Ship track characteristics derived from geostationary satellite observations on the west coast of southern Africa

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ABSTRACT

Observations of the instrument SEVIRI (Spinning Enhanced Visible and Infra-Red Imager) onboard the geostationary orbit Meteosat-8 were analyzed to study the diurnal behaviour, length and lifetime of so-called ship tracks near the west coast of southern Africa. Several days of data between May and November 2004 from the SEVIRI 3.9 µm-channel were used to analyse the characteristics of more than 230 ship tracks by visual analysis. The results show a diurnal variation with maximum occurrence around 10 am. The length and lifetime of the 230 ship tracks shows significant variation: the mean lifetime detected by means of the visibility in the 3.9 µm channel, was 18 h (±11 h), but lifetimes up to 60 h have also been observed. The mean observed length is 458 km (±317 km), with an observed maximum of 1500 km, showing a high dependence on wind direction in the region of interest. To take into account the high variations of the examined variables, we also present distribution functions for the length and the lifetime of ship tracks. The distribution functions can be used to improve estimates of radiative forcing from polar orbiting satellites and for parameterisations of sub-grid scale processes in global model simulations.

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1. Introduction

The effect of anthropogenic aerosol and their precursors on clouds, the so-called indirect aerosol effect, is a factor of high uncertainty in climate research (IPCC, 2007). The emitted aerosols and their precursors can affect climate through their ability to modify the optical properties of clouds by acting as cloud condensation nuclei (CCN), as described e.g. in Twomey (1974). This results in a higher droplet number and a smaller mean droplet radius of the cloud and thereby affects the reflectivity and lifetime of the cloud. The effect is exceptionally drastic over ocean, because here, the amount of CCN is usually small (McInnes et al., 1996) and changes of the CCN-amount result in significant effects. Therefore ship-stack effluents provide the clearest demonstration of the indirect aerosol effect on cloud albedo. The most common effects, curves of larger reflectance in low marine cloud fields, which called ship tracks, can be observed and analysed in satellite imagery (e.g., Conover, 1966; Coakley et al., 1987; Durkee et al., 2000; Schreier et al., 2006; Segrin et al., 2007), but also changes in cloud coverage were observed (Rosenfeld et al., 2006).

These satellite observations as well as global model simulations (Capaldo et al., 1999; Lauer et al., 2007) indicate a strong influence of ship emissions with respect to the first indirect aerosol effect. Although the uncertainties associated with the model studies are still large, the model results indicate that the cooling due to the indirect aerosol effect outweighs the warming effects from shipping by greenhouse gases such as carbon dioxide (CO2) or ozone, overall causing a negative radiative forcing from shipping today (Lauer et al., 2007). Seagoing ships have a high contribution of exhaust gases and particles to the total emissions from the transportation sector (Eyring et al., 2005) and in addition to climate impacts have negative impacts on human health (Corbett et al., 2007).
To better compare the results of model estimates and observed ship tracks, satellite observations on the development and influence of the indirect aerosol effect from ships are needed from the local to the global scale. On the local scale, there are several observations from satellite instruments in polar orbit (e.g., Platnick et al., 2000; Schreier et al., 2006; Segrin et al., 2007), showing non-negligible local effects on cloud modifications in certain areas. However, first estimates of the global radiative forcing using data from polar orbiting satellites show an almost negligible effect due to visible ship tracks, reaching from $-0.4$ to $-0.6 \text{ mW m}^{-2}$ (Schreier et al., 2007). Compared to the global model results, which calculate an indirect radiative effect of $-0.1$ to $-0.6 \text{ W m}^{-2}$ (Capaldo et al., 1999; Lauer et al., 2007), this contribution from observed ship tracks to the total indirect effect from ships is small. This indicates that the ship plumes mix with the ambient air and affect the surrounding clouds on a larger scale than visible in ship tracks. However, there is a lack of understanding between analyses from remote-sensing observations and global model estimates, because it is not clear how ship tracks mix with the ambient cloud layer.

