UNIVERSITY OF COLOGNE

ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes and Feedback Mechanisms (AC)³

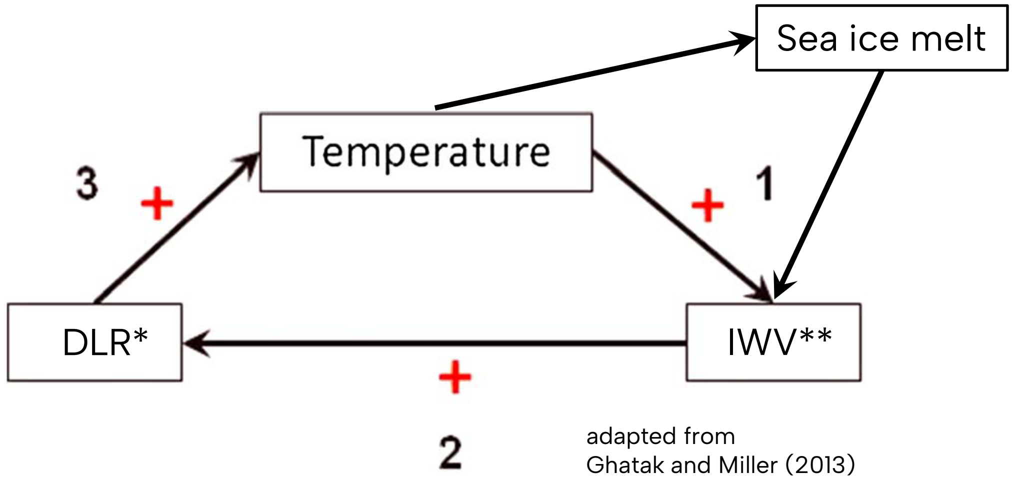
MOSAiC International Arctic Drift Expedition

Evaluating water vapour products of state-of-the-art models and satellite products in the Arctic Ocean

By **Andreas Walbröl**, Kerstin Ebell and Susanne Crewell

Motivation

- Water vapour
  - …has important direct and indirect warming effects in the Arctic [1–3]
  - …contributes to rapid Arctic warming through water vapour feedback loop [2]



adapted from
Ghatak and Miller (2013)

*Downwelling Longwave Radiation
**Integrated Water Vapour

Motivation

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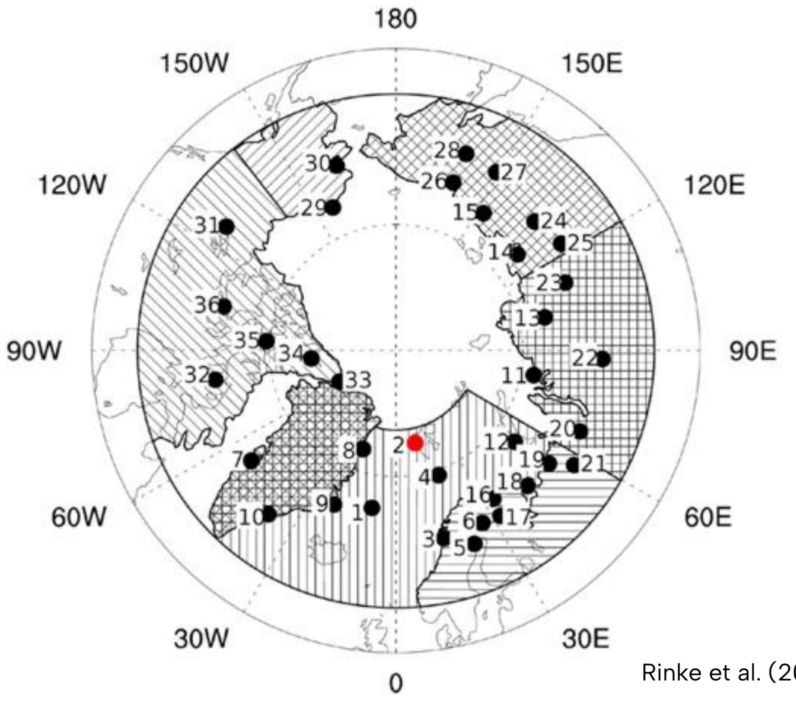
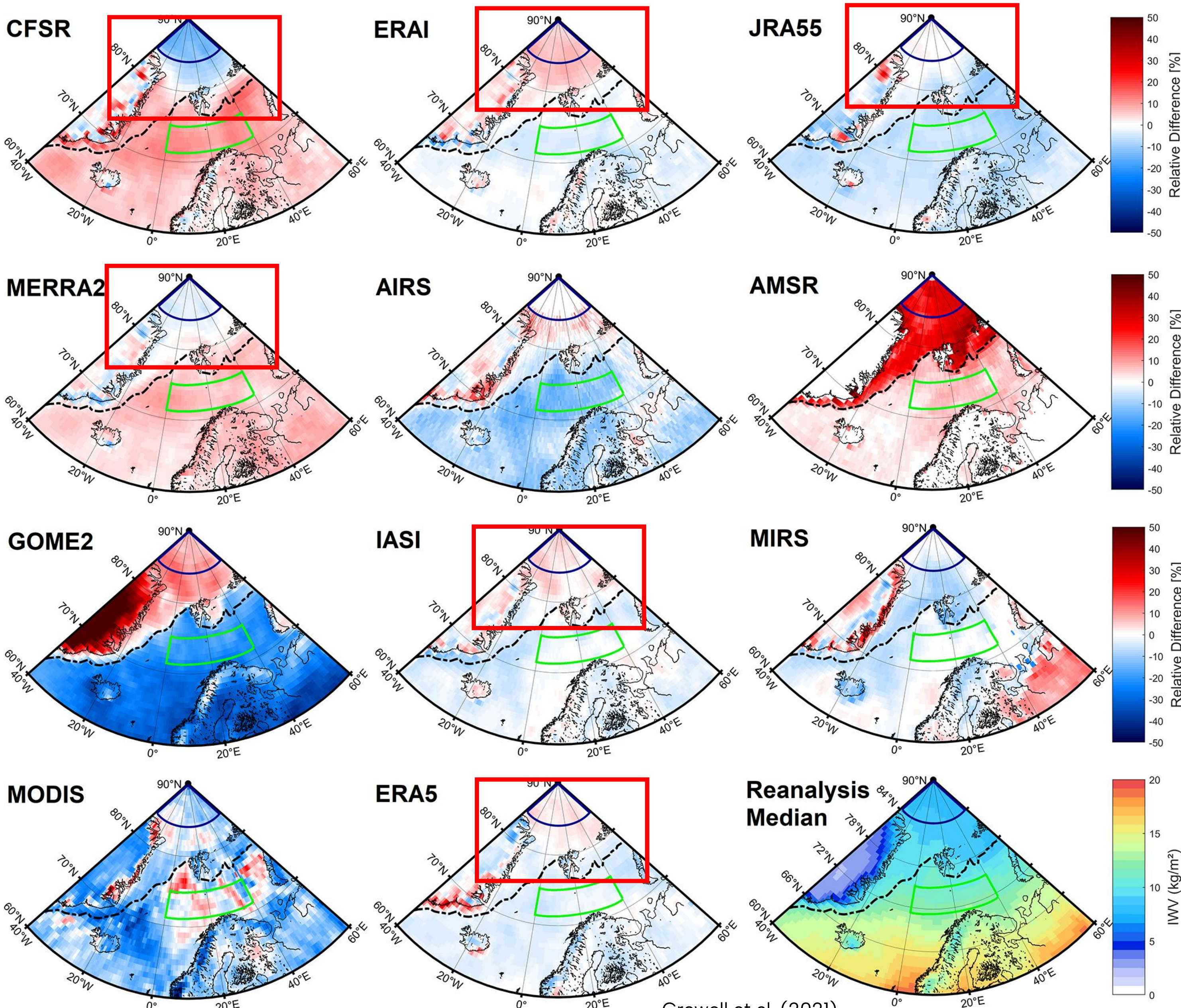
  - …measurements are uncertain in the Arctic [4]



Rinke et al. (2019)

