Rayleigh Scattering Approach and results from DIMITRI-Toolbox

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GSICS VIS/NIR meeting: Video-conferencing

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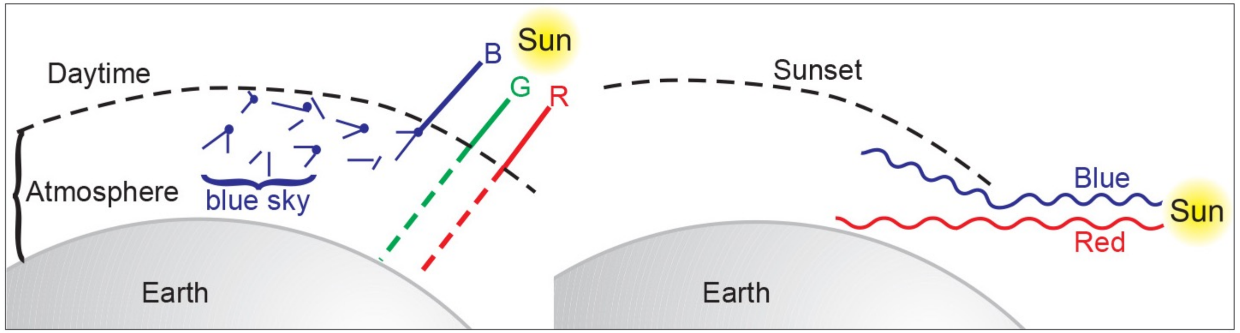
Agenda

- What is Rayleigh Scattering
- Rayleigh Scattering method in DIMITRI-Toolbox
- Results from MERIS-3RP radiometric validation
- Conclusion

What is Rayleigh Scattering



Why the sky is blue and the sunset is red?

- **Rayleigh scattering is purely electric dipole**
- **The scattering phase is symmetric**
- **The scattering amount varies proportionally to the 4th power of wavelength**
- **The main contributor to the TOA reflectance signal over ocean.**

$$I = I_0 \times e^{-t \times m}$$

$$t = t_{sg} + t_{ag} + t_{sp} + t_{ap}$$

$I \equiv$ radiation intensity (e.g., F)

$I_0 \equiv$ radiation intensity above atmosphere

$m \equiv$ air mass

$t \equiv$ attenuation coefficient due to

- absorption by gases (ag)
- scattering by gases (sg)
- scattering by particles (sp)
- absorption by particles (ap)

$t_{sp} \propto \lambda^{-n}$ *much more complex*

Rayleigh scattering $t_{sg} \propto \lambda^{-4}$

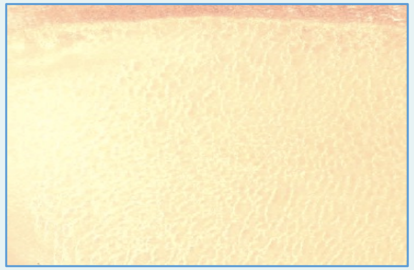
Deep UV – O, N_2, O_2
Mid UV & visible – O_3
Near IR – H_2O
Infrared – CO_2, H_2O, others
$t_{ag} \propto \sigma$

