28th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Ocean, and Land Surface @ AMS 2024, Paper 7.5, January 30, 2024 2:45 pm Eastern, Tuesday

Impact of Assimilating AMV Winds Using a Variational Feature Track Correction (VarFTC)

Ross N. Hoffman[1,2], Hui Liu[1,2], Kevin Garret[3], Kayo Ide[4], and Katherine E. Lukens[1,2]

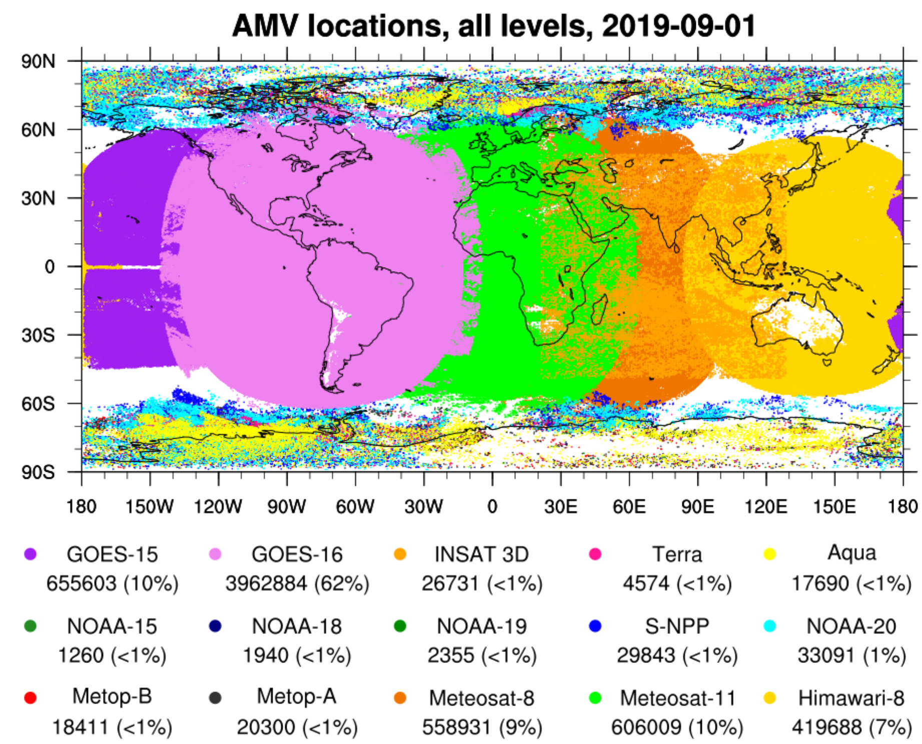
1: NOAA/NESDIS/Center for Satellite Applications and Research (STAR), College Park, MD
2: Cooperative Institute for Satellite Earth System Studies (CISESS), University of Maryland
3: NOAA/NWS/Office of Science and Technology Integration (OSTI), Silver Spring, MD
4: University of Maryland, College Park, MD

National Environmental Satellite, Data, and Information Service

January 30, 2024

Key Points

- AMVs are almost everywhere.
- Experiments were conducted to optimize the use of atmospheric motion vectors (AMVs) in NWP by accounting for their error characteristics.
- Application of the variational feature track correction (VarFTC) method to AMVs has a positive impact on forecast skill.
- The anticipated synergy of VarFTC and Aeolus winds was not apparent in the current experiments.



Introduction

- AMV winds are assimilated in NWP systems and shown positive impact.
- Can we improve how we characterize AMVs' errors and how we assimilate AMVs ?
  - AMVs may have bias/uncertainty due to height assignment errors.
  - AMVs may have additional wind speed biases.
  - AMVs may be representative of a thick layer motion with depth up to a few hundred hPa, not a single atmospheric level.
- A feature track correction (FTC, Hoffman et al, 2022) statistically accounts for these aspects of AMVs using higher quality wind profiles as a reference.
- ESA Aeolus winds provided high vertical resolution and accurate global 3D wind profiles observed. Can these anchor the FTC procedure ?
- A prototype of the FTC is implemented in NCEP/GSI data assimilation (DA) and tested with and without Aeolus winds to assess the impact of Aeolus winds on the VarFTC assimilation of the AMVs.

VarFTC OSE Setup

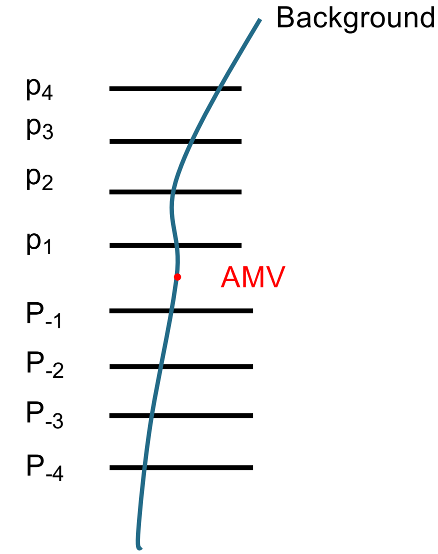
- OSEs
  - Base: Operational setting
  - FTC: Base + VarFTC observation operator (for all AMVs)
  - DWL: Base + (all) Aeolus winds
  - FTC+DWL: Base + VarFTC observation operator + Aeolus winds
- NCEP global-work flow v15.3 at C384L64 resolution (see Garrett et al. 2022)
- The OSEs are run from Aug 2 to Sep 16, 2019.
- The results are presented Aug 7 – Sept 16, 2019.
- Forecast verification is relative to ECMWF analyses.

VarFTC OSE Motivation

- Base: Operational settings
- FTC: Base + VarFTC observation operator
  - What is the impact of the VarFTC method alone ?
- DWL: Base + Aeolus assimilation
  - What is the impact of the Aeolus data alone ?
- FTC+DWL: Base + VarFTC + Aeolus
  - What is the synergy of VarFTC and Aeolus ?
  - Does Aeolus provide useful anchoring observations ?

The Feature Track Correction (FTC)

- The FTC is implemented as a vertical averaging observation operator of background winds (u and v) around each AMV wind location:
  - $u^b = \sum(W_k\ u_k) + \Delta_u$
  - $v^b = \sum(W_k\ v_k) + \Delta_v$
  - Where
    - u_k, v_k : background u and v estimate for FTC averaging grid k
    - W_k : weight at FTC grid k
    - Δ_u, Δ_v : FTC estimated u and v bias correction terms
    - k is the index of the FTC averaging grid around each AMV
      - K= -12 to 12
      - $p_k = p^o +/- k\ \delta_p$, with $\delta_p = 25$ hPa
      - k=0 is the AMV level, $p=p^o$;
      - u^b, v^b : background estimates of the AMV u and v

