# 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

First of all I want to thank my main supervisor Jón Egill Kristjánsson for an interesting project and for the opprtunity to come and work at NCAR for a couple of weeks. I also want to thank my other supervisor Kari Alterskjær for her "poking" and setting deadlines and pushing me for the last six months. I greatly appreciate their guidance and critisism throughout this project, and the doors that were always safe to knock on. Thank you so much to Anne Claire Fuillioux for helping me with setting up and getting started with WRF, and to both her and Kjell Andresen for help with technical problems during my work with this thesis. Thanks also to Gregory Thompson whom Jón Egill and I met with in Boulder, for meeting with us and answering all my e-mails about running the new aerosol-aware microphysics scheme in WRF. These past two years have been very enjoyable in all their stress thanks to Marta and Helle especially, for all their positiveness. Last, but not least, I would like to thank Henrik, for great technical help and moral support.

# 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. Arctic amplification - reduction in sea ice amount!

Diminishing sea ice 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 to the lower atmosphere. The lack of sea ice would also increase the likelyhood that the sea could be used for shipping, which would pollute the area.

## 1.1 Main goal

According to the IPCC report by Boucher *et al.* [2013] the study by Eastman & Warren [2010] 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 posistive 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 enhace downwelling longwave radiation and decrease upwelling shortwave radiation, both of which have warming effects.

## 1.2 My contribution

The findings in my thesis have been achived with some of the most recently developed code (by Greg Thompson [Thompson & Eidhammer, 2014]) for cloud microphysics and aerosols and their effects on radiation, in modelling. 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 done in this thesis is in the Arctic, north of the United States of America and 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. Therefor there are many studies on Arctic clouds that include this study area and data from some of the mentioned field campaigns. This provides a science basis for my study and selection of literature and studies for comparison and questions.

## 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 in chapter 5. The results are further discussed in chapter **??**. A summary of main findings and conclusions

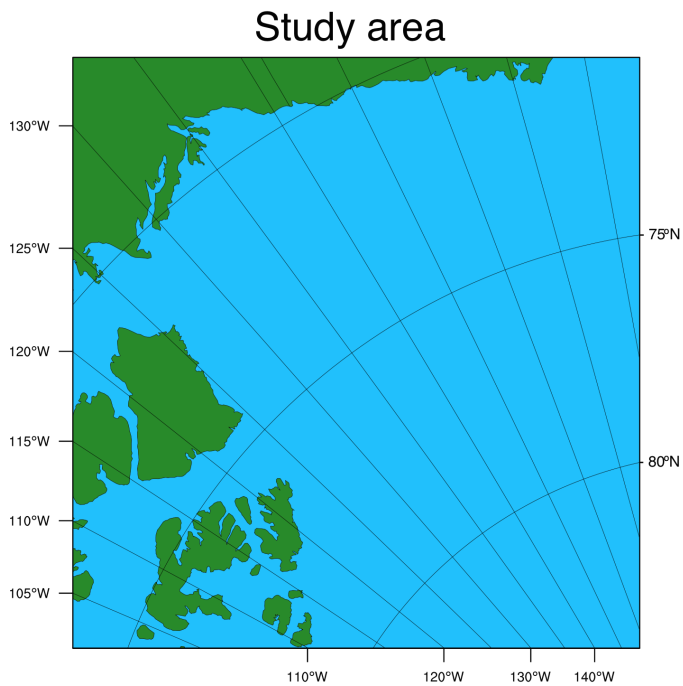


Figure 1.1: An overview of the study area. The bottom right corner is the northernmost point and the y-axes show longitude and latitude to the left and right, respectivly.

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. 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.

Is my work new thinking and does it seem to be very extensive?

Should this whole chapter be a part of introduction..?

Previous studies, shed light on why my study is interesting and may be of importance.

Palm, Kay and Gettleman, Eastman and Warren according to the IPCC report!

