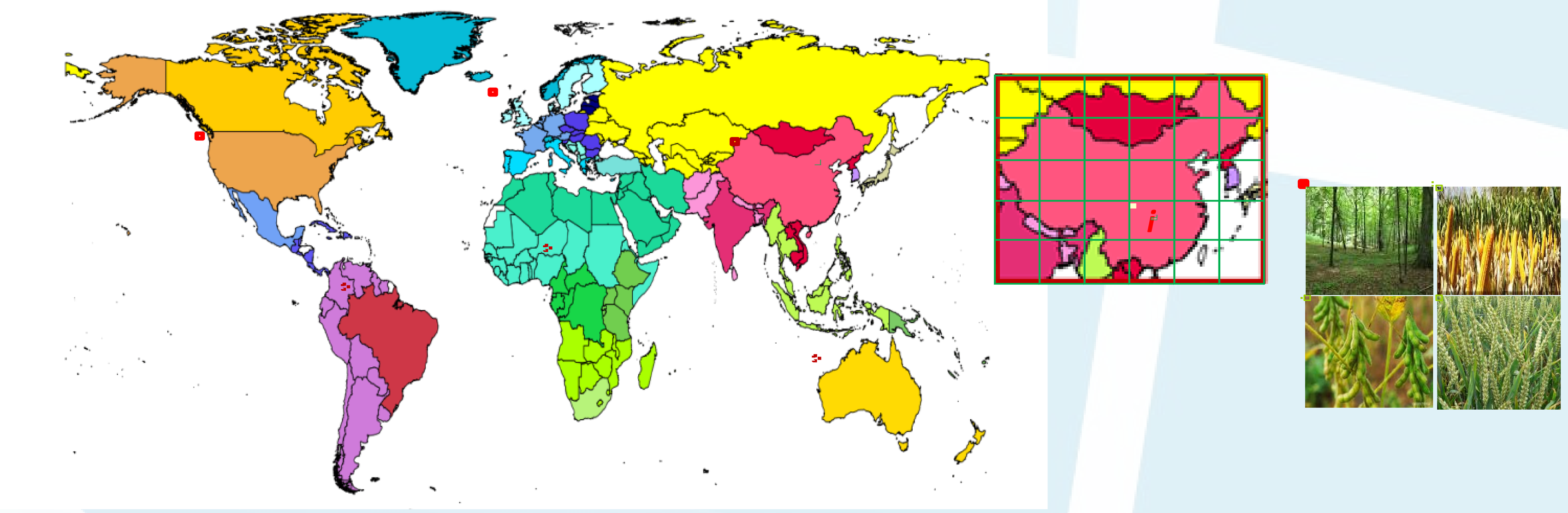
Robust Rescaling Methods for Integrated Water, Food, Energy Security Management under Systemic Risks and Uncertainty

Yuri Ermoliev[1], Tatiana Ermolieva[1], Petr Havlík[1], Aline Mosnier[1], David Leclere[1], Steffen Fritz[1], Nikolay Khabarov[1] , Michael Obersteiner[1], Sergey Kyryzyuk[2], Yuriyu Kostyuchenko[3]

