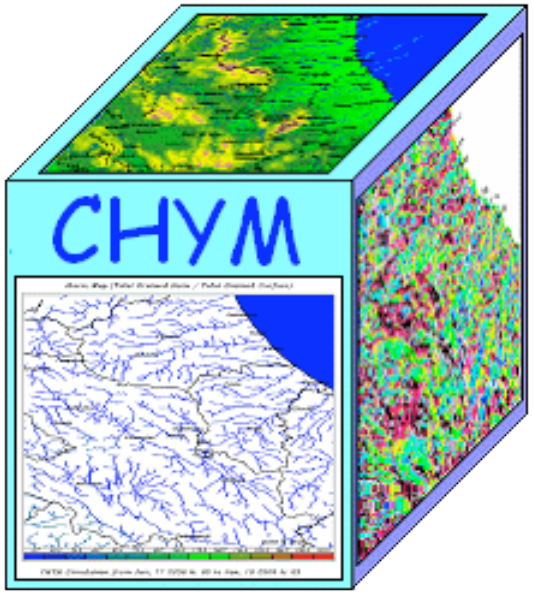
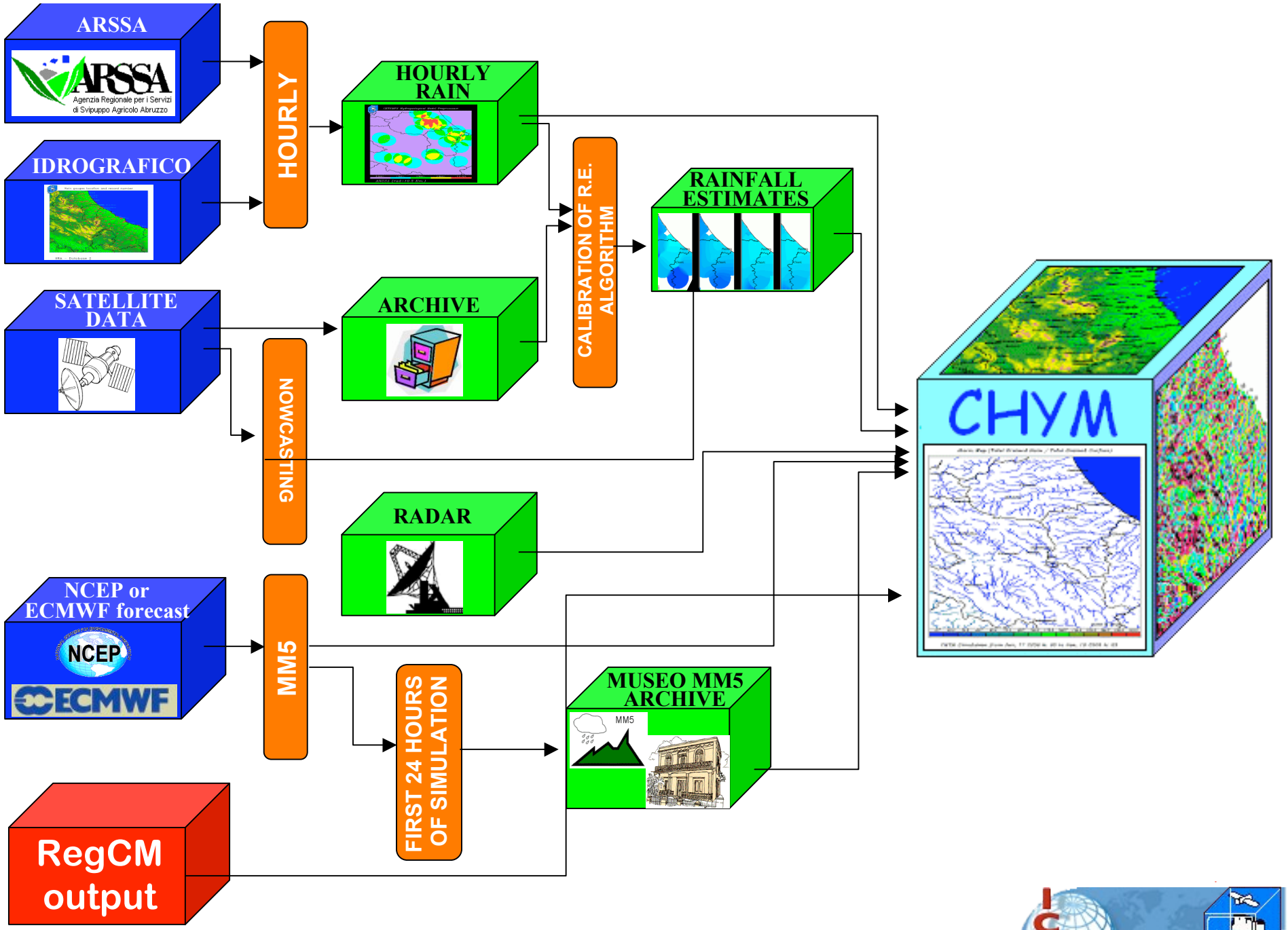
CETEMPS Hydrological Model



E. Coppola, B.Tomassetti , M.Verdecchia
CETEMPS, University of L'Aquila, Italy


ARSSA
Agenzia Regionale per i Servizi di Sviluppo Agricolo Abruzzo
IDROGRAFICO
SATELLITE DATA
NCEP or ECMWF forecast
NCEP
ECMWF
RegCM output
HOURLY
NOWCASTING
MM5
FIRST 24 HOURS OF SIMULATION
HOURLY RAIN
ARCHIVE
RADAR
MUSEO MM5 ARCHIVE
MM5
CALIBRATION OF R.E. ALGORITHM
RAINFALL ESTIMATES
CHYM

Why to develop a new Hydrological Model?

- It has been thought for operational purposes
- It is a good "exercise"

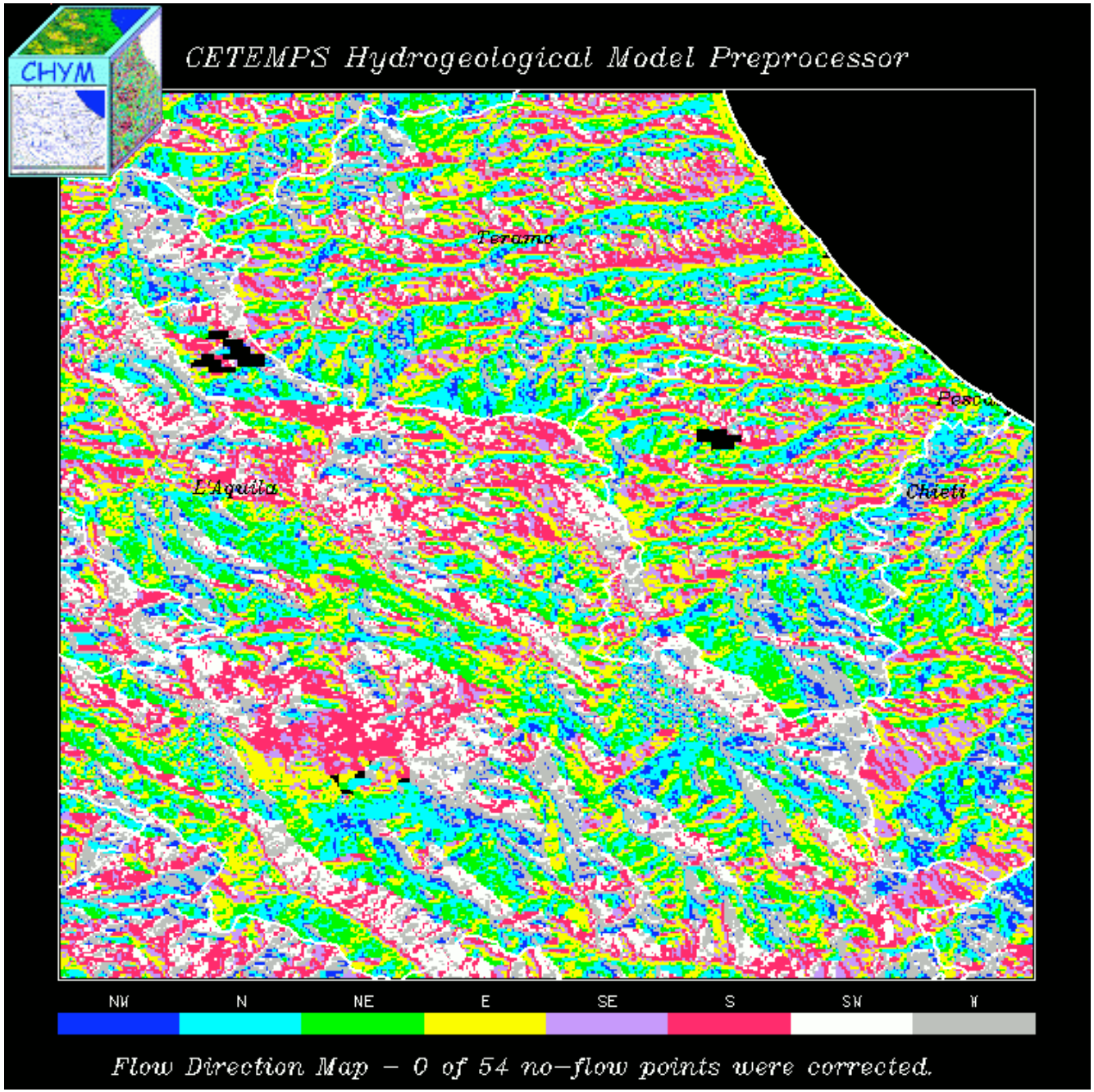
Step 1: generating streamflow network from DEM

DEM matrix for the selected domain and resolution is generated

Flow direction matrix is computed

Validation

"Pits" and singularities are corrected



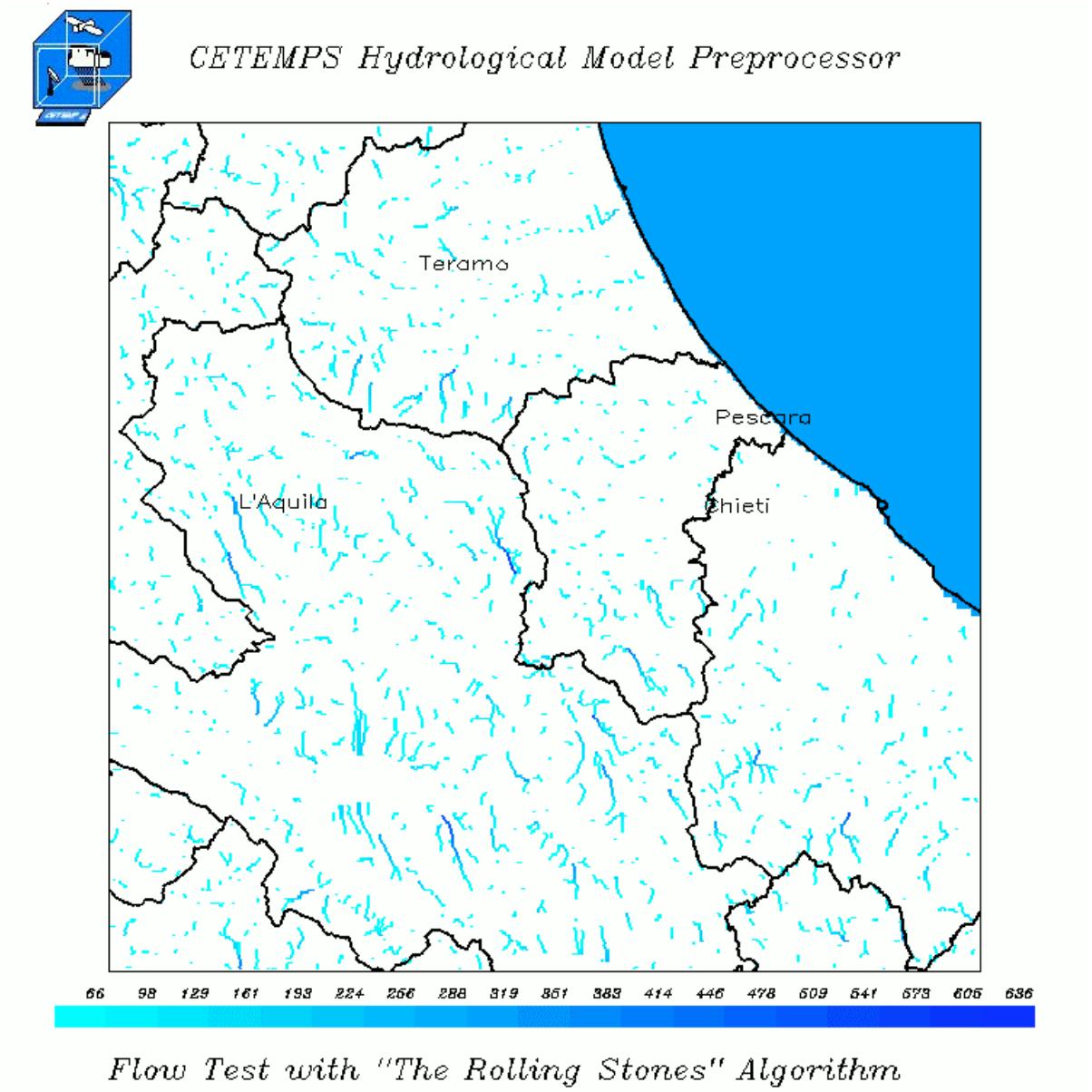
DEM is available with a resolution of 300 m

For each cell the slope is computed as: $\operatorname{atan}\frac{\ddot{A}h}{\ddot{A}x}$

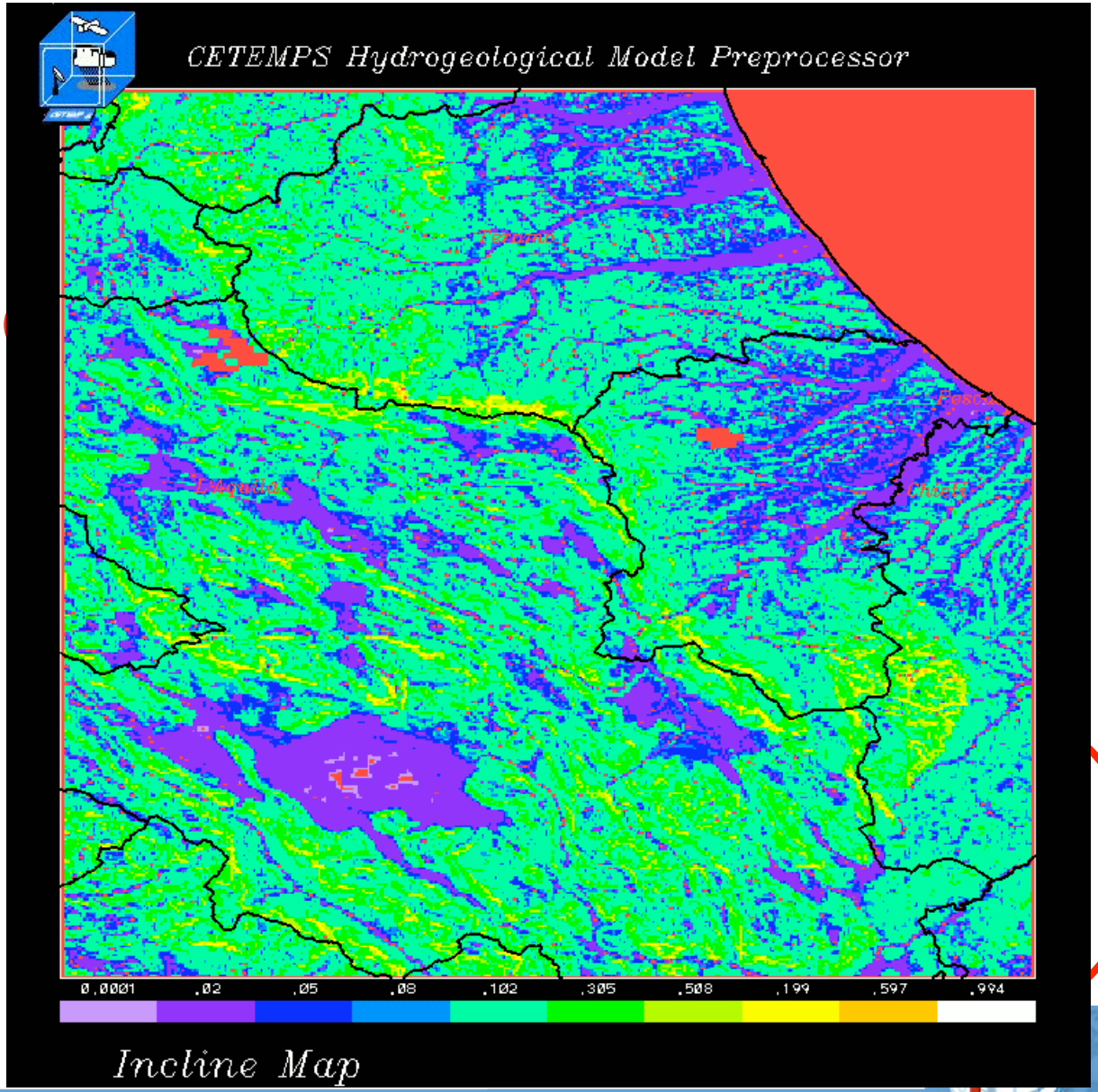
Max slope

Runoff direction

CHyM: Drainage network test

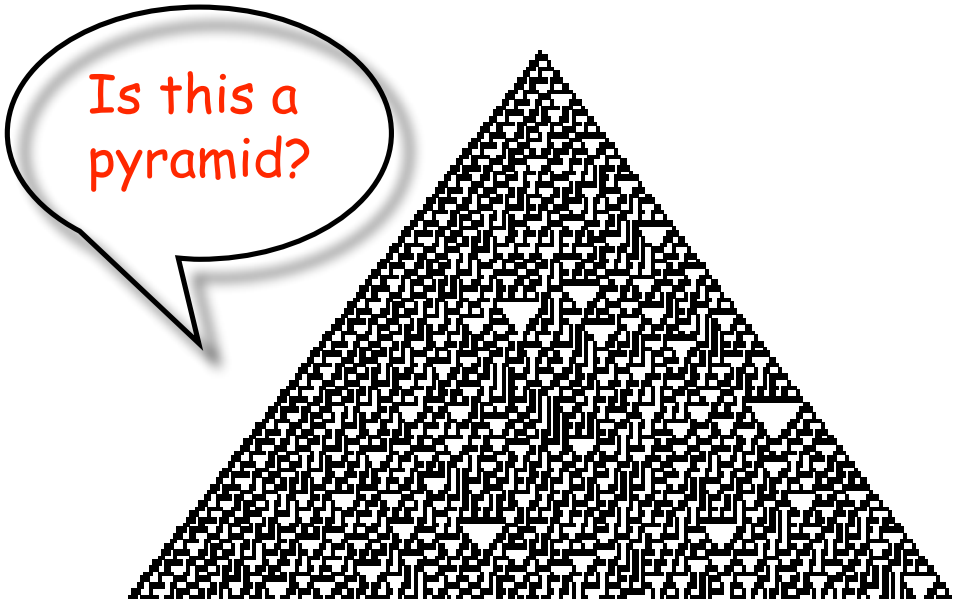


CHyM: Drainage network test

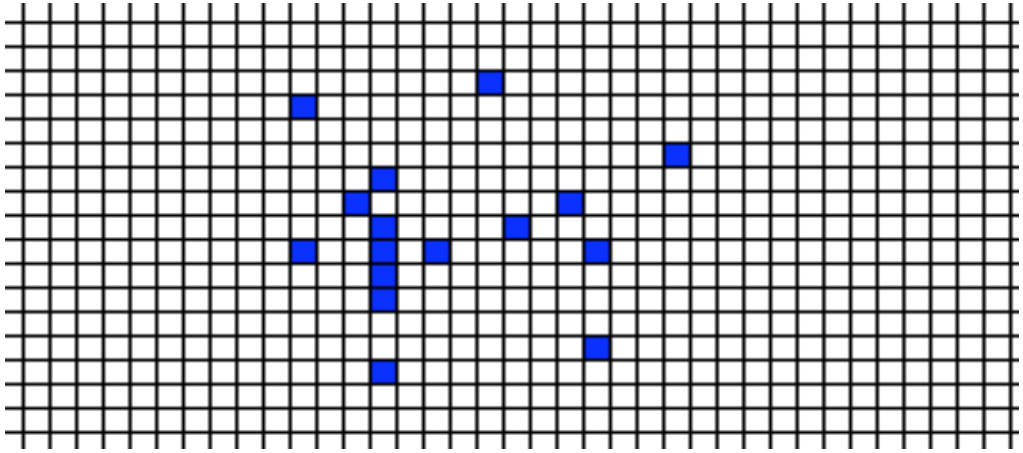


Cellular Automaton CA

Automata generated using Rule 30 appear in nature, on some shells.

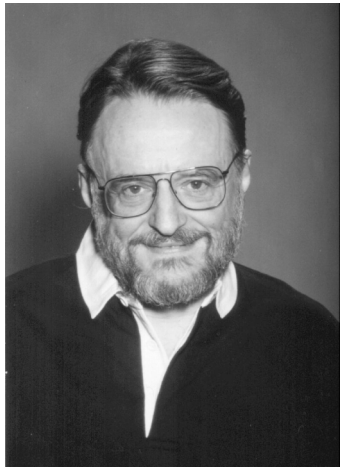


A Cellular Automata definition

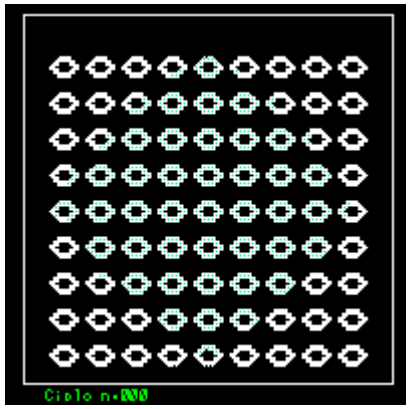


- A cellular automaton is a **discrete dynamical system**
- Space, time and states of the system are discrete quantities
- Each point in a regular spatial lattice, called a cell, can have anyone of a finite number of states
- The state of the cells in the lattice are updated according to a **local rule**
- All cells on the lattice are **updated synchronously**

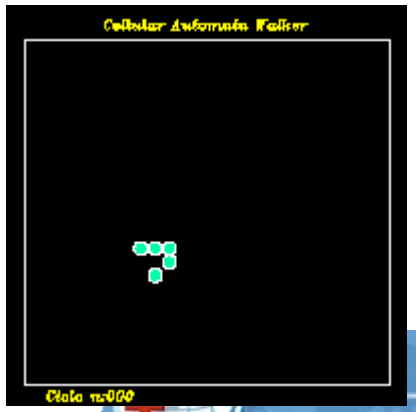
The game of life



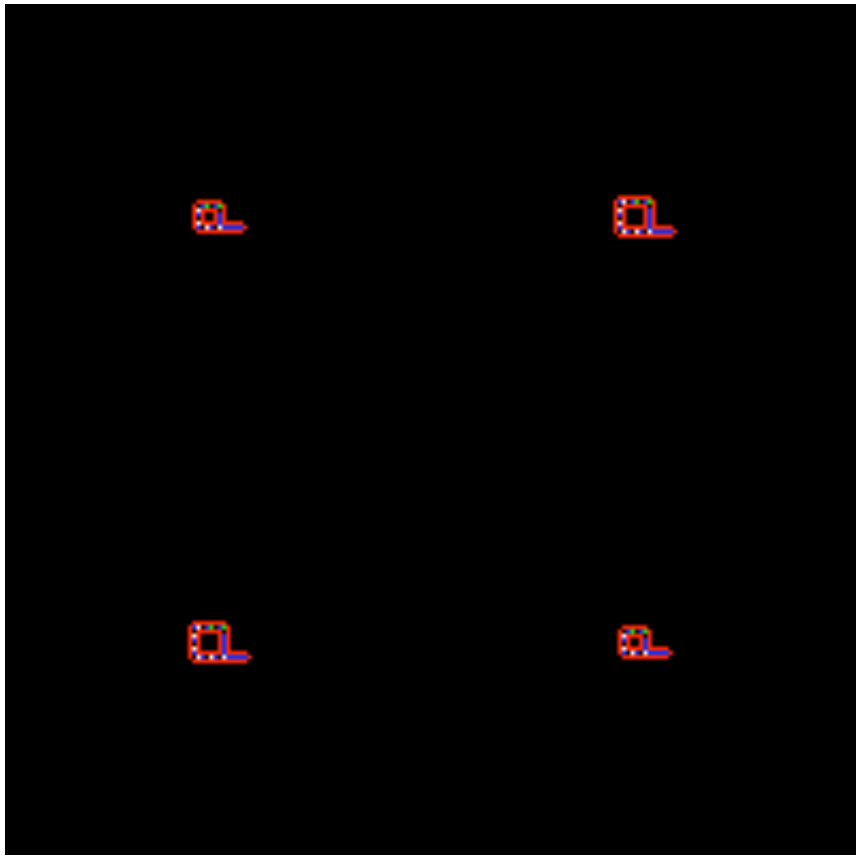
Life rules by Chris G. Langton



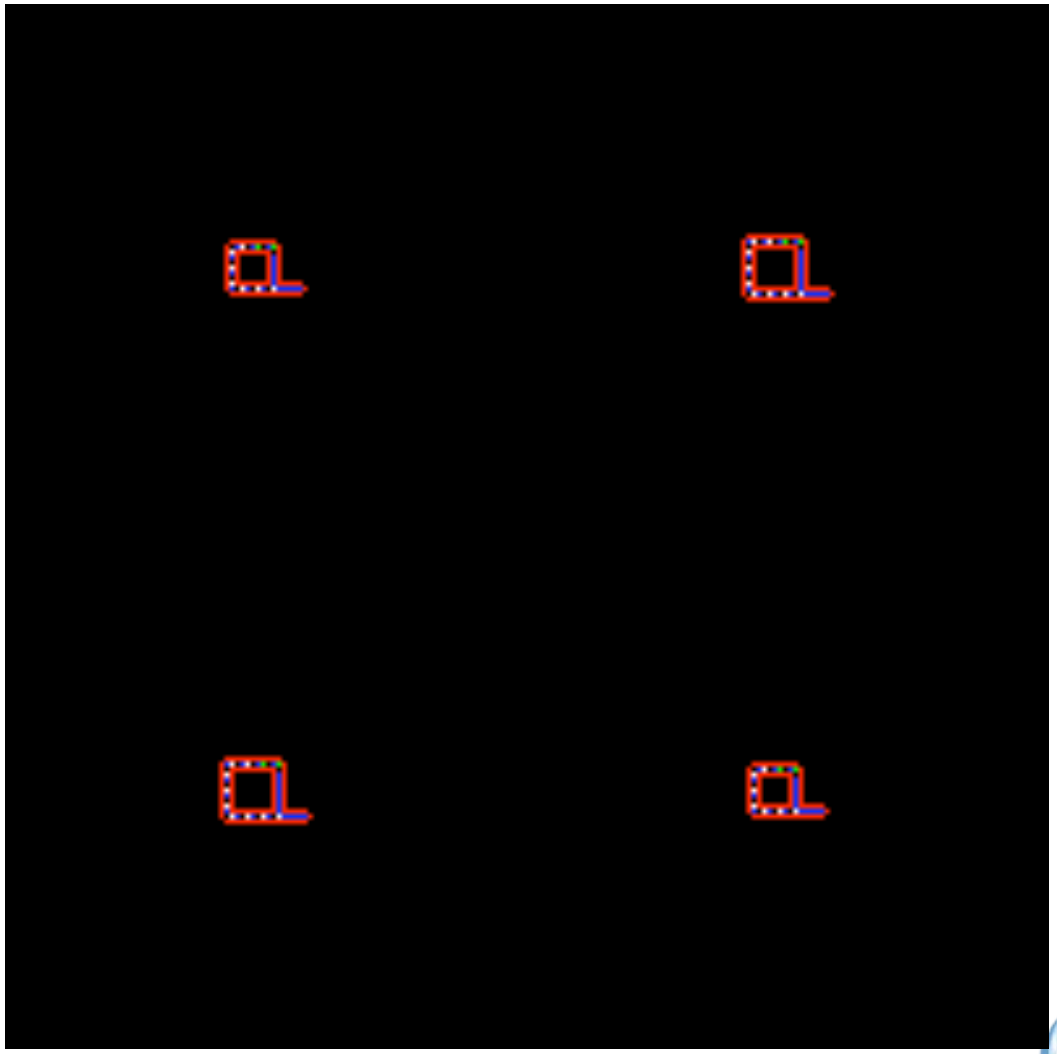
- The status of each CA can be ON or OFF
- If more than 3 CA in the neighborhood are ON CA became OFF
- If less than 2 CA in the neighborhood are ON, CA became OFF
- Otherwise CA became ON



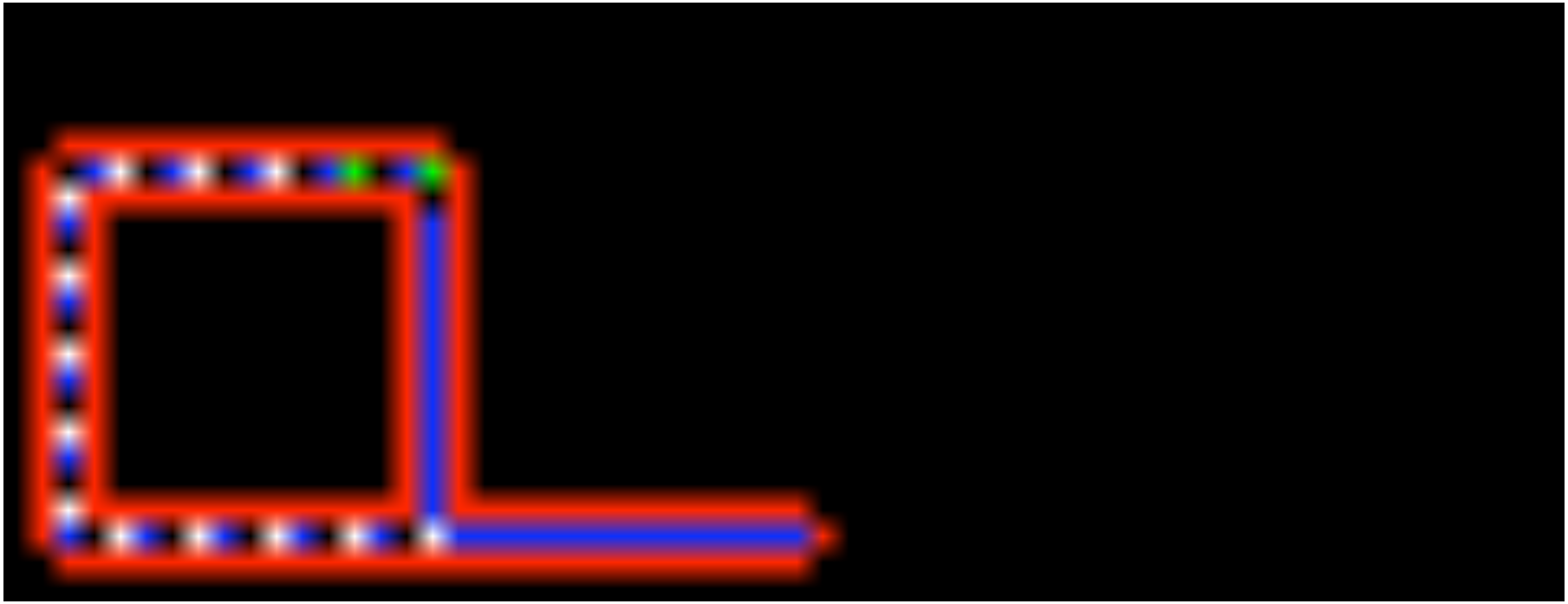
One of the infinitive effects that are possible to get using the Langton (1) rule



