1D-Var Retrievals of Temperature, Humidity and LWC

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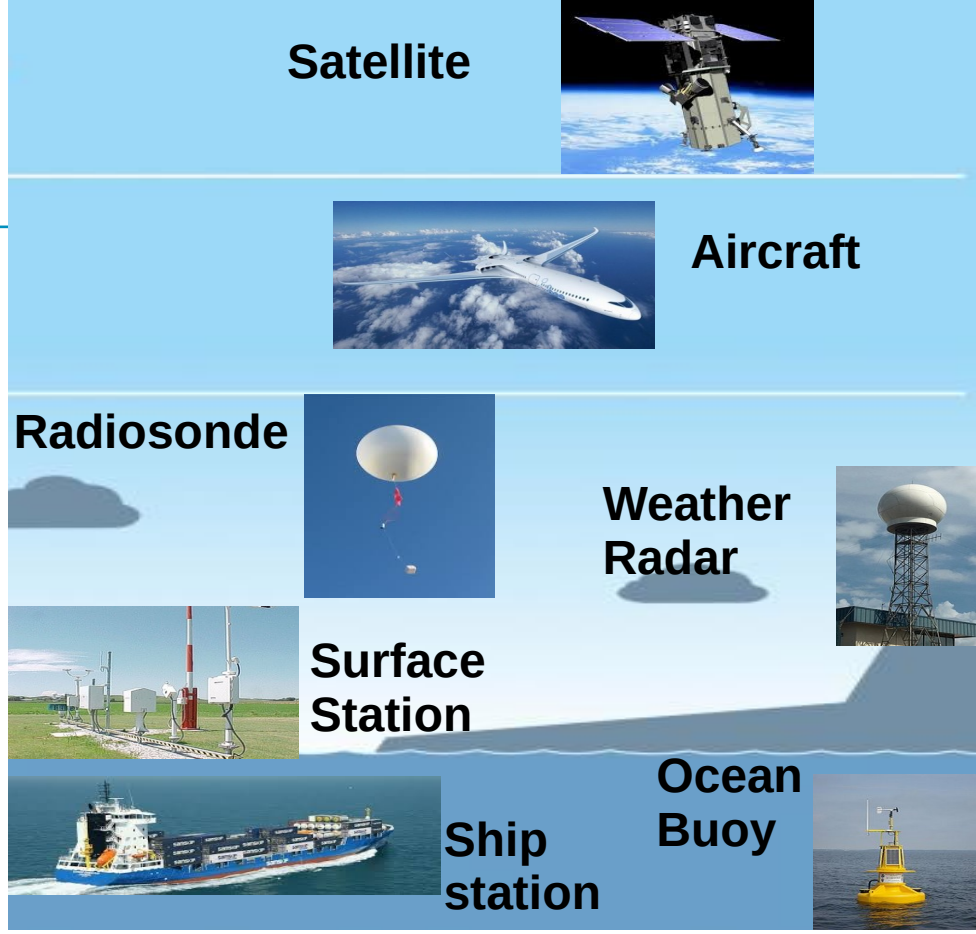
Context

- Incorrect **fog forecasting** has a large economic cost
- **Observation gaps** within the boundary layer
- Development of affordable ground-based remote sensing instruments
- Aim : Improvement of forecast through **assimilation** of **cloud radar/microwave radiometer** data



BASTA Cloud Radar

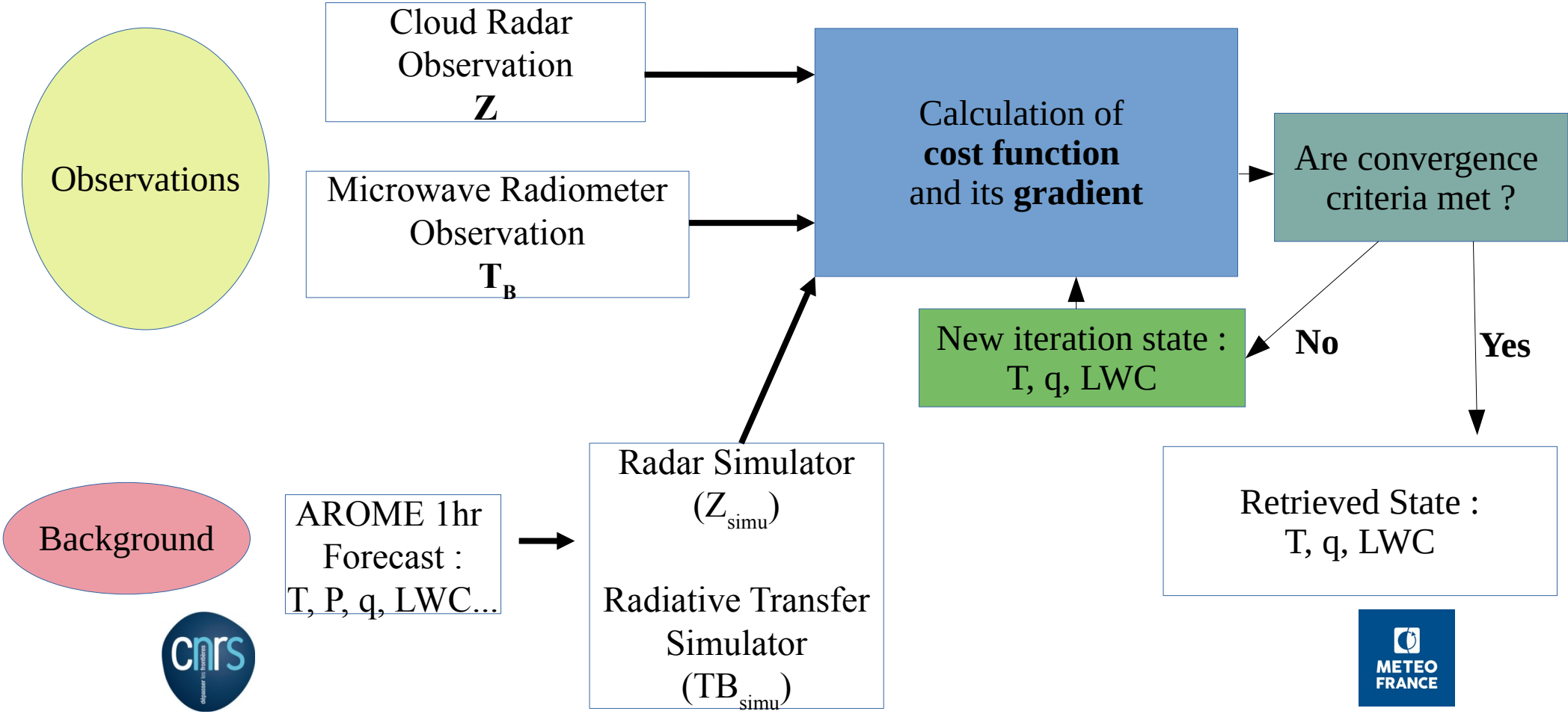
- Retrieves Radar Reflectivity and Doppler Velocity
- 95 GHz transmission frequency
- Continuous transmission
- Frequency modulation allows for locating the target
- Lower cost than traditional weather radar
- Minimum measurement distance 40m
- Scanning possible
- Highest resolution 12.5m (with range up to 12 km)

