Water vapour from microwave radiometers and IASI during MOSAiC

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1) MOTIVATION

- Large integrated water vapour (IWV) uncertainties among reanalyses and satellite products [1, 2, 3]
- Sparse ground observations and difficulties in satellite remote sensing limit the knowledge of water vapour in the Arctic[3] (esp. profiles)
- High quality MOSAiC observations
- ...are essential to evaluate water vapour (WV) products from satellites and reanalyses
- ...provide information on temporal and vertical WV variability and impact on downward longwave radiation

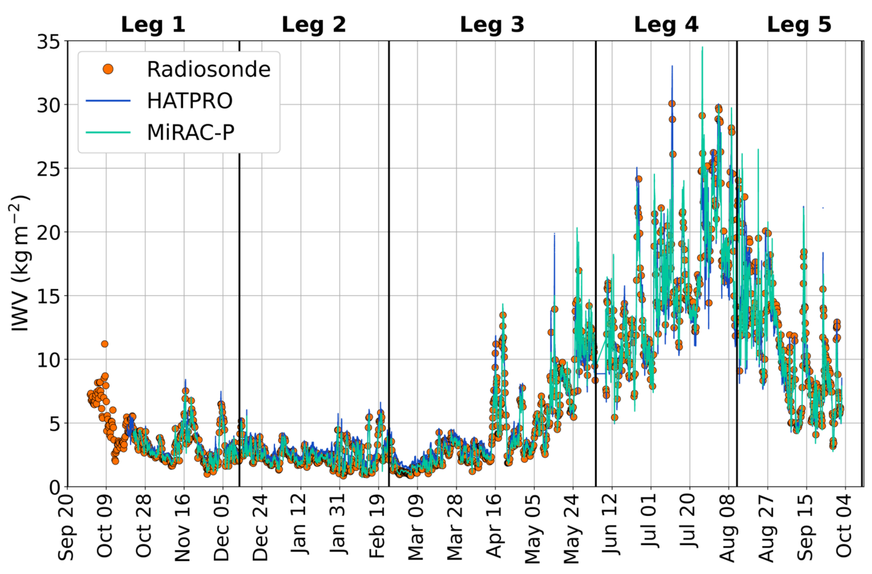


Fig. 1: IWV time series from **HATPRO**, **MiRAC-P** and radiosondes during MOSAiC[4].

2) DATA AND METHODS

We derive IWV, liquid water path (LWP), as well as temperature and humidity profiles from radiances (expressed as TBs) from the two following microwave radiometers (MWRs):

- **HATPRO:** Regression retrieval trained with radiosondes from Ny-Ålesund for IWV, LWP, temperature and humidity profiles [4]
- **MiRAC-P:** Neural Network (NN) retrieval trained with ERA-Interim for IWV [4]

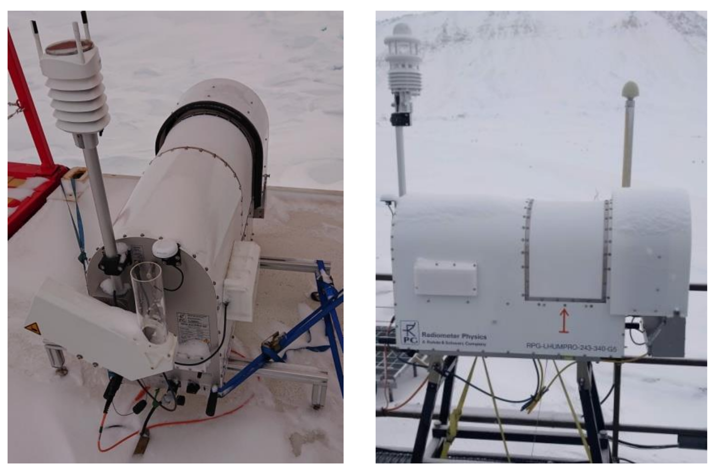


Fig. 2: **HATPRO** (left) and **MiRAC-P** (right) onboard R/V Polarstern.

