SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	An evaluation of the advanced model physics in cycle 46 of HARMONIE-AROME
Computer Project Account:	SPIEGLEE
Start Year - End Year :	2022-2024
Principal Investigator(s)	Emily Gleeson
Affiliation/Address:	Met Éireann
Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

The purpose of the special project was to test various new, and more advanced, physics options using HARMONIE-AROME cycle 46 and cycle 49. The main testing was done using aerosol configurations, but other tests were also conducted including experiments on fog microphysics, cloud droplet number concentration, surface roughness and the LFAKETREE option and the ICE-T add-on to the microphysics scheme to improve the representation of supercooled liquid.

Summary of problems encountered

My main problems were with delays in having versions of the code ready to test. There were long delays with cycle 46, as is natural in this type of field. Cycle 49 is not fully ready for in-depth testing just yet. As a result, I didn't use all of my SBU quotas. In 2024, due to a file being copied to my $HOME, my SBUs were billed from my national allocation rather than the special project, so my usage is more than suggested by the SBU reporting.

Experience with the Special Project framework

Very happy with the process. No complaints. Also, I like the SBU website for keeping track of my usage. Having such special projects really enables me to thoroughly test physics options.

Summary of results

The results from some of the experiments are included in the 3 scientific publications listed in the next section but a few results are also included here as an illustration, including some results that have not yet been published.

1. **Aerosol Experiments**

Cloud aerosol radiation interactions has been a large area of development for us in recent years. Some results from 2024 in particular are included in a report copied to https://drive.google.com/file/d/1upezwtuUk7RefHaZjcjNQ3z4yetIpe6W/view?usp=drive_link. I ran a series of 2-week experiments over an Irish domain (November 1-14th 2019, June 1-14th 2018) for the following aerosol configurations: **1)** Tegen climatology **2)** CAMS climatology **3)** CAMS climatology where the climatological mass mixing ratios are used to calculate the effective radius (an option called LAEROMIC) **4)** A version of 3 but with modified code to produce a better cloud droplet size distribution **5)** Near real-time (NRT) aerosols **6)** Like 5 but with the code modification as before.

General comments on the results:

- The Tegen and CAMS climatologies are quite similar in terms of overall biases.
- CAMS (with the LAEROMIC option) and CAMNRT lead to too little cloud, too much global shortwave radiation.
- 2D and 1D histograms of clear-sky index (CSI, global shortwave radiation divided by clear-sky global shortwave radiation) are also similar, except that CAMS has more high CSI values.
- Regarding the histograms, CAMS with LAEROMIC and CAMSNRT give much less low CSI values, which is inline with observations.
- The impact of the code change re the size distribution is that there a general shift towards lower CSI, so now a bit worse at the low CSI end compared to without the code change and a bit better at the high CSI end. Similar conclusion for CAMS (with LAEROMIC=T) and CAMSNRT.
- For the Autumn period, the climatologies perform well. Using NRT CAMS or CAMS with LAEROMIC, which impacts on the effective radius of the cloud droplets and also on the

microphysics, result is poorer results overall, positive biases compared to ground station observations and satellite-derived global shortwave radiation (SWD hereafter).

- Compared to the satellite-derived SWD for the Autumn period, the Tegen and CAMS climatologies (LAEROMIC=F) look best, with the other options resulting in too much SWD south of Ireland. Caveats with this are that the domain is small and that can have an impact. In addition, the satellite product has its own biases that have not been accounted for here.
- Considering the experiment data only, all bar the CAMS climatology (LAEROMIC=F) show an average positive bias in SWD compared to Tegen of the order of 10-20 W/m^2.
- For the Summer period, CAMSNRT with the code change performs comparably to Tegen and CAMS climatology. Other configurations give more positive bias in SWD, like in the Autumn period.
- LAEROMIC with CAMS improves the low CSI but at high CSI, there’s a large degradation.
- For the Summer period, as well as the climatologies, CAMS with LAEROMIC and NRT, with the code change, give comparable SWD to the satellite product but there seems to be too little cloud if the cloud particle size distribution code change is not employed.
- The figures below show the 14-day mean global SWD for the Autumn and Summer periods respectively.

