Atmospheric correction in DESIS and EnMAP processing chains – An overview

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Hyperspectral sensors specifications

- **DESIS**:
  - λ = [0.4 – 1.0] µm, $\Delta\lambda$ = 2.55 nm (235 channels)
  - 1024 pixels across-track
  - Off-nadir < 40º
  - Atmospheric correction over land (PACO SW package)

- **EnMAP**:
  - 2 sensors:
    - VNIR: λ = [0.42 –0.96] µm, $\Delta\lambda$ = 6.5 nm (88 channels)
    - SWIR: λ = [0.90 – 2.44] µm, $\Delta\lambda$ = 10 nm (130 channels)
  - 1000 pixels across-track
  - Off-nadir < 30º
  - Atmospheric correction over land (PACO SW package) and over water (MIP SW package, EOMAP GmbH)

L2A processor: Atmospheric Correction

- Extra-terrestrial solar irradiance based on the 'medium 2' solar activity of Fontenla (Fontenla, J.M. et al, 2011)
- MODIS database as input to selection of atmospheric LUTs:
  - Ozone column: MOD08_E3 (061) (only for EnMAP) (Platnick, s. et al, 2015)
  - Season (LST): MOD11C3.006 (Wan, Z. et al, 2015)

Atmospheric correction over **land**:

- PACO (Python-based Atmospheric Correction, DLR):
  - python 2.7 parallel development of the atmospheric correction SW package ATCOR, developed by DLR.
  - Monochromatic LUTs (MODTRAN 5.4.0, Berk et al, 2016)

Atmospheric correction over **water** (only for EnMAP):

- MIP (Modular Inversion Processor, EOMAP GmbH)
  - Monochromatic LUTs (Kiselev et al, 1994, Bulgarelli et al, 1999)
  - Pixel-wide adjacency, atmospheric and water surface correction (Kiselev, V., Bulgarelli, B. and Heege, T., 2015; Heege, T. et al 2014; Richter, R. et al, 2014)

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L2A Processor parameters

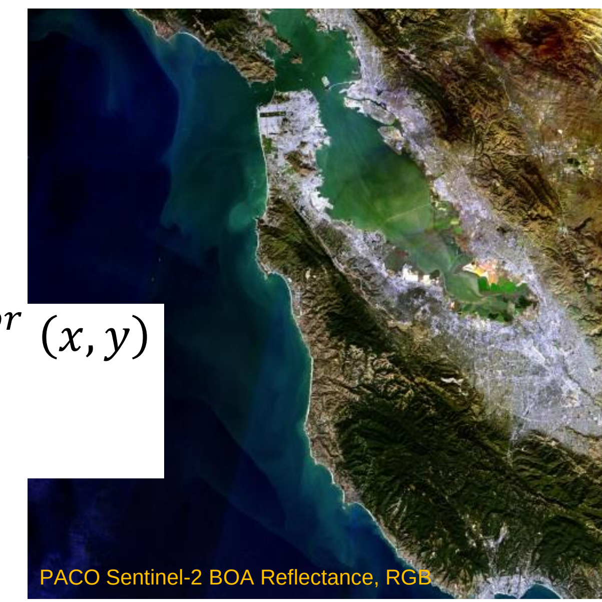
- **Ozone correction**: ozone column (DU) (Richter, R. et al, 2014, Int. J. Remote Sensing, Vol. 35, 8044)
  - DESIS: chosen by user
  - EnMAP: chosen by user or selected using MODIS DB (Automatic)
- **Terrain correction** (DESIS / EnMAP):
  - Automatic or No
  - Note: Flat-terrain is automatically activated when N pixels (slope > 6%) < 1%.
- **Aerosol type**:
  - EnMAP: ‘rura’ (rural/continental MODTRAN model)
  - DESIS: automatic estimation
- **Season** (summer/winter):
  - DESIS: automatically selected using MODIS DB
  - EnMAP: chosen by user or automatic (MODIS)
- **Correction_Type** (EnMAP):
  - Land, Water or Combined (Land+Water)
- **Water type** (EnMAP):
  - Clear / turbid and high turbid LUTs
- **Cirrus/haze removal** (EnMAP):
  - Cirrus or Cirrus_and_haze

