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Size resolved measurements of springtime aerosol particles over the northern South China Sea

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HIGHLIGHTS

- ► The marine boundary layer aerosol was a mixture of pollution, dust and sea salt.
- ► Strong vertical wind shear decoupled transport across the boundary layer inversion.
- ► Aerosol optical thickness was largely uncorrelated with surface mass concentrations.

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ABSTRACT

Large sources of aerosol particles and their precursors are ubiquitous in East Asia. Such sources are known to impact the South China Sea (henceforth SCS), a sometimes heavily polluted region that has been suggested as particularly vulnerable to climate change. To help elucidate springtime aerosol transport into the SCS, an intensive study was performed on the remote Dongsha (aka Pratas) Islands Atoll in spring 2010. As part of this deployment, a Davis Rotating-drum Uniform size-cut Monitor (DRUM) cascade impactor was deployed to collect size-resolved aerosol samples at the surface that were analyzed by X-ray fluorescence for concentrations of selected elements. HYSPLIT backtrajectories indicated that the transport of aerosol observed at the surface at Dongsha was occurring primarily from regions generally to the north and east. This observation was consistent with the apparent persistence of pollution and dust aerosol, along with sea salt, in the ground-based dataset. In contrast to the sea-level observations, modeled aerosol transport suggested that the westerly flow aloft (~700 hPa) transported smoke-laden air toward the site from regions from the south and west. Measured aerosol optical depth at the site was highest during time periods of modeled heavy smoke loadings aloft. These periods did not coincide with elevated aerosol concentrations at the surface, although the model suggested sporadic mixing of this free-tropospheric aerosol to the surface over the SCS. A biomass burning signature was not clearly identified in the surface aerosol composition data, consistent with this aerosol type remaining primarily aloft and not mixing strongly to the surface during the study. Significant vertical wind shear in the region also supports the idea that different source regions lead to varying aerosol impacts in different vertical layers, and suggests the potential for considerable vertical inhomogeneity in the SCS aerosol environment.

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1. Introduction

The region surrounding the South China Sea (also known as the East Sea, henceforth SCS) is routinely impacted by aerosol outbreaks from the surrounding Asian regions (Lin et al., 2007a, 2009; Verma et al., 2009; Reid et al., 2009; Cohen et al., 2010a,b;

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Wang et al., 2011). These papers showed that in the springtime in particular, the SCS is impacted from dust and pollution from China as well as biomass burning from Southeast Asia. These aerosol types may interact in a complex manner with the background marine aerosol environment. In addition to the obvious impacts on visibility and atmospheric radiative transfer, modeling studies of aerosol–cloud–precipitation interactions suggest that cloud systems such as those found in the SCS region may be susceptible to the introduction of smoke, dust and pollution particles (Sorooshian et al., 2009, 2010; Jiang et al., 2010; Yuan et al., 2011). At the same time, the Southeast Asian subcontinent may be among the most susceptible regions in the world to climate change (Yusef and Francisco, 2009). Understanding the nature, sources, and transport of particulate matter is thus critical to understanding the climate, visibility, and precipitation patterns in the region.

The potential for strong aerosol–cloud interactions in the SCS demonstrates the need to characterize particles and their sources in both the marine boundary layer (MBL) and in the free tropospheric air above it. Height dependent air masses with different particle loadings are transported into the area intermittently and are likely to contribute unequally to measured aerosol optical thickness (AOT) and composition. The remoteness of the SCS has resulted in relatively few measurements that are removed from the immediate influence of local sources, and thus few datasets are representative of the "regional" aerosol. Existing aerosol observations in the SCS are summarized by Chuang et al. (2013).

An opportunity arose in spring 2010 to sample aerosol particles entering the SCS. As part of the 7 SouthEast Asian Studies (7SEAS) campaign, the National Central University of Taiwan, supported by the Taiwan Environmental Protection Administration and the National Research Counsel, led an international field mission to study the transport of smoke and pollution from Indochina to Taiwan. As part of this project, a comprehensive supersite was deployed at Dongsha Island in the northern SCS (Wang et al., 2011; Lin et al., 2013) from mid-March through mid-May, 2010. Prevailing low-level winds place Dongsha Island in a region which may be frequently impacted by Asian sources. In addition, there is minimal human activity on the island, so it is generally free of local pollution sources that would be more typical of mainland sites. The site thus provided a unique opportunity to study MBL aerosol composition and sources, and assess their representativeness of the larger SCS environment. The focus here is on using in-situ aerosol size and composition data, along with additional observations and model output, to identify transport patterns for aerosol affecting the SCS region. Using five weeks of data from a size-resolved aerosol cascade impactor, we look for elemental markers that may help identify specific sources. These data, combined with Navy Aerosol Analysis and Prediction System (NAAPS) aerosol reanalysis and NOAA HYSPLIT backward and forward trajectories, are used to analyze springtime aerosol sources and transport patterns in the northern SCS.

