Long-term Global Morphology of Gravity Wave Activity Using UARS Data

Contract NAS5-98045

Quarterly Report

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Principal Investigator

Stephen D. Eckermann

CPI

Computational Physics, Inc.
Suite #600
2750 Prosperity Avenue
Fairfax, VA 22031
(703)204-1301; FAX (703)204-9121
http://www.cpi.com
eckerman@cpi.com

Co-Investigators

Julio T. Bacmeister

Naval Research Laboratory
E.O. Hulburt Center for Space Research
Code 7641.2
Washington DC 20375
(202)767-2821; FAX (202)404-8090
http://uap-www.nrl.navy.mil
julio@ismap5.nrl.navy.mil

Dong L. Wu

Jet Propulsion Laboratory
California Institute of Technology
Mail Stop 183-701
4800 Oak Grove Drive
Pasadena, CA 91109
(818)393-1954; FAX: (818)393-5065
http://mls-www.jpl.nasa.gov
dwu@mls.jpl.nasa.gov

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1. Work and Results this Quarter

1.1 Preliminary Analysis of Small-scale CRISTA Temperature Variances

In collaboration with scientists at the University of Wuppertal, Germany, we have recently started analyzing high resolution temperature profiles derived from data from the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA[1]) instrument. The data in question were acquired during the first CRISTA-SPAS mission, in which the CRISTA-SPAS satellite was deployed by the space shuttle Atlantis on November 4, 1994 and retrieved 8 days later[2] [*Offermann and Conway*, 1995]. The vertical resolution of the acquired temperature fields is ~1-2 km and vertical profiles show considerable variability superimposed upon the basic mean profiles. This structure appears to be geophysical and one likely source of such activity is gravity waves. In collaboration with Dr. P. Preusse at the University of Wuppertal, we have begun studying the nature of this small-scale temperature structure. Plate 1 shows a sequence of global plots of the CRISTA

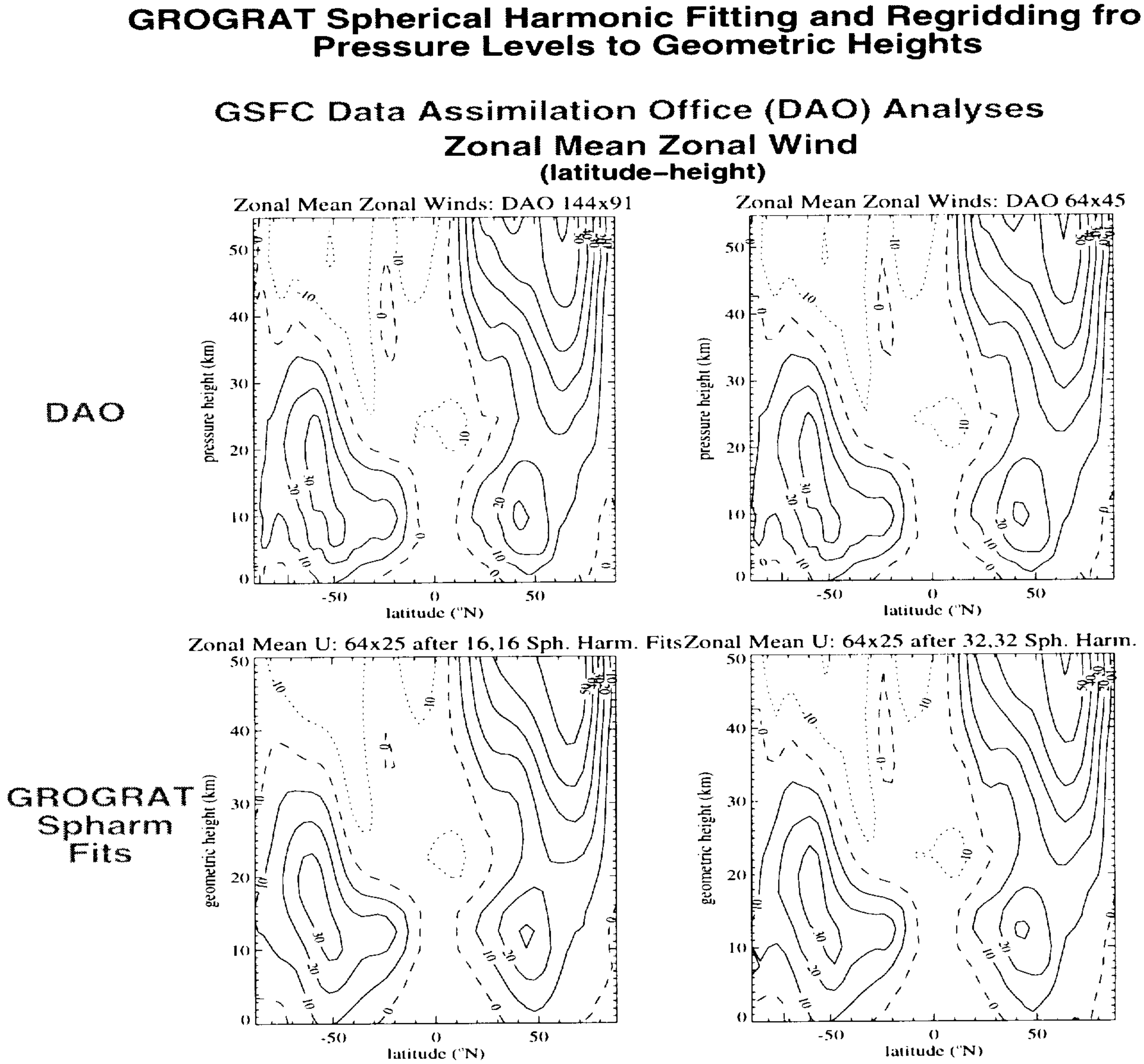

Figure 1: Top Row: DAO zonal-mean zonal winds (contour labels in m s^{-1} eastward) as a function of latitude and pressure height for 5th. November, 1994, derived from original 144x91x18 data (top-left) and resampled 64x45x18 data (top-right). Bottom Row: The same zonal-mean zonal winds after the 64x45x18 DAO data were regridded by GROGRAT onto a regular geometric height grid and fitted with spherical harmonics to order 16x16 (bottom-left) and 32x32 (bottom-right). Note that both plots compare well with the original data, but that some of the finer-scale wind structure is lost in the 16x16 spherical harmonic fits.

