**Response to Reviewer #1:**

Reviewer #1: Nettesheim et al present first Antarctic CMMT climatology and they further investigate how these events vary during different climate phenomena that influence natural variability in the Southern Hemisphere. I will keep the review short and to the point. I think the subject is of importance and such climatology is needed, among other reasons, to fully understand the impact of transport on the Antarctic radiation budget. The analysis approach is reasonable and I do not have any major criticism as such. On the contrary, I liked the fact that the authors, apart from presenting just the climatology, took the efforts to investigate CMMT connections to climate indices. However, surprisingly, they find no such connection, which I really have hard time to understand as I would have expected that the variability in large-scale circulation during these climate phenomena may affect CMMT. Unfortunately, there is not much discussion about this. If some phenomena have local effects, then why study them in the first place?

*This is a good point.* Explain in importance of studying phenomena with local effects, suggest reason why connection may not have shown up?

My another concern here is regarding the subjective detection of CMMT events. This detection is the backbone of the entire study and yet the efficacy and sensitivity of such detection is not described/evaluated adequately (only a para or so in Section 2c). *Agreed, we added information regarding detection \_\_\_\_\_\_\_*.

For example, what if the calibration of sensors is changed, either entirely or over the period of time. *Calibration is internal to McIDAS.*

Would you be able to visually analyse images with the same accuracy if the thermal contrast is weakened? *No dramatic thermal contrast exists.?*

What is the impact of merging data from different sensors with different sensitivities to clouds and water vapour and their different calibration? *IR and WV channels on modern satellites (those employed in this study) are so common and typical that this should not be an issue. WV channel played a small role in this analysis, primarily to round out specific start and end times associated with a select few events.*

If one is using the subjective detection, it has to rigorously evaluated and tested. *We agree with the reviewer. We have added additional explanations of the detection process in Section 2c. Ask Matt for help with this.*

**Response to Reviewer #2:**

Reviewer #2: Review of 'Antarctic cloud mass meridional transport' by Nettesheim et al.

Recommendation: Minor revisions

The manuscript presents a study of the meridional cloud mass transport in Antarctica. It uses satellite data to detect CMMT events. Using this data the study provides a statistical analysis about the preferred areas of occurrence of CMMTs. The study also analyses the occurrence of CMMTs with modes of climate variability. This is a worthwhile study and I recommend to consider it for publication once my below comments have been addressed.

1) It is stated that there was a hiatus in CMMT activity in the period 1998-2000 and this was likely caused by a La Nina event. However, the hiatus started before the onset of La NIna which makes me wonder whether there is a strong connection between La Nina and CMMT events or not. This could just be a coincidence. I suggest that more robust statistics are presented before such claims are made.

*We agree with the reviewer. More robust statistics are presented in \_\_\_\_\_.* Masha can help with this.

2) A few climate indices have been used to examine whether they influence CMMTs. However, important climate modes such as blocking

e.g. O'Kane et al., 2013: Changes in the meta-stability of the mid-latitude Southern Hemisphere circulation and the utility of non-stationary cluster analysis and split flow indices as diagnostic tools. J. Atmos. Sci., 70, 824-842. doi: 10.1175/JAS-D-12-028.1

or

Turner, J., J. C. Comiso, G. J. Marshall, T. A. Lachlan-Cope, T. Bracegirdle, T. Maksym, M. P. Meredith, Z. Wang, and A. Orr (2009), Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent, Geophys. Res. Lett., 36, L08502, doi:10.1029/2009GL037524.

or the PSA teleconection pattern

e.g. Mo and Higgins (1998). The Pacific-South American modes and tropical convection during the Southern Hemisphere winter. Monthly Weather Review, 126, 1581-1596.

doi:10.1175/1520-0493(1998)126<1581:TPSAMA>2.0.CO;2

Because these modes of variability have strong meridional components they might have a stronger influence on CMMTs. These modes should at least be discussed in the manuscript.

*Great point. We added (discussion of) climate modes that include blocking \_\_\_\_\_.* (Use the Turner paper).

3) I would find it insightful if also the average duration of CMMTs would be discussed. The number of days affected by CMMTs is provided but not their duration.

*The durations of the CMMT events are discussed in each subsection of Section 3 of the manuscript.*

4) There is a typo in Eq. (1). It should read Yn-Y0.

*Edited as suggested. (Line:\_\_\_)*

**Response to Reviewer #3:**

Reviewer #3: Review of MWR-D-15-0199 6/30/2015

Title: Antarctic cloud mass meridional transport

Authors: Nettesheim et al.

