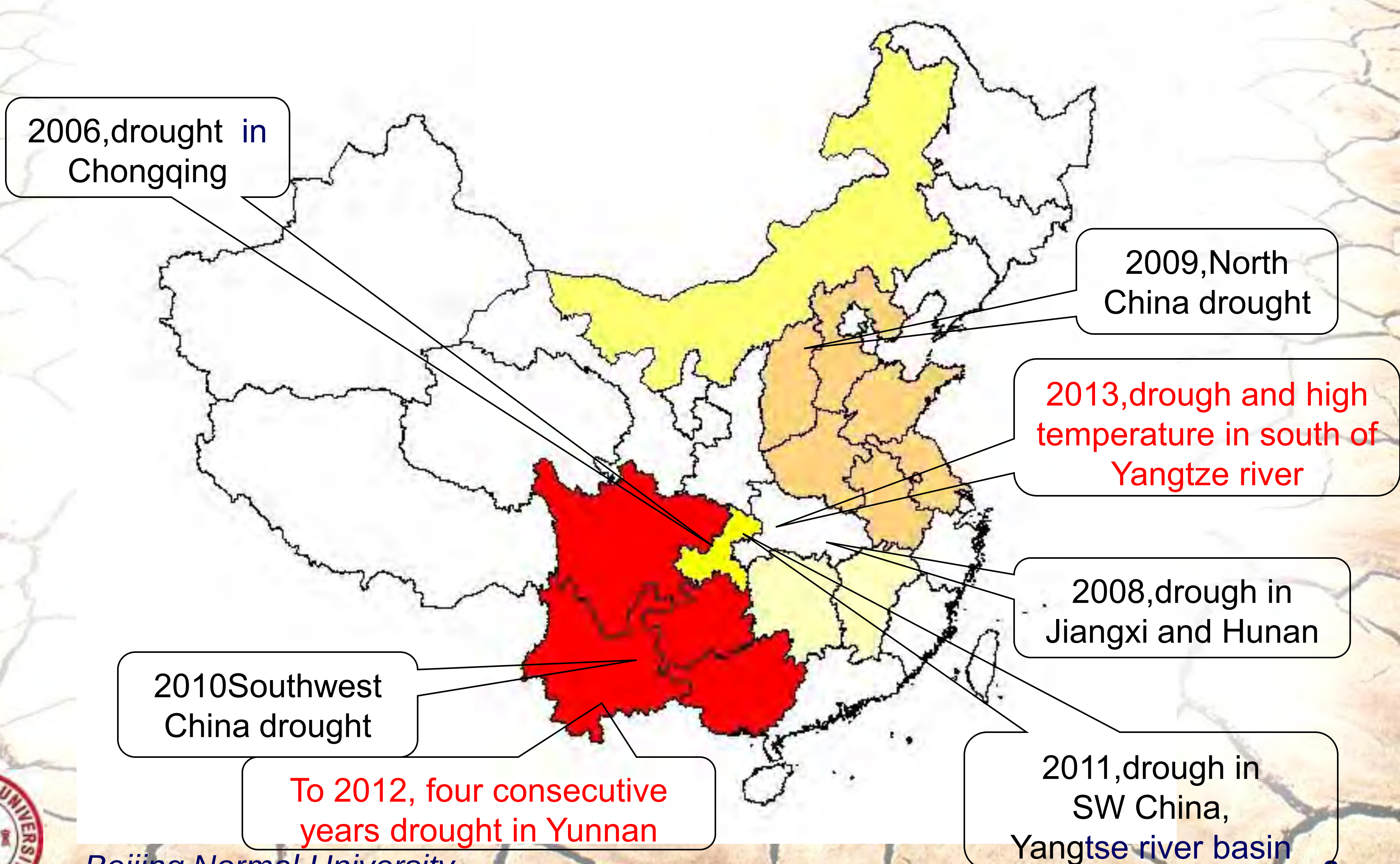
United Nations International Conference on Space-based Technologies for Disaster Management, October 23-25, 2013

The Integrated Surface Drought Index (ISDI): Construction, Validation, Application, and Assessment for drought monitoring in Mid-Eastern China

ZHOU LEI, WU JIANJUN
Beijing Normal University
jjwu@bnu.edu.cn

Drought events in China is increasing



Drought is different and difficult

Drought differs from other natural hazards and is difficult to deal with

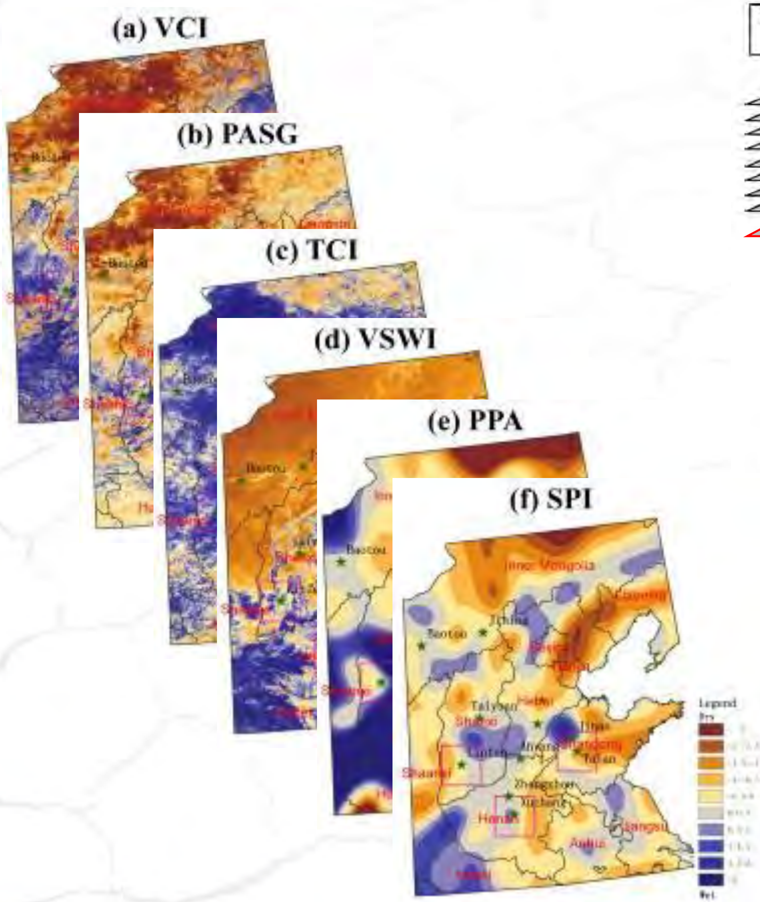
- *the absence of a precise and universally accepted definition-----difficult to be defined*
- *it is accumulate slowly----<u>difficult to be monitored</u>*
- *impacts are less obvious and spread over a larger geographical area------difficult to quantify the loss and to relief the disasters*

Introduction & objective

- **Introduction**
  - Drought has a very complex mechanism of the occurrence and development;
  - It is difficult to assess drought by one single drought monitoring index;
  - Few researchers have detailed analyzed and assessed the monitoring effect of all kinds of monitoring indices and the drought monitoring characteristics [1].
  - Vegetation Drought Response Index (VegDRI) has been used for monitoring drought ,but VegDRI which is at the stage of developing and perfecting is still needed to improve.[2].
- **Objective**
  - Compare the correlation among the MODIS- and meteorological-derived drought monitoring indices using spatial and temporal trend comparison analysis;
  - Establish a new integrated model of drought monitoring through comparative analysis to determine the optimal precision the combination of independent variables.
  - Multi-year, multi-source field observed data were used to test the performance of the constructed integrated model.

[1] Bayarjargal, Y., Karnieli, A., Bayasgalan, M., Khudulmur, S., Gandush, C., Tucker, C.J., 2006. A comparative study of NOAA-AVHRR derived drought indices using change vector analysis. Remote Sensing of Environment 105, 9-22.
[2]VegDRI. *VegDRI frequently asked questions* 2011; Available from: http://www.drought.unl.edu/vegdri/VegDRI_faq.htm.

Integrated Surface Drought Index (ISDI) for drought monitoring



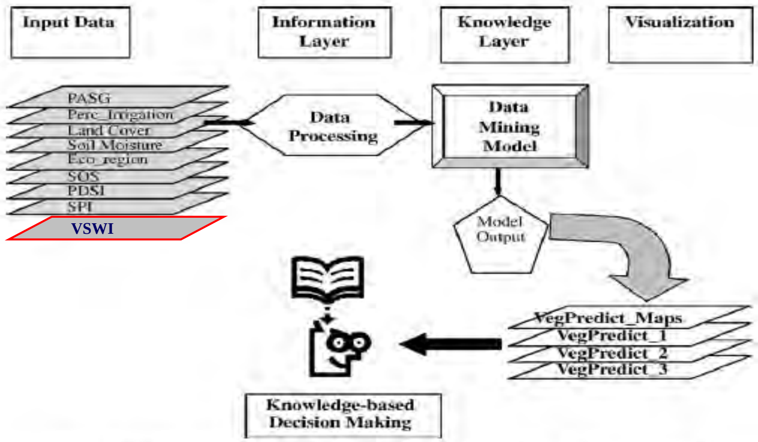
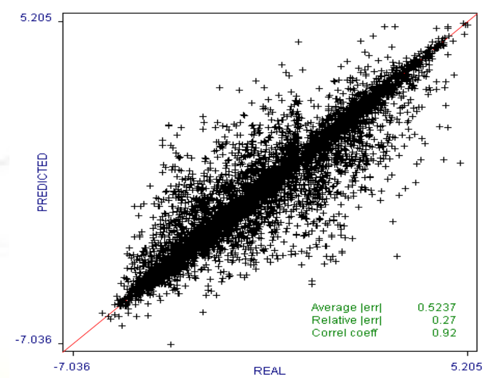


Fig. 1. Flow-chart of the process used to produce the VegPredict maps for decision-making.

