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

Mari Fenn Kristiansen

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

Must rewrite: Aside from producing precipitation, clouds have a profound effect on our climate. If you consider the overall effect of all clouds on the surface temperature, they have a cooling effect because they block incoming solar radiation. However, the effect of an individual cloud depends on many factors such as its height, thickness, location, and whether it is day or night. .... tatt fra nettet, Colorado State, CMMAP. Througout this thesis shortwave (SW) radiation means solar radiation and longwave (LW) radiation covers the terrestrial infrared radiation.

Here I will write my introduction. Needs a proper "målbeskrivelse"! Something about how low clouds in the Arctic have a warming affect as opposed to the cooling effect they have on lower latitudes. This warming is due to the lack of SW radiation flux to reflect, and the emission of LW radiation flux to the ground therefore makes a greater difference.

(Something citing the IPCC report 2013 on the ice conditions in the Arctic, and something about Arctic clouds and radiation?)

Clouds are an important regulator of the Earth's radiation budget. They cover approximately 60% of the Earth's surface [12]. It is well know that low clouds have a cooling effect at the surface due to their reflecting of incoming solar radiation. However, the effect is opposite in the Arctic, which I will elaborate on in Chapter 3 about clouds and radiation. Therefore it is important to investigate the changes in low clouds and their properties in the Arctic.

1.1 Main goal

1.2 My contribution

The findings in my thesis have been achived with some of the most recently developed code (by Greg Thompson) for cloud microphysics and their effects on radiation, in modelling. The results build further on the work of many researchers @name-some-and-cite and contribute and may raise some questions for further research within the field.

1.3 Structore of the thesis

In the following chapter 2 Background I will present the background for my thesis; what work I hope to compare with and relate my thesis to. Also I will touch upon why the subject of my thesis is important. In chapter 3 Theory 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 Model and methods is where I explain how I have worked with different tools to get the results presented in chapter **??** which are further discussed in chapter **??**. A summary of main findings and conclusions are presented in the last chapter **??** Summary and conclusions, before the lists of figures and references at the very end.

1.4 Area description

Here I should describe the area I have studied, and why it was chosen. Shown in figure **??** in Chapter 4 Model and methods. The area was chosen because it had some ice in september, and because there have been research campaigns over the area with focus on clouds in the arctic (which is what I am studying). (show a map..?) Know the correct names of the seas and the land!!

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.* [15], Wu & Lee [28] 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..?

Chapter 3

Clouds and Radiation

In this chapter, a brief overview of clouds in the Arctic is presented first. In general clouds consist of droplets that absorb and scatter shortwave (SW) radiation and absorb and emit longwave (LW) radiation. Throughout this thesis, solar radiation is referred to as SW radiation, whereas the LW radiation covers the terrestrial infrared radiation, emitted by the Earth and clouds. How clouds affect both the SW and LW radiation reaching the surface is important knowledge when studying the potential climatic effects of clouds. There are several cloud properties that affect how the cloud affects the radiation from the sun and the Earth. These will be described in the second part of this chapter. Last in this chapter a small section on aerosols is included. Aerosols act as cloud condensation nuclei (CCN) and ice nuclei (IN), where water vapor condensates or freezes on the aerorol and becomes a cloud droplet or ice particle.

3.1 Arctic clouds

The Arctic cloud cover is dominated by low clouds, and most high amounts of stratus clouds are over the oceans [10]. The Arctic is the only region where the season of maximum stratus does not correspond to the season of greatest lower troposphere static stability [10], which could be due to lack of evaporation during the cold winter months. According to Klein & Hartmann [10] 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.

