Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and Environment.

TROPOS

Freie Universität Berlin

EarthCARE level 2 development projects APRIL, CLARA and DORSY
final presentation

M-AOT processor and M-AOT product developed in APRIL

Nicole Docter, Rene Preusker, Jürgen Fischer

Contact: nicole.docter@wew.fu-berlin.de

10 March 2021, webex

M-AOT v8.x overview

Freie Universität Berlin

- MSI stand-alone aerosol processor
- Daytime and cloud-free only
- Output resolution on native MSI grid
- Purpose: offer information on horizontal aerosol distribution complementing vertical nadir information from ATLID

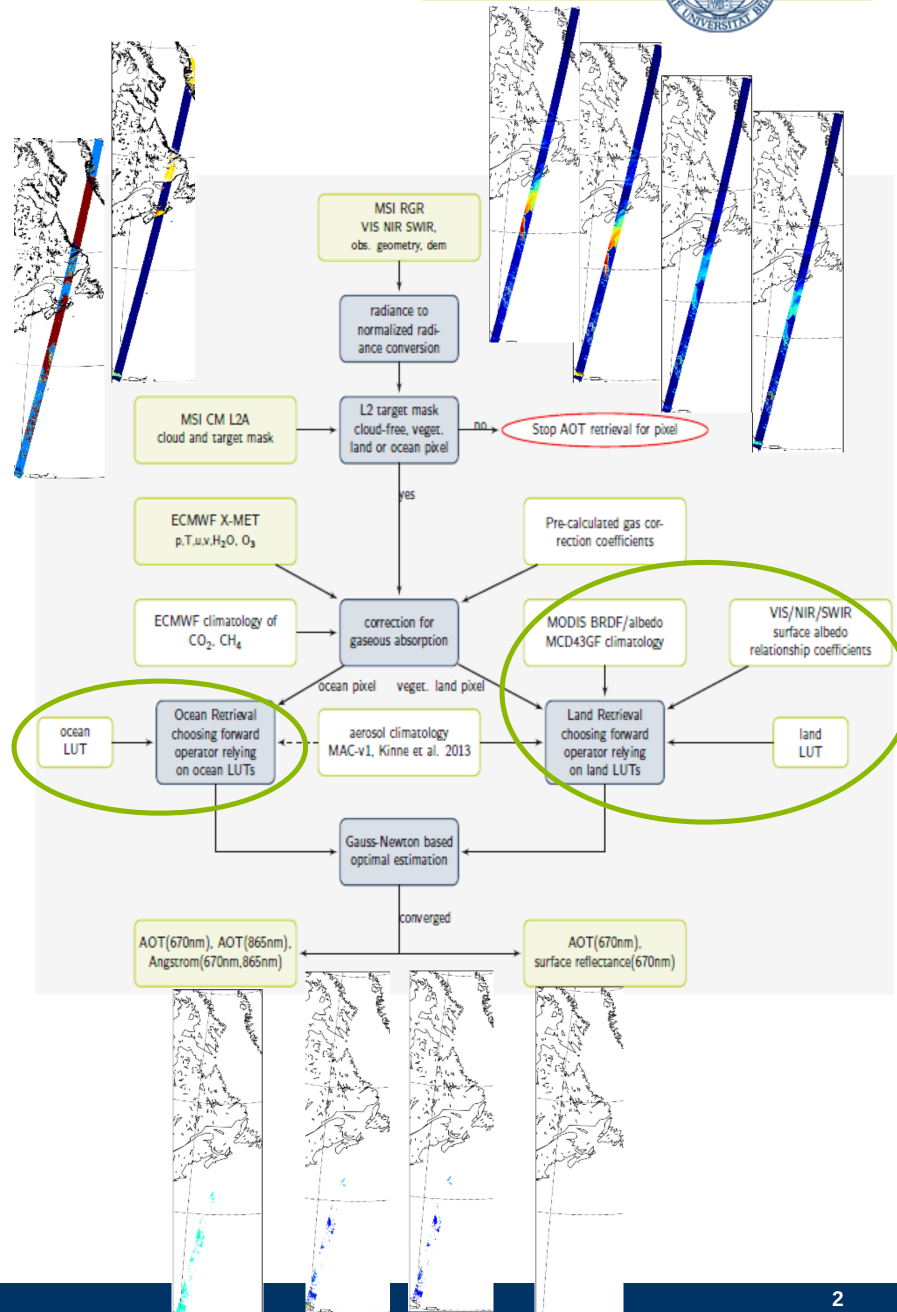
- Optimal estimation based retrieval approach of aerosol optical thickness (AOT)
  over ocean, and where possible land, at 670 nm
  and over ocean at 865 nm

