Implementing heritage AC algorithm for hyperspectral Rrs retrieval

Atmospheric gases correction

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Objective

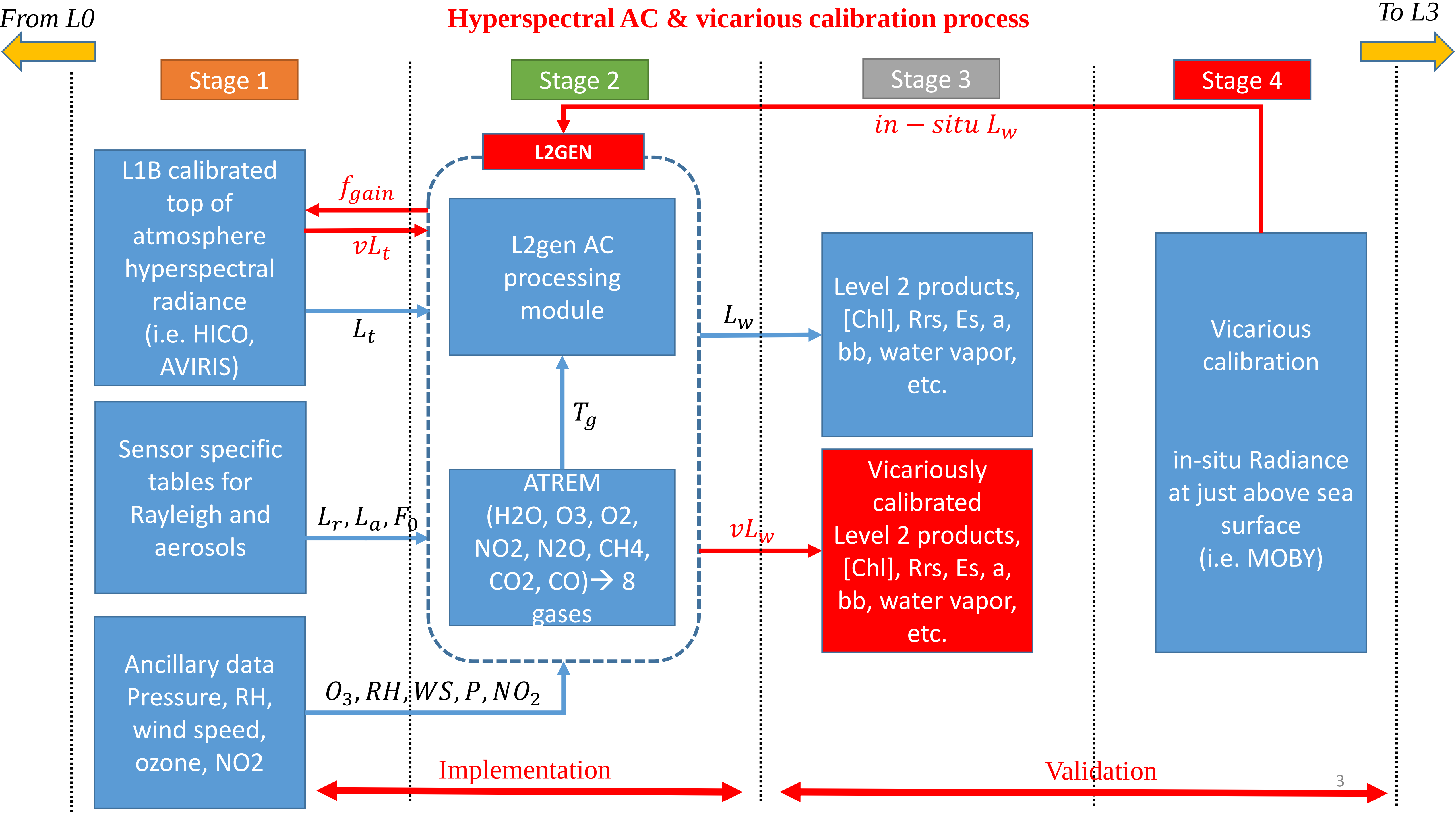
- Background: current NASA atmospheric correction approach

$$\underbrace{L_t = (L_r + [L_a + L_{ra}] + t_{dv}L_f + t_{dv}L_w)}_{\text{Defines aerosols, Rayleigh scattering, and water radiance contribution to the TOA radiance}}\underbrace{t_{gv}t_{gs}}_{\text{Sun-surface-sensor gases transmittance } T_g}f_p$$

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

Sun-surface-sensor gases transmittance $\boldsymbol{T_g}$

The Goal of this work is to implement a *hyperspectral* atmospheric correction algorithm to extract L_w from TOA radiance

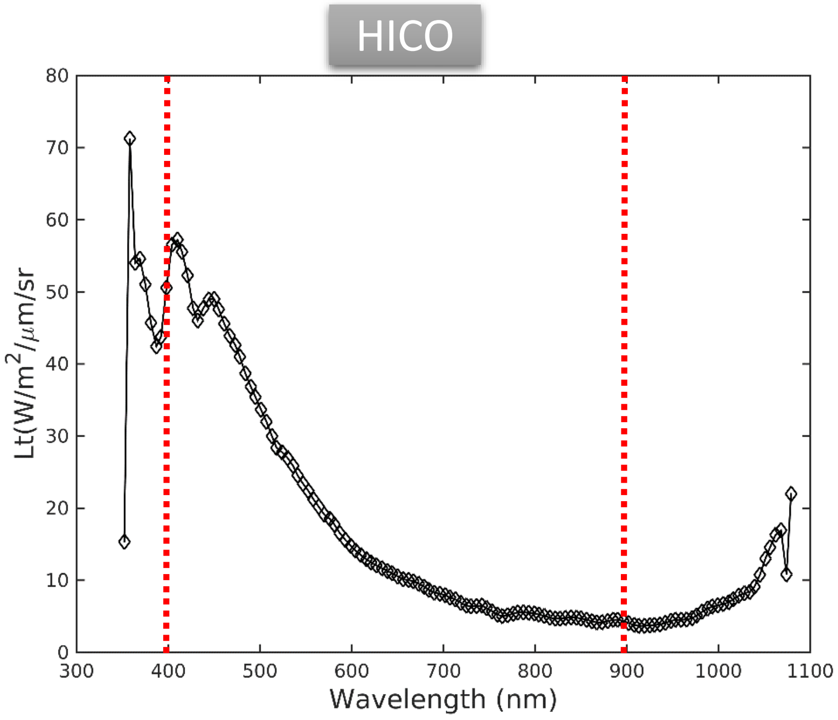

From L0
Hyperspectral AC & vicarious calibration process
To L3
Stage 1
Stage 2
Stage 3
Stage 4
$in - situ\ L_w$
L2GEN
L1B calibrated top of atmosphere hyperspectral radiance (i.e. HICO, AVIRIS)
f_{gain}
vL_t
L_t
L2gen AC processing module
L_w
Level 2 products, [Chl], Rrs, Es, a, bb, water vapor, etc.
Vicarious calibration
in-situ Radiance at just above sea surface (i.e. MOBY)
T_g
Sensor specific tables for Rayleigh and aerosols
L_r, L_a, F_0
ATREM (H2O, O3, O2, NO2, N2O, CH4, CO2, CO)→ 8 gases
vL_w
Vicariously calibrated Level 2 products, [Chl], Rrs, Es, a, bb, water vapor, etc.
Ancillary data Pressure, RH, wind speed, ozone, NO2
O_3, RH, WS, P, NO_2
Implementation
Validation

