

Final report for the grant

## High Resolution Doppler Imager

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4/1/96 - 3/31/99

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## I. Introduction

This report summarizes the accomplishments of the High Resolution Doppler Imager (HRDI) on UARS spacecraft during the period 4/1/96 – 3/31/99 in which Grant NAG5-3180 was in effect. During this period, HRDI operation, data processing, and data analysis continued, and there was a high level of vitality in the HRDI project. The HRDI has been collecting data from the stratosphere, mesosphere, and lower thermosphere since instrument activation on October 1, 1991. The HRDI team has stressed three areas since operations commenced: 1) operation of the instrument in a manner which maximizes the quality and versatility of the collected data; 2) algorithm development and validation to produce a high-quality data product; and 3) scientific studies, primarily of the dynamics of the middle atmosphere.

There has been no significant degradation in the HRDI instrument since operations began nearly 8 years ago. HRDI operations are fairly routine, although we have continued to look for ways to improve the quality of the scientific product, either by improving existing modes, or by designing new ones. The HRDI instrument has been programmed to collect data for new scientific studies, such as measurements of fluorescence from plants, measuring cloud top heights, and lower atmosphere  $\text{H}_2\text{O}$ .

## II. Algorithm Development and Validation Activities

### II.1. Algorithm Development

Version 4.4 of the HRDI data processing software (production data version 11) was delivered to CDHF in March 1996 and integrated into the production processing in early April. This version includes the recovery of mesospheric temperatures and  $\text{O}_2$  band volume emission rates, which have not been recovered from the HRDI measurements before. The range of these recoveries is from 65 to 105 km for temperature, and 50 to 115 km for volume emission rate. The new software also included updated zero wind reference position for the mesospheric wind recovery, increasing the accuracy of these recoveries.

During this period version 4.5 of the HRDI data processing software was prepared to be delivered later in 1999. This new version includes the recovery of mesospheric ozone and  $\text{O}(^1\text{D})$ , mesospheric  $\text{O}_2$  density, and the recovery of aerosol stratospheric extinction coefficient near 630 nm. This new version will also include a new analysis of the zero wind reference.

As indicated in the HRDI publications, a significant part of our effort during this grant period has been dedicated to data validation. The mesosphere and lower thermosphere winds have been mature and reliable for some time, but validation efforts have continued in order to ensure that the new data is of the same high quality as the older data.

### II.2. Validation Activities

Further validation of the HRDI mesosphere/lower thermosphere (MLT) wind product has been performed beyond that described by *Burrage et al.* [1996]. Wind offset errors were determined to be less than  $\pm 5 \text{ ms}^{-1}$  up until the solar array drive failure of April 1995. After HRDI was reactivated in July 1995, a significant shift ( $10\text{--}20 \text{ ms}^{-1}$ ) in zero position had occurred, presumably due to the unusually low temperatures experienced by the instrument while it was switched off. The resulting error was accurately characterized and corrected in version 11 of the MLT wind product. The wind speed bias between HRDI and the MF radars first reported by *Burrage et al.* [1996] is still not fully understood, but there appears to be no systematic discrepancy between HRDI and Wallops Island rocket winds. This issue is of vital importance, since prior to HRDI MLT dynamicists relied exclusively on wind measurements from the global MF radar network. Consequently, additional studies have been carried out, including further

comparisons with MF radar data, and with WINDII, the other wind measuring instrument on UARS. It was shown by *Meek et al.* [1997] that the larger standard deviations in the HRDI measurements relative to those of the radar observations results in an underestimation of the MF/HRDI median speed ratio. However, this effect is not large enough to completely explain the discrepancy. A new HRDI validation study using meteor radars has also been completed [*Hasebe et al.*, 1997]. An important result of this investigation is that no wind speed bias was found between HRDI and the meteor radars.

