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

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GRUAN ICM-14

Summary

1. Confirmation GRF model for WV < 6 km
2. Fine details of RTM
3. Permanent Bias
4. Conclusions

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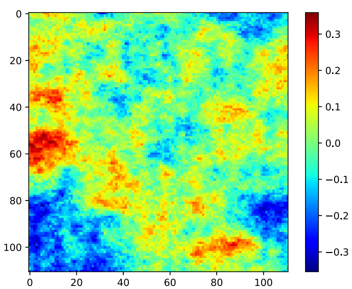
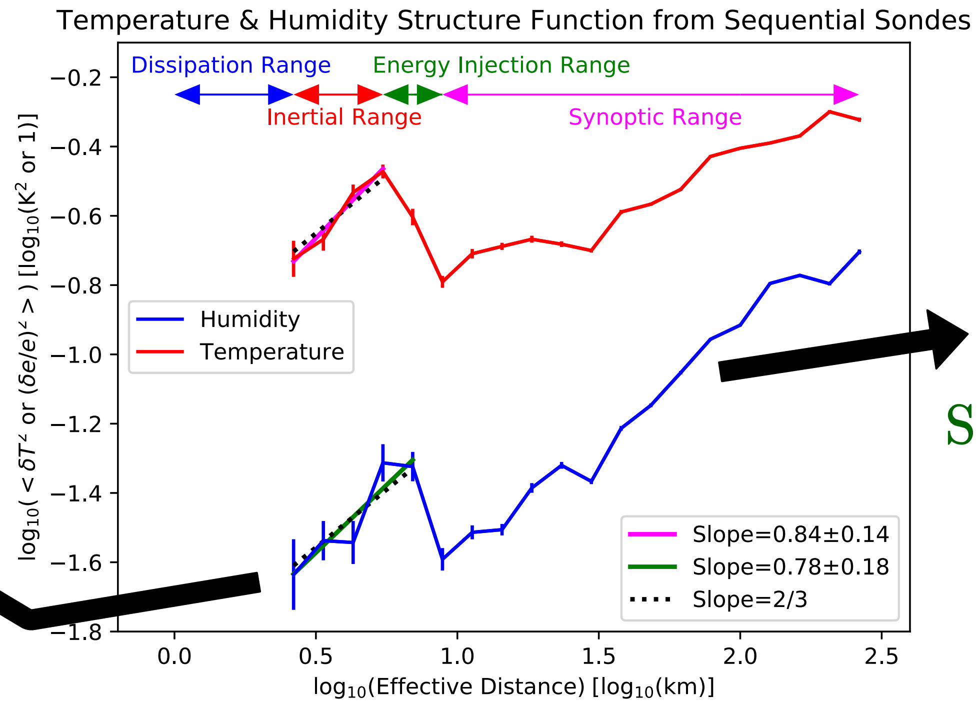
Variability of Water Vapour

