ACDC

- Advanced Climate Dynamic Courses

Advanced Climate Dynamics Course – ACDC2017

September 11th – 22nd, 2017

Rondane National Park, Norway

The dynamics of the seasonal cycle

Bjerknes Centre for Climate Research

UNIVERSITY OF BERGEN

TEXAS The University of Texas at Austin

UNIVERSITY OF WASHINGTON

SIU SENTER FOR INTERNASJONALISERING AV HØGRE UTDANNING

CHESS

ICCP IBS Center for Climate Physics

We thank the Norwegian Centre for International Cooperation in Higher Education (SIU), the Norwegian Research School on Changing Climate in the coupled Earth System (CHESS), the Bjerknes Centre for Climate Research, the University of Bergen, the University of Texas at Austin, the University of Washington and IBS Center for Climate Physics for supporting this summer school.

ACDC

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Final Report

The Advanced Climate Dynamics Courses (ACDC) is a series of annual summer schools aimed at advanced PhD students. The courses are coordinated by the University of Bergen (UoB) in collaboration with University of Texas at Austin, and the University of Washington (UW) in Seattle. Core funding for the summer school is provided by a SiU (Norwegian Centre for International Cooperation in Education) Partnership Program in higher education and the Norwegian Research School on Changing Climate in the coupled Earth System (CHESS), and this year also with additional funding from IBS Center for Climate Physics in Busan, South Korea. Detailed information regarding the summer school can be found at http://www.uib.no/en/rs/acdc.

This year's summer school was the ninth in the series. It was held at Rondvassbu, in Rondane National Park in Norway September 11^{th} to 22^{nd}, 2017.

The main focus was on understanding the dynamics of the seasonal cycle. And as in previous years the goal was to mix students and lecturers with both empirical and dynamical training within climate sciences.

25 students were admitted to the summer school, represented by 13 nationalities: 6 Americans (1 Princeton University, 2 University of Wisconsin-Madison, 1 MIT / WHOI, 1 MIT, 1 California Institute of Technology), 3 Chinese (1 Harvard University, 1 University of Texas at Austin, 1 Bjerknes Centre for Climate Research / University of Bergen), 3 British (1 Columbia University,1 University of Exeter, Imperial College London), 2 Danish (1 University of Bergen, 1 Niels Bohr Institute/University of Copenhagen), 2 German (1 Scripps Institute of Oceanography/University of San Diego, 1 University of Tromsø), 2 Indian (1 University of Chicago, 1 University of Colorado Boulder), 1 Hong Kong (University of Bergen), 1 South Korean (IBS Center for Climate Physics), 1 Norwegian (University of Bergen), 1 Taiwanese (1 California Institute of Technology), 1 South African (University of Cape Town), 1 Nepalese (University of Bergen), 1 Australian (University of Adelaide).

A complete list of participants is presented in the program. The majority of the lecturers and all of the students spent the entire 12 days of the summer school together in Norway with scientific talks, field excursions, discussions and social activities and networking.

Photo: Iselin Medhaug

Field trip week one to Klarabotn. Photo: Iselin Medhaug.

Scientific topics / content of the summer school

Each day of the first week consisted of two fundamental lectures on core topics followed by student presentations. The second week each day consisted of 2 specialized lectures on advanced topics. Every morning started with student lead summaries of the previous day's lectures followed by a discussion. The summary groups also wrote a written summary from each lecture. These texts can be found further down in this report.

The first week we arranged an afternoon field trip to Klarabotn, led by Øyvind Paasche that aimed at giving the students a short introduction to how different landforms can be connected geological and glaciological process. The students were encouraged to look for special features in the landscape that seemed to stand out. Afterwards, there was a joint discussion with input both from the students and lecturers about the features that were identified. The excursion continued into an empty cirque – Klarabotn – where students got to see the landform with their own eyes. The characteristic features of cirques were discussed and also the importance of how small glaciers, given that the climate conditions are favourable, can mold any glaciated landscape.

Over the weekend fieldtrip we took a boat across Rondvatnet and hiked to Bergdalstjønnin. The day ended with setting up basecamp for the two nights and having a hearty meal prepared by our eminent chef, Kristian Tinnen. Our goals for the fieldtrip included learning to recognize and interpret glacial geomorphic features, and identifying and improving our understanding of the history of the landscape changes in Rondane. Underway Øyvind Paasche lectured on the research that had been done in the area to uncover the history of the formation and evolution of the landscape, with emphasis on the continued difficulties in providing a reliable timeframe for past ice sheet evolution.

Weekend field trip. Photo: Iselin Medhaug

Tree ring coring. Photo: Jane Baldwin and Iselin Medhaug

All students took part in a group project lead by one of the lecturers. The topics this year were:
• Understanding phase coupling between ENSO and the annual cycle (Axel Timmermann)
• The seasonality of surface temperature variability (Peter Huybers)
• Evaluating tree ring density as a proxy for temperature (Zan Stine)
• Summertime surface temperature variability in CMIP5 models (David Battisti)

After the summer school, the participants submitted a proposal for a session at EGU2018, and it was accepted. The session was called "The Dynamics of Seasonal Cycle and its Signature Across All Timescales", and is to be convened and coordinated by the summer school participants themselves. More information about the session can be found here: http://meetingorganizer.copernicus.org/EGU2018/session/27954

Social Activities

The social aspect is an important part of the summer school. Upon arrival, half way between parking lot at Spranget to Rondvassbu, the students were met with an ice breaker to get to know each other and to socialize before the program commenced on Monday. During the first week, we had an international coffee break, where all of the students and lecturers had been asked in advance to bring along a food or snacks from their country for an international coffee break.

After the weekend trip Kristian organized an outdoor dinner including a two-course meal prepared over an open fire, and ended with a disco and dancing in the ACDC tent (lavvo). In addition to the two scientific fieldtrips the participants took advantage of the spectacular location for hiking during the lunch breaks.

The evenings were often busy with the students working on summarizing the day's lectures and working on the group projects, but still this did not prevent socializing. The evenings were filled with international movie screenings, guitar playing and lively discussions. In addition, the snow arrived while we were there, so the students and lecturers spent time playing in the snow snow and making a snow man.

Photo: Jane Baldwin, Iselin Medhaug and Katherine Hutchinson

Outreach

During the summer school, we were lucky to have two high school classes visiting us, one at Rondvassbu and one in the field. At Rondvassbu David Battisti gave a presentation about climate change and the evidence behind it, and two of the students, Katherine and Johannes, presented stories and pictures from fieldwork in the Southern Ocean and in Antarctica. The second school visit were guided by two ACDC students, Astrid and Georgina and two lecturers, Peter Huybers and Øyvind Paasche, in the field to learn about climate change and how to reconstruct past climate including the extraction of tree ring records. This was all documented by a reporter from NRK (Norwegian Public Broadcasting) and broadcasted in the TV news in NRK Østlandssendingen (https://tv.nrk.no/serie/distriktsnyheter-oestnytt/DKOP99092217/22-09-2017#t=9m20s).

ACDC
- Advanced Climate Dynamic Courses

Program

Advanced Climate Dynamics Course (ACDC2017)
Rondane National Park, Norway, 11th – 22nd September, 2017

Dear participants!

Welcome to the Advanced Climate Dynamics Course (ACDC2017) in Rondane National Park!

The summer school is the ninth summer school organized jointly by the Bjerknes Centre for Climate Research and the University of Bergen in collaboration with North American partner Universities.

The main focus for the next two weeks is to mix students and lecturers with empirical/proxy and dynamical training within climate science and focus on understanding the dynamics of the seasonal cycle, based on theory, models, observations, and proxy data. This will be achieved through a mixture of fundamental and advanced lectures together with student presentations and discussions.

This year the school is based in Rondane National Park, providing a unique location for field excursions and hiking in the Norwegian mountains.

We hope that you will enjoy your stay, and have a stimulating, fun and interesting summer school!

Sincerely,
Kerim Nisancioglu, Øyvind Paasche & Iselin Medhaug
(University of Bergen)

On behalf of the ACDC steering committee:
Kerim Nisancioglu, David Battisti, Tore Furevik, Patrick Heimbach, and Jake Gebbie.

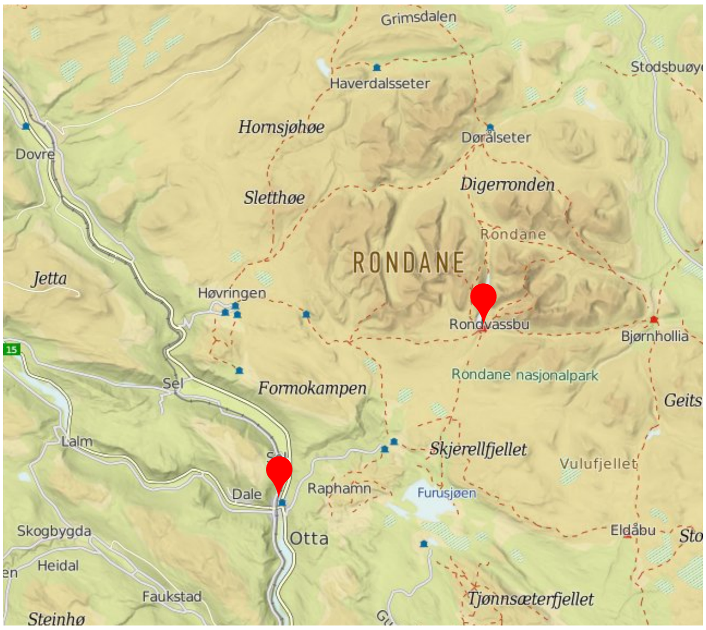
Rondane National Park

Rondane was the first National Park in Norway. It was listed in 1962, and today covers almost 1 000 km^2 in the counties of Oppland and Hedmark. The tallest peak, Rondeslottet ("The Rondane castle") extends to an elevation of 2 178 m.a.s.l. and is the highest peak in Hedmark county. In total, there are 10 peaks above 2 000 m inside the park.

The mountains are divided by marked valleys through the landscape; the deepest valley is filled by Rondvatnet, a narrow lake filling the steep space between the large Storronden-Rondeslottet massif and Smiubelgen ("The blacksmith's bellows"). The central massif is also cut by "botns": flat, dead stone valleys below the steep mountain walls of the peaks. Generally, Rondane does not receive enough precipitation to generate persistent glaciers, but glacier-like heaps of snow can be found in the flat back valleys.

The bedrock in Rondane comes from a shallow sea floor, created 500 to 600 million years ago. From this, changes in the Earth's crust created a mountain area of metamorphic rock and quartz. There are no fossils found in Rondane today and so it is thought the sea where the rock came from contained no animal life. The present landscape was mostly formed by the last ice age.

Source: Wikipedia



Source: ut.no

SUMMER SCHOOL PROGRAMME

Sunday 10th of September

Participants arrive by train from Oslo to Otta at 17:33. From Otta we have organized bus transport from to Rondvassbu, where the summer school is held.

The last 6 km between “Spranget” (where the bus stops) to Rondvassbu we will have to walk (~1.5h). On arrival Rondvassbu there will be an icebreaker and a late dinner.

