ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ УЧРЕЖДЕНИЕ НАУКИ САНКТ-ПЕТЕРБУРГСКИЙ НАУЧНЫЙ ЦЕНТР РОССИЙСКОЙ АКАДЕМИИ НАУК

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A scheme of construction of imaging systems based on a complex modulated illuminating beam and the received echo signal processing is proposed, which involves the extraction of the modulated component and its matched filtering is discussed. The approached model of a signal taking into account the effect of surface waves and multiple scattering in water is constructed. The system limiting longitudinal and transverse resolutions determined by random light refraction on the surface and scattering in water are estimated. Characteristics of imaging systems with extremely high frequency of beam modulation are estimated.
Key words: underwater imaging, modulated beams of light, dispersion of modulation waves, compression of complex signal, random refraction, wavy surface hydrodynamically rough.

Likhacheva M.V., Sheberstov S.V., Kopelevich O.V. Modified Algorithm of Atmospheric Correction for MODIS Satellite Data…………………………………………………………..…… 18

New approach to MODIS data processing, joined of algorithm for sun glint area and low-parametric algorithm of atmospheric correction is presented. Software package processing MODIS imagery has been developed. Validation of this algorithm with in situ measurements of the water radiance reflectance ρ(λ) in most cases shows better accuracy then the SeaDAS 6.1 data as in the presence of sun glint and without glint. As a result of applying of new algorithm, the area of solving the inverse problem increased.
Key words: atmospheric correction, sun glint, ocean color sensors.

Trees C., Pennucci G. About the Distrotions of the Pulsed Light Beam in the Medium with Strongly Anisotropic Scattering……………………………………………….……………...… 26

One of the principle advantages of gliders is that they provide high-resolution measurements at small temporal and spatial scales. They also autonomously operate 24/7 under a variety of weather and sea-state conditions, they increase sample measurement densities (shipboard sampling 87 profiles day-1 as compared to 665 profiles day-1 from a glider), they are relatively low cost, easily re-locatable and finally, they have low power requirements for extended deployment periods. The goals of this study were (1) to determine the radiometric uncertainty of downwelling irradiance (Ed) measurements made from gliders, (2) to apply the Submerged Remote Sensing (SRS) technique for calculating mean K's (average K over some depth interval from just below the surface to the sensor depth) from validated glider Ed data and (3) to invert mean K's to local K's (K over some smaller depth increment ~1–2 m to generate a vertical profile of K) under varying incident solar fluxes (cloud cover/atmospheric conditions).
Key words: slocum gliders, underwater irradiance, vertical attenuation coefficient.

Dolin L.S. About the Distrotions of the Pulsed Light Beam in the Medium with Strongly Anisotropic Scattering…………………………………………………………………………...… 30

The method for analysis of spatially - temporal distortions of a pulsed light beam in the stratified turbid medium with narrow scattering phase function (in particular, sea water) is developed. It is shown that the radiative transfer equation in the refined small-angle approximation is reduced to a set of equations for longitudinal moments of a pulsed light field which is solved rigorously unlike the analogous equations for temporary moments of pulse. Recurrence relations, which permit to calculate the moments of the higher order based on the zero moment, are obtained. The formulas for calculating the first three moments, defining the average radiance (or irradiance), the distance between the leading front and the "centre of gravity" of pulse as well as the longitudinal scale of its smearing, are given. Formulas for definition of time characteristics of pulse from its spatial moments are obtained.
Key words: laser impulse, turbid medium, light scattering, radiative transfer equation, light field, a method of the moments.

Rodionov M., Dolina I., Levin I. Correlations Between Depth Distributions of Water Attenuation Coefficient and Density in the North Seas ……………………………………...…….. 39

The paper contains the data on measurements of depth distributions of attenuation coefficient and fluid density in the Barents, White and Kara Seas together with results of analysis the correlations between these distributions. We founded that in many cases correlations between parameters of the functions used for distributions approximation are rather high, namely, between the horizons of maximal change of attenuation coefficient and the pycnocline depth, between widths of pycnocline and the layer of attenuation coefficient jump, as well as between the gradient of c and the buoyancy frequency.
Key words: correlations, depth profiles, attenuation coefficient, fluid density.

