Universität Stuttgart

Geodätisches Institut

# Titel der Studien- oder Diplomarbeit evtl. eine zweite Zeile

Studienarbeit im Studiengang

**Geodäsie und Geoinformatik**

an der Universität Stuttgart

Vorname V. Name

Stuttgart, Monat 20xx

**Betreuer:** Prof. Dr.-Ing. Nico Sneeuw
Universität Stuttgart

Dr.-Ing. Heinz Obermann
Technische Universität Unterdorf

# Erkl%■rung der Urheberschaft

Ich erkl%■re hiermit an Eides statt, dass ich die vorliegende Arbeit ohne Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt ¸bernommenen Gedanken sind als solche kenntlich gemacht. Die Arbeit wurde bisher in gleicher oder %■hnlicher Form in keiner anderen Pr¸fungsbehˆrde vorgelegt und auch noch nicht verˆffentlicht.

Ort, Datum                                        Unterschrift

In diesem kurzen Text erfolgt die Zusammenfassung der Arbeit oder – auf Englisch – das Abstract.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

## 1.1 Water Cycle

Water is one of the most necessary resources for human beings. It is the most important ingredient of life; it has a regulating effect on climate and all industries can not function well without it. However, 98 % of the water on the earth is in the oceans, 1.6% is in ice caps, which means only 0.4 % is the fresh water on land. So, a very little variability of the hydrology cycle can have big effects on water resources.

The hydrology cycle (see figure 1.1) includes 3 major parts: evaporation, precipitation and runoff. The water evaporates from the oceans and the land surface as vapor to become part of the atmosphere along with water from evapotranspiration, which is water transpired from plants and evaporated from the soil and the cooler temperature causes the vapor into clouds. The clouds fall out of the sky as precipitation, which includes rain, snow and ice. Most precipitation falls back into the oceans or onto land. Precipitated water may be intercepted by vegetation, become overland flow over the ground surface, flow through the soil as subsurface flow and discharge into streams as surface runoff. The process can be simplified as:

$$Pre - ET - R = \frac{dS}{dt} \tag{1.1}$$

where

| | |
|---|---|
| $Pre$ | Precipitation |
| $ET$ | Evatranspiration |
| $R$ | Surface Runoff |
| $dS/dt$ | total water storage change |

### 1.1.1 Precipitation

Precipitation is any form of water particle, solid or liquid, that falls from the atmosphere and reaches the ground. Precipitation can include drizzle, rain, snow, sleet, and hail. Precipitation forms in the clouds when water vapor condenses into bigger and bigger droplets of water. When the drops are heavy enough, they fall to the Earth. If a cloud is colder, like it would be at higher altitudes, the water droplets may freeze to form ice. These ice crystals then fall to the Earth as snow, hail, or rain, depending on the temperature within the cloud and at the Earth's

