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AEMet Agencia Estatal de Meteorología

Small Scale Variability of Water Vapour in the Atmosphere

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19 November 2021
GRUAN ICM-13

Summary

1. Evidence of small scale WV behaving as a Random Gaussian Field (RGF)

2. Effects in the Radiative Transfer Modelling

3. Test Case

4. Permanent biases in WV IR Remote Sensing WV measurements?

5. Consequences

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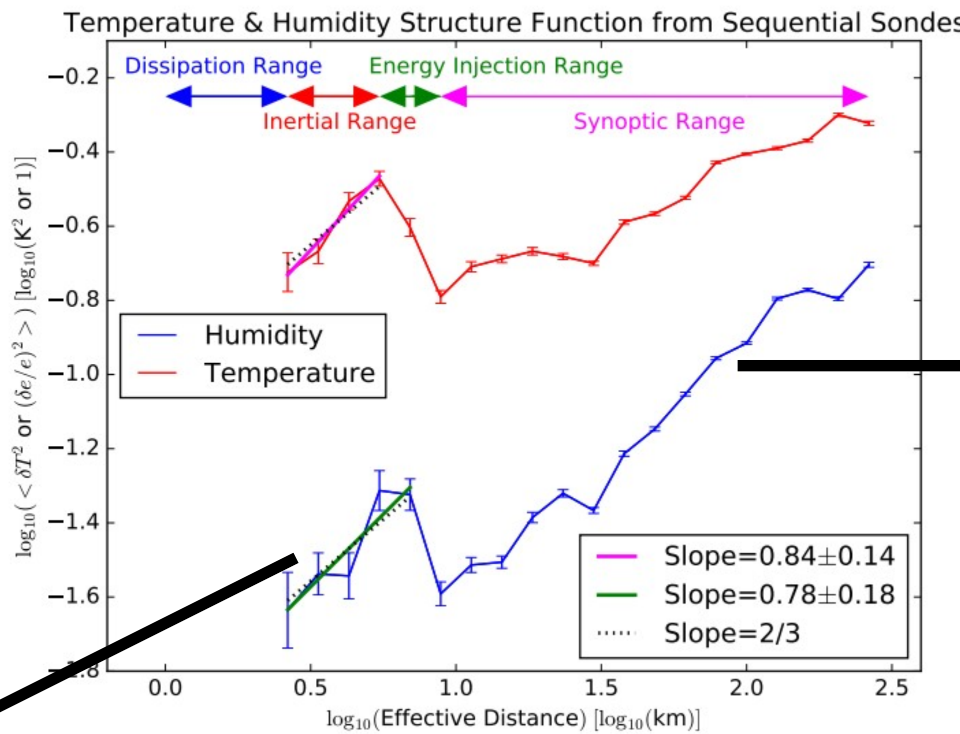
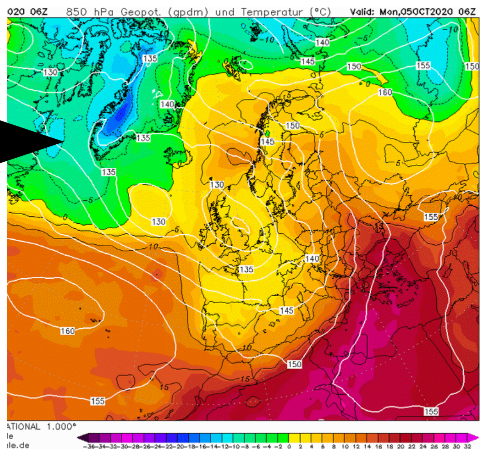
Variability of Water Vapour

Two different scales

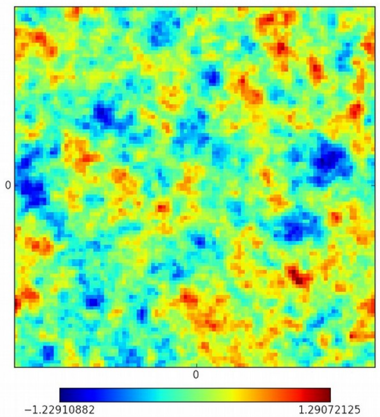


Calbet et al. 2018, AMT

Scales > 10km
Smooth Field



Scales < 6 km
Random
Gaussian Field



Simulation

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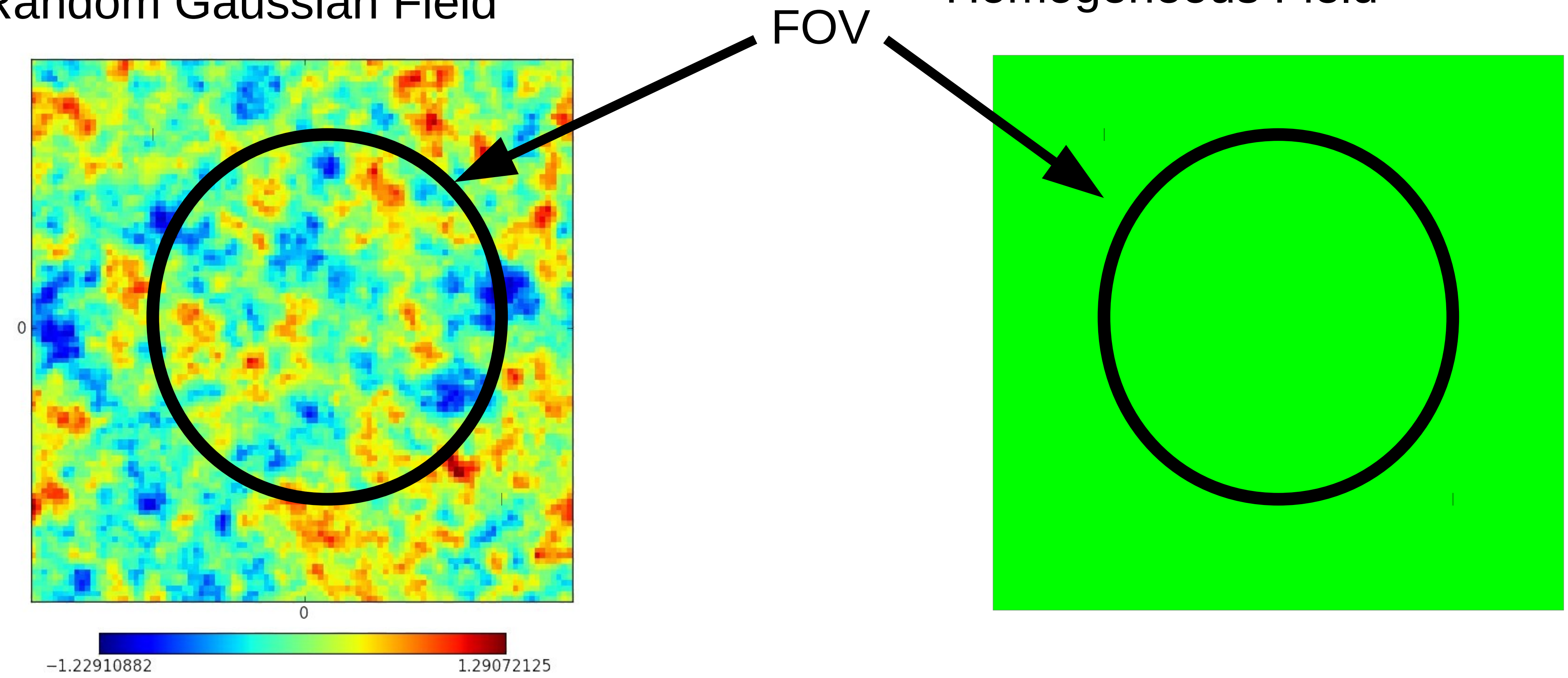
Variability of Water Vapour within FOV