Vasulia S.V., Kopelevich O.V. Comparative Estimates of the Budget of Photosynthetic Available Radiation (PAR) in the Barents, White, Kara and Black Seas Derived From *in situ* and Satellite Data………………………………………………………………………...… 47

The comparative assessment of all components of the PAR budget (incident on the sea surface, reflected from the rough sea surface, penetrating to the different depth in the water column, water-leaving and absorbed in water) made by using satellite and *in situ* data in the Barents, Black, Kara, and White seas is presented. Water quality is varied from clear with the diffuse attenuation coefficient $K_d(555) \approx 0.13$ m^{-1} to very turbid with $K_d(555) = 0.42$ m^{-1}. These differences cause the essential discrepancy of components of the PAR budget in different seas. An agreement between the estimates of PAR penetration in the upper layer derived from in situ and satellite data is quite satisfactory.
Key words: photosynthetic available radiation, PAR budget, satellite data.

Ficek D., Meler J., Zapadka T., Stoń-Egiert J. Modelling the Light Absorption Coefficients of Phytoplankton in Pomeranian Lakes (Northern Poland) ……………...…………………...… 54

In 2004-08 the absorption properties of phytoplankton was measured in 15 northern Polish lakes of different trophicity. At the same time the concentrations of optically active substances in these lakes were also measured. These data were used to test the model of the absorption properties of phytoplankton, derived by Bricaud et al. for case 1 oceanic waters (hereafter referred to as Bricaud's parameterisation), to predict the spectra of light absorption by phytoplankton a_{ph} for lakes in Pomerania. This study shows the limitations of this model to lacustrine phytoplankton; and the reasons for them are discussed. In addition, an analogous model of light absorption by phytoplankton in the investigated lakes was derived on the same mathematical basis as Bricaud's model, but with different values of the relevant empirical parameters. For the sake of simplicity, the analysis covered the coefficients of light absorption only by surface water phytoplankton. The results were compared with those obtained for case 2 waters by other authors using similar models.
Key words: phytoplankton absorption spectra, lakes, bio-optical modelling.

Pennucci G., Alvarez A., Trees C. A Satellite Covariance-Based Method to Support AERONET Ocean Color Validation Activities ……………………………………………...…..… 64

The objective is to determine the location(s) in any given oceanic area during different temporal periods where in situ sampling for Calibration/Validation (Cal/Val) provides the greatest improvement in retrieving accurate radiometric and derived product data (lowest uncertainties). A method is presented to merge satellite imagery with in situ samples and to determine the best in situ sampling strategy suitable for satellite Cal/Val efforts. This methodology uses satellite acquisitions to build a covariance matrix encoding the spatio-temporal variability of the area of interest. The covariance matrix is used in a Bayesian framework to merge satellite and in situ data providing a product with lower uncertainty. The best in situ location for Cal/Val efforts is retrieved using a design principle (A-optimum design) that looks for minimizing the estimated variance of the merged product.
Key words: satellite images, field measurements, calibration-validation, merged product.

Tolkachenko G.A., Kalinskaya D.V., Smirnov A.V., Prohorenko Y.A. Evalution of Spatial Scales of Aerosol Atmosphere over the Black Sea …………………………………...…..… 69

Results of researches of spatial correlation of atmosphere optical heterogeneities above the Black sea are presented. Measurements of aerosol optical thickness are carried out by two spaced sun photometers. The spatial correlation radius of aerosol optical thickness is estimated and constitutes in order of 160 km. Possibility of revealing the absorbing aerosols properties above the sea is shown on a concrete examples. The recommendations on application of portable photometers in sub-satellite measured experiments are given.
Key words: aerosol, correction atmosphere, spatial correlation, undersattelite experiment.

