Land cover land use change effects on surface water quality: Integrated MODIS and SeaWiFS assessment of the Dnieper and Don River basins and their reservoirs

Anatoly Gitelson[1], Geoffrey M. Henebry[2], Wesley Moses[1], Valeriy Kovalskyy[2] & Daniela Gurlin[1]

[1]Center for Advanced Land Management Information Technologies (CALMIT)
School of Natural Resources, University of Nebraska-Lincoln

[2]Geographic Information Science Center of Excellence (GIScCE), South Dakota State University

CALMIT
Center for Advanced Land Management Information Technologies

Overview

Our questions:

(1) Can we see the significant changes in land cover and land use following the collapse of the Soviet Union using satellite data?

(2) Can we use satellite data to generate new products that enable monitoring of key surface water quality variables?

First, we analyzed land surface phenology within specific land cover categories using the nonparametric seasonal Mann-Kendall trend test adjusted for autocorrelation to NDVI image series from AVHRR (PAL and GIMMS) for the Soviet (1982-1988) and post-Soviet (1995-2000) epochs and from MODIS (MOD43C NBAR) for the recovery (2001-2006) epoch. This analysis identified the spatial location and extent of temporal trends and assessed their direction and statistical significance. About 90% of croplands and forested land in Dnieper Basin showed no significant trends during the Soviet epoch. There was little [much] area in significant negative trends during the [post-]Soviet epoch. During the recovery epoch, forested lands in the Don Basin exhibited fewer significant positive trends than in the Dnieper Basin.

Second, we (a) calibrated and validated the three-band model as well as its special case, the two-band model, using datasets collected over a considerable range of optical properties, trophic status, and geographical locations in turbid, productive lakes and reservoirs; (b) evaluated the extent to which the two-band model could be applied to the MODIS and three-band model could be applied to the MERIS to estimate chla in turbid, productive waters, and (c) estimated uncertainties of chlorophyll-a retrieval from MODIS and MERIS data taken over Ukrainian and Russian test sites.

1. Changes in Land Use Intensity Within the Don and Dnieper River Basins

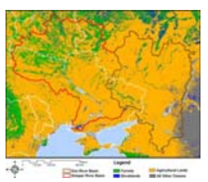
Data Sources, Data Processing and Methodology

Following data sources were used:

- Pathfinder AVHRR Land (PAL) NDVI 10-Day composites at 8 km from *ftp://disc1.gsfc.nasa.gov/data/avhrr/global_8km*
- GIMMS NDVI 15-Day composites at 8 km from *ftp://disc1.gsfc.nasa.gov/data/avhrr/global_8km/*
- MODIS LC Type Global 1km 2001 MOD12Q1 V004 LC Product from *http://edcdaac.usgs.gov/modis/mod12q1.asp*
- MODIS Nadir Reflectance BRDF-Adjusted 16-Day L3 0.05Deg CMG(2001-2006) from *http://edcdaac.usgs.gov/modis/mod43c4v4.asp* and *http://www-modis.bu.edu/brdf_albedo/nbar.html*

Data Processing Steps:

- 17 IGBP land cover classes from MOD12Q1 V004 were aggregated to 8 super-classes.
- Each super-class was masked separately for each river basin and rescaled to 8 km using a majority filter.
- Analyses were restricted to the Forests, Shrublands, and Croplands super-classes.
- Analyses were restricted to the composite periods from April to October in each year.
- Three epochs were analyzed: Soviet (1982-1988), post-Soviet (1995-2000), and recovery (2001-2006)
- Satellite data from NOAA-11 were excluded due to sensor artifacts (de Beurs & Henebry 2004b).
- Trends were assessed using the non-parametric Seasonal Mann-Kendall trend test adjusted for autocorrelation (de Beurs & Henebry 2004b; 2005).

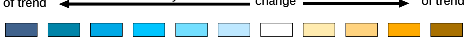


Methodology:

- Seasonal Mann-Kendall (SMK) nonparametric trend test corrected for first-order temporal autocorrelation (de Beurs & Henebry 2004b, 2005)
- Data were analyzed using a version of the SMK test in IDL by Dr. K. M. de Beurs and P. de Beurs. The resulting test results were reclassified in to 6 categories based on confidence intervals, directions, and amplitude of phenological shifts to delineate the extents of changed LSP (see legend below).