# 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 incuded.

## 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

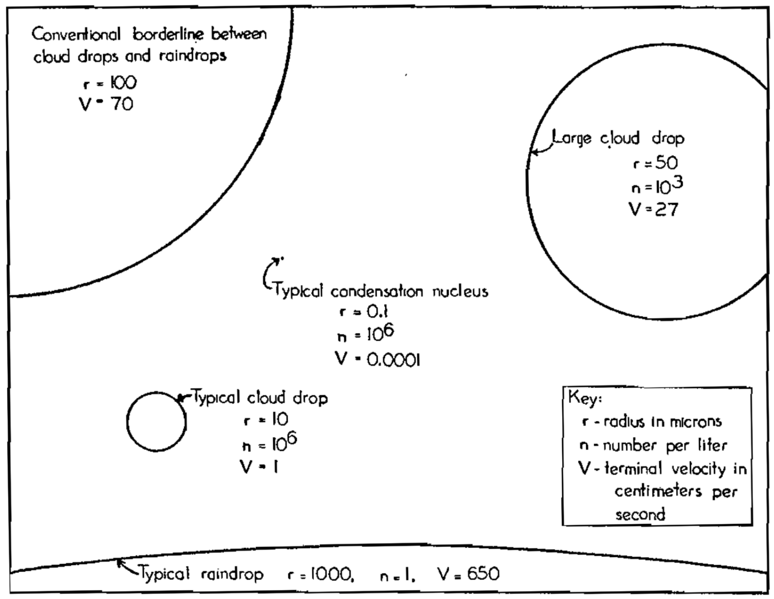


Figure 3.1: Size of CCN, typical cloud droplet, large cloud droplet, boarderline between cloud droplets and raindrops and typical size of raindrop.From [McDonald, 1958].

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, $\epsilon$, 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, $\tau_\lambda$ 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 $k_\lambda$ is the mass absorption coefficient, which has units of $m^2\ kg^{-1}$, $\rho$ 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 consentration. 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, $\overline{r}$ ($\mu\ m$), the LWC can be written

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

where the last equation shows the proportionality of LWC to the cloud droplet number concentration $N$, and to $\overline{r}$. $\rho_L$ 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.

$$LWP = \int_{base}^{top} LWC \cdot dz \tag{3.8}$$

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 ($\epsilon$) [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

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

where $r_e$ is the effective radius.

It is obvious from equations for $A$ and $\epsilon$ 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$^o$C)@? are necessary. If an IN hits a cloud droplet with temperature below zero, a supercooled 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 condensating on CCNs and possibliy 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

## 4.1 Description of the WRF-ARW Modeling System

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, Version 3.6.1, 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

WPS is used primarily for real data simulations [Wang *et al.* , 2015], like the study presented in this thesis. Its 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

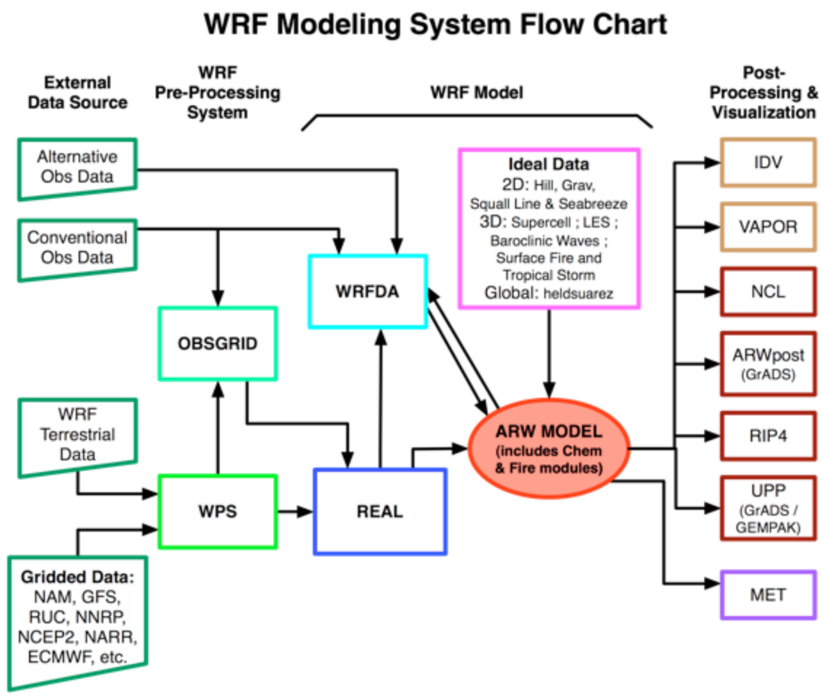


Figure 4.1: Flowchart for the WRF ARW Modeling System Version 3. From Wang *et al.* [2015].