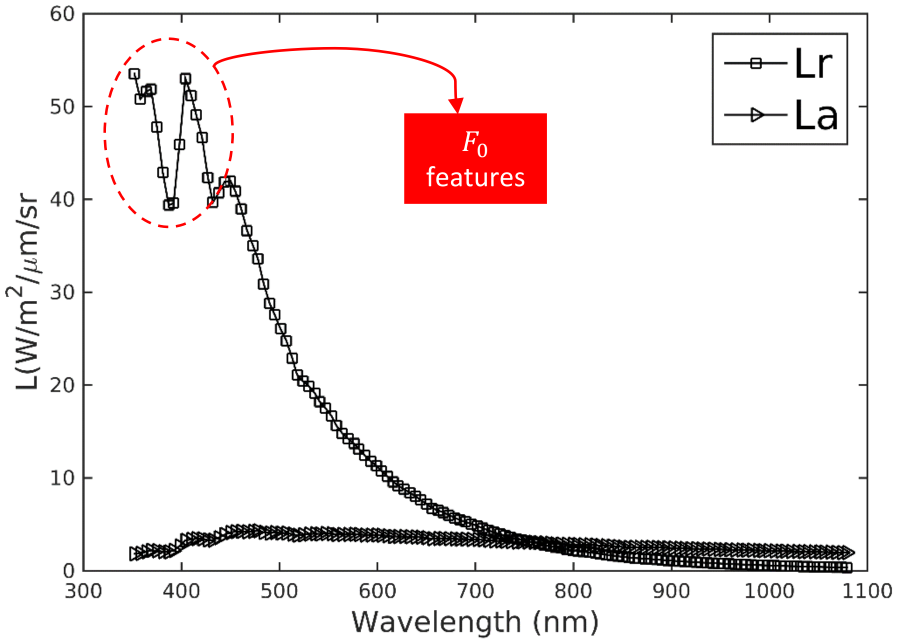
Stage 1: L_t, L_r, L_a, F_0

- Hyperspectral TOA radiance (L_t) can be obtained from either air-borne sensors (AVIRIS, PRISM) or space-borne radiometer (HICO, PACE)

- Hyperspectral aerosol and Rayleigh contribution radiance (L_a 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)



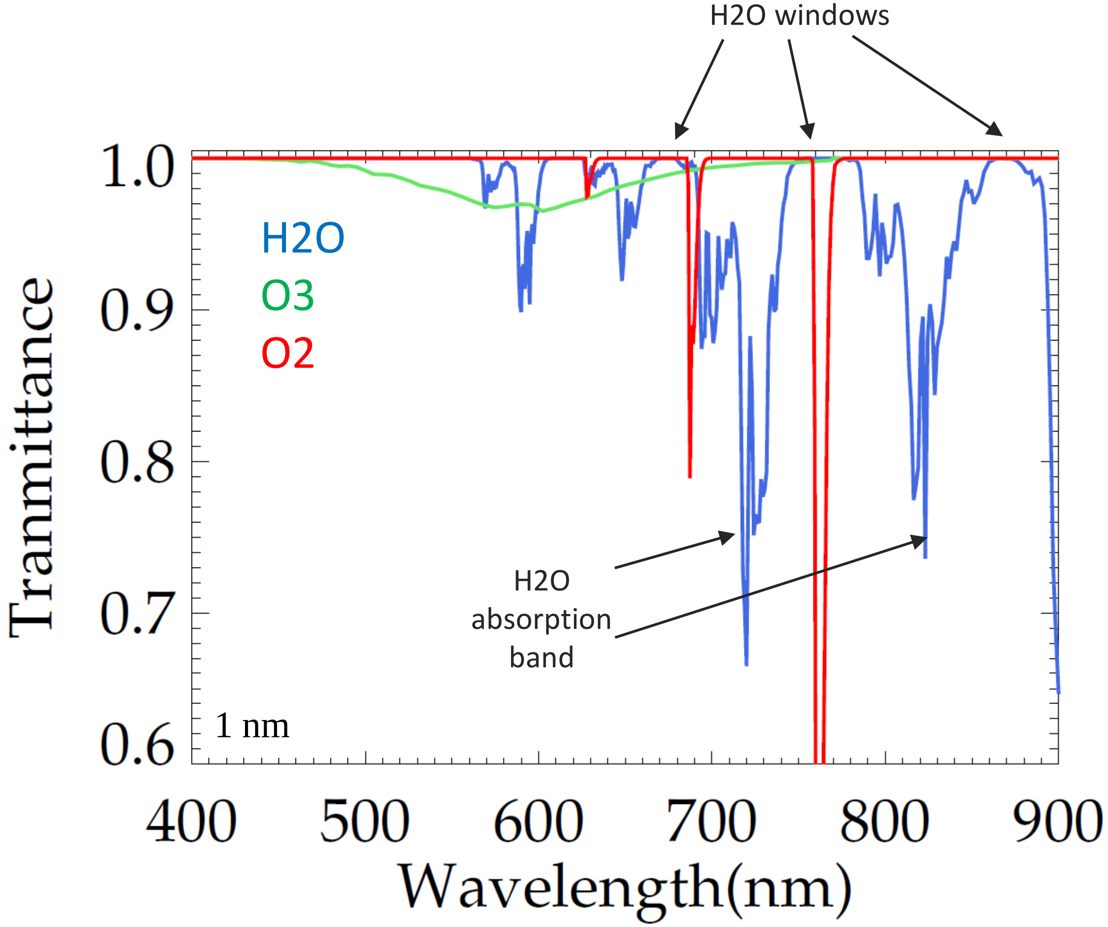


Stage 2: L2GEN/ATREM

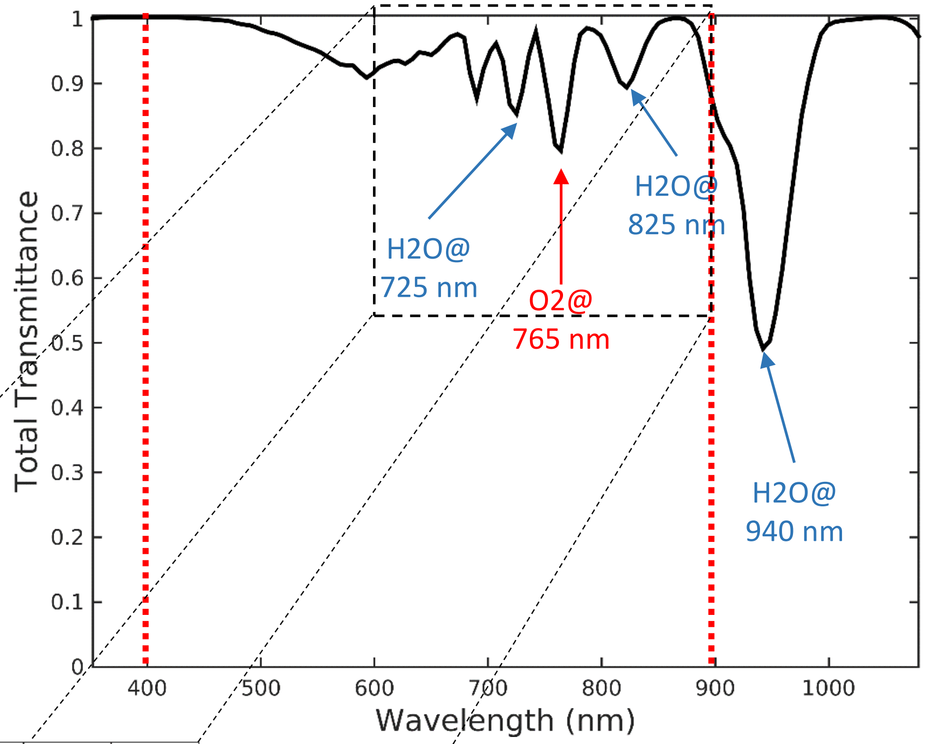
- We use 2-band NIR ratio algorithm to remove aerosol effects (for now)
  1. Calculate epsilon, $\varepsilon = \frac{\rho_a(787)}{\rho_a(867)}$ (for HICO), from aerosol reflectance
  2. Constrain aerosol model selection based on relative humidity (NCEP)
  3. Extrapolate aerosol radiance to visible based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