Motivation for downscaling

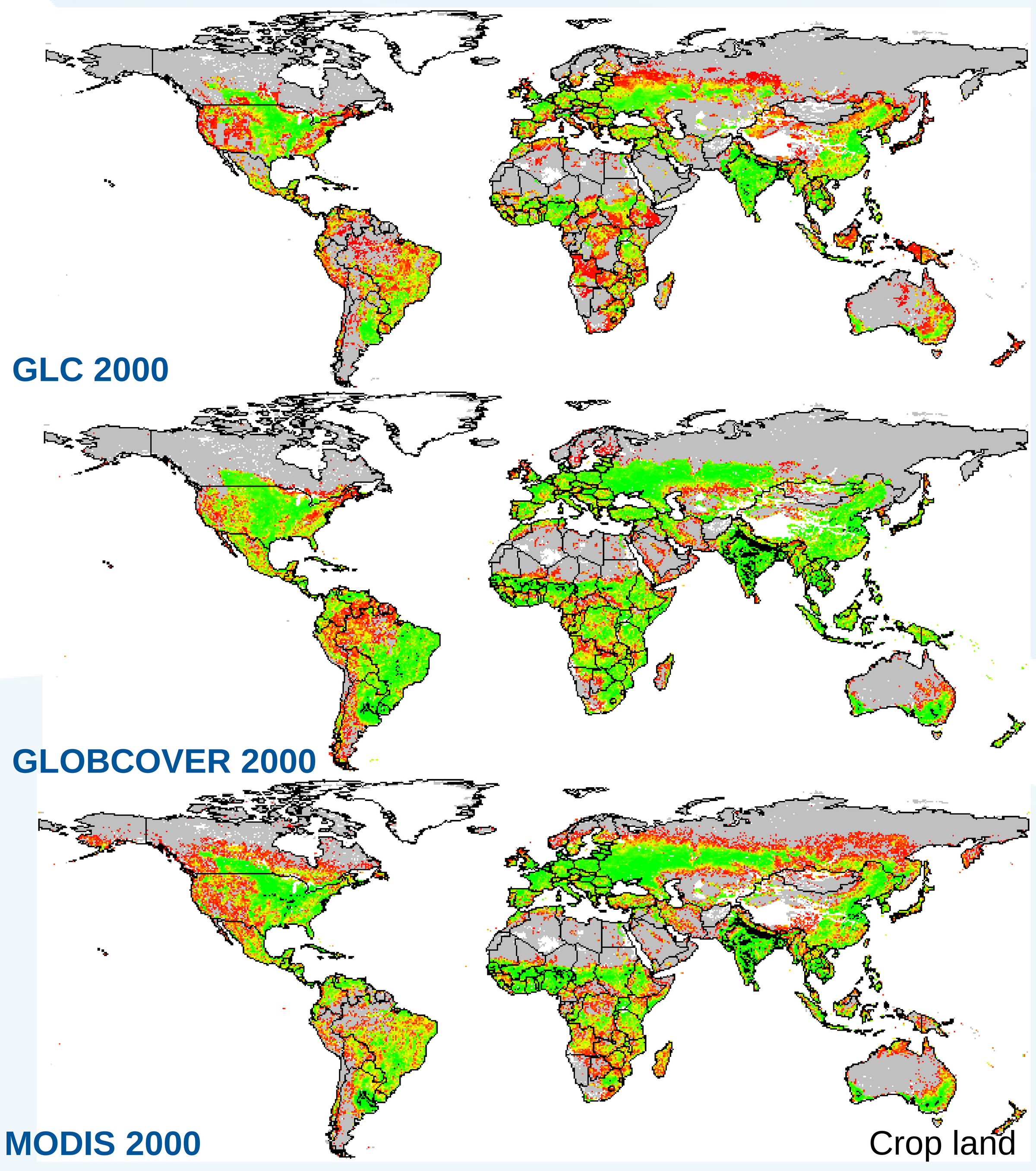
- Systems analysis of global change (including climate) processes requires new approaches to integrating and rescaling of models, data, and decision-making procedures between various scales.
- For example, in the analysis of water security issues, the hydrological models require inputs that are much finer than the resolution of, say, the economic or climatic models generating those inputs.
- In relation to food security, aggregate national or regional land use projections derived with global economic land use planning models give no insights into potentially critical heterogeneities of local trends.
- High spatial resolution land use and cover change projections are also required as one of the crucial inputs into Global Circulation Models.
- The problem of deriving spatially resolved estimates consistently with aggregate regional and global trends is a major challenge.



- Downscaling can be termed as a **"New Estimation Problem"**. While traditional statistical estimation problems are based on the ability to obtain observations from unknown true sampling model, for downscaling (and upscaling) problems we may have only **aggregate, uncertain data with very restricted samples of real local observations**.
- Downscaling enables interface and compatibility between global and local models and decisions under uncertainty of global and local data and processes.

Large uncertainty in local data (priors): land cover maps

- Existing global land cover maps (e.g. GLC2000, GLOBCOVER2000, MODIS2000) differ in terms of spatially resolved estimates of land use (e.g., crop, forest, and grass land).



Robust downscaling from GLOBIOM

- Robust downscaling is being applied for data harmonization, designing hybrid maps, downscaling regional and global projections.
- The procedure has been integrated with (stochastic) Global Biosphere Model (Havlík et al. 2011; Ermolieva et al., 2015, 2014), for the analysis of food, energy, water security issues and sustainable development trends at global, regional, country and local levels.

Main challenge for downscaling – uncertainty of local and global data and processes

- For example, available yield estimates derived with different biophysical models show major difference.
- Existing global land cover maps (GLC2000, MODIS2000, GLOBCOVER2000) differ in terms of spatially resolved estimates of land use (e.g., crop, forest, and grass land).
- Many practical studies analyzing regional developments use cross-entropy minimization as an underlying principle for estimation of local processes.

