森林生态水文长期监测与研究

刘世荣

中国林业科学研究院

Distracting our focus from carbon to water

Trading Water for Carbon with Biological Carbon Sequestration

Robert B. Jackson,[1*] Esteban G. Jobbágy,[1,2] Roni Avissar,[3]
Somnath Baidya Roy,[3] Damian J. Barrett,[4] Charles W. Cook,[1]
Kathleen A. Farley,[1] David C. le Maitre,[5]
Bruce A. McCarl,[6] Brian C. Murray[7]

Carbon sequestration strategies highlight tree plantations without considering their full environmental consequences. We combined field research, synthesis of more than 600 observations, and climate and economic modeling to document substantial losses in stream flow, and increased soil salinization and acidification, with afforestation. Plantations decreased stream flow by 227 millimeters per year globally (52%), with 13% of streams drying completely for at least 1 year. Regional modeling of U.S. plantation scenarios suggests that climate feedbacks are unlikely to offset such water losses and could exacerbate them. Plantations can help control groundwater recharge and upwelling but reduce stream flow and salinize and acidify some soils.

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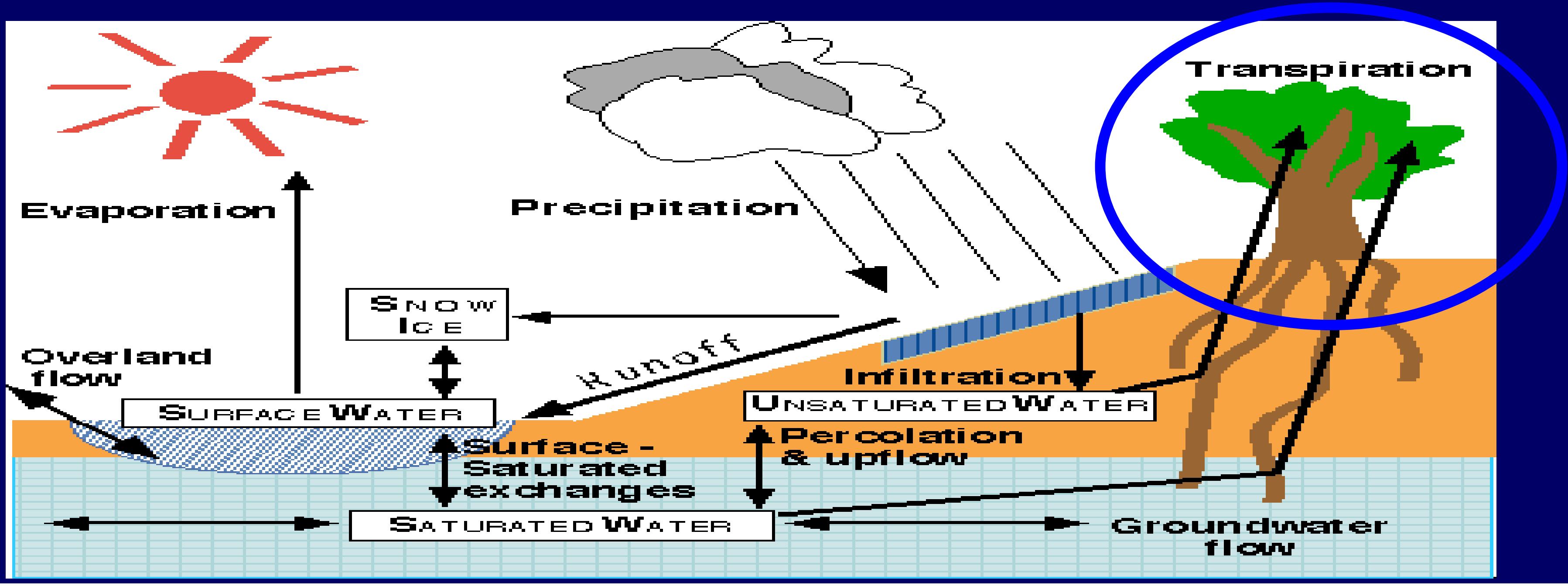
森林水文研究的由来

- 研究如何利用森林来防止水土流失、控制洪涝灾害和稳定河川径流；
- 1900年在瑞士Sperbelgraben和Rappengraben两个流域首次开展集水区研究；1909年在美国科罗拉多州南部的 Wagon Wheel Gap建立了世界第一个配对集水区开展径流观测与研究；
- 森林水文研究经历了从神话、传说、观测到科学论证不断发展的过程，但是长期以来一直存在的关于森林对径流影响的激烈的争论，至今有关森林与径流关系的认识仍然未能达成广泛的共识；

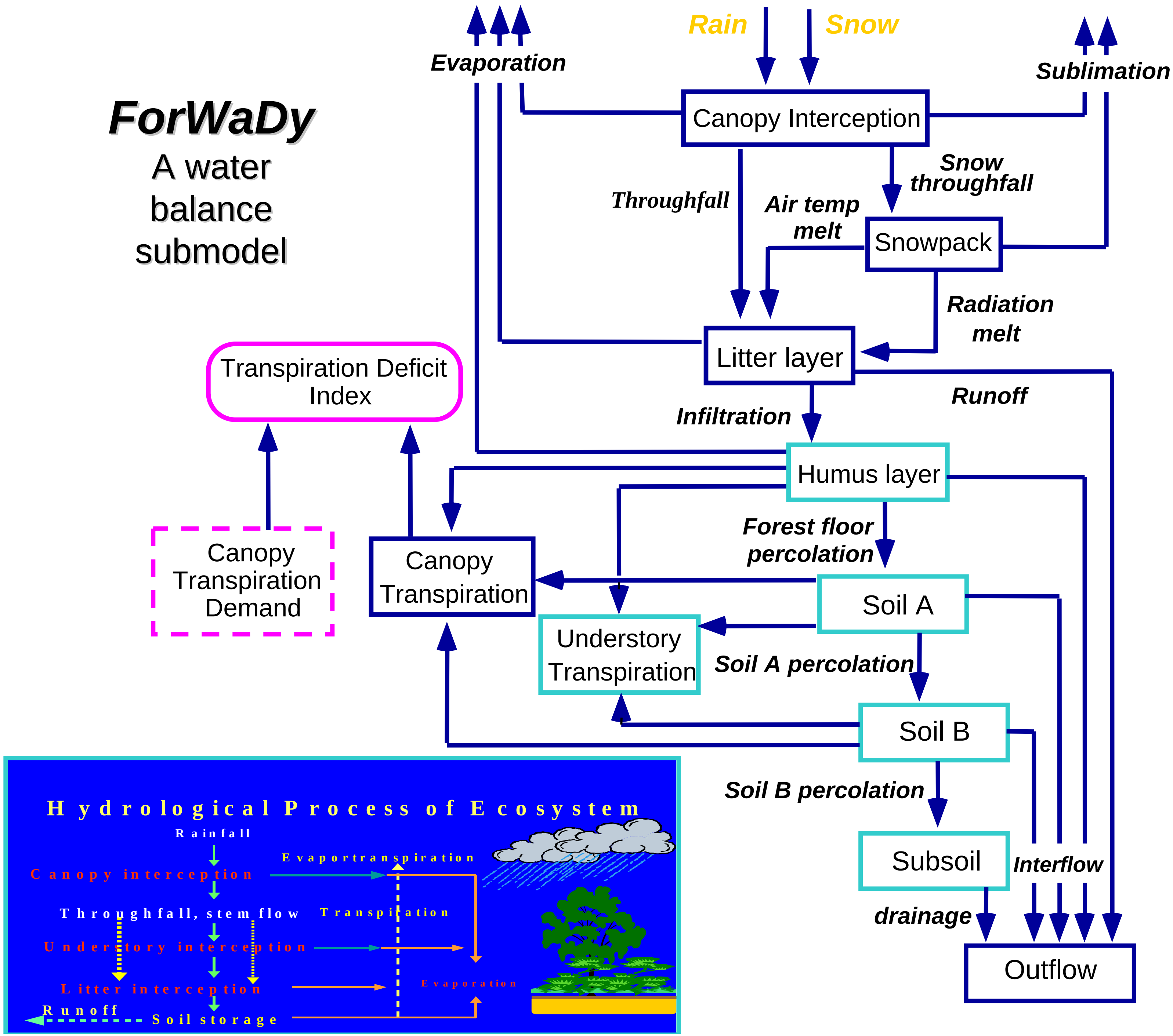
森林流域水文循环过程的复杂性

- 水的自然属性：高度流动性和形态变化
- 生命构成物质并联结其它功能过程的纽带和媒介
- 大气、植被、土壤之间的相互作用对径流产生影响
- 降水时空异质性、森林植被动态变化、流域下垫面的空间异质性造成水文过程的非线性变化与尺度效应



ForWaDy

A water balance submodel



生态与水文的耦合过程

现代森林水文研究的目的

- 科学评价集水区生态系统对自然干扰、经营管理活动和其它全球变化相关的各种人类干扰（环境变化、土地利用和土地覆盖变化等）的响应与适应机制；
- 为有效发挥集水区生态系统的服务功能和实施集水区生态系统的可持续管理提供科学依据。


森林水文研究的重点领域

- 森林集水区生态系统的结构、功能变化和其中的陆地、河岸与水域各组分之间的相互作用机制研究；
- 自然资源管理对森林集水区生态系统影响的评价原理、方法和技术规范；
- 开展长期生态水文学过程观测研究，发展森林集水区生态系统的长期观测与网络化研究，深化生态格局－水文过程－尺度效应的理论认识。

美国Coweeta森林水文的长期研究

（Paired Watershed Approach）

- 1934建立，基础设施是公共建设项目资助；
- 1936-1939 观测规范化、标准化过程；
- 1940's初期和1960's开展土地利用管理示范
- 1940's至1960's后期开展径流/水量观测研究；
- 从1968至今，开展集水区生态系统长期研究。

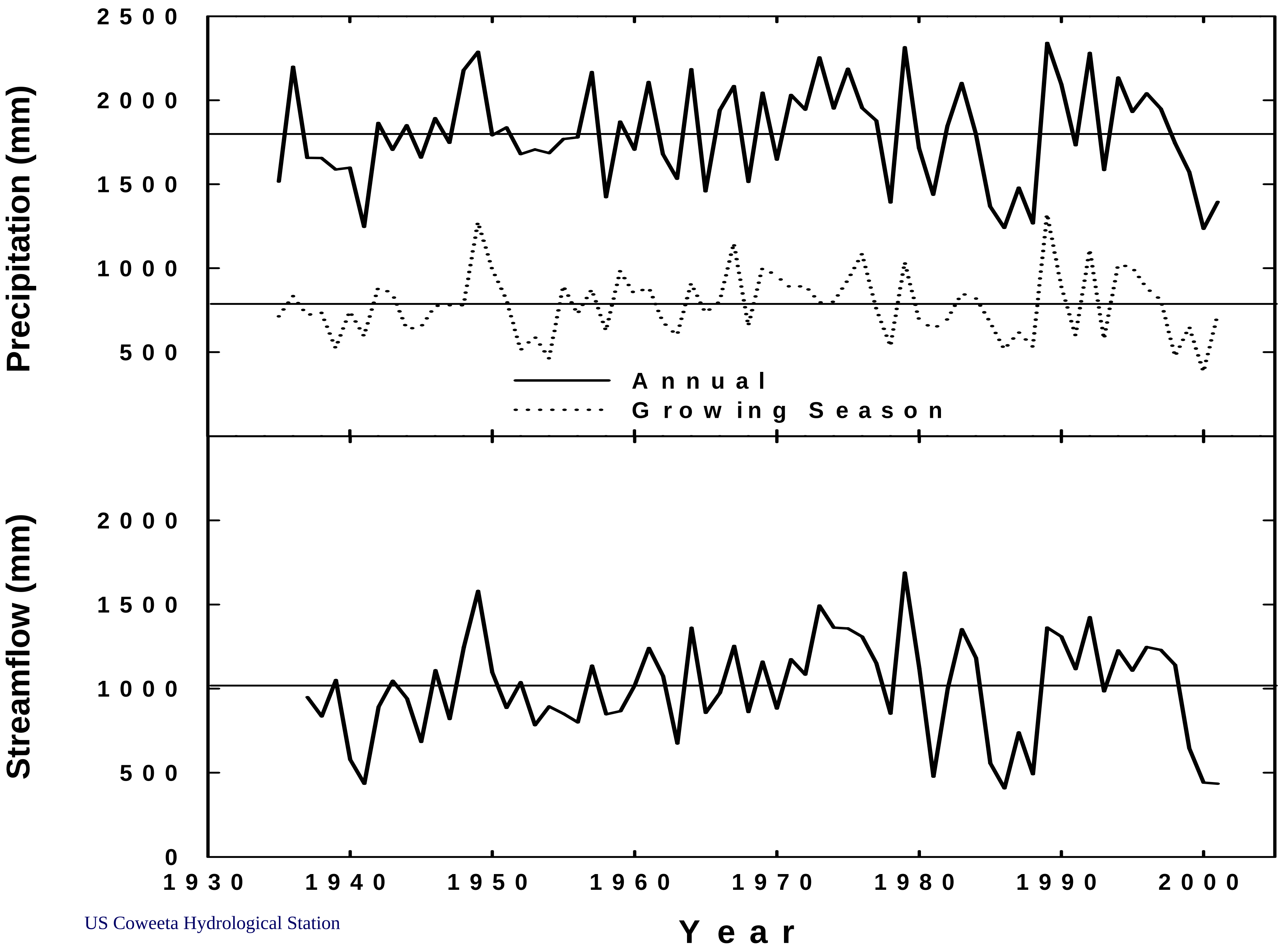
Coweeta Climate Station CS01 - 1934

Coweeta Climate Station CS01 - 2004


Weir Construction – mid 1930's

Ball Creek Weir - 2004

2007-1-4



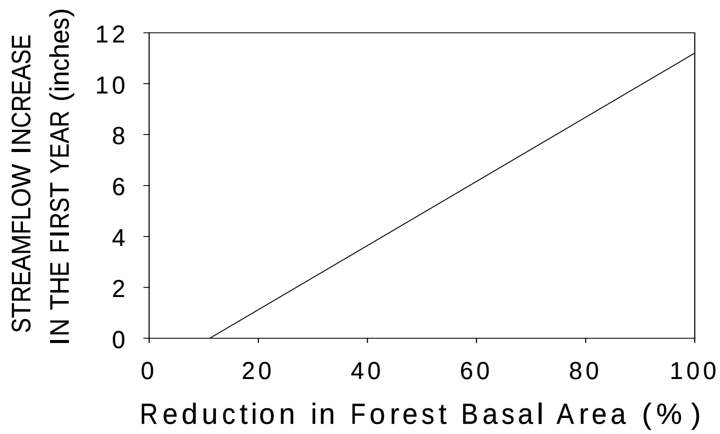
US Coweeta Hydrological Station

长期水文研究获取的宝贵经验

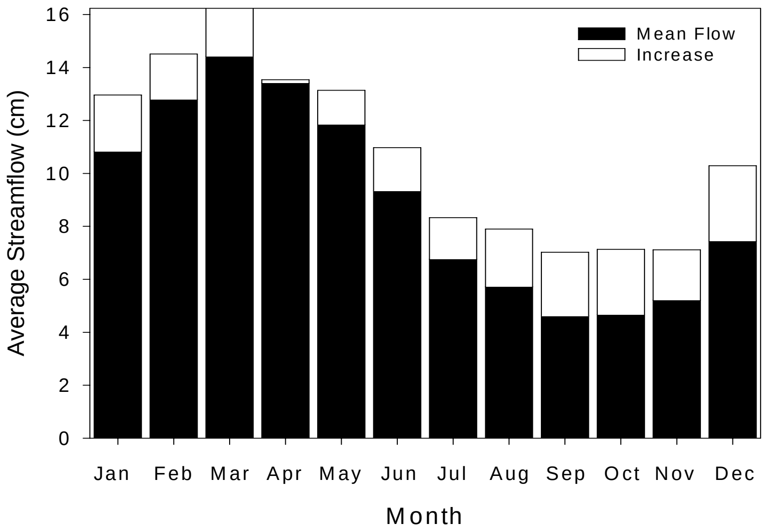
- 需要付出真正的努力和承诺去收集和积累长期的观测数据；
- 数据质量控制和质量保证至关重要；
- 完好记录、数据库和档案管理相当重要；
- 长期连续的数据是相当罕见的，而高质量的长期观测数据是价值无比。

Coweeta Water Yield Studies Have Produced an Understanding Of the Relationships Among Vegetation, Site, and Streamflow

