ENHANCED CLOUD ALGORITHM FROM COLLOCATED CALIPSO, CLOUDSAT AND MODIS GLOBAL BOUNDARY LAYER LAPSE RATE STUDIES

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ABSTRACT

Coincident profile information from CALIPSO's lidar and CloudSat's radar offers a unique opportunity to map the vertical structure of clouds over the globe with accuracies never before realized. At Langley NASA, both CALIPSO and CloudSat are collocated with each MODIS 1-km pixel to create a new data set named C3M (Figure 1). A year (July 2006 - June 2007) of C3M data is used to derive global lapse rate maps, as an enhancement to NASA Langley's CERES Cloud Property Retrieval System (CCPRS) [1]. The lapse rates are derived for boundary layer clouds using the the cloud-top temperature from Aqua MODIS level 1 data, skin temperature over ocean and surface temperature over land from the GMAO GEOS-4, and cloud-top height from CALIPSO. The derived global lapse rate maps are used to process a month of CERES-MODIS data to calculate cloud top heights, which are compared with CALIPSO cloud top height. The comparisons shows good agreement between CERES-MODIS and CALIPSO.

***Index Terms*—** Lapse rate, CERES, MODIS, CALIPSO.

1. INTRODUCTION

Cloud effective radiative temperatures are typically retrieved from satellite imager data as the first step in determining the cloud-top height. It is a challenge to accurately calculate cloud heights from low-cloud temperatures due to temperature inversions that are not well represented in numerical weather analyses. The lack of accurate inversion base temperatures often results in significant overestimates of boundary-layer cloud-top heights. To overcome this lack of information, the CCPRS Edition-2 [1] uses a boundary-layer temperature profile defined by lapse rate of -7.1 Kkm^{-1} anchored to the sea surface or land surface air temperature. This lapse rate, determined from measurements over the northeastern Pacific [2], is generally effective over ocean but does not account for the observed variability. For example, [3] found that the lapse rate can be parameterized as a function of the boundary layer height, while [4] found the lapse rates vary from 7.5 to 8.5 K km^{-1} for marine boundary layer clouds. From initial comparisons between CCPRS-derived low cloud top heights and surface measurements [5] and CALIPSO, it is clear that a separate lapse rate over land is indeed needed. This paper introduces a way of deriving a static global low cloud lapse rate map for each month over ocean and land for day and night.

2. DATA AND METHOD

By using collocated CALIPSO and MODIS data, the ocean and land boundary-layer lapse rates can be expressed as:

$$\gamma = (T_{top} - T_{skin}) / (Z_{top} - Z_{sfc}) \quad (1)$$

and

$$\gamma = (T_{top} - T_{sfc}) / (Z_{top} - Z_{sfc}), \quad (2)$$

respectively, where T_{skin} is the skin temperature over ocean and T_{sfc} is the 24-hour mean surface air temperature over land from GMAO GEOS 4.0.3, which is used in the CERES-MODIS CCPRS processing. T_{top} comes from the CCPRS retrieved cloud-top temperature processing with Aqua MODIS level 1 data. Z_{top} is the CALIPSO cloud-top height, obtained from CALIPSO/CloudSat/MODIS collocated product C3M. Z_{sfc} denotes the surface elevation.

The lapse rate is calculated for each collocated single layer cloudy pixel with cloud top heights less than 4 km, as determined by CALIPSO, and water cloud phase determined by the CCPRS retrieval. The calculated seasonal lapse rates are then averaged in 5° x 5° and 20° x 20° grid boxes. Over a coastal grid region, it is likely that both ocean and land co-exist. Because ocean and land lapse rates are expected to be different, global lapse rate maps are created for ocean and land separately. The CERES-MODIS cloud retrieval is processed over a 16 x 16 km tile. If the tile contains coastal pixels, then the coastal lapse rates are calculated with ocean and land lapse rates in the tile by weighting number of ocean and land pixels in the tile. Due to CALIPSO's limited spatial coverage, the lapse rates can be noisy. Therefore residual error maps are created. A value of 0.5 Kkm^{-1}is chosen as the threshold for lapse rate cut-off. The lapse rates in 5° regions with residual errors exceeding 0.5 Kkm^{-1} are removed and filled with lapse rate values calculated in 20° x 20° grid box. Over areas having no A-Train overpasses, an IGBP lapse rate mean is used. Finally, a 9-point smoothing technique is used to avoid discontinuities between the 5° grid boxes.

The monthly lapse rate map is then interpolated between the neighboring seasons. The CERES lapse rate database includes 48 5° x 5° lapse rate maps: 4 lapse rate maps per month with 2 maps for day and 2 maps for night, each over ocean and land respectively.

