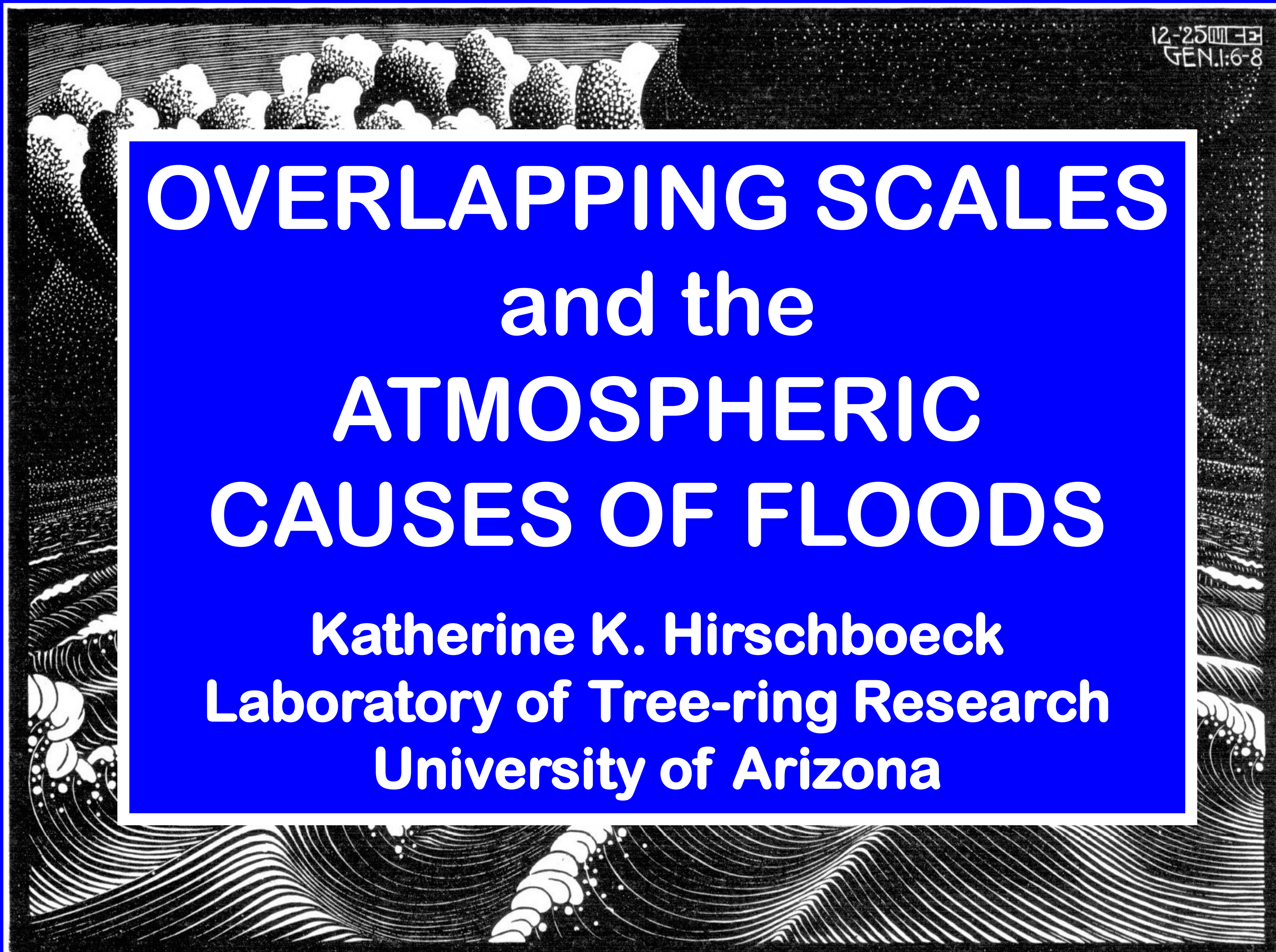
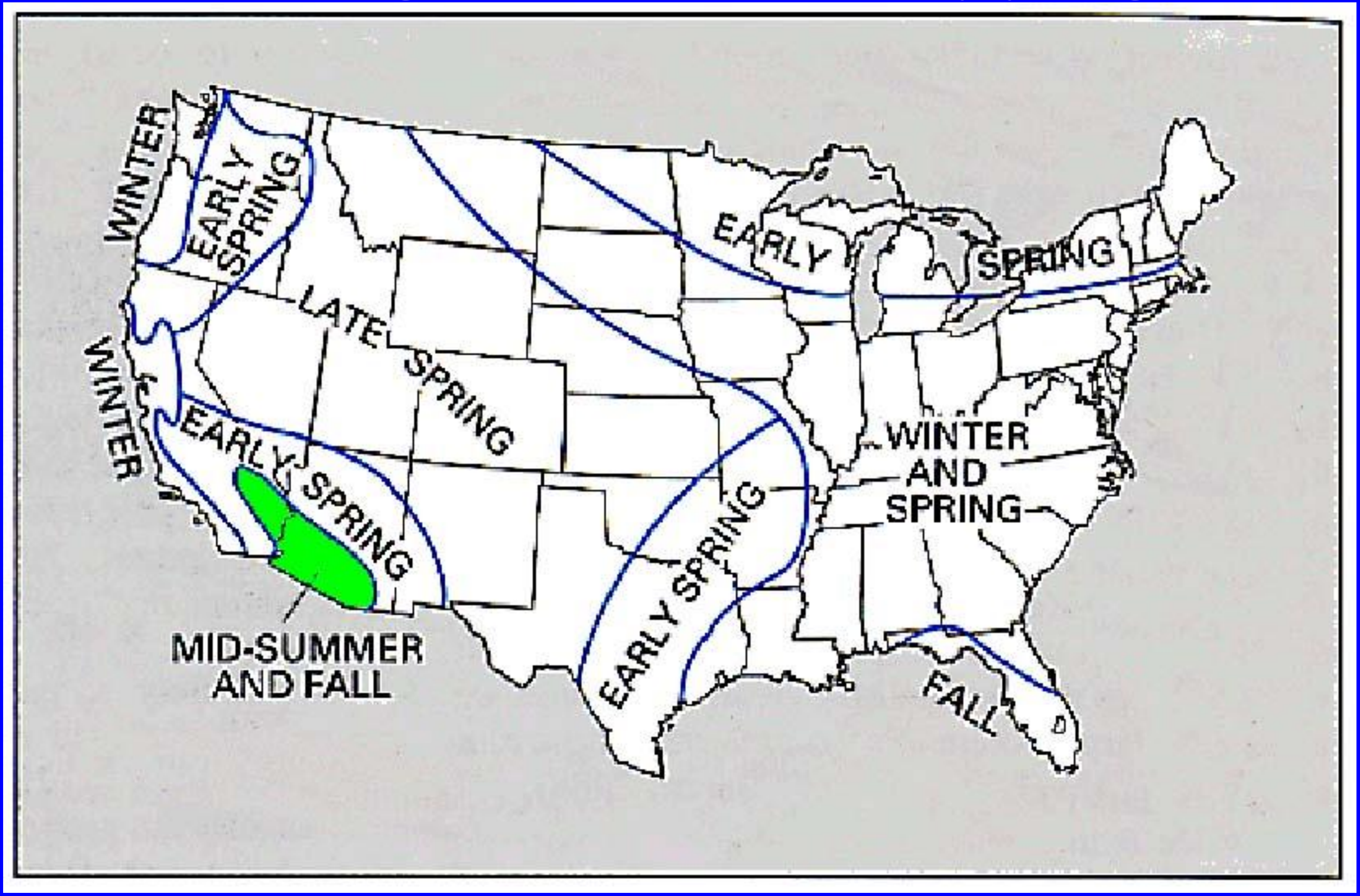


OVERLAPPING SCALES and the ATMOSPHERIC CAUSES OF FLOODS

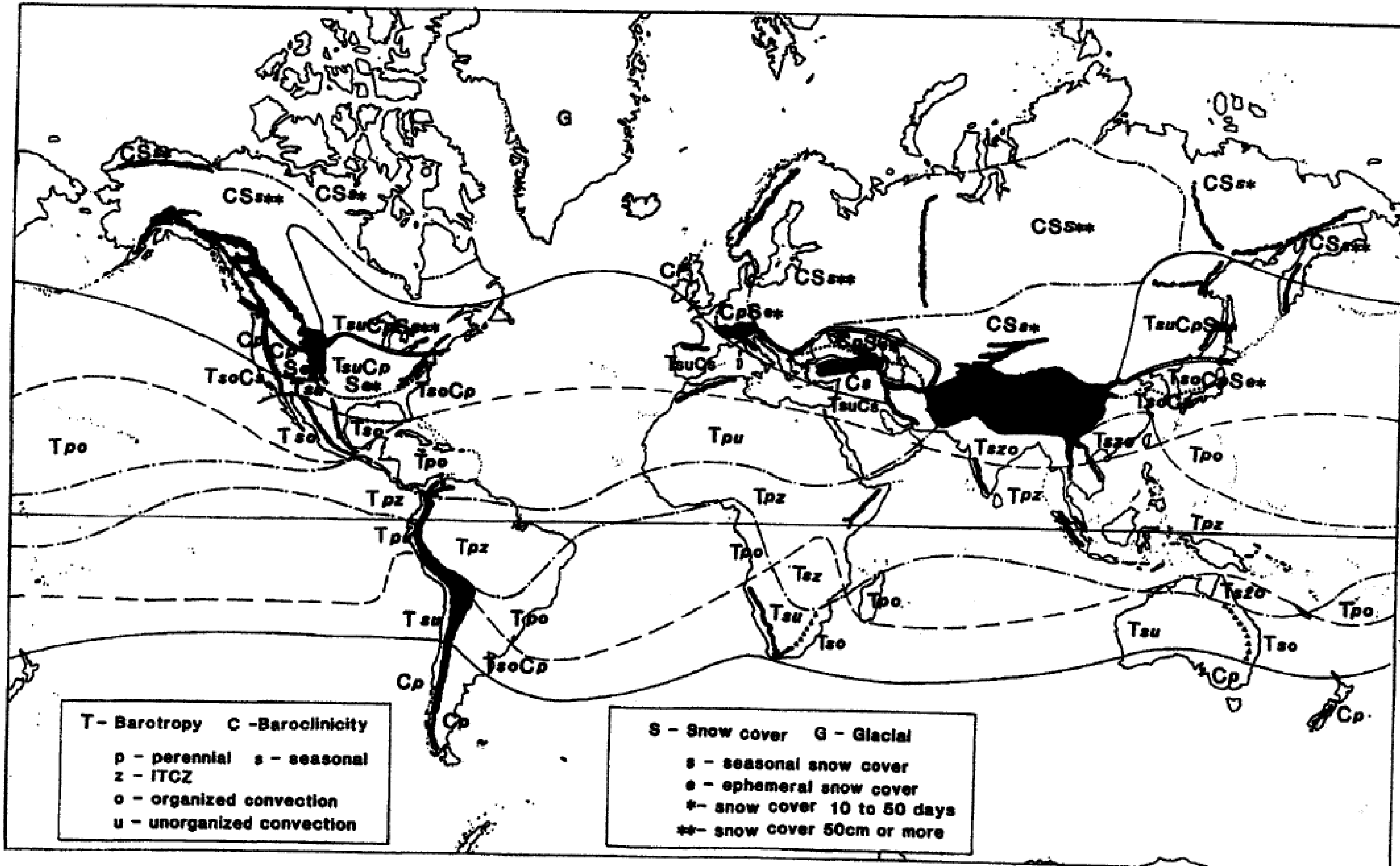
Katherine K. Hirschboeck
Laboratory of Tree-ring Research
University of Arizona

Regional Flood Mapping



from Hirschboeck, 1991; modified from Baldwin & McGuinness, 1963

Hayden's Flood map:



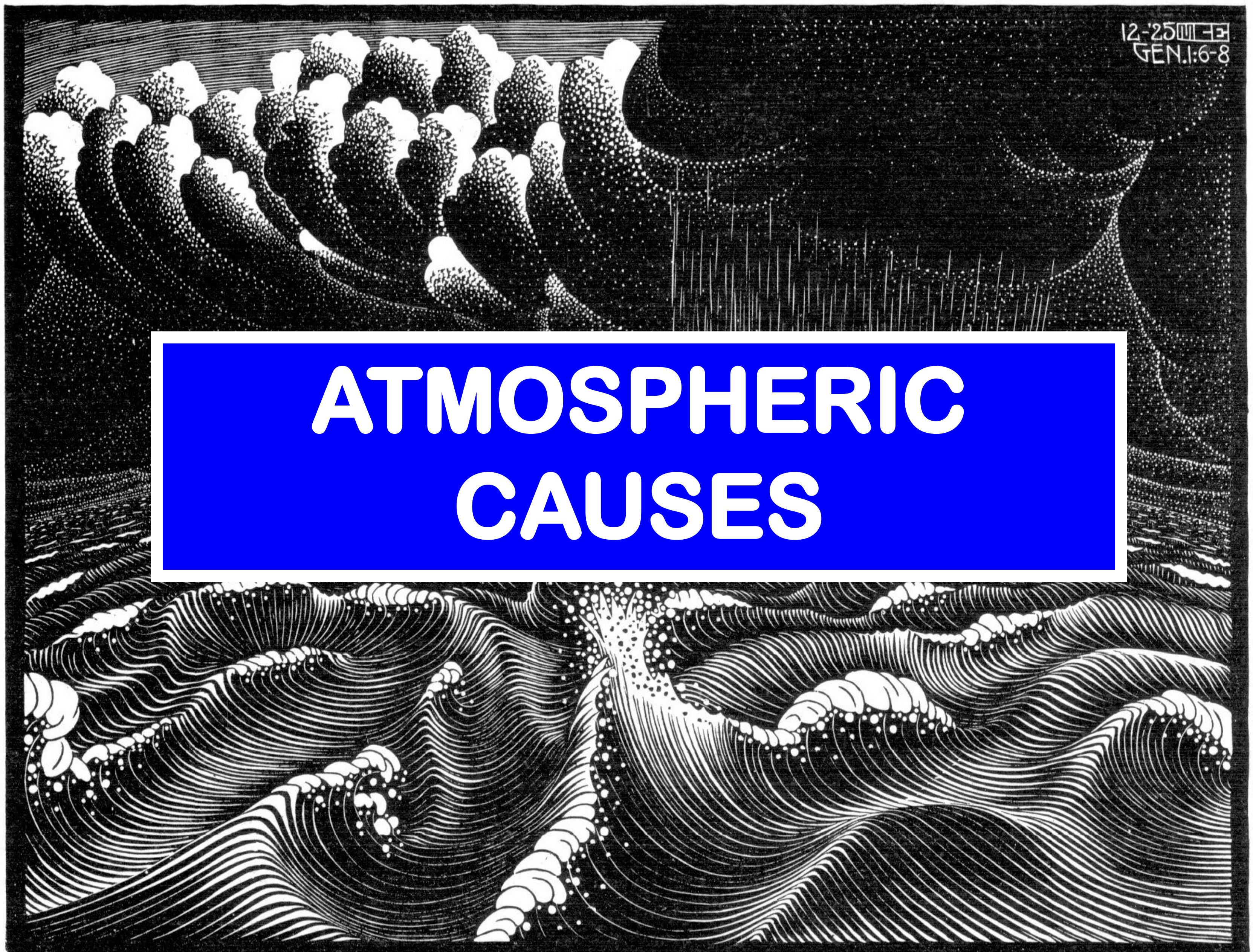
PURPOSE

- Overview of atmospheric causes of floods
- Issues related to overlapping scales
- Implications
- Concluding remarks

Flood studies / observations:

- urban flash flooding; small basin floods in U.S.
- Basin-wide and regional flooding in AZ, LA, and Mississippi RB
- Largest US rainfall-runoff floods
- Global flooding events in the Dartmouth Flood Observatory

ATMOSPHERIC CAUSES



CAUSAL ELEMENTS OF FLOODS

- INGREDIENTS
- PROCESS
- PATTERN
- PERSISTENCE
- SYNERGY

INGREDIENTS

after Doswell et al. (1996)

Heavy Precipitation

"The heaviest precipitation occurs where the rainfall rate is the highest for the longest time."

INGREDIENTS

after Doswell et al. (1996)

High Precipitation Rate (R)

- Rapid ascent of air
- Substantial water vapor
- Precipitation efficiency

INGREDIENTS

after Doswell et al. (1996)

Sustained Duration

- System Movement Speed
- System Size
- Within-System Variations in Rainfall Intensity

INGREDIENTS SUMMARY

- Heavy Precipitation
- High Precipitation Rate
- Sustained Duration

INGREDIENTS SUMMARY

Rainfall rates associated with deep, moist convection are higher than with other rain-producing systems

Meteorological processes bring these basic ingredients together

CAUSAL ELEMENTS OF FLOODS

- INGREDIENTS
- **PROCESS**
- PATTERN
- PERSISTENCE
- SYNERGY

PROCESS

Heavy flood-causing precipitation can be associated with a wide variety of storms types:

- Multicell or supercell convection
- Squall lines
- Mesoscale convective systems (MCS, MCC)

PROCESS

Tropical Storms

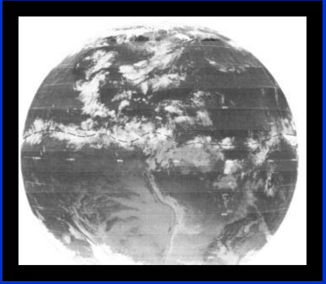
Extratropical Cyclones & associated Fronts

Snow events w/ Extratropical Cyclones, etc.

