Bayesian Approach to Atmospheric Correction of Satellite Ocean-Color Imagery: Confidence Domains of the Retrieved Water Reflectance

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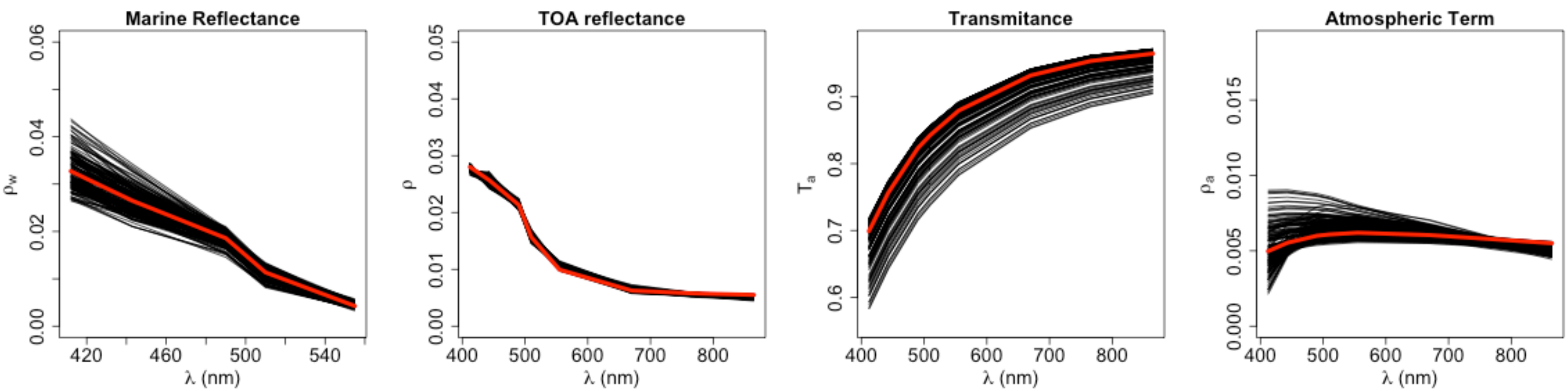
Ill-posed Nature of the inverse Problem

-The ocean color inverse problem (or atmospheric correction) is the retrieval of water reflectance from TOA reflectance.

-Multiple combinations of atmospheric and oceanic parameters (or pre-images) yield the same TOA reflectance. This places the inverse problem in a probabilistic context.

$$\rho \approx \rho_a + \rho_w T_a$$



Example of pre-images. Actual values of ρ_w , ρ, T_a, and ρ_a are displayed in red, and the pre-images at a distance no more than δ = 0.001 are displayed in black. The search spaces for the pre-images include NOMAD and AERONET-OC data sets and maritime, continental, and urban aerosols in various proportions and amount.

Bayesian Methodology

-The forward model is written as: $\rho = \phi(\rho_w, x_a) + \varepsilon$, where ρ is the TOA reflectance, ρ_w is the water reflectance, x_a denote the atmospheric parameters, and ε is a random noise.

-In the Bayesian approach to inverse problems, ρ_w and x_a are treated as random variables. This defines a probabilistic model, where any vector of measurements ρ^{obs} is considered a realization of the random vector ρ.

-The probabilistic model is specified by the forward model together with the distributions of ε and of (ρ_w, x_a). The distribution of (ρ_w, x_a), called the prior distribution, describes in a probabilistic manner the prior knowledge one may have about ρ_w and x_a before the acquisition of the data.

Bayesian Methodology (cont.)

-The Bayesian solution of the inverse problem of retrieving (ρ_w, x_a) from ρ is defined as the conditional distribution $P[(\rho_w, x_a)/\rho]$. It is called the posterior distribution. Hence, given the observation ρ^{obs}, the solution is expressed as the probability measure $P[(\rho_w, x_a)/\rho = \rho^{obs}]$.