Reality: Scales < 6 km
Random Gaussian Field

Currently assumed:
Homogeneous Field



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Variability of Water Vapour within FOV

Reality: Scales < 6 km
Random Gaussian Field

FOV

Currently assumed:
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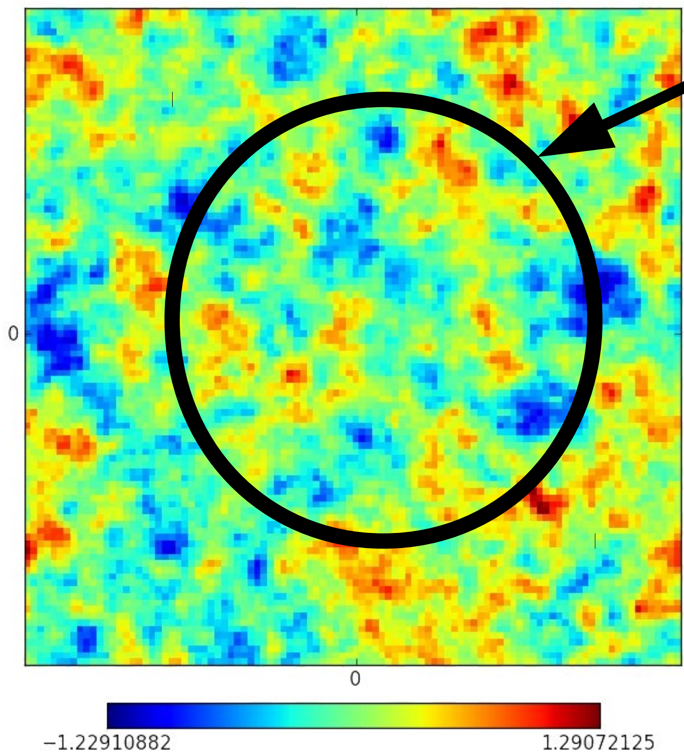
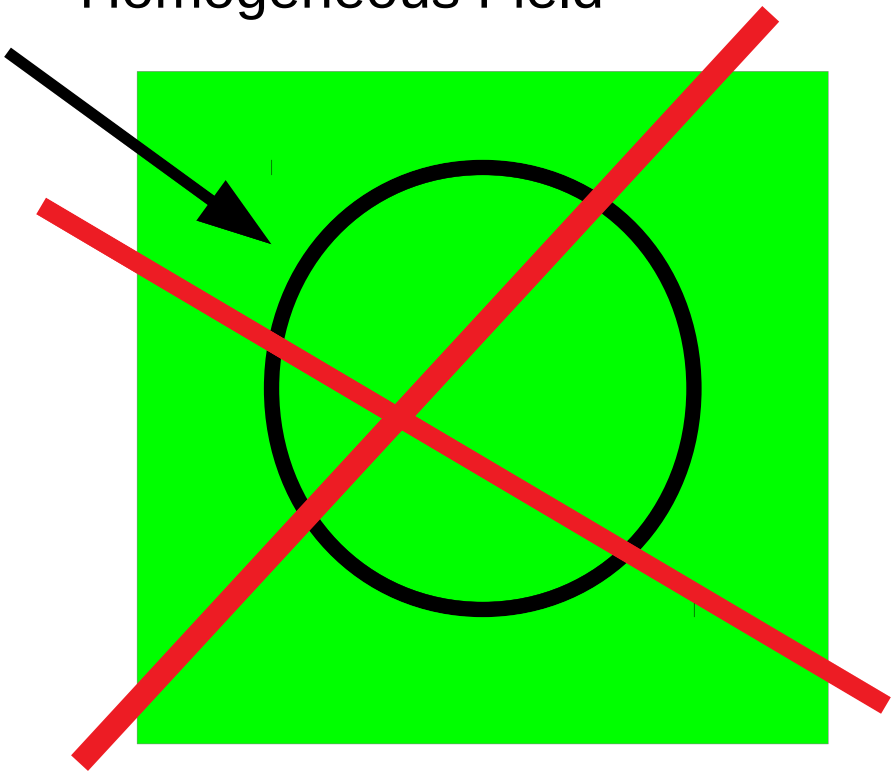
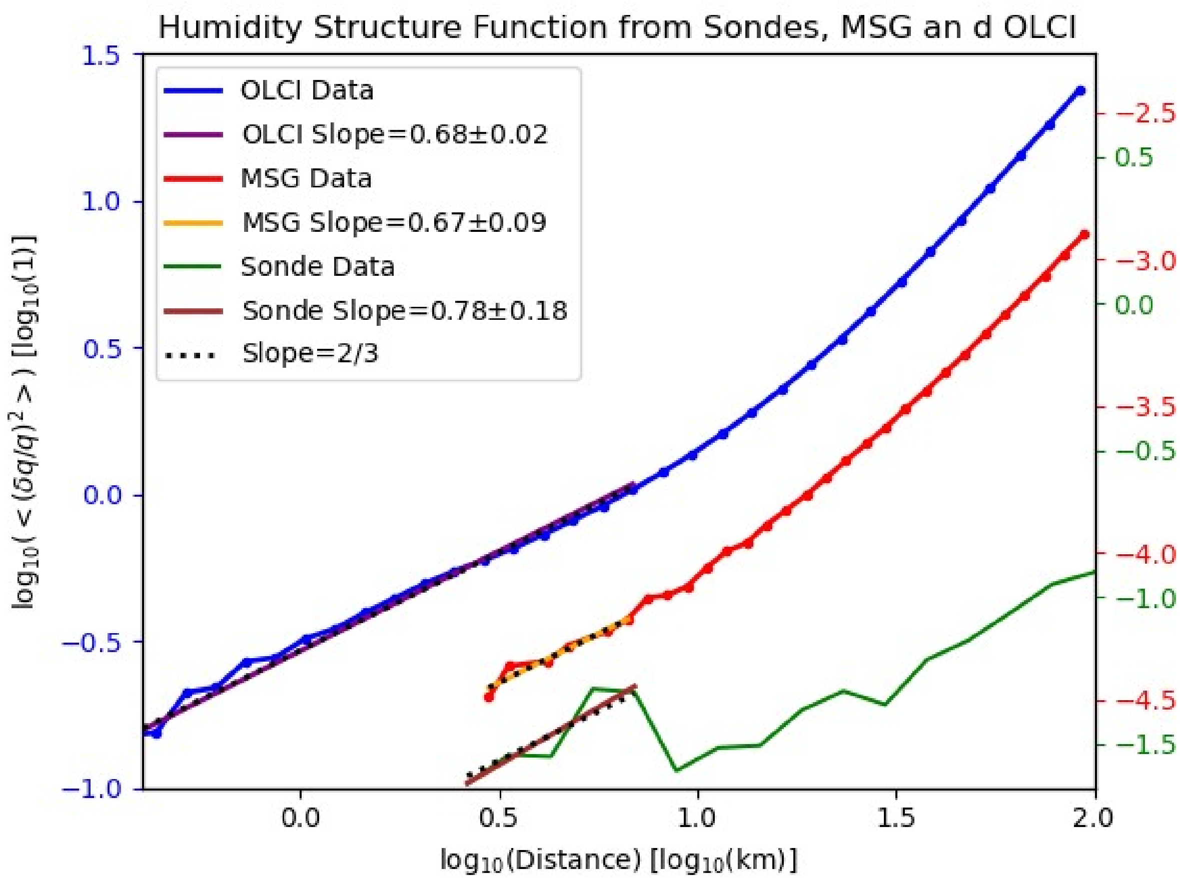




