A Multi-method Generalized Approach to Assess Sensitivity of Complex Watershed Models

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INTRODUCTION

Dynamical physically-based watershed models are being increasingly used as the primary tool for water resources planning and management due to advances in computational power and data availability. For an enhanced and efficient development and application of these complex models, it is critical to understand the dynamical behavior of these models and identify the most influential factors (e.g., parameters) controlling it. Global Sensitivity Analysis (GSA) techniques can be used for this purpose.

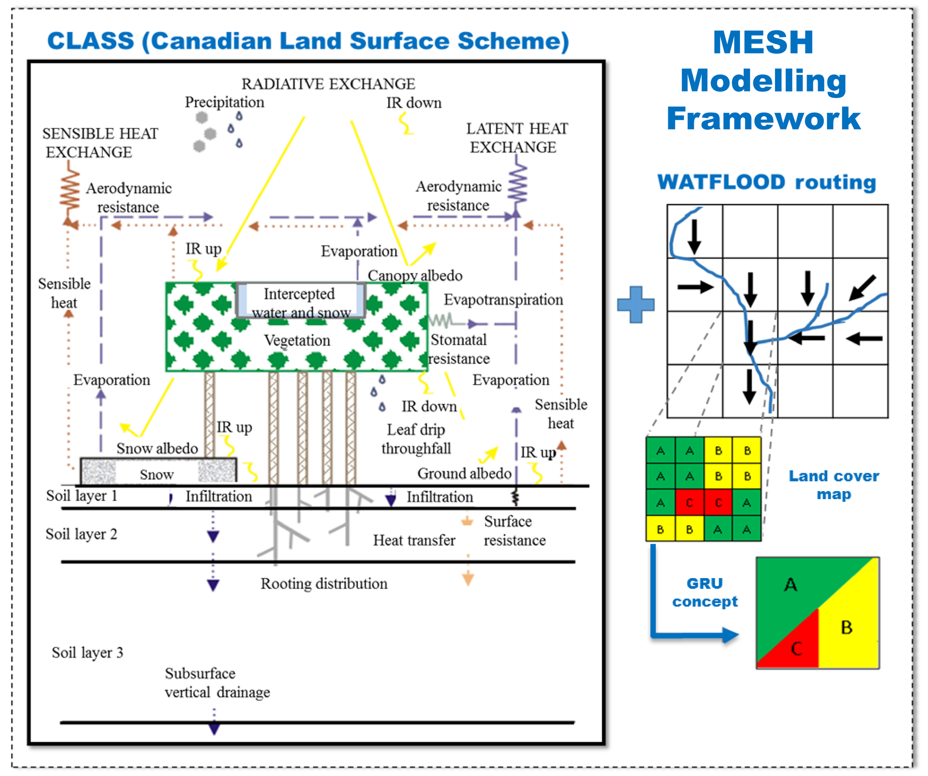
The challenge is that GSA results depend on the GSA approach (e.g., derivative-based, variance-based, or variogram-based), and the type of model response considered. They can also vary with time. To address these challenges a new approach called Generalized Global Sensitivity Matrix (GGSM) is proposed. When coupled with STAR-VARS algorithm, GGSM, can use any GSA approach, and model response, and time-aggregated or time-varying sensitivity indices, to conduct a comprehensive GSA, and produce a wealth of model sensitivity information, with only one single GSA experiment.

