A MODELING STUDY OF A WARM CLOUDS EXTREME EVENT IN SANTA CATARINA, BRAZIL

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1. INTRODUCTION

In 2008, November 21st-24th, the eastern portion of the Santa Catarina (SC) state in southern Brazil was subject to an extreme event of rain that lasted four days. Accumulated precipitation was ~ 700 mm, daily rain reached 280 mm and the total monthly rain was up to 1000 mm (INPE, 2009).

Beyond the serious social and economical consequences of this huge amount of precipitation, a surprising fact was the weak ability of models operational in Brazil by that time to forecast correctly the magnitude of the event. ETA model forecast indicated precipitation amount up to 200 mm for the period 20-24/november, as shown in Figure 1.

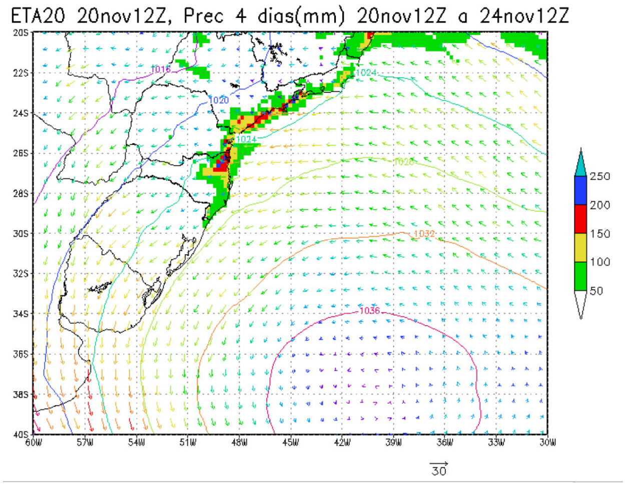

Figure 1: ETA model operational forecast (top) for total precipitation between 20-24/nov/2012.

From the synoptic point of view, the driver for this event was a stationary high pressure in the South Atlantic that advected very humid air masses from the ocean to the continent. Because the topography of the area is characterized by a mountain range following the coastline, the combination of these two facts resulted in very efficient formation of warm clouds with tops below 5000 m and precipitation due to the forced lifting of quasi-saturated air-masses from the ocean.

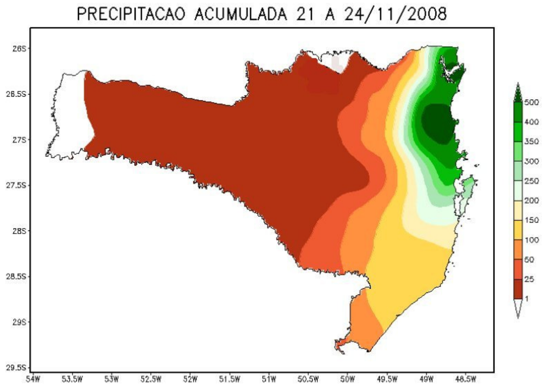

Figure 2: observed precipitation derived by pluviometers between 21-24/November/2008.

Another important feature of this event was that the 700 mm of rain did not precipitated in one or two storms. Instead, it was characterized by mid size but constant storm intensity. In Figure 3 it is shown the time series of the precipitation rate.

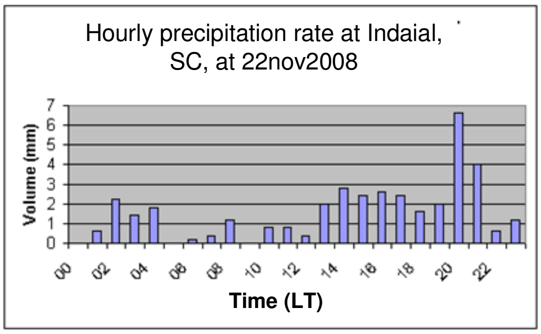

Figure 3: hourly mean precipitation observed at the city of Indaial, which is close to the maximum observed accumulated precipitation.

2. OBJECTIVE

The objective of this study was to investigate the ability of numerical models in correctly forecast events like this with respect to storm size and time-integrated volume of precipitation. In particular we tested how effective is the increase in spatial resolution (both in horizontal and vertical directions), different resolutions of topography, and the employment of full microphysics for resolution about 2 km.