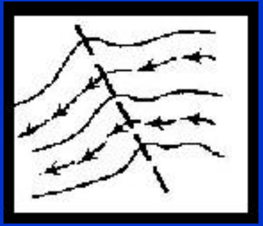
SCALE OF DISTANCE

	10,000 km	1000 km	100 km	10 km	0 km
	WORLD SCALE	SYNOPTIC SCALE	MESO-SCALE	CONVECTIVE OR SMALL SCALE	
Extra-Tropical	Long or Rossby waves Hadley cells or subtropical anticyclones	Depressions Anticyclones	Fronts Lee waves Squall lines in troughs	Cumulonimbus showers Tornadoes	
Tropics	I.T.C.Z. Easterly waves	Cloud clusters Tropical cyclones	Meso-scale convective cells	Convective elements	
	1000 h	100 h	10 h	1 h	0 h

SCALE OF TIME

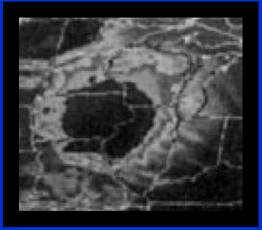


ITCZ

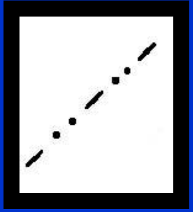


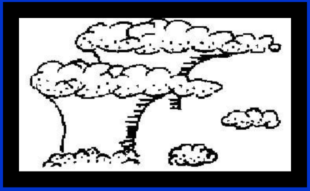
EASTERLY WAVE

TROPICAL STORM



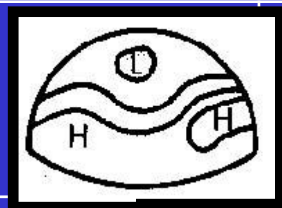
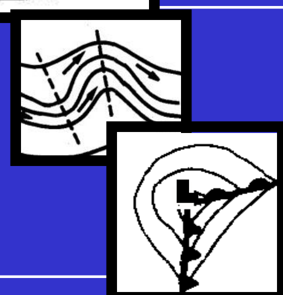
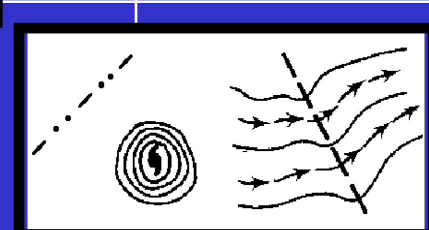
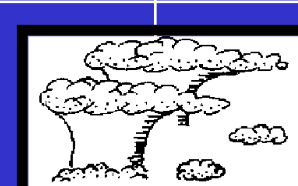
MESOSCALE CONVECTION



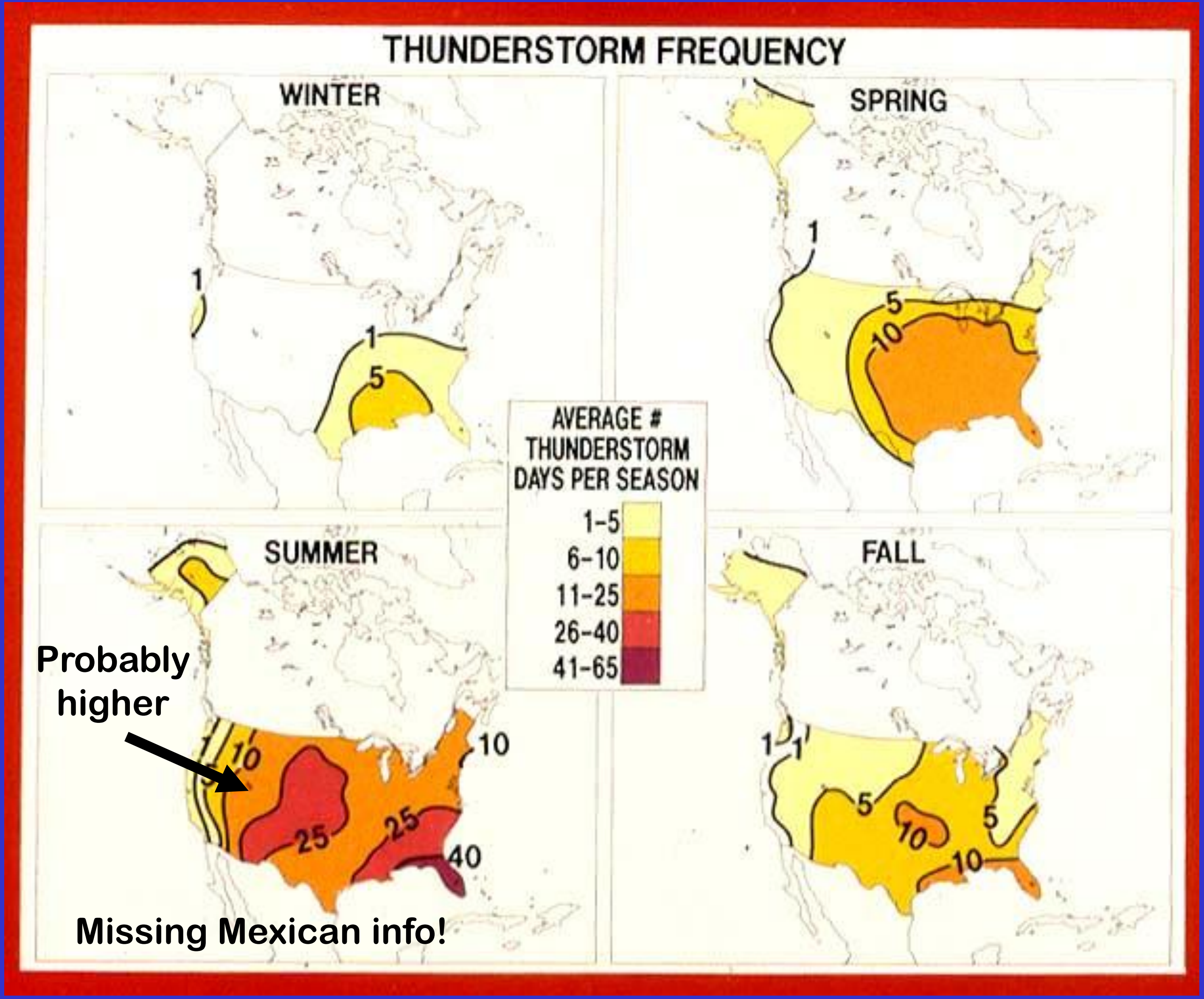


ORGANIZED CONVECTION

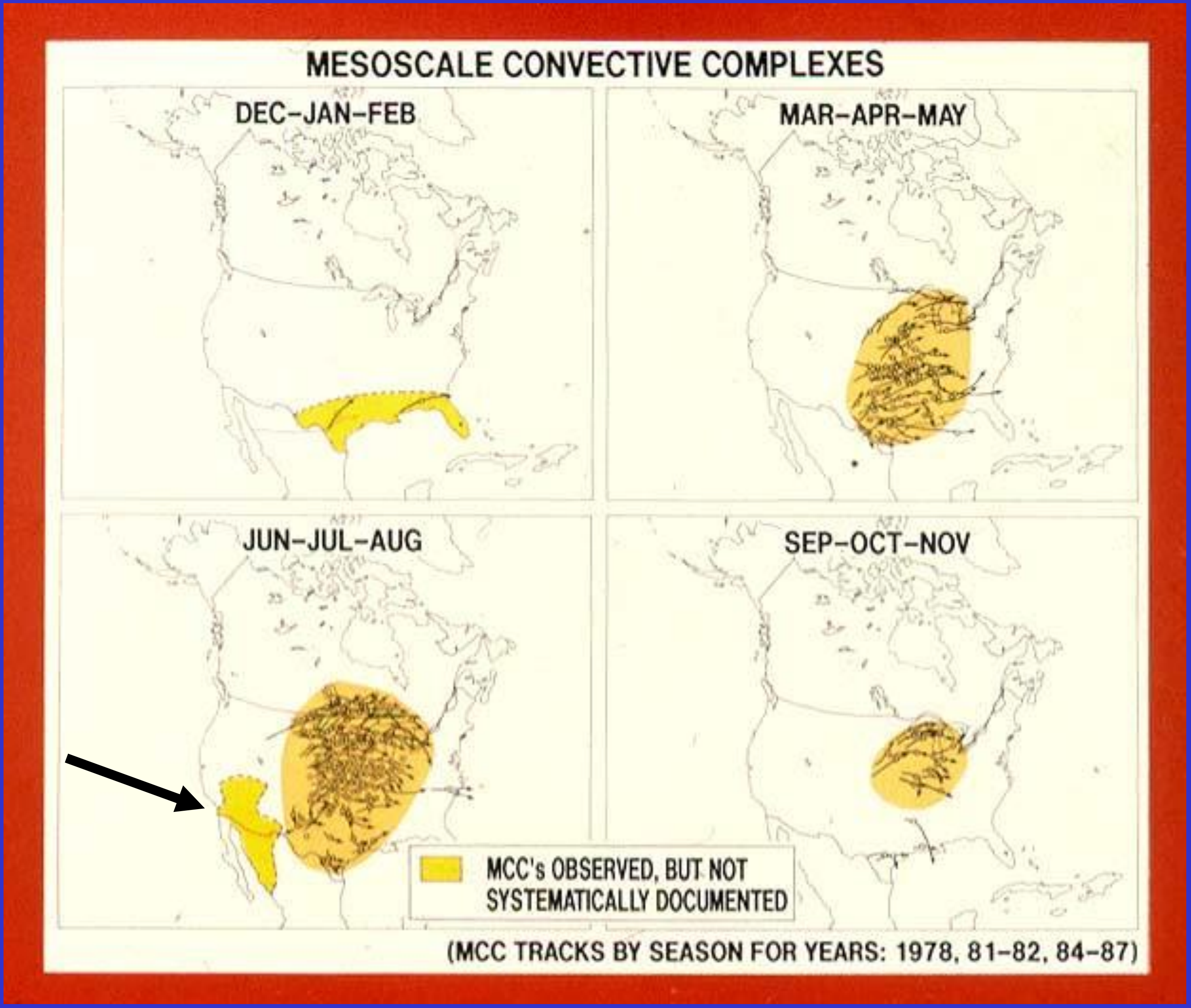
SCALE TERMINOLOGY (after Hirschboeck et al, 2000)

Length Scale (km)	Time Scale				Term
	←	1 month	1 day	1 hour	
>10,000					Macro-scale
10,000 to 2,000					Synoptic scale
2,000 to 50					Meso-scale
50 to 5					Storm scale

U.S. overview of climate and floods

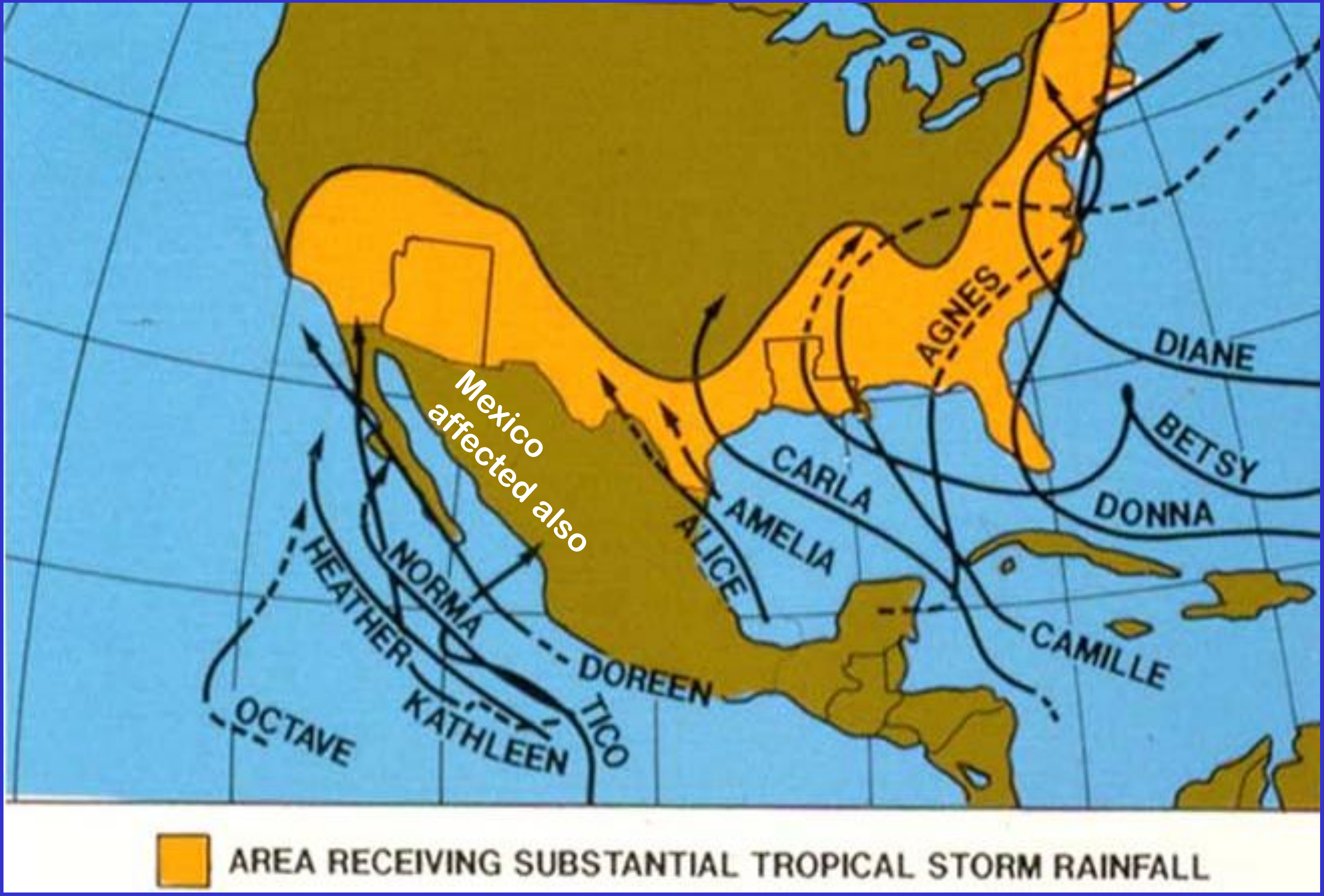


From Hirschboeck, 1991; based on earlier thunderstorm studies



from Hirschboeck, 1991; based on series of published & unpublished data from Maddox et al

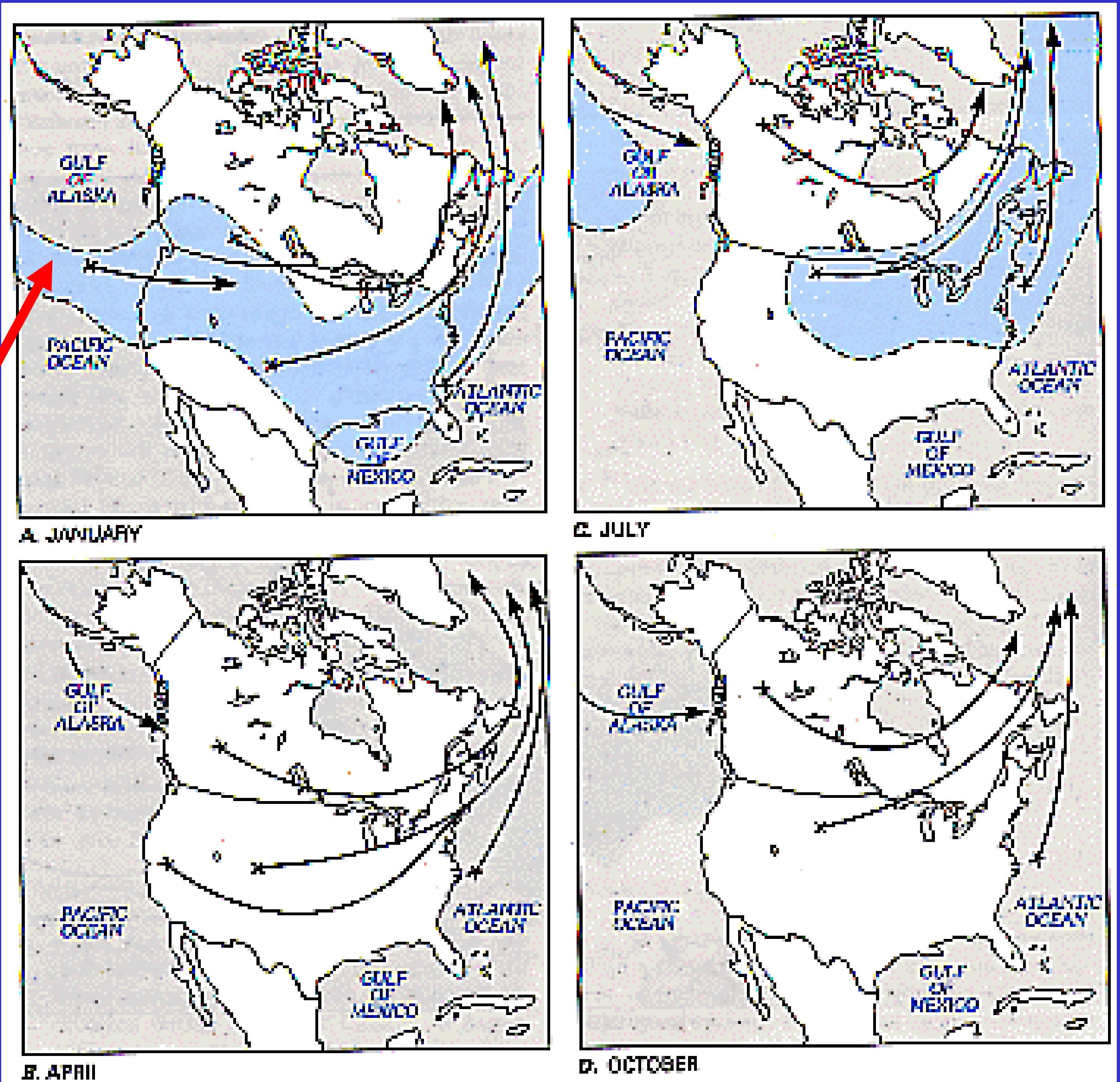
Some important flood-generating tropical storms



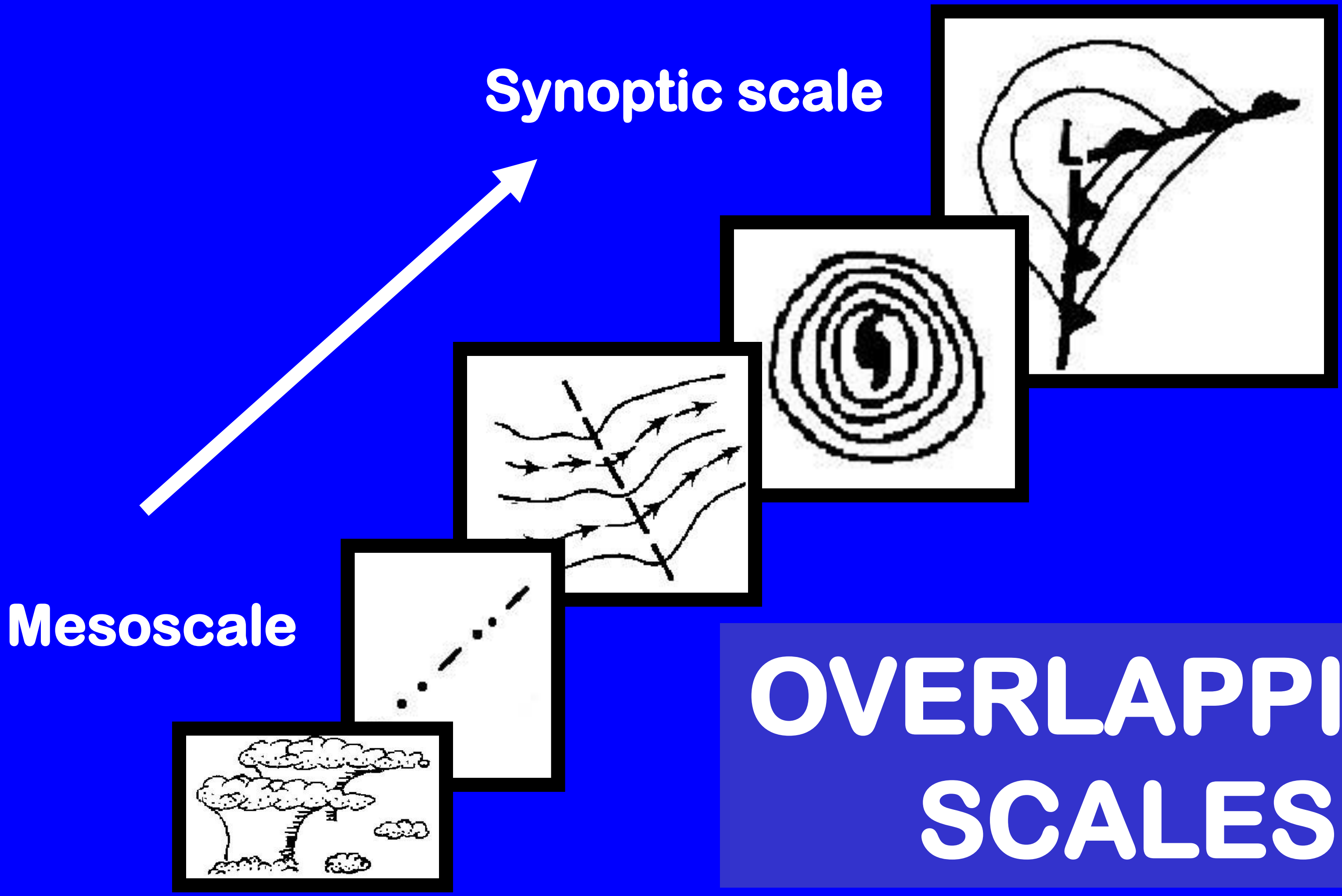
from Hirschboeck, 1991

Synoptic Scale

Areas in which FRONTS associated with extratropical cyclones occur more than 50 % of the time

