

RADAR OBSERVATIONS OF A TORNAIDO-SPAWNING STORM COMPLEX IN SOUTHEAST BRAZIL AND MESO-ETA FORECASTS OF THIS EXTREME EVENT



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INTRODUCTION

- The structure of severe storms, causing enormous damage in the State of São Paulo, due to strong winds, hailstones, lightning and floods, has been studied since 1992, using IPMet's two S-band Doppler radars;
- Until about 2004, it was thought, that tornadoes are rather rare events in Brazil and only few cases of these tornadic cells had been captured by radars, but recently, occurrences are reported more frequently due to higher awareness and efficient communication available to the broad public;
- On 22 September 2013, a tornadic cell, which spawned a T3 tornado, had been observed in the central part of the State of São Paulo by IPMet's S-band Doppler radars within a range of 135 km south-southwest of Bauru;
- The tornado traversed a small town, Taquarituba, resulting in vast damage to industrial installations, houses and overturned a large bus, killing 2 persons and injuring 63 along its path from south-southwest to north-northeast;
- The objective of this study is, to find relevant signatures in radar and lightning observations, which could be used for nowcasting and an early alert system for the population in Southeast Brazil, as well as verify the forecasts of the Meso-Eta model for a 48-hour period.

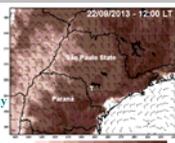
IPMet's RADAR CHARACTERISTICS & SOFTWARE



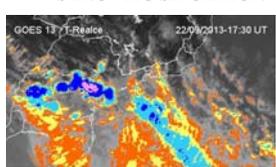
- S-band Doppler Radars (EEC WSR-88S), Bauru (BRU) and Presidente Prudente (PPR), S.P.; operated 24h for precipitation surveillance;
- Beam width 2°, resolution 250 m radially, 1° in azimuth;
- Threshold for this analysis Z = 10 dBZ;
- Surveillance (0.3° PPI, 450 km, black circles) every 15-30 min;
- Volume scans (16 scans from 0.3° to 45°, 240 km, red circles) every 7.5 min when rain occurs ≤240km range;
- Sigmat processors under IRIS Operating System;
- Automatic alert for severe storms currently based on VIL;
- TITAN: centroid tracking threshold 40 dBZ & >16 km³; resolution 500 m horizontal & vertical within the 240km radar range.

Meso-Eta MODEL

- Domain covers amply the State of São Paulo with 10x10 km resolution;
- Non-hydrostatic model with 38 levels from 1000 to 50 hPa;
- Initiated twice daily (NCEP analysis, Eta-40km, updated 6-hourly), output 3-hourly;
- Convection parameterization scheme of Betts-Miller-Janic and Kain-Fritsch, respectively, and Cloud microphysics based on Ferrier scheme; Model domain, Topography & Wind at 10m;
- Generating a variety of convective parameters, as well as Skew-T x Log-P profiles ≤100 hPa at any specified grid point.



SYNOPTIC SITUATION AND GENERAL STORMS ON 22 September 2013

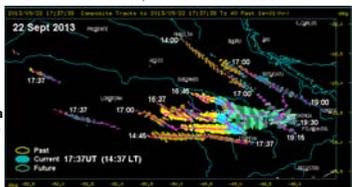


The synoptic pattern was very favorable for the development of severe weather conditions over Southeastern Brazil, due to a strong cold front approaching through Paraná and reaching the south-eastern part of the State São Paulo, creating extremely unstable conditions that led to deep convection and overshooting towers up to 20 km. Pre-frontal and frontal convective cells were tracked throughout their life-time by IPMet's Doppler radars, which cover the western and central regions of the State São Paulo, as well as northern Paraná State.

Extract from GOES-13 on 22/09/2013, 14:30 LT

General Storm Situation:

- Unstable atmospheric conditions, responsible for widespread severe storms during the afternoon of 21/09/2013, continued throughout the night with convective activity in the western and central parts of the State lasting until the early hours of the morning (08:00 LT).
- Renewed convection commenced again on 22 September 2014 at around noon over northern Paraná, rapidly intensifying in the northeastern corner of the State;
- The majority of the cells moved at speeds ranging from 60-100 km.h⁻¹ in easterly directions (W-E in the south to NW-SE in the northwest corner of the Figure, right), with maximum reflectivities between 50-60 dBZ;
- Echo tops (10 dBZ contour) reached up to 20 km, with the 40 dBZ contour extending up to 12-16 km;
- The VIL (Vertically Integrated Liquid water content) reached values of 20-50 kg.m⁻² during the peak activity;
- The storms dissipated over the southeastern State of São Paulo after 16:30 LT (LT=UT-3h).