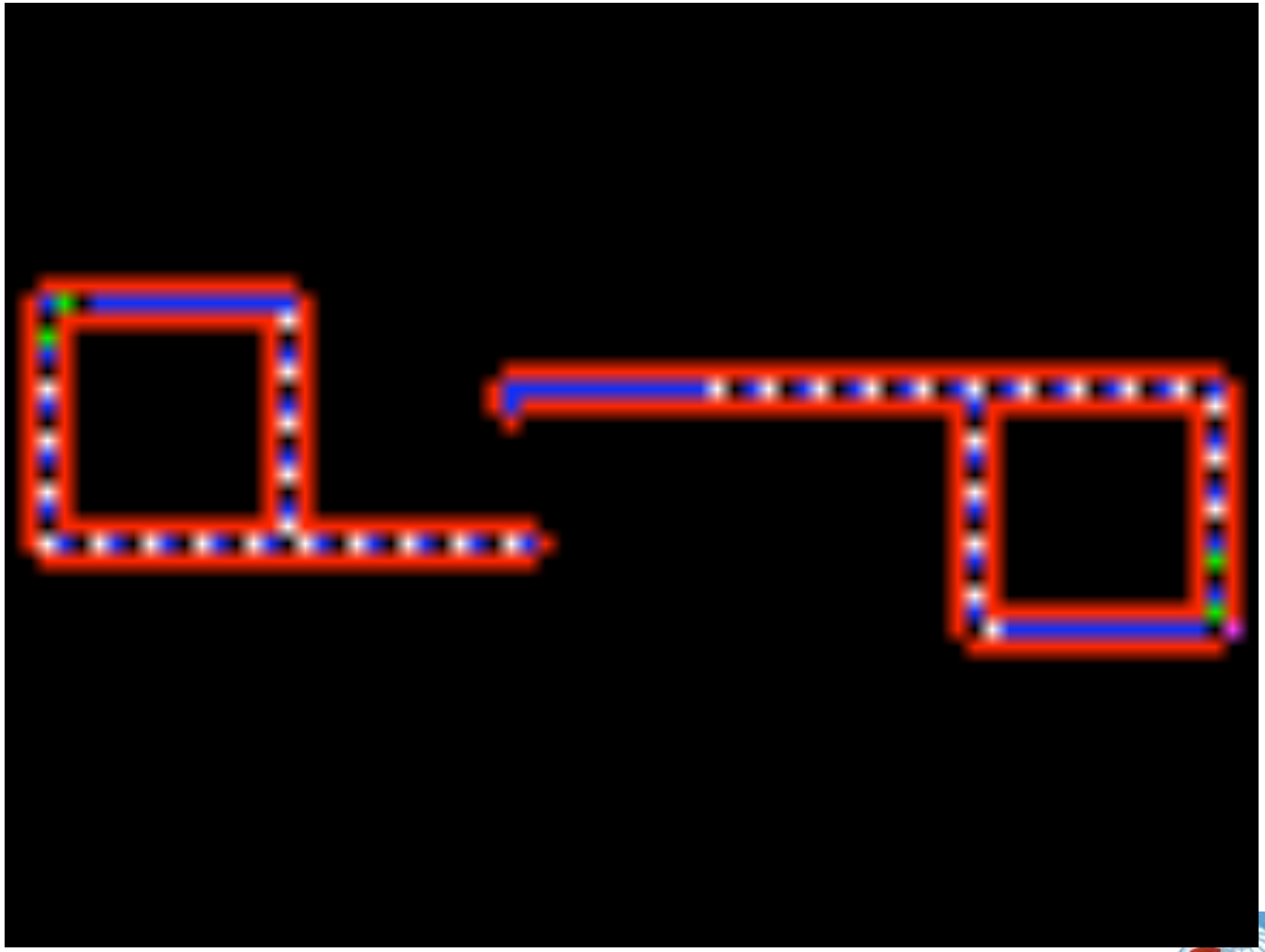
One of the infinitive effects that are possible to get using the Langton (2) rule



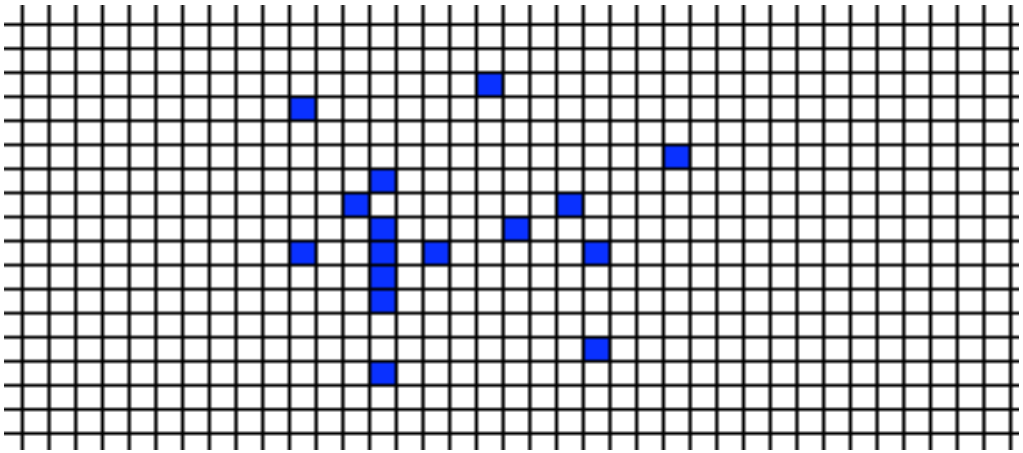
Self reproducing CA – Langton rules (3)



Takeover of the arm caused by the collision of two *evoloops*



CA for CHyM applications



- CHyM grid is considered an aggregate of cellular automata
- The status of a cell corresponds to the value of a ChYM matrix (DEM)
- The state of the cells in the lattice is updated according to following **rule**

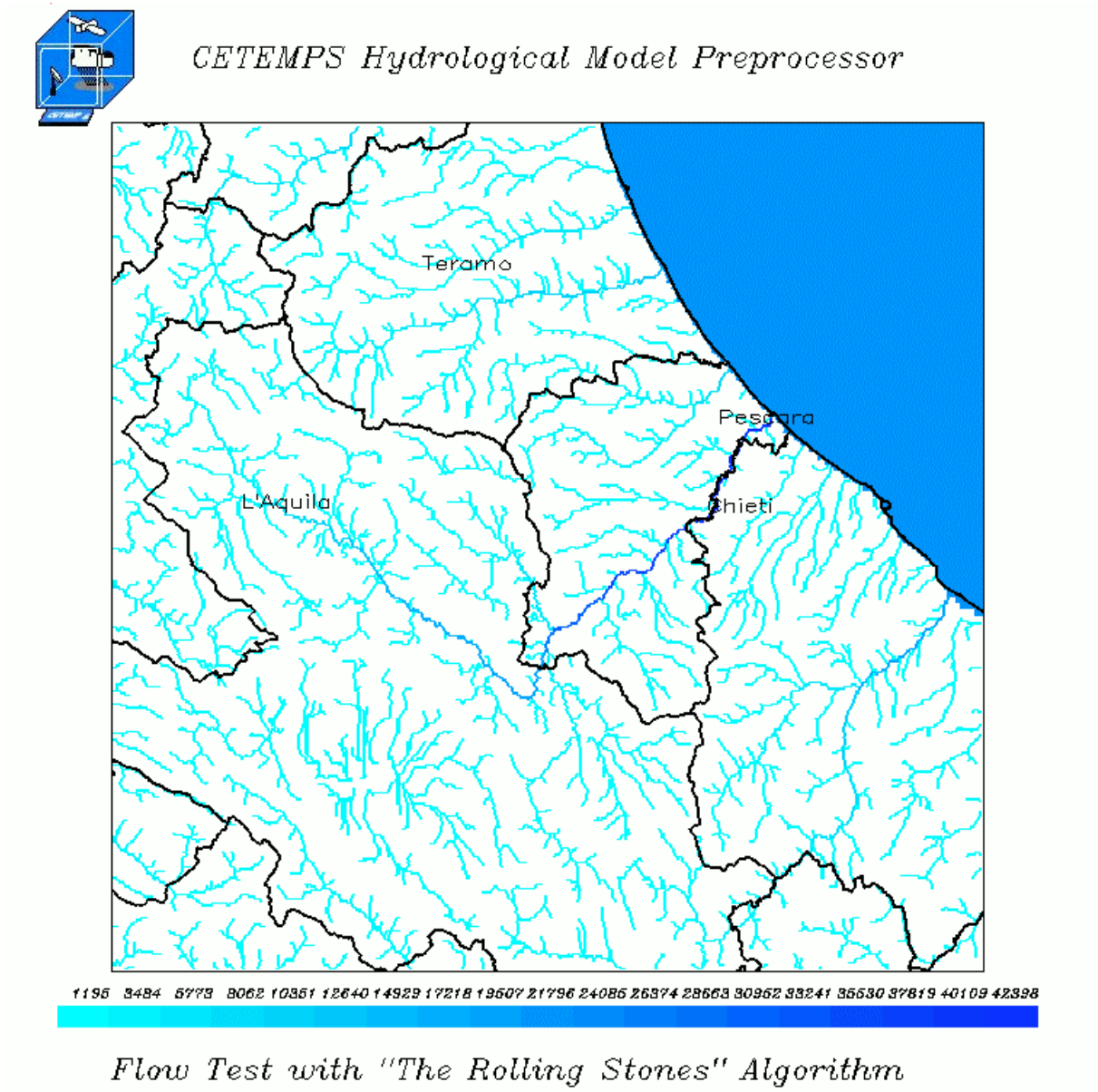
$$h_i \rightarrow h_i + \acute{a}\left(\sum_{J}^{8} \hat{a}_j (h_j - h_i)\right)$$

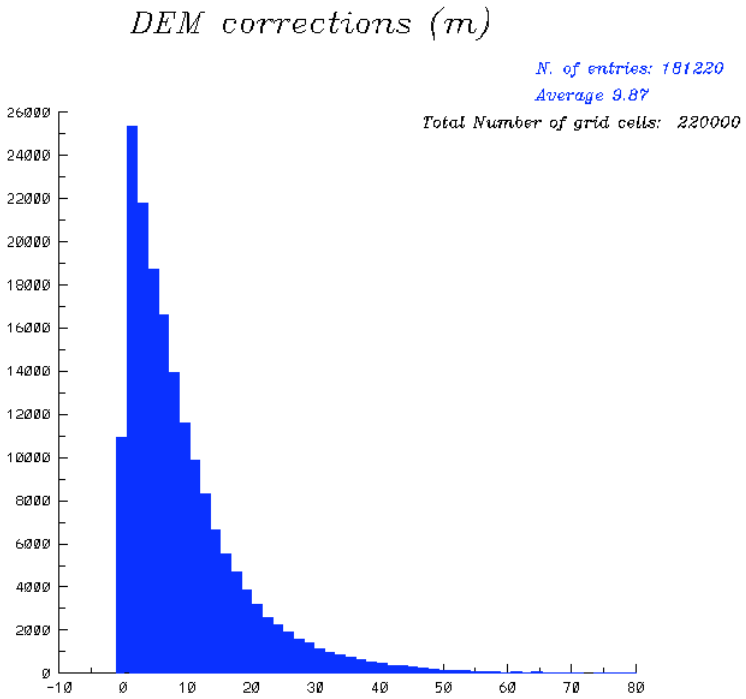
- All cells on the lattice are updated synchronously
- Update ends when flow scheme is OK

CHyM: Recipe for DEM pit correction

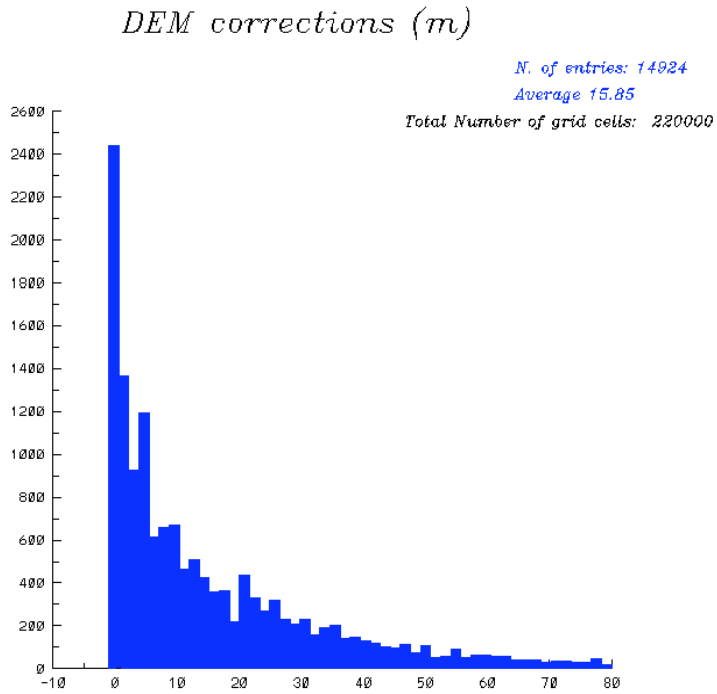
- Smooth DEM using CA rules until FD can be obtained for all the cells
- Generate streamflow network using smoothed DEM
- Use "true" DEM and modify ONLY the cells draining toward an higher cell

CHyM: Drainage network test



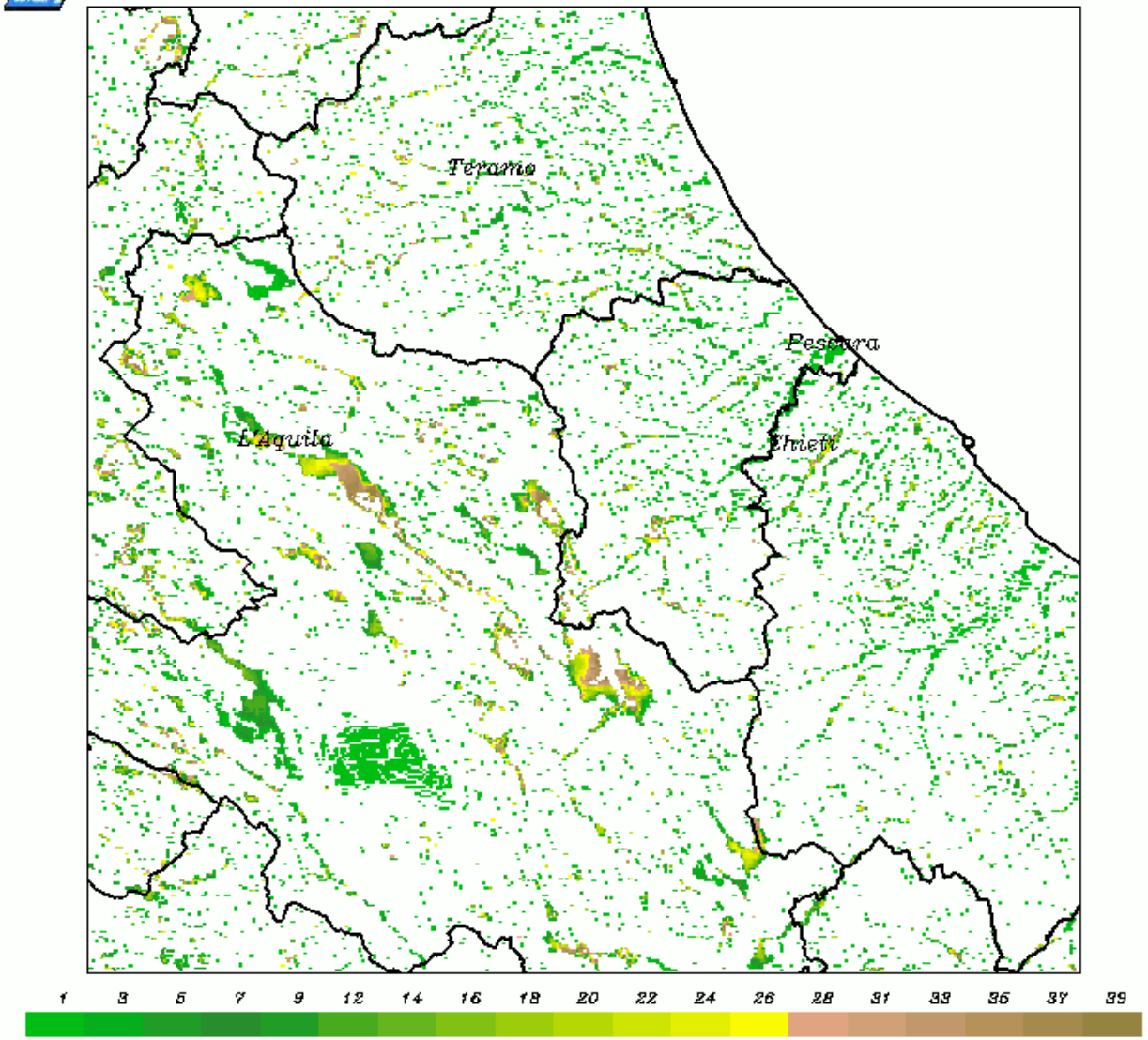


DEM Smooting Algorithm 1 (DSA1)



DEM Smooting Algorithm 2 (DSA2)

Dem differences



CHyM: DEM pit correction

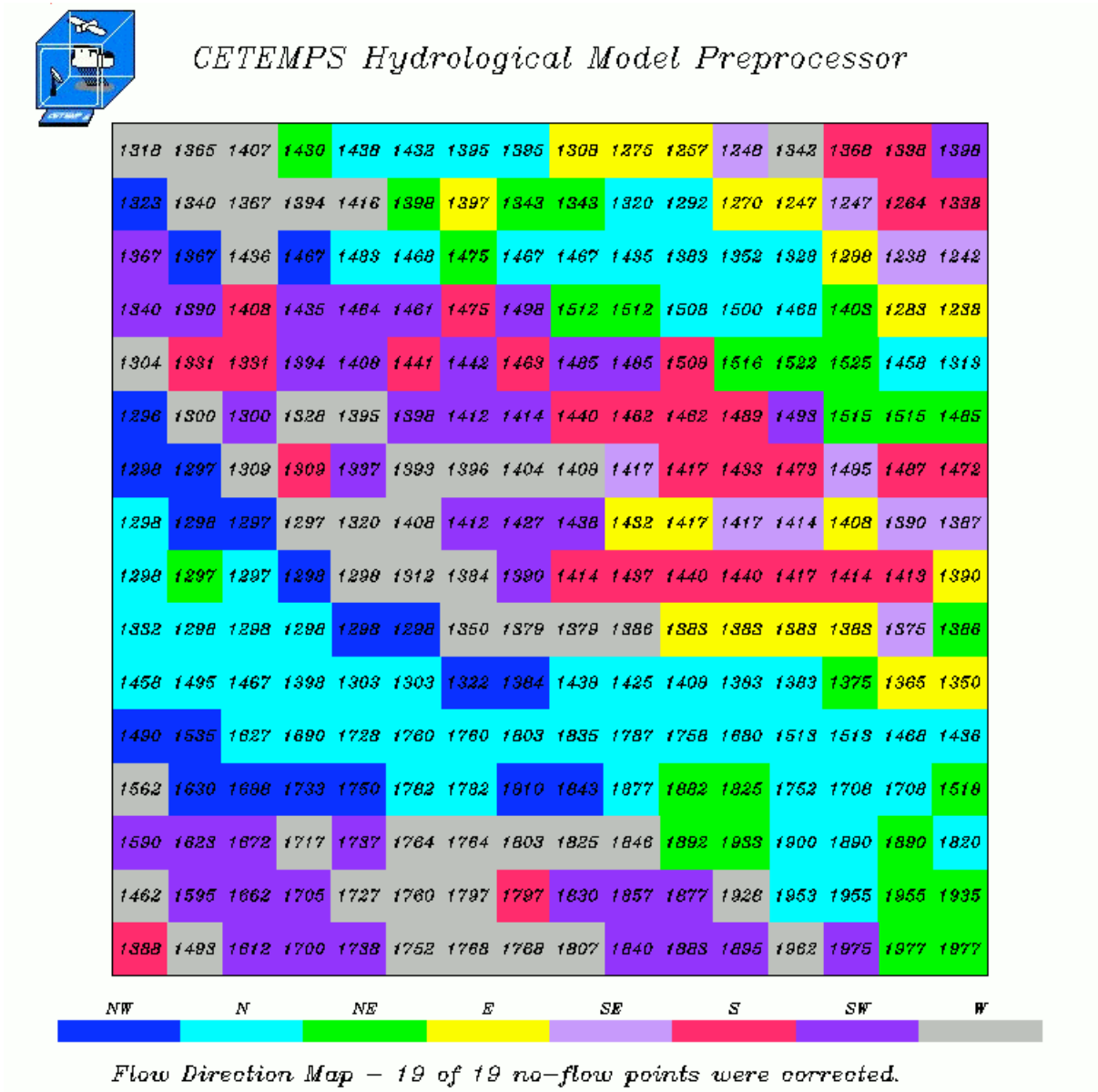
CETEMPS Hydrological Model Preprocessor

930	872	848	865	862	862	875	872	872	885	928
828	828	824	828	838	838	842	848	858	880	952
835	828	824	824	828	832	832	844	848	885	980
824	824	824	825	831	832	832	834	835	872	1010
824	824	824	824	825	827	830	830	835	870	950
824	824	824	824	824	824	824	824	828	862	915
824	824	823	823	823	824	823	824	824	840	862
830	825	823	823	823	823	823	823	823	824	845
895	895	842	823	823	823	823	823	823	823	837
922	922	910	848	825	823	823	823	823	823	831
941	938	938	903	870	823	823	823	830	830	842
908	902	902	894	880	848	823	831	838	844	844
895	872	825	852	855	827	802	805	818	812	825
862	846	810	810	782	784	785	795	787	852	870
825	818	787	768	768	765	763	762	776	787	880
828	790	765	763	763	760	758	765	772	778	852
835	810	765	758	760	760	755	750	756	762	778

NW N NE E SE S SW W

Flow Direction Map – 19 of 19 no-flow points were corrected.

CHyM: DEM pit correction



CHyM: DEM pit correction

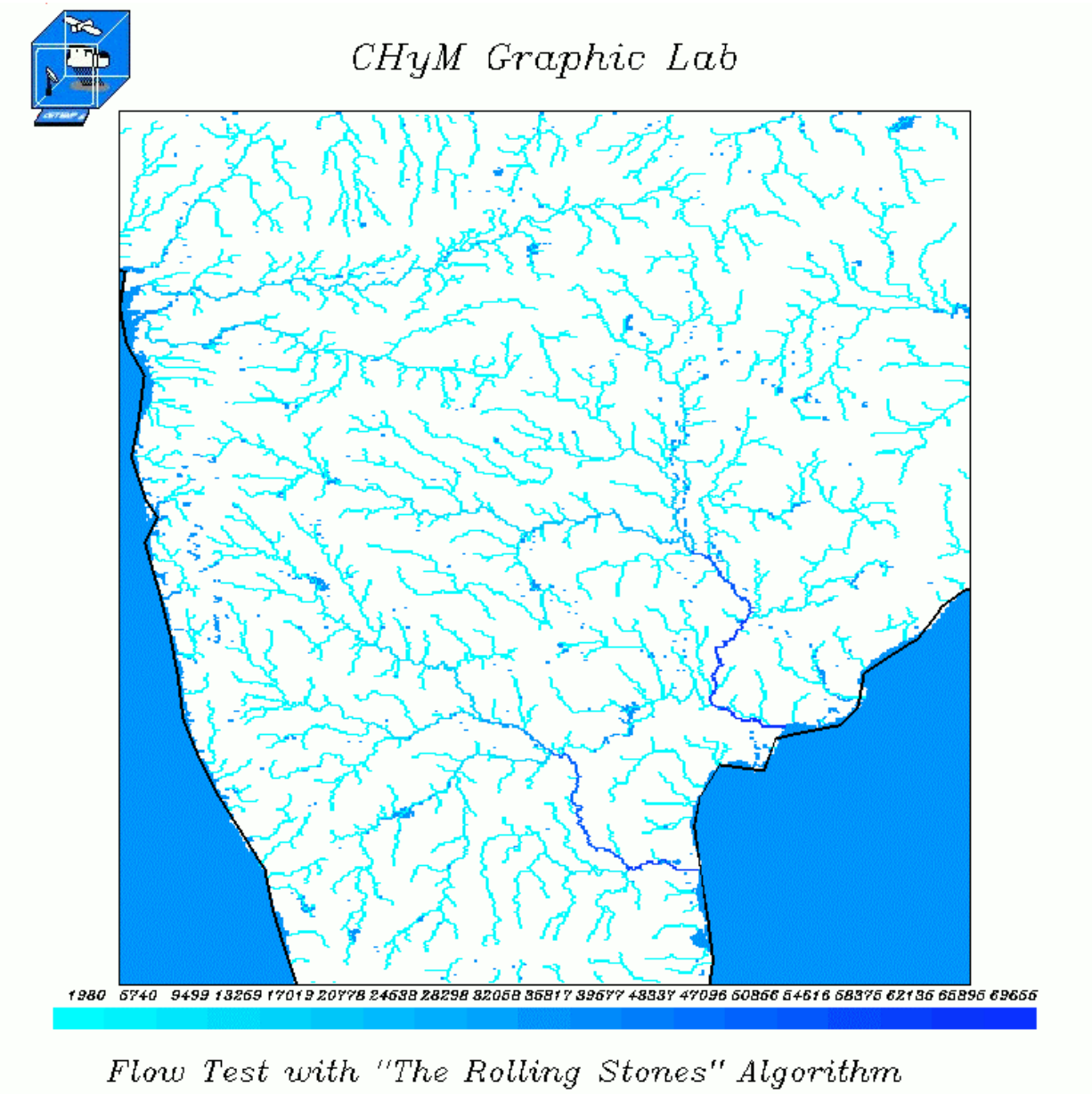
CETEMPS Hydrological Model Preprocessor

343	370	408	442	486	486	478	460	458	436	387	395	395	361	344	338
373	416	466	477	463	463	423	488	607	502	490	460	460	438	406	396
419	462	475	462	415	404	404	495	491	484	498	468	438	433	405	375
412	437	436	437	368	370	376	390	454	505	510	475	447	447	424	400
374	356	338	370	365	376	376	425	440	500	490	487	465	441	441	396
333	333	322	320	323	346	367	402	408	441	456	453	441	430	430	377
372	372	358	330	319	360	390	390	402	350	432	404	425	408	365	365
415	408	408	401	329	319	295	304	304	307	305	318	305	334	314	285
411	432	388	388	347	290	285	285	295	285	295	278	272	302	292	270
366	362	315	315	307	330	318	331	330	330	324	318	288	270	267	264
325	323	332	328	341	373	385	367	378	375	375	363	340	343	300	283
337	352	355	343	365	390	401	392	395	423	432	432	397	390	375	335
353	375	357	348	382	379	365	365	356	370	372	372	348	340	352	334
360	377	370	377	372	348	342	341	341	341	340	340	340	340	340	374
415	395	388	377	365	365	352	342	341	341	340	340	340	340	385	408
410	405	420	415	378	378	363	363	360	341	358	372	372	400	440	440

NW N NE E SE S SW W

Flow Direction Map – 19 of 19 no-flow points were corrected.

CHyM: Examples of Drainage Network Extraction



CHyM: the Rolling Stones Algorithm (RSA)

1. Starting from each cell a stone rolls up to the river's mouth

2. Each time that the stone goes through one cell for this cell a counter is incremented by 1

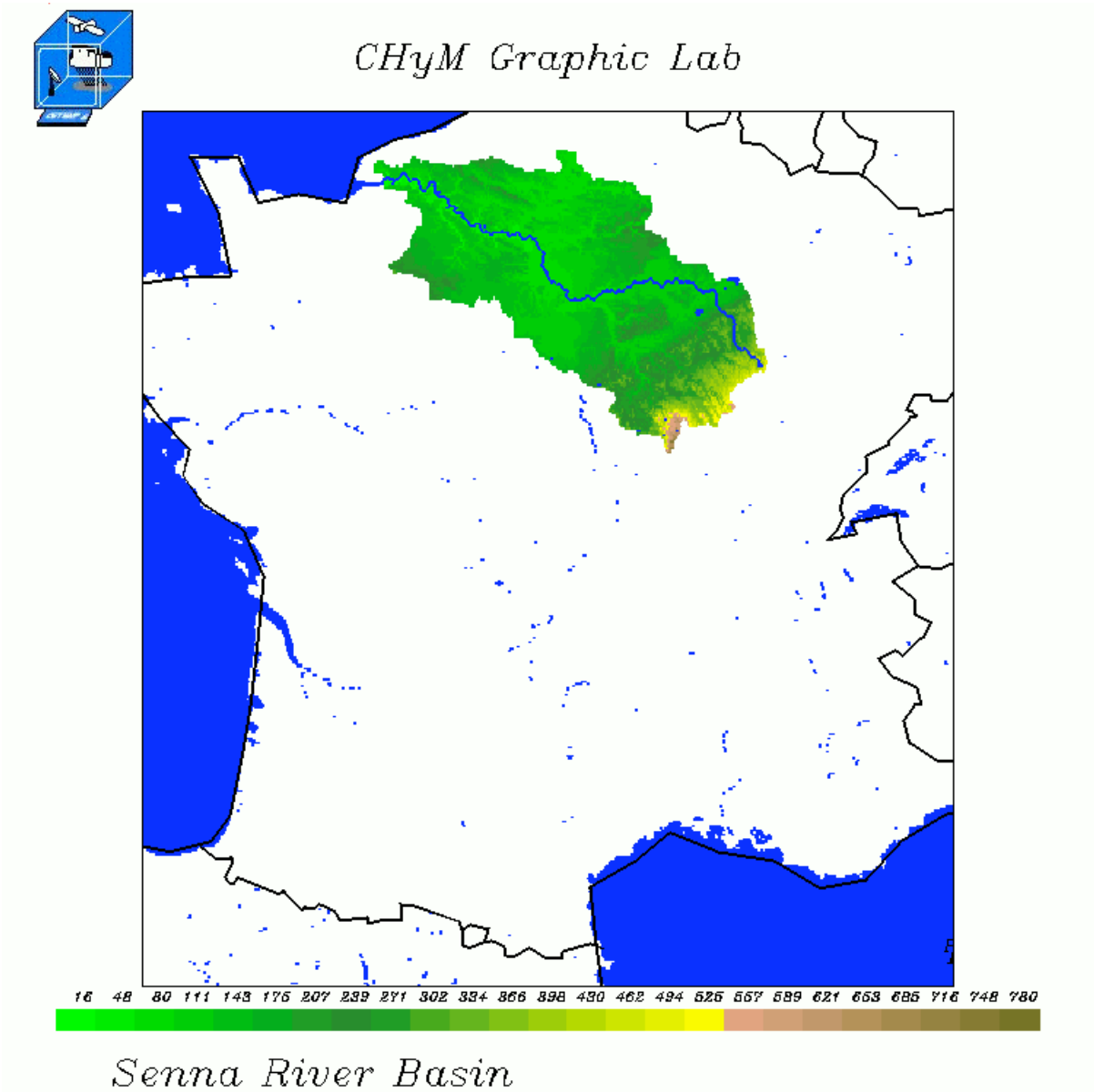
3. If a quantity A is associated to each stone where A is equivalent to the surface where the stone was at the beginning, for each cell it can be computed the upstream drained surface

$$\sum_{i=1}^{N} A_i$$

4. If a quantity R is associated to each stone where R is equivalent to the precipitation where the stone was at the beginning, for each cell it can be computed the upstream drained precipitation

$$\sum_{i=1}^{N} R_i$$

CHyM: the Rolling Stones Algorithm (RSA)



Step 2: Building Precipitation Fields using different Data Sources

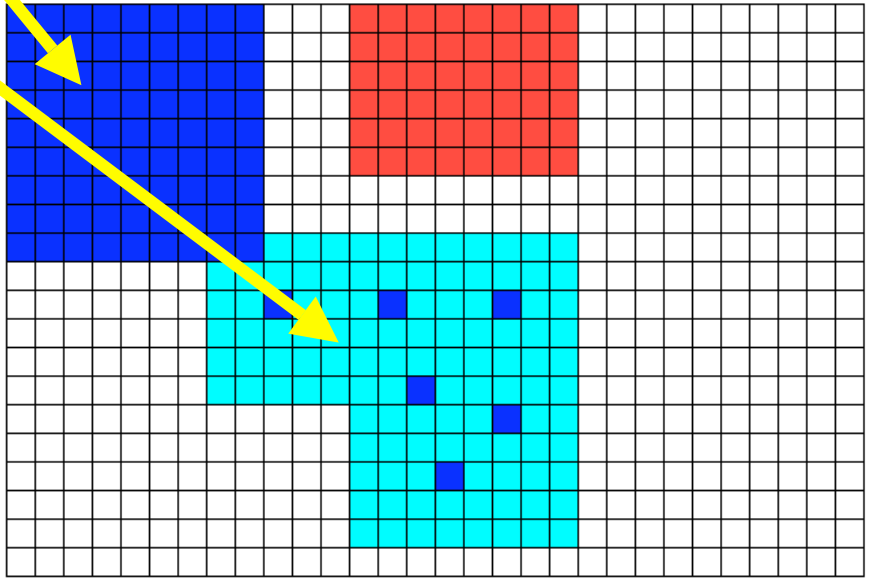
Module 1

Module 2

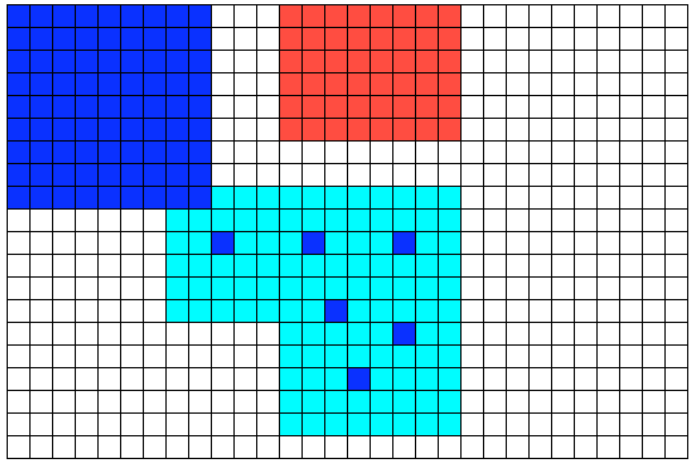
Module 3

Module n

- Define subdomain
- Fill cells corresponding to rain gauges
- Fill subdomain matrix – Cr. Formula
- Smooth subdomain matrix using CA algorithm



