A physics-based improved model for light absorption by colored dissolved organic matter

Børge Hamre[1], Jakob J. Stamnes[1], Knut Stamnes[2], Yi-Chun Chen[1], Ciren Nima[3], Torbjørn Taskjelle[1], and Øyvind Frette[1]
[1]University of Bergen, Norway, [2]Stevens Institute of Technology, USA, [3]Department of Physics, Tibet University, Lhasa, Tibet Autonomous Region, China
Email: borge.hamre@uib.no

We suggest an improved model for the spectral absorption coefficient of colored dissolved organic matter. The new model is based on a Lorentz harmonic oscillator, and it seems to fit measured spectra from different water types better than the traditional exponential model, in particular when a wide wavelength range is considered.

Introduction

Colored dissolved organic matter (CDOM) is one of the most important modifiers of underwater light spectra. It strongly absorbs the ultraviolet (UV) and blue-green part of the visible spectrum, providing protection for aquatic life against high-energy photons, but also causing significant reduction in light levels for photosynthesis and visual feeding for higher organisms.

Traditional model

The CDOM absorption coefficient *a* varies in general smoothly with the wavelength λ, and within a limited wavelength interval, it is to a good approximation decaying exponentially with increasing wavelength [1]:

$$a(\lambda) = a(\lambda_0)\exp\left(-S(\lambda-\lambda_0)\right)$$

where λ_0 is a reference wavelength and *S* is the slope of the log-transformed spectrum (Fig. 1).

