Statistical downscaling for singapore winds

Contents

Statistical downscaling for Singapore Winds

Drumhead

As local clime increasingly become more susceptible to alterations in clime, the effects of these alterations on the environment and society becomes progressively critical. As such, surveies on the impact of clime alterations like statistical downscaling, which depends on the use of local clime measurings as inputs, becomes highly relevant in the present context. In this survey, an bing statistical downscaling technique which was developed by Pryor et Al. is being reformulated and applied. On top of it, two alternate statistical downscaling techniques are discussed as good. The 2nd method proposed is an extension to the attack by Pryor et Al. (2005) while the concluding method involves the usage of normal mixture theoretical account. These methods are assessed in the survey with the usage of air current velocity observations measured at assorted meteoric Stationss situated in Singapore. At the same clip, projections of future wind velocity of these Stationss are being made.

The writer ' s parts are summarized as follows: Sections 1. 1, 1. 4, 1. 5, 3. 1 and 3. 3 contain infusions from a figure of literatures, including research documents and books on statistical techniques which are used in the survey. Section 2. 1 is a reformulation of the method described in 1. 5 and contains writer ' s ain work. Sections 2. 2, 3. 2 and 3. 4 and, Chapters 4 and 5 are contributed by the writer, including Theorem 1 which is found in Section 2. 2. The statistical package used in this survey is R, SAS and SPSS. Programing codifications for R and SAS, which are used for Chapters 2, 3 and 4, are all written by the writer and can be found in the affiliated Cadmium.

Recognitions

This thesis would non hold been possible without the support of a several of import persons and it is my pleasance to thank them.

I deeply appreciate the support and forbearance given by my supervisor Assoc. Prof Nott, David John. With his counsel and aid, I was able to derive new cognition in statistical constructs such as EM algorithm and finite normal mixture mold.

I am really grateful to the confederates of the undertaking, Dr Liong Shie Yui, Deputy Director of the Tropical Marine Science Institute (TMSI) of the National University of Singapore, and Dr Nguyen Hoan Huy. Without them, I would non hold been able to work on such an interesting and meaningful subject. In add-on, I am thankful for their priceless inputs and advice with respects to statistical downscaling and the dataset.

Last but non least, I would wish to thank the testers, Assoc. Prof Chaudhuri and Asst. Prof Alkema, for their constructive feedback during the undertaking advancement presentation, leting me to better on my undertaking.

Chapter 1:

General Introduction

1. 1. Background

Empirical-statistical downscaling (ESD) can be considered to hold originated from Klein ' s history in " Winter Precipitation as related to the 700mb Circulation " which was published in 1948 (Benestad, Hanssen-Bauer, & A ;

Deliang, 2008) . Hence, downscaling can be regarded a comparatively immature scientific discipline with a history of less than a century. One ground which can explicate the outgrowth of downscaling is the recent promotion in the clime scientific discipline community and the development of planetary clime theoretical accounts (GCMs) , which is an of import constituent in statistical downscaling. A more elaborate account of GCMs will be given in later in the subdivision of the chapter.

In recent old ages, most of the surveies on downscaling are conducted in Europe, even though there are documents which explore other parts such as North America, Australia, New Zealand, Africa and Southeast Asia. These ESD surveies chiefly focused on meteoric elements such as precipitation and temperature while surveies on air current governments have attracted less involvement from the clime scientific discipline community. However, wind velocity tendencies are highly of import and have impacts on many facets of society. An illustration would be alterations near-surface wind speed tendency in Singapore would impact coastal eroding and substructure design (Pryor, Schoof, & A ; Barthelmie, 2005) . Therefore, this paper will be researching and discoursing statistical downscaling of air current governments. In add-on, the footings " statistical downscaling " and " empirical downscaling " will be considered synonymous and can be used interchangeably for the remainder of the paper.

Downscaling, in general, is defined as a technique of happening the relationship between the variables stand foring a big infinite (known as the " big graduated table ") and the variable stand foring a much smaller infinite (known as the " little graduated table ") (Benestad, Hanssen-Bauer, & A ;

Deliang, 2008) . The large-scale variable has a alone belongings whereby it varies easy and swimmingly in infinite. Another characteristic which is really critical is that the nexus between the large-scale and small-scale is near, existent and physical, holding a strong relationship. The nexus should non be simply attributed to a statistical fluctuation or by opportunity. In add-on, it is assumed that the relationship that is based on historical informations observed would keep for the hereafter.

Alternatively, ESD can be perceived merely as a sophisticated statistical analysis of theoretical account end products. In the theoretical account, there would be two constituents present. The first constituent would be the small-scale variable which represents measuring at local conditions Stationss or known as the predictand. The 2nd constituent would be the large-scale variable that represents the circulation form over a big part or known as the forecasters. For case, the hourly local air current velocity observed at Changi can be considered the predictand. In Figure 1, the fluctuation of the air current velocity in Changi for the month of December 2000 is shown in the clip series secret plan. Meanwhile, end products such as average sea degree force per unit area or temperature from a planetary general circulation theoretical account (GCM) such as NCEP are illustrations of the forecasters in the theoretical account. The clip series secret plan in Figure 2 shows the day-to-day end product of the forecaster nceptempas, which describes the temperature constituent of a specific grid, from the NCEP theoretical account.

Global clime theoretical accounts (GCMs) are mathematical theoretical accounts that are driven by computing machine simulations. Mathematical constructs such as differential equations are used in the GCMs. To use these spherical-shaped planetary clime theoretical accounts, three dimensional grids are used to split the domain which represents the Earth surface. Subsequently, by detecting historical informations and analyzing the assorted atmospheric and pelagic interactions, systems of differential equations based on cardinal natural philosophies, chemical science and fluid kineticss are formulated to explicate these interactions in the grids. Consequently, the theoretical account is able to do possible projections of the clime as a whole, based on how factors which affect the clime alterations in the hereafter. In add-on, the projections of single grids can be obtained every bit good.

However, the GCMs 3-dimensional grids normally have coarse spacial declaration and hence non capable of supplying a realistic description of the local clime in general. For case, the GCMs are unable to explicate important differences in air current velocity differences within different parts of Singapore as they are able to explicate differences that are over a few 100 kilometres in distance apart.

However, ESD has a figure of benefits which are attractive. One benefit of utilizing ESD would be the method used for calculation is comparatively fast and " inexpensive " without the demand of advanced equipment and engineering. This allows users to execute statistical downscaling utilizing basic computer science tools. Another utile belongings of empirical downscaling would be the ability of utilize a statistical theoretical account to different GCMs and place with the uncertainnesss or mistakes that are related to these GCMs. Statistical downscaling is besides known to be various. The terminal users are able to optimise the statistical theoretical account harmonizing to their penchants and orient them for specific utilizations. An illustration would be obtaining the projection of certain parametric quantities at a specific location of involvement.