3.7 Daily Mean SWD, averaged over 14 days - without ICE-T

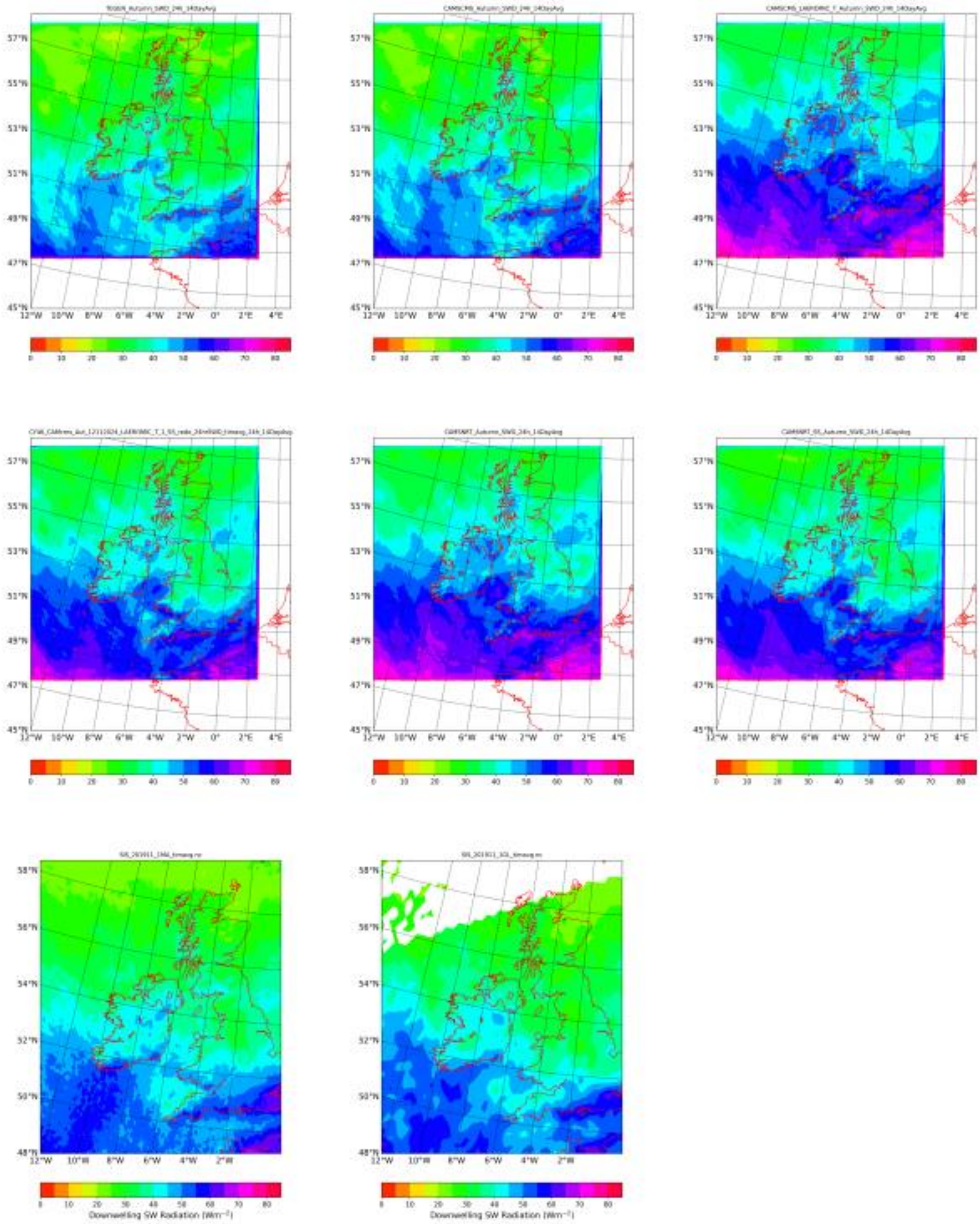

Figure 7: 14-day average of 24-hour SWD accumulations (converted to Wm^{-2}) (from top left to bottom right): TEGEN, CAMSCMS, CAMSCMS+LAEROMIC=T, CAMSCMS+LAEROMIC=T+SS, CAMSNRT, CAMSNRT+SS. Final two panels are the SIS MVIRI-SEVIRI 14-day daily mean global SW, and the SIS AVHRR on polar orbiting satellites 14-day daily mean global SW.

