Environnement et Changement climatique Canada | Environment and Climate Change Canada

Canada

NWP Centre reports:

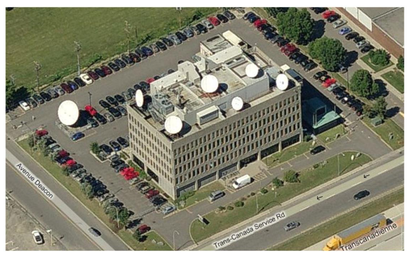
Recent upgrades and developments in the use of satellite radiances at ECCC

J. Aparicio, S.-J. Baek, M. Bani Shahabadi, P. Beaudoin, A. Beaulne, J. Bédard, M. Buehner, J.-F. Caron, C. Côté, J. DeGrandpré, P. Du, G. Gobeil, N. Gagnon, S. Heilliette, A. Komarov, E. Lapalme, T. Milewski, Y. Rochon, S. Skachko, A. Tatarevic, K. Tereszhuk

Environment and Climate Change Canada
Canadian Meteorological Center, Dorval, Québec, Canada

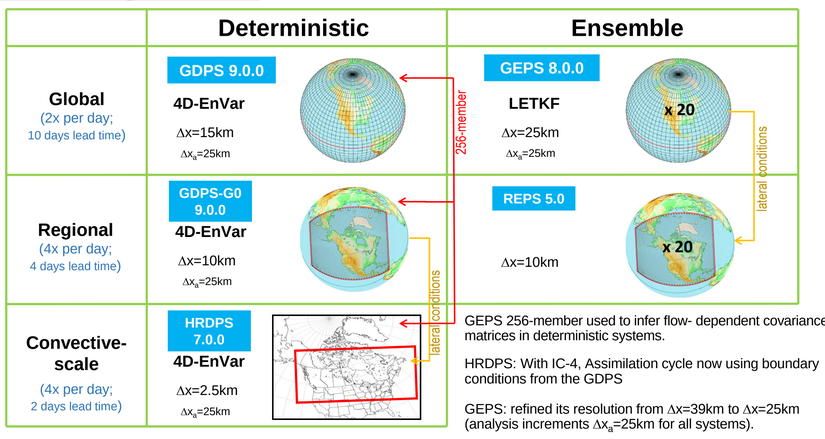
Contact:
aleksandra.tatarevic@ec.gc.ca

The 25th international TOVS Study Conference (ITSC-25) Goa, India 8 - 14 May 2025



Environment and Climate Change Canada (ECCC) implemented major upgrades to its weather and environmental prediction systems on June 11, 2024, bringing over 100 scientific innovations in more than 30 atmospheric, oceanic, hydrological and surface forecasting systems. Refinements to radiance data assimilation methodologies were done in two operational deterministic (global and high-resolution) systems using an 4D-EnVAR analysis scheme and one ensemble (global) system using a LETKF analysis scheme. They include updating the RTTOV observation operator to version 13 as well as the use of RTTOV-SCATT, extending all-sky assimilation to ATMS temperature channels 5 and 6 and MHS humidity channels, the use of purely flow-dependent background error covariances and, for the ensembles, their own separate processing of observations. Moreover, the FSOI system was upgraded to use a wet norm, and a new norm was added between 100hPa and 1hPa for the Global domain, while an automatic anomaly detection was added to the PSMON observation monitoring system.

NWP Systems



GEPS 256-member used to infer flow- dependent covariance matrices in deterministic systems.

HRDPS: With IC-4, Assimilation cycle now using boundary conditions from the GDPS

GEPS: refined its resolution from Δx=39km to Δx=25km (analysis increments Δx_a=25km for all systems).

IC-4 Data Assimilation Innovations (June 2024)

Observation-related changes

- RTTOV: upgraded from version 12 to version 13
- All-sky assimilation for ATMS temperature and AMSUB/MHS humidity channels (Shahabadi and Buehner, 2021 and 2024)
- Optimal use of radiosondes in BUFR
- Use of all available SYNOP BUFR reports
- Modifications of hyperspectral infrared QC to cope with albedo changes
- Assimilation of SWOB and METAR reports

Ozone

- Applying piecewise weighted averaging interpolation as alternative to piecewise linear interpolation (Rochon et al, 2007)
- Applying weighted integration to total column ozone observations as strong constraint on increment profiles

