Model estimates of lightning in convective systems in southern Mexico and the Gulf of Tehuantepec

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Convection in southern Mexico during the rainy season can lead to extreme precipitation and flooding. Often, such precipitation events lead to landslides, loss of properties, and lives in the mountainous regions. Convective systems can be the result of synoptic scale forcing in the tropics (e.g. easterly waves) and can be either precursors of tropical systems or remnants of landfalling tropical depressions / storms. Three case studies of extreme precipitation observed in 2008 were selected to evaluate their lightning potential. The systems were simulated with the Weather Research and Forecasting (WRF) model, at high resolution (3 and 1 km horizontal spacing). Lightning flash rates were determined for a variety of proxies, calculated from the modelled values and compared against observations made with the Worldwide Lightning Location Network (WWLLN). Six model parameters were calculated: precipitation ice mass, ice water path, updraft volume, cloud top height, maximum vertical velocity (Barthe et al. 2010), and lightning potential index (LPI, Yair et al. 2010). Note that the cited studies pertain to mid-latitude convective storms and this study attempts to assess if the parameters selected in those studies are relevant for tropical regions in Mexico. Correlation coefficients showed good agreement between four model parameters (precipitation ice mass, updraft volume, maximum vertical velocity, and LPI) and the observations. It is worth noting that neither cloud top height nor ice water path were useful as proxies for lightning, since the threshold for reflectivity was never reached in the simulations of these tropical systems.

1. Introduction

Over Southern Mexico, specifically in the Mexican states of Oaxaca and Chiapas, floods and landslides are often present during the yearly rainy season. Precipitation over this region mainly originates from deep convection, which may be associated with orographic forcing or tropical systems. The migration of the Inter-Tropical Convergence Zone, easterly and Rossby waves, the Madden-Julian Oscillation, and the intensification of the jet of Tehuantepec are among the most important atmospheric phenomena over the Gulf of Tehuantepec, located approximately at 16°N 97°W.

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During the rainy season (from May to October) over the Gulf of Tehuantepec and adjacent land areas, the precipitation distribution shows two maxima. The first maximum is observed in June while the second is in September-October. Between them, there is a decrease in precipitation of up to 40% (this period is known as the Mid Summer Drought). Most of the precipitation in this region is associated with tropical convective systems (Magaña et al. 1999 and Magaña and Caetano 2005). During the Mid Summer Drought, when there is a minimum in precipitation, lightning increases. In September, a maximum in precipitation is observed over the ocean as well as over the continent. However, in both July and August, the decrease in precipitation is higher over the ocean (Kucienska et al. 2012). The convection that results in precipitation often also generates lightning.

In regions with sparse radar coverage, detection and prediction of lightning could contribute to better characterize intense precipitation events. Presently, the electrification processes inside thunderclouds are not well understood and several electrification mechanisms have been proposed. The non-inductive mechanisms are the most accepted due to the fact that they do not depend on the presence of an external electric field. The electric charge transfer occurs during collisions between ice crystals and graupel, (Saunders, 2008).

The use of correlations between lightning flashes and modelled parameters could be a way to predict lightning flash rates. In this study, we use numerical simulations with the Weather Research and Forecasting (WRF) model in 3 extreme precipitation events to test six model parameters against observations of lightning: precipitation ice mass, ice water path, updraft volume, cloud top height, maximum vertical velocity (Barthe et al. 2010), and lightning potential index (LPI, Yair et al. 2010).

2. Observations

We use the database of cloud-to-ground lightning obtained from the World Wide Lightning Location Network (WWLLN), operated by the University of Washington. This network is composed by a number of sensors located in universities and research facilities around the world. Each sensor detects signals corresponding to VLF (3-30 kHz) and in order to determine the spatial location of the lightning stroke, the VLF signal must be detected by at least 5 sensors. The distance between sensors may be of thousands of kilometers.

In 2008, WWLLN was comprised of 32 stations and its detection efficiency for cloud-to-ground lightning was approximately 10.3%. The errors in location were 4.03 km in longitude and 4.98 km in latitude (Abarca et al. 2010).

3. Methodology

Three case studies of extreme precipitation in 2008 were selected for this study: i) 3-6 June; ii) 6-7 July; and iii) 24 September. Three microphysical parameterizations (Lin et al. 1983, Thompson et al. 2004, and WSM5) were assessed to determine which one reproduced better the selected systems. The Weather Research and Forecasting (WRF) model version 3.4.1 (Skamarock et al. 2008) was used for the simulations at high resolutions with 3 and 1 km horizontal spacing. The innermost domains in Figure 1 correspond to these resolutions.

