World coastal turbidity analysis dedicated to spatial bathymetric Lidar acquisitions.

C.Chailloux, C. Delacourt, M. Lennon, Y.Pastol, A. Deschamps

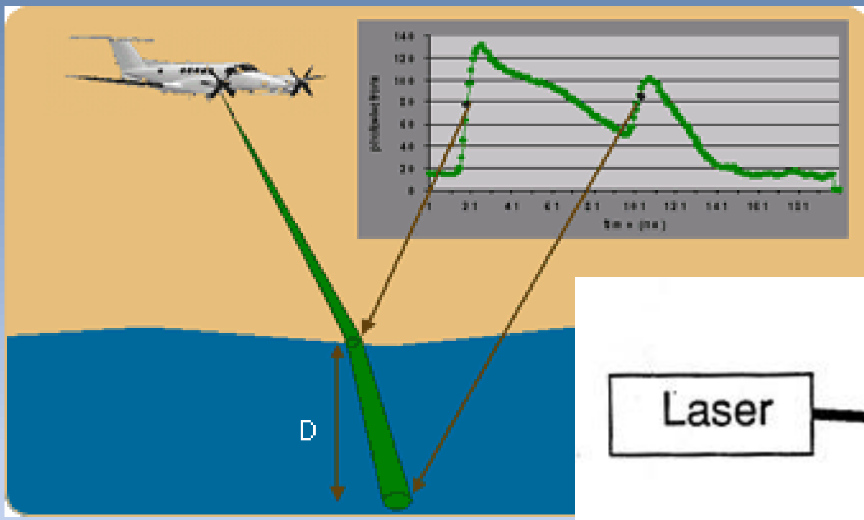
CNES: Ultimate step of the 0 phase for spatial bathymetric Lidar, Case 2 water type in costal zones.

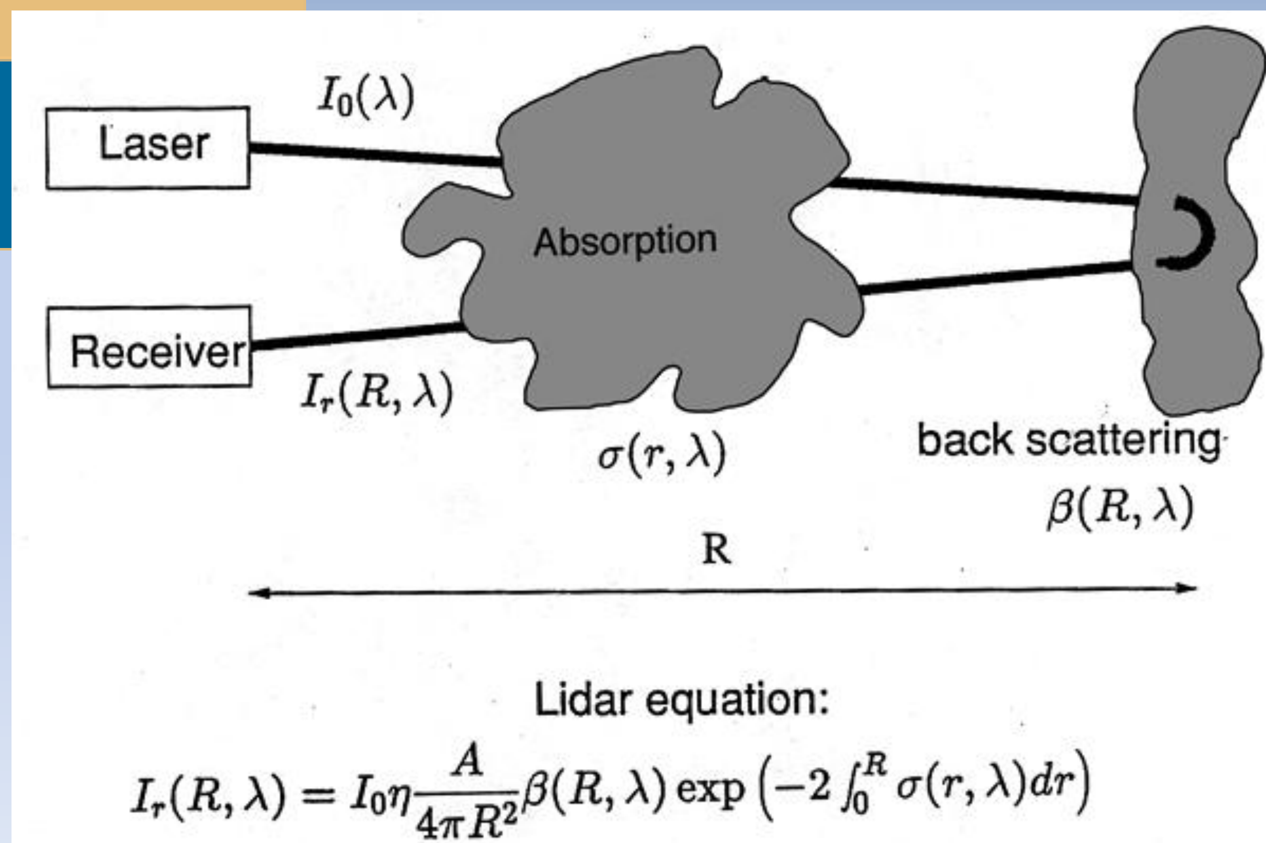
Question: which area a spatial bathymetric Lidar can cover?

