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Spatio-temporal detection of fog and low stratus top heights over the Yellow Sea with geostationary satellite data as a precondition for ground fog detection — A feasibility study

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ABSTRACT

An accurate cloud top retrieval from geostationary (GEO) and low earth orbit (LEO) platforms is still a pending problem. This particularly holds for low level clouds. Furthermore, cloud top height is a crucial parameter to calculate cloud immersion of underlying terrain from GEO/LEO data and thus, for the discrimination between low level stratus and ground fog, where the latter is a main obstruction for air, land and sea traffic. All problems are particularly evident for ocean areas such as the Yellow Sea where no ground observations are available. In this paper, a novel method is presented to retrieve low stratus/fog top heights with special reference to the Yellow Sea and its surroundings, based on GEO data of MTSAT-1 and MTSAT-2 (JAMI sensor) and LEO data (MODIS sensor on Terra and Aqua) using the infrared (IR) water vapor and split-window bands. Two cases with very good data coverage are discussed where the retrieved low stratus/fog heights are compared to CALIPSO cloud top heights, and simulated data using the mesoscale model WRF. The comparison of JAMI retrievals with the spatial data sources used shows an encouraging accuracy (root-mean-square error, RMSE, around 300 m) in comparison to other retrieval schemes base on IR data hitherto published. A validation of the retrievals for the position of two radiosonde stations using available sounding data of seven foggy days revealed an even better performance with an average deviation of 184 m (standard deviation of 132 m). However, the validation revealed that the application of the underlying equations to retrieve inversion strength and thickness under foggy conditions would need some adjustments because the equations taken from the work of Liu and Key (2003) were originally developed for clear sky situations. Thus, the adaptation of the original scheme during future work should especially address cloudy conditions under moderate inversion strengths which could lead to an improvement of the retrieval accuracy.

1. Introduction

Fog and low stratus are significantly influencing the earth's radiation balance. At the same time, particularly ground-touching stratus layers (fog with horizontal visibility < 1 km) are an obstacle to sea, air and road traffic (Bendix et al., 2011). While fog and low stratus are relatively well-studied over land areas, knowledge of sea fogs is inferior, among others due to the lack of routine observational data on the open sea (e.g. Gultepe et al., 2007). Recent efforts try to understand the dynamics and occurrence of sea fogs over frequently affected areas such as the Chinese seas (e.g. Fu et al., 2012). A particularly threatened area regarding fog/low stratus occurrence is the Yellow Sea which is even posing a problem to proper visibility forecasts for air traffic and aviation industry along the surrounding shorelines (e.g. DeMarco, 2012).

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Several case studies using scarce observational and satellite data as well as numerical models are conducted to understand the dynamics and structure of Yellow Sea fog. Cho et al. (2000) found a maximum of fog occurrence in July. Mostly, the fog could be related to temperature inversion in a layer of 100–350 m above the sea surface due to southerly airflow (Zhang et al., 2009b). Heavy episodes of advection cooling sea fog showed temperature inversions of up to 600 m thickness Gao et al. (2007). Li et al. (2012) found a major importance of the Northwest Pacific Ocean high (NPH) on fog and inversion formation while Zhang et al. (2012) revealed that spring fogs are shallower, characterized by a robust temperature inversion. Summer fogs appeared deeper at a weaker stability which is due to adiabatic sinking of the western Pacific subtropical high contributing to the weaker inversion in summer.

Even if the general dynamics of the Yellow Sea fog seems to be generally understood, a systematic long-term study of the spatio-temporal occurrence and dynamics over the Yellow Sea using a comprehensive dataset is hitherto missing. Satellite data have been generally proven to be a reliable tool to provide spatio-temporal information of low-stratus and fog over longer term periods (e.g. Bendix, 2002; Cermak et al., 2009; Zhang et al., 2009a). Due to the temporal dynamics of fog, data from the geostationary orbit (GEO) are the preferred operational data source (Thies and Bendix, 2011). The current GEO systems operationally capturing data over the Yellow Sea are the Japanese MTSAT (Multifunctional Transport Satellite) with its five-band imager JAMI (Japanese Advanced Meteorological Imager) (Puschell et al., 2002) and the South Korean COMS-1 (Communication, Ocean and Meteorological Satellite) with a five-band Meteorological Imager (MI) comparable to MTSAT JAMI in the IR bands (Ou and Jae-Gwang-Won, 2005). Fog/low stratus detection schemes could be successfully developed e.g. based on GEO systems as Meteosat Second Generation (Bendix and Bachmann, 1991; Cermak and Bendix, 2007, 2008) and MTSAT (Gao et al., 2009). The latter also applied a simple empirical equation to calculate cloud top height from IR temperature differences described by Ellrod (1995) based on GOES data. Zhang and Yi (2013) recently proposed a dynamic procedure to detect sea fog during daylight relying on MODIS data, restricted to the overflight times of the MODIS sensor on the TERRA (around 10:30, GMT + 8) and AQUA (around 14:00, GMT + 8) platforms.

