COSMIC/JCSDA Workshop and IROWG-10
Boulder, CO, USA, 17 Sept. 2024

Humidity profiles from GNSS radio occultation for observing atmospheric rivers and the influence of background data

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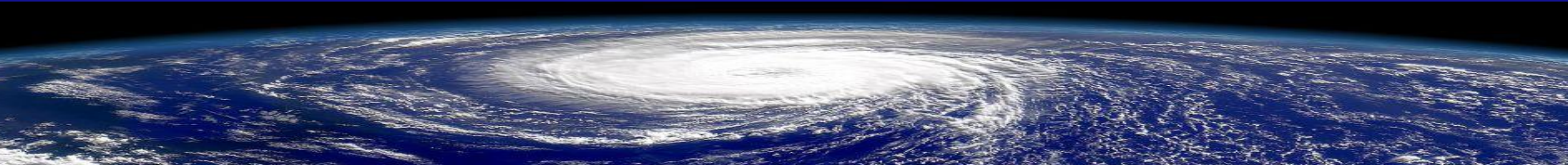
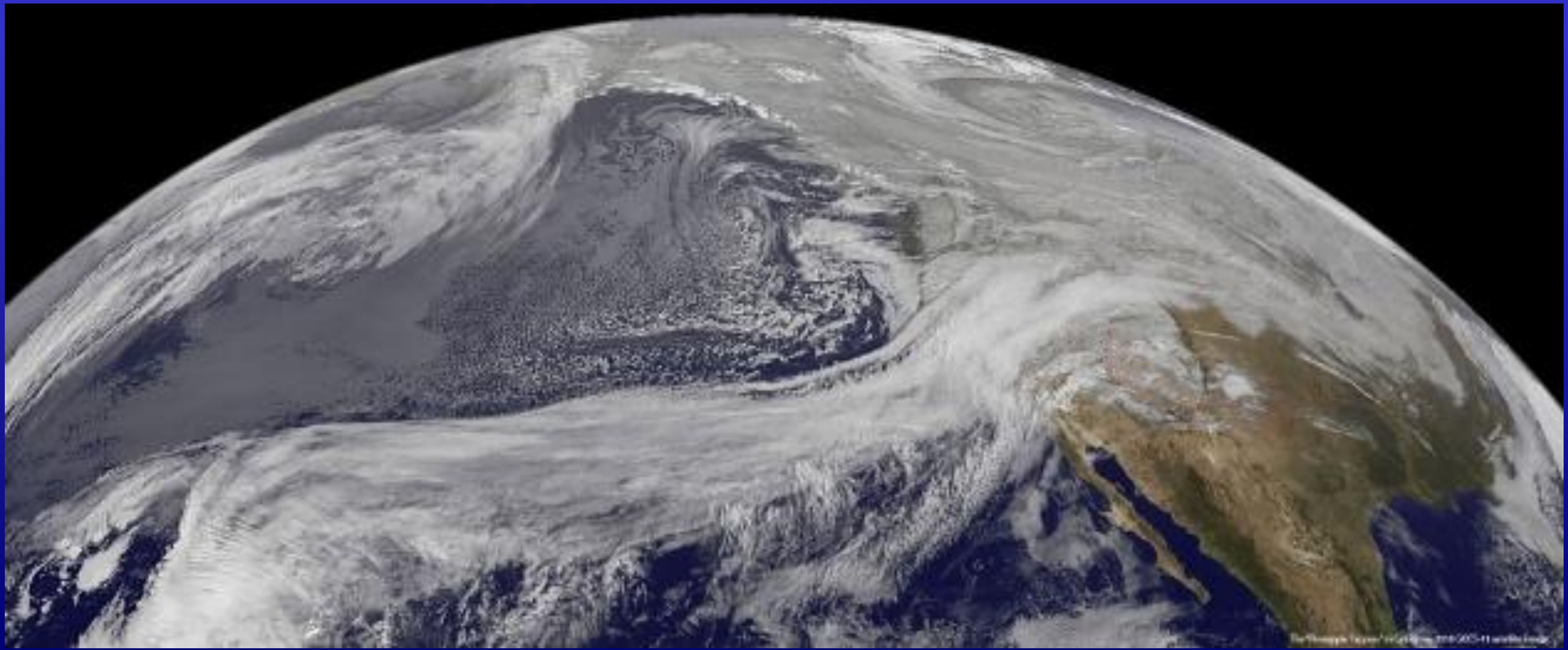
Funded by the Austrian Science Fund FWF,
Research Grant W1256 and by the University of Graz



Atmospheric Rivers

Atmospheric Rivers (AR) are comparatively narrow regions in the **lower troposphere** that are responsible for **most** of the horizontal transport of water vapor in the extratropics and for many **extreme precipitation events** and floodings at mid-latitudes, including Europe and the US.

A famous example is the “Pineapple Express” (credit: NOAA).



Precipitable Water

ARs are often represented as precipitable water (vapor):

Integrated Water Vapor [kg/m²]

