The Modernization of Surface and Atmospheric components in the high-resolution Canadian NWP model (HRDPS): a collaborative approach

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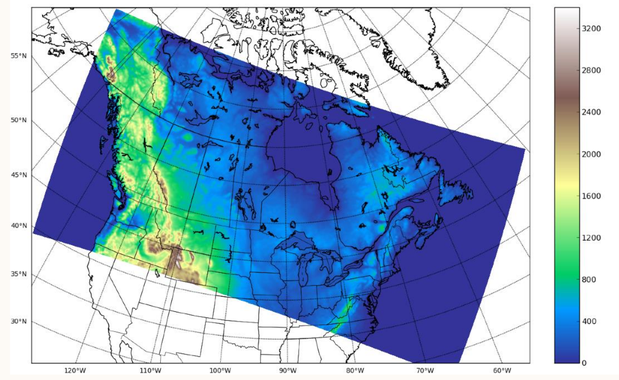
CONTEXT OF THE HRDPS AND ITS CURRENT LIMITATIONS

- The **H**igh **R**esolution **D**eterministic **P**rediction **S**ystem of ECCC is used for short-term prediction (6-48h) over Canada with a **2.5 km Δx**
- Based on the Global Environmental Multiscale (**GEM,** Zadra et al 2008) model similarly to the other lower-resolution NWP models used at the Meteorological Service of Canada
- **Current surface scheme ISBA** (Bélair, 2003) is out of date and too-simplistic for proper environmental prediction (e.g. hydrology, hydro-electricity, agriculture, etc.)
- **The new surface scheme SVS** (Snow, Vegetation and Soil, Leonardini et al, 2021) is only used in off-line mode for the moment (forced by the atmosphere) to serve specific client needs (HRDLPS)
- In the past, **innovation propositions** for operational systems were coming from **individual research group**: dynamics, atmospheric physics, land-surface physics, land-surface assimilation, atmospheric assimilation or ocean physics and assimilation) -> that led to **failing attempts to change the land-surface scheme in major operational models**
- This led to the creation of the **MOSA working group**, a new **collaborative** and **incremental approach** that includes 4-5 different research groups to propose a common innovation for the HRDPS with a new and up-to-date **surface physics and assimilation components** as well as a new **atmospheric physical package**. It will also include updates to the dynamic and atmospheric assimilation.

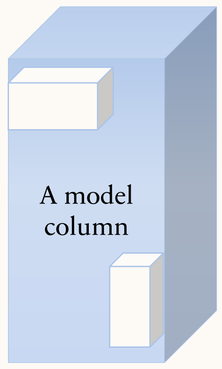


Dynamics / Numerics
Non-hydrostatic primitive equations
2-time-level fully implicit scheme
3D semi-Lagrangian advection
∇^2 horizontal diffusion on mom.
One-way lateral boundary nesting
dx=2.5 km, dt=60 s, dt_{rad}=15 min

THE COUPLED SYSTEM IN THE MOSA PROJECT

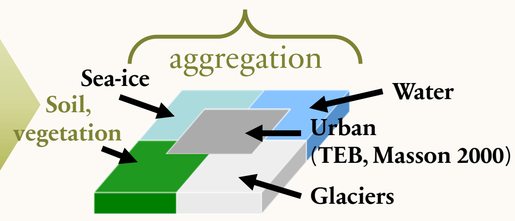
Operational Atmospheric Physics	Updates (following McTaggart-Cowan et al 2019)	ISBA (operational surface scheme)	SVS (surface scheme to be implemented)
Kain and Fristch deep convection (1990, 1993)	➢ Updates to the scheme ➢ Revisiting triggering parameters	**Single energy budget** (and temp.) **for snow, bare ground and vegetation**	**Separate energy budget** (and temp.) **for bare ground, vegetation and snow**
Kuo Transient shallow convection (Belair et al, 2005)	➢ Switch to Bechtold with no precipitation production	**2 soil** (**moisture**) **layers** and force-restore approach	**Multi-layer soil** (**moisture**) with vertical soil water diffusion based on Richard's equation and N soil layers
moisTKE (Belair et al, 1999)	➢ Revisiting PBL cloud production ➢ TKE advection ➢ Lmin approach ➢ Implicit fluxes	**Single snowpack** with snow temperature parameterized using average land surface temperature	**2 snowpacks with separate energy/water budget for each**: under high vegetation, and over low veg./bare ground
Correlated-k radiation (Li & Barker, 2005)	➢ Mainly updates and bugfixes		**Photosynthesis used for plant transpiration**
P3 microphysics (Morrison & Milbrant, 2015)	➢ Inclusion of a cloud fraction ➢ Better diagnostic of precip type		**Updated** surface roughness and land/vegetation characteristics such as sparseness, albedo and emissivity, **Updated** snow melt, surface runoff etc.