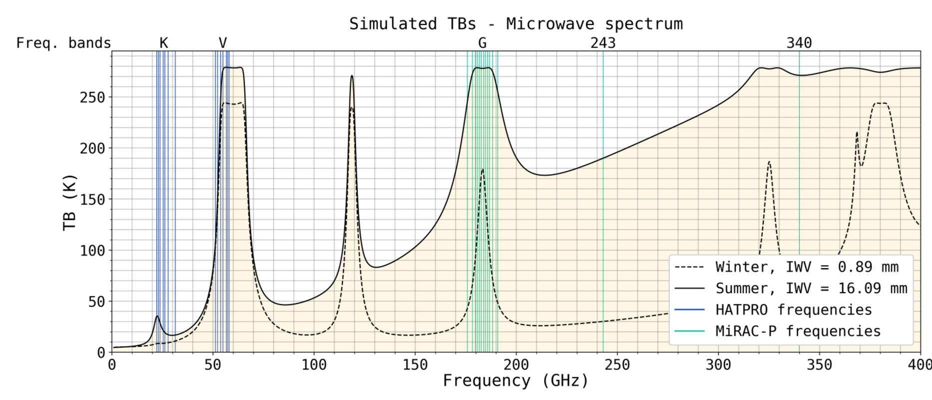


Fig. 3: TBs in the microwave spectrum for low and high IWV in the Arctic. Vertical lines indicate the measurement frequencies of **HATPRO** and **MiRAC-P**.

Further WV products:

- Radiosonde: Vaisala RS41, which measures temperature, pressure, and humidity profiles
- IASI Level 2 PPF v6.5: Statistical retrieval combined with Optimal Estimation (when cloudfree) retrieval based on IASI and, if available, AMSU/MHS measurements

3) SYNERGY OF HATPRO AND MiRAC-P

3a) Synergetic retrieval setup:

Neural Network retrieval of WV profiles and IWV combining HATPRO and MiRAC-P frequencies. The NN is trained with ERA5 reanalysis data and simulated TBs from the forward model PAMTRA[5]. Temperature, pressure and humidity profiles from ERA5 were used as input for PAMTRA. Below, we show predicted quantities (from simulated TBs) with respect to the true ERA5 profiles (or IWV) for various frequency combinations.

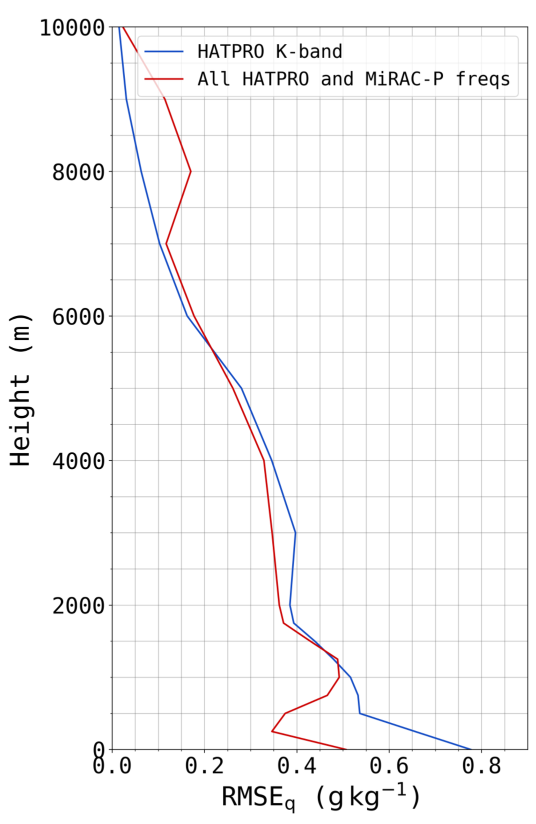


Fig. 4: Root mean squared error (RMSE) of specific humidity profile with respect to the truth (ERA5).