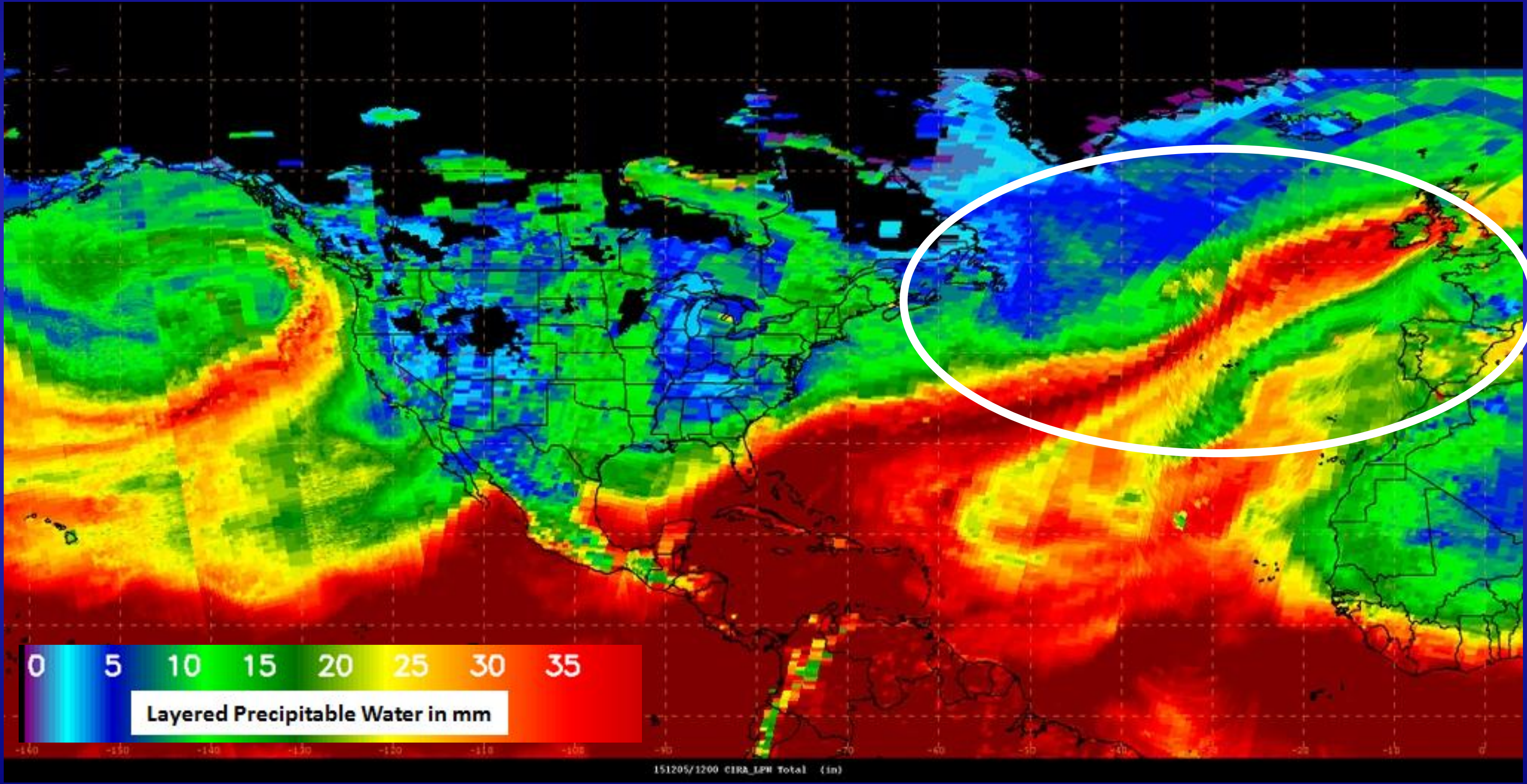
$$IWV = \int_0^\infty \rho_w(z)\,dz$$

asks for data down to the surface, ρ_w is the water vapor density in [kg/m^3].

Precipitable water (vapor), usually expressed in [mm], where ρ_l is the density of liquid water.

$$PW = \frac{IWV}{\rho_l}$$

Atmospheric Rivers



Precipitable water, Dec. 5, 2015 (NOAA), resulting in …

Extreme Precipitation

Storm Desmond in UK/Ireland (Synne in Norway) with rainfall totals exceeding 200 mm (Rolling News, Getty Images).

Observing ARs with RO

Can we observe ARs with RO?

Modest horizontal resolution, but good vertical resolution and coverage of the oceans.

Do RO Humidity profiles contain information that was not already in the background?

