II – Curriculum Advancements

Introduction

By Patrick Parrish

Our workplaces are changing. Whether you work in operations, administration, or in academia, you are facing rapid changes in what knowledge and skills are required to be successful in your work. The audiences requiring a higher level of knowledge in the sciences is also growing. This section describes several innovations in curricula, or in how curricula are being designed and updated.

- Stones tells the story of an innovative needs assessment conducted to the identify the needs of current and future operational meteorologists at the Met Office.
- Persson makes a strong case for using new arguments and methods in teaching "intuitive statistics," background knowledge required for all forecasters who need to include information on uncertainty in their forecasts.
- Chopra et al. have developed a compelling strategy to offer resources for teaching elements of climate science across the curricula in secondary education and undergraduate levels in order to raise awareness of the challenges faced in a changing climate.
- Garbanzo-Salas and Jimenez-Robles describe an innovative way to teach critical programming skills focused on functional sections of code rather than programming languages.
- Holloway and Charlton-Perez also address the need to develop programming skills in higher education, introducing innovations to align and better integrate how programming is taught across the meteorology, climate, and environmental physics curricula.
- Bykova et al. describes how a university collaborates with the labor market to design a curriculum that prepares students for faster integration into the aviation industry.
- Inness offers an engaging and practical programme for preparing students of meteorology for the communication tasks required of contemporary weather forecasters.
- Sealy et al. present their online program designed to develop a background in meteorology for geography educators in secondary schools.

1. Approach to Conducting a top-level learning needs analysis for the Operational Meteorology Profession at the Met Office

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Abstract

The Met Office is currently renewing its portfolio of Continuing Professional Development (CPD) learning opportunities for Operational Meteorologists. As part of this project, we identified a need to analyse the learning requirements of the profession, specifically looking at projected future requirements of Met Office customers, new technology, and the role of the Operational Meteorologists relative to these. In the next five years, we expect a continuing trend of increased embedded working with the customer and supporting the customer with the interpretation and analysis of large data sets. As NWP capabilities improve, there will be an increasing demand to extend forecast lead times and better communicate uncertainties based on ensembles. In parallel to these changing parameters, there exists a necessity to ensure our meteorologists maintain expert meteorological knowledge to provide meaningful interpretation of data; communicate background, context, and impacts to customers; and maintain credibility.

To produce the analysis, we collected information from a range of sources, including interviews with senior leadership to discuss the future direction of the organisation, and customer feedback to understand what we do well now and the customers' perception of what we could do better. A survey was sent to all Operational Meteorologists to assess current gaps in the skills, knowledge, and understanding from their point of view; the survey response rate was approximately 50%. We analysed results from the senior Operational Meteorologist promotion exams to find specific gaps in theoretical knowledge and understanding. We collated and mapped this information against the existing skills framework for the profession, giving increased priority to those areas deemed most significant in the future, to identify those gaps best suited to be addressed by learning interventions. This allowed us to write a set of top-level learning outcomes, which we subsequently used to provide a prioritised structure for the development plan. The learning consultants are working using an Agile approach, meaning that detailed learning outcomes are developed with learner involvement as part of the design process to allow flexibility during this time of change, both for the business and the profession.

Keywords: operational meteorology, profession, training, learning needs analysis, TNA, professional development, CPD, e-learning

Introduction

The goal of this ongoing needs analysis is to provide sustainable access to resources for Operational Meteorologists' (Op Mets) professional development that enable the delivery of the best possible services to customers. As with other Meteorological agencies, there are many changes currently in motion, both internally and externally. Internally, we are working to improve the efficiency of our services, including reducing the number of forecast products produced by Op Mets and the way we access our data. Externally, people are changing how they learn, with an increasing number accessing learning remotely and learning in bite-size chunks via apps on phones and tablets. These changes are ongoing; hence it is vital that new resources are adaptable, and that content can be clearly linked to its purpose through updates that are as simple and focussed as possible.

The intended outcome of this analysis is to create a set of prioritised learning outcomes on which to base the design of the new portfolio of continuing professional development (CPD) learning interventions. The learning outcomes should be direct and unambiguous, directly relating to trends in data and taking into account the future needs of the business. At this stage, it will also be useful to indicate anticipated relative time spent developing learning material per unit of time spent learning. We will endeavour to spend more time developing material for higher priority learning outcomes and less time on those which likely to become less important or expire over time. This information can be derived from the same sources of data collected for this training needs analysis (TNA). It will be important to consider business priorities and the rate of refresh (due to updates in technology, such as remote sensing products), as well as the potential usefulness of the learning intervention in five years' time and beyond.

1.1. Methodology

As a baseline for the required skills, knowledge and competencies required for the role, we employed the Met Office Operational Meteorologist Skills Framework. This document gives a description of the skills, knowledge and competencies required for the different levels of Operational Meteorologist. At the UKMO, these are Trainee Op Met, Op Met, Senior Op Met, Expert Op Met and Principal Op Met. The framework is broadly split into eight categories:

Skills Framework Category	Description
1	Meteorological Insight and Independence
2	Underpinning Meteorological and Technical Skills, Experience and Knowledge
3	Strategic Thinking
4	Leadership, Coaching and Mentoring
5	Communication
6	(Application of) Operational Systems
7	Operational Priority
8	Services and Customer Collaboration

Before use in this analysis, the framework was updated by the Head of the Op Met Profession at the UKMO to ensure it was up to date and fit for purpose.

The next step was for us to gather information from Op Mets, their managers, key internal stakeholders and a range of customers. We then coordinated a team to collate all the gaps in the skills, knowledge and competencies found in the various streams of data, in line with the Skills Framework, in order to assess the combined size of the skills gap. The information was sourced as follows:

1.1.1. Surveys

Surveys were sent to all Op Mets, including their line managers, using Office 365 Forms. The questions focussed on the key areas of the skills framework and included multiple opportunities for free text entry to avoid the propagation of preconceptions. The survey also asked questions about the individual forecasting benches and locations; details from these responses are now being used when designing each learning intervention, which are designed for a specific forecasting task or set of tasks when efficiencies make this possible. Approximately half of all Op Mets responded to the survey (totalling 161), with an average of 32 minutes spent on each survey. Approximately a third of surveys were completed by Op Met line management, with separate questions to be answered from a manager's point of view, when applicable, in the second half of the survey. The tick-box answers and text boxes were analysed together and mapped to the amended version of the skills framework.

1.1.2. Existing data

We used three main streams of existing documentation for the analysis; firstly, we filtered a large database of customer feedback to find specifics relating back to Meteorologists, either directly or indirectly. We then mapped points to the amended skills framework. Secondly, we incorporated trends in the results from recent Senior Op Met promotion exams to highlight knowledge gaps with the same methodology applied to the customer feedback. Finally, in order to capture the activities on as many benches/locations as possible, we collected utilisation reports which give detailed information on tasks carried out on shift.

1.1.3. Stakeholder Interviews

To provide input on priorities for Operational teams both now and for the future, we interviewed representatives from relevant MO management teams and the Guidance Unit consisting of Expert and Principal Op Mets. These included perspectives from all forecasting areas including defence, civil aviation, marine, media, natural hazards, and public service forecasting. Again, we mapped the points made in each interview against the Skills Framework where appropriate and stored this information to give us detail in later design and development work.

Some data, such as tick-box answers in the survey, were simple to map against the Skills Framework, since they were built into the design of the survey. Other data were much more subjective, and hence a team of Learning Consultants and Op Mets came together to map the data to the most appropriate category. To give visual clarity and encourage discussion, we divided a meeting room into eight columns, each headed by each one of the eight Skills Framework categories. The skills gap statements were written on post-it notes and placed under the headings. The group and the room in use can be seen in Figure 1.1.

Figure 1.1. The "TNA room" used to map data to categories of the Skills Framework

1.2. Results and Next Steps

1.2.1. Collective skills gaps from combining data source

Without taking into account the specialist elements of different Op Met jobs within the network, it is possible to identify some trends in skills gaps using the amended Skills Framework as a baseline.

Three of the largest skills gaps identified were:

- Communication Skills
- Underpinning Meteorological knowledge
- Application of Operational Systems

We then combined the data from all sources to write a set of top-level, prioritised learning outcomes. These learning outcomes have formed the basis of planning the design and development of the new learning interventions for Op Mets.

> *"Maintain up-to-date knowledge of foundation-level meteorological theory and be able to explain most aspects to a range of audiences."*
>
> *"Apply an appropriate breadth and depth of meteorological knowledge and understanding to elements of the customer's business that could be significantly impacted."*
>
> *"Maintain up-to-date knowledge of how our Unified Model works; how primary fields are calculated and how other fields are derived. Relate this to knowledge of the current strengths and weaknesses of the model to understand how and why value can be added to model output."*
>
> *"Using knowledge of the customer's geographical areas of activity, be able to explain and apply knowledge of meteorological effects in these areas."*

Some examples of these learning outcomes are:

The data also highlighted a growing need for new ways to deliver CPD. Before this analysis, the majority of formal learning was delivered face-to-face in the College at Met Office HQ. It has become increasingly difficult to co-ordinate the desired amount of training in this way given working patterns and the cost and carbon emissions due to travel, but neither does it align with current trends in online learning and delivery in bite-sized chunks.

1.2.2. Moving to the design phase

When scheduling work on the design and development of the new learning resources, several factors had to be considered: the availability of meteorological subject matter experts (SMEs), access to skilled online training designers and ensuring that training on seasonal weather phenomena became available when these would be most likely to affect customers. We also needed to develop and release the online learning interventions as soon as possible due to the increasing logistical constraints of face-to-face training. Addressing these points, we decided on the following;

1. Use an "Agile" approach to develop and release training in a fixed time window[1].

2. Employ use of the University College London "ABC" learning design toolkit.[2]

3. Task Learning Consultants with the completion of the majority of online learning intervention development work using the Met Office learning management system (LMS).

The main benefit of using Agile methodologies is that it has allowed us to release learning interventions for testing and use as soon as they are drafted. It also has encouraged innovation through taking risks and not being afraid to learn from failures. The alternative, which was to commence work on the whole portfolio of learning, would result in a wait of over 15 months for any training, by which time some of the earlier development may need updating.

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[1] See for example.: https://www.apm.org.uk/resources/find-a-resource/agile-project-management/

[2] https://blogs.ucl.ac.uk/abc-ld/

The ABC design toolkit, by separating decisions regarding delivery mode from learning methods, helps people that have experience in teaching, but not necessarily in online training design, to produce online training materials that use effective learning methods.

Our Learning Consultants are experts in classroom teaching and particular elements of Operational Meteorology, but are not yet expert in online learning design. The ABC design toolkit was key to ensuring that this team was able to effectively and efficiently design the learning packages. This method also negated the need for frequent and potentially lengthy conversations and potential misunderstandings between the Learning Technologists and Learning Consultants. Carrying out the development work was then relatively straight forward for the Learning Consultant team using built-in tools within Moodle, the learning management system used by the college.

The Learning Technologists, who are specialists in online learning design, completed the final stage of the development work by applying a “house style” to ensure consistent and professional-looking presentation, changing some of the more technical settings within the package and enrolling testers and users on the courses.

1.2.3. Current Progress

For the Winter season, two learning packages were designed, developed and released for Op Mets to use around the themes of fog and minimum temperature forecasting. Each can be completed in chunks taking 20-30 minutes, with a variety of learning methods used for each section, including audio clips, social learning, quiz questions and scenarios. When all sections are complete, the user obtains a badge for that particular topic. An example from the fog package is shown in Figure 1.2, Concepts are brought together in the final section and framed in a scenario.

Figure 1.2. Screenshot from the fog forecasting online learning package

1.2.4. Feedback

Feedback on the new online learning resources, which must be submitted by the user before obtaining the badge at the end, has been collected via the Moodle feedback tool. Although this new style and delivery method of learning and instruction has been well-received in general, some users have reported that they would prefer to learn in even smaller chunks so they can fit it around their operational work. Others have requested increased use of audio and video options. These comments have been taken into account in the next planned window of design and development time.

1.2.5. Summary

The Met Office College team conducted a comprehensive, forward-looking review of the ongoing learning and development needs of Met Office Operational Meteorologists, providing an evidence base for our future L&D portfolio. We have adopted an agile approach to accelerate delivery of useful, quality learning interventions while involving experts and Op Mets themselves to ensure we understand and address their needs. The results so far have been well received and are improving meteorologists' engagement with learning and career development.

2. Three paradoxical reasons to learn intuitive statistics in operational meteorology

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Abstract

This chapter argues for the need to teach intuitive statistics to operational weather forecasters to help them better make the transition to producing forecasts with implicit uncertainty information. Drawing from the work of economist Daniel Kahneman, the chapter offers three paradoxes that must be understood to develop a deeper understanding of the qualities and benefits of probabilistic information. Several examples are offered that can be useful for teachers of statistics and forecasting to help their students develop a stronger and more intuitive feel for statistics.

Introduction

Because meteorology is a branch of physics, its education naturally involves the dynamics and physics of the atmosphere (radiation, cloud physics, turbulence theory etc). However, any science based on numerical values regulated by physical laws must have these values organized, analysed, interpreted and presented. This involves by necessity an intuitive feeling for mathematical statistics. Such an education is still lacking in meteorology.

The dominating thinking in operational weather forecasting has, for historical reasons, always been physical or deterministic, in other words, perfect observations and perfect mathematical methods or models will ideally yield perfect forecasts. But already in the 1860's, at the start of weather forecasting, meteorologists relied on "intuitive statistical thinking" (and still do) without really being aware of it. Perhaps this is what is what is hiding behind the vague term, "forecast experience"?

The concept of *intuitive statistics* was introduced to a broader public by Daniel Kahneman, awarded the Nobel Prize in Economics in 2002, in his book "Thinking, fast and slow" (Kahneman, 2011). Most of the contents of the book applies to our science and can easily be translated into meteorological vocabulary. The aim of this article is to suggest that operational weather forecasters would benefit from being trained to take a conscious intuitive statistics approach. The article will present three paradoxes regarding probabilistic thinking that would be helpful to include within forecaster training programmes.

2.1. The three paradoxes

In line with the main theme in Kahneman's book, meteorologists can be separated into "fast" and "slow" thinking groups. Weather forecasters and communicators, who work under time constraints, have to make quick decisions, whereas climate scientist and numerical weather prediction (NWP) modelers can take their time. The receivers of the weather forecasts may be categorized as both "fast" and "slow" thinkers. For each of these three groups we can formulate three paradoxical statements.

The first paradox was coined by professor Tim Palmer at ECMWF. It applies primarily to meteorologists dealing with statistical verifications and validations: *what looks good can be bad; what looks bad can be good.* As we will see, even seemingly simple equations can be difficult to interpret.

The second paradox applies mainly to the users of weather forecasts: *It is not necessary that the weather forecasts are "good" as long as they are useful.* The value of a forecast lies in the decisions that follow from it whatever the verifications will eventually indicate (Katz and Murphy, 1997).

Finally, the third paradox, applying to weather forecasters, reminds them that in situations with forecast uncertainty they not only can make their best contributions to society, but they also have *the best opportunities to fully demonstrate their knowledge and experience.*

2.2. Paradox 1: What looks good can be bad: what looks bad can be good

Although NWP modelers and climate scientists, unlike weather forecasters, can take their time, there are still statistical pitfalls they may stumble into due to mathematically simple equations that may be difficult to interpret.

2.2.1. Systematic forecast errors are not only biases

The most trivial of equations, the arithmetic mean, harbors a lot of redundant duplicity and confusion. Figure 2.1 shows 2-m temperature forecasts for Tromsö in northernmost Norway. The forecasts are clearly too cold, they have a cold bias. But the mean error varies, it is not a "flat bias".

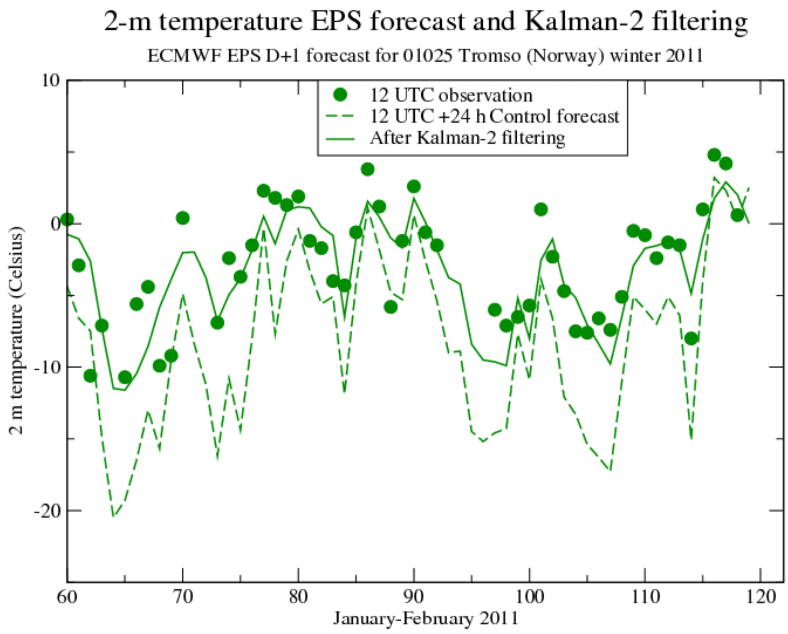

Figure 2.1. Observed (dots) and forecast 2-meter temperature (dashed line) for Tromsö, N Norway, in winter 2011. The full line is the result of a statistical adaptive correction based on a 2-dimensional Kalman filter algorithm, used to correct the most recent forecast recursively in light of the performance of previous forecasts.

But forecast errors can be *systematic* without constituting simple flat biases. A closer look reveals that the error depends on the forecast, smaller for mild conditions, larger for cold.

False systematic errors

Any NWP model has its own climate, in other words, average values and variability of meteorological parameters. For an ideal NWP model these values agree with corresponding values of the real climate. The model climate should also be *stable*, i.e. not change during the forecast lead time. However, verifications might sometimes misleadingly appear to indicate a *model drift*, with mean errors increasing with forecast time (Figure 2.2).

