The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2210-8

MedCLIVAR Workshop on: "Scenarios of Mediterranean Climate Change under Increased Radiative Active Gas Concentration and the Role of Aerosols

23 - 25 September 2010

Cyclone intensity changes and risk of tropical cyclone development over the Mediterranean Sea in climate change scenario simulations

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Cyclone intensity changes and risk of tropical cyclone development over the Mediterranean Sea in climate change scenario simulations

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UCLM

Aims of the study

Analyse changes in extremes of cyclone intensity associated to climate change

Analyse reasons of intensity changes: is it possible that tropical cyclones develop over the Mediterranean Sea under future climate change conditions?

Why should this risk be taken into account?

- There is a physical mechanism supporting tropical cyclone development over such high latitudes:

TROPICAL TRANSITION

Baroclinic cut-off lows → Tropical cyclones

- Partially tropical cyclones have been already observed over the Mediterranean ("*medicanes*")

- Observed hurricanes can develop at high latitudes over relatively cool waters: Hurricane Vince (2005) developed near Madeira Islands (SST: 24ºC)

Data

- Three different ensembles of RCM simulations:

  - **PRUDENCE** European project: **multi-model ensemble** of **9 regional climate models** (horizontal resolution: 50 km)

  - **AMAVEC** Spanish project: **mixed-physics ensemble** of **6 simulations** with PROMES regional climate model (horiz. res.: 50 km)

  - **ENSEMBLES** European project: **multi-model ensemble** of **17 RCM simulations** (horiz. res.: 25 km)

Analysis with PRUDENCE data

- **Two 30-year time-slice** simulations: control run (1961-1990, CTRL) and A2 scenario run (2071-2100, SCEN)

- **Analysis focused on September**, because:

  - SSTs are near their highest annual value

  - Summer subsidence over the Mediterranean Sea is weakening

- Cyclone detection method:

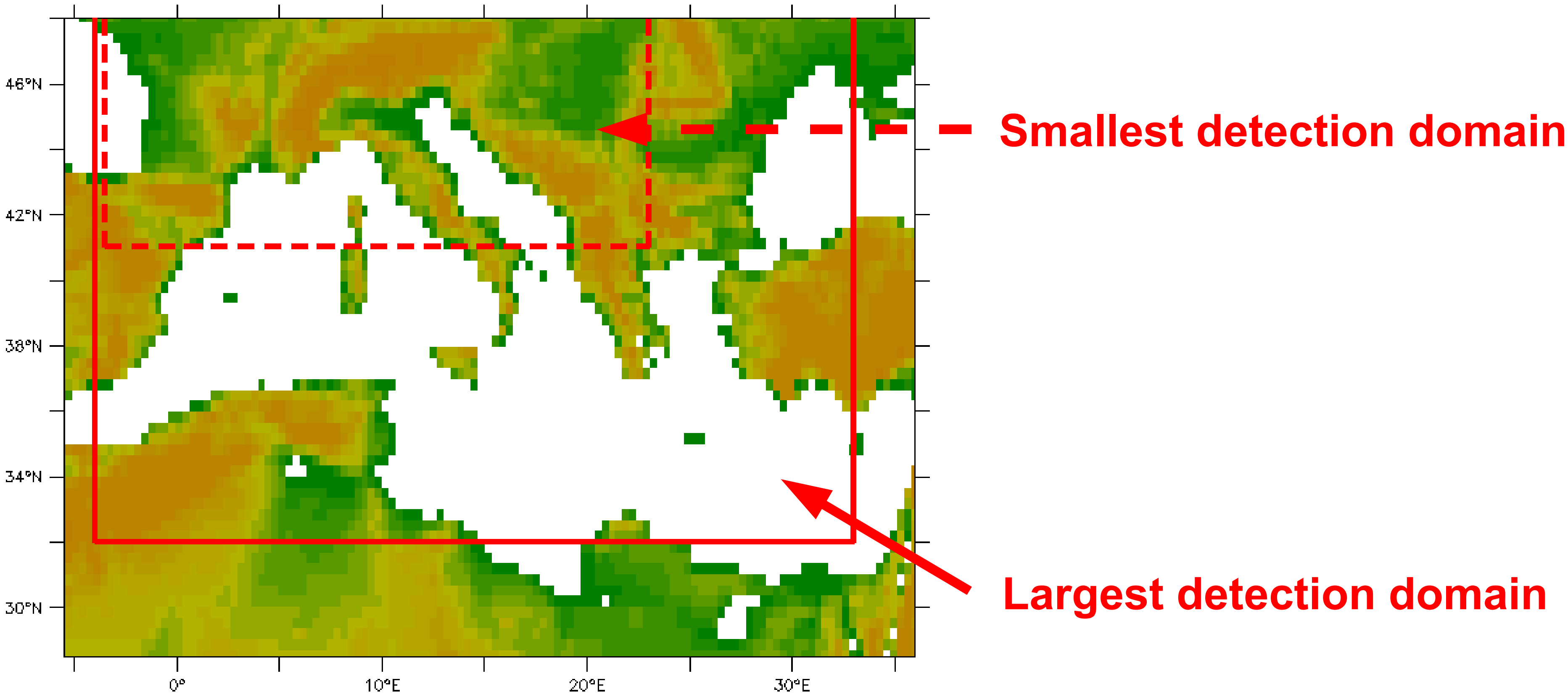
  - Objective cyclone detection method (*Picornell et al.*, 2001)

  - Cyclone intensity: geostrophic vorticity at low center (surface level pressure)

Analysis with PRUDENCE data

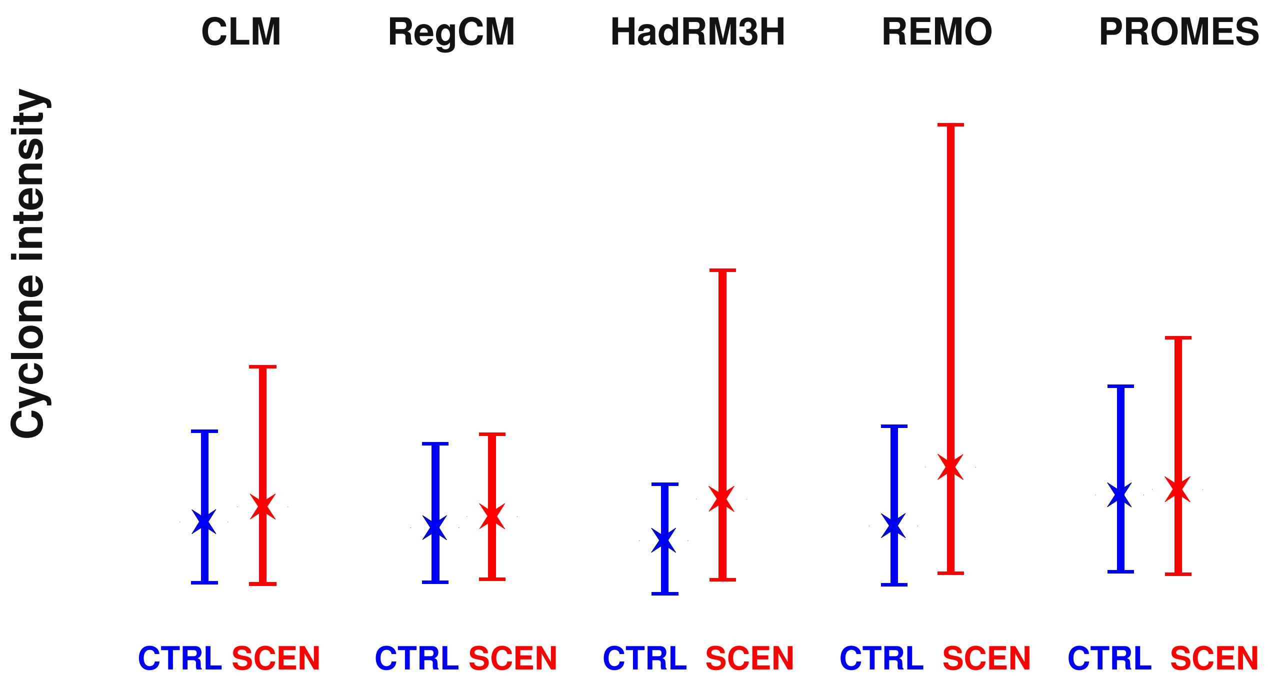
- Limitation of the cyclone detection method for PRUDENCE DATA

- Radius of 400 km around SLP minimum → cyclone detection area is smaller than model domain (some cyclones missed)



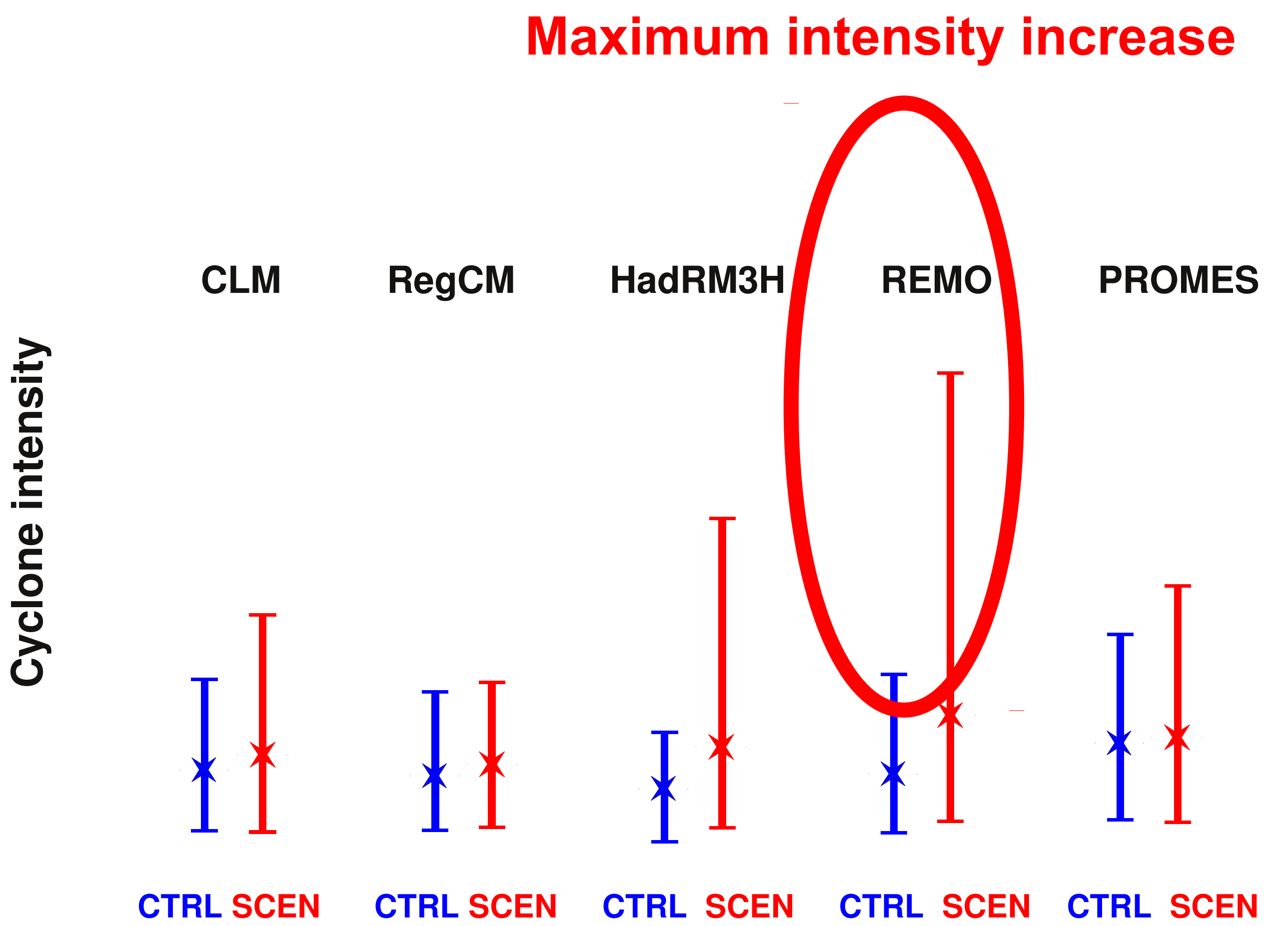
Change of cyclone intensity

- Analysis focused on 5 models with large detection area



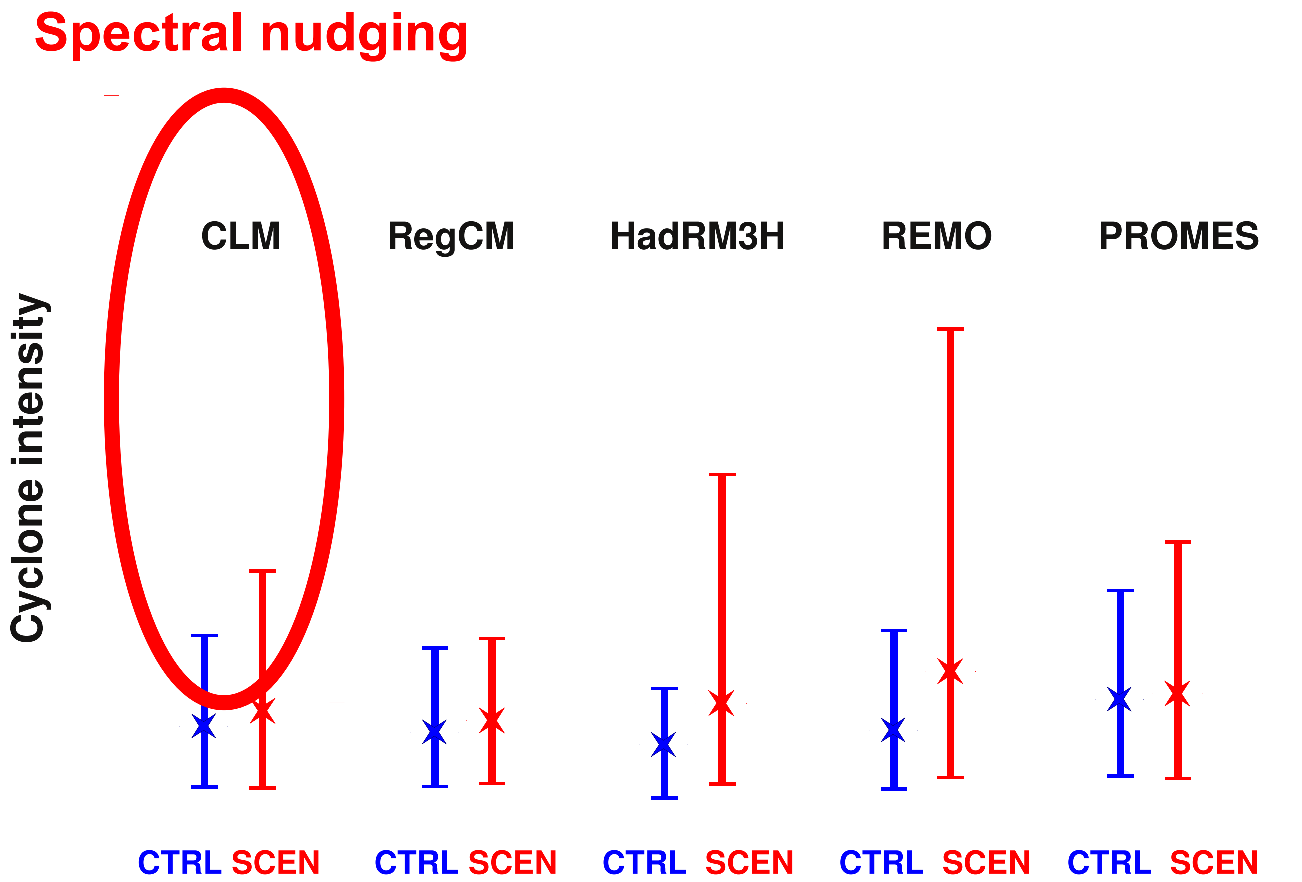
Limits of bars: 5th and 95th percentiles of cyclone intensity