Atmospheric assimilation (Buehner et al 2015)



coupling by turbulent fluxes

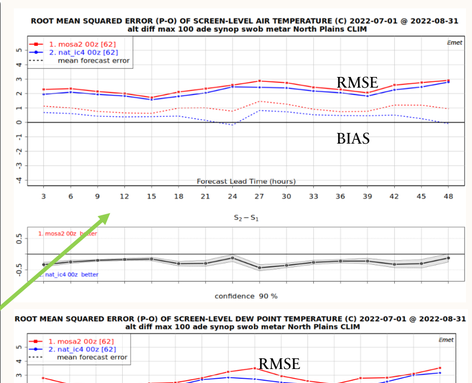
Surface assimilation (Carrera et al 2019)

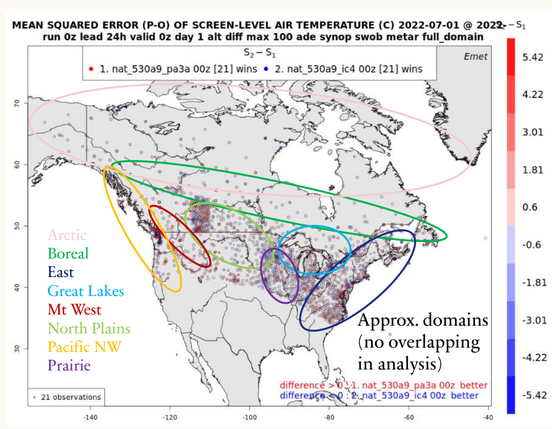


THE INCREMENTAL APPROACH AND RESULTS … SO FAR

First attempt to connect SVS in the HRDPS in a coupled assimilation cycle

rmse mosa2 / nat_ic4		20211006 / 20211231			20220101 / 20220331			20220401 / 20220630			20220701 / 20220831		
		00z	12z	All	00z	12z	All	00z	12z	All	00z	12z	All
Arctic plus CLIM	TD	-0.078	-0.1	-0.1	-0.21	-0.22	-0.22	0.3	0.35	0.33	-0.14	-0.1	-0.13
	TT	-0.14	-0.15	-0.14	-0.23	-0.25	-0.25	0.14	0.16	0.16	0.1	0.16	0.14
Boreal CLIM	TD	0.011	-0.0074	0.0067	-0.0024	-0.041	-0.018	-0.024	-0.033	-0.032	-0.33	-0.37	-0.36
	TT	-0.031	-0.088	-0.059	-0.0015	-0.02	0.0	0.17	0.11	0.14	-0.17	-0.17	-0.17
East CLIM	TD	-0.011	-0.013	-0.014	0.053	0.05	0.044	-0.2	-0.23	-0.25	-0.64	-0.73	-0.71
	TT	-0.19	-0.2	-0.19	-0.11	-0.15	-0.12	-0.021	-0.028	-0.02	-0.34	-0.41	-0.4
Great Lakes CLIM	TD	-0.082	-0.06	-0.05	0.021	-0.018	0.0088	-0.2	-0.26	-0.25	-0.58	-0.69	-0.66
	TT	-0.18	-0.19	-0.18	-0.046	-0.069	0.0	-0.036	-0.094	-0.065	-0.34	-0.37	-0.38
Mt West CLIM	TD	-0.038	-0.039	-0.027	0.12	0.046	0.1	-0.091	-0.12	-0.11	-0.41	-0.4	-0.4
	TT	-0.38	-0.44	-0.4	-0.098	-0.17	-0.13	0.031	0.0067	0.015	-0.24	-0.21	-0.24
North Plains CLIM	TD	-0.11	-0.14	-0.1	-0.07	-0.11	-0.1	-0.23	-0.27	-0.31	-0.31	-0.39	-0.35
	TT	-0.13	-0.19	-0.16	-0.17	-0.2	-0.19	0.012	-0.032	-0.004	-0.25	-0.26	-0.27
Pacific North West CLIM	TD	-0.13	-0.14	-0.14	-0.072	-0.12	-0.097	-0.087	-0.11	-0.096	-0.43	-0.42	-0.44
	TT	0.037	0.0026	0.022	0.02	-0.033	0.0	0.078	0.042	0.064	-0.08	-0.052	-0.063
Prairie CLIM	TD	-0.21	-0.22	-0.23	0.2	0.11	0.048	-0.27	-0.38	-0.36	-1.5	-1.7	-1.6
	TT	-0.27	-0.33	-0.3	0.18	0.13	0.14	-0.035	-0.075	-0.055	-0.93	-1.1	-1.1