Both HRDI and WINDII on UARS measure winds by sensing the Doppler shift in atmospheric emission features. Because the two observation sets are frequently nearly coincident in space and time, each provides a very effective validation test of the other. Discrepancies due to geophysical differences should be much smaller than for comparisons with other techniques (radars, rockets, etc.), and the very large sizes of the coincident data sets provide excellent statistics for the study. A significant zero wind position difference of  $\sim 9 \text{ ms}^{-1}$  has been identified for the zonal component, while altitude offsets appear to be relatively small and do not exceed 1 km. In addition, no evidence is found for the existence of a systematic wind speed bias between HRDI and WINDII. However, considerable day-to-day variability is seen in the quality of the agreement, and RMS differences are surprisingly large, typically in the range of  $20\text{-}30 \text{ ms}^{-1}$  [*Burrage et al.*, 1997].

### III. Scientific Highlights

In this section short descriptions of some the more interesting scientific studies carried out under this grant are presented.

#### III.1. A Study of Stratospheric Dynamics with HRDI Wind and MLS Temperature Fields

The equatorial stratospheric wind and temperature fields have been observed by the High Resolution Doppler Imager (HRDI) and the Microwave Limb Sounder (MLS) instruments, both aboard the Upper Atmospheric Research Satellite (UARS), since September 1991. Winds are measured by HRDI during local daytime and MLS temperature measurements are made during both day and night local times. Spectral analysis of the HRDI-measured wind field cannot be performed using conventional exact techniques [*Salby*, 1982] due to the presence of data voids in HRDI data. A constrained least squares (CLS) method has been developed for the purpose of analyzing HRDI wind measurements. In the CLS method, observations are analyzed by fitting them to a basis series. A singular value decomposition constraint is imposed on the fit to reduce the effects of under-determined (null space) coefficients of the basis series on the analysis.

Kelvin waves are analyzed through a CLS projection of the HRDI and MLS data sets onto a basis series consisting of Hermite and Fourier functions. The recovered spectra from HRDI winds and MLS temperatures are compared for zonal periods between 5 and 15 days per cycle for zonal wavenumbers 1 and 2. The vertical wavelengths of each Kelvin wave event in the two fields compare well. The temperature and the zonal wind fields are not in exact quadrature due to the first-order effects of dissipation, density gradient, and shear. The analyzed Kelvin waves are projected on a numerical model which involves these first-order effects. Values of thermal dissipation rate obtained from these projections range from  $0.16$  to  $0.5 \text{ day}^{-1}$ .

The balance of the steady state conservative horizontal momentum equations is studied using HRDI wind and MLS temperature measurements. Using this model, *Randel* [1987] solved for the wind field from geopotential field through an iterative technique. Although winds derived using this model are qualitatively better than geostrophic winds in the mid-latitudes, in the tropics and high latitudes winds cannot be derived using this procedure due to iterative instability problems. It is found that small-scale geopotential features in the tropics and high latitudes set

off the iterative instability. The iterative procedure was modified for stability and iterative convergence was obtained. Small-scale geopotential features resulted in unphysically large derived winds. Filtering away these small-scale features substantially improved the quality of derived winds.

