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PROCEEDINGS OF THE 20TH SIRWEC CONFERENCE, DRUSKININKAI, LITHUANIA (14-16TH JUNE 2022)

2022

SURFACE TRANSPORT FORECASTING AT THE MET OFFICE: LOOKING TO THE FUTURE

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Summary

The Met Office is currently developing a new Surface Transport Forecast (STF) system, centred around a community numerical land surface model called the Joint UK Land Environment System (JULES). This new system has been designed to support future user requirements, especially from the emerging Future of Mobility sector, including Connected and Autonomous Vehicles (CAVs). In this talk, we will discuss the modifications we have made to JULES to enable it to model road surfaces, as well as discussing the future capabilities this system will enable.

Abstract

For more than 35 years the Met Office has been delivering key road weather information to infrastructure decision-makers across the United Kingdom, allowing them to anticipate and react to road weather hazards and thus reduce risk to members of the public [1]. So-called surface transport forecasts are currently generated using the Met Office Road Surface Temperature (MORST) model. Originally developed in the early 2000s, MORST is a bespoke surface energy exchange and water balance scheme which takes forecast outputs from numerical weather prediction (NWP) models and evaluates the surface conditions for a list of predefined locations.

In addition to forecasting road surface temperatures, MORST also provides forecasts of road surface states: for example, whether a particular road surface will be dry, damp, wet, or icy.

Both the way road forecast data is accessed, and the specific types of forecast metrics users are interested in, are likely to significantly evolve in the coming years. Currently, the Met Office is developing a new Surface Transport Forecast (STF) system designed to accommodate these future user requirements, especially from the emerging Future of Mobility sector, including Connected and Autonomous Vehicles (CAVs). Automation of weather-related decisions by vehicles and supporting systems will drive increased demand for direct machine-to-machine communication of real time weather analysis and forecast data. The new STF post-processing architecture (described below) is designed to accommodate this evolution, with the provision to provide on-demand forecasts for new locations near-instantly via application programming interfaces (APIs).

STF has historically focused on determining the state of a road surface in order to provide decision support to winter road maintenance. Although still an important use case, with the development of CAVs the ability to accurately – and consistently – describe a broader range of weather conditions may also become equally vital to ensuring safety and efficiency on road networks. For example, road spray, rain, localised fog, and the accretion of precipitation to sensors or targets, can all degrade the performance of CAV sensors [2]. Standard CAV sensors have different and pronounced responses to a range of weather types with, for example, lidar and daytime camera performance being significantly more impacted by fog than infrared and radar (Fig. 1). Additionally, settled snow also has the potential to obscure road markings, which can impede vehicle manoeuvring when using camera systems. The Met Office aims to provide the best possible decision support to mitigate weather impacts; it is therefore important that the Met Office is able to accurately evaluate and forecast all relevant hazardous weather conditions so that the CAV ecosystem can function within its Operational Design Domain (ODD; the conditions within which CAV systems can competently and safely operate) [3].

