Impact of microwave radiometer accuracy and stability on retrieved parameters

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Radiometer Physics
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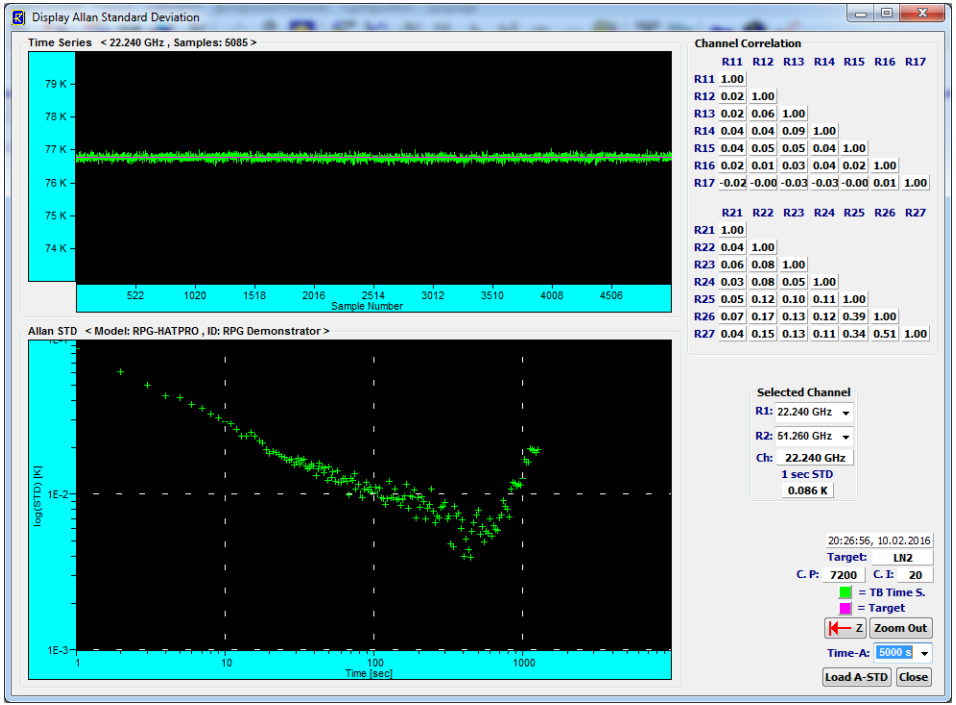
Recap

RPG-HATPRO generation 5 improvements

- **Rapid noise switching** (64 Hz) and rework of data acquisition system (4 kHz)
  1. **Correction of gain drift** on short time scales
     Allan Standard Deviation shows -1/2 slope
     100 s integration → reduction of NeDT by 10
  2. **Reduction of NeDT**
     0.07 K in K-band @ 1s integration time
     0.05 K to 0.14 K in V-band @ 1s
  3. **Uncorrelated channel noise**

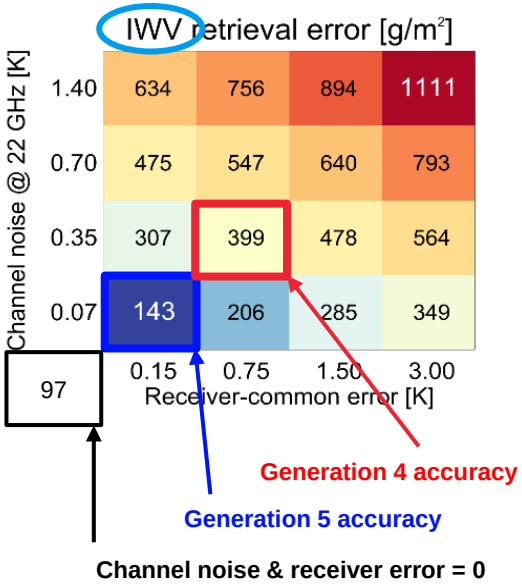
- Improved **calibration process**
  1. **Improved cold load**: no secondary reflector, no reflection, **no standing waves**, no condensation and oxygen entrainment
  2. **Improved ambient load**: finer calibration of temperature sensors.