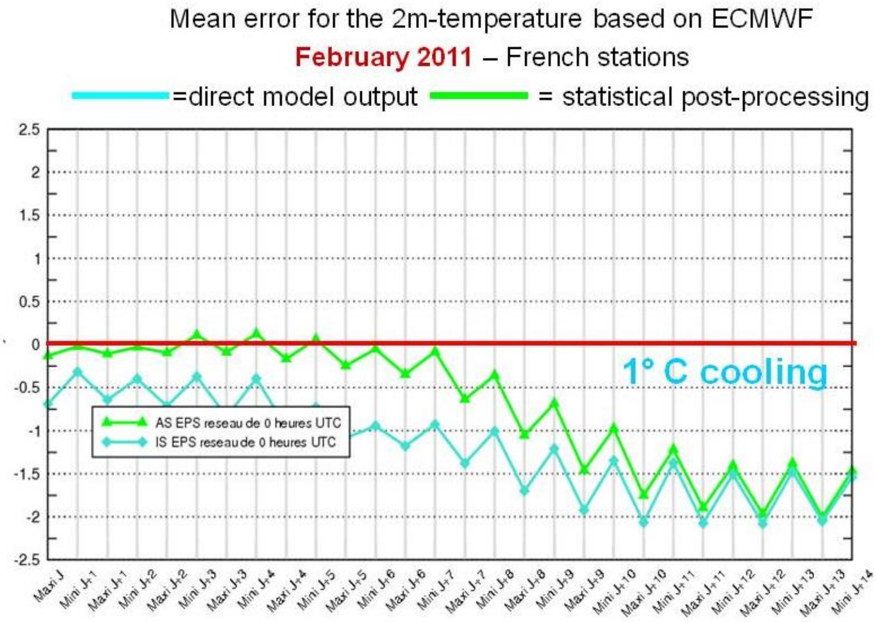

Figure 2.2. Verification statistics for the ECMWF model from Météo France in February 2011 with an apparent systematic error in the 2-meter temperature forecasts developing after some days increasing to an average 1.5-2 °C cooling (blue curve). Intriguingly the systematic cooling appears also when some statistical bias-correction has been applied (green curve).

But there might NOT be a problem with the model. Instead it might be due to the so called "regression to the mean effect" (Kahneman, 2011, pp. 175 ff).

When the forecasts at longer forecast ranges loses skill they increasingly randomly scatter around the model climate, which, as mentioned above, for a good model is the same as the real climate. This implies that over *long time verification periods* the mean of the forecast errors is zero. But over *shorter time spans*, weeks or even months, this might not be the case if the weather is abnormal. So for example, in February 2011, the mean temperature in France happened to be 1½-2 degrees warmer than the normal climate and thus the model climate. Consequently the forecasts for *longer rang*es, scattering around the model climate, *as they should*, gave an impression of a gradually cooling, or a false model drift. "*Looks bad, but is in fact good.*

There is much more to say about the "regression to the mean effect" in operational meteorology. As well as constituting a devious statistical artefact, it can also appear as a positive mechanism, e.g. the gradual approach of the NWP ensemble mean towards the climate average for longer forecast ranges.

Larger errors = better forecasts?

Another paradox is that a *good* NWP model may on average not necessarily have lower forecast errors than a *bad* model. To show this we will analyse the properties of the common verification parameter, the Root Mean Square Error (RMSE): in other words, the forecast (f) minus observations (o) summed and averaged over time (and/or place) after which the square root is calculated.

If we square the RMSE the mathematics will be more tangible and can be decomposed around climate (c) into three terms, each having its own story to tell (Figure 2.3).

$$\overline{(f-o)^2} = \overline{(f-c)^2} + \overline{(o-c)^2} - \overline{2(f-c)(o-c)}$$

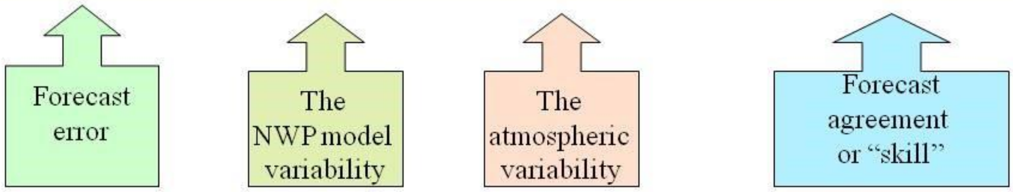

Figure 2.3. A decomposition of the square of the RMSE (left hand side) into terms of model and atmospheric variability (middle terms) and the covariance of the forecast and observed anomalies (far right-hand side term).

The RMSE (the left-most term) is not only dependent on the predictive skill of a model (last term on the right hand side) but also on the variability of the atmosphere and model (first two right-hand side terms). For an ideal NWP model these two terms should be the same. A deficient model that has lower variability than the atmosphere may therefore yield a lower RMSE for the wrong reason. What *looks good is in fact bad.*

Correlations and "jumpy" NWP output

Not only meteorologists but also the general public, in consulting their apps, for example, tend to judge the reliability of the automated forecasts from their steadiness. If they jump or wobble from one run to the other they are considered less reliable. Doing so is, however, to apply human moral criteria on soulless machines!

Assume we are interested in the weather three days ahead. If the first forecast we get is for dry weather, but the following two forecasts predict rain, we are more confident that rain will come than after a sequence that wobbles between dry and rainy weather (Figure 2.4).

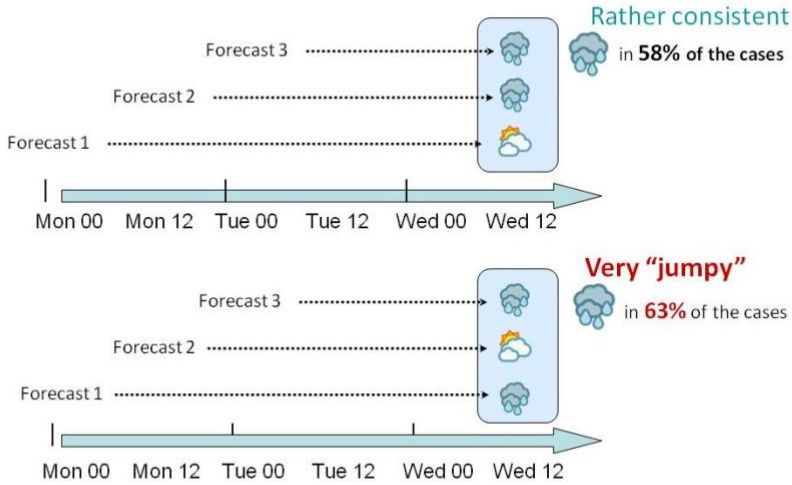

Figure 2.4. Schematic representation of cases with rather consistent and "jumpy" forecasts. Rain is slightly more likely after "jumpy" forecasts.

Verifications of the ECMWF and UK Met Office model output has shown that, contrary to popular belief, it is quite irrelevant if the last two forecasts are jumpy or not. The reliability is about the same or perhaps even slightly higher in the jumpy case. *What looks bad is good.*

This brings in the importance of correlations. There is always a temporal correlation between successive NWP runs because of inertia inherent in the data assimilation. The forecast agreement between two NWP forecasts only 6 or 12 hours apart should not be overestimated compared to an agreement between two NWP forecasts 24 hours apart, which are less correlated.

2.3. Paradox 2: It is not necessary that the forecasts are good as long as they are useful

How *bad* forecasts can be *good* can be demonstrated by analysing weather forecasts from a private weather company, Krick Weather Service (KWS) in 1930's California. At the time it successfully challenged the US Weather Bureau (USWB) forecasts and earned large amounts of money by issuing, by most standards, poor rain forecasts. Nevertheless they were very useful for important sectors of society (Lewis, 1994, p.73-74).

2.3.1. Rain forecasts in the 1930's California

The relevant statistics from this case are lost, so what follows is a reconstruction where we (for pedagogical reasons) assume a rather wet climate for California, with three rainy days out of 10. We further assume that the USWB in those days issued rain forecasts with the same frequency as they occurred, and one day ahead correctly forecast rain in 2/3 of the cases (Figure 2.5).

Ob / Fc	rain	dry
rain	20	10
dry	10	60

Figure 2.5. The forecast verification matrix assumed to reflect the skill of the USWB's one day rain forecasts in the 1930's. (Fc = forecast, Ob = observed)

The KWS relied on two important and money-rich clients: the Hollywood movie industry and the Californian hydraulic power companies. The former was sensitive to rain—if they'd arranged an outdoor shooting scene with thousands of extras and then it rained, they would lose a large sum of money invested in salaries. To them, the KWS provided forecasts which heavily over-forecast rain.

The power companies were in the opposite situation—if they used their water power faster than the stream flow coming in, the level of the water in the reservoir went down and the energy they could get out of each drop of water went down. If they thought it was going to rain and it didn't—that was very bad. To them, the KWS provided forecasts which heavily under-forecast rain.

So the KWS had these two prime sets of clients. The verifications of these heavily biased forecasts might have looked something like this (Figure 2.6 a and b):

Ob / Fc	rain	dry
rain	30	20
dry	0	50

Ob / Fc	rain	dry
rain	10	0
dry	20	70

Figure 2.6. The possible verification matrices of the KWS over-forecasts of rain (left) for the movie industry and under-forecast of rain (right) for power companies. In the first case rain was forecast almost twice as often as it occurred, in the latter only 1/3 of the cases it occurred.

The clients didn't bother about the over-all statistical skill of the forecasts. The movie industry wanted perfect forecasts for when dry weather was predicted, the power industry perfect forecasts when rainy weather was predicted.

2.3.2. How the US Weather Bureau could have fought back

It is not known what the USWB did to meet the competition. What follows is a counterfactual speculation to show what actions could have been taken. The USWB could, for example, have decided not to issue weather forecasts on occasions when they were uncertain, about 40% of the time. This sounds ridiculous, but let us see what it leads us to.

Ob / Fc	rain	dry
rain	20	10
dry	10	60

Ob / Fc	rain	dry
rain	10	0
???	20	20
dry	0	50

Figure 2.7. The USWB forecast matrix when it abstains from making forecasts (indicated by "???") on 40 days out of 100.

The movie industries' moguls and the power industries' tycoons might then have reasoned like this: "To be on the safe side, let us interpret '???', in our own interest, as if 'no rain' or 'rain' respectively had been forecast." In the case of the movie industry this would have resulted in the forecast matrix in Figure 2.8a.

Ob / Fc	rain	dry
rain	10	0
???	20	20
dry	0	50

Ob / Fc	rain	dry
rain	30	20
dry	0	50

Figure 2.8a. The movie industry interprets the "???" forecast as if rain is possible and acts accordingly.

The power industry would, on the other hand, in the absence of forecasts would have taken actions as if "no-rain" had been forecast and this would have resulted in this forecast matrix.

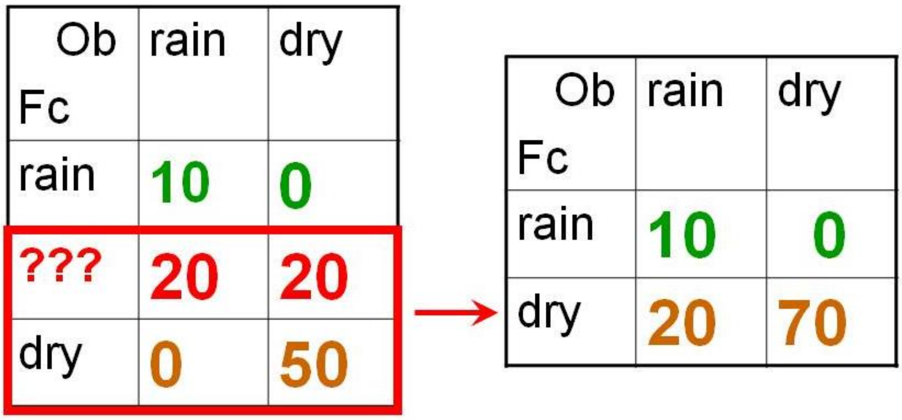

Figure 2.8b. The power industry interprets the "???" forecast as if rain is not likely and acts accordingly.

By comparing Figures 2.8a and 2.8b with Figure 2.6, we can see that the USWB, with this hilarious approach, would have been able to provide the movie and power industry customers with information of equal value as the KWS—and probably for free!

It is, however, not a very attractive policy for a weather service to abstain from giving forecasts just because the atmospheric situation is difficult to predict. The USWB could therefore had gone one step further and asked their weather forecasters to specify their uncertainty in more detail, to break it down into categories of "almost certain," "rather certain," "fairly uncertain" and "rather "uncertain". To each a probability value could then be attached. We would then have the right hand matrix in Figure 2.9.

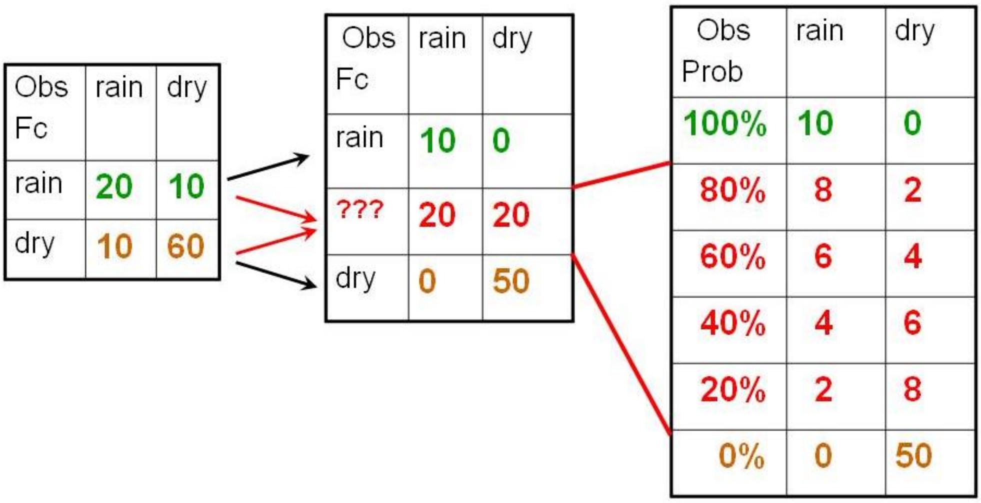

Figure 2.9. The break-down of purely categorical, yes-no, forecasts into forecasts of increasingly non-categorical (probabilistic) nature.

The USWB would then, in a short period of time, have been able to abandon the approach of abstaining from making forecasts and instead issue probability forecasts in a spectrum of 0%, 20%, 40%, 60%, 80% and 100%. The movie industry would then be free, if they so wanted, to act only on 100% probability forecasts, the power industry only on 0% probability forecasts. Other customers, or the general public, could, depending on their specific interest, have reacted at other probability values.

It is worth noting that probability forecasting has old roots in American forecasting, having been championed by the former chief of USWB Cleveland Abbe (1838-1916), among others.

2.3.3. The necessity of over-forecasting extreme events

We saw that the movie and power industry, when provided with categorical forecasts, were best served if "their" weather was over-forecast. It is a general rule that if weather forecasters, for one reason or the other, cannot issue probability forecasts, the best way to provide useful forecast information of significant or extreme weather events is to over-forecast them. *It may be better to warn once too much than once too little.*

Venn diagrams, named after its inventor John Venn (1834-1923), are a useful tool for intuitive statistics and help to clarify this. In Figure 2.10 the green circle represents the rare frequency of "bad weather" in some region. The equally sized red circle represents forecasts which are "well-tuned," in other words, they are issued with the same over all frequency as the "bad weather" but misplaced in time or location.

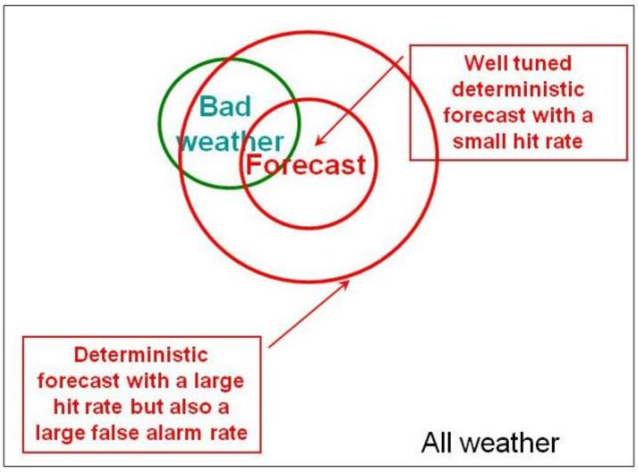

Figure 2.10. A typical Venn diagram with circles representing "bad weather" and two types of forecasts. See text for further details.

Only a fraction of "bad weather" cases are precisely captured. By over-forecasting (the larger red circle) most cases are caught, but at the price of many false alarms. Since bad weather is harmful to society, this over-forecasting may be beneficial and justified.

2.3.4. The difference between "probable" and "typical"

According to Kahneman (2011, pp 156 ff), humans have difficulties distinguishing between the terms "typical" and "probable." Some meteorologists tend to have more confidence in full-scale deterministic NWP forecasts, which look realistic, than smooth ensemble mean maps, since they look unrealistic, although the predicted values in the latter are more "probable", or in other words, more likely to be closer to the truth (Figure 2.11, image b).

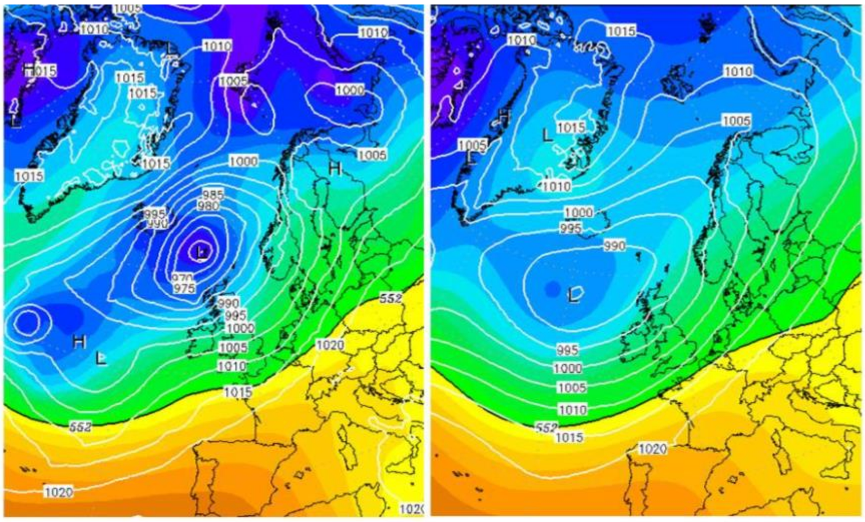

Figure 2.11. The NWP forecast map to the left (a) depicts a "typical" weather situation in the medium range as produced by the NWP. Values taken from the "atypical" ensemble mean map to the right (b) are actually more "likely" or "probable".