HATPRO Microwave Radiometer

- Two-band (22-31 and 51-58 GHz) passive microwave profiler with 14 channels
- Continuous profiling during cloudy and clear conditions
- Allows for retrievals of :
  - -Temperature profiles
  - -Humidity profiles
  - -Liquid water path (LWP)
  - -Integrated water vapour

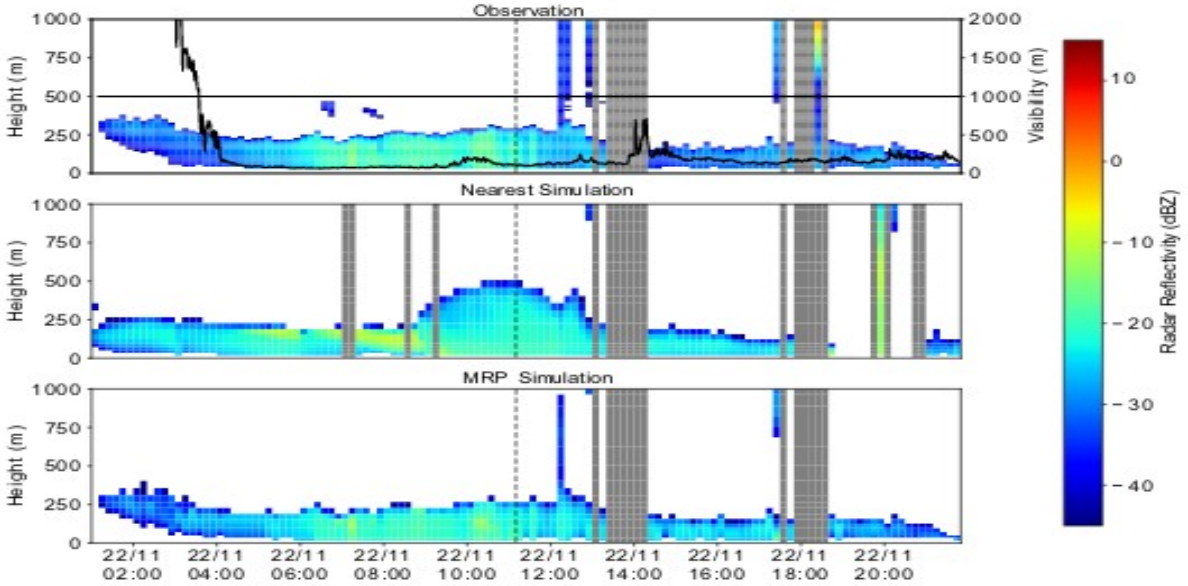
1D-Var

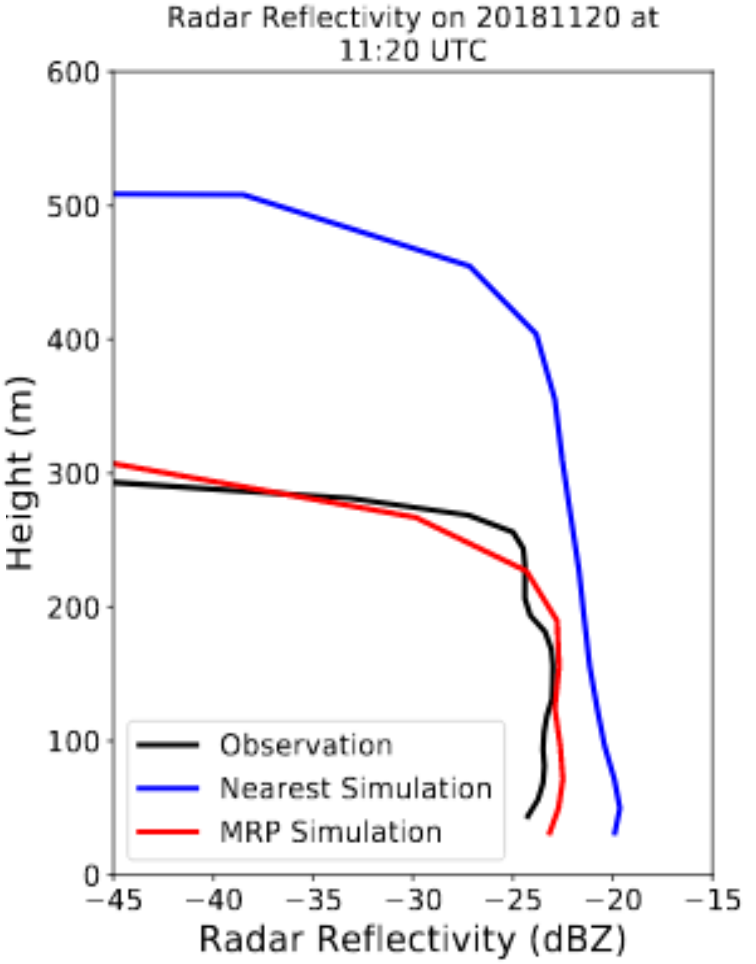
- 1D-Var is a method of optimal estimation
- The cost function is calculated from the background, observation and current iteration state, as well as background and observation **errors**
- The derivatives of Z_{simu} and TB_{simu} with respect to T, q and LWC are needed to calculate the gradient of the cost function



MRP Method

- 1D-Var more likely to converge and to give good retrieval if background is close to true state
- Found significant temporal and spatial errors in fog forecast prediction by AROME
- MRP uses radar observation to pick a background profile from 28 x 28 km domain and 6 hour time window





*Bell, A., et al. "**W-band Radar Observations for Fog Forecast Improvement: an Analysis of Model and Forward Operator Errors.**" Atmospheric Measurement Techniques Discussions (2021)

1D-Var : Testing the Algorithm

- First tests on a newly developed algorithm can be done on synthetic profiles
- This involves creating a background profile and observations from the model
- Retrievals can be compared with the ‘truth’ to verify that the algorithm works correctly and make studies

