30-day Hourly and Daily Point Forecasts

This document describes the methodology used to generate both hourly and daily point forecasts of temperature and precipitation with 30-day horizons. Deterministic (ensemble mean/median) and probabilistic forecasts are produced daily for each station location (specified by BC Hydro). Both the hourly and daily products are initialized from 00 UTC, though not all ensemble members are initialized at this time. Ensemble forecasts are generally available by 0700 PST (0800 PDT), following daily download of individual ensemble member files, individual member bias-correction, and ensemble combination.

Daily forecasts of minimum and maximum temperatures (TMin and TMax, respectively) and of 24-hour accumulated precipitation (Precip24) are computed from ensemble member output over 24-hour periods beginning at 06 UTC each day. Not all ensemble members produce forecasts at hourly time-steps, and 6 hours is the lowest temporal resolution available (from the models with lower spatial resolution). The 06-06 UTC window is also close to a 00-24 PST window, which is used for computing the observed daily TMin/TMax/Precip24 values used to post-process and verify forecasts.

The Ensemble

The same ensemble members are used for all products. The ensemble members are specified in Table 1.

Table 1. *Ensemble members included in the daily and hourly forecast superensembles.*

Name	**Number of Members**	**Providing Agency**	**Initialization Time (UTC)**	**Forecast Horizon**
RDPS	1	ECCC	06	48 hours (2 days)
GDPS	1	ECCC	00	240 hours (10 days)
GFS	1	NCEP	06	256 hours (10.6 days)
NAEFS	42	ECCC/NCEP	00	384 hours (16 days)
UBC SREF	34	WFRT	00	Various, up to 180 hours (7.5 days)

CFS	16	NCEP	00/06/12/18	720 hours (30 days)
Climatology	1	ECCC/BCH (depending on station)	n/a	720 hours (30 days)
Historic Traces	20	ECCC/BCH (depending on station)	n/a	720 hours (30 days)
TOTAL	**116**			

The UBC SREF includes all available grids (ranging from 1.3 km to 108 km) from 00-UTC-initialized WRF3GEM, WRF3NAM, WRF3GFS, WRF2NAM, WRF2GFS, MM5NAM, MM5GFS, and two additional WRF3GFS members run on the Google Cloud Platform. The CFS ensemble members have forecast horizons of up to 9 months, but only the first 30 days are stored locally after download, to save space.

Climatology and Historic Traces are observation-based forecast guidance. For climatology, the "forecast" is taken to be the climatological mean of a forecast variable for a particular location on each calendar day beginning on the forecast issue date and ending 30 days later. Climatologies are typically only available for daily forecast values (TMin/TMax/Precip24). The RChill R library (based on Linville, 1990) was used to transform TMin/TMax values into hourly temperature traces. This method uses a sine curve to model the daily increase in temperature from TMin to TMax, and a logarithmic decay function to model temperatures as they decrease to the next TMin value. Daily Precip24 values are transformed into hourly precipitation amounts by a simple division by 24.

The use of historic traces as forecast guidance is based on the Extended Streamflow Forecasting method of Day (1985), which assumes that weather sequences that have happened in the past are likely to occur again (at least approximately) in the future. 20 historic trace members are produced based on weather conditions that were observed over a 30-day period beginning on the forecast day's calendar date in years 1996 through 2015. Both climatology and historic trace ensemble members are treated like any other ensemble member from model output, and undergo the same post-processing treatment (except for interpolation to station location).

All 116 members are included in the superensemble for their full forecast horizon. Some experimentation was done with excluding low-resolution or assumed low-skill members (i.e., climatology, historic traces) at short lead-times, in order to let the more skilful, higher-resolution models have a bigger impact on the ensemble mean, but there was little or no benefit in doing so. An alternative ensemble member selection scheme was tested in COMPS, in which the *n*-best members (based on their recent Mean Absolute Errors) were included in the superensemble and the others omitted. Results from these tests indicated that larger (i.e., n=20 or the full ensemble) ensembles were better, and that the reduced ensembles (i.e., any number less than the full ensemble size) resulted in some erratic behaviour from the probabilistic forecasts, as COMPS had difficulty fitting parameters to an ensemble whose members were potentially changing on a daily basis. See previous progress reports for details.

COMPS

The COmponent-based Post-processing System (COMPS) is used to carry out the daily forecast post-processing, including individual ensemble member bias-correction and member combination into a superensemble.

