Environment and Climate Change Canada
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Implementation of slant-path radiative transfer in Environment Canada's Global Deterministic Weather Prediction system

Maziar Bani Shahabadi, Mark Buehner, Josep Aparicio, and Louis Garand

Environment and Climate Change Canada

Background

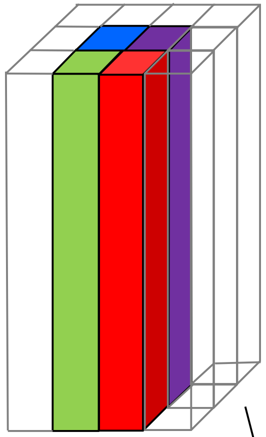
- The standard approach in NWP for assimilation of the radiances is to interpolate all levels of the 3D background (and increment) field to the same horizontal location as input to the radiative transfer model.
  - This neglects that the instrument line-of-sight is slanted through the atmosphere for off-nadir observations.
  - Consequently, this approach adds significant error for radiative transfer simulation, especially at large zenith angle.
- Bormann (2017) used a 2D interpolator to construct a series of vertical profiles along the observation azimuthal plane that are then horizontally interpolated at each model level to approximate the viewing path.

Background

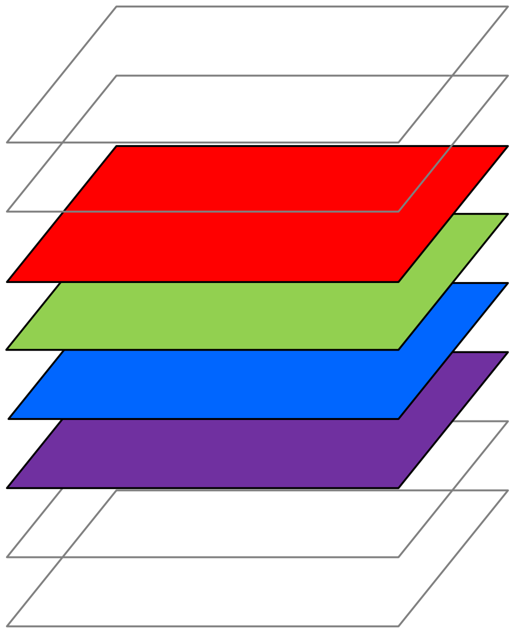
- In our recent effort at ECCC, we used coarse-resolution background horizontal gradients to build slanted line-of-sight for the simulation of radiance observations (Bani Shahabadi et al., 2018).
    - Gradients were calculated offline.
    - Only the non-linear observation operator used the slant path calculation, while the tangent linear/adjoint operators used the vertical profiles.
- All studies show forecast improvement at high latitudes in the stratosphere and during first 3 days in troposphere, when compared against own analyses.
- Our current focus is to perform slant-path RT calculation directly within 4D-EnVar for non-linear, tangent linear, and adjoint observation operators.
- Involves extra MPI communication so that each MPI task has a complete 2D field for one level and variable at the time of horizontal interpolation

Methodology

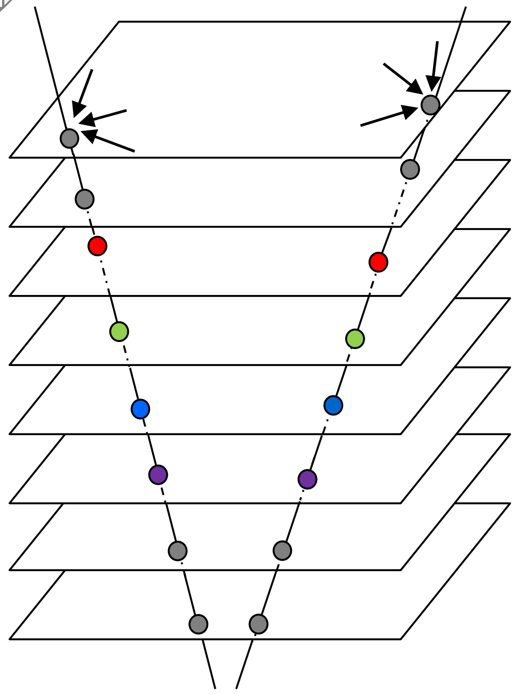
Each color represents a different MPI task