From a remote-sensing point-of-view, the main reason for this lack of understanding is that so far polar orbiting instruments have been used for the analyses of ship tracks from space. Polar orbiting instruments have the advantage of global coverage and, more important, have high horizontal resolution, which is needed to observe small-scale phenomena such as ship tracks in satellite data. However, the analysis from polar orbiting instruments cannot be used to characterize the behaviour of ship tracks over longer time periods, because the satellite platforms change position with respect to the surface and therefore show only snapshots in a more or less daily cycle per area. Therefore, currently there is a lack of quantitative information on the mean lifetime, length and width of ship tracks. This information would allow looking into connections between large-scale global modelling studies and the development of ship tracks on the sub-grid scale. Such information on the development of ship tracks will also help to improve global estimates from polar orbiting satellites and could help to parameterise sub-grid scale processes in global models. A first description of the composite ship track characteristics was presented by Durkee et al. (2000) for the Monterey Area Ship Track (MAST) observation period on the west coast of North America. They report a mean length of $296 \pm 233$ km, and a mean age of $7.3 \pm 6$ h. However, time varying information was not included as observations from several polar orbiting instruments were used so that additional information such as ship position and ship speed was needed to derive ship track characteristics.

In this study, we provide a new approach for statistical analysis of ship track characteristics (diurnal cycle, length, and lifetime) by using the new generation of satellite instruments for weather observation in geostationary orbit. We show, that it is possible to use data from the instrument SEVIRI (Spinning Enhanced Visible and Infra-Red Imager) onboard Meteosat-8 to study diurnal development, lifetime and size of ship tracks in an accurate way for certain areas. We also show in a case study, that the additional use of the HRV-channel (High Resolution Visible) gives the possibility, to examine small-scale cloud development inside a ship track. The instrument, study region and dates as well as the visual analysis to extract ship tracks are described in Section 2. Results on the distribution of ship tracks in the area of interest, the number of ship tracks, as well as main characteristic such as lifetime and length of ship tracks are presented in Section 3, together with distribution functions that could be used to parameterise sub-grid scale processes in global models or to improve radiative forcing estimates from polar orbiting instruments.

2. Data analysis

The selected instrument was SEVIRI (Spinning Enhanced Visible and Infra-Red Imager) onboard Meteosat-8, which is in a geostationary orbit at point $0^\circ/0^\circ$. The instrument is scanning the Earth line by line within the area from $80^\circ$S to $80^\circ$N and from $80^\circ$W to $80^\circ$E every 15 min. Because of the curvature of the earth, the resolution of the data is decreasing when stepping away from the sub satellite point at $0^\circ/0^\circ$. The resolution of the data is also depending on the channel. SEVIRI has 12 channels from 0.4 to 13.4 μm. The channel with the highest resolution is the HRV-channel, which is a solar broadband-channel (0.5 to 0.9 μm) and has a resolution of $1 \times 1$ km at sub satellite point. As will be explained below, the most important channel for the observation of cloud modifications is channel 4 (3.9 μm). We mainly used this channel 4, which has a resolution of approx. $3 \times 3$ km for the sub satellite point. For the area investigated here, the resolution varied between $3 \times 3$ km and $5.2 \times 3.7$ km. The resolution is higher than for the instruments on Meteosat-1 to $7 \times 5 \times 5$ km on sub-point) and is suitable for observation of ship tracks and other small-scale cloud modifications, as was already shown by Rosenfeld et al. (2006). Due to the temporal resolution of 15 min the transport and development of clouds can be observed in an accurate way in a visual analysis.

SEVIRI offers several channels for observation from the visible to the infrared spectrum. The visibility of ship tracks is highly variable and depends on atmospheric factors like aerosol amount and potential CCNs. But they are best visible in most cases at near-infrared (NIR)-wavelengths greater than 1.6 μm, when compared to unpolluted clouds, because here the single-scattering albedo of cloud droplets is decreasing with decreasing droplet radius and increasing droplet number (Coakley et al., 1987; Kokhanovsky, 2004). This results in a smaller absorption and a higher reflectance for smaller droplets with increased droplet number concentration. The selected wavelength was therefore 3.9 μm (Channel 4), as also proposed by Lensky and Rosenfeld (2008), because here the single-scattering albedo is relatively small and the increased reflectance can be seen very well. The signal of the channel was corrected for CO₂-absorption, to increase the contrast of the single-scattering albedo signal compared to surrounding clouds during daytime. Similar to Lensky and Rosenfeld (2008), we also observed that ship tracks are visible in the brightness—temperature signal of the 3.9 μm channel at nighttimes, showing here a decreased emission compared to surrounding areas. Therefore, we were able to observe the development of ship tracks even at nighttimes by analysing the emissivity instead of the reflectivity.
SEVIRI therefore offers the possibility to observe the transport and development in an accurate way. The selected ship tracks have been identified by visual analysis, because an automated extraction of ship tracks is not reliable and highly depending on the chosen parameters and pre-selection of the data (Coakley and Walsh, 2002; Schreier et al., 2006; Segrin et al., 2007). The identified ship tracks were assigned manually using a graphics tool on every time step and the marked regions on the different time steps were compared to follow the development of the ship track.