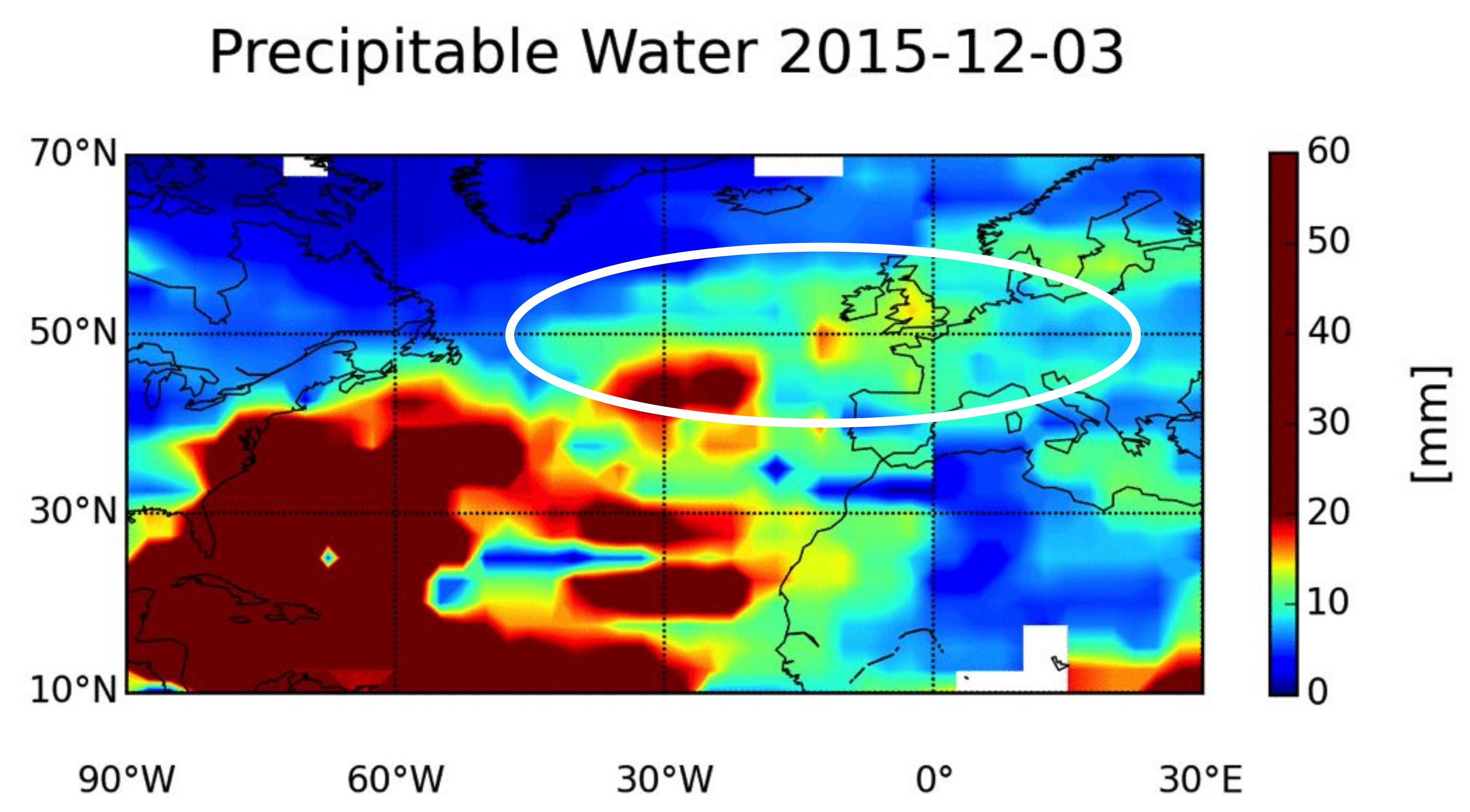
Humidity retrieval requires background information.

We have to expect a systematic underrepresentation of the total precipitable water, since we miss some of the water vapor in the lowest kilometer(s) – not covered in this talk, details:

Rahimi and Foelsche, *AMTD*, 2024, doi:10.5194/amt-2024-81

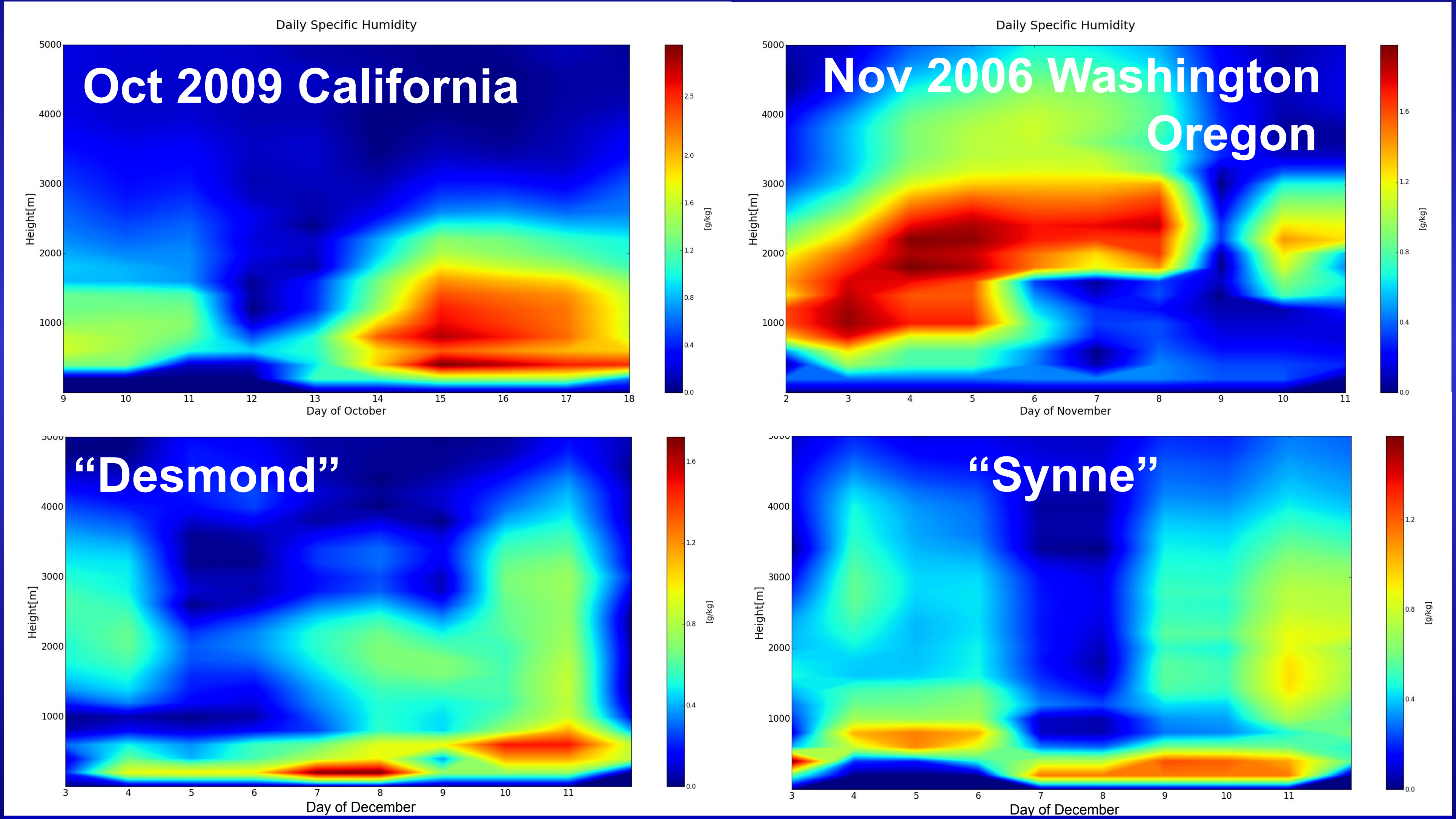
https://amt.copernicus.org/preprints/amt-2024-81/