CA for CHyM applications

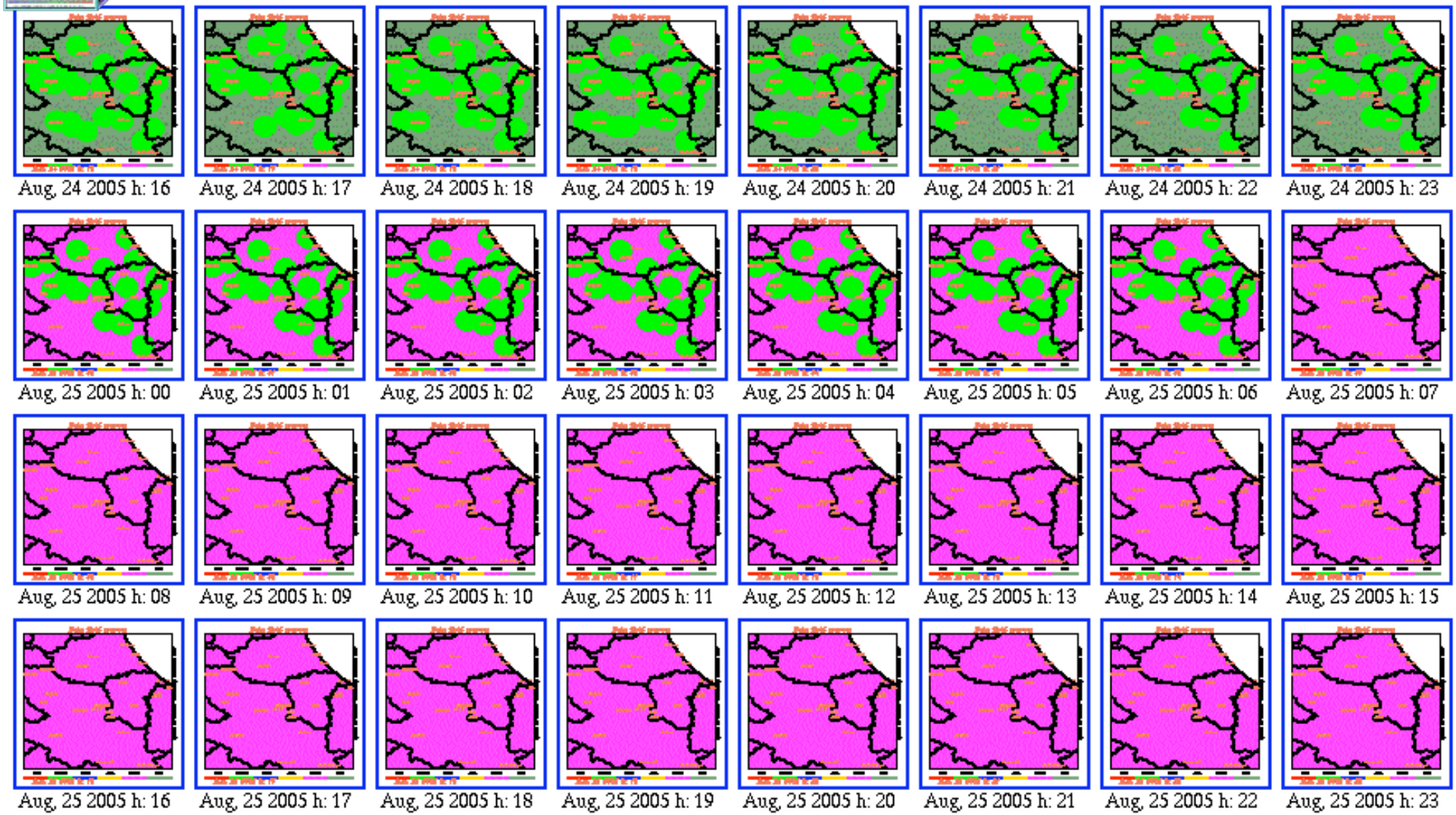


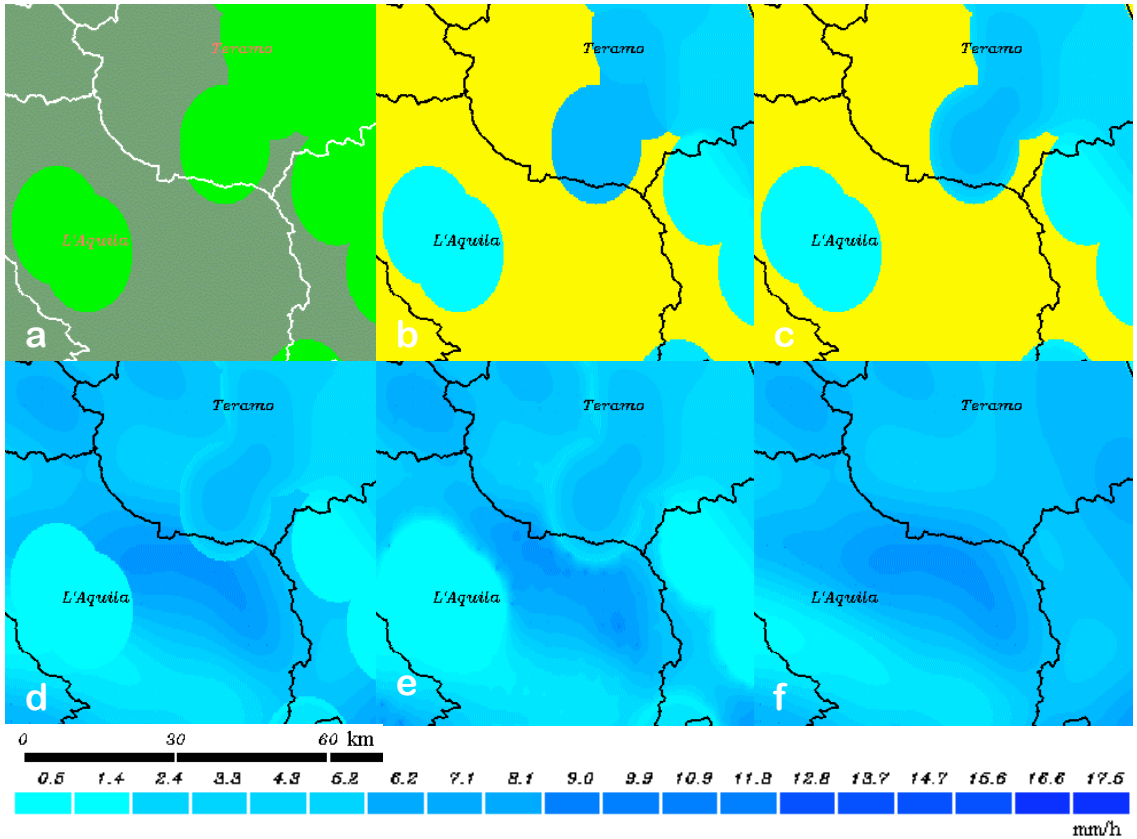
- CHyM grid is considered an aggregate of cellular automata
- The status of a cell corresponds to the value of a ChYM matrix (DEM)
- The state of the cells in the lattice is updated according to following **rule**

$$h_i \rightarrow h_i + \alpha\left(\sum_{j}^{8} \hat{a}_j (h_j - h_i)\right)$$

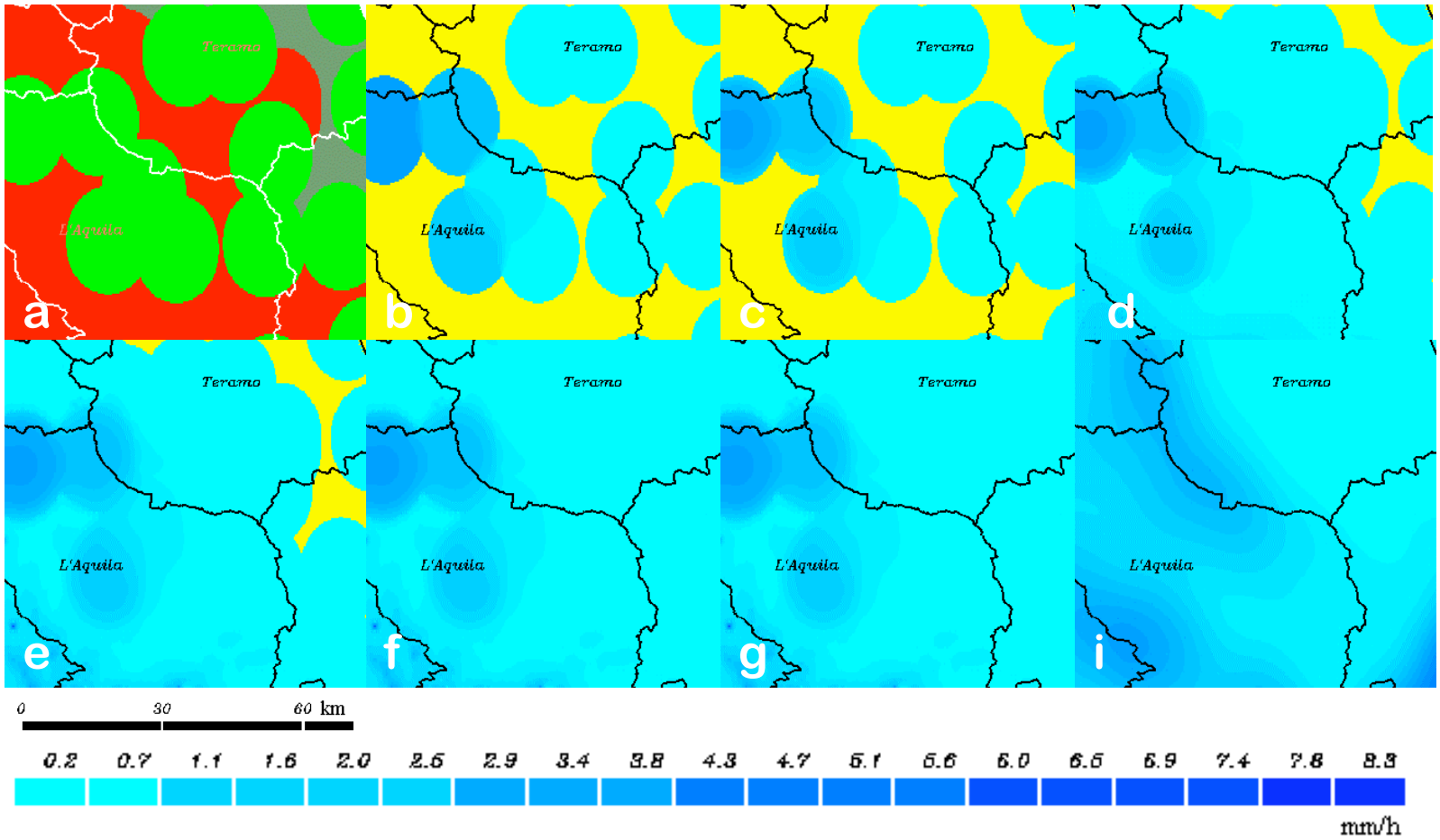
  But cells corresponding to rain gauges or defined in a previous module are not updated
- All cells on the lattice are updated synchronously
- Update ends when a stable state is reached

CHyM Rain field sources: an example





Rainfall data assimilation for 4 August 2005 (11:00 UTC). Panel (a) shows the rain source available at each grid point (green: gauges; grey: model meteorological output used as a source when measurements are not available). In panel (b) only the gauge measurements are used and merged with the Cressman algorithm. The yellow area indicates that for this module there are no available data in these grid points. In panel (c) the same gauge measurements are used but merged using the CA algorithm. In panel (d) the rainfield is shown when the MM5 rainfield is added to the previous one of panel (c) using a Cressman algorithm; and in panel (e) the same field is reported when the CA algorithm is used. Panel (f) is for comparison, to show the rainfield as it is forecast by the MM5 model.

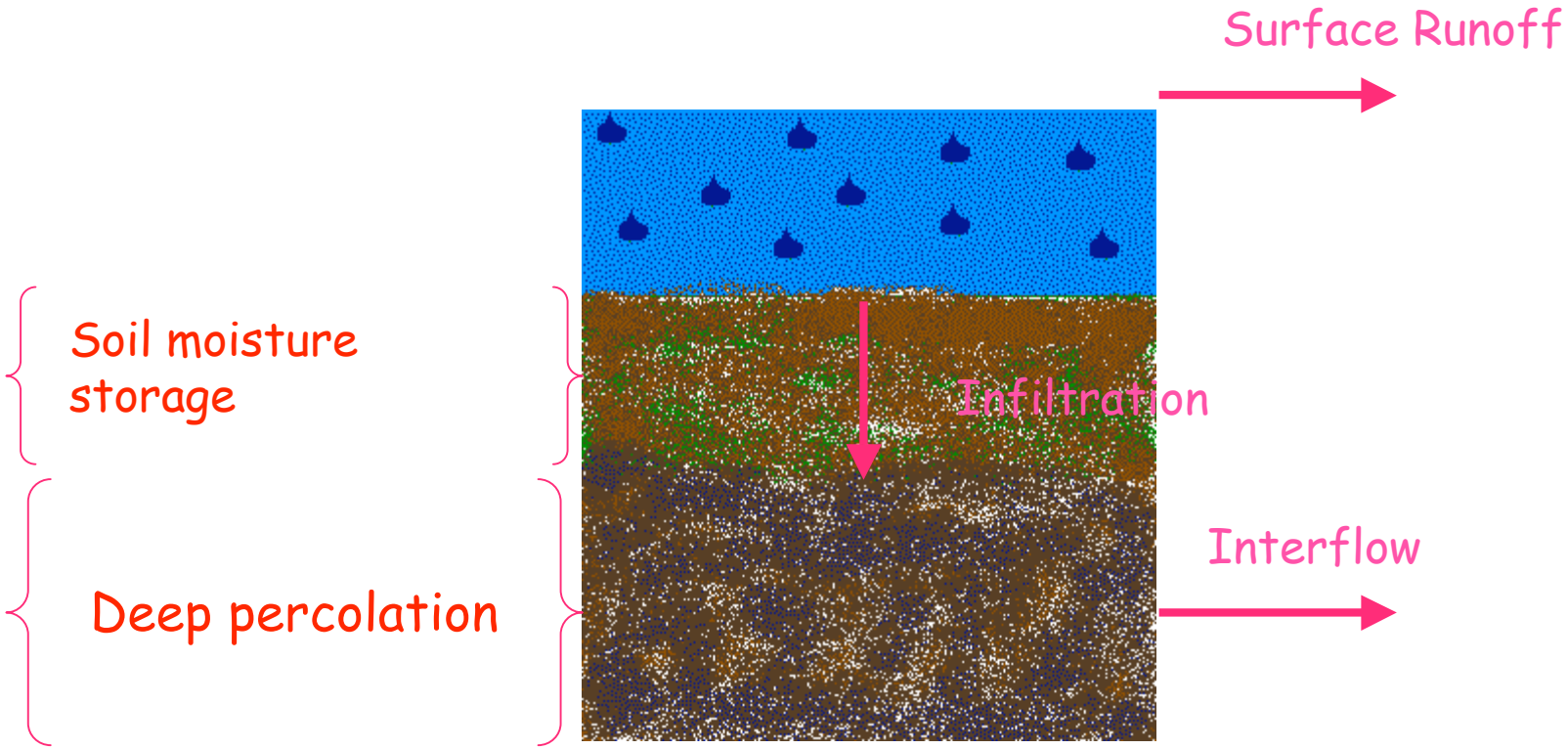


E. Coppola, B. Tomassetti, L. Mariotti, M. Verdecchia and G. Visconti, Cellular automata algorithms for drainage network extraction and rainfall data assimilation, Hydrological Science Journal, 52(3), 2007

For each cell the simulated processes are:

Runoff
Evapotraspiration
Infiltration
Rainfall

CHyM: Infiltration



CHym: Evapotraspiration

Thornthwaite Formula (Thornthwaite and Mather, 1995)

$$E_{th}(i) = 16\frac{n(i)}{30}\frac{N(i)}{12}(10\frac{\bar{T}(i)}{K_1})^{K_2}$$

$$N = \text{daylenght}$$
$$K_1 = \text{thermal index}$$
$$K_2 = f(K_1)$$

CHym: Runoff

Continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c$$

A= cross sectional area of the river
Q= flow rate of water discharge
q_c= rain for length unit

Momentum equation

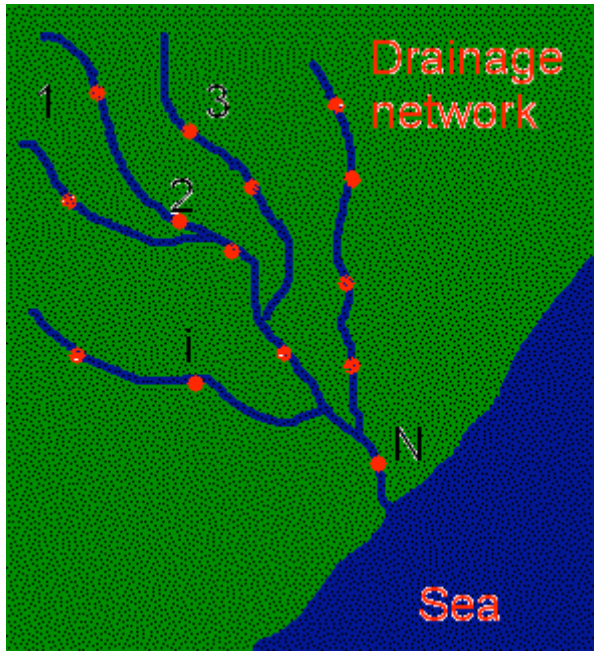
$$Q = \frac{S^{1/2} R^{2/3}}{n} A$$

S= slope

1/R= wetter perimeter

n= Manning's roughness coefficient

CHyM: Stress index



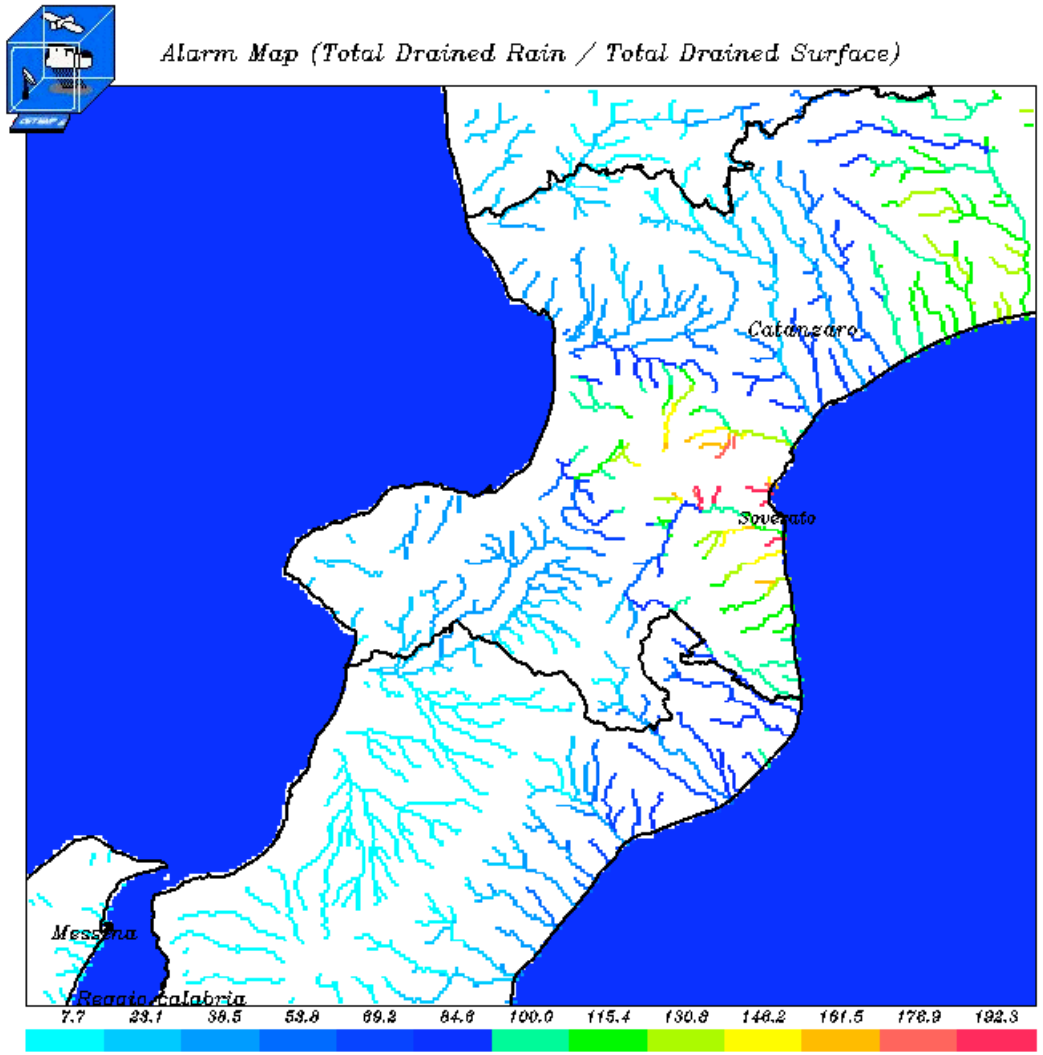
$$\frac{\sum_{i=1}^{N} R_i}{\sum_{i=1}^{N} A_i} = AI$$

R_i = rain

A_i = drained surface

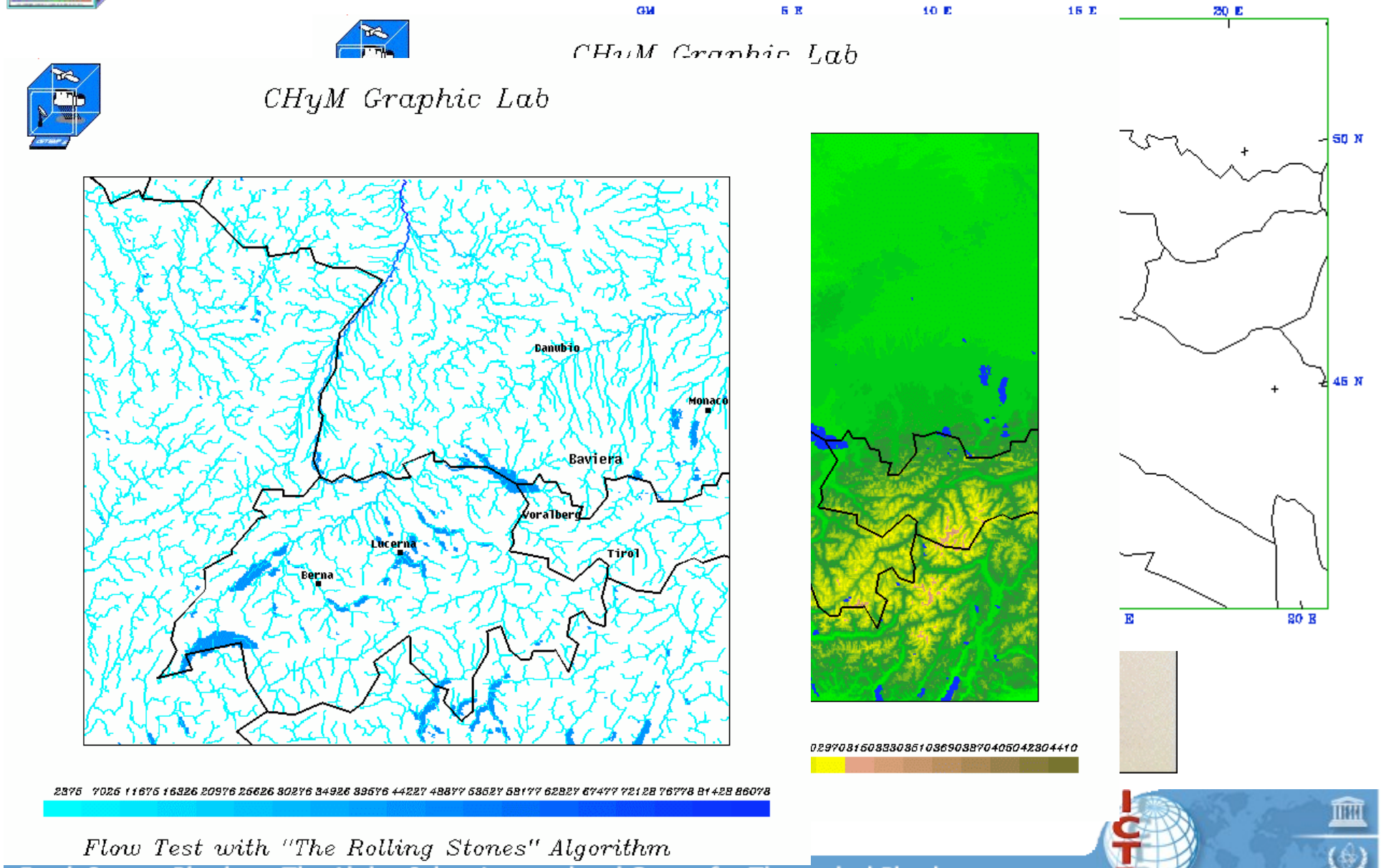
AI= Alarm Index

Soverato Flood simulation



Simulation from September, 09 2000 h: 12 to September, 11 2000 h: 12

CHyM: simulation of Aug 22-23 2005 event



f Aug 22-23 2005 event

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ALLUVIONI IN AUSTRIA, SALE A TRE IL NUMERO DEI MORTI

E'salito a tre il bilancio delle vittime del maltempo in Austria nelle ultime ventiquattr'ore. A Ruethe, nella provincia di Vorarlberg, nella parte ovest del Paese, le squadre di soccorso hanno recuperato oggi da un seminterrato allagato il cadavere di un uomo di 52 anni. Ieri una persona era stata travolta e uccisa da una frana a Langenfeld, nel Tirolo; nella Stiria una cinquantenne era stata trascita via dall'acqua che aveva invaso la sua abitazione. All'appello manca ancora una persona; altre diciassette sono rimaste ferite. Le piogge hanno interessato in particolare le province del Vorarlberg e del Tirolo, dove sono stati registrati i danni maggiori. I meteorologi annunciano un miglioramento delle situazione gia' da oggi. "Il peggio e' passato", ha affermato Siegfried Jaches, portavoce del ministro dell'Interno. Nei prossimi giorni si potra' fare una stima dei danni.

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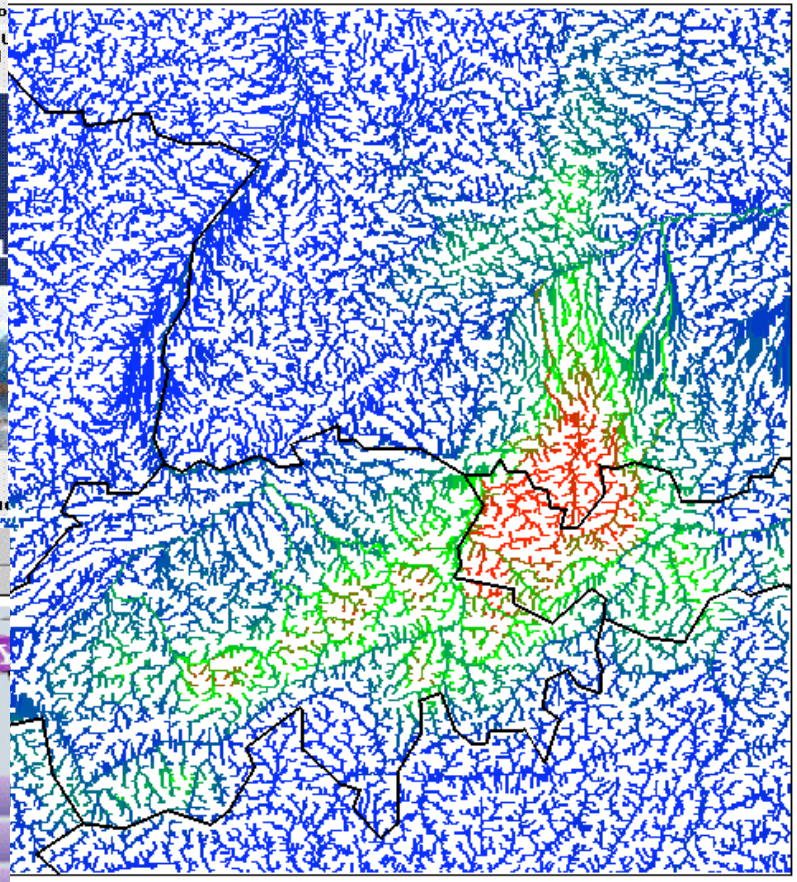
mercredi 24 aout 2005, 13h34

Inondations: les pays alpins en état d'alerte

agrandir la photo

VIENNE (AFP) - La Suisse, l'Autriche et le Sud de l'Allemagne et des pays d'Europe de l'Est sont en état d'alerte depuis plusieurs jours après des inondations meurtrières, les plus graves depuis 1999 dans l'arc alpin, qui ont déjà provoqué des millions d'euros de dégâts.

ap (Total Drained Rain / Total Drained Surface)

