A discussion on the paper “Evidence of deuterium excess in water vapor as an indicator of ocean surface conditions”

By Ryu Uemura et al., 2008

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2015.09.18
Outline

- Background
- Objectives
- Methods
- Results and Discussions
- Conclusions
Background

- The isotopic composition of most of meteoric water is found in a graph of $\delta D$ versus $\delta^{18}O$ along the “Global Meteoric Water Line”: $\delta D = 8\times\delta^{18}O + 10\%$; the deuterium excess $d$ has been defined as the difference $d = \delta D - 8\times\delta^{18}O$. [Craig, 1961; Dansgaard, 1964]

- The glacial-interglacial changes in $d$ were interpreted as changes in relative humidity and temperatures at the moisture source ocean. [Jouzel et al., 1982; Cuffey and Vimeux, 2001]

- The interpretation of $d$ which relies on various models predicts a close relationship between $d$ and ocean surface conditions.

- A few in situ measurements of vapor isotopes in the oceans have been reported, but $d$ has not been observed except for subtropical oceans and the Mediterranean Sea. [Craig and Gordon, 1965; Gat et al., 2003]

- In this study, we measured isotope compositions of air moisture in the Southern Ocean, then discussed the observation results and simulations from a couple of isotope GCMs.
A global-scale closure assumption \((\delta_{V0} = \delta_{E})\)

\[
1 + \delta_{V0} = \frac{1}{\alpha} \frac{(1 - k)}{1 - kh} (1 + \delta_{\text{ocean}}) \ldots \ldots (1)
\]

\(\delta_{V0}\) — the initial isotope content in the water vapor;
\(\delta_{E}\) — the isotope contents of the evaporating water;
\(\delta_{\text{ocean}}\) — an ocean isotope composition;
\(k\) — a kinetic fractionation factor;
\(\alpha\) — an equilibrium fractionation factor;
\(h\) — relative humidity defined as a value normalized on the SST \((h^*)\) in the model.

[Merlivat and Jouzel, 1979]
Objectives

- Showing the isotope ratios of atmospheric water vapor near the ocean surface in middle and high latitudes of the Southern Ocean.

- Showing the correlations between deuterium excess \((d)\) versus relative humidity \((h)\) and \(d\) versus sea surface temperature (SST).

- Using atmospheric general circulation models (GCMs) to predict the isotope ratios of marine vapor and validating GCMs through data.
Outline

♦ Background
♦ Objectives
♦ Methods
  – Ship observation
  – A vapor sampling system
  – Isotope general circulation model
♦ Results and Discussions
♦ Conclusions
Measurements

Air temperature and relative humidity were measured at 15 m altitude on the ship.

**Figure 1.** Sampling sites on a map of the ship route (gray).
Figure 2. Schematic of the sampling system installed on the ship.
Isotope general circulation model

A global-scale closure assumption \((\delta_{V0} = \delta_{E})\)

Systematic bias

An atmospheric general circulation models (GCMs)

The GCMs explicitly simulate the global and regional features of atmospheric dynamics and thermodynamics and the detailed hydrological cycles.

1. **Isotope Global Spectral Model (iso-GSM)** [Yoshimura et al., 2008]
   - 200 km horizontal resolution + 28 vertical sigma levels

2. **NASA Goddard Institute for Space Studies (GISS) GCM II** [Jouzel et al., 1987]
   - \(8^\circ \times 10^\circ\) resolution + 9 vertical sigma levels
Outline

- Background
- Objectives
- Methods
- Results and Discussions
  - A. Isotope ratios in vapor
  - B. Deuterium excess in vapor
  - C. Comparison with GCMs
- Conclusions
## Results and Discussions

**Table 1.** Isotope Ratios in Water Vapor and Meteorological Conditions Along the Ship Route

<table>
<thead>
<tr>
<th>Sampling Start Time (UTC)</th>
<th>Sampling Duration (h)</th>
<th>Latitude (°S)</th>
<th>Longitude (°E)</th>
<th>Atmospheric Pressure (hPa)</th>
<th>Air Temperature (°C)</th>
<th>SST (°C)</th>
<th>h(%)</th>
<th>δ¹⁸O(‰)</th>
<th>δD(‰)</th>
<th>d(‰)</th>
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<tbody>
<tr>
<td><strong>Leg 1 (Cape Town to Antarctica)</strong></td>
<td></td>
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<td>5 Jan. 0413</td>
<td>01:42</td>
<td>38.91</td>
<td>20.11</td>
<td>1017</td>
<td>18.3</td>
<td>22.8</td>
<td>63.7</td>
<td>-15.71</td>
<td>-91.7</td>
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<td>03:00</td>
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<td>20.53</td>
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<td>-86.5</td>
<td>30.0</td>
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<td>18.7</td>
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<td>-96.3</td>
<td>19.5</td>
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<td><strong>Leg 2 (Antarctic Coastal Area)</strong></td>
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<td>34.54</td>
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<td>-0.3</td>
<td>0.1</td>
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<td>-17.24</td>
<td>-132.2</td>
<td>5.8</td>
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<tr>
<td>11 Jan. 1145</td>
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<td>65.46</td>
<td>34.55</td>
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<td>-1.6</td>
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<td><strong>Leg 3 (Antarctica to Fremantle)</strong></td>
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<td>67.3</td>
<td>-14.60</td>
<td>-97.9</td>
<td>18.9</td>
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</table>

*a*Latitude and longitude are shown in decimal system.
Figure 3. Latitudinal distribution of $\delta D$, $\delta^{18}O$ and $d$ in water vapor.
Figure 4.
Time series of isotope compositions and metrological conditions.
Figure 5. Correlations of $d$ in vapor versus relative humidity and SST.

A multilinear regression analysis of $d$, $h$ and SST

$$d = 0.45 \text{ SST} - 0.42 \ h + 37.9 \quad R^2 = 0.73$$
Figure 6. Comparison with GCM.

- **blue line** — the $d$ in marine vapor predicted by the iso-GSM
- **blue shaded area** — 1σ
- **slashed area** — 2σ

(the standard deviations of the model predicted $d$)
Conclusions

- The large variation of $\delta D$ and $\delta^{18}O$ found south of $65^\circ S$ is attributed to the mixture of marine and Antarctic vapors.

- The $\delta D$ in vapor decreases along with higher latitude from $30^\circ S$ to $60^\circ S$, the gradient of $\delta^{18}O$ from $30^\circ S$ to $60^\circ S$ is flat in comparison to that of $\delta D$ because of kinetic fractionation during the evaporation.

- The $d$ in vapor shows statistically significant correlations with $h$ and SST, then provides the first evidence for a close relation between $d$ and ocean surface conditions in different southern oceans.

- The observations are consistent with isotope ratios simulated by the iso-GSM, and thus validate the simulation.
THANK YOU