De-cirrus / de-hazing (EnMAP)

- De-cirrus (Richter, R. et al, 2011; Xu, M. et al, 2014): cirrus thresholding using cirrus band (~1.38 µm)
- De-cirrus and de-haze: combined haze/cirrus removal using visible and cirrus band to calculate the haze thickness map (HTM) per band (i) (Makarau, A. et al, 2016)


Sentinel-2 TOA Reflectance, RGB

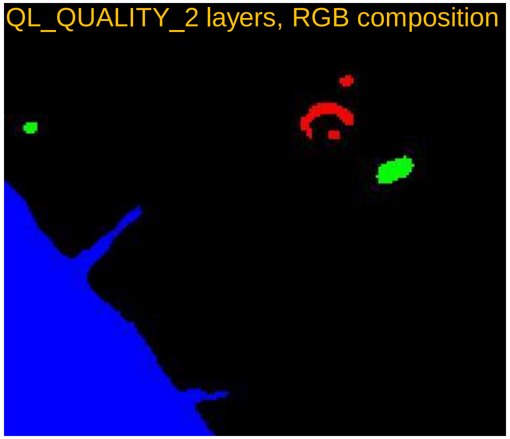
$$DN_i(x,y) = DN_i^{sensor}(x,y) + HTM_i(x,y)$$


PACO Sentinel-2 BOA Reflectance, RGB

Masking / pre-classification

Output product but also used internally as pixel masks for atmospheric correction algorithms.

- ***DESIS***: QL_QUALITY-2
  1. Shadows
  2. Visible land
  3. *Snow*
  4. Haze over land
  5. Haze over water
  6. Cloud over land
  7. *Cloud over water*
  8. Visible water



- ***EnMAP***: QL_QUALITY_
  - CLASSES:
    1. Background (0)
    2. Land (1)
    3. Water (2)
  - CLOUD:
    - None (0)
    - Cloud (1)
  - CLOUDSHADOW:
    - None (0)
    - Cloud shadow (1)
  - HAZE:
    - None (0)
    - Haze (1)
  - CIRRUS
    - None (0)
    - Thin (1)
    - Medium (2)
    - Thick (3)
  - SNOW
    - None (0)
    - Snow(1)

Aerosol Optical Thickness

Dark Dense Vegetation pixels (DDV): pixels masked during the pre-classification process

Negative reflectance pixels in red (660 nm) and NIR bands (850 nm) reduce the visibility over vegetation and water surfaces

- DESIS: DDV VNIR (Richter et al, 2006)

