# Impact of Aeolus on wind predictability, globally and as a function of length scale

**Chih-Chun (Gina) Chou[1], Paul J. Kushner[1], Stéphane Laroche[2]**

[1]University of Toronto, Department of Physics, Toronto, Canada.
[2]Environment and Climate Change Canada

University of Toronto

Environment and Climate Change Canada

## Introduction and Experimental Setup

### Introduction

- Laroche (2020)[1] has shown using ECCC OSEs that by adding the Aeolus wind product (2B06), the forecast error in the troposphere can be reduced by approximately 0.5%
- M1 bias corrected products improve the forecasts
- ECMWF, DWD, and MeteoFrance found similar results
- Boer (1994 and 2003)[2,3] showed the predictability as a function of length scale using spherical harmonic analysis
- This poster will show the impact of the reprocessed Aeolus winds globally and as a function of length scale

### Aeolus Product Used

- Period: 2 August to 30 September 2019
- Reprocessed Level-2B product (2B10)

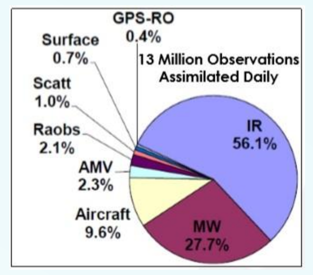



Figure 1. All operational observations used in ECCC GDPS.

### The ECCC Global Deterministic Prediction System (GDPS)

- 15 km horizontal grid spacing
- Atmospheric GEM model coupled with NEMO ocean model
- 4D-EnVar data assimilation system with 33% $B_{nmc}$ and 66% $B_{ens}$
- $B_{ens}$ estimated from 256 members at 39 km horizontal resolution

### Simplifications made for the OSEs

- 39 km horizontal grid
- No ocean coupling
- $B_{ens}$ operational 256 members interpolated onto a 66 km grid
- Same $B_{ens}$ used in all experiments
- Slight changes in the GEM model physics

### Observing System Experiments

1. All operational observations (CNTRL)
2. HLOS winds are added to all observations (CNTRL+Aeolus)
3. Winds are removed from all observations (CNTRL-winds)

## Global Tropospheric Impact

- The forecasts from the OSEs are compared to the reanalysis ERA5 from ECMWF
- The impact is defined as the percentage difference between the root-mean-square of the forecast error (RMSE) across experiments
- The impact increases with forecast lead time in the NH extra-tropics
- In tropics and SH extra-tropics, the impact is the greatest in short-range forecasts
- The vector wind, zonal and meridional wind fields all show similar impact in the troposphere with forecast lead time

