Replies to reviewer 2

The replies are introduced in "italics" below each comment of the reviewer

Major comments:

1) The methodology used in section 3.3 for studying aerosol effects on clouds is problematic. The examination of the monthly variability of lighting activity, rain, winds, convergence and AOD, over the golf of Tehuantepec, is not enough for studying the aerosol effect on clouds. There is no deep investigation of the meteorology role in the correlations between lightning and aerosols. The meteorology may be the driver of both the convective intensity (electrical activity) and aerosol loading. Examination of wind and convergence on a monthly scale is not sufficient. There is a need to study lightning density per given meteorological condition and to examine more meteorological parameters. In addition there is no information about other cloud properties beside lightning density. Maybe different meteorological conditions produce different types of clouds with different electrical activity. Moreover, the monthly averages used are not suitable for this analysis. Daily data is more appropriate for that. A monthly basis for consideration of aerosol effect on clouds involves different meteorological conditions and it makes it harder to separate the aerosol effect from the meteorology. The meteorological conditions at the beginning of the month are different from those at the end of the month. Looking on the data on a daily basis makes it more accurate for this purposes.

Reply:

Below we discuss the reasons for analyzing monthly variability of lightning and we summarize the meteorology of the region of interest. We also present new results based on daily data of AOD and lightning. Large parts of this discussion will be introduced into the new version of the paper.

We analyze monthly variability of lightning over the golf of Tehuantepec for a very specific reason. The hypothesis of this study is that the increase of lightning during mid-summer is related to the intensification of the Jet of Tehuantepec during July and August. The variability of the Jet of Tehauntepec exhibits a clear monthly pattern which has an impact on the monthly variability of precipitation. The decrease of precipitation during July and August over this region (so-called mid-summer drought) is related to the intensification of the Jet of Tehuantepec which causes a reduction in moisture over coastal areas and displaces convergence areas away from the coast (Romero-Centeno et al., 2007). Monthly patterns of both wind velocity and precipitation repeat from one year to another, although there are some years when the influence of other phenomena (e.g.. ENSO) somewhat modify *this pattern. In this study we hypothesize that the monthly variability of the Jet of Tehuantepec has an influence not only on the monthly pattern of precipitation but* ***also*** *on that of lightning.*

The meteorology of this region was studied in detail in the Ph.D. thesis of Rosario Romero-Centeno (who is a coauthor of this paper) and summarized in Romero-Centeno et al. (2007). Their study includes a deep analysis of the influence of the mid-summer strengthening of the Jet of Tehuantepec on the low-level circulation over the northeastern Tropical Pacific. During the seven-year period analyzed (1999-2005), the percentage of occurrence of northerly winds over the Gulf of Tehuantepec always increased in July or (and) August. Also, the wind velocity increased during mid-summer period. This intensification of northerly winds is caused by an increase of the pressure difference between the Gulf of Mexico and the Gulf of Tehuantepec, induced by the westward elongation of Azores-Bermuda High.

The table below (presented in the Ph.D. thesis of Rosario Romero-Centeno, 2007) shows the percentages of occurrence of northerly winds over the Gulf of Tehuantepec, their standard deviations and mean velocities for all months of the years 1999-2005

	ENE	**FEB**	**MAR**	**ABR**	**MAY**	**JUN**	**JUL**	**AGO**	**SEP**	**OCT**	**NOV**	**DIC**
1999								58.1	40.0	67.7	96.7	87.1
2000	77.4	69.0	54.8	76.7	35.5	70.0	83.9	87.1	60.0	83.9	76.7	100
2001	83.9	89.3	45.2	76.7	48.4	73.3	64.5	80.6	56.7	83.9	86.7	96.8
2002	96.8	92.9	67.7	66.7	58.1	43.3	80.6	90.3	43.3	83.9	93.3	93.5
2003	100	82.1	61.3	60.0	51.6	40.0	87.1	80.6	60.0	71.0	96.7	93.5
2004	87.1	75.9	87.1	56.7	74.2	70.0	80.6	58.1	80.0	61.3	93.3	96.8
2005	93.5	92.9	74.2	73.3	45.2	60.0	80.6	61.3	76.7	80.6	83.3	90.3
Porcentaje Mensual	**89.8**	**83.5**	**65.0**	**68.3**	**52.2**	**59.4**	**79.6**	**73.7**	**59.5**	**76.0**	**89.5**	**94.0**
Std (%)	8.5	9.8	14.8	8.6	13.1	14.5	7.8	14.1	15.1	9.3	7.6	4.3
$\bar{v}$	**-7.7**	**-6.0**	**-3.5**	**-3.0**	**-2.2**	**-1.5**	**-3.0**	**-2.7**	**-1.3**	**-4.7**	**-7.7**	**-8.6**
Std (*v*)	6.0	6.0	6.0	5.4	4.6	4.1	3.6	3.7	3.7	5.5	6.0	5.9

