

Background

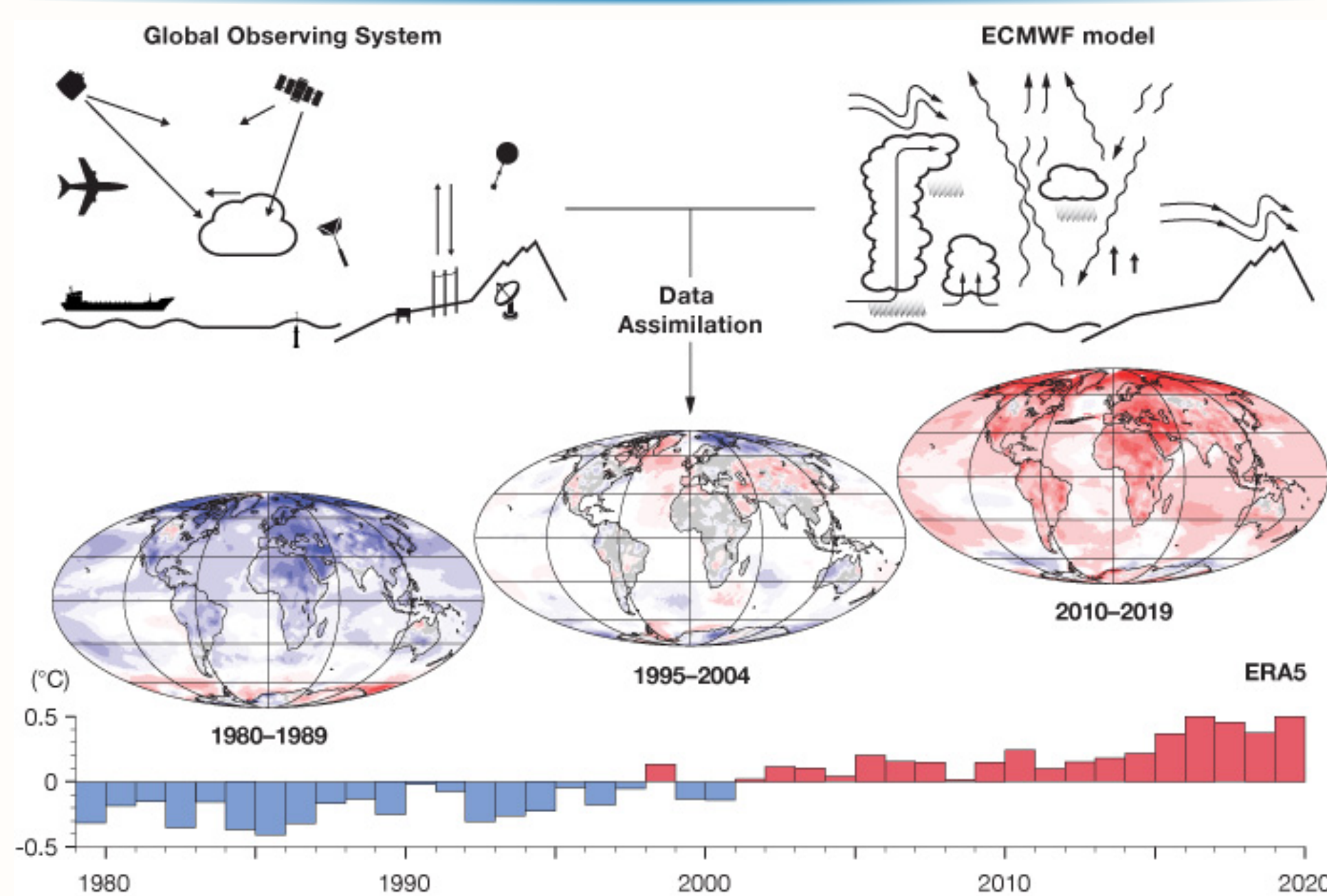


Figure 1: Schematic representation of climate reanalysis through data assimilation. *Source: ECMWF (2023).*

- Climate reanalyses combine observations with numerical models through data assimilation to produce consistent, long-term datasets.
- However, differences in model parameterisations and assimilation methods can lead to discrepancies, particularly during Sudden Stratospheric Warmings (SSWs).