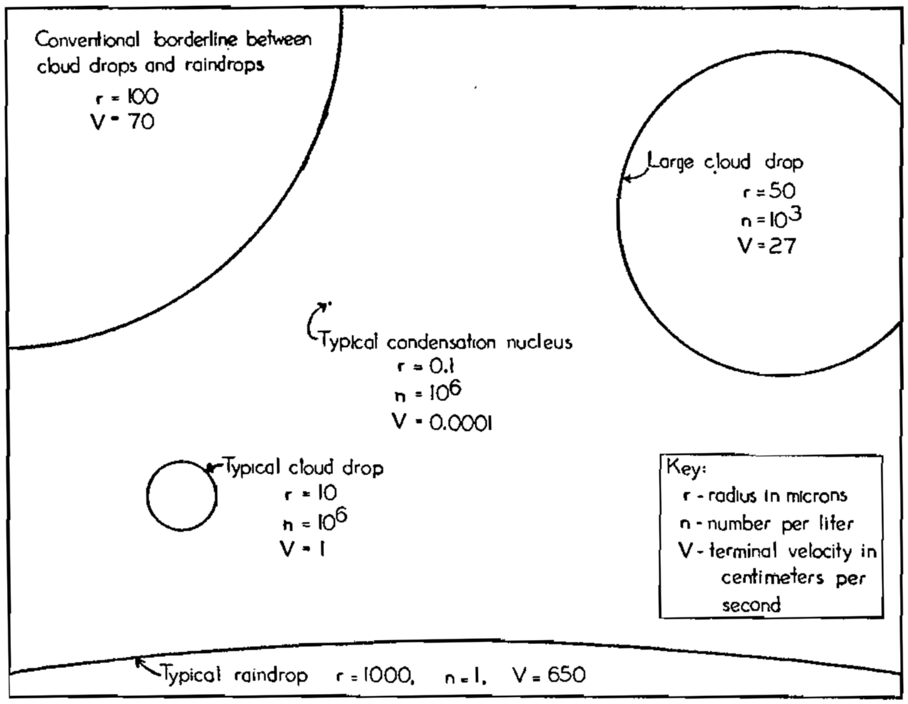

Figure 3.1: Size of CCN, typical cloud droplet, large cloud droplet, boarderline between cloud droplets and raindrops and typical size of raindrop.From [13].

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 [1].

3.2 Cloud effects on radiation

3.2.1 Liquid Water Content and Path

The cloud microphysical properties that determine the cloud radiative properties include: the amount of condensed water, the size and shape of the cloud particles, and the phase of the particles/and if the particles are liquid or ice [3]. 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 consentrations when we use the median volume radius, $\overline{r}$, $\mu\ m$. From Rogers & Yau [17] we can express the number of droplets with radius r by

$$N = \int n(r)dr \tag{3.1}$$

where N is the cloud droplet number concentration cm^{-3}, and $n(r)$ is the number of droplets with radius r. The LWC can be written

$$\begin{aligned} LWC &= \int \rho_L \frac{4}{3}\pi r^3 n(r)dr && (3.2)\\ &= \frac{4}{3}\pi\rho_L \int r^3 n(r)dr && (3.3)\\ &= \frac{4}{3}\pi\rho_L \overline{r}^3 \int n(r)dr && (3.4)\\ &= \frac{4}{3}\pi\rho_L \overline{r}^3 N && (3.5) \end{aligned}$$

where the last equation shows the proportionality of LWC to the cloud droplet number concentration N, and ρ_L is the density of liquid water.

If the LWC is integrated over the height of the cloud, from the cloud base to the cloud top, we find the liquid water path (LWP) of that cloud.

$$LWP = \int_{base}^{top} LWC \cdot dz \tag{3.6}$$

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

3.2.2 Cloud droplet effective radius

The cloud droplet effective radius determines several important radiative properties of a cloud and is therefore of particular interest. For example it determines the cloud albedo [4], which I will go more into when describing the first indirect effect later in this chapter.

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

$$r_e = \frac{\int r^3 n(r)dr}{\int r^2 n(r)dr} \tag{3.7}$$

where r_e is the effective radius.

3.2.3 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 [11]. For a gray body, like a cloud, the equation can be written

$$F = \epsilon \sigma T^4 \tag{3.8}$$

where the emissivity of the greybody, 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.

3.2.4 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 [26]. The optical depth can be expressed as

$$\tau_\lambda = \int_z^\infty k_\lambda \rho R dz \tag{3.9}$$

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 Introduction 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 to 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.

I

3.3 Aerosols and clouds

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.

@introduction?— 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 @cite. The lack of sea ice would also increase the likelyhood that the sea could be used for shipping, which would pollute the area @cite. —-

There are two known indirect effects that aerosols have on radiation, through clouds. The first indirect effect was proposed by Twomey [24] and is often referred to as the Twomey effect. The second indirect effect was proposed by Albrecht [2] and is also known as the lifetime effect.

3.3.1 The first indirect effect

The first indirect effect, suggested by Twomey [24], 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 [25]. 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 [24].

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 [2]. This effect has been estimated to be roughly as large as the first indirect effect [12].

