P1.13

FACTORS INVOLVED IN THE FORMATION AND DEVELOPMENT OF SEVERE WEATHER CONDITIONS OVER THE MEGACITY OF SÃO PAULO

Edmilson D. Freitas*, Pedro L. Silva Dias, Vanessa S. B. Carvalho, Caroline R. M. Rocha, Lelia D. Martins, Jorge A. Martins, and Maria F. Andrade

Department of Atmospheric Sciences
Institute of Astronomy, Geophysics and Atmospheric Sciences
University of São Paulo

ABSTRACT

This work explores the interaction between the Urban Heat Island (UHI) and the sea breeze on a severe weather episode that occurred in February 01, 2003 in the Metropolitan Area of São Paulo. The work was developed through numerical modeling of the atmosphere using the Regional Atmospheric Modeling System (RAMS) with high spatial resolution and with a physically appropriate parameterization for urban areas (TEB). A factor separation method, which allows the identification of individual contribution of each factor and their interaction on a specific meteorological field, was used in order to identify the contributions of the UHI and the sea surface temperature (SST) to the event. The results show that UHI positively contributes to the total precipitation occurred during the event and that this contribution is dependent on SST, with distinct responses to its increasing or decreasing. With an increase of 2ºC in the observed SST the UHI can cause an increase of 28% in the total accumulated precipitation in the grid domain. The same temperature increase in a situation that the SST is 2ºC colder results in an increase of 14% only.

1. INTRODUCTION

The Metropolitan Area of São Paulo (MASP) is one of the most urbanized regions in the world, comprising 39 cities covering an area of 8000 km2. About 1500 km2 of its area is very urbanized. In this region, especially during the summer, the occurrence of severe weather, with intense precipitation, wind gusts and hail, causing a large number of floods, landslides, and other problems to the population and to the economy of the region is frequent. The severe weather events in the MASP can be a consequence of many meteorological phenomena, which occur in local or synoptic scales. Some examples of these phenomena are the circulations generated by the urban heat island (UHI) and sea-breeze, frontal systems, and the South Atlantic Convergence Zone (SACZ). These phenomena can act isolated or together, being 60% of flood cases that occurred over the MASP in the last years associated to the sea-breeze and the UHI interaction during the afternoon period with the air temperature higher than 30ºC. In response to the stronger heating due to the large number of anthropogenic heat sources, the thermal properties of the materials of the constructions, and the low ventilation the unstable condition of the atmosphere favors strong upward motion in the urban centers. The moisture transported by the sea-breeze is elevated and, under appropriate thermodynamic conditions, there is the formation of convective cells. Based on these facts, the main goal of this work is the identification, through numerical modeling of the atmosphere and the method of factor separation, of the relative role of the urban heat island (UHI) and the sea surface temperature (SST) anomalies along the coast of São Paulo and the nonlinear interaction between these two factors, during a severe weather event occurred in February 1st, 2003 over the MASP.

2. METHODOLOGY

Numerical modeling of the atmosphere with the Regional Atmospheric Modeling System (RAMS, Cotton et al., 2003) was the main tool for the identification of the effects caused by the interaction between the urban heat island and the SST anomalies on the formation and development of the thunderstorms over MASP on February 1st 2003. The model version used in this work was coupled to the Town Energy Budget urban parameterization (Masson, 2000) as described in Freitas et al (2007), which verified that this model is capable of satisfactorily represent the interactions between the urban heat island of the MASP and other types of local circulations, such as the sea/land breeze.

Two sets of experiments were carried out, each formed by 4 simulations. The changes in these simulations were the land use (substitution of the urban area by the vegetation class closed shrub land) and the SST anomaly (increasing or diminishing the weekly observed value in 2 degrees Celsius). The analyses were made using the factor separation method (STEIN & ALPERT, 1993), also known as factorial planning (BARROS NETO et al., 1995). This method allows the identification of the individual contribution of each of the parameters involved in the forecast of a meteorological field. In the current analysis, two parameters are varying. Therefore, in order to identify their contribution 4 simulations are necessary (the number of simulations is equal to 2n, being n the number of parameters involved). Table 1 shows the simulations performed in each of the experiments.

