Verification Notes

April 9, 2019

1 Paper Summaries

1.1 Bureau of Meteorology (2010)

ACCESS uses the scheme of Lock et al. (2000) for mixing in unstable layers. 7 classification types for boundary layers. Cumulus mixing uses the mass-flux convection scheme. Entrainment rates across the inversion at the top of the boundary layer are parametrised using the eddy diffusivity scheme of Lock (1998; 2001) scaled using cloud-top cooling rates. Mixing in stable boundary layers uses the local Richardson number first order closure of Louis (1979) with stability dependent surface exchanges calculated using Monin-Obukhov Similarity.

1.2 Louis (1979)

1.3 Lock et al. (2000)

1.4 European Center for Medium Range Weather Forecasting (2018)

1.5 Bishop & Abramowitz (2013)

1.6 Basu et al. (2008)

1.7 Kumar et al. (2006)

1.8 Zhang & Zheng (2004)

Great resource on character of diurnal cycle of winds in the PBL. Performs a comparison of five different parametrisation schemes.

1.9 Holtslag et al. (2013)

Great summary article. Discusses evaluation studies of Svensson et al. (2011). “The modeled diurnal cycle of the 10-m wind speed does not resemble the observations in many cases, most models overestimate the wind speed during night, and the speed does not increase enough after the morning transition (Fig. 8b).” Also noted the importance of associating forecast scores with degree of mixing etc (page 1701).

1.10 Hoxit (1975)

Provides good figures showing the diurnal evolution of wind speed and direction.

1.11 Englberger & Dörnbrack (2018)

Discusses effect of PBL diurnal cycle on the wake structure of wind turbines and wind farms.

1.12 Liu & Liang (2010)

PBL height.

1.13 Stensrud (1996)

Low level jets.

1.14 Svensson et al. (2011)

Evaluation of model performance. Crucial article.

1.15 Zhang & Zheng (2004)

Quotes Dai and Deser paper reporting diurnal variability of surface winds could account for 50-70% of total wind variability.

1.16 Mass et al. (2002)

Discusses predictability, and errors growing when horizontal resolution is reduced. Claims arguments of Lorenz (1969) may be overly pessimistic. Notes that some studies have argued errors in synoptic forcing may contribute more to mesoscale errors than the mesoscale processes/resolutions themselves. Rotation suppresses energy cascade even at mesoscales, e.g. in supercells! "It is clear that additional approaches should join the current verification toolbox. For example, one could verify the maximum wind or 1-h rainfall predicted by a forecast model over the subsequent day at a location. Time-averaged or spatially averaged parameters as well as model variability could be evaluated. Temporal or spatial shifting of model fields could be used to verify model structures. If suitable objective verification approaches can be devised, it may be possible to demonstrate increased value of high-resolution NWP."

1.17 Brooks & Doswell III (1993)

Sounds warning about failure to implement ensemble forecasting, and the continuous drive toward higher resolution NWP.

1.18 Lorenz (1969)

Discusses different spatial and temporal scales of predictable motion.

1.19 Lorenz (1982)

Discusses upper and lower bounds of predictability in ECMWF.

1.20 Rife & Davis (2005)

Comments on the need for "feature based" mesoscale verification. This assumes that a forecast resolving a feature is better than one that doesn't even if the feature is spatiotemporally displaced. Ebert & McBride (2000) provides one example of a feature based verification method. But in my context, the "features" being resolved by the higher resolution models, i.e. the additional random turbulence, are precisely what we're *not* interested in! It appears that the greatest benefit of the finer resolution is an increased ability to resolve the statistics of different scales of motion. In the present context this translates into improved forecasts of temporal variance, with the implication that the growth of errors is more realistic in the finer resolution (Rife & Davis 2005).

1.21 Pinson & Hagedorn (2012)

Proposes station-oriented view of the verification problem (which is what we are doing). Notes that there is a "representativeness issue" in that station-data is resolving processes at physical scales the model is infact not intended to resolve. Notes that from the users perspective this is irrelevant. *How could forecasters or post-processing incorporate this uncertainty into the forecast?* Discusses in detail the bilinear interpolation process for downscaling forecast data to location of stations. *What is Jive's procedure for doing this?* Forecasts are benchmarked against 1-6 climatology based forecasts. Notes that observational uncertainty is known to be non-negligible, while surface effects introduce additional noise beyond what the numerical models intend to represent (or are capable of representing.) Representativeness issue ignored here for above reasons. Notes one method of dealing with observational uncertainty when performing ensemble (probabilistic) forecast verification is by transforming observations into random variables. Impact of observational uncertainty can then be assessed using methods like those of Pappenberger et al. (2009). Note that Pappenberger still applies only to probabilistic forecasting.

