Reply to the two reviewers

We would like to thank the reviewers for their efforts and comments that helped us improve the paper and make it clearer. We have addressed below the two reviewers' comments point by point (the answers are in blue with text cited from the revised manuscript appears in *italics*).

Reviewer # 1:

General comments:

This is very interesting study in understanding the linkage between SWD and properties of the over lying clouds and could be useful in improving the climate modeling capabilities. I think it would be to strengthen the quantification aspect in this research paper as compare with the qualitative description.

Answer: We thank the reviewer for the warm words. We were glad to see that the reviewer likes the paper and thinks it is interesting and beneficial to climate modeling. We have added to the revised manuscript quantification aspects, both in the description of previous works and in our analysis' results regarding the link between surface wind divergence, SST and cloud properties. Please see detailed answers below.

Minor comments:

1. The past studies have presented the quantitative estimates e.g. Cold tongue, warmer ITCZ, increase in the mass flux related to acceleration of the trade winds, the authors may like to consider the same for this study.

Answer: Thank you for this comment. Past studies showed the effect of SST on trade winds that cross the cold tongue towards the ITCZ. Together with the increase in SST the sea surface heat fluxes increase, the vertical mixing increases and the atmospheric boundary layer deepens. As a result they showed that the downward flux of momentum

from above increases, the surface winds accelerate and create the surface wind divergence over the SST gradient. Several observational studies presented and quantified these changes in heat fluxes across the equatorial cold tongue-ITCZ complex [*Small et al.*, 2005; *Thum et al.*, 2002; *Zhang and McPhaden*, 1995]. They estimated a change in sensible heat flux of 6.5-7.5 W m^{-2}, and a change of 25-35 W m^{-2} in latent heat flux both for a 1°C change in SST. We insert these quantitative estimations into the revised introduction section.

Page 1560, the revised text following line 11:

"Moving northward from the equatorial cold tongue, the atmospheric conditions change gradually. Aircraft measurements at 30 m height in the eastern equatorial Pacific (along 95°W) showed nearly zero latent and sensible heat fluxes over the cold tongue waters (~18°C) and maximal heat fluxes of 160 W m^{-2} and 30 W m^{-2}, respectively, over the warmer waters (~24°C) around 2°N [deSzoeke et al., 2005]. Additional observational studies for the same geographical region [Zhang and McPhaden, 1995; Thum et al., 2002; Small et al., 2005] estimated changes in fluxes in the range of 6.5-7.5 W m^{-2} in sensible heat flux and 25-35 W m^{-2} in latent heat flux both for 1°C change in SST. Over the same region, observations of the marine boundary layer (MBL) depth based on a radiosonde transect along 2°N showed vertical displacement of the inversion layer base height from 1 km over the cold water of the TIW (126°W) to 1.5 km over the warm water (123°W) [Xie, 2004]."

2. Authors may like to illustrate the robustness of the correlation in bringing out the linkage between SWD and cloud properties.

Following this comment we have added the revised paper a new analysis that presents the correlation between the SST gradient, SWD and cloud optical thickness in a clear way. The new figure (Fig. 8), that was added at the end of the results section, presents the new results. A quantitative estimation of the link between SWD and cloud optical depth was added into the text.

Page 1565, from line 19:

"The boreal summer seasons with cold SST, sharp gradSST and strong SWD were characterized by optically thinner clouds (low COT) and a decrease in cloud cover. On the other hand, the boreal winter and spring seasons were characterized by warm SST, mild gradSST, negative SWD and therefore optically thicker clouds (high COT) with larger cloud cover. The evolution of the Atlantic cold tongue and the SWD belt is illustrated by a decrease in SST, increase in gradSST and a sharp transition to minima in COT and CF.

The links between gradSST to SWD and the associated cloud optical thickness were further examined during the boreal summer months. Daily data (in 1° degree) were used for the period of JJA 2007, for the area between 0°–3°N and 30°W–10°W (to ensure large enough dataset). Clear positive correlations are shown between gradSST (R^2=0.75) and SWD and inverse correlations with COT. We estimated that in this case and resolution, COT decreased by ~0.57±0.1 for increase of $1x10^{-5}s^{-1}$ in SWD."