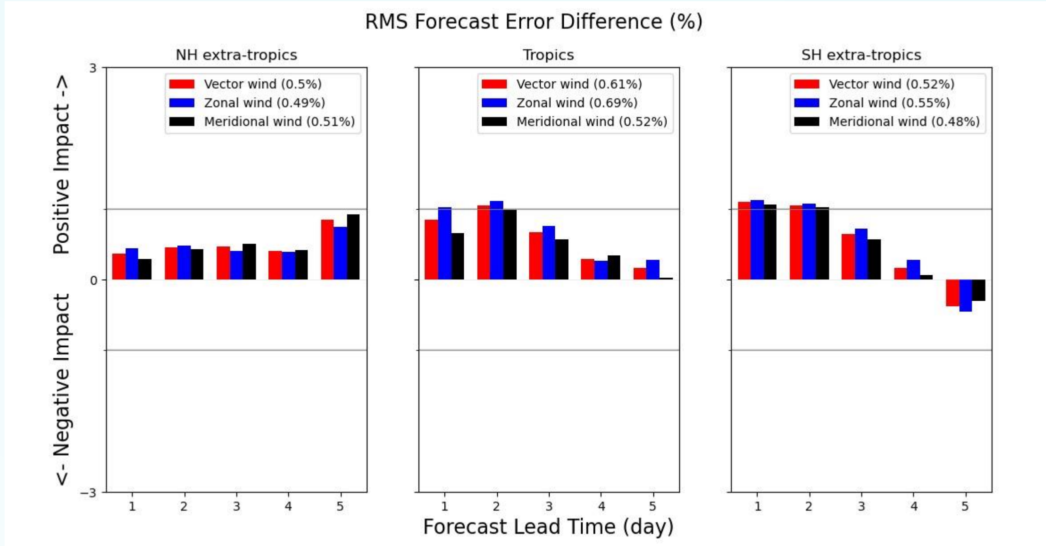
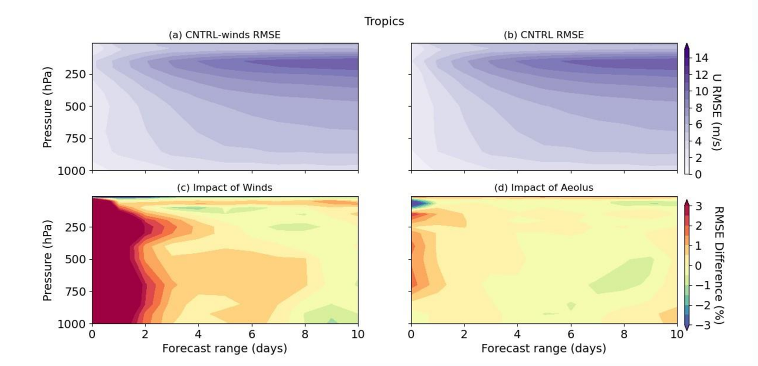



Figure 2. Global tropospheric (100, 250, 500, and 850 hPa) RMSE difference for the vector wind, zonal and meridional wind fields between CNTRL and CNTRL+Aeolus. Positive impact means that the forecast has improved by adding Aeolus winds.

## Vertical Structure of Impact across Regions

- Operational winds largely improve the forecasts of the tropical zonal wind field throughout the period
- Aeolus winds further improve the field in the mid-to-upper troposphere in the short- to medium-range forecasts
- The improvement in the NH extra-tropics is more homogeneous across the levels



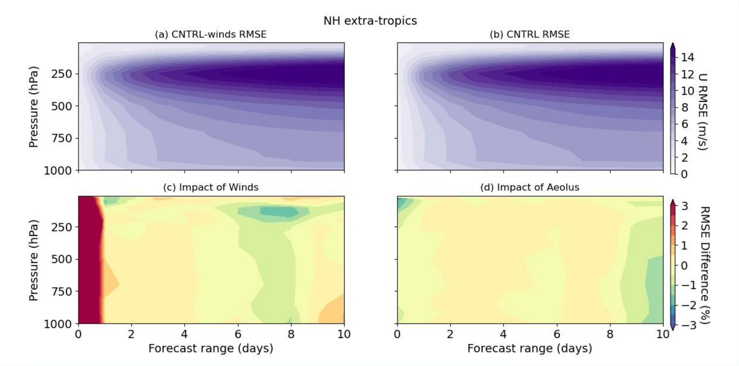




Figure 3. Evolution of the tropical (20S-20N) RMSE zonal wind field with forecast range as a function of pressure from the (a) CNTRL-winds and (b) CNTRL experiments. (c) Impact of the operational winds and (d) impact of the Aeolus winds on the zonal wind field in the tropics compared to CNTRL.

Figure 4. Similar to Fig.3, but in the NH extra-tropics (20N-90N).