-One is generally interested in certain relevant characteristics of the posterior distribution: its mean, which gives an estimate of the parameters to retrieve (ρ_w and x_a), and its covariance, which provides an accompanying measure of uncertainty.

-One may also compute a p-value, i.e., the probability that ρ takes a value at least as extreme as ρ^{obs}. Since the whole procedure consists of inverting a forward model (a component of which is a RT model), the p-value allows one to detect situations for which the forward model is unlikely to explain the data.

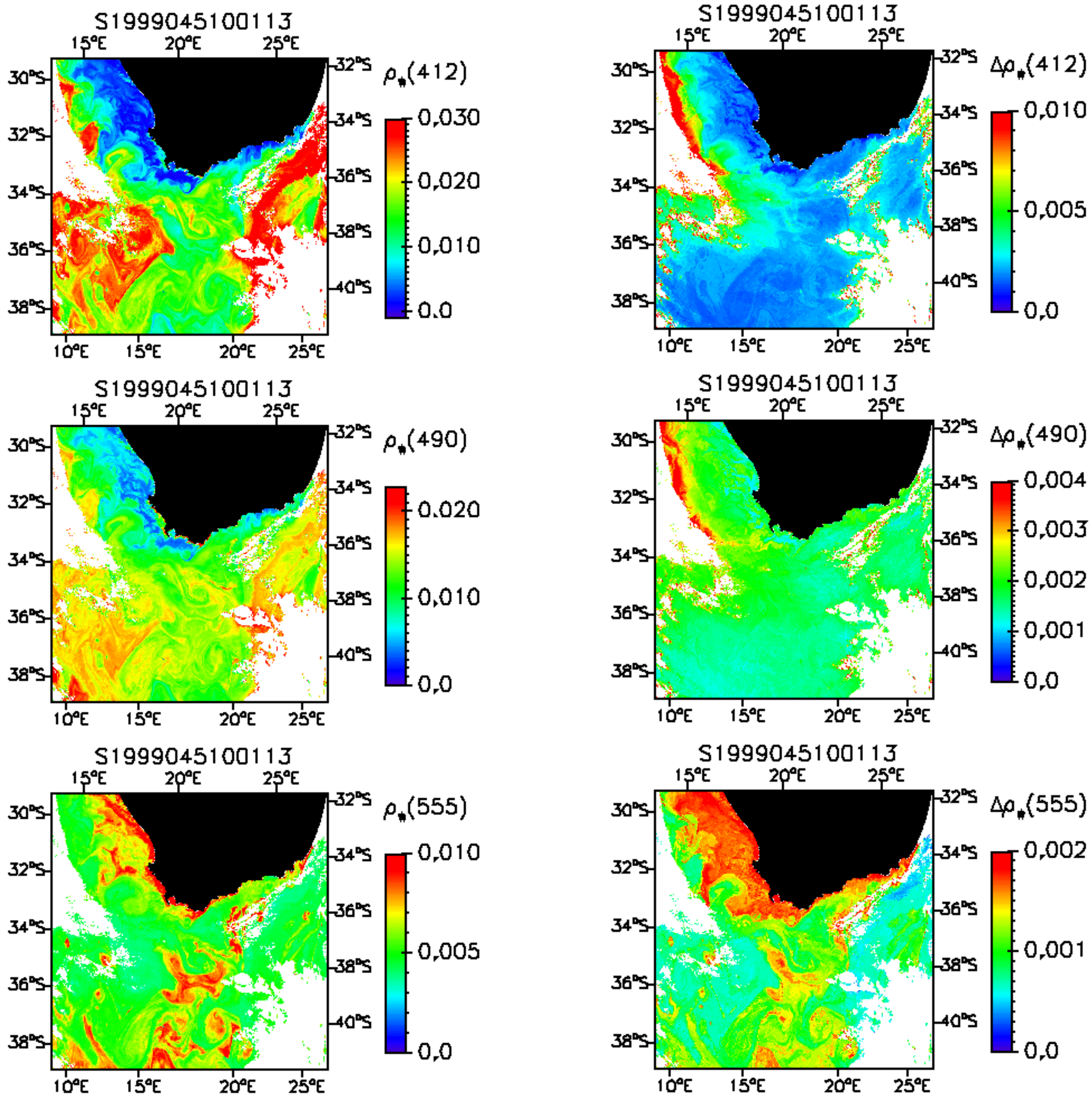
Connection with the Classical Scheme

-Consider the conditional expectation $E[\rho_w/\rho]$. Since $E[\rho_w/\rho]= E[E[\rho_w/\rho, x_a]/\rho]$, we see that $E[\rho_w/\rho, x_a]$ can be modeled first, and then averaged conditionally on ρ in a second time.

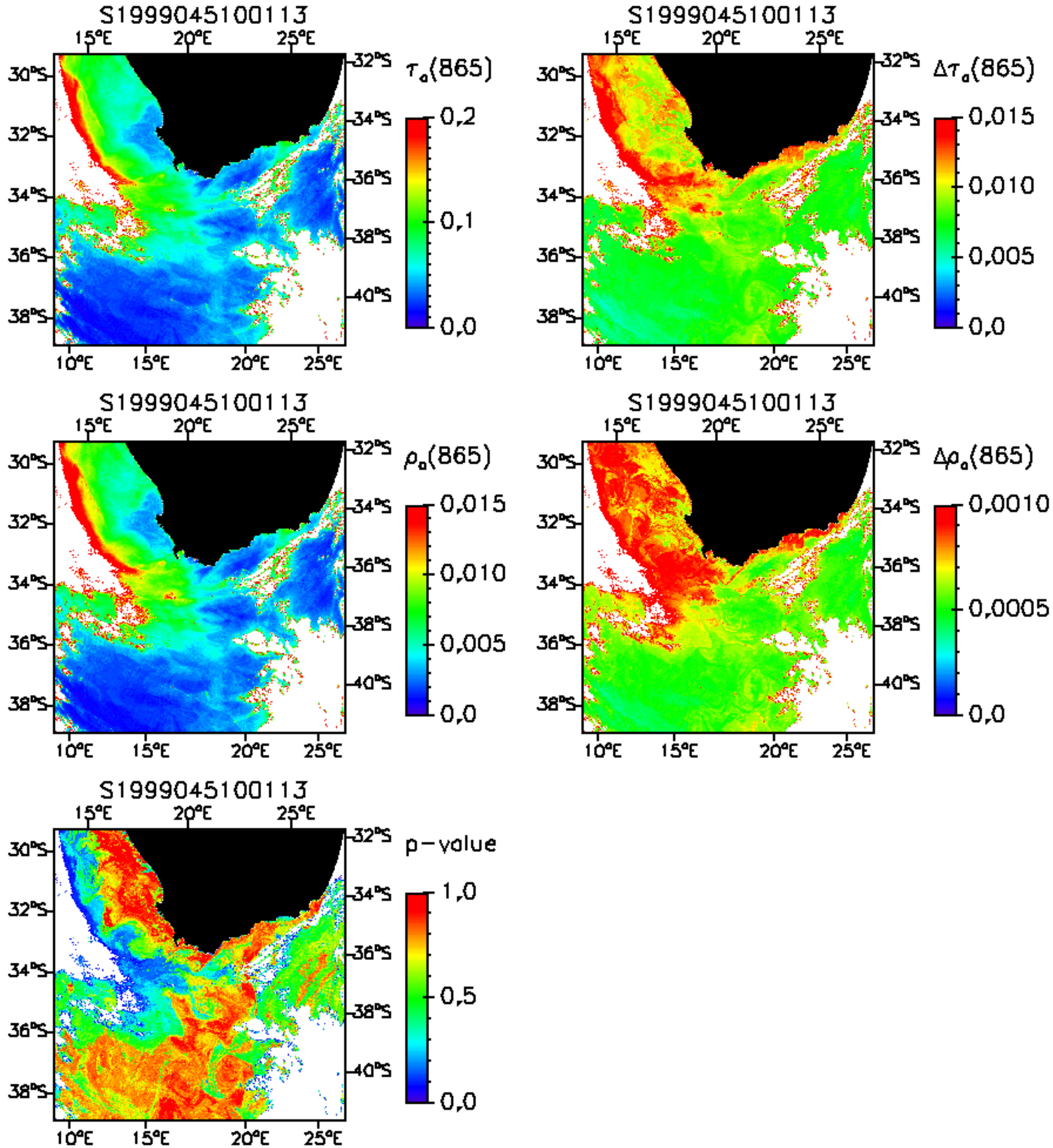
-This corresponds to inverting ρ assuming that the atmosphere is in the state x_a, and then averaging the results according to the distribution of x_a given ρ.

