Implementing heritage AC algorithm for hyperspectral Rrs retrieval

Atmospheric gases correction
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Objective

• Background: current NASA atmospheric correction approach

\[ L_t = (L_r + [L_a + L_{ra}] + t_{dv}L_f + t_{dv}L_w)t_{gv}t_{gs}f_p \]

Defines aerosols, Rayleigh scattering, and water radiance contribution to the TOA radiance

The Goal of this work is to implement a *hyperspectral* atmospheric correction algorithm to extract \( L_w \) from TOA radiance
L1B calibrated top of atmosphere hyperspectral radiance (i.e. HICO, AVIRIS)

Sensor specific tables for Rayleigh and aerosols

Ancillary data Pressure, RH, wind speed, ozone, NO2

Stage 1

Stage 2

Stage 3

Stage 4

Hyperspectral AC & vicarious calibration process

From L0

L1B calibrated top of atmosphere hyperspectral radiance (i.e. HICO, AVIRIS)

Sensor specific tables for Rayleigh and aerosols

Ancillary data Pressure, RH, wind speed, ozone, NO2

L2gen AC processing module

ATREM (H2O, O3, O2, NO2, N2O, CH4, CO2, CO) → 8 gases

Level 2 products, [Chl], Rrs, Es, a, bb, water vapor, etc.

Vicariously calibrated Level 2 products, [Chl], Rrs, Es, a, bb, water vapor, etc.

Vicarious calibration in-situ Radiance at just above sea surface (i.e. MOBY)

Implementation

Validation

L2GEN

f_{gain}
vL_t
L_t
L_w
T_g
L_w
vL_{lw}
O_3, RH, WS, P, NO2

Stage 1

Stage 2

Stage 3

Stage 4

To L3

in – situ L_w

Level 2 products, [Chl], Rrs, Es, a, bb, water vapor, etc.
Stage 1: \( L_t, L_r, L_a, F_0 \)

- Hyperspectral TOA radiance \( (L_t) \) can be obtained from either airborne sensors (AVIRIS, PRISM) or space-borne radiometer (HICO, PACE)
- Hyperspectral aerosol and Rayleigh contribution radiance \( (L_a \text{ and } L_r) \) are pre-computed from a vector RT simulations (Ahmad and Fraser)
- Radiances are a function of solar and viewing geometry, wind speed, and atmospheric pressure
- Rough sea surface effects are accounted for
- Ancillary data such as ozone concentration (OMI/TOMS), atmospheric pressure (NCEP), relative humidity (NCEP), wind speed (NCEP), NO2 concentration (OMI), and water vapor (NCEP)
Stage 2: L2GEN/ATREM

- We use 2-band NIR ratio algorithm to remove aerosol effects (for now)
  1. Calculate epsilon, \( \varepsilon = \frac{\rho_a(787)}{\rho_a(867)} \) (for HICO), from aerosol reflectance
  2. Constrain aerosol model selection based on relative humidity (NCEP)
  3. Extrapolate aerosol radiance to visible based on model

- Gases compensation (i.e. absorption) is assumed as an independent process from scattering (valid assumption except in turbid atmosphere)
- ATREM is the hyperspectral gases correction code developed by Bo-Cai Gao to compensated for 8 gases in the atmosphere.
- Latest version of ATREM is based on the line-by-line calculations of gases transmittance in the atmosphere
- ATREM is computationally fast in certain scenarios (i.e. assuming a constant solar and viewing geometry across the scene especially for water vapor)
Gases Transmittance in the atmosphere from VIS to NIR

After applying HICO band pass filter

H2O windows

H2O absorption band

Wavelength (nm)

400 500 600 700 800 900

Transmittance

1.0

0.9

0.8

0.7

0.6

1 nm
Water vapor correction

• ATREM’s importance arises for water vapor compensation in the radiance (i.e. water vapor correction)
• Water vapor $\rightarrow$ complex profile, other gases $\rightarrow$ either well mixed or simple profile
• The transmittance of water vapor is calculated from line-by-line absorption coefficients of 19 layers of the atmosphere.
• The atmosphere is assumed isothermal, while water vapor mixing ratio and pressure profile changes (7 models).
• Line-by-line ATREM is computationally costly for pixel by pixel calculations (2 secs/pixel)
• Example: HICO scene is 512 pixel/scan line, and there are 2000 scan line/image (total processing time = $2 \times 512 \times 2000 = 23.7$ days)

How to make ATREM faster?