Furthermore, Romero-Centeno et al. (2007) analyzed the relationship between the Jet of Tehuantepec and the moisture fluxes, horizontal divergence and precipitation over the zone where mid-summer drought occurs, as well as the impact of the jet on zonal winds over the northeastern Tropical Pacific (10°N-15°N, 115°W-95°W). They found that the mid-summer intensification of the Jet of Tehuantepec reverses the low-level wind circulation over the northeastern Tropical Pacific, which shows an eastward (toward the coast) orientation in June and September and a westward (off the coast) orientation in July and August. This reversal of zonal winds during mid-summer changes the direction of moisture fluxes (off the coast during July and August) and shifts convergence areas away from the coast. These changes in circulation contribute to the decrease of precipitation. Using daily *observations, Romero-Centeno evaluated the synoptic scale variability of wind velocity and direction with precipitation and found a significant correlation at this time-scale. The correlation between zonal winds over the northeastern Tropical Pacific and precipitation over the mid-summer drought region is 0.84.*

The synoptic phenomena that affect precipitation in the region studied include easterly waves that originate in the Atlantic and cross over to the Pacific region, other tropical wave activity (such as mixed Rossby gravity waves as studied by Torres-Puente and Raga (2011, WCRP Open Science Conference, unpublished), which all modulate the strength and location of the Inter-tropical Convergence Zone (ITCZ), and eventual tropical cyclones that move onshore during the early season (May-June). The region exhibits low variability in terms of temperature (less than 1K between ridges and troughs of easterly waves in the mid-to-lower troposphere, Petersen et al, 2003) and humidity (less than 10% difference) during the rainy months.

The region studied is unique because of the presence of a phenomenon which seems to have opposite effects on precipitation and lightning. The influence of the Jet of Tehuantepec on lightning is quite complex as the same factors that have a negative effect on precipitation (reduced moisture and convergence) are supposed to have a negative effect on lightning (reduced moisture may lead to lower ice content and less convergence would result in lower updrafts). However the increase of lightning during the months corresponding to the mid-summer drought indicates the existence of another factor which seems to have different impact on lightning that on precipitation. We hypothesize that this factor is the presence of continental aerosols transported by the Jet of Tehuantepec over the maritime regions.

Recent studies indicate that there is certain range in the aerosol optical depth (AOD) values for which a very strong positive impact of aerosol particles on lightning can be observed (Altaratz et al. 2010, Yuan et al. 2011). Continental aerosol particles transported by the Tehuantepec Jet probably influence rainfall too (e.g. Koren et al. 2012), however high values of lightning registered during May (biomass burning period) and during midsummer (northern wind intensification) indicate that over this region the impact of particles on lightning is larger than on rainfall. Also lightning maximum registered in May over the ITCZ region located further from the coast points toward the role of aerosols.