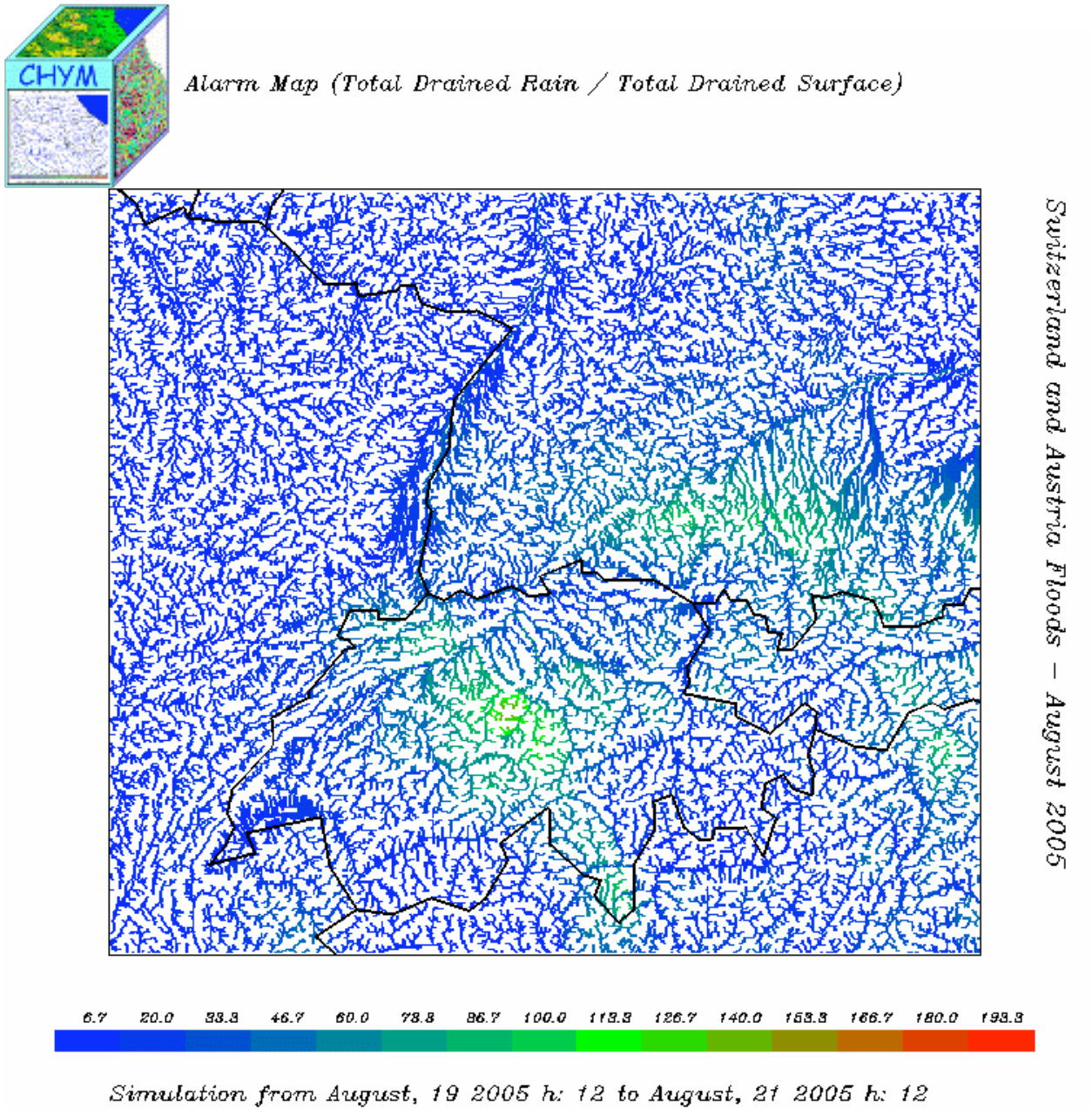


Switzerland and Austria Floods – Aug. 21/23, 2005

7 60.0 73.3 86.7 100.0 113.3 126.7 140.0 153.3 166.7 180.0 193.3

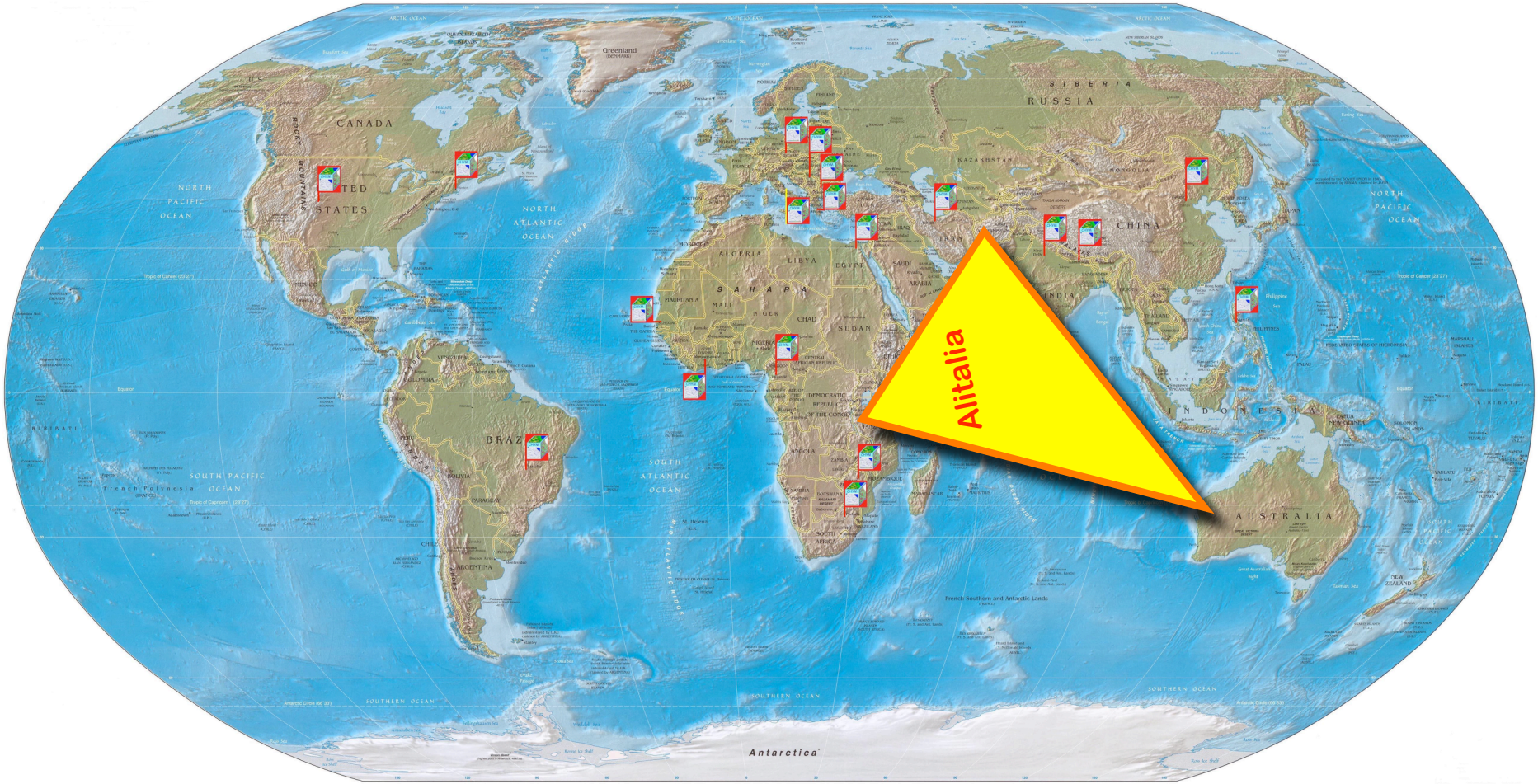
m August, 21 2005 h: 12 to August, 23 2005 h: 12

CHyM: simulation of Aug 22-23 2005 event



First ICTP workshop on RegCM-CHYm coupling June 2006

Chym is flying all over the world ….

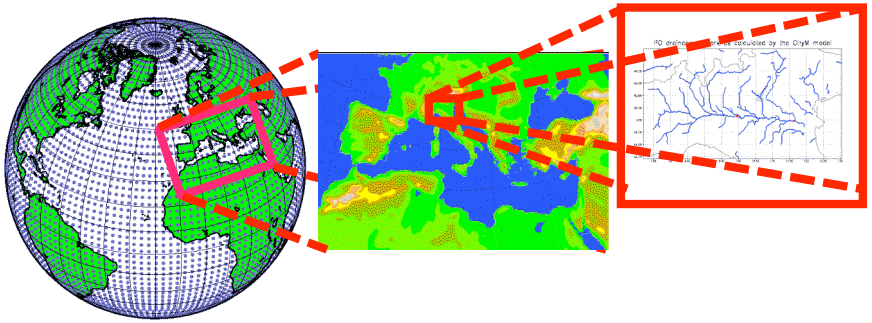


Impact of Climate Change in the Po valley: downscaling high resolution RegCM output by coupling with ChYM hydrological model

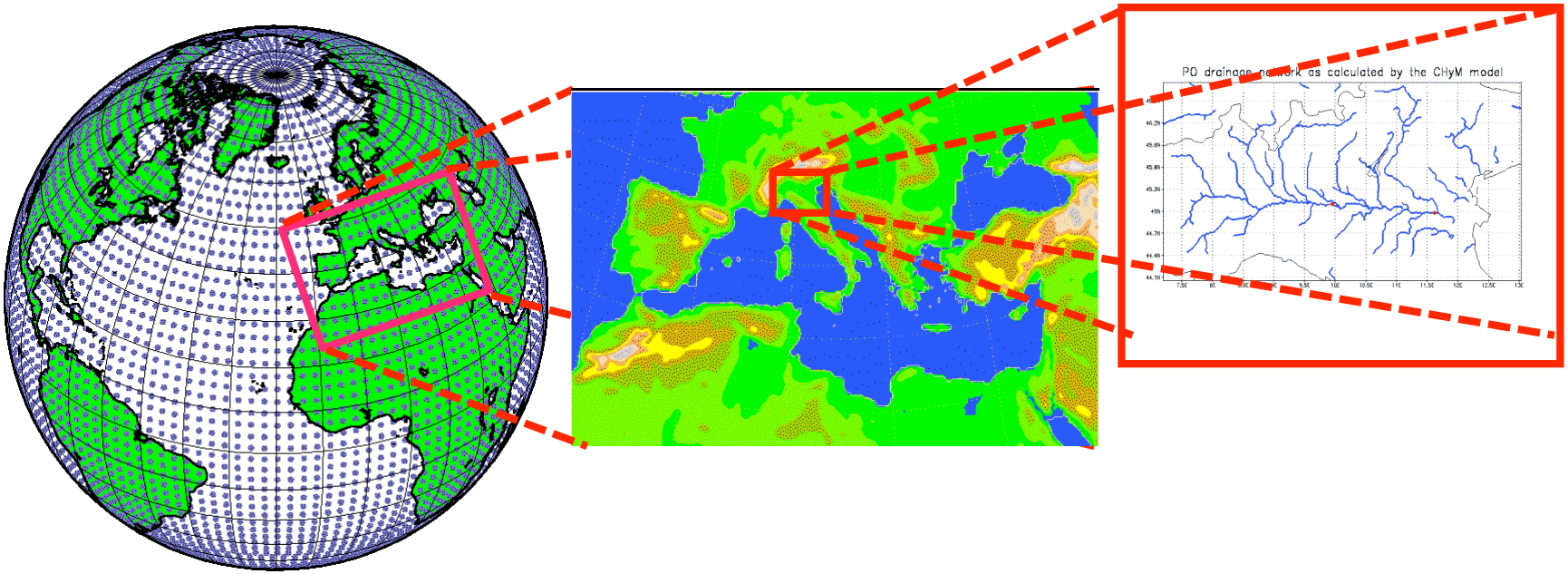
E. Coppola (1), F. Giorgi (1), X. Gao (2), L. Mariotti (1,3), B. Tomassetti (3), M. Verdecchia (3)

(1) The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

(2) National Climate Center of CMA, China,
(3) CETEMPS, University of L'Aquila, Italy
(coppolae@ictp.it)

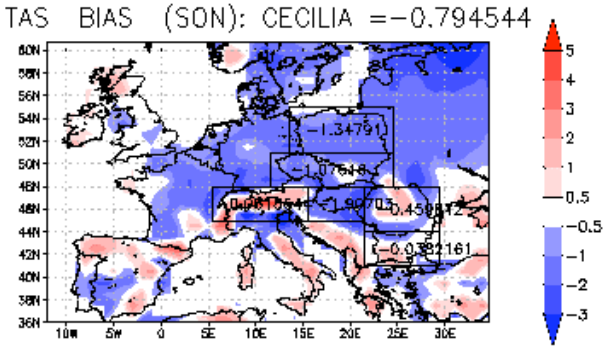


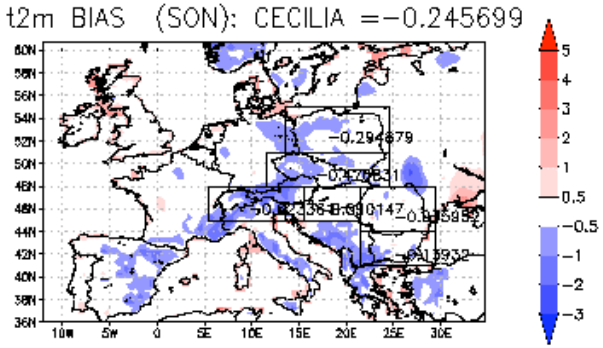
Dowscaling from large scale to hydrological scale

