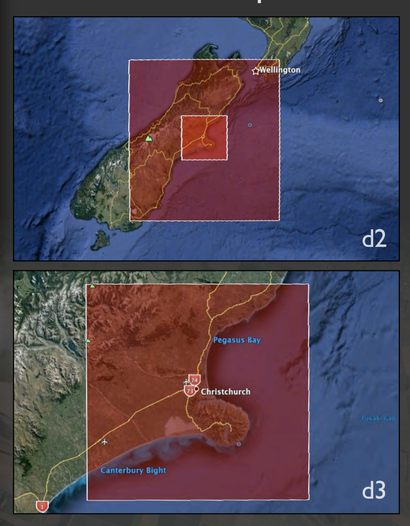
WRF 1.5km Christchurch
Skills and limitations of high-resolution modelling over the shaken city

Dominikus Heinzeller (heinzeller@metservice.com), Cory Davis and Graham Rye
Meteorological Service of New Zealand Ltd., Wellington, New Zealand

Following the 7.1 and 6.3 magnitude Christchurch earthquakes in September 2010 and February 2011, we set up a high resolution (1.5km) domain centred over Christchurch to assist earthquake rescue and recovery operations. The geographic location of the city with the marine area to the east, the peninsula to the south, the plains and mountain ranges to the west, and the quickly changing weather over New Zealand made this model an interesting object of study. It also became a valuable source of information for issuing the Christchurch marine forecasts. We discuss orographic effects, numerical artefacts arising from nesting a high-resolution domain in difficult terrain, and limitations of physical parameterisations stemming from running WRF at this resolution. We also present verifications of this domain against our operational 4km and 8km models over New Zealand and show that the higher-resolution models can reproduce some synoptic situations of the Christchurch area better than the lower-resolution domains.

Model setup

The double-nested 1.5km d3 domain (112x109x50) is centred over the city. It covers the Banks peninsula, the Christchurch marine area and extends to the ranges in the north-west. The outer 13.5km d1 domain is initialised off the GFS 0.5 degree global model four times daily, running out to 42 hours. Grid-nudging and observation-nudging of about 300 stations (synop, metar, amdar, ship, buoy, pilot, AMVs) is applied for the first six hours.

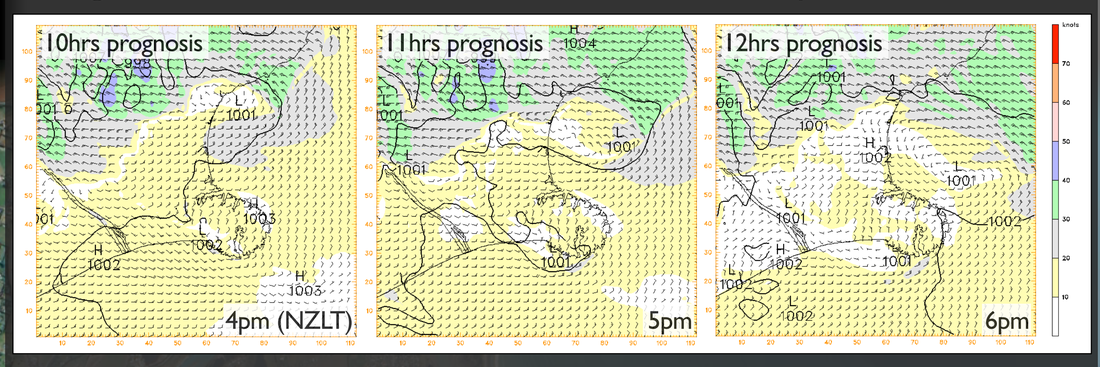


Configuration options:

- WSM 6-class microphysics scheme
- rrtm/Dudhia long-/shortwave radiation scheme
- MM5 Monin-Obukhov surface layer scheme
- Thermal diffusion land-sfc model (USGS 30")
- YSU planetary boundary layer scheme
- Kain-Fritsch cumulus / explicit convection (d3)