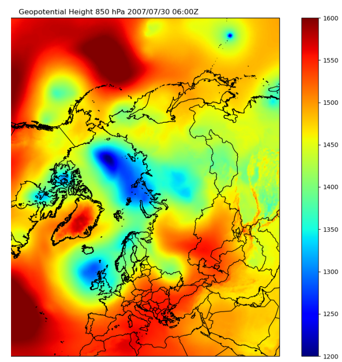
Two different scales

Scales $\lesssim$ 6 km

Gaussian Random Field







Scales $\gtrsim$ 10 km

Smooth Field

Calbet et al. 2018, AMT

Calbet et al. 2022, AMT

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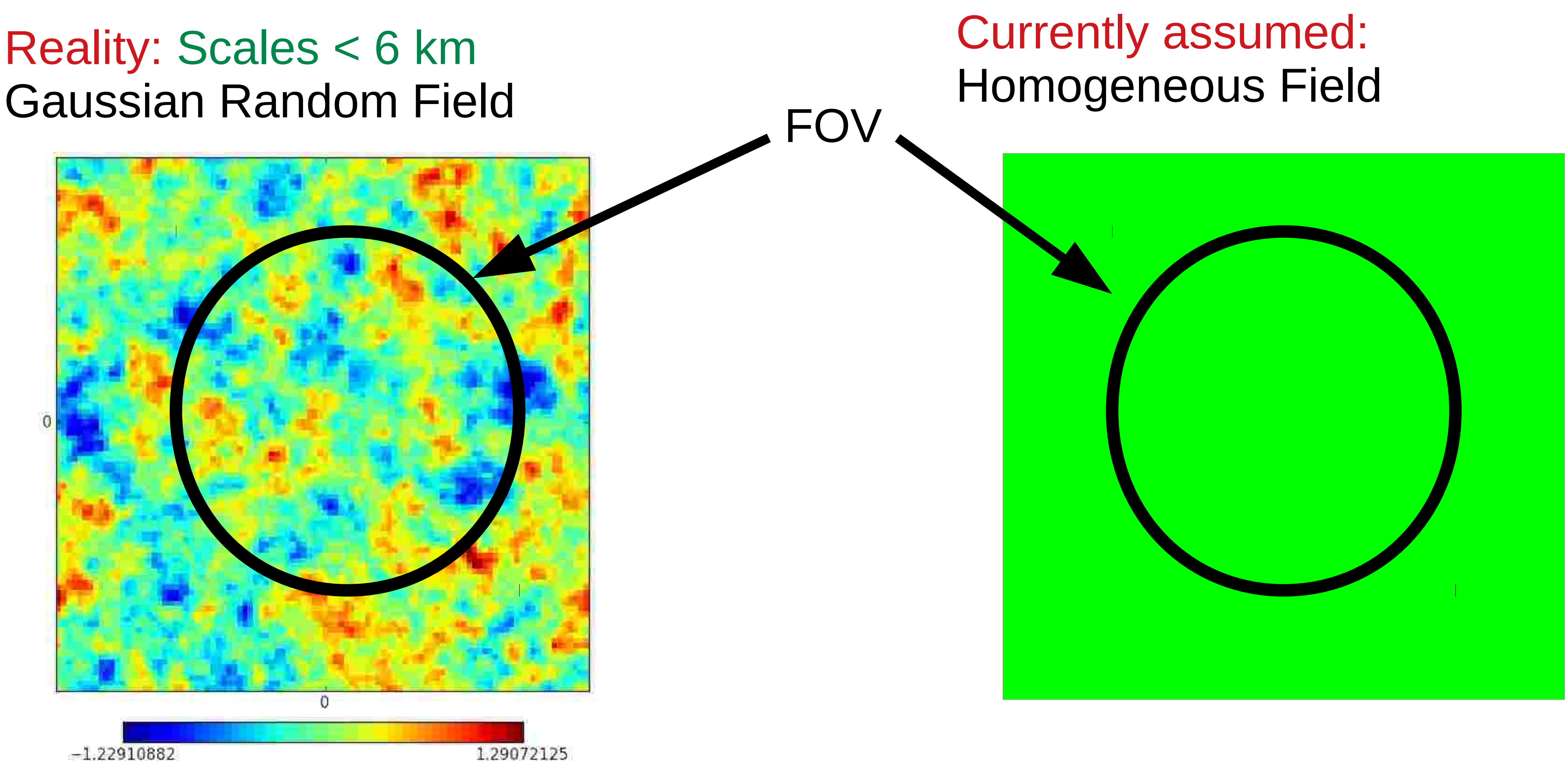
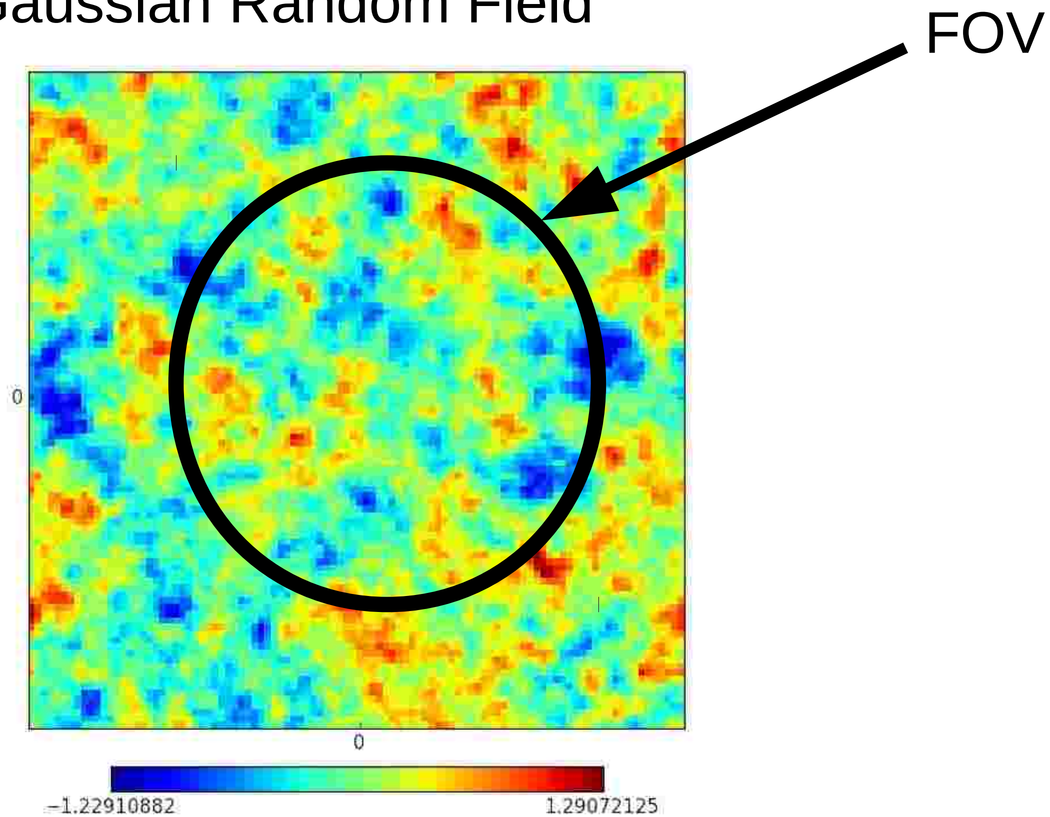
Variability of Water Vapour within FOV

