Present and Future of Rainfall in Antarctica

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Snowfall-Rainfall in Antarctica: insignificant phenomenon or serious issue?

January 2016 extensive summer melt in West Antarctica favoured by strong El Niño

Julien P. Nicolas, Andrew M. Vogelmann, Ryan C. Scott, Aaron B. Wilson, Maria P. Cadet, David H. Bromwich, Johannes Verlinde, Dan Lubin, Lynn M. Russell, Colin Jenkins, Heath H. Powers, Maciej Ryckebusch, Gregory Stone & Jonathan D. Wiles

‘Rain fell over parts of the Ross Ice Shelf at the beginning of the event, which may have preconditioned the snow surface for prolonged melting’
Snowfall Rainfall in Antarctica: insignificant phenomenon or serious issue?

Rain fell over parts of the Ross Ice Shelf at the beginning of the event, which may have preconditioned the snow surface for prolonged melting.' Small chicks are covered with a downy plumage that has little – if any – waterproofing ability. With unusual rain in this normally dry and cold desert, the chicks’ thermo-regulation capacities weakened rapidly. 

A complete breeding failure in an Adélie penguin colony correlates with unusual and extreme environmental events.

Yan Ropert-Coudert, Akiko Kato, Xavier Meyer, Marie Pellé, Andrew J. J. MacIntosh, Frédéric Angelier, Olivier Chastel, Michel Widmann, Ben Arthur, Ben Raymond and Thierry Raclot

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“Small chicks are covered with a downy plumage that has little – if any – waterproofing ability. With unusual rain in this normally dry and cold desert, the chicks’ thermo-regulation capacities weakened rapidly.”

→ How often and how much rain falls over the Antarctic?
→ How rain will change (or not) in the future?
How to detect/measure rainfall in Antarctica?

Rainfall rate in Cloudsat

No rainfall?
rare rain events and low overpass frequency
+ no measurements below 1500 m a.g.l. (below the melting layer)
How to detect/measure rainfall in Antarctica?

Rainfall rate in Cloudsat

Ground-based measurements

- radars
- ‘precipitation camera’

No rainfall? rare rain events and low overpass frequency + no measurements below 1500 m a.g.l. (below the melting layer)

High-vertical resolution near the surface (below the melting layer)

Short times series at a few single locations
How to detect/measure rainfall in Antarctica?

Rainfall rate in Cloudsat

Ground-based measurements

Visual observations by meteorologists

No rainfall?
- rare rain events and low overpass frequency
- no measurements below 1500 m a.g.l. (below the melting layer)

High-vertical resolution near the surface (below the melting layer)

Short times series at a few single locations
How to detect/measure rainfall in Antarctica?

- 10 permanent stations (data all year long)
- Meteorological reports for several decades
- Different Antarctic sectors

<table>
<thead>
<tr>
<th>station</th>
<th>period</th>
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<tbody>
<tr>
<td>DDU</td>
<td>01/01/1982-31/12/2015</td>
</tr>
<tr>
<td>Casey</td>
<td>01/01/1989-31/12/2017</td>
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<td>Davis</td>
<td>01/01/1958-31/12/2017</td>
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<td>Mawson</td>
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<td>Syowa</td>
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<td>Neumayer</td>
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<tr>
<td>Halley</td>
<td>01/01/1957-31/12/2016</td>
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<tr>
<td>FV</td>
<td>01/01/1979-31/12/2015</td>
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<tr>
<td>Rothera</td>
<td>01/01/1977-31/12/2008</td>
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<tr>
<td>South Pole</td>
<td>01/01/1992-31/12/2017</td>
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</table>
**Occurrences of rainfall at present**

- Rainy day = day with at least one obs. of rain (for ERA5, dominant « liquid » precipitation type during at least 1h)

- Coast of East-Antarctica: between 1 to 5 rainy days per year in average (max 21 in 1 year)

- Western Peninsula: 50 (93) days with rain per year at Rothera (Vernadsky)

- No rain in coastal Victoria Land, drizzle at South Pole

- Mostly in summer but not only

- ERA5 generally underestimate the occurrence of rainfall
Dynamics of rainfall events

- Composite of 500hpa temperature, geop. Height and wind anomalies during rainy days
- Composite of IWV anomalies during rainy days
- **blocking anticyclone** anomaly to the east of the station *(stronger than during snowfall events)*
- Warm and moist anomaly *(NE-SW tongue)*
• **East-Antarctica**: slight but significant decrease in the number of annual rainy days at Mawson and Casey in the past 25 years

• **Peninsula**: significant increase until ~1998 then **strong decrease** in rain occurrence at Faraday-Vernasky station: - 35 days dec⁻¹ (similar but less pronounced signal at Rothera)
Rainfall amount in the future

- 7 CMIP6 models
- 2 scenarios (moderate emissions SSP2.45, high emissions SSP5.85)
- Liquid precipitation corresponds to 0.5%–3.9% of the current total precipitation amount in models