Global all-to-all MPI communication

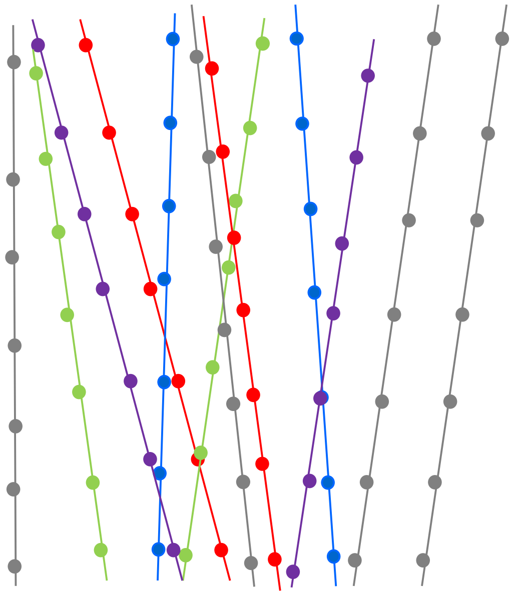


Horizontal+time interpolation



Global all-to-all MPI communication

Random subset of obs on each MPI task



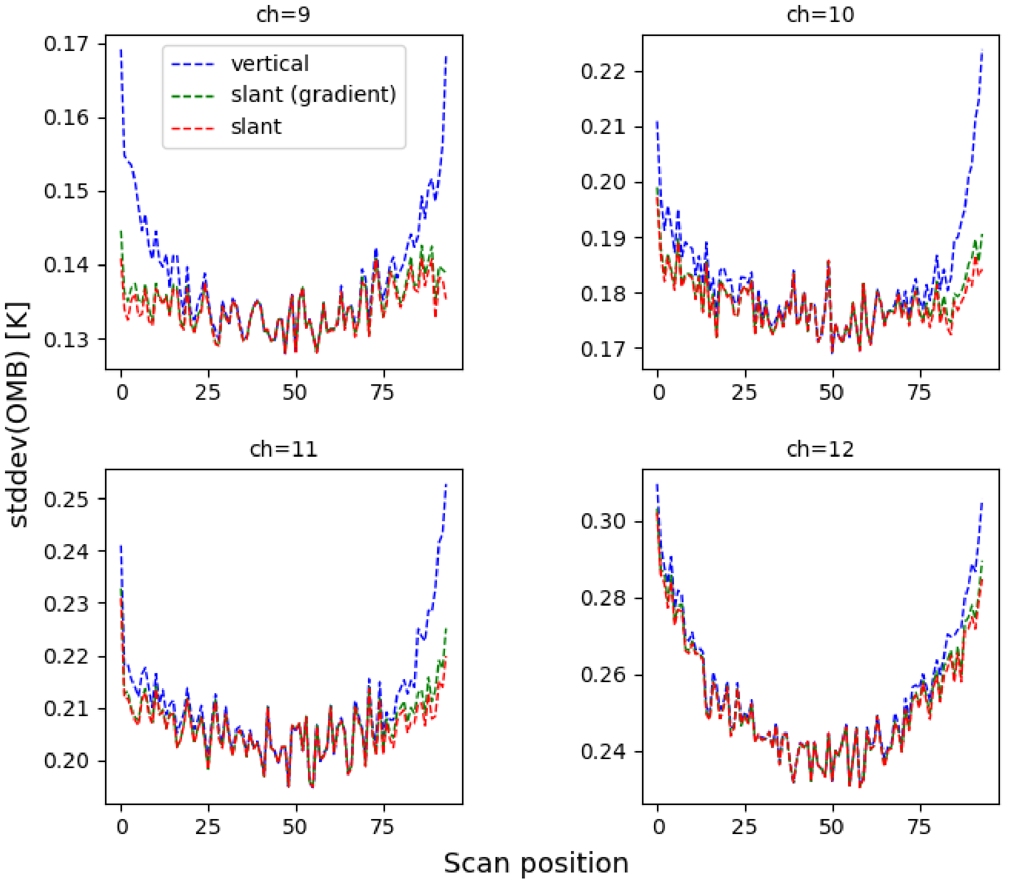
Additional motivation

- The introduced changes to horizontal interpolation for the slant-path calculation are flexible and the same code can be used in global and high-resolution regional deterministic assimilation systems.
- Performing horizontal interpolation on complete 2D fields facilitates use of a foot-print observation operator:
  - Important when model resolution much finer than observation footprint size.
  - Already used for sea-ice data assimilation.
  - Will be used in the high resolution NWP (2.5 km background state) for all radiance observations.
  - In the old method, the required extra MPI communication would be less straightforward.
- Weather radar data assimilation
  - Representing each radar beam as a slanted path simplifies the structure and processing of radar data.

