Geostationary High Resolution Optical Mission: How to perform Atmospheric Correction

A simple "pseudo-spherical" analytical model

Addendum to:

HYGEOS and RBINS (2013). Atmospheric correction for Geostationary High Resolution ocean applications (GSP 1-7084/12). ESA contract 4000107111/12/NL/AF. Deliverable D5. Sensitivity Analysis report.

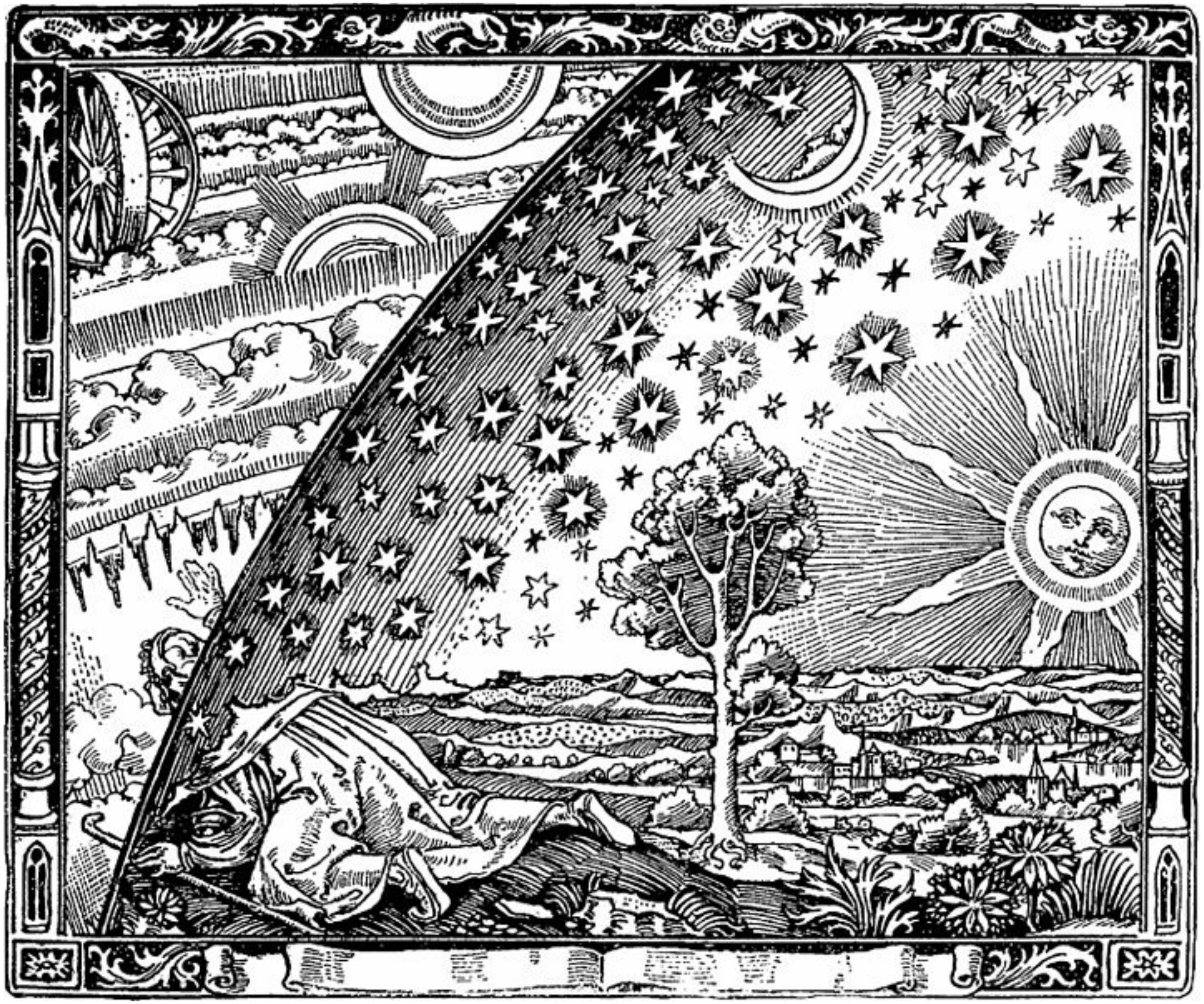
See also section 4.2.3 of

Ruddick, K. G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.

and (context of direct solar attenuation)

Spurr, R. J. D. (2002). "Simultaneous derivation of intensities and weighting functions in a general pseduo-spherical discrete ordinate radiative transfer treatment." Journal of Quantitative Spectroscopy and Radiative Transfer 75: 129-175.

Plane Parallel Atmosphere (PPA) OR Spherical Shell Atmosphere (SSA)?



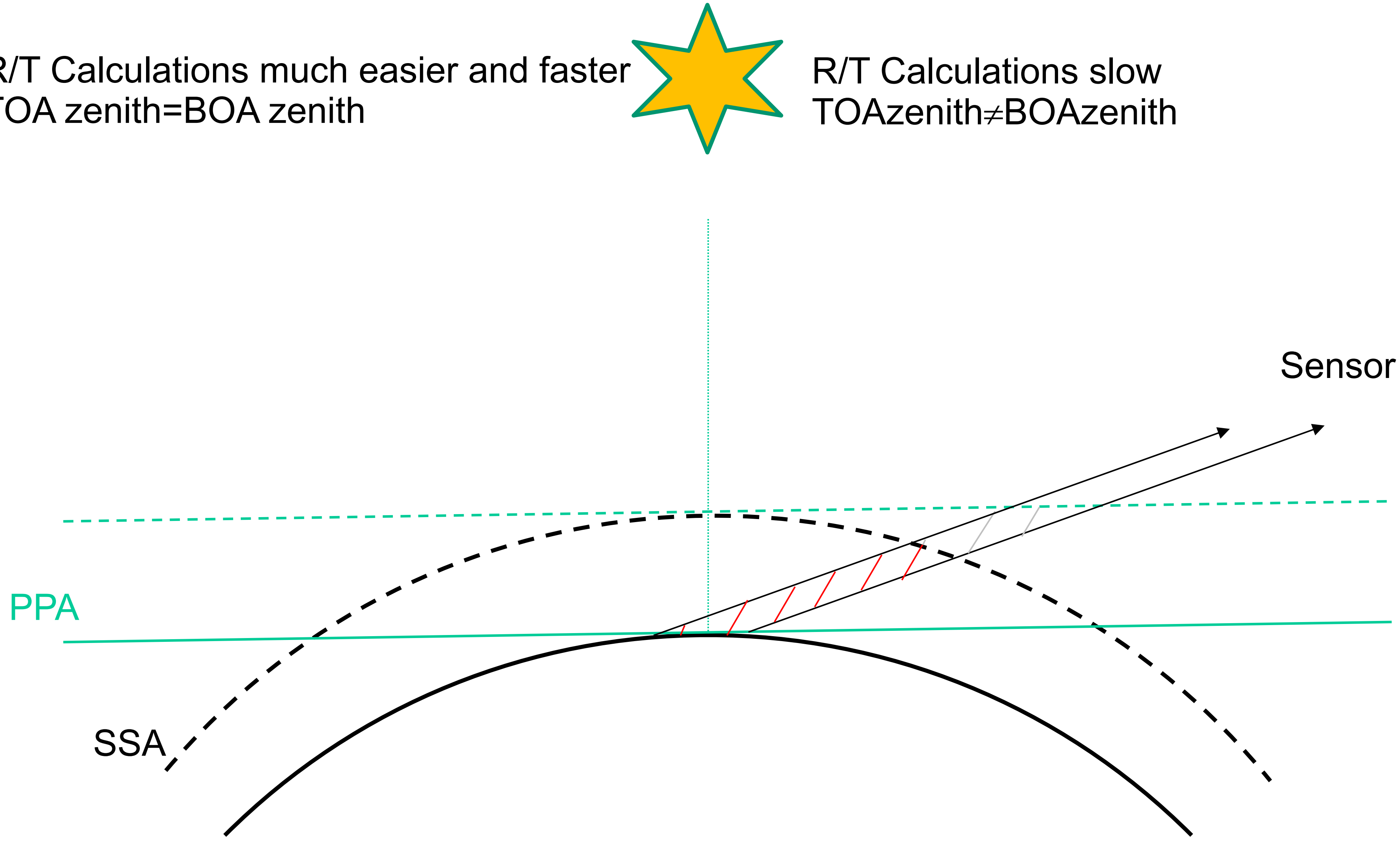
« Un missionnaire du Moyen Âge raconte qu'il avait trouvé le point où le ciel et la Terre se touchent ... »

[Camille Flammarion, L'Atmosphere: Météorologie Populaire, 1888]

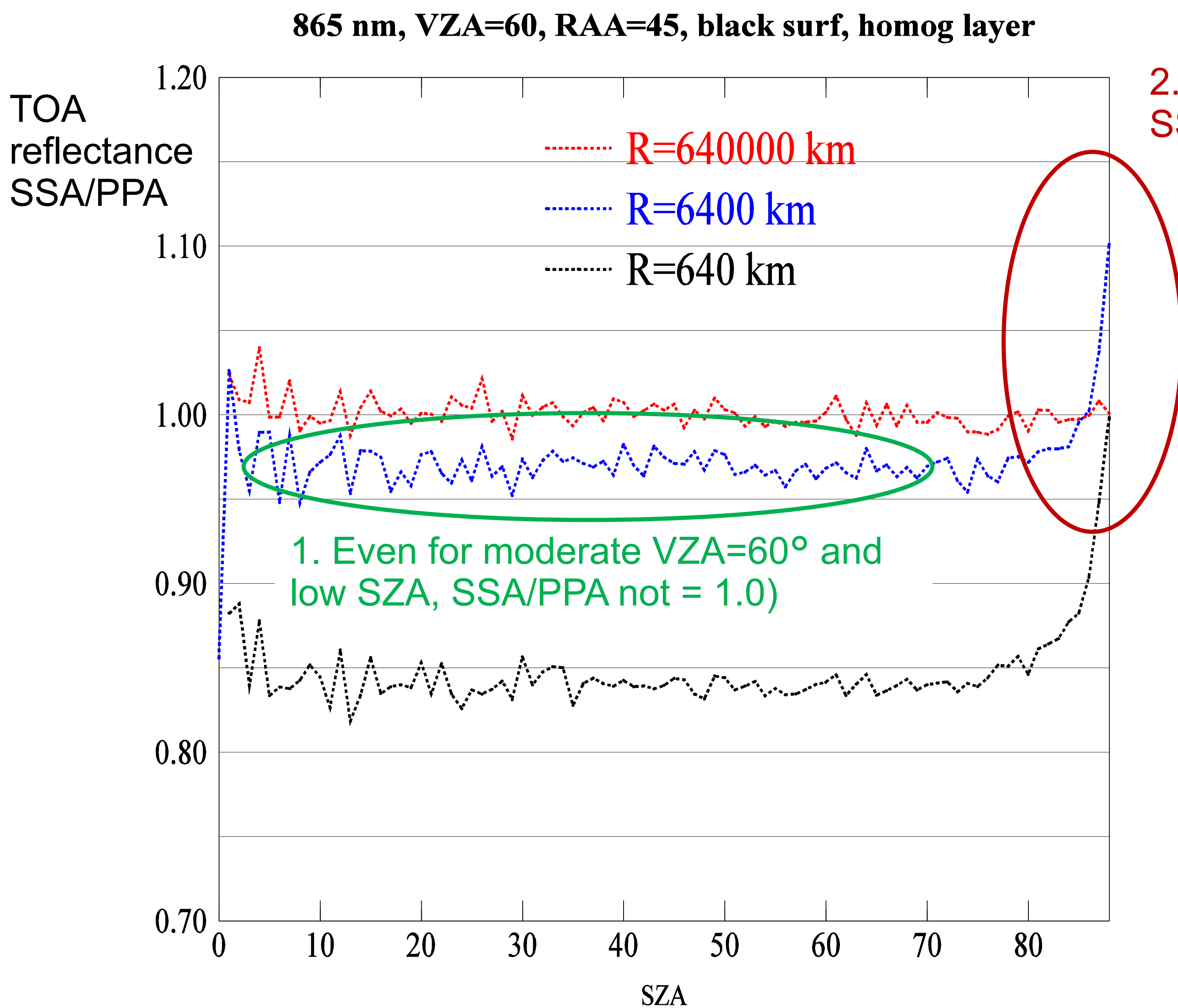
Plane Parallel Atmosphere (PPA) OR Spherical Shell Atmosphere (SSA)?