Anyone who strives to make a "perfect forecast" should choose the full-scale deterministic forecast, because it is not impossible that it verifies! However, another strategy is to always make forecasts which are *as little wrong as possible*, which would favor the use of the smooth forecast.

2.3.5. More from Kahneman's book

There are other examples of intuitive statistics relevant for operational meteorology.The "availability error" (Kahneman, 2011, pp. 129 ff), the ease which instances come to mind, might explain why afternoon thunderstorms forecast by humans seem to be better 18-24 hours ahead than 6-12 hours ahead. The former are made in the afternoon the day before, when there often are a lot of thunderstorms "available". The 6-12 hour forecasts are made in the early morning with mist and low stratus often covering the sky, making the forecaster concentrate on forecast of visibility and cloud bases.

Another example is the "framing effect" (Kahneman, 2011, pp. 363 ff),which explains why the statement, "the bottle is half full," tends to be regarded as more favorable than the mathematical equivalent formulation, "the bottle is half empty." Framing may help meteorologists present probability forecasts or help the users to make correct interpretations. A major city in Britain was once warned about a 20% probability for a severe thunderstorm *on their specific location*. No action was taken, in contrast to when the forecasters on a later, and meteorologically similar occasion, gave them the equivalent forecast of a 70% probability for a severe thunderstorm *somewhere in the region*.

In cases of forecasting rare events it may be helpful to know the climatological probability or "base rate" (Kahneman, 2011, pp 146 ff). A forecast of 20% for an event with "base rate" 2% will get more attention if presented as "10 times more likely than normal".

The "confirmation bias", the "halo effect" and the "primacy effect" (Kahneman, 2011, pp.79 ff) explain the tendency to base decisions on the NWP that arrives first, and then judge the following NWP forecasts in the light of this, in particularly when it comes from a model with high reputation.

2.4. Paradox 3: It is in uncertain situations that the weather forecaster can excel

It always impresses humans when someone takes personal responsibility. The same applies to the public in their relation to weather forecasters. Forecasters ought to treat irritating problems with jumpy computer forecasts, misleading statistical interpretations or missing data as internal matters of the forecast office.

Jumpy, inconsistent and diverging NWP forecasts are likely a reflection of a difficult weather situation. These situations greatly interest the public and the end-users, not the technical details. Therefore, from operational experience the following communication approaches regarding uncertainty have proved useful.

1. Invite the customer/public to share your inside information by giving a brief description of the complexity of the weather situation, avoiding discussion of the technical details of NWP jumpiness, misleading statistics, and missing data.

2. Formulate the uncertainty in an appropriate way, from verbal expressions such as "probable", and "possible" to providing numerical probabilities for those who can make use of these.

3. If appropriate, couch the forecast in more concrete, possible actions in general terms such as "If I were you...I wouldn't risk . . .," for example.

The TV forecaster in Figure 2.12 on one hand avoids the Scylla of being overconfident and categorically promising no thunderstorms and on the other hand avoids the Charybdis of appearing helpless by referring to contradicting computer guidance.

Figure 2.12. By taking personal responsibility this forecaster displays her knowledge of convective processes and long experience of summertime weather. Her qualitative probability forecast provides a good basis for decisions because it can be understood by everybody.

This way of communicating is facilitated by insights into elementary intuitive statistics. Since the start of weather forecasting in the 1860's meteorologists have more or less knowingly applied intuitive statistics. It should improve the forecasters self-confidence to know that their forecast experience has support in mathematical theories.

2.4.1. Summary and a look ahead

The science of meteorology displays some paradoxical features, often against common sense. It has been shown that verification statistics are sometimes highly deceptive, that weather forecasts can be less useful when they are accurately formulated than when they are less precise and finally that it may be in cases when weather forecasters feel they are in trouble due to highly uncertain situations that they have their best opportunities to excel.

These paradoxes are not explained by shortcomings in the science of meteorology, but limitations in our human common sense. As Daniel Kahneman shows in his book about intuitive statistics, we also run the risk of misleading ourselves in other walks of life.

Education programmes in intuitive statistics for meteorologists are not supposed develop expert statisticians, but well-informed users of statistical information. Such studies will help forecasters not only better understand how to draw the right conclusions from their experiences, but also how to make their forecasts more useful, understand how their customers react to their forecasts and of course, how to better communicate with them.

2.4.2. Acknowledgement

Most of the ideas presented in this article derive from my own experience as an all-round forecaster at the Swedish Met Service (SMHI), as a senior scientist at ECMWF and, in particular, discussions with colleagues at the British Met Office during my time there 2008-10. The idea of meteorologists as intuitive statisticians was first presented in an interview in the ECMWF Newsletter (Persson, 2011, see also Persson 2014a and b). See also Doswell III (2004) for views similar to those expressed in this article.

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3. Educational strategies to achieve global awareness of climate change and its impact

Rahul Chopra, Trans-disciplinary Research Oriented Pedagogy for Improving Climate Studies and Understanding (TROP ICSU) and Indian Institute of Science Education and Research (IISER), Pune, India; Anita Nagarajan and Aparna Joshi, Indian Institute of Science Education and Research (IISER), Pune, India; Nathalie Fomproix, and L.S. Shashidhara, International Union of Biological Sciences (IUBS), Paris, France. This has been submitted on behalf of all the partners of the TROP ICSU project

Abstract

Climate change constitutes a global challenge with significant adverse impacts on sustainable and equitable development. A critical step towards addressing this challenge is to increase the awareness of climate change and the understanding of climate science among current and future generations. Education will help increase the knowledge required to identify appropriate mitigation and adaptation actions that could minimize or even reverse the impacts of climate change at global, regional and national levels. The Trans-disciplinary Research Oriented Pedagogy for Improving Climate Studies and Understanding (TROP ICSU) project provides educational resources that can be used by teachers to increase the awareness of the causes and effects of climate change among students at the high school and undergraduate levels. The TROP ICSU project has collated and curated a repository of teaching resources that can be used by educators to teach a topic in a discipline by using examples, case studies, and activities related to climate change. The project demonstrates a novel way of integrating climate change education with the existing curriculum. The TROP ICSU digital resources, while being globally relevant, can be easily adapted to local contexts. The usage of these teaching aids is a novel form of pedagogy that can create an interactive and engaging learning experience. This methodology will help in the development of critical thinking and reasoning skills among students while, at the same time, enhancing their conceptual understanding of topics in the discipline. This is an incentive built into these modules so that a large number of teachers would use them globally. Detailed lesson plans that can serve as guidelines for teachers at high school and undergraduate levels have been developed under this project. These have been reviewed and validated by subject experts for scientific correctness and by teachers for ease of use in their teaching.

Keywords: education, climate change, climate change education, curriculum, digital pedagogy, teaching resources, lesson plan

Introduction

Climate change is one of the most significant issues of our times. Its impacts include increased temperatures, rise in ocean levels, ocean acidification, loss of terrestrial and marine biodiversity, increased health risks, and reduced agricultural productivity. Potential solutions to address impacts of climate change require an awareness of the risks it poses to humanity. Considering that future generations are likely to be more impacted by climate change than the current generation, education has to equip all learners to address the challenges posed by climate change. To this end, there is a need to create, employ, and adopt educational modules that are effective in imparting climate change-related awareness among students.

3.1. Climate Change Education Today

Most of the resources available for climate change awareness have been developed as extra-curricular content[3]. They are reviewed in Chopra et al. (2020) and listed on the TROP ICSU website at https://tropicsu.org/un-resources/ and https://tropicsu.org/educational-resources/. As core curriculum, climate and climate change education is currently underrepresented in most parts of the world (Wise, 2010). It is most commonly offered only at the undergraduate level and typically as part of the Earth Sciences or Environmental Sciences majors; many countries offer specialized, skills-oriented courses at the graduate level. Thus, the current curricular structures severely restrict the number of learners of climate science and climate change.

Climate change adaptation and mitigation require local solutions that may or may not be scalable or adaptable to different parts of the world. Thus, people and experts from all over the world should be involved in addressing this issue systematically and innovatively. For this to happen, a large number of people across the world must be competent and sensitive to the problems of climate change. Therefore, it is vital that the education system allows increased opportunities for learning about this critical issue. While significant changes to the curricular structures in different countries can often be challenging and time-consuming, new pedagogical interventions are more acceptable. The challenge lies in ways of training teachers, who are teaching their discipline-specific topics, to introduce climate-change related content in their classrooms.

3.2. The TROP ICSU Project: Integrating Climate Change Education with Existing Curriculum

The Trans-disciplinary Research Oriented Pedagogy for Improving Climate Studies and Understanding (TROP ICSU) is a global project funded by the International Science Council (ISC), led by the International Union of Biological Sciences (IUBS), and co-led by the International Union for Quaternary Research (INQUA). The project partners include several other international science unions, national academies of several countries, national research centers, and United Nations agencies. The project aims to increase the awareness of climate science, climate change, and related impacts among all high school and undergraduate students globally.

The TROP ICSU project has developed, collated and curated, as well as validated, novel pedagogical tools that are easy for any high school or undergraduate teacher to use without deviating from their regular discipline-specific teaching. Detailed information and lesson plans provided by the TROP ICSU project explain how a climate change topic can be used as an example, case study, assignment, or activity for better explanation of a discipline-specific topic. This approach allows high school and undergraduate teachers of different disciplines to continue to teach using their existing syllabi in the curriculum of their respective countries. Additionally, the use of TROP ICSU resources will lead to increased awareness of climate change among students in their classrooms. This approach strengthens the educational system by providing better clarity of core curriculum concepts to students and increased opportunities to develop and enhance

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[3]Available educational resources for climate change include Science Education Resource Center at Carleton College (https://serc.carleton.edu/climatechange/index.html), NASA's Global Climate Change (https://climate.nasa.gov/resources/education/), Climate Literacy & Energy Awareness Network (https://cleanet.org/index.html), University Corporation for Atmospheric Research (https://scied.ucar.edu/climate-change-activities), The Teacher-Friendly Guide to Climate Change (https://teachclimatescience.wordpress.com/chapters/), the UN CC:e-Learn resources (https://unccelearn.org/), MetEd resources of the COMET program (https://www.meted.ucar.edu/index.php), WMO Learn from the WMO Global Campus portal (https://public.wmo.int/en/resources/training/wmolearn), individual faculty teaching webpages (e.g., David Archer http://forecast.uchicago.edu/index.html).

their critical thinking and analytical abilities. Thus, this novel method to integrate climate education with the core curriculum has the opportunity to positively impact learning outcomes of our current educational system by further enhancing the general preparedness of the future generation in addressing problems of climate change.

3.3. TROP ICSU Resources for Teachers: Teaching Tools and Lesson Plans

The TROP ICSU website contains the suite of collated, curated, and reviewed digital educational resources described above. These include teaching tools and lesson plans that a teacher from a particular discipline can use to teach a topic using a climate-related example, activity, or case study, thereby integrating climate education in their existing syllabi. All resources collated or developed under this project have been reviewed and validated by subject experts for scientific correctness and by teachers for ease of use in their teaching. To ensure that the resources are useful globally, subject experts and teachers in various countries were involved in the feedback and review of the teaching tools and lesson plans through a series of face-to-face workshops. A detailed description of the methodology, which includes a multi-stage review process, can be found at https://tropicsu.org/project/methodology/.

3.3.1. Teaching Tools

The TROP ICSU website currently contains approximately 150 computer-based teaching tools (https://tropicsu.org/resources/pedagogical-tools-examples/) that can be used to teach a topic in a particular discipline with the help of a climate-related example. The Teaching Tools are categorized by Discipline, Tool Type, Climate Topic, Grade Level, Region, and Language.

Currently, the teaching tools cover the following disciplines: Biological Sciences, Chemistry, Earth Sciences, Economics, Environmental Sciences, Geography, Humanities, Mathematics, Physics, Social Sciences, and Statistics.

A select list of topics in Mathematics that can be taught using a climate-related example is shown in Figure 3.1 as an example. A complete list of topics from all disciplines that can be integrated with climate education can be found at https://tropicsu.org/resources/pedagogical-tools-examples/pedagogical-tools/, organized under the respective disciplines.

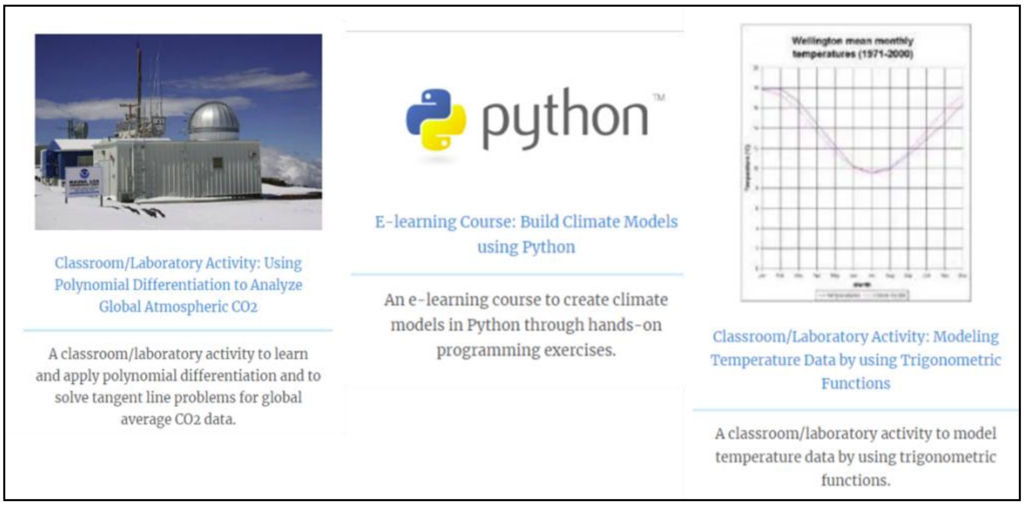
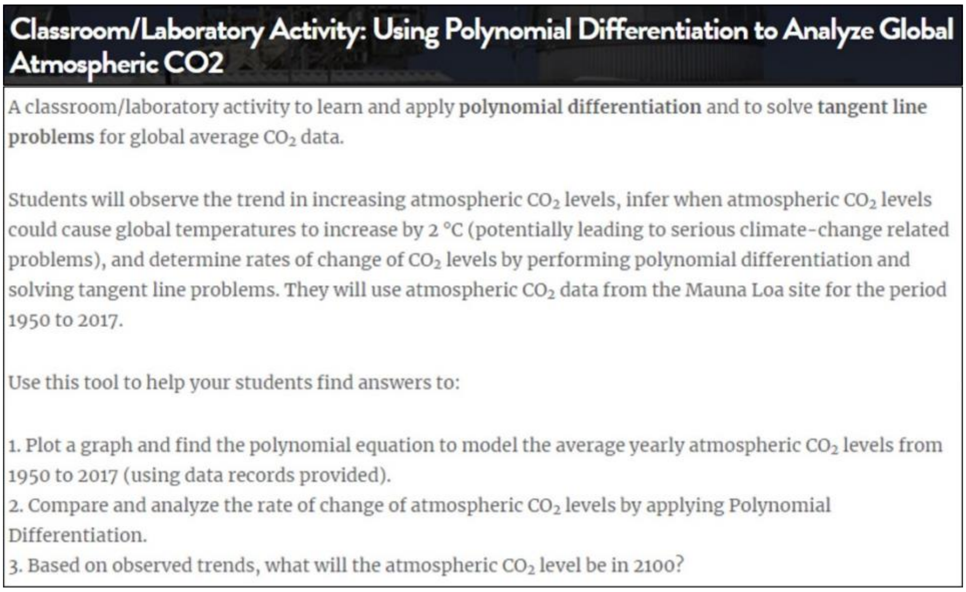


Figure 3.1. Snapshot of different teaching tools that a Mathematics teacher can use to teach topic(s) in their curriculum using a climate-related example.

Topics in this image include Calculus, Trigonometry, Functions, Polynomial Differentiation, Numerical Modeling, Mathematical Modeling, Computer Programming, and more.

For each teaching tool, the topic(s) in the discipline that can be taught using the tool, a summary of how the tool integrates climate understanding for the learner, questions to assess student learning, and detailed information about the tool are provided. Figure 3.2 shows the description for a sample teaching tool in Mathematics.



Classroom/Laboratory Activity: Using Polynomial Differentiation to Analyze Global Atmospheric CO2

A classroom/laboratory activity to learn and apply **polynomial differentiation** and to solve **tangent line problems** for global average CO_2 data.

Students will observe the trend in increasing atmospheric CO_2 levels, infer when atmospheric CO_2 levels could cause global temperatures to increase by 2 °C (potentially leading to serious climate-change related problems), and determine rates of change of CO_2 levels by performing polynomial differentiation and solving tangent line problems. They will use atmospheric CO_2 data from the Mauna Loa site for the period 1950 to 2017.

Use this tool to help your students find answers to:

1. Plot a graph and find the polynomial equation to model the average yearly atmospheric CO_2 levels from 1950 to 2017 (using data records provided).
2. Compare and analyze the rate of change of atmospheric CO_2 levels by applying Polynomial Differentiation.
3. Based on observed trends, what will the atmospheric CO_2 level be in 2100?

Figure 3.2. Sample teaching tool in Mathematics for teaching introductory calculus by using atmospheric CO_2 concentrations. This tool was developed by Thomas Pfaff and is available at http://sustainabilitymath.org/calculus-materials/. See the description of this teaching tool at https://tropicsu.org/mauna-loa-yearly-average-co2/.

Teaching tools are of different types such as classroom/laboratory activity, reading, video, audio, game, visualization, e-learning course, and teaching module. They are also mapped to climate topics and grade level**.** Location-specific tools and tools in different languages are also provided.

3.3.2. Lesson Plans

The TROP ICSU website contains detailed lesson plans that integrate several topics in the Biological Sciences, Chemistry, Earth Sciences, Economics, Environmental Sciences, Geography, Humanities, Mathematics, Physics, Social Sciences, and Statistics with climate-related topics. These lesson plans, each with a detailed step-by-step guide, show teachers how different digital teaching tools can be used to integrate the teaching of a topic in their discipline with a climate topic.