On the other manus, ESD has a figure of defects. First, the parts and elements of downscaling are subjected to the handiness of past informations (Benestad, Hanssen-Bauer, & A ; Deliang, 2008) . Without holding any historical informations, executing empirical downscaling would be impossible. In add-on, the relationship of the historical information, dwelling of both forecasters and predictand, would ensue in the development of a transportation map. Consequently, this map would be able to bring forth the local projections of involvement. Therefore, this highlights the dependance of ESD on the handiness and truth of the historical informations used. Another failing of ESD would be the debut of excess uncertainness to the theoretical account. However, ESD is believed to be able to explicate and give a better description of the local statistics observed (Benestad, Hanssen-Bauer, & A ; Deliang, 2008) .

1. 2. Aims

In this survey, one of the primary aims would be to research new techniques or generalise existing attacks for the empirical downscaling of air current velocities. As mentioned antecedently, ESD of air current has been comparatively narrow and limited unlike other climatology elements precipitation and temperature. Thus the survey aims to research the possibilities of new attacks. In add-on, there is besides possible in bettering on the bing techniques available presently.

By using statistical downscaling technique to the informations collected from the four conditions Stationss in Singapore allows the survey to detect the local air current velocity tendencies. Another intent of the survey would be to find the alterations in air current velocity denseness projected in the hereafter, from 2060 to 2099, through the application of statistical downscaling tools. Additionally, the survey would compare the projections derived from statistically downscaled air current velocity denseness for the Canadian Centre for Climate Modeling and Analysis (CCCma) Coupled planetary theoretical account, version 3 and the Hadley Centre Coupled theoretical account, version 3, besides known as the CGCM3 and HadCM3 in short, severally.

1. 3. Datas description

The informations used in this survey is provided by the TMSI. The information has a sum of three constituents, including the local air current velocity observations, the National Centers for Environmental Prediction (NCEP) forecasters and the Global General Circulation Model Predictors.

The local air current velocity observations, which would be the “ small-scale ” variable in the survey, were measured hourly (in meters per second) for the period 1983 to 2000. The measurings were taken from four meteoric Stationss located in different parts of Singapore as shown in the Figure 3. The Changi and Seletar Meteorological Station are situated in the eastern and northern parts of the island severally. The staying two Stationss, Jurong and Tengah, are found in the western portion of Singapore.

The 2nd constituent of the dataset is the NCEP forecasters. These forecasters are considered the perfect measured informations with a 2. 5 ten 2. 5A° spacial declaration, where 1 A° E? 108 kilometer. The NCEP informations were measured daily, with 365 and 366 observations for non-leap old ages and leap old ages, severally. The NCEP forecasters were interpolated individually to match to the grid of the two Global General Circulation Models – CGCM3 and HadCM3 as they the two theoretical accounts use different grids. Therefore, the interpolated NCEP forecasters for the two GCMs differ and would dwell of different NCEP forecasters. The figure of NCEP forecasters interpolated to the CGMC3 and HadCM3 grids is seven and eight correspondingly. The forecasters are as shown in Table 1:

As for the Global General Circulation Model Predictors, they are obtained from a grid with a coarser spacial declaration when compared with the NCEP information. There are 2 types provided in the survey – the Canadian Centre for Climate Modeling and Analysis (CCCma) Coupled Global theoretical account, version 3 (CGCM3) and the Hadley Centre Coupled theoretical account, version 3 (HADCM3) . For the CGCM3 theoretical account, the figure of observations per twelvemonth is 365 while the HadCM3 theoretical account has 360 observations in a twelvemonth. Both theoretical accounts contain informations for 2 possible emanation scenarios, A1B and A2 for the CGCM3 theoretical account, and A2a and B2a for the HadCM3 theoretical account. Similar to the NCEP forecasters, the figure of variables for the CGCM3 theoretical account and the HADcm3 theoretical account is seven and eight severally. The forecasters are found in Table 2:

1. 4. Literature Reappraisal

As mentioned antecedently, statistical downscaling of air current is an country which has attracted less attending compared to temperature and precipitation. Nevertheless, limited involvements in it do be and new methods have been developed while bing methods have been improved upon. An illustration of a fresh attack is being developed by Pryor et Al. (2005) is described in the paper “ Empirical Downscaling of Wind Speed Probability Distributions ” . In this method, air current velocities are assumed to hold a peculiar distribution and the parametric quantities depicting the distribution is estimated and downscaled statistically. Another case of a new method is the method proposed by Bernadin et Al. in the paper “ Stochastic downscaling method: application to weave polish ” . The attack here involves the usage of a local stochastic theoretical account and purpose to better the anticipations at a local degree with the proviso of big scale anticipations (Bernardin, Bossy, Chauvin, Drobinski, Rousseau, & A ; Salameh, 2008) . On the other manus, extensions to bing empirical downscaling methods of air current are besides being developed. The paper “ Probabilistic downscaling attacks ; Application to weave cumulative distribution maps ” describes an extension to the Quantile-matching method by Panovsky et Al. (1958) . The method proposed by Michelangeli et Al. (2009) is developed to bring forth local cumulative distribution maps (CDFs) of surface clime variables from big scale-fields and is based on obtaining local-scale CDFs through a transmutation applied to large-scale CDFs (Michelangeli, Vrac, & A ; Loukos, 2009) .

Having briefly presenting a figure of possible techniques, one of the above-named methods is chosen and applied to the context of our survey. The method chosen is the attack developed by Pryor et Al. (2005) . One ground for following the method is the attractive proposition of the method as compared to the remainder. This method merely requires working with the parametric quantities of the air current velocity distribution instead than the air current speeds themselves. Hence, the method is less computationally intensive as compared to working with the air current velocity observations straight. On the other manus, the method of Pryor et Al. (2005) is non perfect and has failings which can be addressed. Some of the failings of the method would be identified and assessed at the terminal of the undermentioned subdivision after the Pryor et Al. method has been discussed.

1. 5. Description of the method by Pryor et Al. (2005)

In this subdivision the Pryor et Al. method is being described in the original signifier. Let yijk denote the kth wind velocity observation for station I, i= 1, … , S, month J, j= 1, … , 12, where k= 1, … , nij. We write yij. for the set of all observations for station I and month J,

yij.= yijk: k= 1, … , nij.