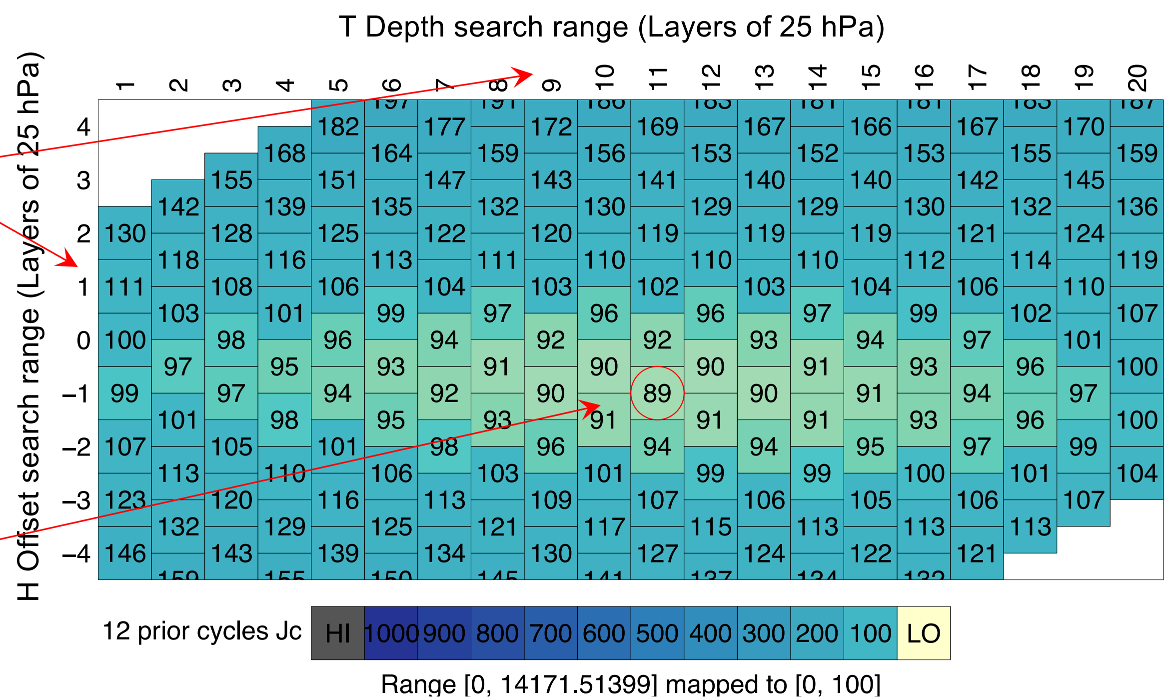


The FTC average grid can move up/down wrt to the AMV OBS; and has tunable depths

Calculation of the FTC Parameters

- FTC minimizes a cost function of the innovations based on the FTC observation operator
  - Define a search list of averaging layer of thickness (T) and offset (H) wrt the AMV OBS level.
  - For each pair T and H, linear regression to find the multiplicative and additive coefficients of FTC.
  - Find the optimal T and H with minimum of the cost function.

Example: AHVRR IR in SHX; low layer (Samples ~600/cycle)



Implementation of FTC Operator in GSI: Offline

CISESS
COOPERATIVE INSTITUTE FOR SATELLITE EARTH SYSTEM STUDIES

In GSI: DA cycle *n :*
Output wind background at AMV location/time to files

Optimize FTC (offline GSI)

Interpolate background winds to FTC averaging grid for each AMV

Calculate cost function sums of all AMVs in current cycle

Minimize the sums of previous 12 cycles for regions/layers

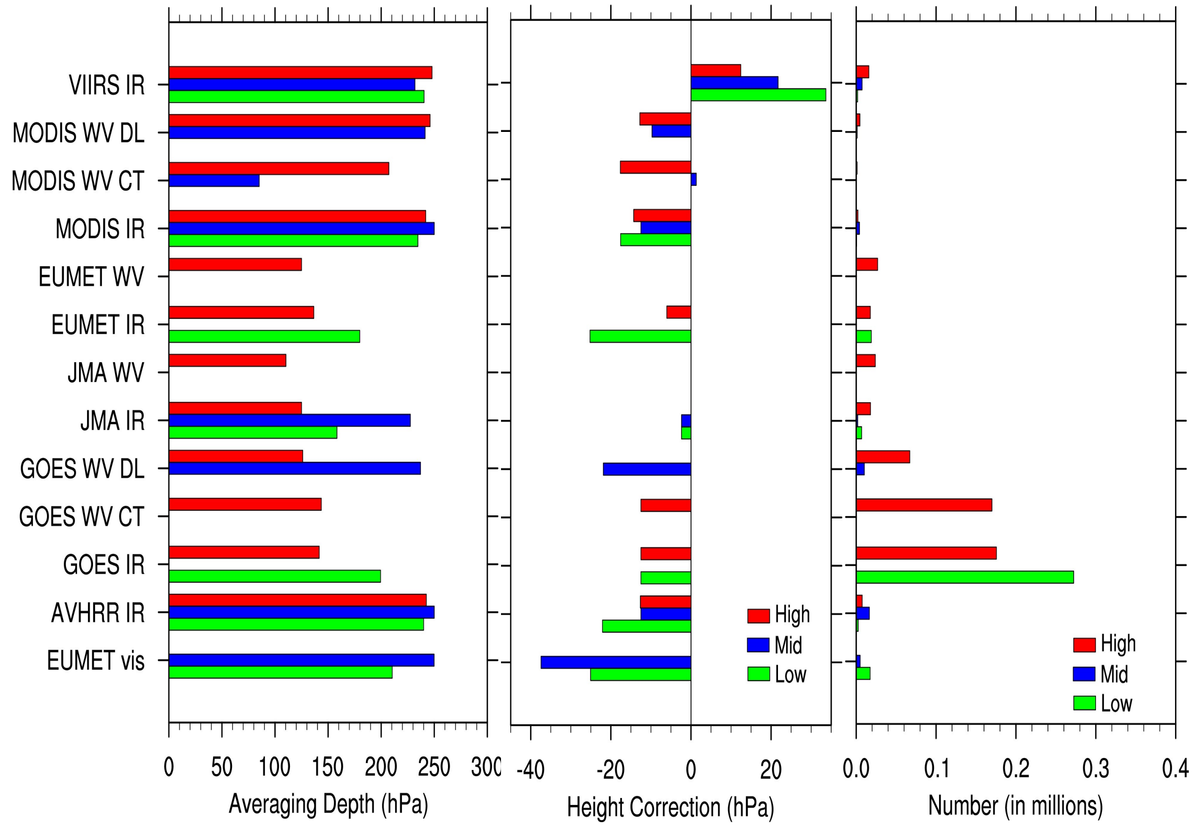
Find FTC T/H and coefficients for regions/layers

Back in GSI:
DA cycle *n+1 :*
Calculate OmB with FTC

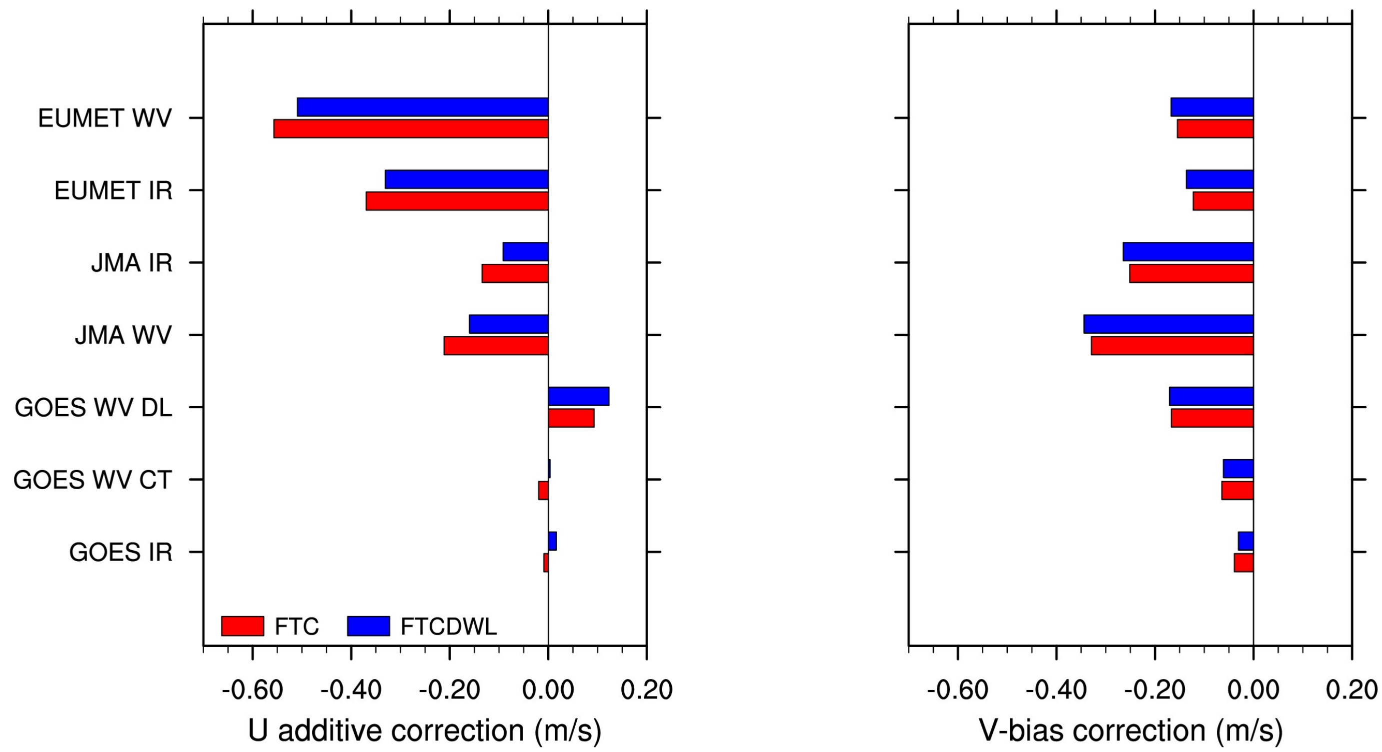
- Calculate FTC separately for each subset defined by AMV type, region (NHX, Tropics, SHX) and layer (low, mid, high).
- The FTC minimization is based on samples from the previous 12 DA cycles.
- FTC parameters are interpolated at the boundaries for the regions (at 20 degrees) and layers (at 450 and 800 hPa).

