HDO/H$_2^{16}$O observations from IASI to investigate hidden humidity tropospheric processes

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(1) Water vapour uncertainties & added value of isotopologues

(2) Retrieval of HDO/H$_2$O ratios: challenge & methodology

(3) Results above specific hydrological regions

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3. Laboratoire de Météorologie Dynamique (LMD), Paris, France
Water vapour uncertainties & added value of its isotopologues
Water vapour uncertainties

Key role of tropospheric water vapour:

→ Water vapour feedback: strongest infrared absorber, main contributor to the GHE (Schmidt et al., JGR, 2010)

→ Clouds feedbacks (Sherwood et al, 2010)

→ Deep convection (Derbyshire et al, 2004)


Dispersion due to different ways to represent hydrological processes

Water isotopologues reveal ‘hidden’ processes

They can served as diagnostic tool to evaluate processes representation in the models
Isotopologue | Isotopic abundance(%)  
---|---
\( \text{H}_2^{16}\text{O} \) | 99.7317  
\( \text{H}_2^{18}\text{O} \) | 0.199983  
\( \text{H}_2^{17}\text{O} \) | 0.0372  
\( \text{HD}^{16}\text{O} \) | 0.031069

Evaporation:

\[
\frac{\text{HDO}}{\text{H}_2\text{O}} 
\]

Condensation:

\[
\frac{\text{HDO}}{\text{H}_2\text{O}} 
\]

Sensibility to phase changes

Integrated footprint

\[
\frac{\text{HDO}}{\text{H}_2\text{O}} 
\]

Processes discrimination

How do water isotopologues reveal “hidden” hydrological processes?
Spatial distribution of δD

Isotope fractionation expressed in δ notation: $\delta D = 1000 \times \left( \frac{HDO/ H_{2}^{16}O}{SMOW} - 1 \right)$

Processes controlling water distribution also control isotopic composition.
How do water isotopologues reveal hidden hydrological processes?

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$p_0$ H$_2^{16}$O $>$ $p_0$ HDO $>$ $p_0$H$_2^{18}$O

**Evaporation**

**Condensation**

**Integrated footprint**

**Processes discrimination**

**Identification** of misrepresented processes

**Improvement of H$_2$O distributions**

**Sensibility to phase changes**

**δD Measurements**

**Isotopes GCM**
IASI performances for isotopologues applications

- **Spectral resolution** = 0.5 cm\(^{-1}\)
  Isotopologues spectral signatures well detected
- **Radiometric noise** \(\sim <0.25-0.5\) K
  Natural variations of \(\delta D >\) noise  \(\text{Not for } \delta^{18}\text{O}\)

★ **IASI sampling characteristics**
(2) Retrieval of HDO/H$_2$O ratios: challenge & methodology
Difficulties:

- High variability of water, in space and in time.
- High precision needed to capture isotopic variations (Δ 20‰ ≈ 2%)

Original approach:

**Introduction of correlation information between HDO and H₂O in the retrieval (optimal estimation method)**

*Schneider et al., ACP, 2006; Worden et al., JGR, 2006*

+ retrieval performed on a logarithmic scale

\[
\hat{x} = x_a + (K^T S_{e}^{-1} K + S_a^{-1})^{-1} K^T S_{e}^{-1} (y - Kx_a)
\]

\[
\begin{bmatrix}
\log H_2O_{1 \text{ km}} \\
\vdots \\
\log H_2O_{10 \text{ km}} \\
\log HDO_{1 \text{ km}} \\
\vdots \\
\log HDO_{10 \text{ km}}
\end{bmatrix}
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\vdots \\
\log HDO_{10 \text{km}}
\end{bmatrix}
\]

Retrieval methodology: adding a constraint in the OEM

+ retrieval performed on a logarithmic scale
The \textit{a priori} covariance matrix $S_a$:

- Sparse dataset available
- \textit{A priori} information built from isotope enabled GCM (LMDZ-iso)
- Covariance from the whole globe and an entire year
- Decrease of the inter-species elements of the $S_a$

\begin{itemize}
  \item Original \textit{a priori} variability from LMDZ
\end{itemize}
The *a priori* covariance matrix $S_a$:

- **Sparse dataset available**

- **A priori** information built from isotope enabled GCM (LMDZ-is)

