# How air-sea interactions are modulated by synoptic weather systems: a stable water isotope perspective

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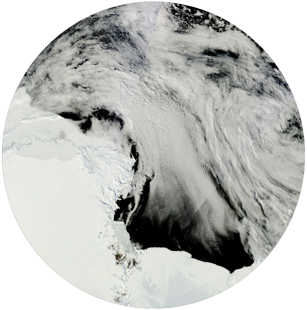
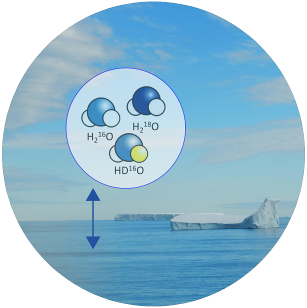
Air-sea interaction due to synoptic weather systems

Stable water isotopes as tracers of moist processes

ACE measurement campaign around Antarctica



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# The use of stable water isotopes as tracers for air-sea interactions induced by large-scale cold and warm advection associated with extratropical cyclones

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Weather systems shape the atmospheric water cycle on the synoptic timescale. Due to the passage of extratropical cyclones and their associated frontal systems, cold and warm air masses are advected and can be observed as cold-air outbreaks in the cold sector or atmospheric rivers in the warm sector. The advection of air masses induces moisture fluxes between the ocean and the atmosphere such as evaporation, precipitation and water vapour deposition. A climatological analysis of the importance of cold and warm advection for freshwater fluxes done with the ERA-Interim dataset reveals that a large share of the atmospheric moisture turnover is associated with cold advection.
Measuring and monitoring the atmospheric water cycle is a challenge, especially turbulent fluxes are difficult to measure over the ocean. A very useful tool to investigate water cycling and trace moist atmospheric processes are stable water isotopes (SWIs). Isotopic fractionation during phase changes and molecular diffusion processes leave a distinct fingerprint in SWIs of atmospheric moisture. SWIs thus provide important insights into moist processes associated with extratropical cyclones.
Here, we present in situ measurements of SWIs in atmospheric water vapour in the marine boundary layer (MBL) during the Antarctic Circumnavigation Expedition in combination with radio sonde profiles, micro rain radar measurements and ECMWF analyses. A quasi-climatological composite analysis of SWIs in atmospheric water vapour is conducted and exemplified by two case studies. Hereby, we focus on the specific air-sea interaction and SWI signals that occur in the MBL during contrasting large-scale conditions characterized by cold and warm air advection, respectively. The MBL during cold or warm air advection is characterized by distinct air-sea moisture gradients and vertical mixing. The second-order isotope variable deuterium excess shows high/low values in the cold/warm sector, respectively, of extratropical cyclones due to the opposing moisture fluxes and non-equilibrium fractionation in the two sectors.
This study demonstrates the use of SWI measurements in the MBL for gaining a better understanding of turbulent moisture fluxes and air-sea interaction that occur during the passage of synoptic scale weather systems.

▸ 2mins

# The use of stable water isotopes as tracers for air-sea interactions induced by large-scale cold and warm advection associated with extratropical cyclones

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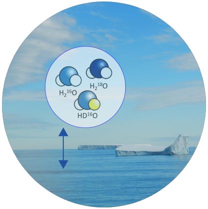
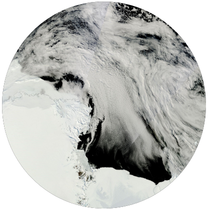
▸ Abstract

▸ Conclusions

▸ Stable water isotopes

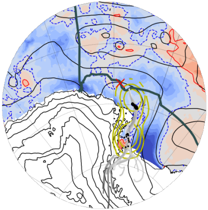



▸ Cold/Warm air advection

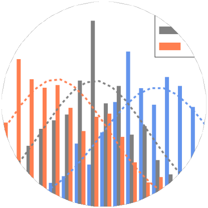


▸ ACE

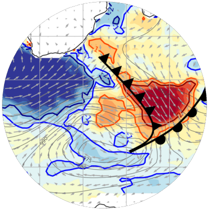
▸ Case study



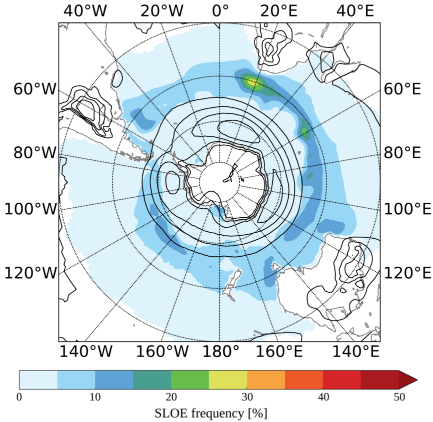
▸ Composites



▸ Advection climatology



# Air-sea interactions triggered by synoptic weather systems




Strong large-scale ocean evaporation (colors) and cyclone (black lines) occurrence frequency in DJF.

