PACE Multi-angle polarimetry update
Kirk Knobelspiesse
PACE Science & Applications Team meeting
October 7, 2021

1. Algorithm development
   a) Overview
   b) Data product selection process
   c) Documentation
   d) Validation
2. Simulator and synthetic data production
3. Project science activities
4. Presentations
5. Frontiers journal special issue
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## Algorithm development status

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>RemoTAP-ocean</th>
<th>RemoTAP-land</th>
<th>GRASP</th>
<th>MAPP</th>
<th>Liquid Cloud</th>
<th>Ice Cloud</th>
<th>Ocean Ref. Idx.</th>
<th>FastMAPOL</th>
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<tbody>
<tr>
<td>Sensor(s)</td>
<td>SPEXone</td>
<td>SPEXone</td>
<td>HARP2</td>
<td>HARP2, SPEXone, OCI</td>
<td>HARP2</td>
<td>HARP2, SPEXone</td>
<td>HARP2</td>
<td>HARP2</td>
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<td>Atmosphere: aerosol optical properties</td>
<td>coarse mode AOD</td>
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<tr>
<td>Ocean optical properties</td>
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<td>Other</td>
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<td></td>
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<td>water refractive index</td>
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</table>

**Team**

<table>
<thead>
<tr>
<th>Team</th>
<th>SPEXone team</th>
<th>SPEXone team</th>
<th>HARP2 team</th>
<th>Stamnes / Chowdhary / van Dierdenhoven / van Dierdenhoven / Geogdzhayev / Geogdzhayev</th>
<th>Ottaviani</th>
<th>PACE project (Gao)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

**Data product selection status**

- SOT initiated, SRON data processing review passed, code being tested at GSFC
- SOT initiated, SRON data processing review passed, code being tested at GSFC
- SOT first meeting discussion
- SOT initiated, code being tested at GSFC

**Product change request form submitted**

- yes
- yes
- no
- no
- no
- no
- no
- yes
- yes

**PADD created**

- no
- no
- no
- no
- no
- no
- no
- no
- no

See individual PI presentations for more details.
Making an algorithm? Start the data product selection process!

- First submit a “Science Product Change Request” then have a review by the Science Operations Team (SOT). They start the process of implementation and testing.
- Science Operations Board (SOB) approves when ready.
- Also needs a Product and Algorithm Description Document (PADD, like ATBD, but as a living document).
- So far, we have started the process for
  - RemoTAP: the SRON/SPEXone aerosol algorithm
  - FastMAPOL: the project science aerosol algorithm (Meng Gao)
  - PI Matteo Ottaviani for his ocean refractive index algorithm.
Product and Algorithm Description Document (PADD) example

Diffuse attenuation coefficient for downwelling irradiance at 490 nm (Kd_490)

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1 - Product Summary

This algorithm returns the diffuse attenuation coefficient for downwelling irradiance at 490 nm (Kd_490) in m⁻¹, calculated using an empirical relationship derived from in situ measurements of Kd_490 and blue-to-green band ratios of remote sensing reflectances (Rs).

Implementation of this algorithm is contingent on the availability of Rs in the blue-green spectral region (e.g., 490 - 565 nm), CZCS, OCTS, MODIS-Aqua and -Terra, MERIS, SeaWIFS, VIIRS, and others are all supported.

Algorithm Point of Contact: P. Jeremy Werdell, NASA Goddard Space Flight Center

Z - Algorithm Description

Inputs:

K0, near 490 nm and between 547 and 555 nm

Output:

Kd_490, diffuse attenuation coefficient of downwelling irradiance at 490 nm in m⁻¹

General Algorithm:

The algorithm is a fourth-order polynomial relationship between a ratio of K0, and Kd_490:

\[ \log_{10}(Kd_{490}) = a_0 + \sum_{i=0}^{4} a_i \left( \frac{K0_{547/555}}{K0_{547/555}} \right)^i \]

\[ Kd_{490} = K0_{490} + 0.0166 \]

the coefficients for which are sensor-specific:

<table>
<thead>
<tr>
<th>sensor</th>
<th>blue</th>
<th>green</th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
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<tbody>
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<td>555</td>
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</table>

The coefficients were derived using version 2 of the NASA bio-Optical Marine Algorithm Data set (NO MAD)}
3 - Implementation

Click `get_Kd.c` to view source code.

Calling in L2DEN
- `ldprod = Kd, Kd2`, each satellite will use its sensor-specific coefficients and wavelengths (e.g., SeaWiFS defaults to K2D)
- to override the coefficients: `Kd_coef = [a0,a1,a2,a3,a4]`
- to override the wavelengths: `Kd_wave = [numerator wavelength, denominator wavelength]`

4 - Assessment

Satellite-to-in-situ validation results are available from the SeaWiFS Bio-Optical Archive and Storage System (SeaBASS):
- SeaWiFS
- MODIS Aqua
- MODIS Terra
- VIIRS
- OCTS
- CZCS
- MERIS

Algorithm Development:

![Graphs of Kd2s, Kd2m, Kd2h]
Algorithm developers: how will you validate your algorithm?

