

Simulation of Ocean, Atmosphere and Climate (**SOAC**), NS-MO501M - 2021

A course given by **Michiel Baatsen** (projects) &
Aarnout van Delden (elementary numerical methods and exercises)

Today (Tuesday, 7 Sep. 2021,
13:15-15:00, Room 001, Buys Ballot Gebouw)

Now: Lecture 0
Introduction to the course

Next: Lecture 1
Canonical equation of Geophysical Fluid Dynamics
Introduction to exercise 1

See:

https://osiris.uu.nl/osiris_student_uuprd/OnderwijsCatalogusSelect.do?selectie=cursus&cursus=NS-MO501M&collegejaar=2021&taal=en

<http://www.staff.science.uu.nl/~delde102/SOAC.htm>

Lecture 0 SOAC

Introduction to the course

Content

philosophy of simulation

Grading

Programming languages

Computers

Literature

Use and misuse of simulation

Schedule

Content of SOAC 2021

Simulation is an important component of research and practice in Climate Physics. Think, for example, of numerical weather prediction and the making of climate projections.

This course will give you a flavour of what it means to **simulate** the ocean, atmosphere and climate.

The **programming language in this course is Python.** Python is a very versatile computer language.

SOAC is a very practical course!
It does not follow a particular book.

You learn by “doing”.

Content of SOAC 2021

See the schedule of the course at the end of this lecture



Part 1

The **first part of the course** consists of **five lectures**, given in weeks 36 and 37, starting on **Tuesday 7 September 2021 at 13:15 in room 001 BBG**. These five lectures introduce numerical methods to solve the canonical equations of Geophysical Fluid Dynamics, in particular the *advection equation* and the *shallow water equations*. **Three exercises** are introduced, which count for 30% of the grade.

Hand in before or on

The **answers** can be handed in in **groups of up to 3 persons**.

Exercise 1: Thursday 16 September 2021
Exercises 2 and 3: Monday 4 October 2021

Exercise 1 consists of simulating inertial oscillations and determining the accuracy of numerical approximations to the time-derivative.

Exercise 2 consists of simulating the advection of a passive scalar, testing the accuracy of different numerical methods (grid-point and spectral) to the linear advection equation.

Exercise 3 consists of simulating gravity wave propagation in shallow water using staggered and non-staggered grids.

Part 2

The **second part of the course** consists of executing a small research project in couples and presenting the results, both orally and in a written report.

The philosophy of simulation

SOAC addresses 14 aspects of simulation listed below

- 1) Simulation allows you to **study a phenomenon that is not understood yet**
- 2) Begin by formulating a **hypothesis** based on (qualitative) theory
- 3) What is the **theory** (physics, chemistry, biology)?
- 4) What are the **equations** and boundary conditions (mathematics)?
- 5) Introduce **numerical approximations** to the equations
- 6) Define the domain of solution
- 7) Specify boundary conditions, e.g. the **initial state (data assimilation)**
- 8) Write a **computer program**
- 9) **Test the model** (comparing with an analytical solution, *if it exists*)
- 10) Devise and perform **experiments**
- 11) Decide what **output** you need?
- 12) **Verify** (compare with observations)
- 13) **Analyse** and **interpret** the results (statistics)
- 14) **Visualise** (animate) the results

Grading and deadlines of SOAC 2021

The **concise answers to the three exercises** must be handed in before or on a prefixed deadline-date.

Exceptions are possible for those that want to spread the work over two periods, but please make arrangements for this with the teachers.

The *three exercises* determine 30% of the final grade

The **second part of the course** consists of a **bigger project** (70%), performed by couples, supervised by an IMAU staff-member. The topics will be introduced by Michiel Baatsen on Tuesday, 14 September 2021, 13:15-...

You must write a concise **report** and give an oral **presentation** on this project.

Programming languages used in Climate science

Fortran:

High performance computing. Most climate models written in Fortran.

C/C++:

High performance computing. Favourite of Theoretical Physics.

Pascal:

“Dead”. Very popular in the 1980’s and 1990’s.