TB error impact on level 2 products

- How reduced noise and improved stability impact retrieved (level 2) products?
- In this study we quantify this impact for several products

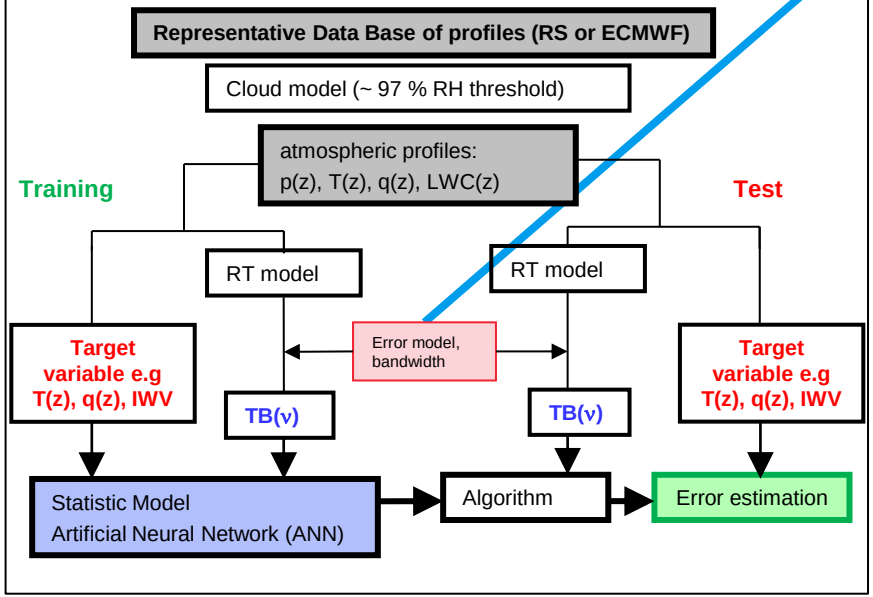
- In these examples the **IWV** retrieval accuracies are plotted as a function of
  - Receiver common error – **x-axis**
  - Individual channel noise – **y-axis**
- Generation-5 RPG radiometer performance is enclosed in blue square.
- The previous generations has both errors increased by a factor 5 (red square).
- Retrieval with no added noise are shown at bottom left corner
- **Lindenberg** (central European) radiosondes profiles (~35 k) have been used



Methodology:

train several ANN with different error assumptions

Retrieval concept and **error estimation**



From **RTM** results to simulated **observations**

The radiative transfer model (RTM) creates noise-free monochromatic brightness temperature.

To convert them to realistic measurements:

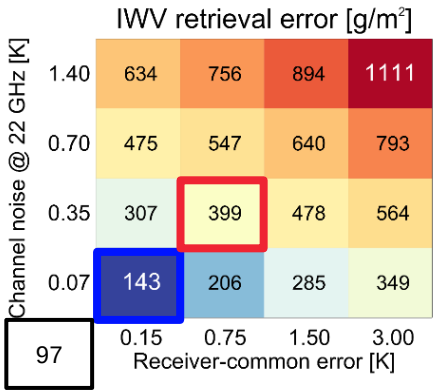
- Integrate over the bandwidth
- Introduce channel noise (uncorrelated among different channel) and receiver-correlated error:
  - Gaussian distributed with stdev = estimated error
  - **Channel noise** is measured as the stdev of the TB of each channel while looking at a blackbody
  - **Receiver-common** for G5 radiometers error is associated to the calibration accuracy (0.15 K)