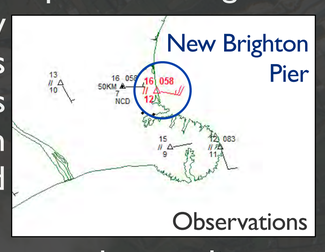
Case study: Closed flow over the bay

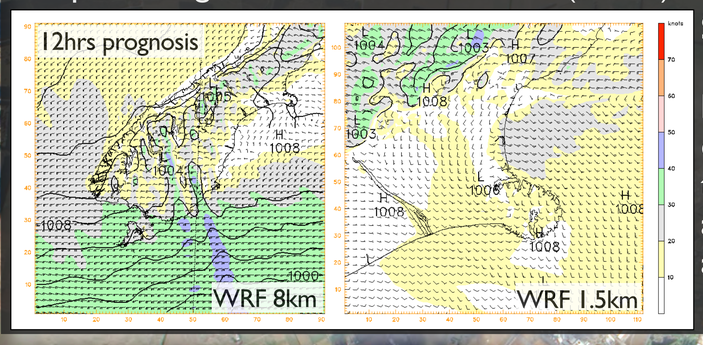
On 24th November 2011 in the evening (NZLT), an orographic trough moved offshore and the wind at New Brighton Pier went from north-east to a south-east. This occurred as a brief transition from a north-easterly to a westerly wind, but it happened in daylight hours where a number of boats are out in the bay. The 1.5km domain was the only model that picked the formation and right timing of the closed flow and the associated south-easterly winds.



Case study: Strong easterly change

At midnight on 19th January 2012 (NZLT), a cold front passed through the marine area with a high building to its south. The New Brighton Pier AWS reported strong easterly winds (30kt) for 2 hours. The 12km and 8km WRF models maintained a SW wind through all night, while the 1.5km model produced the correct wind direction/speed and temperature gradient well ahead of time (6-8hrs).

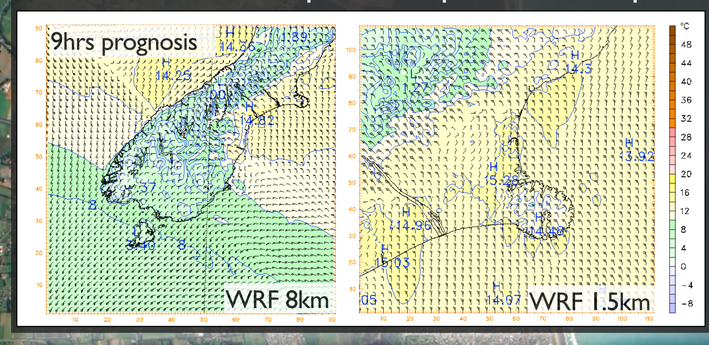




Strong south-easterlies are rare features in this area, here due to a pre-frontal density surge together with topographical funnelling along Banks Peninsula. Only a high-resolution model can reproduce this behaviour.

Case study: Canterbury Nor'wester

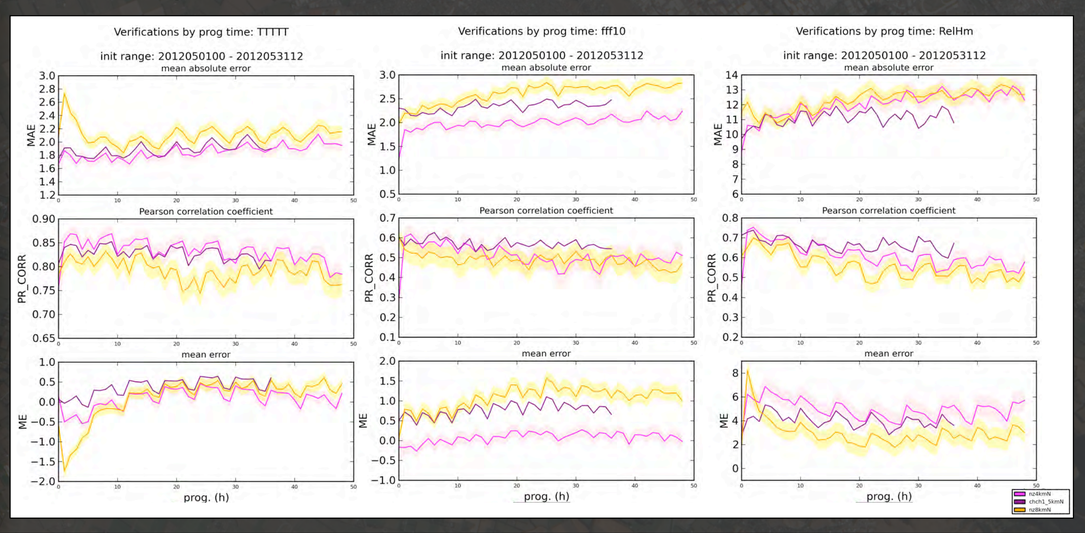
The northwesterly wind in the South Island is a foehn wind. When warm moist air is pushed up and over the Southern Alps, it cools rapidly, dumping much of its moisture on the West Coast. Once over the alps, the dry air drops rapidly and flows at significant speeds over the Canterbury plains. This situation can also produce an apparent arch of high white cloud in an otherwise blue sky over the Southern Alps, known as Nor'west arch. For this situation to occur, the wind direction/speed, temperature and pressure differences must match.



