A long-term sensitivity analysis of DNDC model

Xiaobo Qin, Hong Wang, Yu'e Li

Institute of environment and development in agriculture, CAAS
Semiarid prairie agricultural research centre, Agriculture and Agri-Food Canada

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Objective

- Demonstrate a dynamic sensitivity analysis of DNDC model over a long-term period using the method of BACCO GEM-SA

Contents

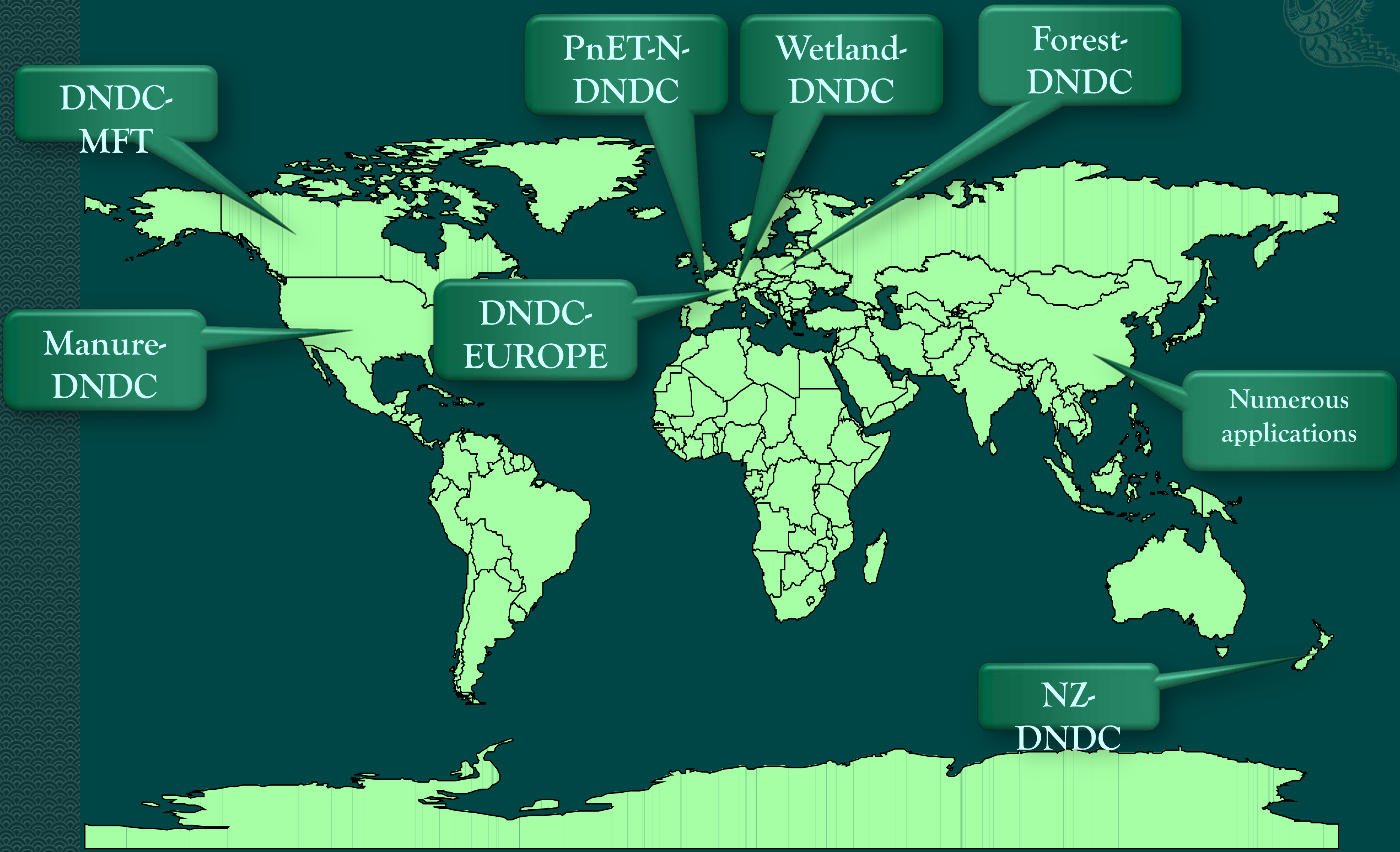
2.1 DNDC model
——DeNitrification and DeComposition

DNDC model structure

- **Input data**
  - Climatic
  - Soil properties
  - Agricultural practices
- **Submodel**
  - Thermal-Hydraulic
  - Aerobic decomposition
  - Denitrification
  - Fermentation
  - Plant growth
- **Outputs**
  - Nitrogen dynamic
  - Carbon cycling
  - Greenhouse gasses flux: CO_2, CH_4, N_2O
  - Climate: temperature, precipitation
  - Crop: yield

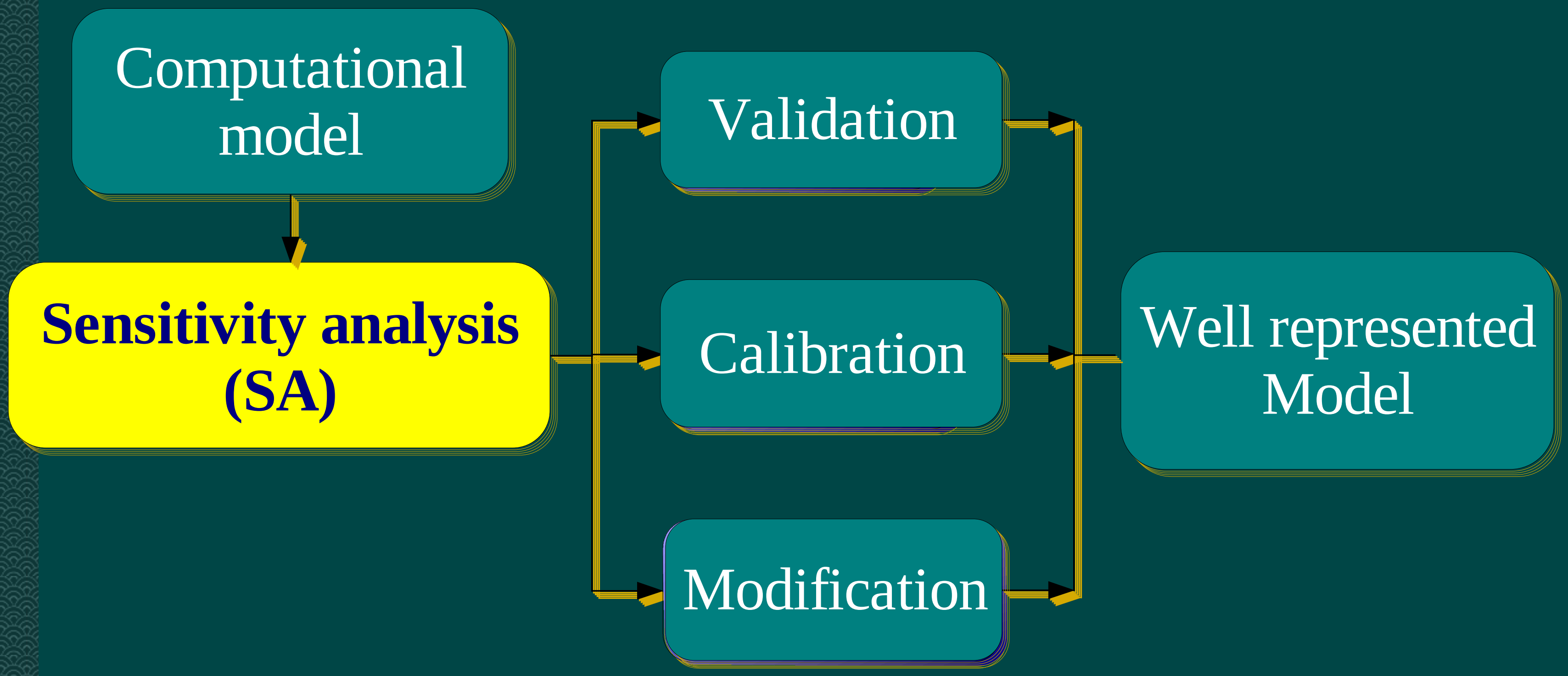
(Li et al., 1992a,b; 2012)