Change of cyclone intensity



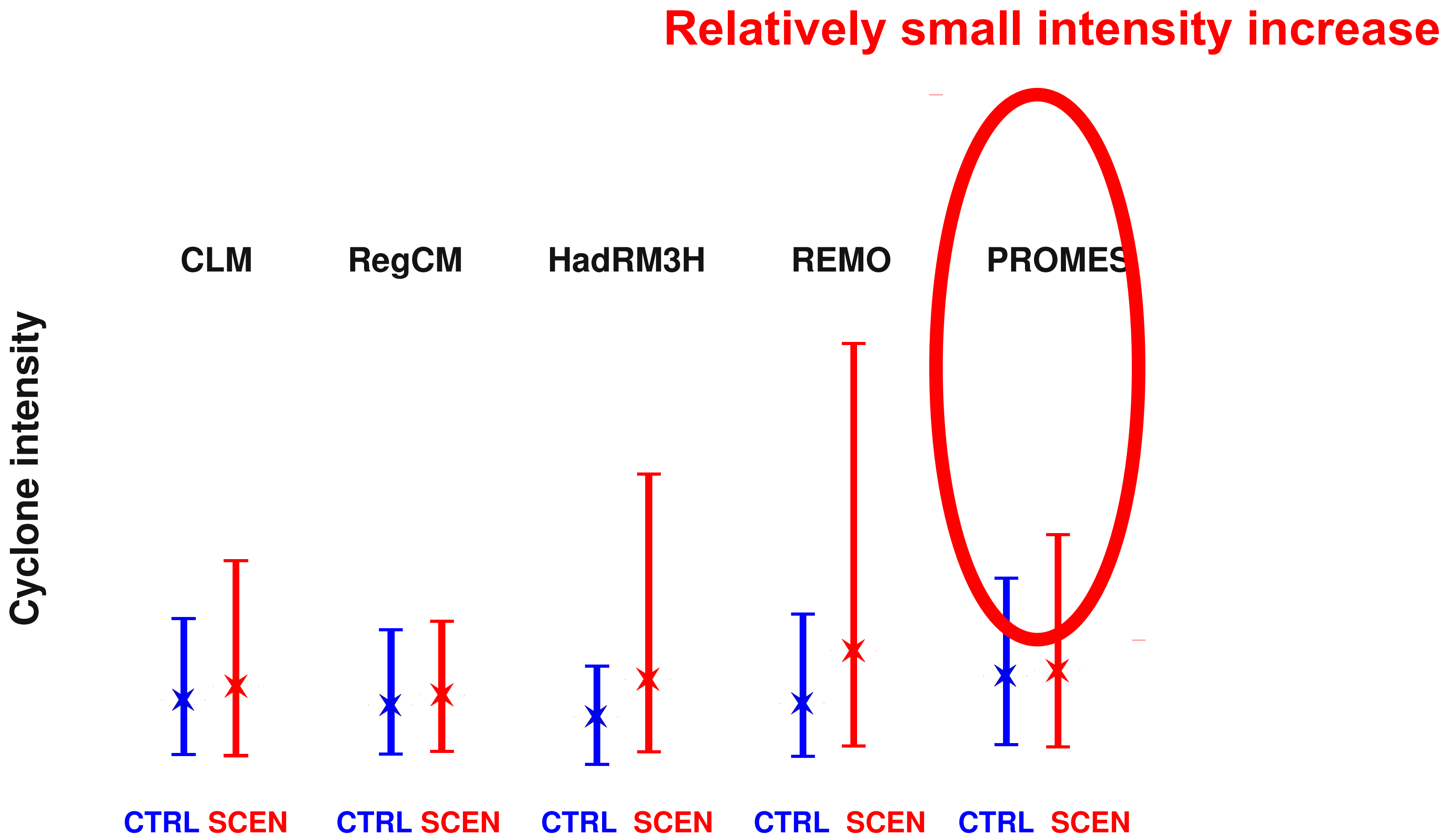
Limits of bars: 5th and 95th percentiles of cyclone intensity

Change of cyclone intensity



Limits of bars: 5th and 95th percentiles of cyclone intensity

Change of cyclone intensity



Limits of bars: 5th and 95th percentiles of cyclone intensity

Reason for the increase in extreme intensity of cyclones?

↓

Vertical structure - Cyclone phase space analysis (Hart, 2003)

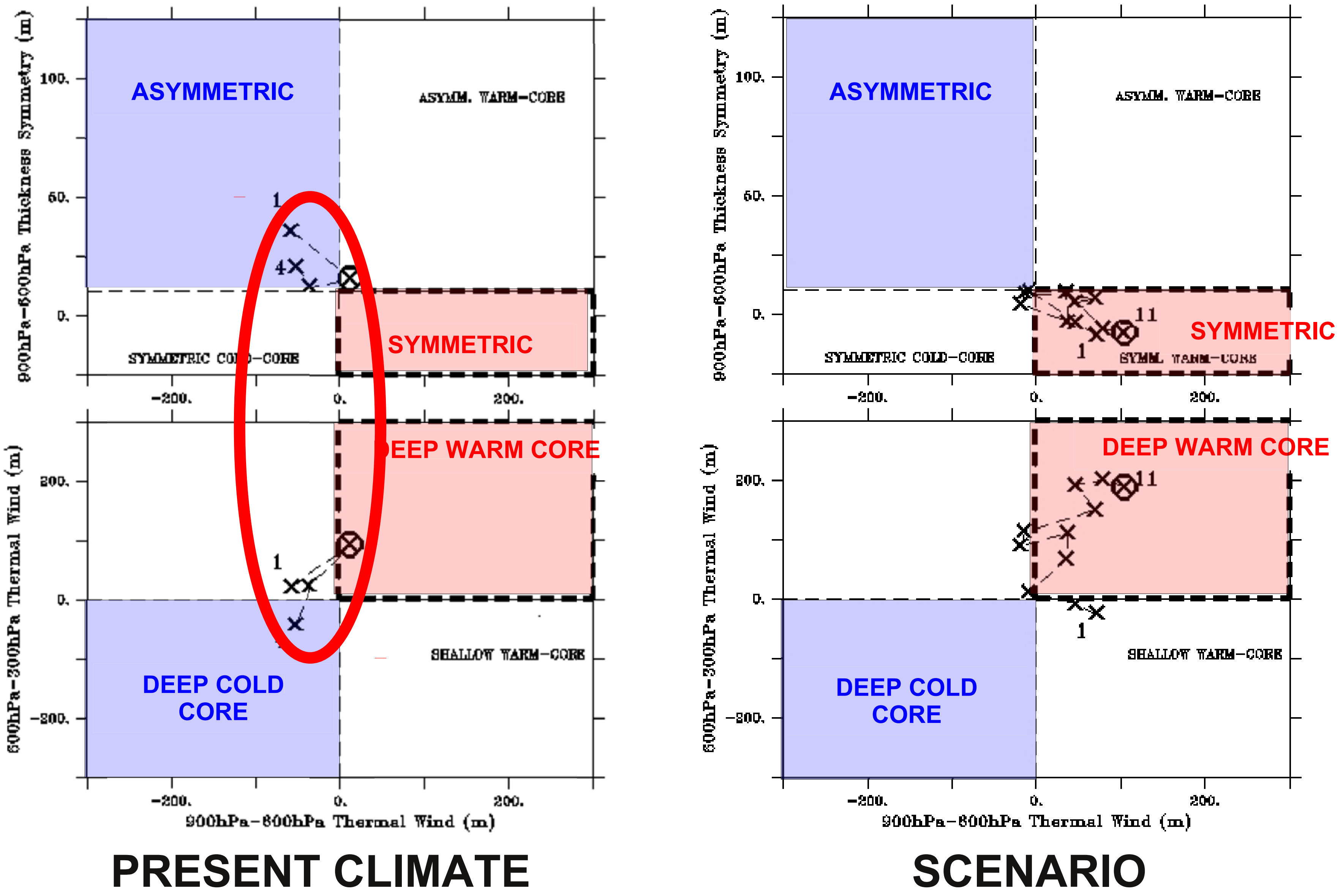
3 PARAMETERS:

- **Thermal symmetry (frontal/non-frontal structure)**
- **Lower troposphere thermal wind (cold/warm core)**
- **Upper troposphere thermal wind (cold/warm core)**

Tropical cyclones are thermally symmetric lows with a full-tropospheric warm core

Vertical structure - Cyclone phase space analysis

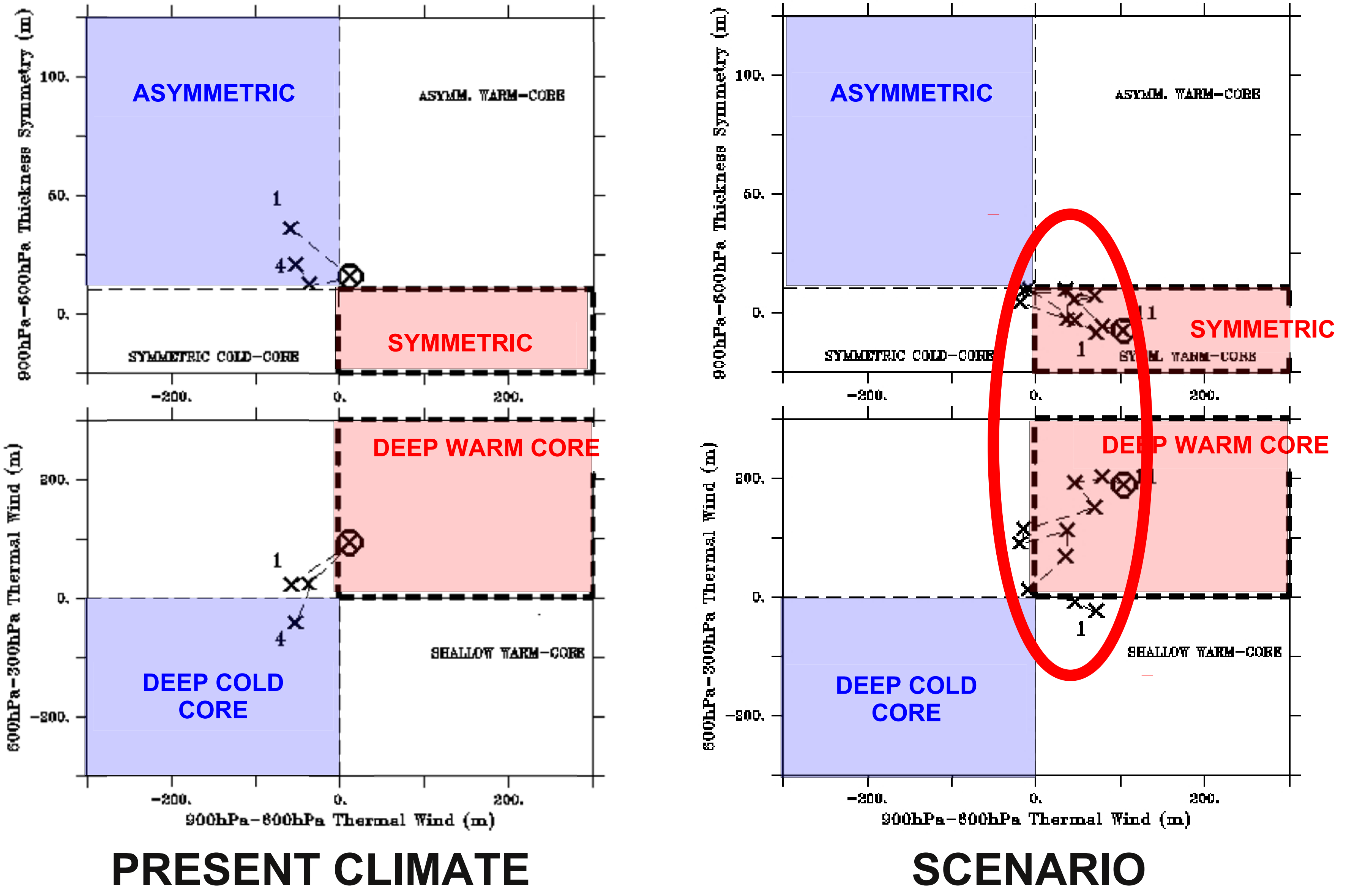
Most intense cyclones (REMO)



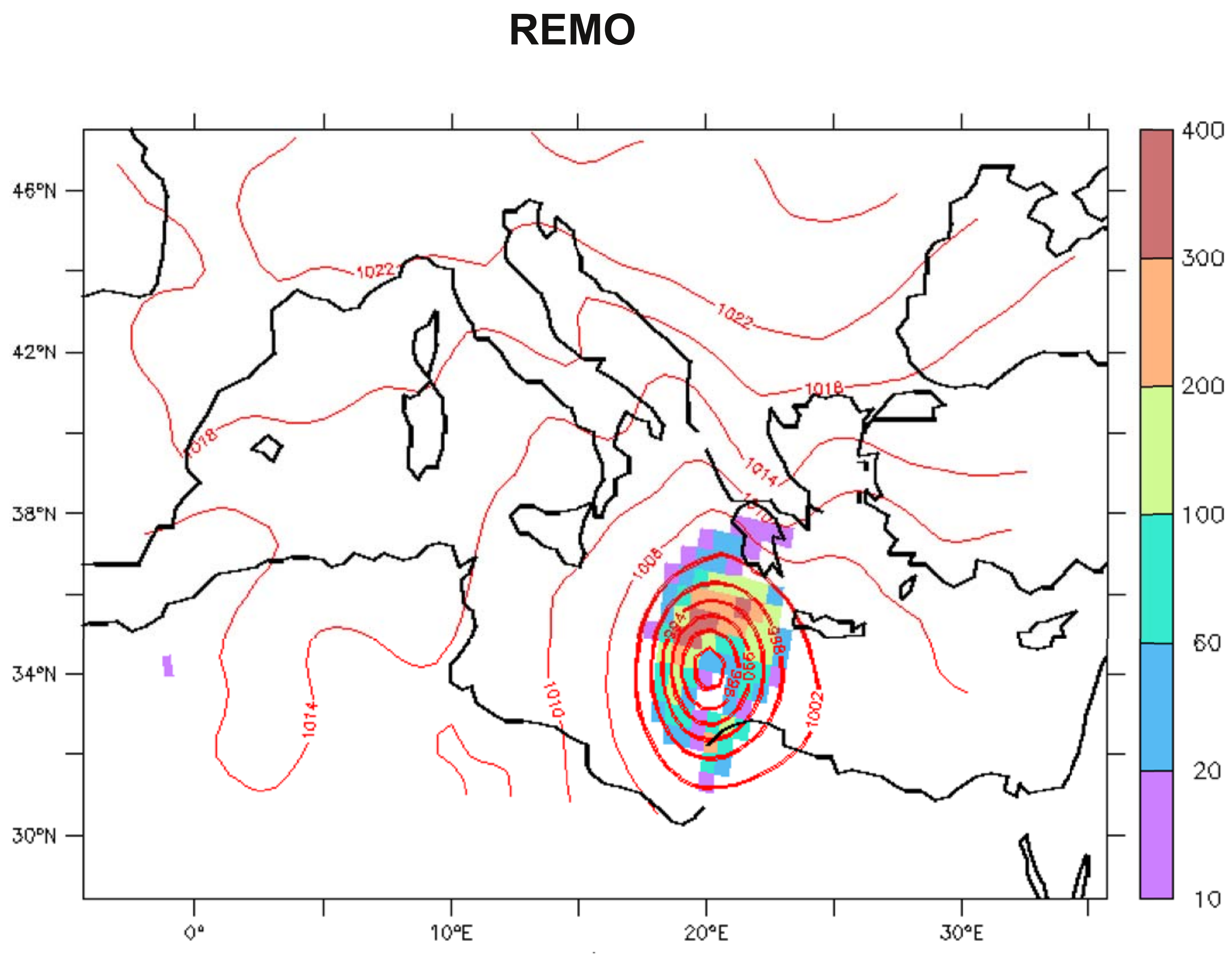
Vertical structure - Cyclone phase space analysis

Most intense cyclones (REMO)

SCENARIO CYCLONES ARE TROPICAL CYCLONES

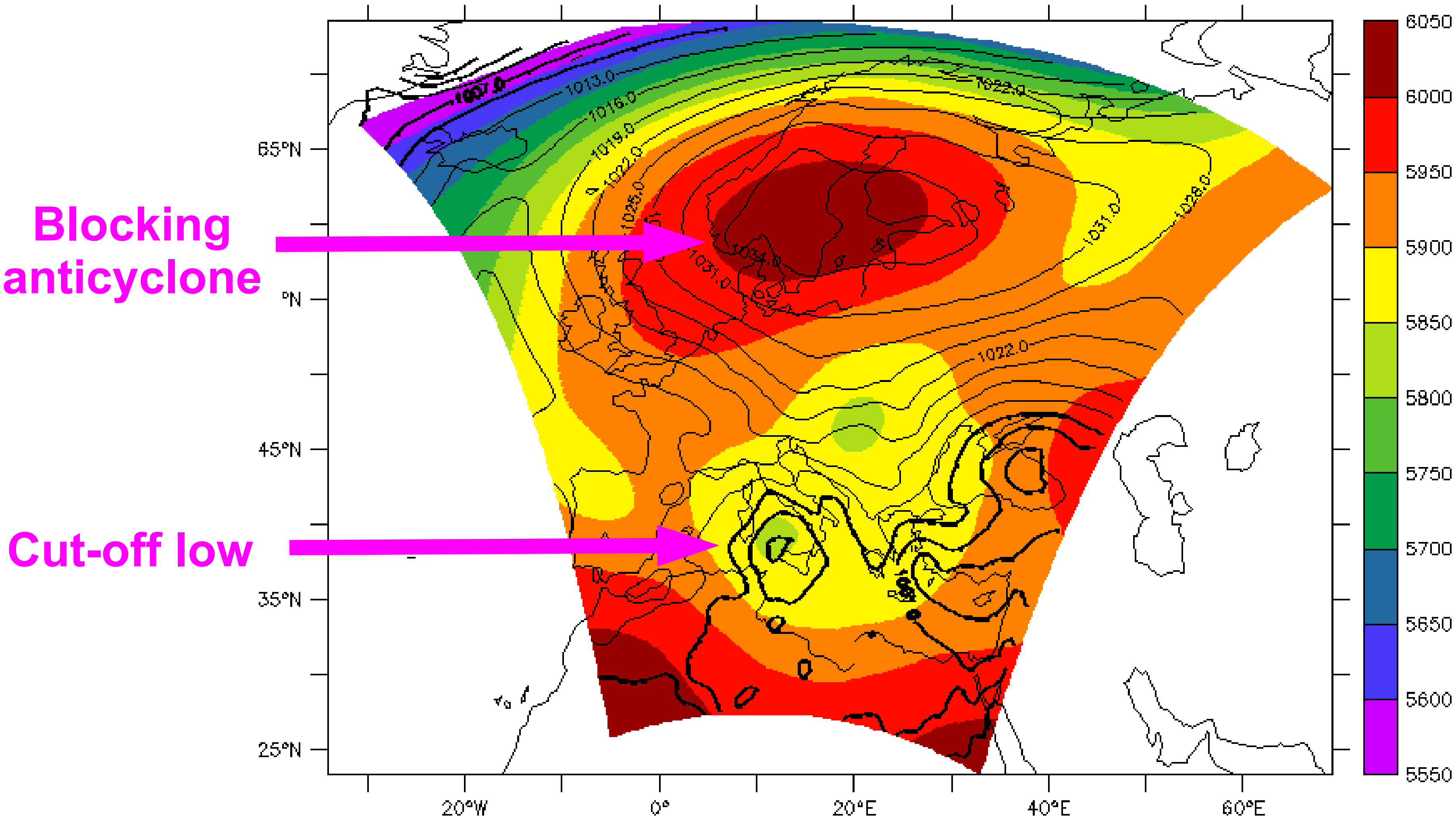


Most intense cyclone centre



Sea level pressure (contours, hPa)
1 day precipitation (coloured shading, mm)