OBJECTIVES

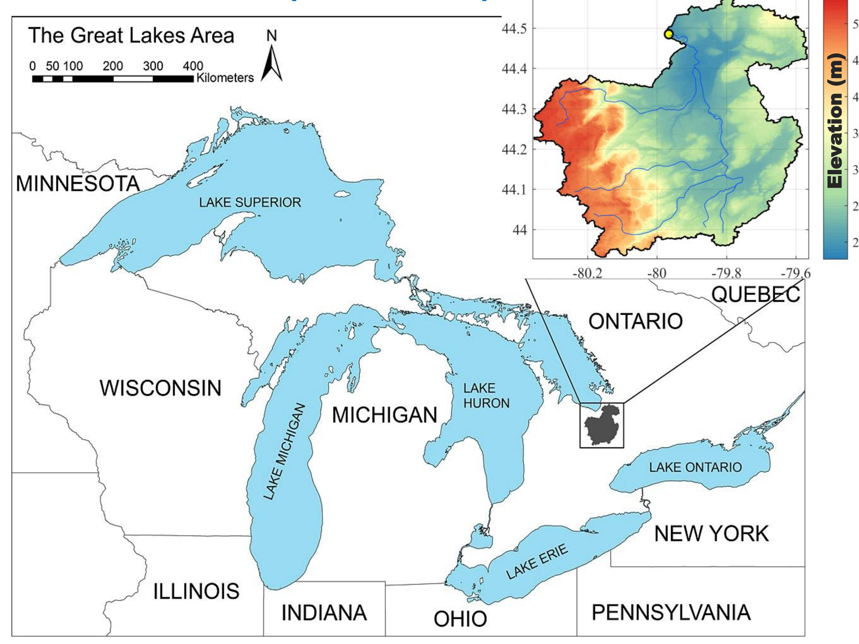
To illustrate how STAR-VARS algorithm coupled with the GGSM approach facilitates a computationally-efficient comprehensive GSA using different methods, and how it enables learning about the temporal variability of dominant factors in response of distributed watershed models. For this purpose, we use the VARS-TOOL software toolbox (vars-tool.com), a comprehensive GSA toolbox, developed based on VARS (variogram analysis of response surfaces) approach.

CASE STUDY

Application of MESH (Modélisation Environmentale–Surface et Hydrologie) to Nottawasaga river basin in Canada.
MESH is a semi-distributed physically-based coupled land surface-hydrology modelling system developed by Environment and Climate Change Canada (ECCC) for various water resources management purposes in Canada. MESH couples the Canadian land surface scheme (CLASS) with a routing module, WATROUTE.



Nottawasaga River Basin (~2700 km²)