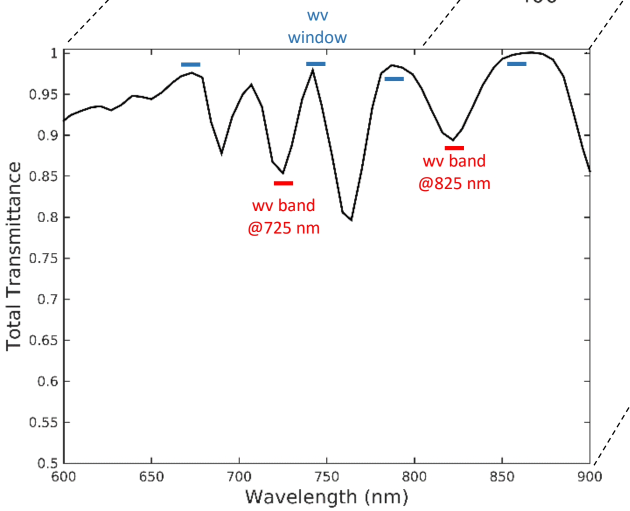
- Gases compensation (*i.e.* absorption) is assumed as an independent process from scattering (valid assumption except in turbid atmosphere)
- ATREM is the hyperspectral gases correction code developed by Bo-Cai Gao to compensated for 8 gases in the atmosphere.
- Latest version of ATREM is based on the 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





Water vapor correction

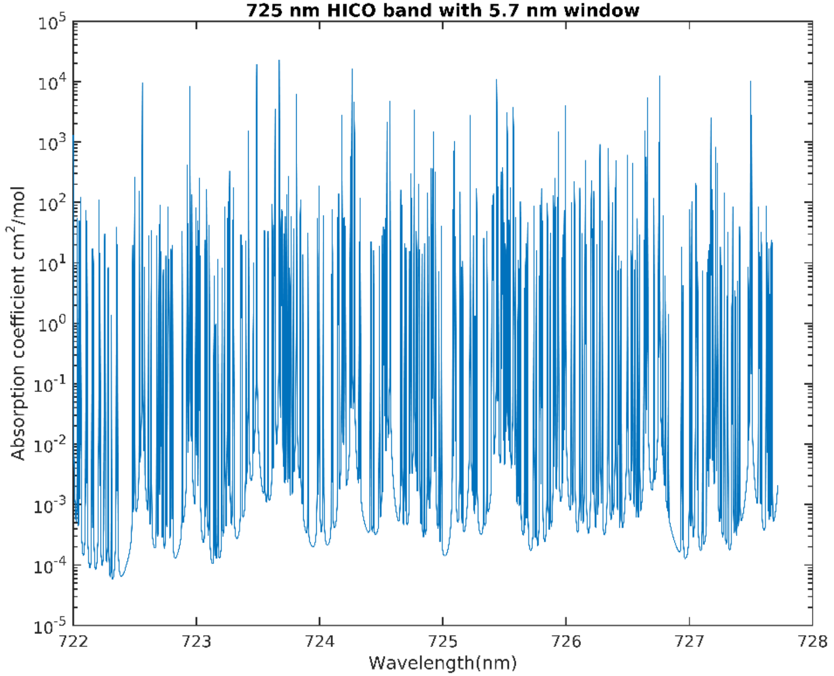
- ATREM's importance arises for water vapor compensation in the radiance (i.e. water vapor correction)
- Water vapor → complex profile, other gases→ either well mixed or simple profile
- The transmittance of water vapor is calculated from line-by-line absorption coefficients of 19 layers of the atmosphere.
- 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 x 512 x 2000 = 23.7 days)

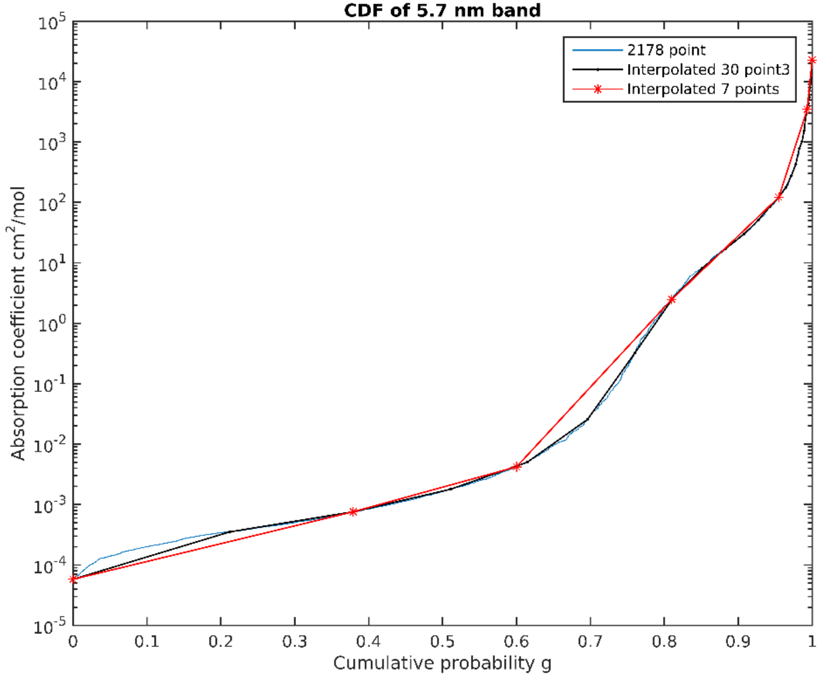
How to make ATREM faster?

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 → Cumulative probability in absorption coefficient domain).
- The mathematical transformation is exact, as long as the spectral window is selected carefully.