R/T Calculations much easier and faster
TOA zenith=BOA zenith

R/T Calculations slow
TOAzenith≠BOAzenith



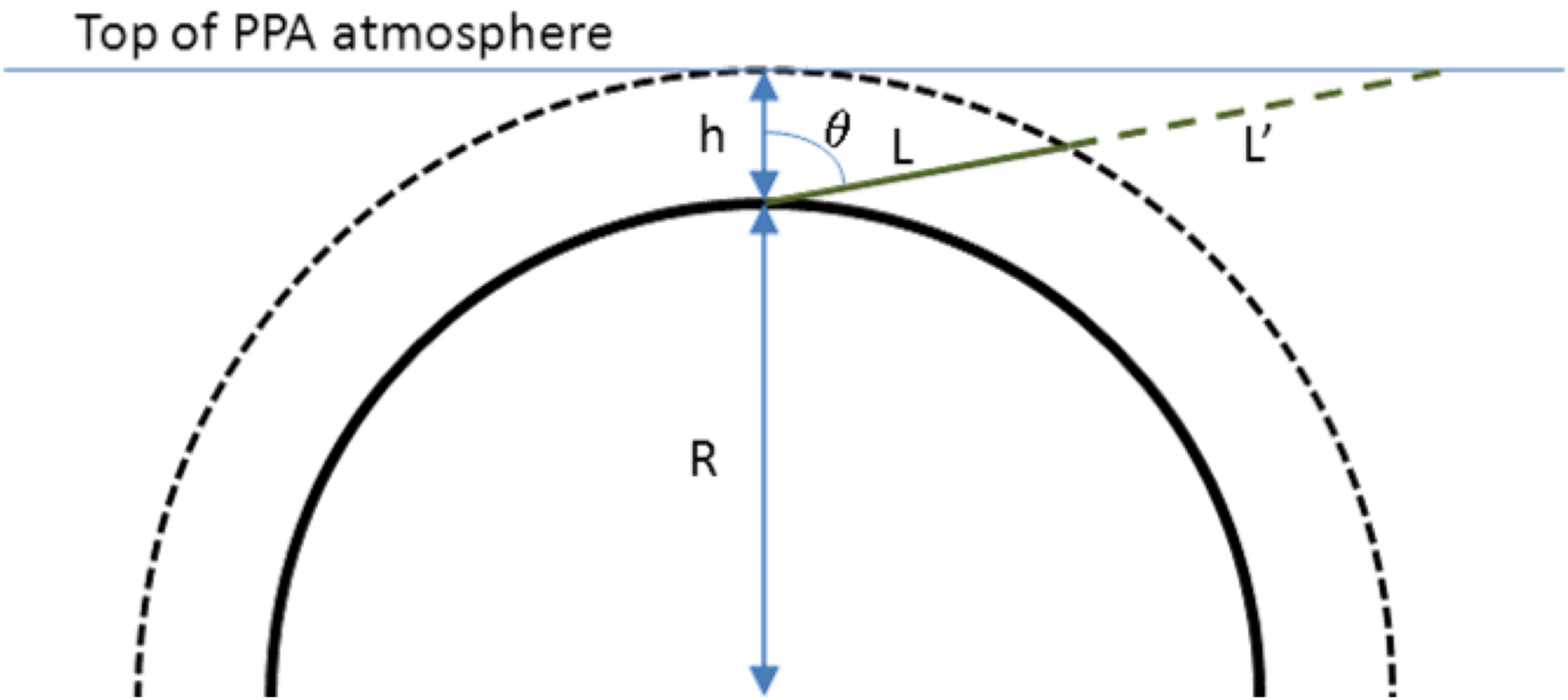
Objective: to explain simplest SSA simulations



Simulation:

- Rayleigh only (H=100km)
- Black surface
- 865nm
- VZA=60°
- Relative azimuth=45°
- Different Earth radius (660km, 6 400km, 640 000km)

Optical path length in SSA < PPA



$$F = \frac{L}{L+L'} = \frac{-RCos\theta + \sqrt{R^2Cos^2\theta + 2hR + h^2}}{h/Cos\theta}$$

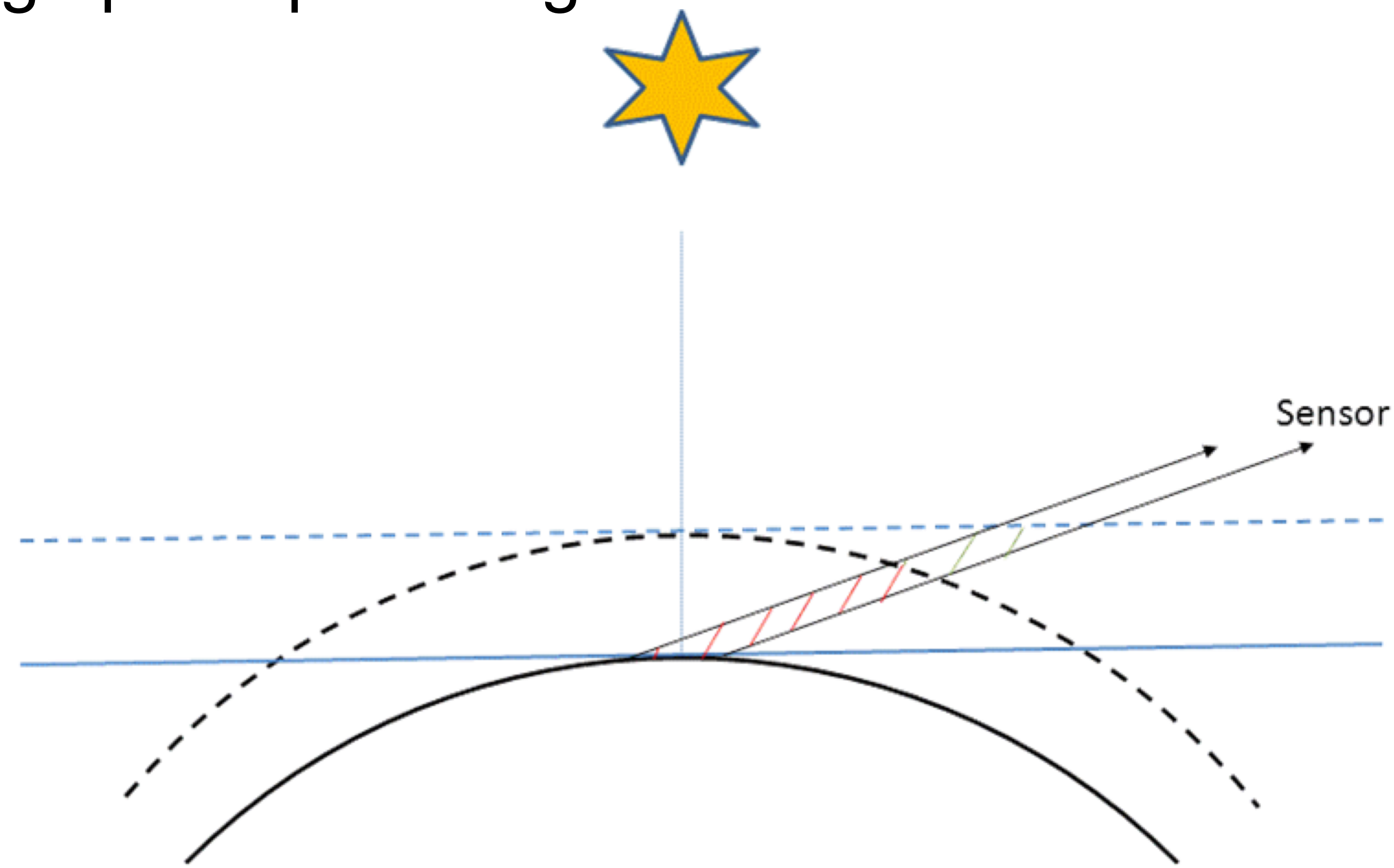
$$= \frac{Cos\theta\left(\sqrt{Cos^2\theta + 2\delta + \delta^2} - Cos\theta\right)}{\delta} \quad where \quad \delta = h/R$$

$$\rightarrow 1 \quad as \quad \delta \rightarrow 0$$

θ can be either SZA or VZA

Process 1. VZA effect: illuminated volume

Single scattering TOA reflectance SSA/PPA given simply by viewing optical path length ratio



$$\frac{\rho_R^{SSA}}{\rho_R^{PPA}} = F_v$$

$$\text{where } F_v = \frac{L_v^{SSA}}{L_v^{PPA}} = \frac{Cos\theta_v\left(\sqrt{Cos^2\theta_v + 2\delta + \delta^2} - Cos\theta_v\right)}{\delta} \qquad \text{where} \quad \delta = h / R$$