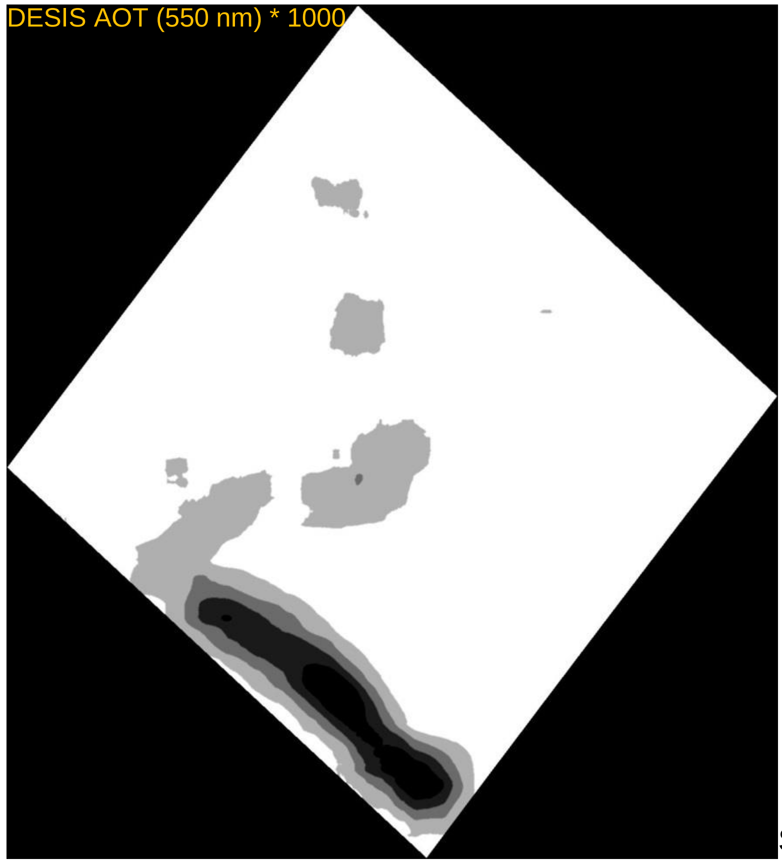
$$\rho_{red} = 0.1\,\rho_{NIR}$$

- EnMAP: DDV SWIR (1.6 or 2.2 µm) (based on Kaufman et al 1997)
  - 2.2 µm: $\rho_{red} = 0.5\,\rho_{2.2}$

$$\rho_{blue}(480\,nm) = 0.5\,\rho_{red} + 0.005$$

Aerosol optical thickness (DESIS)

Output product as quality layer



- ***DESIS***: QL_QUALITY-2
  1. Shadows
  2. Visible land
  3. Snow
  4. Haze over land
  5. Haze over water
  6. Cloud over land
  7. Cloud over water
  8. Visible water
  9. AOT
  10. WV

Scene average AOT (550 nm) = 0.127

Aerosol type estimation (DESIS)

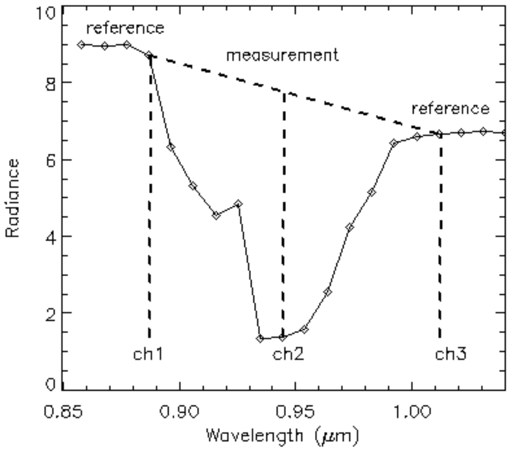
Ratio (d_p) between L_p (blue)/L_p (red) of the scene and MODTRAN closer to 1.
RT LUTs corresponding to different MODTRAN built-in simulated aerosol types:

$$d_p = \frac{\left({L_{p,blue}} / {L_{p,red}} \right)_{scene}}{\left({L_{p,blue}} / {L_{p,red}} \right)_{MODTRAN}}$$

- ‘rura’: rural/continental
- ‘urba’: urban
- ‘dese’: desert
- ‘mari’: navy maritim

Water vapor

Atmospheric Precorrected Differential Absorption (APDA) ratio relation with water vapor column (u) (Makarau, A. et al, 2017):



$$R_{APDA}\,(\rho,u) = \frac{\left(L_2(\rho_2) - L_{2,p}\right)}{\frac{\lambda_3-\lambda_2}{\lambda_3-\lambda_1}\left(L_1(\rho_1) - L_{1,p}\right) + \frac{\lambda_2-\lambda_1}{\lambda_3-\lambda_1}\left(L_3(\rho_3) - L_{3,p}\right)} = a_0 \exp(-a_1 u^{a_2})$$

- DESIS :
- $\text{ch}_{\text{water absorption}}$ = 820 nm
  - ch2 ~ 820 nm
  - [ch1, ch3] ~ [795, 840] nm

Automatic channel selection for different “binning”.