International evening

To celebrate all the nationalities represented at ACDC, we ask all participants to bring a food item (e.g. a cheese, jam, chocolate, biscuits, a drink) from their home country to share during one evening of the course.

Friday 22nd of September

The summer school program will end in the afternoon on Friday the 22nd of September. We will walk to Spranget, where there will be a bus waiting to take us to Otta train station in good time for the departure of the 18:38 train from Otta to Oslo Airport and Oslo S.

Contact acdc@uib.no for details on transportation arrangements.

Venue - Rondvassbu

The cabin Rondvassbu is situated in the heart of Rondane and is a part of the Norwegian Trekking Association’s (DNT) suit of cabins. The cabin was built in 1903 and is the largest DNT cabin in Rondane. Since being built, the cabin has been rebuilt and expanded several times. During the summer season the cabin is manned and can accommodate 128 people overnight.

The cabin is idyllically located at the southern end of Rondvatnet, with the Rondane massif in the background.

At the cabin, it is possible to rent bikes, canoes and rowing boat to explore the surrounding area.

Enjoy your stay! https://rondvassbu.dnt.no/

GENERAL INFO:

Each day will start with summaries of the previous days lectures prepared by groups of students. This ensures that the main topics are understood and give the opportunity to pick up on any unanswered questions/topics.

In the first, week we will also have time slots for short presentations by each student, where you can show a few slides (8 minutes and maximum 8 slides) describing your PhD work or current research topic.

There will also be the opportunity to join small projects together with a few of the lecturers during the summer school. This will be organized during the first week and the results from the group projects will be presented on the last day of the school.

Part of the time during the last two days of the summer school will be used to prepare a written summary/discussion of the main findings/conclusions of the summer school. This will later be submitted to an appropriate journal by the students.

As in previous years we encourage the students to submit a proposal for a session at EGU or AGU focusing on the main topics of the summer school.

You can find all the daily summaries and the final submitted paper from previous summer schools on the ACDC www site.

First week:

	Monday 11th	Tuesday 12th	Wednesday 13th	Thursday 14th	Friday 15th	Saturday 16th
Morning	Core 1	Core 3	Group Projects	Core 5	Core 7	Field
Afternoon	Core 2	Core 4	Field	Core 6	Intro to field	Field

Second week:

	Sunday 17th	Monday 18th	Tuesday 19th	Wednesday 20th	Thursday 21st	Friday 22nd
Morning	Field	Topical 1	Topical 3	Topical 5	Topical 7	Discussion
	Field	Topical 2	Topical 4	Topical 6	Topical 8	Summary
Afternoon	Field	Group work	Group work	Group work	Group work	Departure

Safety:
Please be aware that each participant is responsible for bring appropriate personal gear for hiking and camping (see ACDC www site). Each day we will have sign-up sheets where you are required to note your destination and estimated return when out hiking. Remember to always bring a partner and emergency gear. Mountain weather changes quickly, trails can be challenging to find, and there is no cell phone reception.

11th – 16th September: *Fundamental lectures on core topics*
2 x 45 min lectures including 15 min for coffee, questions and discussion.

Monday 11th of September (day 1)

08:00-9:30: Breakfast (and preparation of packed lunch)

10:00-10:30: **Opening of summer school, presentation of program, and introduction of students and lecturers as well as group projects – Kerim H. Nisancioglu (University of Bergen)**

10:30-12:00: Core Lecture 1: Terrestrial (2 x 45 min)

Historical variability in the seasonal cycle of surface temperature
Zan Stine (San Francisco State University)

- A simple model for the thermal control of seasonality
- Observed changes in seasonality
- The role of atmospheric dynamics in observed trends

12:30-15:00: Lunch and free time (to hike, talk and work on summaries and group projects)

15:00-16:30: Core Lecture 2: Atmosphere (2 x 45 min)

Seasonal Cycle of Temperature
David Battisti (University of Washington)

- Forcing: Insolation
- Albedo
- Local Radiative equilibrium
- Role of transport (meridional)
- Role of transport (zonal)

17:00 – 18:30: **Short research presentations by Georgy, Momme, Sunil, Jane and Chris (5 x 8 min):**

19:00: Dinner

Tuesday 12th of September (day 2)
2 x 45 min core lectures including 15 min for coffee, questions and discussion.

8:00-9:00: Breakfast

10:00-11:00: **Short summaries of previous day's lectures by students**
Zan's lecture: Jane, Prachi and Georgy, **David's lecture:** Kat, Chris and Johannes

11:00-12:30: Core Lecture 3: Atmosphere (2 x 45 min)

Seasonal cycle of the extratropical atmosphere
Camille Li (University of Bergen)

- Observed seasonality of the extratropical jet streams and storm tracks
- Aspects that fit with our conceptual understanding of what controls the seasonality...
- … and what can break (or modify) this: North Atlantic versus North Pacific, Pacific midwinter suppression, South Pacific, "external" forcings such as topography changes, etc.
- Seasonality shifts with climate change and associated impacts

12:30-15:00: Lunch and free time (to hike, discuss and work on summaries and group projects)

15:00-16:30: Core Lecture 4: Ocean (2 x 45 min)

The annual cycle in the tropics and its role in generating climate variability
Axel Timmermann (IBS Center for Climate Physics)

- Why is there an annual cycle of SST in the eastern tropical Pacific and not a semi-annual cycle, as in the western tropical Pacific?
- How does the seasonal cycle interact with ENSO and why is ENSO seasonally modulated?
- The concept of Combination Modes and its universality in climate research

17:00 – 18:30: **Short research presentations by Astrid, Jun-Eung, Ally, Sarah and Mads (5 x 8 min)**

19:00: Dinner

Wednesday 13th of September (day 3)

8:00-9:30: Breakfast (and preparation of packed lunch)

9:30-11:00: Project work

Introduction to group projects

- Suggested topics:
  - Evaluating tree ring density as a proxy for temperature (Zan)
  - Summertime surface temperature variability (David)
  - Understanding phase coupling between ENSO and annual cycle (Axel)
  - The seasonality of surface temperature variability (Peter)

12:00-13:00: Lunch

13:00-17:00: Afternoon field trip

Short excursion to Klarabotn
Øyvind Paasche

- We will hike to Klarabotn (cirque).
- Study the landscape and discuss possible geomorphological features

  We'll have a barbecue before returning.

19:00: Dinner

Thursday 14th of September (day 4)
2 x 45 min core lectures including 15 min for coffee, questions and discussion.

8:00-9:00: Breakfast (and preparation of packed lunch)

9:00-10:00: **Short summaries of Tuesday's lecture by students**
Camille: Zack, Mads Sarah, **Axel:** Melissa, Vineel, Anne-Katrine

10:00-11:45: Core lecture 5: Radiation (2 x 45 min)

Can we infer long-term responses from the annual cycle?
Peter Huybers (Harvard University)

- Milankovitch forcing as perturbations of the annual cycle
- Gain of temperature to radiative forcing at annual and longer periods
- Interactions between mean and seasonal climate variability

12:45-15:00: Lunch and free time (to hike, talk and work on summaries and group projects)

15:00-15:30: International coffee break

15:30-15:45: Extraordinary lecture: Alyson Cobb - "Bjerknes compensation"

15:45-17:30: Core lecture 6: Cryosphere (2 x 45 min)

Annual mean responses and feedbacks to the seasonal cycle
Kerim H. Nisancioglu (University of Bergen)

- Dynamics and modelling of ice shelves and ice streams
- Seasonal cycle of snow and ice
- Non-linear feedbacks to radiation
- Ice cores and seasonality
- Marine sediments and seasonality

17:40 – 18:30: **Short research presentations by Johannes, Peter, Vineel, Zach, Prachi (5 x 8 min)**

19:00: Dinner

Friday 15th of September (day 5)
2 x 45 min core lectures including 15 min for coffee, questions and discussion.

8:00-9:30: Breakfast (and preparation of packed lunch)

Check out of the rooms and store luggage

10:00-11:00: **Short summaries of previous day's lectures by students**
Peter: Mark, Ruth and Laura. **Kerim:** Ally, Sunil and Momme

11:00-12:30: Core Lecture 7: Ocean (2 x 45 min)

Seasonal processes of the subtropical, subpolar, and polar oceans
Jake Gebbie (WHOI)

- How special is winter? The mixed-layer demon
- How deep does seasonal variability penetrate?
- Signal of seasonal processes on long timescales? Proxy observations
- Influence of sea ice, stratification, gravity currents, and other good stuff

End of core lectures

13:00-14:00: Lunch

14:00-14:30: Fieldwork

Cirque glaciers, seasonality and the landscape of Rondane
Øyvind Paasche (University of Bergen)

- Cirque glacier-climate interactions: Winter versus summer
- How to reconstruct cirque glaciers
- Patterns of change and cirque glacier's role in forming Rondane

15:00 -> : **Fieldwork including 2 nights camping**

Boat across Rondvatnet at 15:00 and hike to the camp site

(19:00: Dinner outside)

Friday 15th – Sunday 17th of September:

Weekend overnight fieldtrip

Overnight hiking trip to the heart of Rondane

We will leave Friday evening 16:00 for an overnight trip to the central part of the national park. All gear and equipment must be packed and ready prior to the afternoon lecture. We will hike up-valley where we will strike a camp. We will explore the area around camp the first and the following day before returning

During this trip, we will visit different types of quaternary deposits and landforms and learn what they potentially can teach us about past glaciers and ice sheets. During the Last Glacial Maximum Rondane was arguably covered by a large ice sheet, and is one of the areas last to be deglaciated some 10 000 years ago, providing an interesting glaciological context for the field observations to be made.

If the weather permits, we will visit the only remaining glacier (Skrufonna) in the national park, close to Mt. Vassberg.

Please prepare lunch for the two days, including a thermos and a water bottle (water can be refilled during the trip). Make sure to bring everything you need for two nights in a tent, and wear layered clothing.

Packing list:

- Wind and waterproof clothing (jacket and trousers)
- Warm (several layers instead of thick) clothes
- Hat, scarf and mittens
- Lunch box, water bottle, thermos
- Plate, cup, fork, spoon and knife
- Camera
- Sunglasses and sun screen
- Backpack
- Proper hiking boots
- Mosquito repellent
- Sleeping mat
- Sleeping bag
- Tent

We will take the boat back at 16 and we can check in again when we get there. If weather permits, we will have dinner outside prepared by our ACDC chef Kristian Tinnen.

18th – 22nd September: *Topical Lectures*

1 x 60 min lectures with 30 min for coffee, questions and discussion.