http://homework.uoregon.edu/pub/class/atm/scatter.html

Vicarious CalVal methods in DIMITRI-Toolbox

DIMITRI

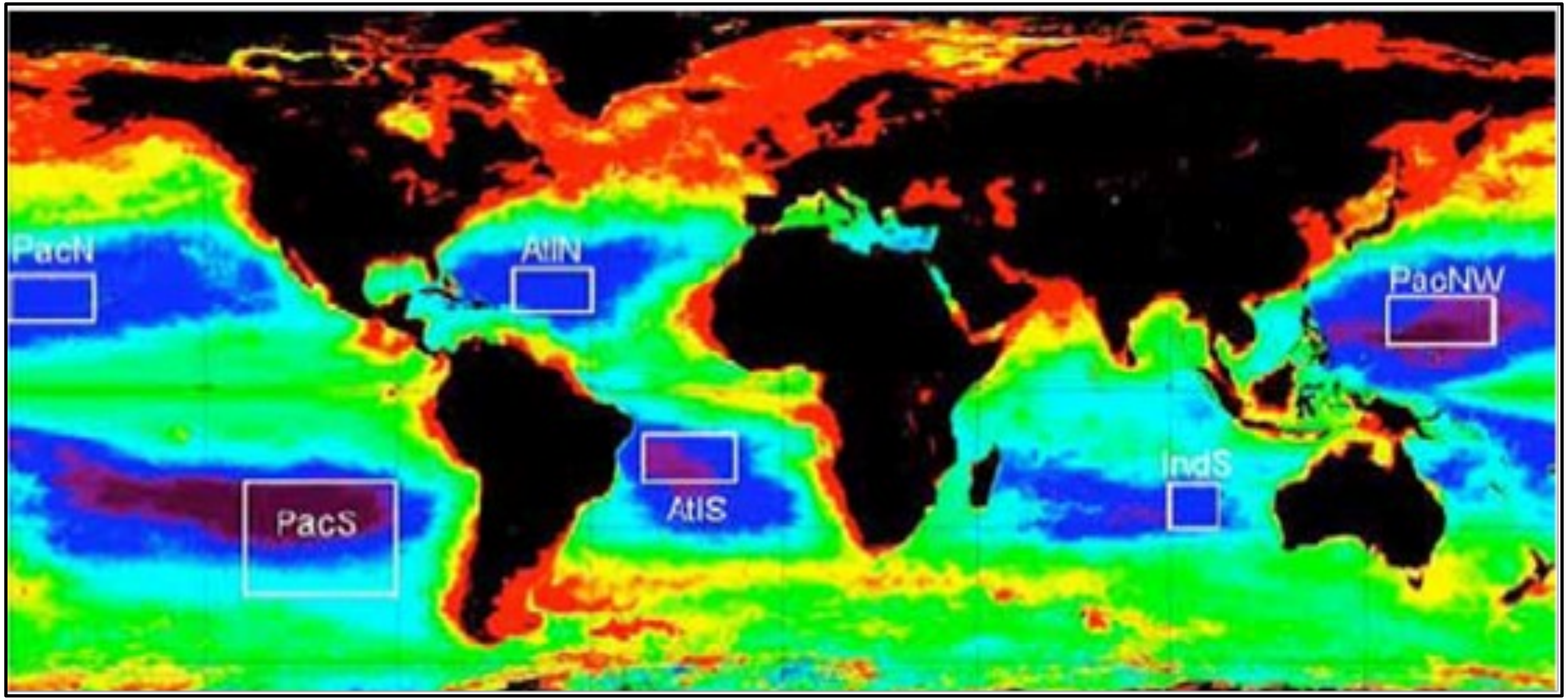
Database for Imaging Multi-spectral Instruments and Tools for Radiometric Intercomparison

Rayleigh scattering calibration	Sun-Glint inter-bands calibration	Desert (PICS) calibration	Sensor-to-Sensor intercalibration
			
Absolute calibration coefficient: as ρ^{obs}/ρ^{sim}	Absolute Inter-band calibration coefficient: as $\rho^{B(i)}/\rho^{B(ref)}$	Relative calibration coefficient: as ρ^{obs}/ρ^{sim} (MERIS as REF)	Absolute inter-calibration coefficient: as ρ^{obs}/ρ^{REF}