31 parameters for Crop GRU

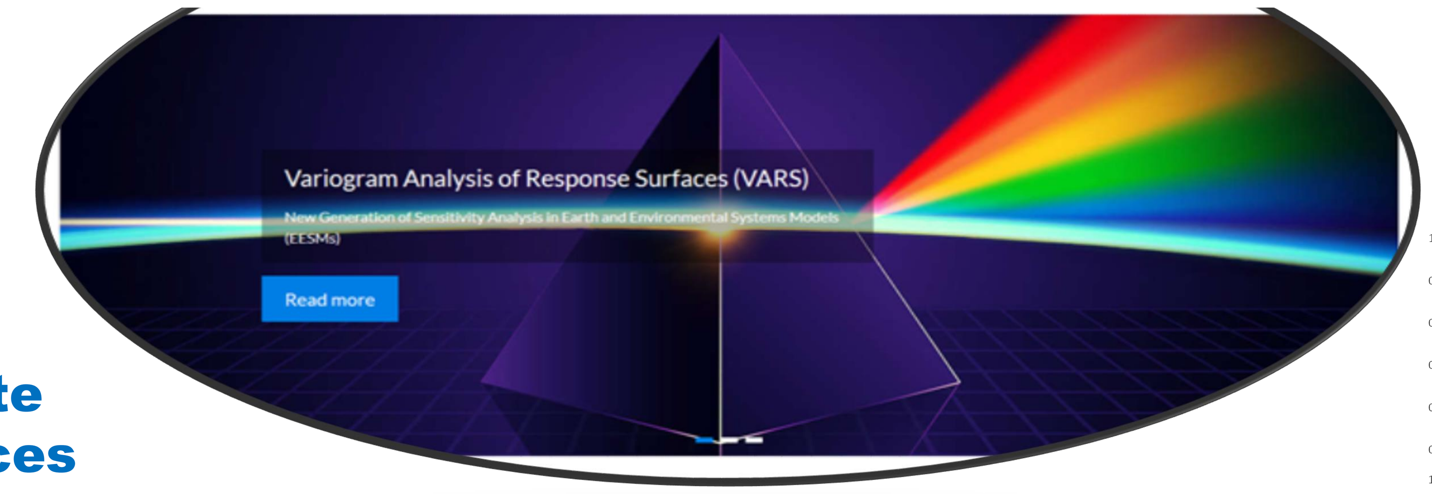
Parameter	Description	Range
LAMAX	Annual maximum leaf-area index	(3, 6)
LNZ0	Natural logarithm of the roughness length	(-2.6, -1.3)
ALVC	Average visible albedo when fully-leafed	(0.04, 0.08)
ALIC	Average near-infrared albedo when fully-leafed	(0.2, 0.5)
CMAS	Annual maximum canopy mass (kg m^{-2})	(2, 5)
ROOT	Annual maximum rooting (m)	(0.2, 4)
RSMN	Minimum stomatal resistance (s m^{-1})	(60, 110)
QA50	Reference value of shortwave radiation (W m^{-2})	(10, 50)
VPDA	Vapour pressure deficit coefficient 'A'	(0.2, 0.8)
VPDB	Vapour pressure deficit coefficient 'B'	(0.7, 1.3)
PSGA	Soil moisture suction coefficient 'A'	(75, 125)
PSGB	Soil moisture suction coefficient 'B'	(2, 8)
SANDi[a]	Percent sand in the mineral soil of layer i (%)	(85, 100)[1] sandy soil (0, 45)[2] clay loam & silty clay loam
CLAYi	Percent clay in the mineral soil of layer i (%)	(0, 10)[1] sandy soil (30, 40)[2] clay loam & silty clay loam
ORGi	Percent organic matter in the mineral soil of layer i (%)	(0, 5)
SDEP	Soil permeable (Bedrock) depth (m)	(0.1, 4.1)
ZSNL	Threshold depth above which snow coverage is considered 100% (m)	(0.05, 0.2)
ZPLS	Maximum water ponding depth for snow-covered areas (m)	(0.02, 0.15)
ZPLG	Maximum water ponding depth for snow-free areas (m)	(0.02, 0.15)
DDEN	Drainage density (km km^{-2})	(2, 100)
XSLP	Estimated average slope of the GRU type	(0.0001, 0.04)
GRKF	Ratio of saturated horizontal hydraulic conductivity at a depth of 1 meter to the saturated horizontal hydraulic conductivity at the surface	(0.0001, 1)
MANN	Manning's roughness coefficient 'n'	(0.02, 2)
RATIO[b]	The ratio of horizontal to vertical saturated hydraulic conductivity	(2,100)
WFR2	Channel roughness factor	(0.02, 2)

[*] ranges are based on the crop vegetatoin type
[a] i indicates soil layer number (1 to 3)
[b] a parameter introduced by authors representing the horizontal saturated hydraulic conductivity