Perturb by Background Errors

Truth
From AROME

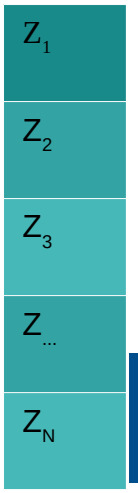
T_1	$\mathbf{q_1}$	LWC_1
T_2	q_2	LWC_2
$T_{...}$	$q_{...}$	$LWC_{...}$
T_N	q_N	LWC_N

Simulate from truth and perturb by observation errors

Background

T_back_1	$\mathbf{q\_back_1}$	LWC_back_1
T_back_2	q_back_2	LWC_back_2
$T\_back_{...}$	$q\_back_{...}$	$LWC\_back_{...}$
T_back_N	q_back_N	LWC_back_N

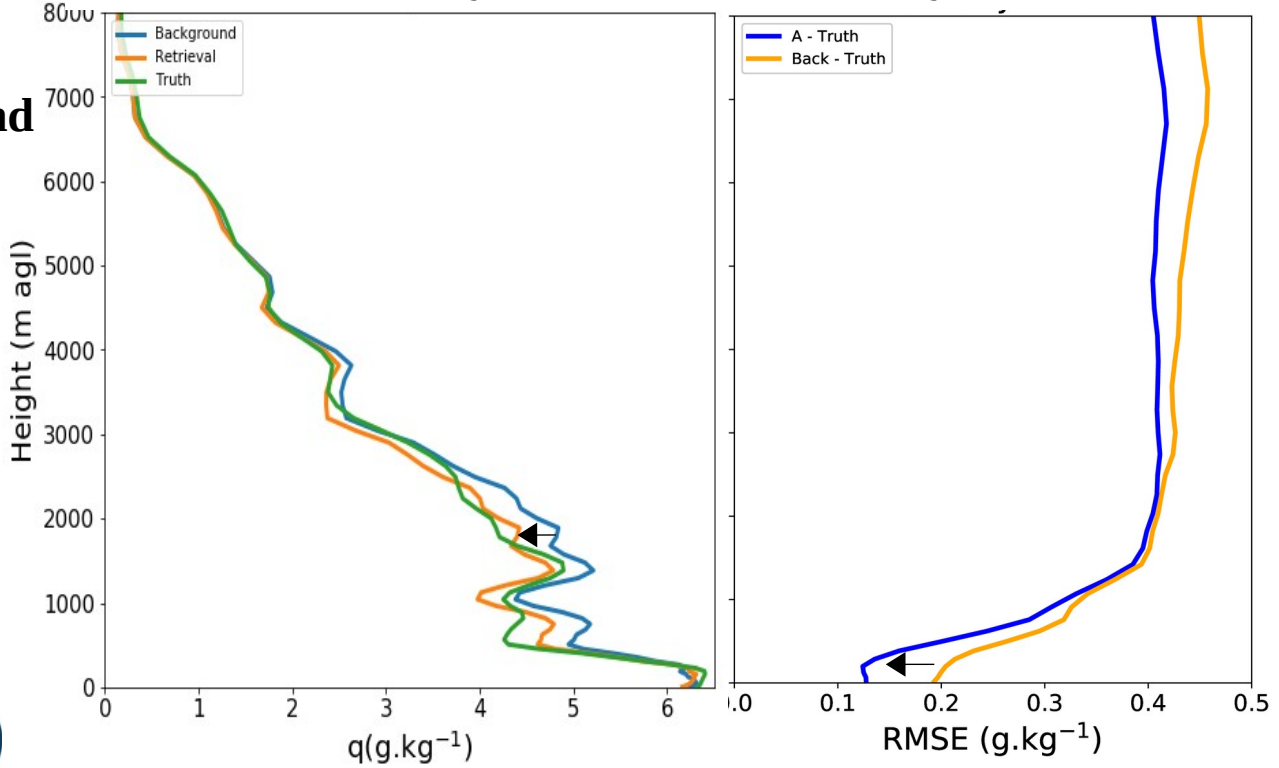
Observations



Results : Humidity

- Example case study where fairly accurate retrieval made
- RMSE of retrieval – truth reduced when compared to the background profile
- Addition of radar observations to retrieval algorithm did improve nor degrade retrieval

