Determining soil moisture and land cover to assist in flood prediction and early warning

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Index to determining soil moisture and land cover to assist in flood prediction and early warning

- Soil moisture and flood
- Land cover and flood
- Remote Sensing-based soil moisture monitoring
- Remote Sensing-based land cover monitoring

Flood disaster

Flood is one of the important disasters for mankind

Flood disaster

September ,2004, in Dazhou,Sichuan Province

Flood loss statistical chart

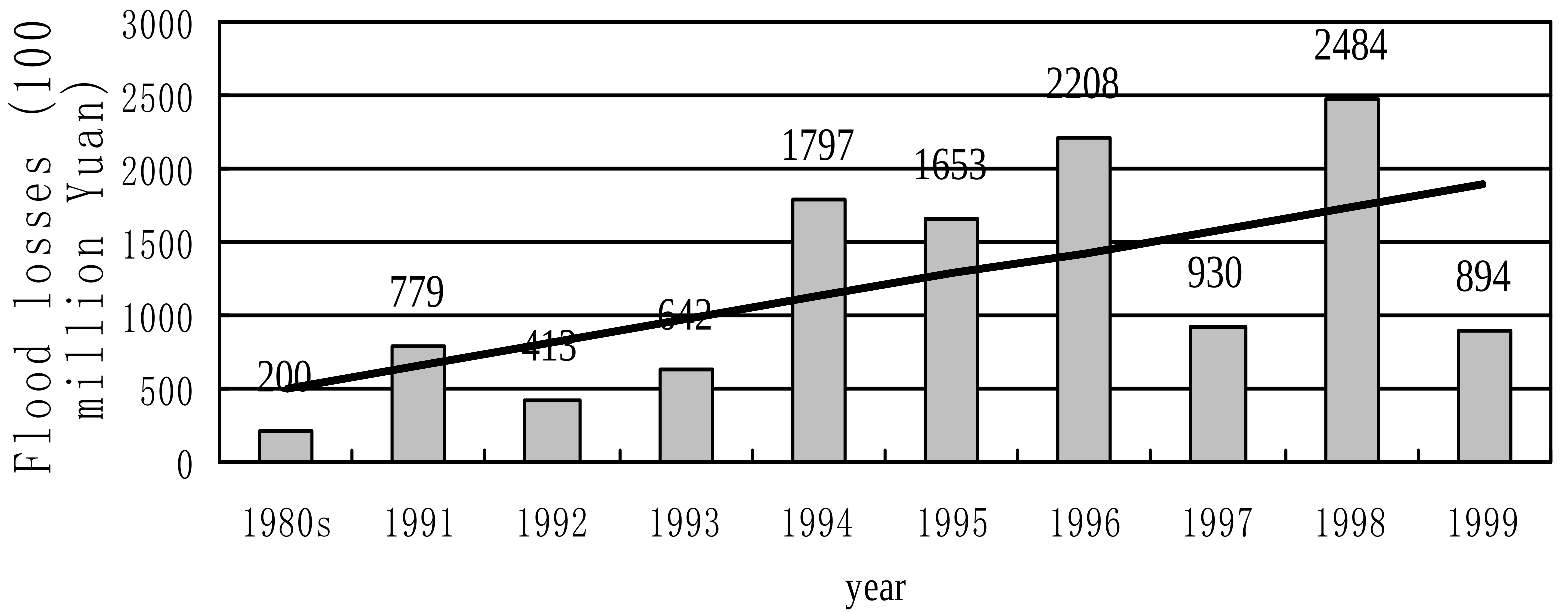
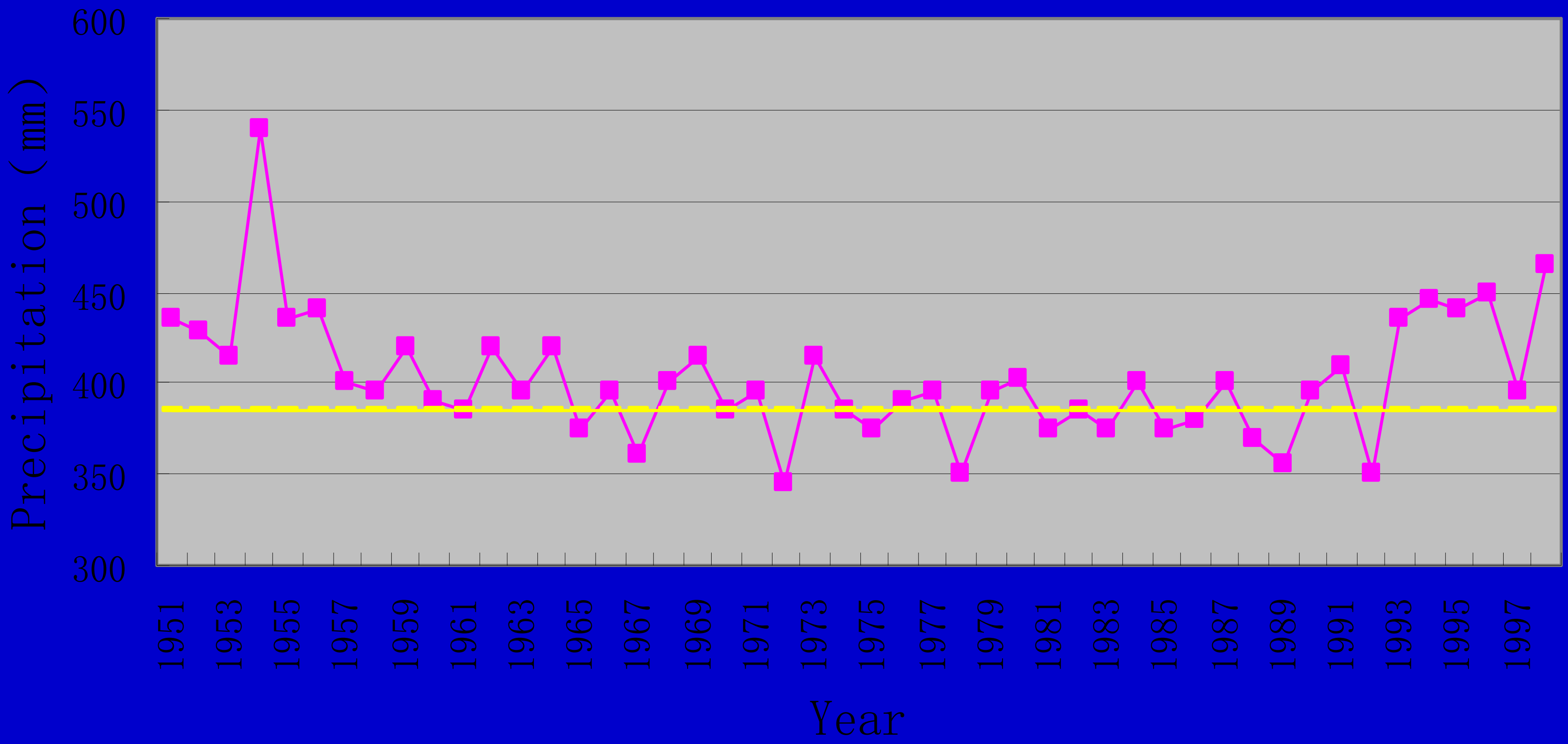