Global application of DNDC model

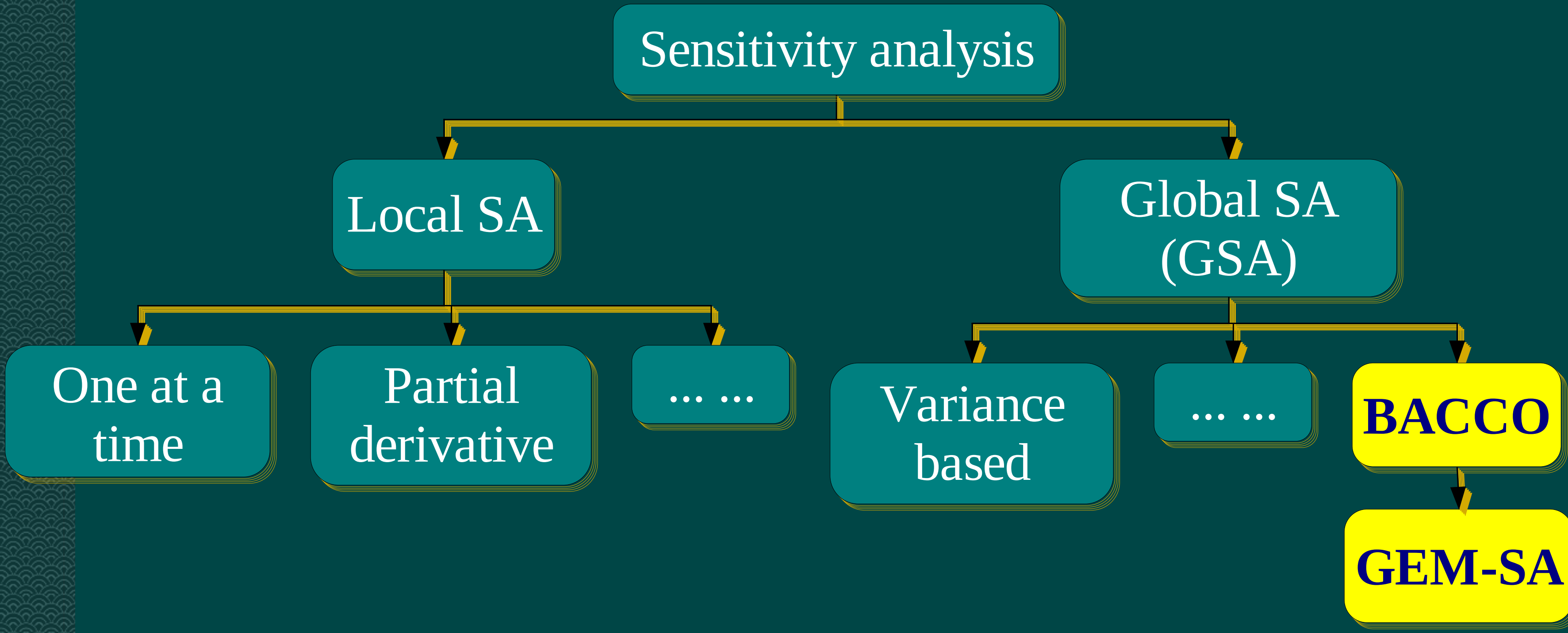


2.2 Sensitivity analysis

Why SA?