→ Which turbidity is characterizing world costal zones (0-20m)?

NB: constraining parameters as sea surface state, bottom reflectance, etc, are not considered in this study.

Bathymetric Lidar system





$$\lambda = 532\ nm$$

Optical water column characteristics

Beer-Lambert law: $$I_{\lambda}(z) = I_{0\lambda} \exp(-\sigma_{\lambda} z)$$

→ for a giving wavelength : $$\sigma_{\lambda} = \frac{\ln(I_{0\lambda} / I_{\lambda}(z))}{z}$$

Global attenuation coefficient: $$c(\lambda) = a(\lambda) + b(\lambda)$$

$$a(\lambda) = a_{w}(\lambda) + a_{p}(\lambda) + a_{ds}(\lambda)$$

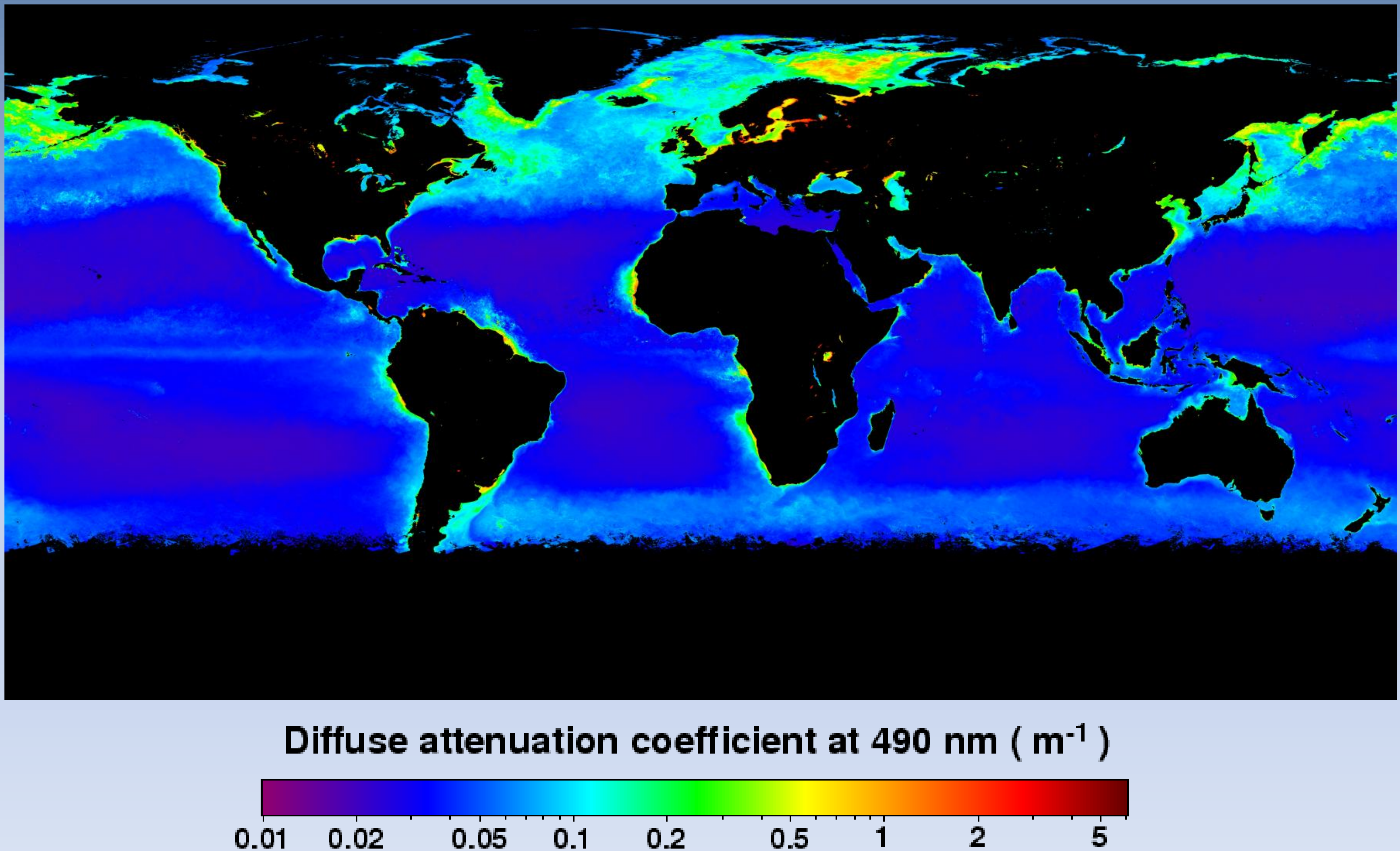
$$b(\lambda) = b_{w}(\lambda) + b_{p}(\lambda)$$