Deviation of monthly mean IWV (June 2017)



Crewell et al. (2021)

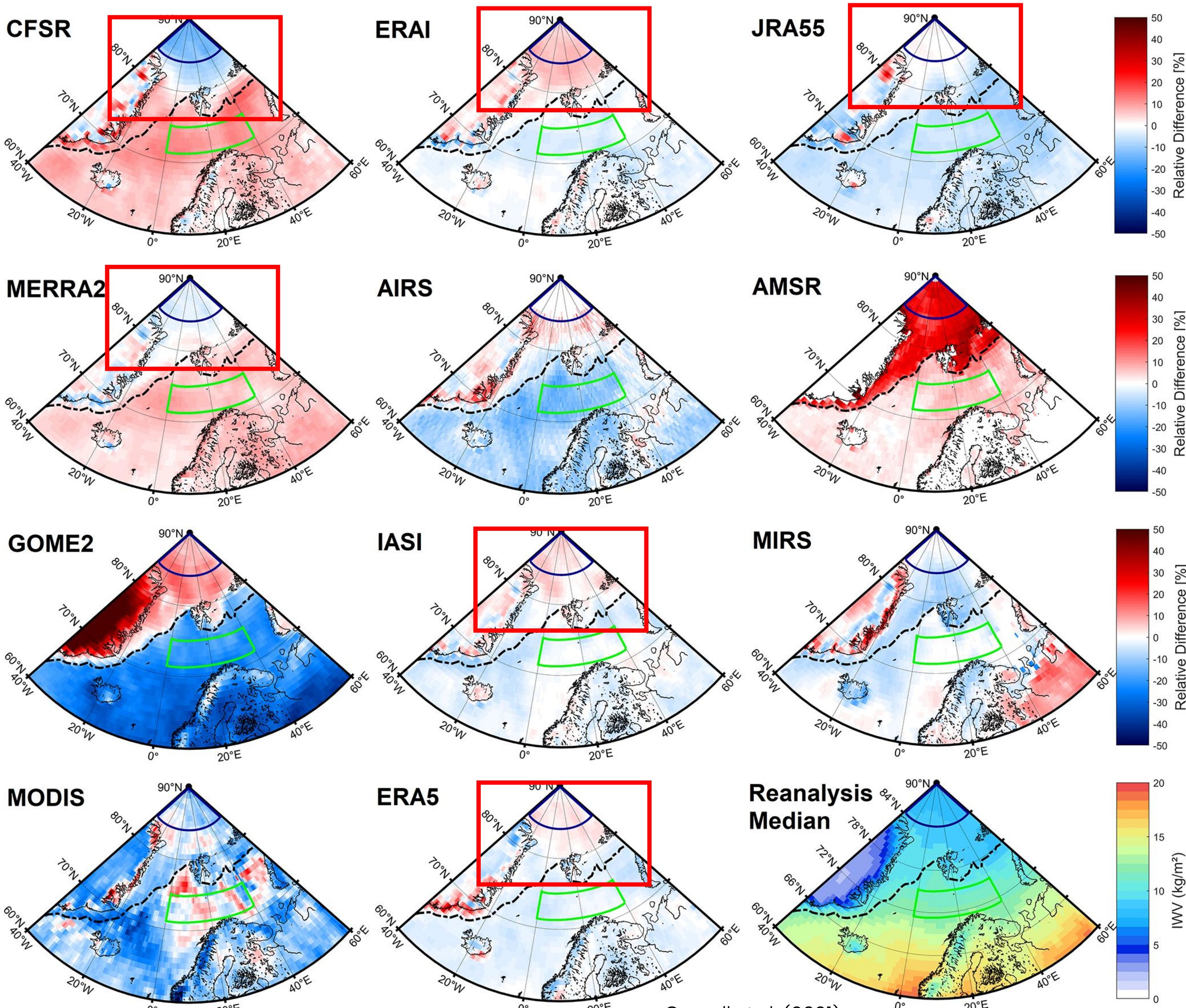
Motivation

- Water vapour
  - …has important direct and indirect warming effects in the Arctic [1–3]
  - …contributes to rapid Arctic warming through water vapour feedback loop [2]
  - …measurements are uncertain in the Arctic [4]
  - …trends have been observed in some regions and seasons but are also uncertain [5–7]

- Reference observations in the Arctic Ocean required to evaluate models and satellite products

→ MOSAiC International Arctic Drift Expedition [8]

Deviation of monthly mean IWV (June 2017)

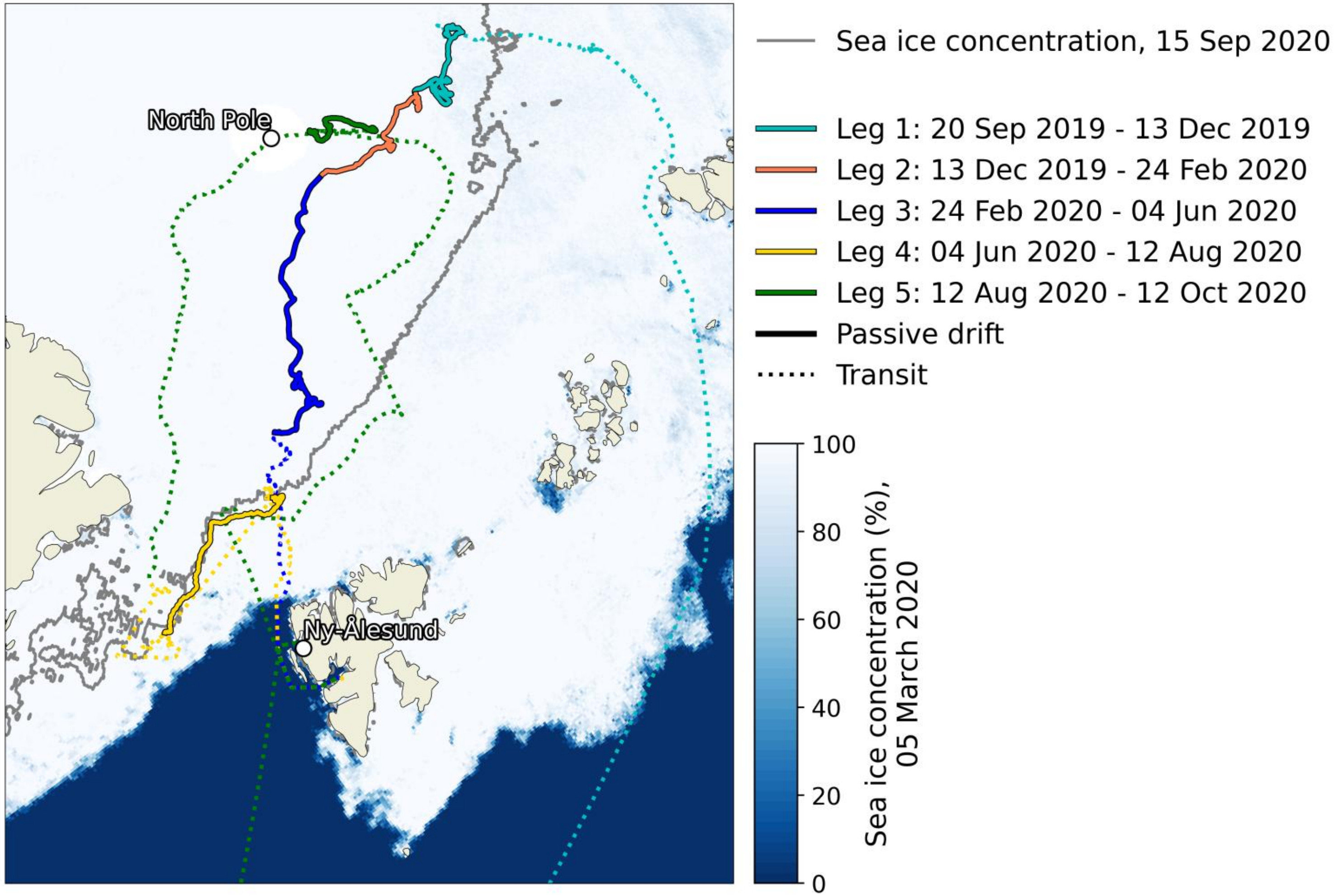


Crewell et al. (2021)

