Implementing inelastic raman scattering in polarized radiative transfer for coupled atmosphere and ocean systems

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Introduction

- Scattering and absorption of light in ocean waters include both elastic and inelastic processes.
- The inelastic processes mainly include Raman scattering by pure liquid water and fluorescence by phytoplankton.
- The contribution of Raman scattering to the underwater radiation field is significant in the visible region for clear waters.
- We have implemented Raman scattering in a vector radiative transfer model based on the successive order of scattering method
- Similar radiative transfer tools will be needed for the development of algorithm development for the next generation of ocean color missions.

Radiative transfer equation:

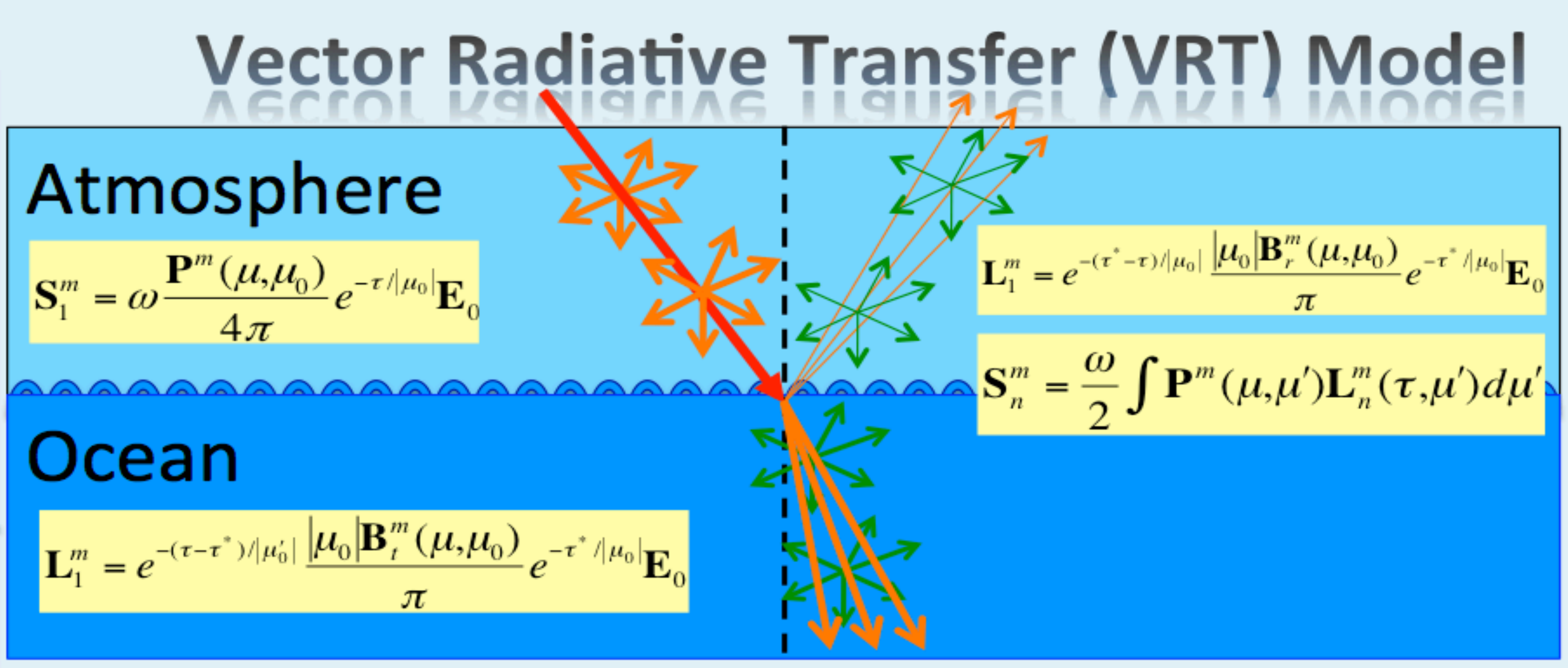
$$\mu\frac{d\mathbf{L}(\mathbf{z},\mu,\phi,\lambda)}{dz} = -c(z,\lambda)\mathbf{L}(\mathbf{z},\mu,\phi,\lambda)+\mathbf{S}(z,\mu,\phi,\lambda)+\mathbf{S}_R(z,\mu,\phi,\lambda)$$