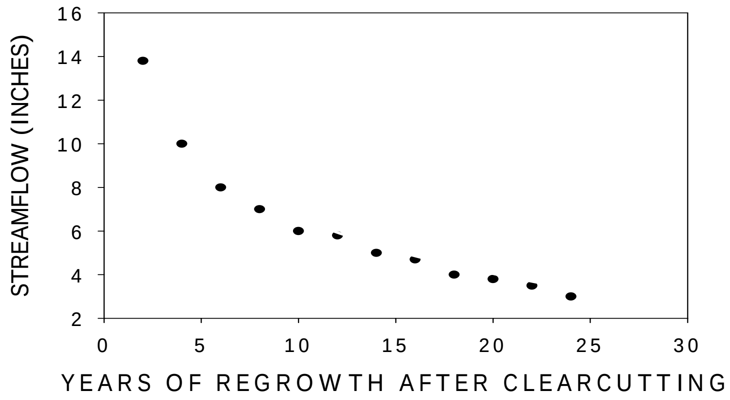
Amount of Increase



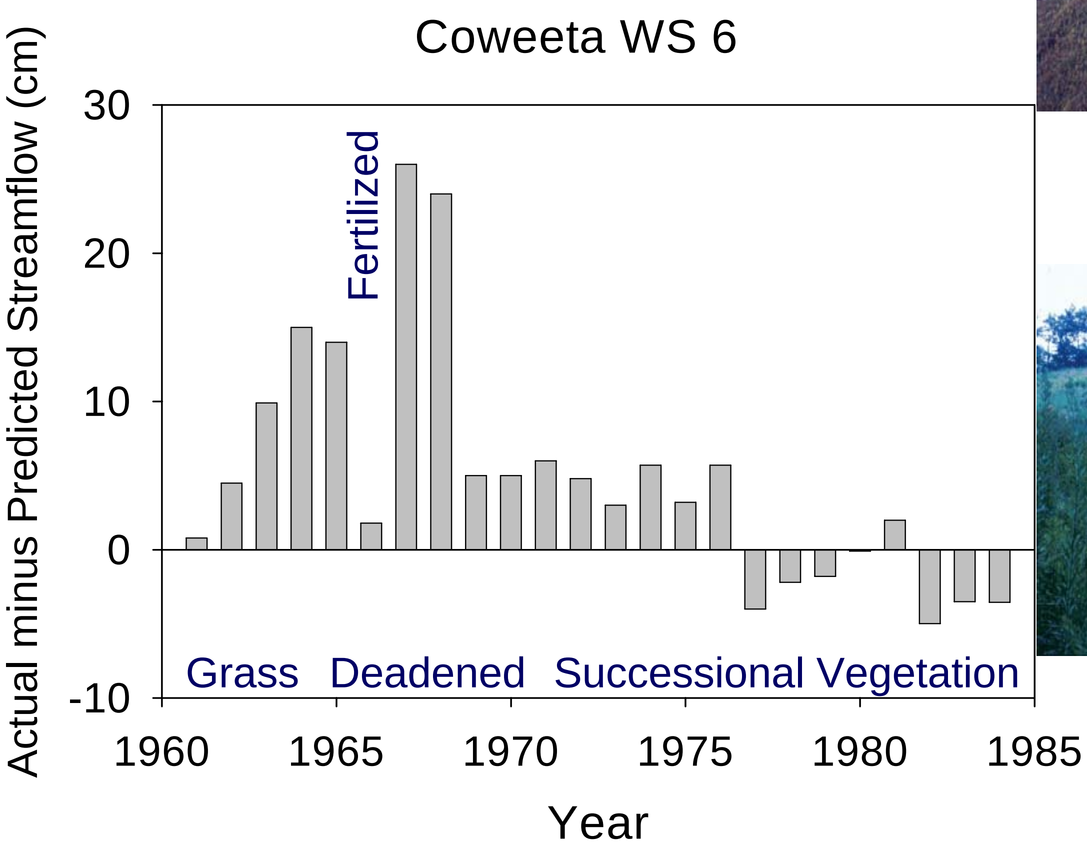
Timing

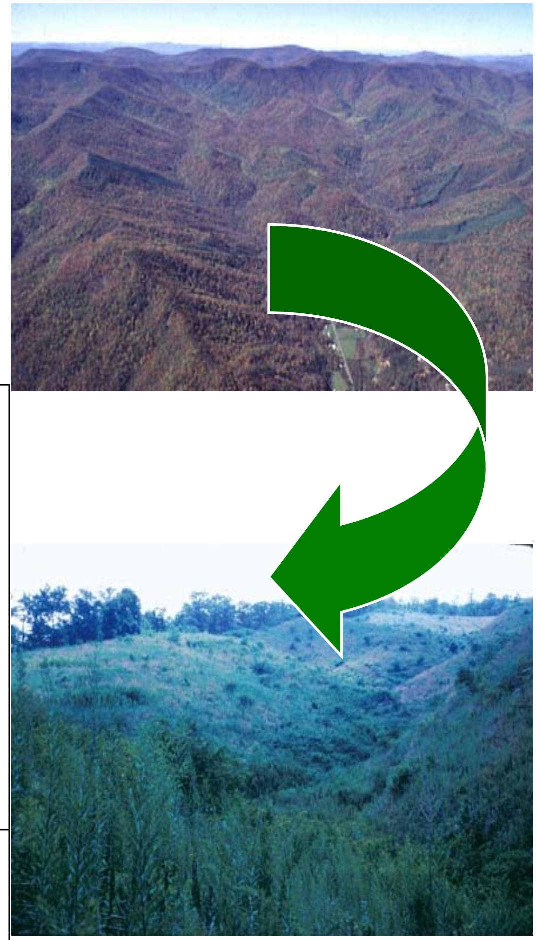


Duration



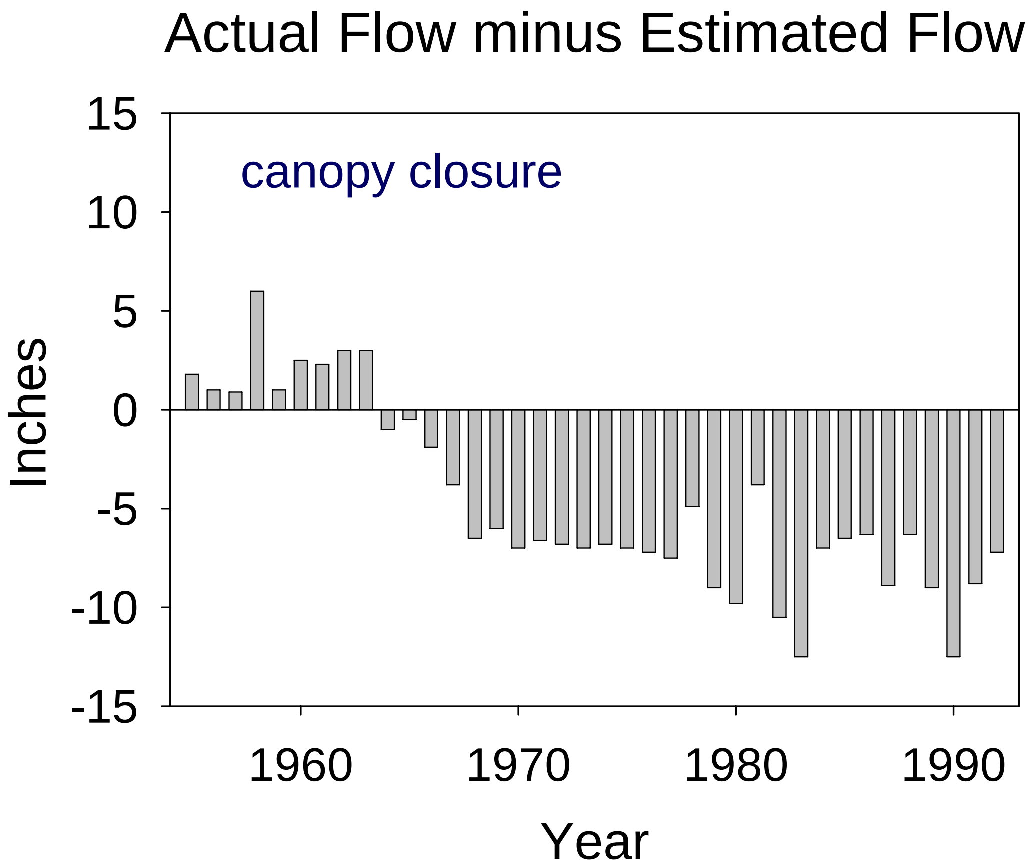
US Coweeta Hydrological Station



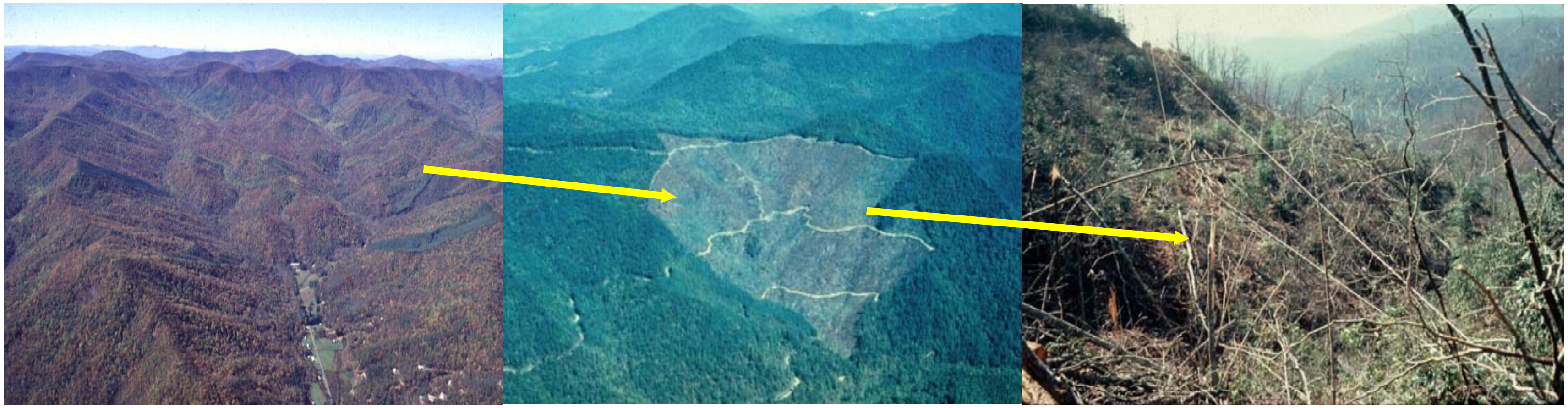


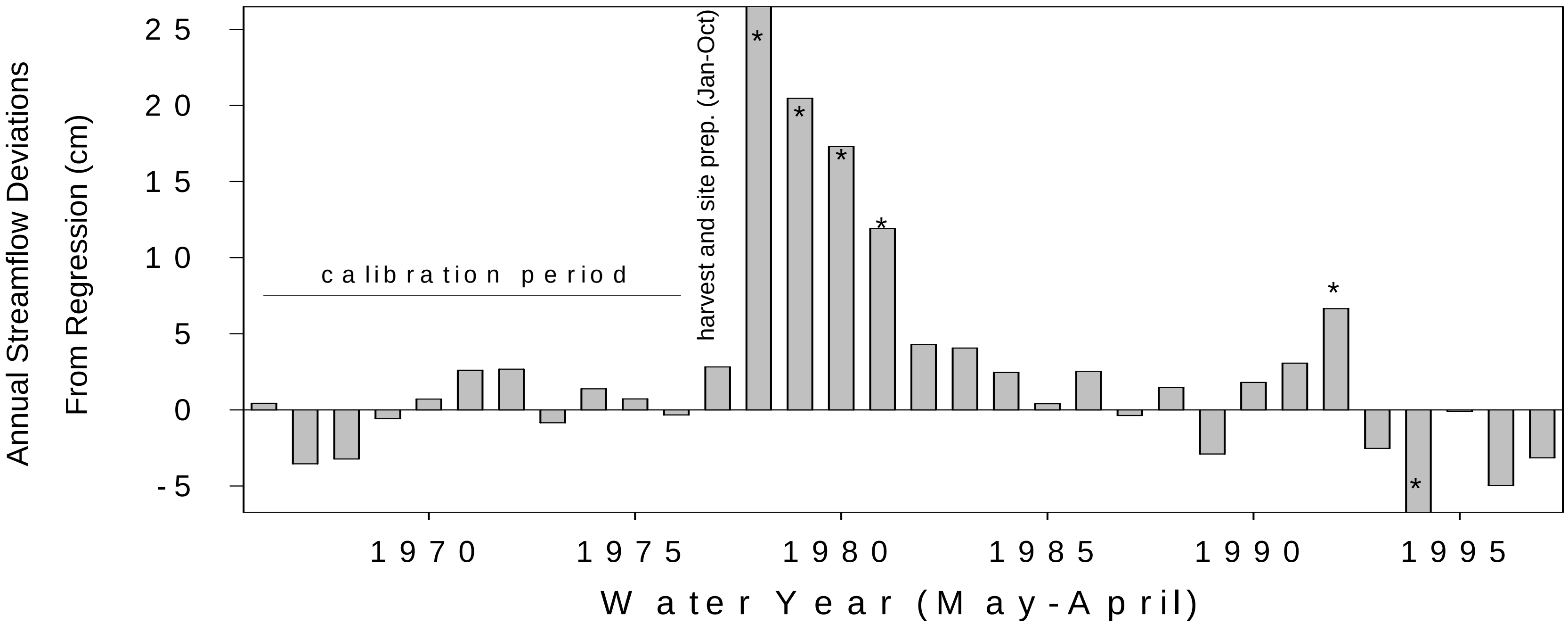
处理前是草地，1966－67年除草剂处理清除草本植物，然后经历自然演替恢复过程

US Coweeta Hydrological Station



改变树种的水文长期观测试验：从阔叶树种转为栽种白松人工林的水文效应研究

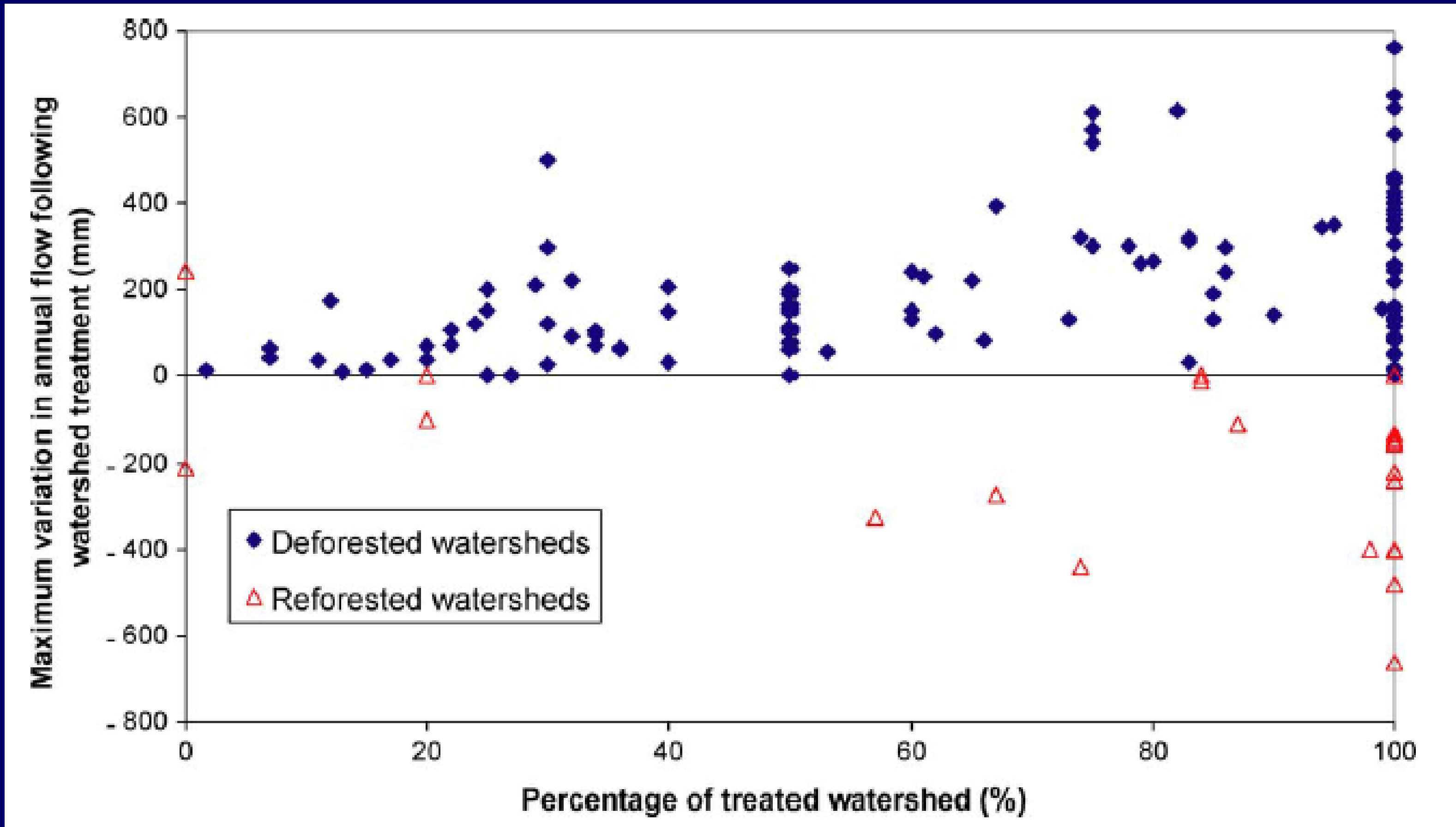




皆伐作业和整地后天然更新的水文长期观测试验

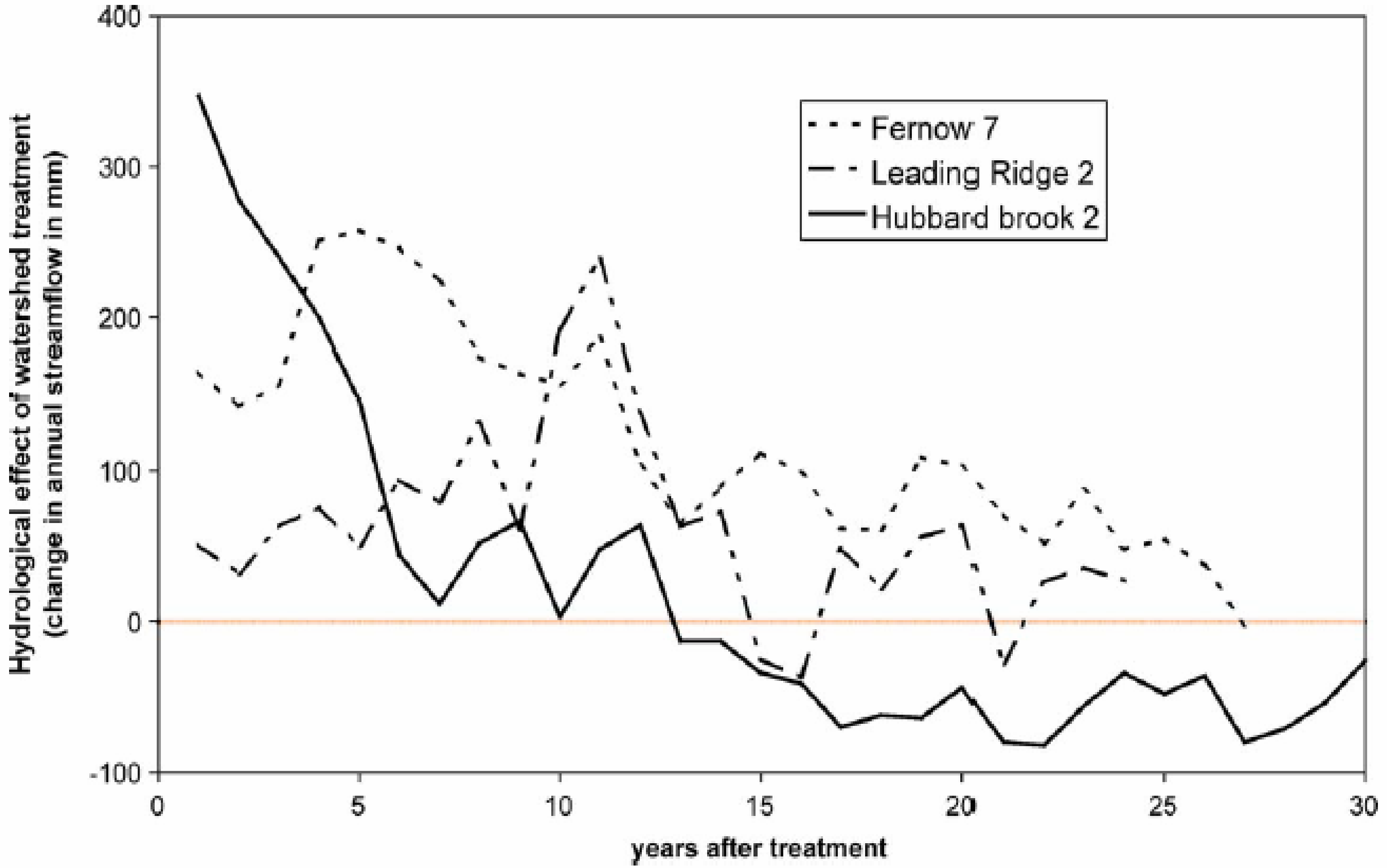
US Coweeta Hydrological Station

Bosch和Hewlett（1982）137个对比流域实验(115个森林采伐和22个造林)结果，80%流域面积小于2km^2



1. Bosch J M, Hewlett J D, 1982. A review of catchment experiments to determines the effects of vegetation change on water yield and evapotranspiration. **Journal of Hydrology**, 55:3~22
2. Stednick J D, 1996. Monitoring the effects of timber harvest on annual water yield. **Journal of hydrology**, 176:79~95
3. Hibbert, A.R, 1965. Forest treatment effects on water yield. In: W.E.Sopper and H.W.Lull (Editors), Int. SVmp. For. Hydrol., Pennsylvania, September 1965. Pergamon, Oxford.

美国东北部3个流域森林采伐的影响随着伐后时间推移逐渐减小（V. Andréassian,2004）



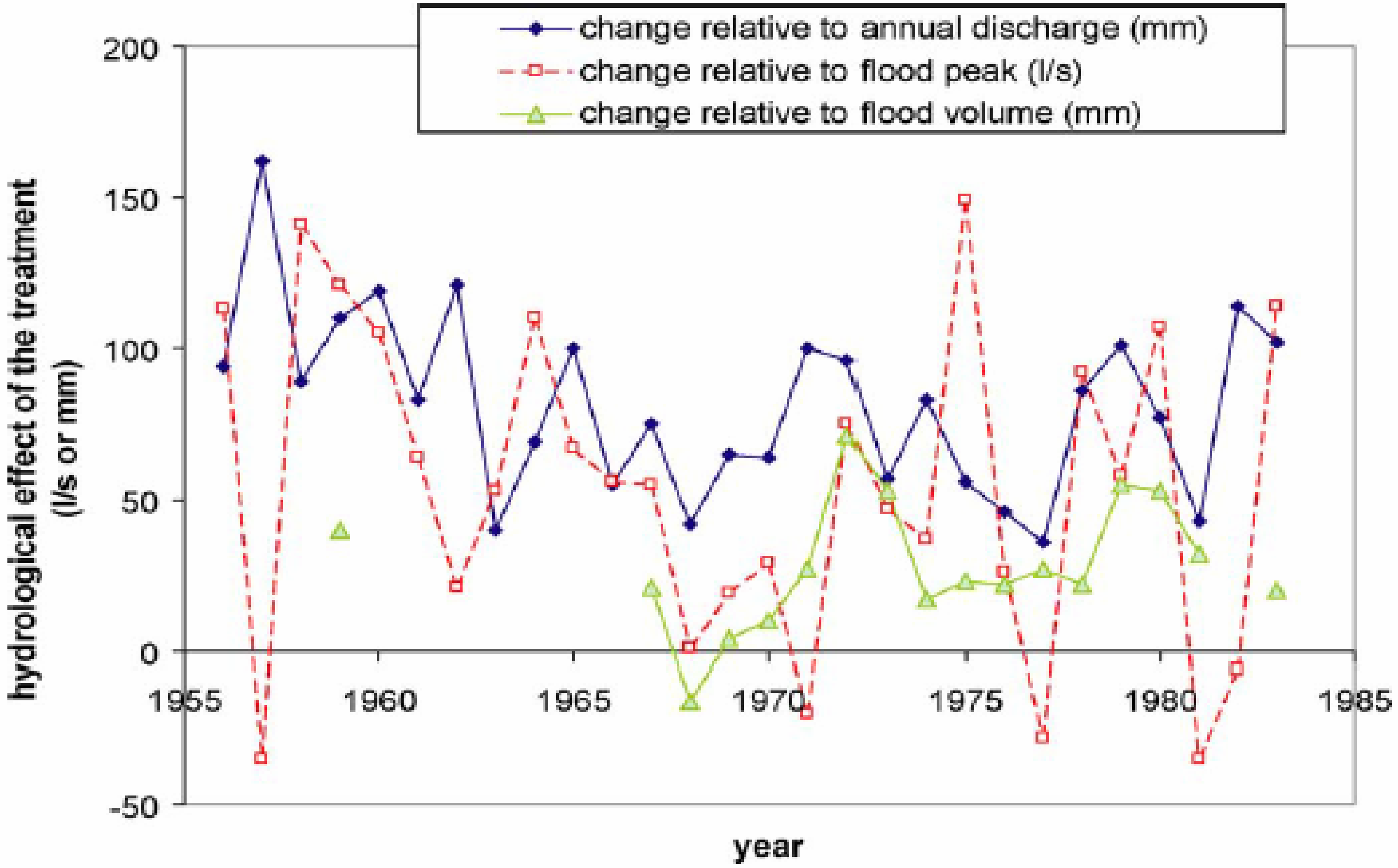
Andréassian, V. 2004. Waters and Forests: from historical controversy to scientific debate. Journal of Hydrology 291:1-27.

森林采伐对洪水影响的观测结果（V.Andréassian,2004）

Watershed	Surface area (km^2)	Reference	Treated area (%)	Variation in flood peak	Variation in flood volume
