eScience course 2022: Groups, project descriptions and research questions

Please feel free to contact your assistant prior to the course if you already have questions.

Group 1

Project Title: Process based evaluations of climate models in the polar regions
Assistant: Sara Blichner [sara.blichner@aces.su.se]
Students: Stefan, Ingvild, Lovisa

Background/motivation:
Aerosol particles influence the climate both directly and through interacting with clouds. Both of these effects, but especially cloud aerosol interactions, are highly dependent on particle size. Aerosols in the atmosphere can form in a huge size range. As an example: A single 1 um particle contains as much mass as 1000 particles of a 100 nm. This means that our models can do well in terms of predicting aerosol composition without doing well at all in predicting climate relevant properties like cloud condensation number (CCN) concentration (usually in the size order of magnitude of a 100 nm). Considering relationships between aerosol bulk properties (such as chemical composition of particles) and particle size properties can therefore hold much information to which extent models represent specific aerosol processes well.

Overall research question: How do the relationships between aerosol composition and size distribution compare in models and observations in the Arctic region?

Research question(s):
- What is the relationship between main aerosol chemical composition and particle number in CCN relevant sizes? How do modeled relationships compare to the observed?
- Do these relationships change with time of year?
- How do cloud properties (represented by effective radius of cloud droplets) relate to the composition and size of particles?
- Are fast responses (day to day variability) a good measure of response to emission changes? How do the relationships calculated with daily median/means compare to similar statistics calculated from monthly means, or even from one decade to the next?

Data:
- Aerosol composition (filter) data from Zeppelin Observatory (EBAS)
- Size distribution data from Zeppelin Observatory (EBAS)
- High resolution model output provided by Sara (at least NorESM, maybe also ECHAM-SALSA)
- Particle and cloud properties from Zeppelin Observatory (https://bolin.su.se/data/zeppelin-cloud-aerosol-1)

Reference(s):
- Introduction in
    - Karlsson, L. (2022). Aerosol–cloud interactions in a warming Arctic [Doctoral thesis, comprehensive summary, Department of Environmental Science,

Stockholm University]. DiVA.
http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-204133

Group 2
Project Title: Polar ozone responses to volcanic eruptions
Assistant: Zhihong Zhuo [zhihong.zhuo@geo.uio.no]
Students: Emma, Sigrid Marie Vildskog

Background/motivation:
Explosive volcanic eruptions release volcanic volatile, forming sulfate aerosols in the stratosphere that reflect incoming shortwave radiation and absorb longwave radiation, leading to a significant surface cooling and stratosphere warming, and change the profile of many regional climatic impact-drivers (Robock et al., 2000; Lee et al., 2021). Volcanic eruptions can disturb stratospheric ozone (Tie and Brasseur, 1995; Muthers et al., 2015), which is related to the polar vortex (Muthers et al., 2015) and sea ice response (Gagné et al., 2017) to volcanic eruptions. How long can volcanic eruptions cause these changes? Will these changes be amplified in the polar region? What are the interactions among them? How do ozone responses to volcanic eruptions relate to the background atmosphere conditions? How can model simulation be affected whether to include interactive chemistry? These are all important questions to be answered, in order to understand the ozone response to volcanic eruptions in the polar region.

Research question(s):

- How do volcanic eruptions affect ozone in the polar region?
    - Ozone response in a pre-industrial or anthropogenic background atmosphere?
    - Ozone response in a model with and without interactive stratosphere chemistry model?
- How do volcanic eruptions affect the sea ice and polar vortex in the Arctic region?