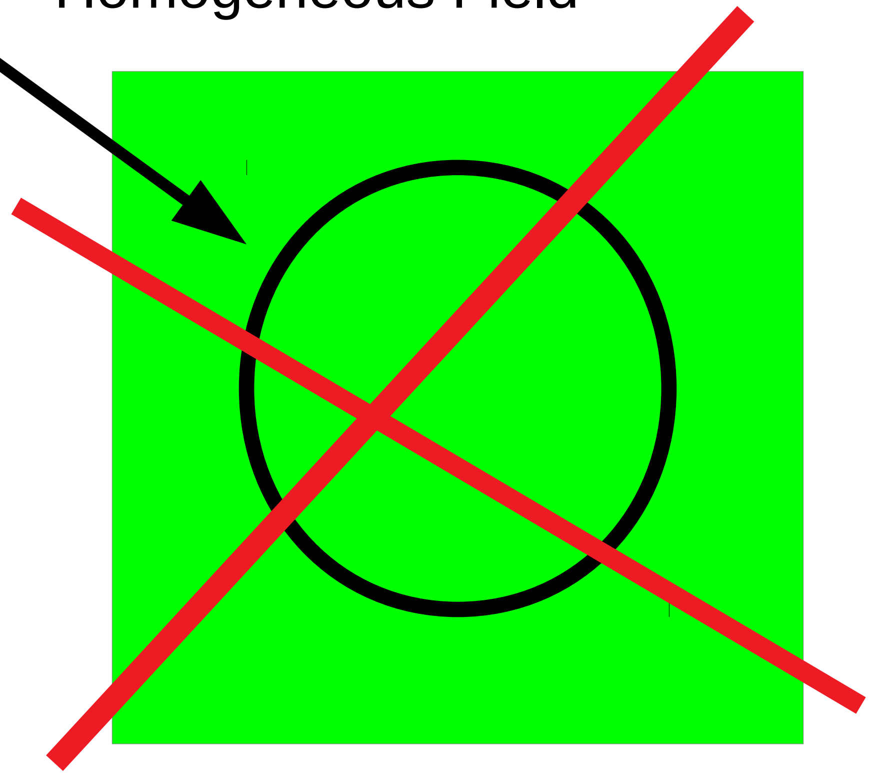


Variability of Water Vapour within FOV

Reality: Scales < 6 km
Gaussian Random Field

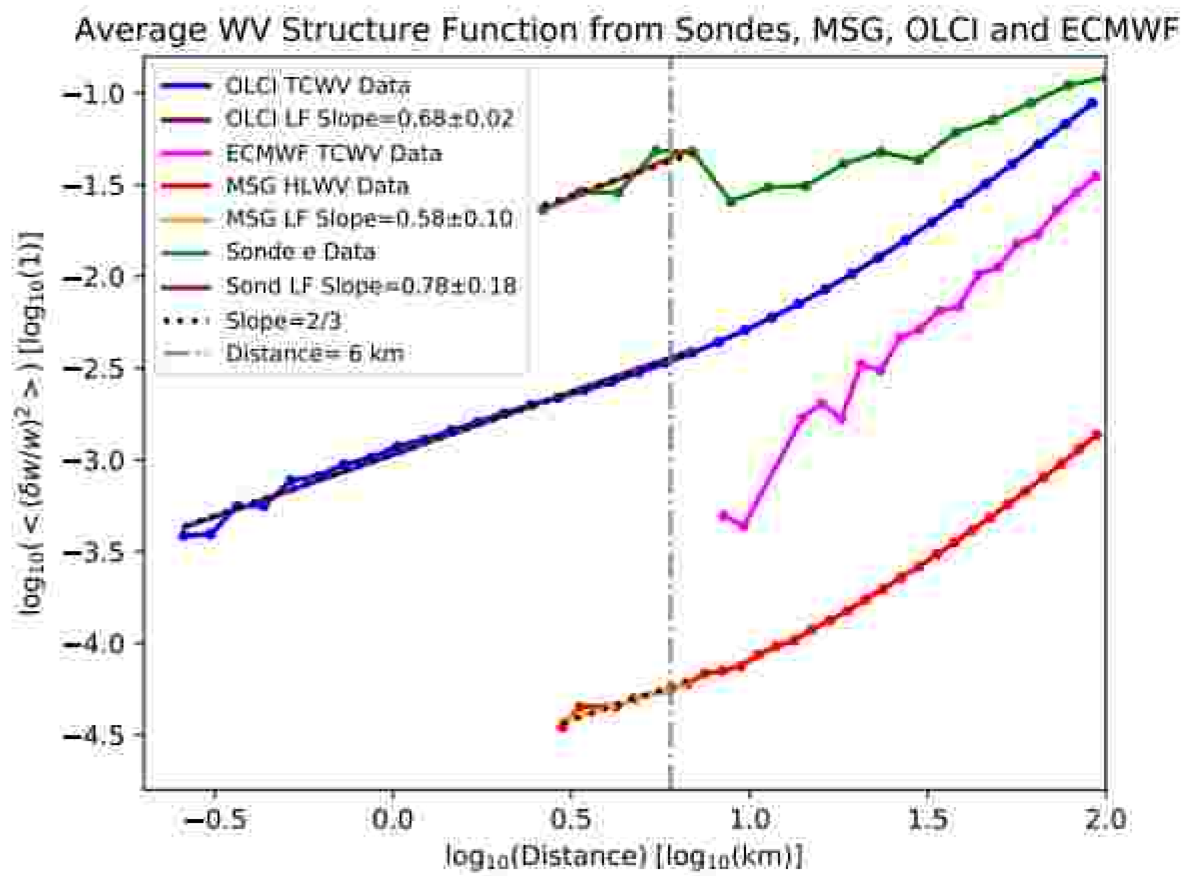


Currently assumed:
Homogeneous Field



Structure Function of WV from Sondes, MSG and OLCI

Structure function confirmed!!



