ESA CCI+ Water Vapour (H$_2$O)

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Importance of water vapour (H$_2$O)

- H$_2$O is key component in Earth’s hydrological cycle.
- H$_2$O is key mediator of the Earth’s energy cycle.
  - Most important natural greenhouse gas
  - Strong positive feedback to anthropogenic climate forcing from CO$_2$
- Remote sensing yields global perspective.
- Identified as essential climate variable by GCOS.
### GCOS requirements

<table>
<thead>
<tr>
<th>Product</th>
<th>Frequency</th>
<th>Resolution</th>
<th>Uncertainty</th>
<th>Stability dec$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCWV</td>
<td>4h</td>
<td>25km</td>
<td>2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Tropospheric profiles</td>
<td>4h</td>
<td>25km / 2km</td>
<td>5%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Stratospheric profiles</td>
<td>Daily</td>
<td>100-200km / 2km</td>
<td>5%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

- GCOS requirements are a challenge in particular for observations from the past generation instruments.
Importance of tropospheric H$_2$O

- 95% of H$_2$O resides between the surface and 5 km.
- Essential for development of clouds, precipitation, and extreme weather.
- Influences Earth’s radiative balance directly and indirectly (via clouds).
- Impacts surface fluxes and soil moisture (drought).

**Processes controlling atmospheric water vapour distributions**

- Upper (300-100 hPa): Last saturation, horizontal isentropic mixing, subsidence
- Mid (700-300 hPa): Entrainment Detrainment, MOIST
- Low (850-700 hPa): Local evaporation

**Stratosphere**

- Extra-tropical dehydration
- Isentropic mixing

**Troposphere**

- Boundary layer

**Subtropics**

Sherwood et al., Rev. Geophys. 2010
Importance of stratospheric H$_2$O

- H$_2$O is critical in determining stratospheric ozone levels.
  - Leads to ozone destruction via the HO$_x$ catalytic radical cycle.
- Largest radiative forcing effect from H$_2$O changes around tropopause.
  - Can lead to important temperature biases in NWP models and reanalyses.

Forster & Shine, GRL 1999

A stratospheric water vapour trend of 0.4 ppmv/decade (Boulder trends) would have led to global surface warming that was 44% of that from CO$_2$ alone.
Statements from IPCC AR5

Because of large variability and relatively short data records, confidence\(^2\) in stratospheric H\(_2\)O vapour trends is low. Near-global satellite measurements of stratospheric water vapour show substantial variability but small net changes for 1992–2011. \(\{2.2.2.1\}\)

It is very likely that global near surface and tropospheric air specific humidity have increased since the 1970s. However, during recent years the near surface moistening over land has abated (medium confidence). As a result, fairly widespread decreases in relative humidity near the surface are observed over the land in recent years. \(\{2.4.4, 2.5.4, 2.5.5\}\)

Confidence is low for a global-scale observed trend in drought or dryness (lack of rainfall) since the middle of the 20th century, owing to lack of direct observations, methodological uncertainties and geographical inconsistencies in the trends. Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, this masks important regional changes: the frequency and intensity of drought have likely increased in the Mediterranean and West Africa and likely decreased in central North America and north-west Australia since 1950. \(\{2.6.2.2\}\)

Note, there is no statement on upper tropospheric water vapour despite its importance for radiative forcing and lapse-rate feedback.
Instrument types

Microwave Sounders and Imagers: MHS, AMSU, SMMR, SSM/I, AMSR, SSMIS
TIR Imaging Spectrometers: MVIRI, SEVIRI, ...
NIR Imaging Spectrometers: MERIS, MODIS, OLCI, ...
UV/Vis Spectrometers: GOME, SCIAMACHY, GOME-2, OMI, Sentinel-5P

Technical challenges: NIR and microwave

- Differing validity under clear sky and (near) all sky conditions.
- Long-term stability of NIR data record.
  - Demonstrating stability will be challenging globally and regionally.
- Processing of MERIS, MODIS, and in particular OLCI requires substantial resources.
- Merging between measurements over land and ocean.

→ → → ECV-1 and ECV-2
Vertically Resolved Observations

**Stratospheric Limb Sounders:**
SAGE, HALOE, SCIAMACHY, MIPAS, GOMOS, ACE-FTS, SMR, MLS

**IR Spectrometers:** HIRS, AIRS, IASI, CrIS

**GNSS Radio Occultation:** COSMIC, CHAMP, GRAS ...

**Technical challenges:**

- Less than 1% of H$_2$O is found in the stratosphere.
- Strongly limited spatial and temporal resolutions of limb sounders
- Quality of satellite measurements in UTLS is not known.
  - Strong gradients across the tropopause & horizontal fine scale structure.
  - Differing vertical resolution and hence information content.
  - In situ reference datasets for validation are limited.

⇒ ⇒ ⇒ ECV-3 and ECV-4
Deliverables – ECV Products

Total Column Products

Vertically Resolved (Profile) Products

Baseline ECV-1 & 2

Baseline ECV-3

Baseline ECV-4
Example merging (stratosphere)

Hegglin et al., *Nature Geosci.* 2014

- Large biases prevent straightforward merging.

- Using a chemistry-climate model as transfer function.

- Result: homogenized time series of stratospheric water vapour, which can be merged.
User community

- **Climate Modelling Centers**
  - Validation of climate models through comparisons with ECVs
  - Model development
  - Improvement of radiation budgets and hydrological processes
- **GDAP, G-VAP, SPARC CCMI, and CMIP6 AerChemMIP, PDRMIP, RFMIP**
  - Model intercomparisons and benchmarking
  - Emergent constraints
- **NWP centers (ECWMF)**
  - Development of climate reanalyses or weather forecasting
- **General climate researchers**
  - Process-studies (e.g., freeze-drying at cold-point tropopause)
  - Climate studies (variability and trends) on both global and regional scales
- **Climate services (C3S, ...)**
  - Climate information
Activity goals

- Delivering **high quality** ECV products that work towards fulfilling GCOS requirements within the assessed limitations of available observing systems.
  - **ECV-2** will deliver a merged homogenised TCWV product over land and ocean.
  - Merging of **ECV-4** requires particular innovation since methods are non-existing (stratospheric and tropospheric observations have historically been treated separately).

- Start preparing a **pre-operational** production and validation system.

- Analyzing variability and trends on different spatial and temporal scales, including **consistency** between observations and theoretical expectations (or models).

- Quantifying **uncertainties** that are useful to the end users.

- Connecting to end users through early involvement in the
  - Definition of user requirements
  - Definition of case studies that answer outstanding research questions.
THANK YOU FOR YOUR ATTENTION