Environment and Climate Change Canada | Environnement et Changement climatique Canada

ECCC'S ENSEMBLE SYSTEM DEVELOPMENT AND PLAN

Normand Gagnon
Deputy Director, National prediction development
CCMEP, MSC, ECCC

NCEP Ensemble Users Workshop, August 21-24 2023

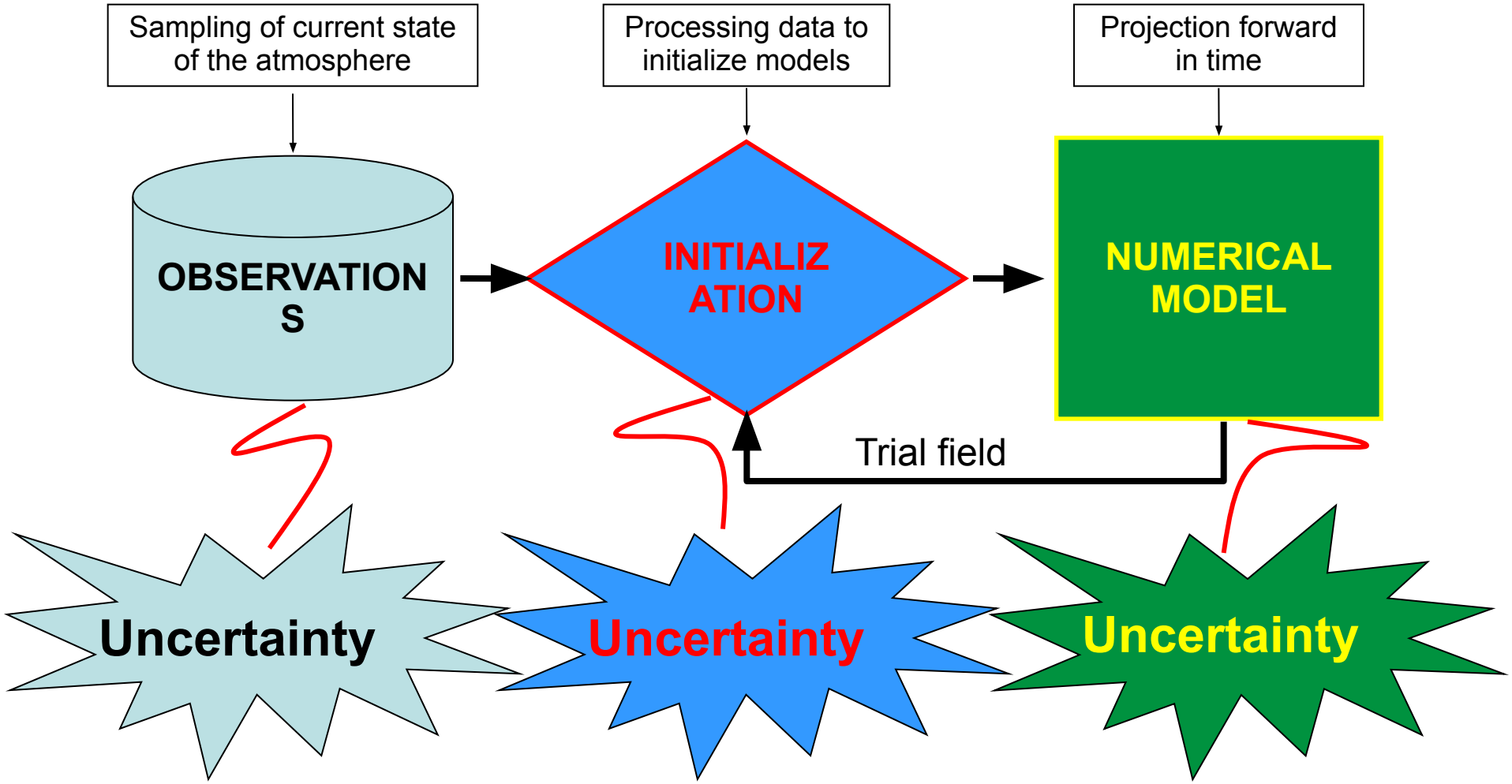
CONTRIBUTORS

- Baek S.-J., Blain P., Buehner M., Caron J.-F., Charron M., Deng X., Du, P., Dupont F., Fontecilla J. F., Houtekamer P., Lemay F., Lin H., McTaggart-Cowan R., Muncaster R., Peterson A., Separovic L., A. Patoine, Vaillancourt P., Yang J., Zadra A., B. Pouliot, O. Huzyi, D. Deacu, S. Bélair, D. Szimajovski, D. Durnford, S. Keita, M. Markovic, G. Diro, and many others…

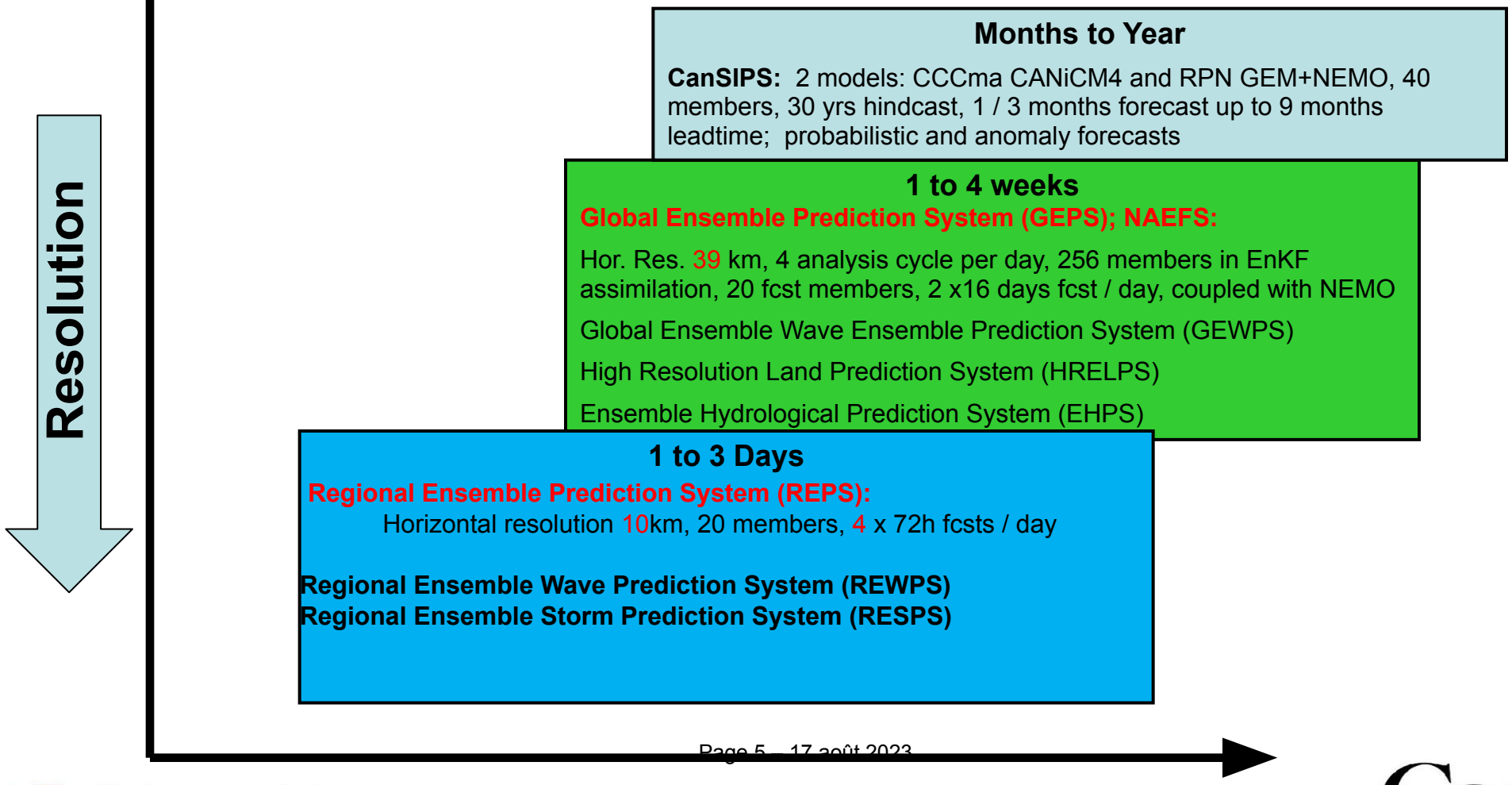
Content

- Review of our current ensemble systems
  - Seasonal, CanSIPS (not discussed)
  - Global, GEPS
  - Regional, REPS
  - Waves, GEWPS, REWPS
  - Storm Surge, RESPS
  - Land surface, HRELPS (still experimental)
  - Hydrological, EHPS (still experimental)
- Planned upgrade in 2024
- Main challenges

Sources of error – uncertainties



Our operational ensemble capacities:
from global to regional to local



2019 (August): The Canadian Seasonal to Interannual Prediction System (CanSIPSv2)

- Developed at CCCma (BC) and MRD (QC)
- Operational at CMC-Montreal since August 2019
- 2 models CanCM4i and Gem-Nemo, 20 ensemble members each (new system)
- Forecasts initialized at the start of every month
- Hindcast verification period = 1991-2020
- Operational forecasts contribute to **NMME** and WMO/APCC/IRI ensembles
- Forecast range = 12 months

CanSIPSv2.1 Models

CanCM4i

CanAM4 Atmospheric model
- T63/L35 (≈2.8° spectral grid)
- Deep conv as in Zhang & McFarlane (1995)
- Shallow conv as per von Salzen & McFarlane (2002)
- Improved radiation, aerosols

CanOM4 Ocean model
- 1.41°×0.94°×L40
- GM stirring, aniso visc
- KPP+tidal mixing
- Subsurface solar heating climatological chlorophyll

GEM5-NEMO

Gem 5.1 Atmospheric model
- Resolution 1° x 1° Yin-Yang grid
- -85 levels, top at 0.1 hPa
- Time step: 30 minutes
- Land surface scheme: ISBA
- Deep convection scheme: modified Kain-Fritsch
- Shallow convection scheme: Bechtold scheme
- Surface flux scheme: implicit flux

Nemo: Ocean model
- -NEMO (3.6)
- ORCA1 grid: Horizontal resolution: 1°× 1° , 1/3 degree meridionally near the equator
- 50 vertical levels
- Time step: 30 minutes
- coupled with sea ice CICE (with five-category sea ice)
- GEM5 and NEMO are coupled every time step through GOSSIP coupler

CanSIPSv2.1 Initialisation

GEM5-NEMO, **forecast mode:**

Atmosphere: 10 members from ENKF of GEPS

Land: offline SPS forced by CMC analysis at lowest model level

Ocean: CMC GIOPS

Sea ice concentration: CMC GIOPS

Sea ice thickness: CMC GIOPS

GEM5-NEMO, **hindcast mode:**

Atmosphere: ERA5 10 members (random isotropic perturbations)