Retrieved Humidity Profile **Humidity RMSE**



Background

Retrieval

Truth

Retrieval - Truth

Background-Truth

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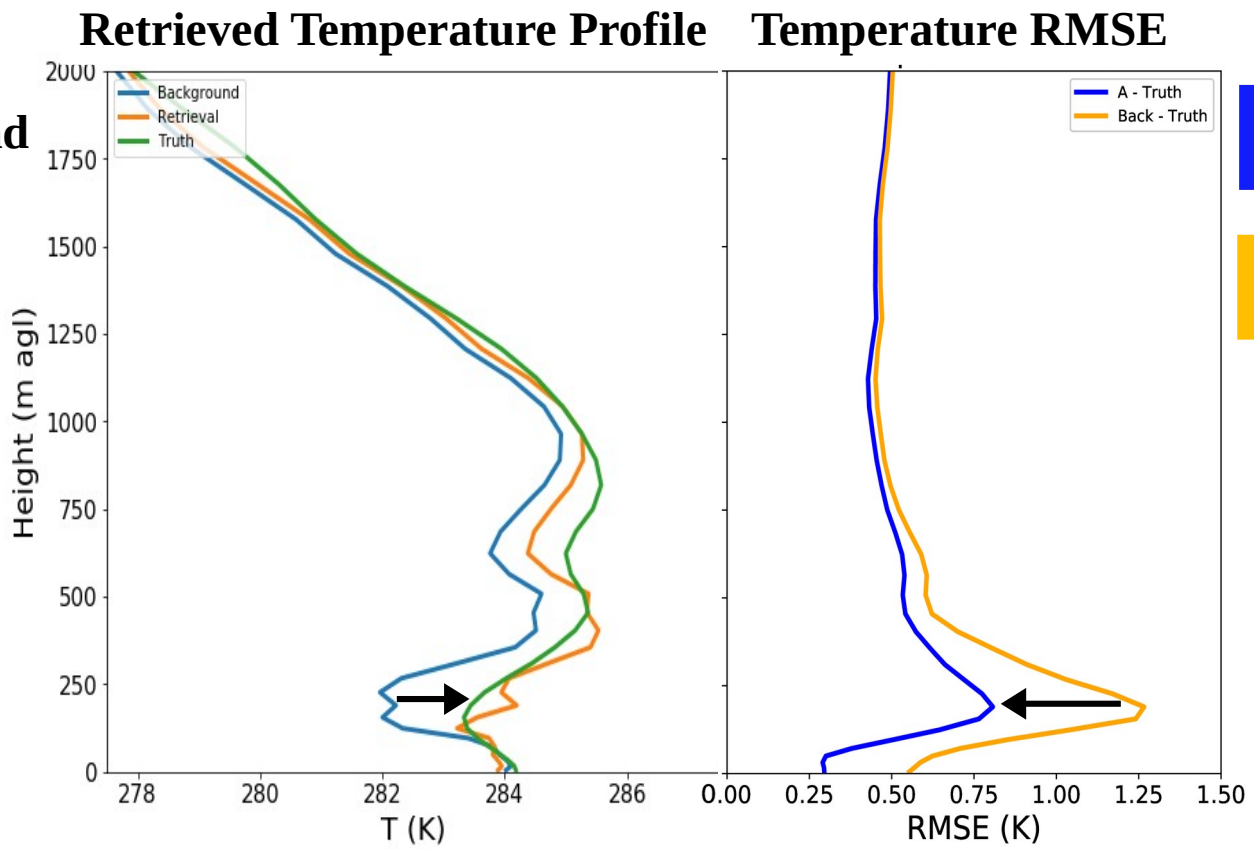
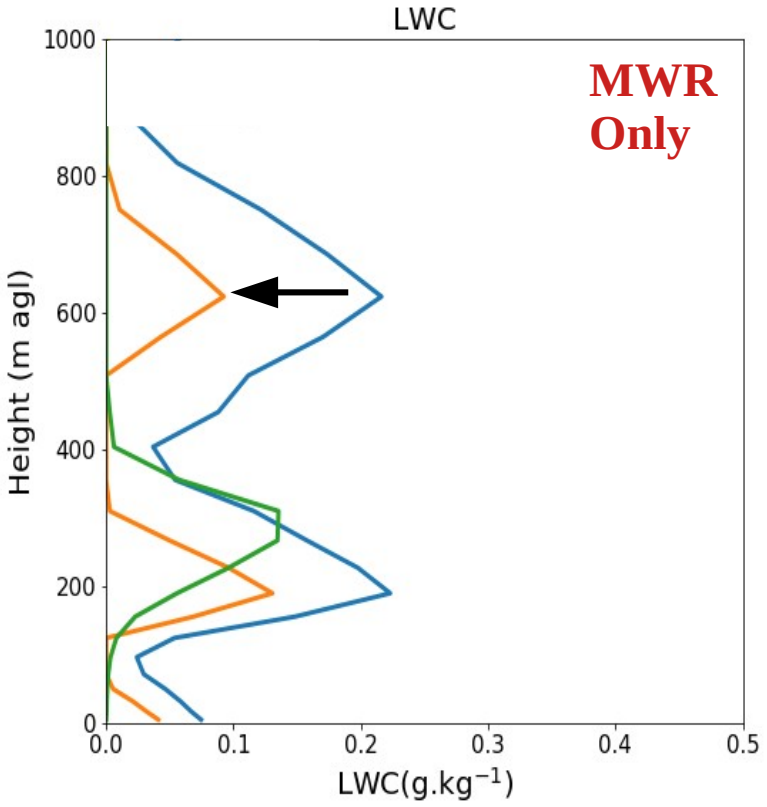


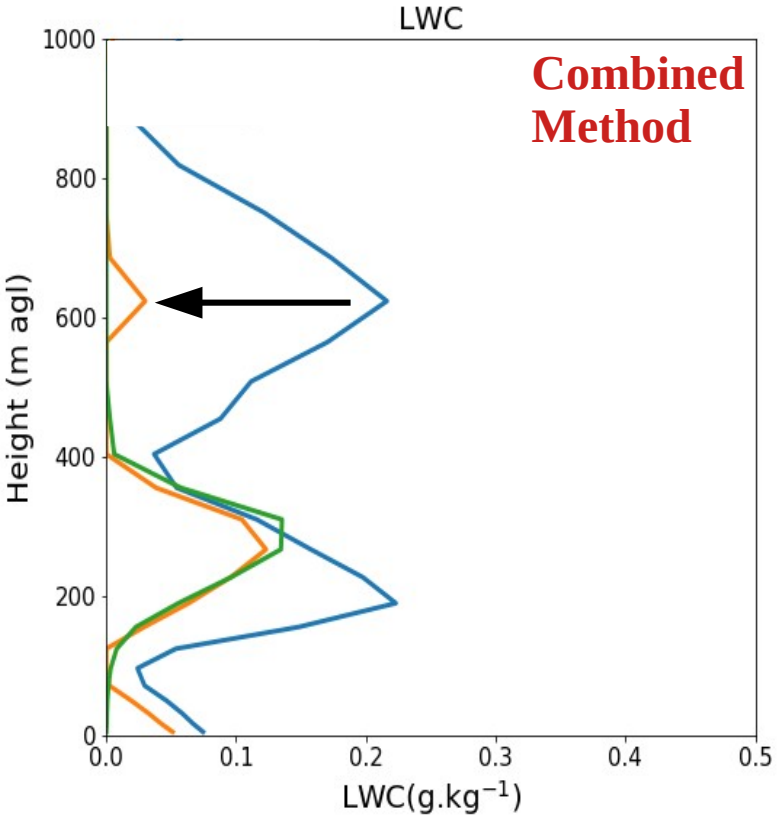
Retrieval - Truth

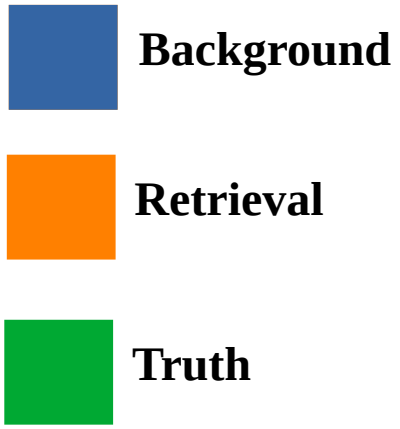
Background-Truth

Case study : Benefit of Radar to LWC Retrieval

- Algorithm was run with only Radar, only MWR and with both instruments
- The sensitivity of the Microwave radiometer to vertically integrated LWC means that without the radar, the algorithm is able to reduce the LWC
- When radar observations are included in the algorithm, the right amount of LWC is put at the correct height