in this study. The ARW solver is the key component of the modeling system, which is composed of several intialization programs for idealized, and real-data simulations, and the numerical integration program [Wang *et al.* , 2015]. Fully compressible nonhydrostatic equations with hydrostatic options, regional and global applications, complete coriolis and curvature terms and that vertical grid-spacing can vary with height are among the WRF models key features according to Wang *et al.* [2015].

The model can be run for ideal cases or real-data cases. I have run the real-time WRF, real.exe — to produce inputfiles for the ARW solver, wrf.exe.

The continuous equations solved in the ARW model are the Euler equations cast in a flux form where the vertical coordinate, $\eta$, is defined by a 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

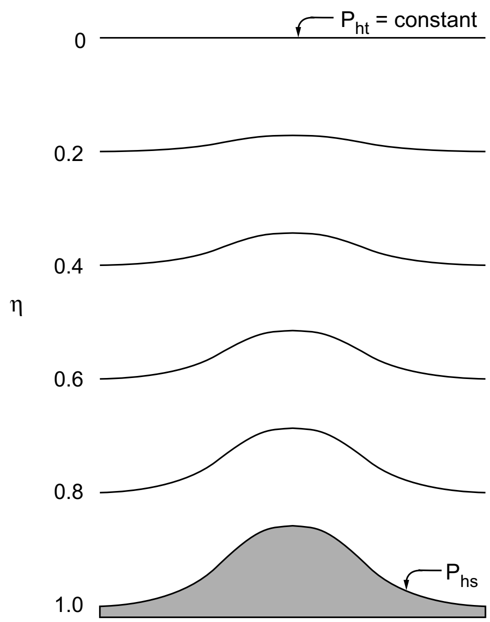


Figure 4.2: This figure is shown as presented in Skamarock & Klemp [2008], and is a schematic of the terrain following a $\sigma$ coordinate. $P_{hs}$ and $P_{ht}$ is the hydrostatic pressure at the surface and the top respectively.

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 $\sigma$ coordinate used in many hydrostatic atmospheric models, shown in a diagram in figure 4.2.

### 4.1.1 Physics, radiation and interactions in WRF

Based on the WRF-ARW Version 3 User's Guide by Wang *et al.* [2015]. The physics options in WRF fall into several categories, each containing several choices. Table 4.1 shows som of the different categories and the choice of scheme within each category.

Table 4.1: 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 microphysics includes explicitly resolved water vapor, cloud, and precipitation processes. The aerosol-aware scheme was chosen to have scavenging of aerosols and have proper enough representation of aerosols to study aerosol-cloud interactions, without using the WRF model coupled with chemistry (WRF-Chem).

The choice of cumulus parameterization was based on the grid resolution, and the best fit for it. A horisontal grid spacing of 4 km can be fine enough to not use cumulus parameterization, but in this thesis we chose a parameterization that was more suitable for grid sizes less than 10 km, the Grell 3D parameterization. Grell 3D is an improved multi-closure, multi-parameter ensamble method with typically 144 sub-grid members, that may be used on high resolution [Wang *et al.* , 2015], like my 4 km grid spacing.

Yonsei University scheme was chosen for the PBL. It is a non-local-K scheme with explicit entrainment layer and parabolic profile in unstable mixed layer [Wang *et al.* , 2015].