Wagon Wheel Gap	0.81	Bates and Henry (1928)	100	+50%	+30%
Coweeta	0.44–1.44	Swank et al. (1988)	100	+7 to +30%	
Hubbard Brook	0.16–0.35	Hornbeck et al. (1997)	100	−40 to +63%	
Fool Creek	2.89	Troendle and King (1985)	40	−18 to +108% (mean +23%)	−5 to +18% (mean +8%)
Réal Collobrier	1.5	Lavabre et al. (1993)	85	0 to +200%	+30% to +40%
ECEREX (basins A, C, D, E, G, H, I, J)	0.01–0.016	Fritsch (1990)	100	+17% to +166%	+21% to +104% (mean +57%)
Brownie creek	21.34	Burton (1997)	25	+45%	

Andréassian, V. 2004. Waters and Forests: from historical controversy to scientific debate. **Journal of Hydrology** 291:1-27.

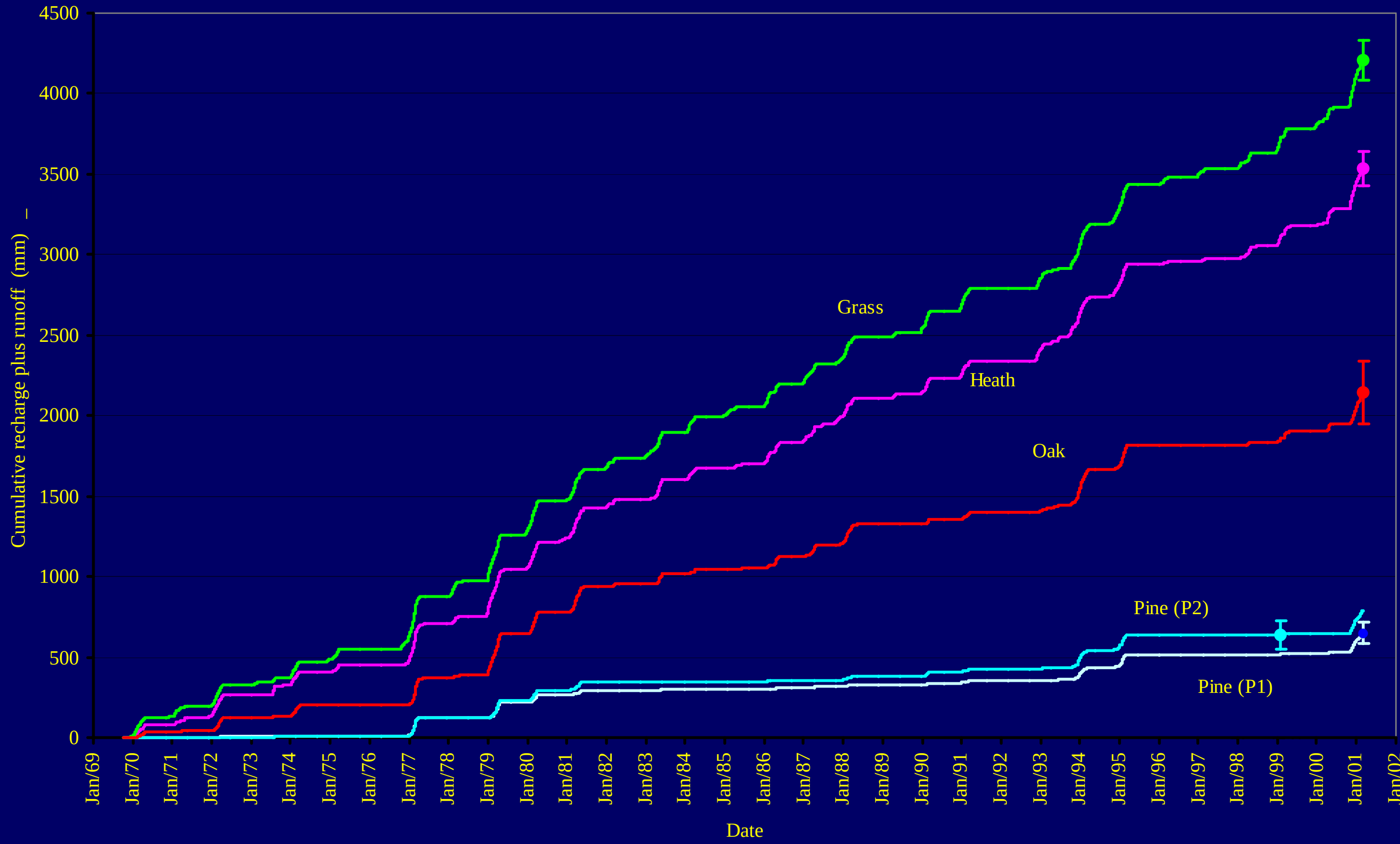
美国科罗拉多州Fool Creek流域森林采伐40％后洪水径流3个参数的年变化（Troendle 和 King,1985)



Approaches	Impacts of Forest				Data Source
Hydrological parameter	**Annual mean flow**	**Peak flow**	**Low flow**	**Overland flow**	Case Studies in China
Small runoff plots (2 m2)	↓	↓	--*	↓	Wei and Zhou 1991
Paired watersheds (0.2-2 km^2)	↓	↓	--	↓	Wang and Zhou 1994
Regression analysis (2-100 km2)	↓	↓	↓	--	Zhou et al. 1994
Regression analysis (>100 km2)	↑	↓	↑	--	Cao et al. 1994
Small runoff plots (100 m2)	↓	↓	↓	↓	Lei et al. 1994
Paired watersheds (3-4 km2)	↑	↓	↑	↓	Liu et al. 2001
Small runoff plots (142-356 m2)	↓	↓	↑	--	Tian et al. 1994
Single watershed (300 m2)	↓	↓	↑	↓	Zhou et al. (1994)

Wei X.H., Liu S.R. Zhou G. Y. & C. Wang. 2005. Hydrological processes in major types of Chinese forest. Hydrological Processes. 19,63-75.

