In this lecture we will give you a brief history of ECMWF and present the main areas of NWP research that is currently being carried out in the centre. We then look at current research challenges and present some of the latest developments that will soon become operational.

By the end of the lecture you should be able to:

- List the main research areas at ECMWF and describe the latest model developments.

Erland Källén, Sarah Keoley

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.15</td>
<td>In this lecture we will give you a brief history of ECMWF and present the main areas of NWP research that is currently being carried out in the centre. We then look at current research challenges and present some of the latest developments that will soon become operational.</td>
<td>Mike Fisher</td>
</tr>
</tbody>
</table>
The aim of these sessions is to understand the role of land surface data assimilation on medium range weather forecasts.

We will give an overview of the different approaches used to assimilate land surface data and to initialise model data assimilation structure within ECMWF system.

By the end of the session you should be able to:

- identify the different observations used for snow and soil moisture data assimilation
- define land surface data assimilation approaches used for NWP
- describe the role of land surface data assimilation on medium-range weather forecasts

Patricia de Rosnay
The aim of this session is to present an overview of the current observing systems used in Numerical Weather Prediction. We will discuss our observational requirement, and how close the current observing system is to meeting our needs. We will also discuss areas where our requirements are evolving. We will learn about WMO's OSCAR database that describes the Global Observing System. We will learn how the large diversity of observations now available, are monitored to ensure only good observations are presented to an operational system.

By the end of the session you should be able to:

- be able to describe the main types of observations used in data assimilation for Numerical Weather Prediction;
- be aware of how large volumes of observations are exchanged, implemented and monitored in operational systems;
- be aware of WMO's OSCAR database, how to access it and what type of information it can provide.

Steve English

The background error is central to the performance of the analysis system and tells how much confidence to put in the best available forecast which is to be updated with new observations. The lecture will review how background errors are estimated and represented for current variational algorithms.

Elias Holm

BGErr_lecture_2016.ppt

GlobalObservingSystem.pptx
In this lecture the variational bias correction scheme (VarBC) as used at ECMWF is explained. VarBC replaced the tedious job of estimating observation bias off-line for each satellite instrument or in-situ network by an automatic self-adaptive system. This is achieved by making the bias estimation an integral part of the ECMWF variational data assimilation system, where now both the initial model state and observation bias estimates are updated simultaneously.

By the end of the session you should be able to realize that:
- many observations are biased, and that the characteristics of bias varies widely between types of instruments
- separation between model bias and observation bias is often difficult
- the success of an adaptive system implicitly relies on a redundancy in the underlying observing system.
The aim of these sessions is to understand the role of land surface data assimilation on medium range weather forecasts.

We will give an overview of the different approaches used to assimilate land surface data and to initialise model variables in NWP. We will present the current observing systems and describe the land data assimilation structure within ECMWF system.

By the end of the session you should be able to:

- Identify the different observations used for snow and soil moisture data assimilation
- Define land surface data assimilation approaches used for NWP
- Describe the role of land surface data assimilation on medium-range weather forecasts

A single observation can under some conditions undermine the quality of a global analyses. The lecture will go through methods used to make the analysis more robust against outlier or wrong observations, with focus on variational quality control.

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30-10:45</td>
<td>Meet the students</td>
<td>The infrared spectrum-measurement, modelling and information content Tony McNally SAT_TC_The_IR_spectrum_TM.ppt</td>
<td>GPS Radio Occillation: Extended applications Sean Healy gpsro_lecture2_2016_nwpsaf.ppt</td>
<td>Observation errors for satellite data assimilation Niels Bormann ObsErrors_2016.ppt</td>
<td>Satellites for environmental monitoring and forecasting Richard Engelen NWP_SAF_Engelen.ppt</td>
</tr>
<tr>
<td>14:00-15:15</td>
<td>Theoretical background (2) Data assimilation algorithms, Key elements and inputs Tony McNally SAT_TC_Data_assimilation_key_elements_TM.ppt</td>
<td>Satellite information on the ocean surface (SCAT) Giovanna De Chiara training_course_2016_GDC_no_notes.ppt</td>
<td>The detection and assimilation of clouds and rain in microwave radiances Alan Geer sat_microwave_2016_2.ppt</td>
<td>Satellite information on the land surface Patricia de Rosnay Land_satellite_NWP_SAF.ppt</td>
<td>Current satellite observing network and its future evolution Stephen English CurrentAndFutureSatellite.ppt</td>
</tr>
<tr>
<td>15:45-17:00</td>
<td>The microwave spectrum, measurement, modelling and information content Alan Geer sat_microwave_2016_1.ppt</td>
<td>A Practical guide to IR and MW radiative transfer – using the RTTOV model and GUI James Hocking (UK Met Office) SAT_RT_modelling_lecture_JAH.ppt SAT_RT_modelling_practical_JAH.ppt</td>
<td>Wind information from satellites (Atmospheric Motion Vectors) Katie Lean 1DVar theory, simulator + practical session on background and observation errors Tony McNally SAT_TC_1DVAR_practical.ppt</td>
<td>Question and answer session, course evaluation</td>
<td></td>
</tr>
</tbody>
</table>
The goal of this session is to provide an overview of the use of generalised curvilinear coordinates in atmospheric numerical models.