$$b(z,\lambda)\int_0^{2\pi}\int_{-1}^{1}\mathbf{P}(z,\mu,\phi,\mu',\phi',\lambda)\cdot\mathbf{L}(z,\mu',\phi',\lambda)d\mu'd\phi'$$

$$\mathbf{R}(\pi-i_2)\cdot\mathbf{F}(z,\Theta,\lambda)\cdot\mathbf{R}(-i_1)$$

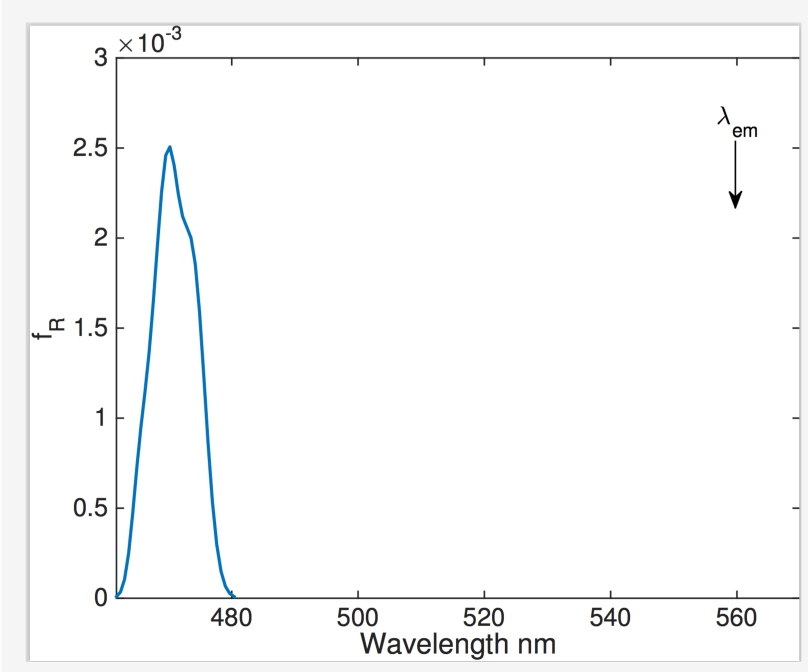
$$\int_0^{\lambda}\int_0^{2\pi}\int_{-1}^{1} b_R(z,\lambda,\lambda_e)\mathbf{P}_R(z,\mu,\phi,\mu',\phi',\lambda,\lambda_e)\cdot\mathbf{L}(z,\mu',\phi',\lambda_e)d\mu'd\phi'd\lambda_e$$

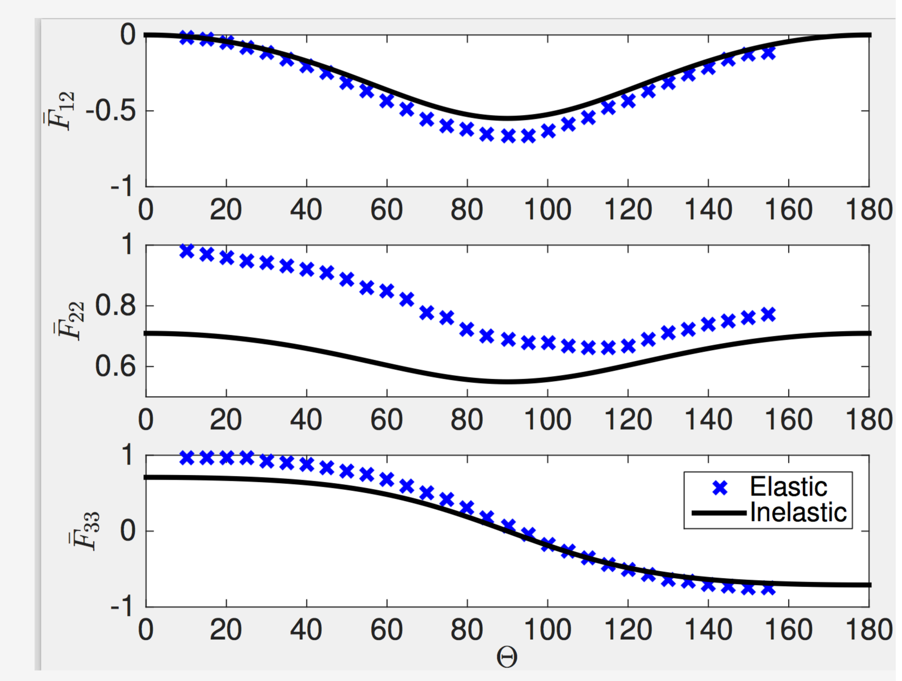
$$b_R(\lambda',\lambda) = a_R(\lambda)f_R(\lambda',\lambda) \qquad a_R(\lambda) = 2.7\times10^{-4}\cdot\left(\frac{488}{\lambda}\right)^{5.3}$$



