Assessment of MODIS low-level cloud top height using CALIOP

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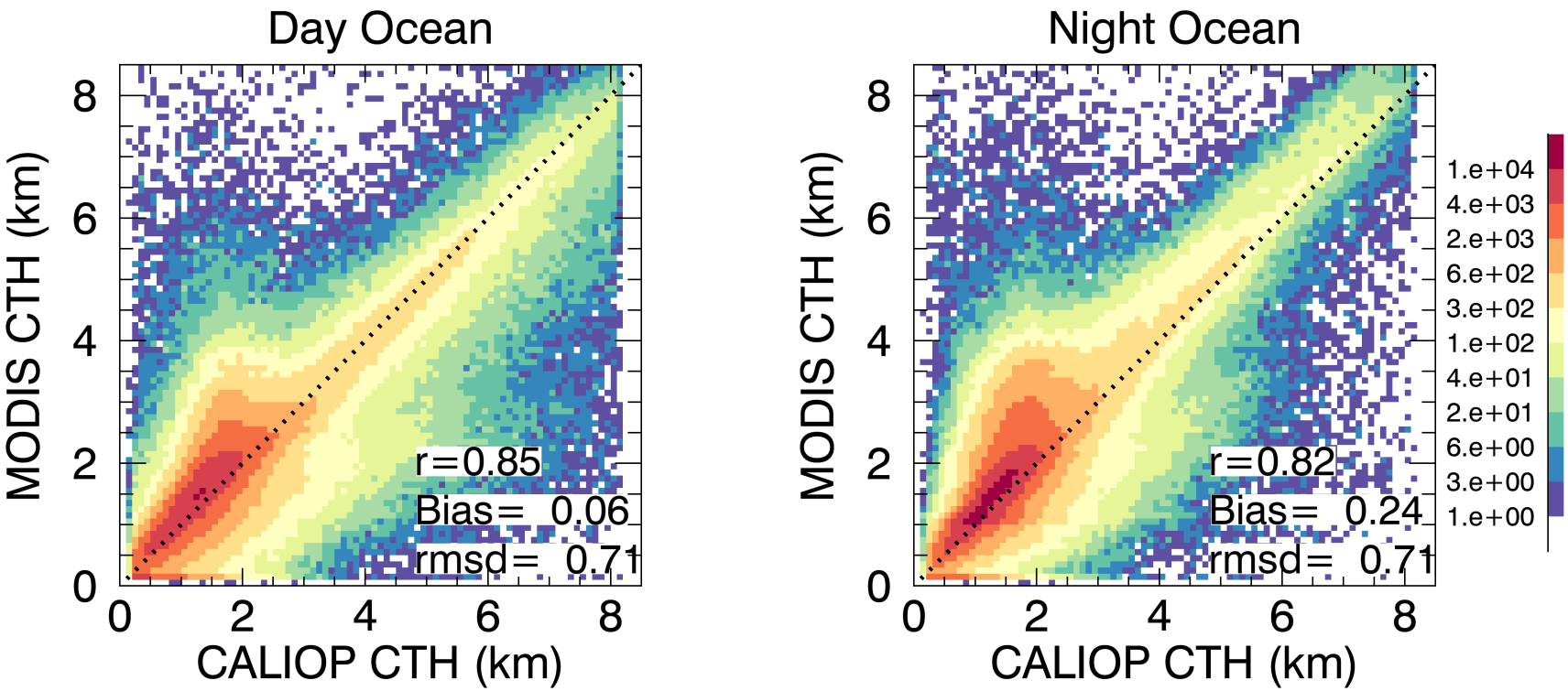
CERES Science Team Meeting April 28-30, 2020

Motivation and goals

1. CERES Edition 4 (Ed4) algorithm for cloud top height (CTH) is based on an empirical lapse rate method derived from regional maps estimated from Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP).
2. Ed4 CTH method is a substantial improvement compared to other standard methods based on matching satellite retrievals with a numerical weather prediction (NWP) temperature profile.

Motivation and goals



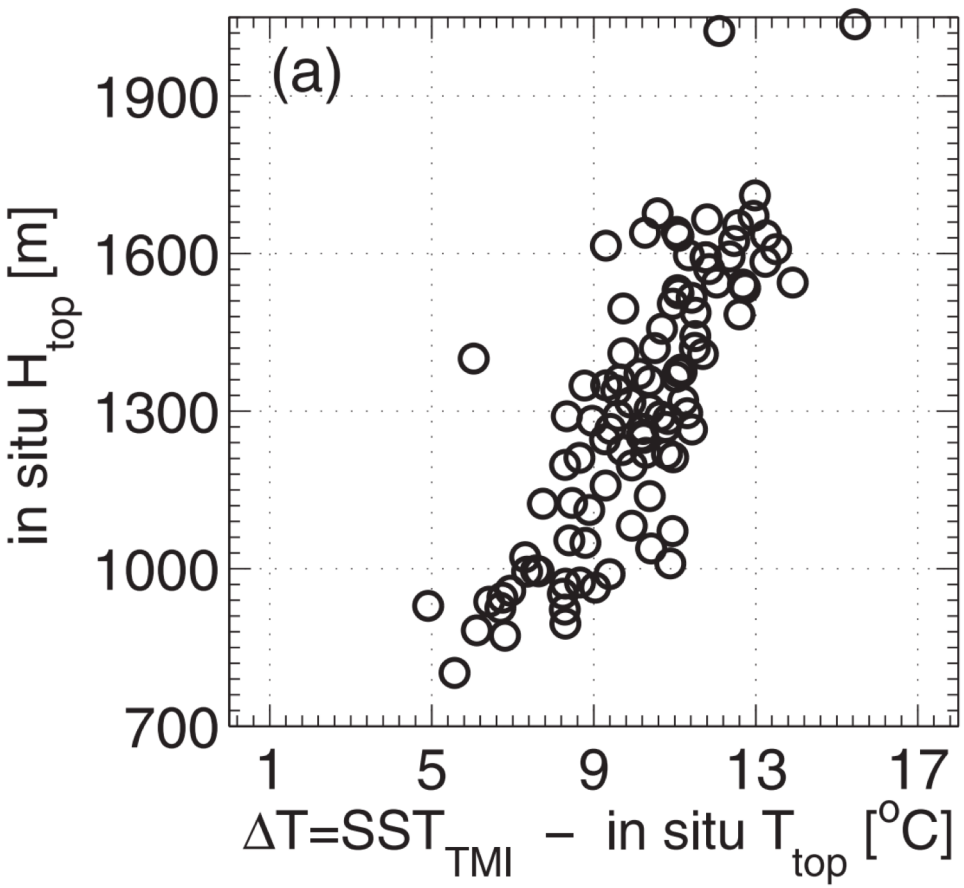
1. However, comparison with CALIOP indicates that at low-levels Ed4 CTH under/overestimates the actual cloud height.
2. Here we explore the possibility of achieving good low-level cloud top height agreement with CALIOP with an alternative simpler method.

