Monitoring strong gravity wave signatures in the stratosphere due to extratropical cyclones through high resolved radio sounding data

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Strong cyclones can be hazardous atmospheric systems. Their enormous energy content and the resulting precipitation are parameters which have to be observed and analysed in detail. Consequently, improved understanding of the life-cycle of strong cyclones and their physics is important. Atmospheric waves, especially gravity waves, which are radiated from a storm system, are investigated to serve as a proxy for the changing energy content of the storm itself: in several case studies higher gravity wave activity in the lower and middle stratosphere related to the passage of fronts, which are part of extratropical cyclones, are observed. Gravity wave characteristics are discussed. All analyses are based on high resolution radio sounding data of a measuring campaign on Mallorca 2011.

1. Introduction

It is well-known that gravity waves (GW) play a significant role in the dynamics of the middle atmosphere. Several mechanism types can be responsible for the radiation of gravity waves. Among flow over mountain ranges or land-sea transitions convective systems are prominent tropospheric sources [1]. High-resolution radiosonde data are used to study a possible correlation between high background wind due to fronts and GW activity in the lower stratosphere (17-25 km).

2. Data Description and Analyses Approach

The data used in this study were derived during a measuring campaign at Mallorca covering three months (October – December 2011). It consists of seven periods of different lengths (see Table 1). A total of 106 radiosondes was launched with a maximum of eight balloons per day at 0200, 0500, 0800, 1100, 1400, 1700, 2000 and 2300 UTC. Generally, temperature, pressure, horizontal wind data and humidity are available. The soundings are made with Väisäla RS92-SGP radiosondes and TOTEX TA500 balloons. They typically reach altitudes of 25–30 km. Data were sampled every 2 s during a balloon ascent, corresponding to a height spacing of about 10 m. The vertical velocity of the balloon accounted for about 5 m s^{-1}.

Separating fluctuations caused by GW activity from the non-gravity-wave fluctuations is the most difficult task of the study. A simple superposition principle of GW perturbations concerning temperature, zonal and merdional wind (T’, u’ and v’) on a background structure (T_0, u_0 and v_0) is used [2, 3]: $T = T_0 + T'$. The separation of these parts is realized by a cubic spline method where the cut-off wavelength of the filter is chosen to be 7 km. Afterwards, the perturbations are calculated by subtracting the background from the original profile. For the purpose of a measure for GW activity in the stratosphere, the residuals are squared and summed up for a specific height range (17-25 km).

3. Results and Discussion

Cyclones are one of several sources that can lead to gravity wave generation. Since a vertical momentum is needed for the generation of GW the centre of a low-pressure system is one possible source for GW. Furthermore, extratropical cyclones have strong convective regions with high temperature gradients on a small horizontal range, called fronts. An ideal extratropical cyclone has two fronts, a warm one followed by a cold one. Between these two fronts the isobars are densely spaced yielding to increased horizontal wind speeds along the isobars (geostrophic wind). Therefore, the velocity of the horizontal wind is taken as a proxy for the strength of a front. Several case studies relating stratospheric GW and tropospheric frontal activity at Mallorca are performed.

During the 7th period of the measuring campaign a strong low-pressure system crossed northern Germany. Figure 1 shows the background wind speeds and the temperature perturbations in the altitude range from 0 to 30 km during this 7th period of the campaign at Mallorca (for details see table 1). On the left side of figure 1 the black solid line represents the stratospheric gravity wave activity, which was calculated from the residuals (see section 2). In general, the background wind speeds are

Table 1: Measuring campaign on Mallorca

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Start	19.10.2011	26.10.2011	02.11.2011	08.11.2011	02.12.2011	10.12.2011	14.12.2011
End	21.10.2011	29.10.2011	06.11.2011	09.11.2011	03.12.2011	12.12.2011	18.12.2011
Soundings	16	24	32	12	11	14	34

higher near the tropopause than below. Due to the upcoming cold front of the cyclone the wind increases around the 24th sounding (figure 1 left). This effect is accompanied by two short peaks in the stratospheric gravity wave activity. Corresponding to this, pronounced gravity waves with downward phase propagation (black lines, hand drawn to guide the eye) can be observed at heights between 17 and 28 km (figure 1 right).

Although a correlation between wind and gravity wave activity can be seen, two things have to be mentioned. Firstly, there is a little time shift between the enhanced GW activity and the increased wind speed. Secondly, the GW signatures are not present over a long time period but more or less restricted to the presence of the front. That can be interpreted in terms of a non-uniform GW radiation in each direction and is in accordance with modelling studies [4, 5]. One possible reason for both effects might be that a low-pressure system leads to a destabilization of the troposphere resulting in a worsening of the propagation possibilities of GW.

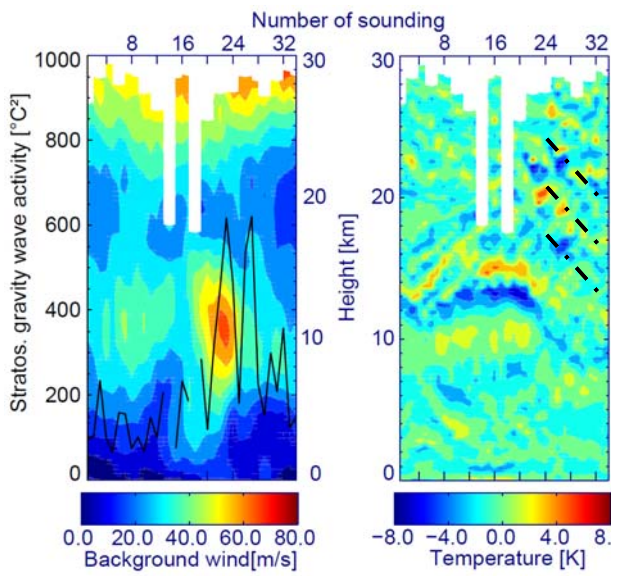

Figure 1. 7th measuring period on Mallorca from 14th December at 23 UTC till 18th December at 17 UTC with one sounding every 3 hours:
(left) background wind speed (in colour, m/s) and stratospheric gravity wave activity (solid black line, °C²)
(right) temperature perturbations (in colour, K) and downward phase propagation (black lines)

The closer the source is to the troposphere, the more possible cyclone-induced stratospheric wave activity is.

In order to determine wave propagation directions a hodograph analysis will be applied. Therefore, the gravity wave horizontal-velocity perturbations are plotted vectorially and values at successive heights are interconnected. The resulting velocity hodographs frequently reveal elliptical wave frequency induced velocity 'spirals' as function of height [6]. Due to different occurring wavelengths in one height range, the hodographs are separated with the aid of a spectral analysis method.

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4. References

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