Ocean: ORAS5 from ECMWF - T, S, H, U, V

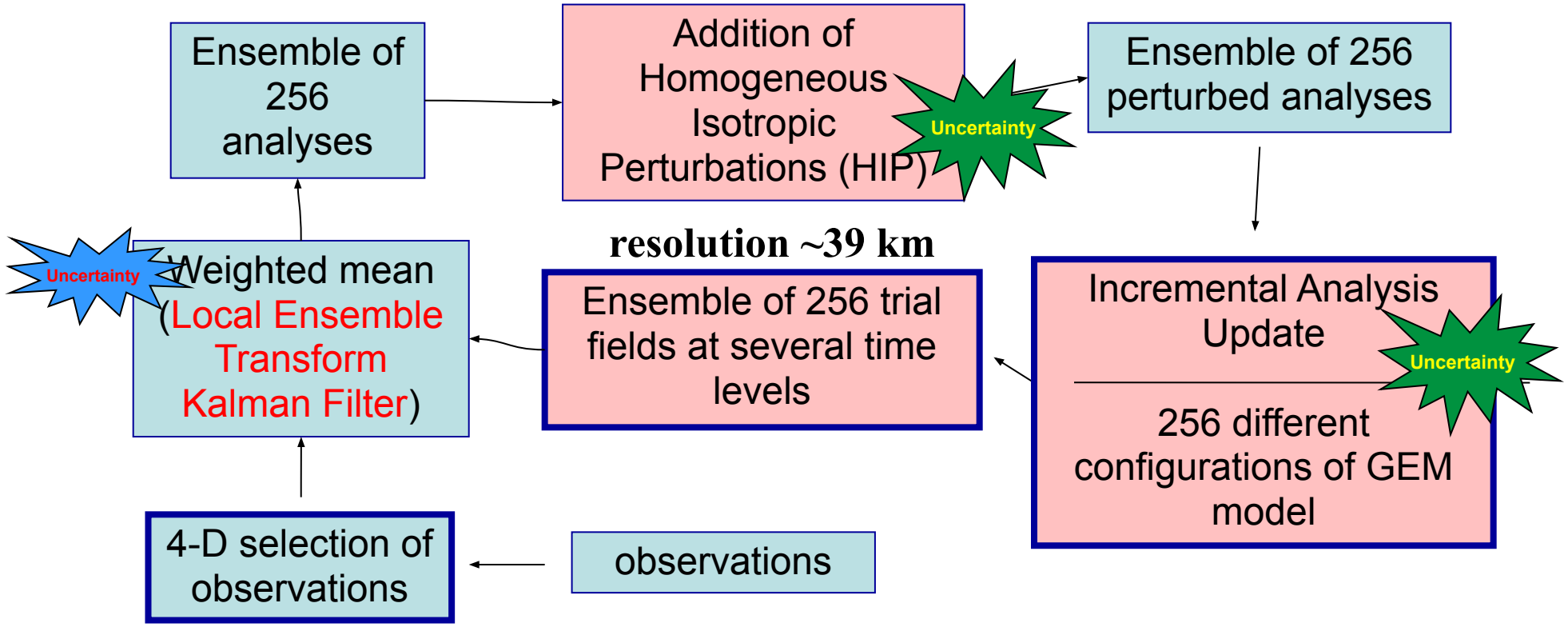
Land: off-line SPS forced by ERA5 atmosphere at lowest model level

Sea ice concentration: Had2CIS/GIOPS

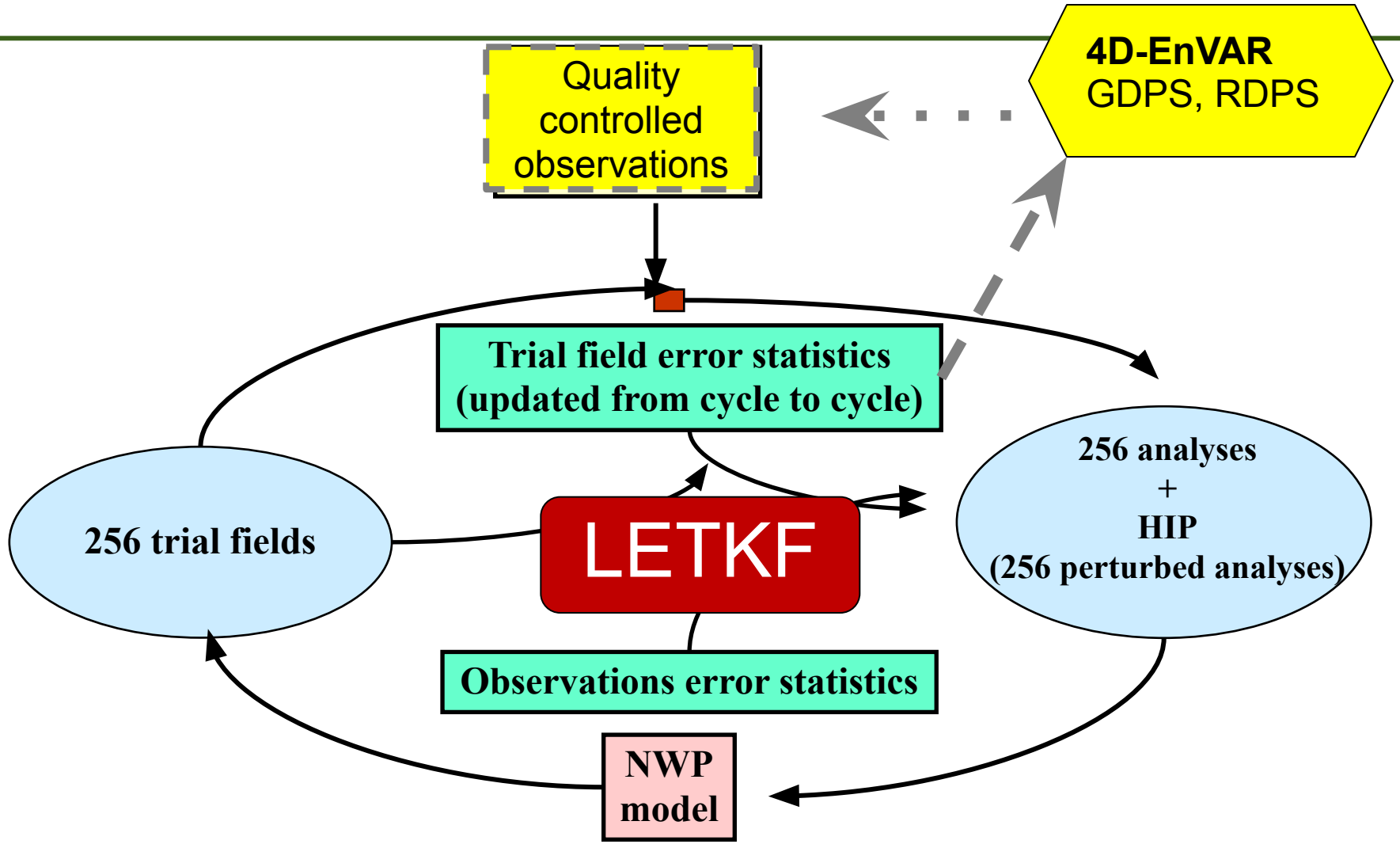
Sea ice thickness: ORAS5

°C

Canadian GEPS - Data assimilation

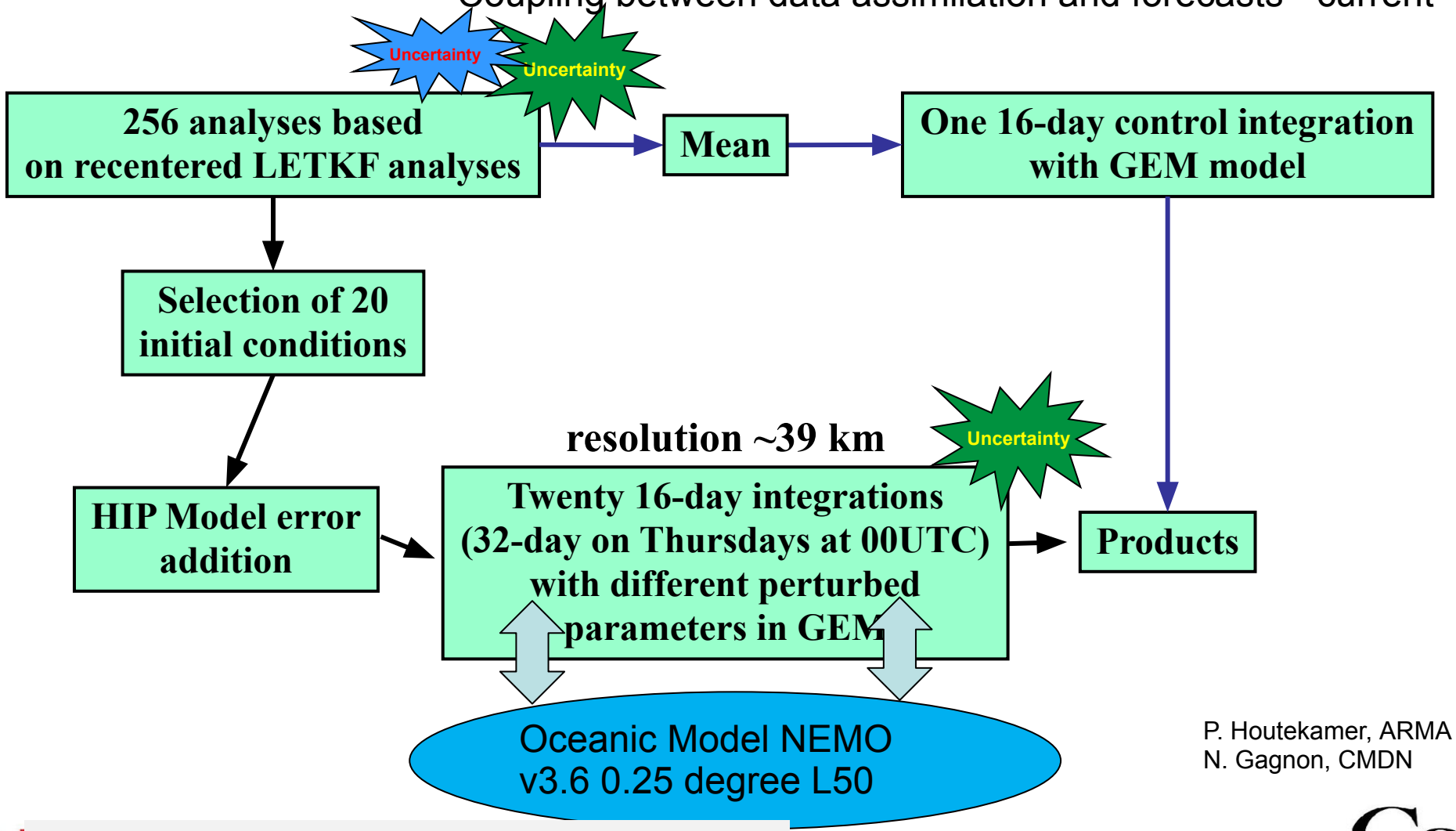


Canadian GEPS – Data Assimilation



Canadian GEPS – Forecasts

Coupling between data assimilation and forecasts - current



P. Houtekamer, ARMA
N. Gagnon, CMDN

Integration done twice a day (00 and 12 UTC)

