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COMPARISON OF SOME LIMITS FOR STABILITY CLASSIFICATION

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ABSTRACT: Stability parameters (Monin-Obukhov length *L*, gradient Richardson number ***Ri*** and bulk Rischardson number ***Ri***), which are applicable in urban environment, were discussed for ways of calculating classification standards. Gradient observations from a 325-m meteorological tower in Beijing are used to categorize ***Rib*** based on three different standards of stability proposed by D. Golder, Irwin and Houghton. The results show that it is relatively reasonable for the region of Beijing to apply the classification standard by Irwin.

Key words: classification of atmospheric stability; limit of stability classification; Beijing

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1 INTRODUCTION

Used in a number of models for pollution dissipation as the only factor to define the state of atmospheric turbulence or describe the capability of atmospheric diffusion, atmospheric stability is one of the essential parameters in the study on the atmospheric boundary layer. Whether the stability is correctly categorized immediately affects the computations of diffusion models with plumes of various types. Much work has been done at home and abroad on the classification of stability to arrive at ten plus kinds of methods[1, 2], comparisons and analysis of them conducted[3, 4], and distribution of stability studied[5, 6]. There are, however, not many research results on classification standards, except for the coastal areas. It is noted by the authors that the standards of stability classification tend to have larger effects on the results than the parameters of stability do. For the stability parameter commonly used in theory and application — Monin-Obukhov length (*L*), gradient Richardson number (***Ri***) and bulk Rischardson number (***Ri***), there is no unified standard of classification so that it is computed and applied without specific rules. For the purpose, the gradient observations from the 325-m meteorological tower are used to compare and analyze the three common methods of classification in an attempt to locate the one that fits the condition in the Beijing region.

2 DATA ACCOUNT AND PRE-PROCESSING

The 325-m tower of the Institute of Atmospheric Physics, Chinese Academy of Sciences, measures gradient data of mean fields of wind and temperature at 15 levels of 8, 16, 32, 47, 65, 80, 103, 120, 140, 160, 180, 200, 240, 280 and 320 m. The datasets were taken from four seasons of 2000, respectively on Jan. 24 – Feb. 4, Apr. 24 – May 4, Jun. 26 – Jul. 9, and Sept. 30 – Oct. 9.

Between the third and fourth road rings of Beijing, the tower (116°22′E, 39°58′N) is in an area which is typical of inhomogeneous urban underlying surface consisting of rough elements

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and gives a group of gradient data of the mean field every 20 s. For detailed description of data collection and output system, see reference [8]. As pre-processing, all of the data have been cleared of unreliable points (whose values are larger than variances that are 5 times its hourly mean), supplemented through linear interpolation and sought for hourly mean.

3 PARAMETERS OF ATMOSPHERIC STABILITY AND METHODS OF STANDARDS CLASSIFICATION

Of the ten plus kinds of stability classification methods, those combining turbulence / thermodynamic and dynamic factors have the most definite implications of physics. Next come some of them that are applied more than the others in urban environment.

3.1 *Monin-Obukhov length (the L method)*

Following the relationship between the gradient Richardson number (*Ri*) and *L*, the Monin-Obukhov length *L* is sought from *Ri*, usually with the expression in [9]:

$$\begin{cases} L = \dfrac{Z}{Ri} & Ri < 0 \\ L = \dfrac{Z \cdot (1-5Ri)}{Ri} & Ri > 0 \end{cases} \tag{1}$$

At present, there are three main ways of calculating the stability classification for *L*.

(1) In 1972, D. Golder[10] was the first to show a graphic chart displaying corresponding relationship between the Monin-Obukhov length (*L*), level of P-T stability and ground roughness (z_0) based on large amount of field observations in addition to theoretic study. For each of the determinate z_0, the corresponding relationship can, based on the chart, be determined between *L* and the level of P-T stability. For the region of Beijing, $z_0 \approx 3.5$ m[11], and the standard of stability classification is set following the chart (Tab.1).

Tab.1 The classification standard of stability *L* following D. Golder's method

Coeff. of P-T	A	B	C	D	E	F
L	-10.64<*L*<0	-19.23<*L* <-10.64	-55.56<*L*< -19.23	*L*<-55.56 *L*>200.00	83.33<*L*< 200.00	0<*L*<83.33

(2) In 1979, Irwin[11] gave an empirical fitting equation of $1/L=az_0^b$, which demonstrated the links between z_0, level of P-T stability and *L*. The standard of stability *L* classification as well as the values of *a* and *b* in the P-T level of stability are listed in Tab.2.