Evidence for WV Random Gaussian Fields at small scales: Structure Function of WV from Sondes, MSG and OLCI

Structure function confirmed!! →
RGF
useful concept for practical purposes



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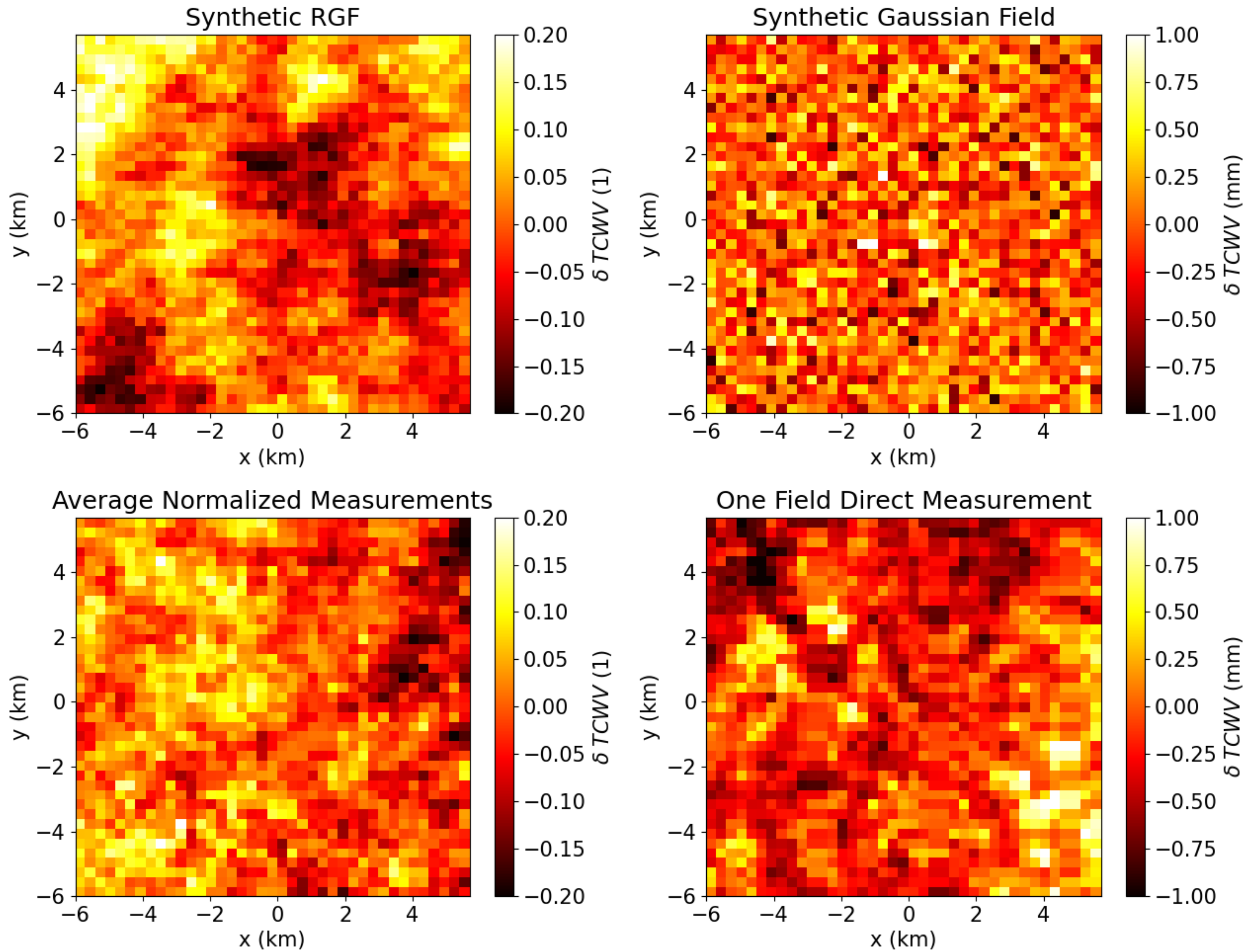
Evidence for WV Random Gaussian Fields at small scales: Small scale WV fields from OLCI

Small scale WV fields do have the texture of RGF



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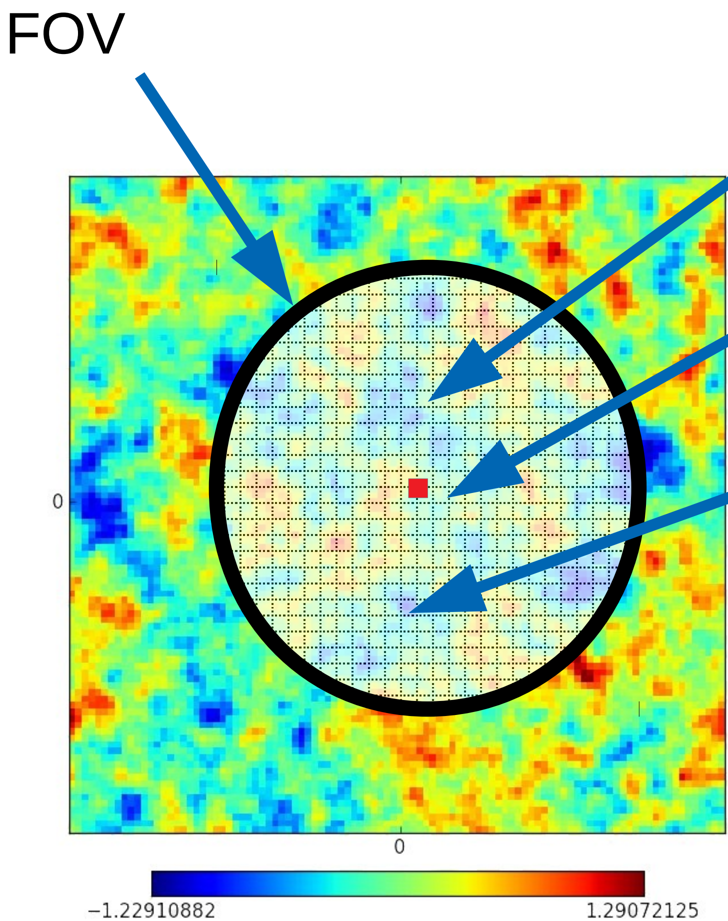
RTM in an inhomogeneous FOV