- Measured signal will be corrected for gaseous absorption in advance

$$T_{gas}(\lambda) = \exp\left(-AMF \cdot \left(a(\lambda) + b(\lambda) \cdot gas + c(\lambda) \cdot gas^2\right)\right)$$

used correction coefficients are based on line-by-line code included in MOMO (Doppler et al. 2014) applying HITRAN 2012 (Rothman et al., 2014) database

- Forward operators consist of interpolation in LUTs created with FUB in-house radiative transfer model MOMO (Hollstein and Fischer, 2012, Doppler et al. 2014)
- LUT definition / assumptions:
  25 aerosol component mixings via AOT ratios of the four basic HETEAC types (Wandinger et al. 2016)



M-AOT – **LAND** retrieval approach

Freie Universität Berlin

- Assumed signal dependence $\rho_\lambda(\phi_{rel}, \theta_{sun}, \theta_{sat}, \tau_{aer}, \alpha_\lambda, p, mix_{aer})$
- Aerosol component mixing chosen from MAC v1 (Kinne et al., 2013) climatology

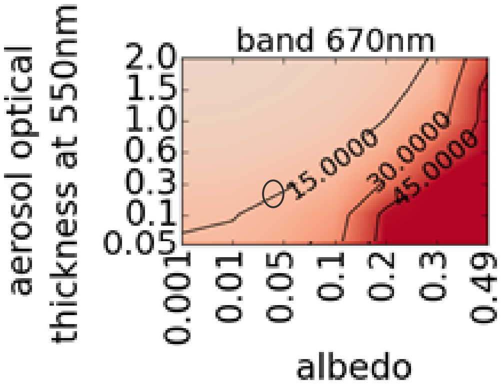
Land retrieval – sensitivity

Assumptions:
- other parameters are perfectly known
- One channel at a time considered

$$\rho(\tau,\alpha) = \rho(\tau_0,\alpha_0) + \frac{\partial\rho}{\partial\tau}\Delta\tau + \frac{\partial\rho}{\partial\alpha}\Delta\alpha$$

- Error propagation factor $\boldsymbol{E}$ (worst case):
  Assuming that $\boldsymbol{\rho(\tau,\alpha) = \rho(\tau_0,\alpha_0)},\ \boldsymbol{\Delta\rho = 0}$:
  $\boldsymbol{\Delta\tau = -E\Delta\alpha}\,,\ \mathbf{E} = (\boldsymbol{\partial\rho/\partial\alpha})/(\boldsymbol{\partial\rho/\partial\tau})$

$\boldsymbol{abs(E)}$



Case study
- HETEAC fine mode less absorbing aerosol
- SZA=40°
- RAA=140°
- VZA=0°
- Pressure=1013.25hPa

→ Assuming state: AOT = 0.2, albedo = 0.05
absolute error propagation factor of ~15 -> **albedo error of 0.01** would lead to **AOT error of 0.15**

→ Need for climatological albedo update that represents the current surface state reasonably well

- Optimal estimation measurement $\vec{y}$ and state vector $\vec{x}$:

$$\vec{y} = \begin{pmatrix} \rho_{VIS} \\ \rho_{SWIR1} \\ \rho_{SWIR2} \end{pmatrix},\ \vec{x} = \begin{pmatrix} \tau_{aer} \\ \alpha_{SWIR2} \\ NDVI_{SWIR} \end{pmatrix}$$

