# Fog and Low Level Stratus Forecasting using Satellite Products; A Case Study of Jomo Kenyatta International Airport, Kenya

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***Abstract***

*The occurrence of fog and low level stratus at airports causes a number of negative impacts ranging from delays, diversions, cancellations, extra fuel leading to reduced loading capacity and customer discomfort. Some of the impacts can be greatly minimized if the occurrence of fog and low level stratus are accurately, reliably and timely forecasted.*

*The study aimed at investigating the utilization of METAR and satellite products, as well as their performance in issuance of Terminal Aerodrome Forecast at the Jomo Kenyatta International Airport. The study is based on a case study of 20th and 21st August 2012, utilizing TAFs, Water Vapour imagery of satellite and METARs, High Resolution Visible, Infra-red channels. The fog and low level stratus were observed to form at around 0100 and 0500 UTC and dissipate at around 0500 UTC. The dissipation is mainly attributed to the incoming solar radiation.*

*The satellite observations replicated the METARs issued. The study therefore recommends further utilization of satellite products and METAR reports in the issuance of Terminal Aerodrome Forecasts to help in minimizing the impacts associated with fog and low level stratus at the airport. However, the study calls for quantitative verification of the performance of the satellite products is however recommended to ascertain the accuracy of the products.*

**Key Words:** Fog, Stratus, TAF, Satellite, METAR

## Introduction

Fog is the suspension of very small water droplets in the air, they are known to reduce surface-based visibility to less than one kilometer (WMO, 1992; Glickman 2000). Humidification can be achieved through temperature advection or cooling or through addition of moisture to attain saturation. Fog is forecasted to occur when the air temperature decreases to a 'crossover temperature' which is usually below the dew point (Baker et al., 1992). The process through which fog and low level stratus forms is the same. Although most of the physical processes that cause fog and low stratus ceilings have been studied and understood for a relatively long time (Willett, 1928; Cotton and Anthes, 1989; Petersen, 1956: Dupont et al. 2012; Gultepe et al. 2007; Niu et al. 2010; Zhang et al., 2014; Hu et al., 2014), their accurate prediction has remained difficult due to the requirement for very high resolution in modeling and initial data observations (e.g. Peak and Tag, 1989; Baker et al., 1992).

Jomo Kenyatta International Airport (JKIA) in Kenya lies within the tropics; hence, humidification in the region is through radiative cooling. Fog and/or low level stratus is a common occurrence during both the northern summer (June-July-August) and southern summer (December-January-February) (Mwebesa, 1980). The study reported that at JKIA, fog occurs when air temperature is cooled to reach saturation below 16°C and in most cases occurs between 2200Z and 0700Z. Fog is of considerable socioeconomic importance, especially in terms of traffic safety, visibility and air quality (Elias et al., 2009; Gultepe et al. 2009; Niu et al., 2010; Tardif and Rasmussen, 2007). Muiruri (2011) observed that, among all the meteorological parameters causing disruption to aircraft operations at JKIA, fog is rated highly, hence it's proper and timely forecast can greatly reduce its impact on the airlines.

Different data sources are required in fog/low status forecasting, ranging from synoptic to micro scale phenomena. However, fog's extent and dynamics cannot be adequately now-casted using conventional ground-based meteorological measurements (Jacobset al., 2003). In this regard satellite

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imageries play a critical part in observing the conditions that necessitate fog occurrence. Polar-orbiting satellites such as TERRA/AQUA and geostationary platforms such as Meteosat 8 offer sensors with improved spatial, spectral and temporal resolutions. The detection of fog/low stratus layers with satellite data has been undertaken for many years using the AVHRR 3.7 µm channel aboard the NOAA satellite series (e.g. Bendix, 2002). According to Bendix and Bachmann (1981), the detection was especially successful during night, when the emissivity of fog is lower than that of all other clouds, due to the similarity of wavelength and mean droplet size.

Despite the existence of satellite platforms, some problems still exist in the remote sensing of fog. From the satellite point of view, it is very difficult to discriminate whether a low stratus layer is actually fog (Bendix et al., 2005). The most effective method for timely production of long term forecasts of fog and stratus over large areas still remains a diagnostic approach (Zhou and Du, 2010).

The occurrence of fog depends on the presence and strength of inversion separating the dry areas from the moist regions (COMET, 2003a, b; ASMET, 2013). The sounding outlines the wind fields and indicates the presence of wind shears. From the METAR reports the conditions prevalent for fog occurrence can be established especially if it is a typical radiative fog situation (COMET, 2003c, d).