The main effect of UHI is given by:

---

[*] *Corresponding author address*: Edmilson D. Freitas, Department of Atmospheric Sciences, IAG-USP, Rua do Matão, 1226, Cid. Universitária, São Paulo, SP, Brazil, CEP 05508-090; e-mail: efreitas@model.iag.usp.br

$$UHI\_E = \frac{1}{2}\left[\left(P_2 - P_1\right) + \left(P_4 - P_3\right)\right], \tag{1}$$

where UHI_E is the urban heat island effect, P1, P2, P3 and P4 refers to the precipitation field during simulations 1, 2, 3, and 4 respectively. Similarly, the main effect of SST over the precipitation field is given by:

$$SST\_E = \frac{1}{2}\left[\left(P_3 + P_4\right) - \left(P_1 + P_2\right)\right], \tag{2}$$

Where SST_E is the SST effect. The interaction between both parameters is given by:

$$UHI\_SST = \frac{1}{2}\left[\left(P_1 + P_4\right) - \left(P_2 + P_3\right)\right]. \tag{3}$$

Table 1: Procedure used during experiments 1 and 2.

Experiment 1			
Simulation	**Land Use**	**SST**	**Precipitation**
1	Modified (without city) (-)	Weekly (-)	P_1
2	Original (+)	Weekly (-)	P_2
3	Modified (without city) (-)	Increase of 2 ºC (+)	P_3
4	Original (+)	Increase of 2 ºC (+)	P_4
Experiment 2			
Simulation	**Land Use**	**SST**	**Precipitation**
1	Modified (without city) (-)	Diminishing of 2 ºC (-)	P_1
2	Original (+)	Diminishing of 2 ºC (-)	P_2
3	Modified (without city) (-)	Weekly (+)	P_3
4	Original (+)	Weekly (+)	P_4

During the simulations two nested grids were used (16 and 4 km). All simulations used CPTEC-INPE meteorological fields as initial condition. The model was integrated over a 24 hour period, started at 00 UTC, February 1st, 2003. GOES-8 Infrared satellite images provided by MASTER IAG-USP laboratory (www.master.iag.usp.br) were used in order to qualitatively evaluate the model ability in simulating the observed thunderstorm.

3. RESULTS AND DISCUSSION

Figure 1 shows a comparison between the simulated precipitation rate (mm h^{-1}) and the infrared satellite pictures from GOES-8 on February 1st 2003. The panels with simulation results (left) are presented at two hour interval and are compared with the infrared satellite pictures (right panels) that were closest in time to the model outputs. One can note in this figure the arrival of the sea-breeze front approximately at 18 UTC (note the region with wind in opposite directions close to the surface in Fig. 1). From this figure it is possible to see that, at least spatially, the simulation was able to represent the thunderstorm event.

