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REGIONALIZATION FOR LARGE AREA CROP ESTIMATES BY REMOTE SENSING
——A Case Study of Chinese Wheat

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ABSTRACT: The crop estimates by remote sensing, developing quickly in recent decades, is a up-to-date technique. Regionalization for large area crop estimates by remote sensing, a special applied regionalization, is the foundation of crop estimates in a large area by remote sensing. According to the actual demands of wheat yield estimation by remote sensing and wheat agroclimatic demarcation of China, this paper first puts forward some principles upheld in this regionalization and analyses its main bases. Secondly, it works out the classificatory schemes about the optimum temporal for estimating wheat yield by remote sensing, information sources of space remote sensing and landuse structure in China. Finally, According to the regionalization indices, this study divides the wheat plantable region of China into 14 regions of crop yield estimates and 31 subregions of crop yield estimates.
KEY WORKS: wheat yield estimates, remote sensing, crop estimates, regionalization

The crop estimates by remote sensing, developing quickly in recent decades, is a up-to-date technique. Some systems of crop estimates by remote sensing on various scales have been set up in many countries. Based on numerous regional experimental studies, a set of nationwide practical systems of the crop estimates by remote sensing will be established in China, which will standardize the crop estimates. China has a vast territory, complicated natural and social economic conditions, various crops and cropping systems, obviously different crop calendars between different regions, and obvious inter-regional differences of ground types and combinations, therefore much work in the crop estimates in China by remote sensing needs to be based on the national regionalization schemes for crop estimates by remote sensing.

At present the studies on the regionalization for crop estimates by remote sensing are quite weak, the regionalization theories are immature and regionalization schemes are inapplicable either. Wheat, one of the main crops in China, is a focal point of the crop estimates, but the nationwide regionalization for estimating wheat yield by remote sensing has not been developed so far. To satisfy the needs of national wheat yield estimates by remote sensing, the paper attempts to develop a regionalization scheme for wheat yield estimates in China by remote sensing based on theoretical analyses.

I. REGIONALIZATION PRINCIPLES AND BASES

The regionalization for wheat yield estimates by remote sensing, a fore work of wheat yield estimates by remote sensing, is a special applied regionalization. It intends to offer a spatial framework suitable to the system of the wheat yield estimates by remote sensing, and to provide the scientific bases for determination of information sources and temporals of remote sensing, and for the selection of methods for information processing, wheat discrimination, and wheat area and yield estimates. The regionalization principles and bases in this regionalization must be determined according to the actual demands of wheat yield estimates by remote sensing.

Some principles must be upheld in this regionalization, which is a complex work. Firstly, it involves a lot of elements, processes and relations, therefore it must be on the principle of combining the integrative analysis with the analysis of leading factors and the principle of combining the regionalization with classification. Secondly, it must involve all factors related to wheat yield on the one hand, much attention has to be paid to the actual demands of remote sensing of agriculture on the other hand, in other words, the principle of combining crop analysis with condition analysis of remote sensing must be upheld. Thirdly, spatial analysis is a central task in all regionalizations, but this regionalization involves many processes, so combining spatial analysis with process analysis is a cardinal principle. Fourthly, the theoretical bases of wheat yield estimates by remote sensing are the relations between the relative factors consisting of mapping relationships, such as the relations between crop growing situation and remote sensing information or spectral information of crop, and essential relations, such as the relations between wheat yield and agro-ecological conditions, that is, combining the analysis of elements with the analysis of their relations is important. Finally, because administrative departments are the main users of estimative results of wheat yield, the regionalization must be on the principle of keeping grass-roots administrative regions unbroken.

The regionalization bases include the rules of regional differentiation of the geographical and agricultural elements, processes and relations relative to wheat yield estimates by remote sensing. Firstly, remote sensing images or data reflect ground types and their combinations. In wheat yield estimates by remote sensing, wheat information must be extracted from various ground spectral information on the basis of understanding spectral properties of every ground clearly. Because the bases, methods and accuracy of information extraction vary with the ground types and combinations, the law of regional differentiation of the ground structure is an important regionalization basis. Secondly, the seasonal variations of field vegetation indices depend on succession of crop aspects which are decided by cropping system and succession of crop growing stages. Succession of wheat aspects makes the significance of wheat spectral information on the remote sensing images, varying with the remote sensing temporals, the relations between wheat yield and spectral information and environmental conditions vary with wheat growing stages. It is obvious that the law of regional differentiation of the succession of crop aspects must be taken as an important basis in the regionalization. Thirdly, wheat yield estimates by remote sensing need to establish the models of the yield per unit area, which is on the basis of relations between the yield per unit area and wheat spectral information, meteorological factors, wheat growing process and social economic input, so regional differentiation of these relations is also an important basis. Finally, wheat spectral information is, in general, disturbed by topographic features, soil properties (brightness, tone and moisture) (Huete *et al.*, 1985; Elvidge *et al.*, 1985; Bausch, 1993; Huete *et al.*, 1991), atmospheric absorption and scattering (Gilabert *et al.*, 1993; Huete *et al.*, 1994), cloud cover and solar altitude, therefore these factors must be also involved in the regionalization bases.