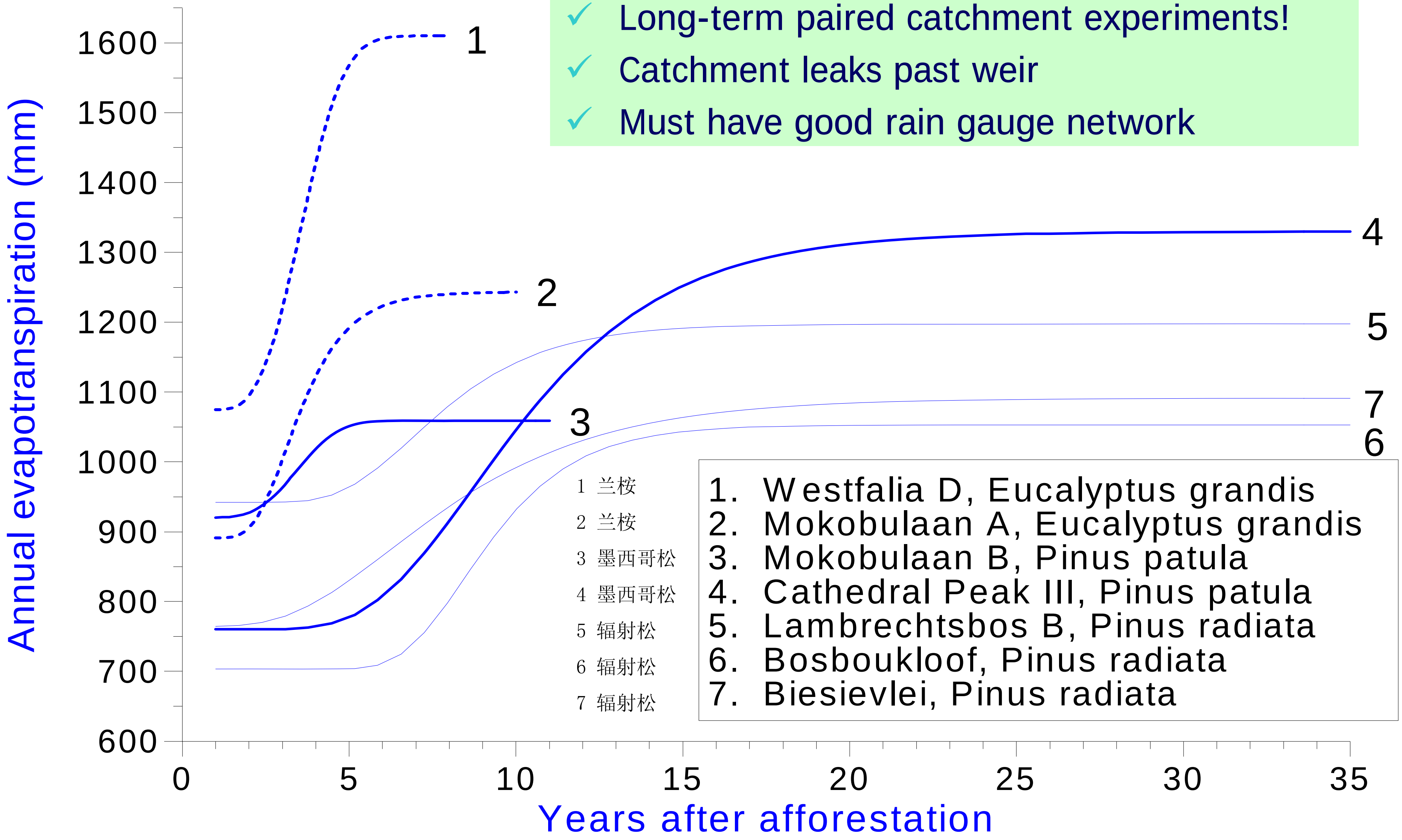
Vegetation effect in UK



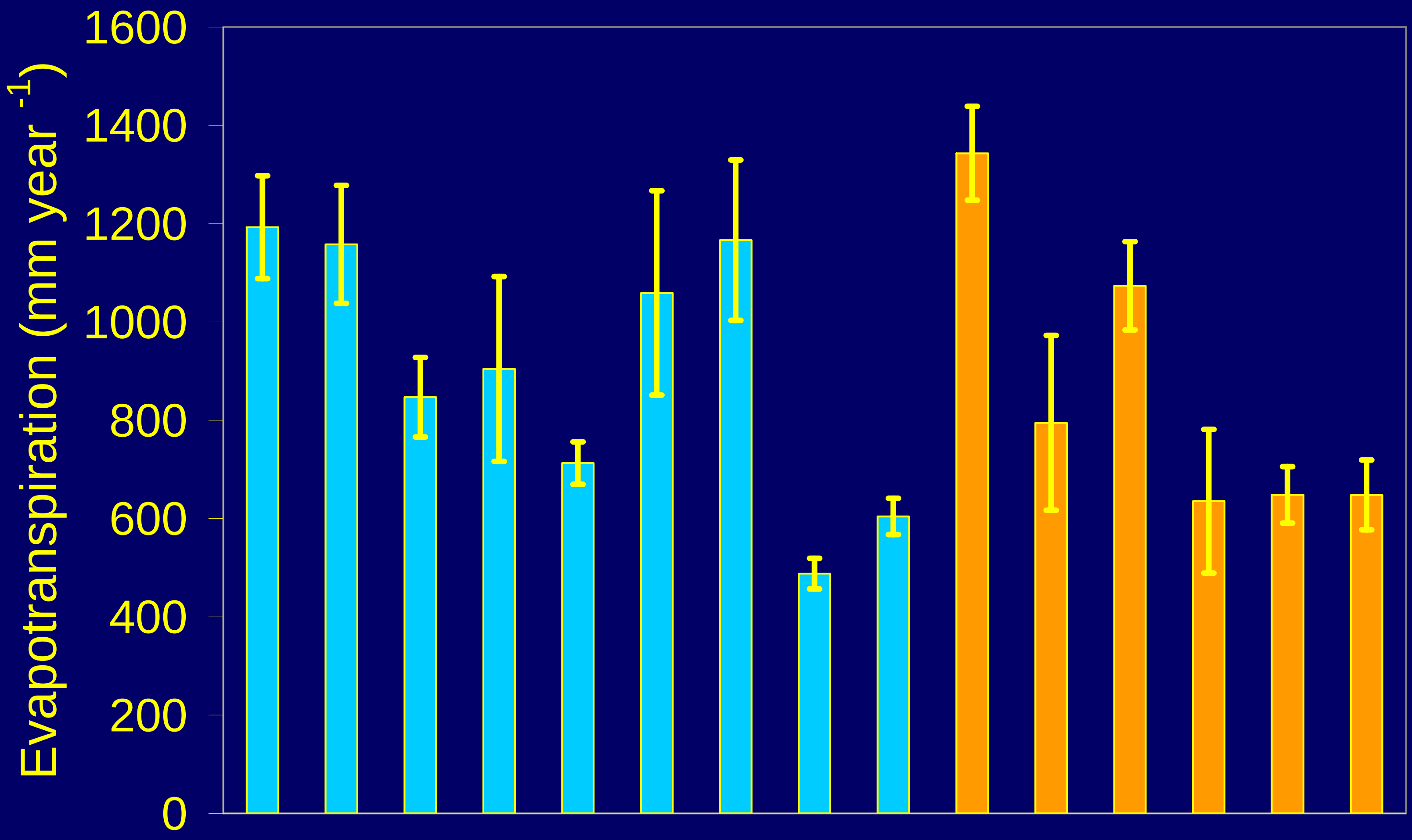
- Sherwood Forest Studies indicate reduced recharge under pine (1/4) and under oak (1/2) as compared with grassland. Also water quality problems. Results supported by UK Forestry Commission.

Species effect in South Africa

- Long-term paired catchment experiments!
- Catchment leaks past weir
- Must have good rain gauge network

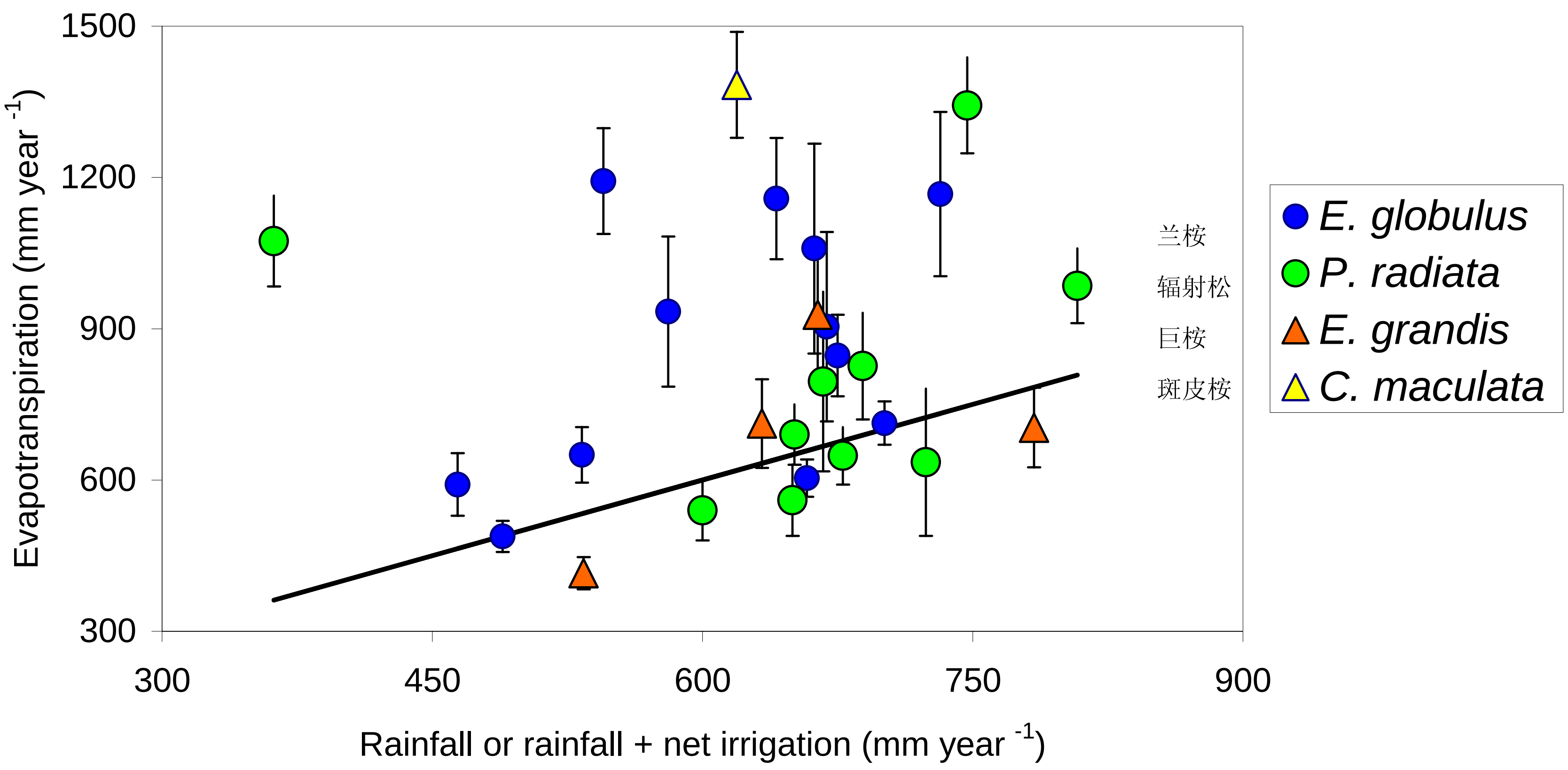


Spatial variability in Eucalyptus in Austrilia

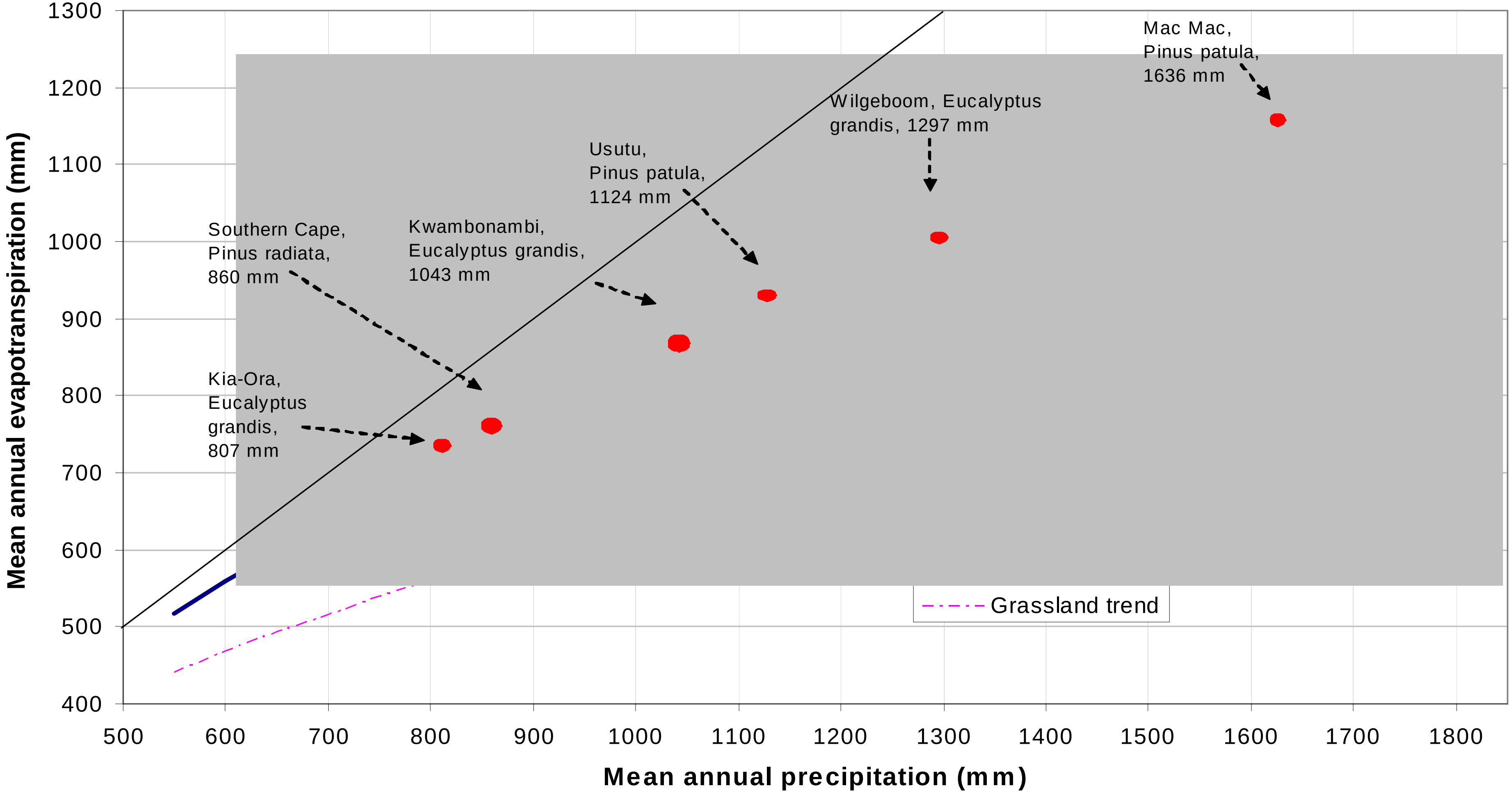


Error bars indicate 90% confidence limits

Relationship between rainfall and water use at various plantation research sites in Austrilia



Relationship between rainfall and water use at various plantation research sites in South Africa



森林植被对径流影响

- 同一流域采伐先后对比、多林与少林流域对比，或成对集水区法分析，结论一致性和复杂性，尚需深入的长期观测研究
  - 森林采伐通常增加产水量，造林则减少产水量
  - 造林减少枯水流量，采伐则增加枯水流量
  - 采伐通常增加洪峰和洪水流量
- 森林与径流关系的复杂性表现为较大变异和不确定性（树种、土壤、气候和各种干扰等）

科学问题思考（1）

- 森林植被在陆地生态水文循环过程不是孤立的水文景观静态要素，森林植被的生长、结构和功能的动态变化直接影响陆地水文循环过程
- 采用小尺度配对集水区试验，或以森林植被面积与覆盖率为表征，将集水区生态系统视为黑箱，而忽略森林物候、结构及其演替变化的影响，难以真正体现森林植被空间格局及结构动态变化对水文过程的影响

科学问题思考（2）

- 陆地生态水文过程存在着高度的非线性和时空异质性，例如，流域下垫面的植被、土壤和地形的空间异质性，各种气候、气象要素和干扰因素的时空异质性变化等;
- 缺少生态水文过程的耦合与尺度匹配和转换的理论与方法，坡面和小流域尺度所得出的研究结论带有明显的局限性，无法将小尺度集水区的实验结论直接推绎大流域景观尺度上的水文循环过程与机制

Gap Analysis:

Why large-scale forest hydrology?