Data:
CMIP6 historical experiment (1850-2014), model: CESM2,CESM2-WACCM, MPI-ESM1-2-LR, MPI-ESM-1-2-HR,NorESM2-LM, NorESM2-MM

Reference(s):

Robock, 2000, Volcanic eruptions and climate, Reviews of Geophysics, 38, 191-219, doi:10.1029/1998RG000054
(https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/1998RG000054)

Tie, X., and G. Brasseur, 1995. The response of stratospheric ozone to volcanic eruptions: Sensitivity to atmospheric chlorine loading, Geophys. Res. Lett., 22, 3035-3038

(https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/95GL03057)

SPARC CCMVal (2010), SPARC Report on the Evaluation of Chemistry-Climate Models, V. Eyring, T. G. Shepherd, D. W. Waugh (Eds.), SPARC Report No. 5, WCRP-132, WMO/TD-No. 1526, chapter 8, especially 8.8 Volcanic Aerosols.
(https://www.atmosp.physics.utoronto.ca/SPARC/ccmval_final/PDFs_CCMVal%20June%2015/ch8.pdf)

Muthers, S., Arfeuille, F., Raible, C. C., and Rozanov, E., 2015, The impacts of volcanic aerosol on stratospheric ozone and the Northern Hemisphere polar vortex: separating radiative-dynamical changes from direct effects due to enhanced aerosol heterogeneous chemistry, Atmos. Chem. Phys., 15, 11461–11476, https://doi.org/10.5194/acp-15-11461-2015. (https://acp.copernicus.org/articles/15/11461/2015/)

Gagné, M.-È., M. C. Kirchmeier-Young, N. P. Gillett, and J. C. Fyfe, 2017, Arctic sea ice response to the eruptions of Agung, El Chichón,and Pinatubo, J. Geophys. Res. Atmos.,122, 8071–8078,doi:10.1002/2017JD027038. (https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2017JD027038)

Toohey, M., Krüger, K., Bittner, M., Timmreck, C., and Schmidt, H., 2014, The impact of volcanic aerosol on the Northern Hemisphere stratospheric polar vortex: mechanisms and sensitivity to forcing structure, Atmos. Chem. Phys., 14, 13063–13079, https://doi.org/10.5194/acp-14-13063-2014. (https://acp.copernicus.org/articles/14/13063/2014/)

Group 3
Project Title: Connection between polar sea ice melt and aerosols
Assistant: Dominic Heslin-Rees [Dominic.Heslin-Rees@aces.su.se]
Students: Maher, Kei

Background/motivation:
Atmospheric particles can form via a process known as New Particle Formation (NPF). Globally, NPF has been estimated to make up around 45% of global low-level Cloud Condensation Nuclei (CCN) (Merikanto et al., 2009); as a result NPF events have climatic relevance given their ability to influence cloud formation. Polar environments are considered more sensitive to changes in aerosol number concentrations, due to the much lower background concentrations; leading to the suggesting that by altering cloud properties, NPF events can play a role in Arctic Amplification. The processes and sources driving NPF in the Arctic are diverse, and vary depending on location (Schmale & Baccarini., 2021). For example, on Svalbard, nucleation of sulphuric acid and Ammonia (NH_3) is believed to be the main process governing the formation of new particles.
In this project, students will use a combination of both climate model data and in-situ observations to investigate the links between a dramatically changing Arctic and the NPF events. Using aerosol size distributions and different tracers (e.g. MSA), students will try to identify and charactercise nucleation events. In combination with observations, HYSPLIT back trajectories will be utilised to explore source types and regions.

Research question(s):
For this report, we would like to focus on trying to answer the following research questions:
- What processes drive NPF in the Arctic, and how might these evolve in a changing Arctic?
- How do models and observations compare with respect to NPF and their drivers?

Data:
Observation data: Size distribution (DMPS), Methanesulphonic acid (MSA), NH_3, rates of phytoplankton net primary production, sea surface temperature, sea ice extent and Chlorophyl A.

Model data: Aerosol number concentration data from some of the latest Coupled Model Intercomparsion Projects (CIMP6) models (e.g. UKESM).