The land-surface model choice came to Noah Land Surface Model. The Noah Land Surface Model, is a unified NCEP/NCAR/AFWA (National Centers for Environmental Prediction, National Centre for Atmospheric Research, Air Force Weather Agency) scheme with soil temperature and moisture in four layers which provides sensible and latent heat fluxes to the PBL scheme [Wang *et al.* , 2015]. Additionally, it predicts soil ice, and fractional snow cover effects, which could be important in the Arctic, but it is probably not the most important choice, since there is very little land in the area investigated, see figure 1.1 in Chapter 1.

The radiation schemes were chosen simply because they are the best match for the microphysics scheme at the time of writing. According to Thompson & Eidhammer [2014] the Rapid Radiative Transfer Model (RRTM) for General Circulation Models (GCMs) (RRTMG) schemes for SW and LW are the only radiation schemes which include the effects of the effective radii calculated in aerosol-aware. 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].

## 4.2 Schemes

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] which is a development of the bulk microphysisc scheme described in Thompson *et al.* [2008], to include aerosols and scavenging of them. The scheme is a true double moment scheme and therefore treats cloud water, cloud ice, rain and snow in a complex and detailed way [Thompson & Eidhammer, 2014]. At the time of writing, the only radiation schemes that make use of the effective radii are the RRTMG radiation schemes [Iacono, 2003, Iacono *et al.* , 2000, 2008, Mlawer *et al.* , 1997] for both SW and LW. These were therefore used in combination with the aerosol-aware cloud microphysics scheme.

### 4.2.1 The aerosol-aware scheme

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 4.5 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 microphysics option 28, 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).

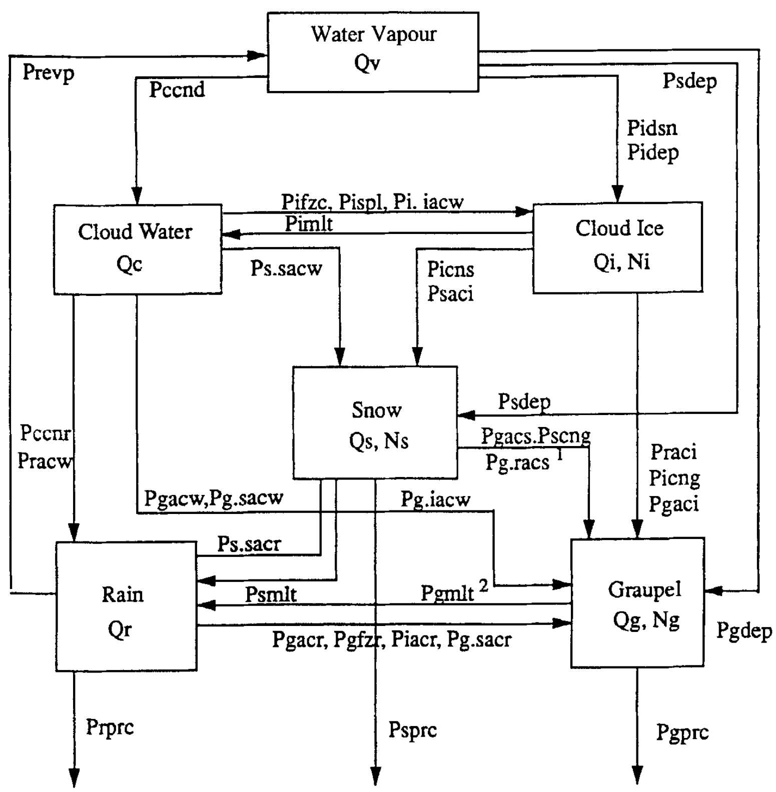


Figure 4.3: Cloud microphysical parameterization scheme typically used i NWP models as shown in Reisner *et al.* [1998]. A full list of the acronyms used in the schematic can be found in Reisner *et al.* [1998].

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.

### 4.2.2 The RRTMG radiation schemes

The RRTM scheme described in Mlawer *et al.* [1997] uses the correlated-k method, which is an appriximated technique for the accelerated calculation of fluxes and cooling rates for inhomogeneous atmospheres [Mlawer *et al.* , 1997]. The correlated-k method is capable of achieving accuracy comparable with that of line-by-line models with an extreme reduction in the number of radiative transfer operations performed [Mlawer *et al.* , 1997], which by that reduces computational cost and increases computational efficiency. The Line-By-Line Radiative Transfer Model (LBLRTM) is used both to calculate the absorption coefficients used to generate the k distributions needed by RRTM and to evaluate the RRTM calculations of fluxes and cooling rates [Iacono *et al.* , 2000].