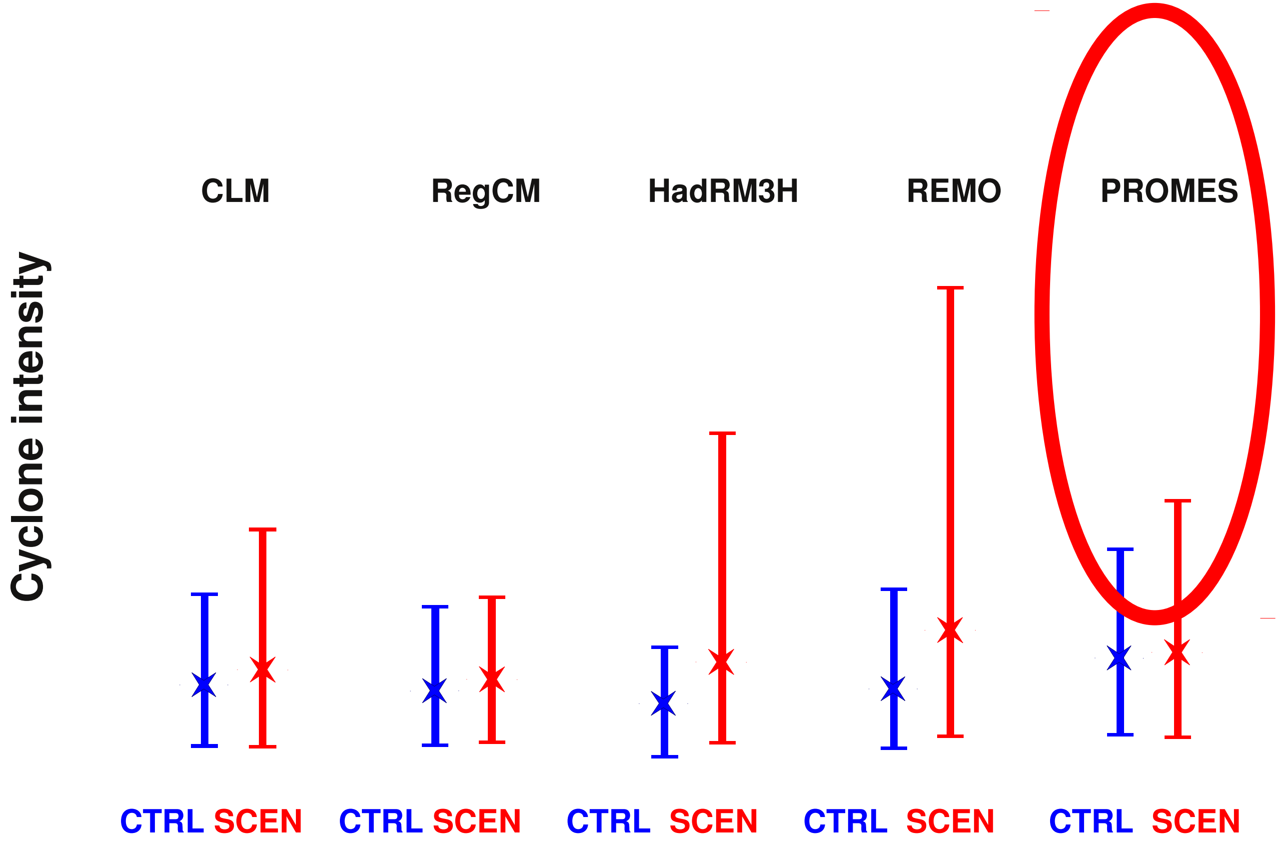
Synoptic situation for the development of this cyclone



Most intense cyclone (REMO) – first day

Another ensemble – PROMES model

PROMES model: relatively small intensity increase in the multi-model ensemble



Limits of bars: 5th and 95th percentiles of cyclone intensity

Mixed physics ensemble – cyclone analysis

10-year simulations (1981-1990, 2091-2100) with **6 different combinations of physics parameterizations** in PROMES model

Late summer cyclone with a very high spread in intensity among ensemble runs

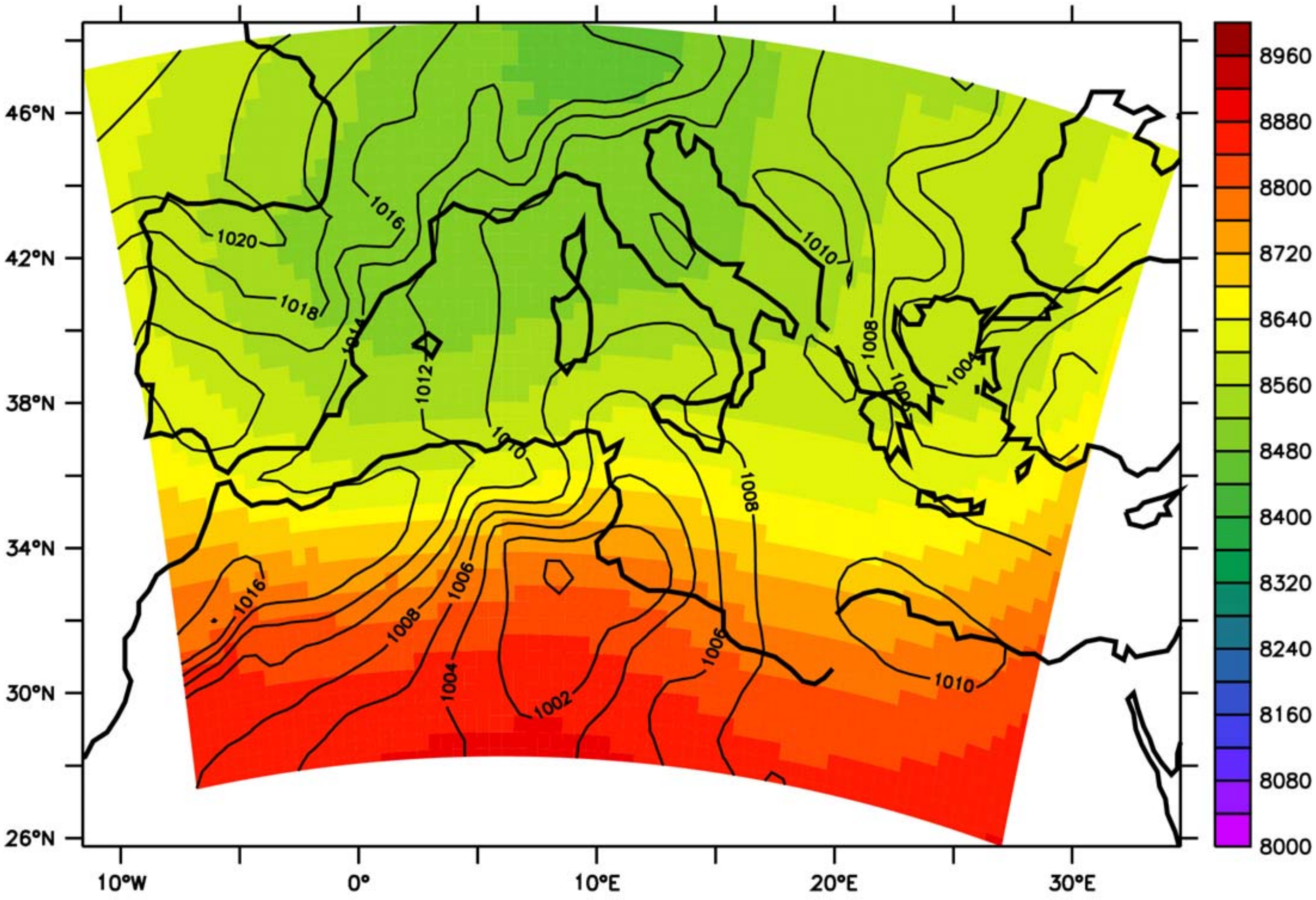
Ensemble member	Maximum cyclone intensity (hPa)	Maximum wind (m/s)
1	997	17
2	977	32
3	**No closed depression**	
4	990	28
5	**976**	**35**
6	980	33

Differences show no clear relation to the parameterization changes → ¿internal variability?

Mixed physics ensemble – cyclone analysis

Ensemble member 5

24 August

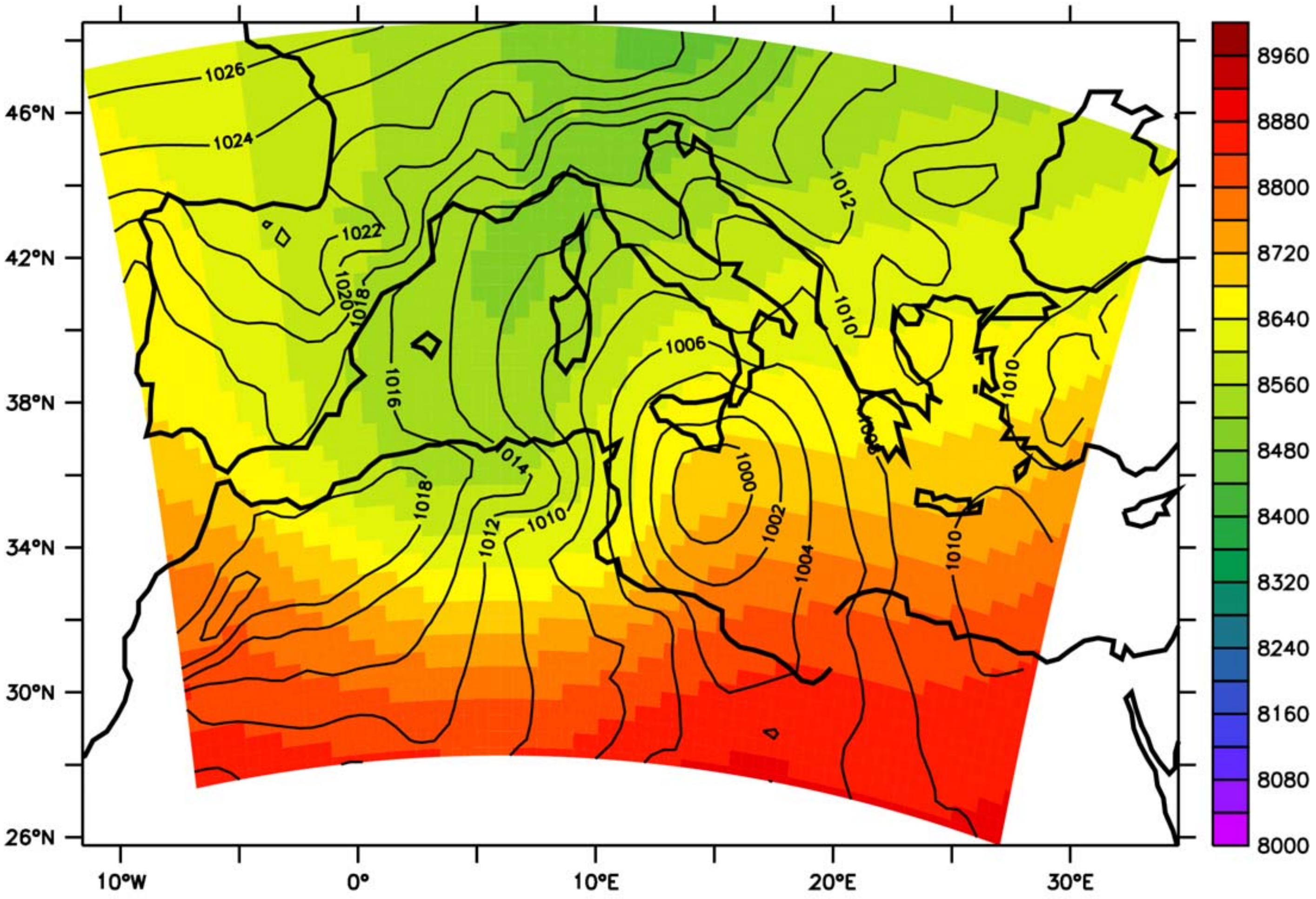


Sea level pressure (hPa) + geop. thickness (300 hPa – 900 hPa, m)

Mixed physics ensemble – cyclone analysis

Ensemble member 5

25 August

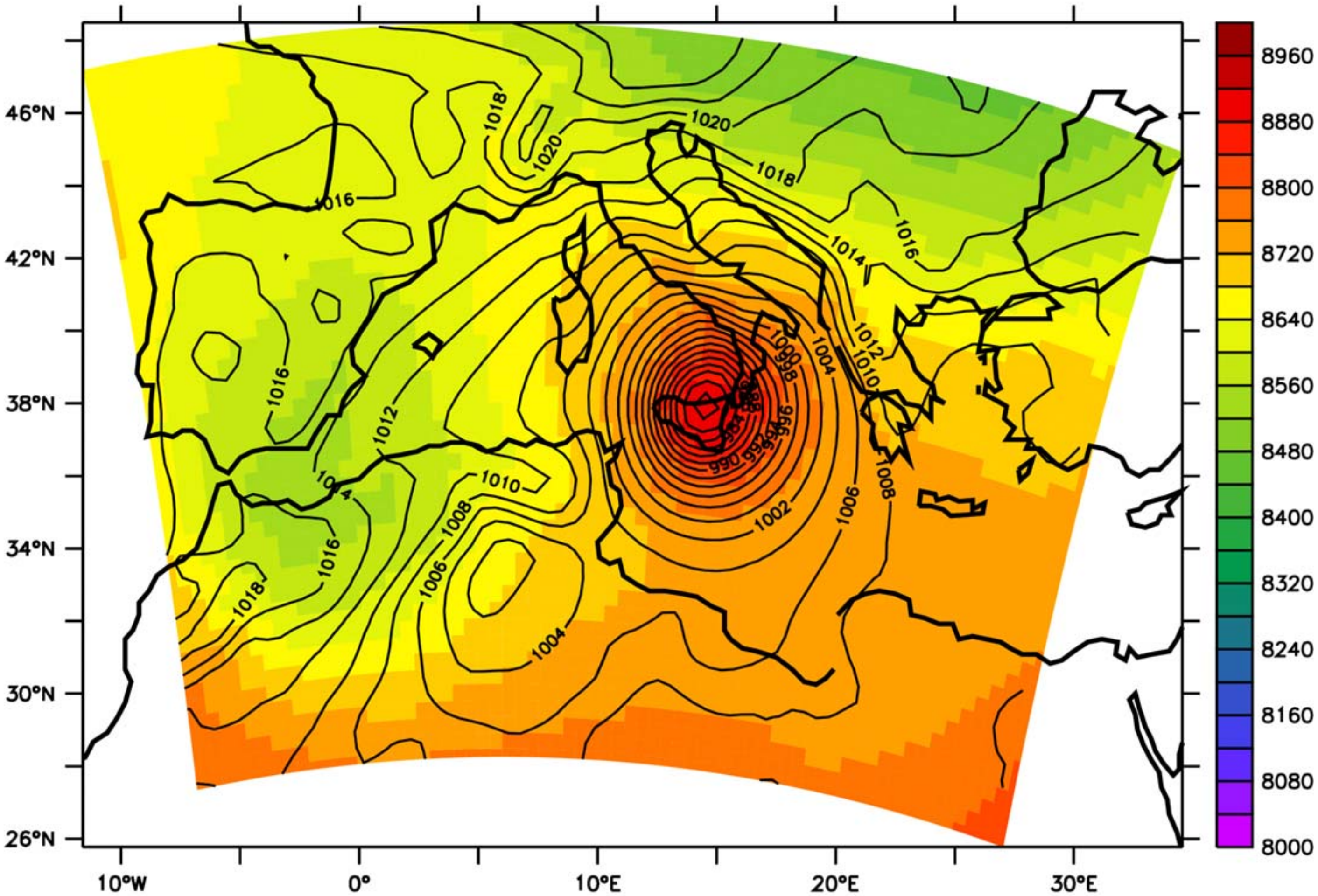


Sea level pressure (hPa) + geop. thickness (300 hPa – 900 hPa, m)