Reference(s):
Core reading:

Schmale, J. and Baccarini, A.: Progress in unraveling atmospheric new particle formation and growth across the Arctic, Geophysical Research Letters, 48, e2021GL094198. https://doi.org/10.1029/2021GL094198

Dall´Osto, M., Beddows, D., Tunved, P. *et al.* Arctic sea ice melt leads to atmospheric new particle formation. *Sci Rep* 7, 3318 (2017). https://doi.org/10.1038/s41598-017-03328-1

Additional suggested readings:

Beck, L. J., Sarnela, N., Junninen, H., Hoppe, C. J. M., Garmash, O., Bianchi, F., et al. (2021). Differing mechanisms of new particle formation at two Arctic sites. *Geophysical Research Letters*, 48, e2020GL091334. https://doi.org/10.1029/2020GL091334

Lee, H., Lee, K., Lunder, C. R., Krejci, R., Aas, W., Park, J., Park, K.-T., Lee, B. Y., Yoon, Y. J., and Park, K.: Atmospheric new particle formation characteristics in the Arctic as measured at Mount Zeppelin, Svalbard, from 2016 to 2018, Atmos. Chem. Phys., 20, 13425–13441, https://doi.org/10.5194/acp-20-13425-2020, 2020.

Merikanto, J., Spracklen, D. V., Mann, G. W., Pickering, S. J., and Carslaw, K. S.: Impact of nucleation on global CCN, Atmos. Chem. Phys., 9, 8601–8616, https://doi.org/10.5194/acp-9-8601-2009, 2009.

Group 4
Project Title: Polar oceans in a changing climate
Assistant: Antoine Haddon [ahaddon@uvic.ca]
Students: Jessica, Mateusz

Background/motivation:
Climate change is particularly prominent in the polar oceans, with important modifications of the coupled physical, chemical and biological processes. The arctic ocean is freshening due to a variety of factors, such as increased freshwater inputs from river runoff and higher imports of relatively fresh Pacific waters through the Bering Strait. This is reflected in changes in the thermohaline structure of the ocean, with potentially important consequences on ocean circulation and stratification. These physical transformations of the polar environment lead to modifications of the biogeochemical cycles and the ocean's biology. In turn, the polar oceans can impact the climate by providing gaseous precursors for aerosol formation in the atmosphere, such as dimethylsulfide (DMS). In remote regions, bioaerosols may constitute most of the available ice nucleating particles and in a changing climate, these could play a bigger role in the Arctic. Ecological impacts can also be important and certain species are experiencing changes to their core habitat, which can be defined in terms of the environmental characteristics that are considered the most important. For instance, the habitat of ringed seals in the eastern canadian arctic can be characterized by snow and sea ice seasonality, and then the impact of climate change can be assessed by studying changes in these variables.

Research questions: How well do models represent the following aspects of the polar oceans in comparison to observations? What have been the consequences of the changing climate in the last decades and are these trends reproduced by models? How are these different aspects interconnected?

- Salinity, fresh water content and its impact on stratification
- DMS concentrations in the ocean and flux to the atmosphere
- Environmental characteristics of ringed seals habitat

Data:

- Salinity : CMIP6 model data ; satellite data (Martínez 2022), WOA, PHC
- DMS : CMIP6 model data (NOAA, GFDL-CM4 and NCAR, CESM2-WACCM) ; Observation and satellite climatologies (Galí 2019, Wang 2020, Hulswar 2022)
- Seal habitat : CMIP6 model data (UKESM, HadGEM3), Satellite data (G. Spreen, AMSR2 ASI sea ice concentration data and AMSR-2 winter snow depth on Arctic sea ice) ; Sea-ice observations from the Canadian Ice Service ; Aerial surveys of ringed seals hauled out on sea ice (S. Ferguson)

Suggested reading : [introductions]

Cottier, F., Steele, M., & Nilsen, F. (2017). Sea ice and Arctic Ocean oceanography. In D. Thomas , Sea Ice (3 ed., pp. 195-217). [chapter 7] WILEY Publications. https://doi.org/10.1002/9781118778371.ch7

Levasseur, M. Impact of Arctic meltdown on the microbial cycling of sulphur. *Nature Geosci* **6**, 691–700 (2013). https://doi.org/10.1038/ngeo1910