Currently available validation data
Simulated data, such as SPEXone L1C

Validation after PACE launch
PACE Validation Plan (PVP)

Airborne data, such as ACEPOL

Data description paper
DOI: 10.5194/essd-12-2183-2020

Data archive @ ASDC DAAC
https://asdc.larc.nasa.gov/soot/power-user/ACEPOL/2017

PACE Postlaunch Airborne eXperiment (PACE-PAX)
See my talk
9:40-10:00am Friday
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Simulators and synthetic data

Research informing the ocean radiative transfer
- Mike Twardowski’s ZTT ocean color model incorporating multi-angle and polarimetric aspects
- Xiaodong Zhang’s investigations of χ factor improvement with multi-angle measurements

Pengwang Zhai’s PACE radiative transfer simulator, a coupled atmosphere-ocean model with:
- flexible scattering properties for atmosphere and ocean
- polarization
- trace gas absorption
- inelastic scattering

SPEXone simulated data in Level-1c format
- AOD & land BPDF from POLDER L2 products
- aerosol microphysical properties from ECHAM-HAM simulations
- clouds, Chl-a, land BRDF from MODIS L2 products
- BRDF spectral dependence from GOME-2

Research Scanning Polarimeter (RSP) airborne data in Level-1c format
- RSP is a line scanner instrument whose capabilities (spectral bands, # of view angles, accuracy) exceeds that of HARP2 and SPEXone

https://oceancolor.gsfc.nasa.gov/data/pace/test-data/

https://data.giss.nasa.gov/pub/rsp/data/PACE/
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**PACE Project Science** polarimetry relevant activities

**Meng Gao’s FastMAPOL neural network-based retrieval algorithm development**
- See mini-talk from Wednesday
- Recent paper: https://doi.org/10.5194/amt-14-4083-2021

**Level-1c (unified sensor) format development**
- Martin Montes is developing code to create Level-1c files within the data processing system
- Minor changes to format specification. We now include scattering angle. https://oceancolor.gsfc.nasa.gov/data/pace/format/

**MODIS Ocean Color with MISR Atmospheric Correction (MOCMAC) project**
- Prototype for how we can pass polarimetric ‘knowledge’ to help OCI atmospheric correction
- Proof of concept analysis paper: https://doi.org/10.5194/amt-14-3233-2021
- Refunded to continue with full concept →

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**MOCMAC Bayesian Inference approach**

- A priori probability distribution functions (PDFs)
  - Wind speed
  - AOD(866nm)
  - Fine mode fraction
  - Aerosol relative humidities

- Bayesian inference
  - MISR 665nm multi-angle (3) observations
  - MODIS a posteriori probability distribution functions

- Data uncertainty estimates
  - Wind speed
  - AOD(866nm)
  - Fine mode fraction

- Model uncertainty estimates
  - MISR 665nm multi-angle (3) observations
  - MODIS a posteriori probability distribution functions

- MODIS multi-spectral observations
  - Aerosol relative humidity

- Data uncertainty estimates
  - Wind speed
  - AOD(866nm)
  - Fine mode fraction
We adapted the differentiable renderer Mitsuba 2, designed for computer graphics applications, to solve radiative transfer problems relevant to atmosphere and ocean remote sensing and of interest for the upcoming PACE mission. It is capable of both forward simulation (transforming a given set of parameters into radiance) and inverse simulation via gradient descent optimization (retrieving the parameters that could have created a radiance measurement). We validated the accuracy of our forward simulation pipeline against eGAP, an adding-doubling radiative transfer code. Mitsuba 2 is computationally efficient and capable of simulating complex 3D scenes and may become an important component of PACE data analysis.
Multi-angle polarimetric instruments, such as those on the upcoming NASA PACE mission, will need to automatically identify clouds. Most algorithms for doing so use radiometric thresholds and spectral information to perform this segmentation, but PACE will have multi-angle and polarimetric information as well. We plan to exploit machine learning techniques, such as Multi-Layer Perceptrons (MLPs) and DCNNs, for this complex analysis. The first step is to assemble a training set, which combines Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar (PARASOL) observations with data from CloudSat. The dataset is formatted for ease-of-use by machine learning researchers and will be made publicly accessible.
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Polarmetry segment presentations and publications

- 2020/10/05 Bastiaan van Diedenhoven, Brian Cairns: ACCP mission
- 2020/11/30 Bertrand Fougnie: EUMETSAT 3MI instrument
- 2021/02/22 Rich Ferrare: evidence of non-spherical sea salt aerosols from lidar
- 2021/03/15 Vanderlei Martins: HARP2 status
- 2021/04/19 Athanasios Tsikerdekis: Estimating aerosol emission using SPEXone observational capabilities and an ensemble Kalman smoother: Observing System Simulation Experiments (OSSEs)
- 2021/05/10 Siyao Zhai: Optical backscattering and linear polarization properties of the colony forming cyanobacterium Microcystis
- 2021/05/24 Yongxiang Hu: A potential positive feedback mechanism of springtime Arctic ice algae and Arctic clouds
- 2021/08/16 PI updates
- 2021/09/20 PI updates

Some of these are posted here: https://pacesat.marinesciences.uconn.edu/polarimetry/

Rich Ferrare (NASA LaRC) → Evidence of optically non-spherical marine aerosols from HSRL (airborne lidar) observations
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Frontiers in Remote Sensing research topic (special issue)

Polarization of Light as a Tool for Characterizing Different Facets of the Atmosphere-Ocean System

Due date is soon! October 15th

https://www.frontiersin.org/research-topics/19225/polarization-of-light-as-a-tool-for-characterizing-different-facets-of-the-atmosphere-ocean-system#articles
Thanks!