3. METHODOLOGY

The model employed in this study was the BRAMS Model (Brazilian developments on the Regional Atmospheric Modeling System) (Freitas et al., 2009), which is a tropicalized version of the RAMS Model (Pielke et al., 1992). The microphysics component is as described in Meyers et al. (1997).

Two kinds of simulations were performed. The first kind (type C simulation) focused on less vertical resolution and 2 nested grids with resolution 20km and 5km. First and second grids accounted, respectively, with 50 x 60 and 102 x 154 grid points. Grell convective parameterization (Grell and Dévényi, 2002) was turned on(off) for grid 1(2). First level in the vertical coordinate started with 120 m, with a vertical grid stretch ratio of 1.2 (maximum Δz = 1000m), in a total of 32 levels (top at 21 km). This configuration is more representative of the upper operational limit of most forecast centers, and we aimed to provide a somehow "control" configuration.

The second type of simulation (type F simulation) employed finer vertical resolution, (first level of 60, vertical stretching ratio of 1.15 (maximum Δz = 1000 m) and 37 levels (top at 18 km)). Simulations were performed with 1, 2 and 3 nested grids. Resolution was, respectively 40km, 10km and 2.5km.

We made different combinations with respect to topography and cumulus parameterization. One case was the "F1" simulation, where it was employed gradually enhanced topography. Thus, 1st/2nd/3rd grid were set to 10km/1km/200m topography, respectively. As an opposite case "F2" simulation was set to 10km resolution for topography in spite that grid points were smaller than it. The objective was to investigate the actual role of resolution of topography in the final results.

Cumulus parameterization (CP) was always turned "on" in the 1st (40km) and "off" in the 3rd (2.5km) grids. Three simulations were performed with respect to the effect CP "on" and "off" in the 2nd grid. In two of these cases simulation was performed only with 2 grids, and the third case we run 3 grids with CP "off" in the second grid to test whether it could affect the ability of microphysics module of the model in correctly generate rain in the 3rd grid. A fourth simulation, with CP "on" in 1st and 2nd grid and with 3 grids could not be run due to numerical instabilities generated during the run.

Simulation type	C	F1/F2
Simulated period	19nov2008_00Z	26nov2008_00Z
Number of grids	1, 2	1, 2, 3
Grid points (per grid)	50 x 60 102 x 154	150 x 150 102 x 154 200 x 200
Spatial resolution (per grid)	20 km, 5 km	40 km, 10 km, 2.5 km
Vertical resol.: ΔZ_0, dZ ratio, ΔZ_{max}, n_{levels})	100 m, 1.2, 1000m, 32	60 m, 1.15, 500 m, 37
Time step	50s, 10s	50,12.5, 2.5
Topography resol.	10 km, 1 km	F1: 10km/1km/200m F2: 10km for all grids
Flag of cumulus parameterization	On/off	2 grids: on/off and on/on 3 grids: on/off/off
Input from borders	NCEP reanalysis	NCEP Reanalysis

Table 1: Configurations of the performed simulations. Type C (S) corresponds to Coarse (Fine) vertical resolution. Type F simulations can be separated in F1 type, with 10 km coarse topography for all grids, and F2, with finer topography for higher spatial resolution.

Bulk microphysics in BRAMS (and also in RAMS) is not grid selective, i.e., the same configurations apply to all grids. However, it is expected that it become more sensible at higher resolution (~5 km and less). In our case we employed the most prognostic as possible settings for microphysics. It means that starting from a fixed number of Cloud Condensation Nuclei (CCN) the model is able to calculate prognostic size and number distributions of liquid and ice phase hydrometeors, as well as mixing ratios (Meyers et al., 1997).

A general view of the simulations settings is shown in Table 1.

4. RESULTS

In Figure 4 it is shown the total precipitation for the entire simulated period. It is possible to see that type C simulations presented good agreement (Figures 4a and 4b). A good agreement was also achieved by type F simulation with 1 single grid. On the other hand, type F simulations with 2 and 3 grids reduced the total precipitation field in the target area, i.e. the SC state. Instead of it, is shifted the maximum precipitation to northern portions of the coast, and almost vanished precipitation in the SC coast.

This is an unexpected result, since it is expected that cloud mechanisms should be better represented with models working under higher spatial – specially vertical - resolution.

