Is there a positive feedback between Arctic stratus and Arctic sea ice changes?
Master thesis

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Abstract

This will be my abstract.
Write it later....
No more than a page and should contain:
- main findings - how it compares to others - a conclusion?

Acknowledgements

Contents

Chapter 1

Introduction

Low clouds have a net warming effect in the Arctic [Intrieri *et al.* , 2002b], as opposed to the well known net cooling effect they have at lower latitudes. Low layered clouds (stratus) also dominate the Arctic cloud cover. The Arctic climate changes have been greater than the global mean and have become known by the term "Arctic amplification" [Graversen *et al.* , 2008]. Therefore the climate effect of low clouds in the Arctic is an interesting topic to study.

Decreasing sea ice extent could lead to an increase in the aerosol number concentrations in the area where ice has retreated. The open sea surface it self would lead to an increase in release of sea salt and DMS (dimethyl sulfide) to the lower atmosphere. The lack of sea ice would also increase the likelihood that the sea could be used for shipping, which would pollute the area.

The enhancement of evaporation from diminishing sea ice and the increase in aerosol number concentration from open water and shipping could lead to denser and longer-lived low clouds in the area of sea ice retreat. A followup question to that is if these clouds would then have a slightly different radiative effect, and by that influence the further retreat of sea ice.

1.1 Main goal

According to the IPCC report by Boucher *et al.* [2013] the study by Eastman & Warren [2010a] using visual cloud reports from the Arctic, with surface and satellite observations, and the studies by Kay & Gettelman [2009] and Palm *et al.* [2010] using lidar and radar observations have confirmed that the low-cloud amount over the Arctic oceans varies inversely with sea ice amount.

This means that there is an increase in cloud amount when there is less sea ice. Now what we want to know is if these clouds are also denser and more persistent, and could lead to an enhanced warming and reduced sea ice amount, a positive feedback.

With this thesis I try to find if a decrease in Arctic sea ice lead to denser and more persistent clouds. It has been suggested that the decline in sea ice extent would allow for more pollution in the Arctic, as a consequence of more open water and ship traffic. The effect of increase in aerosol concentrations from shipping and open water, and the effect of enhanced evaporation from open water are studied separately and combined. With the main goal to find if this would lead to changes in clouds that could enhance downwelling long wave radiation and decrease upwelling short wave radiation, both of which have warming effects.

1.2   My contribution

The findings in my thesis have been achieved with some of the most recently developed code (by Greg Thompson [Thompson & Eidhammer, 2014]) for cloud micro physics and aerosols and their effects on radiation, in modeling. The results build further on the work of other researchers @name-some-and-cite and may raise some questions for further research within the field.

1.3   Area description

The area of the study in this thesis is in the Arctic, north of the United States of America and north-west of Canada. The study area covers the Beaufort Sea and a small part of Alaska and Canada, and can be seen in figure 1.1.

There are a few reasons for choosing this as the study area. First it is in the Arctic, and sea ice is present there in autumn, even in 2012 when there was record low sea ice extent. Also it has been exposed to field campaigns: Surface Heat Budget of the Arctic Ocean (SHEBA) [Uttal *et al.* , 2002], First International Satellite Cloud Climatology Project Regional Experiment Arctic cloud Experiment (FIRE ACE) [Curry *et al.* , 2000], Mixed-Phase Arctic Cloud Experiment (M-PACE) [Verlinde *et al.* , 2007] and more. Therefore there are many studies on Arctic clouds that include this study area and data from some of the mentioned field campaigns. This provides parts of the science basis for my study and selection of literature and studies for comparison and questions. Quite a few studies are based on satellite data
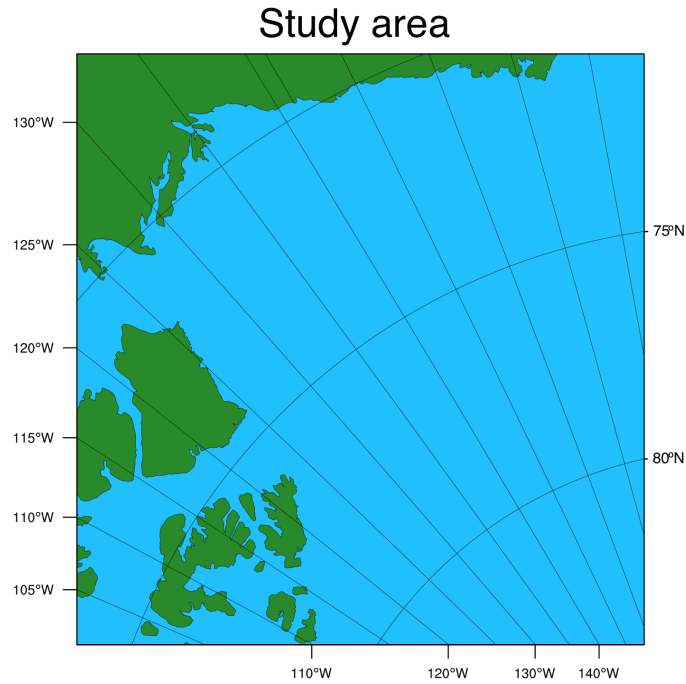
Figure 1.1: An overview of the study area. The bottom right corner is the northernmost point and the y-axes show longitude and latitude to the left and right, respectivly.

