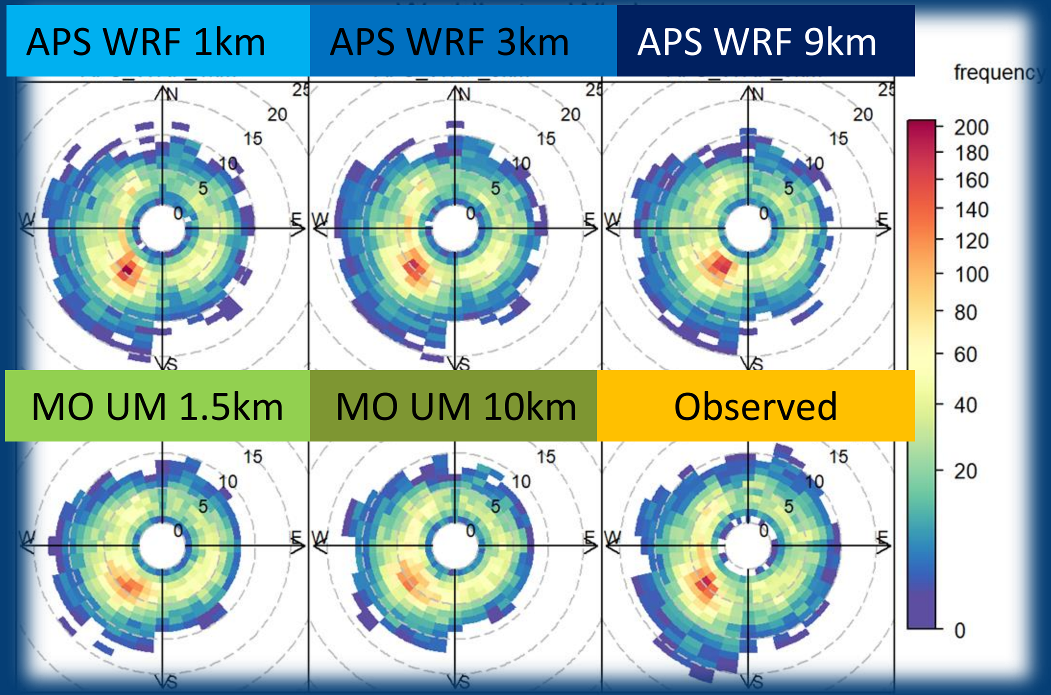
Evaluating modelled met data: does grid resolution matter?



Christina Hood, CERC

ADMS 6 User Group Meeting

16 November 2022

Birmingham

Overview

- Introduction
- Locations and datasets considered
- Summary of evaluation outcomes
  - Wind speed and direction
  - Temperature
  - Cloud cover
  - Precipitation
- Effects of WRF configuration and extraction method
- Conclusions and next steps

Project team

CERC

James O'Neill
Rose Jackson
Jakub Mizkech
Jenny Stocker
Sarah Strickland
David Carruthers

UK Health Security Agency (UKHSA)

Peter Bedwell
Joseph Wellings

Data suppliers

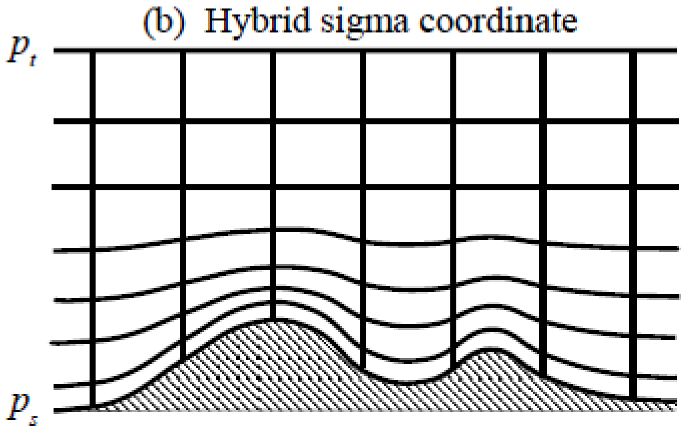
UK Met Office

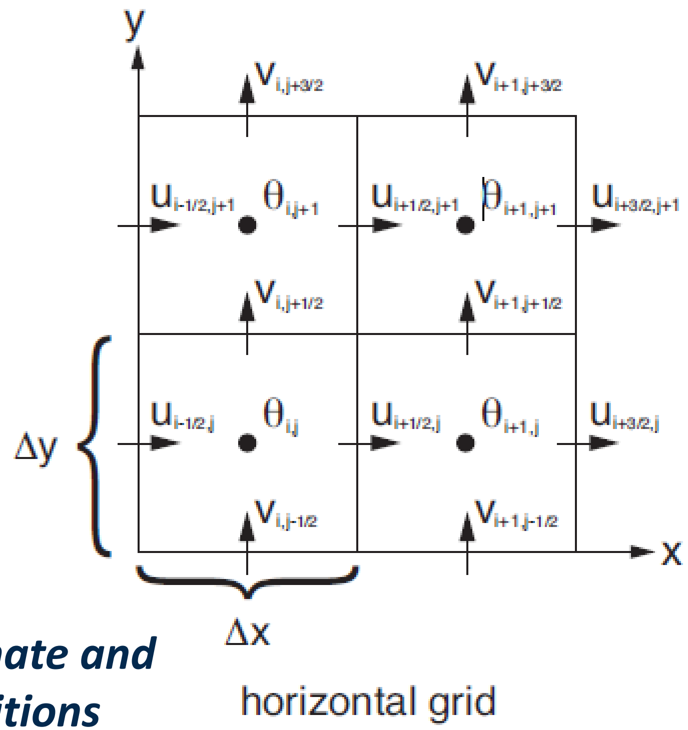
APS

Lakes

Introduction to Numerical Weather Prediction (NWP)

- Numerical Weather Prediction: models used to calculate meteorological datasets, NWP models include Unified Model (UM – Met Office), Weather Research and Forecasting (WRF - NCAR), Integrated Forecasting System (IFS - ECMWF), Global Forecast System (GFS - NCEP)
- 3D gridded calculations of meteorological parameters
- Takes into account terrain, land use
- Fine-scale models driven by coarser resolution global models
- Can incorporate measured meteorology (data assimilation)
- Parameterisation of processes happening at length scales smaller than grid size, eg. convective cloud and precipitation
- Differences from measured meteorology due to:
  - Grid-cell average vs point data
  - Resolution and representation of input terrain and land use data
  - Specific difficulties with precipitation and cloud cover





WRF v4 vertical coordinate and staggered grid definitions

Introduction to project

Atmospheric Dispersion Modelling Liaison Committee (ADMLC) admlc.com

- ADMLC funded research project to investigate the impact of applying **different grid resolutions** of **NWP met** data in **atmospheric dispersion modelling**
- Use of NWP met data for dispersion modelling and other applications becoming more common:
  - Reduced number of operational met measurement sites
  - Improved performance of NWP data
  - Increased availability of NWP data

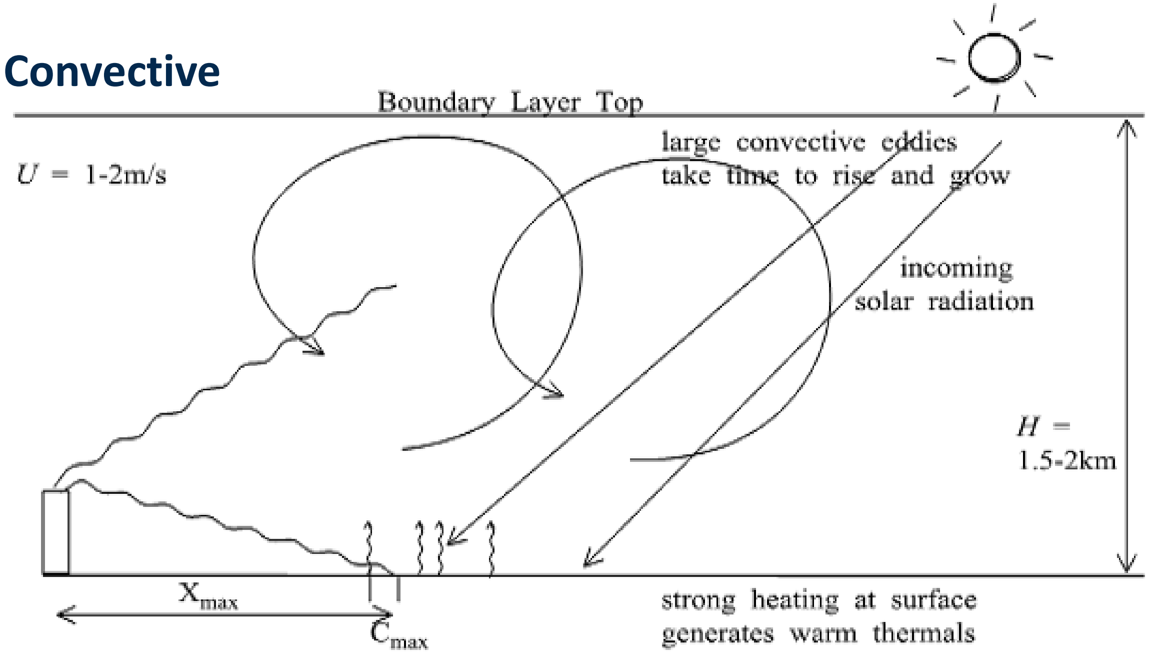
Today's presentation → Task 2

Task	Description	Organisation	Status
1	Literature review of NWP models	CERC	Complete
2	Comparison of NWP datasets and observed met data	CERC	Complete
3	Comparison of regulatory dispersion modelling with observed and modelled met data	CERC	In progress
4	Investigation of possible double-counting of terrain effects in local modelling	CERC	In progress
5	Effect of NWP grid resolution on probabilistic accident consequence assessments	UKHSA	In progress