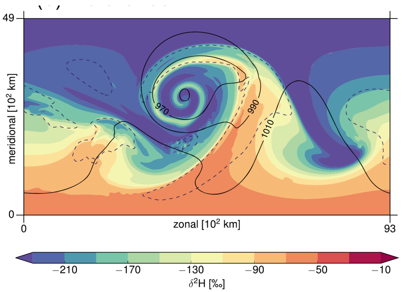
Air-sea interaction, as for example ocean evaporation, is modulated by synoptic weather systems. In mid- to high-latitudes, large-scale ocean evaporation is triggered by the advection of cold, dry air masses in the cold sector of extra-tropcial cyclones (Aemisegger and Papritz, 2018).

A useful tracer to study the influence of atmospheric dynamics on moist processes are stable water isotopes (SWIs).

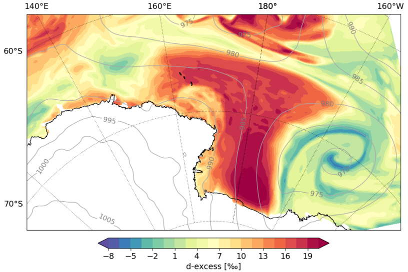
SWIs and weather systems

# SWIs in weather systems

## The isotopic composition of air masses is used to trace moist processes in the atmosphere.

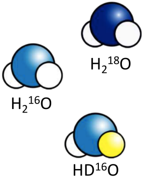



Cold/warm air masses are characterised by water vapour that is poor/rich in heavy isotopes ($\delta^2$H and $\delta^{18}$O) as visible in the warm and cold sector of extra-tropical cyclones (Dütsch et al. 2016, COSMOiso simulation).




To study air-sea interaction such as evaporation, the second-order isotope parameter d-excess ($\delta^2$H - 8$\cdot\delta^{18}$O) serves as a measure for such non-equilibrium processes. Shown is the high d-excess during evaporation in the Ross Sea from a COSMOiso (Pfahl et al. 2012) simulation.

▸ more on SWIs




Stable water isotopologues, here called isotopes, are molecules with different molar mass.
The $\delta$-notation [$\delta^2$H, $\delta^{18}$O] represents the abundance of the heavy isotopes in a sample relative to an international standard.

Due to their different thermodynamic properties (bonding strength) and molar mass, isotopic fractionation occurs during phase-change processes. Thus, they are used as natural tracers of moist processes in the atmospheric water cycle. They provide information on

- atmospheric conditions (RH, T) in the moisture source region.
- history of moisture in the air.
- air-sea interaction.
- phase-change processes such as rain evaporation or condensation.

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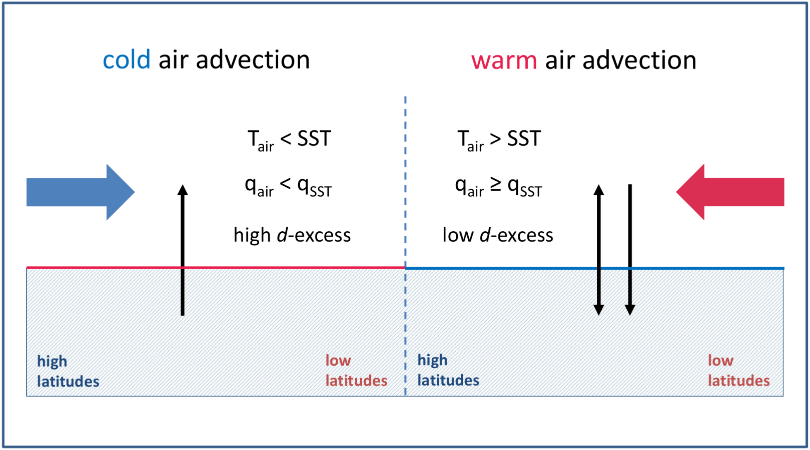
# Air-sea interaction during cold and warm air advection




Different air-sea temperature and humidity gradients and, thus, different moist processes are expected during cold or warm advection. These processes leave opposing isotopic imprints in the air masses.

▸ more . . .