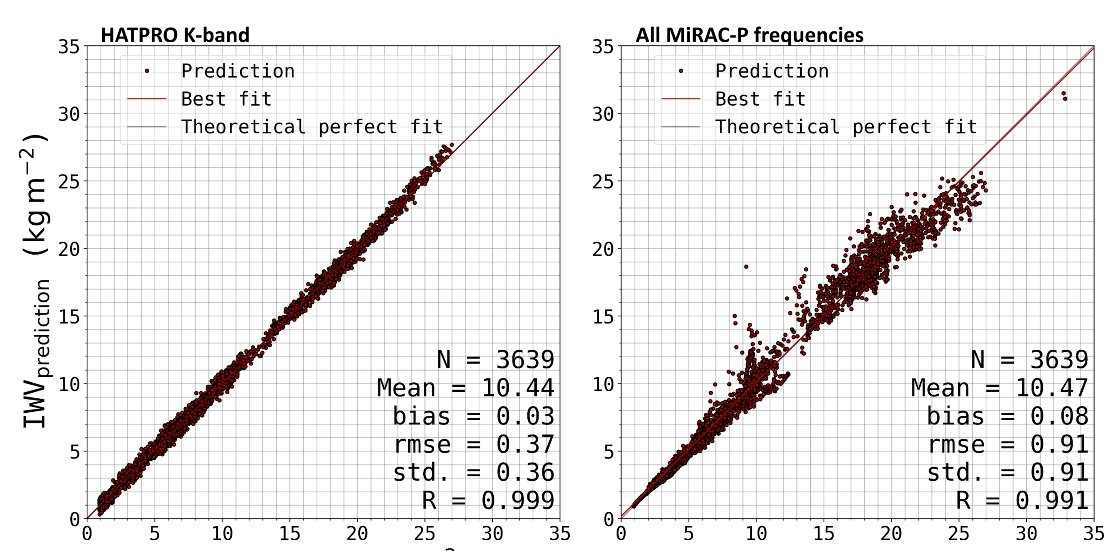
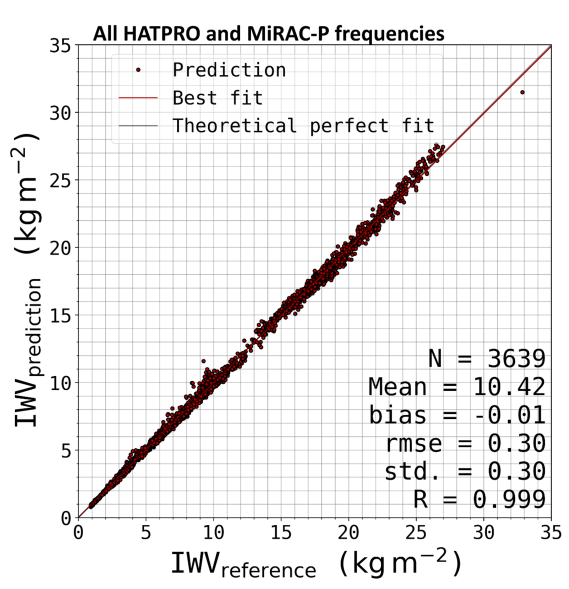


Fig. 5: Scatter plots of predicted and reference IWV for different frequency combinations in the NN retrieval.



Lower RMSE especially in low altitudes, and overall reduced IWV uncertainties.

HYPOTHESIS

Combining low and high frequency microwave radiometer measurements sufficiently improves the vertical resolution of water vapour profiles to analyse the variability of humidity inversions.