Accurate and timely forecasting of fog and low level stratus is importance; it helps to minimize the impacts associated with their occurrence in the airports. There are different flight categories which have been developed depending on the severity of fog and ceiling conditions and are being used globally.

According to Guidard and Tzanos (2007) there exist specific meteorological and aerosol conditions that guide in estimation of the probability of fog occurrence, the use of satellite and near-surface instruments is among them. Nowcasting of low level stratus and fog at JKIA explores satellite images. This study investigates the utilization and performance of satellite products and METAR reports in issuance of Terminal Aerodrome Forecast (TAFs) at the JKIA.

## Materials and Methods

The study utilized observed and forecasted data during the occurrence of fog and low level stratus over the airport on August 20th and 21st, 2012. The study discusses the forecast vis-à-vis the satellite images from Infra-red (IR) 10.8-3.9, and Water Vapour (WV) 6.2 and HRV observed during the corresponding time.

## Results and Discussion

The pre-conditioning of fog/stratus formation starts by considering the existing/initial TAF. The TAF issued at 1630Z read:

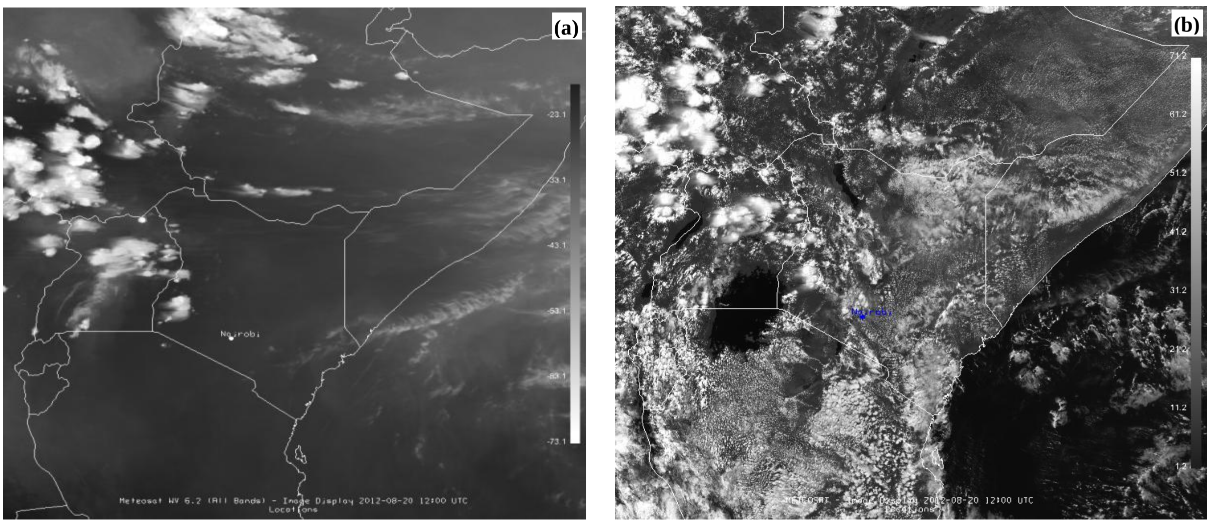


**Figure 1: (a)** WV 6.2 on 2012-08-20 1200 UTC **(b)** HRV on 2012-08-20 1200 UTC

TAF HKJK 201630Z 2018/2124 15005KT 9999 SCT021 TEMPO 2100/2106 VRB05KT -DZ FEW006 BKN017 BECMG 2108/2111 15010KT SCT023 TEMPO 2112/2118 VRB10KT -SHRA FEW022CB BKN023 BKN080 BECMG 2120/2123 16005KT SCT021

During the time of study the region was experiencing cool moist maritime winds from the South-west Indian Ocean caped with a dry East Africa Low Level Jet (EALLJ) aloft. The satellite images, HRV and WV showed moist lower levels and drier upper levels respectively (Figure 1).