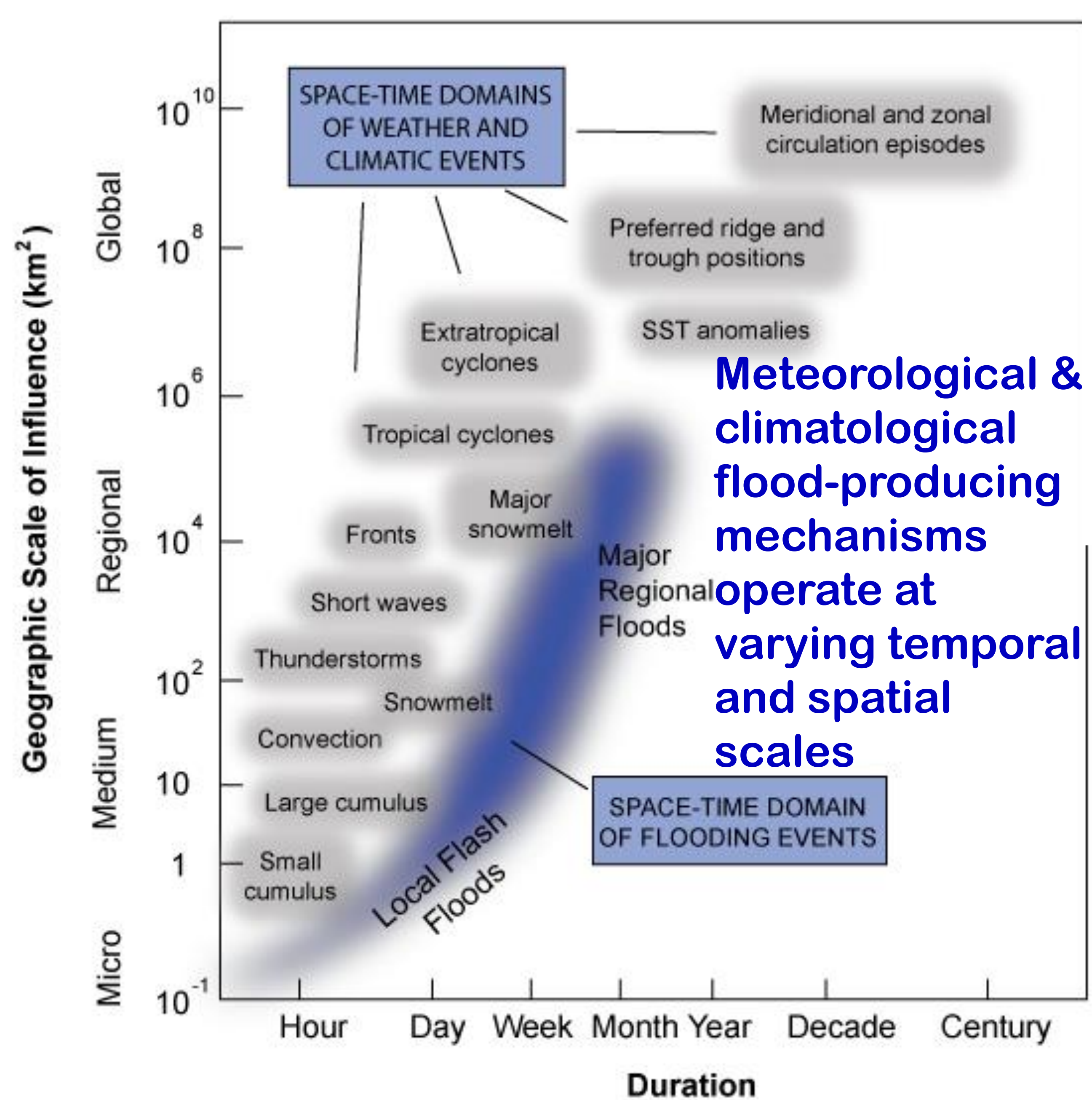


PROCESS



OVERLAPPING SCALES

FLOOD-CAUSING MECHANISMS



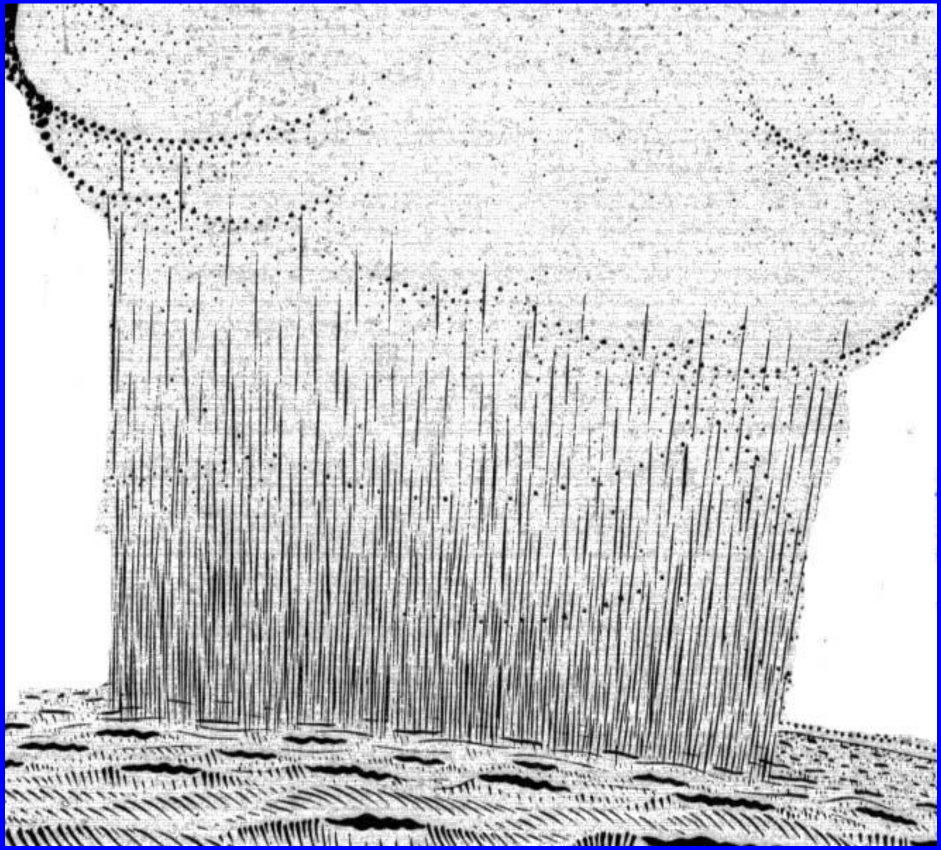
Meteorological & climatological flood-producing mechanisms operate at varying temporal and spatial scales

precipitation systems which occur at one scale . . . .

. . . Are strongly interconnected with systems at other scales . . .

. . . and larger scale processes set the stage for activity at smaller scales.

Scale factors are critical determinants of whether a given atmospheric mechanism will cause a flood.



PROCESS

Large-scale vertical motions typical do not initiate convection . . .

. . . but there is a connection between synoptic-scale weather systems and deep, moist convection

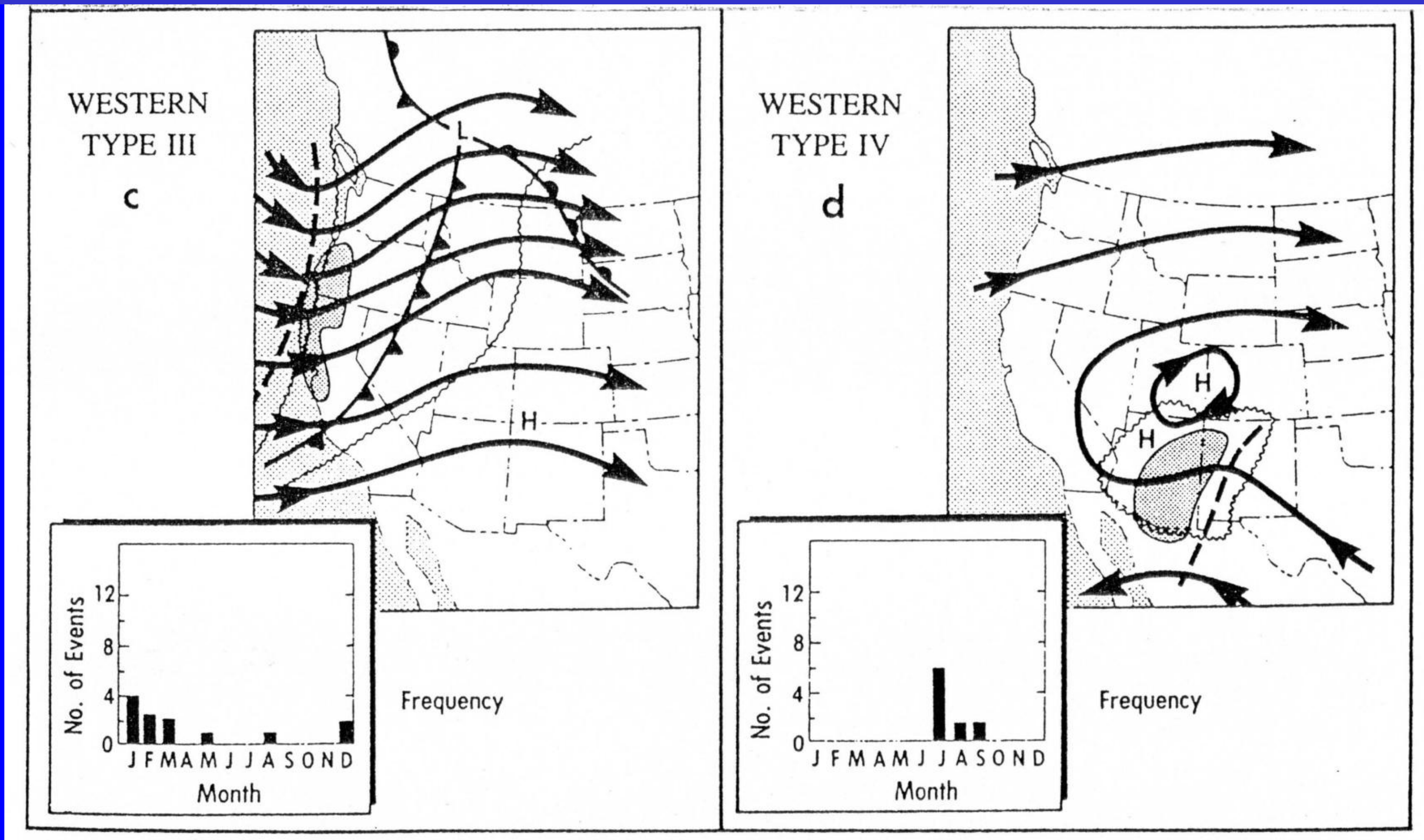
PROCESS

Connection:

. . . via moistening and destabilization created by the modest but persistent SYNOPTIC-SCALE vertical ascent ahead of short-wave troughs

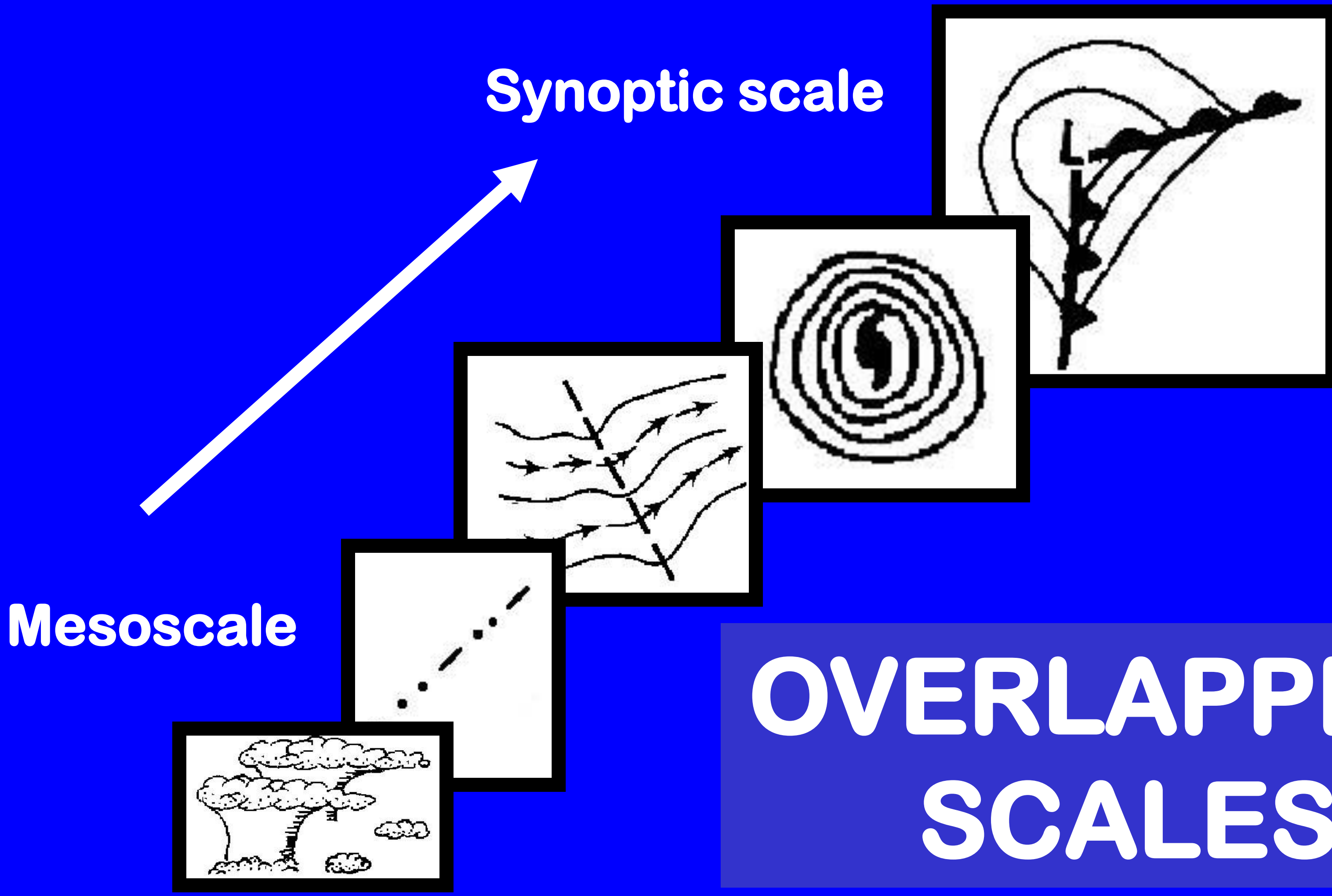
Doswell 1987, Doswell et al. (1996)

Mesoscale → Synoptic Scale connection in meteorology of flash floods



Based on Maddox et al. (1980)

PROCESS SUMMARY



OVERLAPPING SCALES

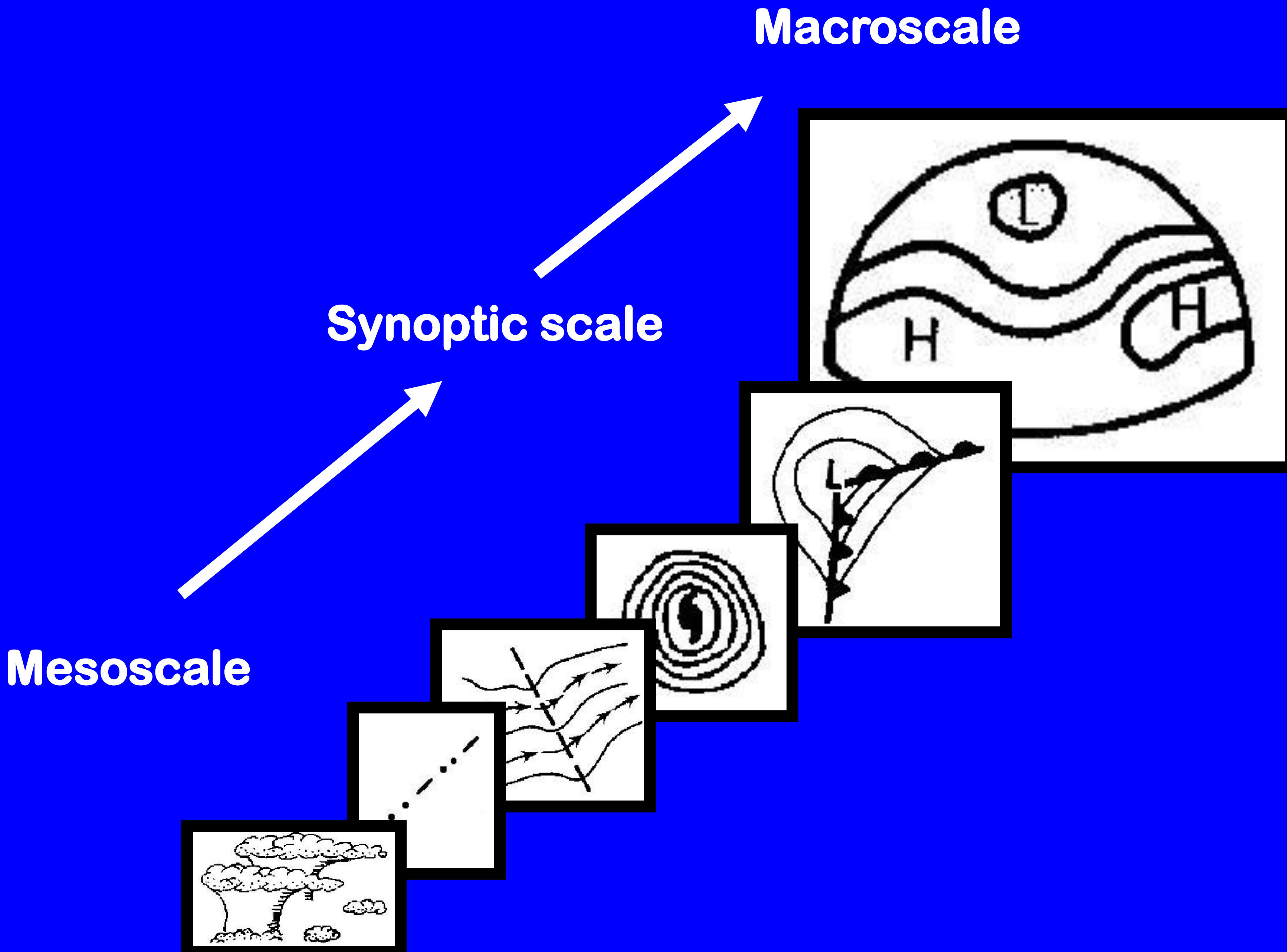
PROCESS SUMMARY

- Linkage across scales does not necessary imply that there is a *seamless process continuum* in the nature of flood-causing storm systems