3b) Benefit of vertical information content:

To evaluate the benefit of the synergy, we use Optimal Estimation theory to compute the vertical information content of the derived WV profiles. The trace of the Averaging Kernel matrix (**A**), which is computed as

$\mathbf{A} = (\mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1} \mathbf{K}^T \mathbf{S}_\varepsilon^{-1} \mathbf{K}$ with **K** as Jacobian, $\mathbf{S}_\varepsilon$ ($\mathbf{S}_a$) as covariance matrices of the observation error (humidity profiles of a test data set),

yields the Degrees Of Freedom (DOF), a measure of how many independent height levels can be resolved.

Synergy of **HATPRO** and **MiRAC-P** increases the Degrees Of Freedom!

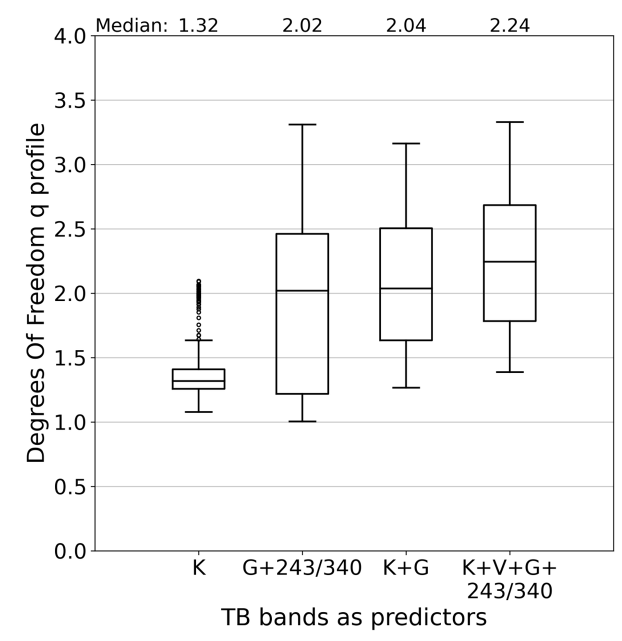


Fig. 6: DOF for various frequency combinations in the NN retrieval. The boxes (lines) indicate the interquartile range (median) of DOF over the ERA5 data set. Whiskers lie outside the boxes by a factor of 1.5 times the interquartile range.

4) COMPARISON WITH SATELLITE (IASI) WV PRODUCTS

Our MWR products[4] and the radiosonde measurements are compared with IASI data in a 50 km radius around R/V Polarstern. Here, we show the strong warming event in mid-April 2020.