Mixed physics ensemble – cyclone analysis

Ensemble member 5

30 August



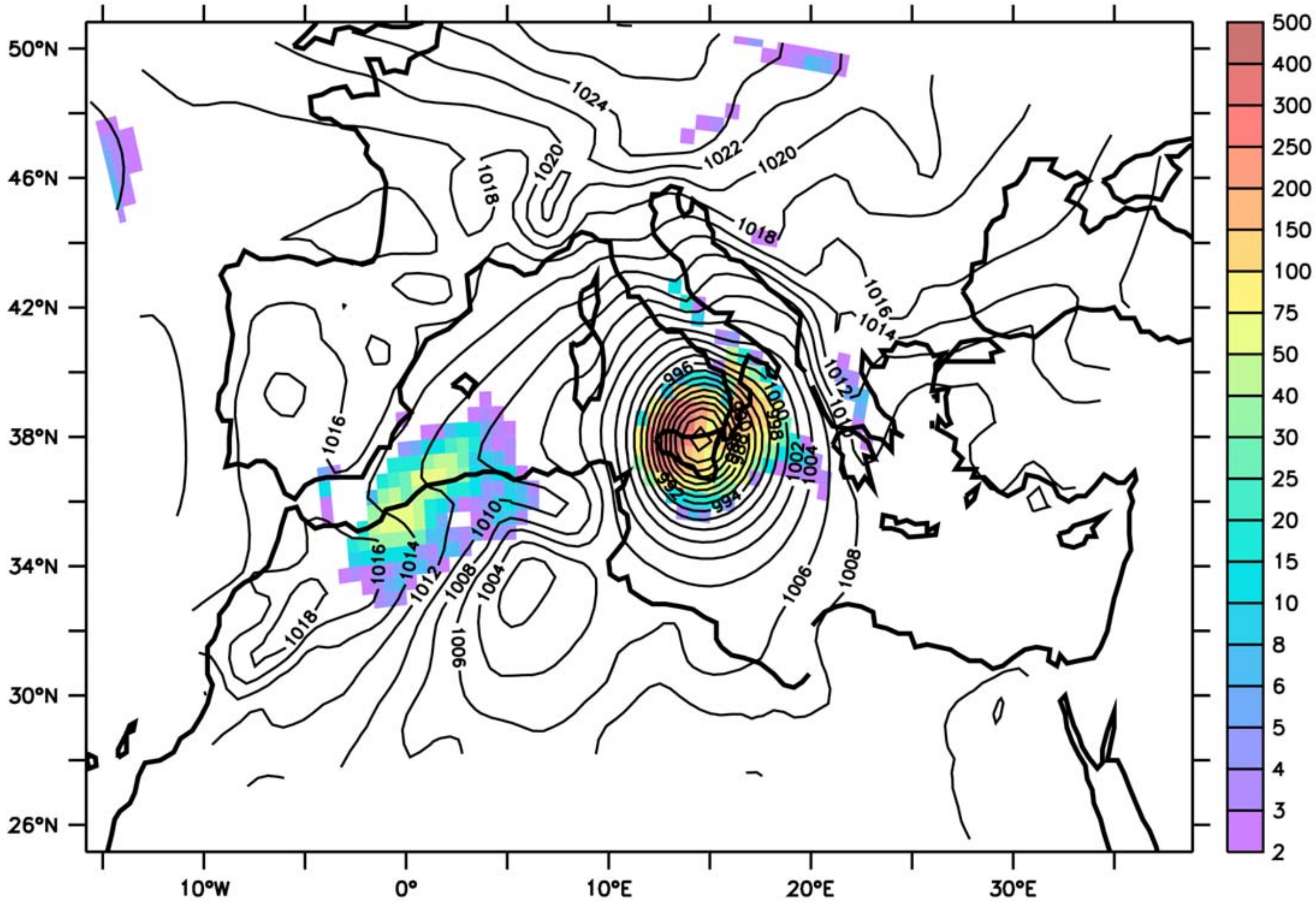
Sea level pressure (hPa) + geop. thickness (300 hPa – 900 hPa, m)

Mixed physics ensemble – cyclone analysis

Appearance of such cyclones: large impact on precipitation and wind extremes

Ensemble member 5

1 September



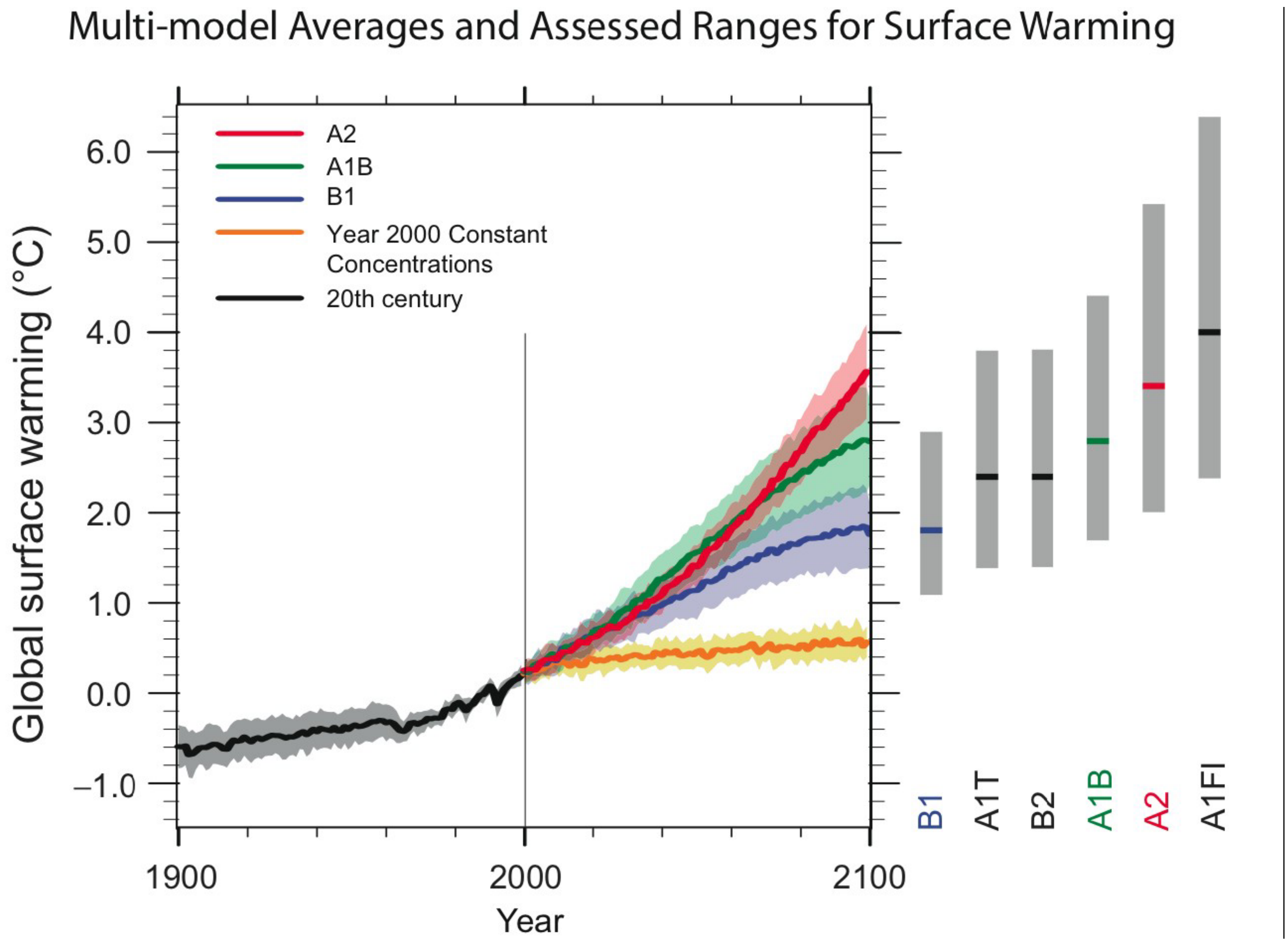
Sea level pressure (hPa) + 1 day precipitation (mm)

Analysis with ENSEMBLES data

Differences with PRUDENCE simulations

- Continuous simulations (1950-2050, 1950-2100): first decades of 21st century can be analysed
- Several different GCMs
- Different emission scenario (A1B vs. A2)
- Higher resolution (25 km vs. 50 km)
- Analysis extended to other months (August, October, November)
- Analyzed variables: decadal percentiles of intensity (95), decadal frequency of low centers

SRES A1B and A2 emissions scenarios



ENSEMBLES GCM-RCM combination matrix

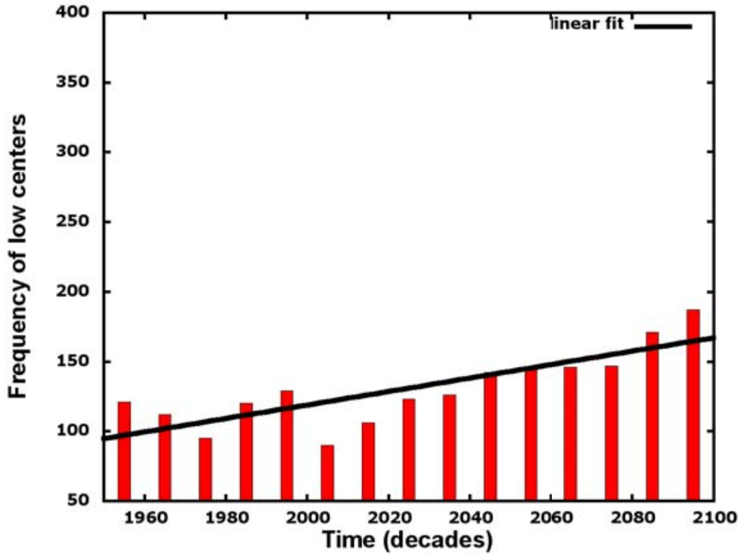
ENSEMBLES GCM-RCM Matrix 8/6/2010

Global model Regional inst.	METO-HC Standard	METO-HC Low sens.	METO-HC Hi sens.	MPIMET Standard	MPIMET Ens.m. 1	MPIMET Ens.m. 2	IPSL	CNRM	NERSC	MIROC	CGCM3	Total number
METO-HC	2100	2100*	2100*	2100 (late 2010)								4
MPIMET				2100			2050*					2
CNRM								2100				1
DMI				2100*				2100	2100*			3
ETH	2100											1
KNMI				<u>2100</u>* 2100	<u>2100</u>*	<u>2100</u>*				<u>2100</u>*		1+4
ICTP				2100								1
SMHI		2100*		<u>2100</u>* 2100*					2100			3+1
UCLM	2050											1
C4I			2100*		2050 (A2)*							2
GKSS							2050*					1
METNO	2050*								2050*			1
CHMI								2050* (12/2009)				1
OURANOS**											2050*	1
VMGO**	2050*											1
Total (1951-2050)	5	2	2	7+2	0+1	0+1	2	3	3	0+1	1	25+5

Red: Online now; *: non-contractual runs; **:affiliated partners without obligations; <u>underscore</u>: 50km resolution; (in parantheses): Expected date. For partner acronym explanations, see the participant list. **NOTE** that all partners also did an ERA-40 driven analysis 1951(1961)-2000

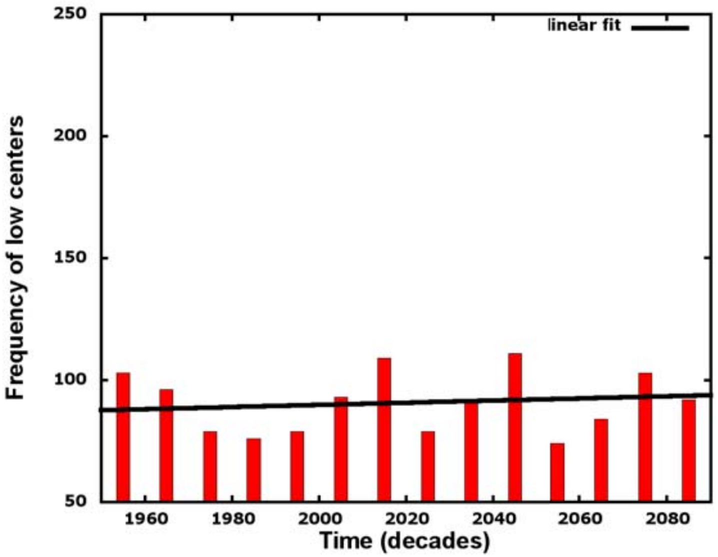
General results - September

RACMO2 (ECHAM5)

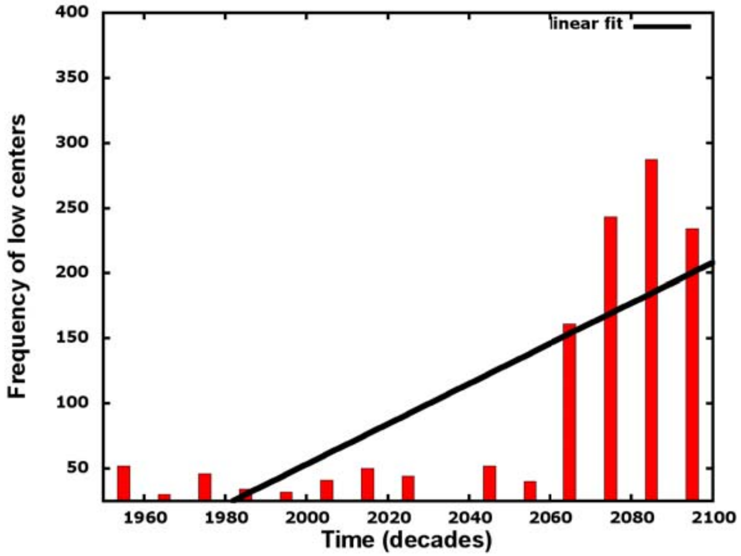


FREQUENCY:
All 17 simulations show a positive trend

HadRM3Q0

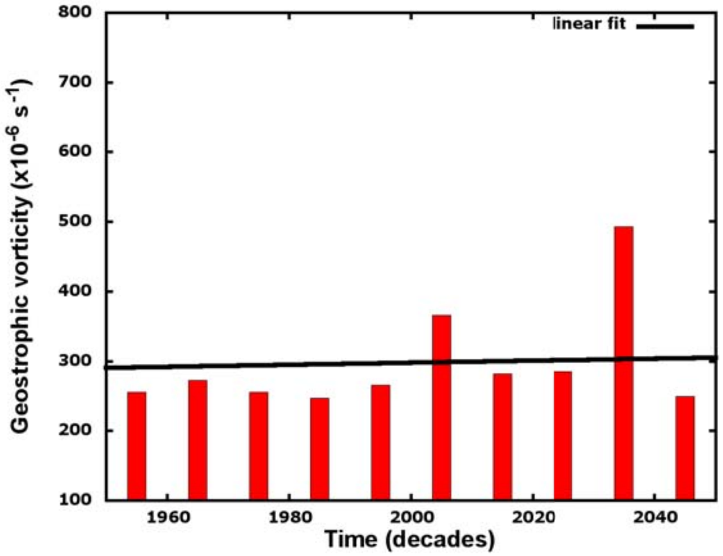


DMI-HIRHAM5 (ARPEGE)



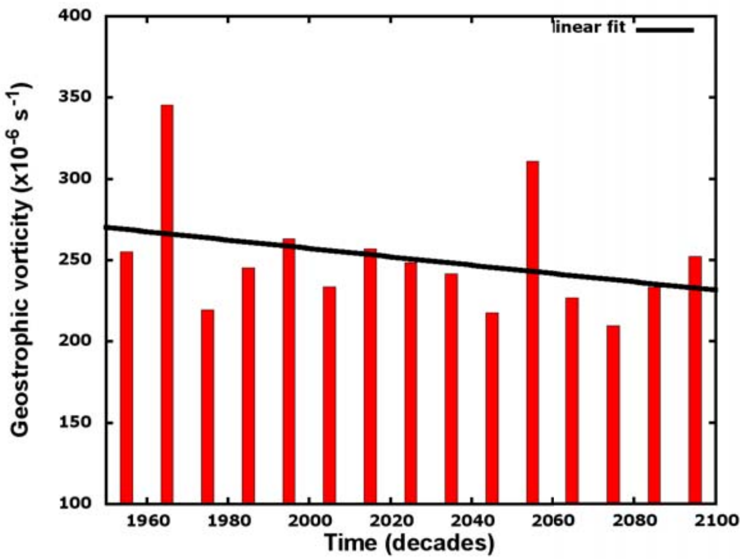
General results - September

PROMES

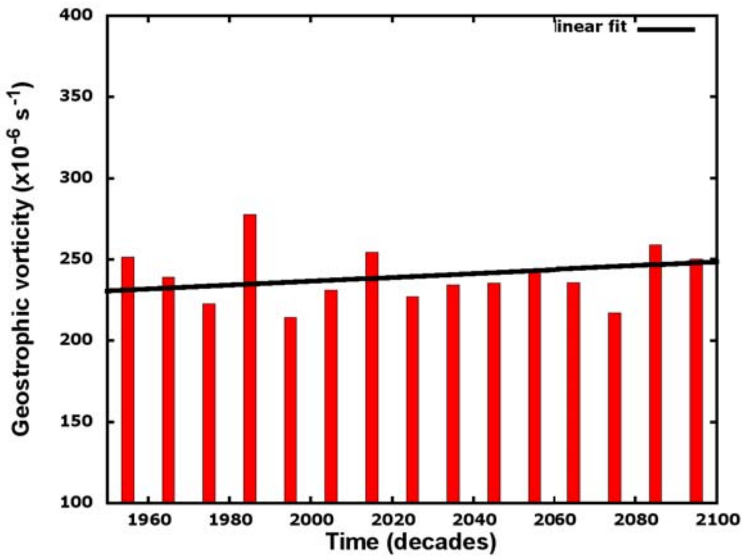


INTENSITY (95 pctl.)
12 simulations show positive trend

RCA (HadCM3Q3, low sensitivity)