Flow Chart of Integrated Surface Drought Index

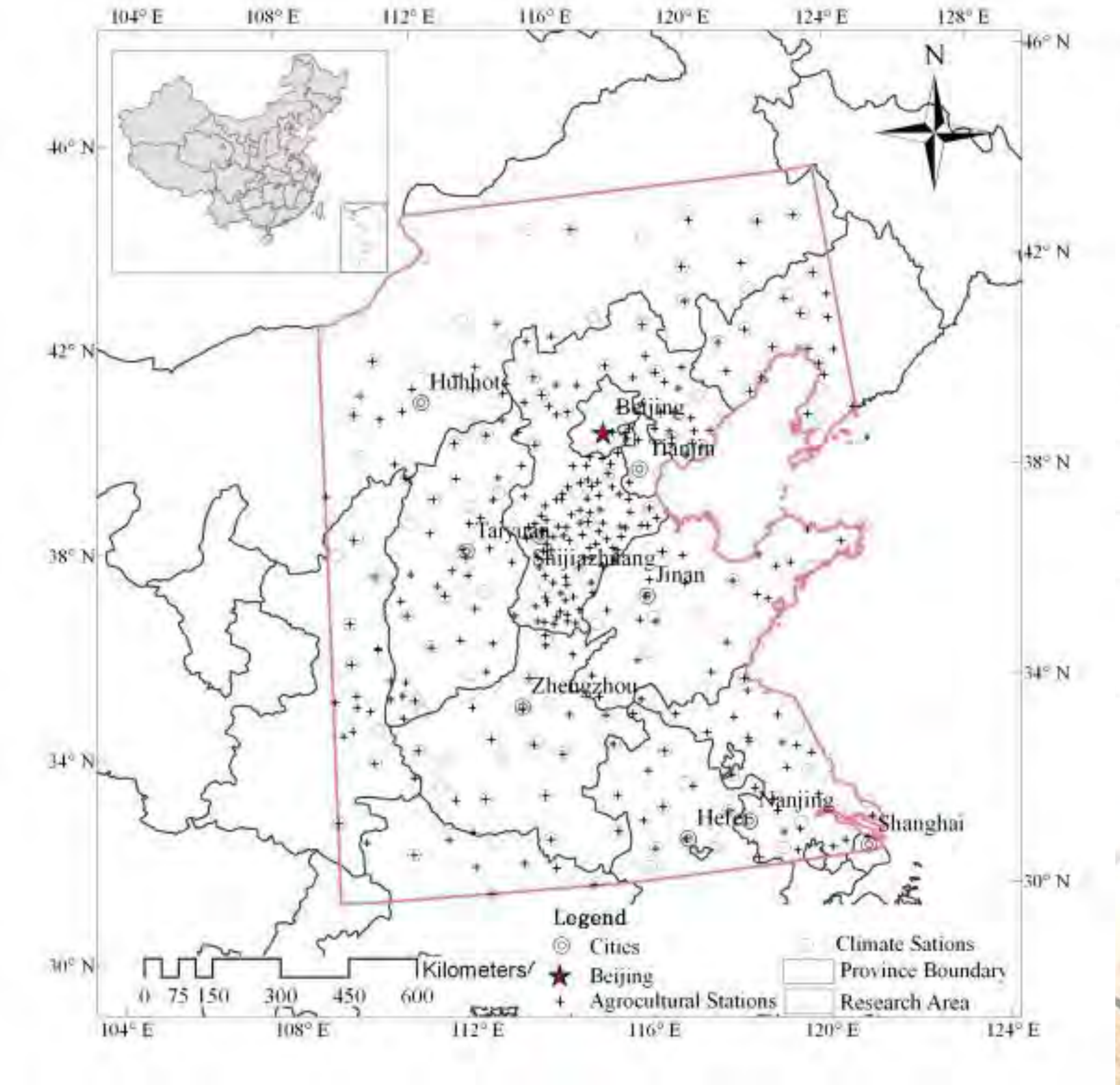


Comparison of Remote Sensed and Meteorological Data Derived Drought Indices

Cross plots for plan 7 predicted values and real values

•Zhou, L., Zhang, J., Wu, J., zhao, L., Liu, M., LÜ, A., wu, Z., 2012. Comparison of Remote Sensed and Meteorological Data Derived Drought Indices in Mid-Eastern China. International Journal of Remote Sensing 33(6), 1755-1779.
•Brown, J., Wardlow, B., Tadesse, T., Hayes, M., Reed, B., 2008. The Vegetation Drought Response Index (VegDRI): a new integrated approach for monitoring drought stress in vegetation. GIScience & Remote Sensing 45(1), 16-46.

Study Area


104° E
108° E
112° E
116° E
120° E
124° E
128° E
46° N
42° N
38° N
34° N
30° N
N
Huhhot
Beijing
Tianjin
Taiyuan
Shijiazhuang
Jinan
Zhengzhou
Nanjing
Hefei
Shanghai
Legend
Cities
Beijing
Agrocultural Stations
Climate Sations
Province Boundary
Research Area
Kilometers
0 75 150 300 450 600

Data

- **MODIS data**
  - The 16 day Maximum Value Composited (MVC) MODIS NDVI time series products (MOD13A2, 1km*1km) from 2000 to 2009;
  - 8 day average value composited Land Surface Temperature (LST) products (MOD11A2, 1km1km) from 2000 to 2009;
  - The land cover data (MOD12Q1, 500m*500m) for 2007;
- **Meteorological data**
  - daily precipitation, relative air humidity and temperature data during 50 years (1960-2009) from 130 weather stations.
  - Agro-meteorological disasters ten-day observation dataset of 11 agro-meteorological stations were derived from China Meteorological Data Sharing Service System.
- The original images were spliced and projected to Albers Equal-Area Conic projection;
- LST 8-day products are composed to 16-day products by calculating the average value of adjacent images

Methodology

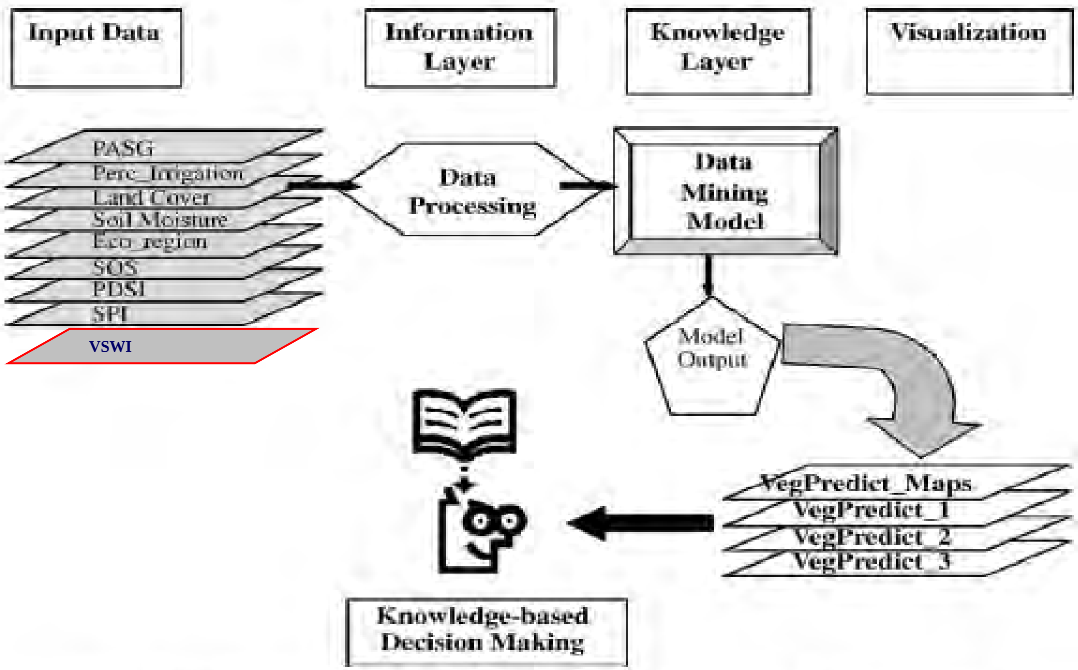


Fig. 1. Flow-chart of the process used to produce the VegPredict maps for decision-making.

Brown, J., Wardlow, B., Tadesse, T., Hayes, M., Reed, B., 2008. The Vegetation Drought Response Index (VegDRI): a new integrated approach for monitoring drought stress in vegetation. GIScience & Remote Sensing 45(1), 16-46.