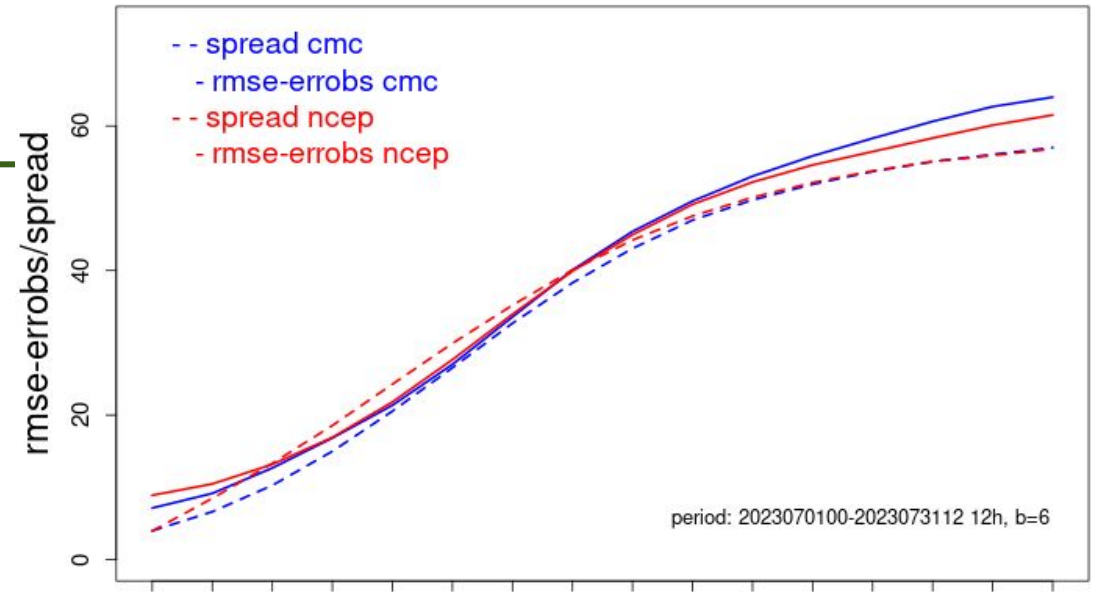
Canada

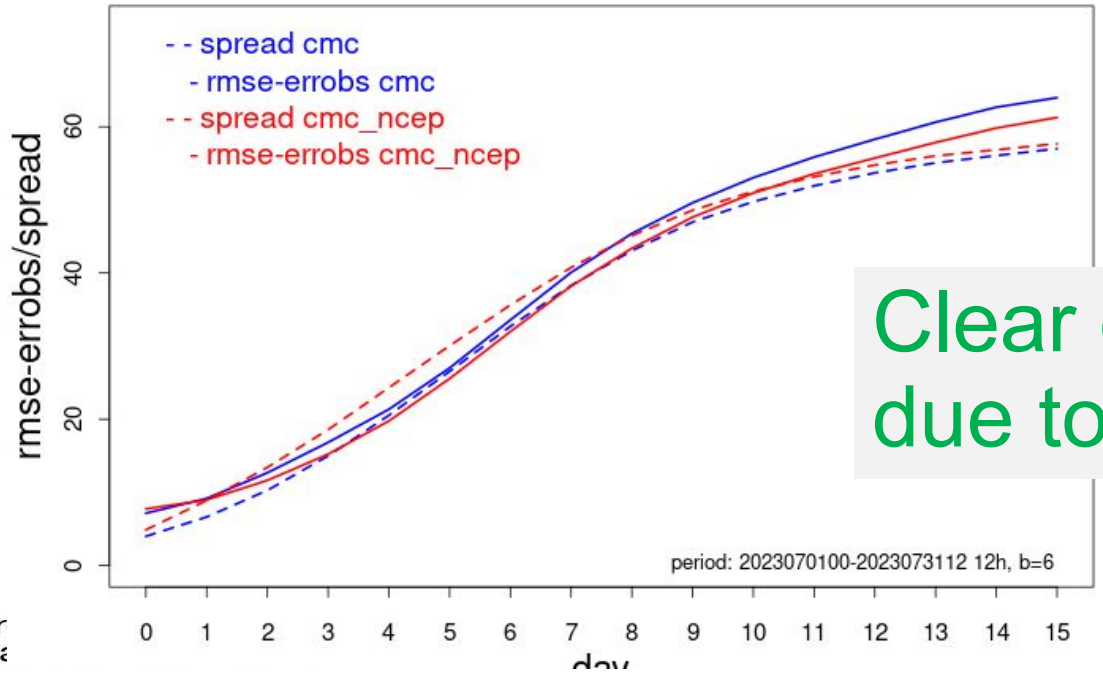
Canadian GEPS – Forecasts

- Number of members: 20+1
- All members use the GEM model as dynamical core
- Initial conditions uncertainty simulation using LETKF (Buehner, 2020) analyses (recentered around 4D-EnVar analysis). HIP are added to the initial conditions to account for the unknown sources of model error
- Model uncertainty simulation using:
  - Stochastic Parameter Perturbation (SPP) (McTaggart-Cowan et al. 2022) (replaced the Stochastically Perturbed Parameterization Tendency (SPPT) and Multi-Physics (MP) algorithms)
  - Stochastic Kinetic Energy Backscatter (SKEB) (Shutts, 2005) (applied to dynamics tendencies of wind and temperature)

Example of added value given by NAEFS

RMSE and standard deviation of GZ500 ensemble mean for the Northern Hemisphere (radiosoundings), July 2023

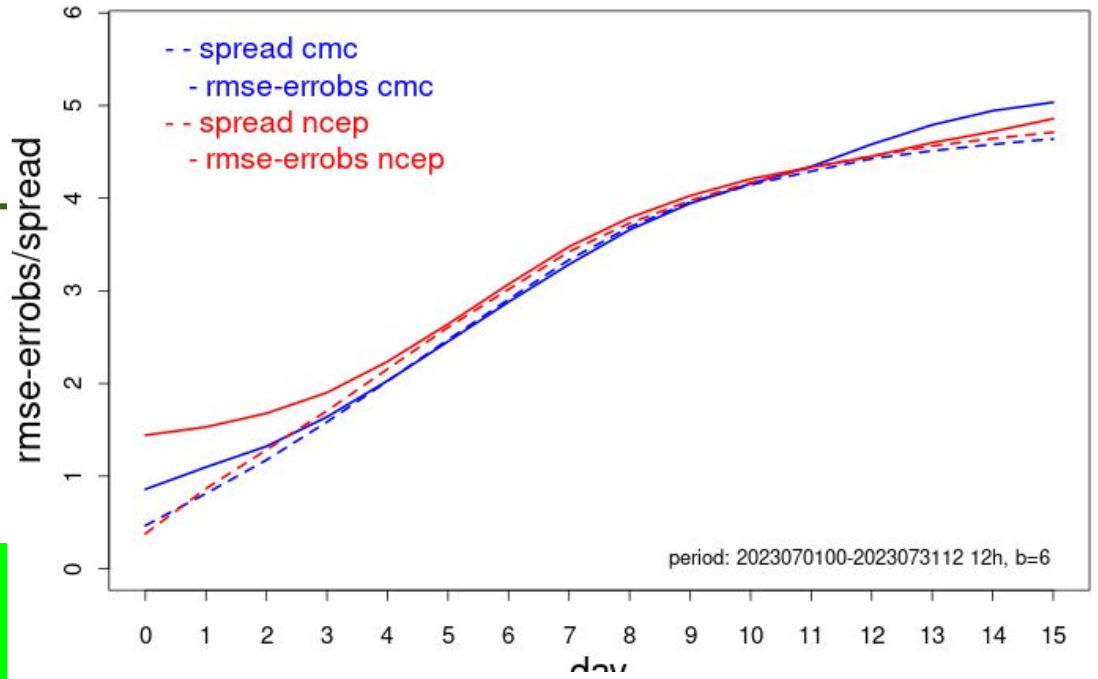


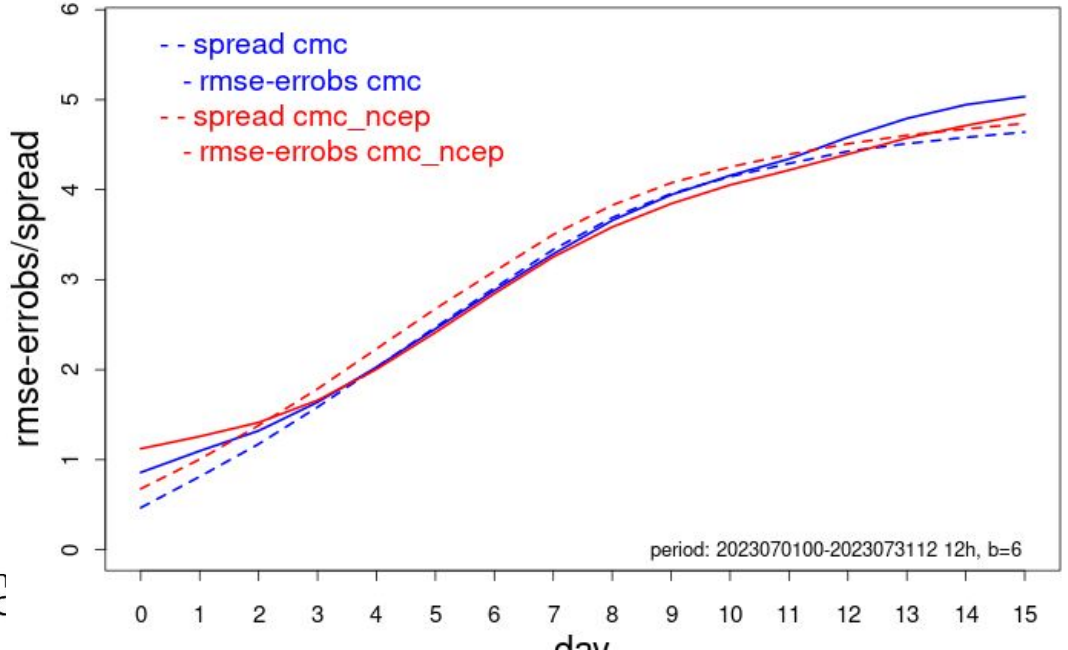


Clear gain due to NAEFS!