- EnMAP:
- $\text{ch}_{\text{water absorption}}$ = 940 and/or 1130 nm
  - ch2 ~ 940 nm
    - [ch1, ch3] = [895, 1010] nm
  - ch2 ~ 1130 nm:
    - [ch1, ch3] = [1080, 1220] nm

Surface reflectance (BOA)

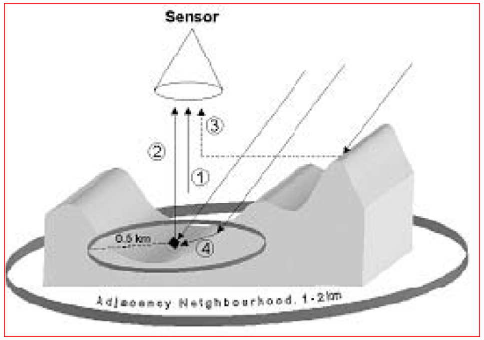
- Flat-terrain:

radiative transfer equation for a homogenous surface under clear sky conditions:

$$L = L_p + \frac{\tau \left(E_{dir} \cos \theta_s + E_{dif}\right) \rho / \pi}{1 - \rho s}$$

where at-sensor radiance (L) relates with the path radiance(L_p), ground-to-sensor transmittance (τ), direct (E_{dir}) and diffuse (E_{dif}) solar flux on the ground, solar zenith angle (Θ_s), surface reflectance (ρ) and spherical albedo (s) of the atmosphere.

- Rugged-terrain:
  - Illumination map produced with a digital elevation model (DEM)



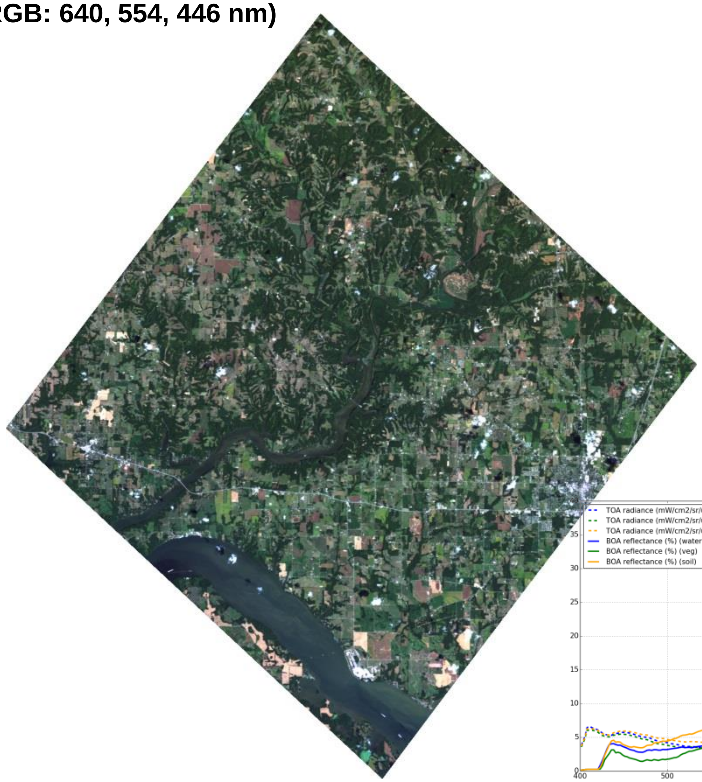
  - Additional radiance component (Adjacency neighborhood ~ 1 km) included

Surface reflectance (DESIS)