Monday 18th of September (day 6)

8:00-9:30: Breakfast (and preparation of packed lunch)

10:00-11:00: **Short summaries of previous day's lectures and field trip by students**
Jake: Astrid, Peter, Ho-Hsuan, Xian. **Øyvind:** Matt, Shengping, Jun-Eung

11:00-12:00: Topical Lecture 1: Atmosphere

The annual cycle in precipitation: when is a monsoon not a monsoon?
David Battisti (University of Washington)

- Monsoons

12:30-15:00: Lunch (and time to hike, talk and work on summaries and group projects)

15:00-16:00: Topical Lecture 2: Radiation

Changes in the seasonal cycle of extremes
Peter Huybers (Harvard University)

- Estimating trends in distributions
- Controls on winter extremes
- Controls on summer extremes

16:30-17:00: Coffee

17:00 – 18:00: **Short research presentations by Melissa, Matt, Ho-Hsuan, Shengping, Xian (5 x 8 min)**

18:00 – 19:00: Dedicated time to work in groups on project topics.

19:00: Dinner

International movie night

Tuesday 19th of September (day 9)
1 x 60 min lectures with 30 min for coffee, questions and discussion.

8:00-9:30: Breakfast (and preparation of packed lunch)

10:00-11:00: **Short summaries of previous day's lectures by students**
David: Prachi, Georgy and Melissa. **Peter:** Sunil, Zach and Matt

11:00-12:00: Topical Lecture 3: Terrestrial

Seasonal proxies
Zan Stine (San Francisco State University)

- The summertime observational bias in paleoclimate
- Tree rings as summertime and rainy season proxies
- The documentary record as a wintertime proxy

12:30-15:00: Lunch (and time to hike, talk and work on summaries and group projects)

15:00-16:00: Topical Lecture 4: Terrestrial

Sub-Antarctic Glacier Variability since the Antarctic Cold Reversal
Øyvind Paasche (University of Bergen)

- An introduction to sub-Antarctic glaciers with emphasis on South Georgia
- Is there regional consistency in glacier variability?
- Can shifts in the Westerlies explain past glacier variability?

16:30-17:00: Coffee

17:00 – 18:00: **Short research presentations by Mark, Anne-Katrine, Kat, Laura, Ruth (5 x 8 min)**

18:00 – 19:00: Dedicated time to work in groups on project topics.

19:00: Dinner

Wednesday 20th of September (day 10)
1 x 60 min lectures with 30 min for coffee, questions and discussion.

8:00-9:30: Breakfast (and preparation of packed lunch)

10:00-11:00: **Short summaries of previous day's lectures by students**

11:00-11:20: Extraordinary lecture: Anne-Katrine: "Introduction to stable water isotopes in Greenland Ice cores"

11:20-12:00: Topical Lecture 5: Models

Seasonality in changing climates
Kerim H. Nisancioglu (University of Bergen)

- Glacial versus warm climate states and changes in seasonality
- Seasonal changes in sea ice and dynamics of abrupt climate changes

12:30-15:00: Lunch (and time to hike, talk and work on summaries and group projects)

15:00 – 19:00: Dedicated time to work in groups on project topics.

19:00: Dinner

Thursday 21st of September (day 11):
1 x 60 min lectures with 30 min for coffee, questions and discussion.

8:00-9:30: Breakfast (and preparation of packed lunch)

10:00-11:00: **Short summaries of previous day's lectures by students**

11:00-12:00: Topical Lecture 6: Ocean

Reconstructing surface conditions through the Common Era
Jake Gebbie (WHOI)

- How the ocean circulation records surface conditions like a "borehole"
- Historical sea-surface temperature versus "subduction temperature"
- Bridging the instrumental-proxy divide of the last few centuries
- Accounting for the seasonal cycle in centennial-scale climate records
- The memory of the Medieval Warm Period and Little Ice Age in today's ocean

12:30-15:00: Lunch (and time to hike, talk and work on summaries and group projects)

15:00-16:00: Topical Lecture 7: Modelling

Detecting future changes in models
Iselin Medhaug (University of Bergen/ETH Zürich)

- Future scenarios for climate change
- Comparing observations and models
- Future modelled changes in light of natural variability

16:30-17:00: Coffee

17:00 – 19:00: Dedicated time to work in groups on project topics.

19:00: Dinner

Friday 22nd of September (day 12)

8:00-9:30: Breakfast (and preparation of packed lunch)

Check out

10:00-11:00: **Short summaries of previous day's lectures by students**
Jake: Xian, Peter, Ruth and Shengping. **Iselin:** Vineel, Anne-Katrine and Laura

11:00-13:00:

Presentation of group projects

- Students present their group projects.
- Discussion, feedback and outlook.

Preparation of short summary article (e.g. EOS)
Everyone!

- Students will be in charge of preparing an article summarizing the main findings and conclusions of the summer school (see previous years for examples).

13:00-14:00: Lunch

14:00-15:00: Summary and Evaluation – David Battisti and Øyvind Paasche

15:00: Departure from Rondvassbu to Spranget (on fot)

17:00: Bus leaving from Spranget to Otta train station

18:38: Train departure from Otta to Oslo Airport/Oslo main train station (arrival Oslo Airport 21:33).

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Rondvassbu Foto: Morten Helgesen

Results from the evaluation of ACDC 2017

KEYS TO ANSWER

Ns	1	2	3	4	5
Don't know/Not applicable	Strongly disagree /Very bad	Disagree/ Bad	Neutral/ OK	Agree/ Good	Strongly agree/ Very good

	Ns	1	2	3	4	5
A – Before the beginning						
A1 Information received before registration	0	0	0	8	6	11
A2 The registration process was effective and efficient	0	0	0	1	3	21
B – Aim pursued in participating in the school						
B1 Interest in your general training	0	0	0	2	6	17
B2 Complement to your university degree	3	1	1	5	7	8
B3 Updating knowledge	1	0	0	0	6	18
B4 Demand or requirement of your university	10	9	0	2	1	3
B5 Improving your CV	1	4	4	5	8	3
B6 Networking	0	0	1	2	4	18
C – Development of the courses						
C1 The level of the courses, in general, could be easily followed	0	0	1	5	14	5
C2 The lectures were well structured and clear	1	0	0	3	13	8
C3 The lectures were interesting and stimulating	0	0	0	0	10	15
C4 Lecturers were approachable and responsive to students' needs	0	0	0	0	3	22
C5 The length of the lectures has been adequate	0	0	0	5	8	12
C6 The programme you have received have been a good and useful guide	0	0	0	1	8	16
C7 The timetable has been properly publicised	0	0	1	4	4	16
C8 The preassigned literature was useful	1	1	0	9	10	4
C9 The time management was good	0	0	0	5	10	10
C10 The quality of learning experience from the student projects was good	0	0	0	5	9	11
D – Global assessment of the school						
D1 On the whole you are satisfied with the level of training gained.	0	0	0	1	7	17
D2 I have clear understanding of how the school courses fit into my research	0	0	0	6	12	7
D3 The school was what I expected, based on the stated aims and objectives	0	0	0	3	9	13
D4 During the school I was able to develop professional relationships and networks	0	0	0	3	6	16
D5 Overall rating of the courses is good	0	0	0	0	5	20
D6 Information about the school and its general organization was good	0	0	0	2	9	14
D7 The quality of practical arrangements was good	1	0	0	1	6	17
D8 You will recommend the school for other students	1	0	0	0	0	24

Additional feedback – recommendations for future summer schools

- I loved 2 days in the field - better bonding. Flexibility in schedule of the course was nice - allowed for good weather, interesting sub-topics, etc.

- A little more info on the style of student projects, maybe, so we could have been a little prepared with papers, analysis software maybe.

- Easily the best + most interactive summer school I've been to. I learned so much and the lecturers were incredible. The weekend trip was really fantastic + catered well for varying levels of location and athletic enthusiasm.

- It would be nice to have more information earlier so that we can prepare better. It is nice to have summary. The instructors are very nice. Thanks for all the efforts the organisers & instructors put and make the summer school work well!

- I believe student projects can be an effective way to learn, but gives the limited time to work on them I think they were too unconstrained and the learning goal too diffuse.

- Great school!

- The daily based schedule could be a bit busy, especially when people have summary & work on project on the same day. Maybe more guide for field trip, especially for people with no experience.

- Had a great time + useful - Thanks! Very valuable having attendees from many countries, e.g. ... Knowledge!

- By far the best short course I've taken in grad school (3 prior courses)! Great group of lecturers + students. The course organizers should be commended on making the course rigours + busy, while retaining a very cheerful + positive atmosphere during the two weeks.

- This is a very awesome summer school. Everything is very well organized. Staying with top scientists and excellent peers. I feel inspired and learned a lot from them!!!

- Good organization. Can provide more material.

- ACDC went beyond my expectations in terms of the material, people, accommodations and scenery!!! Loved it, sad it's over and happy I was able to be a part of it.

- A broader mix of backgrounds (empirical vs modelling) would have been nice

- The hiking trip was great and a good balance for the different levels of experience of people

- Really generous, engaging lecturers - thanks!

- Øyvind's outdoor lecture could be supplemented with drawings/figures wile in the field. Summaries is a great concept.

What can we do differently?

- Core lectures could have been more basic - for example ENSO, eddy-driven vs subtropical jets, and paleo-eras were all very important but never explained in a basic way. Would have been nice to start group projects end of first week to have more time.

- Shorter lectures, more discussion/questions. - more "core" lectures. - Even focus ocean – atmosphere.

- Not much! Brilliant lecturers + also so helpful and friendly. Was ace. - bit of local knowledge of climate might have helped a little. It seemed a bit chillier than the weather forecast suggested. - it was a bit modelling/dynamics/NH focused (to the detriment of SH/proxies) but that wasn't really a bad thing I think; more a result of the expertise of lecturers. - would have been nice to squeeze in a bit more time for walking/sightseeing (earlier starts maybe), though it was great that we covered so much material.

- I know it's hard, but it might be good to have portable white board-like stuff. It would be so since for all the discussions & lecture (can use it when explaining & discussing stuff). -It would be nice to have internet for group project. We can look up information, papers, etc. But without internet, it might be good for interaction. Maybe it's good to find a balance between this.

- I think an alternative to the group projects is to turn them into exercise sessions that explore the depth and details of each of the lectures. For example, the students could work with EBMS and add additional layers of complexity to what David lectured on.

- 1) More blackboard-chalk /whiteboard-marker talks. 2) Lectures can be more structured.

- Even more specific info about equipment needed for camping (e.g. Roll mat + sleeping bag). Maybe an ice breaker activity in the 1st week?

- No major critiques. One suggestion for the future would be a seminar/lecture devoted to sharing techniques + suggestions on how to respond (professionally) to non-scientific criticism, navigating media communication/outreach; talking about climate change with deniers + the public at large. This is something that I think is becoming an increasingly important skill in climate science, and is one that is not formerly taught in most cases.

- Thanks for the organization, for everything!

- Also students have to read material before they came.

- Earlier info about logistics and backpacking gear would have been nice - sort of surprising!

- More oceanography

- Shorten the basic courses. -Less moving around between the lecture rooms. - We somehow always lost a lot of time in the morning. We could have a more condensed program in the morning with small breaks and more free space in the afternoon.

- Maybe be useful, if possible, to get more student presentations done in first week. Leaves more time for group projects in second week & good to know what students are working on earlier in the summer school. Would also be nice to have a short overview in the booklet about each student's expertise/studies, to make sure we make + maintain useful connections.

- I think it was too hard to find time to do student projects and student summaries at the same time. Logistically it was hard to find time to do both.