In Figure 5 it is shown the average field of cloud water mixing ratio in several heights for the 3rd grid in F1 and F2 simulations. It is possible to see that the model was able to create a cloud field over the target region. However, it is possible to see that most of cloud water was over the ocean, and not over the continent. It shows that not only the rain formation was harmed but also the cloud formation over the expected area.

Figure 6 shows vertical profiles of the different simulations. Relative humidity is shown in the first column. Simulation type C (1st line) shows a saturated profile from ground up to 3500 m, which means that model could represent very well the actual humidity profile that occurred during the target period.

5. DISCUSSION

The objective of this study was to figure out the reason for the fail in the correct forecast of this extreme event. The initial hypothesis was that the enhancement of spatial resolution – both in horizontal and vertical directions – would be enough to improve the representation of this convective event.

The results showed that a two-grids simulation, with inner grid resolution with $\Delta x = \Delta y = 5km$ and $\Delta z_0 = 100m$ represented the precipitation field much better than a three-grid simulation, with $\Delta x = \Delta y = 2.5km$ and $\Delta z_0 = 60m$.
In fact, type C simulations resulted in a reasonable uniform precipitation field over the SC state coast line, as shown in Figures 4a (1ST grid) and 4b (2nd grid). Beyond that, type C simulations also correctly assigned the location of maximum accumulated precipitation, which is in the northern portion of the coast, around lat = -27S and lon = -49W as can be seen in the observed precipitation field (Figure 2). Further, it resulted in weekly precipitation volume up to 500 mm, which is quite close to the observed maximum.

The precipitation fields for type F simulation are displayed in Figures 4c-4f. The simulation with one grid (4c) agreed quite well with observed precipitation field presenting precipitation maxima up to 270 mm. It is also similar to the type C/1st grid simulation both in terms of spatial distribution and total precipitation.

Precipitation for the type F simulations with higher resolution is showed in figures 4d (2 grids) and 4e/f (3 grids). It is promptly realized that total precipitation is significantly reduced in the two cases.

With respect to the 2-grids simulation (Figure 4d) it is important to highlight that cumulus parameterization was activated, as well as microphysics. A possible explanation for this reduction in precipitation is the fact that CP is designed to work better in more coarse resolutions. In fact, the 2nd grid in the 2-grid simulation was set to 10km resolution. Several modeling studies have shown that the domain within the 1 – 10 km range is not ideal neither to CP or microphysics.

The same fields for the 3-grid simulations are shown in figures 4d-4f. The differences in these simulations are only due to the different resolution in the topography, which is finer (200m) in figure 4f.

Surprisingly, it did not improve the precipitation field. When compared to the 2-grid simulation, it was reduced even more.

A important feature of these 3-grid simulations is that CP was “off” in the 2nd grid, and possibly caused some influence in the 3rd grid yielding this low amount of rain. This hypothesis will be tested in a future simulation with CP “on” in 1st and 2nd grids.

All these observations are corroborated by the modeled vertical profiles, which are shown in Figure 6 for the location of the maximum measured precipitation (lat = 27S; lon = 49W). The first figures on the left correspond to relative humidity (RH). The first RH profile shows that the mean atmosphere was almost all the time saturated up to 4000m, which agrees with observational data like those ones shown in Figure 3, i.e., weak but constant rain. In the next plot (type F, 2nd grid) the profile is also saturated but reducing above 2000m. The scenario goes in the same direction for type F/3-grids/3rd grid profiles, which presented high RH but not saturated profiles. It means that microphysics module was unable to generate clouds.

The same analysis holds for the 2nd column plots (rainwater). With respect to rain efficiency (defined as the ratio rainwater/totalwater) the profiles are very similar, but it does not implicate in higher precipitation once total water was significantly smaller in type F cases. Snow profile (last column) was quite similar in all profiles.

6. CONCLUSION

This study investigated the effect of different settings of BRAMS regional model in its ability to correct forecast an extreme precipitation event in the Santa Catarina state in Brazil. Different resolutions were tested as grid point size, topography and selective activation of cumulus parameterizations in different grids. The results showed that higher resolution was not sufficient to improve the prediction in precipitation fields. Apparently the disabled cumulus parameterization in 2nd grid (type F simulation) induced a significant reduction in the 3rd grid ability to predict precipitation. Further simulations have to be performed to test this hypothesis.