EnVar-related changes

- Various changes
  - Background error covariances : Using a fully ensemble-derived **B** in 4DEnVar instead of NMC
  - A small reduction of the horizontal localization for the largest scales
  - Using the same vertical levels as in GEPS (84 staggered hybrid levels instead of 80) for the computation of the analysis increments and in quality control for obs-minus-background computation
  - Removal of the Hessian matrix cycling
  - Reference state for the radiance bias correction coefficients computation: Moving from 3DVar to 3DEnVar with a fully ensemble-derived **B**
- Correction to the minimum humidity threshold for $\mathbf{B}_{ens}$
- Correction to the water saturation functions
- Use of **25 km** (instead of 39 km) **ensemble of backgrounds from the new GEPS**

FSOI https://hpfx.collab.science.gc.ca/~smco500/psmon/FSOI_monitoring

- The wet norm used in addition to the dry norm
- Addition of a new norm from 100hPa-1hPa for Global domain
- Use of simplified observation error covariance matrix R for radiance observation

Ensemble

- **Global Horizontal resolution** of 25 km instead of 39 km
- Its own separate treatment of observations (background check, bias correction, etc.)
- **Upgraded EnVAR** and **revisited a hybrid gain approach**

PSMON https://hpfx.collab.science.gc.ca/~smco500/psmon/monitoring/g2

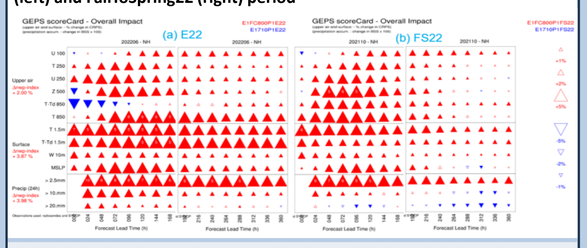
- New observations monitoring system **with automatic anomaly detection**

Modifications to the assimilation component of the GEPS and GDPS

The major change resulting in significant forecast improvements is the increase in horizontal resolution from 39 km to 25 km. Other changes enhance consistency between GEPS and GDPS, including the introduction of observation background checks and bias correction procedures in GEPS identical to those used in the GDPS. The 4D-EnVar configuration in GEPS now utilizes a fully ensemble-derived B matrix, the same horizontal localization parameters as the GDPS, including scale-dependent localization, and eliminates the need for cycling of the Hessian matrix.

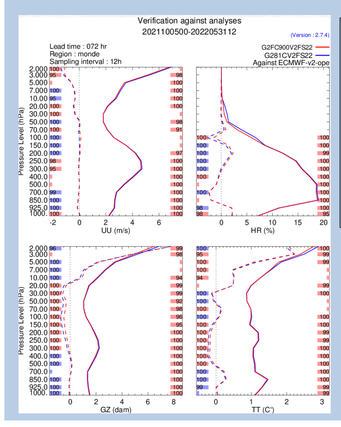
Additional changes in the data assimilation component, aligned with the GDPS, include the use of RTTOV-13, optimal usage of radiosonde data, incorporation of all available SYNOP BUFR reports, assimilation of SWOB and METAR reports, corrections to water saturation functions, updates to the sources of sea-ice concentration, snow depth on sea ice, and ice thickness, and modifications to hyperspectral infrared quality control to accommodate albedo changes.

Summary of probabilistic verifications on Northern Extratropics in the form of scorecard showing percentage change in CRPS for upper air and surface fields and in BSS for 24h precipitation accumulation during Summer22 (left) and FallToSpring22 (right) period



Red (blue) triangles indicate an improvement (deterioration), filled triangles indicate that it is significant based on block bootstrapping. The size of the triangles represents the amplitude of the change in percentage as shown by the legend on the right. Changes larger than 5% are labelled within the triangles. The labels on the left identify the variable and pressure level (hPa) for upper-air fields (threshold for precipitation). U = u-wind component, Z = Geopotential Heights, T-TD = Dew point depression, T = Temperature, W = wind speed. (a) E22; (b) FS22.

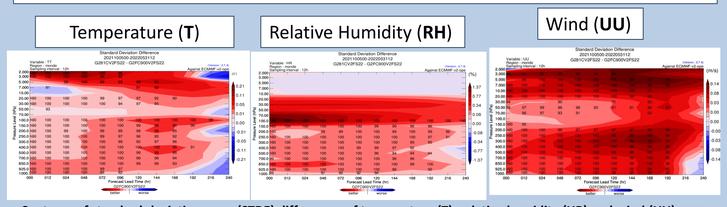
Upper-air verification scores of forecasts at 72h lead time from GDPS 9.0.0 (red) and GDPS 8.1.0 (blue) against ECMWF operational analysis over the World during the extended fall-to-spring 2021- 2022 season.