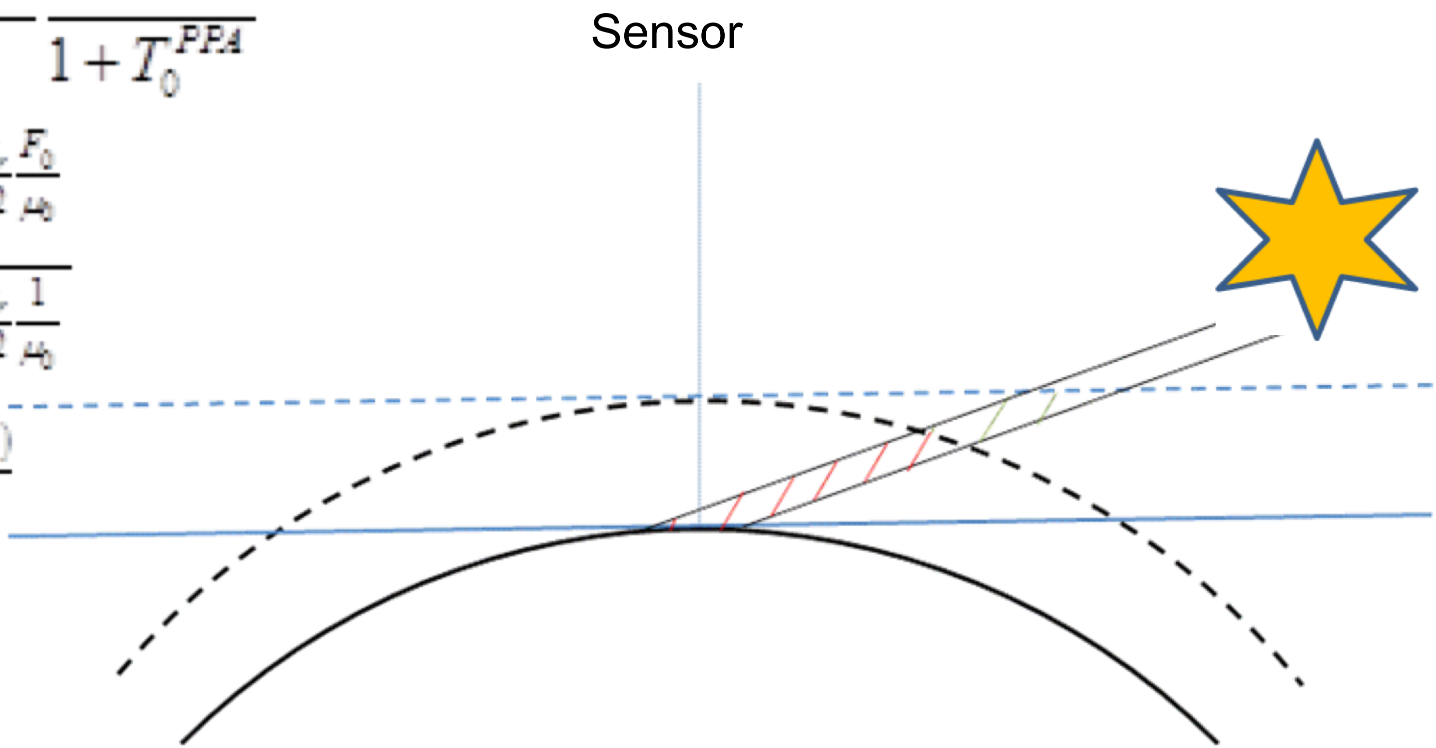
Process 2. SZA effect: attenuation of Ed

TOA reflectance SSA/PPA given by attenuation of downward direct solar beam through different optical path length ratio

$$E_0^{SSA:PPA} = \frac{1+T_0^{SSA}}{2}\frac{2}{1+T_0^{PPA}}$$

$$= \frac{1+e^{-\frac{\tau_v}{2}\frac{F_0}{\mu_0}}}{1+e^{-\frac{\tau_v}{2}\frac{1}{\mu_0}}}$$

$$\approx e^{\frac{\tau_v}{2}\frac{(1-F_0)}{2\mu_0}}$$

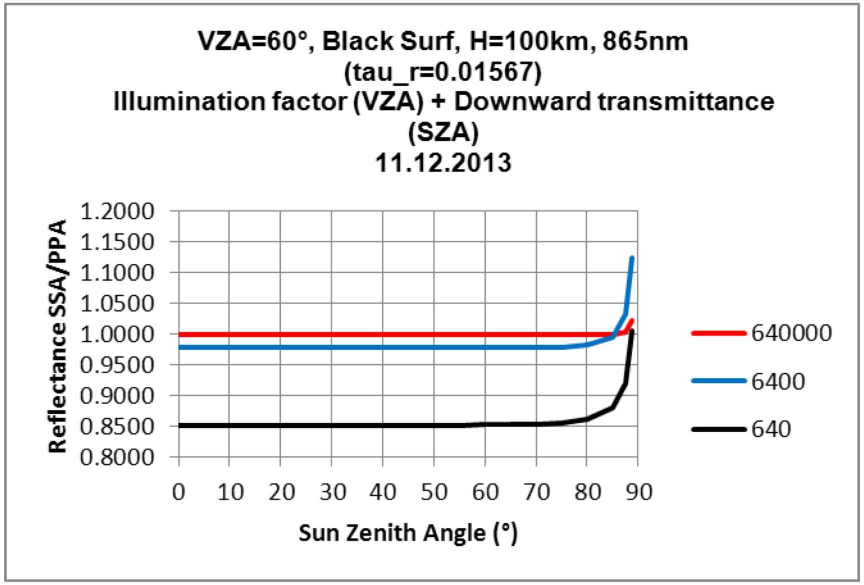


Combining these two processes

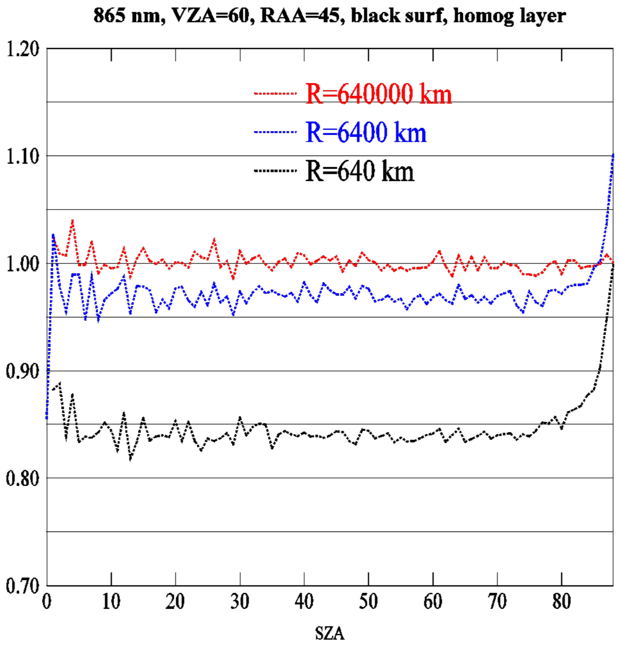
Simple pseudo-spherical analytical model

$$\frac{\rho_R^{SSA}}{\rho_R^{PPA}} = F_v * E_0^{SSA:PPA}$$

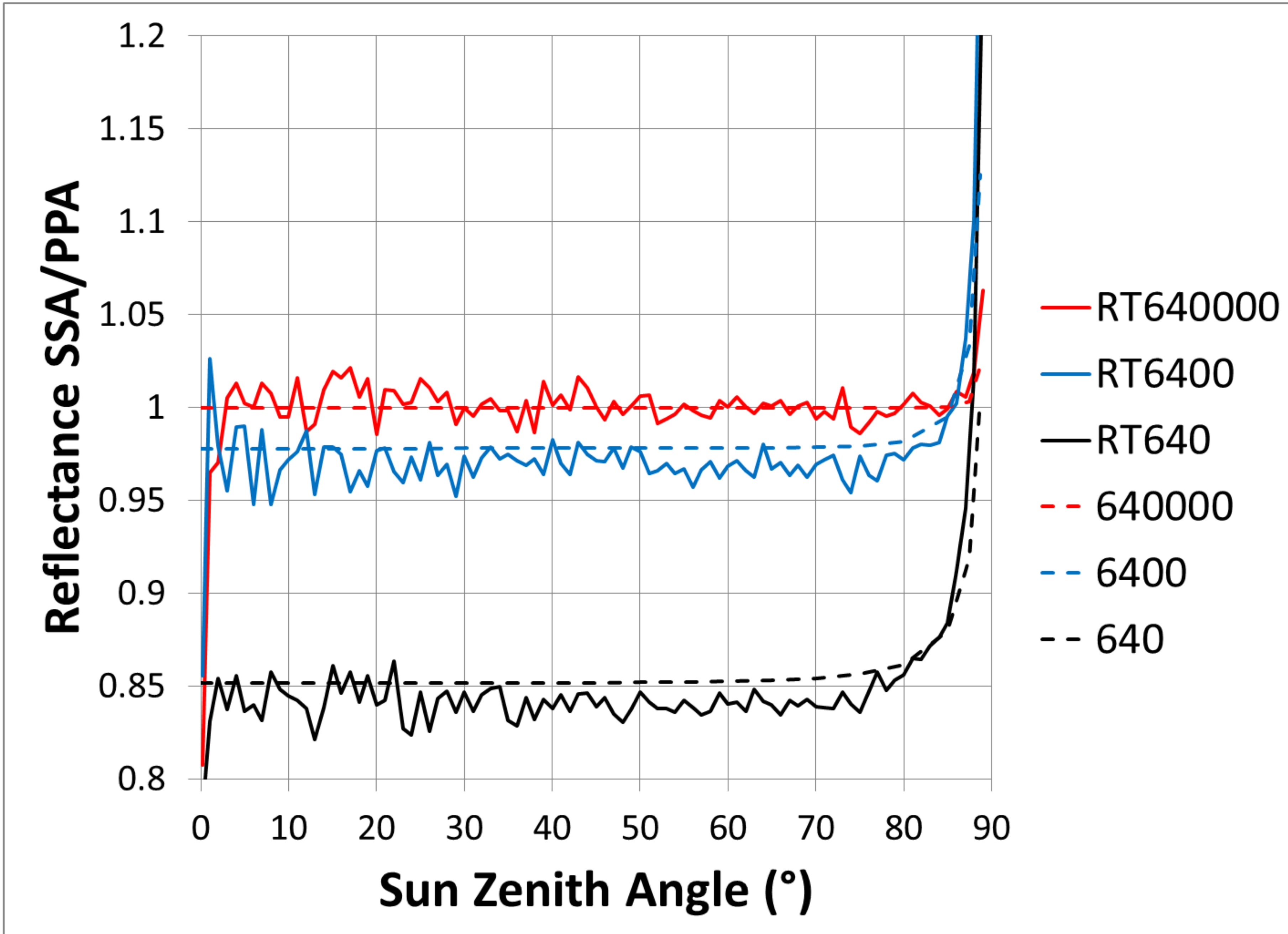
$$= F_v * e^{\frac{\tau_v}{2}\frac{(1-F_0)}{2\mu_0}}$$



Full SSA R/T simulations:



Analytical vs Full SSA/PPA R/T simulations for different Earth Radius



Conclusions

A simple pseudo-spherical analytical model allows to understand the SSA/PPA reflectance in terms of the two dominant processes:

1. Reduced illuminated volume in SSA (VZA effect)
2. Reduced attenuation of downward solar beam in SSA (SZA effect)

Not done yet: adding surface reflectance, aerosols, different vertical profiles for Rayleigh, etc.