CERES Ed4 algorithm

- The method identifies CTH as the lowest level where the cloud top temperature from satellite measurement $T_t = T$ on the temperature profile
- It primarily uses the GEOS-5 temperature profile
- The temperature profile of the boundary layer is modified using a constant apparent lapse rate anchored to the GEOS-5 surface temperature (GMAO GEOS-5 analyses)
- The following rules are applied for the modification of the profile:
  - P1 , P2 (P1 > P2) are two pressure levels dependent on regions
  - P > P1 : use the "apparent boundary layer lapse rate" anchored to the GEOS-5 surface temperature to construct new temperature profile
  - P1 > P > P2 : GEOS-5 temperature profile if less than the adjacent lower level, otherwise linear interpolation is used between T at P1 and P2
  - P < P2 : GEOS-5 temperature profile
- If $T_t > T$ anywhere, CTH = 0.1 km above surface

(*Sun-Mack et al.* 2014)

Motivation: linear relationship between the temperature difference and the cloud-top height



Painemal et al., (2013)
Using VOCALS-REx data

- VOCALS-REx data indicate that a linear regression as a function of ΔT (SST – T_t)can be used to derive stratocumulus CTH.
- A regression implies a variable lapse rate as a function of ΔT

$$H_{\text{top}} = \frac{\Delta T + 2.3}{0.0095} [\text{m}].$$

Based on *Painemal et al.* (2013, JAS), we will attempt to develop regressions that can be applied to CERES-MODIS

Data

- 2018 daytime and nighttime
- CALIOP: 1/3 km horizontal average cloud top height, overcast single-layer water cloud top < 3 km
- MODIS : Ed 4 cloud top height (H < 3 km); effective radiating temperature at the cloud top
- MERRA-2: Surface skin temperature, 1 hourly, 0.5 $^{\circ}$ x 0.625°
- Data are matched to CALIOP by using the nearest available value

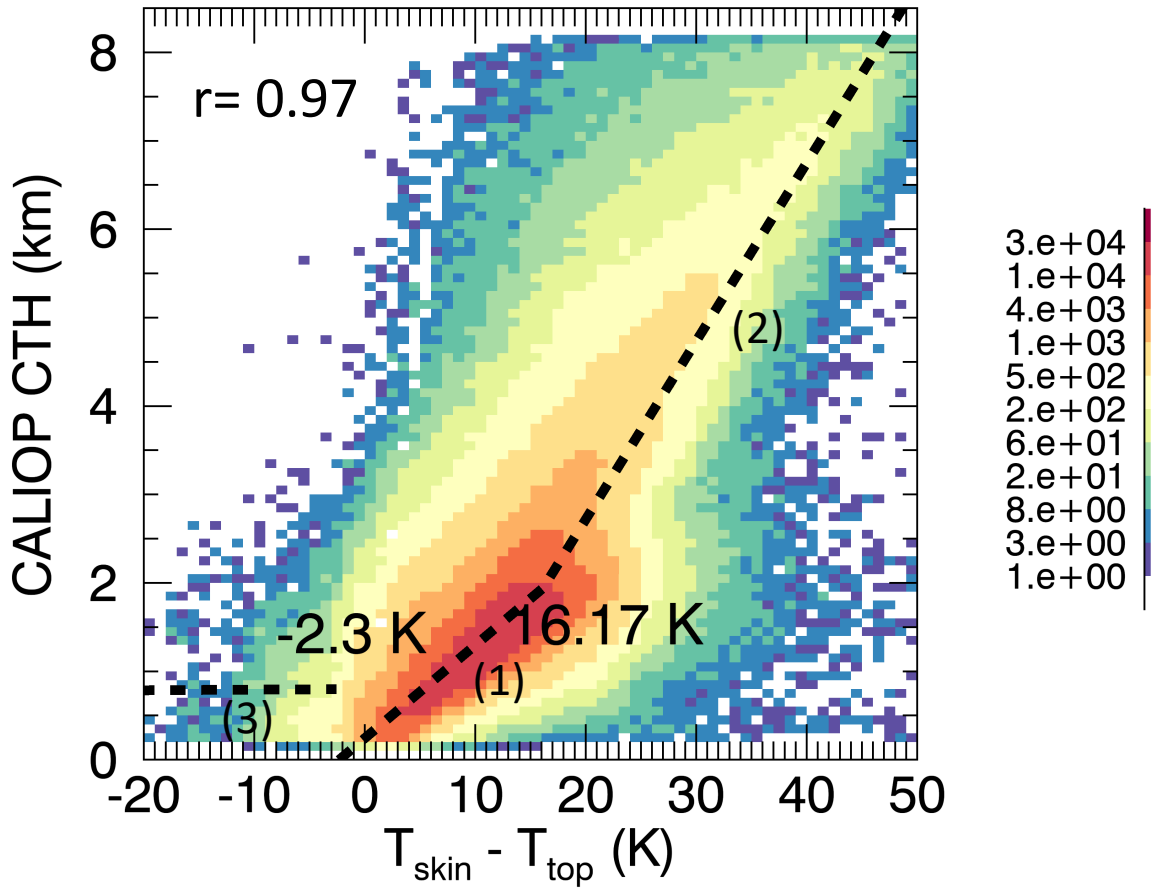
Ice-free ocean: linear regression for new CTH