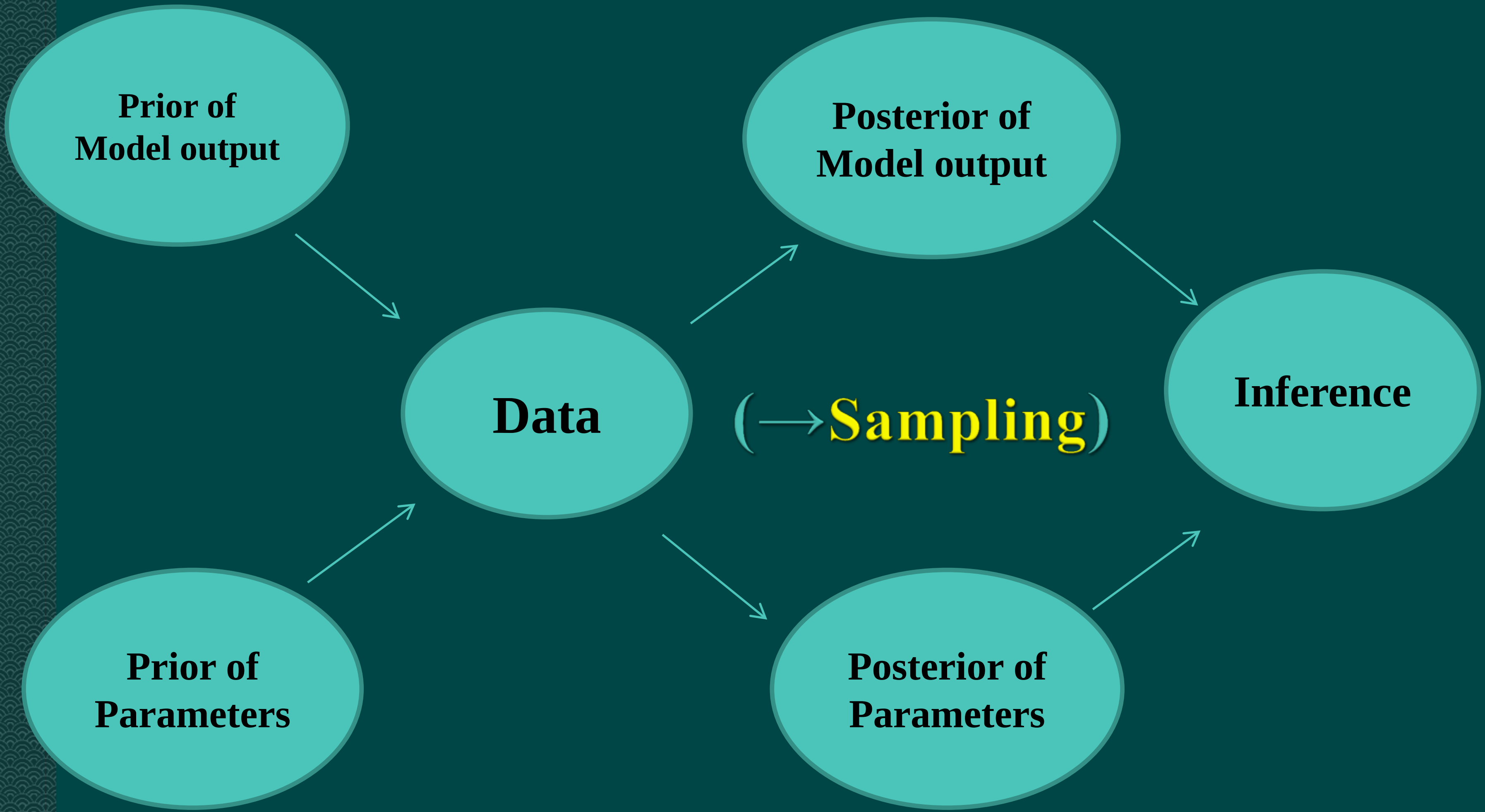

Computational model
Sensitivity analysis (SA)
Validation
Calibration
Modification
Well represented Model

Classification of SA



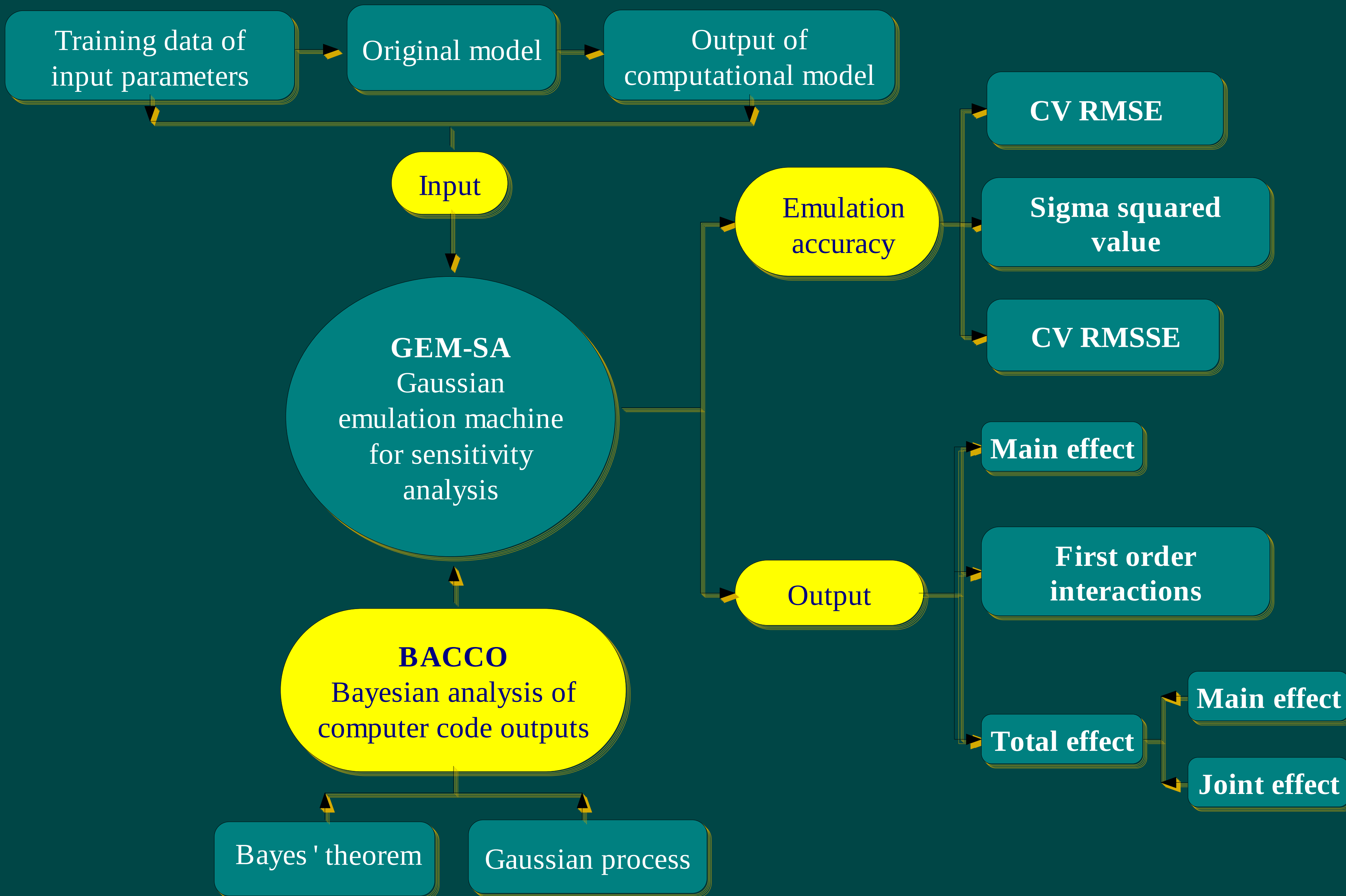
(Saltelli et al., 1999; Annoni et al., 2011)

Schematic of the GSA approach



(Petropoulos et al., 2013)

2.3 BACCO GEM-SA



(Oakley and O'Hagan, 2004; Kennedy et al., 2009)