Diffuse attenuation coefficient: $$K_{d} = D_{d} c(\lambda)$$

With a distribution function: $$D_{d} \approx \frac{1}{\cos(\theta_{w})}$$

θ_{w} : zenithal solar angle

Kd : Diffuse attenuation coefficient



Aqua MODIS May 2003-2011, Source:http://oceancolor.gsfc.nasa.gov/cgi/l3

Kd(490) expression on Aqua MODIS

Mueller empirical model:

$$K_d(490) = K_w(490) + A\left(\frac{nL_w(490)}{nL_w(555)}\right)^B$$

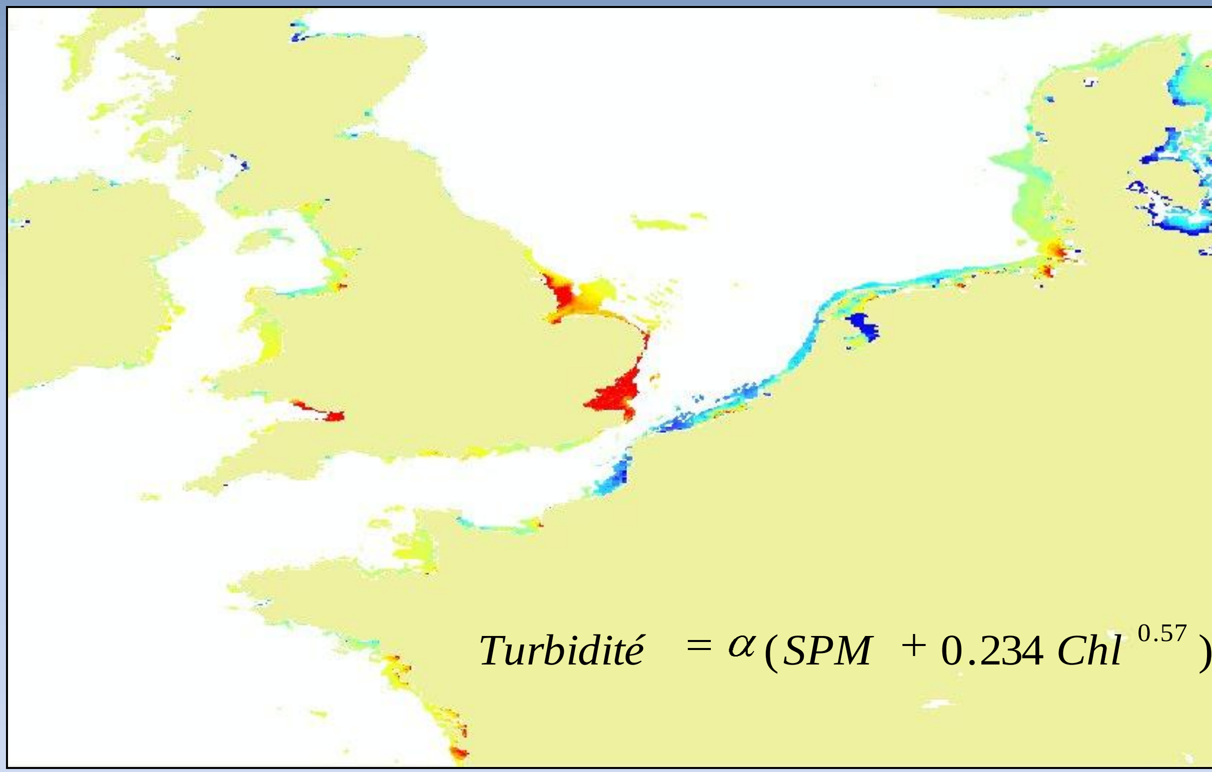
$$K_w(490) = 0$$

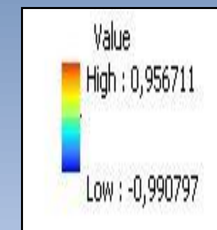
$$A = 0.1853$$

$$B = -1.349$$

Well adapted for waters with Kd < 0.25 m^{-1}

Anomaly study: Kd(490) map / Ifremer turbidity map (NTU)





Turbidity anomaly for the april (2003-2009) period with real turbidity map (Gohin[18]) and Kd (490) Aqua modis data. Estuary are enhanced by positive anomaly (red) while algual bloom are identified by negative anomaly (blue).

Comparison with Secchi depth data: quantitative approach.

- Kd(490) underestimates turbidity in comparison with Secchi depth because of:

Limited approach of Secchi (in terms of spatial and temporal) / Low resolution approach of the Kd(490) (4x4 km), smoothed, and integrated on a 10 years period.