K-distribution method

• We propose to use the k-distribution method to calculate the transmittance of water vapor more efficiently.
• Widely used in Atmospheric RT models.
• The approach is based on the mathematical transformation of domains (Absorption coefficients in wavenumber domain $\rightarrow$ Cumulative probability in absorption coefficient domain).
• The mathematical transformation is exact, as long as the spectral window is selected carefully.
Example of k-distribution

Transformation from wavelength/number to smooth CDF

\[
f(k) = \int_{v_1}^{v_2} k_v \, dv \quad \text{PDF to CDF} \quad K(g) = \int_{-\infty}^{v} f(k) \, dk \quad \text{CDF to } T(u) \quad T(u) = \int_{0}^{1} e^{-K(g)u} \, dg
\]

The smooth CDF can be easily approximated with carefully spaced interpolation or a polynomial
Calculating Transmittance

**Inputs**
- TOA reflectance
- Location and time/date of the scene
- Ancillary data

**ATREM Look-up tables generation and search**
1. ATREM LBL (slow)
2. ATREM using K-distribution method (fast)

**Output**
- Gases Transmittance (sun-surface-sensor path)
- Column water vapor

- Gases Transmittance look-up table (Per pixel) for 60 wv values

**Equations**
- \( \rho_t(\theta_{sol}, \theta_{sun}, \lambda) \)
- \( T_g(\theta_{sol}, \theta_{sun}, \lambda) \)

**Option 1.** for HICO scene proc. time is ~ 23 days
**Option 2.** for HICO scene proc. time is ~ 30 mins
Validation/testing process

HICO

• Why HICO?
  ➢ HICO is a space-borne hyperspectral radiometer that can be used as a proxy sensor to the one planned for PACE (128 bands, 350 nm to 1050 nm)
  ➢ HICO allows us to understand the logistical challenges of hyperspectral TOA data archiving, processing, and obtaining OC products
  ➢ Utilize the advantage and understand challenges of having extra bands for AC (i.e. spectral matching (NIR), or joined retrieval)

• L2gen/ATREM can handle air-borne radiometers processing as well (such as AVIRIS and PRISM) ➔ (still in testing)
Validation: HICO
Stage 3: Level-2 Products $L_w$

No Gases correction
Only Rayleigh and aerosols

With Gases correction
+ Rayleigh and aerosols
HICO-MODISA-MOBY match-ups
Water vapor retrieval
Stage 4: HICO hyperspectral vicarious calibration

- We selected MOBY site near Hawaii (Lanai Island) for ViCal:
  - Stable aerosols and atmospheric conditions
  - Minimal anthropogenic impacts
  - Less complex waters
- HICO has collected ~100 scenes for different days
- After cloud screening and coincident MOBY measurements QA (30 min window), we ended with 4 scenes
- We took average of 4 scenes to calculate vicariously calibrated gain factors
Hyperspectral gain factors (HICO)

Gain factors between 400 to 800 nm are changing within 5%
Rrs match-ups comparison
HICO & MODISA comparison in more productive waters

Perc_diff(%) = 200*(hico-modis)/(hico+modis)
Perc_diff(%) = 200*(hico-modis)/(hico+modis)
Conclusion

1. Integrated ATREM into L2gen to perform hyperspectral atmospheric correction of TOA measurements
2. Speed up ATREM water vapor correction using k-dist (~$1e3$ faster)
3. Retrieved ocean color (i.e. $L_w$, [chl], etc.) and water vapor
4. Tested and validated implementation using HICO measurements
5. Applied hyperspectral vicarious to HICO/MOBY match-ups
6. L2gen can perform hyperspectral AC with good accuracy

Future work

1. Validate hyperspectral retrieval of $L_w$ with SeaBASS
2. Use water vapor (RH) to constrain aerosol model selection (per pixel)
3. Utilize the hyperspectral information in NIR to estimate aerosol model