Study Objective

- Examine the upper-stratospheric evolution of zonal-mean temperature (ZMT) and zonal-mean zonal wind (ZMW) during Northern Hemisphere (NH) winters.
- Assess how consistently ERA5 [1], MERRA-2 [2], and JRA-3Q [3] capture ZMT and ZMW responses to polar-vortex variability, with reanalysis temperatures further evaluated against Aura MLS [4] observations.

Materials and Methods

Northern Hemisphere Winter Case

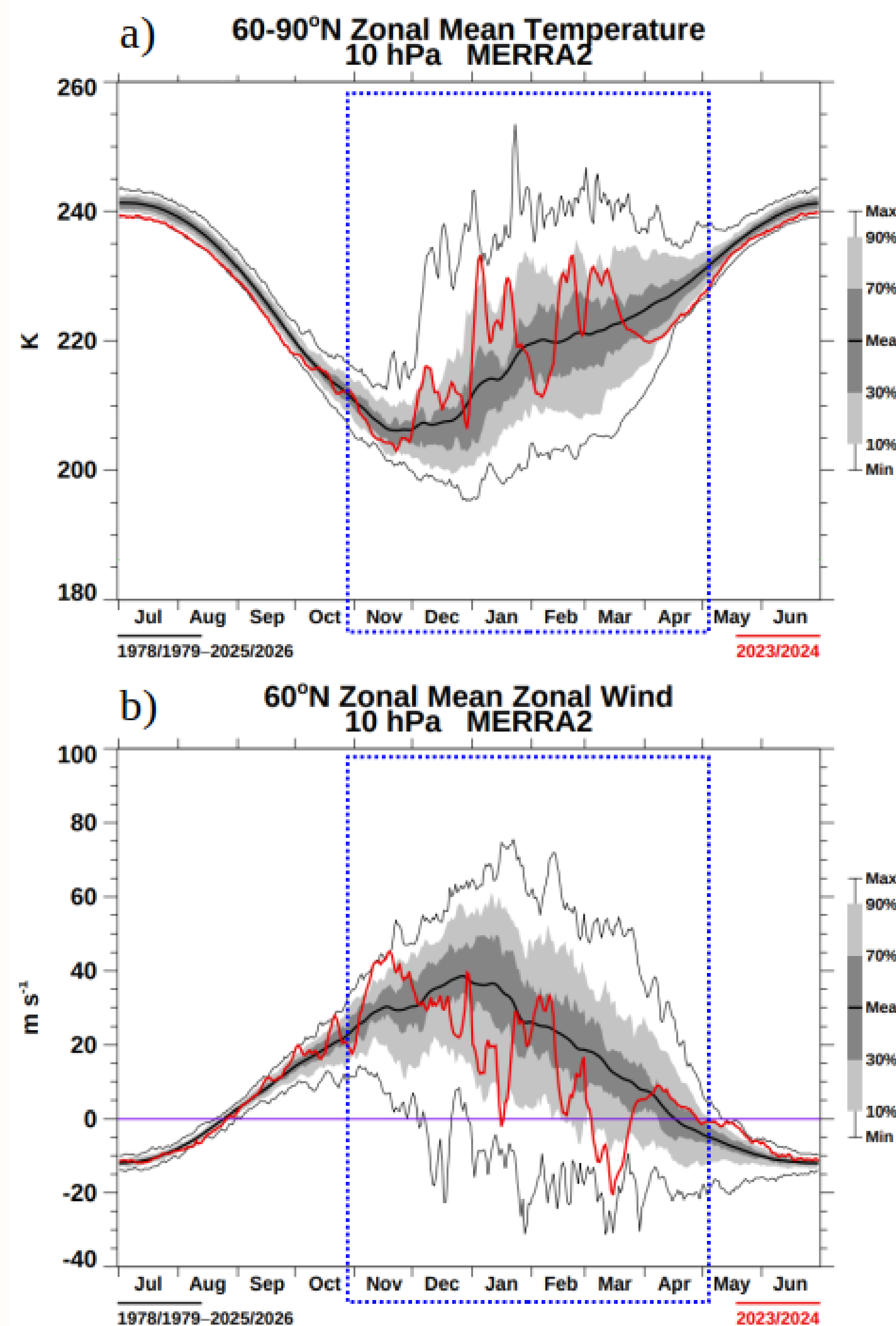


Figure 2: ZMT (a), averaged over 60°–90°N, and ZMW (b) at 60°N and 10 hPa from MERRA-2 during 2023–2024. Blue boxes indicate the winter analysis period. *Source: NASA GSFC.*

Data and Methods

- Daily ZMT and ZMW are analysed over 60°–90°N across the upper (1–5 hPa), middle (7–30 hPa), and lower (50–100 hPa) stratosphere.
- Daily pairwise differences between ERA5, MERRA-2, and JRA-3Q assess systematic bias and day-to-day variability.
- Aura MLS ZMT is compared with reanalyses at 1, 10, and 50 hPa for December–February (2004–2022).