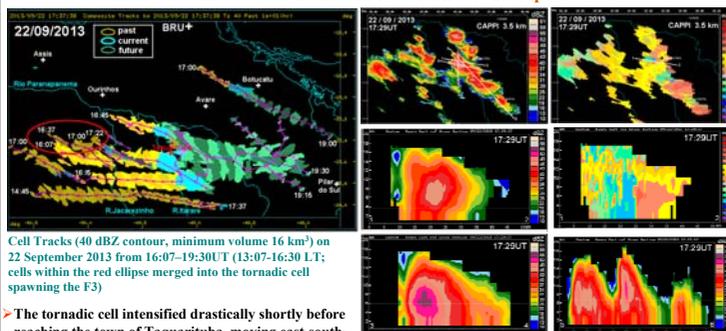
Cell Tracks (40 dBZ contour, minimum volume 16 km³) on 22 September 2013 from 11:00 - 16:30 LT

THE F3 TORNAIDO OF TAQUARITUBA



Tornado Path (red) across Taquarituba on 22 September 2013, ca 14:30 LT (Photos credit: BOL Notícias, Aline Oliveira, Folha & GI)

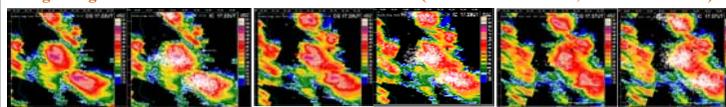
TITAN ANALYSIS OF TORNAIDIC CELL ON 22 September 2013



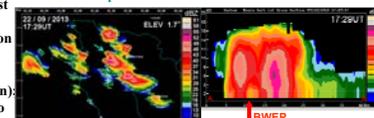
Cell Tracks (40 dBZ contour, minimum volume 16 km³) on 22 September 2013 from 16:07-19:30UT (13:07-16:30 LT); cells within the red ellipse merged into the tornadic cell spawning the F3)

- The tornadic cell intensified drastically shortly before reaching the town of Taquarituba, moving east-south-eastwards at 74-85 km.h⁻¹, with the 40 dBZ contour extending to 16.6km and echo top (10 dBZ) up to 20km;
- This cell displayed an extremely strong radial shear just above the cloud base (about -25 to +15 m.s⁻¹) shortly before reaching Taquarituba, which led to the formation of a deep mesocyclone up to 9 km, from which the tornado spawned on its left flank and touched down at around 14:30 LT (destruction path 3 km during 3.5 min);
- VIL increased drastically from 13:14 LT (7.2 kg.m⁻²) to a maximum of 75.2 kg.m⁻² at 14:22 LT, indicative of destructive winds reaching the ground, coincident with the tornado touch-down;
- The accumulated hail mass aloft increased to 1120 ktons at 14:30UT, which subsequently dropped to the ground, also confirmed by the likewise decrease of VIL.

Lightning Characteristics 17:22-17:37UT: BrasiliDAT (CG = Cloud-Ground; IC = Intra-Cloud)



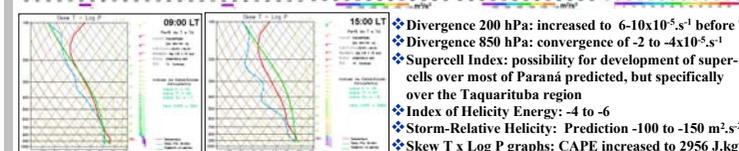
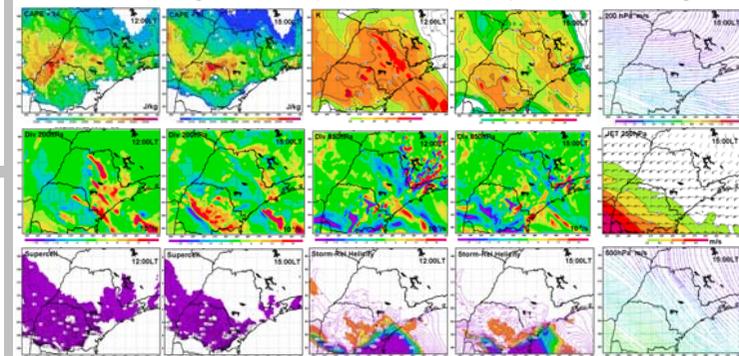
CAPPI at 3.5 km amsl, 22 September 2013, 17:29UT (14:29 LT); Reflectivity in dBZ (top, left); Radial velocities in m.s⁻¹ (top, right). White lines correspond to the baselines of the vertical cross-sections.