Each lesson plan contains the following sections:

- *Introduction* **–** highlighting the topic(s) in a discipline and the link to a climate topic;
- *About the Lesson Plan* **-** including approximate time required and grade level;

- *Contents* **–** listing the different digital teaching tools used in the lesson plan;
- *Step-by-Step User Guide* **-** consisting of a detailed set of instructions on the use of different digital tools to explain the topic in the discipline while integrating it with climate science or climate change;
- *Questions/Assignments;*
- *Learning Outcomes*;
- *Additional Resources*;
- *Credits/Acknowledgements* of the authors**.**

Each lesson plan is provided as a template, and individual teachers can customize the lesson plan to best suit their requirements.

Figure 3.3 shows an example of a lesson plan from the Biological Sciences. A complete list of lesson plans can be found at https://tropicsu.org/resources/lesson-plans/ under the respective disciplines.

About Lesson Plan

Grade Level	High school, Undergraduate
Discipline	Biological Sciences
Topic(s) in Discipline	• Natural Selection, Selective Pressure • Evolution, Speciation • Evolutionary Hotspots, Genetic Polymorphism • Genetic Variants, Allelic Frequencies,
Climate Topic	Climate and the Biosphere
Location	Global
Language(s)	English
Access	Online
Approximate Time Required	30-60 min

Questions

Use this lesson plan to help your students find answers to:.

1. *What is Darwin's theory of natural selection? Illustrate this with an example.*
2. *What is genetic polymorphism?*
3. *Why is genetic variation critical to the survival of a species?*
4. *What is selective pressure?*
5. *How does it affect allelic frequencies in successive generations of a population of*

Contents

Reading (~10 min)	An in-chapter reading that briefly introduces Darwin's theory of natural selection. Go to the Reading (Chapter 3, pgs 11-16)
Interactive video (10 min)	An interactive video to illustrate Darwin's theory of natural selection. It uses the example of fur coat colour in pocket mice. Go to the Video
Video and associated reading (~10 min)	A video and associated reading that shows that climate change can be a selective pressure in natural selection. It uses the example of coat colour in the Snowshoe hare populations in North America. Go to the Video Go to the Associated reading
Classroom/Laboratory Activity (Optional) (~15-30 min)	An optional computer lab-based simulation activity to illustrate the changes in single gene allelic frequencies under a varying selective pressure. Go to the Activity

Step-by-Step User Guide | Questions/Assignments | Learning Outcomes | Additional Resources | Credits

Here is a step-by-step guide to using this lesson plan in the classroom/laboratory. We have suggested these steps as a possible plan of action. You may customize the lesson plan according to your preferences and requirements.

Step 1: Topic introduction and discussion (Reading)

1. Use the in-chapter reading, "Major Themes in Evolution", from the National Academies Press (Chapter 3, pgs 11-16) to introduce the topic of natural selection.
2. Use this resource to explain how Darwin and Wallace proposed the theory of natural selection on variants within a species that explained the process of evolution.
3. Also explain how Mendel's work explained how favored characteristics are inherited and eventually lead to speciation.
4. Go to the Reading

Step 2: Illustrate the theory with an example (Interactive video)

1. Use this interactive resource titled "The Making of the Fittest: Natural Selection and Adaptation" by Howard Hughes Medical Institute to illustrate an example of natural selection.
2. Explain how a selection pressure of dark coloured surfaces on light coloured pocket mice has resulted in a natural selection for darker coloured pocket mice that are better camouflaged against predators.
3. Use the questions from this resource to quiz students on their understanding of the theory of natural selection when a selective pressure is in play.

Step 3: Correlate this understanding to a climate related example of natural selection in another species (video and associated reading)

1. Play the video, "Will Snowshoe Hares Win the Race between Evolution and Climate Change", by National Geographic to explain how reduced snowfall due to a warming climate, behaves as a selective pressure on the seasonal coat colour polymorphism of the Snowshoe hares in North America.
2. Snowshoe hares change coat colour in different seasons- white when the ground is snow covered and brown when it is not-to protect themselves from predators. Use the resource to stress that that snowshoe hares from areas where the ground is snow-covered or from areas where the ground is rarely covered with snow through the year, show no seasonal change in coat colour.
3. Emphasize that the areas in between these regions are where most hares that seasonally change their coat colour can be found.
4. Use the associated reading, "Mills Lab publishes new article in Science: Research identifies areas where evolution could rescue animals threatened by climate change" by the Mills Lab, University of Montana, to show that research on the Snowshoe hares has established that these intermediary zones are evolutionary hotspots that show a higher percentage of non- colour changing brown snowshoe hares due to the ground remaining snow free for longer as a result of a warming climate.
5. Explain how this is an example of 'evolutionary rescue' of a species by selection for a character that affords better protection from predators in a changing environment, in this case, due to climate change.
6. Go to the Video
7. Go to the associated reading

Figure 3.3. A sample lesson plan describing how a Biology teacher can teach natural selection using climate-related examples.

3.4. Results, Challenges, and Future Work

The TROP ICSU team has been conducting workshops with high school and undergraduate teachers and climate experts in several countries. So far, workshops have been conducted for teachers in India, Uganda, Bhutan, South Africa, Egypt, and Australia. The aim of these workshops is to introduce teachers to the teaching tools and lesson plans. Additionally, participants carry out several group activities such as online reviews of teaching tools and lesson plans from their discipline for appropriateness and ease of use in their classrooms and the creation of lesson plans that integrate topics in their discipline with a climate topic. Group discussions help in the review of teaching resources and the exchange of ideas across disciplines. Several interesting lesson plan ideas from workshop participants have been developed into lesson plans published on the TROP ICSU website. These teacher-submitted lesson plans can be found at https://tropicsu.org/resources/lesson-plans/teachers-lesson-plans/.

Preliminary results of the feedback received from teachers indicate that most teaching tools and lesson plans are effective in explaining one or more topics in different disciplines and in integrating these topics with climate science. According to most teachers, the usage of these teaching tools and lesson plans will increase the awareness of climate change among their students. A majority of the teachers intend to use the teaching tools and lesson plans in their classrooms for their students after slight modifications. A majority of the teachers indicate that they would prefer to use educational resources from their location and that the TROP ICSU project should list more such location- and language-specific teaching tools on the platform. Overall, teachers have been extremely enthusiastic to use new digital pedagogical tools and to create lesson plans that integrate topics in their discipline with climate topics using tools from their region so that their students will have greater awareness of climate change.

Some of the challenges faced during the implementation of the TROP ICSU project include teachers' unfamiliarity with digital pedagogical techniques and digital pedagogical resources. Furthermore, several teachers of different disciplines are not confident about climate topics because they have not received training in the field. The latter challenge has been addressed by providing several introductory climate science resources for teachers on the project website at https://tropicsu.org/resources/pedagogical-tools-examples/climate-topics/intro-to-climate-change/.

The TROP ICSU project will continue to develop and increase the number of educational resources for teachers from different disciplines. The number of disciplines and topics within these disciplines that can be integrated with climate science will be increased. Validation of the educational resources with climate experts will continue.

The next phase of the project involves disseminating the TROP ICSU educational resources through the global partner network and building new partnerships with educational agencies and other organizations.

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4. Teaching Programming to Meteorology Students with Functional Sections of Code Instead of Traditional Methods

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Abstract

The WMO Regional Training Center at the University of Costa Rica has been improving the way programming is taught to meteorology students. Traditional methods can focus on the syntax of one specific language or computer technicalities that are of little use to the new programmer in the area of meteorology. We are teaching programming by using Functional Sections of Code (FSCs) and interpreted languages like Python. Using small sections of functional code has allowed students to overcome the challenges of computer programming by understanding first how to instruct computers, how the code works to achieve specific functions and only later the technical aspects of the language. This method has prepared students better for assignments, projects and research. It has already been used for two years in the Meteorological Instruments course and the Scientific Programming course, the latter dedicated to capacity building for undergraduate students in Meteorology and Physics.

Keywords: Meteorology; Programming; Python; Flipped Classroom

Introduction

Since the advent of modern, accessible computers, computers have been incorporated in many (if not all) areas of meteorology. Personal computers, scientific workstations as well as large-scale servers are regularly used by professional and technical meteorologists. From measurement of atmospheric variables to generation of synoptic maps and climate studies, computers serve us in many ways. However, the products generated by computers are only as good or fitting as the programs utilized. This can be particularly important in operational meteorology and research.

Meteorology curricula are usually filled with courses in science and its applications. Physics, mathematics, fluid dynamics, synoptic meteorology and alike subjects are covered vastly in most undergraduate programs. On the other hand, important aspects from Computer Science and Software Engineering are regularly left out or poorly covered, leaving it to the student to obtain these capacities and gain practical experience. A direct consequence of not covering computer programming and programming languages appropriately is that students can struggle with assignments, projects and thesis work that require such competencies. Similar gaps can occur in the workplace or graduate school nevertheless, the software created by scientists can be of good quality. (Easterbrook & Johns, 2009).

Traditional courses in computer programming are focused on the syntax of specific programming languages. For example, courses on one specific language can focus on words that describe a certain action within the language (e.g. providing memory for a variable), with exercises and problems that are completely unrelated to meteorological applications. The methodology used in traditional courses combined lectures, homework and laboratory activities. This method was not enough for meteorologists (Davenport, 2018). The flipped classroom is an alternative approach to traditional teaching that takes lectures outside the class and class time can be dedicated to problem solving and discussion, as described by Puarungroj (2015). In the case of our courses, we prepared slides with textual information shared in our institutional site, as well as short videos, or online resources such as tutorials or modules (for example, from the MetEd website). The flipped classroom can be used for teaching programming to meteorologists

(Davenport, 2018; Mithun & Evans, 2018). Mithun and Evans (2018) found that switching from a traditional to a flipped, active classroom better prepared students and created an improvement in the relationship with the teacher, hence increasing participation. Mithun and Evans showed that students' performance in problem-solving and modeling skills increased.

In traditional courses very little attention is paid to the action of instructing a computer with an algorithm (programming), the logic behind those instructions, and ultimately the structure and its consequences. Most meteorologists that are trained this way end up with a collection of files (such as scripts and/or programs) that contain large numbers of lines of code that together generate a specific action, but they gain limited understanding of the logic and/or the syntax.

According to a poll that took place in 2016 among meteorology alumni at University of Costa Rica (UCR), there were too few computer programming skills being taught in the undergraduate program in meteorology. The Department of Atmospheric, Oceanic and Planetary Physics (DFAOP in Spanish), in charge of the Meteorology program, decided that actions were necessary to incorporate appropriate changes in the curriculum. Such changes can take a long time and at this moment the meteorology program at the University of Costa Rica is under review and will consequently adapt to new requirements and needs of students and stakeholders. In the meantime, current students needed to be better exposed to computer programming, and several changes, especially in the teaching methodology, were applied immediately. As a WMO Regional Training Center, we welcome students from the region with very different backgrounds. Speeding the learning process in programming while maintaining quality appears to be crucial for the student's success. In this chapter, innovations in teaching computer programming and programming languages are described. An example of how to apply this methodology to programming in satellite meteorology to obtain a simple product is included.

Innovation

At UCR we have implemented a non-traditional approach to teaching scientific programming for students of Meteorology and Physics. We flipped the classroom by asking students to learn the basic concepts by reading online books (freely available) and specific chapters of textbooks. The teacher utilizes (during class) some case studies to present how specific problems have been solved using scientific programming. Later, a current need or problem is presented along with Functional Sections of Code (FSCs, as we have come to name them in class) that could be used to provide a solution. From this moment on, the students work in a collaborative environment to understand the functionality, applications, and adaptation of the FSC.

We have also flipped the contents. Instead of teaching syntax at the beginning we start by showing how instructions work, the meaning of variables within instructions, and how a chain of events and actions (algorithm) can take us from a problem/need to a solution. For example, instead of teaching the word for allocating memory, we first teach why this is necessary with realistic and applied problems. When the time comes to look at code, instead of teaching words that have meaning only within the computer language we start with a small FSC that have meaning (functionality) for the students. Such functionality can be as simple as plotting a time series, calculating statistical values or reading a netCDF files' contents.

An FSC is not necessarily a minimum working example, as it groups a few lines of code that entail certain functionality for meteorologists. The syntax is later studied (if there is a need) to better understand and/or improve the already functional sections of code. This has allowed us to have better results in our institution as meteorology students lose the fear of programming and easily incorporate their creativity and knowledge into their programs.

This innovative change in how to teach computer programming is composed of different tactics from Active Learning Environments and Flipped Classrooms, creating a gradual change in the students' roles. The main role in the classroom moves from the teacher to the student, as discussed by Cesar et al. (2017), to maximize practical application and increase participation. An important variation compared to other methods is that we go from the general usage of FSC to the detail of the programming language.

Interpreted languages (specifically Python) have been chosen for the implementation of this methodology as it is considered to facilitate the learning process. The basic steps in this methodology can be summarized as follows:

- Begin the process with programming logic and how to write an effective algorithm. The first few lessons of programming should be devoted entirely to problem solving, organization of instructions and the logic behind the algorithm. The block diagram in Figure 4.1 shows how during a specific program information should be extracted from data files, then processed and later visualized. The colour-coded text in the diagram will be useful when introducing code that carries out those actions, as it can be presented with the same colouring scheme.

- Use a tool that facilitates the interaction between the student and the computer. Traditionally, an integrated development environment (IDE) has been used for teaching programming, nevertheless the utilization of an interactive computing tool like Jupyter Notebooks can be more effective while teaching programming to scientists. An IDE will be a natural choice for more elaborate work once the student is more skilled in programming.

- Never introduce programming with the technical aspects about the language (e.g. syntax, programming paradigm). Instead, use small functional sections of code (FSC) to show how it can be applied to solve problems in a simple and elegant manner. Once students see that the section of code is understandable, they will no longer be intimidated by it.

- Use tiny FSCs first, then complicate the code as needed to improve functionality or the products. The FSCs used in class should change with time. We have found that an iterative and incremental development fits the needs of meteorologists because it is easier to see the program grow based on needs. At the same time, it introduces a useful way of developing software. For more information in this process see Hossain et al. (2009).

- Explain the details about the programming language only as needed. Some students bring questions to class, for example: What is Object-Oriented Programming (OOP)? or, what is a Method in Python? These opportunities should be used to move students further into the language.

These previous considerations have served us well to improve programming skills in meteorology students. Some additional considerations regarding developer skills and previous experience have been found and will be mentioned below.

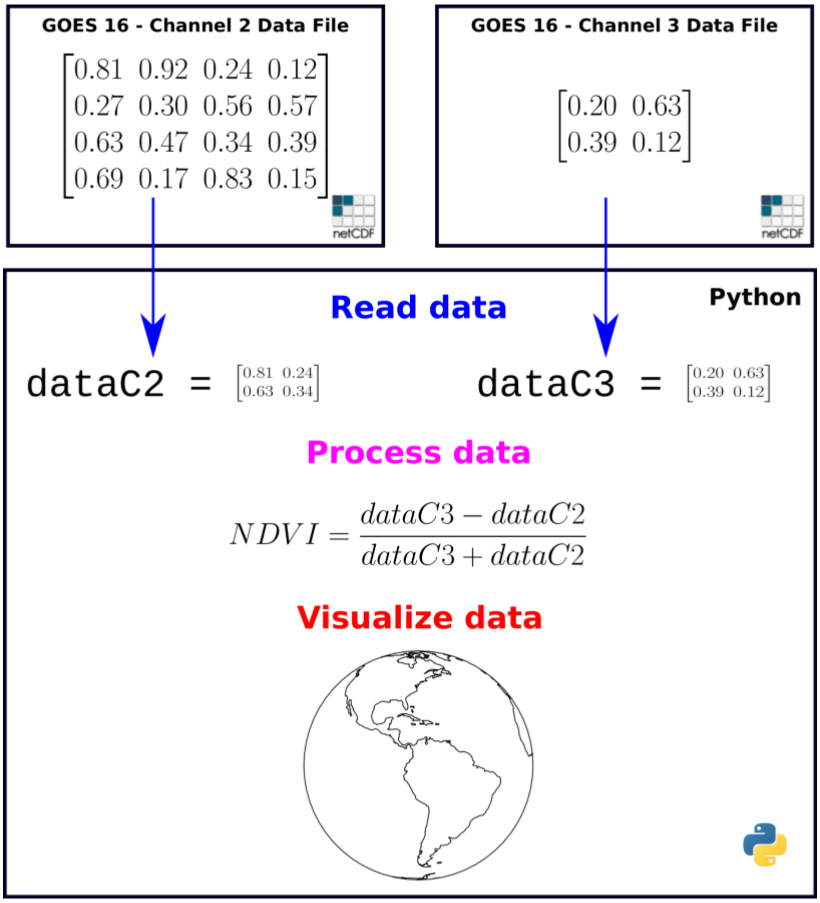

Figure 4.1. Block diagram including relevant parts of the analysis and design stages necessary for a clear road map of the input, processing and output of the program. The text in colour is important as lines of code could later be associated to those actions based on their colour.

Challenges

During the implementation some setbacks and/or problems have been found. Most Meteorology students are not aware of software life cycles, as this topic is usually covered in programs related to Software Engineering. Knowledge of software life cycles provide meteorologists a road map of how to proceed during software development. Without a road map, the development of a piece of software lacks a clear view of requirements (for example, desired products, input data, processing functions, algorithms) and hence the outcome is unknown or unpredictable. It is not uncommon to see students jumping directly to coding after the problem has been presented without an appropriate plan. Some level of success can be obtained, however most of the effort is lost when trying to reuse or share the program. To prevent fruitless attempts, a better understating of software life cycles is needed. To improve in this area, we have included a short introduction to this topic in the Scientific Programming Course.

The stages of software life cycles that we cover in our course are analysis, design, development and implementation. Needs and requirements are accounted for during the analysis stage. The blueprints of the program are created in the design stage. Most Software Engineers utilize the Unified Modeling Language (UML) to create standard designs that are independent of the language chosen for the next stage. During development the code is written to match the design and satisfy the needs. Finally, the code is implemented to solve the needs it was created for. Following these four simple steps can make a difference during software development at any level, from first year meteorology students to professional meteorologists. Many other types of life cycles exist (for example, interactive, cascade, spiral), and could be considered.