Simulation of observations

- The background states (3-9 h short-range forecasts) discretized in 15-min timeslots are interpolated in time and to the observation horizontal location. Both vertical and slanted profile are extracted and fed to RTTOV to simulate the observation.

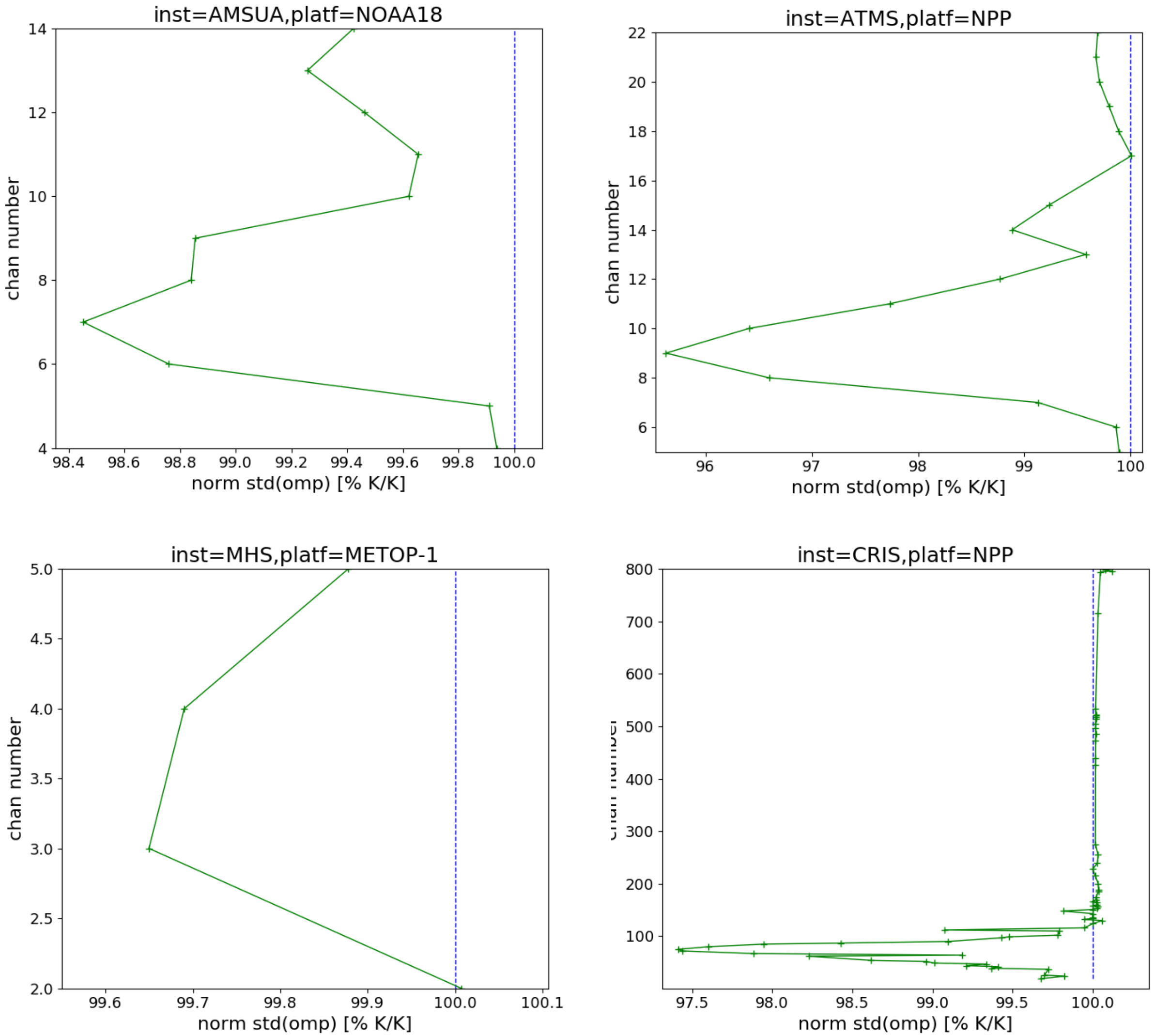
stddev of ATMS channel 9-12 innovations as function of scan position, using vertical profiles (blue), slant profiles from gradient approximation (green), and slant profile from current approach (red). The statistics are calculated based on global, bias-corrected, and thinned observations for the period 8-10 June 2016.