Upper-air verification scores of forecasts at 72h lead time from GDPS 9.0.0 (red) and GDPS 8.1.0 (blue) against ECMWF operational analysis over the world. The standard deviation (solid lines) and bias (forecast minus analysis; dashed lines) are shown for u-wind component (UU; upper left panels), relative humidity (HR; upper right panel), geopotential height (GZ; bottom left panel), temperature (TT; bottom right panel). Scores are averaged over all cases. Boxes on the left (right) indicate the level of statistical significance for bias (standard deviation). Red (blue) boxes indicate that version 9.0.0 has a lower(higher) bias or standard deviation above a 90% confidence level than version 8.1.0. No box means no significant difference between the two versions.

Difference in Error standard deviation of GDPS forecast against the analyses (ECMWF)

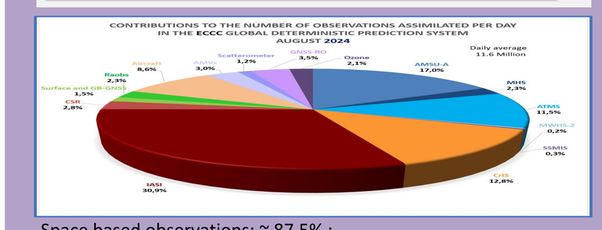
Temperature (**T**) | Relative Humidity (**RH**) | Wind (**UU**)



Contours of standard-deviation error (STDE) differences of temperature (T), relative humidity (HR) and wind (UU) versus ECMWF operational analysis from the surface to 1 hPa as a function of forecast lead time during the extended fall-to-spring 2021-2022 season. Red (blue) mean that GDPS 9.0.0 leads to lower (higher) STDE value than GDPS 8.1.0.

Comparison against ECMWF operational analysis shows significant improvements in the STDE for nearly all heights, variables, and lead-times in the troposphere. There is a slight tendency towards tropospheric warming due to a newly introduced correction related to the double application of deep convection trends in the GEM model. For the upper stratosphere, significant improvements in the STDE of the wind, geopotential and temperature are also seen in all regions, notably in the Tropics (not shown). Improvements in upper tropospheric temperature STDE and mean bias are partly related to the transition to a fully ensemble-derived B matrix for the 4D-EnVar. A moistening tendency and a reduction in standard deviation of RH around the tropopause level are related to the correction to the water saturation functions and the correction of the minimum humidity threshold for **B**ens.

Assimilated radiance data



Space based observations: ~ 87,5% ;
Terrestrial based observations: ~12,5%

These tables indicate the current usage of the various instruments assimilated into the global, regional and high-resolution deterministic systems. Instruments written in green background are planned for on-the-fly implementation within the next year.

Use of Microwave Sounder radiances

Instruments	Satellites	DBNet	Channels			
			sea	sea/low topo	sea/land	All-sky
AMSU-A	NOAA-15/18/19 Metop-B/C	Yes	4, 5	6	7 - 14	4, 5
MHS	NOAA-19 Metop-B/C	Yes	2, 5		3, 4	Yes
ATMS	NPP, NOAA-20/21	No	5, 6, 17 - 19	7, 8, 20 - 22	9 - 15	5, 6
MWHS-2	No Global obs	FY-3D, FY-3E	10, 14 - 15	11 - 13		No

Use of Microwave Imager radiances

Instruments	Satellites	DBNet	Channels			
			Sea	sea/low topo	sea/land	All-sky
SSMIS	DMSP-17/18	No	12 - 18			No

Use of Geostationary infrared radiances

Instruments	Satellites	Channels				
		sea	sea/low topo	sea/land	CSR	ASR
SEVIRI	MeteoSat-9/11		6.2, 7.3 um		N/A	Yes
ABI	GOES-16, GOES-18		6.2, 6.9, 7.3 um		Yes	No
AHI	Himawari-9		6.2, 6.9, 7.3 um		Yes	No

Use of Hyperspectral Infrared Sounder radiances

Instruments	Satellites	DBNet	Number of channels							
			LW (CO2)		LW (Window)		MW (H2O)		SW (CO2)	
			land	ocean	land	ocean	land	ocean	land	ocean
CrIS	NOAA-20/21	No	44		0	17	29 N/A on NPP		0	13
IASI	Metop-B/C	No	75		0	23	35		0	9

R&D innovations towards IC-5

Upgrade to RTTOV v14

- Use of the latest version of the radiative transfer model.