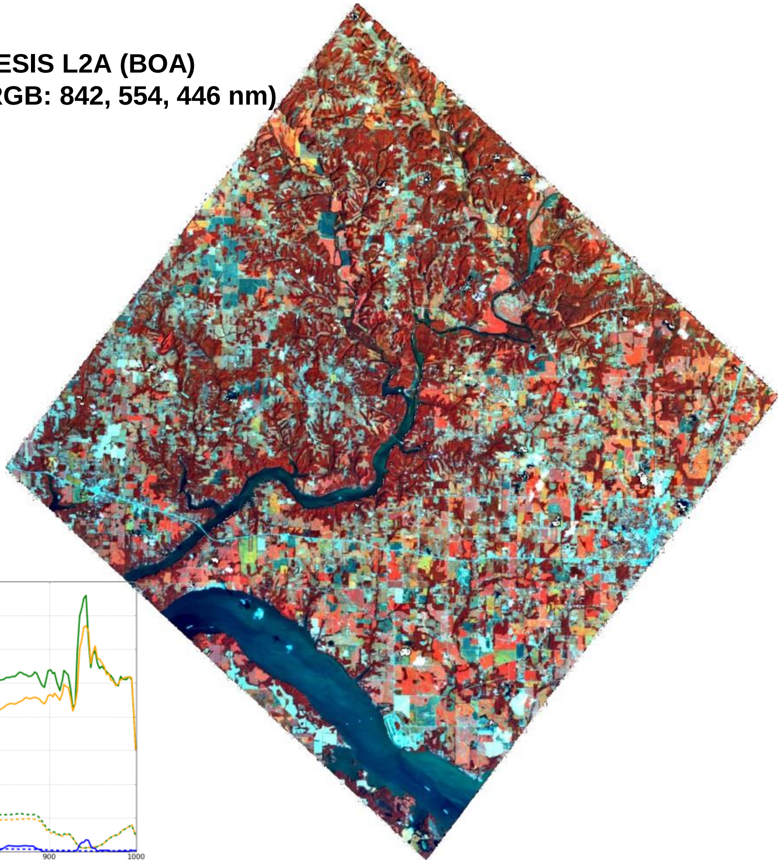
- Flat-terrain atmospheric correction

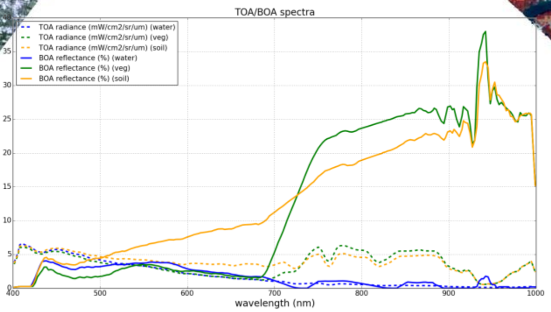
(Terrain_correction = 'No'):

DESIS L1C (TOA)
(RGB: 640, 554, 446 nm)



DESIS L2A (BOA)
(RGB: 842, 554, 446 nm)