FTC Statistics in OSE FTC (all layers, global, Aug 7 - Sep 16, 2019)

- Typical averaging layer is 150 hPa
- Typical height correction is 15 hPa (except for VIIRS);
- That is, compare the AMVs to the 150 hPa layer average background 15 hPa higher in the atmosphere
- Note much larger numbers for GOES AMVs.
- Additive corrections are order 0.25 m/s (seen on next slide)

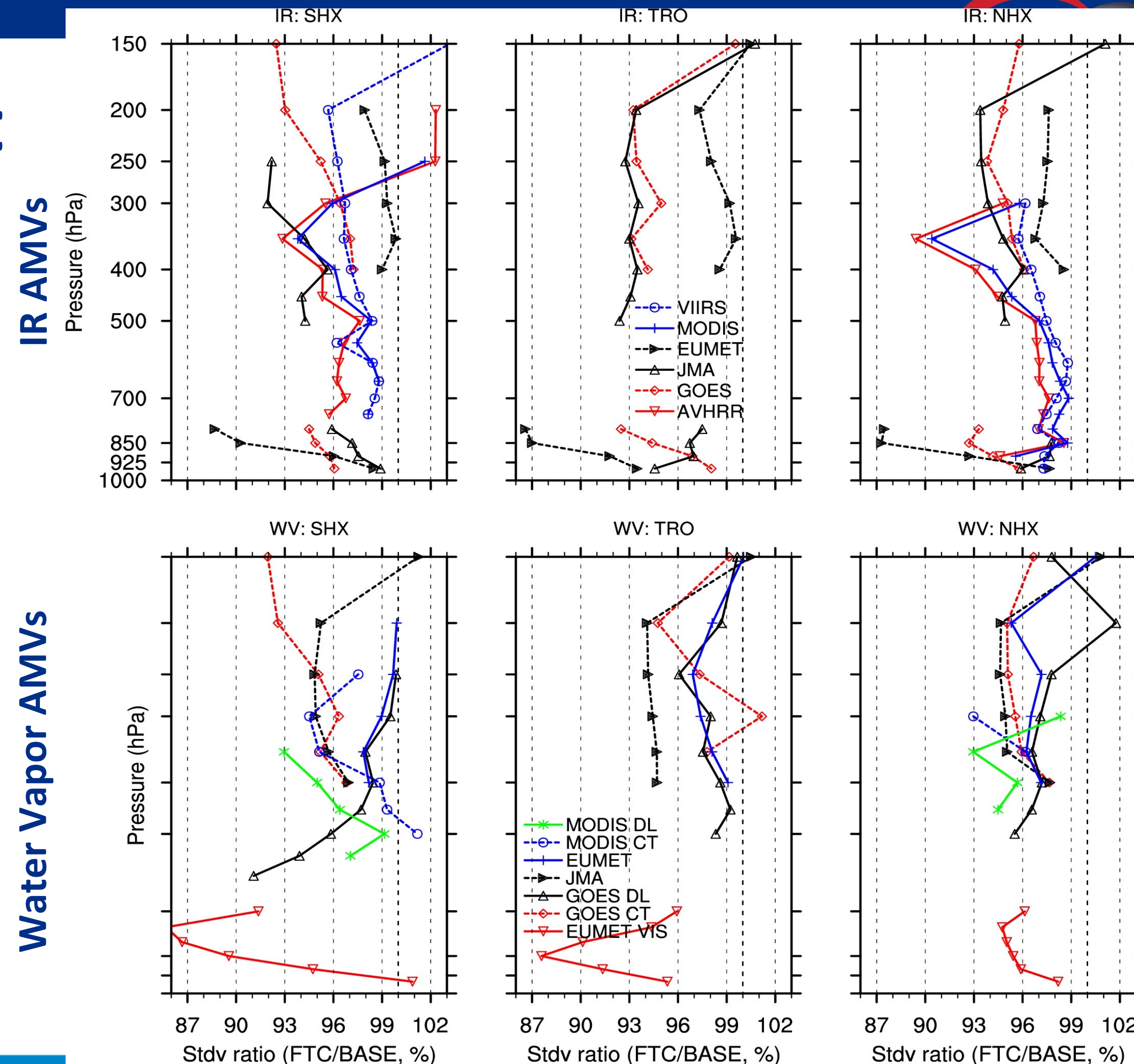


Impact of Aeolus on FTC Bias Correction
(High Layer, Tropics, Aug 7 - Sep 16, 2019)



FTC Improvement in Fit

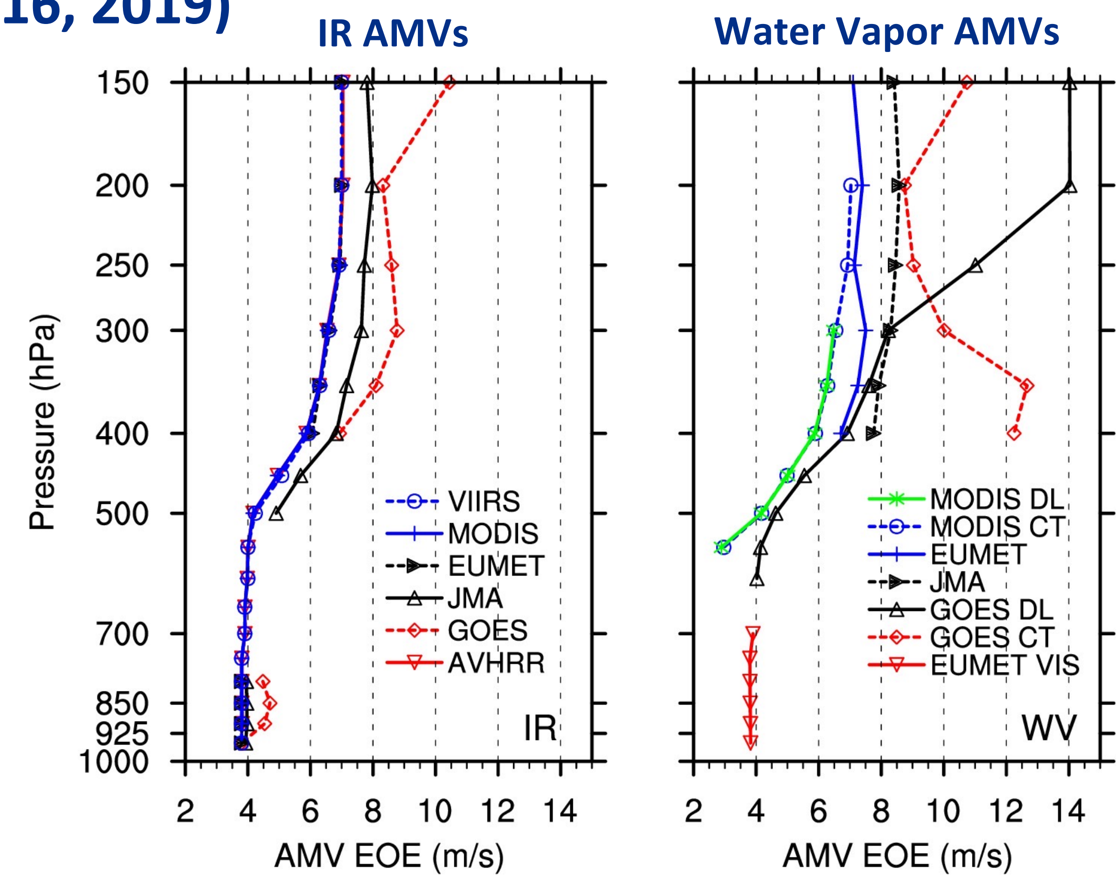
(SHX, Tropics, NHX, Aug 7 - Sep 16, 2019)



