Visualising remote sensed weather phenomena with ground measurements in Namibia

Background information

The western coast of Namibia and its inhabitants are often subjected to overcast skies: A usually large stratus cloud layer just off the coast Namibia represents a meteorological phenomenon affecting wildlife and humans alike. This stratus often makes landfall, either at the coast or in the hinterlands and thus is classified as fog in this case, depending on height above ground and visibility (< 1000 m, Met Office UK). Just how often this stratus makes landfall and can be called fog, how much (fog) water remains at the surface is subject to debate as is its genesis: Recent literature suggests that a larger than previously thought percentage of fog events originates as radiation fog, i.e. local growth of fog instead of advection fog.

Despite this new finding, the detailed processes of the advection fog remains unclear. Especially what induces the stratus to move inland until it becomes fog. Since the nature of advection includes the movement of air masses over a (large) distance, the large area that has be investigated requires many field stations. This comes with personal and material costs in addition to the many challenges in upkeep and data sampling. To augment, or amend, the weakness of the previous, remote sensing techniques, specifically satellite data, can be used.

This allows for the coverage of a bigger area, but comes with shortcomings. Usually a trade-off between high temporal and spatial resolution is incurred. Furthermore, some of the satellite sensors, depending on wavelength, are able to see through the fog while others are not. While this makes for great flexibility, it also constrains the amount of viable information. Finally, it is possible to glimpse movement and surface (stratus/fog or land) processes, the ability to gather all the information a meteorological station measures without any additional algorithms (and thus in a viable time for production) is very limited.

Therefore, the ideal solution takes the best parts of both approaches. In a first step, a simple visualisation of stratus extent in combination with the measurement data of fog precipitation amount and wind direction yields sufficient information about whether the stratus makes landfall with water deposition on the ground and what the usual advection pathway, derived from wind direction and speed, could be. This combination allows a unique view into the process.

Part Remote Sensing

As the fog occurrence usually only last for a few hours during the night, a satellite with high temporal resolution is needed in order to arrive at a meaningful combination product. The sensible choice for this is the Meteosat second generation (MSG), operated by ESA/Eumetsat. For further information, see the corresponding homepage of ESA. While the spatial resolution is limited to 3 kilometres, the frequency of 15 Minutes balances this low resolution.

Assembling, calibration and saving the data of all satellite bands is done by the MCR at the University of Basel for a part of Namibia around Walvis bay, respectively coast and hinterlands. The approximate extent is 10.5° E to 18.9° E and 20.4° S to 26.6° S, with about half of the area covered by the South Atlantic Ocean.

Table 1 Meteosat Band wavelengths and where/what they usually represent

Channel/Band	Central Wavelength [µm]	Indicative of
1	0.635	Visible Blue
2	0.81	Visible Green
3	1.64	Visible Red
4	3.92	Near Infrared
5	6.25	Water Vapour
6	7.35	Water Vapour
7	8.7	Infrared
8	9.66	Ozone Channel
9	10.8	Infrared
10	12	Infrared
11	13.4	CO_2
12	0.65	High Resolution Visible

Since the bands of MSG detect information at different wavelengths (see Tab. 1), they can be combined or used for calculation to make fog more distinct in a RGB picture. For an overview of available combination and their interpretation, see the training site of EUMETSAT. However, many of the given examples are used for other climates, specifically Europe and the United States of America. As such, some combination do not allow the same interpretation in other locations. For this reason, alteration of the recipes have been and should be generated. For example, the “Fog Recipce” yields not a very clear picture of the fog over Namibia. Therefore, the most promising results, the “Dust Recipe”, or very similar band combinations are used. The combination is featured in table 2, and is used for the default product. Single bands or band combination are scaled to the typical image range of 0 – 255 (almost all picture formats except TIFF) after calculations have been conducted.

