Bayesian Methodology for Atmospheric Correction of PACE Ocean-Color Imagery

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Objectives

-The first objective is to evaluate, using the Bayesian approach to inverse problems, the gain in marine reflectance accuracy expected by 1) including observations in the UV and SWIR and 2) further including polarimetric and directional observations in selected spectral bands. This for the PACE spectrometer threshold aggregate bands, as defined in the PACE SDT report, with respect to the standard MODIS set of bands used to generate ocean color products.

-The second objective is to assess, also in a Bayesian context, the utility of hyper-spectral information for improving atmospheric correction in the aggregate bands, and to quantify the accuracy of the atmospheric correction at 5 nm resolution for separating ocean constituents and characterizing phytoplankton communities.

Approach

-The TOA signal measured by the PACE spectrometer and the eventual polarimeter will be simulated for a variety of realistic atmospheric and oceanic conditions.

-Typical prior distributions for the aerosol, water reflectance, and surface parameters, suitable for utilization at a global scale, will be used, as well as noise distributions. The noise will encapsulate all the sources of uncertainties in the RT modeling and include sensor noise.

-The inverse models will be constructed based on several considerations, i.e., computational cost, convenience to approximate the conditional covariance (a second order quantity), and detection of abnormal values (due to limitations of the forward model).

-Ways to improve performance by specifying prior distributions from independent information about regional and temporal variability (e.g., from output of numerical transport models) will be investigated, and practical implementation of the Bayesian methodology will be outlined for routine application.

Bayesian Methodology

General presentation

-The forward model is written as: $\rho = \phi(\rho_w, x_a) + \varepsilon$, where ρ is the TOA reflectance, ρ_w is the marine 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 y^{obs} is considered a realization of the random vector y. 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.

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

-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 matrix, which provides an accompanying measure of uncertainty.

Inverse modeling in practice

-Specify the distributions of ε and of (ρ_w, x_a). Models or observations can be used for ρ_w and x_a. (Using observations is preferable, especially for ρ_w, but the number of observations may be too small.) The noise distribution may be estimated by comparing TOA values from selected imagery with forward model predictions.

-Approximate numerically expectation and covariance of posterior distribution. Method selected is based on models constructed on a partition of the space of TOA reflectance. These models allow one to keep the execution time small.

-Compute a p-value, which gives the probability that y takes a value at least extreme as the one which has been observed. 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.