Despite its merit, the study also shows that a proper discrimination between low stratus and fog from satellite data remains challenging. Other possibilities to detect fog touching the ground by using an optical and microphysical parameter retrieved from satellite data are described by Bendix et al. (2005) and Cermak and Bendix (2011), the latter developed for the Meteosat Second Generation's SEVIRI instrument. One crucial parameter in this approach is the proper determination of low stratus/fog top heights from satellite data. As Marchand et al. (2010) stressed in their review, cloud top height retrievals are a hitherto not yet solved problem. Most applications are retrieving cloud top

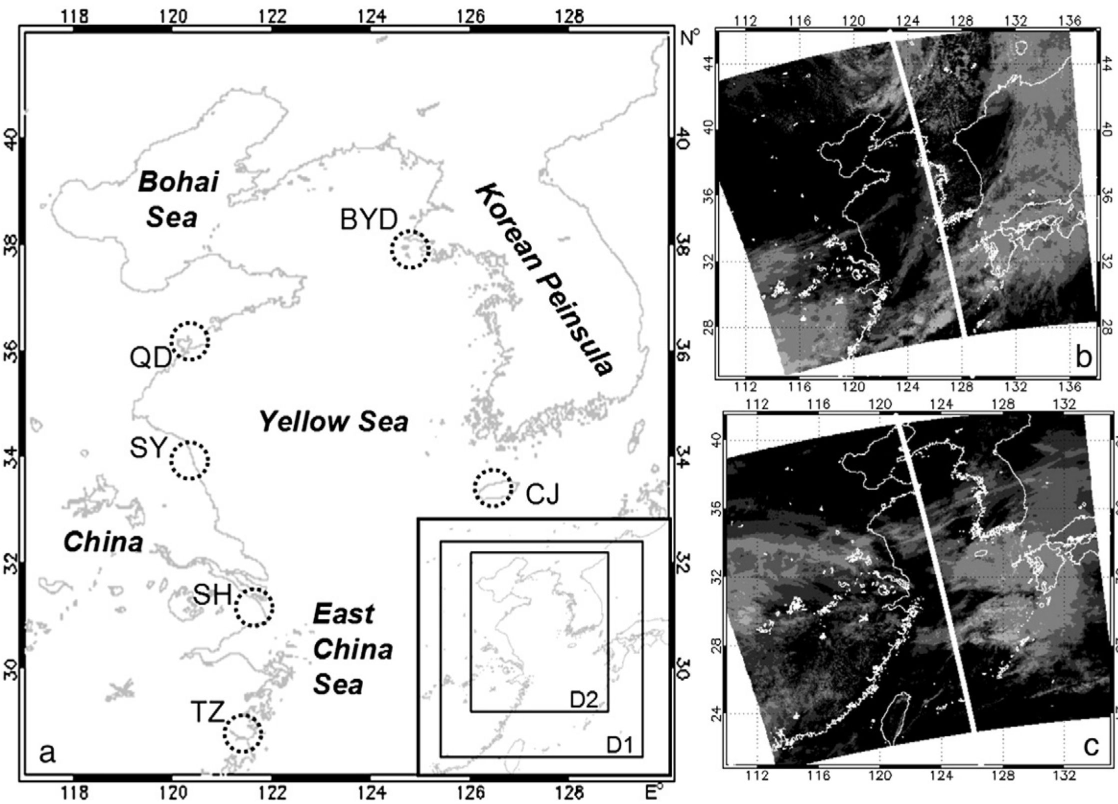

Fig. 1. (a) Study area where the inset map shows the study area D2 in relation to the domain, D1 used for WRF simulations. For acronyms of the stations, refer to the text. (b) MODIS 0.645 μm channel image at 19th May, 2010 and (c) for 22nd March, 2013 used for this study. The white line marks the corresponding CALIPSO nadir trace.