Climatologies of ultra-low clouds over the southern West African monsoon region and their representation in WRF

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MOTIVATION

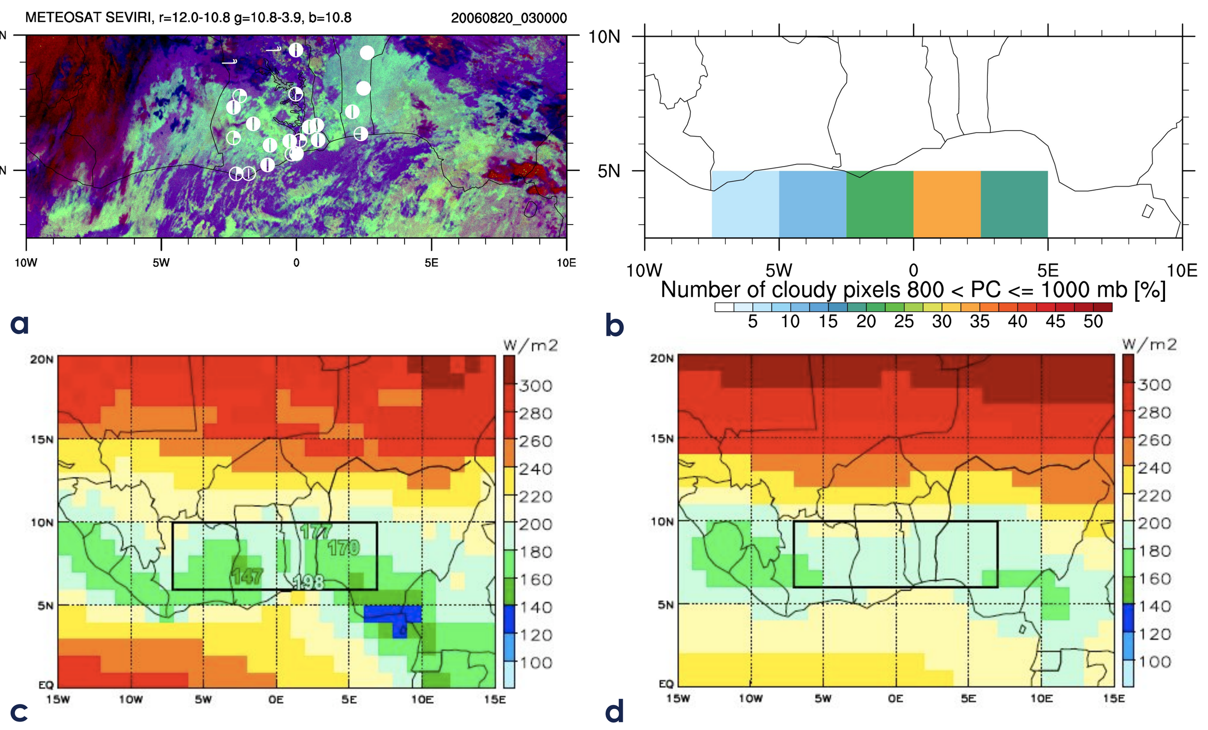

Figure 1: (a) 20 August 2006 MSG SEVIRI **R**ed **G**reen **B**lue (RGB) composite at 0300 UTC with ground observations of low-cloud cover in octas and (b) ISCCP D1 3-hourly mean low-cloud cover [%] centered on 0300 UTC. In (a) low clouds appear greenish. (c) Summer (JAS) climatologies of solar irradiance [W/m²] at the surface from GEWEX satellite data 1983-2007 and four ground station observations plotted as numbers and (d) CMIP3 mean solar irradiance [W/m²] at the surface (19 models) for 1961-1999 (Knippertz et al. 2011).

- A shallow, non-precipitating nocturnal stratus cloud deck is frequently observed in southern West Africa during the summer monsoon (Fig. 1a).
- Satellite observations of stratus are challenging (Fig. 1b).
- Large impact of stratus cloud decks on solar irradiance due to late dissipation during daytime (Fig. 1c).
- Insufficient representation in global climate models that show a positive solar radiation bias over southern West Africa (Fig. 1d).
- Proposed dynamics of the formation of stratus cloud decks: Vertical mixing and ensuing turbulence by **n**ight-time **l**ow **l**evel **j**et (NLLJ) (Schrage and Fink 2012; see also Fig. 4).