### ***III.2. A Study of Internal Gravity Waves Using HRDI Nightglow Measurements Gathered Between 1992 and 1996***

Between early 1992 and mid-1996 the UARS High Resolution Doppler Imager collected daily maps of the O<sub>2</sub> atmospheric band nightglow. Each day's collection of measurements provides a near-global view of the nightglow near the mesopause. The spatial variability in the observed airglow intensity suggests significant differences in the vertical transport of odd oxygen from place to place. This transport is associated with vertical tidal winds and turbulent mixing due to internal gravity wave activity. Variabilities in the observations on seasonal time scales have been examined to produce a climatology of the nighttime airglow between 1991 and 1996. In search of an explanation for the observed variabilities in the airglow, the potential role of wave filtering has been examined. A uniform spectrum for the vertical eddy momentum flux as a function of horizontal phase speed has been combined with UKMO and HRDI wind measurements to yield estimates of critical level filtering at different locations. The initial comparison between the filtering index and the airglow suggests some correlation between the two. However, some of the flaws inherent in assuming that the airglow brightness varies directly with gravity wave activity have postponed the completion of this project. Recently, a statistical study on the variation of the airglow brightness under different seasonal and tidal conditions has been completed. Using a method similar to histogram specification (often used in the enhancement of digital images), a technique for removing tidal variations in the data has been established. This technique allows one to compare daily airglow variations in different parts of the world without the comparison being disrupted by tidal structures, and it produces a variable that is more likely to scale directly with internal gravity wave activity than the airglow brightness itself. With a reliable method for analyzing daily airglow data established, the filtering study described above may now be completed. Finally, an existing ray-tracing model will be used to search for correlations between HRDI airglow observations and gravity wave sources in the lower atmosphere.

### ***III.3. Investigation of MLT Photochemistry with UARS Data***

Since atmospheric tides perturb the MLT's temperature, density, and composition, they affect its photochemistry and hence the airglow. Until now studies of the interaction between tides and airglow have focused almost entirely on nighttime observations. For example, *Burrage et al.* [1994] showed that variations in the O<sub>2</sub> atmospheric band nightglow at 94 km were consistent with the (1,1) diurnal tide mode. Using an inversion technique discussed by *Ortland et al.* [1998], daytime O<sub>2</sub> atmospheric band volume emission rates have been added to the available HRDI data set. This has allowed us to study tidal effects on O<sub>2</sub> dayglow. HRDI measurements made during equinox were analyzed and showed an afternoon enhancement in emission near 90 km that was not observed during solstice. To resolve whether this is a tidal phenomenon, we compared these results with model simulations based on a reference atmosphere perturbed with diurnal tides obtained from the Tuned Mechanistic Tidal Model [*Yudin et al.*, 1997]. Only after incorporating the perturbation induced by tidal vertical motions did the modeled emission rate exhibit the observed afternoon enhancement near 90 km seen during equinox. The model shows that when tidal amplitudes are large (during equinox) the afternoon enhancement in emission is due to vertical advection of oxygen-rich air from the lower thermosphere.

### ***III.4. Analysis of Airglow Images***

The airglow imaging mode is run whenever HRDI is activated for nighttime operations, and since its first implementation in March 1996, the data set has grown to a total of 214 calendar days. During the first 9 months of 1998, airglow image data were collected on 78 days, an average of 8.7 days of data per month. Over the past year, the data analysis focus has been largely on studying the large-scale longitudinal variations in the airglow brightness. Clear seasonal patterns have been shown to repeat from year to year, but enough data at the same season is now available from three different years (1996, 1997, 1998) to begin to identify differences between years which suggests interannual variability is quite important. Not enough nightglow image data are gathered to sample the complete 36-day progression through the 12 nighttime hours in local time (LT) in any given month or season, but nightglow brightness patterns which are largely independent of LT (and clearly, therefore, are not the result of the migrating tide) have nonetheless been observed on a number of occasions where the data span enough hours in LT within a particular latitude band to resolve the diurnal phase progression. A number of different planetary-scale waves with zonal wavenumbers of 1, 2, and 3 have been identified, including a very clear example of a quasi-two-day wave in the southern hemisphere summer during January 1998. A consistent global longitudinal pattern tends to be produced by these coherent planetary structures with the bright enhancement progressing westward as one tracks it equatorward. This westward/equatorward pattern is ubiquitous in both hemispheres at all seasons, so the underlying mechanism(s) must produce a symmetric rather than antisymmetric response about the equator. Several spectral techniques, including Lomb-Scargle periodogram and Fourier spectral analysis, are being developed to study the global spatiotemporal structure of these planetary wave patterns in more quantitative detail.

