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Effects of inhomogeneities within the Field of View in satellite Water Vapour measurements

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Summary

1. Theoretical Background
2. Plan
3. Structure Function
4. Test Case
5. Outlook

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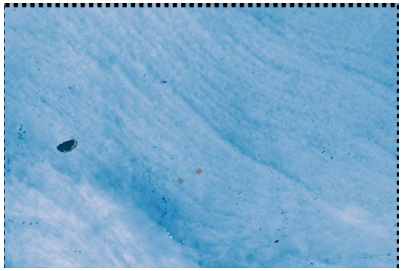
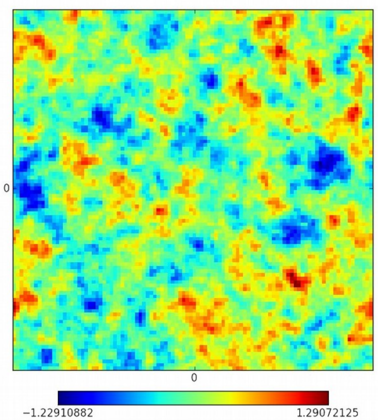
Variability of Water Vapour

Two different scales

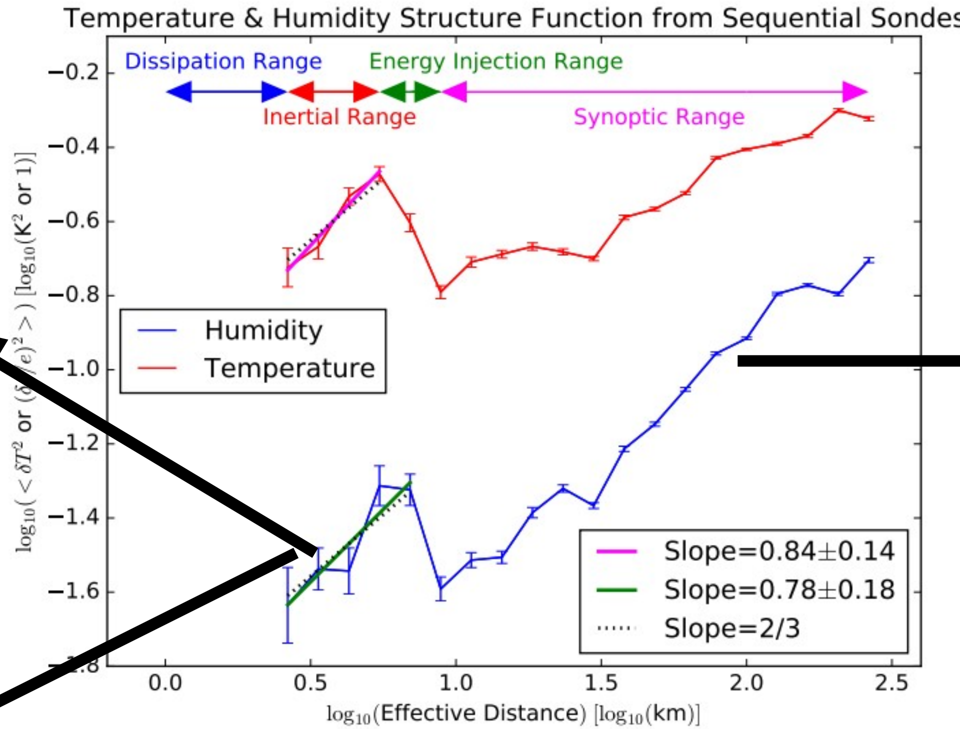
Reality (see Carbajal-Henken et al., 2015, GRL)



Scales < 6 km
Random
Gaussian Field

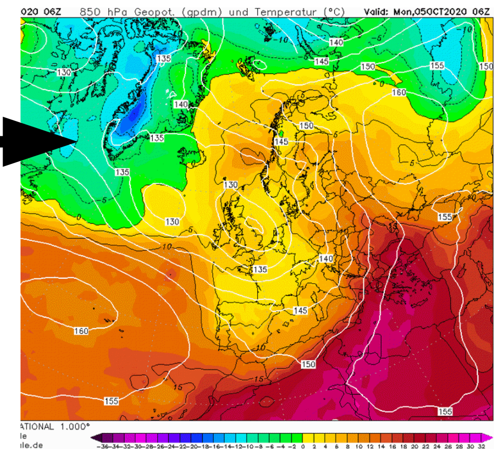


Simulation



Calbet et al. 2018, AMT

Scales > 10km
Smooth Field



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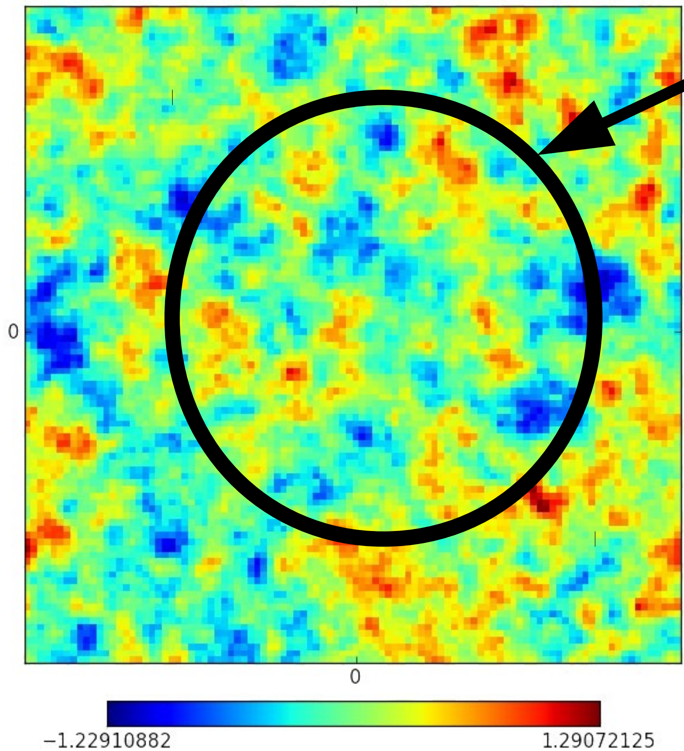
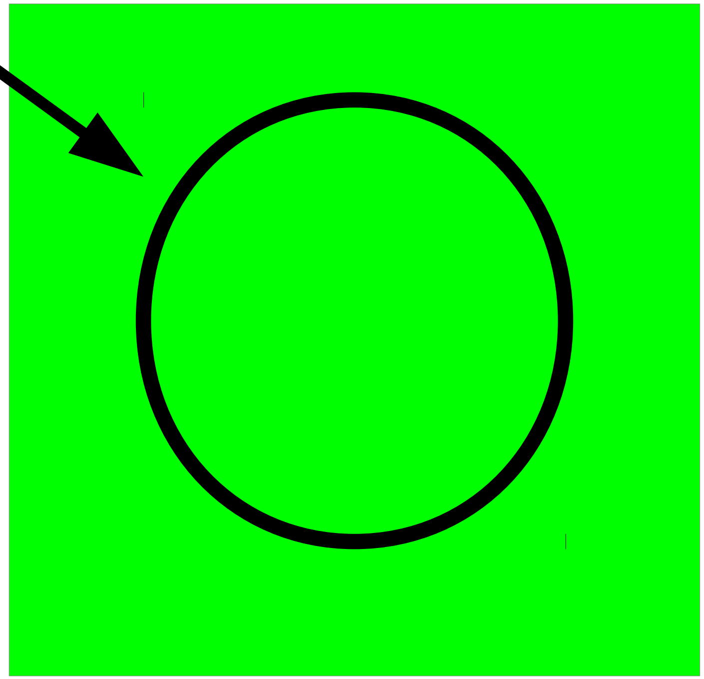
Variability of Water Vapour within FOV