Tab.2 The classification standard of stability *L* following Irwin's method

Coeff. of P-T	A	B	C	D	E	F
a	-0.0875	-0.0385	-0.0081	0.0	0.0081	0.0385
b	-0.103	-0.171	-0.305	0.0	0.305	0.171
L	-13.00<*L*<0	-32.18<*L*<-13.00	-180.91<*L*<-32.18	*L*<-180.91 *L*>84.25	20.97<*L*<84.25	0<*L*<20.97

(3) In 1985, Houghton[12] proposed an empirical fitting equation, $1/L = a \cdot [\lg_{10}(z_0) - 1]$. The standard of stability *L* classification as well as the values of *a* and *b* in the P-T level of stability are listed in Tab.3.

Tab.3 The classification standard of stability *L* following Houghton's method

Coeff. of P-T	A	B	C	D	E	F
a	0.05	0.026	0.015	0.004	-0.009	-0.023
L	-43.87<*L*<0	-84.36<*L*< -43.87	-146.23<*L*<-84.36	*L*<-548.32 *L*>243.70	95.36<*L*< 243.70	0<*L*<95.36

3.2 *Gradient Richardson number* (*Ri*)

The gradient Richardson number is usually derived with the following equation:

$$Ri = \frac{g}{\bar{T}} \bullet \left[\frac{\Delta T}{\sqrt{z_1 z_2} \bullet \ln(z_2/z_1)} + \gamma_d \right] \bullet \left[\frac{\sqrt{z_1 z_2} \bullet \ln(z_2/z_1)}{\Delta \bar{u}} \right]^2 \quad (2)$$

In the equation, $\bar{T}$ is the mean absolute temperature of air layer, *g* the gravity acceleration speed (m/s^2), γ_d the dry adiabatic temperature lapse rate, and ΔT and $\Delta \bar{u}$ are temperature difference and wind speed difference at the upper and lower air layer, respectively. The calculations represent the value of *Ri* for mean geometric height ($\bar{z} = \sqrt{z_1 z_2}$). The *x* coordinate takes the same direction as ***u***.

Ri relates with *L* in the following way[15]:

$$Ri = \frac{Z}{L} \cdot \frac{f_h}{f_m^2} \quad (3)$$

Specifically, the equation of dimensionless profile function is given as follows (Businger-Hick[3]):

$$\begin{cases} f_m = 1 + 4.7 \cdot Z/L & Z/L > 0 \\ f_h = 0.74 + 4.7 \cdot Z/L & Z/L > 0 \\ f_m = (1 - 15 \cdot Z/L)^{-1/4} & Z/L < 0 \\ f_h = 0.74 \cdot (1 - 9 \cdot Z/L)^{-1/2} & Z/L < 0 \end{cases} \quad (4)$$

$$f_m = 8 - \frac{4.25}{Z/L} + \frac{1}{(Z/L)^2} \qquad Z/L \ge 0.5 \quad (5)$$

From Eqs.(3), (4), (5) and the results of classification as presented in Tabs. 1 – 3, the standards of stability classification of *Ri* can be known (Tab.4).

3.3 *Bulk Richardson number* (*Rib*)

In working environment, *Ri* is usually replaced with *Rib* when high-accuracy wind measurements are not available.

Rib is defined as

$$Rib = \frac{g}{\bar{q}} \bullet \frac{\partial \bar{q}}{\partial z} \bullet \frac{\bar{z}^2}{\bar{u}^2} \approx \frac{g}{\bar{q}} \bullet \frac{\Delta \bar{q}}{\Delta z} \bullet \frac{(\sqrt{z_1 z_2})^2}{(\sqrt{u_1 u_2})^2} \quad (6)$$

where $\bar{z} = \sqrt{z_1 z_2}$, $\bar{u}$ is the wind speed at height $\sqrt{z_1 z_2}$, and $\partial \bar{q}/\partial z$ the rate of potential temperature change within the levels of corresponding heights[16].

Rib relates to *L* in the following way[3]:

$$BRi = (Ri) \bullet \frac{\left[\frac{\partial u}{\partial (\ln z)} \right]^2}{u^2} = \frac{Z}{L} \cdot \frac{f_h}{[\ln(z/z_0) - y]^2} \quad (7)$$

where ψ is the dimensionless function associated with j_m.