MATLAB:

Graphics and “toy” models. Very popular after 2000, superceded by...

Python (<https://www.python.org>):

Python has evolved in the the 1990’s in Amsterdam (by Guido van Rossum) out of the “ABC programming language”. Sophisticated graphics packages were added later, notably “Matplotlib” (by John Hunter).

Python is used to devise “toy” models and for “big data”-analysis

R (<https://www.r-project.org>): data-analysis and statistics**Julia** (<https://julialang.org>): relatively new (2009) language. Faster than Python

...

Advantages of Python

Advantages of Python over other programming languages:

- 1) Python code is more **compact and readable** than FORTRAN-code (or C-code or Matlab-code)
- 2) The Python world is big, **free** and open
- 3) Python offers a wide choice in **very good graphics** packages

Disadvantage

- 1) Python scripts do **not always run very efficiently**, except if you extensively use libraries (modules), such as *numpy*, which are written in C. Computationally intensive models must be programmed in C or FORTRAN. (however, evaluation and interpretation of model output cannot be done easily in C or FORTRAN).

Python

My digital toolbox: Climate scientist Damien Irving on Python libraries

Preset software packages in Python allow for custom scientific analysis.

<http://www.nature.com/news/my-digital-toolbox-climate-scientist-damien-irving-on-python-libraries-1.16805>

<https://www.python.org/>

<http://www.numpy.org/>

<http://matplotlib.org/index.html>

<http://www.johnny-lin.com/pyintro/>

<http://www.nature.com/news/programming-pick-up-python-1.16833#/related-links>

NATURE | TOOLBOX



Programming: Pick up Python

A powerful programming language with huge community support.

Jeffrey M. Perkel

04 February 2015



PDF



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Illustration by the Project Twins

Computers

<https://en.wikipedia.org/wiki/TOP500>

Top 10 positions of the 57th TOP500 in June 2021^[32]^[needs update]

Rank (previous)	Rmax Rpeak (PFLOPS)	Name	Model	CPU cores	Accelerator (e.g. GPU) cores	Interconnect	Manufacturer	Site country	Year	Operating system
1	442.010 537.212	Fugaku	Supercomputer Fugaku	158,976 × 48 A64FX @2.2 GHz	0	Tofu interconnect D	Fujitsu	RIKEN Center for Computational Science Japan	2020	Linux (RHEL)
2▼ (1)	148.600 200.795	Summit	IBM Power System AC922	9,216 × 22 POWER9 @3.07 GHz	27,648 × 80 Tesla V100	InfiniBand EDR	IBM	Oak Ridge National Laboratory United States	2018	Linux (RHEL)
3▼ (2)	94.640 125.712	Sierra	IBM Power System S922LC	8,640 × 22 POWER9 @3.1 GHz	17,280 × 80 Tesla V100	InfiniBand EDR	IBM	Lawrence Livermore National Laboratory United States	2018	Linux (RHEL)
4▼ (3)	93.015 125.436	Sunway TaihuLight	Sunway MPP	40,960 × 260 SW26010 @1.45 GHz	0	Sunway ^[33]	NRCPC	National Supercomputing Center in Wuxi China ^[33]	2016	Linux (Raise)
5▲ (new)	64.590 89.795	Perlmutter	HP	? × 64 Epyc 7763 @2.45 GHz	? × 108 Ampere A100	Slingshot-10	Nvidia	NERSC United States	2021	Linux (Cray Linux Environment)
6▼ (5)	63.460 79.215	Selene	Nvidia	1,120 × 64 Epyc 7742 @2.25 GHz	4,480 × 108 Ampere A100	Mellanox HDR Infiniband	Nvidia	Nvidia United States	2020	Linux (Ubuntu)
7▼ (6)	61.445 100.679	Tianhe-2A	TH-IVB-FEP	35,584 × 12 Xeon E5-2692 v2 @2.2 GHz	35,584 × 128 Matrix-2000 ^[34]	TH Express-2	NUDT	National Supercomputer Center in Guangzhou China	2013	Linux (Kylin)
8▼ (7)	44.120 70.980	JUWELS (booster module) ^{[35][36]}	BullSequana XH2000	1,872 × 24 AMD Epyc 7402 @2.8 GHz	3,744 × 108 Ampere A100	Mellanox HDR Infiniband	ATOS	Forschungszentrum Jülich Germany	2020	Linux (CentOS)
9▼ (8)	35.450 51.721	HPC5	Dell	3,640 × 24 Xeon Gold 6252 @2.1 GHz	7,280 × 80 Tesla V100	Mellanox HDR Infiniband	Dell EMC	Eni Italy	2020	Linux (CentOS)
10▼ (9)	23.516 38.746	Frontera	Dell C6420	16,016 × 28 Xeon Platinum 8280 @2.7 GHz (subsystems with e.g. POWER9 CPUs and Nvidia GPUs were added after official benchmarking ^[10])	0	InfiniBand HDR	Dell EMC	Texas Advanced Computing Center United States	2019	Linux (CentOS)