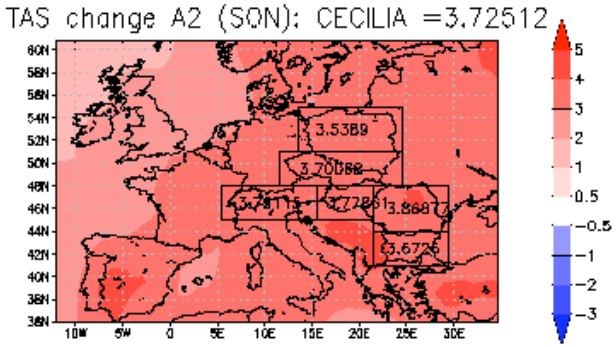


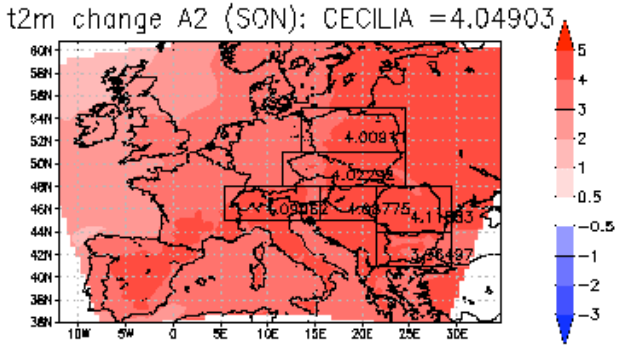
CMIP3 models

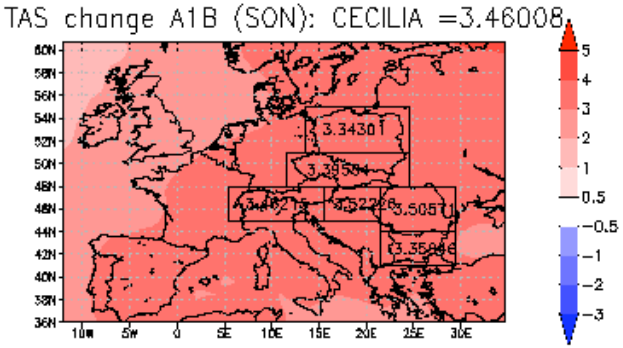
RCM

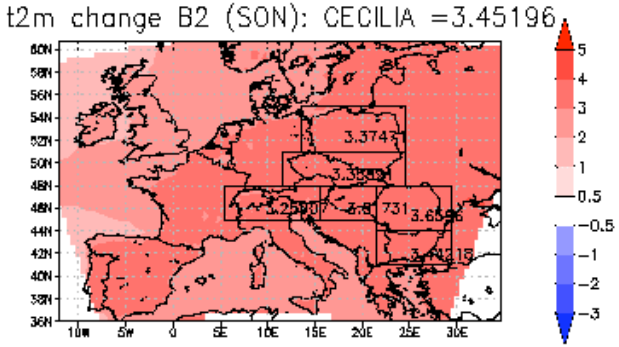






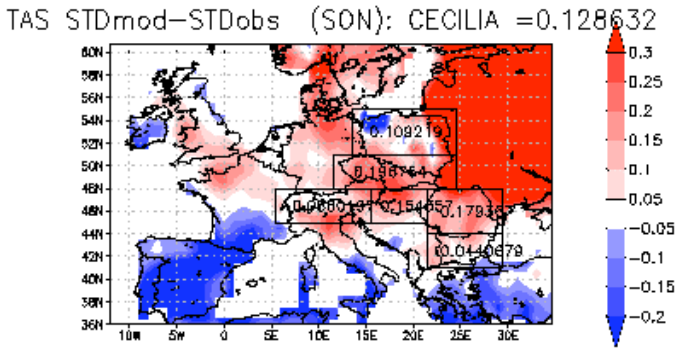


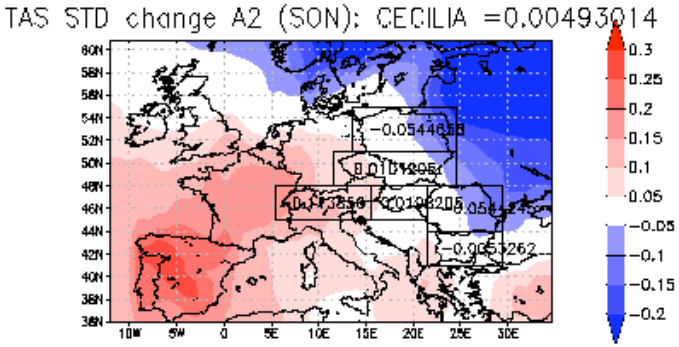


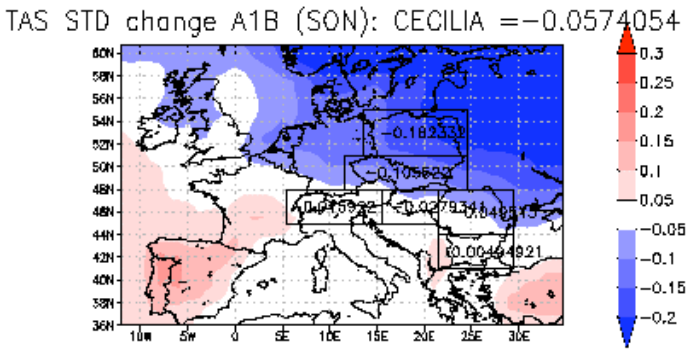


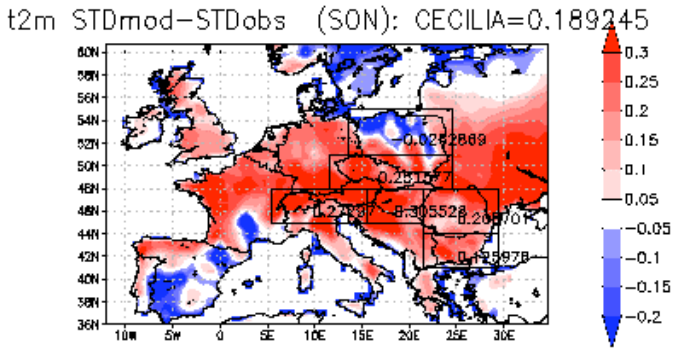
CMIP3 models

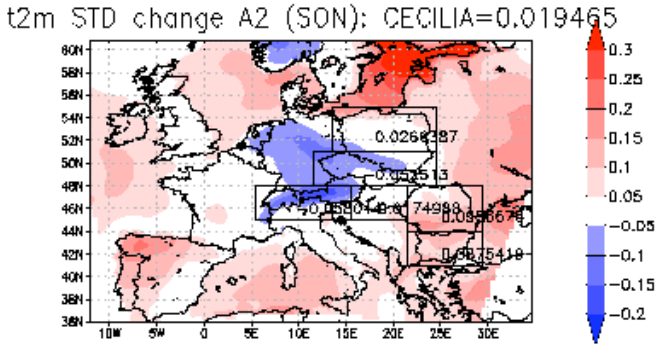
RCM

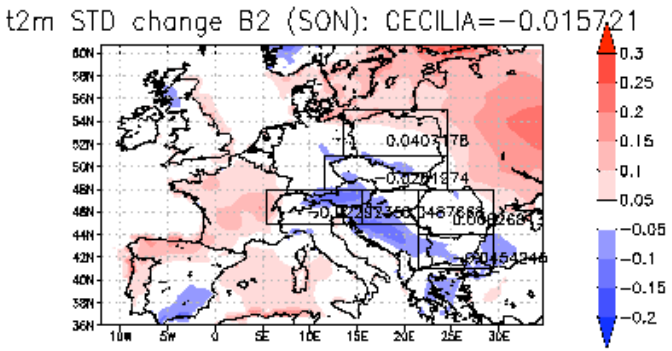






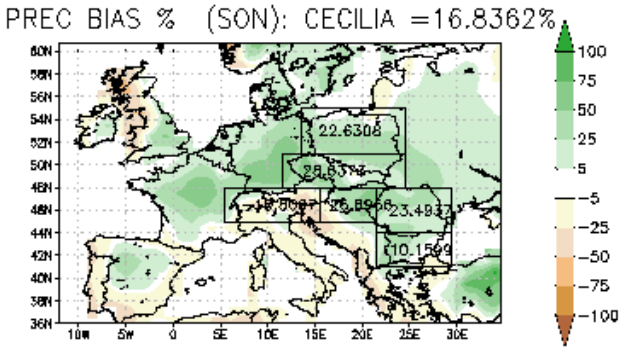


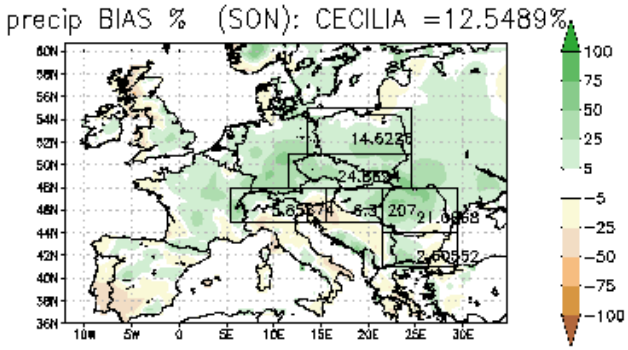


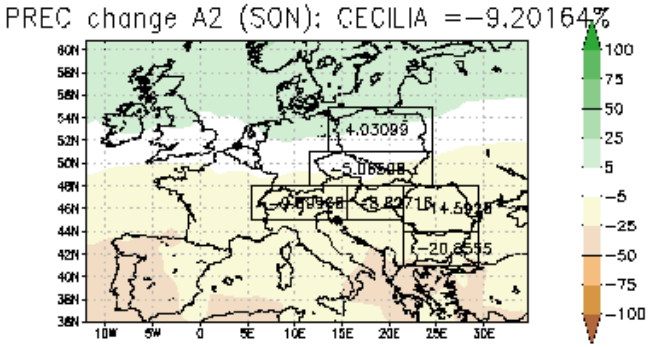


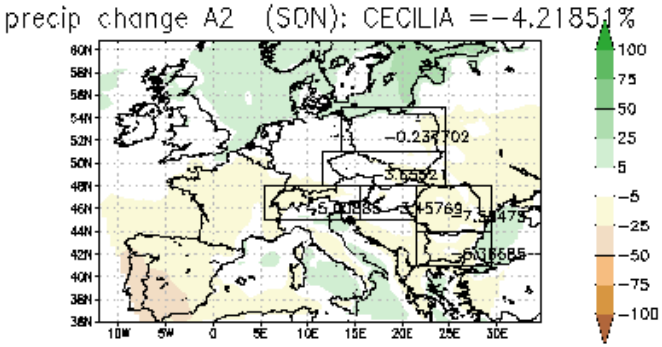
CMIP3 models

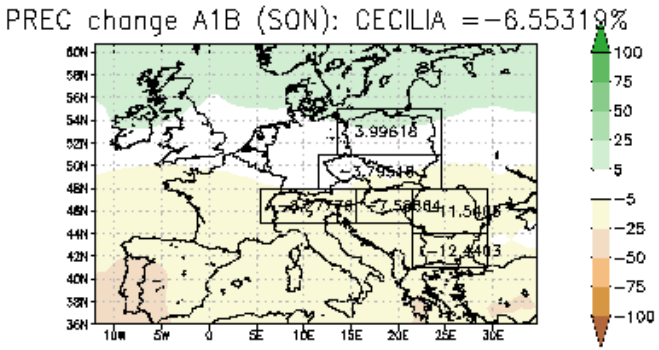
RCM

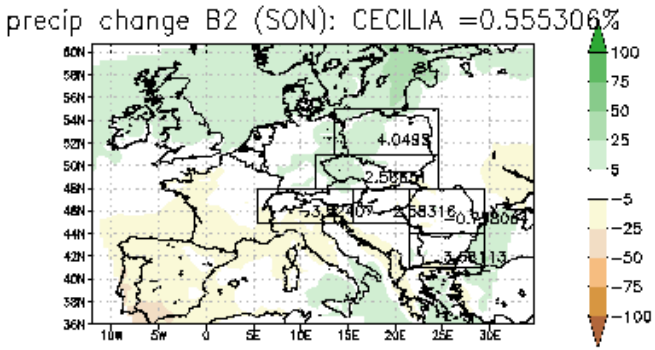






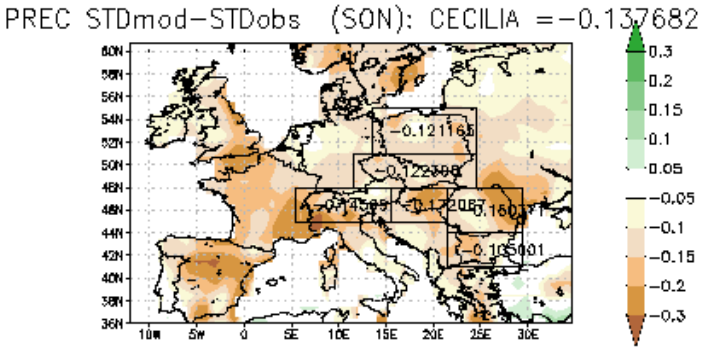


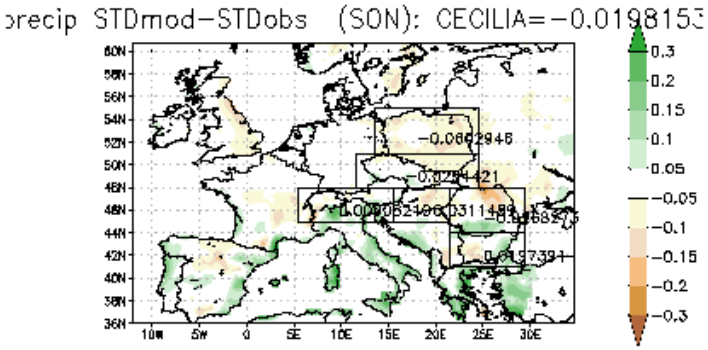


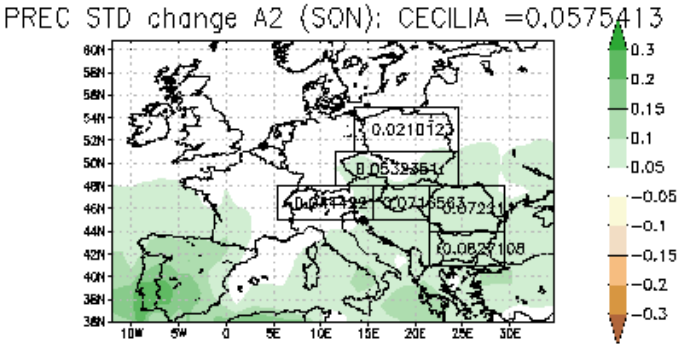


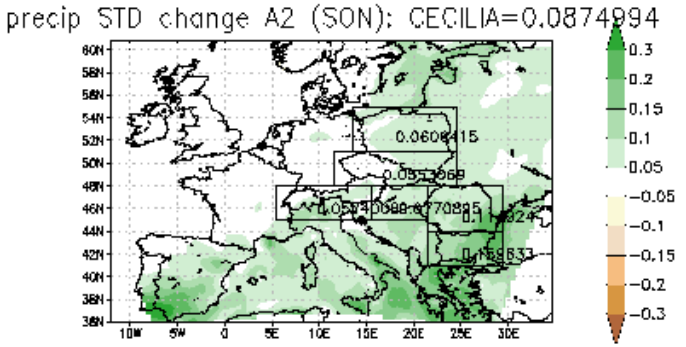
CMIP3 models

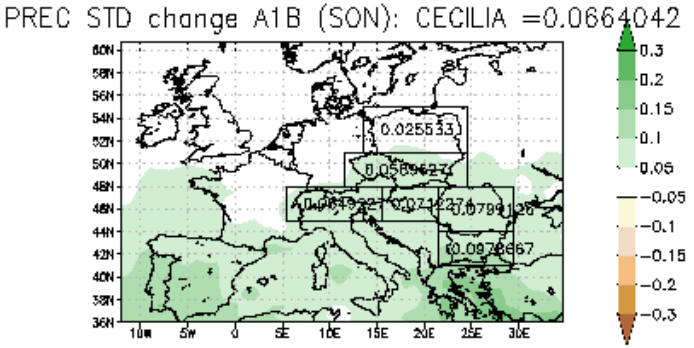
RCM

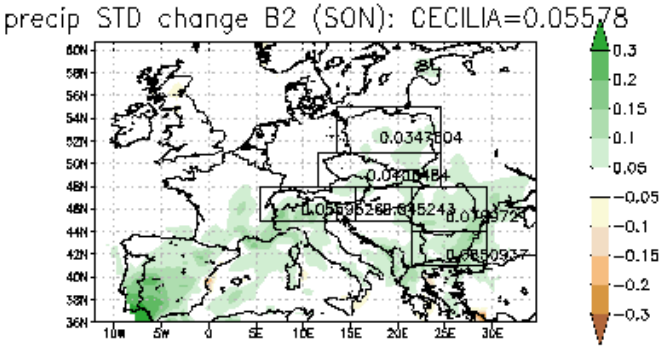




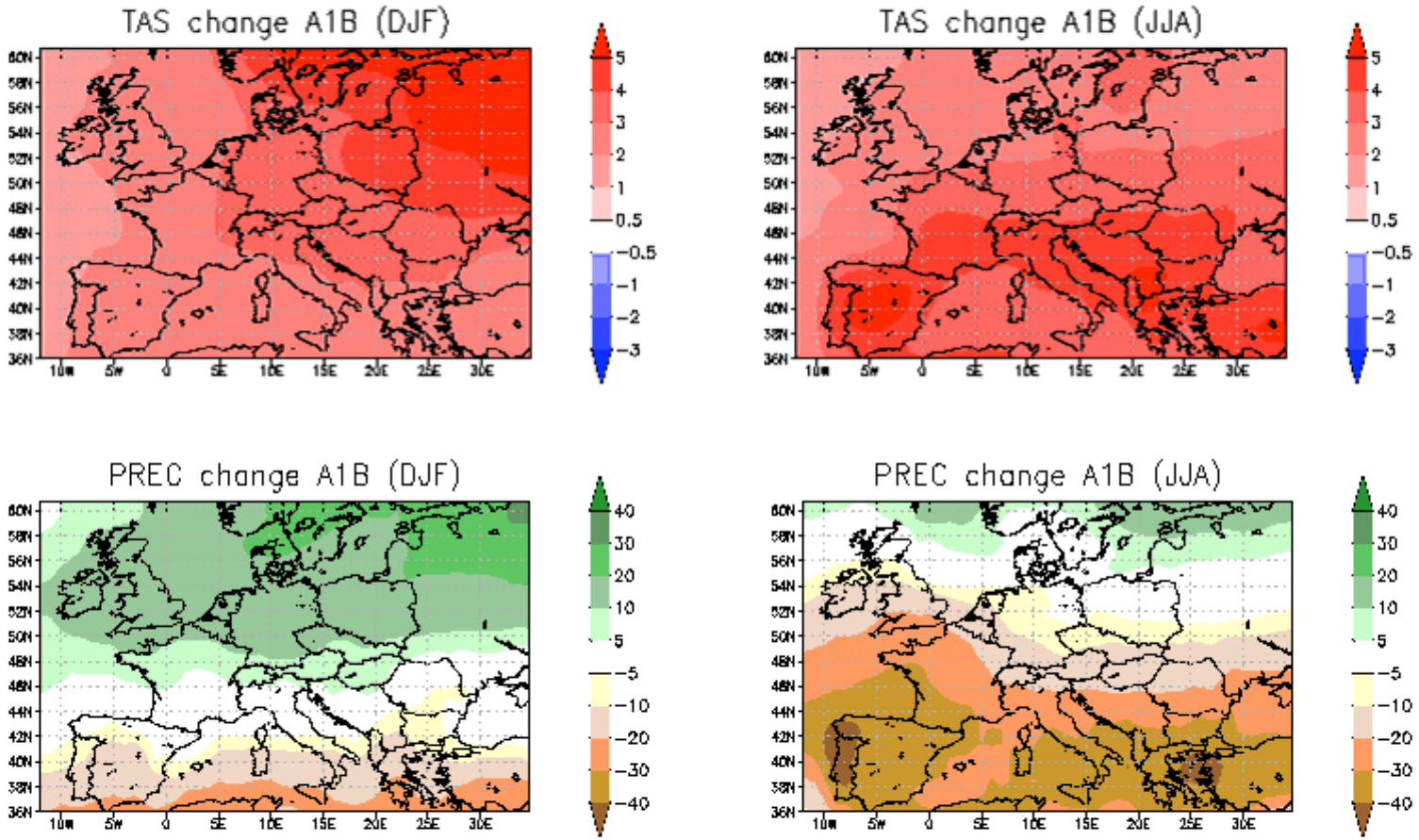




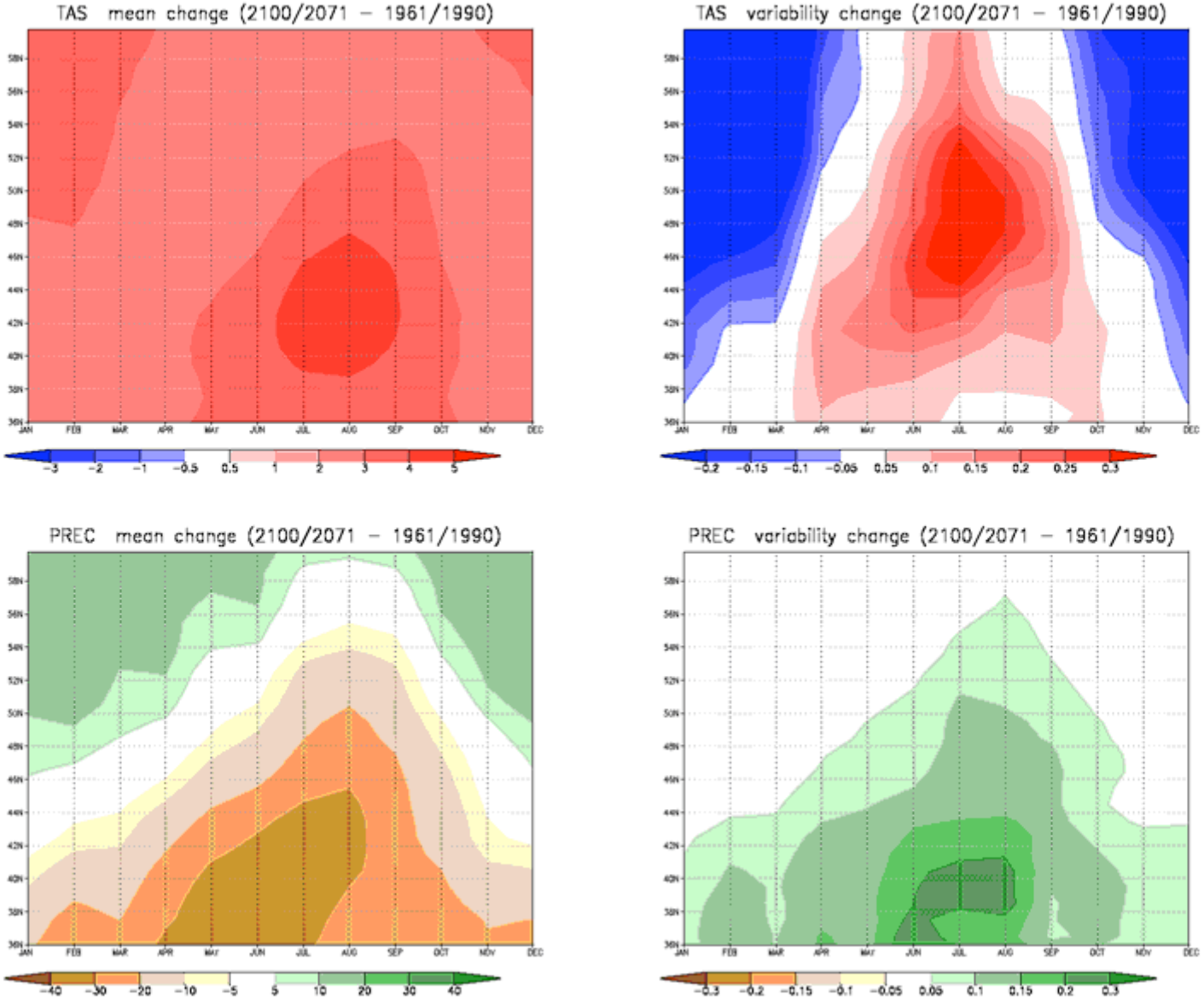




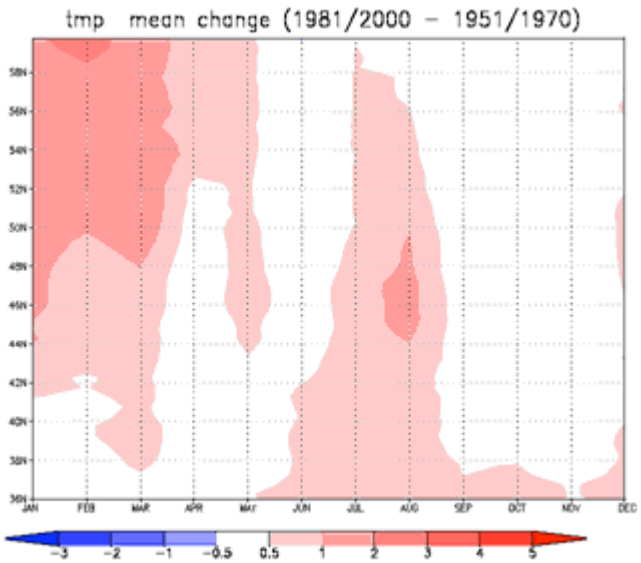
ECO summary

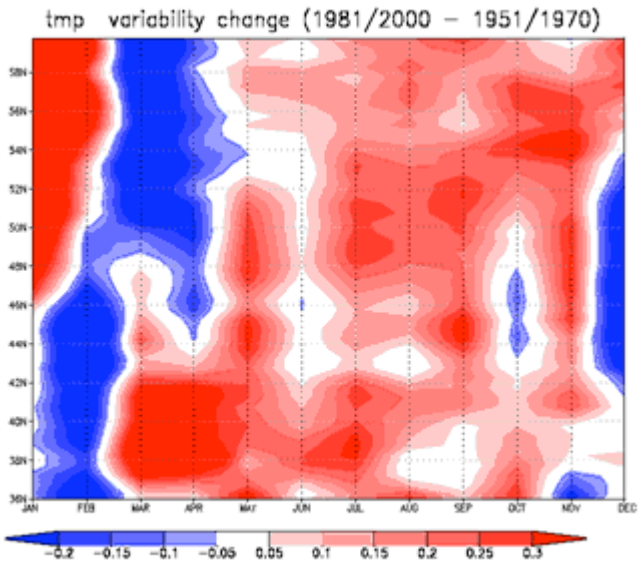

TAS change A1B (DJF)
TAS change A1B (JJA)
PREC change A1B (DJF)
PREC change A1B (JJA)
60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N
10W 5W 0 5E 10E 15E 20E 25E 30E
5 4 3 2 1 0.5 −0.5 −1 −2 −3
40 30 20 10 5 −5 −10 −20 −30 −40

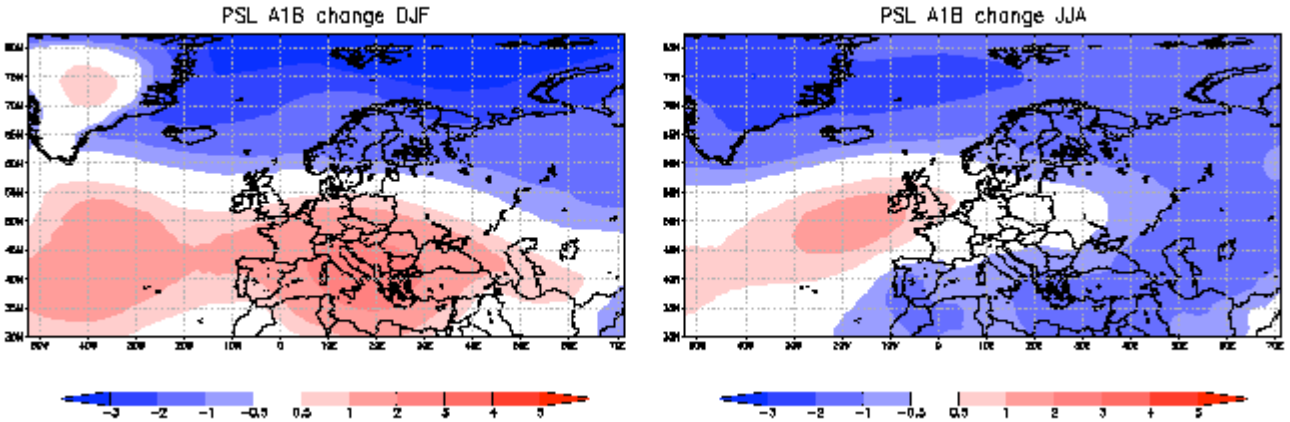
Zonal average of ECO signal

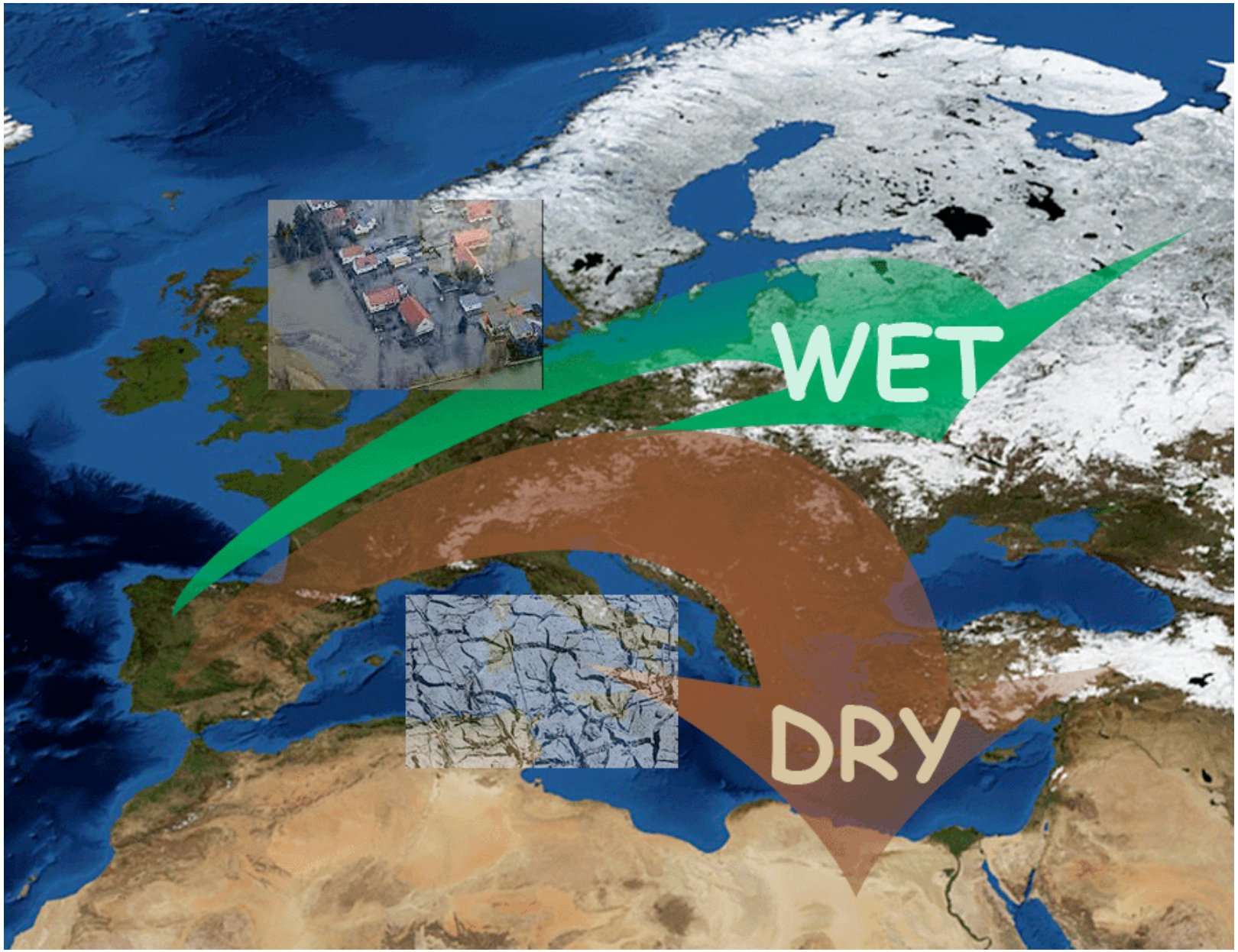


Zonal average of ECO signal in the observations





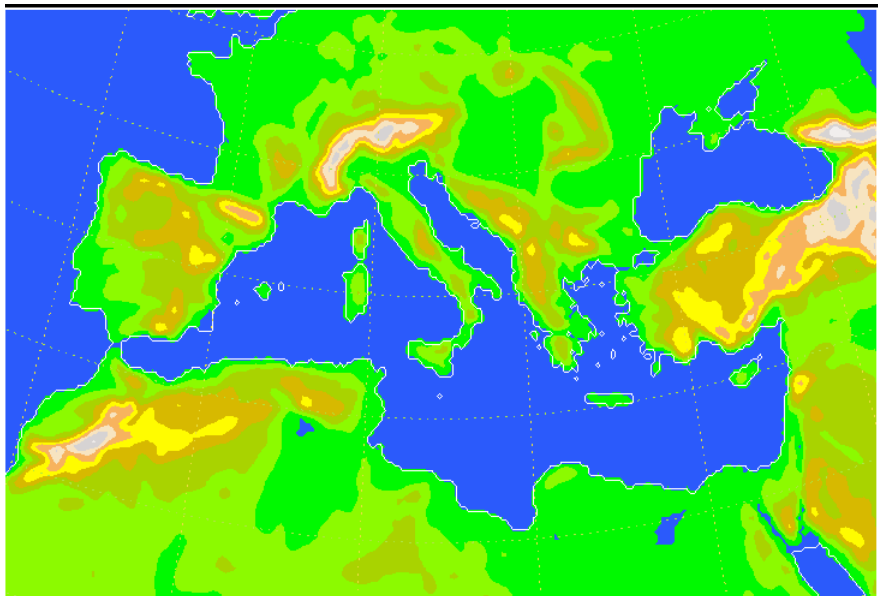

PSL A1B change DJF
PSL A1B change JJA

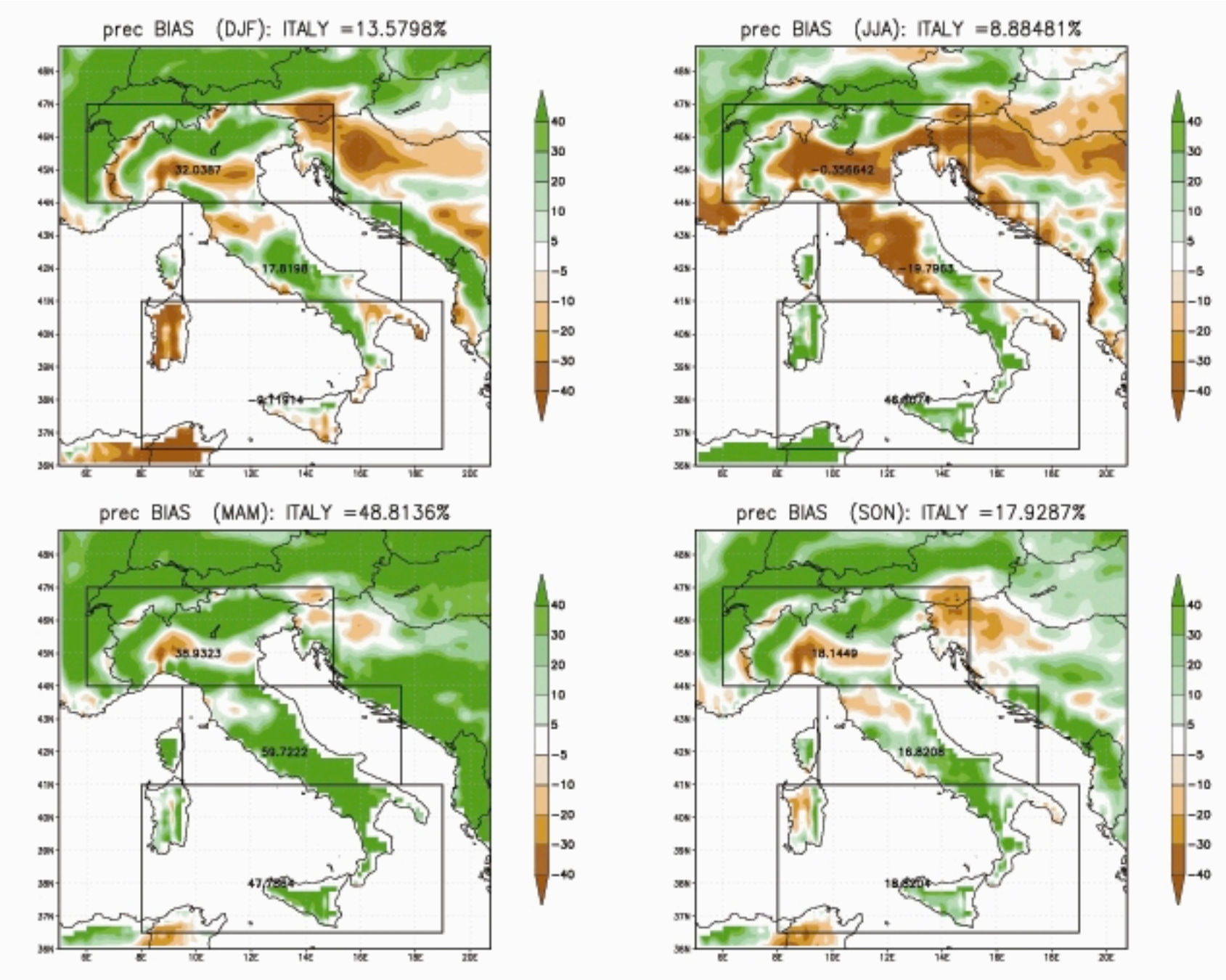


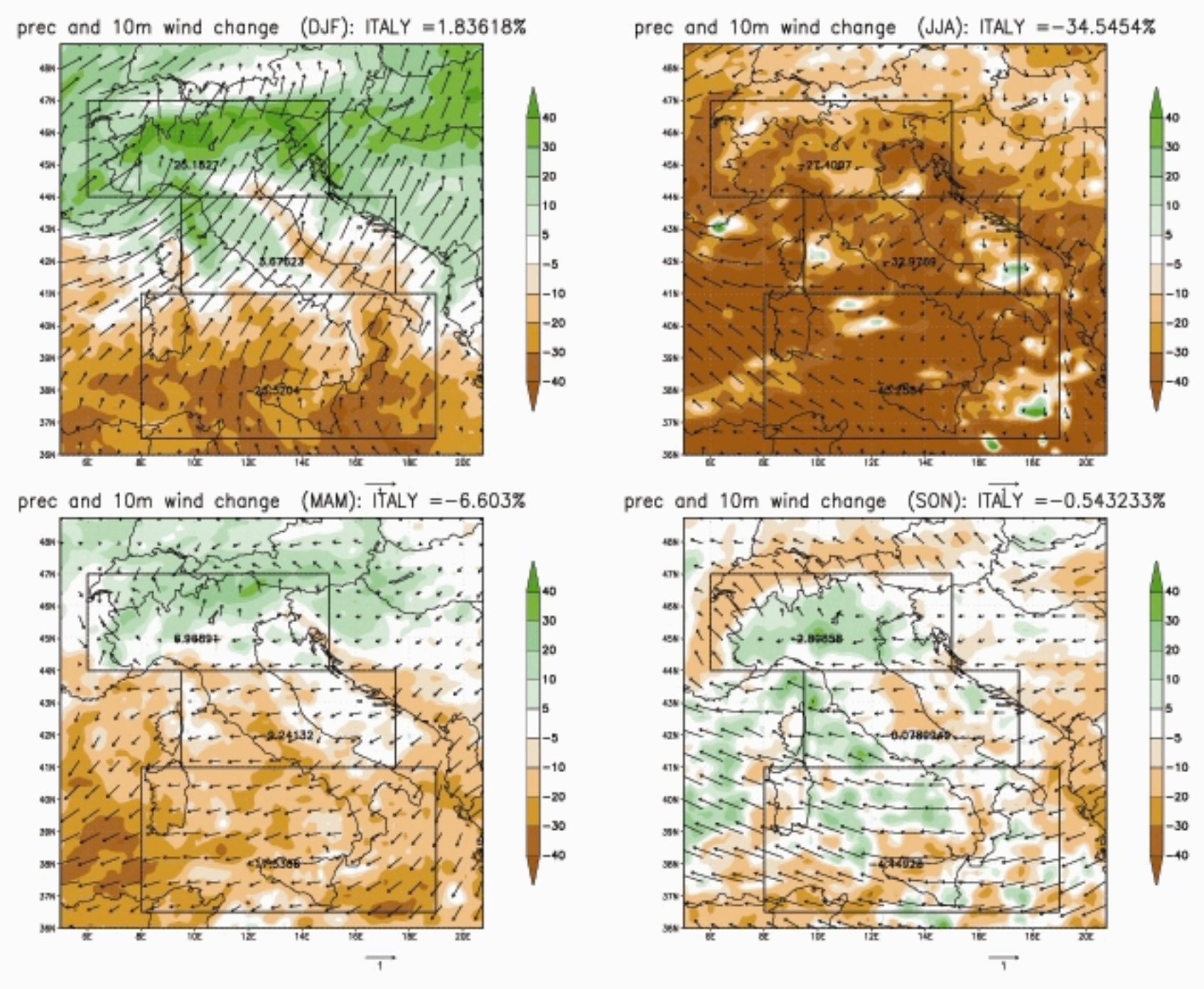
Giorgi, F., and E. Coppola (2007), European climate-change oscillation (ECO), *Geophys. Res. Lett.*, 34, L21703, doi:10.1029/2007GL031223

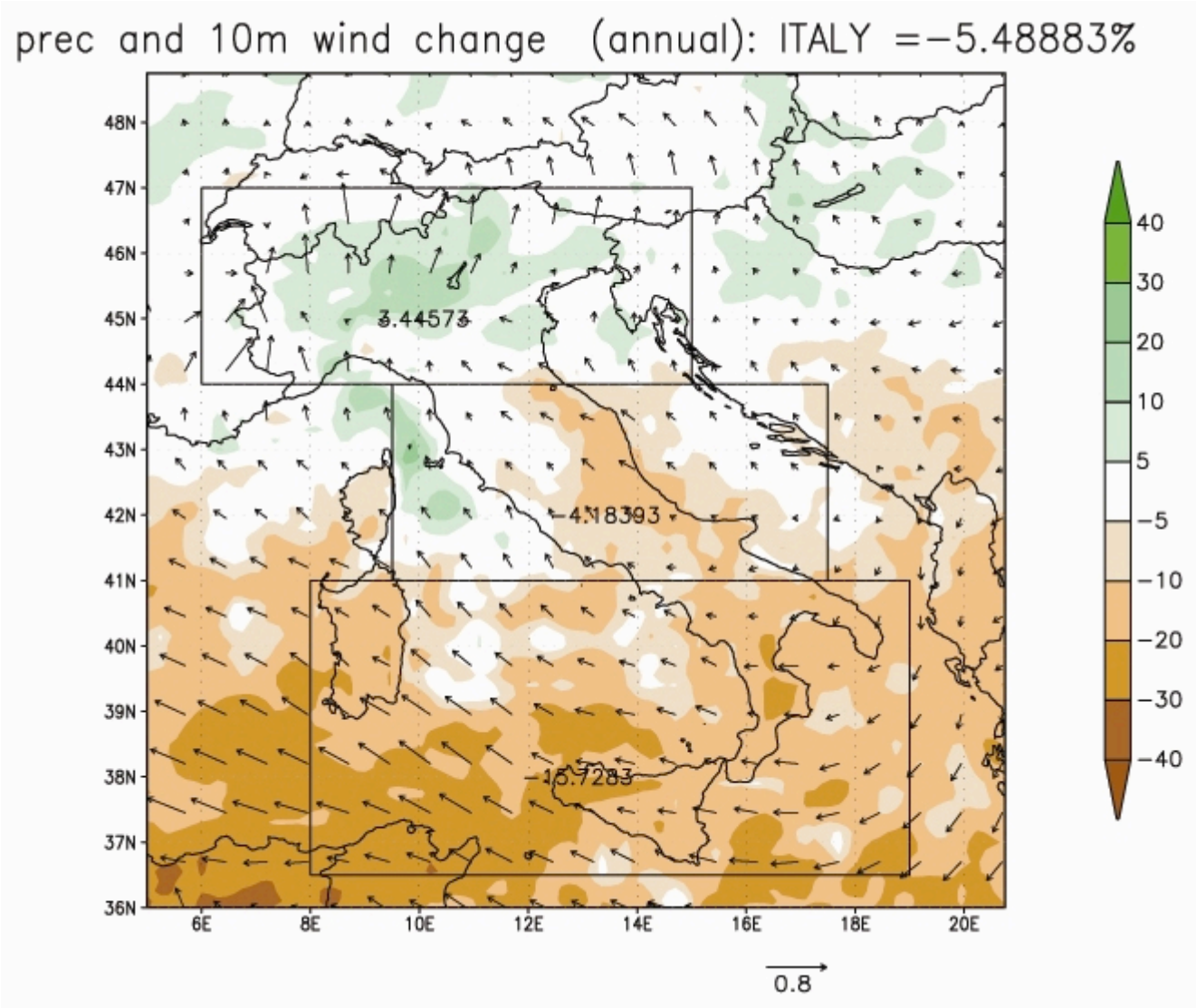
High resolution experiment over the Mediterranean basin

- Model configuration
  - 20-km grid point spacing
  - Full Mediterranean domain
- Experiment design
  - Forcing fields from PRUDENCE RegCM simulations at 50 km.
  - Reference simulation
  - (1961-1990)
  - A2, B2 scenario simulations (2071-2100)




prec BIAS (DJF): ITALY =13.5798%
prec BIAS (JJA): ITALY =8.88481%
prec BIAS (MAM): ITALY =48.8136%
prec BIAS (SON): ITALY =17.9287%
40
30
20
10
5
-5
-10
-20
-30
-40

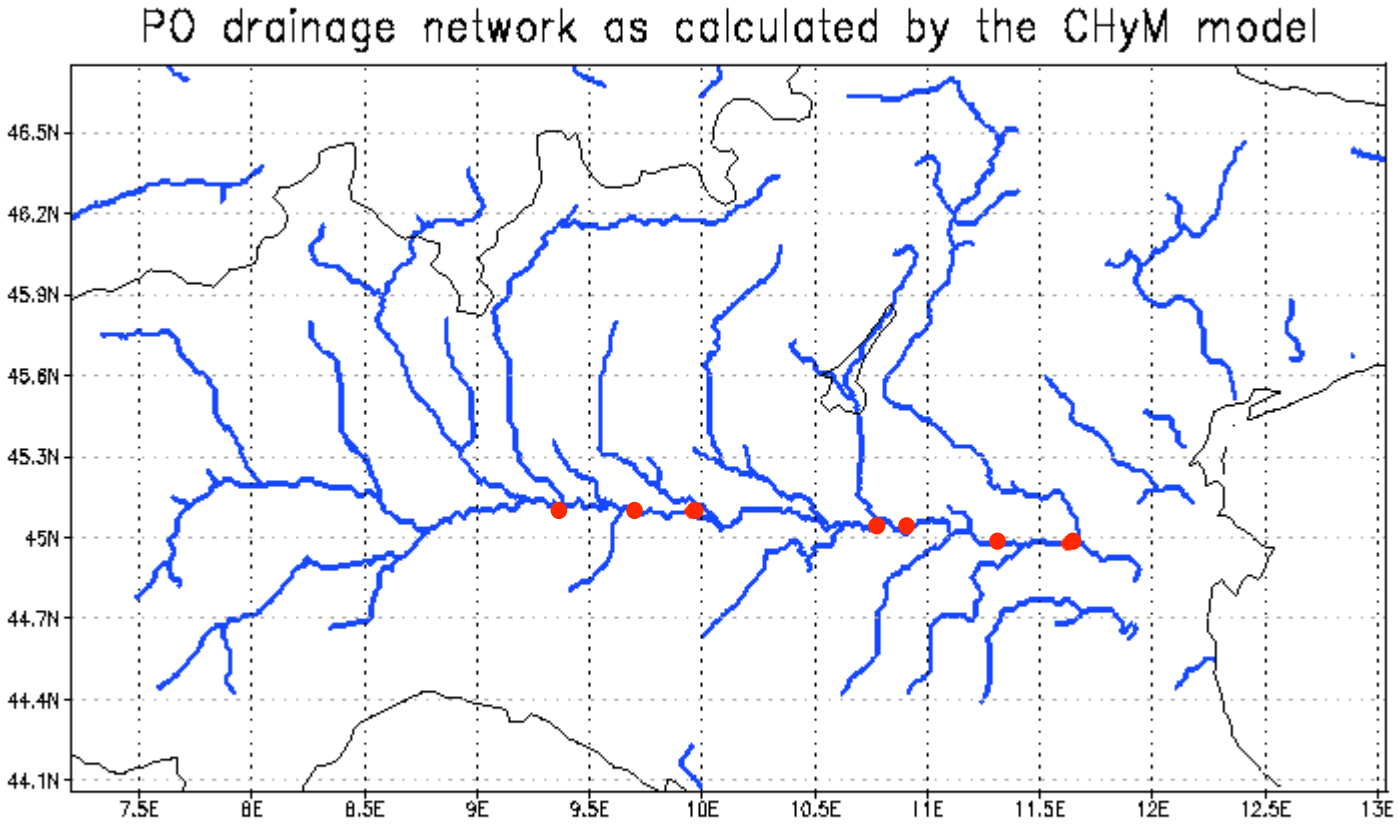

prec and 10m wind change (DJF): ITALY =1.83618%
prec and 10m wind change (JJA): ITALY =−34.5454%
prec and 10m wind change (MAM): ITALY =−6.603%
prec and 10m wind change (SON): ITALY =−0.543233%



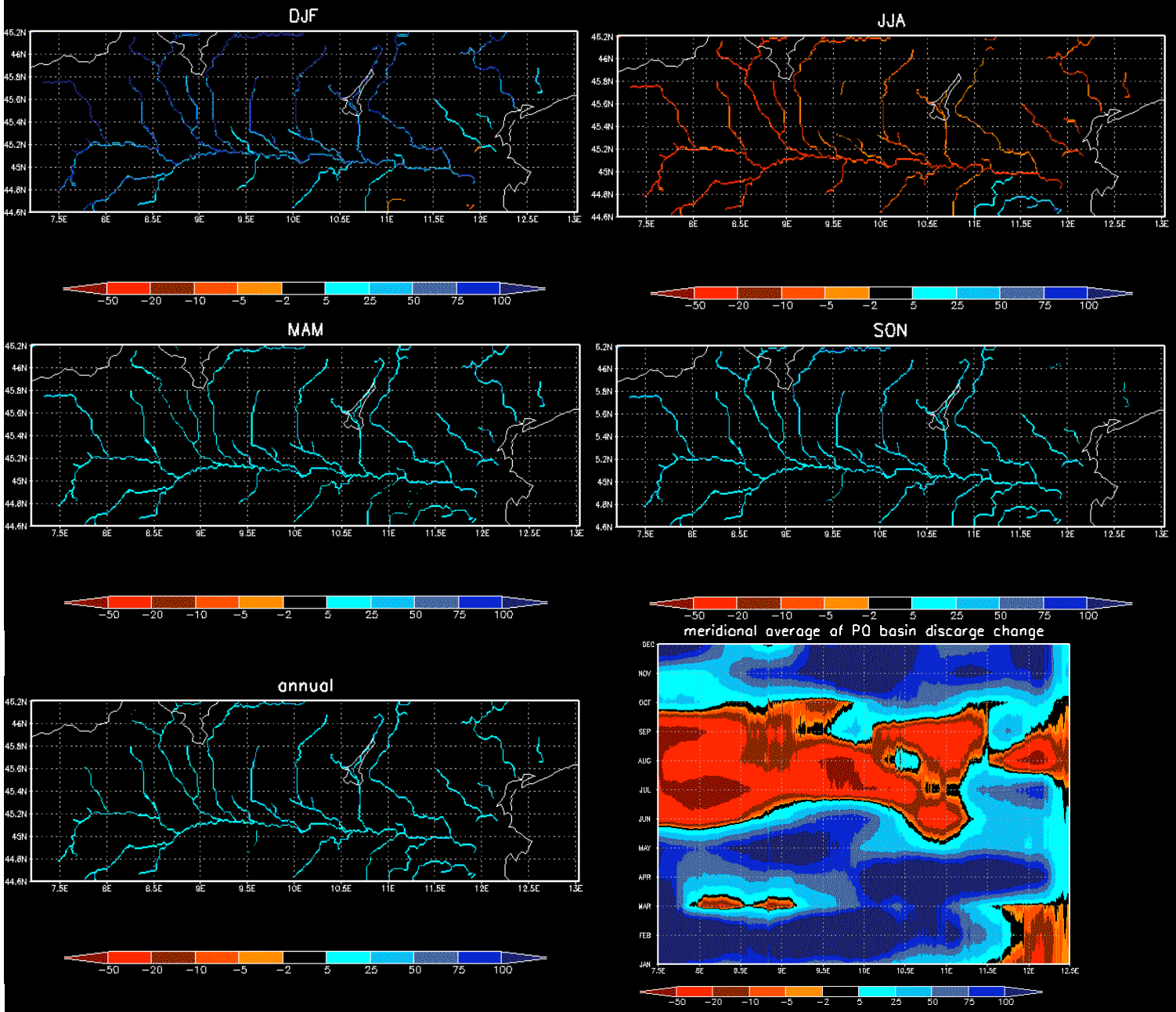
Gao X, Pal JS, Giorgi F. 2006. Projected changes in mean and extreme precipitation over the Mediterranean region from high resolution double nested RCM simulations, *Geophysical Research Letters* **33**: L03706.