The selected area of interest was defined as a result of previous analysis of ship tracks on the global scale (Schreier et al., 2007) from the polar orbiting instrument AATSR (Advanced Along Track Scanning Radiometer), which showed high occurrence of ship tracks in the region west of southern Africa. The global model study by Lauer et al. (2007) also indicates a strong influence of ship traffic on the low marine clouds in this area. Therefore, the area of 5 to 40°S and 10°W to 25°E was chosen for further examination (see Fig. 1).

The previous satellite analysis also revealed the days with high ship track occurrence in this area, which has been used here for further examination. To maximize the amount of observable ship tracks the dates of ship track occurrence from the previous study were used here as a starting point in order to derive a statistical distribution with a minimum amount of data. For further analysis also the days before and the following days of the chosen dates were examined, to observe the development of ship tracks and investigate possible variations due to a changing environment. More than 230 ship tracks were marked by visual analysis in the described area for the given dates and the development and behaviour was examined. By knowing the resolution of the instrument-channel at sub-point 0/0 and the latitude/longitude-curvature on the place of the ship track, the distance between the beginning and the end within the ship track-marking can be calculated. The time of the visibility of the ship track, means from the first occurrence of the ship track to the dissolution in the surrounding cloud, was taken as the lifetime. This is depending on the contrast with the surrounding of the ship track and therefore depends on the observer. However, as will be shown in Section 3, an observer is able to follow the ship track in an accurate way until the contrast compared to the surrounding clouds is smaller than 5%, which is much better than any automated contrast-filtering within cloud observations.

3. Results

3.1. Occurrence of ship tracks

Fig. 1 shows the overlay of the observed ship tracks in the area of interest between May and November 2004 on the selected dates (see Table 1). According to the AMVER-Dataset (Automated Mutual-Assistance Vessel Rescue System, see e.g. Wang et al. (2008)), the main shipping route in this area of interest leads from South Africa to Cape Verde, which is indicated by the two arrows in Fig. 1, pointing in the direction of the main shipping route. The increased amount of ship tracks can be clearly distinguished here. There is also high development of ship tracks along the coast, where high vessel traffic occurs. Additionally there are a few stronger lines heading across the Atlantic towards North- or South-America. Basically the entire area is more or less covered by ship tracks, resulting from winds that are moving the ship tracks away from the shipping route and also from ships, which are not following the main shipping routes. Therefore, almost all low marine clouds in this area are affected by ship emissions in some way. But it has to be kept in mind, that this analysis covers a period over several months, so the ship tracks in Fig. 1 did not occur all at the same time and in most cases, did not influence each other. The distribution of the ship tracks over the examined area indicates that the influence of ship emissions on the clouds in this area restricted to a few main shipping routes, but is spreading over the entire area.

3.2. Diurnal variation of the occurrence of ship tracks

In the first step of the temporal analysis, we examined the diurnal variation of ship track occurrence, which is shown in Fig. 2. The highest occurrence of identified ship tracks on the west coast of southern Africa is between around 9:00 to 10:00 am (UTC), whereas a smaller number is found any other time of the day. The development of ship tracks is highly depending on the amount of clouds in the area; therefore this changing behaviour over the day can be explained by the diurnal variation in marine low cloud cover. Rozendaal et al. (1995) indicated a high amplitude of

![Fig. 1. Distribution of observed ship tracks in the area of interest (grey lines) between May and November 2004. The arrows indicate the main shipping route in this area, according to the AMVER-dataset.)](image)