The COMPS system uses adaptive updating of parameters, rather than rolling-window computation, in order to maintain computational efficiency. What this means is that in order to compute today's bias-correction factor for a 12-hour forecast horizon temperature at YVR, COMPS requires only (1) yesterday's correction factor for the 12-hour temperature forecast for YVR, and (2) the most recent forecast-observation pair for a 12-hour temperature forecast at that site. This can be contrasted with an *n*-day rolling-window computation that would require, each day, the retrieval of *n* days of recent past 12-hour temperature forecasts at YVR (where *n* is typically on the order of 30-60 days).

Adaptive parameter updating is done according to the formula:

$$\theta_{t+1} = \frac{\tau - 1}{\tau}\theta_t + \frac{1}{\tau}\theta^* ,$$

where θ_t is the best estimate of a parameter at time *t*, θ^*_t is the new parameter information computed solely based on new information obtained at time *t* and used to update the parameter to a new value θ_{t+1}, and τ is a unitless timescale (analogous to a rolling window length) that describes how quickly the effect of new information diminishes over time.

While this adaptive scheme has a distinct advantage in terms of computational efficiency, work in this project (see previous progress reports) has suggested that it may not be suitable for long-range forecasting (i.e., beyond 15 days) or for removing bias from observation-based forecast guidance. Namely, the most recent observations (i.e., yesterday's) receive more weight, with older observations being weighted less and less over time, but in theory always remaining in the corrector's memory. Since the goal with bias-correcting the observation-based forecast traces is to remove large-temporal-scale biases (caused by, e.g., oscillations such as El-Niño), we suspect that a scheme that applies equal weighting across a moving window may be more suitable both for individual member bias-correction and for computing probability model parameters for long forecast lead-times. Unfortunately, this is beyond the abilities of the COMPS system.

Kyle Sha is currently working on producing 30-day hourly and daily *gridded* forecasts for BC Hydro, post-processed using machine learning methods. We suspect that such methods may work better than the COMPS adaptive scheme for long-range point forecasts, and recommend that his post-processed gridded forecasts be interpolated to station locations and compared to the COMPS output described in this document.

Ensemble Member Post-Processing

Each ensemble member undergoes interpolation and bias-correction in COMPS independently of the other members.

Spatial Interpolation

The gridded ensemble member forecast fields are interpolated to specified station locations using the nearest neighbour method. The method is computationally simple and justifiable because subsequent bias-correction takes care of any biases that result from incorrect station location/elevation.

Temporal Interpolation

For models that generate hourly output, no temporal interpolation is necessary for producing hourly forecasts. For models with 3- or 6-hourly output, a simple linear interpolation is used for temperature, and division is used for precipitation. TMin and TMax are computed over appropriate 24-hour windows based on whatever temporal resolution is available (namely, there is no temporal interpolation done prior to selecting the min/max value), and Precip24 is computed either by accumulating forecast output hours or by de-accumulating, depending on the format of the particular forecast model input.

Temperature Bias Correction

All temperature forecasts are corrected using the COMPS MeanBias scheme. The bias-correction factor is calculated using the formula

$$MB_{t+1} = \frac{\tau-1}{\tau} MB_t + \frac{1}{\tau}(f^* - o^*),$$

where *MB* is the MeanBias correction factor, and f^* and o^* are the new forecast and observation pair used to update the previous *MB* estimate. A bias-corrected temperature forecast is calculated by taking the raw temperature forecast and subtracting the updated MB value.

For hourly temperature a dimensionless timescale of τ = 30 (analogous to a 30-day moving window) was found to work best for all ensemble members. For the daily TMin/TMax forecasts, τ = 30 worked best for model-based guidance, but τ = 90 was best for observation-based (climatological and historic) guidance.

The Kalman Filter (KF) bias corrector was originally used early in this project, but it was pointed out that KF can't be applied to the historic trace members because the nature of their biases does not match the assumptions of the KF method. The MeanBias scheme was then tested and found to perform better than KF for all members.

Precipitation Bias Correction

All precipitation forecasts are corrected using the COMPS DegMassBal (degree of mass balance) scheme. The bias-correction factor is calculated using the formula

$$DMB_{t+1} = \frac{\tau-1}{\tau}\frac{\bar{o}_t}{\bar{f}_t} + \frac{1}{\tau}\frac{o*}{f*},$$

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where *DMB* is the DegMassBal correction factor, $\bar{o}_t$ and $\bar{f}_t$ are adaptively-updated running mean forecasts and observations, and f^* and o^* are the new forecast and observation pair used to update the previous *DMB* estimate. A bias-corrected precipitation forecast is calculated by taking the raw precipitation forecast and multiplying by the DMB factor.