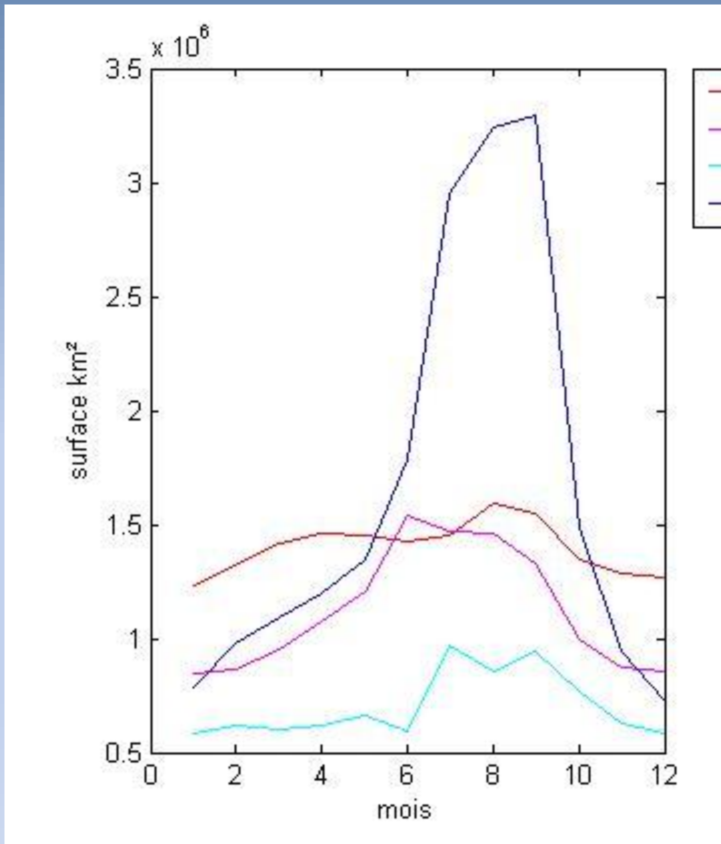
Water types classification based on turbidity

- Very clear water (lagoon), $0 \le K_d(490) \le 0.1$, SD=14m, Z(lidar)=28m
- Clear water (mediterranean), $0.1 \le K_d(490) \le 0.2$, SD=7 m, Z (lidar)=14 m
- Turbid water (Brittany), $0.2 \le K_d(490) \le 0.3$, SD= 4.6m, Z (lidar)=9.3 m
- Very turbid water (North sea, estuary), $0.3 \le K_d(490) \le 6.4$

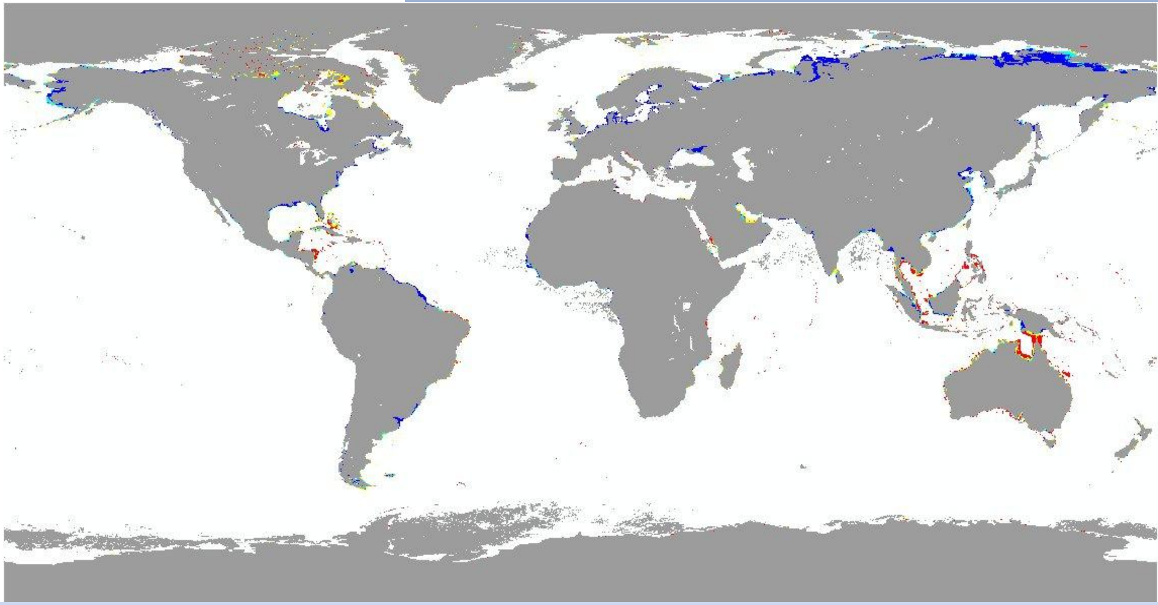
Kirk equation relating Secchi depth to Kd:

$$K_d(490) \times SD = 1.4$$

Water types distribution on coastal zones (0-20m) in function of turbidity.