In this method, it is assumed that the yijk are independent, with

yijk~weibullkij, Aij

where the notation U ~ Weibull (K, A) for K & gt ; 0 and A & gt ; 0 agencies that the random variable U has the Weibull denseness map pU= Ka (UA) k-1exp? [– (UA) k-1] , ? U= 0, A & gt ; 0, K & gt ; 0

Pryor et Al. (2005) foremost estimate the parametric quantities kij and Aij from the informations yij. for the false Weibull densenesss of air current velocity for all station Is and month J. The parametric quantities could be estimated in a figure of different ways, but Pryor et Al. (2005) recommended a method based on fiting the mean and average observed air current velocity. In peculiar, if yij. is the mean of the yij. and yij. denotes the median of the yij. , so fiting the sample mean and average air current velocity involves work outing

Mean wind velocity yij.= AijG1+1kij

Median air current velocity yij.= Aijln (2) 1/kij

for Aij and kij. Pryor et Al. (2005) suggest this attack instead than a more conventional attack such as maximal likeliness because they suggest it will be more robust to the low declaration of air current velocity measurings, which are frequently measured to merely one denary topographic point.

Once the parametric quantities are estimated, we have estimations kij and Aij of kij and Aij, i= 1, … , S and j= 1, … , 12. The following measure is to associate these estimated parametric quantities to historical GCM informations utilizing a arrested development theoretical account. Following this, the fitted arrested development theoretical account can so be used to calculate air current velocity distribution parametric quantities for the hereafter based on projected GCM forecasters. In peculiar, Pryor et Al. (2005) see the theoretical account

Aij= ? 0+ l= 1L? lxijl+ & A ; epsi ; ij

kij= a0+ l= 1Lalxijl+? ij

where the mistake footings? ij~N0, s? 2 and? ij~N0, s? 2 are independent for different Stationss and old ages and are independent of each other. The forecasters xijl are mean values of GCM Fieldss interpolated to post locations averaging over all observations in month J for the historical information, and where l= 1, … , L indexes the different theoretical account Fieldss (for illustration, one field might stand for sea degree force per unit area, another might stand for temperature, and so on) . After suiting the above arrested development theoretical account, we obtain estimations apand ? p of ap and ? p for p= 0, … , L.

For projecting future clime, we so foremost obtain averaged GCM projected end product for a given emanations scenario and station, once more averaging over months for all yearss in the projection period. Write zijl for the theoretical account forecaster for station I, month J and field cubic decimeter, l= 1, … , L. Then specify kij* and Aij* through the fitted arrested development theoretical account as

Aij*= ? 0+ l= 1L? lxijl

kij*= a0+ l= 1Lalxijl

Then our projected air current velocity distribution for the given emanations scenario, station Is, month J is Weibull (kij* , Aij*) .

We now describe some of the failings of this attack. Some but non all of these failings will be addressed in the ulterior chapters of the thesis. First, clearly some strong premises are being made. Most crucially, a additive arrested development theoretical account is assumed for the kij and Aij and besides the mistakes in this additive arrested development are considered independent. A 2nd important premise in the method of Pryor et Al. (2005) (and common to all statistical downscaling methods) is that the relationship between the GCM forecasters and the little graduated table observations is stable over clip. This means that forecaster pick in a statistical downscaling method like this one involves some physical cognition. Third, the method assumes that the Weibull Distribution would be able to depict the air current velocity chance distributions at each station I, i= 1, … , S adequately. Furthermore, the estimated parametric quantities, as shown antecedently, were non transformed to a log graduated table before suiting the arrested development theoretical account and this could ensue in negative anticipations of these parametric quantities in the projection phase.

Chapter 2:

Reformulation of and, extension attack to the method by Pryor et Al. (2005)

2. 1 Reformulation of method by Pryor et Al. (2005)

In this subdivision the Pryor et Al. method is being reformulated and presented. The modified method is so applied to the information of our survey. Let yijk denote the kth wind velocity observation for station I, i= 1, … , S, month J, j= 1, … , 12, where k= 1, … , nij. We write yij. for the set of all observations for station I and month J,

yij.= yijk: k= 1, … , nij.

Similar to the Pryor et Al. (2005) method, it is assumed that the yijk are independent, with

yijk~weibullkij, Aij

where the notation U ~ Weibull (K, A) for K & gt ; 0 and A & gt ; 0 agencies that the random variable U has the Weibull denseness map

pU= Ka (UA) k-1exp [– (UA) k-1] , ? U= 0, A & gt ; 0, K & gt ; 0

Then, the parametric quantities kij and Aij from the informations yij. for the false Weibull denseness of air current velocity for all station Is and month Js are estimated. The parametric quantities are estimated utilizing the manner which Pryor et Al. (2005) recommend which is based on fiting the mean and average observed air current velocity. In peculiar, if yij. denotes the mean of the yij. and yij. denotes the median of the yij. , so fiting the sample mean and average air current velocity involves work outing

Mean wind velocity yij.= AijG1+1kij

Median air current velocity yij.= Aijln (2) 1/kij

for Aij and kij.

Once the parametric quantities are estimated, we have estimations kij and Aij of kij and Aij, i= 1, … , S and j= 1, … , 12. The following measure is to associate these estimated parametric quantities to historical GCM informations utilizing a multiple additive arrested development theoretical account. Following this, the fitted arrested development theoretical account can so be used to calculate air current velocity distribution parametric quantities for the hereafter based on projected GCM forecasters. In peculiar, the estimated parametric quantities are transformed into a logarithm graduated table and hence, see the theoretical account

logAij= ? 0+ l= 1L? lxijl+i= 1S-1? iyij+ & A ; epsi ; ij

logkij= a0+ l= 1Lalxijl+i= 1S-1? iyij+? ij

where the mistake footings? ij~N0, s? 2 and? ij~N0, s? 2 are independent for different Stationss and old ages and are independent of each other. The forecasters xijl are mean values of GCM Fieldss interpolated to post locations averaging over all observations in month J for the historical information, and where l= 1, … , L indexes the different theoretical account Fieldss. The forecasters yij are dummy variables used to distinguish the assorted Stationss, and where yij= 1 for the appraisal of parametric quantity at station I, i= 1, … , S-1 and 0 otherwise. After suiting the above arrested development theoretical account we obtain estimations ap, ? p, dq and? Q, of ap, ? p, dq and? Q for p= 0, … , L and q= 0, … , S-1.

For projecting future clime, we so foremost obtain averaged GCM projected end product for a given emanations scenario and station, once more averaging over months for all yearss in the projection period. Write zijl for the theoretical account forecaster for station I, month J and field cubic decimeter, l= 1, … , L. Then specify kij* and Aij* through the fitted arrested development theoretical account as

logAij*= ? 0+ l= 1L? lxijl+i= 1S-1? iyij

logkij*= a0+ l= 1Lalxijl+i= 1S-1? iyij

Then our projected air current velocity distribution for the given emanations scenario, station Is, month J is Weibull (kij* , Aij*) .

