Calculations of the three dimensional morphology of Gravity Wave Drag

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1 INTRODUCTION

It has been known for some time that the time mean momentum balance of the upper middle atmosphere requires considerable gravity wave drag in order to close off the polar night and summer mesospheric jets. For example, previous work has demonstrated that zonal mean accelerations of the order of 10-100 m/s/day are required to close off the summer mesospheric jet, and radar observations have demonstrated that small scale vertical momentum fluxes from gravity waves consistent with this hypothesis exist.

In this paper, a technique first introduced by Marks (1989) is used to calculate the small scale drag required for dynamic balance in the CIRA model atmosphere. Although the CIRA data used is clearly very coarse, both in spatial resolution, and possibly more importantly, temporaral resolution, it is shown that the accelerations obtained are qualitatively consistent with those expected from gravity wave breaking. The method will also be applied to ISAMS data when available; if possible preliminary results will be presented at this meeting. It is expected that the higher resolution ISAMS data will give a more accurate picture of the morphology of the gravity wave drag.

2 DATA AND METHOD

The data used is the CIRA model atmosphere temperatures; limited to the vertical range 10-80 km interpolated to 2km intervals on a horizontal grid with longitudinal resolution of 22.5 degrees and latitudinal resolution of 5 degrees (87.5S - 87.5N). The temperatures are then stacked on the CIRA 30mb geopotential field in order to obtain the geopotential heights.

Estimations of the gravity wave drag are obtained by making an initial guess for the horizontal wind via geostrophic balance. Improved wind estimates are obtained by obtaining a vertical wind from the thermodynamic equation — the MIDRAD radiation scheme (Shine, 1987) is used to evalute the heating — followed by better zonal and meridional wind estimates from the meridional momentum and the continuity equations respectively. After a number of iterations, the zonal momentum equation is used to evaluate the drag as a residual of the other terms[3].

The method converges to a solution within four to eight iterations, depending on the numerical relaxation used. For the results presented here, we used six iterations and no relaxation, all fields were smoothed using spherical harmonics after each iteration. Despite the smoothing however, there often remains considerable numerical noise near the poles, which we attribute to the poor accuracy involved in integrating the continuity equation near there.

There is one crucial assumption and one important data dependent simplification in the method used. Firstly, in order to have a tractable algebraic problem (five variables - u, v, w, T, D from five equations), we assume that the gravity wave effects only manifest themselves in the zonal momentum equation (i.e. no small scale drag in the meridional momentum equation and an effective Prandtl number of infinity). Although there is a reasonable body of work which suggests that these are reasonable first order assumptions (S.D. Eckermann, *pers com,* and Huang and Smith, 1991), there is also recent work (Murphy, 1990) which must cast doubt the validity of assuming no acceleration in the meridional momentum equation. Secondly, the heating is calculated using a radiation scheme which assumes climatological zonal mean ozone. While this is probably adequate in the summer (where there is little non-zonality), on the edge of the polar night it probably contributes to inaccurate results. This is one area where the improved ISAMS data will be of benefit: clearly we can use the retrieved ozone as well as temperature.

3 RESULTS

As an initial test of the retrieved drags, we have compared zonal mean fields of the drag obtained with the drag obtained using a Lindzen parameterization. The parameterization used was tuned to get similar magnitude drags for both hemispheres in July (figure 1). It can be seen that the main features are similar, and this is in fact the case for the entire year.

Some synoptic pictures of the drag obtained for the southern hemisphere in July are presented in figure 2, which compares the perturbation[4] geopotential with the perturbation fields of both our calculated drag and that obtained from the Lindzen approximation. It can be seen that the observed drags are much more non-zonal than those produced by the Lindzen parameterization. In this case, the wave one structure appears similar, with more higher-order variability in the calculated drag. In the November northern hemisphere case (figure 3) there is not much in common between the two methods of cal-

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[3]The mathematical details can be found in Marks (1989)

