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23 - 25 September 2010

Mediterranean Sea Heat Budget: observed estimates, present-climate model evaluation and climate change scenarios

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Mediterranean Sea Heat Budget: observed estimates, present-climate model evaluation and climate change scenarios

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special thanks to E.SanchezGomez, A.Alias, S.Calmanti, B.Decharme, M.Déqué, M.P.Moine, F.Sevault, B.Rossow, Y.Zhang, P.Stackhouse, L.Yu, S.Josey, B.Nardelli, F.Orain, Bentamy, M. Rixen, D.Pettenuzzo, N.Pinardi, L.Brunault, CORIOLIS data center, ENSEMBLES modellers, CIRCE modellers

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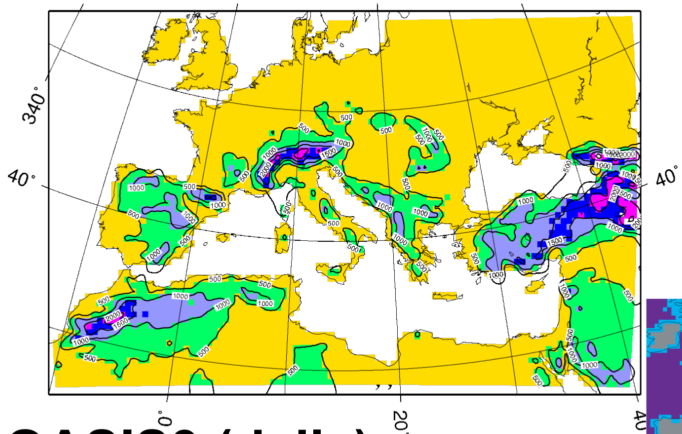
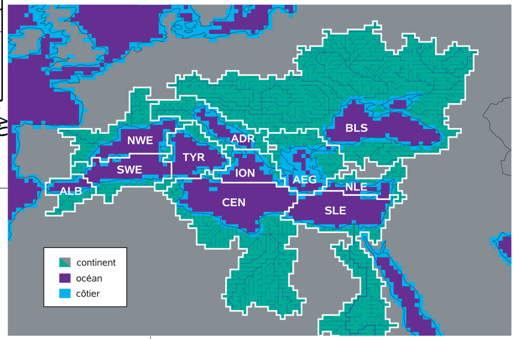
Regional climate system models for Mediterranean climate study

ALADIN-Climat v5 (ERA40, ERAInterim, GCM forcing) 50 km
(Déqué and Somot, 2008; Colin et al. 2010)

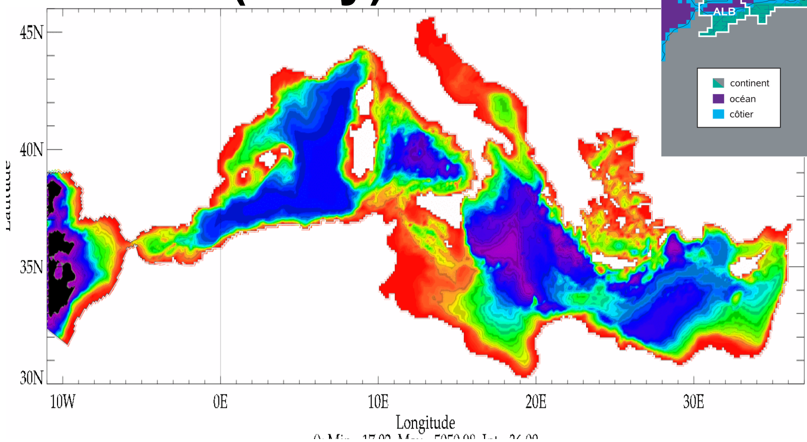


First simulation:
ERA40 period,
1958-2001

OASIS3 (daily)



TRIP river routine scheme at 50 km
(CNRM version, B.Decharme, pers.comm.)



NEMOv2-MED8 (10 km)
(Sevault et al. 2009, Beuvier et al. 2010)