In the reformulation of the method, the estimated parametric quantities are transformed to a log graduated table before suiting the arrested development theoretical account, which prevents the possibility of obtaining negative anticipations of these parametric quantities in the projection phase. A 2nd alteration made to the method of Pryor et Al. (2005) is the inclusion of the dummy variables. The intent is to let these excess variables to explicate the station effects since the theoretical account Fieldss do non change spatially.

2. 2 Extension attack to the method by Pryor et Al. (2005)

The following method which is traveling to be discussed is an extension the method of Pryor et Al. (2005) . In this extension attack, a more flexible attack is being discussed as this attack does non necessitate the rigorous premise of holding observations from any Stationss at any month to follow a Weibull distribution.

Let yijk denote the kth wind velocity observation for station I, i= 1, … , S, month J, j= 1, … , 12, where k= 1, … , nij. We write yij. for the set of all observations for station I and month J,

yij.= yijk: k= 1, … , nij.

The air current velocity observations yijk are transformed to the logarithm graduated table and denoted by zijk where

zij.= log (yij.) .

In add-on, zij and sij denote the average log wind velocity and standard divergence of log wind velocity severally where

zij= k= 1nijzijk/nij

sij= 1nij-1k= 1nij (zijk-zij) 2

at station I, i= 1, … , S and month J, j= 1, … , 12.

Then, denote omega ij. * to be derived from the transmutation of zij. where

omega ij. *= zij. -zij sij

for station I, i= 1, … , S and month J, j= 1, … , 12. By executing this transmutation, omega ij. * for station I, i= 1, … , S and month J, j= 1, … , 12 will as a consequence belong to a common distribution. Following, allow y ij. * be the exponential of omega ij.* . Therefore,

Y ij. *= exp (zij. *) omega ij.*= expzij. 1sij. exp-zij1sij

where it is assumed that the yij. are independent, with y ij. *~weibullk, A for k & gt ; 0 and A & gt ; 0. By replacing zij.= log (yij.) and rearranging the above look, we would obtain yij.= expzij. y ij. *sij.

In other words, this would intend that Y ij. * could be transformed to yij. by a transmutation in the signifier of Z= c (U) P, where degree Celsius and P are invariables. Furthermore, y ij. *~weibullk, A for k & gt ; 0 and A & gt ; 0. Thus this indicates that yij. is besides a 2-parameter Weibull distribution with

yij.~weibullfij, ? ij

where fij & gt ; 0 and? ij & gt ; 0 for station I, i= 1, … , S and month J, j= 1, … , 12.

Theorem 1:

By a transmutation in the signifier of Z= c (U) P, where degree Celsius and P are invariables, it can be shown that if U is a 2-parameter Weibull distribution, so Z is a 2-parameter Weibull distribution.

Proof:

Let U be a 2-parameter Weibull distribution where

U~weibullk, A, ? U= 0, A & gt ; 0, K & gt ; 0

and the Weibull denseness map of U is

pU= Ka (UA) k-1exp [– (UA) k-1] , ? U= 0, A & gt ; 0, K & gt ; 0

and the cumulative distribution map (CDF) of U is

P (U) = 1-exp (– (UA) K)

Let Z= c (U) P, where degree Celsius and P are invariables.

Rearranging the look, we get

U= (Zc) 1p

In order to obtain the denseness map of Z, first allow PZ be the CDF of Z. Hence, for z= 0

PZ= z= P (copper) p= z= P (U= (Zc) 1p) = 1-exp (– (1A) K (Zc) kitchen police) = 1-exp (– (Zc) kitchen police (1A) K)

Then we obtain the denseness map of Z by taking the derived function of PZ= z, and we get

ddzPZ= z= kp1Ak1ckp1AkZkp1Ak-1exp-Zckp1Ak

= kp1Ak1cZckp1Ak-1exp-Zckp1Ak

= qcZcq-1exp-Zcq, where q= kp1Ak

Therefore, Z is a 2-parameter Weibull distribution where

Z~weibullq, degree Celsius, Z= 0, Q & gt ; 0, degree Celsius & gt ; 0

Consequently,

yij.~weibull (ksij. 1Ak, expzij) ,

where fij= ksij. 1Ak and? ij= expzij are the form and graduated table parametric quantities of yij. severally. The significance of the transmutation is that yij. for station I, i= 1, … , S and month J, j= 1, … , 12 would follow a Weibull distribution with parametric quantities fij and? ij that are related to the average zij and standard divergence sij while K and A are parametric quantities which are obtained from the common distribution Y ij.* . Hence, the Weibull distribution parametric quantities of the assorted yij. ‘ s varies due to the parametric quantities, average zij and standard divergence sij. This implies that the premise of a Weibull distribution for all yij. for station I, i= 1, … , S and month J, j= 1, … , 12 can be relaxed. Alternatively of gauging the Weibull parametric quantities fij and? ij, it is sufficient to gauge the average zij and standard divergence sij for station I, i= 1, … , S and month J, j= 1, … , 12.

Once the parametric quantities are estimated, we have estimations zij and sij of zij and sij, i= 1, … , S and j= 1, … , 12. The following measure is to associate these estimated parametric quantities to historical GCM informations utilizing a multiple additive arrested development theoretical account. Following this, the fitted arrested development theoretical account can so be used to calculate air current velocity distribution parametric quantities for the hereafter based on projected GCM forecasters. In peculiar, the estimated parametric quantities are transformed into a logarithm graduated table and hence, see the theoretical account

zij= ? 0+ l= 1L? lxijl+i= 1S-1? iyij+ & A ; epsi ; ij

logsij= a0+ l= 1Lalxijl+i= 1S-1? iyij+? ij

where the mistake footings? ij~N0, s? 2 and? ij~N0, s? 2 are independent for different Stationss and old ages and are independent of each other. The forecasters xijl are mean values of GCM Fieldss interpolated to post locations averaging over all observations in month J for the historical information, and where l= 1, … , L indexes the different theoretical account Fieldss. The forecasters yij are dummy variables used to distinguish the assorted Stationss, and where yij= 1 for the appraisal of parametric quantity at station I, i= 1, … , S-1 and 0 otherwise. After suiting the above arrested development theoretical account we obtain estimations ap, ? p, dq and? Q, of ap, ? p, dq and? Q for p= 0, … , L and q= 0, … , S-1.

