Evaluating Arctic Diurnal Water Vapour Cycles in ERA5 and Canada's Weather Forecast Model

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Introduction

The diurnal water vapour (WV) cycle is a critical component of the larger hydrological cycle. Accurate measurements of the diurnal WV cycle can improve precipitation rate and cloud type predictions in forecast models. However, fewer studies have been conducted exploiting height-resolved measurements. Water vapour DIfferential Absorption Lidars (DIALs) can provide high vertical resolution measurements within the boundary layer. We evaluate the WV diurnal cycles in ERA5 reanalysis and Environment and Climate Change Canada (ECCC) forecast model (GEM-HRDPS) against GPS and DIAL measurements at the Iqaluit, Nunavut ECCC supersite (63.75ºN, 63.5ºW). Both models are unable to replicate the semidiurnal (12hr) water vapour cycle at higher altitudes but perform best below 800 m altitude.

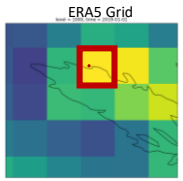
Models and Instrumentation

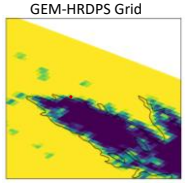
GEM-HRDPS

- Specific humidity pofiles (g/kg)
- 62 (sigma-hybrid) vertical levels, 100 m altitude resolution
- 1 hr temporal resolution
- 0.0225°x 0.0225° horizontal resolution (~2.5 km)
- 0600 Initialization time, 48 hours lead time

ERA5

- Specific humidity profiles (g/kg)
- 37 Pressure levels
- 200m altitude resolution
- 1 hr temporal resolution
- 0.25° x 0.25° horizontal resolution





Iqaluit GPS

- Vertically Integrated water vapour (IWV)
- Data from 2009 – Present
- Tropospheric parameters processed by the Univ. of Nevada Geodetic Laboratory
- Measurements are smoothed to 1 hr resolution

Vaisala DIAL

- Autonomous , pre-production WV DIAL
- Sept 2018 – June 2020
- WV mixing ratio and attenuated backscatter profiles
- Vertical Resolution:100m
- WV Max vertical range: 3 km
- 20 min temporal resolution

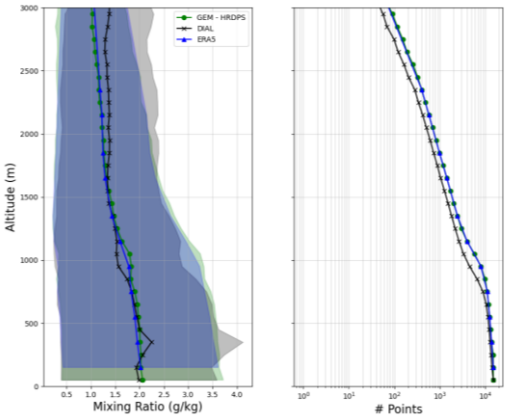
Diurnal and Semidiurnal Cycles

$$I(t') = I_0 + \sum_{n=1}^{2} S_n(t') + R$$

$$S_{n(t')} = a_n \cos(nt') + b_n \sin(nt')$$

- Two main components: *Diurnal* (S_1, 24 hr period) and *Semidiurnal* (S_2, 12 hr period)
- I_0 is the average water vapour content and is subtracted from all solutions to show the relative series.
- Diurnal cycle driven largely via evapotranspiration created via the absorption of solar radiation at the surface
- Drivers of the water vapour semidiurnal cycle in the troposphere are still not well understood
- Equations above applied to all time series (instruments and models) (I(t'))

Average Water Vapour Profiles



Left: Avg Profiles

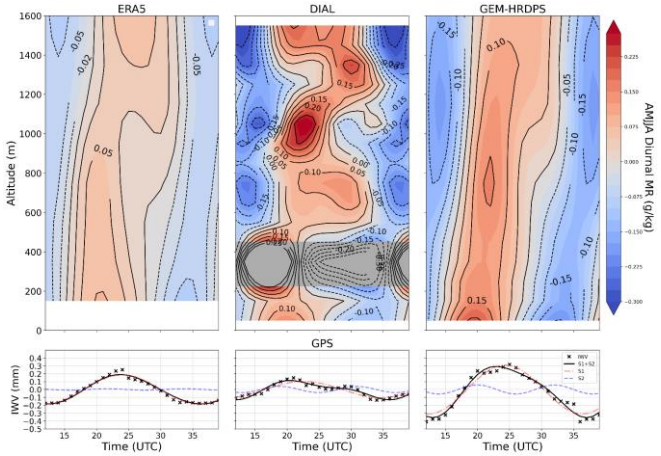
- Shaded region: standard deviation of measurements
- DIAL diverges from ERA5 and GEM due to fewer profiles available at higher altitudes.
- Seasonal averages show good agreement between DIAL and models