[4]i.e. the fields are total field minus zonal means

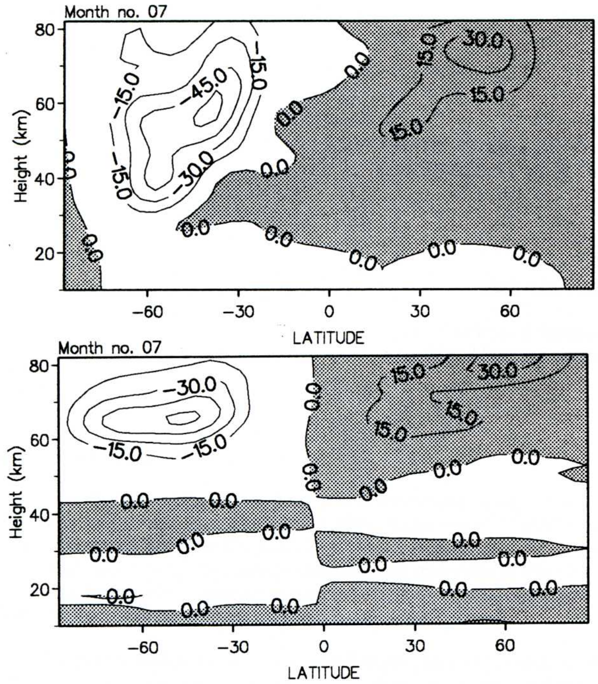

Fig. 1. Comparison of the zonal mean drag (m/s/day): top panel, Lindzen drag for July; bottom panel, calculated drag.

culating the drag. We believe these differences may be attributable to anisotropies in the source distribution of gravity wave activity.

It is difficult to know whether these results are even qualitatively correct, or simply artifacts of the numerical procedures: one of the problems with an iterative method as used here is that the scheme can iterate toward a solution but we have no guarantee that it is the "correct" one. However, the consistency with height and from month to month (figure 4) coupled with quite a different morphology in the two hemispheres, suggests that we are looking at a physical result.

Because of the nature of the climatology (monthly means), there is potential also for the drag obtained to include accelerations due to transience on planetary scales. However, we believe these to contribute minimally to the monthly mean balance, particularly in the mesosphere. In addition the time series obtained above Kyoto are consistent with those from radar measurements (Tsuda *et. al.* 1990) of gravity wave drag there (Lawrence and Marks, 1992) — however, at Kyoto, the background field is near zonal anyway so this is not a very discerning test. It is hoped that independent verification will be obtained with radar results from a site in a more "disturbed" location! Further, some numerical modelling studies are being undertaken to see if algorithmic verification can be

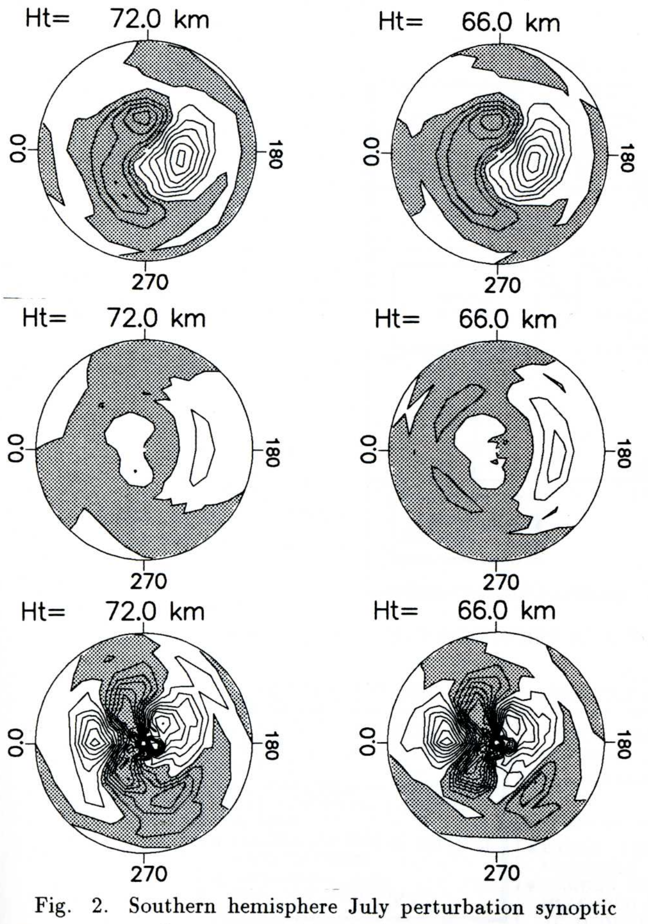

Fig. 2. Southern hemisphere July perturbation synoptic maps: top panel, geopotential height (con. int. 100m, positive values shaded); middle panel, Lindzen drag ; bottom panel, calculated drag. In all figures of g.w. drag in this paper the contour interval is 15 m/s/day and positive values are shaded.