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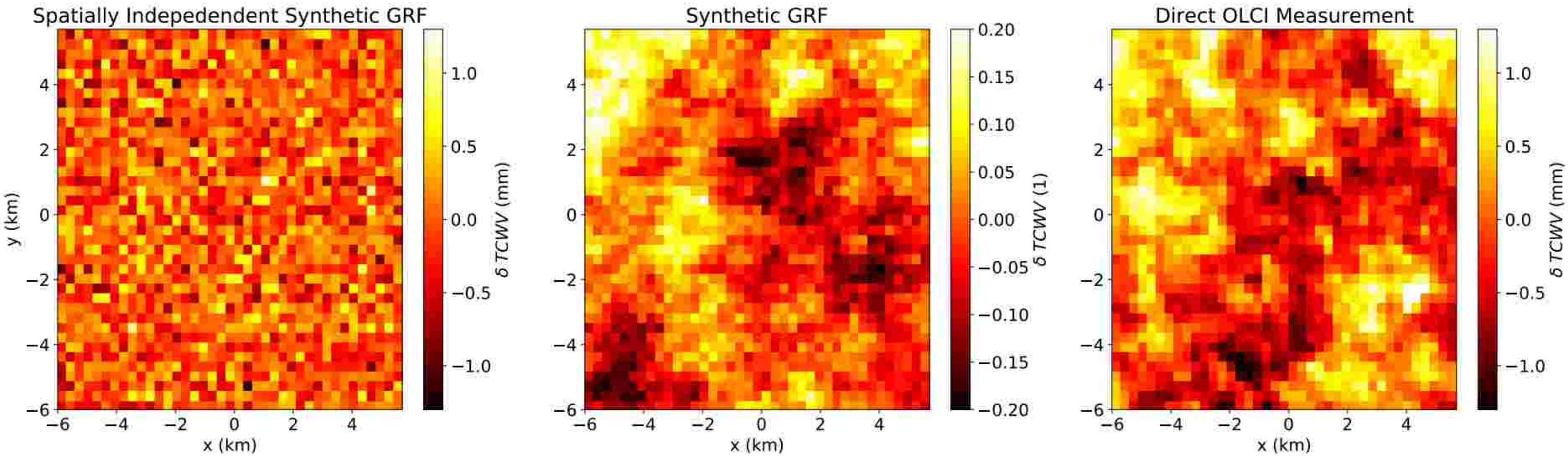
Gaussian Random Field seen from OLCI

GRF function confirmed!!



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Confirmation GRF of WV < 6 km

- It is useful to have a model of the behaviour of WV at scales < 6 km for many applications:
  - Fusion of WV measurements from different instruments at different scales
  - Fine details of Radiative Transfer Modelling

Calbet et al. 2022, AMT

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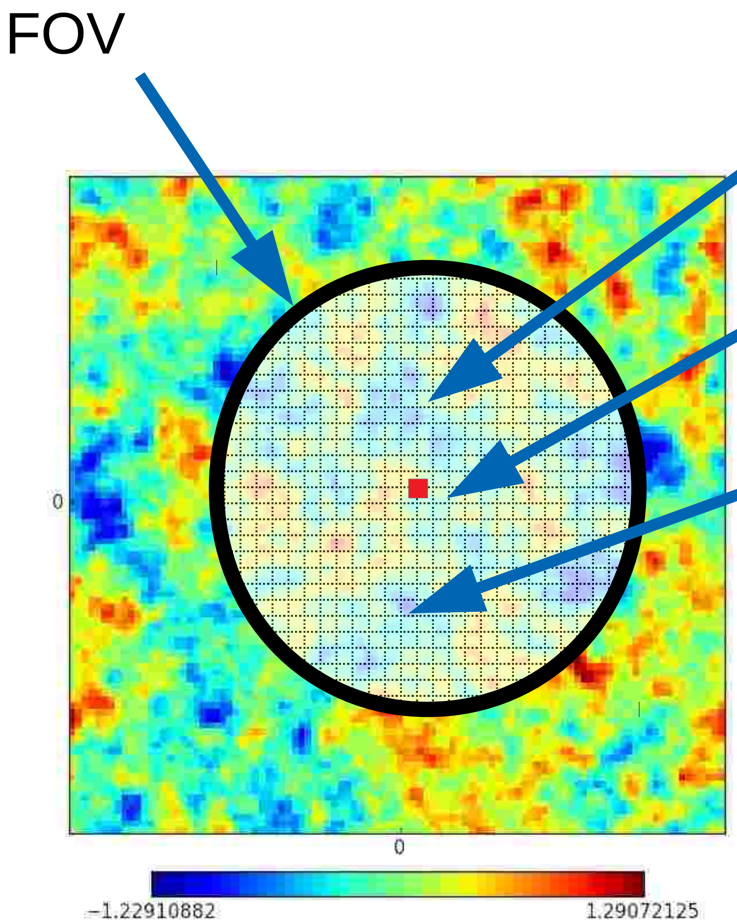
RTM in an inhomogeneous FOV



- 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:
  $\langle\delta R\rangle=dR/dw\,\langle\delta w\rangle+1/2\, d^2R/dw^2\,\langle\delta w^2\rangle$
- 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