This DMB scheme works very well for daily Precip24 forecasts, for which it has been used operationally (for BC Hydro Precip24 forecasts) for years. In applying the scheme to hourly precipitation forecasts, an issue was encountered where large precipitation misses (i.e., little or no precipitation in the forecast corresponding to a large observation) caused the DMB correction factor to blow up. This blow-up would result in significant correction factors that persisted for weeks as the old forecast-miss information became gradually less and less important in the adaptive updating scheme. Such events are typically associated with missed thunderstorm activity, which are not the type of error that the bias-correction scheme is meant to address (such as precipitation errors caused by a model thinking that a particular location is on the windward side of a mountain range when it is actually in the lee). A mitigation strategy was coded into COMPS to prevent these types of events from blowing up the bias corrector. The mitigation is triggered if three criteria are met:

1) The updated DMB correction factor (DMB_{t+1}) is more than 3x yesterday's value (a very significant jump);
2) This sudden change is due to a large increase in the running mean observation, rather than due to a large change in the running mean forecast (namely, today's running mean observation is more than 3x yesterday's value);
3) The hourly observation is more than 10 mm greater than the forecast (this final rule ensures that these changes are due to large absolute differences in observations; without this criteria, cases where the forecast is 0.001 mm and the observation is 0.2 mm could unnecessarily trigger the mitigation scheme in a very dry location).

If these criteria are all met, rather than increasing the DMB by a large factor, the mitigation scheme simply increases the value by 20%.

Precip24 forecasts are corrected with the mitigation scheme turned on, but it is triggered extremely rarely (if at all). For these forecasts, a dimensionless timescale of $\tau = 30$ worked best for model-based guidance, but $\tau = 180$ was best for observation-based (climatological and historic) guidance.

An additional bias-correction strategy is being tested on hourly precipitation forecasts. This involves applying Precip24 DMB factors computed for a station to the hourly forecasts. This method has the advantage that it produces bias-corrected hourly forecasts that sum to the same value as bias-corrected daily Precip24 forecasts (though this isn't critical because there are no stations for which we predict both hourly and daily precipitation). Using daily forecast/observation pairs also serves to mitigate things like thunderstorm misses and timing errors. Both the hourly (with mitigation) and daily bias-correction schemes are applied to the hourly precipitation forecasts, and both schemes use dimensionless training timescales of $\tau = 30$ for all inputs (longer training was not found to be beneficial for observation-based guidance at hourly timescales). Only the hourly scheme is used as input to the superensemble. In the fall of 2018, Greg West will carry out a comparison of the two bias-correction methods to determine which performs best. If the daily correction factor works best, West can very easily change the superensemble input so that it uses these corrected forecasts.

Superensemble Processing

Once all of the individual ensemble members have been post-processed, they are merged into a single COMPS input text file for each forecast location and variable.

Deterministic Forecasts

Hourly temperature = mean
Hourly precipitation = mean and median (will be compared at end of 2017-18 water year; forecasts currently sent to BC Hydro use ensemble mean)
TMin/TMax = mean
Precip24 = mean

Probabilistic Temperature Forecasts

Hourly = Method of moments ("MM2"), normal distribution with spread parameter = *a* + *b***ensVar*, where *a* and *b* are regression parameters trained based on past values of *ensVar* (ensemble variance) and the errors of the ensemble mean (i.e., they describe the spread-skill relationship); fitted to full ensemble mean
Daily = MM2 trained with e-folding time of both 30 and 90 (both being run for evaluation in fall 2018; addition of full CFS ensemble changed ensemble characteristics enough that it was not possible to select between the two, so a longer verification period is needed before the winner can be selected). The two methods will be compared at the end of the 2017-18 water year. Forecasts sent to BC Hydro are from MM2 trained with e-folding time of $\tau = 30$.

Probabilistic Precipitation Forecasts

Daily = NormCal, i.e., MM2 fitted to ensemble mean, $\tau = 30$, calibrated using e-folding time of $\tau = 60$ to transform Gaussian into more of a gamma shape; discrete POP is Consensus (percentage of ensemble members predicting >0 precipitation)
Hourly = NormCal, i.e., same as for P24, fits to ensemble mean no matter if mean/median is selected as deterministic output
For both, Gamma distributions did not do as well as calibrated normal distributions

Graphics/Text Forecast Production

All text file formats were developed in consultation with Greg West and Georg Jost. These are made available via the same ftp and web channels used for the 15-day forecasting system.