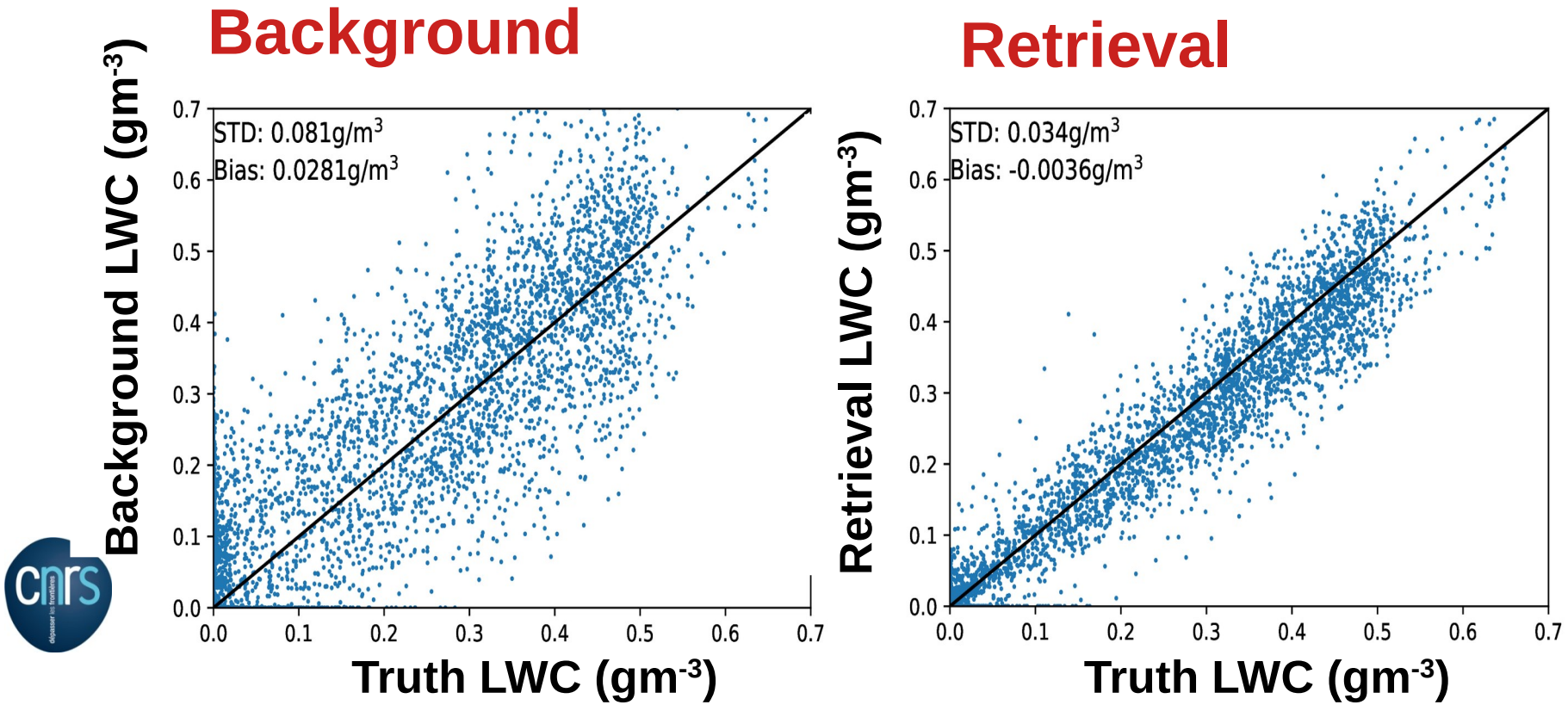




METEO FRANCE

Results : LWC Retrievals

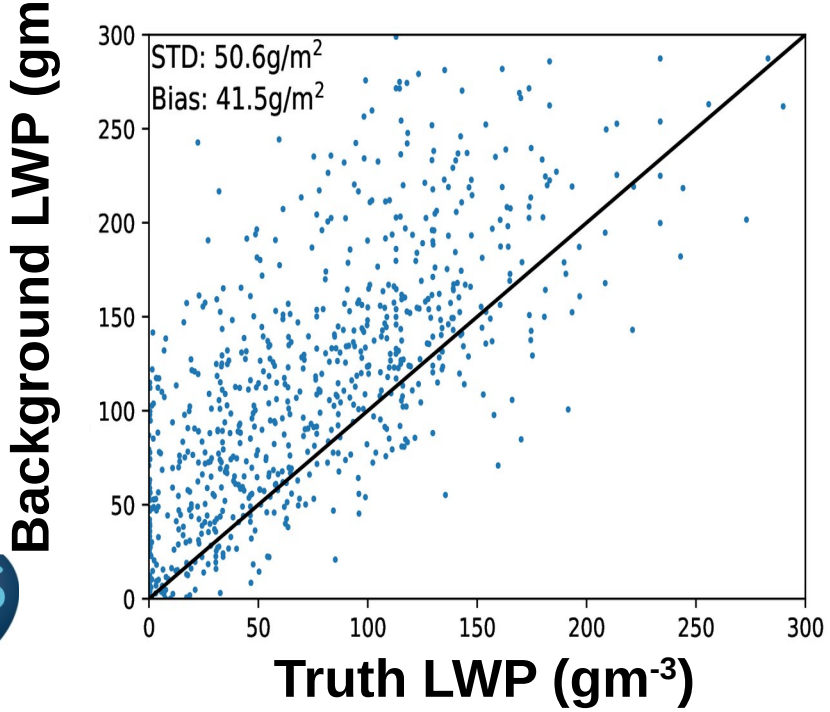
- Retrievals of LWC significantly reduce error when compared to the background profile
- Slight bias was seen in background due to method of generating ‘observations’
- The algorithm was able to correct for this
- On the plots, points on the black line represent a perfect retrieval