OBJECTIVES

- Set up of a multi-year stratus cloud climatology with suitable remote sensing methods.
- Extend the observational work of Schrage and Fink (2012) by a modelling approach using the **W**eather **R**esearch and **F**orecast model (WRF) to gain further insights into processes of genesis and lysis of ultra-low stratus cloud decks over West Africa.

OBSERVATIONS OF STRATUS

- Satellites:
  Advantages: High temporal resolution, large spatial coverage, and information about vertical structure.
  Disadvantages: Short observation periods, problems with high and upper level clouds, sampling problems.
- Surface stations: Eye observations by observers of synoptic stations.
  Advantages: Long-time series available, no problems with upper- and mid-level clouds.
  Disadvantages: Subjective, problematic during darkness, insufficient spatiotemporal coverage.

Objective: To investigate which combination of satellite platforms and derived satellite products is best suited to set up a climatology of ultra-low clouds in southern West Africa.

Comparison of MSG SEVIRI and CloudSat/CALIPSO merged product

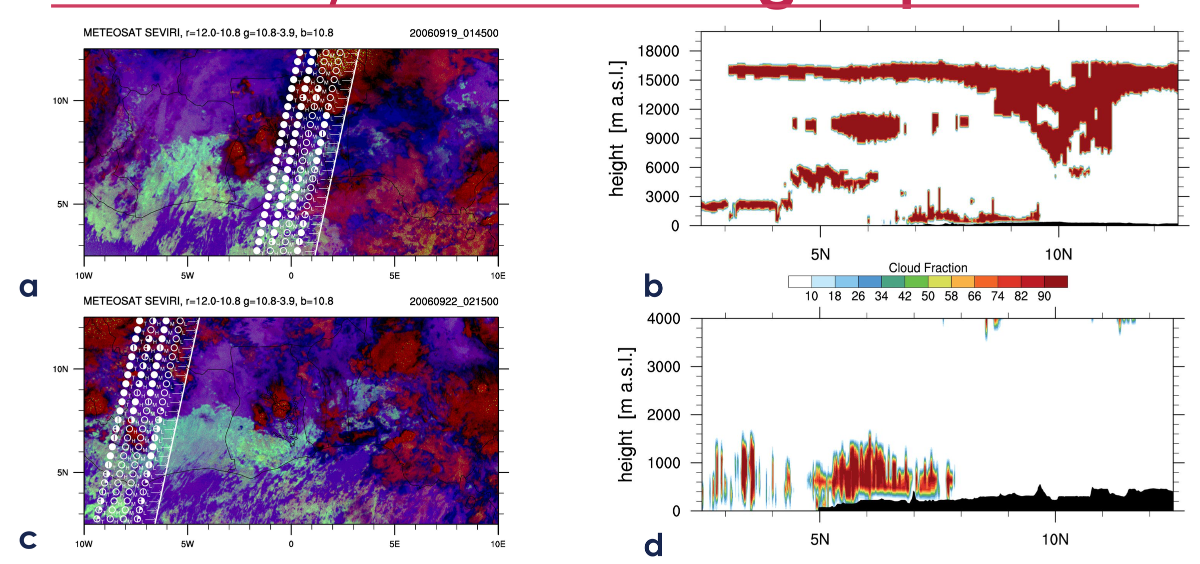

Figure 2: Two cases of low cloud cover at the Guinea Coast: MSG SEVIRI RGB composites for (a) 19 Sept. 2006 0145 UTC and (c) 22 Sept. 2006 0215 UTC with **t**otal (T), **h**igh (H), **m**iddle (M), and **l**ow (L) cloud cover (from left to right) from CloudSat/CALIPSO merged product (2B-GEOPROF-LIDAR) in octas and corresponding cross sections of merged CloudSat/CALIPSO cloud fractions [%] (b) and (d), respectively.

