The Nature and Extent of Optically-Thin Low Clouds

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Why study optically-thin low clouds?

Marine low clouds according to MODIS

Cumulative fraction

Cloud Optical Depth

0.1 1 10 100

0.0 0.2 0.4 0.6 0.8 1.0

90 m CALIOP receiver footprint

MODIS pixel 1 km

fraction of pixels

fraction of cloud albedo

? 10 year cdf of cloud optical thickness
Clouds of all sizes contribute significantly to cloud cover

Each decade contributes equally

\[ \frac{dn}{dx} \times \left( \frac{N_{cl,0}}{N_{cl,0}} \right) \]

\[ \beta = 2 \]

…..implies that very small clouds contribute importantly to global cloud cover

…..what about albedo?

See also Wood and Field (2011)
CALIOP Data

- Use CALIOP Vertical Feature Mask (VFM) at highest resolution (90 m FOV, 330 m spacing)
- Only low clouds ($z_{top} < 3$ km) included
- An optically-thin cloud is defined as a cloud detected at full-resolution that does not fully attenuate the lidar signal such that the surface is also detected in the same profile
- For a cloud uniform across the FOV, this would corresponding to cloud optical depth ($\tau_{cld}$) less than 3
- Clouds broken at the FOV scale are also classified as optically thin
Integrated attenuated backscatter

\[ \gamma'_{532 \text{ nm}} = \int_{z_1}^{z_2} \beta'(z) \, dz \]
Optically-thin low cloud ubiquitous

Low Cloud Cover

\( f_{\text{cld}} \quad 0.50 (0.25) \)

Optically-thin Low-Cloud Cover

\( f_{\text{thin}} \quad 0.23 (0.09) \)

Optically-thin fraction of Low Cloud

\( f_{\text{thin,cld}} \quad 0.45 (0.28) \)
Optically thin fraction decreases with cloud cover
Optically thin low clouds are small

- Clouds with >90% optically thin profiles are termed “majority optically thin”
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- Most clouds smaller than a few km consist primarily of optically thin shots
- Clouds > 100 km in length are mainly optically thick
Cloud Length at Median Cloud Cover ($L_{50}$)

- **Most** optically thin low clouds in any given region are significantly smaller than optically thick clouds in that region.
Comparison with Higher Resolution Lidar

- NASA’s airborne High Spectral Resolution Lidar (HSRL).
- 4 spatially and temporally matched HSRL underflights of CALIOP over the tropical and subtropical western Atlantic.
- Temporal coincidence within ± 15 minutes
- HSRL footprint 8 x 60 m, contiguous FOVs
Optically-Thin Fraction as a Function of Scale

Cloud length distribution alone explains three-quarters of the variance in $f_{\text{thin, cld}}$:

$r^2 = 0.73$ domain-wide
$r^2 = 0.77$ over the Tropics

Implies that knowledge of how the marine cloud length distribution varies, is sufficient to predict geographical variation in $f_{\text{thin, cld}}$ across most of the ocean!

$$\tilde{f}_{\text{thin, cld}} = \frac{1}{\int_{L_{\text{min}}}^{L_{\text{max}}} L \, n(L) \, dL} \int_{L_{\text{min}}}^{L_{\text{max}}} f_{\text{thin, cld}}^L \, L \, n(L) \, dL$$
Cloud top heights

Stratocumulus Region

Sc–Cu Region

Cumulus Region

$f_{cld} = 0.78$
$f_{thin,cld} = 0.36$

$f_{cld} = 0.70$
$f_{thin,cld} = 0.37$

$f_{cld} = 0.26$
$f_{thin,cld} = 0.84$
Large Eddy Model

CGILS: CFMIP/GCSS Intercomparison
S6: Trade cumulus regime
6 day runs
(Δx=100m, Δz=40m)
Contribution to albedo

Cumulative contribution to cloud albedo

$\tau=3$

Liquid water path [g m$^{-2}$]
Land and Ocean contrasts

Ocean shows tight coupling between low cloud cover and optically thin fraction of low clouds, whereas land does not.
The Scale of Optically-Thin Clouds

Daytime $L_{50}$

Nighttime $L_{50}$

The Scale of Optically-Thin Clouds

Daytime $L_{50}$

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The Scale of Optically-Thin Clouds

Daytime $L_{50}$

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Conclusions

• Over the non-polar oceans, optically-thin clouds comprise 45% of marine low clouds with cloud top height below 3 km.

• The optically-thin fraction of marine low cloud varies inversely with marine low-cloud cover, and reaches a maximum (> 0.80) in trade wind regions.

• Optically-thin marine low clouds are predominantly small clouds, with many smaller than CALIOP field of view.

• The cloud length distribution of all low clouds explains 3/4 of the geographical variance in the optically-thin fraction of marine low clouds.

• The largest optically-thin clouds are found over land regions, despite lower cloud cover over land.