- Large-scale research is very limited
  - Less than 15 papers were found from key hydrological journals
- Scale issues are recognized
  - Temporal and spatial variation of variables at different scales
  - Scaling up to extrapolate results from small-scale to large-scale watershed
- Large-scale forest disturbance and climate change are addressed
- Serving for watershed planning and forest land management in large-scale watersheds

Searching for Research Methods

- Paired watershed experiments: not suitable for large-scale studies
- Statistical approach: small- & large-scale
- Modelling approach: small- & large-scale

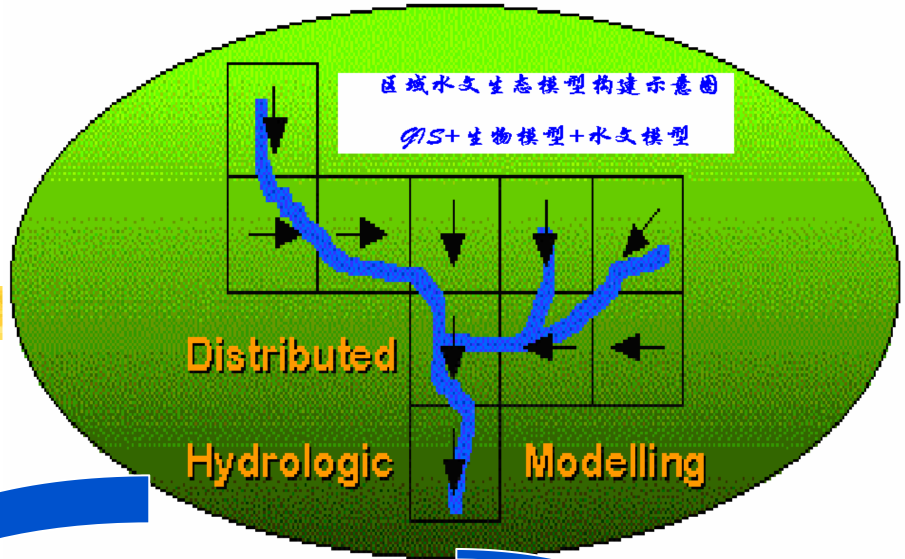
Time series analysis

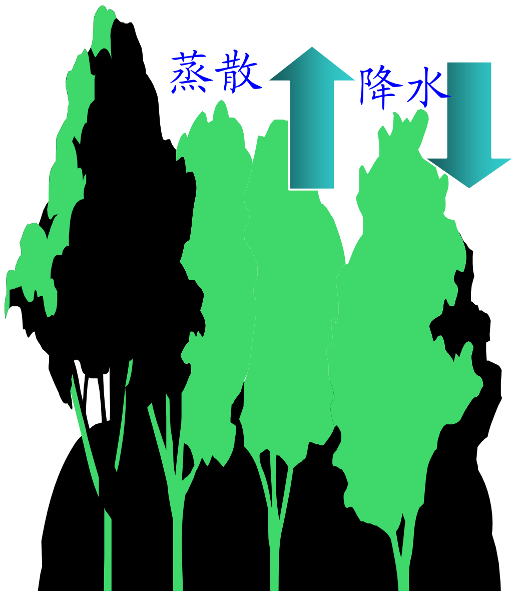
- Cross-correlation analysis
- Intervention analysis
- Wavelet analysis

Artificial neural network (ANN)

植被空间结构及其动态

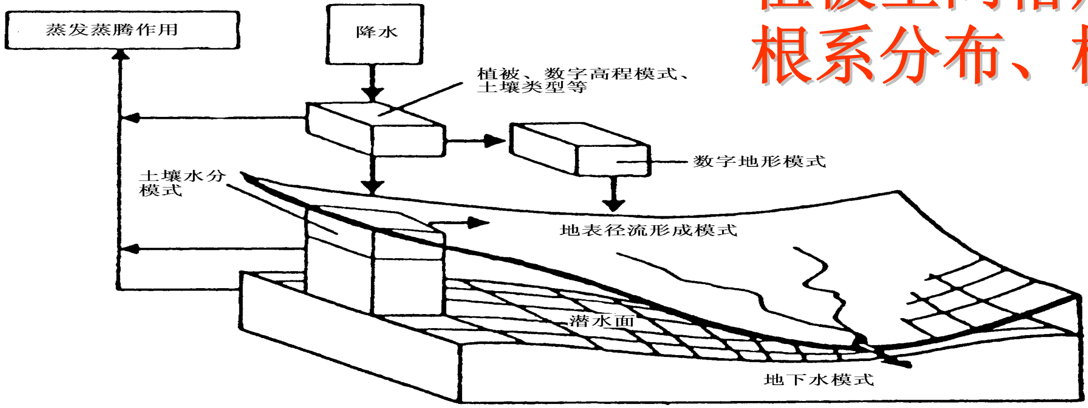
分布式生态水文模型





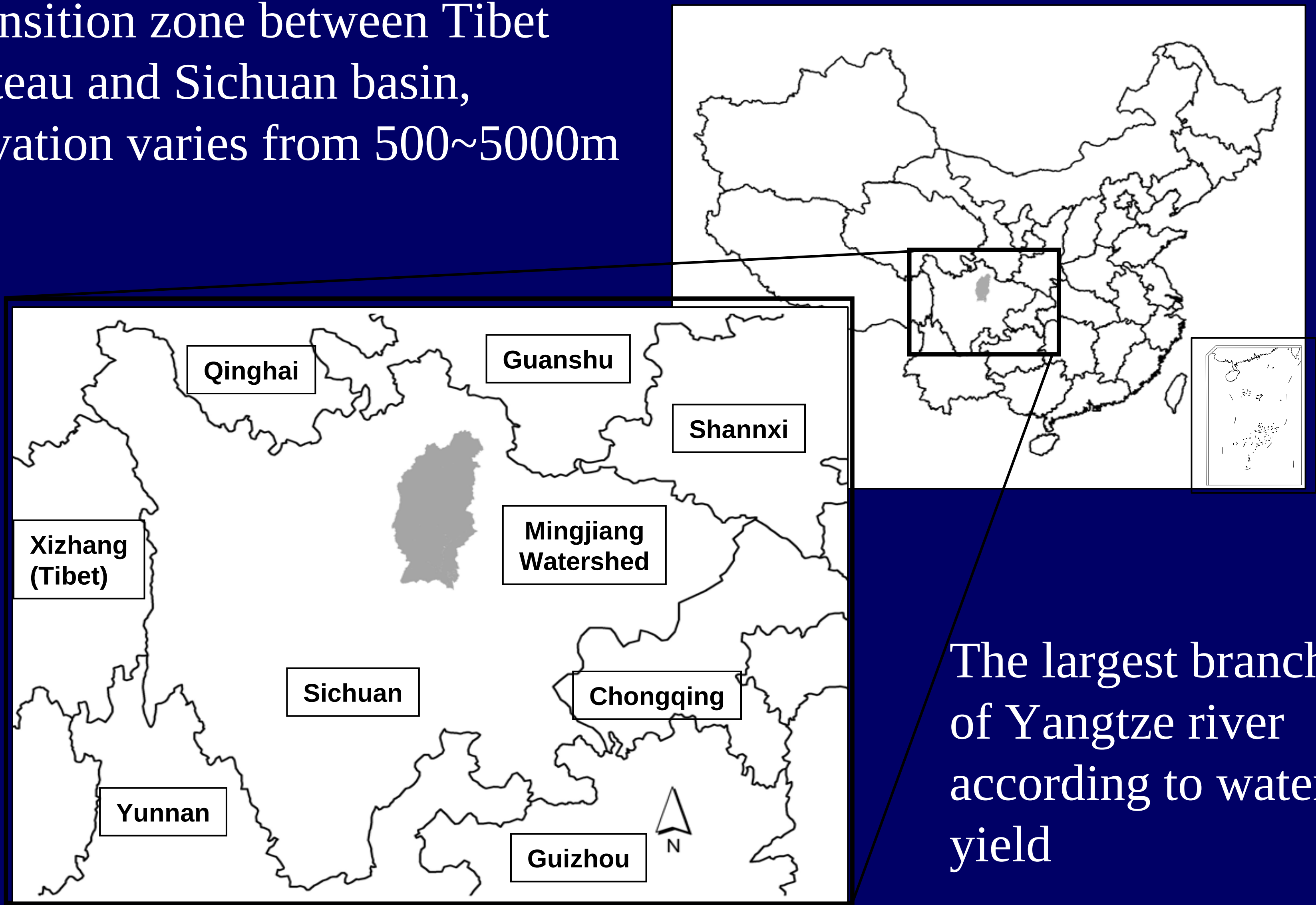
耦合植被生态过程的分布式生态水文模型

植被空间格局、叶面积指数、根系分布、植被生长



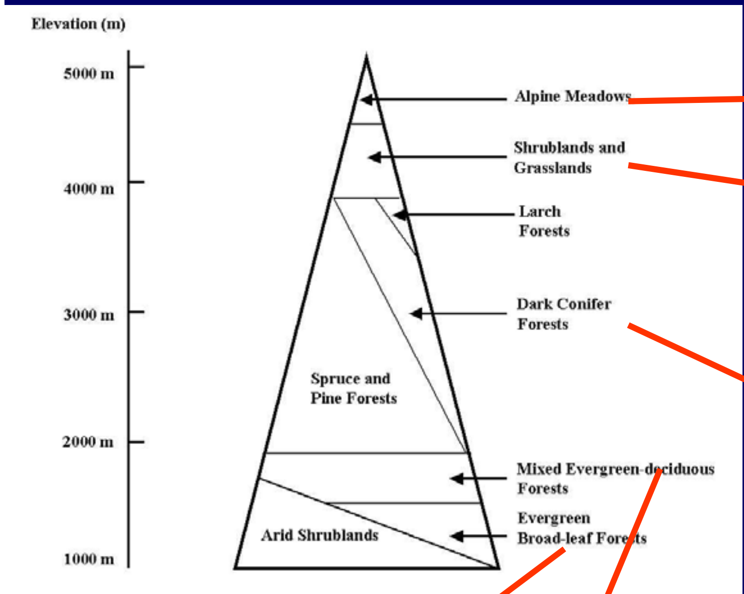
Case study in Minjiang large watershed

Transition zone between Tibet plateau and Sichuan basin, elevation varies from 500~5000m



The largest branch of Yangtze river according to water yield

Location of study area – Spatial pattern of vegetation



>4500m

2000~4000m

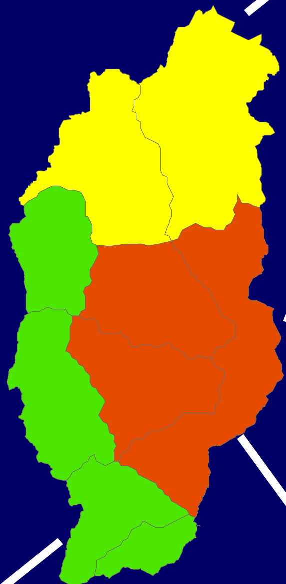
1000~2000m

<1000m

Location of study area – Land use pattern

—Land use and land cover

—Forest & Forestry



—Grassland and meadow & Husbandry

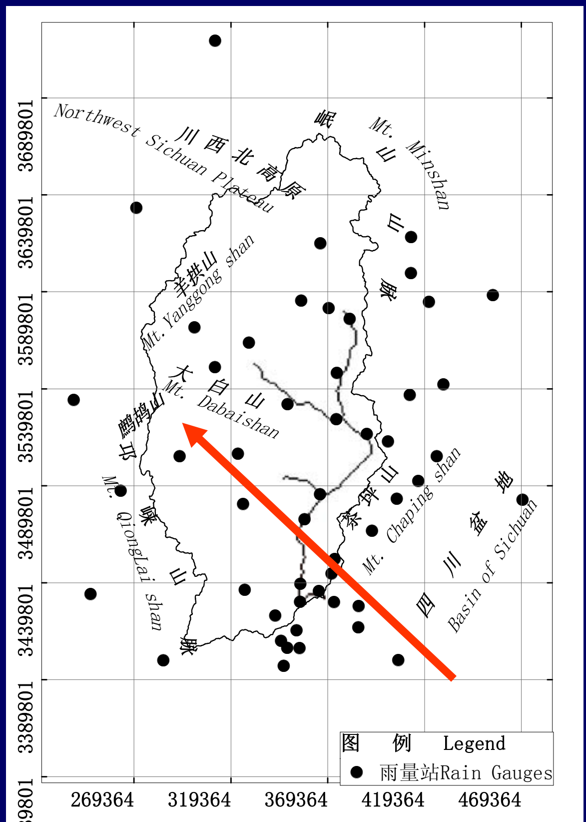
—Farmland
Agriculture

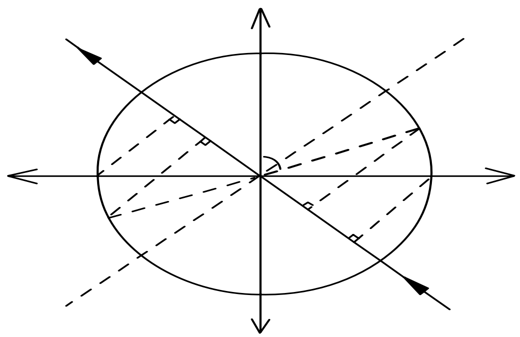
Settlement
Township

流域降水的空间分布模拟

ANUSPLIN4.1
(M.F. Hutchinson)

Centre for Resource and
Environmental Studies (CRES)
Australian National University





效应指数(PWEI)的构建
Establishment of Prevailing Wind-direction Effect Index

$$PWEI = \cos(\pi \cdot (\alpha - \beta + 360)/180) + 1 \qquad (0^\circ \le \alpha < \beta)$$
$$= \cos(\pi \cdot (\alpha - \beta)/180) + 1 \qquad (\beta \le \alpha < 360^\circ)$$

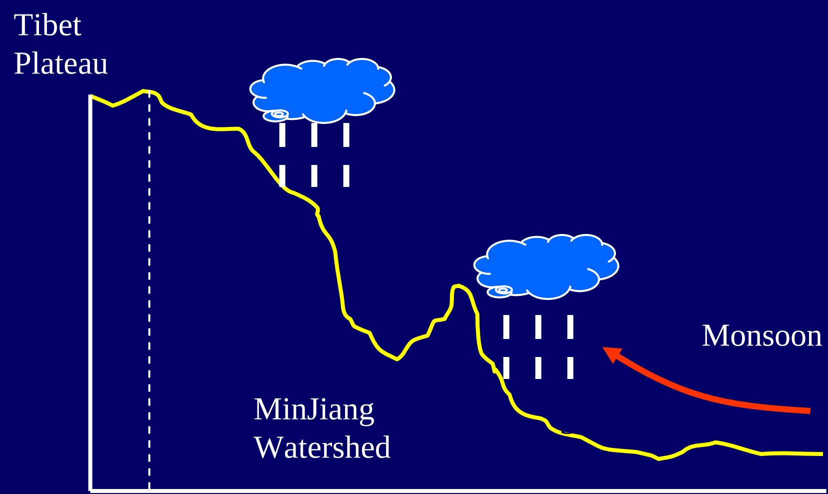
❖构建主风向效应指数**PWEI**，提高降雨模拟精度

X,

Y,

Altitude,

PWEI



流域降水空间分布格局的模拟

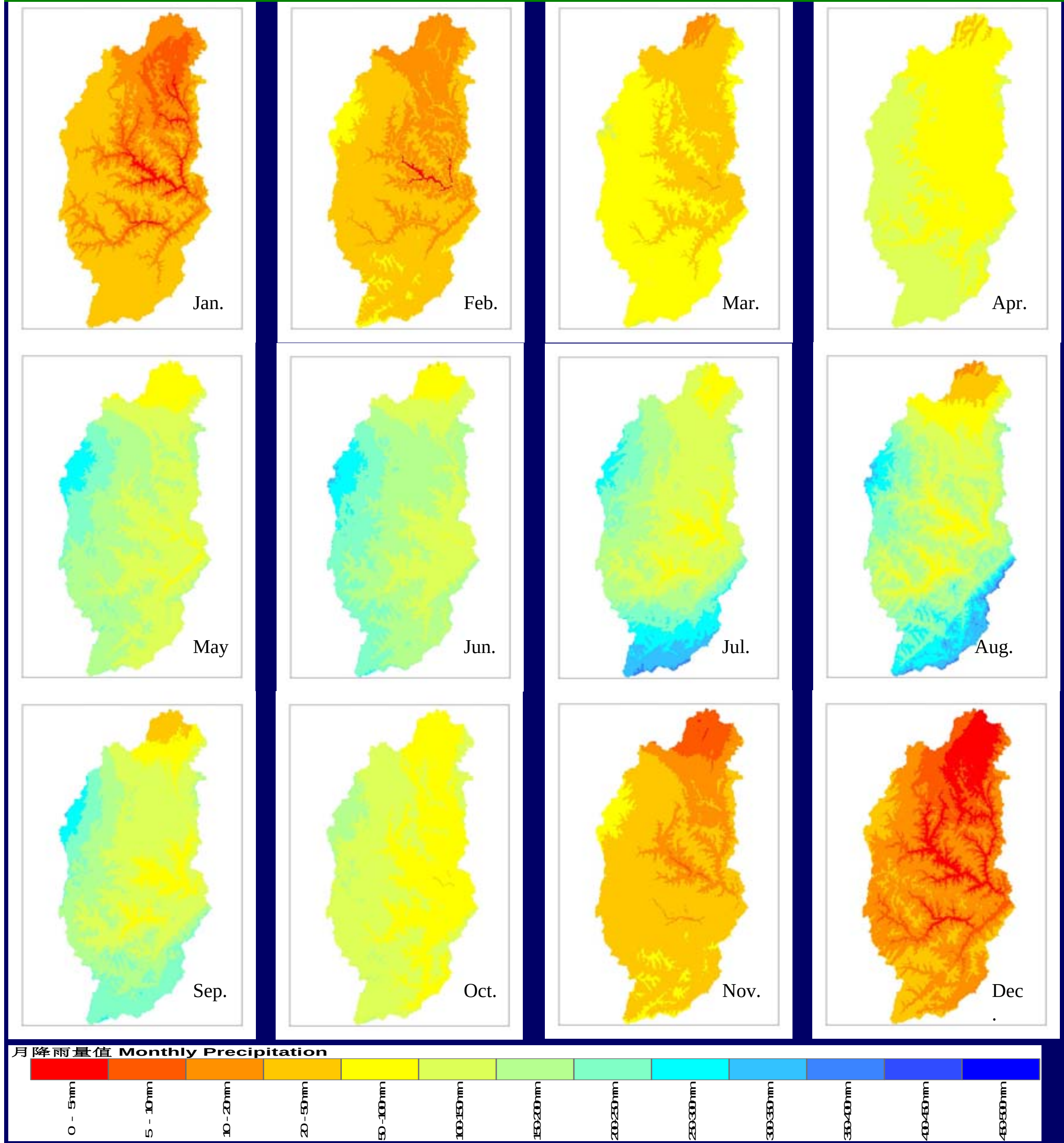


图5 岷江上游降水量多年平均（1988~2002）的季节及空间变化图
Fig.5 Averaged monthly precipitation (1988~2002) and its spatial distribution pattern of USM