- 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

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

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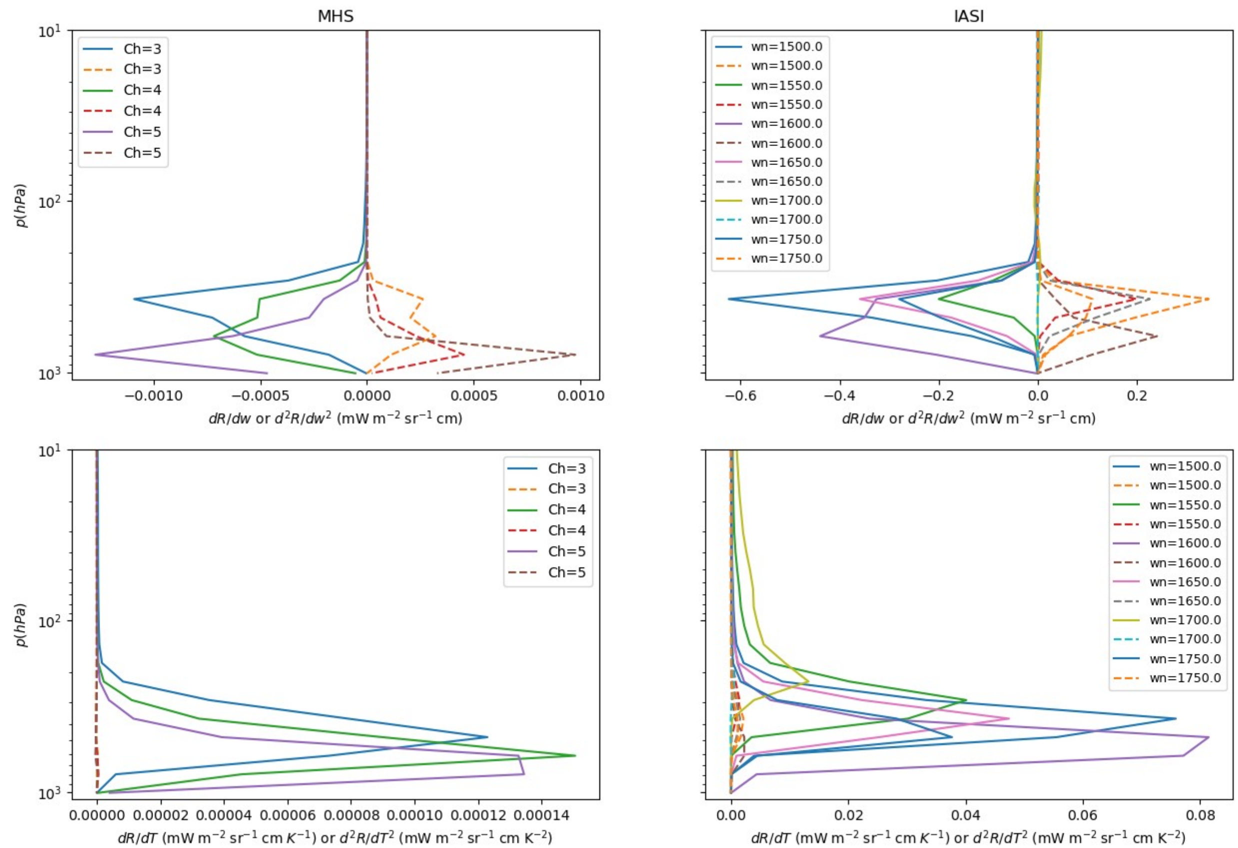
Effect of FOV inhomogeneity

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

MHS IASI

WV

Temperature



Significant 2nd derivatives for WV!!

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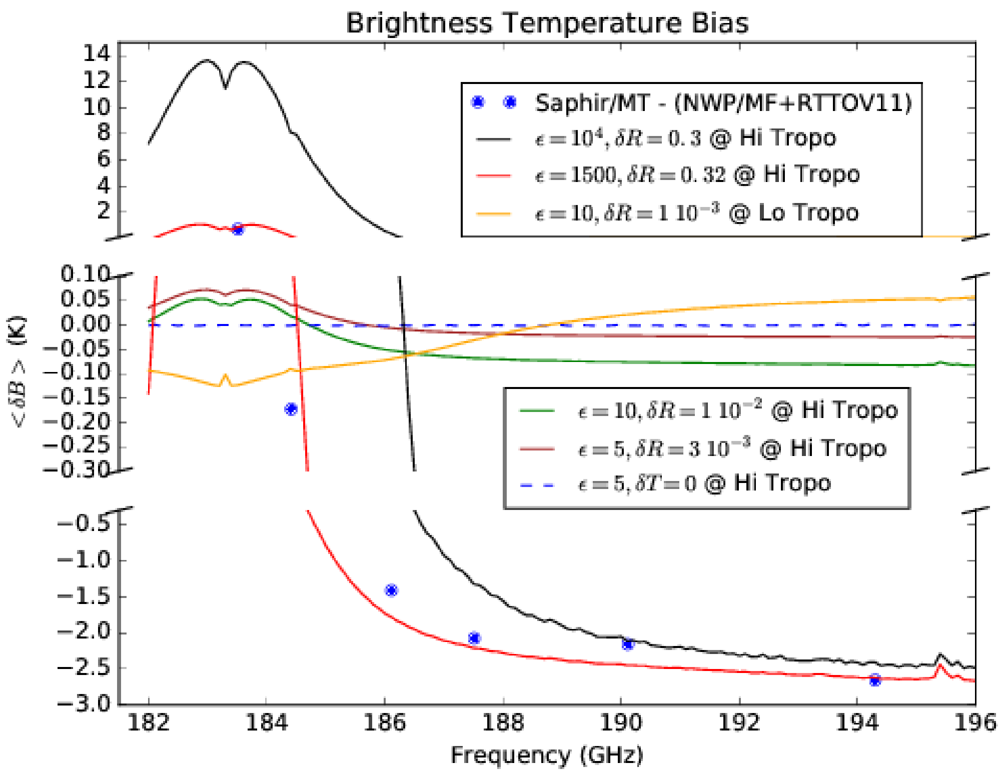
Effect of FOV inhomogeneity

