Skillful weather predictions from observations alone:

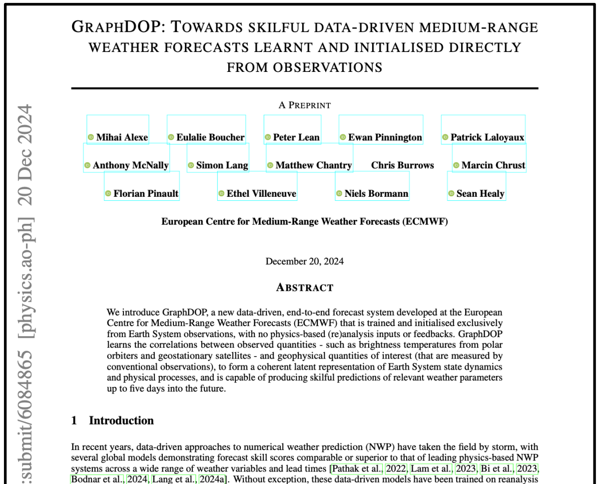
An initial look at the role of radiances in AI-DOP

The AI-DOP team,
notably: Tony McNally, Mihai Alexe, Peter Lean, Eulalie Boucher, Simon Lang, Ewan Pinnington and Christian Lessig

Presented by Niels Bormann

ECMWF

https://arxiv.org/abs/2412.15687



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GRAPHDOP: TOWARDS SKILFUL DATA-DRIVEN MEDIUM-RANGE WEATHER FORECASTS LEARNT AND INITIALISED DIRECTLY FROM OBSERVATIONS

A PREPRINT

Mihai Alexe, Eulalie Boucher, Peter Lean, Ewan Pinnington, Patrick Laloyaux, Anthony McNally, Simon Lang, Matthew Chantry, Chris Burrows, Marcin Chrust, Florian Pinault, Ethel Villeneuve, Niels Bormann, Sean Healy

European Centre for Medium-Range Weather Forecasts (ECMWF)

December 20, 2024

ABSTRACT

We introduce GraphDOP, a new data-driven, end-to-end forecast system developed at the European Centre for Medium-Range Weather Forecasts (ECMWF) that is trained and initialised exclusively from Earth System observations, with no physics-based (re)analysis inputs or feedbacks. GraphDOP learns the correlations between observed quantities - such as brightness temperatures from polar orbiters and geostationary satellites - and geophysical quantities of interest (that are measured by conventional observations), to form a coherent latent representation of Earth System state dynamics and physical processes, and is capable of producing skilful predictions of relevant weather parameters up to five days into the future.

1 Introduction

In recent years, data-driven approaches to numerical weather prediction (NWP) have taken the field by storm, with several global models demonstrating forecast skill scores comparable or superior to that of leading physics-based NWP systems across a wide range of weather variables and lead times [Pathak et al., 2022, Lam et al., 2023, Bi et al., 2023, Bodnar et al., 2024, Lang et al., 2024a]. Without exception, these data-driven models have been trained on reanalysis

Some illustrative examples of AI-DOP forecasts

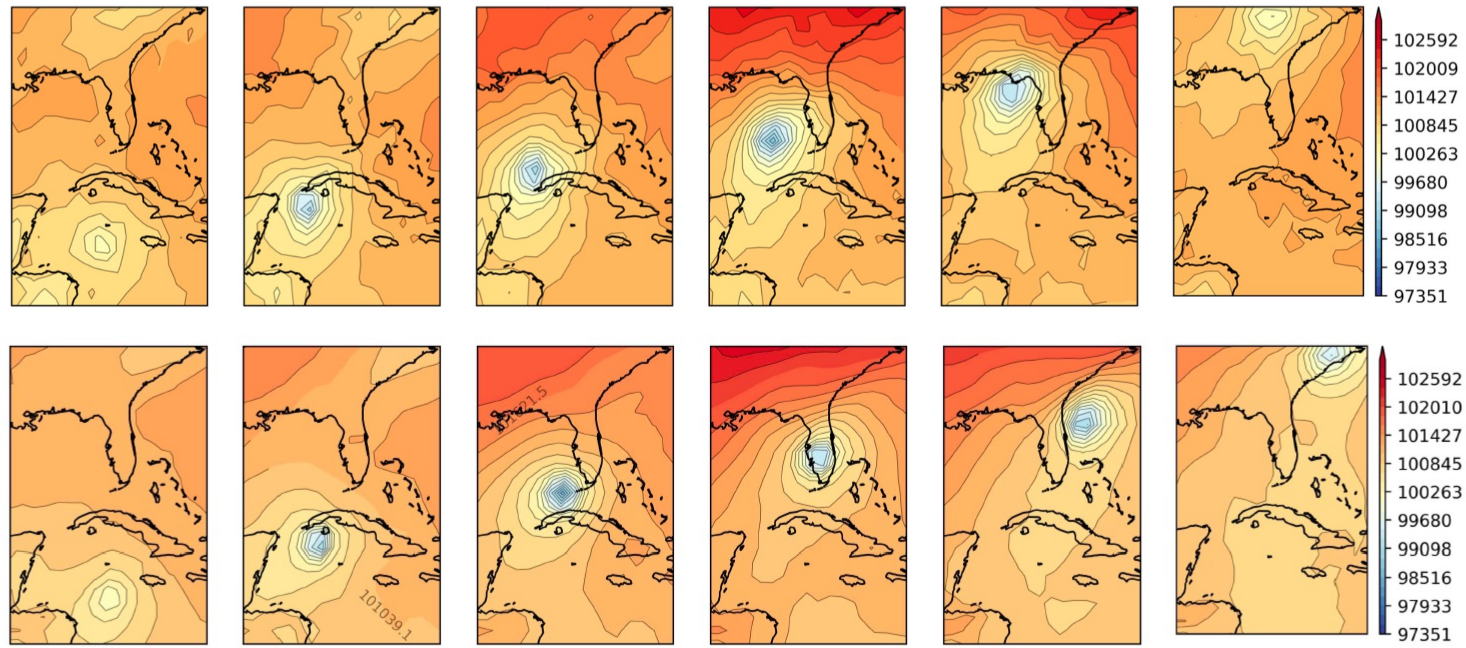
Hurricane Ian (Sept 2022)

AI-DOP initialised 24 Sept 2022, 9-21 Z

+1½ d +2½ d +3½ d +4½ d +5½ d +6½ d

AI-DOP forecast, MSLP [Pa]

ERA-5 analysis, MSLP [Pa]



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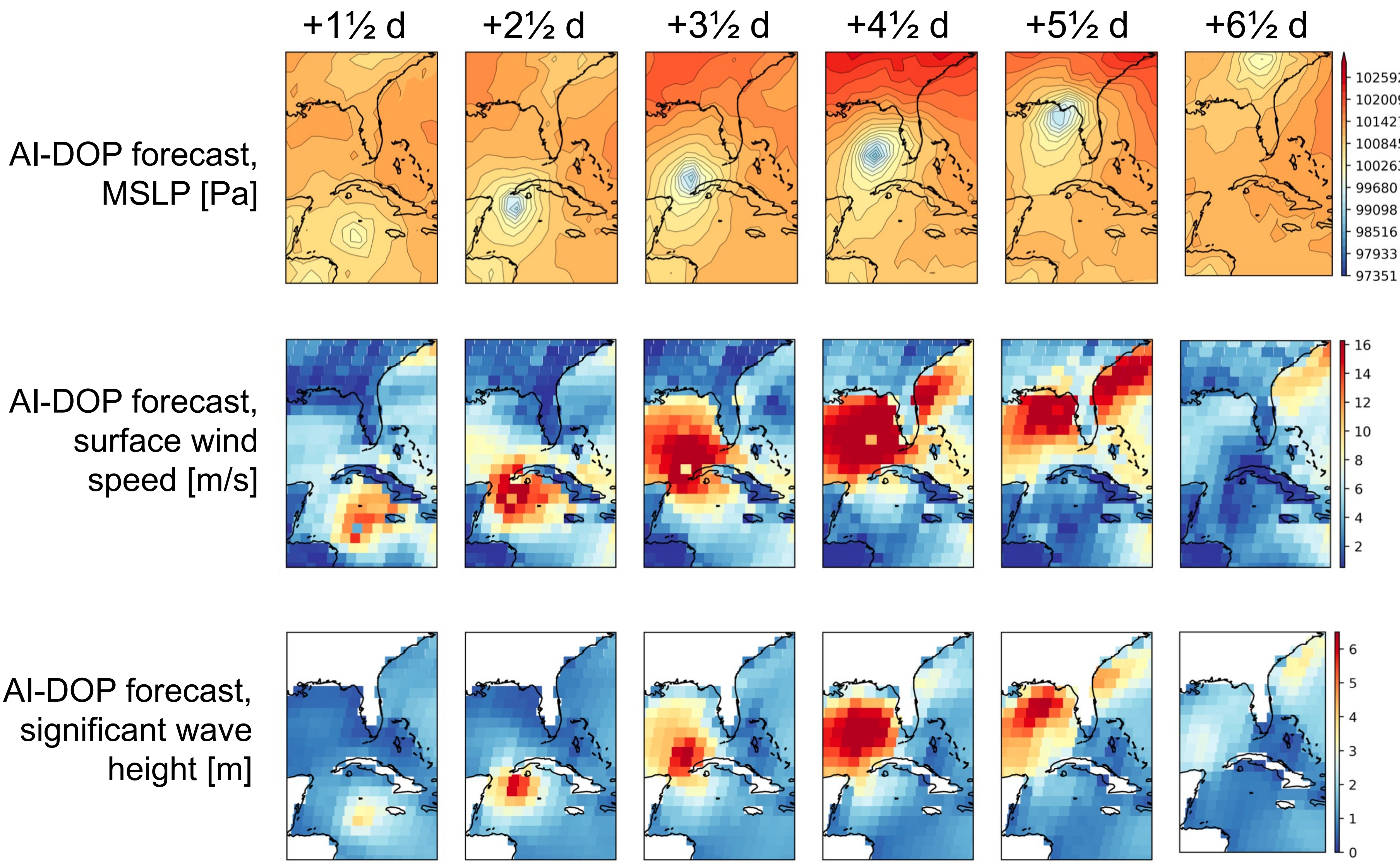