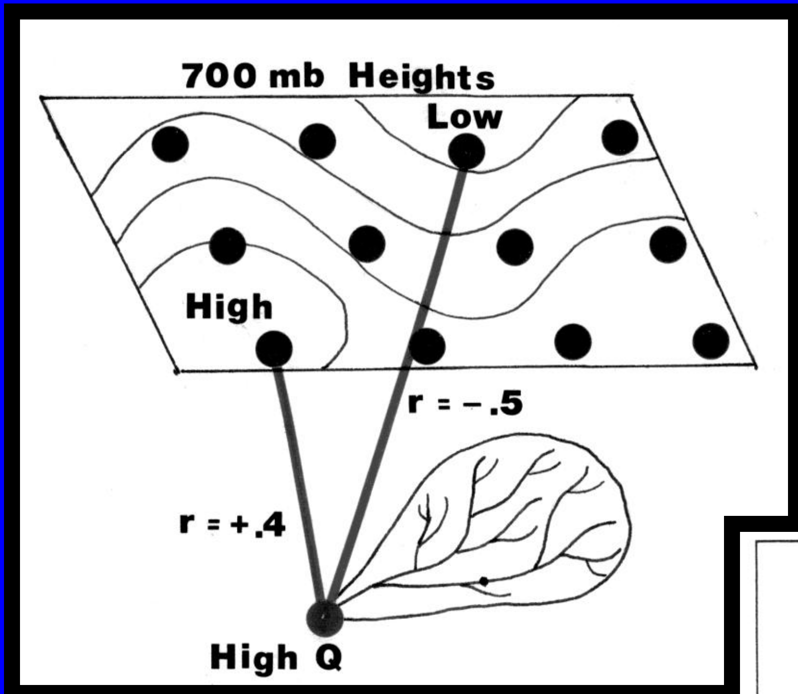
- Distinct processes tend to concentrate around discrete and disparate states

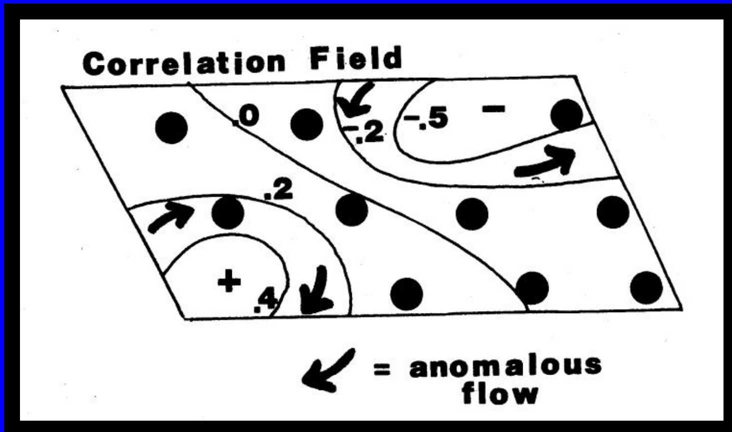
CAUSAL ELEMENTS OF FLOODS

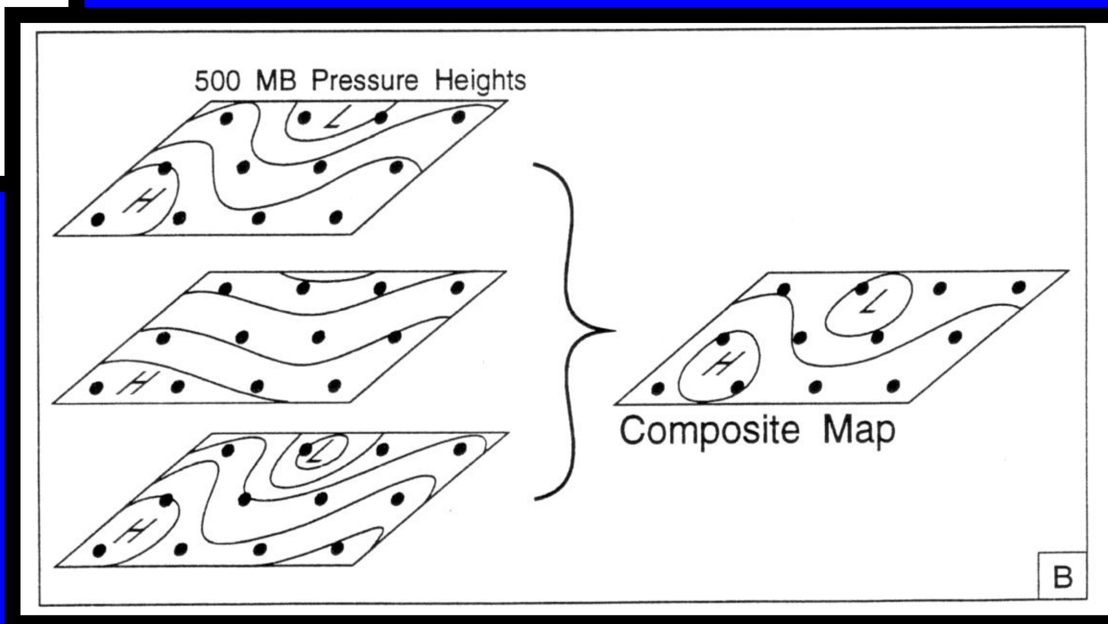
- INGREDIENTS
- PROCESS
- **PATTERN**
- PERSISTENCE
- SYNERGY


Macroscale
Synoptic scale
Mesoscale

PATTERN



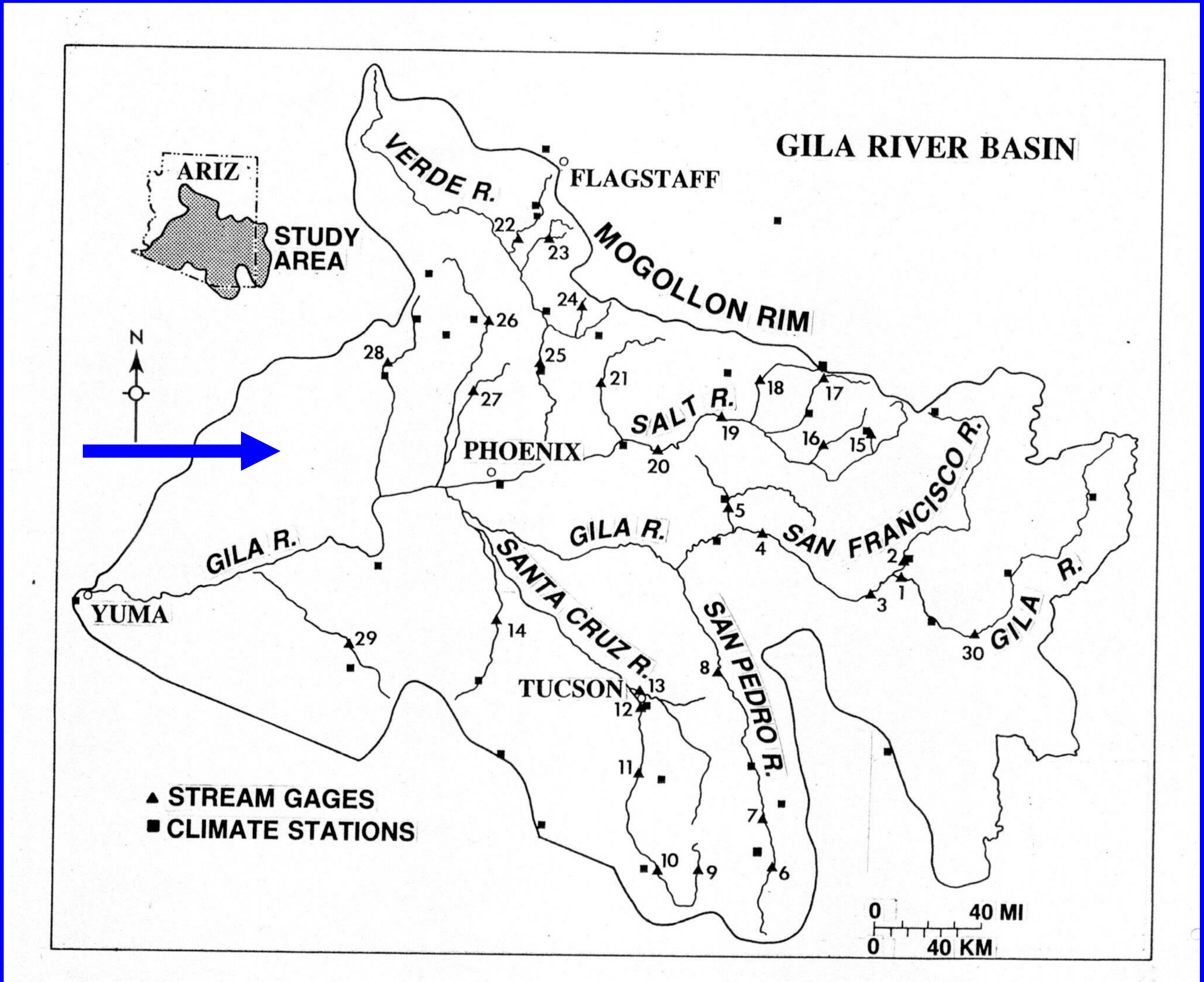




> Correlation fields
> Composites
> Principle components

Flooding in La Paz County, Arizona

October, 2000



GILA RIVER BASIN
ARIZ
STUDY AREA
N
VERDE R.
FLAGSTAFF
MOGOLLON RIM
SALT R.
PHOENIX
GILA R.
SAN FRANCISCO R.
SANTA CRUZ R.
SAN PEDRO R.
GILA R.
YUMA
TUCSON
STREAM GAGES
CLIMATE STATIONS
0 40 MI
0 40 KM
1
2
3
4
5
6
7
8
9
10
11
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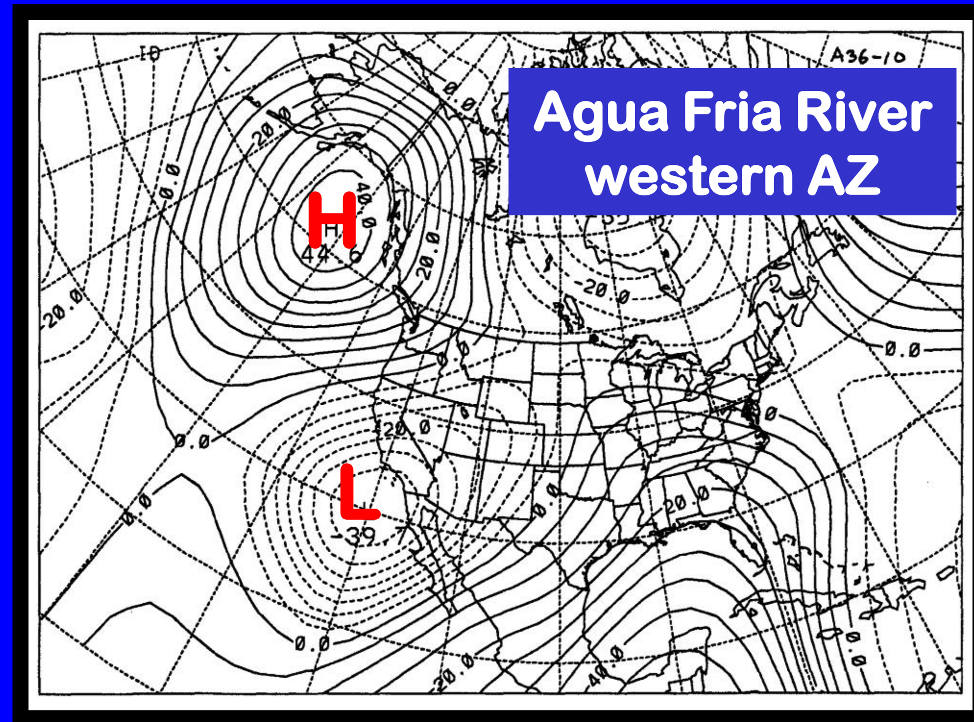
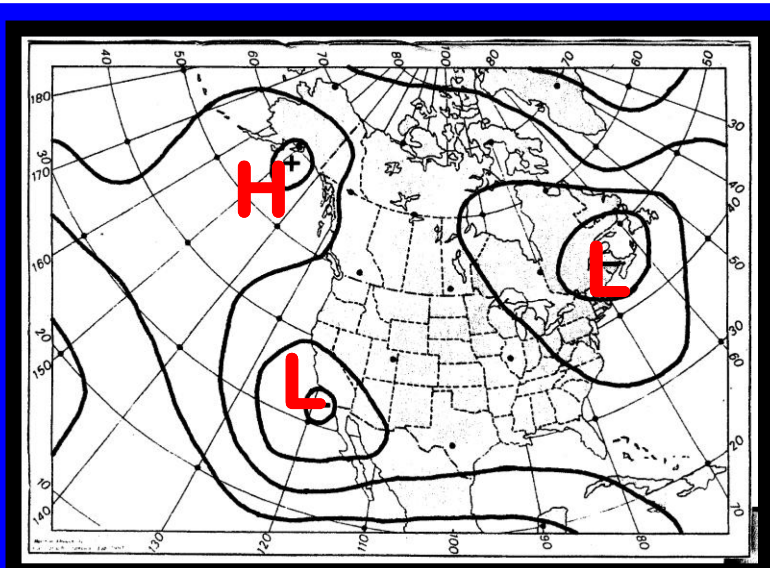
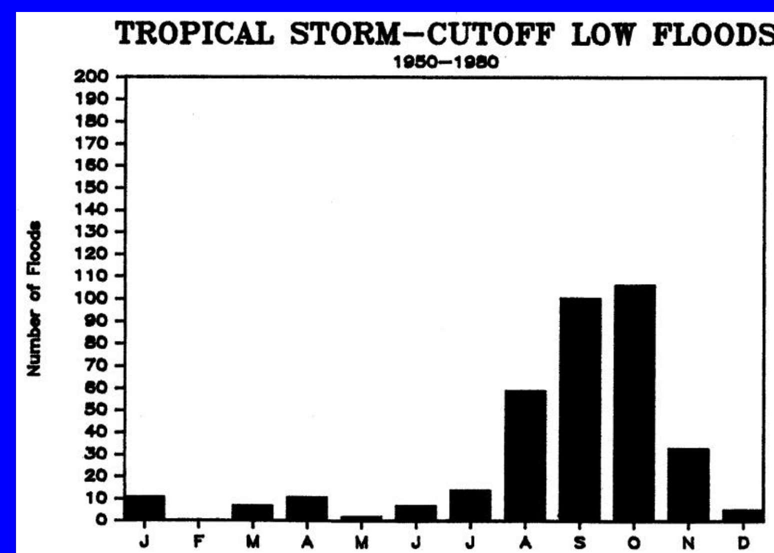
Correlation pattern for peak October streamflow



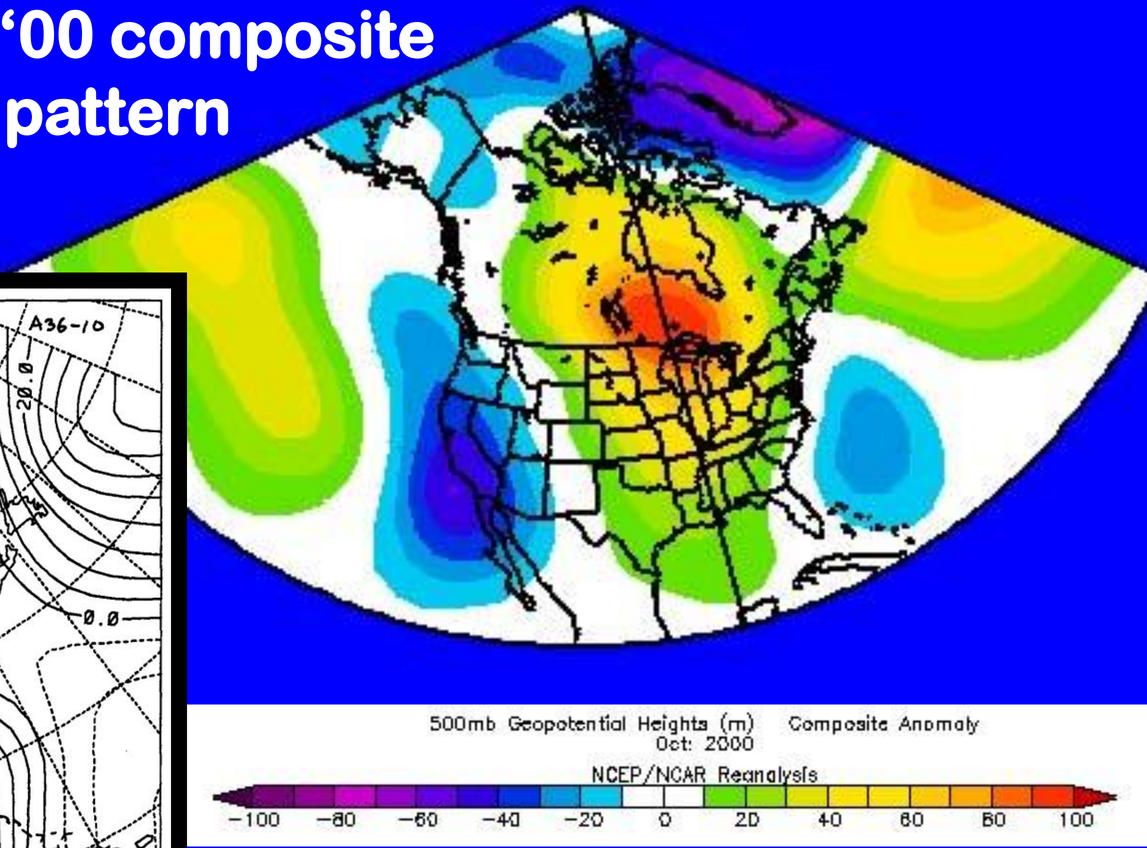
Composite pattern Cutoff Low Floods in AZ