Example of added value given by NAEFS

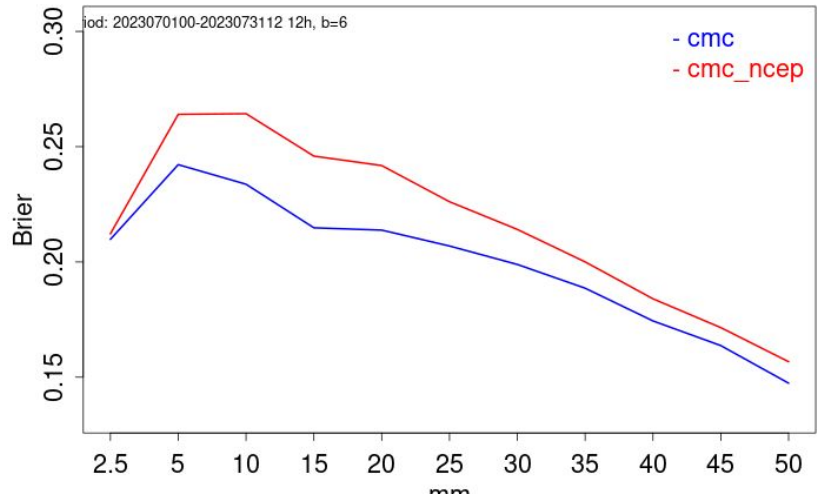
RMSE and standard deviation of MSLP ensemble mean for the Northern Hemisphere (surface station), July 2023



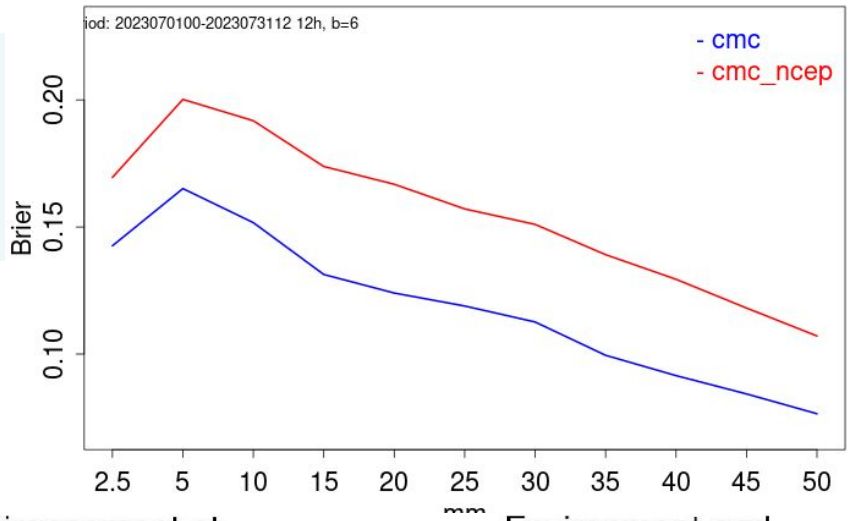


Comparison between operational GEPS and NAEFS in July 2023 for precipitation

BSS 24h



BSS 72h

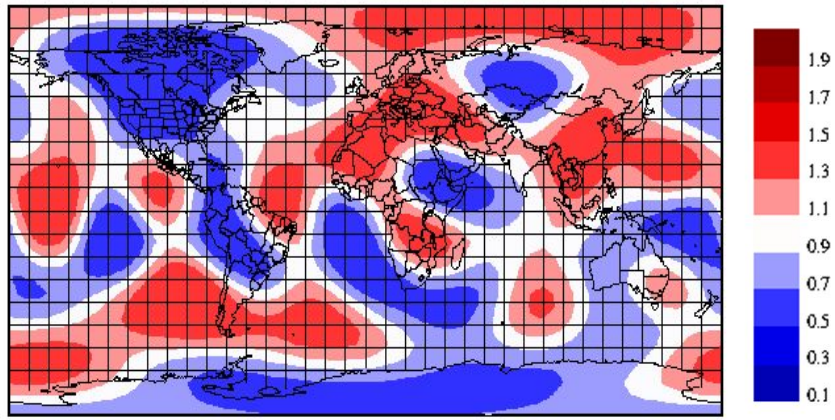


Big gain due to NAEFS!

août 2023

What is SPP?

- Time-evolving 2D fields with prescribed temporal and spatial correlations (Markov chains) used in the SPPT scheme in the GEPS 6.0.0 are repurposed to perturb poorly constrained parameters or uncertain processes.
- The spatial correlations are determined by the cut-off spherical wave-number 8 (about 5000 km).
- The decorrelation time used is 24-36 h.



Example of perturbation field with cut-off spherical number 8 (~5000 km) and 36 hours decorrelation time.

Ensemble SPP list

- Total of 22 parameters or algorithms are perturbed with the SPP scheme, 21 of which concern the model physics and one is related to the dynamics:
  1. **Turbulent surface exchange coefficients for heat and momentum (surface fluxes) ('fh_mult','fm_mult')**
  2. **Boundary-layer mixing length scale ('ml_emod')**
  3. Critical Richardson number for laminar/turbulent flow transitions, turbulent transport of TKE and turbulent flux adjustments for boundary layer clouds ('ricmin', 'tkediff', 'fnnreduc')
  4. Relative humidity and cloud condensates/ice thresholds for stratiform precipitation ('hu0min', 'hu0max', 'cond_hcst', 'cond_iceacc' [REPS only])
  5. Threshold vertical velocities for mid-level *and* deep convection, as well as cloud radius, cloud-rain autoconversion rate, and downdraft detrainment depth in deep convection ('mid_minemf' [GEPS only], 'kfctrig4', 'kfctrigwl', 'kfctrigwh', 'crad_mult', 'deeprate', 'dpdd_mult')
  6. Aerosol concentration and effective cloud water droplet and cloud ice radii for radiative transfer ('aero_mult, 'rew_mult', 'rei_mult')
  7. Parameters related to the gravity wave drag and flow blocking by subgrid-scale orography ('rmscon','sgo_phic')
  8. **Order of interpolation for semi-Lagrangian advection ('adv_rhsint' [GEPS only]).**

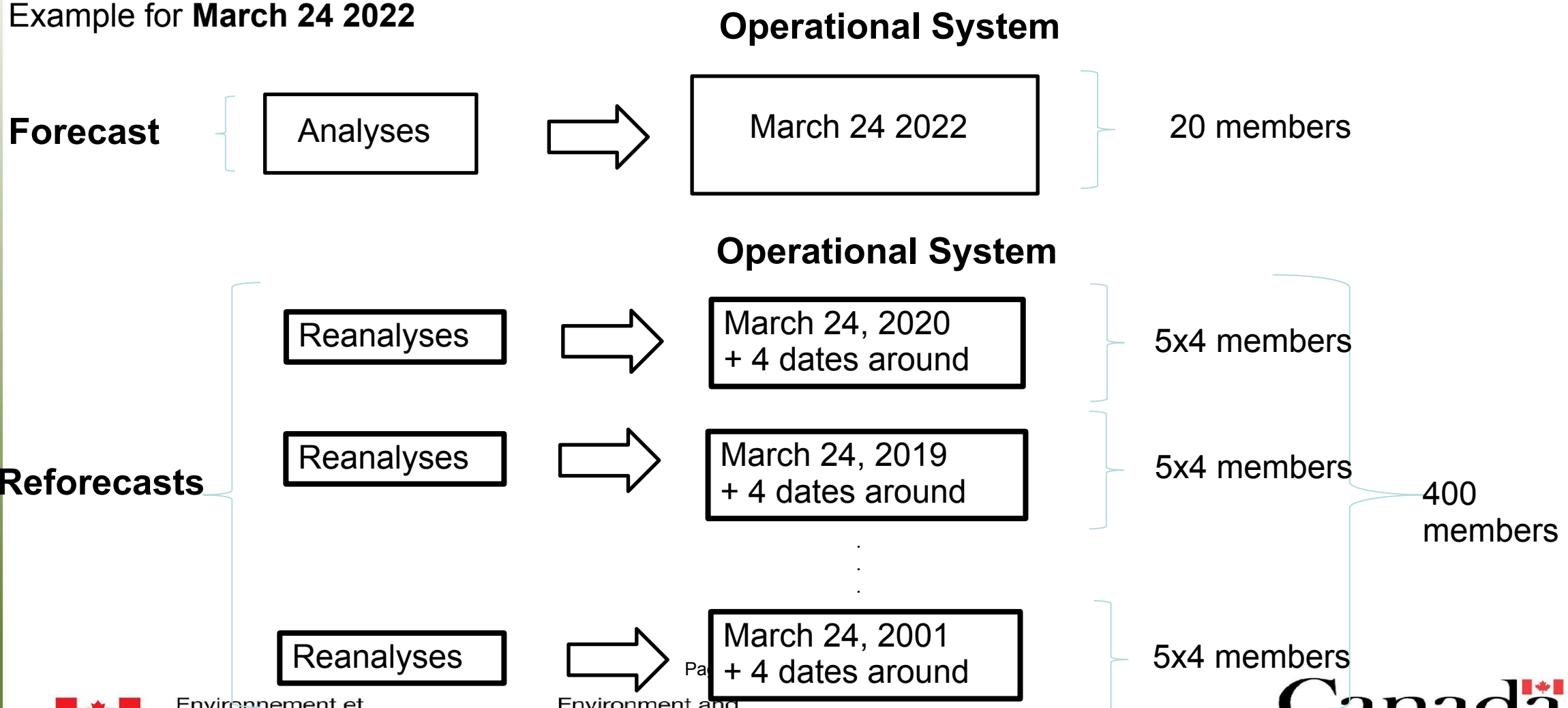
– Highlighted are the three leading-impact SPPs.

Canadian GEPS reforecast

- We have an operational reforecast process running in operation for several years.
- It is used to produce a model climate (mean and standard deviation) required for the monthly forecasts, the calculation of the extreme forecast index and the vigilance product.
- It used an « on-the-fly » approach as Hagedorn (2007).
- The exact model configuration is run over the past 20 years every week (Thursday date). The dataset is then always consistent with the operational configuration. We prefer that approach to a fix reforecast done every X years (like in seasonal forecasting).
- We have 4 members over 20 years once per week.
- The data is available for more than 30 variables here.