- AMV OmB Stdv Reduction by FTC is typically 3-4%

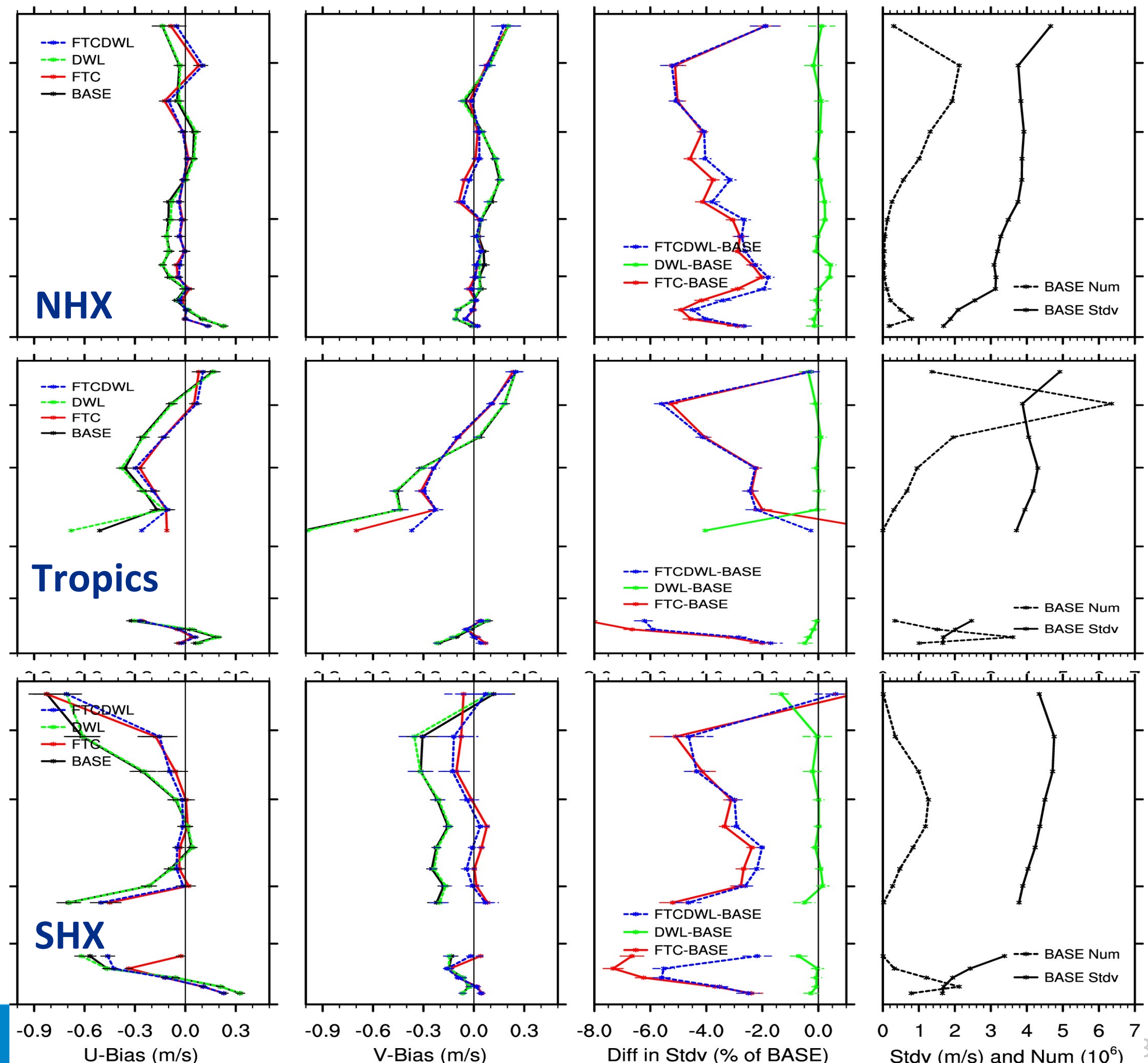
AMV OBS Errors Assigned in GSI
(Global, Aug 7 - Sep 16, 2019)

- GOES AMV errors assigned in GSI are larger than other AMVs
- These were modified to account for the improvement in fit in the FTC experiments



AMV OmB Wind Statistics
(SHX, Tropics, and NHX, Aug 7 - Sep 16, 2019)

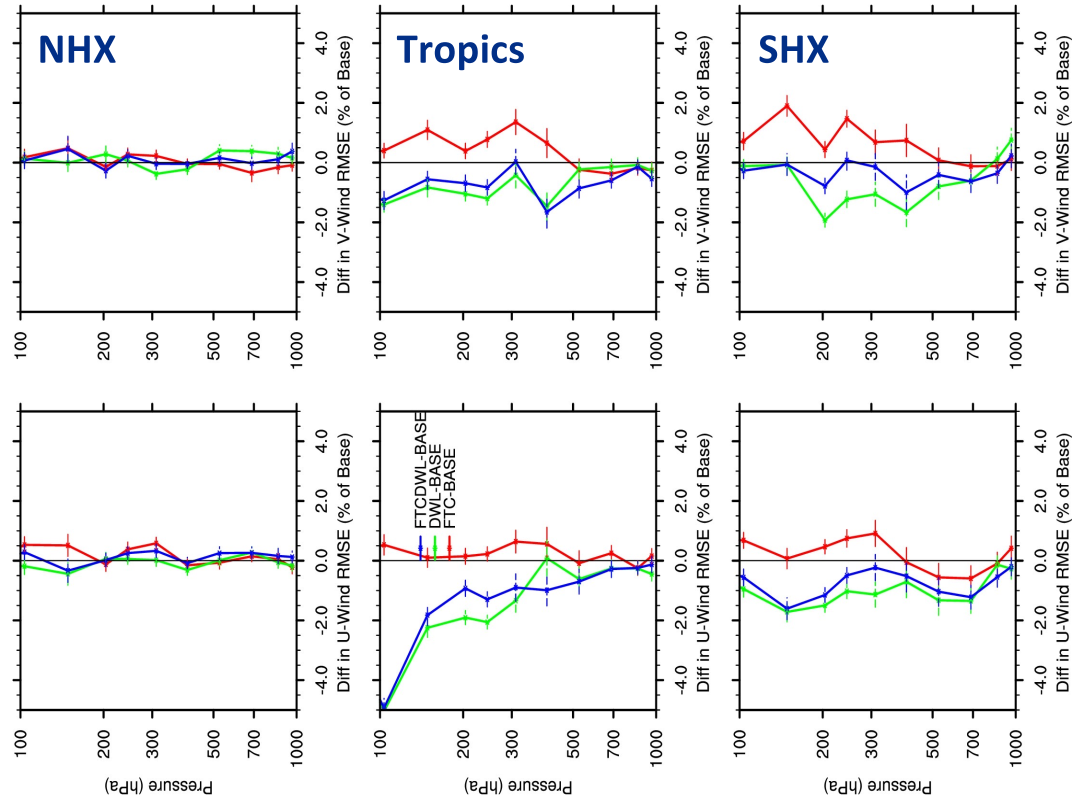
- FTC operator reduces biases.
- FTC operator reduces standard deviation by order 4%.



