Radiation in the next generation of weather forecast models: Workshop report

Robin Hogan, 22 June 2018, ECMWF

1. Overview

From 21 to 24 May 2018, a workshop was held at ECMWF on the topic of "Radiation in the next generation of weather forecast models". Almost all workshops and conferences on atmospheric radiation tend to focus on climate applications, so this workshop filled an important niche by targeting NWP applications (1-50 km resolution, forecast lead times from 1 day to 1 year), while drawing on radiation expertise from the wider community.

The workshop brought together over 50 experts from 12 countries, with 20 oral presentations and 18 posters. Topics included representing complex surfaces (orography, urban areas, forests and snow), faster and more accurate solvers, 3D radiative transfer, improving representation of the properties of clouds, aerosols and gases, observational evaluation of radiation schemes and radiation products, middle-atmosphere radiative transfer, solar and infrared radiance modelling for data assimilation, and pathways by which better treatment of radiative processes can improve predictive skill. The talks may be viewed at the workshop web page: https://www.ecmwf.int/en/learning/workshops/workshop-radiation-next-generation-weather-forecast-models.

The final part of the workshop consisted of three working groups that tackled a range of questions relevant to improving the representation of radiation in models. The remainder of this document summarises the ideas and recommendations that arose from these discussions.

One interesting general question that arose was at what magnitude a radiation error causes a measurable forecast degradation and therefore becomes "actionable". In the context of climate models this is easier to answer in terms of global mean fluxes, but for NWP there are many ways in which radiation is important on regional scales and it would be an interesting task to write a paper to answer it.

2. Ideas for collaborative projects and activities

- **Correlated k-distribution model intercomparison project ("CKD-MIP").** We agreed that it would be desirable for users of radiation schemes to be able to more easily generate their own gas optics parameterizations, in order to make their own trade-off between accuracy and speed. Moreover, an NWP user may not need the capability to vary trace gas concentrations, in which case they could be merged into a single hybrid gas, reducing the number of g-points. We suggested as a starting point an intercomparison exercise to compare different schemes for generating gas optics parameterizations, testing different treatments of spectral overlap, imperfect correlation in the vertical and so on. In addition to standard correlated-k approaches this could include ideas from radiance modelling. Line-by-line calculations on the 100 RFMIP profiles would be an ideal reference dataset. Robin Hogan will contact likely contributors in due course.
- **Urban radiation.** The complexity of urban geometry necessitates many simplifications in treating its interaction with radiation. A collaboration involving at least ECMWF, Meteo-France and the University of Reading will compare new and existing urban radiation parameterizations to Monte Carlo calculations for the building layouts of real cities, and test the validity of each individual simplification made in the parameterization. Observations (e.g. from the BUBBLE campaign in Basel) could be used as well.
- **Atmospheric composition.** Overlapping interests, data and code suggest that there should be closer discussion between ECMWF, the Met Office and KIT on ozone and/or aerosols. For example, ECMWF is planning to test prognostic dust interactive with radiation (tried at MO and KIT); KIT is

planning to test use of ecRad with the ICON-ART aerosol scheme; and the Met Office is planning to test the use of CAMS aerosol and ozone for their UV index forecasts.

- **Radiative coupling between the atmosphere and different surfaces.** Difficulties were highlighted of coupling the fluxes from atmospheric radiation schemes with the schemes used to represent radiation interactions in different types of surface (vegetation, urban areas, sea ice and ocean), for example due to the different and incompatible assumptions made in the surface scheme. Is there a better way to do this? What is the importance of spectral coupling, i.e. passing spectral fluxes to and from the surface?
- **Workshop on NWP and renewable energy.** It would be useful to get together users and providers of radiation data used in forecasting solar power output. Issues are the required angular width of "direct" radiation for different types of solar power installation, the value of spectral solar predictions given the limited spectral response of photovoltaics, and the relevance of prognostic aerosol and ozone to improve solar forecasts.
- **Funding for ambitious projects: 3D radiation in high resolution models.** We discussed the difficulty of obtaining funding for radiation work (except in the context of climate change). There is funding available (e.g. H2020) for big computational challenges, and a candidate raised at the workshop by Bernhard Mayer was performing 3D radiation in high resolution models. This is interesting computationally due to challenge of passing radiation between model columns and therefore passing data between tasks in a parallel environment. Scientific questions would include whether it is sufficient to pass only the solar direct radiation between columns, and how to achieve energy conservation when performing 3D radiation in the presence of orography.

