Build 3D Cloud Properties with A-Train C3M data

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Outline

• Motivation

• 3D-Cloud-Field Construction Algorithm used in C3M data

• Some imagery results of 3D-Cloud-Field

• Examination of MODIS channels used in 3D-Cloud-Field

• Assessment of constructed 3D cloud properties using a month of C3M data

• Summary
Data Used in this study

One month (April 2013) of C3M Pixel Level Data

C3M:
Merged CALIPSO, CloudSat, CERES and MODIS

where
MODIS: CERES derived cloud properties with MODIS data
MODIS: Provides wide Earth coverage, but not clouds distribution in the atmosphere.

CALIPSO: Provides detailed info about clouds, aerosol... in the atmosphere, but much coverage
3D Cloud-Field Construction Algorithm
(Barker et al., 2011, QJRMS)

Cost Function

\[ F(i, j; m) = \sum_{k=1}^{4} \left[ \frac{r_k(i, j) - r_k(m,0)}{r_k(i, j)} \right]^2, \quad m \in [i-100, i+100] \]

1. Donors searching range, \( m \), for each recipient \((i, j)\): \( i - 100 \) ---- \( i + 100 \)

2. Surface types at \((m,0)\) and \((i, j)\) must be same

3. Calculate Cost Function with \( k \) (MODIS channels): 0.6, 2.1, 8.6 and 12 \( \mu \)m

4. Among 3% of the smallest \( F(i, j, m) \), the shortest distance from donor to recipient → final donor for recipient \((i, j)\).

Column:
CALIPSO, CloudSat, CERES and MODIS data
Without 3D:
CERES derived cloud properties with MODIS swath data

With 3D-Orig Chan:
Barker et al., 2011, QJRMS, with original 4 channel:
0.6, 2.1, 8.6 and 12 μm
( Day and Night, Snow / Ice-Free Ocean / Land)
Some 3D Cloud Field Imagery Results
Aqua MODIS
2013 04 01
02h 25min
Pacific Ocean
Day Time
Snow/Ice Free
Ocean

Cloud Phase without 3D
Cloud Phase With-3D using original 4 chan
Aqua MODIS
2013 04  01
02h 10min
Pacific Ocean
Day Time

CALIPSO track

Cloud Phase without 3D

Missed ice clouds. No ice clouds on the track

Cloud Phase with 3D using original 4 chan

water  ice  noRetr  clear
Issues in 8.6 $\mu$m channel
Cloud Phase without 3D
Cloud Phase with 3D using original 4 chan

BTemp (K)
8.6 um
Cloud Phase with 3D using original 4 chan

Aqua MODIS
2013 04 22
00h 10 min

Night Time
With 3D:
Barker et al., 2011, QJRMS, with updated 4 Chan:
- Day Time over Snow / Ice-Free sfc: 0.6, 3.7, 11 and 12 µm
- Day Time over Snow / Ice Covered sfc: 1.24, 2.1, 3.7, and 11 µm
- Night Time over All sfc: 2.1, 11, 12, 13.3 µm

Without 3D: MODIS Swath Cloud Properties Retrieved by CERES Cloud Retrieval

With 3D-Orig Chan:
Barker et al., 2011, QJRMS, with original 4 channel:
0.6, 2.1, 8.6 and 12 µm
( Day and Night, Snow / Ice-Free sfc)
<table>
<thead>
<tr>
<th>Cloud Phase without 3D</th>
<th>Cloud Phase with 3D using original 4 chan</th>
<th>Cloud Phase with 3D</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Legend:
- Blue: Water ice
- Red: NoRetr
- Green: Clear
Zonal Cloud Fraction Difference

C3M, April 2013, Land

Water Clouds, Day Time
Mean (non-polar): -0.0043, 0.0042
Mean (polar): -0.0003, -0.0002

Water Clouds, Night Time
Mean (non-polar): -0.001, -0.001
Mean (polar): -0.003, -0.0018

Ice Clouds, Day Time
Mean (non-polar): -0.0059, -0.0059
Mean (polar): -0.0045, 0.0025

Ice Clouds, Night Time
Mean (non-polar): 0.0031, 0.0036
Mean (polar): -0.0001, 0.0001
3D Cloud Fraction Assessment
### Daytime, Cloud Mask, April 2013, n = 50