### ***III.5. Observations of Mesospheric Ozone***

A method has been developed by which observations, made by HRDI, of molecular oxygen dayglow and temperature are used to infer mesospheric concentrations of ozone. This study was based on five years of measurements with latitude coverage up to 72 degrees and an altitude range of 65-97 km. The observations showed repeatable seasonal variability, with equatorial ozone showing a predominantly semi-annual variation at all altitudes. Equatorial ozone maximizes at equinox, with amplitude of the variation being greater than 15% of the annual mean between 75 and 95 km. At mid-latitudes the variation changes to an annual cycle, with minimum ozone concentrations at 80 km seen during summer solstice. This is coincident with a maximum in water vapor measured by the UARS HALOE Instrument. At 95 km mid-latitude ozone peaks during summer solstice, coinciding with a minimum in observed temperatures. Simulations using a 1-dimensional photochemical model, constrained to observed temperatures and water vapor concentrations, successfully reproduce the relative changes in ozone. The summertime minimum in ozone at 80 km is due to increased destruction of atomic oxygen by the hydrogen species OH and HO<sub>2</sub>. The maximum seen during summer solstice at 95 km is a result of increased photolytic production of atomic oxygen, as well as the temperature dependence on odd-oxygen partitioning.

The HRDI mesospheric ozone data set is unique in that all daylight local times are sampled. In the mesopause region large diurnal variability is observed, which is the result of a combination of chemical and dynamical control of atomic oxygen and hydrogen species. Below 80 km peak ozone values are measured when production of atomic oxygen is at a maximum, and therefore production of ozone maximizes. Minimum values are seen later in the day, when production diminishes and the concentration of hydrogen species increase. Above 80 km modeling studies show that ozone is sensitive to vertical motions. In particular, an enhancement

in afternoon ozone seen during equinox is the result of tidal advection of atomic oxygen from the lower thermosphere. There is evidence that part of the seasonal and inter-annual variability is a result of variations in the amplitude of tides.

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Validation of the HRDI MLT wind product - progress to date (M.D. Burrage, W.R. Skinner, A.R. Marshall, P.B. Hays), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

HRDI observations of gravity waves in the O<sub>2</sub> nightglow layer (J. F. Kafkalidis, P. B. Hays, D. A. Gell, and W. R. Skinner), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

HRDI retrieval of MLT ozone and molecular oxygen and comparison with output from the TIME-GCM (D. R. Marsh, W. R. Skinner, P. B. Hays, J.-H. Yee, R. G. Roble), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Gravity wave variances from the Upper Atmosphere Research Satellite (G. M. Fall, P. B. Hays, G. G. Shepherd, and B. Solheim), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Kelvin waves: A HRDI-UARS view (R. Srikanth, D.A. Ortland, and P.B. Hays), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

HRDI nighttime measurements of the atomic oxygen green line, molecular oxygen Atmospheric band, and OH(9-4) Meinel band (W. R. Skinner, P. B. Hays, M. D. Burrage, J.-H. Yee), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Quasi-Stationary Features and Nonmigrating Tides Detected in HRDI Winds (E. R. Talaat and R. S. Lieberman), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Effects of Geophysical Variance on HRDI Wind Retrievals (D.A. Ortland), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Intercalibration of the HRDI and WINDII wind measurement technique (M.D. Burrage), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996, invited talk.

Lidar measurements in the troposphere/lower stratosphere (P.B. Hays), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996, invited talk.

A comparison of winds measured by HRDI and a MF radar over Yamagawa, Japan (K. Igarashi, R. Yamazaki, Y. Murayama, I. Nishimuta, T. Tsuda, T. Nakamura, F. Hasebe, and M. Burrage), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Comparison of VHF- and MF- radar winds and HRDI wind profiles obtained during the ECHO-94 campaign in Northern Norway (P. Hoffmann, W. Singer, D. Keuer, R. Ruester, A. Manson, F.-J. Luebken, and M. Burrage), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Validation of HRDI MLT winds with the use of meteor radars (F. Hasebe, T. Tsuda, T. Nakamura, and M. Burrage), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Comparisons between Canadian prairie MF radars, and FPI (Green/OH) and UARS (WINDII/HRDI) systems: Statistics, gravity wave and electrodynamic effects (A. Manson, C. Meek, M. Burrage and B. Gault), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Intercomparison of WINDII V4.98, HRDI, and current reference models (E. Fleming, S. Chandra, B. Solheim, G. Shepherd, and M. Burrage), 2nd Workshop on Wind Measurements in the Middle Atmosphere, Toronto, Canada, May 1996.