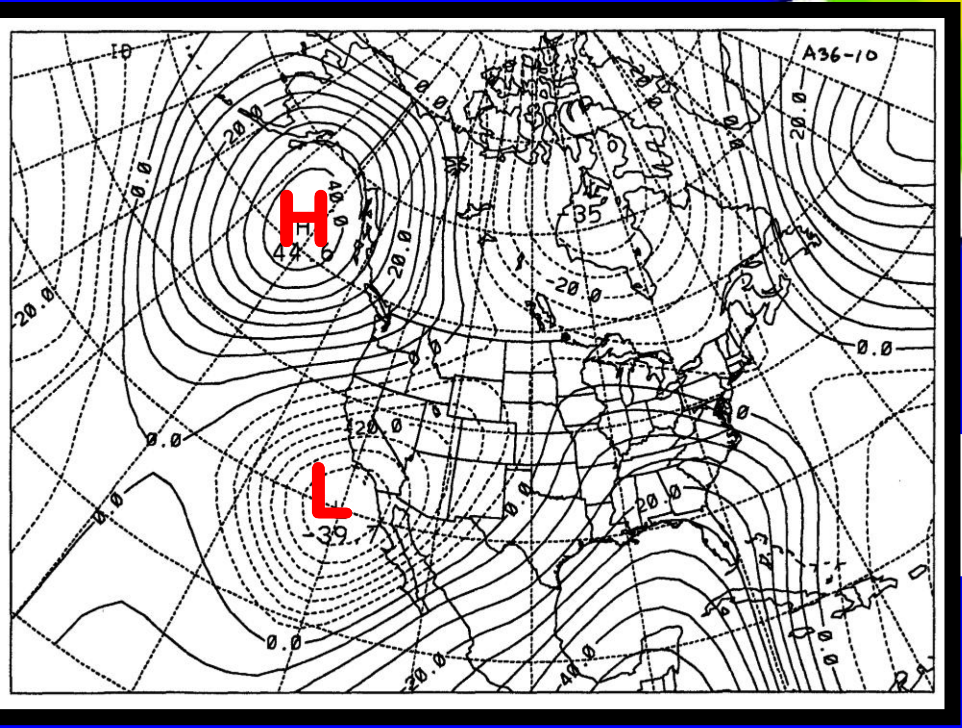




PATTERN

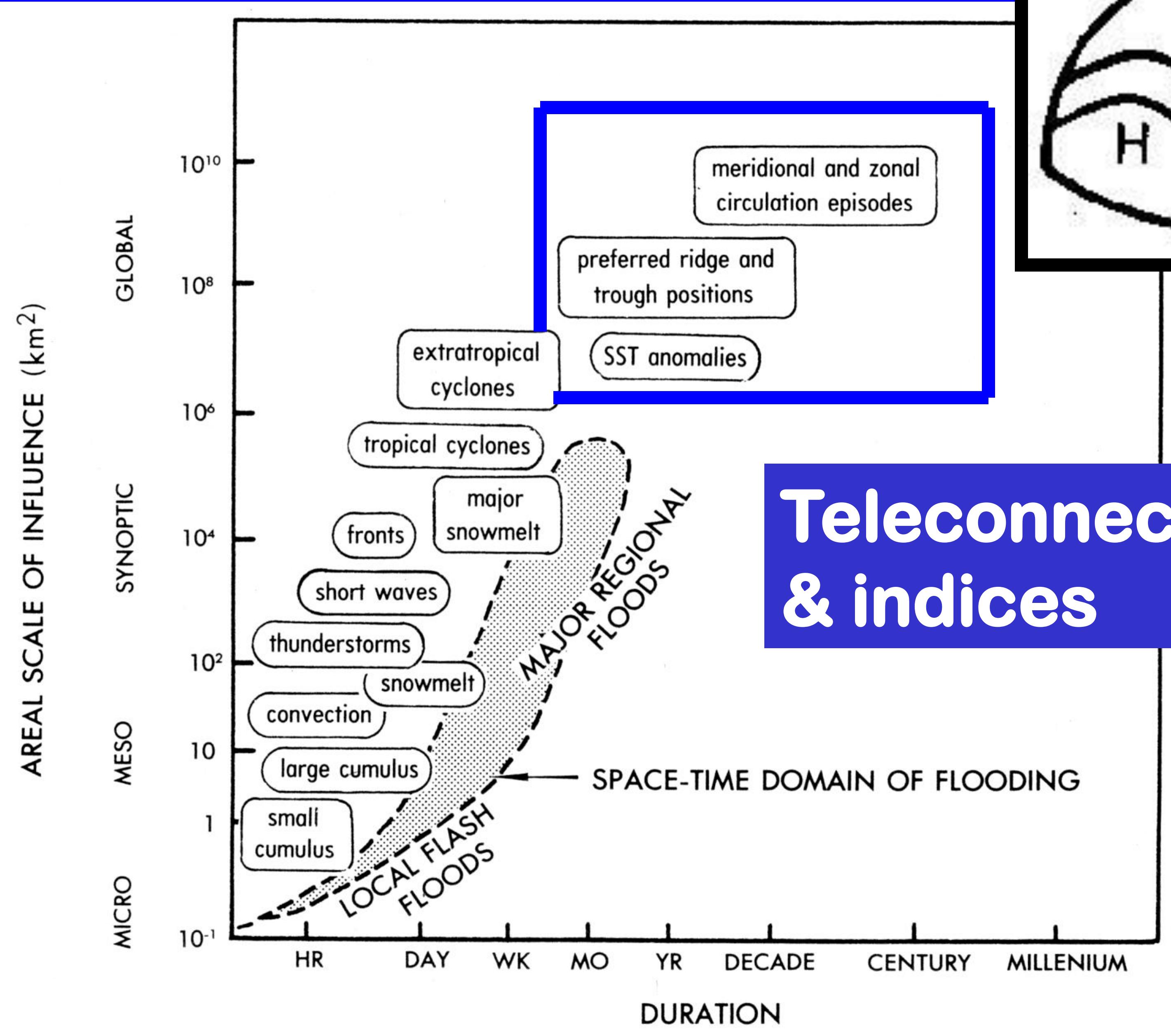
October '00 composite anomaly pattern

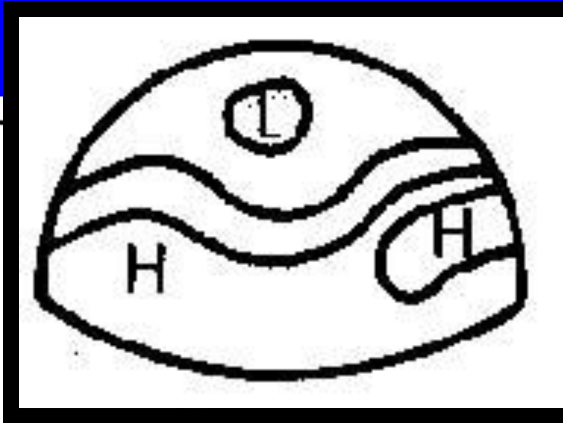




October W. AZ peak streamflow pattern

(Similar to PNA teleconnection pattern)





Teleconnections & indices

PATTERN SUMMARY

- Most floods in studies could be linked to one of several flood-producing synoptic-scale and/or larger-scale patterns
- Patterns change regionally and seasonally
- Frameworks for forecasting and “backcasting”

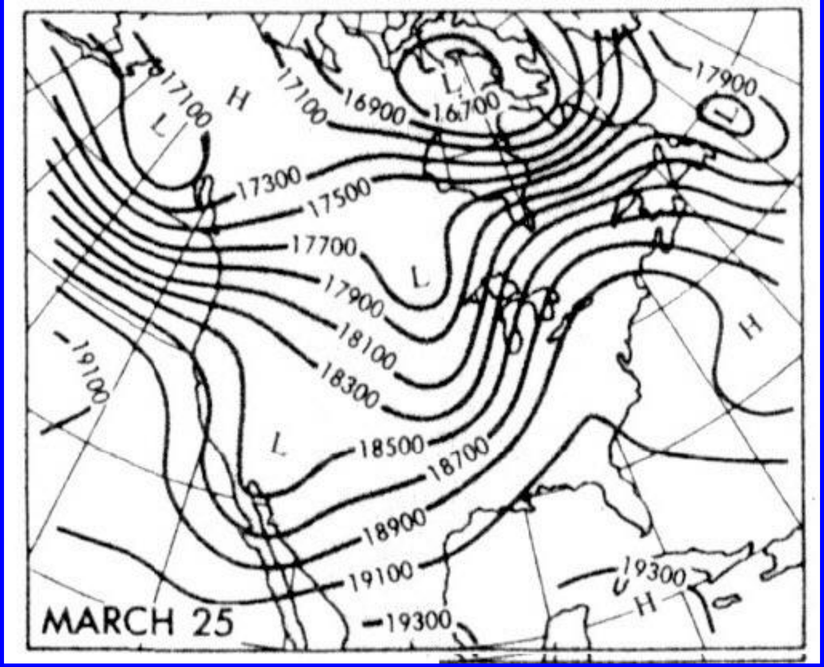
PATTERN SUMMARY

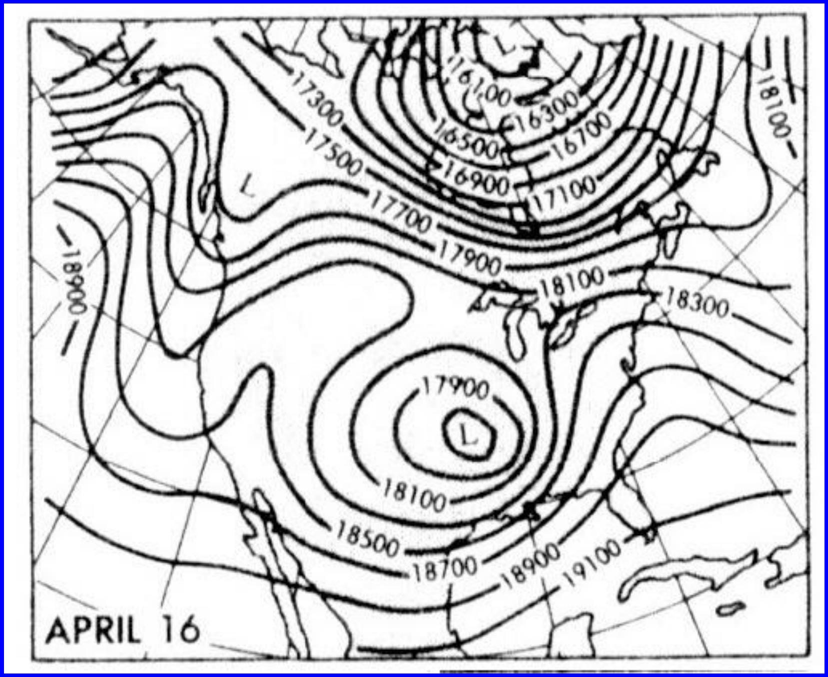
- Pattern alone not always sufficient as causal explanation
- If ingredients are <u>not</u> in place, heavy precipitation / flood may not develop
- If ingredients <u>are</u> in place, a benign pattern may yield anomalous flooding (flash floods)

CAUSAL ELEMENTS OF FLOODS

- INGREDIENTS
- PROCESS
- PATTERN
- **PERSISTENCE**
- SYNERGY

PERSISTENCE

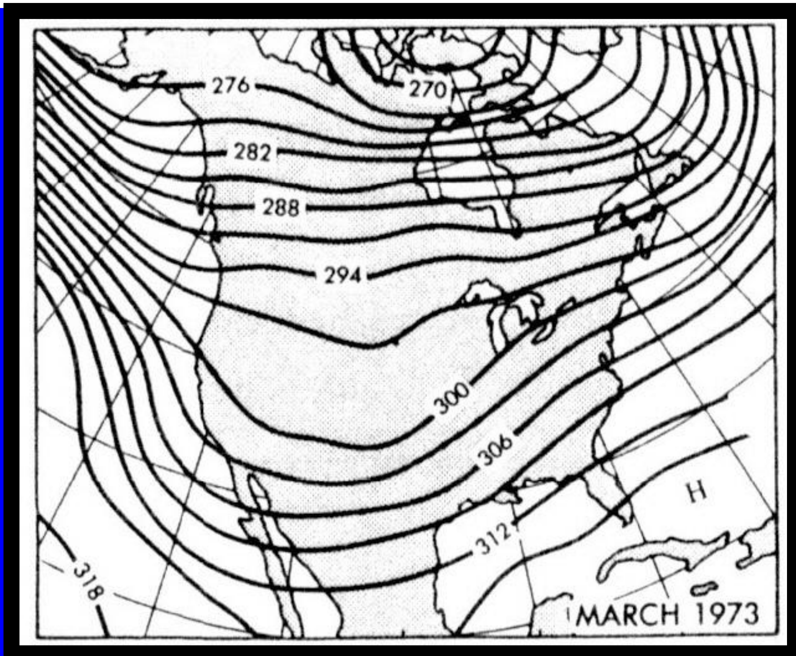


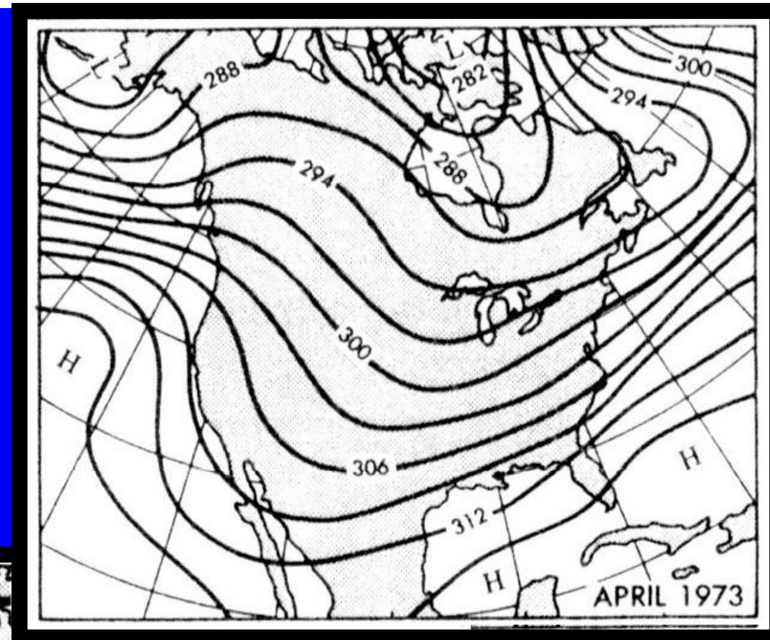


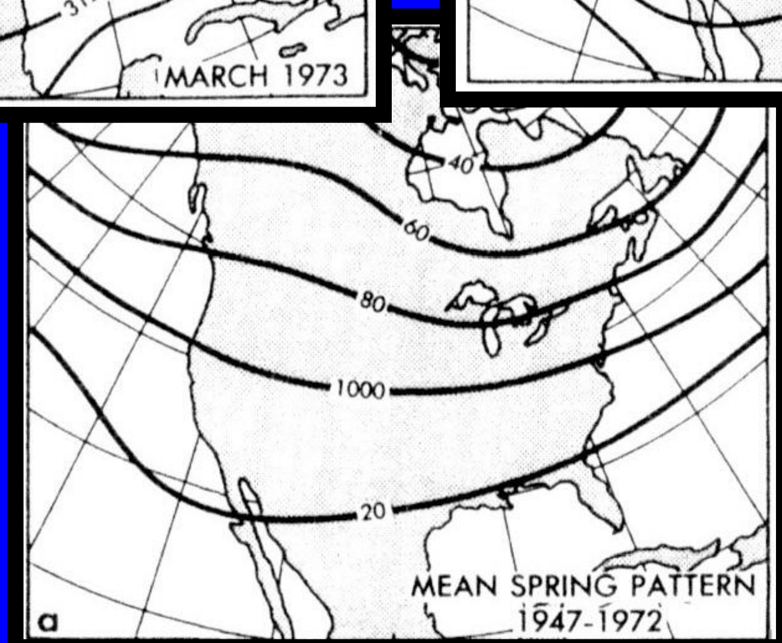
Flooding in the Mississippi River Basin
Spring 1973

Hirschboeck (1985)

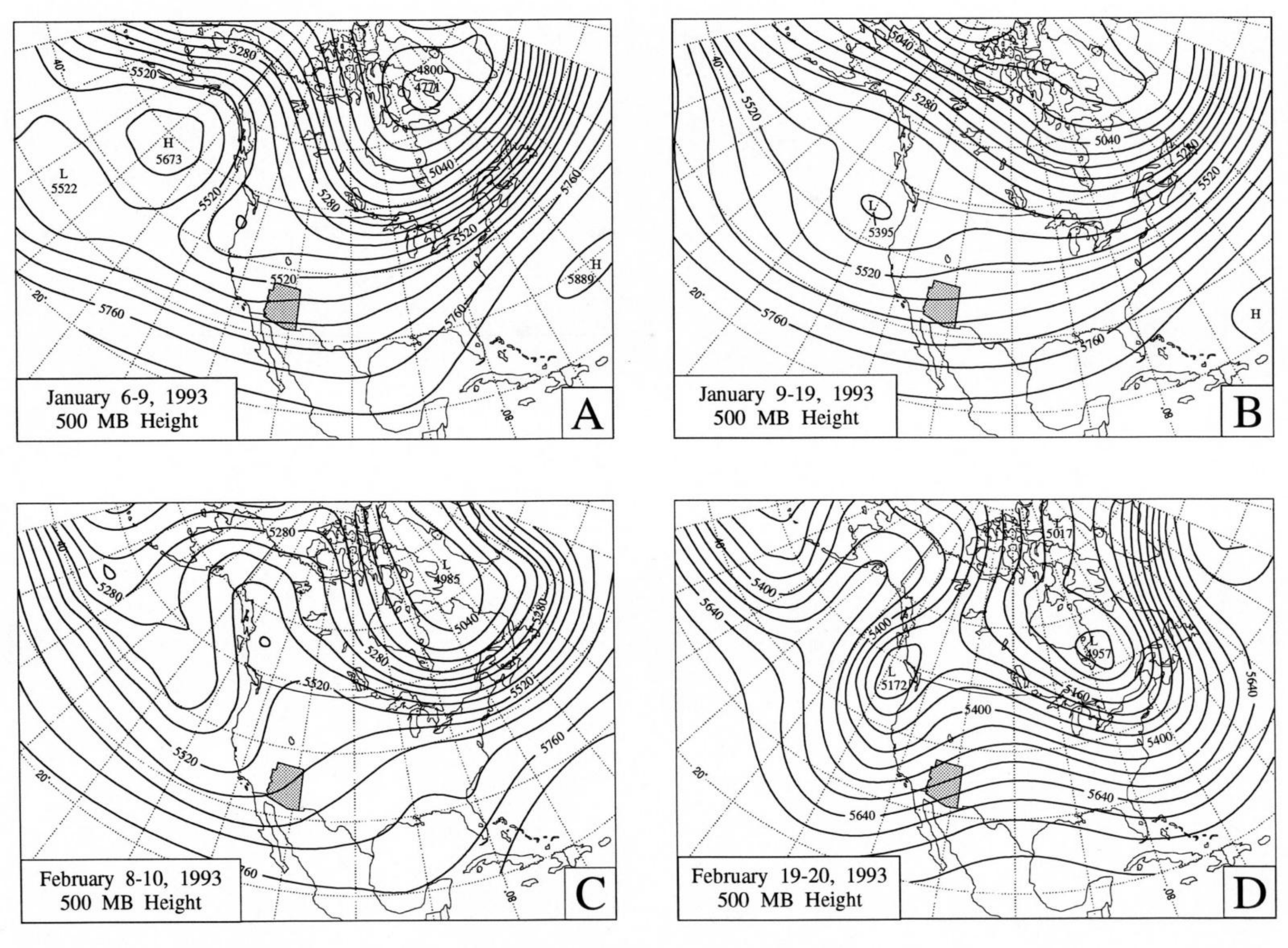
PERSISTENCE







PERSISTENCE



Flooding in Arizona - Winter 1993

House and Hirschboeck (1997)

PERSISTENCE

" moistening and destabilization created by the modest but PERSISTENT synoptic-scale vertical ascent ahead of short-wave troughs"

Doswell 1987, Doswell et al. (1996)

PERSISTENCE SUMMARY

- Persistence of INGREDIENTS (e.g., deep moist convection environment) most important at small scales (flash floods)
- Persistence of PATTERN most important at larger scales (basin-wide / regional floods)