Datasets

- MOSAiC observations:
  - Radiosondes [9] (6-hourly, >1090 sondes)
  - Microwave radiometers (**MWRs**): Synergy of HATPRO (22–58 GHz) and MiRAC-P (183–340 GHz) [10]
- Models:
  - Reanalyses: ERA5 [11] and MERRA-2 [12]
  - Weather forecast: ICON [13] and CAFS [14, 15]
- Satellite products:
  - IASI combined sounding products [16, 17]
  - (IWV retrieval based on AMSR2 [18])
- Time range: **22 Oct 2019 – 05 Aug 2020**

MOSAiC drift track of RV Polarstern

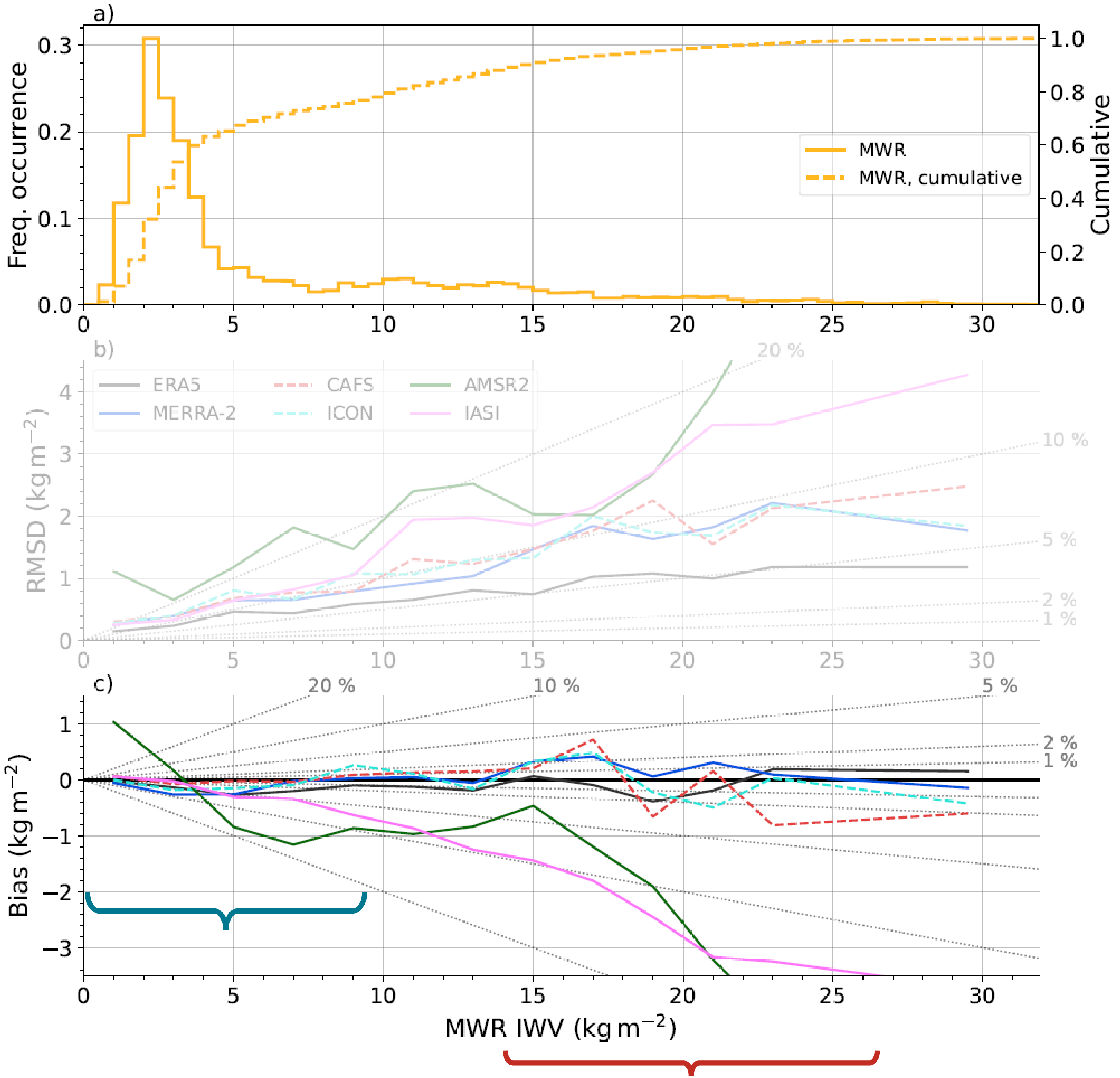


Evaluation – IWV

- Reference: **MWR**

- ERA5 shows best performance regarding RMSD
- Reanalyses and ICON show slight negative bias in dry conditions
- Satellite products have strong negative bias in moist conditions

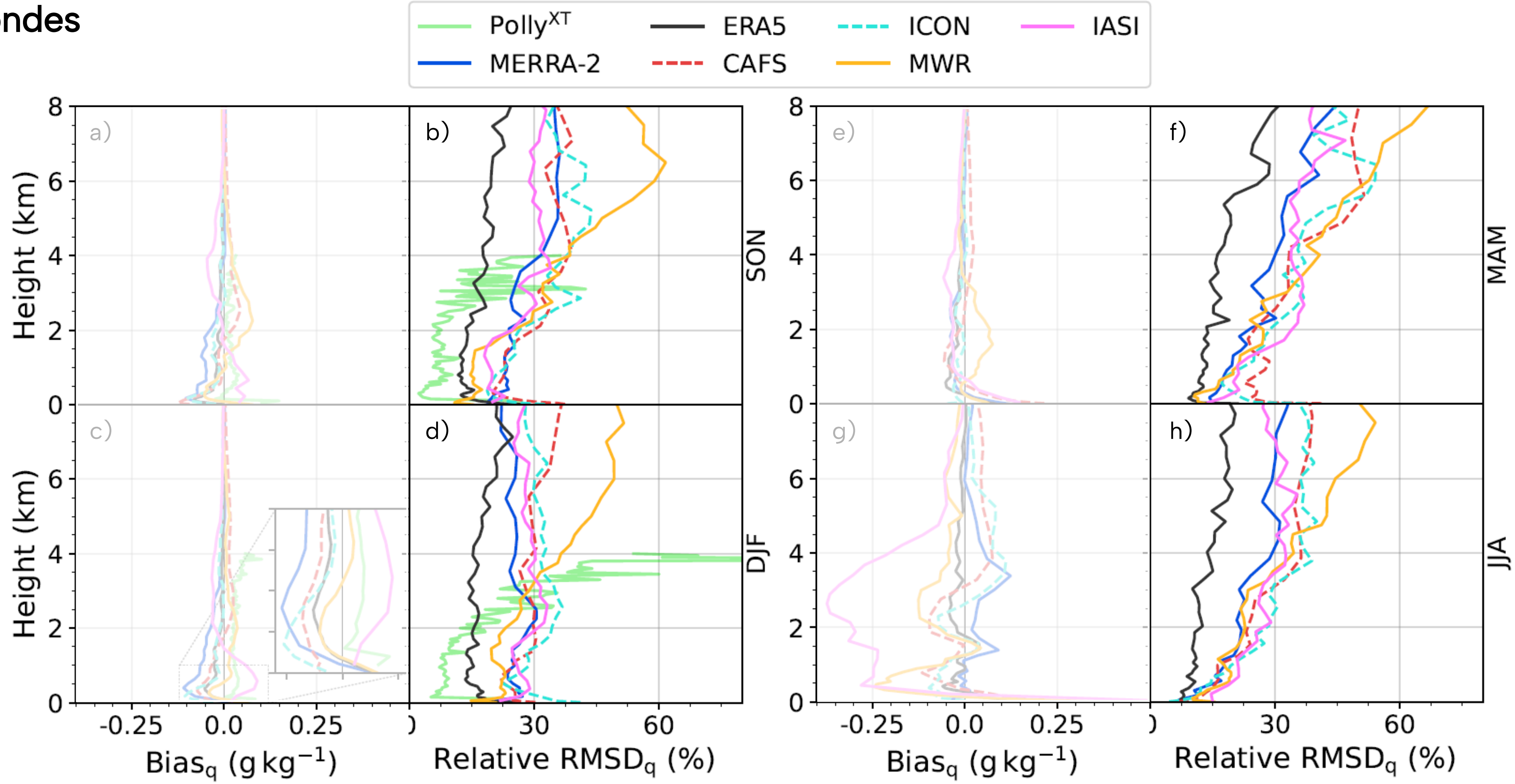
- Contribution of **assimilation** of radiosonde data to performance unclear !! (ERA5, MERRA-2, ICON)