Monitoring winds in the stratosphere by HRDI (D.A. Ortland), 1996 Spring AGU meeting, Baltimore, MD, May 1996. Invited talk.

Retrieval of mesospheric temperature and volume emission rate from HRDI measurements (D.A. Ortland, P.B. Hays, W.R. Skinner, and Jeng-Hwa Yee), 31st COSPAR Scientific Assembly, Birmingham, UK, July 1996.

Influence of tides on the O(<sup>1</sup>S) green line, O<sub>2</sub> Atmospheric band, and OH Meinel band emissions as measured by the High Resolution Doppler Imager (W.R. Skinner, J.-H. Yee, M.D. Burrage, and P.B. Hays), 31st COSPAR Scientific Assembly, Birmingham, UK, July 1996.

HRDI observations of mean meridional winds at solstice (R.S. Lieberman and W.A. Robinson), 31st COSPAR Scientific Assembly, Birmingham, UK, July 1996.

Global temperatures in the mesosphere and lower thermosphere (D.A. Ortland, P.B. Hays, and R.S. Lieberman), 31st COSPAR Scientific Assembly, Birmingham, UK, July 1996.

Overview of mesosphere/lower thermosphere dynamics (P.B. Hays), 31st COSPAR Scientific Assembly, Birmingham, UK, July 1996. (invited)

A QBO signature in the equatorial mesosphere observed by HRDI (M.D. Burrage, R.A. Vincent, and H.G. Mayr), Western Pacific Geophysics Meeting, Brisbane, Australia, July 1996. (invited)

The High Resolution Doppler Imager: Instrument performance in orbit since late 1991 (W.R. Skinner, P.B. Hays, M.D. Burrage, D.A. Gell, A.R. Marshall, and H.J. Grassl), SPIE: Optical Science, Engineering, and Instrumentation, Denver '96 Symposium, Denver, CO, Aug. 1996.

Climatology of tropical stratospheric winds as measured by the High Resolution Doppler Imager (D. Ortland), 1st SPARC General Assembly, Melbourne, Australia, December 1996.

Kelvin waves: A HRDI-UARS view (R. Srikanth and D. Ortland), 1st SPARC General Assembly, Melbourne, Australia, Dec. 1996.

Long-term observations of the diurnal tide at 30-115 km from UARS MLS and HRDI (D. L. Wu, E.F. Fishbein, D.A. Flower, L. Froidevaux, R.F. Jarnot, W.G. Read, J.W. Waters, M.D. Burrage, P.B. Hays, W.R. Skinner, M.E. Hagan), 1996 Fall AGU Meeting, San Francisco, CA, Dec. 1996.

Impulsive gravity wave induced turbulence in the mesosphere (P.B. Hays, J.F. Kafkalidis, and W.R. Skinner), 1996 Fall AGU Meeting, San Francisco, CA, Dec. 1996.

Observations of gravity waves in the O<sub>2</sub> nightglow from space (J.F. Kafkalidis, W.R. Skinner, D.A. Gell, and P.B. Hays), 1996 Fall AGU Meeting, San Francisco, CA, Dec. 1996.

Analysis of Kelvin waves in HRDI stratospheric winds using a constrained least squares method (R. Srikanth, D.A. Ortland, and P.B. Hays), 1996 Fall AGU Meeting, San Francisco, CA, Dec. 1996.

Impulsive gravity wave induced turbulence in the mesosphere (P.B. Hays, J.F. Kafkalidis, W.R. Skinner, and R.G. Roble), UARS Science Team Meeting, San Antonio, TX, Mar. 1997.

