Properties of Gravity Waves in ER-2 Observations During CRYSTAL-FACE and Relationships to Convective Clouds

M. Joan Alexander (Colorado Research Associates/NWRA), M.J. Mahoney (NASA/JPL), and Paul Bui (NASA/Ames)

Abstract

Measurements from the Microwave Temperature Profiler (MTP) and Meteorological Measurement System (MMS) on board the ER2 during CRYSTAL-FACE provide unique observations of gravity waves in the lower stratosphere associated with convective clouds. Here we focus on data obtained during the two southern survey flights on July 9 and 26, 2002. These provide long flight legs uninterrupted by aircraft turning maneuvers and can be used to study a wide range of gravity wave horizontal wavelengths. The time lag between data from the southbound and northbound legs of these flights further provide information on wave frequencies and propagation. Here we show preliminary results describing the wave characteristics and their relationships to the convective cloud developments in the vicinity of the flight paths.

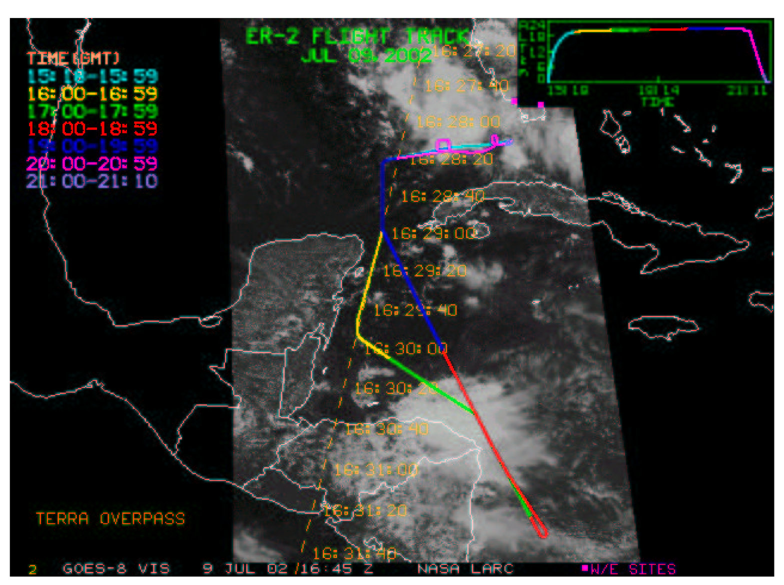
Introduction: Gravity Waves

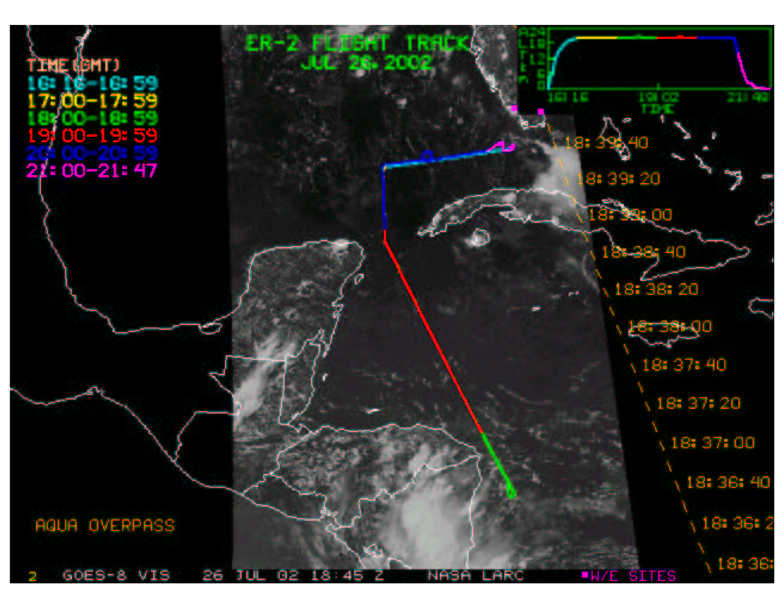
Gravity waves are small-to-medium scale waves that have important roles in the global circulation momentum budget, yet their sources and their properties are highly variable and have been difficult to quantify on a global scale. Global circulation models seeking to quantify these effects must rely on parameterizations to describe the gravity wave propagation, dissipation, and momentum forcing of the circulation. These parameterizations require details about the gravity wave properties like their wavelengths, frequencies, and phase speeds, as well as the net momentum flux they carry.