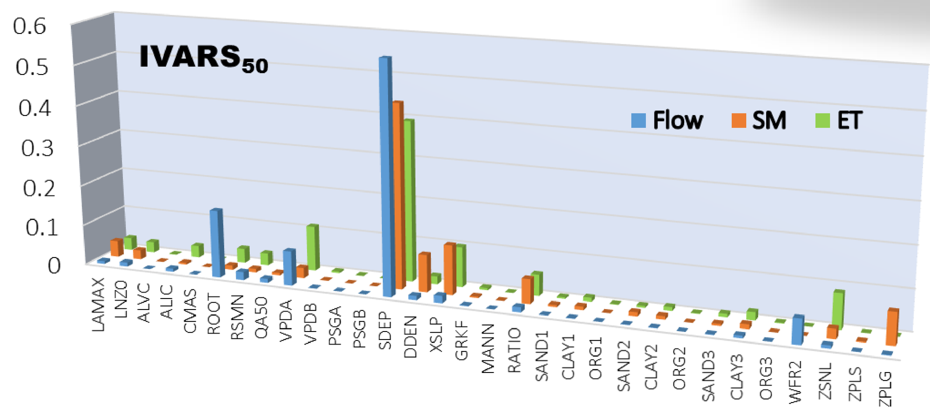
VARS information

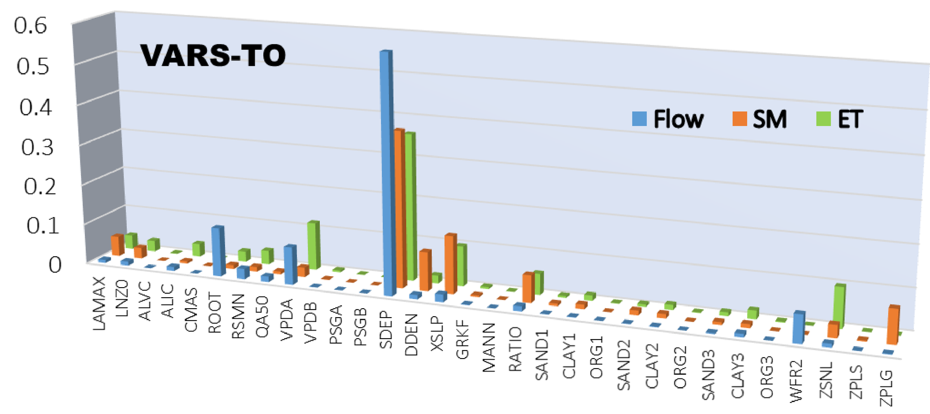
- 100 STARS
- 31 Parameters
- VARS resolution = 0.1
- Total number of model runs = 28000

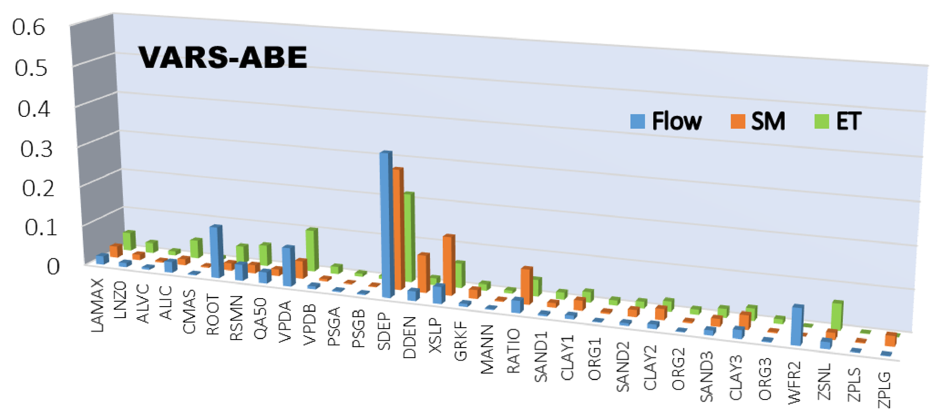
VARS-TOOL (vars-tool.com)