Fig.1 Flood losses in China since 1980s

Cheng Xiaotao , Changes of Flood Control Situation in China & Adjustments of Flood Management Strategies

Precipitation chart



Flood prediction and early warning

- **Flood prediction and early warning system is important and necessary**
- **System using Remote-Sensing technology in flood control in IRSA ,CAS, China**

1. **Reception and pre-treatment of the telemetric data**
2. **Identifying inundated landforms and data retrieval function**
3. **A detailed estimation of the flood-inflicted damage landforms**
4. **Speedy compilation of pictures,photos,data,graphic material,forms and literary reportage**
5. **Communication network for dispersing the monitored and assessed results**

Soil Moisture and Flood

1. soil moisture influences precipitation
   (Randal D. Koster,20 Aug 2004,Vol305, Science www.Sciencemag.org)

- Soil moisture can influence weather through its impact on evaporation and other surface energy fluxes.
- Atmospheric general circulation model(AGCM) studies that in continental midlatitudes during summer ,oceanic impacts on precipitation are small relative to soil moisture impacts.

Soil Moisture and Flood

1. soil moisture influences precipitation
   (Randal D. Koster ,etc.20 Aug 2004,Vol305, Science www.Sciencemag.org)

Different climate position have strong impacts on relativity between soil moisture and precipitation:

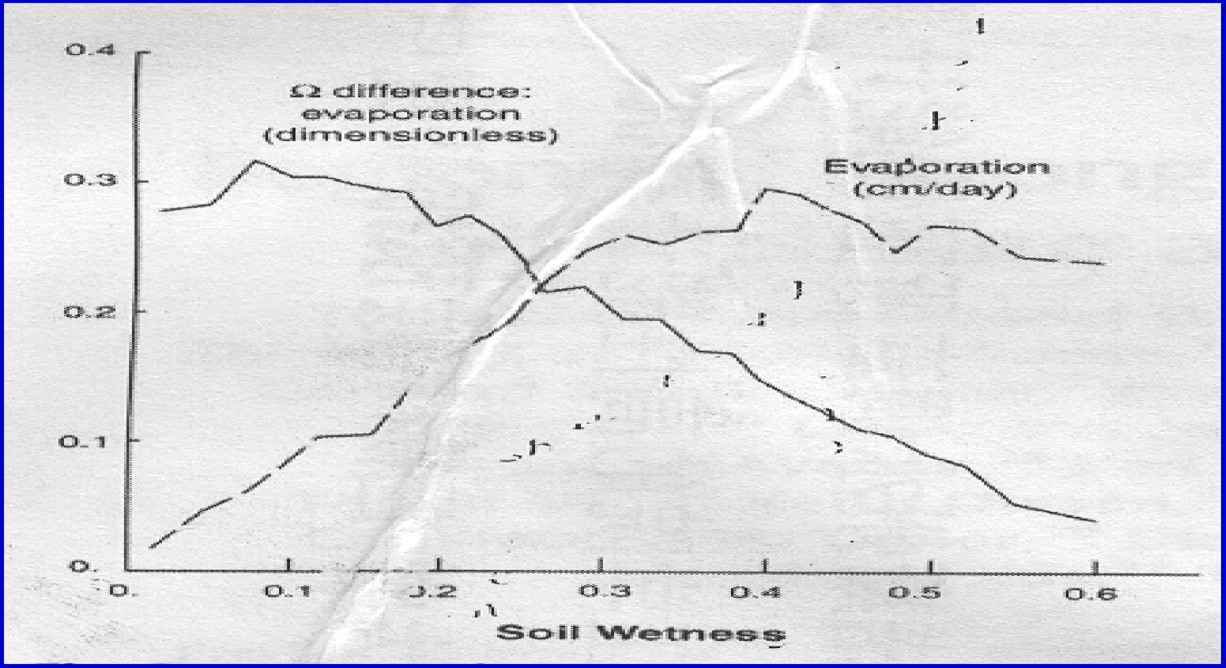
- **Precipitation should not be sensitive to soil moisture in wet climate.**
- **In dry climates,evaporation rates are sensitive to soil moisture but are also ,of course ,generally small**

Soil Moisture and Flood

1. soil moisture influences precipitation

(Randal D. Koster ,etc.20 Aug 2004,Vol305, Science www.Sciencemag.org)

Different climate position have strong impacts on relativity between soil moisture and precipitation:



Soil Moisture and Flood

1. soil moisture influences precipitation

(Randal D. Koster ,etc.20 Aug 2004,Vol305, Science www.Sciencemag.org)

Different climate position have strong impacts on relativity between soil moisture and precipitation:

In the transition zones between wet and dry climates,where evaporation is suitably high but still sensitive to soil moisture, Soil moisture have much impacts on precipitation

Soil Moisture and Flood

2. Soil Moisture impacts on surface runoff

Soil moisture is the important parameter for ground runoff

The popular model of runoff includes:

TOPMODEL

VIC-3L（Variable Infiltration Capacity-3Lays）

…

Soil moisture has strong relativity with Flood through its impacts on precipitation and runoff

Land cover and Flood

- Land cover means the current slipcover on the earth surface formed by natural and human activity.
- It includes soil,vegetation, glacier,lake, swamp,road and so on.
- It is characterized by time and space attributes.

Land cover and Flood

- **Land cover type and its variety have much impact on flood.**

Of all the land cover types, vegetation is an important factor of all factors for forming flood disaster.