The initial and boundary conditions were determined from the NCEP FNL (Final) Operational Global Analysis data. Six lightning estimates were calculated: precipitation ice mass, ice water path, updraft volume, cloud top height, maximum vertical velocity (Barthe et al. 2010), and Lightning Potential Index (LPI, Yair et al. 2010).

4. Results

Time series for each of the lightning estimates and lightning data were obtained from the modelling results. In order to obtain the time series, each of the lightning estimates was averaged, in the domains with horizontal resolution of 1 and 3 km, over the regions with nonzero precipitation. For two of the six lightning estimates (ice water path and cloud top height), the threshold of reflectivity suggested by Barthe et al. (2010) from their study in mid-latitude systems, was never reached in the tropical systems studied here. Both precipitation ice mass and updraft volume were modified in order to better estimate lightning in the tropical systems analyzed. We present below results from each of the 3 cases selected for this study.

4.1. 3-6 June 2008

A mesoscale cyclonic system that developed in the Gulf of Tehuantepec made landfall on 3 June and dissipated over the Sierra Madre in Chiapas, after extreme precipitation that resulted in landslides in the region. The system is reproduced by the WRF simulations with each of the three microphysical parameterizations (Lin et al. 1983, Thompson et al. 2004 y WSM5). However, a one- hour lag was observed between the observations and the simulations, probably due to the WRF spin-up time. Moreover, the spatial distributions are not accurately reproduced in the simulations. Qualitatively, the best spatial distributions were simulated with the Lin et al. (1983) microphysical parameterization. Figures 2 and 3 show spatial distributions of lightning registered by WWLLN on 3 June at 2:00:00 GMT and the LPI calculated -with the Lin et al. 1983 microphysical parameterization- from simulations at 3:00:00 GMT, respectively.

Correlations between the time series of each of the lightning estimates and the observations from WWLLN were calculated. Table 1 shows the correlations obtained over the domain with a horizontal resolution of 3 km. The time series between LPI and WWLLN data, calculated with the Lin et al. (1983) microphysical parameterization, are presented in Figure 4. The correlation coefficients calculated over the innermost domain, with a horizontal resolution of 1 km, are lower than those obtained in Table 1. These lower values could be a consequence of the mismatch between the simulated spatial distributions, for each of the lightning estimates, and the spatial distributions of lightning detected by WWLLN.

4.2. 6-7 July 2008

After a strong confluence over the Tehuantepec isthmus, an extreme precipitation event took place on 7 July at 6:00:00 GMT. A total of 115.3 mm were observed over 24 hours in the town of Puerto Angel in the Mexican State of Oaxaca. The number of lightning discharges detected by WWLLN was very low, and probably only the strongest were detected, in the period of time considered in this case study. As a result, it is not possible to draw conclusions about the accuracy of the lightning estimates calculated from the simulations with WRF. Nevertheless, it is worth mentioning that the lightning flashes detected are located near the regions where the system is located in the simulations. Qualitatively, the best spatial distributions were simulated with the Lin et al. (1983) microphysical parameterization.

A one-hour lag was again observed between the WWLLN data and the simulated lightning estimates. Figure 5 presents the spatial distribution of the strong lightning flashes detected by WWLLN on July 6th at 7:00:00 GMT, while Figure 6 presents the spatial distributions of updraft volume at 8:00:00 GMT, calculated with the Lin et al. (1983) microphysical parameterization.

Time series from each of the lightning estimates from the model indicate 2 maxima, but that the modelled time separation between those maxima is larger than in the observations from WWLLN. This may be due to the fact that the time interval taken by WRF in reproducing a new convective core is longer than the interval in real time. This is shown in Figure 7, which presents the time series for LPI, calculated with the Thompson et al. (2004) microphysical parameterization, and compared with the detected lightning by WWLLN.

4.3. 24 September 2008

Strong rainfall and lightning were generated as a consequence of the passage of the tropical wave number 31, over the Mexican states of Guerrero and Oaxaca, on 24 September. Similarly to the last two case studies, a one-hour lag was observed between the observations and the simulations. The simulated spatial distributions do not reproduce the lightning observations, but the modelled spatial distribution is in the general region where lightning was observed. Qualitatively, the best spatial distributions were simulated with the Lin et al. (1983) microphysical parameterization. Figures 8 and 9 show spatial distributions of lightning registered by WWLLN, on 24 September at 3:00:00 GMT, and the LPI, calculated with the Lin et al. (1983) microphysical parameterization, from the simulations at 4:00:00 GMT, respectively.

