From a polar to a marine environment: has the changing Arctic led to a shift in aerosol light scattering properties?

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Link for discussion: https://www.atmos-chem-phys-discuss.net/acp-2020-521/

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Motivation

Arctic region is **warming** considerably faster than the global average

Range of possible mechanisms

- **Reductions** in Arctic summer sea ice
- Changes in **cloud cover**
- Transportation of heat from the midlatitudes
- Sulphate **aerosol reductions** in Europe (Navarro et al., 2016)

Impacts observed in a multitude of parameters (IPCC, 2019)

- **Reductions** in Arctic summer sea ice
- Appearance of atmospheric circulation anomalies

(Lee et al., 2015)

Aims

Given, **aerosol** exert a considerable **influence** on the **Arctic** climate

i. At what **rate** have key **aerosol light scattering properties** changed at Svalbard, in the Arctic, during the last two decades?

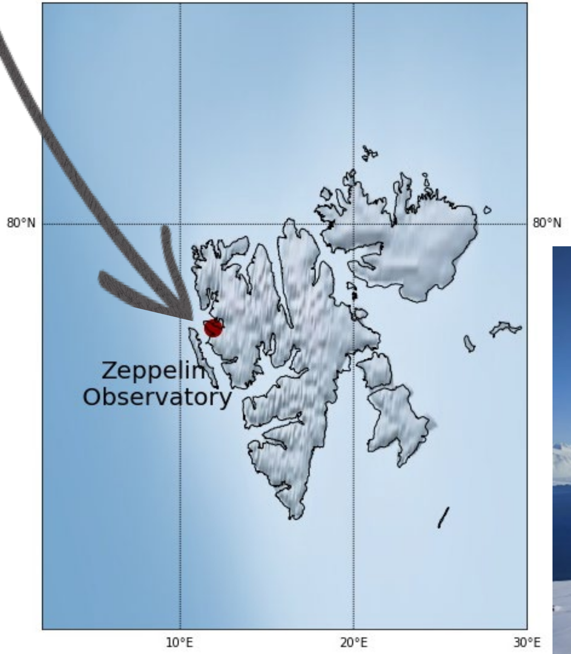
ii. Can changes in long-term aerosol optical properties be explained by **meteorological** parameters and/or changes in **sea ice** coverage

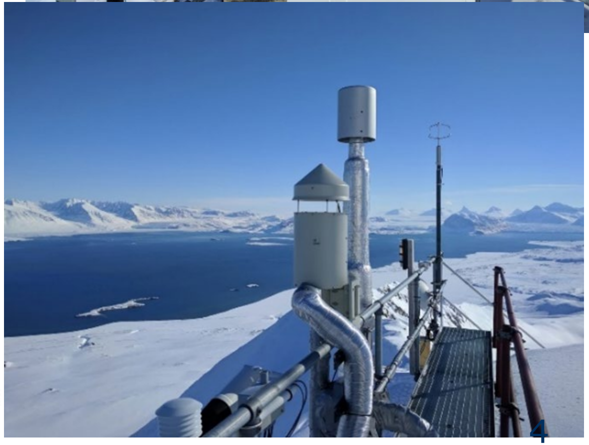
Monitoring site

Zeppelin Observatory, Svalbard
(78.9° N, 11.9° E, **474m** a.s.l.)

Remoteness & **Altitude** ⇒ minimal contamination

Global Atmosphere Watch (GAW) Site



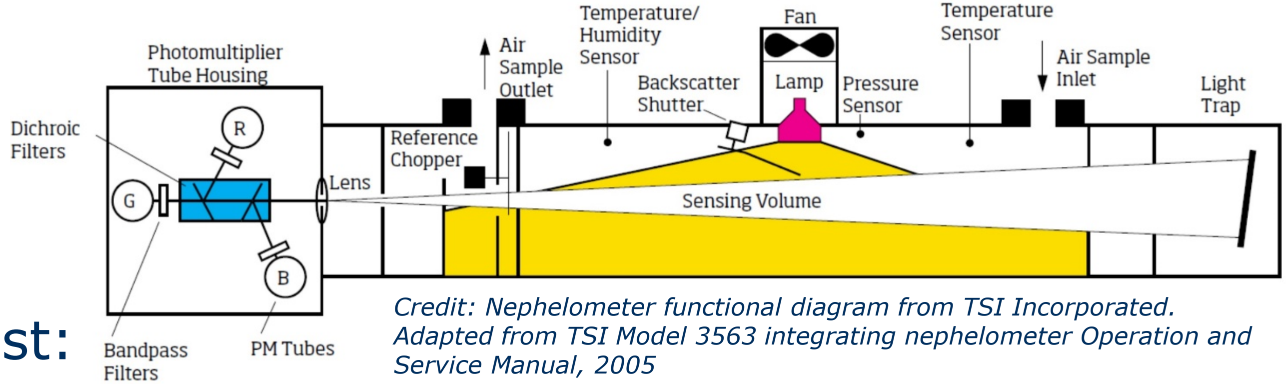


Credit: Paul Zieger

Instrumentation

TSI **nephelometer** 3563

Three-wavelengths: (λ = 450, 550 and 700 nm)



Credit: Nephelometer functional diagram from TSI Incorporated. Adapted from TSI Model 3563 integrating nephelometer Operation and Service Manual, 2005

Parameters of interest:

