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Detection of large-scale concentric gravity waves from a Chinese airglow imager network

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ABSTRACT

Concentric gravity waves (CGWs) contain a broad spectrum of horizontal wavelengths and periods due to their instantaneous localized sources (e.g., deep convection, volcanic eruptions, or earthquake, etc.). However, it is difficult to observe large-scale gravity waves of >100 km wavelength from the ground for the limited field of view of a single camera and local bad weather. Previously, complete large-scale CGW imagery could only be captured by satellite observations. In the present study, we developed a novel method that uses assembling separate images and applying low-pass filtering to obtain temporal and spatial information about complete large-scale CGWs from a network of all-sky airglow imagers. Coordinated observations from five all-sky airglow imagers in Northern China were assembled and processed to study large-scale CGWs over a wide area (1800 km × 1 400 km), focusing on the same two CGW events as Xu et al. (2015). Our algorithms yielded images of large-scale CGWs by filtering out the small-scale CGWs. The wavelengths, wave speeds, and periods of CGWs were measured from a sequence of consecutive assembled images. Overall, the assembling and low-pass filtering algorithms can expand the airglow imager network to its full capacity regarding the detection of large-scale gravity waves.

1. Introduction

Gravity waves (GWs) critically influence the momentum budget and energy transfer throughout the atmosphere. Progresses in GW studies in recent decades was summarized by Fritts and Alexander (2003), and the global GW events that occurred in the stratosphere during 2003–2009 were reviewed by Hoffmann et al. (2013) using the Atmospheric Infrared Sounder (AIRS). Concentric gravity waves (CGWs), constituting a particular category of GW, are distinct for their typical circular patterns in the nightglow. CGW events are often triggered by convective sources, such as thunderstorms (Taylor and Hapgood, 1988; Yue et al., 2009; Xu et al., 2015; Miller et al., 2015), tropical cyclones (Suzuki et al., 2013; Yue et al., 2014), and volcanic eruptions (Miller et al., 2015).

Taylor et al. (1987) presented the first report of CGW events with O_2 (557.7 nm), Na (589.2 nm), and OH (715–810 nm) airglow images, which were captured by a ground-based low-light television system. Based on the observed curved wave pattern, Taylor and Hapgood (1988) later identified a thunderstorm near the center of the circular rings as the possible wave source. Suzuki et al. (2007) used the data from an all-sky airglow imager located in Shigaraki, Japan, to report on a CGW, and they identified the source as a cumulonimbus cloud near the concentric center. The effective detection range of a single all-sky imager is limited by its radial resolution, which decreases with increasing horizontal distance; therefore, GWs with large horizontal wavelengths are difficult to observe using a single imager. Suzuki et al. (2013) also analyzed the CGWs excited by a typhoon, assembling the large-scale concentric rings of CGWs from OH emission images that were observed simultaneously by a chain of three separated all-sky imagers in Japan. To overcome the difficulties associated with observing GWs using a single imager (such as bad weather), an all-sky imager network was constructed in Northern China (Xu et al., 2015). The captured images at different sites inside the network can be seamlessly assembled to visualize the CGWs in a wide area of 1800 km × 1 400 km, thus enabling the frequent observation of large-scale gravity waves (i.e., those with horizontal wavelengths >100 km).

Sensors onboard satellites offer another means of observing CGWs

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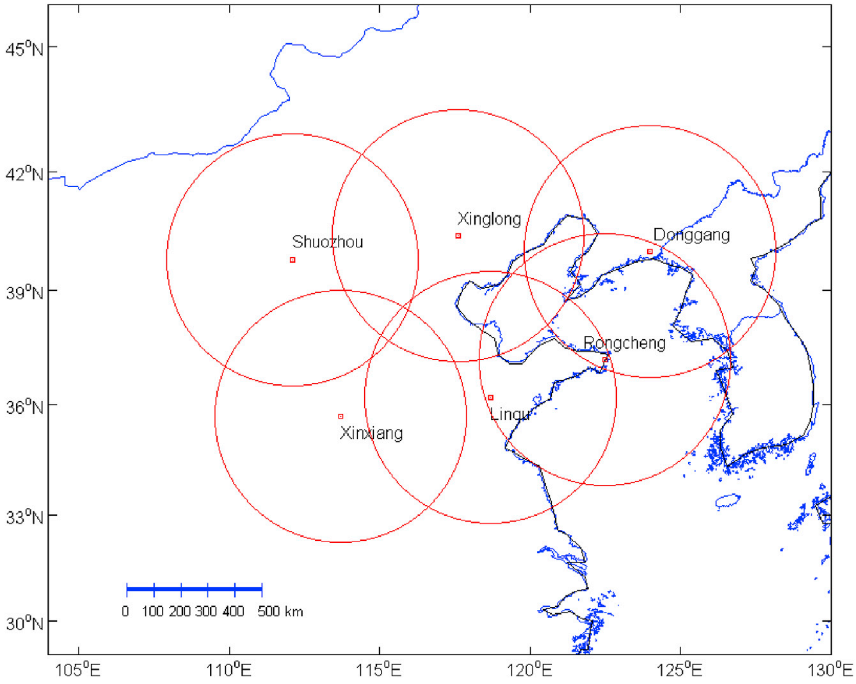

