Training course: Data assimilation

Report of Contributions

https://events.ecmwf.int/e/333

Contribution ID: **1** Type: **not specified**

Introductions

Monday, 22 May 2023 09:00 (1 hour)

In this session we will sort out: general house keeping for the course, such as computing accounts; have an overview of ECMWF research and introduce ourselves to one another.

Primary authors: BROWN, Andy (ECMWF); STEWART, Christopher (ECMWF); STUDENTS

Presenters: BROWN, Andy (ECMWF); STEWART, Christopher (ECMWF); STUDENTS

Contribution ID: **2** Type: **not specified**

Overview of assimilation methods

Monday, 22 May 2023 10:20 (1 hour)

The goal of the ECMWF Earth System data assimilation is to provide an accurate and physically coherent description of the state of the atmosphere, ocean, sea ice and land surface as an initial point for our forecasts.

This requires blending in a statistically optimal way information from a huge variety of observations and our prior knowledge about the physical laws of the Earth system, which is encapsulated in our models.

In this lecture we will lay the general conceptual framework on how to achieve this from a Bayesian perspective. We will then highlight the approximations and hypotheses which are required to make the assimilation problem computationally tractable and which underlie the practical data assimilation algorithms which will be described in detail in this training course.

By the end of lecture you should be able to:

• understand the basics of how a geophysical data assimilation system works;
• understand the main approximations and hypotheses which are required to build practical data assimilation algorithms for large geophysical systems

Presenter: BONAVITA, Massimo (ECMWF)

Contribution ID: **3** Type: **not specified**

Assimilation Algorithms: (1) Basic concepts

Monday, 22 May 2023 11:30 (1 hour)

This lecture will explain the basic concepts of the assimilation algorithms. The terminology used in the next lectures will be introduced. Simple examples will conduce towards the formulation of the optimal minimum-variance analysis. The optimal interpolation method will finally be presented.

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

- Recognize the notations used for the rest of the week
- Solve the optimal minimum-variance analysis problem
- Apply the optimal interpolation method

Presenter: MASSART, Sebastien (ECMWF)

Contribution ID: **4** Type: **not specified**

Conventional and actively sensed observations

Monday, 22 May 2023 13:30 (1 hour)

This lecture will introduce how observations are an essential part of the data assimilation system.

It will focus on in situ (also called conventional) observations, from surface stations, drifters, aircraft and radiosondes. They are important both for direct use in the data assimilation system and for diagnostics. Radiosonde and surface observations also help to control the biases in the assimilation system. However, they are diverse and hey can be complex, so close attention to quality control, observation uncertainty and (in some cases) bias correction is needed to optimise their use. The use of new BUFR format high resolution radiosonde data will also be presented.

The lecture will also introduce the actively sensed satellite observations used for data assimilation at ECMWF: radio occultation data, scatterometer winds, and altimeter wind/significant wave height.

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

• understand how in situ and actively sensed observations are used in data assimilation, including bias aspects and observation uncertainty aspects.

• appreciate the diverse and complex range of in situ observations used in modern NWP.

• understand how radio occultation data, scatterometer winds and altimeter data are used in data assimilation.

Presenter: HEALY, Sean (ECMWF)

Contribution ID: **5** Type: **not specified**

Assimilation Algorithms: (2) 3D-Var

Monday, 22 May 2023 14:50 (1 hour)

This lecture will present the 3D-Var assimilation algorithm. This algorithm is based in the formulation of a cost function to minimize. Minimization methods will be presented together with some information on how to improve their efficiency.

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

- Recognize the 3D-Var cost function
- Explain the various terms of the cost function
- Question the efficiency of methods designed to find the minimum of the cost function

Presenter: MASSART, Sebastien (ECMWF)

Contribution ID: **6** Type: **not specified**

Analysis of radiance observations

Tuesday, 23 May 2023 10:20 (1 hour)

The primary purpose of this lecture is to explore the implications of the fact that satellites can only measure radiation at the top of the atmosphere and do not measure the geophysical variables we require for NWP (e.g. temperature, humidity and wind). The link between the atmospheric variables and the measured radiances is the radiative transfer equation - the key elements of which are discussed. It is shown how - with careful frequency selection - satellite measurements can be made for which the relationship to geophysical variables is greatly simplified. Despite these simplifications, it is shown that the extraction of detailed profile information from downward looking radiance measurements is a formally ill posed inverse problem.

Data assimilation is introduced as the solution to this inverse problem, where background information and satellite observations are combined to produce a best or optimal estimate of the atmospheric state. The main elements of the assimilation scheme (such as the chain of observation operators for radiances) and its key statistical inputs are examined. In particular, it is shown that incorrect specification of observation errors (R) and background errors (B) can severely limit the successful exploitation of satellite data.