Extensive:

Scattering coefficent (σ_{sp})

Backscattering coefficent (σ_{bsp})

Intensive:

Backscatter Fraction = ${}^{\sigma_{bsp}}/{\sigma_{sp}}$ (b)

Scattering Ångström Exponent (α)

Ångström power law

$\boldsymbol{\sigma_{sp}}$ depends on the wavelength

The turbidity coefficient

$$\boldsymbol{\sigma_{sp}(\lambda) = \beta\lambda^{-\alpha}}$$

Ångström exponent

α proxy for **aerosol particle size**

$\boldsymbol{\alpha} \ll \mathbf{1}$ size distributions dominated by **coarse mode** aerosols (i.e. dust and **sea salt**)

$\boldsymbol{\alpha} \gg \mathbf{1}$ dominated by **fine mode** aerosols

Backtrajectory Analysis

HYSPLIT Model – re-analysis data:

7-day back-trajectories arriving at Mt. Zeppelin

1999 - 2016 (temporally collocated)

Variables: Latitude, Longitude, Altitude, **Mixing depth**, Relative Humidity, Temperature

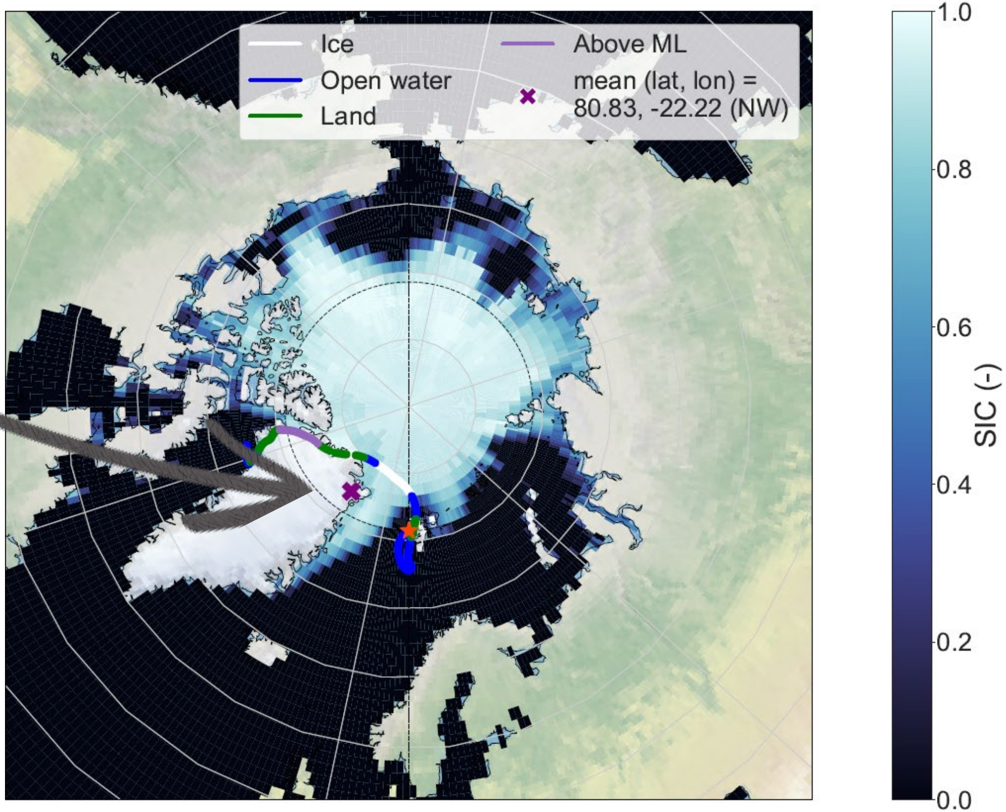
Satellite-derived monthly **sea-ice concentration (sic)** from the Hadley Centre

Surface **residence times** above:

Ice (sic > 0.85), **Land** & **Ocean**

Backtrajectory Analysis

Mean coordinates



Results

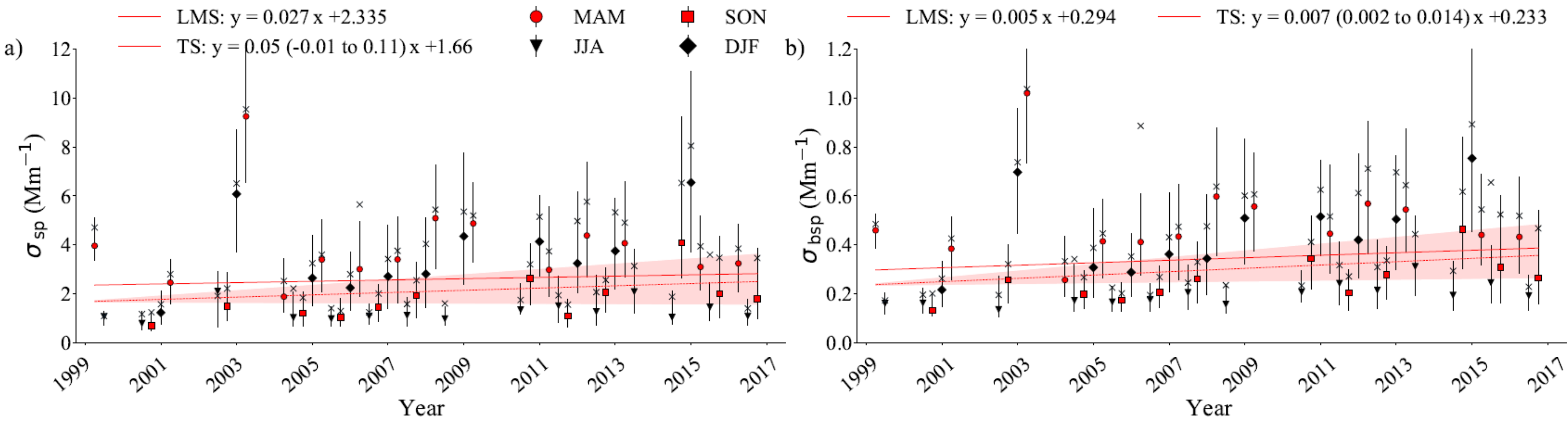
1. Long-term trends in aerosol light-scattering properties