The formation of fog/low level stratus requires relative humidity above 90% within the boundary layer especially at the time of formation. The moisture signature is realised early on especially with early morning cloudiness and afternoon convective cloud development. METAR observations were checked in the afternoon. The moisture and afternoon convection was checked using HRV (Figure 2). The METAR report was;

METAR HKJK 201330Z 12008KT 9999 BKN025 23/08 Q1022 NOSIG

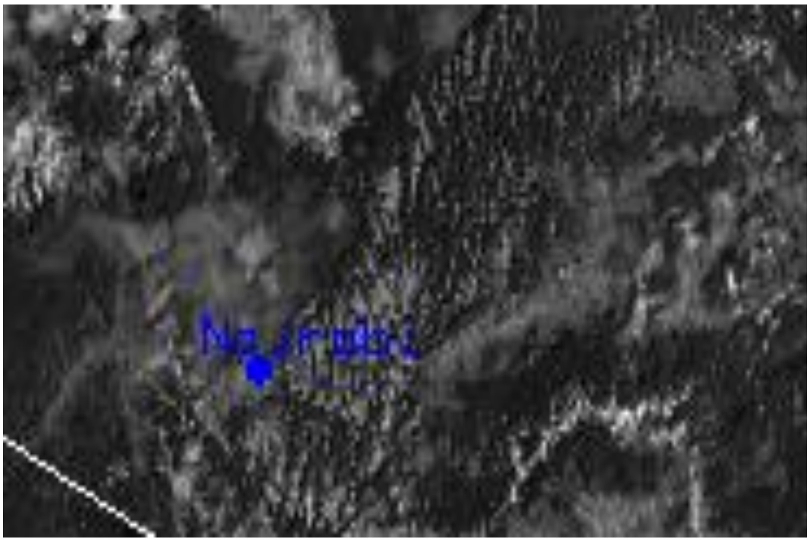

**Figure 2:** HRV on 2012-08-20 13:30 UTC

Rapid radiative cooling was observed after sunset and eventual clearing of the skies. The clear sky eventually appears as see CAVOK or SKC in the METAR.

HKJK 201330Z 12008KT 9999 BKN025 23/08 Q1022 NOSIG

HKJK 201800Z 09006KT 9999 FEW022 17/12 Q1023 NOSIG

HKJK 202000Z 04004KT CAVOK 15/12 Q1024 NOSIG

For fog/low level stratus formation rapid radiation loss is very necessary, this is depicted by rapid fall in air temperature as reported in the METARs. From the first and the second METARs above there is a drop in temperature by 5°C. The first METAR was an observation made at the time of maximum convection, whereas the second METAR is an observation made sometime after sunset as the drop in temperature was being experienced. The last METAR shows the opening of the sky by the occurrence of CAVOK conditions necessitating loss of radiation.

Inversion/stable conditions in the boundary layer are a clear indication of air subsidence in the region. It allows loss of radiation from the surface as the lower layer cools faster compared to the air aloft (Figure 3). The middle and upper atmosphere dryness is depicted on the WV channel. Large scale subsidence is brought about by presence of a ridge in the region.

Calm/light winds ensure little or no turbulent mixing in the lower layer hence allowing the air in the lower layer to reach saturation only through loss of radiation.

HKJK 202100Z 28003KT 9999 FEW019 14/12 Q1024 NOSIG

HKJK 202200Z 23005KT 9999 SCT015 14/12 Q1024 NOSIG

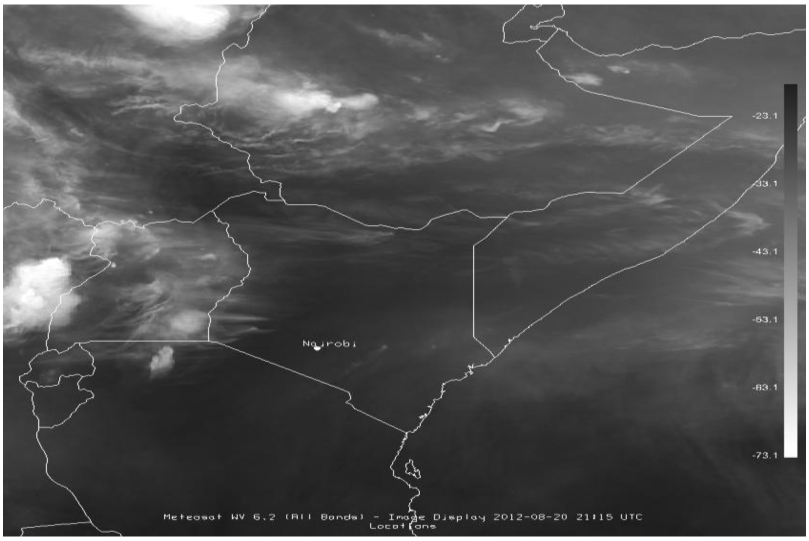


**Figure 3:** WV 6.2 on 2012-08-20 21:15 UTC.

The winds are very light as depicted in the above METARs, plus we see a very narrow temperature depression of 2°C and temperature drop below 16°C. We also see the drop in the height of cloud bar and increase in cloud cover. The cloud cover increases from ‘Few’ to ‘Scattered’ as the height drops from 1900 feet to 1500 feet.