- **Storage much water**
- **Lessening loss of soil and sand**

Land cover and Flood

Vegetation influences the storage of the water on ground surface

- Branch and leaves of tree can head off water on crown of a tree
- Herbage plant also can head off some water.
- Vegetation defoliation acts as sponge
    1. absorbing rain water
    2. Slowing water runoff on the ground
    3. Ameliorate soil structure and store water
- Much roots of vegetation can lessen ground runoff

Land cover and Flood

Vegetation can prevent loss of soil and sand

vegetation

↓ prevent

Loss of soil and sand

↓ Lead to

Jam riverbed and reservoir

↓ Then

Flood disaster

- Then we can find:

  Soil moisture and land cover types and its variety influence flood disaster forming.
- Remote sensing technology can provide a good way to monitoring soil moisture and land cover types and its variety for its large scale and real time.
- Microwave remote sensing and thermal infrared remote sensing technologies have been used to monitor soil moisture and land cover.

Remote Sensing-based soil moisture

1. Monitoring soil moisture using microwave remote sensing technology

Complex dielectric constant impacts back scattering,It is sensitive for soil moisture

(1) Synthetic Aperture Radiometry Measurements for Soil Moisture

- The main difficulty with SAR imagery to perform soil moisture change detection

a. surface roughness

b. vegetation cover and topography

c. The difficulty in separating the vegetation ,roughness, topography and soil moisture effects on radar response using single date, single parameter Radar data(ERS, Radarsat)

Current method to model vegetation backscattering

Emperical model

---developed for a single plant structural type based on the increase of the radar backscattering coefficient with biomass according to a power-law relationship in observational data(Ulaby et al., 1986).

Theoritical model

---the vegetation canopy is normally treated as a uniform layer of some specified height containing a random distribution of scatterers(Attema & Ulaby, 1978; Eom & Fung, 1984; Fung & Ulaby, 1978; Karam & Fung, 1988; Lang & Sidhu, 1983; Tsang & Kong,1981)

(1) Synthetic Aperture Radiometry Measurements for Soil Moisture

- Semi-empirical model-”water-cloud”model
  - ---the canopy is represented by “bulk” variables such as leaf area index (LAI) or total water content, and because of the parsimonious use of parameters, these models can be easily inverted;(Ulaby, 1978; Hoekman. Krul, & Attema, 1982; Paris, 1986; Ulaby, Allen, Eger, & Kanemasu, 1984)

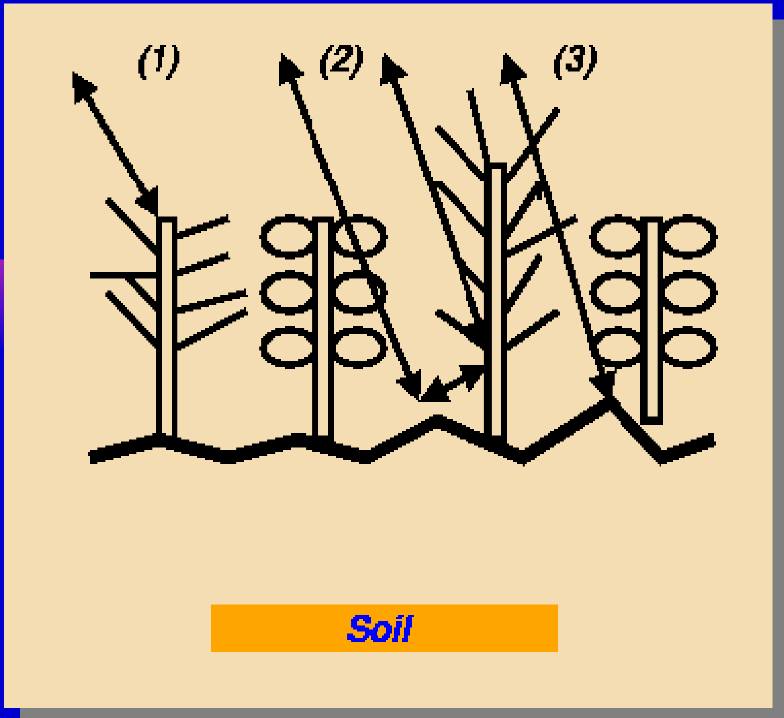
(1) Synthetic Aperture Radiometry Measurements for Soil Moisture

Basic conceptual assumptions in the water-cloud model include:

1. the vegetation is represented as a homogeneous horizontal cloud of identical water spheres, uniformly distributed in space defined by the soil surface and the vegetation height.

2. multiple scattering between canopy and soil can be neglected.