analysis and some of them are presented in the next chapter as background and motivation for my thesis.

1.4 Structure of the thesis

In the following chapter 2 I will present the background for my thesis; what work I hope to compare my results to and relate my thesis to. Also I will touch upon why the subject of my thesis is important. In chapter 3 the most important theory and basic knowledge needed to understand some of the processes in clouds and their possible effect on the sea ice. Chapter 4 is where I explain which model and tools and I have used and how I have worked with them to get the results presented and discussed in chapter 5.A summary of main findings and conclusions are presented in the last chapter **??**, before the list of references at the very end.

Chapter 2

Background

In this chapter I shall present some recent literature on the subject, that forms a basis for the study presented in this thesis.

Some new (and older) research that makes my thesis interesting and relevant to the field. No one has done this study with a weather forecasting model, it is interesting to look at changes in parameters in similar meteorological conditions, the same initial and boundary conditions in every run. Describe some of the work done by Palm *et al.* [2010], Wu & Lee [2012] and others on autumn low clouds in the Arctic to emphasize the importance of my work.

A study by Schweiger *et al.* [2008] investigated the connection between sea ice variability and cloud cover over over the Arctic seas during autumn. They analysed the ERA-40 re-analysis products and some satellite data sets. They found that that sea ice retreat was linked to a decrease in low-level (surface to $\sim$1.9 km) cloud amount and an increase in mid-level ($\sim$1.9 to 6.1 km) clouds. They state that the decrease in static stability and deepening of the atmospheric boundary layer, following ice retreat, contribute to the rise in cloud level.

The study by Vavrus *et al.* [2010] investigated the behaviour of clouds, during intervals of rapid sea ice loss in the Arctic in the 21st century. The study was done by use of the Community Climate System Model (CCSM3). Their results support that cloud changes appear to accelerate rapid loss of sea ice in autumn, and possibly in winter. They also conclude that "the trends in total cloudiness during rapid ice loss events are explained almost entirely by low-level clouds" and that "a positive feedback from primarily low cloud changes amid a warming climate".

Kay & Gettelman [2009] combined satellite data and complementary data

sets to study the Arctic cloud and atmospheric structure during summer and early Autumn over the years 2006-2008. This covers the at the time record low sea ice extent from 2007. In contrast to the study by Schweiger *et al.* [2008] they found more low-level cloud. There are reasons to believe that the observations used in their study are more accurate than the re-analysis used in Schweiger *et al.* [2008].

Eastman & Warren [2010b] analysed visual cloud reports from the Arctic for year-to-year variations

The study by Palm *et al.* [2010] using satellite and lidar data and found that areas of open water were associated with greater polar cloud fraction.

A common uncertainty and missing link in a few of these studies is that they did not look at liquid water content, effective radii and other parameters affecting the radiative properties of the clouds. In this study, that is what I want to look in to, how these properties are influenced by the changing sea ice, and if the cloud enhance the sea ice melt.

Chapter 3

Clouds and Radiation

In this chapter, a brief overview of clouds in the Arctic, with focus on stratus, is presented first. Followed by how cloud properties can influence radiation. Last in this chapter, a section on aerosol-cloud interactions is included.

3.1 Arctic clouds

The Arctic cloud cover is dominated by low clouds, and the largest amounts of low stratus clouds are over the open oceans [Klein & Hartmann, 1993]. According to Klein & Hartmann [1993] stratus in the Arctic basin peaks during summer at nearly 62%, while during the winter season the stratus only accounts for 18% of the cloud cover. This leads them to conclude that the seasonal cycle of stratus in the Arctic is driven by the temperature cycle, thereby moisture content in the atmosphere, rather than the static stability.

The air in the Arctic is very stable in winter (polar night), and clean since there are not many sources for pollution. In Autumn the sea ice extent reaches a minimum after the summer melting and leaves open water to influence low clouds and their properties.