Sonde and Aircraft OmB Wind RMSE

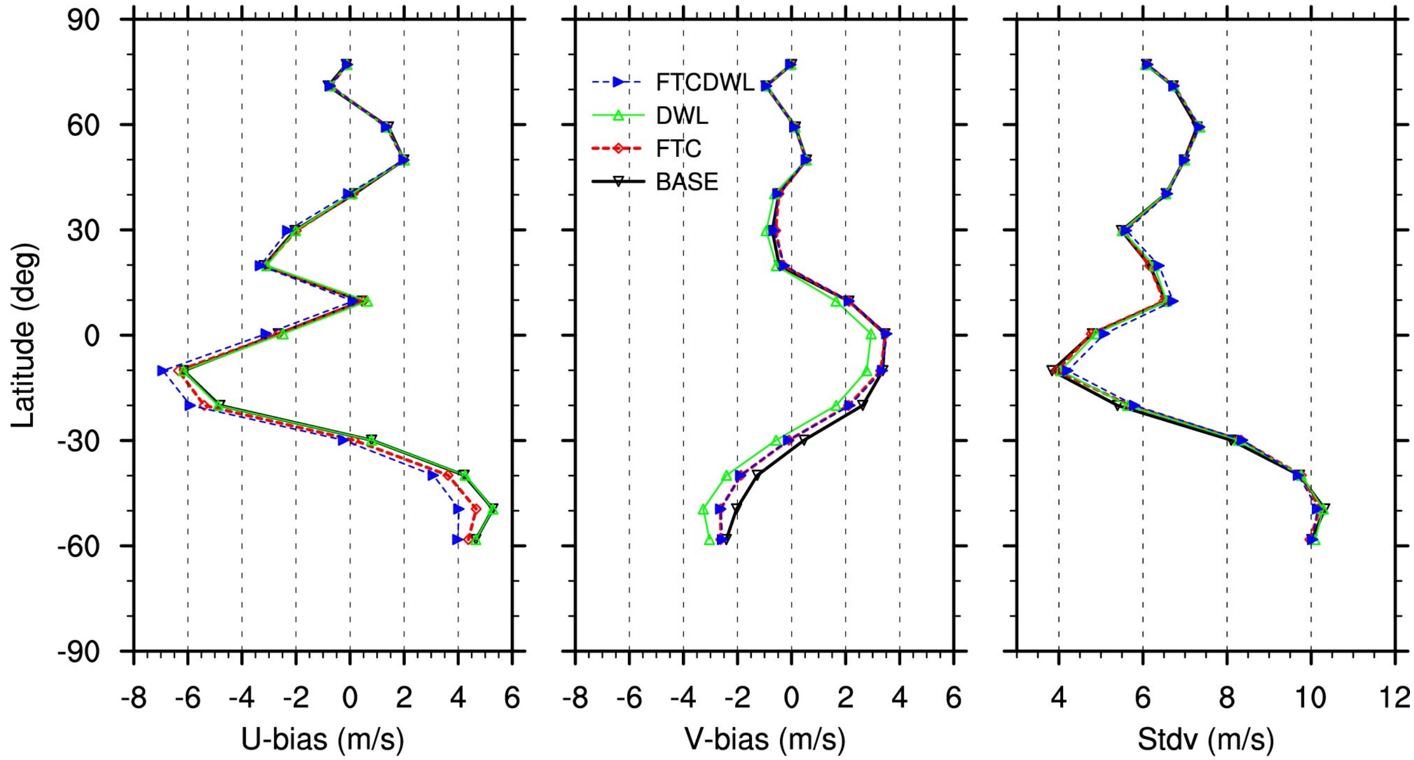
(SHX, Tropics, and NHX, Aug 7 - Sep 16, 2019)

- FTC operator w/o Aeolus slightly increases Radiosonde/ Aircraft OmB RMSD in Tropics and SHX.



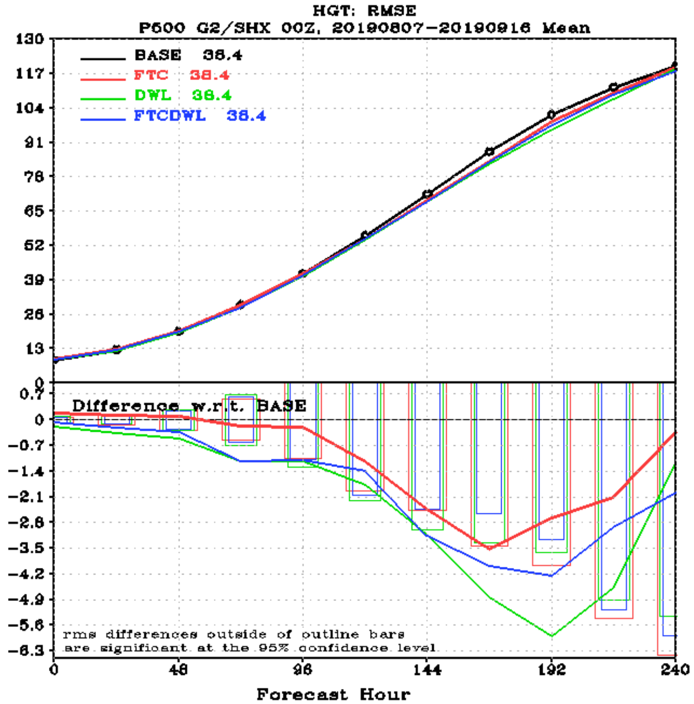
ASCAT OmB Wind Statistics
(SHX and Tropics, Aug 7 - Sep 16, 2019)

- Very minor differences in biases in SHX.

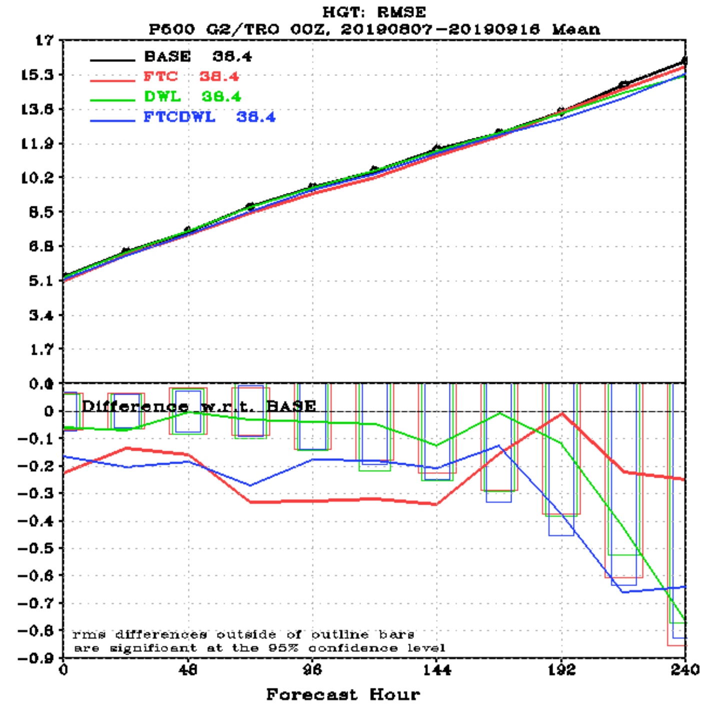


500 hPa Height RMSE Forecast Skill
(SHX and Tropics, Aug 7 - Sep 16, 2019, ECMWF verification)

- In SHX, DWL gives significant improvements
- In Tropics, FTC gives significant improvements



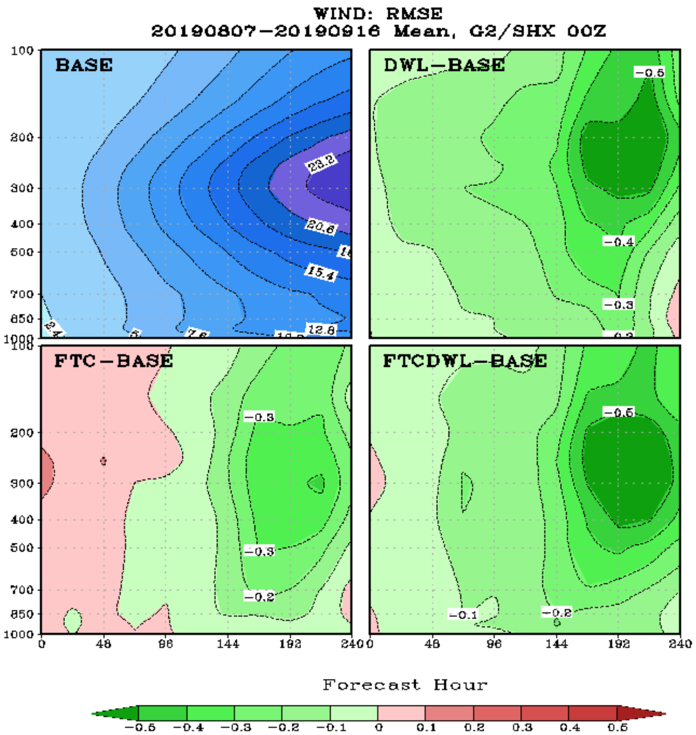
SHX (gpm)