Vermote et al (1992); Hagolle et al (1999)	Hagolle et al (1999; 2004); Nicolas et al (2006)	Bouvet (2014)	Bouvet et al. (2006)
- Over VIS bands - Uncertainty <5% - Very stringent criteria	- Over VNIR bands - Uncertainty <2% - Very stringent criteria	- Over VNIR bands - Uncertainty <5% - Uses surface BRDF	- VIS, NIR & SWIR - Uncertainty <5% - Limited matchups

https://dimitri.argans.co.uk

Rayleigh Cal-method application on MERIS 3RP using DIMITRI-Toolbox

CalVal Sites:



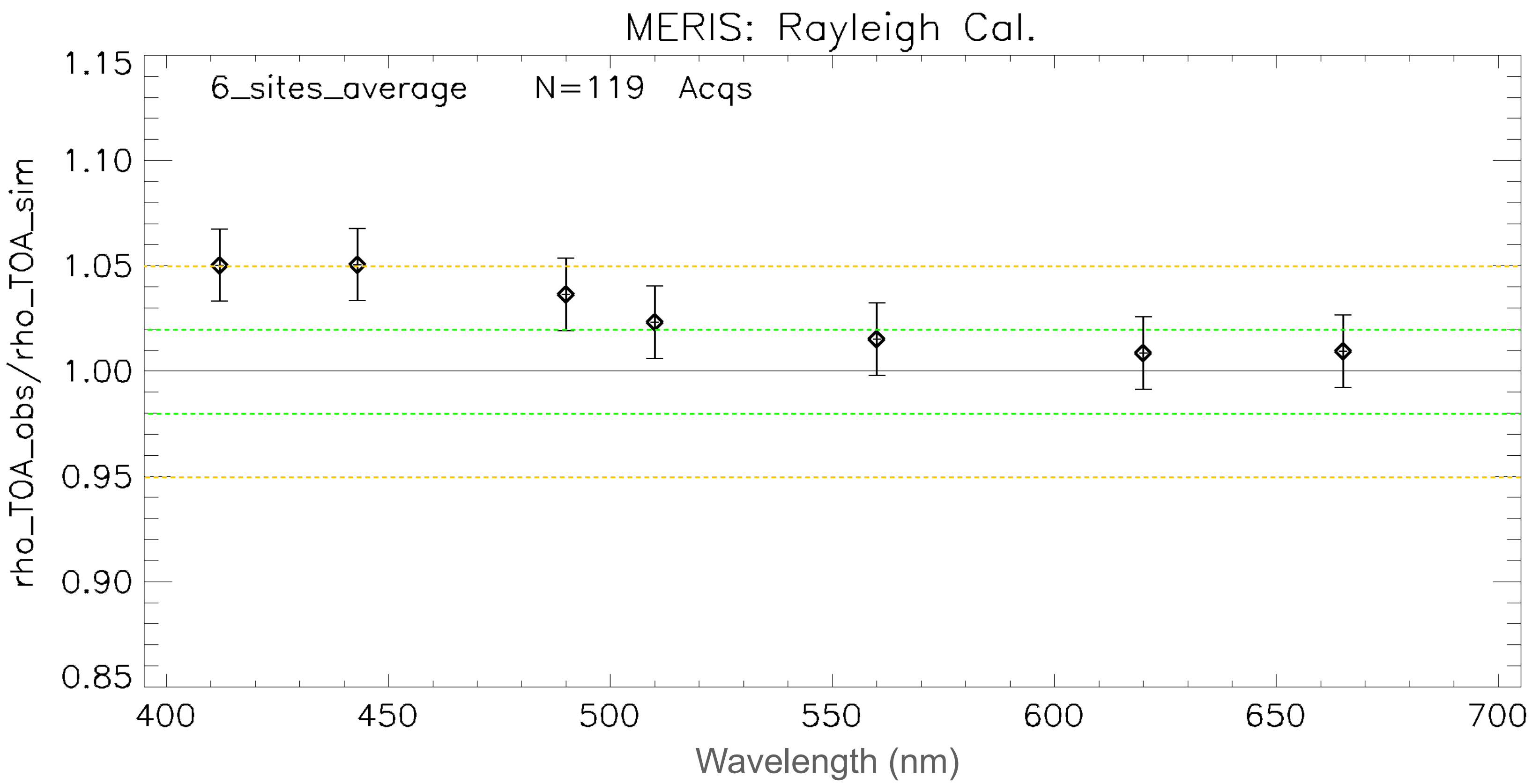
Fougnie and Henry (2002) and Bouvet (2013)