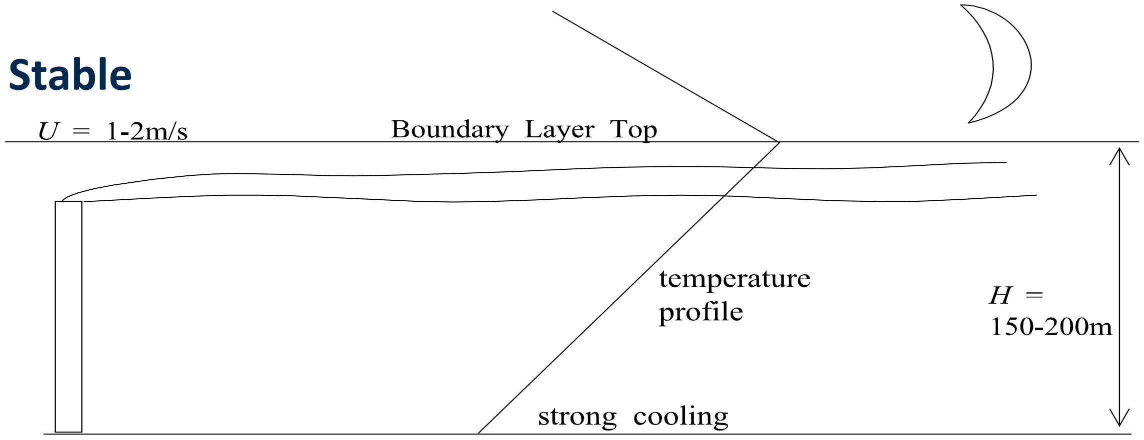
Introduction – influence of meteorology for dispersion

- Wind speed and direction
  - First-order influence on plume direction and spread
  - Affects magnitude and location of maximum concentrations
- Precipitation
  - First-order influence on wet deposition, non-linear relationship ($\propto \sum_{i=1}^{n} P_i^B, B = 0.64$)
  - Variation of precipitation with wind speed and direction can change spatial distribution of deposition relative to concentration
- Temperature and cloud cover
  - Affect modelled stability
  - Indirect (second order) effects on concentration and deposition

Convective



Stable



Locations considered

- 8 meteorological measurement sites
  - Flat terrain – Waddington, Lincolnshire
  - Urban – Northolt, Greater London
  - Complex terrain – Drumalbin, Lanarkshire; Leek Thorncliffe, Staffordshire; Sennybridge, Powys
  - Coastal – Leuchars, Fife; Mumbles Head, Swansea; Newhaven, Sussex
- Some measured met parameters unavailable at Mumbles Head and Newhaven, alternative sites St Athan and Shoreham used for substitute data
- Newhaven anemometer not part of standard measurement network, not used for data assimilation in NWP models

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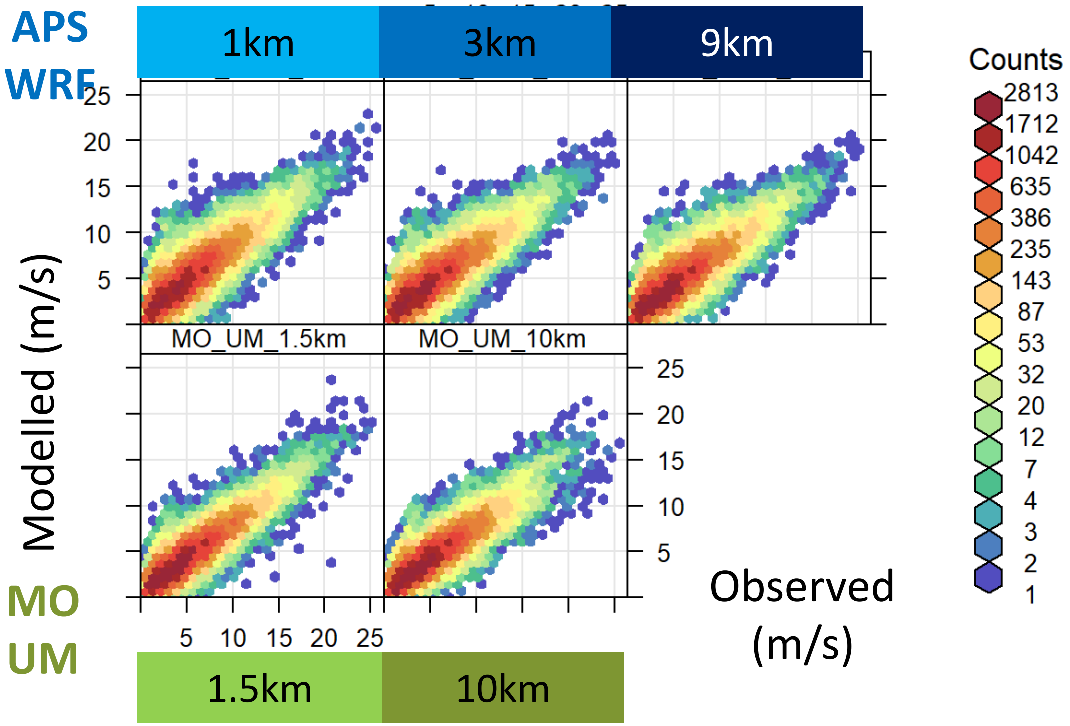
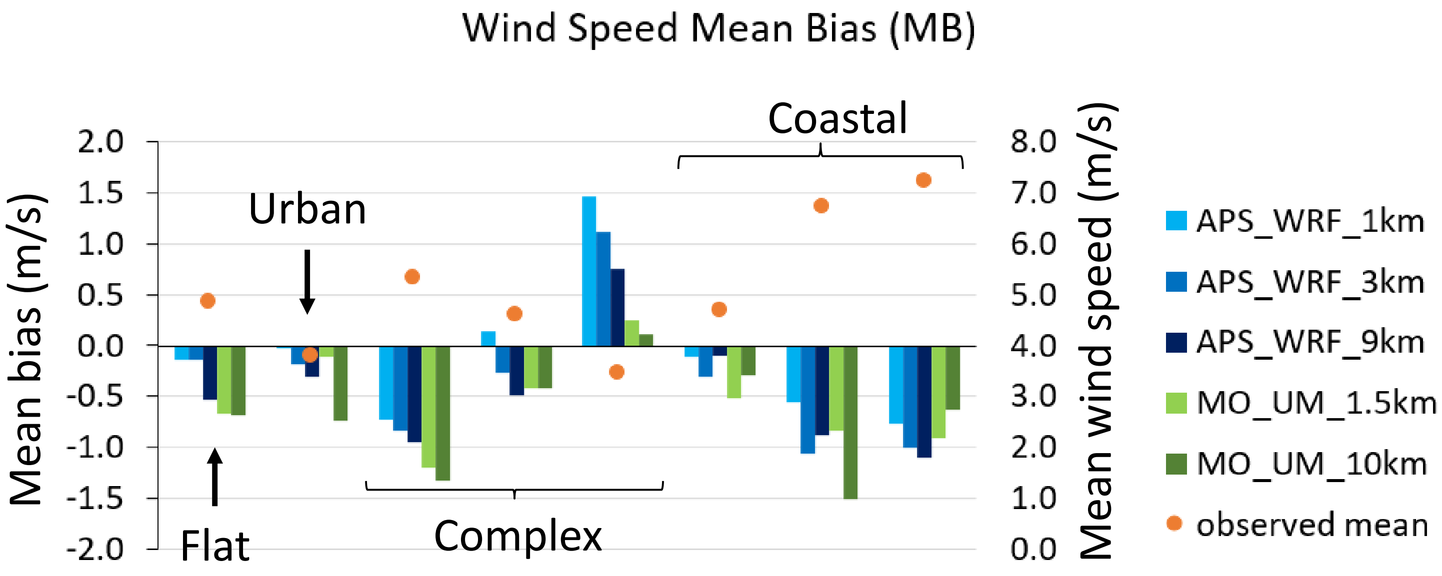
Datasets and parameters

- Evaluated parameters
  - Wind speed and direction
  - Temperature
  - Cloud cover
  - Precipitation rate
- FAIRMODE/US EPA suggested statistical benchmark metrics and thresholds for meteorological models used as context for comparison, based on typical values for US MM5/RANS applications
- Comparisons focusing on effects of resolution (MO, APS at 8 sites) and WRF configuration (APS, Lakes at 4 sites)
- 6 evaluated datasets, all for 2019

Provider	Model	Resolution	Driving data	Data assimilation	Comment
Met Office	Unified Model (UM)	10 km (Global)	n/a	All observed parameters	
		1.5 km (UK)	UM global		1.5 km routinely available
APS	Weather Research and Forecasting (WRF)	9 km	ECMWF ERA5 reanalysis	Wind only	
		3 km	9 km		3 km routinely available
		1 km	3 km		
Lakes		3 km	9 km (NCEP GFS forecast)	None	4 sites only, supplied in AERMOD format