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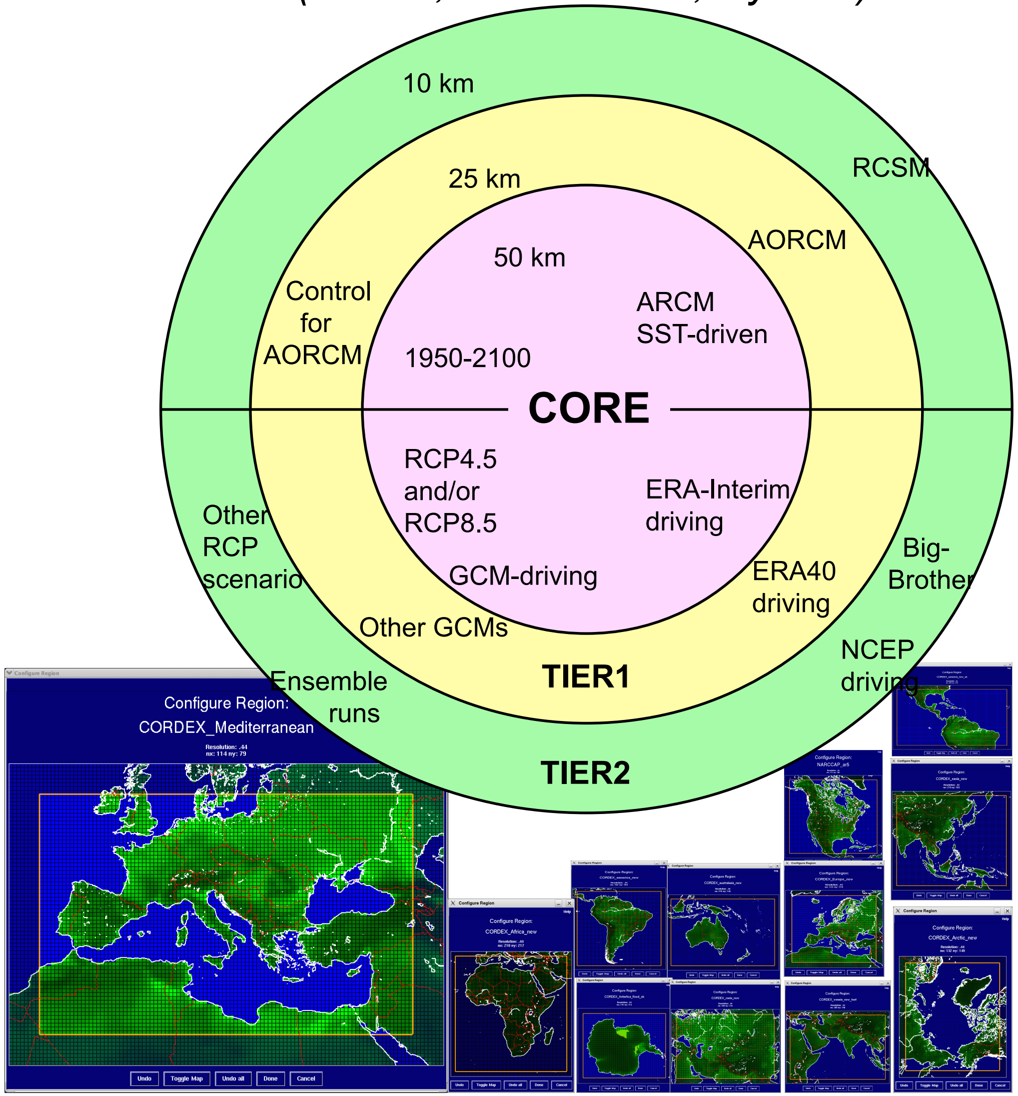
following Somot, 2005, Li et al. 2006, Somot et al. 2008, Artale et al. 2009

Towards a regional climate system model (RCSM) intercomparison: HyMeX & MedCORDEX (www.hymex.org)

Design of the Med-CORDEX exercise (WCRP, MedCLIVAR, HyMeX)



Nine different centres planned to design and use RCSM for the Mediterranean area in the next years (MedCORDEX, HyMeX-TTM3): ENEA-ICTP, IC3, LMD, LATMOS, CNRM, UCLM, Univ of Belgrade, MPI, COSMO-consortium

- How to validate this new models ?
- How to prove their added-value wrt ARCM or ORCM ?
-How to compare them in present climate and future climate ?

-Wind over sea: Sotillo et al. 2005, Ruti et al. 2007, Herrmann et al. (in prep)
-Med Sea Water Budget (E-P-R-B): Sanchez-Gomez et al. 2009, Elguindi et al. 2010, Aznar et al. 2010, SanchezGomez et al. (in revision), Josey et al. (submitted)

Let's start with the Med Sea Heat Budget …

Why to study the Mediterranean Sea Heat Budget (MSHB)

- Basin integrated process depending on complex local processes and different time and spatial scales
- Challenge for the regional climate modelling community (highly variable in space and time, sensitive to extremes, ocean-atmosphere coupling)
- Test-bed for the ocean-atmosphere regional coupled models
- Driver of the Med Sea thermohaline circulation
- Impacted by climate change
- Direct and indirect MSHB estimates are available (closure hypothesis at the Gibraltar Strait)

Requirements to study the MSHB

- High-resolution required
- Ocean-atmosphere interaction
- Interannual and long-term variability taken into account

Goals of the current study

- Estimate the MSHB terms from observations (in-situ, satellite)
- Evaluation of the MSHB of reanalyses, coupled and non-coupled RCMs, intercomparison
- First step towards an improvement of the MSHB in RCMs
- Climate change scenarios with coupled RCMs (CIRCE project)

Principle

- Focus on the 1989-2001 period for the estimation and evaluation
- Climate change scenario for 1950-2050, SRES-A1B, CIRCE models

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Observation estimates 1989-2001:

Short-wave | Long-wave | Latent Heat | Sensible Heat

SWdown + SWup + LWdown + LWup + LH + SH + GHT = dTHC/dt

MSHB | Gibraltar Heat Transport | Thermal Heat Content evolution

<u>GHT:</u>

- Béthoux, 1979: +7 ± 3 W/m2
- Macdonald et al. 1994: +5.2 ± 1.3 W/m2
- Beuvier et al. 2010 (Med Sea model, 1989-2001): +5.8 W/m2