Time series of NDVI curve simulation and testing

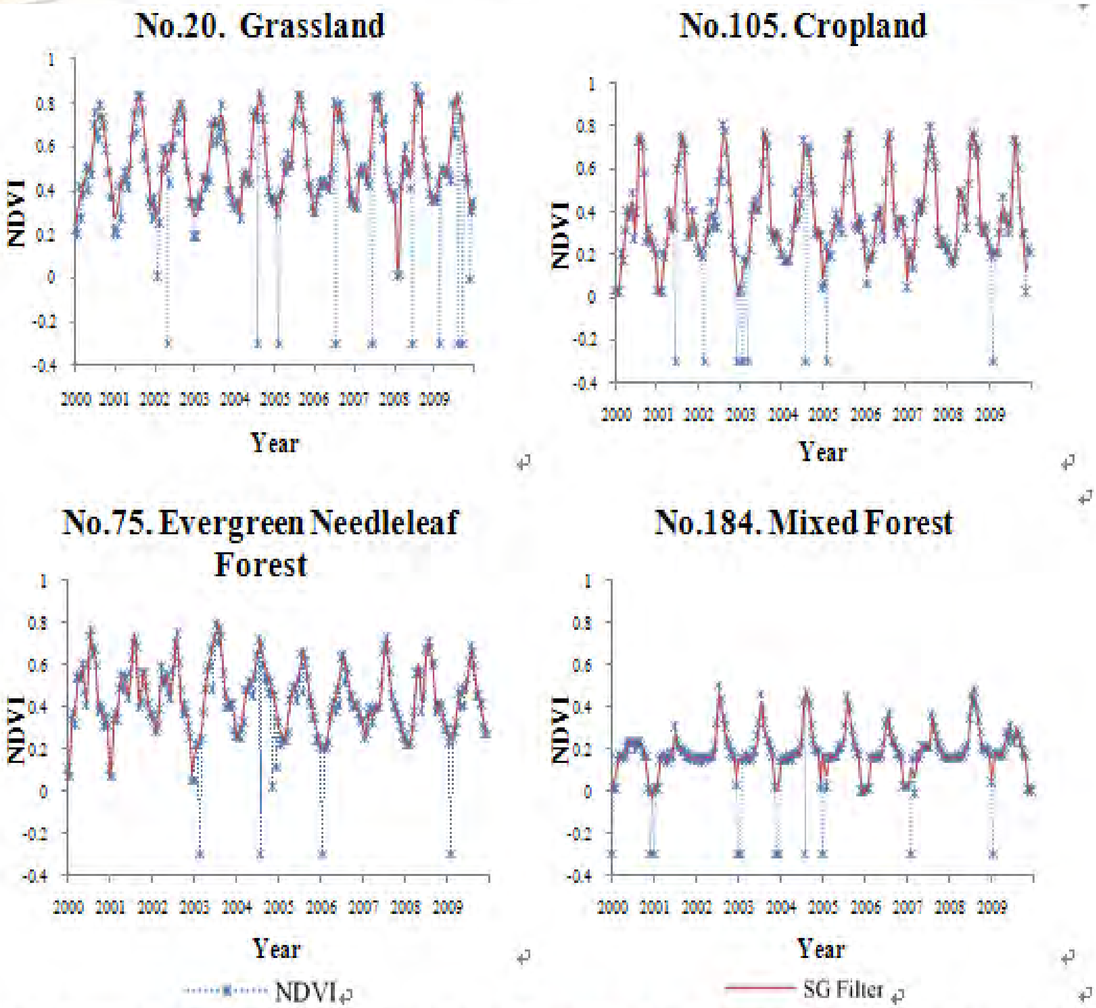


Fig.3 The final smoothed NDVI time-series generated using the Savitzky-Golay filter. The solid blue line with asterisks is the original MVC NDVI time-series; the solid red line is the smoothed NDVI time-series using Savitzky-Golay filter. The values equal to -0.3 among original MVC NDVI time-series are invalid filled values.

- 200 random points were created by ArcGIS 9.2 to test the result of NDVI time series processed by the Savitzky-Golay filter.
  - Lot of invalid values and noise are found in the 10 years NDVI series
  - and most of the noisy points in the NDVI time series were successfully identified and corrected.
  - This method can effectively reduce the impact of cloud or bad weather conditions on calculation of drought monitoring indices when using NDVI time series as input.

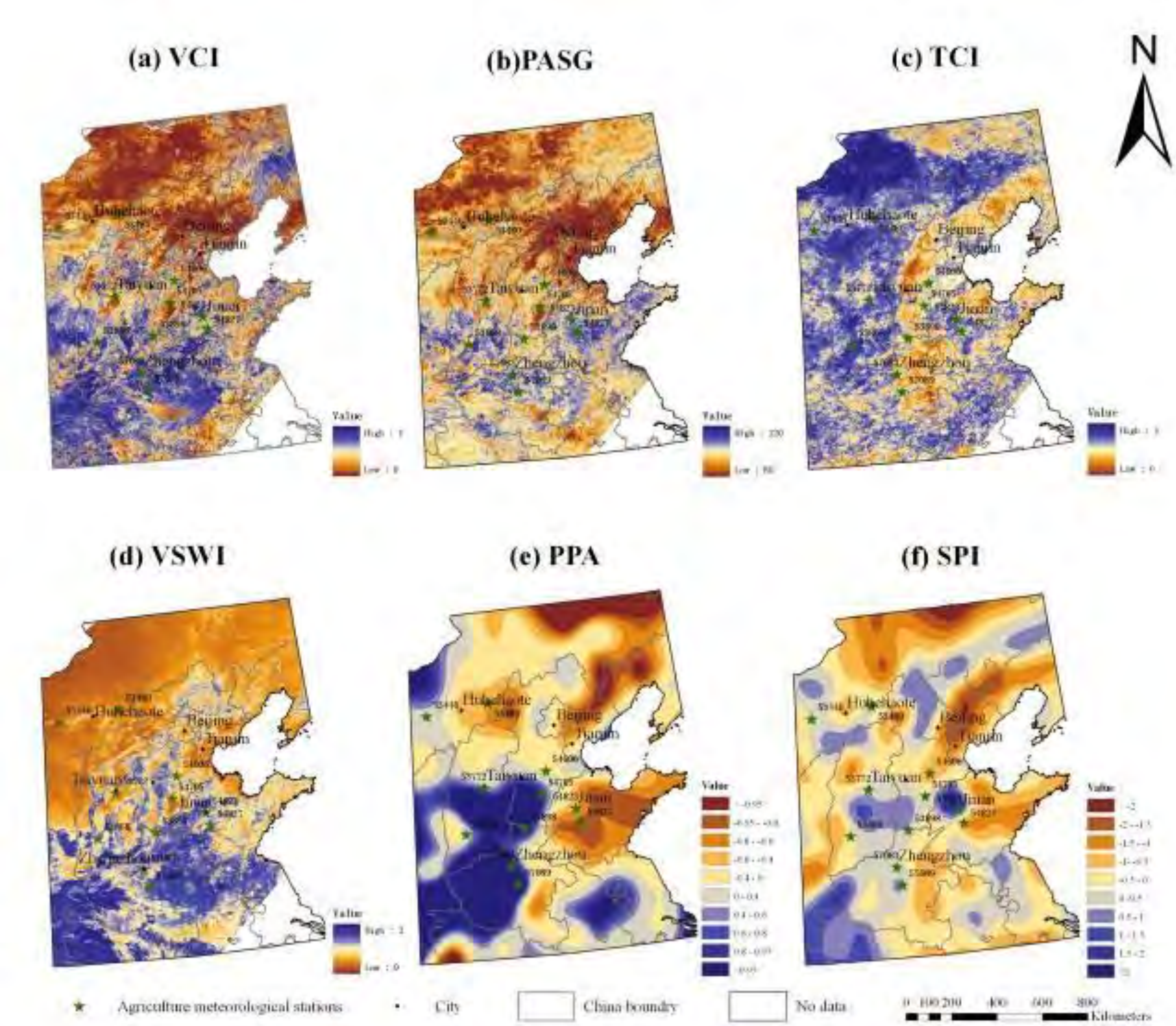


Fig.5 Comparison of MODIS- and meteorological-derived drought indices in the study area for the 129th day in 2006 (May 9th-24th)

Spatial monitoring characteristic of indices

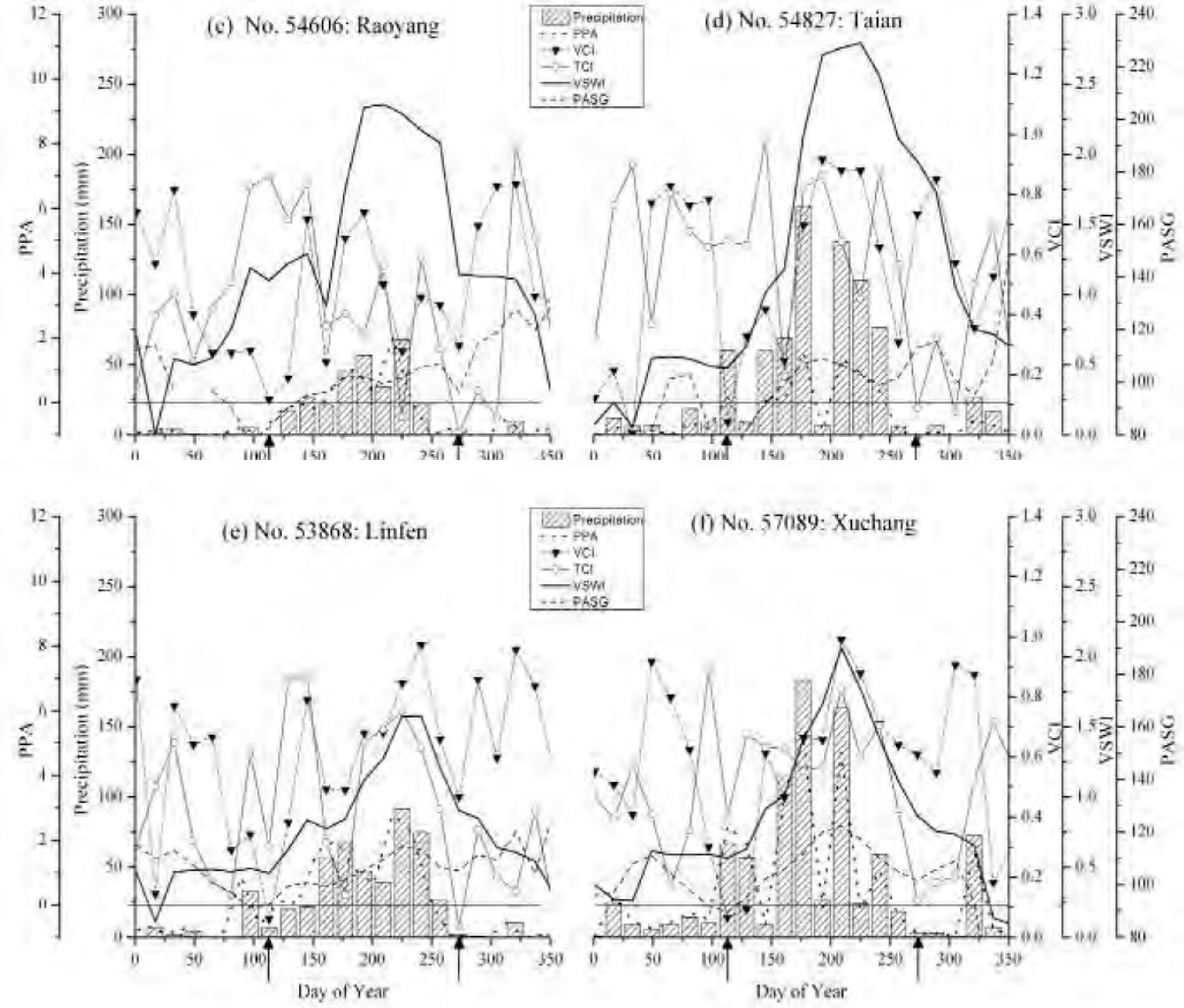
- The south of Shanxi province and North China plain region were affected by varying degrees of drought during April-June 2006.
- Two typical periods (April 23th-May 8th and 9th May-24th May, 2006) of drought monitoring results were selected to compare the spatial monitoring characteristic of drought indices.