4.7 Daily Mean SWD, averaged over 14 days - without ICE-T

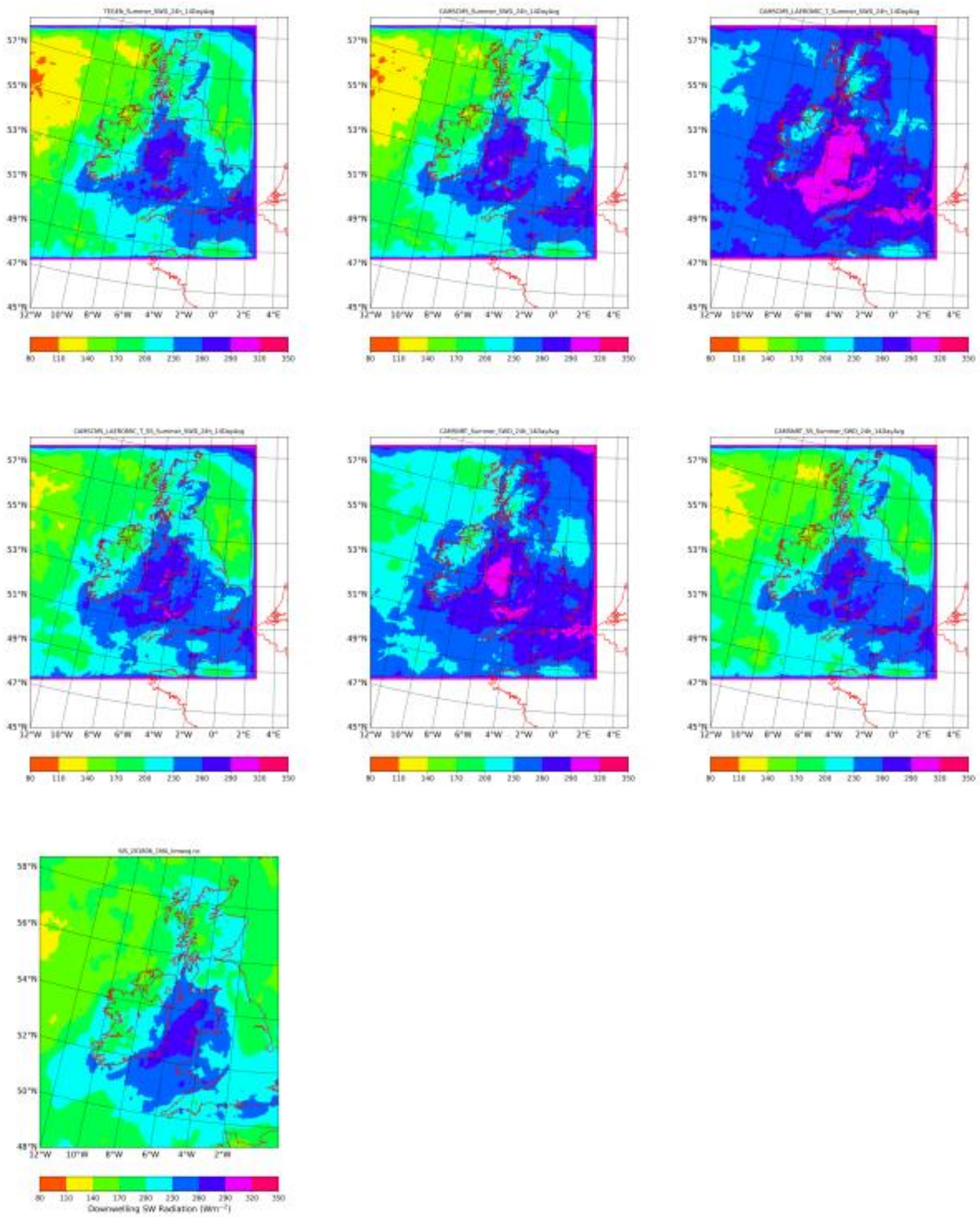

Figure 17: 14-day average of 24-hour SWD accumulations (converted to Wm^{-2}) (from top left to bottom right): TEGEN, CAMSCMS, CAMSCMS+LAEROMIC=T, CAMSCMS+LAEROMIC=T+SS, CAMSNRT, CAMSNRT+SS. Final panel is the SIS MVIRI-SEVIRI 14-day daily mean global SW.

2. ICE-T + Aerosols

The results from these experiments are also included in https://drive.google.com/file/d/1upezwtuUk7RefHaZjcjNQ3z4yetIpe6W/view?usp=drive_link.
ICE-T is an add-on to the ICE3 microphysics scheme used in HARMONIE-AROME. It includes elements of the Thompson scheme, with one of its core aims being to solve an issue with the lack of supercooled liquid in HARMONIE-AROME, which is important especially at high latitudes.

- In general ICE-T results in more cloud, less SWD. This alleviates some of the issue caused by CAMS with LAEROMIC and CAMSNRT. When the aerosols interact with the microphysics (CAMS with LAEROMIC=T and CAMSNRT) the impact of ICE-T is greater, as can be seen in the SWD difference plots of ICE-T minus non-ICE-T -a greater negative difference.
- 1D histograms of CSI show little difference in the Tegen and CAMS climatology experiments, when ICE-T is used compared to not used, but there are differences with CAMSNRT or when LAEROMIC is on with the CAMS climatology.
- When ICE-T is used there is generally a bit less SWD (up to 10 W/m^2). The biases are mixed when the climatologies are used but mostly negative with NRT and AEROMIC=T with the CAMS climatology.
- For the Summer period the +/- biases compared to station data over Ireland mostly cancel out when ICE-T is used except for the CAMS LAEROMIC and CAMS NRT cases, where the cloud droplet size distribution code was not modified. The SWD differences for ICE-T minus ICE-T are mostly negative and more than -20 W/m^2 for the CAMS LAEROMIC configurations.
- The figures below show the difference in global SWD for the various aerosol configurations when ICE-T was used compared to when it was switched off.