PERSISTENCE SUMMARY

- In the largest and most extreme floods studied, PERSISTENCE was always a factor
- Persistence bridges meteorological and climatological time scales
- Persistence = underlying factor in atmosphere / basin synergy

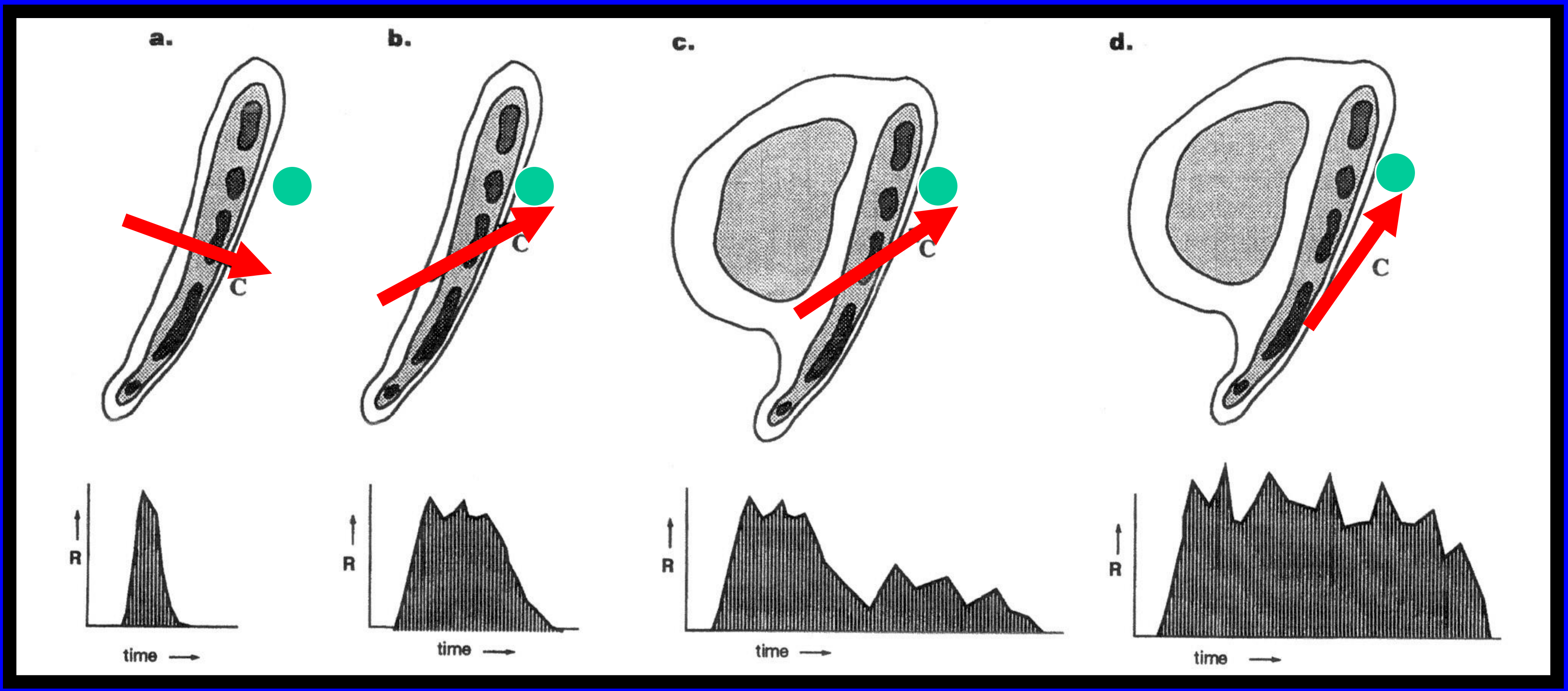
CAUSAL ELEMENTS OF FLOODS

- INGREDIENTS
- PROCESS
- PATTERN
- PERSISTENCE
- **SYNERGY**

SYNERGY

SYNERGY = A combined action or operation; a mutually advantageous conjunction or compatibility of distinct elements

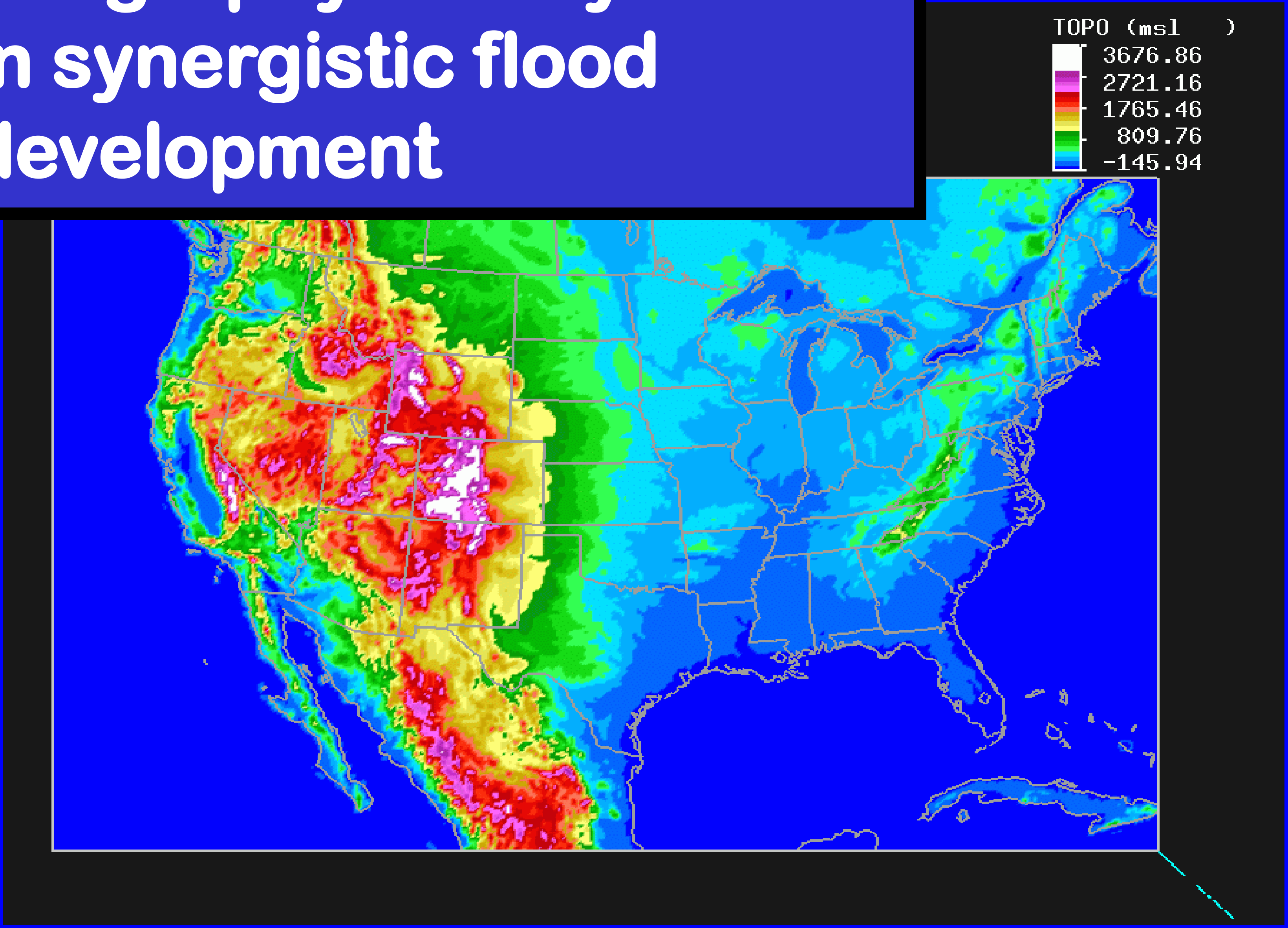
> slow movement of system
> large area of high R along motion vector
> both occurring together (as in d)



From Doswell et al. (1996)

The ways in which precipitation is delivered in both space and time over drainage basins of different size strongly influence the occurrence and type of flood event.

Orography = a key factor in synergistic flood development



Source: National Severe Storms Lab

SYNERGY SUMMARY

Synergistic relationships between:

> meteorological & climatological processes;

> basin size, shape, and orientation;

> orography

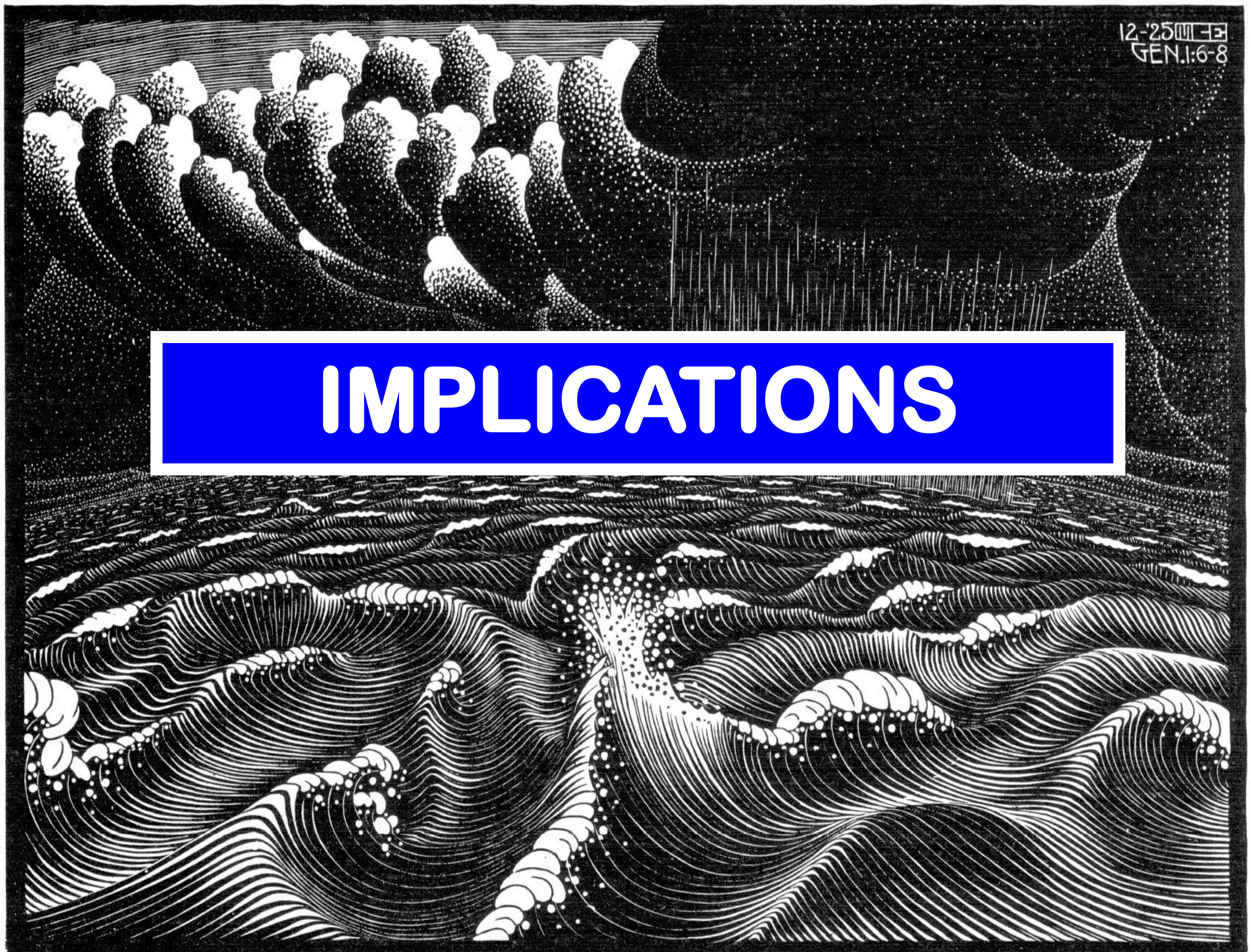
were factors in many of the extreme flood peaks, esp. in small basins

SYNERGY SUMMARY

Synergistic factors can both supercede the influences of PATTERN

. . . or enhance the influences of PATTERN

IMPLICATIONS



KEY QUESTION:

Can flood-causing mechanisms be analyzed as a *process continuum* . . .

. . . using statistical techniques, (e.g. “upscaling” or “downscaling”) . . .

. . . Or do they concentrate around discrete scales?

Are there limits in space and time to our ability to transfer causal-process information observed at one scale to that of another?

Can processes and scale relationships observed in the gaged record be applied over longer time scales?

- assess paleoflood causes
- develop climatic forecasts for floods

What about

GLOBAL FLOOD

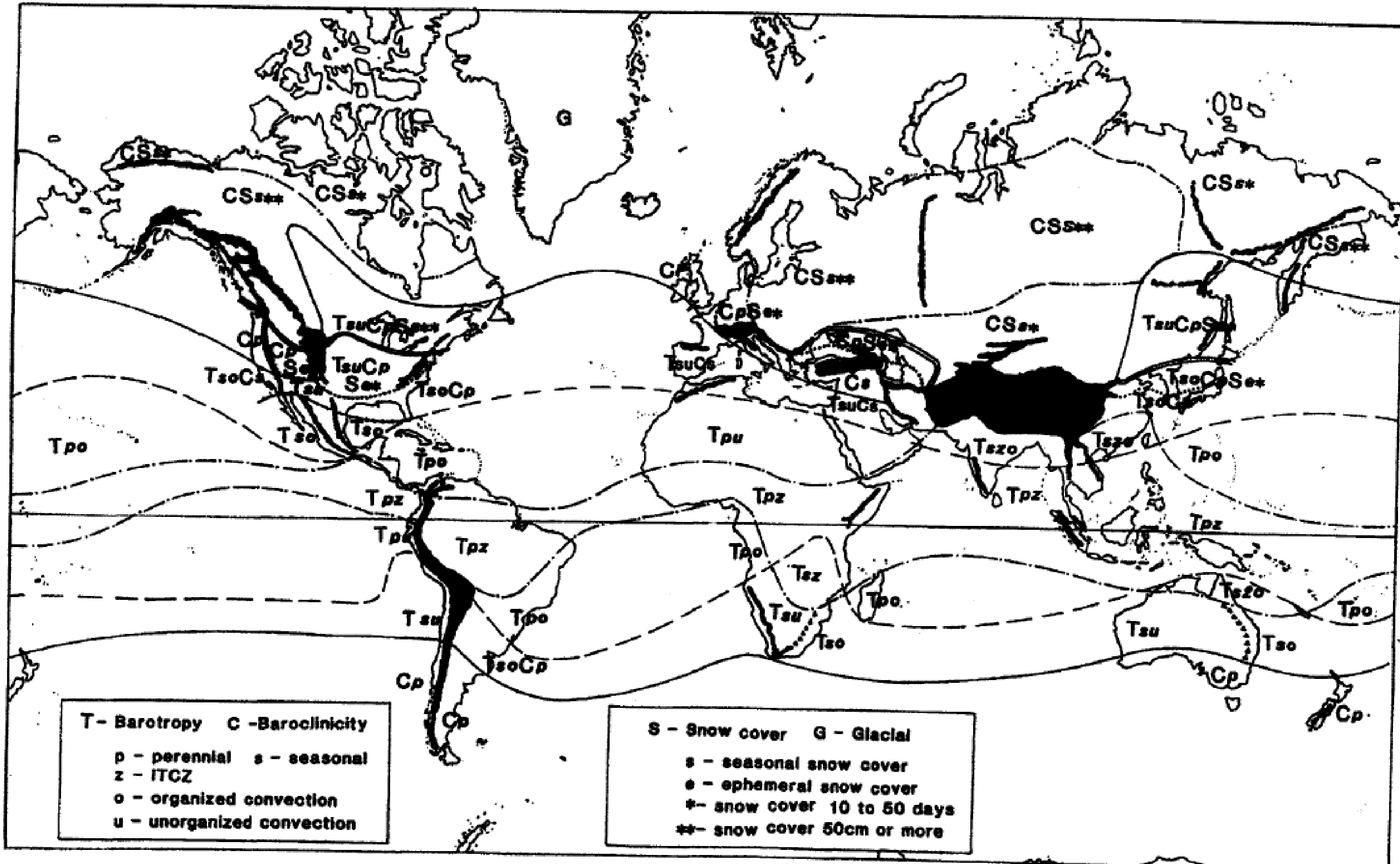
PATTERNS?

Can they be identified?

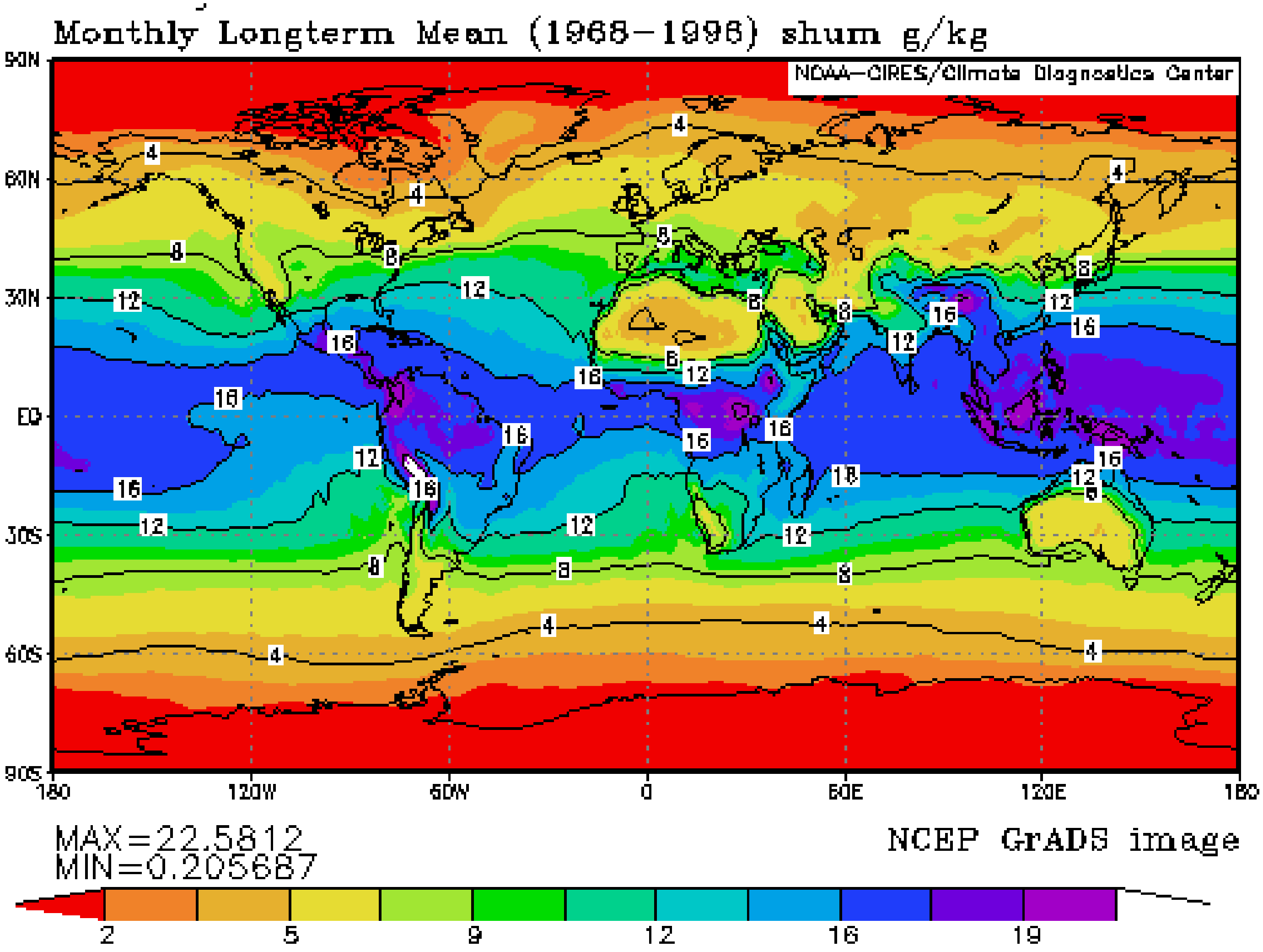
Quantified?