Table 2 Field drought observations of Linfen, Taian and Xuchang during April-June 2006

Station ID	Station Name	Year	Month	Disaster Type	Object	Intensity	Affected Area (Mu)	Percentage
53868	Linfen	2006	4	Drought	Winter Wheat	Mild	150000	30-39%
53868	Linfen	2006	5	Drought	Winter Wheat	Mild	200000	40-49%
53868	Linfen	2006	6	Drought	Winter Wheat	Mild	200000	40-49%
54827	Taian	2006	4	Drought	All Crops	Mild	150000	10-19%
54827	Taian	2006	5	Drought	All Crops	Mild	150000	10-19%
57089	Xuchang	2006	4	Drought	Winter Wheat	Mid	Unknown	Unknown
57089	Xuchang	2006	5	Drought	Winter Wheat	Mid	Unknown	Unknown

Field observation data are derived from China agro-meteorological disasters ten-day dataset of China Meteorological Data Sharing Service System.

Trend analysis of drought indices time series



Correlation and regression analysis

Drought indices	Precipitation	Relative air humidity	VSWI	VCI	TCI	PASG	PPA	SPI
2006 (a dry year)								
Precipitation	1							
Relative air humidity	**0.545****	1						
VSWI	**0.620****	**0.916*****	1					
VCI	-0.289	0.486	0.295	1				
TCI	0.474	**0.866*****	**0.684****	0.520	1			
PASG	0.132	**0.829*****	**0.672****	**0.825*****	**0.800*****	1		
PPA	**0.507**	0.081	0.024	-0.540*	0.007	-0.187	1	
SPI	0.255	-0.229	-0.372	-0.347	-0.133	-0.308	**0.781*****	1

Higher correlations are marked in bold. *** represent the significant values at the p<0.01.** represent the significant values at the p<0.05. * represent the significant values at the p<0.1.

regression analysis

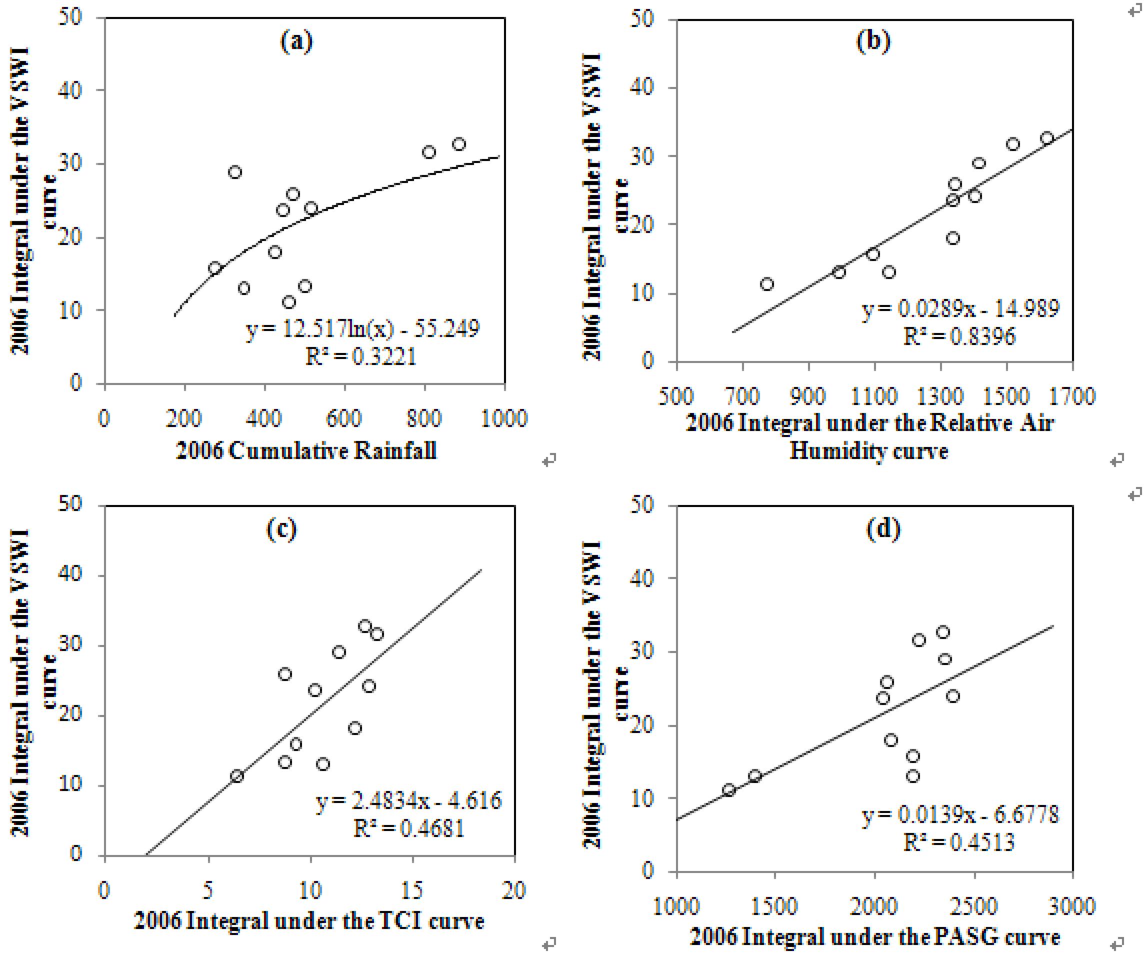
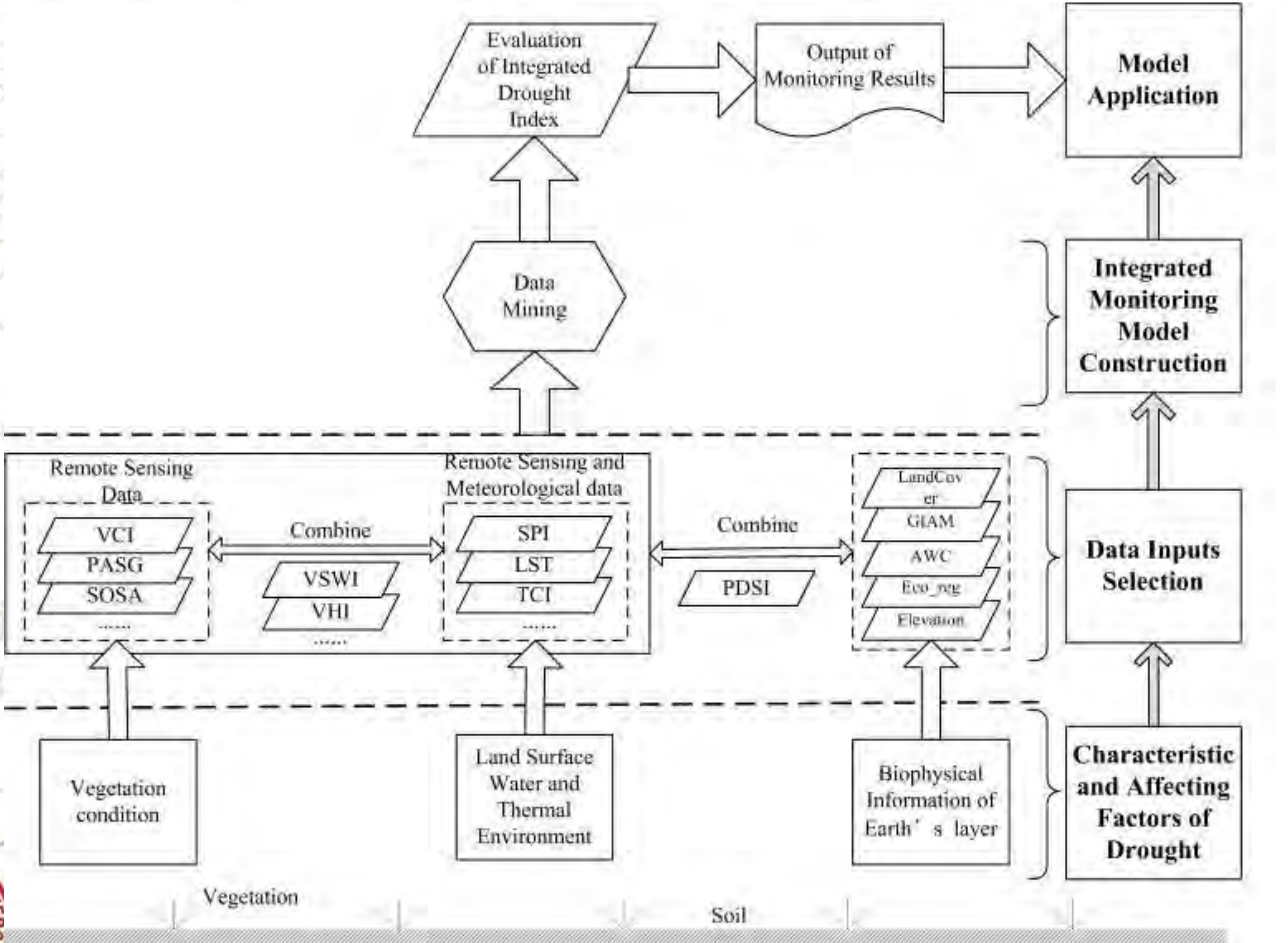


Figure 7. Cross plots and regression relationships for the 11 agro-meteorological stations during 2006 of: (a) integral under the VSWI curve and the cumulative rainfall; (b) integral under the VSWI curve and integral under the Relative Air Humidity curve; (c) integral under the VSWI curve and integral under the TCI curve; (d) integral under the VSWI curve and integral under the PASG curve.