Gravity waves also are known to affect cloud formation via the temperature perturbations they cause, and these effects can be significant in conditions that are otherwise marginal for cloud formation. Clouds forming in the cold phases of gravity waves have been shown to affect ozone chemistry in the Arctic lower stratosphere. Cirrus clouds at lower latitudes near the tropopause can also form in the cold phases of gravity waves. If the wave period is slow enough, ice crystal growth may proceed quickly enough to allow the ice to fall to lower altitudes prior to the onset of the warm phase of the wave, and can affect a net dehydration near the tropical tropopause. To better understand the effects of gravity waves on cloud formation, we need measurements of the temperature perturbation amplitudes, wave intrinsic frequencies (frequency in a frame of reference moving with the background wind), and their geographic locations.

Because the properties of gravity waves are known to be highly variable, an understanding of their global effects is tied to an understanding of the mechanisms that generate them and which properties of the wave sources that control the properties of the waves. Flow over topography is one source for gravity waves that is fairly well understood. Generation by convection is another important mechanism that is less well understood. The CRYSTAL-FACE observations provide an opportunity to quantify detailed properties of gravity waves observed in the vicinity of tropical and subtropical convection. We seek to quantify the wave properties in detail and to search for evidence of their sources and a better understanding of the detailed mechansims that generate the waves.

Flight Summaries





The images above taken from the NASA Langley CRYSTAL-FACE satellite page summarize the ER-2 flight paths for July 9 and July 26, 2002 superimposed on GOES visible images. The flights flew west from Key West, then turn south for ~1000 km before turning north to return. The duration of both flights were ~5 hours. We examine two portions of each flight: The southbound portion starting at the point the aircraft turns south at $\sim 24^\circ$ latitude to the turnaround point near 14° latitude, and the northbound portion returning from 14° to 24° latitude.

The flight paths include overflights of convection near Honduras and also flight time in the vicinity of later-developing convection over Cuba and the Yucatan Penninsula. The outbound and return legs of the flights provide interesting information on the time development of the waves and convection near this Cuba-Yucatan passage.

MTP and MMS Gravity Wave Observations

The MTP observes gravity waves as temperature perturbations against the background as a function of height and time along the flight path. The MMS observes the wind perturbations caused by the waves at the flight level only. To first approximation, the time along the flight path can be thought of as sampling the horizontal patterns through an approximately stationary wave field. This assumption holds for large-scale low frequency waves, and also for high frequency waves if their scales are short enough.

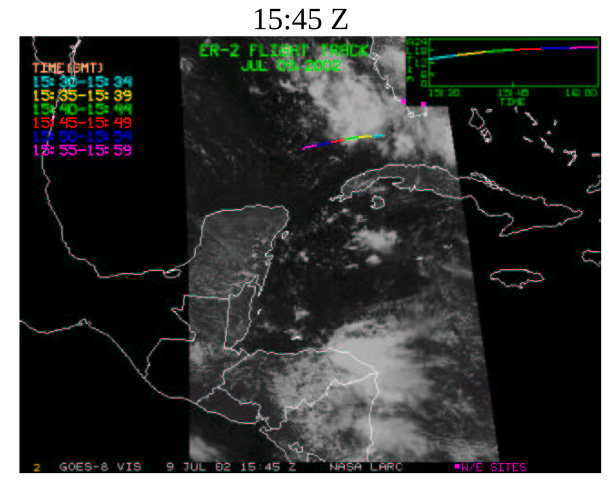
Our analysis first examined the power spectrum of wave temperature perturbations as a function of horizontal wavelength measured by the MTP and averaged over the 1.6 km altitude range surrounding the flight level. The analysis shows important perturbations at both large (> 100 km) and small (< 100 km) horizontal scales. We examine these separately with filtering techniques.