Summary: This study shows a 20-year climatology of poleward-moving cloud masses over Antarctic. These events, termed cloud mass meridional transport (CMMT) events, produce hazardous weather conditions at the ground, impacting research operations and air travel. CMMT events are most common in October, and least common overall in austral summer. The authors performed the painstaking task of manually tracking and counting CMMT events using available satellite imagery for the 20-year period 1992-2012. Based on the results shown, it appears that the frequency of CMMT events does not have a strong correlation with El Nino-Southern Oscillation and other large-scale teleconnection indices.

The climatology provides a nice framework in which additional work can be done to better understand what factors drive the variability of CMMT events. Also, I'm still a bit unsure what exactly CMMT events are, physically. Are they poleward water vapor transport ahead of synoptic-scale troughs? Are they associated with extratropical cyclones?

*We define CMMT events as the poleward transport of cloud masses associated with extratropical cyclones. Added clarification on line \_\_\_\_.*

How does the CMMT climatology match with storm track climatology by Hoskins and Hodges (2005)? *See comments below.* My recommendation is that this paper be rejected. I think the authors have two possible avenues here. First, they can significantly shorten the length of the current study and resubmit the work. There are seven figures and 24 pages of text in the current manuscript. Perhaps trim 7-10 pages off the paper and eliminate a couple of the figures. This will streamline the work into a compact manuscript. Given the amount of new results shown, I do not think the paper needs to be very long. A second option is for the authors to add a significant amount of diagnosis and interpretation to these CMMT events. Much of the following comments are centered on trying to add more synoptic-dynamic meteorological reasoning and interpretation of the results shown.

Specific comments:

1. Can the authors provide more instruction on how the start and end of CMMT events were defined? I appreciate that the climatology was subjective, but were there a specific set of rules the authors used to define the life cycle of a CMMT event? Continual propagation and penetration describes the life cycle, but does that mean for a given weather system that as long as clouds are moving poleward over the coastal zone that the event is ongoing? What if the CMMT is entirely onshore, but still within the pre-defined geographical zones?

*CMMT events that are entirely onshore are difficult to discern over the continent given the IR imagery used. Because of this limitation, we restricted the definition to strictly within the coastal zone. Because of this, we normalized our results by coastal length as opposed to geographical zone area, since the coast is representative of our area of interest. We have clarified this point on Line \_\_ in Section 2b* Check with Matt on this response

2. On skirt events: These events move from sector to sector, but does this have to occur along the coast or can it also occur farther inland?

*We have elaborated further (L\_\_\_ in Section 2b) that this movement from one sector to another must occur in the coastal zone.*

3. Figure 7: I'm not sure about the usefulness of the pressure time series. So these features are associated with pressure minima. Does this mean that CMMT events are associated with extratropical cyclones?

*Yes, the events are associated with extratropical cyclones (clarified on L\_\_\_).*

Are changes to Figure 7 needed? Is it useful?

4. L100: Are there fewer events in summer because of decreased baroclinicity and a weaker jet in the Antarctic coastal zone? How does this relate to the storm track climatology by Hoskins and Hodges (2005) and other similar studies? Same for L260.

Compare to Hoskins and Hodges (2005).

5. L279-286: An interesting difference between east and west Antarctica on Fig 4. West is favorable anytime from March to November, whereas the east region is favored in the later part of the year. Can this difference in climatological frequency be explored?

Explore (Similar to reviewer 4?)

6. It certainly appears that these CMMT events are worthy of study, given their sensible impact at the ground. Here are some thoughts on further analyses/calculations:

Address this later

-       Generate composite mean maps for CMMT events in each geographical sector. The composites should be in CMMT-relative coordinates, where the center of the composite map is located at the landfall point of the CMMT. Try the following composite maps: 1.) Sea-level pressure, 1000-500 hPa thickness, total column precipitable water; 2.) 500 hPa geopotential height, temperature, vector wind; 3.) 250 hPa geopotential height and wind speed; 4.) 1000-300 hPa integrated water vapor transport (IVT; Moore et al. 2012); 5.) 700 hPa geopotential height, temperature, Q-vectors, and Q-vector convergence; 6.) 850 hPa potential temperature, vector wind, and convective available potential energy; 7.) 700 hPa geopotential height, relative humidity, and vertical velocity.

-       Plot a histogram of meridional moisture flux at coastal zone to better understand the "intensity" of these events.

-       What is the moisture source for these events? The tropics, subtropics, and/or midlatitudes? To introduce the LaGrangian perspective, I think computing air parcel trajectories for a select number of representative cases would be instructive. The NOAA HYSPLIT trajectory model may be useful here.