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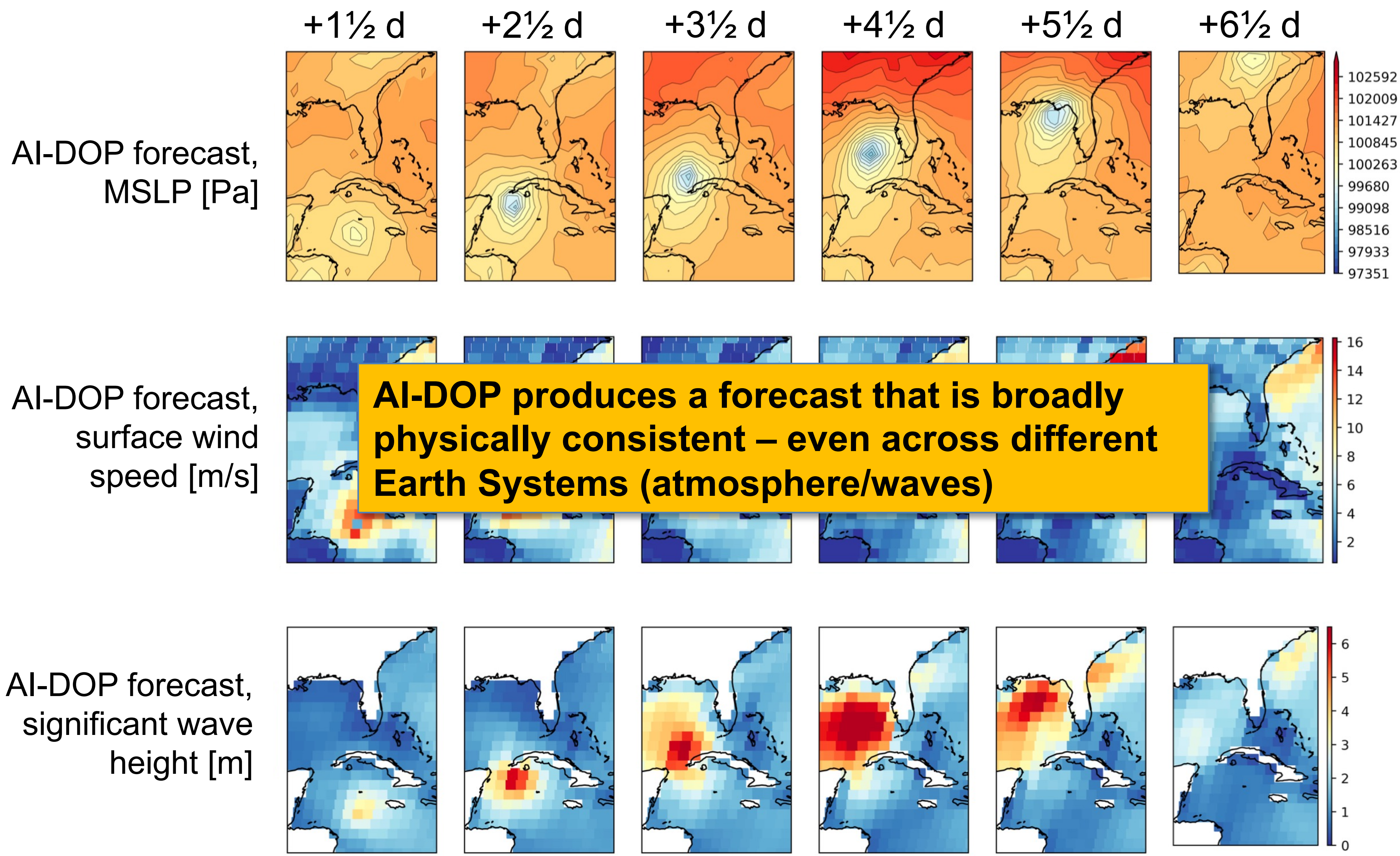


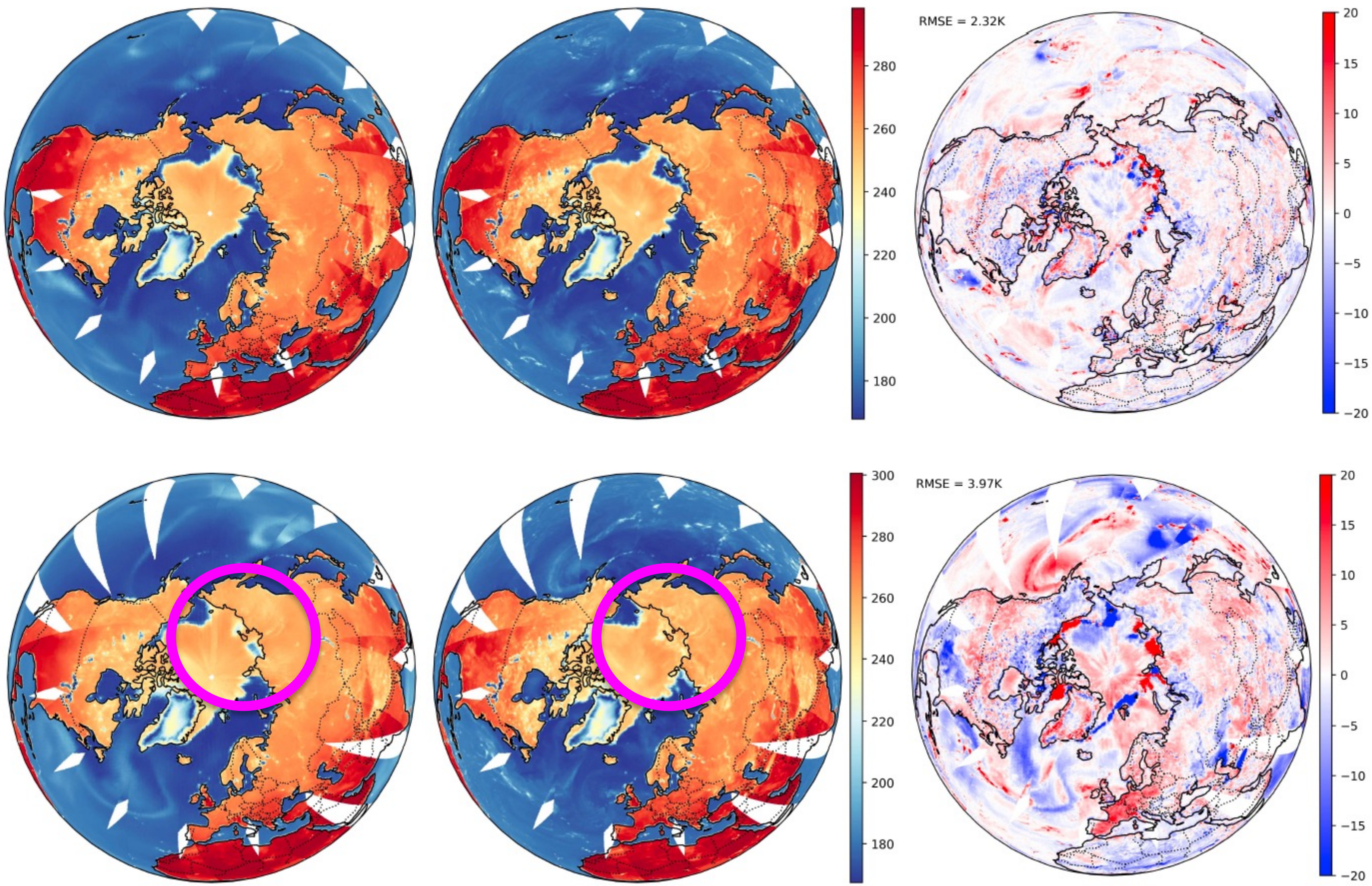
AI-DOP produces a forecast that is broadly physically consistent – even across different Earth Systems (atmosphere/waves)