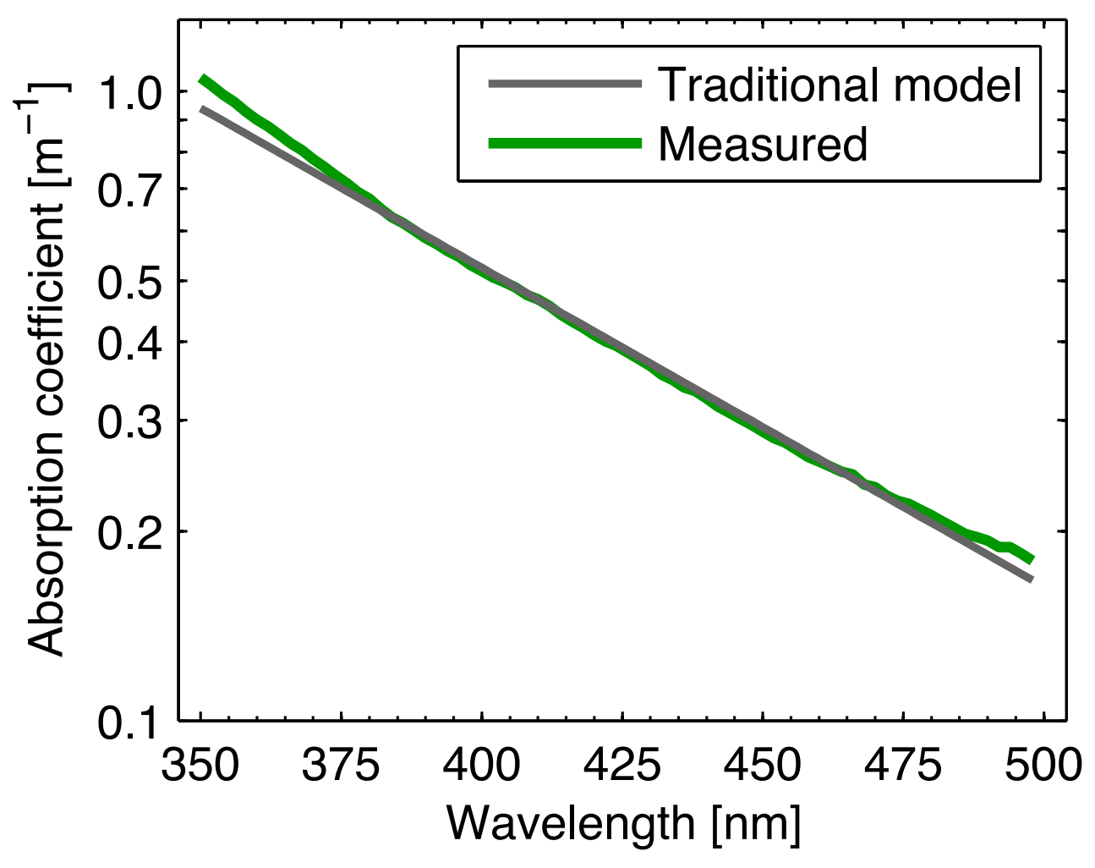

Fig. 1. *Traditional CDOM absorption model compared to a measured spectrum.*

Weaknesses in traditional model

The traditional model has some potential weaknesses. It lacks physical foundation, and different wavelength intervals seem to require different slopes. Moreover, for red and near infrared radiation, the traditional model fits only after a seemingly unnecessary baseline correction (Fig. 2).

