Heat Island, Sea Breeze and HP Thunderstorms in Metropolitan Area of São Paulo

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1. INTRODUCTION

The MASP is composed of 39 cities including São Paulo city and occupies an area of 8051 km^2 of the São Paulo State (SPS). In 2014, the population was close to 21 million inhabitants, 50% of the total population of São Paulo State (SPS) according to the Brazilian Institute of Geography and Statistics (IBGE).

Several types of weather systems cause major socio-economic impacts in MASP frequently such as cold fronts, sea breeze circulation, mesoscale convective systems (MCS) and isolated convection. Very often, the SB triggers SCMs over MASP with heavy rainfall, wind gusts, hail and lightning (Pereira Filho et al., 2004; Pereira Filho et al. 2002; Pereira Filho, 2000).

SB fronts reach MASP (Fig. 1) about 50% of the days as can be seen in. Oliveira and Silva Dias (1982) indicated wind veering from NE to SE, backing from NW to SE and intensification of the SE wind. According to Pereira Filho et al. (2005), weak synoptic conditions, air temperature above 30°C and dew point above 20°C in the afternoon hours tend to yield greater rainfall amounts over MASP due to heat island effect. Oliveira and Silva Dias (1982) observed that many instances the precipitation over MASP was preceded by wind direction change to SE in the summer, with subsequent temperature decrease and dew point increase.

SB interacts with local circulation in urban areas. In MASP during summer, this interaction produces deep convection over it. The urban area size, the distance between the urban area and ocean and the topography modulates the intensity of the SB (Thompson et al. 2007; Dandou et al. 2009). The steep topography, termed Serra do Mar, accelerates the SB by warming along the mountain (Atkinson, 1981). The distance travelled by the SB front in land depends on the slope, length, height and location of the topography to the coast and atmospheric stability (Porson et al. 2007).

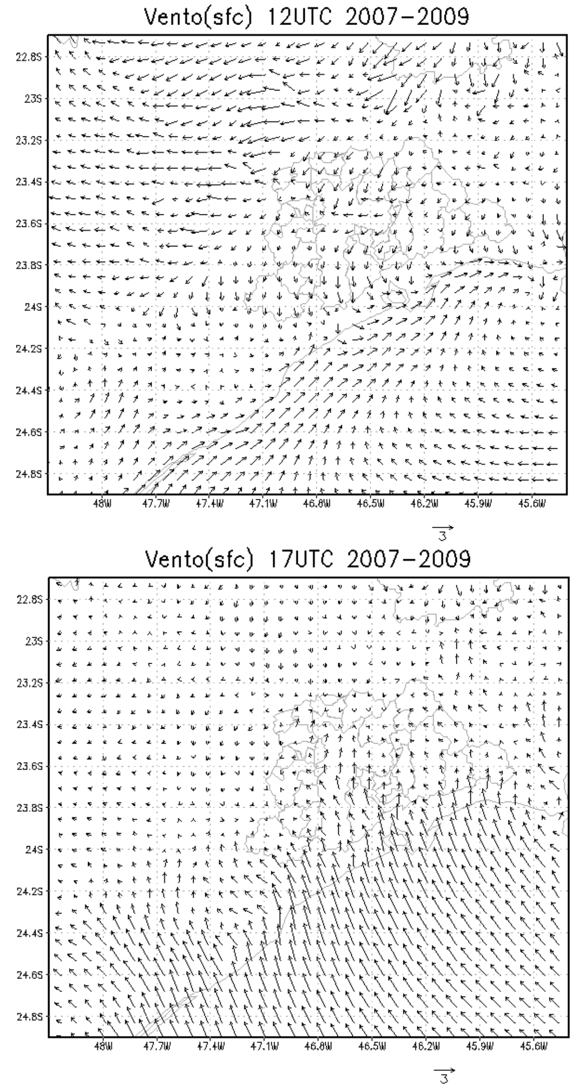

Figure 1: Wind field average at 1200 UTC and 1700 UTC for 2007 to 2009. Latitudes, longitudes, geographic boundaries in MASP are indicated.

In MASP, the topography on the east coast (Fig. 2) accelerates the SB at Serra do Mar, so it reaches MASP and interact with local circulation generated by urban area to trigger deep convection.