   - Seasonal trends

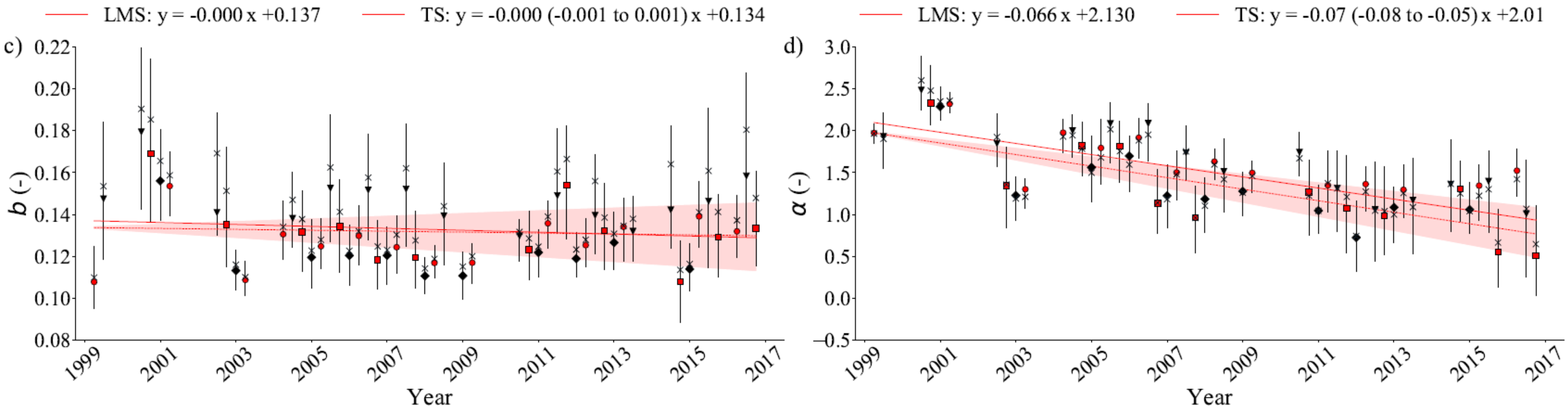
2. Back tracjectory analysis

   - Surface residence times
   - Wind speed
   - Regional contributions

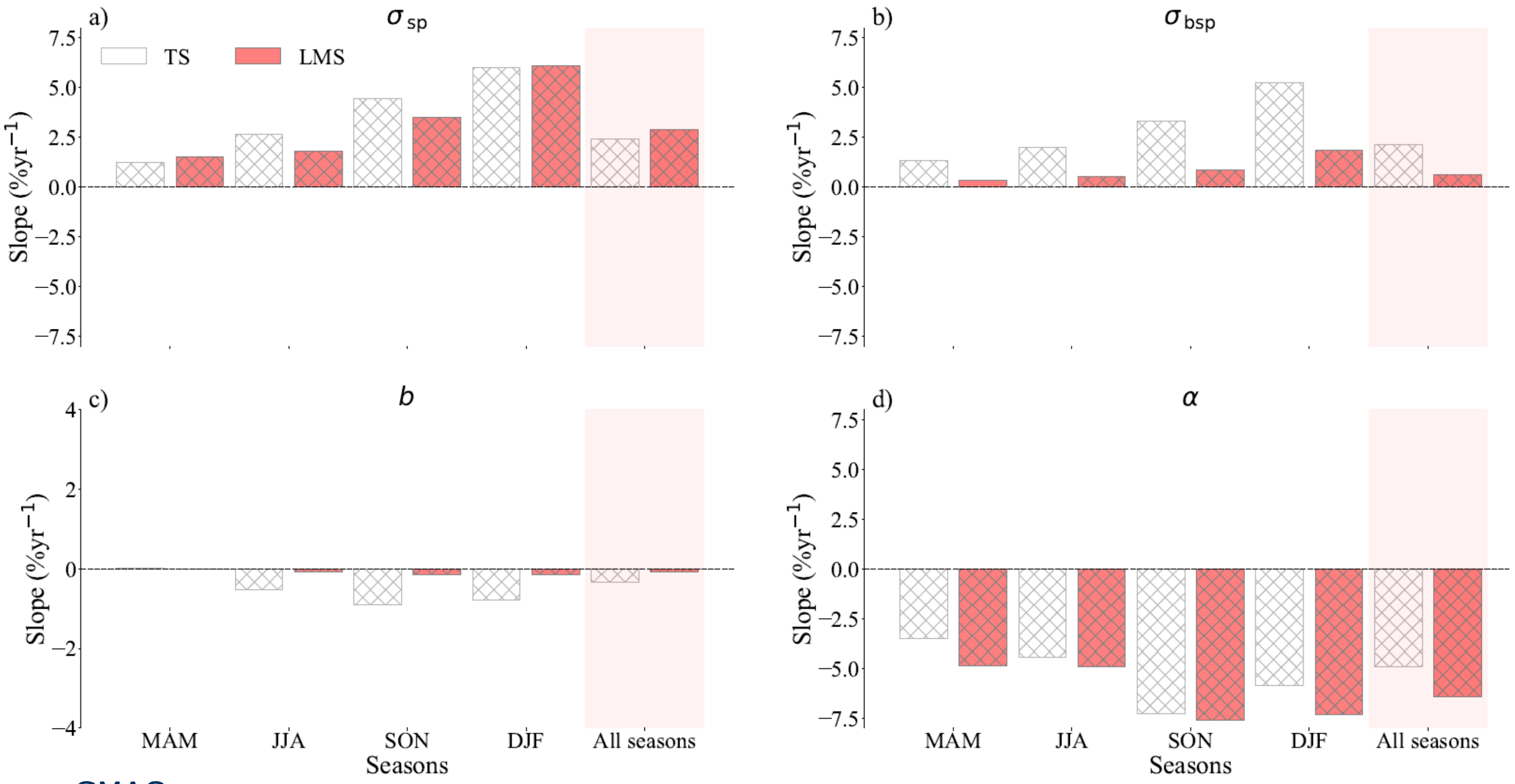
Small s.s. positive trend in σ_{sp} & σ_{bsp}