Table 1

<table>
<thead>
<tr>
<th>Examined ship track dates</th>
</tr>
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<tbody>
<tr>
<td>20.05–22.05.2004</td>
</tr>
<tr>
<td>20.06–21.06.2004</td>
</tr>
<tr>
<td>07.08–14.08.2004</td>
</tr>
<tr>
<td>20.08–22.08.2004</td>
</tr>
<tr>
<td>07.09–13.09.2004</td>
</tr>
<tr>
<td>24.09–26.09.2004</td>
</tr>
<tr>
<td>29.10–31.10.2004</td>
</tr>
<tr>
<td>15.11–18.11.2004</td>
</tr>
</tbody>
</table>
low marine clouds in this area at a similar time of the year, with a maximum in the morning, supporting this interpretation. However, there are also possible reasons for the diurnal variation of ship track occurrence, like possible diurnal behaviour of ship traffic in this region, which could trigger or enhance this diurnal behaviour of ship track occurrence.

As described in Section 2, it is also possible to observe a high amount of ship tracks at night, using the brightness–temperature. The radiative forcing is negligible, but the data during nighttimes are still useful to follow ship tracks over several days, if needed. Whereby it has to be pointed out, that the visibility is worse then during day, even by using visual analysis and this could result in a loss of number during nighttimes and as can be seen, the number of occurrences is smaller during night. There is a slight increase of ship tracks during the night from 6 pm to 6 am, which could also be connected to change of cloud cover in this region. Radiative cooling from the top of the clouds is the important factor for the convection in the marine stratocumulus clouds. Therefore, the extent of clouds reaches its maximum in the early morning, and so are the ship tracks. The solar heating warms the marine boundary layer and works against the thermal radiative cooling resulting in a minimum of marine stratocumulus in the afternoon and the following night, also affecting the ship track distribution. The time-intervals of sunrise (around 5:00 to 7:30 am) and sunset (5:00 to 7:30 pm UTC) — indicated by the grey areas in the picture — are the most uncertain times for ship track identification, due to the change in observation from emissivity to reflectance within the same satellite channel. Whereas emissivity of ship tracks shows a decreased signal when compared to the surrounding clouds, the reflectance of ship tracks shows an increased signal. The calculation of percentage of emissivity or reflection in the signal of the channel is based on some assumptions and therefore during dusk or dawn there is sometimes no obvious contrast of ship tracks in neither the emitted infrared nor the solar reflected signal of 3.9 µm, when comparing them to the surrounding cloud. This results in a gap of observation, which is obvious in the data.

Regarding observation times for polar orbiting instruments, the data indicates, that the best time of ship track observation from polar orbiting satellite platforms is between 9:00 and 11:00 am. Envisat with AATSR (10:00 am) — which was used in the global ship track examination by Schreier et al., 2007 — or MODIS (MODerate resolution Imaging Spectrometer, 10:30 am) on the platform Terra have overpass times in this range. Other satellites, reaching the area in the afternoon, would see less ship tracks, because there is a slight decrease over the day.

The non-equal distribution of ship track occurrence over the day is an important factor when it comes to the radiative forcing, because the radiative forcing is depending on the amount of ship tracks and also the solar zenith height. This indicates that radiative forcing by ship tracks is largest between 10 am and noon, because of a high occurrence of ship tracks combined with a high solar zenith angle. In the afternoon, the radiative forcing diminishes because of less ship track development.

3.3. Development of ship tracks: length and lifetime

Even with the 15 min-interval of SEVIRI, comparison of the reflectance of ship tracks to surrounding clouds over time is difficult as a result of the high variation and the movement of the cloud layer from one observation to the next. The best way to accomplish this task is again by visual analysis. Fig. 3 shows a good example of a ship track development from several attempts to produce a meaningful comparison. The ratio of two different areas of cloud reflectance is displayed: An area of around 10×10 km within the ship track is compared during daytime from 8:00 to 16:00 UTC to a nearby similar area outside the ship track, which was observed since several hours before and marked as not influenced by ship emissions. The reflectance in the 3.9 µm channel is enhanced by 20 to 30% for more than 6 h and then slowly decreasing. After 10 h, the ship track cannot be distinguished from the environment, the contrast was far below 5%. It has to be noted, that the observed ship tracks broadened and when diminishing, dissolved partly into the surrounding clouds. This indicates an impact on the surrounding cloud layer, even after these 10 h, when the ship tracks are not visible anymore. However, by visual analysis, only the properties of ship tracks themselves can be estimated. By analysing the marked ship tracks, the maximum length, mean covered distance, and
the duration of visibility, mean lifetime of the ship tracks that can be observed.