?? October: Expert presentation on **Computer Hardware** by Michael Kliphuis (IMAU)

Information and literature

Information:

- **Blackboard**

Recommended books and lecture notes:

Benoit Cushman-Roisin, Jean-Marie Beckers, 2011: **Introduction to Geophysical Fluid Dynamics - Physical and Numerical Aspects**. 2nd Edition, Academic Press (chapters 5 & 6)

Dale R. Durran, 2010: **Numerical Methods for Fluid Dynamics – With applications to geophysics**, 2nd Edition, Springer

Thomas Stocker, 2011: **Introduction to Climate Modelling**. Springer. 179 pp. This book is available as e-book from the University Library.

Rudy Slingerland and Lee Kump, 2011: **Mathematical Modelling of Earth's Dynamical Systems**. Princeton University Press.

Roger K. Smith and Wolfgang Ulrich, 2008: **Lectures on Numerical Meteorology**.

<https://www.meteo.physik.uni-muenchen.de/~roger/manuskripte/NumericalMeteorology.pdf> .

Use and misuse of simulation

1) **Weather prediction** (very useful)

Expert presentation on **Numerical weather prediction** by Sander Tijm (KNMI)

2) **Climate prediction** (useful, but not in accord with rules of science...)*

Expert presentation on **Climate models** by Leo van Kampenhout (IMAU)

3) As a **tool to increase our understanding** of the atmosphere, ocean and climate, which are very complex non-linear systems (very useful if applied with intelligence)

*Roger Pielke (2012):

<https://pielkeclimatesci.wordpress.com/2012/02/20/the-misuse-of-the-scientific-method-a-nature-geosciences-article-changes-in-hail-and-flood-risk-in-high-resolution-simulations-over-colorado-mountains-by-mahoney-et-al-2012/>

Recently, there were two articles in Nature Geosciences which concluded, based on multi-decadal climate model predictions, that there would not be hail in Colorado by the end of the current century. This study illustrates the misuse of the scientific method where a top-down multi-decadal climate prediction, which has shown no skill at predicting changes in hail statistics in hindcasts, is used to make forecasts decades from now.