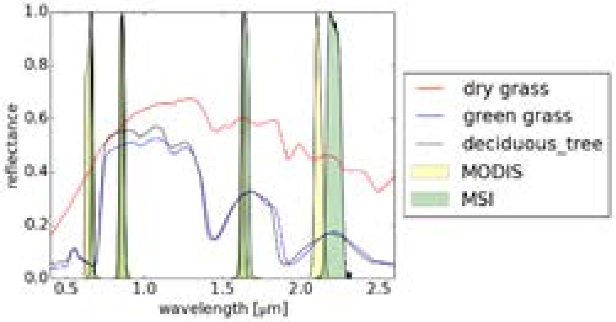
- Forward operator approach:
  - Usage of surface parameterization
  - linear interpolation in LUTs
  - inverse distance weighting of aerosol component mixing

M-AOT – **LAND** retrieval approach

Freie Universität Berlin

Land retrieval – empirical surface parameterization

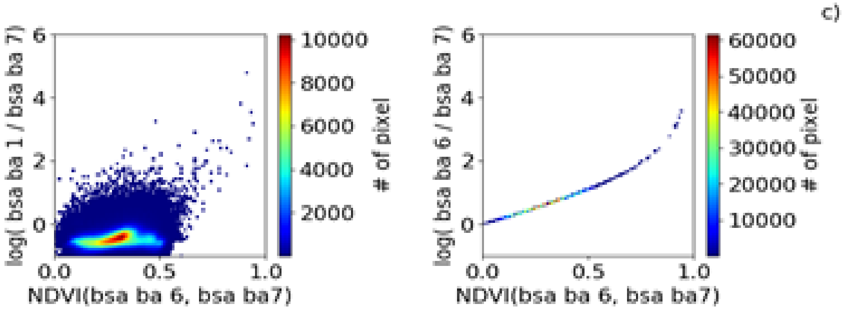
- MODIS BRDF/albedo climatology (provided by Environment Canada) has been analysed and used to create a parameterization
- Estimation of VIS, SWIR-1 albedo using SWIR-2 black sky albedo and greenness:



$$\boldsymbol{\alpha_\lambda = \alpha_{SWIR2} \cdot exp\left(a_{\lambda,SWIR2}{}^{NDVI_{SWIR}+b_{\lambda,SWIR2}} + c_{\lambda,SWIR2}\right)},$$

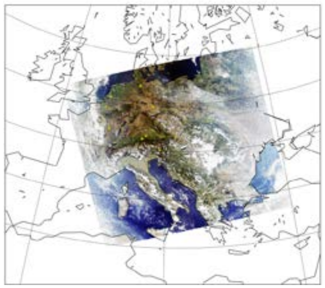
where

- $a_{\lambda,SWIR2}, b_{\lambda,SWIR2}, c_{\lambda,SWIR2}$ stored in LUT
- greenness dependence via $\mathrm{NDVI}_{\mathrm{SWIR}} = \frac{\rho_{SWIR1} - \rho_{SWIR2}}{\rho_{SWIR1} + \rho_{SWIR2}}$
- dependent on SZA, surface biome (IGBP)

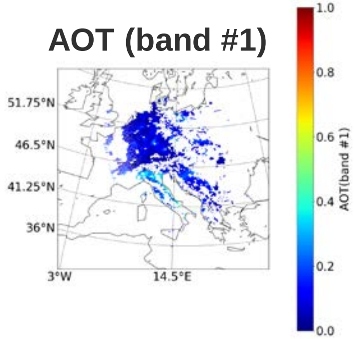


MODIS input based M-AOT **LAND** retrieval verification

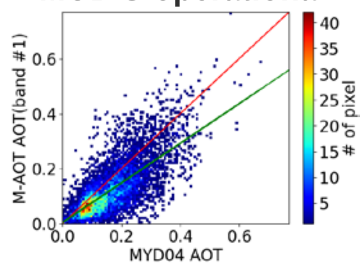
Europe - MYDX.A2016257.1150.006.*



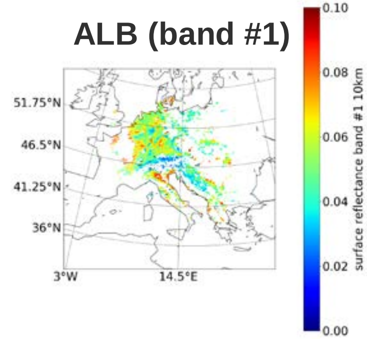
AOT (band #1)