3.10 Daily Mean SWD, averaged over 14 days - ICE-T minus without ICE-T

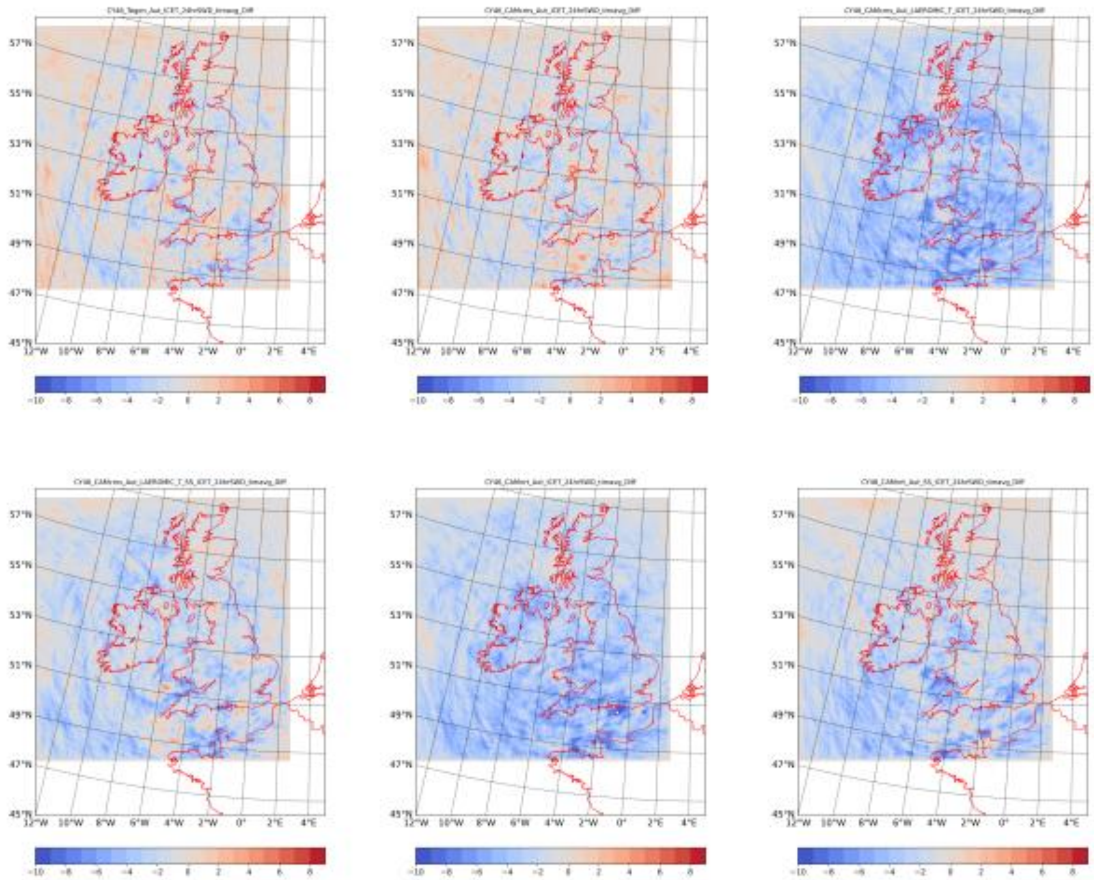

Figure 10: 14-day average of 24-hour SWD accumulations (converted to Wm^{-2}) ICE-T minus non-ICE-T (from top left to bottom right): Tegen, CAMSCMS, CAMSCMS+LAEROMIC=T, CAMSCMS+LAEROMIC=T+SS, CAMSNRT, CAMSNRT+SS.