Atmospheric Rivers



From previous work – presented at IROWG-7 – we know that we can see ARs in gridded RO data – here "Desmond" and "Synne", December 2015

Different Cases

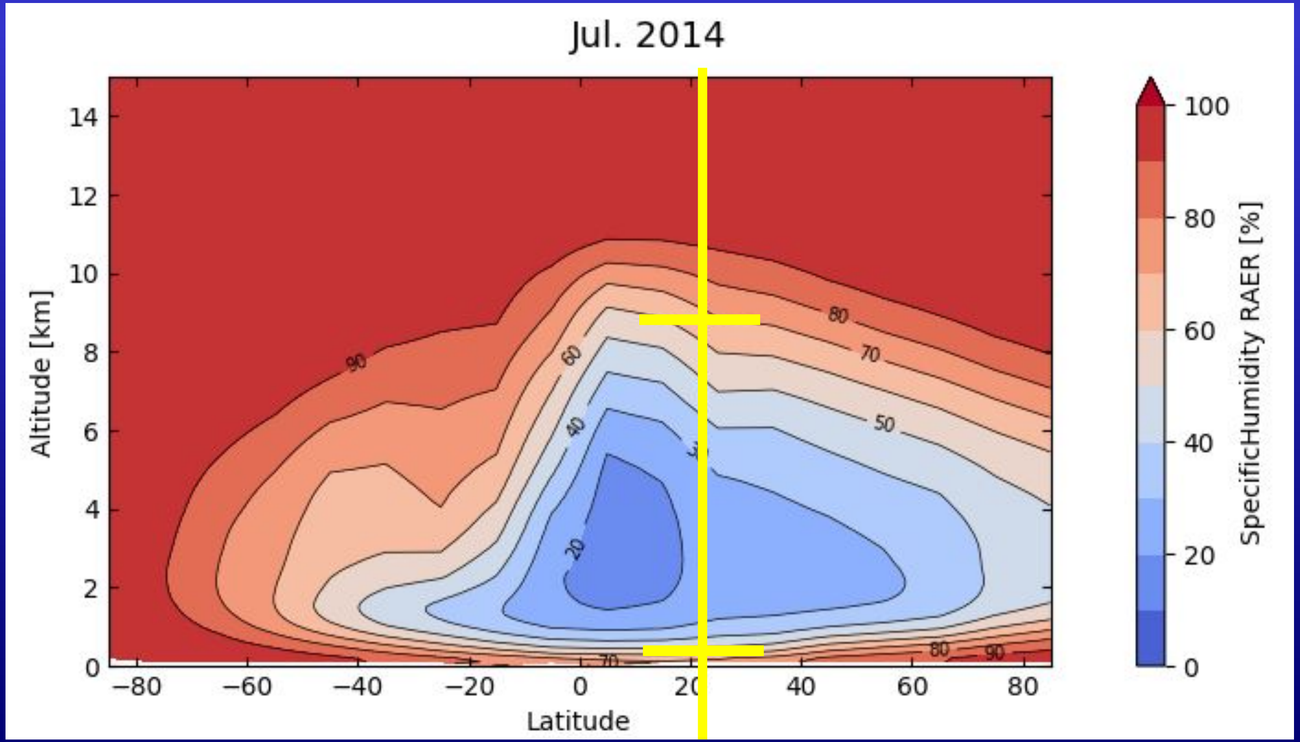


And we know that they can have different structures.