Rayleigh Scattering method in DIMITRI-Toolbox

$$RA(\lambda) = \frac{\rho_{TOA}^{oz}(\lambda)}{\rho_{TOA}^{theo}(\lambda)}$$

(Rayleigh Calibration coefficient)

MERIS 3RP 2002-2012



Rayleigh Scattering method in DIMITRI-Toolbox

Theoretical background:

$$\rho_{TOA}(\lambda) = t_{gas}(\lambda)\left(\rho_{path}(\lambda) + t_{down}(\lambda) * t_{up}(\lambda) * \rho_w(\lambda) + T_{down}(\lambda) * T_{up}(\lambda)\rho_G\right)$$

$$\rho_{path} = \rho_r + \rho_a + \rho_{ra}$$

Could be estimated using aerosol models:
Marine models of Shettle and Fenn (1974)
Several relative humidities

$$\rho_{path}(\lambda)_{|P} = \rho_{path}(\lambda)_{|P_{std}} * \left(1 + \frac{\Delta P}{P_{std}}\eta(\lambda)\right)$$

$$\eta(\lambda) = \frac{\tau_R(\lambda)}{\tau_R(\lambda)+\tau_a(\lambda)}$$

Antoine and Morel (2011)

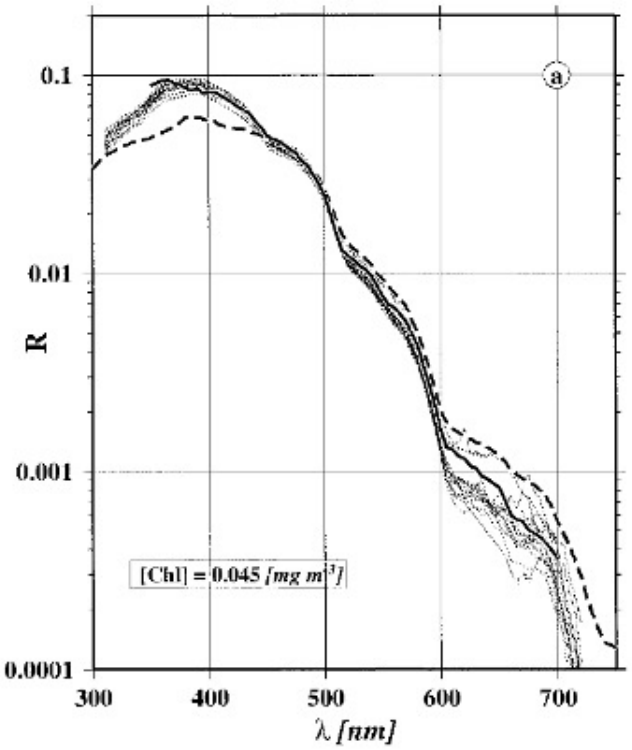
Rayleigh Scattering method in DIMITRI-Toolbox