- (a) shows a logarithmic relationship between integral of VSWI and cumulative precipitation.
- The stations which receive less precipitation have a lower measure of VSWI, and vice versa.
- Integral under VSWI curve for 2006 has obvious linear regression with integral under the relative air humidity (RAH) curve.
- This also indicates that the value of VSWI is more easily influenced by the thermal information than the reflective information.

The method of building the integrated model



Data Inputs for ISDI

Name	Type	Acronym	Source
Palmer Drought Severity Index	Climate	PDSI	China Meteorological Data Sharing Service System
Standardized Precipitation Index	Climate	SPI	China Meteorological Data Sharing Service System
Normalized Difference Vegetation Index	Satellite	NDVI	Land Processes Distributed Active Archive Center (LP DAAC) LP DAAC
Land Surface Temperature	Satellite	LST	LP DAAC
Vegetation Condition Index	Satellite	VCI	LP DAAC
Temperature Condition Index	Satellite	TCI	LP DAAC
Vegetation Supply Water Index	Satellite	VSWI	LP DAAC
Start of Season Anomaly	Satellite	SOSA	LP DAAC
Percent of Average Seasonal Greenness	Satellite	PASG	LP DAAC
Elevation	Biophysical	Ele	Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China
Ecological Regions	Biophysical	EcoRe	China's Eco_Geographical Region Map
Land Cover	Biophysical	NLCD	NASA Goddard Space Flight Center (MODIS Land Products)
Soil Available Water Capacity	Biophysical	AWC	International Geosphere-Biosphere Programme, IGBP
Irrigated Agriculture Region	Biophysical	IrrAg	Global Map of Irrigated Area (GIAM)

- **MODIS data indices**
  - NDVI
  - LST
  - VCI
  - TCI
  - PASG
  - SOSA
  - VSWI
- **Meteorological indices**
  - PPA
  - SPI
  - PDSI

Biophysical Data

- **16 day PPA, SPI data in a tabular form were spatially interpolated into a raster image format by using spline method of ArcMap.**

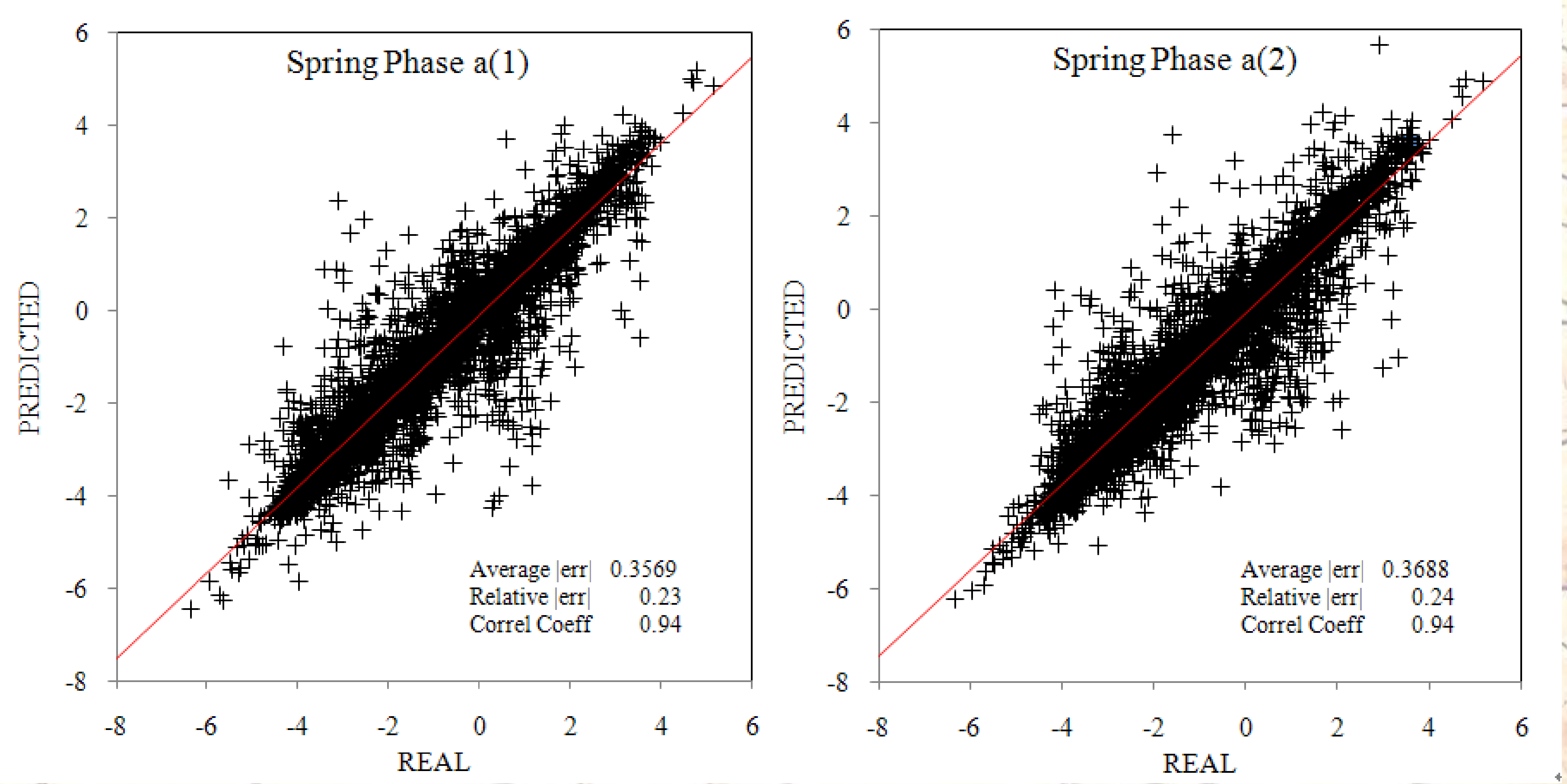
Building the model and intersect validation

NO.	Variables	NO. of Variables	Phase	Average error	Relative error	Correlation coefficients
1	PASG、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.3688	0.24	0.94
			Summer	0.7152	0.42	0.87
			Autumn	0.3984	0.2	0.95
2	VSWI、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.4444	0.29	0.91
			Summer	0.8025	0.47	0.83
			Autumn	0.5396	0.28	0.92
3	VCI、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.5754	0.38	0.88
			Summer	0.9007	0.53	0.81
			Autumn	0.5873	0.31	0.91
4	TCI、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.651	0.43	0.85
			Summer	0.8894	0.52	0.82
			Autumn	0.6044	0.32	0.90
5	LST、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.5376	0.35	0.89
			Summer	0.8312	0.49	0.84
			Autumn	0.5091	0.27	0.92
6	NDVI、SOSA、SPI、Landcover、AWC、GIAM、Eco_region，PDSI	7	Spring	0.4605	0.3	0.91
			Summer	0.7621	0.45	0.85
			Autumn	0.5733	0.3	0.91

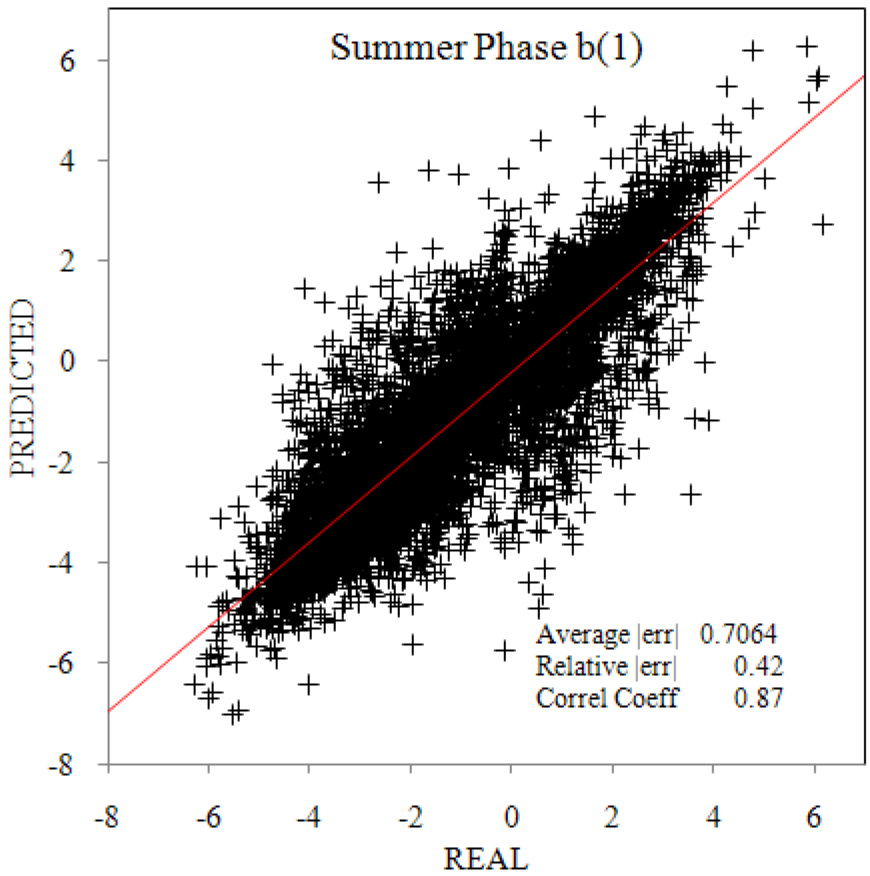
Building the model and intersect validation