Evaluation – Specific humidity profiles

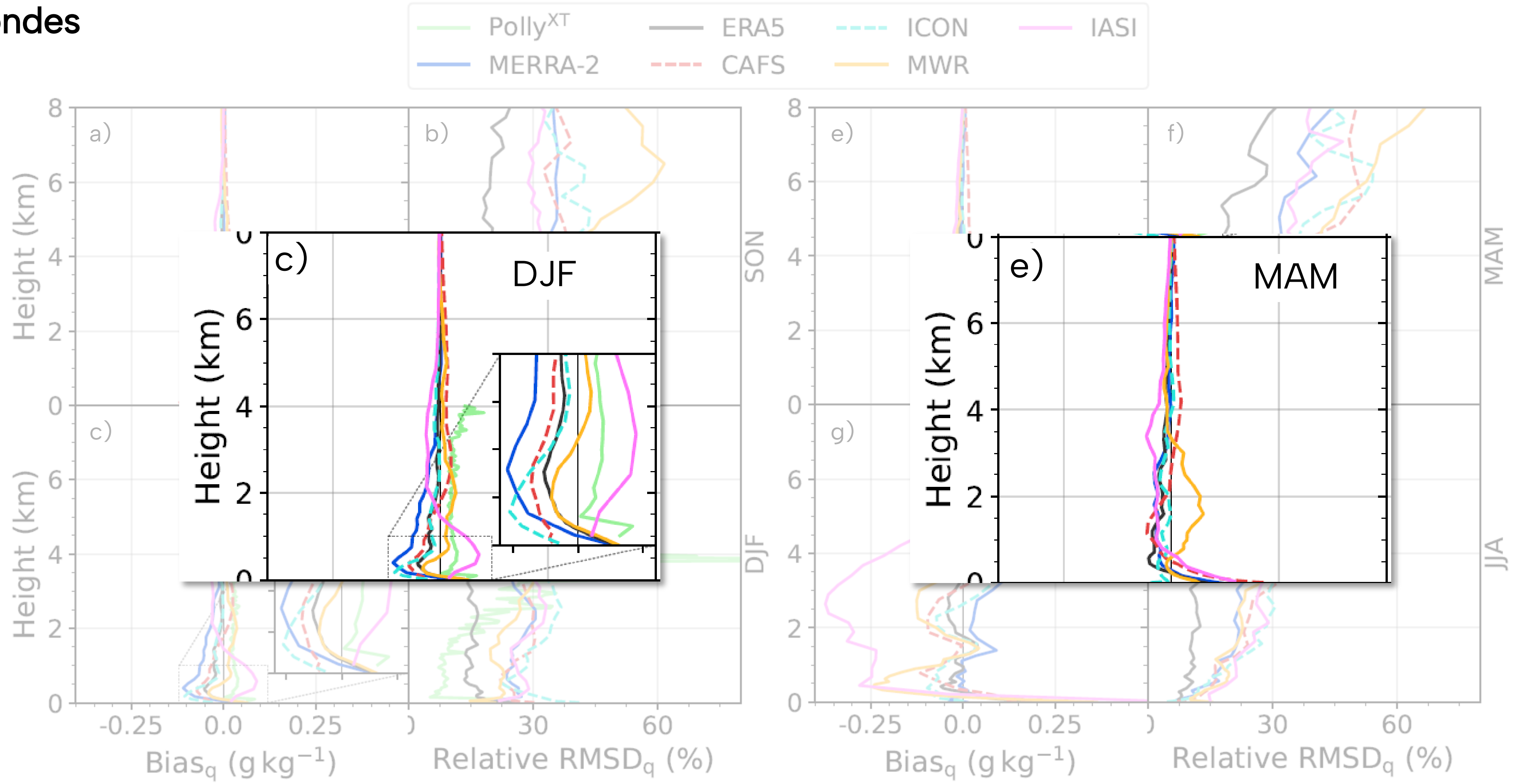
- Reference: **Radiosondes**

- ERA5 has overall smallest RMSD
- RMSD of MWR synergy ≤ most models



Evaluation – Specific humidity profiles

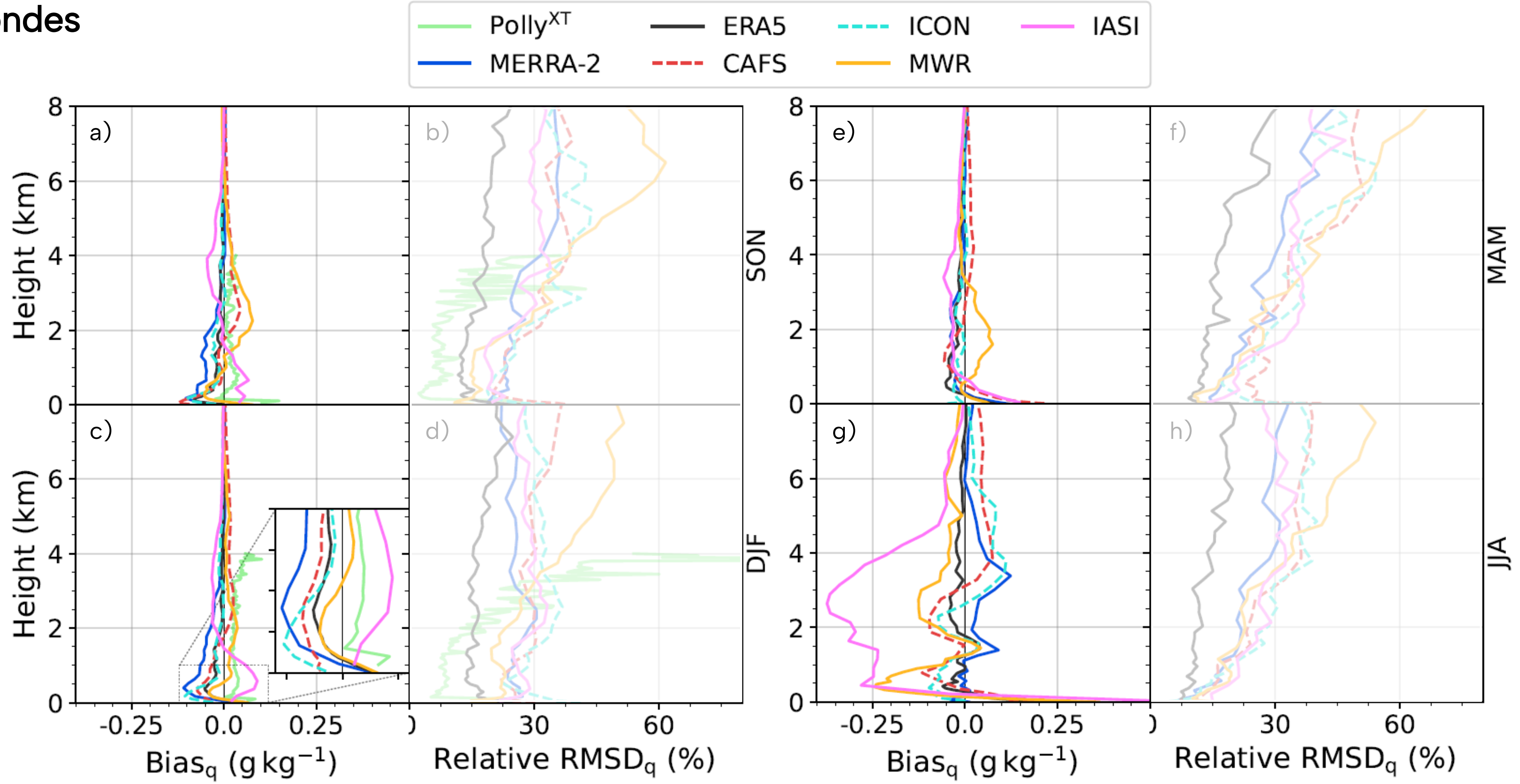
- Reference: **Radiosondes**



- Models have dry biases in the cold seasons
- Some data sets have moist bias at the surface in winter and spring