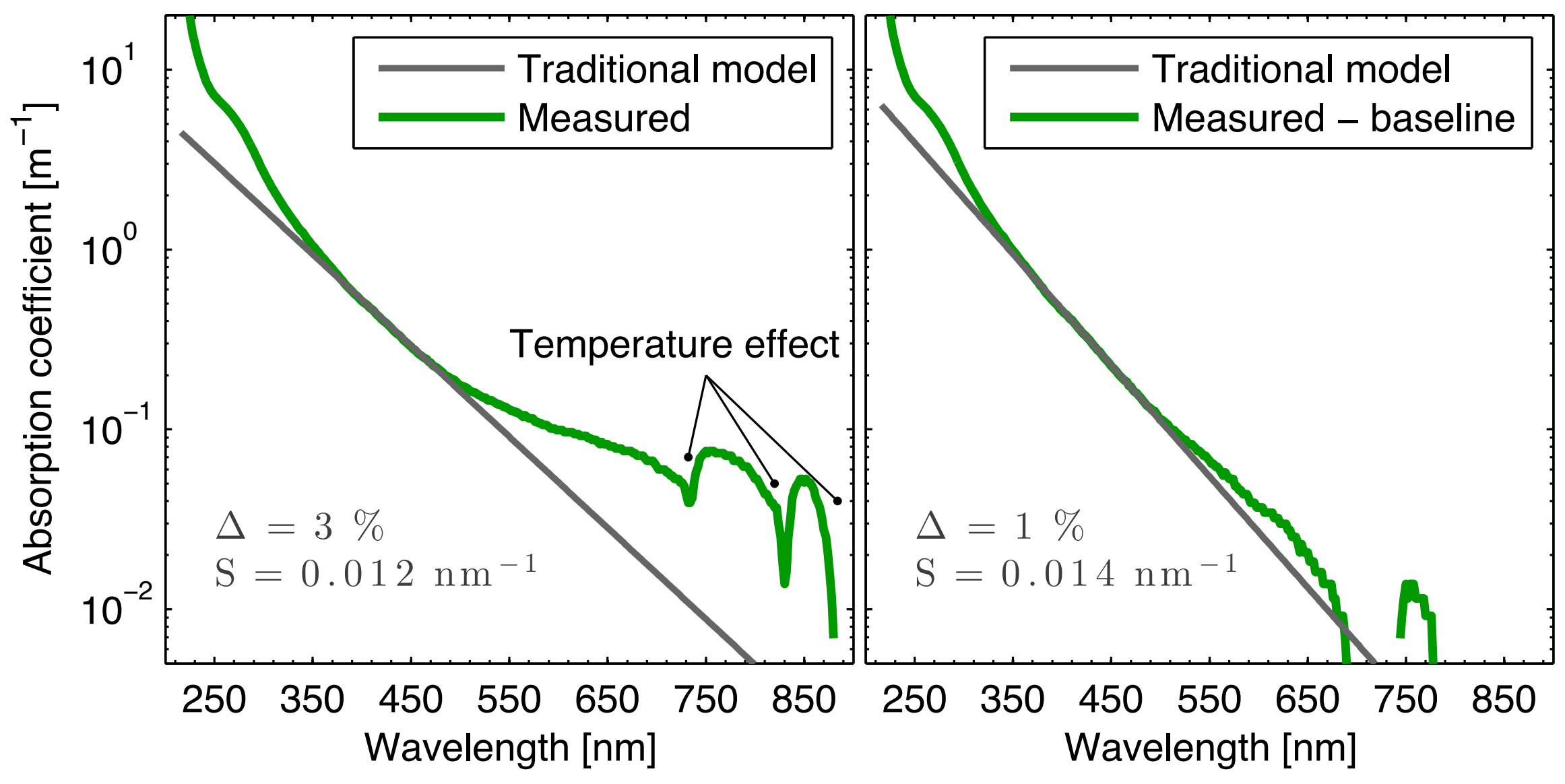

Fig. 2. *Traditional CDOM absorption model compared to a measured spectrum, where there is no baseline correction in left panel, but subtraction of* `a(700)` *in right panel. Oscillations in the near infrared region are caused by pure water absorption due to difference in temperature between sample and blank. Deviation (Δ) is computed as the average percentage difference for wavelengths between 350 and 500 nm.*

Lorentz model

A candidate for a physics-based model is the Lorentz harmonic oscillator [2]. In this model, the electrons of the CDOM molecules are assumed to vibrate with resonance frequencies corresponding to the UV radiation, and they are assumed to be forced to oscillate by time-varying incident electric fields. Absorption is taking place due to damping mechanisms within the molecules. Figure 3 shows absorption predicted by such a Lorentz model with only one effective resonance. It seems to fit very well for all wavelengths ranging from UV to near infrared. For shorter wavelengths (higher frequencies), additional resonance frequencies would be needed.