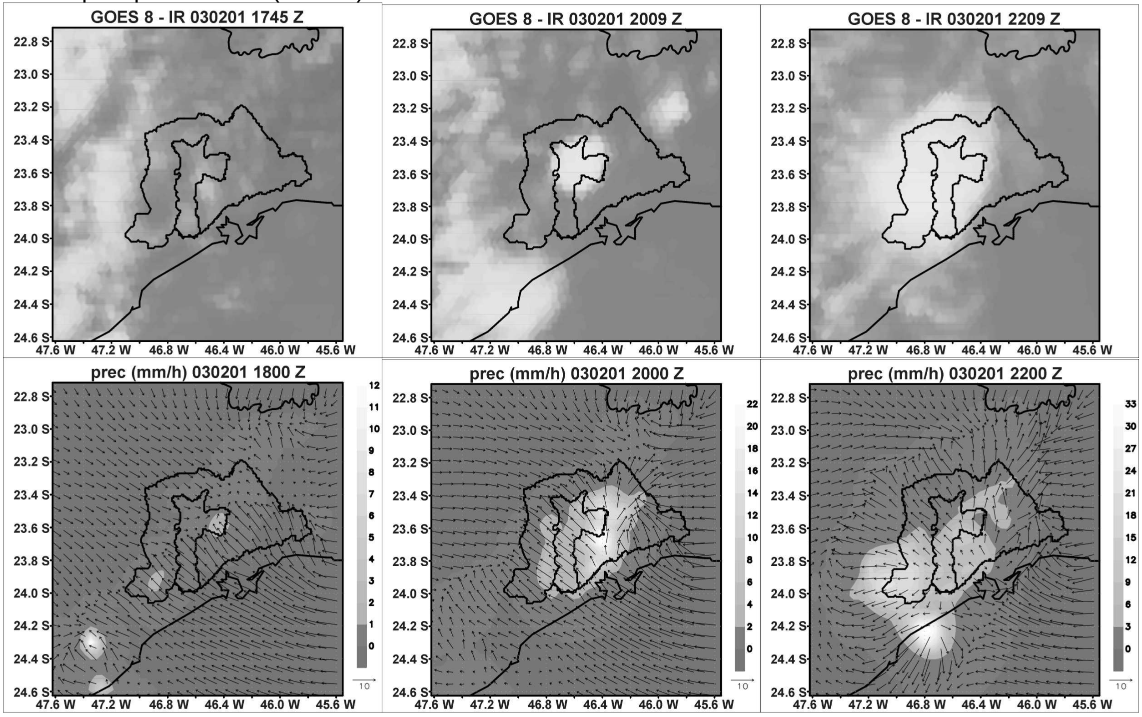
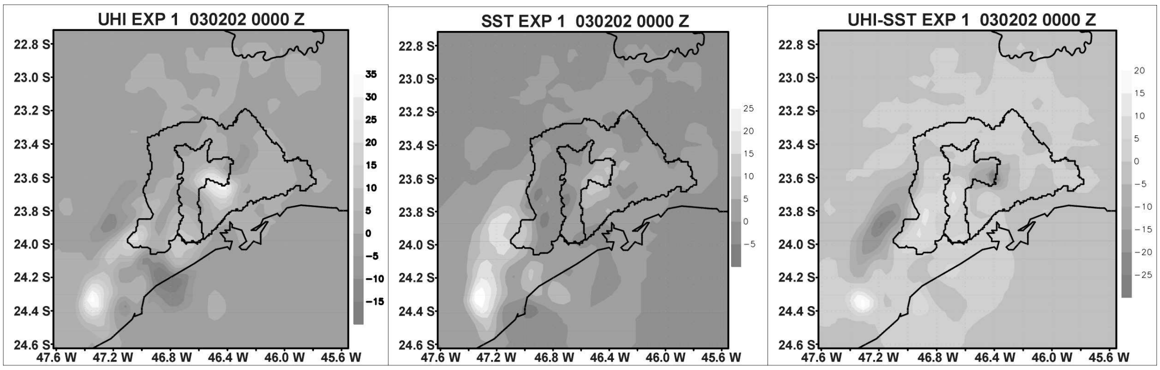


Figure 1: Time evolution of precipitation rate (mm h-1) obtained by the control simulation with RAMS (bottom panels) and infrared satellite pictures for the closest time (top panels). The near surface winds are also showed in the panels. The wind vectors are plotted every each 2 grid points. The results are from the second grid of the model, with horizontal resolution of 4 km.

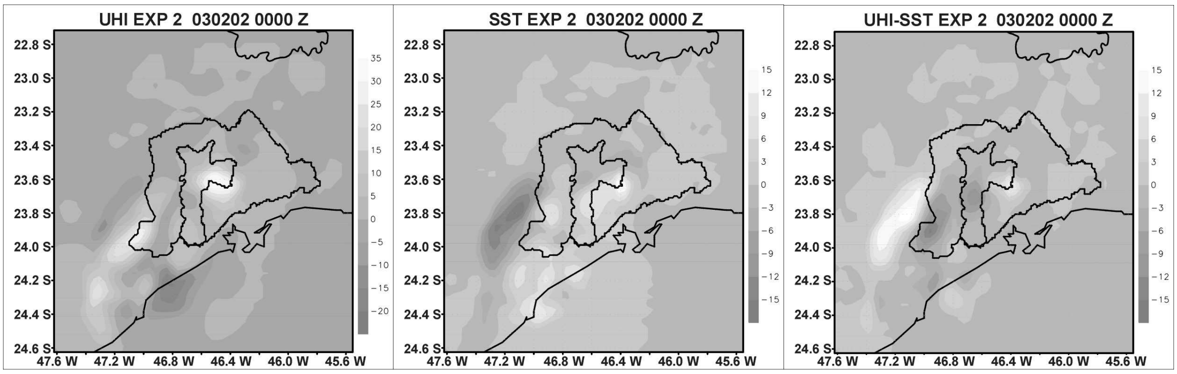
Using equations 1-3, we obtain the main effects of each factor and the interaction between them. Figure 2 (a – c) presents the fields obtained after the application of these equations for the Experiment 1 (EXP 1), with a +2 ºC SST anomaly.