Tentative results for MW



Calbet et al. 2018, AMT

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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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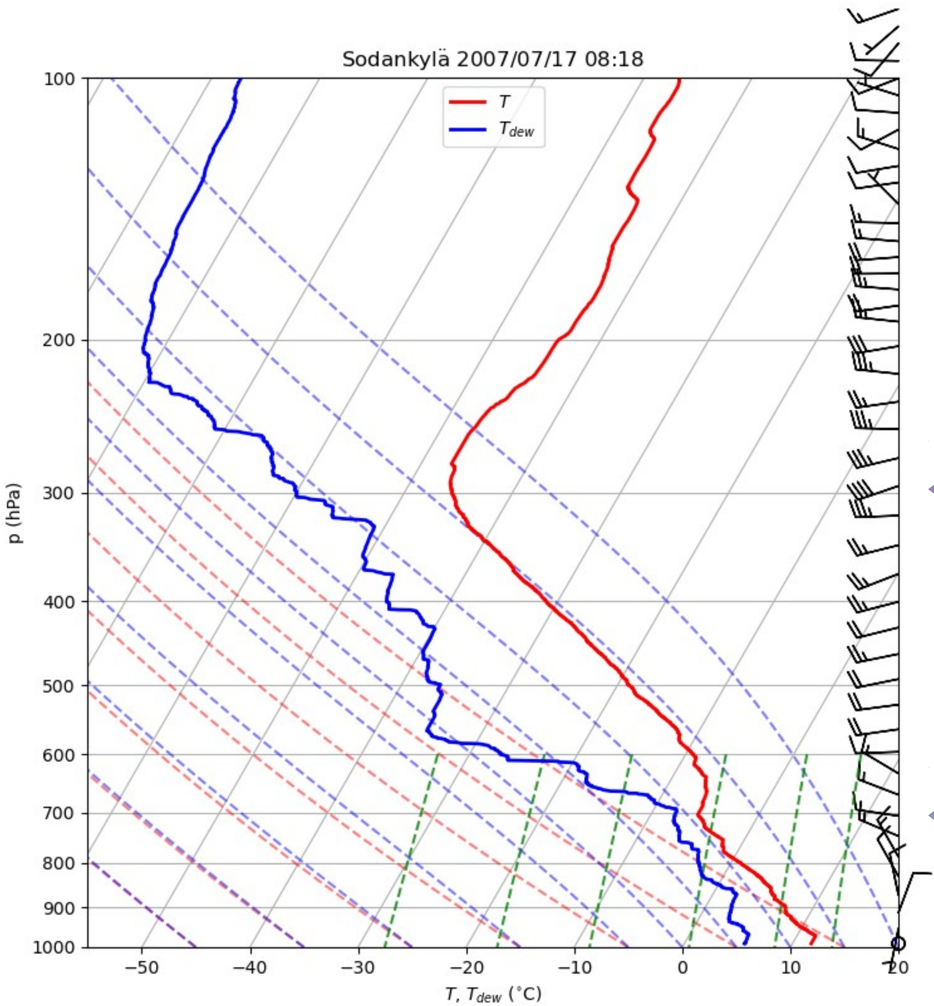
Test Case: Sonde profile



Tropopause

Inversion

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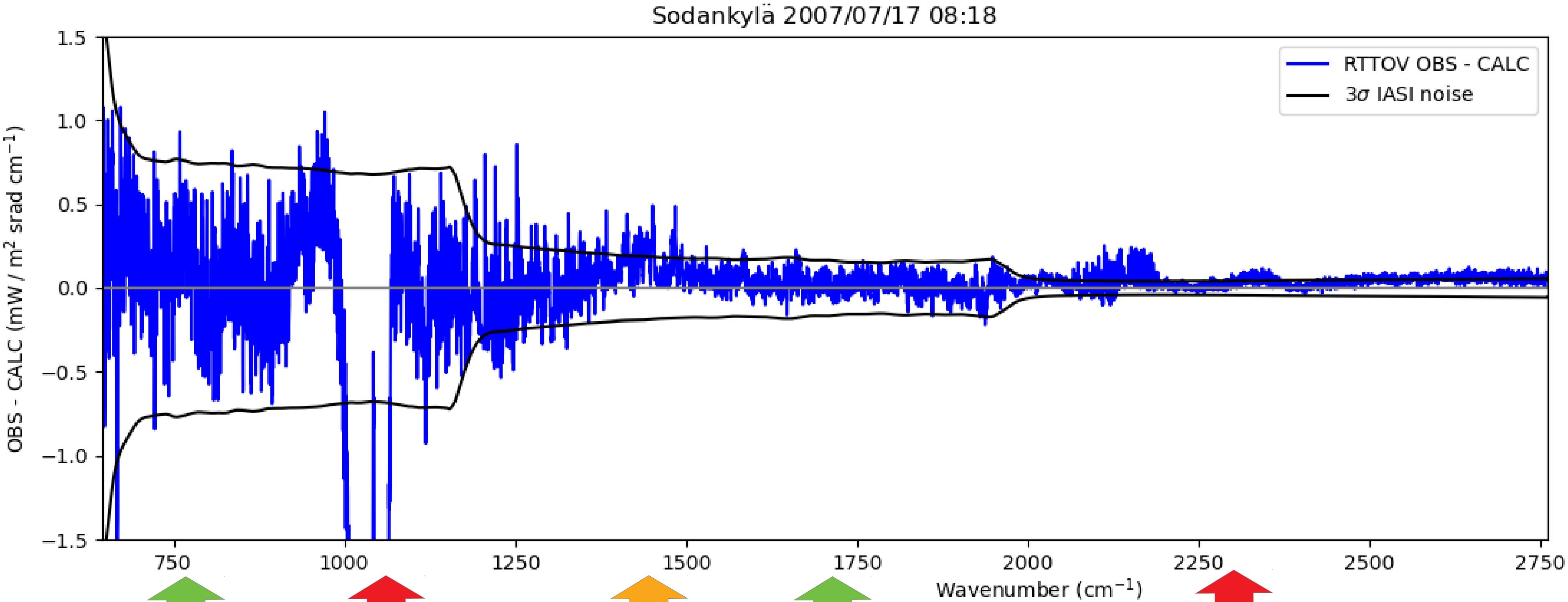
RTTOV IASI Radiances from Best State Estimate



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 et al. 2016, AMT; Sun et al. 2021, Remote Sensing