3. the only significant variables are the height of the canopy layer and the cloud density, the latter assumed to be proportional to the volumetric water content of the canopy.



$$\sigma^{\circ} = T^2\sigma_s^{\circ} + \sigma_{dv}^{\circ} + \sigma_{\text{int}}^{\circ}$$

$$\sigma_s^0 = f(\theta, SR) \cdot T^2 \cdot R$$

1) volume scattering in the canopy itself;

2) surface scattering by the underlying ground surface.

3) multiple interactions involving both the canopy and the ground surface.

Soil moisture change detection methods development

1.IEM simulation of soil surface backscattering coefficient

$$\sigma_{hh}^{s}(s)=\frac{k^2}{2}\exp(-2k_z^2\sigma^2)\sum_{n=1}^{\infty}\sigma^{2n}\left|I_{hh}^{n}\right|^2\frac{W^n(-2k_x,0)}{n!}$$

τ

$$\sigma_{veg}=\sigma_t^{\circ}-T\cdot\sigma_s^{\circ}$$

$$T=\exp(-2\cdot\tau\cdot\sec(\theta))$$

τ = b*vwc

$$b=b'*(\lambda)^x$$

(1) Passive Microwave Measurements for Soil Moisture

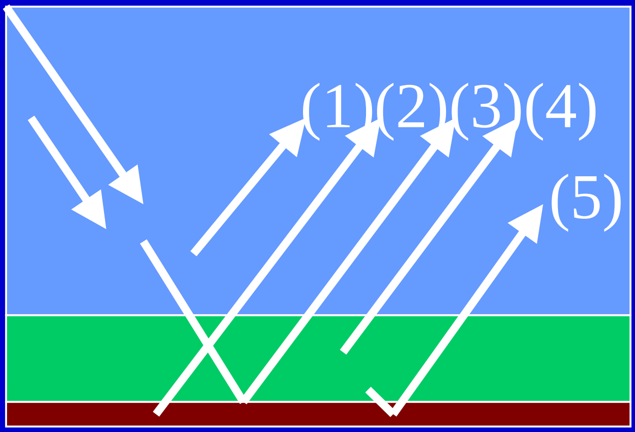
Theoretic base of soil moisture retrieval using passive microwave remote sensing technology

$$I_R \sim T_B = eT_S = (1 - r_S)T_S$$

Soil radiation:

$$e_P = 1 - \Gamma^*_{S_P} = 1 - \left|R_P(\varepsilon_S, \theta)\right|^2 \qquad (1)$$

Transmission equation of passive microwave



a) No atmosphere, no vegetation (2)

$$T_B = \varepsilon T_S$$

b) No vegetation (1), (2), (3)

$$T_{BS} = T_{au} + (1-\varepsilon)[T_{ad} + T_{sky}\exp(-\tau_{at})]\exp(-\tau_{at}) + \varepsilon \mathrm{T}_S \exp(-\tau_{at})$$

c) full solution (1) – (5)

$$T_B = cT_{BV} + (1-c)T_{BS}$$

$$\begin{aligned} T_{BV} = {} & T_{au} + \exp(-\tau_{at})[T_{ad} + T_{sky}\exp(-\tau_{at})](1-\varepsilon)\exp(-2\tau^*) \\ & + \exp(-\tau_{at})[\varepsilon T_S \exp(-\tau^*) + T_V(1-\omega^*)(1-\exp(-\tau^*)) \\ & (1+(1-\varepsilon)\exp(-\tau^*))] \end{aligned}$$

Remote Sensing-based soil moisture

2. Using thermal infrared remote sensing technology to monitoring soil moisture covered by vegetation

1. Energy balance model

2. Vegetation Condition Index model (VCI)

3. Normalized Difference Water Index model (NDWI)

Models

1. Energy balance model

$$A = R_n - G$$

$$= \lambda E + H$$

Rn is net wavelength radiation (units W m-2)

G is the heat flux into the soil or other storages (units W m-2),

E is the Evapotranspiration (ET) flux (*m sec*-*1*) of water vapour;

λ is Latent heat of vaporisation of water (*J m*-*3*); and

H is sensible heat flux (*W m*-*2*), or the energy involved in the movement of the air and its transfer to other objects

λE is the flux of water as water vapour expressed as the energy used to change the water from liquid to vapour.