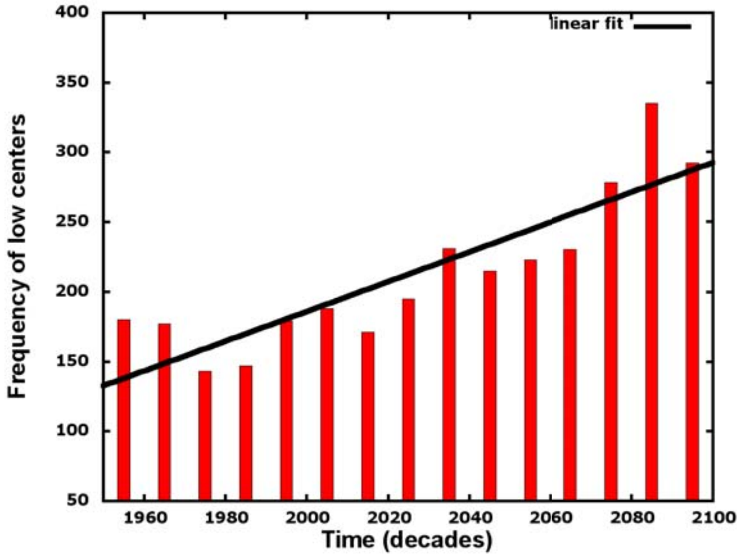


RCA (ECHAM5)



General results - August

RACMO2 (ECHAM5)



FREQUENCY:
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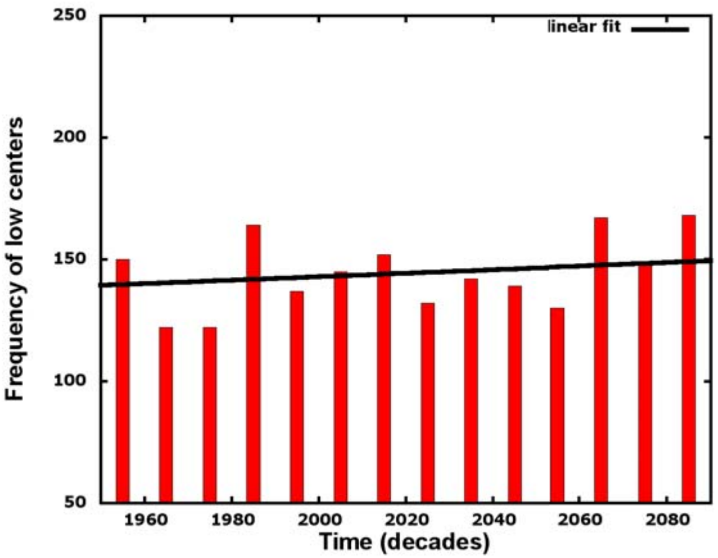
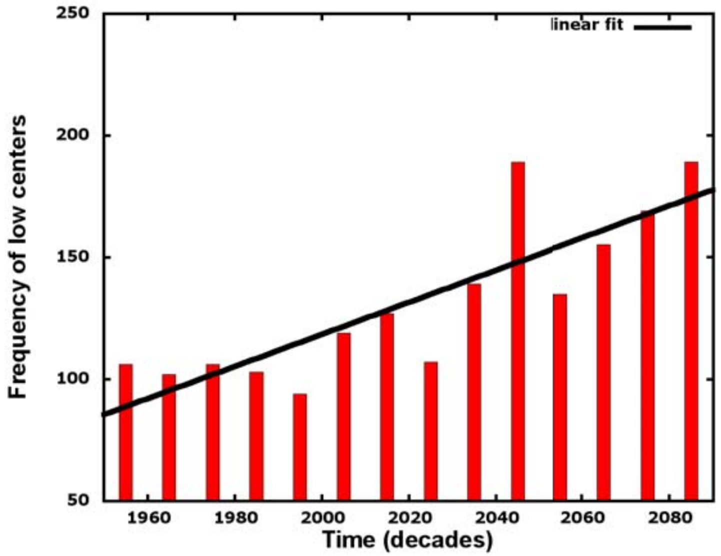
HadRM3Q3 (low sensitivity)

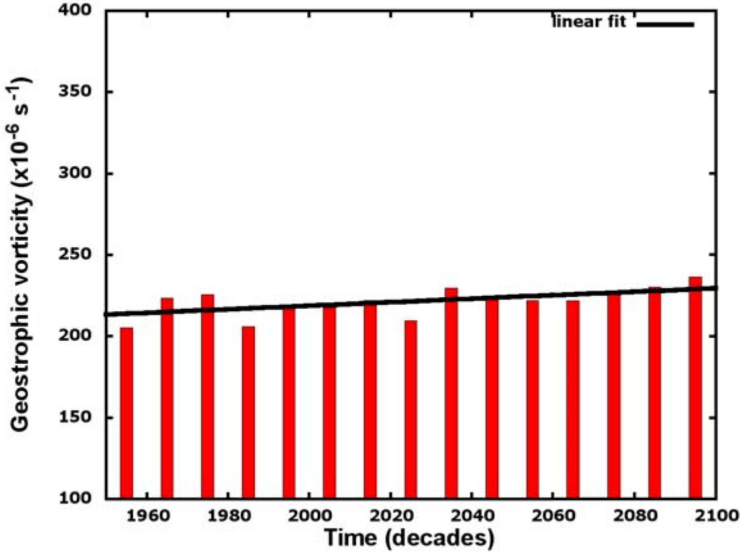


RCA (HadCM3Q3, low sens.)



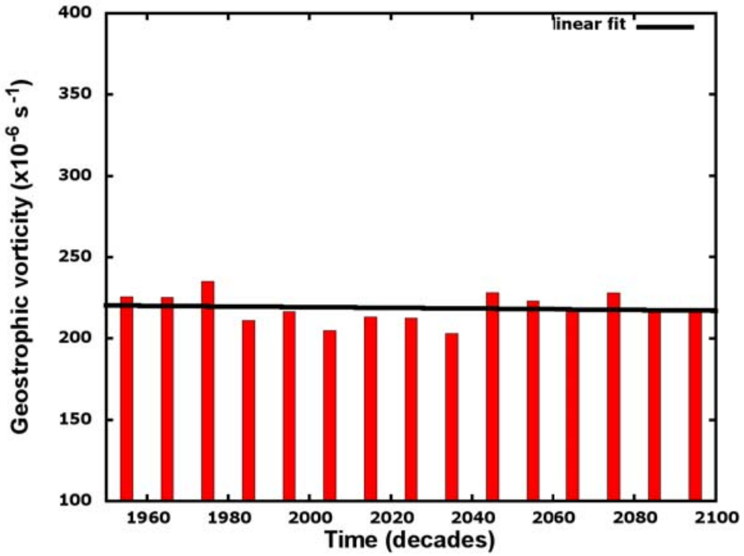
General results - August

RM5.1 (ARPEGE)

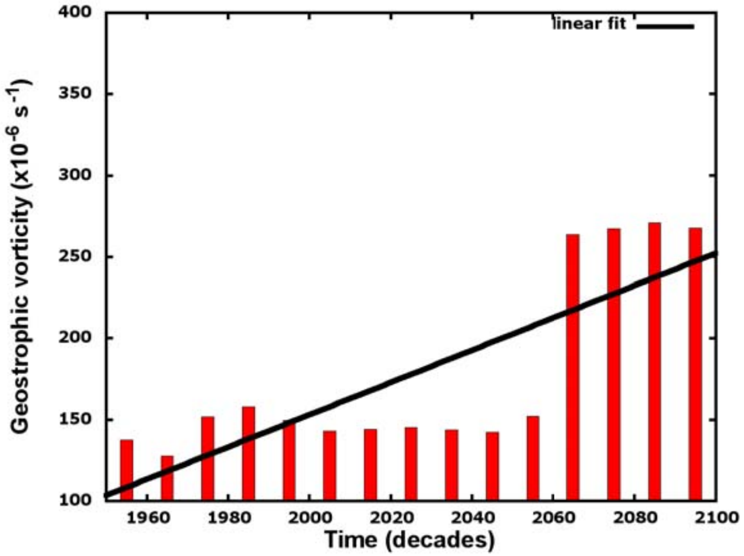


INTENSITY:
14 simulations show positive trend

RegCM3 (ECHAM5)

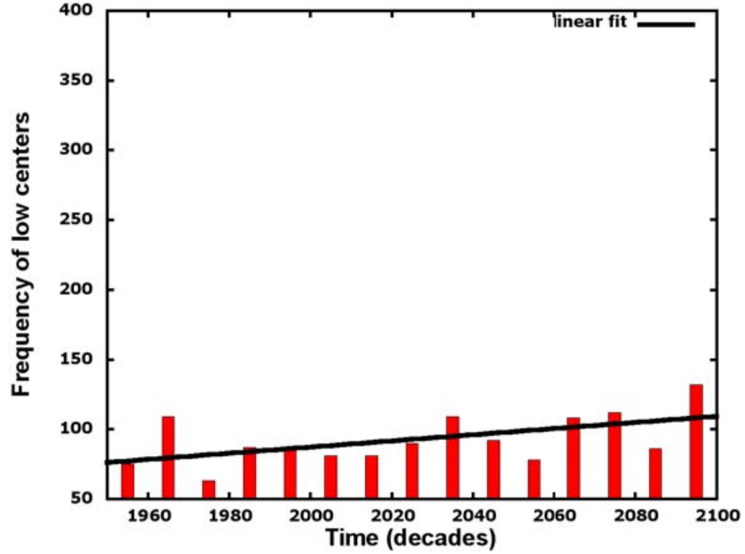


DMI HIRHAM5 (ARPEGE)



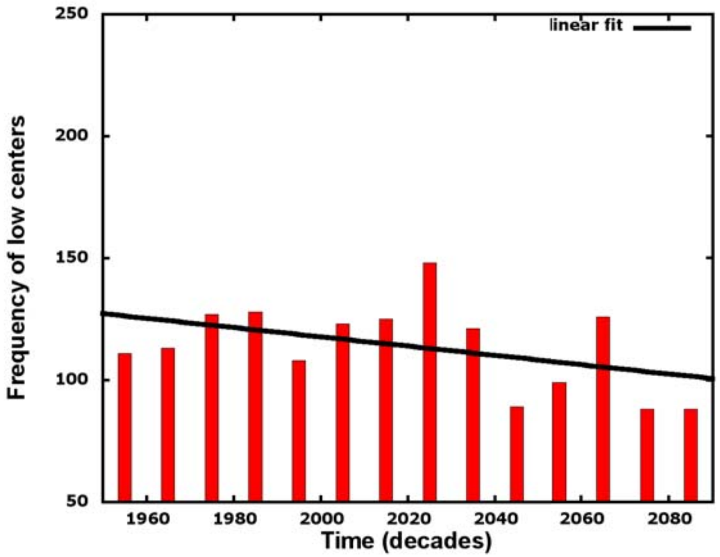
General results - October

RACMO2 (ECHAM5)

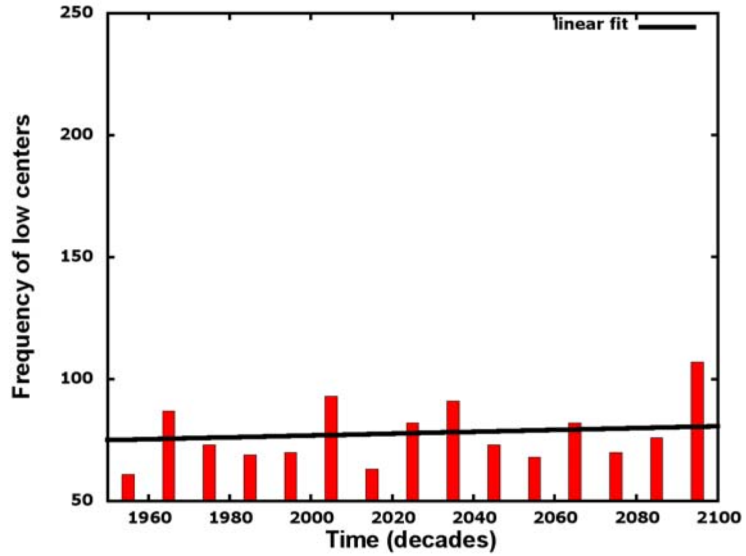


FREQUENCY:
14 simulations show a positive trend

HadRM3Q0 (ref.)

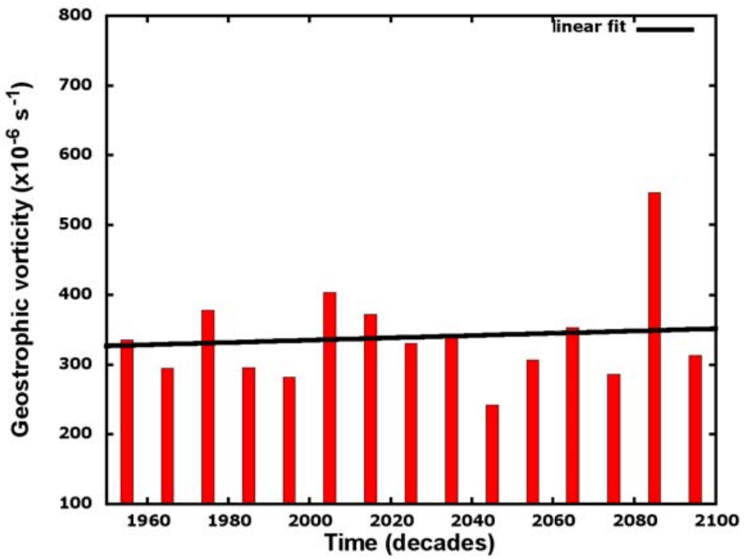


RCA (ECHAM5)



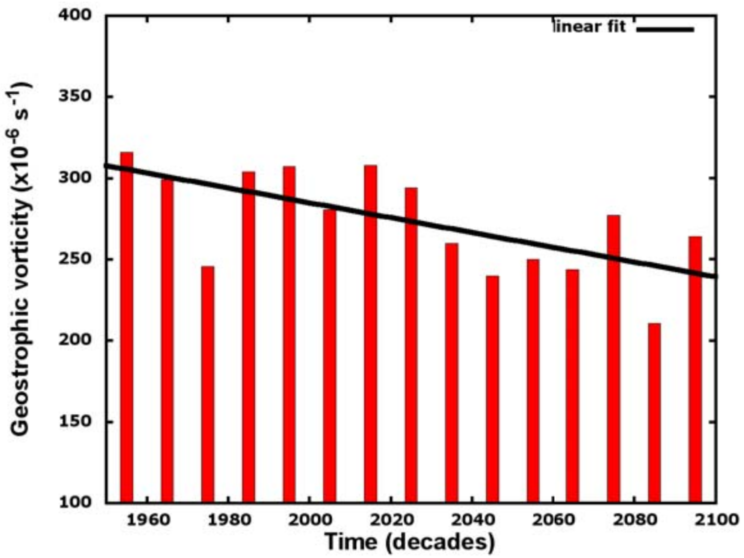
General results - October

HadRM3Q0 (ref.)