Evaluation summary – wind speed

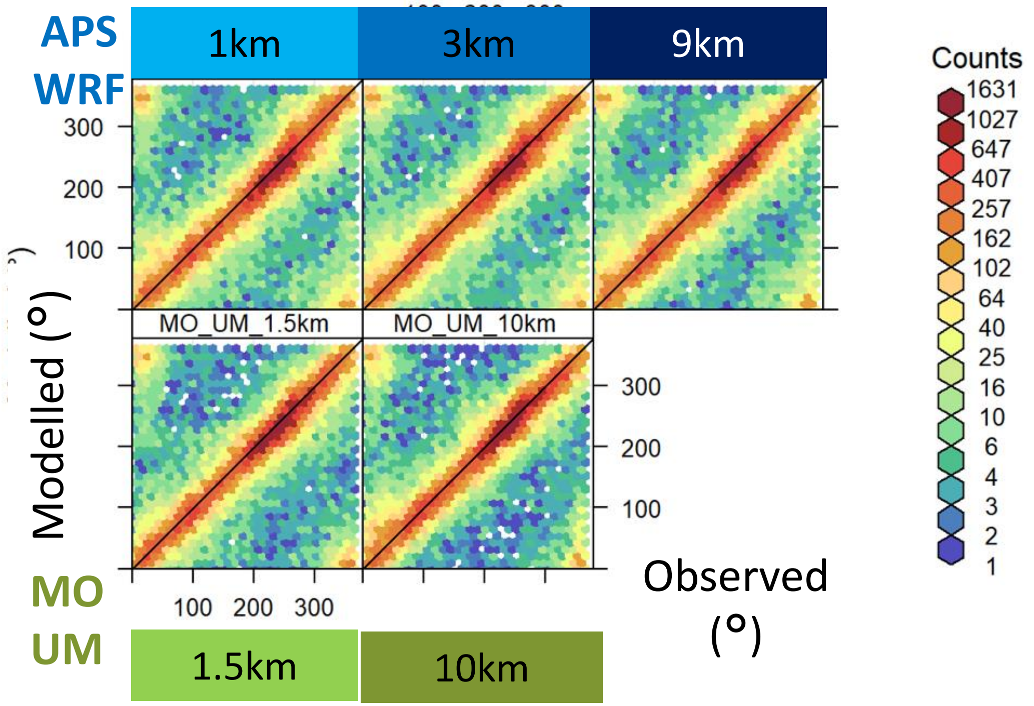


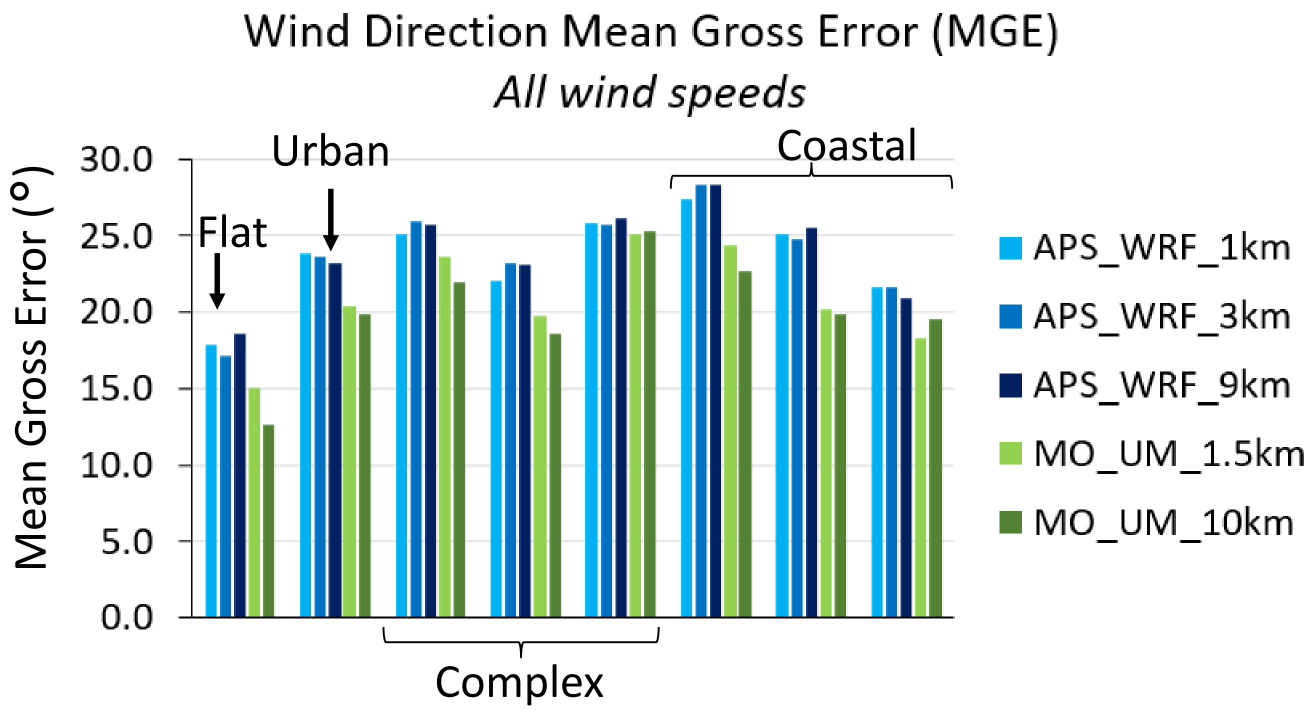


Model	Grid size (km)	Mean (m/s)		MB (m/s)	RMSE	R
		Obs	Mod			
APS WRF	1	5.09	4.99	-0.09	1.74	0.85
	3		4.75	-0.34	1.78	0.85
	9		4.63	-0.45	1.80	0.85
MO UM	1.5		4.53	-0.55	1.62	0.89
	10		4.40	-0.69	1.77	0.87

- Generally good agreement in hourly wind speed, strong correlation and small mean bias
- Highest measured hourly wind speeds all at coastal sites
- Models slightly underpredict mean wind speeds and underpredict variation of mean wind speed between sites
- More difference due to model used than resolution
- Some improvement in model results at finer resolution at most sites

Evaluation summary – wind direction





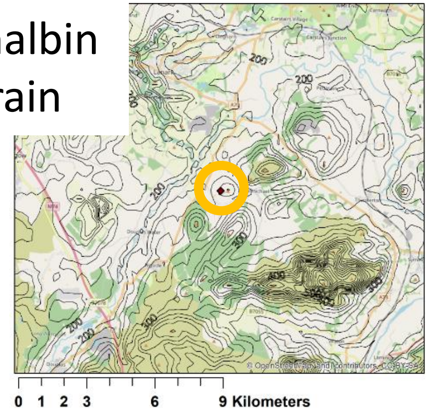
Model	Grid size (km)	Mean (°)		MGE (°)
		Obs	Mod	
APS_WRF	1	243	229	23.6
	3		230	23.8
	9		230	24.0
MO_UM	1.5		233	20.8
	10		234	20.1

- Mostly good performance for hourly wind direction, mean gross error comparable to 10° sector size in which observed data are reported
- Greater uncertainty in measured wind direction at low wind speed, affects urban and some complex terrain sites more than flat or coastal
- More challenging to match measured wind direction for complex terrain and coastal sites
- Greater variation between models used than resolution
- No clear change of performance with resolution

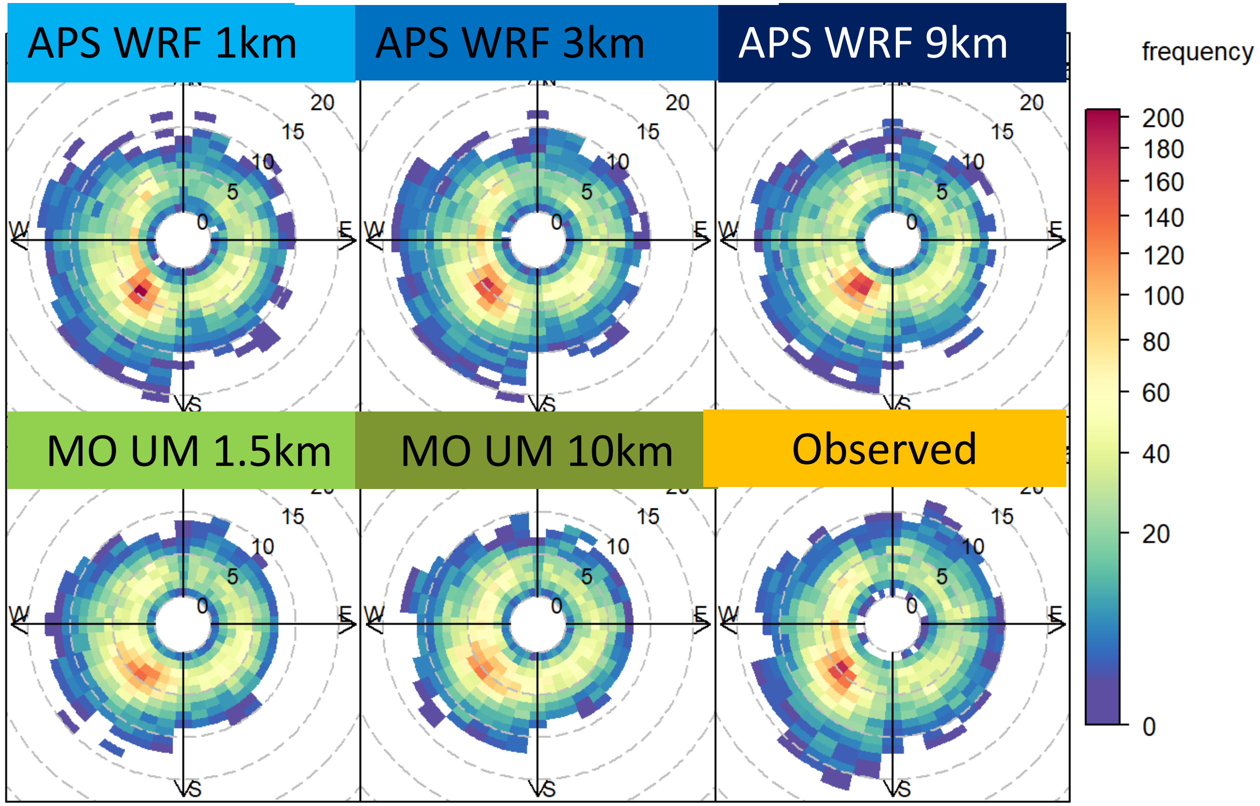
Evaluation summary – wind speed and direction

- Polar plots showing modelled and observed distributions of hourly wind speed and direction
- Generally good matching at Waddington (flat), more variation due to model than resolution, inconsistent changes due to resolution
- More differences between observed and modelled at Drumalbin (complex), variation due to both model and resolution, some improvement in distribution for finer model resolution