Table 2 Default band combination

Colour	Red	Green	Blue
Band	10 - 9	9-7	9
Wavelengths [µm]	12 – 10.8	10.8-8.7	10.8

This scaling can be done by using minimum and maximum, by removing an amount of upper/lower percentile counts or by employing the mean with a settable factor of standard deviations as range. The first two methods usually make for a bigger coverage of all values, but lesser contrast and makes features harder to identify. The default option as of end of October 2017 is to scale by the method with the mean and a range of two times the standard deviation of pixel values for each band.

The above given recipe interpretation describes, that a dust layer absorbs differently in Band 10 than in Band 9, and that Dust would be in shades of red/purple in this band combination. Nevertheless, this combination also allow so see the extent of fog in about the same reddish hues (orange to brown/purple).

To illustrate the pixel ranges before this scaling, the histogram of a MSG picture of the default bands is shown in figure 1. The first two bands are red and green. Red shows the difference of band 10 minus 9 and Green shows the same for band 9 minus 7. Both distributions are around zero since they represent the difference of bands not that different from each other in terms of wavelength. The Blue band, which represents band 9, shows two peaks, both of which are present in the Red band as well.

Band 10 shows a lower emission than band 9, which can be seen in their negative difference. Both are representative of the earth surface temperature (see table 1), but band 9 is closer to the maximum wavelength of terrestrial radiation (~10 µm or ~290° K). In this particular product, the radiometric calibration of all bands converts bands to brightness temperatures, which is in $W/m^2/sr/um$ and not K as would usually be expected for thermal bands.

The two peaks in Red and Blue show the cloudy stratus over sea and land, but also a small peak for the open sea in this particular example. The lower, wider peak in the band is the land surface, whereas the steeper peek around -0.3 is the fog, whereas the small peak at around -0.5 below represents the small stretch of open sea, visible also in figure 2. The reason for the bigger difference of the two bands over lands is supposedly due to the higher emission of the land surface and fog/stratus surface in the band 9 than in band 10. Both bands are measured at similar wavelengths, but band 10 shows generally lower values than band 9, since the sensitivity is further away from the maximum emissivity peak (c.f. Planck curves) of the surface temperature.

The Green band (difference band 9 minus band 7) shows indirectly how much water vapour (see table 1) is occurring in a pixel. The surface brightness in band 9 is higher than in band 7 and as such the result of the difference is positive. Values are higher when less water vapour is in place.

In short, this combination depicts the bare land areas from land areas with at least some vegetation. This vegetation apparently allows for some humidity/water vapour in the air, e.g. location like Etosha Pan or the high lands. As such, the fog/stratus pixel values fall between the extremes of the distribution: The Minimum occurs over parts of the land with some vegetation (high values in band 7), the maximum shows bare land (high values in band 9).