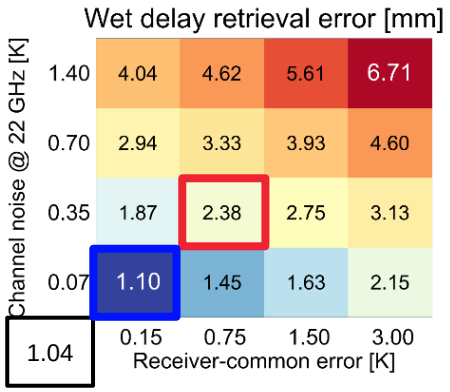
Integrated variables

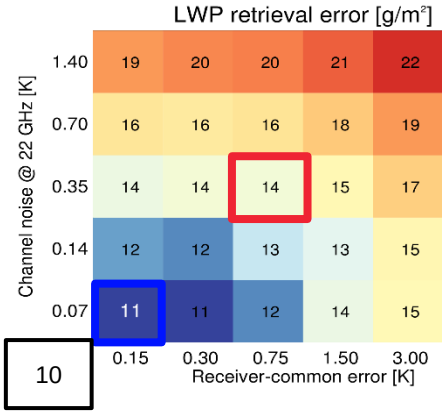
Level-2 Root Mean Squared (**RMS**) errors are calculated for zenith viewing.

- IWV, wet delay, and LWP are all sensitive to both error types: channel noise and receiver-common bias
- Increasing the channel noise has stronger impact than increasing by the same factor the receiver-common bias on integrated product
- Due to redundant information contained in the 7 K-band HATPRO channels, doubling of the channel-noise do not imply doubling of the retrieved product RMS error

WMO goal for NWP: 1 kg/m²





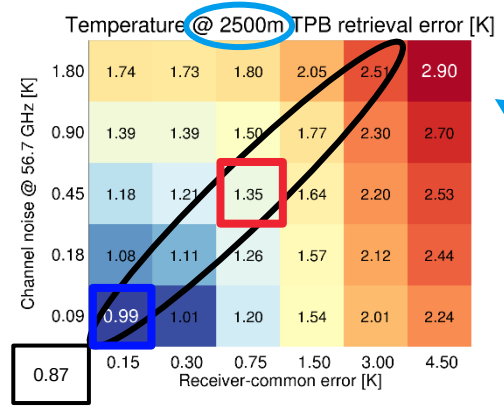


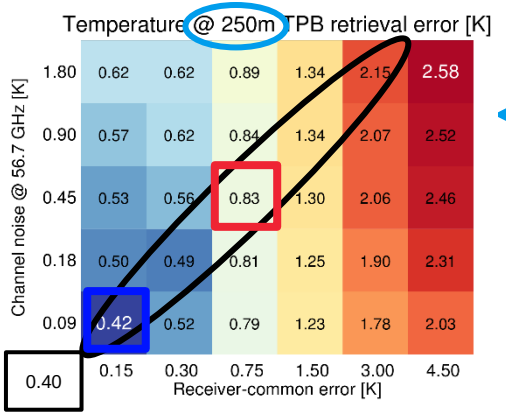
Temperature profile:
multi-angle retrieval

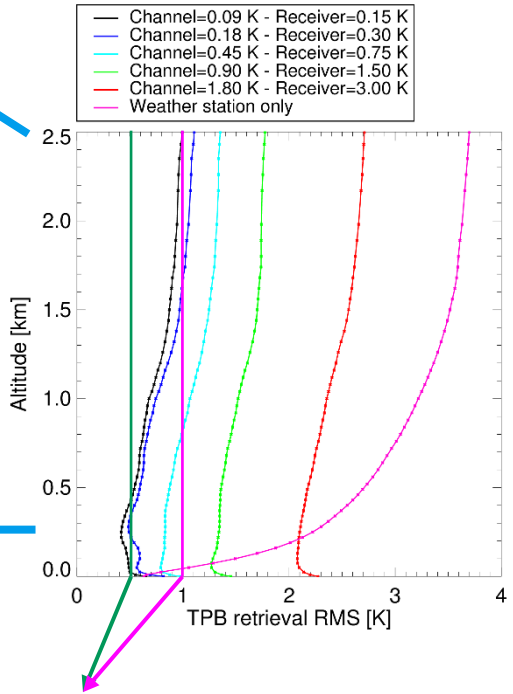
Tables show the temperature profile dependence of RMS on receiver-common and channel noise
Plot shows the vertical profile of RMS for error along the diagonal of the tables