We followed the suggestion of the reviewer and studied daily variability of lightning and AOD. A repeatable pattern of high lightning density in May and midsummer (July or August) could be observed in the daily time series. Also a pronounced AOD peak was observed in May and a slight increase in AOD was registered during midsummer. However, daily series of AOD and lightning didn't show a correlation between the magnitudes of both variables. We did some additional investigation on *the impact of different ranges of AOD values on lightning density and noticed that the highest values of lightning were observed on days with medium AOD (0.2-0.35).*

We will include a couple of additional figures in the revised manuscript (corresponding to numbers 13 and 14) that we describe here. In Figure 13, we present the difference between the average value of lightning registered on days with medium AOD (0.2-0.35) and low AOD (0.05-0.15). The AOD values were derived from the MODIS instrument located on the sun-synchronous Aqua satellite, with overpasses at about 1.30pm local time. The lightning flashes used to produce the figure were summed between 8am and 5pm local time. The grid resolution is 1 degree. The calculations were done for the year 2009, when the detection efficiency of WWLLN was highest (within the analyzed period: 2005-2009) and the amount of data samples in each AOD range was sufficient to calculate lightning difference for most of grid squares. White squares represent regions where the number of data samples was less than 8 for one or two AOD ranges.

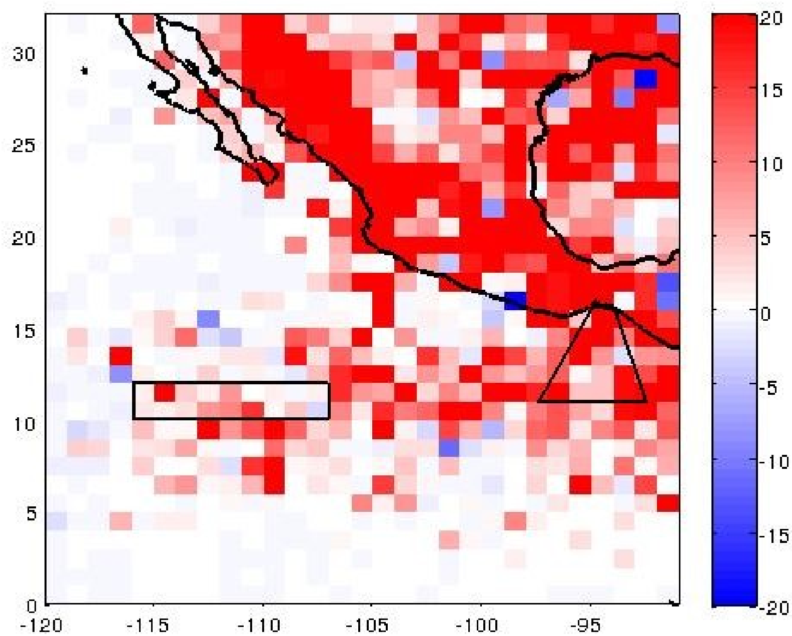

Figure 13. Differences between average numbers of lightning flashes registered during days with medium AOD (0.2-0.35) and low AOD (0.05-0.015)

The results presented in Figure 13 show that there are more lightning flashes recorded on days with medium AOD than on days with low AOD over the Tehuantepec Jet region, Gulf of Mexico, Continental Mexico and some areas of ITCZ. However, the results change drastically when the difference between lightning recorded on days with high AOD (0.4-1.5) and medium AOD (0.2-0.35) is *calculated.*