CHyM hydrological model set-up

- 1 km resolution; 110945.0 km^2 drained area
- control run 1961-90 driven by RegCM control run
- scenario run 2071-2100 driven by RegCM A2 scenrio run



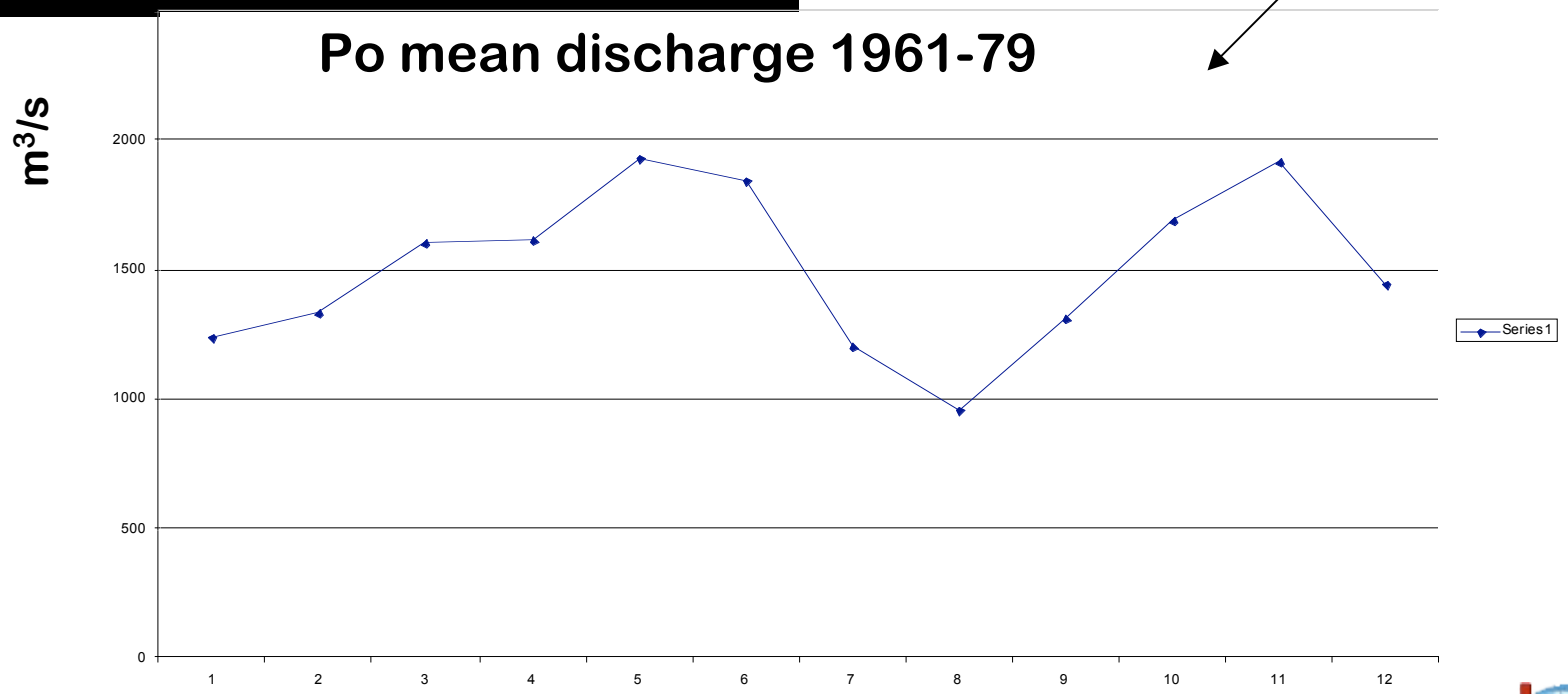
Po river discarge change



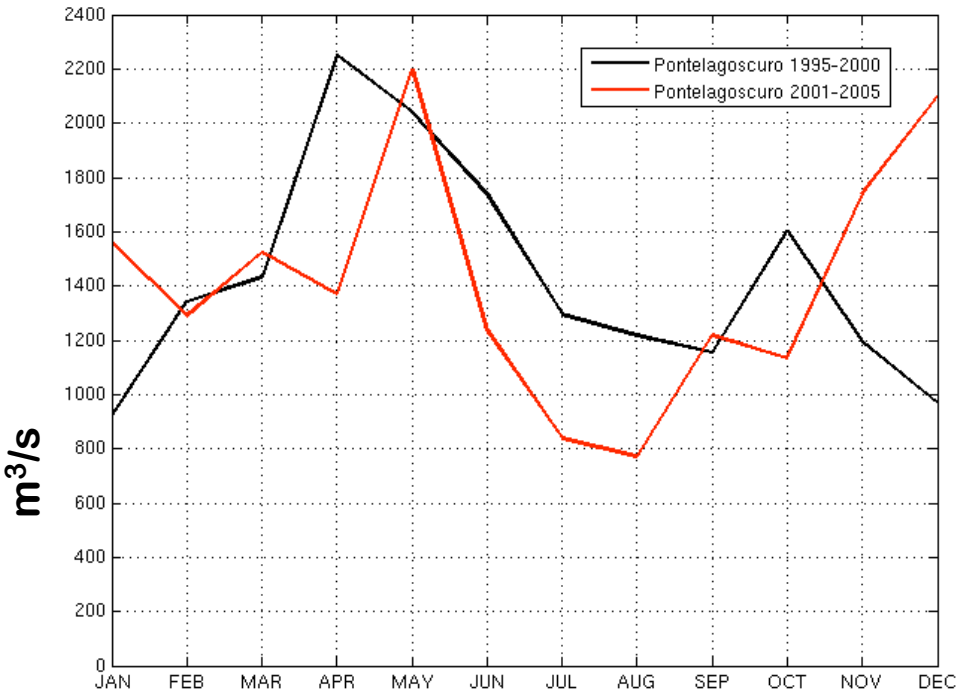
1918-1979

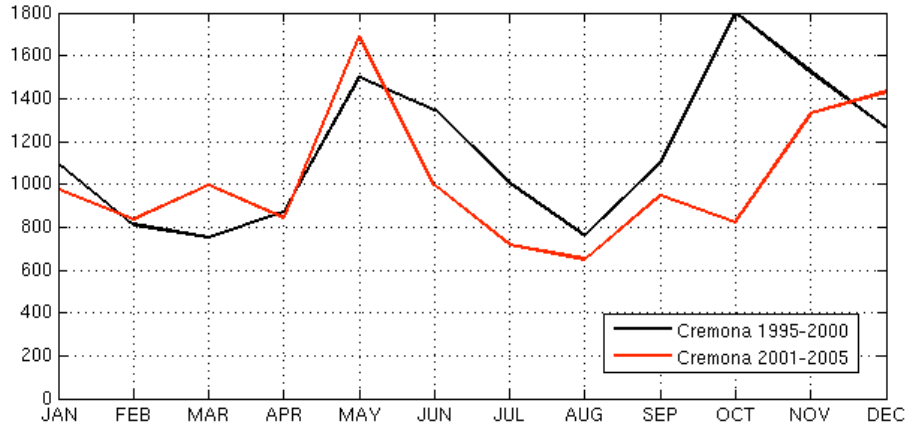
CHyM model

Observations



Observations

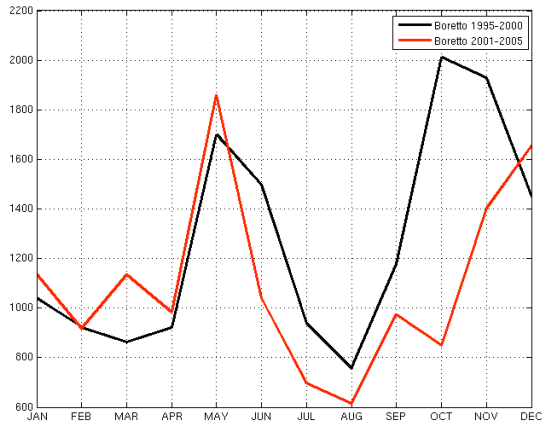


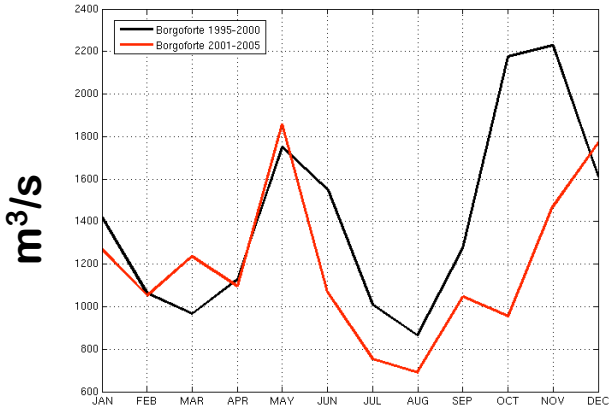


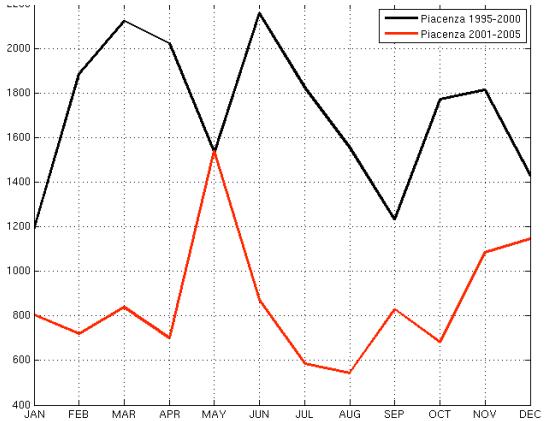
Boretto

Borgoforte

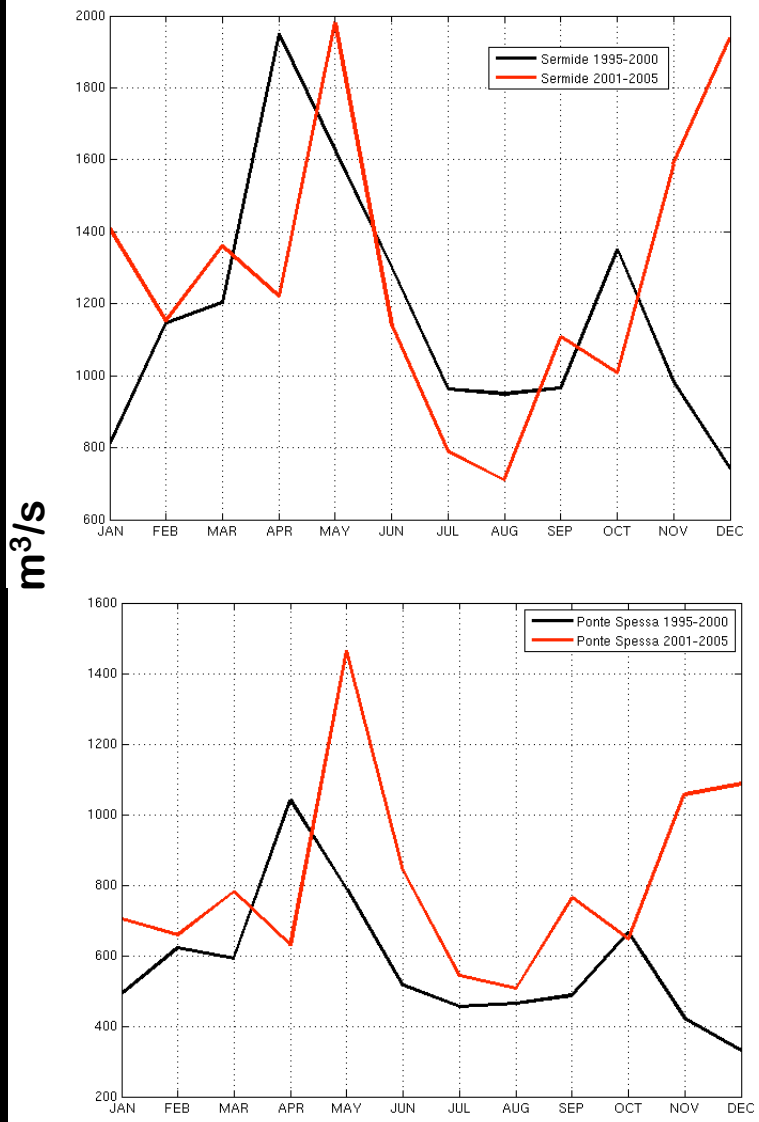
Observations



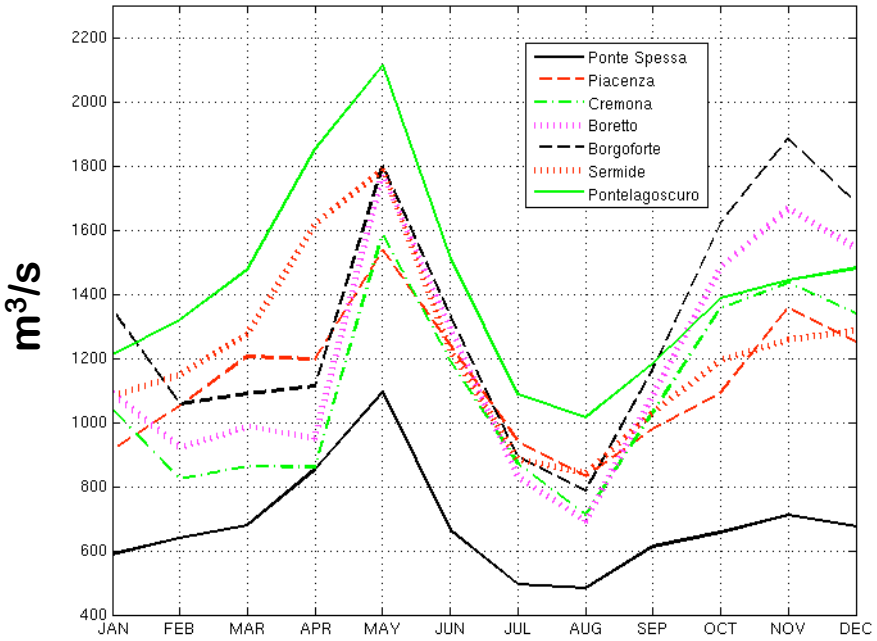


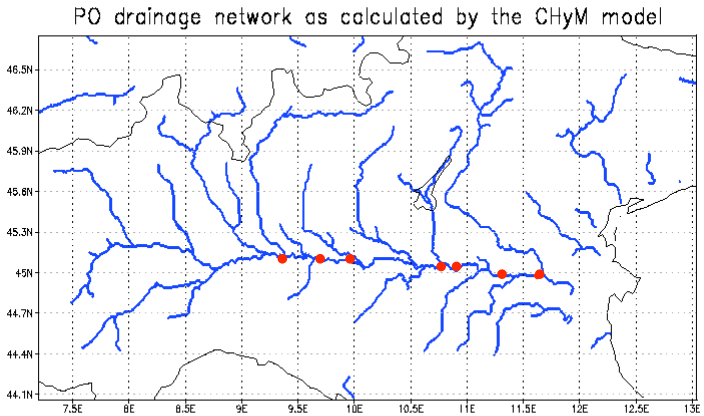


Observations

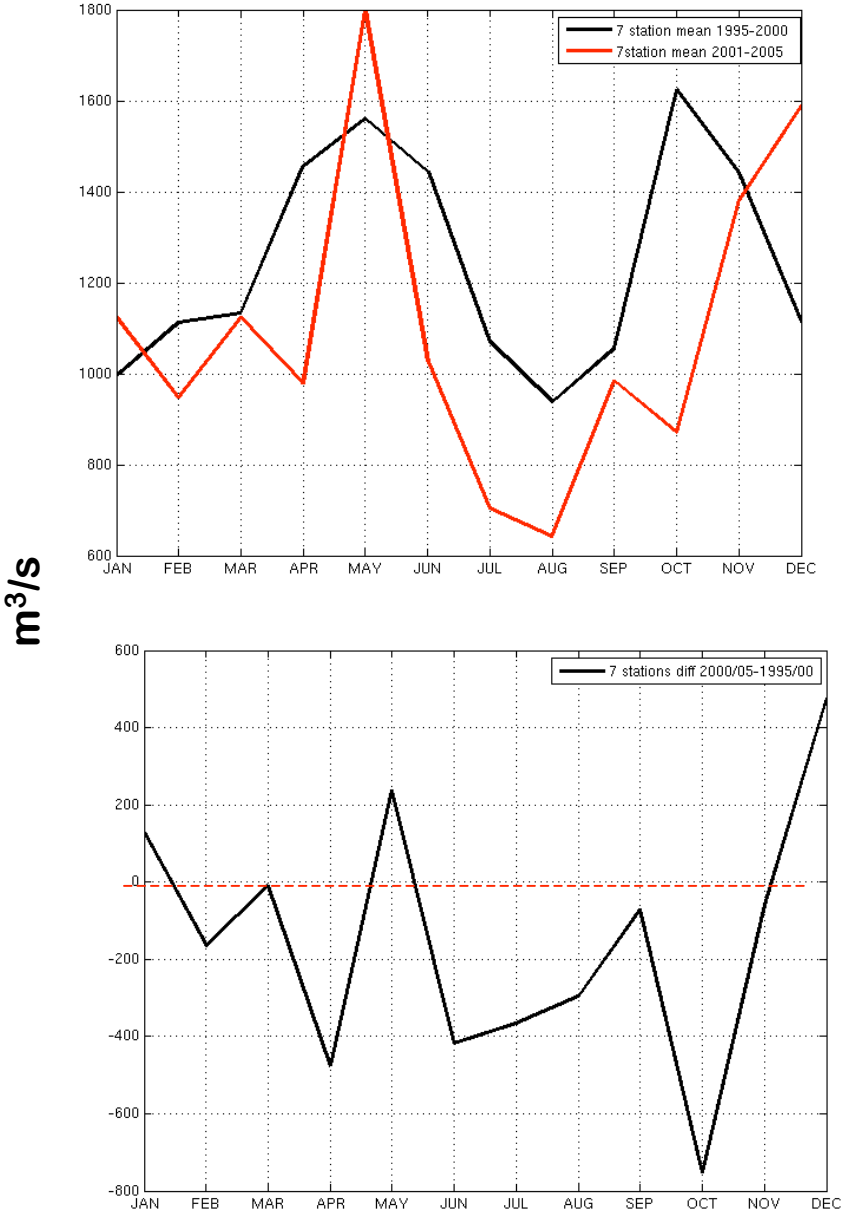


Observations





Observations



Climate change effects on the Po basin: conclusions

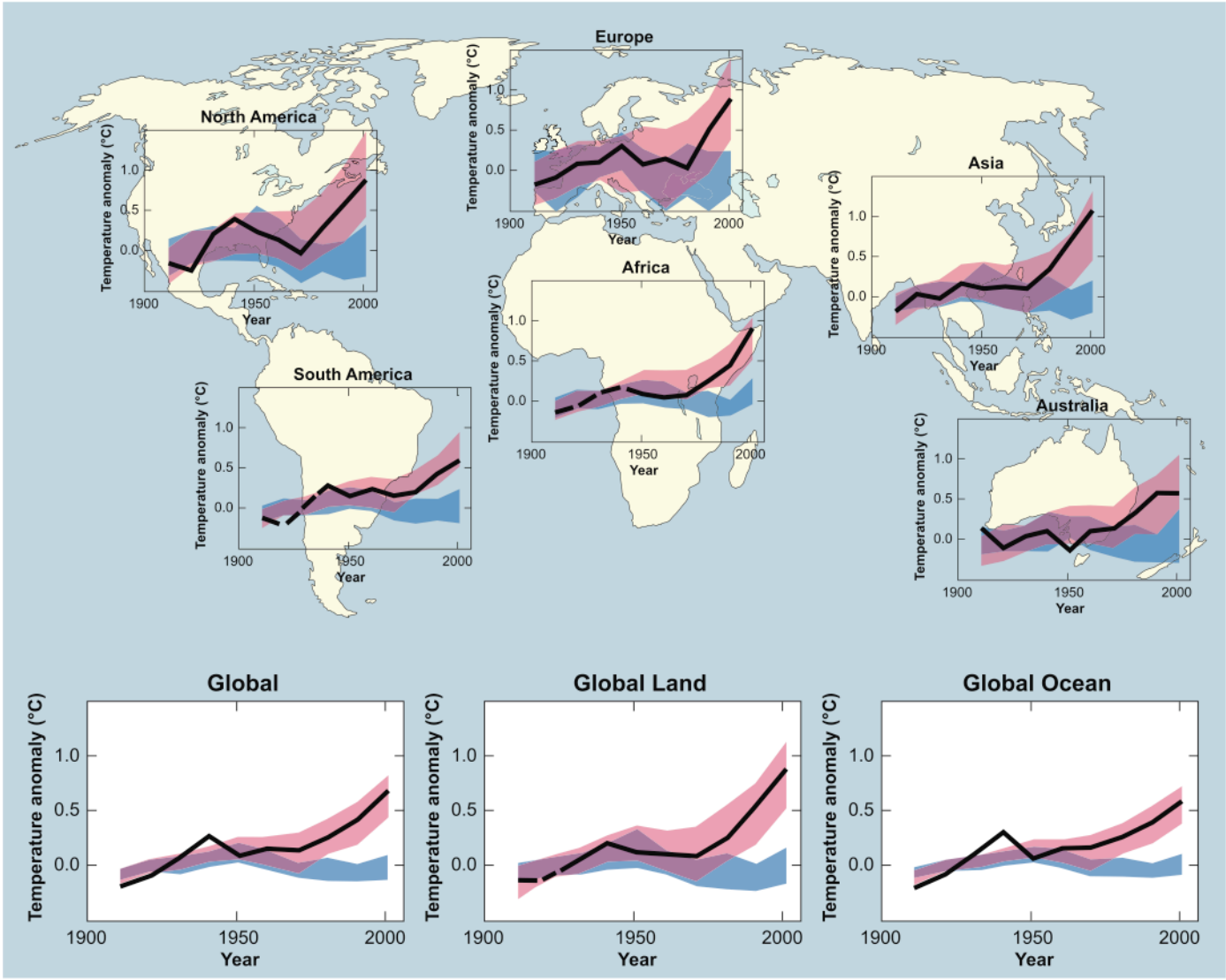
Increase in precipitation in winter-spring lead to and increase in discharge for winter and early spring for all the whole PO basin as previously found for the Danube and Rhine catchment (Hageman and Jacob, 2007, Climate Change; Graham et al., 2007)

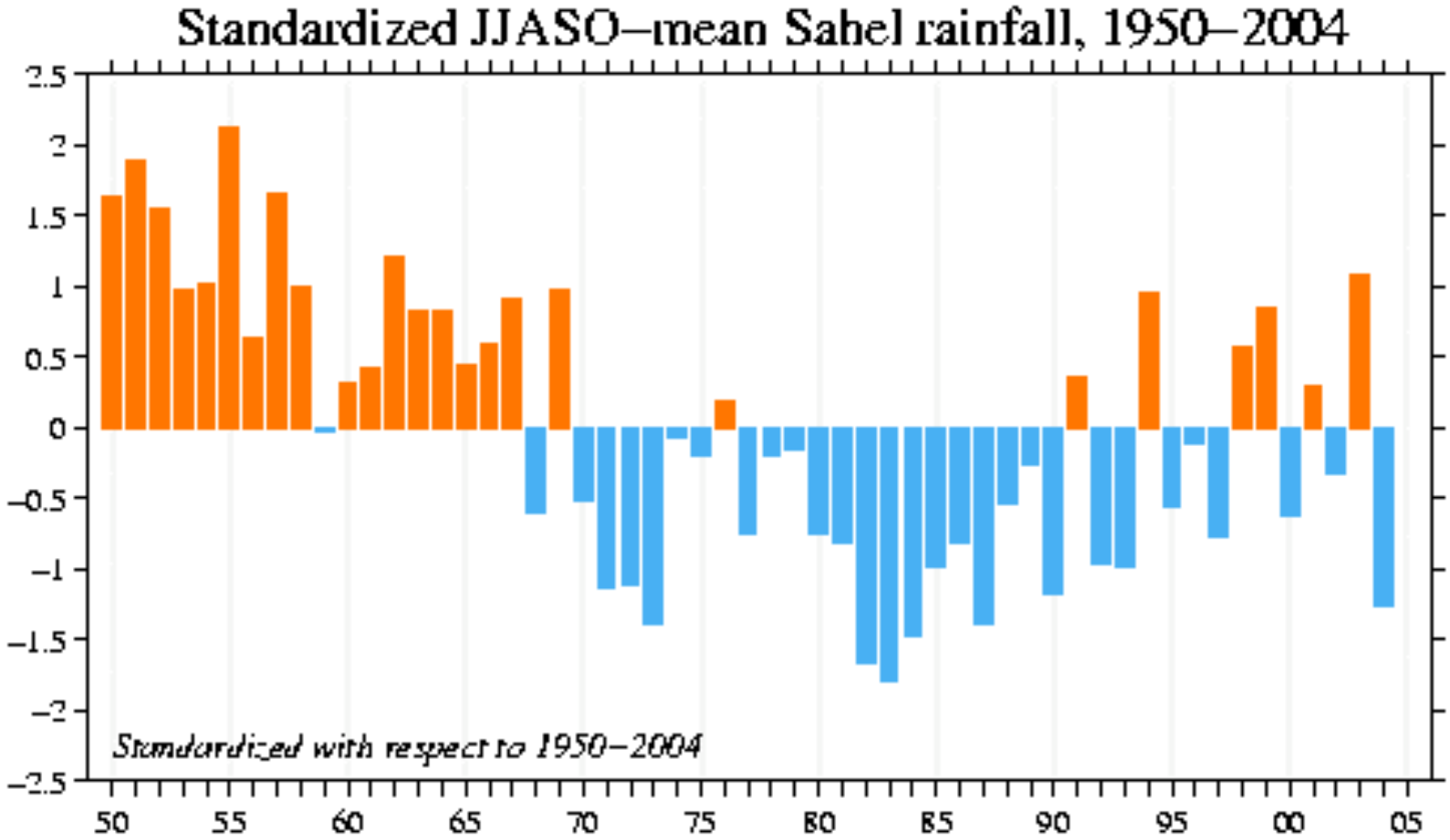
Peak spring flows occurs about one month earlier in the basin as it was also found for the Lule River Basin (Graham et al., 2007, Climate Change)

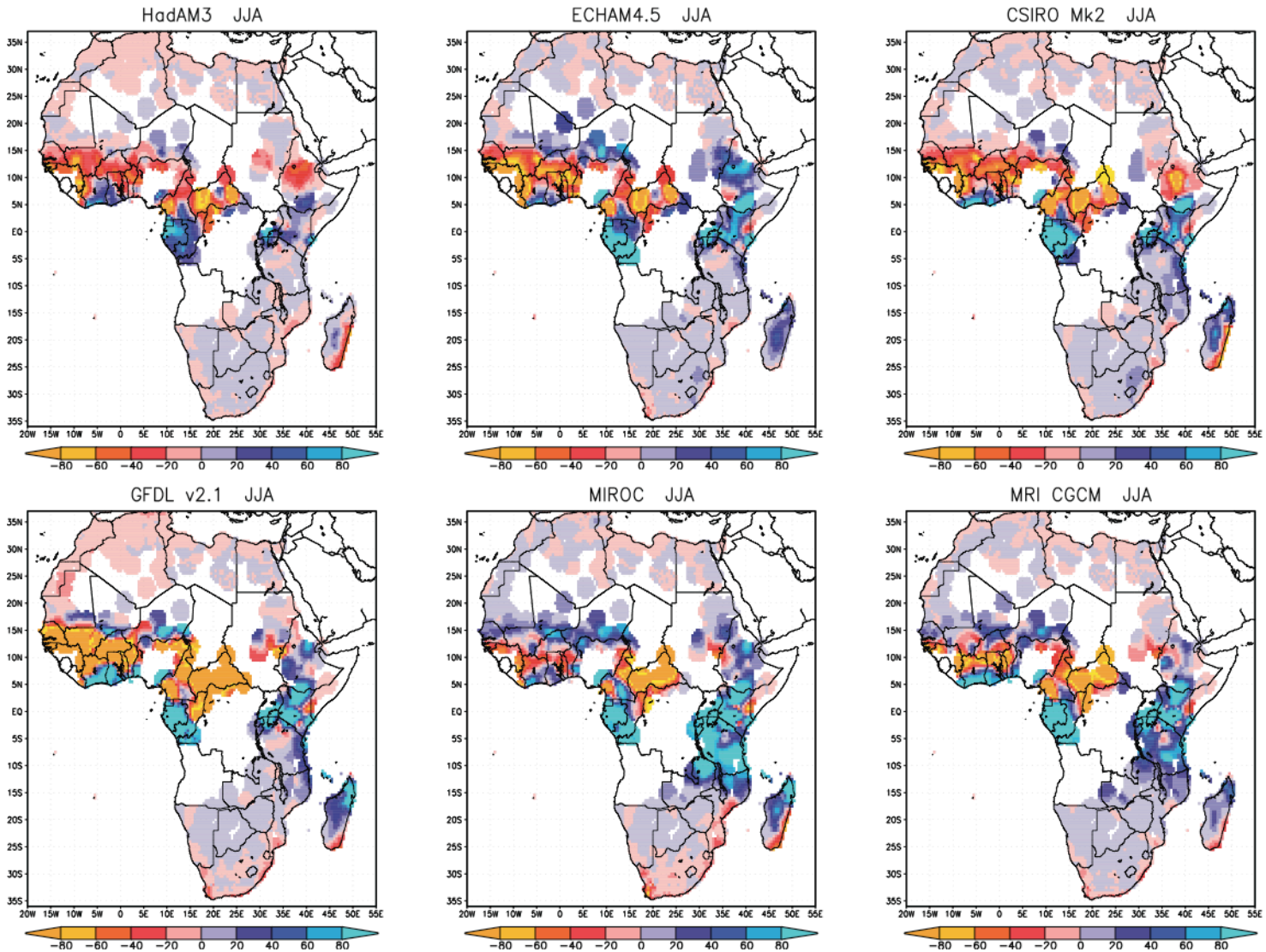
Reduction up to 70% of the basin discharge is found from May to November mainly in the upper part of the basin. An increase in the river discharge is observed in winter months.