- At **low altitude** (250 m):
  - strong sensitivity to receiver-common bias
  - high redundancy of multi-channel, multi-angle retrieval → low sensitivity to channel-noise
  - receiver-common bias (calibration error) results in biased retrieved temperature
- At **2.5 km** channel noise and receive-common error have similar impact
- G5 radiometer RMS is meeting WMO breakthrough below 2.5 km

RPG do NOT use ground temperature readings for temperature profiling





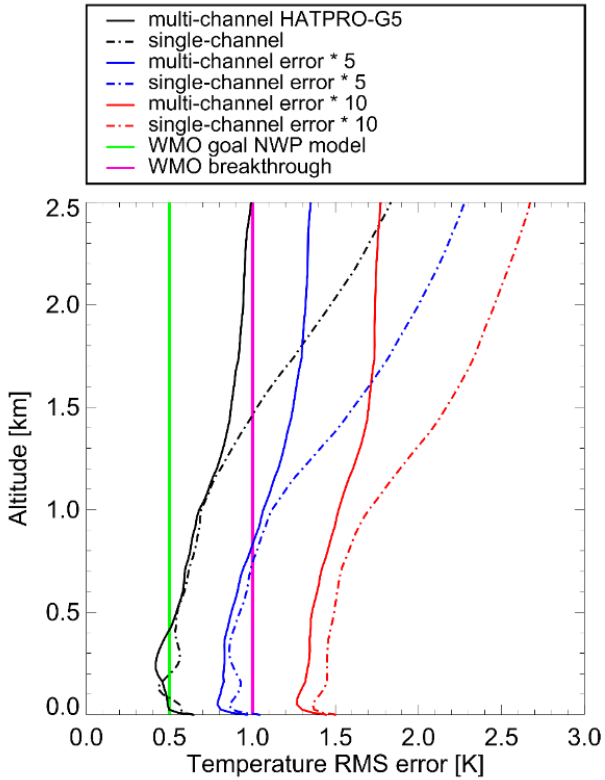


WMO goal and breakthrough for NWP

Temperature profile:
multi- versus single-channel retrieval

Plot: thin solid lines are for multi-angle **multi-channel** retrieval; dashed lines for multi-angle **single-channel**.

- Multi-channel RMS error is similar to single-channel RMS up to 1 km
- Above 1 km multi-channel retrievals outperform single-channel ones because of the information of the more transparent channels



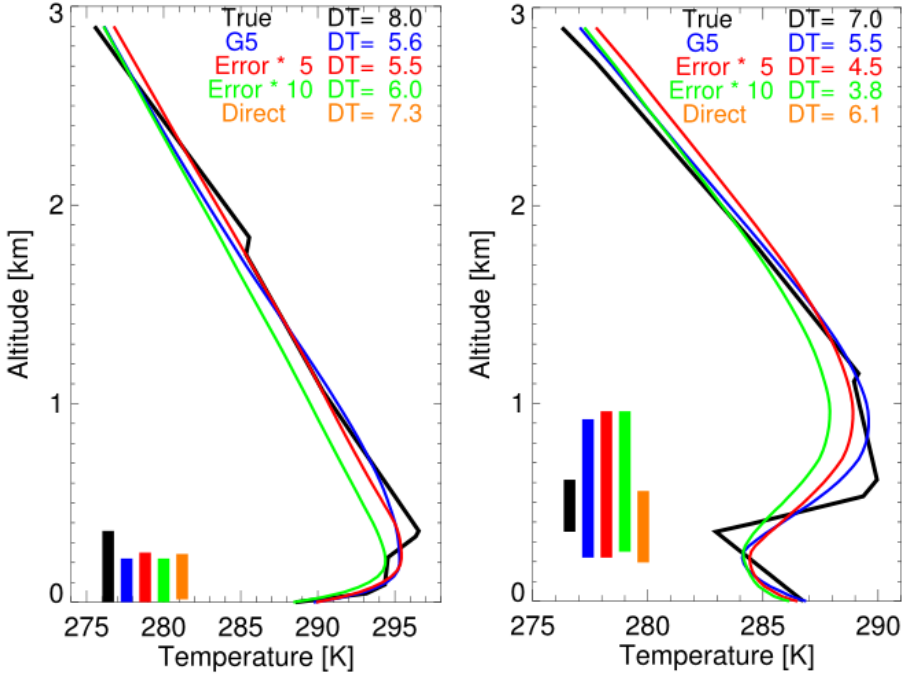
Temperature inversion: Direct retrieval

- RPG developed a new direct retrieval for temperature inversions
- The retrieval use as target the inversion height, strength, and thickness
- The advantage is that the cost function minimized for the retrieval training is not the RMS for the whole profile