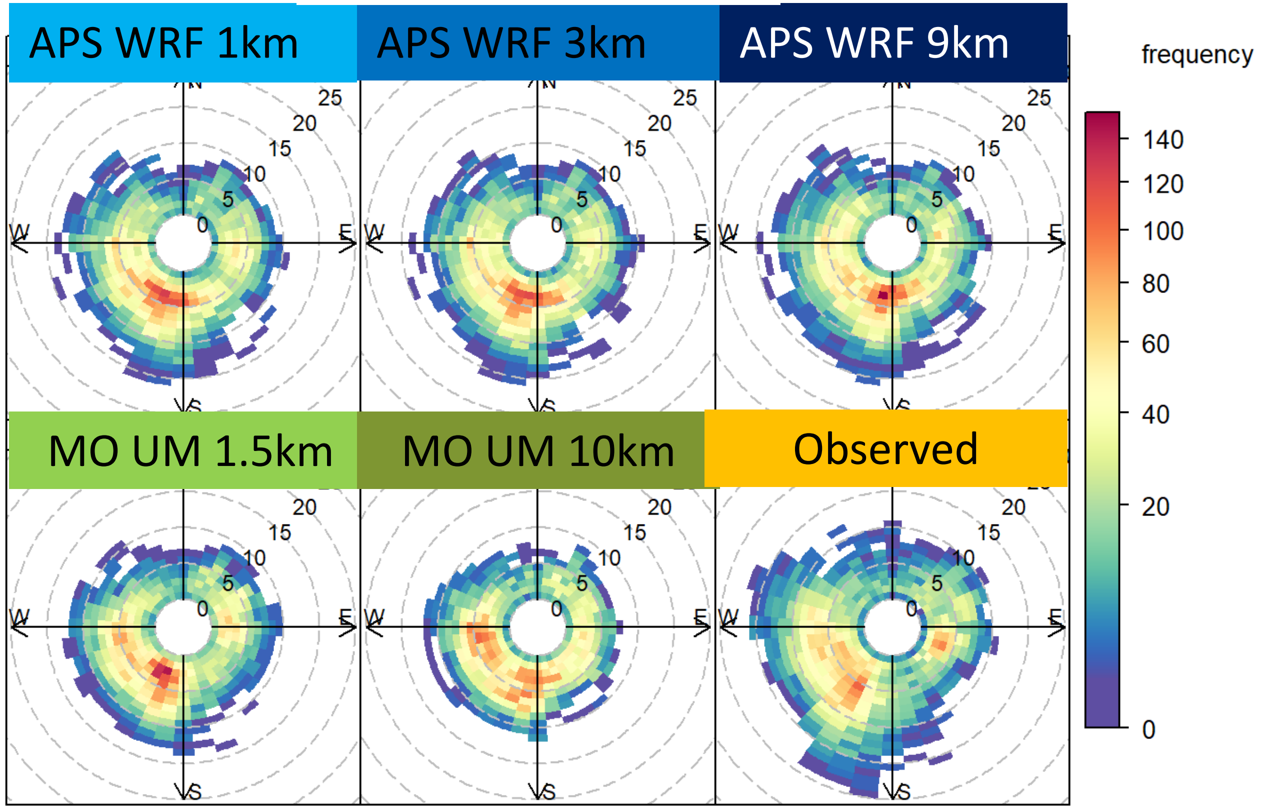
Drumalbin terrain



Waddington Wind



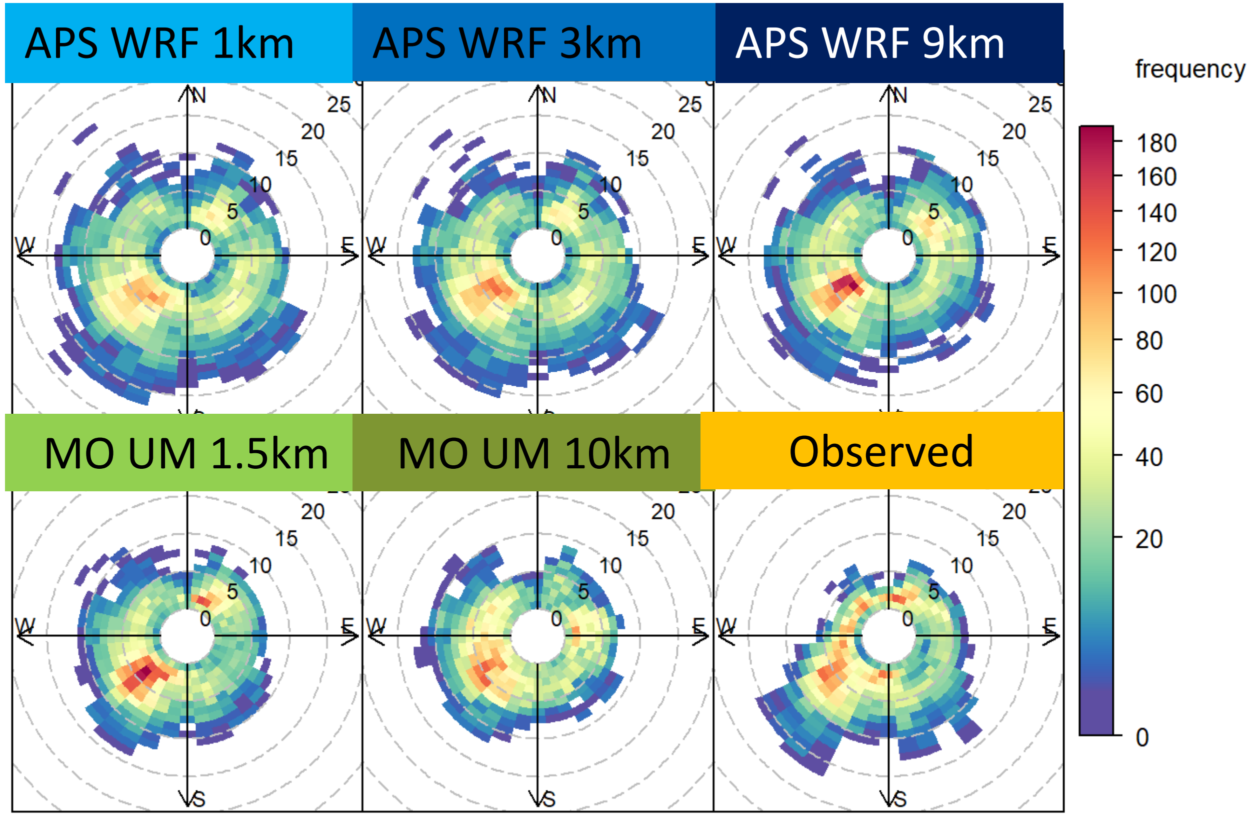
Drumalbin Wind



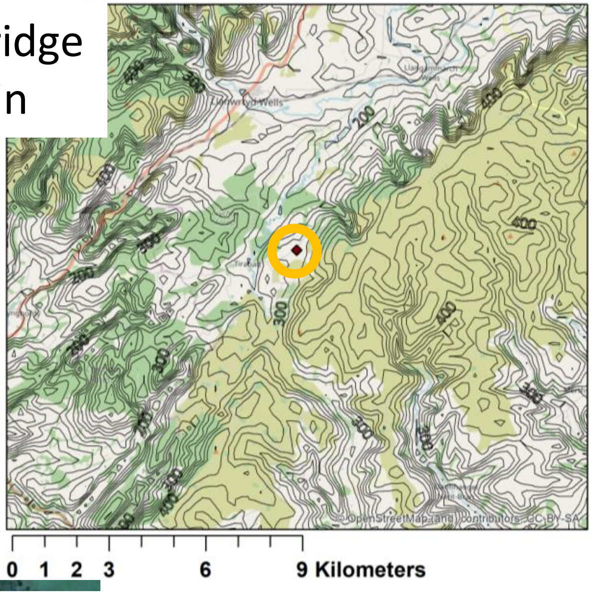
Evaluation summary – wind speed and direction

- Additional challenges at Sennybridge (complex) where some observed features may be due to very local tree effects – reduced observed wind speeds in NW quadrant not captured by models
- Variations in model output due to both model and resolution
- No clear trend in performance with model resolution