II. REGIONALIZATION INDICES AND METHODS

In wheat yield estimates by remote sensing, every work involves many factors which differ from some of the other works. According to the law of regional differentiation of the factors relative to the concrete work, the regionalization must determine classification indices and work out classification schemes to meet the needs of the work. The selection of the optimum temporal is one of the basic tasks in wheat yield estimates by remote sensing. The selection bases include differences of reflectance spectrums and/or phenological calendars between wheat and other crops, key periods of wheat production in total growing period, changes of solar altitude, changes of the spectral noise from soil, and possible reduction of wheat area in its total growing period. The optimum temporals for wheat yield estimates by remote sensing in China are selected and regionalized in this study. Because most of the selection bases of the optimum temporals are the factors on latitudinal zonality and the processes of some elements and relations, the distribution characteristic of the optimum temporals on latitudinal zonality is obvious.

The selection of information sources is also one of the basic tasks. The selection bases consist of the resolution of sensors (spatial resolution and time resolution) and cloud cover. According to the resolutions of meteorological satellite (MET/SAT) and land satellite (LANDSAT), this study classifies the wheat planting region of China into 4 types of the information sources for wheat yield estimates by remote sensing using the monthly days of clear sky (D_c) and overcast sky (D_o) in the optimum temporals as classification indices (Table 1), which is based on the classification map of the optimum temporals, and presents reference information sources of every type.

In wheat yield estimates by remote sensing, the main tasks are the design of sampling allocation, remote sensing identification of wheat, processing of remote sensing information and estimation of wheat area which are disturbed by the complex distribution of the ground types and combinations. The ground structures depend mainly on the landuse structures, spectral information of crops is mainly disturbed by that of forest and pasture. By collecting the area data of every landuse type of every county (not including Taiwan Province) over China in 1986 and calculating the ratio of area of every landuse type to the total land area in every county, this study classifies the landuse structures of China into 10 types using the ratios of farmland(A_f), Woodland (A_w) and pasture land(A_p) as the main indices with reference to the study on agricultural types of China (Guo, 1991): 1) the landuse structures of $A_f \geqslant 60\%$ are called farmland type (F); 2) those of $A_w \geqslant 60\%$ are called woodland type (W), with $A_f < 10\%$; 3) those of $A_p \geqslant 60\%$ are pasture land type (P), generally with $A_f < 10\%$; 4) if A_f and A_w are greater than the others and A_f is equal to 30% to 60%, those are farmland-woodland type (Fw); 5) if A_f and A_p are greater than the others and A_f is equal to 30% to 60%, those are farmland-pasture land type (Fp); 6) those with greater A_w and A_f being 10% to 30% are called woodland-farmland type (Wf); 7) if A_p is greater than the others and A_f is equal to 10% to 30%, those are pasture land-farmland type (Pf); 8) those with greater A_w and A_p and $A_w < A_p$ are called woodland-pasture land type (Wp), generally with $A_f < 20\%$; 9) if A_f is equal to 20% to 40% and close to A_p and A_w, then those are complicated type (FWP); and 10) if the ratio of desert area is not less than 60%, those are called desert type(X), generally with $A_f < 10\%$. Because the landuse structures depend on topographic and water conditions, the distribution characteristic of non-latitudinal zonality and azonality is obvious.

Table 1 The classification indices of information sources for wheat yield estimates by remote sensing

	LANDSAT type (L)	LANDSAT-MET/SAT type (LM)	MET/SAT-LANDSAT type (ML)	MET/SAT type (M)
D_c(d)	≥6	3-6	1-3	< 1
D_o(d)	< 10	10-15	15-20	≥20
Main source	LANDSAT	LANDSAT	MET/SAT	MET/SAT
Ancillary source	—	MET/SAT	LANDSAT	—

One of the main works in wheat yield estimates by remote sensing is to establish the models of the yield per unit area, of which the main bases are the relationships between the wheat yield and remote sensing information, environmental conditions and social economic input. The establishment of a nationwide system of these relationships needs a lot of remote sensing data and ground data and must be supported by experimental studies standardized from national experimental network. At present, these data and studies are lack and have not been systematized and standardized, so it is very difficult to work out the national classificatory schemes of these relationships.