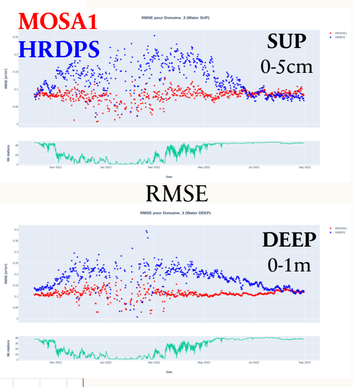
Examples of individual contributions

Individual tests are not done in fully coupled-assimilation cycles:

- Offline tests for surface forced by an atmospheric model
- Hindcasts for atmosphere from an existing analysis cycle

Many experiments later (over a 2-year period)

Soil water content evaluation



rmse 530a8_ms31f / 521_ms30s		20211006 / 20211130			20211201 / 20220228			20220301 / 20220531			20220601 / 20220831		
		00z	12z	All	00z	12z	All	00z	12z	All	00z	12z	All
Arctic plus CLIM	TD	0.45%	0.00%	0.33%	2.65%	2.28%	2.47%	0.69%	0.71%	0.44%	1.32%	1.42%	1.24%
	TT	1.69%	0.97%	1.23%	3.43%	3.11%	3.27%	2.53%	2.09%	2.30%	-0.28%	-0.82%	-0.46%
Boreal CLIM	TD	0.32%	-0.12%	-0.11%	2.28%	2.37%	2.59%	0.82%	0.96%	0.81%	1.40%	1.50%	1.65%
	TT	1.48%	0.00%	0.51%	3.42%	3.62%	4.11%	-0.40%	0.04%	0.21%	0.62%	1.28%	1.05%
Central CLIM	TD	0.10%	0.45%	0.36%	1.86%	1.95%	1.89%	0.69%	1.06%	0.73%	-2.05%	2.33%	2.19%
	TT	1.10%	1.29%	0.92%	3.57%	4.02%	3.88%	-0.06%	-0.37%	-0.29%	2.69%	4.17%	3.36%
East CLIM	TD	0.69%	0.72%	0.81%	0.19%	0.39%	0.28%	0.03%	0.27%	-0.20%	-2.06%	1.96%	2.09%
	TT	-1.50%	-1.16%	-2.45%	-0.42%	-1.47%	-1.16%	-1.46%	-1.79%	-1.53%	3.29%	2.25%	2.29%
Great Lakes CLIM	TD	-0.90%	-0.82%	-0.95%	0.49%	0.33%	0.31%	-0.12%	-0.10%	-0.20%	0.35%	8.33%	8.37%
	TT	-1.10%	-1.90%	-1.62%	1.12%	0.61%	0.73%	-0.80%	-0.16%	-0.86%	0.48%	1.73%	0.41%
Mt West CLIM	TD	-0.72%	-0.83%	-0.84%	-1.52%	-2.26%	-2.05%	0.52%	0.82%	0.75%	8.74%	8.60%	8.66%
	TT	-5.08%	-2.45%	-3.11%	-1.91%	-1.63%	-1.73%	-8.55%	-8.60%	-9.12%	13.65%	9.97%	11.74%
Pacific North West CLIM	TD	3.33%	2.23%	3.40%	2.98%	2.22%	3.37%	4.27%	3.69%	4.29%	6.12%	5.08%	5.63%
	TT	-0.57%	-0.56%	-0.28%	0.69%	0.04%	0.16%	-0.92%	-2.48%	-1.86%	6.66%	5.94%	5.85%