At 2230Z a new TAF was issued as below;

TAF HKJK 202230Z 2100/2206 24005KT 9999 SCT017 TEMPO 2100/2106 VRB05KT -DZ FEW006 BKN017 BECMG 2108/2111 15010KT SCT023 TEMPO 2112/2118 VRB10KT FEW022CB BKN023 BECMG 2120/2123 23005KT SCT020 TEMPO 2200/2206 VRB05KT -DZ FEW005 BKN015=

From the TAF the sector in which fog is expected contains drizzle, it is however challenging differentiating fog from drizzle hence appearance of drizzle in the TAF.

The observations that followed were;

HKJK 202300Z 23003KT 9999 FEW009 BKN015 14/13 Q1023 NOSIG

HKJK 210100Z 00000KT 9999 SCT015 14/13 Q1023 NOSIG

From the above METARs the wind is weakening and even gets calm as the temperature depression becomes narrow. The low level stratus are also observed to start forming.

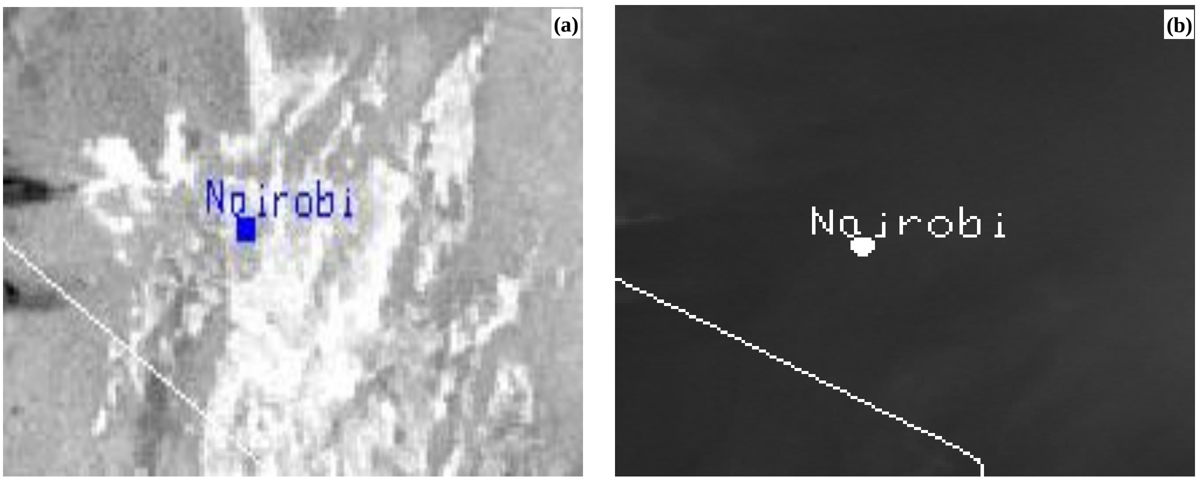


**Figure 4: (a)** IR 10.8-3.9 on 2012-08-21 01:00 UTC, **(b)** WV 6.2 on 2012-08-21 01:00 UTC

At this point all the conditions: calm wind, narrow temperature depression, high relative humidity (RH) in lower levels, drier and sinking motion aloft, and temperature below 16°C support the formation of fog. The formation of low level stratus is also observed in the IR imagery (Figure 4a) while WV 6.2 shows a very dry middle and upper atmosphere (Figure 4b).

The low level clouds appear light in the IR imagery. The WV 6.2 shows a very dry middle and upper atmosphere, implying that the moisture observed in the IR 10.8-3.9 channel is in the lower atmosphere hence fog and low level stratus.