Levin I., Darecki.M., Sagan S., Kowalczuk P., Zdun A., Radomyslskaya T., Rodionov M. Can the Known Models of Seawater Optical Properties Be Applied to the Baltic Sea?............... 80

Commonly used optical models of natural waters have been analyzed in the context of their applicability in the Baltic Sea. By use of a large data set collected at the Baltic, we found that published before relationships between scattering, attenuation and backscattering coefficients at wavelength 550 nm in ocean waters are valid for Baltic as well. When the same data were used for validation of the relationships connecting absorption and scattering coefficients of the chlorophyll and absorption coefficients of Colored Dissolved Organic Matter (CDOM) with chlorophyll concentration, the result shows a large discrepancy, disqualifying them in the complicated environment of the Baltic Sea.
Key words: inherent optical properties, phytoplankton, yellow substance.

Sukhorukov A.L., Titov M.A. Use of Gliding Effect for Motion of Underwater Vehicles …..…..…… 88

This study defines hydrodynamic characteristics of underwater gliders based upon numeric solution of Reynolds-averaged Navier-Stokes equation. The characteristics were compared with experimental data and it was shown that it is possible to use numeric methods of viscous fluid dynamics for development of a shape of such objects. Mathematical model of glider's motion was designed. Feasibility of its use as a towing vehicle for another underwater object was studied. Analytical estimations of glider motion parameters were obtained at steady-state modes with and without account of towing force.
Key words: underwater vehicle, glider, numeric methods, mathematical model of motion, towing, excessive buoyancy.

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СПУТНИКОВЫЙ МЕТОД, ОСНОВАННЫЙ НА КОВАРИАЦИИ, ДЛЯ ПОДДЕРЖКИ ДЕЯТЕЛЬНОСТИ АЭРОНЕТ – ВЕРИФИКАЦИЯ ДАННЫХ ПО ЦВЕТУ ОКЕАНА

Цель работы – определить места в исследуемой области океана, где натурные измерения для калибровки/верификации (Cal/Val) в течение различных периодов времени обеспечивают наибольшее улучшение радиометрической точности и достоверности результатов, получаемых по спутниковым данным. Представлен метод объединения спутниковых изображений с данными натурных измерений и выработки наилучшей стратегии проведения натурных измерений, подходящей для проведения спутниковой калибровки/верификации. Эта методология использует спутниковые данные, чтобы построить ковариационную матрицу, содержащую информацию о пространственно-временнóй изменчивости в исследуемой области. Ковариационная матрица используется в Байесовском методе для объединения спутниковых и натурных данных и создания продукта с наименьшими ошибками. Наилучшее место для калибровки/верификации находится с помощью метода оптимального планирования (A-оптимальный план), который минимизирует расчетную дисперсию объединенного продукта.

Ключевые слова: спутниковые изображения, натурные измерения, калибровка/верификация, объединенный продукт.

With the increasing availability of satellite time-series imagery of sea surface temperature (SST) and ocean color (e.g. from Moderate Advanced Very High Resolution Radiometer-MODIS), it has become possible to monitor temporal and spatial variation of coastal and open waters. These data improve our view of the ocean when compared to the very limited spatial sampling offered by *in situ* observations (e.g. ships and moorings). Generally, merging remote sensing data with *in situ* measurements has become a standard procedure to increase the quality of satellite derived products. Conventionally, covariance analysis is applied to oceanographic and meteorological data sets to decompose space and time distributed data into modes ranked by their temporal variance, while optimum sampling analysis is applied to find adequate number and allocation of *in situ* data to improve satellite quality by reducing the overall observational error. In this paper, different fields needed for implementing such concepts are studied and presented.

These methodologies were implemented on several available data sets (e.g. using satellite MODIS time series and optical *in situ* platform, such as the AErosol RObotic NETwork – AERONET and the Marine Optical Buoy-MOBY platforms).

Methods. *Theoretical Approach.* Time series of satellite images can be employed to build a covariance matrix encoding the spatio-temporal variability of an area of interest. *In situ* observational resources can then be adaptively distributed following a covariance-oriented criterion, to assign the best value of the *in situ* observed field at grid points of a regular grid coincident with the centers of satellite pixels. The best *in situ* location can be found implementing optimum design procedure, such as A-optimum design.