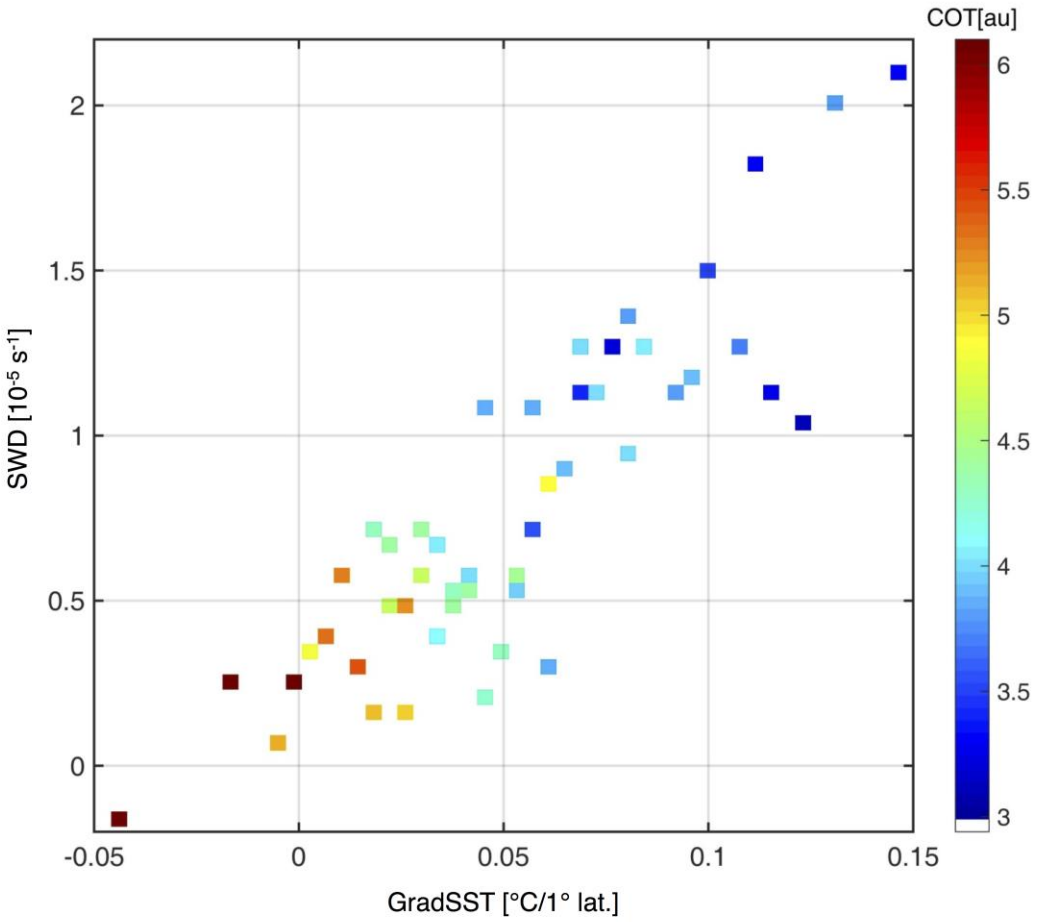

Figure 8. *Three-dimensional scatter plot displays the link between daily values of GradSST [°C/1° lat.], SWD [$10^{-5}S^{-1}$] and COT [au] over the SWD belt (Latitudes/ Longitudes: 0°-3°N/30°W-10°W), during June, July, and August 2007. Data is divided into 50 equal samples bins.*

3. Figure 3a: The legends on X and Y – axes are missing.

Thank you for this comment. Please see below figure 3a with legends on the axes. The information about latitudes and longitudes clarifies the region of interest as presented in the figure.