The TAF was amended before occurrence at the terminal as;

TAF AMD HKJK 210100Z 2101/2206 24005KT 9999 SCT015 TEMPO 2101/2106 VRB05KT 0400 FG SCT002 BKN015 BECMG 2108/2111 15010KT SCT023 TEMPO 2112/2118 VRB10KT FEW022CB BKN023 BECMG 2120/2123 23005KT SCT020 TEMPO 2200/2206 VRB05KT -DZ FEW005 BKN015=

In the amended TAF, the drizzle was replaced by fog reducing the visibility to 400 metres and ceiling reduced to 200 feet. The flight category drastically changed to from MVFR to VLIFR.

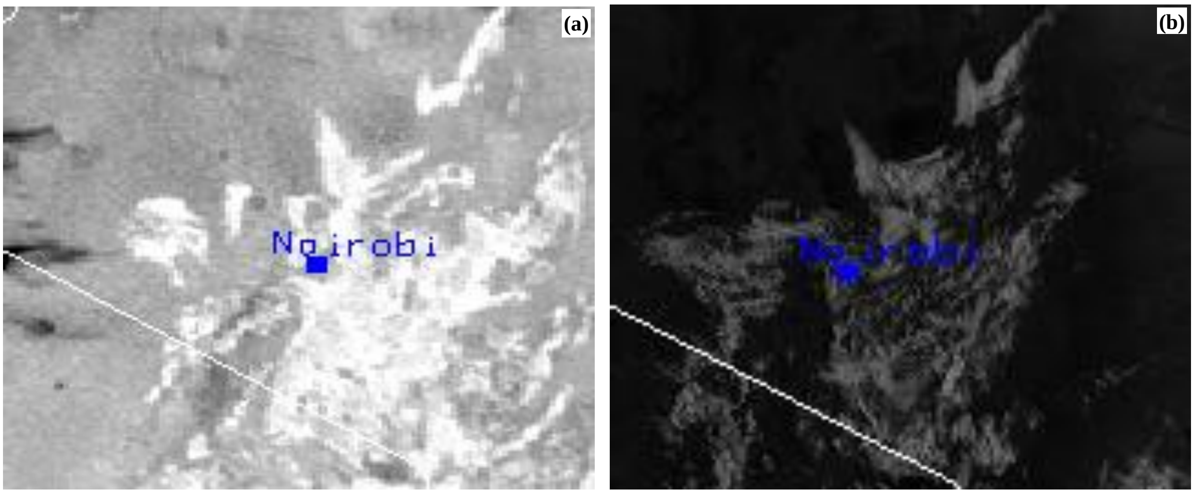


**Figure 5: (a)** IR 10.8-3.9 on 2012-08-21 01:30 UTC, **(b)** HRV on 2012-08-21 05:15 UTC

At the onset; 01:30 UTC, 2012-08-21, IR 10.8-3.9 and HRV, 2012-08-21, 05:15 UTC showed a band of fog and low stratus (Figure 5).

The band of fog and low stratus observed in Figure 5 was also evidenced in the METARs;

HKJK 210130Z 36003KT 0900 FG SCT006 14/13 Q1023 TEMPO 0500 FG SCT005 SCT015

HKJK 210200Z 01003KT 0400 FG SCT005 13/13 Q1023 TEMPO 0500 FG SCT005 SCT015

HKJK 210230Z 00000KT 0500 FG SCT002 SCT120 13/13 Q1023 BECMG 0800 FG SCT015

HKJK 210300Z 00000KT 0400 FG SCT002 13/13 Q1023 BECMG 0800 FG SCT015

HKJK 210330Z 28003KT 0400 FG SCT003 SCT120 13/13 Q1023 BECMG 0800 FG FEW005 SCT017

The dissipation of the fog was observed in the strengthening of the wind and setting in of the sun evidenced by temperature increase;

HKJK 210400Z 19003KT 2000 MIFG FEW015 13/12 Q1023 TEMPO 0800 BCFG SCT016

HKJK 210430Z 24003KT 4000 BR SCT018 14/13 Q1024 BECMG 9999 SCT018

HKJK 210500Z 27003KT 9999 BKN019 15/13 Q1024 NOSIG

Strong wind speeds enhance turbulence mixing in the lower level leading to dissipation. The sun rays on the other hand heats the ground, raising the temperature in the lower layer that heats the fog/ stratus resulting in their dissipation, this is in agreement with observation made by (Zhou and Ferrier, 2008).

At 05:45 UTC, 2012-08-21, HVR showed fragmented clouds indicating dissipation of fog and low level stratus (Figure 6).