Input space design in GEM-SA

- GEM-SA can generate 2 types of design
  - LP-τ design
  - Maximin Latin Hypercube designs (MLH)

- Both have good space-filling properties
  - Ensure all regions of the input space are well represented

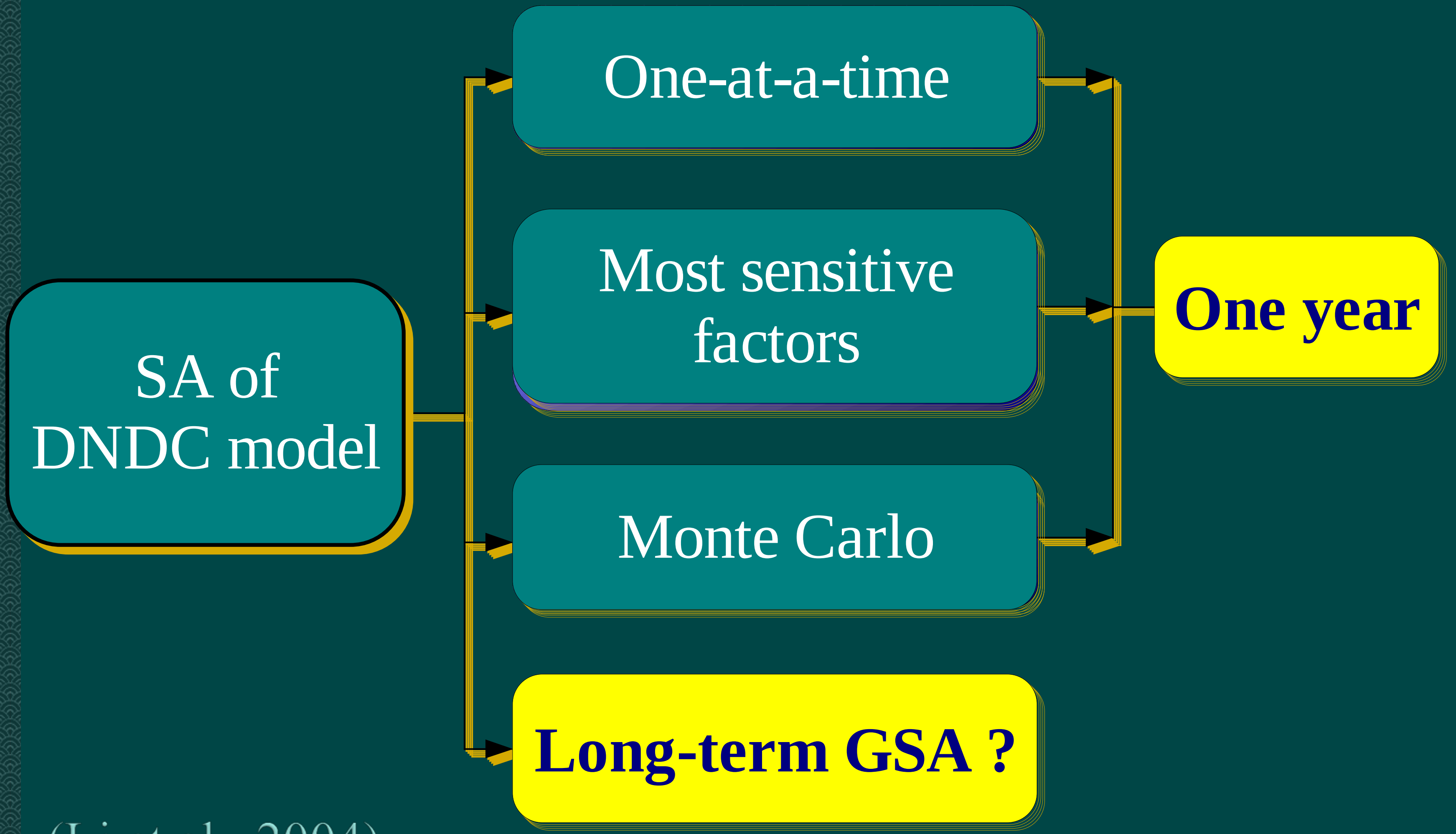
Input space design in GEM-SA

- **LP-τ**
  - Very quick to generate
  - Deterministic set of uniform points

- **MLH**
  - Maximise the minimum distance amongst all pairs of points
  - Can take a long time to generate

2.4 Long-term SA of DNDC model

Sensitivity analysis of DNDC



(Li et al., 2004)

Long-term SA of DNDC

- **Weather**: Three Hills, Alberta, Canada, from 1921 to 2006
- **27** input parameters and **400** DNDC runs
- **Ten snapshot years**: 0, 10, 20, 30, 40, 50, 60, 70, 80, 86, from the year 1921
- **Outputs: Annual change of SOC (dSOC), N_2O flux**, spring **wheat yield**