$$CTH = \frac{\Delta T + 2.3}{0.0095} \text{ (m)} \qquad (1)$$

$$CTH = \frac{\Delta T - 6.53}{0.00496} \text{ (m)} \qquad (2)$$

$$CTH = \frac{\Delta T + 1103}{1.38} \text{ (m)} \qquad (3)$$

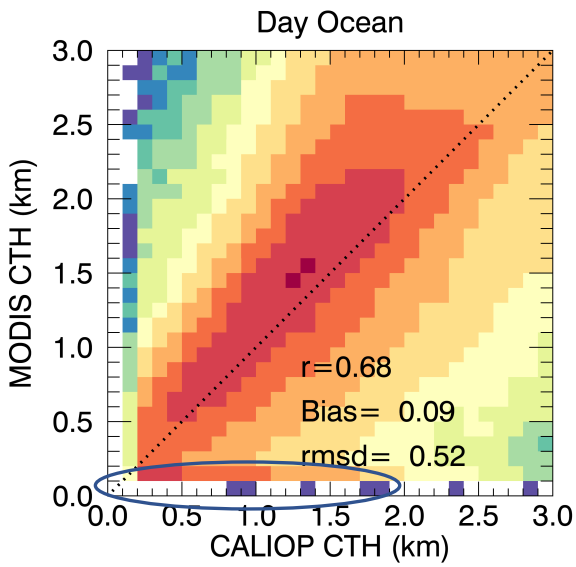
- Use the linear regression from *Painemal et al.* (2013) for $-2.3 < \Delta T < 16.17$ K
- Fit a linear regression for $\Delta T > 16.17$ K and $\Delta T < -2.3$ K, separately, by minimizing the chi-square error

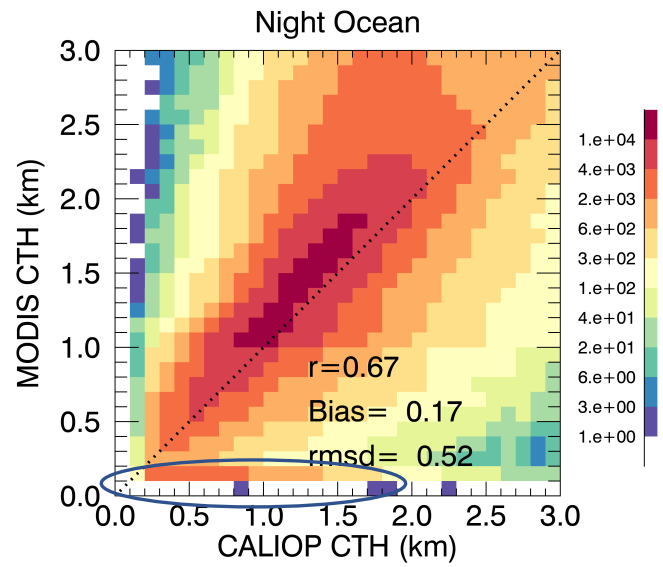


Ice-free ocean: all-year CTH

Ed 4 CTH:

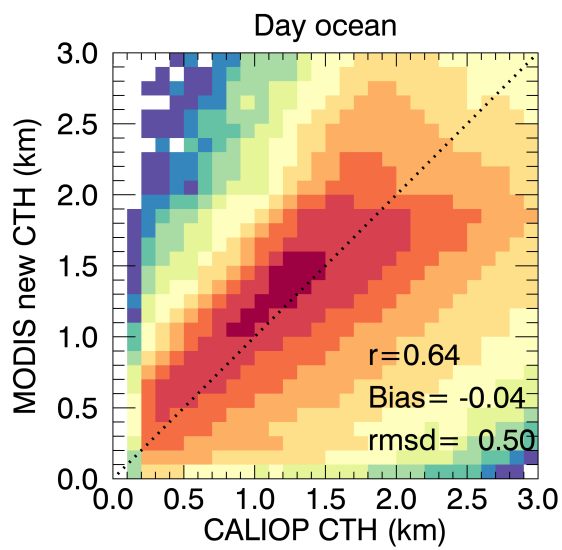
- Overestimate CTH especially for nighttime CALIOP between 1.5 ~ 2 km