Likewise, standards of ***Rib*** as classified with Eqs.(4), (5) and (7) and Tabs.1 – 3 are given in Tab.5.

Tab.4 The classification standard of ***Ri*** stability (47 m)

Levels of stability	D. Golder	Irwin	Houghton
A	*Ri*≤-4.199	*Ri*≤-3.433	*Ri*≤-1.004
B	-4.199≤*Ri* <-2.315	-3.433≤*Ri* <-1.375	-1.004≤*Ri* <-0.514
C	-2.315≤*Ri* <-0.789	-1.375≤*Ri* <-0.233	-0.514≤*Ri* <-0.291
D	-0.789≤*Ri* <0.098	-0.233≤*Ri* <0.145	-0.291≤*Ri* <0.087
E	0.098≤*Ri* <0.147	0.145≤*Ri* <0.636	0.087≤*Ri* <0.137
F	0.147≤*Ri*	0.636≤*Ri*	0.137≤*Ri*

Tab.5 The classification standard of ***Rib*** stability (47 m)

Levels of stability	D. Golder	Irwin	Houghton
A	*Rib*≤-1.200	*Rib*≤-0.756	*Rib*≤-0.111
B	-1.200≤*Rib*<-0.361	-0.756≤*Rib*<-0.166	-0.111≤*Rib*<-0.053
C	-0.361≤*Rib*<-0.084	-0.166≤*Rib*<-0.024	-0.053≤*Rib*<-0.030
D	-0.084≤*Rib*<0.032	-0.024≤*Rib*<0.069	-0.030≤*Rib*<0.026
E	0.032≤*Rib* <0.069	0.069≤*Rib* <0.219	0.026≤*Rib* <0.062
F	0.069≤*Rib*	0.219≤*Rib*	0.062≤*Rib*

It is known from analyzing Tabs.1 – 5 that there is large difference in the standards of stability as classified with the methods of D. Golder, Irwin and Houghton and it immediately affects the division of stability levels. It will result in one calculated parameter of stability being classified to different groups just because the standards used are different. For instance, ***Rib*** is 0.065 at 47 m from calculation based on observations. Differences are quite large when it is classified according to the standards: it is in Group E by the standard of D. Golder, Group D by that of Irwin and Group F by that of Houghton.

4 RESULTS AND CONCLUSIONS

It is most appropriate to use ***Rib*** to classify the stability when high-accuracy wind measurements are not available. Stability classification is carried out hereafter using ***Rib*** to compare the standards.

4.1 *Comparisons of one stability parameter with different classification standards*

Tabs.6 and 7 show the results of ***Rib*** with the gradient data from the meteorological tower over a period of 48 days and statistics of stability classification using the three standards. The longitudinal columns of the tables are the results with the Irwin standard and the traverse columns those with the D. Golder and Houghton standards.

Tab.6 Comparing classification standards (Irwin vs D. Golder)

	D. Golder	A	B	C	D	E	F
Irwin	A	152	82	0	0	0	0
	B	0	220	338	0	0	0
	C	0	0	290	312	0	0
	D	0	0	0	656	347	0
	E	0	0	0	0	47	664
	F	0	0	0	0	0	1013

Tab.7 Same Tab.6 but for Irwin vs Houghton

	Houghton	A	B	C	D	E	F
Irwin	A	234	0	0	0	0	0
	B	558	0	0	0	0	0
	C	182	255	121	44	0	0
	D	0	0	0	580	412	11
	E	0	0	0	0	0	711
	F	0	0	0	0	0	1013

From Tab.6 and 7, it is known that results can be large with different standards of classification. The following is the general discovery. (1) The D. Golder standard yields more results that are mostly steady than the Irwin one does. For the 711 classifications of Group E with the Irwin standard, for instance, it is 47 classifications of Group D with the D. Golder standard and 664 classifications of Group E. (2) The Houghton' standard gives more results that are mostly unsteady in Groups A and B but mostly steady in Groups D, E and F. For the 234 classifications of Group A with the Irwin standard, for instance, it is 974 classifications of Group A with the Houghton standard and for the 711 classifications of Group E with the Irwin standard, all of them are classified into Group F with the Houghton standard. It clearly shows the effects of different stability standards on the results of classification.