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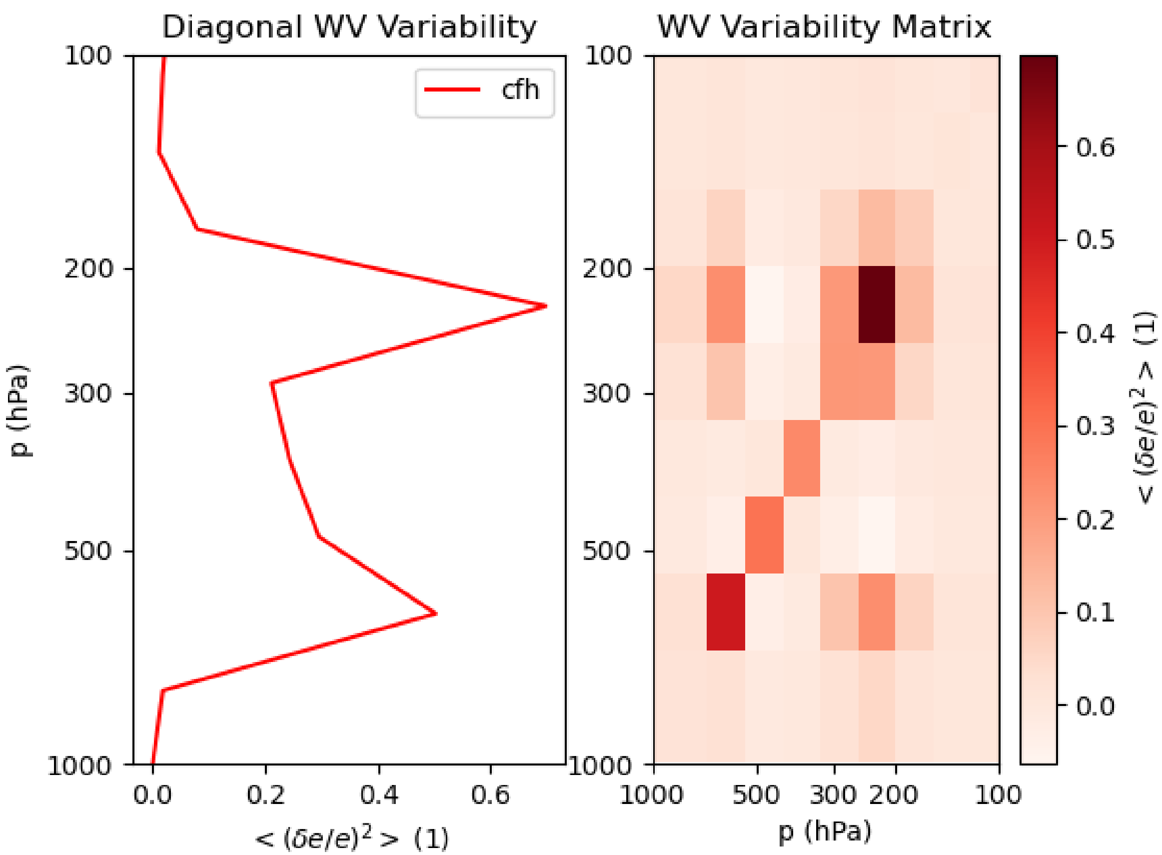
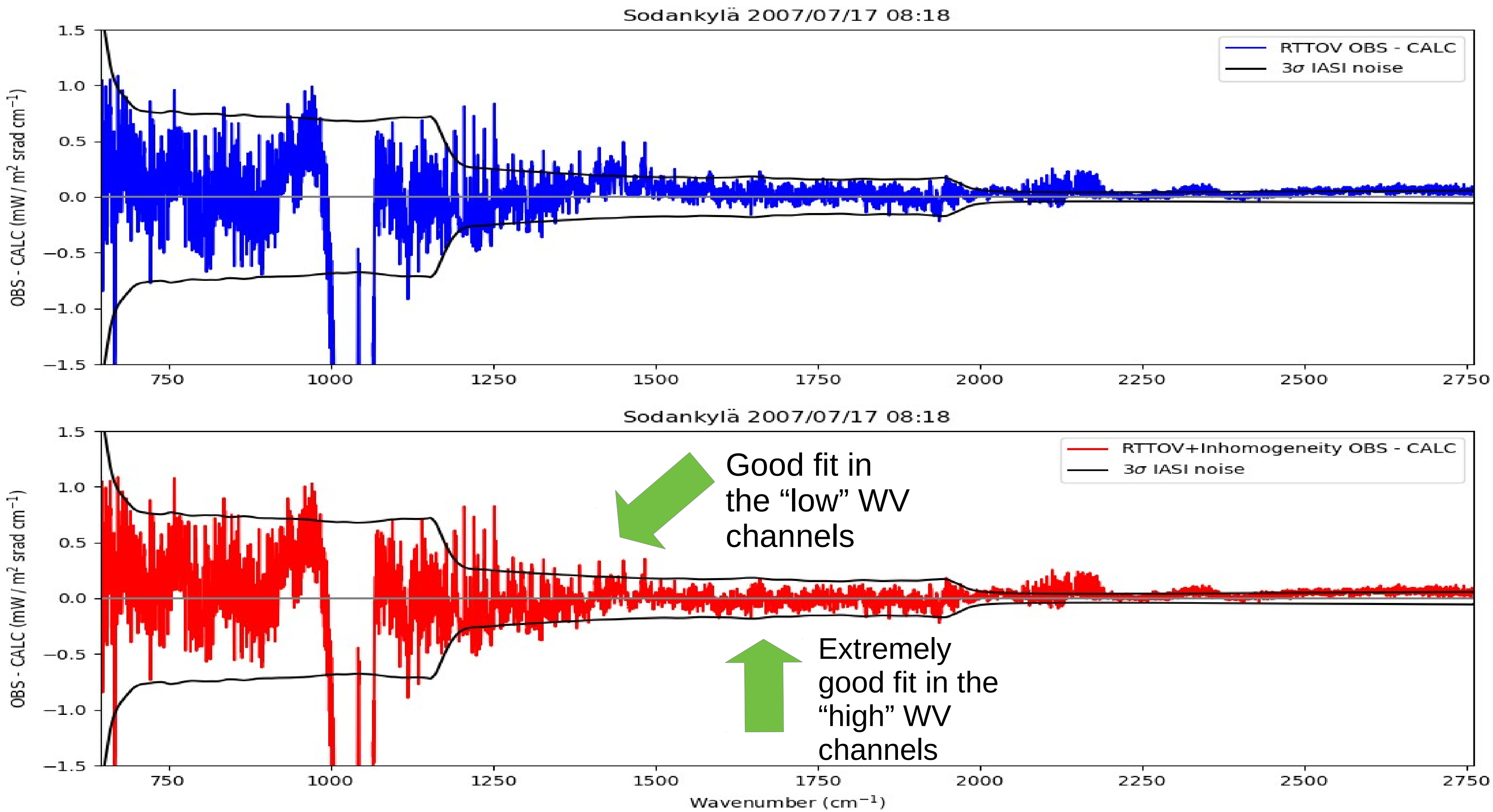
WV Variability Matrix

Measured from Sequential Sonde data ← Not Robust!

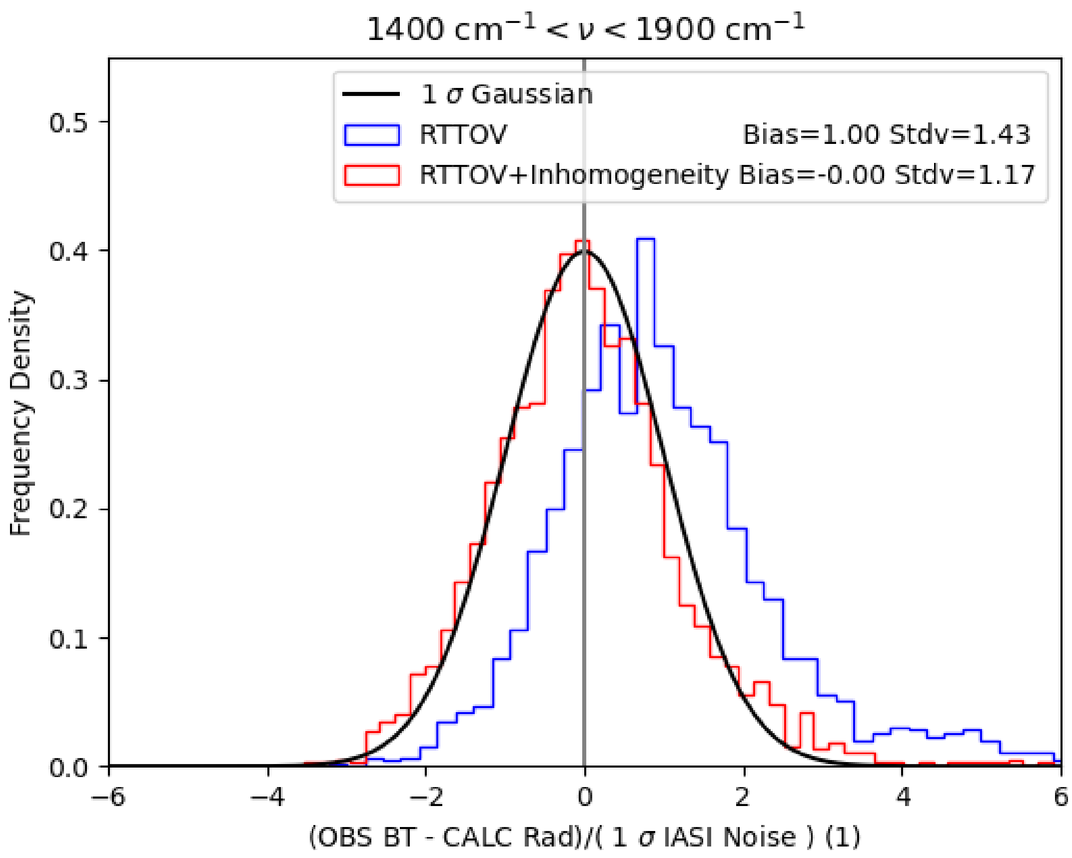


Highest variability: tropopause and inversion?