The same set of equations was applied to Experiment 2 (EXP 2), on which the SST was diminished by 2 ºC. It is important to note that the Simulation 1 is the base point for the analyses. Figure 3 (a – c) shows the results for this experiment.



(a) (b) (c)

Figure 2: Terms of equations 1-3, applied to the experiment 1, showing the main effects of the UHI (a), of the SST (b) and of the interaction of these factors (c) over the accumulated precipitation (mm) after 24 hours of integration.



(a) (b) (c)

Figure 3: Same as in Fig. 2, but for the experiment 2.

It is interesting to analyze the effect of these factors over the whole area of simulation domain. Table 2 presents, for the two experiments, the accumulated precipitation during the 24 hours of integration over the second grid of the model (with a 4 km horizontal resolution). In this table also are presented the percentage rate of increase in the accumulate precipitation compared to Simulation 1 of each experiment, considered here as the control simulation.

Table 2: Total accumulated precipitation during experiments 1 and 2.

Experiment 1		
Simulation	**Prec. (mm)**	**Increase (%)**
1	14991.11	-
2	16705.31	11.43
3	18548.23	23.73
4	19218.72	28.20

Experiment 2		
Simulation	**Prec. (mm)**	**Increase (%)**
1	14636.45	-
2	16625.67	13.59
3	14991.11	2.42
4	16705.31	14.13

From Table 2 one can see that the simulated precipitation in the control simulation of the two experiments presents just a small difference (about 2.4 %), indicating that with a -2ºC SST anomaly, the total precipitation is just slightly decreased. In general, the increase of SST anomaly contributes to the increase of the total precipitation, no matter what kind of initial condition is used.

In a similar way, the effect of the UHI positively contributes to the total precipitation. However, given the high non-linearity of the process, we verify that the increase of the total precipitation due to this factor is more significant in Experiment 1, on which the SST was 2ºC higher than the observed SST (weekly). In this case, the UHI contributed for a 28.2 % increase in the accumulated precipitation in the second grid of the model configuration. For Experiment 2, on which the

SST was also increased in 2ºC, but from a lower initial condition, the UHI contribution is smaller, causing an increase of only 14.13 %. Comparing Simulation 2 of both experiments we can verify that the relevant contribution of the UHI that is a little higher when the SST is lower. The opposite effect is observed in the SST contribution. Comparing Simulation 3 of both experiments we note that the exclusive contribution of SST, when it is higher, causes an increase of 23.73% over the accumulate precipitation. The increase of SST starting from lower temperatures causes an increase of only 2.42 %.

Although the effects caused by UHI and SST are observed in practically the whole domain of the analyzed grid, in some regions the influence is more pronounced. Figure 4 shows one of these regions where a significant increase was observed during the event. Figure 4a shows the accumulated precipitation for Simulation 1, on which weekly SST and the modified land use (urban classes changed by vegetation) were used. In this case, we can see that the precipitation would be relatively well distributed over the area, with maximum values ranging from 40 to 50 mm. When the urban areas are considered (Fig. 4b), maximum value of 90 mm is observed close to the point 46.4 W – 23.6 S, presenting an increase of about 100 % in the accumulated precipitation. The analysis of Figure 4c also shows that the effect of an increase of 2ºC in the SST contributes for a significant increase of the precipitation in this region. However, when the two factors are analyzed together, the increase of SST makes the UHI influence smaller. This can be seeing in Figure 4d, on which the difference field between Simulation 4 and 2, i.e. SST anomalies 2ºC higher with urban areas and weekly SST. In this figure one can note negative values over the area where higher precipitation took place, confirming the previous statement.

