HYDROMETEORS PRODUCTION AND ADVECTION IN A GRAVITY WAVE ENVIRONMENT

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Abstract: Production and advection of precipitating water in a prescribed, time dependent flow is investigated by means of a simple 2D model in order to predict the periodical behaviour of rain rate and pressure which was observed in the Po valley during IOP8 of MAP. The (x,z,t)-dependent wave perturbations on wind and temperature fields were derived from a linear stability analysis and are superimposed on z-dependent background fields. The wave influence on the hydrometeors production and advection is discussed.

Keywords – Gravity wave, hydrometeors, MAP

1. INTRODUCTION

On 21 October 1999 (IOP8 of MAP), during stratiform precipitation conditions, periodical variations of the rain rate were observed for 6 hours in the western part of the Po valley of Italy. During this interval a mesoscale gravity wave travelling northward with a phase speed of about 25 ms^{-1} and a wavelength of about 100 km was detected by a microbarometric network.

Spectral analysis showed significant peaks in both rain rate and pressure signals, with periods of (66±3) and (64±3) min respectively. A significant correlation was found, the rain increase following the pressure rise with a 15 min lag (Richiardone and Manfrin, 2003).

Wind profilers data showed the coincidence of the maximum of the wave activity when the tropospheric jet stream transited above the site, and a linear stability analysis predicted the existence of a ducted mesoscale wave with period and wavelength in agreement with observations (Richiardone et al., 2003).

In order to explain the 15 min lag between the rain rate and pressure that was observed at ground, a simple 2D model of production and advection of precipitating hydrometeors has been developed and is here described.

2. THE MODEL

The conservation of precipitation's mass

$$\frac{d\rho_p}{dt} = -\rho_p \nabla \cdot \vec{V}_p + S \tag{1}$$

is integrated on a (x,z) domain with a semi-Lagrangian method and periodic boundary conditions at lateral boundaries until the amplitude of the rain rate modulation reaches a stationary state. In the above equation ρ_p and $\vec{V}_p$ are the mass concentration and velocity of the precipitating hydrometeors, and *S* is the source/sink term. A constant horizontal grid step and variable vertical steps, depending on fall speed, have been used.

The background state $u_0(z)$, $w_0=0$, $T_0(z)$ (from measurements, see Fig. 1) and the wave-induced perturbations $u_1(x,z,t)$, $w_1(x,z,t)$, $T_1(x,z,t)$ (from stability analysis) are prescribed. Temperature T and the two components u_p and w_p of the hydrometeors velocity are the sum of the background and perturbation values, i.e. $T=T_0+T_1$, $u_p=u_0+u_1$, $w_p= w_1 - v_f$, where $v_f=v_f(T)$ is the terminal fall velocity.

Perturbation η_1 of variable η is expressed as

$$\eta_1 = \mathrm{Re}\,(\,\hat{\eta}_1(z)\,e^{i(\omega t - kz)}\,) \quad , \tag{2}$$

where $\hat{\eta}_1$ is complex and ω and k have the usual meaning of frequency and horizontal wave number.

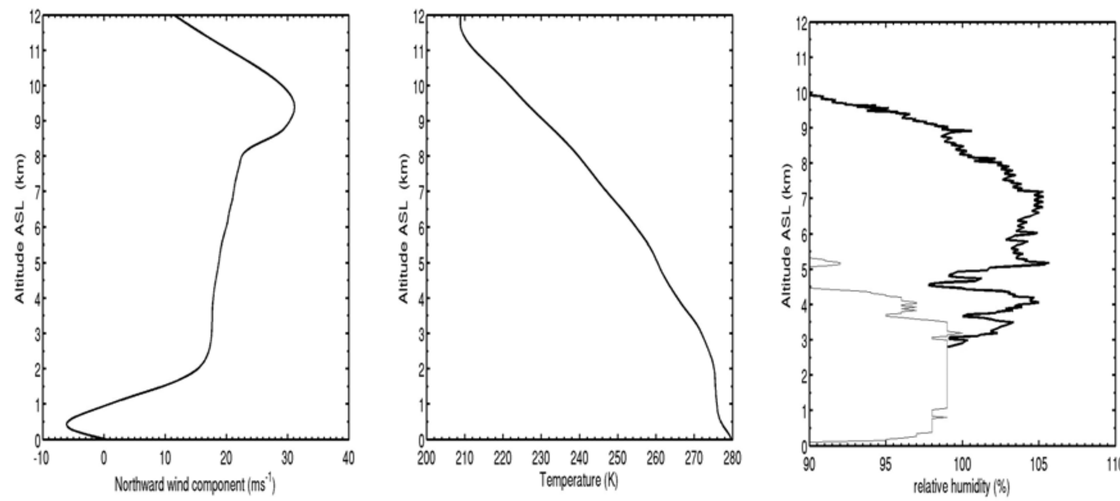

Figure 1 Left: interpolated northward component of the background wind profile. Center: interpolated background temperature profile. Right: relative humidity profiles measured over water from radiosounding (thin line) and evaluated over ice (bold line).