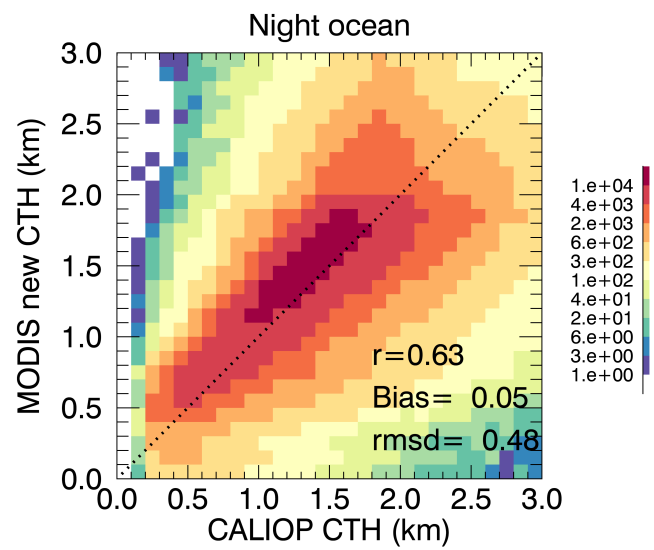




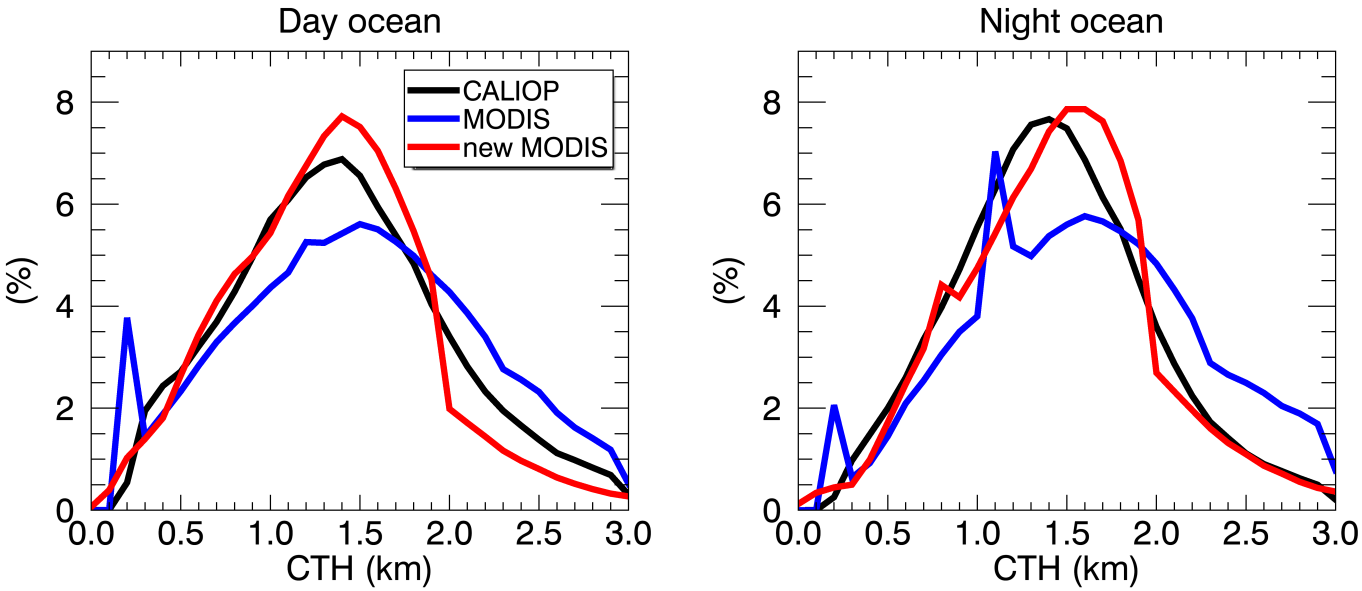
Regression method:

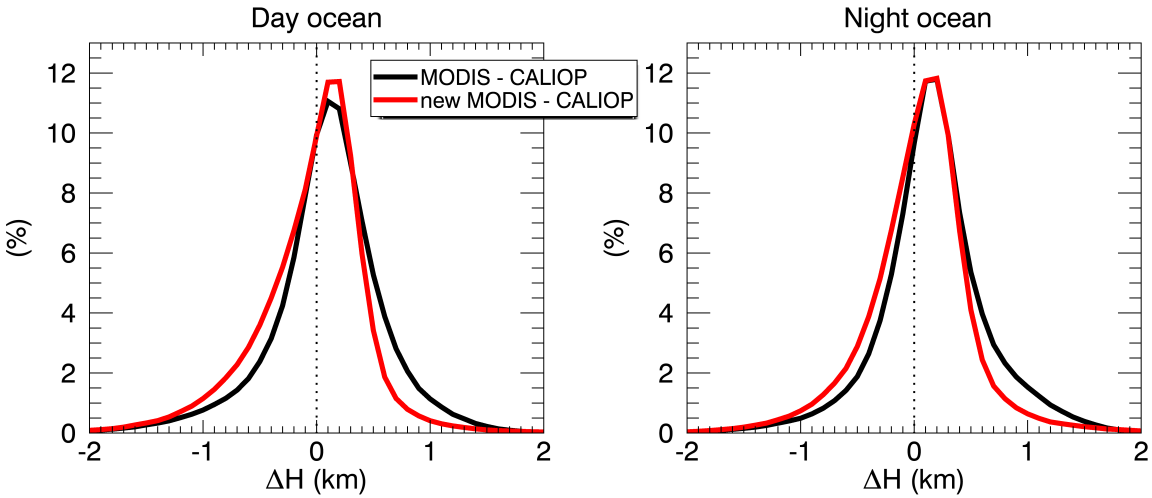
- Smaller bias and slightly smaller rmsd
- No unrealistic cloud heights at 0.1 km
- Underestimate CTH for CALIOP above 2 km