Introduction and Overview to High air mass and geostationary observations: characteristics and challenges

Based largely on:

International Ocean Colour Coordinating Group (IOCCG) (2012). Ocean Colour observations from a geostationary orbit, D. Antoine (Ed.), IOCCG Report No.12: 102.

RBINS and HYGEOS (2013). Atmospheric correction for Geostationary High Resolution ocean applications (GSP 1-7084/12). ESA contract 4000107111/12/NL/AF. Deliverable D1. Literature review.

Ruddick, K.G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.

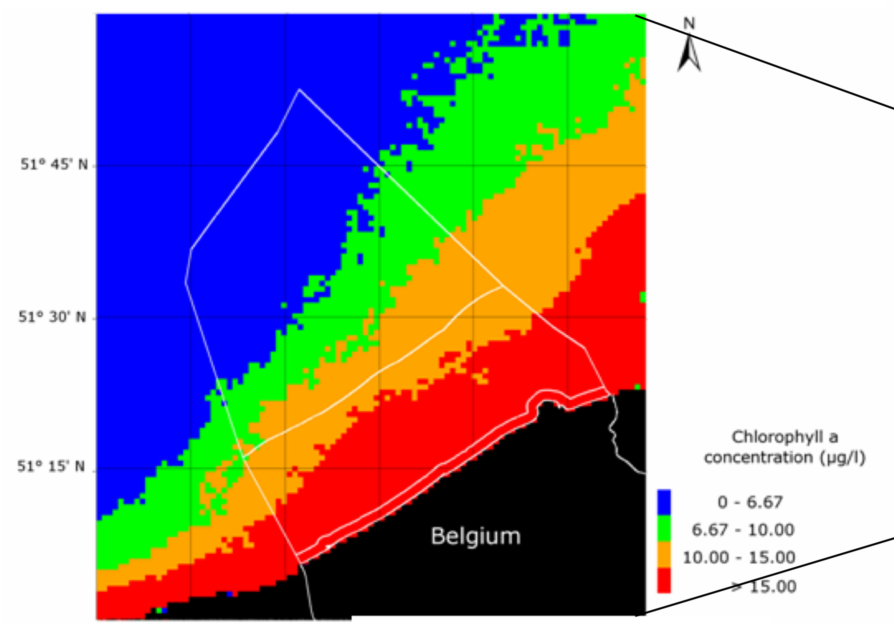
Ocean Colour applications

Water quality monitoring (EU Water Framework Directive … Marine Strategy Framework Directive)

Sediment transport: dredging/dumping, EIS offshore construction, etc.

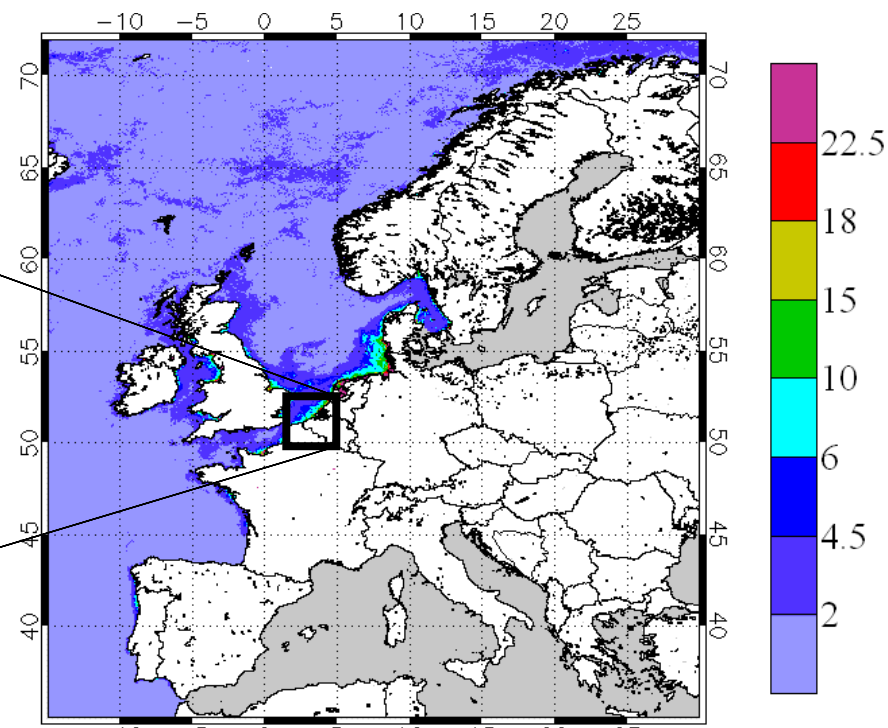
Belgian CHLa 90% Mar-Oct 2005-2010, Water Framework Directive product

[L3 processing by RBINS (D. Vanderzande); L2 MERIS data from ACRI-ST]



MarCoast
a GMES Services Network

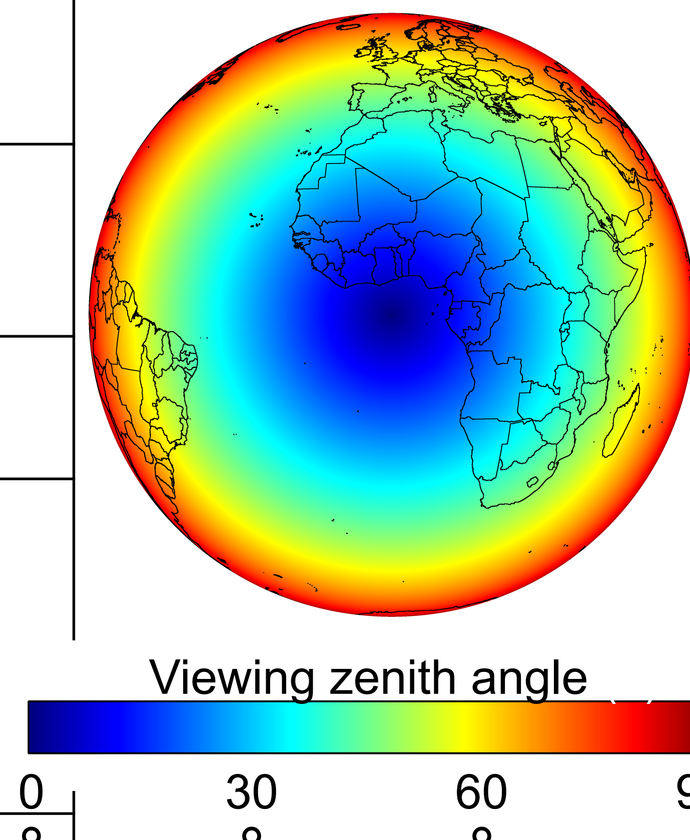
CHLa 90 percentile (MERIS,2005)



Remote sensing is neutral, transparent, and spatially extensive (cross-boundary)

Orbits: Near-polar sun synchronous (SSO⊂LEO) vs Geostationary (GEO)

	SSO e.g. MODIS, MERIS	GEO e.g. SEVIRI, GOCI
Altitude	~750km	35 786km
Spatial coverage	Global	Constant disk
Spatial resolution	~250-1000m	~500-5000m
Temporal resolution	~1/day	~1/hour or better
VIEW zenith	<60°	0-X°≤90° Constant per location
SUN zenith	<70° (processing)	Noon-Y°≤90°



SEVIRI image every 5 mins (MSG3: 2.5 mins)

GOCI for Korea/China /Japan every hour (*8)

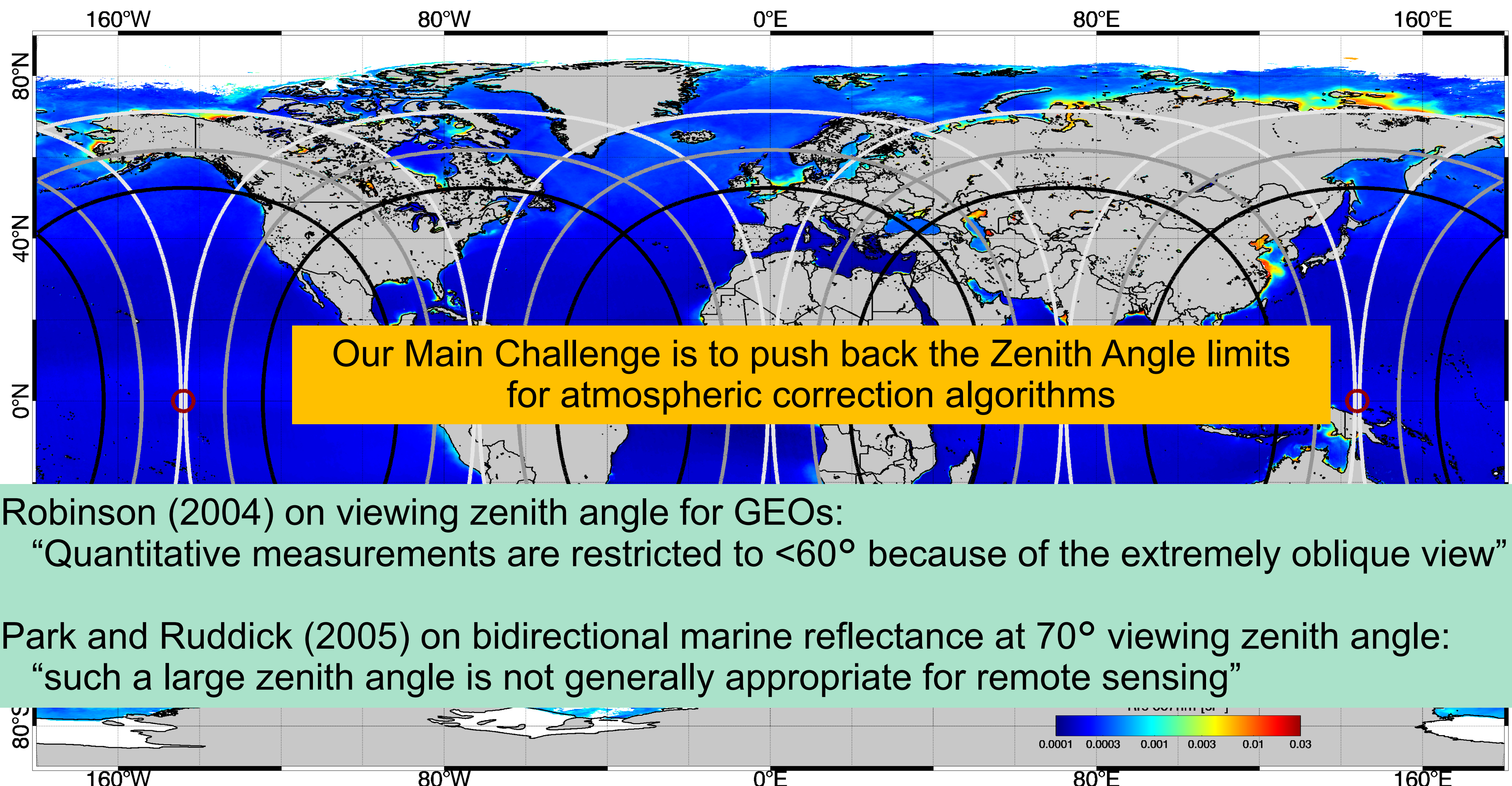
GEO ocean colour – international context

- Since 2004: MSG/SEVIRI (meteorology + turbid waters)
- Since 2010: GOCI for S. Korea/China/Japan
- ...
- From 2015: MTG/FCI
- From 201x: KIOST/GOCI-2 for S. Korea + Asia seas
- ? ESA/GEO-OCULUS over Europe/land ?
- ?? CNES+/GEO-OCAPI ??
- ?? NASA/GEOCAPE ??