Another challenge faced during the implementation of this innovation was leaving the "old ways" of coding. Once students develop a habit in programming, it will be used as the first option before attempting alternative solutions, even if they are proven to be simpler, better and/or faster. High-level programming languages can do more with less code than low-level languages. Nevertheless, low-level coding can end up being programmed into high-level languages. It usually takes months of training in programming before students can see for themselves the benefits of using modern tools and coding techniques. For this reason, we take students without any previous programming experience in the Scientific Programming Course. This has allowed us to offer the first experience in programming in a course specifically designed for meteorologists, allowing them to use modern tools and techniques from the start.

Satellite Imagery

To exemplify this innovation, it will be applied to the case of developing a satellite derived product. Let's study the realistic case of Agrometeorology students calculating the Normalized Difference Vegetation Index (NDVI) at one specific time for all the American continents using GOES 16 data. This exercise was carried out during May of 2019 at UCR during an Agrometeorology course. Following the guidance about using software life cycles and the FSC presents a possible solution to the problem.

First the needs and requirements are analyzed. The calculation of the NDVI requires two satellite channels to be compared, one from the visible spectrum in the red region and another channel in the near infrared region (GOES 16 - Bands 2 and 3 respectively). The data needs to correspond to daytime as these bands do not generate information at night. The expected output is an image with the NDVI information for the field of view of GOES 16.

The design stage can include the following.

I. Data needs to be downloaded/gathered for Bands 2 and 3[4].

II. The matrices obtained from the files must have the same dimensions. The resolution of Band 2 can be reduced to 1 km to match the dimensions.

III. The appropriate library is needed to open/read the netCDF files and extract the information.

IV. The equation for the NDVI should be evaluated for all available locations.

V. The appropriate library with functions for the visualization of a matrix of data is needed.

Up to now, no code should have been written, and only the design of the program should exist. A block diagram with this process has already being presented in Figure 4.1. The diagram produced should be clear and provide the meteorologist with a simple view of the inputs, processing and outputs. Figure 4.2 illustrates the developed FSC.

[4] There are many ways of doing this: AWS, GRB station, Unidata's IDD, GeoNetCast-Americas, NOAA-Class, PDA. For more information look into WMO's RA 3-4 Satellite Data Requirements (SDR) Group.

```
from netCDF4 import Dataset
import pylab as plt
ncCH02 = Dataset('datafileCH2.nc')
ncCH03 = Dataset('datafileCH3.nc')
dataCH02 = ncCH02.variables['Rad'][:][::2,::2]
dataCH03 = ncCH03.variables['Rad'][:]
NDVI = (dataCH03 - dataCH02)/(dataCH03 + dataCH02)
plt.imshow(NDVI,vmin=-1,vmax=1,cmap='PiYG')
```

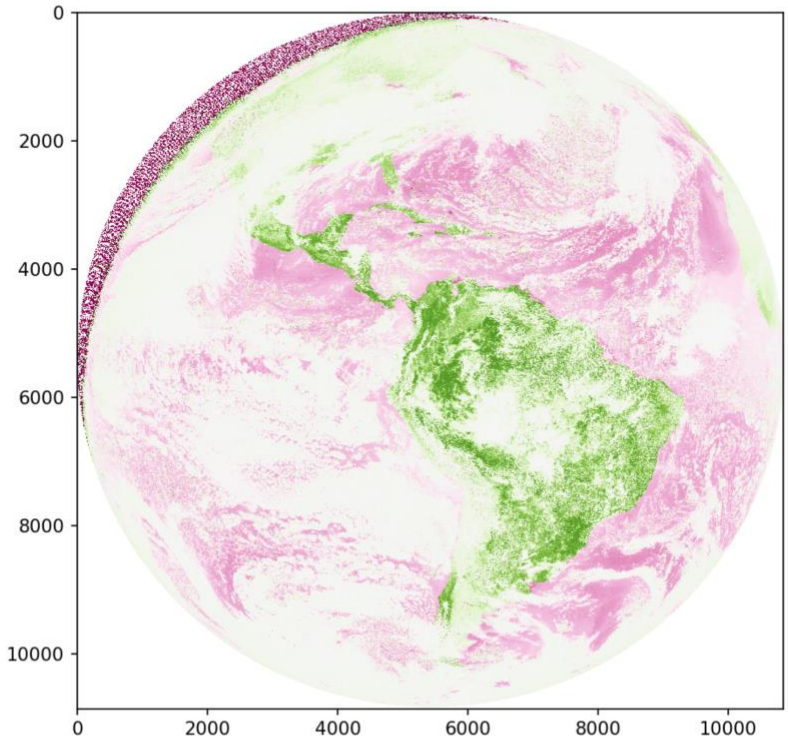

Figure 4.2. Minimum Functional Section of Code (FSC) necessary to generate the Normalized Difference Vegetation Index (NDVI) product (also shown). The eight lines of code shown can be divided in four categories: (i) Black lines: Loading required libraries, (ii) Blue lines: Loading and slicing data, (iii) Purple line: Processing equation, and (iv) Red line: Plotting of the information for the output.

During the development stage, a programming language is chosen based on the necessary libraries (as designed previously). In this example Python is used to show how to apply the FSC approach. Figure 4.2 shows an FSC consisting of only eight lines, which is the minimum working example needed to generate an NDVI product. In those lines, the program loads the libraries (2 black lines), reads and slices the data to the appropriate dimensions (4 blue lines), calculates the NDVI (1 purple line) and finally generates a plot with the information (1 red line). Consistency is important for students, and the colours used in Figure 4.1 to name the process are also used in the code shown in Figure 4.2. This helps students to track the code back to the original design.

As mentioned earlier, the development process is iterative, contributing code only to improve functionality or products. To exemplify the iterations, let’s review the output (NDVI product) in Figure 4.2. The output image generated by the code shows the information, but it is lacking a colour bar to allow interpretation and a background map. To obtain these improvements, some extra libraries and more lines of code are needed.

Figure 4.3 shows this revised code and its generated image. The new FSC now contains 5 lines for loading libraries, the 4 lines for reading and slicing are kept intact, the NDVI is calculated with the same equation as before in one line, the map is generated with four new lines (green text), and the plotting of the information now takes five lines. The third line for plotting limits the values of the NDVI, removing the values over the ocean (negative values). This new code holds 19 lines, an increase of 57.8 percent, but produces a much-enhanced final graphical product compared to the one presented in Figure 4.2 with just one iteration of changes.

```
import matplotlib.pyplot as plt
import numpy as np
from netCDF4 import Dataset
import cartopy.crs as ccrs
import cartopy.feature as cpf
ncCH02 = Dataset('OR_ABI-L2-CMIPF-M3C02_G16_s20190011515366_e20190011526133_c20190011526204.nc')
ncCH03 = Dataset('OR_ABI-L2-CMIPF-M3C03_G16_s20190011515366_e20190011526133_c20190011526204.nc')
dataCH02 = ncCH02.variables['CMI'][:][::2,::2]
dataCH03 = ncCH03.variables['CMI'][:]
NDVI = (dataCH03 - dataCH02)/(dataCH03 + dataCH02)
geos = ccrs.Geostationary(central_longitude=-75, satellite_height=35786023.0, sweep_axis=('x'))
fig = plt.figure(figsize=[7, 7], dpi=100)
ax = fig.add_subplot(1,1,1, projection=geos)
im = ax.imshow(NDVI, vmin=0, vmax=1 , origin='upper', extent=(-55e5, 55e5, -55e5, 55e5), cmap='Greens', transform=geos)
plt.colorbar(im,ax=ax,orientation="horizontal", label='NDVI Values', fraction=0.046, pad=0.04)
plt.title('GOES-16 - NDVI', loc='center', fontweight='bold', fontsize=15)plt.show()
ax.coastlines(resolution='50m', color='black', linewidth=1)
ax.add_feature(cpf.BORDERS, linestyle='-', edgecolor='black', linewidth=0.5)
ax.gridlines()
```

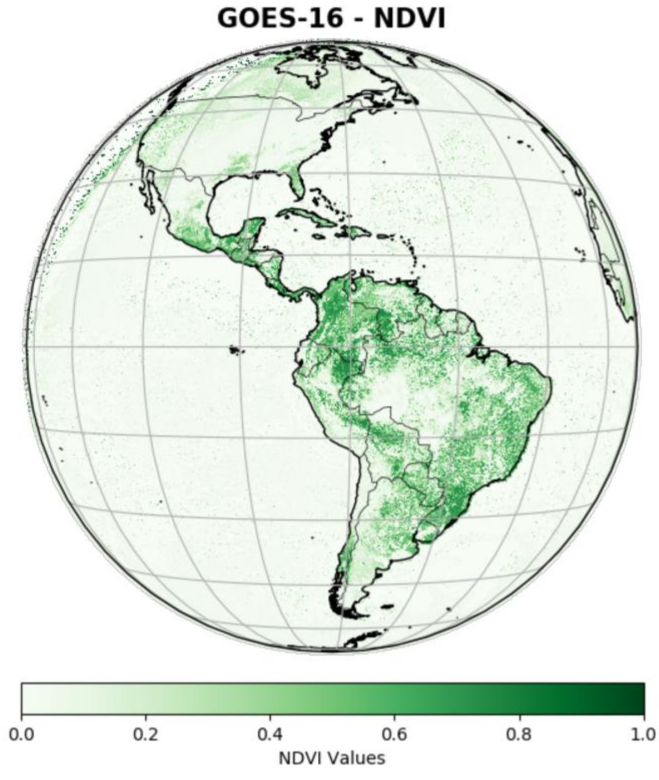

Figure 4.3. Example of an elaborate Functional Section of Code (FSC) product of improving on the code shown in Figure 4.2. Text in green can be seen in this FSC indicating the lines dedicated to generating the satellite view, map, meridians and parallels.

Finally, after programming is done it can be implemented. Nevertheless, it should include additional testing and documentation in order to have a better life cycle.

Results

The innovation in teaching programming described here has contributed towards our student's advancement in several different ways. As the students get more programming practice and apply the methods themselves, they get a boost in confidence. Such confidence has proven important when moving on to other courses, collaborating as research and/or teaching assistants, and even when applying to higher education programs. Due to the activities described above, the teacher's role as a presenter of information in class decreases with time. As the student's role becomes more active, the teacher is more available to support the students in need of attention. Therefore, the class is more uniform, and lessons move at a faster pace.

An important result of implementing the new method is that the complexity of projects assigned to the students was immediately increased. This is a direct consequence of better understanding what the code does and how to improve on it. For example, in previous years, when using the traditional teaching method, most of the projects in the Scientific Programming course were limited to Newtonian Physics and solutions of differential equations. After utilizing the new methodology, the projects have included Quantum and Monte Carlo simulations.

To supply an external perspective on the innovation, two recent graduates from the meteorology program have shared their comments to support the results they obtained.

Student's Perspectives

> *Meteorologist Dayanna Arce (personal communication, May 23, 2019)*: During the meteorology program the Meteorological Instruments course has been very useful as we were taught how to program using Python, which is an important tool in data processing. Before taking that course, I had some knowledge about other programming languages (i.e. Matlab) that I learned by reading tutorials and helped me better understand the new way of programming and the Python syntax. It was simple and fast to learn to program thanks to the methodology used by the professor. Small sections of code were used at first to understand the functionality, what calculations it could do and why it was useful for a meteorologist. After internalizing these concepts, we were able to create more complicated programs and functions that I still use today for calculations and visualization as a research assistant at the Center for Geophysical Research (CIGEFI in Spanish). A year after taking the programming course I took another programming course in a different university and the professor used complicated and long programs which made the class too dense for first time programmers. In that course I realized that many of the libraries and functions, as well as the methodology for programming was covered in the programming course at the University of Costa Rica.

> *Meteorologist Anthony Segura (personal communication, May 21, 2019)*: The way programming is taught during the meteorology program is not conventional. The methodology used worked for me greatly and motivated me to research more into the language and be independent in future programming tasks. The functional sections of code are useful but what I consider more important is that there is always dispositioned to help understand past the topics covered in class. After I took the course I worked as a research assistant and the way I learned to program allowed me to complete successfully and diligently the various tasks assigned by the researcher. It is important to remark that using Python helped me as the syntax is easy to understand and is simple and elegant, which might not be the case in other languages where learning the syntax before utilizing and coding is mandatory. This way of learning programming may

not be appropriate for everyone, as it requires practice, participation, independent study and some degree of curiosity.

Conclusions and Future Work

The methodology used for teaching programming has been implemented in the Meteorological Instruments course, where students need to program to visualize automatic weather station information, as well as radar and satellite data. An elective course on Scientific Programming is also using this new methodology. As the number of students is not large in the meteorology program a control group has not being used so far to test the comparative effectiveness of this new methodology. Nevertheless, the students have shown satisfaction with the changes and have been creating better programs for their assignments and exams.

This methodology was first implemented in 2017 during the Scientific Programming course for Meteorology and Physics students. It was later implemented in 2018 during the Meteorological Instruments course for Meteorology students. During the second term of 2019, the Scientific Programming course will include mostly Meteorology students and the numbers of students have tripled for two consecutive years. This increase in students could be attributed to the student satisfaction.

Finally, a recommendation to meteorology students and teachers: Do not use IDEs to teach programming to newcomers. Instead use interactive computing tools like Jupyter Notebooks that allow students to approach programming with an interface that is much easier to understand that IDEs. Jupyter Notebooks can also be used simultaneously for documentation and writing reports.

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5. Aligning the Teaching of Computing Across Meteorology Programmes

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Abstract

This article describes the process of linking and aligning the teaching of computing skills across the BSc and MSc programmes in Meteorology and Climate and in Physics of the Environment at the Meteorology Department of the University of Reading. After surveys and interviews showed the use of different programming software and platforms, and that a limited picture existed to show how the learned computer skills should work together toward clear computing competencies, the Department was determined to better integrate teaching and learning of computer skills. In reaction to these findings, the Department took steps to (1) standardize all teaching of computing skills to a single software (Python) and single software platform, and also (2) provide students and instructors with a roadmap of the computer skills they needed to master the various programmes of the department. Students have shown a positive reaction to the more integrated Python approach, and the teaching staff is also positive about integrating their teaching and the skills learned across the modules within their programmes as a whole.

5.1. Defining the Problem

The Programmes for BSc and MSc in the Meteorology Department of the University of Reading contained various modules that used computer programming for data analysis, problem solving, research, and/or understanding numerical modelling of the Earth system. However, these modules were not explicit in outlining what their contribution would be to students' overall computing competency. They also often used different programming software. Even those with the same software sometimes used different platforms and setups, so it was difficult for students to connect their learning from different modules and build on their skills throughout the programme. We decided to form a Computing Working Group (CWG) in the Department to link the teaching of computing throughout the BSc and MSc programmes.

Our first step was to analyse the results of a survey that had been done in 2015 covering all teaching staff in the Meteorology Department. The survey asked about the use of computing in teaching and assessment in modules, which had never been systematically surveyed before. The survey confirmed our views that there were a large number of courses and assessments that involved computing and that several different kinds of programming and analysis software were being used. Indeed, atmospheric science lends itself to learning technical and analytical skills via analysis of datasets (Kirk et al., 2014). However, instructors often complained that students did not seem to bring previous computing skills even though they had used computing in earlier modules.

Based on a recent survey of 13 employers of graduates from our MSc programme, we found that they are most interested in students having good quantitative problem-solving skills and the ability to analyse output from climate and weather models. These skills often rely on using computer software for data analysis. Employers who took the survey also have a significant interest in students having the ability to write and understand programming code. Our students also value programming skills and see them as important for employability. (This was confirmed by a survey of 6 undergraduate students in Meteorology and/or Maths for a group project that the first author conducted during a training course as well as in the 2016 Postgraduate Taught Experience Survey [PTES] of postgraduate students). However, we needed to better connect the teaching of computing skills in our programmes and let students know where we expected them to be at each stage so that they could take ownership of their own learning.

5.2. Designing a Solution

The overall vision was to migrate, as much as possible, toward a single computer programming software system and a single platform where students could access their scripts over the whole programme. Furthermore, we would make sure key skills were taught at the time in the programme that they are needed. Finally, students would be given a "roadmap" of what skills they would acquire during each phase of their programme. One main goal of the roadmap was for students to take ownership of their learning (Fry et al. 2007) and become partners in assessing their own transferrable computing skills. This would also be more inclusive of students who may benefit from seeing skill development goals in advance, such as those with specific learning disabilities.

We emailed a few key staff members who teach the most computer-intensive courses in our Department to invite them to join the new CWG, along with a few other key members of the Department. During the first meeting, we agreed to the overall vision and chose to use python as the principle software because it is open-source and therefore free, which means students with access to computers can use it regardless of economic means and continue to use it wherever they end up after University. Python is also widely used in the geosciences (Jacobs et al. 2016). We discussed the different modules that provide the most (or require the most) computer skills for our students and began to outline skills taught and needed for each module.

We followed this up by emailing all other staff members who had indicated in the survey that their modules involved computing skills to ask about the skills taught and needed by students. We also shared our preliminary vision with these staff members, encouraging them to move towards python if they weren't already using this, and asked whether such a change would be a considerable burden for them. Many said they were already considering the change, while a few cited the benefits of Excel spreadsheets for certain kinds of pre-designed analyses (e.g. lab work).

The chosen design strategy reflects a combination of approaches to integrating computing skills into our BSc and MSc programmes in Meteorology and Climate and in Physics of the Environment. Fallows (2007) describes several models of incorporating a skills agenda for a higher education institution as a whole, but we believe that they can also apply to a specific Department, School or programme, and in that light our programmes partly rely on Fallows's "skills module model" and partly on his "totally embedded model". The "skills module model" applies to several required modules, or parts of modules, that teach programming skills as applied to data analysis and numerical modelling of atmospheres and oceans. These modules already existed, but they needed to be better aligned with the rest of the programmes and with each other in terms of the skills needed throughout the students' computing experience. The "totally embedded model" relates to the much larger number of modules which involve some computer skills but do not focus on these skills as their main aim. Our strategy was largely to better articulate this combination of models and align the skill development across the different modules in each programme; we also wanted to make the skill development clear to students.

5.3. Actions Taken

The CWG continued to meet several times in early 2016, and we agreed on a specific setup for Python. This included actions for the university Information Technology (IT) services to provide students with accounts and storage and to provide instructors with the correct version of Python, along with a few required computer libraries, installed on computers in classrooms used in their modules. Instructors teaching the most computing-intensive courses all agreed to use the shared technical solution, ensuring that students have all their scripts in one folder and use the same version of python for all courses. Other instructors also agreed to use Python in their courses for programming and/or data analysis work, although a few will still use Excel for reasons mentioned above.