Minor comments:

1. L 250: Reference Fig. 3a here.

*Edited as suggested (Line \_\_\_)*

2. Show table 2 as a figure.

Make table 2 a figure

**Response to Reviewer #4:**

Review of MWR-D-15-0199, Nettesheim et al, Antarctic Cloud Mass Meridional Transport

Recommendation: Accept with minor revisions

A. Overall Evaluation

This manuscript presents a new and potentially very useful climatology for meridional cloud mass transport events into the Antarctic continent. This climatology represents an immense amount of manual effort leveraging the UWisconsin satellite composite archive. Results are both scientifically and, for the various national Antarctic research programs, operationally valuable. The main topic I would like to see explored more deeply is the area of the mechanisms that lead to the switch from zonal to meridional flow. *See below.* The authors mainly approach this question via correlations with climate indices and this is entirely appropriate (even though results were somewhat sparse beyond the relationship seen with La Nina). Ideally, though, a useful next step (to add to those in the final section) could be to explore these mechanisms. Results from the current manuscript are still solid enough without this analysis to support acceptance.

B. Journal-suggested Reviewer Questions

Does the paper fit within the stated scope of the journal? Yes.

Does the paper identify a gap in scientific knowledge and add new knowledge to the overall body of scientific understanding, or repeat another study to verify its findings? Yes. It takes some existing results and extends them significantly and with additional analyses and insights not previously published.

Is the paper free of errors in logic? Yes.

Do the conclusions follow from the evidence? Yes.

Are alternative explanations explored as appropriate? Yes.

Are biases, limitations, and assumptions clearly stated, and uncertainty quantified? Yes. There are a few places where additional statistical tests to evaluate uncertainty could be added to improve the analysis but the manuscript is still quite useful without that level of testing.

Is methodology explained in sufficient detail so that the paper's scientific conclusions could be tested by others? Yes, as long as the new investigators have similar access to the nontrivial resources (McIDAS, the satellite composites) used by the authors and are willing to put in the very significant manual effort required to work with 20 years of satellite composites.

Is previous work and current understanding cited and represented correctly? Yes although some modest improvements could be made with respect to the literature on accumulation (see below).

Is information conveyed clearly enough to be understood by the typical reader? Yes.

Are all figures and tables necessary, appropriate, legible, and annotated (as appropriate)? Yes although I have made some suggestions for improvements *(addressed below)*.

C. Main comments/questions

1. Coastal/regional latitudes: The authors have used length-of-coastline to make inter-region comparisons more robust. Is it possible that differences in the regional coastal latitude would have any effect on the results? That is, suppose that the source region for the CMMT was always at the same latitude, then the distance to the coast would vary by region which might influence the behavior of the event. Of course, annual variations in sea ice extent could play a similar modulating role and it may not be possible to disentangle the different influences (particularly with a relatively small sample size). The range of coastal latitude may also be relatively small compared to the spatial extent of the source area, i.e., variability in the source region dominates any differences in coastal latitudes. While a new quantitative analysis looking at these questions would be nice (albeit challenging), I would be happy to see the authors simply mention these possibilities. Note that I do see a reference to the effect of CMMT events on sea ice (pg 17), i.e., the other direction of influence.

Mention the possibilities. Next paper? Rephrase what he asks for? Ask Masha for help with this.

2. pg 4/lines 95-98: Not sure “interplay between” is really what is being described since it feels more like comparing behaviors in different seasons. “Interplay” implies a temporal

connection. Is the “distribution” mentioned in line 96 spatial or something else?

*We agree with this point. We have changed ‘interplay’ to ‘relationship’ and ‘distribution’ to ‘occurrence’ (Line \_\_)*

3. CMMT event definition (pg 6, line 135): What is the basis for the 48-hour lower limit? Is this a threshold to exclude random (or otherwise different) events? It seems quite reasonable but if there’s more to this decision, then it should be mentioned. And even though the reader just saw the timestep size available in the satellite data, it would be nice to mention how many timesteps there are in this 48-hour threshold.

*The 48 hour lower limit exists because we wanted to only include events that are sustained.*

Include sustained in paper, and mention time step and # of time steps

4. Continent-wide climatology statistics (Figure 3): Given the total number of events, is it

possible to determine statistical significance of the individual monthly “normalized days”

values? It seems reasonable that September and October are quite different but the

differences are less clear in other cases. Such an analysis (if possible) might distinguish truly interesting parts of the year from a background of random variation.

Ask Masha for help with this.