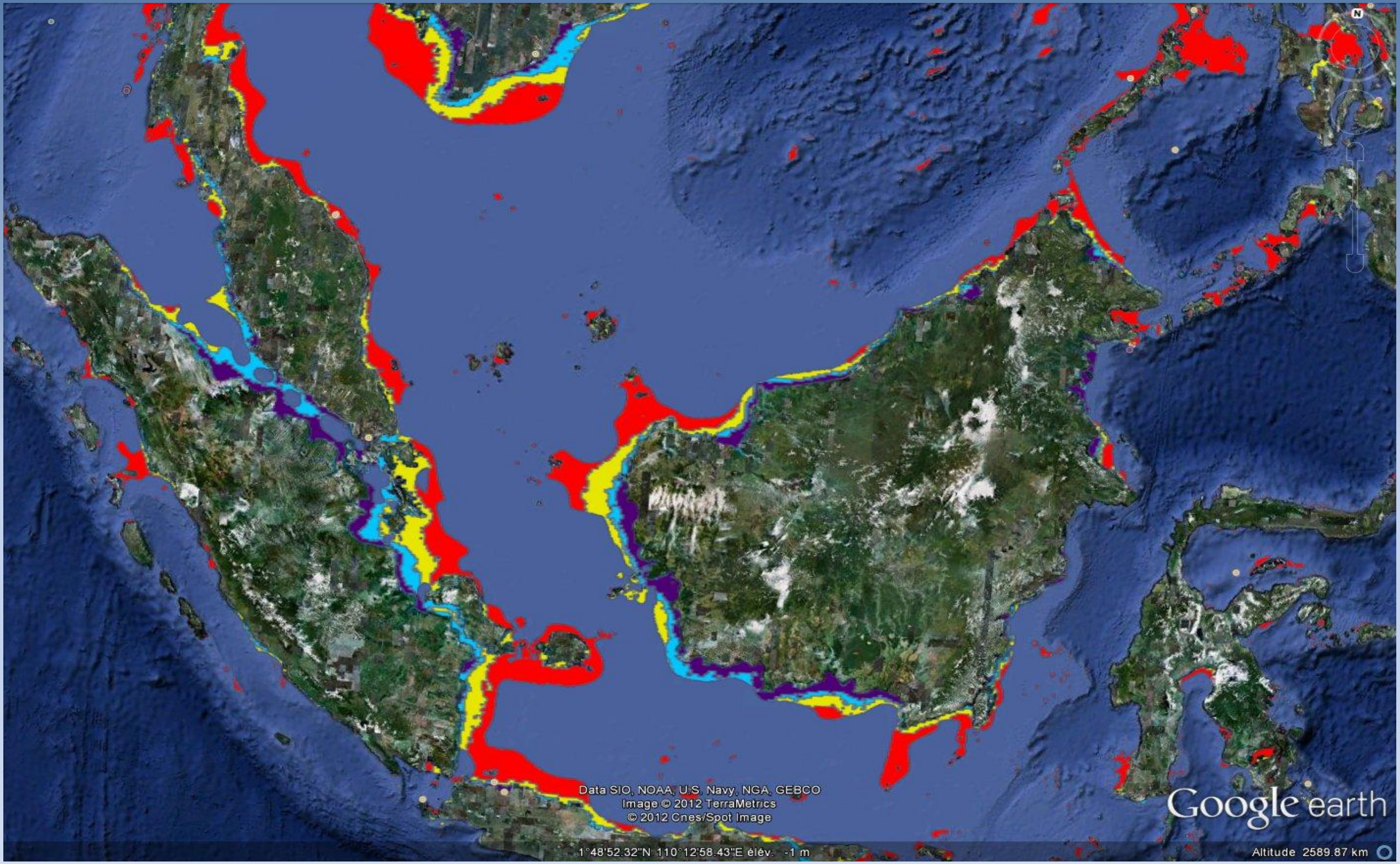


Water types distribution based on a year average turbidity result.