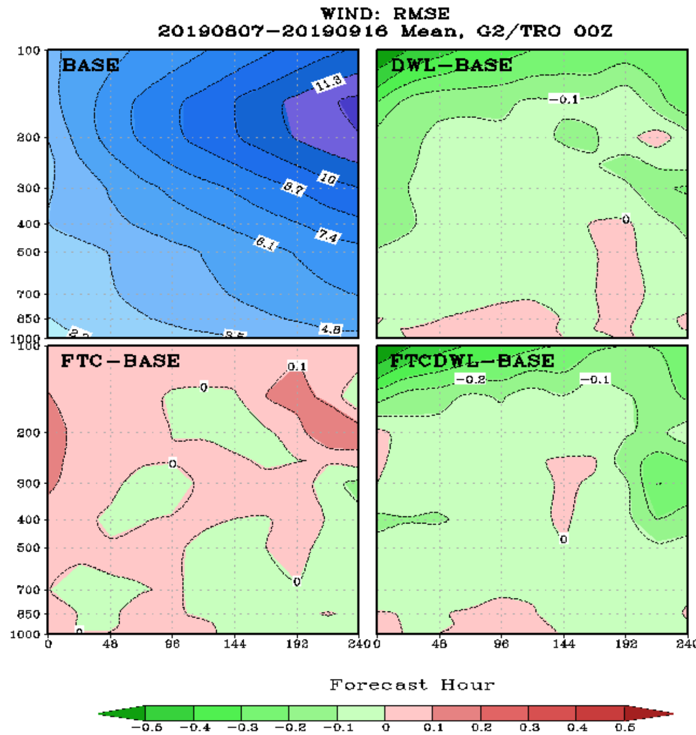
Tropics (gpm)

Wind RMSE Differences

(SHX and Tropics, Aug 7 - Sep 16, 2019, ECMWF verification)



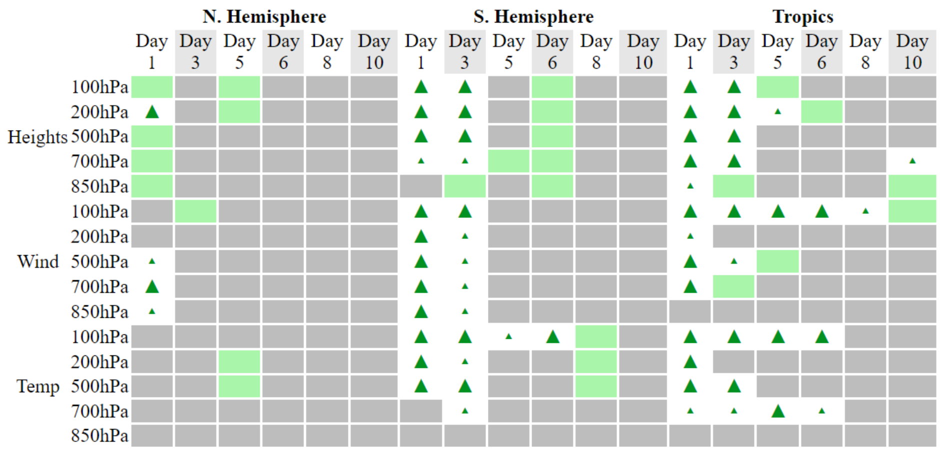
SHX (m s^{-1})



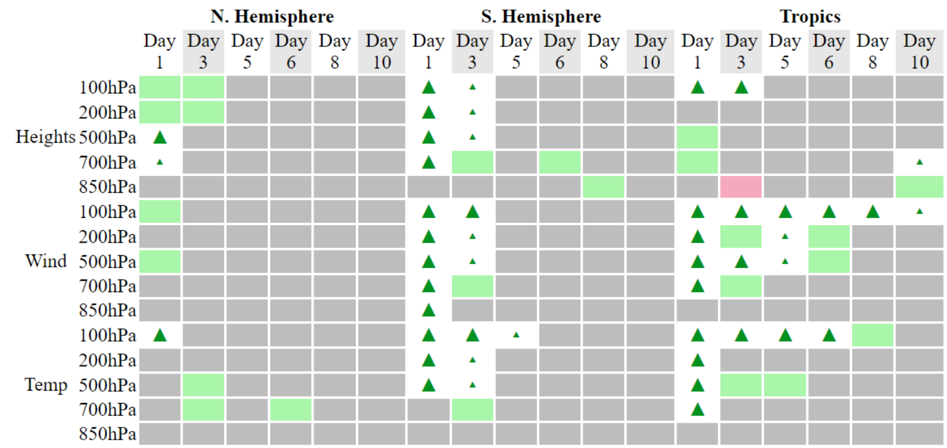
Tropics (m s^{-1})

Forecast Score Cards (RMSE, Aug 7 - Sep 16, 2019, ECMWF verification)

