Perfecting imperfect models

Around 170 people gathered on 19 January 2005 in London to attend a meeting in which prominent scientists presented their results and views on the 'state-of-the-art' of weather and climate models. This was, by far, the best attended Wednesday meeting of the RMetS in a long time (in spite of the UK Met Office now being 200 miles away from London). The reason for gathering was certainly not the rather cryptic title "Perfecting imperfect models", as clearly models will never be perfect. Most likely, it was because of the relevant topic – what are the Achilles' heels of numerical models and what should we be doing to improve these models in the near future while at the same time using them to produce forecasts? The series of talks, coupled with the concluding panel discussion session resulted in a lively and informative meeting.

The theme of the meeting was dictated by the following contentious questions, sent to the six speakers and the organiser prior to the meeting when they were debating ways to stimulate some dialectical discussion:

- Should we use all the available computer power on improving resolution with the view that, at very high resolution, parameterisations might be a thing of the past in a few decades?
- Given that users often want probabilities of outcomes, could we say that models are as accurate now as they will ever need to be and therefore we could stop all this model physics development work?
- How do we balance these opposite views and have both reduction and quantification of uncertainty?
- Can we make better use of available observations to improve modelled physical processes and/or what type of observations would be most needed?

Clearly, these are all open issues which cannot be solved by an afternoon meeting. Nonetheless, the outcomes of the meeting might help to identify the best path for future model development.

It was noted in the introduction that typically these questions are timescale dependent and so the speakers were lined up in an appropriate way. It was therefore *Anton Beljaars* (European Centre for Medium-Range Weather Forecasts (ECMWF)) who began with the medium-range timescale, roughly corresponding to the weather forecasts we are used to. He started by emphasising that, in principle, weather models should not differ from climate models, resolution being the only main variable. This challenge i.e. to eventually reach a seamless system, can only be achieved by constant confrontation between the way in which models 'view' physical processes and the actual observations. That is, models have to be carefully validated against all available observations. However, he pointed to some caution as two contrasting situations can be faced: on the one hand it might be hard to link a model improvement with the reason why this has happened, implying that one could in principle improve the model for the wrong reasons, and on the other hand it might happen that there is degradation of the model performance even if one is confident that the ameliorated processes should be improving the skill of the model. An example for the latter was the case of an encouraging stable boundary layer formulation, which clearly degraded the 500 hPa geopotential height scores in the ECMWF system. A likely culprit appears to be the lack of a sufficiently well-defined drag coefficient. But how to measure such an insidious quantity is clearly not straightforward.

Steve Woolnough (University of Reading) again stressed that weather systems are the building blocks of climate. It looks as if this concept of trying to 'unify' the two different timescales of daily-to-seasonal and climate timescales is really taking route in the atmospheric/climate community, although arguably most of the push comes from the smaller timescale end. Thus far, climate models have been seen as something quite distinct from weather models, mainly because errors are so large that climate change modellers are forced to go down the models at equilibrium route. Now there is the impression that a more purist approach could also be investigated. To me, this process is reminiscent of the unification of the quantum field (the very small) and the gravitational field (the very large), which still is open debate in theoretical physics after almost a century. Clearly this is a tougher problem, but even the climate one has its long-standing difficulties. The more purist approach I was hinting at would essentially be based on something similar to what seasonal forecasts do. For the seasonal timescale, it is acknowledged that although model biases are substantial, as we were reminded by *Mike Davey* (UCL/UK Met Office), there are viable approaches which make seasonal predictions a real possibility. This is not to say that model errors are not important but the advantage of having a fully coupled model outweighs the model drift disadvantage. Still, we clearly need to reduce coupled model biases, by comparing observed and model processes.

From the seasonal to the climate change timescale, the jump is very big. And as discussed above, the approach to climate change forecasts definitely changes gear. Models at equilibrium *must* therefore be used since drifting models would be considered ignominious by the establishment. Now the emphasis is more on achieving a measure of uncertainty of model outputs, *David Sexton* (UK Met Office) told the audience. To do this, model imperfections are taken into consideration by generating an ensemble of experiments in which each member has their specific perturbation to some known-to-be uncertain physical parameter. They also introduced a metric to measure how good a member is when compared to a set of observations. The trouble with this type of evaluation though is that it so happens that the member which best simulates surface temperature is the worst at simulating high thick cloud fraction, and almost conversely, the best at high thick cloud fraction is mediocre at surface temperature – and very bad at humidity. Notwithstanding these problems related to the imperfect models, this is certainly one of the most sensible approaches to trying to better quantify uncertainties. Clearly, even climate modellers would welcome model improvements.

There are other, possibly better, ways to perturb the model, contended *Tim Palmer* (ECMWF), via a specifically targeted stochastic physics, for instance. His argument, which would apply to all timescales, is that "long-standing biases in weather/climate prediction models could be associated with structural error in their underlying formulation" and that "at each timestep stochastic parameterisation generates a specific realisation, and not an ensemble mean, of the sub-grid circulations". This philosophy is certainly more appealing than a mere twiddling of parameters and it would be good if this "bold" approach (as Paul Mason, chairman of the Global Climate Observing System Steering Committee, defined it) turned out to be beneficial.