By the end of the session you should be able to:
- describe some important aspects of the formulation and implementation of the governing equations in generalised coordinates
- describe various vertical coordinates employed in atmospheric models
- indicate the use of generalised coordinates to employ moving mesh adaptivity

Christian Kühnlein

During this presentation, we will discuss two of the questions faced by numerical weather prediction scientists as forecast models reach horizontal resolutions of 6 to 2 km:
- Do we need to abandon the primitive equations for a non-hydrostatic system of equations?
- Do we still need a deep convection parametrisation?
and we will show what answers to these questions are given by very high resolution simulations of the IFS.

By the end of the presentation, you should be able to:
- discuss the limits of the hydrostatic approximation for numerical weather prediction
- explain the dilemma of parametrizing deep convection versus permitting explicit deep convection at resolution in the grey zone of convection

Sylvie Malardel

The aim of this lecture is to systematically build theoretical foundations for Numerical Weather Prediction at nonhydrostatic resolutions. In the first part of the lecture, we will discuss a suite of all-scale nonhydrostatic PDEs, including the anelastic, the pseudo-incompressible and the fully compressible Euler equations of atmospheric dynamics. First we will introduce the three sets of nonhydrostatic governing equations written in a physically intuitive Cartesian vector form, in abstraction from the model geometry and the coordinate frame adopted. Then, we will combine the three sets into a single set recast in a form of the conservation laws consistent with the problem geometry and the unified solution procedure. In the second part of the lecture, we will build and document the common numerical algorithm for integrating the generalised set of the governing PDEs put forward in the first part of the lecture. Then, we will compare soundproof and compressible solutions and demonstrate the efficacy of this unified numerical framework for nes idealised flow problems relevant to weather and climate.

By the end of the lecture you should be able to:
- explain the form, properties and role of alternative systems of nonhydrostatic PDEs for all scale atmospheric dynamics;
- explain the importance and key aspects of continuous mappings employed in all-scale atmospheric models;
- explain the difference between the explicit and semi-implicit algorithms for integrating nonhydrostatic PDEs, the importance of consistent numerical approximations, and the fundamental role of transport and elliptic solvers.

Piotr Smolarkiewicz

Willem Deconinck

The aim of this session is to learn about recent developments in discontinuous higher order spatial discretization methods, such as the Discontinuous Galerkin method (DG), and the Spectral Difference method (SD). These methods are of interest because they can be used on unstructured meshes and facilitate optimal parallel efficiency. We will present an overview of higher order grid point methods for discretizing partial differential equations (PDE's) with compact stencil support, and illustrate a practical implementation.