A rapid freezing event in the Arctic, as seen by AMSR2 10.65 GHz v-channel (Oct 2022)

AI-DOP forecast | Target observations | Difference

12h forecast

10-day forecast



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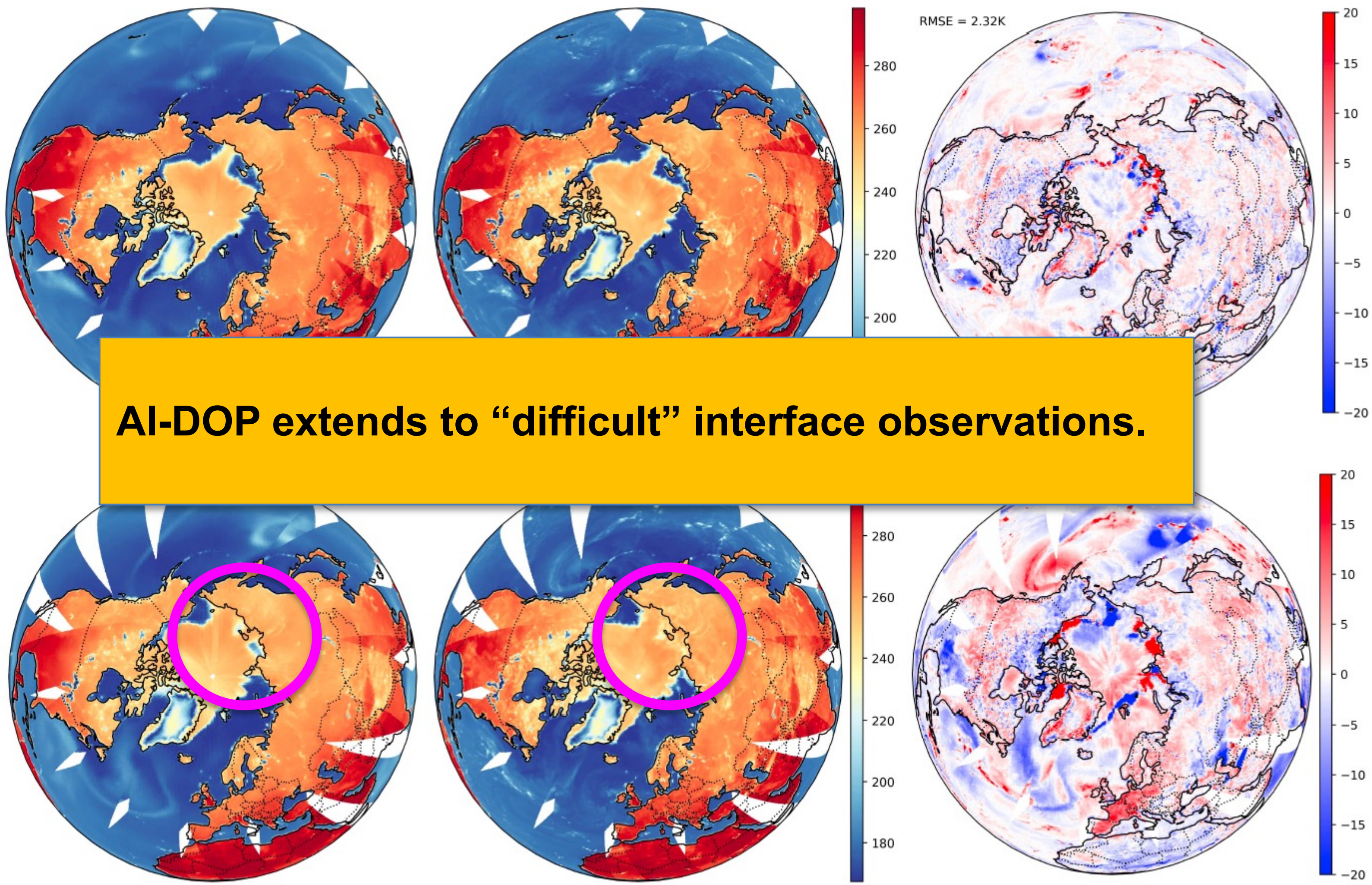

AI-DOP extends to “difficult” interface observations.

What observation impact do we see in AI-DOP?

Observing system experiments for IFS and AI-DOP

IFS:

- Observation denials vs a Control with the full observing system
- TCo 399 (~28 km) resolution

AI-DOP:

- Observations denied at **inference stage only**, from a system trained with the full observing system
- Use the latest AI-DOP model; trained with observations from 2004 – 2021

Note: The ”full observing system” is different between IFS and AI-DOP!

Denials for both systems:

- No conventional obs (aka surface-based/in-situ)
- No IR radiances (IR sounders and geos)
- No MW radiances (sounders and imagers)
- No cross-track MW sounders (ATMS, AMSU-A, MHS, MWHS-2)
- No MW imagers (AMSR2, GMI, SSMIS)

Period: 1 June – 31 Aug 2022

Observations used in inference

IFS	AI-DOP
Conventional Sondes, aircraft, synops, buoys, etc	**Conventional** Sondes, aircraft, synops, buoys, etc
Cross-track MW sounders 5 AMSU-A (Metop-B, -C; NOAA-15, -18, -19) 3 MHS (Metop-B, -C; NOAA-19) 2 ATMS (NOAA-20, S-NPP) 3 MWHS-2 (FY-3C, -3D, -3E)	**Cross-track MW sounders*** 4 AMSU-A (Metop-B, -C; NOAA-18, -19) 3 MHS (Metop-B, -C; NOAA-19) 2 ATMS (NOAA-20, S-NPP)
MW imagers AMSR-2 GMI 2 SSMIS (F-17, -18)	**MW imagers*** AMSR-2 GMI
IR radiances 2 IASI (Metop-B, -C) – 220 channels each AIRS – 135 channels 2 CrIS (NOAA-20, S-NPP) – 208 channels each 5 geostationary imagers (ASRs: Met-9 (IODC); Met-11. CSRs: Him-8/9; GEOS-16; GEOS-17/18)	**IR radiances** 1 IASI (Metop-B) – 17 channels + AVHRR visible 4 geostationary imagers (ASRs: Met-11. CSRs: Him-8/9; GEOS-16; GOES-17/18)
AMVs 5 geostationary imagers; up to 7 polar imagers	**AMVs**** 5 geostationary imagers; up to 7 polar imagers (as used in ERA-5)
GNSS-RO Various (Metop-B, -C; TerraSar-X; Sentinel-6A; COSMIC-2E; KOMPSAT-5; GRAC-C; Tandem-X; Spire)	
Scatterometer 3 satellites (Metop-B, -C; HY-2B)	
Others Doppler Wind Lidar Ground-based radar rain rates Ozone retrievals: OMI, SBUV, GOME-2	**Others** SARAL radar altimeter wave heights