Simulation of observations

Stddev of innovation from slanted profiles, normalized by the stddev of innovation from vertical profiles for instruments/platforms. The statistics are calculated based on global, bias-corrected, and thinned observations for the period 8 June to 8 July 2016.

The Stddev of innovation is reduced up to **5%** for ATMS onboard NPP.



Assimilation experiments

- Three global deterministic prediction system experiments performed (4D-EnVar with 15km forecast model and 39km analysis increments):
    1. Vertical columns used RT calculations (noSlant).
    2. Slant-path calculation only for the background state (Slant_nl).
    3. Slant-path calculation for the background state and increments (Slant_nltlad).
- Tests performed over 2.5 months period, 2016-06-15 to 2016-08-31.
- Slant-path calculation is only performed on the microwave sounders AMSUA, AMSUB, MHS, ATMS and hyperspectral infrared sounders AIRS, IASI, and CrIS.
- Changes to the fit of the background state to the observations are compared.
- Medium-range forecasts are evaluated against both Era5 and own analyses.
    - Evaluation against radiosondes gave no statistically significant differences between the experiments

Fit of the background state to radiance observations

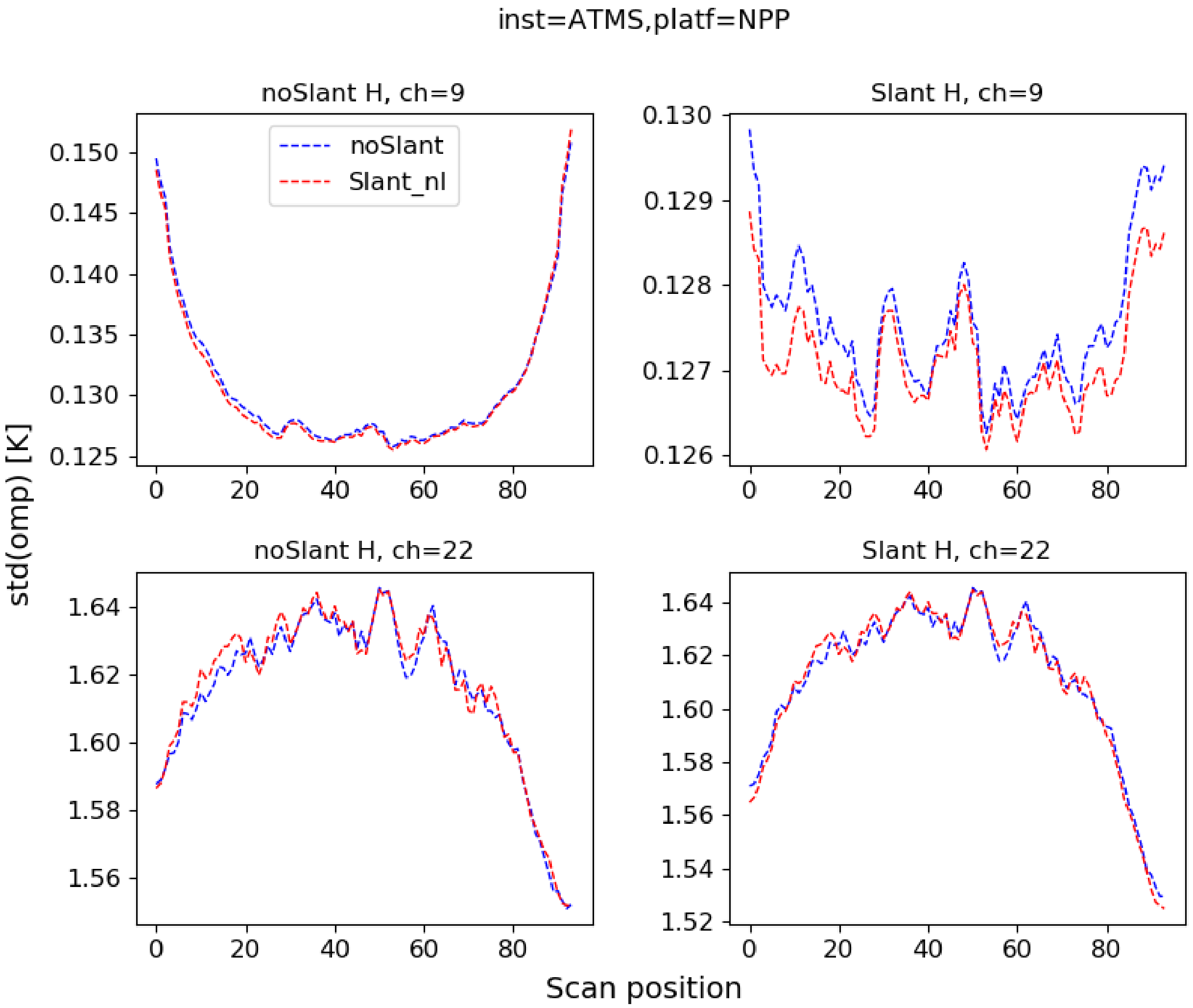
Changes to background state:

Stddev of innovation for common set of observations for noSlant and Slant_nl assimilation cycles (15 June to 26 July 2016).

Re-computed y-H(x) using either the noSlant (left) or Slant (right) observation operator.

When Slant (noSlant) operator is used, bias-corrected observed values are taken from Slant_nl (noSlant) experiment (consistency between H and bias-correction).

Improvement of the global fit to the observation due to better background state is small (**~0.1%**).



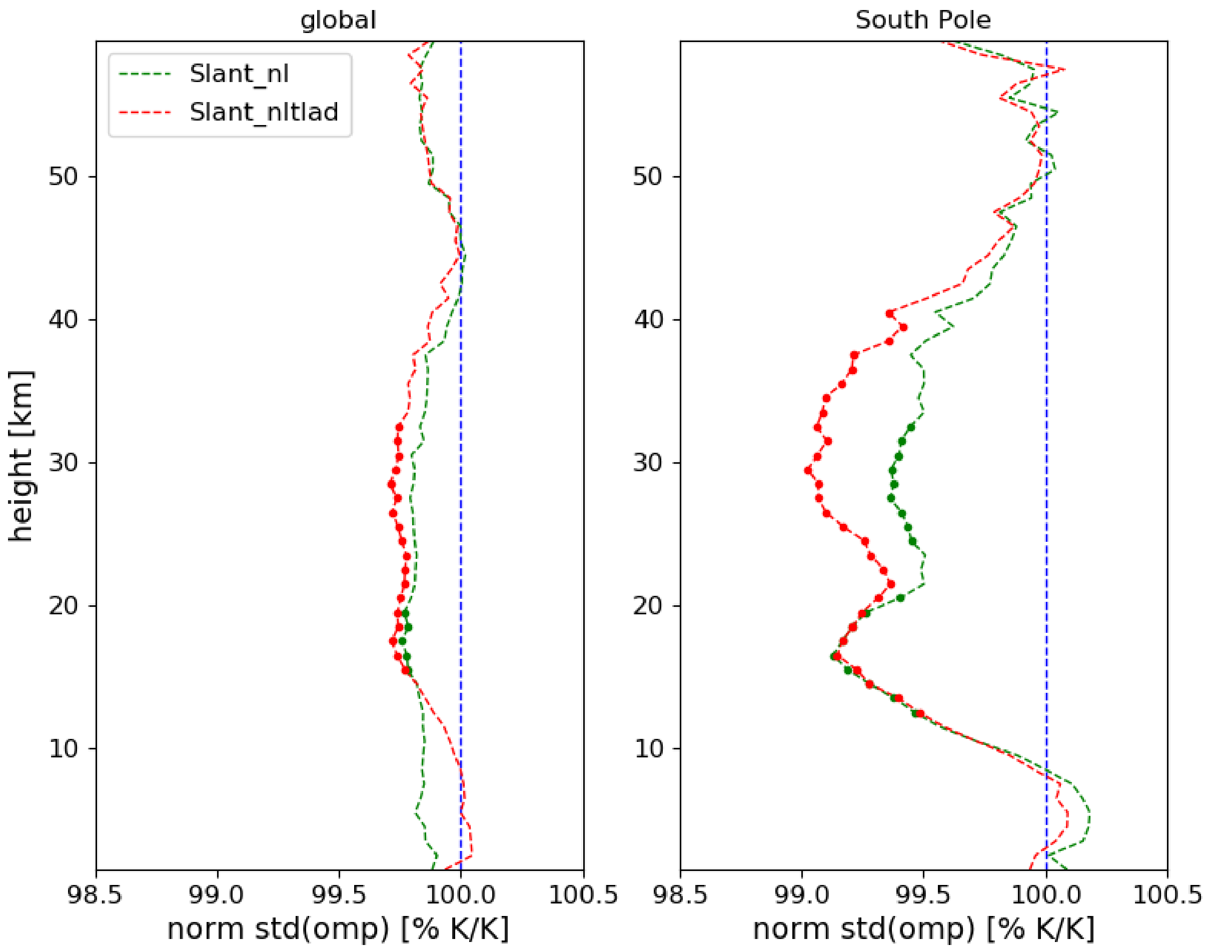
Fit of the background state to GPSRO observations