By the end of the session you should be able to:
- list what are the advantages offered by discontinuous higher order methods
- describe how to solve PDE's with discontinuous methods
- identify the key elements that contribute to a PDE solver
<table>
<thead>
<tr>
<th>Time</th>
<th>Session Title</th>
<th>Presenter(s)</th>
<th>Notes</th>
</tr>
</thead>
</table>
| 10:35 | Using the 30-year history of ECMWF’s Integrated Forecasting System (IFS) as an example, this lecture is an introduction to the development and current state-of-the-art of global numerical weather prediction (NWP), as well as to the challenges faced in the future. It is intended to provide an overview and context for the topics covered in more detail during the course. By the end of the session you should be able to:  
  - describe some important aspects of the formulation and implementation of the governing equations in generalised coordinates  
  - describe various vertical coordinates employed in atmospheric models  
  - indicate the use of generalised coordinates to employ moving mesh adaptivity | Christian Kühnlein | Nils Wedi, Lecture 1_wedi.pptx |
|       | Practical Session                                                             | Willem Deconinck, Christian Kühnlein                                           |       |
|       | The aim of this session is to provide an overview of the use of generalised curvilinear coordinates in atmospheric numerical models. By the end of the session you should be able to:  
  - explain the form, properties and role of alternative systems of nonhydrostatic PDEs for all scale atmospheric dynamics  
  - explain the importance and key aspects of continuous mappings employed in all scale atmospheric models  
  - explain the difference between the explicit and semi-implicit algorithms for integrating nonhydrostatic PDEs, the importance of consistent numerical approximations, and the fundamental role of transport and elliptic solvers | Piotr Smolarkiewicz | Willem Deconinck |
|       | The aim of the lecture is to systematically build theoretical foundations for Numerical Weather Prediction at nonhydrostatic resolutions. In the first part of the lecture, we will discuss a suite of all-scale nonhydrostatic PDEs, including the anelastic, the pseudo-incompressible and the fully compressible Euler equations of atmospheric dynamics. First we will introduce the three sets of nonhydrostatic governing equations written in a physically intuitive Cartesian vector form, in abstraction from the model geometry and the coordinate frame adopted. Then, we will combine the three sets into a single set recast in a form of the conservation laws consistent with the problem geometry and the unified solution procedure. In the second part of the lecture, we will build and document the common numerical algorithm for integrating the generalised set of the governing PDEs put forward in the first part of the lecture. Then, we will compare soundproof and compressible solutions and demonstrate the efficacy of this unified numerical framework for two idealised flow problems relevant to weather and climate. By the end of the lecture you should be able to:  
  - explain the form, properties and role of alternative systems of nonhydrostatic PDEs for all scale atmospheric dynamics  
  - explain the importance and key aspects of continuous mappings employed in all scale atmospheric models  
  - explain the difference between the explicit and semi-implicit algorithms for integrating nonhydrostatic PDEs, the importance of consistent numerical approximations, and the fundamental role of transport and elliptic solvers | Christian Kühnlein | kuehnlein_EC_TC2016_W.pdf |
|       | The aim of this session is to learn about recent developments in discontinuous higher order spatial discretization methods, such as the Discontinuous Galerkin method (DG), and the Spectral Difference method (SD). These methods are of interest because they can be used on unstructured meshes and facilitate optimal parallel efficiency. We will present an overview of higher order grid point methods for discretizing partial differential equations (PDE’s) with compact stencil support, and illustrate a practical implementation. By the end of the session you should be able to:  
  - explain what are the advantages offered by discontinuous higher order methods  
  - describe how to solve PDEs with discontinuous methods  
  - identify the key elements that contribute to a PDE solver | Willem Deconinck | |
The success of the spectral transform method in global NWP in comparison to alternative methods has been overwhelming, with many operational forecast centres (including ECMWF) having made the spectral transform their method of choice. The lecture will introduce the basic elements of the spectral transform, explain why it has been successful and describe recent developments such as the fast Legendre transform.

By the end of the session you should be able to:

- explain in what the spectral transform method is, how it is applied, and describe the latest developments at ECMWF
- give reasons why it is successful for global NWP and climate
- identify potential disadvantages of the method

Jean Bidlot
Advance numerical method for earth modeling_Jean_Bidlot.pptx

Recently, there is an increasing interest in trying to understand the properties of coupled atmosphere, ocean-wave, ocean/sea-ice models with an ultimate goal to start predicting weather, waves and ocean circulation on time scales ranging from the medium-range to seasonal timescale. Such a coupled system not only requires the development of an efficient coupled forecasting system but also the development of a data assimilation component.

During the two lectures I will briefly describe the components of the coupled system, it will be made plausible that ocean waves are an essential element of such a coupled system as through the wave action, momentum and heat are transferred from atmosphere to ocean. Also, the sea state determines to a considerable extent the efficiency with which momentum is transferred from atmosphere to waves, while ocean waves also play a decisive role in the evolution of the sea-ice edge. Results showing the importance of ocean waves on upper-ocean mixing and on atmospheric circulation are discussed as well, while I will finish the lectures by presenting preliminary results from coupled data assimilation experiments.

By the end of this session, the student will be able to:

- discuss the impact of ocean waves on the coupled system
- describe the different wave processes that are modelled in the ECMWF system
- describe the impact of ocean circulation on the atmosphere

George Mozdzynski
Massively Parallel Computing.pdf

The aim of this session is to understand the main issues and challenges in parallel computing, and how parallel computers are programmed today.