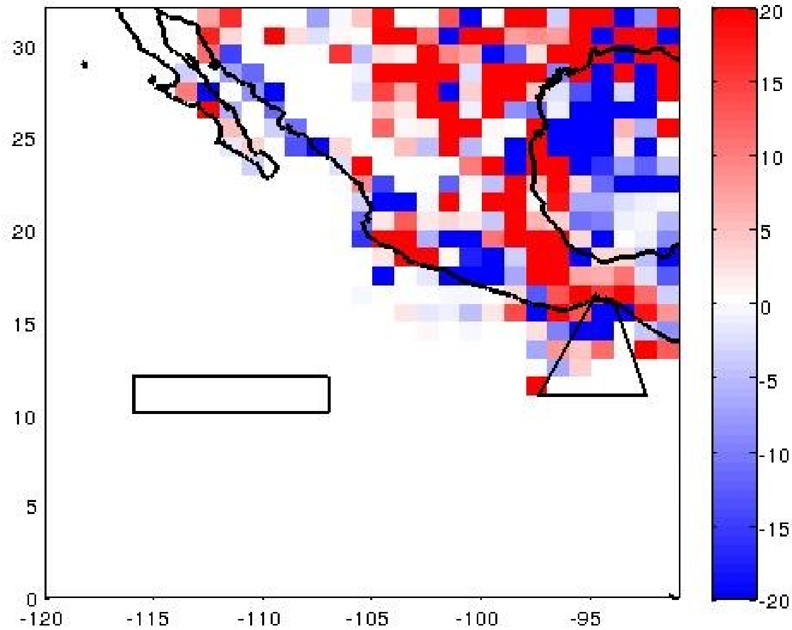

Figure 14. Differences between average numbers of lightning flashes registered during days with high AOD (0.4-1.5) and medium AOD (0.2-0.35)

In contrast with the results in Figure 13, the differences between lightning flashes on days with high and mean AOD (Figure 14) are negative for the Gulf of Tehuantepec, most of the Gulf of Mexico and continental regions of Sierra Madre Occidental, close to Pacific coast. These results indicate that very high values of AOD may decrease lightning and even inhibit it. The results presented in Figures 13 and 14 show that the influence of AOD on lightning depends on ***the range of AOD****. And this fact is the reason why there is no direct correlation between the magnitudes of AOD and lightning in daily time series. Our results are in agreement with the results of Altaratz et al. (2010), who observed that in the regions affected by Amazonian fires, the lightning density increases when AOD increases for AOD values smaller than 0.35 and decreases for AOD larger than 0.4.*

Among the analyzed years, 2007 was the only one that didn't show a lightning peak in May. During most of the days of May, the AOD was much higher than 0.4 and the average AOD in May of 2007 was 0.48 which was the highest value among the analyzed years. These results indicate that very high values of AOD may have suppressed convection and lightning in May 2007.

Moreover, the results shown in Figures 13 and 14 indicate that the increase of both lightning and AOD is not likely driven by the same meteorological conditions, as the relation of proportionality *between these two variables is only valid for a limited range of AOD. These results rather point toward the relation of cause-effect between AOD and lightning density.*

2) Microwave radiometry is known to have difficulties in rainfall retrieval near coastlines and over land (e.g., Nesbitt et al. 2004, J. Appl. Meteor., 43, 1016-1036; McCollum and Ferraro, 2005, J. Atmos. Oceanic Tech., 22, 498-512). It makes the comparison of continental and Oceanic TMI data of rain and hydrometeors vertical profiles very uncertain. How do you resolve this issue?

Reply:

It is true that the 2A12 TRMM product has deficiencies that are not described in the present version of the paper. The weaknesses of this product will be presented in the revised version of the paper and the profiles of hydrometeors will be interpreted with more caution. The interpretation based on small differences between the regions will be removed from the paper unless there is additional information based on a dataset different than 2A12 that confirms the interpretation. The largest uncertainties are expected for the continental region, however the subject of our study are oceanic regions, and the continental profiles are presented only for comparison.

In addition we would like to clarify that the main conclusions of the paper are not based on the 2A12 TRMM product. The main results of this paper are obtained from the relation between lightning (WWLLN data), surface rainfall (3B42 TRMM product) and AOD (MODIS data). The results are supported by some characteristics of hydrometeor profiles that provide an insight into microphysical processes, but the 2A12 product is not the most important source of information in this study.

Also, the comparison between the continental and maritime precipitation characteristics is primarily based on the number of flashes per rainfall. The 2A12 TRMM product is used to obtain some additional information about differences in precipitation ice and latent heating, but most of the 2A12 data in section 3.2 are interpreted together with WWLLN results and other findings reported in the scientific literature.

3) The detection efficiency of the lightning WWLLN system depends on the location and on the characteristic flash current distribution (due to the WWLLN low detection efficiency and its bias toward strong current lightning flashes). How do you resolve these issues in the current study and what are the possible implications on the presented results.