Example of k-distribution



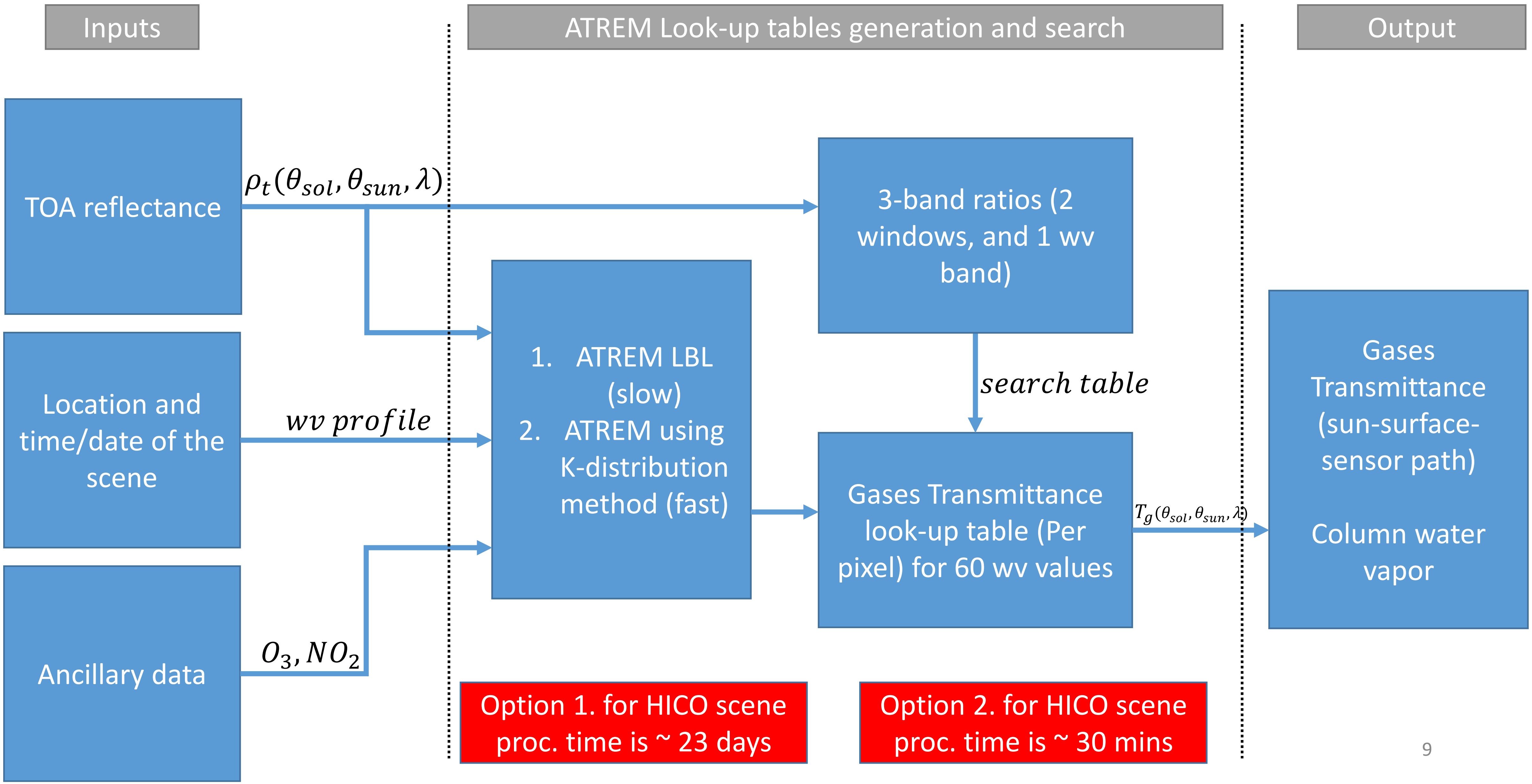


Transformation from wavelength/number to smooth CDF

$$f(k) = \int_{v_1}^{v_2} k_v \; dv \xrightarrow{\text{PDF to CDF}} K(g) = \int_{-\infty}^{v} f(k)dk \xrightarrow{\text{CDF to T(u)}} \mathrm{T}(u) = \int_{0}^{1} e^{-K(g)u} dg$$

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

Calculating Transmittance



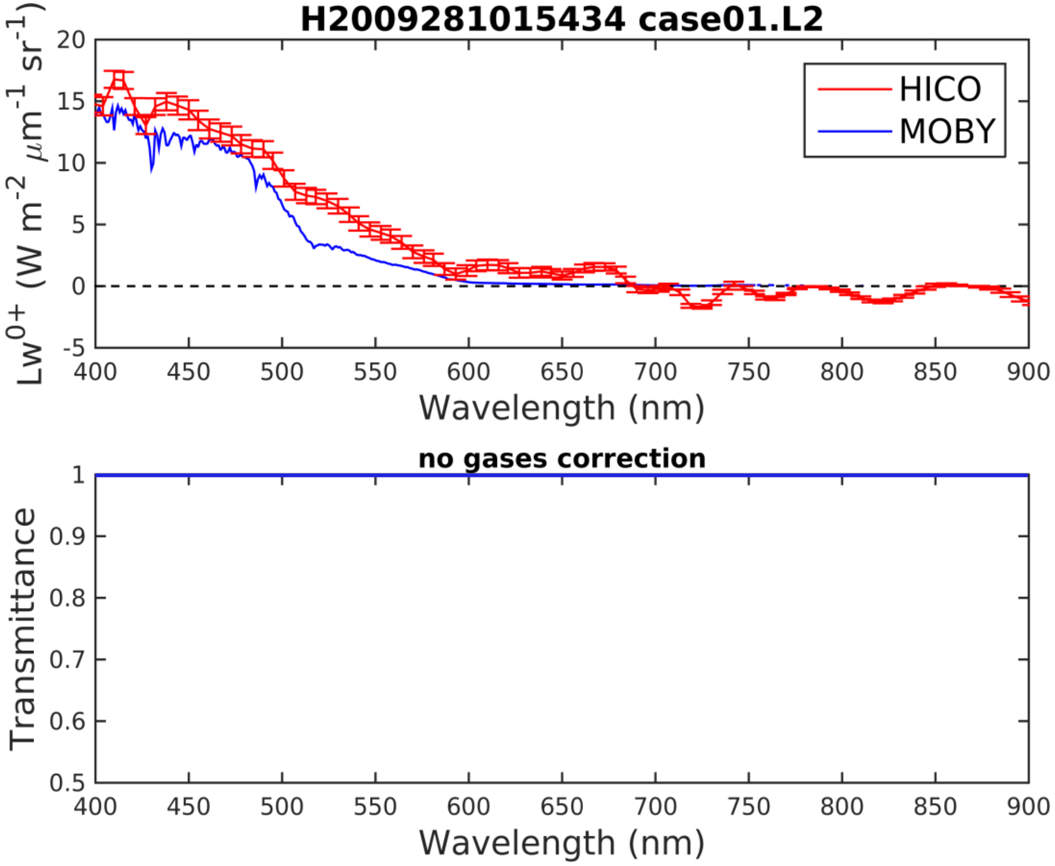
Validation/testing process
HICO

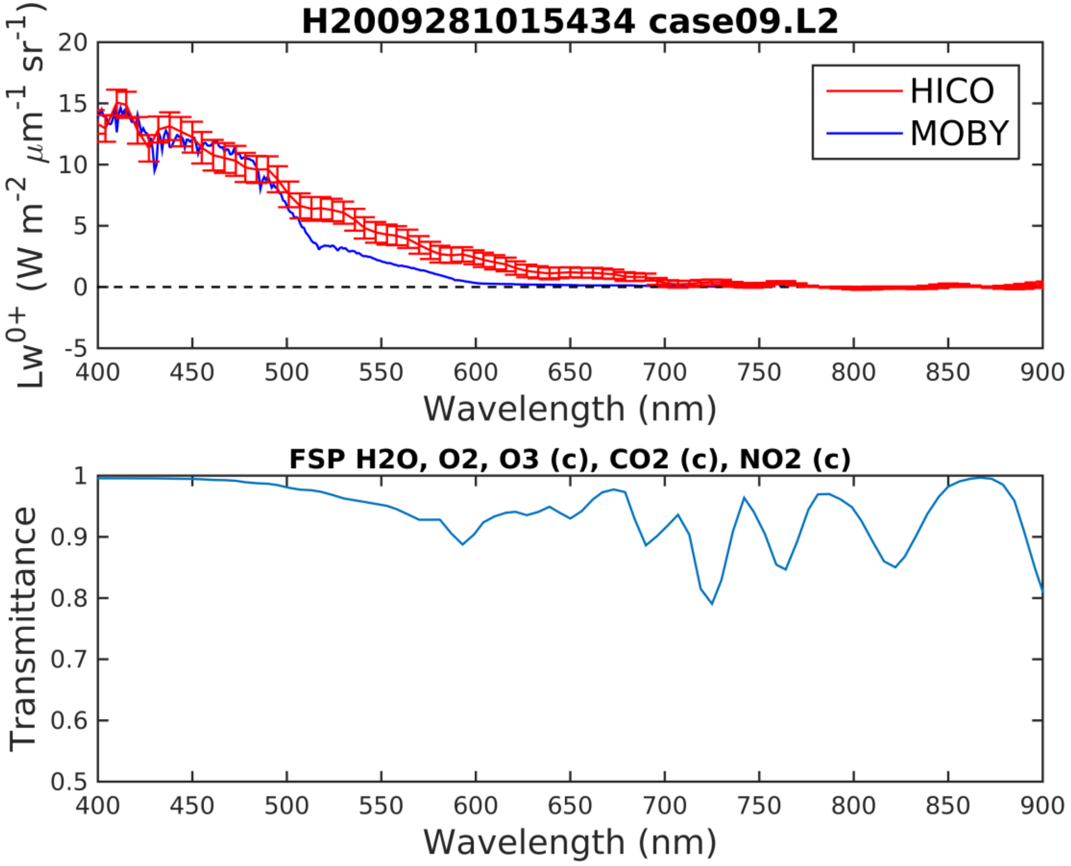
- Why HICO?
  - ➢ HICO is a space-borne hyperspectral radiometer that can be used as a proxy sensor to the one planned for PACE (128 bands, 350 nm to 1050 nm)
  - ➢ HICO allows us to understand the logistical challenges of hyperspectral TOA data archiving, processing, and obtaining OC products
  - ➢ 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