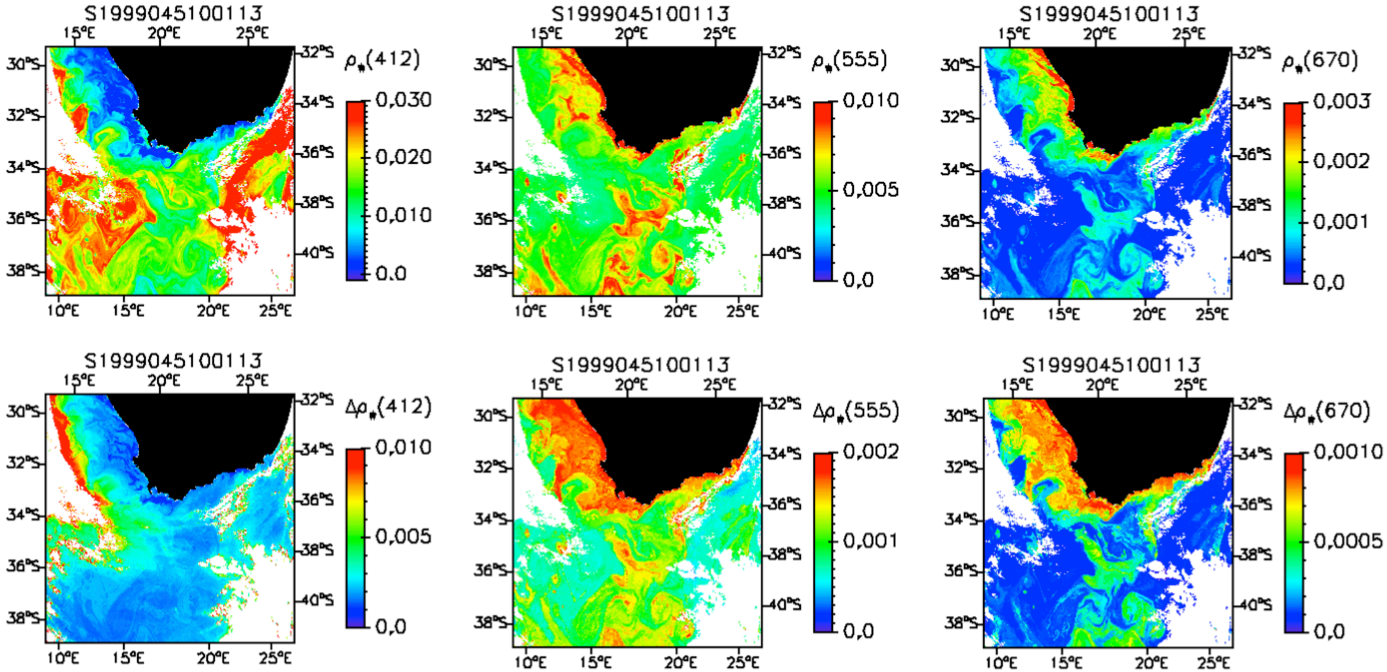
Connection with the classical approach

-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.

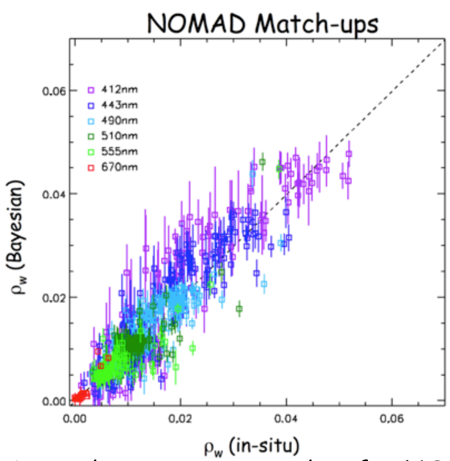
-This correspond to inverting ρ assuming that the atmosphere is in the state x_a, and then averaging the results according to the distribution of x_a given ρ.

-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.

Illustration on SeaWiFS data



Estimated ρ_w and associated uncertainty $\Delta\rho_w$ at 412, 555, and 670 nm by the Bayesian methodology applied to SeaWiFS imagery acquired on 14 February 1999 over South Africa.



Comparison Statistics

λ (nm)	Average ρ_w	r^2	Bias	RMS Difference	No. Points
412	0.02049	0.838	0.00164	0.00593	158
443	0.01799	0.806	0.00088	0.00449	158
490	0.01545	0.670	-0.00025	0.00346	158
510	0.01155	0.587	-0.00049	0.00301	158
555	0.00712	0.722	-0.00074	0.00258	158
670	0.00133	0.820	-0.00008	0.00121	158
All	0.01418	0.852	0.00023	0.00403	948

Estimated versus measured ρ_w for NOMAD match-up data. Left: Scatter plot including uncertainty on the Bayesian estimates (vertical bars); Right: Comparison statistics.

Year 1 work plan

-RT simulations of the TOA signal measured by the PACE spectrometer for a variety of atmospheric and oceanic conditions and solar and viewing geometries.

-Specification of noise and prior distributions and determination of inverse models for the PACE spectrometer threshold aggregate bands.

-Evaluation, for the PACE spectrometer threshold aggregate bands, of the gain in accuracy obtained by using observations in the UV and SWIR.

Requirement from IOP sub-group

-Comprehensive data set of marine reflectance representative of open and coastal waters. This to specify prior distribution of ρ_w. The data set may originate from in situ measurements (preferable, since the objective is to retrieve marine reflectance) or models. If models are used, they should take into account as much as possible natural correlations between optical variables.

Connection to the larger PACE Group

-Participation in the generation of simulated data to evaluate AC schemes.

-Participation in activities to improve and extend the standard, heritage AC algorithm.