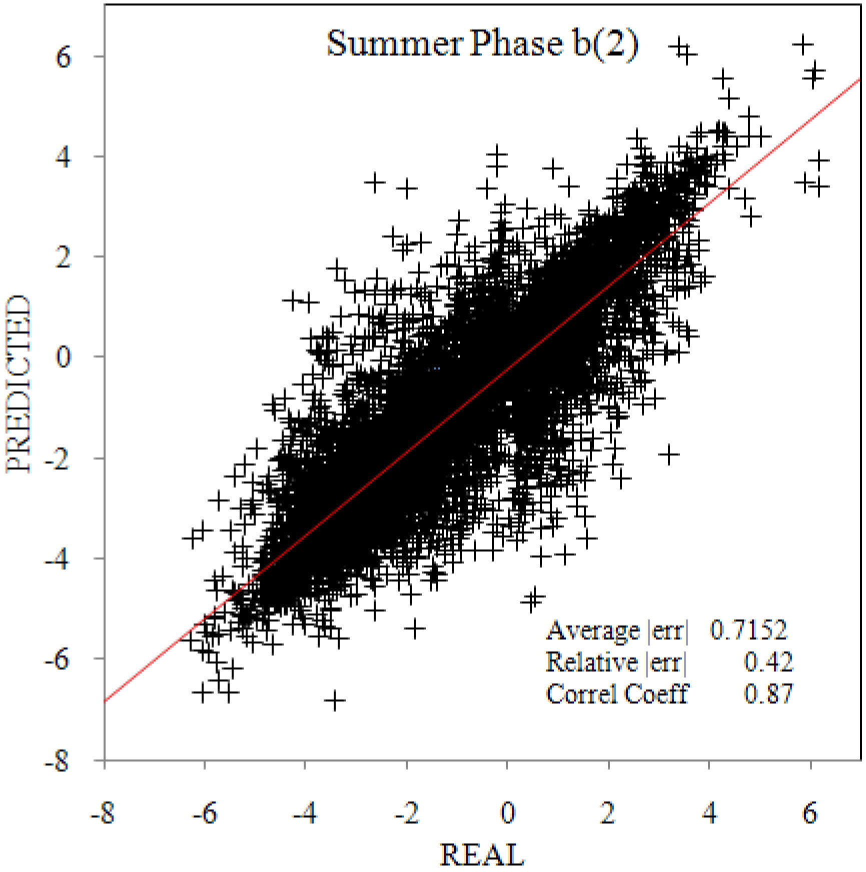
7	**VSWI、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI**	**8**	**Spring**	**0.3569**	**0.23**	**0.94**
			Summer	**0.7064**	**0.42**	**0.87**
			Autumn	**0.4105**	**0.22**	**0.95**
8	TCI、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI	8	Spring	0.5522	0.36	0.90
			Summer	0.7922	0.46	0.86
			Autumn	0.4625	0.24	0.94
9	LST、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI	8	Spring	0.4467	0.29	0.92
			Summer	0.7257	0.43	0.87
			Autumn	0.4078	0.21	0.95
10	NDVI、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI	8	Spring	0.3619	0.24	0.94
			Summer	0.6376	0.37	0.89
			Autumn	0.4291	0.22	0.94
11	PASG、TCI、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI	9	Spring	0.5399	0.35	0.89
			Summer	0.7398	0.43	0.87
			Autumn	0.4524	0.24	0.94
12	VCI、TCI、SOSA、SPI、elevation、Landcover、AWC、GIAM、Eco_region，PDSI	9	Spring	0.6209	0.41	0.88
			Summer	0.7976	0.47	0.86
			Autumn	0.5579	0.29	0.92

The compare of regressive result between the ISDI and the original model

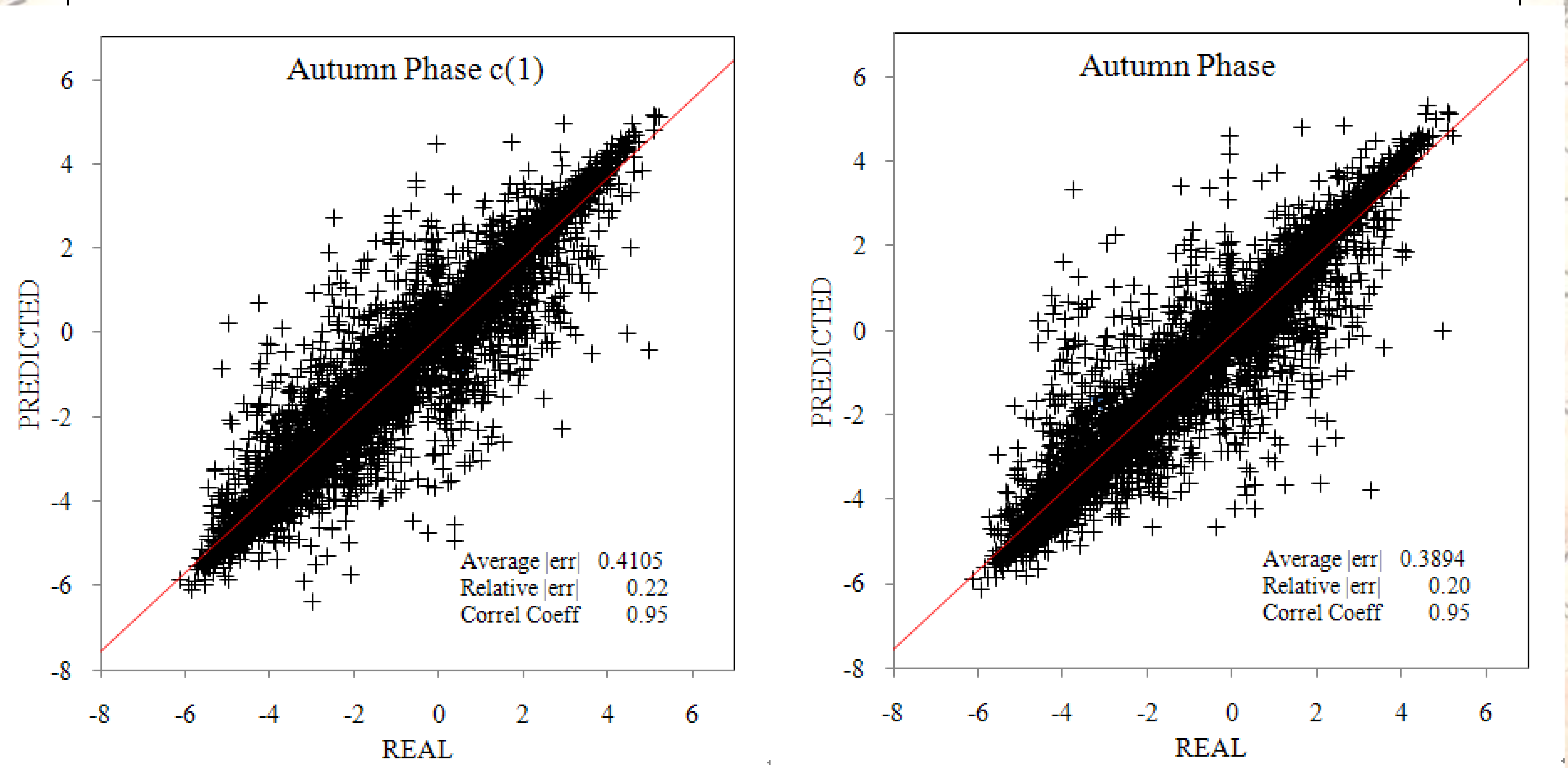


The compare of regressive result between the ISDI and the original model





The compare of regressive result between the ISDI and the original model



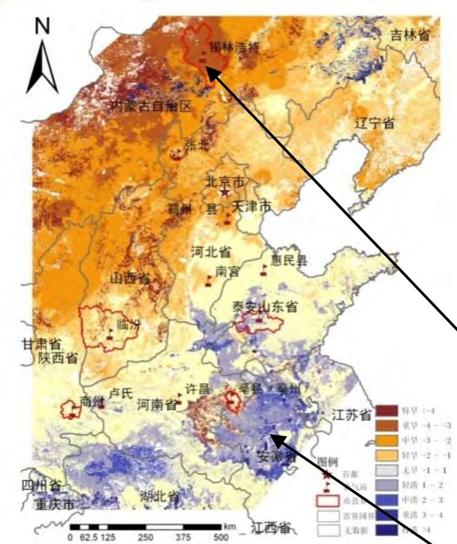
The contribution of all the input variables to ISDI model (%)

ISDI Variables	Spring Model		Summer Model		Autumn Model	
	C	U	C	U	C	U
SPI	100	100	84	100	78	100
SOSA	-	54	70	54	38	37
VSWI	-	40	24	44	-	34
Elevation	63	100	84	77	84	80
AWC	-	4	34	67	57	71
Land cover	-	-	36	-	10	-
GIAM	-	-	14	-	73	-
Eco_region	-	-	29	-	-	-

C (Condition): the approximate percentage of cases for which the attribute concerned appears in a condition of an applicable rule;
U (Usage): the percentage of cases for which the attribute appears in the linear model of an applicable rule;
Attributes for which both these values are less than 1% are not shown;

- SPI and elevation information have the most influential effect on the ISDI model results.
- ISDI has good applicability in the study area, which can accurately reflect the regional and temporal differences of drought. The influence of different factors on the drought condition varies a lot as the different onset and region of drought.