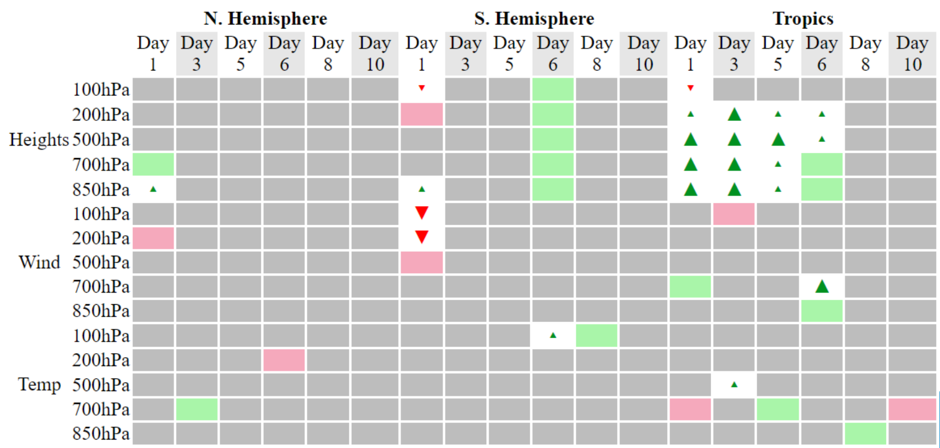
FTCDWL vs. BASE



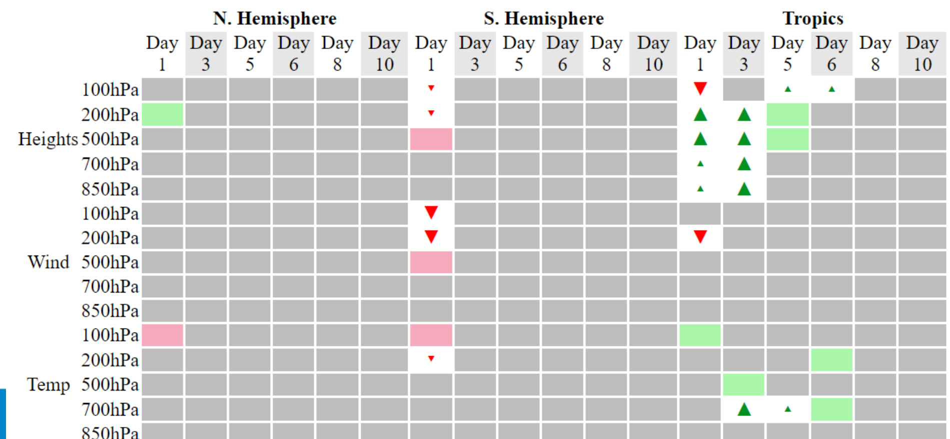
DWL vs. BASE



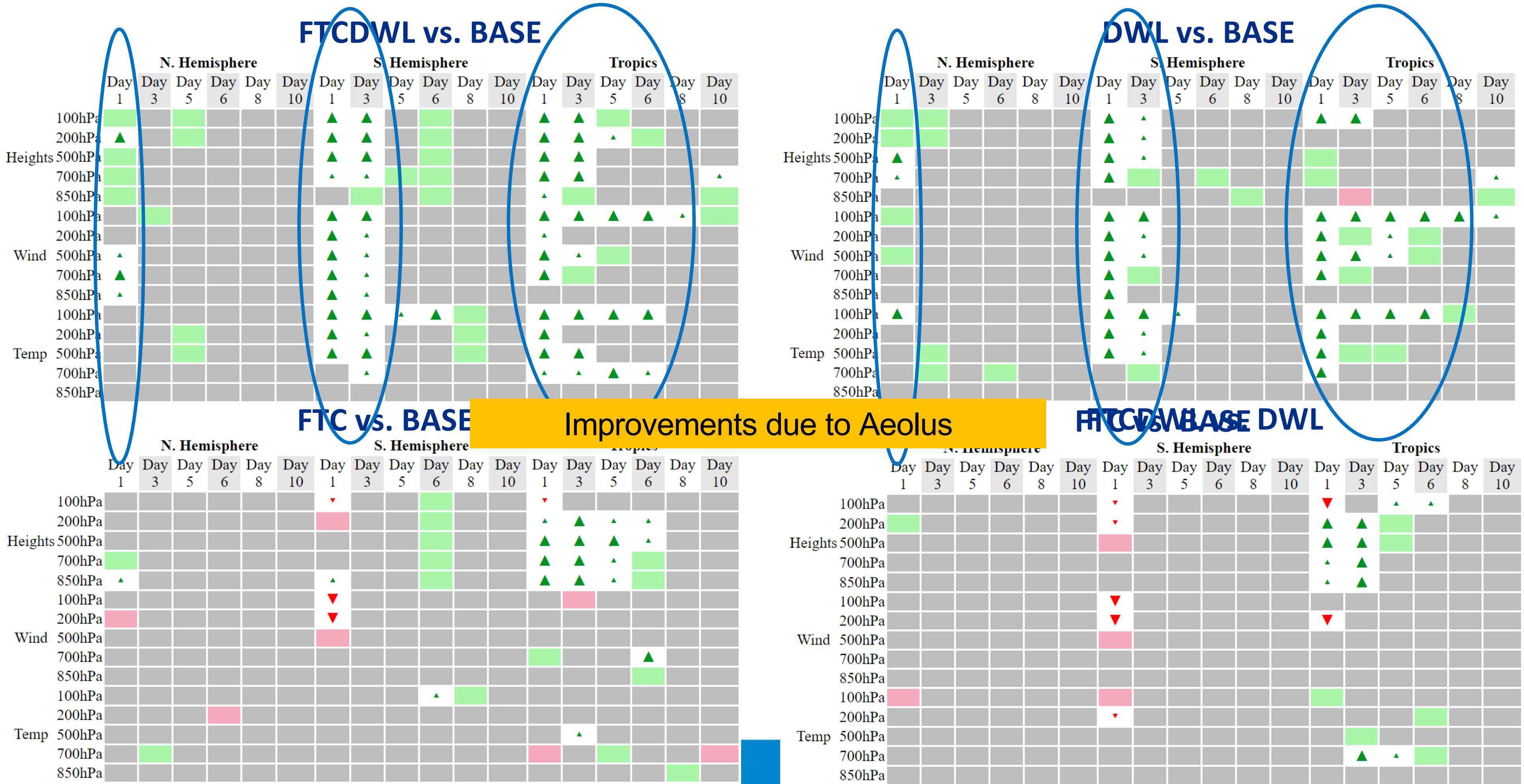
FTC vs. BASE



FTCDWL vs. DWL

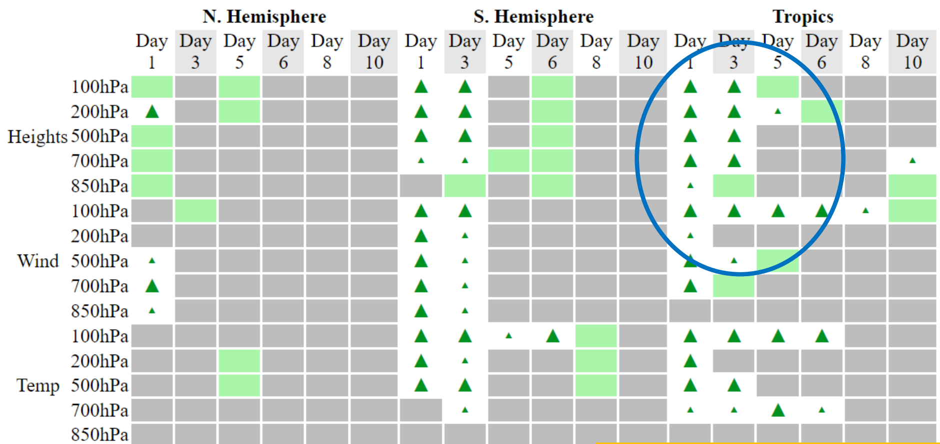


Forecast Score Cards (RMSE, Aug 7 - Sep 16, 2019, ECMWF verification)

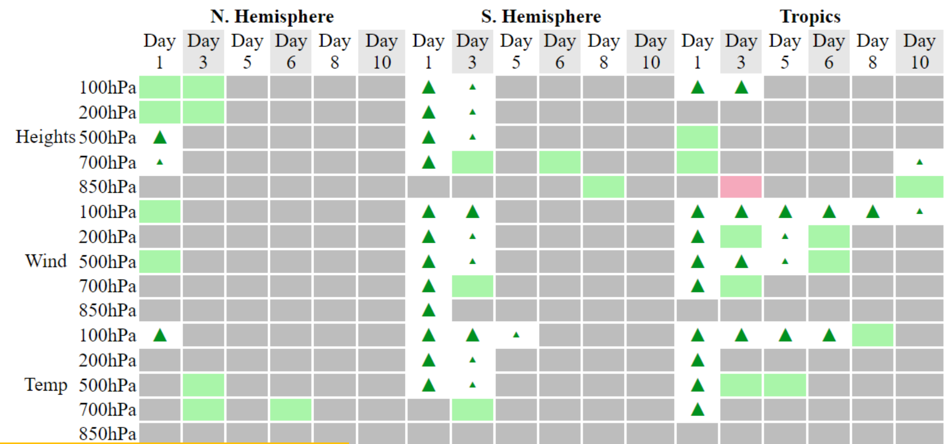


Forecast Score Cards (RMSE, Aug 7 - Sep 16, 2019, ECMWF verification)