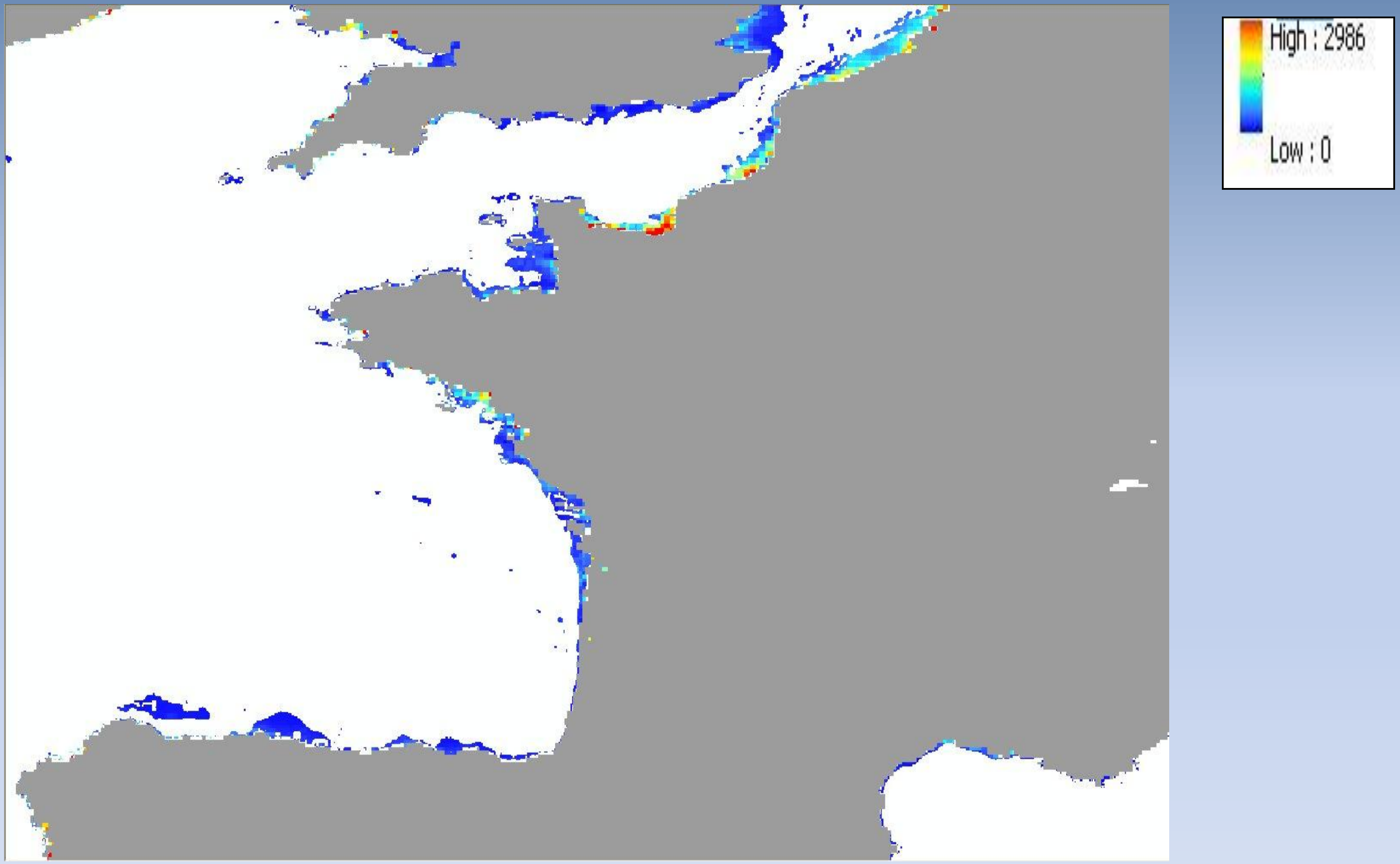
	Winter	Spring	Summer	Fall
Very clear water	1 072 174	1 104 070	1 227 429	1 098 744
Clear water	750 118	902 227	1 151 586	722 898
Turbid water	487 215	556 712	753 465	563 632
Very turbid water	908 025	1 421 051	3 340 503	891 778
Total	3 217 534	3 984 061	6 472 985	3 277 054