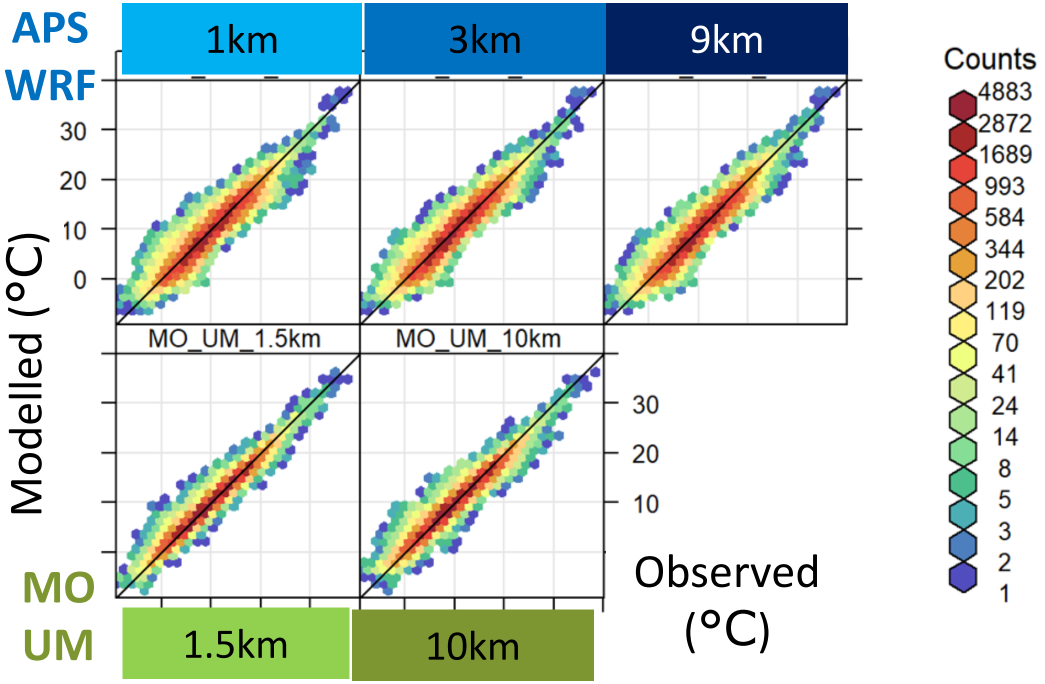
Sennybridge Wind



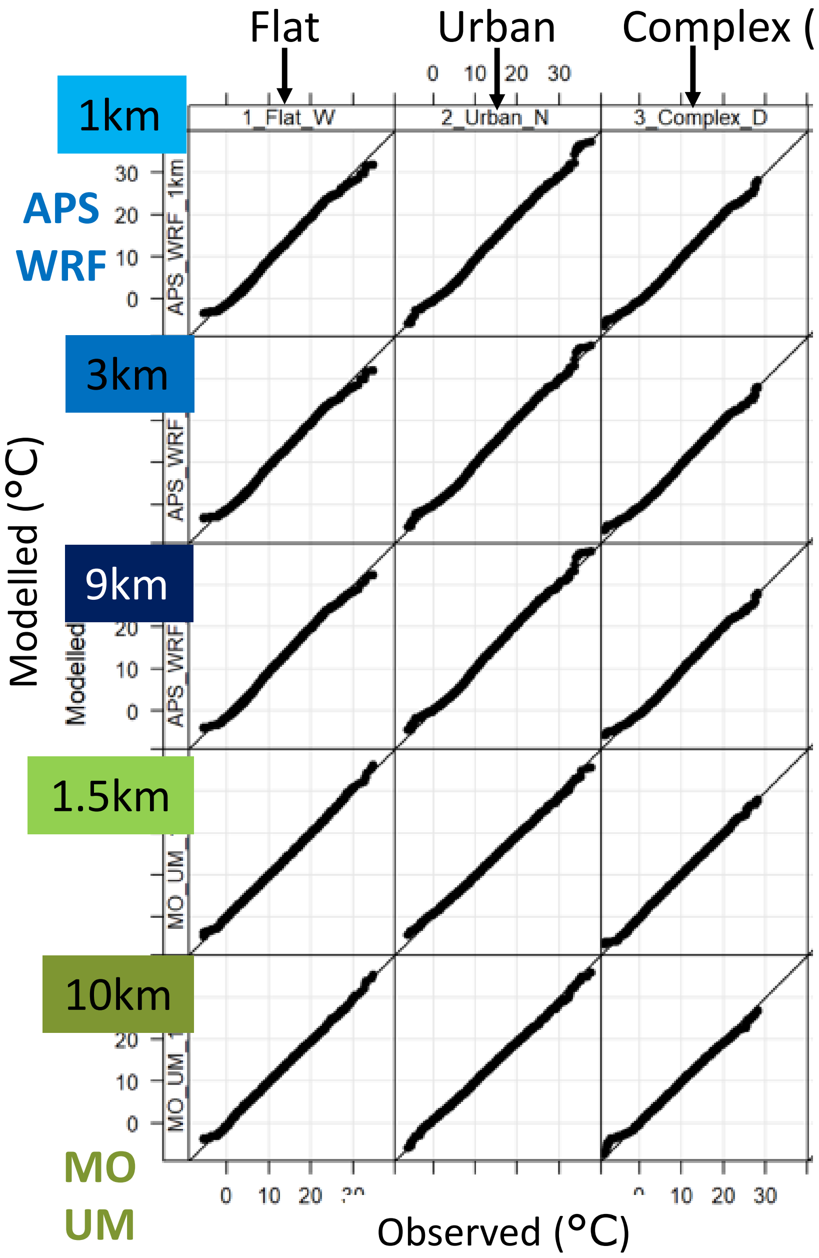
Sennybridge terrain



Evaluation summary - temperature



Model	Grid size (km)	Mean (°C)		MB (°C)	RMSE	R
		Obs	Mod			
APS WRF	1	9.92	9.58	-0.34	1.89	0.84
	3		9.68	-0.24	1.75	0.85
	9		9.71	-0.21	1.77	0.85
MO UM	1.5		10.01	0.08	1.04	0.92
	10		9.87	-0.05	1.26	0.91

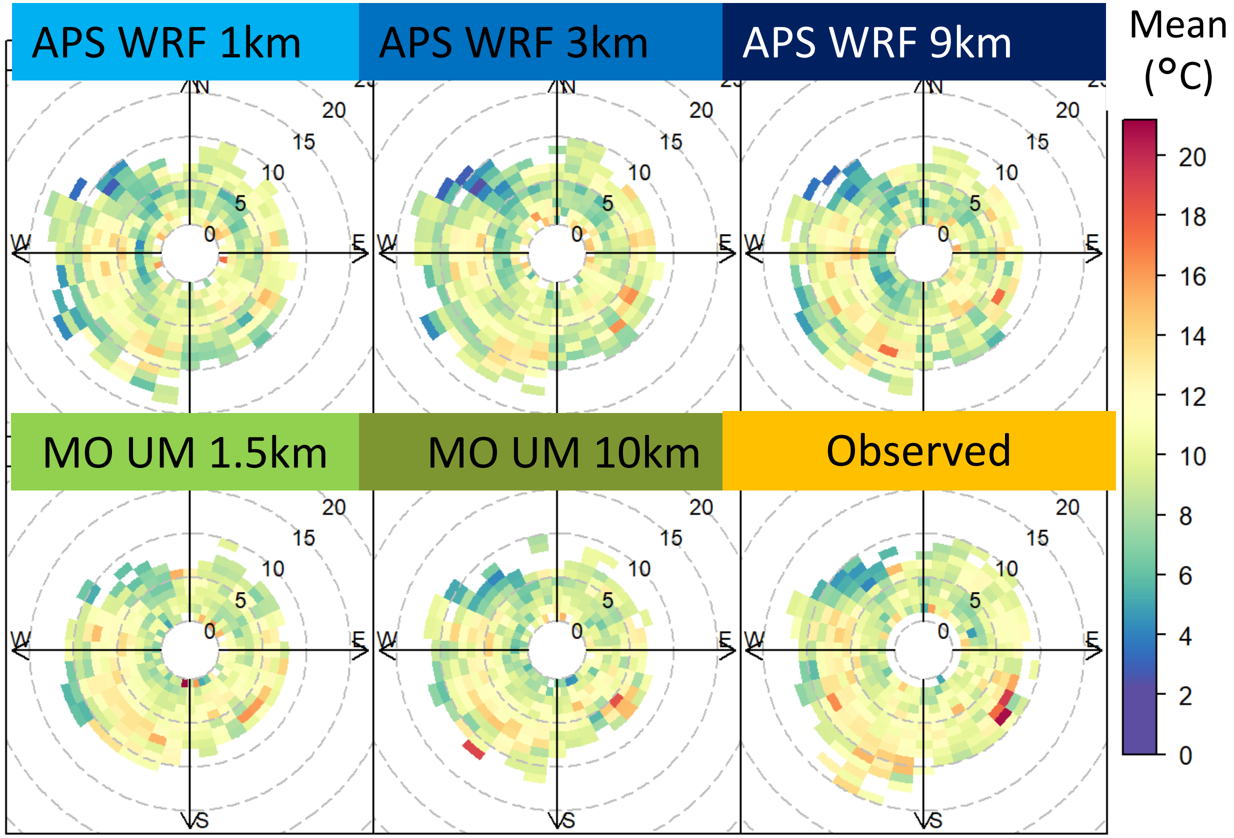


- Generally very good performance for hourly temperature, high correlation and small mean bias
- Some underestimate of measured temperature variation, with overestimate of the coldest measured hourly temperatures
- More variation due to model than grid resolution
- Inconsistent change in model performance with grid resolution

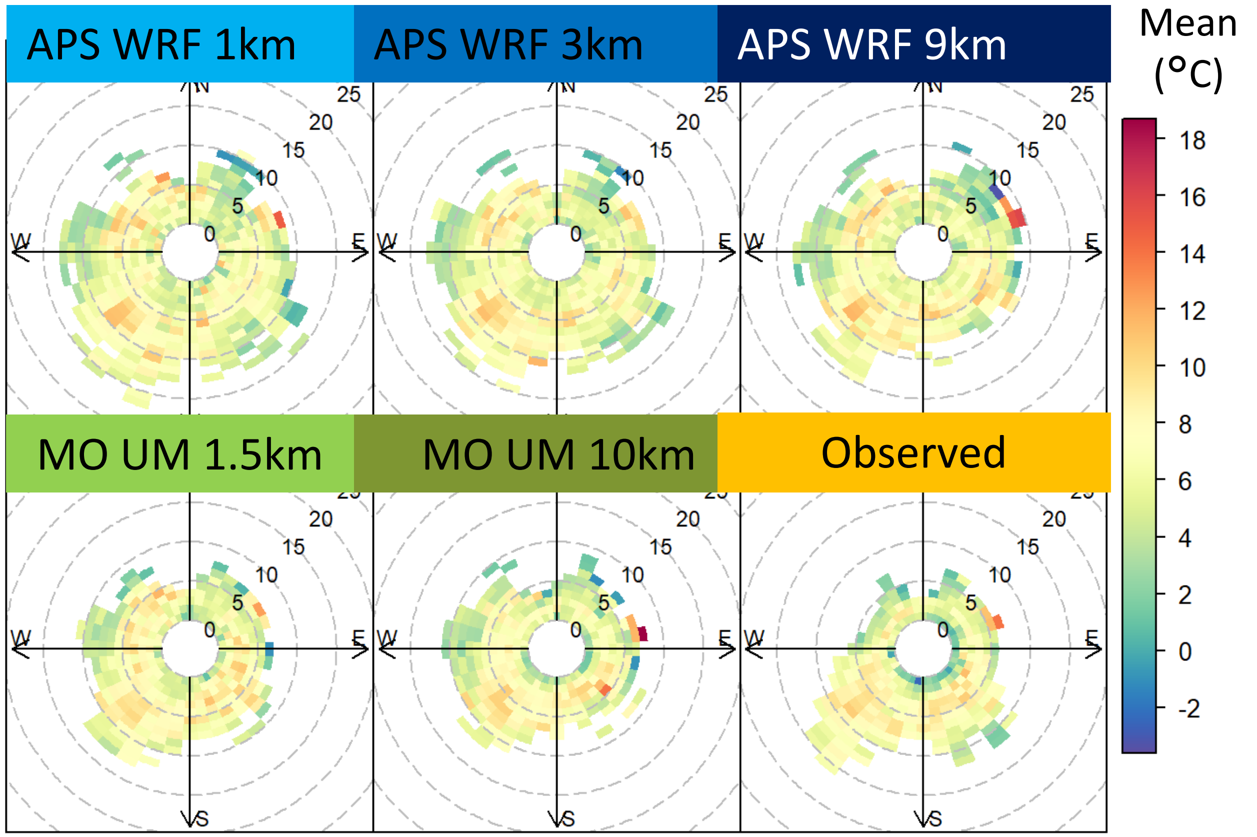
Evaluation summary – temperature and wind distribution