Reality: Scales < 6 km
Random Gaussian Field



FOV

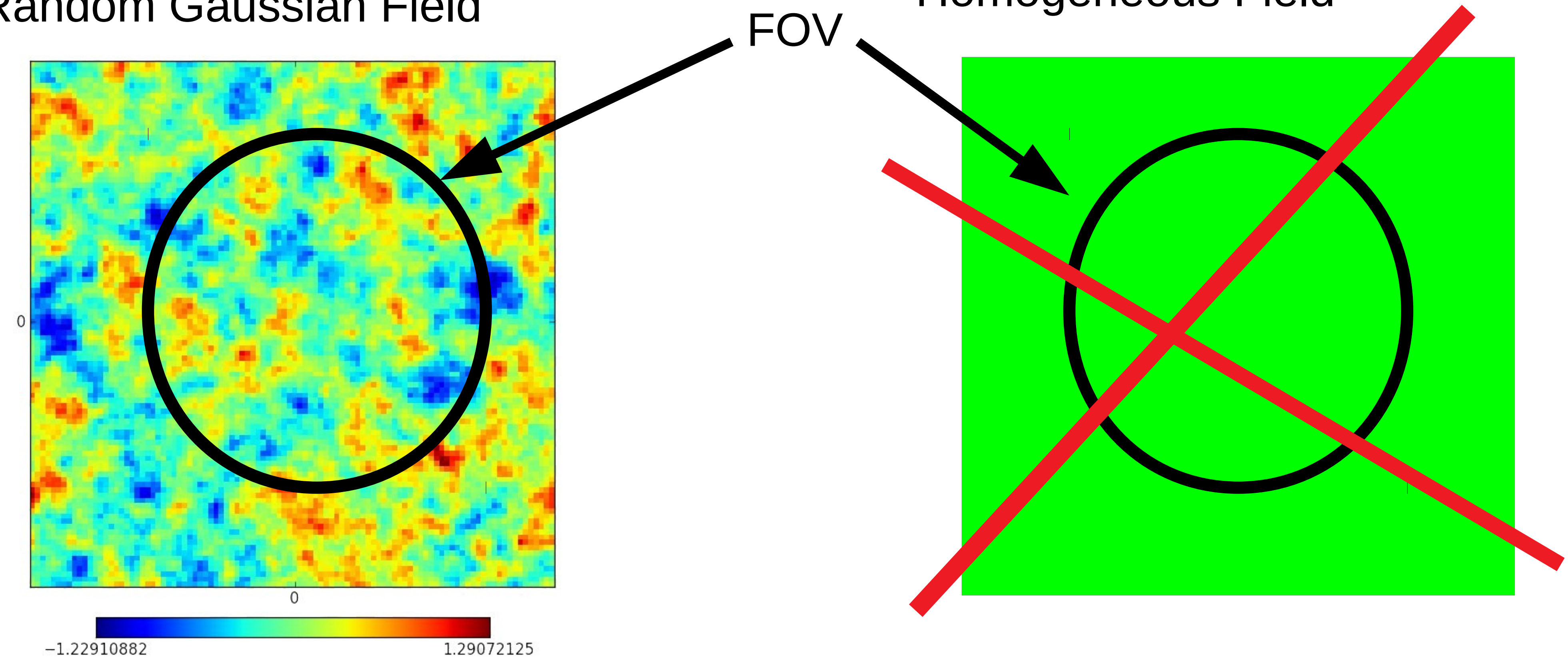
Currently assumed:
Homogeneous Field



Variability of Water Vapour within FOV

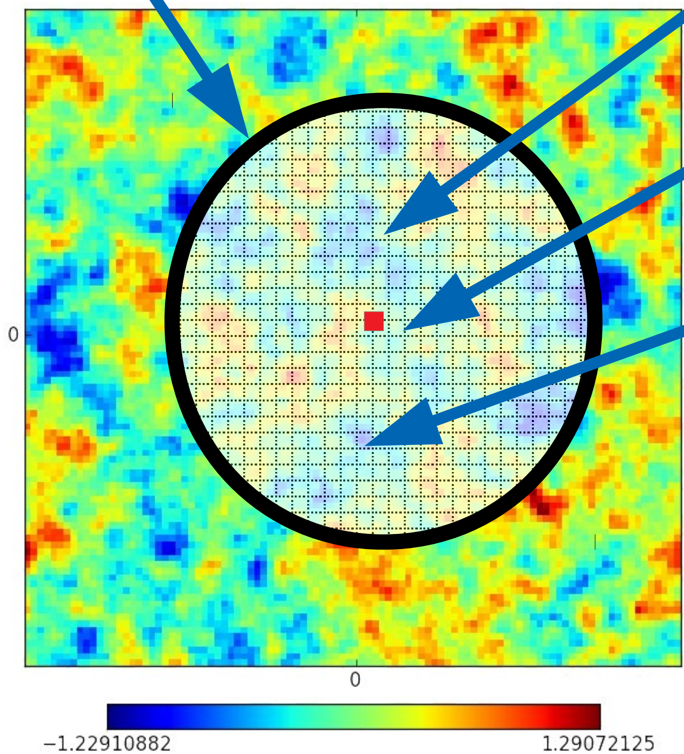
Reality: Scales < 6 km
Random Gaussian Field

Currently assumed:
Homogeneous Field



RTM in an inhomogeneous FOV

FOV



- Subdividing the FOV in small parcels, we can calculate the radiance R using the RTM at each parcel as a function of the WV profile w:
  $R = RTM(w)$

- We now calculate the RTM for a parcel in the center (marked as a red square) which we call w_0 :
  $R_0 = RTM(w_0)$

- For all the other parcels, w_j, we assume a Taylor expansion with respect to R_0 is enough:
  $R_j=R_0+ dR/dw\,(w_j-w_0)+1/2\, d^2R/dw^2(w_j-w_0)^2$

- Changing notation by defining: $\delta R_j = R_j-R_0$ and $\delta w_j=w_j-w_0$ we have:
  $\delta R_j=dR/dw\,\delta w_j+1/2\, d^2R/dw^2\,\delta w_j^2$

- The space sensor will detect the integral, or equivalently, the average of all the radiances. Doing the spatial average, <>, over the j indices, we get:
  $<\delta R>=dR/dw <\delta w>+1/2\, d^2R/dw^2 <\delta w^2>$