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[1] see the CRISTA homepage, at http://www.crista.uni-wuppertal.de.

[2] see http://titania.osf.hq.nasa.gov/shuttle/sts66/spas.html for a full description of the first CRISTA-SPAS mission.

temperature variance in the 20-30 km height range on each day from 5th-10th November, 1994, as given by the most recent inversions of the data. The data show interesting reproducible features, including large variances in the equatorial belt, and considerable geographical and day-to-day variability. On the latter point, we note episodic bursts of variance near the southern tip of South America and near the Russia-China region. Variances also seem to remain large over the India-Indonesia region.

1.2 Preliminary Global Modeling of Gravity Wave Activity During the CRISTA Missions

Given that much of the structure in Plate 1 may be produced by gravity waves, we have conducted a series of global simulations of gravity wave activity using the Gravity-wave Regional or Global Ray Tracer (GROGRAT[3]). We used daily winds and temperatures from 3rd-14th November, 1994, as issued by the Data Assimilation Office at NASA's Goddard Space Flight Center, which extend from the ground up to ~0.4 hP (~50 km). The data are issued at 18 standard pressure levels every 2.5° in longitude (144 points) and 2° in latitude (91 points). To speed the GROGRAT simulations, it is desirable to reduce the size of these data files, since we are interested primarily in the basic mean structures. Nevertheless, we also wanted to retain as much tropospheric "weather" structure in the data as possible too. After a series of tests and visual inspections (see Figure 1), we decided to resample these data onto a grid of 64 equispaced longitudes and 45 equispaced latitudes. Gaps at low levels (due to the pressure gridding yielding subterranean regions for which there are obviously no atmospheric data) were interpolated using an off-line algorithm we developed based on nearest neighbor averaging in the horizontal (with boundary checks) and log-pressure linearity imposed vertically. Interpolation of these subterranean values was required to allow GROGRAT's internal regridding algorithm to work properly (interpolates were omitted from later analyses). When running GROGRAT, these data were then resampled onto a regular geometric height grid and then fitted globally at each level with spherical harmonics. As shown on the bottom row of Figure 1, we chose 32x32 spherical harmonic fits since these proved better than the 16x16 spherical harmonic fits at capturing smaller-scale features in the winds.

Initially, we used an isotropic launch spectrum of gravity waves, as shown in Figure 2. We used a globally- and temporally-invariant spectrum of waves as a control experiment aimed at separating features due to propagation and filtering from features which may be source-related, following Eckermann [1992]. As shown in Figure 2, the spectrum contains 24 different waves, and was launched from a height of 2 km from 32 equispaced longitudes and 17 equispaced latitudes (544 "launch spots" in all), giving a total of ~13000 gravity waves launched uniformly over the globe. These simulations were performed for each day of a nominal CRISTA-SPAS mission period, which we defined as 3rd-14th November (12 days in all). Sample results from these simulations at 40 km for 5th. November are plotted in the bottom-left of Figure 2. Collated results for the 6th. November at various heights are shown in Plate 2 for the 20 ms^{-1} phase speed waves.

We also conducted some simulations of mountain wave forcing by interfacing the Naval Research Laboratory Mountain Wave Forecast Model (NRL/MFWM) [Bacmeister *et al.* 1994] with global DAO surface winds and temperatures for the CRISTA-SPAS mission period to generate a series of forced mountain waves over the globe for each day of the mission. These mountain waves were then propagated away from their source level using GROGRAT with DAO winds and temperatures. Simulated global mountain wave activity at 25 km from 5th-10th November, 1994 are shown in Plate 3.

Some of these results were presented by Dr. Eckermann in an invited presentation at the DYSMER Symposium in Kyoto, March 15-20, 1998.

1.3 Preliminary Analysis of MLS Gravity Wave Product

Work commenced this quarter in collaboration with Dr. Wu in further analysis of the MLS data products that contain measured gravity wave fluctuations [Wu and Waters, 1996a, 1996b, 1997]. Specifically, around 100 days of data were downloaded from the JPL web site and preliminarily profiled. Additionally, we became aware that Dr. Wu was also collaborating with Dr's McLandress and Holton of the University of Washington in the development and analysis of longer-term climatologies and trends in the MLS gravity-wave data. Therefore, we have initiated interactions by phone and email with Dr. McLandress in the further analysis of the MLS data. Dr. McLandress' extended study of the MLS data is a six-month duration project which should finish around the middle of 1998, at which point we will take over the further analysis of the data based on extended insights and databases that have been developed in that study.

We are also in contact with Dr. Ruth Lieberman at Colorado Research Associates, who has initiated a study to extract possible gravity wave data from HRDI wind data, and with Dr. Greg Fall at the University of Michigan, who is studying possible gravity wave signatures in HRDI nightglow data (see section 1.4).