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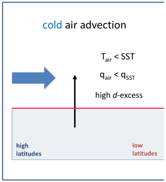



## Cold air advection [CAA]

### Occurence

CAA occurs in the cold sector of extratropical cyclones. Furthermore, the movement of terrestrial air masses over the ocean often leads to CAA, such as in cold air outbreaks in polar regions.

### Air-sea fluxes

The air-sea humidity and temperature gradients due to the avection of cold,dry air masses over a warmer ocean lead to strong latent and sensible heat fluxes from the ocean into the atmosphere.

### Isotopes in water vapour

Due to non-equilibrium fractionation during evaporation, a high d-excess and drops in delta values are expected in the atmosphere (Aemisegger and Sjolte, 2018).

## Warm air advection [WAA]

### Occurence

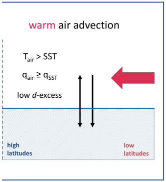
WAA is expected in the warm sector of extratropical cyclones or over cold surface ocean currents.

### Air-sea fluxes

During warm air avection, warm, moist air masses are advected over a relatively colder ocean. This is often accompagnied by an oversatured atmosphere leading to sensible **and** latent heat fluxes from the atmosphere into the ocean.

### Isotopes in water vapour

The moisture fluxes into the ocean lead to non-equilibrium fractionation. A low d-excess with peaks in delta values are expected.

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## Antarctic Circumnavigation Expedition

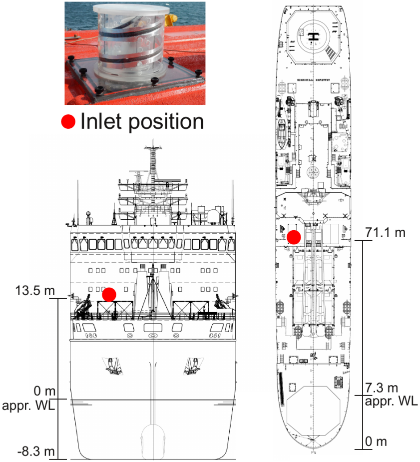

SWISS POLAR INSTITUTE

- Three-month continuous measurements of SWIs in water vapour in the Southern Ocean.
- Investigation of air-sea interaction using SWI signals
- SWI measurements in water vapour using Picarro laser spectrometer.

▸ measurement set up

Measurement set up:

- inlet position at 13.5m height
- measurements using a Picarro laser spectrometer L2130 with standard delivery module
- data calibration with isotope-humidity correction and slope correction using the two measured standards

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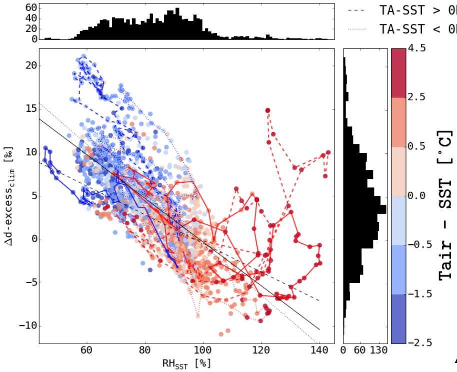
# Distinct SWI composition of cold vs. warm advection during ACE

- High d-excess during cold advection ($T_{air}$-SST $< 0$)
- Low/negative d-excess during warm advection ($T_{air}$-SST $> 0$)



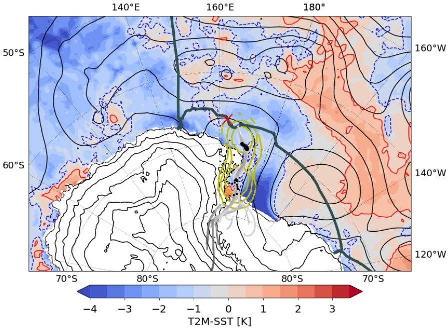

Choose case study for details:

- 17. - 18.01.17
- CAA case study 03. - 06.02.17
- 13. - 16.02.17
- 26. - 28.12.16
- 30.12.16 - 01.01.17
- WAA case study 03. - 04.01.17

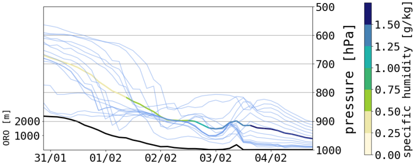
$\Delta$d-excess$_{clim}$ is the difference of the measured d-excess to the expected d-excess from climatology using the closure assumption by Merlivat & Jouzel 1979. This measures takes into account the temperature dependency of the d-excess.

# Cold air outbreak in Ross Sea 03. - 06.02.17

Air masses originate from the Antarctic continent and took up a substantial amount of moisture from the Ross Sea.