Covariance – Consider a generic time-series $\{\psi(x, y, t_i)\}_{i=1}^{N}$ measured from satellite with a given observational error. The dataset is a three-dimensional grid that depends on longitude (x), latitude (*y*) and time (*t*). Alternatively, this gridded data can be reshaped into a two-dimensional grid of *M* rows by *N* columns:

$$T_{NM} \equiv T(N, M),$$

where *M* represents the number of spatially distributed points (the product of *x* by *y*) and *N* represents the number of points over time (*t*). Using this representation, the covariance matrix (*C*) can be numerically evaluated by multiplying *T* by its transpose:

$$C \propto (T_{NM})' \cdot T_{NM}.$$

Because the covariance matrix *C* is derived from satellite observations, it will contain contributions from the sensor noise (σ^2_{sat}). For this reason we have studied a methodology to remove the impact of the sensor noise (supposing that σ^2_{sat} is known *a priori*) on the covariance matrix. To achieve this, we have decomposed C in two orthogonal matrixes that verify the following equation:

$$C \cdot V = V \cdot D. \tag{1}$$

These matrices are the eigenvalues (*D*) and eigenvectors (*V*) of *C*; in particular, *D* is the *canonical form* of *C* (a diagonal matrix with *C*'s eigenvalues on the main diagonal), while *V* is the *modal matrix* (its columns are the eigenvectors of *C*). Assuming the sensor noise as a white noise stochastic process, its impact on the covariance matrix *C* is limited to the diagonal terms. These characteristics make it possible to remove the sensor noise by using the eigenvalues of *C*; therefore the matrix *D* will be modified as follow:

$$D = \left(D - \left(\frac{\sigma^2_{sat}}{M} \right) I \right),$$

where *I* is the *MXM* identity matrix. Finally, replacing the negative eigenvalues with zeros, the new covariance matrix can be evaluated using the formula:

$$C = VDV'. \tag{2}$$

Merging procedure – Merging remote sensing data with *in situ* measurement is a standard procedure that allows increasing the quality of the satellite-derived products. The idea is to study the spatial-temporal variability of the satellite data and to distribute the *in situ* sample over the image following the covariance criterion. Therefore, once the covariance *C* has been obtained from eq.(2), a new field, merging *in situ* and satellite data, is retrieved maximizing the following probability distribution:

$$P(\psi_K) \propto \exp[-(\psi_{obs} - H\psi_k)^T \textstyle\sum_{obs}^{-1} (\psi_{obs} - H\psi_K) - (\psi_K - \overline{\psi})^T C^{-1} (\psi_K - \overline{\psi})]$$

Where ψ_K represents the vector of pixel values, ψ_{obs} is the observation vector, *H* is the observation matrix, $\sum_{obs}$ is the observation error matrix and $\overline{\psi}$ is the average field. The first part in the exponential represents the likelihood density while the second product of matrices represents the *a priori* probability. The merging procedure is performed maximizing the *a posteriori* probability distribution; therefore the best estimation is represented by the field ψ_{merged} that verifies:

$$\psi_{merged} = \arg\min_{\psi_k} \left((\psi_{obs} - H\psi_k)^T \textstyle\sum_{obs}^{-1} (\psi_{obs} - H\psi_k) - (\psi_k - \overline{\psi})^T C^{-1} (\psi_k - \overline{\psi}) \right). \tag{3}$$

The solution of eq.(3) represents the merged image, fig.1 show an example of merging using SST AVHRR image and an *in situ* track.