* Bias corrected, using ERA-5
** After ERA-5 quality control

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MW image AMSR-2 GMI 2 SSMIS (F-17	**MW image** AMSR-2 GMI
IR radianc 2 IASI (Metop- AIRS – 135 ch 2 CrIS (NOAA- 5 geostationar ... : Him-8/9; GEOS-16; GEOS-17/	**IR radiance** 1 IASI (Metop-E 4 geostationary ... 16; GOES-17/18)
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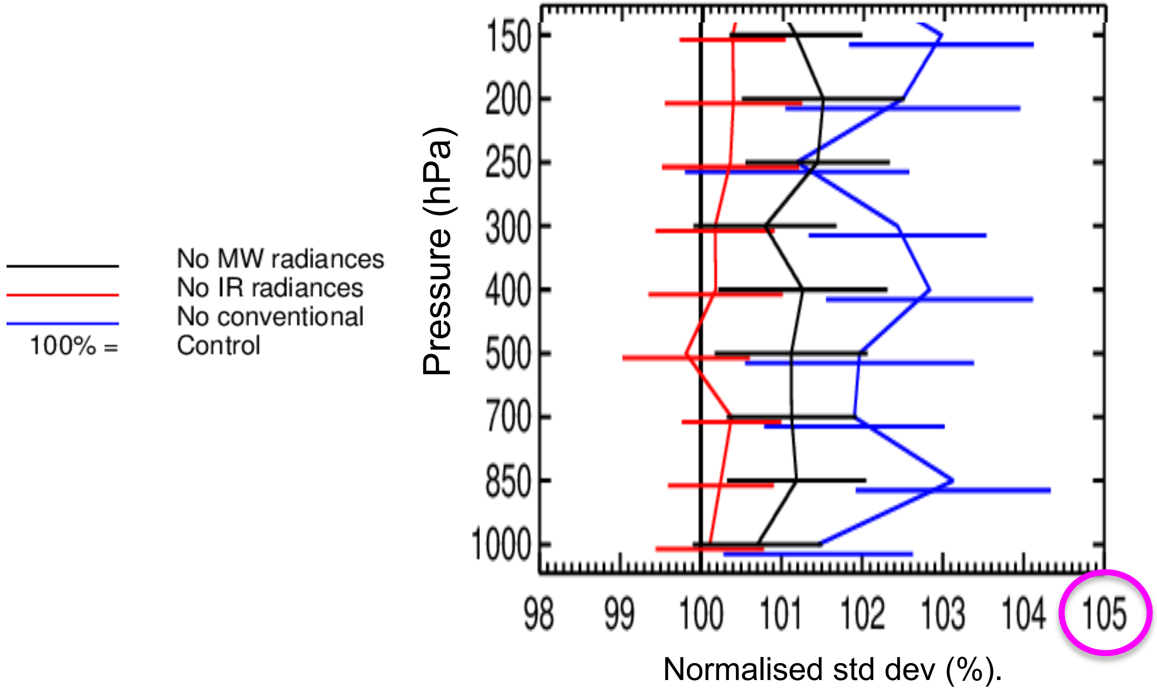
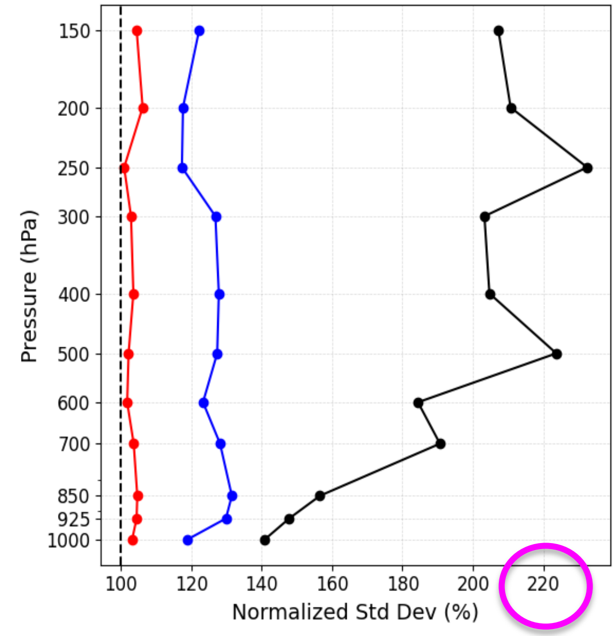
Temperature impact, day 4, N.Hem., verified vs sondes

IFS



AI-DOP



Withdrawal of observations has a much larger impact in AI-DOP

- Other observations used less well when some observations are missing?
- Different training approach or fine-tuning without the denied observations may help
- Physics-constraints help in IFS?

Much larger impact of MW radiances in AI-DOP than in IFS

- AI-DOP over-reliant on MW data?
- <u>Much less IR data in AI-DOP</u>
- <u>Forecasts of temperature would not be possible in AI-DOP without conventional data</u>

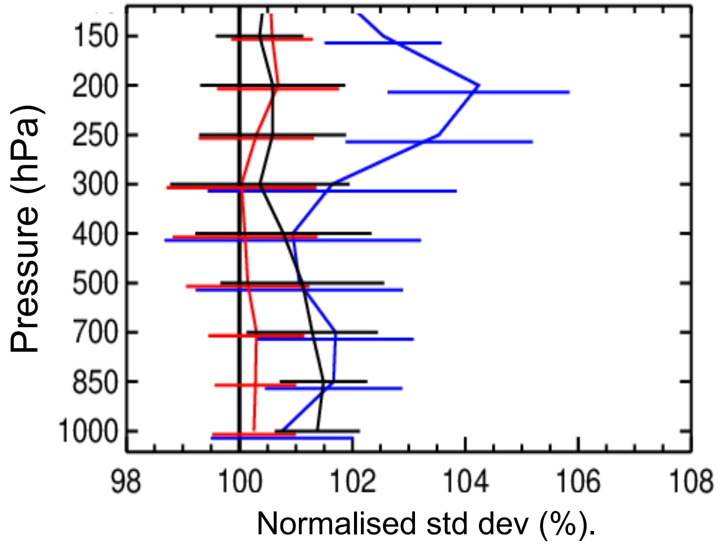
Zonal wind, day 4, vs conventional wind observations

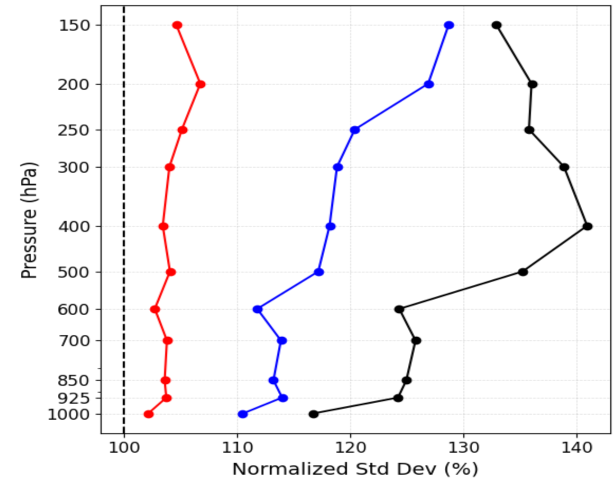
Less impact from conventional data over S.Hem. in both systems.

IFS

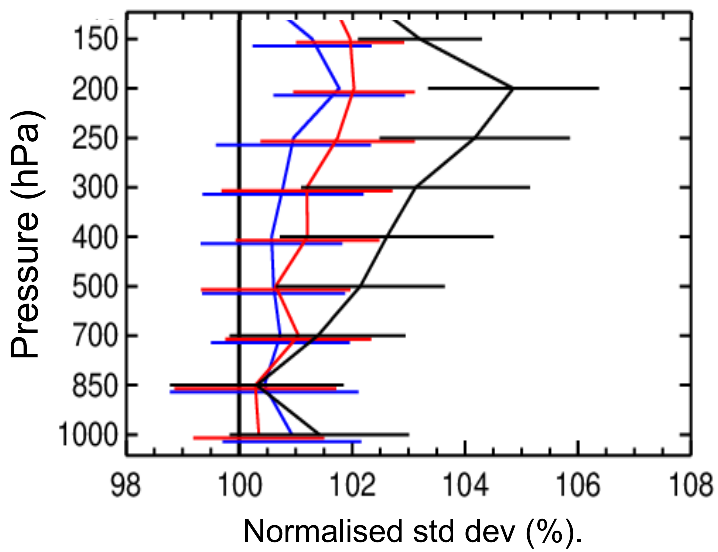
AI-DOP

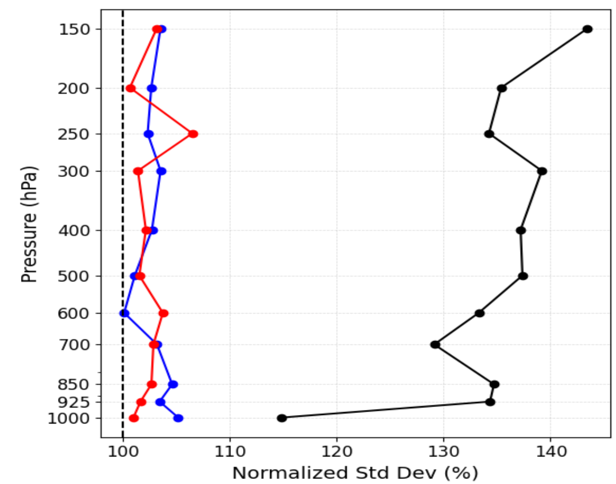
N.Hem.





S.Hem.