Clear s.s. **negative** trend in α



Seasonal trends



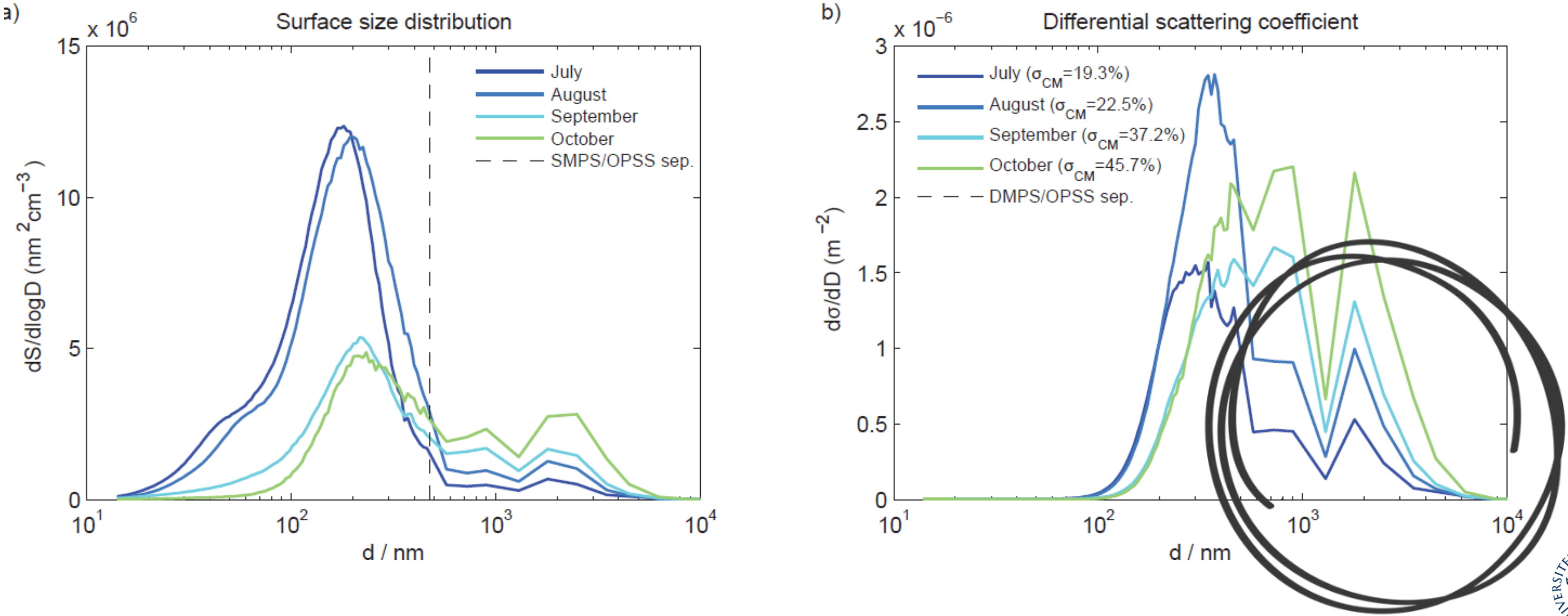
- **Increase in σ_{sp}** (~2.4 to 2.9%yr^{-1}), whilst

- Strong **decrease** in α (-4.9 to 6.3%yr^{-1})

Previous ZEP studies:

- **Reductions** in eBC (Stone et al., 2014; Eleftheriadis et al., 2009; Hirdman et al., 2010)
- **Reductions** in measured total sulphate concentrations (Hirdman et al., 2010)
- **Decrease** in anthropogenic **accumulation** aerosol (Tunved et al., in preparation).