Ice-free ocean: CTH and CTH difference distribution

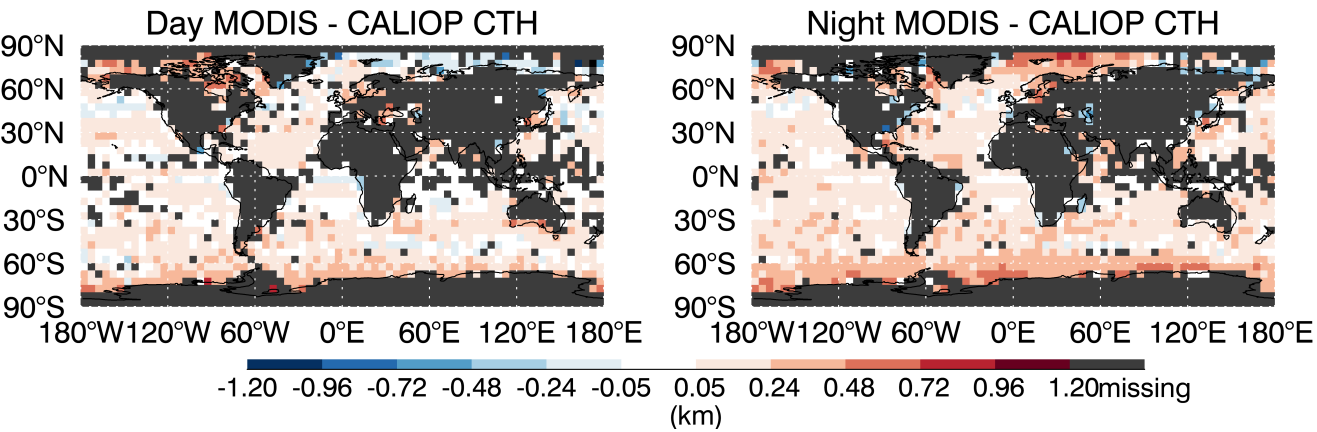


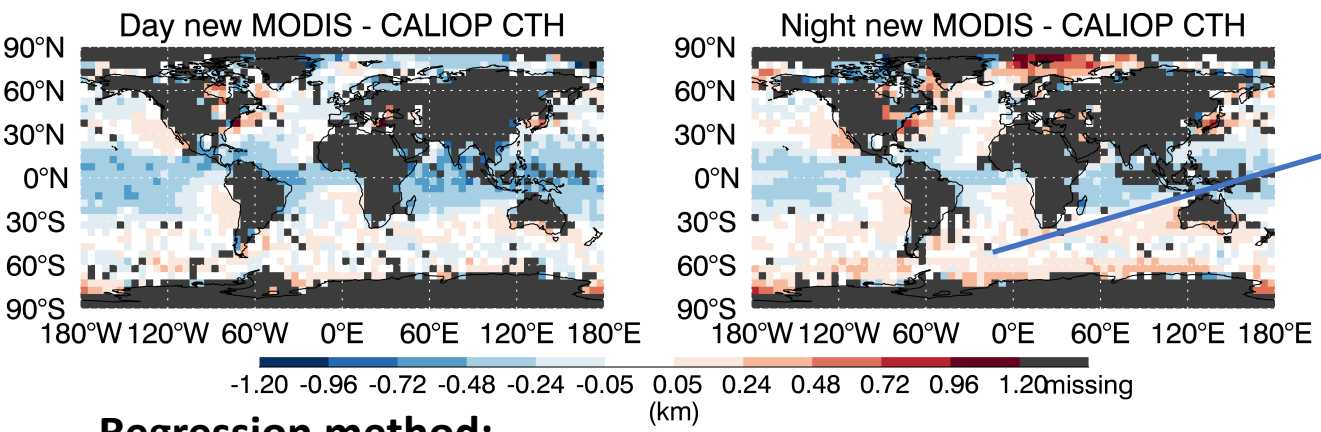


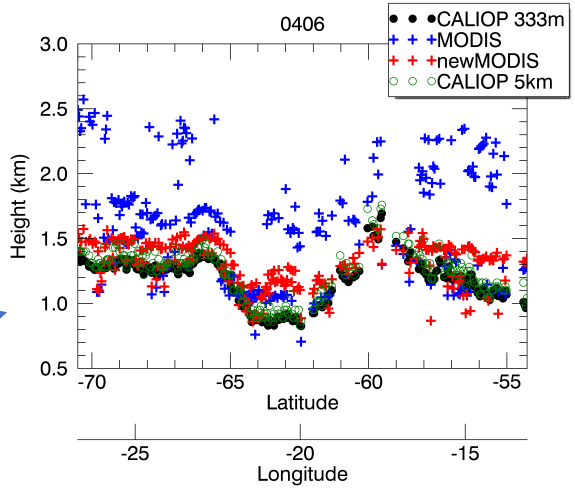
The regression method:

- No CTH peak at 0.1 km
- Less CTH above 2 km
- The difference shifts toward negative values

Ice-free ocean: CTH difference averaged for 5 ° x 5 ° grid







Regression method:

- Significant improvement over the Southern Ocean (stratiform clouds)
- Negative bias over the tropics where cumulus clouds dominate and the CTH are the highest (grid average CTH > 2 km)