Zhai, P, Y. Hu, J. Chowdhary, C. R. Trepte, P. L. Lucker, D. B. Josset, "A vector radiative transfer model for coupled atmosphere and ocean systems with a rough interface," J Quant Spectrosc Radiat Transf, **111**, 1025-1040 (2010).

Raman Scattering Features:



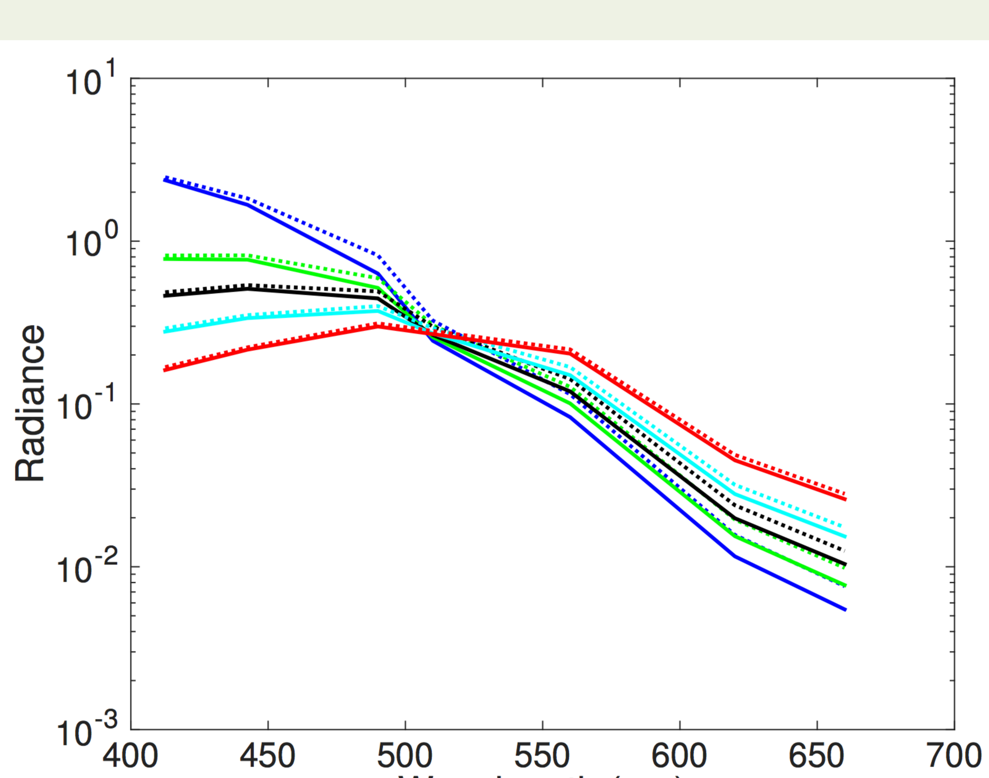


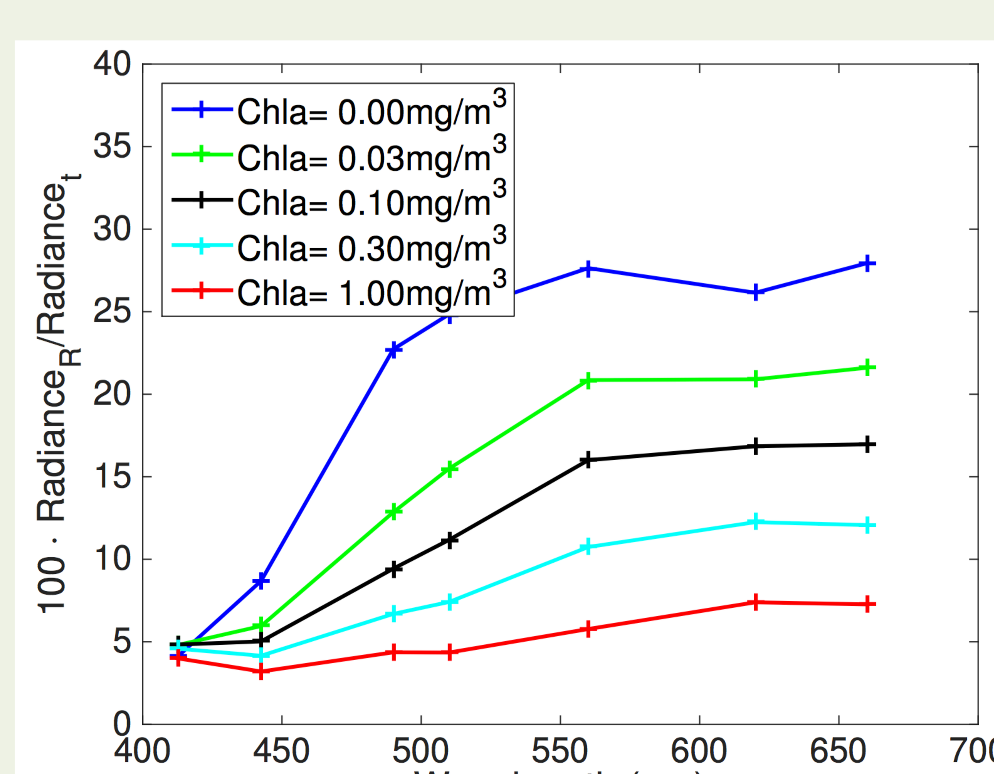
- The mean frequency shift is around 3000 cm^{-1} between excitation and emission wavelengths.
- Inelastic scattering depolarizes the scattered light more than elastic scattering.

Radiative transfer solution procedure:

1. determine a range of excitation wavelengths which have significant contributions to the emission wavelength based on the Raman scattering distribution function f_R.
2. Discretize the excitation wavelength range based on the normalization condition of f_R.
3. Run the vector radiative transfer model to find out the polarized radiation field for each excitation wavelength.
4. Evaluate the inelastic scattering source matrix based on the polarized radiation field found in the last step.
5. Run the vector radiative transfer model to find out the total radiation field at the emission wavelength with both the elastic and inelastic scattering source matrix included.