Models

1. Energy balance model

$$\lambda E = (R_n - G) - H$$

The (Energy Balance) moisture availability

$$m_a(EB) = \lambda E / \lambda E_p$$

Crop Water Stress Index (CWSI)

$$CWSI = 1 - m_{ad}$$

$$= 1 - \frac{E_d}{E_{pd}}$$

Models

1. Energy balance model

Normalized Difference Temperature Index (NDTI)

$$m_a(EB) \approx NDTI$$

$$= \frac{T_\infty - T_s}{T_\infty - T_0}$$

T_∞ is the surface temperature which would theoretically occur if there
T_0 was no available water - modelled as infinite surface resistances,
is the temperature that would theoretically occur for fully available moisture - modelled as zero resistance

Models

1. Energy balance model

For vegetation-covered one layer model was used to estimate evapotranspritation

$$\lambda E = R_n - G - H \qquad R_n = (1-\alpha)R_s + \varepsilon\sigma(\varepsilon_a T_s^4)$$

$$\varepsilon_a = 1.24(e_a / T_a)^{1/7} \qquad G = G_f R_{ng}$$

$$R_{ng} = (1 - f_v)R_n \qquad G = (0.1 - 0.042h)R_n$$

$$\lambda E = \frac{\rho C_p}{\gamma}\frac{(e_s(T_e) - e_a)}{r_a + r_s} \qquad m_a(EB) = \frac{r_a}{r_a + r_s}$$

Models

1. Energy balance model

For partial vegetation-covered two layer model which was considered soil and vegetation respectively was used to estimate evapotranspritation

$$\lambda E_v = \frac{\rho C_p}{\gamma}\frac{(e_s(T_{vs}) - e_e)}{r_v + r_{vs}}$$

$$H_v = \rho C_p \frac{T_v - T_e}{r_v}$$

$$\lambda E_s = \frac{\rho C_p}{\gamma}\frac{(e_s(T_g) - e_e)}{r_g + r_{gs}}$$

$$H_g = \rho C_p \frac{T_g - T_e}{r_g}$$

$$\frac{1}{\rho C_p}A_v = \frac{1}{\gamma}\frac{(e_s(T_v) - e_e)}{r_v + r_{vs}} + \frac{(T_v - T_e)}{r_v}$$

$$\frac{1}{\rho C_p}A_v = \frac{1}{\gamma}\frac{(e_s(T_g) - e_e)}{r_g + r_{gs}} + \frac{(T_g - T_e)}{r_g}$$

$$\frac{(T_e - T_a)}{r_a} = \frac{(T_v - T_e)}{r_v} + \frac{(T_g - T_e)}{r_g}$$

$$\frac{(e_e - e_a)}{r_a} = \frac{(e_s(T_v) - e_e)}{r_v + r_{vs}} + \frac{(e_s(T_g) - e_e)}{r_g + r_{gs}}$$

Models

1. Energy balance model (two layer model)

$$m_{av} = \lambda E_v / \lambda E_{vp}$$

$$m_{ag} = \lambda E_g / \lambda E_{gp}$$

$$m_a(EB) = \frac{\lambda E_v + \lambda E_g}{\lambda E_{vp} + \lambda E_{gp}}$$

$$T_g = f_v T_v + (1 + f_v) T_g$$

$$P = r_v H_v^2 + r_g H_g^2 + r_a H^2$$

$$H = \rho C_p \frac{T_e - T_a}{r_a}$$

$$r_a' = f_v^2 r_v + (1 - f_v)^2 r_g$$

$$\rho C_p \frac{T_s - T_a}{r_a + r_a'}$$

$$T_g = \frac{r_a'}{r_a + r_a'} T_a + \frac{r_a}{r_a + r_a'} T_s$$

Models

1. Energy balance model

For low vegetation-covered or bare soil thermal inertia model was used to estimate soil moisture

$$P=\sqrt{\rho c\lambda}=\sqrt{C\lambda}=\sqrt{C^2k}=C\sqrt{k}$$

$$T\big|_{t=0}=T_0$$

$$\rho c\frac{\partial T}{\partial t}=\lambda\frac{\partial^2 T}{\partial z^2}$$

$$\frac{\partial T}{\partial x}\Big|_{x=o}=0$$

$$G=\left(-\lambda\frac{\partial T}{\partial z}\right)_{z=0}=R_s+R_L-R_e-H-LE\cong R_s-A-BT_g$$