Optimum design and Uncertainty Index – Sampling strategies of *in situ* observational resources driven by a design principle called A-optimality could substantially improve the accuracy of the final blended products. The scope of A-optimal designs is to minimize the variance of the estimated field with respect the sample locations. This optimal criterion will select locations in regions with low uncertainty and large spatial representation. Like other standard variance-oriented criteria in optimal experimental design, a covariance model must be known *a priori*. *In situ* observational resources could be adaptively distributed following the variance-oriented criterion, to assign the best values of the *in situ* observed fields at grid points of a regular grid coincident with the center of satellite pixels. This procedure would ensure the optimality of merged products for limited *in situ* observational resources on the basis of an Uncertainty Index (UI). The implementation of this technique was initially performed using a Genetic Algorithm (GA) that minimizes the process of natural evolution. This algorithm is iteratively used to search the best *in situ* position minimizing the variance of the retrieved solutions. The optimization problem was also investigate using a Simulated annealing (SA) strategy that is a generic probabilistic metaheuristic for the global optimization problem of locating a good approximation to the global optimum of a given function in a large search space. The retrieved optimization results from GA and from SA are comparable; therefore the SA method results more efficient in term of computation (faster) than GA.

a *b*

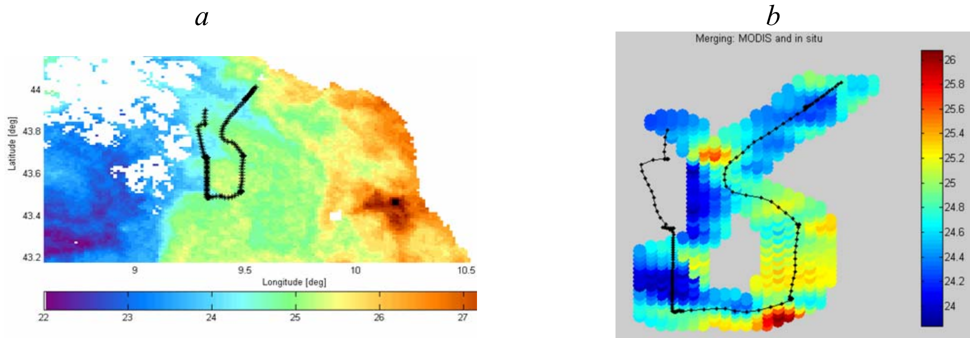

Fig.1. AVHRR SST image and *in situ* ship data (black dots) – *a*; colored circles display the field resulting from merging ship and satellite observations of the sea surface temperature – *b*.

Results. Implementation of the procedures described above focuses on the AErosol RObotic NETwork (AERONET) sites. AERONET program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and other national collaborators. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, mircrophysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases [3, 4]. In particular we focus the attention on the Venice Acqua Alta AERONET site that is located 13 KM of the cost of the Venetian lagoon (as in fig.2).

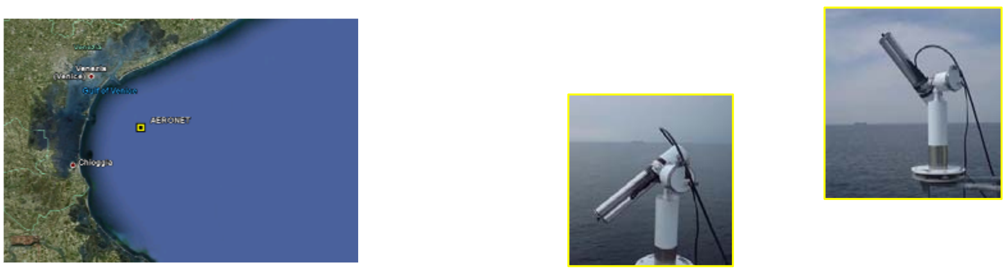

Fig.2. The northern-East Italy coast region, showing the location of the AERONET site.

To evaluate the AERONET *in situ* position in terms of uncertainly we have implemented the proposed procedure on monthly satellite time-series that have been retrieved using several Moderate Advanced Very High Resolution Radiometer (MODIS) images acquired on the area of interest with 1 km at nadir of ground resolution. In particular we have performed the following steps.