At the same time, we used our notes and discussions to build a "roadmap" for the MSc and BSc programmes (see Figure 5.1 for one example page of the BSc roadmap). This allows students to explicitly see what skills they should gain during the programme, and which modules will teach and/or use these skills. Students can participate in their own learning assessment by ticking the skills that they judge to be adequately learned and explaining how they mastered them.

Computing Working Group | Meteorology Student computing checklist

Skill	Resources	Modules	I've mastered it (tick and explain how)
Variables – different types of python variables (integer, float, string); how to define them and how they differ	See chapter 3 of Johnny Lin's book: http://www.johnny-lin.com/pyintro/ed01/free_pdfs/ch03.pdf A simple description of python variable types can be found here: http://www.learnpython.org/en/Variables_and_Types	*Taught:* MT12C *Used:* MT24C, MT2ACT, MT25F, MT26E, MT37J, MT38A, MT38B, MT38C, Dissertation	
Arrays – how to store variables in arrays and how to index the array to retrieve slices	See chapter 4 of Johnny Lin's book: http://www.johnny-lin.com/pyintro/ed01/free_pdfs/ch04.pdf You will need the numpy library (http://www.numpy.org) which will be included with your distribution A simple introduction to arrays with exercises: http://nbviewer.jupyter.org/github/mbakker7/exploratory_computing_with_python/blob/master/notebook2/py_exploratory_comp_2_sol.ipynb	*Taught:* MT12C *Used:* MT24C, MT2ACT, MT25F, MT26E, MT37J, MT38A, MT38B, MT38C, Dissertation	
Loops and if statements– how to perform repeated calculations using for and while loops and make branches with if and else	See chapter 3 of Johnny Lin's book: http://www.johnny-lin.com/pyintro/ed01/free_pdfs/ch03.pdf An introduction to loops and if/else statements with exercises: http://nbviewer.jupyter.org/github/mbakker7/exploratory_computing_with_python/blob/master/notebook3/py_exploratory_comp_3_sol.ipynb	*Taught:* MT12C *Used:* MT24C, MT2ACT, MT25F, MT26E, MT37J, MT38A, MT38B, MT38C, Dissertation	
Line plots – how to make simple line graphs of two variables, change the properties of the plot and	For this you will need the matplotlib library (http://matplotlib.org) which comes with most python distributions and has a great set of help pages and examples.	*Taught:* MT12C *Used:* MT24C, MT2ACT,	

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Figure 5.1. An example page from the BSc computer "roadmap" showing computer skills attained during the course along with resources to learn more, modules where the skills are taught and used, and a blank space for students to document how they have attained

5.4. Future Work: Evaluation

We have begun to survey students, and the students have a positive view of the programming skills they are gaining through the integrated Python approach. The teaching staff is also positive about linking their teaching and the skills learned and used across the modules within their programmes as a whole. We now present the roadmap to first-year students at their autumn orientation week, and it is also available online for them to access. The current second-year BSc students are the first to be presented with the roadmap in this way, so we will continue to assess the impact of this innovation in the coming years. We see this as a great model for embedding other key skill sets, e.g. mathematics, across our programme in the future.

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6. Education and training of personnel for the meteorological provision of civil aviation in the Russian Federation

By Svetlana Bykova, "Aviamettelecom of Roshydromet", Director of the North-West Branch in St. Petersburg; Alla Yurova, St. Petersburg State University, Chair of Climatology and Environmental Monitoring and Maria Mamaeva, WMO Executive Council Panel for Education and Training

Abstract

This article describes an example of effective cooperation between representatives of the labour market and a university that trains specialists in the field of meteorology. The best practices of such cooperation in the aviation industry are considered, and the advantages of such collaborative efforts for both sides are presented. Also presented are the results of education and training needs assessment for the meteorological provision for civil aviation for North-West Russia. Innovative approaches in the field of aeronautical meteorology education, training and qualification development are discussed.

Keywords: aeronautical meteorology, competency-basedtraining, cooperation, partnership

In recent years, Aviamettelecom of Roshydromet has performed a significant amount of work on implementation of WMO/ICAO standards. To date, we have fully applied all requirements related to ensuring the necessary qualifications and competencies of aeronautical meteorological personnel (AMP). Success is achieved thanks to a newly-implemented model of sustainable capacity building with an emphasis on human resources.

Currently, the North-West branch of "Aviamettelecom Roshydromet" (N-W Branch) employs 68 people (34 forecasters and 34 meteorological technicians). A recent assessment revealed a need to a need to recruit 2–3 forecasters and 4 meteorological technicians per year. In 2011, N-W Branch implemented a quality management system (QMS), which guarantees the provision of meteorological services for aviation with the proper quality. Within the framework of the QMS, AMP periodically undergo a competency assessment, the results of which identify the areas where new knowledge, skills and, accordingly, additional professional training are required. In order to meet the training needs identified in this way, the N-W Branch participates in the development and delivery of training courses based on a competence-based curriculum. A competency-based approach is focused on the development of a person's ability to realize certain competencies, to teach how to act effectively in a real work environment. We consider distance learning to be both cost-effective and efficient for the delivery of such training.

The concept for the socio-economic development of the Russian Federation until 2020 states that "development of the professional education system foresees increased participation of employers at all stages". Federal state educational standards applied at the Russian universities provide opportunities to develop competency-based curricula with a focus on the needs of the labour market and in close cooperation with its representatives. The expansion of the autonomy of universities in the development of such curricula is accompanied by increased university responsibility for the quality of education and training. An important condition for ensuring the quality of competency-based curricula is their design with the participation of all stakeholders interested: teachers, students, employers.

In this regard, the N-W Branch cooperates with universities that offer programmes in meteorology and related subjects. For example, operational staff of the N-W Branch provide training for students of the St. Petersburg State University, Russian State Hydrometeorological University, Perm State National Research University and Hydrometeorological College.

Training is usually organized in an interactive way with well-organized feedback and two-way exchange of information. This interactive model aimed at organizing comfortable learning conditions in which all students interact with each other and operational staff providing training. The training involves modeling actual working situations, and analysis of real circumstances and conditions. In 2018 the N-W Branch hosted students of the St. Petersburg State University (http://earth.spbu.ru/en) for practical training.

St. Petersburg State University (SPbSU) was the first university in Russia; it was founded by decree of Emperor Peter I in 1724. For almost three centuries, thousands of scientists, politicians, writers, artists and musicians have studied and worked at SPbSU. In 2009, the President of Russia signed a law on the special status of St. Petersburg and Moscow State Universities. SPbSU was given the status of a unique scientific and educational complex. This implies that there is a separate line in the budget of the Russian Federation for SPbSU and the Rector is appointed by the President of the Russian Federation. In addition, SPbSU has the right to (a) conduct additional tests on all major educational programmes, (b) independently set its own educational standards, (c) award its own degrees, (d) determine its own rules for conducting competitions for academic staff, and (e) issue diplomas of its own design.

The Department of Meteorology and Climatology became a part of the SPbSU in 1925. The department provides two educational programmes: "Bachelor of Hydrometeorology" (four years) and "Master of Hydrometeorology" (two years). There is also a PhD course, “Meteorology. Climatology. Agrometeorology". The learning process is built in such a way that the future specialists are trained to (a) collect the necessary information both through independent observations and through the use of data banks, (b) process data based on the latest and innovative technology and (c) perform theoretical analyses of the results based on a deep study of the laws of atmospheric processes and methods of computer modeling of climate processes. Students in the department also take part in expeditions including those to the Arctic and Antarctic. The educational programmes include both classroom lessons and the obligatory passing of a summer field training.

After the practical training in the N-W Branch of Aviamettelecom of Roshydromet in 2018, a joint concluding meeting was held at which the ways of improving existing and further interaction between the two organizations were agreed. These discussions took into account the results of a survey that assessed the effectiveness of the training and how it might be improved. Five students were interviewed using twelve questions dealing with self-assessment and goal setting for job qualification. Overall, after the final year of study and practical experience, the majority of students (4 of 5) felt sufficiently prepared to take on the job of a synoptic meteorologist. They all made good use of available resources, but in some cases they did not know what resources were available. In conclusion, almost all students agreed that their work and efforts are something for which they can be proud, and that they would willingly show their results to a large, global audience. Students had a great experience which helped clarify their future job prospects.

Thanks to such cooperation, it is possible for a university to find the optimal balance between the academic approach and the practical skills required by employers. As a result, students supplement their theoretical knowledge gained in lectures with practical and operational skills. At the same time, the N-W Branch can assess the potential of the students, which could lead to some of them being invited to join the workforce. The N-W

Branch also arranges for its staff to participate in (a) the work of graduation and expert commissions and (b) the development of new and modernization of existing university curricula and programmes that meet national and international standards. Internships for teachers are also provided by N-W Branch.

In addition to the traditional interaction, the national law "About Education in the Russian Federation" defines other forms of cooperation, such as creation of networks that include universities and industry enterprises, implementation of joint university-industry educational and training programmes, introduction of competency-based higher education programmes (like applied bachelor programmes), development of industrial university departments and university departments based at industrial partners. All of these developments provide promising future directions.

In general, we believe that the higher professional education system should take into account employers' requests and international requirements and standards, and be quickly responsive to changes in the labour market. This is only possible if there is close cooperation and integration of all labour market participants, including representatives of employers and educational service providers. To this end, it is advisable to continue building a holistic system of interaction by creating platforms and forums for permanent constructive dialogue and interaction between all stakeholders. This paradigm also underlies the WMO Global Campus initiative.

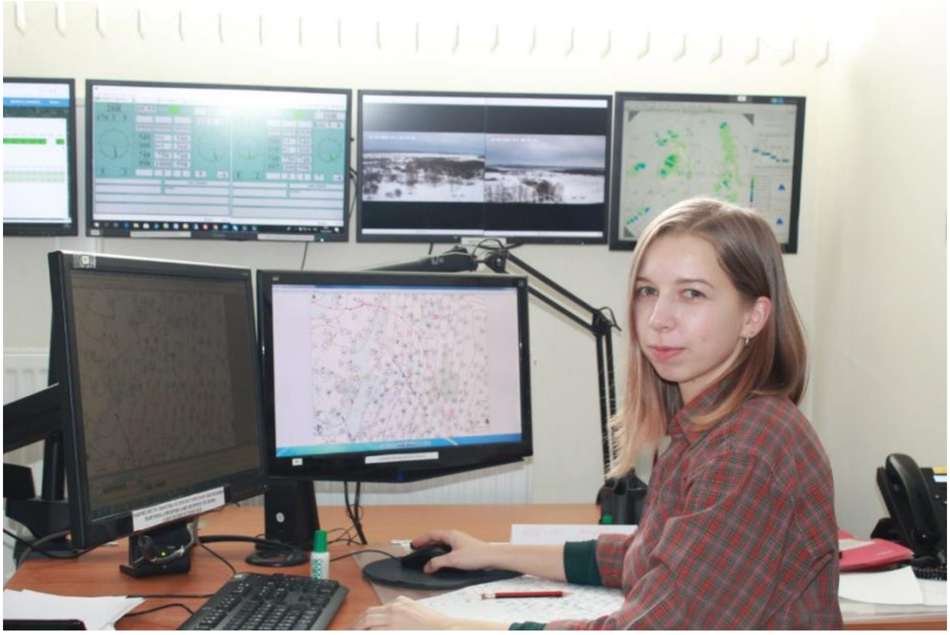


Figure 6.1. University students undertaking forecasting training at the North-West Branch of Aviamettelecom of Roshydromet

7. Enhancing student learning through weather forecasting activities: University of Reading Approach

Dr Peter Inness

Abstract

This article presents three innovations introduced in the degree programmes of the Department of Meteorology, University of Reading, to broaden students' experience in producing and presenting weather forecasts. A major innovation is to provide students an optional module on "Weather Forecasting: Practice and Presentation" within our degree programmes. The other two are offered to students as extra-curricular activities, including: (i) providing the Student Meteorological Society with a portable "green-screen" TV studio with all the relevant hardware and software to produce video weather forecasts; and (ii) "live forecasting" sessions in which students use live weather data to produce weather forecasts for a range of different customers such as aviation, utilities and broadcast media. The purpose of introducing students to these innovations is to give them a flavour of what the job may involve and also to instil some of the transferable skills of weather forecasting such as team-working, presentation skills, working to deadlines and providing feedback to peers that are applicable in a wide range of careers. We feel that the combination of these innovations gives our students a useful set of transferable skills that they can take forward into whatever career they choose.

Introduction

The Meteorology Department at the University of Reading offers two undergraduate degree programmes in Meteorology and Climate; a 3 year BSc degree and a 4 year Integrated Masters which includes a year studying at the School of Meteorology, University of Oklahoma, USA. Both of these degree programmes focus largely on the underpinning science of the atmosphere and oceans with additional, mainly optional, modules on more applied aspects of the subject such as remote sensing, numerical weather prediction (NWP) and meteorological field-work. Each year, a significant number of our graduates move into employment or training as weather forecasters. Although our degree programmes have not been designed as training for weather forecasters, we have considered how we might include more activities which give students a flavour of operational forecasting both within our degree programmes and alongside them as extra-curricular activities. Even for students who are not considering a career in weather forecasting, gaining experience in aspects of forecasting such as team-working, working to deadlines and presenting information to a range of different audiences both verbally or in written/graphical form is extremely valuable for future employability.

In order to broaden our students' experience of producing and presenting weather forecasts, we have introduced 3 innovations, one of which is an optional module within our degree programmes and the other 2 are offered to students as extra-curricular activities.

1. The inclusion of an optional module in part 2 of our undergraduate degree programmes called "Weather Forecasting: Practice and Presentation" which includes an opportunity to film a "live" weather forecast in a professional TV studio,
2. Provision to our Student Meteorological Society of a portable "green-screen" TV studio with all the relevant hardware and software to produce video weather forecasts,

3. Fortnightly extra-curricular "live forecasting" sessions in which students use live weather data to produce weather forecasts for a range of different customers such as aviation, utilities and broadcast media.

The following is a description of the approach that was adopted to introduce the students to the innovation and it potential effect on students' learning.

The approach

The optional module on forecasting was introduced several years ago in order to give students an idea of how modern weather forecasters work and some experience in producing operational forecasts, as well as an opportunity to develop their presentation skills, leading up to a filmed "live" TV weather forecast in a professional studio environment. The module is jointly convened by members of the teaching staff from the Department of Meteorology and the Department of Film, Theatre & Television (FTT).

The first four weeks of the eight-week module focus on meteorological aspects of the job of the modern weather forecaster. Each week includes a lecture on an aspect of forecasting such as the tools and information available to forecasters or the different types of forecasts produced by a large meteorological organisation such as a National Meteorological Agency. It also includes a forecasting practical in which students produce forecasts of increasing complexity for specific audiences. The first of these is a simple prediction of the overnight minimum temperature for Reading using "pre-NWP" empirical techniques. This exercise is formative – i.e. it is marked and feedback is given to the students but the mark does not count towards the final grade for the module. Even so, students take it very seriously and there is a distinctly competitive atmosphere as they try to produce the most accurate forecast!

The next two forecasts are assessed summatively (in other words, the mark counts towards the final module grade). The first of these is a "guidance" forecast, written as if the student were the senior forecaster within their organisation, setting out the main aspects of the forecast situation over the next 48 hours for the other forecasters within their organisation who are producing forecasts for customers. The second assessed forecast is the production of an aviation "low level significant weather" chart for use by military and civil aircraft in UK air-space. For this forecast we use a case study of a classical Norwegian frontal model cyclone over the UK so that the students can use their knowledge of this type of system from earlier modules and interpret the weather conditions in terms of hazards to aviation. The deadlines for submitting these forecasts are shorter than the usual deadlines for University coursework. This is to give students the feeling that operational weather forecasters are always working to tight deadlines and whilst it might be possible to make a forecast more accurate by spending more time on producing it, timeliness is a key aspect of forecast production. For both of these assessed forecasts, some marks are awarded for the accuracy of the forecast, but the bulk of the marks are for the presentation of the forecast, clear use of language and graphics to get the forecast message over and at an appropriate level of technical detail for the target customer group. In the fourth week of the module, the practical session is given over to collecting real-time weather information that will be used by the students to produce a TV weather forecast in the second part of the module.

At this stage we move over to the Minghella Building, the home of the FTT Department. Within this department there is a professional standard TV studio with a green-screen backdrop onto which graphics can be projected in the same way that many actual TV weather forecasts are produced (see Figure 7.1). In the first week in the studio, students are given an introduction to the equipment and a briefing on their task of producing a TV forecast. Perhaps most importantly they all get a chance to film a short piece on camera, describing the main features on a weather map. This allows them to get the awkwardness of talking to a camera out of the way. Some students find this a fairly stressful experience and are unable to produce a coherent presentation at this early stage, but in all cases, the improvement over the next few weeks is remarkable.

Figure 7.1. A student in the TV studio in front of the green screen (left) and the image with weather graphics superimposed that appears on the studio monitor (right)

Over the next 3 weeks, students rehearse their TV weather forecast, using the data that they collected earlier to produce accompanying graphics. As well as producing a general forecast for the whole of the UK for the next 48 hours, students are also required to produce a forecast for a particular weather-sensitive event somewhere around the country. This does not need to be a real event and often students make up an event based on their own interests, such as the national kite flying championships, or a sporting event involving their own team. The reason for including this is to get the students to consider which aspects of the weather could affect such an event and to present the forecast in a way that is appropriate to participants and spectators.

In rehearsal sessions, the students are split into small groups of 4 or 5. Each student records their forecast and then the group gets together with the staff to watch each forecast in turn to give and receive feedback. This is a crucial stage of the process and students often comment in evaluation questionnaires that this is some of the most detailed, useful and supportive feedback that they have ever received on any of their work. Staff and fellow students give feedback on use of voice, body language, the quality of the graphics, phrasing of the forecast and aspects of the forecast that did or didn’t work well. Students can then respond to the feedback and make their own comments on how they felt the forecast was presented and how they might improve it. Students also keep a record of the feedback they were given and, in a final written reflective piece produced at the end of the module, discussed how they used the feedback and their own critical analysis to improve on their performance.

For the final assessed forecast, the conditions in the studio are treated as if the forecast was being broadcast live. Throughout the rehearsal process students are encouraged to develop techniques for carrying on with their forecast after a mistake – a useful skill in many aspects of presentation other than TV forecasting. Figure 7.2 shows a still image from a student’s final forecast recording.