IASI Radiances with and without WV Inhomogeneities



IASI Radiances with and without WV Inhomogeneities



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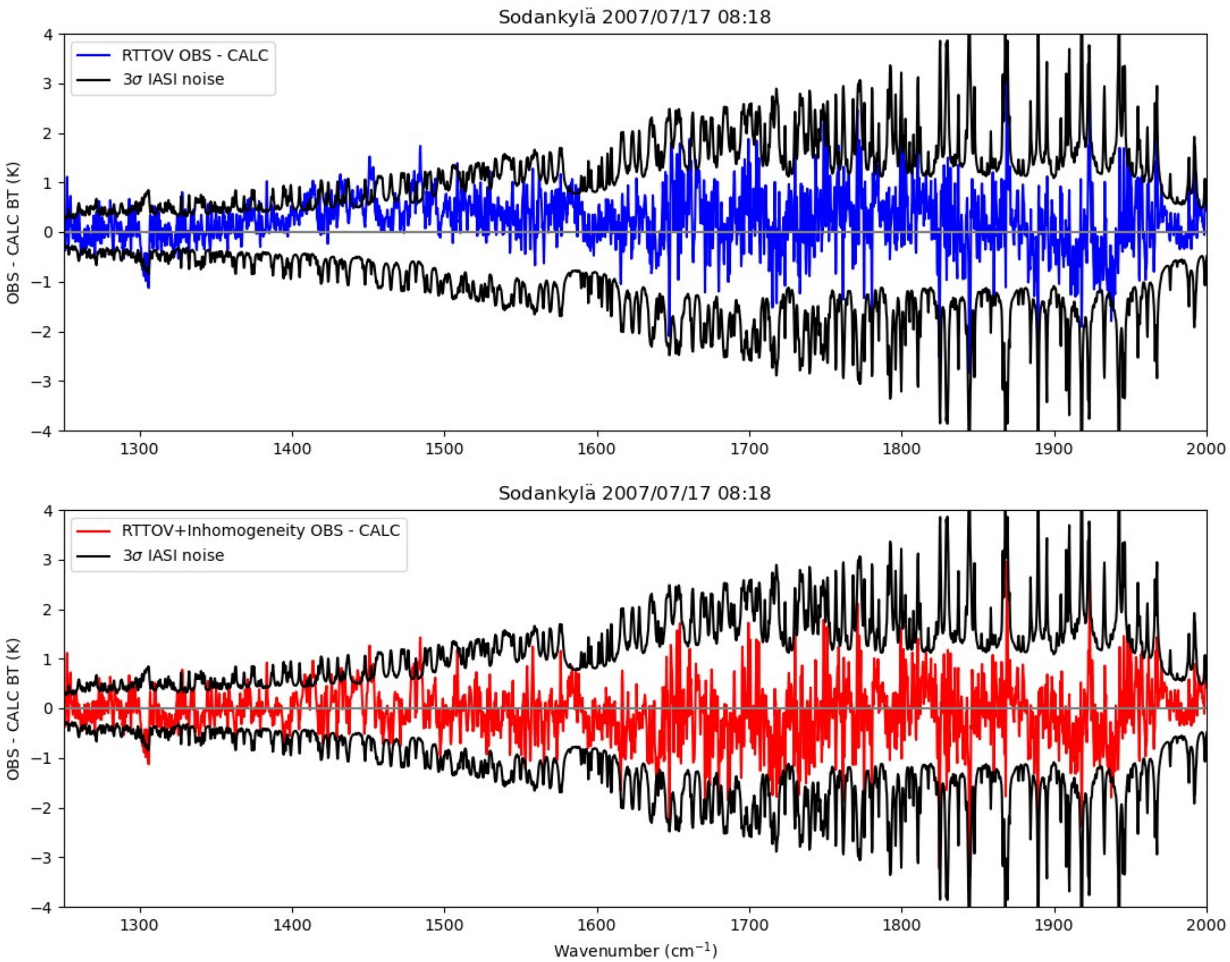
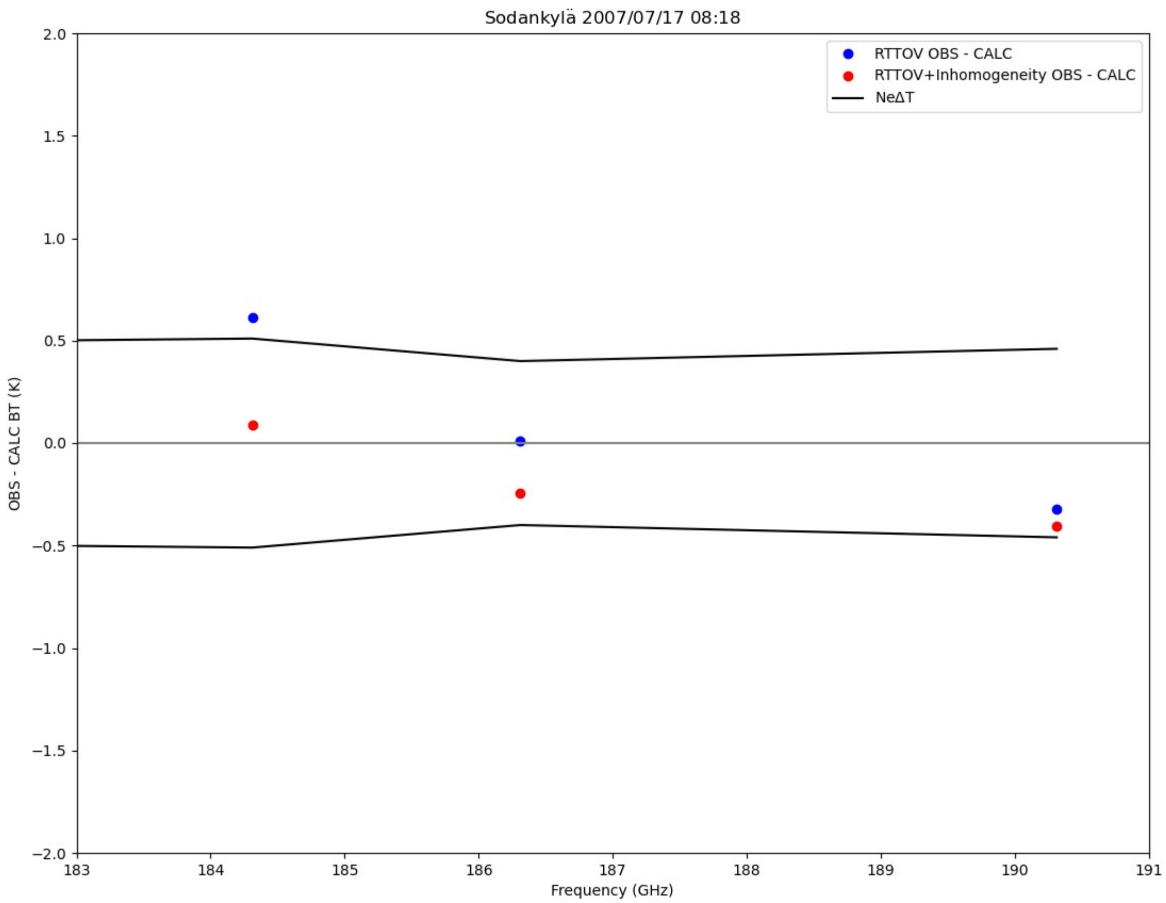