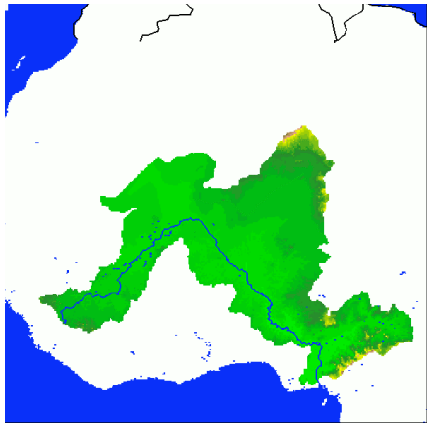
Aerosol effects on hydrological cycle

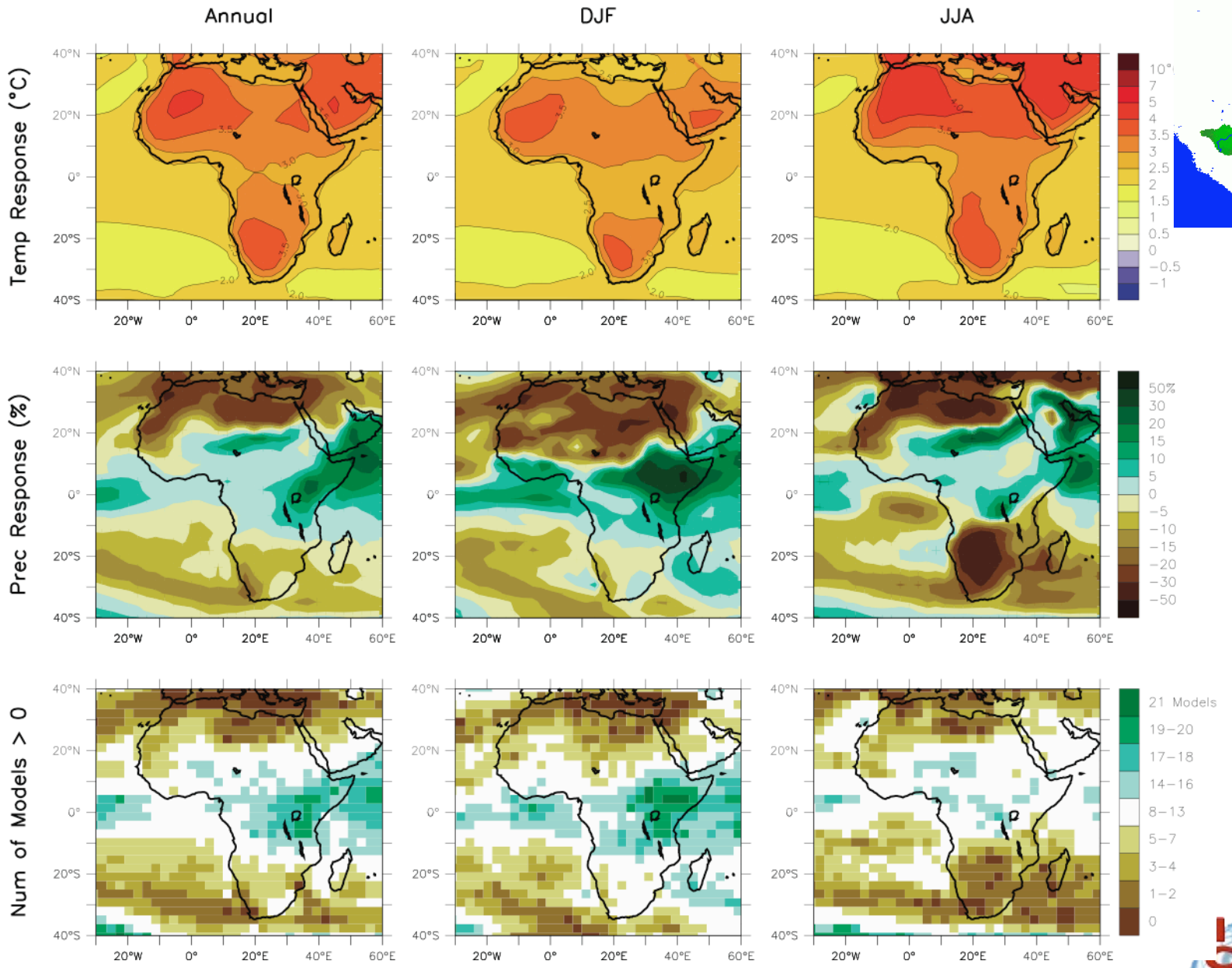
Erika Coppola, Laura Mariotti et al.

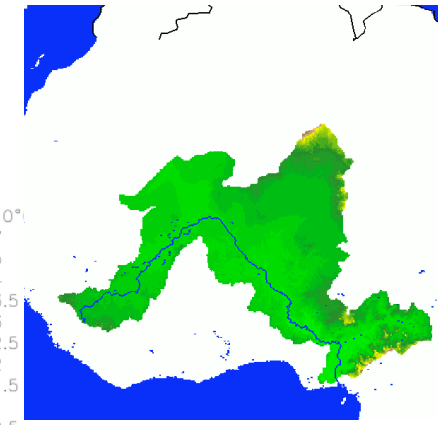



Standardized JJASO–mean Sahel rainfall, 1950–2004
2.5
2
1.5
1
0.5
0
–0.5
–1
–1.5
–2
–2.5
Standardized with respect to 1950–2004
50
55
60
65
70
75
80
85
90
95
00
05

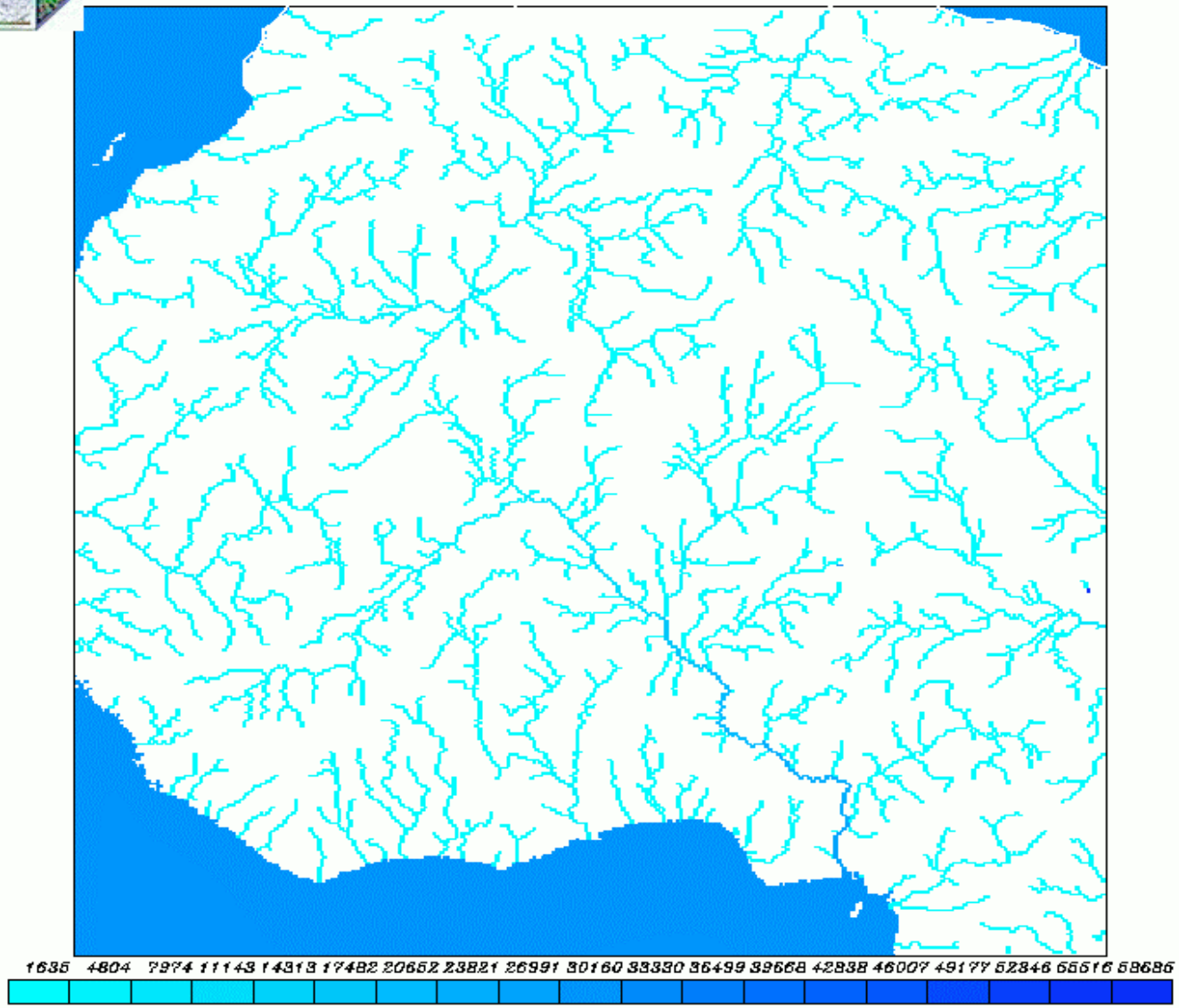

HadAM3 JJA
ECHAM4.5 JJA
CSIRO Mk2 JJA
GFDL v2.1 JJA
MIROC JJA
MRI CGCM JJA
35N 30N 25N 20N 15N 10N 5N EQ 5S 10S 15S 20S 25S 30S 35S
20W 15W 10W 5W 0 5E 10E 15E 20E 25E 30E 35E 40E 45E 50E 55E
-80 -60 -40 -20 0 20 40 60 80




Annual
DJF
JJA
Temp Response (°C)
Prec Response (%)
Num of Models > 0
40°N
20°N
0°
20°S
40°S
20°W
0°
20°E
40°E
60°E
10°
7
5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
50%
30
20
15
10
5
0
−5
−10
−15
−20
−30
−50
21 Models
19−20
17−18
14−16
8−13
5−7
3−4
1−2
0

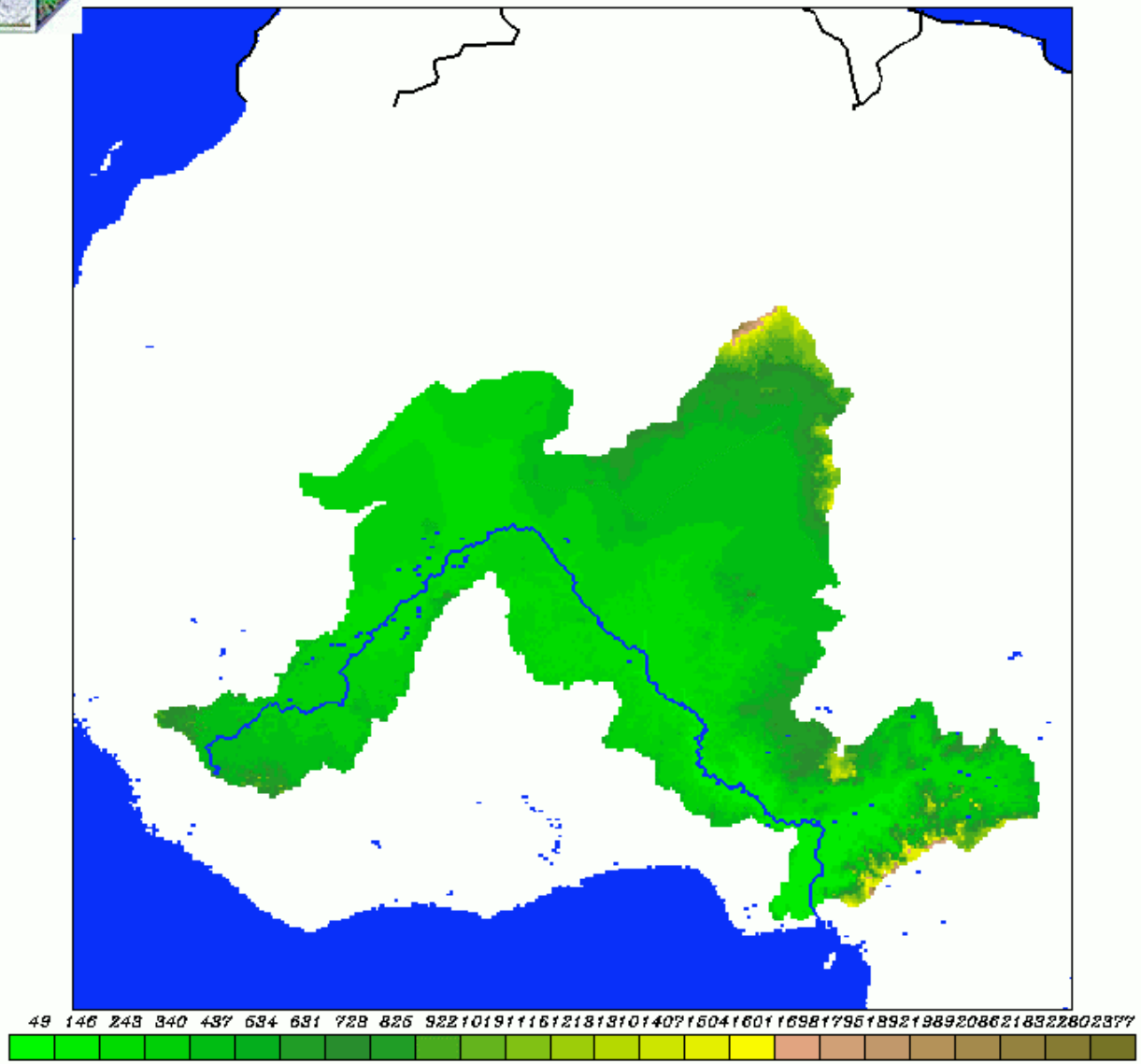


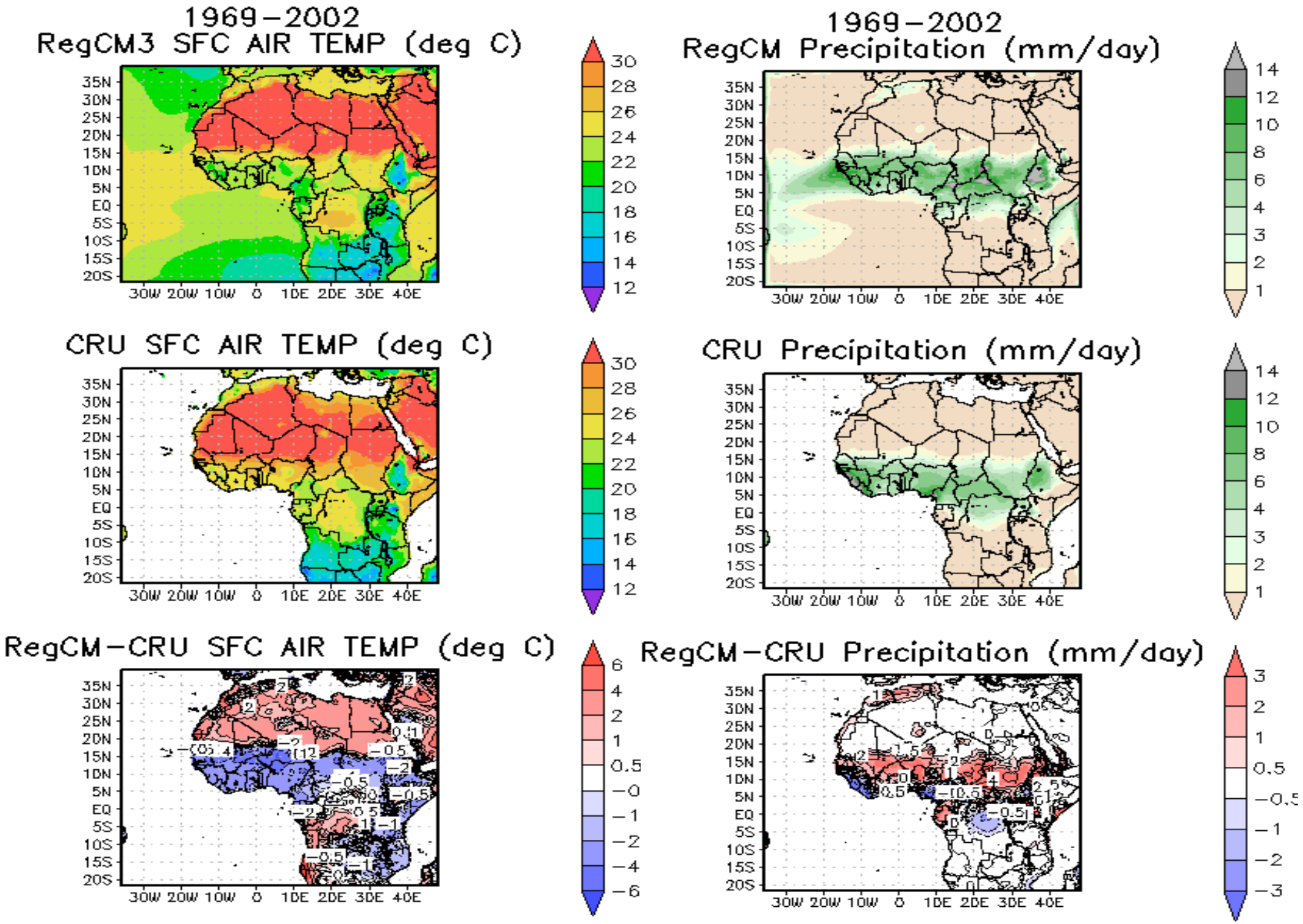
CETEMPS Hydrological Model Preprocessor



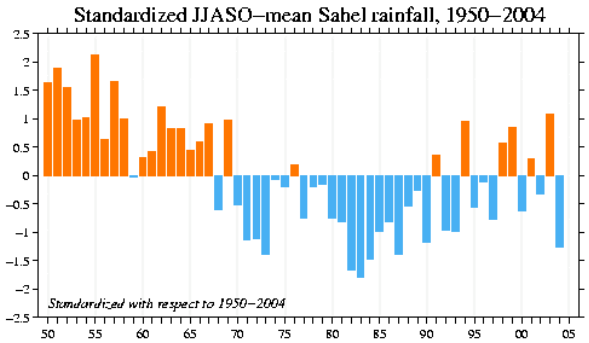
Flow Test with "The Rolling Stones" Algorithm

CHyM Graphic Lab



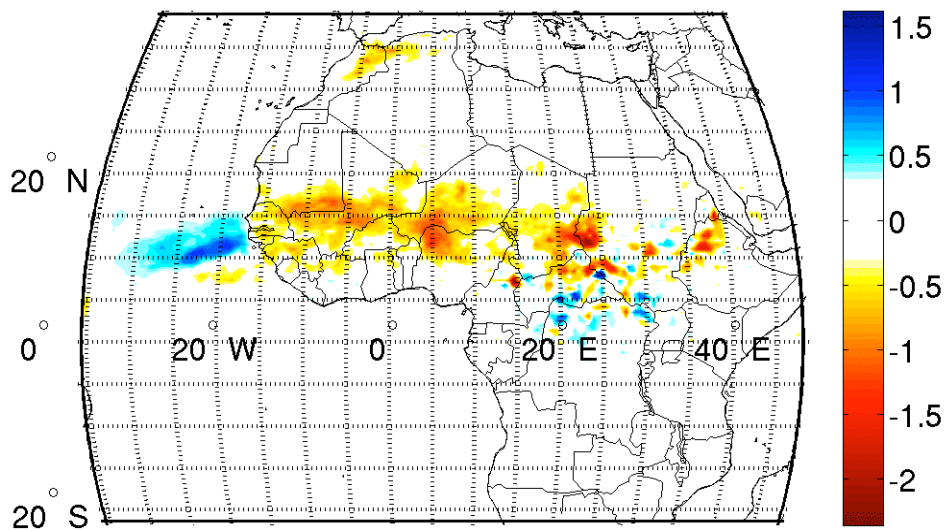


Courtesy of F. Solmon

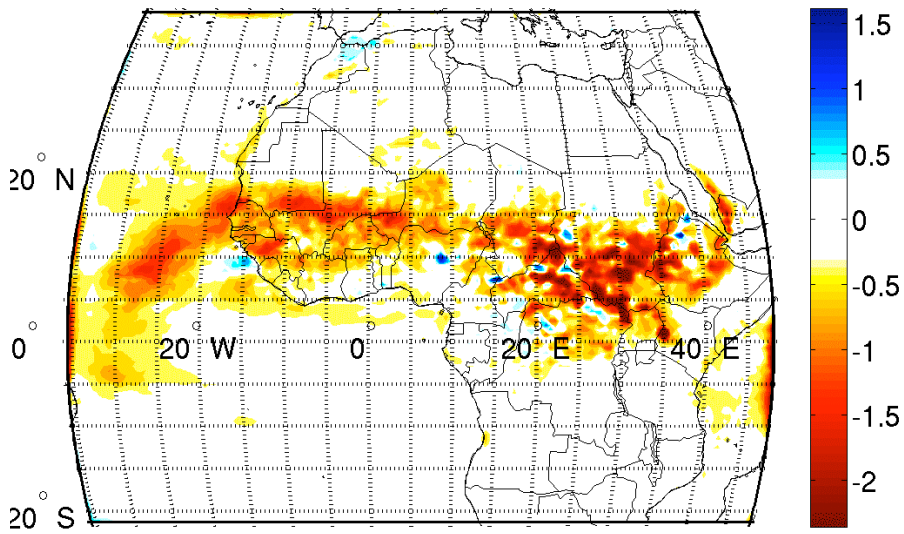


Precipitation differences 1969-2006

mm.d-1



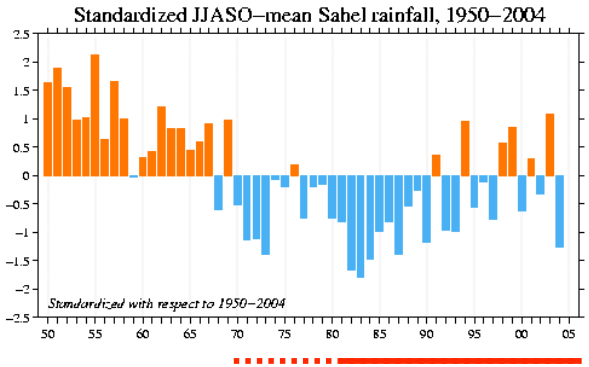
DUST - NODUST



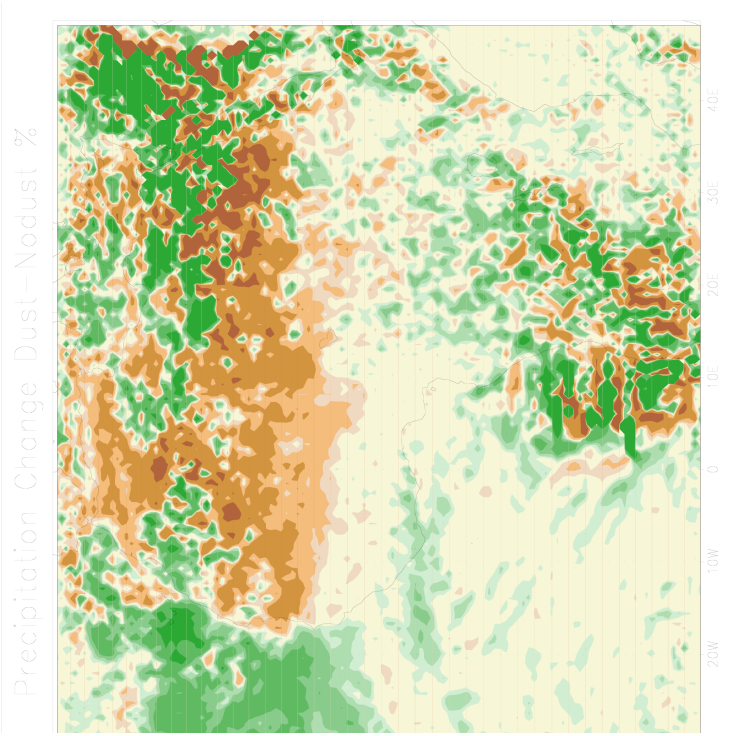
DRY _ WET Years

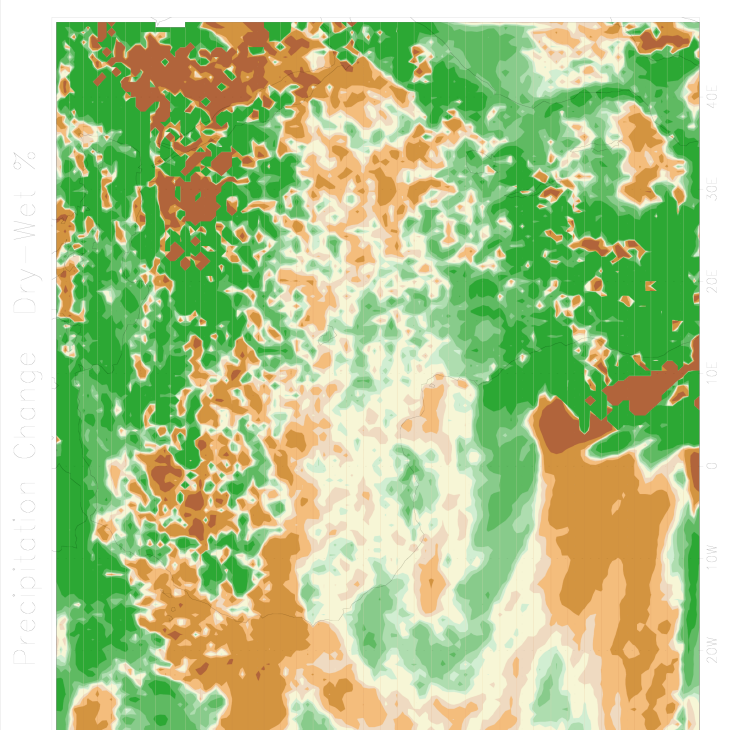
Based on WMO standardized mean Sahel rainfall

Courtesy of F. Solmon

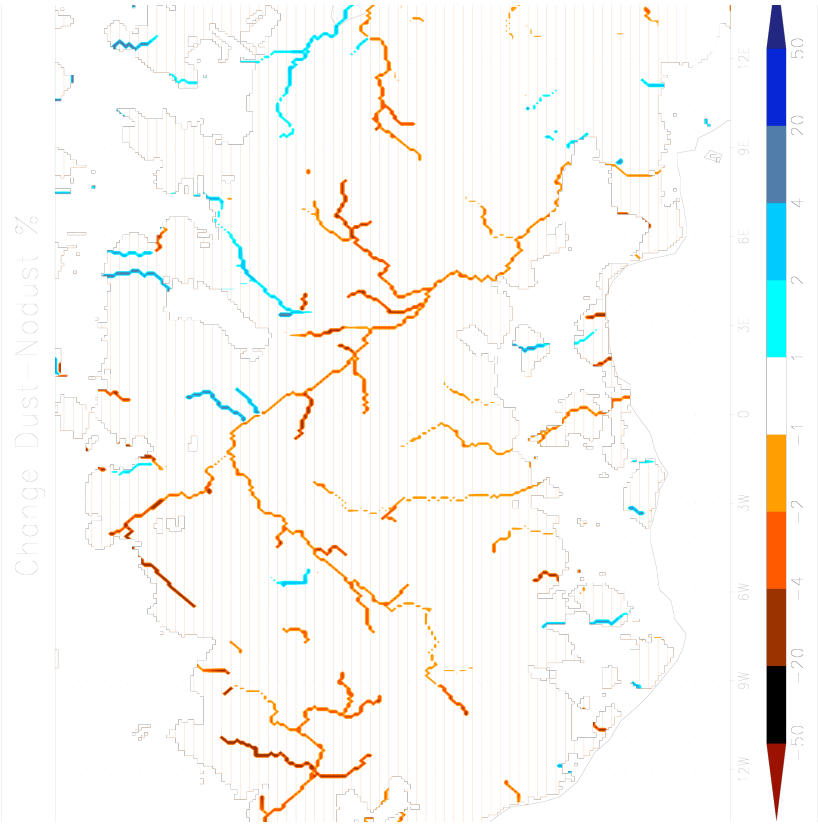


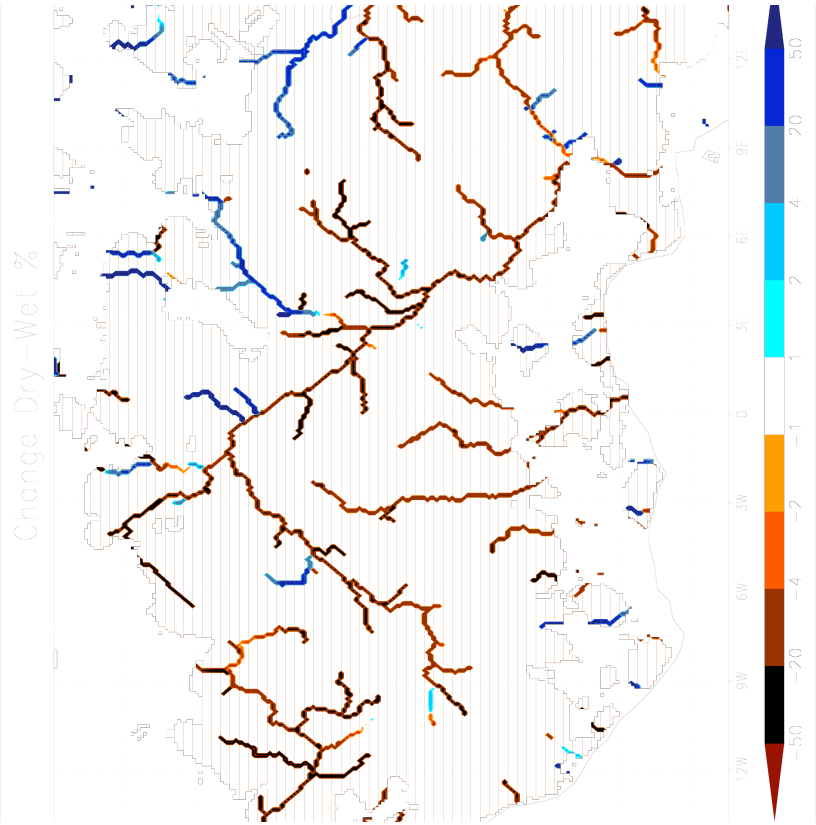
Precipitation differences % (1982-2006)