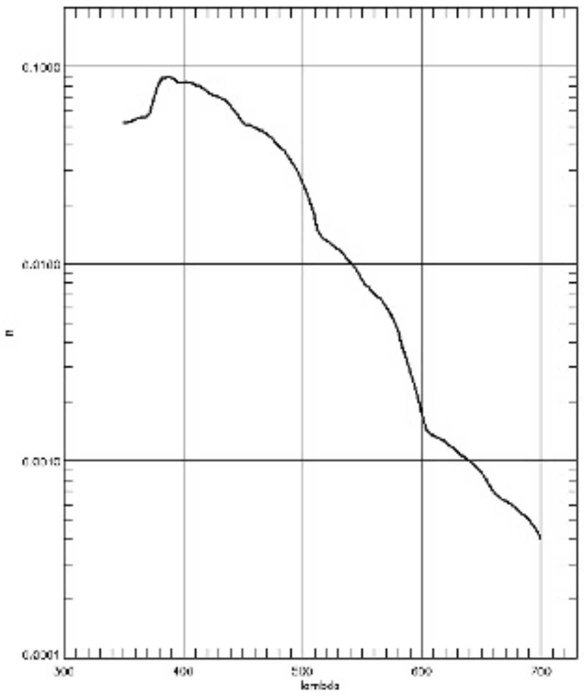
Theoretical background:

$$\rho_{TOA}(\lambda) = t_{gas}(\lambda)\left(\rho_{path}(\lambda) + t_{down}(\lambda) * t_{up}(\lambda) * \rho_w(\lambda) + T_{down}(\lambda) * T_{up}(\lambda)\rho_G\right)$$

$$\rho_w(\lambda) = \pi \frac{\Re}{Q} R(0^-)$$

Marine model follows:
Morel and Maritorena (2001),
Morel and Gentili (1996)





Rayleigh Scattering method in DIMITRI-Toolbox

Theoretical background:

$$\rho_{TOA}(\lambda) = t_{gas}(\lambda)(\rho_{path}(\lambda) + t_{down}(\lambda) * t_{up}(\lambda) * \rho_w(\lambda) + T_{down}(\lambda) * T_{up}(\lambda)\rho_G)$$

ρ_G

Sun glint reflectance is filtered by RCNR865 : [0.002 - 0.02]
We follow Hagolle et al. (1999) by considering the Rayleigh corrected normalised radiance at 865 nm (directly related to aerosol amount)

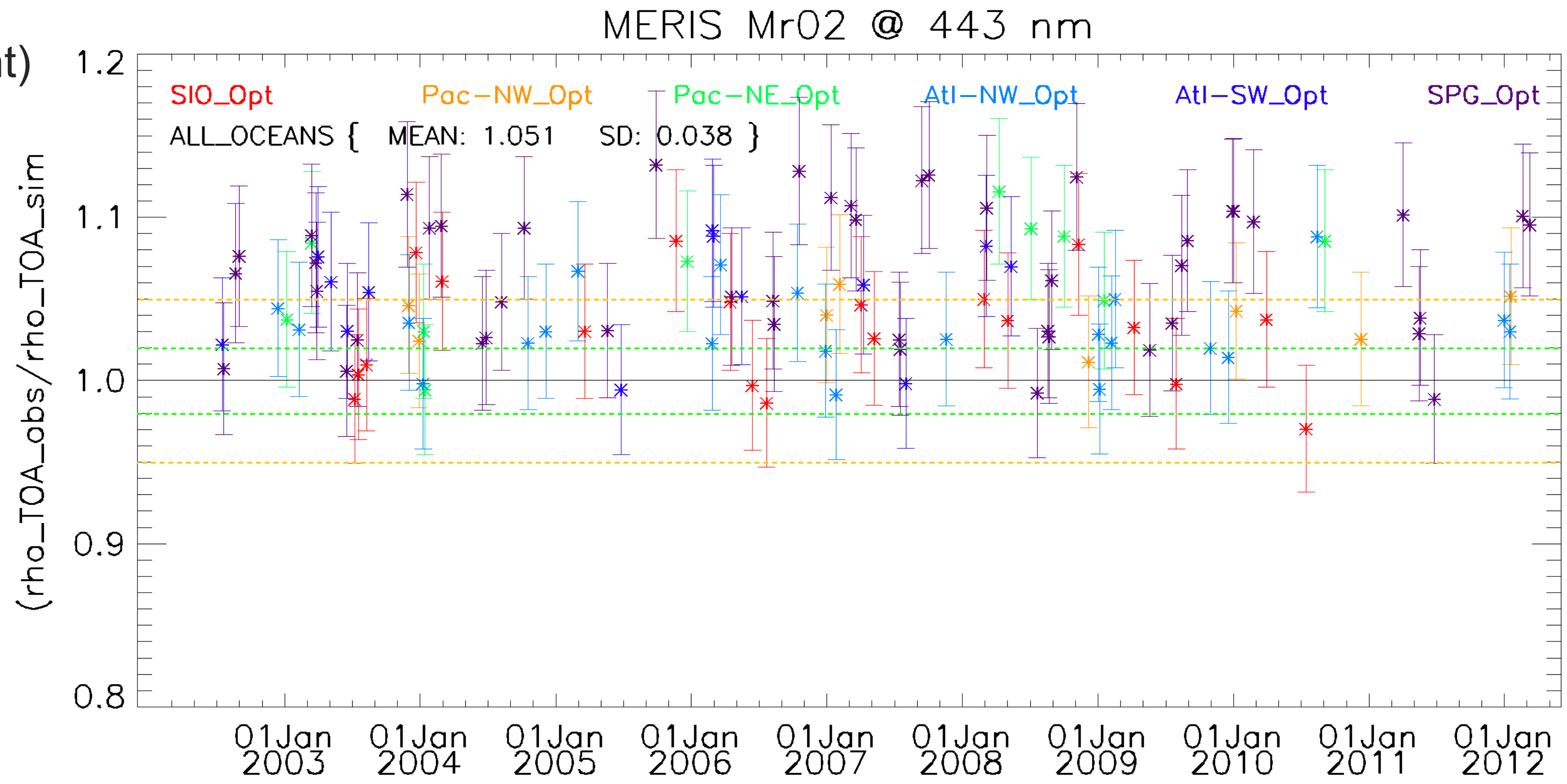
$$R_{RC}(865) = (\rho_{TOA}(865) - \rho_R(865)) \cos\theta_s$$