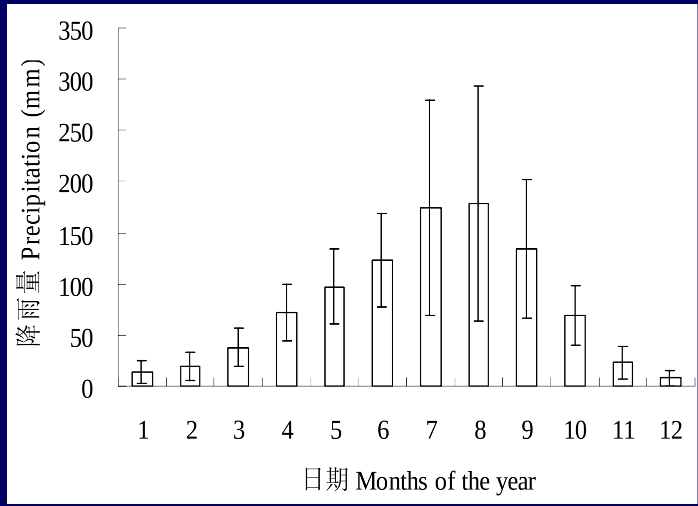
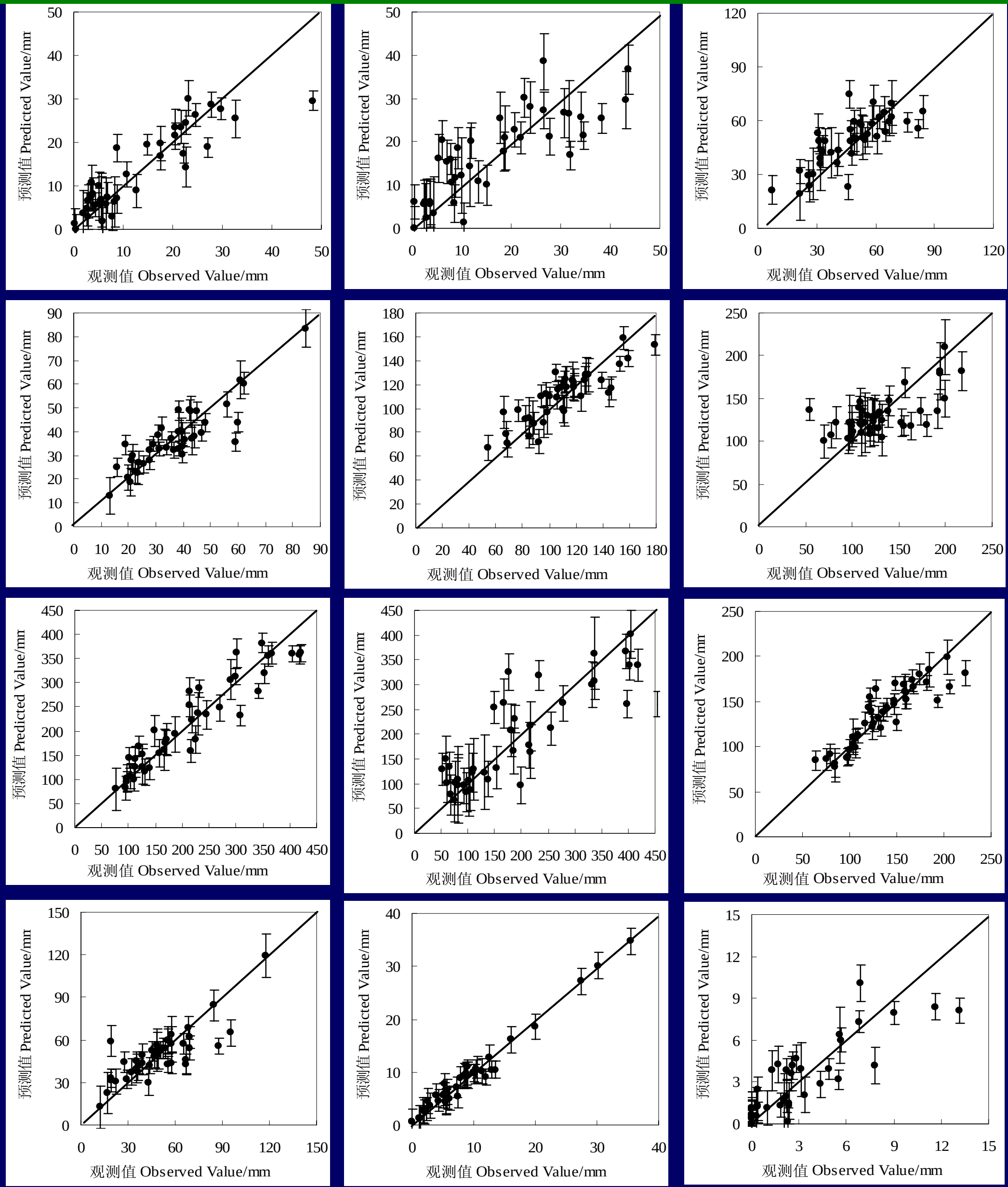


图3月降水量平均值及其季节变化
Fig. 3 Fitted mean monthly precipitation and seasonal variation.

Precipitation appeared to be high elevation & aspect relevant;

Lower precipitation in the middle valley demonstrated the cause of dry valley.

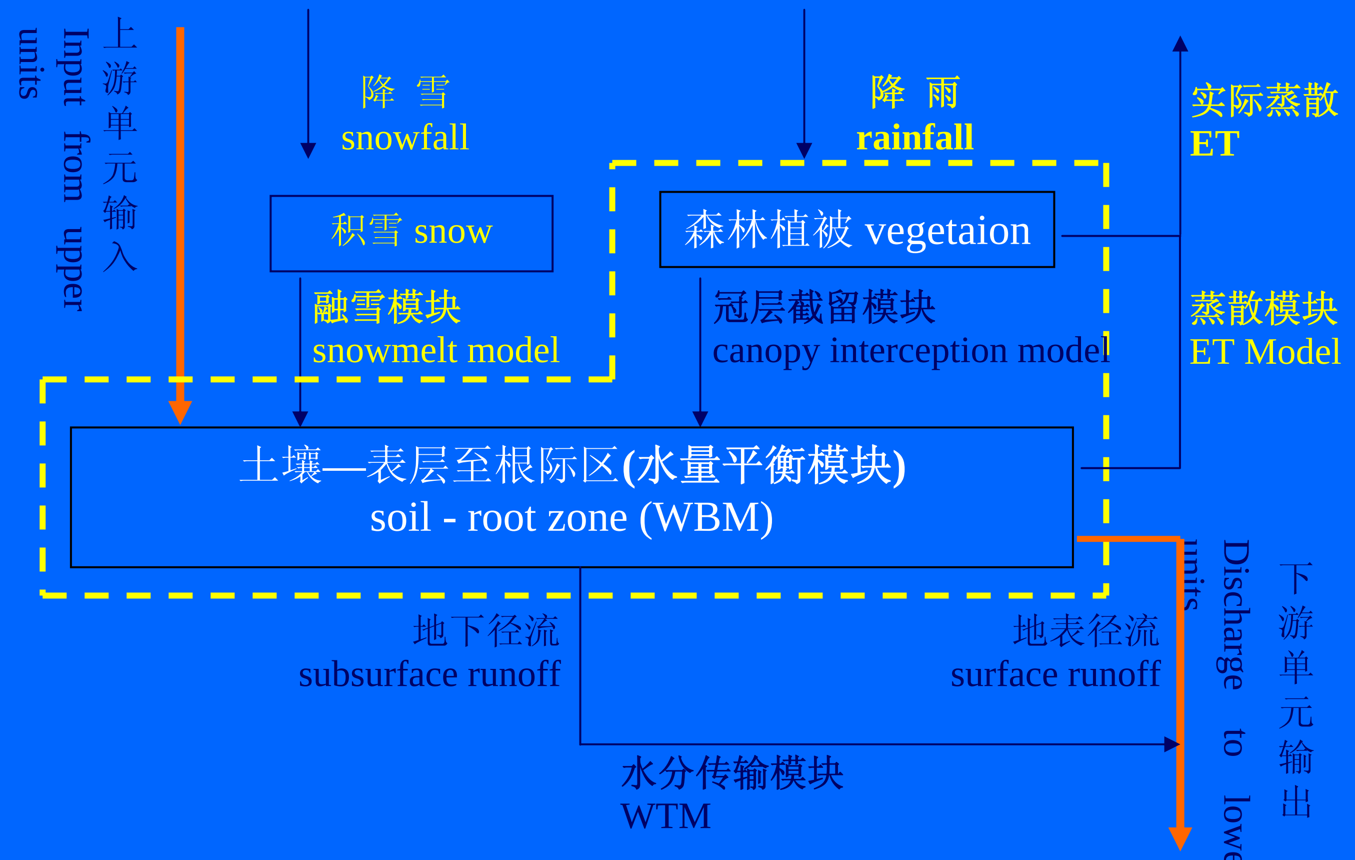
流域降水空间分布格局的模拟



预测精度比单纯使用单一地形变量提高3~11%

图4 岷江上游降水量的观测值和模拟值
Fig. 4 Scatterplots of Observed versus predicted precipitation for USM

大尺度分布式生态水文过程耦合模型



Structure of Large-scale Ecohydrological Modelling System **(LEMS)**

1、if Pr + Rs >= Ep, SM <FC,　　$dSM/dt = Pr + Rs - Ep$

2、if Pr + Rs >= Ep, SM =FC,　　$dSM/dt = 0$

3、if Pr + Rs < Ep,　　$dSM/dt = -\alpha SM(Ep-(Pr+Rs))$

AET Estimation by Priestley-Taylor equation

aET $= p$ET $\quad\quad Pr + Rs >= p$ET

aET $= Pr + Rs - dSm/dt \quad Pr + Rs < p$ET

Surface latent flux (general form),

$$\lambda E = \beta\left[A(R_n - G)\frac{\Delta}{\Delta+\gamma} + B\frac{\Delta}{\Delta+\gamma} f(u)(e_a^* - e_a)\right]$$

Priestley-Taylor (for large spatial scale):

Putting: $A=\alpha$, $\beta=1.0$, $B=0$

$$\lambda E = \alpha\beta[(R_n - G)\frac{\Delta}{\Delta+\gamma}]$$

$\alpha \approx 1.26$, dry area: $\alpha \approx 1.7\text{-}1.75$

To apply for a wide range of surface conditions and Remote estimation;

$$\lambda E = \phi[(R_n - G)\frac{\Delta}{\Delta+\gamma}]$$

ϕ represents a complex effects parameter that absorbs the combined effects of Priestley-Taylor α and β. has a range between 0 and $(\Delta + \gamma)/\Delta$.

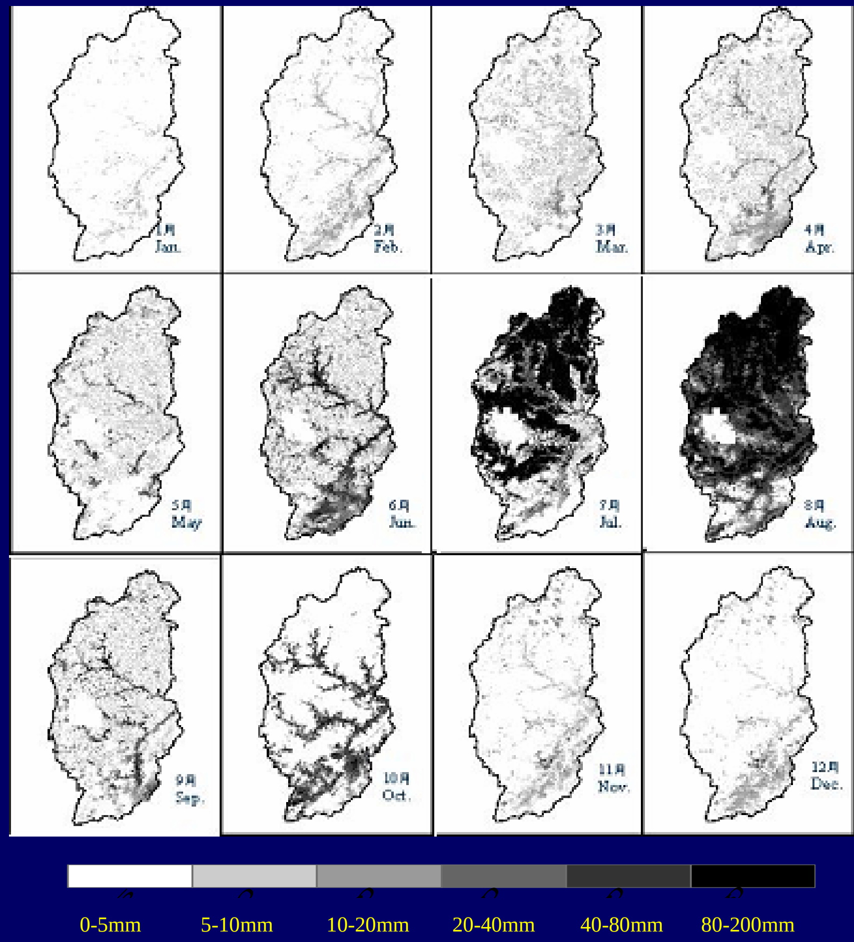


Fig.3 Averaged monthly AET produced by LEMS at 1000 m resolution in USM.