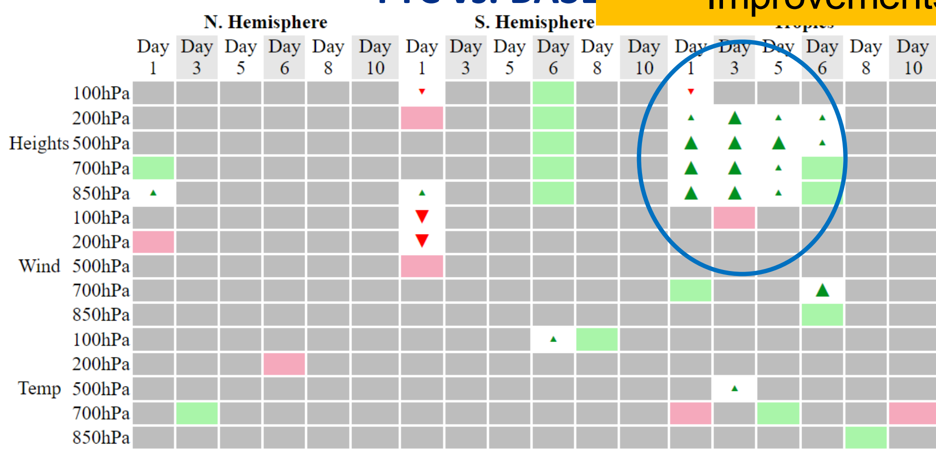
FTCDWL vs. BASE



DWL vs. BASE

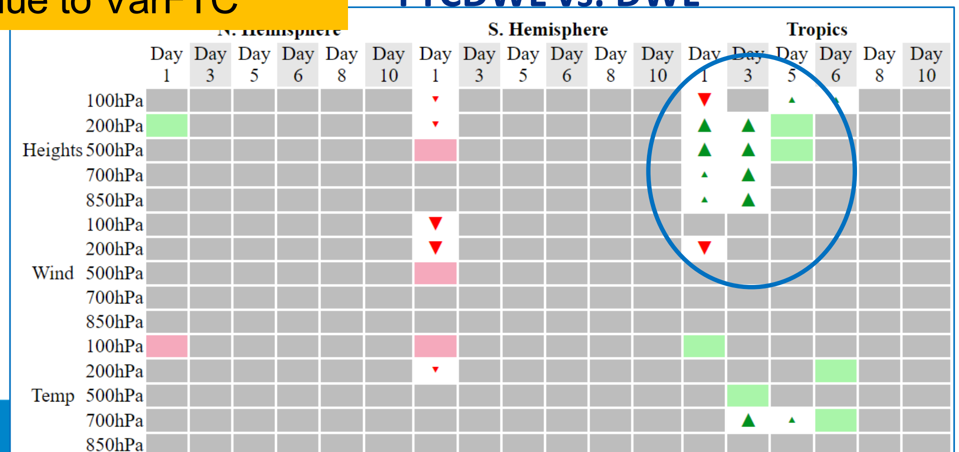


FTC vs. BASE



Improvements due to VarFTC

FTCDWL vs. DWL

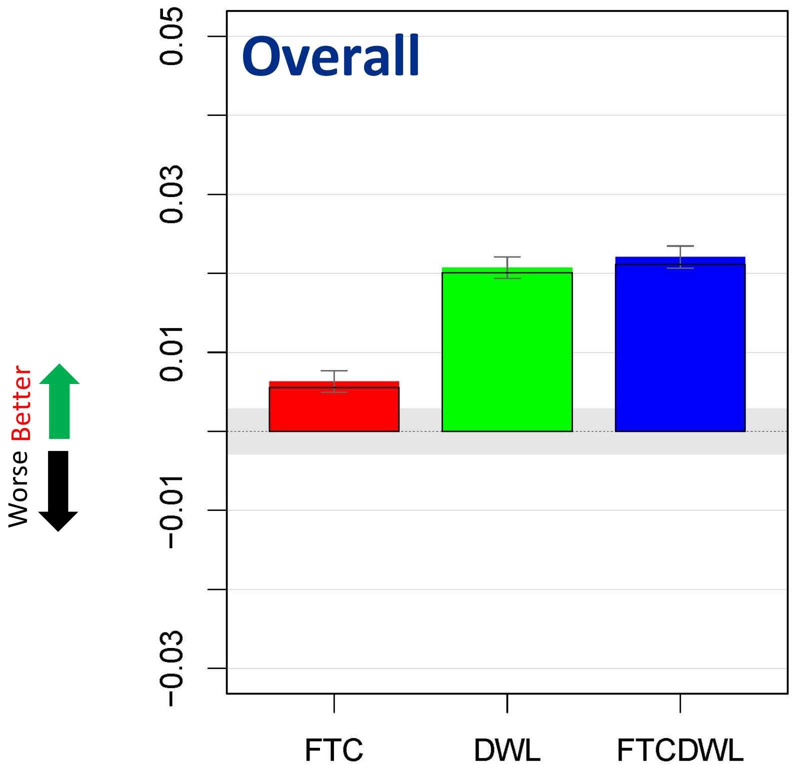


Quantitative Assessment of Forecast Skill (SAMs)

(Summary Assessment Metrics, Aug 7 - Sep 16, 2019, ECMWF verification)

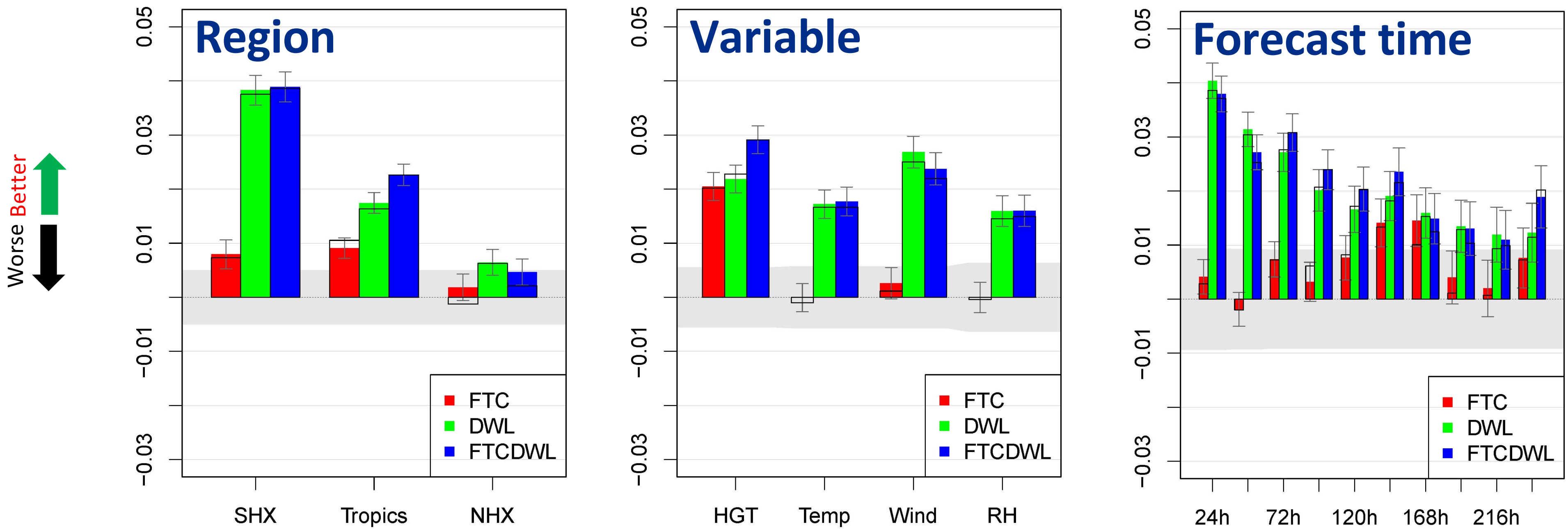
Overall
- FTC improves forecast skill modestly;
- DWL improves forecast skill significantly;
- DWL+FTC not significantly better than DWL alone.

Positive impacts of FTC are seen in the next slide mostly
- In the Tropics and SHX and
- For height and
- For forecast times centered on days 6-7



Quantitative Assessment of Forecast Skill (SAMs)

(Summary Assessment Metrics, Aug 7 - Sep 16, 2019, ECMWF verification)



Conclusion

- Variance explained by the FTC operator on the dependent sample is on the order of 3-4%
- In the data assimilation experiments the standard deviation of OMB is reduced on order of 4%.
- Overall, FTC improves forecast skill modestly, DWL significantly, and DWL+FTC not significantly better than DWL alone.
- Will a future DWL provide better anchoring of wind observations?

Thank you

COOPERATIVE INSTITUTE FOR SATELLITE EARTH SYSTEM STUDIES

- Contact: ross.n.hoffman@noaa.gov

- Previous project studies
  - Aeolus OSE study: Garrett et al. 2022, QJRMS, doi: 10.1002/qj.4331
  - FTC study: Hoffman et al. 2022, QJRMS, doi: 10.1002/qj.4207
  - Aeolus AMV collocation study: Lukens et al. 2022, AMT, 10.5194/amt-15-2719-2022
  - Aeolus TLS bias correction study: Liu et al. 2022, AMT, 10.5194/amt-15-3925-2022
  - Aeolus background sensitivity: Liu et al. 2023, QJRMS, 10.1002/qj.4600
- Acknowledgments

  - The authors acknowledge support from the NOAA/NESDIS Office of Projects, Planning, and Acquisition (OPPA) Technology Maturation Program (TMP) through CICS and CISESS at the University of Maryland/ESSIC (grant nos. NA14NES4320003 and NA19NES4320002) and CIMSS at the University of Wisconsin-Madison (grant no. NA20NES4320003).