Low clouds have bases below 2000 m. Stratus (St) are layered clouds that form when extensive areas of stable air are lifted. Stratus clouds are normally between 0.5 and 1 km thick, whereas they can be several km wide [Aguado & Burt, 2010].

3.2 Cloud effects on radiation

The cloud microphysical properties that determine the cloud radiative properties include: the amount of condensed water, the size and shape of the
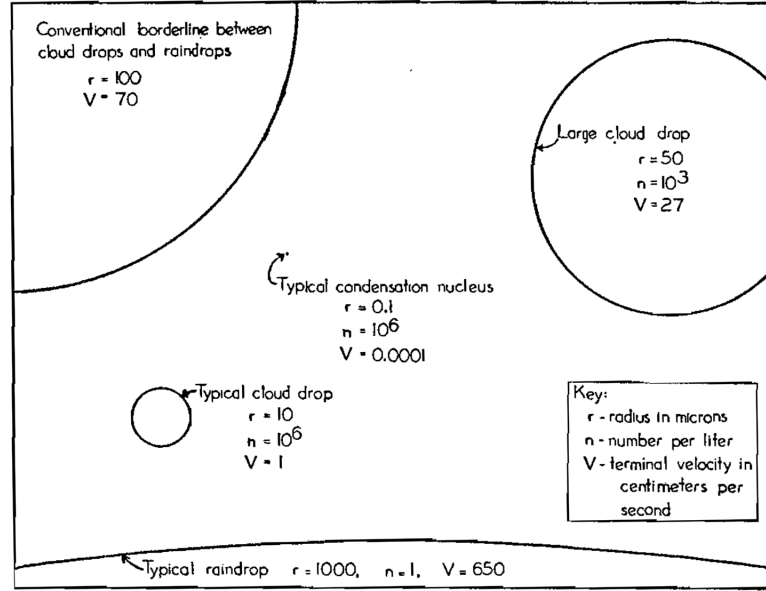
Figure 3.1: Size of CCN, typical cloud droplet, large cloud droplet, borderline between cloud droplets and raindrops and typical size of raindrop.From [Mc-Donald, 1958].

cloud particles, and the phase of the particles/and if the particles are liquid or ice [Curry *et al.* , 1996].

3.2.1   The Cloud – a gray body

Stefan–Boltzmanns law states that the flux density emitted by a black body is proportional to the fourth power of the absolute temperature [Liou, 2002]. For a gray body, like a cloud, the equation can be written

$$F = \epsilon \sigma T^4 \tag{3.1}$$

where the emissivity of the gray body, ϵ, is included. $F[W\ m^{-2}]$ is the flux density emitted by the gray body, and $\sigma = 5.67 \cdot 10^{-8} Jm^{-2} sec^{-1} deg^{-4}$ is the Stefan–Boltzmann constant.

3.2.2 Cloud optical depth

Change to CLOUD optical depth Normal optical depth or optical thickness, τ_λ is a measure of the cumulative depletion that a beam of radiation directed straight downward (zenith angle $\theta = 0$) would experience in passing through a defined layer [Wallace & Hobbs, 2006]. The optical depth can be expressed as

$$\tau_\lambda = \int_z^\infty k_\lambda \rho R dz \tag{3.2}$$

where k_λ is the mass absorption coefficient, which has units of $m^2\ kg^{-1}$, ρ is the density of air, which has units of $kg\ m^{-3}$, and R is the mass of the absorbing gas per unit mass of air.

As mentioned in Chapter 1 there is no solar radiation to reflect during winter and the polar night in the Arctic, whereas in the summer the zenith angle is so high that even though there is sunlight 24 hours a day the cooling effect in summer does not average out the heating effect the clouds have in winter. A high zenith angle, means that the radiation has to travel through more atmosphere, which gives a higher optical depth and stronger depletion of the radiation beam. Consequently, the low clouds' ability to absorb and emit terrestrial radiation dominates over their reflective effect on the solar radiation.