<u>dTHC/dt:</u>

- Rixen et al. 2005: +0.2 W/m2
- CORA2.2: too short
- Beuvier et al. 2010 (Med Sea model, 1989-2001): +2.2 W/m2

<u>Indirect estimate for the surface MSHB:</u> Maximum range [-10 ; -1] W/m2

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Observation estimates 1989-2001:

SWdown + SWup + LWdown + LWup + LH + SH + GHT = dTHC/dt

SW:

- radiation + cloud + albedo + aerosols + gaz

- ISCCP-FD2, ~~SRB-GSW~~, SRB-QCSW, NOCS, ~~AJONC~~

strange time series — too short, no direct aerosol effect

LW:

- radiation + cloud + vertical profile of humidity and temperature + GHG

- ~~ISCCP-FD2~~, SRB-GSW, ~~SRB-QCSW~~, NOCS, ~~RSST OIv2~~, ENEA-OISST

Breaks in the time series — Very low values — Low resolution

LH, SH:

- humidity + atmo temperature + SST + wind + bulk formula

- OAFLUX, NOCS, ~~HOAPS-G~~, ~~IFREMER~~

Pb with the spatial coverage — Pb with coastal points

Other key points:

- Land-sea mask, horizontal resolution, length, mixed sea-land points

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Observation estimates 1989-2001:

W/m2	SW	LW	SH	LH	MSHB	Indirect
Obs Range	**[178;186]**	**[-77;-84]**	**[-6;-13]**	**-89**	**[-8;-1]**	**[-10;-1]**
NOCS (1°) *	**185**	**-84**	**-6**	**-89**	(+6)	
ISCCP-FD2 (2.5°)	**186**	X				
SRB-QC (1°)	**178**	X				
SRB-GEWEX (1°) **	X	**-77**				
AJONC (0.1°)	X					
OAFLUX (1°)			**-13**	**-89**		
IFREMER (0.5°)			X	X		
HOAPS (0.5°)			X	X		

* NOC1.1 Mediterranean Sea version (S.Josey, see Sanchez-Gomez et al., in revision)
** LWup: OISST from ENEA (daily, 10km), -418 W/m2 (OI RSST: -419 W/m2)

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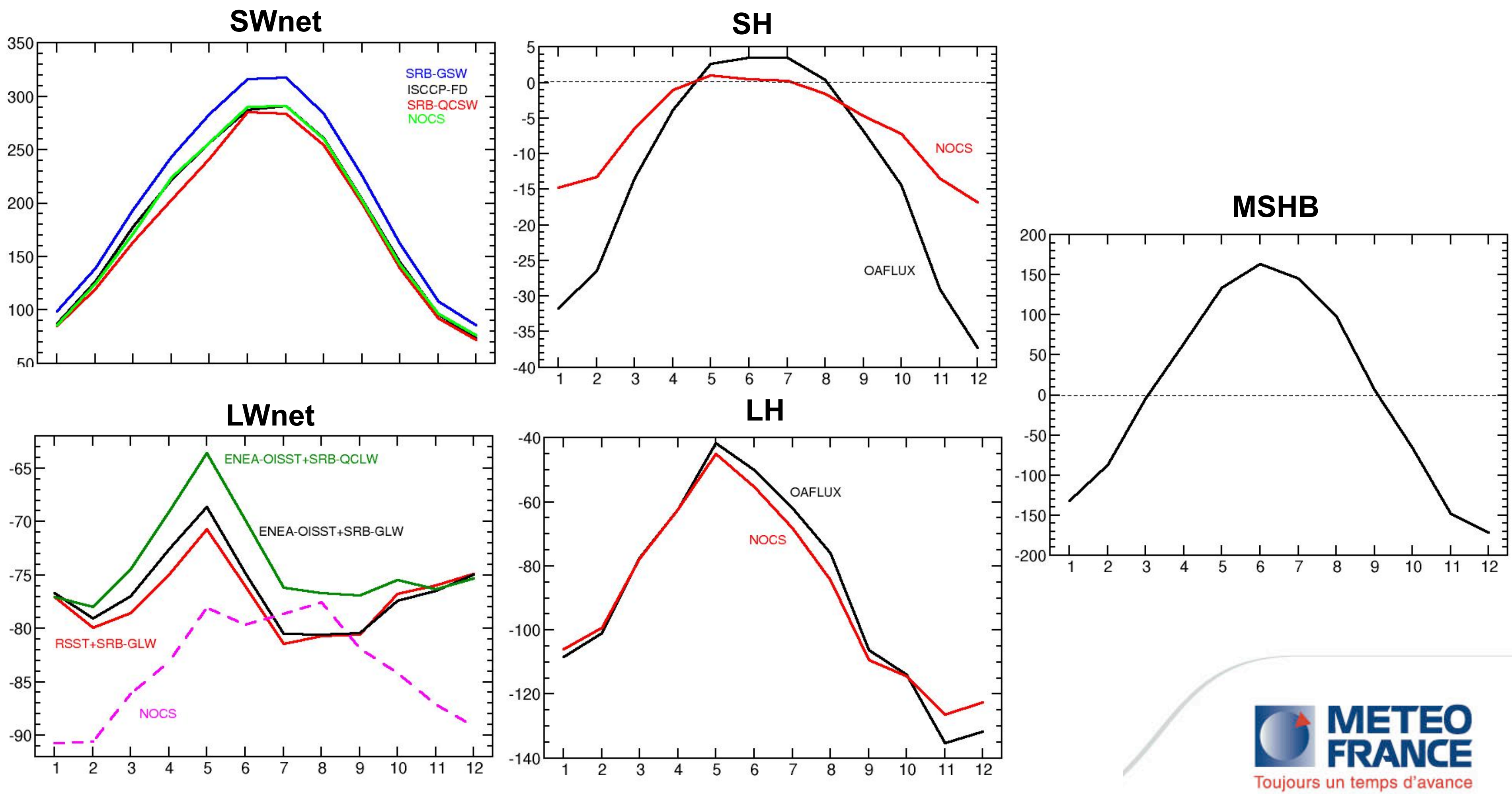
Observation estimates 1989-2001:

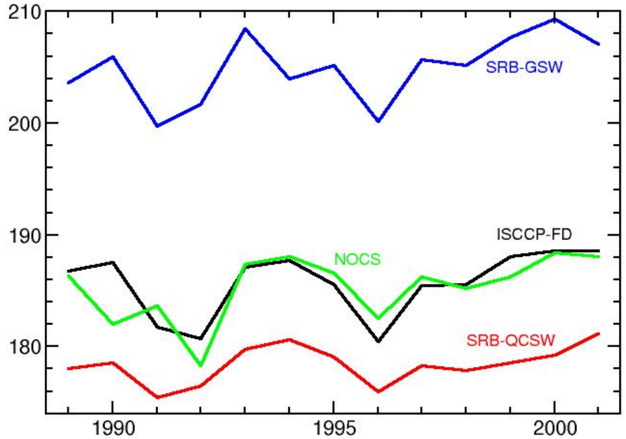
Mean seasonal cycle



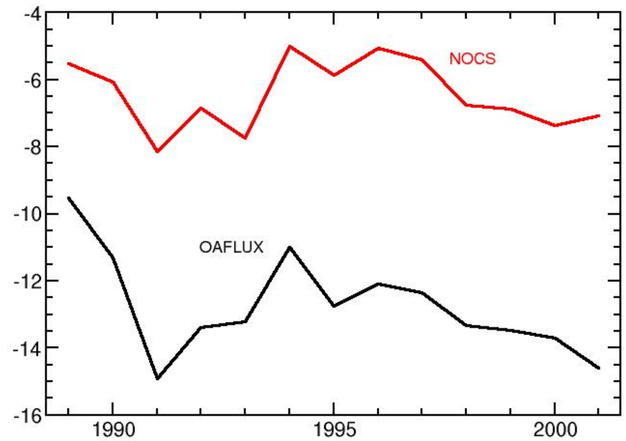
Observation estimates 1989-2001:

Interannual variability 1989-2001

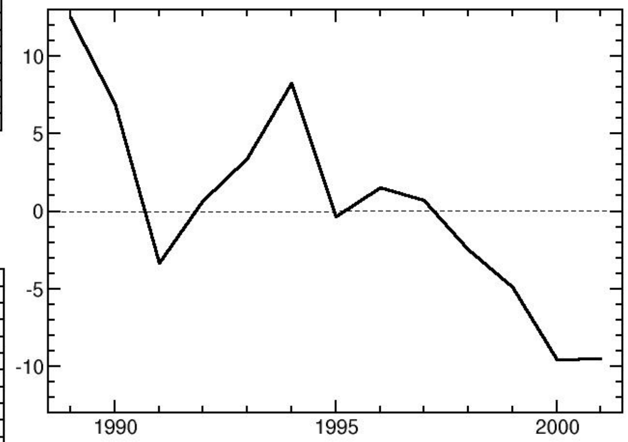
SWnet



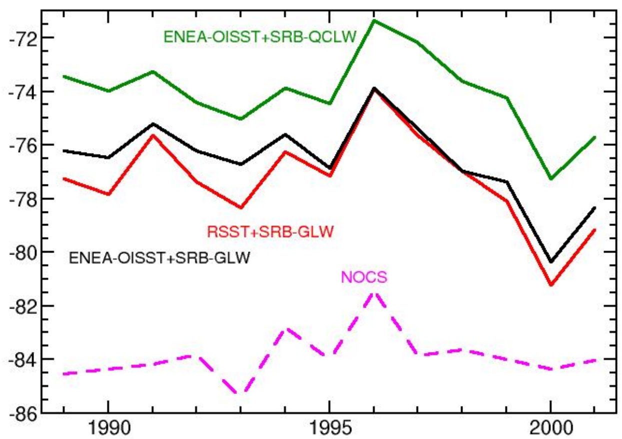
SH



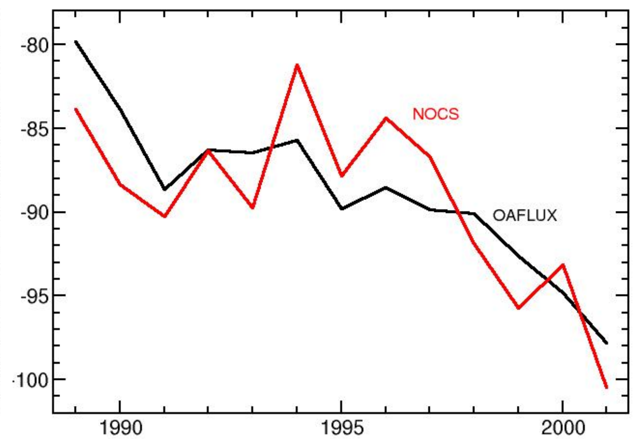
MSHB



LWnet



LH



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Data to evaluate: 1989-2001

Dataset to evaluate

- ERA40, ERAInterim
- INGV, ERA40 adjustment or Statistical Downscaling, *Pettenuzzo et al. 2010*
- HIPOCAS, Dynamical Downscaling of NCEP, *Sotillo et al. 2005* (not included)
- ARPERA, Dynamical Downscaling of ERA40, *Herrmann and Somot, 2008, Beuvier et al. 2010*

W/m2	SW	LW	SH	LH	MSHB	
Range	**[178;186]**	**[-77;-84]**	**[-6;-13]**	**-89**	**[-8;-1]**	
ERA40	**167**	**-80**	**-9**	**-93**	**-15**	
ERAInterim	**198**	**-83**	**-11**	**-95**	**+9**	
INGV-SDS-ERA40	**180**	**-80**	**-14**	**-91**	**-5**	
CNRM-DDS-ERA40	**187**	**-79**	**-12**	**-110**	**-13**	

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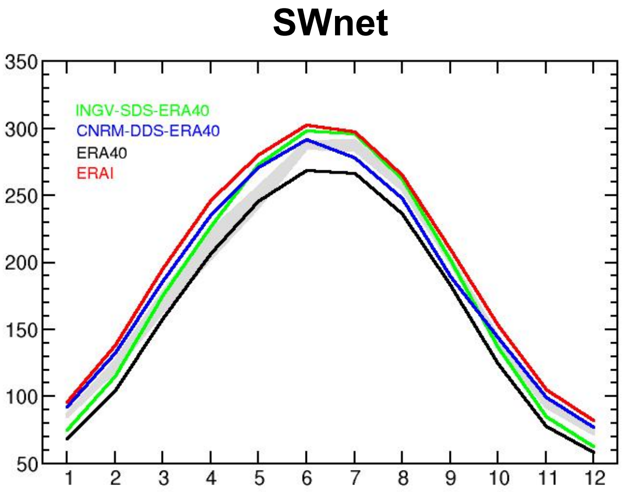
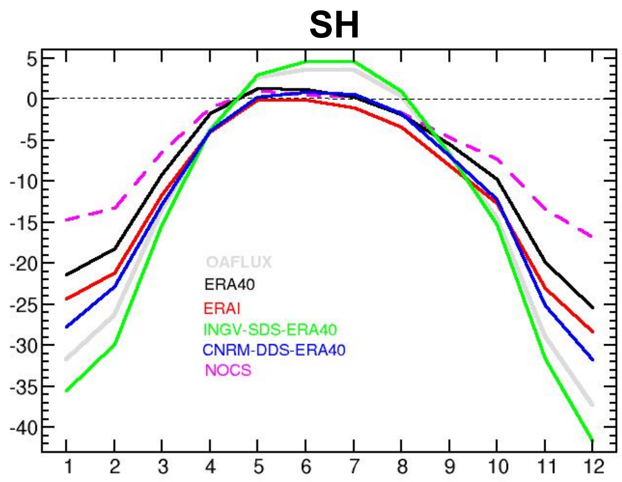
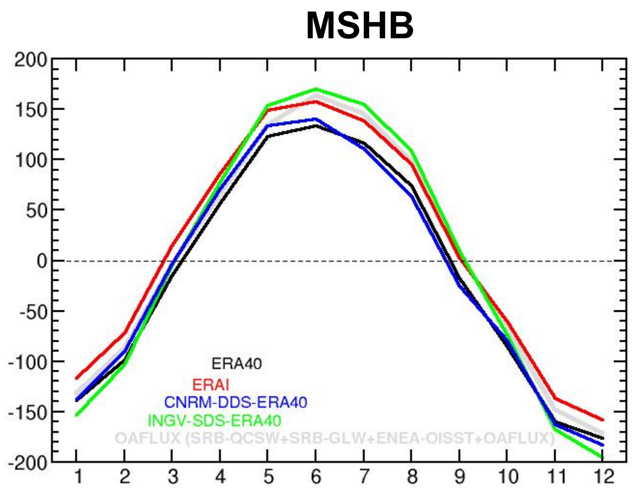
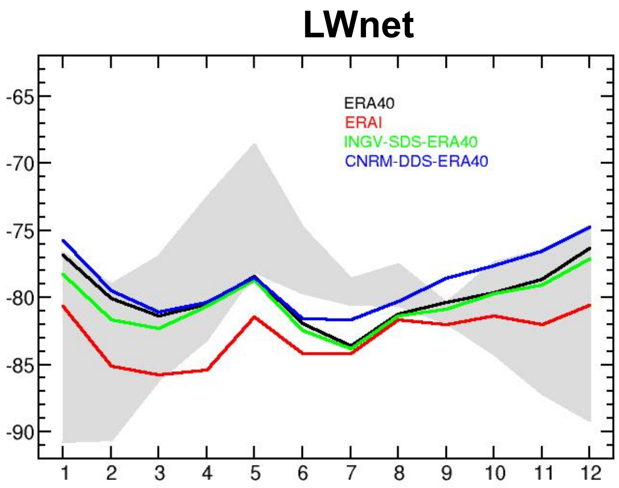
Data to evaluate: 1989-2001