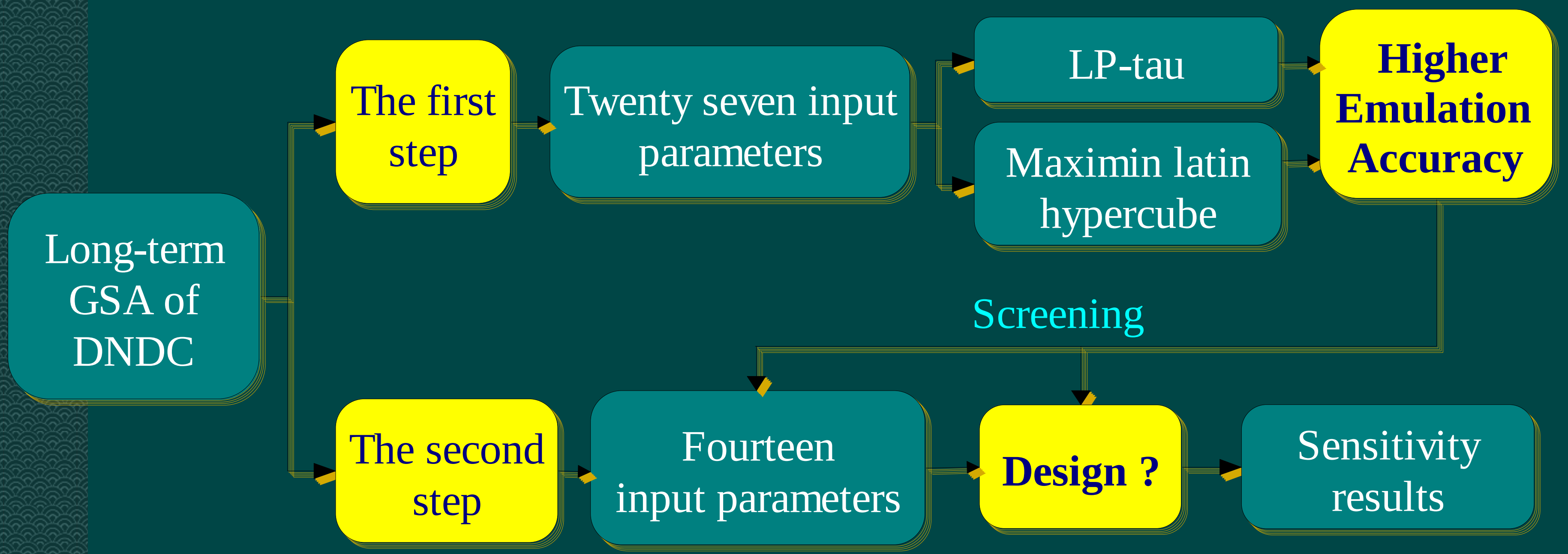
Summary of input parameters

Parameters	Actual name of the model input	Unit	Minimum	Maximum
NRAIN	Atmosphere N deposition concentration in rainfall	ppm	1.3	1.9
NATM	Atmosphere background NH_3 concentration	µgN/m^3	0.01	0.1
CO2	Atmosphere CO_2 concentration	ppm	320	450
DEN	Soil bulk density	g/cm^3	0.5	2.25
PH	Soil pH	NA	4.5	9.1
ISOC	Initial SOC (Soil organic carbon at surface 0-5 cm)	kgC/kg	0	0.5
CLAY	Soil clay content	NA	0	1
LITSOC	Litter SOC	NA	0.005	0.02
NO3	Soil NO_3^--N density	mgN/kg	8.5	15.5
NH4	Soil NH_4^+-N density	mgN/kg	0.85	1.5
MOI	Soil moisture	NA	0.27	0.65
FC	Field capacity	WFPS	0	1

Summary of input parameters

Parameters	Actual name of the model input	Unit	Minimum	Maximum
WILP	Wilting point	NA	0	1
HYDC	Hydro-conductivity	m/hr	0.01	0.025
PORO	Soil porosity	NA	0.2	0.8
SOCPA	Depth of soil profile with uniform SOC content	m	0.04	0.15
SOCPB	SOC decrease rate below top soil	NA	0.5	5
GRESD	Ground residue	ratio	0	1
MYD	Maximum yield	kgC/ha	1000	2000
CNG	Grain C/N ratio	NA	20	35
CNS	Shoot C/N ratio	NA	45	55
CNR	Root C/N ratio	NA	55	65
WTREQ	Water requirement demand	g water/g DM	100	250
DTILL	Tillage depth	cm	1	4
UREA	Urea application amount	kgN/ha	0	180

Schematic of this study



(Qin et al., 2013)

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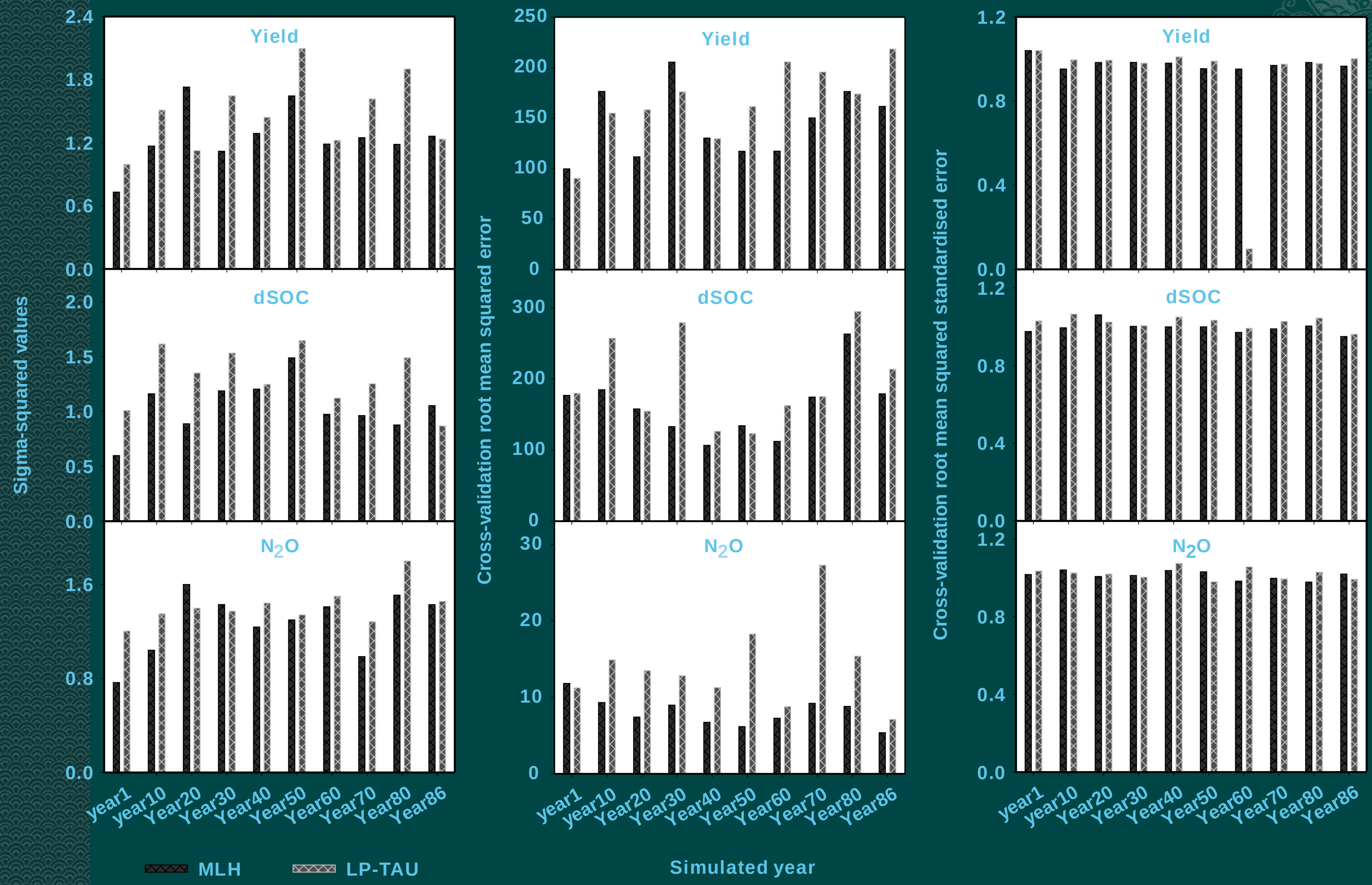
3.1 Emulation accuracy