1.4 Climatological Simulations of Mesospheric Gravity Wave Activity for Comparisons with Gravity-wave Data Inferred from UARS Data

Extended gravity-wave data from analysis of MLS already exist, which show interesting global, seasonal and interannual trends [Wu and Waters, 1997]. Recent work by Alexander [1997] using ray-tracing methods pointed out some important instrument-selectivity issues in the analysis of MLS gravity-wave data from the stratosphere. However, little if any analysis has yet been done on existing MLS gravity-wave data from the mesosphere. In our first efforts to simulate and

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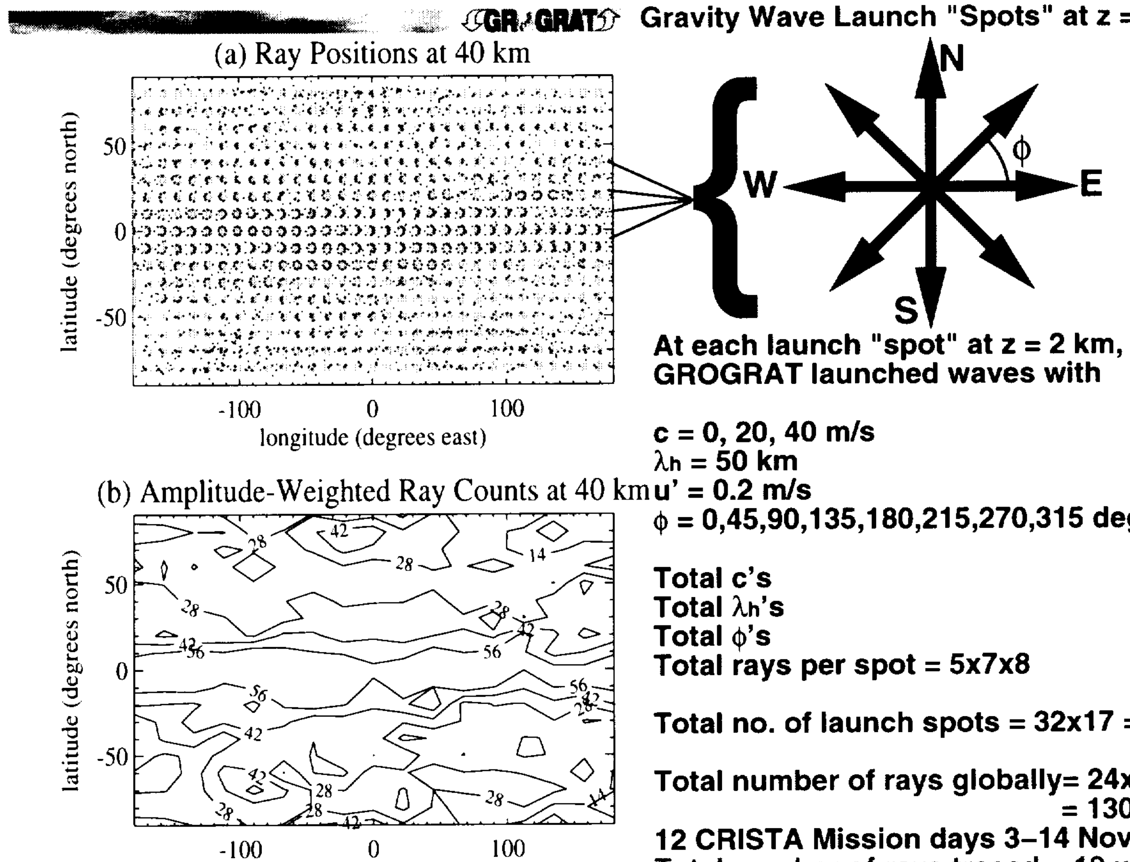
[3] see the GROGRAT home page (uap-www.nrl.navy.mil/dynamics/html/grograt.html) for more information on the model.

understand climatological features of MLS gravity-wave data at mesospheric heights, we conducted GROGRAT simulations using winds and temperatures from the 1993 version of the Horizontal Wind Model (HWM-93) [Hedin *et al.*, 1996], which extends from the ground to ~500 km into the thermosphere. A set source of gravity waves similar to that in Figure 2 was used, except here we used a much larger spectrum of waves (280 different waves in all) and launched them globally through HWM-93 winds and temperatures for each month of a climatological year. As an example of some of the results we have obtained, Plate 4 shows climatological global wave activity at 95 km collated from these coupled HWM-93 GROGRAT simulations. Some of these results were presented by Dr. Eckermann in an invited presentation at the DYSMER Symposium in Kyoto, March 15-20, 1998.

In these simulations, we assumed a time-invariant background atmosphere, whereas strong diurnal and semidiurnal tides exists in the mesosphere which produce significant changes in simulated gravity-wave propagation and amplitudes [e.g., Eckermann and Marks, 1996]. We have initiated collaboration with Dr's Valery Yudin and Marvin Geller at the State University of New York (SUNY) at Stony Brook to interface their assimilated models of UARS-derived mean winds and tidal structures [e.g., Khattatov *et al.*, 1997] with GROGRAT to look at the impact of tidal modulation on global gravity-wave climatologies. These collaborative simulations continue. Plate 5 shows initial simulations with Dr. Yudin of mesospheric wave activity and inferred K_{zz} in January using UARS, CIRA and HWM-93 climatological zonal winds. The different wind patterns lead to quite different inferred wave activity and K_{zz} values in these preliminary simulations. These results were presented by Dr. Yudin at the 1998 UARS meeting in Pasadena, and we are presently investigating these trends in more depth.