Rossby wave propagation into the tropical stratosphere observed by the High Resolution Doppler Imager (D.A. Ortland), UARS Science Team Meeting, San Antonio, TX, Mar. 1997.

Stratospheric aerosol measurements by HRDI (M.D. Burrage, D.A. Ortland, W.R. Skinner, and P.B. Hays), UARS Science Team Meeting, San Antonio, TX, Mar. 1997.

Eliassen-Palm fluxes of the 2-day wave (R.S. Lieberman), UARS Science Team Meeting, San Antonio, TX, Mar. 1997.

Rossby normal modes observed in HRDI lower thermospheric winds (R.S. Lieberman), 10th Conf. on the Middle Atmosphere, Tacoma, WA, June 1997.

HRDI observations of intraseasonal variability in the equatorial mesosphere and lower thermosphere (R.S. Lieberman), 10th Conf. on the Middle Atmosphere, Tacoma, WA, June 1997.

Rossby wave propagation into the tropical stratosphere observed by the High Resolution Doppler Imager (D.A. Ortland), 10th Conference on the Middle Atmosphere, Tacoma, WA, June 1997.

A comparison of direct wind measurements to winds derived from temperature measurements (D.A. Ortland), 10th Conference on the Middle Atmosphere, Tacoma, WA, June 1997.

Gravity Wave Enhancements in the Molecular Oxygen Airglow Observed from Space (J.F. Kafkalidis, P.B. Hays and W.R. Skinner), AMS 10th Conference on the Middle Atmosphere, Tacoma, WA, June 23-27, 1997.

HRDI observations of planetary-scale variability in the equatorial stratosphere, mesosphere and lower thermosphere (R.S. Lieberman), 8th Scientific Assembly of IAGA with ICMA and STP Symposia, Uppsala, Sweden, Aug. 1997.

Middle atmosphere wind systems observed by UARS (M.D. Burrage), 8th Scientific Assembly of IAGA with ICMA and STP Symposia, Uppsala, Sweden, Aug. 1997.

Variabilities of atomic oxygen between 85 and 105 km as observed by HRDI/UARS (J.-H. Yee, W.R. Skinner, P.B. Hays, X. Zhu, D.F. Strobel), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

Tidal influences on O<sub>2</sub> atmospheric band dayglow: Model simulations vs. HRDI observations (D.R. Marsh, W.R. Skinner, and V.A. Yudin), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

Relating HRDI airglow imagery to gravity wave sources and sinks in the lower and middle atmosphere (G. Fall and P.B. Hays), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

A dramatic gravity wave event in the O<sub>2</sub>(0,0) nightglow over North America in May 1997 imaged by HRDI (J. Kafkalidis), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

Rossby wave propagation into the tropical stratosphere observed by the High Resolution Doppler Imager (D. Ortland), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

A study of the temperature-wind relationship in the stratosphere using MLS and HRDI data (R. Srikanth and D.A. Ortland), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

Intraseasonal variability of HRDI winds in the equatorial mesosphere and lower thermosphere (R. Lieberman), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

Climatology of the semidiurnal tide derived from HRDI wind observations (M.D. Burrage), 3rd Workshop on Wind Measurements in the Middle Atmosphere, Ann Arbor, MI, Oct. 1997.

HRDI: A study of dynamics (P.B. Hays), 1997 Fall AGU Meeting, San Francisco, CA, Dec. 1997. Invited Talk.

Analysis of temperatures and winds in the mesosphere and lower thermosphere measured by HRDI (D.A. Ortland), 1997 Fall AGU meeting, San Francisco, CA, Dec. 1997. Invited Talk.

Seasonal variability in MLT ozone observed by HRDI (D.R. Marsh and W.R. Skinner), UARS Science Team Meeting, Pasadena, CA, March 1998.

