Investigating the relationship between ozone and water-ice clouds in the martian atmosphere

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INVESTIGATING THE RELATIONSHIP BETWEEN OZONE AND WATER-ICE CLOUDS IN THE MARTIAN ATMOSPHERE

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Ozone on Mars

- Trace gas in the martian atmosphere <0.01%¹
- Breaks down in ultraviolet (UV) light; 220-280nm¹,²
- Used to track general circulation of the atmosphere and other trace gases²
- Is anticorrelated with water vapour (can be used as a proxy)²,³,⁴
- Varies diurnally and seasonally⁴

Composition of martian atmosphere

<table>
<thead>
<tr>
<th>Gas</th>
<th>Volume / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>95.32</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.7</td>
</tr>
<tr>
<td>Argon</td>
<td>1.6</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.13</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.08</td>
</tr>
<tr>
<td>Water</td>
<td>Trace</td>
</tr>
<tr>
<td>Ozone</td>
<td>Trace</td>
</tr>
</tbody>
</table>

¹Barth et al. (1973); ²Clancy and Nadir (1996); ³Lefèvre and Montmessin (2013); ⁴Perrier et al. (2006)
**Aim:** Improve the current understanding of the chemical processes in the martian atmosphere by investigating the interaction between ozone and water-ice and heterogeneous chemistry.

**Method:** Use the 1-dimensional Laboratoire de Météorologie Dynamique (1-D LMD)\(^1\,^2\) model to simulate a column of the atmosphere.

Test 1-D model:
- Current hetero/homogeneous chemistry
- Equatorial and polar latitudes

**Model:** The 1-D model is a physical submodel from the LMD global climate model (GCM) suited for testing chemical processes as it is not as computationally expensive as a full GCM.

1 Forget et al. (1999); 2 Lefèvre et al. (2008)
**Martian atmospheric chemistry**

Water vapour: $\text{H}_2\text{O}(g)$

**Reactions impacting $\text{O}_3$**

- Forms $\text{O}_3$
- Destroys $\text{O}_3$
- Neutral

**Hydroxyl radicals**

- $\text{O} + \text{OH}$

**Ozone**

- $\text{O}_3 + \text{HO} \rightarrow \text{O}_2 + \text{HO}_2$

Sunlight; $h\nu$

Clancy et al. (1996, 2016); Lefèvre et al. (2004, 2008)
Water vapour
\[ \text{H}_2\text{O}(g) \]
\[ + \]
\[ \text{O} + \text{OH} \]
\[ \text{hv} \]

Ozone
\[ \text{O}_3 \]
\[ + \]
\[ \text{O} + \text{O}_2 \]
\[ \text{hv} \]

Hydroxyl radicals
\[ \text{HO, HO}_2, \text{H}_2\text{O}_2 (\text{HO}_x) \]

Water-ice
\[ \text{H}_2\text{O}(s) \]

Water-ice clouds act as a sink for \( \text{HO}_x \)

Ozone abundance increases as \( \text{HO}_x \) are adsorbed onto the surface of water-ice clouds.

Reactions impacting \( \text{O}_3 \)

Heterogeneous
Forms \( \text{O}_3 \)

Destroy \( \text{O}_3 \)

Neutral

Lefèvre et al. (2004, 2008)
Current models

The heterogeneous GCM run over-predicts ozone abundance during aphelion, while the homogeneous run under-predicts during the start of aphelion.

Neither model captures the increase in ozone just before $L_s$ 50° well.

The heterogeneous model captures the increase in ozone from $L_s$ 150° onwards.
1-Dimensional modelling (diurnal)

Simulated diurnal vertical profile of ozone with heterogeneous chemistry (left), and homogeneous chemistry (right) over one sol, at latitude 0° and $L_s$ 0°.
1-Dimensional modelling (diurnal)

Simulated diurnal vertical profile of ozone with heterogeneous chemistry (left), and homogeneous chemistry (right) over one sol, at latitude $0^\circ$ and $L_s 0^\circ$.

Water-ice clouds form at night when the temperature drops and water vapour condenses.
1-Dimensional modelling (annual)

Full martian year of simulated ozone with heterogeneous chemistry (left) and homogeneous chemistry (right) at latitude 0° with 48 timesteps per sol. Time is given in solar longitude, $L_s$. 
The ozone abundance is a result of a feature called the Aphelion Cloud Belt; water-ice clouds form between 30-40 km during aphelion when the temperature is cold enough for water vapour to condense. Water-ice clouds also form at high latitudes during the winter.

References:
1. Benson et al. (2010);
2. Benson et al. (2011);
3. Mateshvili et al. (2007);
4. Wolff et al. (2019)
The ozone abundance is a result of a feature called the Aphelion Cloud Belt; water-ice clouds form between 30-40 km during aphelion when the temperature is cold enough for water vapour to condense.  

Water-ice clouds also form at high latitudes during the winter\textsuperscript{1,2}.  

Water-ice clouds form around 30 km altitude\textsuperscript{3}.  

\textsuperscript{1}Benson et al. (2010); \textsuperscript{2}Benson et al. (2011); \textsuperscript{3}Mateshvili et al. (2007); \textsuperscript{4}Wolff et al. (2019)
The ozone abundance is a result of a feature called the Aphelion Cloud Belt; water-ice clouds form between 30-40 km during aphelion when the temperature is cold enough for water vapour to condense\(^3,4\).

Water-ice clouds also form at high latitudes during the winter\(^1,2\).

The current heterogeneous scheme over-predicts ozone abundance (Clancy et al. 2016).
Next steps

- Test 1-D model at high latitudes where clouds are expected to form
- Use observed vertical profiles of water vapour to simulate a more accurate water cycle
- Develop heterogeneous reactions between hydroxyl radicals and water-ice clouds
- Validate/compare results with ozone and water-ice observations from ExoMars Trace Gas Orbiter
Summary

- Ozone is photosensitive and anti-correlated with water vapour
- Current global climate models either over- or under-predict ozone abundance depending if the model is run with heterogeneous chemistry
- This project uses a 1-D model to test and develop the heterogeneous chemistry, using ozone abundance to highlight these effects