3.2.3 Liquid Water Content and Path

The amount of condensed water can be expressed by the liquid water content (LWC) in the cloud, often presented with units g m^{-3} and is proportional to the cloud droplet number concentration. From Rogers & Yau [1989] we can express the number of droplets with radius r by

$$N = \int n(r) dr \tag{3.3}$$

where N is the cloud droplet number concentration (c m^{-3}), and $n(r)$ is the number of droplets with radius r. When we use the median volume radius,

$\bar{r}$ (μ m), the LWC can be written

$$
\begin{aligned}
LWC &= \int \rho_L \frac{4}{3}\pi r^3 n(r) dr & (3.4) \\
&= \frac{4}{3}\pi \rho_L \int r^3 n(r) dr & (3.5) \\
&= \frac{4}{3}\pi \rho_L \bar{r}^3 \int n(r) dr & (3.6) \\
&= \frac{4}{3}\pi \rho_L \bar{r}^3 N & (3.7)
\end{aligned}
$$

where the last equation shows the proportionality of LWC to the cloud droplet number concentration N, and to $\bar{r}$. ρ_L is the density of liquid water.

Another common measure of condensed water is the liquid water path (LWP). If the LWC is integrated over a column, from the base to the top, it gives the LWP of that column.

$$
LWP = \int_{base}^{top} LWC \cdot dz \qquad (3.8)
$$

The LWP is the column of liquid water in a cloud and is usually expressed by g m^{-2}.

How does this influence the radiation???!! A higher LWC or LWP increases the reflectivity of the cloud, and thereby reduces the SW radiation reaching the surface.

3.2.4   Cloud droplet effective radius

The cloud droplet effective radius determines important radiative properties of a cloud, cloud albedo (A) and cloud emissivity (ϵ) [Hansen & Travis, 1974], and is therefore of particular interest.

The cloud droplet effective radius is a weighted mean of the size distribution of cloud droplets. The effective radius may be written

$$
r_e = \frac{\int r^3 n(r) dr}{\int r^2 n(r) dr} \qquad (3.9)
$$

where r_e is the effective radius.

It is obvious from equations for A and ϵ that a when r_e is small - the albedo increases, and when it is larger the cloud albedo decreases. What about emissivity??

3.3 Aerosols and clouds

For low clouds to form there must be available aerosols. Aerosols act as cloud condensation nuclei (CCN) by letting water vapor condense on them. This is how a cloud droplet is formed. For an ice particle to be present in a low cloud, an ice nuclei (IN) and low temperatures (-5 to -20°C)@? are necessary. If an IN hits a cloud droplet with temperature below zero, a super-cooled droplet, the droplet will freeze.

Aerosols have a direct effect on the climate by scattering and absorbing SW radiation, and scattering, absorbing and emitting LW radiation.They also have numerous effects on clouds by for example acting as CCNs and INs. The amount of CCNs and INs available affect the properties of the clouds in the area. If there are few CCNs in an area, a cloud formed there would be a clean cloud with few, but large droplets and therefore have a low albedo and precipitate easily. If the area had high aerosol concentration, the cloud would be polluted and have more numerous but smaller droplet, which means it would have a higher albedo and precipitation would be suppressed.

Not only the aerosol burden is important, if it is the same for two areas with different meteorological forcing that would also affect the cloud properties. Say an area has a weaker updraft than another area, a cloud formed due to the weaker updraft will have lower LWC, lower albedo and little precipitation. The cloud formed in a stronger updraft will have higher LWC, higher albedo and be more precipitating.

There are two known indirect effects that aerosols have on radiation, through clouds. The first indirect effect was proposed by Twomey [1974] and is often referred to as the Twomey effect. The second indirect effect was proposed by Albrecht [1989] and is also known as the lifetime effect.

3.3.1 The first indirect effect

The first indirect effect, suggested by Twomey [1974], describes the enhancement of cloud albedo as a consequence of an increase in aerosol content and thereby available CCNs. In short, the first indirect effect is a cloud albedo enhancement. By increasing droplet concentration and hence the optical thickness of a cloud, pollution acts to increase the reflectance of clouds [Twomey, 1977]. The optical thickness is increased when the number of CCN is increased. Although the changes are small, the long term effects on climate can be profound [Twomey, 1974].

The optical depth will change with changes in aerosol number concentrations and changes in clouds and their properties. For instance if a cloud has

many small droplets, the optical depth will be higher. Whereas fewer cloud droplets will yield a lower optical depth, resulting in more SW radiation reaching the ground — possibly having a warming effect on the area.

Include a figure showing the indirect effect? :)

3.3.2   The second indirect effect

The second indirect effect, or the cloud lifetime effect, suggests more numerous but smaller droplets reduce the precipitation efficiency and by that enhances the cloud lifetime and hence the cloud reflectivity [Albrecht, 1989]. This effect has been estimated to be roughly as large as the first indirect effect [Lohmann & Feichter, 2005].