- Finally, if we take the effects of all the vertical profile levels, we get the equation from the following slide

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RTM in an inhomogeneous FOV

RTM calculation for an inhomogeneous FOV, where:

- < > means spatial average
- R are radiances
- w is humidity
- i, j are the vertical level indices

$$< \delta R > \approx \sum_{i=1}^{All\ Levs} \frac{dR}{dw_i} < \delta w_i > + \sum_{i=1}^{All\ Levs} \sum_{j=1}^{All\ Levs} \frac{1}{2} \frac{d^2 R}{dw_i dw_j} < \delta w_i \delta w_j >$$

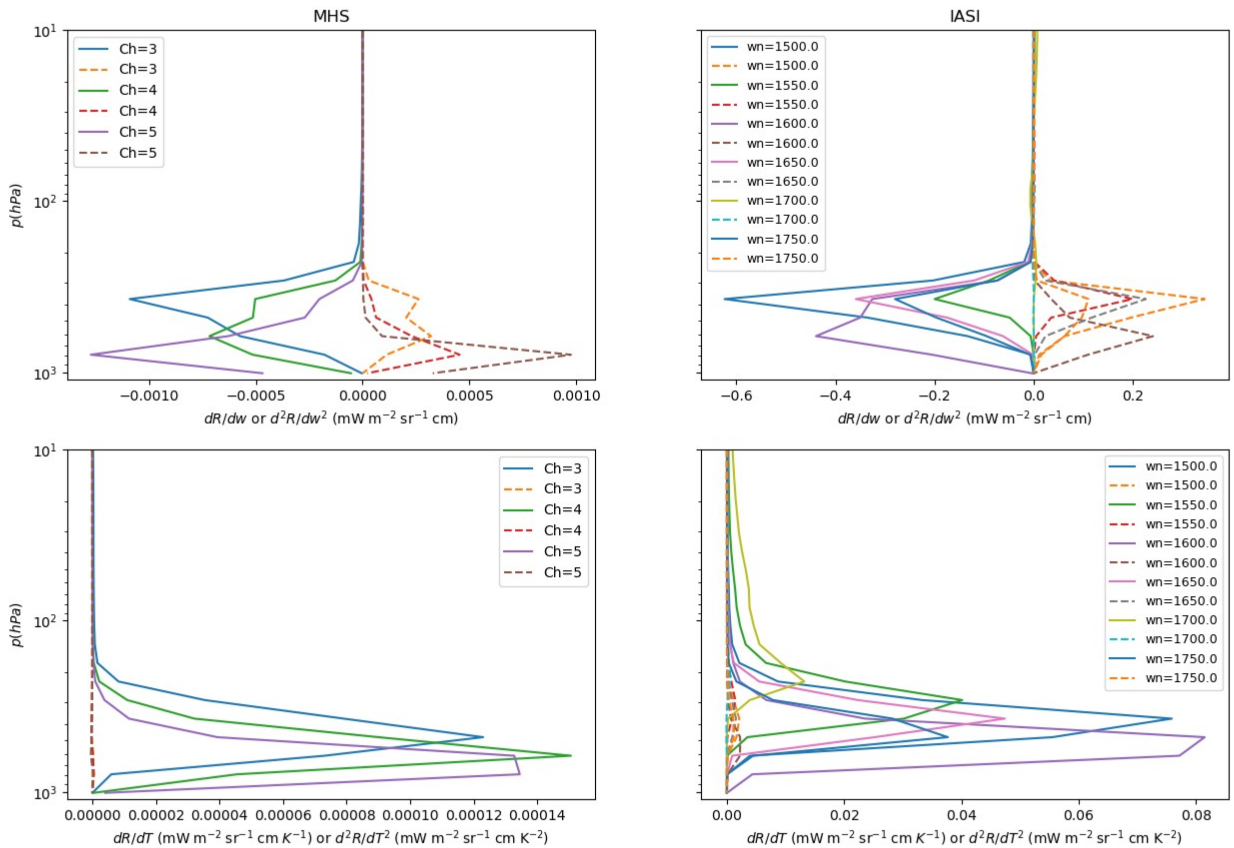
Effect of FOV inhomogeneity

MHS and IASI Jacobians (solid lines) and 2nd Derivatives (dashed lines)

MHS | IASI

WV

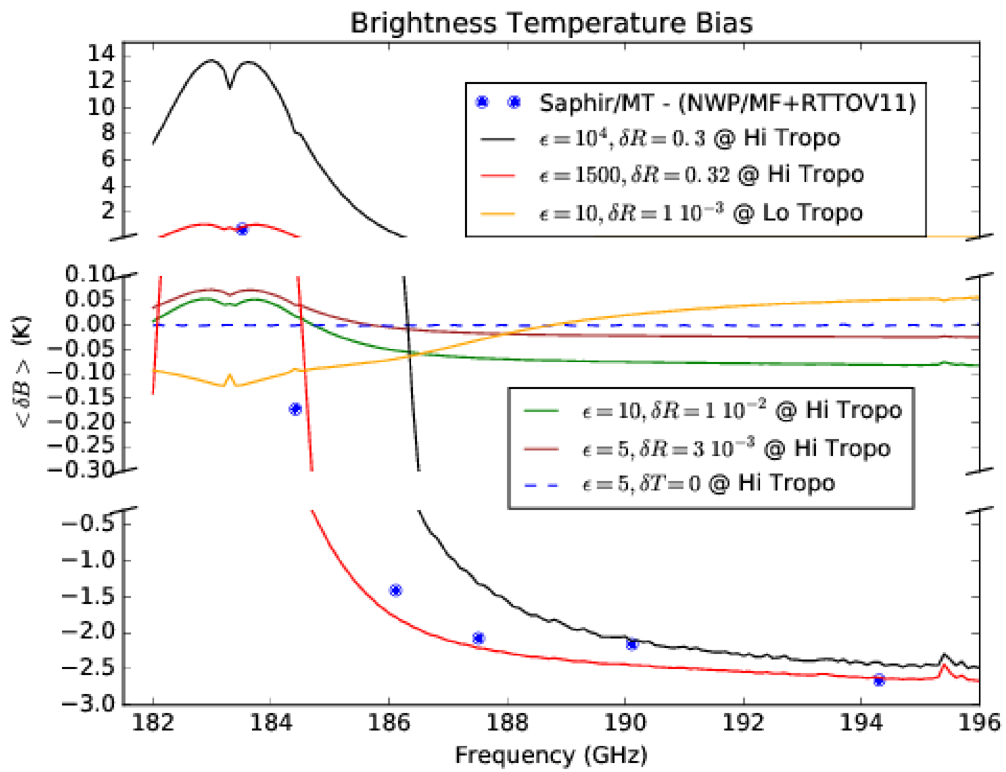
Temperature



Significant 2nd derivatives for WV!!

