Trends in Atmospheric Humidity and Temperature above Dome C, Antarctica Evaluated from Observations and Reanalyses

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1) One of the largest and most rapid warmings recorded on Earth is occurring over the Antarctic Peninsula (Western Antarctica) with values of $\sim 0.5^\circ \text{C dec}^{-1}$ since 1950.

2) Over the Antarctic Plateau (Eastern Antarctica), the temperature trends depend upon the season with significant cooling in autumn and significant warming in spring.

3) Temperature trends over Antarctica are attributed to the influence of the Southern Annular Mode (SAM). The phase of the SAM is determined by the position of the westerly winds that surround the Antarctic continent, and the occurrence of high or low pressure over Southern Australia.

→ Trends in humidity and temperature over Dome C are evaluated in line with SAM time evolution.

Motivations

The data sets

- **Dome C, Concordia (75°06'S, 123°21'E, 3233 m)**

  **Observations**
  - Radiosondes (1/day)
    - 10-m T, T(z), H2O(z) & IWV
    - 2005-2017
  - HAMSTRAD microwave radiometer (60 & 183 GHz)
    - 10-m T, IWV
    - 2012-2017

- **Reanalyses**
  - ERA Interim
  - ERA5
  - MERRA2
  - JRA-55
    - Near-surface Temperature & IWV
    - 1980-2017

- **SAM index**
  - 1980-2017
• The annual cycle indicates a dry (IWV ~ 0.1 kg m\(^{-2}\)) and cold (~205 K) winter in JJA followed by a moist (IWV ~ 0.6-0.8 kg m\(^{-2}\)) and warm (~250 K) summer in DJF, consistent with numerous studies.
• In summertime, the atmosphere can be very humid, reaching daily values greater than 1.0 kg m\(^{-2}\), and as high as 1.7 kg m\(^{-2}\), such as in 2010-2011, 2013-2014 and 2016-2017, and extremely warm (~255 K) such as in 2010-2011 and 2013-2014.
Correlations: T-IWV vs H2O-IWV

- From 100 to 1000 m, $R_{T-IWV}$ is rather constant with height: from 0.90-0.95 to 0.75-0.85. Below 100 m, $R_{T-IWV}$ decreases to reach ~0.70 near the surface (10 m) in all seasons but spring (~0.60).
- From 100 to 1000 m, $R_{H2O-IWV}$ ranges between 0.85-1.0. Below 100 m, $R_{H2O-IWV}$ tends to decrease to 10 m, with $R_{T-IWV} > R_{H2O-IWV}$ except in summer
→ The near-surface temperature can be considered as a better proxy of the time evolution of IWV in the Dome C atmosphere than the near-surface water vapor
• The vertical distribution of H2O does not peak at the surface but around 100-200 m and dramatically decreases to 10 m
• The planetary boundary layer is clearly identified from the surface to about 100-200 m with a thermal stratification greater in winter (18 K / 200 m) than in summer (3 K / 200 m)
• 10-m atmosphere very dehydrated in all seasons but summer ($R_{T-IWV} > R_{H2O-IWV}$ in all seasons but summer)
• Significant warming /moistening trends in summer 2005-2017 (as at South Pole and Vostok: 1999-2016*)
• Significant cooling/drying in winter and autumn 2005-2017 (winter warming at South Pole and cooling at Vostok: 1999-2016*)


<table>
<thead>
<tr>
<th></th>
<th>Summer (DJF)</th>
<th>Autumn (MAM)</th>
<th>Winter (JJA)</th>
<th>Spring (SON)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAMS 2012-2017</td>
<td>0.09 ± 0.22</td>
<td>-0.05 ± 0.07</td>
<td>-0.04 ± 0.09</td>
<td>0.02 ± 0.28</td>
<td>0.04 ± 0.06</td>
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<tr>
<td>RS 2012-2017</td>
<td>0.04 ± 0.17</td>
<td>-0.08 ± 0.07</td>
<td>-0.06 ± 0.08</td>
<td>0.01 ± 0.12</td>
<td>-0.07 ± 0.05</td>
</tr>
<tr>
<td>RS 2005-2017</td>
<td>0.08 ± 0.06</td>
<td>-0.04 ± 0.03</td>
<td>-0.05 ± 0.03</td>
<td>0.01 ± 0.04</td>
<td>-0.01 ± 0.04</td>
</tr>
<tr>
<td>HAMS 2012-2017</td>
<td>8.68 ± 8.77</td>
<td>-3.18 ± 3.66</td>
<td>-7.10 ± 3.15</td>
<td>2.69 ± 11.42</td>
<td>1.33 ± 0.96</td>
</tr>
<tr>
<td>RS 2012-2017</td>
<td>0.79 ± 1.00</td>
<td>-10.03 ± 1.30</td>
<td>-9.88 ± 3.70</td>
<td>-1.99 ± 3.24</td>
<td>-2.65 ± 0.72</td>
</tr>
<tr>
<td>RS 2005-2017</td>
<td>1.08 ± 0.55</td>
<td>-2.43 ± 1.16</td>
<td>-5.06 ± 1.99</td>
<td>-0.30 ± 1.35</td>
<td>-1.80 ± 1.54</td>
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</tbody>
</table>