By the end of this session you should be able to:

- explain the difference between shared and distributed memory
- describe the key architectural features of a supercomputer
- describe the purpose of OpenMP and MPI on today’s supercomputers
- identify the reasons for the use of accelerator technology

Massively_Parallel_Co.pdf
The aim of this session is to introduce the basis of finite volume and continuous finite element discretisations and relate them to corresponding data structures and mesh generation techniques. The main focus will be on unstructured meshes and their application to global and local atmospheric models. Flexibility, communication overheads, memory requirements and user-friendliness of such meshes will be contrasted with those of structured meshes. The most commonly used mesh generation techniques will be highlighted, together with mesh manipulation techniques employed in mesh adaption approaches and will be followed by a discussion of alternative geometrical representations of orography. An example of unstructured meshes’ implementation to non-hydrostatic and hydrostatic atmospheric solvers will provide an illustration of their potential and challenges.

By the end of the lecture you should be able to:
- understand applicability, advantages and disadvantages of selected mesh generation techniques for a given type of application.
- appreciate importance of data structures in relation to atmospheric models and mesh generation.
- gain awareness of issues related to flexible mesh generation and adaption.

Joanna Szmelter
2016.ppt2016.ppt
During this presentation, we will discuss two of the questions faced by numerical weather prediction scientists as forecast models reach horizontal resolutions of 6 to 2 km:

- Do we need to abandon the primitive equations for a non-hydrostatic system of equations?
- Do we still need a deep convection parametrisation?
- and we will show what answers to these questions are given by very high resolution simulations of the IFS.

By the end of the presentation, you should be able to:

- discuss the limits of the hydrostatic approximation for numerical weather prediction
- explain the dilemma of parametrizing deep convection versus permitting explicit deep convection at resolution in the grey zone of convection

The aim of two lectures is to introduce basis of finite volume and continuous finite element discretisations and relate them to corresponding data structures and mesh generation techniques. The main focus will be on unstructured meshes and their application to global and local atmospheric models. Flexibility, communication overheads, memory requirements and user friendliness of such meshes will be contrasted with those of structured meshes. The most commonly used mesh generation techniques will be highlighted, together with mesh manipulation techniques employed in mesh adaption approaches and will be followed by a discussion of alternative geometrical representations of orography. An example of unstructured meshes’ implementation to non-hydrostatic and hydrostatic atmospheric solvers will provide an illustration of their potential and challenges.

By the end of the lecture you should be able to:

- understand applicability, advantages and disadvantages of selected mesh generation techniques for a given type of application.
- appreciate importance of data structures in relation to atmospheric models and mesh generation.
- gain awareness of issues related to flexible mesh generation and adaption.

Sarah Keeley and Erland Källén
ECMWF-Past-FutureNM_2016_EK.pptx
The aim of this session is to describe alternative (to the semi-Lagrangian) numerical techniques for integrating the transport equation sets encountered in NWP models. We will present an overview of different Eulerian time-stepping techniques and discuss the advantages and disadvantages of each approach.

By the end of the session you should be able to:

- recognize the basic differences between semi-Lagrangian and Eulerian approaches
- describe the strengths and weaknesses of different time-stepping approaches such as split-explicit time-stepping, Runge-Kutta time-stepping
- describe the basic features of different time-stepping schemes used in other weather forecasting models such as WRF, ICON
<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
</table>
| **Introduction to the course**  
Erland Källén / Students | This session describes the representation of subgrid-scale variability of humidity, cloud and precipitation and how this can be parametrized in atmospheric models.  
By the end of the session you should be able to:  
* recognise the reasons for representing the subgrid variability of humidity and cloud in an atmospheric model  
* explain how the key quantity of cloud fraction is related to subgrid heterogeneity assumptions  
* describe the different types of subgrid cloud parametrization schemes.  
Richard Forbes  
TC2016_Forbes_L2_cloud_colphases.pptx | This session will have two mains components:  
* An overview of the role of snow in the climate system from observations, models and forecasts.  
* Description of the current representation of snow in the ECMWF model, evaluation examples and ongoing developments.  
By the end of the session, the students should be able:  
* Identify the main processes associated with snow in the climate system  
* Describe the main components of the snow scheme in the ECMWF model  
Emanuel Dutra  
pa_surf_2_cold_20160518.pptx | By the end of the session, the students should be able:  
* relate flux and storage  
* recognise land surface predictors and land diagnostic quantities  
Gianpaolo Balsamo  
surf2.pptx | This three-hour lecture will start by explaining the role and main ingredients of data assimilation in general. The widely used framework of variational data assimilation will then be gradually introduced. The challenges associated with the necessary inclusion of physical parametrizations in the data assimilation process will be highlighted. The concept of adjoint model as well as the techniques to derive it will be introduced. The importance of the linearity constraint in 4D-Var and the methods to address it will be detailed. The set of linearized physical parametrizations used at ECMWF will then be briefly presented. Finally, various examples of the use of physical parametrizations in variational data assimilation and its impact on weather forecast quality will be given.  
By the end of the session, the students should be able:  
* to name the main ingredients of a data assimilation system.  
* to tell why physical parametrizations are needed in data assimilation.  
* to identify the role of the adjoint code in 4D-Var.  
* to recognize the importance of the regularization of the linearized code.  
Philippe Lopez  
TC_PA_lopez_2016_main.ppt |
This module aims to introduce the fundamentals of radiative transfer theory and its role within the global atmospheric circulation. The lectures will also cover the techniques of numerical modelling of the radiative transfer equations in global-circulation models with a particular focus on the code in use in the ECMWF Integrated Forecasting System.