References: [model evaluations and data references]

- Salinity

Khosravi, N., Wang, Q., Koldunov, N., Hinrichs, C., Semmler, T., Danilov, S., & Jung, T. (2022). The Arctic Ocean in CMIP6 models: Biases and projected changes in temperature and salinity. Earth's Future, 10(2). https://doi.org/10.1029/2021EF002282

Martínez, J., Gabarró, C., Turiel, A., González-Gambau, V., Umbert, M., Hoareau, N., González-Haro, C., Olmedo, E., Arias, M., Catany, R., Bertino, L., Raj, R. P., Xie, J., Sabia, R., and Fernández, D. (2022). Improved BEC SMOS Arctic Sea Surface Salinity product v3.1, Earth Syst. Sci. Data, 14, 307–323, https://doi.org/10.5194/essd-14-307-2022

- DMS

Hulswar, S., Simó, R., Galí, M., Bell, T. G., Lana, A., Inamdar, S., Halloran, P. R., Manville, G., and Mahajan, A. S. (2022) Third revision of the global surface seawater dimethyl sulfide climatology (DMS-Rev3), Earth Syst. Sci. Data, 14, 2963–2987. https://doi.org/10.5194/essd-14-2963-2022

Galí, M., Devred, E., Babin, M., & Levasseur, M. (2019). Decadal increase in Arctic dimethylsulfide emission. *Proceedings of the National Academy of Sciences*, *116*(39), 19311-19317. https://doi.org/10.1073/PNAS.1904378116

Wang, W. L., Song, G., Primeau, F., Saltzman, E. S., Bell, T. G., & Moore, J. K. (2020). Global ocean dimethyl sulfide climatology estimated from observations and an artificial neural network. *Biogeosciences*, *17*(21), 5335-5354. https://doi.org/10.5194/bg-17-5335-2020

- Seal habitat

Ferguson SH, Young BG, Yurkowski DJ, Anderson R, Willing C, Nielsen O. 2017. Demographic, ecological, and physiological responses of ringed seals to an abrupt decline in sea ice availability. PeerJ 5:e2957. https://doi.org/10.7717/peerj.2957

Ferguson, S.H., Yurkowski, D.J., Young, B.G., Fisk, A.T., Muir, D.C., Zhu, X. and Thiemann, G.W., 2020. Comparing temporal patterns in body condition of ringed seals living within their core geographic range with those living at the edge. Ecography, 43(10), pp.1521-1535. https://doi.org/10.1111/ecog.04988

McCrystall, M.R., Stroeve, J., Serreze, M. et al. New climate models reveal faster and larger increases in Arctic precipitation than previously projected. Nat Commun 12, 6765 (2021). https://doi.org/10.1038/s41467-021-27031-y

Crawford, A., Stroeve, J., Smith, A. et al. Arctic open-water periods are projected to lengthen dramatically by 2100. Commun Earth Environ 2, 109 (2021). https://doi.org/10.1038/s43247-021-00183-x

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Group 5

Project Title: Atmospheric rivers and aerosol transport to the poles
Assistant: Rémy Lapere [remy.lapere@univ-grenoble-alpes.fr]
Students: Lea, Julia

Background/motivation:
Atmospheric rivers (AR) are narrow, long, transient, water vapor-rich corridors of the atmosphere that greatly affect the hydrological budget in polar regions [Nash et al., 2018]. They are relatively rare (~12 per year in West Antarctica) but important contributors to snowfall accumulation in East Antarctica, sea ice decline in the Arctic and the decreasing ice mass on the Greenland ice sheet due to the enhanced downward longwave radiation and warm air advection [Wille et al., 2019]. The frequency and intensity of warm and moist air-mass intrusions (associated with AR) into the Arctic have increased over the past decades and have been related to sea ice melt [Caballero & Woods, 2016]. In the spring of 2020, a major warm air mass intrusion event was recorded in the high Arctic, associated with the transport of large quantities of aerosols originating from Europe, possibly affecting Arctic clouds properties [Dada et al., 2022]. This project aims at studying the transport of aerosols associated with such events and evaluating possible implications for polar climate.