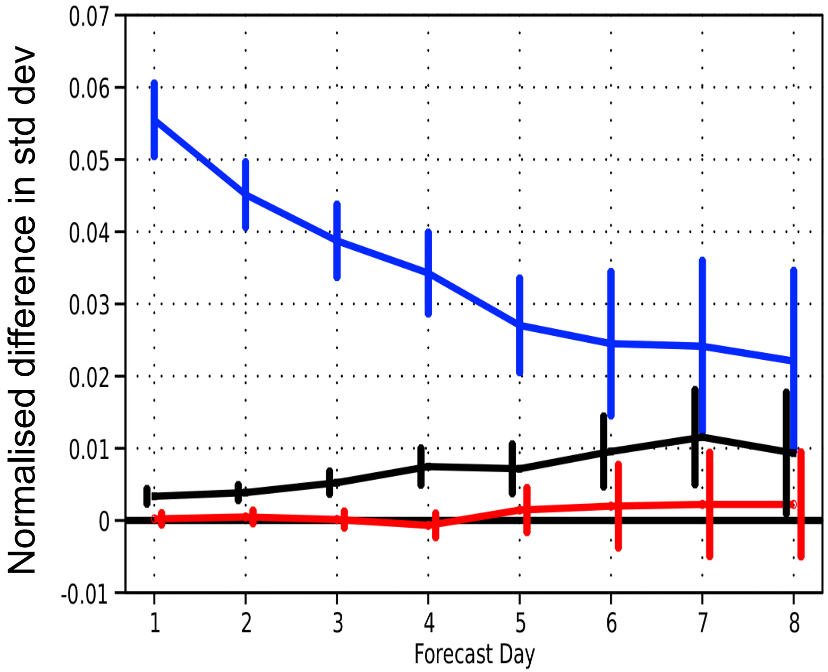




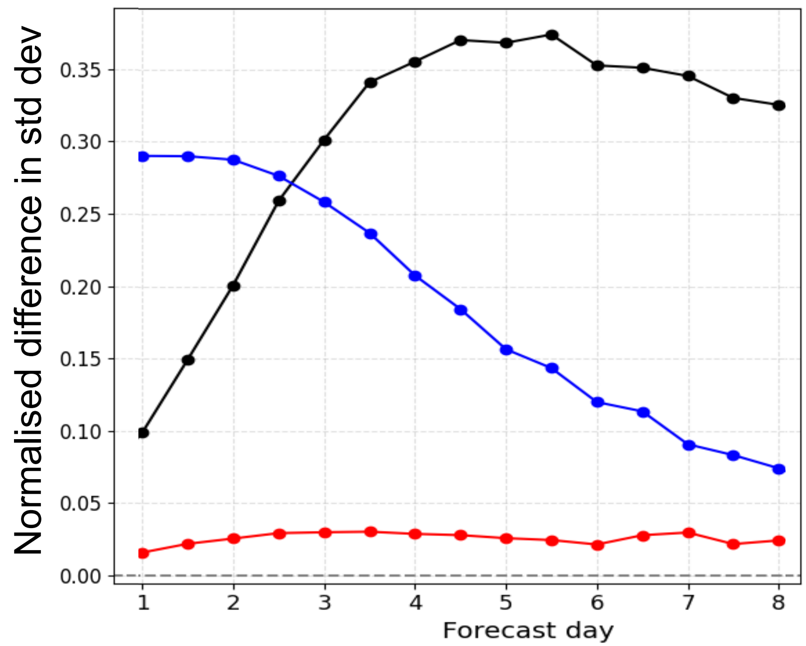
No MW radiances
No IR radiances
No conventional
100% = Control

2m-temperature, N.Hemis, vs synop observations

IFS



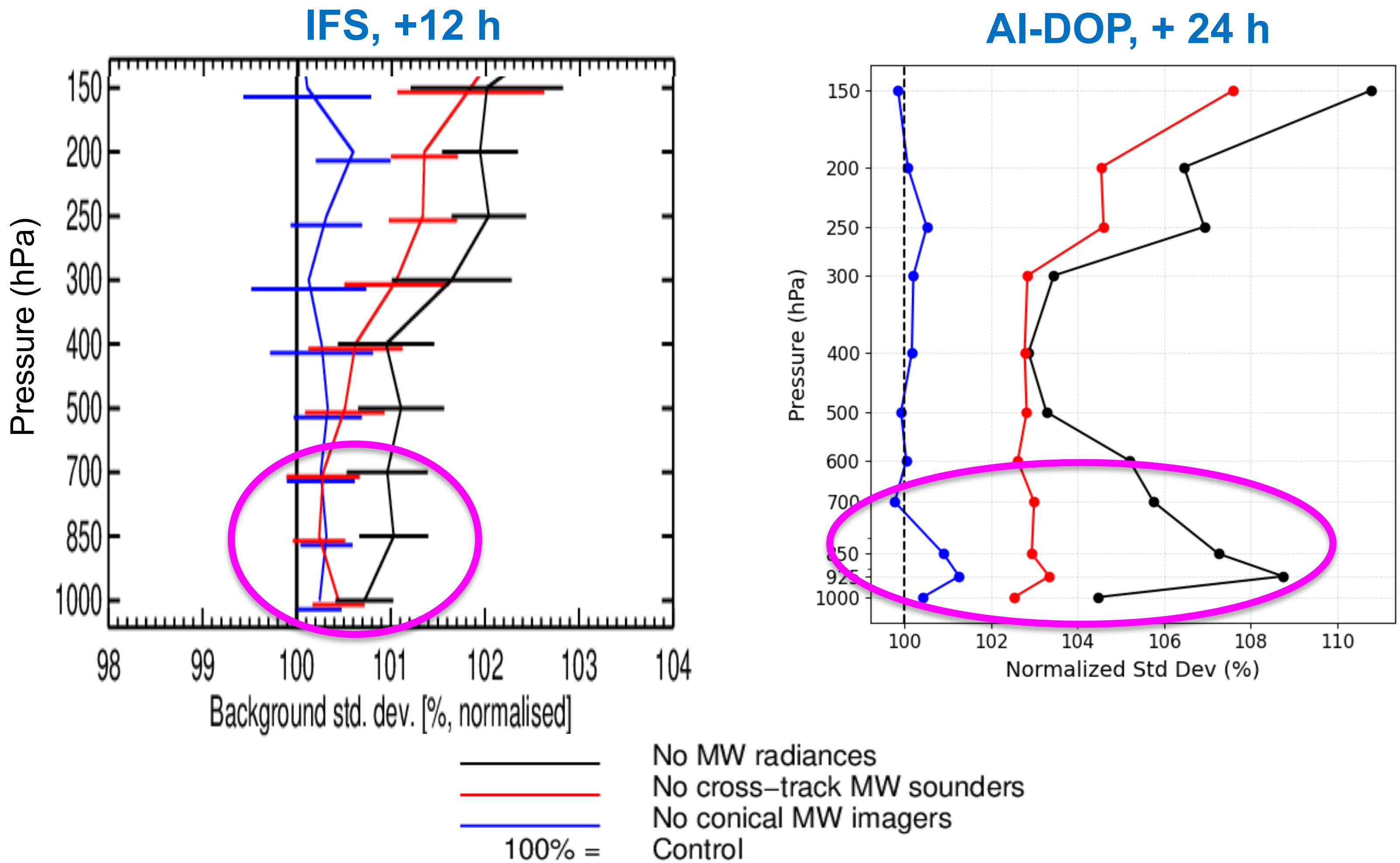
AI-DOP



Larger relative importance of satellite radiances for 2m temperature in AI-DOP

No MW radiances
No IR radiances
No conventional

MW impact from sounders & imagers
Zonal wind, tropics, vs conventional wind observations



Synergistic use of cross-track MW sounders and MW imagers to achieve wind impact in the lower tropical troposphere.