By the end of this lecture you will:

• understand exactly what a satellite actually measures (radiance)
• appreciate the complex relationship between what is measured and what we wish to know for NWP
• how information is extracted from satellite measurements in data assimilation

Presenter: MCNALLY, Tony (ECMWF)

Contribution ID: **7** Type: **not specified**

Assimilation Algorithms: (3) 4D-Var

Tuesday, 23 May 2023 09:00 (1 hour)

Presenter: MASSART, Sebastien (ECMWF)

Contribution ID: **8** Type: **not specified**

Assimilation Algorithms: (4) Ensemble Kalman filters

Tuesday, 23 May 2023 11:30 (1 hour)

The aim of this lecture is to introduce the concept of the EnKF in the context of atmospheric data assimilation. Strengths and weaknesses of the algorithm will be discussed and results of the ECMWF implementation will be presented.

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

• Describe the basic EnKF algorithm and its connections with the Kalman Filter;
• Discuss some of the advantages and the limitations of EnKF algorithms with respect to more established variational algorithms;
• Be aware of recent developments in hybrid variational-EnKF data assimilation

Presenter: BONAVITA, Massimo (ECMWF)

Contribution ID: **10** Type: **not specified**

Tangent linear and adjoints

Tuesday, 23 May 2023 14:50 (1 hour)

The goal of this lecture is to familiarise the student with the notion of tangent linear and adjoint models, and their use in variational data assimilation. A general overview of the current use of tangent linear and adjoint models in the ECMWF system will also be provided. Theoretical definitions and practical examples of tangent liner and adjoint models will be given. The student will be invited to work some simple tangent linear and adjoint derivations together with the instructor. A brief introduction to automatic differentiation software will also be given.

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

- define what tangent linear and adjoint models are
- derive tangent linear and adjoint equations for a simple nonlinear equation
- describe the use of tangent linear and adjoint codes within the ECMWF's 4D-VAR system.

Presenter: CHRUST, Marcin (ECMWF)

Contribution ID: **11** Type: **not specified**

Practical session: Tangent linear and adjoints

Tuesday, 23 May 2023 15:50 (55 minutes)

Presenters: CHRUST, Marcin (ECMWF); MASSART, Sebastien (ECMWF)

Contribution ID: **12** Type: **not specified**

Assimilation Algorithms: (5) Hybrid data assimilation methods

Wednesday, 24 May 2023 13:30 (1 hour)

Presenter: BONAVITA, Massimo (ECMWF)

Contribution ID: **13** Type: **not specified**

Bias correction methods

Wednesday, 24 May 2023 09:00 (1 hour)

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.

Presenter: BORMANN, Niels (ECMWF)

Contribution ID: **14** Type: **not specified**

Model error in data assimilation

Wednesday, 24 May 2023 11:30 (1 hour)

In this lecture, the impact of model error on variational data assimilation will be presented. This lecture will introduce weak-constraint 4D-Var as a way to account for model error in the data assimilation process. Several examples of results from simplified implementations in the IFS will be shown.

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

- describe the impact of model error on the data assimilation process,
- explain the difficulties in properly accounting for model error in data assimilation.

Presenter: LALOYAUX, Patrick (ECMWF)

Contribution ID: **15** Type: **not specified**

Background error modelling in data assimilation

Wednesday, 24 May 2023 10:20 (1 hour)

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.

Presenter: HOLM, Elias (ECMWF)

Contribution ID: **16** Type: **not specified**

Practical session: DA experiments

Wednesday, 24 May 2023 14:50 (1 hour)

Presenters: CHRUST, Marcin (ECMWF); BONAVITA, Massimo (ECMWF); LALOYAUX, Patrick (ECMWF)

Contribution ID: **17** Type: **not specified**

Data assimilation diagnostics - forecast sensitivity

Thursday, 25 May 2023 09:00 (1 hour)

Presenter: GEER, Alan (ECMWF)

Contribution ID: **18** Type: **not specified**

Parametrization and data assimilation

Tuesday, 23 May 2023 13:30 (1 hour)

This one-hour lecture will identify the challenges associated with the use of physical parametrizations in the context of four-dimensional variational data assimilation (4D-Var). 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 be briefly presented. Examples of the use of physical parametrizations in variational data assimilation and its impact on forecast quality will be given.