An additional interesting observation is the strongly enhanced reflectance in the visible and near-infrared channels in the first hour, which disappears later on (see Fig. 3). This behaviour indicates that more has occurred than just a change of an already existing cloud layer. It was already mentioned in the Introduction, that the modification of already existing clouds by ship emissions is not the only observable effect within ship tracks. For example, Rosenfeld et al. (2006) describe an example of change of convection from ship emissions and Ackerman et al. (2003) propose an enhanced cloud development in broken clouds. SEVIRI provides a good possibility with its high-resolution channel, to examine possible additional cloud development, as described by Ackerman et al. (2003). Fig. 4 shows a case study of ship track development near a cloud edge with broken cloud cover taken on the 8th of August 2004 in the area of interest around 0.7°E and 33.9°S. The upper panel shows obvious ship tracks observed with 3.9 µm, near the edge of a cloud layer. The lower panels show a more detailed view for 3.9 µm (left) and the HRV-channel (right). The development of the ship track is visible at 3.9 µm by enhanced reflectivity in some pixels, but due to the coarse resolution there is no additional information available. The same areas in the reflectance of the HRV-channel represent higher reflectances within a broken cloud field, indicating more continuous cloud cover. The use of the low resolution of Channel 4 in combination with the HRV helps therefore, to examine ship track development in more detail and could help, to better understand ship track development.

3.3.1. Length of ship tracks

The length of an aged ship track is important, because it defines the area of maximum coverage of the indirect aerosol effect due to ship tracks. Fig. 5 shows the occurrence of

![Image](image_url)

**Fig. 4.** Detailed examination of development of a ship track in a broken cloud layer on 8th August 2004 at 0.7°E and 33.9°S: right side shows the observation in 3.9 µm and right side shows HRV. The closer observation in the HRV with higher resolution indicates increased cloud coverage with developing ship track in the broken cloud layer.
maximum length of ship tracks in kilometres. The maximum length of a ship track is given by the longest length that was observed during the track’s lifetime, the time between the instant the track was first observed to the time the track disappeared. Most ship tracks have a length below 500 km, but some can reach values above 1000 km. The mean covered distance is 458 km (±317 km), which is larger than the estimation by Durkee et al. (2000). One explanation of this difference is that our observations with SEVIRI were made with a coarser resolution than the study of Durkee et al. (2000), shifting the distribution of the ship track-length and thereby the mean value in the direction of larger values. Identification of the ship track was possible up to the threshold of the contrast being less than 5%, as Fig. 4 indicates. In Eq. (1) we provide a distribution function, which is approximated by a Gaussian function, to parameterise the dependence of the occurrence of a ship track for a given length:

\[
\text{Occurrence}(\text{Length}_{\text{Ship track}} [\text{km}]) = \frac{130 [\text{km}]}{\sqrt{2\pi}\sigma} \exp \left(-\frac{(0.01\text{Length}_{\text{Ship track}} - \mu)^2}{2\sigma^2}\right);
\]

\[
\sigma = 3.8 \text{ km}, \quad \mu = 2 \text{ km}
\]

The parameters \(\sigma\) and \(\mu\) were derived by visual fitting. From the maximum length of the ship track, its occurrence can be estimated. For analysis of polar orbiting satellites, this could be helpful, to estimate the maximum range of an observed ship track. On the other side, model estimations can parameterise the ship track lengths by this formula.

Fig. 6 shows the length of the observed ship tracks as a function of wind direction. The stars indicate the values, whereas the bars (solid line) indicate the mean values according to 10-degree-steps. The length of the ship track peaks around 135° wind direction. This is when the wind is coming from Southeast, along the main shipping route, and the ship track length under these conditions can reach values above 1000 km. The 10-degree-mean-value has also a peak here with 600 km. The maximum ship track length on other wind directions is small and also the mean value is decreasing rapidly in other directions. Therefore, the length covered by ship tracks is highly depending on the wind orientation for the region west of southern Africa.