Rayleigh Scattering method in DIMITRI-Toolbox

$$RA(\lambda) = \frac{\rho_{TOA}^{oz}(\lambda)}{\rho_{TOA}^{theo}(\lambda)}$$

(Rayleigh Calibration coefficient)

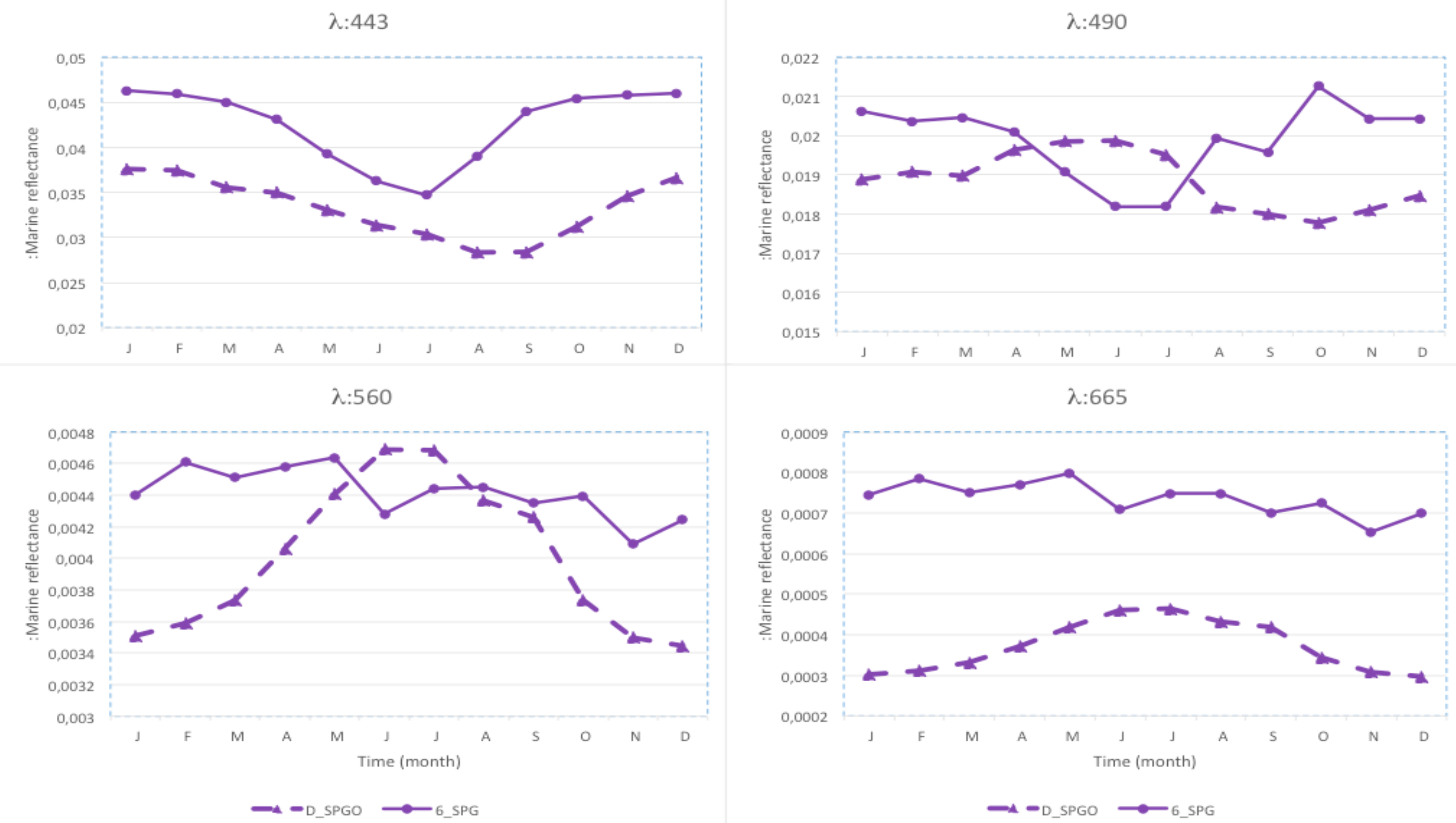
MERIS 3RP 2002-2012



Rayleigh Scattering method in DIMITRI-Toolbox

Marine-reflectance CNES vs DIMITRI

$$Chl, \theta_s \rightarrow \rho_w(\lambda)$$



Rayleigh Scattering method in DIMITRI-Toolbox

Marine-reflectance CNES vs DIMITRI

Rayleigh	aerosols	marine	Transmission	Absorption	Average measured reflectance	Average marine reflectance	typical marine reflectance difference DIMITRI vs. CNES	typical marine reflectance difference DIMITRI vs. CNES (%)	typical calibration difference DIMITRI vs. CNES (%)
80%	2%	18%	0,998	0,20%	0.147	0,035	0,005	14,29%	2,57%
83%	3%	14%	0,983	1,70%	0.103	0,019	0,001	5,26%	0,74%
89%	6%	5%	0,918	8,20%	0.055	0,004	0,0005	12,50%	0,63%
87%	11%	2%	0,969	3,10%	0.028	0,0006	0,0002	33,33%	0,67%

Provided by V. Lonjou (CNES)

Note: Chl-DIMITRI: Globcolour climatology.

Rayleigh Scattering method in DIMITRI-Toolbox

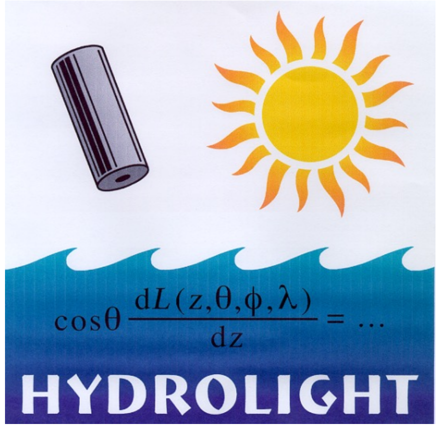
Marine-reflectance BRDF improvement

$\rho_w(\lambda)$

Aim is to replace with version that is dependent on solar-view geometry (using **BRDF**)

$\rho_w(\lambda, \theta, \theta_0, \Delta\phi)$

$$L_w(\theta, \theta_0, \Delta\phi) = E_d(0^+)\Re(\theta)\frac{f}{Q}\frac{b_b}{a}$$

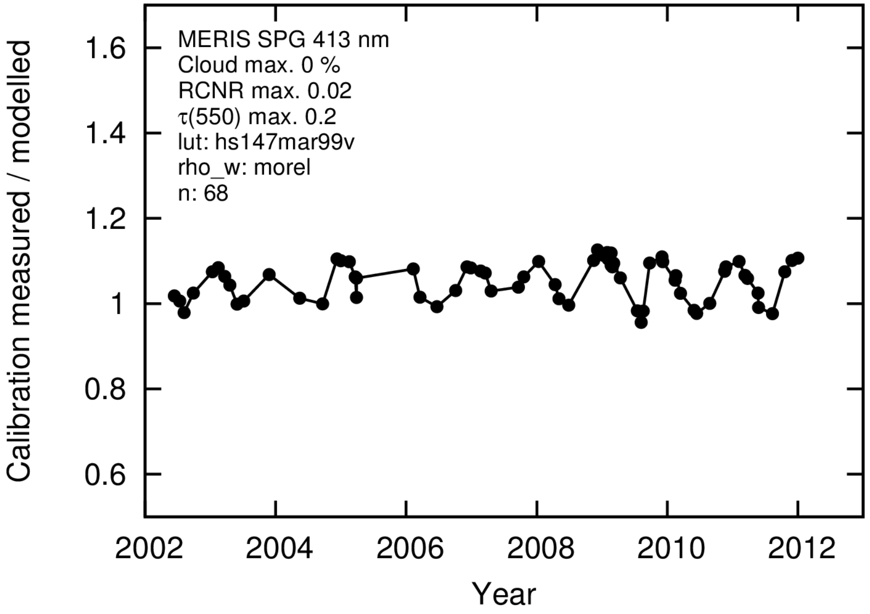


- Can get L_w, E_d, b_b and a from the model and calculate the BRDF factor.
- Just assume BRDF has a dependency on θ, θ_0 and $\Delta\phi$ and tabulate it.