Objective of current study (ESA SOW)

1. Identifying and implement solutions to the shortcomings of atmospheric correction schemes for ocean apps
2. Consolidating the Geo-Oculus requirements, esp. radiometeric

5 GEO coverage for VZA=60° (black), 70° (grey), 80° (white) [Ruddick et al, 2014]



Robinson (2004) on viewing zenith angle for GEOs:
"Quantitative measurements are restricted to <60° because of the extremely oblique view"

Park and Ruddick (2005) on bidirectional marine reflectance at 70° viewing zenith angle:
"such a large zenith angle is not generally appropriate for remote sensing"

State of knowledge: Then and Now

ESA SOW (Feb 2012) High air mass Atmospheric correction:

- Limitation of Plane Parallel Atmosphere (PPA) ... need for Spherical Shell Atmosphere (SSA) [Ding and Gordon,1994]
- Signal:noise and importance of radiometric requirements
- Limitations of analytical models of transmittances, adjacency effects, case 2, backscattering geometries, etc.
- Validation against match-up in situ and satellite data

Not so clear in Feb 2012:

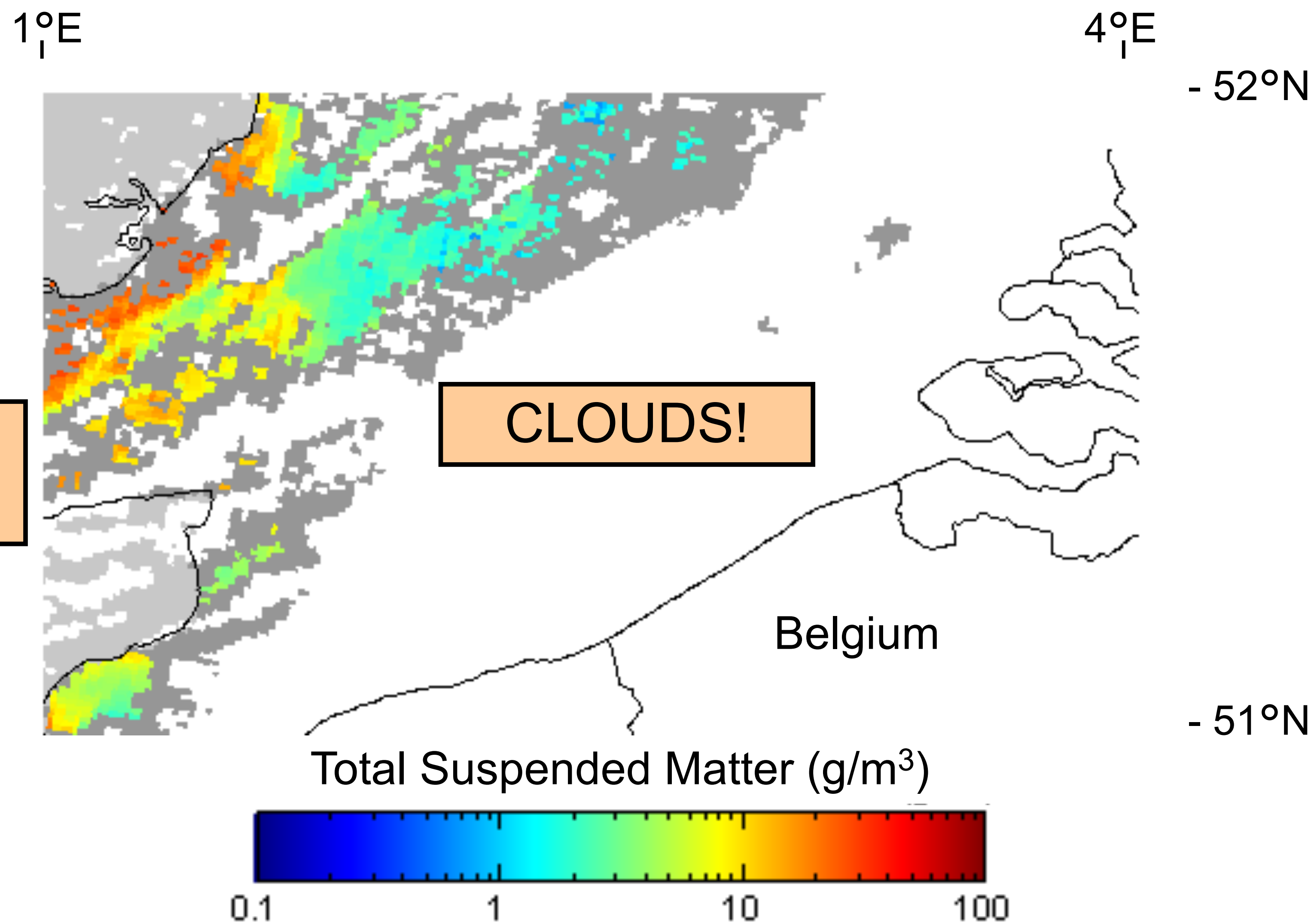
- All the other high air mass atmospheric corr probs (surface!)
- Usefulness of MERIS high latitude data for validation in this study
- Relevance of this study for MERIS/OLCI low sun data
- Degradation of spatial resolution with VZA

Motivation – why go GEO? (1/2)

What is the main obstacle to operational applications of ocean colour remote sensing?

MERIS
21.6.2006
(10:05 UTC)

Tidal variability!



Motivation – why go GEO? (2/2)

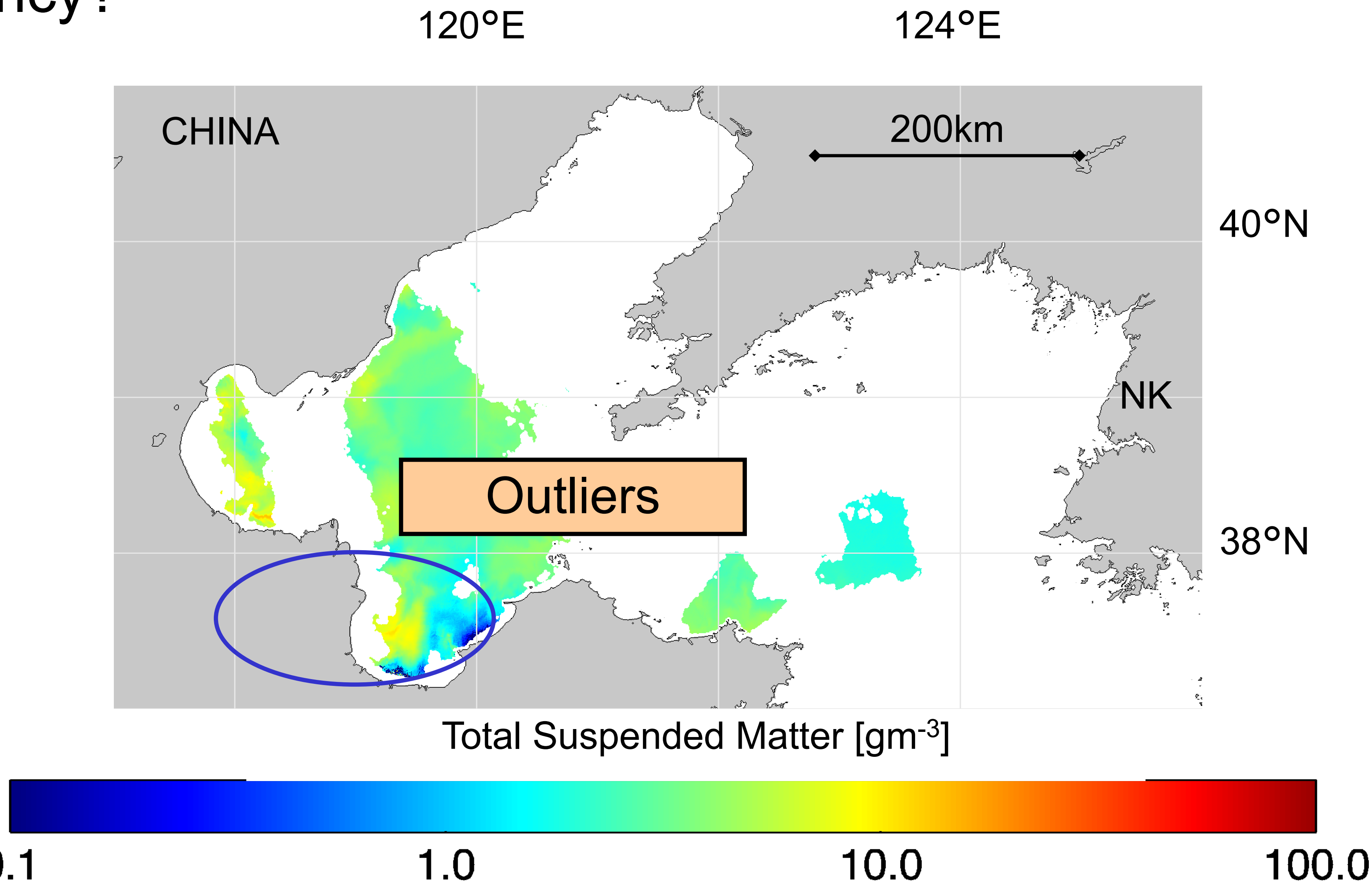
Can we improve data quality by exploiting temporal coherency?