3. LAPSE RATE RESULTS

A year of collocated data, June 2006 - July 2007, was used for this study. Figure 2(a) shows the lapse rate map during summer (June/July/Aug) over land surfaces. The corresponding residual map is shown in Figure 2(b). Figure 2(c) shows the lapse rate map after the removal of the lapse rates in Figure 2(a) having residual errors greater than 0.5 Kkm^{-1}. Figure 2(c) shows the final map after filling in with the lapse rate values calculated in the 20° grid box and in the IGBP means. Figure 3 shows the seasonal lapse rates over ocean during day time where the majority lapse rates are between -9 to -6 K km^{-1} with local variations. Figure 4 shows the seasonal lapse rates over land during day time where a majority of the lapse rates are between -7 and -4 K km^{-1}. Smaller lapse rates over land will result higher clouds which is expected. Seasonal lapse rate maps were also developed over ocean (Figure 5) and land (not shown) during night time.

4. VALIDATIONS

Based on the derived lapse rate global maps, low cloud top height statistics can be estimated and compared with the results using Ed3 Beta2 latitude dependent lapse rate where day time ocean is -8.2+0.0137 x latitude K km^{-1} and day time land -4.1+0.0018 x latitude K km^{-1}. The month of December 2007, which is not part of the year used to derive global lapse rate maps, was selected for validation.

Cloud top heights computed from the CERES-MODIS CCPRS is compared with the corresponding geo-located CALIPSO cloud top height for the same pixels. The histogram of cloud top height differences between CALIPSO and CERES-MODIS is shown in Figure 6 for day time ocean and Figure 7 for day time land. The red and black curves indicate results from using the regional lapse rates developed here and the Ed3 Beta2 lapse rate, respectively. Statistically, over ocean, the agreement with CALIPSO by using a latitude dependent lapse rate is just as effective as using global lapse rates (Figure 6). Over ocean the agreement is within 50 meter with a standard deviation 0.5 km for both lapse rates. However over land, agreement is within 70 meters with global lapse rate map versus 250 meters with -4.15+0.0018 x latitude K km^{-1} (standard deviation for both cases are about 1 km.)

5. CONCLUSION

This paper reports on the preliminary global lapse rate studies for low cloud height retrievals. The cloud top heights computed with the global lapse rates show a slighlty improved agreement compared with CALIPSO.

6. REFERENCES

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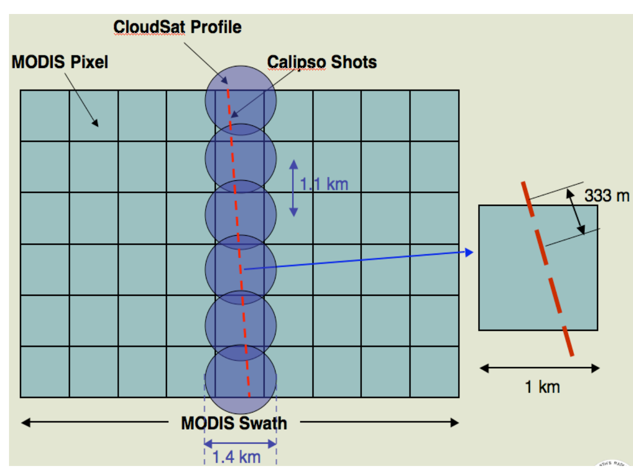

Figure 1. Sketch of collocated CALIPSO/CloudSat/MODIS.