By the end of the lecture, the students should be able:

- to tell why physical parametrizations are needed in data assimilation.
- to recognize the importance of the regularization of the linearized code

Presenter: LOPEZ, Philippe (ECMWF)

Contribution ID: **19** Type: **not specified**

Land data assimilation

Thursday, 25 May 2023 11:30 (1 hour)

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

Presenter: DE ROSNAY, Patricia (ECMWF)

Contribution ID: **20** Type: **not specified**

Practical Session: DA experiments

Thursday, 25 May 2023 13:30 (1 hour)

Presenters: CHRUST, Marcin (ECMWF); BONAVITA, Massimo (ECMWF); LALOYAUX, Patrick (ECMWF)

Contribution ID: **21** Type: **not specified**

Practical session in Gather.Town: DA experiments with OOPS

Presenters: CHRUST, Marcin (ECMWF); BONAVITA, Massimo (ECMWF); LALOYAUX, Patrick (ECMWF)

Contribution ID: **22** Type: **not specified**

Data assimilation of atmospheric composition

Friday, 26 May 2023 09:00 (1 hour)

At ECMWF, atmospheric composition data are assimilated into the IFS as part of the Copernicus Atmospheric Monitoring Service. On a global scale, atmospheric composition represents the full state of the global atmosphere covering phenomena such as desert dust plumes, long-range transport of atmospheric pollutants or ash plumes from volcanic eruptions, but also variations and long-term changes in the background concentrations of greenhouse gases.

The aim of this lecture is to give an overview of the work that is carried out at ECMWF regarding the assimilation of atmospheric composition data, and to address why this is of interest and which special challenges are faced when assimilating atmospheric composition data.

By the end of the session you should:

• have some understanding of the work carried out at ECMWF to assimilate data of atmospheric composition

Presenter: ENGELEN, Richard (ECMWF)

Contribution ID: **23** Type: **not specified**

Ocean data assimilation

Friday, 26 May 2023 10:20 (1 hour)

This lecture provides an overview of a typical ocean data assimilation system for initialization and re-analyses application. The lecture uses as an example the ECMWF ocean data assimilation system, which is based the NEMOVAR (3Dvar FGAT). This will be used to discuss design of the assimilation cycle, formulation of error covariances, observations assimilated and evaluation procedure, among others.

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

- describe the different components involved in an ocean data assimilation system
- list the commonalities and differences between ocean and atmosphere data assimilation
- describe the basics of the physical ocean observing system
- explain the essential multivariate relationships between ocean variables
- identify the limitations of the existing systems.

Presenter: ZUO, Hao (ECMWF)

Contribution ID: **24** Type: **not specified**

Reanalysis methods

Friday, 26 May 2023 11:30 (1 hour)

The aim of this session is to understand how data assimilation can improve our knowledge of past weather over long time-scales. We will present recent advances that help capture changes over time in observing system networks, and project this variation in information content into uncertainty estimates of the reanalysis products. We will also discuss the applications of reanalysis, which generally put weather events into the climate context.

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

• explain what are the goals of data assimilation in a reanalysis data assimilation system
• list the key aspects that require particular attention in reanalysis, as compared to numerical weather prediction
• describe the most common problems in reanalysis products

Presenter: SCHEPERS, Dinand (ECMWF)

Contribution ID: **25** Type: **not specified**

Coupled data assimilation opportunities and challenges

Thursday, 25 May 2023 10:20 (1 hour)

At ECMWF, we are striving to move towards an Earth System approach to our data assimilation techniques. We currently have models not only of the atmosphere, but of the ocean, the land surface, sea ice, waves, and atmospheric composition. These systems interact with each other in different ways and all need to be initialised through the incorporation of observational data.

The aim of this lecture is to recognise the benefits and challenges associated with data assimilation in coupled models.

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

• Recall the challenges associated with variational data assimilation in systems with different timescales and computer codes.
• Describe the benefits of having more consistently balanced coupled systems from coupled data assimilation.
• Explain the differences between weakly and strongly coupled data assimilation approaches.
• Discuss the various methods that are in use at ECWMF and explain the planned developments of the systems.

Presenter: BROWNE, Phil (ECMWF)

Contribution ID: **26** Type: **not specified**

Final discussion and Q&A

Friday, 26 May 2023 14:50 (1 hour)

Presenters: HOLM, Elias (ECMWF); CHRUST, Marcin (ECMWF); BONAVITA, Massimo (ECMWF); LALOYAUX, Patrick (ECMWF); MASSART, Sebastien (ECMWF)

Contribution ID: **34** Type: **not specified**

Data Assimilation and Machine Learning

Friday, 26 May 2023 13:30 (1 hour)

Presenter: GEER, Alan (ECMWF)

Contribution ID: **35** Type: **not specified**

Ice breaker

Tuesday, 23 May 2023 16:45 (1 hour)

Contribution ID: **36** Type: **not specified**

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