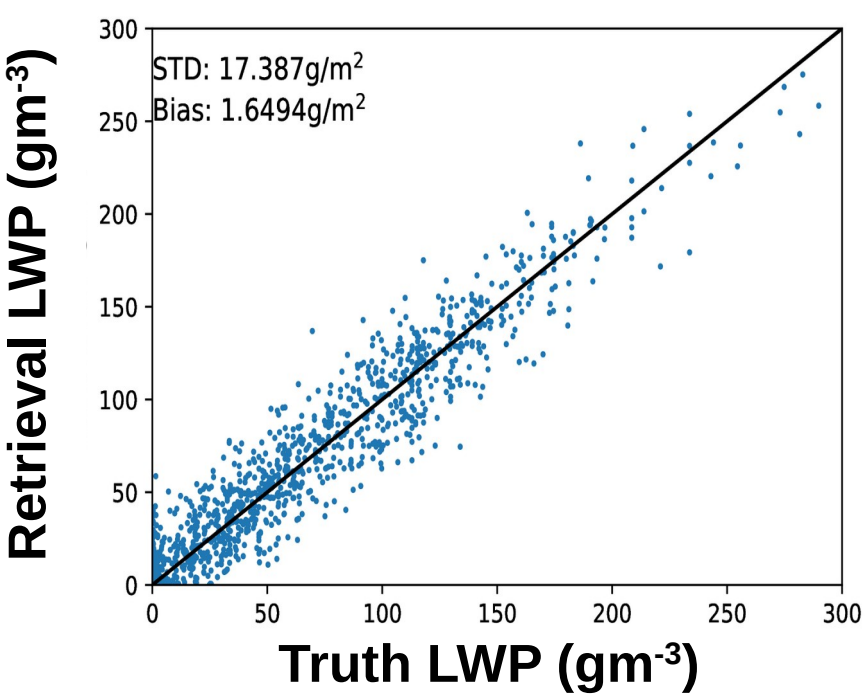
Results : Liquid Water Path from Retrieved LWC Profiles

- MWR is sensitive to LWP
- A large bias can be seen in the LWP of the Background profiles due to correcting for negative values of LWC
- The algorithm was able to correct for this to have a bias of 1g/m²
- On the plots, points on the black line represent a perfect retrieval
- Dual instrumental retrieval improves standard deviation of LWP error (11.5 vs 17.4 for MWR only

Background



Retrieval MWR Only



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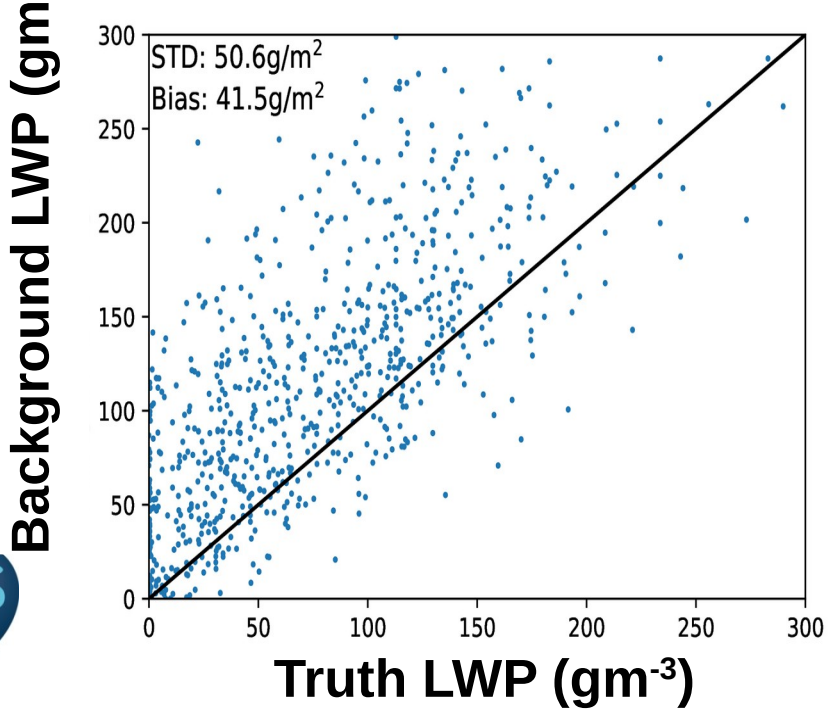
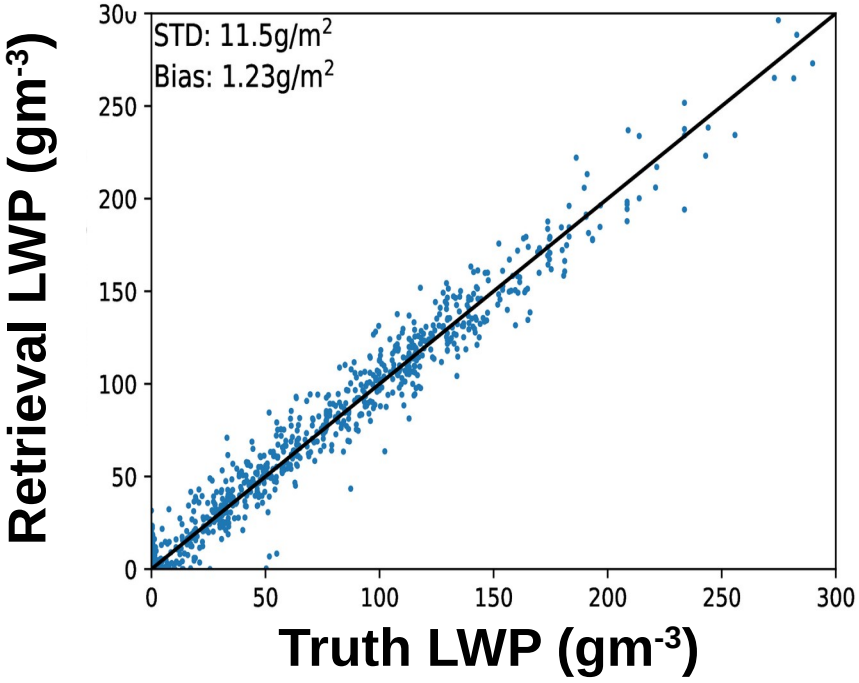
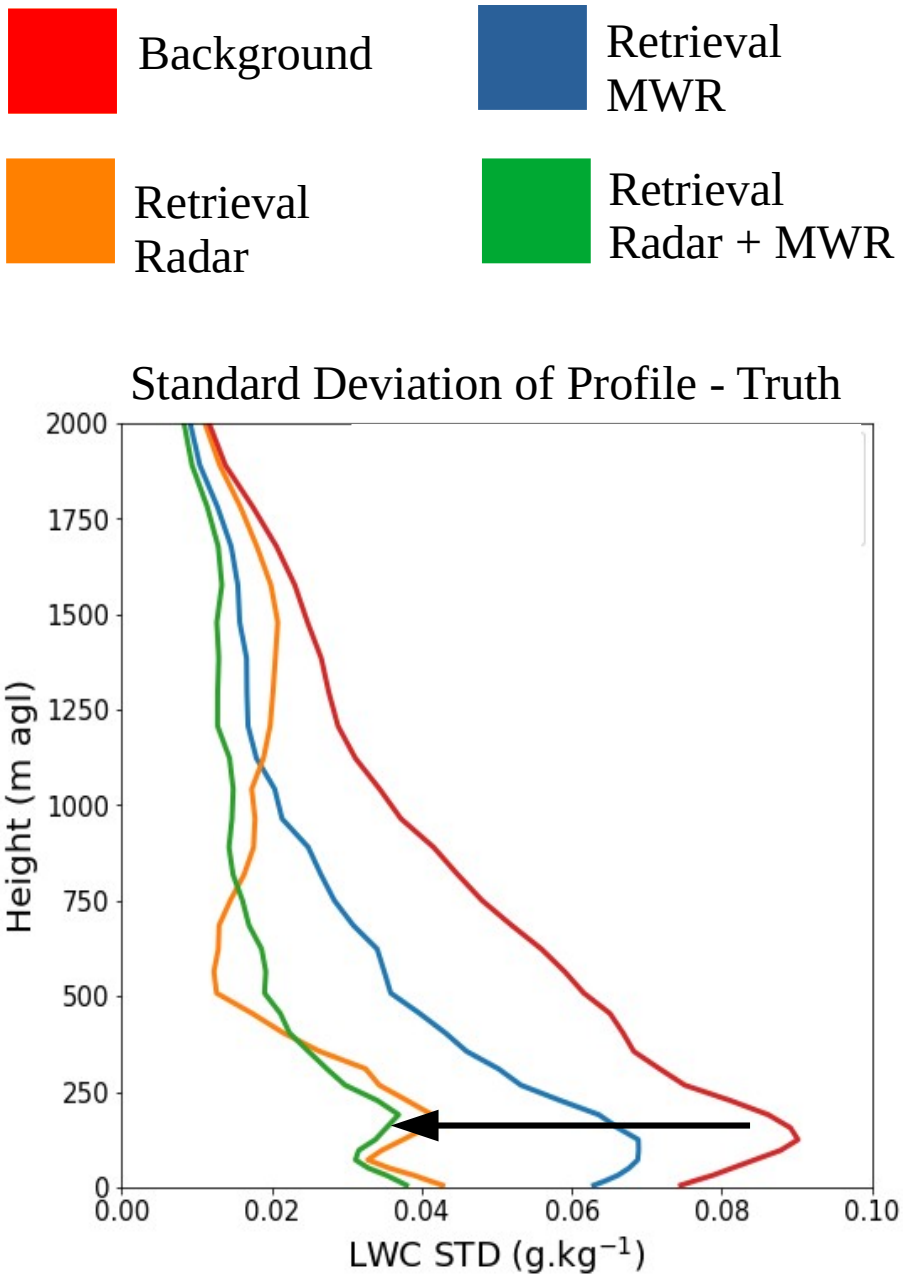