Very important - notes that the most poorly performing locations across Europe are the Alps and coastal regions, and that "This could be expected since near-surface local effects [e.g. mountain and sea-breezes] are difficult to resolve at the fairly coarse resolution (50 km) of the ECMWF ensemble prediction system. [What is the spatial resolution of the ECMWF, ACCESS data used in GFE?] Authors comment on "...questionable quality of the ensemble forecasts, for instance due to local effects not represented in a model with such a coarse spatial resolution". Could also be ensemble averaging process suppressing local processes.

Key discussion - "The periodic nature of the RMSE curves is linked to the diurnal cycles in the wind speed magnitude, the amplitude of such periodicities varying throughout Europe. To identify better the effect of the diurnal cycle on verification statistics, one may refine the analysis performed here by verifying forecasts depending on the time of the day (instead of the lead time), or by making a difference between forecasts issued at 0000 and 1200 UTC." So diurnal cycles are mentioned in passing here - good reference to make.

Regarding observational uncertainty - the effect of uncertainty diminishes as the number of stations or the length of the evaluation period increases. "This effect was observed to become negligible if looking at more than 100 stations over periods of more than a month (with two forecast series issued per day). For certain sites with strong local regimes though, one retrieves a more intuitive result that ensembles significantly underestimate wind speed.

1.22 Lynch et al. (2014)

Focuses more on longer term forecasts. Interesting note that there is little difference in performance between 10m and 100m winds. Applies verification to forecast anomalies (from seasonal and diurnal cycles). SImilar approach to me, but work out average for each hour for each day of year, averaged over 32 years of ERA-Interim record. Note that I'm also avoiding the "aritificial skill" associated with the seasonal cycle by restricting to just a particular season. I'm not convinced that seasonal skill is necessarily "artificial" however! Both pinson and lynch use the CPRS score. Interesting notes on the large costs associated with wind farm station maintenance, and the need for probabilistic forecasts in order to manage these costs.

1.23 Ebert (2008)

Not easy to prove the value of mesoscale forecasts using traditional point-by-point verification results. At small scale features unpredictable - e.g. intermittant convective rainfall - in the example of winds the cold pool dynamics. Mesoscale forecasts typically verified against high-resolution gridded datasets, e.g. radar mosaics or reanalysis. Spatial verification techniques that do not require the forecasts to exactly match the observations at fine scales. Use of "object oriented" techniques. The term 'fuzzy' is consistent with the general concept of 'partial truth' introduced by Zadeh. Does Ebert's fuzzy scheme require gridded data? No. "Fuzzy verification assumes that it is acceptable for the forecast to be slightly displaced and still be useful. Fuzzy concept can be applied in space or time. Really we're doing "upscaling" rather than "fuzzy" verification. Uncertainty in the observations represented by using neighbouring grid boxes. Less useful to me because "event" framework not entirely appropriate to diurnal cycles. I am using an "upscaling" approach. "From the perspective of the forecast user, fuzzy verification gives important information on the scales and intensities at which the forecasts should be trusted."

1.24 Ebert & McBride (2000)

N/A

1.25 Yates et al. (2006)

N/A

1.26 Mason (2008)

Discusses practical methods for identifying in a yes/no sense whether a sea-breeze will occur. Discusses techniques for diagnosing speed and direction. Paper pretty old - would be good to have some references for up to date practices.

1.27 Ferro (2017)

Presents mathematical results regarding the calculation of verification statistics in the presence of observational error.

1.28 Wilks (2011)

Practical way to deal with autocorrelation is to think in terms of "effective sample size"

$$n' \approx n\frac{1-\rho_1}{1+\rho_1}. \tag{1}$$

Simply replace n with n' in appropriate places in t-test.

2 Notes

1. To investigate the impact these representation issues have on discussed the WPI method outlined above is modified so that the performance of the Official forecast can Two methods are used to investigate how the representation issues discussed above effect verification statistics of the diurnal wind cycle.

2. To assess how well the diurnal perturbations of an overall region are predicted, for instance those of the Victorian coastal station group (see Fig. **??**), the perturbations across each station group are averaged before WPI values calculated. The temporal means and sampling distributions of the WPI are then calculated as before, with each value of WPI calculated from the spatially averaged perturbations treated as a single observation. This provides a conservative method for dealing with spatial correlation in the perturbations.