- Do more group activities such as films in first week rather than second week when students are busier with projects.

Lecture summaries

Fundamental lectures

Zan Stine - "Observed variability in the annual cycle of Earth's surface temperature"
Summarized by Georgy, Jane, and Prachi

INTRODUCTION: Whilst changes in temperature are often thought of as changes in the annual mean, when temperature data is viewed on a monthly basis, the seasonal cycle overwhelms these trades. This motivates two related topics addressed in this lecture: (1) how does the seasonal cycle of temperature vary spatially and temporally, and what controls these variations, and (2) have there been observed trends in the seasonal cycle of temperature, and if so what drives these trends?

METHODOLOGY: Seasonal cycles of temperature can be well approximated by a sinusoid, and thus characterized by an amplitude and phase. In the Northern Hemisphere (NH) extratropical latitudes, the seasonal cycle of temperature was determined by taking a Fourier transform of observed CRU surface temperature data, and calculating the amplitude and phase of the seasonal cycle at each grid point. When normalized to the amplitude and phase of solar insolation, which better highlights the local effects of interest, these terms are respectively called gain and lag (lag because surface temperature always lags insolation). Trends in lag and gain are calculated over each grid point for 1954-2007 and a reference period of 1900-1953. Significance of trends in the later period is tested by comparing to trends in the reference period.

RESULTS: Gain is generally higher over land than the ocean, while lag is greater over ocean than land. This is due to the lower heat capacity of the land versus the ocean. However, gain and lag are not spatially uniform over land versus ocean. Gain increases eastward over land, and decreases over ocean. In contrast, lag decreases eastward over land, and increases over ocean. This can be explained simply by the land and ocean points being connected through the atmosphere – trends in gain and lag follow the progression of the westerly winds. It is demonstrated that the zonal pattern of changes in gain and lag can be simply modeled through assuming a one-layer atmosphere coupled to an energy balance model with constant eastward advection.

Trends in the temperature seasonal cycle over 1954-2007 are somewhat opposite over land versus ocean. Over land, gain and lag decrease; over the ocean, gain exhibits negligible trend and lag increases, though not significantly. These trends are driven by trends in modes of internal variability. In particular, gain and lag over extratropical NH land are significantly correlated with variations in the Northern Annular Mode (NAM) and Pacific-North America Mode (PNA). Positive changes in both these modes result in increased winter and spring temperatures over land, due to increased zonal wind strength and increasing homogenization of ocean and land temperatures. The winter warming decreases gain, and the spring warming decreases lag. Over 1954-2007, both the PNA and NAM exhibited increasing trends, and the magnitude of these trends can well explain the trends in gain and lag of land points.

CONCLUSION: Zonal winds and their variations play a crucial role in determining the spatial pattern of the seasonal cycle of the NH extratropics, as well as determining variations and trends in the cycle. This is done by the atmosphere blending the differential seasonal cycles of ocean and land points, rooted in their differential heat capacities.

David Battisti – "Seasonal Cycle of Temperature"
Summarized by Katherine, Chris and Johannes

The lecture started off with a theoretical explanation of radiation energy balance of Earth, the so-called "zero-dimensional energy balance model". This model describes the energy balance at the Earth's surface as the sum of the incoming short wave solar radiation, plus incoming long wave radiation re-emitted from the atmosphere minus the long wave radiation from Earth's surface. The energy balance of the atmosphere in the model is equal to the energy it receives from the surface of Earth minus the energy the atmosphere radiates into space and back towards the Earth. For the time being, dissipation and divergence are ignored. Emission of long wave radiation follows Stefan-Boltzmann's law. While Earth can be seen as a perfect blackbody, this is not true for the atmosphere. If the atmosphere were a perfect blackbody (emissivity = 1), it would absorb all the incoming energy. Inversely, if the atmosphere was "transparent" (emissivity = 0) then all energy would escape out to space. In the latter case, the Earth would be un-inhabitable with a mean temperature of -18°C. In reality, the emissivity of the atmosphere is approximately 0.76, meaning that a portion of the long-wave radiation is absorbed and re-emitted, and a portion escapes directly out to space. The process where the atmosphere absorbs and re-emits a portion of energy back to Earth is called the Greenhouse Effect. The resulting average surface temperature is approximately +15°C.

Taking the model one step further, we introduce dependency on latitude (one-dimensional model). The tropics receive solar insolation at a steeper angle than the higher latitudes, so at high latitudes the same amount of solar energy is spread over a larger area due to the curvature of the Earth's surface. This results in a surplus of energy at low latitudes and a deficit at high latitudes. Pressure gradients are consequently set up, and meridional transport of heat ensues. The resulting temperature distribution on Earth has warmer tropical and colder polar regions.

For the final step of the model, we now want to include the seasonal cycle and therefore introduce time dependency. Again, we set up the energy balance equations for the surface and the atmosphere, which now contain different heat capacities of the atmosphere, ocean and land. Comparing typical values, we see that the heat capacity of the ocean is an order of magnitude larger than that of the atmosphere, and two orders of magnitude larger than that of the land. These differences in ability to store heat results in some interesting patterns of the seasonal variability in temperature at different latitudes, which we will discuss later on.

The differential equations from the one-dimensional time-dependent energy balance model can be linearized and solved for the cases of land and ocean, under the assumption that $C_o >> C_a$ and $C_a >> C_l$. Plugging in typical values of solar insolation at mid-latitudes results in typical seasonal variations of surface and atmospheric temperature and an associated time lag of response. These values can now be compared to observations to validate the model. The Northern Hemisphere has a much larger proportion of land compared to the Southern Hemisphere. The amplitude of temperature variability in the northern half on the globe is therefore much larger as land heats up and cools down quickly due to its small heat capacity. The southern portion of the globe is dominated by ocean regions which take a long time to heat and cool, thus resulting in very small amplitudes of the seasonal cycle in temperature in the Southern Hemisphere mid-latitudes. Another interesting point is that, for the southern hemisphere, the seasonal cycle in the air is twice as large as that of the ocean. It turns out that the air absorption of shortwave radiation plays an important role in heating the air.

Looking pole-ward of 42° in both hemispheres, there are significant differences in the energy budgets. In the Southern Hemisphere, the surface heat flux is from the atmosphere to the ocean. The inverse is true for the Northern Hemisphere where the landmasses act to heat the atmosphere through sensible heat fluxes. Lastly, the zonal circulation of heat must be considered as the northern extra-tropics have a mix of land and ocean, and thus a strong contrast in heat retention at different longitudes. The zonal transport of energy from the land to the ocean acts to dampen the seasonal cycle over land and magnify the seasonal cycle over the ocean. The observations indicate that extra-tropical regions can be viewed as possessing an average between the pure land and the pure ocean solutions. Finally, topography is added into the mix and we start to see how these zonal flows are impeded by topographic barriers, adding further complexity to the circulation.

Camille Li – "Seasonal cycle of the extratropical atmosphere"
Summarized by Zach, Sarah, Mads

The circulation of the atmosphere is usefully studied from a zonally-averaged viewpoint given its strong zonality. The troposphere of the zonally-averaged atmosphere features a strong eastward jet in the mid-latitudes of either hemisphere, as well as westward trade winds at the equator. The eastward jets are associated with the relatively strong meridional temperature gradient in the mid-latitudes through the thermal wind balance.

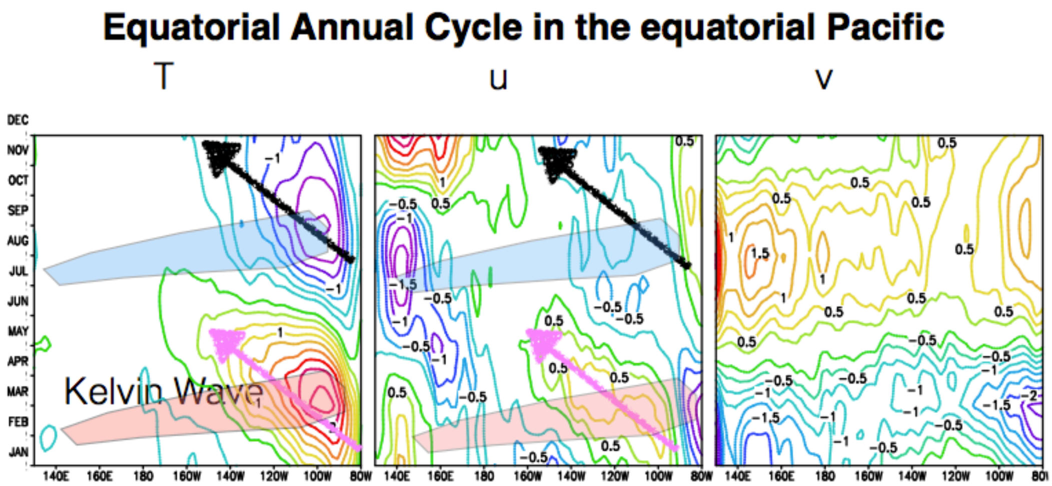
Fluxes of physical properties can be decomposed into mean quantities (zonal and time average), standing waves (time average), and transient eddies. The mean fluxes are due to large-scale circulations in the flow (e.g. Hadley cell). Standing waves are excited primarily by orography (e.g. the Rocky Mountains), and transient eddies arise from baroclinic instability of the zonal flow. These eddies erode the meridional temperature gradient and flux various physical properties (such as heat, momentum and moisture) poleward in each hemisphere. In the extra-tropics, the meridional heat transport is dominated by the eddies. In the Northern hemisphere, the eddy heat fluxes are primarily due to standing waves. Opposite, in the Southern hemisphere the heat transport is driven by transient eddies due to less orography.

As seen from the zonally-averaged atmosphere, the mid-latitude westerlies in either hemisphere intensify and move equatorward in the winter months. This is related to a stronger meridional temperature gradient that follows from the cooling at high latitudes. This in turn increases the baroclinicity and hence the poleward eddy transport of heat. The eddy moisture transport shows minimal seasonality with the largest values concentrated near the surface where moisture is abundant. In terms of the meridional circulation, the Hadley cell intensifies and moves equatorward in the winter hemisphere. This is also associated with the meridional shifts of the ITCZ. Seasonal differences tend to be stronger in the northern hemisphere than the southern hemisphere, likely due to northern hemisphere continents.

Storm tracks, which are preferred regions of weather activity, are “anchored” to the jet stream in each hemisphere and tilt poleward and eastward (due to prevailing westerlies). In the winter hemisphere, the storm tracks intensify because of the increased meridional temperature gradient, and the growth of the storms can be approximated by the Eady parameter $\sigma = 0.31 \frac{f}{N}\frac{\delta u}{\delta z} = -0.31 \frac{g}{NT}\frac{\delta T}{\delta y}$ (using thermal wind balance). This idea is well-shown in the north Atlantic Ocean, where stronger meridional temperature gradients lead to a stronger jet and stronger storm tracks. In the north Pacific Ocean, however, this simple concept breaks down in January, possibly due to seasonal suppression of initial perturbations upstream of the storm tracks. In the southern hemisphere, the seasonal cycle of both the jet stream and the storm track intensification is much less pronounced. Much of our intuition, which is built up from Northern hemisphere dynamics associated with continents and standing Rossby waves, no longer applies because there is not a clear preferred storm track.