<table>
<thead>
<tr>
<th></th>
<th>Without 3D</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With 3D</td>
<td>Clear (%)</td>
<td>Cloud (%)</td>
</tr>
<tr>
<td></td>
<td>Clear (%)</td>
<td>66.41</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td>Cloud (%)</td>
<td>2.56</td>
<td>28.36</td>
</tr>
<tr>
<td></td>
<td>Agreement (%)</td>
<td>94.77</td>
<td></td>
</tr>
<tr>
<td>Ocean (ice-free)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With 3D</td>
<td>Clear (%)</td>
<td>Cloud (%)</td>
</tr>
<tr>
<td></td>
<td>Clear (%)</td>
<td>48.65</td>
<td>3.26</td>
</tr>
<tr>
<td></td>
<td>Cloud (%)</td>
<td>3.28</td>
<td>44.81</td>
</tr>
<tr>
<td></td>
<td>Agreement (%)</td>
<td>93.46</td>
<td></td>
</tr>
<tr>
<td>Land (snow-free)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With 3D</td>
<td>Clear (%)</td>
<td>Cloud (%)</td>
</tr>
<tr>
<td></td>
<td>Clear (%)</td>
<td>46.07</td>
<td>3.04</td>
</tr>
<tr>
<td></td>
<td>Cloud (%)</td>
<td>3.38</td>
<td>47.51</td>
</tr>
<tr>
<td></td>
<td>Agreement (%)</td>
<td>93.58</td>
<td></td>
</tr>
<tr>
<td>Snow / Ice covered sfc</td>
<td>Without 3D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With 3D</td>
<td>Clear (%)</td>
<td>Cloud (%)</td>
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n = Number of MODIS pixels or distance (km) from track that 3D cloud field is built on

CALIPSO Track

< 101 pixels >
Cloud Mask Agreement between 3D and without 3D

Cloud Mask Agreement between with-3D and without-3D, as a function of n (distance from track).

Mask:
- Agreement > 92% for all n’s for all sfc types except night time over snow-ice
- Night time over snow-ice, agreement ~ 90% n=5, ~87% n=25 and drops to 85% when n=50
April 2013, **Day Time, Ice-Free Ocean**

Cloud Fraction

- Agree well for all n’s, for altitude < 16 km

- z > 16 km, agree to some degree for n < 30, disagreement increases with increasing n

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**Eff Cloud Height (km)**

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Without 3D    With 3D
Cloud Fraction Comparison (with-3D and without-3D) as a function of cloud altitude

<table>
<thead>
<tr>
<th></th>
<th>Day Time</th>
<th>Night Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean (Ice-Free)</strong></td>
<td>• $z &lt; 16$ km, agree well for all n’s</td>
<td>• Similar as for day time</td>
</tr>
<tr>
<td></td>
<td>• $z &gt; 16$ km, agree to some degree for n &lt; 30, disagreement increases with increasing n</td>
<td></td>
</tr>
<tr>
<td><strong>Land (Snow-Free)</strong></td>
<td>• $3 &lt; z &lt; 6$ km, 3D slightly under detected clouds for all n’s (1-2%)</td>
<td>• $5 &lt; z &lt; 16$ km, disagree somewhat for all n’s, less than 1%, under detected</td>
</tr>
<tr>
<td></td>
<td>• $z &gt; 16$ km, somewhat over detected (~1%)</td>
<td>• $z &lt; 5$ km, good agreement for all n’s</td>
</tr>
<tr>
<td></td>
<td>• rest of $z$, good agreement for all n’s</td>
<td>• $z &gt; 16$ km, agree well for n &lt; 30</td>
</tr>
<tr>
<td><strong>Snow-Ice Covered Sfc</strong></td>
<td>• $z &lt; 4$ &amp; $z &gt; 14$ km, agree well for ~ all n’s</td>
<td>• $z &lt; 13$ km, agree well for all n’s, ~</td>
</tr>
<tr>
<td></td>
<td>• $4 &lt; z &lt; 14$ km, small disagreement for ~ all n’s, almost no bias</td>
<td><strong>$z &gt; 13$ km, large disagreements occur for all n’s.</strong></td>
</tr>
</tbody>
</table>
• Night time 3D does not use 3.7 µm.

• 3D clouds are more correct than without 3D.