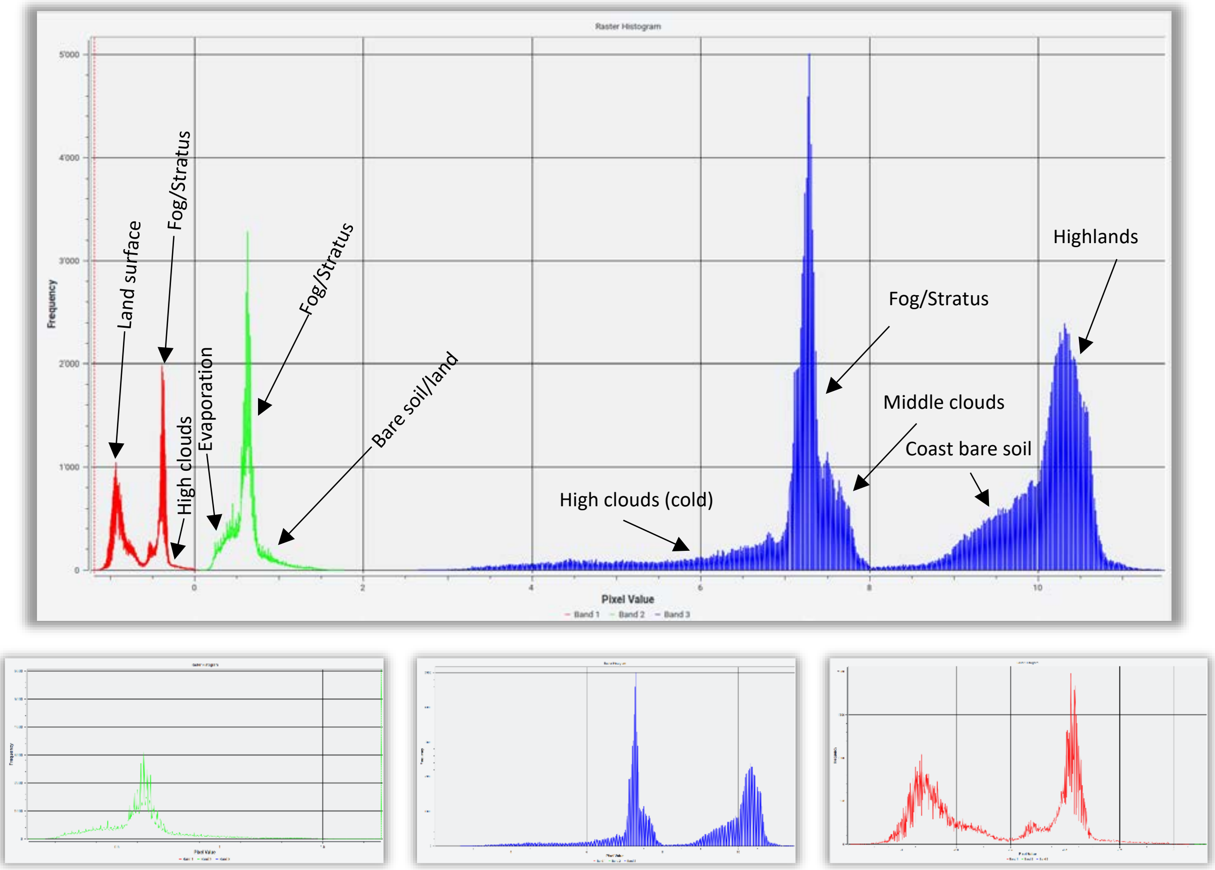

Figure 1: Example histograms of the three used bands, resp. band combinations with identifier for specific surfaces/features

Hence, the combination and scaling of all three bands will show high values for fog in strong red, middle green and lower middle tones of blue, i.e. the above-mentioned range of brown/red/purple, depending on time/sun height and thickness. In case of missing satellite pictures, the colour channel of the corresponding band is set to grey (value of 80 for all pixels).

Another viable option is to replace the band 9 with the difference of band 9 minus band 4 (near infrared) instead, which theoretically makes low clouds distinct from fog as denoted on Eumetrain. This band combination is mainly used in the microphysics products and in Europe, which may make its application possibly valuable, but does not enhance the identification compared to the default combination. The IR temperatures of low cloud and fog are too close to improve the product much.