Additionally, collaborations were initiated with Dr. Greg Fall at the University of Michigan who is investigating possible gravity wave signatures in nightglow data from HRDI. Early preparations for some GROGRAT simulations were planned with Dr. Fall to see whether the simulations could explain some features he observes in these data. We are also investigating whether ISCCP data (essentially, satellite measurements of tropospheric cloud top heights), which he has access to, can also be used to infer convective sources of waves, which GROGRAT may then trace to mesospheric heights. Reverse ray-tracing experiments (i.e. tracing features in the HRDI data back to potential source regions) are also being contemplated.

Global Multi-Ray Simulations using DAO Analyses



Gravity Wave Launch "Spots" at z = 2 km

At each launch "spot" at z = 2 km, GROGRAT launched waves with

c = 0, 20, 40 m/s
λ_h = 50 km
u' = 0.2 m/s
ϕ = 0,45,90,135,180,215,270,315 deg.

Total c's	**3**
Total λ_h's	**1**
Total ϕ's	**8**
Total rays per spot = 5x7x8	**24**

Total no. of launch spots = 32x17 = 544

Total number of rays globally= 24x544
= 13056
12 CRISTA Mission days 3-14 Nov 94
Total number of rays traced = 12 x 13056
= 156672

Figure 2: Simulated isotropic gravity wave spectrum of 24 different gravity waves, launched through DAO winds and temperatures during the CRISTA period from a height of 2 km at 544 different "launch spots" (covering the globe). Resulting simulated wave activity at 40 km is shown in the bottom-left plot.

1.4 Simulations of Gravity Wave Measurements from Space-based Platforms like UARS

Work also continued this month in developing both the theory and models that are needed to study just how satellite-based instruments detect and resolve gravity waves. Firstly, our work on formalizing and applying adiabatic parcel advection methods to simulate gravity wave perturbations of the atmosphere was completed, written up and accepted for publication [Eckermann *et al.*, 1998]. This methodology will prove key in simulating a wave-perturbed atmosphere which we will remotely sense via a model simulation from a space-based platform, using the Small-scale Parcel Advection Model (SPAM) that now exists. Additionally, we have initiated collaboration with Dr. S. Palo of the High Altitude Observatory at NCAR, who has developed a general algorithm for computing the orbital specifics and observational geometries of a variety of atmospheric satellite sounders, including UARS and TIMED. We have begun working with his code, with a view to using it to simulate the remote observation of a global gravity-wave-perturbed atmosphere from space.

2. Analysis

2.1 Interpretation of Results Obtained to Date

The modeling to date already has simulated features which have much in common with the data from UARS and CRISTA-SPAS. For example, the large temperature variances in the equatorial belt in Plate 1 are also simulated using the GROGRAT/DAO simulations in Plate 3. Similarly, the bursts of activity near the tip of South America observed in Plate 1 are also reproduced using simulations which incorporate realistic mountain wave forcing, shown in Plate 4. Specifically, forcing of mountain waves along the Andes gives simulated intermittent bursts of wave activity in the 20-30 km height range in Plate 4 which resemble similar intermittent bursts in Figure 1.

The simulated mesospheric climatologies also resemble aspects of the MLS data [Wu and Waters, 1997], LIMS gravity wave data [Fetzer and Gille, 1994], and data from a range of ground-based observational sites. We are in the process of fully assessing the comparisons between our simulations and these various long-term data bases.

2.2 Recommended Further Action

A number of other questions remain or were generated from the first three months' work, and will be tackled in the next 3 months. Some of these questions are as follows:

- In Plate 4, simulated bursts of mountain wave activity also occur over the Eurasian region which are not observed in the CRISTA variances of Plate 1. Initial indications are that this may be due to instrument selectivity issues in the CRISTA data which may cause preferential detection of only the South American waves. This possibility and others will be considered and assessed.
- Plate 5 indicates that interannual variability in mesospheric winds during the UARS period may affect simulated gravity wave climatologies each year. Tides should also affect the climatologies significantly, based on earlier theoretical studies [Eckermann and Marks, 1996]. These possibilities will be studied further.
- Only mountains have been considered as a possible source. Convection may also be very important, perhaps explaining the zonal asymmetry in equatorial activity observed in Plate 1 with largest variances over the convectively active India-Indonesia sector. Using satellite convective data, we will investigate the possibilities of parameterizing convective sources using such data, based on conversations with Dr. Greg Fall (see section 1.4) and Dr. Robert Vincent of University of Adelaide (currently on sabbatical at NCAR in Boulder, CO).

The mesospheric simulations (e.g. Plate 4) show synoptic features which agree with aspects in the MLS gravity wave variances [Wu and Waters, 1997], but others which do not. Before detailed comparisons and inferences can be made, we need to adjust these data to take into account the MLS weighting functions, following the stratospheric analysis of Alexander [1997]. Similar comparisons will also be made to the LIMS gravity wave data presented by Fetzer and Gille [1994].

Presently the weighting functions of each satellite-based remote sounding instrument to gravity waves have been inferred using simplified arguments. To get a better hold on the true instrument functions, we will continue developing both the SPAM model and the orbital code of Dr. S. Palo with a view to developing an entire numerical simulation model of the remote detection of gravity wave fluctuations from space-based platforms, which will allow better characterization of true selectivity of various satellite instruments to gravity waves.