- Variation of temperature with wind speed and direction
- Models may miss observed cold low wind speed conditions
- More variation with model used than grid resolution
- No clear pattern of variation with grid resolution

Waddington Temperature (°C)

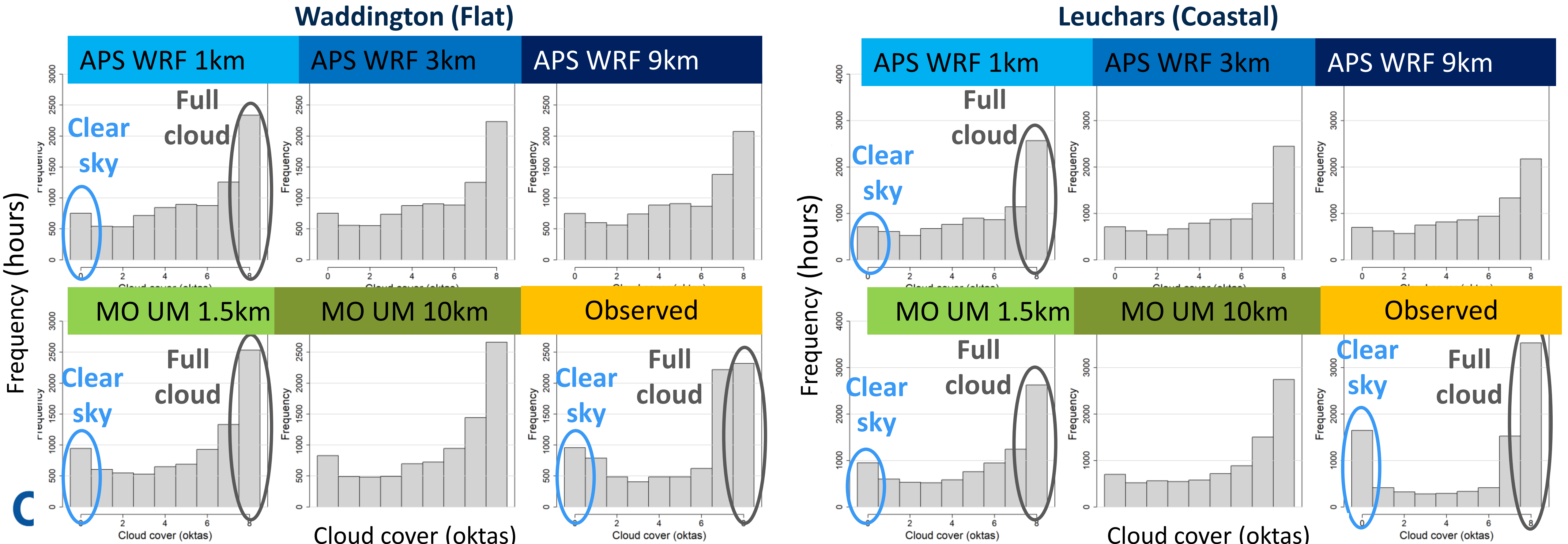


Sennybridge Temperature (°C)

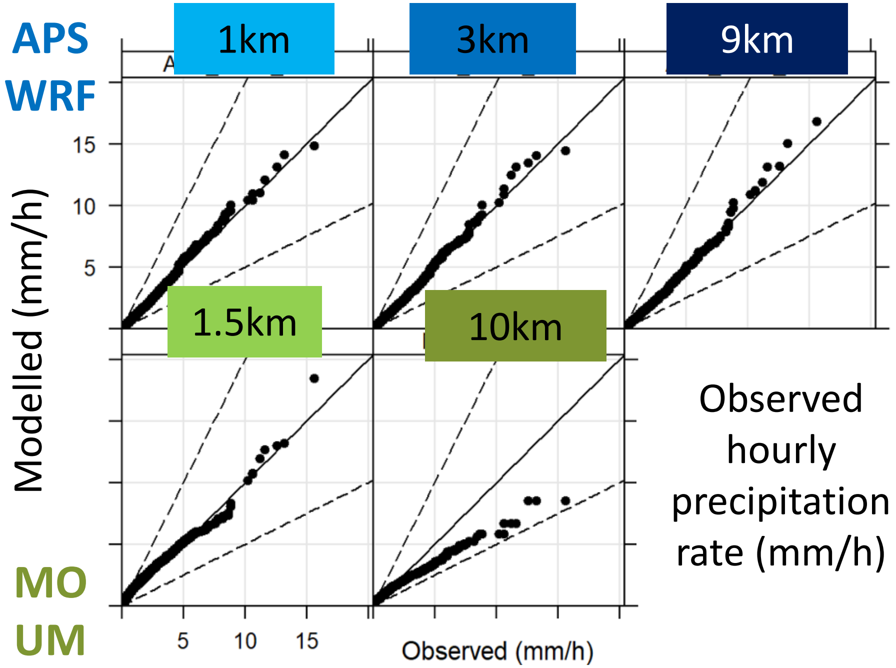


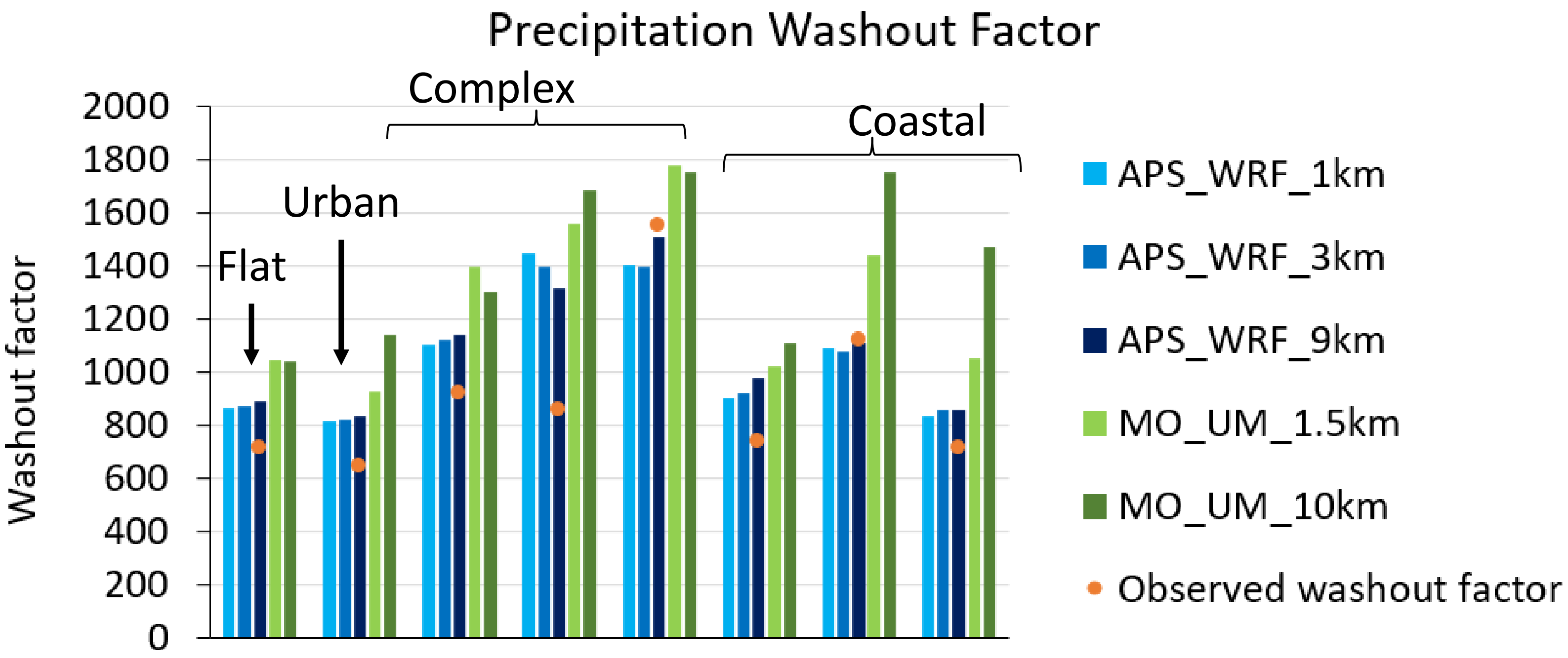
Evaluation summary – cloud cover

- Models calculate clouds separately in different vertical layers, not trivial to derive total sky cover
- Observations are based on total sky cover, substantial uncertainty (±2 oktas)
- Observed values are reported as integer oktas, dominated by values 0, 7, 8
- Models can underestimate frequency of clear-sky conditions, may affect stability estimates
- MO UM 10 km has poorer overall evaluation statistics for hourly cloud cover due to parameterised convection, otherwise unclear variation of performance with grid resolution