Coarse-mode particles contribute a significant proportion of the overall **scattering** observed at ZEP



What is the reason for the **increase** in **coarse mode** particles?

1. Increased influence of mineral dust

2. Retreat of Arctic Sea-ice ⇒ more **open oceans** ⇒ SSA?

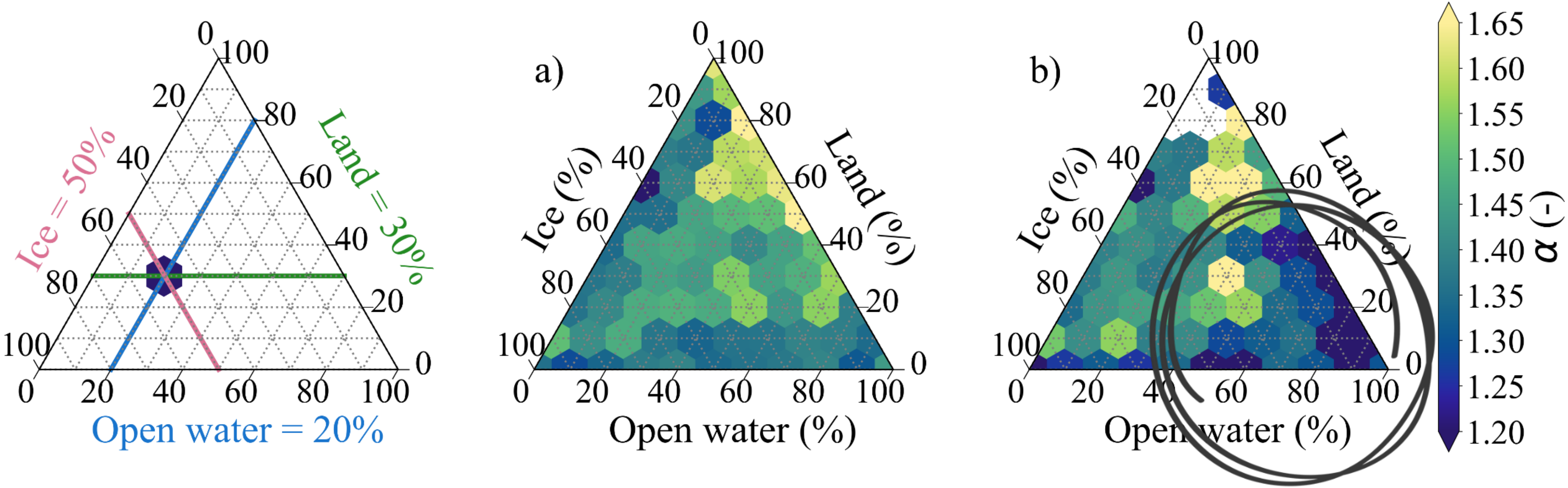
3. Changes in air circulation patterns?

