



Weather types organize fog and low-cloud variability along the South-Western African coastline

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Abstract. The hyperarid Namib Desert relies on fog and low clouds (FLCs) as a critical water source, a role likely to grow in importance under a warmer, drier climate. While the climatological mean conditions favoring FLC formation are well understood, its day-to-day drivers are less clear. FLCs have been linked to transient synoptic-scale disturbances, but previous studies relied on two-state (e.g. fog versus clear-sky) composites, which mixed different synoptic states and could not resolve a disturbance's evolution across the coast. To fill this gap, we extend an existing weather-type (WT) classification of the south-eastern Atlantic atmospheric circulation to the full annual cycle, and combine it with 22 years of satellite FLC observations, ERA5 reanalysis, and more than a decade of station observations. We find that in the Namib, FLC occurrence is strongly tied to the life cycle of eastward-propagating mid-latitude disturbances, that drive long-range moisture transport ahead of mid-latitude troughs, and favor free-tropospheric drying and boundary-layer deepening on their rear flanks. This response persists for around three days and is state-dependent, varying with season and latitude. Along the south coast where radiation and advection-radiation fog rather than stratus-interception fog dominate, FLC occurrence instead responds oppositely to the same weather types, pointing to a systematic link between dominant fog type and synoptic sensitivity. These results establish transient mid-latitude disturbances as a unifying, multi-scale control on Namib fog variability and a physical basis for anticipating its response to future circulation change.

1 Introduction

The hyperarid Namib Desert (hereafter the Namib) is a roughly 2,000 km long coastal desert and one of the driest regions on Earth. It is bounded by the Atlantic Ocean with its cold Benguela current to the west and the Great Escarpment to the east (Fig. 1a). Within this roughly 120–200 km wide desert, precipitation is rare with around 15–25 mm in its hyperarid core in the central Namib (Lancaster et al., 1984; Eckardt et al., 2013) and fog constitutes the only reliable water source enabling life for many plant and animal species (Hamilton and Seely, 1976; Seely, 1979; Ebner et al., 2011, 2025; Mitchell et al., 2020). With climate projections suggesting a warmer and even drier future for southern Africa (Munday et al., 2025), the region's comparatively resilient fog system (Mass et al., 2026b) may become an even more important water source. Despite



this ecological importance, the mechanisms driving day-to-day fog and low-cloud variability along the south-western African coastline remain incompletely understood.

25 In the Namib, fog occurs throughout the year. In situ observations of local meteorology and fog have led to the distinction of two fog types that occur regularly in the region: advection fog and high fog (Seely and Henschel, 1998). Advection fog forms at the surface when a warm and moist air mass passes over a cool ocean (Gultepe et al., 2007) and is then advected onshore. It has been reported that advection fog occurs on more than 100 days per year at the coast (Seely and Henschel, 1998), but the occurrence of advection fog is confined to a narrow coastal region of a few kilometers. While measurements of the immediate
 30 coastal environment are sparse, existing station observations indicate that advection fog peaks during fall and winter (Lancaster et al., 1984; Formenti et al., 2019; Mupambwa et al., 2025), in agreement with offshore ship observations of sea fog (Dorman et al., 2019). Further inland, fog occurs when advected marine stratus clouds intercept the terrain ('high fog'; Seely and Henschel 1998), with cloud base height determining the spatial fog distribution (Andersen et al., 2019; Malik et al., 2026b). Stratus-interception fog peaks 25–45 km away from the coastline at altitudes of 200–400 m above sea level, creating a fog belt.
 35 Marine stratus frequency and altitude feature seasonal cycles, with a moister and deeper coastal boundary layer during summer leading to stratus-interception fog peaking in frequency and inland extent during this time (Andersen et al., 2019; Malik et al., 2026a). Analyses of stable fog water isotopes have been interpreted as an indication for the presence of radiation fog (Kaseke et al., 2017, 2018), i.e., fog forming locally at the land surface due to radiative cooling under clear-sky conditions (Gultepe et al., 2007). However, measurements of stable water isotopes are ambiguous with respect to fog-formation mechanisms; it is
 40 therefore assumed that fog in the Namib forms primarily over the ocean and is advective in nature, as suggested by the other observations. At Cape Town, at the south-western edge of the African coast, however, radiation fog and radiation-advection fog have been reported to dominate (Van Schalkwyk and Dyson, 2013). This study focuses on the Namib, with the south coast, where a different fog type dominates, serving as a contrasting case to test whether synoptic sensitivity depends on fog type.

The large-scale climatological conditions along the south-western African coastline favor the formation of fog and low
 45 clouds (FLC). These are mainly the low sea-surface temperatures of the Benguela upwelling system, which, together with the large-scale subsidence, create a shallow marine boundary layer that is capped by a strong and low-lying inversion, typical of continental west coasts (Wood and Bretherton, 2006). These FLC-controlling factors have recently been shown to largely drive the interannual fog and low cloud variability along the coast (Mass et al., 2026a). At a regional scale, the Namib features distinct thermotopographic winds that drive pronounced diurnal boundary-layer oscillations (Tyson and Seely, 1980; Lindesay
 50 and Tyson, 1990) and have been linked to fog occurrence (Seely and Henschel, 1998; Spirig et al., 2019). A coastal south-westerly sea breeze carries advection fog onshore, while a north-westerly plain-mountain wind transports marine stratus inland. Its nocturnal reversal, a south-easterly mountain-plain wind, can block or mix with the advected marine boundary layer. These winds follow a regular diurnal and seasonal rhythm with onshore flow strongest in summer during daytime, and offshore flow strongest during winter nights. These oscillations are only sporadically interrupted by a hot, dry easterly bergwind (Lindesay
 55 and Tyson, 1990; Seely and Henschel, 1998). While these aspects of the regional climatology are connected to FLC occurrence along the coastline, they cannot explain its substantial day-to-day variability.

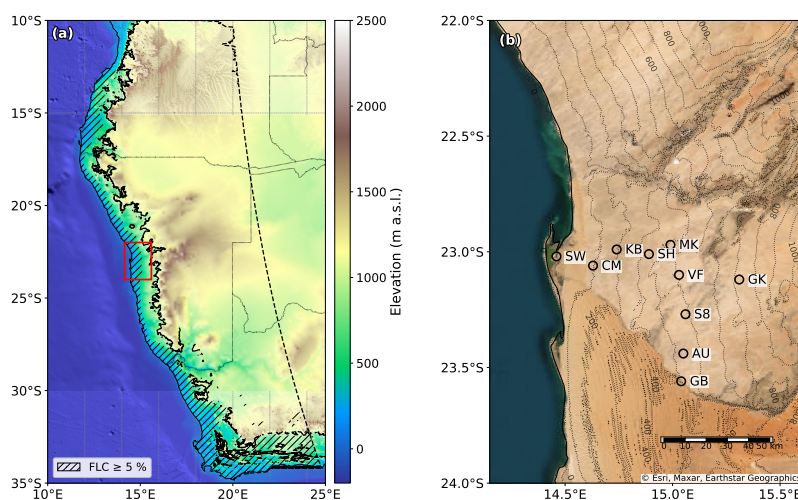


Figure 1. Overview over the study domain. a) The topography of southern Africa, the black solid line indicates 1000 m altitude in coastal vicinity (200 km) to indicate the Great Escarpment. The dashed line indicates the region of the Satellite fog and low cloud detection technique by Andersen and Cermak (2018), and the hashed regions indicate climatological fog and low cloud occurrence $> 5\%$. The red box shows the central Namib that is shown in more detail in b) where the locations of FogNet stations are highlighted.

Day-to-day FLC variability in the Namib has been linked to transient synoptic-scale disturbances (Andersen et al., 2020). FLC days and clear days differ significantly in air mass, surface pressure and temperature, and free-tropospheric geopotential and moisture, suggesting that mid-latitude troughs facilitate FLC occurrence and establishing such disturbances as a first-order control on Namib FLCs. This is a notable result given the region's subtropical location, where the climatological circulation is dominated by the South Atlantic High rather than the mid-latitude storm track. Two mechanisms have been proposed that link synoptic-scale perturbations to FLCs: first, a drier free troposphere facilitates longwave cloud-top radiative cooling that maintains clouds. Second, modulated coastal wind anomalies alter onshore advection of marine air. This process is reinforced during April–June by free-tropospheric moisture transport into the continental interior that leads to a heat-low anomaly, reinforcing onshore advection. Backward-trajectory analysis further showed that the marine air masses advected onshore on FLC days are consistently moister than those on clear days over the preceding 24 hours, implying a longer-range, upstream moistening of the boundary layer (Andersen et al., 2020). However, how this is linked to the synoptic-scale perturbation itself has not yet been established. More recently, Hipler et al. (2026) reported that coastal stratus altitude, which determines fog patterns (Malik et al., 2026b), is also largely controlled by synoptic-scale mechanisms. Comparing nights with fog vs. nights with elevated stratus, Hipler et al. (2026) found that a stronger South Atlantic High is associated with a deeper marine boundary layer and elevated stratus, with the deeper boundary layer driven by strengthened upstream cold-air advection. However, the two-state (FLC versus clear, fog versus elevated stratus) composite analyses of Andersen et al. (2020) and Hipler et al. (2026) necessarily mix many different synoptic configurations together and cannot resolve how a given disturbance evolves as it approaches, crosses, and recedes from the coast.



75 This study addresses that gap by extending an existing regional weather-type classification from Gaetani et al. (2021),
 developed originally for austral-winter biomass-burning transport, to the full annual cycle, and applying it to better understand
 and resolve the temporal sequence of synoptic-scale FLC forcing and how it depends on season and latitude. The research
 question of this study is: How are day-to-day patterns of fog variability along the south-western African coast related to
 transient mid-latitude weather types? The underlying hypothesis is that mid-latitude trough passage drives Namib FLCs through
 80 a phase-dependent sequence: the trough's leading sector leads to long-range transport of moisture into the marine boundary
 layer, while its trailing sector combines a dry free troposphere that facilitates longwave radiative cooling with near-surface
 cold-air advection that increases boundary-layer depth, jointly governing fog variability by controlling marine stratus amount
 and altitude.

2 Data and Methods

85 2.1 Satellite observation of FLCs

FLCs along the south-western African coast are observed using data from the Spinning Enhanced Visible and Infrared Imager
 (SEVIRI) sensor, mounted on the geostationary Meteosat Second Generation (MSG) satellites. The sensor has a spatial
 resolution of 3 km at nadir, and scans its full hemispheric disc every 15 minutes (Schmetz et al., 2002). In this study, 22
 years (2004–2025) of SEVIRI data are used to detect FLCs with the algorithm developed by Andersen and Cermak (2018).
 90 The algorithm uses only data from the thermal infrared bands and involves several spectral threshold tests to screen out high
 clouds and land surfaces, and a structural similarity test that compares each individual scene to that of a clear-sky composite
 to further separate FLCs from the land surface. This leverages the temporally constant but spatially heterogeneous thermal
 infrared pattern of the bare desert surface and enables the separation of FLCs from the land surface despite their similar
 spectral signature in these wave lengths. The algorithm has been extensively tested against FogNet station observations in the
 95 Namib (see Fig. 1b for an overview of the stations) and shown to have a good performance (97 % classification accuracy). For
 the analysis, a daily mean FLC cover is calculated using a noon-to-noon day definition as fog is a nocturnal event (Andersen
 and Cermak, 2018).

2.2 FogNet Station Data

To assess how regional fog patterns in the central Namib relate to weather types at station level, data from 10 FogNet stations
 100 are used. The stations are aligned in a north-south transect and a west-east transect (cf. Fig. 1b), cover an altitude range of
 5-733 m a.s.l., and were set up in the framework of the Southern African Science Service Centre for Climate Change and
 Adaptive Land Management (SASSCAL) initiative to study fog processes in the region (Kaspar et al., 2015). Since 2014,
 FogNet stations measure standard meteorological variables (relative humidity, air temperature, radiation and wind) at 1 minute
 resolution and additionally measure passive fog collection with Juvik-type fog collectors (Juvik and Nullet, 1995). These fog
 105 collectors comprise a louvered aluminium cylinder that is mounted above a tipping-bucket rain gauge. Fog water running off



from the collector into the rain gauge is registered in discrete 2 ml increments. The instrument includes a protective rain shield that reduces radiative cooling of the mesh to suppress dew formation on the collector. Here, Juvik fog collector data are used for the period of 2014 to 2025 to define fog days (noon-to-noon) at station level, i.e. days when any amount of fog water was collected. At some stations, substantial data gaps in the observational records exist, which are removed from the analysis. A full overview of the data availability is shown in Fig. A1. At the coastal station Saltworks, fog-water measurements are subject to larger uncertainties than at the other stations: the tipping-bucket mechanism of the original rain gauge failed repeatedly in the first years of operation and was replaced by a gauge with a plastic tipping bucket in July 2018. Such malfunctions can cause fog events to go undetected, whereas the registration of fog water when no fog occurred is not expected. Fog-day frequencies at Saltworks are therefore more likely to be underestimated than overestimated, and the record should be interpreted with caution.