Evaluation – Specific humidity profiles

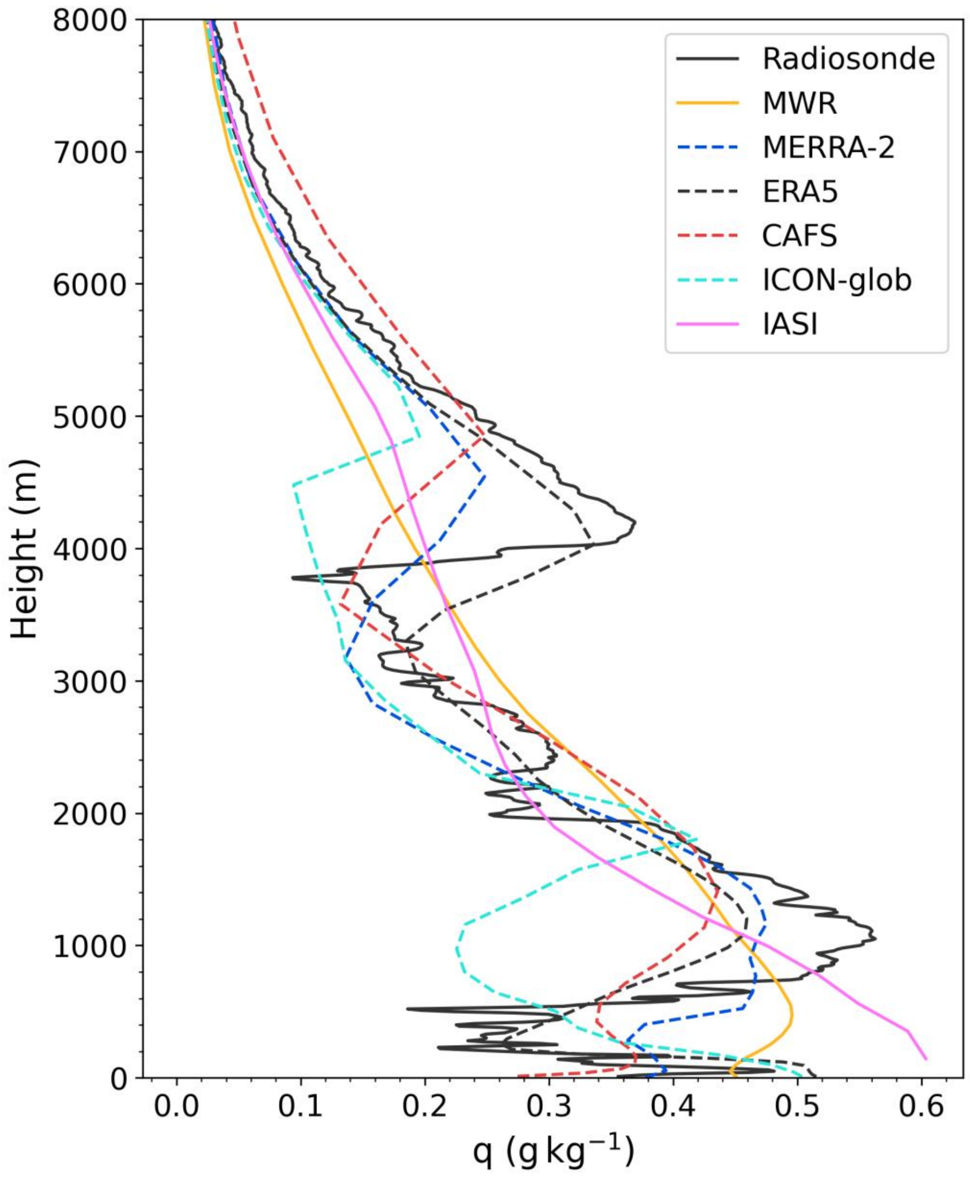
- Reference: **Radiosondes**



- Models have dry biases in the cold seasons
- ERA5 & MERRA-2 have moist bias at the surface in winter and spring
- Many biases are related to **humidity inversions**!