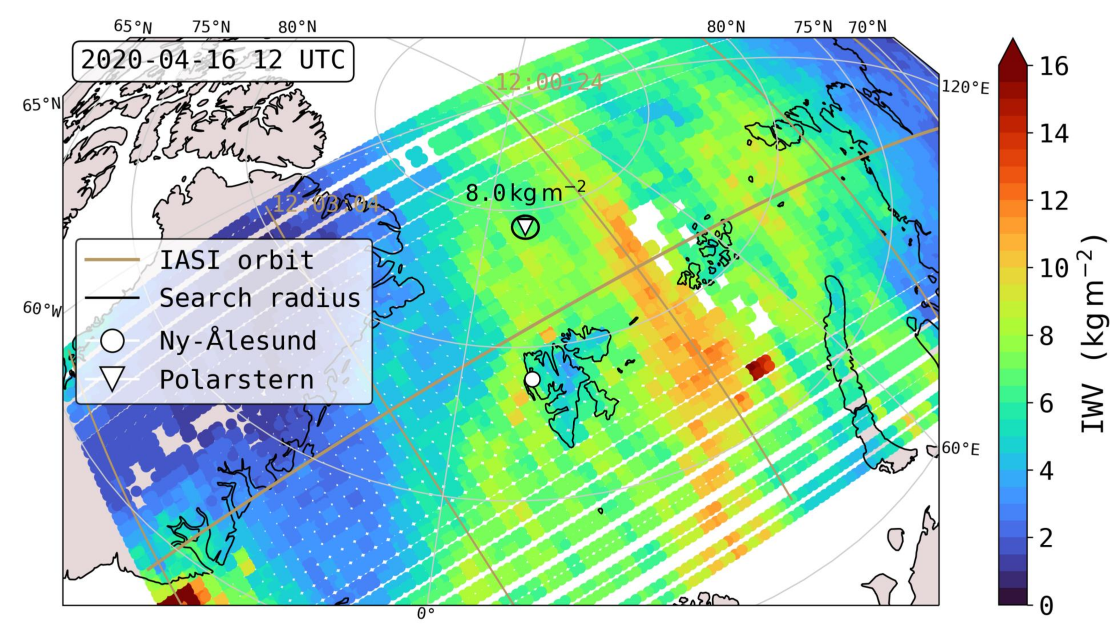
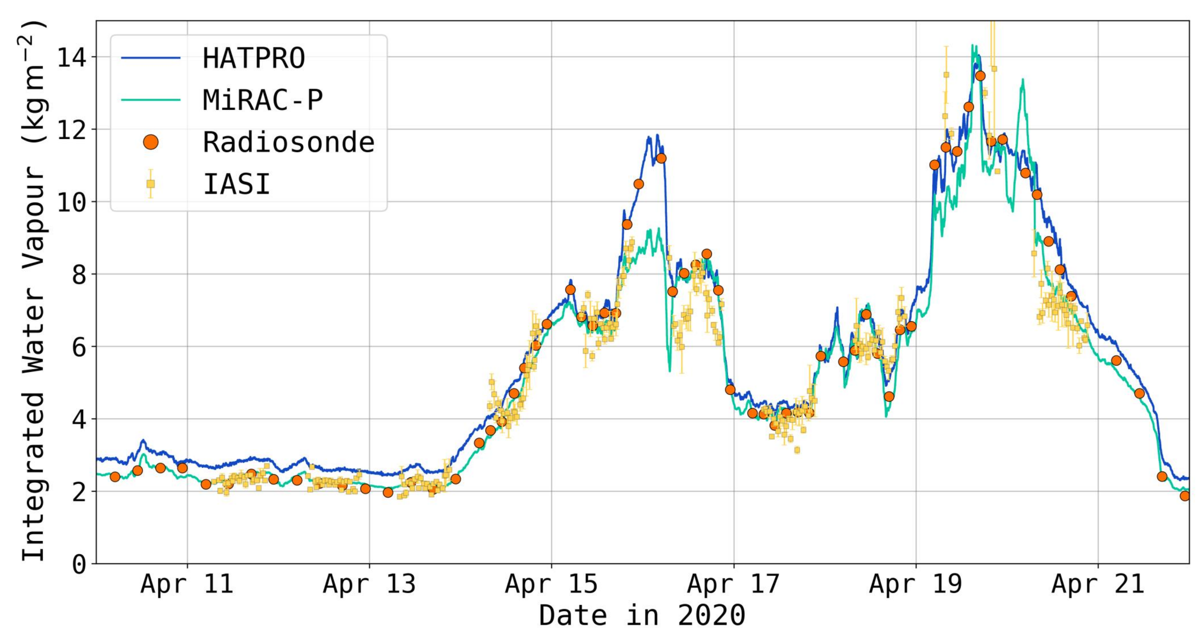


Fig. 7: IWV from IASI swaths on 16 April 2020 12 UTC.



IASI compares well except for the peak IWV where it overestimates it by up to 11 kg m^{-2}.

Fig. 8: IWV time series from **HATPRO**, **MiRAC-P**, radiosonde and IASI. IASI data not fulfilling quality controls have been removed.