2.3 ERA5 reanalysis

Meteorological variables from the fifth generation ECMWF reanalysis (ERA5; Hersbach et al. 2020), available at hourly time steps and 0.25° horizontal resolution, are used to classify the atmospheric circulation into weather types (WTs) for the period 1979–2025, and to characterize the meteorological conditions associated with each WT over the period when the satellite FLC product is available (2004–2025). Meteorological variables that capture atmospheric dynamics or are relevant for FLCs and marine boundary layer development are assessed: geopotential height (Z) at 850 and 700 hPa, specific humidity (Q) and winds (U and V components) in the boundary layer and free troposphere (950 and 700 hPa), sea surface temperature (SST), 2 m air temperature (T2m), mean surface latent heat flux (LHF), boundary layer height (BLH) and lower tropospheric stability (LTS) computed as the difference between potential temperature at 700 hPa and T2m. All data are used at 6 UTC when FLC frequency is close to its daily peak (Andersen and Cermak, 2018).

2.4 Weather type classification

Here, we adapt the WT classification defined by Gaetani et al. (2021), which was successfully designed to analyze wintertime aerosol transport and its link with mid-latitude transient circulations in coastal Namibia. The original classification consists of a k-means clustering applied to geopotential height anomalies at 700 hPa, and was performed at daily resolution over the period August–September–October 1981–2017 in the domain 20°W–40°E, 40°S–Equator (the reader is referred to Gaetani et al. (2021) for details on the method). The original six centroids are reused to extend this classification to the whole year and the period 1979–2025, at 6-hourly time steps. This is achieved by ascribing each instantaneous anomaly field to the nearest centroid, using Euclidean distance as a dissimilarity metric. Prior to the analysis, we verified (i) that distance statistics do not show spurious values or statistically different distributions (two-tailed t-test at $p < 0.05$) between the shorter period used for defining the clusters, and the extended period used in this analysis, especially for seasons and years not considered in Gaetani et al. (2021): see appendix Fig. B1; (ii) that these distances are not statistically larger than those from a new clustering applied to the whole period (using a t-test at the 95% confidence level); and (iii) that the composite mean anomaly fields associated with the clusters over the entire period are similar to the original ones (appendix Fig. B2). This procedure, which fully satisfies



these three criteria, allows us to obtain clusters that are comparable to those already presented in the literature. In this study, we use the 6 UTC time slots that falls into a noon-to-noon day to define the daily WT.

140 2.5 Composites and anomaly calculations

For every weather type (WT) k , composite anomalies are computed by subtracting a smooth climatological annual cycle from each field's time series and averaging the resulting residual over all days (or synoptic time steps) classified as WT k . The annual cycle is estimated at every grid point (or, where noted below, along-coast bin or station) by a least-squares fit of a three-harmonic Fourier series to the full multi-year record. For the ERA5 fields, which retain a diurnal cycle at their native
 145 hourly resolution, this fit is performed separately for each hour to avoid mixing diurnal and seasonal variability. Statistical significance is assessed with a two-sided, one-sample t -test of each WT's composite-mean residual against a null of zero, at $p < 0.01$.

This deseasonalized approach is used for the all composites and is employed because the WTs feature a seasonal cycle, which would bias a direct comparison of one WT vs. all others. For the FLC composites (Fig. 3), grid cells whose full-record
 150 climatological mean FLC frequency is below 3 percentage points are excluded from the significance test, to avoid flagging spurious "significant" anomalies in areas that are almost never foggy. For the day-by-day evolution composites, WT onset is defined as the first day of a spell classified as the target WT, following at least two preceding days classified as a different WT. The seasonal cycle of the FLC response to WTs is assessed in the same way, applied to FLC averaged within 0.5° along-coast bins (extending 50 km inland from the coastline, cf. appendix Fig. D1) and composited separately for each calendar month
 155 rather than for the full record or by season, in order to resolve the annual cycle of the WT-FLC association itself.

3 Results and Discussion

Figure 2 shows composite mean anomalies of geopotential height at 700 hPa (Z_{700}) for each of the six weather types (WTs). Two WTs capture variability of the subtropical South Atlantic high-pressure system: SA+ is characterized by a strengthened high-pressure anomaly over the South Atlantic toward the south-western African coastline, accompanied by a more pronounced
 160 midlatitude westerly flow, whereas SA− corresponds to a strengthened South Atlantic High that is displaced southwestward, away from the continent. The remaining four WTs, ML1–ML4, represent the fingerprint of eastward-propagating disturbances of the westerly flow (Gaetani et al., 2021), i.e. the life cycle of transient Rossby waves as they traverse the domain, encompassing both trough and ridge phases. Individual WT occurrences are generally short-lived. ML1–ML4 typically persist 1–2 d before transitioning into the next stage of the wave's life cycle, following a preferred sequence of ML1 → ML2 → ML3 → ML4
 165 (transition probabilities given in appendix Table B1), consistent with the eastward propagation of the disturbance (Gaetani et al., 2021). SA+ and SA− tend to persist longer, with self-transitions around 60 % of the time (appendix Table B1). The two more persistent WTs SA+ and SA− occur more frequently during summer (Supp. Fig. B3) when the South Atlantic High is shifted towards the southeast (Sun et al., 2017), whereas WTs ML1–ML4 are slightly more frequent during winter when the

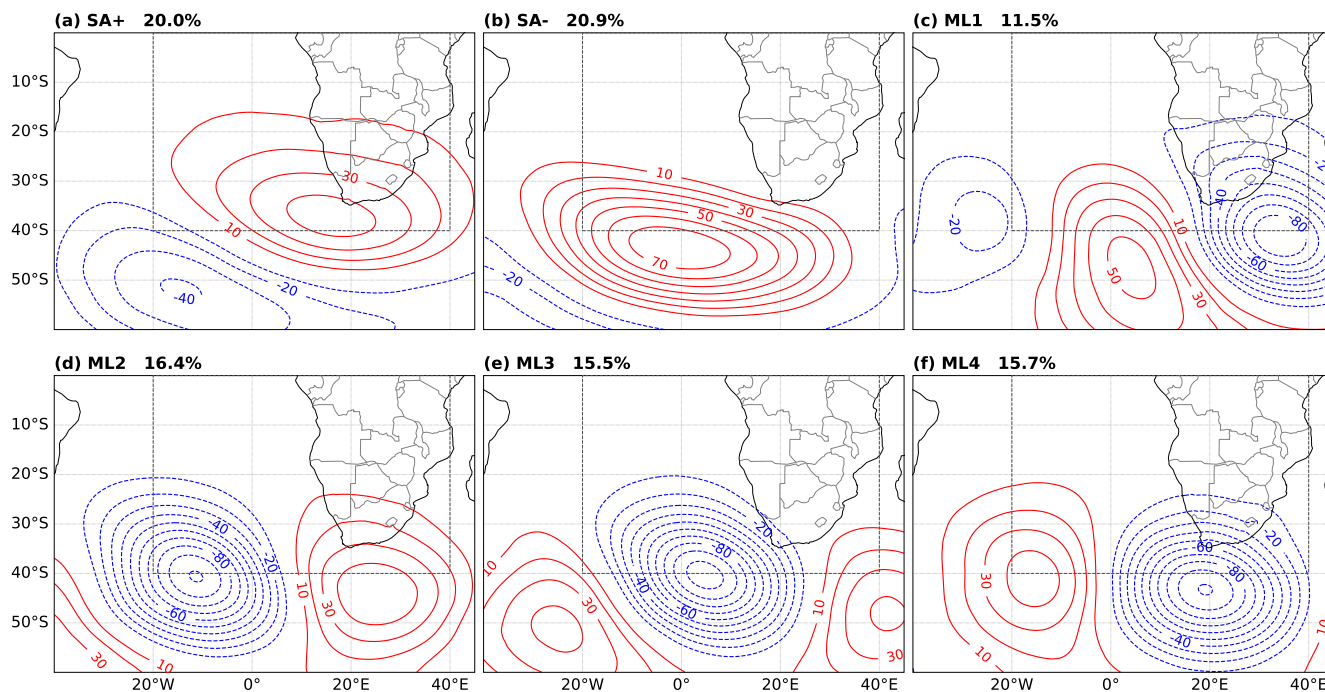


Figure 2. Composite mean anomalies of geopotential height at 700 hPa (Z_{700} , m) for each of the six weather types (WTs) following Gaetani et al. (2021), extended here to the full annual cycle (Sect. 2.4): (a) SA+, (b) SA-, (c) ML1, (d) ML2, (e) ML3, (f) ML4. Panel titles give each WT's relative occurrence frequency over the period of concurrent satellite FLC data (2004–2025). The domain used for the original WT classification by Gaetani et al. (2021) is highlighted by the dashed line.

mid-latitude's wave activity disperses further north (Nakamura and Shimpo, 2004). Building on this characterization, we next
 170 examine how FLC occurrence relates to each WT.

FLC occurrence along the entire south-western and southern African coastline is significantly related to the WTs, though
 the associations differ by coastline and sector (Fig. 3). Along the Namib, FLC occurrence increases during the passage of a
 midlatitude trough (WTs ML3→ML4→ML1), peaking when the trough is overhead (ML4). To a lesser extent and only in
 a central Namib sector between 20 and 28°S, FLC is increased during a southwestward-shifted South Atlantic High (SA–).
 175 ML2, the remaining WT in the wave cycle, instead represents its ridging-high phase and is associated with a significant
 decrease in FLC occurrence along the entire coastline. Along the southern coast, by contrast, FLC occurrence decreases as the
 trough approaches and passes overhead (ML3, ML4), but increases once the trough has passed (ML1) and during SA–. The
 mechanisms underlying these FLC-WT associations are explored and discussed in the following.

Figure 4 shows composite mean anomalies of geopotential height at 850 hPa (Z_{850}), specific humidity at 950 hPa (Q_{950}), and
 180 near-surface wind for each WT. A clear connection between the WTs and Q_{950} patterns is apparent: the marine boundary layer
 (MBL) is significantly moistened ahead of mid-latitude troughs and on the rear flank of ridges, and significantly dried ahead of
 ridges and on the rear flank of troughs. Near-surface wind anomalies accompany this moisture pattern: anomalously poleward

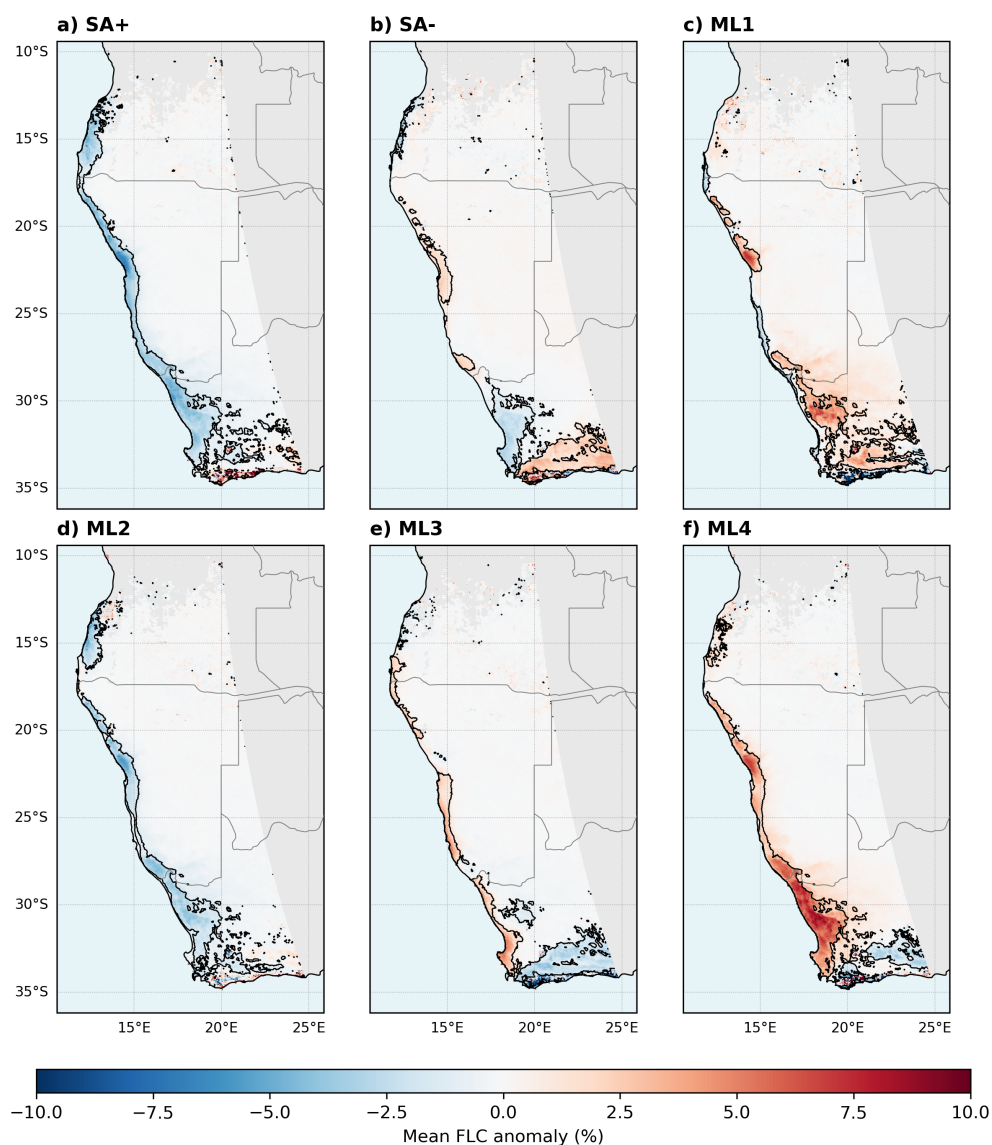


Figure 3. Composite mean anomalies of fog and low-cloud (FLC) occurrence along the south-western and southern African coastline for each of the six weather types (WTs), following the same panel–WT association as Fig. 2: (a) SA+, (b) SA-, (c) ML1, (d) ML2, (e) ML3, (f) ML4. The contours indicate statistically significant anomalies (one-sample t-test of the composite-mean residual against zero, $p < 0.01$) in regions where climatological FLC occurrence exceeds 3 percentage points.