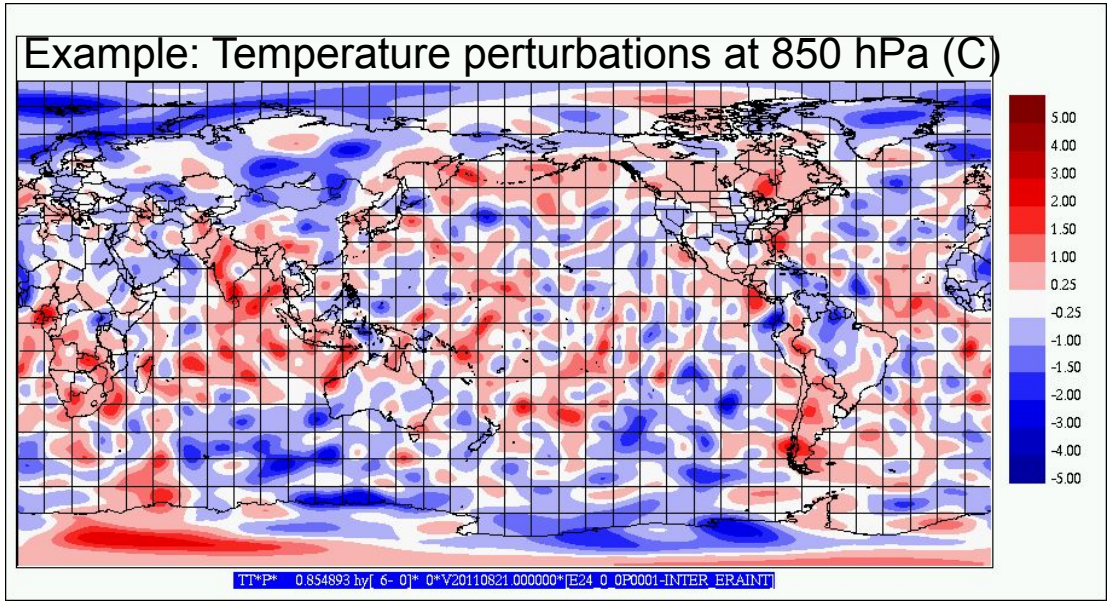
Reforecast for the GEPS monthly forecast

Example for **March 24 2022**

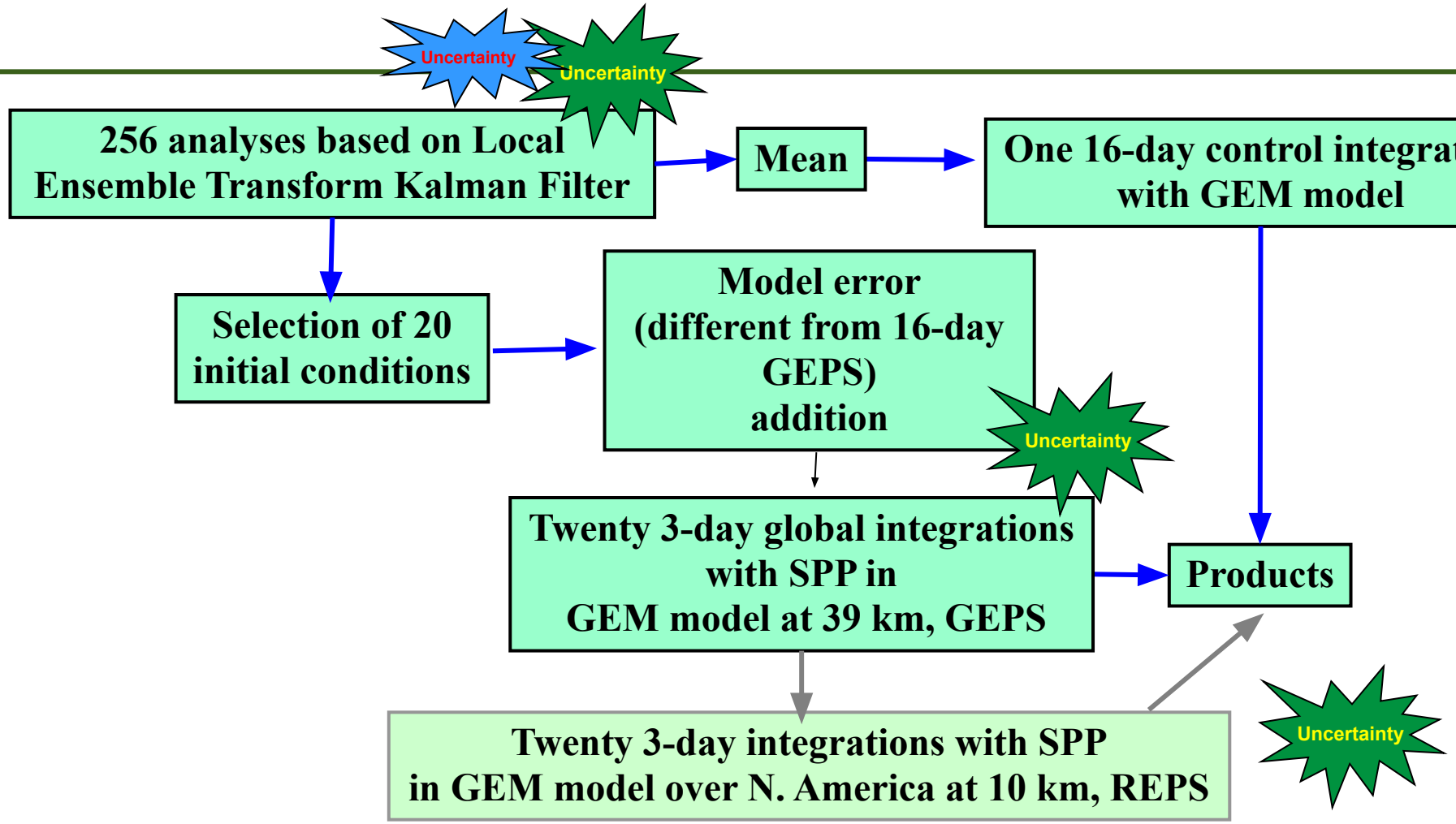


Initial conditions in GEPS reforecasts

- The reforecast system and the GEPS system are very similar, the only important difference are the initial conditions.
  - Atmosphere: random isotropic perturbations added to ERA5
  - Land Surface : We run the surface prediction system (SPS) forced by the atmospheric fields from near-surface ERA5 in the past 20 years to generate surface fields consistent with the model surface scheme.
  - Ocean: ORAS5



MSC REPS

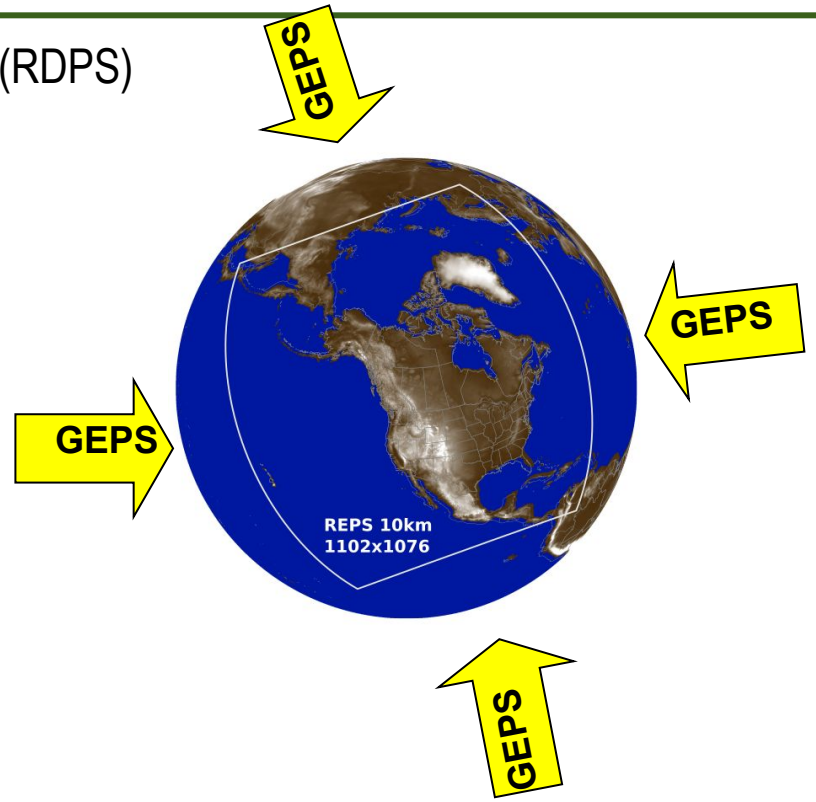


Integration done 4 times a day (00, 06, 12 and 18 UTC)

Current operational REPS description

- Similar domain as the Regional Deterministic Prediction System (RDPS)

- Horizontal resolution ~10 km grid spacing
- Vertical resolution: 68 vertical levels and model top of 17 hPa
- Model: GEM 5.1.0
- Time step of 5 mins.
- Runs/day: 4x (00, 06, 12, 18 UTC)
- Forecast range: 72 hours (3 days).
- Lid nesting

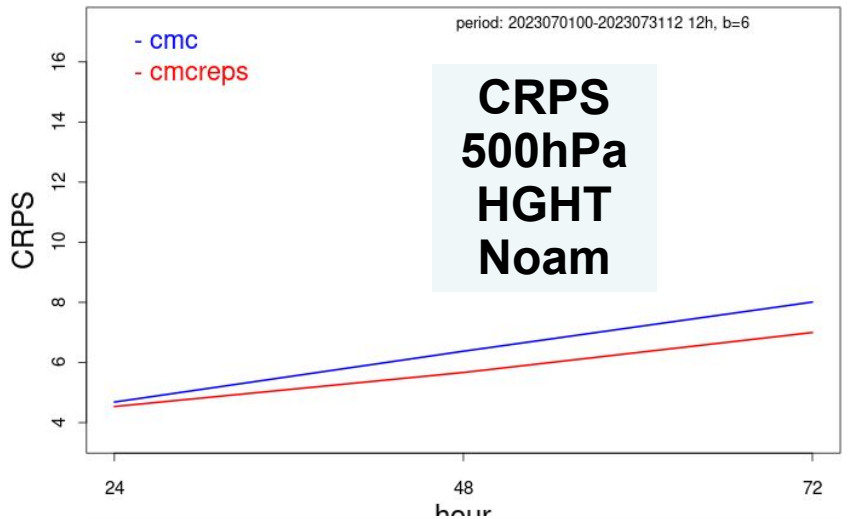


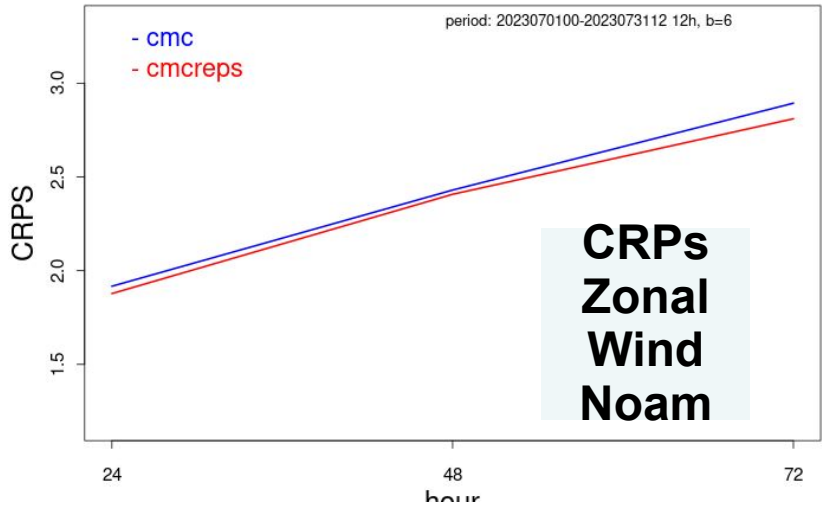
See the technical note of Patoine et al. 2021:
http://collaboration.cmc.ec.gc.ca/cmc/CMOI/product_guide/docs/tech_notes/technote_reps_e.pdf
See the specification table of the system :
http://collaboration.cmc.ec.gc.ca/cmc/CMOI/product_guide/docs/tech_specifications/tech_specifications_REPS_e.pdf