By the end of the session students should be able to:

- Identify the key processes controlling the atmospheric radiative balance
- Recognize the role of the radiative transfer in the Earth energy balance
- Estimate the impact of changes in the radiative parameterizations on climate

Additional outcomes:

- Develop skills in data analysis and numerical modelling

Robin Hogan
hogan_ecmwf_radiation_lecture1.pptx

This module aims to introduce the fundamentals of radiative transfer theory and its role within the global atmospheric circulation. The lectures will also cover the techniques of numerical modelling of the radiative transfer equations in global-circulation models with a particular focus on the code in use in the ECMWF Integrated Forecasting System.

By the end of the session students should be able to:

- Identify the key processes controlling the atmospheric radiative balance
- Recognize the role of the radiative transfer in the Earth energy balance
- Estimate the impact of changes in the radiative parameterizations on climate

Additional outcomes:

- Develop skills in data analysis and numerical modelling

Robin Hogan
hogan_ecmwf_radiation_lecture2.pptx

Convection affects all atmospheric scales. Therefore, the convection session aims to provide a deeper understanding of the atmospheric general circulation and its interaction with convective heating and vertical transports. The notions and techniques acquired during the course should be useful for developers of convective parametrizations, forecasters and for analysing output from high-resolution convection resolving models.

By the end of the session you should become familiarised with:

- the interaction between the large-scale circulation and the convection including radiative-convective equilibrium and convectively-coupled large-scale waves
- the notion of convective adjustment and the mass flux concept in particular
- the basic concepts behind the ECMWF convection parametrization and some useful numerical tricks
- forecasting convection including convective systems and the diurnal cycle
- diagnose forecast errors related to convection.

Peter Bechtold
CONVECTION_T3_2016.ppt

This short lecture is an introduction to the questions of time splitting and process splitting in a numerical weather prediction model and to the problems resulting from the interaction of different numerical solvers inside the same model.

After this introduction, you should

- be fully aware that each parametrisation is only a small part of a much larger system, usually one term in the full system of equations which needs to be solved by the forecast model,
- remember, when working on your own parametrisation(s), that parametrisations are also subject to the constraints imposed by numerical analysis and algorithmic, as is the solver in the dynamical core.

Sylvie Malardel
PDC_2016.pdf
<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irina Sandu</td>
<td>pbl1_is_2016.pdf</td>
<td></td>
</tr>
<tr>
<td>Alessio Bozzo</td>
<td>Bozzo_Radiation_Lecture3.pptx</td>
<td></td>
</tr>
<tr>
<td>Peter Bechtold</td>
<td>CONVECTION_T2_2016.ppt</td>
<td></td>
</tr>
<tr>
<td>Irina Sandu</td>
<td>pbl1_is_2016.pdf</td>
<td></td>
</tr>
<tr>
<td>Richard Forbes</td>
<td>TC2016_Forbes_L1_cloud_4dvar.pptx</td>
<td></td>
</tr>
<tr>
<td>Richard Forbes</td>
<td>TC2016_Forbes_L3_cloud_subgrid.pptx</td>
<td></td>
</tr>
<tr>
<td>Philippe Lopez</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mike Ahligrimm</td>
<td>CldPblVeri2016.ppt</td>
<td></td>
</tr>
<tr>
<td>Anton Beljaars</td>
<td>subgrid_orography_2016.ppt</td>
<td></td>
</tr>
</tbody>
</table>

This session gives a theoretical introduction of the planetary boundary layer, including its definition, classification, notions about turbulence within the boundary layer, differences between clear and cloudy boundary layers, and equations used to describe the mean flow in a numerical model.