Tidal influences on O<sub>2</sub> atmospheric band dayglow: Model simulations vs. HRDI observations (D.R. Marsh, W.R. Skinner, V. Yudin, and R.G. Roble), UARS Science Team Meeting, Pasadena, CA, March 1998.

A method for determining tides and the mean state from HRDI wind and temperature measurements in the MLT (D. Ortland), UARS Science Team Meeting, Pasadena, CA, March 1998.

Determination of aerosol extinction at 630 nm from HRDI stratospheric measurements (D. Ortland), UARS Science Team Meeting, Pasadena, CA, March 1998.

A study of balance in the stratosphere using HRDI winds and MLS temperatures (R. Srikanth and D. Ortland), UARS Science Team meeting, Pasadena, CA, March 1998.

Molecular oxygen density in the lower thermosphere as measured by HRDI (W.R. Skinner, D.R. Marsh, and A.R. Marshall), UARS Science Team Meeting, Pasadena, CA, March 1998.

Longitudinal variability in the molecular oxygen nightglow observed by HRDI (J.F. Kafkalidis and P.B. Hays), UARS Science Team Meeting, Pasadena, CA, March 1998.

Mesosphere and lower thermosphere coupling from UARS/HRDI (M.D. Burrage), 32nd COSPAR Scientific Assembly, Nagoya, Japan, July 1998. Invited paper.

Longitudinal variability in the molecular oxygen nightglow observed by HRDI (J.F. Kafkalidis and P.B. Hays), International Symposium on Dynamics and Structure of the Mesopause Region, Kyoto, Japan, March 1998.

Observations of mesospheric temperature inversions by the High Resolution Doppler Imager (HRDI) (J.F. Kafkalidis, W.R. Skinner, D.R. Marsh, and P.B. Hays), AGU Fall meeting, San Francisco, CA, Dec. 1998.

Chemical heating rates in the mesopause region determined by HRDI/UARS (B. Swartz, J.-H. Yee, X. Zhu, W.R. Skinner, and P.B. Hays), AGU Fall meeting, San Francisco, CA, Dec. 1998.

The global pattern of mesospheric temperature inversions observed by HRDI (J.F. Kafkalidis, D.R. Marsh, and D.A. Ortland), Chapman Conference: Atmospheric Science Across the Stratopause, Annapolis, Maryland, April 1999.

UARS observations and modeling of the diurnal cycle in mesospheric ozone (D.R. Marsh, W.R. Skinner, P.B. Hays, and M. Allen), Spring AGU, Boston, MA, June 1999.

HRDI observations of the  $O_2(0,0)$  atmospheric band nightglow: A seven-year climatology (J.F. Kafkalidis, G.M. Fall, and P.B. Hays), IUGG-99, Birmingham, England, July 1999.

The High Resolution Doppler Imager: Instrument performance from late 1991 to mid 1999 (W.R. Skinner, D.A. Gell, A.R. Marshall, P.B. Hays, J. F. Kafkalidis, and D. R. Marsh), SPIE: Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III, Denver, CO, July 1999.

HRDI atmospheric bands, clouds and water observations (P.B. Hays and J. Garten), CloudSat Science Team meeting, Oxnard, CA, August 1999.



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1 October 1999

Ms. Brenda Smith Code 216  
NASA GSFC  
Greenbelt, MD 20771

Subject: Final Technical Report Grant NAG 5-3180

Dear Ms. Smith:

On behalf of Paul Hays, the project director, and in compliance with the requirements of the Grant NAG 5-3180 entitled "High Resolution Doppler Imager", I am forwarding the enclosed final technical report.

If you have any questions or need additional information please contact Paul Hays at (734)764-7220.

Sincerely,

A handwritten signature in cursive script, appearing to read "Cheri Hovater".

Cheri Hovater  
Administrative Assistant

ch

encls.

cc: C.Jackman Code 916, Technical Officer  
CASI  
N.Gerl w/o encls.  
ONRRO w/o encls  
file 034035