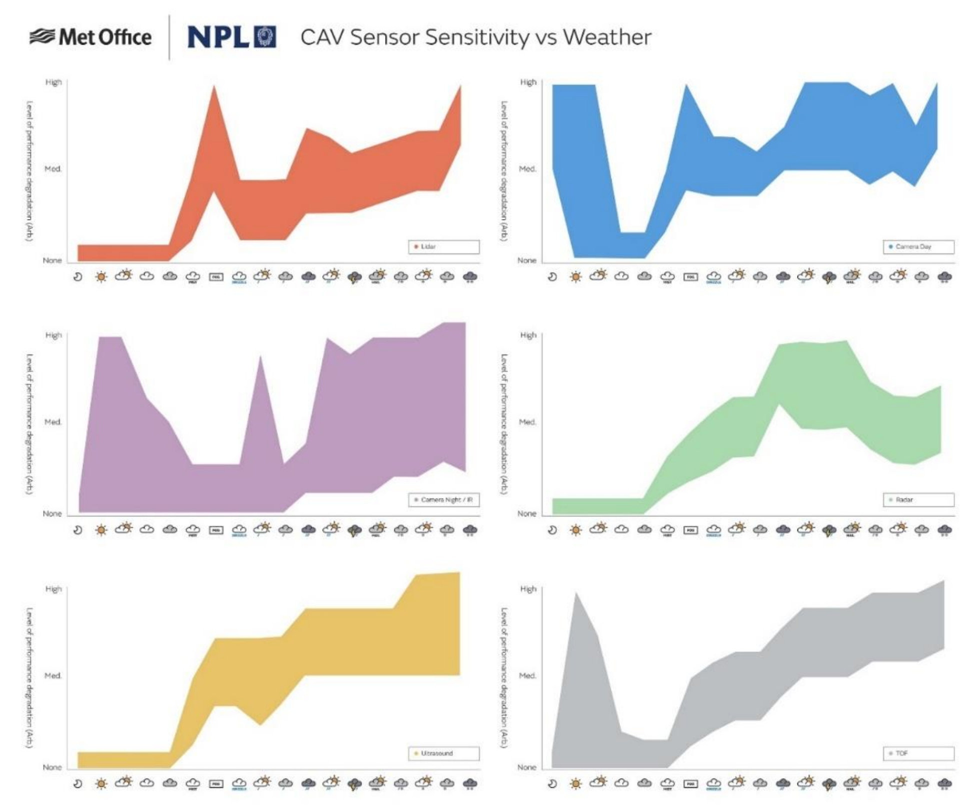

Fig. 1. Plots of sensor performance degradation (y-axis), from none to high, against various weather types (x-axis). Top left to bottom right: lidar, camera (day), camera (night, infrared), radar, ultrasound, TOF. The type of weather can have a significant impact on sensor performance, however the magnitude of the impact depends upon the sensor type. [2]

At the centre of the new STF system is a community land surface model called the Joint UK Land Environment System (JULES) [4]. JULES is the land surface model integrated into the Met Office Unified Model for coupled atmospheric weather and climate modelling, but it can also be used as a stand-alone land surface model driven by forecast output from

Numerical Weather Prediction (NWP) models. It is used in the latter mode in the STF system, since this allows site-specific (point based) forecasts. Since JULES was originally developed to describe soil-vegetation-atmosphere interactions for application to atmospheric modelling, several modifications have had to be made to the physics of the model to enable the STF system to use it for the bespoke purpose of generating site-specific forecasts of road surface temperature and road state.

These modifications are based around adjusting the properties of the surface to better represent those of a road. In its standard form, JULES recognises nine surface types: bare soil, urban, inland water, and ice, along with five types of vegetation. These nine surface types are modelled as nine different “tiles”. To allow JULES to model a road surface, a bespoke “road” tile has been developed by modifying the standard urban tile to make it impermeable; that is, water cannot penetrate from the surface to the sub-surface but it can be stored in, and evaporate from, a small store on top of the surface. Since this effectively takes away a removal mechanism for the surface water store (penetration into the subsurface), this modification led to JULES modelling more water on the road than was physically observed. To account for this a water runoff scheme has been implemented for the new JULES road tile, in which the effect of the camber of road surfaces on the surface water store is numerically modelled. Investigations have also been performed into which values should be used for physical parameters such as emissivity, albedo, and conductivity, to best represent the construction of a road surface.

The range of different applications for surface transport forecasts means that further modification of the JULES physics will be required to better represent the processes which affect the temperature and/or state of the road surface. Future developments that have been prioritised include a traffic scheme to capture the mechanical removal of water, the turbulence introduced by traffic, and the thermal influence of vehicles.

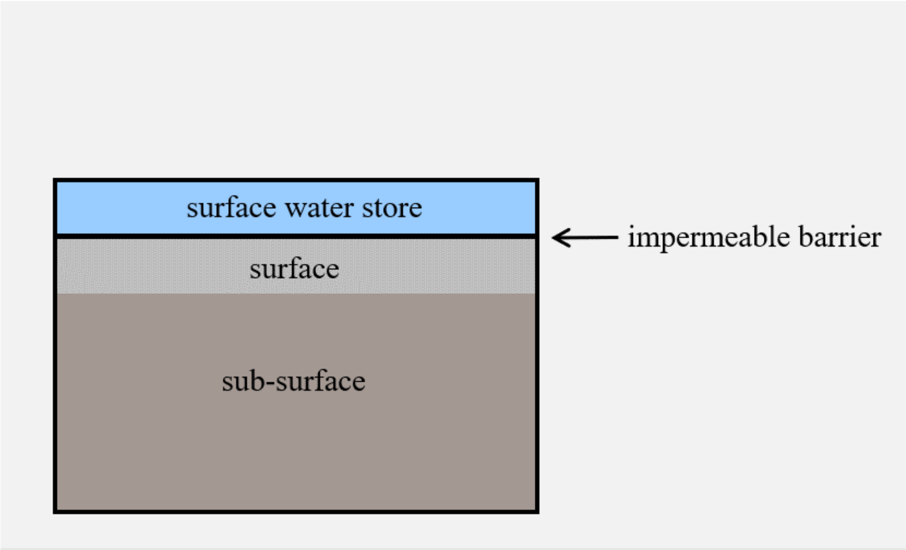

Fig. 2. Schematic diagram of a JULES “road” tile. Here the surface is a thin skin over the sub-surface, which approximates a standard road construction. The surface water store is located on top of the impermeable surface.