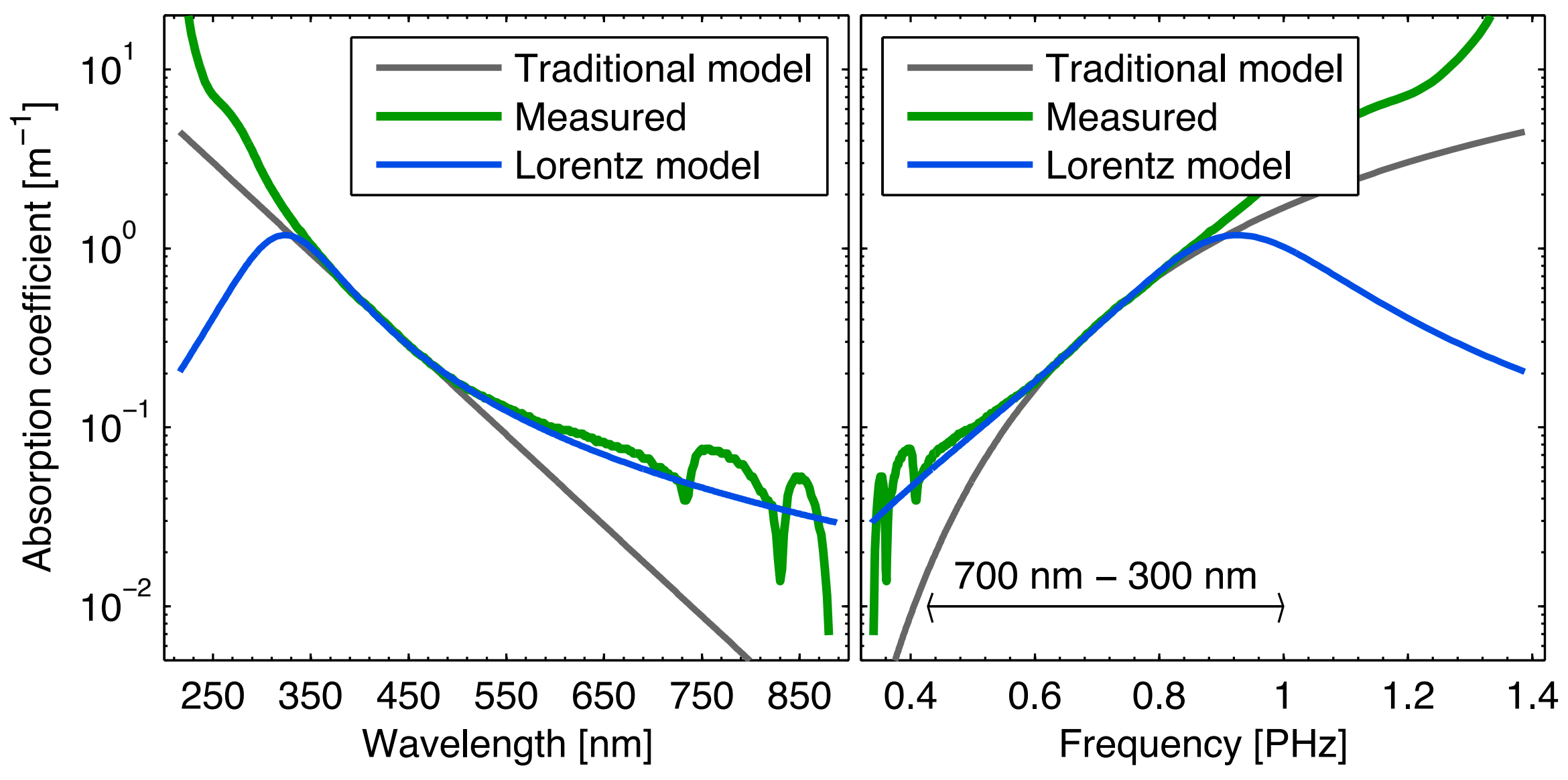

Fig. 3. *One-resonance Lorentz model compared with both the traditional model and a measured CDOM absorption spectrum.*

Suggested improved model

As can be seen in Figure 3, the one-resonance Lorentz model predicts an absorption spectrum that is, after making a log-transform, linearly dependent on frequency (reciprocal of wavelength), and the linearity is ranging from near infrared and far into the UV-region. We therefore suggest the following new physics-based model for the CDOM absorption coefficient:

$$a(\lambda) = a(\lambda_0)\exp\left(\gamma\left(\frac{\lambda_0}{\lambda}-1\right)\right)$$

where *γ* is a dimensionless constant that can be shown to depend on the position of the resonance frequency and the amount of damping of the oscillating electrons.

Validation of suggested model

Figure 4 shows that the suggested new simple exponential model seems to fit very well for all wavelengths of interest for ocean optics and optical remote sensing. And it fits better than the full one-resonance Lorentz model in the far UV-region. The excellent fit in the red and near infrared regions, also suggests that baseline correction by subtracting an absorption coefficient at those wavelengths should not be done.