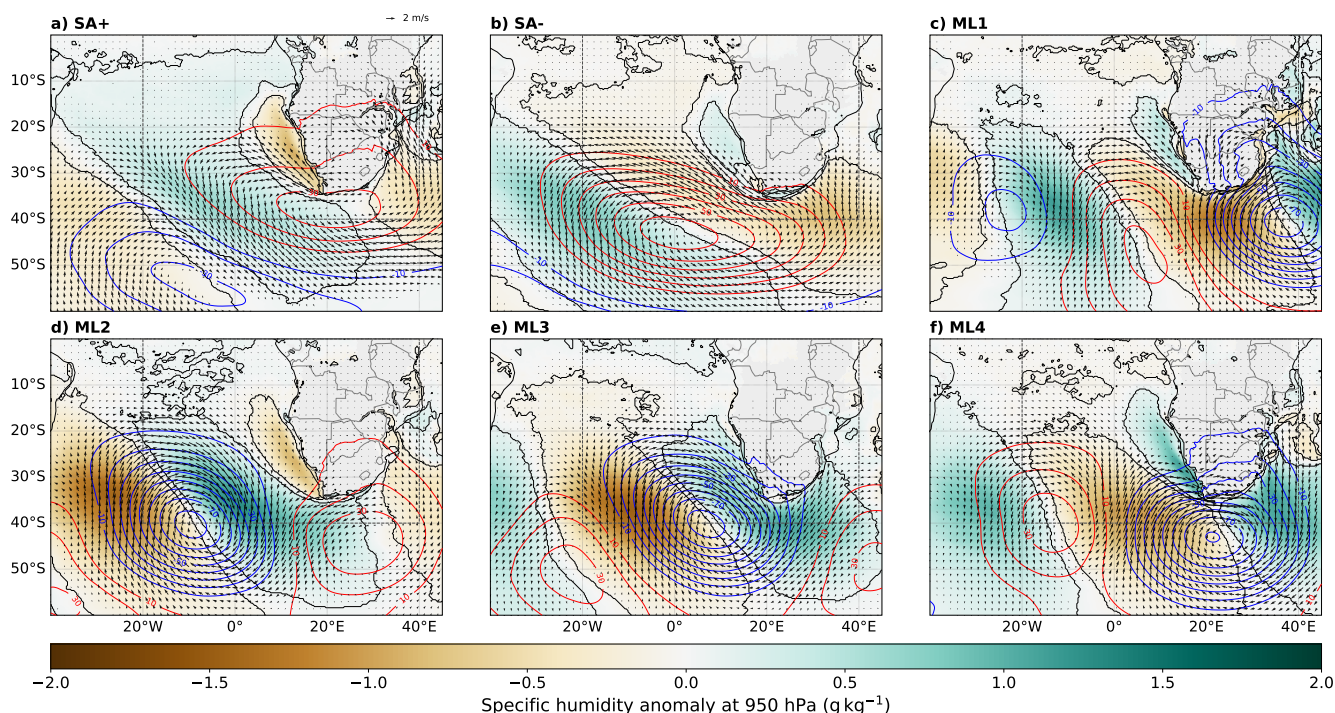


Figure 4. Composite mean anomalies of geopotential height at 850 hPa (Z_{850} , m; red positive/blue negative contours), specific humidity at 950 hPa (Q_{950} , g kg^{-1} , color), and near-surface wind (vectors) for each WT, following the same panel-WT association as Fig. 2. Anomaly calculation and significance testing follow Fig. 3; black contour lines outline regions of statistically significant Q_{950} anomalies ($p < 0.01$), and wind vectors are shown only where at least one wind component is significant at the same level. Grid points where the 950 hPa level lies climatologically below the surface are masked.

flow ahead of the trough, consistent with the moistening there, and anomalously equatorward flow on its rear flank, importing cooler, drier air from higher latitudes and consistent with the dry anomalies there. These wind anomalies are smaller than the climatological mean flow along the Namibian coastline ($7\text{--}10 \text{ m s}^{-1}$, Lima et al. 2019), and the MBL moisture anomalies move together with the systems rather than developing locally, pointing to long-range transport of MBL moisture ahead of the trough, rather than local, trough-driven import, as the origin of the coastal moisture anomaly. Viewing the progression of ML2 → ML3 → ML4 → ML1 as a trough cycle, the moist anomaly is already present offshore before the trough reaches the coast and is subsequently separated from the propagating system by the topographic barrier of the Great Escarpment (ML4), persisting at the coast rather than being advected onward with it (ML1). At the coast, the local wind anomaly opposes and weakens the climatological coast-parallel wind as the trough approaches, reducing ventilation of the marine boundary layer and allowing the imported moisture to persist rather than being flushed away. The upstream origin of this moisture is more speculative: one plausible interpretation is that it was picked up from the tropics earlier in the trough's life cycle and further west, where the northerly wind anomaly on the trough's leading flank would encounter a weaker climatological southerly wind.



195 These MBL moisture anomalies appear to directly connect the WTs to FLCs in the Namib: FLC increases where the coastal MBL is moistened, both during trough passage and during the southwestward displacement of the South Atlantic High (SA–). Together, these results suggest that MBL moisture supply from mid-latitude troughs is likely the primary factor governing marine stratus (and by extension stratus-interception fog) variability in the Namib. Independent support for this comes from Mass et al. (2025), who used statistical learning to attribute longer FLC persistence on days with high biomass-burning aerosol (BBA) loading in the Namib primarily to anomalies in MBL moisture and coastal circulation. The associated synoptic pattern in such days when BBAs are advected southwards towards the Namibian coastline (Fig. 4 in their paper) resembles the approaching-trough configuration identified here (WTs ML3/ML4), suggesting the same MBL-moistening mechanism may also underlie the longer fog persistence they observe under high-BBA conditions. The response along the south coast, where radiation and advection-radiation fog types dominate (Van Schalkwyk and Dyson, 2013), is opposite in sign (FLC reduced) for ML3 and ML4 (approaching and overhead trough). Here, FLCs are increased under SA– and ML1 (trough has passed). To investigate the underlying mechanisms further, we provide a more complete meteorological discussion of ML4 first and then SA– in the following.

Figure 5 shows the composite mean meteorological anomalies associated with ML4, the trough-overhead WT associated with the largest increase in FLC occurrence along the entire west coast. In addition to the increase in near-surface moisture (Q_{950}) along the coast, onshore advection of marine boundary layer air is pronounced in the coastal sector immediately north of the trough center, where the FLC response to ML4 is strongest, as already shown in Fig. 4. In addition, the free-tropospheric moisture (Q_{700}) is significantly decreased over the Namibian coastline north and northwest of the trough center, which facilitates cloud-top radiative cooling and helps maintain coastal stratus coverage, as described in Andersen et al. (2020). The stronger radiative cooling leads to a sharp land/ocean contrast in near-surface temperature anomalies along the coastline, which additionally acts to change regional-scale pressure gradients and can influence onshore advection of MBL air masses (Andersen et al., 2020). Over the ocean, SSTs are decreased on the rear flank of the trough where equatorward winds import cool surface water from the south, but also along the northern Namibian and Angolan coastline where the strengthening of the climatological coast-parallel wind likely acts to enhance upwelling and inhibit the southward intrusion of warm tropical water (Mass et al., 2026a). On the western part of the South African coastline, SSTs are increased, likely due to the onshore winds. On the rear flank of the trough and ahead of the ridge, cold and dry air is imported from the south, leading to significant increases in LHF, deepening the MBL in agreement with findings from Hipler et al. (2026). This tends to increase the altitude of the marine stratus deck, and subsequently for fog occurrence patterns in the Namib (Malik et al., 2026b; Hipler et al., 2026). While this trough passage generates fog along the west coast, it suppresses fog formation along the southern coast, where radiation fog and advection-radiation fog types dominate (Van Schalkwyk and Dyson, 2013). This is sensible as radiation fog requires calm conditions and strong radiative cooling, typically found under high-pressure conditions (Gultepe et al., 2007; Van Schalkwyk and Dyson, 2013), both of which are disrupted by the passing trough. In the following, the temporal evolution of the passing trough and its consequences for the coastal MBL are assessed in more detail.

The ± 2 -day evolution composite (Fig. 6) shows the geopotential height anomaly propagating eastward and strengthening throughout the 5-day window as the trough approaches and crosses the classification domain, migrating by roughly 45° in

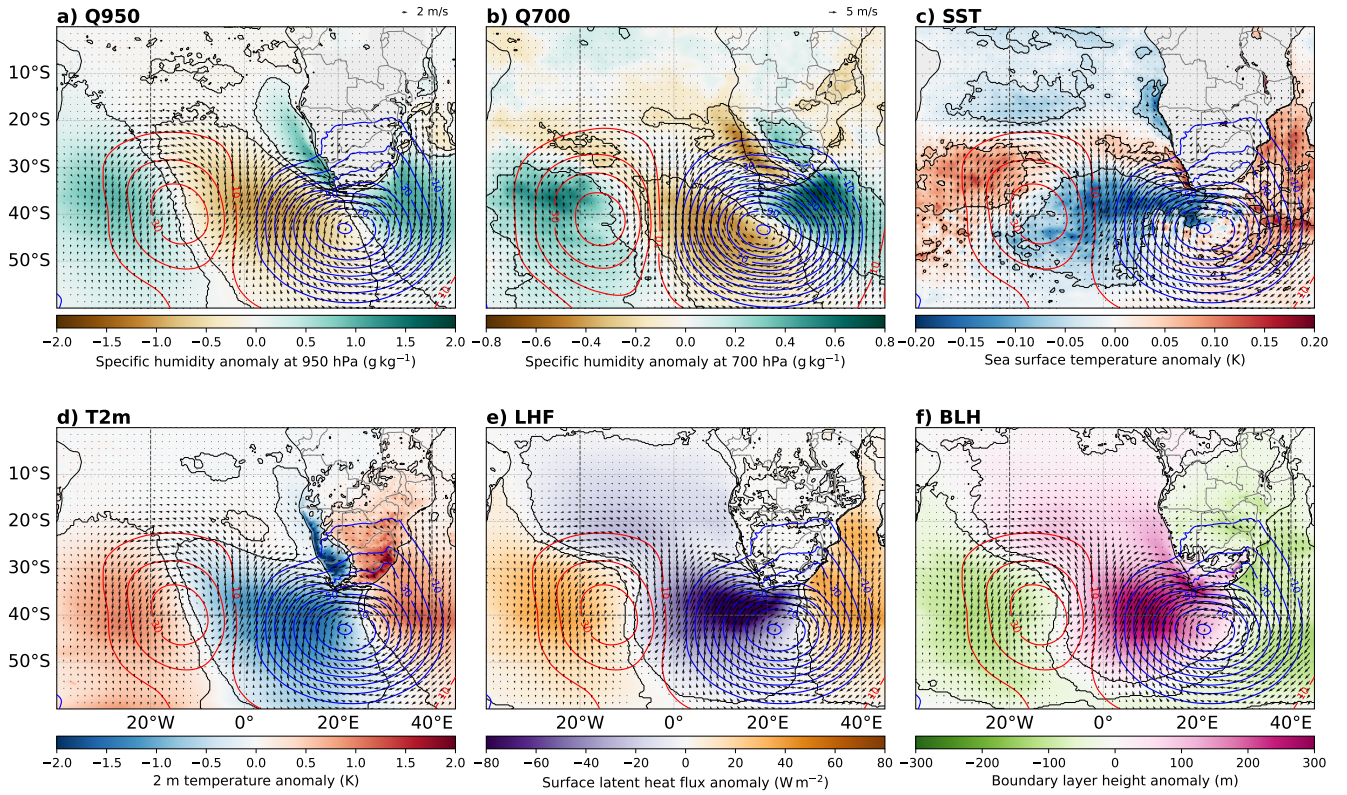


Figure 5. Composite mean anomalies of (a) specific humidity at 950 hPa (Q_{950} , g kg^{-1}), (b) specific humidity at 700 hPa (Q_{700} , g kg^{-1}), (c) sea surface temperature (SST, K), (d) 2 m air temperature (T_{2m} , K), (e) mean surface latent heat flux (LHF, W m^{-2}), and (f) boundary layer height (BLH, m) for WT ML4. Contours, wind vectors, and significance masking follow the same convention as Fig. 4: geopotential height anomalies (Z , red positive/blue negative contours) and wind anomalies (vectors, shown only where significant) are overlaid on each panel, with black contour lines outlining regions where the respective color field is statistically significant ($p < 0.01$). All panels show Z_{850} and near-surface (10 m) wind, except panel (b), which instead shows Z_{700} and 700 hPa wind alongside Q_{700} .