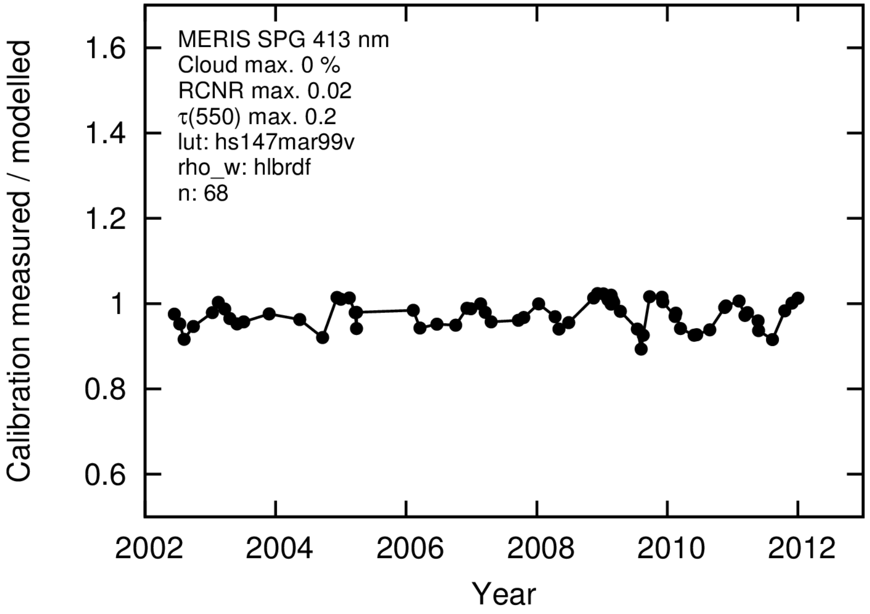
Rayleigh Cal-method application on MERIS 3RP using DIMITRI-Toolbox

Results over SPG-site:

Original water-leaving reflectance



New BRDF



- Slight improvement
- Physically could not account for all of it - observed dependency is almost as big as the whole water-leaving reflectance.

Rayleigh Scattering method in DIMITRI-Toolbox

Theoretical background:

$$\rho_{path}(\lambda)_{|P} = \rho_{path}(\lambda)_{|P_{std}} * \left(1 + \frac{\Delta P}{P_{std}} \eta(\lambda)\right)$$

Antoine and Morel (2011)

$$\eta(\lambda) = \frac{\tau_R(\lambda)}{\tau_R(\lambda)+\tau_a(\lambda)}$$

$$\tau_r(\lambda) = \sigma \frac{PA}{m_a g}$$

Bodhaine et al. (1999)

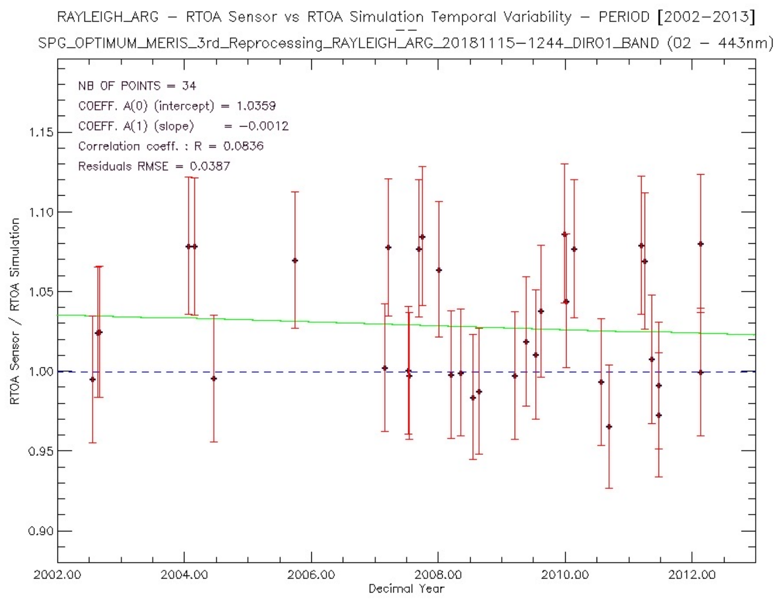
$$g(\phi) = 980.6160(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi)$$

Rayleigh Cal-method application on MERIS 3RP using DIMITRI-Toolbox

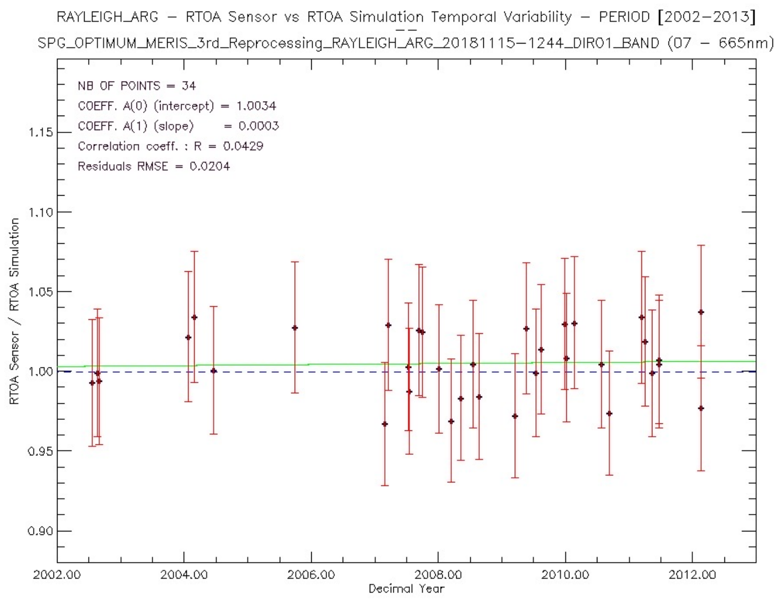
Results over SPG-site:

Before : HS-LUTs + Atmos-P-adjustment

(N: 34)



(443 nm)



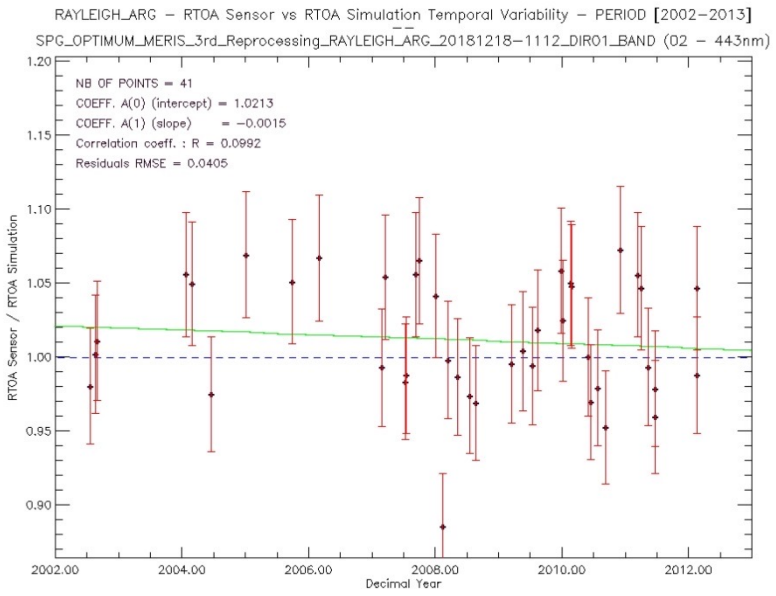
(665 nm)

Rayleigh Cal-method application on MERIS 3RP using DIMITRI-Toolbox

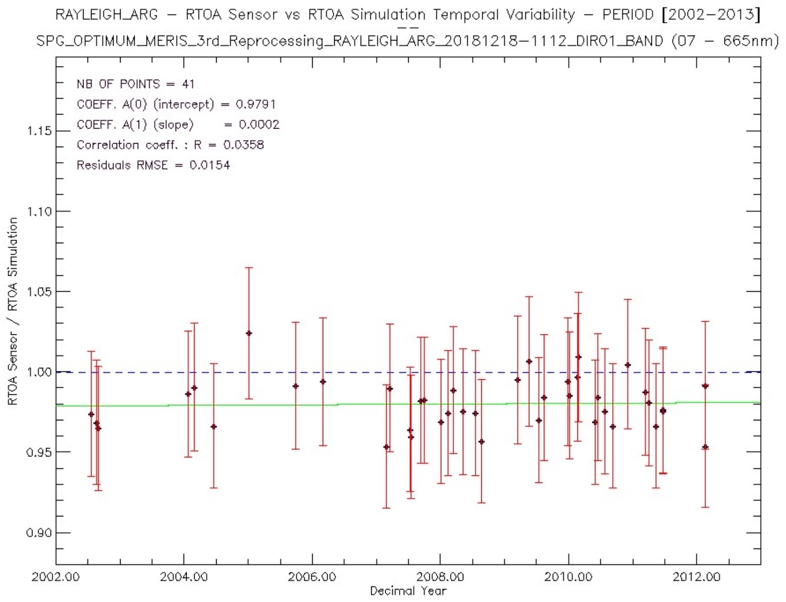
Results over SPG-site:

After : HS-LUTs + Atmos-P-adjustment

(N: 41)



(443 nm)



(665 nm)

Conclusions

- Clear improvement over Rayleigh results from MERIS.
  - Hyperspectral Atmospheric LUTs
  - Atmos-pressure adjustment.
  - Introducing the directional effects (BRDF)

- Still observe a seasonal variability and site dependency.

- Next:
- To perform the intercomparison between MERIS/MODIS and MSI/OLCI using Rayleigh Scattering method (DIMITRI).

Invitation to submit Manuscript for a Special-Issue of Remote sensing MDPI

MDPI

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Expected topic areas covered by Copernicus Sentinels missions but are not limited to:

- **remote sensing of atmospheric composition, land, ocean, snow and ice surface,**
- **calibration and sensors' intercomparison,**
- **validation of geophysical data products,**
- **innovations to products' retrieval algorithms and Cal/Val techniques,**
- **Fiducial Reference Measurements (FRM) for satellite data validation.**

Guest-Editors:
Dr. B. Alhammoud, Dr. S. Clerc, Dr. S. Dransfeld, Dr. J-C. Lambert, Mr. P. Féménias

Deadline for manuscript submissions:
30 June 2023

https://www.mdpi.com/journal/remotesensing/special_issues/J3CYH3OQV0#editors

Thank you!

Thanks to:

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