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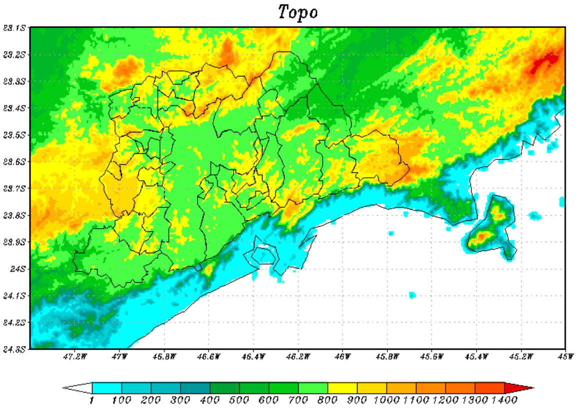


Figure 2: MASP topography. Latitudes, longitudes, and political boundaries are indicated. Altitudes (m) in color scale.

Pereira Filho et al. (2004) analyzed 18 floods events over MASP. Most of them were associated to SB. The mixing of relatively warm and dry urban air with relatively cold and moist ocean lowers the static stability in the boundary layer. But the SB front lifts air parcels upwards and releases latent heat and so deep convection is triggered.

2. URBAN HEAT ISLAND

The temperature gradient between urban and surrounding areas is called urban heat island (UHI). The average annual temperature in the inner city is higher than in its surrounding. In dry winter days the contrast reaches 10^{o} C or more in early evening (Freitas and Silva Dias, 2005; Oke, 1987). The UHI is caused by anthropic sources of heat in the city and urban land, that stores and converts solar radiation into sensible heat (Ferreira, 2010). Under clear sky conditions during the night, the temperature depends on micro scale urban features (Eliasson, 1996).

The MASP topography varies between 650 m and 1200 m altitude (Fig. 2). This complex topography near the Atlantic Ocean and the urbanization affects circulation patterns to induce peculiar conditions over MASP. In low latitude regions, direct circulation induced by differential heating are more intense and persistent due to higher solar radiation (Fast and McCorcle, 1990).

The formation of UHI in MASP in association with SB moist advection yields convergence, moist instability and heavy rainfall over MASP (Pereira Filho et al., 2004; Pereira Filho at al. 2002). Freitas et al. (2007) showed the UHI tend to accelerate the SB toward the city with intense updrafts.

These local circulations were simulated with the ARPS system (Xue et al., 1995) at 12-km spatial resolution for 125 days for deep convection cases associated with SB in between January 2005 and April 2008. Near surface average conditions were estimated as well as mid and upper level variables such as CAPE e LI.

Simulated wind fields in 125 events were compared to available weather stations. Model thermodynamic indexes were compared to soundings. The 11 JAN 2010 SB event was used to analyze soil cover impacts on rainfall for urban and rural surfaces conditions. The ARPS uses desert surface conditions over urban areas. ARPS simulations have indicated differences among SB episodes such as the depth of SB layer. In some instances, the SB front propagates over MASP without triggering convection, even under unstable conditions (e.g, 21 FEB 2010).

3. SB EVENTS RELATED TO STORMS

A total of 125 SB events related to severe rainfall occurred in three and half years. The data used to analyze were GOES IR, surface weather variables, radio-soundings, weather radar reflectivity (Z) at constant altitude plan position indicator (CAPPI) of 3-km from the São Paulo weather radar (PSWR) and the mobile weather radar (MXPOL) and the Global Forecast System (GFS) of National Centers for Environmental Prediction (NCEP) in USA.

The Marshall and Palmer (1948) ZR relationship was used to estimate rainfall intensity from measurements of Z. SB events with rainfall intensity greater than 30 mm h^{-1} in 10 minutes anywhere in the MASP were selected. Fig. 3 shows an instance of a maximum vertical reflectivity CAPPI of a storm caused by interaction among local circulations.

Soundings, surface data, weather radar and satellite images were used to identified storms caused by SB and UHI. In 74% of SB events, the wind backed from NW to SE between the morning and afternoon. The mean air temperature decreased from 29.7° C to 25.8° C, and dew point increased from 17.9° C to 20.7 °C with the SB incoming. The average SB front speed was 9 m s^{-1} at 1800 UTC at the southern border of MASP.

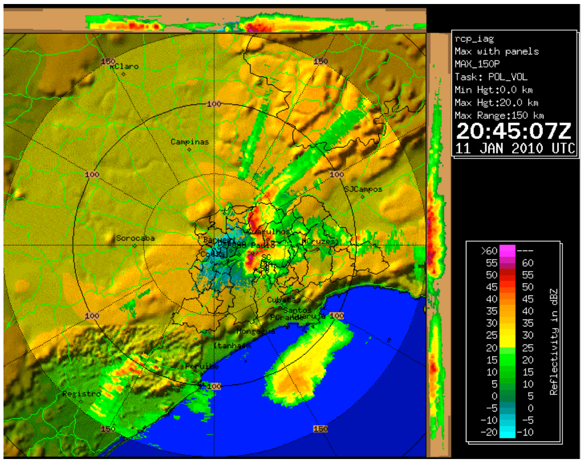


Figure 3: MXPOL **m**aximum vertical reflectivity CAPPI on January 11, 2010 at 2045 UTC a storm.