Case: July 9, 2002

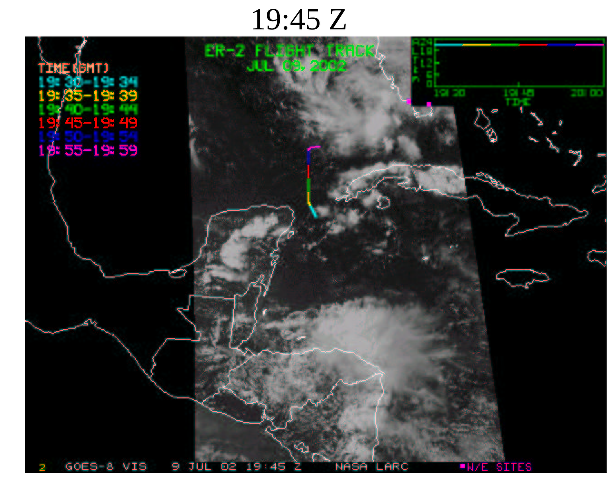
The panels below show sections of the ER2 flight path superimposed on GOES visible cloud imagery near the beginning and end of the flight to show the early and late convection development. The convection over Cuba and the Yucatan does not develop until around 18:00Z. The cloud sheild over Honduras develops early and is in the decaying stage during the aircraft overflight.

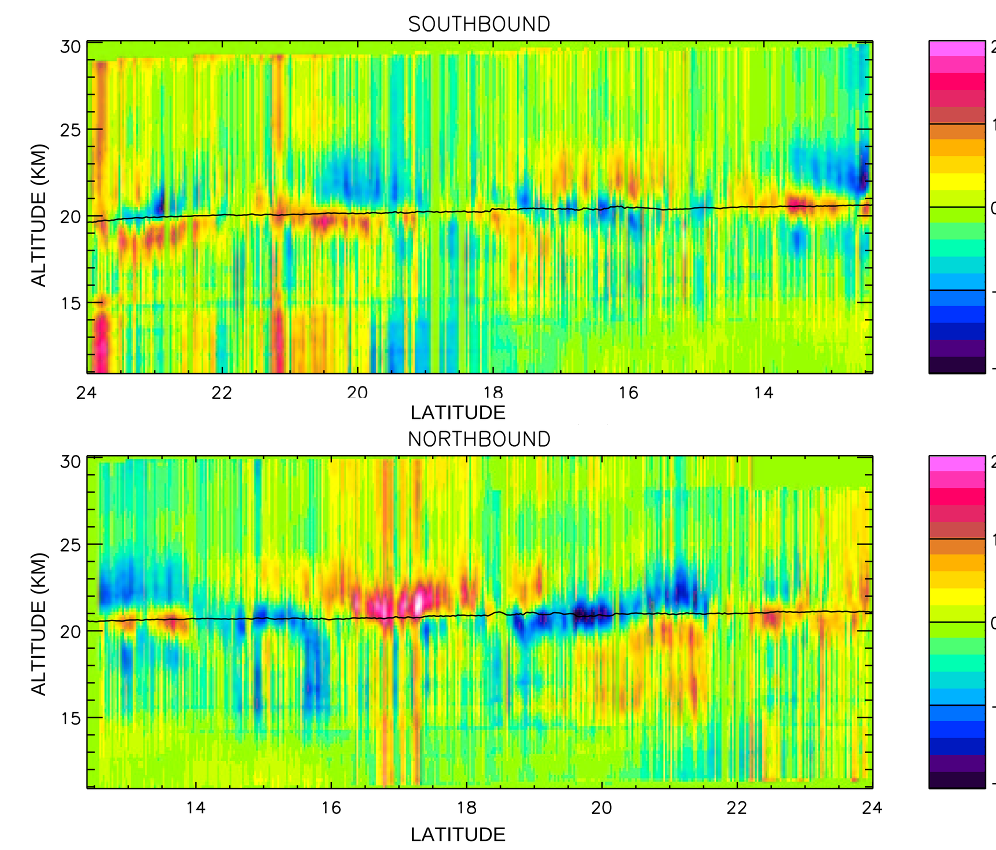
July 9, 2002: from the NASA Langley CRYSTAL-FACE satellite page