In the final week, students and staff attend a screening of the forecasts in the FTT Department’s cinema. Final feedback on the forecasts is given and the students are invited to give an assessment of their own performance. Almost without exception students are proud of their work and impressed by their own improvement and that of their peers over what is a fairly short period. Some students who knew that they would find presenting in front of a camera or to an audience stressful have used this module to try and overcome their anxiety. They often comment that the skills they have developed and the feedback they have received have helped them to improve their confidence.

Figure 7.2. A still from a student's assessed broadcast

In order for students to continue practising the skills learned in the forecasting module, the Meteorology Department has provided students with a portable green-screen video studio. This consists of a small video camera with built-in microphone, two small studio lights with stands, a green backdrop and an Apple Mac Mini with appropriate editing software. Students use this equipment to produce video forecasts which they upload to YouTube (see https://www.youtube.com/channel/UC_jX8-NvK37oWsew7gC0VhQ). Providing the equipment to the student Meteorology Society gives the students a sense of ownership of the process of producing their own forecasts and more freedom to experiment with formats and presentation styles.

Figure 7.3. Some Meteorology students setting up their portable green-screen studio prior to filming a weather forecast for their Youtube channel

In the third innovation, approximately fortnightly during term time we convert a small computer laboratory into a forecast office for students to prepare weather forecasts for a range of different customer groups. The Student Meteorological Society organises the forecasting roster with students signing up to take on the roles of chief forecaster, aviation, media and utility forecasters. A set of tasks are provided for each of the forecasters. These include preparing scripts for the video forecasts described above and for local and national radio broadcasts by the media forecasters, writing Terminal Aerodrome Forecasts (TAFs) and preparing significant weather charts by the aviation forecasters and preparing simple energy demand forecasts by the utilities forecaster. The Chief Forecaster provides an overview briefing for the forecasting team at the start of the session and works with the other forecasters to ensure consistency across all the forecast products. Student forecasters are encouraged to work as a team as they produce their forecasts, and strict deadlines are provided for each forecast product to reflect the time limitations of a real forecast production centre.

Concluding remarks

Our approach is not to train our students to be weather forecasters through these innovations. We recognize that every meteorological forecasting centre, whether a National Meteorological Service or a commercial provider, will have its own procedures and will use different NWP forecast products depending on availability and geographical location, and so will have its own specific training programmes. What we are trying to do is give the students a flavour of what the job may involve and also to instil some of the transferable skills of weather forecasting, such as team-work, presentation skills and working to deadlines, that are applicable in a wide range of careers.

Producing a weather forecast for a TV or video audience requires a unique combination of skills. In addition to the scientific understanding of atmospheric processes and a knowledge of the strengths and weaknesses of NWP, forecasters need a set of presentation skills which include an appreciation of the level of audience understanding, an ability to select appropriate graphics and a great deal of self-awareness in terms of the use of voice, body language and self-projection. We feel that combining these skills with those of team-work, providing feedback to their peers and working to tight deadlines gives our students a useful set of transferable skills that they can take forward into whatever career they choose. Additionally, by giving our students a taste of the job of an operational forecaster they can make better informed decisions about whether this is the right career choice for them. Finally, by bringing on board staff from the Department of Film, Theatre & Television we can provide our students with professional guidance on presentation together with high quality feedback on their performance.

8. Meteorology for the Geography Educator (Pilot E-Course)

Andrea Sealy, Rebecca Chewitt-Lucas, Kathy-Ann Caesar and David Farrell, Caribbean Institute for Meteorology and Hydrology (CIMH)

Abstract

This brief highlights the support of the Caribbean Institute for Meteorology and Hydrology (CIMH) to secondary school educators in the region to effectively deliver a course on Weather and Climate concepts to Geography students. It describes the content and effectiveness of the online two-month course developed by the CIMH to assist regional secondary school Geography teachers who wished to have a greater understanding of the fundamentals of meteorology applicable to the CXC Secondary Education Certificate (CSEC)/ Caribbean Examinations Council (CXC) Advanced Proficiency Examination (CAPE) Geography syllabus. The effectiveness of the CIMH Module is assessed and its replicability in other WMO regions and other courses for stronger foundations for meteorologists discussed.

Keywords: teachers, geography, secondary school, weather and climate

8.1. Problem addressed

Most Geography teachers in the Caribbean usually cringe when asked if they feel confident teaching Weather and Climate to senior students (16-19 years) in their secondary schools. The Caribbean Examinations Council (CXC) Advanced Proficiency Examination (CAPE) (http://www.cxc.org) reported that in the period 2004-2015, the students' responses to the Weather and Climate questions in the CAPE Geography exams were unsatisfactory for most of that period.

At the same time, the CXC Secondary Education Certificate (CSEC) for students aged 15 to 16 added more Weather and Climate content to their syllabus. This implies an even greater need to equip teachers to deliver this content throughout the senior levels of secondary schools in the Caribbean region.

The Caribbean Institute for Meteorology and Hydrology (CIMH), a WMO Regional Training Centre (RTC) and regional meteorological services as part of their outreach efforts during the last ten (10) years have assisted secondary school educators with the delivery of Weather and Climate content to Geography students. Discussions with national Ministries of Education in Caribbean Meteorological Organization (CMO) Member States on the competence of educators to deliver training on the concepts have indicated much concern in this area.

To address the concern and the region's expressed desire to strengthen its weather and climate resilience, CIMH created an online, two-month course. The objective was to assist regional secondary school Geography teachers who wished to have a greater understanding of the fundamentals of meteorology applicable to the CSEC/CAPE Geography syllabus. The course first ran from 9 July to 10 September 2017. The following describes the content of the course, its delivery methodology and value, as ascertained by the initial beneficiaries.

8.2. The unique CIMH distance learning approach

Asynchronous distance learning was carried out via the use of CIMH Moodle, a virtual learning environment that was utilized by instructors and participants of the e-course. The course modules were developed based upon basic meteorological concepts taught by

CIMH in the Basic Instructional Package for Meteorological Technicians (BIP-MT), the Basic Instructional Package for Meteorologists (BIP-M) and B.Sc. Meteorology courses (CIMH Training Schedule, 2017). The course also sought to help develop competency under the UNESCO ICT Competency Framework for Teachers (UNESCO, 2011) in terms of pedagogical ICT Competency with respect to student learning, lesson plan development and implementation where possible.

The course also utilized a combination of COMET modules and other online resources along with lecture slides made available through the CIMH Moodle and WizIQVirtual Classroom platforms, which also encouraged interaction and discussion among participants and instructors. The course design followed best practices in learning and development, as depicted in Figure 8.1.

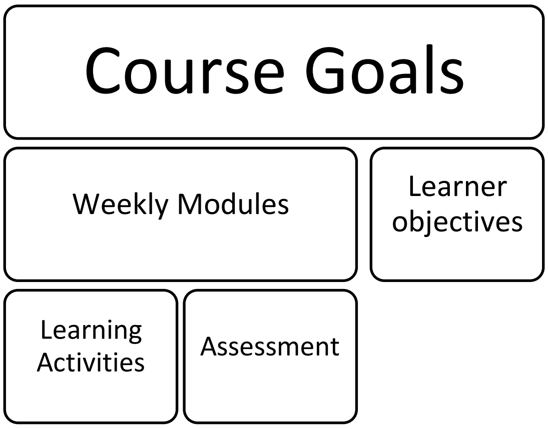
Practices for Development of and e-Course	**Course Design Matrix**
• Alignment with CIMH • organizational objectives • Learner-focused and self-paced • Designed to embed learning into workflow • Learner interface and experience • Interaction- within the Moodle platform • Delivered via a multi-media approach – using a blend of delivery methods to suit learning preferences and participants' needs	

Figure 8.1. Course design

The e-course consisted of six (6) Modules that were preceded by a pre-assessment. The modules covered the following topics:

- Overview of the Atmosphere
- Atmospheric Moisture
- Atmospheric Stability
- Weather Systems
- Climate Variations
- End-of-course Project

The majority of the modules were composed of notes, video clips, activities and discussion forums (Figure 8.2).

The in-module activities and the end of module activities (Figure 8.3) were essential to the assessment of each module and illustrated the integration of technology to the participants. The activities were created with the intention of arousing critical thinking skills, analytical and problem-solving skills. One of the main objectives of the course was to make learner activities as authentic and relevant as possible.

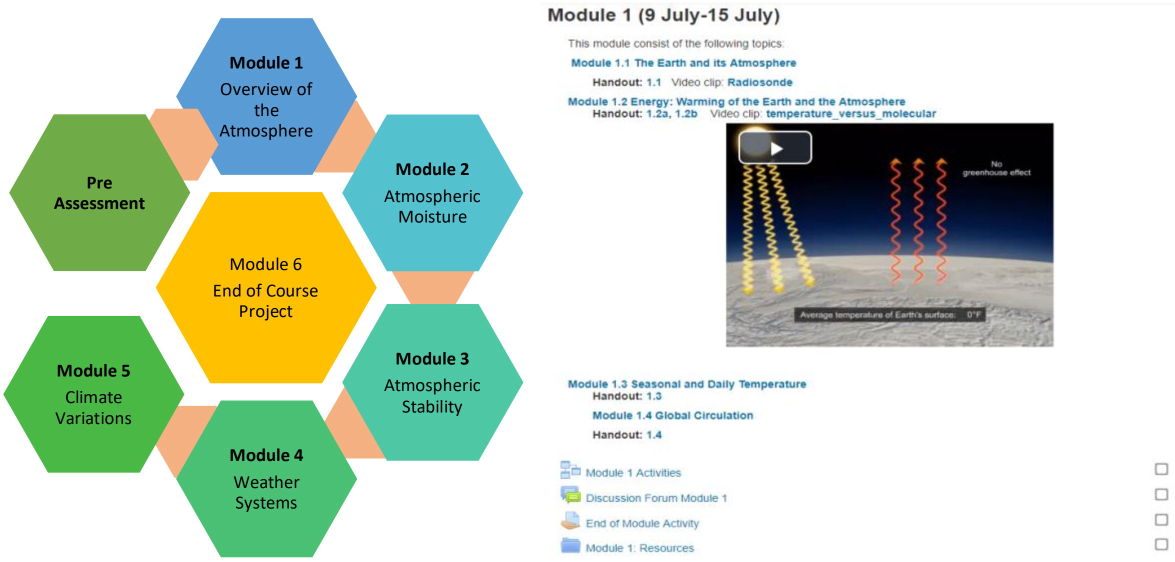


Figure 8.2. Module topics (left) and example of module layout (right).

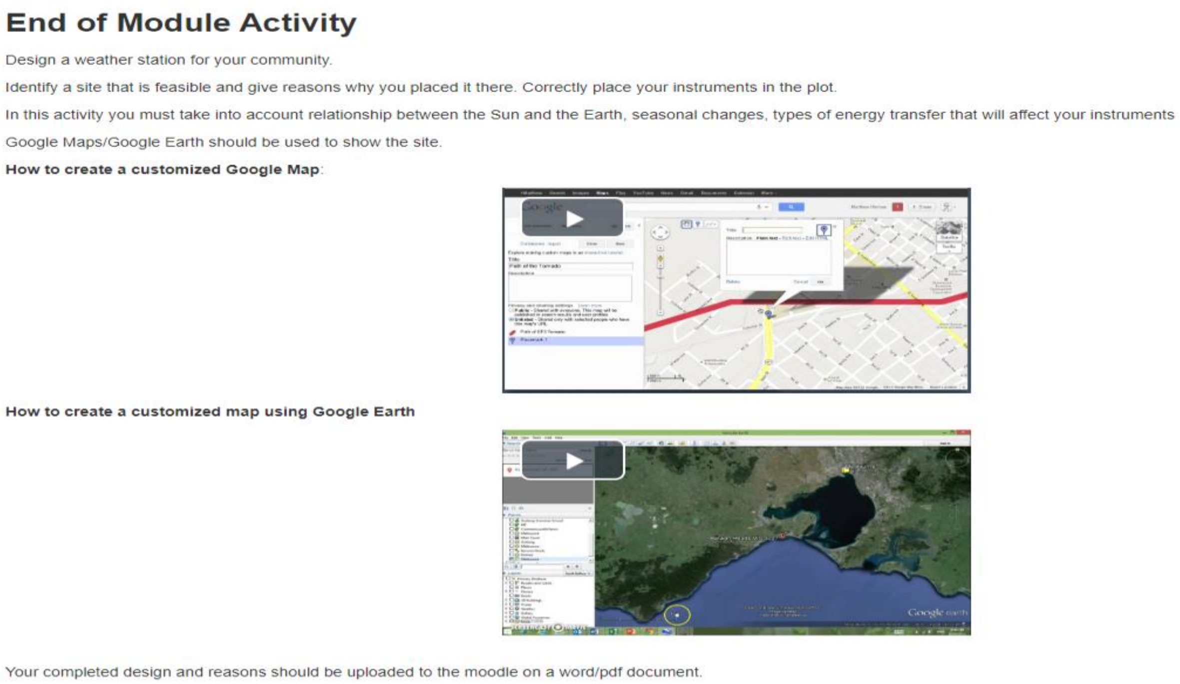


Figure 8.3. Example of an end of module activity.

In Discussion Forums, the participants were given scenarios that would impact their teaching of the Weather and Climate concepts. Collaborative and active learning was expected to be a driving force in the discussions to ensure understanding. For example, during one week, a discussion forum was initiated by asking participants to "Share with your colleagues how you would go about creating a lesson plan, clearly describing the significance of Atmospheric Density and Atmospheric Pressure." The resulting discussion helped all participants generate better ideas for lesson plans.

8.3. Assessment

Diagnostic Assessment (Pre-assessment)

Before the official commencement of the course, participants were pre-assessed via two COMET modules: MET 101 (Introduction to the Atmosphere) and MET 101 (Basic Weather Processes), which include final quizzes. The aim of this pre-assessment was to evaluate participants' strengths, weaknesses, knowledge and skills on Basic Meteorology concepts. This knowledge also assisted in the development of the course. A short survey was also emailed to the participants to assess how comfortable they were with using technology.

From the pre-assessment, we learned that most of the participants appeared to have a good understanding of some basic weather and climate concepts. Also, most participants were comfortable with the use of technology. Some of the participants' weaknesses included practical skills (e.g. basic synoptic chart analysis) and poor comprehension of some concepts such as atmospheric stability and lapse rates. Guidelines on the use of the CIHM Moodle and WizIQVirtual Classroom platforms were distributed to them before the course officially began.

Formative Assessment

The CXC CSEC/CAPE syllabi required skills such as basic interpretation of synoptic charts. As a result, there was continuous formative assessment of participants' activities and discussion responses. For example, real world scenarios were simulated where participants shared with their colleagues how they would go about teaching particular weather concepts from those given scenarios.These learning activities were assessed via rubrics which assessed discussion/participation, completion of activities, quizzes/assignments and the course project (see Table 1).

Summative Assessment

Summative assessments were done at the end of most of the Modules as an Assignment or Quiz to evaluate if the participants had achieved the learning objectives. The final assessment (Module 6) was a Project for the CXC School Based Assessment (SBA) and Internal Assessment component (IA) from meteorological components taught in the course and how they would teach the research process to their students.

Using the concepts taught in the course, the participants had to give a detailed outline as to how they would design and teach the research process to their students for both CSEC and CAPE research projects.

Table 8.1 shows the breakdown of the grading for the various forms of assessment, which were done mainly by rubrics (see Figure 8.4). Participants were expected to have a minimum of 70% overall grade to pass the course.

End of Module Activity Rubric

Objective/Criteria	Performance Indicators			
	Exceptional	**Meets Expectations**	**Needs Improvement**	**Unacceptable**
Quality of Information	(20 points) Information clearly relates to the main topic. It includes several supporting details and/or examples.	(15 points) Information clearly relates to the main topic. It provides 1-2 supporting details and/or examples.	(10 points) Information clearly relates to the main topic. No details and/or examples are given.	(5 points) Information has little or nothing to do with the main topic.
Amount of Information	(20 points) All topics/concepts are addressed and all questions answered with at least 3 sentences about each.	(15 points) All topics/concepts are addressed and most questions answered with at least 3 sentences about each.	(10 points) All topics/concepts are addressed, and most questions answered with 1 sentence about each.	(5 points) One or more topics/concepts were not addressed.
Organization	(20 points) Information is very organized with well-constructed paragraphs and subheadings.	(15 points) Information is organized with well-constructed paragraphs.	(10 points) Information is organized, but paragraphs are not well-constructed.	(5 points) The information appears to be disorganized.
				out of 60

Figure 8.4. Example of end of module activity rubric

Table 8.1. Overall assessment break-down

Assessment	Percentage
Discussion (Participation)	10
Completion of Activities	40
Quizzes/Assignments	20
Course Project	30

8.4. Effectiveness of the training

Fourteen (14) participants drawn from five (5) Caribbean territories (Jamaica, Turks and Caicos Islands, St. Kitts and Nevis, Barbados and Trinidad and Tobago) took part in the training. Of the 14, seven (7) completed the course with grades above 80%, three (3) below 50% and four (4) who did not complete the course due to time limitation and/or personal reasons.

Course evaluation surveys, using the SurveyMonkey website, were done at the mid-point and at the end of the course. At the mid-point of the course, the instructors/developers wanted to examine the participants' feelings and thoughts about the course at that point in time (Figure 8.5).