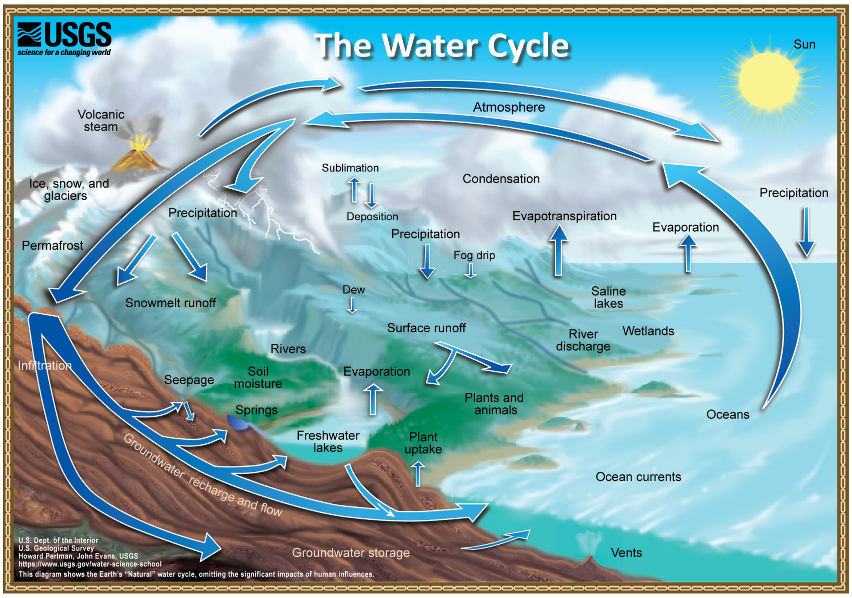


*Figure 1.1:* *Horologic Cycle*

surface. Most rain actually begins as snow high in the clouds. As the snowflakes fall through warmer air, they become raindrops.

### 1.1.2 Evatranspiration

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata. These are small openings on the plant leaf through which gases and water vapour pass. The water, together with some nutrients, is taken up by the roots and transported through the plant. The vaporization occurs within the leaf, namely in the intercellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant.

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. In Figure 2 the partitioning of evapotranspiration into evaporation and transpiration is plotted in correspondence to leaf area per unit surface of soil below it. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration.[1]

### 1.1.3 Runoff

Runoff is quantity of water discharged in surface streams. Runoff includes not only the waters that travel over the land surface and through channels to reach a stream but also interflow, the water that infiltrates the soil surface and travels by means of gravity toward a stream channel (always above the main groundwater level) and eventually empties into the channel. Runoff also includes groundwater that is discharged into a stream; streamflow that is composed entirely of groundwater is termed base flow, or fair-weather runoff, and it occurs where a stream channel intersects the water table.

## 1.2 Observation from Satellite

It was extremely difficult to measure the global water storage change consistently. In some way, remote sensing with satellite is the perfect tool for hydrology research, which has the ability to provide the data globally in a long term.

The GRACE mission is a joint partnership between the National Aeronautics and Space Administration (NASA) in the United States, the Deutsche Forshungsanstalt fuer Luft und Raumfahrt (DLR) in Germany. The Grace Satellites launched on 17 March 2002, are making detailed measurements of Earth's gravity field, which are caused by monthly changes in mass. The mass changes can be thought of as concentrated in a very thin layer of water thickness changes near the Earth's surface by moving ocean, atmospheric and land ice masses and by mass exchanges between these Earth system compartments.

The two identical satellites orbit one behind the other in the same orbital plane at an approximate distance of 220 km (137 miles). As the pair circles the Earth, areas of slightly stronger gravity (greater mass concentration) will affect the lead satellite first, pulling it away from the trailing satellite, then as the satellites continue along their orbital path, the trailing satellite is pulled toward the lead satellite as it passes over the gravity anomaly. The change in distance would certainly be imperceptible to our eyes, but an extremely precise microwave ranging system on GRACE is able to detect these miniscule changes in the distance between the satellites. A highly accurate measuring device known as an accelerometer, located at each satellite mass center, will be used to measure the non-gravitational accelerations (such as those due to atmospheric drag) so that only accelerations caused by gravity are considered. Satellite Global Positioning System (GPS) receivers will be used to determine the exact position of the satellite over the Earth to within a centimeter or less. Members of the GRACE science team can download all this information from the satellites, and use it to construct monthly maps of the Earth's average gravity field.

The component parts of GRACE: (figure 1.2) [3]

- K-band Ranging System (KBR): Provides precise (within 10 micrometre) measurements of the distance change between the two satellites needed to measure fluctuations in gravity.
- Ultra Stable Oscillator (USO): Provides frequency generation for the K-band ranging system.