Results and Discussion

Vertical Evolution of the Polar Vortex

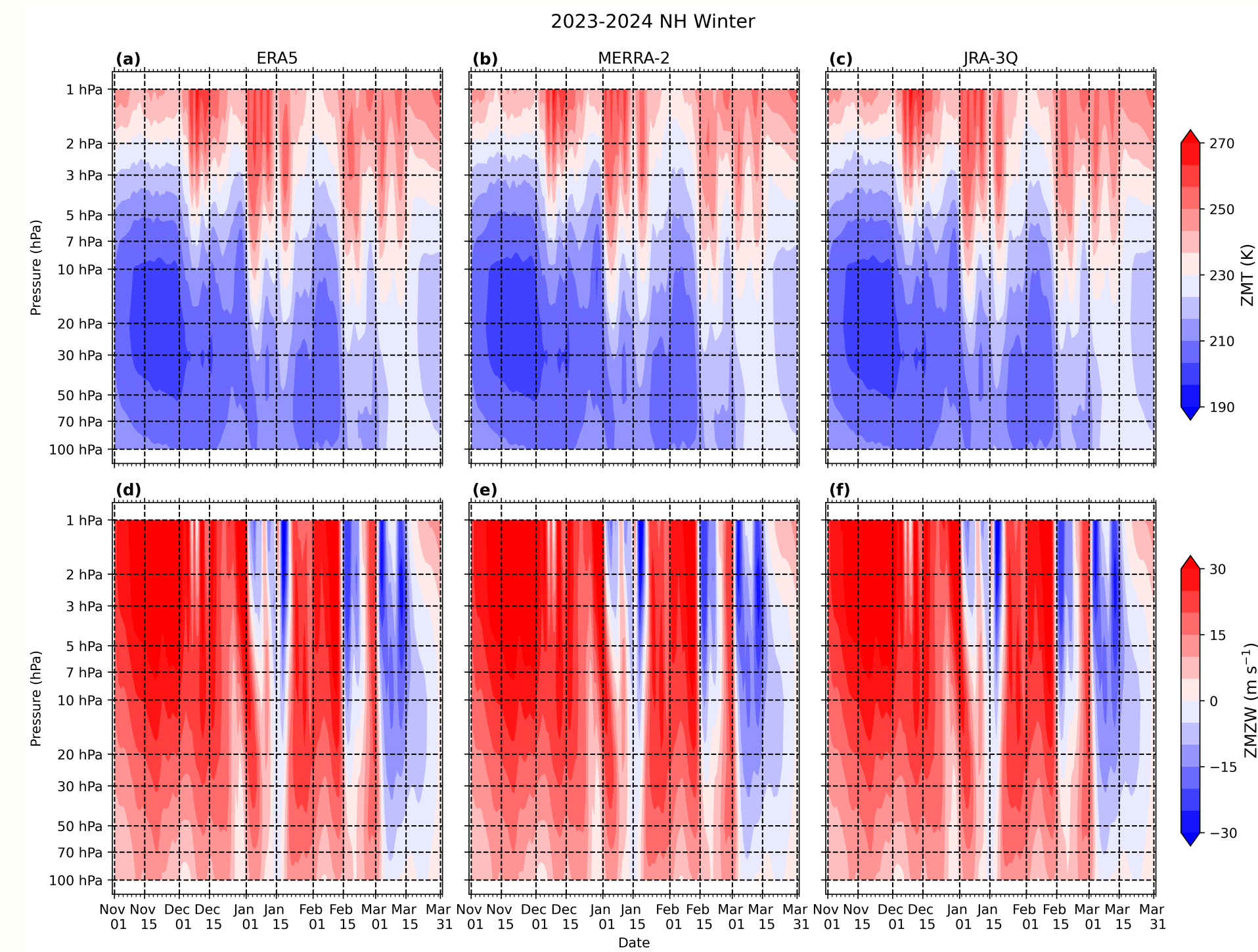


Figure 3: Vertical evolution of ZMT (a–c) and ZMW (d–f) during the 2023–2024 NH winter.

- Early January 2024:** Wind reverses at 1 hPa before 10 hPa and propagates downward into the mid-January major SSW (Fig. 3), suggesting that the 10-hPa criterion may miss early SSW development.
- Mid-February 2024:** Wind reversal extends from 1–20 hPa. At 10 hPa on 19 February, winds are westerly at 60°N but easterly over 60°–90°N (Fig. 3), highlighting the latitude sensitivity of SSW classification.