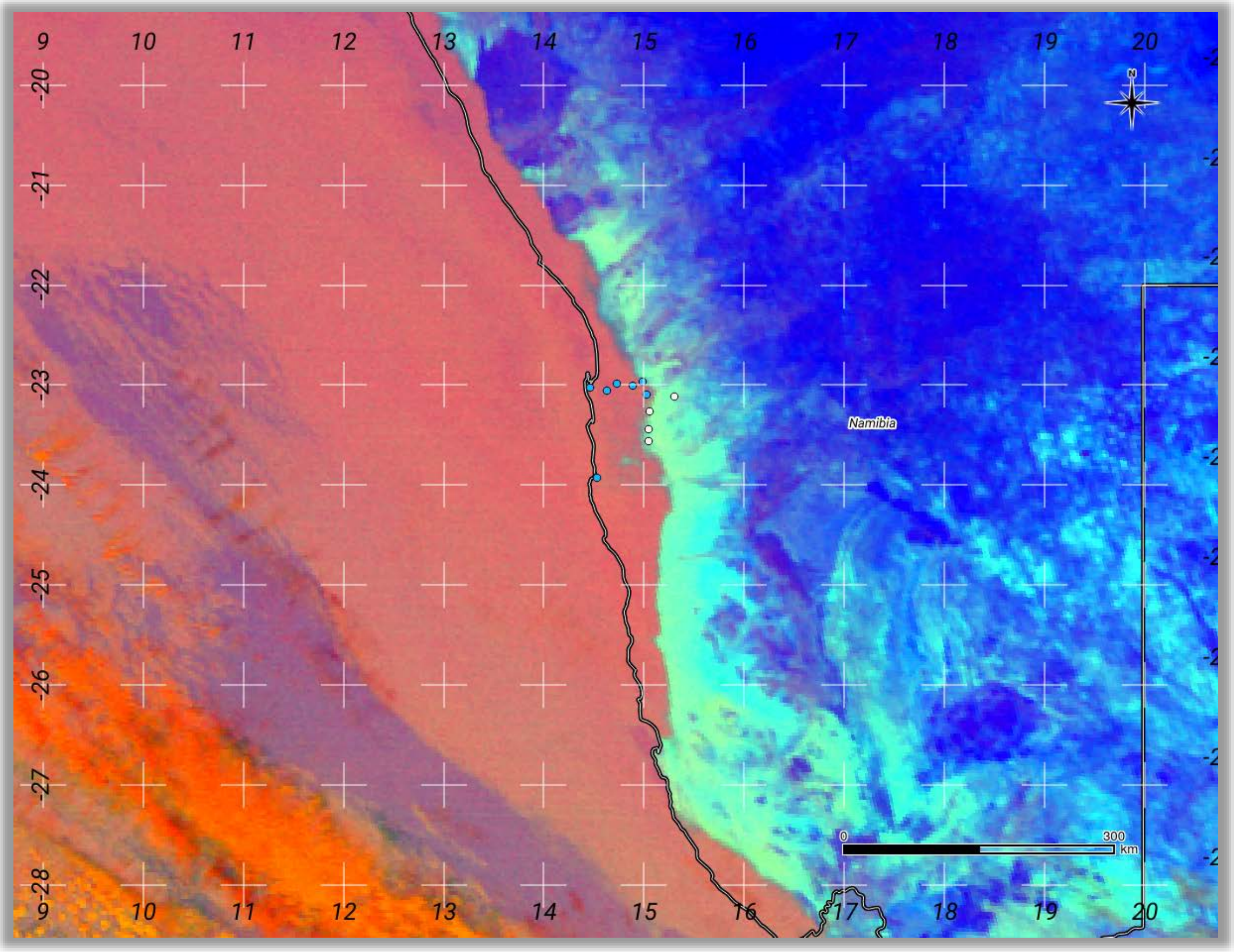

Figure 2: Example of the default band combinations of MSG for 08:00 UTC on the 19.9.2017. Red channel is band 9, green is band 9 minus 7, blue is band 10 minus 9. Map elements here are exemplary and different from the end product version to be better used in an example.

Part Field Measurements

The raw measured values are taken from the FogNet stations at the east-west and north-south transects. Since the position of the station limits the decipherable amount of information in a map, an inset of the extent of the station network is used. This smaller inset shows the same RGB composite as the bigger map. Additionally, the inset shows wind direction, speed and the amount of precipitation by the size of the station marker.

Because MSG takes pictures every 15 minutes, the ground measurement date have to be aggregated beforehand. The wind is calculated by vector averaging, whereas fog precipitation is gets summed up. As is common, wind barbs show wind speed and direction, but instead of knots, the barbs show meters per second, c.f. text in final product. The measured fog precipitation by the rain gauges scales the radius of the station marker, i.e. the bigger the symbol the bigger the circle.

Table 3 lists the usual measurement and devices as well as the coordinates of the stations. Either a weather transmitter from Vaisala or a propeller vane from R.M. Young measure wind direction. In case of the weather transmitter, the wind velocity is recorded with the same device using sonic technology. For the propeller vane, as the name suggests, it consists of vane and propeller, measuring both at the same time. A R. M. Young rain gauge (52202/52202H/52203) or a Lambrecht rain gauge is used to record the fog amount a is used.