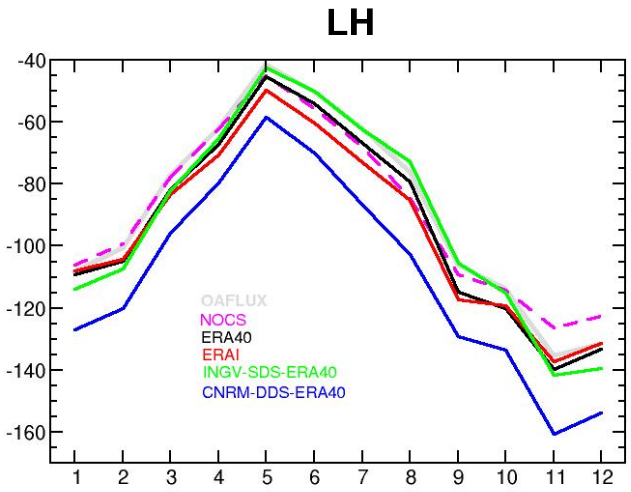
Mean seasonal cycle











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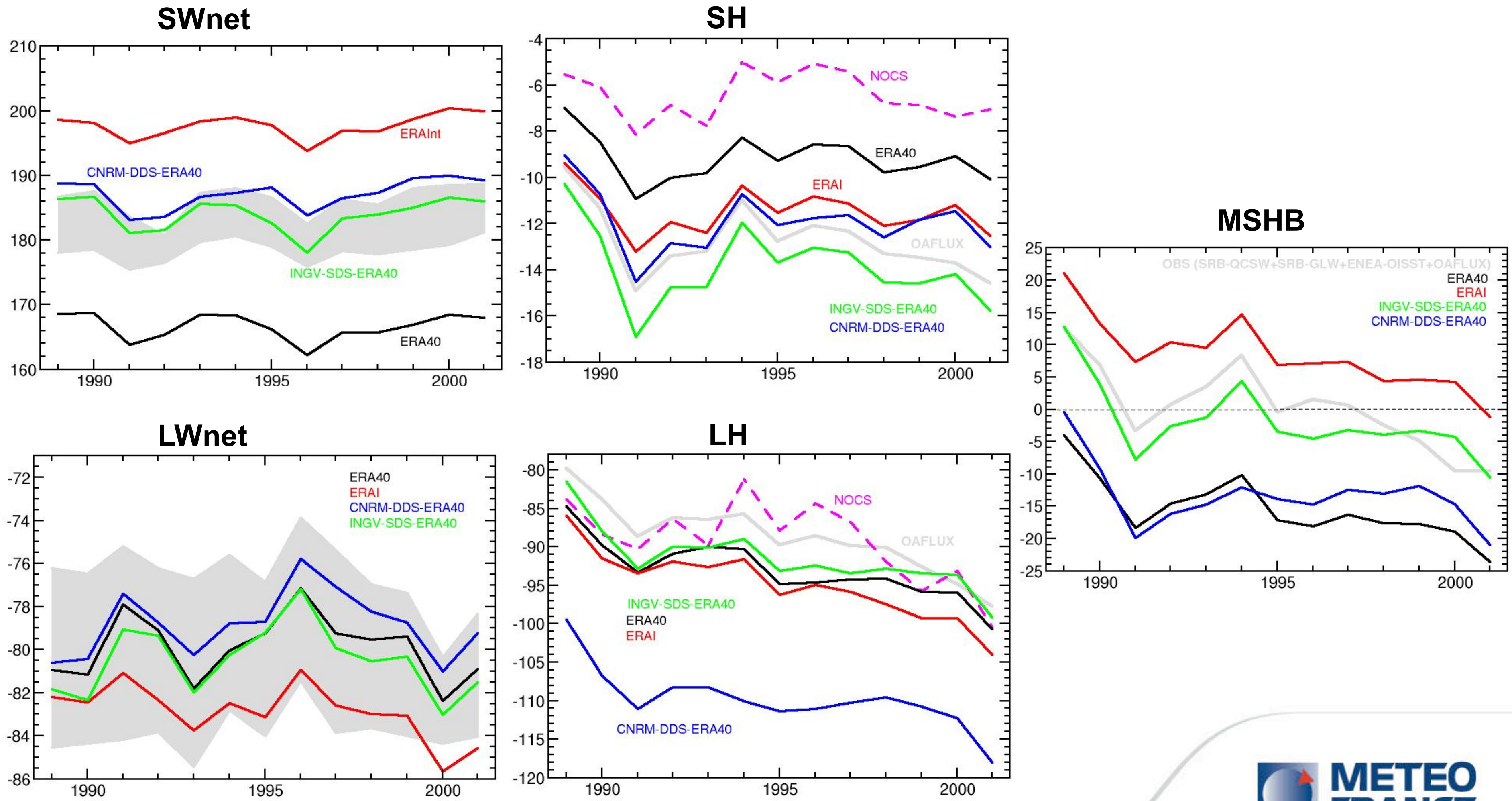
Data to evaluate: 1989-2001