For projecting future clime, we so foremost obtain averaged GCM projected end product for a given emanations scenario and station, once more averaging over months for all yearss in the projection period. Write zijl for the theoretical account forecaster for station I, month J and field cubic decimeter, l= 1, … , L. Then specify zij* and sij* through the fitted arrested development theoretical account as

zij*= ? 0+ l= 1L? lxijl+i= 1S-1? iyij

logsij*= a0+ l= 1Lalxijl+i= 1S-1? iyij

Then, recall that

yij.= expzij. y ij. *sij

and

Y ij. *= (yij. expzij) 1sij

Hence,

Dy ij. *dyij.= 1sijexpzij yij. expzij 1sij-1

Following Lashkar-e-Taiba Y ij. *~fY ij. * (y ij. *) and suit a meat denseness is fitted to all the Y ij. * from station I, i= 1, … , S, month J, j= 1, … , 12. Hence, the denseness of yij. , is

fYij. yij.= fY ij. * (y ij. *) 1sijexpzij yij. expzij 1sij-1

and the projected air current velocity distribution for the given emanations scenario, station Is, month J can be obtained by replacing the average zij* and standard divergence sij in fYij. yij. with the estimated mean zij and estimated standard divergence sij

Chapter 3:

Finite Mixture Modeling Approach

3. 1. Introduction

The finite mixture attack is an original method of empirical downscaling of air current velocity chance distributions. This method basically follows the same line of concluding as the paper by Pryor et Al. However, this method would try to bring forth a more flexible parametric signifier than the method of Pryor et Al. (2005) .

Finite mixtures of distributions have created a mathematical-based technique for statistical mold of an extended scope of random phenomena and have been successfully applied to Fieldss such as uranology, biological science, medical specialty and many other countries. The popularity of this attack could be attributed to its highly flexibleness in patterning. Besides being flexibleness, mixture theoretical accounts besides provide a convenient semi-parametric model in which to pattern unknown distributional forms for denseness appraisal (Geoffrey McLachlan, 2000) . Another characteristic of the mixture theoretical account would be its ability to pattern even complicated distributions through the suited choice of constituents to stand for the local parts of support of the true distribution accurately. Hence, mixture theoretical accounts are able to cover with fortunes where a individual parametric household is unable to show an equal theoretical account to explicate local differences in the ascertained measurings.

3. 2 Normal Mixtures

Let yhjk denote the kth wind velocity observation for station H, h= 1, … , S, month J, j= 1, … , 12, where k= 1, … , nhj. We write Lolos for the set of all observations for station H and month J,

yi= yhjk: h= 1, … , S ; j= 1, … , 12 ; k= 1, … , nhj.

for i= 1, … , n where n= h= 1Sj= 112nhj

Besides, allow Yi denote a random sample for i= 1, … , n and the denseness of Yi be

fyi= j= 1gpjfjyi

where fjyi are component densenesss. pj are the mixing proportions for j= 1, … , g where 0= pj= 1 and j= 1gpj= 1.

In a mixture theoretical account incorporating p normal constituents the denseness of Yi is given by

fyi= j= 1p? j? (Lolo ; Aµj, sj2) ,

where Aµj and sj2 are the mean and discrepancy, pj is the proportion of the jth constituent for j= 1, … , g.

3. 3. EM algorithm

In the last 30 old ages, there has been important advancement in the adjustment of finite mixture theoretical accounts, particularly through the maximal likeliness (ML) method. However, there had been unwillingness to utilize ML suiting due to miss of apprehension of concerns that arise with the adjustment. These concerns include the being of multiple upper limit in the mixture likeliness map and the " unboundedness " of the mixture likeliness map in the instance of normal constituents with unequal covariance matrices (Geoffrey McLachlan, 2000) . Subsequently, with the publication of the paper " Maximal likeliness from uncomplete informations via the EM algorithm " in 1977 by Dempster et al. , the trouble of suiting mixture theoretical accounts by ML is made simpler when the EM algorithm would see the ML appraisal from informations as being uncomplete (Geoffrey McLachlan, 2000) .

Now the application of the EM algorithm to obtain the commixture distribution will be described. The EM algorithm is an iterative process which consists of two stairss, the outlook measure (E-step) and the maximization measure (M-step) . First we write the denseness of Yi as

fyi ; ?= j= 1gpjfjyi ; ? j

where ?=? 1, ? 2, … , pg-1, ? 1, ? 2, … , ? g is the vector incorporating all the unknown parametric quantities while ? j? T are known to be distinguishable for j= 1, … , g. We besides write the log likeliness map for ? and is given by

logL?= i= 1nlogfyi ; ?= i= 1nlogj= 1gpjfjyi ; ? j.

Before initialising the EM algorithm, we need to explicate it such that the observed informations are considered uncomplete. Let y1, y2, … , yn ~ f be the ascertained sample where the observations yi are independent and the observed-data vector is denoted as

y= y1T, y2T, … , ynTT.

Y is considered uncomplete due to the losing associated dummy constituent vector z1, z2, … , zinc with

z= z1T, z2T, … , znTT.

In this construction, each Lolo, where i= 1, … , n is assumed to belong to one of the constituents of the mixture theoretical account being fitted. Meanwhile, each zi is a g-dimensional vector where each zij= 1 or 0 based on whether Lolo belong to the jth constituent of the mixture. Hence, the complete-data vector yc, which consist of yT and zT, is given by

yc= yT, zTT.

The constituents z1, z2, … , zn are losing and considered the accomplished values of the corresponding random vectors Z1, Z2, … , Zn. Z1, Z2, … , Zn are assumed that to be independently and identically distributed based on a multinormal distribution and is given by

Z1, Z2, … , Zn~ i. i. dMultg1, P.

This premise indicates that the distribution for the complete-data vector yc would propose a suited distribution for the incomplete-data vector Y. Now we can specify the complete-data log likeliness for ? and it is denoted as

logLc?= j= 1gi= 1nzij (logpj+logfjyi ; ? j) .

The preparation has now completed and we can continue to the EM algorithm, get downing with the description of the E-step. The E-step is basically taking the conditional outlook of logLc? given the uncomplete informations Y. At the beginning of the E-step, ? (0) is defined as the initial value of ? before executing the first loop. Hence in the first loop, the conditional outlook of logLc? given Y is given by

Q? ; ? 0= E? 0logLc?| y,

and in the (k+1) Thursday loop, the conditional outlook of logLc? given Y is given by

Q? ; ? k= E? ? logLc?| y,

where ? k is the value of ? following the (K) Thursday loop. We so allow qij be the bing conditional outlook of Zij given Y in the (k+1) Thursday loop of the E-step would be

E? k Zijy= Pr? k Zij= 1y= pjkfjyi ; ? j (K) h= 1gpjkfhyi ; ? h (K)

for i= 1, … , n and j= 1, … , g. E? k Zij| y is besides known as the posterior chance of the ith observation of Y and found in the jth constituent of the mixture theoretical account. And,

Q? ; ? k= j= 1gi= 1nqij { log? j+logfjyi ; ? j (K) }

where qij=? jkfjyi ; ? j (K) /j= 1g? jkfjyi ; ? j (K) .

Now, we proceed to depict the M-step which in general, is the planetary maximization of Q? ; ? k with regard to ? in the (k+1) Thursday loop, and giving the estimation of ? k+1.