2.3 Relation to Ultimate Objectives of the Research Contract

The work outlined to date in section 1 represents significant progress in all areas of the proposed contract research (see section 2 of the original proposal). Specifically, data analysis and interpretation using both UARS and CRISTA-SPAS data are progressing, numerical simulations using GROGRAT and NRL/MWFM are proceeding and yielding exciting new results which pertain to the aforementioned data, and a new model based on SPAM and satellite orbital codes is being developed to better characterize the detection of gravity waves from space-based platforms.

A prime focus of the research is to yield new results on the long-term and synoptic trends in global gravity wave activity in the middle atmosphere, based on both data and modeling. Plates 1-5 already represent significant progress to that end goal.

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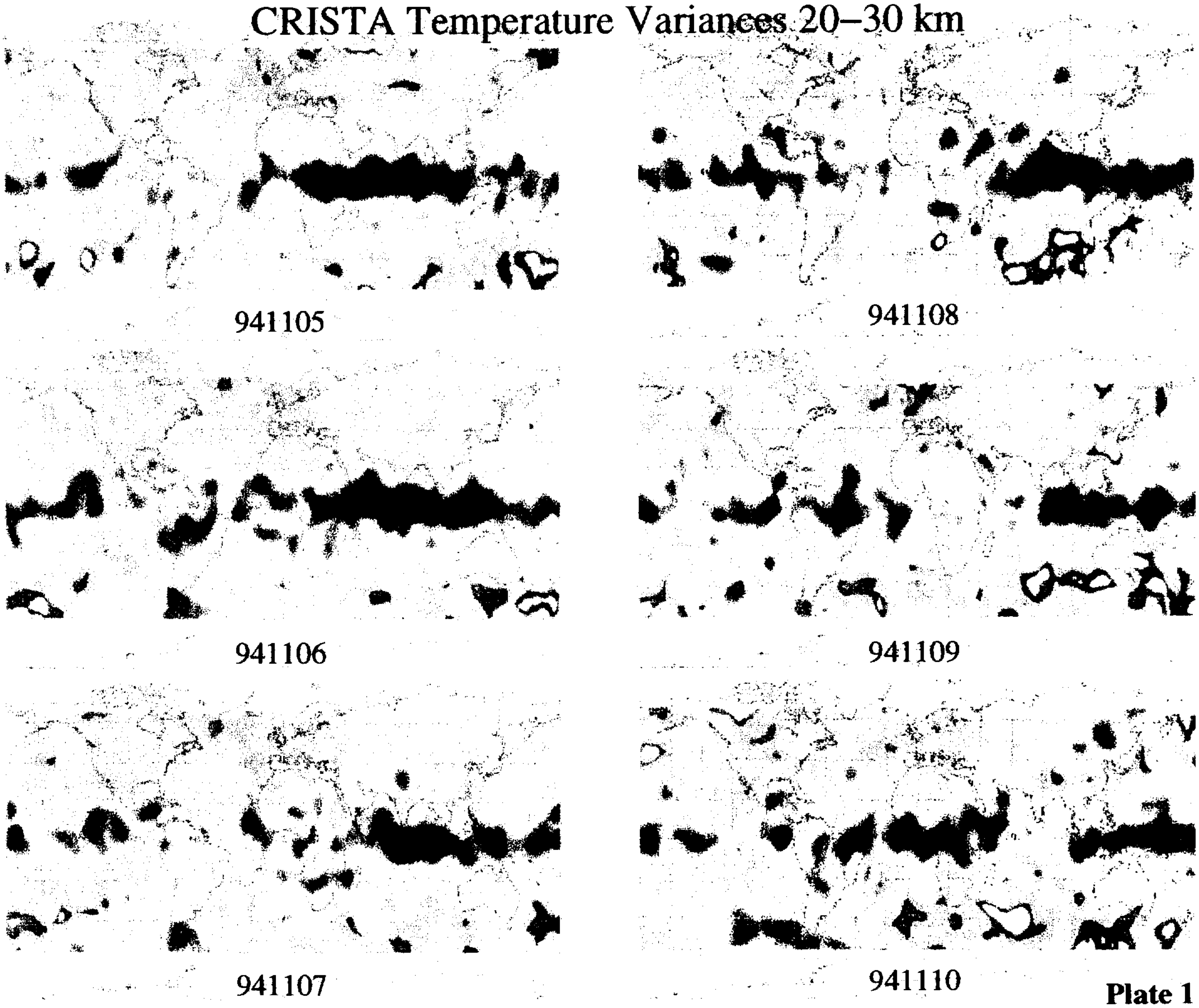

CRISTA Temperature Variances 20–30 km

941105

941108

941106

941109

941107

941110

Plate 1

Plate 1: Variance in vertical temperature profiles derived from the CRISTA instrument for the dates indicated on each plot. The largest vareiances (shown in red) correspond to temperature variances of ~1K^2. Results are for the height range 20–30 km.

GROGRAT

Gravity-wave Regional Or Global RAy Tracer

DAO Analyses [Schubert et al., 1993]
Amplitude-Weighted Ray Counts: c=20 m/s
6th. November 1994