Synoptic conditions of these events were computed using GFS and ARPS runs at 12-km resolution. The ARPS simulations provided circulation patterns and thermodynamic index by simple means.

Synoptic conditions of SB events occurred in association to the Bolivia High pressure system over Brazil and subtropical high over South Atlantic Ocean with north winds in São Paulo State in the morning. SB circulation is a common feature throughout the coastline of Brazil in the afternoon. Extreme SB events are associated to a moving cold front in Southern South America with CAPE and the LI at 2000 J kg^{-1} and -4.0ºC, respectively.

4. SB RAINFALL

Fig 4 shows a 600-mm high rainfall accumulation right over MASP associated to the UHI under SB events. This is downstream from maximum urbanization area in the MASP where NDVI is low (Fig 5).

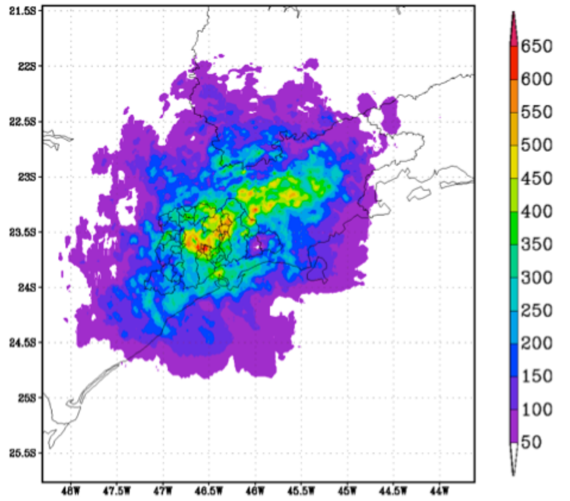


Figure 4: Rainfall accumulation (mm) estimated with the São Paulo Weather Radar for all SB events in 2007. Latitudes, longitudes, and political boundaries are indicated. Color scale indicates Rainfall accumulation (mm).

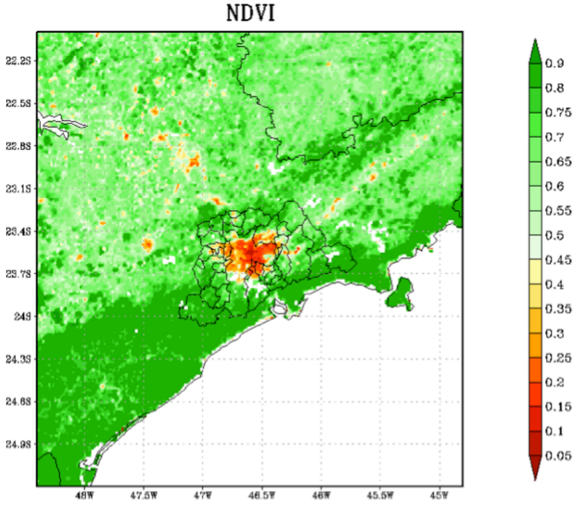


Figure 5: Normalized Difference Vegetation Index (NDVI) in the same region shown in Fig. 4.

5. SEA BREEZE MODELING

The average fields of all SB simulations indicate the mean circulation patterns. Fig. 6 shows 850-hPa wind field average in the early afternoon (NW) and late afternoon (SE). A clockwise rotation of the wind occurs during the day, consistent with surface measurements (not shown). At the upper levels the pattern is also coincident with the Bolivian high pressure system (not shown). The ARPS simulations also produced maximum precipitation along the coastline passing over the MASP (not shown).