- **M**eteosat **S**econd **G**eneration (MSG) SEVIRI is a passive, geostationary and CloudSat/**C**loud-**A**erosol **L**idar and **I**nfrared **P**athfinder **S**atellite **O**bservations (CALIPSO) are active, polar-orbiting remote sensing instruments.
- MSG SEVIRI produces a full disk image every 15 minutes, whereas CloudSat/CALIPSO overpasses the region between approx. 0115 and 0130 LT.
- CALIPSO can detect small droplets, but cannot detect lower level clouds overlaid by optically thick clouds.
- CloudSat signals can penetrate through thick clouds.
- Ground clutter prohibits stratus detection with CloudSat in the lowest kilometer above ground.
- Thus, ultra-low level clouds are detected by the CloudSat/CALIPSO merged product (2B-GEOPROF-LIDAR) only in cases of optically thin higher level clouds or in cases of cloud base heights of more than one kilometer above ground (Fig. 2b/d).
- MSG SEVIRI cannot detect stratus clouds overlaid by higher level clouds (Fig. 2a/c).

SAFNWC Cloud Type

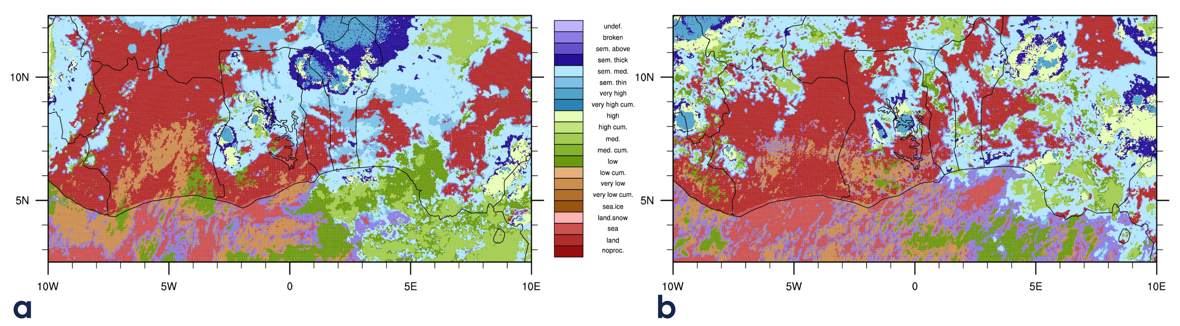

Figure 3: The same examples as in Figure 2 for the SAFNWC cloud type classification algorithms. (a) 19 Sept. 2006 0145 UTC, (b) 22 Sept. 2006 0215 UTC (source: AMMA database).

- Algorithm by the **S**atellite **A**pplication **F**acility on Support to **Nowc**asting and Very Short Range Forecasting (SAFNWC; Derrien & Le Gléau 2005).
- Multi-spectral threshold technique used for a cloud type classification of pixels that are flagged as cloudy by a cloud mask algorithm.
- The SAFNWC cloud classification algorithm has apparently deficiencies in detecting the extent of low-level clouds at night (cp. Fig. 2 & Fig. 3; SAFNWC 2012). It is hoped that for the period 2006-2011, enough nights with good low-level cloud coverage can be detected to create a climatology of the nocturnal spread of low-level clouds into southern West Africa.

SUMMARY

- CloudSat/CALIPSO merged product (2B-GEOPROF-LIDAR) is best suited for setting up a climatology of ultra-low clouds - including vertical structures.
- In a multi-year period, climatologies of the formation and dissipation of the stratus clouds can likely be inferred from the SAFNWC cloud classification based on MSG SEVIRI – provided that a sufficient number of cases with low mid- and high-level cloudiness can be detected.