Cold, dry Antarctic airmasses transported over Ross Sea invoke moisture uptake (yellow lines) along trajectories (grey lines).



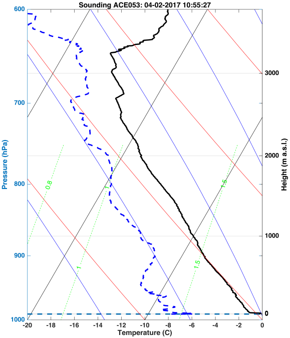

Backward trajectories starting in marine boundary layer (light blue) overlaid by the mean specific humidity (colored) along the trajectories.

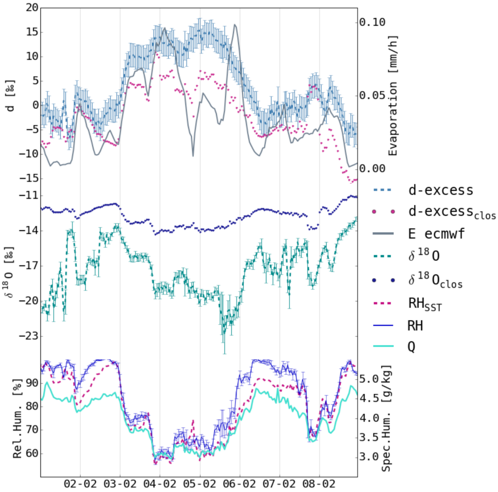
The trajectories are calculated using Lagranto (Sprenger and Wernli, 2015), the moisture source according to Sodemann et al. 2008.

▸ case study overview ▸ next

# Cold air outbreak in Ross Sea 03. - 06.02.17

- Conditionally unstable, deep, undersaturated boundary layer during strong ocean evaporation.
- Strong increase in d-excess with simultaneous drop in $\delta^{18}$O.



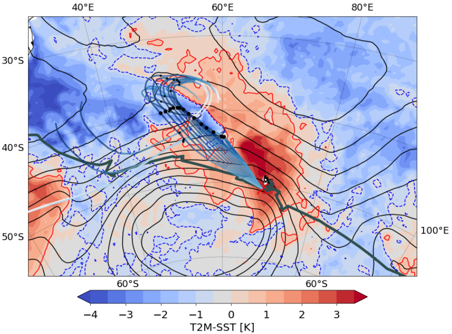




back
case study overview

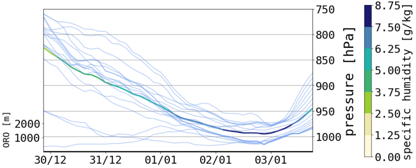
clos denotes calcuations using the closure assumption by Merlivat & Jouzel 1979.

# Water vapour deposition in warm sector 03. - 04.01.17

Warm air advection within warm sector of extratopical cyclone triggering precipitation and vapour deposition.




Southwesterly airmasses start ascending in warm sector before arrival at ship's position.



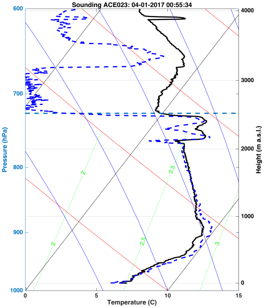

Backward trajectories starting in marine boundary layer (light blue) overlaid by the mean specific humidity (colored) along the trajectories.

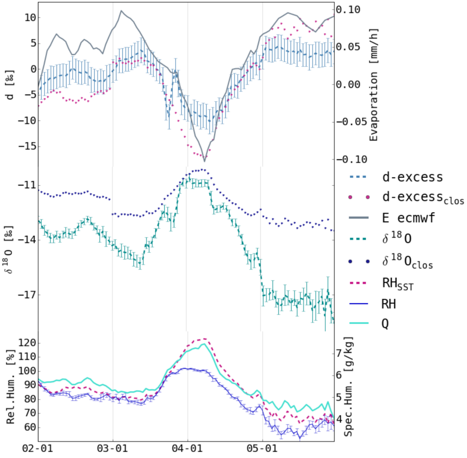
Backward trajectories are calculated using Lagranto (Sprenger and Wernli, 2015), the moisture source according to Sodemann et al. 2008.

case study overview next

# Water vapour deposition in warm sector 03. - 04.01.17

- Stable, shallow, (over-)saturated boundary layer.
- Strong decrease in d-excess with simultaneous peak in $\delta^{18}$O. The oversatured atmosphere and negative d-excess are indicators for water vapour deposition during this warm advection event.