Effect of FOV inhomogeneity

Tentative results for MW



Calbet et al. 2018, AMT

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How to Test or use Operationally

- We need to have a model for the small scale WV variability → Structure Function
- We need to test it in some cases to see if the WV inhmogeneity is really significant

Ongoing Work and Future Plan

Complementary Instrument	Structure Function	RTM testing
Sequential Sondes	YES	YES
MSG	YES	NO
GOES	Ongoing	NO
OLCI	YES	NO
LIDAR	NO (long term)	NO (long term)

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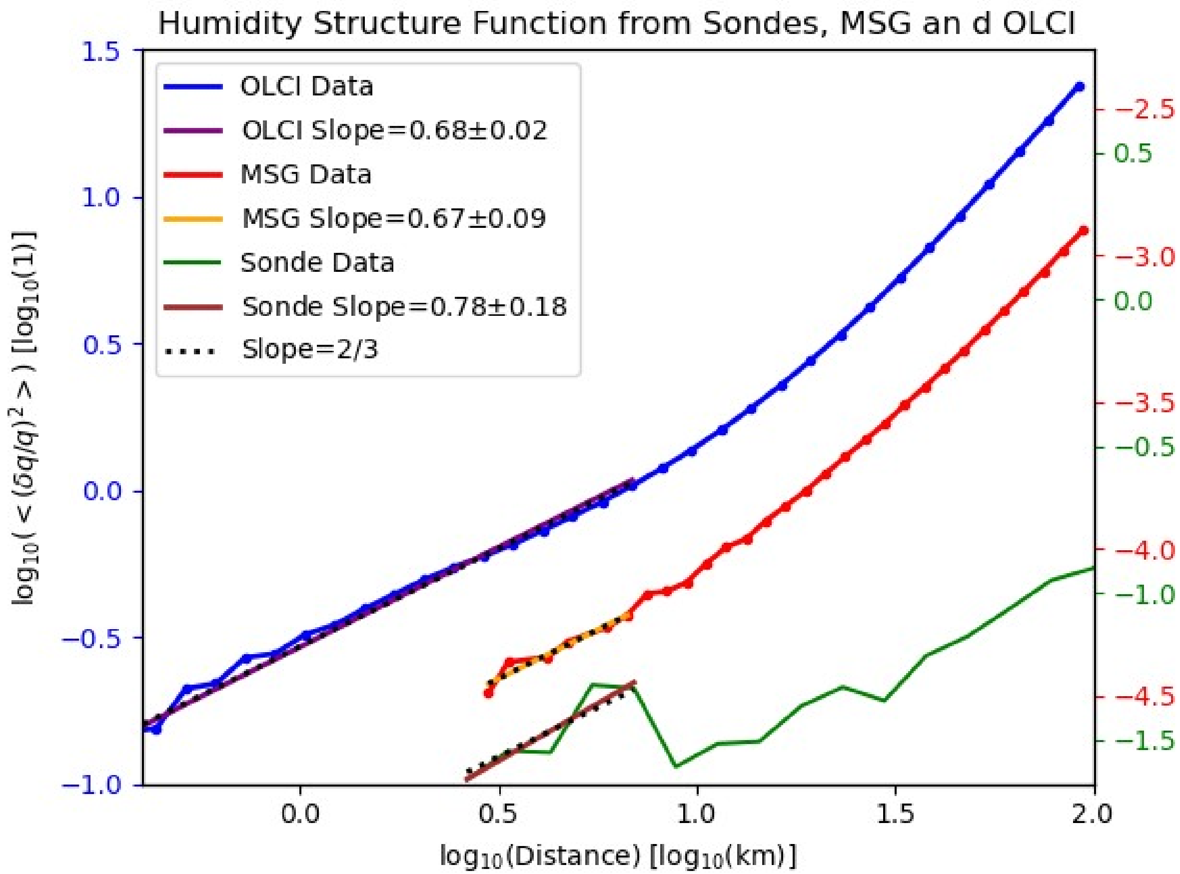
Structure Function of WV from Sondes, MSG and OLCI



Structure function confirmed!!
Useful concept for practical purposes

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Test Case

- One well known case from the EPS/MetOp Campaign (from 2007 described in Calbet et al. 2011, AMT)

- Sequential Sondes with:
  - One CFH + RS92 sonde flown 1 hour before overpass time
  - One RS92 sonde flown 5 minutes before overpass time
- Allowing WV bias correction by comparing CFH versus RS92
- Estimation of the Best State of the Atmosphere (Tobin interpolation)
- In this presentation only IR will be shown. Similar results should be obtained for MW