Daily Deterministic Forecasts

COMPS outputs are transformed from NetCDF format to ASCII text format for ingestion into BC Hydro models. A script reads the deterministic (ensemble mean/median) forecast from the NetCDF forecast output file and writes it in a single file containing TMin, TMax, and Precip24 for each station and each forecast day (1-30). The general csv format displays 3 rows per station (one for each of TMin, TMax, and Precip24), with 30 forecast values following the station/variable information in each row.

Hourly Deterministic Forecasts

A script reads the deterministic (ensemble mean/median) forecast from the NetCDF forecast output file and writes it in a single csv file with one time step (forecast hours 1-720) per line, and one column per station and variable.

Daily Probability Forecasts

BC Hydro requires for their models a set of equally-likely forecast scenarios of equal length, sampled from the probability distribution. Ensemble copula coupling (e.g.., Schefzik et al., 2013) is used to select forecasts from the PDF that respect relationships between physically dependent variables. Recall that bias-correction and probability modelling of temperature and precipitation is done independently for each forecast location. This process breaks any spatio-temporal relationships between temperature and precipitation. Namely, the 10^{th}-percentile precipitation forecast at Day 1 may be linked to the 70^{th}-percentile precipitation forecast for Day 2, and to the 90^{th}-percentile temperature forecast. Providing a 10^{th}-percentile forecast of both temperature and precipitation is unlikely to produce skilful hydrologic forecasts that reflect the spatio-temporal evolution predicted by any of the models.

To work around this, the ensemble copula coupling methodology samples 37 percentiles from the forecast CDF. This number was selected because it is the minimum number of ensemble members available at any given forecast horizon time (assuming that all models are available). At each forecast offset, the bias-corrected ensemble members are ranked based on their forecast values (lowest temperature = rank 0, highest = rank 37). Each percentile value (from lowest to highest) is assigned to the ensemble member with its corresponding rank. This ranking procedure re-establishes the broken spatio-temporal links between the forecast offsets and variables.
The 37 members selected to produce the ranks for forecast days 1-16 are 19 from the Canadian NAEFS members and 18 from the American NAEFS members. For forecast horizons beyond 16 days, the 16 CFS members, climatology, and the 20 historic traces are used. The NAEFS are used for the short-to-medium-range horizons because they are aware of predicted atmospheric dynamics, and have been previously shown to be quite skillful at these lead-times. Note that the full 116-member ensemble size could be used, but since some ensemble members have short forecast horizons (e.g., 48 hours for RDPS), this would produce members of differing forecast length. It is not uncommon for the historic traces to have brief periods of missing data, which means that there occasionally isn't enough information to rank 37 members for certain forecast lead times. For such cases, any missing ranks are assigned randomly. This ensures a consistent 'ensemble' size in forecast text output sent to BC Hydro.

Hourly Probability Forecasts

The same ensemble copula coupling scheme used for daily probability forecasts (described above) is applied to the hourly probability forecasts.

How to bulk upload forecasts for BCH

From time to time, BCH may request a set of past forecast files.

1. Navigate to hourly and/or daily forecast dirs, e.g. model@levant:~/HydroMet30/setup/results/ASCII/superensDailyMM2
2. Tar the files you want, e.g., tar -cvf 202012dly.tar 202012* ...in this example we're tarring the whole December 2020 dir
3. Transfer them to the G Suite bchydro drive, e.g., rclone copy ./202012dly.tar GSbchydro:WEFfcsts ...where WEFfcsts is any dir you create in the G Suite bchydro drive to put them in
4. Remove the tar files you created

References

Day, G., 1985. Extended Streamflow Forecasting Using NWSRFS. *J. Water Resour. Plann. Manage.*, **111**(2), 157-170.

Linville, D.E., 1990. Calculating Chilling Hours and Chill Units from Daily Maximum and Minimum Temperature Observations**.** *HortScience*, **25**(1): 14-16*.*

Schefzik, R., T.L. Thorarinsdottir, and T. Gneiting, 2013. Uncertainty Quantification in Complex Simulation Models Using Ensemble Copula Coupling. *Statistical Science*, **28**(4): 616-640.