In this case we also note that the correlation coefficients calculated over the innermost domain, with a horizontal resolution of 1 km, are lower than those obtained over the domain with a horizontal resolution of 3 km. Note that also the frequency of detection was low, probably only the strongest ones being detected. Table 2 shows the correlations obtained over the domain with a horizontal resolution of 3 km. Figure 10 presents the time series between LPI and WWLLN data, calculated with the Lin et al. (1983) microphysical parameterization.

5. Conclusions

Both the spatial distributions and time series of the lightning estimates are dependent on the kind of microphysical parameterization used. In the first and third case studies, a one-hour lag between the flashes detected by WWLLN and the simulations is observed. This one-hour lag is probably related to the time of spin-up from WRF.

Neither cloud top height nor ice water path were useful as proxy for lightning in all of the case studies since the threshold for reflectivity suggested by Barthe et al. (2010) was never reached, indicating that there is a need to determine the characteristics of convention in tropical regions of Mexico in order to validate the parameterizations included in widely-used mesoscale models.

For the first and third case studies, the greatest correlations were obtained over the domain with a horizontal resolution of 3 km. The low correlations in the innermost domain, with a resolution of 1 km, may be a consequence of the mismatch between the simulated spatial distributions and the observations. In the third case study, the time interval in the WRF simulations in reproducing a new convective core is longer than the interval in real time.

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6. Figures

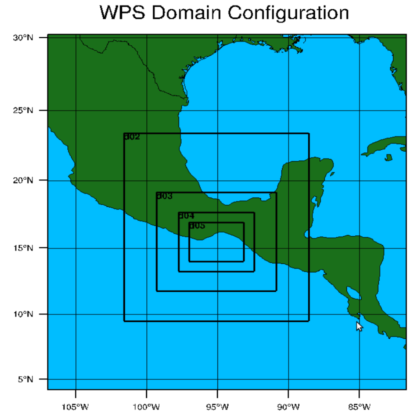

Figure 1. WRF domains.

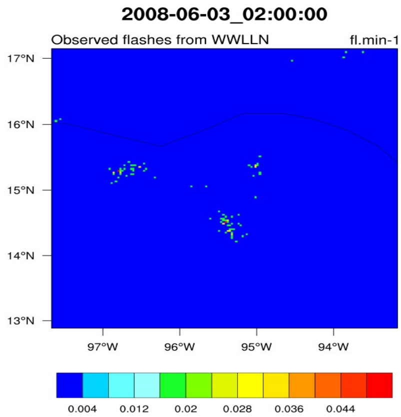

Figure 2: Observed flashes on 3 June at 2:00:00 GMT.

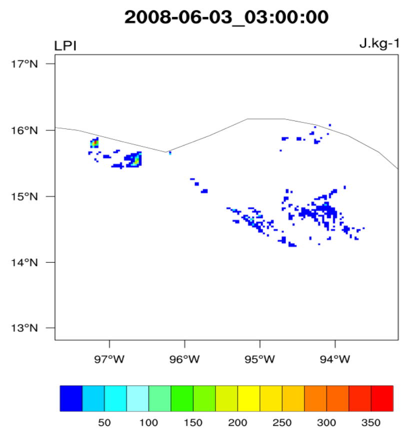

Figure 3: LPI calculated with the Lin et al. 1983 microphysical parameterization.

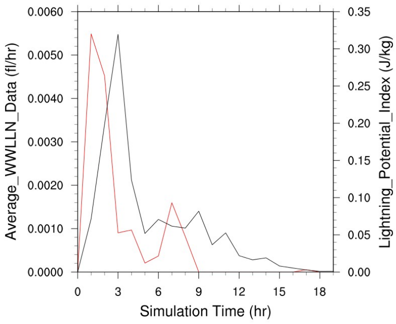

Figure 4. WWLLN (red) and LPI (black) calculated with the Lin et al. 1983 microphysical parameterization.