The reason for this distribution is the connection of common wind direction and ship-direction in this area. The highest possibility of stretching ship tracks over long distances is for a wind direction, which is opposite to the orientation of the ship route. The result is a ship track stretched by the wind over several hundred km. The main shipping route orientation in the days of our observations seems therefore to be opposite to 135° and the main wind direction was 135°, means south-east. This should not change much over the year, because the common wind direction in the lower atmospheric layer in this area is from Southeast-direction: the wind field from the trade winds in the southern hemisphere. The main shipping route from Cape Verde to the Cape of Good Hope in the area is following a similar direction, as is indicated by the dashed line in Fig. 1. Therefore, this distribution should be similar for the days, which were not examined, and points out the high importance to consider wind fields and movement of emission source, when examining the size of ship tracks and the resulting radiative relevance or other connected indirect aerosol effects.

To make the distribution more convenient, we also calculated an approximation function by a Gaussian distribution function, to describe dependence of ship track length on wind direction. Because of the high variation of values, two functions were approximated. Eq. (2) gives an envelope function of the maximum values possible depending on wind direction (dotted line) and Eq. (3) provides the distribution of mean values on a 10-degree-interval (dashed line).

\[
\text{MaxLength}_{\text{Ship track}} [\text{km}](\text{Wind direction}[\circ]) = 150 [\text{km}]
\]

\[
+ \frac{10^5 [\text{km}]}{\sqrt{2\pi}\sigma_{\text{max}}} \exp \left[-\frac{(\text{Wind direction} - \mu_{\text{max}})^2}{2\sigma_{\text{max}}^2}\right]
\]

\[
\sigma_{\text{max}} = 25 [\circ], \mu_{\text{max}} = 135 [\circ]
\]
The distribution function could help, to estimate the development of observed ship tracks from polar satellite data in combination with wind direction from reanalysis data as e.g. the ERA-40 data by ECMWF (Simmons and Gibson, 2000). The factor $\mu = 135^\circ$ indicates hereby the opposite direction to the main shipping route ($180^\circ - 135^\circ = 45^\circ$). Therefore the formula can be adapted to other areas with different main shipping routes by replacing $\mu_{\text{mean/max}}$, which is opposite to the new main shipping route in the new area, if the meteorological conditions are similar. In case of more than one main shipping route, addition of the functions with respect to the probability density is possible. So, by assuming, that the behaviour of ship tracks in the areas of interest is representative to other ship tracks in other areas of the world, like e.g. the west coast of North America, the dependence of the ship track coverage on wind orientation could help to improve model estimations of the effect of ship tracks and further indirect effects.

### 3.3.2. Lifetime of ship tracks

Another important point for the influence of ship tracks on climate is the lifetime of ship tracks, i.e. how long they could possibly influence the atmospheric radiation budget compared to the surrounding clouds. Therefore, when a ship track appeared in the examined region, the ship track was followed until it disappeared, means the contrast was less then 5%. The time between first appearance and end of visibility was calculated as “lifetime” of the ship track. The resulting distribution of the lifetime is shown in Fig. 7. There is a high variation, because some ship tracks disappeared after a few hours and some lasted for several days, visible also at night.

![Fig. 7. Distribution of the lifetime of the observed ship tracks in hours. The dashed line shows the log-Gaussian approximation.](image)

The mean ship track lifetime is 18 h (± 11 h) and only a few ship tracks lasted for more than 24 h. The resulting fitting function for the lifetime is a log-normal-distribution and is shown in Eq. (4):

$$\text{Occurrence}_{\text{Ship track}}(t) = \frac{160}{\sqrt{2\pi} t^{\frac{3}{2}}} \cdot \exp \left[ -\frac{(\ln t - \ln t_0)^2}{2\sigma^2} \right];$$

$$t = \text{lifetime in hours}, \sigma = 0.5, \ln t_0 = 2.8$$

For polar orbit satellite observations, this formula can help, to estimate the age or remaining occurrence of an observed ship track. It is also possible, to calculate the possibility of observing the same ship track in a region again, depending on the repeating cycle of the instrument. For model estimations, the parameterisation of lifetime of a ship track could help to estimate the time of influence of ship emissions on clouds.