LEMS特点：

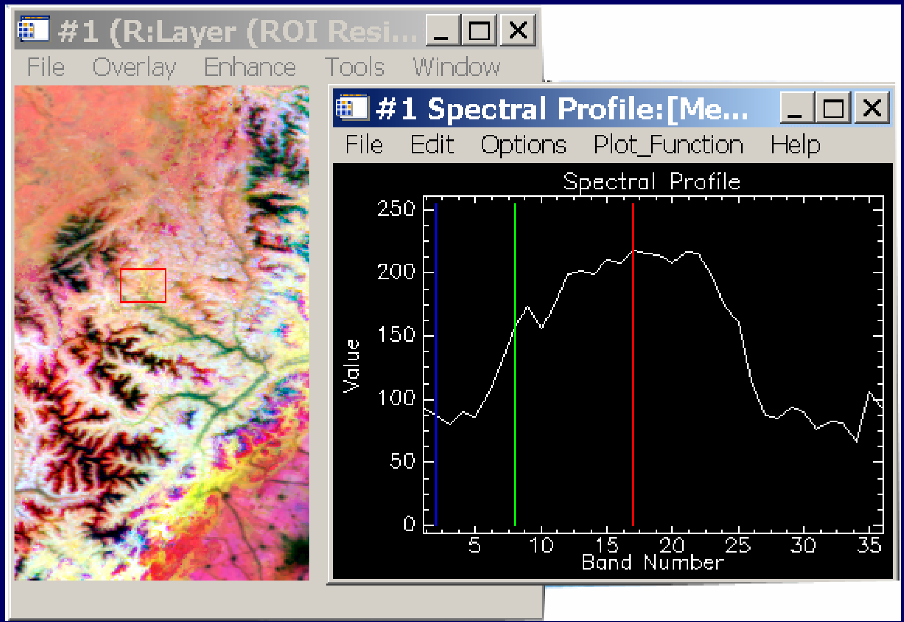
- ✓ 植被格局/结构特征及其动态
- ✓ 环境参量及其变化
- ✓ 积雪与融雪过程
- ✓ 栅格单元的水量平衡各分量计算
- ✓ 基于水文响应单元(HRU)的汇流量计算

LEMS忽略以下过程：

- ✗ 降雨—入渗过程
- ✗ 坡面水分运移—产流过程
- ✗ 径流在河道传输过程

LEMS的创新性：

❖将动态植被结构特征运用到流域水文过程模拟



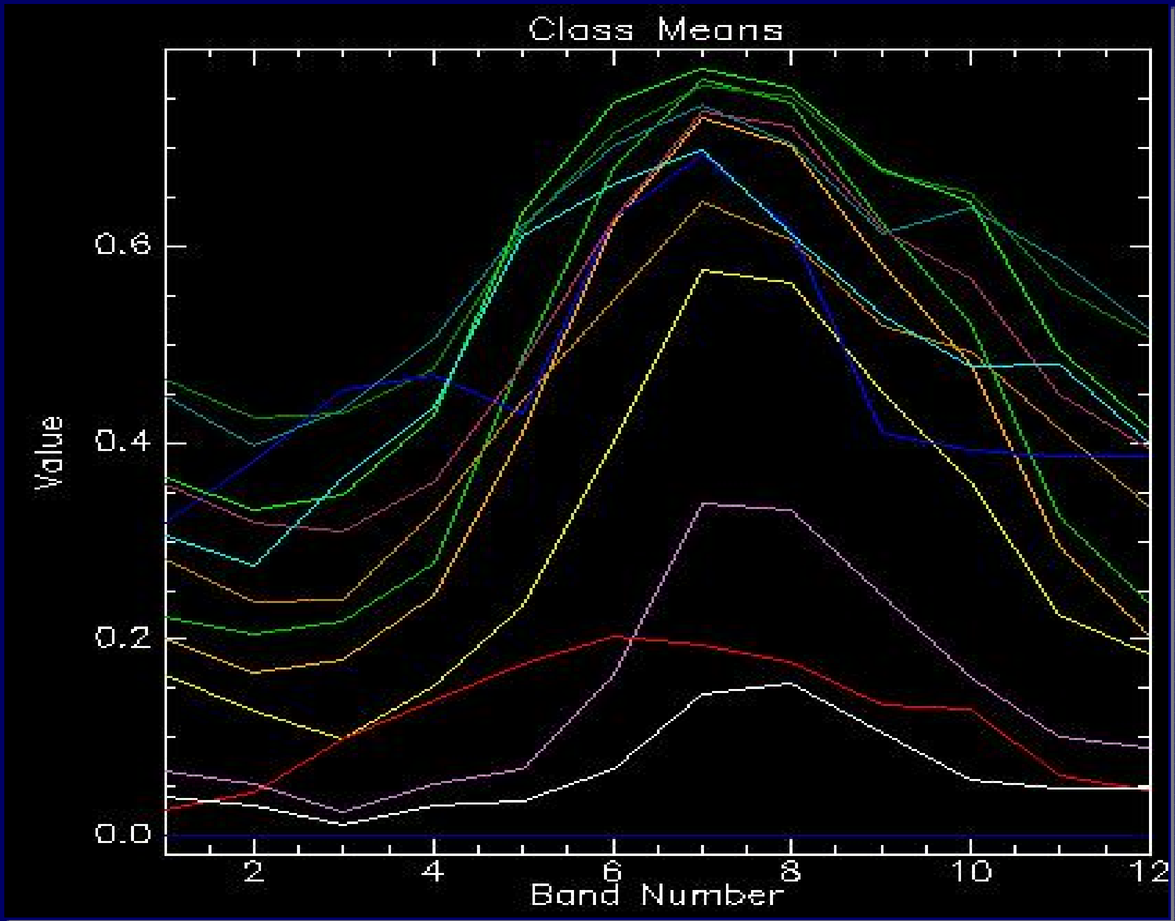
- 粗糙率
  —水文景观中的静态部分
- 植被覆盖率
  —几十年不变
- 植被分类概化
  —空间分异特征初考虑
- 盖度和叶面积指数
  —季节和物候变化
- 地表反照率/反射光谱特征
  —更精确的短周期遥感信息源

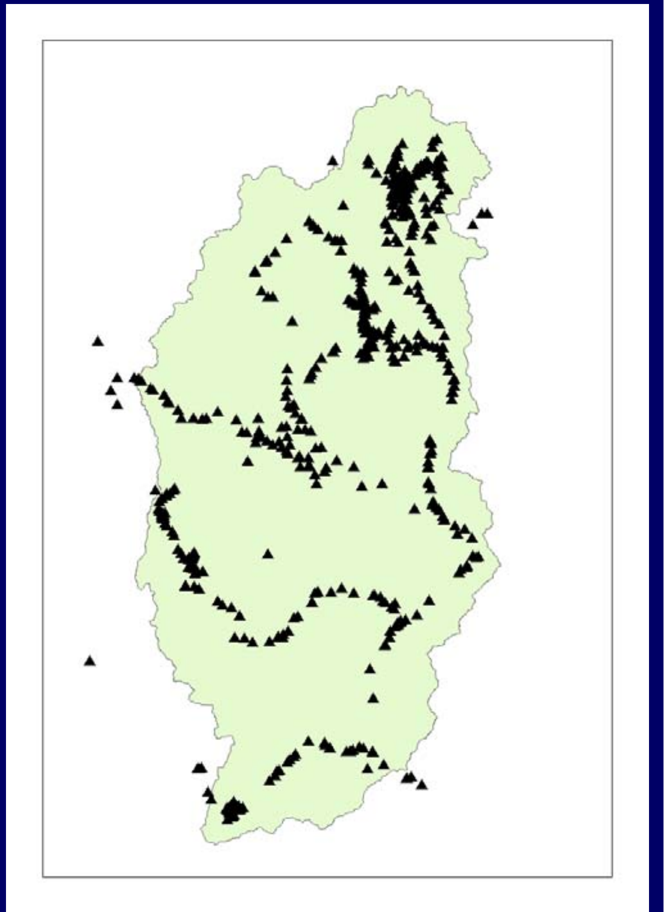
LEMS 利用动态的基于物候变化的NDVI, 体现植被结构和植被格局的时空变化，从而实现植被的基于物候变化的生态过程与水文过程之间的耦合。 以后将更多考虑功能参数...

NDVI phenology-based vegetation classification

ENVI 4.2 (RSI inc.)

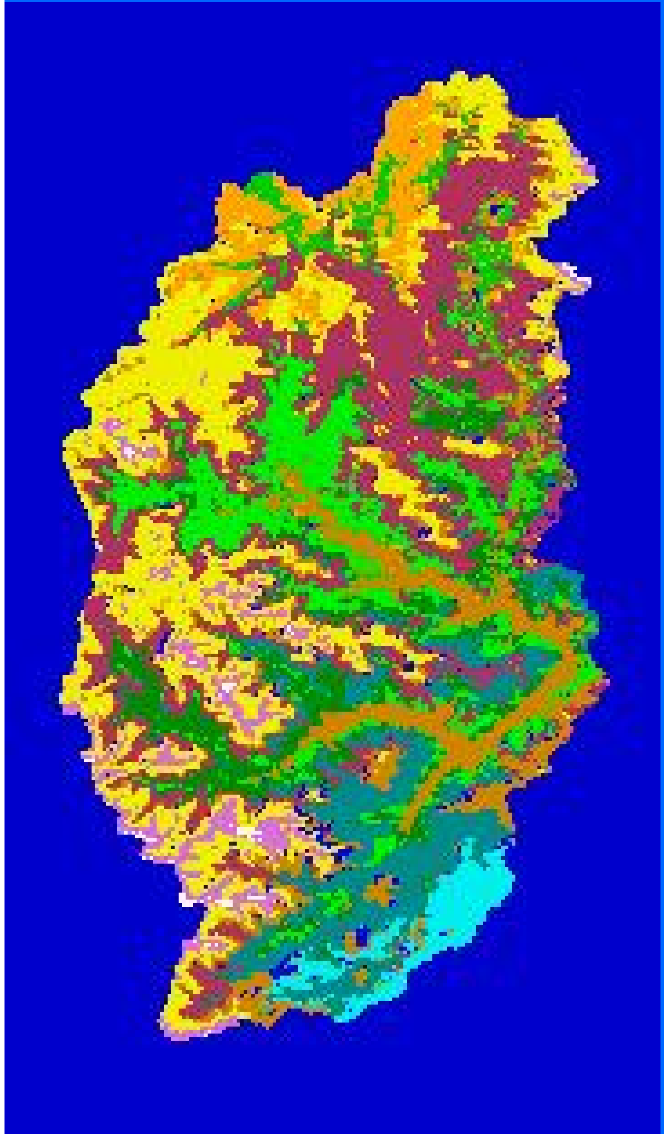
SPOT VGT NDVI, 1km **Maximum Likehood**





Averaged endmemebers' phenological curve

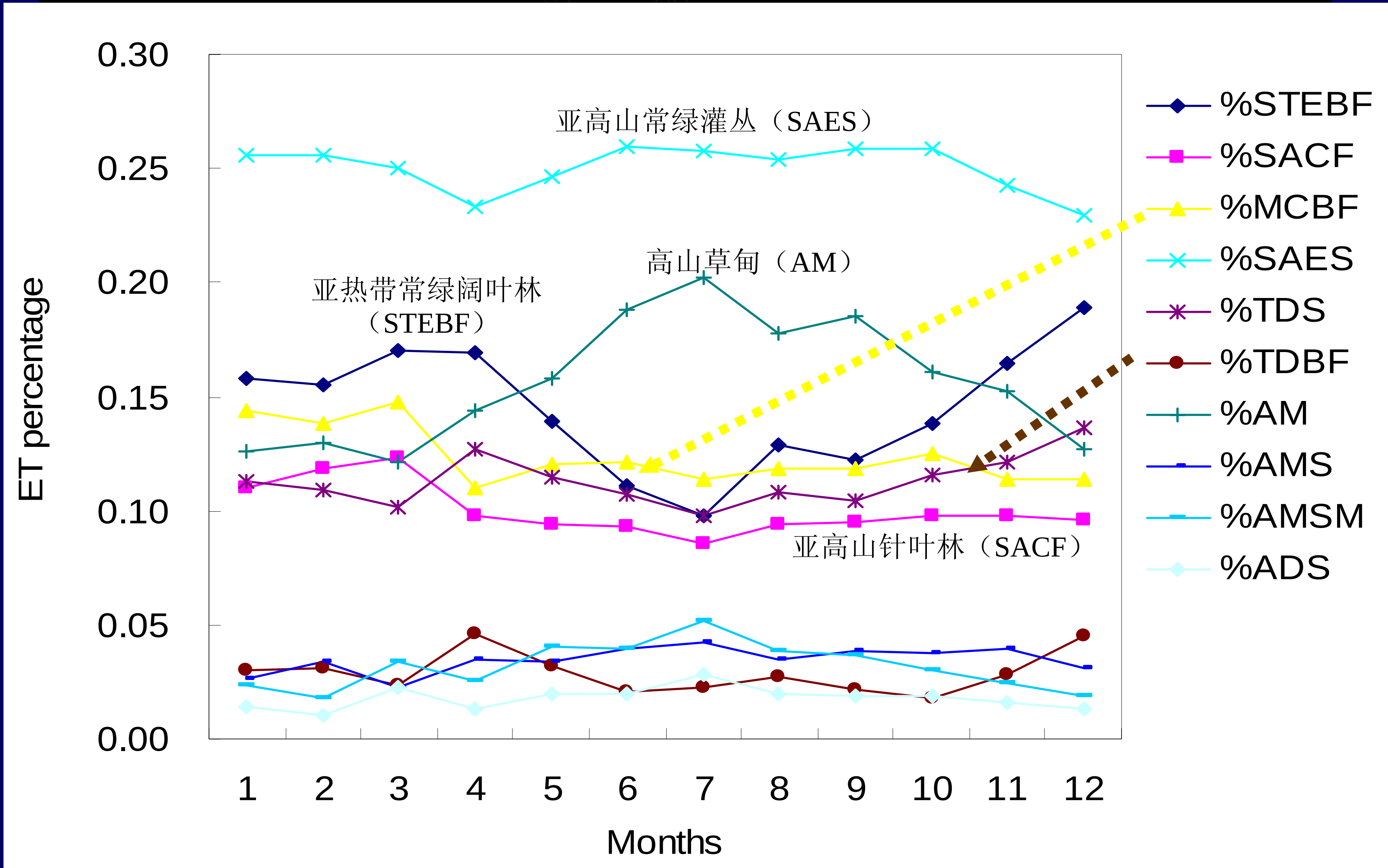
Statistics of Classification



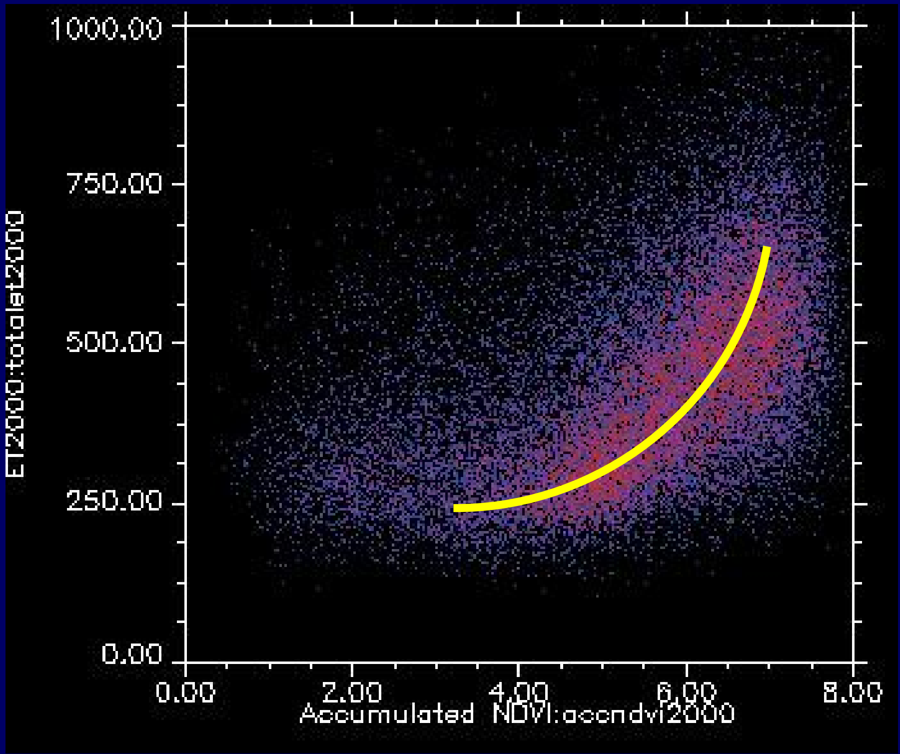
Landcover	Class	%	Group
Meadow 29.6%	AM	19.7	A
	ASM	4.3	A
	AMSM	5.7	A
Shrub 37.6%	ADS	3.3	A
	SAES	23.2	SA
	TDS	11.1	T/ST
Forest 30.9%	SACF	7.8	SA
	MCBF	10.4	SA
	STEBF	9.9	T/ST
	TDBF	2.8	T/ST
Other 2.0%	SIR	0.4	/
	CL	1.6	/

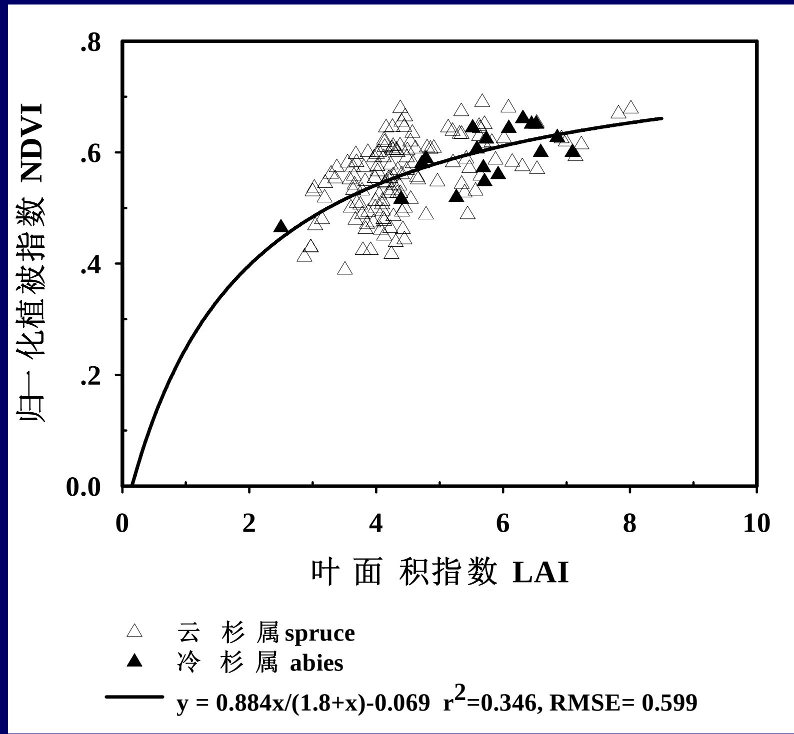
A: alpine (>4000m), SA: Sub-alpine (2500-4000m); T/ST: Temperate and Sub-Tropical (<2500m)