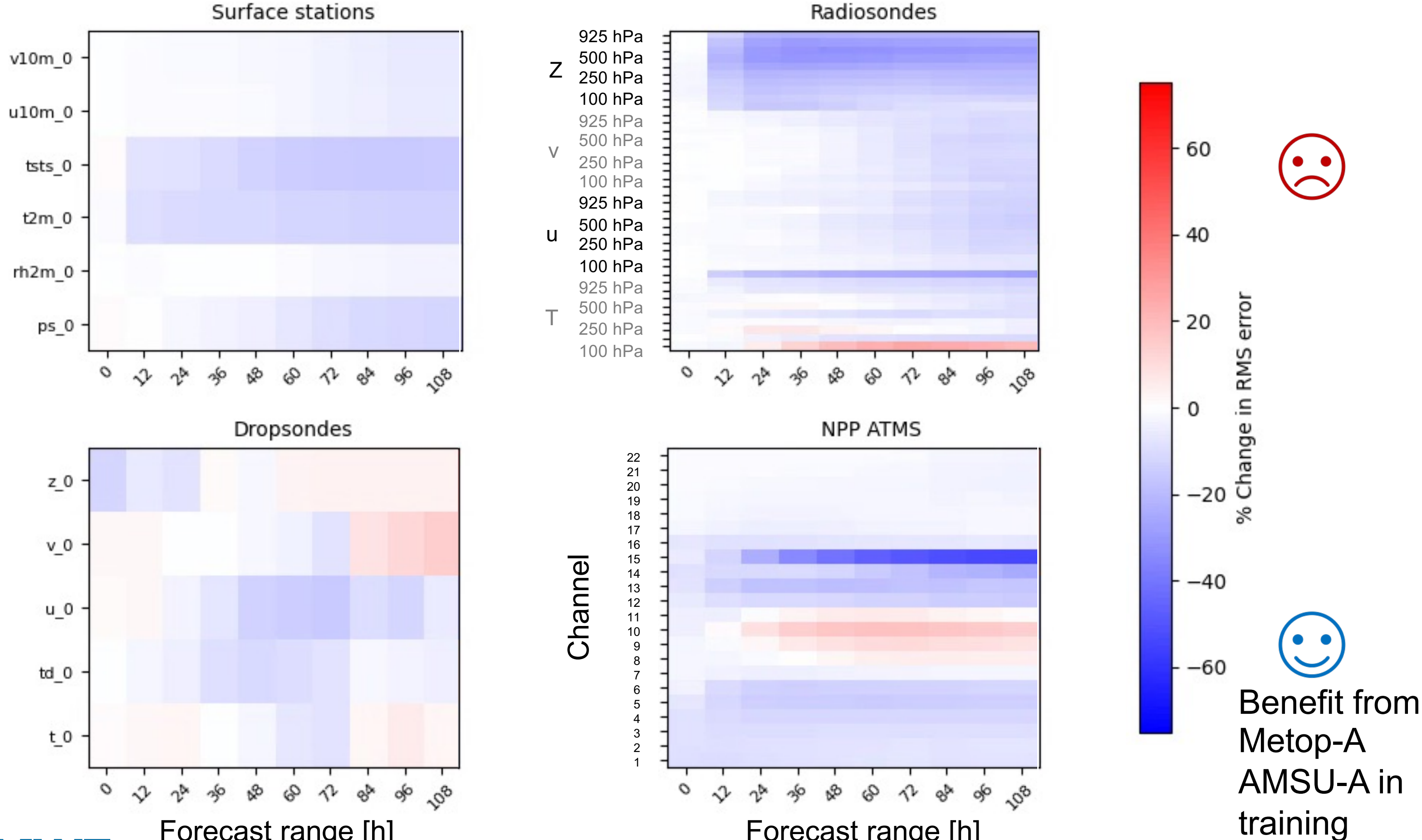
What about the value of past observations?

Impact in training: the value of observations “lives on”

Exp1: Trained without Metop-A AMSU-A data

Exp2: As Exp1, but with Metop-A AMSU-A added

Exp2 – Exp1, evaluated over a test period when **no Metop-A AMSU-A** data is available:



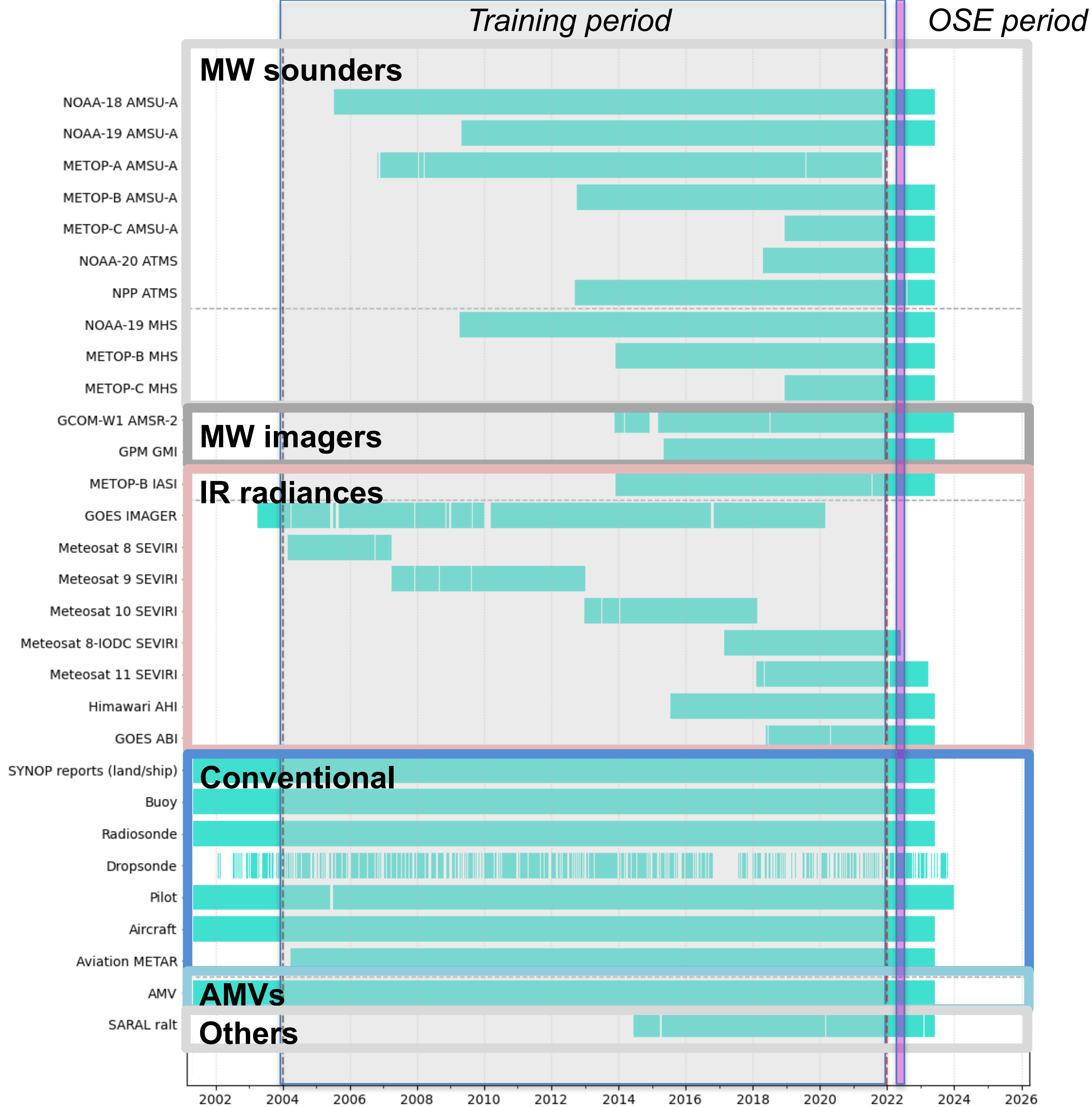
Summary/conclusions

- **AI-DOP produces forecasts that appear broadly physically consistent.**
- **AI-DOP extends to interface observations that are difficult to handle in physically-based systems.**

- **Preliminary first Observing System Experiments with AI-DOP suggest:**
  - Current AI-DOP is less robust than the IFS against the loss of observations.
  - MW radiances have a very large impact in the current AI-DOP system.
    - Probably over-reliant?
    - Can this be addressed through different training approaches, fine-tuning?
  - Large benefit from satellite radiances in AI-DOP for forecasts on 2m temperature.
- **Caveats:**
  - First OSEs for AI-DOP – lots to learn and develop – **results will change!**
  - Significant differences in the observing systems between IFS and AI-DOP. Especially: much less IR sounder data and no radio occultation in AI-DOP