### 4. Conclusion

Characteristics of ship tracks for the region on the west coast of southern Africa have been studied with satellite data from the instrument SEVIRI (Spinning Enhanced Visible and Infra-Red Imager) onboard Meteosat-8, to analyse ship track characteristics like diurnal cycle, lifetime and length with a geostationary platform. The data of the geostationary orbit were analysed for certain days in the period May to November 2004. Because of the high variability of ship tracks, the analysis was done by visual analysis, using information of the 3.9 µm channel.

The observations in the area of interest showed that ship tracks mainly form along the main shipping route from Europe around South Africa along the line from 4°S/8°W to 35°S/18°E. However, ship emissions also influence clouds over the entire area, therefore, the entire region is influenced by ship emissions, highly depending on the wind field. The main aim of this study was to derive variation of ship track occurrence during the day, together with mean values and distributions of ship track length and lifetime. The analysis of the diurnal cycle showed a peak of ship track occurrence around 10:00 am and a decrease of occurrence during the afternoon. The mean ship track length was found to be 458 km (± 317 km), but varies from only a few km to more than 1000 km. The largest ship tracks were found for wind directions from Southeast, which is along the main trading route in this area, pointing out the importance to connect wind field and vessel direction for ship track analysis. The endurance of ship tracks, hereby called lifetime, showed also a high variation. The mean value was around 18 h (± 11 h), but some ship tracks lasted from a few hours up to 60 h and more. It was possible to follow the development of ship tracks over several days, because the ship tracks could also be observed during nighttime by using the emissivity at 3.9 µm.

Because of the high variation of the ship track characteristics, we also provide distribution functions. Formulas are provided for the variations that describe the behaviour of ship tracks in the studied area. These distribution functions for the observed attributes could be used for model estimates, to estimate sub-grid processes of the indirect aerosol effect by connecting ship track development and large-scale cloud
processes, or as additional information for polar orbit observations by including the derived ship track length and lifetime in order to estimate further development of observed ship track for a better calculation of the influence on radiation. Additionally, the combination of the provided distribution functions from this analysis within model estimates or observations by polar orbiting satellite instruments could also help, to improve the error analysis of the results.

For the area under investigation in this study a mean length of 458 km (± 317 km) and a mean lifetime of 18 h (± 11 h). Both mean characteristics for the composite ship track are higher than the results by Durkee et al. (2000). They derived a mean length of 296 ± 233 km and a mean age of 7.3 ± 6 h from the analysis of ship tracks on the west coast of North America using data from polar orbiting satellite instruments and information on ship speed and position. It has to be noted that for this study and Durkee et al. (2000) the definition of parameters and the location of observation differ, indicating also the possibility of regional variations. Similar to the study of Durkee at al, our study is restricted to a selected area at a selected time. Nevertheless, our study describes a new approach for the analysis of ship tracks, derived using geostationary observations having a high temporal sampling, allowing for a good temporal and spatial coverage of the area of interest and thereby a large number of ship tracks to be analysed. This study was focused on a specific area, but the method can also be applied to other regions, assuming that geostationary imagery is available for that region. This work also demonstrated the possibility to derive mean lifetime and length of ship tracks by using geostationary platforms without using additional information of ship position or speed and is pointing out the strong dependence on factors like wind direction relative to the mean shipping route. Several geostationary satellites specifications similar to Meteosat-8 are already in orbit and making measurements above areas having a high density of ship track occurrence. This provides the opportunity, to make similar observations and compare it with these results yielding the possibility of deriving and comparing global and local ship track characteristics. We also showed in a case study, that the combination of the HRV-channel together with the 3.9 µm channel can be used, to understand possible anthropogenic influence on cloud development in critical situations like cloud edges. This would help to better understand the possible influences of anthropogenic emissions on clouds. Instruments like SEVIRI on Meteosat-8 provide therefore important additional information, which helps to understand anthropogenic cloud modification like ship tracks and the additional indirect aerosol effect, especially with respect to the duration of the effect. This study provides first statistical information about ship track development as observed by a geostationary satellite platform, but it also represents only a first step in the statistical analysis of ship track development and can be used as a basis for further examinations of this cloud phenomenon.

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