SIMULATED FORMATION

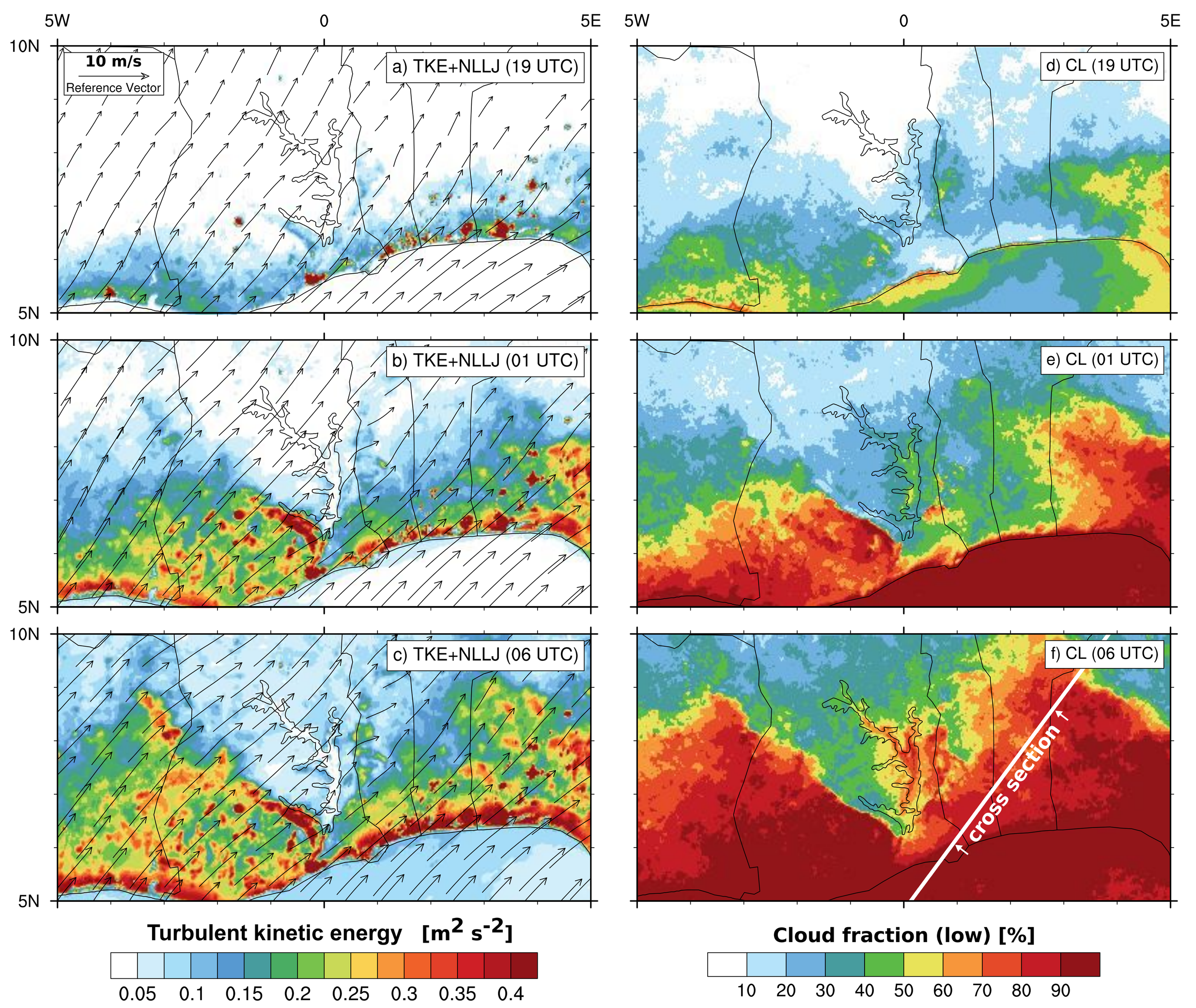

Figure 4: (a-c) Turbulent kinetic energy per unit mass, mass-weighted average over the lowest ten model layers (approx. 600 m a.g.l.). Arrows represent the wind speed maximum of the **n**ight-time **l**ow **l**evel **j**et (NLLJ). (d-f) Spatial distribution of low level clouds (CL). All values represent averages over 90 WRF simulations. The position of the cross section shown in Figs. 5-7 is illustrated by (f).