3. Ideas for observational analysis

- **Separating radiation errors from state errors.** State errors (errors in model prognostic variables related to cloud) often dominate in cloudy situations, e.g. mixed-phase clouds in the Southern Ocean and stratocumulus off the western coasts of sub-tropical continents. Stratifying data by non-radiation variables should help to understand errors at BSRN sites, for example clear/cloudy stratification (e.g. using coincidences of the ceilometer and surface radiation network), stratifying clear skies by aerosol optical depth and water vapour path, and stratifying cloudy skies by liquid water path.
- **Spectral evaluation** could help to understand causes of errors, e.g. in the longwave to identify the source of the 5 W m^{-2} underestimate of surface longwave reported by Thomas Haiden.
- **The Arctic MOSAiC campaign** will be an excellent opportunity to collaborate with the wider community to understand errors in NWP models in the Arctic: http://www.mosaic-expedition.org.
- **The MARCUS/SOCRATES observations** provide a similar opportunity to understand errors in the Southern Ocean.
- **Supersites** can help unpick model errors, and some programmes compare several NWP models already; see the Sodankyla mast comparison at http://fminwp.fmi.fi (login details available from Laura Rontu of FMI), and the Cloudnet analysis at many sites: http://cloudnet.fmi.fi.
- **Water vapour continuum absorption in the infrared window** may be worth revisiting; although better understood than the continuum in the near infrared, there is lots of energy in the infrared window so errors in continuum models could be important. There are now more AERI observations than 15 years ago when this was last tackled within ARM. (It was noted that HITRAN errors are believed to be of second-order importance for fluxes, but can be important for radiances.)

4. Codes that could be shared to enhance collaboration

- **Spherical geometry.** James Manners described the comprehensive treatment of spherical geometry particularly in the context of the propagation of direct solar radiation through the upper atmosphere. This code is available in the SOCRATES radiation package (free software).
- **Orography.** Code to compute horizon angles for 16 directions and the sky-view factor using the model grid (whatever resolution that may be) will be added to SOCRATES. Note that some features are available in the geospatial data abstraction library at http://www.gdal.org. See also

http://viewfinderpanoramas.org/dem3.html. A document and/or some tools for preparation of local horizon angle and building blocks for general orographic radiation parametrizations could be provided by the HIRLAM radiation team by the end of 2018. A related question was raised as to whether we can validate fluxes over complex orography.
- **Non-LTE**. The Fomichev code is the only one suitable for use in weather and climate models, but needs to be adapted to work up to the 4x CO2 scenario, and work with different spectral discretizations. Jiangnan Li and Manuel Lopez-Puertas to look into this.
- **3D radiation.** The SPARTACUS solver for 3D radiative transfer in clouds is part of the ecRad radiation scheme, available for non-commercial research and education from the ECMWF web site.

5. Ideas for modifications to the IFS and other NWP models

- Consider running the radiation scheme at a lower spectral and/or temporal precision later in the forecast, for efficiency. Note that those IFS configurations that use 3-h radiation already often run radiation every 1 h in the first 12 hours of the forecast.
- Jim Haywood's presentation described the Malavelle et al. (Nature 2017) finding that a large volcanic emission of tropospheric sulphate had a measurable impact on cloud albedo (the first indirect effect) but not on cloud cover or water path (second indirect effects). This supports the suggestion to add the first indirect in the IFS (even if using climatological aerosol to estimate cloud droplet number concentration), but not any other aerosol indirect effects.
- Consider using solar observations to modify the solar spectrum at g-point level rather than the band level. This could lead to better mean temperatures in the stratosphere. Note that CMIP6 have settled on the NRLSSI dataset, but there is a need to resolve the lack of consistency between the UV and near-IR.
- More surface variables could be perturbed in ECMWF's Stochastically Perturbed Parametrisations (SPP) scheme, e.g. the properties of leaves and the albedo of snow-covered forests.
- Processes that could be imported from Earth System Models and which might improve seasonal forecasting include interactive dust, and prognostic Leaf Area Index (previously tested at ECMWF but with unmodified albedo) but ideally with better radiative transfer in forests. Better land-surface data could be obtained from NASA for tree height, the Global Human Settlement Layer, and ECOCLIMAP for PDFs of land types.
- It should be a priority to make the radiation, clouds and convection schemes consistent in terms of assumptions on particle size, overlap, sub-grid heterogeneity and scattering properties.
- When combining columns for spatially coarser radiation calculations, one could use the spatial distribution to provide sub-grid information for the radiation calculation, such as the fractional standard deviation of water content, or the cloud scale for 3D radiative transfer in SPARTACUS.
- Although neural networks may struggle to reproduce the features of a full radiation scheme, machine learning might be useful to provide an efficient means to correct the broadband fluxes to account for, for example, 3D radiative effects.
- The question was asked as to whether middle-atmosphere biases have been removed for the right reasons. Further processes to consider might be thermalization of absorbed solar radiation for ozone, variations in the carbon-dioxide profile, the role of non-LTE effects, and uncertainties in the mean and the diurnal cycle of ozone.