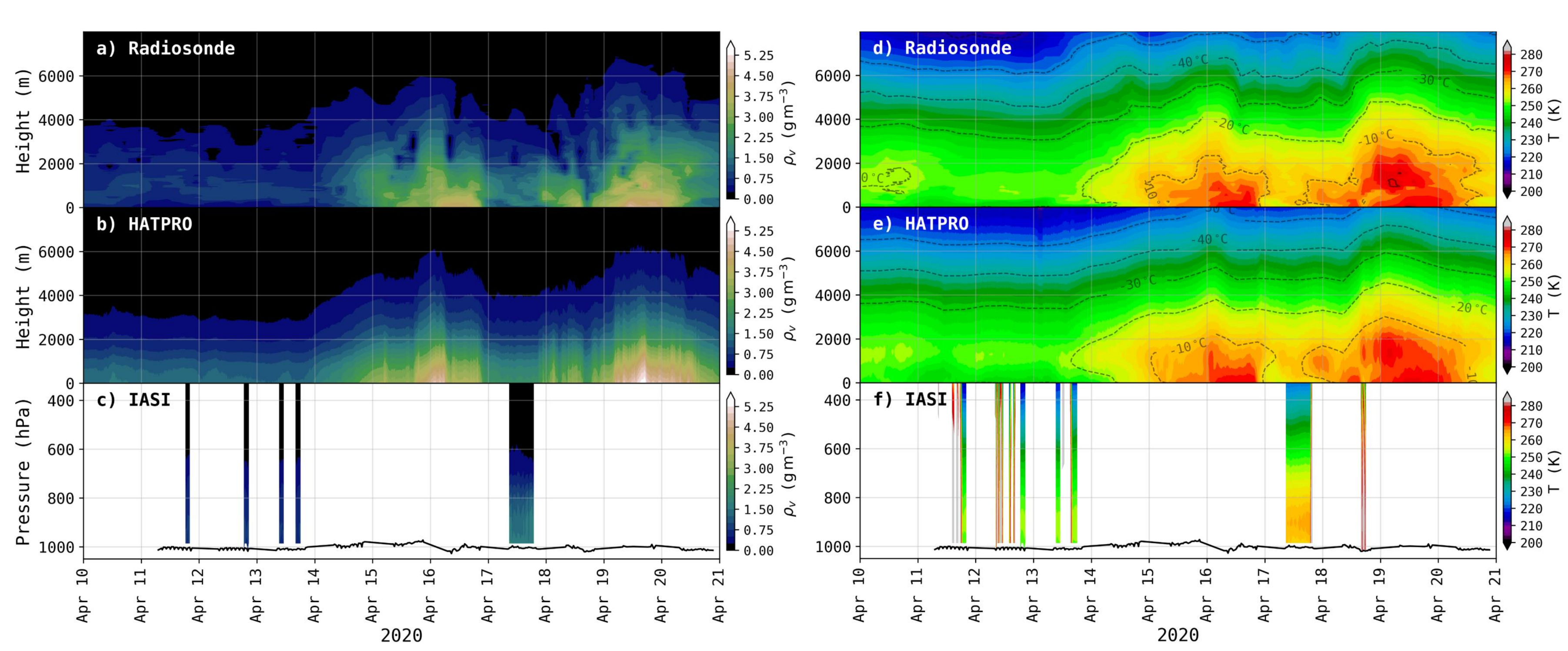


Fig. 9: (Left) Absolute humidity and (right) temperature time-height cross sections from (top) radiosondes, (middle) **HATPRO**, and (bottom) IASI. The black line indicates the surface pressure.

5) CONCLUSION & OUTLOOK

- Synergy of **HATPRO** and **MiRAC-P** demonstrated using synthetic observations:
  - Reduced uncertainties of water vapour products compared to single-instrument retrievals
  - Increased the vertical information content → better for resolving humidity inversions
- IWV from IASI compares well to radiometers, but overestimates during the peak of the warming event
- **Outlook**: **HATPRO** and **MiRAC-P** data[4] (available on PANGAEA) look promising for the upcoming in-depth evaluation of satellite and reanalysis data

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