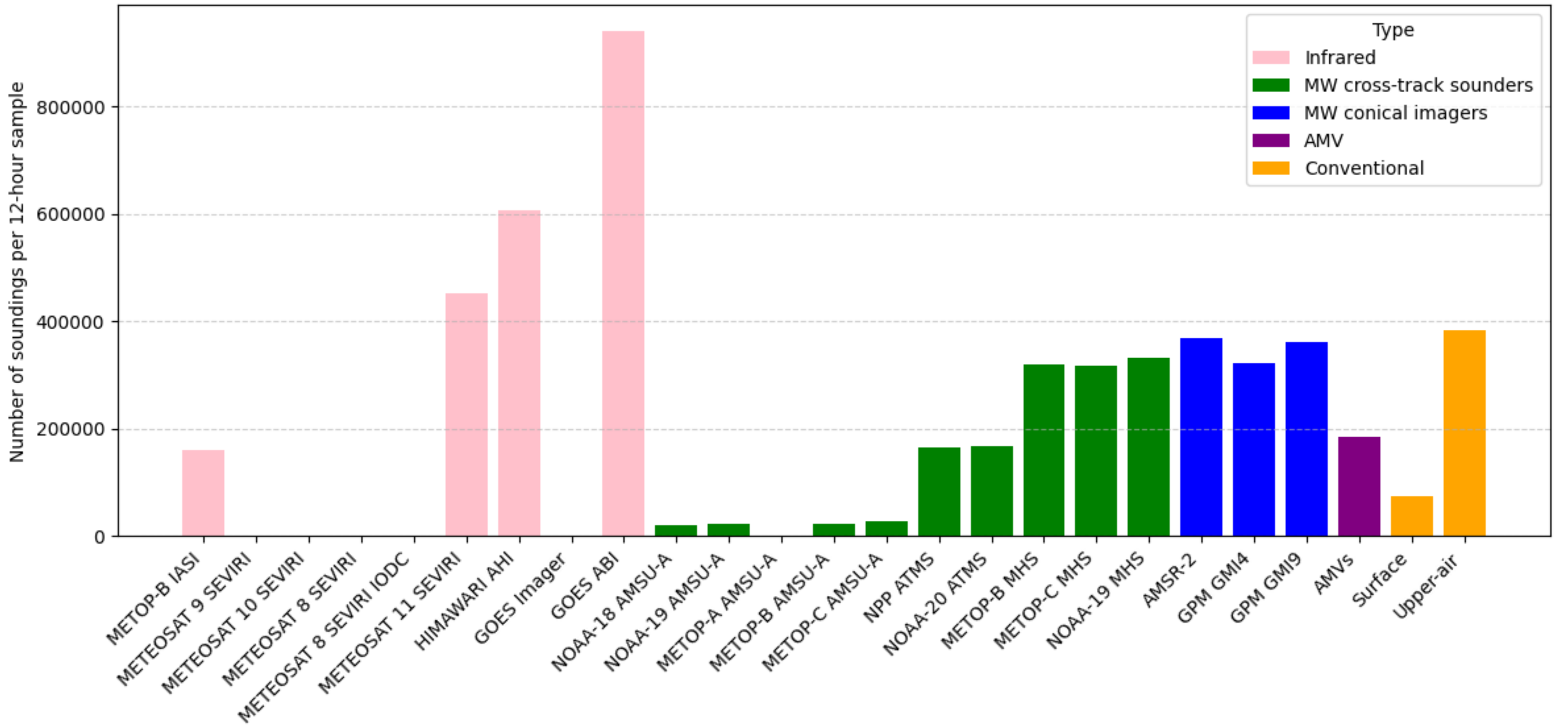
Bonus slides

Datasets



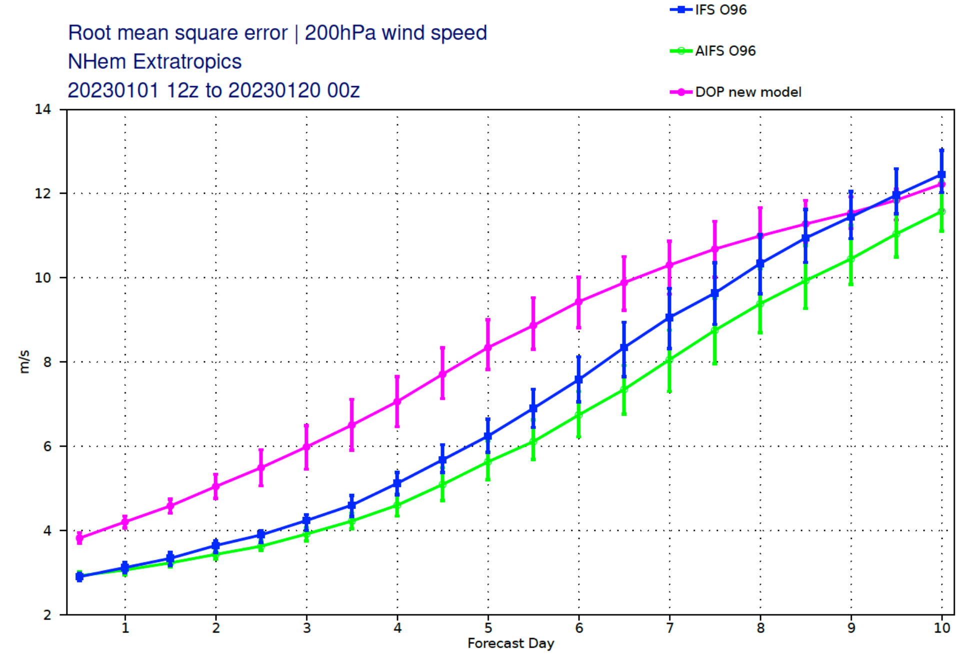
Training period
OSE period
MW sounders
NOAA-18 AMSU-A
NOAA-19 AMSU-A
METOP-A AMSU-A
METOP-B AMSU-A
METOP-C AMSU-A
NOAA-20 ATMS
NPP ATMS
NOAA-19 MHS
METOP-B MHS
METOP-C MHS
MW imagers
GCOM-W1 AMSR-2
GPM GMI
IR radiances
METOP-B IASI
GOES IMAGER
Meteosat 8 SEVIRI
Meteosat 9 SEVIRI
Meteosat 10 SEVIRI
Meteosat 8-IODC SEVIRI
Meteosat 11 SEVIRI
Himawari AHI
GOES ABI
Conventional
SYNOP reports (land/ship)
Buoy
Radiosonde
Dropsonde
Pilot
Aircraft
Aviation METAR
AMVs
AMV
Others
SARAL ralt
2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026

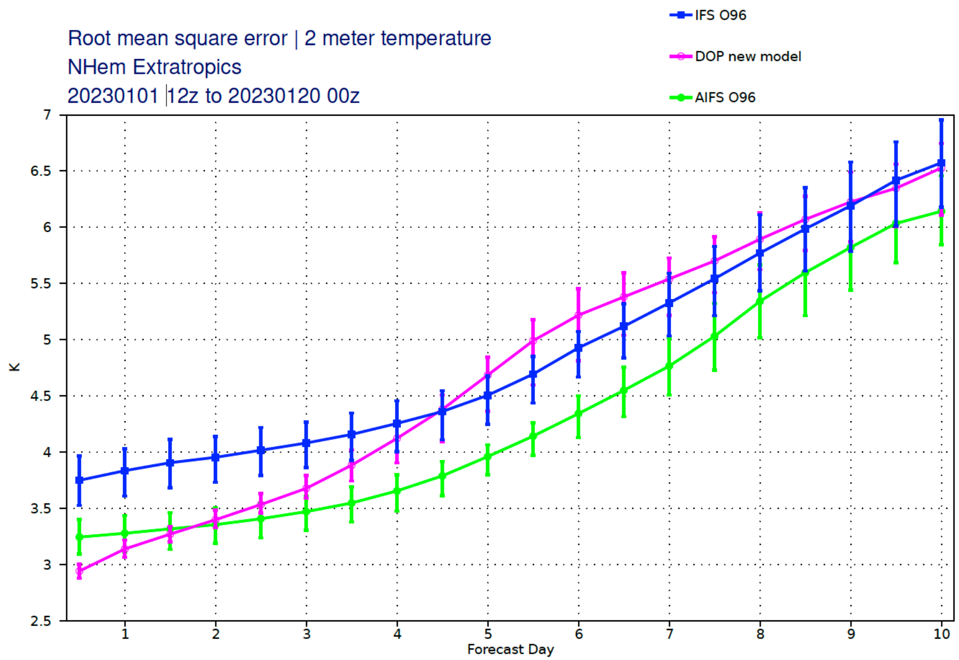
Average number of locations in 12-hours used by AI-DOP during the OSE period



