PACE OCI
cloud algorithms

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With thanks to decades of hard work by the MODIS team and others
This lecture

• Why?
• OCI cloud products and processing flow
• Algorithms
  • Cloud mask
  • Cloud top pressure/height
  • Cloud optical properties
... to know where clouds are not

... to understand Earth’s radiation balance and climate

... for forecast and hazard tracking
Clouds don’t all look the same

### Geophysical product

<table>
<thead>
<tr>
<th>Geophysical product</th>
<th>Acronym</th>
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<tbody>
<tr>
<td>Cloud mask</td>
<td>-</td>
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<tr>
<td>Cloud optical thickness at mid-visible wavelengths</td>
<td>COT</td>
</tr>
<tr>
<td>Cloud droplet size distribution effective radius</td>
<td>CER</td>
</tr>
<tr>
<td>Cloud top pressure, height, temperature</td>
<td>CTP, CTH, CTT</td>
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<tr>
<td>Cloud phase</td>
<td>-</td>
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<tr>
<td>Liquid/ice water path</td>
<td>LWP/IWP (CWP)</td>
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</table>

- **Where** are the clouds?
- **How strongly** do they scatter and absorb light?
- **How large** are the droplets within the clouds?
- **How high** up are the tops of the cloud?
- Are they made of **liquid** or **ice**?
- **How much water** is in them?
Overall processing flow is MODIS/VIIRS-like

Cloud mask

Cloud altitude & phase

COT, CER, phase

Water path

MODIS/VIIRS heritage

Multispectral grouped threshold tests

Thermal brightness temperatures & meteorological profile

Bispectral retrieval (Nakajima-King) aka CHIMAERA code

One-line calculation (with assumptions on vertical structure)

PACE OCI at-launch approach

Multispectral grouped threshold tests or neural network

O₂ A-band inversion & meteorological profile
Obtain an estimate of whether a pixel is covered by clouds or not

- A *categorical* cloud mask
  - Confidently cloudy
  - Probably cloudy
  - Probably clear
  - Confidently clear

- Further processing for some applications
  - Combine categories to give a *binary* mask
  - Add an *adjacency* barrier
We need statistics of cloudy and cloud-free scenes to inform appropriate thresholds.

• Inputs could be theoretical, from similar sensors and algorithms, or from human-labelled data.

• Overlapping distributions signal ambiguity.

• We use published MODIS thresholds directly.

From MOD35 ATBD [here](#).
Use thresholds as bounds to define a ‘probability of clear sky’ for each test

From MOD35 ATBD [here](#)
Combine result from similar tests to get an overall probability of cloudiness

- **Group I (Simple IR threshold test)**
  - $BT_{11}$
  - $BT_{13.9}$
  - $BT_{8.7}$
  - Surface Temperature

- **Group II (Brightness temperature difference)**
  - $BT_{8.6} - BT_{11}$
  - $BT_{11} - BT_{12}$
  - $BT_{3.3} - BT_{11}$
  - $BT_{11} - BT_{3.9}$
  - $BT_{8.6} - BT_{3.3}$

- **Group III (Solar reflectance tests)**
  - $R_{0.65}$ or $R_{0.86}$
  - $R_{0.86}/R_{0.65}$

- **Group IV (NIR thin cirrus)**
  - $R_{1.38}$

- **Group V (IR thin cirrus)**
  - $BT_{3.9} - BT_{12}$

- **Determine the lowest probability** of clear-sky conditions from tests in each group
- **Combine** results from multiple groups
- **Q score** determines pixel category

From MOD35 ATBD [here](#)
Lack of thermal bands means majority of MODIS/VIIRS heritage tests are inapplicable

- Determine the lowest probability of clear-sky conditions from tests in each group
- Combine results from multiple groups
- Q score determines pixel category

From MOD35 ATBD [here](#)
Solar-only works quite well over water, less over land.
Obtain an estimate of the altitude of the top of the cloud

- OCI is sensitive to pressure (CTP)
  - Coordinate transform to height (CTH) and temperature (CTT) with meteorological profiles
- New algorithm based on O₂ A-band absorption
OCI samples strong $\text{O}_2$ absorption features

- Combine *window* channels near $\text{O}_2$ absorption band with channels *inside* it
  - $\text{O}_3$ absorption is weak; need to avoid $\text{H}_2\text{O}$ features
  - Short spectral range means cloud, aerosol, surface properties are fairly flat
The A-band signal is sensitive to COT, surface albedo, and cloud vertical structure

- **Simultaneously** retrieve COT, CTH, and surface albedo
  - Strong albedo prior constraint
- Assume other quantities
  - Cloud vertical structure, aerosol, etc
- Estimate cloud phase by running retrieval for *both liquid and ice* and see what fits best

*Aug 3 2022*
Sentinel-3 OLCI is a useful OCI proxy for this algorithm

- Similar capabilities within the A-band
- Similar pixel size
- Can evaluate algorithm prior to launch
Cloud optical properties
Obtain estimates of cloud light extinction, cloud droplet particle size, and total amount of water

- Use CHIMAERA code from MODIS/VIIRS group
  - Retrieve COT, CER, and phase estimate
  - Derive LWP/IWP

- Last in processing chain:
  - Needs cloud mask to *identify pixels*
  - Needs CTH for *trace gas correction*
  - Benefits from altitude *phase estimate*


Aug 3 2022 PACE class 2022
The bispectral approach has >30 years heritage

- Bispectral approach (Nakajima-King)
  - 650 or 865 nm where cloud absorption is negligible
  - 1.6, 2.1, or 2.2 μm where cloud absorption is significant
- Assume surface albedo known

From Platnick et al., *IEEE* (2017)
Different swIR bands have different penetration depths

• Photon penetration depth depends on cloud water absorption
• Multiple retrievals inform on cloud *vertical structure*
  • PACE OCI is first time we’ll have 2.1 and 2.2 μm together
  • Won’t have 3.7 μm

From Platnick *JGR* (2000)
Summary

• Cloud remote sensing from passive multispectral imaging has a long history

• PACE OCI will mostly rely on MODIS/VIIRS heritage approach at launch
  • Threshold-based cloud masking
    • Neural network in development as an alternative
  • Cloud top pressure is a new retrieval using absorption in O2 A-band channels
    • Necessary because no thermal infrared bands on OCI
    • Heritage on European sensors and EPIC
  • Running the CHIMAERA code for optical properties

• All processed on single pixels at a time
References and resources

- Satellite imagery (true-colour and level 2) is MODIS and VIIRS on July 21 2022, mostly from https://worldview.earthdata.nasa.gov

- MODIS/VIIRS heritage cloud mask

- CHIMAERA code and related papers

- Cloud top pressure