Bohai Sea

GOCI

12.6.2011

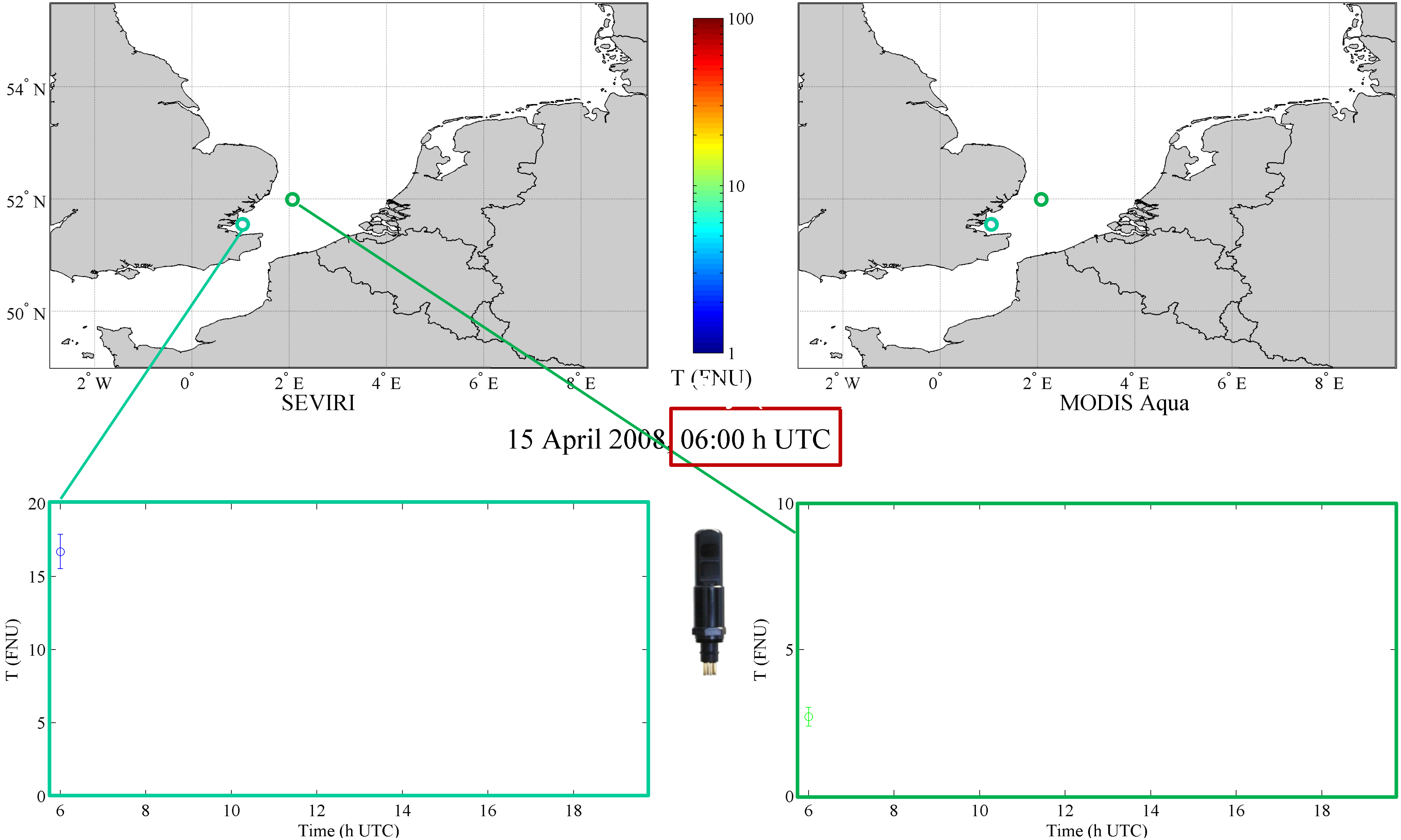
07:16 UTC



[Ruddick, Vanhellemont, Yan, Neukermans, Wei and Shang (2012). **Variability of suspended matter in the Bohai Sea from the Geostationary Ocean Color imager (GOCI).** Ocean Sci. J, 47(3), 331-345]

[Neukermans, Ruddick and Greenwood (2012). Diurnal variability and light attenuation in the southern North Sea from the SEVIRI geostationary sensor. Rem Sens Env, 124, 564–580]

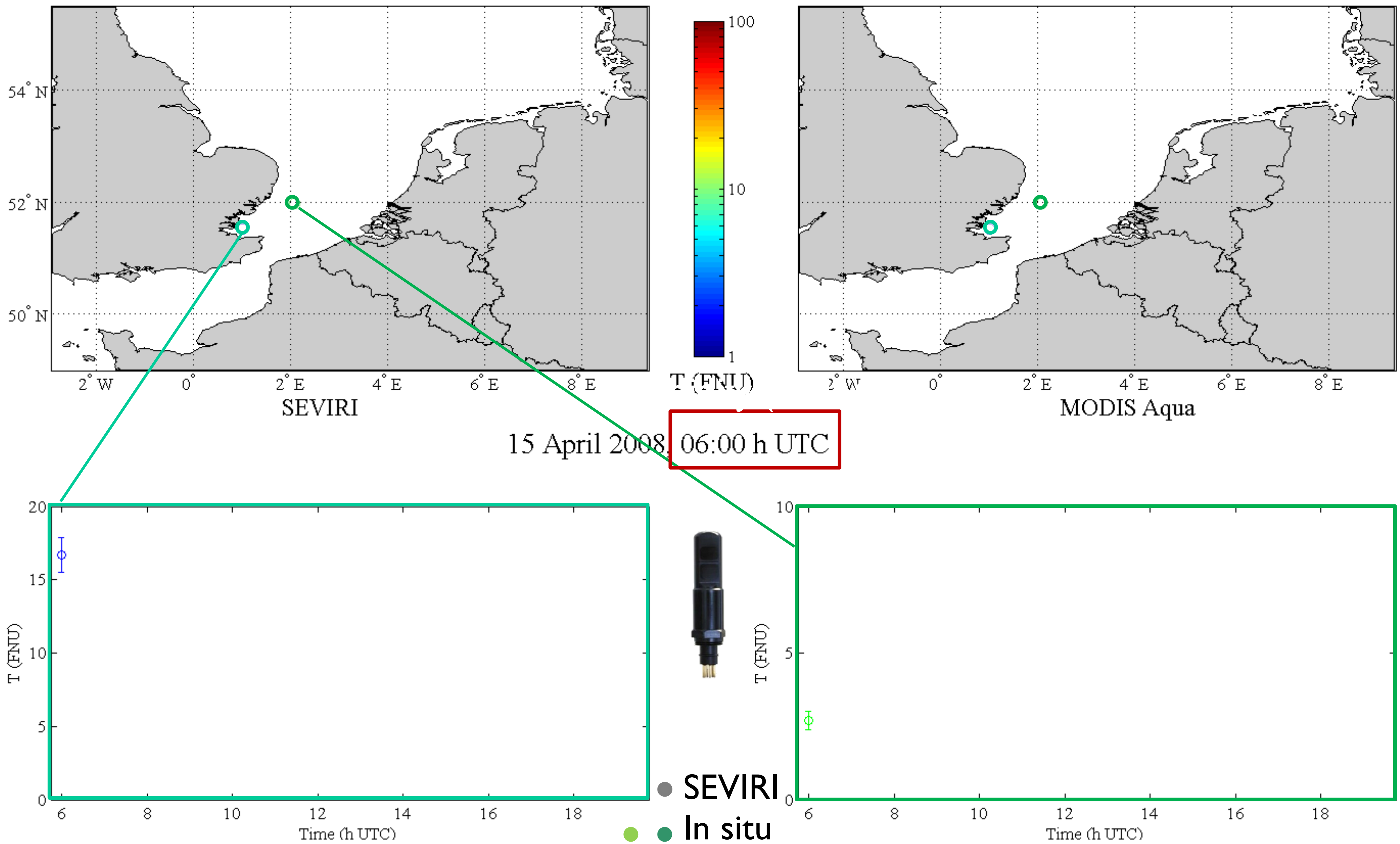
(quadri-) Diurnal variability of Turbidity



[Neukermans et al, 2012; Neukermans, 2012]

[Neukermans, Ruddick and Greenwood (2012). Diurnal variability and light attenuation in the southern North Sea from the SEVIRI geostationary sensor. Rem Sens Env, 124, 564–580]

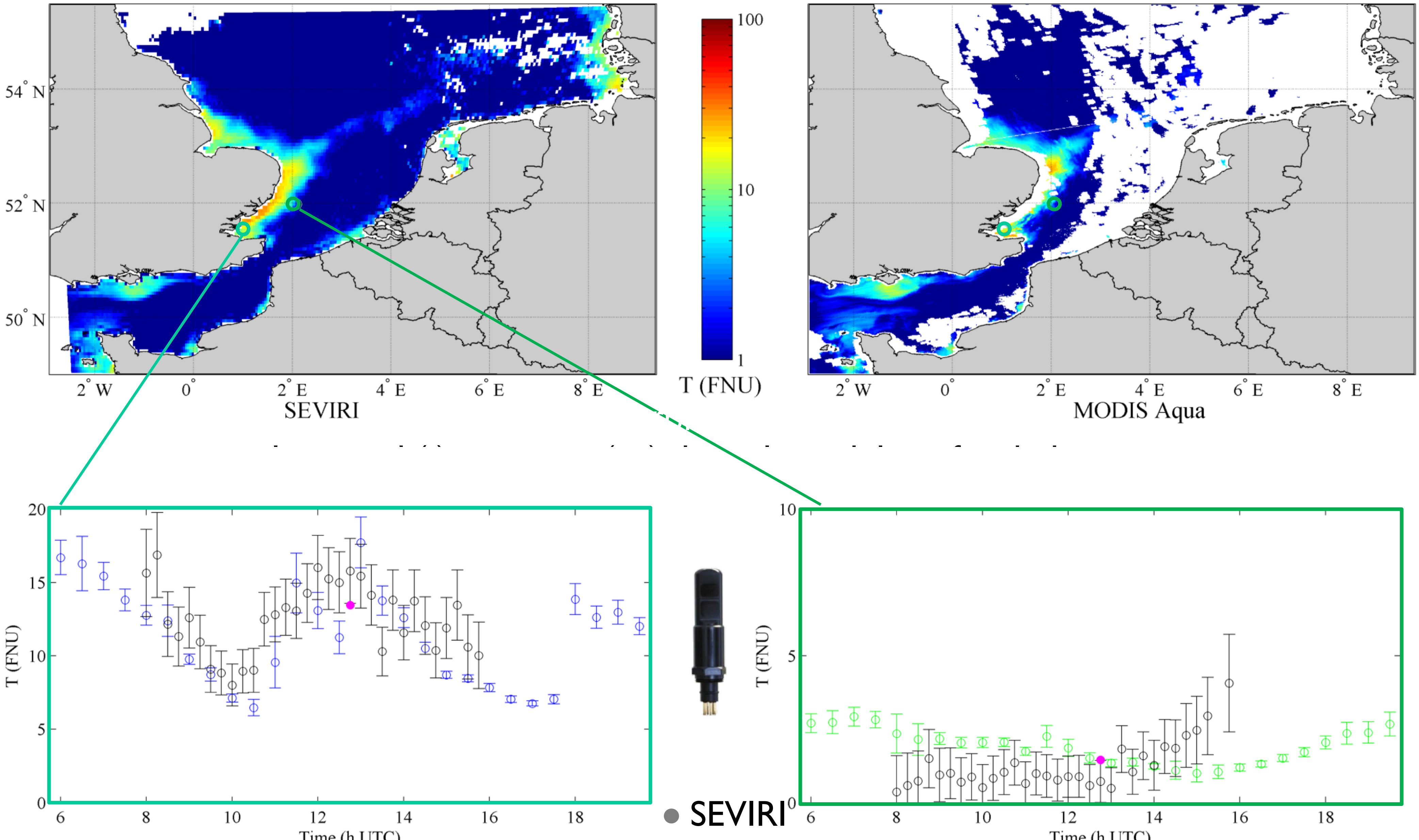
(quadri-) Diurnal variability of Turbidity