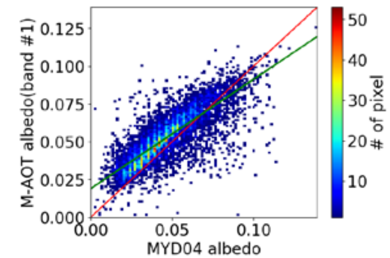
AOT (band #1)
M-AOT vs
MODIS operational



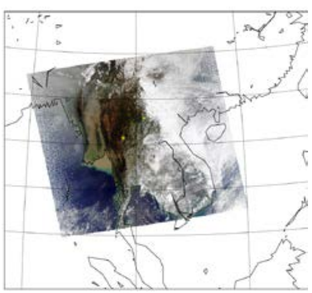
ALB (band #1)



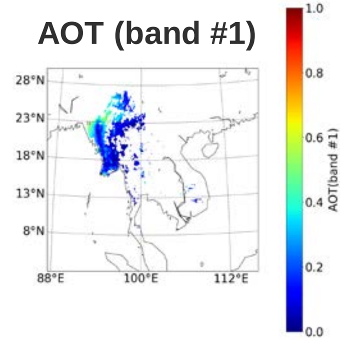
ALB (band #1)
M-AOT vs
MODIS operational



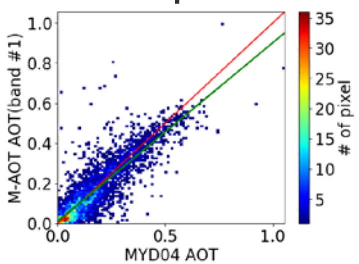
Southeast Asia - MYDX.A2018031.0640.006.*



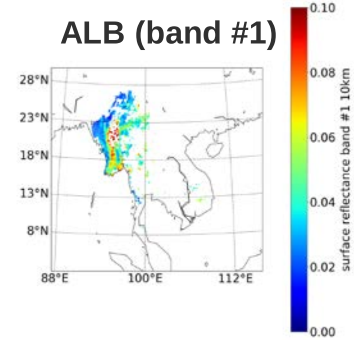
AOT (band #1)



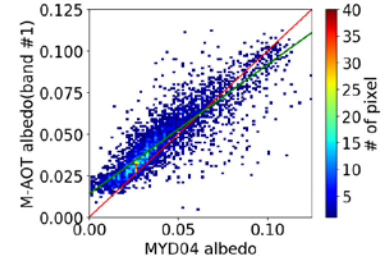
AOT (band #1)
M-AOT vs
MODIS operational



ALB (band #1)



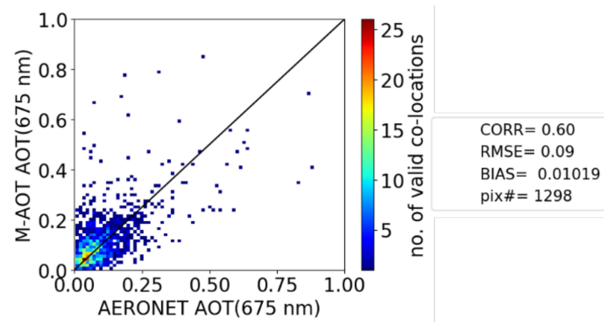
ALB (band #1)
M-AOT vs
MODIS operational



Verification using M-AOT processed MODIS scenes and comparison with AERONET
for 1298 match-ups:

- time difference of 15 minutes
- spatial distance of 6 km

shows reasonable agreement



M-AOT – **OCEAN** retrieval approach

- Assumed signal dependence: $\rho_\lambda(\phi_{rel}, \theta_{sun}, \theta_{sat}, \tau_{aer}, ws, p, mix_{aer})$
- Aerosol component mixing chosen from MAC v1 (Kinne et al., 2013) climatology
- Ocean surface is parameterized via wind speed following Cox and Munk (1954)
- Strong glint areas excluded from retrieval

