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Atmospheric Measurement Techniques
Discussions

Interactive comment on "The response of super pressure balloons to gravity wave motions" *by* R. A. Vincent and A. Hertzog

Anonymous Referee #1

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SUMMARY: This is a concise and well-written paper on an important measurement technique for stratospheric gravity waves, a specific and poorly observed source of dynamical variability and momentum and energy transport in the atmosphere. The present paper focuses on the *in situ* sampling of atmospheric gravity waves by onboard sensors carried into the stratosphere by super pressure balloons (SPBs). Such measurements are valuable, and warrant a detailed assessment as provided here, given the unique Lagrangian perspective they provide on the wavefield, which is valuable dynamically since it removes the Doppler-shift distortion of gravity-wave measurements from ground-based profilers and remote sensors.

The authors starting point is the fluid dynamical force equation governing buoyant balloon motion in a stratified atmosphere (Nastrom 1980). They progress through a series

of simplifications to this starting equation, and substitution of terms using gravity-wave polarization relations derived from a linearization of the Navier-Stokes equations, to derive a complex transfer function Z as equation (11) that relates gravity-wave input variables to SPB observables. This relation is tested against full numerical solutions omitting the analytical approximations, showing generally close agreement, and reproducing earlier results, such as the odd wavenumber higher order harmonic content in the SPB response. From there a comprehensive series of numerical experiments is performed that prescribes wave packets with different frequencies, wavenumbers and propagation directions, then simulates the observation of these waves using the SPB transfer relations based on values appropriate for CONCORDIASI balloons. The analysis compares inferred wave properties from the simulated SPB output, such as wave momentum flux, with the known input values. Limits on momentum flux versus frequency are inferred.

I enjoyed reading the paper. The results are clear and accessible and so should be a valuable resource for future gravity wave studies using SPB data. I recommend publication after the authors have considered the mostly minor comments provided below.

GENERAL COMMENTS

1. The initial derivations seem to omit a lot of important additional detail. For example, the simplification from eq. (1) to eqs. (2) and (3) involves a series of important and unstated assumptions, including (a) a Boussinesq approximation, (b) a spherical SPB, (c) small vertical displacements and (d) no significant vertical shear in the background horizontal wind (see Nastrom 1980). Second, below eq. (6) it is stated ω_b is always larger than N, but this is not obvious given that there is an unstated analytical relation given by eq. (10) of Nastrom (1980) [though his relations seem to contain a sign error] that yield $\omega_N^2 = 2/3N^2 + 2/3g^2/(TR_a\gamma)$ which does not suggest ω_N^2 is always greater than N^2. These relations and the stratospheric values should be explained a bit more to help the uninitiated reader.

2. The authors generalize the Boccara et al. (2008) relations to more general gravity-wave dispersion and polarization relations containing both rotational and nonhydrostatic modifications, which is highly worthwhile given that much momentum flux is probably contained at high intrinsic frequencies where nonhydrostatic corrections may be important. But the derivations are perhaps not as general and accurate as the writeup suggests. For example, Fig. 3 inputs gravity waves at frequencies $\omega > N$ where waves cannot exist, which suggests something a little odd in the analytical wave inputs. More to the point, there are important deep gravity-wave modifications that relate less to the $(1 - \omega^2/N^2)$ factor, and come in due to compressibility effects as $|m|$ becomes small and compressibility effects become significant. The modifications to eq. (9) can be seen, for example, in eq. (B9) of Eckermann et al. (JAS, 55, 3521-3539, 1998) through the compressibility terms $a(m, \omega)$ and $b(m, \omega)$ which, as shown in their Fig. B1, lead to significant magnitude and phase deviations from the hydrostatic simplification given by eq. (9) as m becomes small. All this is to say that some of the small errors at nonhydrostatic gravity-wave scales defined from the present analysis need to be benchmarked in terms of the errors expected from the incompressible approximations in the current analysis. This is not really to criticize what the authors have done, which I believe to be excellent and appropriate, but merely to provide an additional theoretical perspective for benchmarking SPB gravity-wave errors for deep fast nonhydrostatic gravity waves.

3. The authors' analysis of wave packets in section 5.3 is extremely thorough, but some brief discussion or speculation should be offered as to how (if at all) these results change it there is a linear (or even nonlinear) superposition of collocated wave packets, as most likely occurs routinely in the stratosphere away from strong sources.

MINOR COMMENTS

P10798 L17: please explain what "semi-Lagrangian" means in this context.

P10803 L12-17: please add "a" and "b" labels to Figure 1, so that L12 becomes "Figure 1a" and Line 17 becomes "Fig. 1b."

P10806 L1-3 and Fig. 3: there is confusing use of undefined symbols τ_N and τ_b to describe the "buoyancy" and "Brunt" periods (see Fig. 3 caption). This is confusing since N is commonly referred to synonymously as either the buoyancy frequency, or the Brunt (or Brunt-Vaisala) frequency. So which one applies to N and which one applies to ω_B? This should be made clear to avoid needless confusion. Also, why are input gravity waves used in Figure 3 that have intrinsic frequencies greater than N (periods less than the Brunt period), which cannot exist?

P10809 L12: "meridional position" is a bit confusing. I guess you're referring to the movement along x as intercepting different longitudes or meridians, but this nomenclature is confusing since north-south displacements and velocities are generally referred to as "meridional." So I'd replace "meridional" here with "zonal" or "longitudinal."

P10810 L2: "l, k" should be corrected to "k, l."

P10810 L4: f should be changed to $|f|$ since f is negative at southern CONCORDIASI latitudes.

Interactive comment on Atmos. Meas. Tech. Discuss., 6, 10797, 2013.