230 longitude over the period shown. The coastal MBL moisture anomaly (Q_{950}) is already present at day -2 , but remains offshore and out of contact with the coast. Only by day 0, as the trough reaches the continent, does the moist anomaly extend across the full coastal MBL. As the trough subsequently crosses the continent, this coastal part of its moisture anomaly is cut off from the system by the topographic barrier of the Great Escarpment and persists as a narrow band hugging the coastline over the following days, before the dry MBL anomaly on the trough's rear flank starts to displace it (day $+2$). At 700 hPa, the moist
 235 anomaly ahead of the trough is only weakly developed at day -2 and intensifies over the course of the trough's life cycle, while dry, cold air is imported from higher latitudes on the trough's southwestern (rear) flank. After the trough passes the continent, this dry anomaly intensifies on the northwestern flank as a dry intrusion over the coast. BLH anomalies evolve in step with this progression: the boundary layer is shallow ahead of the trough, within the warm and moist sector, and deepens on its rear flank



once the trough has passed, consistent with the enhanced surface fluxes driven by cold, dry advection there. Significant SST
 240 anomalies develop and strengthen alongside the propagating system as well, with a consistent dipole of warmer SSTs on the
 trough's northeastern (leading) flank and cooler SSTs on its rear flank. The corresponding evolution of FLC occurrence (Fig. 7)
 confirms that the trough-driven FLC enhancement persists for approximately three days on average before being replaced by the
 ridge-driven decrease. This pattern broadly follows the WT life cycle $ML3 \rightarrow ML4 \rightarrow ML1 \rightarrow ML2$ (trough approaching
 $\rightarrow$ overhead $\rightarrow$ passed $\rightarrow$ ridging high), though somewhat less pronounced, since the composite days on either side of
 245 onset are not themselves constrained to a single WT and therefore mix different WT states. This carries two implications for
 FLC occurrence in the Namib: while the trough is overhead, FLC increases despite locally warmer SSTs, indicating that the
 moisture-import controls described above dominate over the thermodynamic SST influence at this stage. Once the trough has
 passed, SSTs turn cooler along the coastline, particularly in the northern section of the Namib, where coast-parallel winds
 strengthen, possibly reflecting enhanced coastal upwelling. At the south coast, this rear flank of the trough leads to onshore
 250 advection over the cooler SSTs, and is associated with higher FLCs.

We now turn to SA-, a less obvious choice than ML4 at first glance, since it is not one of the explicitly trough-labeled WTs,
 but one that is responsible for an FLC increase along both the west and the south coast and, as its evolution reveals below,
 is itself driven by a trough-like disturbance. The Z anomaly evolution for SA- differs markedly from ML4: a weak trough
 ahead of the main ridge crosses the continent during days -2 and -1 , after which the ridge itself follows but propagates at
 255 roughly half the pace of ML4's trough and is stretched zonally (east-west) rather than migrating as a compact feature, as a
 consequence of the larger persistence of SA- (Fig. B3d). The coastal MBL is moistened by this weak leading trough at day
 -2 . As the ridge subsequently approaches, this persists as a slightly moister patch in front of the central Namibian coastline
 where the FLC increase under SA- is observed. South of $30^\circ S$ where SA- is associated with decreased FLC occurrence,
 by contrast, the southeasterly, offshore advection on the ridge's flank dries the coast on days 0 and $+1$. At the south coast,
 260 this same southeasterly wind anomaly translates into onshore advection over cool SSTs, and tends to lie beneath a dry free
 troposphere, similar to day $+1$ and $+2$ of ML4 (Fig. 6). This combination is consistent with the formation of radiation or
 advection-radiation fog known for this region. Aloft, the Q_{700} dipole associated with the system develops together with the
 ridge, with dry air on its southwestern flank and moist air to the northeast. Over the continent, a moistening at 700 hPa appears
 to develop locally rather than being advected, possibly indicating boundary-layer moisture being mixed upward into the lower
 265 free troposphere as ventilation weakens under the building ridge, though this interpretation remains speculative and is not
 directly tested here. BLH anomalies otherwise mirror the established pattern: the boundary layer deepens in the region ahead
 of the ridge, in the wake of the passing trough, consistent with the same cold, dry advection mechanism identified earlier. SST
 anomalies are particularly striking in this composite: at day -2 only a weak dipole is present, with slightly cooler SSTs ahead
 of the ridge and warmer SSTs on its rear flank, but as the ridge itself propagates so slowly, this pattern has time to develop
 270 and intensify over the following days, strengthening steadily through day $+2$, when significantly colder SSTs cover the ridge's
 entire northeastern flank, extending along the whole coastline and stretching out across the South Atlantic to within reach of
 South America. This slow build-up is consistent with a sustained wind-driven ocean response accumulating over the ridge's
 much longer residence time relative to ML4's faster-moving trough.

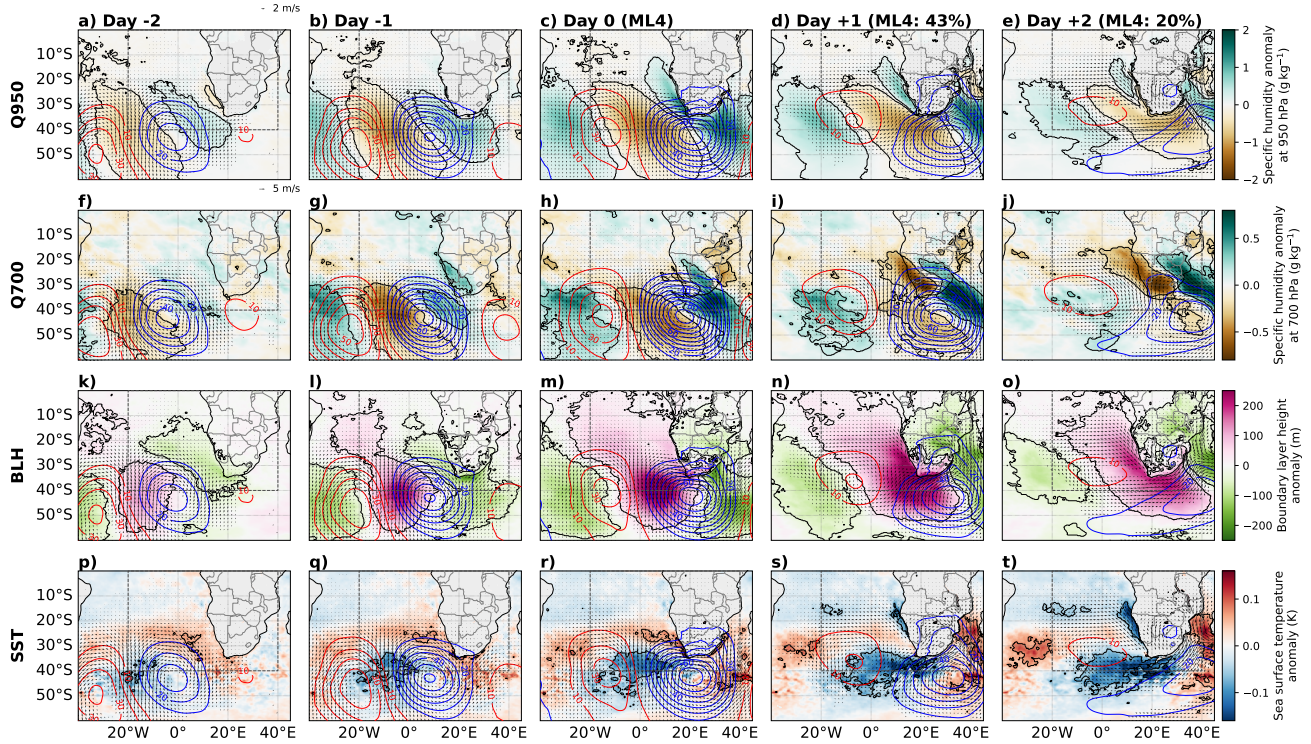


Figure 6. Temporal evolution of the composite anomalies shown in Fig. 5, over a 5-day window centered on ML4 onset (day 0). Rows show (top to bottom) specific humidity at 950 hPa (Q_{950} , g kg^{-1}), specific humidity at 700 hPa (Q_{700} , g kg^{-1}), boundary layer height (BLH, m), and sea surface temperature (SST, K); columns show day -2 , day -1 , day 0 (ML4 onset), day $+1$, and day $+2$. Day 0 is defined as the first day of every ML4 period in the record, with days -2 and -1 required to not themselves be classified as ML4; days $+1$ and $+2$ are left unconstrained and may still be ML4 if the WT persists, with the corresponding fraction annotated directly above each of those two columns. This yields $n = 658$ onsets, constant across all five columns by construction.

The response of FLCs in the central Namib to synoptic-scale disturbances has been shown to vary with season, as differences in large-scale meteorology between fog and clear days have been found to be more pronounced during winter (Andersen et al., 2020), which, in this region, is the season when FLC occurrence is at a minimum (Andersen et al., 2019). Here, we systematically assess the FLC response to WTs across seasons along the coastline (Fig. 9). In agreement with Andersen et al. (2020), FLC responses to WTs along the west coast are strongest during winter, in particular for WTs ML4 and SA+ north of 29°S . However, the trough position (WTs ML3 $\rightarrow$ ML4 $\rightarrow$ ML1) that maximizes the FLC response itself shifts with season and latitude. The arriving trough (ML3) is most impactful during late winter and early spring (July/August) in the northern part of the Namib, but also during summer south of 29°S . When the trough center is directly overhead/at the coast (ML4), FLC response peaks during winter north of 29°S , but is pronounced all year in the southern part of the west coast. The strongest FLC increase associated with a passing trough (ML1) occurs during October–April in northern parts of the coastline ($18\text{--}23^\circ\text{S}$).

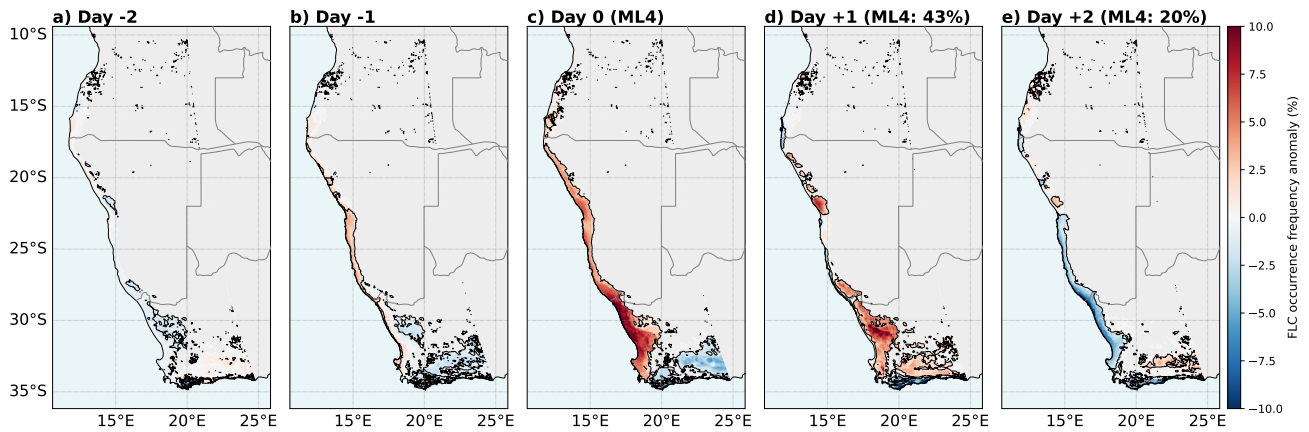


Figure 7. Temporal evolution of FLC anomalies (%) over a 5-day window centered on ML4 onset (day 0). Columns and data selection as in Fig. 6.