Comparison in Brightness Temperature Space → Improvement of around 0.5K

MHS Radiances with and without WV Inhomogeneities



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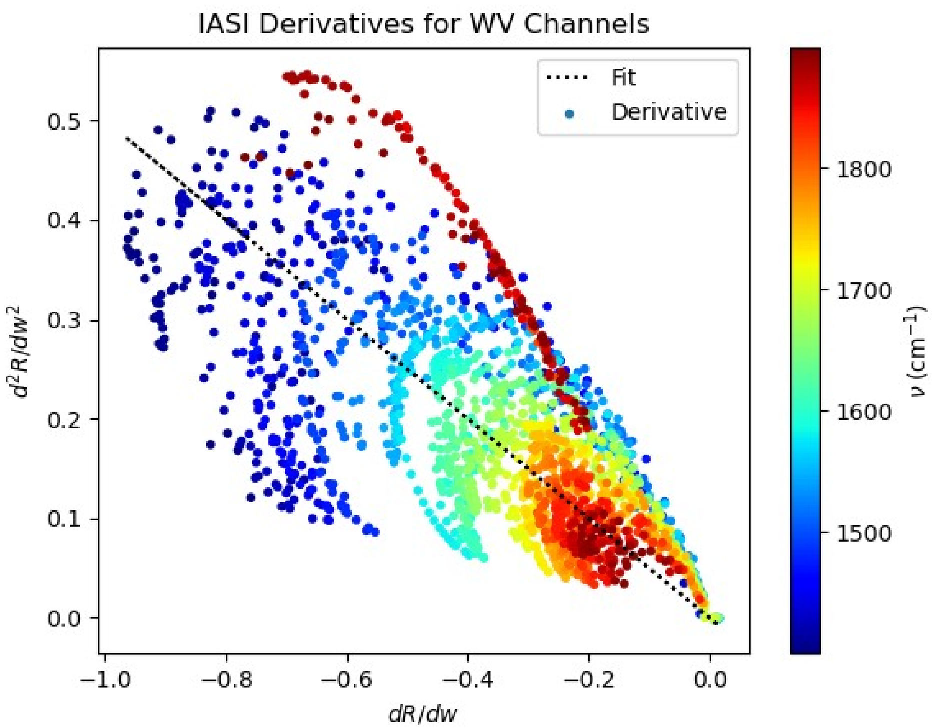
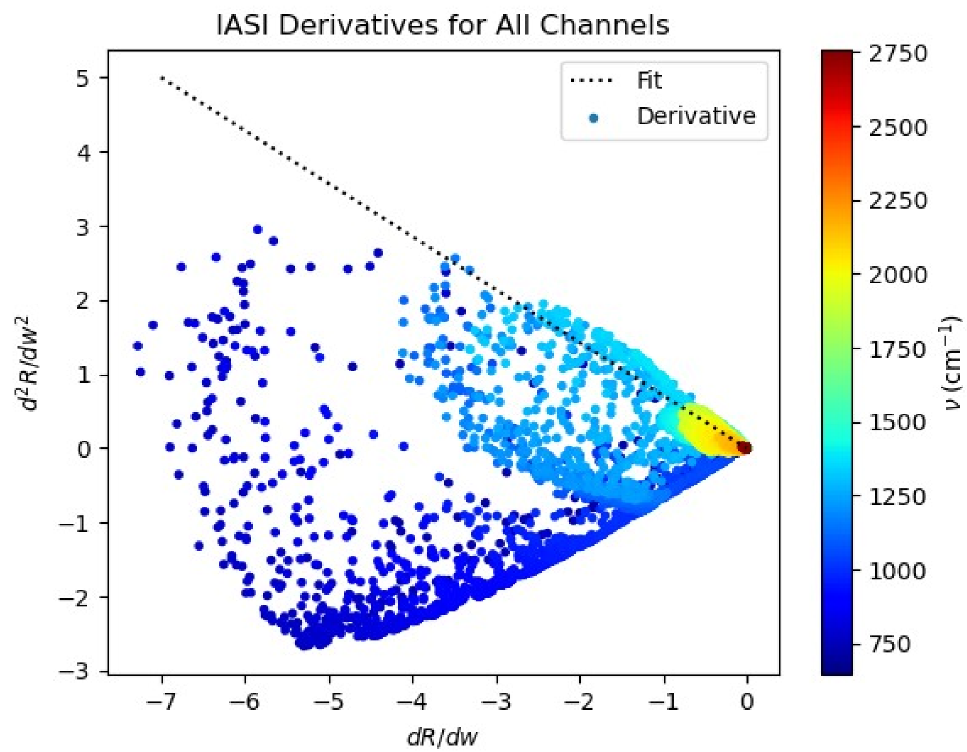
dR/dw versus d^2R/dw^2

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 inhomogeneity from WV content

- Retrievals without turbulence, $\langle dw' \rangle$:

  $\langle dR \rangle = dR/dw \, \langle dw' \rangle$
- Retrievals with turbulence, $\langle dw \rangle$:

  $\langle dR \rangle = dR/dw \, \langle dw \rangle + ½ \, d^2R/dw^2 \langle dw^2 \rangle \sim$

  $dR/dw \, \langle dw \rangle - 1/2 * 0.5 \, dR/dw \, \langle dw^2 \rangle =$

  $dR/dw \, \{ \langle dw \rangle - 0.25 * \langle dw^2 \rangle \}$
- Equating both results:

  $\langle dw \rangle \sim \langle dw' \rangle + 0.25 * \langle dw^2 \rangle \;\; \rightarrow \;\; \langle dw \rangle$ greater than $\langle dw' \rangle$

IR Remote Sensing WV concentration is perhaps always underestimated!!
Consistent with Carbajal-Henken, 2020, Remote Sensing

Instrument	N	Bias	RMSE	Std	Mean (x)	Mean (y)	R	Slope	Intercept
IASI	88336	-1.77 ± 0.006	2.74	2.09	16.17	14.40	0.959	0.866 ± 0.001	0.387 ± 0.015
MIRS	41948	1.36 ± 0.016	3.77	3.50	15.98	17.36	0.881	0.807 ± 0.002	4.453 ± 0.037
MODIS	17438	1.11 ± 0.021	3.11	2.91	16.18	17.28	0.959	1.117 ± 0.003	-0.781 ± 0.046
MODIS-FUB	17437	-0.31 ± 0.019	2.52	2.50	16.18	15.87	0.955	0.967 ± 0.002	0.226 ± 0.041

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Consequences of WV RGF behaviour

- Instruments with a large FOV (several km) will notice this effect
- Inhomogeneities can be mistaken for WV concentrations → Biases in the observations
- Point WV measurements in the atmosphere (sondes, etc.) will be different if taken in different space/time positions just due to turbulent effects
- These biases could be "permanent" for some instruments → permanent biases in the measurements (RO?, GNSS?) → Need to check whether non-linear effects are important → Size of second derivative

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