   Increased influence from **southwesterly winds** (i.e. North Atlantic) ⇒ SSA

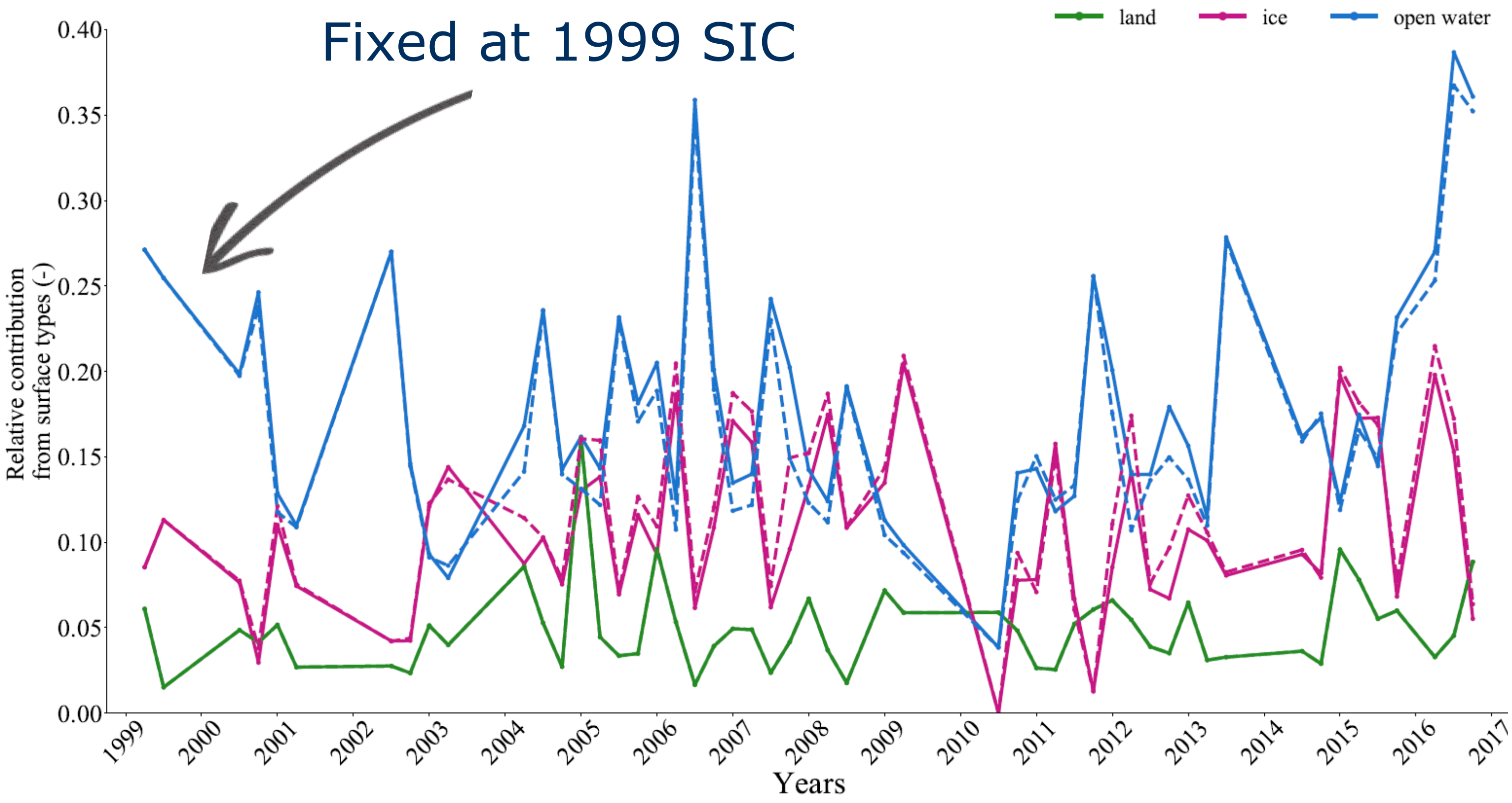
   Increased **wind speeds**

4. Decrease in contribution from **fine-mode** particles?

1. **Lower** α values dependent on **increased** open **water** ⇒ SSA



2. Arctic sea ice retreat



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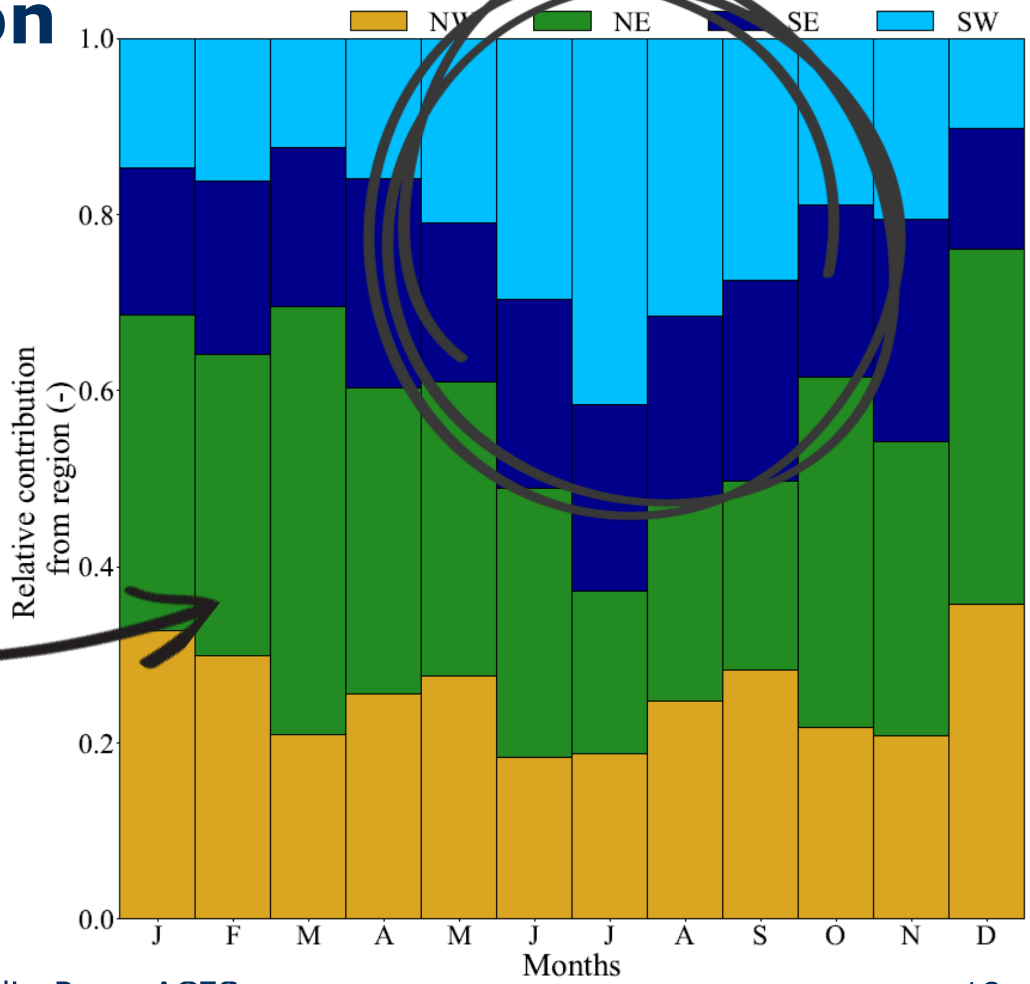
3. **Air circulation**