3.3.3   Aerosol-cloud interactions

Cloud presence is due to water vapor condensing on CCNs and possibly freezing if the aerosol's structure resembles that of an ice crystal, IN. Processes known to affect the local aerosol concentration are: precipitation because the precipitation will bring with it the CCNs and INs that available water vapor has nucleated on (either condensed or frozen), this is also known as scavenging (removal of aerosols by precipitation). Pollution in the area increases the local aerosol concentration. Increases in aerosol concentration might inhibit precipitation and cause longer-lived, more persistent clouds, which will in turn affect the radiation balance.

Chapter 4

Model and methods

To produce results for the thesis, a formulation of the Weather Research and Forecasting (WRF) Model called the Advanced Research WRF (ARW) has been used. The model is described in the first part of this chapter. Then follows a description of the model setup and the different physics schemes that were chosen for this study, before a summary of the different runs that were performed. Ending the chapter are two short sections on the input data and processing of the model output.

4.1 Description of the WRF-ARW Modeling System

The version of the WRF-ARW modeling system used is 3.6.1, which was released in April 2014. The model is primarily developed at the National Centre for Atmospheric Research (NCAR) in Boulder, Colorado. The ARW model is the first fully compressible conservative form nonhydrostatic model designed for both research and operational numerical weather prediction (NWP) applications [Skamarock & Klemp, 2008].

As can be seen from figure 4.1 the WRF-ARW Modeling System consists of four major programs [Wang *et al.* , 2015]:

- The WRF Prepocessing System (WPS)

- WRF-Data Assimilation (WRF-DA)

- ARW solver

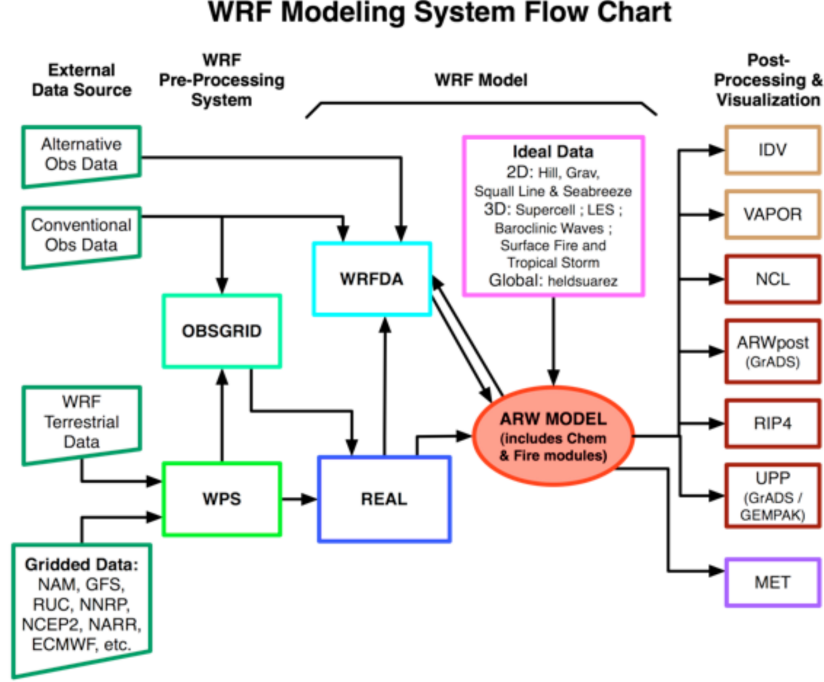- Post-processing & Visualization tools

Figure 4.1: Flowchart for the WRF ARW Modeling System Version 3. From Wang *et al.* [2015].

WPS is used primarily for real data simulations [Wang *et al.* , 2015], like the study presented in this thesis. A real-data simulation means that it has been initialized by observations and reanalysis, not artificial data. WPS' functions include defining simulation domains, interpolating terrestrial data and degribbing and interpolating meteorological data from another model to this simulation domain [Wang *et al.* , 2015]. WRF-DA is optional and can be used to ingest observations into the interpolated analyses created by WPS [Wang *et al.* , 2015], but was not used in this study. The ARW solver is the key component of the modeling system, which is composed of several initialization programs for idealized, and real-data simulations, and the numerical integration program [Wang *et al.* , 2015].