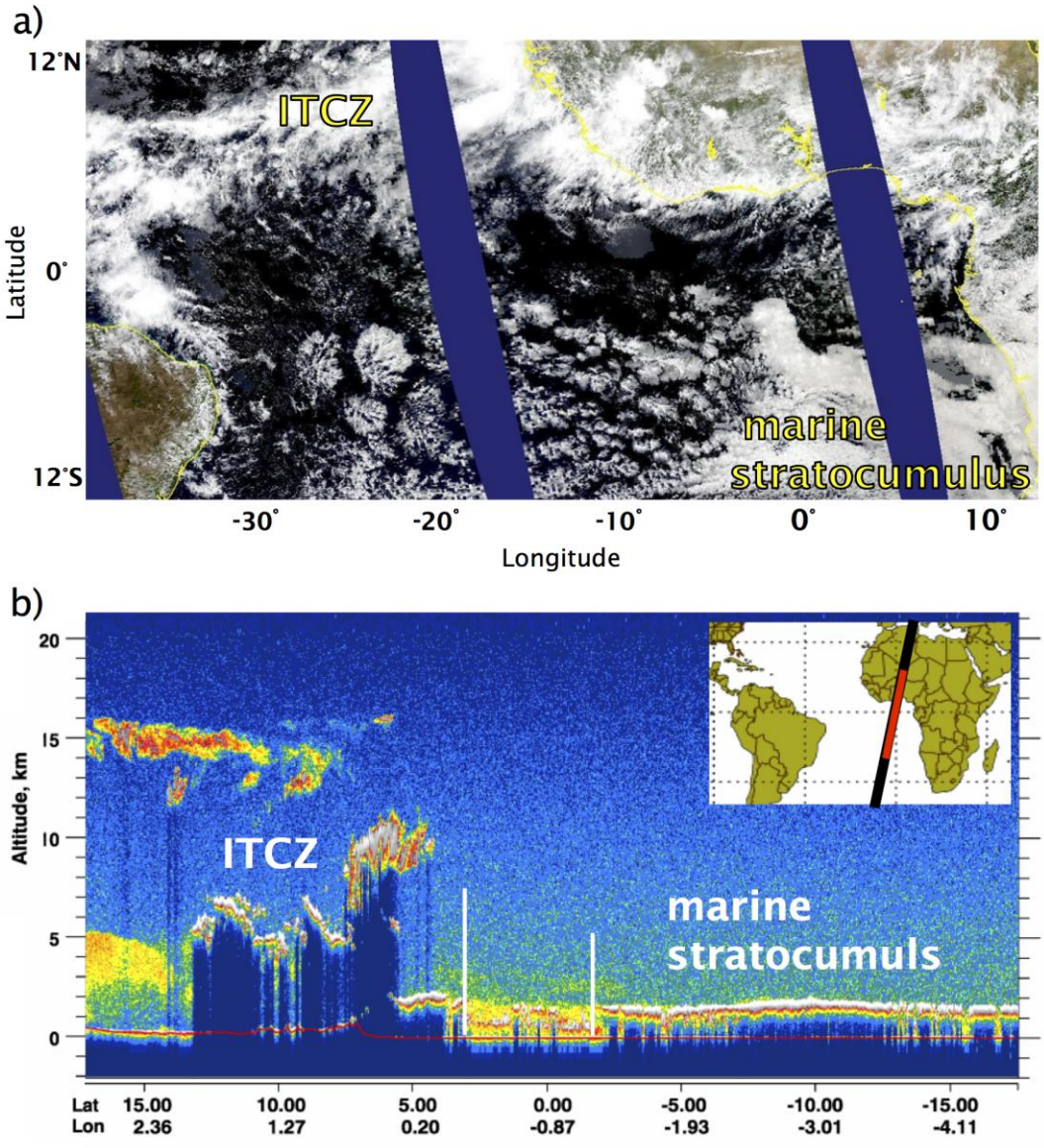

Figure 3. *(a) Aqua MODIS true color image (RGB) of the tropical and southern hemisphere subtropical Atlantic Ocean on 8 July 2012. (b) CALIPSO CALIOP 532 nm total attenuation backscatter presenting a vertical profile of cloud and aerosol while crossing the eastern Atlantic Ocean on the same day. Note the area of relatively less cloud amount between the tropical deep convective clouds and subtropical marine stratocumulus decks.*

Reviewer # 2:

General comments:

The authors describe a region of significant surface wind divergence between the warm and cool SST region in the equatorial Atlantic that has implications to distinct cloud properties during the boreal summer months, which should be considered as a separate entity for understanding the cloud processes and associated transitions. The findings from the observations are interesting and very well linked to the recent hypotheses proposed by various other researchers. As low level cloud representations in climate models are still intricate, the findings from this study will certainly shed light for improvements. However, there are a few grammar revisions, but minor, that can be taken care of before publication.