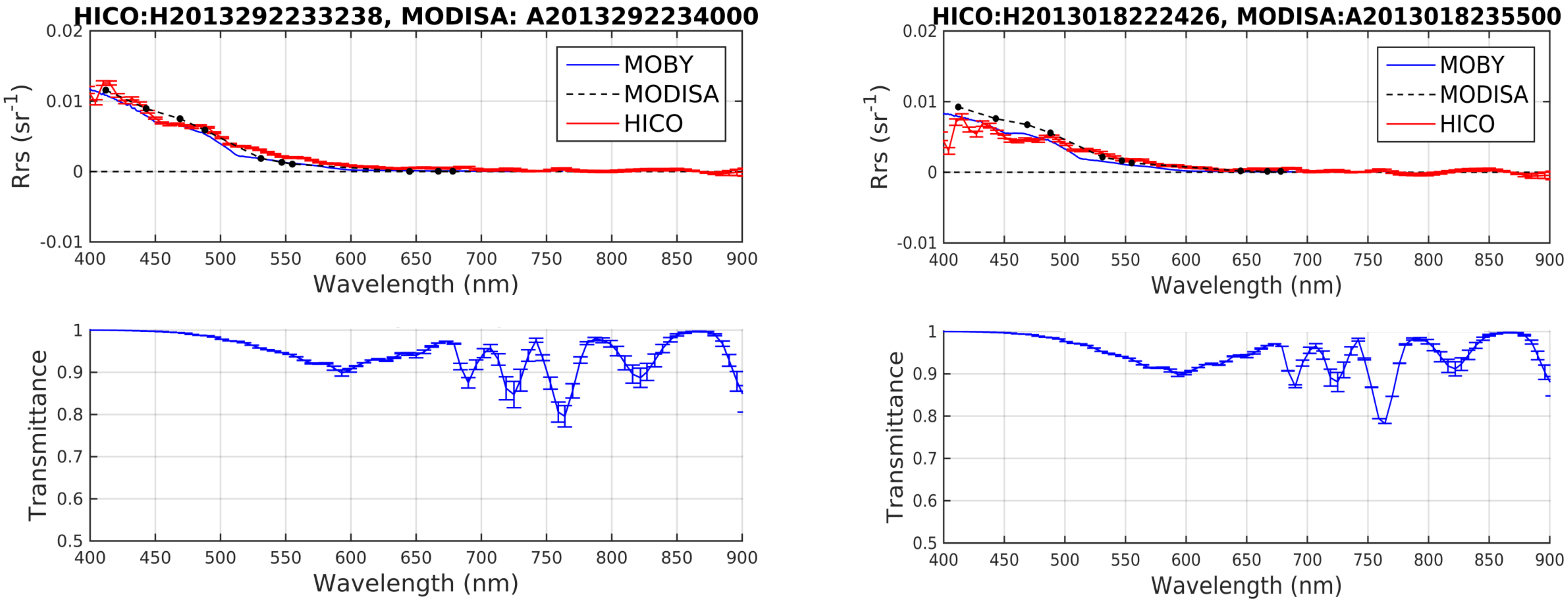




No Gases correction
Only Rayleigh and aerosols

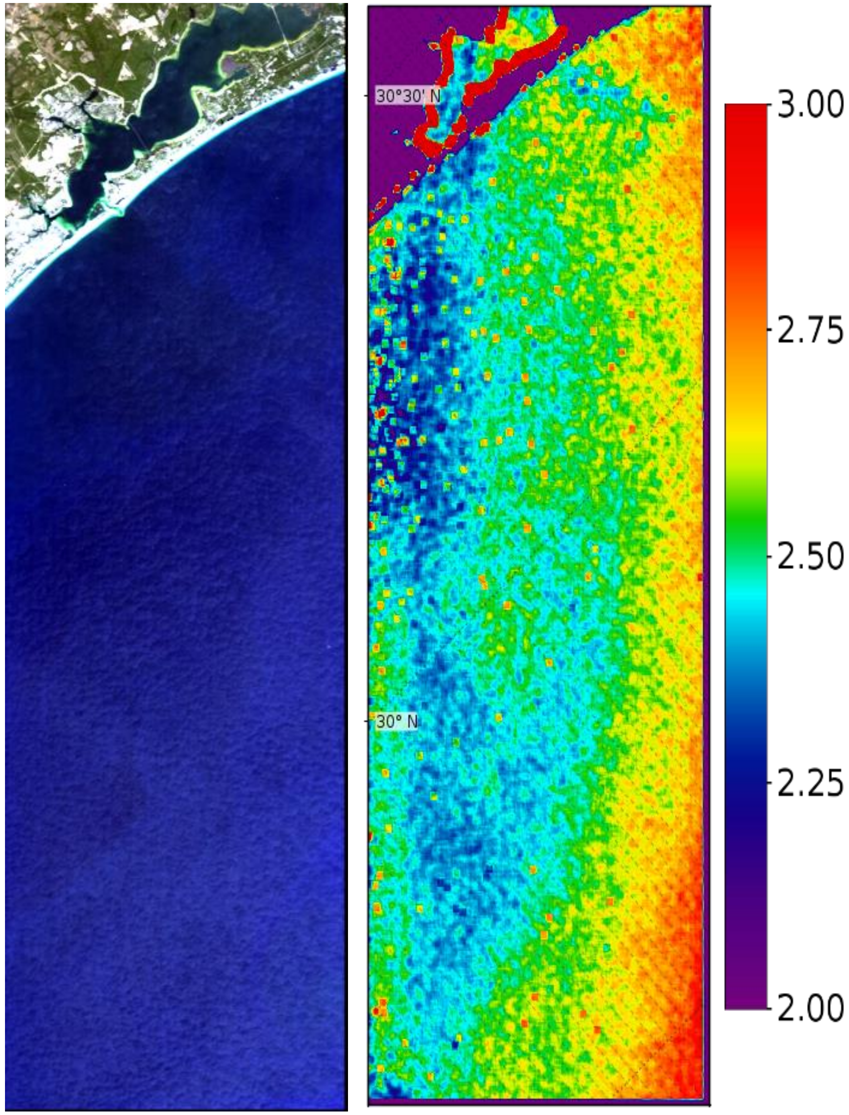
With Gases correction
+ Rayleigh and aerosols