The continuous equations solved in the ARW model are the Euler equations cast in a flux form where the vertical coordinate, η, is defined by a
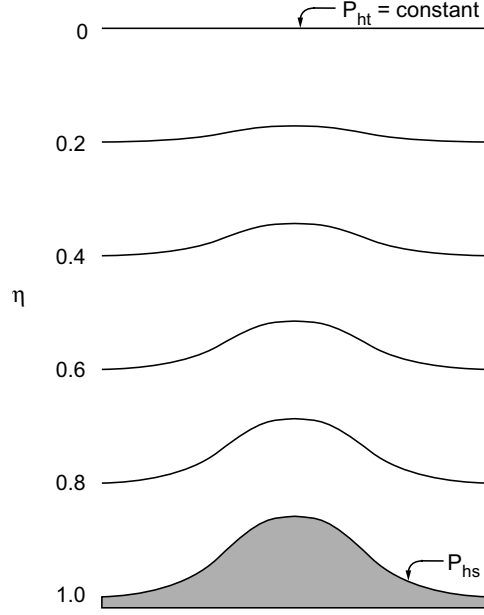
Figure 4.2: This figure is shown as presented in Skamarock & Klemp [2008], and is a schematic of the terrain following a σ coordinate. P_{hs} and P_{ht} are the hydrostatic pressure at the surface and top respectively.

normalized hydrostatic pressure,

$$\eta = (p_h - p_{ht})/\mu \tag{4.1}$$

where $\mu = (p_{hs} - p_{ht})$ [Skamarock & Klemp, 2008]. p_h is the hydrostatic component of the pressure and p_{hs} and p_{ht} are the values of the hydrostatic pressure in a dry atmosphere at the surface and top boundaries respectively [Skamarock & Klemp, 2008].

The vertical coordinate is the traditional σ coordinate used in many hydrostatic atmospheric models, shown in figure 4.2.

The selection of physics schemes in WRF-ARW are numerous. The choice of schemes treating microphysics in clouds and aerosols, and the radiation are presented in the following section about the model setup.

4.2 Model setup

The model was ran with a 4 km×4 km horisontal grid point spacing, with 300×300 grid points, and 72 vertical layers, with the model top at 10 hPa. The area covers parts of the Beaufort Sea, by Canada and Alaska. This area was chosen because data from the area has been used for related studies [Intrieri *et al.* , 2002a, Kay & Gettelman, 2009, Palm *et al.* , 2010, Schweiger *et al.* , 2008, Shupe & Intrieri, 2004, Wu & Lee, 2012] as mentioned in Chapter 1 and described in Chapter 2.The area is not completely ice free any part of the year,and provides a good place to simulate cloud-sea ice interaction. The area is over several time zones but is approximately 7 hours behind UTC time. The times given in the WRF-ARW modeling system are UTC. The model was ran for a period of 5 days, 1st to 6th of September 2012. This is approximately when the record low ice extent in the Arctic was set (eg. National Snow and Ice Data Centre, U.S.A., Beitler [2012]).

The vertical layers in the ARW model are often referred to as eta levels, because of the choice of η as the vertical coordinate. These levels have uneven vertical spacing. The fact that this η is the traditional σ-coordinate, means that the altitude of each level is dependent on pressure, therefore the level height varies in both time and space. As a consequence of pressure dependence, the levels in the lower troposphere are closer to each other than the levels higher up in the troposphere. Therefore the low clouds in the area can be resolved. Approximate heights for the lowest 11 eta levels is shown in Table 4.1.

Table 4.1: Approximate height for each level in meters above the surface.

Eta level	Approximate height
1	10 m
2	50 m
3	130 m
4	230 m
5	370 m
6	530 m
7	650 m
8	950 m
9	1250 m
10	1400 m
11	1600 m

4.2.1 Choices of physics in the model

The physics options in WRF fall into several categories, each containing several choices. Table 4.2 shows some of the different categories and the choice of scheme, for this study, within each of those categories.

Table 4.2: Table of physics categories and choice of scheme for this thesis

Physics categories	Scheme selected within category
(1) microphysics	aerorol-aware [Reisner *et al.* , 1998, Thompson & Eidhammer, 2014, Thompson *et al.* , 2004, 2008]. Option 28.
(2) cumulus parameterization	Grell 3D @cite authors. Option 5.
(3) planetary boundary layer (PBL)	Yonsei University scheme @cite authors. Option 1.
(4) land-surface model	Noah Land Surface Model @cite authors. Option 2.
(5) radiation	RRTMG LW & SW [Iacono, 2003, Iacono *et al.* , 2000, 2008, Mlawer *et al.* , 1997]. Radiation options 4.