## Impact as a Function of Latitude

### The Impact on the U250 Field

- Operational winds have largely improved the forecasts in the short-range forecasts, especially in the tropics
- The impact of Aeolus winds in the tropics is positive through the forecast period
- Most of the impact is positive and significant in the short- to medium range
- Note: The impact that is significant at 90% using a bootstrapping method is marked with a '+' sign

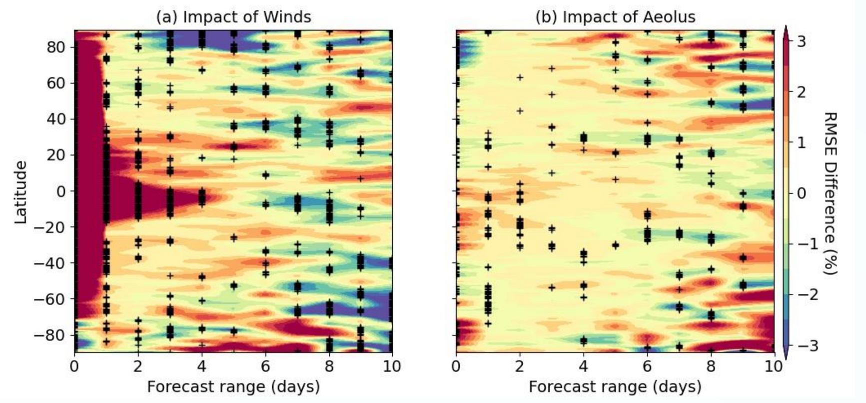



Figure 5. Impact of the (a) operational winds and (b) Aeolus HLOS winds on the U250 field as a function of forecast range and latitude.

## Spherical Harmonic Decomposition

- Each field can be decomposed using the spherical harmonic decomposition:

$$x(\lambda,\varphi,p,t) = \sum_{n=0}^{N}\sum_{m=-n}^{n} x_m^n(p,t)e^{im\lambda}P_n^m(\varphi)$$
$$= \sum_{\alpha} x_\alpha Y_\alpha(\lambda,\varphi)$$

- The spectrum of the KE field is calculated using the vorticity and divergence:

$$E_n = \frac{1}{4}\frac{a^2}{n(n+1)}\sum_{m=-n}^{n}\left(\overline{|\zeta_n^m|^2} + \overline{|\delta_n^m|^2}\right)$$

- The field can further be decomposed into the mean and transient components:

$$< \overline{e^2} > = < \bar{e}^2 > + < \overline{e'^2} >$$

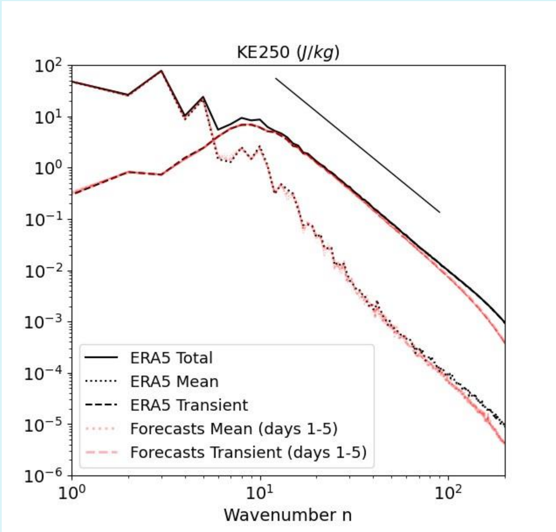
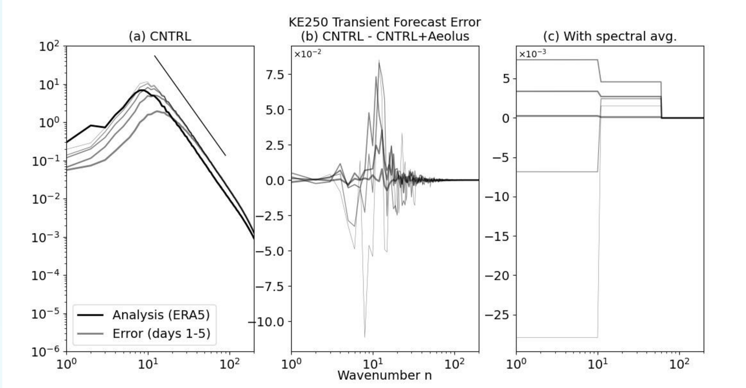



Figure 6. Spectra of the total, mean, and transient components of the 250-hPa kinetic energy (KE250) field for the reanalysis ERA5 (black lines) and for the days 1 to 5 forecasts (red lines), with a line of slope of -3 for reference.