Reply:

Abarca et al. (2010) compared the records of WWLLN with the National Lightning Detection Network data and found that the location accuracy of WWLLN has average errors of 4.03 km in the *north-south direction and 4.98 km in the east-west direction. The resolution of the results presented in our study is 0.25 degrees, which is more than 5 times greater than average location errors of WWLLN. The detection efficiency of WWLLN is biased toward stronger currents, which implies that the results based on WWLLN data are valid for intense lightning flashes and not necessarily for the total number of cloud-to-ground lightning flashes.*

Abarca et al. (2011) showed that the WWLLN reproduces quite well spatial patterns of lightning activity (Fig. 5) and Kucienska et al. (2012) compared monthly variabilities of WWLLN data and Lightning Imaging Sensor (LIS) on TRMM satellite records, and found that although the detection efficiency of WWLLN is much lower than that of LIS, the monthly distributions of lightning retrieved from both datasets are very similar, especially for coastal regions of the Pacific affected by the Tehuantepec Jet (and adjacent to Mexican states of Oaxaca and Guerrero). Both datasets show a bimodal distribution of lightning for this region, with the first peak observed in May and the second in August (during mid-summer drought).

Specific Comments:

1) Please provide a general short synoptic overview of the conditions in the region of interest along the year for the reader who is unfamiliar with this region. It will enable also a better understanding of the role of the Tehuantepec Jet.

Reply:

This suggestion has been taken fully into account and the following text is included in the revised manuscript:

"The wind and precipitation patterns in the region are influenced by the complex topography and are determined by meso- and synoptic-scale systems related with the latitudinal shift of the ITCZ, the presence of easterly waves and other tropical waves (e.g. such as mixed Rossy-gravity and Kelvin), the intrusion of mid-latitude dry and cool continental air masses, the occurrence of tropical cyclones, the seasonal variability of the high pressure systems over the North Pacific and Atlantic basins, and the land-sea breezes, among other processes.

Northerly winds funneled through the narrow mountain pass across the Isthmus of Tehuantepec can be very intense, reaching gale (≥ 34 kt), storm (≥ 48 kt) or even hurricane (≥ 64 kt) force (Brennan et al., 2010), and have a large impact on cooling the sea surface temperature of the Gulf of Tehuantepec that extends very far into the Pacific ocean (e.g., Barton et al., 1993). This strong gap outflow, known as the Jet of Tehuantepec, is the result of a pressure gradient between the Gulfs of Mexico and Tehuantepec (Romero-Centeno et al., 2003) and is clearly identifiable by satellite remote *observations, in particular from the NASA scatterometers NSCAT and QSCAT (Chelton et al., 2000, 2004).*

Tehuantepec wind jets can last from several hours to a few days; they are more frequent and intense during fall-winter, associated with cold fronts of midlatitude origin that move southward and penetrate into the Gulf of Mexico (Schultz et al., 1997), and they decrease in number and intensity towards the summer season in response to a weaker pressure gradient across the Isthmus. However, due to the intensification and westward elongation of the North Atlantic Subtropical High by mid-summer, there is a slight increase of these events during this time of the year (Romero-Centeno et al., 2003). A bimodal behavior is also observed in the annual cycle of precipitation in southern Mexico, showing minimum precipitation rates in winter, maximum in June and September, and a rainfall decrease in July-August, when a reduction in the number of tropical cyclones generated in the eastern North Pacific also occurs (Magaña et al., 1999).”

2) Part 2. Database: Please provide more information about the times of measurements of the data used in this work.

Reply:

The information about the times of measurement of satellites Aqua, Terra and QuikSCAT will be introduced in the section 2 of the revised manuscript.

3) Results: There is a need to add the number of analyzed TRMM profiles to the relevant analyses and figures in order for the reader to estimate the statistical significance of the results.

Reply:

Done. The following table is introduced in the new version of the paper:

Table 1. Number of hydrometeor profiles registered during day (6am-6pm) and night (6pm-6am) that were averaged over five study regions. Only the pixels with non-zero surface precipitation were taken into account.