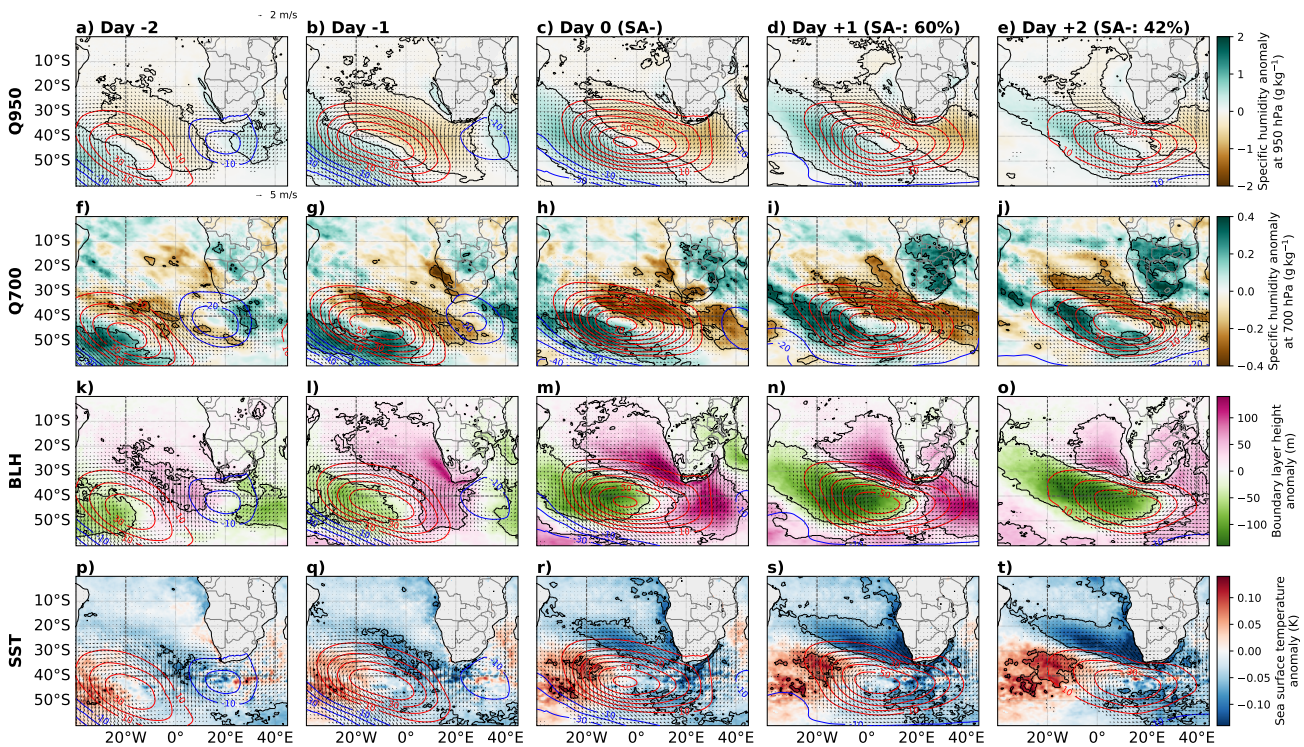


Figure 8. Temporal evolution of the composite meteorological anomalies, analogous to Fig. 6, but centered on SA- onset (day 0). Figure organization, anomaly calculation and significance testing follow the same convention as Fig. 5, yielding $n = 555$ onsets.

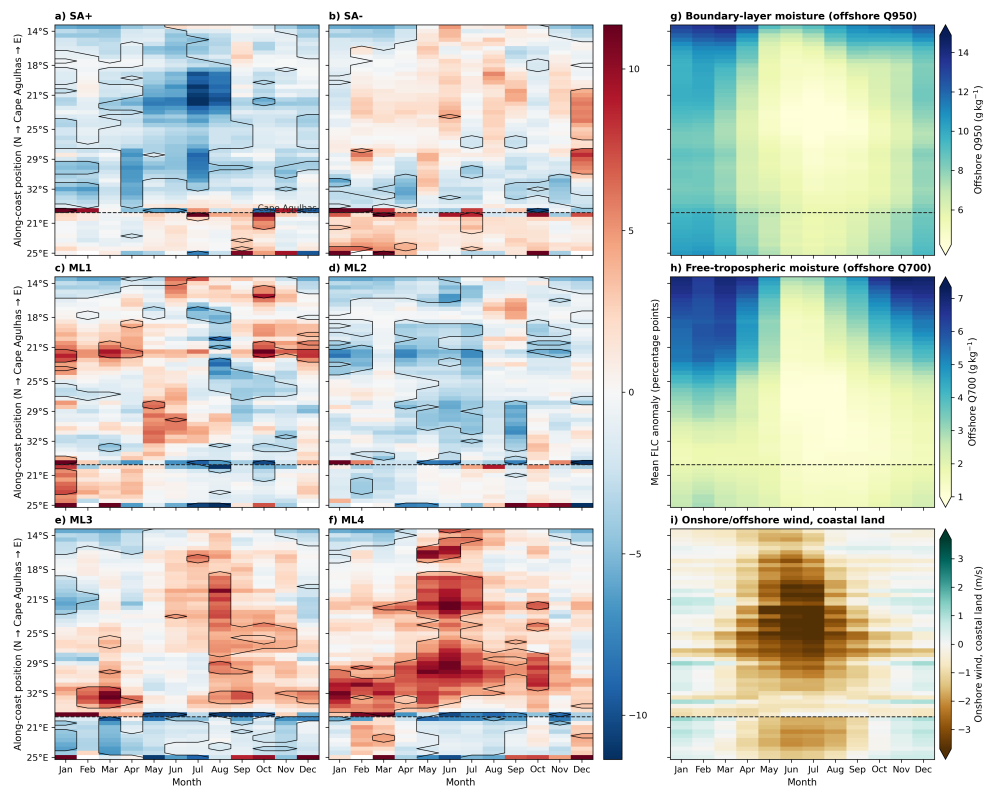


Figure 9. Seasonal cycle of the WT-FLC association along the coastline (panels a–f) alongside the climatological mean state of coastal moisture and winds (panels g–i). Panels a–f show Hovmöller diagrams of deseasonalized FLC occurrence anomalies for SA+ (a), SA– (b), ML1 (c), ML2 (d), ML3 (e) and ML4 (f), as a function of calendar month (x-axis) and along-coast position (y-axis). Black contours show grid cells where the anomaly is statistically significant (one-sample t -test against zero, $p < 0.01$). Panels g–i show the climatological monthly mean state on the same month/along-coast axes: offshore Q_{950} (g), offshore Q_{700} (h), and near-surface onshore/offshore wind over coastal land (i, positive = onshore, projected onto the locally estimated coastline-normal direction). The along-coast axis combines two segments into one continuous index: the west coast, binned into 0.5° -latitude strips, and the south coast (east of Cape Agulhas, 20.0°E), binned into 0.5° -longitude strips (see Fig. D1). The dashed horizontal line marks the Cape Agulhas transition. FLC values in panels a–f are averaged over the coastal strip extending 50 km inland from the coastline; panels g–i use an offshore box adjacent to the same coastline segment.

Along the south coast, the trough-related FLC decrease tends to be stronger during fog season for ML4 (winter, (Van Schalkwyk and Dyson, 2013)) and the transition seasons (ML3). In the following, we use the climatological seasonal cycle of coastal MBL moisture, free-tropospheric moisture, and near-surface winds (Fig. 9g–i) to explain why these FLC-WT associations shift with season and latitude as described above.

Climatological Hovmöller plots of moisture in the MBL (Q_{950}) and free troposphere (FT, Q_{700}), and coast-perpendicular near-surface winds are shown in the right-hand column of Fig. 9. Aside from the intensification (Fig. B3) and further northward dispersion of mid-latitude variability during winter (Nakamura and Shimpo, 2004), two main factors likely contribute to the



amplified wintertime FLC response to WT_s in the northern parts of the west coast. During winter, the west coast MBL is dry (Fig. 9g), and coastal winds are dominated by offshore flow (Fig. 9i) due to the presence of the continental anticyclone (Andersen et al., 2020). Under these conditions, FLC_s rarely occur, as reflected by its seasonal minimum during this time (Andersen et al., 2019). This likely makes the moistening MBL and onshore flow anomalies associated with the arrival of the
 295 trough critical for the formation and onshore advection of marine stratus clouds where it manifests as stratus interception fog. During summer, when the climatological coastal MBL is moist enough to regularly form stratus clouds (Fig. 9i), the relevance of MBL moistening from the trough's leading flank is reduced. However, the free-tropospheric dry slot on the trough's north-western rear, which develops over the coastline as the trough passes the continent (Fig. 6i,j) and facilitates cloud-top cooling, becomes more important during this time, as reflected by the positive FLC response to ML1, which peaks around 23°S. This
 300 is consistent with a moist free troposphere at this time of year in this region (Fig. 9h). In the southern parts of the west coast, the influence of synoptic-scale variability as expressed by the WT_s remains relevant throughout the year, possibly reflecting the increased mid-latitude synoptic variability at higher latitudes discussed above. At the south coast, the overhead trough (ML4) that hinders radiation fog formation peaks in its negative influence on FLC occurrence during fog season there (winter: Van Schalkwyk and Dyson 2013), and similarly during the transition seasons for ML3. Even though we do not analyze the south
 305 coast in similar detail here, the common theme between the seasonal FLC response at both coastlines is that FLC sensitivity to transient mid-latitude disturbances is found to be state-dependent and peaks during the times of year when FLC occurrence is at a minimum (maximum) for a FLC facilitating (inhibiting) WT.

While the WT classification captures the dominant large-scale meteorological states associated with FLC occurrence, it summarizes synoptic conditions only broadly, and day-to-day FLC variability within a given WT can be expected to remain
 310 substantial. To assess the extent to which the relationships found between WT_s and FLC are consistent within-WT_s, and to identify what additional factors distinguish FLC-favorable from FLC-unfavorable days within the same WT, we compare the composite large-scale meteorological anomalies between the top and bottom tercile of west-coast FLC occurrence within each WT (averaged within the west-coast portion of the coastal domain shown in appendix Fig. D1). Consistent with Andersen et al. (2020), across all WT_s, days with high west-coast FLC occurrence are characterized by a weak geopotential height
 315 anomaly resembling an overhead trough anomaly (approximately 15 % of the amplitude of most WT trough anomalies), and an anomalous onshore near-surface wind, relative to that WT's low-FLC days, illustrated in Fig. 10 for two representative WT_s, ML4 and SA+. This indicates that trough-like disturbances and their associated onshore moisture transport modulate FLC occurrence not only between WT_s, but also as a source of variability within each WT. The free-tropospheric dry slot along the coast is only present during the wet season (not shown). High-FLC days are further characterized by cooler SST_s
 320 along the coast and a more stable lower troposphere (LTS) across a large-scale coastal region, as shown for ML4 and SA+ in Fig. 10. The SST/LTS differences are largest in the anticyclonic WT_s SA+ and ML2, and comparatively weaker in the trough-associated WT_s, particularly ML3 and ML4. This likely reflects the absence of a competing large-scale forcing mechanism in the anticyclonic, subsidence-dominated WT_s: without a trough-driven moisture supply modulating MBL moisture and FLC occurrence, local SST variability becomes the dominant remaining driver of day-to-day FLC variability. In the comparison of
 325 FLC and clear sky days in Andersen et al. (2020), this SST difference was not statistically significant, which was attributed to

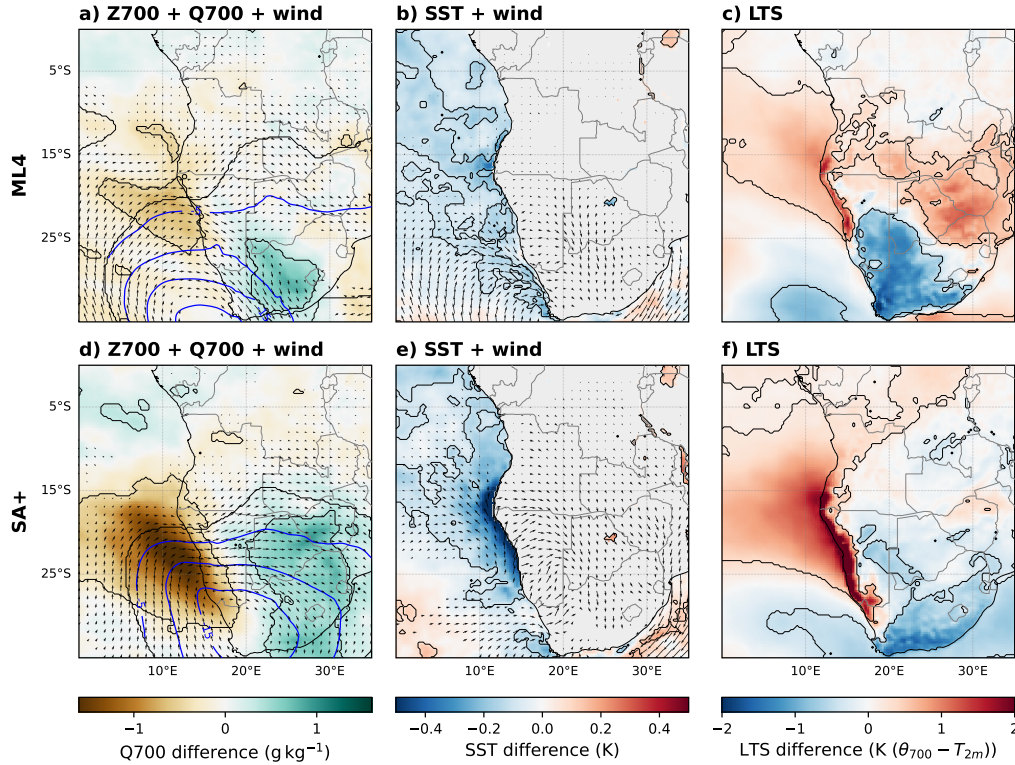


Figure 10. Composite differences in geopotential height (*Z*, contours), sea surface temperature (SST, color, K) and lower-tropospheric stability (LTS, color, K) between FLC-favorable and FLC-unfavorable days within ML4 (a–c) and SA+ (d–f), for the full record (not split by season). For each WT, days are ranked by west-coast-mean FLC occurrence and split into the top and bottom tercile; panels show the composite difference (high-FLC minus low-FLC). Black contours (SST, LTS) and solid/dashed contour lines (*Z*) mark statistically significant differences (Welch's *t*-test, *p* < 0.01, both groups *n* ≥ 5 days).

a lag in the wind-driven upwelling response and taken to imply that SST's influence on FLC variability is most pronounced on seasonal-to-interannual rather than synoptic timescales. However, our findings indicate that the earlier WT-unaware analysis obscured a robust synoptic-scale SST-FLC relationship rather than reflecting its absence. This is produced by a Simpson's paradox (a reversal or masking of a true relationship once data are pooled across a confounding grouping variable Simpson 1951): ML3 and ML4 facilitate FLC occurrence through moisture transport into the coastal MBL, but are also associated with increased SSTs on the trough's leading flank (Fig. 6), so that these disproportionately fog-prone, warm-baseline WTs bias the pooled, WT-unaware SST-FLC relationship toward zero. By conditioning explicitly on WT, our framework disentangles this compositional confound from the true, negative within-WT relationship between SST and FLC occurrence.