The preliminary verification work has involved comparisons of the JULES output to a series of representative road surface observations sites in the United Kingdom over five years of historic data, with the goal to check that the modelled road surface temperature and water surface depth (among other physical diagnostics) align with observations. It was found that the modelled road surface temperature accurately matches observations. When there is a discrepancy it tends to be attributable to errors in the driving NWP output, due to hard to model weather conditions such as patchy cloud cover, convective regimes, or the precise timing of weather fronts. Our work (not described in this abstract or talk) to build a probabilistic road surface forecast using an ensemble approach aims to resolve this issue (see associated abstract Eyles et al., this conference).

The new STF system will be capable of delivering both scheduled hourly forecasts, as well as new on-demand forecasts via an API. To do this, a cloud-based architecture is used. By building a modular system, in which steps that are common across both workflows need only be built once, the development work in building two types of services can be minimised. For example, the physics scheme JULES is required to produce both types of forecasts, and so would be shared across both types of services, however, the initial conditions are generated using different techniques across the two types of services, and thus would not be shared.

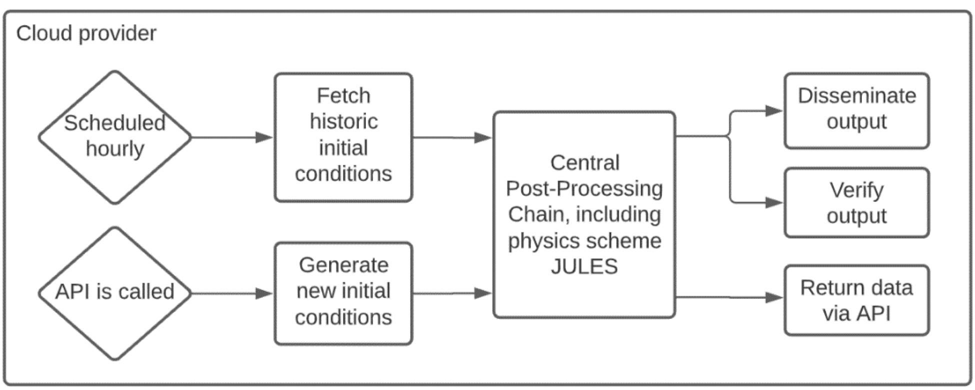

Fig. 3. High level schematic of the cloud based STF system, showing modules that are shared between the scheduled and API workflows (the central post-processing chain, described below), and the modules that are unique to each workflow (the modules that fetch or generate initial conditions).

Although the dominant step in the STF system is the land surface model JULES, there are a number of auxiliary steps that are vital to providing accurate forecasts over diverse road and traffic types. These steps, considered together, form a post-processing chain, so called because the processing happens after the Met Office’s main NWP model has run. The post-processing chain contains two steps that correct the NWP output (which is used to drive JULES) for local effects. The first of these is to apply additional incoming longwave radiation to account for the impact of traffic heating. The magnitude of the additional longwave radiation depends upon on a model for traffic volume and speed. This model takes into account the type of road (including the speed limit and number of lanes), the day of the week, and the time of day. The second of these applies a shading scheme to the incoming shortwave radiation. This uses local topographic information, along with the height and angle of the sun, to set direct shortwave radiation to zero when the site is in shadow. Finally, a bias correction scheme based on machine learning is applied to the JULES output to yield a more accurate forecast.

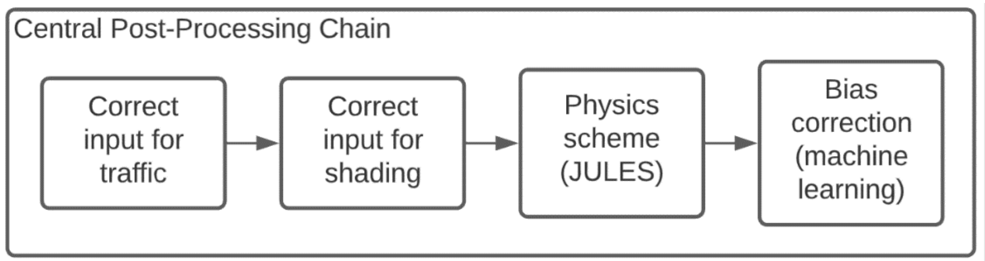

Fig. 4. Schematic of the "post-processing chain" in the new STF system. Here there are two initial steps to correct the NWP output for local effects. This corrected NWP output is then used to drive JULES. The output from JULES is then bias corrected by a machine learning scheme.

In this presentation we will discuss the motivations for the development of a new STF system at the Met Office, present some initial results from our new JULES-based STF system, and discuss the further scientific development required to enable us to provide skilful forecasts of the range of weather conditions required to ensure safety and efficiency of future road networks, with a particular focus on the requirements of the emerging CAV sector.

References

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