Atmospheric physics upgrades

- Increased vertical resolution in the PBL
- Reduced horizontal diffusion
- Switch to Bechtold for shallow convection
- Update to KF deep conv. Scheme
- Updates to the PBL schemes: TKE advection, better dissipation, etc
- Lmin approach and implicit fluxes for the surface layer
- Bugfixes in radiation and microphysics, etc

rmse 521_ms30s / 520rc3_ms30a		20211006 / 20211130			20211201 / 20220228			20220301 / 20220531			20220601 / 20220831		
		00z	12z	All	00z	12z	All	00z	12z	All	00z	12z	All
Arctic plus CLIM	TD	0.05%	0.00%	0.00%	-0.01%	0.02%	-0.00%	-2.08%	-1.88%	-1.91%	0.28%	0.82%	0.23%
	TT	0.04%	-0.12%	0.04%	0.00%	0.00%	0.01%	-0.19%	-0.38%	0.27%	-1.70%	-1.43%	-1.69%
Boreal CLIM	TD	0.68%	0.24%	0.43%	0.11%	0.15%	0.10%	2.59%	2.19%	2.39%	1.78%	6.23%	5.14%
	TT	-0.25%	-0.38%	0.24%	-0.01%	-0.00%	-0.01%	-0.98%	-1.21%	-1.06%	1.27%	1.65%	1.75%
Central CLIM	TD	-1.07%	-1.07%	-1.19%	-0.18%	-0.26%	-0.20%	2.34%	2.57%	2.77%	9.29%	10.53%	9.98%
	TT	-0.48%	-0.49%	-0.52%	-0.07%	-0.05%	-0.05%	-0.87%	-0.99%	-0.96%	8.02%	9.33%	9.59%
East CLIM	TD	0.03%	0.54%	0.52%	-0.22%	-0.12%	-0.17%	-0.82%	-0.44%	-0.56%	15.51%	13.55%	15.66%
	TT	-0.54%	-0.89%	-0.70%	-0.37%	-0.42%	-0.37%	-0.36%	-0.11%	-0.20%	10.37%	10.44%	11.05%
Great Lakes CLIM	TD	-0.92%	-0.97%	-1.02%	0.04%	-0.03%	0.01%	-2.14%	-1.93%	2.32%	15.97%	16.93%	16.62%
	TT	-0.64%	-0.67%	-0.63%	-0.04%	-0.03%	0.00%	-1.30%	-1.36%	-1.43%	11.99%	11.02%	12.21%
Mt West CLIM	TD	-0.64%	-0.76%	-0.59%	0.19%	-0.18%	0.06%	-1.36%	-1.83%	1.98%	5.29%	5.84%	5.27%
	TT	-0.76%	-0.84%	-0.75%	-0.12%	-0.16%	-0.11%	-1.90%	-2.27%	-1.99%	3.39%	3.66%	3.49%
Pacific North West CLIM	TD	1.01%	1.14%	1.25%	0.53%	0.59%	0.53%	0.95%	0.87%	1.07%	8.35%	10.03%	9.48%
	TT	-0.22%	-0.28%	-0.21%	-0.04%	-0.13%	-0.10%	-0.59%	-0.61%	-0.51%	3.84%	3.01%	3.68%

Bug correction in soil textures

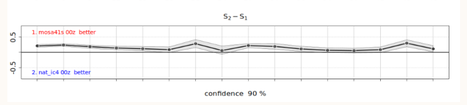
Latest coupled assimilation cycle with updated SVS and atmos. physics package