Finally, we relate daily fog occurrence at 10 FogNet stations spanning the coast-to-inland Namib transect (5–733 m a.s.l.; Fig. 1) to the WTs, to test whether the coast-wide FLC-WT associations described above are also reflected in independent, ground-based station observations (Fig. 11). For each station and WT, we compute the relative anomaly in the frequency of



fog days, expressed as a percentage of that station's own full-record mean to account for the large differences in absolute fog frequency along the elevation transect. The local fog response at the stations is consistent with the coast-wide satellite-derived responses described above, including their seasonality (seasonal FogNet results shown in appendix Fig. E1). Fog occurrence is increased at all stations under ML4 (trough overhead) and ML3 (trough approaching), and, consistent with the mechanism proposed above, under SA– (even though significance is not always reached), where residual moisture from a preceding weak trough anomaly persists along the coastline as a high pressure anomaly is slowly propagated towards the coastline. Comparing the station response to ML3 and ML4 as a function of elevation reveals a distinct, trough-position dependent fog signature along the transect: while both WTs increase fog occurrence, ML4, which, in addition to moistening the coastal MBL, is associated with a deeper coastal boundary layer (Fig. 5), increases fog occurrence most strongly at stations above 400 m a.s.l., and produces its largest relative anomaly (59 %) at Garnet Koppie, the highest elevated and furthest inland station in the network (733 m a.s.l., 85 km from the coast).

Conversely, and again consistent with the Namib-wide response, fog occurrence is significantly reduced at all stations under SA+ when the South Atlantic High anticyclone extends toward the coastline and, under ML2, the ridging-high phase following a trough's passage. Under ML2, however, one station deviates from this pattern: Saltworks, located in the immediate vicinity of the coastline (1 km, 5 m elevation), and owing to this proximity, the only station in the network that plausibly experiences advection fog in addition to stratus-interception fog (Seely and Henschel, 1998), shows a slight but insignificant fog increase under this WT, whereas all other stations are negatively associated with this WT. This association is pronounced and significant, though, in winter (Fig. E1), challenging the classical conception of advection fog in Namibia as simply forming when a warm, moist marine air mass is advected over the cold Benguela sea surface and cooled to saturation (Seely and Henschel, 1998). Instead, the ridging-high driven fog increase identified at Saltworks during winter is more consistent with the mechanism producing sea fog along the California coast, which is similarly tied to a warm, dry offshore flow (the Santa Ana wind) that establishes a strong inversion at the surface, beneath which a dense sea fog can form (Leipper, 1994). This mechanism is also consistent with the seasonal occurrence of fog at the immediate Namibian coastline, which peaks during austral fall and winter (Lancaster et al., 1984; Mupambwa et al., 2025; Dorman et al., 2019), when the offshore wind regime occurs regularly owing to the presence of the continental anticyclone over southern Africa. This interpretation is further supported by recent in-situ observations made during the AEROFOG campaign in Henties Bay, Namibia (also located on the immediate coast) in May 2024, where dense fog was observed in a shallow boundary layer capped by warm, dry, subsiding easterlies that were associated with a ridging high (Wu et al., 2026). The fact that wintertime fog occurrence at Saltworks has such a strong connection to a ridging-high anomaly (ML2: 37 % relative anomaly) suggests that the observations made during the AEROFOG campaign at Henties Bay may be representative of winter fog formation conditions in Namibia at the immediate coast. Together, these results indicate that the sensitivity of fog occurrence to synoptic-scale forcing is fog-type dependent, and underscore that this region is characterized by (at least) two distinct fog-formation mechanisms whose relative dominance varies systematically with distance from the coastline.

Taken together, the results presented in this study establish trough position along the mid-latitude WT life cycle (ML3-ML4-ML1) as a unifying, multi-scale control on FLC variability in the Namib. The same underlying mechanism, meridional

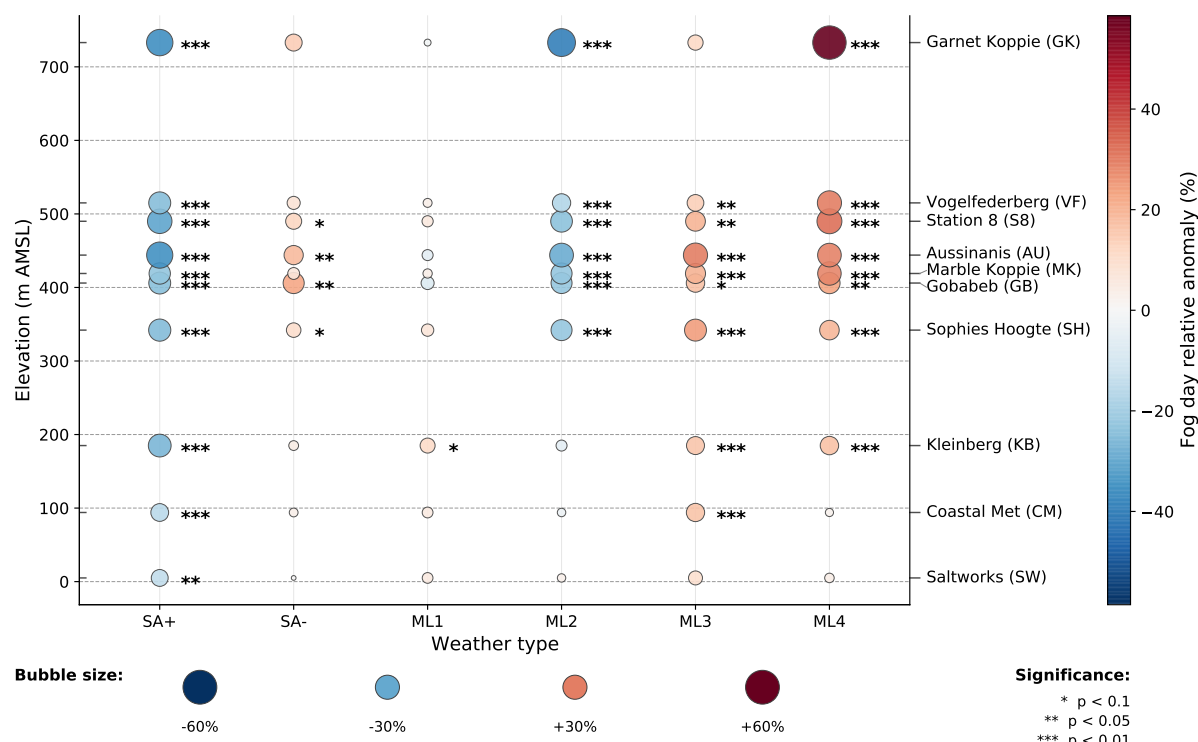


Figure 11. Weather-type dependence of fog occurrence at the FogNet stations, ordered by elevation (5–733 m a.s.l.). Each bubble shows that station’s fog-day frequency anomaly for a given WT, computed as a harmonic-deseasonalized, one-sample composite relative to the station’s own fitted annual cycle and expressed as a percentage of that station’s full-record baseline mean fog-day frequency, so that stations with very different absolute fog frequencies are shown on a common relative scale. Bubble area scales with the magnitude of the anomaly, and color indicates its sign (red: more frequent than normal; blue: less frequent), and significance is indicated by the star markers. A fog day is defined as a noon-to-noon 24h window during which any measurable (> 0 ml) amount of fog water was collected by Juvik-type fog-collectors (see Sect. 2.2).

long-range MBL moisture transport and onshore flow anomalies tied to a mid-latitude trough, organizes the synoptic-scale composite response (Fig. 3), its day-to-day evolution (Fig. 6), its seasonal modulation (Fig. 9), and, as shown above, the response of individual FogNet stations across the coast-to-inland elevation transect. This single mechanism does not hold at 1) the immediate coastline in the central Namib, where fog occurrence is shown to be increased under ridging high conditions, and 2) along the south coast, advection and radiation fog dominate, which are facilitated by calm conditions (SA-) and onshore flow on the rear flank of a trough (ML1). This multi-scale, mechanism-resolving analysis goes beyond the two-state (fog vs. clear day) composites of previous synoptic studies of this region and provides a basis for the climate-change and forecasting implications discussed next.



380 4 Conclusions and Outlook

This study analyzes the connections between fog and low clouds (FLCs) and synoptic-scale variability along the south-western African coastline using a weather-type (WT) classification. Specifically, this study set out to test the hypothesis that mid-latitude trough passage drives Namib FLCs through a phase-dependent sequence, long-range moisture transport into the marine boundary layer ahead of the trough, and a combination of free-tropospheric drying and boundary-layer deepening on its trailing flank, which could not be resolved by the two-state (e.g. FLC versus clear-sky days) composite analyses used in previous studies (Andersen et al., 2020; Hipler et al., 2026). Using an extended WT classification, the results confirm this phase-dependent sequence directly, and show that it operates not only in the synoptic-scale composite response, but continuously within individual weather types, across the seasonal cycle, and at the scale of individual FogNet stations. At the immediate coastline and along the south coast, different fog-formation mechanisms are found to dominate. The main findings are:

- 390 – The WT classification resolves two large-scale regimes relevant to Namib FLCs: variability of the South Atlantic High (SA+, SA–) and the life cycle of an eastward-propagating mid-latitude disturbance (ML1–ML4), which transitions in a preferred sequence (ML1→ML2→ML3→ML4) tracing a full trough-ridge cycle, from a trough having passed (ML1), through the following ridging-high phase (ML2), to the approach (ML3) and arrival (ML4) of the next trough.
- Along the west coast of the Namib, where stratus interception fog dominates, FLC occurrence is systematically tied to mid-latitude trough position: it increases as a trough approaches and peaks when the trough is overhead (ML4), and after passing of the trough (ML1) decreases during the following ridging-high phase (ML2). The south coast, dominated by different (radiation and advection) fog types, responds with the opposite sign to an approaching or overhead trough but is favored once the trough has passed (ML1) and by SA–.
- 395 – The underlying mechanism linking mid-latitude troughs to Namib FLCs combines two processes: long-range meridional transport of marine boundary layer (MBL) moisture into the coastal zone ahead of the trough, and, on its rear flank, free-tropospheric drying that promotes cloud-top radiative cooling together with southerly cold-air advection that deepens the boundary layer. This refines the mechanism proposed by Andersen et al. (2020) by identifying the long-range transport of MBL moisture ahead of the trough as a primary control of FLCs in the Namib.
- 400 – Day-by-day evolution composites resolve this mechanism operating in time: the coastal MBL moisture anomaly reaches the coast only as the trough arrives, persists for several days after being cut off from the propagating system by the topography of the Great Escarpment, and is progressively displaced by drier air of the following ridge. The associated FLC enhancement persists for approximately three days, broadly tracking the ML3→ML4→ML1 life cycle.
- 405 – The strength of the WT-FLC association varies systematically with season and latitude, tied to the climatological mean state of the coastal MBL and the free troposphere above, and the large scale circulation. Along the northern Namib, where the winter MBL is dry and winds are climatologically offshore, the trough’s moistening and onshore-flow anomalies are critical for FLC formation, and the WT response is strongest in winter. Along the southern parts of the Namib, where synoptic variability remains elevated year-round, the WT response persists across seasons.
- 410



– Even within a single WT, day-to-day FLC variability remains substantial and is systematically related to a trough-like geopotential and onshore-wind anomaly, showing that the same mechanism identified between WTs also operates continuously within them. High-FLC days within a WT are further distinguished by cooler coastal SSTs and a more stable lower troposphere, a relationship strongest in the anticyclonic WTs (SA+, ML2) and weaker in the trough-associated WTs (ML3, ML4). Conditioning explicitly on WT resolves an apparent absence of an SST-FLC relationship reported by Andersen et al. (2020). This is caused by a Simpson’s paradox present in WT-unaware analyses where this relationship is masked, because the fog-prone moist MBL on the trough’s leading flank simultaneously features higher SSTs.