China has a vast territory and complex relief, zonality and azonality of the regionalization bases are very obvious. In this study, the first level regions called regions of crop estimates are mainly conditional on the zonality laws and processes of the factors; the second level regions called subregions of crop estimates are conditional on the non-latitudinal zonality and azonality laws.

The division of the regions of crop estimates serves mainly the selection of remote sensing temporals and also meets the demands of wheat identification and establishment of the models of yield per unit area. It takes the optimum temporal of wheat yield estimates by remote sensing as a leading index and the total growing period, breed type, climatic yield and cropping system as reference indices which are determined on the basis of wheat climatic regionalization(Cui, 1987). The optimum temporal of wheat yield estimates by remote sensing is determined according to the differences of reflectance spectrums and phenological calendars between wheat and the other crops, changes of solar altitude, key periods of wheat production in total growing period, changes of the spectral noise from soil and possible reduction of the area of wheat in its total growing period, so it is a complex index.

The division of the subregions of crop estimates serves mainly the wheat identification, processing of remote sensing information, design of sampling allocation and wheat area estimation and also takes account of the selection of information sources. It takes the ratio of farmland area (A_f) and the ratio of wheat area to the total sown area of all main crops(A_{wh}) as leading indices and the monthly days of clear and overcast sky in the optimum temporals as reference indices. Based on the classification of landuse structures, the limits of A_f and A_{wh} are determined (Table 2) through analysing the distribution of national A_f in 1986 and A_{wh} in 1984–1990.

Table 2 The main dividing indices for the subregions of crop yield estimates

A_f(%)	Subregion	A_{wh}(%)	Subregion
≥60	most farmland	≥60	most wheat
30–60	more farmland	30–60	more wheat
10–30	less farmland	10–30	less wheat
< 10	few farmland	0–10	few wheat
		0	no wheat

III. REGIONALIZATION RESULTS

According to the above regionalization indices, this study divides the wheat plantable region of China into 14 regions of crop yield estimates and 31 subregions of crop yield estimates (Fig. 1) their characteristics are listed in Table 3 and Table 4 respectively.