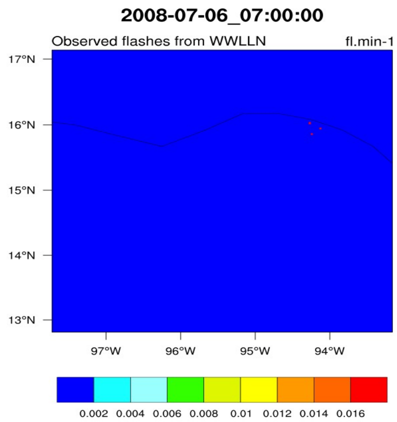

Figure 5: Observed flashes on July 6th at 7:00:00 GMT.

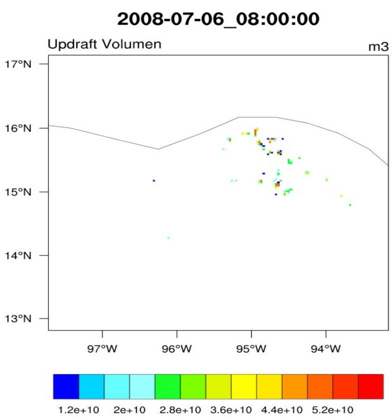

Figure 6: Updraft volume calculated with the Lin et al. 1983 microphysical parameterization.

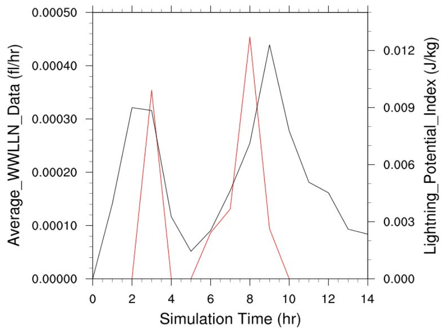

Figure 7: WWLLN (red) and LPI (black) calculated with the Thompson et al. 2004 microphysical parameterization.

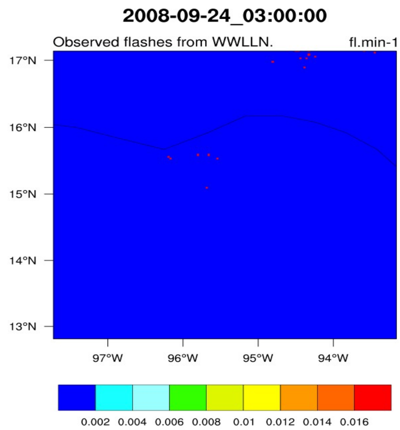

Figure 8: Observed flashes on September 24th at 3:00:00 GMT.

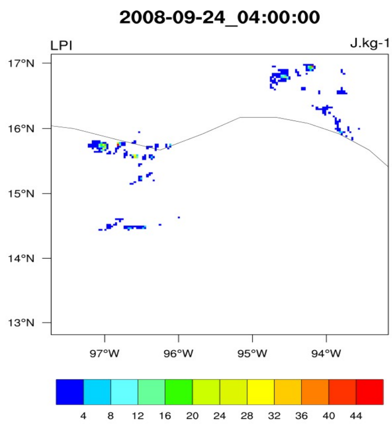

Figure 9: LPI calculated with the Lin et al. 1983 microphysical parameterization.

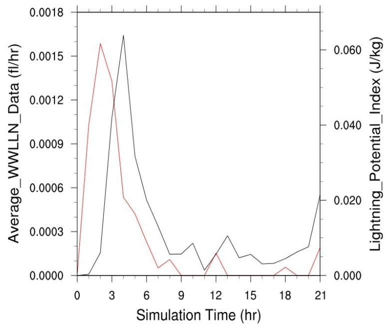

Figure 10. WWLLN (red) and LPI (black) calculated with the Lin et al. 1983 microphysical parameterization.

7. Tables

Parameterization / Lightning estimate	Lin	Thompson	WSM5
LPI	0.705	0.827	0.765
Precipitation Ice Mass	0.781	0.593	0.551
Updraft Volume	0.756	0.846	0.738
Maximum Vertical Velocity	0.756	0.720	0.526

Table 1. Correlation coefficients obtained from each of the lightning estimates for the first case study over the domain with a horizontal resolution of 3 km.

Parameterization / Lightning estimate	Lin	Thompson	WSM5
LPI	0.814	0.560	0.803
Precipitation Ice Mass	0.696	0.276	0.526
Updraft Volume	0.762	0.389	0.618
Maximum Vertical Velocity	0.625	0.372	0.315

Table 2. Correlation coefficients obtained from each of the lightning estimates for the third case study over the domain with a horizontal resolution of 3 km.

8. References

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