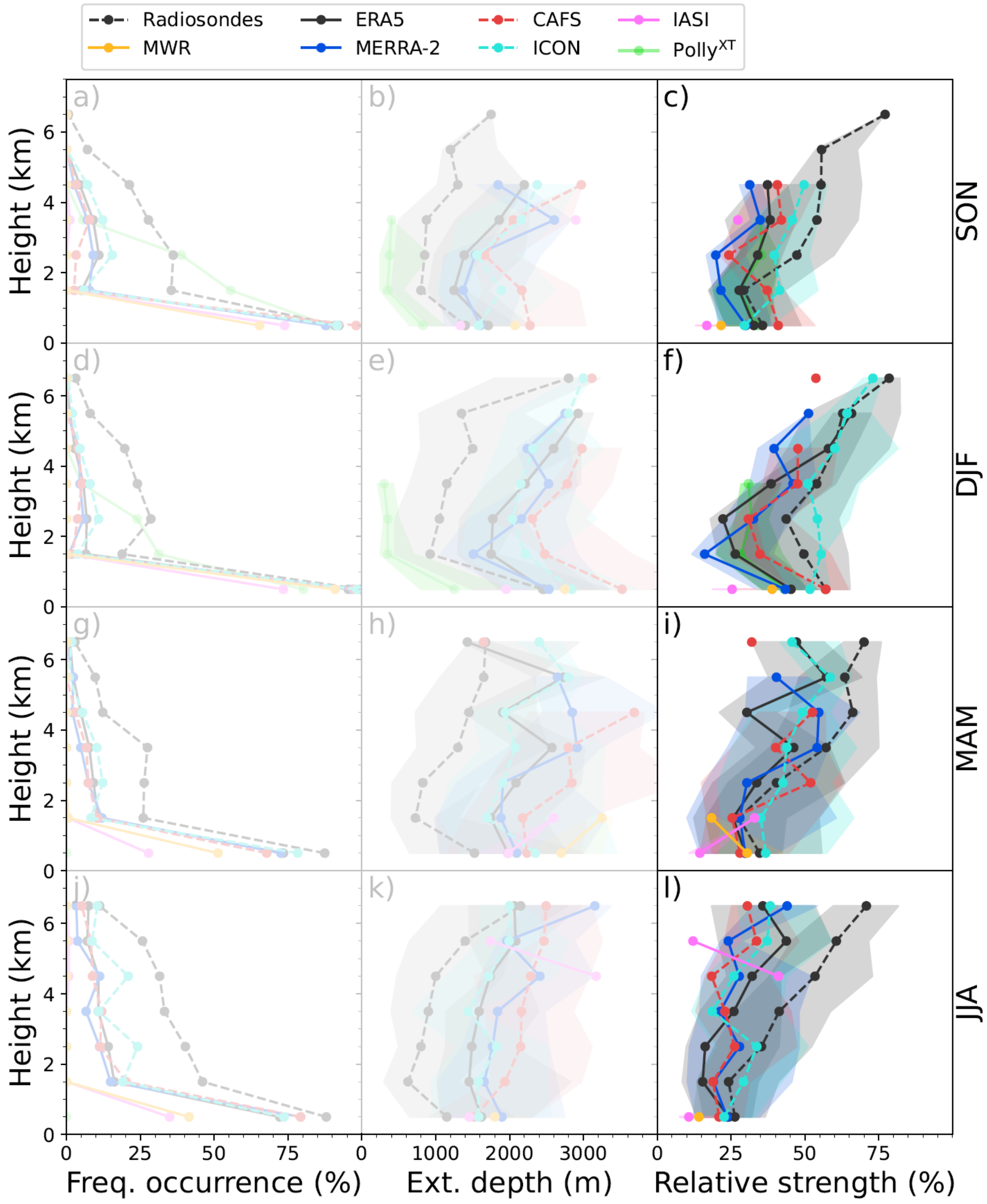
Humidity inversions

Specific humidity profile example
on 06 December 2019



Evaluation – Humidity inversions

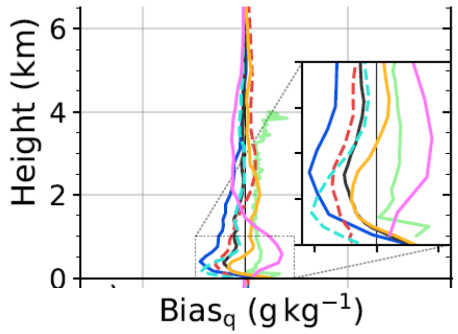
- Occurrence of near-sfc inversions well caught by almost all data sets in autumn and winter
- Occurrence of elevated inversions:
  - Has a seasonal cycle
  - Underestimated by models and remote sensing obs by 10–30 %
- Inversion strength underestimated & depth overestimated
- ERA5 did not perform better than the other models despite higher vertical resolution and 4D-var assimilation



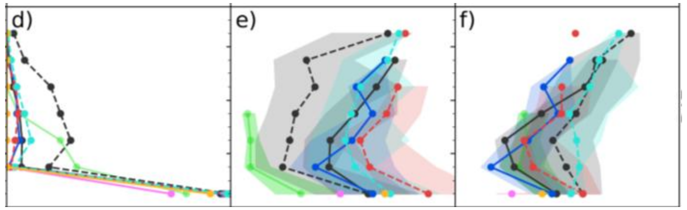
Conclusions

- Satellite products have strong dry biases in high IWV conditions

- ERA5 had smallest specific humidity and IWV errors
- MWR specific humidity profiles are similarly good as most other models
- Negative specific humidity biases in the cold seasons at 0.2–2 km



- Occurrence and strength: underestimated, depth: overestimated
- Surprisingly, ERA5 did not perform better regarding the inversion representation



- Reanalysis and ICON evaluation problem:
  Evaluation is strongly influenced by assimilation of campaign data!

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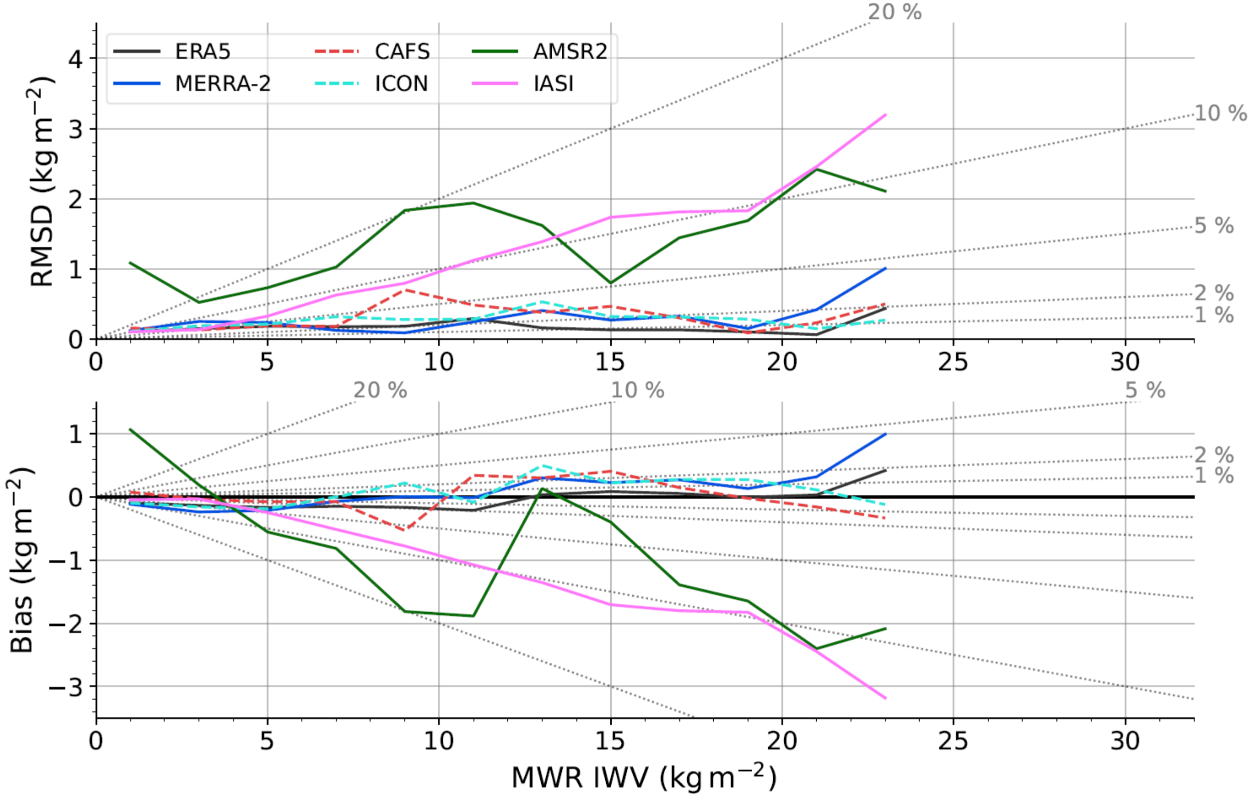
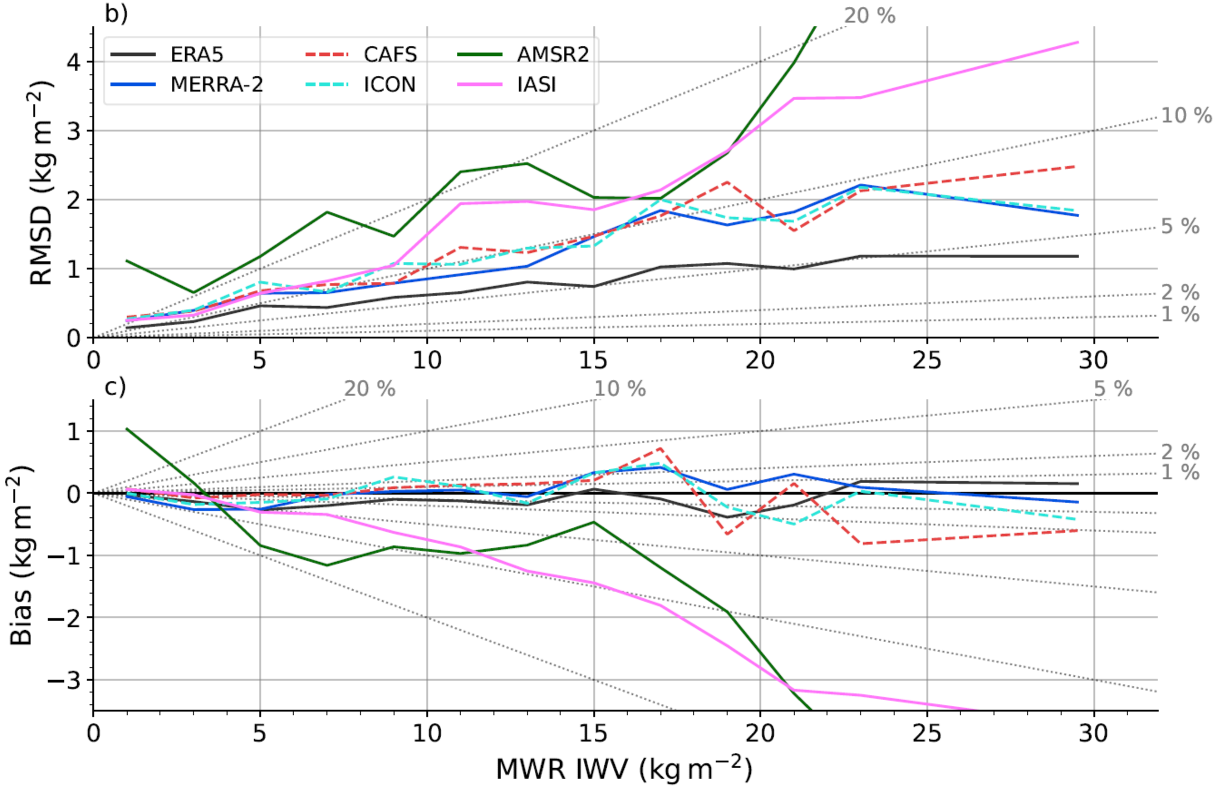
Evaluation – IWV: 7-day running mean