rmse mosa41s / nat_ic4		20211006 / 20211231			20220101 / 20220331			20220401 / 20220630			20220701 / 20220930		
		00z	12z	All	00z	12z	All	00z	12z	All	00z	12z	All
Arctic plus CLIM	TD	-0.0079	-0.028	-0.017	0.013	0.021	0.018	0.36	0.39	0.39	-0.062	-0.039	-0.052
	TT	-0.032	-0.044	-0.031	-0.00047	-0.0069	-0.0092	0.17	0.15	0.16	0.093	0.087	0.094
Boreal CLIM	TD	0.048	0.029	0.052	0.11	0.075	0.08	0.11	0.12	0.11	-0.011	-0.026	-0.021
	TT	0.0	-0.0024	0.0	0.11	0.1	0.089	0.21	0.13	0.17	0.061	0.034	0.056
East CLIM	TD	0.018	0.047	0.048	0.0044	-0.0094	0.0063	0.088	0.077	0.052	-0.17	-0.15	-0.15
	TT	-0.16	-0.22	-0.19	-0.029	-0.097	-0.051	0.091	0.076	0.089	0.0029	0.0021	-0.0024
Great Lakes CLIM	TD	0.058	0.091	0.075	0.1	0.087	0.096	0.14	0.11	0.12	0.034	0.061	0.053
	TT	-0.085	-0.12	-0.062	0.094	0.035	0.061	0.094	0.063	0.079	0.049	0.075	0.049
Mt West CLIM	TD	-0.013	-0.034	-0.0049	0.065	0.049	0.078	0.23	0.22	0.21	0.13	0.13	0.13
	TT	-0.44	-0.52	-0.48	-0.13	-0.24	-0.19	0.021	-0.024	-0.03	0.7	0.61	0.68
North Plains CLIM	TD	0.059	0.039	0.053	0.092	0.053	0.063	-0.059	-0.05	-0.064	0.13	0.15	0.16
	TT	0.065	0.0019	0.025	0.018	-0.038	0.0079	0.15	0.095	0.13	0.16	0.12	0.15
Pacific North West CLIM	TD	-0.07	-0.083	-0.075	-0.055	-0.09	-0.083	0.0019	-0.013	-0.013	-0.0036	-0.012	-0.0023
	TT	0.072	0.0099	0.039	0.044	-0.055	-0.0071	0.14	0.096	0.12	0.25	0.17	0.21
Prairie CLIM	TD	-7.2e-05	0.011	0.013	0.33	0.33	0.34	0.069	0.043	0.051	-0.58	-0.58	-0.61
	TT	-0.12	-0.22	-0.16	0.32	0.24	0.29	0.14	0.081	0.12	-0.27	-0.28	-0.31

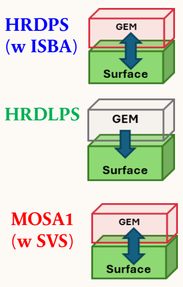
rmse 530a9_ms32a / 530a8_ms31f		20211006 / 20211130			20211201 / 20220228			20220301 / 20220531			20220601 / 20220831		
		00z	12z	All	00z	12z	All	00z	12z	All	00z	12z	All
Arctic plus CLIM	TD	0.40%	0.14%	0.35%	0.54%	0.50%	0.55%	6.79%	6.76%	6.65%	-0.75%	-0.51%	-0.60%
	TT	0.76%	0.66%	0.75%	0.64%	0.54%	0.60%	0.45%	0.64%	0.43%	0.64%	0.65%	0.63%
Boreal CLIM	TD	0.82%	0.99%	0.86%	0.73%	0.41%	0.64%	8.45%	7.88%	8.70%	4.33%	6.47%	5.61%
	TT	0.72%	0.69%	0.64%	0.89%	0.93%	0.92%	2.62%	3.16%	2.81%	3.61%	3.04%	3.40%
East CLIM	TD	3.30%	3.56%	3.60%	3.15%	3.73%	3.36%	6.47%	4.43%	6.13%	8.21%	9.64%	8.99%
	TT	2.39%	2.13%	2.26%	2.13%	2.78%	2.32%	3.45%	4.45%	4.04%	5.24%	6.80%	5.72%
Great Lakes CLIM	TD	9.20%	8.36%	9.60%	0.41%	1.85%	1.10%	10.17%	10.95%	11.36%	5.09%	7.08%	6.06%
	TT	4.44%	5.09%	4.93%	2.37%	1.74%	1.96%	5.29%	5.49%	5.65%	3.66%	2.44%	3.38%
Mt West CLIM	TD	1.67%	1.83%	1.63%	-1.14%	-0.20%	-0.58%	5.10%	5.39%	5.88%	8.14%	9.70%	8.48%
	TT	1.00%	1.30%	1.17%	0.66%	0.94%	0.63%	-2.73%	-3.54%	-2.91%	0.41%	-0.50%	0.03%
North Plains CLIM	TD	7.25%	6.96%	7.94%	1.88%	3.71%	2.84%	12.43%	10.95%	13.03%	3.56%	4.28%	3.76%
	TT	2.61%	2.72%	2.82%	0.84%	1.53%	1.18%	2.59%	4.12%	3.73%	3.78%	4.44%	4.47%
Pacific North West CLIM	TD	3.40%	4.10%	3.98%	2.32%	4.43%	3.65%	3.98%	2.98%	3.60%	3.65%	4.71%	4.19%
	TT	0.01%	0.33%	0.05%	0.63%	0.94%	0.59%	0.93%	1.30%	1.17%	-0.32%	-1.23%	-0.72%
Prairie CLIM	TD	14.89%	14.59%	16.44%	3.58%	4.82%	3.83%	16.88%	17.28%	18.58%	11.24%	13.50%	12.54%
	TT	6.82%	7.84%	7.81%	2.37%	1.93%	1.92%	6.62%	7.46%	7.72%	7.17%	9.44%	8.59%