Interannual variability 1989-2001



RCMs to evaluate

Regional climate modelling tools

- **ENSEMBLES ARCMs,** 15 models, 25km, ERA40 driven (available on 1989-2001), also see Sanchez-Gomez et al. 2009 and Sanchez-Gomez et al. (in revision)

KNMI (the best ENSEMBLES RCMs when forced by ERA40)

MPI (REMO)

ICTP (RegCM)

CNRM (ALADIN)

- **CIRCE-HyMeX AOR-RCMs or RCSM (Regional Climate System Models)**, 30-50km, ERA40 driven (available on 1989-2001)

LMD (LMDZ/NEMOMED8)

MPI (REMO/MPIOM/River)

ENEA (PROTHEUS: RegCM/MITgcm/IRIS)

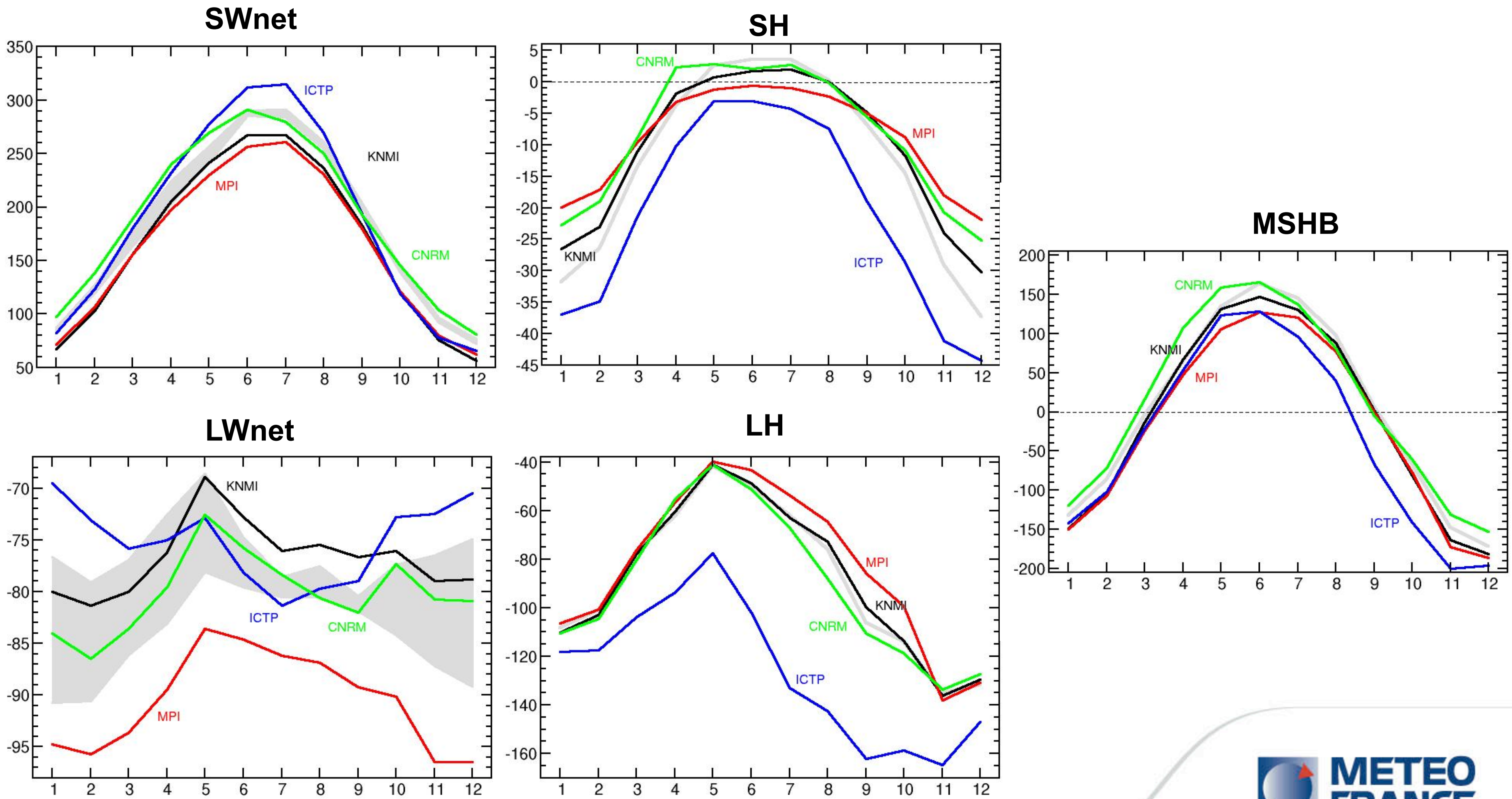
CNRM (ALADIN/NEMOMED8/TRIP)