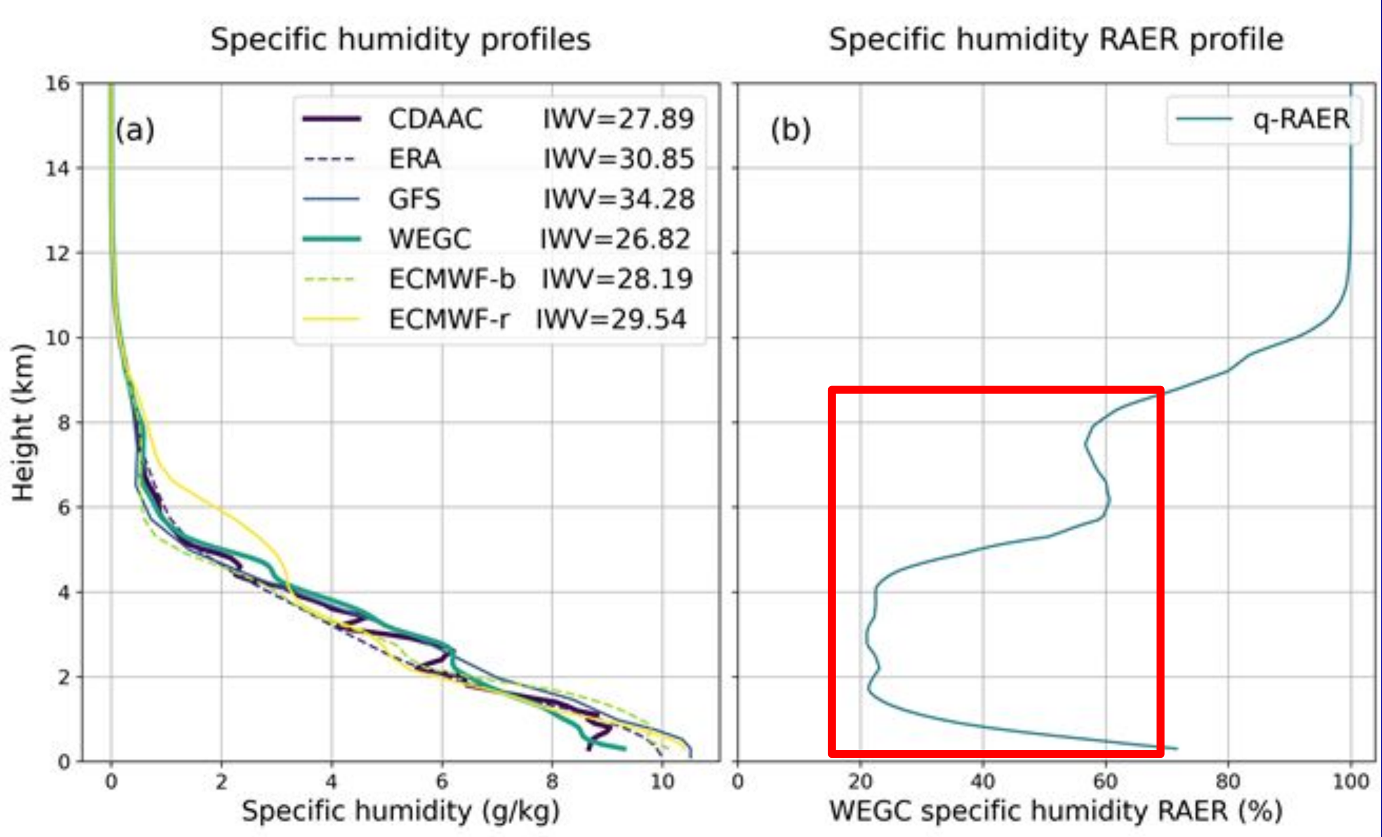
Water Vapor from RO

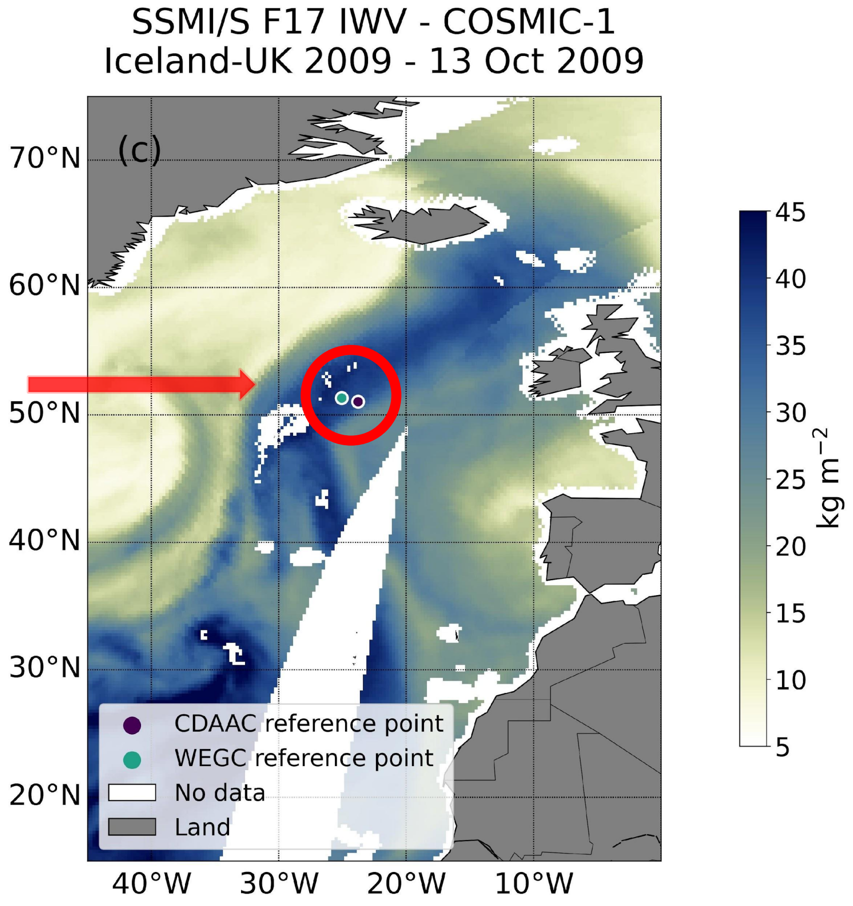
WegCenter **OPSv5.6** moist air retrieval, quasi 1DVar: Below 14 km: retrieval of T and p using **ECMWF** short-range **forecast** specific humidity q_B; q and p using ECMWF SR-FC temperature T_B; statistical optimization of T and q with q_B and T_B, background error from ROPPv6.0 45 (*Culverwell and Healy*, 2011), RO obs. error (*Scherllin-Pirscher et al*., 2011).

Zonal mean **Specific Humidity Retrieval-to-a priori error ratio** (RAER), **July** (Marc Schwärz, WEGC). When **RAER < ~70 %, observations dominate**.