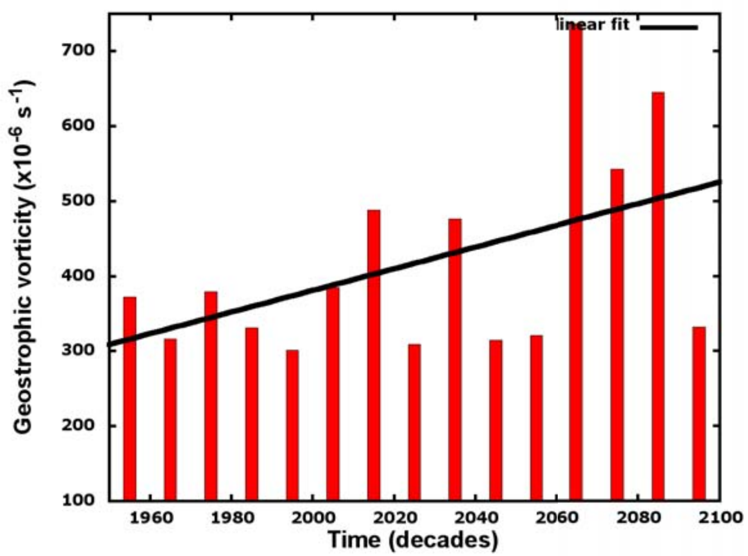


INTENSITY (95 pctl.): 13 simulations show positive trend (strong contrasts between simulations)

RACMO2 (ECHAM5)

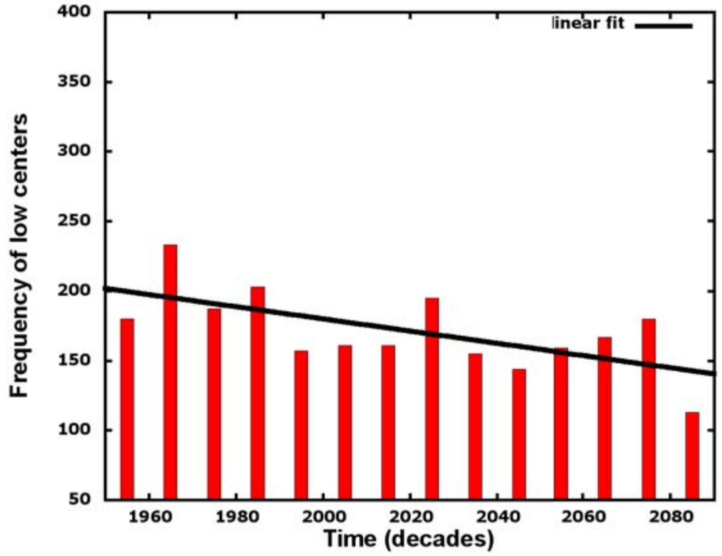


CLM (HadCM3Q0, ref.)



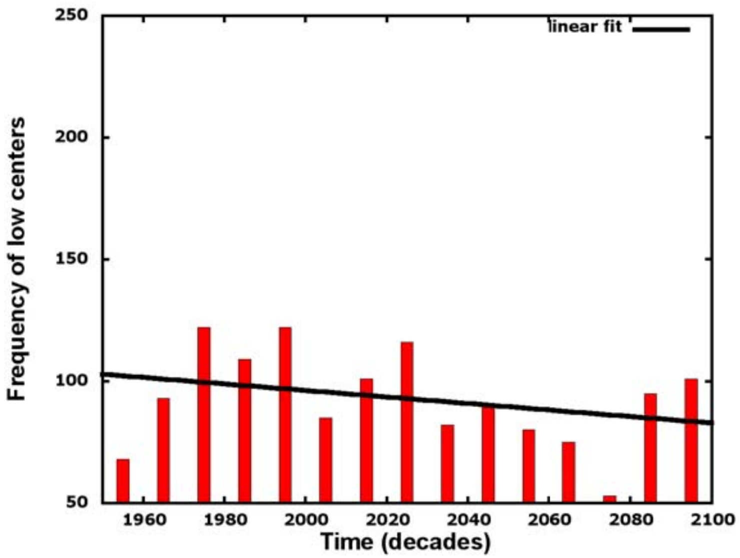
General results - November

CLM (HadCM3Q0, ref.)

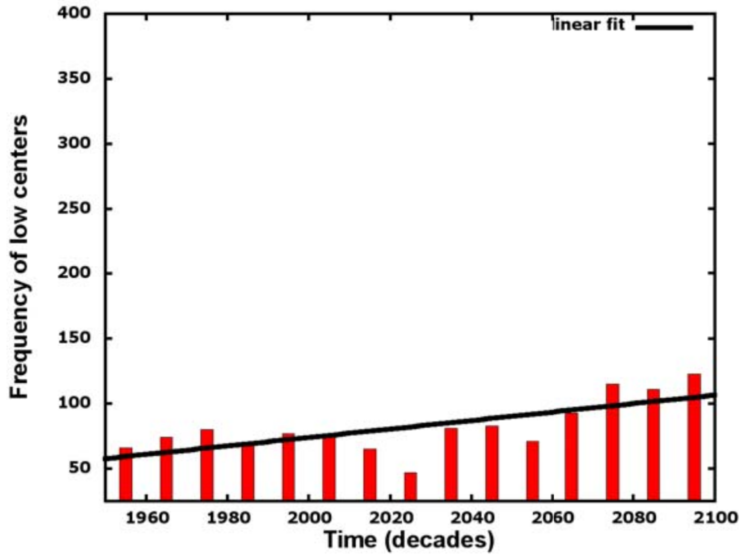


FREQUENCY: 14 simulations show negative trend

REMO (ECHAM5)

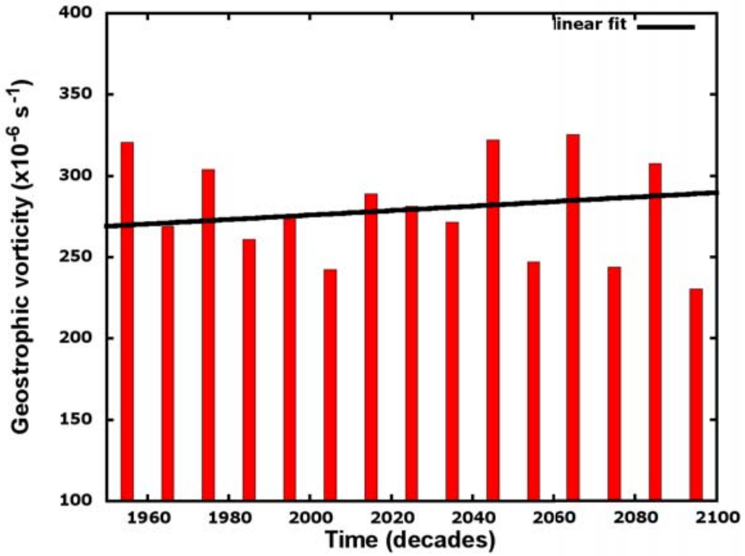


DMI HIRHAM5 (ARPEGE)



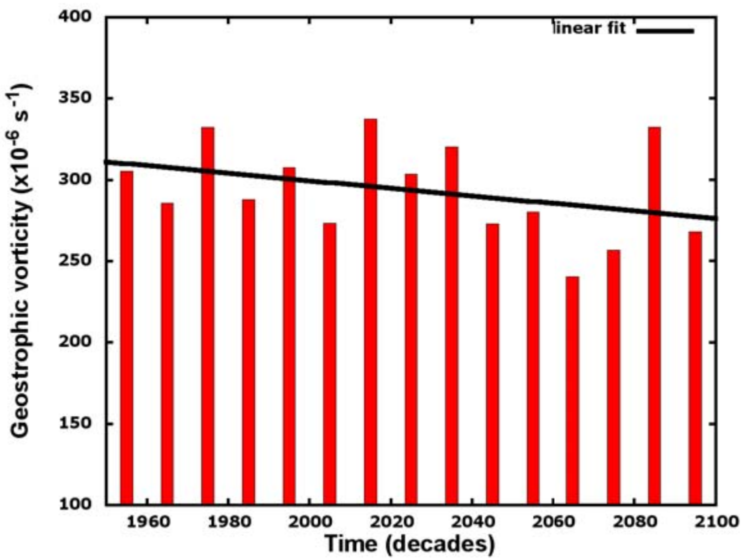
General results - November

RACMO2 (ECHAM5)

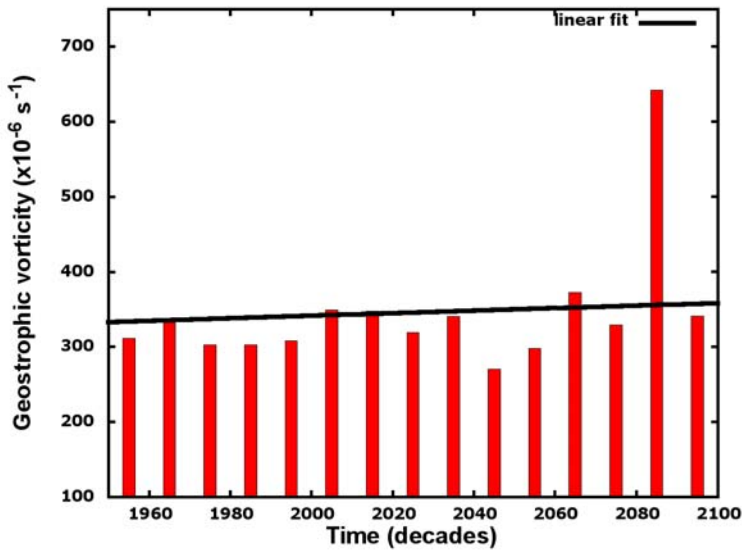


INTENSITY (95 ptcl.): 12 simulations show positive trend (strong contrasts between simulations)

RegCM3 (ECHAM5)



CLM (HadCM3Q0, ref.)

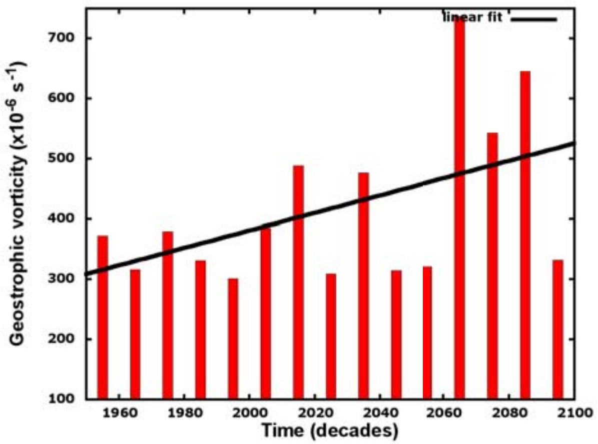


GCM effects on results

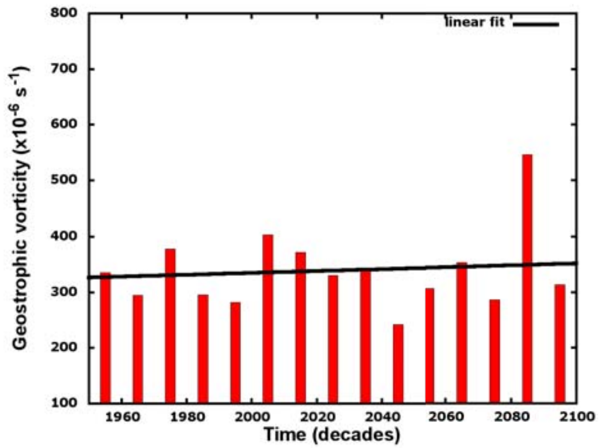
RCM simulations nested in HadCM3Q0 (reference sim.)

Positive trend

CLM (HadCM3Q0)

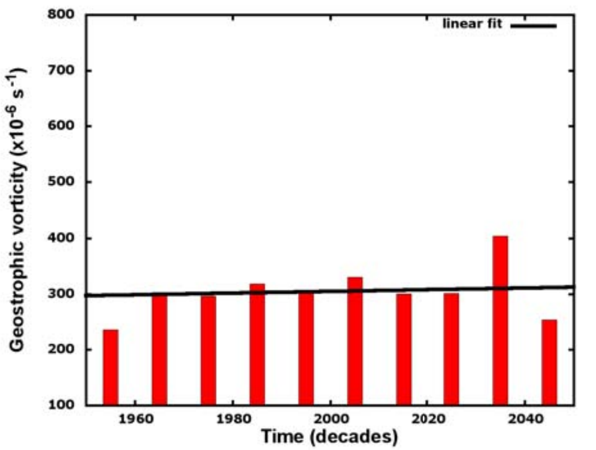


HadRM3Q0

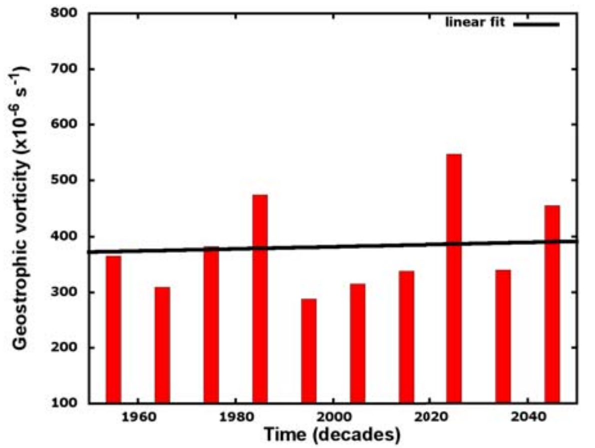


Intensity October

METNO-HIRHAM



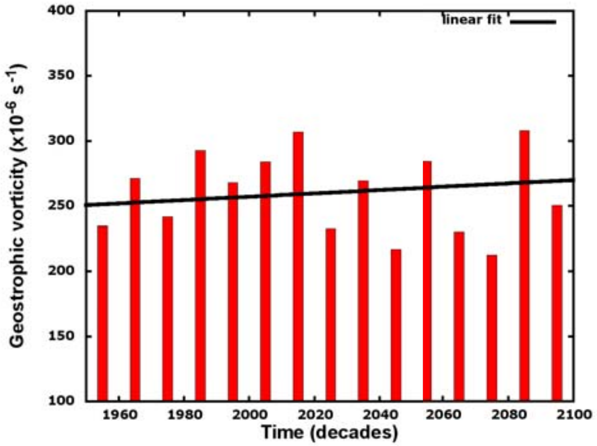
PROMES



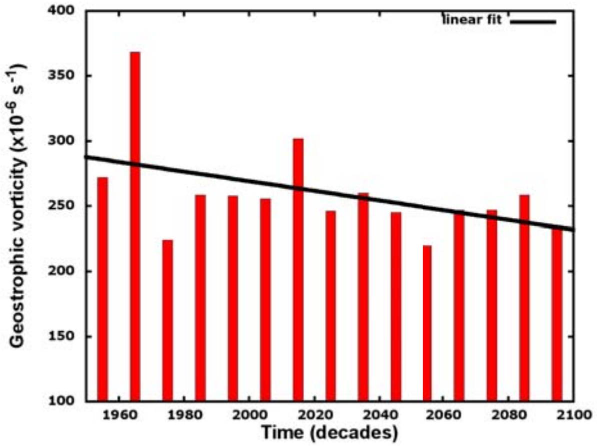
GCM/RCM impacts on uncertainty

RCM simulations nested in ECHAM5

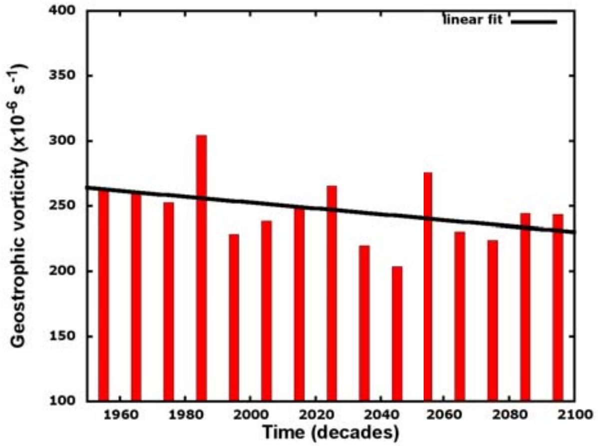
REMO (ECHAM5)



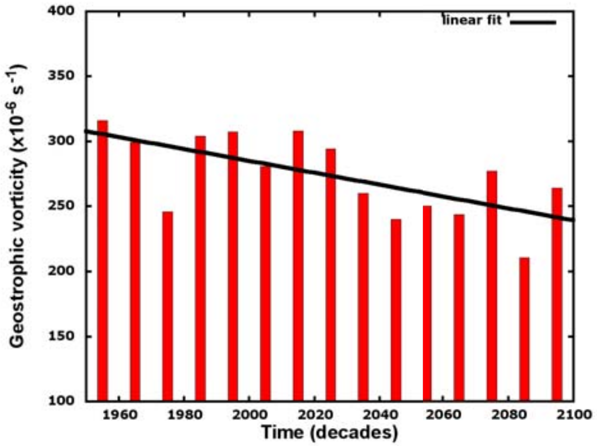
DMI-HIRHAM



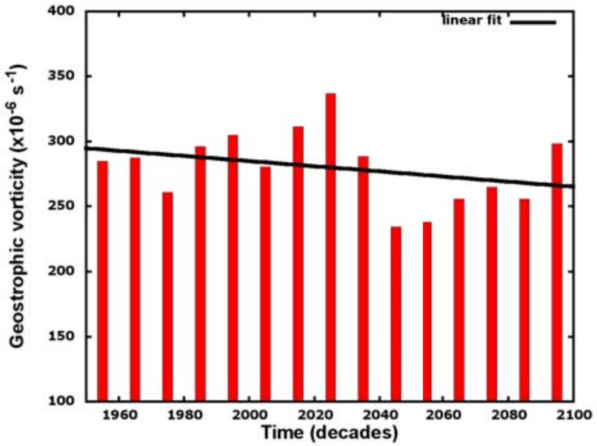
RCA



RACMO2



RegCM3



Intensity October

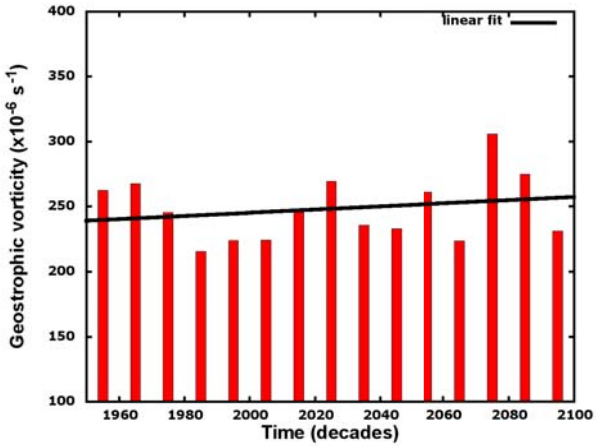
All simulations with negative trend nested in ECHAM5