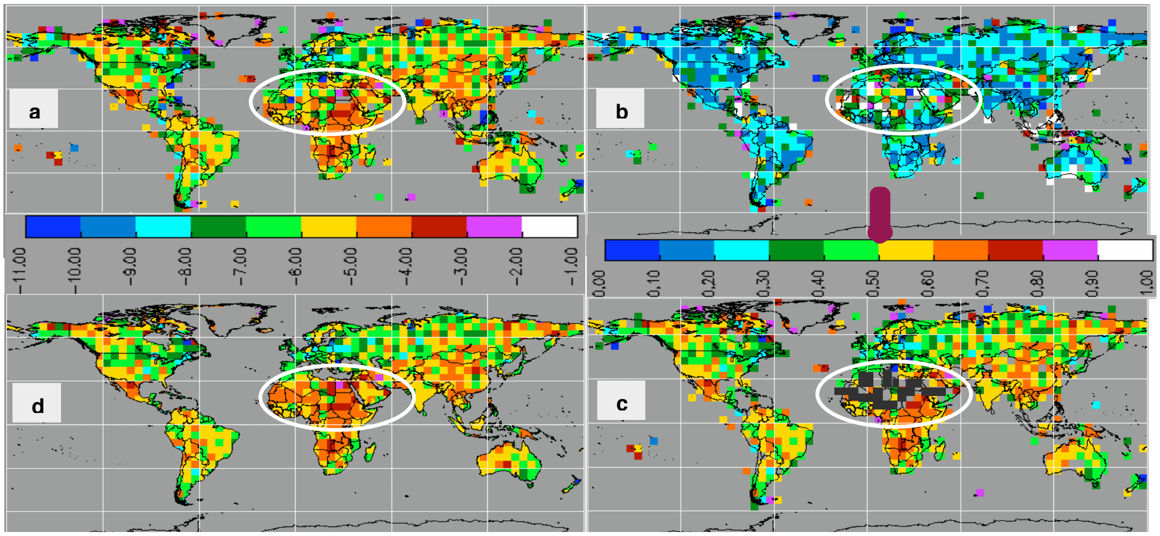

Figure 2. (a) Lapse rates over land for fall season. (b) Residual errors of map (a). (c) Lapse rates after the removal of the lapse rates in (a) having residual errors > 0.5 Kkm^{-1}. (d) Final lapse rate after filling in with the lapse rate values calculated in the 20° grid box and in the IGBP means.

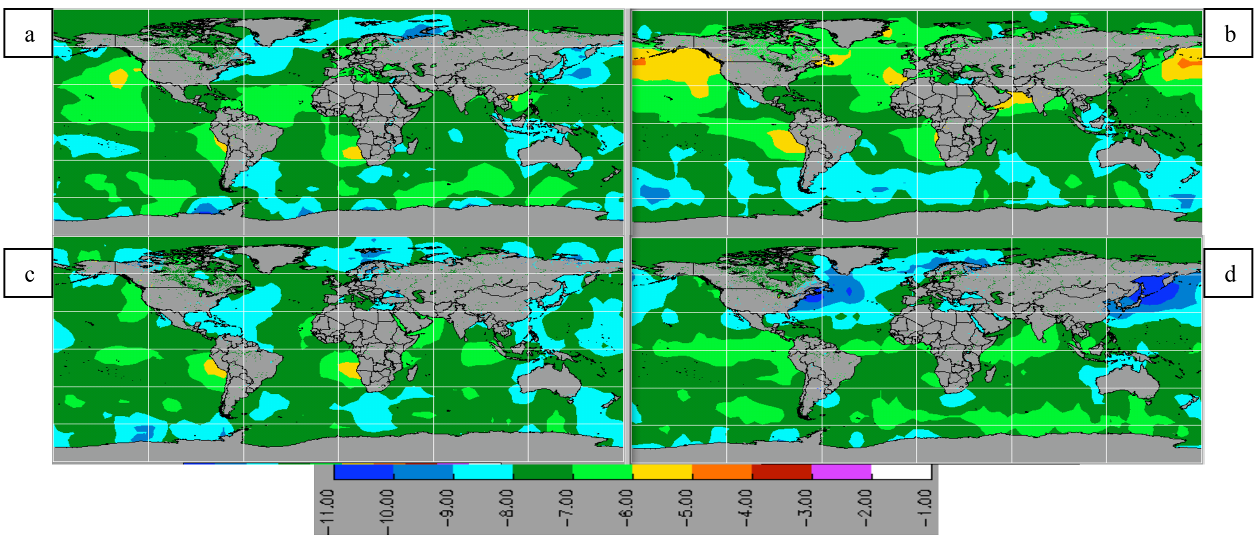

Figure 3. Day time lapse rates over ocean for seasons: spring (a), summer (b), fall (c), and winter (d).

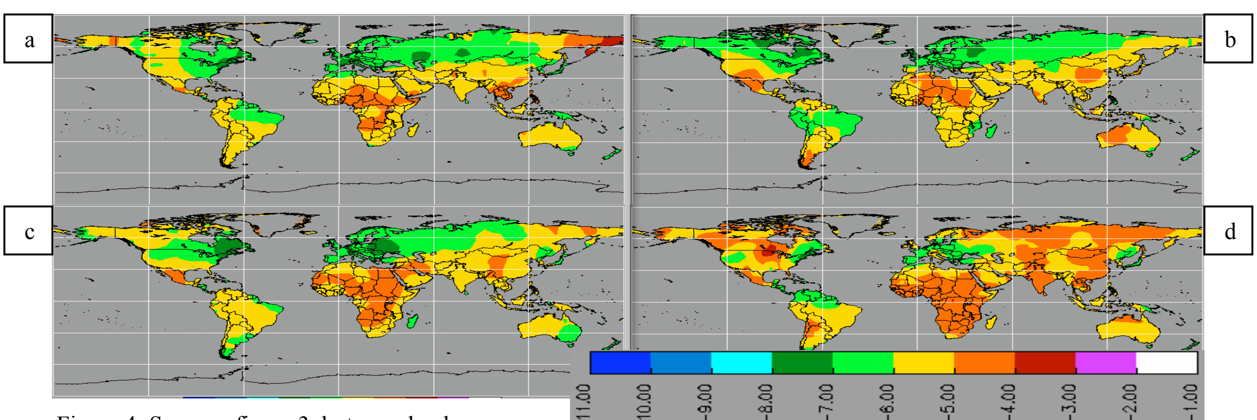

Figure 4: Same as figure 3, but over land.