3. One factor that complicates interpretation of statistics of WPI, is that the near surface winds observed in AWS data are consistently noisier than those of the Official, ECMWF and ACCESS forecasts. This is likely due to unresolved subgrid scale turbulence in the Official, ECMWF and ACCESS model datasets. It would be unreasonable to expect forecasters to be able to predict this essentially random additional observed variability, and so a direct comparison of observed and modelled diurnal cycles is overly stringent.

4. Note that subtracting background winds may raise concerns, because perturbations obviously depend on background winds. However, the forecaster does not have knowledge of the observations when they make the diurnal process edits. They are implicitly assuming that the true mean state will be close enough to the predicted mean state - however this prediction is produced - to justify making diurnal edits on the basis of the predicted mean state.

5. To reduce the significance of unpredictable noise, we also compare temporal averages of the perturbations for each dataset. These comparisons have less operational significance: people generally care how well the actual weather forecast performed, not whether the average of a predicted quantity matched the average of an observed quantity. However, comparisons of averages arguably better represent what we can realistically expect from human forecaster edits, and from weather forecasts overall, particularly in regards to small

scale processes like sea-breezes. Furthermore, when temporal averages of perturbations are considered, the diurnal signal becomes dramatically clearer, and structual differences become much easier to diagnose.

6. To quantify how closely the temporally averaged Official forecast perturbations match those of the AWS observations, we calculate $|\overline{\boldsymbol{u}}_{\mathrm{AWS}} - \overline{\boldsymbol{u}}_{\mathrm{O}}|$ for each hour. To assess the performance of the Official temporally averaged perturbations against those ACCESS,

7. Two edits are commonly involves changing the surface wind fields near coastlines to try to represent sea-breezes more realistically. Forecasters invest time in making sea-breeze edits because accurate predictions of near-surface winds are highly valued by a number of users, such as the aviation and energy (Smith et al. 2009) industries. Accurate sea-breeze forecasts are also valuable to environmental monitoring authorities, as these winds provide ventilation to coastal urban areas.

8. Assessing the accuracy of a weather forecast is a task far more nuanced than it might first appear. For instance, attempting to assess the accuracy of a precipitation forecast by comparing the rainfall amounts measured at an individual weather station to the closest grid point of a model prediction will often give poor results. Although the synoptic drivers of convection are usually well predicted, excatly where convective cells form, and where the most rain falls, is highly unpredictable. As such, it is often appropriate to use "fuzzy" verification metrics which measure the agreement between prediction and observation in a more indirect way. For instance, one approach known as "upscaling" is to first average forecast and observational data over a given spatial domain before calculating verification scores. Ebert (2008) provided a review of current "fuzzy verification" methodologies, and a framework for how they can be used to determine the spatial scales at which a given forecast has predictive skill.

9. Lynch et al. (2014) also performed a verification study of ECMWF 10 m wind speed data, with the goal of assessing skill at lead times of between 14 to 20 days. They compared ECMWF 32-day forecast model wind speeds with gridded ERA-Interim wind speeds between 2008-12, with both datasets analysed at a six hour temporal resolution. Before conducting the comparison, the wind speed data were transformed into wind-speed "anomaly" data by first calculating the mean wind speed at 0000, 0600, 1200 and 1800 UTC for each calendar day from the entire ERA-Interim record, and from a 20 year ECMWF 32-day model hindcast, then subtracting these means from the ERA-Interim and ECMWF 32-day model data respectively. Wind speed anomaly data was used so that stable seasonal and diurnal cycles did not contribute to verification scores. At the 14-20 day timescale around western Europe, the greatest skill was found in the boreal winter (austral summer) months of December, January and February.

10. Pinson & Hagedorn (2012) and Lynch et al. (2014) restricted their verification studies to wind speeds, but wind directions are also crucial to diagnosing whether land sea breezes - and the diurnal wind cycle more generally - are being forecast correctly. Furthermore, no previous published work has proposed a verification methodology to assess the accuracy of the diurnal wind cycle in forecasts, or of the contributions made to this accuracy by human

forecaster edits of model output. Finally, no previously published work has considered the performance of ACCESS near surface winds, which together with ECMWF, are the model guidance products most widely used by Australian forecasters.

11. Example figure with one day diurnal cycles for both AWS, Official, ECMWF and ACCESS winds, perturbations, and perturbation climatology. Just one season.

12. Airport breakdown for one season, WPI, CWPI for one season, for both ACCESS and ECMWF. Second season in online supporting material.

13. Example results for straight coastlines - perhaps north, northeast, northwest, south, southeast, southwest? Again, just do one season, include second season in online supporting material?