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

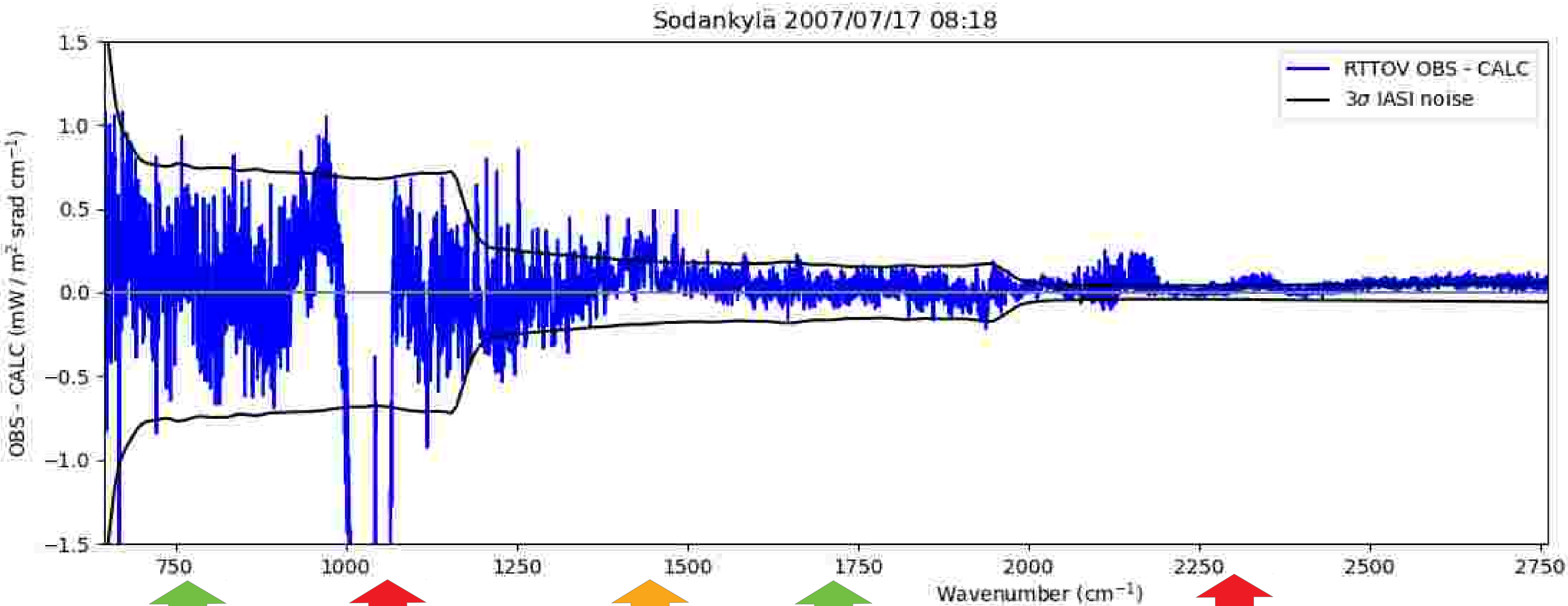
Calbet et al. 2018, AMT

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

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

Sun et al. 2021, Remote Sensing

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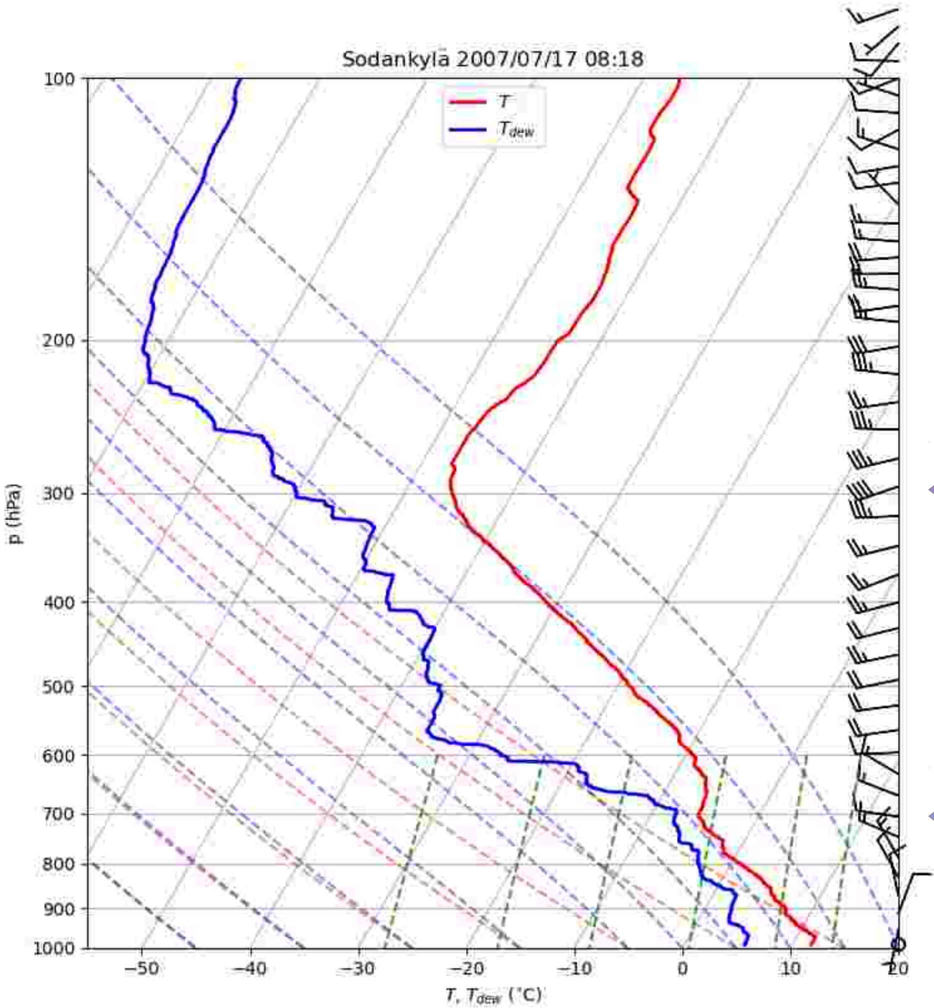
Test Case: Sonde profile