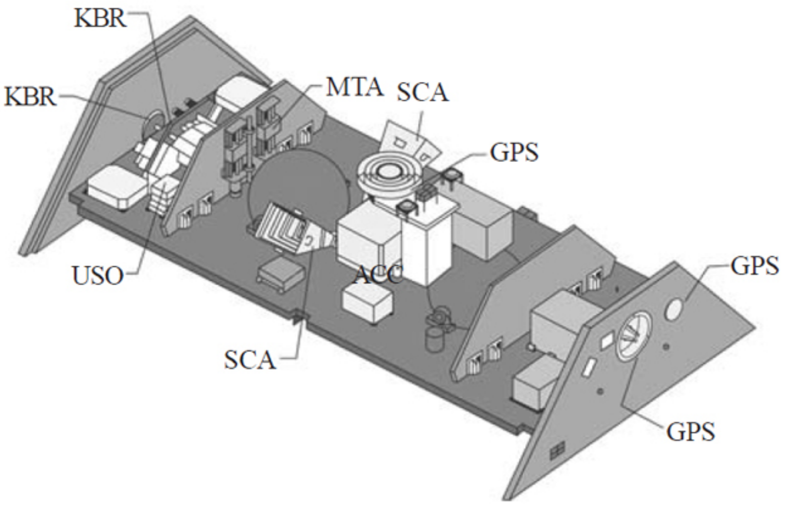


***Figure 1.2:*** *GRACE Component*

- SuperSTAR Accelorometers (ACC): Precisely measures the non-gravitational accelerations acting on the satellites.

- Star Camera Assembly (SCA): Precisely determines the two satellite's orientation by tracking them relative to the position of the stars.

- Coarse Earth Sun and Sensor (CES): Provides omnidirectional, reliable, and robust, but fairly coarse, Earth and Sun tracking. Used during initial acquisition and whenever GRACE operates in safe mode.

- Center of Mass Trim Assembly (MTA): Precisely measures the offset between the satellite's center of mass and the "acceleration-proof" mass and adjusts center of mass as needed during the flight.

- BlackJack GPS Receiver and Instrument Processing Unit (GPS): Provides digital signal processing; measures the distance change relative to the GPS satellite constellation.

- Globalstar Silicon Solar Cell Arrays (GSA): Covers the outer shell of the spacecraft and generates power.

It is shown, that GRACE delivers the highest temporal resolution and is thus able to observe monthly mass variation with a spatial resolution of less than 1000 km. In [5] it was predicted that GRACE would be able to measure these effects with an accuracy of about 2 mm of water equivalent heights. Though this accuracy has not yet been achieved because of the errors in spherical harmonic coefficients of short-wavelength, it was shown in many publications that the Stokes coefficients from GRACE indeed contain hydrological signals as the monthly solutions from GRACE showed a good agreement with mass variations from hydrological models.