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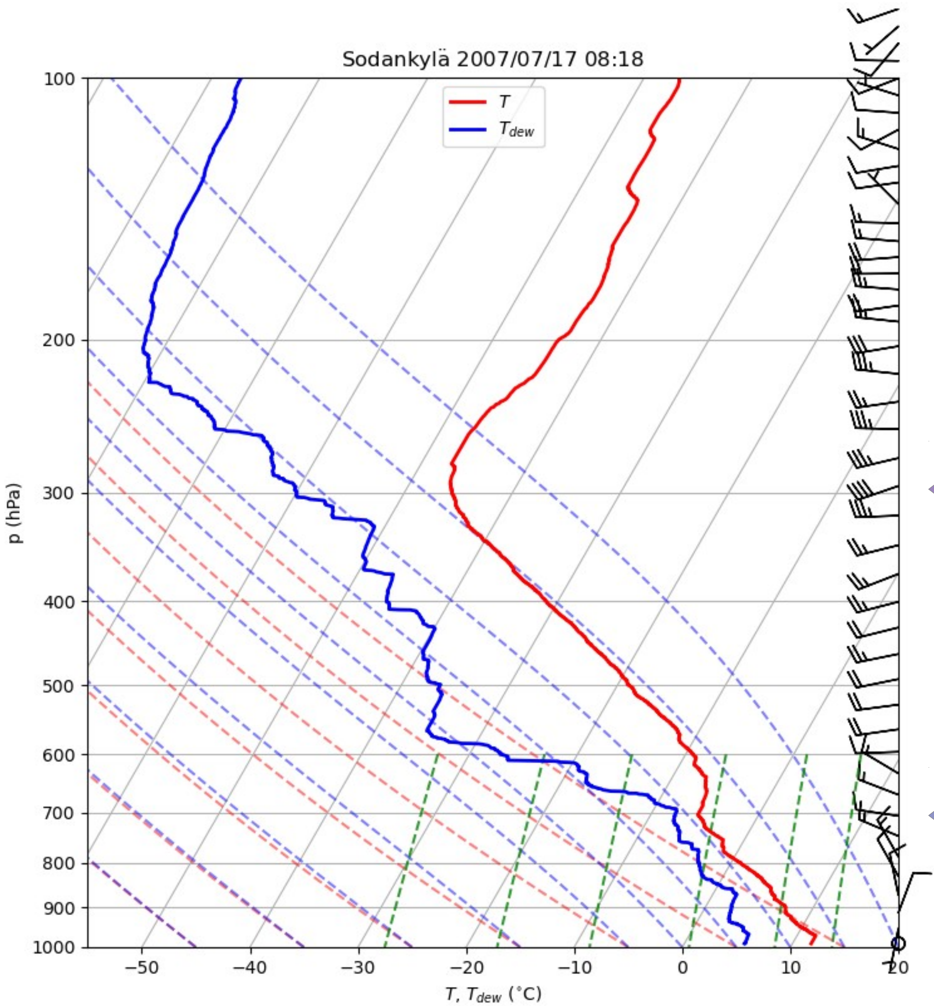
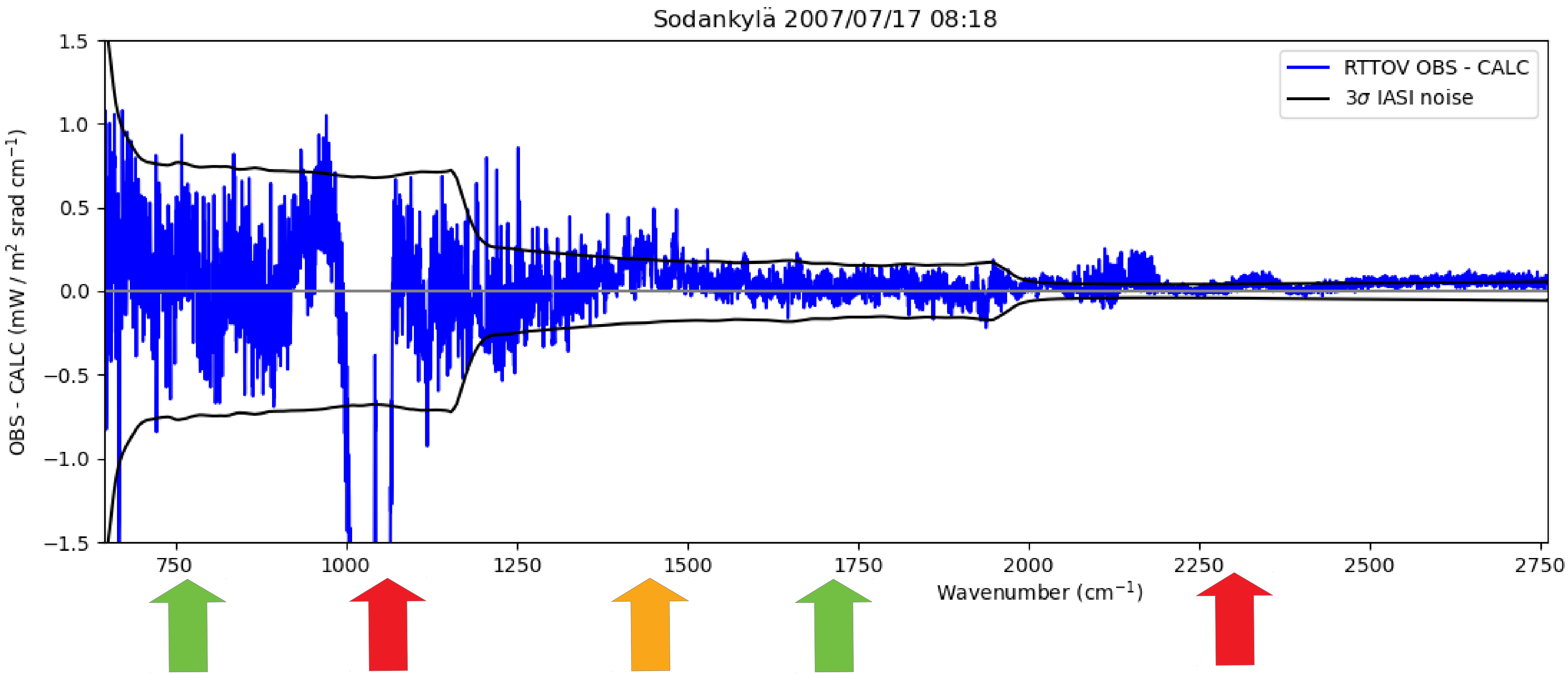
Test Case: Sonde profile



Tropopause

Inversion

RTTOV IASI Radiances from Best State Estimate



Good fit in the CO2 and Window channels

Wrong Ozone profile

Not so good fit in the “low” WV channels

Extremely good fit in the “high” WV channels

Bad fit in the “solar” channels

Calbet 2016, AMT

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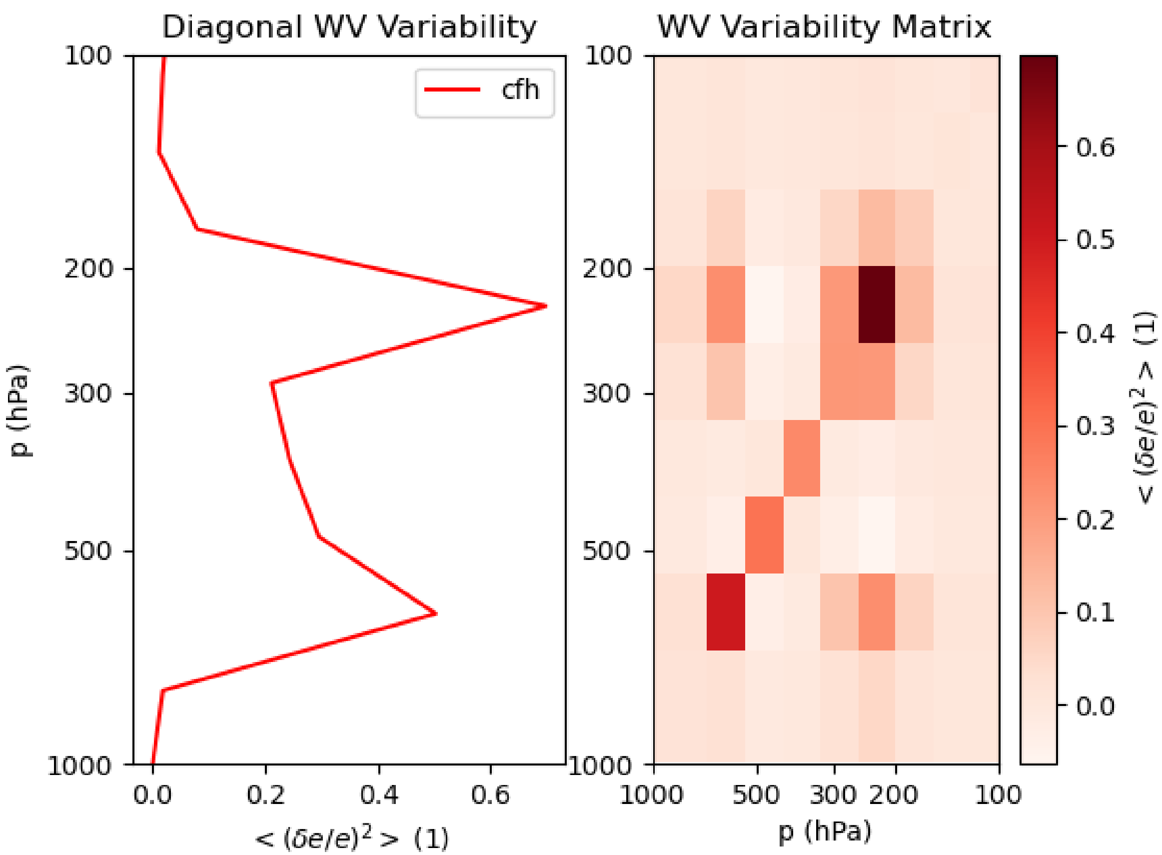
WV Variability Matrix

Measured from Sequential Sonde data ← Not Robust!