Influence of the Background

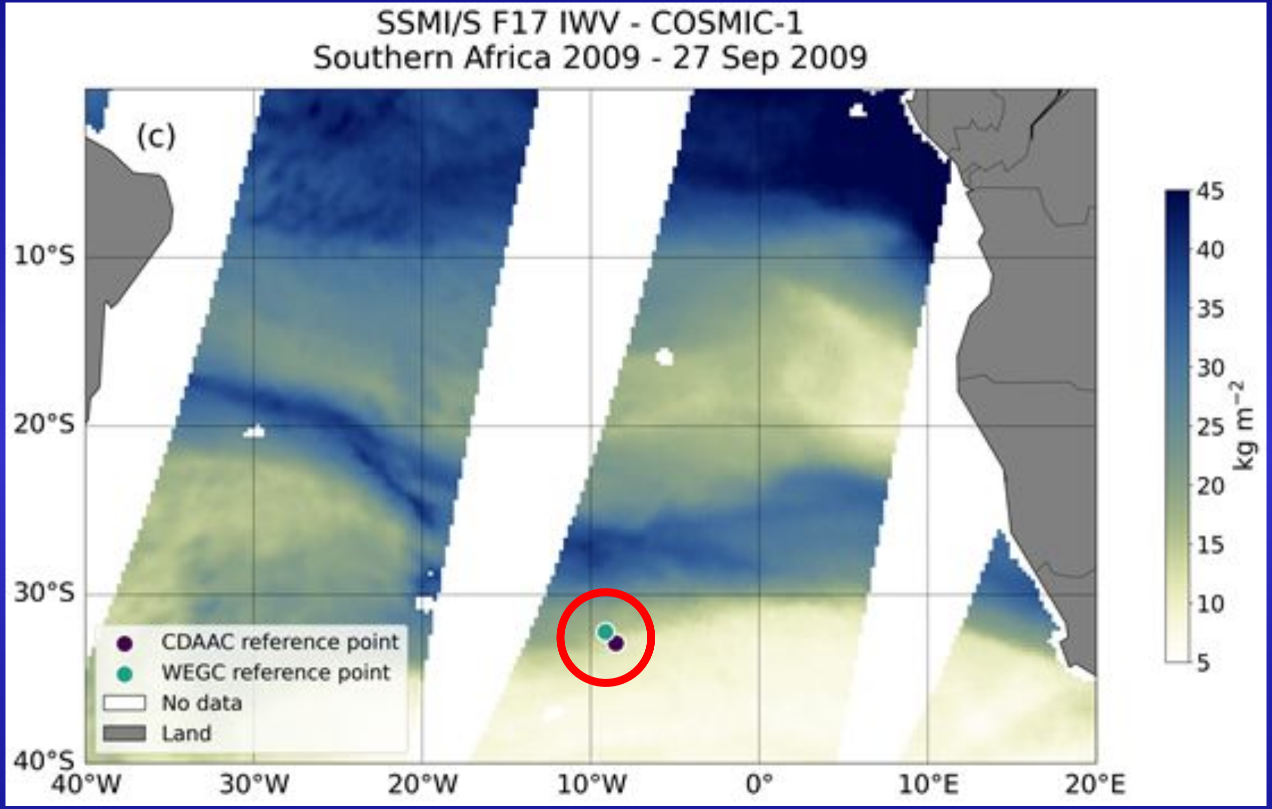


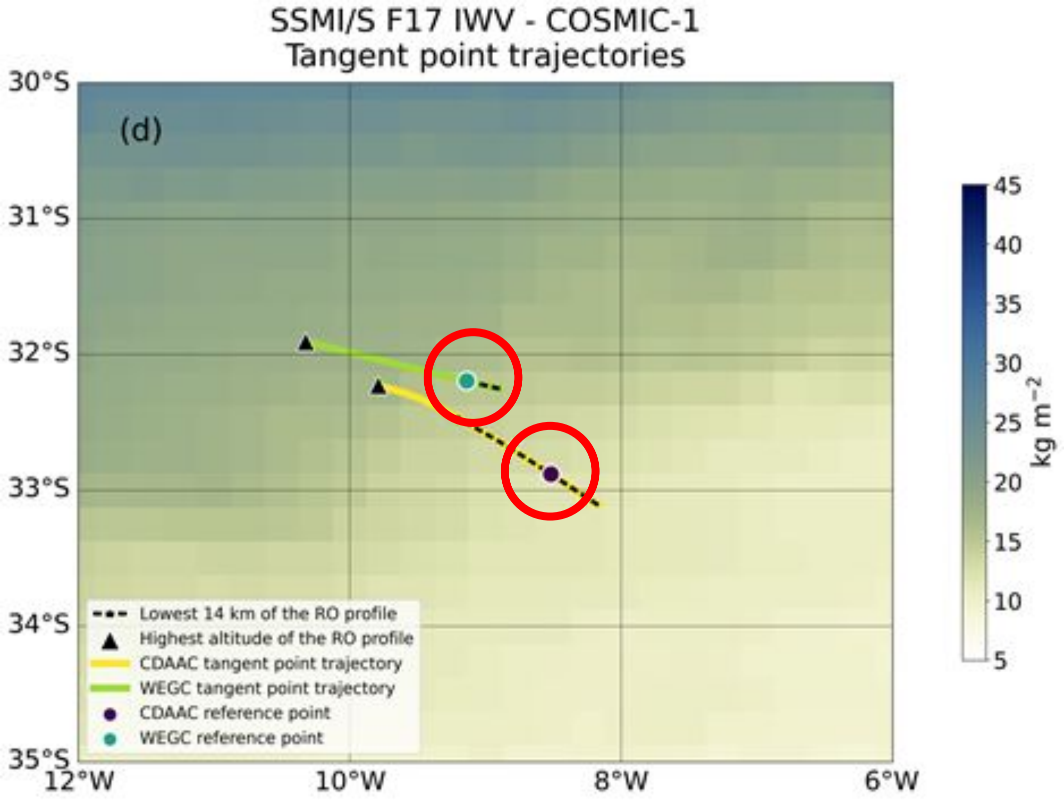


CDAAC and **WGC** specific humidity profiles with respective **background** and **reference** profiles. Within the red rectangle, we can expect the WEGC profile to differ considerably from its background.
In the **core of the AR** there is generally **good agreement**.