4.10 Daily Mean SWD, averaged over 14 days - ICE-T minus without ICE-T

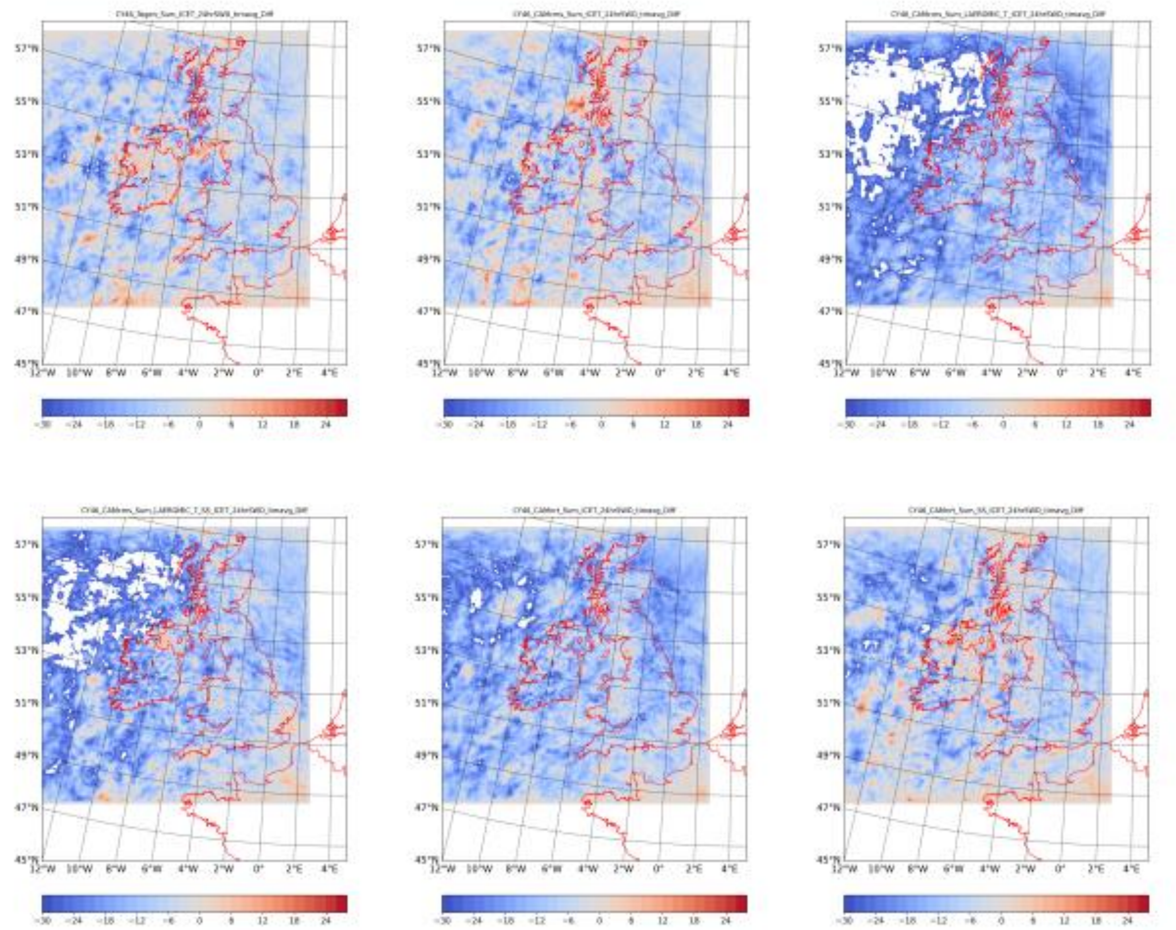

Figure 20: 14-day average of 24-hour SWD accumulations (converted to Wm^{-2}) ICE-T minus non-ICE-T (from top left to bottom right): Tegen, CAMSCMS, CAMSCMS+LAEROMIC=T, CAMSCMS+LAEROMIC=T+SS, CAMSNRT, CAMSNRT+SS.

3. Impact of Cloud Droplet Number Concentration (CDNC)

These results are included in the MDPI publication on HARMONIE-AROME cycle 46. The tests were done with SBUs from this special project as in 2022/2023 we were testing using cycle 43 of the code.

In the current default version of HARMONIE-AROME Cycle 46 (where NRT aerosols are not used), microphysically important variables are prescribed. The values are either height dependent, or approximated processwise. One such important meteorological variable is the cloud droplet number concentration (CDNC). It is used in the parametrization of various processes leading to the growth of activated cloud droplets to liquid and solid precipitation. In HARMONIE-AROME Cycle 43, constant values of CDNC were used, with a value of 500 cm^{-3} for urban areas, 300 cm^{-3} over land, and 100 cm^{-3} over the sea/ocean. With these values, fog and cloud condensate in the lowest thickest clouds were over-estimated. An example of the problems with forecasting low thick clouds is shown in the figure below. In this figure, a meteosat second generation (MSG) visible satellite image is shown, along with the MSG Seviri cloud water path product from the Dutch Meteorological Service, KNMI, and cloud water condensate fields from two HARMONIE-AROME Cycle 43 experiments, for

12 UTC on 8 July 2019. One experiment used the default configuration in HARMONIE-AROME Cycle 43, and the other one used CDNC values of 50 cm^{-3} everywhere. You can see from the figure that the integrated cloud water was overestimated in the default HARMONIE-AROME Cycle 43. A CDNC value of 50 cm^{-3} gave much better results.

In HARMONIE-AROME Cycle 46 CDNC has a vertical dependence with height, with the same profile over land and sea. The reason for this is to eliminate the artificial reduction in stratiform precipitation that occurred in HARMONIE-AROME Cycle 43 at the land sea boundaries, due to the use of different CDNC values. At the lowest model level, CDNC is multiplied by a factor of 0.25. This is to improve predictions of low visibility and fog. The current configuration of HARMONIE-AROME Cycle 46 shows improvements in the cloud water prediction. See information of the latest CDNC in Contreras et al., 2022.