GCM/RCM impacts on uncertainty

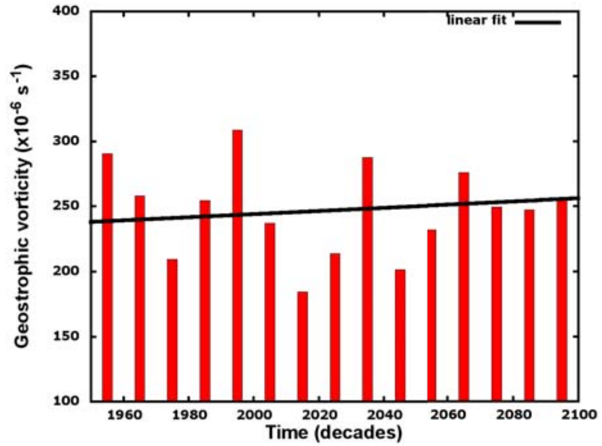
RCM simulations nested in ARPEGE

Positive trend

RM5.1



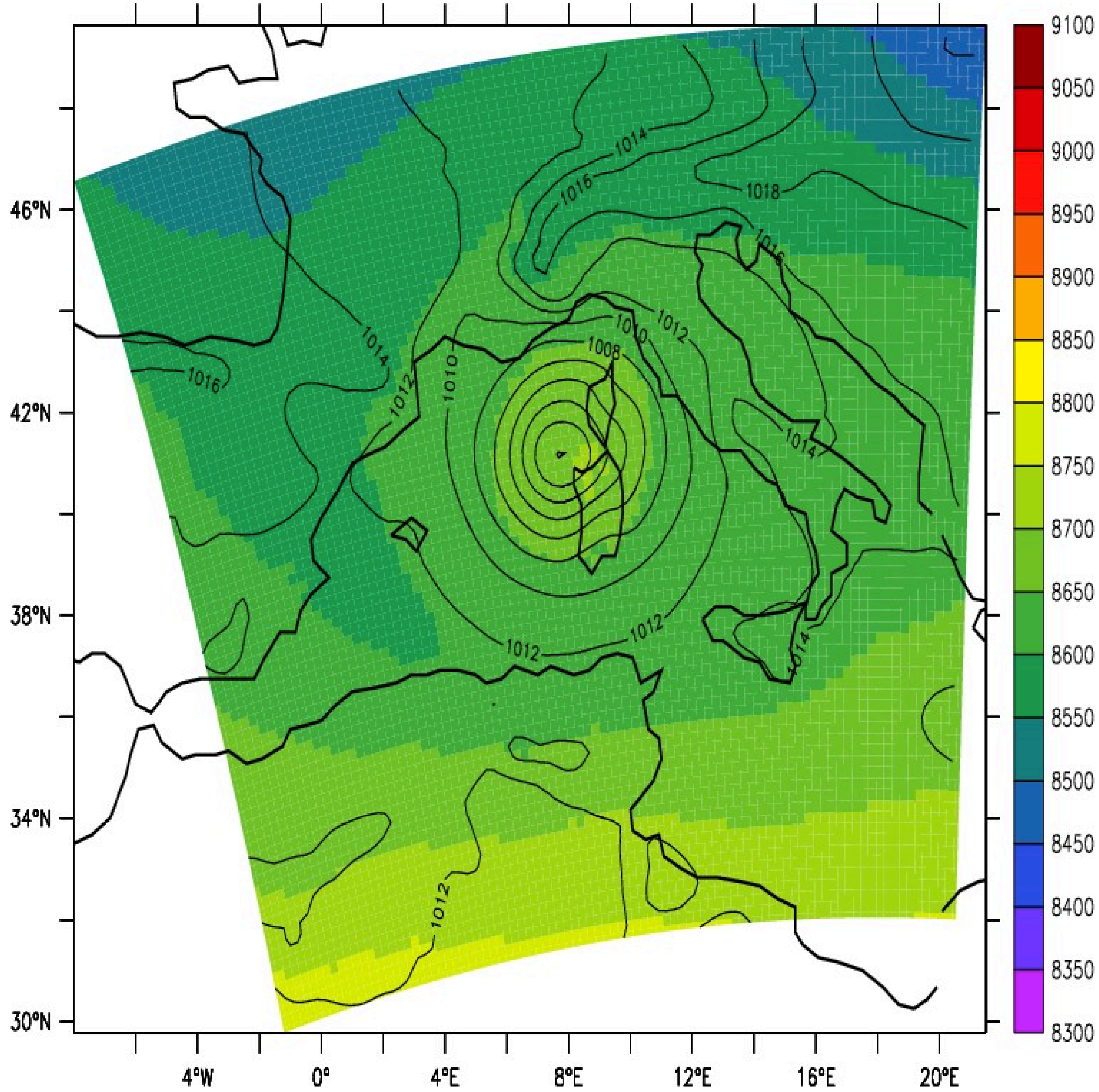
DMI-HIRHAM



Intensity
October

Preliminary analysis of most extreme cyclones

August – Present climate



METNO-HIRHAM (BCM)
1996

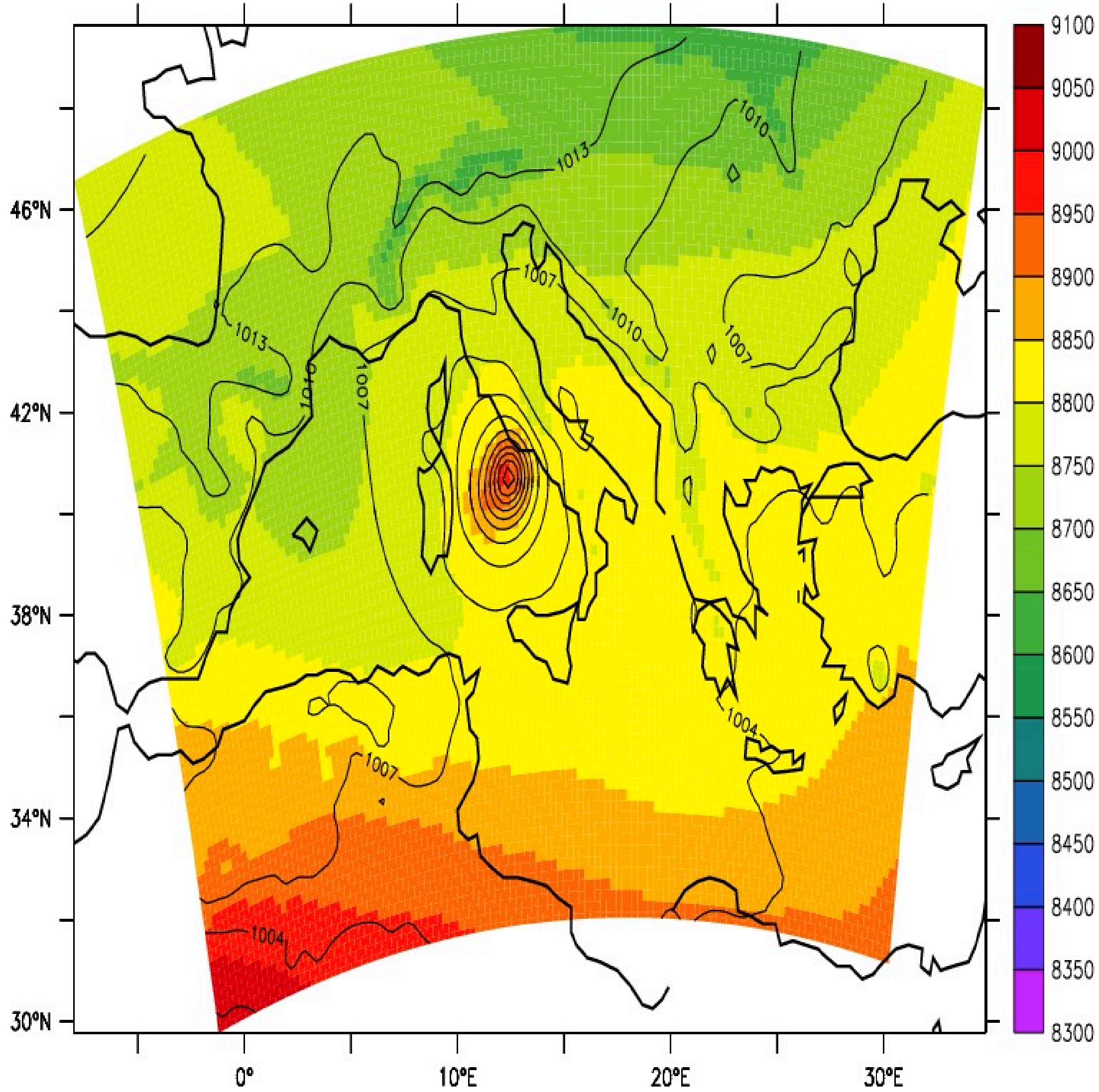
Intensity: 598 x 10^{-6} s^{-1}

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

August – Future climate



RCA (HadCM3Q3)
2079

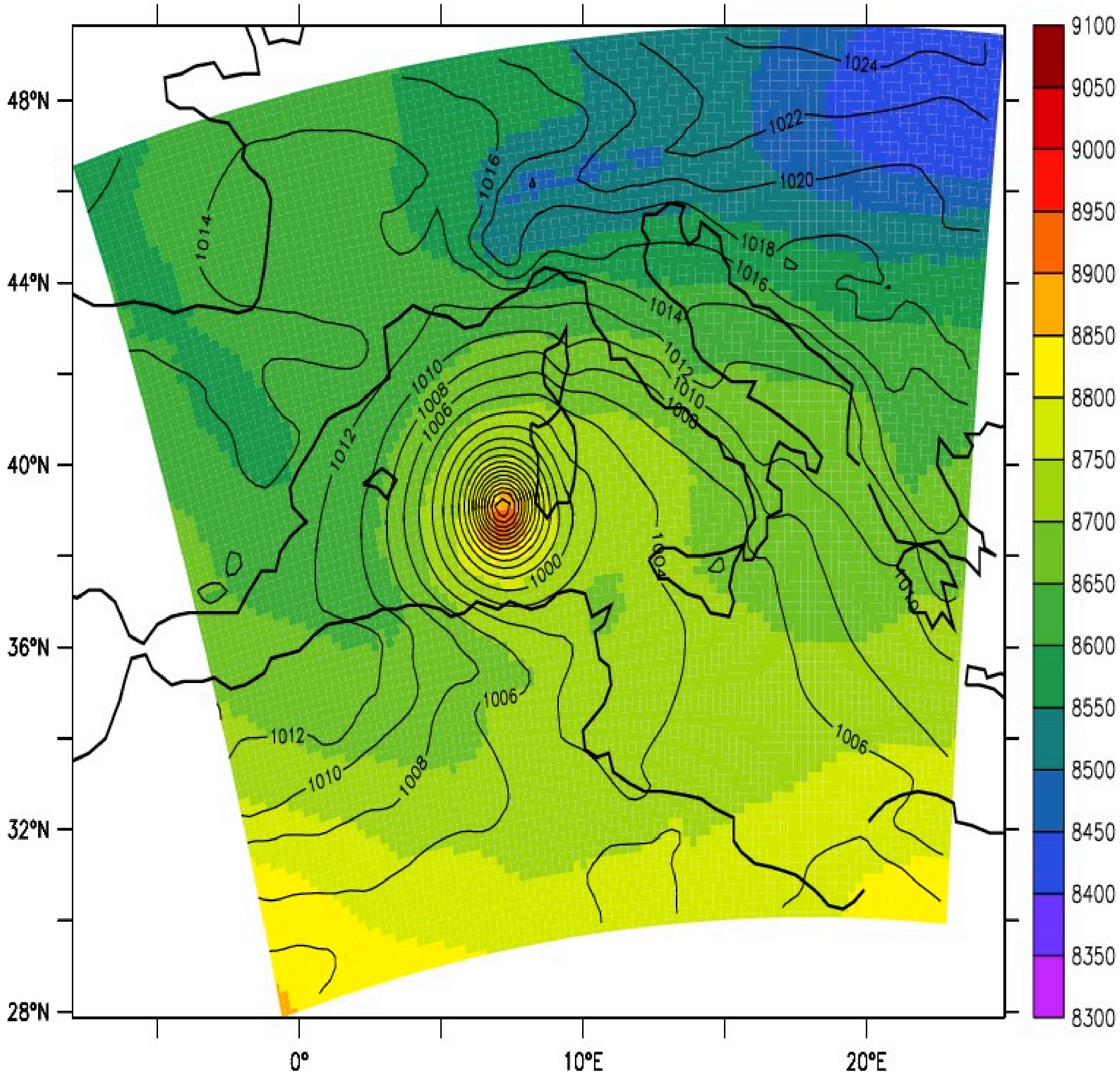
Intensity: 1272 x 10^{-6} s^{-1}

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

September – present climate



METNO-HIRHAM (HadCM3Q0)
1982

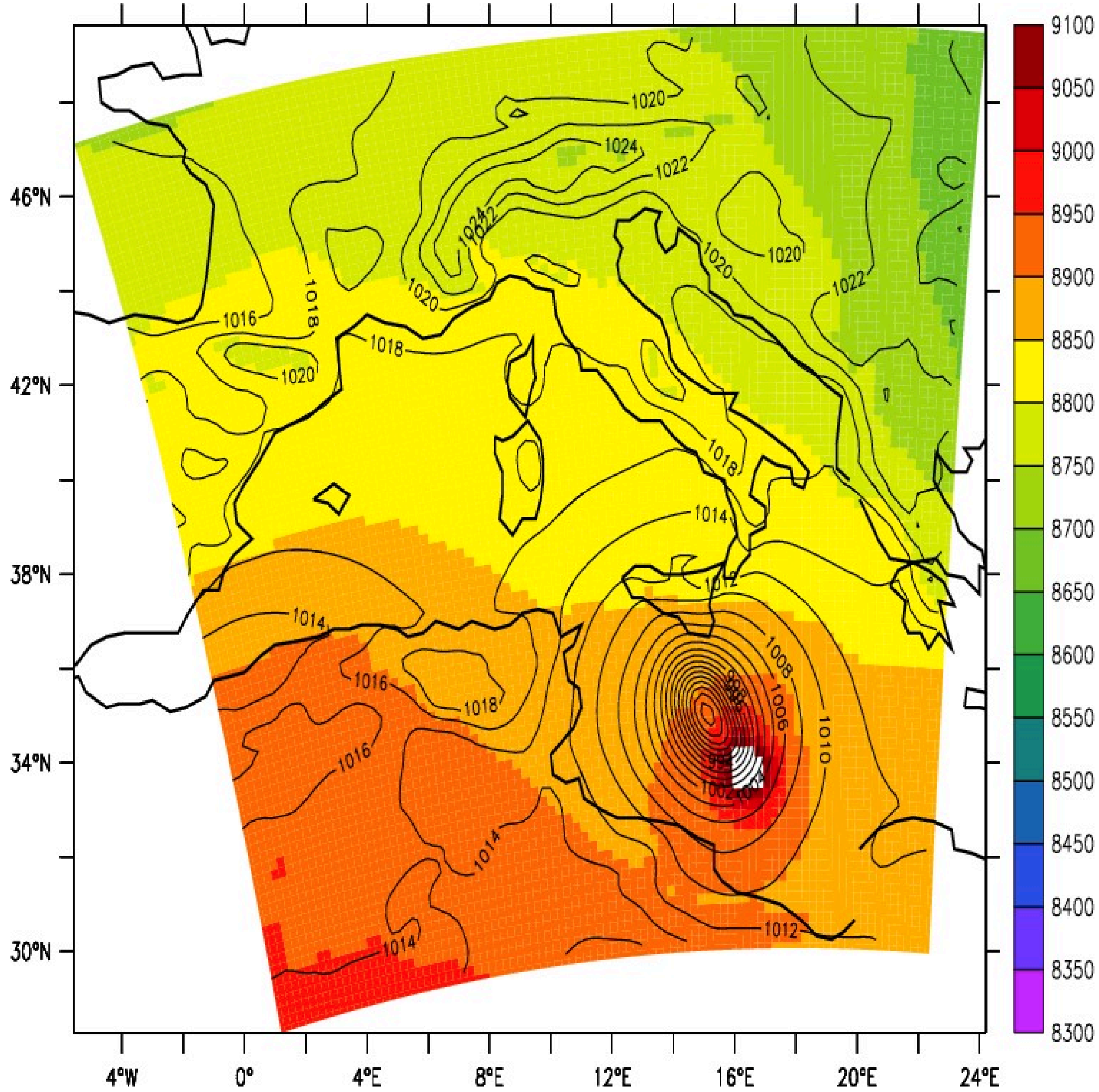
Intensity: 1560 x 10^{-6} s^{-1}
988 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