HICO-MODISA-MOBY match-ups

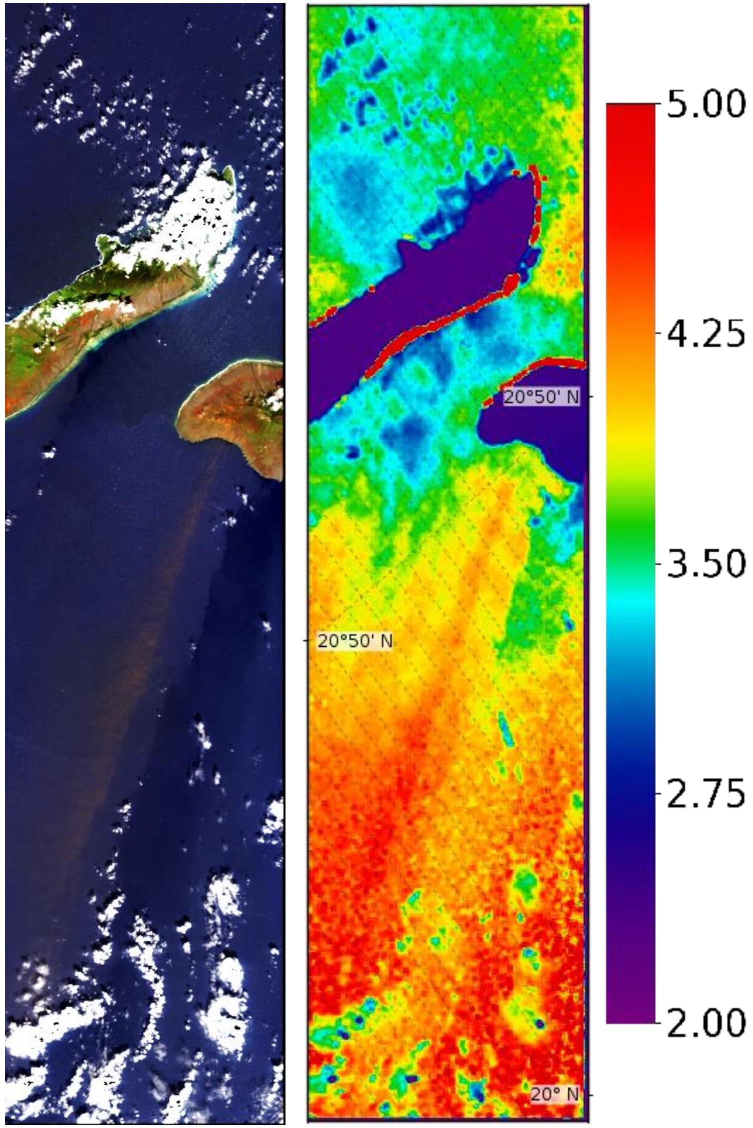


Water vapor retrieval

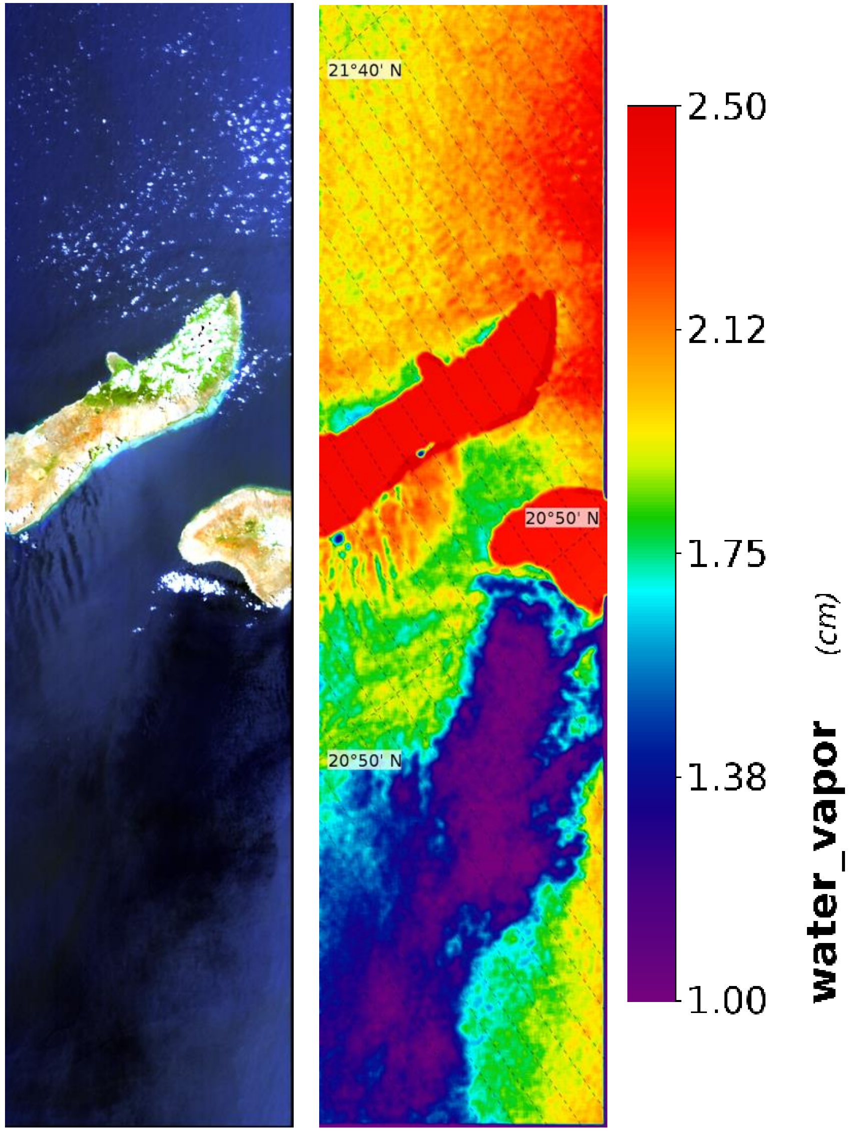
Gulf of Mexico H2011304175228



Hawaii H2013050000822



Hawaii H2012238220952

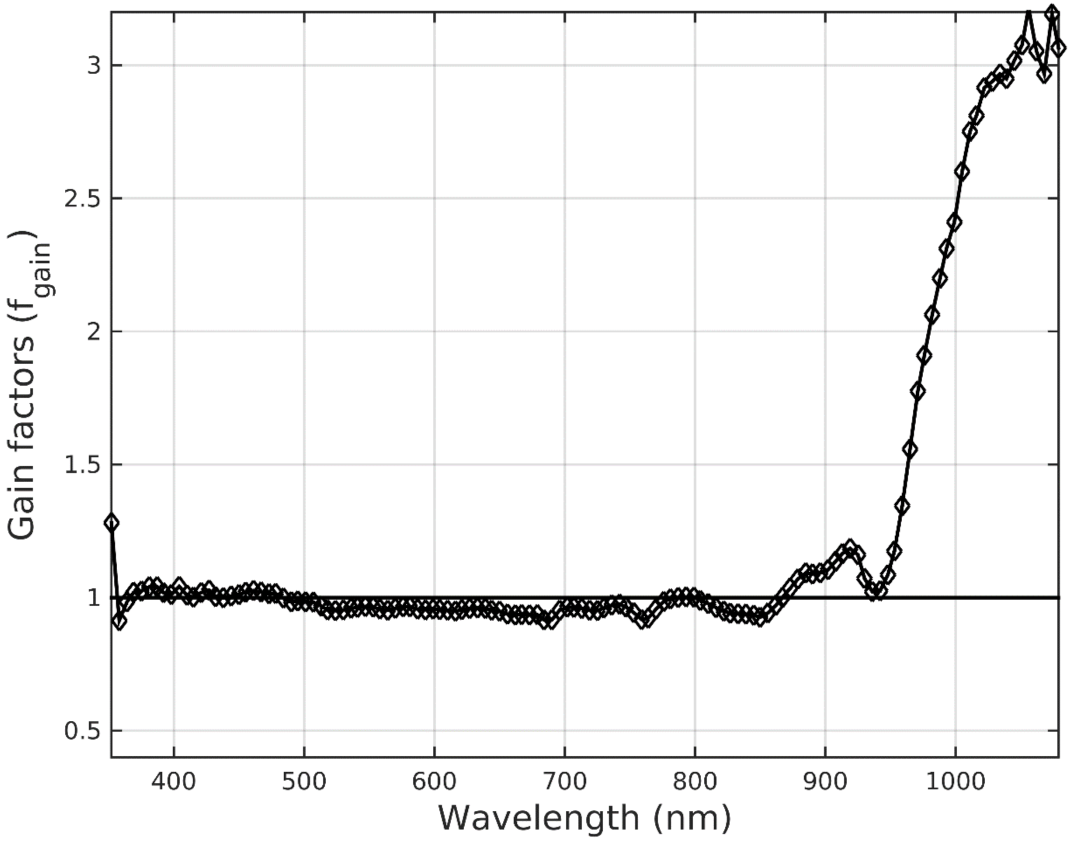


Stage 4: HICO hyperspectral vicarious calibration

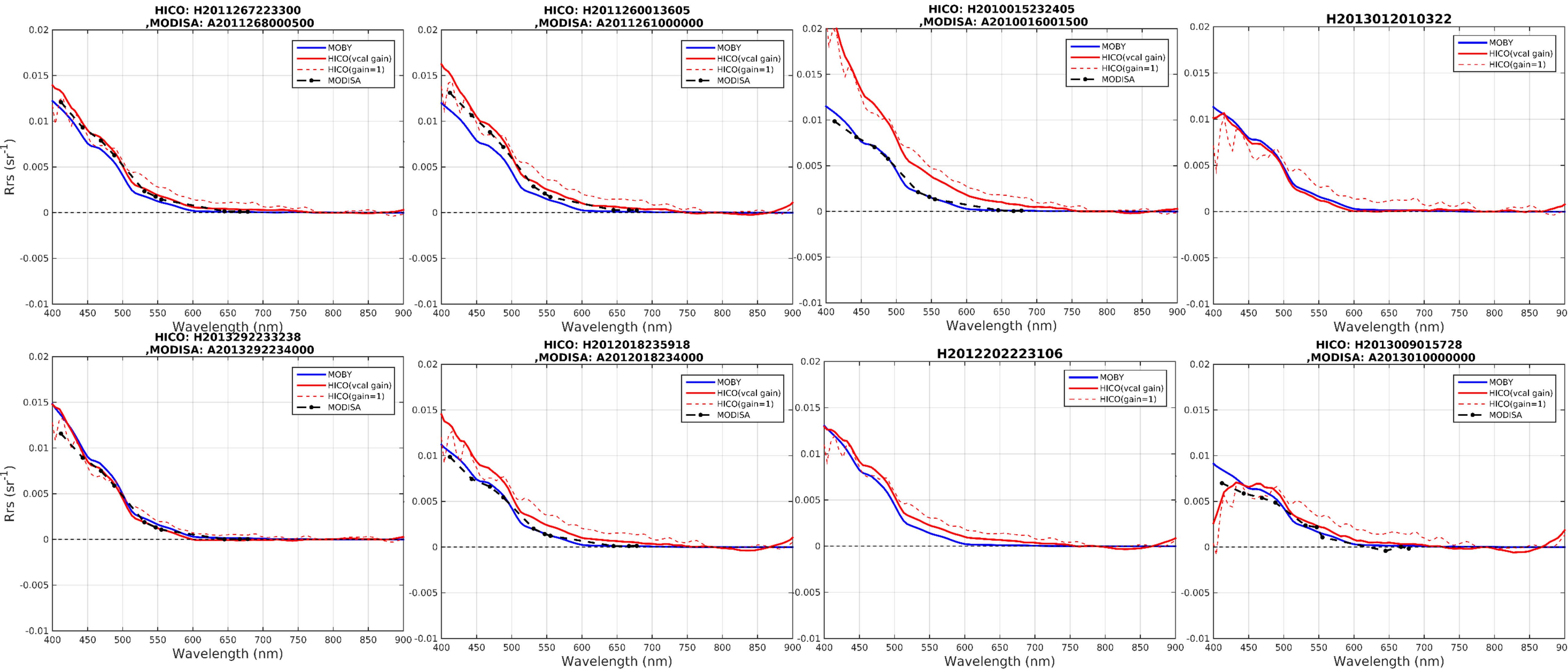
- We selected MOBY site near Hawaii (Lanai Island) for ViCal:
  - Stable aerosols and atmospheric conditions
  - Minimal anthropogenic impacts
  - Less complex waters
- HICO has collected ~100 scenes for different days
- After cloud screening and coincident MOBY measurements QA (30 min window), we ended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

Hyperspectral gain factors (HICO)

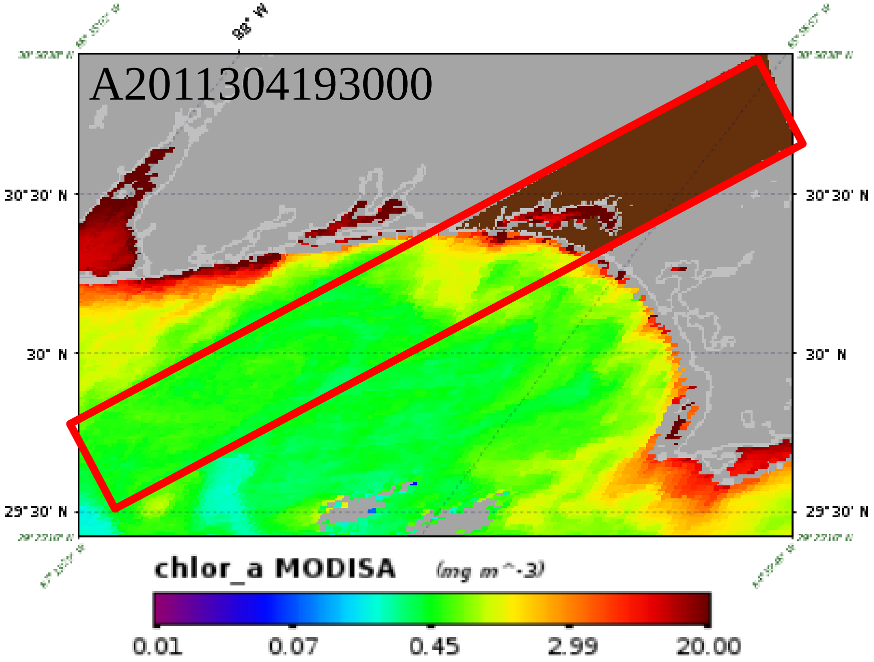
Gain factors between 400 to 800 nm are changing within 5%