Right: Diurnal Cycles

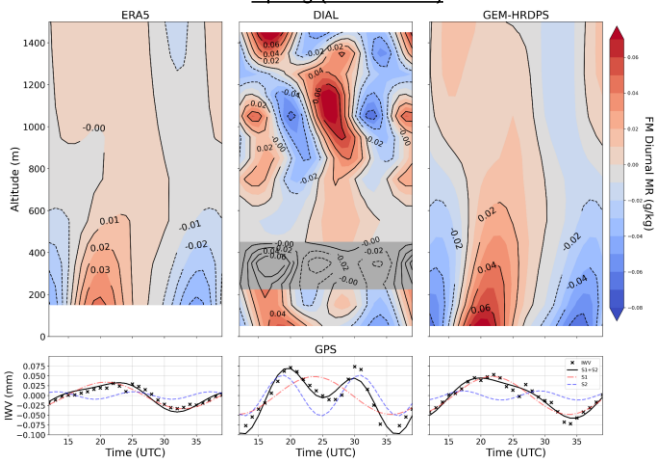
- Grey region: solar noise contamination in DIAL
- Red: increasing WV, Blue: decreasing WV
- Summer dominated by 24 hr component and models have good agreement
- Spring dominated by 12 hr component which is not well produced in models

Diurnal Cycle Solutions

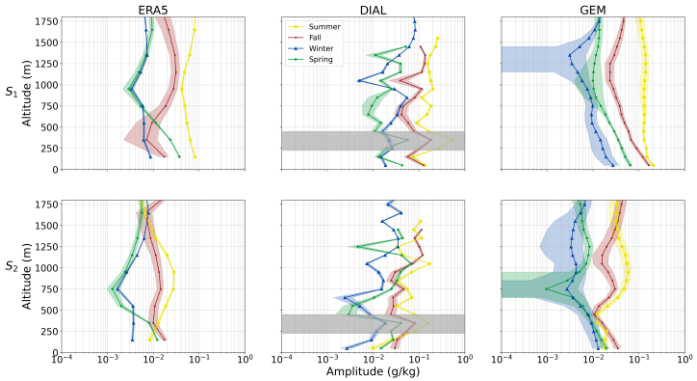
Summer (Apr. – Aug.)



Spring (Feb. – Mar.)

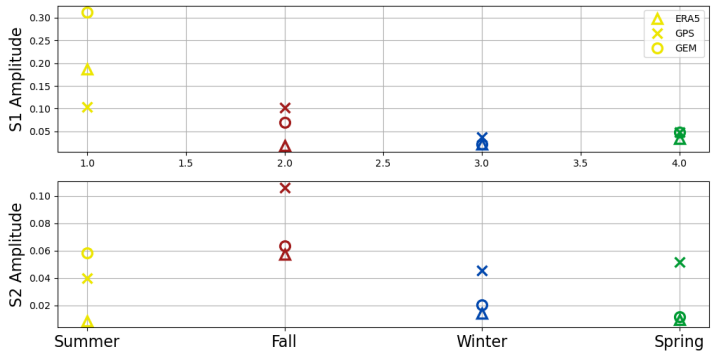


Height-Resolved Amplitude Solutions



- GEM and ERA5 S1 and S2 magnitudes are lower than DIAL magnitudes
- GEM solutions are stable with lead time as shown by low std deviation (shaded)

IWV Amplitude Solutions



- GEM and ERA5 IWV S1 and S2 amplitudes are generally lower than GPS
- GEM Summer S1 amplitude higher than GPS due to assimilation uncertainties

Conclusions and Future Work

- Differences between observations and models may be due to lack of observations informing models: only radiosondes, satellite, aircraft (not ideal for high temporal resolution measurements)
- GEM-HRDPS generally better at resolving cycles than ERA5 – likely due to higher resolution
- GEM-HRDPS has slight excess moisture in the first 100 m
- Both models perform well in producing the phases below 1 km
- Both models perform well in the first 500 m where S1 dominates
- **Both models under-represent the S2 cycle above 1 km**
- **Lack of S2 component in both height-resolved and IWV solutions suggest some process(es) may not be completely represented in the models.**
- Currently submitted to QJRMS for review
- Lidar, GPS, and Surface solutions validated in:
  - Hicks-Jalali et al.,2021: https://doi.org/10.1002/qj.4175

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