Map: **IWV** data from **SSMI/S** (Special Sensor Microwave Imager/Sounder) – only available over the ocean.

An unplanned Experiment

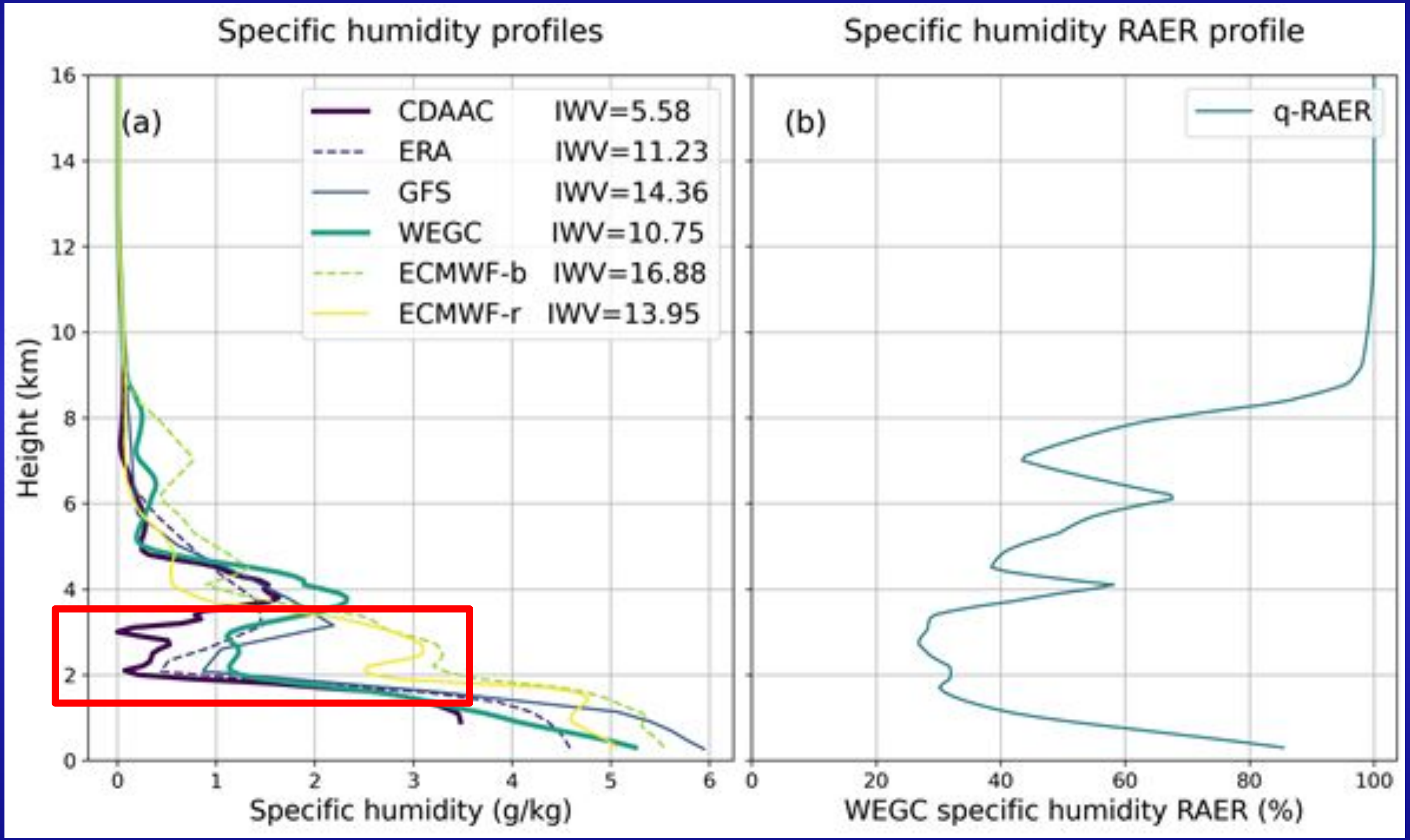




At the edge of ARs there are strong gradients – resulting in interesting effects – in particular at the western (here southern) edge.
CDAAC and WEGS (OPSv5.6) compute the RO reference point (and the TPT) in different ways.