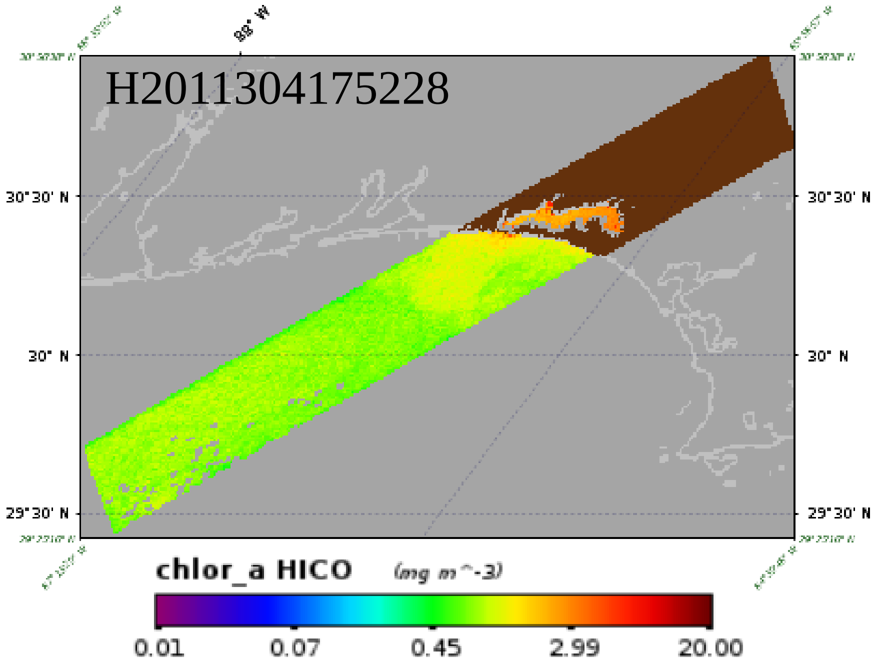


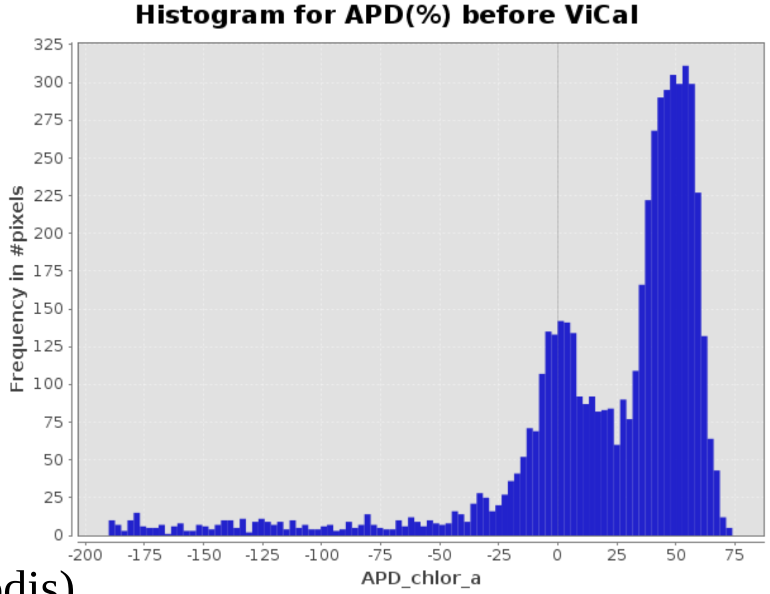
Rrs match-ups comparison



HICO & MODISA comparison in more productive waters

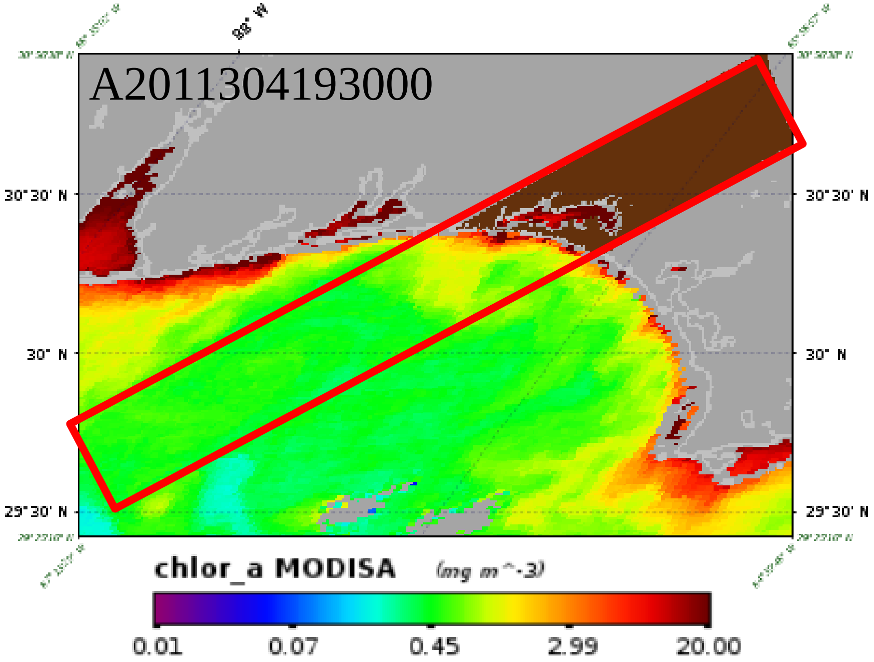


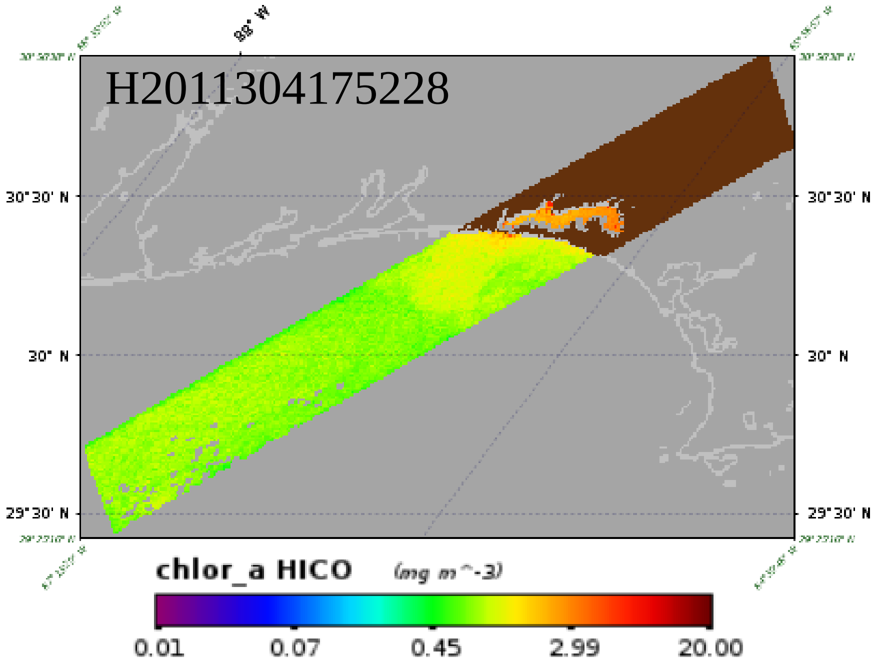


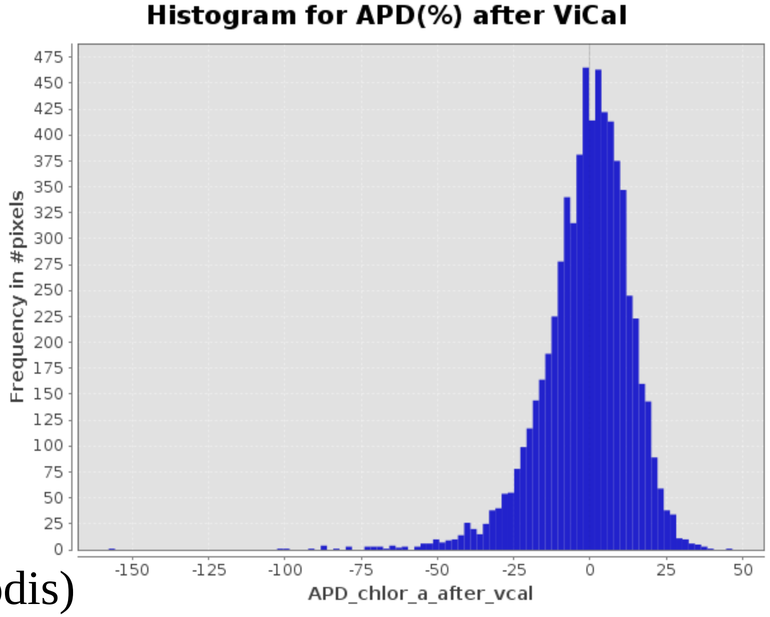


Perc_diff(%) = 200*(hico-modis)/(hico+modis)

HICO & MODISA comparison in more productive waters







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