NE contributions Greater during Arctic Haze

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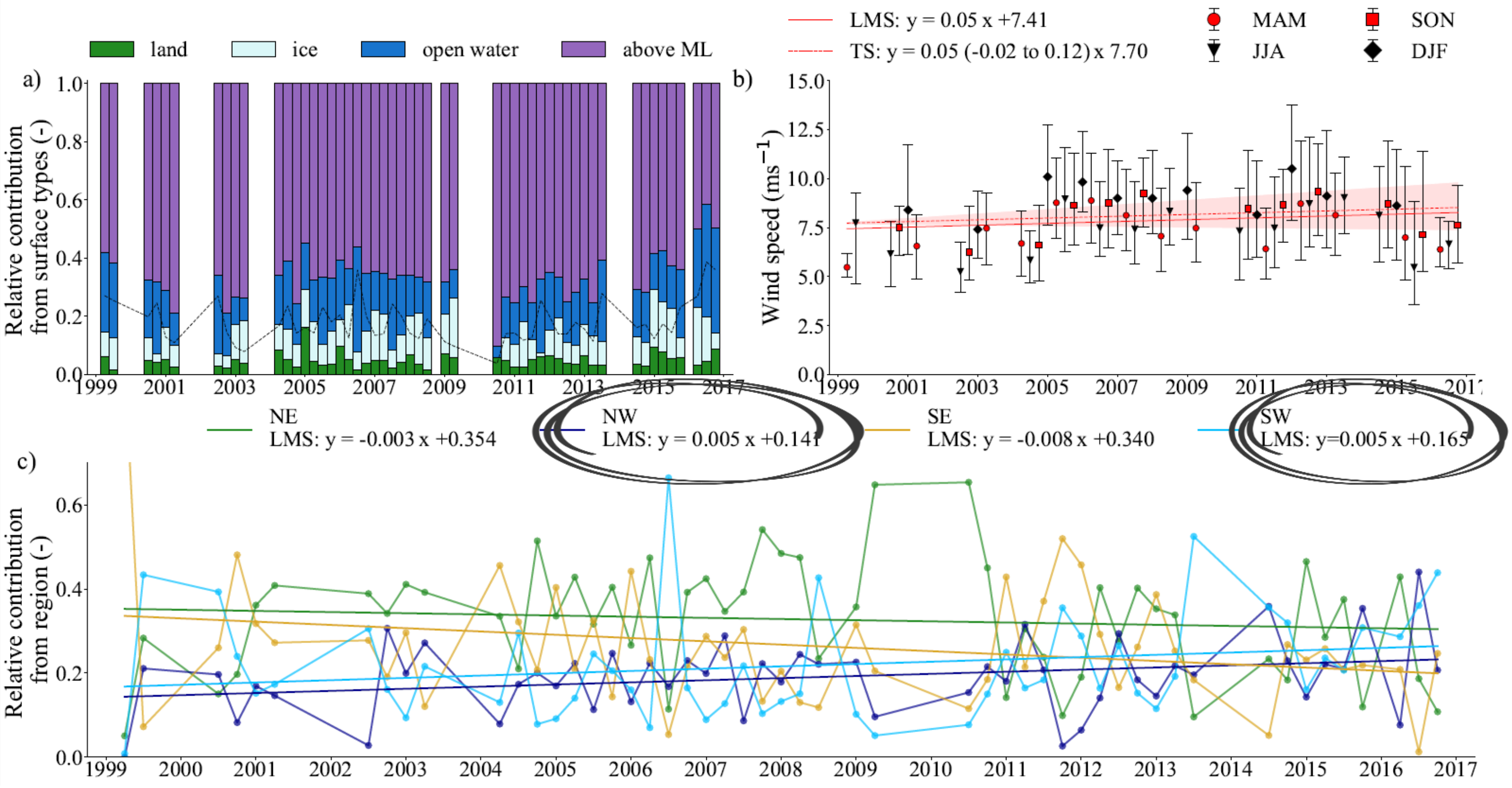
Long-term changes **air circulation**