Retrieval MWR + CR



Statistics : Benefit of Radar to LWC Retrieval

- Significant improvement in analysis with radar compared to background
- Retrievals are more accurate when both instruments used compared to radar only
- When only MWR is used, STD of LWC still improved by .02 $g.kg^{-1}$
- Including radar observations did not affect the statistics of temperature and humidity compared to only MWR retrievals (not shown)

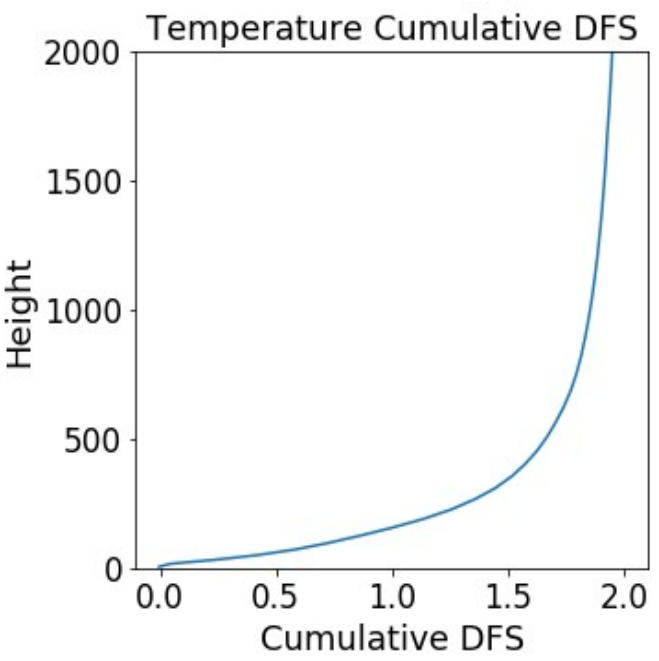


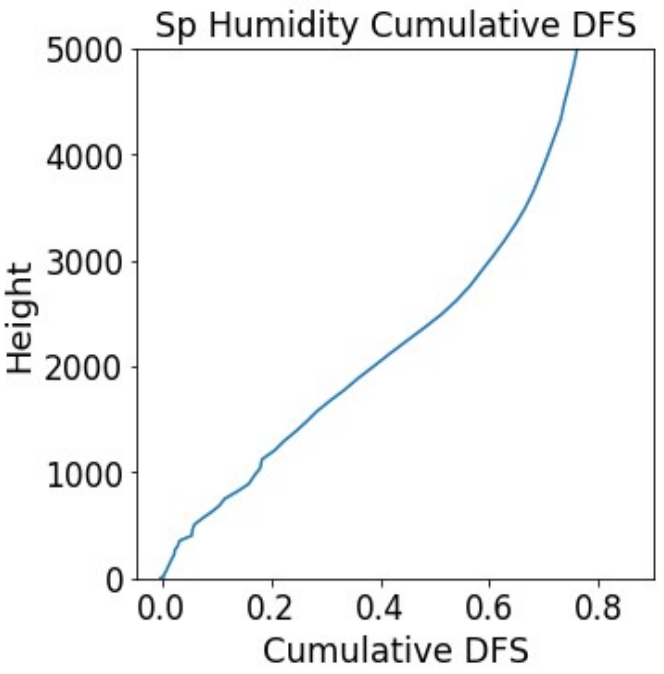
Degrees of Freedom for Signal (DFS)

- It can be useful to know the information content provided by the observations in a retrieval
- The DFS calculates the number of independent pieces of information used in the retrievals
- This is found from the trace of the 'averaging kernel matrix' ($\delta\mathbf{x}_{retrieved}/\delta\mathbf{x}_{Truth}$)
- For a perfect retrieval, the DFS would equal the number of retrieved levels for each variable (in this case 90)
- Synergistic retrievals improve the DFS for LWC
- When instrumental errors are assumed to be lower, the DFS increases
- Most information for temperature profiles in first 500m