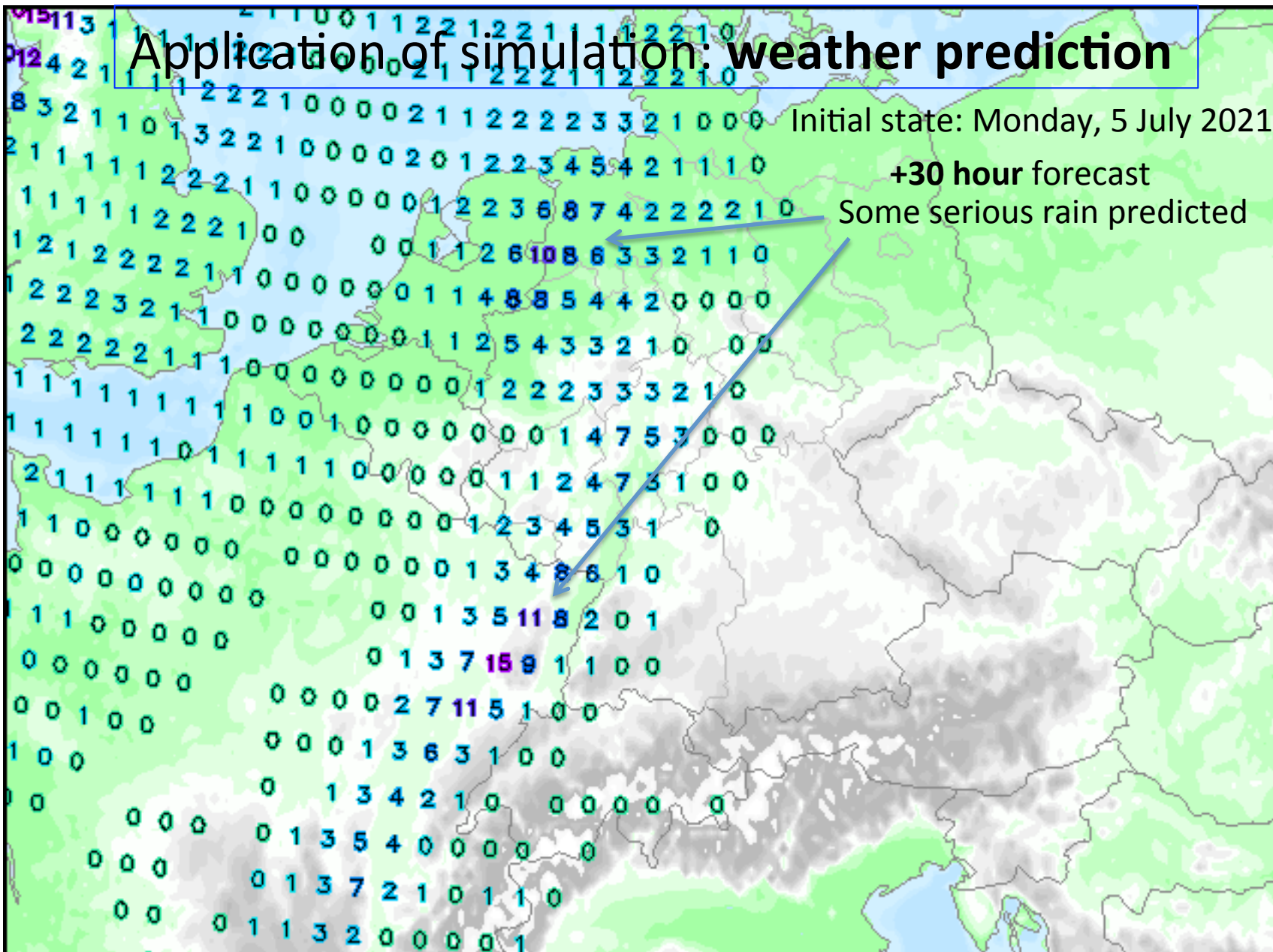
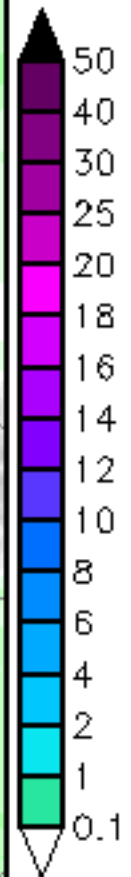
Yet Nature Climate Change elected to publish such an untested paper. This research is another example of the epidemic of papers that purport to be science but are actually just exercises with the models. Nature Climate Change, instead of presenting sound scientific research, apparently publishes anything that promotes their particular agenda in climate science.