2. Sampling site and methods

2.1. Site description

The Dongsha Islands (also known as the Pratas Islands; 20.7° N, 116.7° E) are a small group of low-lying islands forming an atoll located in the northern part the SCS (Fig. 1). Aerosol sources vary throughout the year, largely driven by changing winds associated with the East Asian Monsoon (Lin et al., 2007b). During the November through April winter monsoon season, prevailing winds from the northeast, associated with the passage of cold fronts, bring polluted air masses from regions in China, Japan, and the Korean Peninsula. Tan et al. (2012) and Wang et al. (2011) presented observations of Asian dust transport to the SCS under such

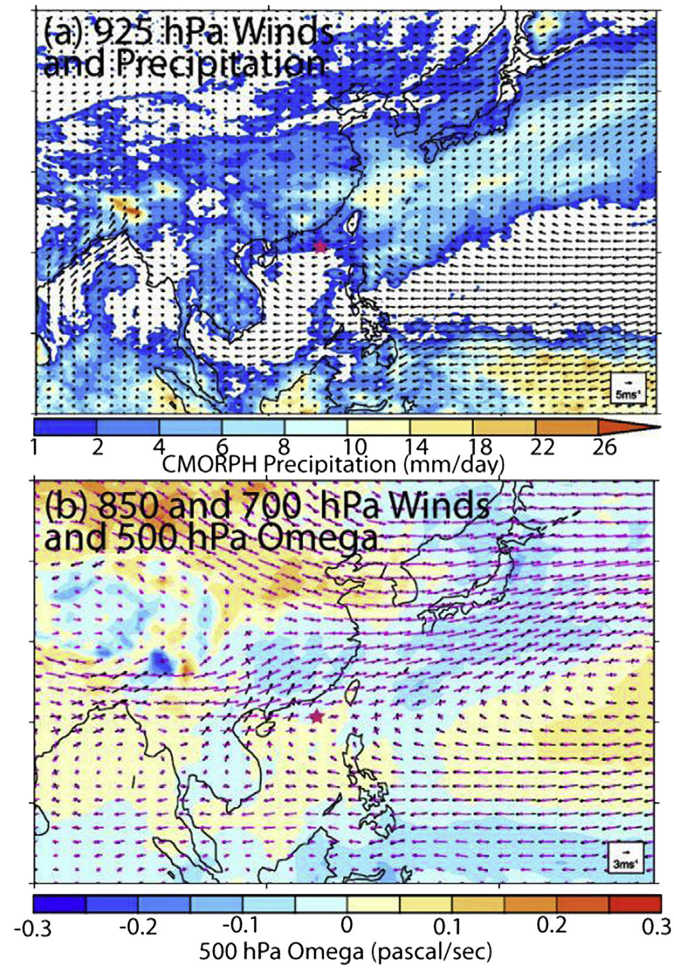

Fig. 1. (a) NOGAPS 925 hPa winds with CMORPH (CPC MORPHing technique (Joyce et al., 2004))Precipitation (mm day^{-1}) and (b) NOGAPS 850 (black) and 700 hPa (red) winds with 500 hPa Omega, for April 2010 during the Dongsha Experiment. Negative omega indicates regions of ascending motion; positive omega indicates regions of descending motion.

meteorological conditions. For example, Ou-Yang et al. (2013) observed elevated ozone, associated with polluted air masses, at Dongsha in spring 2010, and demonstrated the existence of distinct layers in the atmosphere over the SCS in this season. During the spring, the low-level air masses in the SCS laden with Central Asian dust and East Asian pollution have been observed coincident with Southeast Asian biomass burning plumes aloft (Lin et al., 2007b; Wang et al., 2011; Reid et al., 2012; Ou-Yang et al., 2013). AOT in the SCS are generally highest during March and April, with averaged values ranging from 0.1 to 0.6 (Lin et al., 2007a). Onset of the summer monsoon in the SCS typically occurs in early to mid-May, bringing a reversal to low-level southwesterly winds.

Sampling was performed at the NASA COMMIT sampling trailer placed on the eastern side of the ~3 km × 1 km main island. A full description of the site and its instrumentation can be found in Wang et al. (2011); Lin et al. (2013); Bell et al. (2013); and Tsay et al. (2013). Chuang et al. (2013) conducted aerosol sampling at the site for two intensive periods, one of which (10–19 April 2010) overlapped with our study period. There are no indigenous inhabitants on the main island; however, a small population exists for research, fishing and military purposes, with no habitation on other islands in the atoll. The main island and the instrumentation were powered by a diesel generator, and an airstrip hosts flight operations once or twice per