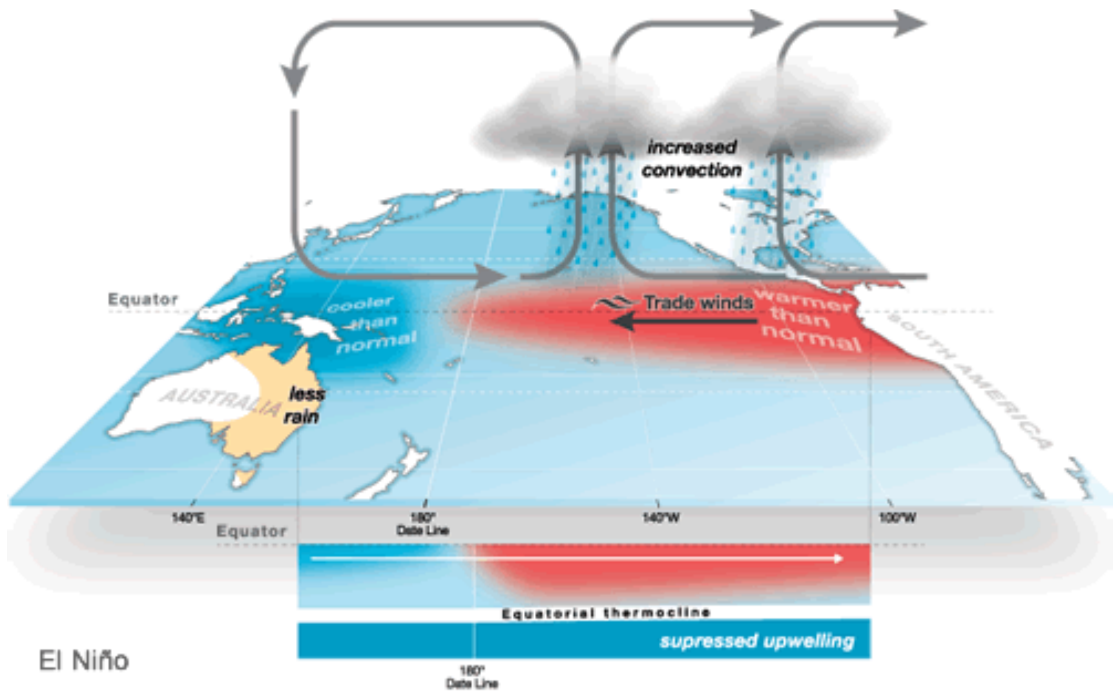
Axel Timmermann – “Seasonal Cycle of Eastern Equatorial Pacific Air-Sea Interactions and their Connection to ENSO”
Summarized by Melissa, Vineel and Anne-Katrine

Surprisingly the eastern equatorial pacific exhibits a seasonal cycle, not a semiannual one, despite the fact that the sun crosses the equator twice per year (Figure 1). This disparity is easily explained by the fact that the dominant forcing of the change in temperature anomalies on the equator is connected to the off-equatorial mean meridional winds, which are forced annually *and* a very shallow mixed layer/thermocline. This effect outweighs that of the semiannual variations in heating. While the anomalous winds change sign from westerly to easterly over the course of the year, the mean background winds lead to a westward propagation of temperature and wind anomalies that are linked through air-sea coupling.



ENSO basics

Sea surface temperatures in the Arctic oscillate between a warm and a cold phase. We call these phases El Niño and La Niña. When an El Niño is triggered, the upwelling of cold water in the eastern pacific is being suppressed. This creates a warm anomaly in the East and a cold anomaly in the West. As a result, the atmospheric Walker Circulation is reduced. Through the discharge-recharge process the conditions in the Pacific transitions from El Niño to La Niña.



Combination modes

Linear theories of ENSO like the recharge/discharge theory, while quite useful, fail to explain several aspects of the phenomenon. For example, they cannot explain the strong seasonal locking of El Niño events. Furthermore, they cannot describe the observational finding that the termination of El Niño events is associated with a Southward shift of westerly wind anomalies about the Equator. The Southward shift of the westerlies induces an upwelling in the equatorial eastern Pacific leading to a weakening and eventual dissipation of the El-Niño. The seasonal locking and termination of El Niño can be understood by taking into consideration the non-linear interactions between the ENSO and the annual cycle. These non-linear interactions give rise to the so-called "combination modes" of tropical Pacific climate with periods of 9 and 15-18 month periods. The combination modes show how the Southward shift of westerly wind anomalies that trigger the termination of the El-Niño arise from the coupling of the ENSO and the annual cycle.

Peter Huybers – "Can we infer long-term responses from the annual cycle?"
Summarized by Mark, Ruth and Laura

Variability is observed on a wide range of timescales, from monthly to millennial. Studying past changes in variability can help improve our understanding of future long-term climate change.

The most dominant frequency of temperature variability is the annual cycle. The peaks at half a year, and a third of a year in the energy spectrum should not be mistaken for real behaviour; this arises from using the sine function as a basis function. Interestingly, in the extra-tropics, trends in surface temperature over recent decades correspond very closely to the amplitude (gains) of the seasonal cycle. This suggests that understanding the seasonal cycle can be a major insight into how our climate will respond in the future. Plotting the auto-bicoherence of temperature records demonstrates that the seasonal cycle influences variability on nearly all other timescales. At higher latitudes variability has the properties of white noise whereas closer to the tropics the spectrum has the properties of red noise. One unanswered question to arise from this session was why the seasonal cycle of temperature variability over land in the Southern Hemisphere seems to align with the Northern Hemisphere seasonal cycle. This question will be further examined during the second half of the ACDC summer school.

On longer timescales, slow changes in the characteristics of the Earth's orbit around the sun result in periods of glaciation. These changes are known as Milankovitch cycles, and relate to changes in the obliquity and precession of the Earth.

Obliquity describes the angle of tilt of the Earth's rotational axis. In the present day, this is 23.5°, but this varies between 22.1° and 24.5°, on timescales of 41,000 years. Obliquity is responsible for the seasonal cycle, bringing each hemisphere closer to the sun for a portion of the year. An increased obliquity results in an increase in insolation during summer, and a smaller decrease in insolation during winter (as the poles are in polar night during winter the insolation cannot be further reduced in this season).

Precession describes the direction of the tilt of the rotational axis. The Earth's orbit is eccentric. Currently, the Earth is at perihelion (closest to the sun) during southern hemisphere summer. The eccentricity of the orbit therefore combines constructively with the southern hemisphere seasonal cycle, and destructively with the northern hemisphere seasonal cycle. The Earth's precession changes on time scales of 22,000 years, changing this interference pattern over time.

The Earth moves fastest when closest to the sun (Kepler's 2nd law), so changes in precession do not result in changes in net insolation when integrated over an annual cycle. However, the annual mean insolation is not the only factor affecting ice development, as it does not always reflect the mean temperature. The number of 'positive degree days', days where temperature exceeds 0°C, is important in the accumulation and ablation of ice.

Long term ice volume records can be obtained by comparing data from marine sediment cores. Calcite shells of marine animals gather in the sediment on the ocean floor. The ratios of oxygen isotopes in the sediment provide information on ice volume and temperature. Shared peaks are identified in different sediment cores, and these can be dated based on the signatures of magnetic reversals. Fourier spectra taken from these long-term datasets reveal the signatures of the Milankovitch cycles.

Records of the early Pleistocene show variability due to obliquity but not due to precession. In warmer conditions, like the early Pleistocene, the number of positive degree days does not change much between perihelion and aphelion. Even though there is more solar insolation at perihelion, the summer season is shorter due to Kepler's 2nd Law. However, in colder conditions, like the late Pleistocene, there is a large difference in positive degree days between perihelion and aphelion. There are still more positive degree days at perihelion, despite the shorter summer, than at aphelion. In the late Pleistocene, it was cold enough that precession affects the variability in temperature, and the spectrum shows a peak in precession.

Kerim Nisancioglu – "Annual mean responses and feedbacks to the seasonal cycle"
Summarized by Ally, Sunil and Momme

The addition of divergence term and albedo to a simple energy balance model (EBM)
The mid-Pleistocene transition of glacial cycles raises fundamental questions about the coupled feedbacks of the earth system. An extension of a zonal mean EBM is used to illustrate the effect of ice-albedo feedbacks on the response of the earth system to changes in the orbital parameters. Two of these, precession and obliquity, effect of earth energy balance in different ways: Precession has no mean annual forcing as there is no change in energy for one latitude averaged over the year, while obliquity has a non-zero annual mean

response in the energy balance. The contribution of both is changing when adding atmospheric transport and ice sheets to the model.

The complexity of atmospheric circulation can be reduced to the need of poleward atmospheric energy transport. This transport is parameterized by a simple diffusivity in the EBM and its strength can be well represented with an analytical function that depends only on surface temperature. 94% of seasonal variance in eddy fluxes in mid-latitudes can be related to changes in the zonal mean temperature gradient. This is a good approximation for extratropical transports but fails in the tropics due to no representation of tropical ocean heat transport. Adding diffusivity to a column energy balance model adds the poleward transport of heat and parameterizes adjustment of energy fluxes of the globe under glacial cycles.

In addition, ice sheets are added to the model using an accumulation and ablation parametrisation, based on the characteristics of the ice and the seasonal temperature. A comparison of the model with and without ice shows that there is a significant annual mean response due to precession compared to an EBM without Ice. Northern hemisphere glaciers add non-linear feedbacks due to the ice-albedo effect. A consequence is an increased NH tropics-to-pol temperature with precession. In addition, the response with Ice-sheets to changes in obliquity also increases the tropics-to-pol temperature contrast, but this effect is also the case without an ice representation.

Jake Gebbie – "Seasonal processes of the subtropical, subpolar, and polar oceans"
Summarized by Astrid, Peter, Ho-Hsuan and Xian

The four seasons: The demon loves winter, forams loves spring and summer, and I love fall

The Part I of the lecture introduces some extratropical physical process that can help us understand whether interior ocean temperature can be inferred from SST. The part II is an introduction of marine proxy records and the uncertainties in the SST reconstruction.

The mixed layer of the ocean is a layer near ocean surface with almost uniform density, temperature, and salinity. The mixed layer develops from summer to winter by the combination effects of cooling at the surface and pure turbulent mixing by wind. From winter to summer, it is restratified by the heating at the surface followed by weak mixing, which helps developing the seasonal thermocline. Therefore, mixed layer depth is shallower in the summer compared to winter time.

The mixed layer demon usually happens near subsiding region (e.g., subtropical gyres). With the large-scale subsidence, in addition to the evolution of the seasonal thermocline, the ocean water would keep subsiding. This means that if mixed layer depth in the second year is not deepening, compared to the first year, as far as the distance of water subsidence, a portion of the seawater in the mixed layer depth would stay underneath the seasonal thermocline in the next year without returning back to mixed layer. This framework also works for explaining the profiles between regions with outcropping region (cold surface and strong wind), and non-outcropping/subducted region.