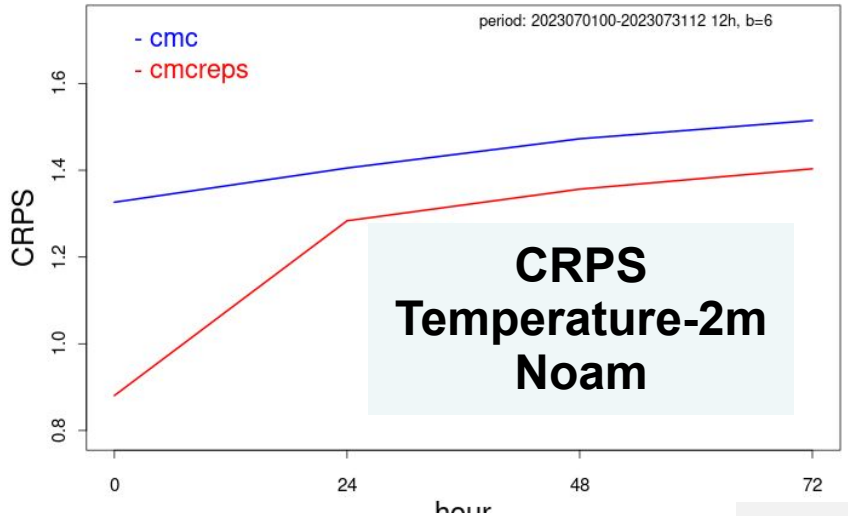
Main differences between REPS and GEPS

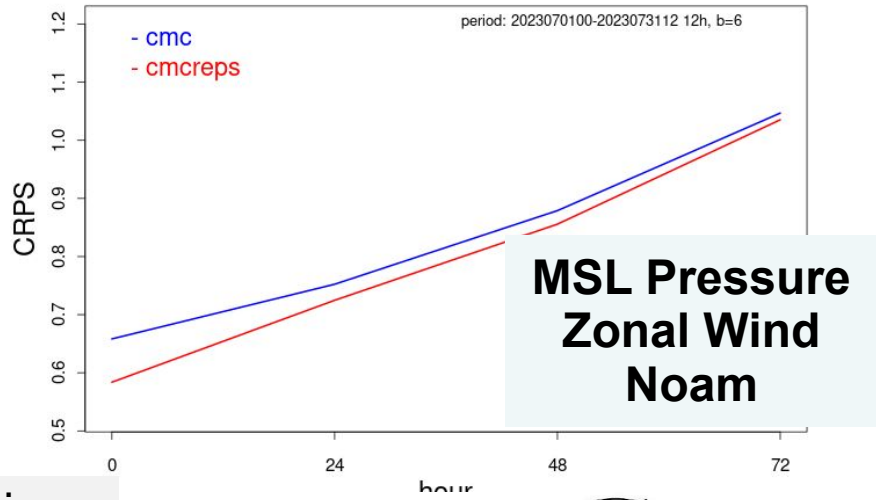
	REPS	GEPS
HIP std dev	0.8 near surface, decreases gradually to 0.5 in the high atmosphere	0.43
SPP	Yes	Yes
No. of SPP list	22	22
Diff in SPP list	cond_iceace (only for REPS)	adv_rhsint (only for GEPS)
Diff in SPP range	Kfctrig4, kfctrigwl, kfctrigwh, mid_minemf, sgo_phic, hu0min, hu0max	
SKEB	No	Yes
Grid spacing	10 km	39 km
Time step	5 min	15 min

Comparison between operational REPS and GEPS in July 2023





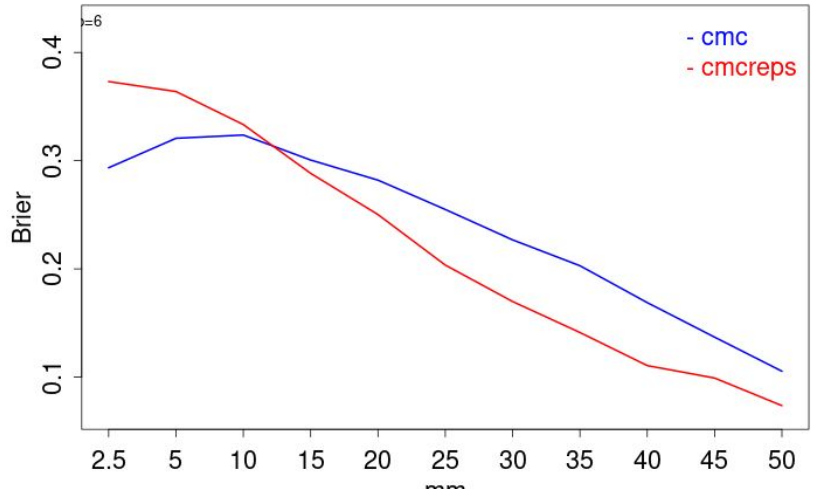




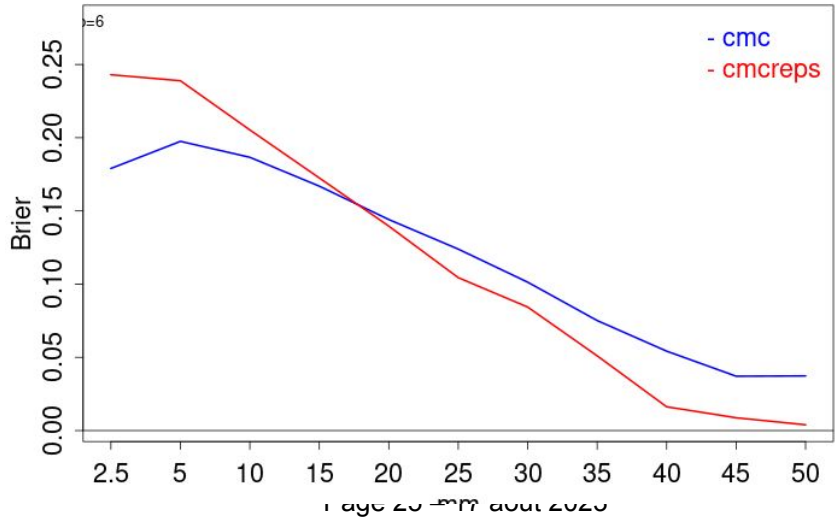
Against SYNOP observations North America

Comparison between operational REPS and GEPS in January 2023 for precipitation

Brier SS 24h



Brier SS 72h



Against SYNOP observations
North America

Canadian Ensemble Wave Prediction Systems

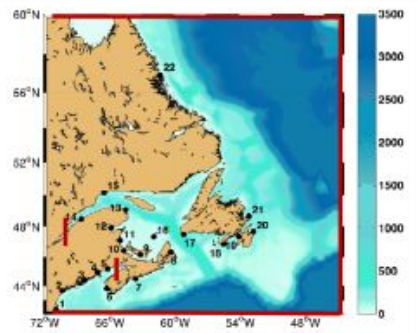
Acronym	GEWPS
Name	Global Ensemble Wave Prediction System
Domain	Global (Yin-Yang)
Model	WW3
Resolution	39 km
Duration	384 hours
Wind	GEPS E1
Ice	GEPS E1
Other	20+1 members

More info

Acronym	REWPS
Name	Regional Ensemble Wave Prediction System
Domain	Great Lakes 
Model	WW3
Resolution	2.5 km
Duration	72 hours
Wind	REPS ER
Ice	WCPS WF
Other	20+1 members

More info

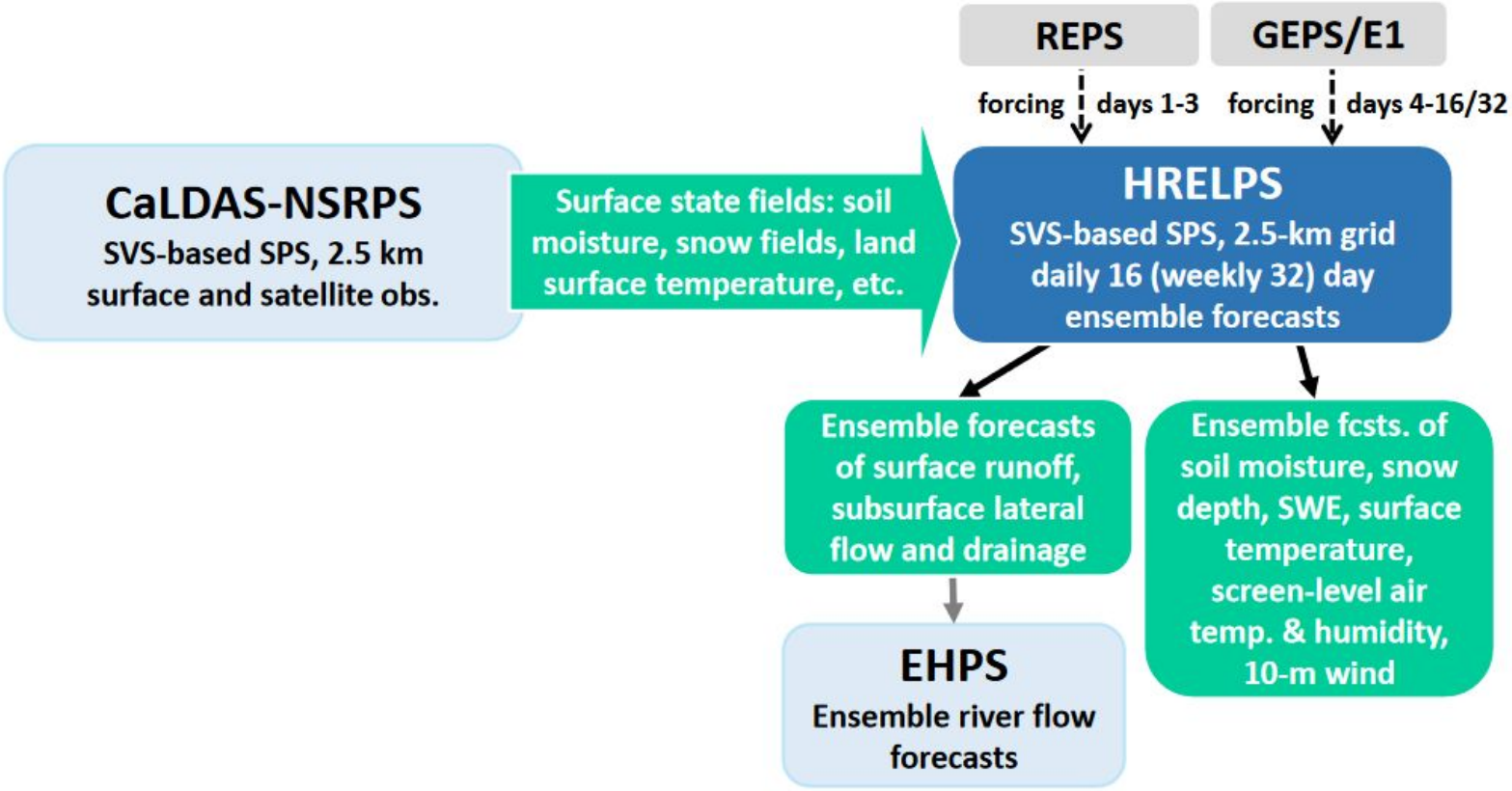
Regional Ensemble Storm Surge Prediction System

Name	Regional Ensemble Storm Surge Prediction System
Model	Dalcoast5, WebTide
Domain	 (1/12°)
Dependencies	(GEPS/e1: PN, UU, VV)
Variables	Storm surge (ETAS), Total water level (TWL, SSH)
Ensemble	20 members (+1 control), perturbed tide BC and atm. forcing

We are working on a global version.