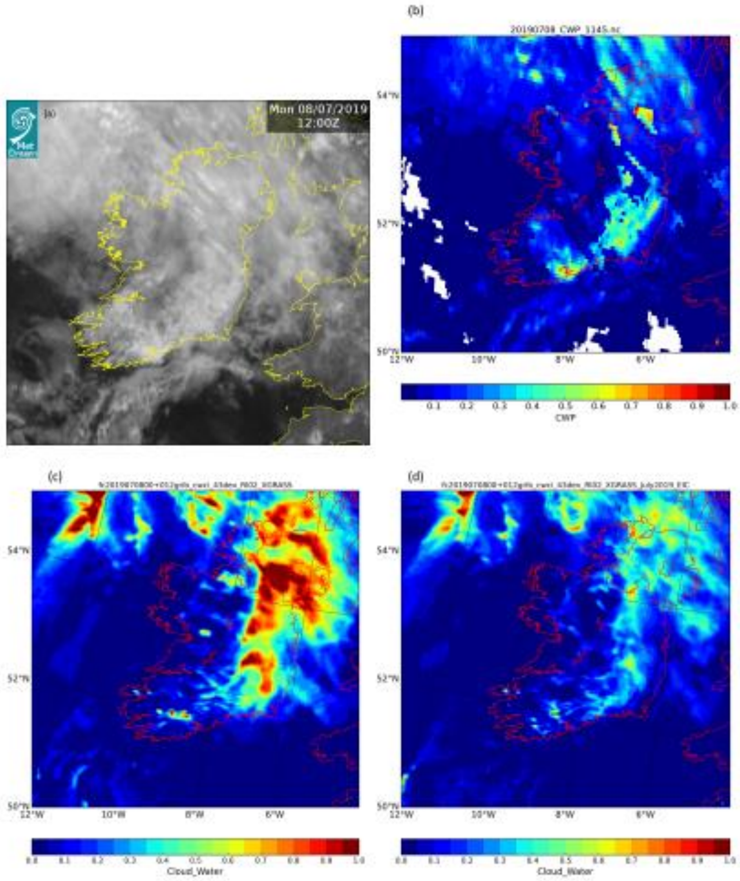

Figure 6. (**a**) MSG visible satellite image. (**b**) MSG Seviri cloud water path product from KNMI. (**c**) Integrated cloud water condensate (gm^{-2}) from the default HARMONIE-AROME Cycle 43 experiment. (**d**) Integrated cloud water condensate (gm^{-2}) from the HARMONIE-AROME Cycle 43 experiment with a CDNC of 50 cm^{-3} and the LW effective emissivity coefficient of Kettler [26]. All at 12 Z on 19 July 2019.

4. Surface Roughness – Wind Speed Biases

In HARMONIE-AROME Cycle 46 compared with Cycle 40, we increased the number of nature patches from 1 to 2 so that we now have distinct patches for low and high vegetation types. While using two patches in combination with the high-resolution ECOCLIMAP Second Generation (ECOSG) land cover map, we experienced an increase in 10 m wind speed forecasts over areas covered mainly by low vegetation. This resulted in a positive bias in 10 m wind, e.g., over Ireland. Only pure land cover types exist in ECOSG, whereas previous versions of ECOCLIMAP had mixed land cover types. At fine resolution, often only low vegetation is present in a nature tile, which leads to quite a smooth surface. As a result, most natural areas in Ireland, for example, are represented as grassland. In reality, even in low-vegetation areas, there are usually some trees, which affect the airflow. Fields are often surrounded by hedgerows and sporadic trees. The absence of such features in the underlying land cover dataset means there is an absence of roughness elements to slow down near-surface winds in the model forecasts. This effect is not important with the one-patch "mean" vegetation approach, but with ECOSG, and the division of vegetation into low and high categories, this becomes important. The option to parametrize this effect by increasing the vegetation height is included in HARMONIE-AROME Cycle 46 (a so-called LFAKETREE option): 10% of the low vegetation (grassland and crops) in each grid box can be replaced by trees of height 10 m. This option only affects the average roughness length of the low vegetation patch through the logarithmic averaging of roughness length and does not affect the rest of ISBA. The figure below shows verification scores for two test periods, with different physics options: HARMONIE-AROME Cycle 40 (red), HARMONIE-AROME Cycle 43 default (green), and HARMONIE-AROME Cycle 43 with "LFAKETREE" (blue). Only results from the 00 UTC forecast cycles are shown in order to highlight any diurnal patterns. From the figure, it is evident that the LFAKETREE option reduces the wind-speed bias