Addition of new satellite observation sources

- Addition of **sea surface wind** observations from the **HSCAT scatterometer** of the **HY-2B and HY-2C** satellites.
- Addition of **ozone total column** observations from the **OMPS** instrument of the **NOAA-21** satellite
- Addition of **NOAA21 ATMS** and **CrIS-FSR** radiances
- Addition of **microwave radiances sensitive to water vapor** from **FY-3D** and **FY-3E DBNets**

All-sky for ATMS humidity channels

- Extension of **all-sky assimilation to ATMS humidity channels** (Shahabadi and Buehner, 2021 and 2024)

Continuous development of MIDAS (Buehner et al. , 2025)

- Finalisation of integration of the quality control processing and thinning procedure for all radiance instruments data.
- Better modularity and consolidation will improve and ease future work in data assimilation development.

A unified global sea ice concentration analysis

- Currently, there is a 10-km global sea ice concentration analysis and a 5-km regional analysis. The proposal is to increase the resolution of the global analysis such that it would fulfil the needs of all applications in a single analysis.

Removal of static bias correction of high-peaking channels

- Currently static for AMSU-A ch. 13-14 and ATMS ch. 14-15 (coefficients based on air-mass predictors) to prevent bias drifts. All other radiances dynamic.
- Planned usage of weighted averages of dynamic and static bias correction (ultimate goal would be purely dynamic bias correction for all radiances).

Further outlook & radiance data assimilation

- Increase the GEPS data assimilation cycle resolution from 25km to 15km
- Improve the spatial observation thinning strategy: develop and use distance dependent thinning methodology instead of the old grid-box based method. Currently the new methodology is applied successfully for ATMS radiances.
- All sky assimilation for IASI
- Introducing an automated channel selection (DFS) procedure for hyperspectral instruments (Coursol et al., 2024)

REFERENCES

- Bani **Shahabadi**, M., and M. **Buehner, 2024**: Implementation of All-Sky Assimilation of Microwave Humidity Sounding Channels in Environment Canada's Global Deterministic Weather Prediction System. Mon. Wea. Rev., 152, 1027–1038, https://doi.org/10.1175/MWR-D-23-0227.1.
- Bani **Shahabadi**, M. , and M. **Buehner, 2021**: Toward all-sky assimilation of microwave temperature sounding channels in environment Canada's global deterministic weather prediction system. Mon. Wea. Rev., 149, 3725–3738, https://doi.org/10.1175/MWR-D-21-0044.1.
- **Buehner**, Mark & **Caron**, Jean-Francois & **Lapalme**, Ervig & **Caya**, Alain & **Du**, Ping & **Rochon**, Y. & **Skachko**, Sergey & Bani **Shahabad**i, Maziar & **Heilliette**, Sylvain & **Deshaies-Jacques**, Martin & **Chang**, Weiguang **& Sitwell**, Michael. (**2025**). The Modular and Integrated Data Assimilation System at Environment and Climate Change Canada (MIDAS v3.9.1). Geoscientific Model Development. 18. 1-18. 10.5194/gmd-18-1-2025.
- **Coursol**, L., S. **Heilliette**, and P. **Gauthier**, 2024: A Comparison of Channel Selection for the Assimilation of CrIS Radiances for NWP. J. Appl. Meteor. Climatol., 63, 665–675, https://doi.org/10.1175/JAMC-D-23-0188.1
- **Rochon**, Y., L. **Garand**, D.S. **Turner** and S**. Polavarapu**. **2007**: Jacobian mapping between vertical co-ordinate systems in data assimilation. Q.J.R. Meteorol. Soc. 133 1547-1558. doi: 10.1002/qj.117
- **GEPS Technical Note, 2024**: Global Ensemble Prediction System (GEPS): Update from version 7.1.0 to version 8.0.0. Canadian Meteorological Centre Technical Note. [Available on request from Canadian Meteorological Centre, development division, 2121 Trans-Canada Highway, Dorval, Québec, H9P1J3 or via the following web site: https://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/tech_notes/technote_geps-800_e.pdf]
- **GDPS Technical Note, 2024**: Global Deterministic Prediction System (GDPS). Update from version 8.1.0 to version 9.0.0 Canadian Meteorological Centre. Technical Note. [Available on request from Canadian Meteorological Centre, development division, 2121 Trans-Canada Highway, Dorval, Québec, H9P1J3 or via the following web site: https://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/tech_notes/technote_gdps-900_e.pdf]