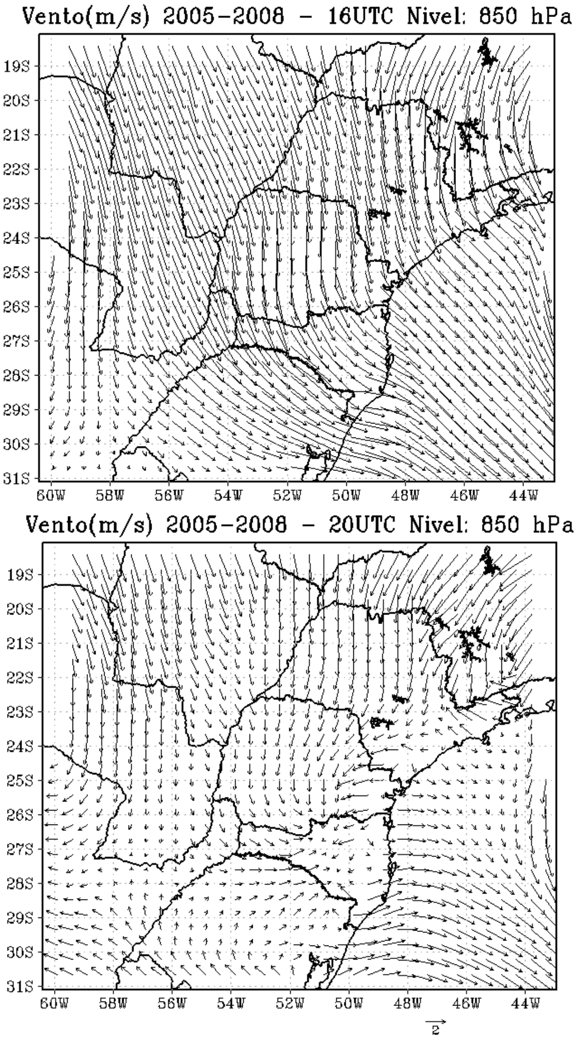


Figure 6: ARPS simulated mean 850-hPa wind field for all SB events between 2005 and 2008. Latitudes, longitudes, and political boundaries are indicated.

The 11 JAN 2010 SB episode showed that without the urban heat island, the total precipitation over MASP is significantly smaller. The sea breeze interacts with heat island circulations and triggers convective cells over MASP as depicted in Fig. 7. The ARPS simulations indicated that without the urban heat island, deep convection is not triggered as depicted in Fig 8, since surface sensible heat flux is reduced.

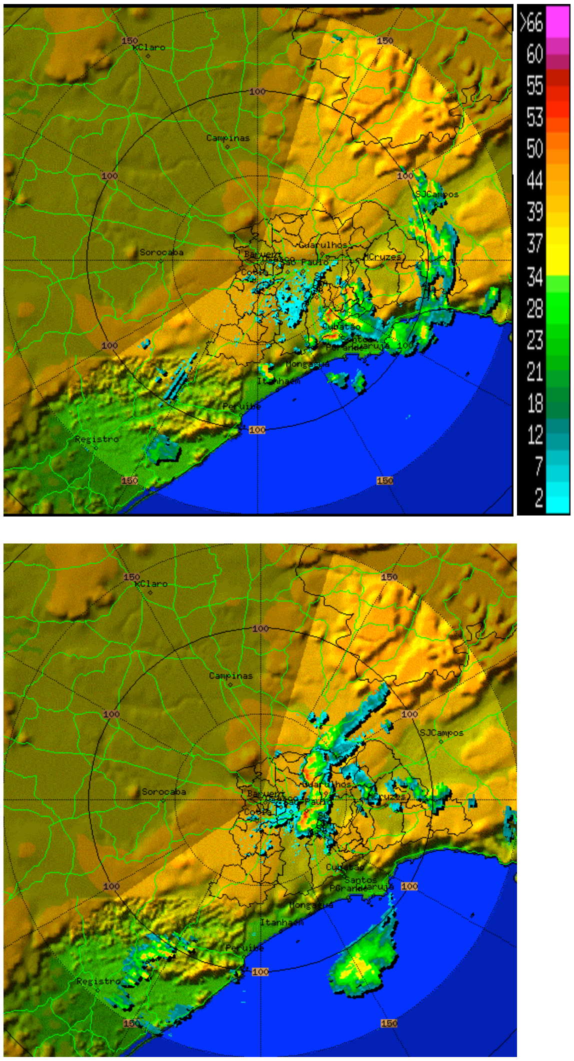
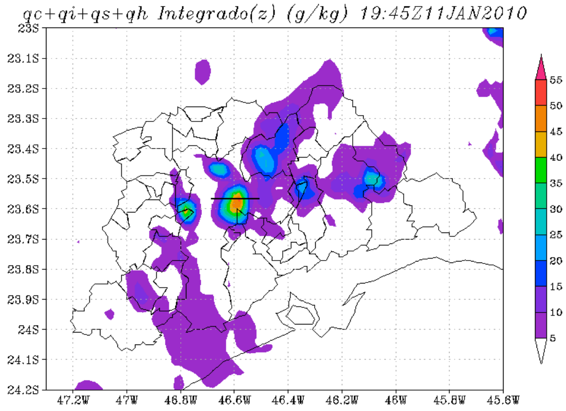


Figure 7: PPI of MXPOL radar at 1753 UTC (top) and 2045 UTC (bottom) on 11 JAN 2011.