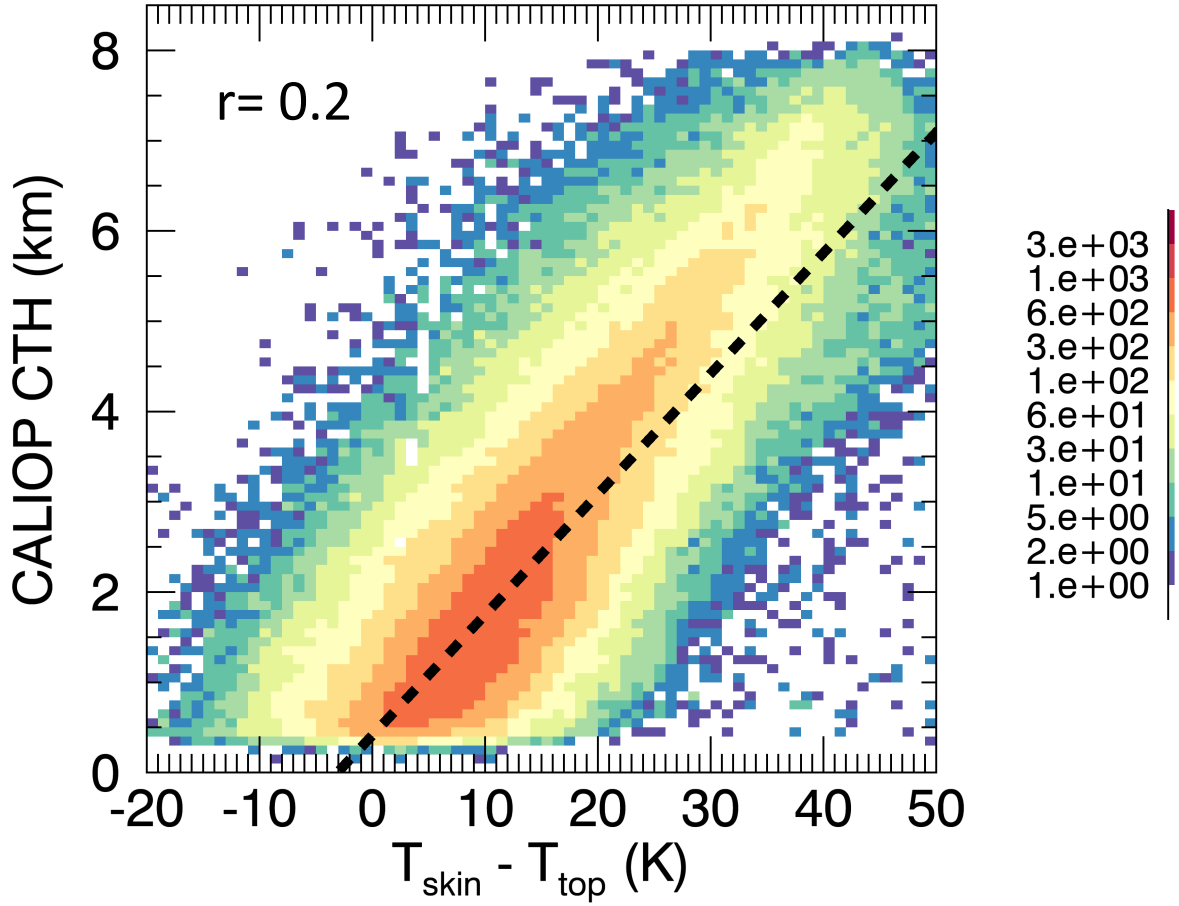
Regression method vs. Ed4 for low-level water cloud top height over ice-free ocean

- Regression method:
  - Simpler approach
  - Does not produce the unrealistic 0.1 km cloud top height
  - Improve the CTH over the Southern Ocean
  - Overall smaller bias and rmsd
- Ed4:
  - Better at identifying CTH over the cumulus dominating tropics

Ice-free land: linear relationship

The relationship is highly scattered with weak correlation

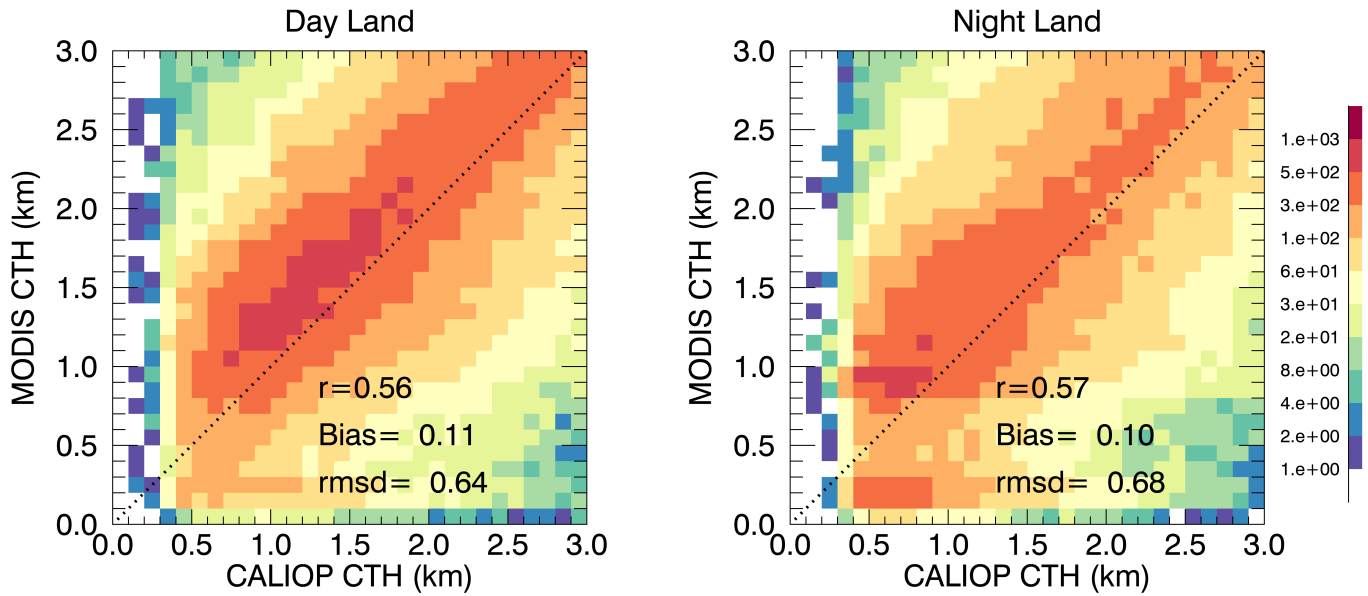
$$CTH = \frac{\Delta T + 3.08}{0.00748} \text{ (m)}$$