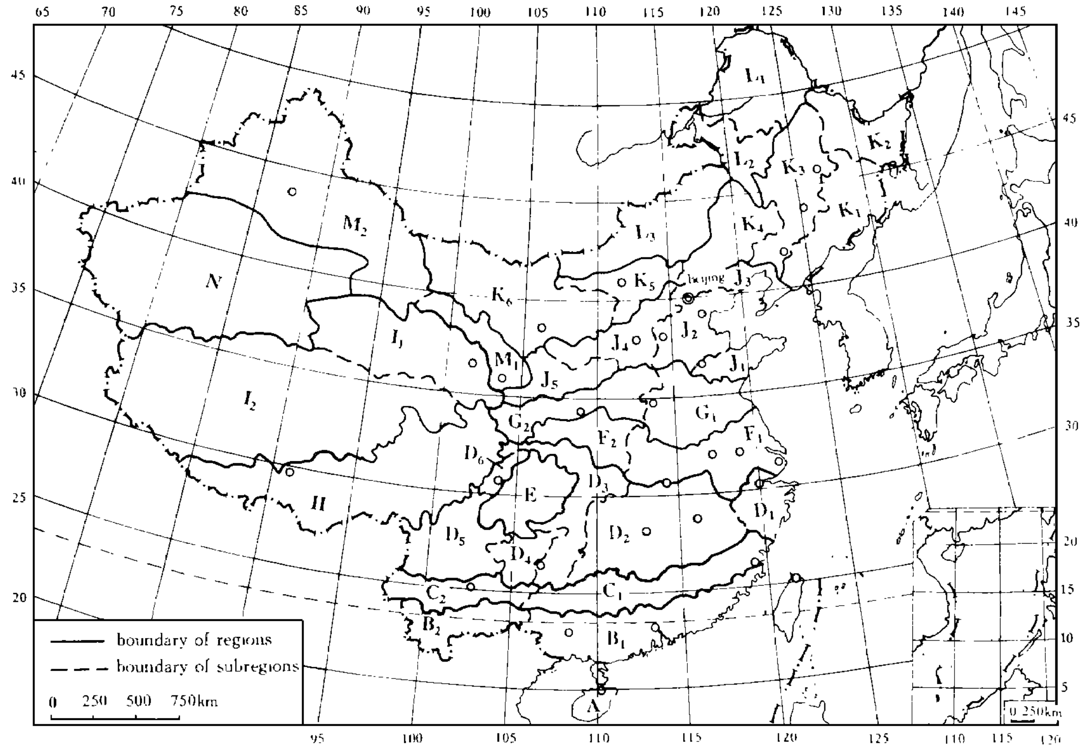

Fig. 1 The regionalization of wheat yield estimates by remote sensing in China

Table 3 The main characteristics of the regions of crop yield estimates

Region symbol	Optimum period	Cropping system	Breed type	Possible growing period (d)	Climatic yield (kg/ha)
A	Dec. – Jan.	Triple cropping	Springness	< 120	< 3750
B	Jan. – Feb.	Triple cropping	Springness	120– 150	3000– 4500
C	Feb. – Mar.	Double or triple cropping	Springness or weak winterness	150– 180	3000– 4500
D	Mar. – Apr.	Double or triple cropping	Weak winterness	180– 210	3000– 6000
E	Mar.	Double or triple cropping	Springness	170– 200	1500– 2250
F	Apr.	Double cropping	Winterness	210– 220	6000– 7500
G	Apr. – May	Double cropping	Strong winterness	220– 260	5250– 6750
H	June– July(w) July– Aug(s)	Single cropping	Spring or winter wheat	> 300(w) 140–170(s)	12000– 14250
I	June– July	Single cropping	Spring wheat	130– 160	2250– 7500
J	May	Double cropping	Strong winterness	260– 280	4500– 6000
K	June	Single cropping	Spring wheat	100– 120	4500– 6750
L	June– July	Single cropping	Spring wheat	120– 130	2250– 6000
M	June(w) June– July(s)	Single cropping	Winter or spring wheat	280– 320(w) 120– 140(s)	< 4500
N	May– June(w) June(s)	Single cropping	Winter or spring wheat	260– 300(w) 120– 130(s)	375– 1500

Note: (w) ——winter wheat, (s) ——spring wheat

Table 4 The main characteristics of the subregions of crop yield estimates

Region symbol	Subregion symbol	Landuse structure type	A_f(%)	A_{wh}(%)	Information source type
A		FWP, Fw	10—50	≈ 0	LM
B	B_1	Fw, FWP, W	10—50	≈ 0	LM
	B_2	Wp, W	10—30	< 10	L
C	C_1	W, FWP	10—30	≈ 0	ML
	C_2	W, FWP	10—30	10—30	L
D	D_1	W, Wf	5—30	10—30	ML
	D_2	Wf, Fw	< 60	< 10	ML
	D_3	FWP, Wp, W	10—30	10—30	ML
	D_4	Fw, FWP	30—60	10—30	ML
	D_5	FWP, W, Wp	10—30	10—30	L
	D_6	F, Fw	30—60	30—60	ML
E		F, Fw	⩾30	⩾20	ML
F	F_1	F, Fw	⩾30	10– 60	ML
	F_2	W, Wp	< 30	30—60	ML
G	G_1	F	⩾60	30—60	LM
	G_2	F, FWP	⩾30	⩾30	LM
H		Pf, Wp, P	< 10	< 30	ML
I	I_1	Pf, X, P	< 10	⩾60	LM
	I_2	—	—	0	—
J	J_1	Fw	30—60	30—60	L
	J_2	F	⩾60	30—60	L
	J_3	FWP, Wp	10—30	< 30	L
	J_4	FWP	30—60	< 30	L
	J_5	FWP	30—60	30—60	L
K	K_1	W	5—20	≈ 0	LM
	K_2	Fw, W	< 30	10—30	LM
	K_3	F, Fw, Fp	⩾30	< 30	LM
	K_4	FWP, P, Wp	10—30	< 10	LM
	K_5	Fp	30—60	10—30	L
	K_6	P	< 20	30—60	L
L	L_1	W, P	< 10	30—60	LM
	L_2	P	< 10	< 10	LM
	L_3	P	< 10	30—60	LM
M	M_1	Pf, Fp, X	10—40	30—60	L
	M_2	P, X	< 10	⩾60	L
N		X, P	< 10	⩾20	L

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