Therefore, maximise j= 1gi= 1nqijlog? j where there is a restraint j= 1g? j= 1. Using the Lagrange multiplier, allow L? j, ?= j= 1gi= 1nqijlog? j +? (i= 1g? j-1) where ? is a changeless.

dLd? l= i= 1nqij? l+? (1)

dLd?= j= 1g? j-1 (2)

From (1) , when dLd? l= 0, so

i= 1nqij? l=-?

Rearranging,

? l= i= 1nqij-? (3)

Since l= 1g? l= 1, so

l= 1g? l= l= 1gi= 1nqij-?= 1

Rearranging the above equation, we get

-?= l= 1gi= 1nqij (4)

Then by replacing (4) into (3) , the proportion of constituent cubic decimeter is given by

? l= i= 1nqijl= 1gi= 1nqij= i= 1nqijn

and at the terminal of the (k+1) Thursday loop of the m-step, the estimated proportion of constituent J is given by

? j (k+1) = i= 1nqijn.

Now, we would wish to obtain the estimations of T (K) . Again, the conditional outlook of logLc? given Y is given by

Q? ; ? k= j= 1gi= 1nqij { log? j+logfjyi ; ? j (K) } .

Therefore, from the above look, we can obtain the estimations of the constituent distribution parametric quantities, ? j (K) for j= 1, … , g. We need to first distinguish the conditional outlook of logLc? given Ys with regard to T (K) giving

dQ? ; ? kdT (K) = j= 1gi= 1nqij { log? j+logfjyi ; ? j (K) } ‘ .

= j= 1gi= 1nqijdlogfjyi ; ? j (K) dT (K)

Then, the estimations of T (k+1) can be obtained by work outing the undermentioned equation

j= 1gi= 1nqijdlogfjyi ; ? j (K) dT (K) = 0

The E-step and M-step are performed repeatedly until the likeliness L? k for k= 1, … , K converges at the Kth loop. From the sequence of the likeliness values L? kk= 1K, we can see convergence to happen when the difference of the likeliness calculated from two back-to-back loops alterations by an randomly little value. Consequently, the EM algorithm process can be stopped and the estimated proportion of each constituent at the Kth loop would be given by

? j (K) = i= 1nqijn.

Similarly, the estimations of T (K) can be obtained at the Kth loop from the process described earlier. Therefore all the parametric quantities of the commixture distribution are obtained and we can continue to the undermentioned subdivision which would be a description of the downscaling attack.

3. 4 Downscaling methodological analysis

Let yhjk denote the kth wind velocity observation for station H, h= 1, … , S, month J, j= 1, … , 12, where k= 1, … , nhj. We write Lolos for the set of all observations for station H and month J,

yi= yhjk: h= 1, … , S ; j= 1, … , 12 ; k= 1, … , nhj

for i= 1, … , n where n= h= 1Sj= 112nhj.

The pooled air current velocity observations yi are so transformed to the logarithm graduated table and denoted by zi where

zi= log (Lolo) .

Then, we will execute the maximal likeliness adjustment of normal mixture theoretical accounts via the EM algorithm on the pooled information. In order to execute the maximal likeliness adjustment of normal mixture theoretical accounts via the EM algorithm, the mclust bundle in R is used. In peculiar, the fitting process utilizing mclust would be similar to the description in the old subdivision. In the normal mixture theoretical account which is considered in this survey, the figure of constituents chosen is six and the pick of the figure of constituents is arbitrary.

From the old subdivision, the conditional chance of the observation zi and found in the pth constituent of the mixture theoretical account is denoted by

qip=? pkfpyi ; ? p (K) /p= 1g? pkfpyi ; ? p (K) for i= 1, … , n, p= 1, … , g. Due to the hapless tantrum of the initial conditional chance qip by mclust (in red) to the observed informations (in black) , we would necessitate to stipulate the initial conditional chance qip manually. Hence the value of initial conditional chance will be given by

qip= 1 if the ith observation is found in the pth constituent

qip= 0 if the ith observation is non found in the pth constituent

for i= 1, … , n, component P, p= 1, … , g. Hence, by stipulating the initial conditional chance qip for i= 1, … , n, component P, p= 1, … , g, manually (in viridity) , a better tantrum was obtained as shown in Figure 4.

Once the commixture proportions are estimated, we have estimations pp, Aµp and sp2 of pp, Aµp and sp2, for constituent P, p= 1, … , g. Let yhjk denote the kth wind velocity observation for station H, h= 1, … , S, month J, j= 1, … , 12, where observation k= 1, … , nij. We write yij. for the set of all observations for station I and month J,

yhj.= yhjk: k= 1, … , nij,

and allow the conditional chance of yhj. found in the pth constituent of the mixture theoretical account to be denoted by

qhjp=? pkfpyhj ; ? p (K) /p= 1g? pkfpyhj ; ? p (K)

for station H, h= 1, … , S, month J, j= 1, … , 12.

The following measure of the process is to utilize the EM-algorithm and estimation ? hjp, the proportion of the pth constituent of each yhj. and it is given by

? hjp= k= 1nhjqhjpp= 16k= 1nijqhjp

for station H, h= 1, … , S, month J, j= 1, … , 12, constituent P, p= 1, … , g. Now, we have estimations ? hjp of ? hjp, for station H, h= 1, … , S, month J, j= 1, … , 12, constituent P, p= 1, … , g. (To see the R codification that was used to gauge ? hjp, please refer to Appendix A.)

Then, we transform the ratios of constituent P and constituent P, p= 1, … , g for station H, h= 1, … , S, month J, j= 1, … , 12 by a logarithm graduated table and it is denoted by

? hjp= logphjpphjg

for constituent P, p= 1, … , g-1, and phjg & gt ; 0 for station H, h= 1, … , S, month J, j= 1, … , 12. The ground for holding g-1 ratios is due to the figure of constituents in the mixture theoretical account.

