Final Report
17 September 1998 – 16 September 1999

Title: HRDI Observations of Inertia-Gravity Waves in the Mesosphere and Lower Thermosphere

Agency:	NASA
Contract Number:	NASW-98029
Principal Investigator:	Dr. Ruth Lieberman Colorado Research Associates 3380 Mitchell Lane Boulder, CO 80301

Individual measurements of HRDI horizontal wind vectors contain information smeared over a 500 sq km area element. This implies that the minimum horizontal wavelength "sensed" by HRDI is 1000 km. HRDI vertical resolution is about 8 km. Using these limiting parameters in the dispersion relation for inertia-gravity waves (IGW) implies that IGW's with intrinsic periods as short as 5 hours can be sensed by HRDI. However, these motions cannot be explicitly resolved in HRDI winds, due to insufficient spatial sampling. Only instantaneous "snapshots" of IGWs are observable in vertical profiles of HRDI horizontal winds. Specifically, IGW signatures are highly visible in vertical profiles of HRDI winds that have been filtered of long horizontal and vertical wavelength motions. Such filtering is performed by subtracting datasets of smoothed HRDI winds from unsmoothed wind, creating profiles of wind "residuals".

A residual wind climatology was created from HRDI zonal and meridional winds spanning December 1992 - January 1999. Small vertical scale HRDI wind variance ($(u'^2 + v'^2)/2$) is minimal between 80 and 100 km, and much larger at levels below 65 km. Little monthly or latitudinal variations are seen between 80 and 100 km. Temporal variations are stronger below 80 km, but other than a weak semiannual variation in the tropical belts (maxima at solstice and minima at equinox), the variation is not systematic. No attempt has yet been made to examine longitudinal dependence of the variance.

Vertical spectra of small vertical scale wind variance are Fourier analyzed, and plots of the power spectral density were consolidated for 3 belts: Northern/Southern hemisphere mid-high latitudes (40-72 degrees), a combined tropical/subtropical belt (32S-32N). The PSD has a universal shape, with an exp(-Km) structure in the 10-20 km wavelength interval. The value of K lies between 2 and 3. This structure is associated with a saturated gravity wave spectrum. A null spectrum derived from HRDI reported measurements convolved with a white-noise spectrum lies well below the observed exp(-Km) in the 10-20 km region. The exponential spectral shape is indicative of IGWs in the HRDI small vertical scale winds.

Stokes parameter analyses were carried out on HRDI profiles of horizontal wind components, and consolidated by month into 5 latitude belts: Northern hemisphere middle and high latitudes (40N-72N), the Northern hemisphere tidal wind belt (32N-16N), a tropical belt (8S-8N), Southern hemisphere tidal wind belt (32S-16S degrees) and Southern hemisphere

middle and high latitudes (40S-72S). Vertical waves between 10 and 15 km in wavelength are about 10-15% polarized everywhere. IGW propagation in the middle and high-latitude Southern hemisphere is predominantly meridional during solstice when strong easterly and westerly jets prevail, and significantly more zonal during equinoxes. Wave amplitudes in both hemispheres are strongest in July, and during April as well in the Northern hemisphere. Directionality of IGW propagation in the MLT is generally interpreted in terms of the filtering of upward propagating waves. Thus, in the presence of strong zonal jets (at solstices), a broad range of zonally-propagating IGW's are prone to critical level filtering, leaving behind the meridionally-propagating spectrum. Similar principles apply in the equatorial belts, where the mean winds are strongly zonal in both the stratosphere and mesosphere (albeit 180 degrees out of phase between the two regions). Statistical orientation angles are strongly north-south during three out of four seasons. In the tidal belts (16--32 degrees, where diurnal meridional winds are strongest), the preferred IGW orientation has a significant zonal component during at least one equinox. The diurnal tides are generally stronger at equinox than at solstice (Hays et al, 1994); thus, if critical level filtering principles are applied, absorption of meridionally-propagating IGW's by diurnal meridional winds would be more significant during equinox.

The PI concludes that HRDI wind component retrievals show evidence for IGWs with horizontal wavelengths longer than 1000 km, and vertical wavelengths between 10 and 20 km. The most compelling arguments in favor of the IGW interpretation are the exponential decay of the PSD with respect to vertical wavenumber, and the relationship between wave propagation direction and the mean winds or tidal winds in light of critical level filtering considerations.

The analyses in this study were confined to HRDI component wind profiles, as these products were deemed useful for inferring IGW polarization characteristics and statistical propagation directions. However, a significant limitation of HRDI zonal and meridional winds for IGW studies is the substantial horizontal smearing of information that occurs during the conversion of HRDI line-of-sight (LOS) winds into vector wind components. This smearing results from the requirement that LOS winds viewed from the "forward" and "backward" directions be matched to a common volume, in order to resolve the zonal and meridional components. This procedure results in the dilution of information over a 400--500 sq. km. area. Moreover, vector winds are recovered using a sequential estimator that employs further spatial smoothing over the common volume. As a result, the smallest horizontal IGW wavelengths "sensed" by HRDI component winds is at least 1000 km.

HRDI LOS winds are obscure products that represent horizontal winds integrated along the LOS. The LOS winds represent information that is subject to significantly less horizontal averaging. An LOS wind profile footprint length is about 1/3--1/4 the length of a component wind footprint. In view of the evidence for large-scale IGWs seen in the HRDI component winds, it seems reasonable to anticipate that LOS winds may contain information about a broader spectral range, specifically those with horizontal wavelengths between 300--1000 km. According to the dispersion relation for IGWs, shorter horizontal waves (whose vertical wavelengths remain between 10 and 20 km) have higher intrinsic frequencies, and larger vertical group velocities. Thus, the additional part of the IGW spectrum in LOS winds may give more information about the source regions for these waves and their propagation pathways directly below the MLT. Very little is currently known about this type of GW motion in the mesosphere.

The observations can be useful for testing theoretical concepts of gravity wave propagation and mean-flow interaction. IGWs observed at mesospheric heights may also have important effects in the MLT region where GW may interact strongly with the tides.

Preliminary examination of HRDI LOS winds indicates the ubiquitous presence of signatures with short vertical wavelengths. Funding shortages have unfortunately precluded any further analysis at this time. Moreover, in light of recent work by Alexander (1998) and McLandress et al, (1999), it is prudent to develop a so-called observational filter associated with the HRDI instrument and the inversion procedures. The filter describes the geometry of the three-dimensional volume of atmosphere over which the HRDI LOS wind information is integrated, as well as the integration weighting function. The observational filter can be used to develop a description of the HRDI observational sensitivity to the multi-dimensional spectrum of gravity wave parameters, including horizontal and vertical wavelengths, intrinsic frequencies, phase speeds, and direction of propagation relative to the LOS. The advantages of LOS wind analyses and observational filter development have been articulated more fully in an ITM proposal to renew the present study.

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Stokes parameters were consolidated by month into Northern and Southern hemisphere middle and high latitudes belts (40-72 degrees), tidal belts (32-16 degrees) and a tropical belt (8S-8N). Vertical waves between 10 and 15 km in wavelength are about 10-15% polarized everywhere. The inferred propagation direction in the middle and high latitude Southern hemisphere is predominantly meridional during solstice, and significantly more zonal during equinoxes. In the tropical belt, the wave orientations are nearly North-South during solstices, with a slightly higher east-west component during equinox. In the tidal belts where the background wind includes a strong meridional tidal wind, the preferred wave orientation has significant a zonal component during equinox. These findings are consistent with the interpretation of wave filtering by the background wind.

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