More Information

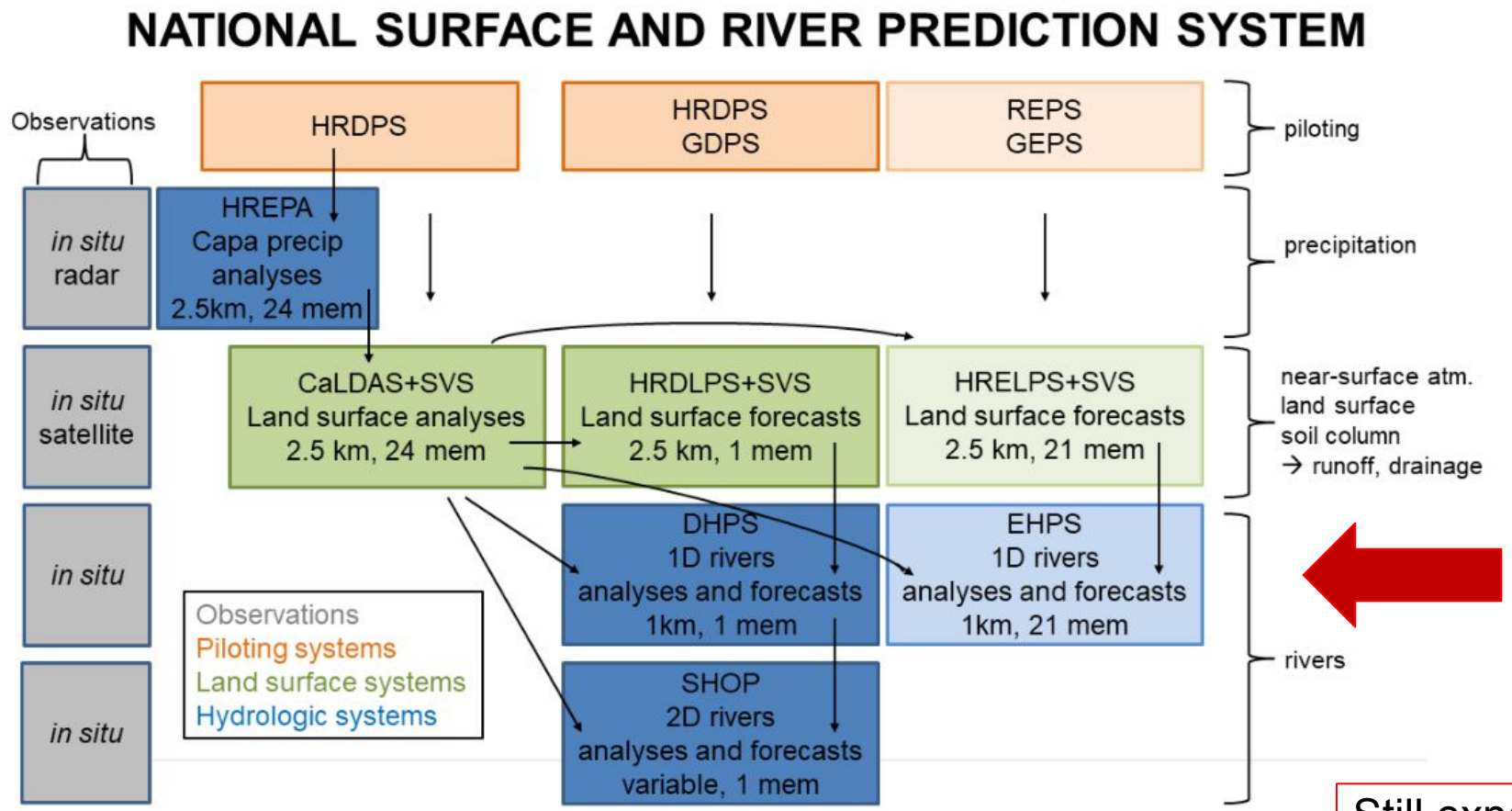
Canadian High resolution Ensemble Land Prediction System



Still experimental

From Deacu and Bélair

Canadian Ensemble Hydrological Prediction System



Still experimental

More information

Plan upgrade in 2024 (Innovation Cycle no.4)

- In May 2024, MSC will have upgraded its suite of NWEP systems to benefit from science innovations (from CCMEP/ASTD/ARQI) and increased computer power (from SSC).
- More specifically the main innovations are

For the GEPS:

- Upgrade the EnVar in the GEPS and revisit the hybrid gain approach
- Increased horizontal resolution from 39 to 25 km with SPP readjustments
- Own observations quality control (no more depency on deterministic system, GDPS)
- Delta-Eddington scheme for sea ice radiative transfer in NEMO

For the REPS:

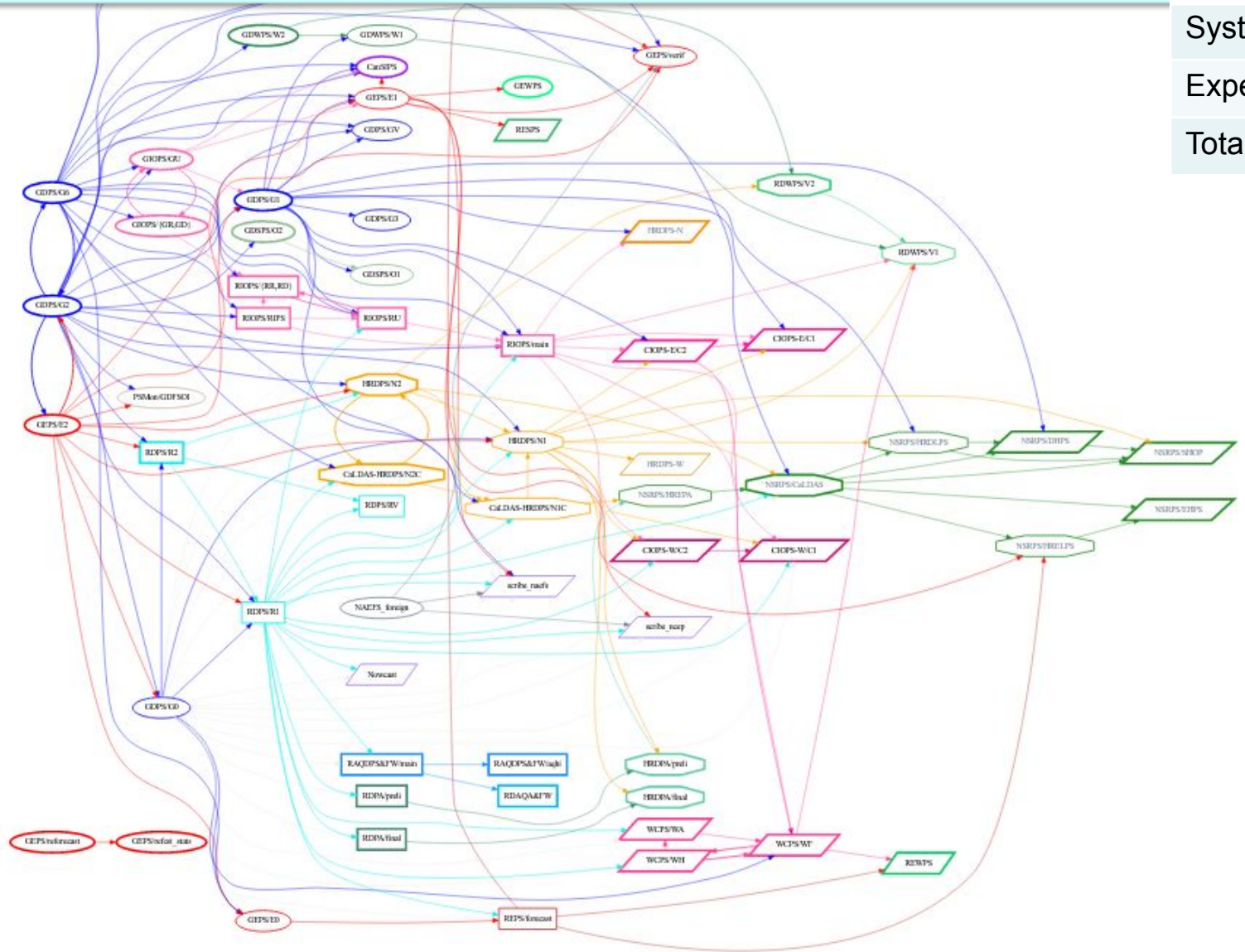
- New geophysical fields and SLEVE vertical coordinate
- RLETKF (for CI-5)

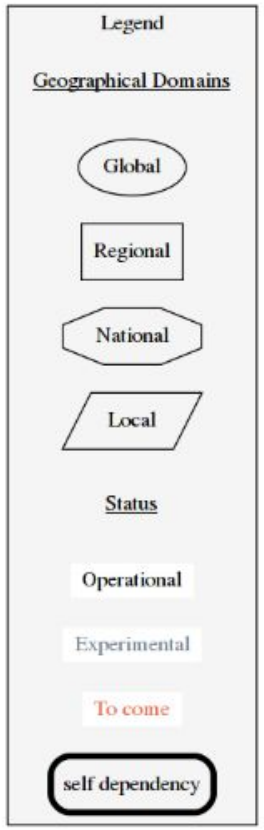
Main challenges

- **Complexity**: Too much system to maintain for the ressources that we have. How to make them converge ?
  - **DigiTal representation of the Earth System**: How to go toward that without getting lost ? Coupled specific components or everything ?