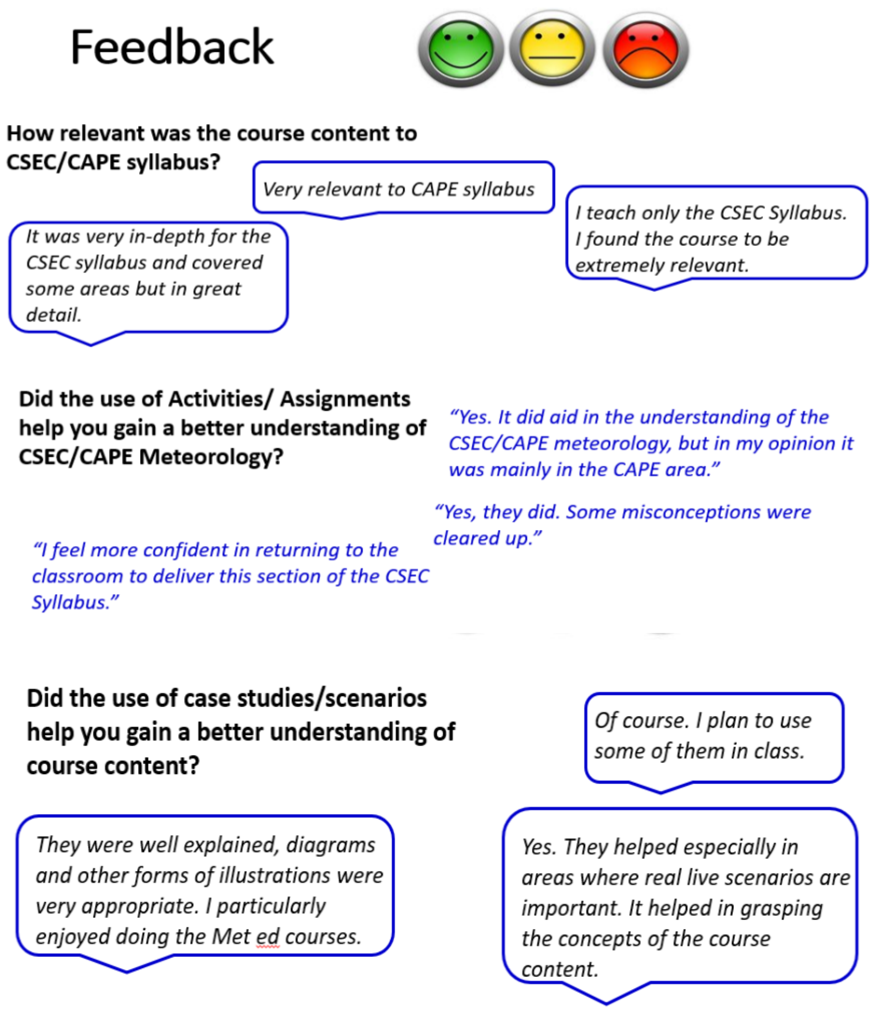


Figure 8.5. Examples of mid-point feedback from the participants.

In the middle of the course the participants generally felt that the use of case studies/scenarios helped them gain a better understanding of the course content. They also felt that the course content was very relevant to the CSEC/CAPE syllabus and the activities/assignments helped them gain a better understanding of CSEC/CAPE Meteorology.

The evaluation administered at the end of the course was more detailed and focused on (i) course design and content; (ii) communication and interaction; (iii) instructors; and (iv) general reactions.

Course design and content

More than 70% of the respondents agreed that the course used various methods that addressed different learning styles, explanation of difficult terms was done in different ways, opportunities were provided to ensure active learning, examples were relevant to participants' experiences and useful in the teaching of Weather and Climate.

Communication and interaction

More than 70% of the respondents agreed that the interaction between participants and instructors was impressive. In the Discussion Forums, participants responded to the discussion statement/question but less than 30% had interaction between them.

Instructors

The respondents strongly agreed that instructors' responses to emails/messages were in a timely manner, less than 48 hours in most cases. More than 80% agreed that instructors provided helpful feedback when necessary and exhibited mastery of course content.

General Reactions

Respondents noted that the lay-out and design of the course could be made easier to navigate. This could be attributed to some of the respondents using an e-learning platform for the first time to take this course. The participants found some of the terms and concepts challenging and the timeframe too short. A suggestion was made to send a Glossary ahead of the course as part of the diagnostic assessment in the future. About 50% of the participants teach only the CSEC syllabus but believe because of the course they are now equipped to teach the advanced CAPE Geography syllabus of Weather and Climate.

8.5. Challenges, Recommendations and Future Plans

Despite the fact that guides were sent on how to use the Module virtual learning environment, some participants had problems maneuvering around the platform. This was mainly due to their lack of using e-learning technology frequently themselves or experience using it in their classrooms.

Discussion Forums evoked good collaboration but did not go into the depth that the instructors were hoping for.

The course fee was $100 US, which may be considered inexpensive for a course such as this, but can pose a challenge for many teachers in developing countries. A small number of teachers were sponsored by their schools or ministries, but others paid out of pocket. Therefore, looking into funding to fully cover the costs of delivering the course and/or sponsoring teachers will be a significant part of future planning.

As the course is offered by the CIMH, which is an accredited institution and a WMO Regional Training Centre, it is recognized by the CXC and the regional Governments as part of the continued professional development for the Geography teachers.

The main component of the course will also be shortened to four (4) weeks with an additional two (2) weeks to complete the pre-assessment before the start of the course. Therefore, former Modules 1 and 2 will be covered in the pre-assessment period and the course period will start with former Module 3.

Part of the future plan is to offer the course annually during the summer holiday (early July to mid-August) for Geography and other interested teachers. There are also future plans to offer meteorological applications and exercises for Mathematics and Physics educators to use in their course delivery at CSEC and CAPE level, which could be replicated in other WMO regions with similar syllabi. Thus, this course should be seen as an innovative initiative, among many other current and future resources and initiatives, to build a stronger foundation for future meteorologists.

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9. CIMH Aeronautical Continuing Professional Development (AeroCPD) Course

Kathy-Ann L. Caesar, Caribbean Institute for Meteorology and Hydrology

Abstract

In 2011, the Caribbean Institute for Meteorology and Hydrology (CIMH) launched the Aeronautical Continuing Professional Development (AeroCPD) for duty forecasters as an online 6-month course, and has since conducted the course six times with tremendous success. The course covers five principle topic areas which came to the forefront as priority needs: radar interpretation, satellite meteorology and interpretation, mesoscale numerical weather prediction products, and operational aeronautical forecasting. AeroCPD employs four methods of assessment: assignments, projects, participation and final oral exams. Participation and attendance are a major part of the course and assessment. While the course was not designed for competency assessment, some surprising gaps were identified and needed to be addressed. In this article, we will describe the AeroCPD course development process, design of modules and assessments, knowledge gaps that we discovered, lessons learned, and future directions.

Keywords: Meteorology education, aeronautical, continuing professional development, online learning, online assessment

Introduction

The 16th World Meteorological Organization (WMO) Congress in 2011 strongly supported the introduction of a competency-based system for personnel in aeronautical meteorology and endorsed the WMO Executive Council (EC-LXII, June 2010) approval of the inclusion of Competence Standards for Aviation Meteorological Forecasting and Observing Personnel in WMO Publication No. 49, Technical Regulations, Volume I. WMO members were expected to provide evidence of their aeronautical personnel's competence as part of their Quality Management System (QMS). Further, Aeronautical Meteorological Personnel (AMP) needed to fulfil the Competence Standards for aeronautical personnel by 1 December 2013 as described by the Commission on Aeronautical Meteorology.

The Caribbean Institute for Meteorology and Hydrology (CIMH) teamed with UCAR's COMET® Program to develop a training program based on the approved Aeronautical Meteorological Personnel Competence Standards for Aeronautical Meteorological Forecasters (AMFs) as defined by the WMO Commission of Aeronautical Meteorology (CAeM). CIMH began work with the COMET Program (COMET) in 2011 on the Aeronautical Continuing Professional Development course (AeroCPD) for duty forecasters of the Caribbean Meteorological Organisation (CMO) member states. The course was populated with new and existing modules and lectures which addressed the needs of competency-based training in the region, some of which were unique to the Caribbean. However, AeroCPD could be easily adapted to any region to address training needs.

In September 2011, the Aeronautical Continuing Professional Development (AeroCPD) for duty forecasters was launched as an online 6-month course. The online format was best for the on-duty forecaster, as it allowed flexibility. It was also affordable for the weather services, as the AMFs remained present and active within their respective services.

CIMH has since conducted the AeroCPD course six times, training 50 regional forecasters, and it has been a tremendous success. The forecasters were able to review basic meteorological theories, refine operational forecasting techniques, and learn new technologies—all allowing the forecasters to meet and maintain their competency requirements. Note that the course is not designed for competency assessment, but there were instances where knowledge gaps were identified, and recommendations were made for further remedial training.

Developing the curriculum for AeroCPD

The goal was to make available to regional forecasters an enhanced and affordable course designed to fulfil training needs for operational Aeronautical Meteorological Forecasters (AMF), provide support to CIMH stakeholders in identifying competency 'gaps' within their workforce, and address these gaps as efficiently as possible. The course strongly relied on the CAeM Toolkit (http://www.14.caem.wmo.int/tt_cat/home.php) for guidance on assessment. The additional training material from the CAeM Aeronautical Training Database is now available through the WMO E-Library site

(https://library.wmo.int/index.php?lvl=etagere_see&id=157&page=1&nbr_lignes=37&nb_per_page_custom=37#.XMcPFehKg2w).

a. *Investigating the needs*

The initial idea for the AeroCPD course was to immediately address the need to have the CMO member states' aeronautical forecasters meet the WMO CAeM competency framework, as well as build the capacity within CIMH to offer continuing professional development for operational forecasters in using new technologies critical to aeronautical forecasting.

Surveys responded by the CMO Regional Directors were assessed to identify the priority needs within the regional NMHSs. Additional priorities came from discussions held directly with regional forecasters and CIMH lecturers. The lecturers reported that they often observed significant errors in the forecast outputs from the NMHSs; errors that needed to be addressed, especially in the context of QMS requirements.

We recognized that meteorological forecasters from NMHSs in CMO Member States are trained professionals who are required to improve and enhance their competency in the field of aeronautical forecasting. Thus, the proposed curriculum also took into consideration the inputs and experiences of the targeted participants.

Five principle topic areas came to the forefront as priority needs: radar interpretation, satellite meteorology and satellite product interpretation, mesoscale numerical weather prediction products, and operational aeronautical forecasting. Supported by training, advice and module development by COMET, we designed the AeroCPD course with a strong focus on tropical meteorology, but it is easily adaptable for any region to facilitate training for any WMO member state. COMET produced two new modules to support the course: Caribbean Radar Cases and Writing an Effective TAF in the Caribbean.

b. *The Curriculum*

The following is a brief description of the initial AeroCPD Units.

a. *Unit 1: Review of Tropical Meteorology Fundamentals*

A review of the basic concepts of meteorology, with a focus on tropical meteorology. The modules include portions of the COMET Introduction to Tropical Meteorology o-line textbook.

b. Unit 2: Satellite Interpretation in the Tropics

A review of operational satellite techniques, cloud signatures associated with most tropical synoptic scale and mesoscale features, as well as the thermodynamics and dynamics associated with the formation of these features. The topics also focused on the use of water vapour imagery to examine upper level dynamics. We utilized online CIRA VisitView modules and COMET modules for Volcanic Ash monitoring

c. Unit 3: Radar Interpretation in the Tropics

The course utilized training material from the United States NWS Warning Decision Training Branch lectures. The lectures covered the fundamentals of Radar, its limitations, types of displays, radar equations, reflectivity and velocity products, range issues, clear air phenomena, convection and practical examples. Most importantly, examples from the region were introduced into the course and gave the participants an opportunity view tropical examples.

d. Unit 4: Interpretation and Use of NWP Mesoscale Models

Regional forecasters have long used Global Scale models in the various iterations. While the performance has been very good and continues improving, the resolution is too large for the Caribbean islands. Higher resolution models needed to be introduced into regional operations. Thus, it is essential that the use of mesoscale (high resolution) models were explored to improve forecasts. CIMH currently runs the MM5 and WRF models for the Caribbean region, providing up to 48 hr forecasts. The course explains the development, use and limitations of mesoscale models.

e. Unit 5: Operational Aeronautical Meteorology

The goal of the entire course was to refine and improve skills of aeronautical weather forecasters. The preceding units are the building blocks to the final unit. The unit introduces two new modules designed specifically for the Caribbean region. The participants go through the TAF formulation process and the process of development of conceptual methods. TAF verification and climatology are also introduced.

The AeroCPD was always meant to be 'fluid' to allow the interjection of topics that could both improve the knowledge of the forecasters and their ability to serve their region. In 2017, new modules were introduced on Next Generation Satellites and on Management for Operational Services. The satellite course was retooled with the launch of the GOES-16 satellite in the region and the introduction of a host of new satellite products.

The Management Studies within the Forecast Office course was a much-needed response to the call from regional Directors for the forecasters to have some training in management skills. Forecasters are in most cases shift managers and future managers within their respective services, thus introducing these skills was important and timely. The course included modules on Management and Leadership; Management of Time, Stress and Crises; and Project Management in the Public Sector.

Assessments

Assessment in online courses can be difficult since participants do much of their work unsupervised. Therefore, we were more diligent as lecturers in assessing the participants carefully and we had to trust in their integrity. More importantly, the course is largely competency-based, so assessment must be based on 'what one can do.' Thus, assessments were built on participation and practical tasks.

AeroCPD employed four methods of assessment: assignments, projects, participation and final oral exams. The assignments were in three forms. Assignments were drawn from a combination of review questions, developed by the lecturers, or adapted from the COMET modules. COMET module quizzes, when used, were weighted less than the lecturer assignments.

Projects were designed to use material from one or more units and were in the form of a submitted paper with supporting images and products. In the Operational Radar Unit, for example, participants made a case-study presentation which was scored as part of the unit grade. Since this introduced a writing element, the participants were asked to follow American Meteorological Society (AMS) Authors' Guide when submitting their work. Given that communication is a major part of the competency standards, we believed that the forecasters should be exposed to the standardized professional writing protocols.

Participation and attendance are a major part of the course and assessment. We took great care not to consume too much of the forecasters' time. We asked the forecasters to commit to an hour of lecture time and two to three hours of study time per week throughout the entire course.

To effectively assess the participants, we needed to engage the participants one-on-one. To this end we conducted a one-hour oral assessment at the end of the entire course, incorporating questions that covered the practical aspects of the units. While this was time-consuming for the lecturers, it was extraordinarily enlightening for both participants and lecturers.

The grades assigned to the units were weighted based on the goals of the course, with the greatest weight assigned to the Operational Aeronautical Meteorology Unit and projects.

The components of the course were weighted as follows:

- Unit Assignments – 50%
- Projects – 30%
- Participation and Attendance – 10%
- Final Oral Assessment – 10%

The following grading scale is the CIMH standard grading scheme.

To attain a **Pass** in the course > 50%

To gain a **Credit** > 70%

Distinction > 86%

To pass the AeroCPD participants had to be graded 70% or greater.

The participation and performance of most of the forecasters was generally good to exceptional. There were a few 'red flags' raised in terms of knowledge gaps—finding these knowledge gaps is one of the goals of the course. This was particularly evident and surprising in the area of satellite interpretation. It was very effective to deal with these gaps in knowledge on a one-to-one basis with the participants. The forecasters were open to comments and very appreciative of the information being presented to them.

Of the few participants who failed to attain the 70% grade, we strongly recommended that they enrol in further Continuing Professional Development courses. Some retook the AeroCPD course, and two participants were recommended for further face-to-face training.

Lessons Learnt

a. Keeping participants engaged

Initially, keeping the participants invested in the course was a concern. Historically, regional forecasters have been often shy about speaking online, which makes engaging learners even more difficult. But from the first groups in the AeroCPD course, it was apparent that the forecasters were readily prepared to participate, and the discussions were lively and encouraging. Of course, there were a few participants who were not very vocal, which is to be expected in any class setting.

Each unit was composed of a series of modules of which one or more were assigned weekly to the participants to complete. In most cases, the assigned modules were discussed in the live sessions, sometimes after a short lecture. Therefore, the discussion sessions were treated as interactive and practical sessions rather than lectures, where the participants were given a chance to interact with the lecturers. In most cases the response was positive. This was also an excellent method to both evaluate students' knowledge and gain some insight into their capabilities.

b. Knowledge Gaps identified

The intent of the course was to have forecasters review basic meteorological theories, refine operational forecast techniques and learn new technologies to allow the forecasters to meet their competencies requirements. While the course was not designed for competency assessment, some surprising gaps were identified and needed to be addressed. These gaps included basic dynamical concepts of divergence and diffluence, satellite interpretation of mesoscale features, and most importantly, WMO/ICAO regulations for Aeronautical meteorological operations.

One of the more difficult challenges was addressing bad practices in Terminal Aerodrome Forecasts (TAFs). There are a few practices which are almost engrained in the operations of regional forecast offices. Some examples of practices that needed to be corrected in TAF writing were including TEMPO groups covering a 24-hour period (or the entire period of the TAF), inclusion of high clouds in the TAF, and not issuing amendments. To counter these trends, the 'Writing the Perfect TAF for the Caribbean' module was developed and used a case in their region with familiar concepts.

Future of AeroCPD

The response from the participants and their administration on the AeroCPD course has been very complimentary and enthusiastic. Most commented that they found the course very necessary and would refer their colleagues to future courses. Some requested to attend future AeroCPD courses. As a result, the Aeronautical Continuing Professional Development course is now a core course offered in the CIMH Curriculum. It continues to support WMO and CMO goals of having all its operational forecasters deemed competent in the field by 2016 and beyond.

The onset of the WMO Global Campus initiative is an important factor in the continued iteration of the AeroCPD. Global Campus allows the interjection of many other possible courses that are not restricted to CIMH and the Caribbean. In the future, CIMH is also considering utilizing the WMO Global Campus to introduce international contributions and collaborations in the AeroCPD course.

Conclusion

One issue which we will have to continuously emphasize to present and future participants of the course is that the course is not intended for gaining a job promotion, but rather for job quality, job sustainability, and job enhancement. Some personal feedback from the participants indicated some confusion in this area even after the QMS process was explained. We hope that educating the aeronautical forecasters (and other AMPs) will allow them to embrace the QMS and competency concepts of good practices that are embedded in securing life and property in aeronautical services.

The AeroCPD course is meeting its goals and is helping the regional forecasters hone their skills. There is still a long way to go and a great deal to be learnt. It has been a learning experience for both participants and lecturers, and a very rewarding experience.

As a pilot program, this course has proven itself to be an effective and beneficial online training course for Caribbean regional forecasters, and a model that could be easily used by other WMO member states to address competency concerns with their aeronautical personnel.

A wealth of resources on other topics can now be accessed with the advent of WMO Global Campus. CIMH will be updating the AeroCPD course to involve far reaching topics, engage with other training institutions, and share lessons learned.

References

World Meteorological Organization, 2018: *Basic Documents, Technical Regulations, Volume I - General Meteorological Standards and Recommended Practices* (WMO-No.49). Geneva.

World Meteorological Organization, 2019: *Compendium of WMO Competency Frameworks* (WMO-No. 1209). Geneva.