15:45 Z



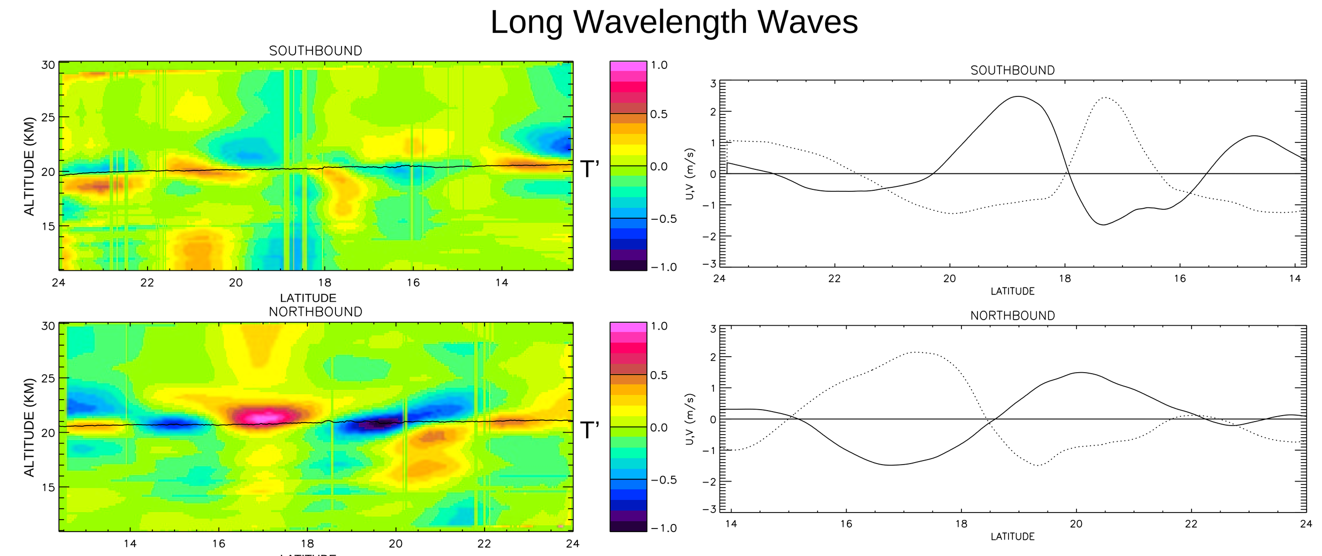
19:45 Z



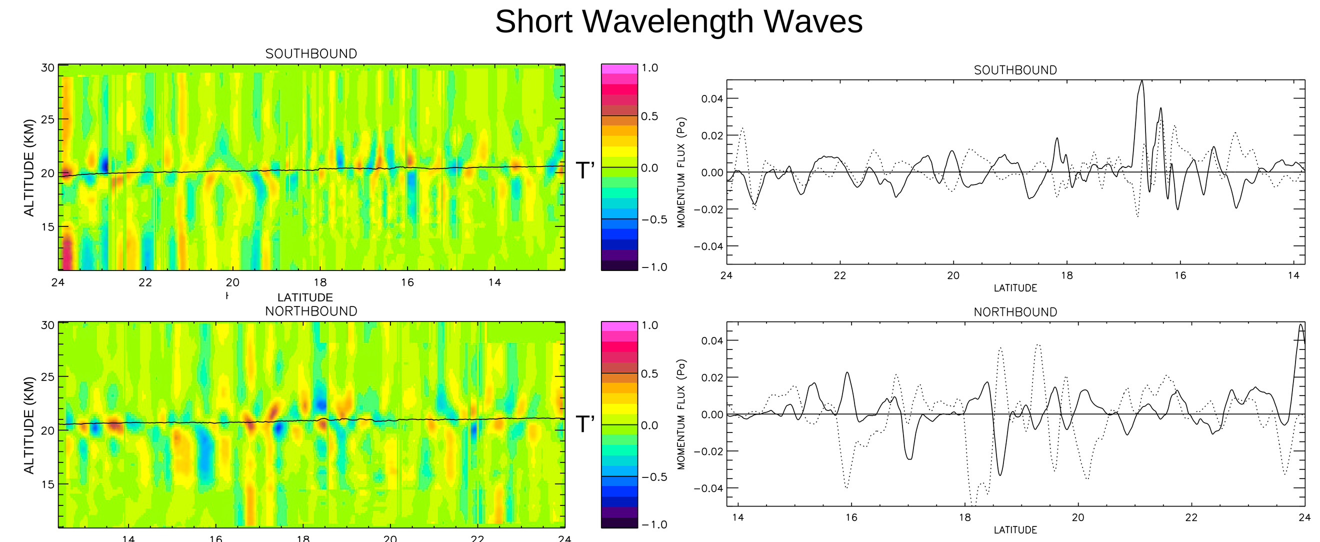


The figure above shows MTP temperature perturbations as a function of height and latitude for all scales < 800 km. These tend to emphasize the larger scales because the temperature spectrum is red. The momentum flux spectrum is conversely much whiter. The MTP vertical resolution is best nearest the flight level (black line). There, between $\sim 18-22$ km, perturbations with sloping phase can be seen, characteristic of the waves.