Verification vs conventional observations

1-20 January 2023

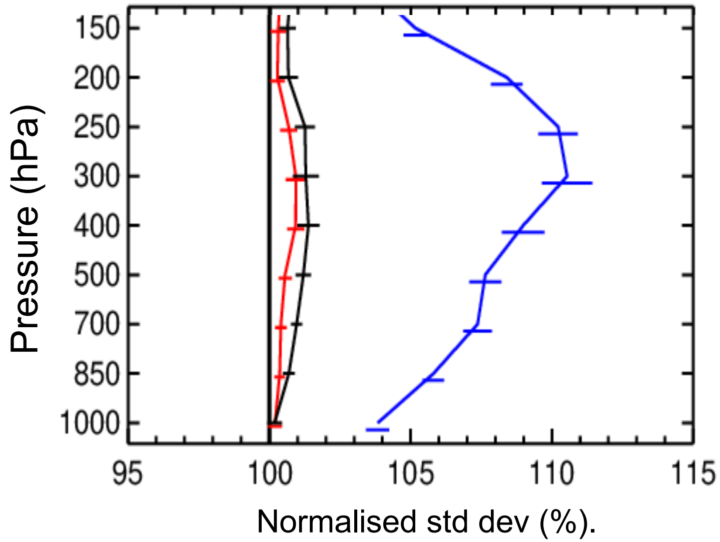


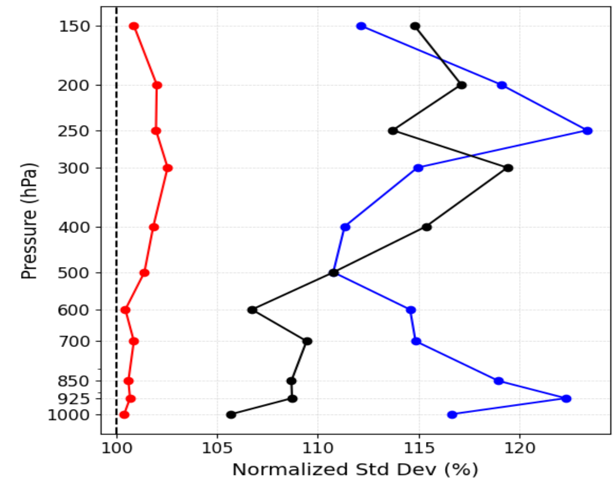


Zonal wind, N.Hem., vs conventional wind observations

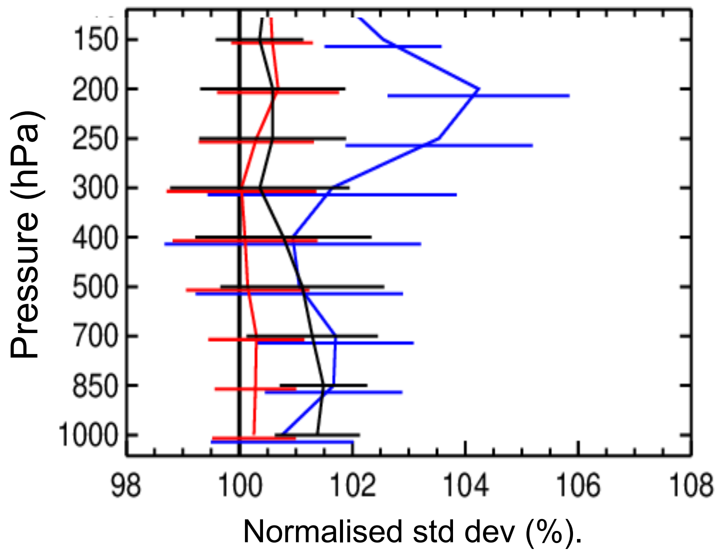
IFS | **AI-DOP**

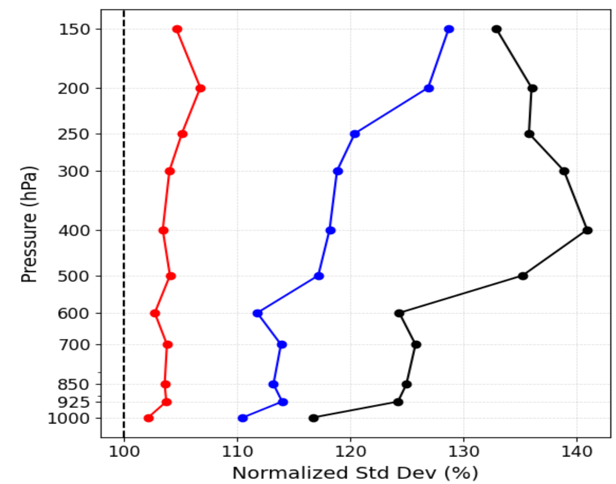
Day 1





Day 4





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No conventional
100% = Control

Zonal wind, S.Hem., vs conventional wind observations

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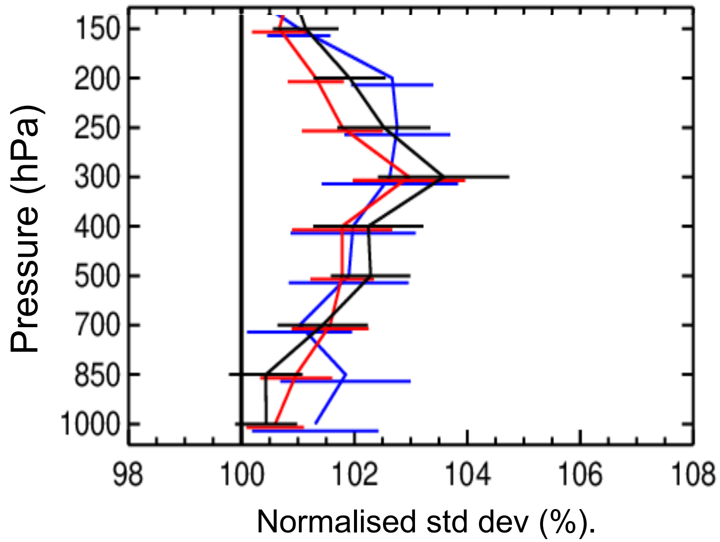
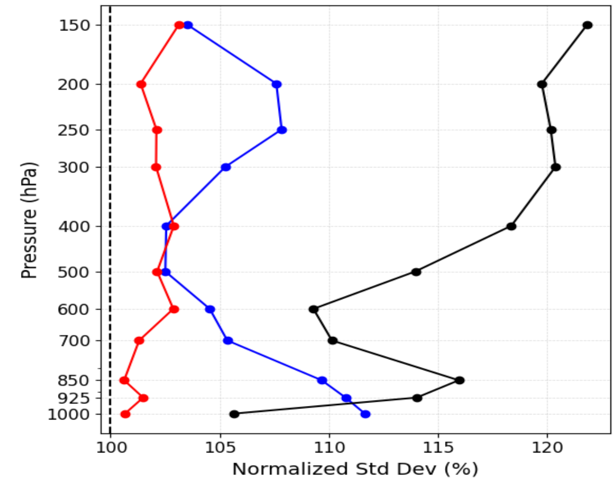
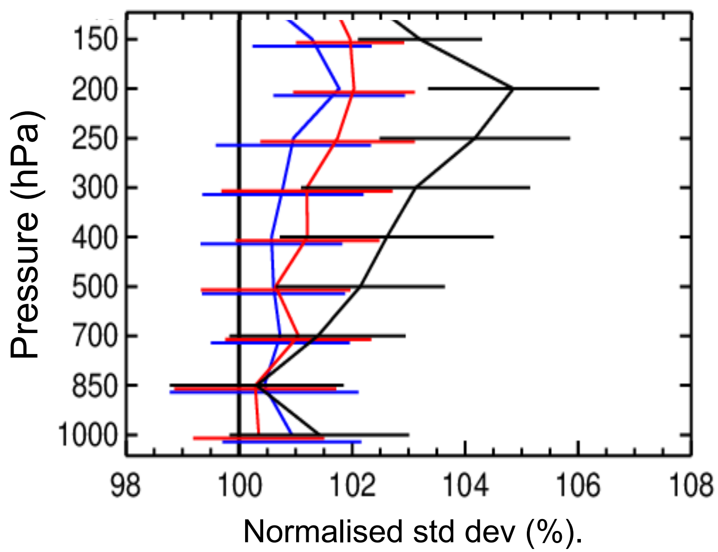
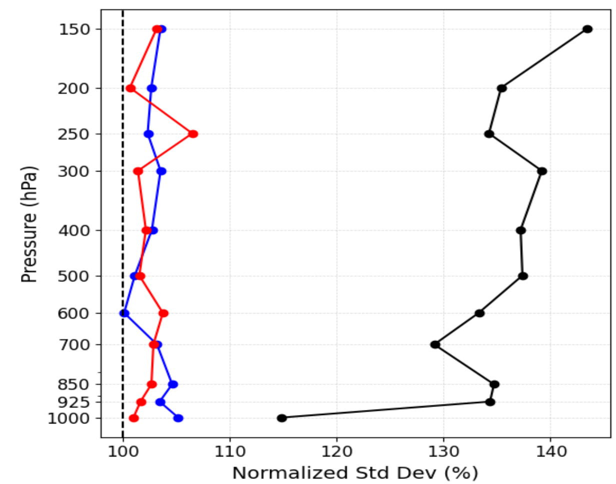




Day 4





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