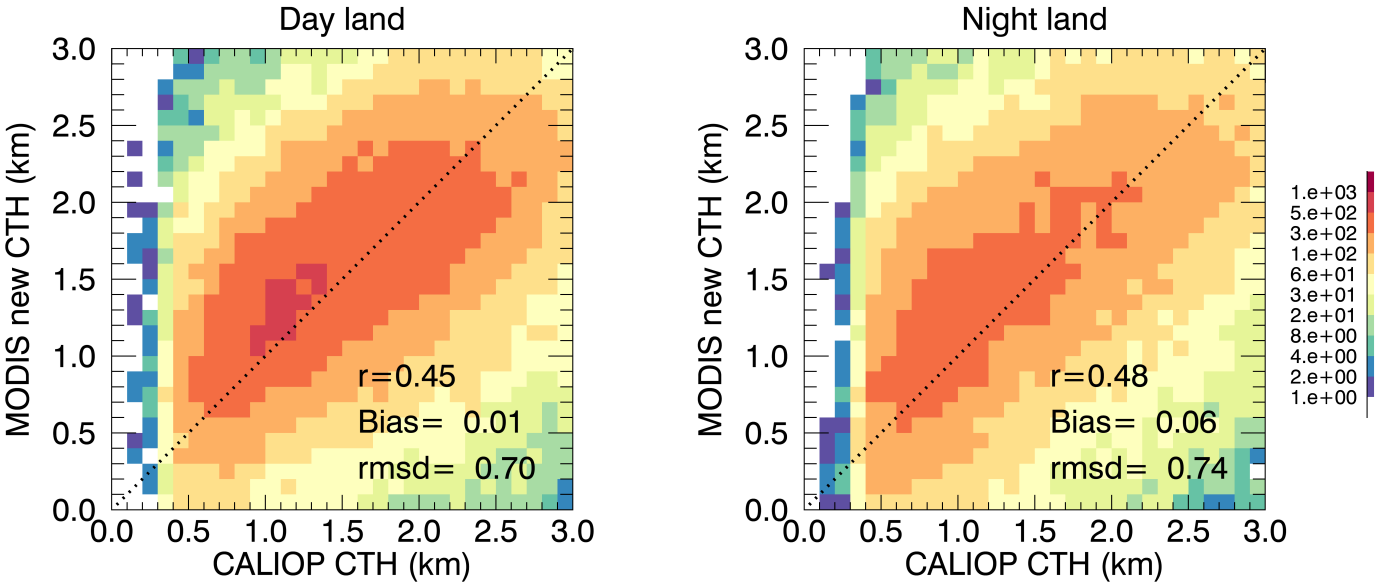
Ice-free land: water cloud top height

Ed 4 CTH:

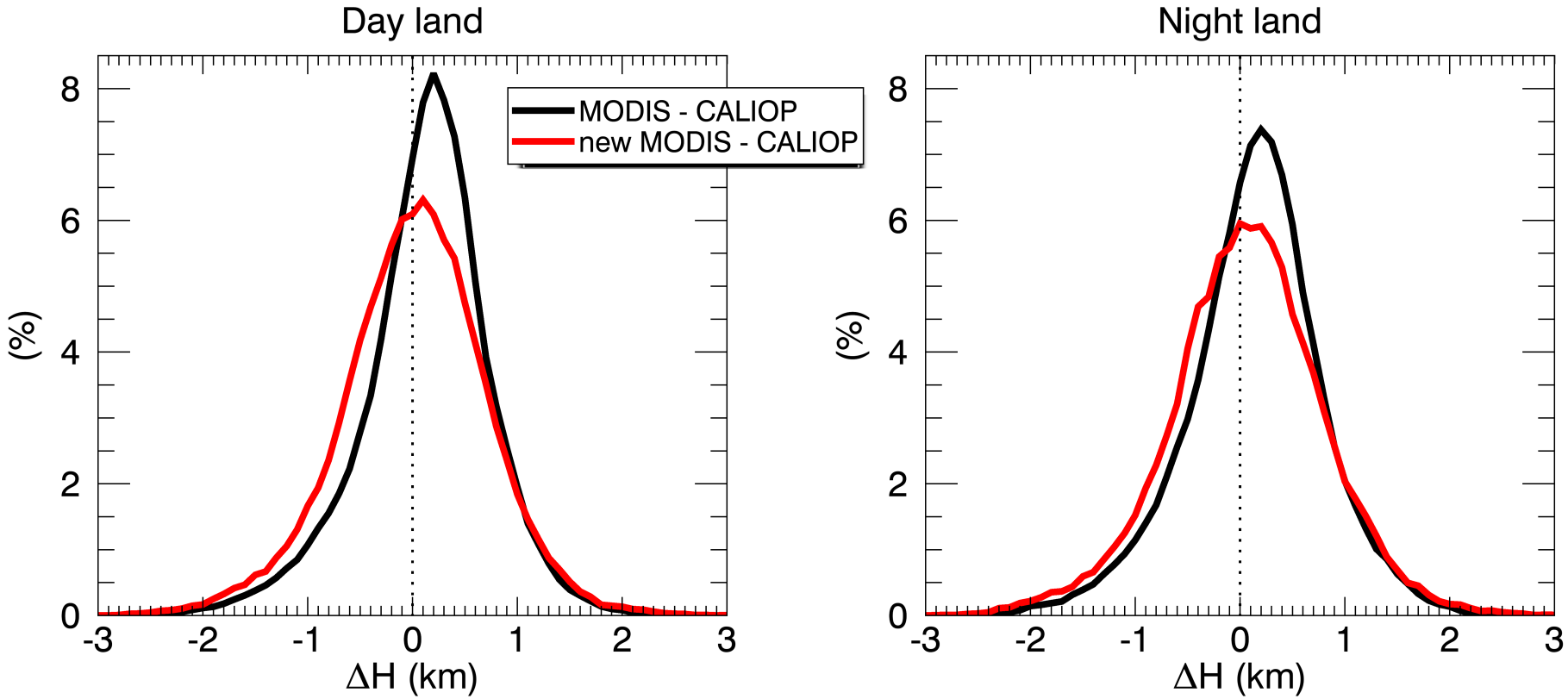
- Stronger correlation
- Smaller rmsd



Regression method:
Smaller bias



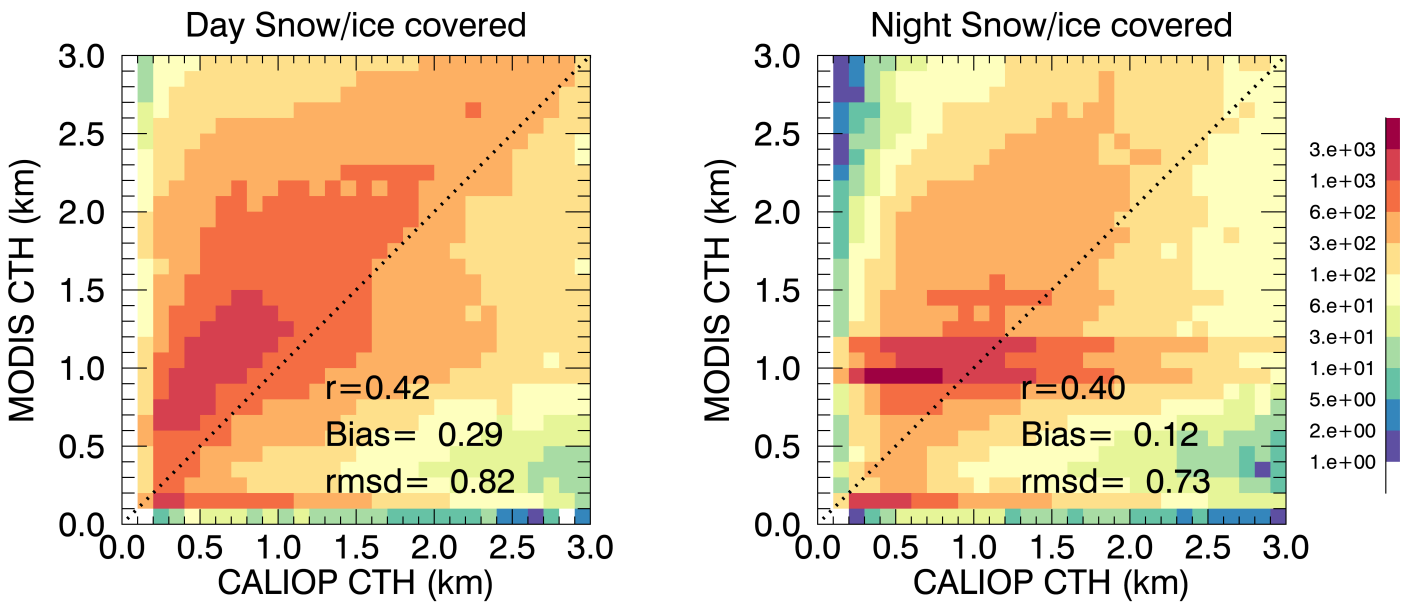
Ice-free land: CTH difference distribution



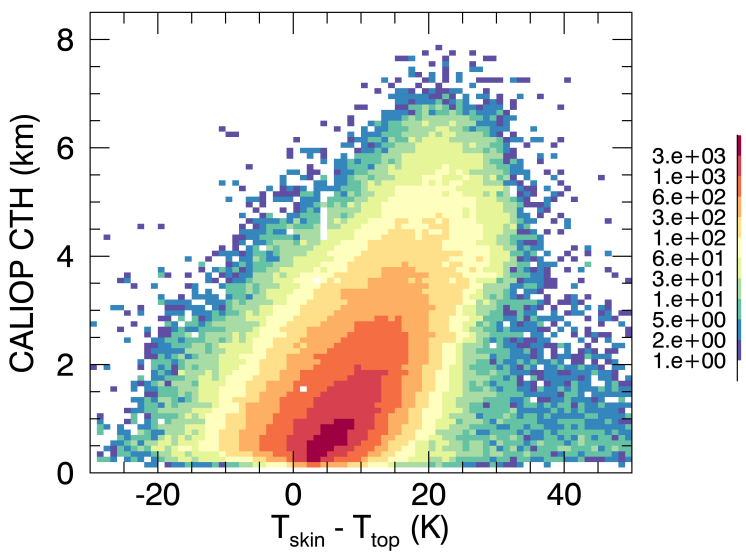
Regression method:

- Wider distribution
- Mode closer to 0

Snow/ice covered surface: Ed4 water cloud top height



- Weaker correlation and larger rmsd than other surface types
- Large positive bias



No significant linear relationship

Summary

- A linear regression method is tested against CALIOP low-level cloud top height, using MODIS cloud top temperature and MERRA2 surface skin temperature
  - The new method does not require the tabulation of regional lapse rate. The regression can be applied to both daytime and nighttime data
  - The new method shows promising results for low-level clouds over the ice-free ocean compared to CERES Ed4
- Over land the regression method does not produce any improvement relative to Ed4.
- Over snow/ice covered surface, the linear relationship is not significant, the MODIS low-level cloud top height has weaker correlation with CALIOP than other surface type, and positive biases greater than 0.1 km.
- The cloud height generated by the regression method could be significant for studying cloud processes