Application of simulation: weather prediction

Initial state: Monday, 5 July 2021, 06 UTC

+30 hour forecast

Some serious rain predicted



6- stündiger Niederschlag bis Dienstag 12 UTC [mm]

Dienstag, 06-07-2021 12 UTC

(GFS 0.5°) (Montag 06 + 30)

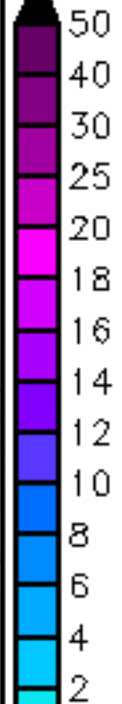
© www.wetter3.de

Application of simulation: weather prediction

Initial state: Tuesday, 6 July 2021, 06 UTC

+6 hour forecast

Some serious rain predicted



lecture by an expert in the field of “Numerical Weather Prediction” (**Sander Tijm, KNMI**)

Comparing successive forecasts for same time is a “poor-mans ensemble forecasting”

3- stündiger Niederschlag bis Dienstag 12 UTC [mm]

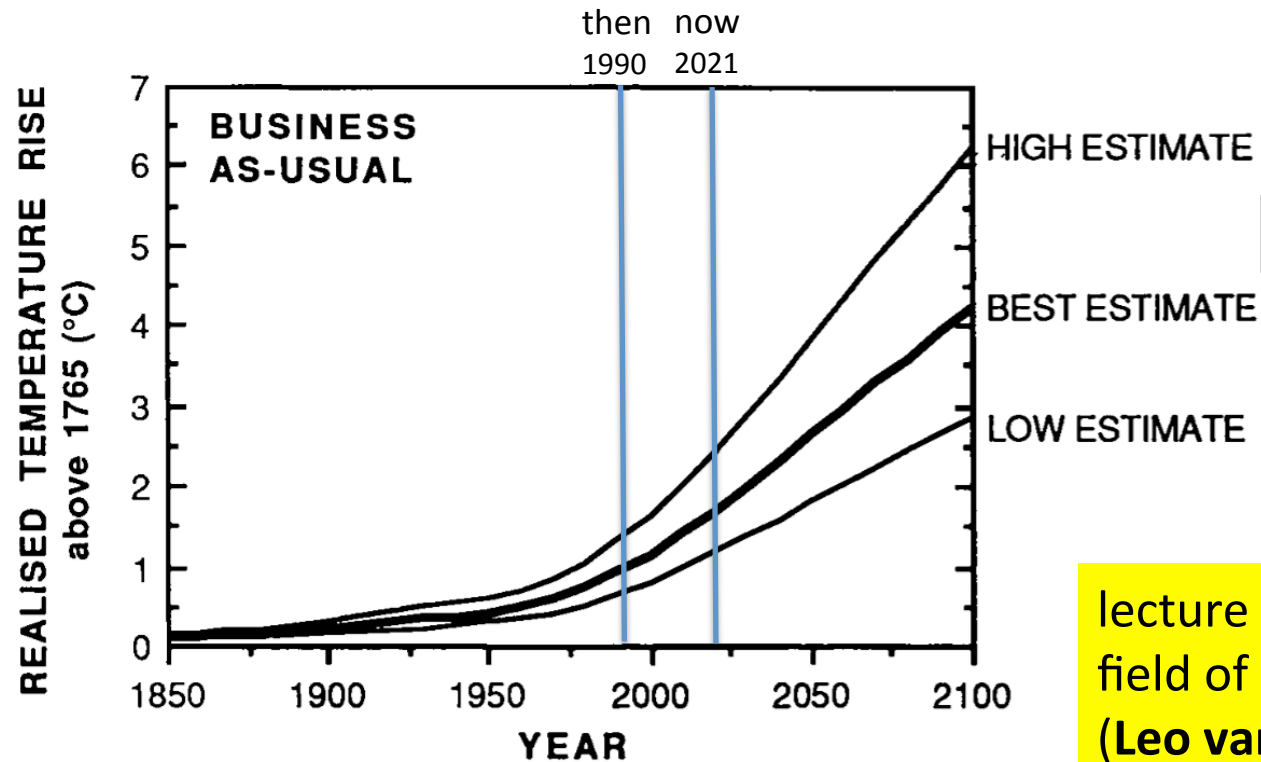
Dienstag, 06-07-2021 12 UTC

(GFS 0.5°) (Dienstag 06 + 06)