## 4.3 Model setup

The covers parts of the Beaufort Sea and the East Siberian 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] which were mentioned in Chapter 2 Background.The area is not completely ice free any part of the year,and provides a good place to simulate cloud and 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. This means that figures showing 1200 UTC are for approximately 0500 h local time in Canada and Alaska.

I ran ARW with a horisontal resolution of 4 km spacing between the grid points, and a vertical resolution of 72 vertical layers from the surface to the model top at 10hPa. This resolution is sufficient to resolve clouds.The vertical layers in the ARW model are often referred to as eta levels, because of the choice of $\eta$ as the vertical coordinate. These levels have uneven vertical spacing. The fact that this $\eta$ is the traditional $\sigma$-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 4.2.

Table 4.2: Approximate height for each level in meters above the sea surface for the part of the level that is over the sea, and meters above topography for the part of the level that is over land.

| **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 |

The sea ice in the area was removed, by editing the input file made by WPS and real.exe, to get results to compare with results from runs with ice.

From diminishing sea ice we might experience an increase in sea traffic, which would lead to an increase in aerosol content in otherwise clean air.To include increase in aerosol concentrations due to lack of sea ice I used the microphysics scheme developed by Greg Thompson and Trude Eidhammer described in Thompson & Eidhammer [2014].

## 4.4 Model runs

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 4kmx4km, dimensons 300x300, vertical layers 72 and time step 24 s.

| Name | Sea ice | Aerosol concentration |
|---|---|---|
| control | initial | control |
| NoIce | removed | control |
| Aero10 | initial | control x 10 |
| Aero10NoIce | removed | control x 10 |
| Aero100 | initial | control x 100 |
| Aero100NoIce | removed | control x 100 |

### 4.4.1 Manipulation of input files

wrfinput_d01 and wrfbdy_d01 are input files for domain 1, in my case the only domain, and are made by real.exe. These files are then used as initialization or forcing when wrf.exe is run. To run the model without ice and with an increased number of aerosols I manipulated the input files for WRF. I used a netCDF Operator (NCO) tool, ncap2. This allowed me to manipulate the netCDF files from my terminal window in the folder where they were located. Elaborate on removal or placing of sea ice. Elaborate on multiplying the aerosol number concentration with a factor 10 or 100. By use of ncap2 from NetCDF (NCO).

### 4.4.2 Changed ice run

The sea ice was removed. The point of this is to compare the run with no ice to the control run, and see if there are any changes to the cloud properties.

### 4.4.3 Changed aerosols run

The increase in aerosol concentration was a bit more complicated, but the same method. The number of water and ice friendly aerosols were multiplied by 100 and so were their tendencies and respective concentrations at the boundaries of the area. The goal is to find changes in cloud properties compared to those in the control run, for that purpose the aerosol concentration was multiplied by a factor of 10 and another by a factor of 100. Hoping to get a signal.

## 4.5 Input data

The model runs were initialized with data downloaded from the European Centre for Medium-Range Weather Forecasts (ECMWF) @cite web page.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 time.Through 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 for real.exe to make input data for water- and ice-friendly aerosols in the wrfinput_d01 and wrfbdy_01 files. The aerosol input data includes mass mixing ratios of sulfates, sea salts, organic carbon, dust, and black carbon from a 7-yr simulation with 0.5$^o$ longitude by 1.25$^o$ latitude spacing [Thompson & Eidhammer, 2014].

## 4.6 Processing of the results

Figures presented in my thesis, I made (unless other is stated) by use of National Centre for Atmospheric Research (NCAR) Command Language (NCL) and 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).

I made all the figures that are over maps with NCL, the others were made with MatLab provided by the University of Oslo.

# Chapter 5

# Results and discussion

## 5.1 one for each result with belonging discussion?

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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