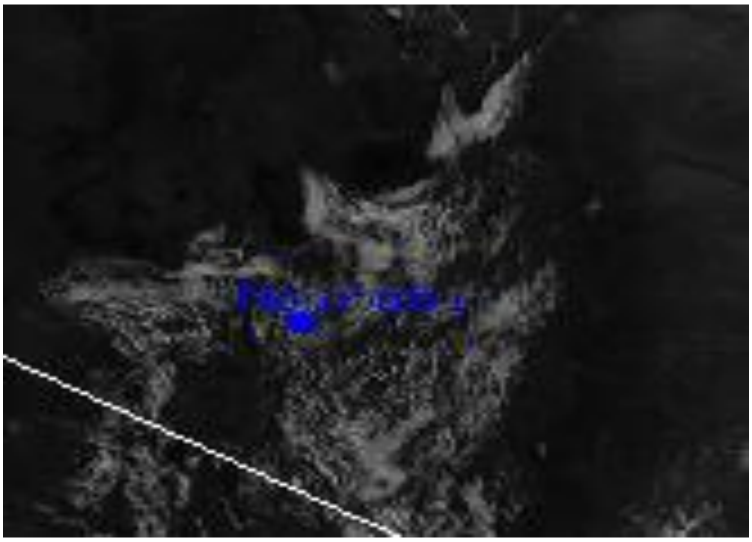

**Figure 6:** HRV on 2012-08-21 05:45 UTC

## Conclusions and Recommendations

This study has investigated fog and low level stratus forecasting carried out at JKIA using satellite products. The fog and low level stratus were observed to form at between 0100 and 0500 UTC and dissipate at after 0500 UTC. The dissipation is mainly attributed to the incoming solar radiation and rise in wind speed.

The satellite images correctly depict what was reported in the METARs allowing for correct issuance and amendment of the TAFs at the airport. The study recommends the utilization of the satellite products to increase the accuracy, reliability and timeliness of the weather forecast. Quantitative verification of the performance of the satellite products is however recommended to ascertain the accuracy of the products.

## Acknowledgement

The authors acknowledge the support from the staff of Kenya Meteorological Service, especially those based at JKIA and EUMETSAT team: Mr. Vesa and Ms. Sarah for the support in the acquisition of the data utilized in the study.

## References

**ASMET, 2013:** Forecasting Fog for Aviation: Kenya Case Study. University Corporation for Atmospheric Research. www.meted.ucar.edu/training_module.php?id=1027 (Accessed on 30.06. 2014).

**Baker, R., J. Cramer, and J. Peters, 2002:** Radiation fog: UPS Airlines conceptual models and forecast methods. Preprints, 10th Conference on Aviation, Range, and Aerospace, Portland, OR, Amer. Meteor. Soc., 5, 11. http://ams.confex.com/ams/pdfpapers/39165.pdf. - (Accessed on 30. 06.2014).

**Bendix, J., 2002:** A satellite-based climatology of fog and low-level stratus in Germany and adjacent areas. Atm. Res., 64, 3-18.

**Bendix, J., and M. Bachmann, 1991:** A method for detection of fog using AVHRR imagery of NOAA satellites suitable for operational purposes (in German). Meteorol. Rdsch., 43,169-178.

**Bendix, J., B. Thies, J. Cermak, and T. Nauss, 2005:** Ground Fog Detection from Space Based on MODIS Daytime Data - A Feasibility Study. Wea. Forecasting, 20, 989- 1005.

**COMET, 2003a:** Synoptic Weather Consideration: Forecasting Fog and Low Stratus. University Corporation for Atmospheric Research. ww.meted.ucar.edu/training_module.php?id=119#.U7z_Z5SSySo–(Accessed on 30.06.2014)

**COMET, 2003b:** Local influences on Fog and Low Stratus. University Corporation for Atmospheric Research. www.meted.ucar.edu/training_module.php?id=118#.U7z_M5SSySo – (Accessed on 30.06.2014)

**COMET, 2003c:** Applying Diagnostic and Forecasting Tools: Forecasting Fog and Low Stratus. University Corporation for Atmospheric Research. www.meted.ucar.edu/training_module.php?id=117#.U7z9jJSSySo–(Accessed on 30.06.2014)

**COMET, 2003d:** Customer Impacts: Forecasting Fog and Low Stratus. University Corporation for Atmospheric Research. www.meted.ucar.edu/training_module.php?id=116#.U7z-GpSSySo (Accessed on 30.06.2014)

**Cotton, W. R., and R. A. Anthes, 1989:** Storm and cloud dynamics. Academic press, Inc, New York

**Dupont, J. C., M. Haeffelin, A. Protat, D. Bounil, N. Boyouk, and Y. Morille, 2012:** Stratus-fog formation and dissipation: a 6-day case study. Boundary-Layer Meteorol., 143, 207–225.