The seasonal subduction of surface water by mixed layer generates the formation of mode water, a vertically homogeneous water mass. Mode water usually forms on the warm side of the strong fronts in the winter season when the mixed layer is deepest. The formed water mass could be further subducted and spread equatorward through ocean gyres, for example, the North Atlantic Subtropical Mode Water could be transported to lower latitudes via the subtropical gyre. Two other important water types are summarized as follows. Intermediate waters are defined as salinity minimum or maximum layers. There are several particular production sites for the formation of these waters. The most typical one is the Mediterranean Overflow Water with salinity maximum resulting from the strong evaporation and cooling in that region. The Deep and Bottom Waters are driven by both salinity and temperature. For instance, the formation of Antarctic Bottom Water is related to the brine rejection and cold temperature along the coast of Antarctic.

The source of seawater mainly originates from the Arctic and Antarctic where the temperature is cold and a large amount of sea and land ices are found. The cold water formed at the surface there promotes the water sink and generates a deep overturning circulation. Generally, there is a time lag of signal between the sea surface and the deep ocean. Sea surface variability can lead the deep ocean by ~1k year in the deep Atlantic Ocean and by ~2k years in the deep Pacific Ocean. The Atlantic Ocean has a smaller lag than the Pacific Ocean because it has a quicker and more complete overturning current. Moreover, high frequency signals will be smoothed out when signal transferring from the sea surface to the deep ocean.

Next, Ekman effect tends to pump the seawater to the right (left) hand side of the wind stress in the Northern (Southern) Hemisphere. This increases the water pressure gradient and this would be balanced back by the barotropic flow. For the seasonal cycle, the oceanic seasonal difference is large between the winter and the summer, and there is a net transport of heat across the equators to the Northern Hemisphere when subtracting the summer oceanic flow from winter. The large-scale zonal-mean of the overturning current depends on the zonal-mean wind stress on the surface, where water sinking happens in the convergence zone and vice versa.

The last part of Jake Gebbie’s talk covered isotopic measurements as a proxy for temperature in the past. Changes in δ18O values are stored in foraminifera and ice. Today's oceans vary in their δ18O between -3 and 2‰. These values are much smaller than those recorded in ice cores on Greenland due to fractionation in precipitation-bringing clouds, but comparable to those recorded in foraminifera. Examining discrepancies observed in planktonic isotope values and those expected from models hints at possibilities of extracting seasonal information by distinguishing between different species and their preferred living depth. However, the scarcity of plankton in winter increases uncertainties. Another factor increasing uncertainties are growing preferences of different species to different temperatures.

Field

Øyvind Paasche - "Cirque glaciers, seasonality and the geomorphology of Rondane"
Summarized by Jung-Eun Chu, Shengping, and Matt

Øyvind's lecture stressed the importance of local seasonality and climatologic influences on the life cycle of glaciers and ice sheets in Norway, and provided critical context for the sedimentary and geomorphological features observed over the past weekend in Rondane National Park. Cirque glaciers, "relatively small, alpine glaciers found in half-open, semi-circular shaped hollows located on mountainsides or in the upper part of valleys (Paasche, 2011)", were a major emphasis in Øyvind's lecture. In Norway and abroad, these glacier-types are of interest to earth scientists due to i) their sensitivity to climatic changes and ii) their distinct ability to sculpt the alpine landscape, via the erosion, transportation, and re-deposition of sediments and unsorted bedrock debris. Importantly, through the erosion of the bedrock on which they are super-imposed, cirque glaciers often produce annual ("varved") sedimentary deposits in proglacial lakes and ponds that can in turn be used to infer glacier-climate feedbacks further back in time. Towards this regard, studies on cirque-like glaciers (e.g., Harmon et al., 2015) have shown that glacial abrasion, or sediment production, is a nonlinear and positively-related function of ice-sliding velocity, which is in turn can be described as a function of ice thickness, ice surface slope, and ambient temperature. As such, an increase in ice flux induced by climatic changes may be accommodated by an increase in downstream sedimentation. Such studies are not without difficulties, however, as key challenges remain in distinguishing extra- and para-glacial sediment contributions from the 'true glacier signal', obtaining reliable age-depth relationships in the sediments, and in achieving near-space reproducibility in records.

As Øyvind pointed out, Norway is in fact rich in glaciers, with current estimates placing the number at >2500. One important concept is that of "glacier mass balance" (b_n), the year-to-year difference in integrated net-accumulation minus ablation (~melting). While only <50 glaciers in Norway appear to have undergone regular monitoring, these studies have shown an overwhelming negative b_n trend over the past few decades, void small period of $b_n > 0$ which appear to correspond to increase moisture transport and precipitation to Norway, as dictated by positive excursions in the North Atlantic Oscillation. Indeed, the climatological balance between wintertime precipitation (accumulation) and summertime temperature (~melting) supports a strong, (positive) nonlinear constraint on the occurrence of glaciers in Norway and other high latitude environments. In particular, this relationship – the "Ahlmann-Liestøl Relationship (ALR)" – suggests glaciers can only exist in regions with warm, summertime temperatures when compensated by an exponentially-large wintertime precipitation. As such, the ALR can be used as a metric for discriminating between glaciers as a function of their winter vs. summer and continental vs. coastal climatologies, as well as a useful tool for predicting glacial sensitivities to future climatic changes.

Finally, as a final note before heading out into the Rondane "wilderness" for the weekend, Øyvind introduced us to the "Rondane Paradox". This notion is predicated on both model-based and empirical evidence suggesting the spatial/volumetric extent of the (cold-based)

Fenno-Scandinavian ice sheet during previous glacial-interglacial cycles has grown progressively larger over the more-recent Quaternary glaciations, culminating with the most-extensive glaciation at the height of the Last Glacial Maximum (~18 kyr before present). Notably, while these larger late-Quaternary ice-sheets would be expected to leave behind larger glacial footprints during periods of ice-sheet decay than previous glaciations (representing relatively smaller Fenno-Scandiavian ice-sheets), Rondane National Park shows abundant evidence of these prior *smaller* glaciations as well, extending back as much as 600 kyr before present (Paasche, *personal communication*). Features which we'll explore this weekend include erosive as well as depositional features, such as meltwater channels and overflow gaps, ice-dammed lakes, landforms (moraines) and sedimentary deposits (deltas).

Cirque glacier are small glaciers found in half-open, semi-circular shaped niches, or hollows located on mountainsides or in upper part of valleys. Cirque glaciers are responsive to climate change and the sediments transported from glacial can be used reconstruct past climate variability. One of the important concepts in glacier is equilibrium line altitude (ELA) which is defined as the altitude balanced between accumulation and ablation. When a glacier erodes, it produces fine sediments transported downstream. Variations in glacier size are reflected by the EA where a lowering will cause the glacier to grow and consequently produce more sediments and vice versa. The mass balance between accumulation and ablation over a year also reflect long-term climate variability. Another important aspect of glacier activity in Norway is that they have winter-type glacier, accumulation in winter and ablation in summer, shows clear relationship between summer temperature and winter precipitation. In other words, winter precipitation is exponential function of summer temperature and coastal areas tend to more sensitive to summer precipitation whereas continental areas tend to more sensitive to winter precipitation.

Rondane is located in southern Norway, in the northern of which remains the last glacier with the equilibrium line altitude of 1450 m. Even though many high-resolution Holocene glacier reconstructions have been obtained from other regions, the glacier reconstructions derived from Rondane are very few. Øyvind gave a lecture on the results based on the series of cores retrieved from the downstream lakes of Skriumfonnen. Skriufonnen has retreated rapidly since monitoring began in 2002. However, the moraine and striations in foreland of the glacier suggest that former extents should be much larger than the present. Variations in magnetic susceptibility from cores indicated that there is a major peak all cores but changes along the depth of the sample retrieved. Meanwhile, all cores have reproduced a similar pattern, implying that the soil samples along the transect running did shared the same sedimentation. Finally, long reconstruction series suggest that the local glaciers present until 10.2 ka when it disappears and reforms around 3.5 ka and peaks at 2.4 ka, which means that the climate became favourable for the Skriufonnen glacier. It is also revealed that the summer temperature is very important for the existence of glacier in Rondane.

Topical lectures

David S Battisti - "Seasonal Cycle in Tropical Precipitation"
Summarized by Prachi, Georgy and Melissa

The seasonal cycle of precipitation in the tropics is dominated by the intertropical convergence zone (ITCZ). The ITCZ migrates northward in the northern hemisphere (NS) summer, and southward in the southern hemisphere (SH) summer, and achieves its zonal mean maximum northerly (southerly) position in August (February). The lag response of oceans to solar heating is approximately three months, and the shorter two-month response time of the ITCZ to the hemispheric solar maxima is therefore attributable to the presence of land masses.

When considering the annual zonal mean, ITCZ is puzzlingly located at approximately 5°N (Fig. 1), despite observations that on average the SH receives more solar insolation than the NH. This meridional asymmetry in the tropical overturning circulation implies net atmospheric heat transport across the equator from the NH to SH. This discrepancy can be explained in the following manner:

1. the SH receives more solar insolation which heats the ocean relative to the NH
2. the ocean transports this excess heat to the NH, where it heats the atmosphere, which now has an energy surplus
3. half of the energy is radiated back to space, while the rest is subsumed into the Hadley cell which then re-transfers the heat to the SH.

Thus, the observed mean position of the Hadley cell, and its center as represented by the ITCZ, is a result of the hemispheric energy imbalance which must be compensated for by ocean and atmospheric circulation.

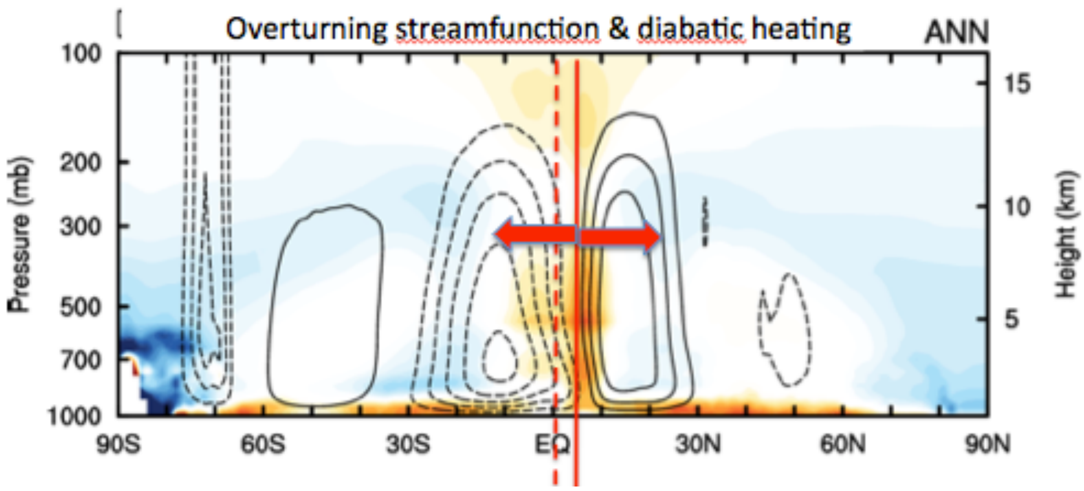


Figure 1: Meridional cross section of the annual and zonal mean overturning circulation.