Without 3D

3.7 BTemp striping

With 3D

3.7 µm BTemp

striping -->

striping in cloud mask
3D Cloud Property Assessment
Cloud Phase Agreement between 3D and without 3D

**Day Time**

- Ice-free ocean
- Snow-free Land
- Snow & Ice

**Night Time**

- Ice-free ocean
- Snow-free Land
- Snow & Ice

Cloud Phase Agreement between with-3D and without-3D, as a function of n (distance from track)

Cloud Phase:
- Day time agreement > 87% for all n’s for both snow free and snow ice covered scenes.
- Night time over snow-ice, agreement > 91% for n=50, ~86% for snow-free surfaces
Histogram of Eff Cloud Height Diff (with-3D – without-3D)

Mean diff (km):
-0.028 (1.18)
-0.028 (1.57)
-0.001 (1.11)

Mean diff (km):
-0.014 (1.34)
0.001 (1.80)
0.003 (1.25)

No bias between with 3D and without 3D
Day Time
Histogram of Particle Size Difference (with-3D – without-3D)

- No bias in water radius between 3D clouds and without-3D clouds
- Bump in water radius at diff ~ 3.3 µm over snow-ice

- Not much bias in ice radius over ocean
- A little questionable over land, 2 bumps, 3D Re smaller
- Wide spread in Ice radius diff over snow-ice surfaces
ISCCP regions 1: **Thin Optical Depth** 0 --- 3.6
2: **Medium Optical Depth** 3.6 --- 23
3: **Thick Optical Depth** 23 --- 150
April 2013, **Day Time, Ice-Free Ocean**, COD: 0 – 3.6

- Excellent agreement for all n’s, at almost all altitudes

Optical Depth
# Cloud Optical Depth Comparison (with-3D and without-3D) as a function of cloud altitude

<table>
<thead>
<tr>
<th></th>
<th>Thin COT &lt; 3.6</th>
<th>Medium COT 3.6 -- 23</th>
<th>Thick COT 23 -- 150</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean (Ice-Free)</strong></td>
<td>• Excellent agreement for all n’s, at almost all altitudes</td>
<td>• Excellent agreement for all n’s, at almost all altitudes</td>
<td>• Excellent agreement for all n’s, at almost all altitudes</td>
</tr>
<tr>
<td><strong>Land (Snow-Free)</strong></td>
<td>• z &lt; 16 km, excellent agreement for all n’s, at almost all z</td>
<td>• Excellent agreement for all n’s, at almost all altitude</td>
<td>• Excellent agreement for all n’s, at almost all altitudes</td>
</tr>
<tr>
<td>• For z &gt; 16 km, disagreements occur for all n’s, worse as n increases, 3D being a slightly thicker</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Snow-Ice Covered Sfc</strong></td>
<td>• z &lt; 13 km, excellent agreement</td>
<td>• z &lt; 13 km, excellent agreement</td>
<td>• 3D clouds thinner at all altitudes for all n’s. <strong>3D being thinner by 2 - 10</strong></td>
</tr>
<tr>
<td>• z &gt; 13 km, a constant COT difference, ~0.3, for all n’s, <strong>3D being thinner by ~ 0.3</strong>.</td>
<td>• z &gt; 13 km, good agreements for n &lt; 20. Disagreement increases as increasing n (n &gt; 20), <strong>3D thinner by ~ 1-2</strong></td>
<td>• z &gt; 12 km, large disagreements occur for all n’s, much thinner. <strong>3D being much thinner</strong></td>
<td></td>
</tr>
</tbody>
</table>
April 2013, Day Time, Snow / Ice Covered, COD: 23 – 150

Optical Depth

3D (red) thinner for all z and all n
much thinner for z < 12 km
Summary

Overall, 3D Cloud Field Algorithm (Barker et al. 2011) works quite well. The agreement of cloud properties (mask, COT, height, sizes) between 3D cloud field and MODIS cloud is very good globally (~ the same as that between CALIPSO and MODIS).

1. Overall, n = 30 is probably a safe choice. C3M pixel level data will have n = 50. Users can choose their own n.

2. For ice clouds during night time over snow-ice (z > 12 km), 3D cloud mask has completely different clouds compared with CERES-MODIS clouds. Might not be 3D issue → likely caused by 3.7 µm striping used in CERES-MODIS cloud mask.

3. Cloud mask, phase, optical depth and height compare well. Overall 3D clouds over snow-ice are thinner → could it caused by CERES-MODIS uses 1.24 µm for optical depth over snow and ice, which is larger than visible optical depth?