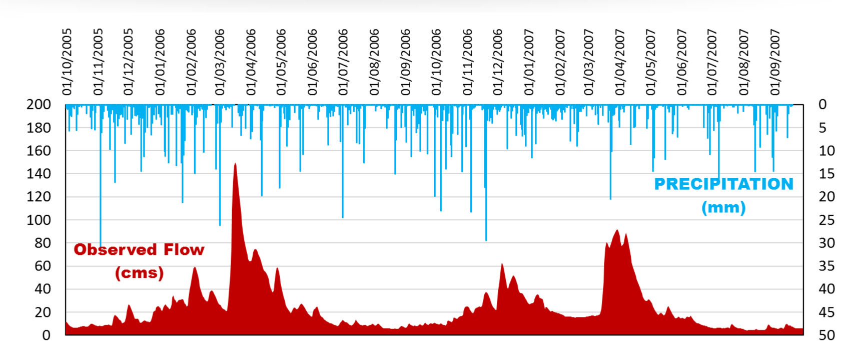


Time-Aggregate Sensitivity Indices

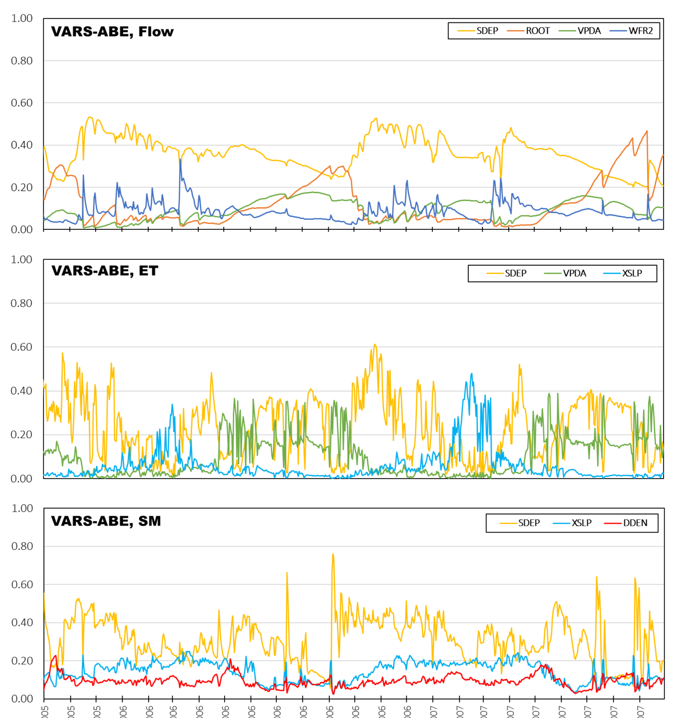


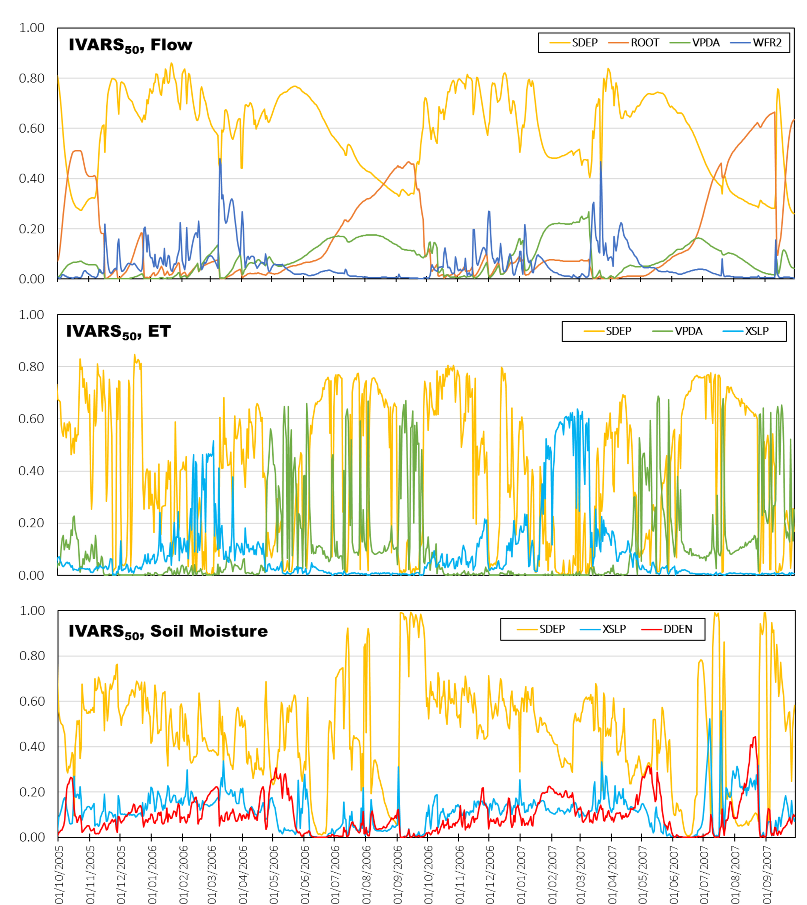


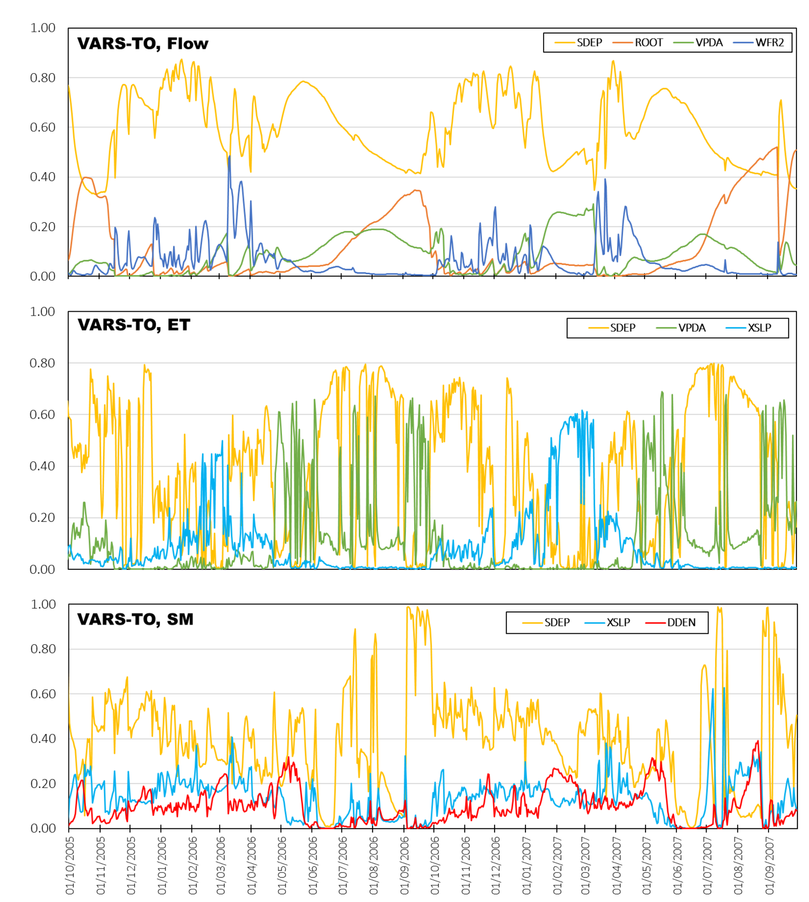




Time-Varying Sensitivity Indices







CONCLUSIONS

1. Based on GGSM approach, VARS-TOOL can efficiently produce series of sensitivity metrics based on multiple GSA methods.
   - This includes IVARS (variogram-based), VARS-TO (variance-based), and (VARS-ABE (derivative-based).
   - Both time-varying and time-aggregate sensitivity metrics can be generated.
2. All 3 GSA methods show similar sensitivity results for all three responses Flow, ET, and Soil moisture.
   - SDEP, ROOT, VPDA, and XSLP are the most influential parameters.
   - Model sensitivity to parameters vary significantly with time. SDEP and XSLP tend to be more influential during higher flows. ROOT and VPDA become more important during the crop growing season and lower flows.

REFERENCES

Haghnegahdar A., Tolson, B. A., Craig, J. R., Paya, K. T. (2015), Assessing the Performance of a Semi-distributed Hydrological Model under various Watershed Discretization Schemes. Hydrol. Process., 29, 4018–4031 doi:10.1002/hyp.10550.

Razavi S., Sheikholeslami R., Gupta H., Haghnegahdar A., (2019), VARS-TOOL: A toolbox for comprehensive, efficient, and robust sensitivity and uncertainty analysis, Environmental Modelling & Software, Volume 112, 95-107, https://doi.org/10.1016/j.envsoft.2018.10.005.

Razavi, S., and Gupta, H. V., (2016), A new framework for comprehensive, robust, and efficient global sensitivity analysis: II. Application, Water Resources Research, 51, doi:10.1002/2015WR017559.

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