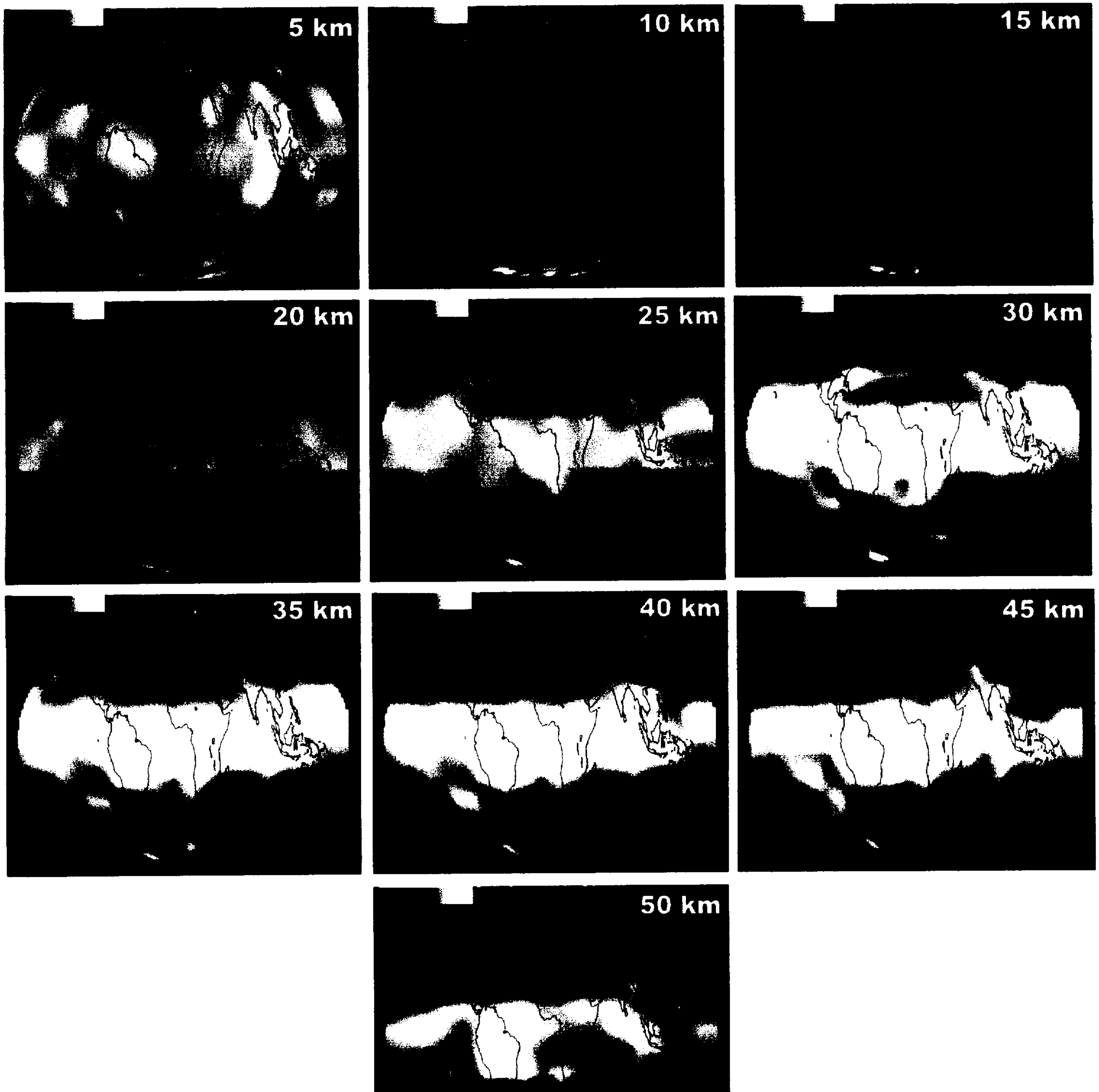

Plate 2: Simulated global gravity wave activity at various heights on 6th. November, 1994 using c=20m/s waves. The activity is the total number of waves within a small latitude-longitude region, weighted according to the amplitude of each wave (so-called "amplitude-weighted ray counts."). Color range is linear.