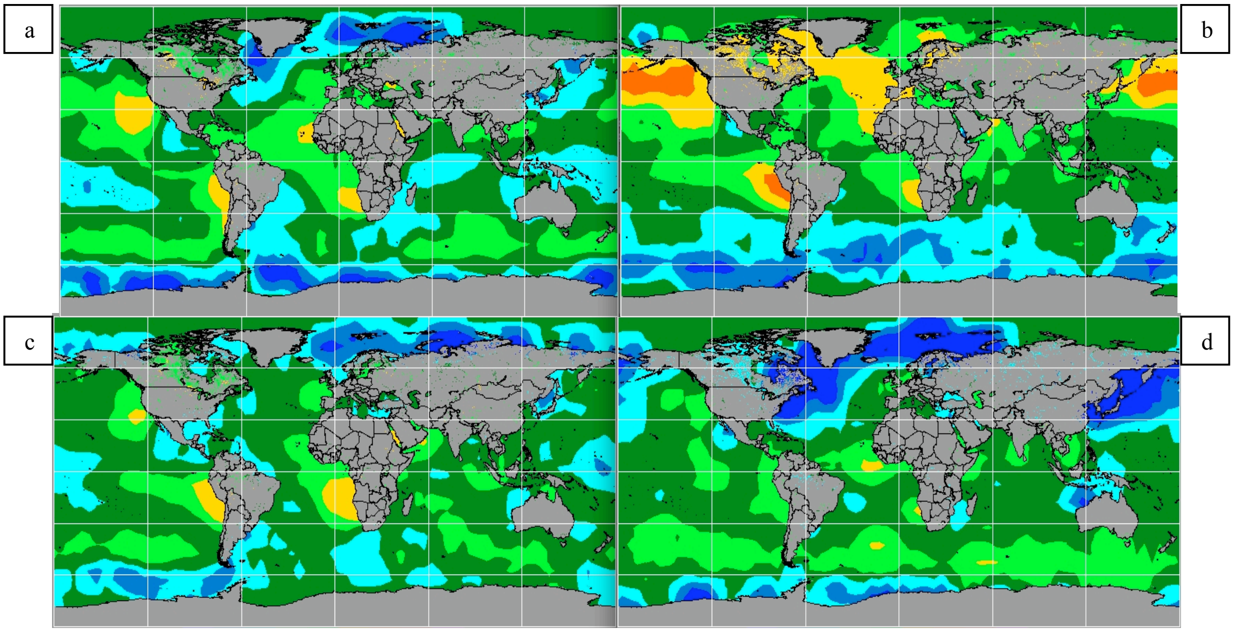

Figure 5. Same as figure 3, but during night time.

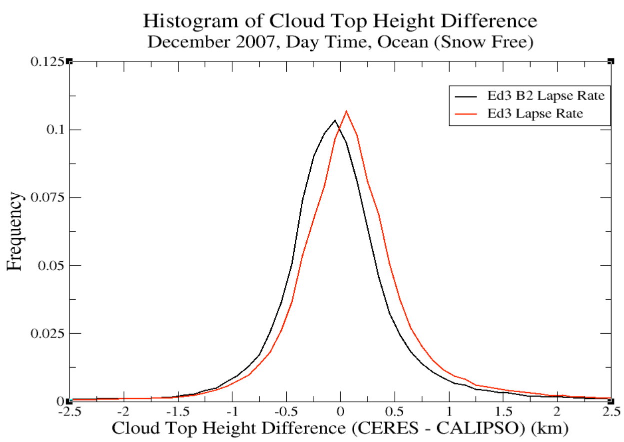

Figure 6. The histogram of cloud top height differences between CALIPSO and CERES-MODIS for day time ocean

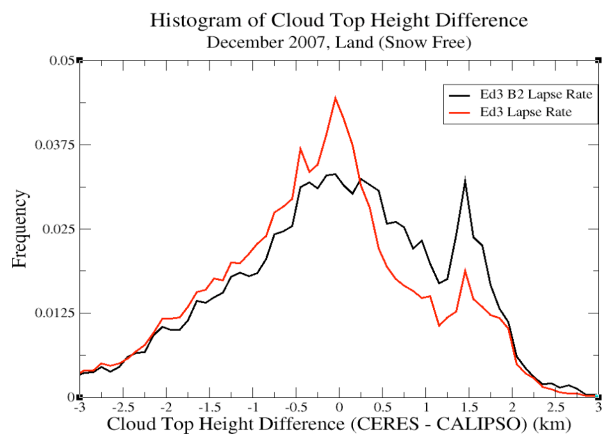

Figure 7. Same as figure 6, but over land.