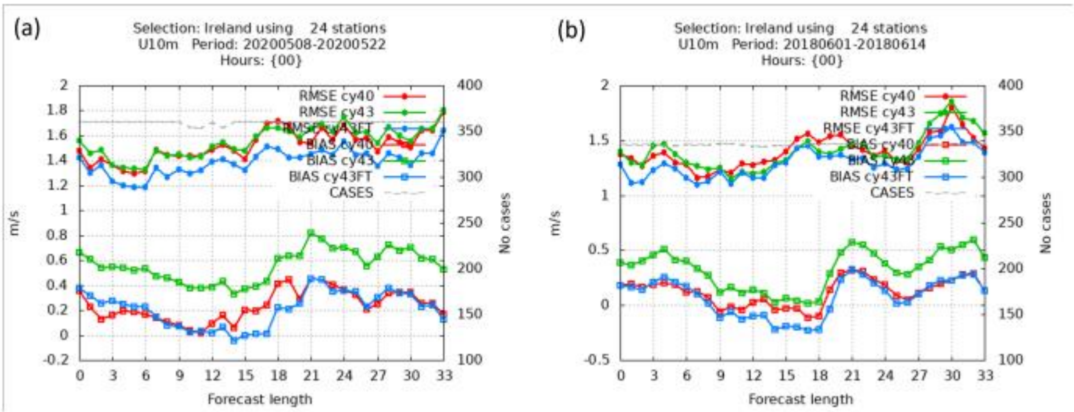

Figure 16. 10 m wind-speed bias and RMSE over Ireland for HARMONIE-AROME Cycle 40 (red), HARMONIE-AROME Cycle 43 default (green), and HARMONIE-AROME Cycle 43 "LFAKETREE" (blue) for 2 two week periods. (**a**) Spring (**b**) summer.

Many iterations of experiments were run during the 3 year special project, including testing of other time periods and cases. The use of LFAKETREES over only certain types of grassland was also experimented with. A suite of tests of fog cases were carried out, some of the results of which are included in the papers below. Experimentation with the calls to the microphysics scheme (rain_ice vs rain_ice_old) also commenced during this special project. Many tests with slightly tuned versions of ICE-T and aerosol options were also run.

List of publications/reports from the project with complete references

1) Gleeson, E., Kurzeneva, E., De Rooy, W., Rontu, L., Martín Pérez, D., Clancy, C., Ivarsson, K.I., Engdahl, B.J., Tijm, S., Nielsen, K.P. and Shapkalijevski, M., 2024. The Cycle 46 Configuration of the HARMONIE-AROME Forecast Model. Meteorology, 3(4), pp.354-390.
2) Martín Pérez, D.; Gleeson, E.; Maalampi, P.; Rontu, L. Use of CAMS near Real-Time Aerosols in the HARMONIE-AROME NWP Model. Meteorology 2024, 3, 161-190. https://doi.org/10.3390/meteorology3020008.
3) Contreras Osorio, Sebastián, Daniel Martín Pérez, Karl-Ivar Ivarsson, Kristian Pagh Nielsen, Wim C. de Rooy, Emily Gleeson, and Ewa McAufield. 2022. "Impact of the Microphysics in HARMONIE-AROME on Fog" Atmosphere 13, no. 12: 2127. https://doi.org/10.3390/atmos13122127.

Future plans

The work is continuing with this year's special project, and will continue next year also as we move to more thorough testing with CY49. My main plan is to thoroughly evaluate the cloud condensate and hydrometeors from the microphysics scheme for warm, cold and mixed phased clouds. I also plan to test the current aerosol options under clear skies and for liquid only clouds. Satellite, CloudNet and radar data will be used to help with the analysis and drawing of conclusions.