Fig. 1. Map of the all-sky airglow imager network in Northern China with the six stations marked. The red circle, with a radius of 420 km, around each station indicates the effective detecting area at the height of OH emission layer (87 km). These six stations constitute an imager network with overlapping detection areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

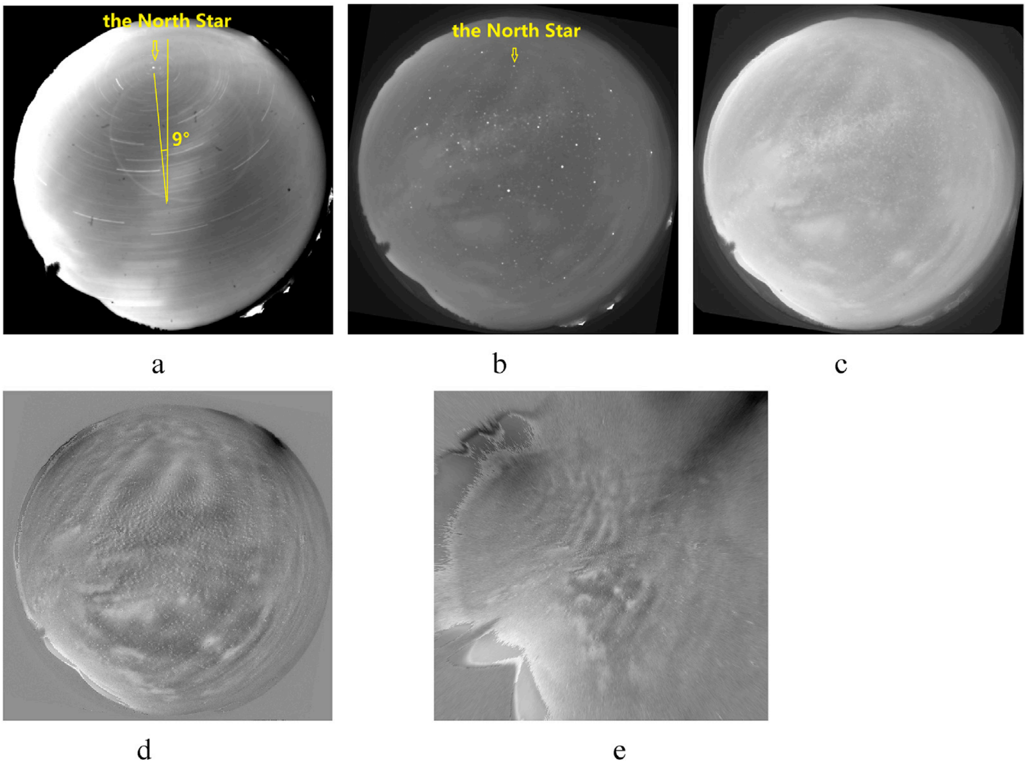

Fig. 2. Single-camera image processing. The presented sample images were captured by the imager at Linqu station on the evening (UTC) of August 13, 2017. (a) Integration of 100 continuous images. The moving stars result in the star-tracks, while the North Star remains at the same position. (b) Reoriented figure. The North Star is now at the center top after the rotation of the image 9° clockwise. (c) Starless image. The bright stars were removed by a median filter. (d) Enhanced image. The wave structure was enhanced by subtracting a 40-min-averaged image from the starless figure. (e) Geographic projection of the GW image. The size of the projected image is 1 024 × 1 024 pixels, but normally only the 600 × 600 area around the center is used.