Different land covers and their contributions to the whole watershed ET



NDVI & ET



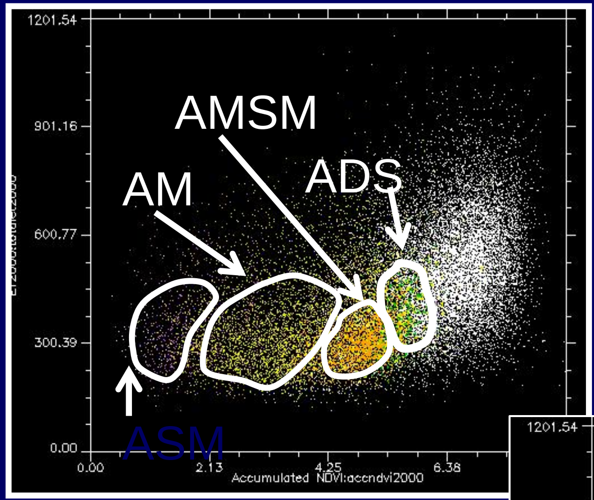


Annual accumulated NDVI vs annual ET in year 2000

NDVI vs LAI

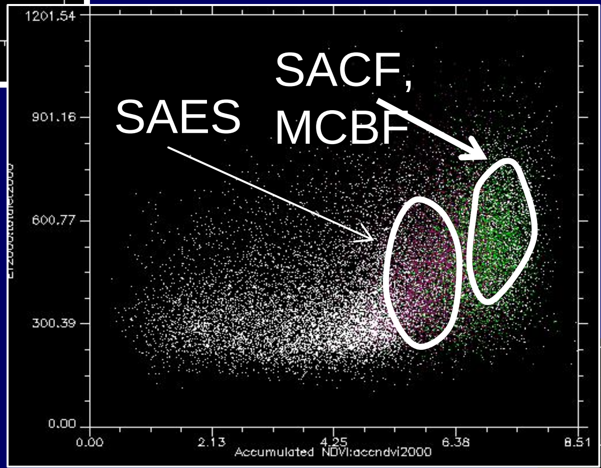
Saturated asymptotically with increasing vegetation density

NDVI & ET

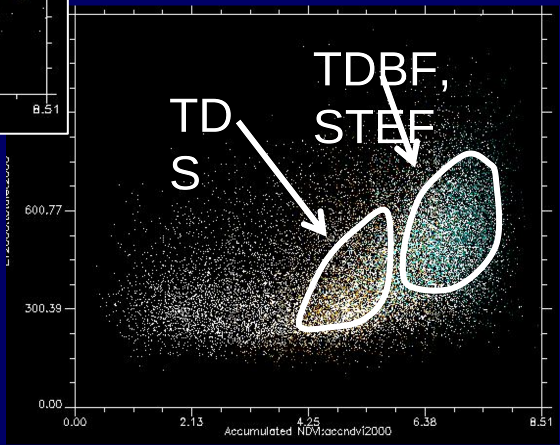


A group

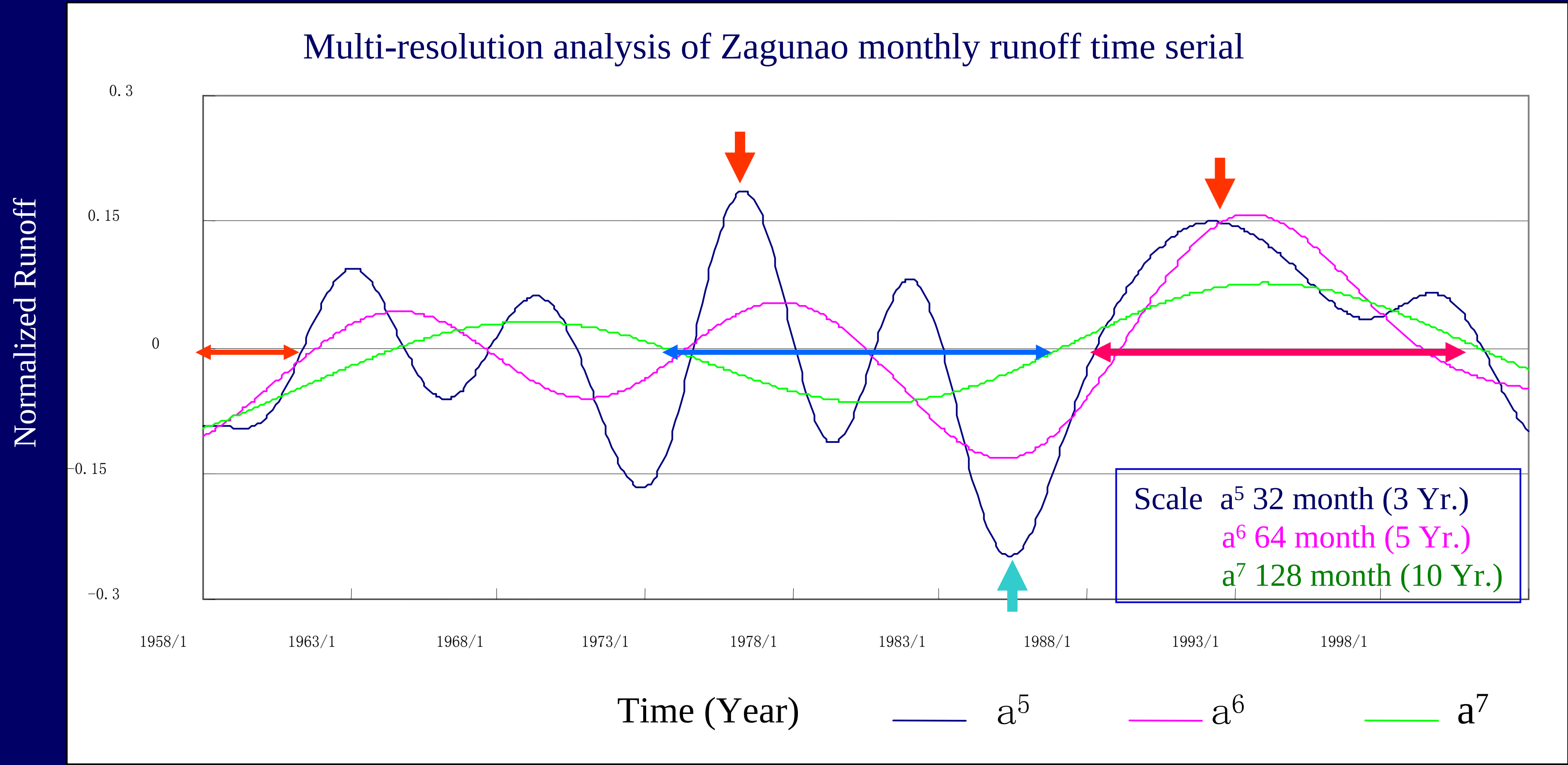
SA group



T/ST group

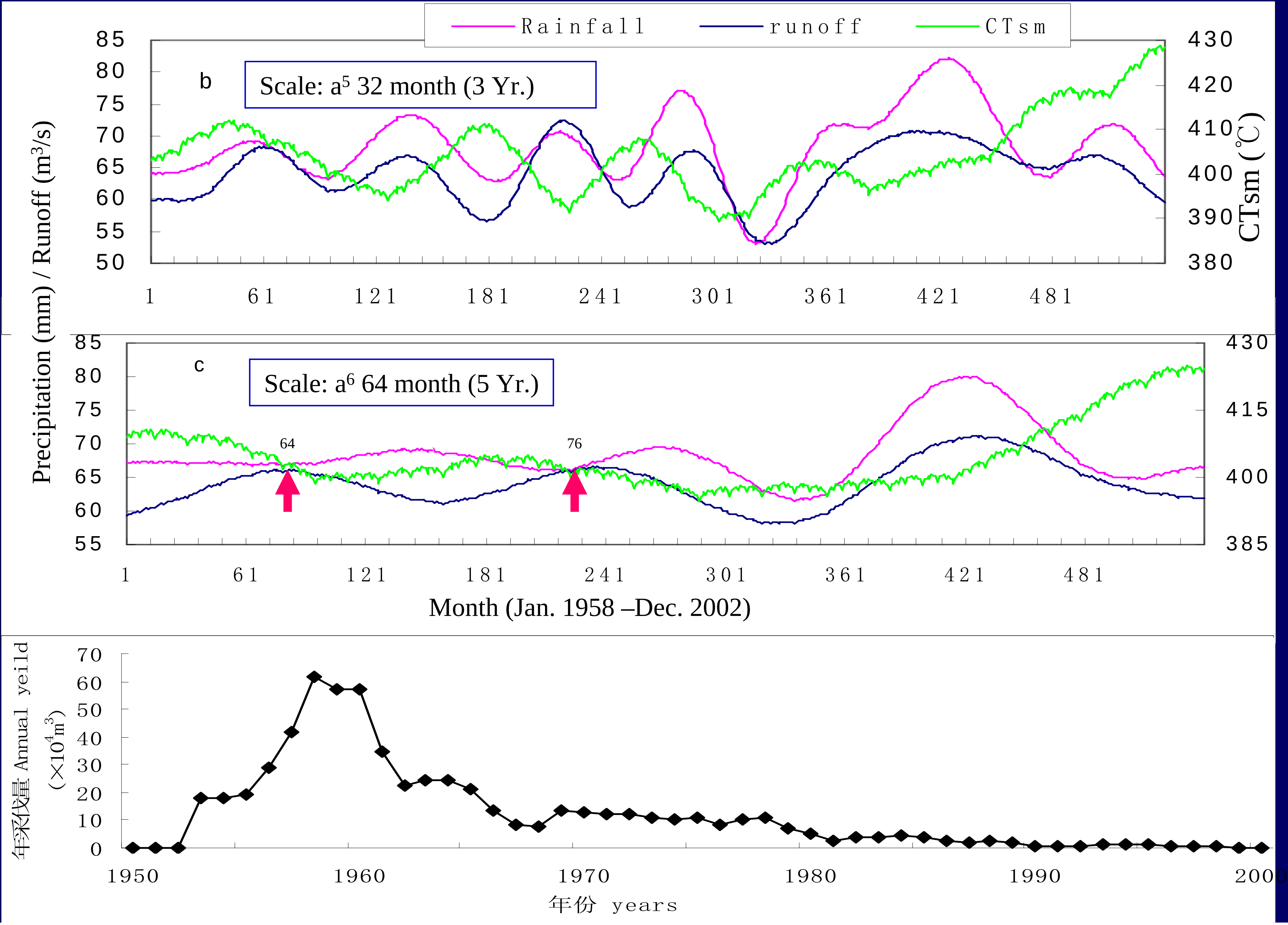


Wavelet analysis of monthly runoff in Zagunao watershed



- Periodicity of runoff time serial depends on temporal scales
- At the scale of 10 year, rich water period was 1988 to 2001, while the low water periods were 1973 to 1988 and 1958-1963;
- At the scales of 3 or 5 year, oscillation frequencies tend to be reduced over time while oscillation amplitudes tend to be large

Wavelet analysis of precipitation, runoff and CTsm



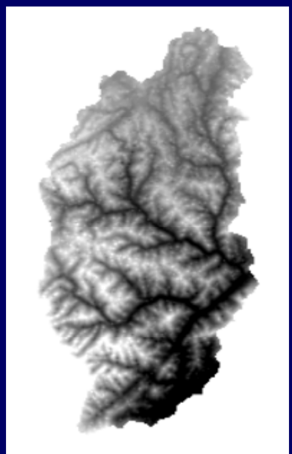
Seasonal impacts: NDVI vs river flow

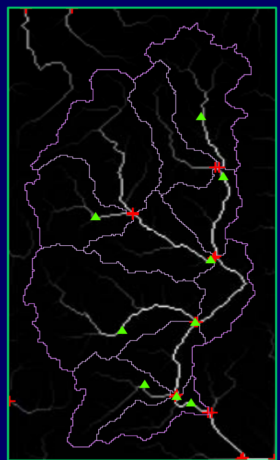
(Partial Mann-Kendall test, 1988-2003, monthly)

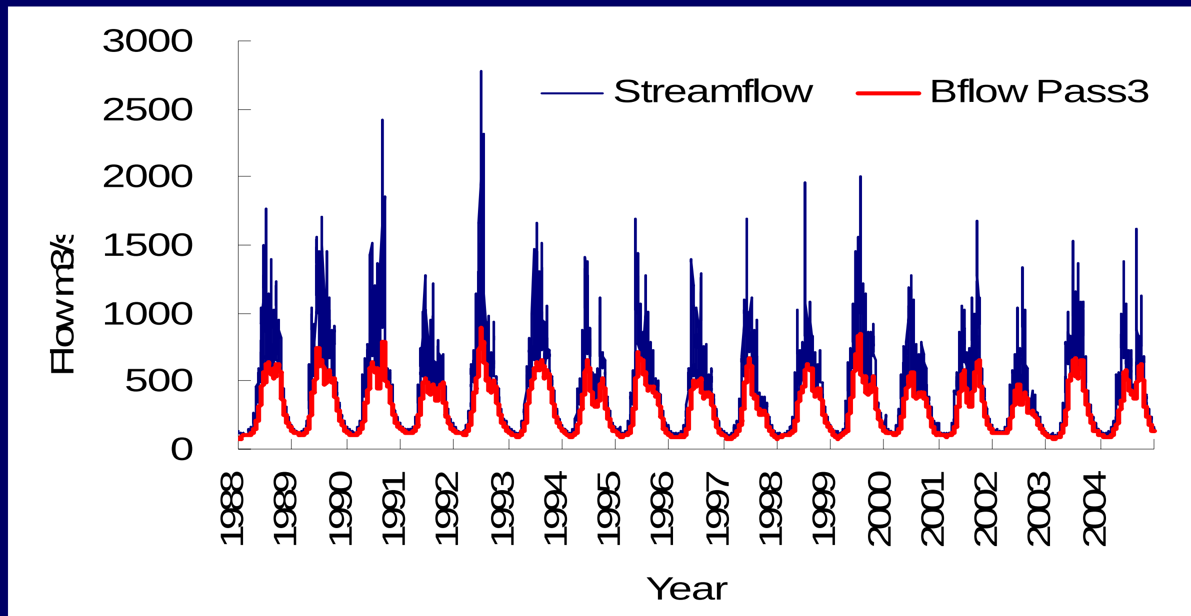
Season	1	2	3	4	5	6	7	8	9	10	11	12
River flow	-0.07	0.35	0.07	-0.31	-0.45	-0.34	-0.28	-0.85	-0.31	-0.40	0.19	0.04
Base flow	-0.20	0.07	0.02	-0.27	-0.42	-0.32	-0.38	-0.63	-0.37	-0.09	0.11	0.17
Surface flow	0.24	0.28	-0.28	-0.41	0.22	-0.20	-0.40	-0.67	-0.61	0.01	0.01	-0.12

Correlation between NDVI and River flow varies with seasons.

Significant at $P < 0.025$







Preliminary Conclusions

In a large watershed as a case of Minjiang or Zagunao catchment

- The multi-resolution analysis of Runoff indicated that the number of pulses increased during the period of extensive over-logging, while pulse number has reduced and pulse duration increased with forest regrowth during restoration process.

- The effects of deforestation on the runoff is scale dependent and it can be inferred to have manifested negative effect on the runoff only at 5-year scale during 1958-1964. The other periods or scales, deforestation was not accompanied with increases in stream flow and base flow of either any catchments or the whole watershed.

Preliminary Conclusions

In a large watershed as a case of Minjiang or Zagunao catchment

- The runoff is likely to increase with increasing temperature that has been observed significantly in the last two decades in the alpine/sub-alpine areas, with the greater effects in non-growth season than in growth season at a given increasing T scenario, indicating the increasing snow melting process.
- NDVI and river flow are negative correlation and this relationship varies with seasons, indicating that forest can have larger effect on water yield than minor vegetation.
- SAES and AM account for the large proportions of hydrological impacts among land cover categories, in terms of their ET contributions in the growing season.


Thank You