5. Figures 3a and 4, part one: I’m not actually sure this is worth doing but it did occur to me that more useful information could be conveyed if these figures were combined as one with a stacked bar chart, i.e., single bars per month each split into West and East. This would both show the total and how each hemisphere contributes. It wouldn’t reduce figure count since you still need Fig 3b but it might still improve the reader’s experience.

*Thank you for this point. Edited as suggested. (Figure \_\_\_\_)*

6. Figures 3a and 4, part two: If the above change is not implemented, it might help to use some shading to distinguish the individual seasons. I think two shades would enough (no reason to go full color). Unfortunately, this advice conflicts with the above suggestion so it’s one or the other.

*We decided to take the advice offered in #5 to improve the readability of Figure 3 and eliminate the need for an extra figure.*

7. pg 12, line 272-276: A reference to Figure 5 should be in here somewhere.

*Edited as suggested (Line \_\_\_\_).*

8. pg 17-18, lines 398-404: The text should make clear that the previous work cited is modelbased; there is also a literature of observationally-based work on accumulation out there that should be mentioned at least briefly.

*We agree with this point. Added comment stating previous work is model based (Line \_\_\_\_) and included Vaughan et al. (1999) citation for observation-based accumulation work.*

9. Summary and Conclusions: Regional variability in monthly activity: I think the authors could actually emphasize the interesting nature of this conclusion a bit more. Ideally, there would be an analysis showing what’s behind the regional differences (and this may already be in the text, just not all in one place) but it would also be okay to comment that it’s a potentially very interesting result. This section might also be better titled “Summary and Future Work”? Although there are some conclusions among the first paragraph sentences, it reads more like a summary at present.

Complete this

D. Minor comments

10. Table 1: This may be just a personal preference, but I’d like to see the longitudes in

monotonically increasing order, i.e., 150-120 W, 120-75 W, … , 30-75 E. This lets me

picture a smoothly increasing progression of sector boundaries more easily. Also, would it be possible to add the coastline lengths as computed by McIDAS?

*Great point. We changed the longitudes to increase monotonically, and included a column of the coastal lengths for each sector.*

11. Figure 1: The “orange outline” appears to be white?

*Edited as suggested.* Get rid of this figure.

12. Figure 2: I think the infrared image is overlaid by the map of the various regions. I’m also curious why the same image from Figure 1 was not used again? Not essential that they are but the large data gap in this figure certainly draws attention (but without explanation) to this problem.

*Fixed wording as suggested and used the same image previously used in Figure 1 because of the better coverage/smaller data gap.*

13. pg 7, first para (lines 154-161) and second para (lines 163-169): Would read better if these were swapped, keeping together the sections of the initial spatial description and the

justification for excluding certain areas. Also line 169: “southward” or “southerly”? I

believe the intention is to say that the mean flow is not as zonal as the other regions hence

these areas are excluded?

*Paragraph ordering is edited as suggested (Lines \_\_\_\_-\_\_\_\_\_). Corrected wording to ‘southerly’ on Line\_\_\_\_.*

14. pg 8, line 181-183: “Reordering” is more appropriate than “reorganization”.

*Edited as suggested (Line \_\_\_\_).*

15. pg 9, lines 206-207; pg 10, line 232: You may consider changing to “We considered four ENSO-related climate indices…” here and in the SAM paragraph indicate it is a fifth index.

*Edited as suggested (Lines \_\_\_\_-\_\_\_\_\_; Line\_\_\_\_).*

16. Section 3c: references to figures need to be introduced more consistently at the beginning of each subsection (i.e., within the first sentence) so that readers will find Figs 5 and 6 more useful. This section also gets longer than it probably needs to be; the information is useful but the word choices and sentence structures could be tightened to get things across more concisely.

*Figure references are included towards the beginning of each subsection consistently (Lines \_\_\_\_\_).*

Tighten up word choice to make this section smaller

17. Figure 7: Would doing these plots as anomalies avoid the need for multiple y-axes? Given that the interesting part is the relative changes (in pressure and timing), the data don’t really need to be shown in actual values. It would also be useful to show station latitude in the legend (or caption) to give the reader a sense for spatial scale. The caption could also be more specific about the date and that this is showing one (?) CMMT event.

Hold off on this

18. pg 21-22: The section on ZW3 deserves its own subsection heading. An explanation for the two-year grouping would be useful.

*ZW3 discussion is given its own subsection heading (Section \_\_).*

Explain two-year grouping

19. References: There are multiple out of order references, e.g., Staude and Steig.

*Reference ordering is fixed*

**Misc To-Do:**

* Fix images (small text). Save in Matlab as a EPS, then use EPS Viewer to convert from EPS to TIFF. Should conserve the size.
* Add links to presentation citations (Lazzara and Snarksi)