Sigma-squared value CV-RMSE CV-RMSSE



3.2 Preliminary BACCO GEM-SA

——Two sampling method

——Identify more accurate design arithmetic

——Screening out parameters with little influence

Input parameters	Total effects (%)		
	dSOC	N_2O	yield
BD	**6.5**	4.1	1.9
CLAY	**8.3**	**9.6**	**10.6**
DFERTI	1.0	**24.9**	1.6
DTILL	**5.7**	**9.9**	0.8
FC	**6.1**	3.0	**11.7**
GRESD	**16.6**	1.5	1.3
ISOC	**26.9**	**13.8**	**20.5**
MYD	**7.8**	2.1	**13.7**
PH	1.0	**15.4**	2.0
PORO	**18.0**	**13.6**	**25.0**
SOCPA	6.9	**6.2**	**9.5**
UREA	2.1	**6.5**	2.6
WILP	**16.3**	3.4	**28.3**
WTREQ	**6.3**	3.6	**22.7**
HYDC	1.3	4.3	1.4
LITSOC	0.6	0.9	1.0
MOI	0.7	0.8	3.5
NATM	0.9	2.0	0.7
NH4	0.3	0.5	0.6
NO3	0.7	2.4	1.0
NRAIN	0.5	0.8	1.4
SOCPB	3.5	4.8	2.3

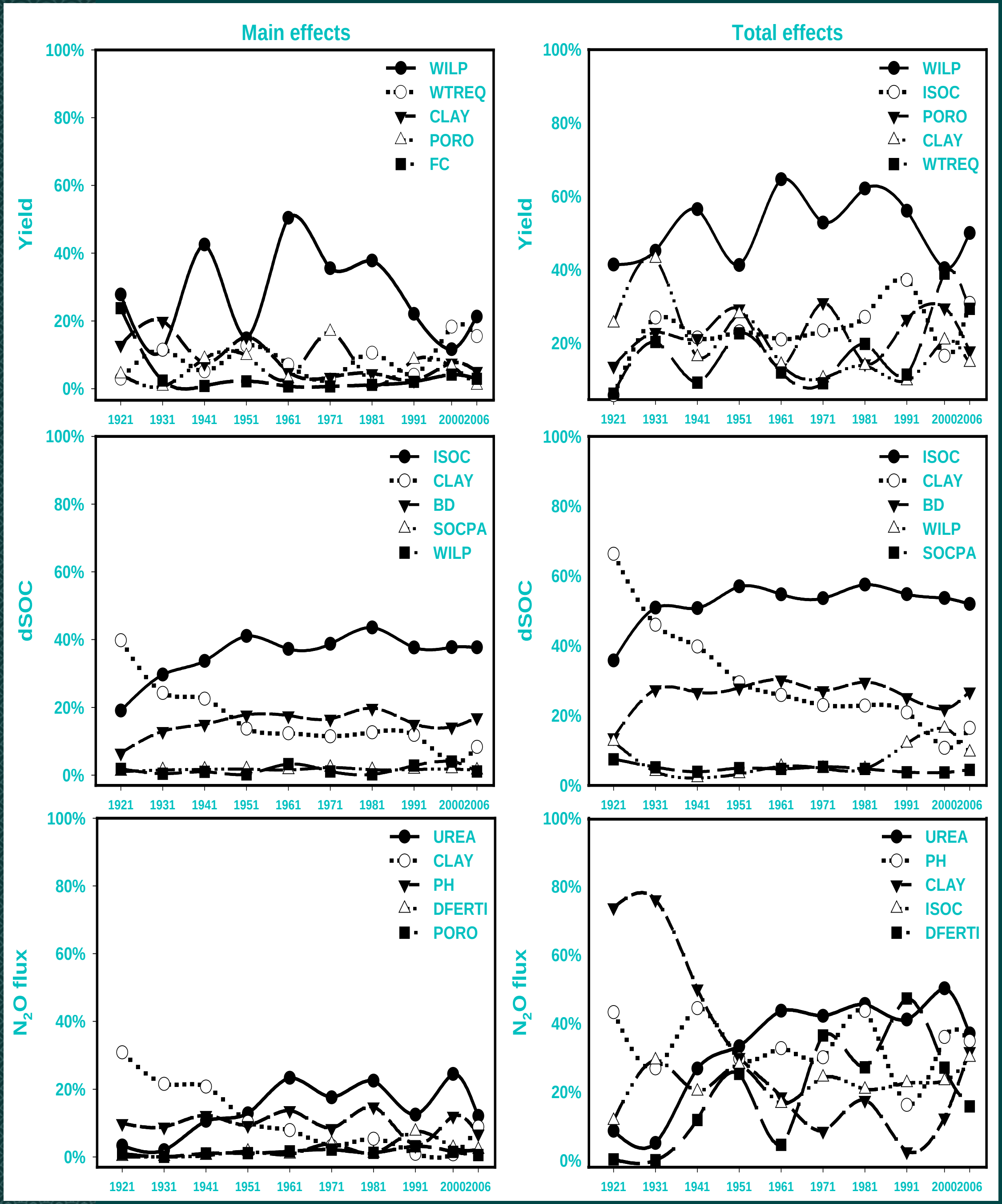
14 important parameters were screened out by their total effects ≥ 5% with respect to the three DNDC outputs

3.3 Second Step of BACCO GEM-SA

——Maximin Latin Hypercube design (MLH)
——Determination of the most important parameters, and the long-term variation of SA scenario

Input Parameters	dSOC		N_2O		Yield	
	Main effect	**Total effects**	**Main effect**	**Total effects**	**Main effect**	**Total effects**
BD	**15.3**	**25.7**	1.1	**9.0**	0.2	2.8
CLAY	**16.1**	**30.1**	**11.1**	**32.2**	**8.4**	**19.7**
DFERTI	0.03	0.6	2.0	**19.6**	0.1	1.3
DTILL	0.1	1.4	0.5	**8.7**	0.1	2.0
FC	0.6	2.8	0.7	2.7	4.1	**16.6**
GRESD	1.1	2.8	0.3	3.4	0.1	1.4
ISOC	**35.6**	**52.1**	1.1	**22.6**	2.0	**23.4**
MYD	0.3	1.7	0.2	3.2	1.4	**6.7**
PH	0.03	0.2	**10.0**	**33.8**	0.1	0.2
PORO	1.0	4.2	1.3	**18.7**	**6.0**	**22.1**
SOCPA	1.6	4.8	0.1	1.9	0.1	2.0
UREA	0.03	0.8	**14.1**	**33.4**	0.3	4.0
WILP	1.6	7.4	0.3	**6.1**	**27.5**	**51.1**
WTREQ	0.3	2.1	0.7	**5.6**	**9.0**	**18.0**
Total % variance	73.7		43.3		59.3	
First order interactions	18.3		27.1		19.5	
2nd or higher order	**8.0**		**29.6**		**21.2**	