Expected outcomes:

- understand what is the boundary layer, its characteristics and why it is important to study it and represent it correctly in numerical models.
- understand the difference between the various boundary layer types.

This module aims to introduce the fundamentals of radiative transfer theory and its role within the global atmospheric circulation. The lectures will also cover the techniques of numerical modelling of the radiative transfer equations in global-circulation models with particular focus on the code in use in the ECMWF Integrated Forecasting System.

By the end of the session students should be able to:
- identify the key processes controlling the atmospheric radiative balance.
- recognize the role of the radiative transfer in the Earth energy balance.
- estimate the impact of changes in the radiative parameterizations on climate.

Additional outcomes:
- Develop skills in data analysis and numerical modeling.

This session explains the different approaches used in numerical models to parametrize the turbulent mixing taking place at the subgrid scale, above the surface layer. Various turbulence closures are presented before describing closure currently used in the ECMWF model.

Expected outcomes:
- understand what a turbulence closure is and what are the types of closures encountered in numerical models.
- have an overview of the parameterization of turbulent mixing in the ECMWF model.

Building on the previous two Cloud sessions, the practical implementation of a cloud parameterization is described, using the ECMWF global model as an example appropriate for global weather forecasting.

By the end of the session you should be able to:
- explain the key sources and sinks of cloud and precipitation required in a parameterization.
- describe the main components of the ECMWF stratiform cloud parameterization.
- recognize the limitations of approximating complex processes.

Richard Forbes

This session gives an overview of techniques and data sources used for the verification of the boundary layer scheme. We will use examples from the IFS to explore how verification methods can help to identify systematic errors in the model's boundary layer parameterization, and guide future model development.

By the end of this session you should be able to:
- identify data sources and products suitable for BL verification.
- recognize the strengths and limitations of the verification strategies discussed.
- choose a suitable verification method to investigate model errors in boundary layer height, transport and cloudiness.

This session gives a brief overview of cloud parameterization issues and an understanding of the basic microphysics of liquid, ice, and mixed phase and precipitation processes.

By the end of the session you should be able to:
- recall the basic concepts for the design of a cloud parameterization.
- describe the key microphysical processes in the atmosphere.
- recognize the important microphysical processes that need to be parametrized in a global NWP model.

This three-hour lecture will start by explaining the role and main ingredients of data assimilation in general. The widely used framework of variational data assimilation will then be briefly introduced. The challenges associated with the necessary inclusion of physical parametrizations in the data assimilation process will be highlighted. The concept of adjoint model as well as the techniques to derive it will be introduced. The importance of the linearity constraint in 4D-Var and the methods to address it will be detailed. The set of linearized physical parametrizations used at ECMWF will then be briefly presented. Finally, various examples of the use of physical parametrizations in variational data assimilation and its impact on weather forecast quality will be given.

By the end of the session, the students should be able to:
- describe the relevant physical mechanisms related to sub-grid orography that have impact on flow in the atmosphere.
- describe the impact of sub-grid orography.

On the basis of simple gravity wave theory, the concepts of sub-grd turbulent form drag, flow blocking, and gravity wave excitation will be introduced. The ECMWF formulations will be described, and the impact will be discussed.

By the end of the session students should be able to:
- describe the relevant physical mechanisms related to sub-grid orography that have impact on flow in the atmosphere.
- describe the impact of sub-grid orography.

Anton Beljaars

subgrid_orography_2016.pptx
By the end of the session students should be able to:

- recognise land elements relevant to weather,
- review land modelling strategies to heterogeneity.

Gianpaolo Balsamo
surf1.pptx

Introduction to the Single Column Model
Filip Vana
Lecture2016.pdf

Review land modelling strategies to heterogeneity
Alessio Bozzo and Robin Hogan
Radiation exercises

Land Surface exercises
Gianpaolo Balsamo and Emanuel Dutra

Boundary Layer & Cloud exercises
Irina Sandu, Maike Ahlgrim and Richard Forbes

Moist Processes Exercises
Richard Forbes and Peter Bechtold

Moist Processes Games
Richard Forbes and Peter Bechtold

Radiation exercises
Alessio Bozzo and Robin Hogan

Land Surface exercises
Gianpaolo Balsamo and Emanuel Dutra

Boundary Layer & Cloud exercises
Irina Sandu, Maike Ahlgrim and Richard Forbes

Course wrap up and certificates

---

**Time:**

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
</table>
| 9.15-10.15 | Introduction to the course with Computer Hall tour | In this session the generation of the perturbed initial condition of the ECMWF ensemble will be presented. We will discuss the ratio behind using singular vectors in the ensemble and how they are calculated. Then it will be explained how the singular vectors are combined with perturbations from the ensemble of data assimilations to construct the perturbations for the ensemble. By the end of the session you should be able to:

- explain the idea behind using singular vectors in the ensemble
- describe how singular vectors are calculated
- describe the construction of the ensemble perturbations

The aim of this session is to introduce the ECMWF ensemble of data assimilation (EDA). The rationale and methodology of the EDA will be illustrated, and its use in to simulate initial uncertainties in the ECMWF ensemble prediction system (ENS) will be presented. By the end of the session you should be able to:

- know what is the ECMWF EDA
- illustrate how the EDA is used to simulate initial uncertainty in ensemble prediction
- understand the main differences between singular vectors and EDA-based perturbations

**Abstract:** The lectures introduce methods of ensemble verification. They cover the verification of discrete forecasts (e.g. dry/wet) and continuous scalar forecasts (e.g. temperature). Various scores such as the Brier score and the continuous ranked probability score are introduced. After the lectures you should be able to:

- explain what a reliable probabilistic forecast is and how to measure reliability
- understand why resolution and sharpness of a probabilistic forecast matter
- compute several of the standard verification metrics used for ensemble forecasts

**Martin Leutbecher**
v2handout.pdf

**Magdalena Balmaseda**
tcourse16_initialization.pptx

**Magdalena Balmaseda**
tcourse16_ocean.pptx

---

**Abstract:** The lectures introduce methods of ensemble verification. They cover the verification of discrete forecasts (e.g. dry/wet) and continuous scalar forecasts (e.g. temperature). Various scores such as the Brier score and the continuous ranked probability score are introduced. After the lectures you should be able to:

- explain what a reliable probabilistic forecast is and how to measure reliability
- understand why resolution and sharpness of a probabilistic forecast matter
- compute several of the standard verification metrics used for ensemble forecasts