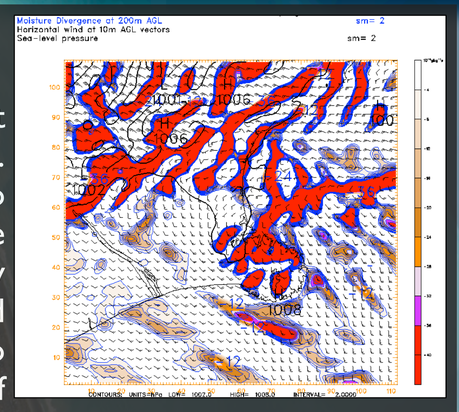
While the coarser models over NZ often struggle to predict this situation, the 4km and the 1.5km domain provide better guidance.
The 1.5km model can also reproduce the temperature gradient across the plains.

Model performance

The Christchurch 1.5km domain generally outperforms the 8km domain over Canterbury. The accuracy of the 4km and 1.5km model are comparable, and the models complement each other: While the 4km domain has been optimised for 10m wind speed forecast (fff10), the wind directions are picked better by the 1.5km domain, in particular in the marine area. With its higher resolution, it is able to resolve terrain-induced behaviour, for example wind funnelling, closed flows and temperature gradients. The MET verifications show a performance gain in 2m temperature (TTTTT), 2m relative humidity (RelHm) and surface pressure with resolution, while rainfall is similar for all domains.



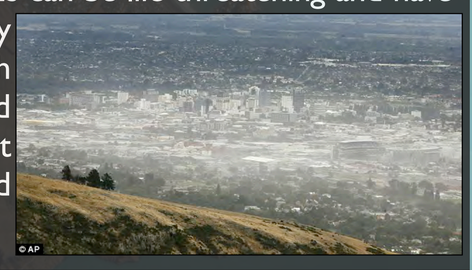
Limitations



The 1.5km domain tends to over-predict situations where the wind turns south-east. This makes it difficult for the forecasters to know when it persists or not. In off-shore wind situations, the model exhibits streaky patterns, which is a known problem for nested domains having their boundaries too close to each other [C. Mass]. Also, the boundary of the inner 1.5km domain lies close to the coast line, which can induce artificial open cell convection [W. Wang, A. Hahmann, J. Dudhia].

A similar problem occurs at the north-west corner, where the boundary between d2 and d3 lies over the ranges. In north-westerly winds, the surface wind speeds can show an oscillating pattern in direction perpendicular to the wind, sometimes at large distances from the ranges.

During an earthquake, large amounts of dust form that are picked up by strong winds and can form thick clouds. These clouds can be life threatening and have a major impact on rescue operations. They can also produce local microclimates with stronger precipitation and more pronounced temperature extremes. This effects are not captured by this model and require a coupled dust dispersion or chemistry module.



The magnitude 6.3 earthquake struck the Canterbury region in New Zealand's South Island at 12:51pm on 22 February 2011 local time. The earthquake was centred 10km south-east of the city centre, 2km west of Lyttleton at a shallow depth of only 5km. It followed nearly six months after the magnitude 7.1 Canterbury earthquake of 4 September 2010, which caused significant damage to Christchurch and the central Canterbury region, but no fatalities. The February earthquake caused widespread damage in Christchurch, especially in the central city and eastern suburbs, and killed 185 people. [Wikipedia]

Satellite image of Christchurch two days after the February earthquake [Google Earth]