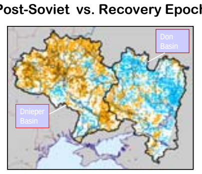
LSP Trend Change Intensity and Direction

Negative change of trend — Intensity — Absence of trend change — Positive change of trend

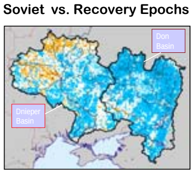


Soviet vs. Post-Soviet Epochs

Post-Soviet vs. Recovery Epochs



Soviet vs. Recovery Epochs



The trend change intensity and direction maps show a predominant pattern of negative trends across both basins in the transition between Soviet and post-Soviet epochs.

However, the results from PAL data exhibit fewer changes in trend direction and the prevalence of negative trends is not as obvious as in GIMMS data.

Both datasets showed agreement in capturing the area of persistent negative changes that stretches from the mid-basin of the Dnieper to the Siverskiy Donets River (a tributary of the Don).

This area covers the most of Ukrainian croplands where agricultural practices changed dramatically during the post-Soviet epoch.

Change in forest trends from positive to negative may be due to increased rates of disturbances, especially wildfire (Ostapchuk, 2005).

Comparison of Trends between Basins

Soviet vs. POST-Soviet Epochs | POST-Soviet vs. Recovery Epochs

Cropland – Don River Basin

POST Soviet ► / Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum POST Soviet	Recovery ► / POST Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum Recovery
% Significant Negative Trend	0.0	2.8	0.8	3.6	% Significant Negative Trend	0.2	6.0	0.1	6.2
% Insignificant Trends	0.0	61.3	34.0	95.2	% Insignificant Trends	3.4	89.0	1.1	93.4
% Significant Positive Trend	0.0	0.5	0.6	1.1	% Significant Positive Trend	0.1	0.3	0.0	0.3
sum Soviet	0.0	64.6	35.4	100.0	sum POST Soviet	3.6	95.2	1.1	100.0

Cropland – Dnieper River Basin

POST Soviet ► / Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum POST Soviet	Recovery ► / POST Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum Recovery
% Significant Negative Trend	0.0	13.5	1.4	14.9	% Significant Negative Trend	0.2	0.6	0.0	0.7
% Insignificant Trends	0.0	75.6	9.3	84.9	% Insignificant Trends	14.2	82.4	0.2	96.8
% Significant Positive Trend	0.0	0.2	0.1	0.2	% Significant Positive Trend	0.5	2.0	0.0	2.5
sum Soviet	0.0	89.2	10.8	100.0	sum POST Soviet	14.9	84.9	0.2	100.0

Forest – Don River Basin

POST Soviet ► / Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum POST Soviet	Recovery ► / POST Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum Recovery
% Significant Negative Trend	0.0	3.4	2.7	6.0	% Significant Negative Trend	0.0	2.0	0.0	2.0
% Insignificant Trends	0.0	58.4	34.9	93.3	% Insignificant Trends	5.4	85.2	0.7	91.3
% Significant Positive Trend	0.0	0.0	0.7	0.7	% Significant Positive Trend	0.7	6.0	0.0	6.7
sum Soviet	0.0	61.7	38.3	100.0	sum POST Soviet	6.0	93.3	0.7	100.0

Forest – Dnieper River Basin

POST Soviet ► / Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum POST Soviet	Recovery ► / POST Soviet ▼	% Significant Negative Trends	% Insignificant Trends	% Significant Positive Trends	sum Recovery
% Significant Negative Trend	0.0	12.4	1.5	13.9	% Significant Negative Trend	0.0	0.0	0.0	0.0
% Insignificant Trends	0.0	79.2	6.8	86.1	% Insignificant Trends	11.1	68.1	0.1	79.3
% Significant Positive Trend	0.0	0.1	0.0	0.1	% Significant Positive Trend	2.8	17.9	0.0	20.7
sum Soviet	0.0	91.7	8.3	100.0	sum POST Soviet	13.9	86.1	0.1	100.0