Table 3 Measurement devices at the FogNet station that are used for the single pictures and which are used to trigger automatic video creation

Station (ordered by Longitude)		Measurements	
Name (Abbrev.)	**Coordinates (Lon./Lat.)**	**Wind speed and direction**	**Fog amount**
Saltworks (FNSW)	14.46 / -23.02	Young Propeller Vane 5106	Rain gauge (Lambrecht)
Conception Water (FNCW)	14.55 / -24.02	Young Propeller Vane 5106	Rain gauge (Lambrecht)
Coastal Met (FNCM)	14.63 / -23.06	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Kleinberg (FNKB)	14.73 / -22.99	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Sophies Hoogte (FNSH)	14.89 / -23.01	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Marble Koopie (FNMK)	14.99 / -22.97	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Vogelfederberg (FNVF)	15.03 / -23.10	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Gobebeb Met (FNGB)	15.04 / -23.56	Weather Transmitter WXT520	Fog Total Collector Grunow (area 200 cm²) + Young Rain Gauge
Aussinanis (FNAU)	15.05 / -23.44	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Station 8 (FNS8)	15.06 / -23.27	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)
Garnet Koppie (FNGK)	15.31 / -23.12	Young Propeller Vane	Rain gauge (YOUNG 52202/52202H/52203)

Part Combination

The two parts above are combined in a visualisation of a map, saved as jpeg and made into a movie.

This process is automatized by a task that runs at 9:30 UTC every day. The task checks for fog sums greater than zero of stations/measurement devices listed in table 3. Conception Water and Saltworks are excluded from this check, because both represent their own regime of fog frequency and amount due to their closeness to the coast. When developing the final product, often data were not available at the time of product creation.

To compensate for this, the fog amount is checked for one day (including the night time) before, e.g. the task that runs on Monday checks the fog amount from Saturday to Sunday (12 UTC to 12 UTC). This makes the process more reliable with respect to delayed satellite picture and field measurement data due unforeseen circumstances or connection problems.

With this mechanism, every time fog occurrence is detected at any station, the product is generated automatically and involved personal is notified by email about the event with a clickable link. The recipient list is extendable as well.

The range of the default product is set to two days, i.e. containing the nightly occurrence of fog in about the middle, but including the morning and afternoon of the checked interval. This allows seeing the development and aftermath of a fog event as well.

As the script is extendable, i.e. bands, band operations, scaling of values, beginning and end timestamp as well as whether the interim images should be cleaned, it can be adjusted to particular needs. This design allows to use MSG data collected in the past to be used in conjunction with the FogNet database and analyse fog events at will. Because the internal data saving policy in the year 2016 was altered, the products may look slightly different though. All available videos can be seen sorted by the year at the Nafolica-F Homepage.

Additional features

To better illustrate the fog occurrence, i.e. how far it reaches into the hinterland, the SRTM DEM is used in isohypses of 100m for the small inset and 500m for the large map. Often this shows that the fog makes landfall at 400 -500 m height above sea level. Barbs represent 1/2/5 ms^{-1} as half line/line/flag instead of the usual increments, but can be adapted.

Usual map markers, e.g. grid and north arrow, are included as is custom.

Links

In order of appearance in the text

http://www.esa.int/Our_Activities/Observing_the_Earth/Meteosat_Second_Generation/MSG_overview2

https://meteo.duw.unibas.ch/index.php?id=50658

http://www.eumetrain.org/RGBguide/rgbs.html?page=1&sat=-1&rgb=-1&colour=-1&recent=false

http://www.eumetrain.org/RGBguide/recipes/recipe_Dust_RGB.pdf

http://www.eumetrain.org/resources/MSG_dust_magenta_sandstorm.html

http://www.eumetrain.org/data/4/410/print_4.htm

https://mcr.unibas.ch/dolueg2/index.php?project=campaigns&subproject=nafolica