Highest variability: tropopause and inversion?

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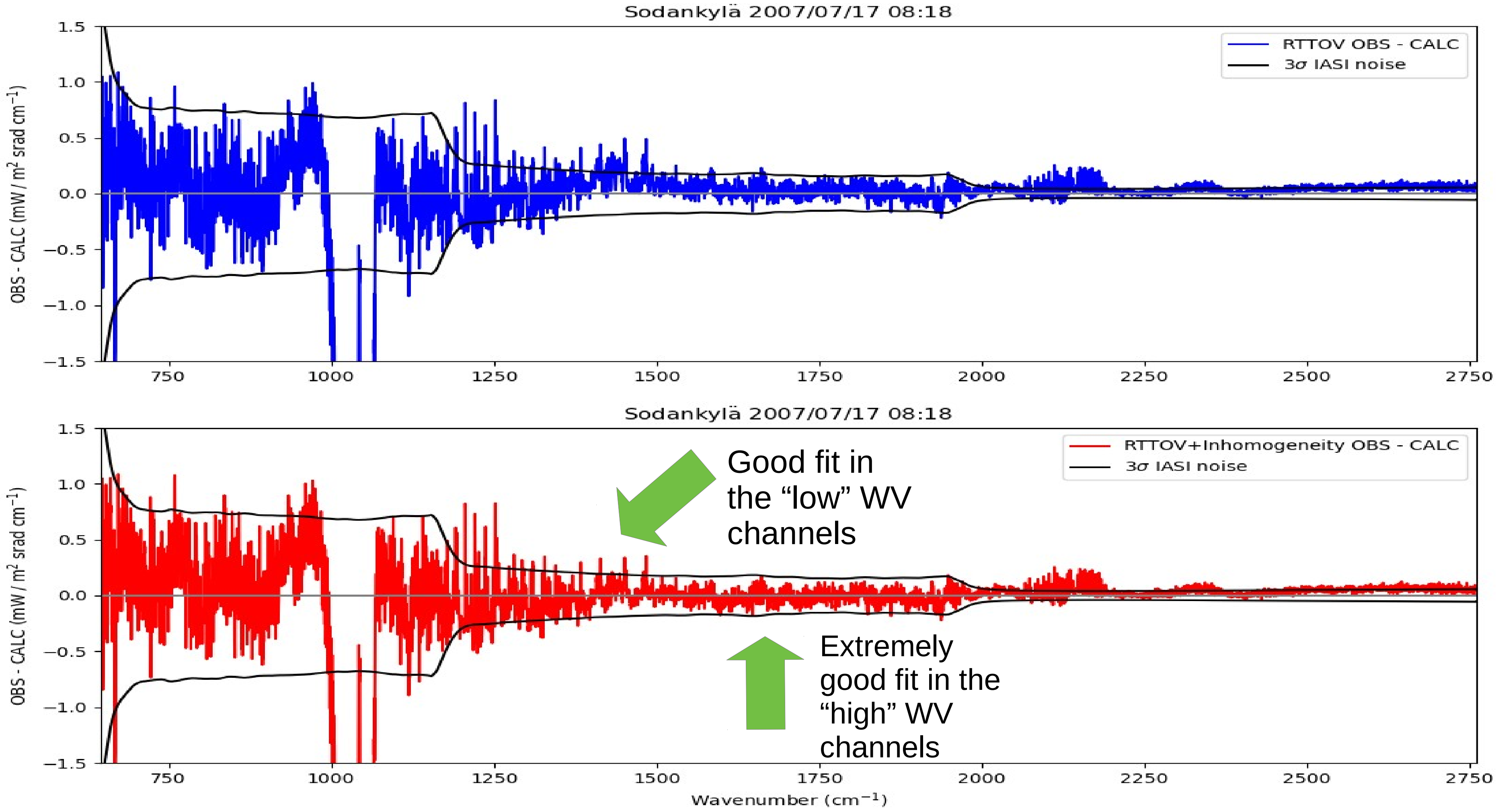
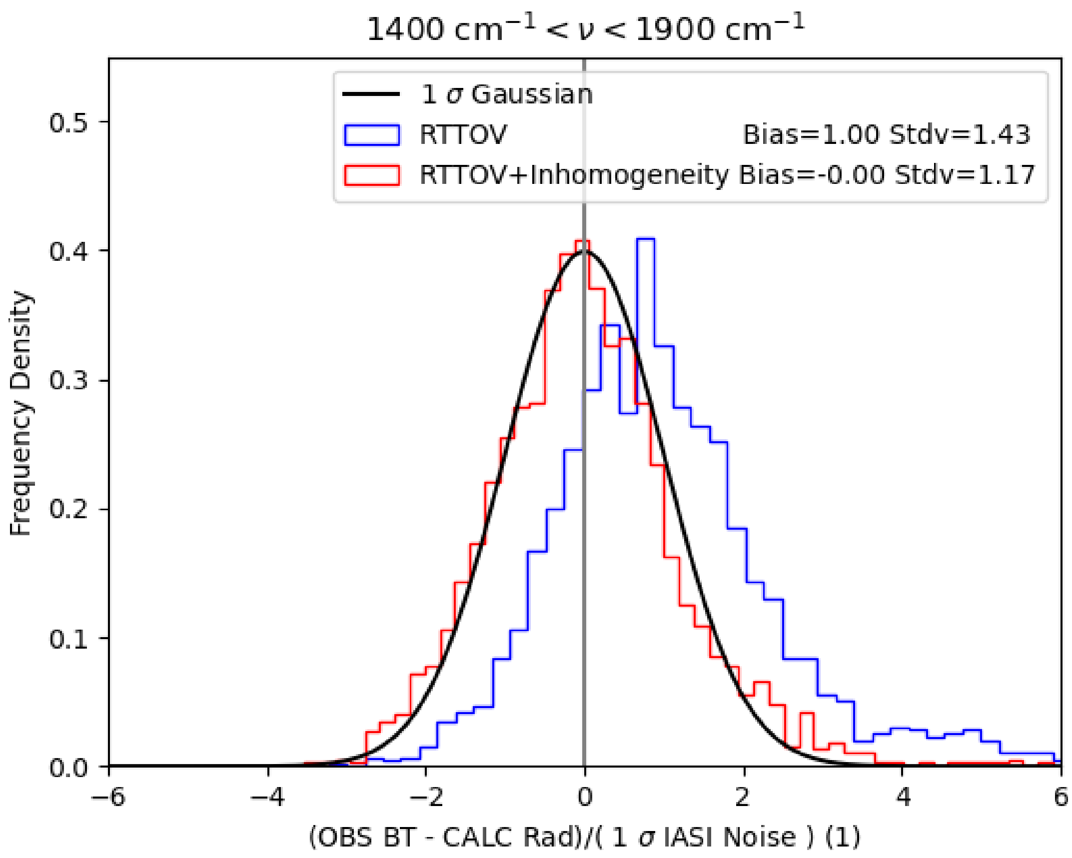
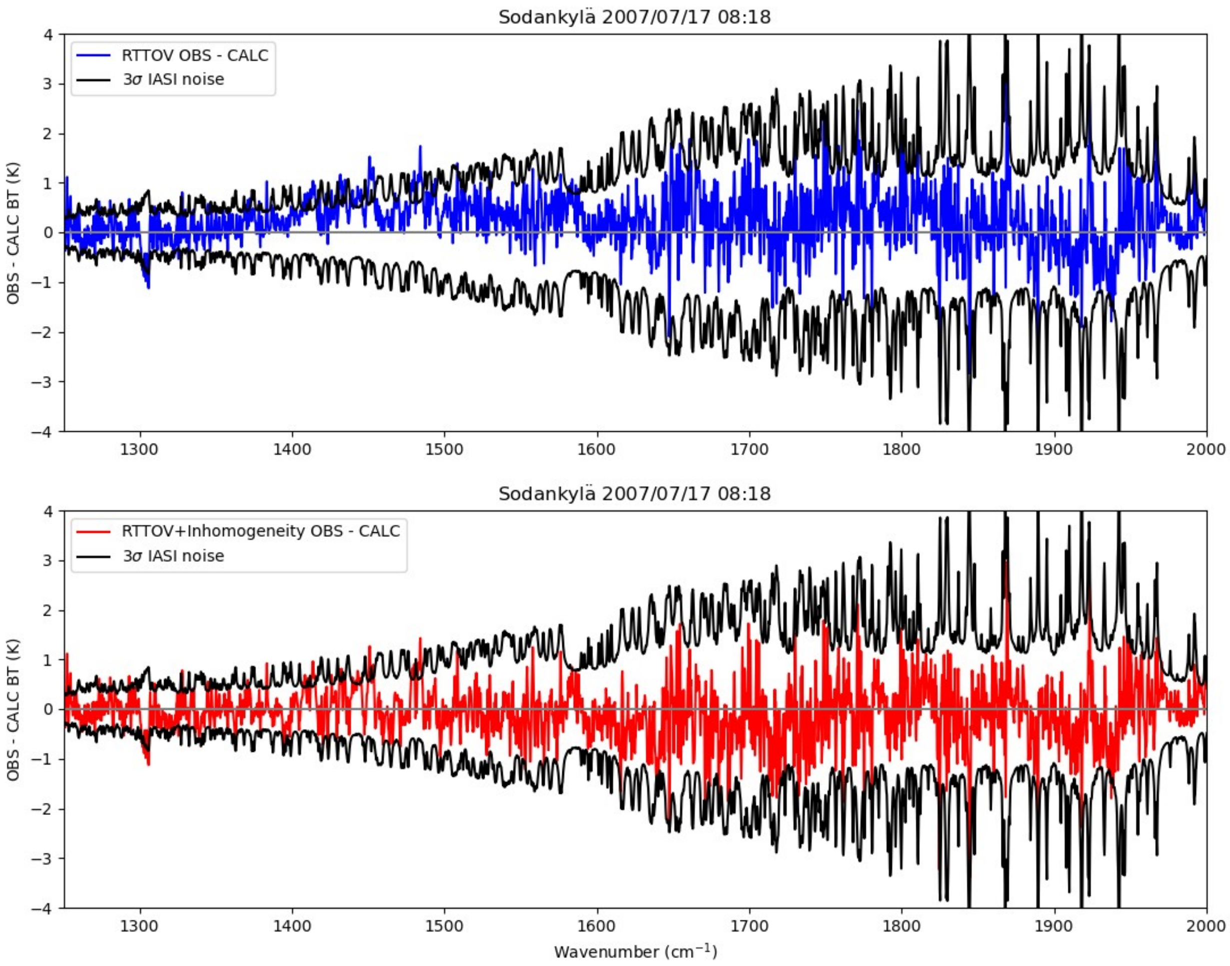
IASI Radiances with and without WV Inhomogeneities