Climatology and seasonal cycle of ITCZ
Precipitable water (or vertically integrated water vapor) is maximum over the region of warm sea surface temperature (SST). However, the region of maximum precipitation and evaporation is determined by the atmospheric circulation. While precipitation and evaporation balance each other in the global budget, they are not equal locally. Precipitation is greatest in a narrow latitudinal region near the equator where low-level winds converge and air is forced to rise, while evaporation is strongest in the subtropics in regions of large-scale subsidence. Easterly winds moving southwest thus gain moisture before converging and rising in the ITCZ.

Role of the Andes
Considering the ITCZ in terms of a zonal mean also results in significant loss of information. One example is provided by the mechanical effect of the Andes on seasonal migration of the ITCZ.

The eastern-central Pacific ITCZ has an annual mean position of $\sim 10^{o}N$, well north of the zonal annual mean of 5°N. The maximum southward displacement of this part of ITCZ is only $\sim 6^{o}N$ in February i.e. in this region, the ITCZ never crosses the equator. Simultaneously, SE Pacific is also anomalously cold. (This mean state asymmetry is fundamental for the existence of El Nino). Takahashi and Battisti (2007 a) showed that mechanical effect of the Andes on the atmosphere and the resulting thermodynamic feedbacks with the ocean keep the ITCZ north of equator in the central-eastern Pacific. An aquaplanet general circulation model was used with fixed zonally symmetric SST plus topography of Andes in the South American continent. Inclusion of topography resulted in removal of the Southern ITCZ in the Eastern Pacific and made the Southern Pacific Convergence Zone (SPCZ) appear in the appropriate place. Takahashi and Battisti (2007 a) concluded that the westerlies flowing along the subtropics are obstructed by the Andes. The part of the resulting wind that deflects equatorward sinks down along the lines of constant potential temperature (owing to the equator to pole potential temperature gradient). This dry air subsidence results in evaporative cooling just south of the equator thus pushing the ITCZ poleward and forming the SPCZ.

Peter Huybers – “Summer temperature extremes and agriculture”
Summarized by Zach, Matt, and Sunil

We use a Bayesian model to estimate true temperature fields in the arctic latitudes from instrumental and proxy (ice core, varve, and tree ring) records. This is essentially an inverse problem, where we assume a given “true” temperature and find the probability that the instrumental and proxy records would give the values we find given that true temperature. The model also finds best-fit parameters that describe the reliability of the instrumental and proxy records, temporal memory in and spatial variance of the temperature field, and tendency of the mean temperature. These parameters are assumed to be constant; thus, our null hypothesis is that global warming changes the mean temperature but not the variance.

We test this model by considering extreme events, i.e. the 5 hottest anomalies in the past 20 years. This necessitates considering the difference between *pointwise* and *pathwise* extremes. A pointwise extreme is one where an event differs from a given number of standard deviations from the mean; that is, one might define an event as extremely hot if it is in the upper 5% of temperatures. Then, the number of extreme events increases proportionally to the number of samples (*n*) – if, for example, instrumental records become denser, you will find more extreme events simply because *n* increases.

A pathwise extreme, in contrast, is one where an event differs from the expected occurrence of that event given a known distribution. For example, the most extreme event shown in the record considered here was in Northern Canada in 1998, approximately 4 K warmer than the mean (after averaging over a 5x5 degree box during summer months and empirically fitting an increase in the mean temperature). From the (shifted) mean temperature, variance (assumed to be constant in time) and *n*, we can calculate a probability distribution function for how anomalously warm we expect the most extreme event to be, and find that the observed +4 K anomaly is well within our expected distribution. We can do the same for the 2^{nd}-5^{th} hottest events, and all fall within the expected distribution for these extreme events. This lends credibility to our null hypothesis: that global warming manifests as a shift in the mean temperature but does not change the variance about that mean.

In a few places – e.g. the US Midwest – there is actually a cooling trends in the 95^{th} percentile of summer temperatures. This, as well as increasing precipitation rates, suggests favorable climatic condition for crop growth. Daily maximum temperature station data from 1910 to 2014 show a statistically significant association between the cooling trends and intensification of agriculture and increased irrigated lands in the Midwest. Agricultural intensification primarily enhances evapotranspiration, increases atmospheric humidity and precipitation, and eventually cools the atmosphere. However, this is only true for the regions with increased irrigation. Regions with rain-fed agriculture show cooling trends only during non-drought periods and warming trends during drought conditions. This is because of insufficient soil moisture during drought years reducing the ability to achieve higher rates of evapotranspiration. Similar results are also obtained for eastern China, where largely irrigated areas with higher primary productivity are collocated with declining summer temperature extremes.

The study of recent trends in temperature extremes in global cropland regions lends itself to evaluating future food productivity. Projections suggest daily food consumption will increase nearly linearly from a current 20 trillion kilocalories per day to approximately 30 trillion kilocalories per day by 2050. While increased agricultural output over past decades – maize in particular – appear to have kept pace with this linear rise, there has been substantial volatility in year-to-year output. A leading predictor of the year-to-year variability is a metric known as the Killing Degree Days (KDD), defined as the sum of temperatures each day of the year where the temperature exceeds 30°C. Projected decreases in temperature extremes in global cropland regions suggest a corresponding decrease in

KDD, and hence in increase in year-to-year agricultural output. On the other hand, since mean temperatures in cropland regions have also risen in response to mean global warming trends, the number of Growing Degree Days (GDD; i.e., the cumulative warmth a plant has received over a growing season) has also increased, promoting an overall increase in agricultural productivity. As such, while year-to-year volatility could prove harmful in future global population growth scenarios, such scenarios could be mitigated somewhat by projected decreases in cropland temperature extremes (<KDD) and increases in average annual temperatures (>GDD).

Zan Stine – "Inverting for summer temperature from annual tree growth"
Summarized by Mark, Chris, Ally

Dendrochronology is a useful method to reconstruct past global temperature prior to around 1850, when thermometer records were local and limited in number. Tree rings are composed of a section of light wood and dark wood, which together indicate a year of growth. The light wood or 'early wood' reflects the growth during the early part of the season, and the dark wood or 'late wood' shows the growth late in the season and is composed of cells that are smaller and have thicker cell walls. There is generally a smooth transition from the early wood cells to the dark wood cells, but there is an abrupt change from the late wood of one year to the early wood of the following year due to the rapid end of the growing season.

Temperature can be estimated using a variety of data from the tree, including cell width, cell wall thickness and density. Density has the best correlation with temperature. Density uses the late wood. Tree rings provide a large and widespread data source to learn about past global climate, but there are a number of limitations. The 'divergence problem' is the term used for the decrease in global temperature shown in tree ring data from the 1960s, which is contrary to the observed increase in global temperature. A possible reason for this is 'dimming', with light being a limiting factor. Another limitation of that there is no theoretical way to deal with the change in the tree's growth during its lifetime, but commonly a negative exponential function is used to correct for this. Density has a strong skew in its distribution and it is therefore not necessarily appropriate to reconstruct the Gaussian temperature function with this distribution. There is also changing environmental control on tree growth. Finally, competition among trees can further obscure any climate signal.

One of the most important finding from ecological studies, Liebig's law of the minimum dictates that if more than one factor is limiting the growth, it is only the most limiting factor that determines growth. Generally, either temperature or moisture are the general limiting factors. Historically, it has been assumed that all trees have a climate signal and noise and can therefore be termed 'noisy thermometers'. It was shown, however, that at high latitudes in the Northern Hemisphere tree growth behaves strongly like Liebig's law and the 'noisy thermometer' approach is not able to detect the climate signal from the trees. This also indicates that using high quantiles rather than the mean value of all records improve the correlation with climate signal, especially under high temperature regime, where the growth of most of the trees is constrained by the local growing factor. Using the 272 sites pole ward 50°N, Zan shows that most of the sites have the best correlation with instrumental temperature, when high quantiles are used to reconstruct tree ring proxies. Also, using 100% quantiles help to solve the divergence problem in the warming climate. The new construction method captures more climate signal and increases the temperature range of the tree ring reconstruction.

Øyvind Paasche – "South Georgia Glaciers"
Summarized by Johannes, Jane, Momme, Sarah

Do shifts in seasonality pace subantarctic glaciers?
South Georgia is an Island in the Atlantic sector of the Southern Ocean. It has been visited by repetitively by explorers and researches that start to observe the glacial development since around 1900. Modern glaciologists and climate scientists have new technics, like exposure dating, glacial lake coring and moraine dating, that open new possibilities to relate local glacial behavior to large scale patterns.

The traditional method for determining past glacier extent utilizes moraines—end moraines work better than side moraines as they are more directly related to glacier extent. If a suitable moraine is found, ELA is estimated from its position using AAR (Accumulation Area Ratio) or other similar methods. Exposure dating of moraines with 14C or 10Be is then used to determine when the moraine was formed, and hence when the glacier had the corresponding ELA.

While the moraine dating method can provide snapshots of past glacier extent in time, a newer method referred to as "glacier fingerprinting" can produce more continuous records of glacier extent. In this method, a sedimentary core is taken from a lake at the bottom of a glacier, analyzed for a number of different chemical constituents, and carbon dated. Fluctuations in the sediment of the core then can be related to glacier extent. Larger fluxes of sediment into the lake generally result when the glacier is larger and has more substantive melt water streams. However, rapid retreat of glaciers can also increase sedimentary flux, adding noise to the signal from this proxy record. At Hodges Glacier on South Georgia, it was found that magnetic susceptibility in the lake core related more closely to fluctuations in glacier extent than the other chemical constituents analyzed. Notably, this glacier fingerprinting process would be significantly complicated if the lake had had sources of sediment other than the glacier of interest.

Comparing the exposure dates of several small glacial System in South Georgia with ice-core temperature proxies from the Antarctic peninsula shows that both places undergo similar transitions. The exposure dating is in agreement with rapid retreat (5 ka and13-10 ka) as well as slow retreats (10-5 ka) and relatively stable periods in the ice record. This relationship holds for well from present day to about 8000 cal. yr BP.

Kerim Nisancioglu – "Seasonality in changing climates"
Sumamrized by Kat, Mads, Chu and Ho-Hsuan

Ice cores from the Greenland ice sheet hold information on past climate. It is possible to derive proxies for various physical quantities from the ice cores, and one of the commonly used proxies for temperature reconstructions is the ratio of stable water isotopes. This ratio, named $\delta^{18}O$, is defined as the difference between the sample $^{18}O/^{16}O$ and a reference $^{18}O/^{16}O$ ratio, divided by the reference $^{18}O/^{16}O$ ratio itself. Physically, when water vapor condenses, the ratio of ^{18}O and ^{16}O changes because ^{18}O prefers to condensate compared to ^{16}O. Consistently, ^{16}O preferentially evaporates compared to ^{18}O. This physical process is known as fractionation.