Key Findings from the Change Analysis:

- Roughly 90% of croplands and forested land in Dnieper Basin showed no significant trends during Soviet epoch;
- Don Basin exhibited more significant positive trends than Dnieper Basin during Soviet epoch;
- Recovery epoch shows minimal presence of significant trends of trends in croplands;
- Substantial disagreement on extent of significant positive trends in Don croplands (35.4% for GIMMS vs. 7.6% for PAL);
- Disagreement on extent of significant positive trends in Don forests during Soviet epoch (38.4% for GIMMS vs. 26.8% for PAL);
- Little area in significant negative trends during Soviet epoch;
- Substantial area with significant negative trends during post-Soviet epoch;
- Disagreement on extent of significant negative trends in Don forests during post-Soviet epoch (6% for GIMMS vs. 24.2% for PAL); and
- Forest in Don Basin exhibited less significant positive trends than Dnieper Basin during the recovery epoch.

2. Surface Water Quality Assessment In the Don and Dnieper River Basins

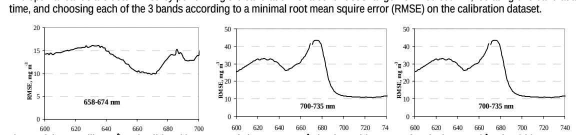
Semi-analytical three-band model for chlorophyll-*a* estimation in turbid waters

$$Chl\text{-}a = [R^{-1}(\lambda_1) - R^{-1}(\lambda_2)] \times R(\lambda_3)$$

and its special case, two-band model

$$Chl\text{-}a = R^{-1}(\lambda_1) \times R(\lambda_3)$$

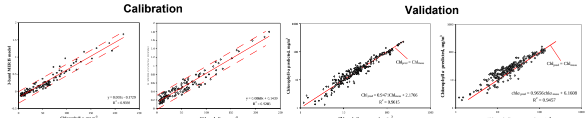
The optimal bands are determined by performing the calibration for a continuous range from 400-800 nm, isolating one band at a time, and choosing each of the 3 bands according to a minimal root mean squire error (RMSE) on the calibration dataset.



The model was calibrated and validated by means of close range sensing in a wide range of optical properties of turbid water bodies in US: Iowa, Nebraska, Minnesota, Chesapeake Bay (Dall'Olmo and Gitelson, 2005; Gitelson et al., 2007).

The 2-band model was calibrated and validated using MODIS spectral bands: λ_1 = 662-672 nm and λ_3 = 743-753 nm. The three-band model was tested using MERIS spectral bands: 660-670 nm, 703.75-713.75 nm, and 750-757.5 nm (Gitelson et al., 2008).

Calibration | Validation



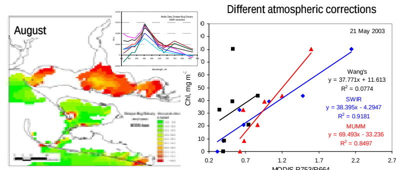
MODIS NIR/Red Model | MERIS 3-band Model | MODIS NIR/Red Model | MERIS 3-band Model

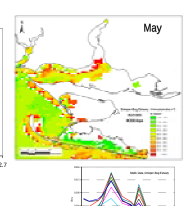
The accuracy of chla prediction in four independent datasets was assessed *without re-parameterization* after initial calibration elsewhere. The validation data set contained widely variable chla (1.2 to 236 mg m^{-3}), Secchi disk depth (0.18 to 4.1 m), and turbidity (1.3 to 78 NTU). Chl-*a* predicted by the three-band algorithm was strongly correlated with observed chla (r^2 >0.96) with average bias across data sets of -4.9% to 11%. Chl-*a* predicted by the two-band algorithm was also closely correlated with observed chla (r^2 > 0.92); however, average bias across the data sets was 18% to 50.3% (Gitelson et al., 2008).