Inter-Reanalysis Differences: ZMT

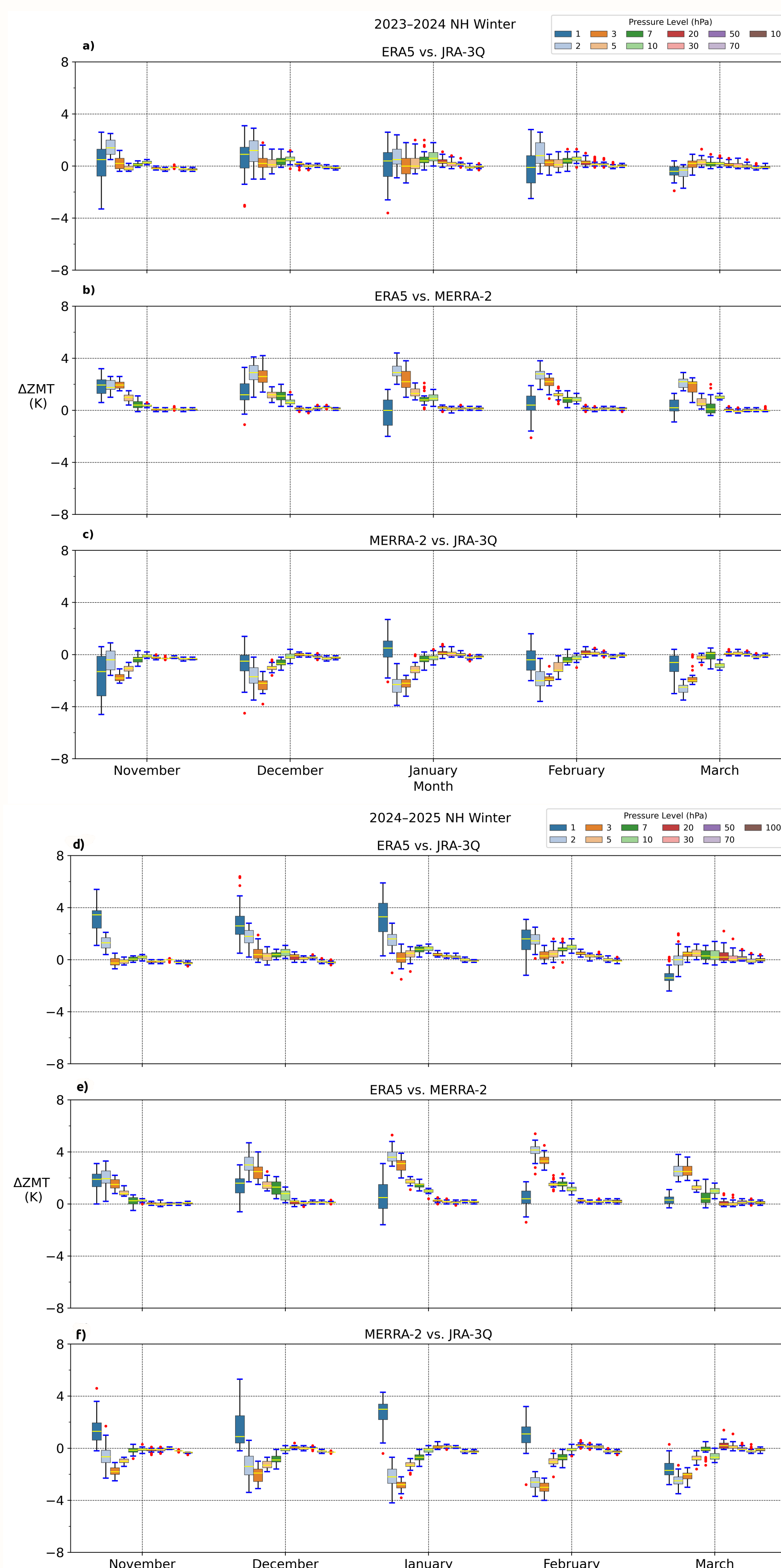


Figure 4: Monthly distributions of daily pairwise ZMT differences (ΔZMT , K) across pressure levels during the 2023–2024 (a–c) and 2024–2025 (d–f) NH winters.

- ZMT agreement is stronger at 7–100 hPa (Fig. 4), while upper-level agreement varies by month and dataset pair.
- ERA5 and JRA-3Q show the most consistent vertical agreement, while agreement involving MERRA-2 is more limited, particularly in the upper stratosphere.

Inter-Reanalysis Differences: ZMW

- ZMW agreement is generally strong at 3–100 hPa (Fig. 5), with the largest variability at 1–2 hPa, particularly during December–January 2023–2024 and February–March 2024–2025.