**Significant trends**
1980–2017 Trends from Reanalyses & SAM

<table>
<thead>
<tr>
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<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IWV (kg m⁻² dec⁻¹)</td>
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<td></td>
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</tr>
<tr>
<td>MERRA2</td>
<td>0.012±0.009</td>
<td>0.006±0.008</td>
<td>-0.004±0.006</td>
<td>0.007±0.004</td>
<td>0.005±0.004</td>
</tr>
<tr>
<td>ERA Interim</td>
<td>-0.035±0.011</td>
<td>-0.008±0.007</td>
<td>-0.015±0.007</td>
<td>-0.001±0.005</td>
<td>-0.015±0.004</td>
</tr>
<tr>
<td>ERA5</td>
<td>-0.017±0.010</td>
<td>-0.007±0.007</td>
<td>-0.014±0.007</td>
<td>0.003±0.005</td>
<td>-0.008±0.004</td>
</tr>
<tr>
<td>JRA-55</td>
<td>-0.010±0.009</td>
<td>-0.001±0.007</td>
<td>-0.009±0.006</td>
<td>0.008±0.004</td>
<td>-0.003±0.004</td>
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<tr>
<td></td>
<td>Near-Surface Temperature (K dec⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MERRA2</td>
<td>0.07±0.16</td>
<td>-0.11±0.25</td>
<td>-0.56±0.35</td>
<td>-0.15±0.19</td>
<td>-0.19±0.17</td>
</tr>
<tr>
<td>ERA Interim</td>
<td>-0.15±0.14</td>
<td>-0.20±0.24</td>
<td>-0.41±0.39</td>
<td>0.01±0.20</td>
<td>-0.19±0.15</td>
</tr>
<tr>
<td>ERA5</td>
<td>0.21±0.15</td>
<td>-0.24±0.24</td>
<td>-0.63±0.36</td>
<td>0.06±0.20</td>
<td>-0.15±0.13</td>
</tr>
<tr>
<td>JRA-55</td>
<td>-0.16±0.11</td>
<td>0.09±0.24</td>
<td>-0.08±0.29</td>
<td>0.40±0.17</td>
<td>0.06±0.14</td>
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<tr>
<td></td>
<td>SAM index (index dec⁻¹)</td>
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</tr>
<tr>
<td>SAM</td>
<td>0.08±0.13</td>
<td>-0.09±0.09</td>
<td>0.20±0.14</td>
<td>0.08±0.12</td>
<td>0.04±0.08</td>
</tr>
</tbody>
</table>

- Only in winter, all the data sets show cooling and drying trends (significant for ERA-Int and ERA5) associated with a significant positive trend in the SAM index

- **Summer moistening/warming and autumn-winter drying/cooling trends** observed in the beginning of the 21st century with RS 1) agree with the reanalyses but 2) are not consistently present at the end of the 20th century
- **Periods of moistening/warming alternate with periods of drying/cooling in seasonal over 1980-2017 → multidecadal variability and not long-term trends of the atmosphere**
• Near-surface temperature highly correlated with IWV ($R \sim 0.7-0.9$) for all seasons
• The SAM index multidecadal variability is clearly anticorrelated to those in IWV and near-surface temperature for all the seasons but spring (SON)
• Larger anticorrelation for IWV than for temperature ($R$ varying from -0.5 to -0.75 and from -0.30 to -0.60, respectively)
Conclusions

- Decadal trends in humidity and temperature at Dome C are evaluated from observations (radiosondes and HAMSTRAD) over 2005-2012 and reanalyses over 1980-2017 and correlated with the evolution of the SAM index.

- A significant moistening trend (0.08 ± 0.06 kg m⁻² dec⁻¹) is associated with a significant warming trend (1.08 ± 0.55 K dec⁻¹) in summer. A significant drying trend of -0.04 ± 0.03 kg m⁻² dec⁻¹ (-0.05 ± 0.03 kg m⁻² dec⁻¹) is associated with a significant cooling trend of -2.4 ± 1.2 K dec⁻¹ (-5.1 ± 2.0 K dec⁻¹) in autumn (winter) with no significant trends in the spring.

- The trends identified from the radiosondes (2005-2017) are also present in the reanalyses.

- The multidecadal variability of IWV and near-surface temperature is strongly influenced by that of the SAM index for all the seasons but spring.

- The decadal trends observed in humidity and near-surface temperature at Dome C since the beginning of the 21st century simply reflect the multidecadal variability of the atmosphere and thus are not indicative of the long-term trends of the atmosphere.
Thank you