Region	Cont. Mexico	Caribbean Sea	Gulf of Mexico	Subtrop. Pacific	Tropical Pacific
Day	615134	232799	558908	158431	1912844
Night	1202671	147558	349204	147120	1574607

4) Subsection 3.3: the convergence analysis. What is the source of the convergence data? What time of the day does it represent? As the authors show in Fig. 7 there is a diurnal cycle of lightning densities. Of course there is a diurnal cycle of dynamical conditions. So it is essential to correlate the time along

the day of the convergence and lighting data. In addition there is a need in explaining what type of convergence is represented by 0.5 degree data resolution. Does it represent a synoptic scale convergence only or smaller scales like the breeze circulation scale that contributes to the lightning production as well (as was discussed in the manuscript).

Reply:

In Section 2 of the manuscript a description of the wind data from the QuikSCAT satellite is already presented, together with a brief explanation of the way these data were processed to get the long-term monthly means of the meridional wind component and wind convergence in the Tehuantepec Jet region. All available data for the region in the daily swaths were averaged, so the resulting values do not represent a specific time of the day. The QSCAT satellite passes covered the Tehuantepec Jet region between 00 and 01 UTC (descending pass) and between 12 and 13 UTC (ascending pass), which make them suitable for synoptic analysis. The 0.5 degree data represent large mesoscale to synoptic scale convergence, so the results presented in the figure 11 reflect basically the signal of the Tehuantepec Jet.

The diurnal variation of the winds in the Tehuantepec region can be analyzed only partially using QSCAT data, since the satellite passes covered this region generally within an hour, twice per day. The hourly wind long-term averages show weaker and divergent winds at 00-01 UTC (18-19 LST), when the sea breeze acts in the opposite direction to the prevailing winds that blow offshore. Stronger and convergent winds are observed at 12-13 UTC (6-7 LST), when the land breeze coincides with the direction of prevailing winds. This is consistent with the observed diurnal cycle of flashes in the Tehuantepec Jet subregion which shows maximum values at night and early morning and minimum values in the afternoon and early evening (Fig. 7).

5) Check the Reference list. It doesn’t include all the papers cited in the manuscript.

Reply:

The missing papers are included in the new version of the paper. Thank you for this observation.

6) Fig 6: Which months were analyzed?

Reply:

The data of four summer months (June to September) are averaged in this figure. The figure caption is corrected in the new version of the paper.

7) Results section 3.3: Please give possible explanations to the opposite variability of lightning and rain

data in the Tehuantepec regime. What are the differences in the clouds properties and how can you support it by additional analysis.

Reply:

We propose to include the following text to address the cloud properties in the region:

"Most of the precipitation and lightning observed in the region is associated with deep convection, reaching cloud tops much higher than the freezing level, located on average around 4.7km (Short and Nakamura, 2000) and presenting very little variability throughout the year. Chui and Chang, (2000) present clout-top heights above 6km in our region of study, for the average of June-July-August, with less than 10% of the cloud with tops below 3km. Nesbitt et al (2000) evaluated the precipitation features in several regions of the globe based on TRMM data, and relevant to our study, show results for the eastern North Pacific. Precipitation features with ice scattering showed a 5.5km median value of the maximum height of the 30dBz reflectivity and 231K median polarization corrected temperature (related to the size of the ice hydrometeors). Petersen et al (2003) analyzed radar observation in a ship located in the region during the EPIC project in September-October 2001 and the results indicated that the tail in the 30-dBZ frequency extends to heights exceeding 11 km, coinciding with the passage of the northerly phase of easterly waves."

Continental aerosol particles transported by Tehuantepec Jet which intensifies in July and August and modifies moisture fluxes, divergence and low-level wind circulation over the northeastern Tropical Pacific is the explanation that we propose for the opposite variability of lightning and rain. We hope the inclusion of Figures 13 and 14 and associated text in the revised version, strengthen our hypothesis. If the editor recommends it, we will analyze cloud properties other than those presented in the Figures 6 and 8. However, we feel that this is a study subject for a new paper.

8) Section 3.1: Regarding the referenced paper Takayabu 2006, please change it to her results instead of his results.

Done. Thank you for this observation.

Additional references:

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