## Impact as a Function of Length Scale

### Three Spatial Regimes

- $1 < n < 10$: the mean flow dominates
- $10 < n < 60$: the transient flow dominates and follows the power law
- $n > 60$: the transient flow dominates and the forecasts deviate away from ERA5



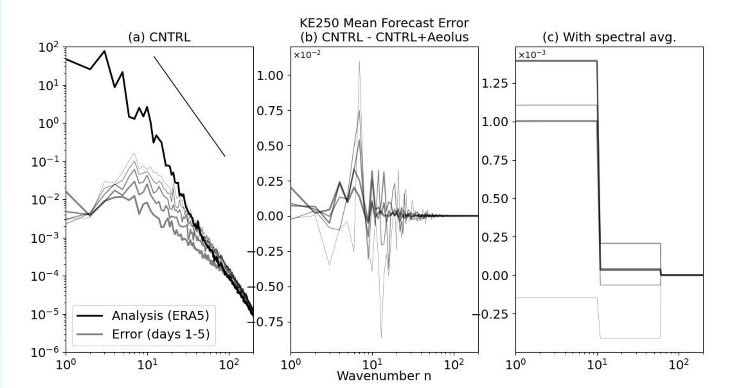




Figure 7. (a) The transient error spectra from the CNTRL for forecasts of the KE250 field for days 1 to 5 (thick to thin) compared to the spectrum of the analyzed field. (b) The difference of the spectra from the CNTRL and CNTRL+Aeolus and (c) the difference of the averaged spectra over small wavenumber (n<10), intermediate wavenumber (10<n<60), and large wavenumber (n>60) regimes.

Figure 8. Similar to Fig.7, but for the mean error spectra.

### The KE250 Error Spectra

- Error saturates immediately at small scales ($\approx 2S_x$)
- The error in spectrum propagates with time up the spectrum to larger scales
- Mean component does not reach saturation in long-range forecast at small wavenumbers

### Aeolus impact on the KE250 Error Spectra

- The largest difference is seen in the intermediate wavenumber range in longer forecasts (panels b)
- With spectral averaging (panels c), Aeolus mostly improves the forecasts in the planetary scale, then the synoptic scale
- The short-range forecasts show positive impact in all three spatial regimes
- The transient flow has a greater impact – the difference is an order of magnitude greater than the mean error

## Conclusions

- Operational winds largely improves the forecasts in all levels, especially in the tropics in short- to medium-range forecasts
- Adding the Aeolus HLOS winds to the forecast system further enhances the forecasts
- Tropical zonal wind improvements from Aeolus are greatest in the mid-to-upper troposphere, while in the midlatitudes, the improvement is more homogeneous across the levels
- Aeolus improves the forecasts of U250 field in the tropics throughout the 10-day forecast period and the impact is significant at 90%
- The impact in the polar regions is more visible in the long-range forecasts
- Using the spherical harmonic decomposition, the 250-hPa kinetic energy field can be decomposed into three spatial regimes
- When assimilating the Aeolus winds, the KE250 error decreases in the shorter-range forecasts in all three spatial regimes for the transient and mean flows
- Aeolus improves the forecasts more in larger scales than smaller scales

## Acknowledgment

We acknowledge the support of the ECCC Meteorological Research Division. In addition, we greatly appreciate the support from the Canadian Space Agency for Ms. Chou's student research funding.

## References

[1] Laroche, Stéphane, and St-James, J., "NWP Impact Study with FM-B HLOS Winds at ECCC," Aeolus NWP Impact Assessment working meeting, June 2020.
[2] Boer, G. J., 1994, "Predictability Regimes in Atmospheric Flow," Monthly Weather Review, 122(10), 2285-2295.
[3] Boer, G. J., 2003, "Predictability as a function of scale," Atmosphere-Ocean, 41:3, 203-215.

gina.chou@mail.utoronto.ca