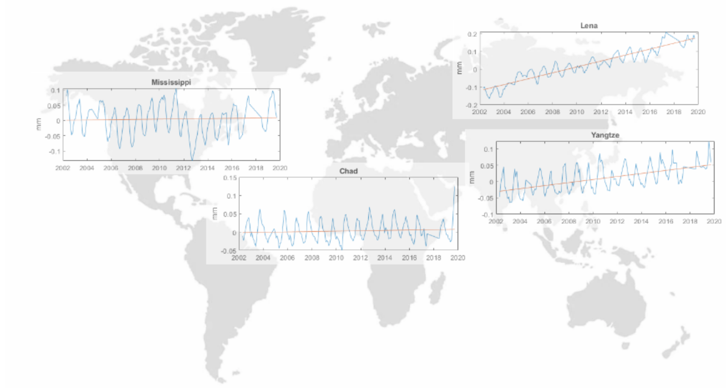


*Figure 1.3:* *Water Storage Change*

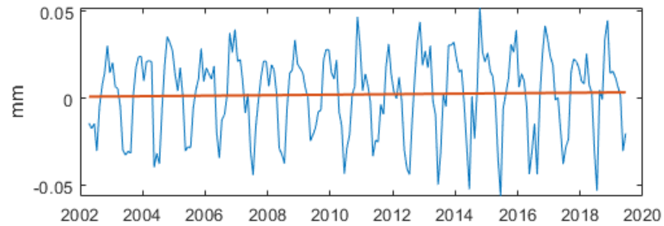


*Figure 1.4:* *Ob basin*

## 1.3 Motivation

A time series is a series of data points indexed (or listed or graphed) in time order. Most commonly, a time series is a sequence taken at successive equally spaced points in time. Thus it is a sequence of discrete-time data. In hydrology, most variables are observed in time series, including Total Water Storage Anomaly(TWSA). In the hydrological cycle, this should reflect seasonal behavior and is in long term relatively stable. However, it was shown that since 2002 the TWSA of many big basins has increased (see figure 1.3). One important basin of them is Ob basin in west Siberia (see figure 1.4). How did this trend happen is a very interesting topic. Through the analysis of the trend of the time series, it is possible to further understand the changes that have taken place before and future changes can also be predicted based on the stationary analysis.

## 1.4 Objective

In this thesis, the beginning point of the changing trend is to be found by analyzing the TWSA time series from GRACE data. In order to find the reason of the change, the precipitation, the evatranspiration along with the runoff in the same period from different data center would also be processed and compared with the TWSA. At the end, how was the changes of the TWSA and the reasons for this change would be discussed.

# Chapter 2

# Study Area

Ob River (see figure 2.1), river of central Russia. One of the greatest rivers of Asia, the Ob flows north and west across western Siberia in a twisting diagonal from its sources in the Altai Mountains to its outlet through the Gulf of Ob into the Kara Sea of the Arctic Ocean. It is a major transportation artery, crossing territory at the heart of Russia that is extraordinarily varied in its physical environment and population. Even allowing for the barrenness of much of the region surrounding the lower course of the river and the ice-clogged waters into which it discharges, the Ob drains a region of great economic potential.


***Figure 2.1:*** *River Basins Ob*

## 2.1 Physiography

The Ob proper is formed by the junction of the Biya and Katun rivers, in the foothills of the Siberian sector of the Altai, from which it has a course of 3 650 km. If, however, the Irtysh River is regarded as part of the main course rather than as the Ob's major tributary, the maximum length, from the source of the Black (Chorny) Irtysh in China's sector of the Altai, is 5 410 km, making the Ob the seventh longest river in the world. The catchment area is approximately 2 975 000 square km. Constituting about half of the drainage basin of the Kara Sea, the Ob's catchment area is the sixth largest in the world. The drainage basin is classified as cropland (36%), forest (30%), wetland (11%), grassland (10%), shrub (5%) , developed (5%) and irrigated cropland (3%).[4]

The West Siberian Plain covers about 85 percent of the Ob basin.[2] The rest of the basin comprises the terraced plains of Turgay (Kazakhstan) and the small hills of northernmost Kazakhstan in the south and the Kuznetsk Alatau range, the Salair Ridge, the Altai Mountains and their foothills and outliers in the southeast.

The huge basin of the Ob stretches across a number of natural zones. Semidesert prevails in the far south around Lake Zaysan (recipient of the Black Irtysh and source of the Irtysh proper), bordered on the north by steppe grassland. The central regions of the West Siberian Plain i.e., more than half of the basin-consist of taiga (swampy coniferous forest), with great expanses of marshland. In the north there are vast stretches of tundra (low-lying, cold-tolerant vegetation).

## 2.2 Climate

The Ob basin has short, warm summers and long, cold winters. Average January temperatures range from $-28$°C on the shores of the Kara Sea to $-16$°C in the upper reaches of the Irtysh. July temperatures for the same locations, respectively, range from 4 °C to above 20°C. The absolute maximum temperature, in the arid south, is 40°C,[2] and the minimum, in the Altai Mountains, is $-60°$. Rainfall, which occurs mainly in the summer, averages less than 400 mm per year in the north, 500 to 600 mm in the taiga zone, and 300 to 400 mm on the steppes. The western slopes of the Altai receive as much as 1 575 mm per year. Snow cover lasts for 240 to 270 days in the north and for 160 to 170 days in the south. It is deepest in the forest zone, where it ranges from 60 to 90 cm, and in the mountains, where it averages 200 cm per year. It is much shallower on the tundra, ranging from 30 to 50 cm, and very thin on the steppe, where 20 to 40 cm fall.[2]