14. Look at timing results by fitting ellipses and checking orientations of major axes. Just one season - both ECMWF and ACCESS? Maybe just ACCESS if ECMWF results are dodgy?

15. Confirm ACCESS and ECMWF are indeed the msot commonly used model guidance products for winds.

16. I tried modifying the pressure perturbation terms $\frac{A}{\pi} + \frac{A}{2}\cos(\omega t)$ so that the new ellipse fit of equations (**??**) and (**??**) are now solutions to equations (**??**) and (**??**), but with no luck. For example, simply changing to $\frac{A}{\pi} + \frac{A}{2}\cos(\alpha(\psi, t))$ doesn't work, nor does expanding this expression as a Fourier series and solving each term individually. This doesn't really matter anyway as my main argument is that this two-dimensional model cannot capture boundary layer mixing processes.

1. In Cairns and Townsville (austral summer), ECMWF understimates the magnitude of the land-sea breeze, leading to ACCESS resolving the diurnal cycle more accurately. During austral winter ECMWF again underperfoms, but (Townsville) more to do with shape of the hodograph and direction of the sea-breeze. At Cairns, it's essentially again because the ECMWF peak seabreeze is slightly (1 knot) too slow.

2. In Darwin - ACCESS perturbations bizarre during austral summer (wet season), but ECMWF also much too weak (about half the amplitude).

3. In Darwin - during austral winter (dry season) - ECMWF very accurate - gets peak of sea-breeze perfectly correct! Also resolves weird bump at 12 UTC quite well. However, does not resolve bump at 1 UTC at all. ACCESS doesn't either really.

4. Interesting - at Melbourne ECMWF and ACCESS essentially agree, but both underestimate the magnitude of the land-sea breeze. True of both seasons.

5. Adelaide - ACCESS and ECMWF almost match at Adelaide. Amplitudes generally slightly too weak compared to observations however.

6. Need to assume independence of measurement and rounding error in observations.

7. The two most important results of section **??** to explain are, first, why equations **??** and **??** provide such a good fit to the climatological perturbations and, second, why there are such substantial changes in the performance of the Official forecast at the different spatial and temporal scales.

   The idea of applying an ellipse fit to the diurnal cycle of surface winds originated with **?**, and was later extended by **?**, who obtained exact solutions for u and v resembling equations (**??**) and (**??**) for the simple model

$$\frac{du}{dt} - fv + ku = F_x - F(t), \tag{2}$$

$$\frac{dv}{dt} + fu + kv = F_y, \tag{3}$$

   where u, v are taken in a coordinate system where the x axis is normal to the coast, f is the Coriolis parameter, k is a linear friction coefficient, (F_x, F_y) represents a constant synoptic scale pressure gradient force, ω is the angular frequency of earth's rotation, and

$$F(t) = \frac{A}{\pi} + \frac{A}{2}\cos(\omega t) \tag{4}$$

   is the pressure gradient force normal to the coastline induced by the diurnally varying air temperature contrast over the land and sea surfaces. The obvious limitations of this model are discussed extensively by **?** and **?**, but the most important for our purposes involve the choice of $F(t)$, which does not sufficiently capture the asymmetries between daytime heating and nighttime cooling (e.g. Svensson et al. 2011), and the fact that the model has no vertical dimension, and therefore cannot capture the boundary layer mixing processes that play a significant role in the diurnal wind cycle (e.g. Hoxit 1975). Note that I tried modifying the pressure perturbation terms $\frac{A}{\pi} + \frac{A}{2}\cos(\omega t)$ so that the new ellipse fit of equations (**??**) and (**??**) become solutions to equations (**??**) and (**??**), but with no luck. For example, simply changing to $F(t)$ to $\frac{A}{\pi} + \frac{A}{2}\cos(\alpha(\psi, t))$ doesn't work, nor does expanding this expression as a Fourier series and solving each term individually.

   ? applied this fit to satellite scatterometer wind observations, which after temporal averaging provided only four temporal datapoints at each $0.25° \times 0.25°$ spatial grid cell. As such, their fit was very good, explaining over 90% of the wind variability in each spatial gridcell. However, the choice of ellipse parametrisation in equations **??** and **??** assumes that datapoints lie on the ellipse at equal intervals of time t. When observational or model data with an hourly or smaller timestep is considered, this assumption becomes too stringent, as heating asymmetries imply that wind perturbations evolve much more rapidly during the day than at night (see Fig. XX). Note I'm also basing this point on knowledge of the land vs sea breeze, and knowledge of heating vs cooling asymmetries (**?**, e.g.).

2.1 Miller et al. (2003)

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