- Optimal estimation measurement $\vec{y}$ and state vector $\vec{x}$:

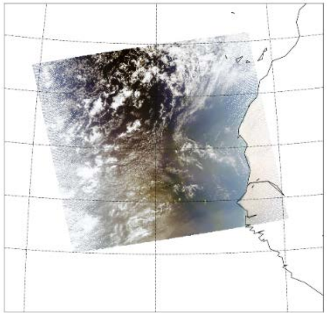
$$\vec{y} = \begin{pmatrix} \rho_{VIS} \\ \rho_{NIR} \\ \rho_{SWIR1} \\ \rho_{SWIR2} \end{pmatrix}, \; \vec{x} = \begin{pmatrix} \tau_{aer} \\ ws \end{pmatrix}$$

- *currently under development:*
  usage of aerosol component mixing based best fit in operational environment that fulfils the runtime requirement
  - development approach
    - optimal estimation of AOT for all 25 pre-defined aerosol component mixings
    - choosing the state vector for which the root-mean-squared error between forward simulated measurement and measurement is lowest

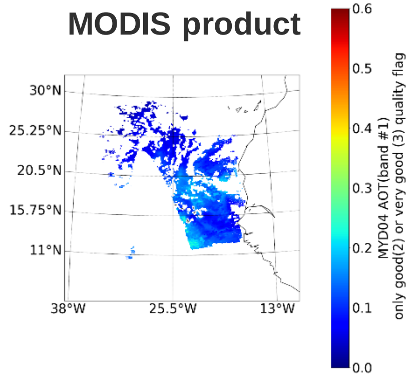
MODIS input based M-AOT **OCEAN** retrieval verification

Freie Universität Berlin

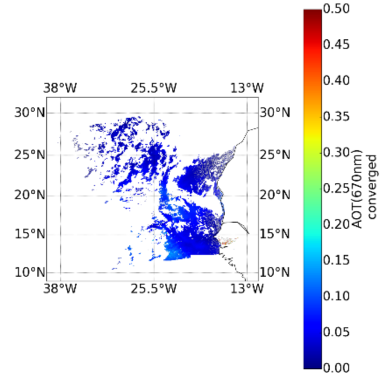
MYDX.A2007344.1500.006.*



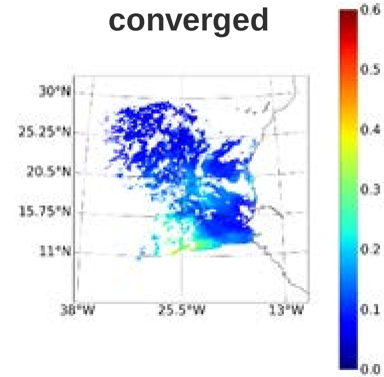
Official MODIS product



M-AOT default

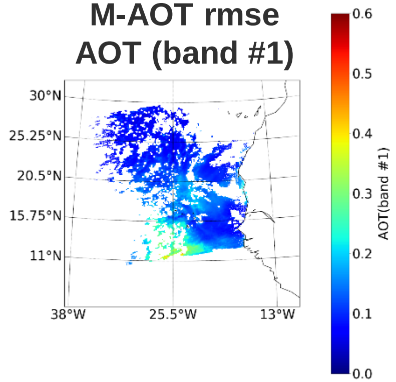


M-AOT rmse approach converged

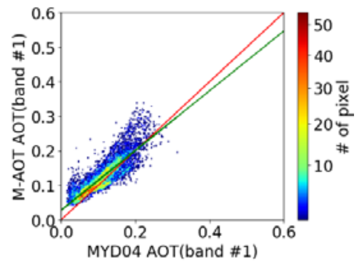


M-AOT rmse approach converged

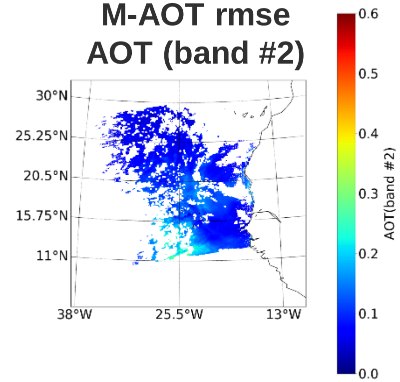
M-AOT rmse AOT (band #1)