Long Wavelength Waves



Short Wavelength Waves

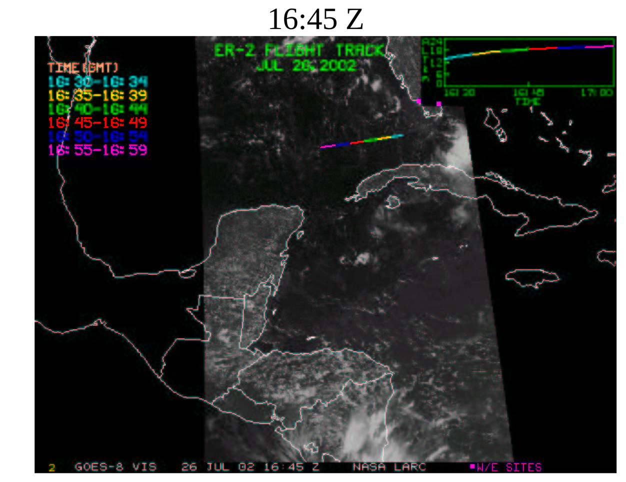


Case: July 26, 2002

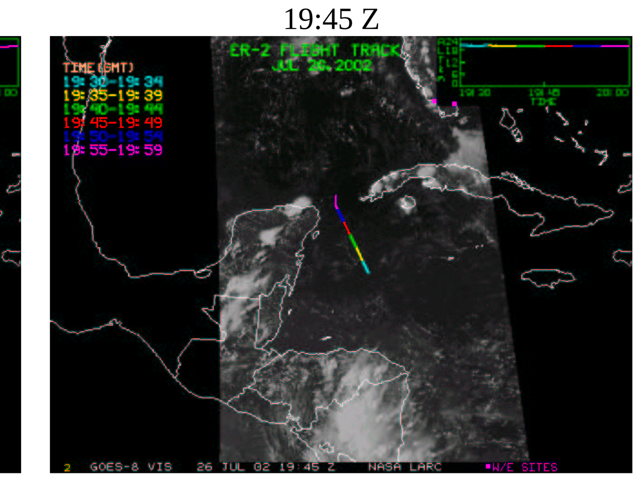
The panels below again show sections of the ER2 flight path superimposed on GOES visible cloud imagery near the beginning and end of the flight to show the early and late convection development. The convection over Cuba and the Yucatan develops similarly in this case around 18:00Z. A large cloud sheild to the south of the southern most flight latitude develops early, then moves over Honduras and localized convective events occur when the aircraft is nearby at 18:00Z.