- Reference: MWR
- Some errors are related to intraweek variability (e.g., storms)
- Most biases exist in both comparisons

With 7-day running mean



Without 7-day running mean

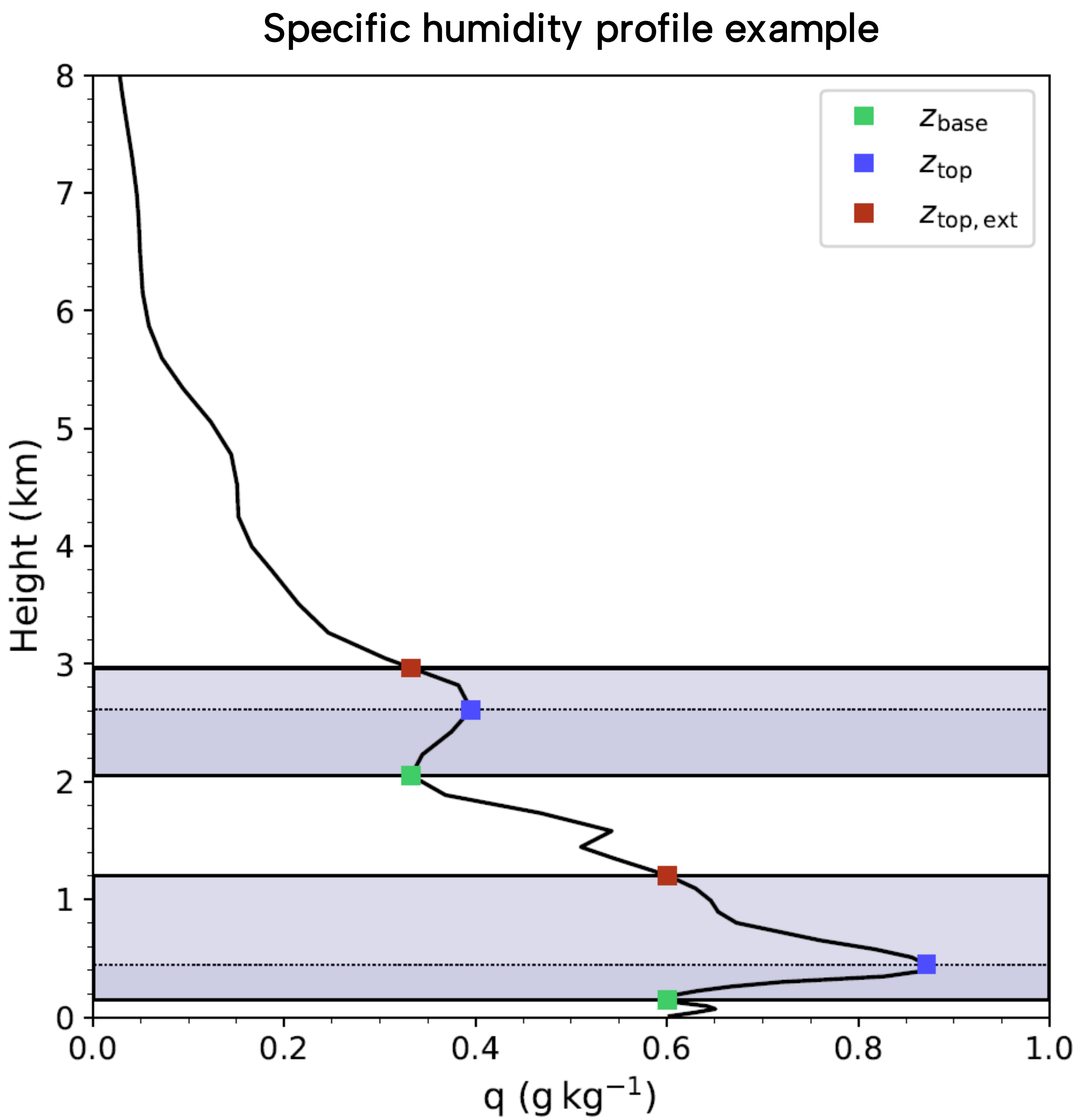


Humidity inversions

- Def.: **Increase of specific humidity with height** [19,20]
- Important for cloud formation and maintenance [21]
- Direct longwave radiative effect [19]
  (detailed quantification missing)

- Main formation mechanisms [22,23]:
  - Radiative cooling
  - Advection

- Detection:
  - Focus on the main inversions
  - Nested inversions often disregarded



Evaluation – Humidity inversion detectability

- Contingency table: Occurrence of at least 1 humidity inversion in a profile

		Radiosonde		
		True	False	Total
Test data	True	Correct +	False +	True in test data
	False	False −	Correct −	False in test data
		True in radiosondes	False in radiosondes	Total

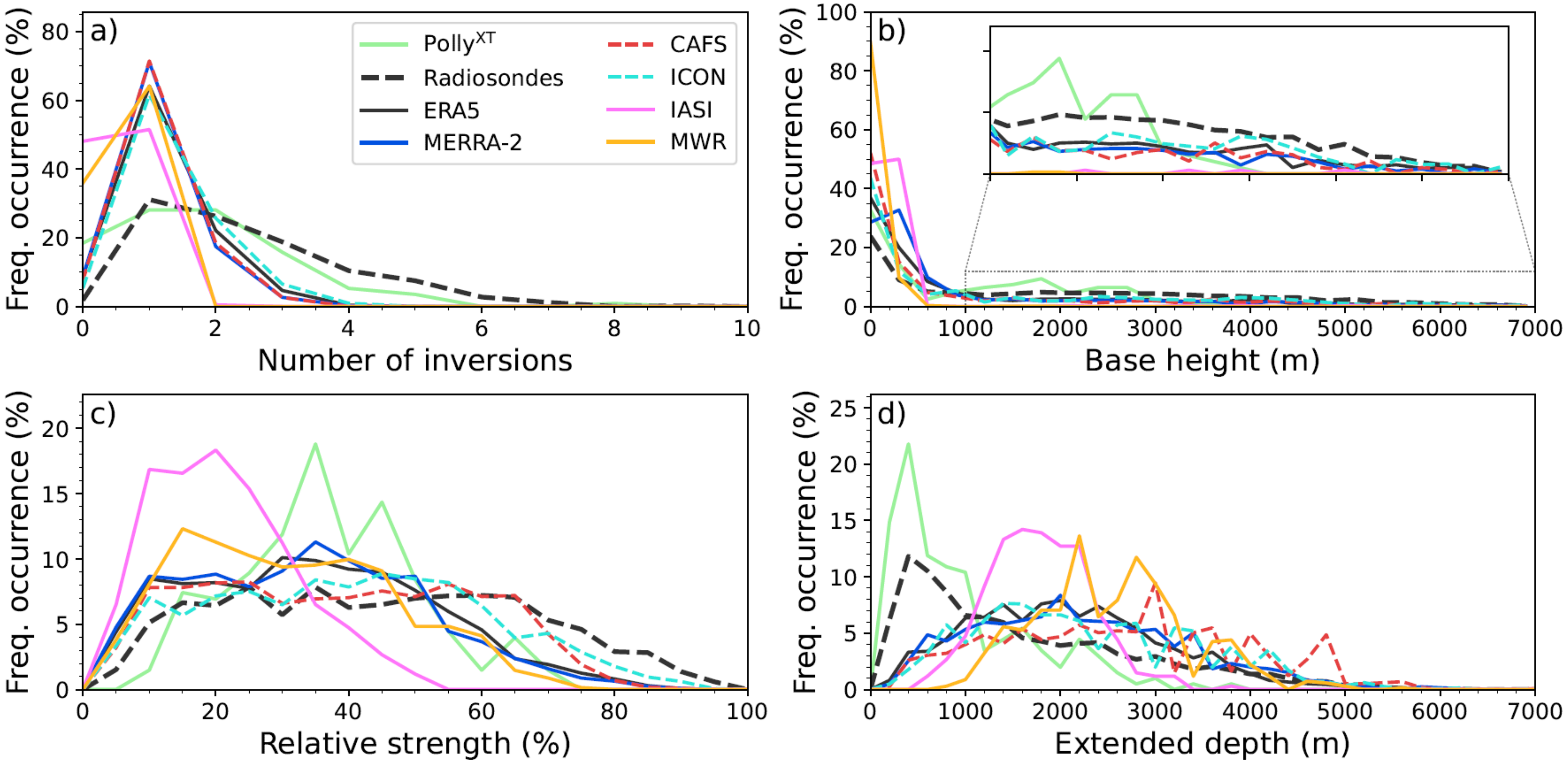
- $\mathrm{Accuracy} = (cp + cn)\,/total$
- $\mathrm{Bias} = (cp + fp)\,/\,(cp + fn)$
- Heidke skill score $\mathrm{HSS} = (cp + cn - e_c)\,/\,(total - e_c)$
  with $e_c = ((cp + fn)(cp + fp) + (cn + fn)(cn + fp))\,/total$