- Covariance from the whole globe and an entire year

- Decrease of the inter-species elements of the $S_a$

- Increase of the *a priori* variability of HDO/H$_2$O ratio

*A priori* variability [%]
**Spectral window:**

Small spectral range from 1195-1253 cm\(^{-1}\)

Gap between 1223 & 1251 cm\(^{-1}\)
  To avoid CH\(_4\) and N\(_2\)O interferences

- Short retrieval time
- Fit close to noise level

**Others:**

- Cloud free spectra (≈ EUMETSAT L2 cloud flag < 10 %)
- Retrieval on the 10 first kilometers of the atmosphere
Sensitivity and error characterization

Sensitivity of the retrieval to HDO/H\textsubscript{2}O ratio

- Smoothing error on log(HDO/H\textsubscript{2}O)
  \( S_{\text{sm}} \)
- A priori variability
  \( S_{a} \)
- Measurement error & T profile error
  Total Error
Smoothing error on log(HDO/H$_2$O)

A priori variability $S_a$

Error reduction $S_{sm}/S_a$

Sensitivity and error characterization
Sensitivity and error characterization

**Sensitivity of the retrieval to HDO/H$_2$O ratio**

<table>
<thead>
<tr>
<th>Altitude [km]</th>
<th>Error [permil]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>0.2</td>
<td>3</td>
</tr>
<tr>
<td>0.3</td>
<td>4</td>
</tr>
<tr>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>0.5</td>
<td>6</td>
</tr>
</tbody>
</table>

**Smoothing error**

Between 3 and 6 km → Precise and sensitive $\delta$D for scientific issues
Results above specific hydrological regions

Subsidence site, Izaña
Convective site, Darwin
Latitudinal gradient
Evaluation of results against model data

Darwin:
Convective site

\[ \delta D \text{ [permil]} \]

\( r = 0.55 \)

\( r = 0.69 \)

Mean bias: 2 \( \% \)

\( \Delta D \text{ [permil]} \)

\( \text{H}_2\text{O} \text{ [g/kg]} \)

Lacour J.-L. et al., ACP 2012
Evaluation of results against model data

Darwin:
Convective site

\[ \delta D \text{ [permil]} \]

Mean bias: 2 \( \% \)

\[ \text{H}_2\text{O [g/kg]} \]

Lacour J.-L. et al., ACP 2012
Evaluation of results against model data

Izaña: Subsidence site

$I = \text{LMDZ-iso}$

$r = 0.64$

$IASI$

$\Delta D$ [permil]

$\Delta$ difference LMDZ-IASI [permil]

January

December
Evaluation of results against model data

Izaña: Subsidence site

$r=0.64$

\[ \delta D [\text{permil}] \]

\[ \delta D \text{ difference LMDZ-ASI} [\text{permil}] \]

January

December
Evaluation of results against model data

Izaña: Subsidence site

Known feature of LMDz:
Underestimation of the seasonality at subtropical latitudes (Risi C. et al, JGR, 2012a)
Short term variability - detrended timeseries

\[ \sigma_{\text{IASI}} (32\%\circ) > \sigma_{\text{LMDZ}} (27\%\circ) \]

\[ \sigma_{\text{IASI}} (37\%\circ) > \sigma_{\text{LMDZ}} (35\%\circ) \]
Maritime continent – Dynamic control on $\delta D$

Monthly mean

January 2011

Convection

Vertical velocity @ 500 hPa [Pa/s]

(< MERRA Monthly History Data Collections via GIOVANNI)
Latitudinal gradients

Retrievals from 60°N to 60°S above the Atlantic
(short longitudinal extent)

→ Investigating the humidity processes responsible of the δD latitudinal variability
Summary and perspectives

- IASI provides $\delta^D$ precise and sensitive enough for scientific use
- $\delta^D$ retrievals ‘evaluation’ against LMDZ-iso shows nice agreements
  - Seasonal -> short term variability in good agreements with LMDZ
  - Main differences model-IASI have already been identified as model issues
- Growing number of possibilities towards validation
  - MUSICA project (Schneider et al, 2012)
  - Airplane $\delta^D$ measurements within HYMEX campaign - cavity ringdown spectrometer (H. Sodemann, EGU 2013)
- CONV-ISO (C. Risi, LMD)
  Studying convective and cloud processes during the MJO and evaluating their representation in climate models by combining humidity, cloud and water isotopic measurements + TES (J. Worden), IASI MUSICA (M. Schneider), GOSAT (C. Frankenberg)

Courtesy of H. Sodemann