Monthly time series have been created using about two acquisitions per days during the period from January 2005 to December 2009, for a total of 2135 images. All the «clear» images (438) were processed focusing the attention on a box area of 30 by 30 km around the AERONET site (this size was fixed for the convenience of computation and analysis). Each monthly time series were arranged into a two-dimensional array $T(x, t)$, where x and t are the spatial and temporal indices. Because the data retrieved from MODIS are much more dense in space than in time ($x >> t$), the covariance matrix was evaluated implementing eq.(1) for each month. To represent the monthly statistic analysis we have evaluate the mean of each time series and we also define a «Historical Covariance Map» (C_{HIST}) that represents the pixel standard deviation of considered time-series, as resumed in fig.3. Using this technique we produce twelve C_{HIST} that have been used to calibrate *in situ* data without satellite acquisitions but taking into account an «satellite statistical behavior».

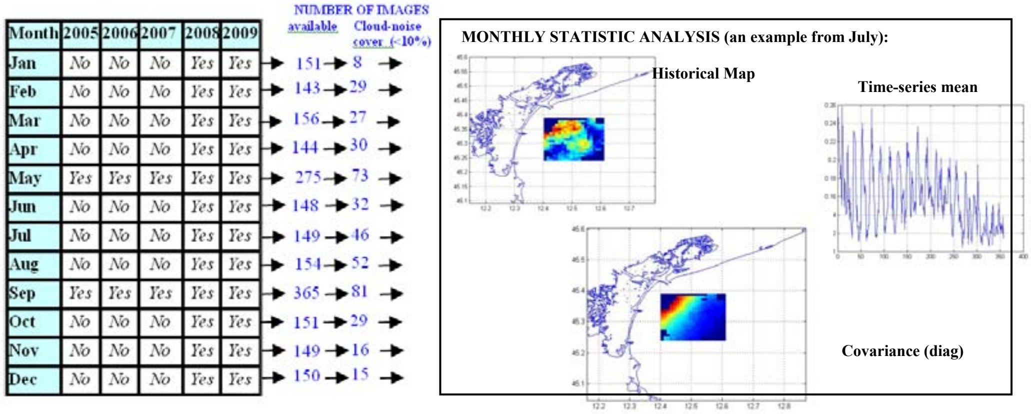

Fig.3. Data processing chain to perform a statistical analysis on the available time series.

A maximum covariance value ($P_{max} = 1/e \sim$ max probability) is defined and just the covariance-pixels lower than P_{max} were considered. This procedure allows retrieving an Uncertainty Map (fig.4, *a*) that represents the reduction of the satellite uncertainly (error) in a particular area.

The *in situ* observational resources were then adaptively distributed following the variance-oriented criterion, to assign the best values of the *in situ* observed fields at grid points of a regular grid coincident with the centres of satellite pixels. We define an Impact Map as the result of the merging between an *in situ* (with hypothetic latitude longitude position) and the Uncertainty Map.

As showed in fig.4, *b*, *c* the Impact Map depends on the *in situ* position. In order to have number that represents this variation, we have defined an Impact Index that takes into account of the effective error reduction (due to the *in situ*) in a fixed area. In particular, we define an Image retrieved from the difference between the Uncertainty Map (fig.5), we consider a box-area (10×10 km) around the *in situ* (*A* pixels) and we fix a threshold (*B*) with the following value:

$$B = \text{Uncertainty\_map}\left(\text{lon}_{\text{in situ}}, \text{lat}_{\text{in situ}}\right) - 3\sigma_{\text{Satellite\_error}}.$$

If *N* represents the number of pixels >B, the Impact Index can be defined as N/A*100. Knowing the Impact Index of each possible *in situ* location allows one to identify which is the best placement in terms of Cal/Val activities.

Conclusion. We have presented a procedure for merging satellite data with *in situ* measurements to increase the quality of satellite derived products. This methodology is used to define the location where *in situ* data should be collected in order to determine the uncertainty of using these data for calibration and validation of satellite products. Satellite products include Sea Surface Temperature, Ocean Color products of water leaving radiance, chlorophyll, inherent and apparent properties (retrieved from AVHRR and MODIS satellite sensors). *In situ* measurements can be obtained from moorings (such as AErosol RObotic NETwork-

AERONET and/or Marine Optical Buoy-MOBY), from ships or from autonomous vehicles (such as Autonomous Underwater vehicle and/or Gliders).