- WRF was used to simulate the stratus formation process during the summer monsoon 2006 (July, August, and September).
- 90 simulations were performed, each starting at 12 UTC, then six hours nudging, then 48 hours free simulation. The AMMA reanalysis was used for initialization and boundary conditions.
- The configuration was determined by an extensive sensitivity study.
- The results are strongly influenced by the land surface model and the vertical resolution in the boundary layer. See Table 1 for details of the WRF configuration.
- The modelled formation of the stratus and the representation of the **n**ight-time **l**ow **l**evel **j**et (NLLJ) are consistent with observations.
- The stratus forms at the coast and spreads inland in the course of the night (Fig. 4).

Table 1: WRF configuration used for all simulations.

Parameterization	Description
Horizontal Res.	Two-way nesting: 9km / 3km
Vertical Resolution	70 Layer, 20 of them below η = 0.8
Boundary Layer	MYNN2: Mellor-Yamada Nakanishi and Niino Level 2.5
Surface	Noah: Noah Land Surface Model
Microphysics	MOR2: Morrison double-moment
Radiation (SW/LW)	RRTMG: Rapid Radiative Transfer Model for Global Climate Model Applications
Convection	Grell 3d: Grell-Devenyi (GD) ensemble scheme (only active in parent domain)

ANALYZED PROCESSES

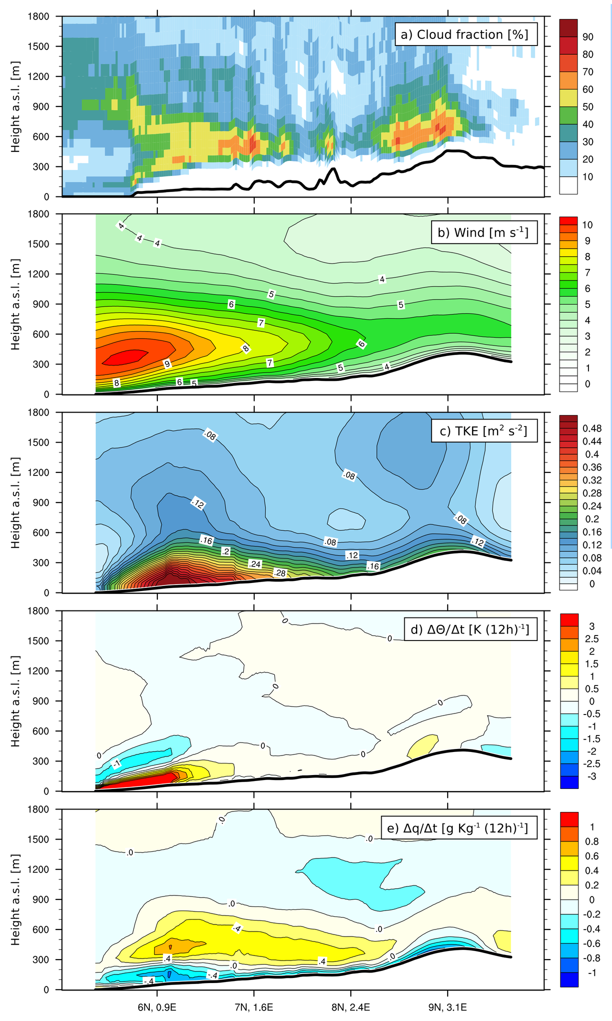

Figure 5: Cross sections along the white line in Fig. 4f, all values shown represent averages over WRF simulations with a domain averaged low cloud fraction larger than 66.6% at 06 UTC (49 simulations). A running mean over 33 grid points (approx. 99 km) was applied in panels (b)-(e). (a) Cloud fraction (06 UTC), (b) wind speed (avg. 18 UTC – 06 UTC), (c) turbulent kinetic energy (avg. 18 UTC – 06 UTC), tendencies caused by turbulent mixing (sum 18 UTC – 06 UTC) of (d) potential temperature and (e) specific humidity.

- Contributions of sub-scale processes, as well as grid scale advection were examined.
- Tendencies of these processes were summed up from 18 UTC to 06 UTC (Figs. 5 and 6).