– Independent, station-based FogNet observations in the central Namib confirm the coast-wide, satellite-derived WT-FLC associations and reveal an elevation-dependent signature of trough position, with the deeper boundary layer associated with an overhead trough (ML4) producing the largest relative fog increase at the highest, most inland station (733 m a.s.l., 85 km from the coast). At the immediate coastline, however, fog during winter instead increases under the ridging-high WT (ML2) (opposite to every other station). This indicates a second, distinct fog-formation mechanism at the immediate coast, more consistent with warm, dry offshore flow inducing a low-level inversion beneath which advection fog forms (analogous to Santa-Ana-driven fog on the California coast Leipper 1994) than with the classical marine-advection-fog model. This is supported by in-situ observations from the 2024 AEROFOG campaign at Henties Bay (Wu et al., 2026) and by the immediate coastline’s distinct fall/winter fog seasonality.

Taken together, these results establish trough position along the ML3–ML4–ML1 life cycle as a unifying, multi-scale control on FLC variability in the Namib. The same long-range moisture-transport and onshore-flow mechanism organizes the coast-wide FLC response, its day-to-day evolution, its seasonal modulation, its expression as intra-WT variability, and its imprint on local fog observations at stations in the central Namib. The immediate coastline and the south coast are two exceptions governed by distinct fog-formation mechanisms.

These findings have several implications beyond the immediate scope of this study. First, by establishing a direct dynamical link between transient mid-latitude troughs and Namib FLCs, they provide a physically grounded pathway for assessing future fog variability under climate change, complementing existing thermodynamic, SST-based framings of interannual FLC variability (Mass et al., 2026a): projected changes in mid-latitude storm-track activity and its subtropical reach could be translated directly into changes in Namib FLC frequency. The results also highlight the relevance of mid-latitude variability for subtropical low clouds more generally, a link that has been established (Szoek et al., 2016; Fuchs et al., 2017, 2018), but maybe underappreciated. Second, the temporal sequence identified in the trough life cycle (Fig. 7) can help forecast fog occurrence with several days of lead time, which can be of practical relevance e.g. for the region’s coastal transport systems or fog-water-harvesting operations (Mupambwa et al., 2025). Third, because synoptic-scale variability does not only organize coastal FLCs, but also aerosol loading and composition in the coastal environment (Formenti et al., 2018, 2019; Gaetani et al., 2021; Desboeufs et al., 2024; Mass et al., 2025; Wu et al., 2026) this WT framework can be used to reduce aerosol-FLC co-variability and improve the attribution of aerosol-cloud-radiation interactions. This need was recently underscored by Tatro and



Zuidema (2026), who showed that in the neighboring southeast Atlantic stratocumulus deck, synoptic-scale variability linked to the mid-latitudes, can mask aerosol-driven cloud brightening. Finally, the identification of a second, spatially confined fog mechanism at the immediate coastline, together with its qualitative parallel to Santa-Ana-driven fog on the California coast, suggests that the multi-scale, WT-based framework developed here may be transferable to other eastern boundary current fog systems, and motivates further targeted process studies, in the spirit of the AEROFOG campaign, to directly characterize the boundary-layer conditions distinguishing the two fog-formation pathways identified in this study.

Appendix A: FogNet station data availability

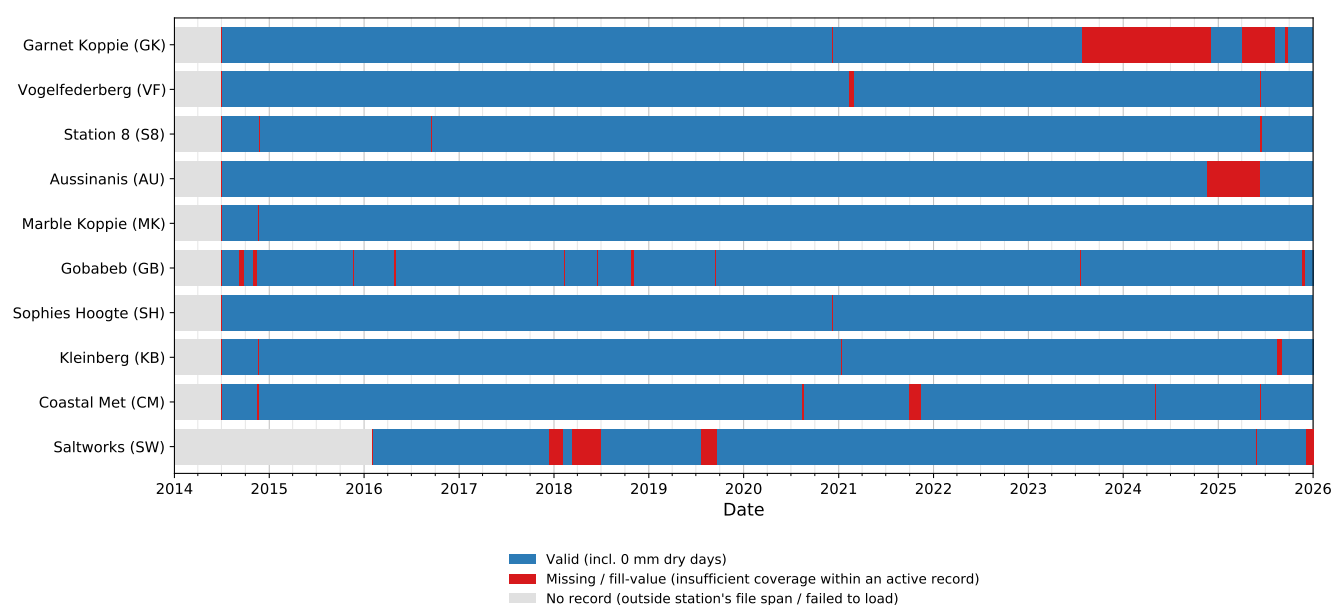


Figure A1. Availability of fog collection data at FogNet stations.



Appendix B: Weather type classification

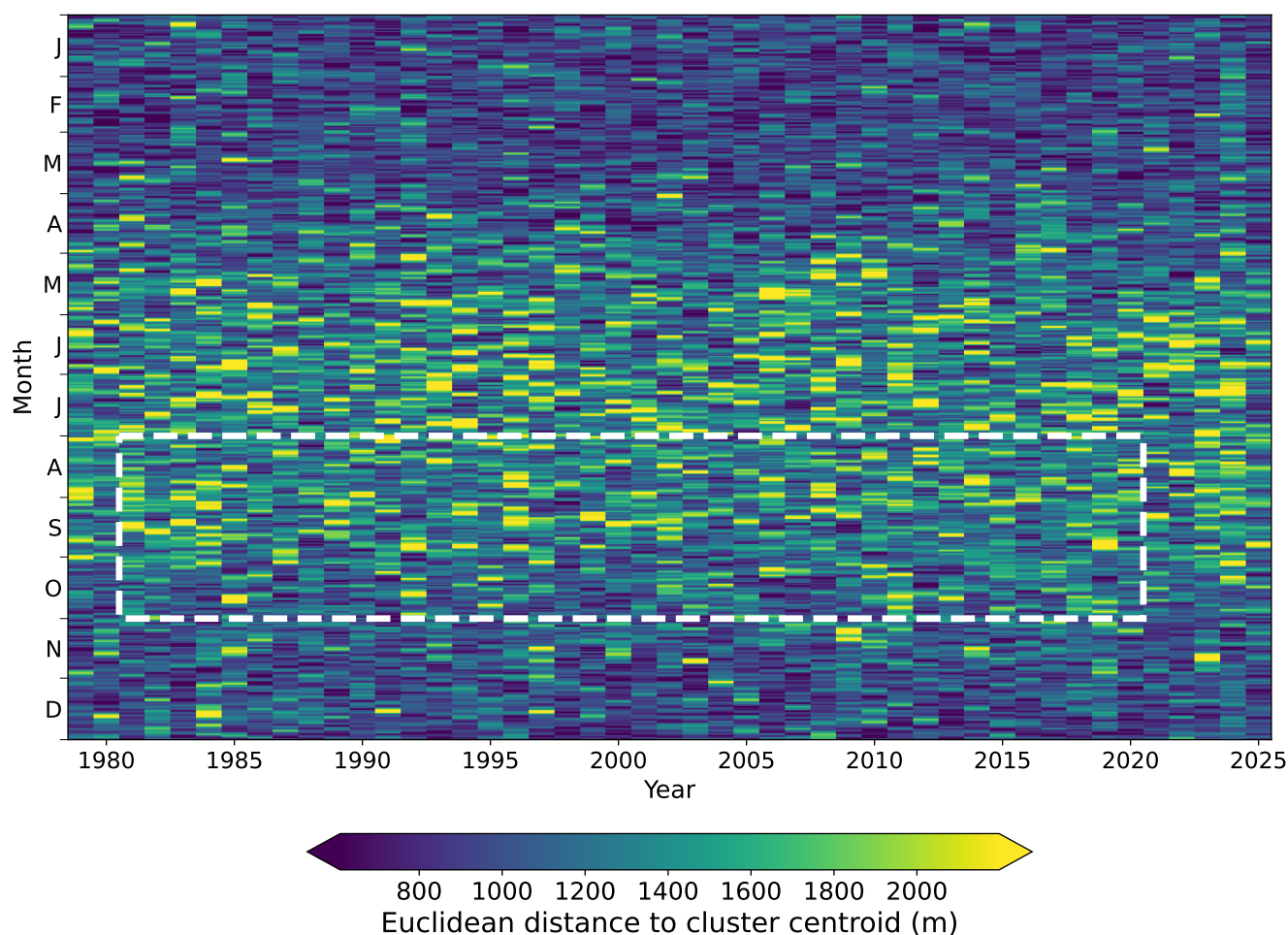


Figure B1. Euclidean distance (m) between each classified timestep (described by its 700 hPa geopotential height anomaly field) and the centroid of its corresponding cluster over the whole ERA5 period (1979–2025). The period initially used to obtain the clusters is indicated by the dashed rectangle.

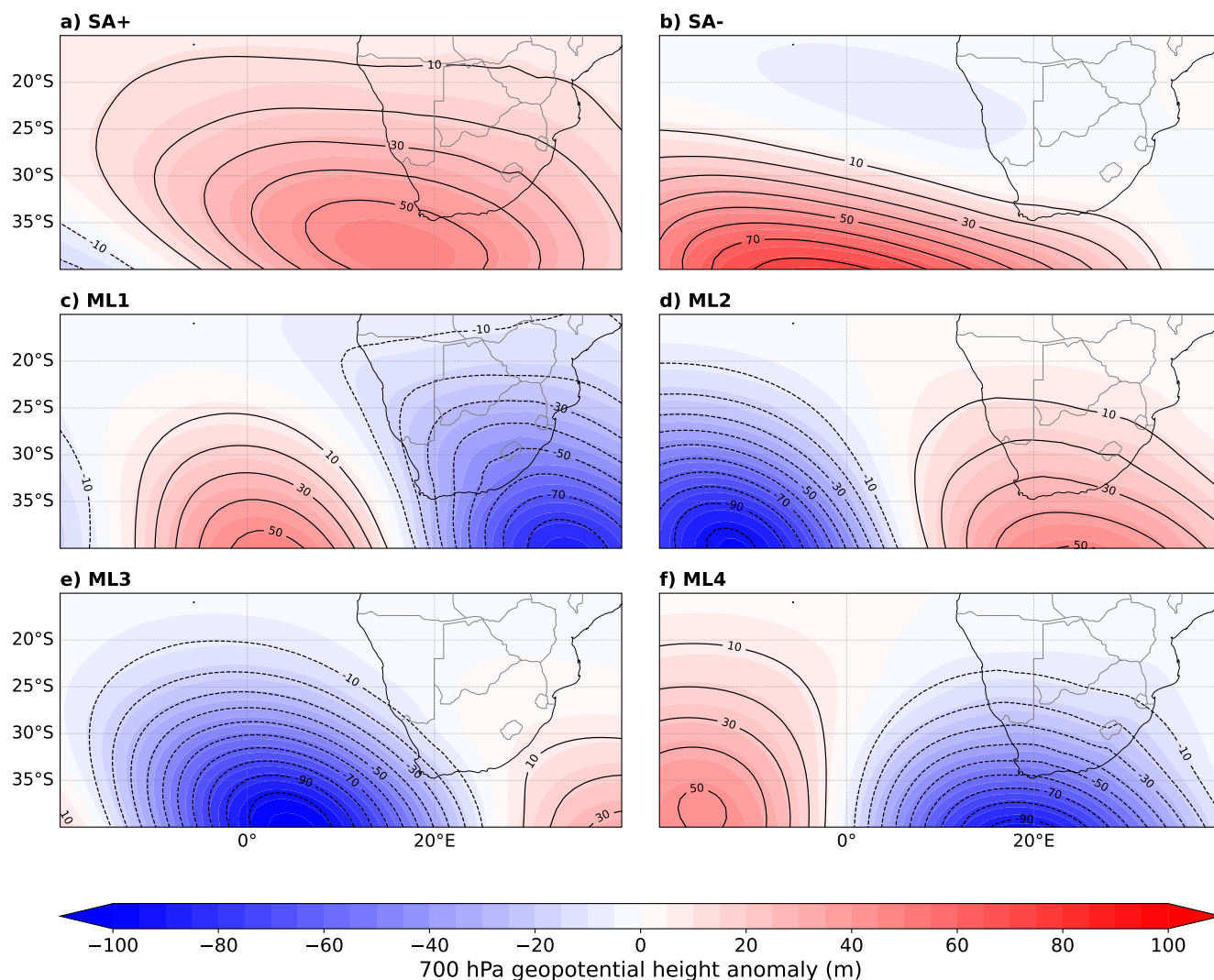


Figure B2. Composite mean 700 hPa geopotential height anomalies (m) associated with the 6 clusters. Colors: whole ERA5 period. Contours: the same during the period August through October (ASO) 1981–2020 used in (Gaetani et al., 2021).