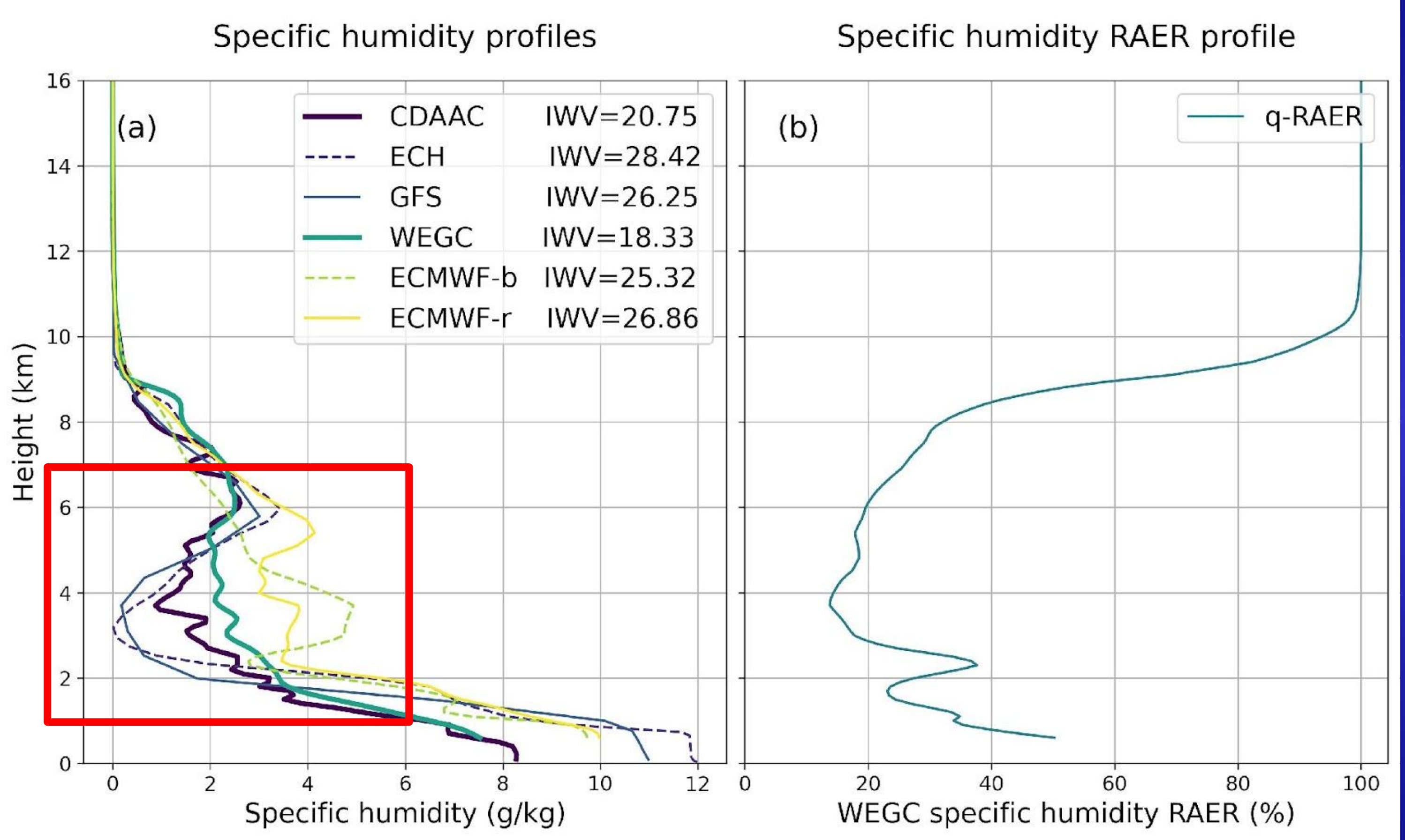
The CDAAC approach is more realistic in the troposphere. Here it means that the background profile is extracted in a much drier area than the WEGC BG. Note: This is the same profile – in different interpretations.

Influence of the Background



In the highlighted area, the RO profile "sees" very dry air. The **CDAAC** retrieval makes a **dry background even drier.** The **WGC starts** with **high** humidity and the retrieval "tries" to make the profile as dry as possible – within the limits allowed by the 1DVar.

Influence of the Background



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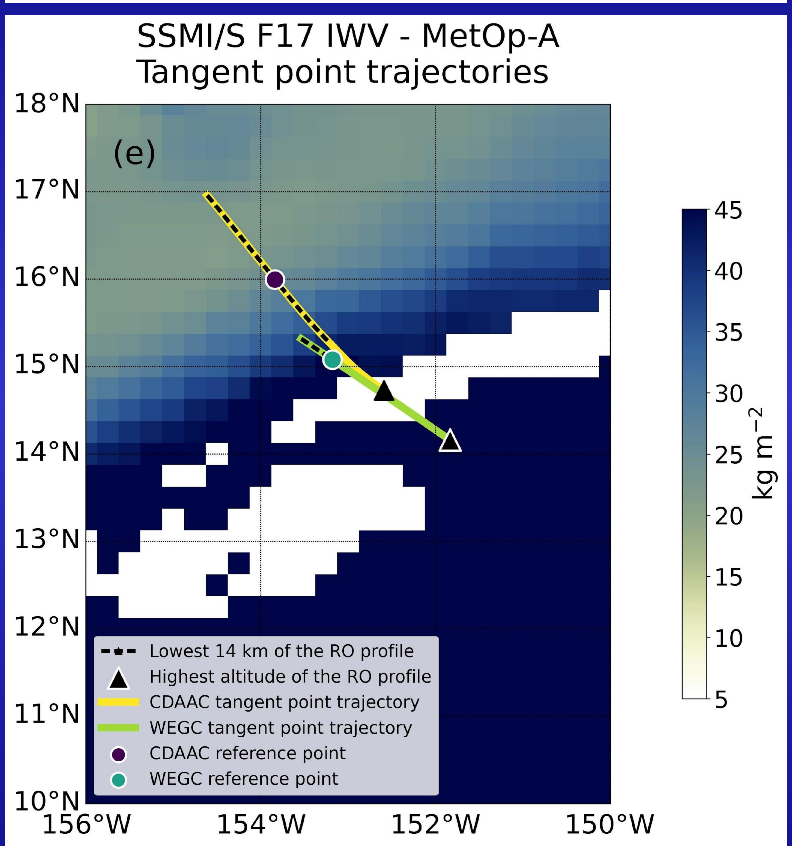

Here, the CDAAC and WEGC specific humidity profiles agree very well, although they start from totally different backgrounds.

Summary

RO humidity profiles clearly contain information that was not already in the background – in the altitude range, where the 1DVar scheme "allows" it.

The good agreement between CDAAC and WEGC Humidity profiles – even when starting from very different backgrounds – increases confidence in the results in this altitude range.

Operational analyses use little of this humidity information.

The tangent point trajectory matters.

A combination of SSMI/S data with high horizontal resolution and RO data with high vertical resolution could provide a good picture of the 3D structure of ARs – in particular in areas, where other data (Airborne RO, dropsondes …) are sparse.

Thank you very much!