July 26,2002: from the NASA Langley CRYSTAL-FACE satellite page

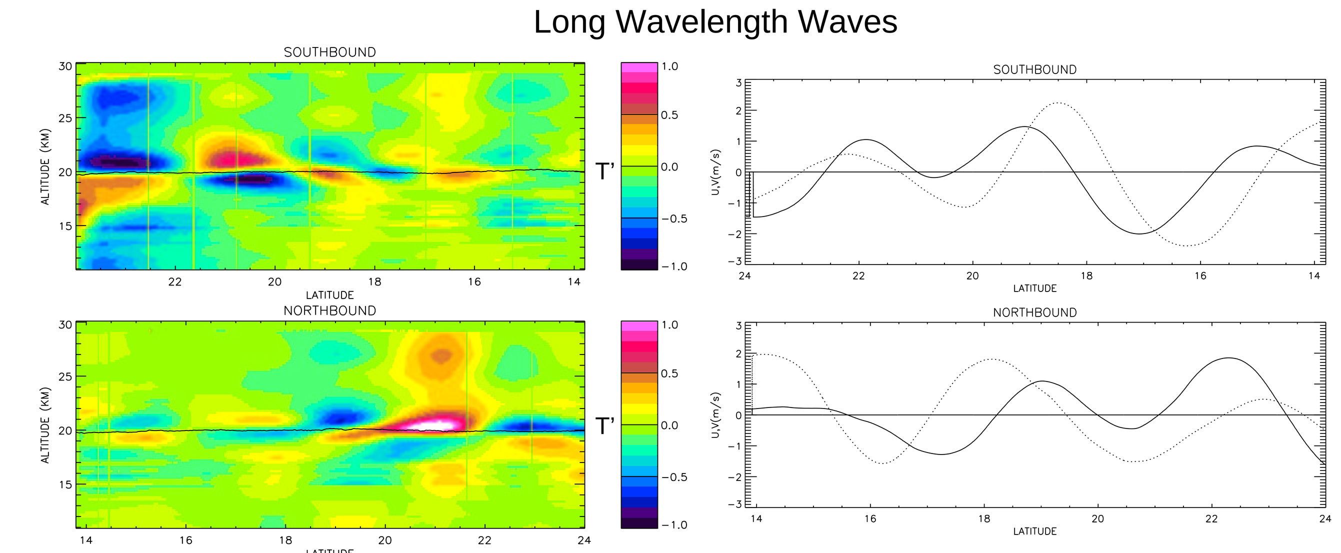
16:45 Z



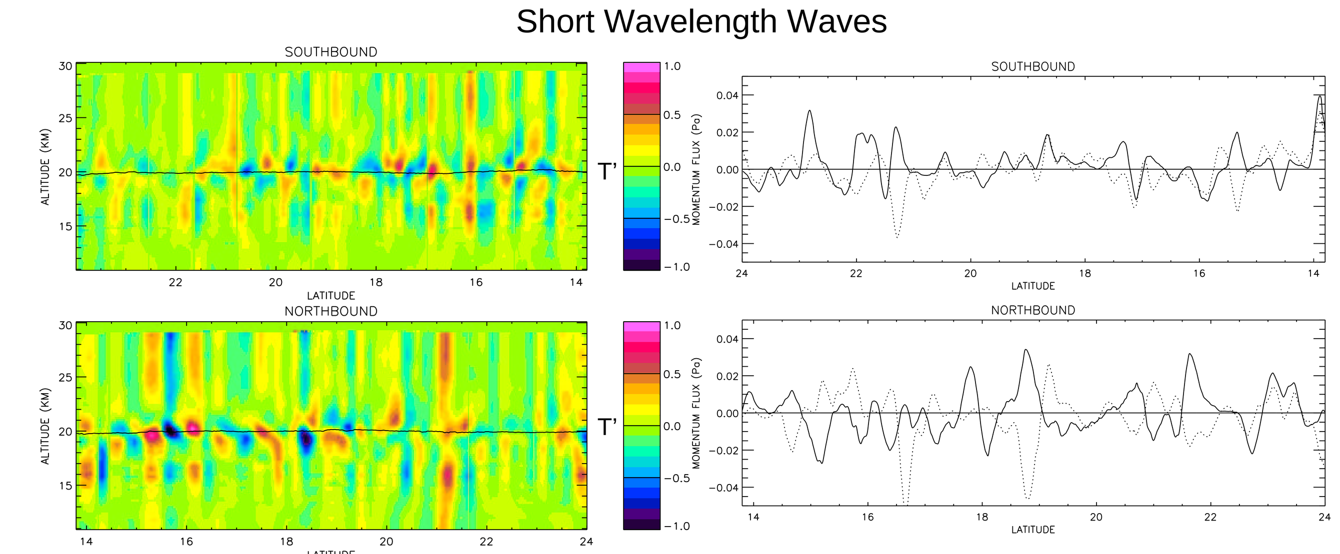
19:45 Z



Long Wavelength Waves



Short Wavelength Waves



Summary

- Two ER2 flights on July 9 and July 26 follow similar paths and fly in the vicinity of very similarly developing convection. We examine the properties of both long and short horizontal wavelength waves observed in data from the MTP and MMS.

- The long waves observed on July 26 display properties of low frequency inertia-gravity waves. These show little horizontal propagation or evolution during the 5 hour flight period. The wave intrinsic period is likely close to the inertial period which is longer than 1 day at these latitudes.

- On July 9, the long waves instead appear to be ordinary gravity waves propagating to the north-west. These evolve considerably during the flight and have higher frequency and phase speed than those observed on July 26. The amplitudes of the waves on both days are similar $\sim 1-2^\circ$K and $\sim 2-3$ m s^{-1}.

- The short wavelength waves show considerable variability on both flights. This would be expected for waves with higher frequencies and phase speeds common for shorter horizontal wavelength waves.

- Momentum flux can only be calculated directly for the shorter wavelength waves. The values are similar in magnitude on the two flight days although the July 9 flight shows weaker activity on the southbound leg, possibly due to the earliear departure and associated timing relative to the diurnal development of convection in the vicinity.

- The results show no overall preference for wave propagation direction for these short waves, although variations along the flight path are clearly observed.

- The momentum fluxes observed are substantial and support an important role for convectively generated gravity waves in the global circulation momentum budget.