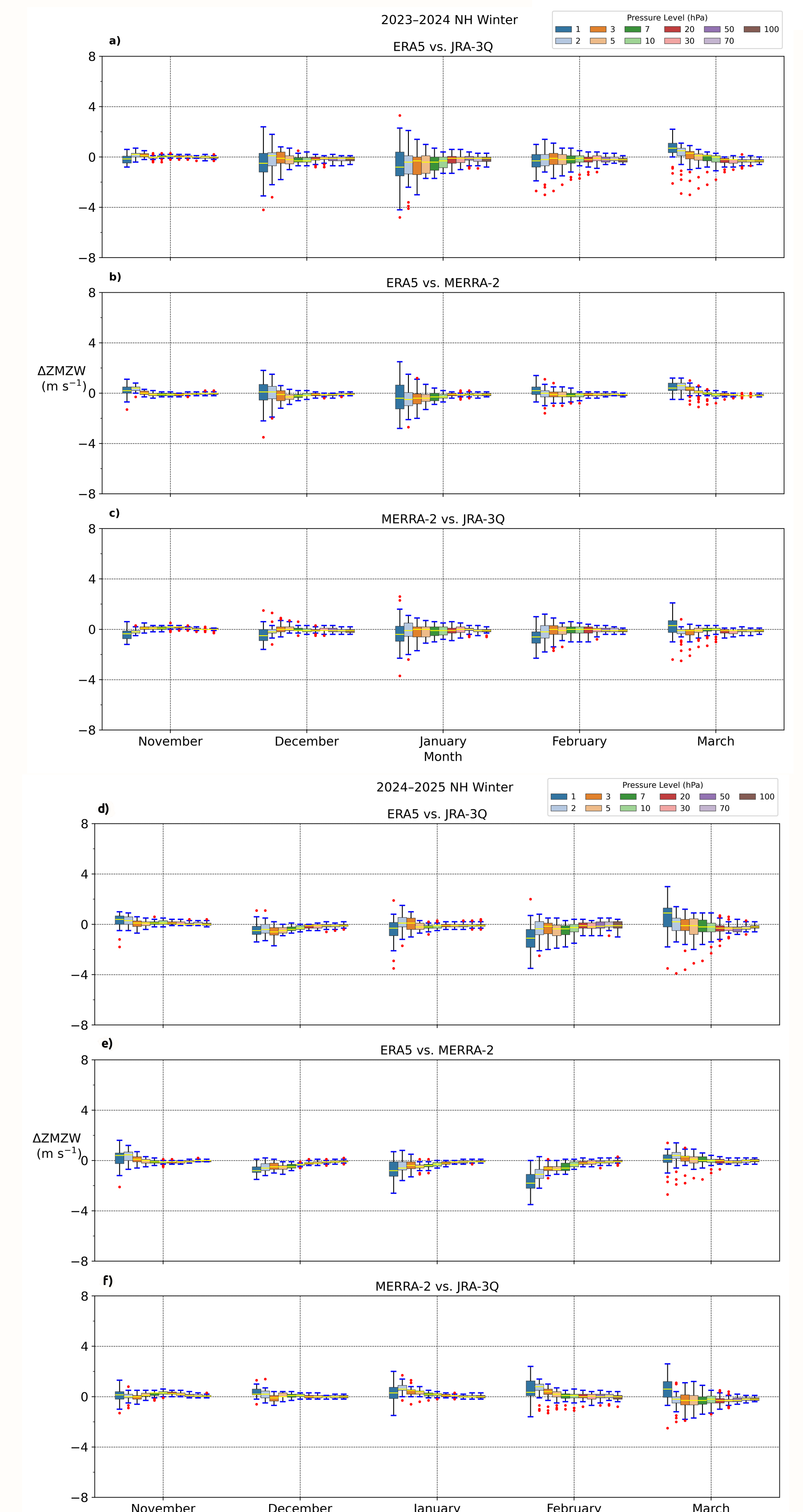


Figure 5: Monthly distributions of daily pairwise ZMW differences (ΔZMW , m s^{-1}) across pressure levels during the 2023–2024 (a–c) and 2024–2025 (d–f) NH winters.