Traditional cross-entropy

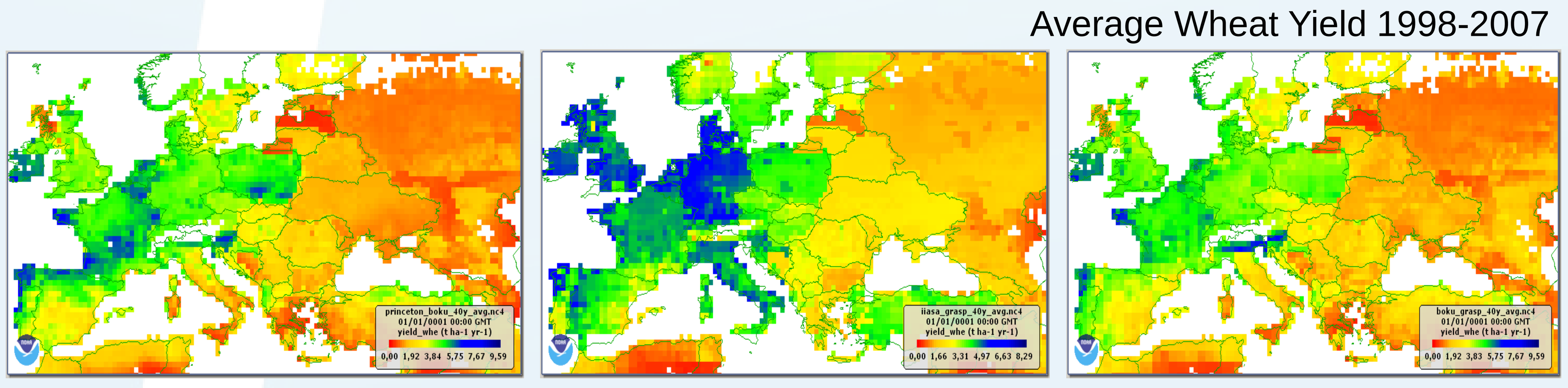
- Cross-entropy approach was designed as an **alternative to traditional statistical procedures**.
- In the absence or uncertainty of direct observations, the approach provides a simple means of incorporating all available relevant information in the form of experts opinion, equations, constraints, and initial prior distribution of plausible estimates. .
- A serious **justification for using the cross-entropy** approach is its connection with a **maximin version of** the central in statistics **maximum likelihood principle** proposed by Fisher R.A. in 1922.
- Solution of the cross-entropy problem minimizes also the **Kulback-Leibler information distance** from some available **prior** distribution providing a plausible initial estimate to the distribution satisfying all available feasibility constraints.
- In other words, **cross-entropy** theory provides a **powerful tool** for data estimation when **information** in locations is **not observed directly** and it is **available in the form of balance equations, constraints, expert opinions**, i.e., in cases when traditional statistical methods are inapplicable.

Uncertainty is not treated in traditional downscaling

- The traditional cross-entropy approach relies on a single prior distribution.
- **In reality, there can be identified a set of feasible priors**, e.g., alternative yield distributions, land use maps (MODIS, GLOBCOVER, GLC2000), inherent uncertainty of local and global processes, etc.

Large uncertainty in local processes (priors): yield estimates by different models

Average Wheat Yield 1998-2007



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Robust non-Bayesian probabilistic cross-entropy: explicit treatment of uncertainties

- **Instead of a uniquely defined prior there is a plausible set of these distributions**.
- Prior distributions **depend on various "environmental" parameters** which may **not** be **known exactly**.
- The estimation of local changes consistent with available aggregate data is formulated as **probabilistic inverse** (from aggregate to local data) problem in the form of, in general, **non-convex stochastic cross-entropy minimization model**.
- By using a specific reparametrization and duality relations for a nested optimization subproblem, the model is reformulated as **nested convex stochastic cross-entropy minimization problem**.
- The duality relation enables to develop a new downscaling procedure allowing to derive **local estimates that are robust with respect to all priors from the feasible set**.
- The procedure treats two main cases of priors: **compound and non-Bayesian priors**.

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Publications: Ermolieva T, Ermoliev Y, Havlík P, Mosnier A, Leclere D, Khabarov N, Kraxner F, Obersteiner M. Systems analysis of robust strategic decisions to plan secure food, energy, water provision based on the stochastic GLOBIOM model. Journal of Cybernetics and Systems Analysis, Volume 51, Issue 1 (2015), pp. 125-133. Ermoliev Y, Ermolieva T, Havlík P, Mosnier A, Leclere D, Obersteiner M, Kostyuchenko Y (2015). Estimating local-global dependencies of land use systems by downscaling from GLOBIOM model. In: Integrated management, Security and Robustness (Eds.: Zagorodny, A.G., Ermoliev, Y.M., Bogdanov, V.L.). Published by Committee for Systems Analysis and Presidium of National Academy of Sciences (Ukraine), National Member Organization of the International Institute for Applied Systems Analysis (IIASA). ISBN 978-966-02-7376-4, Kyiv, 2014 (p. 336), pp. 228-240.

[1] International Institute for Applied Systems Analysis (Laxenburg, Austria); [2] Institute of Economics and Forecasting (National Academy of Sciences of Ukraine, Kiev); [3] Scientific Centre for Aerospace Research of the Earth (National Academy of Sciences of Ukraine, Kiev)