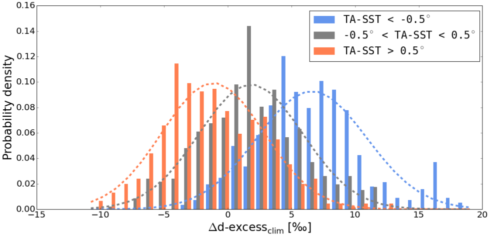


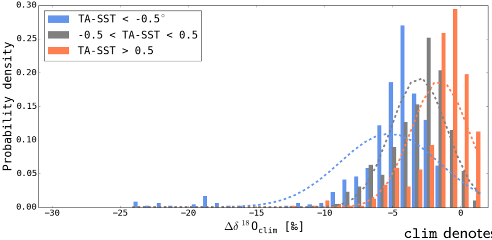




clos denotes calcuations using the closure assumption by Merlivat & Jouzel 1979.

back case study overview

# Composites of SWIs during CAA and WAA in the Southern Ocean




Measured isotopic composition of marine boundary layer water vapour differs between cold and warm advection

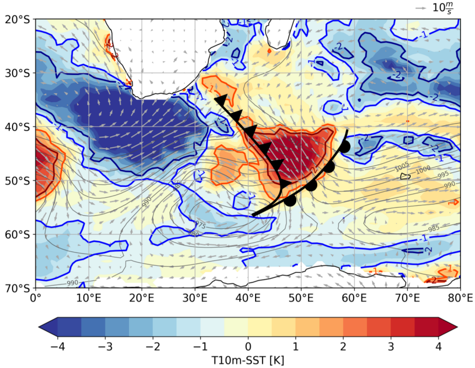
- High d-excess and low $\delta^{18}$O during CAA
- Low d-excess and high $\delta^{18}$O during WAA

`clim` denotes the difference of the measured value to the expected climatological value using the closure assumption by Merlivat & Jouzel 1979. This measures takes into account the temperature dependency of the d-excess and $\delta^{18}$O.

# Climatology of cold and warm air advection

Using ocean-atmosphere temperature gradient $\Delta T = T_{10\mathrm{m}} - SST$ to identify cold and warm air advection:

Warm air advection (WAA): $\Delta T > 1\mathrm{K}$
Cold air advection (CAA): $\Delta T < 1\mathrm{K}$

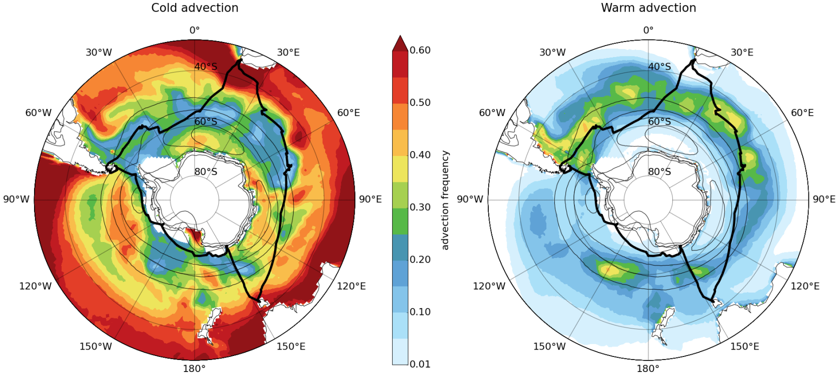



Example of cold and warm advection identification in an extra-tropcial cyclone.

$\Delta T$ (K; shaded), SLP (hPa; black lines), horizontal wind at 10m (m/s; grey arrows), CAA (blue lines) and WAA (red lines) from ECMWF operational data at 06 UTC 03 Jan 2017.

▸ Advection climatologies

# Advection Climatology for ACE-months Dec-March




DJFM climatological means from 1979-2017 using ERAinterim reanalysis data.

High frequency of CAA near ice edge, in regions of high frontal activity and large-scale subsidence.

High frequency of WAA in regions of high frontal activity, north of highest cyclone frequency.

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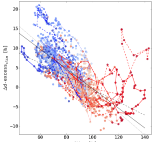
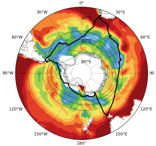
# Conclusions

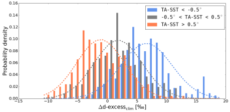
- Large-scale cold or warm advection triggers strong air-sea interactions of opposite sign




- The ocean-atmosphere temperature gradient is a useful index to study cold/warm advection




- Air-sea interactions such as evaporation, precipitation and water vapour deposition, leave a distinct isotopic imprint in airmasses.

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... back

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