Models

1. Energy balance model (thermal inertia model)

$$\Delta T_g = T_{\max} - T_{\min} = (1 - A_s) C_T S_0 \times \sum_{n=1}^{\infty} \frac{A_n \left[\cos(n\omega(t_{\max} - \delta_n)) - \cos(n\omega(t_{\min} - \delta_n))\right]}{(B^2 + BP\sqrt{2\omega n} + P^2 \omega n)^{1/2}}$$

$$\delta = \cot^{-1}[1 + (2/n\omega)^{1/2} B/P]$$

$$A_1 = \frac{2\psi}{n\pi} \sin n\pi + (0.5 \sin 2x + x)$$

$$A_1 = \frac{2\psi}{n\pi} \sin n\pi + \frac{2\theta(n \sin n\pi \cos x - \sin x \cos nx)}{\pi(n^2 - 1)}$$

$$where\ \psi = \sin\delta \sin\varphi$$

$$\theta = \cos\delta \cos\varphi$$

$$x = \arccos^{-1}(\tan\delta \tan\varphi)$$

$$B = g + h\Delta T_g^2$$

$$g = 4\varepsilon\sigma(1 - ac)(b + c\bar{T}_a)^3 + d(1 - a) - en$$

$$h = 3\pi\varepsilon\sigma(b + c\bar{T}_a)(1 - ac)a^2 c^2$$

Models

2. Vegetation Condition Index (VCI)

$$VCI_j = \frac{NVDI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100\%$$

VCI_j is the image of vegetation condition index values for date j;

$NDVI_j$ is the image of NDVI values for date j;

$NDVI_{max}$ is the image of maximum NDVI values from all images within the data set;

$NDVI_{min}$ is the image of minimum NDVI values from all images within the data set.

Models

2. Vegetation Condition Index (VCI)

$$MVCI_{j,\,Jan} = \frac{NDVI_{j,\,Jan} - NDVI_{min,\,Jan}}{NDVI_{max,\,Jan} - NDVI_{min,\,Jan}}$$

$MVCI_{j,Jan}$ is the image of monthly vegetation condition index values for date j, which falls within the month of January;

$NDVI_{j,Jan}$ is the image of NDVI values for the jth image recorded in January;

$NDVI_{max,Jan}$ is the image of maximum NDVI values from all images acquired in January; and

$NDVI_{min,Jan}$ is the image of minimum NDVI values from all images acquired in January.

Models

3. Normalized Difference Water Index (NDWI)

$$NDWI = \frac{P_{SW} - P_R}{P_{SW} + P_R}$$

NDWI is Normalized Difference Water Index

P_{SW} is reflectance at the band of shortwave infrared

P_R is reflectance at red band.

Spectral signature of vegetation canopy at the waveband 1.55-1.75 μm is sensitive to water content in canopy. A Normalized Difference Water Index (NDWI) has been developed to monitor drought during period of crop growing.

Models

4. Other models

Anomalous NDVI model (ANDVI)

$$ANDVI = \frac{NDVI - \overline{NDVI}}{\overline{NDVI}}$$

NDVI **is Normalized Difference Vegetation Index**

$\overline{NDVI}$ **is Average NDVI for many years**

Models

4. Other models

Combination model (CM)

$$CM = \frac{NDVI}{T_S}$$

T_S is surface temperature from NOAA-AVHRR thermal data

Remote sensing-based land cover

- Study of land cover in China mainly means study in large scale.
- So remote sensing technology is inevitable.
- Through analysis of remote sensing image, we can get the types,patterns of land cover in time and space dimension.
- We can find vegetation distribution and variety through land cover classification

Remote sensing-based land cover

- The key of land cover classification is discriminance function and algorithm
- Popular land cover classification algorithms include:

  1、statistical classification algorithm

  2、artificial intelligence algorithm

Remote sensing-based land cover

1、 statistical classification algorithms include:

- K-mean
- Decision-making tree algorithms
- ISODATA
- Blur K-mean
- …

Remote sensing-based land cover

2、 Artificial intelligence algorithm

- BP neural network
- apperceive machine
- ...

Conclusion

- Soil moisture impact on precipitation
- Soil moisture influence runoff
- Land cover type has strong relativity with flood
- Using remote sensing technology can accurately determine soil moisture and land cover type

Reference and expert

Randal D.Koster,etc.20 Aug2004,Vol305,Science

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Thank you.

Questions?

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