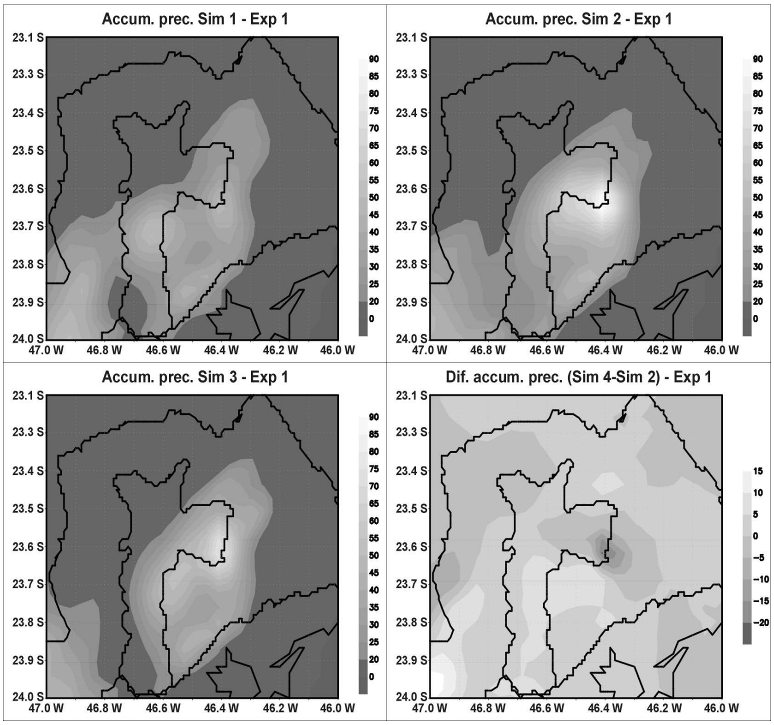


Figure 4: Effects of urban área and SST over the accumulated precipitation after 24 hours of simulation for the thunderstorm event of February 1st, 2003. In (a), weekly SST without city. In (b), weekly SST with city. In (c), weekly SST plus 2 ºC without city. In (d) difference between simulations 4 (weekly SST plus 2 ºC with city) and 2 (weekly SST with city). Color bars indicate accumulate precipitation or the difference in mm.

4. CONCLUSIONS

Some effects of the interaction between the urban heat island of the MASP and variations on the sea surface temperature over the accumulate precipitation during a thunderstorm event on February 1st 2003 were analyzed using numerical simulations with a mesoscale atmospheric model. The analysis indicates that the model is able to satisfactorily represent the spatial distribution of the severe weather system observed in the MASP. Although some regions inside the grid domain are positively affected by the presence of the urban region, the whole domain analysis of the accumulated precipitation shows that the UHI of the MASP contributes for an increase on the simulated precipitation. The same kind of analysis leads to similar conclusions when the SST is studied. An important feature related to SST must be pointed out. During the experiment on which SST was increased by 2 ºC, supposed to be an unfavorable condition to the sea-breeze propagation, since the temperature gradient between the ocean and the continent is reduced, there was a positive contribution for the accumulated precipitation over the east portion of the MASP (Figure 2b).

For an opposite situation analyzed during experiment 2 a positive contribution is also observed over the same region. In this case, the temperature contrast is higher; therefore, there is intensification of the sea-breeze cell and of its associated upward motion. The analysis of the accumulated precipitation associated with the storm on the eastern side of São Paulo shows that the UHI contributed for an increase of the order of 100%. This effect is less significant when there is an increase on the SST.

Although the experiments do not take into account all the factors that can be involved with the formation and development of the severe weather system here analyzed, it is clear that accurate forecast of severe weather by the mesoscale models currently used over the region must take into account precise information about sea surface temperature. Forecasts that use the climatology of this variable, which is usually the case, can give uncorrected information with relation to these events.

5. ACKNOWLEDGMENTS

The authors would like to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), grant number 03/04890-9, and the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq - Brazil, grant number 485961/2006-7, for financial support to this research. We also acknowledge Valery Masson (Centre National de Rescherches Météorologiques) and METEO-FRANCE for use the Town-Energy Budget.

6. REFERENCES

Barros Neto B., Scarmino, I. S., and Bruns, R. E. 1995. Planejamento e otimização de experimentos. Segunda Edição. *Editora da Unicamp*. 299 pp.

Cotton, W. R., Pielke, R. A. Sr., Walko, R. L., Liston, G. E., Tremback, C. J., Jiang, H., Mcanelly, R. L., Harrington, J. Y., Nicholls, M. E., Carrio, G. G., and Mcfadden, J. P., 2003. RAMS 2001: Current status and future directions**.** *Meteor. Atmos. Phys*., **82**, 5-29.

Freitas, E. D., Rozoff, C., Cotton, W. R., Silva Dias, P. L., 2007. Interactions of an urban heat island and sea breeze circulations during winter over the Metropolitan Area of São Paulo – Brazil. *Bound. Layer Meteorol*, **122** (1), 43-65.

Masson, V. A., 2000. Physically-based scheme for the urban energy budget in atmospheric models. *Bound. Layer Meteorol*. **94** (3), 357-397.

Stein, U. and Alpert, P., 1993. Factor separation in numerical simulations. *J. Atmos. Sci.*, **50**, 2107-2115.