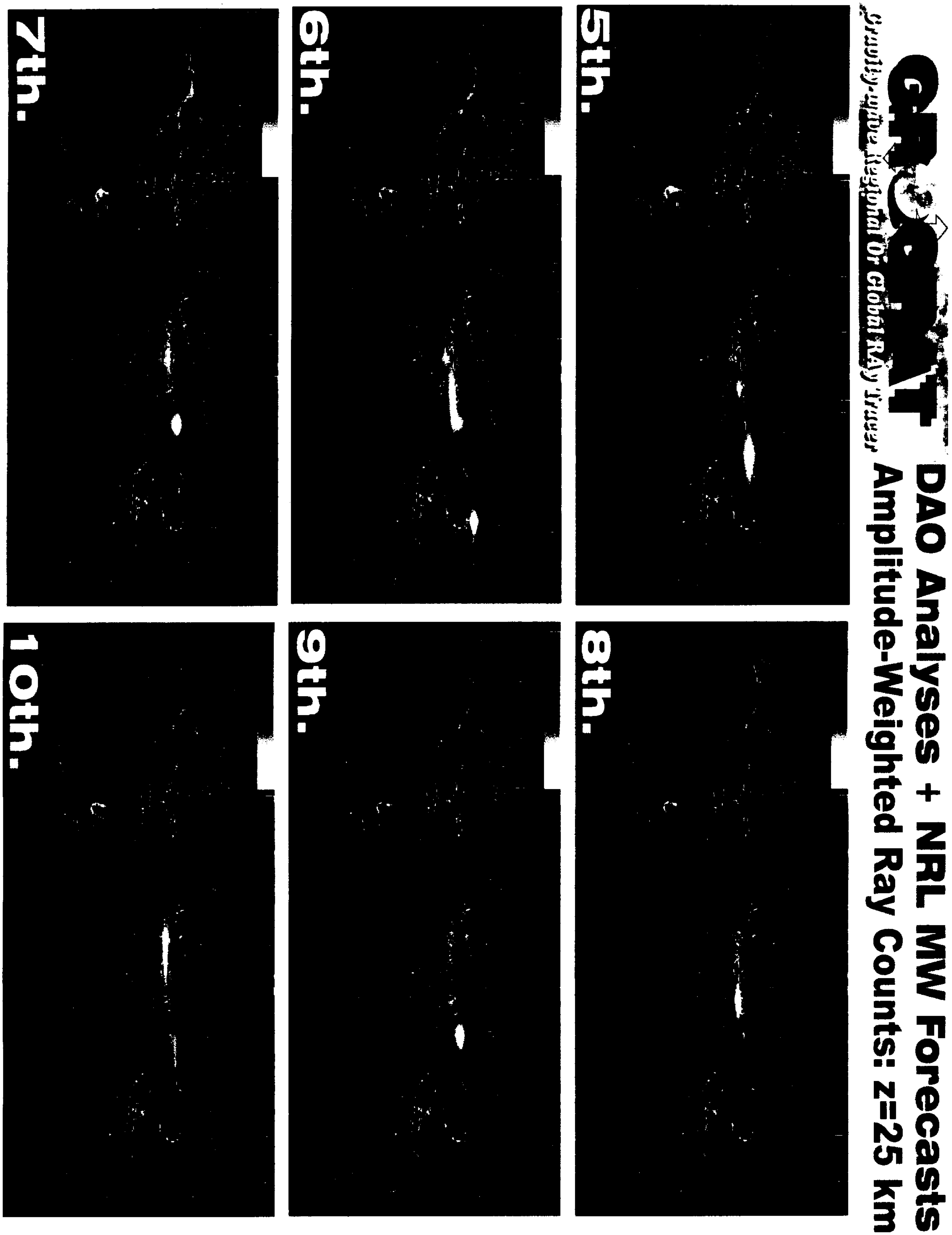

Plate 3: Simulated mountain wave activity at z=25 km for 5th.-10th. November, 1994. Results obtained using NRL/MWFM, GROGRAT and DAO Winds and Temperatures.

GROGRAT

Gravity-wave Regional Or Global RAy Tracer

HWM 93 [Hedin et al., 1996]

Amplitude-Weighted Ray Counts

95 km

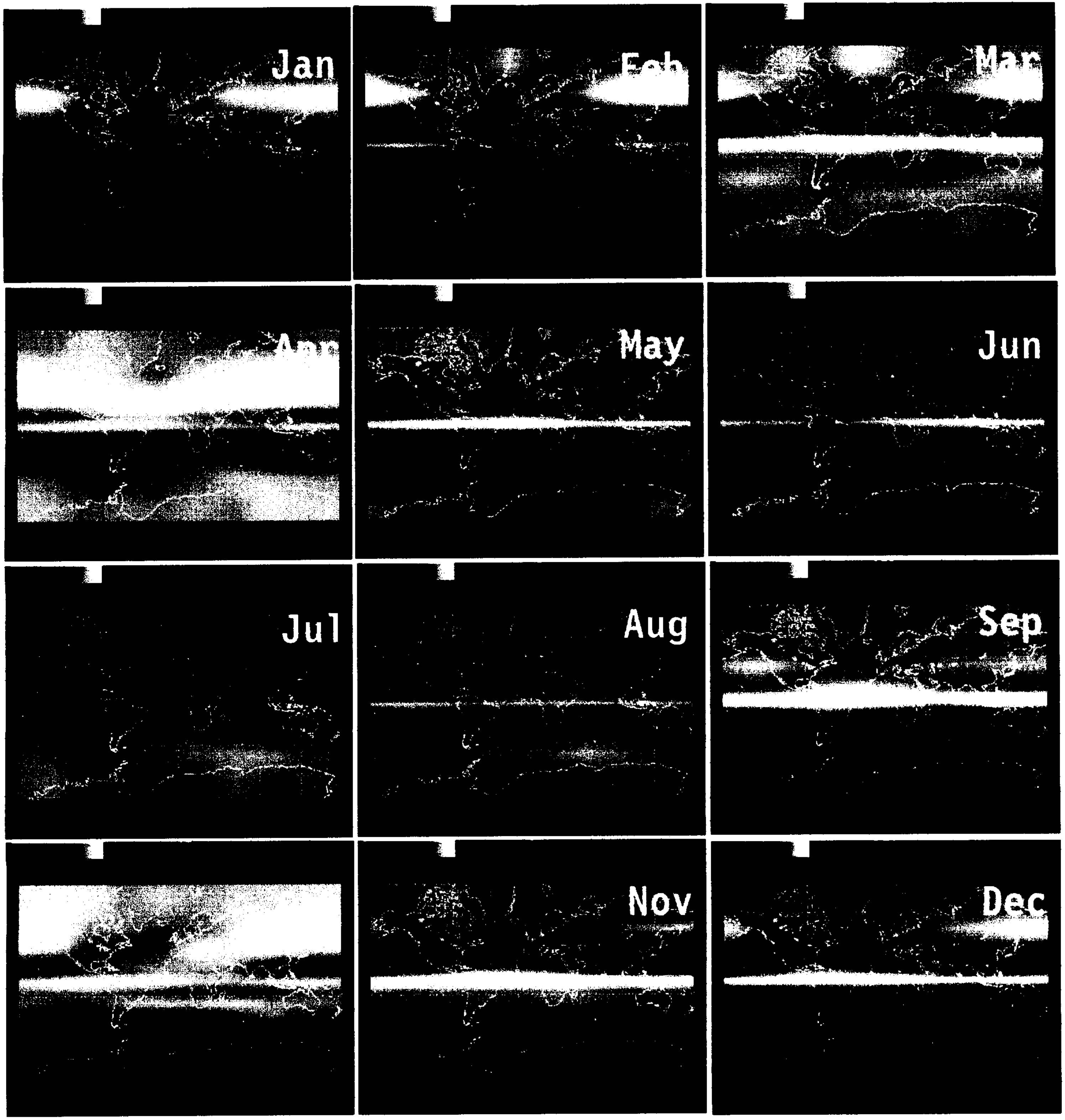

Plate 4: Global gravity-wave activity at z=95 km simulated by GROGRAT using HWM-93 winds and temperatures.