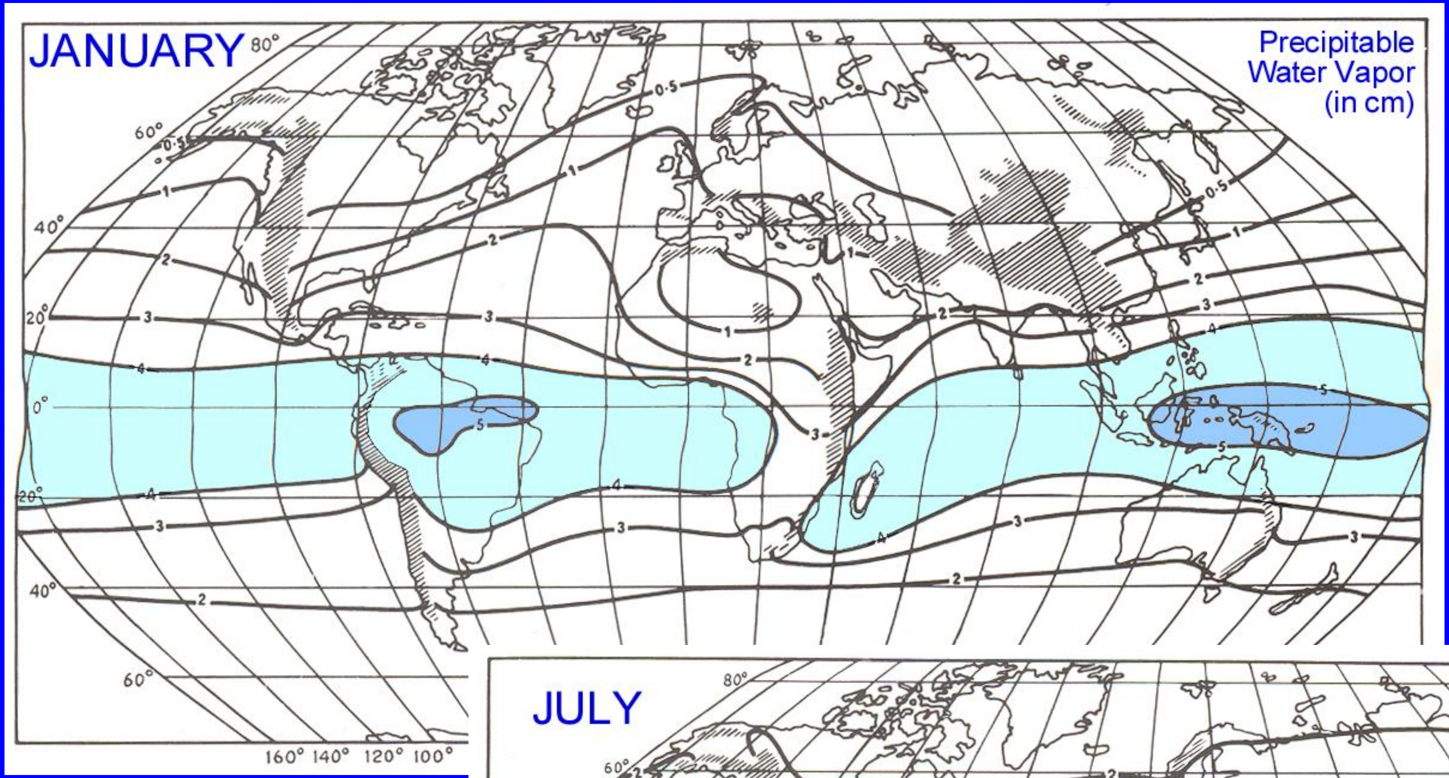
Can trends be seen?

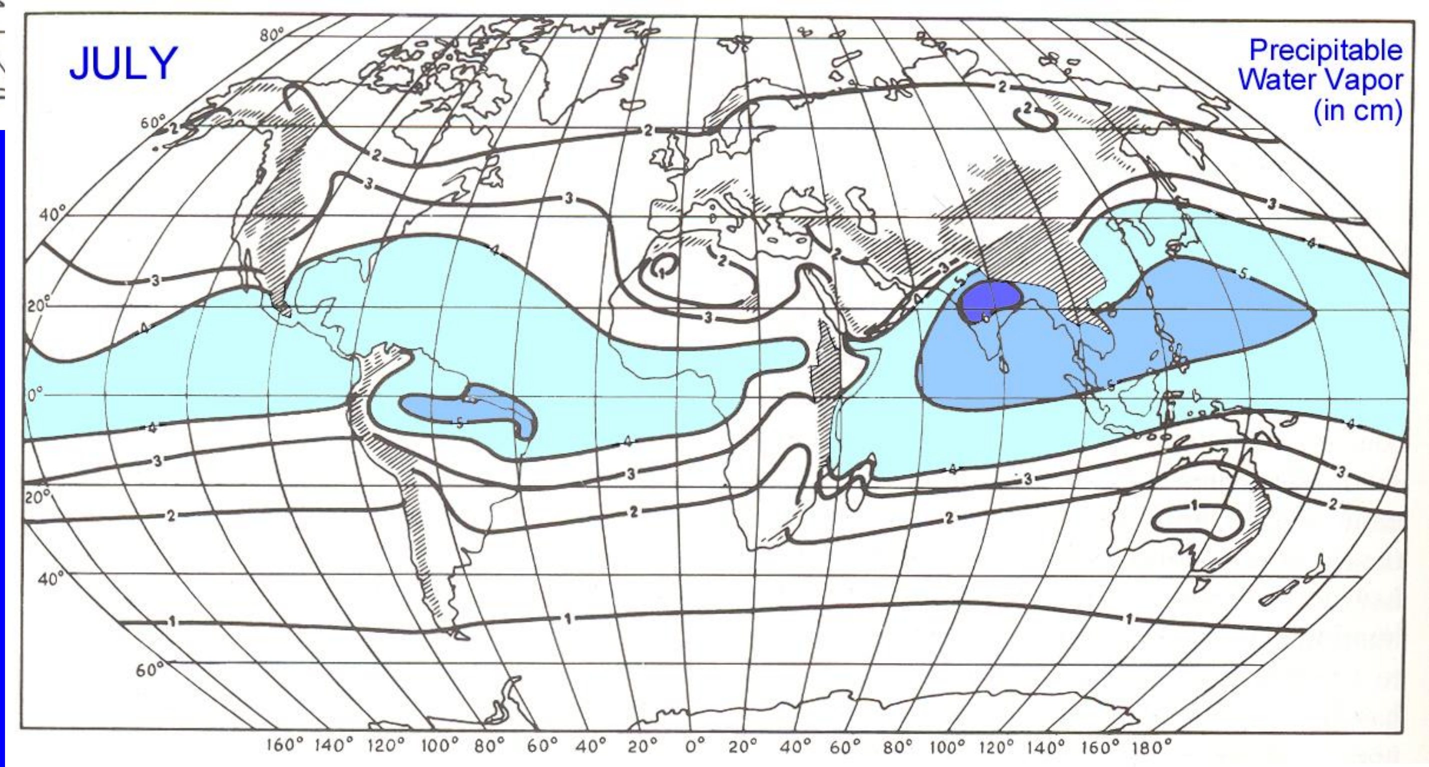
Hayden's Flood map:

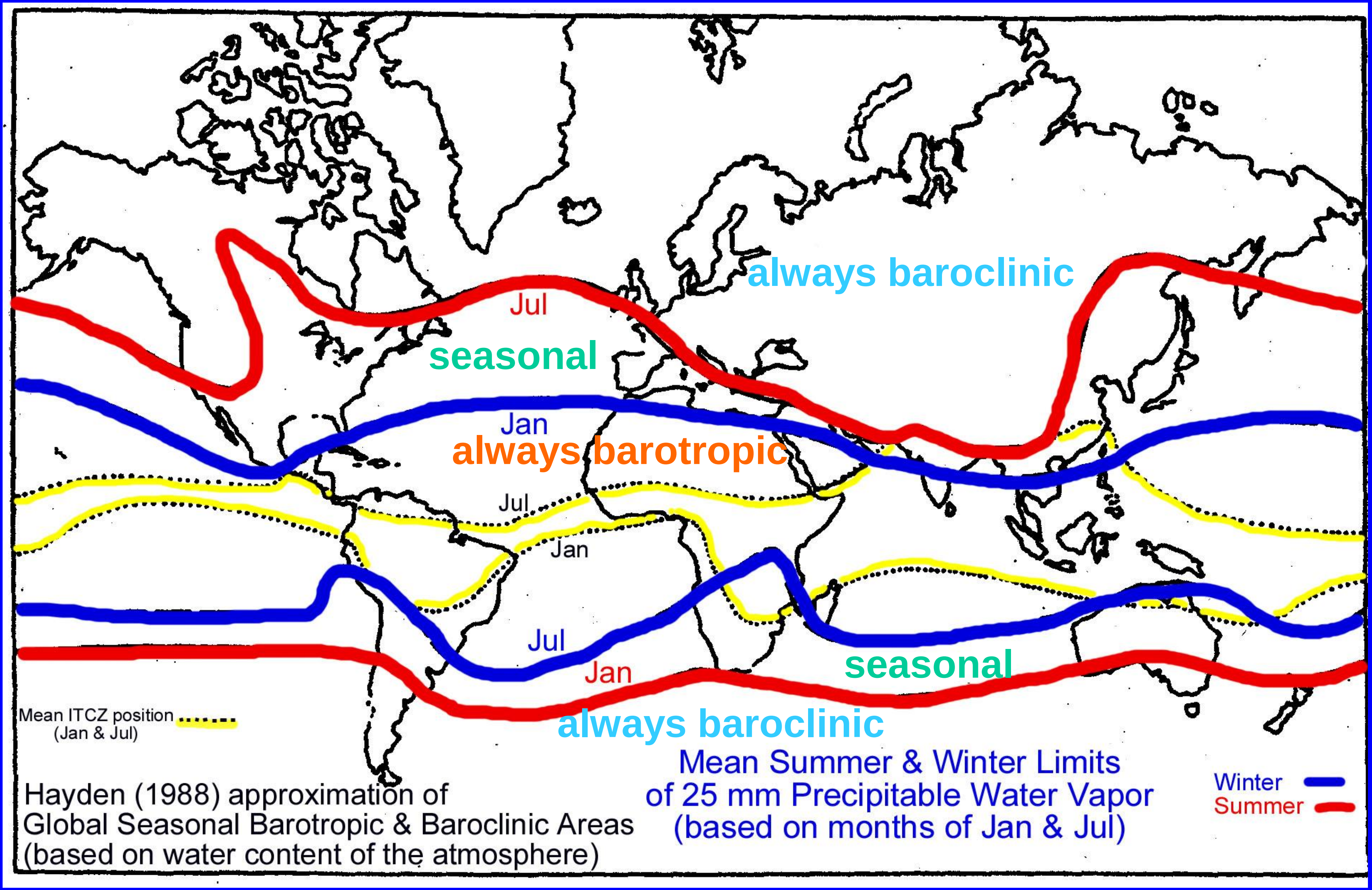


MEAN SPECIFIC HUMIDITY at 1000 mb
Annual (Jan – Dec)



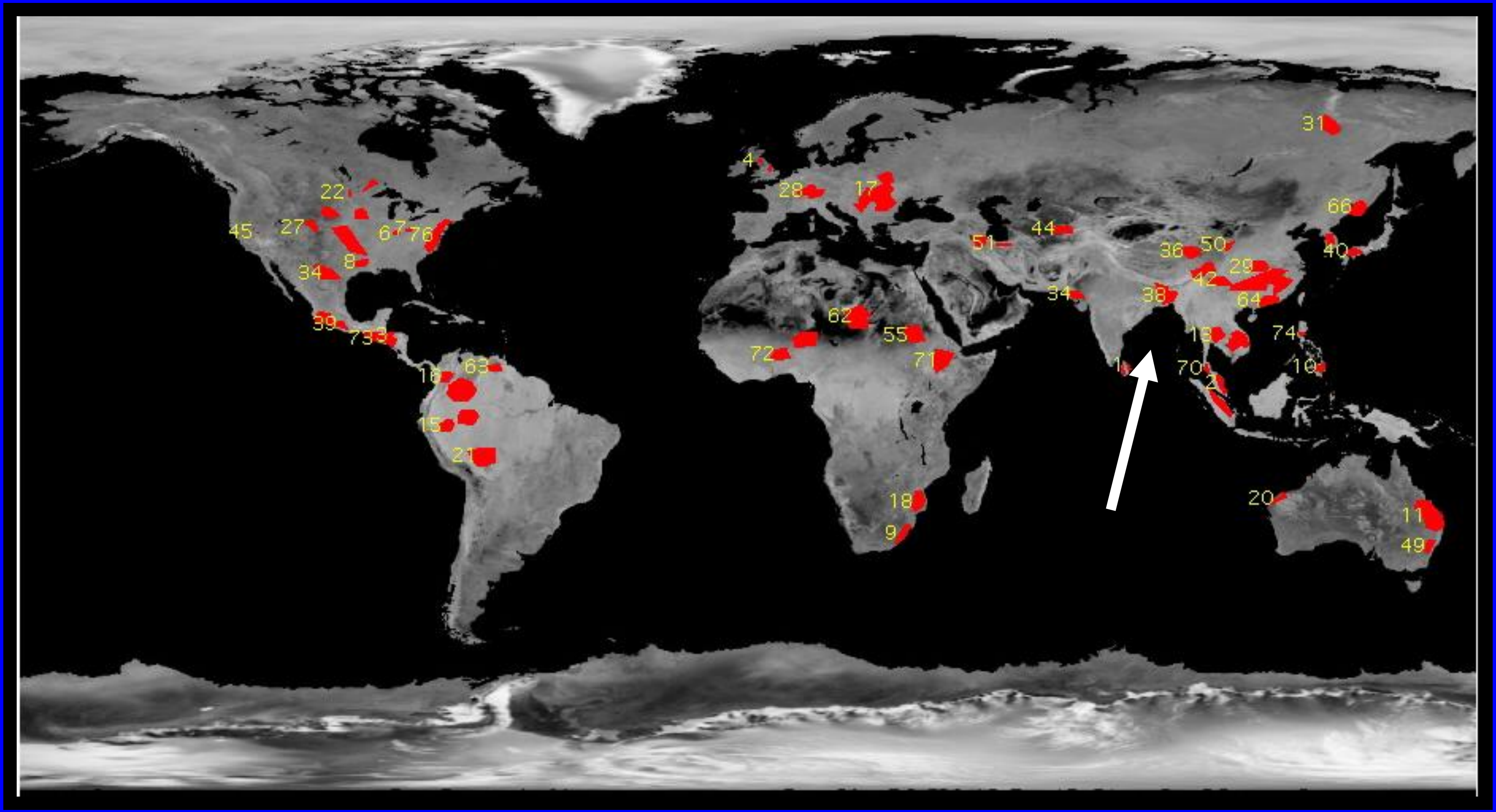

JANUARY
Precipitable
Water Vapor
(in cm)


JULY
Precipitable
Water Vapor
(in cm)
160° 140° 120° 100° 80° 60° 40° 20° 0° 20° 40° 60° 80° 100° 120° 140° 160° 180°



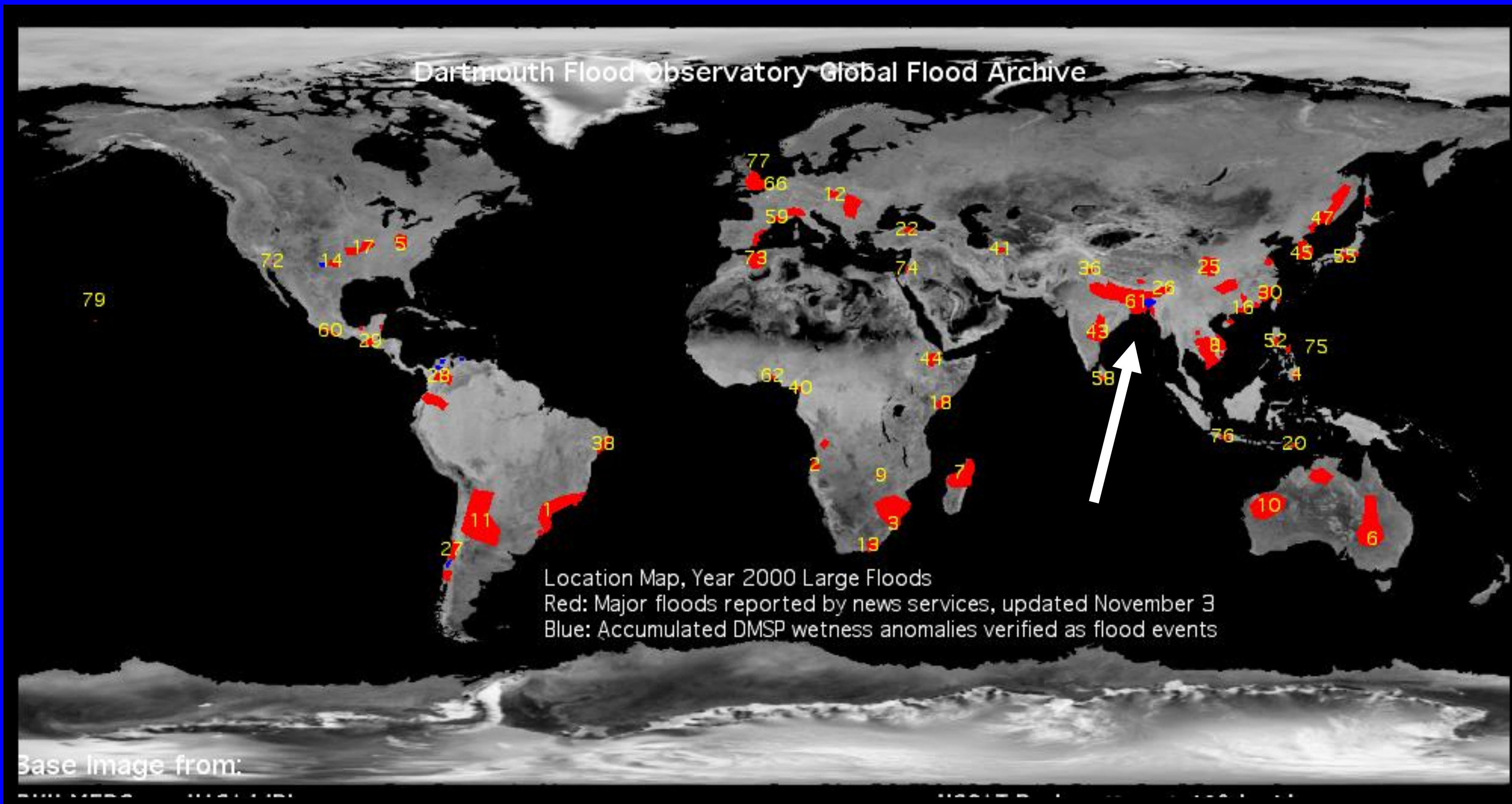
always baroclinic
Jul
seasonal
Jan
always barotropic
Jul
Jan
Jul
Jan
seasonal
always baroclinic
Mean ITCZ position (Jan & Jul)
Hayden (1988) approximation of
Global Seasonal Barotropic & Baroclinic Areas
(based on water content of the atmosphere)
Mean Summer & Winter Limits
of 25 mm Precipitable Water Vapor
(based on months of Jan & Jul)
Winter
Summer