[Neukermans et al, 2012; Neukermans, 2012]

SEVIRI daily composite of 34 images
Quasi cloudfree

MODIS: 1 image
60% clouded

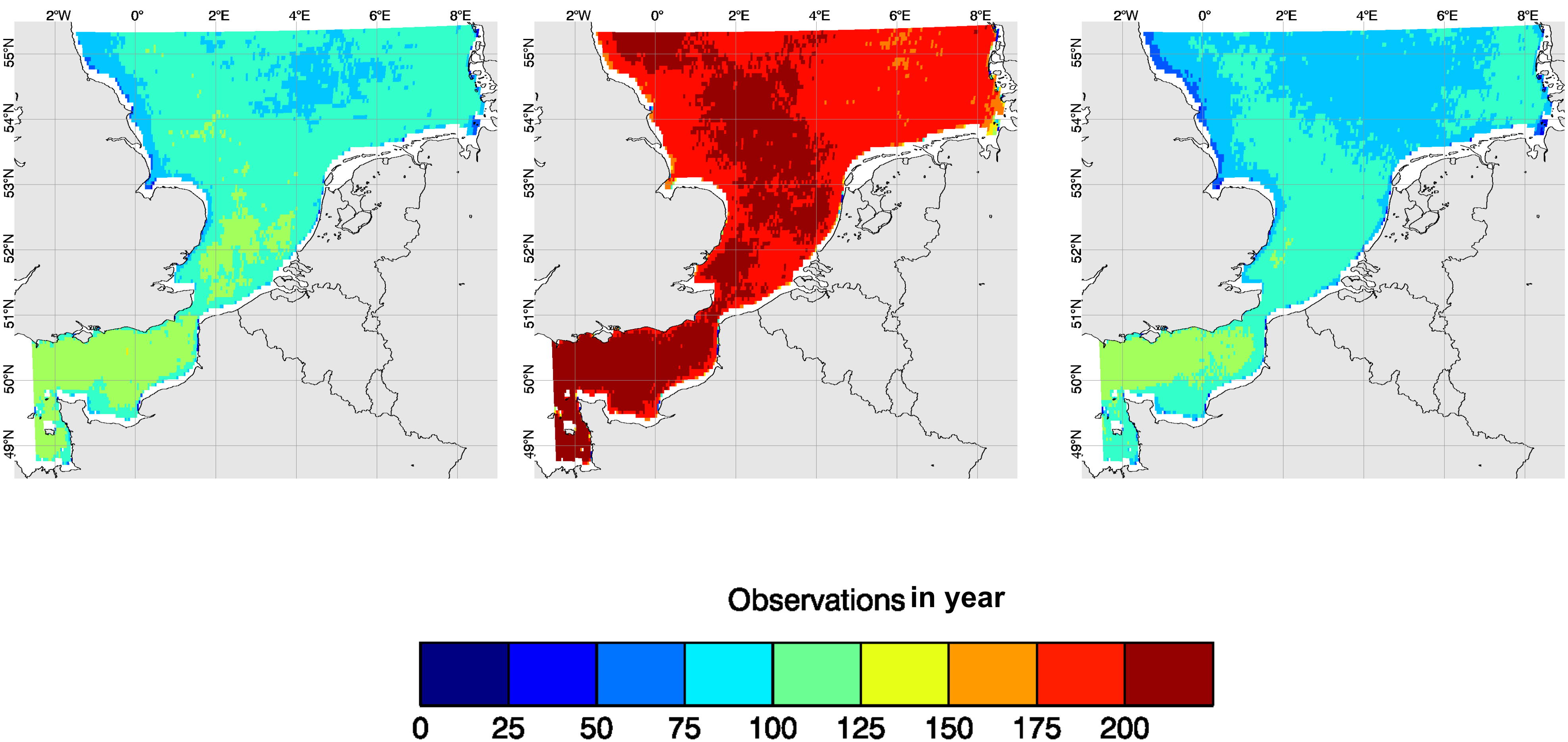


[Neukermans et al, 2012; Neukermans, 2012]

Number of cloud-free SEVIRI observations (2008)

[Ruddick, K.G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.]

Valid data at 12:30UTC	Valid data at least once in day	Valid data for ≥4/6 of hourly 10-15:00
"Wide swath SSO"	"GEO for stable marine"	"GEO temporal vblty"

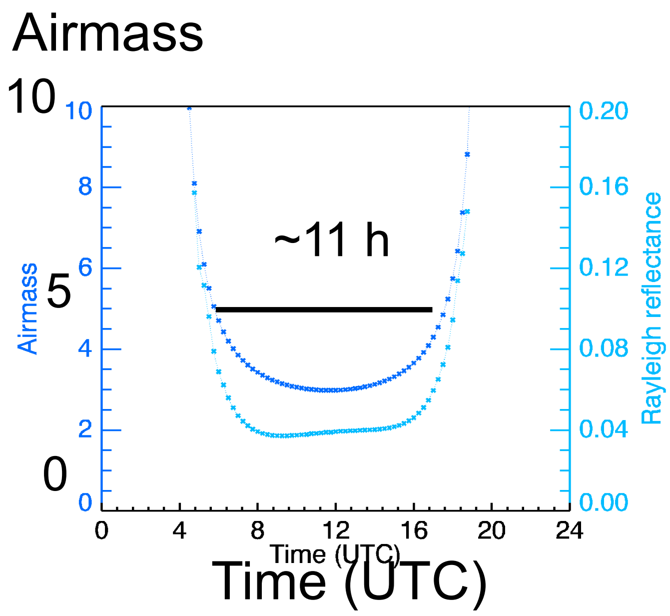


Two-way air mass and Rayleigh reflectance 0.6µm for SEVIRI (0°,0°) for location (5°E, 50°N)

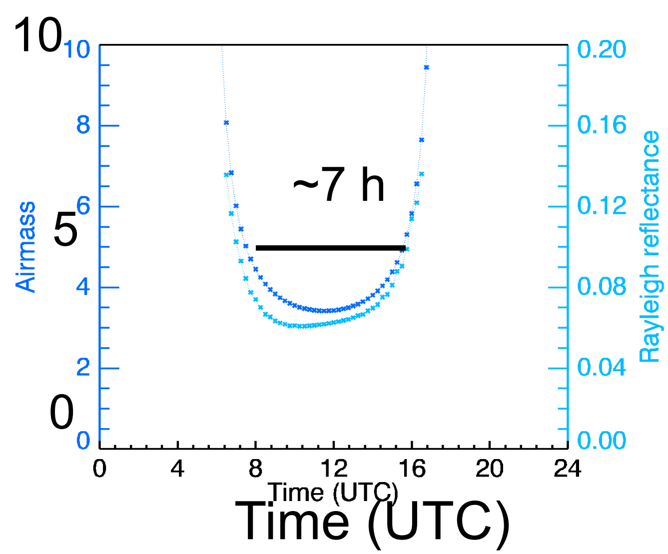
[Ruddick, K.G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.]

Suppose we limit to total air mass=5

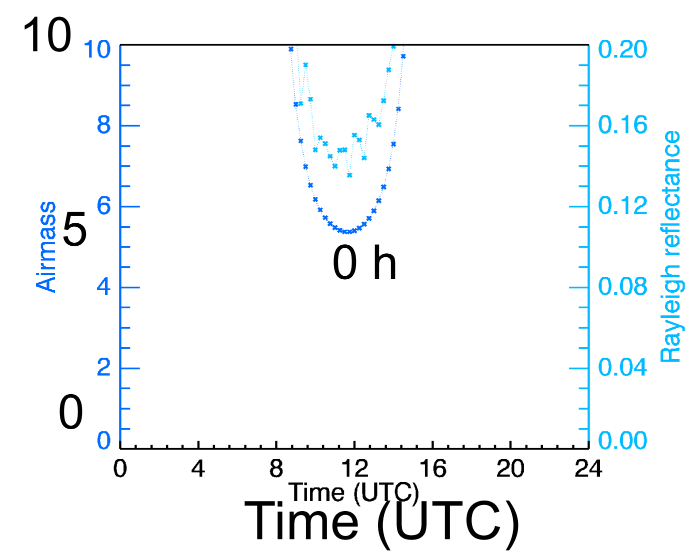
20 June



22 Sept



21 Dec



If we can raise air mass limit
we improve data availability for mid-latitude winter and high latitude spring/autumn

Ocean atmospheric correction State of art

If water-leaving radiance is 10% of Top of atmosphere (90%) and should be estimated with 5% absolute accuracy we need to

- estimate atmospheric path radiance with 0.5% accuracy (direct approach) e.g. Gordon-Wang (1994) OR
- avoid direct calculation of atmospheric path radiance (indirect approach) e.g.
    - Spectral matching (Gordon et al, 1997)
    - Neural network (Doerffer and Schiller, 2008)
    - POLYMER (Steinmetz et al, 2011)

Limitations on Viewing Zenith (VZA) and Sun Zenith (SZA) angles

- MODIS: VZA<60°, SZA<70°
- MERIS: VZA<40° (sensor), SZA<70°

IOCCG (Wang et al, 2010) compare algos up to air mass=5.5 with generally increasing error with air mass

For direct algos, theoretical error increases $\propto$air mass

For indirect algos, error=??? (some success for sunglint!)