PPI at elevation 1.7° at 17:29UT (14:29 LT) showing the hook echo of the "Taquarituba tornadic cell" (arrow); Vertical cross-section along the base line A - B.

Meso-Eta MODEL FORECASTS

- Forecasts of the following model runs were analyzed retrospectively for this study: 21/09/2013-00UT & 12UT, 22/09/2013-00UT & 12UT and 23/09/2013-00UT, corresponding to forecast periods of 42 & 30 hours and 18 hours;
- The analysis of the 22/09/2013-12UT is utilized to verify the respective forecasts for 09:00LT on 22/09/2013;
- The model outputs / forecasts using the Kain-Fritsch convection scheme generally agreed better with the analysis;
- Considering operational aspects, the examples and discussion below are based on the forecasts from the 22/09/2013-00UT model run, which become available to the meteorologist at +06:30 LT, allowing sufficient time for severe storm alerts to be emitted, +15hrs and +18hrs (12:00 & 15:00 LT), respectively.
- Freezing level: from 09:00 LT (analysis) to 15:00 LT: 4700 - 4800 m amsl
- CAPE: 3500-4000 J.kg⁻¹ at 12:00LT in the region of severe cells (Paraná-SP), increasing to +4500 J.kg⁻¹ at 15:00LT
- Index K: at 12:00LT in region of severe cells (northern Paraná - southern SP) 40-42, but later diminishing in area



- Divergence 200 hPa: increased to 6-10x10⁻⁵.s⁻¹ before T
- Divergence 850 hPa: convergence of -2 to -4x10⁻⁵.s⁻¹
- Supercell Index: possibility for development of super-cells over most of Paraná predicted, but specifically over the Taquarituba region
- Index of Helicity Energy: -4 to -6
- Storm-Relative Helicity: Prediction -100 to -150 m².s⁻²
- Skew T x Log P graphs: CAPE increased to 2956 J.kg⁻¹

CONCLUSIONS

- Very favorable synoptic baroclinic situation, due to a strong cold front approaching through Paraná and reaching the southeastern part of the State of São Paulo, creating extremely unstable conditions that led to deep convection and overshooting towers up to 20 km;
- Radar volume scans, generated every 7.5 min, were processed with the TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) Software, yielding the following results:
- The majority of cells on this day moved at speeds ranging from 60-100 km.h⁻¹ in easterly directions with maximum reflectivities of 50-60 dBZ;
- Maximum reflectivities of the tornadic cell varied between 51 and 59 dBZ during 75 min;
- Extremely strong radial shear was observed just above the cloud base (about -25 to +15 m.s⁻¹), creating a deep mesocyclone up to 9 km, from which the F3 tornado spawned on the left flank of the cell (Fujita classification);
- It also displayed the characteristic hook echo on its northwestern rear flank and a Bounded Weak Echo Region;
- The accumulated hail mass aloft was 1120 ktons;
- Echo tops (10 dBZ) up to 20 km at the time of the tornado occurrence, and 40 dBZ reaching up to 16.6 km;
- Maximum values of VIL (Vertically Integrated Liquid water content) up to 75.2 kg.m⁻²;
- Relatively few CG strokes, but hundreds of IC strokes per volume scan were observed by the BrasiliDAT lightning network during the intense stage of the tornadic cell and touch-down;
- The Meso-Eta Model (10x10 km), centered on the BRU radar, predicted the region and timing of extremely severe convection very well >24 hours ahead, especially in the following fields:
- CAPE, K Index, Divergence at 200hPa, Convergence at 850hPa, Supercell Index and Storm-Relative Helicity;
- Skew T x Log P graphs of temperature, humidity & wind, calculated retrospectively at the location of the tornado;
- These results compare well with findings from previous analyses of tornadic cells within the State of São Paulo.