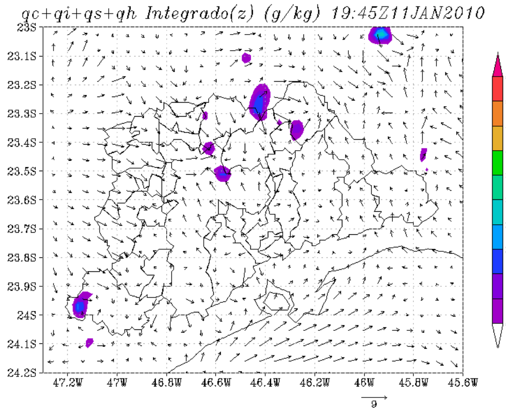


Figure 8: The ARPS **v**ertical integrated cloud water, snow, hail and ice crystals (g/kg) at 1945 UTC on 11 January 2010 for a control run (top) and without UHI (bottom). The line is a cross-section shown in Fig 9.

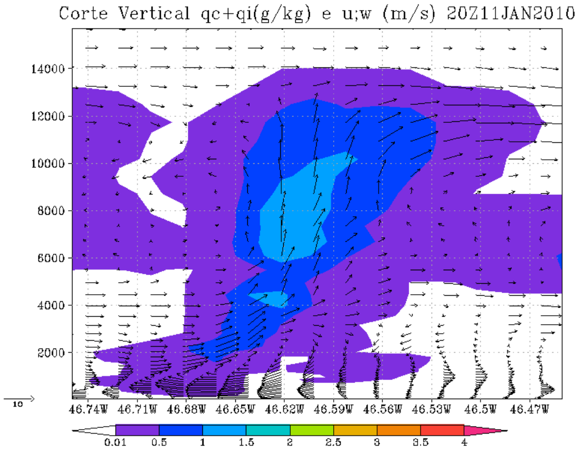


Figure 9: Cross-section of total vertical integrated water (g/kg) shown in Fig 8.

Fig. 9 shows the cross-section of cloud water plus ice crystals in the position of line in Fig. 8A. The simulations indicated a 2000-m SB layer. Numerical experiments show that when this layer is less than 1000 m, it does not produce significant updrafts and so deep convection. The layer must be more than 1500 m deep. Deeper SB fronts tend to increase boundary layer shear and horizontal vorticity that support stronger updrafts able to make the layer unstable to trigger and to maintain deeper convective cells. Moreover, advancing cold fronts in Southern Brazil tend to increase NW warm advection and shear to support a deeper SB front as outlined in Fig 10.

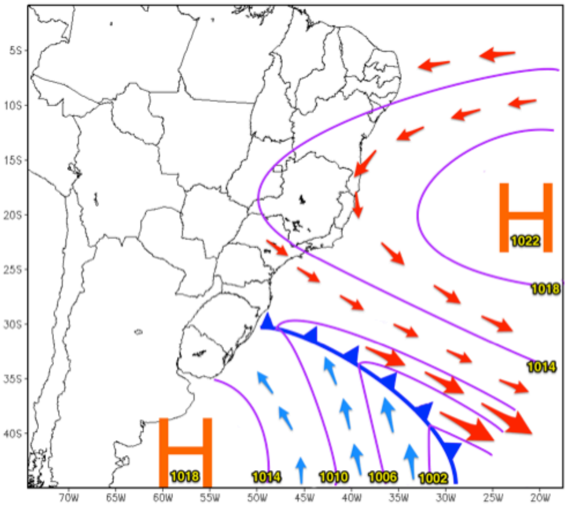


Figure 10: Schematics of a typical synoptic condition associated with deep convection development over MASP caused by intense SB and UHI circulation. Isobar (hPa) and winds and frontal boundaries are indicated. Source: Vemado and Pereira Filho (2015).

6. CONCLUDING REMARKS

The UHI tends to increase precipitation over MASP especially in summer. The warmer urban environment intensifies thunderstorms and given its impervious urban soil conditions, flash floods, high wind gusts and other impacts are common. Deeper SB fronts seem to be associated to cold fronts in Southern Brazil. Thicker SB circulation results in deeper boundary layer shear.

The SB interacts with the MASP heat island circulation and generates deep thunderstorms. Thus, the thickness of SB can be used in nowcasting severe convection in MASP. The MXPOL radar (Pereira Filho, 2012) can be used in conjunction with the ARPS system for that purpose to adequately estimate the SB thickness and thermodynamics to produce more accurate forecasts.

7. REFERENCES

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