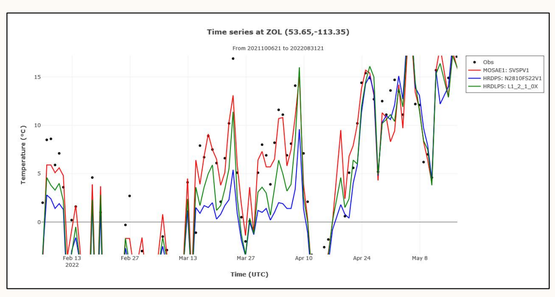
Land surface scheme (SVS) upgrades

- Revisited bare ground evaporation based on Albergel et al (2012) approach (see V. Fortin's presentation)
- Reduced stress vegetation
- Roots depth modifications for crops
- Modification to fraction vegetation in plain regions
- Better use of GSDE and SOILGRIDS datasets for soil depths



THE IMPORTANCE OF COUPLING



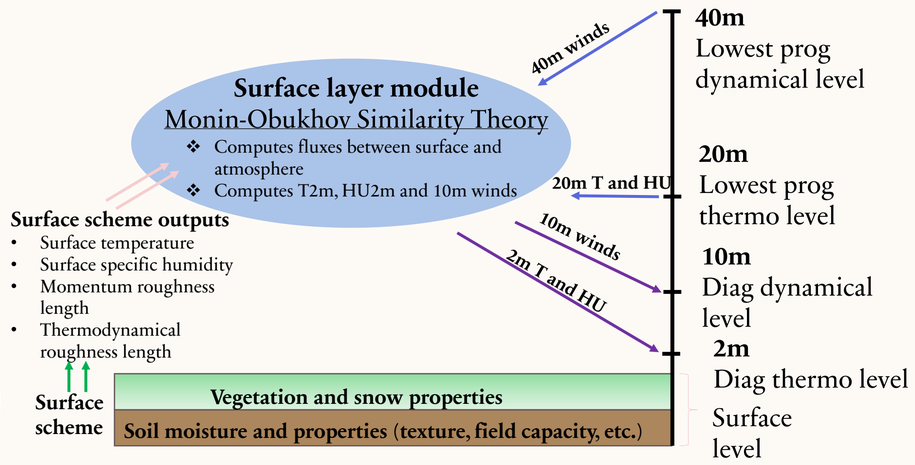


Example of 2m T at a station (Edmonton, AB):

- the HDRPS (with the ISBA surface scheme) is too cold during afternoon when snow is melting;
- even with SVS surface scheme, the offline HRDLPS tends to have similar biases to its driving model;
- the first attempt of coupled MOSA (HDRPS w SVS) experiment shows better temperature results

NEXT STEPS & CHALLENGES

- A variety of climate regimes and vegetation types: very challenging to 1- analyse and 2- improve everywhere 3- in different seasons
- Changing the atmospheric vertical levels has many repercussion on the model balance and parameterizations for both the surface and atmosphere
- Coupled assimilation cycle experiments are expensive and take time (and there's a lot of data!)
- Choosing an appropriate sequence in experiments can be challenging (e.g.: if precipitation is adjusted, how the surface is going to adjust?)
- Understanding the research done by other groups need a good collaboration and patience!
- Much more to come: clouds, precipitation, radiation, snow, etc.



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