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Defining Water Vapour Profiles from Nadir Sounders for the GEWEX Water Vapor Assessment

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1. Introduction: Scopes and Motivations

- **The GEWEX Water Vapor Assessment (G-VAP) was initiated by the GEWEX Data and Assessments Panel (GDAP) with the aim of characterising the current state of the art water vapour products being constructed for climate applications. The result of these efforts is to aid in the selection of suitable water vapour products by GDAP for its production of globally consistent water and energy products.**
- **While legacy satellite observations have produced records of total column water vapour (TCWV), the new generation of nadir hyperspectral infrared sounders such as the Infrared Atmospheric Sounding Interferometer (IASI), Cross-track Infrared Sounder (CrIS) and future missions like IASI-NG will be able to provide a water vapour record with an increased tropospheric resolution spanning at least 30 years. With this in mind, there is a need within G-VAP to characterise water vapour profile products from these sensors for consistent comparisons in the future.**
- **Using output from the University of Leicester Water Vapour Processor (UoL-WVP) for demonstration purposes, we present a new approach where cumulative degrees of freedom are used to define the vertical resolution of the retrieved profile over a series of slab layers. This concept is known as the partial column profile.**
- **This metric which can be applied to other products intended for G-VAP assessment, such as the operational IASI from EUMETSAT.**

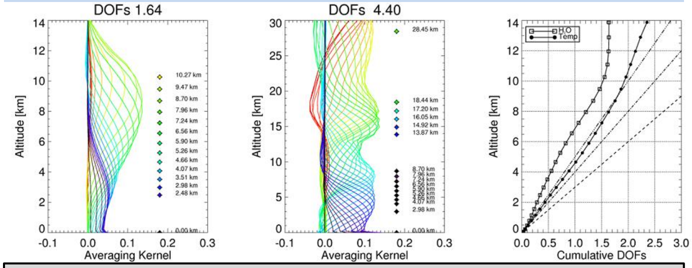

Figure 1. Mean averaging kernels for HIRS UoL-WVP retrieved humidity (left) and temperature (centre) along with their cumulative DOF as a function of altitude (right). Humidity averaging kernels show clearly that the water vapour signal comes predominantly form the free troposphere. The dashed line represents a 3:1 relationship between degrees of freedom and height (e.g. 3 km resolution), the dot-dash line is a 4:1 relationship (4 km resolution) while the dot-dot-dot-dash line is a 5:1 relationship (5 km resolution).

2. Retrieval Information Content as a Metric of Profile Vertical Resolution

- **Nadir profile measurements are not continuous functions of altitude rather a set of discrete atmospheric layers or partial columns. Therefore, the retrieval information content can be used as a measure of the resolution of the retrieved profiles (Rodgers, 2000). By taking the cumulative total of the averaging kernel it possible to view the vertical information content as a function of altitude.**
- **Examination of averaging kernels from tropical UoL-WVP retrievals from HIRS (Figure 1) show that the majority of H2O information comes from free troposphere. Applying the cumulative degrees-of-freedom (DOF) reveal that the 1 DOF level ~6.5km, with information content terminating around 10-12 km (limited by tropopause).**
- **The advantage of hyper-spectral IR sounders like IASI is that they deliver measurements of humidity and temperature within the troposphere (Figure 2). This is demonstrated in Figure 3, with UoL-WVP retrievals from IASI.**
- **Humidity profiles have a general resolution of ~3 km, while temperature profiles on average show a 2 km resolution.**
- **These resolutions degrade as they approach the Upper Troposphere/Lower Stratosphere (UTLS), which is expected with a nadir viewing geometry.**
- **The tropopause and Atmospheric Boundary Layer (ABL) heights will affect these resolutions, as sensitivity to atmospheric concentrations vary affecting the information content within the retrieval.**
- **If the troposphere is considered as three broad layers (0-2, 2-10 and 10-12 km), then it should be possible to more than resolve the upper and lower regions of the troposphere (table 1).**

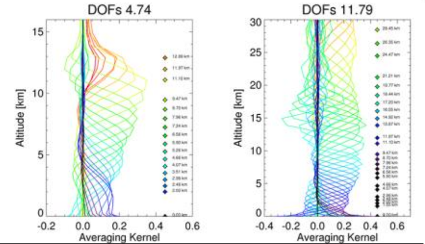

Figure 2. Mean averaging kernels for humidity (left) and temperature (right) from UoL-WVP. Coloured dots up the right hand side of each plot denote the altitude for the specific kernel peak sensitivity.

Table 1. Mean vertical resolution for three tropospheric regions; 1) the atmospheric boundary layer (0-2 km), 2) the free troposphere (2-10 km) and 3) the upper troposphere (10-12 km).

Altitude Range (km)	Resolution (km) H_2O	Temperature
0-2	2.78	1.72
2-10	2.65	2.18
10-12	3.19	2.87

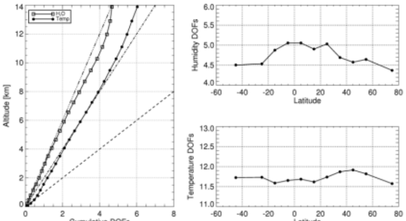

Figure 3. Cumulative degrees of freedom profiles from mean UoL-WVP averaging kernels (Left). The dashed line represents a 1:1 relationship between degrees of freedom and height (e.g. 1 km resolution), the dot-dash line is a 2:1 relationship (2 km resolution) while the dot-dot-dot-dash line is a 3:1 relationship (3 km resolution). Degrees of freedom as a function of latitude for humidity (top right) and temperature (bottom right)