- Simulated results shows better performances of the direct retrieval, especially for **lifted inversion**
- Direct comparison with radiosonde is in progress

- The new retrieval will be implemented into the RPG software after validation

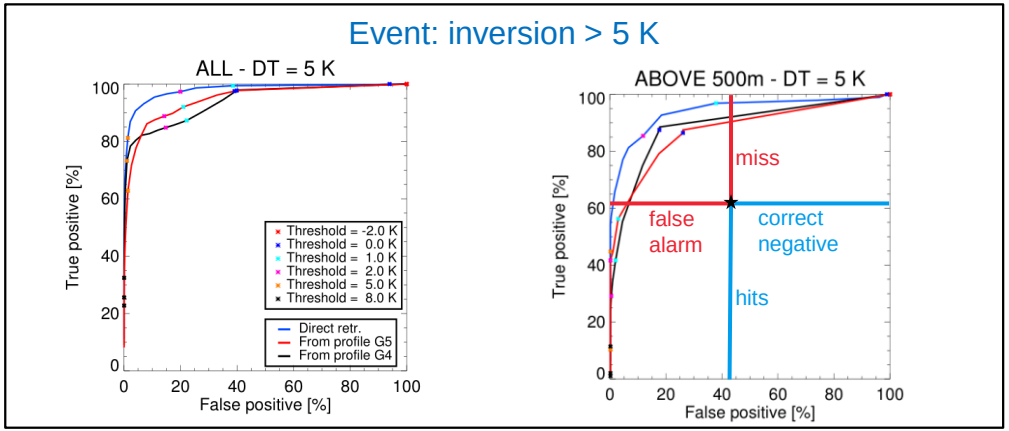
Munich airport radiosondes



Temperature inversion: classification

Receiver Operating Characteristic (**ROC**) **plot:**

- ROC plot summarizes several contingency tables in one plot
- Retrieved strength is used for classification
- By varying the threshold used for detection, different **hits** ratio (true positive) and **false-alarm** ratio (false positive) can be achieved
- Tailored threshold to fit customers needs:
  - E.g. Airports may need 95% **hits** ratio and can leave with 20% **false alarm** ratio



Performance:

- Direct retrieval inversion has better performances than diagnosing inversions from retrieved temperature profiles
- Direct retrieval is especially successful for elevated inversions