The Rayleigh model describes this physical process and can be used to explain the change in the $\delta^{18}O$ of precipitation associated with an atmospheric transport of moisture. Water vapor evaporates from the moisture source (subtropical regions) and subsequently moves poleward. Because the temperature overall decreases with increasing latitude, water vapor tends to condensate and precipitate out. The condensation process depletes the remaining ^{18}O in the water vapor and $\delta^{18}O$ decreases. The $\delta^{18}O$ signal obtained from ice cores is therefore an integrated measure of the fractionation that the water vapor was subject to during transport. A larger temperature difference between the source region and ice core site would result in a more negative $\delta^{18}O$ value. The model thus explains the change in the $\delta^{18}O$, and hence temperature difference between the evaporation and ice core site, and allows us understand the past climate through stable water isotopes.

Moisture sources for the Greenland ice sheet have not been constant over time. Based on trajectory analysis, it was found that during extensive sea ice periods (i.e., relatively cold periods) most of the moisture was transported from the North Atlantic and tropical Atlantic Ocean. Alternatively, for minimal sea ice periods (i.e., relatively warm periods), the source is the polar Atlantic and north Atlantic regions. A change in moisture source has implications for the interpretation of the $\delta^{18}O$ signal. Furthermore, ice cores also resolve the seasonal cycle during the last 7-8000 years. The seasonal cycle can be identified by looking at different molecules in the ice cores. For example, Na^+ tends to peak in winter, Ca^{2+} and dust peak in Spring, and NH_4^+, NO_3^- and often SO_4^{2-} show peak in summer season. Caution is needed in analyzing the upper part (recent part) of the ice core as diffusion acts to smooth the seasonal cycle of the signal. Back-diffusion is often applied to the inferred signal to correct for this process.

Ice cores drilled on the Greenland ice sheet approximately cover the last 130kyr. During this time span, the $\delta^{18}O$ record features the end of the last interglacial (the Eemian), the entire last glacial and the present interglacial (the Holocene). The last glacial experienced abrupt climate changes, and we will here focus on two such events; the climatic transition from the Younger Dryas (YD) to the early Holocene, and so-called Dansgaard-Oeschger (DO) events. The former transition occurs during the termination of the last glacial and takes place on an annual to decadal time scale. Proxies from Greenland ice cores show that the rapid warming inferred from the change in $\delta^{18}O$ signal was associated with more precipitation on the ice core site (thicker annual layers), atmospheric circulation changes (seen from a change in the dust concentration) and change in moisture source (deuterium excess). Ice core evidence of climate transition also indicated a change in the seasonal cycle amplitude mainly due to milder winters in the Holocene. This change is possibly explained by a more extensive winter sea ice cover during the YD, which prohibits exchange of heat between the relatively warm ocean and the cold atmosphere.

The DO events occur multiple times during the last glacial, and feature a rapid warming followed by a gradual cooling on a centennial to millennial timescale. There are two scenarios proposed to explain this abrupt climate change.

The first, 'freshwater hosing', is an introduction of a massive flux of freshwater into the North Atlantic. This freshwater influx is proposed to origin from iceberg calving of the Greenland and Fennoscandian ice sheets. As water travels northwards in the North Atlantic, it cools and its density consequently increases. Dense water sinks in the northern North Atlantic, thereby "pulling" more equatorial water northwards to replace it. The introduced freshwater counteracts the density increase associated with the cooling and weakens the ocean circulation and poleward heat transport. A weakening of the ocean circulation would imply a rapid decrease of temperatures over Greenland and a large decrease in $\delta^{18}O$ in the ice core signal.

The second scenario proposes that changes associated with melting of the Arctic sea ice drive the transition from a cold to warm environment and an input of freshwater drives the transition from warm to cold conditions. In a cooler climate, the sea ice extends far southwards. Under the sea ice, a layer of cold fresh water of low density (due to freshness) would ridge above a tongue of warm North Atlantic water. If the North Atlantic water warmed to such an extent that it became less dense than the overlying freshwater, convection and mixing of the upper water column would ensue. The bottom of the sea ice layer would thus be exposed to warmer water and would consequently melt, facilitating a transition from a cold to warmer Arctic climate. For conditions to return to a cold Arctic with a large ice extent, an inverse process is proposed. Freshwater input from terrestrial sources would accumulate at the surface of the Arctic Ocean, acting to insulate the warm North Atlantic water from heat loss at the surface and facilitate sea ice growth.

Jake Gebbie - "A fossil water mass in today's ocean: deep water from the Little Ice Age"
Summarized by Xian, Peter, Ruth, Shengping

Jake's lecture focused on the question 'Is there deep water from the Little Ice Age in today's ocean?'. During the winter season, via Stommel's 'mixed layer demon', discussed in Jake's first lecture, surface water is subducted to the deeper ocean in localised regions. Proxies indicate that the age of deep ocean water ranges from about 300 to 1400 years old.

Therefore, a question may be easily proposed: Could anomalously cold surface water from the Little Ice Age be subducted into the deep ocean, and still exist in today's ocean?

To investigate this hypothesis, the authors perform a model study, looking at the advection of surface temperature perturbations by the past ocean circulation. The model is an inverse circulation model with 2x2 degree resolution and 33 vertical levels, using today's ocean circulation as the background field. Data available for the Common Era are used as the model boundary condition. The global subduction temperature anomaly may be reconstructed from borehole and recent instrumental data. A variety of marine proxy records provide temperature reconstructions with more specific spatial information. The model was initialised at 1CE.

As the historical subduction temperature includes the temperature fall in the Little Ice Age, the model is also expected to have a negative temperature anomaly in the same period, propagating from the surface to the deep ocean. The downward propagation of such temperature anomalies is observed in the simulation. The model additionally demonstrates that the deep ocean lags the surface in terms of temperature, and the temperature change in the sea surface is much quicker than its deeper counterpart.

The model simulation supports the hypothesis that the oceanic temperature trends of Common Era could be explained by small perturbations to the ocean circulation via subducted surface water. To give further evidence of this, a comparison was conducted between the model simulation and the temperatures observed by the HMS Challenger expedition (1872-1876). The observations are consistent with the model in suggesting that the ocean (from the surface to 5500 km) responded to warm and cool surface temperature anomalies in both the Atlantic and Pacific.

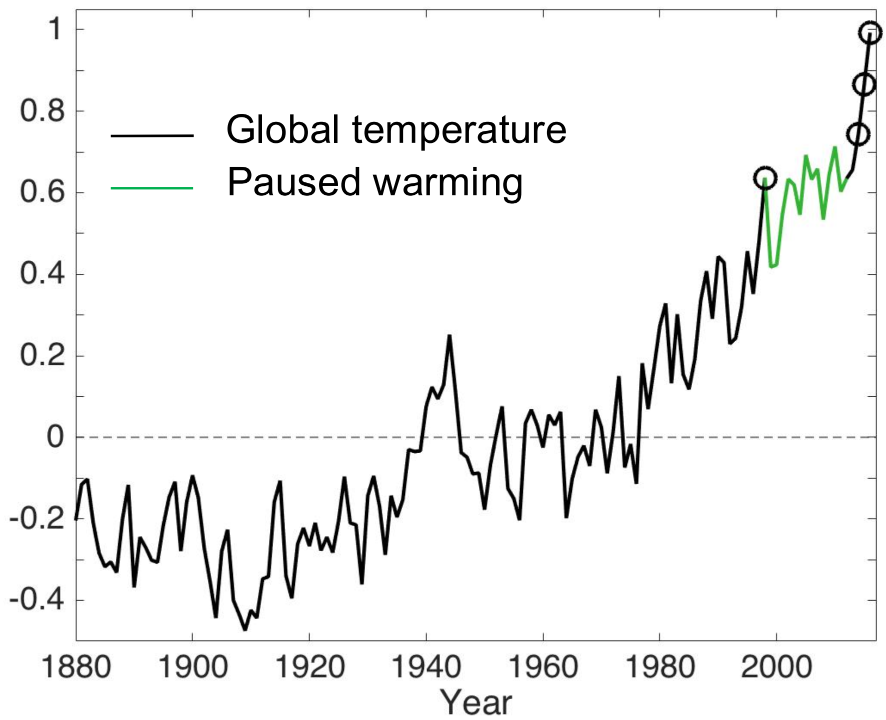
As an additional test of the hypothesis, a model simulation initialised from 1870CE was compared with the simulation initialised at 1CE. While the latter reproduces the cooling of the deep Pacific over the anthropogenic era, the former does not, suggesting that the deep Pacific cooling is remnant of pre-1870 surface cooling. Finally, the authors investigated the subduction temperatures giving the best fit of the model to the Challenger observations. The results imply that if the Little Ice Age had a greater magnitude in the North Atlantic, it would explain the larger Pacific cooling and Atlantic/Pacific difference.

The model, and its consistency with the observational record, indicates that surface temperature anomalies penetrate to the deep ocean, which keeps a memory of these past events for many years. One implication of this is that fluxes to the deep ocean prior to the industrial revolution may not be negligible, as is often assumed, e.g., by CMIP5 models. This assumption may therefore need to be revisited, with potential implications for Energy Balance Models of the atmosphere.

Iselin Medhaug – "Detecting future climate change in models"
Summarized by Vineel, Anne-Katrine, Laura

The global warming hiatus is a slowdown or a pause in the global mean temperature in the late 20th and early 21st century (1986 – 2012, green line in the figure below). While it was occurring, the hiatus generated massive discussion among the public, greatly fueled by inane media speculation of a global warming myth perpetuated by the scientific community. The scientific community proposed various mechanisms that could explain the hiatus. Cooling by tropospheric/stratospheric aerosols, decreases in solar irradiance, deep ocean heat uptake and natural variability related to the Pacific Decadal Oscillation have all been implicated.

The various observational datasets that exist and the time periods they cover lead different conclusions about the hiatus. For instance, the HadCRUT3v2009 dataset that extends up to 2010 shows a zero trend in global mean temperature during the hiatus period. However, on correcting the dataset using observations beyond 2010 leads to a significant trend. Furthermore, differences in the construction of datasets lead to differences in the magnitude of temperature trends during the hiatus period. Further complicating the picture, the trends simulated by the CMIP5 models during the hiatus period show a large spread compared to the observed trends.



In order to know whether the CMIP5 model and observation differences represent flaws in the models we need to understand whether we really are comparing apples to apples. A set of essential corrections to the observational datasets were identified: Updated solar forcing, updated volcanic forcing and correction for areas of missing data. These corrections showed a global mean temperature that did not show a hiatus during the given time period and closer match with the model estimate.

Unlike changes due to forcing, the models would not necessarily reproduce changes due to internal variability of the climate during the same periods that those changes occurred in the observational record. For example, if the Pacific Decadal Oscillation were leading to colder sea surface temperatures during the observed period, the models would not necessarily have a similar PDO pattern during this time period. Instead, you can find similar events, called variability analogues, in a control run in the model to understand how the models would respond if they had been in the same phase of the PDO during the observed period.