Evaluation summary – precipitation



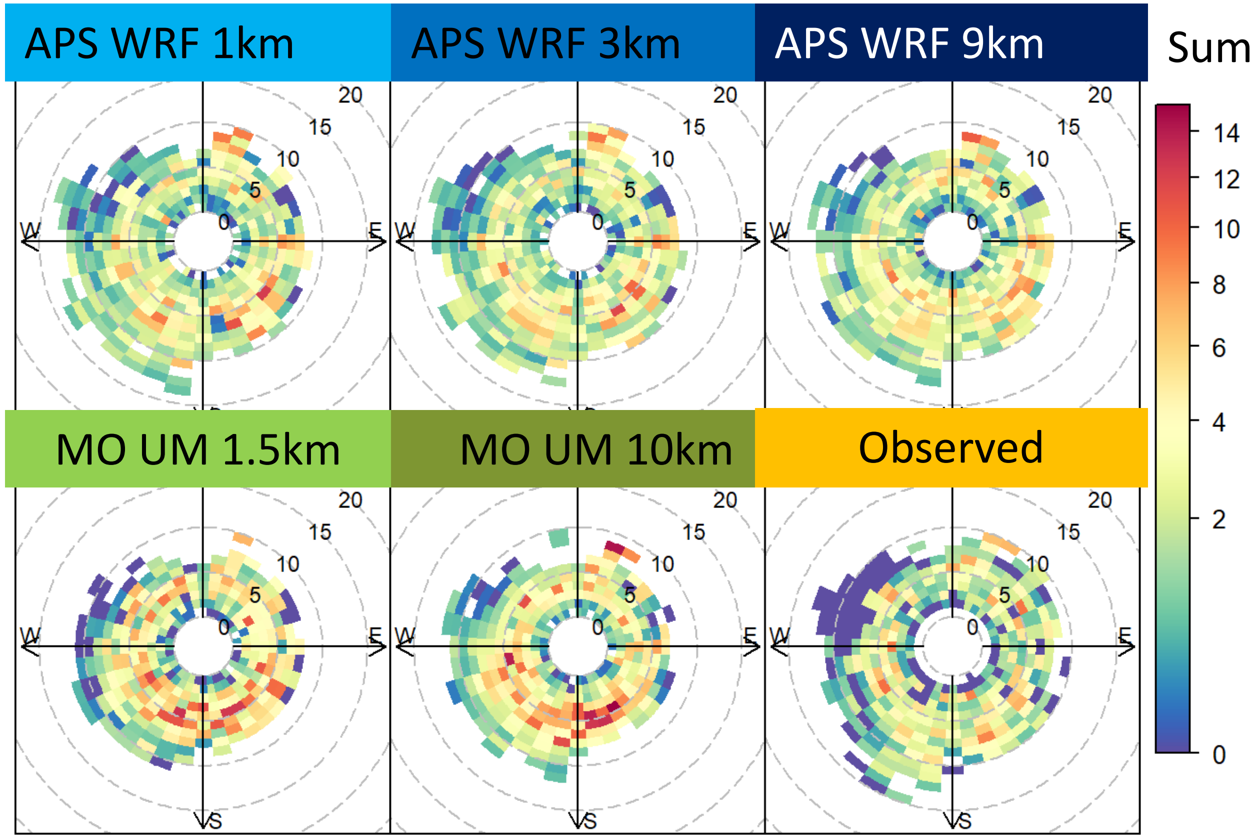


- Observations dominated by hours with zero precipitation
- Models predict fewer hours with zero precipitation, more hours with low precipitation
- Poorer correlation between modelled and observed hourly precipitation than for wind or temperature
- Models predict higher washout factor ($\sum_{i=1}^{n} P_i^B$) compared to observations
- Models may capture variation of precipitation between sites better than observed data from an alternative site
- 10 km MO UM shows poorest performance for precipitation – only configuration with parameterised convection

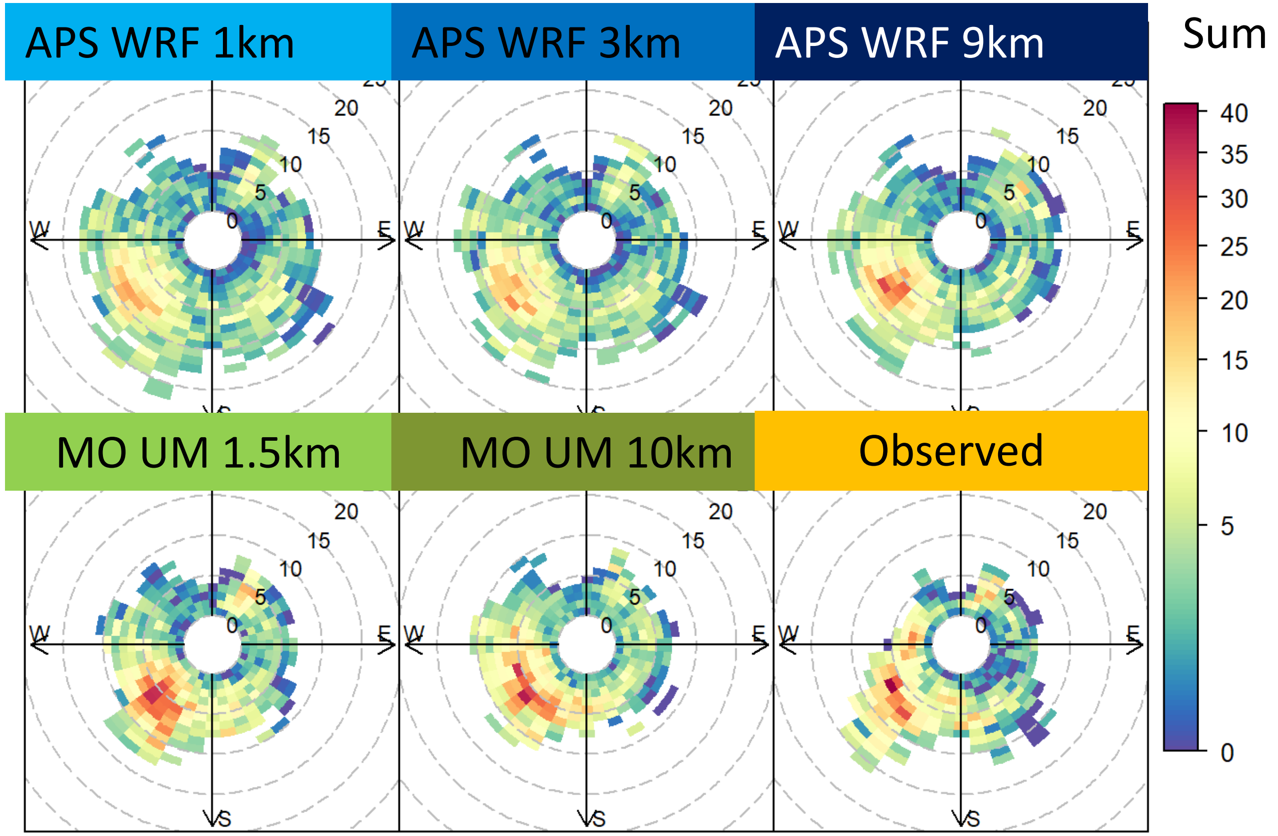
Evaluation summary – precipitation and wind distribution

- Variation of total washout factor with wind speed and direction
- Dominant observed sector at Sennybridge matched by models but magnitude differs
- More variation between models than due to resolution
- No clear trend in variation of performance with grid resolution between models and sites

Waddington Washout factor

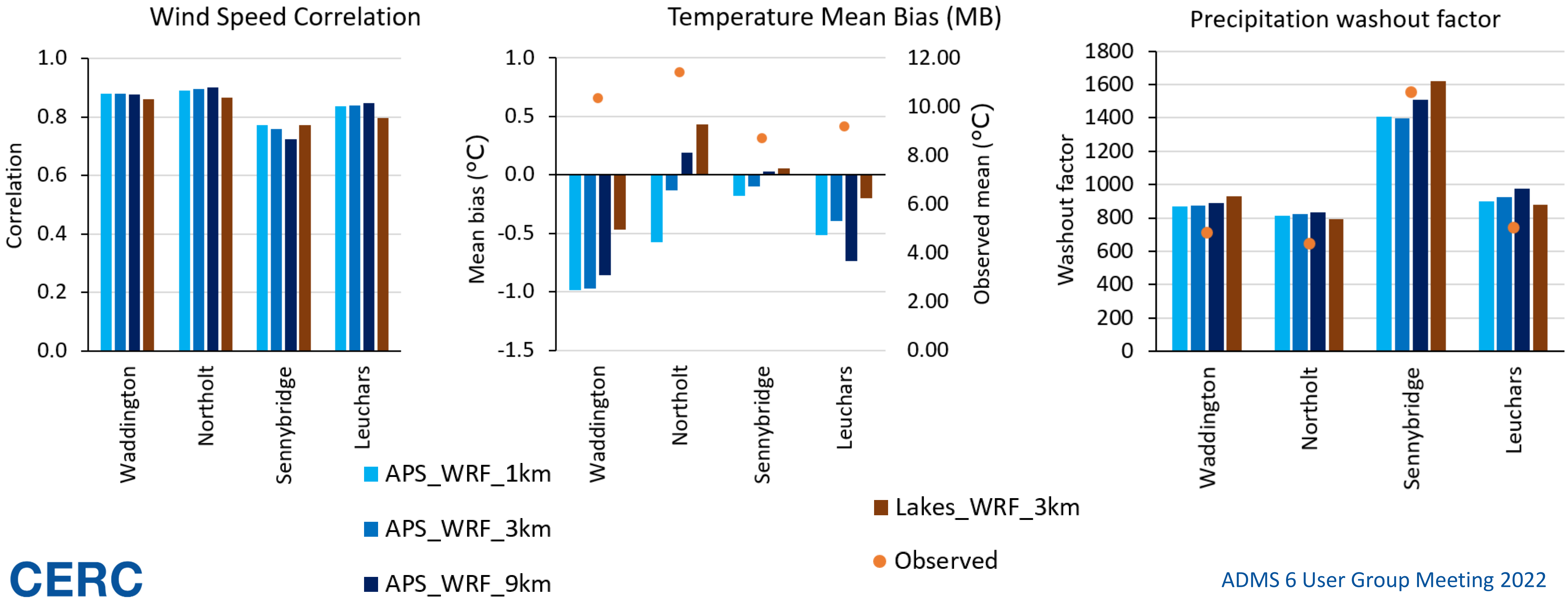


Sennybridge Washout factor



Effects of WRF configuration

- More difference between Lakes and APS WRF at 3 km than between different resolutions of APS WRF for most parameters and metrics
- Differences in driving meteorology, physics schemes and grid definition may all affect outputs