Coastal turbidity distribution



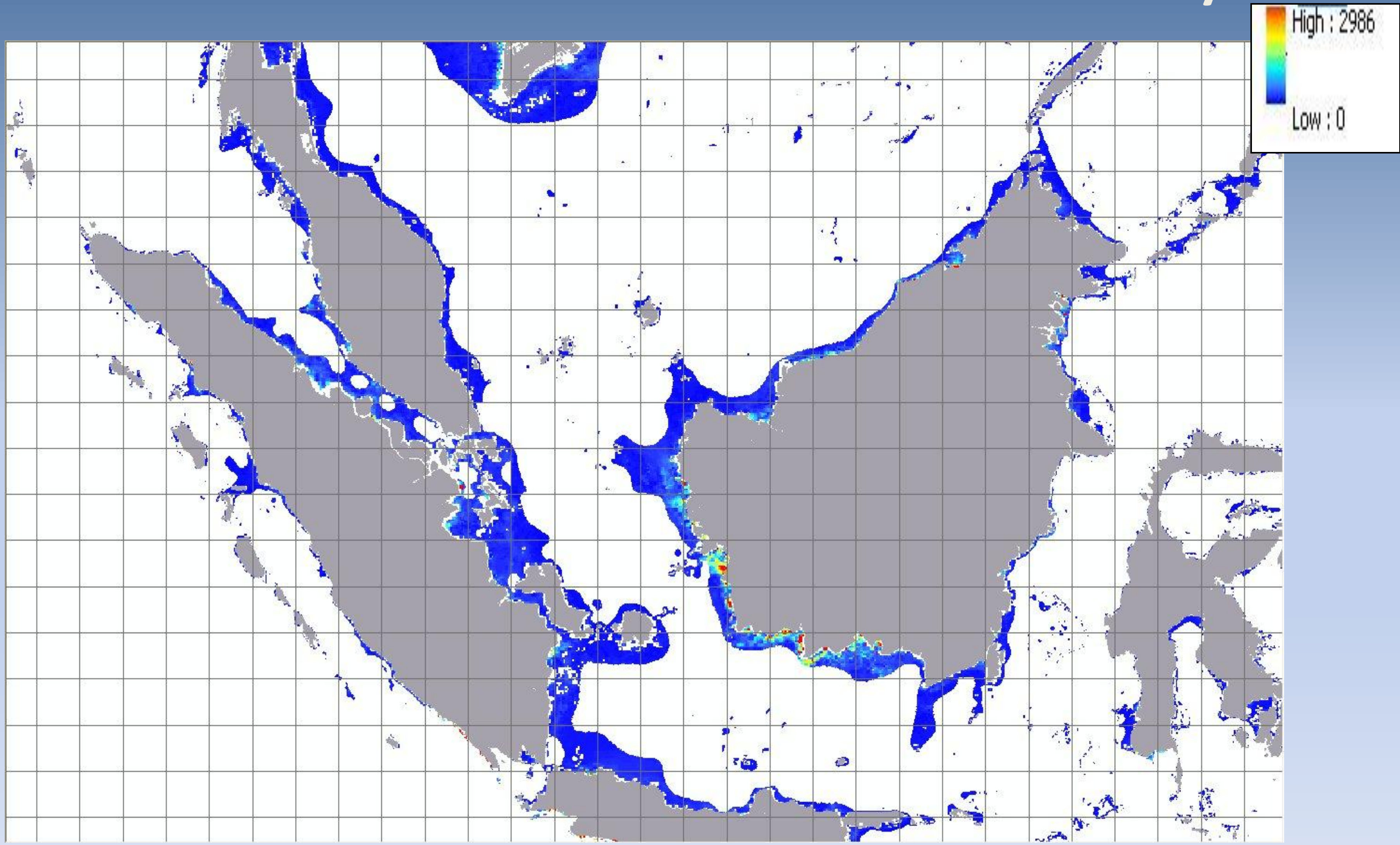
Indonesian archipelago showing the 4 water types distribution in the 0-20m depth during summer (july, august, september): Very clear water in red, clear water in yellow, turbid water in blue, and very turbid water in purple.

Standard deviation of Turbidity



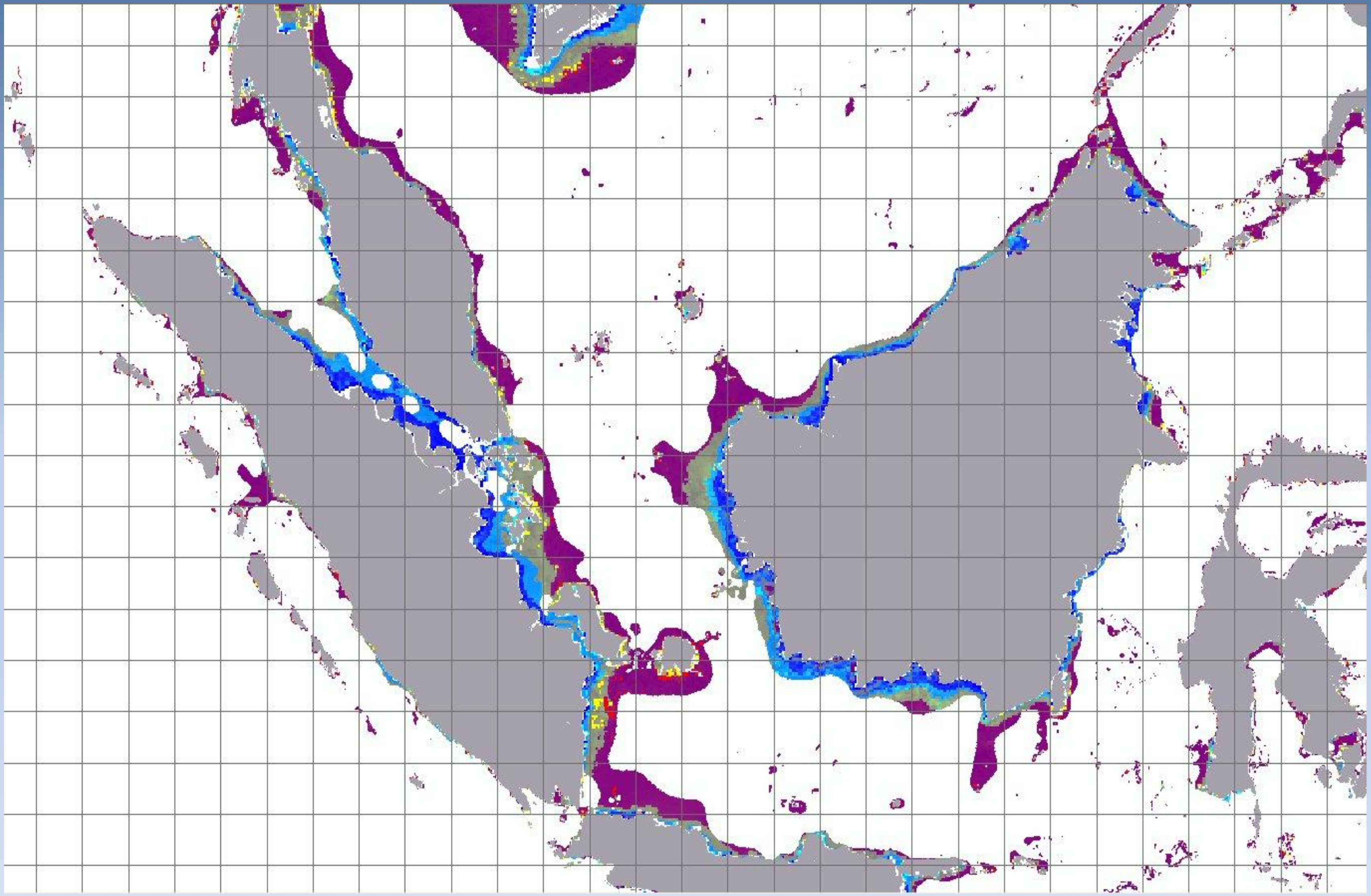
Kd (490) standard deviation during summer, values are in $10^{3} m^{-1}$