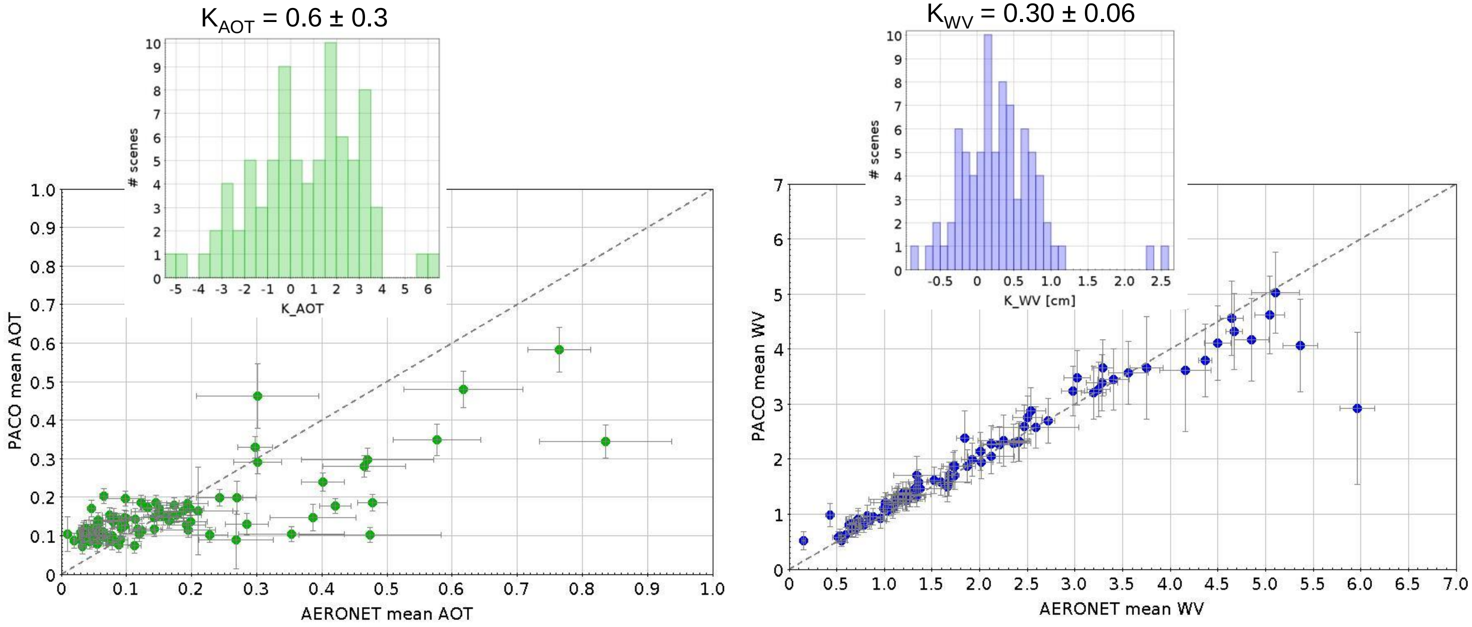




Validation of AOT and WV with AERONET reference data using multi-spectral data (Sentinel-2)

- Sentinel-2:
  - λ = {443.9, 496.5 , 560.0, 664.4, 703.9, 740.2, 782.5, 835.1, 864.8, 945.0, 1373.5, 1613.7, 2202.4} nm
- Atmospheric correction over land: same algorithms (PACO SW)

$$K = \frac{X_{AERONET} - X_{PACO}}{\sqrt{u1^2 + u2^2}}$$



Backup slides

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Bidirectional Reflectance Distribution Function (to be study during commissioning)

For rather steep terrain, isotropic Lambertian surface reflectance (ρ_L) assumption causes overcorrected (bright) values in faintly illuminated areas (small cosβ).

Empirical approach (Richter et al, 2009, *Remote Sensing*, Vol. 1, 184-196).

$$\rho_g = \rho_L G \qquad G = \left\{\frac{\cos\beta_i}{\cos\beta_T}\right\}^b \geq g$$

where $\beta_T = \begin{cases} \theta_s + 20°, & \theta_s < 45° \\ \theta_s + 15°, & 45° \leq \theta_s \leq 55° \\ \theta_s + 10°, & \theta_s > 55° \end{cases}$, $b = \begin{cases} \frac{1}{2}, & for\ soil/sand \\ \frac{3}{4}, & \lambda < 720\ nm \\ \frac{1}{3}, & \lambda > 720\ nm \end{cases}$ and g = 0.25

Aerosol Optical Thickness

Dark Dense Vegetation pixels (DDV): pixels masked during the pre-classification process

Negative reflectance pixels in red (660 nm) and NIR bands (850 nm) reduce the visibility over vegetation and water surfaces

- DESIS: DDV VNIR (Richter et al, 2006)
  - VIS = [10, 23, 60] km
  - RVI/NDVI, ρ_{NIR} and $\rho_{red} \leq [0.04 - 0.025]$

$$\rho_{red} = 0.1\,\rho_{NIR}$$

- EnMAP: DDV SWIR (1.6 or 2.2 µm) (based on Kaufman et al 1997)
  - 2.2 µm: ρ_{th} = [5, 10, 12]%

$$\rho_{red} = 0.5\,\rho_{2.2}$$

  - 1.6 µm: ρ_{th} = [10, 15, 18]%

$$\rho_{red} = 0.25\,\rho_{1.6}$$

$$\rho_{blue} = 0.5\,\rho_{red} + 0.005$$

Aerosol contribution in the blue updated ($VIS_{blue} = VIS_{red}$):

$$L_{p,blue,updated} = L_{p,blue} - \frac{1}{\pi}\tau_{blue}\rho_{blue}E_{g,blue}$$

Water vapor (DESIS)

Output product as quality layer

- ***DESIS***: QL_QUALITY-2
    1. Shadows
    2. Visible land
    3. Snow
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    6. Cloud over land
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Put here DESIS preliminary results for Scene 15b
And 820 nm WV band extraction