In the event of 21 October 1999 the atmosphere was saturated (over ice) up to about 8.5 Km (see Fig. 1). Therefore the rate S at which precipitation is produced or destroyed is calculated in the model from the rate of decrease or increase of the saturated vapour density ρ_v, which is function of temperature only, being $\rho_v = e^*_\omega(T)/R_v T$, where e^*_ω is the saturation vapour pressure and R_d the gas constant for water vapour. S is therefore a known function of dT/dt, the time derivative of the temperature of a water vapour parcel following its motion, i. e.

$$\frac{dT}{dt} = w_0\,\frac{\partial T_0}{\partial z} + \frac{\partial T_1}{\partial t} + u_0\,\frac{\partial T_1}{\partial x} + w_0\,\frac{\partial T_1}{\partial z} + w_1\,\frac{\partial T_0}{\partial z} \quad . \tag{3}$$

A background velocity $w_0(z)$ is used in equation (3) to maintain a background source term, but it is neglected, as said before, in the advection term of equation (1) because the terminal fall velocity already includes it.

The background source term (the first one in r.h.s. of equation (3)) fixes the mean value of rain rate at ground. The other terms are linearly related to wave variables and cause therefore a periodical condensation/evaporation of the water vapor, resulting in a periodical hydrometeors production.

The second and the third term of equation (3) can be written from equation (2) as

$$\mathrm{Re}\Big(i\,(\omega - ku_0)\,\hat{T}_1 e^{i(\omega t - kx)}\Big) \tag{4}$$

In the solid phase the condensation/evaporation of water vapor causes almost immediately an increase/decrease of the mass of preexistent hydrometeors produced by the background flow. In the liquid phase, however, a delay time t_d is required for the growth of the droplets before they reach the size at which they eventually fall at speed v_f. During the growth phase the droplets are advected by the background flow without changing so much their height. Therefore in equation (1) S is calculated at ($\cancel{x}$,z,t-t_d) instead of (x,z,t), where $\cancel{x} = x-u_0\, t_d$ is the x-coordinate at which the parcel reaching the final stage of growth at *(x,z,t)* started growing. Delay t_d being a function of the hydrometeor' state, it has been prescribed as a function of *T*.

Horizontal advection influences the change of the phase lag τ between a parcel and the wave, being

$$d\tau = \left(1 - \frac{u_p}{c}\right) dt\,, \tag{5}$$

where c=ω/k is the wave's phase speed. Therefore the lag between rain rate and pressure at ground depends not only on the time spent by hydrometeors to fall, but also on the horizontal background wind field. The shape of the wind profile has a strong influence on the lag, because at the heights where $u_0 \cong c$ (the upper layers, in the IOP8 case) the hydrometeors drift horizontally almost as the wave does, and so the lag becomes almost insensitive to the time that they spend falling.

3. RESULTS

The ducted wave mode predicted by the stability analysis is characterized by the existence of a node at about 3 km. This implies a phase reversal of $\hat{T}_1(z)$ and $\hat{w}_1(z)$ between the layers below and above the node. All the periodical source terms in equation (3) are affected; this gives rise, in each layer, to a contributions to rain rate at ground whose amplitude is of the same order of magnitude but whose phase delay is greater than a quarter of period.

However, the action of the wave consists not only in increasing or decreasing the hydrometeors production, but also in affecting their fall speed through the influence on temperature (transition from solid to liquid phase).

Even if all the periodical source terms in equation (3) are dropped, the wave-induced variation of temperature causes in fact an oscillation of the melting height resulting in a periodical fluctuation of the rain rate. This term gives a contribution that is in phase with observations and is very sensitive to the shape of the background temperature profile.

The first results show therefore that, depending on temperature profile, the melting factor can help or also overcome the contribution of the periodical source terms in causing the rain rate modulation that was observed.

REFERENCES

R. Richiardone, M. Manfrin, 2003 :A Rain Episode Related to a Mesoscale Gravity Wave., *Bulletin of the American Meteorological Society*, **84**, 1494-1498.

R. Richiardone, M. Manfrin, B. Campistron, V. Klaus, 2003:A Mesoscale Gravity Wave Event during MAP: a Possible Source., *Preprints volume of International Conference on Alpine Meteorology and MAP-Meeting 2003*, Publications of MeteoSwiss, Zurich, Switzerland , 402-405.