The following measure is to associate these estimated parametric quantities? hjr for station h= 1, … , S, month J, j= 1, … , 12 and constituent P, p= 1, … , g-1 to the historical GCM informations utilizing a arrested development theoretical account. However, if any ? hjp= 0 for station h= 1, … , S, month J, j= 1, … , 12 and constituent P, p= 1, … , g-1, we would non include the corresponding ? hjp to the arrested development theoretical account. The ground for making so is that since the peculiar constituent P has estimated blending proportion ? hjp= 0 from the observations, the projected commixture proportion ? hjp* should follow and ? hjp*= 0. Following this, the fitted arrested development theoretical account can so be used to calculate air current velocity distribution parametric quantities for the hereafter based on projected GCM forecasters. In peculiar, in this method, we consider the theoretical accounts

& A ; et ; hjp= ? 0p+ l= 1L? lpxhjpl+h= 1S-1? hpyhjp+j= 111? jpwhjp+ & A ; epsi ; hjp

for constituent P, p= 1, … , g-1, where the mistake footings & A ; epsi ; hjp~N0, ? & A ; epsi ; 2 are independent for different Stationss and old ages and are independent of each other. The forecasters xhjpl are mean values of GCM Fieldss interpolated to post locations averaging over all observations in month J for the historical information, and where l= 1, … , L indexes the different theoretical account Fieldss. The forecasters yhjp are dummy variables used to distinguish the assorted Stationss, and where yhjp= 1 for the appraisal of parametric quantity at station H, h= 1, … , S-1 and 0 otherwise. As for the forecasters whjp, they are dummy variables used to distinguish the assorted months, and where whjp= 1 for the appraisal of parametric quantity at month J, j= 1, … , 11 and 0 otherwise. After suiting the above arrested development theoretical account we obtain estimations ? lp, ? hp and ? jp, of ? lp, ? hp and ? jp for field cubic decimeter, l= 0, … , L, station H, h= 1, … , S, and month J, j= 1, … , 12.

For projecting future clime, we so foremost obtain averaged GCM projected end product for a given emanations scenario and station, once more averaging over months for all yearss in the projection period. Write zhjl for the theoretical account forecaster for station H, month J and field cubic decimeter, l= 1, … , L. Then define ? hjr* through the fitted arrested development theoretical account as

? hjp*= ? 0p+ l= 1L? lrxhjpl+h= 1S-1? hpyhjp+j= 111? jpwhjp

for constituent P, p= 1, … , g-1 and we have the estimations ? hjp* of ? ijp. Taking the exponential of ? hjp* , we will acquire

exp (? hjp*) = ? ijp*? ijg*

Rearranging the above look, we get

? hjp*=? hjg*exp (? hjp*)

Since r= 16? hjp*= 1,

? hjg*exp? hj1*+exp? hj2*+ … +exp? hj, g-1*+1= 1

Rearranging the above look, we get

? hjg*= 1exp? hj1*+exp? hj2*+ … +exp? hj, g-1*+1

and for p= 1, 2, … , g-1, we get

? hjp*= exp? hjp *exp? hj1*+exp? hj2*+ … +exp? hj, g-1*+1

for station h= 1, … , S, month J, j= 1, … , 12 and constituent P, p= 1, .. , g-1. Now, we have the estimations ? hjp* of phjp for station h= 1, … , S, month J, j= 1, … , 12 and constituent P, p= 1, .. , g. Then, use these estimations of the proportion of each constituent to suit the blending distribution of the pooled informations zi= log (Lolo) where yi= yhjk: h= 1, … , S ; j= 1, … , 12 ; k= 1, … , nhj

to obtain the distribution of log? (yhj.) , where

yhj.= yhjk: k= 1, … , nhj.

for station h= 1, … , S, month J, j= 1, … , 12. Therefore, the denseness of yhj. can be obtained by executing an exponential transmutation to the denseness of log (yhj.) .

Chapter 4:

Empirical consequences and analysis of findings

4. 1 Empirical consequences

This chapter, which presents and discourse about the consequences obtained in the survey, will dwell of 3 subdivisions. The first subdivision will show the consequences based on a comparing of the three methods that are describe in Chapters 2 and 3 while the 2nd subdivision will show the consequences based on a comparing of the two GCMS, CGCM3 and HadCM3. In the last subdivision, the hereafter wind velocity denseness projections (from 2060 to 2099) will be discussed.

From Figure 5, the distribution of the air current velocity from the four meteoric Stationss is illustrated. From the secret plan, it can be noticed that there is a crisp and narrow extremum near 0 meters per second (m/s) which decreases aggressively at approximately 1m/s. The general tendency of the secret plan shows that the distribution of the air current velocity tails off as the air current velocity additions with the maximal velocity to be measured at somewhat above 15 m/s. Another characteristic of the secret plan which can be observed is a little addition in denseness between 5-7 m/s.

Now, the air current velocity chance distribution of single Stationss is being described and the secret plans of these chance distributions can be found in Appendix B. Looking at the monthly air current velocity chance distribution of Changi station, it can be seen that it has comparatively low air currents velocity as its highest air current velocity for each month is less than 10 m/s, with most of the observations falling between 0-5 m/s. For most of the months, there is a distinguishable extremum near 0 m/s and this is merely untrue for the month of July and August where two extremums are found.

As for the Jurong monthly air currents velocity chance distribution, the form of the distribution differs at different periods of the twelvemonth. From December to March, the distribution has a extremum at about 6 m/s while from April to November, the secret plans exhibits two extremums, where the other extremum occurs at near 0 m/s. Nevertheless, all the months has experience higher air current as compared to Changi, with the maximal air current velocity measured to be about 15 m/s.

The monthly air current velocity chance distribution in Seletar has two extremums. However, the comparative tallness of one extremum to the other differs and can be classified in to two groups. From December to February, the two extremums, one near 0 m/s and the other at about 6 m/s, are similar in tallness. However, in the months of March to November, the extremum near 0 m/s is much more important compared to the extremum at about 6 m/s.

In Tengah, the form of the monthly air current velocity chance distribution does non differ greatly in the different months. In all the months, the air current velocity chance distribution has a extremum near 0 m/s and a smaller extremum at about 6 m/s. One difference which can be observed would be the extremum near 0 m/s for the month of January and February. These two secret plans illustrated extremums that are lower as compared to the other months.

4. 2 Comparison of the three downscaling attacks

In this subdivision, the consequences from the three downscaling attacks will be presented and the public presentation of the methods will be assessed.

Figure 6 shows 2 lines in the secret plan where the black line represents the chance distribution of the air current velocity observations measured from all the four Stationss. As for the ruddy line, it represents the projection of the air current velocity distribution when fitted with the parametric quantities A and K, which are straight estimated from the informations utilizing the method of Pryor et Al. (2005) . From the secret plan, we can detect that the method of Pryor et Al. (2005) is unable to capture and gauge the distribution at air current velocity really good. It can be seen that the appraisal of the distribution of the air current velocity between 0-5 meters per second (m/s) is non really accurate. In peculiar, the secret plan indicates that the method of Pryor et Al. (2005) did non pull off to capture the extremum which is close to 0 m/s.

Similarly, Figure 7 shows 2 lines in the secret plan where the black line represents the chance distribution of the air current velocity observations measured from all the four Stationss. As for the green line, it shows the projection of the air current velocity distribution when fitted with the parametric quantities zij and sij, which are straight estimated from the informations utilizing the extension method. From the secret plan, we can detect that the proposed extension to the method of Pryor et Al. (2005) is unable to capture and gauge the distribution of the air current velocity, and seems to do worse than the method of Pryor et Al. (2005) . In fact, the method has non managed to gauge chance distribution of the air current velocity observations measured from all the four Stationss.