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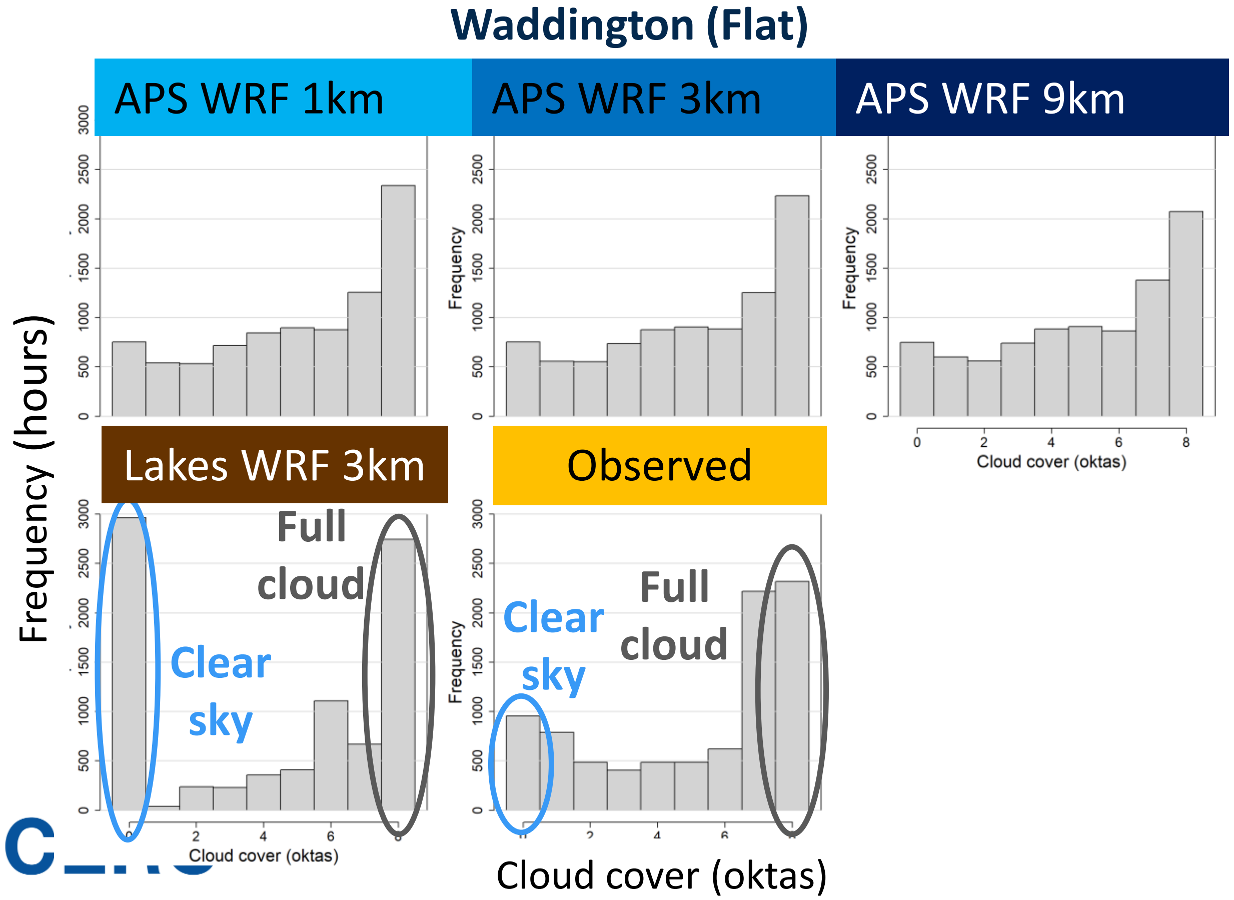
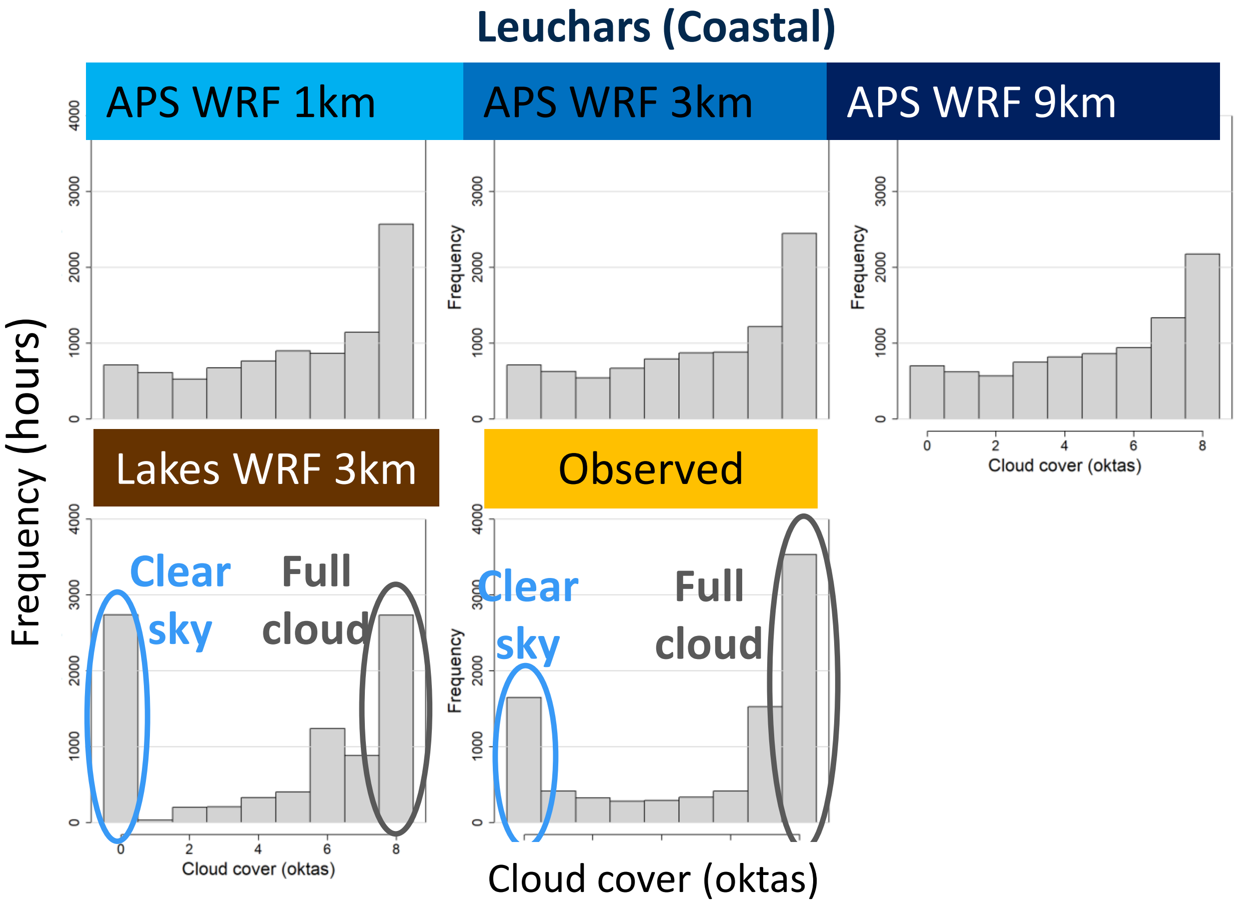
Effects of WRF extraction method

- Lakes extracted cloud cover from WRF using US EPA MMIF tool version 3.4 for this project
  - Derived overall AERMOD cloud cover from maximum cloud fraction over all layers
  - Tends to predict either zero or high values of cloud cover
- Poorer evaluation statistics from Lakes than APS for cloud cover





Conclusions from evaluation

- Generally good NWP performance for wind speed, direction and temperature
- Greater uncertainty in measurements of cloud cover and precipitation and also greater discrepancies between measured and modelled quantities
- Tendency for modelled precipitation to overpredict washout factor compared to observed precipitation
- Greater variation between models than due to model resolution for most metrics and sites, for grid resolutions 1 – 10 km
  - ***If using NWP met for dispersion, model configuration information should be supplied alongside data and reported with dispersion outcomes***
  - ***Important to use model configuration and resolution which resolves convective processes for precipitation and wet deposition***

Possible evaluation extensions

- Relative merits of NWP compared to observed met from comparable sites at different distances
- Seasonal model performance for precipitation
  - Relative significance of convective processes
- ‘Neighbourhood’ comparison of modelled and observed precipitation
  - Allowing for uncertainty in spatial predictions
- Diurnal cycles of temperature in different seasons
  - Understanding modelled temperature variation and effects on stability
- Cloud cover by day/night and season
  - Implications for modelled stability

Next steps

- Assess secondary met variables (solar radiation, heat flux, boundary layer height) from observed and NWP
  - Aiming to recommend best practice for use of NWP in dispersion modelling
  - Will test different combinations of NWP variables in ADMS
- Model dispersion from hypothetical near-ground and elevated sources with observed and NWP met, flat and complex terrain
  - Differences in spatial distributions and magnitude of modelled concentration and deposition with different met datasets, ADMS and AERMOD
- Investigate interaction between NWP resolution and ADMS complex terrain modelling
  - Modify ADMS to remove FLOWSTAR calculations at scales similar to NWP grid resolution
- (UKHSA) Investigate effects of NWP resolution in probabilistic short-term emergency release modelling

To be continued….

see you next year!

Any questions?