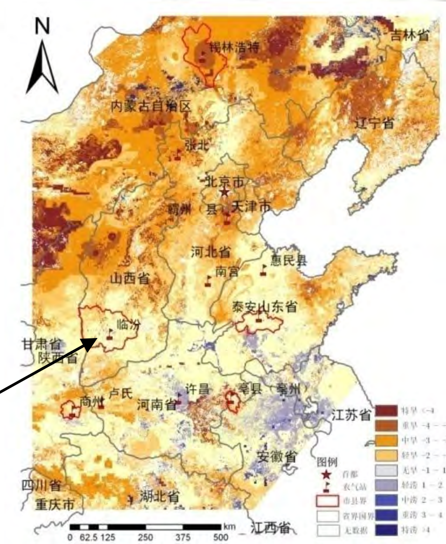
Validation on ISDI model for drought monitoring



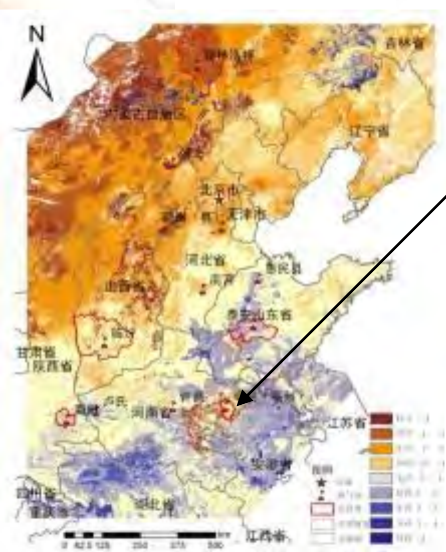
May 25, 2006

Table 4 Field observations of selected 6 agro-meteorological stations in study area for 2006

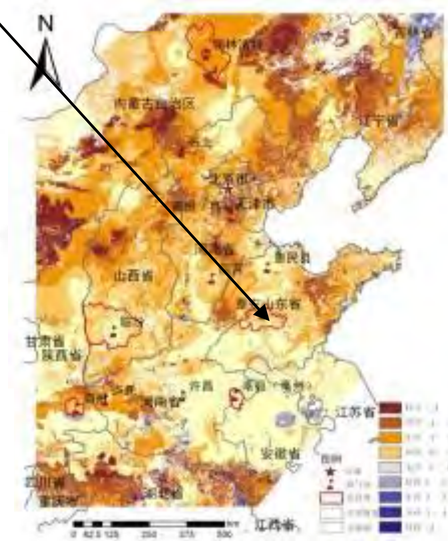
Site name	Longitude (° E)	Latitude (° N)	Drought occurrecce time (2006)
Linfen	111.5	36.06	April
Linfen	111.5	36.06	May to early June
Xilinhot	116.12	43.95	Early May to early September
Taian	117.15	36.16	Late April to early May
Taian	117.15	36.16	Late October to early November
Taian	117.15	36.16	Mid-November to late November
Taian	117.15	36.16	December
Xuchang	113.85	34.01	Mid-April to early May
Shangzhou	109.96	33.86	In mid-June
Haoxian	115.77	33.87	Late April to mid-June



Aug. 29, 2006



June 10, 2006



Nov. 1, 2006

•Wu, J., Zhou, L., Liu, M., Zhang, J., Leng, S., Diao, C., 2013. Establishing and assessing the Integrated Surface Drought Index (ISDI) for agricultural drought monitoring in mid-eastern China. International Journal of Applied Earth Observation and Geoinformation 23(0), 397-410.

The result of the typical sites of the observations of drought

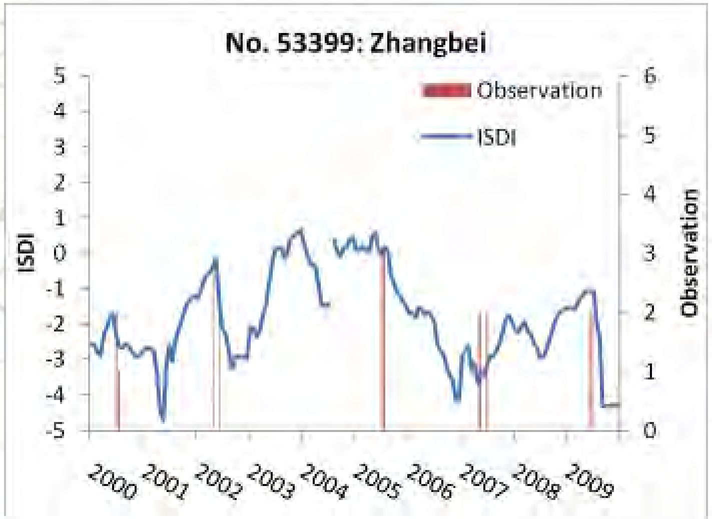
Station Name	longitude	latitude	Time occurrence of drought	Percentage affected
Linfen	111.5	36.06	April	30-39%
Linfen	111.5	36.06	May to early June	40-49%
Xilinhot	116.12	43.95	Early May to early September	90-100%
Taian	117.15	36.16	Late April to Late May	10-19%
Taian	117.15	36.16	Late October to Late November	20-29%
Taian	117.15	36.16	Mid-November to Late November	60-69%
Taian	117.15	36.16	December	30-39%
Xuchang	113.85	34.01	Mid-April to early May	Unknown
Shangzhou	109.96	33.86	Mid-June	10-19%
Haoxian	115.77	33.87	Late April to Mid-June	90-100%

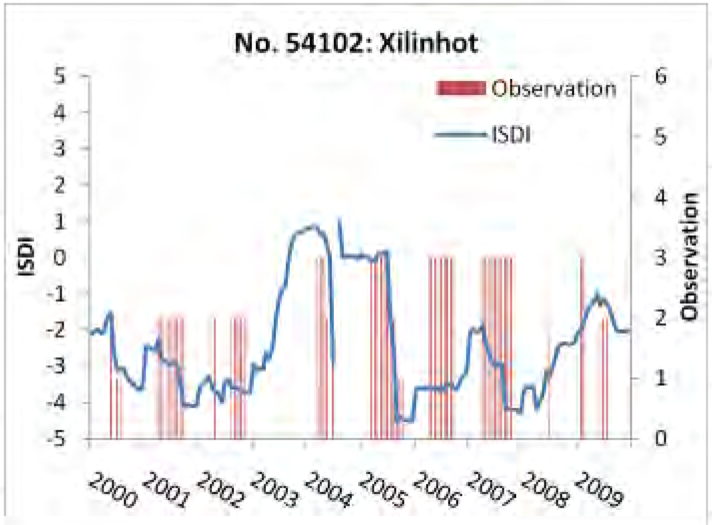
Local scale drought monitoring accuracy

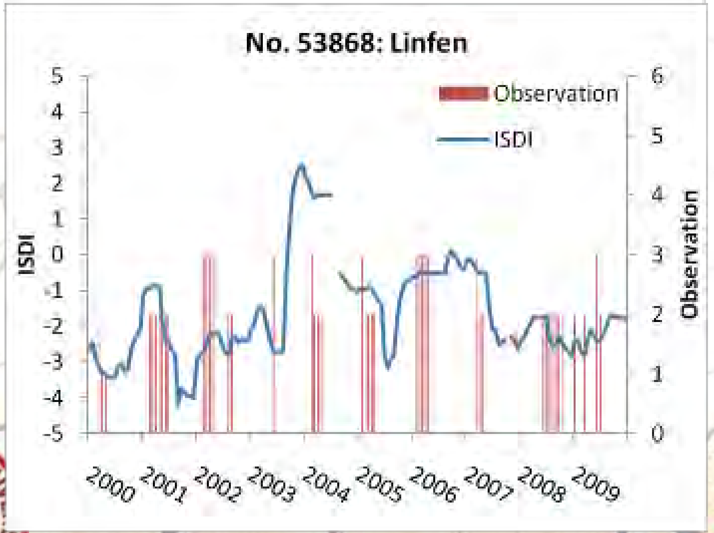
Station Name	Year	Month	Tendays	Intensity	Affected Area (Mu)	Percentage affected	Monitoring time（DOY）	Monitoring Percentage
Xilinhot	2006	5	3	Mild	More than 100,0000	**90-100%**	145	**95.83%**
Xilinhot	2006	6	3	Mild	More than 100,0000	**90-100%**	161	**95.83%**
Xilinhot	2006	9	1	Mild	More than 100,0000	**90-100%**	241	**95.83%**
Linfen	2006	6	1	Mild	20,0000	**40-49%**	145	**55.01%**
Taian	2006	11	2	Mild	60,0000	**60-69%**	305	**50.02%**
Shangzhou	2006	6	2	Mild	11,0000	**10-19%**	161	**9.84%**

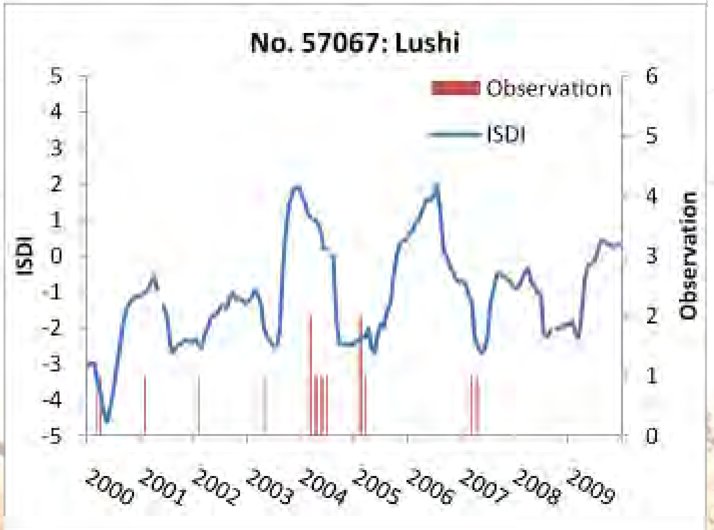
- It is good correspondence between the percentage of the monitoring affected crops and the estimating percentage of the observation of the agriculture meteorological station , **which the overall error is less than 10%。**
- There is an error between the estimating observation and ISDI monitoring；