Summary and outlook

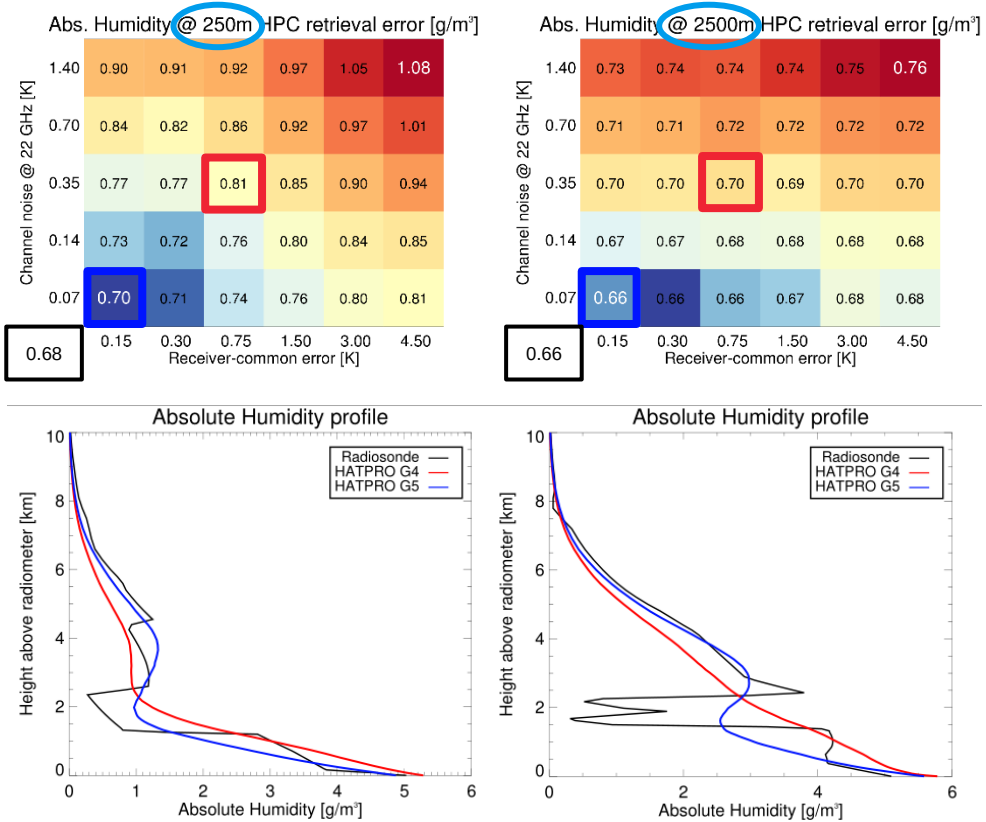
- **Level 2 products accuracy:**
  - IWV and wet-delay are more sensitive to channel noise than receiver-common bias
  - Temperature profile in BL is most sensitive to receiver-common biases
  - Multi-channel multi-angle retrievals perform better above BL than single-channel
  - ➢ Reduced noise and stability are crucial to meet WMO and customer requirements

- **Temperature inversion:**
  - New direct retrieval developed
  - ○ Implementation in RPG software after validation with radiosonde comparison
  - ➢ Direct retrieval shows higher accuracy, especially for lifted inversions

- **Contact:** emiliano.orlandi@radiometer-physics.de

Absolute humidity profile:

- On average, RMS improvements from G4 to G5 series are between 5 and 15%
- Most of the sensitivity to channel noise and correlated error is in the boundary layer
- For non-standard cases, the improvement is significant
- Higher information content → more feature in the vertical profile



Temperature inversion

Definition: atmospheric layers where dT/dz is positive. As opposed to the standard atmospheric behaviour, temperature increases with height.

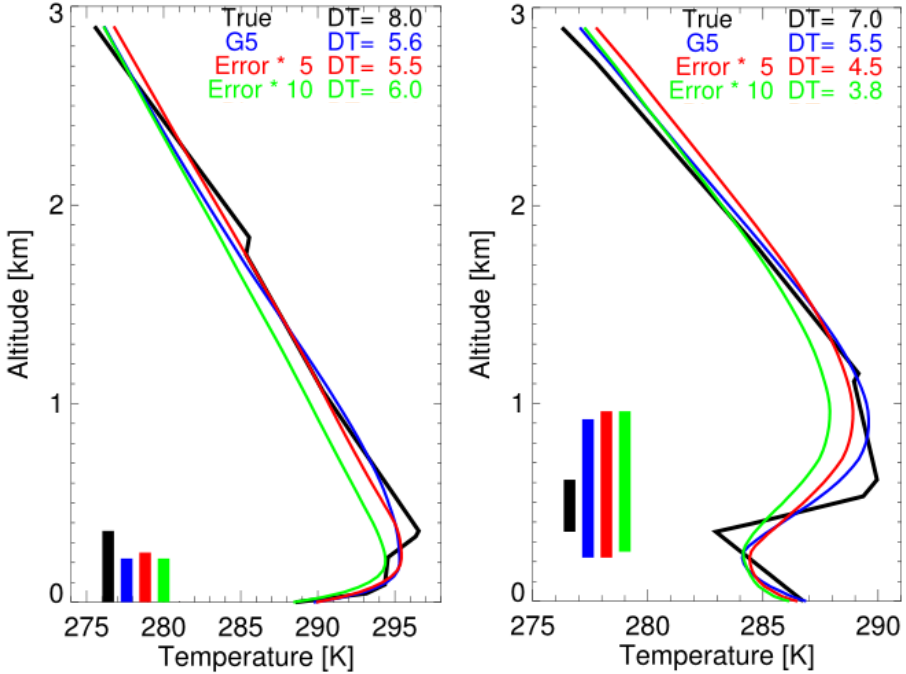
Impacts:

- Vertical motion is inhibited within layers with temperature inversion, pollutants get trapped below inversion top
- Strong wind shear is often found at the inversion top, endangering airport take-off and landing operations
- Ground based inversions are often associated with fog formation, reducing the visibility
- Inversions can lead to imprecise take-off and landing performance calculations.

Mitigation:

- Real-time temperature inversion classification (strength, height) at high temporal resolution
  - helps airport take-off and landing operations
  - helps fog formation and dissipation forecast
  - can be used to regulate emissions (pollutants, PM)

Munich airport radiosondes



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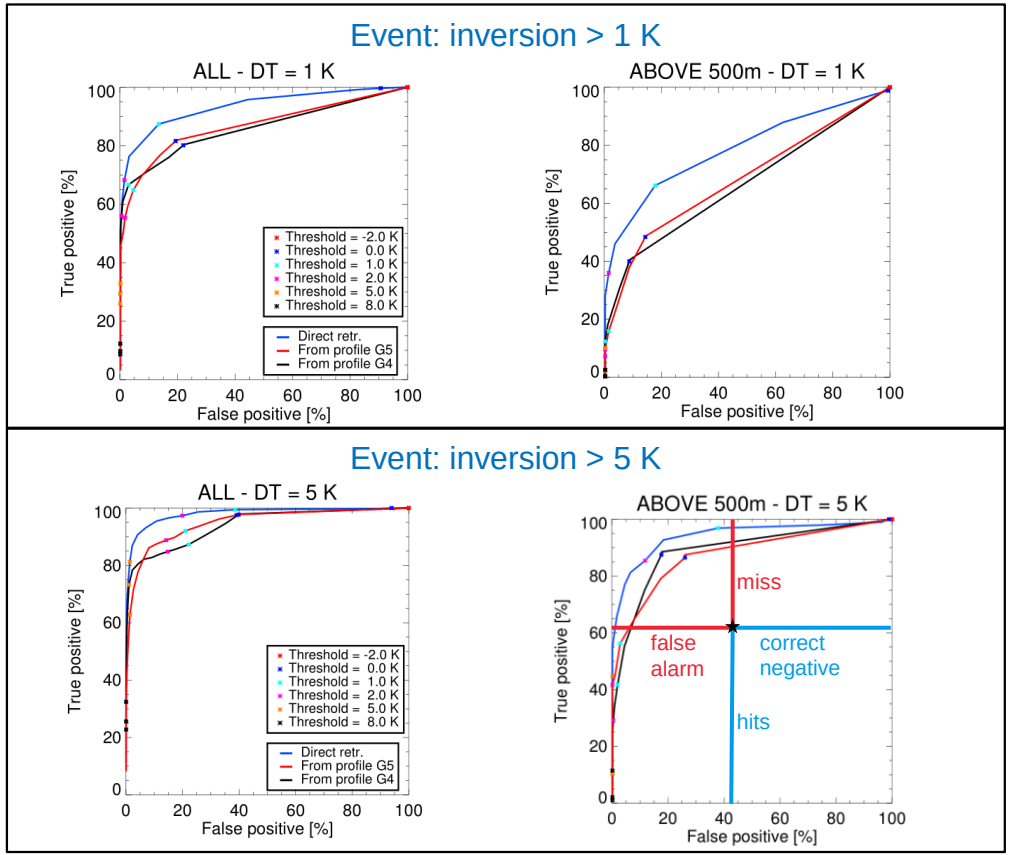