The ARW model offers a wide selection of schemes to treat different physics that one wants represented in the model. The schemes treat the physics slightly differently and some schemes are better for certain horisontal and vertical resolutions than others, so one needs to be careful when choosing how the model is to treat the physics. For my thesis, the especially relevant scheme to mention is the cloud microphysics scheme that I chose, which is the aerosol-aware scheme described in Thompson & Eidhammer [2014]. When studying cloud and rediation response to removal of sea ice we might expect an increase in aerosols from the open ocean and increased sea traffic. The aerosols are therefore also relevant for the choice of schemes, and the aerosol-aware scheme includes the necessary processes for this study.

The aerosol-aware scheme

The microphysics includes explicitly resolved water vapor, cloud, and precipitation processes. The aerosol-aware scheme was chosen so that the study would have scavenging of aerosols included and have proper enough representation of aerosols to study aerosol-cloud interactions, without using the WRF model coupled with chemistry (WRF-Chem). According to the ARW

User's Guide by Wang *et al.* [2015], the aerosol-aware scheme considers water- and ice-friendly aerosols, and a climatological dataset may be used to specify initial and boundary conditions for the aerosol variables. I have used this climatological dataset, which is explained in Section 4.4 Input data. The scheme uses a monthly mean for aerosol number concentrations derived from multi-year (2001-2007) global model simulations in which particles and their precursors are emitted by natural and anthropogenic sources and are explicitly modeled with multiple size bins for multiple species of aerosols by the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model [Thompson & Eidhammer, 2014]. The aerosol-aware scheme [Thompson & Eidhammer, 2014] is built on the schematic shown in figure 4.3, from Reisner *et al.* [1998]. It is a double moment scheme, which means it computes both mass mixing ratios, Q, and number concentrations, N, for the same water species (hydrometeors).

Figure 4.3 show the processes in the microphysics scheme developed by Reisner *et al.* [1998], which the first bulk microphysics scheme by Thompson [Thompson *et al.*, 2004] was based on. The aerosol-aware scheme [Thompson & Eidhammer, 2014] is an extension of the updated Thompson bulk microphysics scheme described in Thompson *et al.* [2008]. The figure shows a schematic of five hydrometeors, cloud water (c), rain (r), ice (i), snow (s) and graupel (g), and if just the mass mixing ratio is calculated or if both the mass mixing ratio and the number concentration is calculated. For each of the hydrometeors, prognostic equations are used with all the sources and sink terms included.

The RRTMG radiation schemes

According to Thompson & Eidhammer [2014] the Rapid Radiative Transfer Model (RRTM) for General Circulation Models (GCMs) (RRTMG) schemes for SW and LW [Iacono, 2003, Iacono *et al.*, 2000, 2008, Mlawer *et al.*, 1997] are the only radiation schemes which include the effects of the effective radii calculated in aerosol-aware. These were therefore used in combination with the aerosol-aware cloud microphysics scheme. The RRTMG schemes are accurate schemes using look-up tables for efficiency, and accounts for multiple bands and microphysics species, and includes the Monte Carlo Independent Column Approximation (MCICA) method of random cloud overlap [Wang *et al.*, 2015].
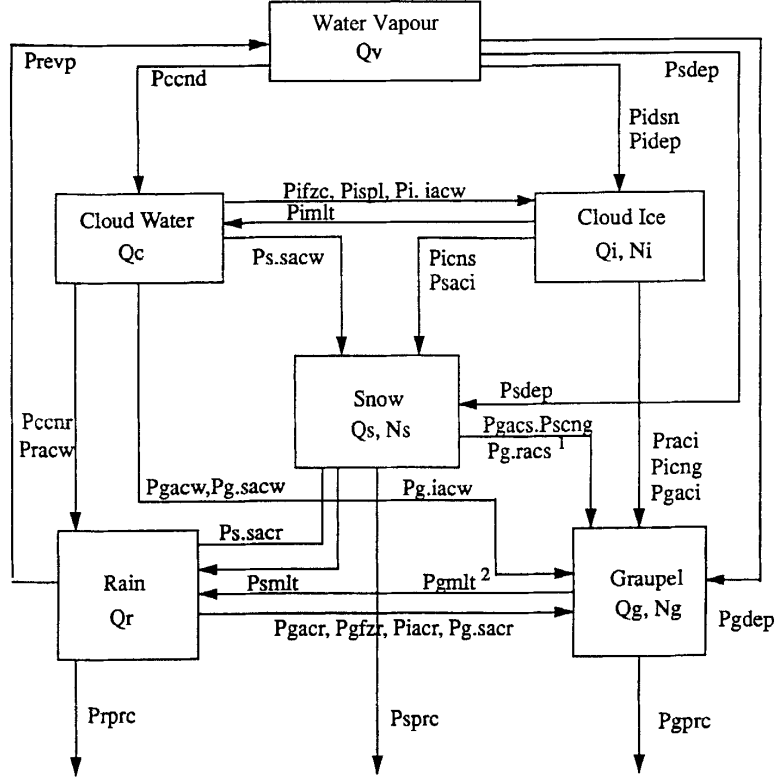
Figure 4.3: Cloud microphysical parameterization scheme typically used i NWP models as shown in Reisner *et al.* [1998]. A full list of the acronyms used in the schematic can be found in Reisner *et al.* [1998].