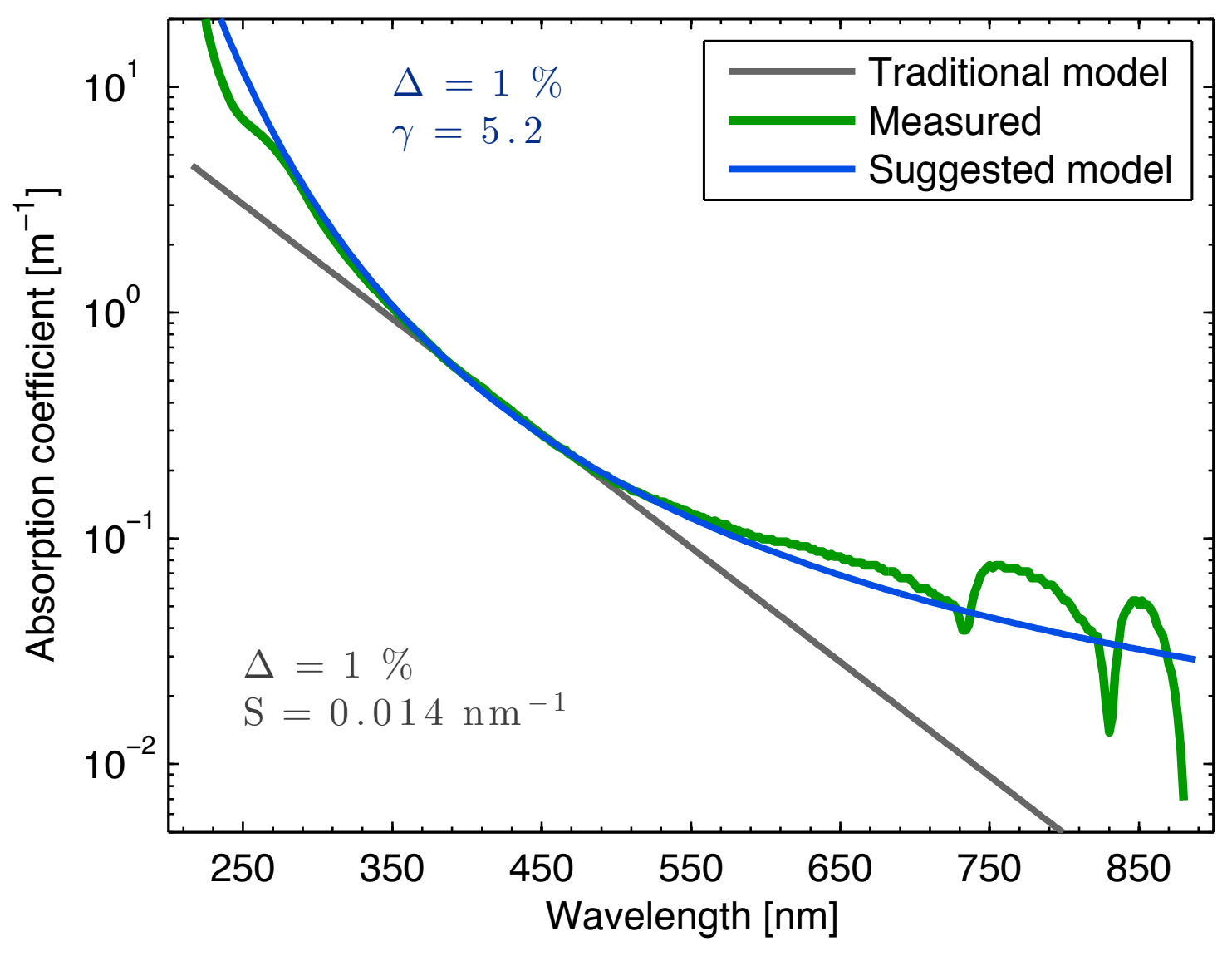

Fig. 4. *Suggested improved CDOM absorption model compared with both traditional model and a measured absorption spectrum.*

Figure 5 shows that the new suggested model seems to fit very well for all relevant wavelengths for and for very different water types.