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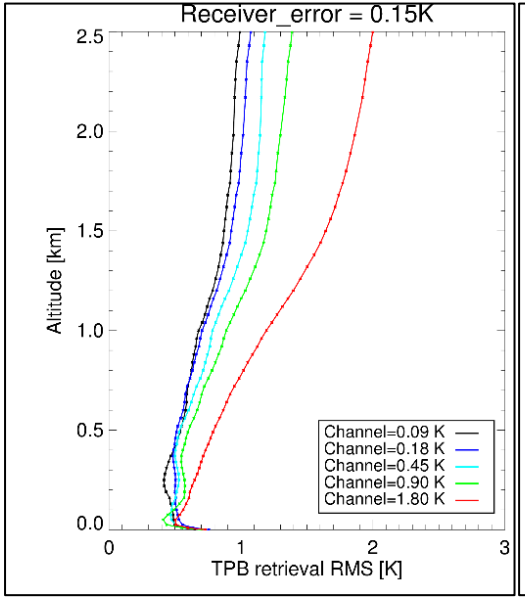
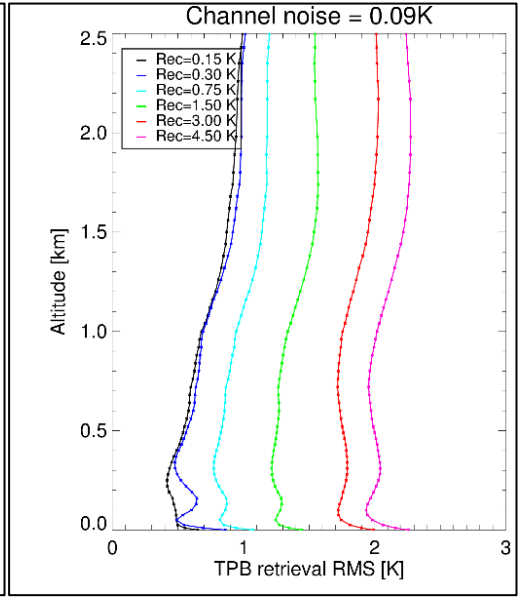
- At 2.5 km the dependency on channel noise is stronger

Variable **channel noise**

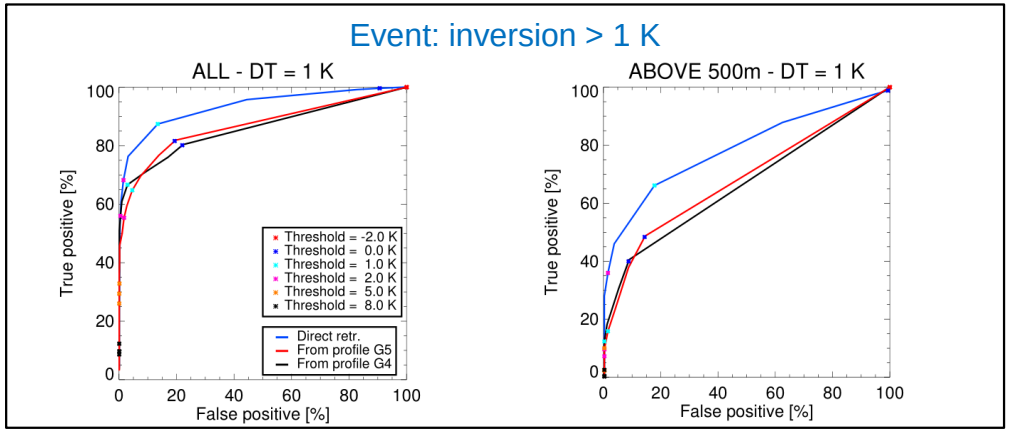


Variable **receiver-common** bias



Temperature inversion: classification

2x2 Contingency Table		Event Observed	
		Yes	No
Event Forecast	Yes	a (hits)	b (false alarms)
	No	c (misses)	d (correct negatives)



True positive rate = probabability of detection (POD)
True positive rate = hits / condition positive
True positive rate = hits / (hits+misses)

False positive rate = probability of false alarm (POFD)
False positive rate = misses / condition negative
False positive rate = misses / (false alarm + corr. negative)