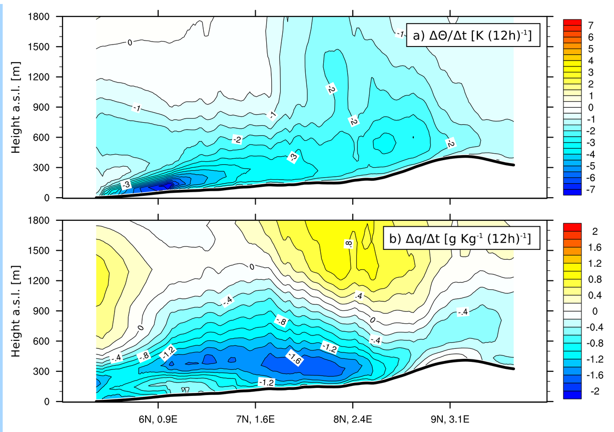

Figure 6: Cross sections along the white line in Fig. 4f, calculated as in Fig. 5b-e. Tendencies caused by grid scale advection (sum 18 UTC – 06 UTC) of (a) potential temperature and (b) specific humidity.

SUMMARY

Essentially, the following processes are involved in the formation of the stratus deck (Fig. 7):

- Upward-oriented flux of latent heat and downward-oriented flux of sensible heat, both caused by shear-driven turbulence below the **n**ight-time **l**ow **l**evel **j**et (NLLJ).
- Cold air advection from the ocean and/or forced lifting at the windward side of orography.

The stratus is not simulated in regions north of the mountain ranges because of:

- High stability inhibits shear-driven turbulence, the critical Richardson number is not reached.
- The clouds at the lee sides of the small mountain ranges are dissipated by Foehn effects.

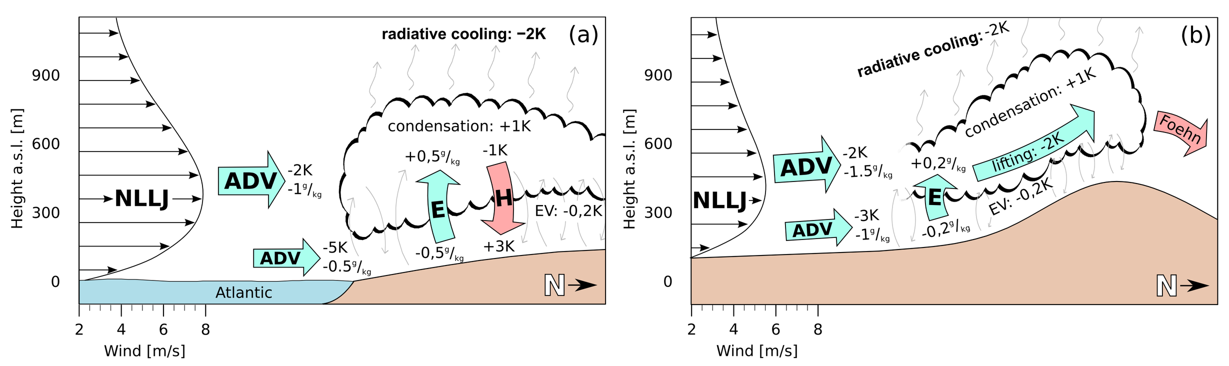

Figure 7: Schematic illustration of the stratus formation along the cross section shown in Fig. 4f. (a) for the first maximum in the cloud fraction shown in Fig. 5a between 6 and 7°N and (b) for the second maximum between 8.5 and 9°N. Abbreviations: ADV: Advection; E: latent heat flux; H: sensible heat flux; EV: Evaporation.

CONCLUSIONS AND OUTLOOK

- **The CloudSat/CALIPSO merged product (2B-GEOPROF-LIDAR) is the best suited satellite product, followed by the SAFNWC cloud type product based on MSG SEVIRI.**
- **A 6-year climatology will be created based on composites of CloudSat/CALIPSO & SAFNWC products.**
- **WRF is able to reproduce the formation process of ultra-low stratus clouds over southern West Africa, which is strongly connected to the night-time low level jet (NLLJ).**
- **Future work should focus on (a) the dissipation process, (b) the influence of the stratus on the energy and moisture budgets, and (c) on the West African monsoon system as a whole.**

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