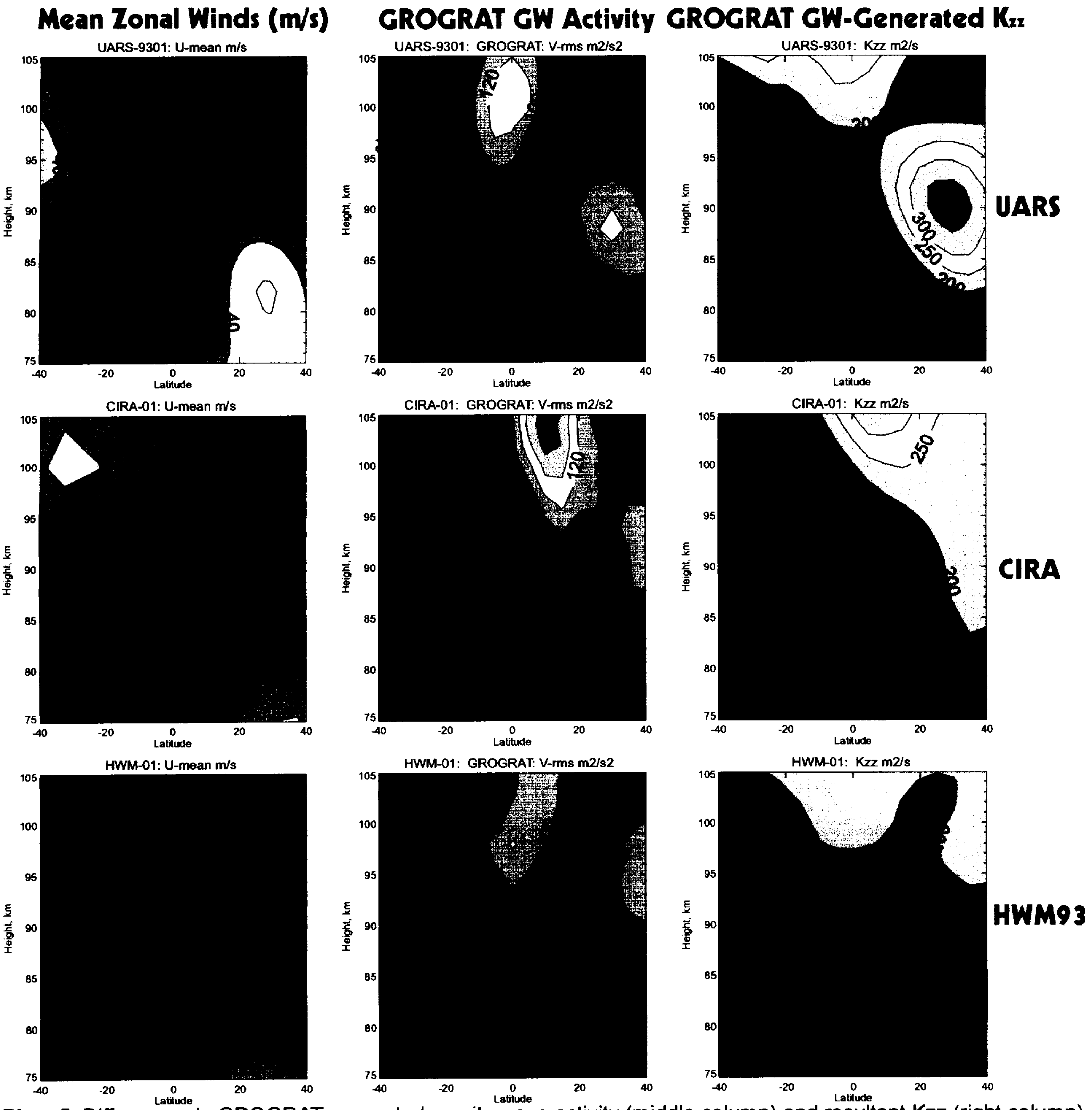

Plate 5: Differences in GROGRAT-generated gravity wave activity (middle column) and resultant Kzz (right column) due to propagation through zonal winds (left column) from UARS (top row), CIRA (middle row) and HWM-93 (bottom row). Results are for January (January 1993 for UARS).

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13. ABSTRACT *(Maximum 200 words)*

This is the first quarter's report on research to extract global gravity-wave data from satellite data and to model those observations synoptically. Preliminary analysis of global maps of extracted middle atmospheric temperature variance from the CRISTA instrument is presented, which appear to contain gravity-wave informaion. Corresponding simulations of global gravity-wave and mountain-wave activity during this mission period are described using global ray-tracing and mountain-wave models, and interesting similarities among simulated data and CRISTA data are noted. Climatological simulations of mesospheric gravity-wave activity using the HWM-03 wind-termperature climatology are also reported, for comparison with UARS MLS data. Preparatory work on modeling of gravity wave observations from space-based platforms and subsequent interpretation of the MLS gravity-wave product are also described. Preliminary interpretation and relation to the research objectives are provided, and further action for the next quarter's research is recommended.

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