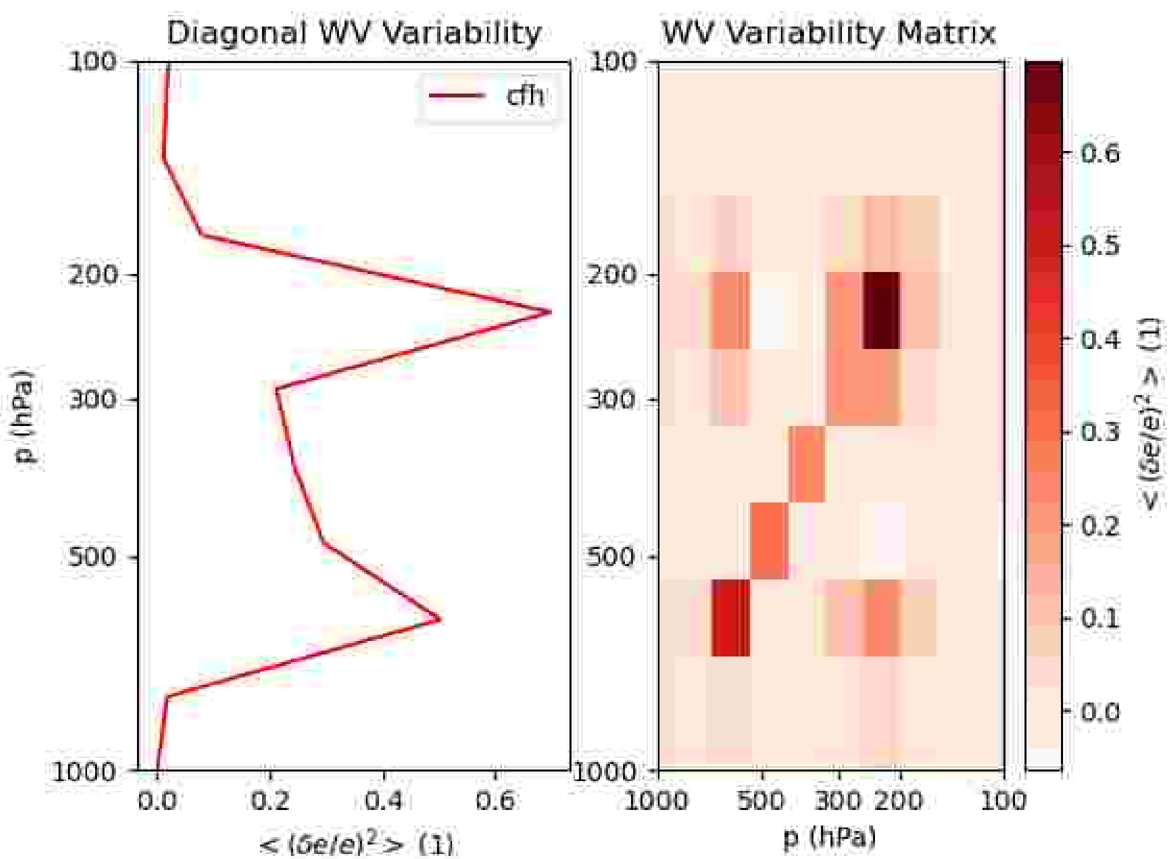


Tropopause

Inversion

WV Variability Matrix

Measured from Sequential Sonde data ← Not Robust!



Highest variability: tropopause and inversion?