Ukraine: Dnieper-Bug Estuary

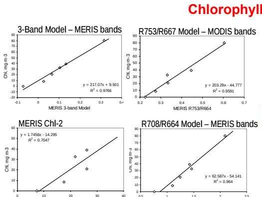
Chlorophyll retrieval - MODIS

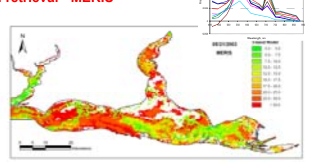
Different atmospheric corrections





Chlorophyll retrieval - MERIS

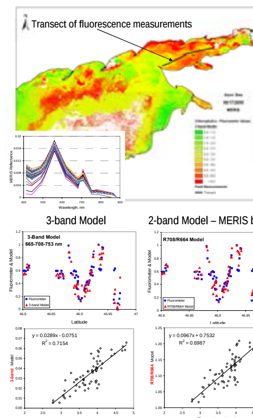




Ancillary data: Institute for Environmental Quality, Kyiv, Ukraine

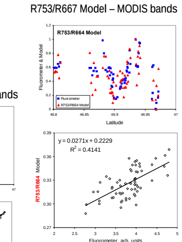
Russia: Azov Sea - 2005

Chlorophyll fluorescence retrieval - MERIS



Chlorophyll fluorescence has been measured continuously during the day at transect shown in the map. The fluorometer readings were compared with different chlorophyll models using MERIS data obtained at day of fluorescence measurement. Scaled fluorometer readings and model estimates $(Y_i - Y_{min})/(Y_{max} - Y_{min})$ are shown below.

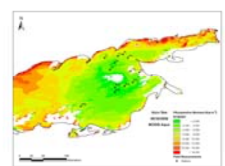
R753/R667 Model – MODIS bands

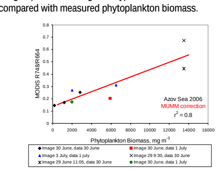


Ancillary data: Southern Scientific Centre of the Russian Academy of Sciences and Southern Federal University, Rostov-on-Don, Russia

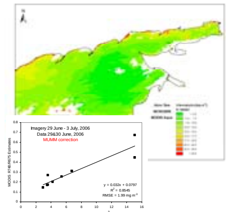
Russia: Azov Sea - 2006

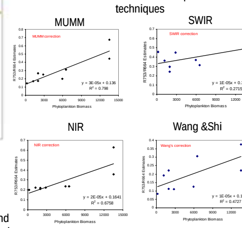
Water samples were taken (29 June and 1 July, 2006) at stations shown in the map and phytoplankton biomass was determined. NIR/Red model was used for biomass retrieval from six MODIS images (29 June through 3 July). These MODIS estimates were compared with measured phytoplankton biomass.





Biomass estimation - different atmospheric correction techniques





Ancillary data: Southern Scientific Centre of the Russian Academy of Sciences, Rostov-on-Don and Southern Federal University, Rostov-on-Don, Russia

Key Findings from the Surface Water Quality Assessment

- Both 2- and 3-band models do not require site-specific parameterization to accurately estimate chl-a in waters with widely varying bio-optical characteristics.
- Provided that an atmospheric correction scheme for the red and NIR bands is available, the extensive database of MODIS and MERIS imagery could be used for quantitative monitoring of chlorophyll-a in turbid waters.
- There are a few caveats that need to be considered when attempting to apply these models to satellite data:
  - The strong absorption by water in the NIR greatly reduces the magnitude of the recorded signal.
  - NIR reflectance is a multiplicative factor in the models, which makes its magnitude very critical for accurate chl-*a* retrievals.
  - Non-uniform residual effects of atmospheric correction across multi-temporal images produce vertical offsets among spectra from multi-date images; this affects the accuracy of chl-a retrieval.
  - The lower magnitudes of reflectance there is increased susceptibility to the effect of spurious signals from neighboring land or cloud pixels.

This heightens the necessity for a highly accurate atmospheric correction procedure that yields reliable surface reflectances.

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Contact info: agitelson2@unl.edu & geoffrey.henebry@sdstate.edu