Research question(s):
- How much aerosols do AR transport toward the pole?
- Where do these aerosols come from? (source, species)
- How do they affect polar clouds?

- Do AR with larger aerosol content have a larger impact on polar climate?
- (bonus: Do CMIP6 models reveal trends in polar AR?)

These questions can be treated for the Arctic or Antarctic (or both) up to the students. The year of study is 2020 because we have the AR detection product for that year, but if the students are VERY motivated, they can try to use the algorithm from Wille et al., 2019 and MERRA2 data to recreate AR detection for other years.

Data:
Reanalysis:

  - MERRA2 3-hourly (temperature, specific humidity, wind, pressure…)
  - CAMS atmospheric composition 3-hourly (aerosol optical depth with speciation, total column carbon monoxide)
- Atmospheric river detection product for the year 2020 based on Wille et al., 2019
- Observations at Zeppelin station (time series of carbon monoxide, vapor, aerosols, aod from aeronet…)
- EBAS platform for additional station data if needed
- (if bonus topic: CMIP6 historical fields of water vapor, winds, pressure)

Reference(s):

Wille et al. West Antarctic surface melt triggered by atmospheric rivers. Nat. Geosci. 12, 911–916 (2019). https://doi.org/10.1038/s41561-019-0460-1

Nash et al., The Role of Atmospheric Rivers in Extratropical and Polar Hydroclimate, J. Geophys. Res., 123 (2018), 10.1029/2017JD028130

Caballero & Woods. The role of moist intrusions in Winter Arctic warming and sea ice decline. J. Clim. 29 (2016), doi.org/10.1175/JCLI-D-15-0773.1

Dada et al. A central arctic extreme aerosol event triggered by a warm air-mass intrusion, Nat. Comm., 13 (2022), 10.1038/s41467-022-32872-2

Group 6

Project Title: Primary production and zooplankton in the polar regions - indicators or actors of climate change?
Assistant: Ada Gjermundsen [adag@met.no]
Students: Anne Gro, Rahul, Stian

The Arctic warms nearly 4 times and the Barents area in particular as much as 7 times faster than the globe (Isaksen, K., et al. Sci Rep. 2022, Rantanen et al. Nat. Commun. 2022). Intertwined with the warming is a reduction in sea ice cover, which increases the amount and duration of solar insolation at the ocean surface.

Phytoplankton exhibit a pronounced seasonal cycle, highly dependent on solar insolation, with a maximum during spring (April - May) and a minimum in the winter and early spring (January-March). However, the inter-annual variability is high. The spring bloom duration lasts typically 3-4 weeks and is followed by a reduction due to exhaustion of nutrients (phytoplankton need nutrients like nitrogen (N)), grazing by zooplankton, vertical mixing and advection from lower latitudes.

Zooplankton plays an important role in the Arctic ecosystem by transferring energy from the primary producers to animals higher in the food chain, as part of the so-called food web. Hence, the zooplankton biomass depends both on primary production and predation pressure (e.g. fish; capelin, herring, cod, and larger plankton; krill, chaetognaths)

Plankton are often indicators of ecosystem change. Warming and sea ice reduction in the Arctic Ocean cause an increase in the primary production, zooplankton and krill. Phytoplankton blooming depends heavily on available sunlight. Hence, more open water due to sea ice loss in the Arctic Ocean promotes increased growing season and production of phytoplankton. However, several of the CMIP6 models exhibit a reduction in phytoplankton associated Chl *a* in the Barents Sea in the future scenarios (SSPs).

Main research questions:

- Seasonal cycle: do you find a relationship between NPP, open water area and duration, sst, and what about zooplankton? Do models at all agree with the observations?
- Research studies indicate that increases in total primary productivity of the Arctic Ocean are driven in large part by reductions in the persistence and extent of sea ice cover. Do you find a similar relationship in CMIP6 models?
- Does the strong relationship between sea ice cover and total annual NPP hold for the past when sea ice cover was greater, and in the future, as sea ice continues to decline. Is there a threshold for sea-ice area below which this relationship no longer holds? How about a new steady state?