Standard deviation of Turbidity



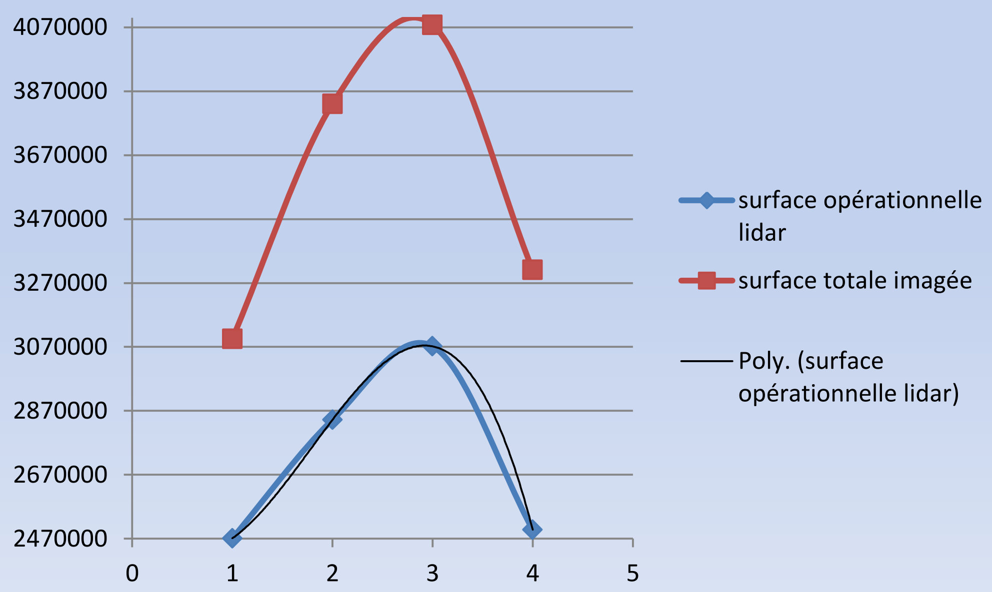
Indonesian archipelago showing the standard deviation of turbidity in the 0-20m depth during summer (july, august, september).

Turbidity ajusted by the standard deviation



Operational application to the spatial bathymetric Lidar

	Operational Lidar coverage(km²)	Op. coverage. / global coverage 0-20m
Winter	2 471 400	26 %
Spring	2 842 095	30 %
Summer	3 071 915	32 %
Fall	2 498 055	26 %



Conclusion

- Diffuse attenuation coefficient Kd(490) is a good estimation of turbidity on coastal zones, excepted on estuaries and on Chl –a bloom zones.
- Good consistency with Secchi results, especially on clear water to turbid water types.
- Weak standard deviation over seasonal period as well over annual period.
- Operational application to spatial bathymetric lidar: **30 %** of coverage at any time during all of the year.
- Physical parameters to integrate to improve results: Sea surface state, bottom reflectance, lidar incidence angle, sun glint, …

Outlook

- Include physical parameters of sea surface state, bottom reflectance, water column stratification to adjust the turbidity prediction.

- Other applications:
  - Habitat classification from bottom reflectance.
  - Water column turbidity, phytoplancton bloom detection, characterization of suspended materials, …
  - Fisheries ressources estimation.