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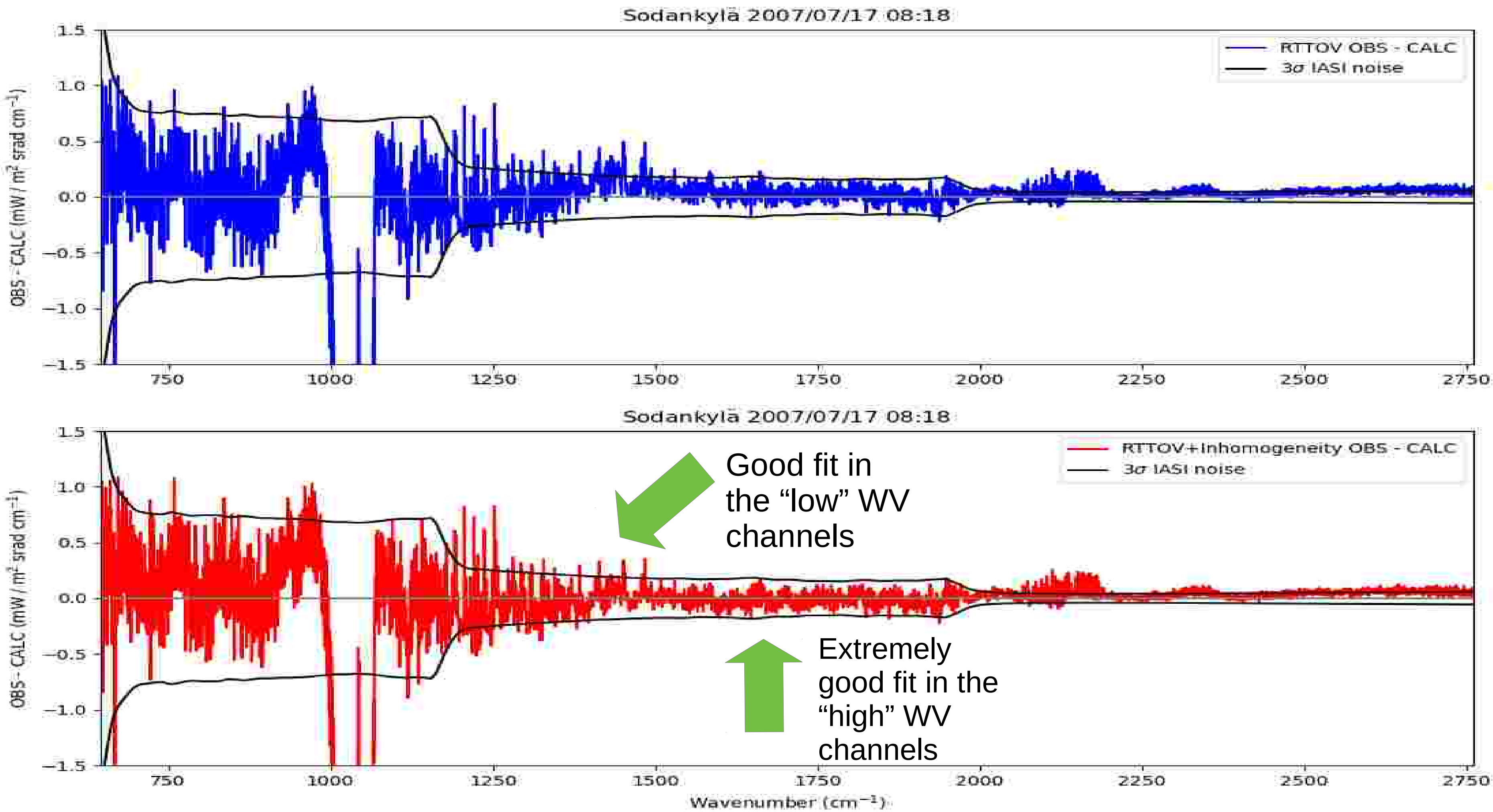
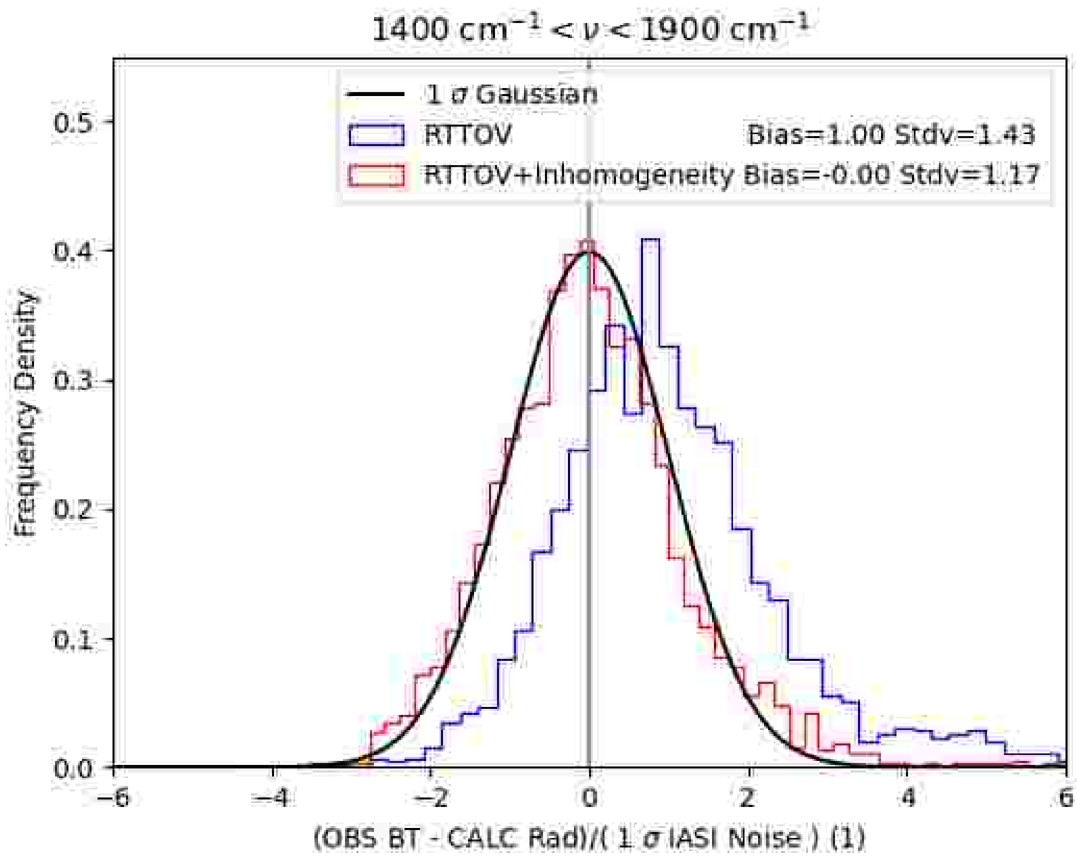
IASI Radiances with and without WV Inhomogeneities