IASI Radiances with and without WV Inhomogeneities



IASI Radiances with and without WV Inhomogeneities



Comparison in Brightness Temperature Space → Improvement of around 0.5K

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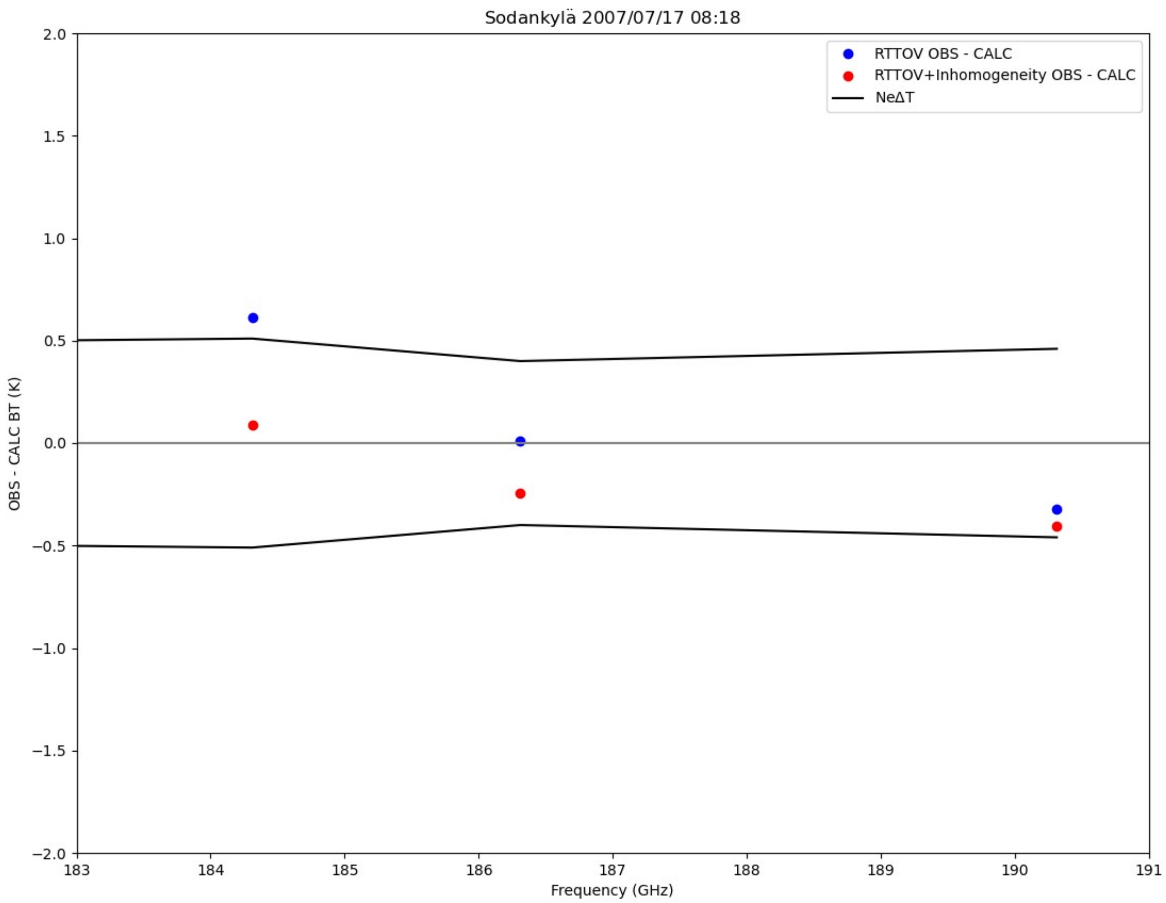
MHS Radiances with and without WV Inhomogeneities