Most of the input parameters contributed little to main outputs of DNDC



SA of parameters changed dramatically over the long-term period

Model calibration and validation

- Spin-up run (1400 years) → equilibrium
- Real observed data → calibration
- Another real data → validation

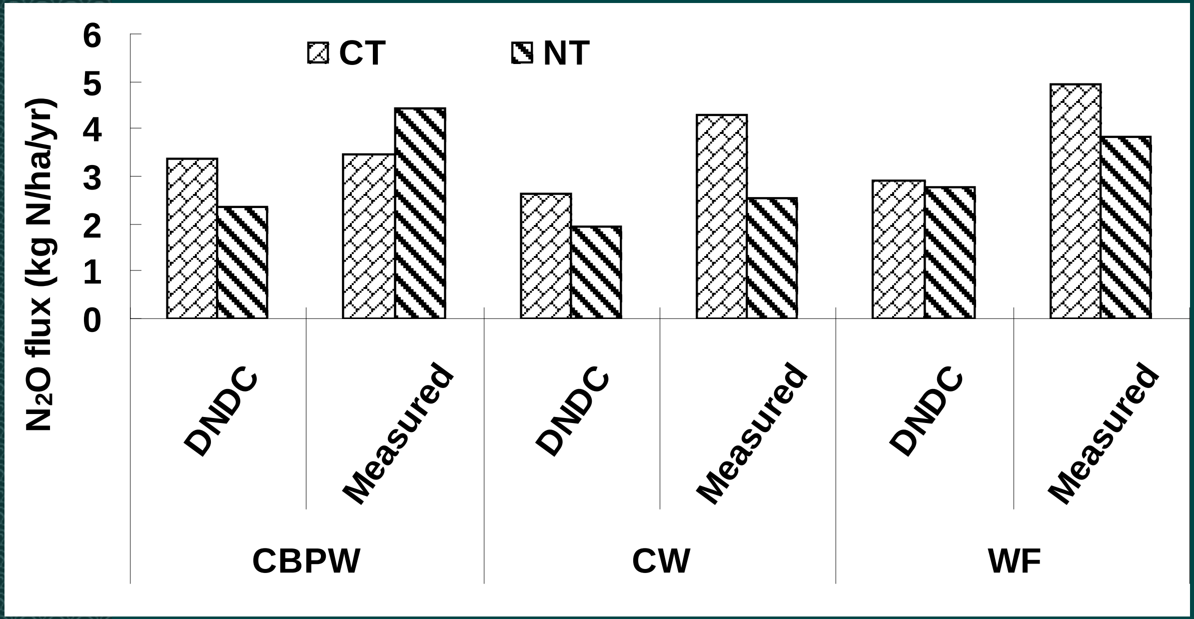
Site and field management history of Three Hills, Alberta, Canada

Items	**Three Hills' information**
Pre-cultivation history	semiarid grassland vegetation-fescue prairie-primarily rough fescue
Land first cultivated	1905 (1900-1910)
From 1905-1975	Cereal-Fallow 2 year Rotation with the cereal phase mostly wheat with barley about every third rotation
From 1976-1985	Canola-Cereal-Fallow 3 year rotation with the cereal phase mostly wheat with barley about every third rotation
From 1986-1991	Cereal-Canola-Cereal-Fallow 4 year rotation with the rotation probably wheat-canola-barley-fallow
Research site opened	1991
Experiment initiated	1992 (continuous wheat, wheat fallow, canola-barley-pea-wheat, etc.)
Location, and elevation	51°42'N, 113°13'W, 923 m
Ecoregion Name	Moist Mixed Grassland
Soil Landscape of Canada (SLC)	546
Initial carbon Ap horizon (%)	3.65
Soil Classification	Solonetic Black Chernozem
Landscape	Undulating
Growing Degree Days (>0°C)	2519
Growing Degree Days (>5°C)	1489
Frost Free Period	113
Growing Season Precipitation (mm)	232 (mean), 98 (min), 378 (max)

Calibration of some important parameters for N_2O of DNDC prediction

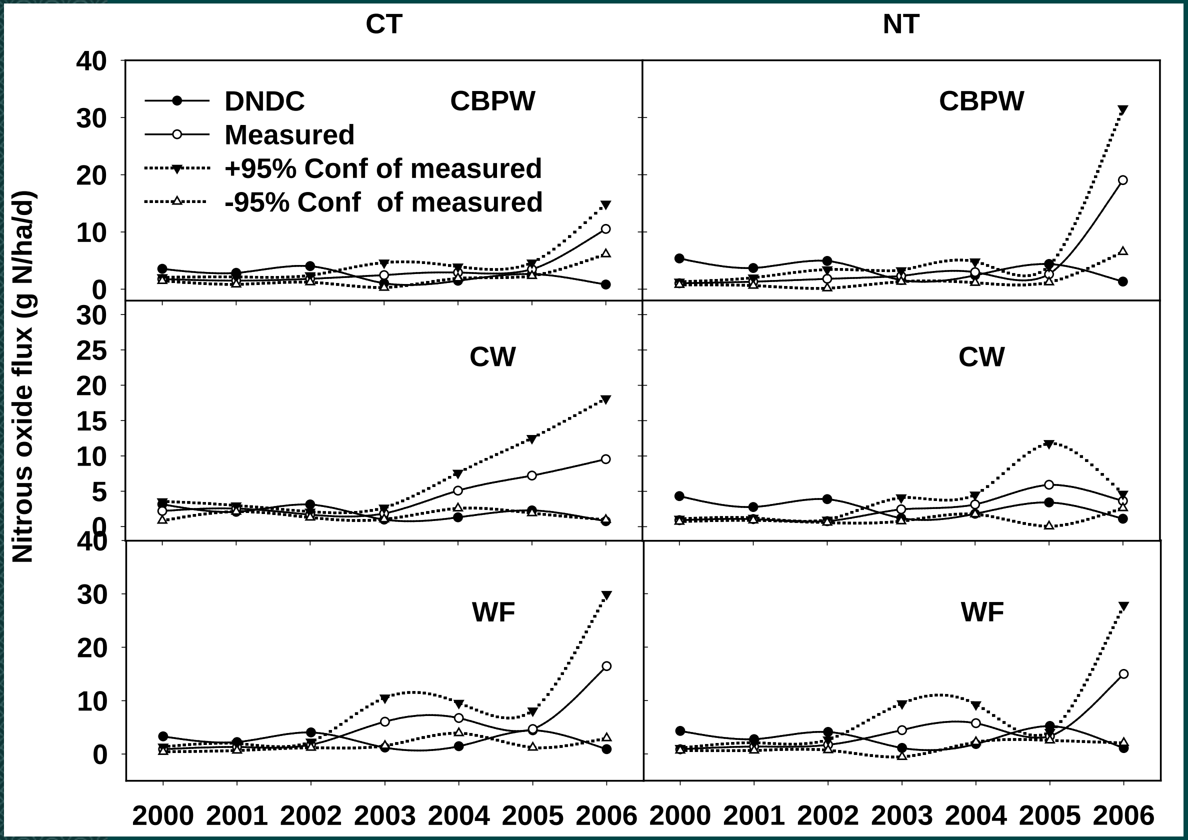
	Calibrated	+10%	-10%
ISOC (kg C kg^{-1})	0.04	0.044	0.036
BD (g cm^{-3})	1.26	1.38	1.13
CLAY (unitless)	0.41	0.45	0.37
DTILL (cm)	10	11	9

