) MSG SEVIRI day natural colours



(b) SAFNWC cloud type

Figure 3: (a) MSG SEVIRI day natural colours RGB scheme and (b) SAFNWC cloud type for 20 August 2006 0800 UTC

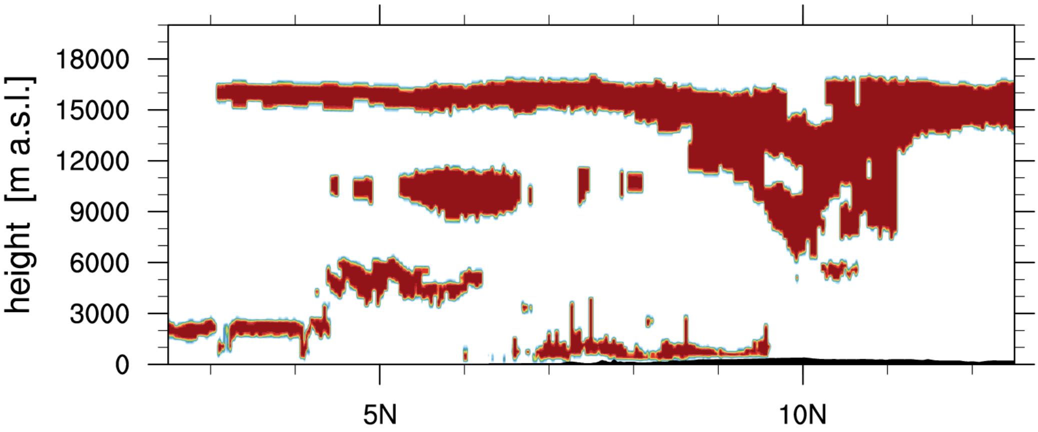
2.3 CloudSat/CALIPSO merged product

CloudSat and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) are two polar-orbiting satellites on the so-called NASA A-Train constellation (http://atrain.nasa.gov). The "A" stands for afternoon and points to the equator crossings of the satellites, namely appoximately at 01:30 p.m. LT. Another equator crossing is at approximately 01:30 a.m. LT. That is why these measurements suit well for the investigation of the vertical structure of clouds at night, when low-level clouds have formed already and are possibly overlaid by higher level clouds. CloudSat is 15 seconds ahead of CALIPSO on the same orbital track. The instruments aboard the satellites (Cloud Profiling Radar (**CPR**) on CloudSat and Cloud-Aerosol Lidar with Orthogonal Polarization (**CALIOP**) on CALIPSO) are active remote sensing instruments that emit energy that penetrates through the atmosphere. A high-resolution view of a limited area is reached from the return pulse of energy detected by the sensor.

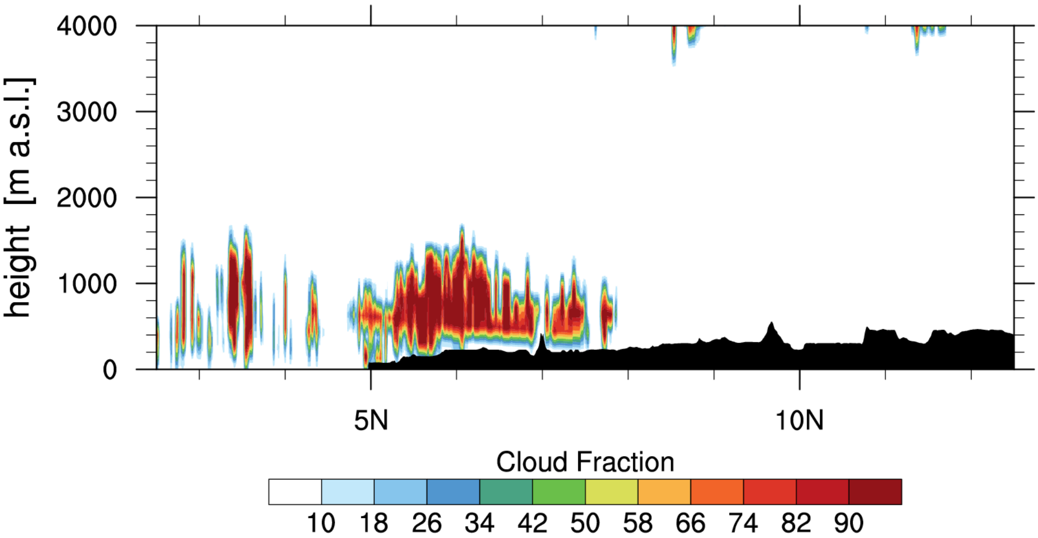
A short laser transmitter wavelength permits CALIOP to sense tenuous cloud layers and clouds close to the ground, but the emitted energy is fully attenuated in the case of high cloud optical depths. CPR measurements complement CALIOP observations by being able to penetrate through thick clouds. The CPR cannot detect very thin clouds as well as clouds approximately in the lowest kilometer above ground due to ground-clutter.