Similarly, Figure 8 illustrates 2 lines in the secret plan where the black line represents the chance distribution of the air current velocity observations measured from all the four Stationss. As for the bluish line, it shows the projection of the air current velocity distribution when fitted with the parametric quantities of the normal mixture theoretical account, which are straight estimated from the informations utilizing the attack described in Chapter 3. From the secret plan, we can detect that the proposed method of utilizing a normal mixture theoretical account is able to gauge the informations reasonably good. In fact, the appraisal of the distribution of the air current velocity fared utilizing the normal mixture theoretical account attack is the best among the three methods presented. However, the secret plan besides indicates that the appraisal can be improved further for the lower air current velocities particularly near 0 m/s.

Besides comparing the projections fitted with parametric quantities straight estimated from the informations, comparing of the methods is besides assessed by the projections fitted with estimations from the additive arrested development theoretical accounts. Based on the different scenarios, these projections stand foring the four Stationss for 12 months are illustrated in Appendix C. In the appendix, one of import point to observe would be the projections to the historical information (1983-2000) for the CGCM3 A1b and CGCM3 A2 are the same. Hence, there are a sum of three columns of the secret plans. Additionally, there are entire of secret plans in each figure, which represents the chance distribution of the observed information (black line) , and the projections fitted with parametric quantities estimated by the three methods (ruddy line represents method of Pryor et Al. (2005) , green line represents extension method and bluish line represents the normal mixture method) .

By detecting each of the secret plans, it is clear that for a big proportion of them indicate that the normal mixture method has projections that are closest to the observed information among the three methods. It is followed by the extension method of Pryor et Al. (2005) which has managed to bring forth close estimations of the ascertained informations on occasion. From the projection secret plans, they show that the method Pryor et Al. (2005) has performed the worse among the three methods.

The projections of the method Pryor et Al. (2005) are merely able to incorporate at most one extremum. Hence, the projection is unable to closely gauge the chance distribution of the air current velocity observations adequately since the chance distribution of the air current velocity observations for bulk of the months contains two extremums. The green lines, which represent the projections utilizing the extension method, showed that the jutting chance distributions were inconsistent. Some projections are found to be able to do an accurate appraisal while some were non. For case, for the projections in Jurong station from January to May did non supply an accurate appraisal of the observation informations. During June and July, the projections were more accurate and closer to the observation informations. Overall, the method is an betterment over the method Pryor et Al. (2005) . However, the projections of the extension method remain to be unable to closely gauge the chance distribution of the air current velocity observations adequately at parts with extremums.

For most of the months at each station, the air current velocity distribution can be described by the normal mixture method reasonably good. Using the mixture theoretical account, which is a combination of normal distributions, allows the projection to be fitted more closely to the chance distribution of the air current velocity observations and depict the characteristics such as the extremums of the chance distribution more adequately.

Therefore, we can reason that the normal mixture method is the most executable method when weighed against the method of Pryor et Al. (2005) and the extension attack. As such, in the subsequent subdivisions of this chapter, where the two GCMS are being compared and the future projections of air current velocity chance distribution are being described, would be based on the projections derived from the normal mixture method.

4. 3 Comparison of GCMs

In this subdivision, the two GCMs are compared to happen out which one is able to supply more accurate projections to depict the air current velocity chance distributions of the observations. To do the comparing, the projections based on estimations from the normal mixture method would be used and compared with the air current velocity chance distributions of the observations between 1983 and 2000. The secret plans used for comparing are found in Appendix D. In each panel would incorporate four lines. The black line represents the chance distribution of the air current velocity observations measured at a peculiar station for a peculiar month while the three coloured lines represent the four scenarios (CGCM3-A1B and CGCM3-A2 represented by green, HadCM3-A2a represented by bluish and HadCM3 B2a represented by Cyan) .

When sing the projections of the Changi station, it is observed that the projections based on the HadCM3 theoretical account tend to overrate the chance distribution of the air current velocity observations near 0 m/s in Changi as illustrated in all the months with the exclusion for November and December where the projection is equal. Similarly, the projections based on the HadCM3 theoretical account tend to overrate the chance distribution of the air current velocity observations near 0 m/s. Although the frequence of overestimate is less compared to projections based on the HadCM3 theoretical account, the overestimate is worse than projections based on the HadCM3 theoretical account, as shown in the months of January, October, November and December. The lone month where the antonym is true occurs in July where CGCM3 has a better projection. There are besides instances where the CGCM3 projections underestimate the chance distribution of the air current velocity observations near 0 m/s and can be seen in March and August. Subsequently, for the staying five months (February, April, May, June and September) , the two theoretical accounts gave rise to similar projections.

As for the Jurong station, the projections from both theoretical accounts are similar for the months January to June and September. For the month of July and August, both theoretical accounts had similar projections except for the projection near 0 m/s. At this part, the projections of the CGCM3 theoretical account exhibited a vale molded characteristic and as a consequence underestimated the chance distribution of the air current velocity observations near 0 m/s. As for the staying months (October to December) , the secret plans showed that the projections based on the HadCM3 theoretical account provided a closer tantrum to the informations.

Meanwhile, the projections from both theoretical accounts for the two Stationss (Seletar and Tengah) are likewise for the months January to June, September and October. For the month of July and August, the lone difference between the projections of the CGCM3 theoretical account and the HadCM3 theoretical account is the presence of a valley-shaped characteristic and as a consequence underestimated the chance of the air current velocity observations near 0 m/s in the projections of the CGCM3 theoretical account. At the same clip, for the staying months (November and December) , the secret plans showed that the projections based on the HadCM3 theoretical account provided a closer tantrum to the information. Hence, it can be regarded that the HADCM3 theoretical account is able to supply a better tantrum of the projection to the chance distribution of the air current velocity observations.

4. 4 Future projections between 2060 and 2099

Based on the normal mixture method, the hereafter projections between the period of 2060 and 2099 are fitted and can be found in Appendix E. Each figure contains five lines. The black line represents the chance distribution of the air current velocity observations between 1983 and 2000, measured at a peculiar station for a peculiar month. There are four other lines that are coloured and stand for the four scenarios (CGCM3-A1B represented by ruddy, CGCM3-A2 represented by green, HadCM3-A2a represented by bluish and HadCM3-B2a represented by Cyan) . For the remainder of this subdivision, the hereafter projections for the four Stationss are being examined and compare how the air current velocity chance distribution differs from the period between 1983 and 2000.

Looking at the hereafter projections for Changi station, it can be seen in all 12 secret plans that the scenarios CGC