Year 1999 Large Floods



Source: Dartmouth Flood Observatory

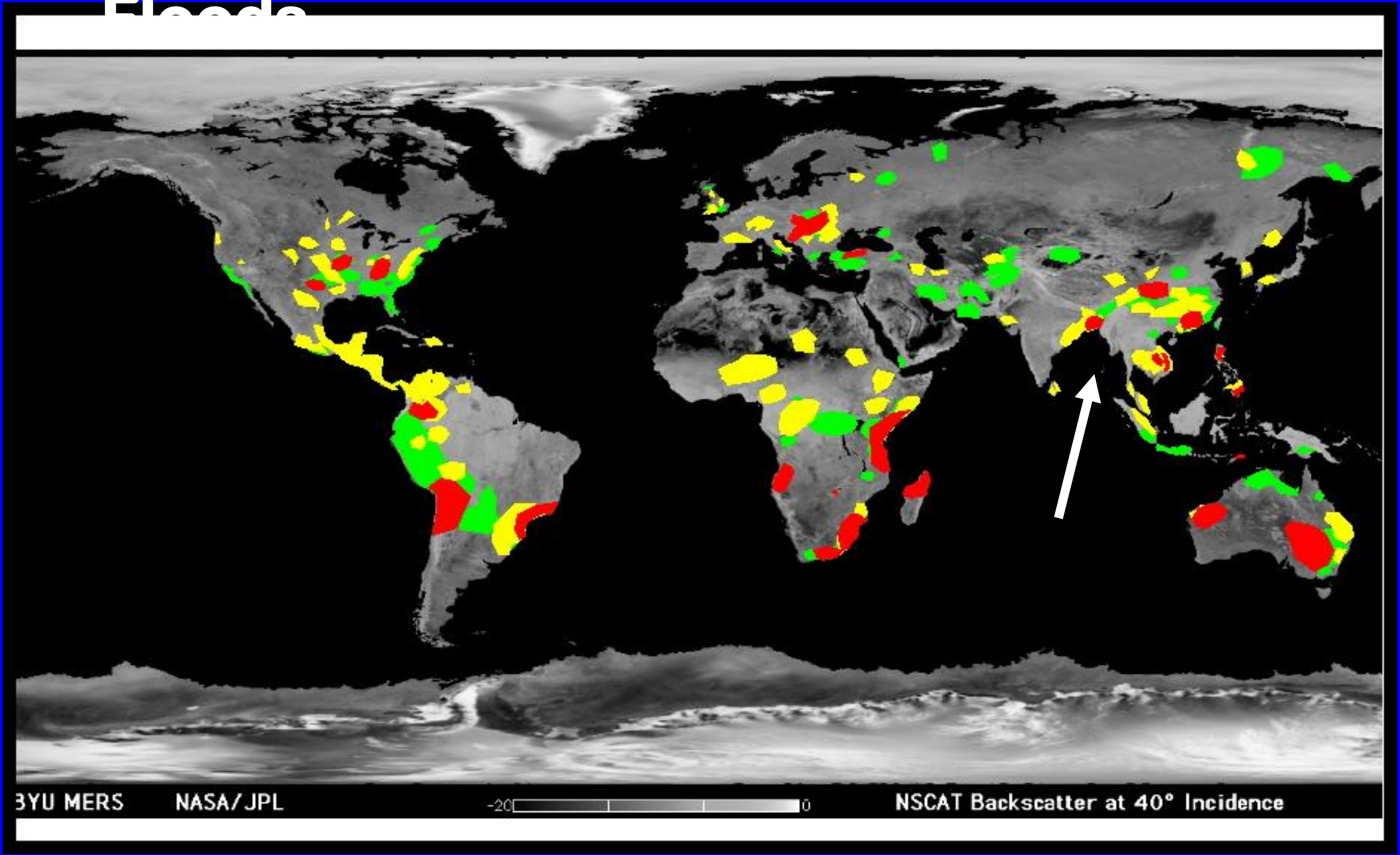
Year 2000 Large Floods



Source: Dartmouth Flood Observatory

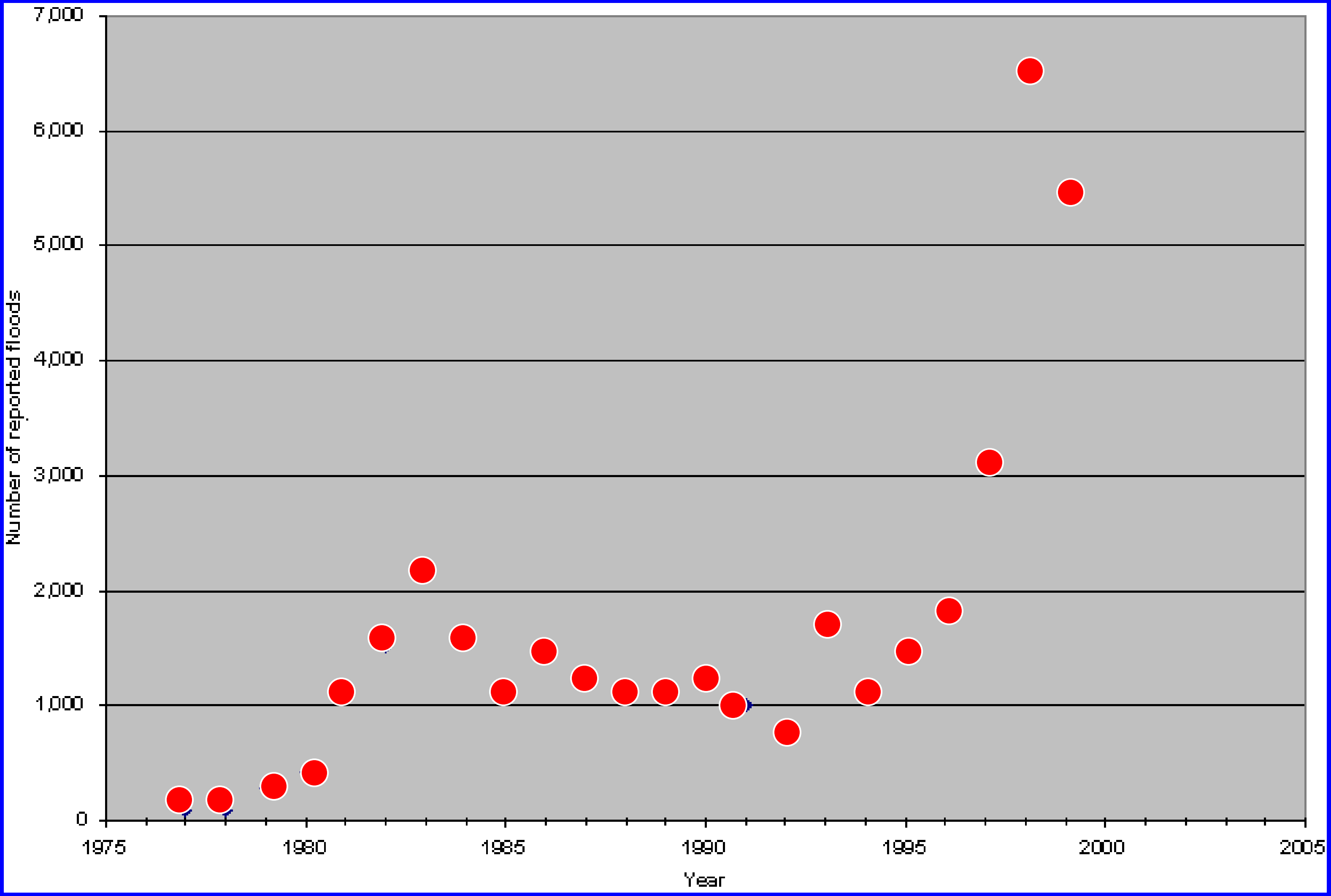
http://floodobservatory.colorado.edu/

1997 – 2000 Composite of Large Floods



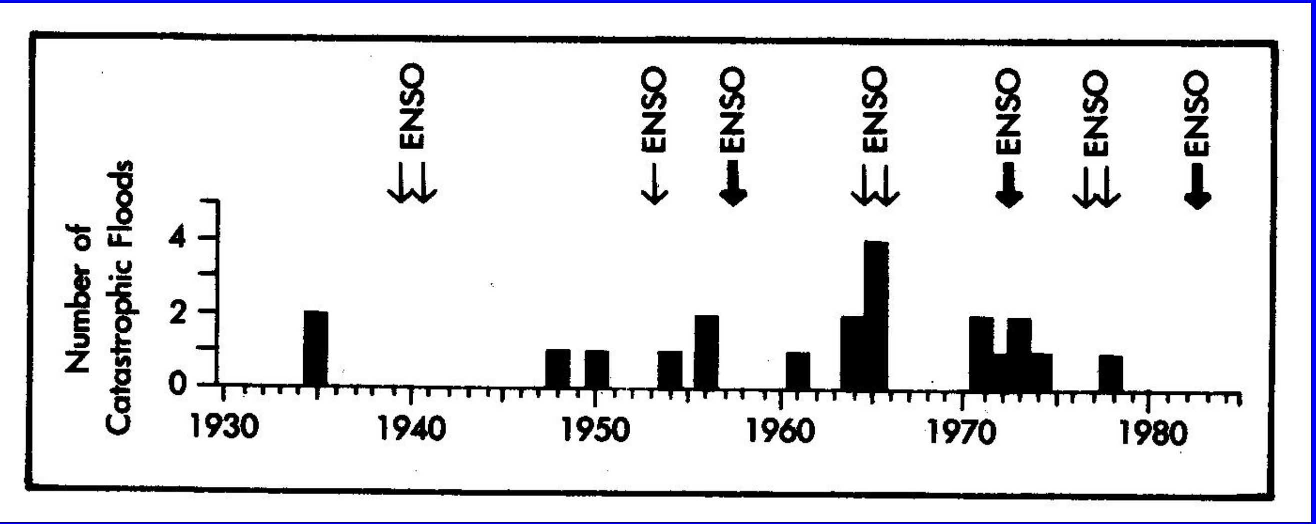
Source: Dartmouth Flood Observatory

Temporal clustering in global floods,
(based on number of reported floods 1975-99)

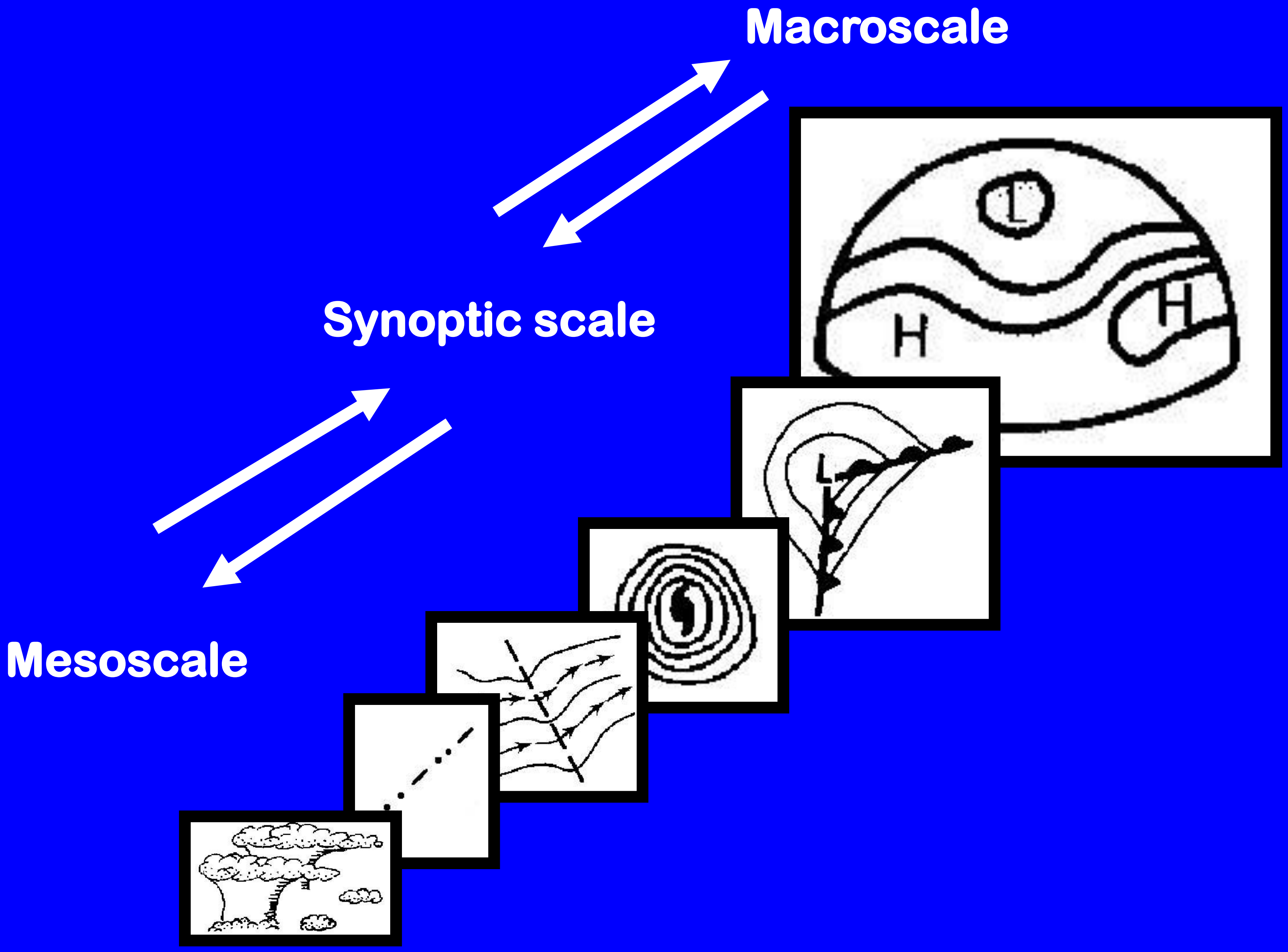


Source: Dartmouth Flood Observatory

Temporal clustering in largest U.S. rainfall / runoff floods (in different size drainage areas)

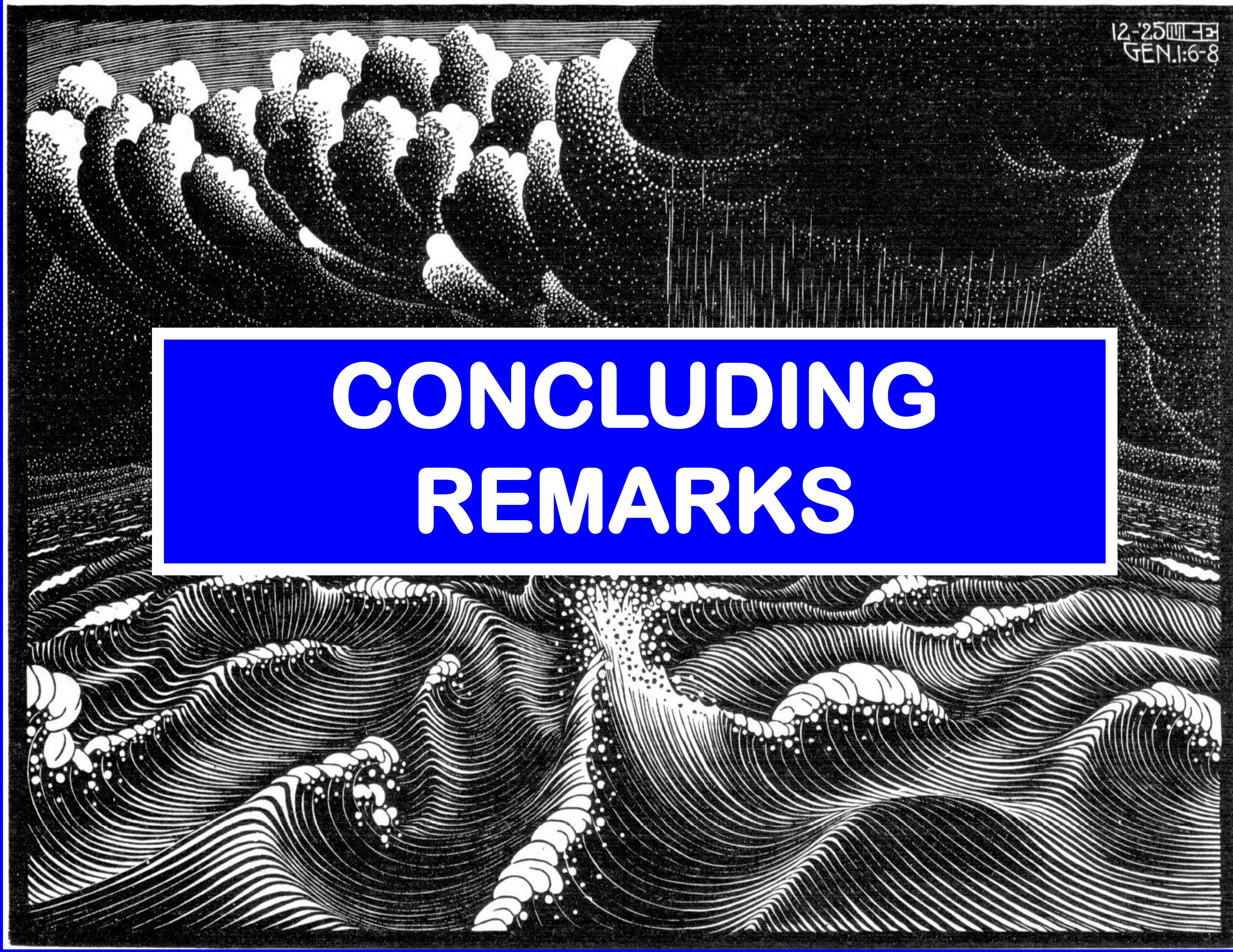


Hirschboeck (1987)



Macroscale
Synoptic scale
Mesoscale
L
H
H
L

CONCLUDING REMARKS



Concluding Remarks

- INGREDIENTS
- PROCESS
- PATTERN
- PERSISTENCE
- SYNERGY

Concluding Remarks

Flood events tend to be discontinuous and episodic in time . . .

. . . and clustered in space

. . . in response to varying states of the atmosphere

Concluding Remarks

Across all scales, the ***persistence*** of a precipitation system is a key element for generating exceptionally large floods

Concluding Remarks

Circulation features which enhance persistence tend to occur as discrete time / space anomalies that are not easily captured by upscaling or downscaling techniques.

Concluding Remarks

Most major floods are characterized by a synergistic combination of atmospheric, hydrologic, and drainage-basin factors that intensify the event and “tip the scales” beyond what might be expected in a smoothly telescoping process continuum.