Mini-research questions for guidance:

- The zooplankton grazes on the primary producers, do you find a dependency in the data?
- Do you find a significant increase in annual NPP?
- Do you find a significant correlation between NPP and mean annual open water area? How about the NPP and length of the open water cycle?
- Is there an increase in the trends? Significance?
- Some studies suggest that climate models fail to capture AA due to the cooling effect of increased/brighter cloud cover, which will also impact the insolation at the ocean surface. Do you find this effect in the data?
- How is the timing of the peak in NPP correlated with open water peak, annual NPP, sea ice cover, mean Chl *a* ?

Data:

- **net primary production (npp):**
  - satellite retrievals (SeaWiFS and MODIS Aqua ocean color data) of chlorophyll *a* (Chl *a*) (http://orca.science.oregonstate.edu/npp_products.php), years 2002 - 2021
  - samples from CTD mounted water bottles. Transects Nord Norge - Bjørnøya, years 1977 - 2017
  - /projects/NS9252K/ESGF_betzy/obsdata/Tier2/ESACCI-OC/OBS-ESACCI-OC_sat_fv3.1_Omon_chl_199701-201712.nc
- **Zooplankton:** samples from ship cruises. Transects Nord Norge - Bjørnøya
  - https://www.st.nmfs.noaa.gov/copepod/content/region_arctic.html
  - Havforskningsinstituttet
- **Sea ice edge:**

- https://osi-saf.eumetsat.int/products/osi-450
    - the OSI-SAF climate product (Lavergne et al., 2019) at 25 km resolution (1979 - 2022)
    - https://modis.gsfc.nasa.gov/data/dataprod/mod29.php
- **HadISST**:
    - https://www.metoffice.gov.uk/hadobs/hadisst/

- **CMIP6 models:** NorESM2-MM, NorESM2-LM, ACCESS-OM2, CESM2, IPSL-CM6A-LR, data from the OMIP experiments to start with

References:

- https://earthobservatory.nasa.gov/features/Phytoplankton
- https://earthobservatory.nasa.gov/images/51765/bloom-in-the-barents-sea
- https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-life/ocean-plants/phytoplankton/
- https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-life/jellyfish-other-zooplankton/
- https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JC007151
- https://www.nature.com/articles/s41558-020-0905-y
- https://www.science.org/doi/full/10.1126/science.aay8380
- https://doi.org/10.5194/tc-13-49-2019
- https://gmd.copernicus.org/articles/10/2169/2017/gmd-10-2169-2017.pdf

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Group 7

Project Title: Effects of precipitation on aerosol populations in polar regions
Assistant: Theodore Khadir [theodore.khadir@aces.su.se]
Students: Arttu, Ingrid, Zhangcheng

Background/motivation:

The Arctic environment is known to be particularly sensitive to perturbations of the radiative budget due to complex climate feedbacks (associated with the land and sea ice, clouds, and atmospheric and oceanic dynamics) and the overall environmental conditions that are characteristic to the Arctic environment. Future changes in the Arctic are projected to progress rapidly, with a diminution in Arctic sea ice (e.g. Wang and Overland, 2009) and a large increase in Arctic precipitation (e.g. Bintanja and Andry., 2017) expected to have a large impact on atmospheric aerosol sources and sinks.

Aerosol particles are key constituents of the atmosphere as they directly affect the Earth's radiative balance by reflecting and absorbing solar and infrared radiation, and as they control the properties of clouds (reflectivity and absorptivity, lifetime, precipitation...) by serving as condensation nuclei for cloud droplets and ice crystals.

While most studies attempt to understand how aerosols impact clouds and precipitation properties, fewer focus on the impact of clouds and precipitation on aerosol populations, which leaves half of the aerosol life cycle less constrained. Here, our objective will be to investigate the effects of clouds and precipitation on aerosol particles using observational data (from in-situ measurements and satellite retrievals) and to evaluate the representation of these effects in GCM models.