MLS–Reanalysis Comparison

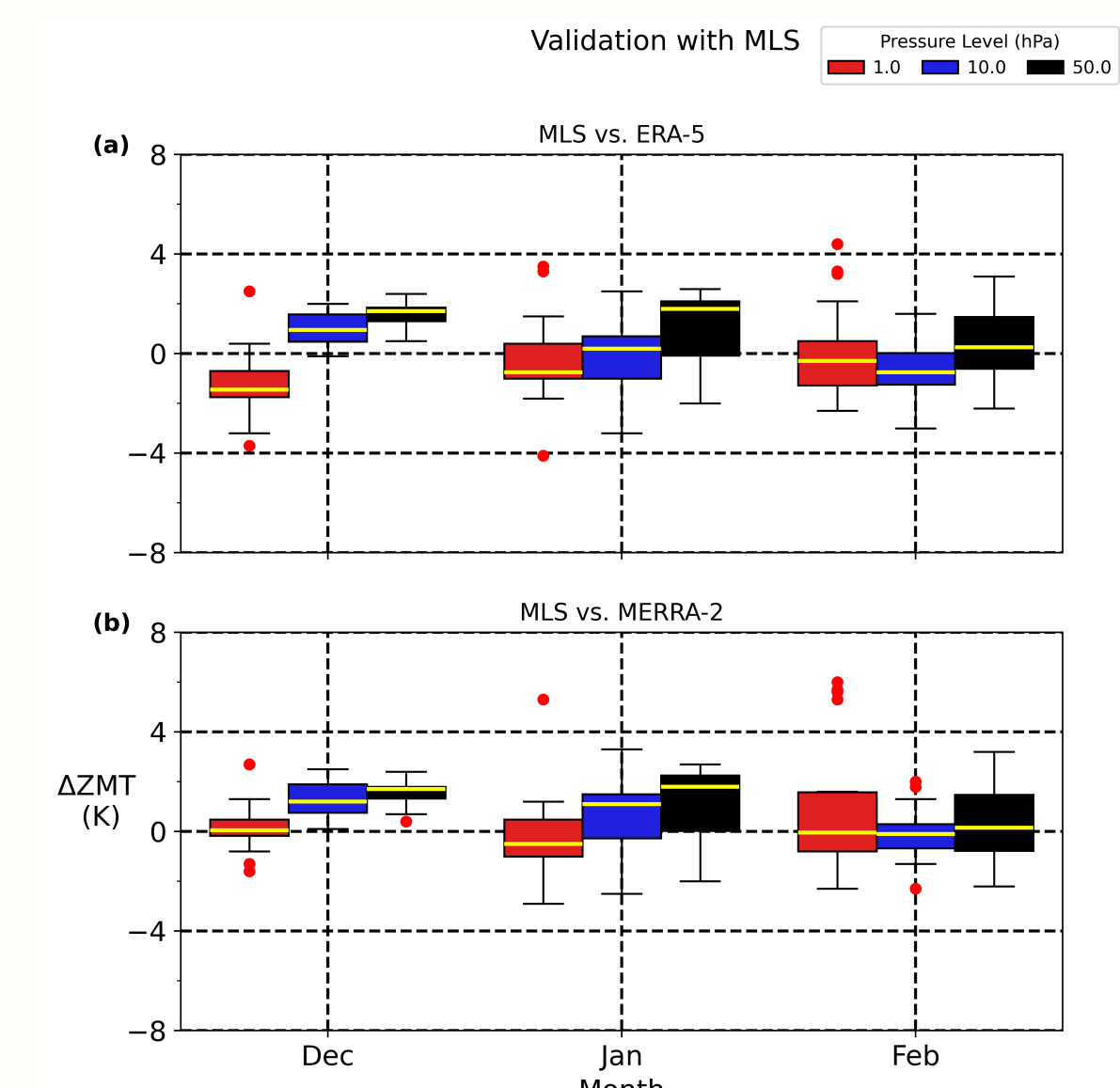


Figure 6: MLS–reanalysis ZMT differences at 1, 10, and 50 hPa during December–February.

- At 1 hPa (Fig. 6), MERRA-2 closely agrees with MLS in December, with greater interannual variability in January–February.
- The reported MLS cold bias [5] may partly explain the colder upper-stratospheric ZMT in MERRA-2 relative to ERA5.

Summary

- Early SSW signatures occur above 10 hPa; SSW classification is also sensitive to latitude.
- Polar-vortex evolution is more clearly reflected in ZMW differences than in ZMT differences.
- ERA5–JRA-3Q agree best; MERRA-2 upper-level differences may partly reflect differences in MLS assimilation.

References

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Acknowledgment

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