**Elias, T., M. Haeffelin, P. Drobinski, L. Gomes, J. Rangognio, T. Bergot, P. Chazette, J. C. Raut, and M. Colomb, 2009:** Particulate contribution to extinction of visible radiation: pollution, haze, and fog. Atmos Res. doi:10.1016/j.atmosres.2009.01.006

**Glickman, T., Ed., 2000:** Glossary of Meteorology. 2nd ed. Amer. Meteor. Soc., 855 pp. http://glossary.ametsoc.org/. (Accessed on 02.01.2015).

**Guidard, V., and D. Tzanos, 2007:** Analysis of fog probability from a combination of satellite and ground observation data. Pure Appl Geophys, 164, 1207 - 1220

**Gultepe, I., G. Pearson, J. A. Milbrandt, B. Hausen, S. Platnick, P. Taylor, M. Gordon, J. P. Oakley, S. G. Cober, 2009:** The fog remote sensing and modelling field project. Bull. Amer. Meteor. Soc., 90(3), 341–359doi:10.1175/2008BAMS2534

**Gultepe, I., M Pagowski and J. Reid, 2007:** Using surface data to validate a satellite based fog detection scheme. Wea. Forecast, 22, 444 - 456.

**Hu, H, Q. Zhang, B. Xie, Y. Ying, and J. Zhang, 2014:** Predictability of an Advection Fog Event over North China. Part I: Sensitivity to Initial Condition Differences, Mon. Wea. Rev., 142, 1803 – 1822. DOI: 10.1175/MWR-D-13-00004.1

**Jacobs, W., V. Nietosvaara, S.C. Michaelides, H. Gmoser, (eds.), 2003; COST 722 Phase 1 Report**: Very Short Range Forecasting of Fog and Low Clouds: Inventory Phase on Current Knowledge and Requirements by Forecasters and Users. 184pp.

**Muiruiri, S., 2011:** Assessment of adverse weather on operation of air transport at Jomo Kenyatta Airport and Wilson airport. MSc Thesis, University of Nairobi- Kenya

**Mwebesa, M. N., 1980:** Studies on fog occurrence at Jomo Kenyatta Airport. East Africa Institute for Meteorological Training and Research. Nairobi. Kenya.

**Niu, S., C. Lu, H. Yu, L. Zhao, J. Lu, 2010**: Fog research in China: an overview. Adv Atmos Sci, 27(3), 639 - 662. Doi: 10.1007/s00376-009-8174-8

**Peak, J.E., and P.M. Tag, 1989:** An expert system approach for prediction of maritime visibility obscuration. Mon. Wea. Rev., 117, 2641-2653.

**Petersen, S., 1956:** Weather Analysis and Forecasting, Vol. 1 and 2. McGraw-Hill, New York, Toronto, London.

**Tardif, R., and R. M. Rasmussen, 2007:** Event-based climatology and typology of fog in the New York City region. J. Appl. Meteor. Climatol., 46, 1141–1168.

**Willett, 1928:** Fog and haze, their causes, distribution and forecasting. Mon. Wea. Rev., 56, 435-468.

World Meteorological Organization (WMO), 1992: International Meteorological Vocabulary, WMO 182, 782pp.

**Zhang, X., L. Musson-Genon, E. Dupont, M. Milliez, B. Carissimo, 2014:** On the Influence of a Simple Microphysics Parametrization on Radiation Fog Modelling: A Case Study During Paris Fog. Boundary-Layer Meteorol, 151, 293–315. DOI 10.1007/s10546-013-9894-y

**Zhou, and Ferrier, 2008:** Asymptotic analysis of equilibrium in radiation fog. J. Appl. Meteor. Clim. 47, 1704 - 1722.

**Zhou, B., and J. Du, 2010:** Fog prediction from a multimodel mesoscale ensemble prediction system. Wea. Forecasting, 25, 303-322.