Answer: We thank the reviewer for the kind words. We are glad that the reviewer found the paper interesting, well linked to previous studies and helpful for future improvements in climate models. The manuscript was revised according to all the comments. Please see detailed answers below.

Minor comments:

1. Abstract: Refer "southern Hadley cell" as the "southern branch of the Hadley cell in the Atlantic" - this way is referred in many places and it will be good if mentioned with better clarity for the readers.

Answer: Thank you for this comment. We changed the manuscript accordingly.

Page 1558, lines 3-6: "*This belt separates the deep convective clouds of the intertropical convergence zone (ITCZ) from the shallow marine stratocumulus cloud decks forming over the cold-water subtropical region of the southern branch of the Hadley cell in the Atlantic.*"

Other places in the manuscript were changed similarly:
Page 1561, lines 14-16: "*Here we argue that when examining meridional features of the southern branch of the marine Hadley cell, the special zone discussed here, located between the cold tongue and the ITCZ, should be considered a unique zone with special wind and cloud patterns.*"

2. "Our findings...." rephrase as "The findings will help to understand the link...."

Answer: Rephrased as suggested.

Page 1558, lines 14-17: "*The findings will help to understand the link between ocean-atmosphere dynamics and cloud properties over this region, and suggest that the SWD zone be considered a unique cloud belt of the southern branch of the Atlantic Hadley cell.*"

3. Introduction: Line 66: Remove: "and dictates the location"

Answer: Changed as suggested.

Page 1558, lines 23-25: "*The ITCZ marks the warmest sea surface temperatures (SST) where the Hadley cells converge.*"

4. Line 69: Remove: "apparently mostly" and rephrase it as "seen"

Answer: Rephrased as suggested.

Page 1558, line 26 – Page 1559, line 3: "*As a part of this band there is an area with a zonal belt of surface wind divergence (SWD) that is seen during the boreal summer months […]*"

5. Line 72: Remove: "suggest" - Rephrase it as "propose"

Answer: Changed as suggested.

Page 1559, lines 4-5: "*In this study, we propose that this oceanic region be considered a unique cloud belt in the southern branch of the Atlantic Hadley cell.*"

6. Line 73: Again mention it as "southern branch of the Atlantic Hadley cell" or you can abbreviate it.

Answer: Changed as suggested.

Page 1559, lines 4-5: "*In this study, we propose that this oceanic region be considered a unique cloud belt in the southern branch of the Atlantic Hadley cell.*"

7. Line 79: Remove "reviewed", just add "e.g.,"

Answer: Changed as suggested.

Page 1559, lines 8-10: "*Studies on the coupling between SST and the magnitude of surface winds clearly show a positive correlation on spatial scales of 25 to 1,000 km [e.g., Small et al., 2008; Chelton and Xie, 2010]*."

8. Line 125: it should be "during the early boreal summer months"

Answer: Changed as suggested.

Page 1560, lines 1-3: "*These waves form in response to intensification of the southeasterly trade winds and the onset of the equatorial cold tongue during the early boreal summer months.*"

9. Line 131: Replace "have shown this coupling" by "corroborate this coupling from satellite observations"

Answer: Thank you for this comment. We revised the text accordingly.

Page 1560, lines 8-10: "*More recent works corroborate this coupling from satellite observations of SST and high-resolution scatterometer measurements of surface winds in the Pacific and Atlantic cold tongues […]*"

10. Line 150: Replace "cloudless" by "cloud-free".

Answer: Changed as suggested.

Page 1560, lines 24-27: "*In agreement, Mansbach and Norris [2007] described a decrease in the amount of low-level clouds over the Pacific cold tongue when it is well defined, highlighting the frequent formation of cloud-free boundary layers over the cold tongue.*"

11. Lines 151-153: How about the turbulence mechanisms associated with the low-level cloud sustenance? you may need to add this ingredient too.

Answer: Thank you for this comment. We have added to text the contribution of turbulence mixing in the cloud layer.