4.2 *Comparisons and analysis of distribution of stability frequency with different classification standards*

Tabs.8 – 12 show the distribution of stability frequency over the four seasons and the whole year using different classification standards. The following is known: (1) Group F takes up the most in the four seasons and the whole year, more than 30%, followed by Groups C and D, in contrast to Groups A, B and E, which have small percentages, when the Standard of D. Golder is used. (2) Groups A, D and F take up the most in the four seasons and whole year, with Group A having a much higher percentage as compared with Groups D and F, being more than 11% in winter. Compared with the standard of D. Golder, that of Houghton gives larger percentage of Group F but smaller percentage of Group D and yet much smaller percentages of Groups B, C and E. (3) Groups D and F take up the majority, followed by Groups E and C, which are comparable, and Group A the least, when the standard of Irwin is used. In summer and autumn, the percentages of Groups A and B are higher than in any other seasons and Group C does not

Tab.8 Distribution of stability frequency with different classification standards (spring)

Standards	D. Golder		Irwin		Houghton	
frequency	times	%	times	%	times	%
A	9	0.86	13	1.24	192	18.32
B	39	3.72	122	11.64	102	9.73
C	186	17.77	235	22.42	57	5.44
D	321	30.66	265	25.29	184	17.56
E	91	8.69	192	18.32	100	9.54
F	401	38.3	221	21.09	413	39.41

Tab.9 Same as Tab.8 but for summer

standards	D. Golder		Irwin		Houghton	
frequency	times	%	times	%	Times	%
A	79	6.28	123	9.76	445	35.35
B	140	11.14	249	19.76	84	6.67
C	260	20.68	192	15.24	26	2.07
D	144	11.46	136	10.79	59	4.69
E	88	7.00	209	16.59	83	6.59
F	546	43.44	351	27.86	562	44.64

take up as large percentage in summer as in spring, but Groups A and B are in higher percentage in summer than in spring, which is reasonable. It is now seen that the distribution of different frequency of stability throughout the four seasons and the whole year, which is determined with the Irwin standard, is continuous and reasonable, with Group D in the majority and comparable rate of appearance for Groups C, E and F. In contrast, the large percentage by Group F with the standards of D. Golder and Houghton is not reasonable.

Tab.10 Distribution of stability frequency with different classification standards (autumn)

Standards frequency	D. Golder		Irwin		Houghton	
	times	%	times	%	times	%
A	50	7.27	72	10.48	205	29.88
B	81	11.77	112	16.30	35	5.10
C	90	13.08	80	11.64	16	2.33
D	98	14.24	92	13.39	54	7.87
E	41	5.96	113	16.45	43	6.27
F	328	47.67	218	31.73	333	48.54

Tab.11 Same as Tab.8 but for winter

Standards Frequency	D. Golder		Irwin		Houghton	
	times	%	times	%	Times	%
A	14	1.24	26	2.30	132	11.69
B	42	3.72	75	6.63	34	3.01
C	92	8.15	95	8.39	22	1.95
D	405	35.87	510	45.05	327	28.96
E	174	15.41	197	17.40	186	16.47
F	402	35.61	229	20.23	428	37.91

Tab.12 Distribution of stability frequency with different classification standards (the whole year)

Standards frequency	D. Golder		Irwin		Houghton	
	times	%	times	%	Times	%
A	152	2.79	234	4.30	974	17.88
B	302	5.55	558	10.25	255	4.68
C	628	11.53	602	11.05	121	2.22
D	968	17.77	1003	18.42	624	11.46
E	394	7.23	711	13.06	412	7.57
F	1677	30.79	1019	18.71	1736	31.87

4.3 *Comparisons of temporal and spatial distribution of stability*

Figs.1 – 3 show the mean atmospheric fields from Jun. 26 to Jul. 27, together with the temporal and spatial profiles of *Rib* classified respectively with the Irwin, D. Golder and Houghton standards.

With Figs.1 – 3, it is known that the results of the three standards for stability classification differ much from each other. The standards of D. Golder and Houghton yield similar results in that unstable stratification appears during noontime in layers below 40 m and between 50 and 60 m while all other layers are of stable stratification almost all of the day. With the Irwin standard, however, results are quite different, as it shows relatively unstable stratification in all layers during noontime. Following patterns of diurnal variation usually observed with the atmospheric stability, heating due to solar radiation becomes the strongest around midday to cause intense thermal convection over the surface so that stable stratification is destroyed and replaced by unstable stratification. It is then known that the results achieved with the Irwin standard agree with the distributions of diurnal variation of general atmospheric stability. In addition, the authors also analyzed the temporal and spatial profiles of stability for Jan., Apr. and Oct. and found that in spite of some differences in distribution, results obtained with the Irwin standard were generally unstable in noontime while other patterns bear much similarity with those with the D. Golder and Houghton standards.