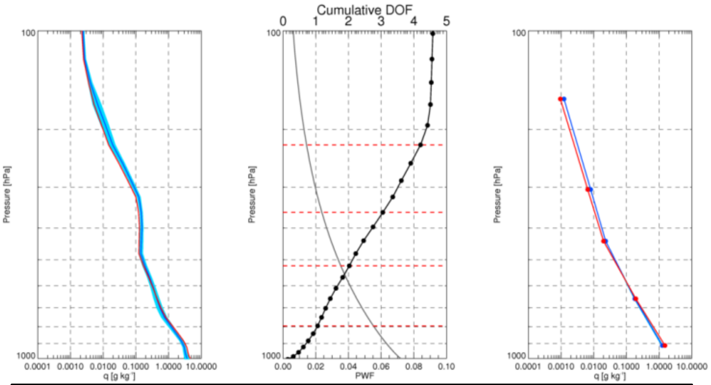

Figure 4. (LHS) Stages in conversion to PH2O profiles. The convolved GRUAN profile (blue line, red line = IASI retrieval) is are converted in to partial columns using the calculated pressure weighting function (middle). The layer boundaries are defined by integer values of the cumulative DOF profile (red dashed lines, middle frame). (RHS) PH2O profiles are then defined on five discrete layers (blue = GRUAN, red= IASI). Six layers are possible however, these would be entirely made up of stratospheric emissions and not would not contain a full piece of independent information.

3. Partial Column Profiles

- **Retrieved UoL-WVP IASI H2O profiles are interpolated into a series of partial columns defined by integer DOF values, using a pressure weighting function (h) which is defined as (Connor et al., 2008):**

$$h_i = \left| \left(-p_i + \frac{p_{i+1} - p_i}{ln\left(p_{i+1}/p_i\right)} \right) + \left(p_i + \frac{p_i - p_{i-1}}{ln\left(p_i/p_{i-1}\right)} \right) \right| \frac{1}{p_{surf}}$$

- **The transpose is then applied to the convolved/retrieved profile (x_{est}) over the atmospheric region where the cumulative DOF = 1,2,3 . . . N:**

$$PH2O_i = x_{est(i:i+n)} h^T{}_{i:i+n}$$

where $PH2O_i$ is the partial column H_2O in layer i of the profile.

- **Temperature profiles (PTMP) are treated in a similar way, however, instead of applying the pressure weighting function, the mean air temperature for the layer is used. Each layer within the profiles is defined by the mean pressure for that layer.**
- **PH2O profiles are defined on five layers and PTMP on seven for comparisons with GRUAN. It should be noted that the layer pressure varies as it is a function of the air mass to which the retrieval is sensitive. Stages of this process are shown in Figure 4.**

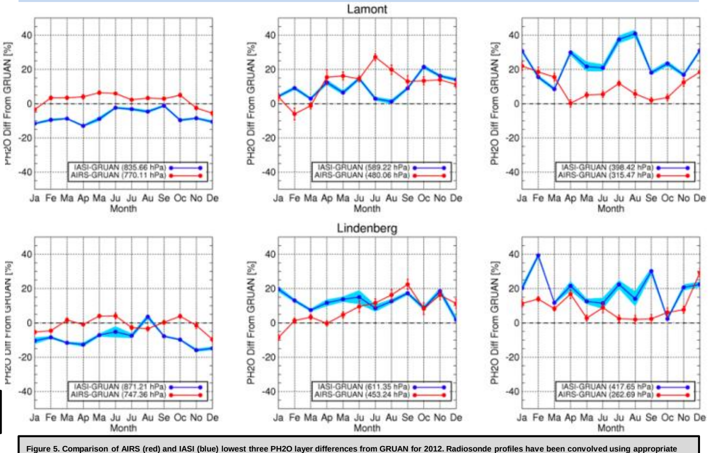

Figure 5. Comparison of AIRS (red) and IASI (blue) lowest three PH2O layer differences from GRUAN for 2012. Radiosonde profiles have been convolved using appropriate averaging kernel and subtracted from the retrieved with the monthly median plotted. Standard uncertainty is represented as a shaded area and error bars. Median layer pressure for the year is displayed in the legend, notice difference in the layer centre between IASI and the lower resolution AIRS.

4. Sensitivity of PH2O Layers

- **Example using UoL-WVP V1 and AIRS V5 PH2O at Lamont (SGP) and Lindenberg GRUAN sites. Differences in vertical resolution results in varying sensitivity to H_2O layers within the troposphere.**
- **With AIRS having a lower vertical resolution than IASI, there are some distinct differences in tropospheric PH2O residuals (Figure 5). Within the troposphere AIRS only has 3 PH2O layers.**
- **At the surface, AIRS insensitivity to the ABL results in a wet bias, while UoI-WVP which has greater sensitivity to the ABL, has a general dry bias compared to GRUAN.**
- **In the upper troposphere (third layer) , AIRS has some sensitivity to the UTLS unlike UoL-WVP. This results in a dampened wet bias in AIRS compared to UoL-WVP.**

References.

- Trent, T.: Climate and variability of water vapour in the troposphere. PhD diss., Department of Physics and Astronomy, 2015.
- Rodgers, C.: Inverse Methods for Atmospheric Sounding: Theory and Practice, Series on Atmospheric Oceanic and Planetary Physics, Volume 2, World Scientific Publishing Company, Incorporated, 2000.
- Connor, B. J., Boesch, H., Toon, G., Sen, B., Miller, C., and Crisp, D.: Orbiting Carbon Observatory: Inverse method and prospective error analysis, Journal of Geophysical Research: Atmospheres, 113, 2008.

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