In SSP5.85:
- **Positive trends** in liquid precipitation and in liquid fraction of precipitation over the 2015–2100 period are significant at the 1% level for all sectors but the Plateau
- On average liquid precipitation will explain (on average) 15.3 % of the increase in precipitation, 56.9 % over the Peninsula
- The contribution of liquid precipitation to total precipitation is expected to increase by a factor of 2–5 by the end of the century
Rainfall in the future at some stations (CNRM-CM6 model, SSP5.85)

Future rainfall
- More frequent
- More intense

Temperature during precipitation days
1995-2014 2081-2100

Daily amount of liquid precipitation
1995-2014 2081-2100

- Daily mean tas [°C]
- Daily liquid precip. [mm]
Rainfall and pre-conditioning of surface-snow melting

- Areas with temperatures greater than 0°C together with significant liquid precipitation amount will increase by a factor of ~ 3 by the end of the century.

- Ronne, Filchner and Ross ice-shelves are expected to be particularly affected.

Change in the annual number of days with $T > 0^\circ C$ and rainfall $> 1$ mm day$^{-1}$. Orange dots indicate pixels where the threshold of 1 day of significant rainfall and temperature $>0^\circ C$ within a year is exceeded.
Conclusions and prospects

- First characterization of present rainfall occurrences in Antarctica (no information on amounts)
- Significant decrease over the western Peninsula between 1998 and 2015
- CMIP6 models predict a significant increase by the end of the century over all sectors but the Plateau
- Main ice shelves should be particularly affected

- Partial disagreement between ERA5 and observation (in terms of rainfall occurrence)
  + discrepancy between CMIP6 models
  → need to work on precipitation parameterization in Antarctica
  → need of observational data to evaluate models in terms of precipitation amount and phase

Reference:
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<tbody>
<tr>
<td>DDU</td>
<td>01/01/1982-31/12/2015</td>
<td>99.7</td>
<td>101.8 (75,147)</td>
<td>1.8 (0, 7)</td>
<td>0.88</td>
<td>0.80</td>
<td>-0.51</td>
<td>-0.47</td>
<td>-0.21</td>
<td>-0.23</td>
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<td>Casey</td>
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<td>99.9</td>
<td>171.5 (121, 209)</td>
<td>3.9 (0, 12)</td>
<td>3.2 (0, 11)</td>
<td>-1.99**</td>
<td>-1.09**</td>
<td>-1.64**</td>
<td>-0.86**</td>
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<td>Davis</td>
<td>01/01/1958-31/12/2017†</td>
<td>92.7</td>
<td>143.4 (108, 202)</td>
<td>2.5 (0, 12)</td>
<td>2.0 (0, 12)</td>
<td>-0.87</td>
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<td>99.8</td>
<td>55.8 (25, 111)</td>
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<td>0.9 (0, 4)</td>
<td>-0.77**</td>
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<td>-0.20**</td>
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<td>0.16</td>
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<td>203 (108, 279)</td>
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<td>86.6</td>
<td>270 (213, 303)</td>
<td>105.2 (40, 169)</td>
<td>93.3 (34, 150)</td>
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<td>-6.24**</td>
<td>-11.81***</td>
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<td>Rothera</td>
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<td>86.3</td>
<td>249.8 (184, 292)</td>
<td>55.6 (19, 113)</td>
<td>50.7 (19, 109)</td>
<td>-12.85</td>
<td>-3.63</td>
<td>7.21</td>
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<td>South Pole</td>
<td>01/01/1992-31/12/2017</td>
<td>93.4</td>
<td>293.4 (188, 344)</td>
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<td>-0.21</td>
<td>-0.07</td>
<td>0.23</td>
<td>0.09</td>
<td>0.20</td>
</tr>
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</table>

**Table S1.** Characteristics of rainy days from visual meteorological reports. ‘Period’ refers to the time period of the dataset. † indicates that entire years have been discarded owing to insufficient number of observations (see Sect. 2 of the main manuscript). ‘% obs’ is the percentage of days with available precipitation observation. Np (resp. Nr) is the annual number of days with precipitation (resp. liquid precipitation) over the respective measurement period for each station. Mean (minimum, maximum) values are provided. Black numbers refer to the total non-frozen precipitation (rain + drizzle). Blue numbers refer to the rain type only. Note that rain and drizzle distinction is not possible at DDU. ‘Trend 92-15’ refers to the annual trend in days per decade over the 1992-2015 period, namely the longest measurement period common to all stations but Rothera for which the reliable observation period extends to 2008 only. ‘Trend % 92-15’ shows the corresponding trend per decade of the annual percentage of days with liquid precipitation with respect to the annual number of days with precipitation. ‘Trend period’ and ‘Trend % period’ show trends over the whole measurement period indicated in the second column for each station. ‘Corr. SAM’ shows the Pearson correlation coefficients between the annual number of rainy days and the yearly mean (black number) or December-January-February mean (grey number) Marshall’s SAM index (Marshall, 2003) over the measurement period. ** and *** indicate trends and correlations significant at a 5% and 1%-level respectively.
Dumont d’Urville, JJA temperature

all

Rainy days