On the upper Ob the spring floods begin early in April, when the snow on the plains is melting; and they have a second phase, ensuing from the melting of snow on the Altai Mountains. The middle Ob, scarcely affected by the upper Ob's phases, has one continuous spring-summer period of high water, which begins in mid April. For the lower Ob, high water begins in late April or early May. Levels, in fact, begin to rise when the watercourse is still obstructed by ice; and maximum levels, which occur by May on the upper Ob, may not be reached until June, July, or even August on the lower reaches. For the upper Ob, the spring floods end by July, but autumn rains bring high water again in September and October; in the middle and lower Ob, the spring and summer floodwaters gradually recede until freezing sets in. On the lower reaches, flooding may last four months. Flooding of the Ob proper and of the Irtysh obstructs the minor tributaries' drainage.

## 2.3 Hydrology

The Ob has the third greatest discharge of Siberia's rivers, after the Yenisey and the Lena. On average, it pours some 400 cubic km of water annually into the Arctic Ocean about 12% of that ocean's total intake from drainage.

The volume of flow at Salekhard, just above the delta, is about 42 000 cubic metres per second at its maximum and 2 000 cubic metres per second at its minimum, while for Barnaul, on the upper Ob, the corresponding figures are 9 600 and 200 cubic metres per second. The average annual discharge rate at the river's mouth is about 12 700 cubic metres per second. Most of the water comes from the melting of seasonal snow and from rainfall; much less of it comes from groundwater, mountain snow, and glaciers.[2]

## 2.4 Plants and animals

Pine, cedar, silver fir, aspen, and birch grow on the banks and occasionally constitute isolated forests on the higher ground of the floodplain. Large areas near the river are covered with willow, snowball trees, bird cherry, buckthorn, currant bushes, and wild roses.

Fur-bearing mammals of the Ob valley include European and Siberian mole, Siberian and American mink, ermine, fox, wolf (in the taiga), elk, white hare, water rat, muskrat, otter, and beaver. Among more than 170 species of birds breeding in the floodplain are grouse, partridge, goose, and duck.

## 2.5 Human use

Basin total population is about 27 million, with 39 cities having a population of more than 100 000. The Ob's immense hydroelectric potential is estimated at some 250 billion kilowatts. Three main stations have been built: one on the Ob proper, at Novosibirsk, and the other two on the mountainous reaches of the Irtysh, at Bukhtarma and Oeskemen. Both industry and agriculture have been intensively developed in the Ob basin. Cities such as Omsk, Novosibirsk, and Barnaul are major industrial and manufacturing centres. The steppe zone, in the southern Ob basin, is the major producer of spring wheat in Russia. The west Siberian oil and gas fields, located in the taiga and tundra zones of the middle and lower Ob, are the most important in Russia, contributing about two-thirds of the country's crude oil and natural gas output.

# Bibliography

[1] Richard G Allen, Luis S Pereira, Dirk Raes, Martin Smith, et al. Crop evapotranspiration-guidelines for computing crop water requirements-fao irrigation and drainage paper 56. *Fao, Rome*, 300(9):D05109, 1998.

[2] Philip P. Micklin Liliya Konstantinovna Malik, Lewis Owen. Ob river.

[3] NASA. Grace mission.

[4] C. Revenga, World Resources Institute, S. Murray, A. Hammond, and J.N. Abramovitz. *Watersheds of the World: Ecological Value and Vulnerability*. World Resources Institute report. World Resources Institute, 1998.

[5] John Wahr, Mery Molenaar, and Frank Bryan. Time variability of the earth's gravity field: Hydrological and oceanic effects and their possible detection using grace. *Journal of Geophysical Research: Solid Earth*, 103(B12):30205–30229, 1998.

# Appendix A

Und das hier ist noch der Anhang...