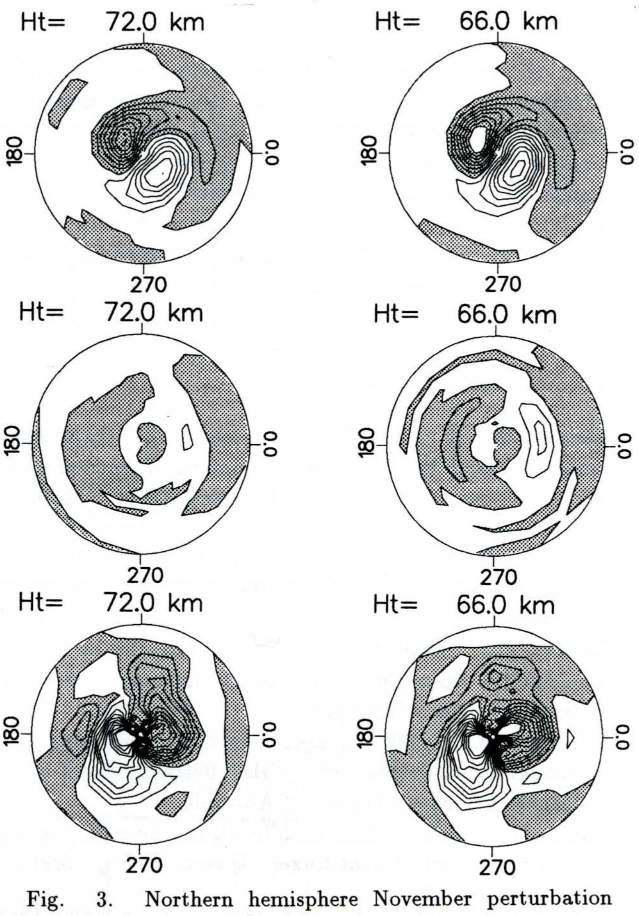

Fig. 3. Northern hemisphere November perturbation synoptic maps: top panel, geopotential height (m); middle panel, Lindzen drag (m/s/day); bottom panel, calculated drag (m/s/day).

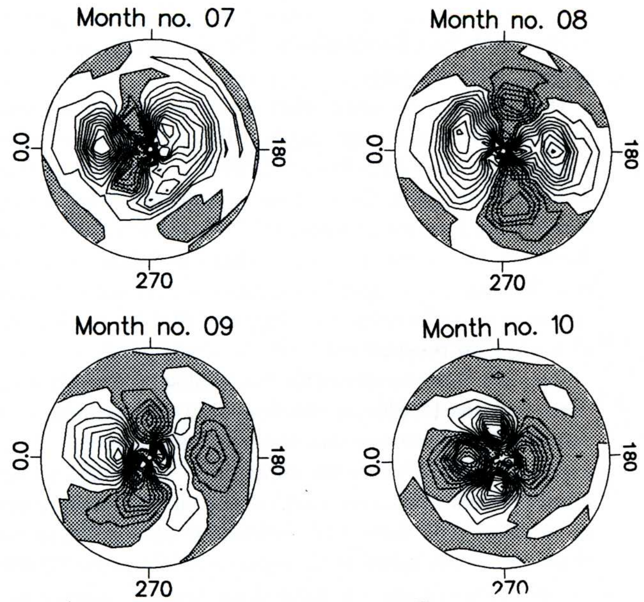

Fig. 4. Southern hemisphere calculated drag (m/s/day) at 66 km: July, August, September and October

found by recovering the model gravity wave parameterization from its geopotential and temperature fields.

4 Conclusion

The method of Marks (1989) can be used to obtain three dimensional fields of gravity wave drag in observational fields by finding residuals in the zonal mean momentum equation. We believe that the drag obtained is at least qualitatively indicative of the real variations in the gravity wave drag. In the one case where we have available corroborative data, the seasonal trend obtained is consistent with the radar results. Further studies are underway to enhance our understanding of the results obtained.

5 References

Huang, T.Y.W. and A.K. Smith, 1991: The mesospheric diabatic circulation and the parameterized thermal effect of gravity wave breaking on the circulation. *J. Atmos. Sci.*,**48**, 1093-1111

Lawrence, B.N. and C.J. Marks, 1992: A comparison of the gravity wave drag at Kyoto and Adelaide. Manuscript in Preparation.

Marks, C.J., 1989: Some features of the climatology of the middle atmosphere revealed by Nimbus 5 and 6. *J. Atmos. Sci.*,**46**, 2485-2508

Murphy, D.J., 1990: Measurements of energy and momentum in the mesosphere. PhD Thesis, Dept. of Phys. & Math. Phys., University of Adelaide.

Shine, K.P., 1987: The middle atmosphere in the absence of dynamical heat fluxes. *Quart. J. Roy. Meteor. Soc.*,**113**, 265-292

Tsuda, T., Y. Murayama, M. Yamamoto, S. Kato, and S. Fukao, 1990: Seasonal variation of momentum flux in the mesosphere observed with the MU radar. *Geophys. Res. Lett.*,**17**, 725-728