IASI Radiances with and without WV Inhomogeneities



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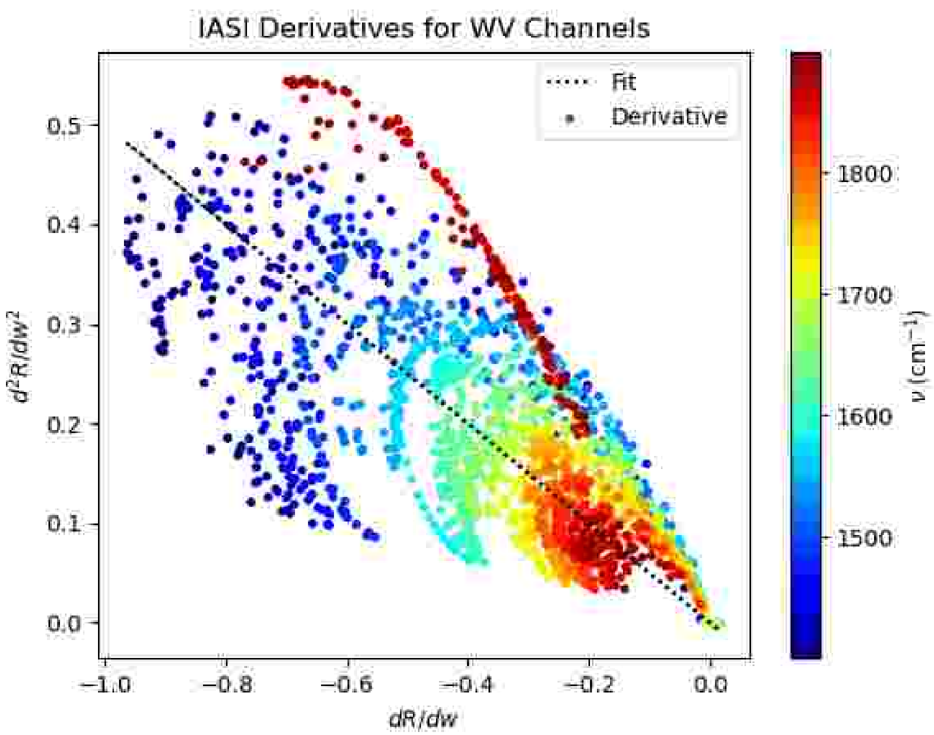
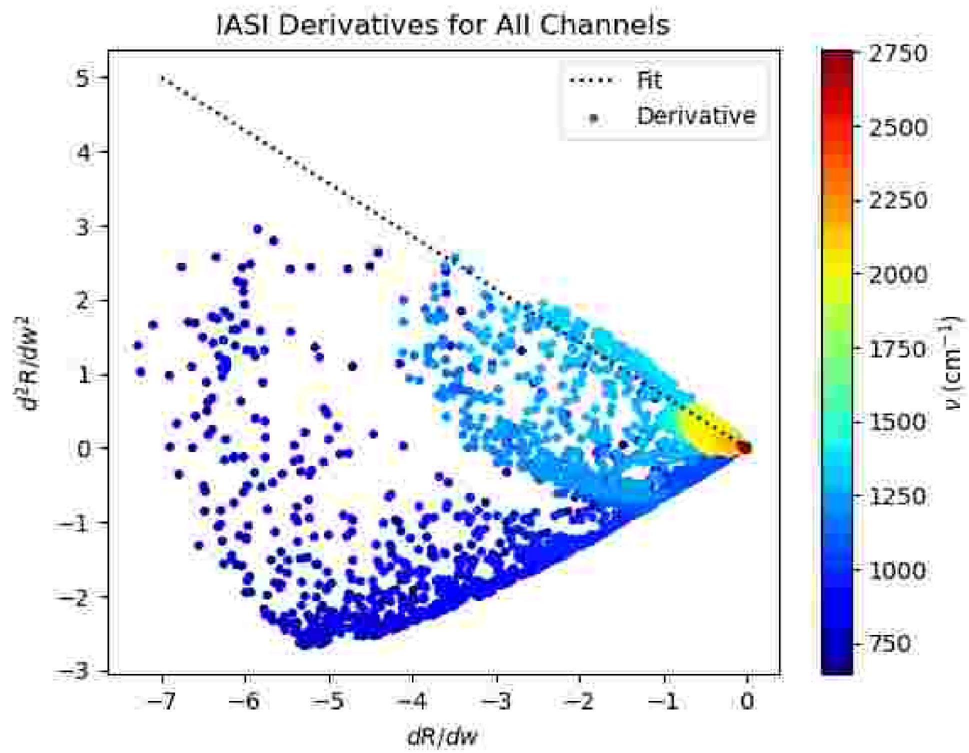
Extra Slide: dR/dw versus d^2R/dw^2

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





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

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IASI separating inhmogeneity from WV content

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

  $$\langle dR \rangle = dR/dw \langle dw' \rangle$$

- 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:

  $$\langle dw \rangle \sim \langle dw' \rangle + 0.25*\langle dw^2 \rangle \rightarrow \langle dw \rangle \text{ greater than } \langle dw' \rangle$$

WV concentration from Remote Sensing
is perhaps underestimated!!

Consistent with Carbajal-Henken, 2020, Remote Sensing

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Conclusions

- Inhomogeneity is significant in RTM: Relatively stable profile has an 0.5K effect in radiances (IASI and MHS) → Other more turbulent profiles might have a higher effect (needs to be confirmed with a bigger sample)

- Value of GRUAN satellite collocated sequential sondes:
  - Derive accurate Best State Estimates
  - Derive WV variability matrix
  - Allows fine detail comparison of RTM and Observations

- Permanent Bias:
  - Inhomogeneity effects can produce a "permanent" bias in some remote sensing WV measurements

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