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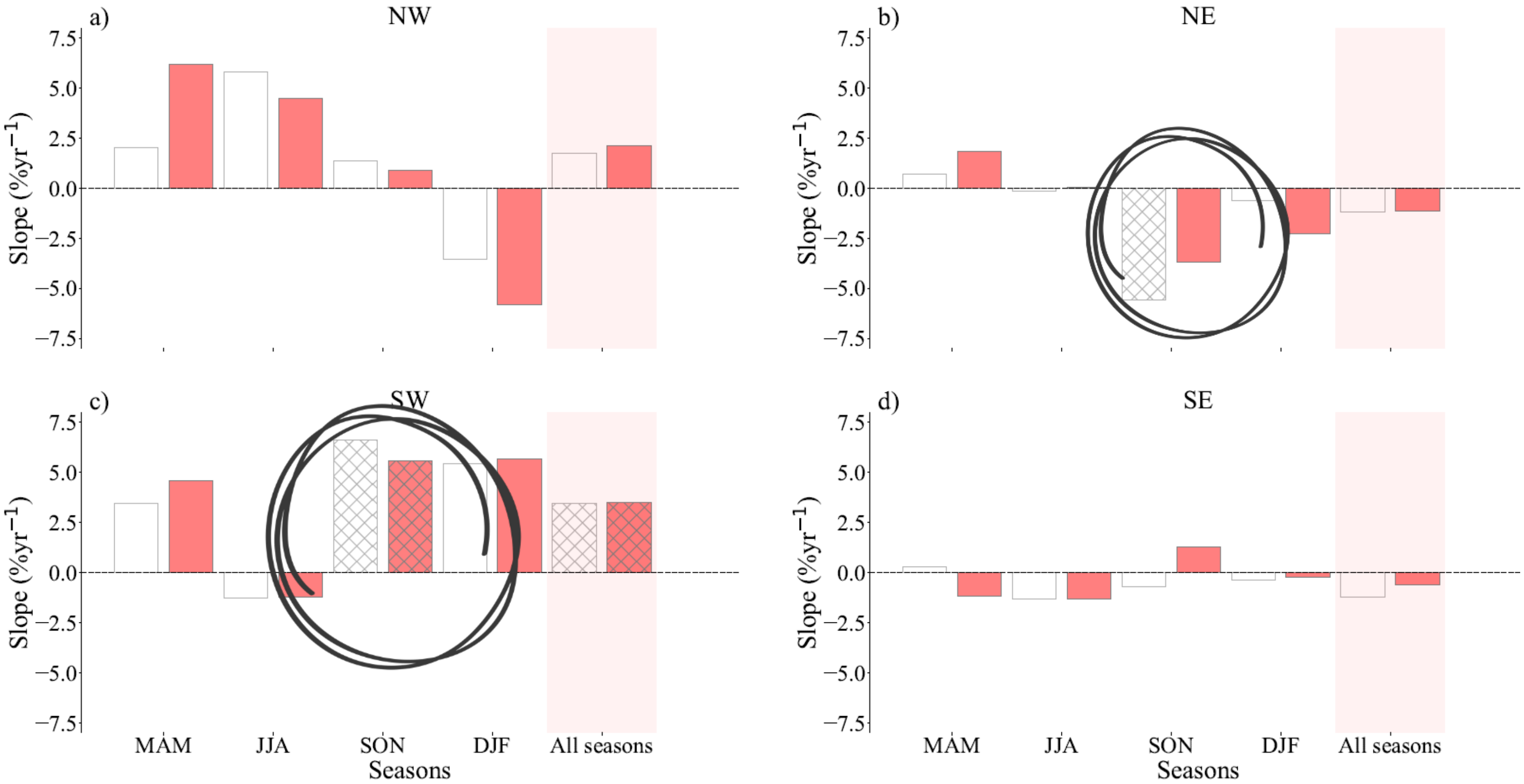
Increased contributions from NW and **SW**



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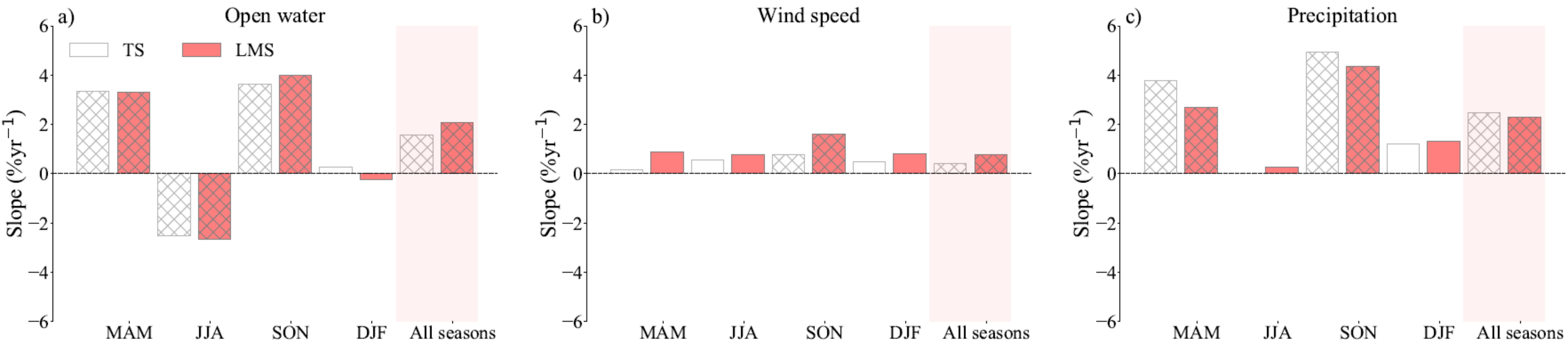
a)
Open water
TS
LMS
Slope (%yr^{-1})
6
4
2
0
−2
−4
−6
MAM
JJA
SON
DJF
All seasons
b)
Wind speed
Slope (%yr^{-1})
MAM
JJA
SON
DJF
All seasons
c)
Precipitation
Slope (%yr^{-1})
MAM
JJA
SON
DJF
All seasons

Regional shifts in weather phenomena

- **AO index** shifted towards more **negative** anomalies in recent years (Maturilli and Kayser, 2017)

- Negative AO increases the amount of **meridional** transport

- Transport through the North Atlantic **more frequent** in the last decades (Mewes and Jacobi, 2019)

Conclusion

Trend analysis:

σ_{sp} and σ_{bsp} show slight s.s. **increases** over the 17 year period

α is decreasing by approximately **0.07yr^{-1}** increased ⇒ presence of **coarse mode particles**

Trajectory analysis:

Open water is indicative of reduced α**.**

Western air masses contributing **more**

Source analysis:

West-to-east increasing gradient in α

Influence from retreating sea-ice minimal

Thank you for listening

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