ISDI and the site observation

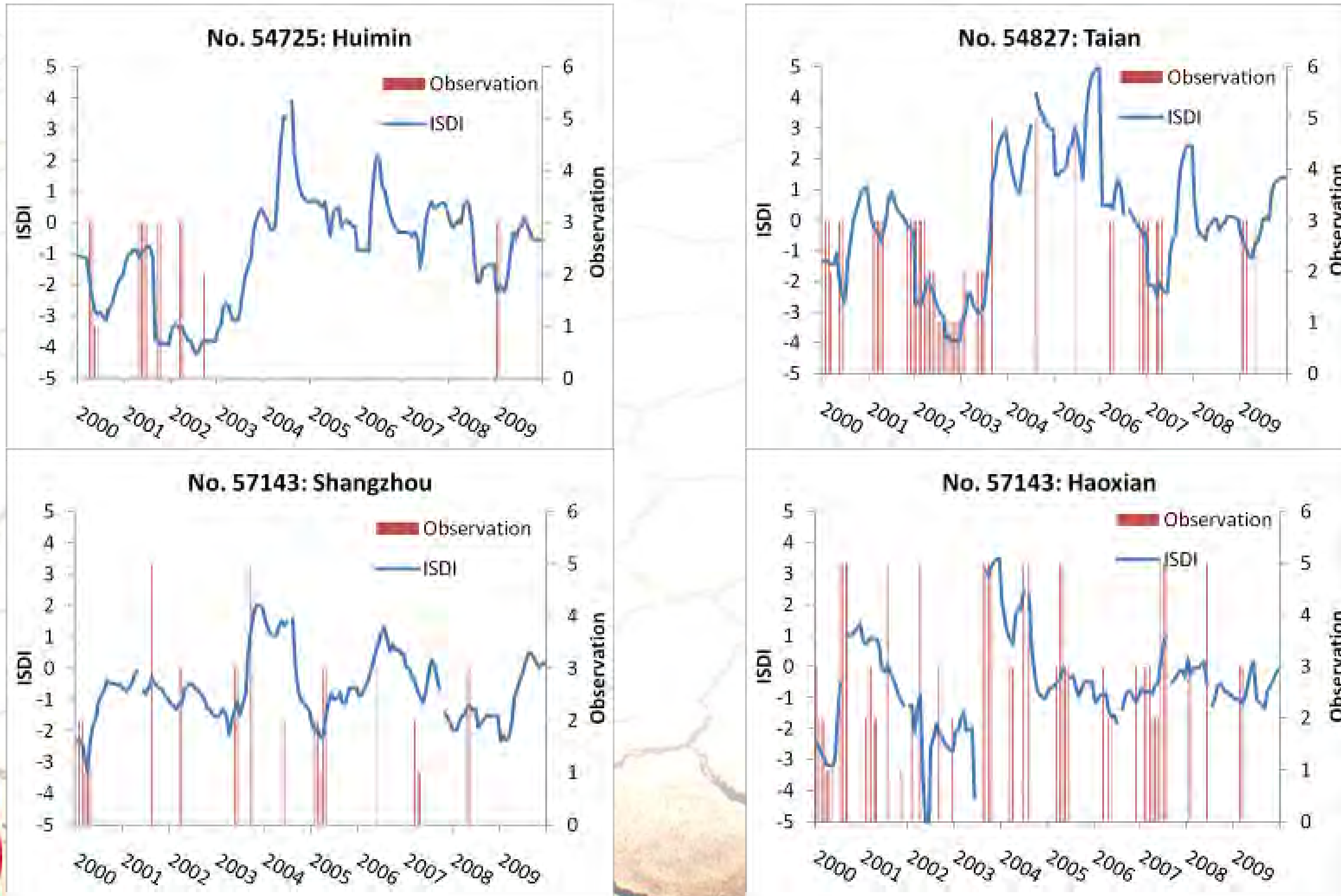








ISDI and the site observation



Comparison to the China integrated drought monitor

China integrated drought monitor (CI) is fit to drought monitor on real time and drought assessment for the period which can be calculated by the following method.

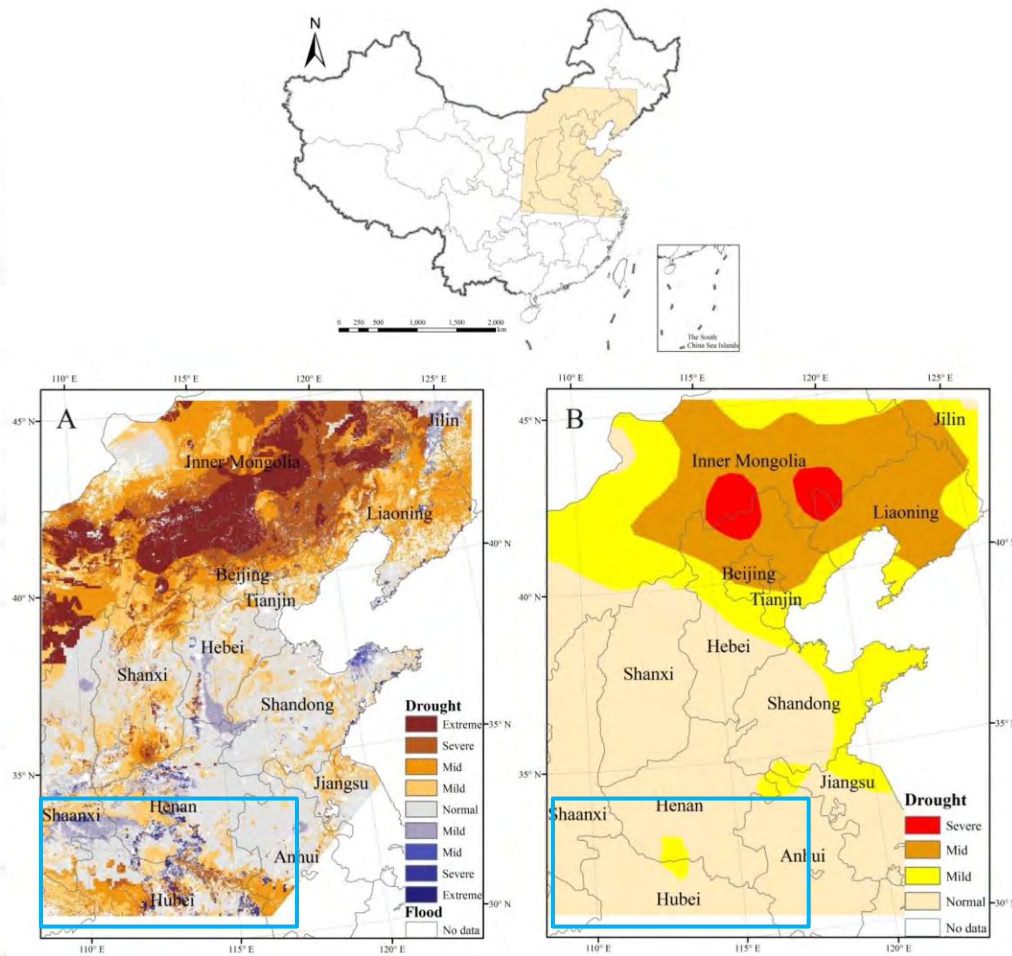
$$CI = aZ_{30} + bZ_{90} + cM_{30}$$

Where Z_{30} and Z_{90} are SPI of recent 30 days and 90 days, represent the abnormal condition on monthly and seasonal scale. M_{30} is relative moisture index of recent 30 days, represent water deficit. M=(P-PE)/PE , PE is potential evapotranspiration, P is precipitation. The parameters a, b, c are assigned as 0.4, 0.4, and 0.8 respectively. CI contains 5 categories of drought degree and ISDI has the same number of drought classification according to the PDSI drought classification scheme.

Grades	Drought	CI	ISDI
1	Normal	-0.6 < CI	-1 < ISDI ≤ 1
2	Milds	-1.2 < CI ≤ -0.6	-2 < ISDI ≤ -1
3	Moderate	-1.8 < CI ≤ -1.2	-3 < ISDI ≤ -2
4	Sever	-2.4 < CI ≤ -1.8	-4 < ISDI ≤ -3
5	Extreme	CI ≤ -2.4	ISDI ≤ -4

Comparison to the China integrated drought monitor

- The spatial distribution characteristics and intensity of drought detected by ISDI and CI were similar.
- The ISDI map shows considerably higher detail at local scale than the CI results.
- There were also some local-scale drought condition differences between the ISDI map and CI map.
- ISDI as a valuable indicator which can provide complimentary information to decision makers and the CI monitored results.



The ISDI map (A) for DOY 2009273 (September 30, 2009) and the CI map (B) for September 23, 2009 over the study area.

Zhou, L., Wu, J., 2013. The Integrated Surface Drought Index (ISDI) as an Indicator for Agricultural Drought Monitoring: Theory, Validation, and Application in Mid-Eastern China. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 6(3), 1254-1262.

Summary

- Combination with VSWI involved, which considered temperature information and has high regression accuracy, is finally selected to calculate the ISDI.
- ISDI is suitable for large-scale (larger than provincial or national area) drought monitoring. Moreover, the ISDI also offers good capability for monitoring spatial variations in drought condition on local scale (same as or less than county areas).
- ISDI can be used to accurately monitor the occurrence of drought and it can characterize detailed drought categories.

Look into the future

- ISDI still has its own limitation and need for further research and improvement.
- We will take more in-depth validation and assessment in our future research with the field observation data increasing and improvement.
  - Including Multi-year, multi-seasonal meteorological and observed vegetation condition and soil moisture data at different sites;
  - Using ISDI to monitor drought in different regions of the world.

Thank you for your attention!

Academy of Disaster Reduction and Emergency Management
Beijing Normal University, Beijing 100875, China
http://adrem.org.cn/
http://adrem.org.cn/Faculty/WuJJ/Index.html