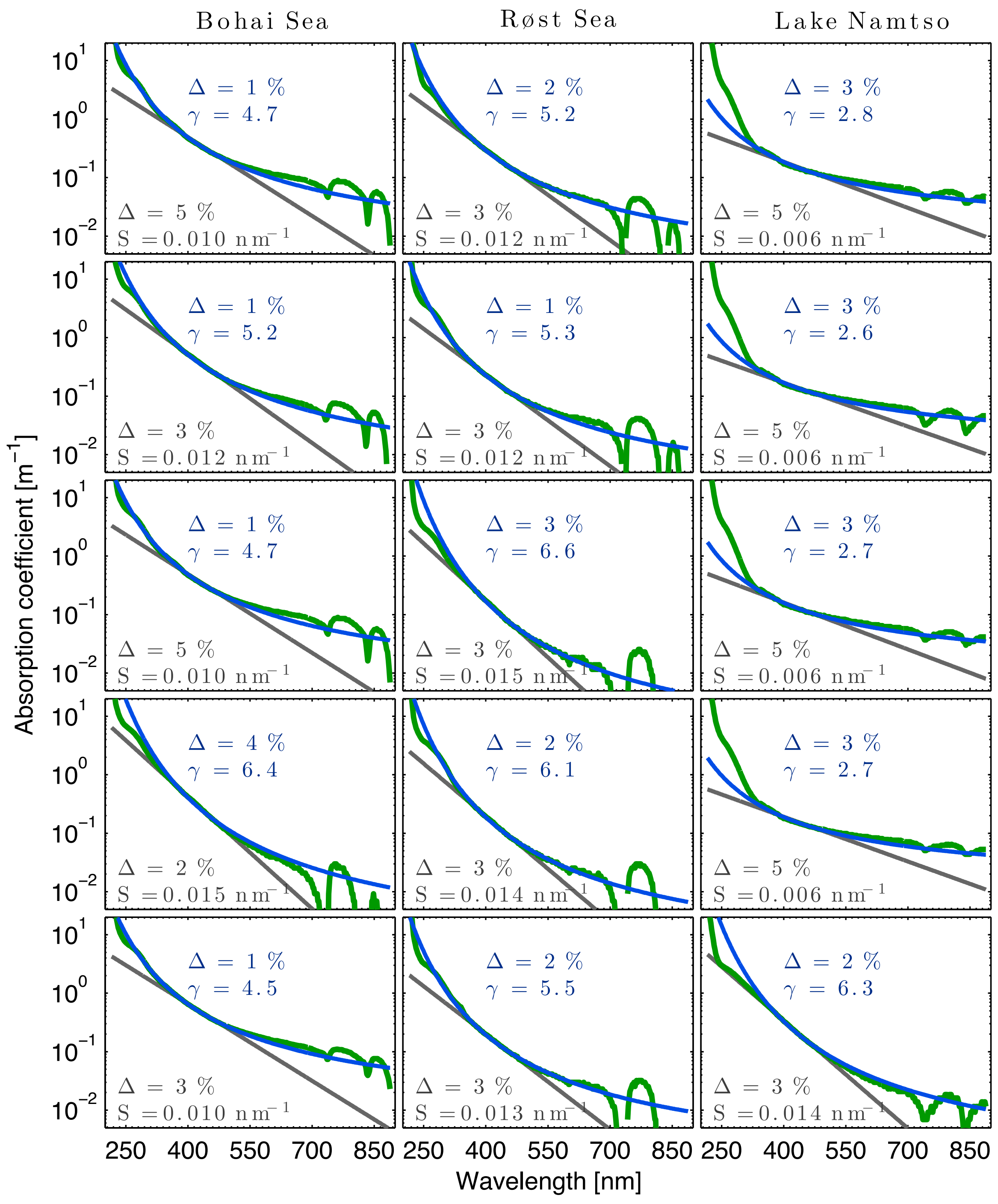

Fig. 5. *Suggested improved CDOM absorption model (blue) compared with both traditional model (grey) and randomly selected measured spectra (green) from turbid coastal water in China, clear coastal water in Norway, and high altitude lake water on the Tibetan plateau [3].*

Conclusion

The suggested physics-based CDOM absorption model seems to fit measured spectra significantly better than the traditional exponential model. In particular, the new model predicts higher absorption in the red part of the spectrum, and it may therefore contribute to more correct simulations of ocean color, and remote sensing signals.

REFERENCES

[1]Jerlov, Nils Gunnar, Optical Oceanography. Elsevier, 1976.
[2]Jackson, John David. *Classical electrodynamics.* Wiley, 1999.
[3]Nima, C., Hamre, B., Frette, Ø. et al. Hydrobiologia (2016) 768: 63. doi:10.1007/s10750-015-2528-2

UNIVERSITY OF BERGEN
Faculty of Mathematics and Natural Sciences