3.3.3 Cloud effects on aerosols/The presence of aerosols

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

The WRF-ARW Modeling System

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 [20].

As can be seen from figure 4.1 the WRF-ARW Modeling System consists of four major programs [27]:

- The WRF Prepocessing System (WPS)
- WRF-Data Assimilation (WRF-DA)
- ARW solver
- Post-processing & Visualization tools

WPS is used primarily for real data simulations [27], 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 [27]. WRF-DA is optional and can be used to ingest observations into the interpolated analyses

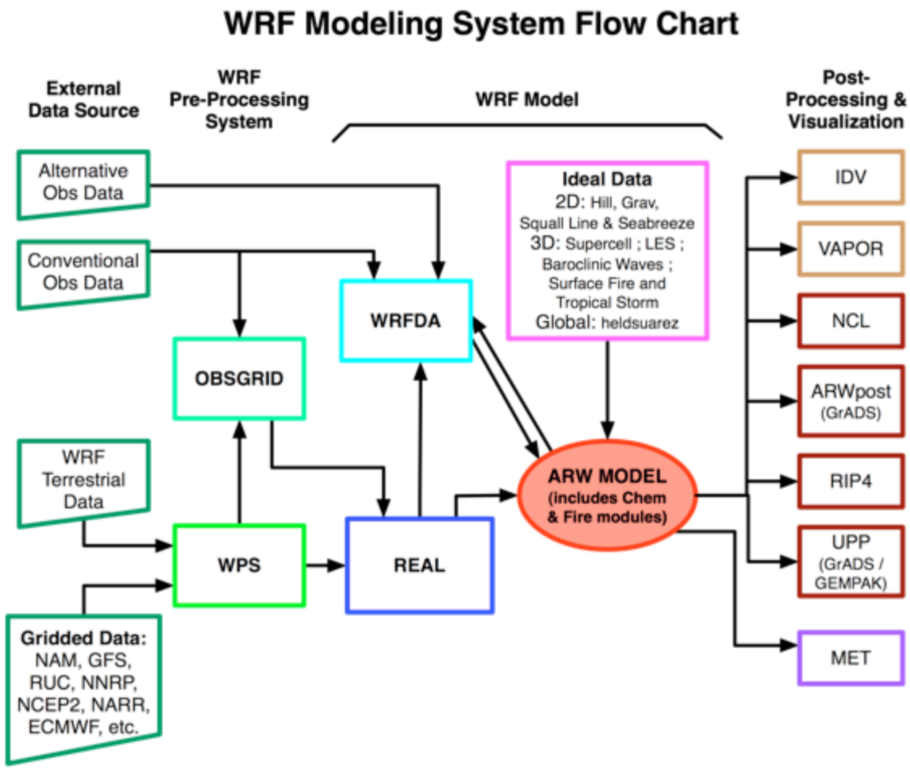

Figure 4.1: Flowchart for the WRF ARW Modeling System Version 3. From Wang *et al.* [27].

created by WPS [27], but was not used 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 [27]. 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.* [27].

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, η, is defined by a

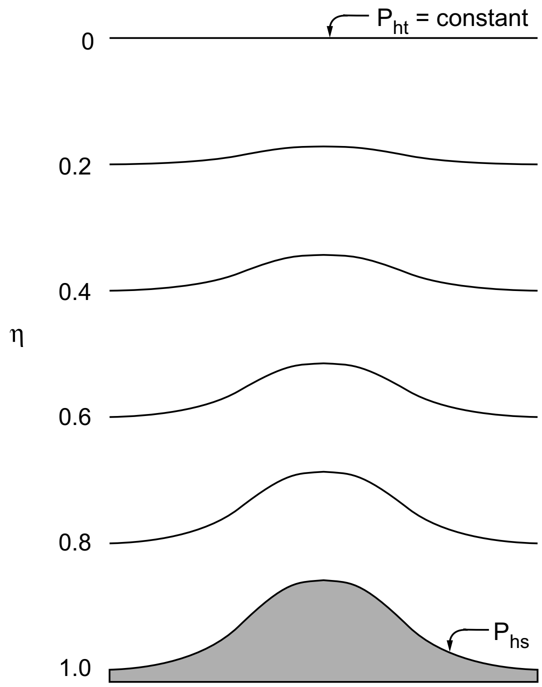

Figure 4.2: This figure is shown as presented in Skamarock & Klemp [20], and is a schematic of the terrain following a σ coordinate. P_{hs} and P_{ht} is the hydrostatic pressure at the surface and the top respectively.

normalized hydrostatic pressure,

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

where $\mu = (p_{hs} - p_{ht})$ [20]. 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 [20].