Comparison in Brightness Temperature Space → Improvement of around 0.5K

Summary

Outlook

- Inhomogeneity is significant: Relatively stable profile has an 0.5K effect in radiances (IASI and MHS) → Other more turbulent profiles might have a higher effect

- Retrievals: Direct retrievals with IR only will be challenging. See likely underestimation in extra slides

- Extensive testing: This will most likely need a multi-team coordinated effort
  - Can be tested with other, larger sonde data
  - To test and operationally use this on a global scale, satellite data needs to be used → Other satellite instruments need to be exploited to retrieve inhomogeneity

- Microturbulence: Only “macroturbulence” has been tested, possible “microturbulence” effect affecting line shapes

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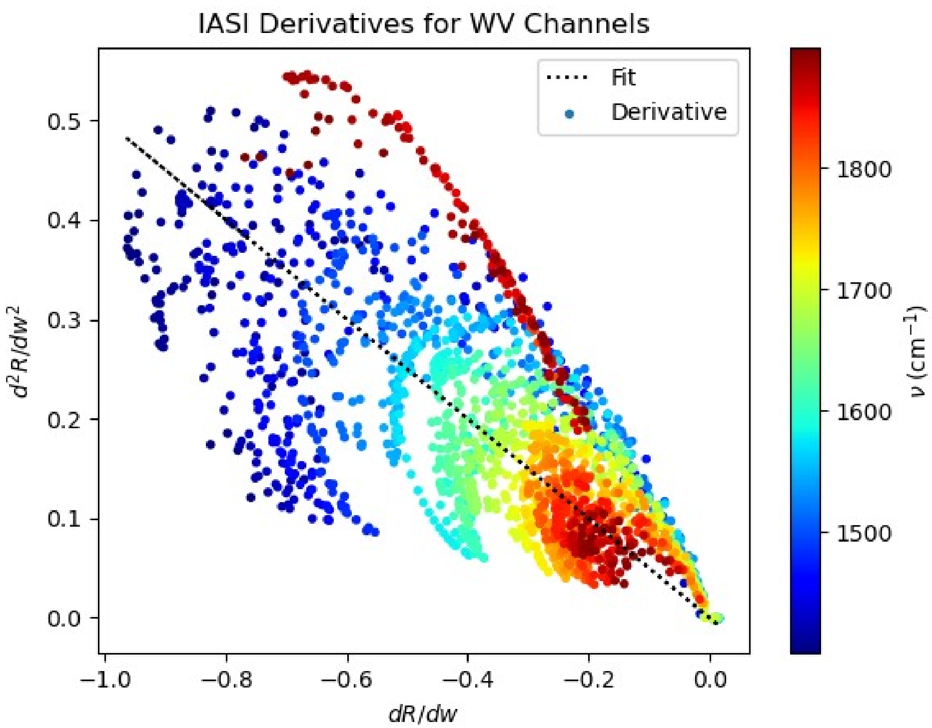
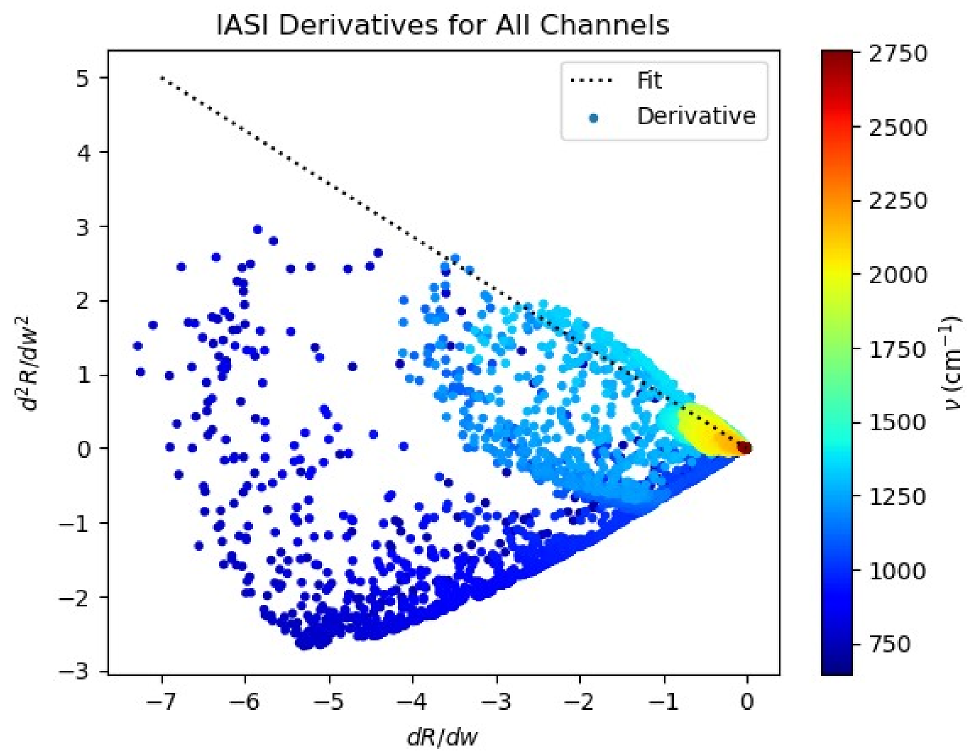
Extra Slide: dR/dw versus d^2R/dw^2

In the WV band, dR/dw is almost linear with d^2R/dw^2 →
Difficult to retrieve both WV profile and WV inhomogeneity





dB/dR ~ -0.5 d^2R/dw^2
Turbulence can be mistaken with
WV concentration!!

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IASI separating inhmogeneity from WV content

- Retrievals without turbulence, <dw’>:

  $<dR> = dR/dw <dw'>$
- Retrievals with turbulence, <dw>:

  $<dR> = dR/dw <dw> + ½ d^2R/dw^2<dw^2> \sim$

  $dR/dw <dw> - 1/2*0.5 dR/dw <dw^2> =$

  $dR/dw \{ <dw> - 0.25*<dw^2> \}$
- Equating both results:

  $<dw> \sim <dw'> + 0.25*<dw^2>$ → <dw> greater than <dw’>

WV concentration is perhaps underestimated!!

Consistent with Carbajal-Henken, 2020, Remote Sensing

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