Page 1561, lines 1-4: "*Under conditions of cold SST and low inversion, inversion-topped marine stratocumulus clouds will form in a structure of closed cells and be maintained by downdrafts driven by cloud-top radiative cooling [Wood, 2012] and turbulent mixing in the cloud layer [Bretherton and Wyant, 1997].*"

12. Line 194: This is not vorticity equation per say. Remove the mention of it.

Answer: We thank the reviewer for this comment. Indeed this is not the vorticity equation. We changed the text to:

Page 1561, lines 25-26: "*The SWD was defined using the divergence term (Eq. 1): SWD = $\partial u/\partial x+\partial v/\partial y$ (1)*"

13. Line 223: Strong convergence "not only" dominates.... Please remove the color specifications from the text, it is very clear in the figures.

Answer: Changed as suggested.

Page 1562, line 26 – Page 1563, line 1: "*Strong convergence dominates over the ITCZ belt north of latitude 5°N (<-1.5 x 10^{-5} s^{-1}) but also in the area south of the equator, induced by the warm-to-cold SST gradient.*"

14. Line 254: It should be "This is when high values of SWD appeared...."

Answer: Changed as suggested.

Page 1563, lines 25 – 28: "*This is when high values of SWD (>1.5 x 10^{-5} s^{-1}) appeared (while the ITCZ moved northward, May–July), suggesting a link to the sharpest meridional gradient in the SST that forms during this period.*"

15. Line 258: It should be "meridional extent" and not "meridional cover"

Answer: Changed as suggested.

Page 1563, lines 28-29: "*Later, when the ITCZ migrated back toward the equator, the SWD belt was still evident but in a weaker form (~0.5 x 10^{-5} s^{-1}) and with smaller meridional extent.*"

16. Line 262: Rephrase as "Clear correlations are evident between..."

Answer: Rephrased as suggested.

Page 1564, lines 3-4: "*Clear correlations are evident between the temporal and spatial variability of the COT and the seasonality and spatial distribution of the SWD belt.*"

17. Line 297: Rephrase as "Zooming in over the SWD region"

Answer: Thank you. Rephrased as suggested.

Page 1564, lines 22-25: "*Zooming in over the SWD region, the link between SST, SST gradient (gradSST) and SWD with time was investigated (Fig. 7), focusing only on the area of the most significant SWD in the central Atlantic (latitudes/longitudes: 0°–2°N/20°W–10°W, green square in Fig. 4a).*"

18. Line 349: Rephrase as "The equatorial Atlantic SWD belt which spans over the central Atlantic between..."

Answer: Changed as suggested.

Page 1566, lines 2-5: "*The equatorial Atlantic SWD belt which spans over the central Atlantic between the equator and 2°N latitude is characterized by a mean monthly divergence higher than ~1.5 x 10^{-5} s^{-1} (for a resolution of 1° x 1°), which is of the same order of magnitude (but opposite sign) as the average ITCZ convergence.*"

19. Finishing line: Consider a better sentence at the end how this study may help to improve the low-level cloud representation and about the implications of this study in the improvement.

Answer: Thank you for this comment. We modified the last line to:

Page 1567, line 3: "*The appearance of SWD belt during the boreal summer over the Atlantic and the quantitative link between its magnitude and COT as presented here can be used for cloud parameterizations in climate models as well as for model validation for cloud resolving ones.*"

New references that were added into the revised text based on the reviewers comments:

Small, R. J., Xie, S.-P., Wang, Y., Esbensen, S. K. and Vickers, D.: Numerical Simulation of Boundary Layer Structure and Cross-Equatorial Flow in the Eastern Pacific, J. Atmos. Sci., 62(6), 1812–1830, doi:10.1175/JAS3433.1, 2005.*

Thum, N., Esbensen, S., Chelton, D. B. and McPhaden, M. J.: Air-sea heat exchange along the northern sea surface temperature front in the eastern tropical Pacific, J. Clim., 15(23), 3361–3378, doi:Doi 10.1175/1520-0442(2002)015<3361:Asheat>2.0.Co;2, 2002.

Zhang, G. J. and McPhaden, M. J.: The Relationship between Sea Surface Temperature and Latent Heat Flux in the Equatorial Pacific, J. Clim., 8(3), 589–605, doi:10.1175/1520-0442(1995)008<0589:TRBSST>2.0.CO;2, 1995.