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Climate prediction: useful

Prediction of **global average temperature** until 2100. From IPCC-report of 1991



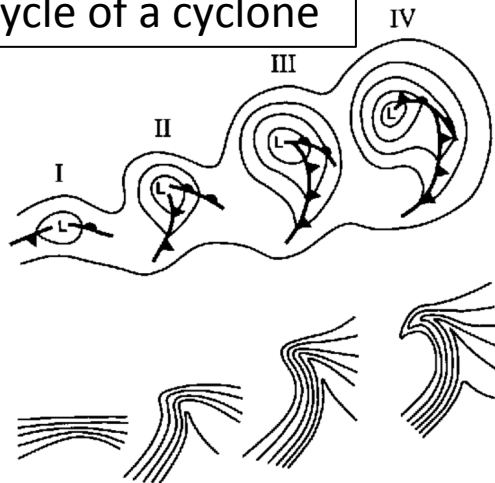
Is this interesting science ?

lecture by an expert in the field of "Climate models"
(Leo van Kampenhout)

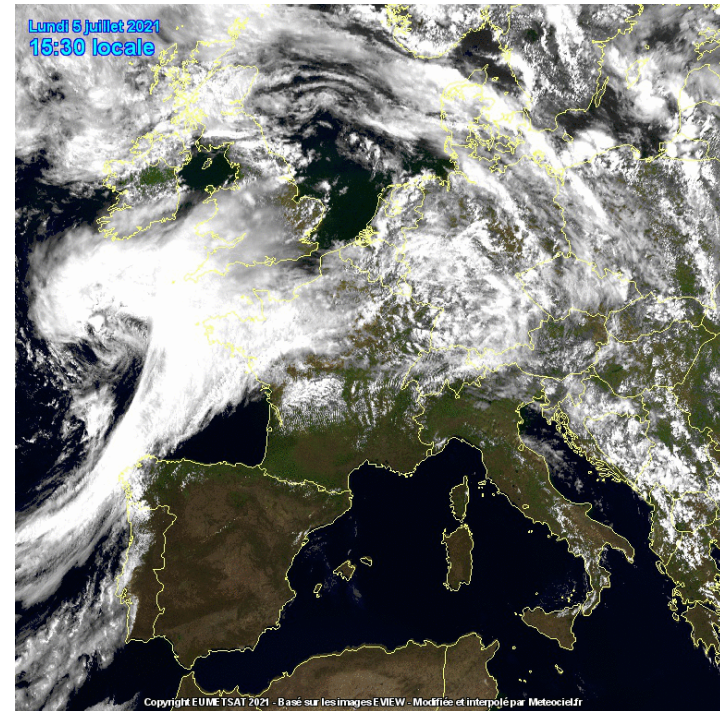
Figure 8: Simulation of the increase in global mean temperature from 1850-1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the Business-as-Usual emissions

Tool to increase our understanding of the atmosphere, ocean and climate (very useful if applied with intelligence)