In summary, it is suggested that the Irwin classification standard be used for the region of Beijing.

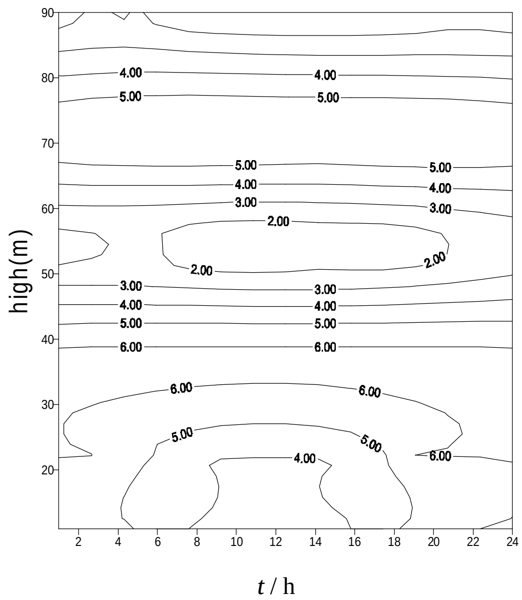

Fig.1 Temporal and spatial distribution of the stability parameter for Jun. 2000 using the classification standard of D. Golder [10]

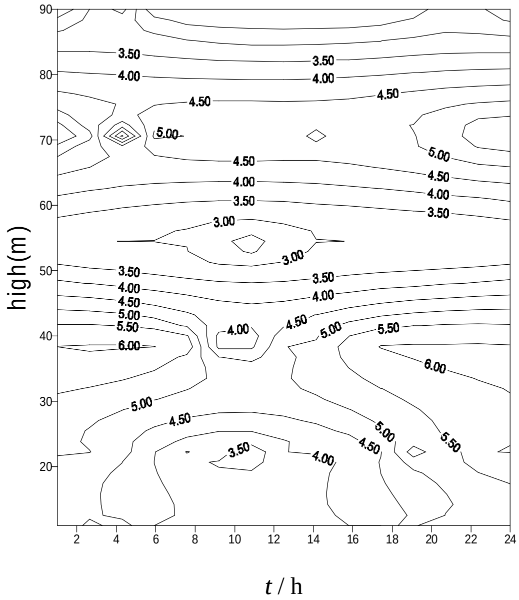

Fig.2 Same as Fig.1 but with the standard of Irwin [12].

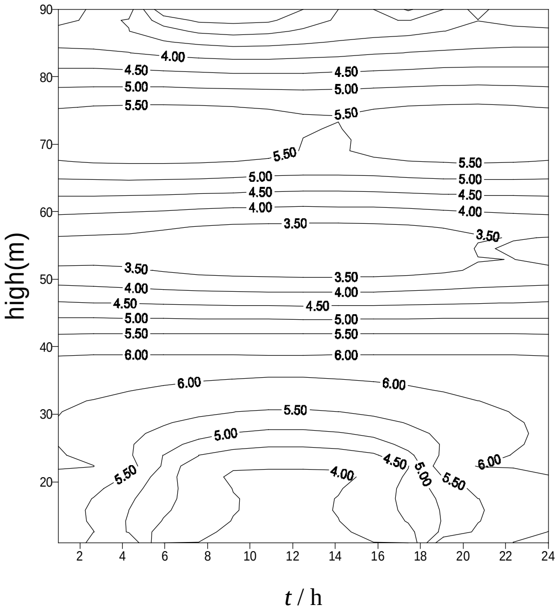

Fig.3 Same as Fig.1 but with the standard of Houghton[13].

5 CONCLUDING REMARKS

a. Results classified with different standards can vary much for the same stability parameter and dataset. With the same stability parameter and same set of observation, results can vary much if different standards are used to classify the stability.

b. Comparisons of three existing classification standards are made with observations from the 325-m tower in Beijing and the results show that it is relatively reasonable to use the Irwin standard to classify stability in the region of Beijing.

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