About the processes:
It is well established that wet scavenging by clouds and precipitation (through *rainout*: under the right thermodynamic conditions, particles that are large enough can activate and form cloud droplets, if these droplets grow enough, the cloud can precipitate and scavenge the particles from the atmosphere; and through *washout*: particles that are located below a precipitating cloud can collide with falling droplets, get trapped and fall to the ground) are the most important sinks for the atmospheric particulate mass and number concentration of the accumulation mode particles (>100nm) (e.g. Seinfeld and Pandis, 2006).

But the net effect (i.e. the magnitude and sign) of clouds and precipitation on aerosol populations, can however vary due to the complex response of atmospheric aerosol dynamics to changes in meteorological conditions. Indeed, precipitation can indirectly enhance concentration of <100nm particles by removing the accumulation mode particles, which are a major sink for the small particles formed by nucleation (e.g. Dal Maso et al., 2004; Riipinen et al., 2011; Westervelt et al., 2013). On the other hand, there are indications of direct production of new particles in the vicinity of clouds (e.g. Ekman et al., Krejci et al., Murphy et al., 2015) and of the downward transport of free-tropospheric particles and vapors during precipitation events (Wang, Krejci et al., Nature 2016).

Research question(s):
- How do precipitation and clouds influence aerosol size distributions?
- Are these effects well represented in GCMs (CMIP6 models)?
- How does the increasing precipitation trend affects aerosol properties in climate projections? - in observations?

Data:
- In-situ particle number size distribution measurements (at Zeppelin Station in Ny-Ålesund, at Hyytiälä in Finland, + for EBAS stations if needed) and air mass history from modeled backward trajectories collocated with reanalysis data
- Freud dataset (https://acp.copernicus.org/articles/17/8101/2017/)
- NorESM simulations (variables: PNSDs, precipitation, aerosol composition, solar radiation...)
- Satellite retrievals:
    - Monthly mean MODIS Aerosol Optical Depth (AOD)
    - GPCP Monthly mean global precipitation data (2.5°x2.5°)
- ERA5 reanalysis
- Collocated L2 MODIS product with MERRA and ERA reanalyses (including precipitation) for the year 2003 over the pacific ocean
- (+ all data that you see in other projects!)

Reference(s):
<u>**On the observation of the effects of precipitation on aerosol populations**</u>

- Tuvned et al., 2013: Arctic aerosol life cycle: linking aerosol size distributions observed between 2000 and 2010 with air mass transport and precipitation at Zeppelin station, Ny-Ålesund, Svalbard - https://acp.copernicus.org/articles/13/3643/2013/
- Wang et al., 2016: Amazon boundary layer aerosol concentration sustained by vertical transport during rainfall: https://www.nature.com/articles/nature19819

On precipitation trends in the Acrtic

- Bintanja and Andry., 2017: Towards a rain-dominated Arctic - https://www.nature.com/articles/nclimate3240.pdf
- Bintanja et al., 2020: Strong future increases in Arctic precipitation variability linked to poleward moisture transport https://www.science.org/doi/10.1126/sciadv.aax6869

Some links

- https://slidetodoc.com/precipitation-processes-types-of-precipitation-stratiform-convective-deep/ : precipitation processes (convective vs. stratiform)

Useful links, tips and tricks …

- CMIP6 data dictionary: https://clipc-services.ceda.ac.uk//dreq/mipVars.html
- CMIP6 data download platform: https://esgf-node.ipsl.upmc.fr/search/cmip6-ipsl/
- Introduction to python links:
  - https://aaltoscicomp.github.io/python-for-scicomp/
  - https://nordicesmhub.github.io/Norway_Sweden_training/pangeo/intro.html
  - http://gallery.pangeo.io/repos/pangeo-gallery/cmip6/index.html#
  - https://rabernat.github.io/research_computing_2018/category/lectures.html