Ocean atm. corr. – other issues

Case 2 waters

- Turbid = GOOD?
- Absorbing => very low signal:noise for blue

Adjacency effects

- Affect greater horizontal distance for high VZA
- Variation of Fresnel land mask during day

Atmospheric backscattering

- High angle backscatter => higher large aerosol particle scattering + angular variability and lack of knowledge

Diffuse atmospheric transmittance

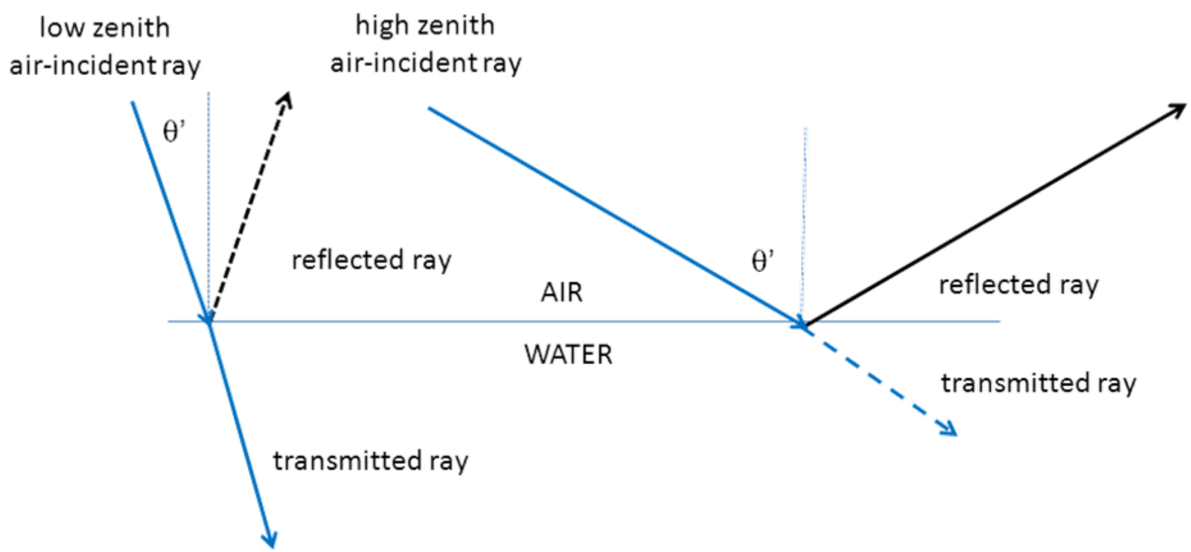
- From sea to TOA not yet considered for high VZA
- From TOA to sea considered for SSA radiance by (Herman et al, 1994)

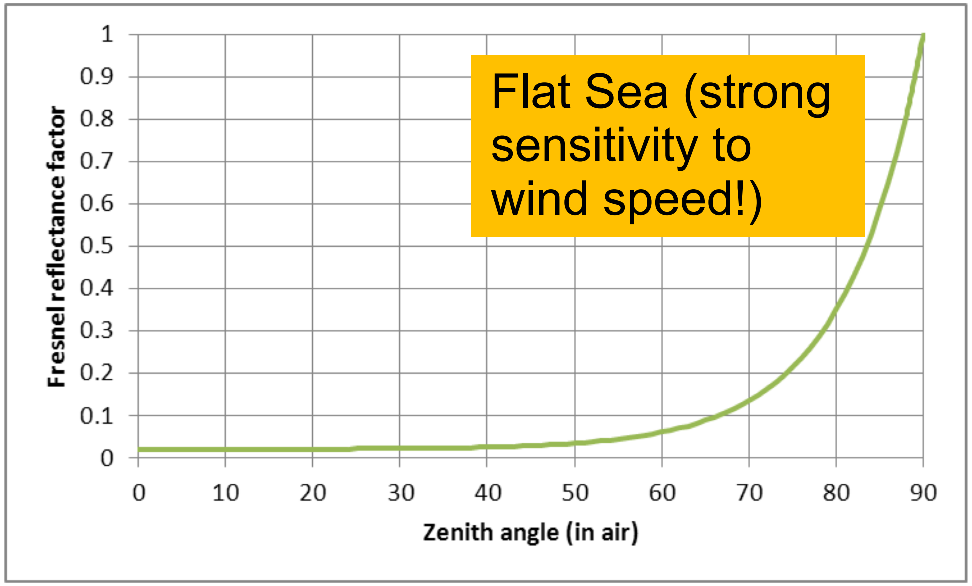
SWIR channels

- GEO-OCULUS (2009) “SWIR channels are not required for the atmospheric correction of ocean colour channels” (invalid argument, SWIR useful for turbid waters)

Extra GEO atm. Corr. issues

Fresnel reflectance of air-water interface=reflected/incident



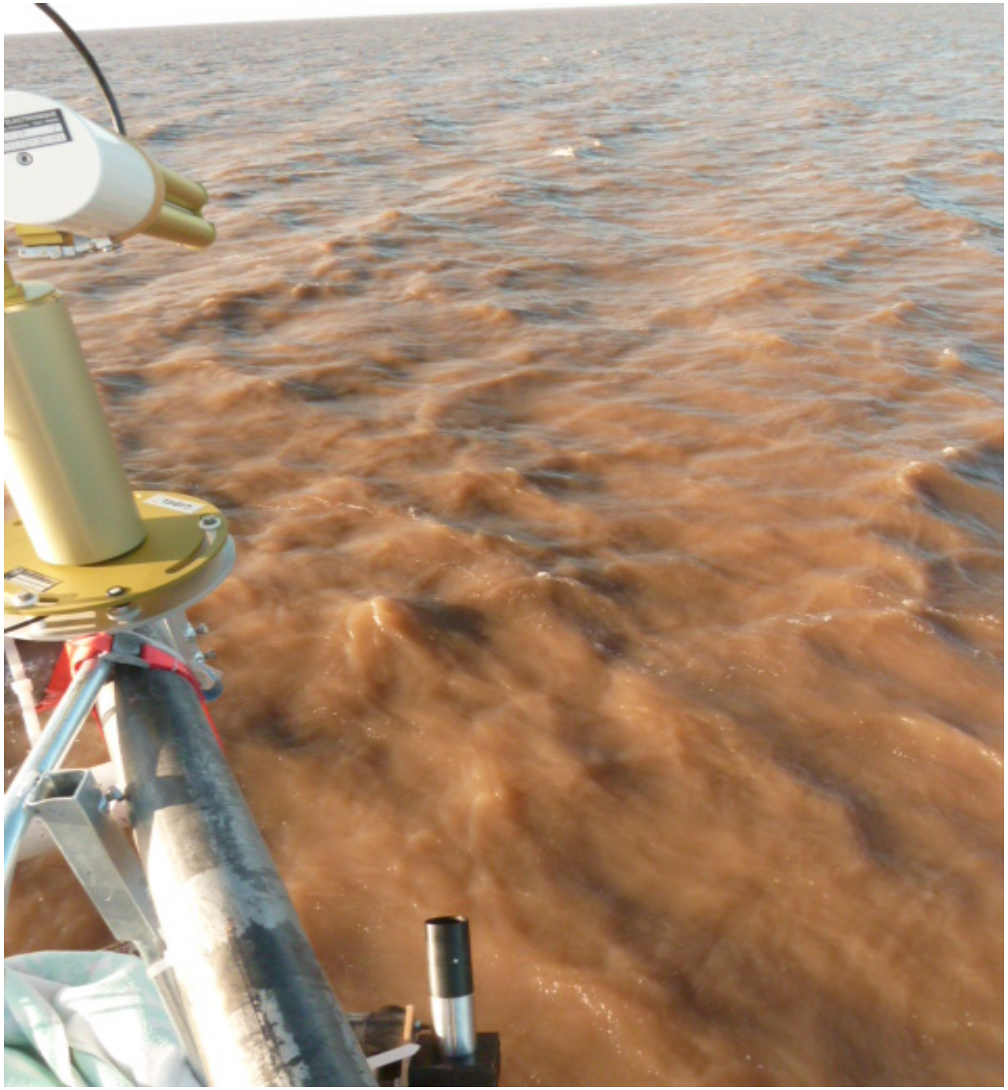


1. Weak sun transmittance at high SZA ("Ed0-reduction") [Wang, 2006]
2. Strong sky reflection at high VZA ("Rayleigh")
3. Weak transmittance of water-leaving radiance for high VZA ("marine BRDF")

For light incident both from air (downward) and from water (upward)

Some new problems?

E.g. Wave shadowing



Rio de la Plata, Nov2012
SZA=75°, wave height=10-20cm
Photo: K.Ruddick

[Ruddick, K.G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.]

… but also some good news

Sunglint is limited for GEO (greater problem for SSO)

Multiple views per day for different air mass may facilitate removal of atmospheric path radiance cf. Langley calibration?

Multiple GEOs at different longitude (different air mass)?

Temporal coherency of marine and/or atmospheric parameters for constraining retrievals or for a posteriori quality control?

Summary of Literature Review

GEO ocean colour will give enormous improvement for applications (more data in cloudy periods, tidal/diurnal processes)

BUT

- High sun zenith angle necessary for coverage of day length
- High viewing zenith angle necessary for high latitudes
- Spatial resolution degrades with air mass

SO Atmospheric correction challenge is significant:

  - For direct algos errors increase with air mass
  - Earth curvature effects can be modelled … efficiently and accurately?
  - Some unforeseen new problems (air-sea interface transmittance for high SZA, air-sea interface reflectance for high VZA, sea-air interface transmittance for high VZA, wave shadowing, etc.)
  - Adjacency effects will contaminate over larger horizontal distance
  - Possible advantages: sunglint, multi-temporal coherency, multiple views (air mass) per day

Acknowledgements and References

Thanks to:

ESA funding of GEO-OCULUS high air mass atmospheric correction study

BELSPO/STEREO funding of GEOCOLOUR project

KOSC/KORDI for GOCI data

EUMETSAT and KMI/IRM for SEVIRI data

ESA for MERIS data

NASA/GSFC for MODIS-AQUA data

CEFAS for Smartbuoy data

More details in:

International Ocean Colour Coordinating Group (IOCCG) (2012). Ocean Colour observations from a geostationary orbit, D. Antoine (Ed.), IOCCG Report No.12: 102.

RBINS and HYGEOS (2013). Atmospheric correction for Geostationary High Resolution ocean applications (GSP 1-7084/12). ESA contract 4000107111/12/NL/AF. Deliverable D1. Literature review.

Ruddick, K.G., G. Neukermans, Q. Vanhellemont and D. Jolivet (2014). "Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results." Remote Sensing of the Environment 146: 63-76.

and references therein

Also:

Ryu, J.-H. and J. Ishikaza (2012). "GOCI Data processing and ocean applications." Ocean Science Journal 47(3): 221. for new GOCI applications (trajectory of dumped matter, ocean currents, etc.)

Vanhellemont, Q., G. Neukermans and K. Ruddick (2014). "Synergy between polar-orbiting and geostationary sensors: Remote sensing of the ocean at high spatial and high temporal resolution." Remote Sens. Environ. 146: 49-62. for MODIS/SEVIRI synergy product with high spatial and high temporal resolution