Table B1. WT transition rates, 2004–2025, computed as the percentage of transitions from a WT (rows) towards the others (columns). By definition, the diagonal represents persistence. Transition rates above 1/6, i.e. the threshold for non-random transitions, are shown in bold. Format follows Table 2 of (Gaetani et al., 2021), computed here from our own ERA5 Z700 classification over the full year, 2004–2025.

WT	SA+	SA-	ML1	ML2	ML3	ML4
SA+	57	10	2	17	5	9
SA-	14	62	8	5	3	8
ML1	13	20	38	15	7	7
ML2	14	2	1	51	29	2
ML3	5	7	4	8	46	30
ML4	8	14	26	3	7	42

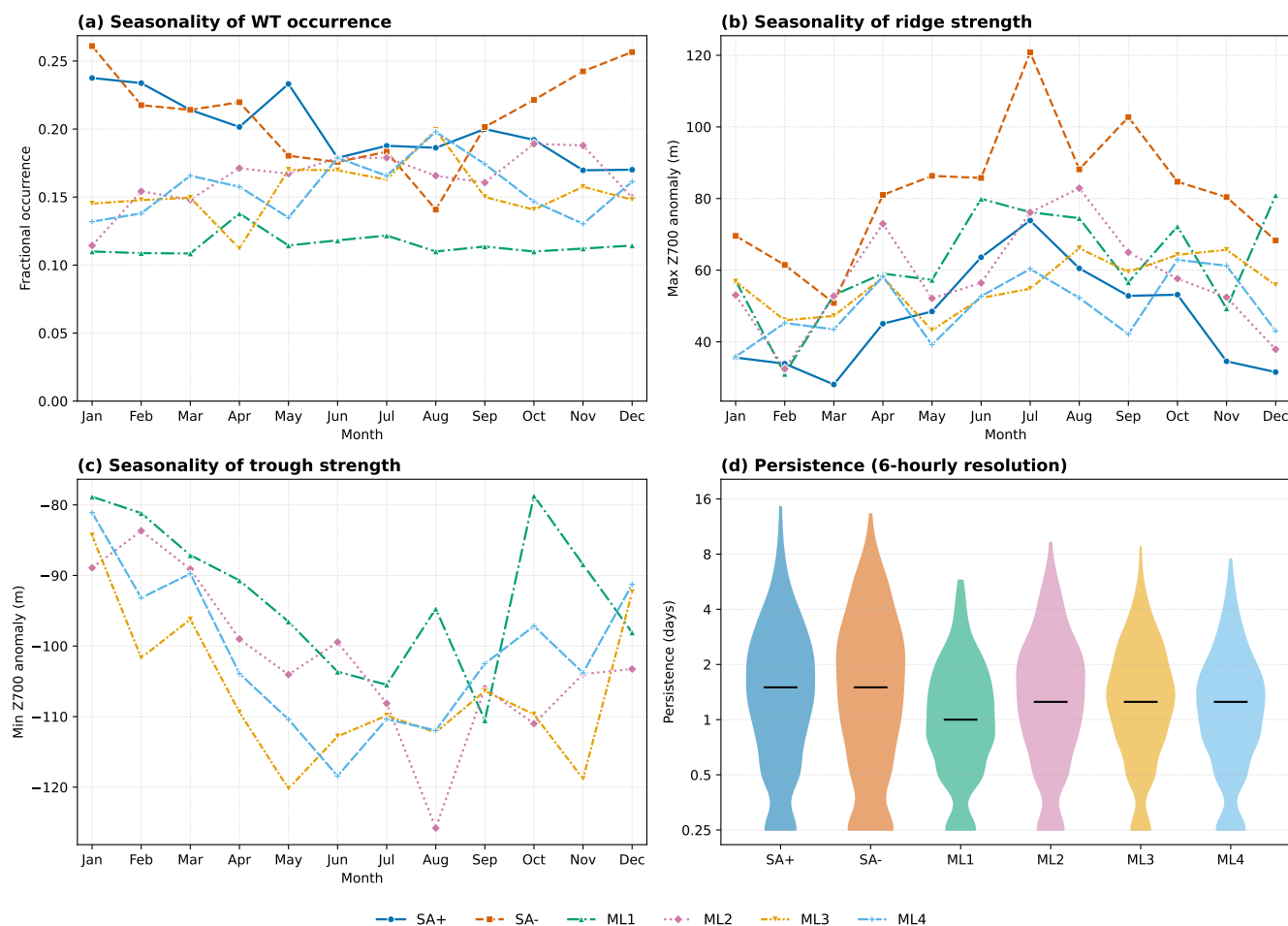


Figure B3. Summary of the seasonal characteristics and the persistence of the WT types using data between 2004 and 2025. The first three panels show the seasonality of a) the fractional occurrence of WT types, b) the maximum ridge strength, and c) the maximum trough strength (calculated as the maximum/minimum from the monthly mean anomaly fields of Z_{700} in the domain of the reanalysis-based figures (e.g. Fig. 2)). Panel d) shows the distribution of WT persistence (log-scaled) using the full 6-hourly resolution of the classification.)



455 Appendix C: FLC response to SA— evolution

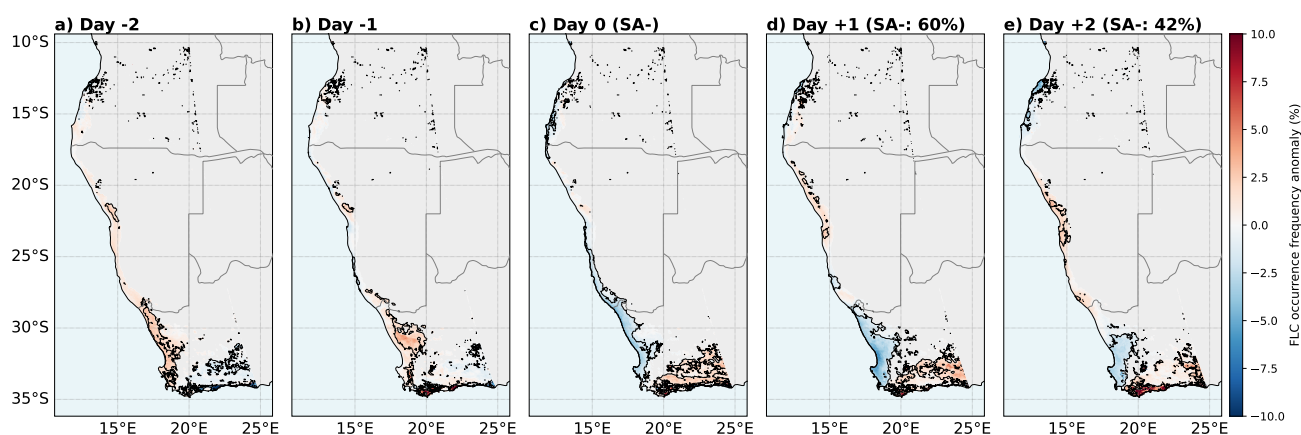


Figure C1. Same figure of temporal evolution of FLC anomalies shown in Fig. 7, but for SA—.

Appendix D: Coastal region binning

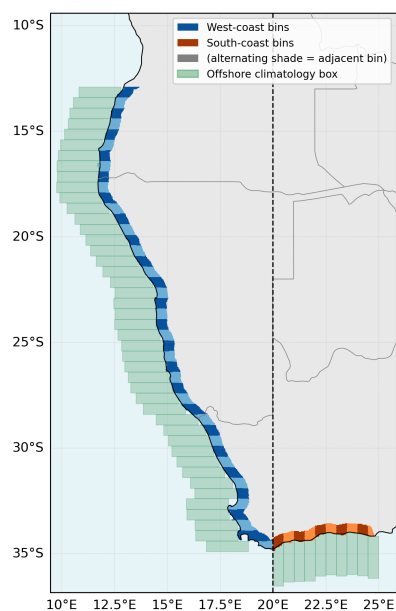


Figure D1. Coastal onshore and offshore bins used for Fig. 9.



Appendix E: Seasonal WT-fog associations at FogNet stations

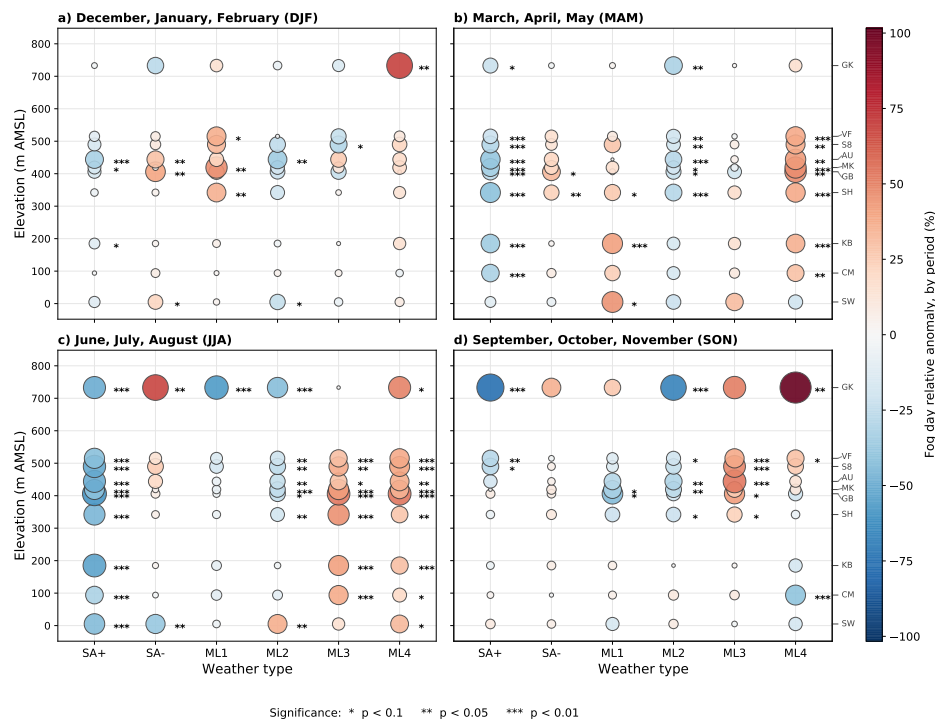


Figure E1. Weather-type dependence of fog occurrence at the FogNet stations during each season, ordered by elevation (5–733 m a.s.l.). Data treatment and processing as in Fig. 11.

Code and Data Availability

ERA5 data were obtained from the Copernicus Climate Change Service via the Climate Data Store (<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview>, <https://cds.climate.copernicus.eu/datasets/reanalysis-era5-pressure-levels?tab=overview>). Code and other data sets will be made available upon the final publication of the manuscript. The satellite-based FLC data set is available from HA upon reasonable request.

Author Contributions

HA had the idea for the analysis, obtained and analyzed the datasets, conducted the original research, and wrote the manuscript with contributions from BP and MG. BP contributed the WT classification with help from MG. All authors jointly contributed to the interpretation of the findings.



Competing interests

MG is member of the editorial board of Atmospheric Chemistry and Physics. HA and MG are associated editors for the inter-journal (ACP/AMT/AR/ESSD) Special Issue “Aerosol, fog, climate, and biogeochemistry in southern Africa”. The authors
470 declare that they have no other conflicts of interest.

Statement on inclusion in global research

This work draws on a long-term research infrastructure at the Gobabeb Namib Research Institute, Namibia, which is a platform for interdisciplinary research on the Namib. Station access and on-site maintenance support was provided by Gobabeb staff. We aim to continue active collaborations with local partners in future work at this site.

475 Acknowledgments

Funding for this study was provided by Deutsche Forschungsgemeinschaft (DFG) in the project Aerosols and fog in southern Africa: processes and impact on biogeochemistry (AeroFog). We thank Roland Vogt (University of Basel) for providing the FogNet data and for valuable comments on these data, and the team of the Gobabeb Namib Research Institute for their contributions in the development and maintenance of FogNet. Calculations for k-means clustering analyses were performed
480 using HPC resources from DNUM CCUB (Centre de Calcul de l’Université Bourgogne Europe).

Financial Support

This research has been supported by the Deutsche Forschungsgemeinschaft (DFG, grant no. CE 163/14-1, project no. 505800970) and the Agence Nationale de la Recherche (ANR, grant no. ANR-22-CE92-0051) within the project Aerosols and fog in southern Africa: processes and impact on biogeochemistry (AeroFog). Marco Gaetani was supported by the project “Dipartimento
485 di Eccellenza 2023–2027”, funded by the Italian Ministry of Education, University and Research at IUSS Pavia.



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