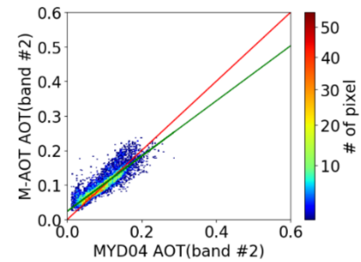
AOT (band #1) M-AOT rmse vs MODIS operational



M-AOT rmse AOT (band #2)



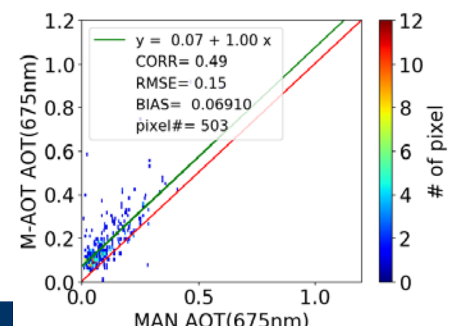
AOT (band #2) M-AOT rmse vs MODIS operational

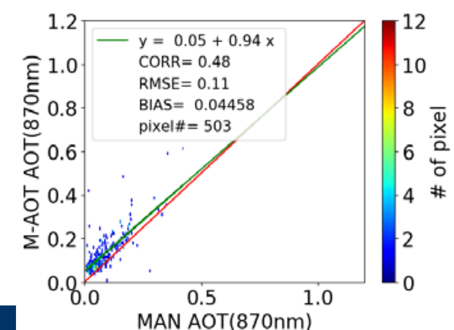


Verification using M-AOT-rmse processed MODIS scenes and comparison with Maritime Aerosol Network (MAN) for 503 match-ups:

- time difference of 30 minutes
- spatial distance of 0.1°

shows reasonable agreement





ECSIM nominal test scenes

M-AOT v8.1

Freie Universität Berlin

- Current used ecsim nominal test scenes for Halifax, Halifax aerosol, Baja and Hawaii

Halifax
- ECA_EXAA_MSI_RGR_1C_20241231T183450Z_**20201125**T180000Z_39316D
- ECA_EXAA_MSI_CM__2A_20241231T183452Z_**20201204**T094523Z_39316D

Halifax aerosol
- ECA_EXAA_MSI_RGR_1C_20241231T185624Z_**20191029**T180000Z_39316D
- ECA_EXAA_MSI_CM__2A_20241231T233450Z_**20200108**T082724Z_39316D

Baja
- ECA_EXAA_MSI_RGR_1C_20250410T213955Z_**20201125**T143000Z_40874D
- ECA_EXAA_MSI_CM__2A_20250410T213958Z_**20201204**T095038Z_40874D

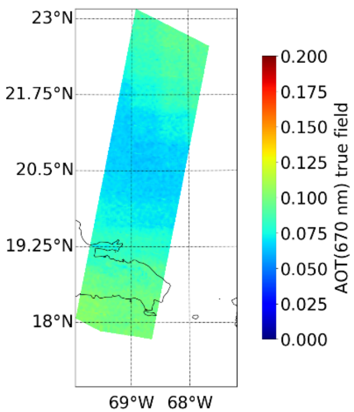
Hawaii
- ECA_EXAA_MSI_RGR_1C_20250625T005649Z_**20201026**T180000Z_42043E
- ECA_EXAA_MSI_CM__2A_20250625T005649Z_**20201204**T095224Z_42043E