Stddev of innovation of GPSRO observations in global and South Pole domains when using slant operator only for the background (Slant_nl), and for the background state and increment (Slant_nltlad), normalized by the stddev of innovations in noSlant experiment (15 June to 26 July 2016).

Filled dots indicate altitudes where stddev are significantly different (at 90% confidence level) from noSlant experiment.

<u>In South Pole:</u>
Applying the slant operator only to the background state lowers the stddev of GPSRO innovations by a maximum **0.5-0.8%** at 20-40 km.

Using the slant operator for both background and increment further reduces the stddev of GPSRO innovations.

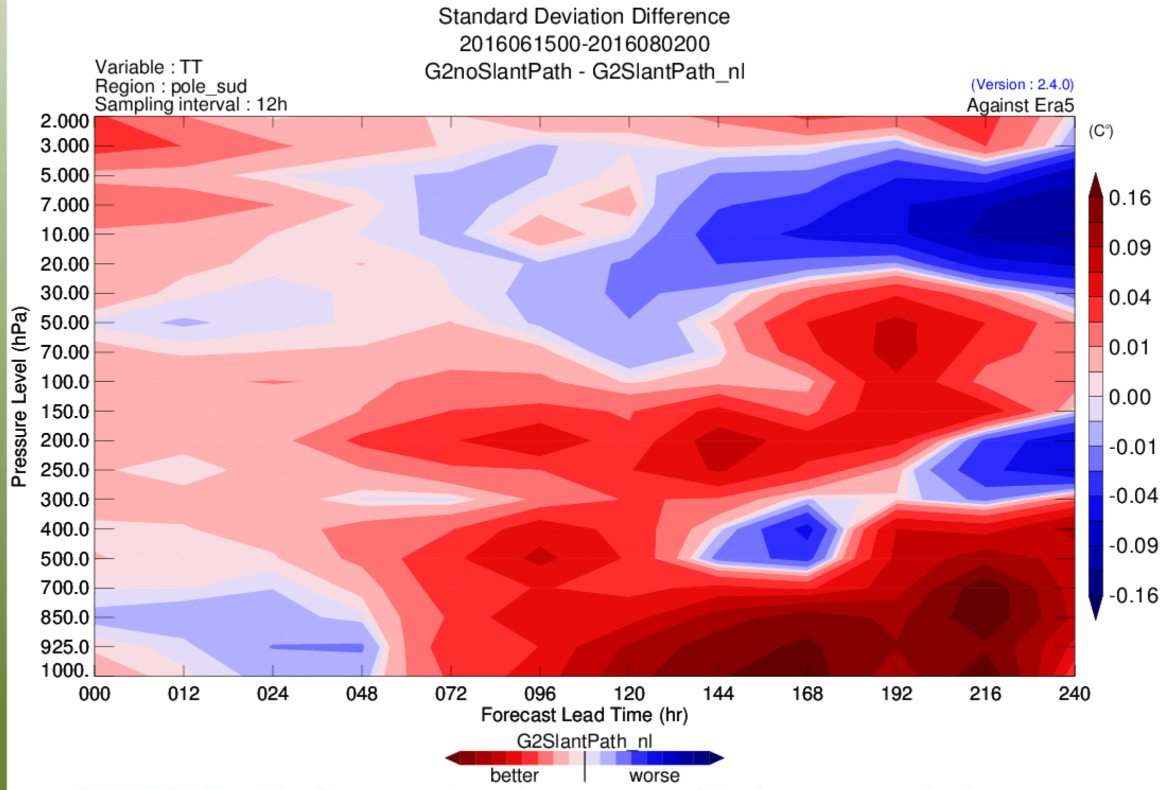


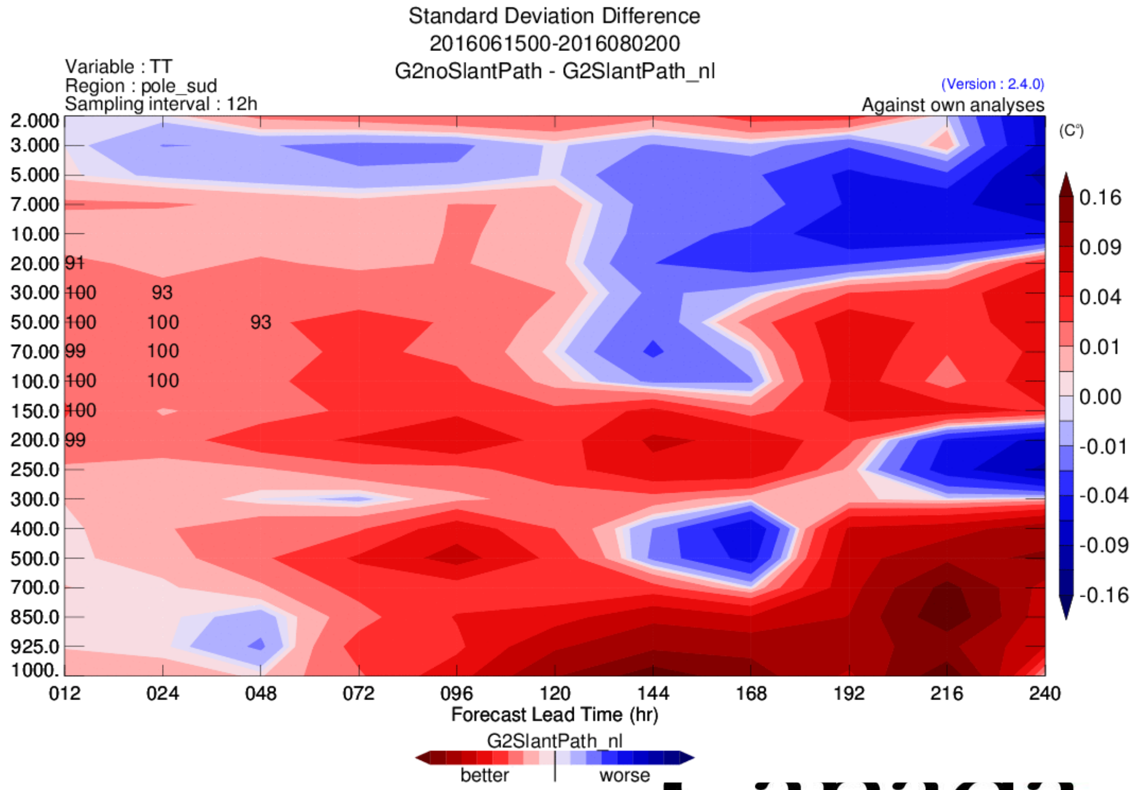
Impact on the forecasts as function of lead time

Evaluation against Era5 and own analyses.

Standard deviation difference of South Pole temperature forecast of noSlant versus Slant_nl experiments. Red (Blue) contours show better Slant_nl (noSlant), compared to the reference analyses.

Statistically significant improvement for forecasts up to 2-days, when compared against own analyses.





Summary

- At ECCC, major changes to horizontal interpolation in 4D-EnVar assimilation system was implemented to allow slant-path radiative transfer (will also be used for weather radar data and will facilitate horizontal footprint operator).
- Simulation of observations shows up to 5% reduction in stddev of innovations for some cases (direct effect by using slant operator instead of no slant).
- Result of the assimilation cycles show much smaller reduction in stddev of innovations when using same observation operator to measure innovations (either slant or no slant): improvement in background state ~0.1%.
- Result of the assimilation cycles show minor statistically significant improvements up to 2-days, when compared against own analyses.
- Having an improved better observation operator, may be beneficial to reduce the observation error to increase the weight of radiance observations.