September – future climate



CLM (HadCM3Q0, ref.)
2079

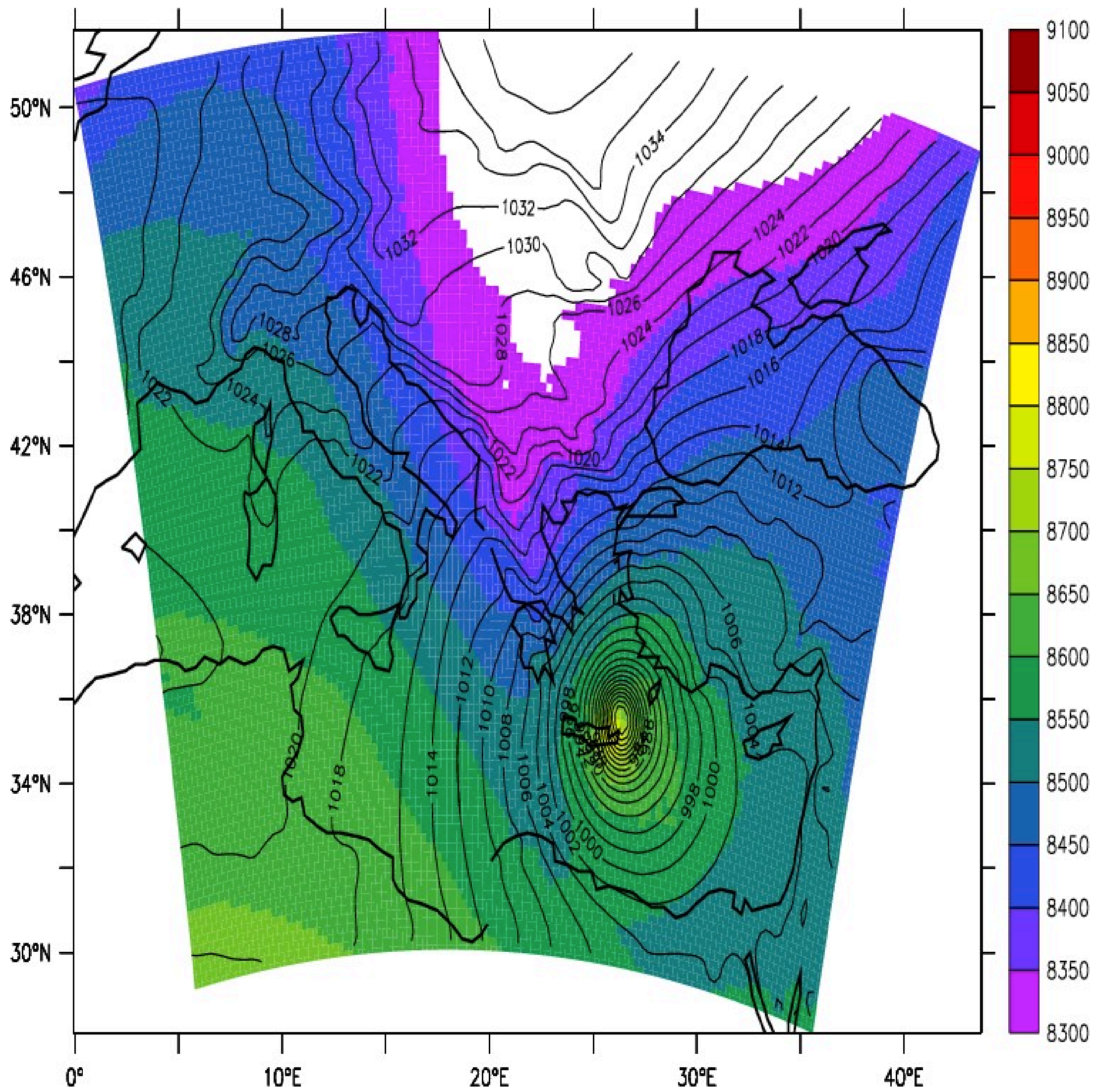
Intensity: 1735 x 10^{-6} s^{-1}
992 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

October – present climate



CLM (HadCM3Q0)
2079

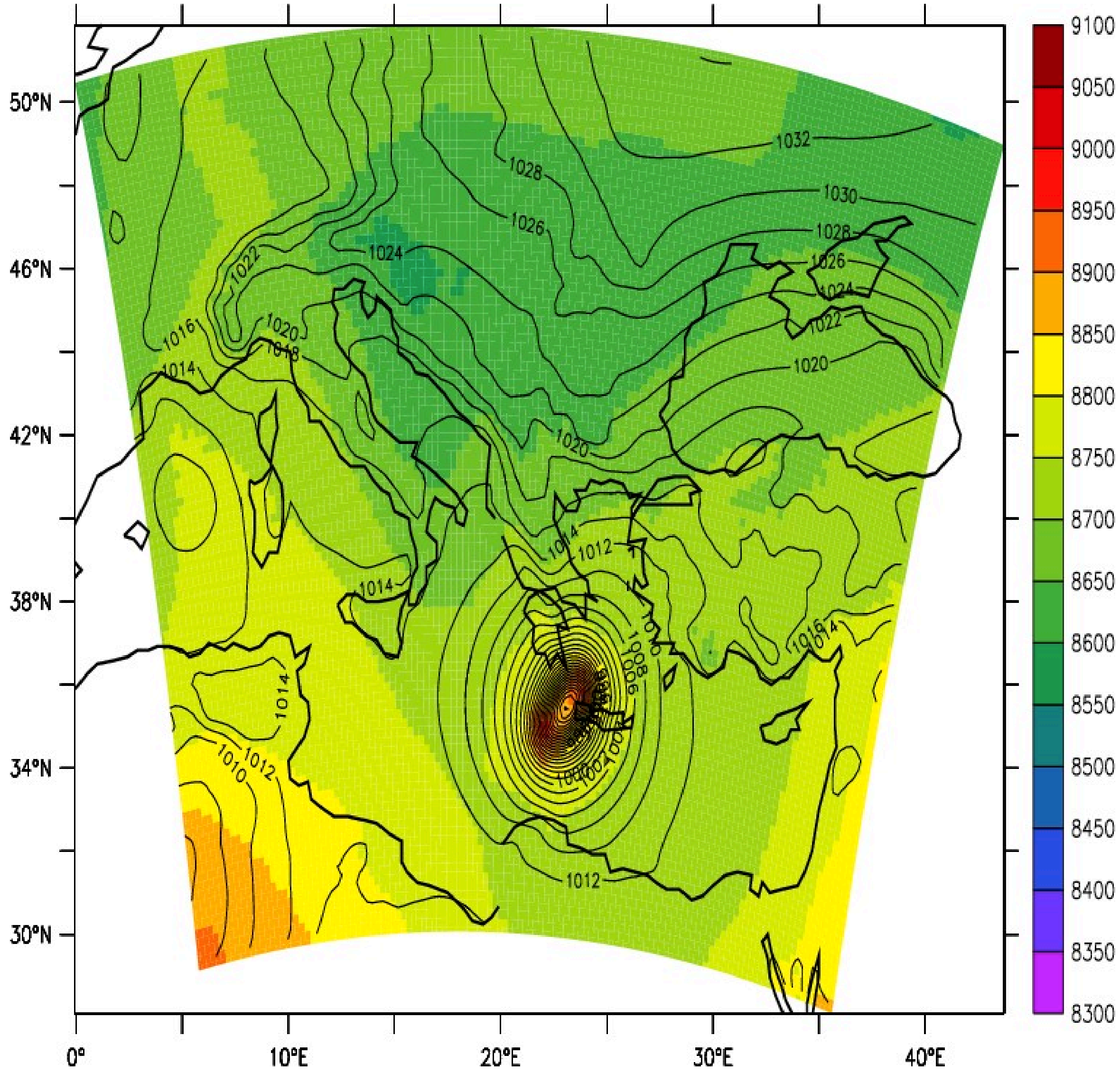
Intensity: 1768 x 10^{-6} s^{-1}
980 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

October – future climate



CLM (HadCM3Q0)
2079

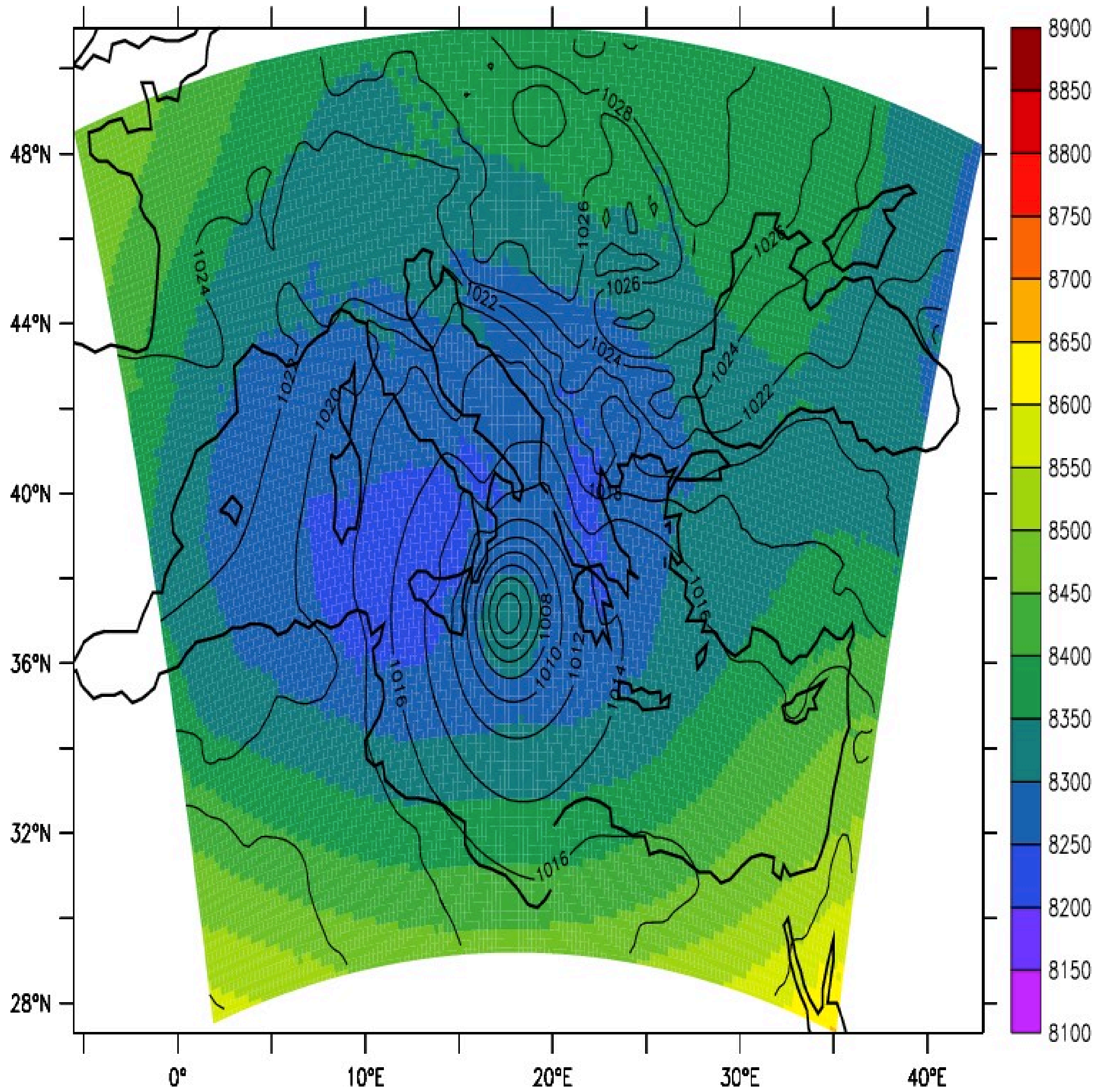
Intensity: 2802 x 10^{-6} s^{-1}
980 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

November – present climate



CLM (HadCM3Q0)
1971

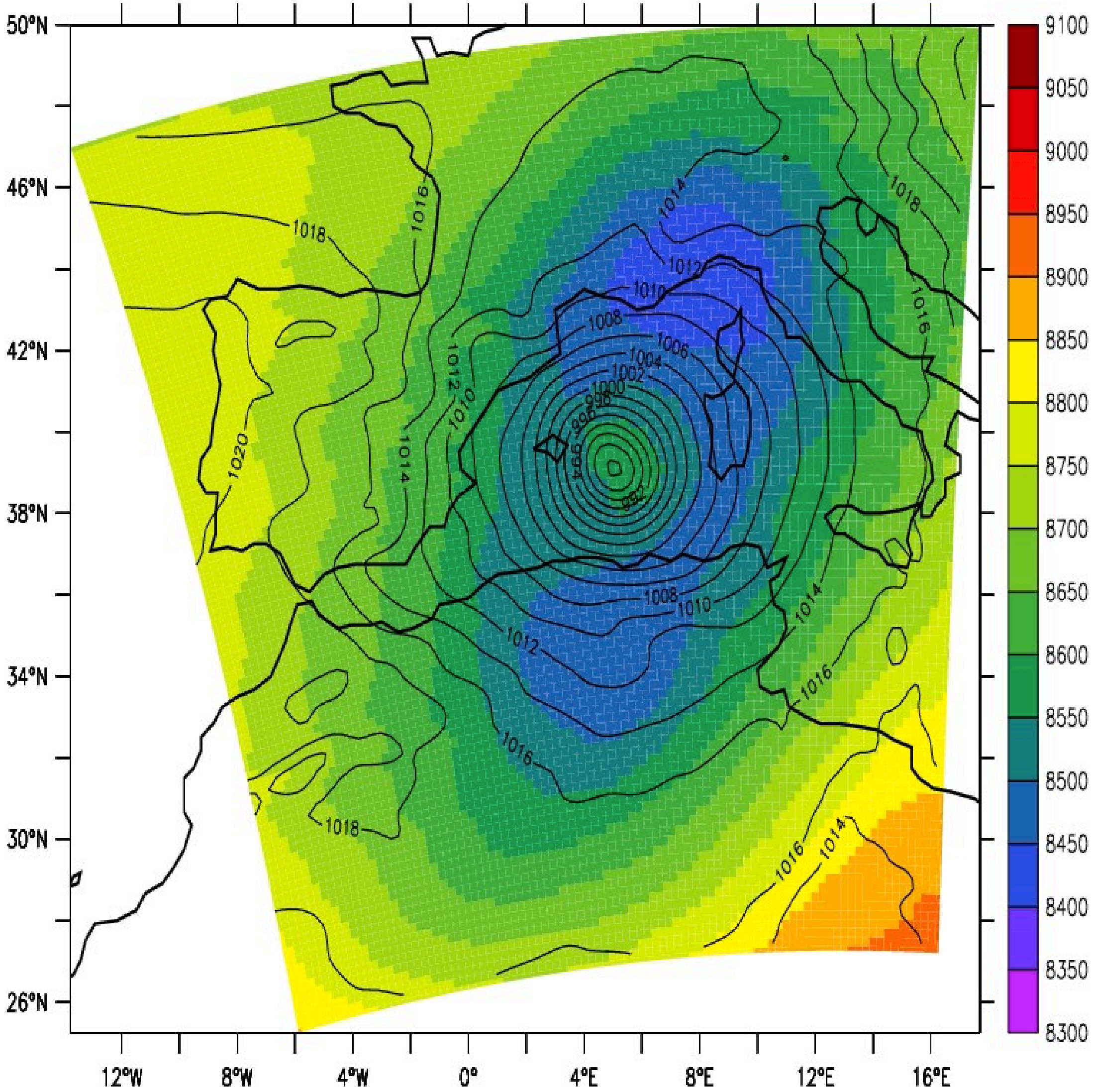
Intensity: 698 x 10^{-6} s^{-1}
1004 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

Preliminary analysis of most extreme cyclones

November – future climate



RegCM3 (ECHAM5)
2085

Intensity: 1025 x 10^{-6} s^{-1}
991 hPa

Sea level pressure (hPa, contours)

Geopotential thickness (300-925 hPa) (m, color)

CONCLUSIONS

- Risk of tropical cyclone development over the Mediterranean Sea for future climate change scenarios

- Risk characteristics: high uncertainty, high impact

- Different sources of uncertainty show important contribution (RCMs, GCMs, different parameterizations)

- Added value of RCMs

- Importance of using simulation ensembles when analyzing extremes

Reference

Gaertner et al. (2007): Tropical cyclones over the Mediterranean Sea in climate change simulations. *Geophysical Research Letters,* Vol 34, L14711, doi: 10.1029/2007GL029977