**Roberto Buizza**
RB_2016_05_TCL2_SVs_EDA.pptx

---

This lecture provides a broad overview of the role of the ocean on the predictability and prediction of weather and climate. It introduces some basic phenomena needed to to understand the time scales and nature of the ocean-atmosphere coupling.
<table>
<thead>
<tr>
<th>Time</th>
<th>Lecturer</th>
<th>Presentation Title</th>
<th>Content &amp; Topics</th>
</tr>
</thead>
</table>
| 10:35-11:35 | Roberto Buizza | RB_2016_05_TCL1_sources_unc.pptx | The aim of this session is to introduce the idea of chaos. We will discuss the implications this has for numerical weather prediction. By the end of the session you should be able to:  
- describe what limits the predictability of the atmosphere  
- understand the need for probabilistic forecasting |
| 11:45-12:45 | Laura Ferranti | TC_clustering_2016.pdf | Abstract: The lectures introduce methods of ensemble verification. They cover the verification of discrete forecasts (e.g. dry/wet) and continuous scalar forecasts (e.g. temperature). Various scores such as the Brier score and the continuous ranked probability score are introduced. After the lectures you should be able to:  
- explain which are the main sources of forecast error  
- illustrate why numerical prediction should be stated in probabilistic terms  
- describe the rationale behind ensemble prediction  
- be aware of:  
  - Some of the weaknesses of the ECMWF forecast system  
  - Some of the diagnostic tools used to identify and understand these weaknesses |
| 11:45-12:45 | Franco Molteni | TCPPR_Molteni_regimes.ppt | The aim of this session is to illustrate the key characteristic of the nine operational global, medium-range ensemble systems. These are the ensembles available also within the TIGGE (Thompson Interactive Grand Global Ensemble) project data-base. Similarity and differences in the approaches followed to simulate the sources of forecast uncertainties will be discussed, and their relevance for forecast performance will be illustrated. By the end of the session you should be able to:  
- illustrate the main similarities and differences of the 9 TIGGE global ensembles  
- link the performance differences of TIGGE ensemble to their design  
- describe the main differences between singular vectors and EDA-based perturbations |
| 11:45-12:45 | Frederic Vitart | TCPPR_Vitart_2016_MJO.pptx | The aim of this session is to provide a general overview of monthly forecasting at ECMWF. We will review the main sources of predictability for the sub-seasonal time scales, including the Madden Julian Oscillation, sudden stratospheric warmings (SSWs), land initial conditions and their simulation by the coupled IFS NEMO system. The skill of the ECMWF operational monthly forecasts will also be discussed. By the end of the session you should be able to:  
- list the different sources of predictability for extended range forecasts  
- describe the operational system used to produce the ECMWF monthly forecasts  
- assess the skill of the monthly forecasting system  
- assess the performance of the monthly forecast system |
| 11:45-12:45 | Tim Stockdale | tc2016_seasonal.pptx | This lecture covers the essentials of building a numerical seasonal forecast system, as exemplified by the present prediction system at ECMWF. By the end of this lecture, you should be able to:  
- explain the scientific basis of seasonal forecast systems  
- describe in outline ECMWF System 4 and its forecast performance  
- discuss the critical factors in further improving forecast systems |
| 11:45-12:45 | Mark Rodwell | 20160512_TCR_Diags_2_02.pdf | The aim of this session is to understand the ECMWF clustering products. By the end of the session you should be able to:  
- explain how the cluster analysis works  
- use the ECMWF clustering products  
- assess the skill of the monthly forecasting system |
<table>
<thead>
<tr>
<th>Time</th>
<th>Session Description</th>
<th>Lecture Content</th>
<th>Other Information</th>
</tr>
</thead>
</table>
| 2.00-3.00| The aim of this session is to understand how we are able to provide forecasts at long time horizons given the chaotic nature of the atmosphere. After this session you should be able to:  
- describe the Lorenz idea of Predictability of the first and second kind  
- list examples of the elements of the Earth system that provide predictability on longer timescales  
- understand the type of forecast that we are able to provide beyond the deterministic limit. | Sarah Keeley  
**Beyond_limit_upd.pptx**  
**StochPhys2016.pdf** |  
**2.45pm Discussion Session in the Wheeler Room**  
The latest medium, monthly and seasonal forecasts will be discussed in terms of outlook and performance. This is a combined event with the weekly weather discussion that ECMWF staff attend.  
**Ted Shepherd**  
**ECMWF_Predictability_2016_new.pdf** |
| 3.30-4.30| The aim of this lecture is to discuss basic concepts behind initial perturbation techniques. After the lecture you should be able to:  
- Understand the difference between singular vectors and breeding (ETKF) vectors  
- Explain why pure random perturbations do not work. | Linus Magnusson  
**training_2016_inipert1_tm.pptx** |  
**Ted Shepherd**  
**ECMWF_Predictability_2016_new.pdf**  
**Practice Session:**  
You get the opportunity to experiment yourself with an ensemble prediction system for a chaotic low-dimensional dynamical system introduced by Edward Lorenz in 1995. Experiments permit to study the role of the initial condition perturbations and the representation of model uncertainties. Various metrics introduced in the ensemble verification lectures will be applied in this session.  
**By the end of this lecture, you should be able to:**  
- describe a wide range of possible calibration methods for ensemble systems  
- explain which methods are suitable in which circumstances  
- discuss the merits of calibration and multi-model combination  
**Linus Magnusson/Sarah Keeley**  
**fred_flooding2016.pptx** |
| 4.30-5.15| Understanding Ensembles Practical  
**5.15 Poster session and ice breaker** | License and Practice Session:  
Abstract: The lecture is a short introduction to operational hydrological ensemble prediction systems, with focus on flooding. The European Flood Awareness System (EFAS) is described. The lecture also contains a short interactive exercise in decision making under uncertainty using probabilistic forecasts as an example.  
By the end of the session you should be able to:  
- Describe the components in hydrological ensemble prediction systems (HEPS)  
- Describe the major sources of uncertainty in HEPS and how they can be reduced.  
- Explain the difficulties in using probabilistic flood forecasts in decision making.  
**Fredrik Wetterhall**  
**fred_flooding2016.pptx** |  
**Practice Session:**  
Ensemble Verification  
**Practice Session:**  
**Linus Magnusson/Sarah Keeley**  
**fred_flooding2016.pptx** |
| 2.45pm | Discussion Session in the Wheeler Room |  
**Sarah Keeley**  
**Beyond_limit_upd.pptx**  
**StochPhys2016.pdf** |  
**Ted Shepherd**  
**ECMWF_Predictability_2016_new.pdf**  
**Practice Session:**  
Ensemble Verification  
**Linus Magnusson/Sarah Keeley**  
**fred_flooding2016.pptx** |