Validation of N_2O



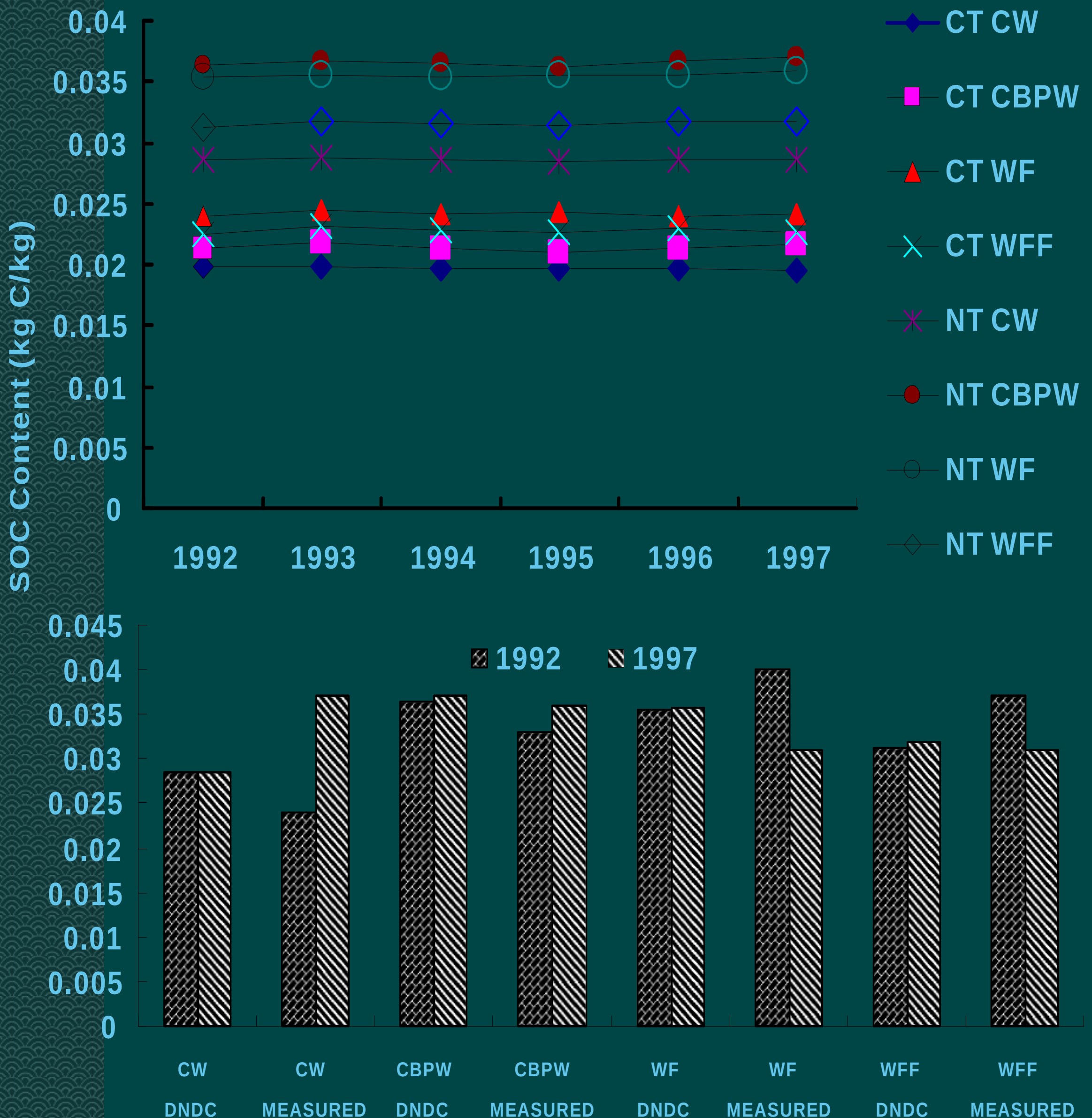
Measured and DNDC simulated N_2O flux of each crop system based on till and no-till management of Three Hills, Alberta from 2000 to 2006

Validation of N_2O



Validation of DNDC model with real measured N_2O flux from Three Hills crop systems 2000~2006. ±95% Conf represent the measured data ±95% confidence interval

Validation of SOC



Soil organic carbon content of Three Hills (1992-1997) by simulation of DNDC model (A) and the soil organic carbon content of the year 1992 and 1997 based on no-till (B)

Contents

Conclusions

- **BACCO GEM-SA, Maximin Latin Hypercube design suitable to DNDC model**

- **Two step of GSA study improved the accuracy of sensitivity analysis**

- **Most of the 27 input parameters contributed little to main outputs of DNDC**
  - Six most sensitive inputs → 80% of total variances of dSOC and N_2O flux
  - Six inputs together → 88% of the total variances of grain yield

Conclusions

- **Initial SOC and soil clay content were commonly shared important ones by the three outputs**

- **Sensitivities of some parameters were time-dependent**
  - Soil clay content for all the 3 outputs
  - Field capacity for yield

- **Long-term global sensitivity analysis is necessary to DNDC model**

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