4.3 Model runs

The results presented in the next chapter are based on six different runs. The control run is the run where the aerosol climatological dataset has been used unchanged, and where the sea ice is kept as it was in the downloaded input data, see Section 4.4. The control run is used as a base to compare the other runs to, those with no ice and/or increased aerosol number concentrations.

There are three runs where the sea ice was removed, NoIce, Aero10NoIce and Aero100NoIce. The point of this is to compare the run with no ice to the control run, and see if there are any changes in the cloud properties, and SW and LW fluxes. For two of those runs the aerosol number concentration was also increased, these can be compared with the control run, and the other

runs that have ice, but the same aerosol number concentrations.

The number of water- and ice-friendly aerosols were multiplied by 10 and 100 both with and without sea ice for 4 runs in total: Aero10 and Aero100 with ice, and as mentioned above, Aero10NoIce and Aero100NoIce without ice. The goal is to find changes in cloud properties, and radiation fluxes compared to those in the control run.

Table 4.3 shows an overview of the different runs that have been executed, whose output have been used for production of figures presented in the next chapter.

Table 4.3: Table showing the names of the runs and if they have sea ice or not, and if the aerosol concentration has been increased by a factor of 10 or 100 through input files. All the runs have the same horisontal resolution of 4 km×4 km, dimensons 300×300, 72 vertical layers and time step 24 s.

Name	Sea ice	Aerosol concentration
control	initial	climatology
NoIce	removed	climatology
Aero10	initial	climatology×10
Aero10NoIce	removed	climatology×10
Aero100	initial	climatology×100
Aero100NoIce	removed	climatology×100

4.3.1 Manipulation of input files

The input files for the ARW solver, created by WPS and REAL (see figure 4.1) were manipulated by use of the NetCDF Operator (NCO) tool ncap2. In these files the sea ice was removed for the runs without sea ice (NoIce, Aero10NoIce, Aero100NoIce) and the aerosol number concentration from the climatological dataset was multiplyed by 10 and 100 for the runs with increased aerosol concentrations by a factor of 10 and 100 respectively.

4.4 Input data

The model runs were initialized with data downloaded from the European Centre for Medium-Range Weather Forecasts (ECMWF)The downloaded data is from the ERA-Interim dataset, which is a global atmospheric reanalysis from 1979 to present and continues to be updated in real timeThrough

WPS the data from ERA-Interim was interpolated over the area, with a 2 degree minute spacing between the points, to be used to initialize the model. The data used is in 6-hourly atmospheric fields on pressure levels, for the first five days of September 2012, which was the period the model was run for. This is done to make sure the initial meteorological conditions are the same in every run, so that the effects of changing a variable in the input files for the modeling system are only due to that change.

To use the climatological aerosol dataset, the file containing monthly means had to be called through WPS. The aerosol input data includes mass mixing ratios of sulfates, sea salts, organic carbon, dust, and black carbon from a 7-yr simulation with 0.5º longitude by 1.25º latitude spacing [Thompson & Eidhammer, 2014].

4.5 Processing of the results

Figures presented in my thesis, I made (unless other is stated) by use of NCL (National Centre for Atmospheric Research (NCAR) Command Language) and/or MatLab. For the NCL scripts I found a lot of help and inspiration from the example scripts for WRF-users available at (URL for examples).

Chapter 5

Results and discussion

5.1   one for each result with belonging discussion?

First lets have a look at the.... changes in something from the control run when the sea ice was removed.

Her kan det være interessant å se på

Differanser i

- SW fluks
- LW fluks
- LH
- SH, følbar varme... har jeg det?
- Dråpestørrelse
- Skyvannmengde

Må få laget disse figurene sånn at Jon Egill og Kari kan se på dem, og sånn at jeg kan tenke på dem og reflektere og diskutere med meg selv!

Må ha skala på labelbar som gjør det leselig, og som fremhever de små forskjellene – for de kan ha stor betydning..!

Hvordan de forskjellige tingene påvirker hverandre må være dekket i teorien.!

Jon Egill hadde tenkt eksamen 22. juni.....

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