ECSIM based M-AOT outputs

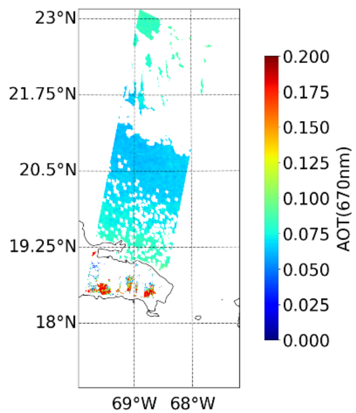
Freie Universität Berlin

Halifax
MSI_RGR_1C v 20201125

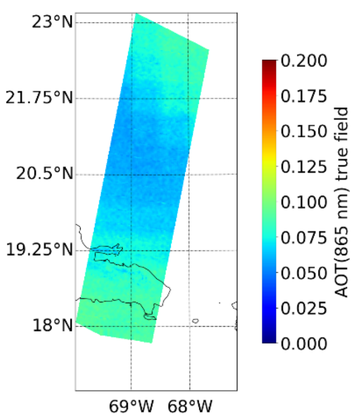
true AOT 670 nm



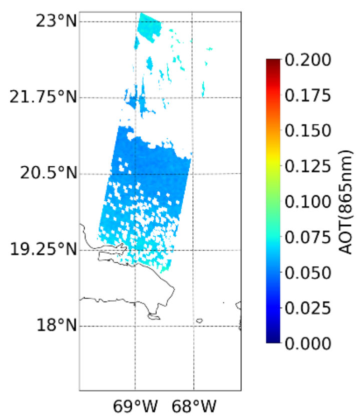
retrieved **AOT 670 nm**



true AOT 865 nm

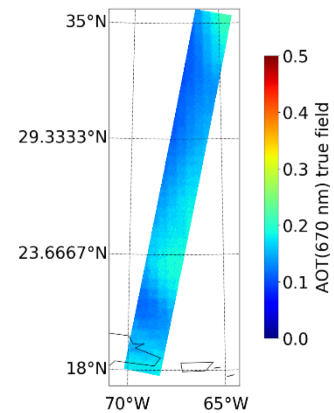


retrieved **AOT 865 nm**

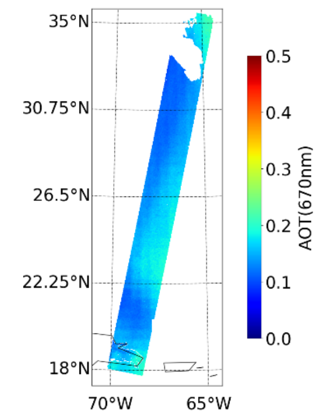


Halifax Aerosol
MSI_RGR_1C v 20191029

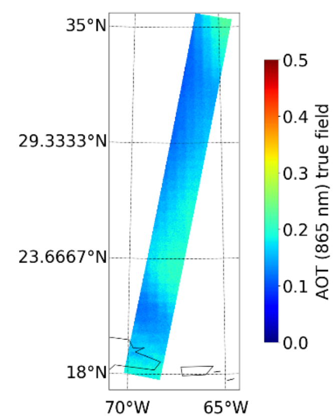
true AOT 670 nm



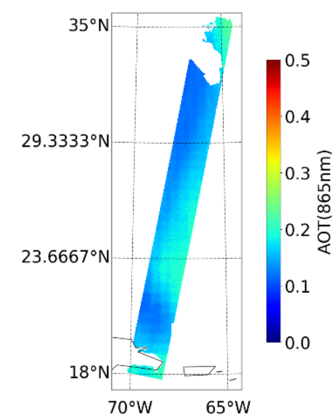
retrieved **AOT 670 nm**



true AOT 865 nm



retrieved **AOT 865 nm**

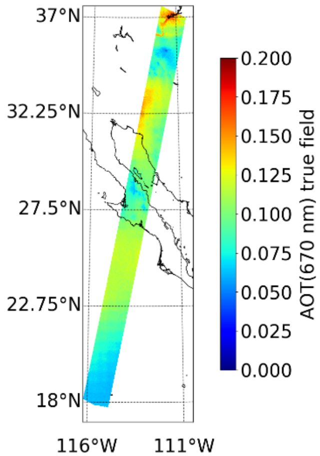


ECSIM based M-AOT outputs

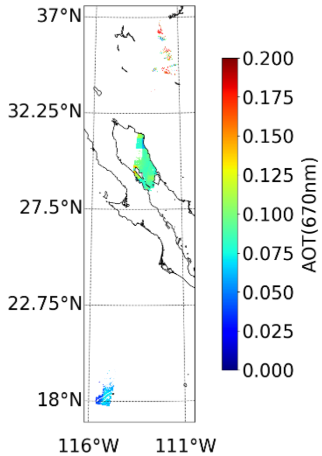
Freie Universität Berlin

Baja
MSI_RGR_1C v 20201125

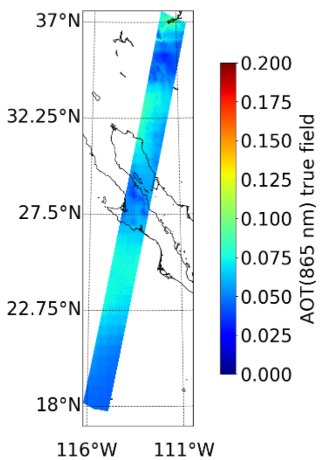
true AOT 670 nm



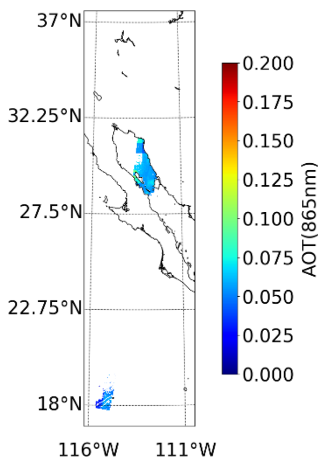
retrieved **AOT 670 nm**



true AOT 865 nm

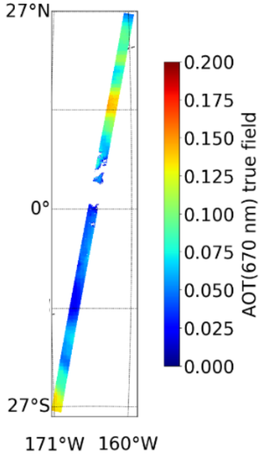