a *b* *c*

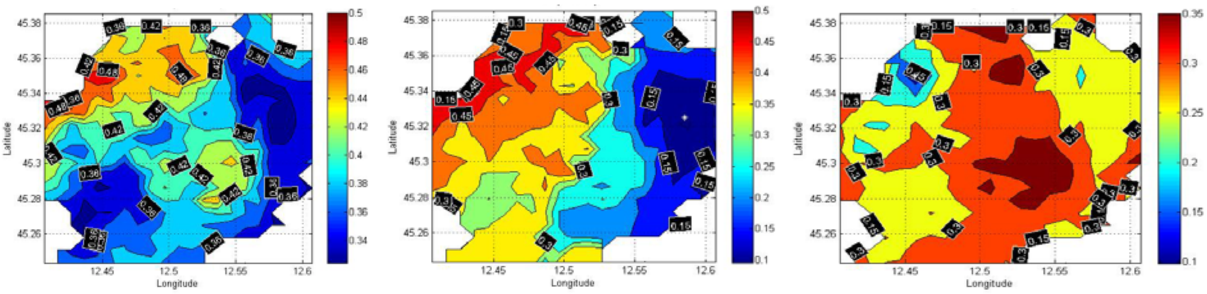

Fig.4. Uncertainty Index map (*a*); Impact Index Map merging with an *in situ* placed in a low uncertainty area (43.325N and 12.583E) (*b*); Impact Index Map merging with an *in situ* in placed in a low uncertainty area (43.325N and 12.583E) (*c*).

a *b*

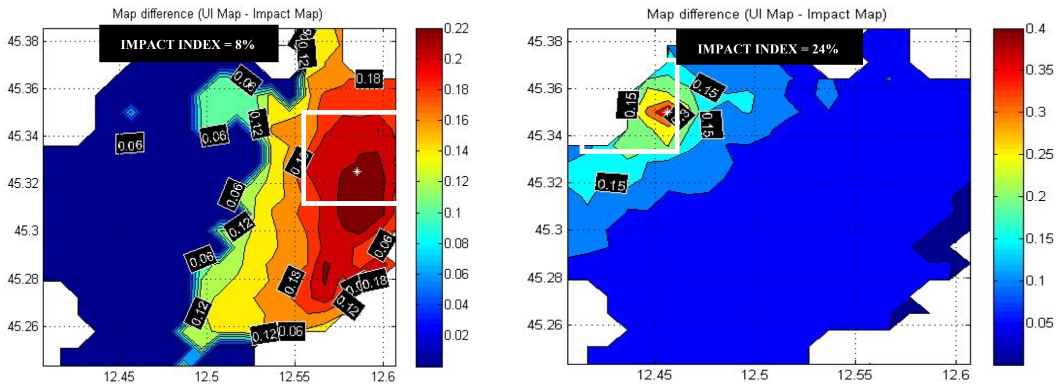

Fig.5. Image Difference and Impact Index merging with an *in situ* placed in a low uncertainty area (43.325N and 12.583E) (*a*); Image Difference and Impact Index merging with an *in situ* placed in a high uncertainty area (43.325N and 12.583E) (*b*).

We also present results using MODIS time-series images and AERONET-OC in the Venice (Acqua Alta) site. The covariance matrix of the time-series was used in a Bayesian framework to estimate the best *in situ* location for Cal/Val efforts using a Simulated Anealling Algorithm. In particular, the covariance has been evaluated using the available monthly time-series MODIS acquisitions from 2005 to 2009. The resulting Historical Maps have been used to calibrate *in situ* data position without satellite acquisitions but taking into account on the "satellite statistical behaviour".

We express special thanks to the Naval Research Laboratory, Stennis Space Center (NRL-SSC) for support to NURC in the participation of the project «Execution of a Calibration/Validation (Cal/Val) Plans for Oceans Environmental Data Records (EDRS) for the Visible Infrared Spectrometer (VIIRS) sensor on the Preparatory Project (NPP) and National Polar Orbiting Operational Environmental Satellite System (NPOESS)».

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