Dataset	N	N_{inv}	Accuracy	Bias	HSS*
MWR	1064	682	**0.66**	0.65	**0.05**
IASI	645	336	**0.53**	0.53	0.02
ERA5	1096	1000	0.93	0.93	0.27
MERRA-2	1096	1001	0.92	0.93	0.24
CAFS	991	917	0.93	0.93	0.10
ICON	1075	1018	**0.95**	**0.96**	0.20

➢ **Models >> MWR > IASI**

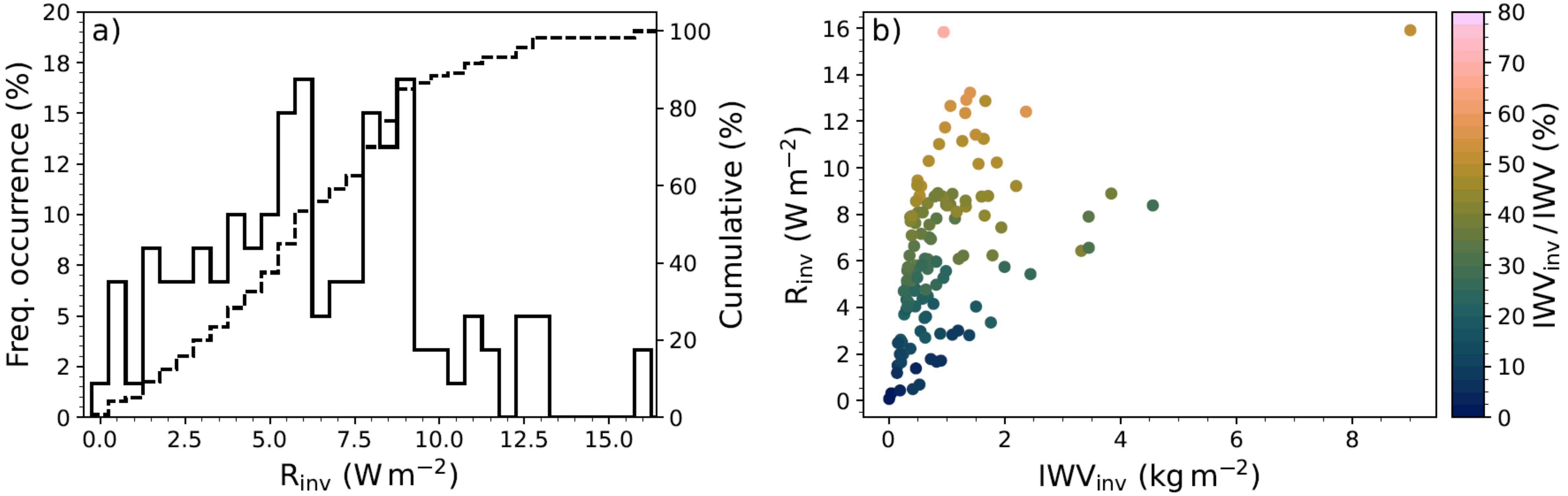
Humidity inversion statistics

- For MOSAiC expedition



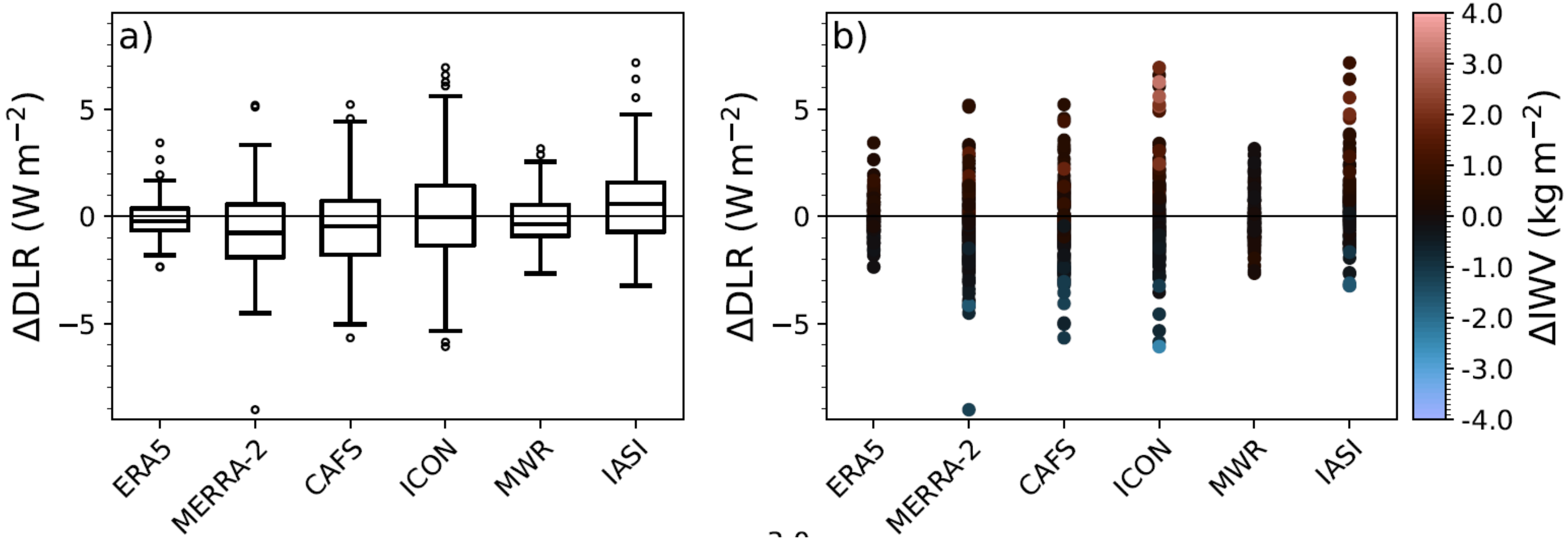
Downwelling longwave radiation effect of humidity inversions

- Radiative transfer simulations [24, 25] of downwelling longwave radiation (**DLR**) in clear sky scenes
- DLR effect of humidity inversions: 1–9 W m^{-2}, and up to 16 W m^{-2} in extreme cases



Longwave radiation effect of different humidity profiles

- Radiative transfer simulations [24, 25] of downwelling longwave radiation (**DLR**) in clear sky scenes
  $\Delta DLR = DLR_{dataset} - DLR_{orig}$



- DLR deviations (ΔDLR) mostly within ±2 W m^{-2} but can be up to ±5 W m^{-2}
- ERA5 and the MWR synergy have the lowest ΔDLR