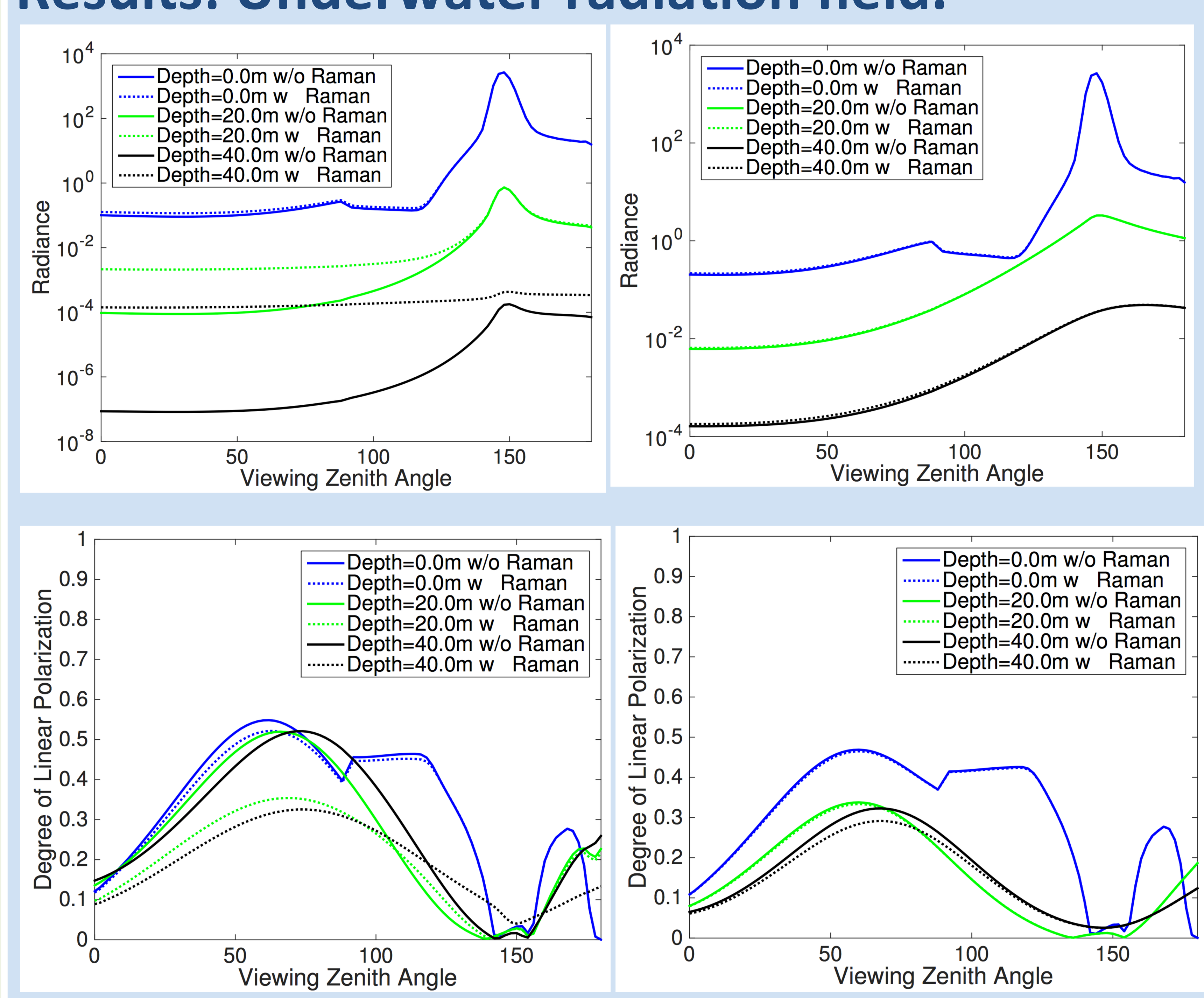
Results: Remote sensing reflectance with Raman scattering contributions





Solar Zenith Angle 45 Deg.; Water cloud optical depth: 5. W=5.0 m/s

Results: Underwater radiation field.



Chla=0.03 mgm^{-3} Chla=1.0 mgm^{-3}

Wavelength=560nm, Viewing Plane: Solar Principal plane.

Summary

- The polarized radiative transfer equation is solved with both elastic and inelastic (Raman) scattering included.
- The angular radiation field can be provided at arbitrary vertical locations in the coupled atmosphere and ocean systems.
- Raman scattering contribution is found to be significant in visible spectrum and clear waters.

Reference:Peng-Wang Zhai, Yongxiang Hu, David M. Winker, Bryan Franz, Emmanuel Boss, "Contribution of Raman scattering to polarized radiation field in ocean waters," Optics Express, Vol. 23, Issue 18, pp. 23582-23596 (2015) •doi: 10.1364/OE.23.023582.