The merged CloudSat/CALIPSO product (**2B-GEOPROF-LIDAR**; Mace et al., 2009) aims at the best possible description of the vertical cloud profile and at the determination of cloud fractions of radar range resolution volumes.

Figure 4 shows along longitude cross-sections of cloud fractions of the merged CloudSat/CALIPSO product for 19 September 2006 and 22 September 2006. For the exact swath see Fig. 1. For 19 September 2006 the vertical axis extends to 20 km to show the existence of higher level clouds overlying low-level clouds, for 22 September it extends to 4 km.



(a) 19 September 2006



(b) 22 September 2006

Figure 4: Same examples as in Fig. 1 for cross-sections of cloud fractions [%] of the merged CloudSat/CALIPSO product.

On 19 September 2006 (Fig.4 (a)) low-level clouds (from close above ground up to roughly 1 km) extend from about 7°N to 10°N. They are overlaid by clouds at about 15 km, that is why these clouds cannot be observed in the corresponding MSG SEVIRI RGB composite (Fig. 1 (a)). On 22 September 2006 (Fig. 4 (b)) low-level clouds extend from 5°N to 8°N as could be seen in the MSG SEVIRI RGB composite (Fig.1 (b)).
Summing up, the merged CloudSat/CALIPSO product can be used to set up a low-cloud climatology and to study the vertical cloud structure.

The formation and dissipation of low-level clouds cannot be investigated, because A-Train satellites are polar-orbiting with equator crossings at approximately 01:30 a.m. and 01:30 p.m. LT.

3 Conclusions and Outlook

MSG SEVIRI can detect low-level clouds if these are not overlaid with higher level clouds. Given that enough nights with low mid- and high-level cloud cover can be detected, MSG SEVIRI suits well to set up a low-level cloud climatology. In this case, MSG SEVIRI images are especially useful for studying the formation and dissipation of low-level clouds.

Low-level clouds can be easily inferred from MSG SEVIRI RGB composites. The possibility of an automatical low-level cloud detection from RGB composites requires further investigation. Moreover, the cloud type algorithm by SAFNWC needs improvement for the nighttime cloud classification if not achieved already.

The merged CloudSat/CALIPSO product is best-suited for setting up a ultra-low cloud climatology, even including information about the vertical cloud structure. The formation and dissipation of clouds cannot be inferred from this product, because CloudSat and CALIPSO are polar-orbiting satellites and thus overpassing the Guinea Coast with equator crossings at approximately 01:30 a.m. LT.

References

Derrien, M., and H. Le Gléau, 2005: MSG/SEVIRI cloud mask and type from SAFNWC, *International Journal of Remote Sensing*, **26**, 4707-4732, doi: 10.1080/01431160500166128

Knippertz, P., A. H. Fink, R. Schuster, J. Trentmann, J. M. Schrage, and C. Yorke, 2011: Ultra-low clouds over the southern West African monsoon region, *Geophysical Research Letters*, **38**, L21808, doi: 10.1029/2011GL049278

Lensky, I. M. and D. Rosenfeld, 2008: Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAP-SAT), *Atmos. Chem. Phys.*, **8**, 6739–6753, doi:10.5194/acp-8-6739-2008

Mace, G. G., Q. Zhang, M. Vaughan, R. Marchand, G. Stephens, C. Trepte, and D. Winker, 2009: A description of hydrometeor layer occurence statistics derived from the first year of merged CloudSat and CALIPSO data, *Journal of Geophysical Research*, **114**, D00A26, doi:10.1029/2007JD009755

Schmetz, J., P. Pili, S. Tjemkes, D. Just, J. Kerkmann, S. Rota,

A. Ratier, 2002: An Introduction to Meteosat Second Generation (MSG). *Bull. Amer. Meteor. Soc.,* **83**, 977–992

Schrage, J. M., and A. H. Fink, 2012: Nocturnal continental low-level stratus over Tropical West Africa: Observations and possible mechanisms controlling its onset, *Monthly Weather Review*, doi: 10.1175/MWR-D-11-00172.1, in press