retrieved **AOT 865 nm**

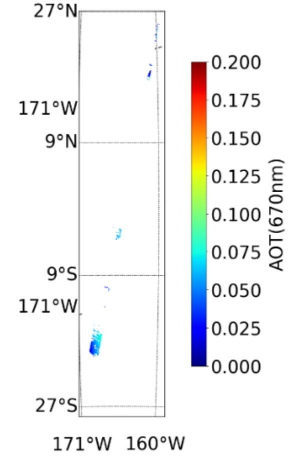


Hawaii
MSI_RGR_1C v 20201026

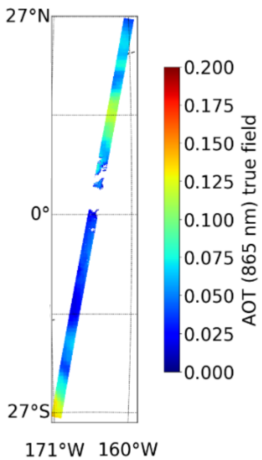
true AOT 670 nm



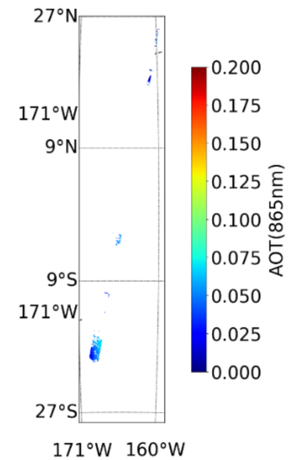
retrieved **AOT 670 nm**



true AOT 865 nm



retrieved **AOT 865 nm**



Summary

Freie Universität Berlin

- M-AOT processor creates the M-AOT product
- aerosol optical thickness retrieval over ocean and, where possible, land that uses multi-spectral imager measurements assuming one central wavelength per VNS band
- Optimal estimation based approach used
- Usage of HETEAC based aerosol classification in M-AOT LUTs to ensure consistency between instruments
- Usage of land surface parameterization that is based on MODIS BRDF / albedo climatology

- M-AOT has been tested with ECSIM and MODIS based inputs
- Verification using true fields of ECSIM simulations and the operational MODIS product and AERONET/MAN AOTs are underway