The vertical coordinate is the traditional σ 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.* [27]. 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 [16, 21–23]. 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 [5–7, 14]. 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 I 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 [27], 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 [27].

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 [27]. 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, figure **??**.

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 [21] 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 [27]. Major trace gases are constant in my runs, and their values are $CO_2 = 379e-6$, $N_2O = 319e-9$, $CH_4 = 1774e-9$ [27].

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 [21] which is a development of the bulk microphysisc scheme described in Thompson *et al.* [23], 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 [21]. At the time of writing, the only radiation schemes that make use of the effective radii are the RRTMG radiation schemes [5–7, 14] 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.* [27], 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 [21]. The microphysics option 28, the aerosol-aware scheme [21] is built on the schematic shown in figure 4.3, from Reisner

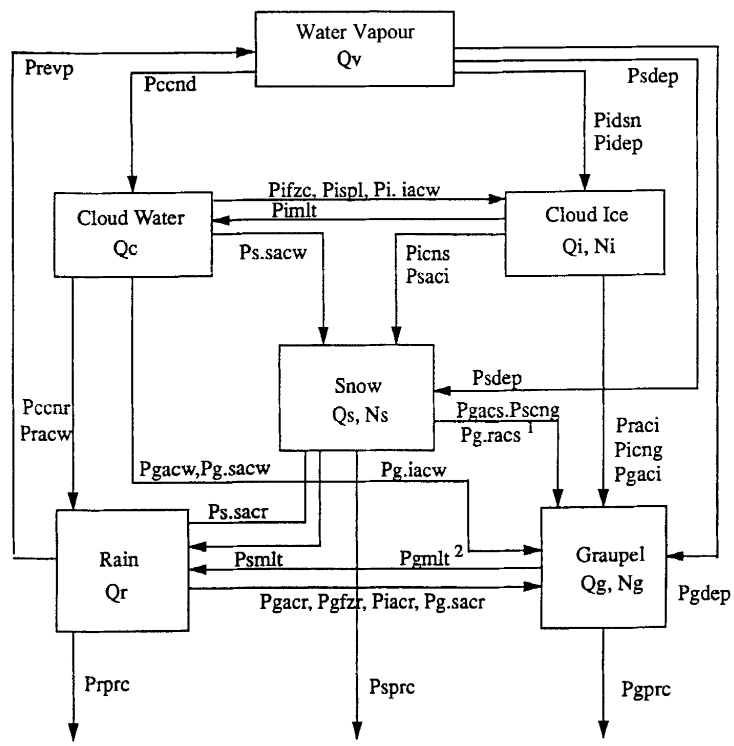

Figure 4.3: Cloud microphysical parameterization scheme typically used i NWP models as shown in Reisner *et al.* [16]. A full list of the acronyms used in the schematic can be found in Reisner *et al.* [16].

et al. [16]. 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.* [16], which the first bulk microphysics scheme by Thompson [22] was based on. The aerosol-aware scheme is an extension of the Thompson bulk microphysics scheme described in Thompson *et al.* [23]. 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.* [14] uses the correlated-k method, which is an appriximated technique for the accelerated calculation of fluxes and cooling rates for inhomogeneous atmospheres [14]. 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 [14], 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 [6].

4.3 Model setup

The area 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 [8, 9, 15, 18, 19, 28] 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 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 10 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 [21].

4.4 Model runs

Table 4.3: Table showing the name of the runs and what is included

Name	Horisontal resolution	Dimensions	Vertical layers	Δt	Sea ice	Aerosol concentration
control	4 km x 4 km	300 x 300	72	24 s	yes	control
NoIce	4 km x 4 km	300 x 300	72	24 s	no	control
Aero10	4 km x 4 km	300 x 300	72	24 s	yes	control x 10
Aero10NoIce	4 km x 4 km	300 x 300	72	24 s	no	control x 10
Aero100	4 km x 4 km	300 x 300	72	24 s	yes	control x 100
Aero100NoIce	4 km x 4 km	300 x 300	72	24 s	no	control x 100

Which table?

Table 4.4: Caption could say: 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 variable in the wrfinput_d01 file was simply multiplied by 0 in every gridpoint and by that 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).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 [21].

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.

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