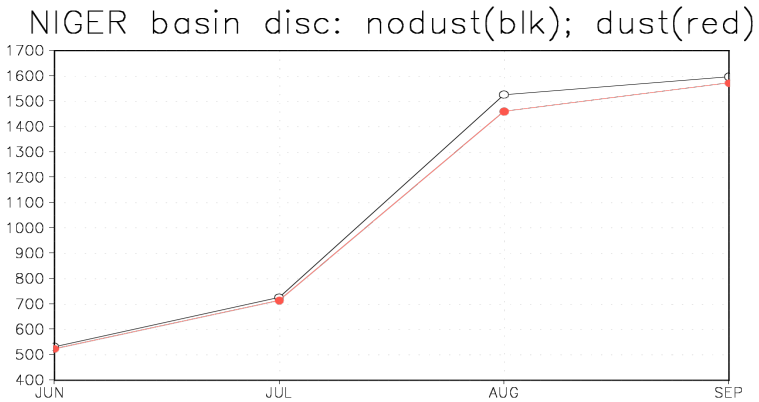


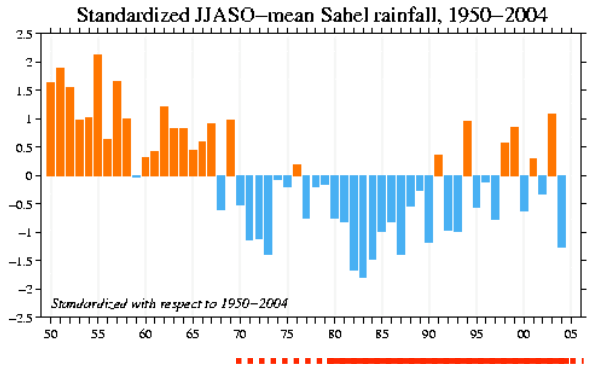


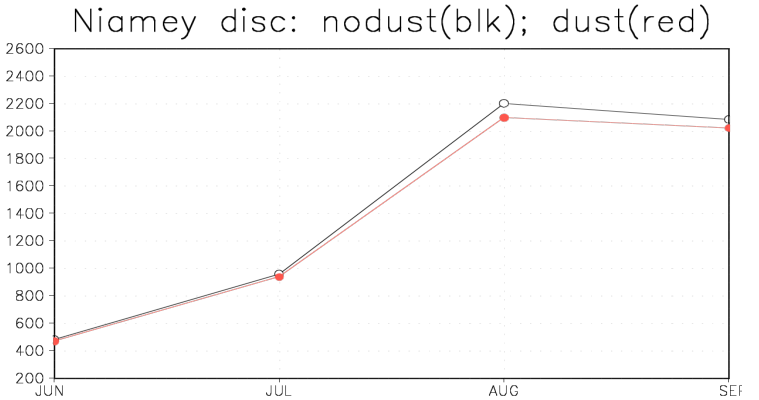
Discharge differences

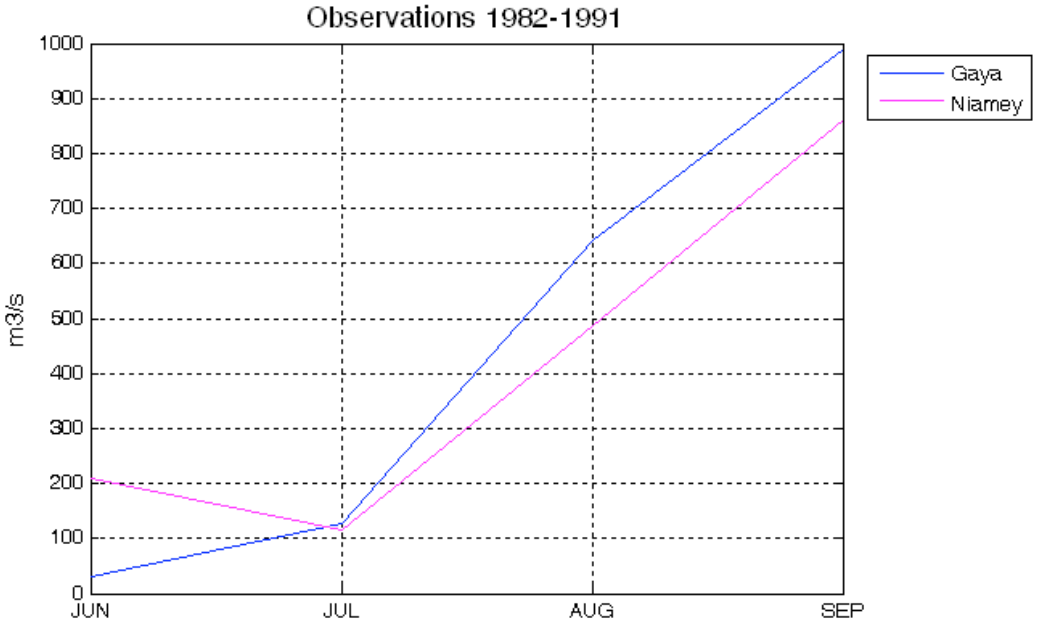


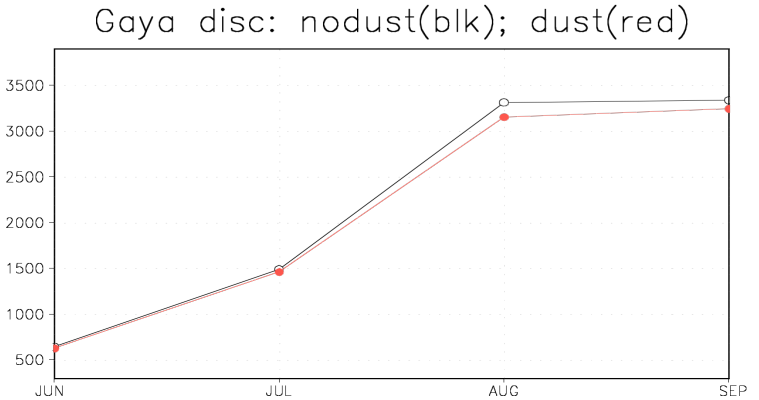


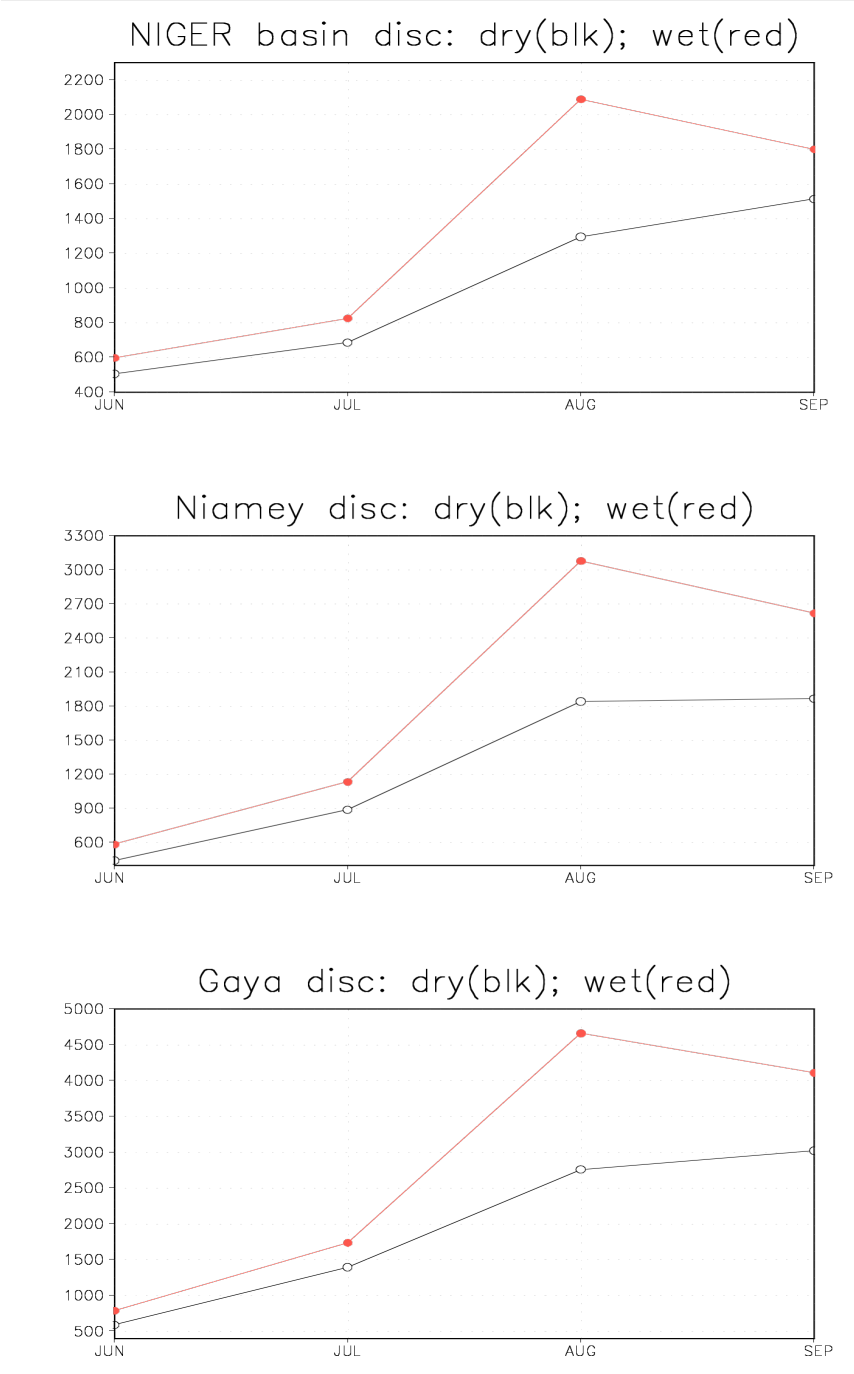

NIGER basin disc: nodust(blk); dust(red)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
JUN
JUL
AUG
SEP

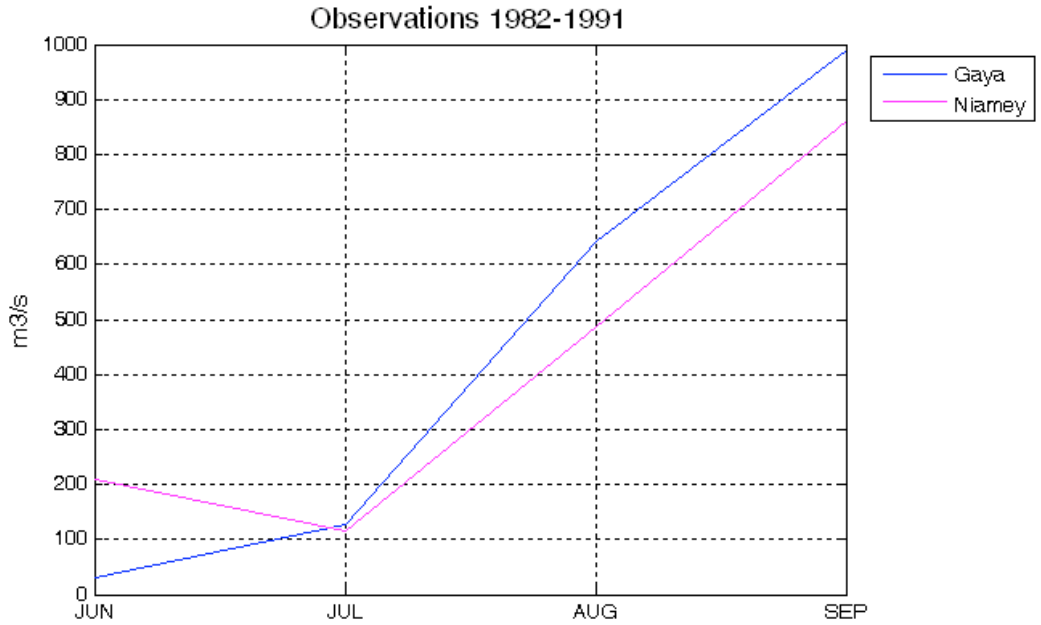

Standardized JJASO–mean Sahel rainfall, 1950–2004
2.5
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
Standardized with respect to 1950–2004
50
55
60
65
70
75
80
85
90
95
00
05


Niamey disc: nodust(blk); dust(red)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
JUN
JUL
AUG
SEP


Observations 1982-1991
m3/s
1000
900
800
700
600
500
400
300
200
100
0
JUN
JUL
AUG
SEP
Gaya
Niamey


Gaya disc: nodust(blk); dust(red)
3500
3000
2500
2000
1500
1000
500
JUN
JUL
AUG
SEP


NIGER basin disc: dry(blk); wet(red)
2200
2000
1800
1600
1400
1200
1000
800
600
400
JUN
JUL
AUG
SEP
Niamey disc: dry(blk); wet(red)
3300
3000
2700
2400
2100
1800
1500
1200
900
600
JUN
JUL
AUG
SEP
Gaya disc: dry(blk); wet(red)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
JUN
JUL
AUG
SEP


Observations 1982-1991
m3/s
1000
900
800
700
600
500
400
300
200
100
0
JUN
JUL
AUG
SEP
Gaya
Niamey

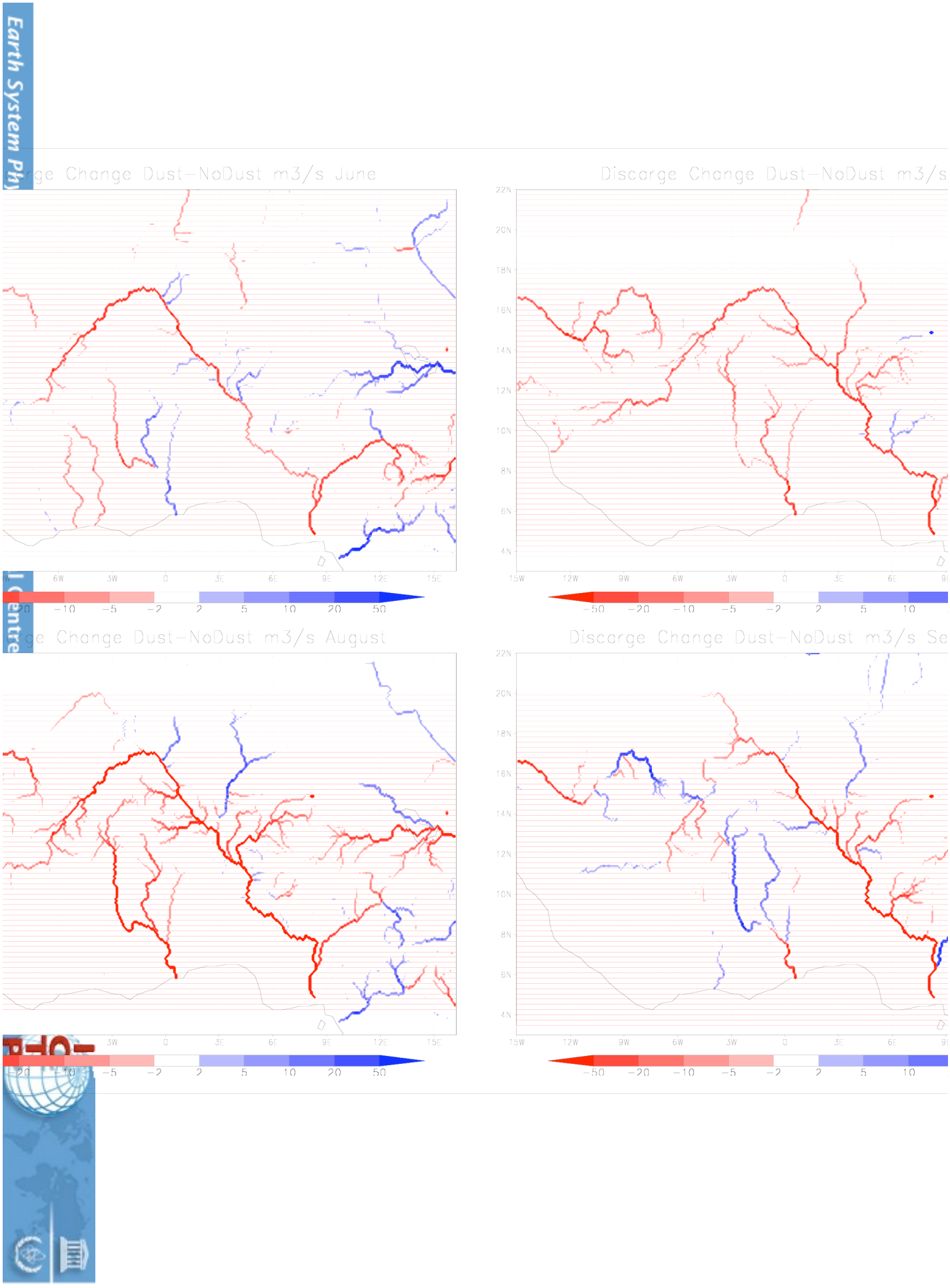
Very preliminary conclusion on dust effects on the Niger basin runoff

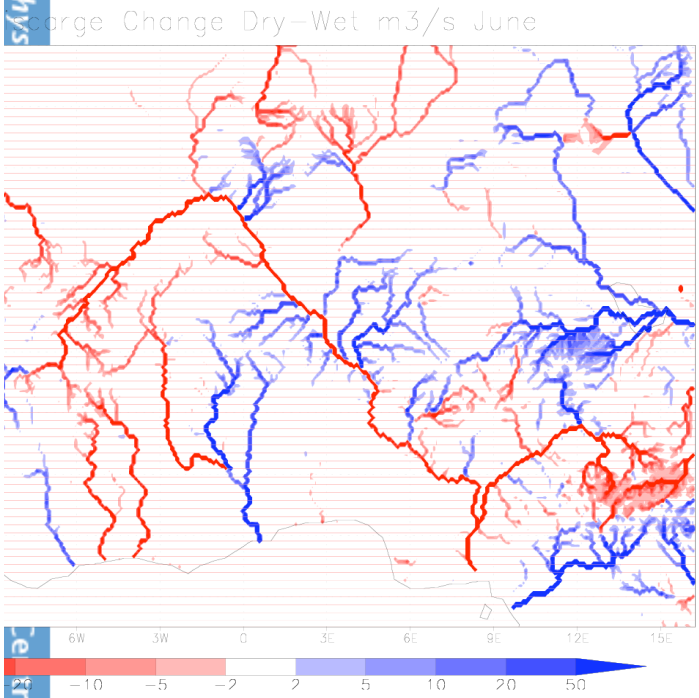
The Niger discharge shows a decrease of runoff up to 15 % although only a 5% of decrease is observed in Precipitation

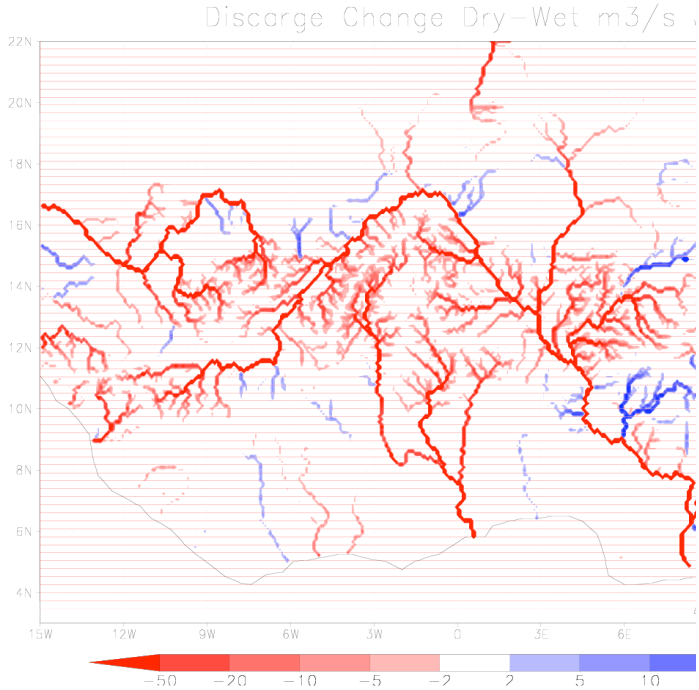
This reduction is found as well if we compute the difference between dry-wet events runoff, although this difference is bigger.

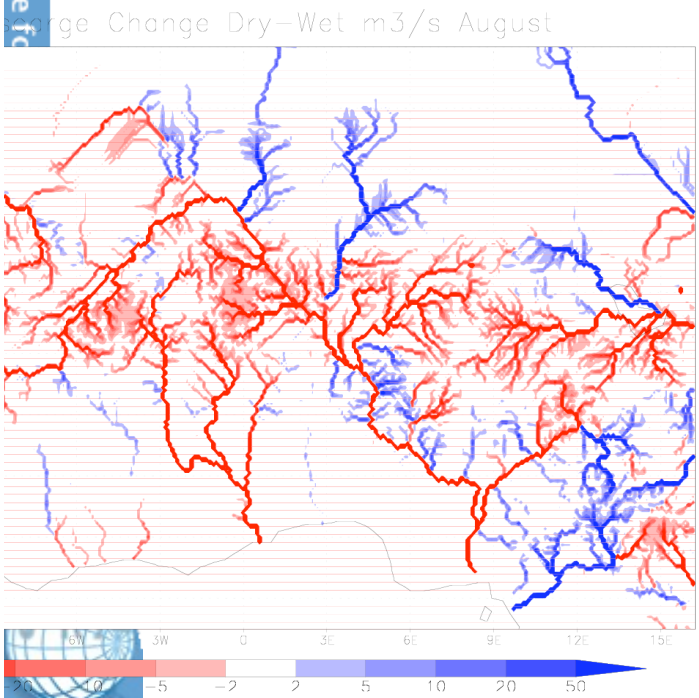
The drying of the basin strength the hypothesis of positive feedback related to dust radiative forcing in the maintenance of dry period over the west African basins as suggested by Konare et al. (2008)
(A regional climate modeling study of the effect of desert dust on the West African monsoon, JJR, accepted)

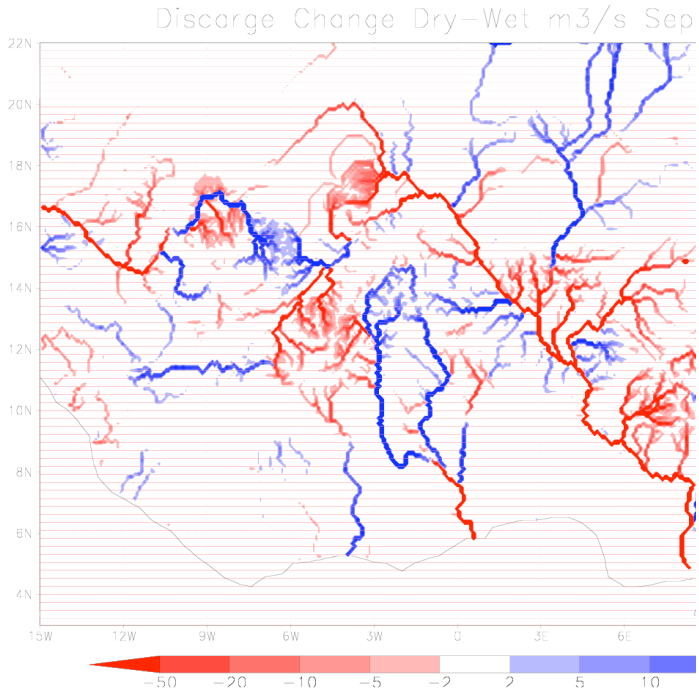
Thanks

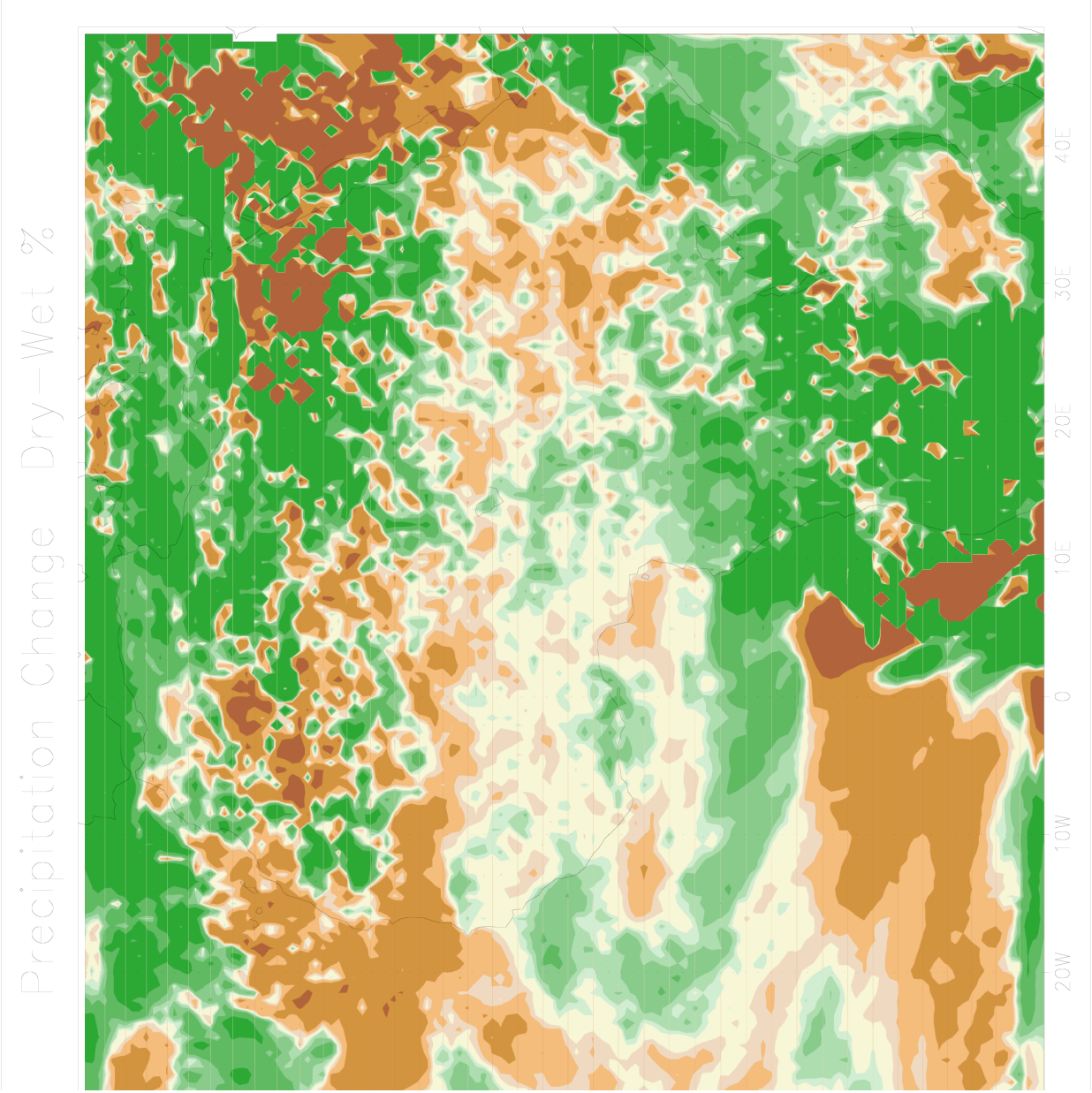

Discarge Change Dust–NoDust m3/s June
Discarge Change Dust–NoDust m3/s
Discarge Change Dust–NoDust m3/s August
Discarge Change Dust–NoDust m3/s Se
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
15W
12W
9W
6W
3W
0
3E
6E
9E
12E
15E
−50
−20
−10
−5
−2
2
5
10
20
50

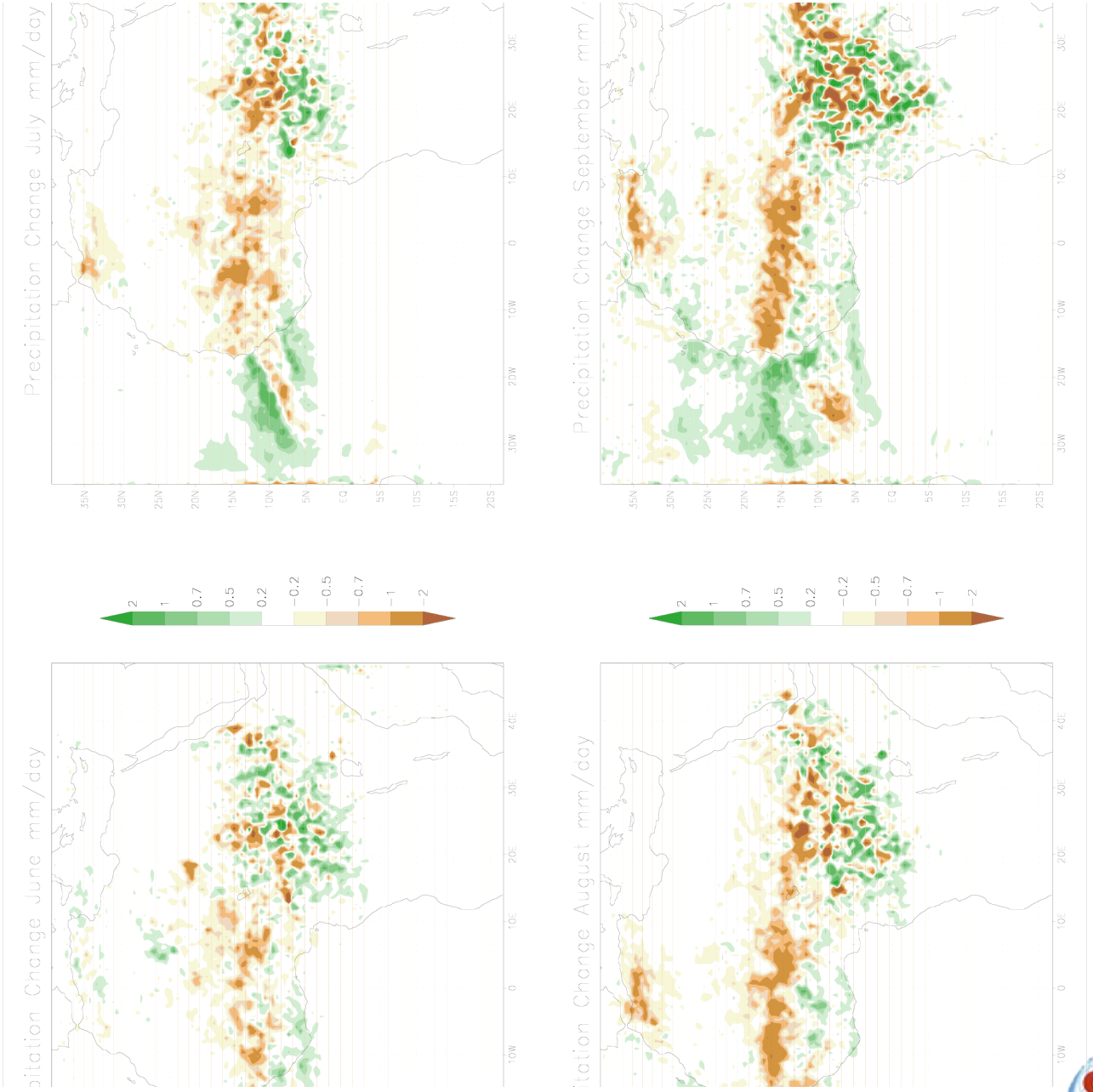

Discarge Change Dry–Wet m3/s June
6W 3W 0 3E 6E 9E 12E 15E
20 −10 −5 −2 2 5 10 20 50

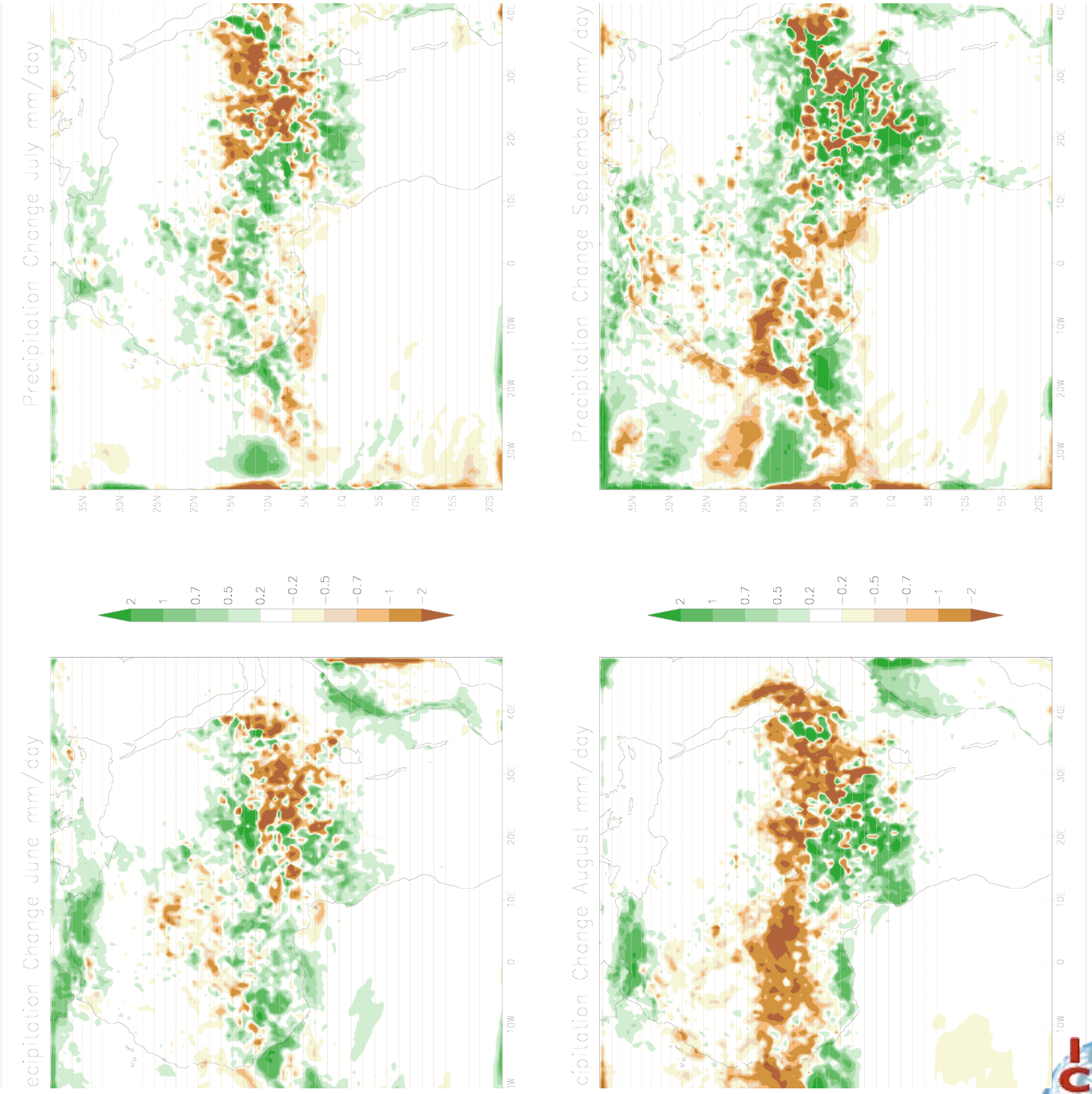

Discarge Change Dry–Wet m3/s
22N 20N 18N 16N 14N 12N 10N 8N 6N 4N
15W 12W 9W 6W 3W 0 3E 6E
−50 −20 −10 −5 −2 2 5 10


Discarge Change Dry–Wet m3/s August
6W 3W 0 3E 6E 9E 12E 15E
20 −10 −5 −2 2 5 10 20 50


Discarge Change Dry–Wet m3/s Sep
22N 20N 18N 16N 14N 12N 10N 8N 6N 4N
15W 12W 9W 6W 3W 0 3E 6E
−50 −20 −10 −5 −2 2 5 10


Precipitation Change Dry–Wet %
20W
10W
0
10E
20E
30E
40E


Precipitation Change July mm/day
Precipitation Change September mm/
pitation Change June mm/day
itation Change August mm/day
2
1
0.7
0.5
0.2
−0.2
−0.5
−0.7
−1
−2
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
30W
20W
10W
0
10E
20E
30E
40E


Precipitation Change July mm/day
Precipitation Change September mm/day
ecipitation Change June mm/day
cipitation Change August mm/day
2
1
0.7
0.5
0.2
−0.2
−0.5
−0.7
−1
−2
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
30W
20W
10W
0
10E
20E
30E
40E