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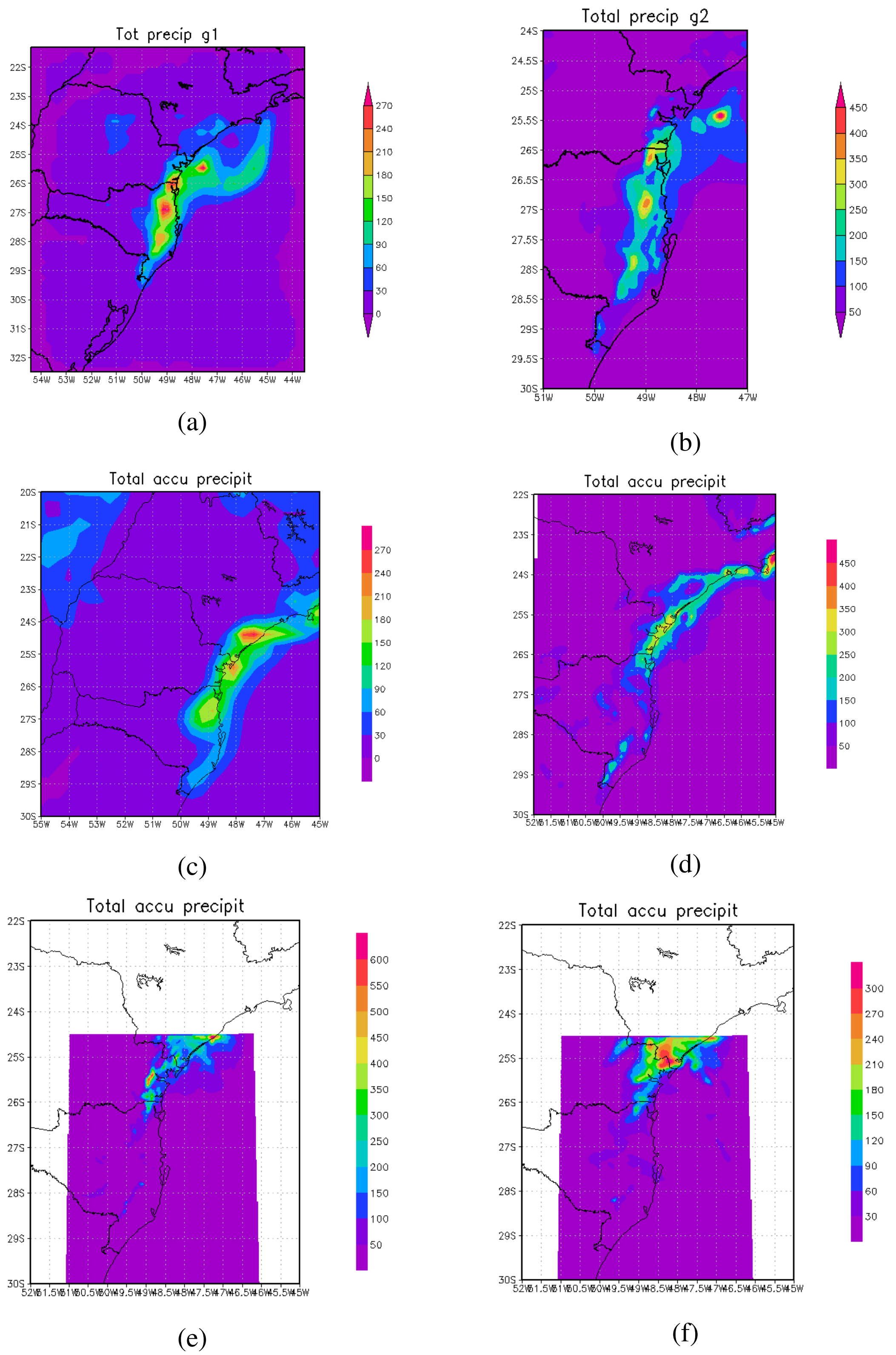

Figure 4: total surface precipitation at the end of each simulation type: (a) type C, one grid simulation (b) C, two grids 2, (c) F, one grid, (d) F, two grid, with cumulus parameterization (e) and (f) F, three grids, with difference in topography resolution being 10 km for all grids in (e), and 10km/1km/200m in (f).