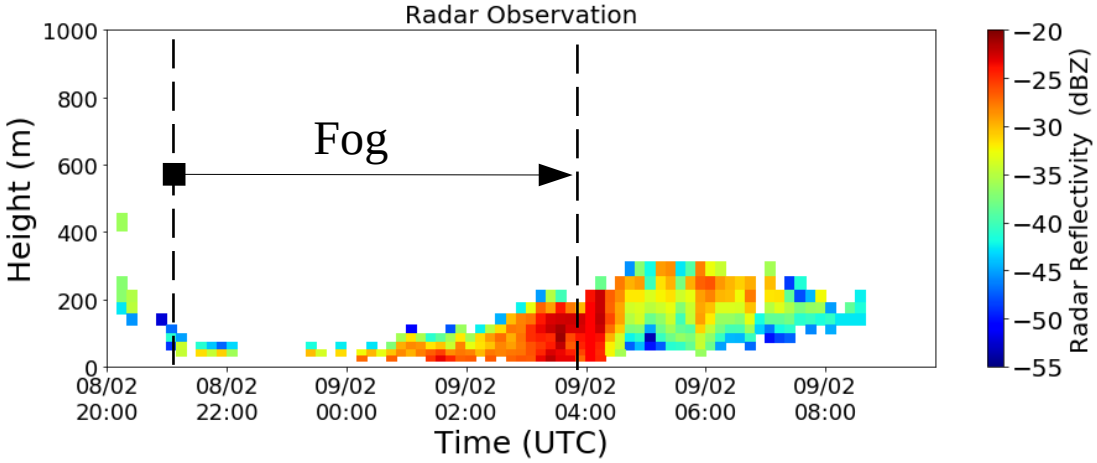
Results

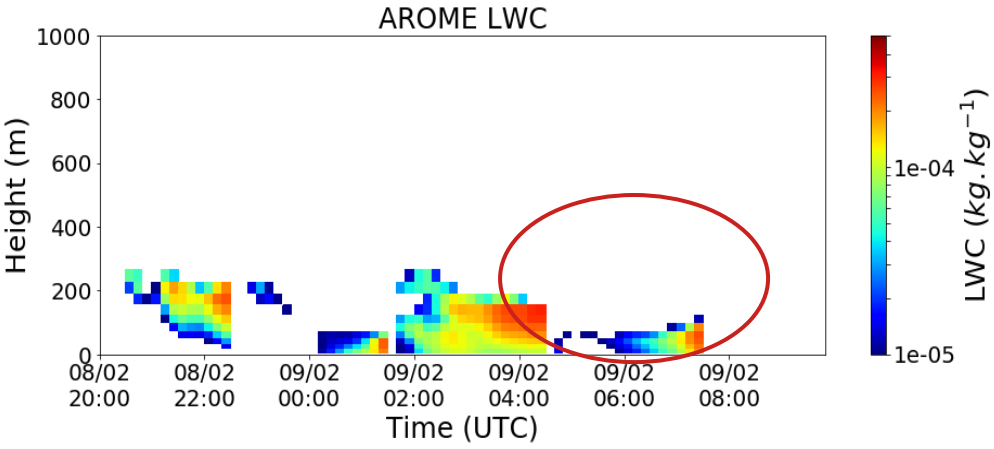
T	q	LWC (%)
Dual Retrieval		
1.99	0.86	38.2
Radar Only		
0.11	0.09	37.0

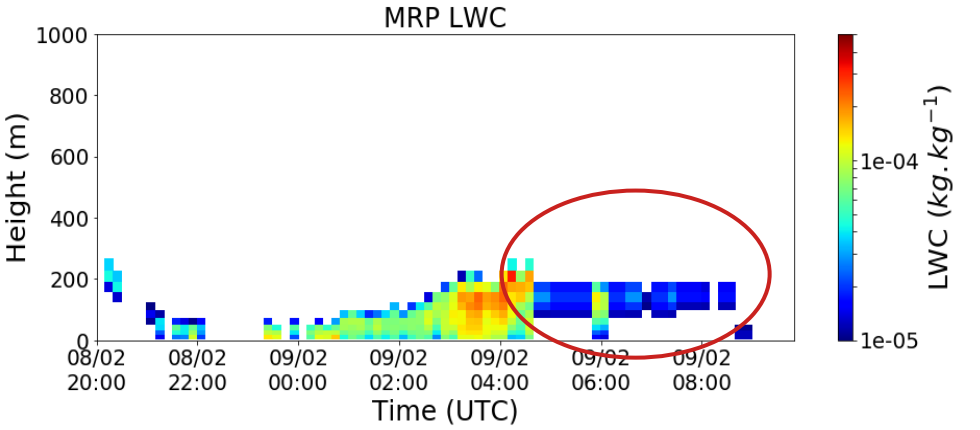


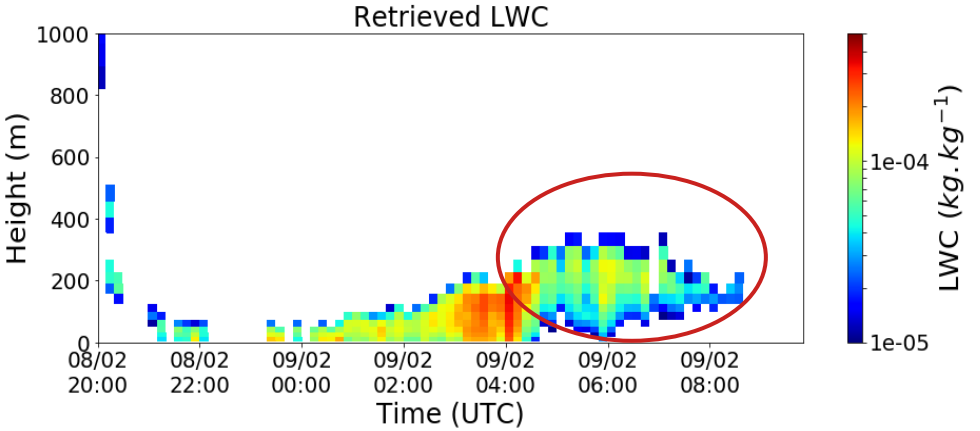


First Retrieval from SOFOG









- Fog event 8-9th February which lasted for ~7 hours
- AROME model predicted fog, but with significant temporal/fog top height errors
- MRP method corrects temporal/ fog top height for most of fog event
- LWC of fog layer increased in retrieval

Future Steps

- Retreival algorithm will be applied to the whole SOFOG dataset at the supersite
- In-situ data taken from the campaign will be used to verify retrievals
- Investigation into the value of MRP vs AROME background
- Experiments with changes in the algorithm e.g. correlated instrumental errors
- … Assimilation of LWC profiles into AROME model to improve fog forecasts