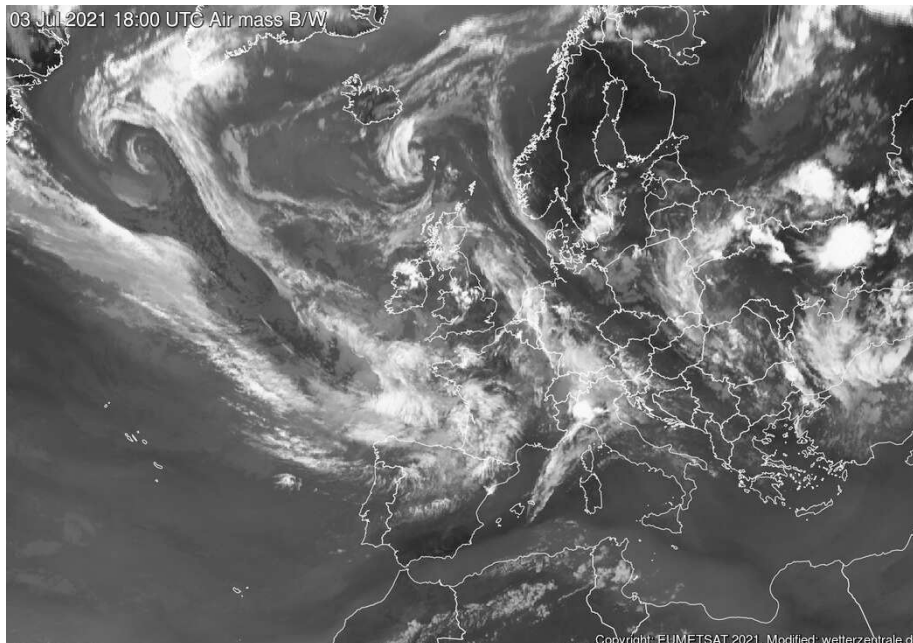
Norwegian model (1919)
of the life-cycle of a cyclone