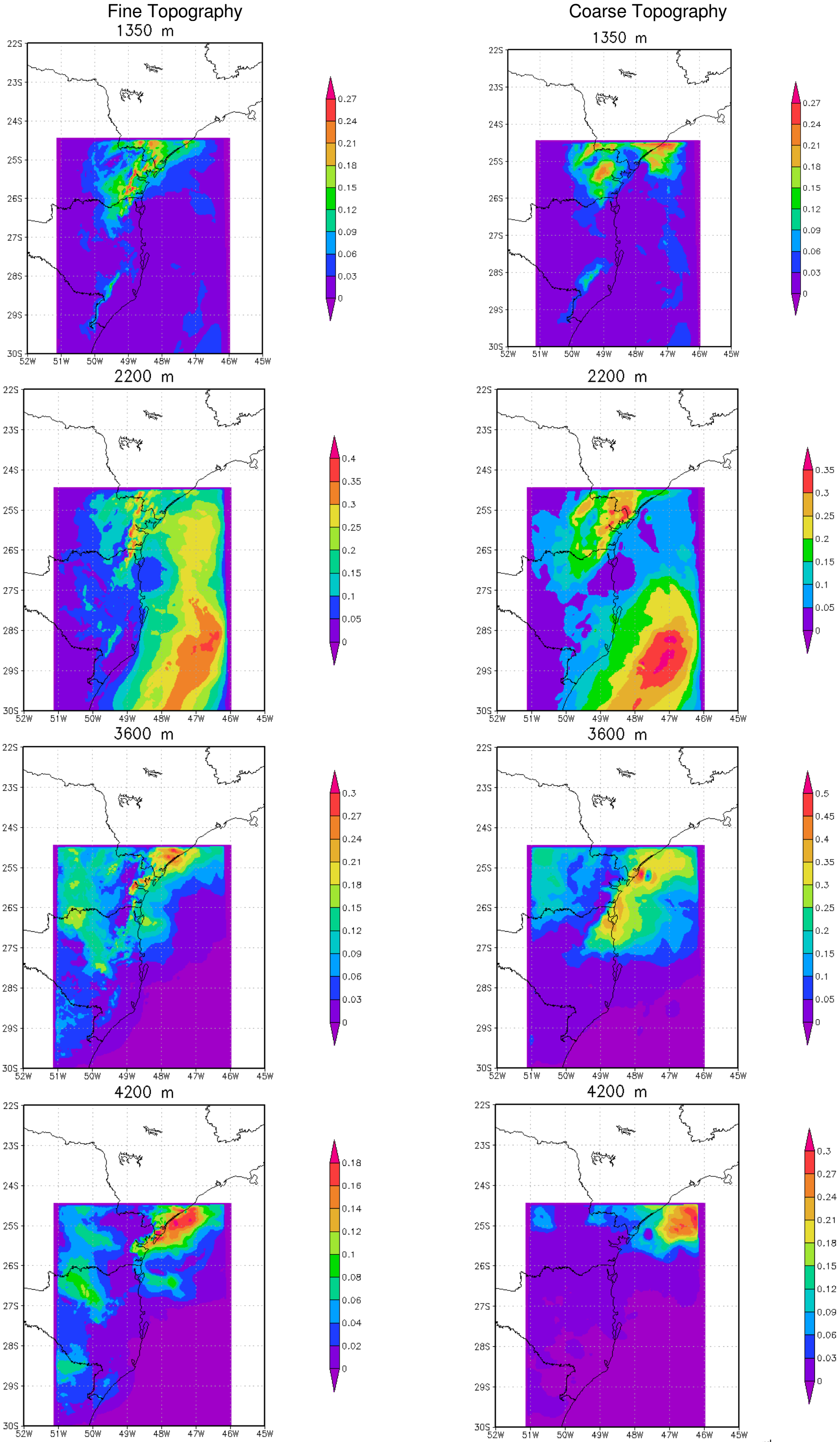

Figure 5: Average cloud mixing ratio fields at different heights for the entire simulated period fot type, 3rd grid simulation. Plots at left (F1) and right (F2) sides differ by the topography resolution, as described in Table 1.