Operational System Diagram
(as of 2023-05-29)

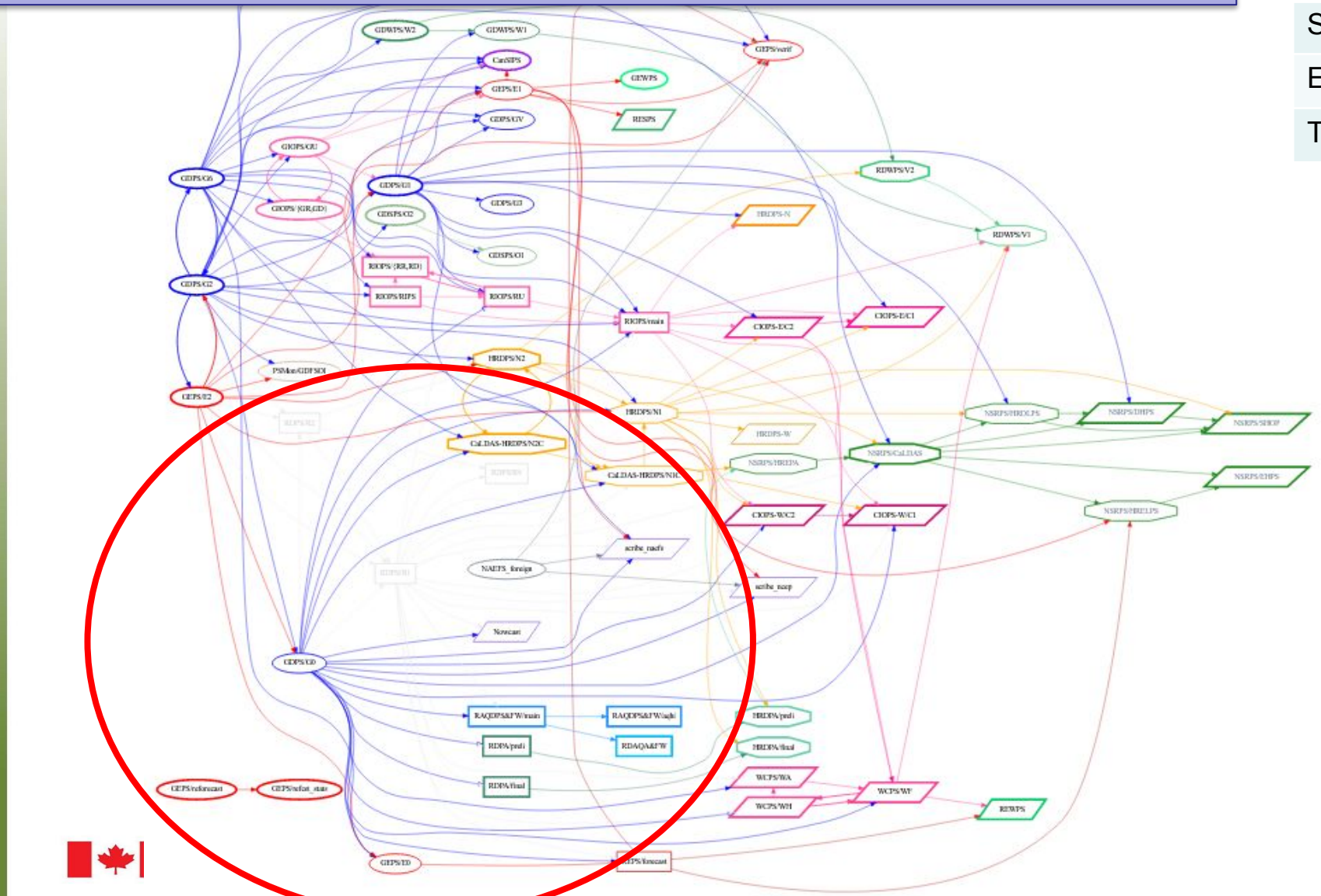
	Nb
Systems	31
Experiments (scheduler)	61
Total Dependencies	189

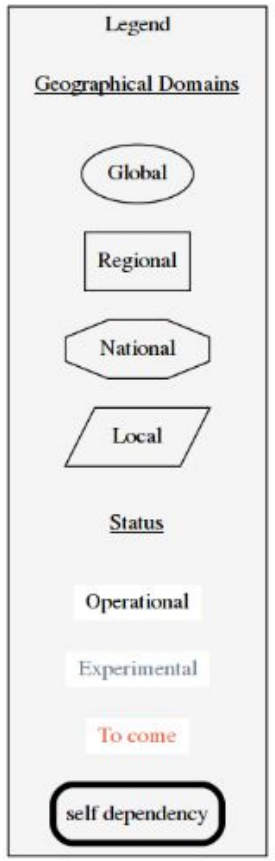




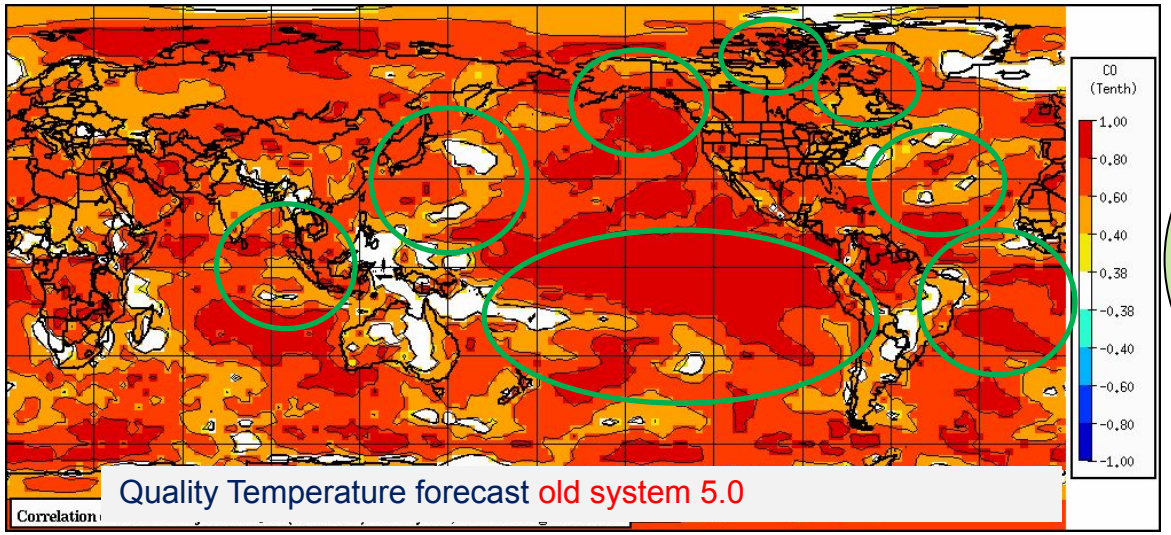
Planned Diagram post Innovation Cycle 4
(expected on 2024-05-01)

	Nb
Systems	32
Experiments (scheduler)	62
Total Dependencies	197

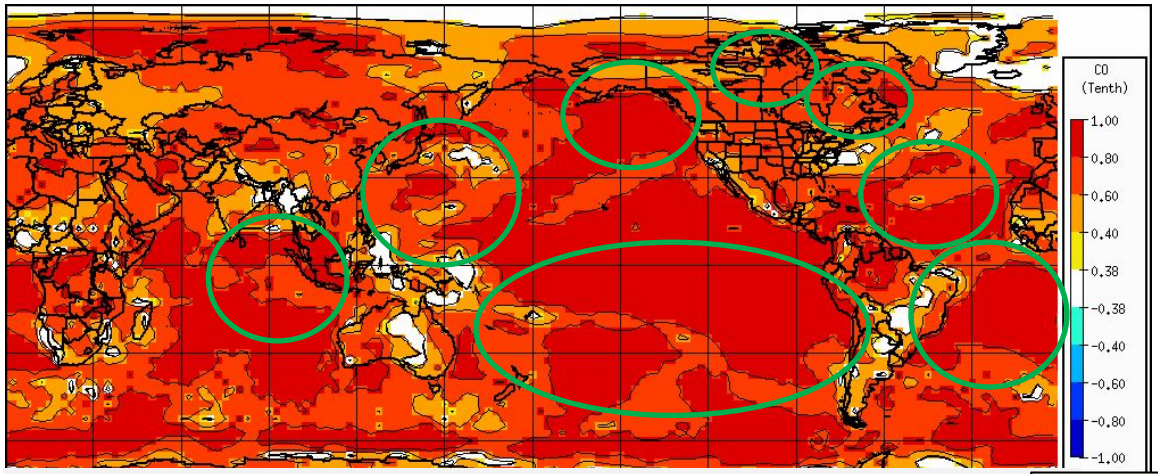




Clear improvement from ocean coupling for the GEPS long range forecasts!



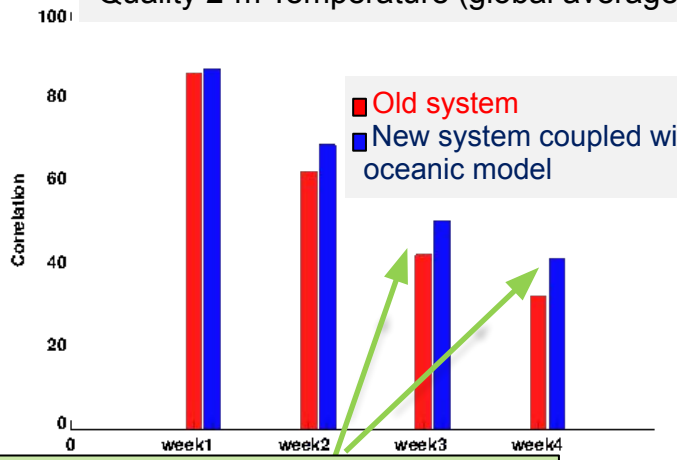
Quality Temperature forecast old system 5.0



Quality Temperature forecast new system 6.0 coupled with oceanic model

Increase of the correlation between the forecast temperature anomalies and those observed over most of the oceans and many parts of Canada!

Quality 2-m Temperature (global average)



The 4th week of the new system is now of same quality as the 3rd week of the previous system!

From J-S Fontecilla

Canada

Main challenges

- **Complexity**: Too much system to maintain for the ressources that we have. How to make them converge ?
  - **DigiTal representation of the Earth System**: How to go toward that without getting lost ? Coupled specific components or everything ?
- **Usage** of ensemble products in the main official forecast is still limited. How to improve on this ? *(More on this in Stéphane Gagnon presentation on Thursday)*
- **Relevance**: Spread versus skill, is it really working spatially ?
- **Surface perturbations** (land, ice and sea): How to do it accurately to represent the uncertainties ?
- **AI/ML**: how to grasp its powerfulness in ensemble forecasting ? What are the implications for our « standard » physically-based systems ?

THANK YOU FOR YOUR INVITATION AND …ATTENTION!