Satellite image of clouds associated with
cyclo-genesis west of Brittany



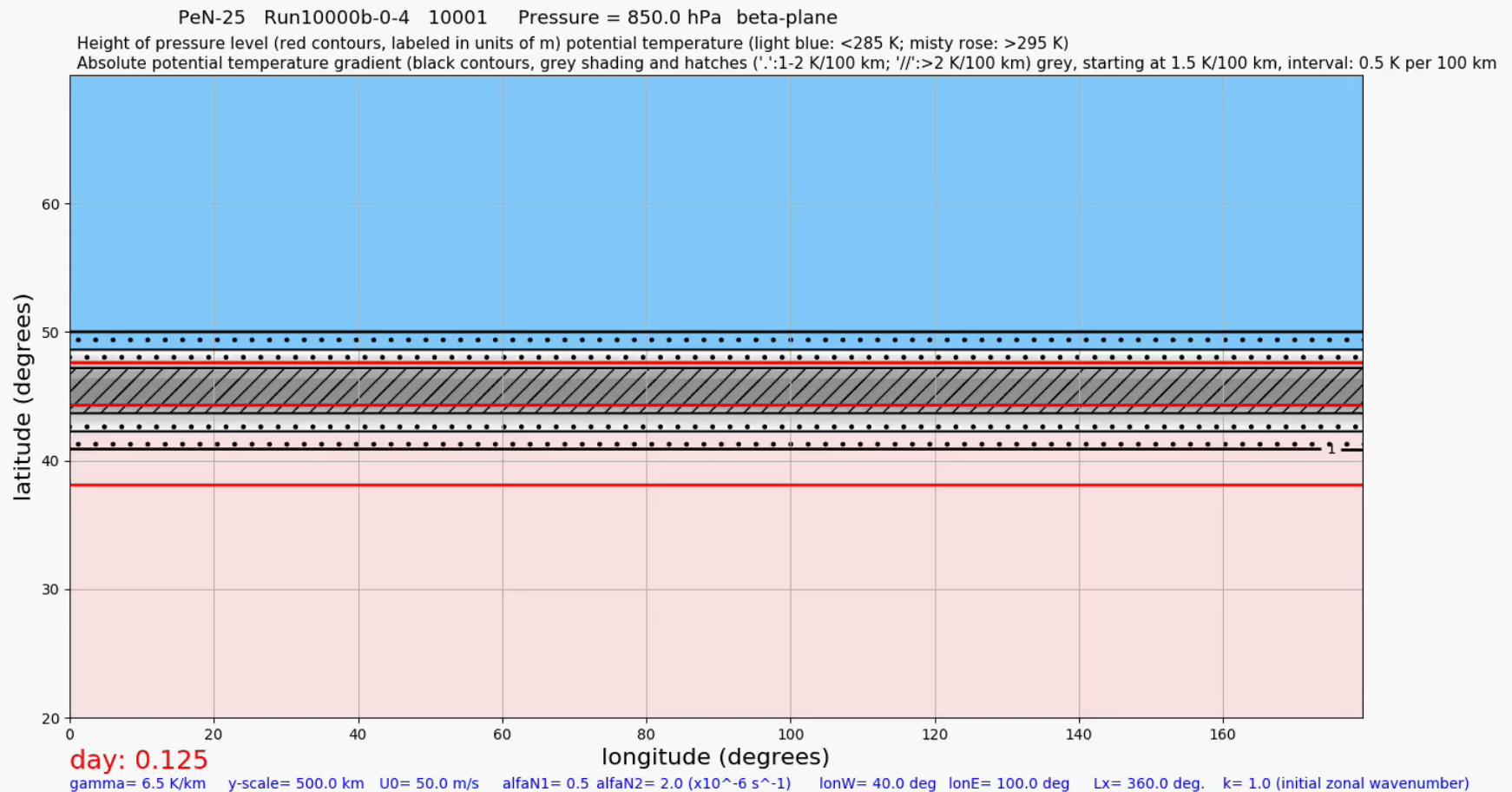
MeteoSat image (VIS) of 5 July 2021



Animation of cyclogenesis on 5 July 2021
(webpace.science.uu.nl/~delde102/Cyclogenesis05072021.mov)

Simulation of baroclinic instability of a zonal front with a 25 level primitive equation hydrostatic model (animation)

Potential temperature(-gradient) and height at 850 hPa



Schedule of the course Simulation of Oceans, Atmosphere and Climate 2021

version of 7 September 2021

Tuesday, 7 September 2021, (week 36), 13:15-15:00 (BBG 001):

13:15-14:00: **Lecture 0:** Introduction, describing the structure and plan of the course.

14:15-15:00: **Lecture 1:** Canonical equations of geophysical fluid dynamics. Analytical and numerical solutions of simplified equations describing inertial oscillations.

Thursday, 9 September 2021, 9:00-12:00 (BBG 001):

9:00-10:45: **Lecture 2:** Multi-step time-differencing.

Exercises 1: simulation of inertial oscillations (hand in on 16 Sep. 2021)

Numerical approximation of the (linear) advection equation: numerical diffusion & numerical dispersion.

11:00-12:00: **Tutorial**

Monday 13 September 2021 (week 37), 13:15-15:00 (MIN 016):

13:15-15:00: **Lecture 3:** Numerical stability (CFL-condition). Lax-Wendroff scheme and spectral method.

Exercises 2: simulation of the linear advection of a passive scalar (hand in on 7 Oct. 2021)

Tuesday, 14 September 2021, 13:15-15:00 (BBG 001):

13:15-15:00: **Lecture 4:** Non-linear advection equation. Pseudo-spectral method. Pole problem. Solution of the linear shallow water equations. Numerical accuracy of simulation of gravity wave propagation. Staggered grid, Aliasing.

Exercises 3: simulation of propagating gravity waves (hand in on 7 Oct. 2021)

Thursday, 16 September 2021, 9:00-10:45 (BBG 219):

9:00-9:45: **Lecture by an expert.** Erik van Sebille (IMAU): *Keeping track of model code: Model Version Control*

10:00-10:45: **Tutorial**

Tuesday, 21 September 2021, 15:15-17:00 (BBG 219):

13:15-15:00: **Introduction to the SOAC-projects** (Michiel Baatsen)

Monday, 8 November 2021 (week 45), 13:15-17:00 (Room ???).

Oral presentations of project (hand in written report at the end of week 45)

Week 5 of 2022:

There will be an additional session of project presentations at the end of period 2 for those who cannot finish in one period.

In weeks 40-44: **Invited talks by experts in the field**

Leo van Kampenhout (IMAU): *Climate Models – 4 October 2021, 13:15 (MIN 016)*

Michael Kliphuis (IMAU): *Computer hardware – ?*

Sander Tijm (KNMI): *Numerical weather forecasting – ?*