-So, compared with the classical approach, instead of picking an aerosol model and then inverting ρ assuming the atmosphere is in the state x_a, the Bayesian methodology amounts to placing a probability distribution on x_a, depending on ρ, inverting ρ for each x_a, and then averaging the results accordingly.

Application to SeaWiFS Imagery, South Africa, 02/14/1999

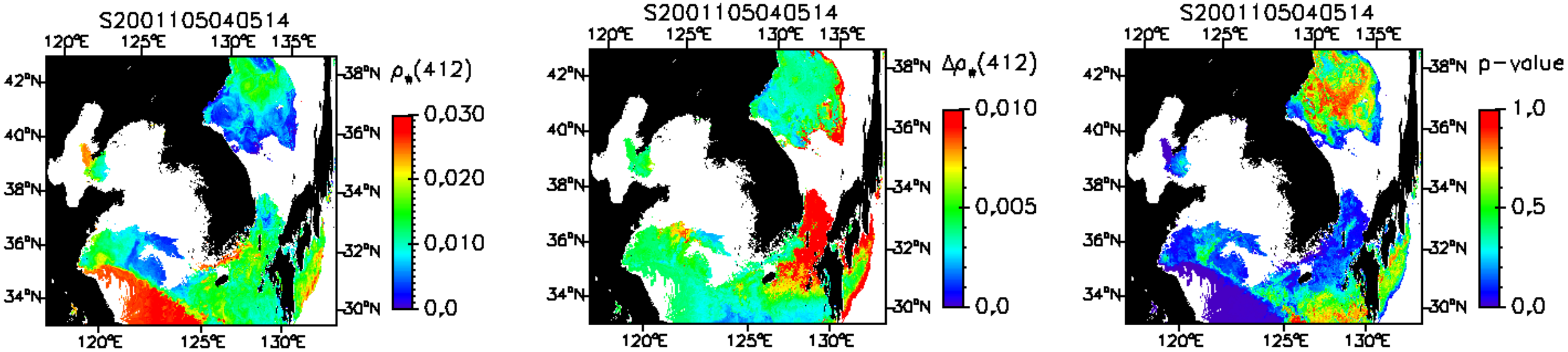


Estimated ρ_w at 412, 490, and 555 nm and associated uncertainty, Bayesian methodology.



Estimated τ_a, ρ_a at 865 nm and associated uncertainty, and p-value, Bayesian methodology.

Application to SeaWiFS Imagery, East Asia Seas



Estimated ρ_w at 412 nm, associated uncertainty, and p-value, Bayesian methodology. Uncertainty in East China Sea is relatively small (0.003-0.004), but p-value <0.01, indicating that model and observation are incompatible.

Conclusions

-The Bayesian approach is adapted to the ill-posed nature of the ocean color inverse problem.

-The solution, expressed as a probability distribution, allows the construction of reliable multi-dimensional confidence domains of the retrieved water reflectance.

-Expectation and covariance can be computed, which gives an estimate of the water reflectance and its uncertainty. The p-value identifies situations for which forward model and observation are incompatible.

-Covariance and p-value are complementary measures of uncertainty and quality. But they should be viewed in the context of a forward model. They do not replace uncertainties obtained by comparing retrievals with in situ measurements.