What is surely not beneficial is the terminology used by many scientists: "Would you expect to gain the attention of policy makers if you told them that models had errors", asked *Alan Thorpe* (newly-appointed NERC CEO). "They would undoubtedly tell you to fix your errors." Hence, attention to semantics is needed. "Modelling systems, observations and analyses have "uncertainties" not "errors"." On the other hand, "forecasts have errors: systematic and non-systematic". Overall, Dr Thorpe claims there is a pressing need "to quantify and reduce uncertainty", and he suggested the community should move towards multi-model multi-analysis ensembles i.e. The Grand Ensemble which, however, is a huge endeavour needing international cooperation.

A 30-minute panel session nicely wrapped up the topics espoused by the six speakers, and a few other points were raised. The consensus seemed to be that models should be run at higher resolution, but it was equally recognised that computer power is not expected to increase enough to get to resolutions at which parameterisations would play a lesser role (possibly ca. 1 km) in the next couple of decades. An apparently partisan view was taken by Tim Palmer who raised the issue of the lack of a concerted effort for climate computing facilities in Europe. If a unified effort was in place, a more genuine intercontinental competition could be achieved. And one of the concluding remarks was put forward by *David Anderson* (ECMWF) who warned the community from the anecdotic "practice of the consensus", which considers as black sheep the institutions with an outlier model.

The final conclusions seemed to be all well balanced:

- Models should be unified across all timescales.
- There should be a balancing act between high resolution and the ensemble approach (however, Prof. Mason suggested that ensembles are "cul-de-sacs", even if, when tackled by Dr Palmer he backed off a little and added that they are "*essential* cul-de-sacs").
- Observations must continue to play a key role in the development of the modelling of physical processes, although the modelling of the physical processes might be helped by the use of some well-devised stochastic physics to allow for some weather-like behaviour i.e. by exploring a wider phase-space.

In the end, many people thought that they had spent three-and-half hours of their time very well. Abstracts are available from the RMetS website: www.rmets.org (under events > meetings > archive).

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Meeting report — Earth observation: New windows on the world

Earth observation is concerned with using remote sensing to determine the properties of the atmosphere and surface. The subject has grown in parallel with the unmanned planetary exploration programme, which often grabs the headlines as with the recent spectacular images of Titan from the Huygens probe. But the results from earth observation can be at least as exciting scientifically, while at the same time making substantial contributions to operational meteorology, oceanography, climate and many other environmental programmes. As with the planetary missions, earth observation continues to benefit from new satellites that push at the boundaries of both technology and remote sensing science. In recognition of this, the applications to atmospheric science of several new satellite missions were highlighted in the RMetS Wednesday meeting held on 8 December 2004.

Andrew Collard (Met Office) reviewed the principles of thermal remote sensing and emphasised the value of high spectral resolution for more precise retrievals of the atmospheric temperature and humidity structure. This is currently being achieved by the Atmospheric Infrared Sounder instrument on NASA's Aqua satellite, which uses a grating spectrometer to provide several thousand channels across much of the infrared spectrum. The high resolution enables retrievals to be made that are close to the theoretical limits of thermal remote sensing, but the huge data volumes remind us of Verner Suomi's comment that processing satellite data is like trying to drink from a fire hydrant. Not surprisingly, innovative schemes are needed for extracting the required signals from the torrent of data.

High resolution in time is also extremely valuable and is provided by geostationary orbits, in which the height is chosen so that the period matches the rotation rate of the Earth, so the satellite appears to hover above a point on the equator. *Jo Schmetz* (EUMETSAT, Germany) showed results from Meteosat-8, the latest European geostationary weather satellite. The operational instrument provides images every 15 minutes over the whole of the planet beneath the satellite, in a series of channels in both the thermal and solar regions of the spectrum. An even faster scan of limited areas is possible to monitor rapidly growing features. The satellite also carries the first Geostationary Earth Radiation Budget (GERB) instrument, described by *John Harries* (Imperial College, London). GERB measures both the reflected solar and emitted thermal radiation with high accuracy and with the same time resolution as the imager. Apart from clouds, Meteosat is well-placed to study the outbreaks of Saharan dust that sweep over the continent and have a substantial impact on the radiation fields.

Measuring precipitation from space poses particular problems and *Steve English* (Met Office) described the various methods that have been applied using microwave remote sensing. While the precipitation radar on the Tropical Rainfall Measuring Mission (TRMM) provides the most direct measurement, this cannot detect the weaker rain rates more typical at high latitudes, where indirect observations of the emitted thermal microwave radiation are more appropriate. Plans for a Global Precipitation Mission thus include a mix of active and passive technologies, flying on several satellites to provide adequate temporal coverage.

Active remote sensing also figured in the final two talks. *Graeme Stephens* (Colorado State University, USA) described the CloudSat mission, scheduled for launch in the summer of 2005. This will make the first direct measurements of the vertical structure of clouds and cloud properties, using a specially designed cloud radar operating at 94 GHz, a much higher frequency than that used by TRMM to see rain. CloudSat will be launched into close formation with four other satellites in the so-called 'A-Train', an unprecedented constellation of satellites with the orbit of CloudSat adjusted regularly to maintain the formation flying.

The meeting closed with a description by *Christian Marquadt* (Met Office) of the use of radio occultation measurements to derive the temperature and humidity structure of the atmosphere. Combinations of satellites in different orbits, including those used in the Global Positioning System for navigation, can provide many transects through the atmosphere as the satellites rise and set relative to each other. Accurate monitoring of the signals can detect the small time delays as the signals intersect different atmospheric layers, from which the atmospheric structure can be derived.

The meeting was very well attended and the audience was treated to six excellent talks by world experts in their fields. We are grateful to everyone who contributed to making this meeting such a success.

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