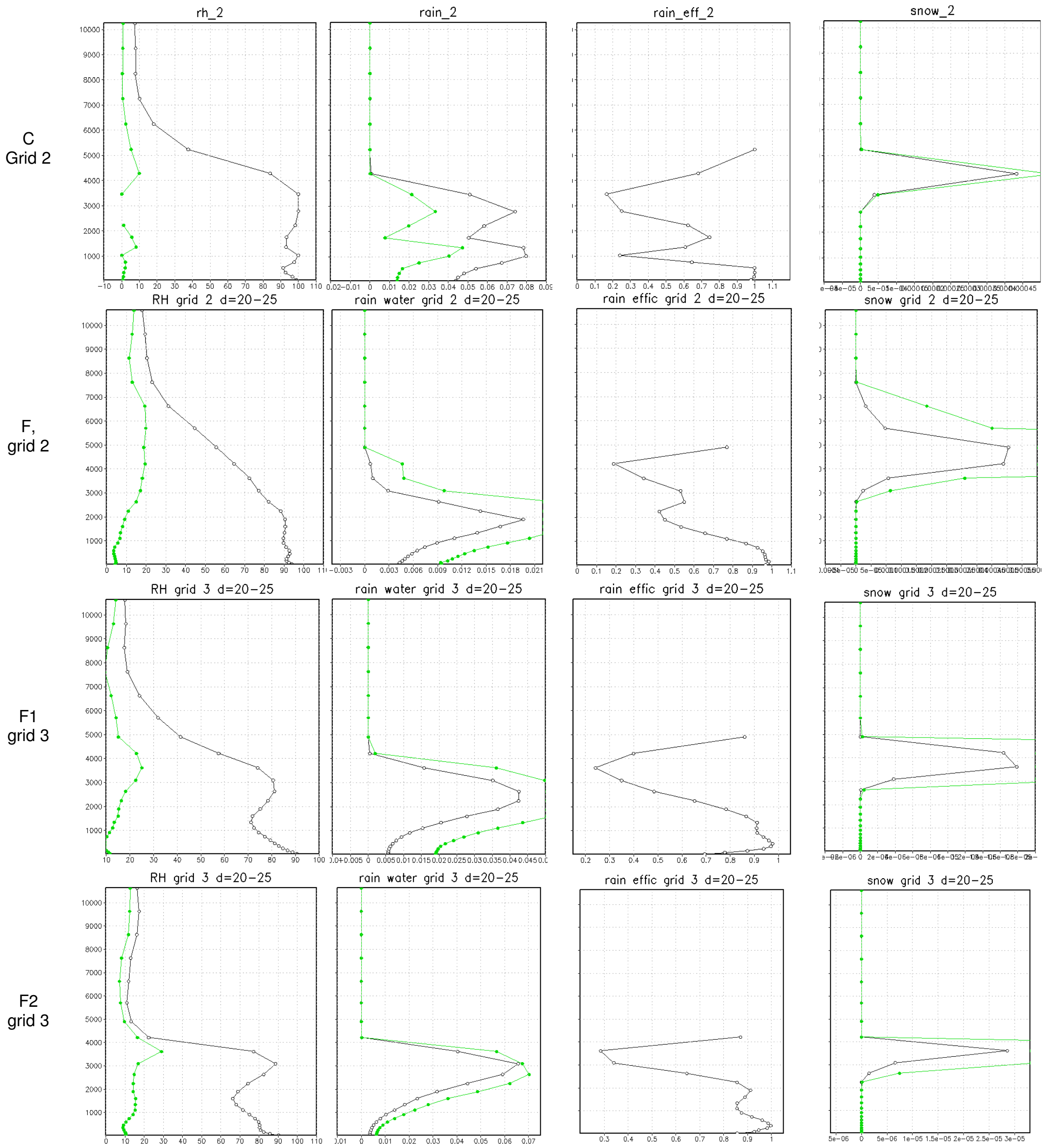

Figure 6: vertical profiles at Blumenau for the performed simulations. From left to right, plots correspond to Relative Humidity (RH), rain droplets mixing ratio (g/m^3), rain efficiency [rain/(cloud+rain)], and snow content (g/m^3).