(AOR)RCMs to evaluate (1989-2001)

W/m2	SW	LW	SH	LH	MSHB	
Range	**[178;186]**	**[-77;-84]**	**[-6;-13]**	**-89**	**[-8;-1]**	**OBS**
ENSEMBLES RCMs						
KNMI (best RCM)	**165**	**-77**	**-11**	**-88**	**-11**	ENS
MPI	**163**	**-91**	**-9**	**-83**	**-20**	ENS
ICTP	**187**	**-75**	**-21**	**-127**	**-36**	ENS
CNRM (v4.5)	**190**	**-80**	**-9**	**-91**	**+10**	ENS
CIRCE RCSMs						
LMD	**208**	**-96**	**-14**	**-102**	**-4**	CIRCE
MPI	**154**	Missing LWup **X**	**-10**	**-80**	**X**	CIRCE
ENEA	**201**	**-81**	**-20**	**-93**	Problem **x**	CIRCE
CNRM (v5.1)	**199**	**-81**	**-11**	**-109**	**-2**	HYMEX

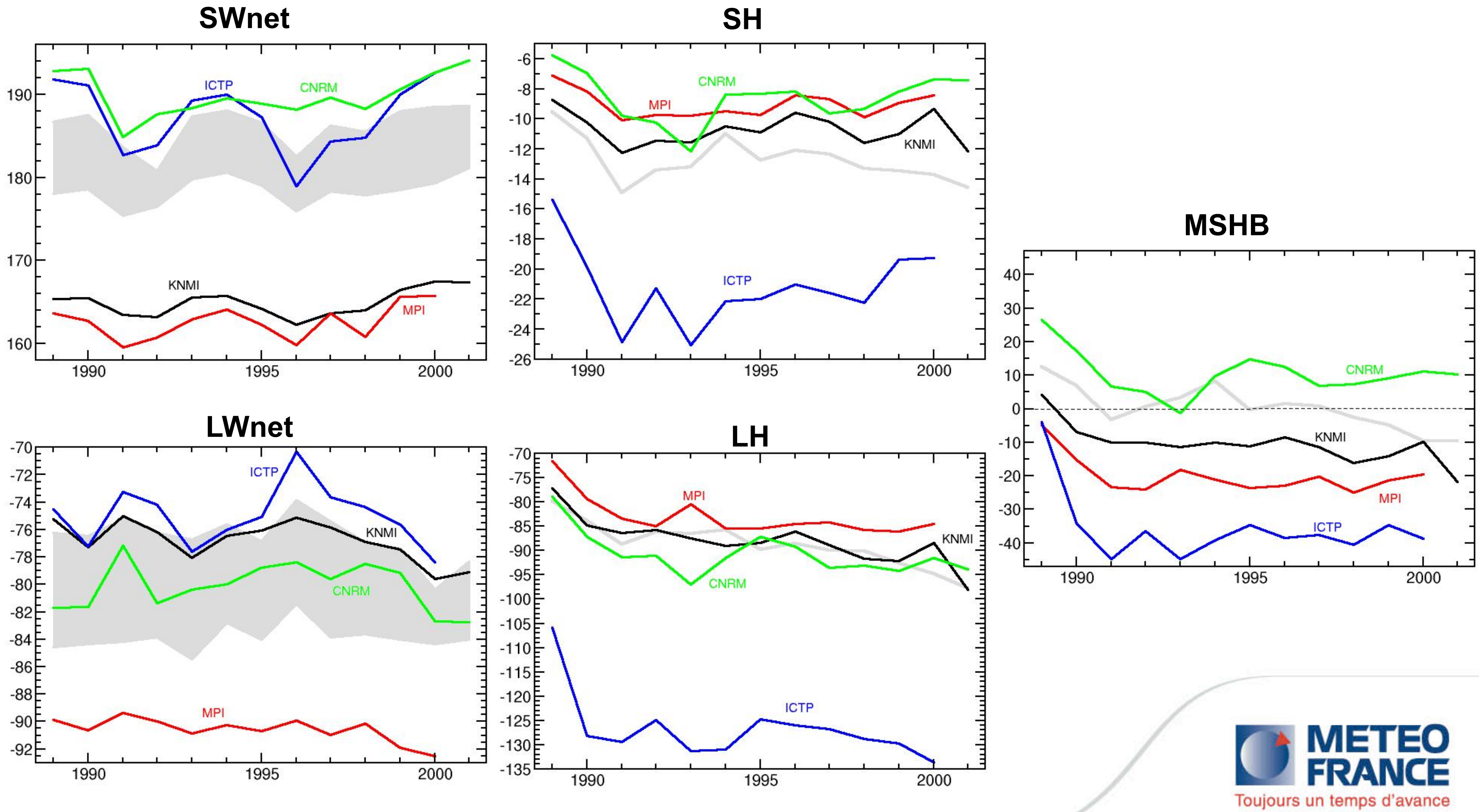
RCMs to evaluate: ENSEMBLES

Mean seasonal cycle



RCMs to evaluate: ENSEMBLES

Interannual variability 1989-2001



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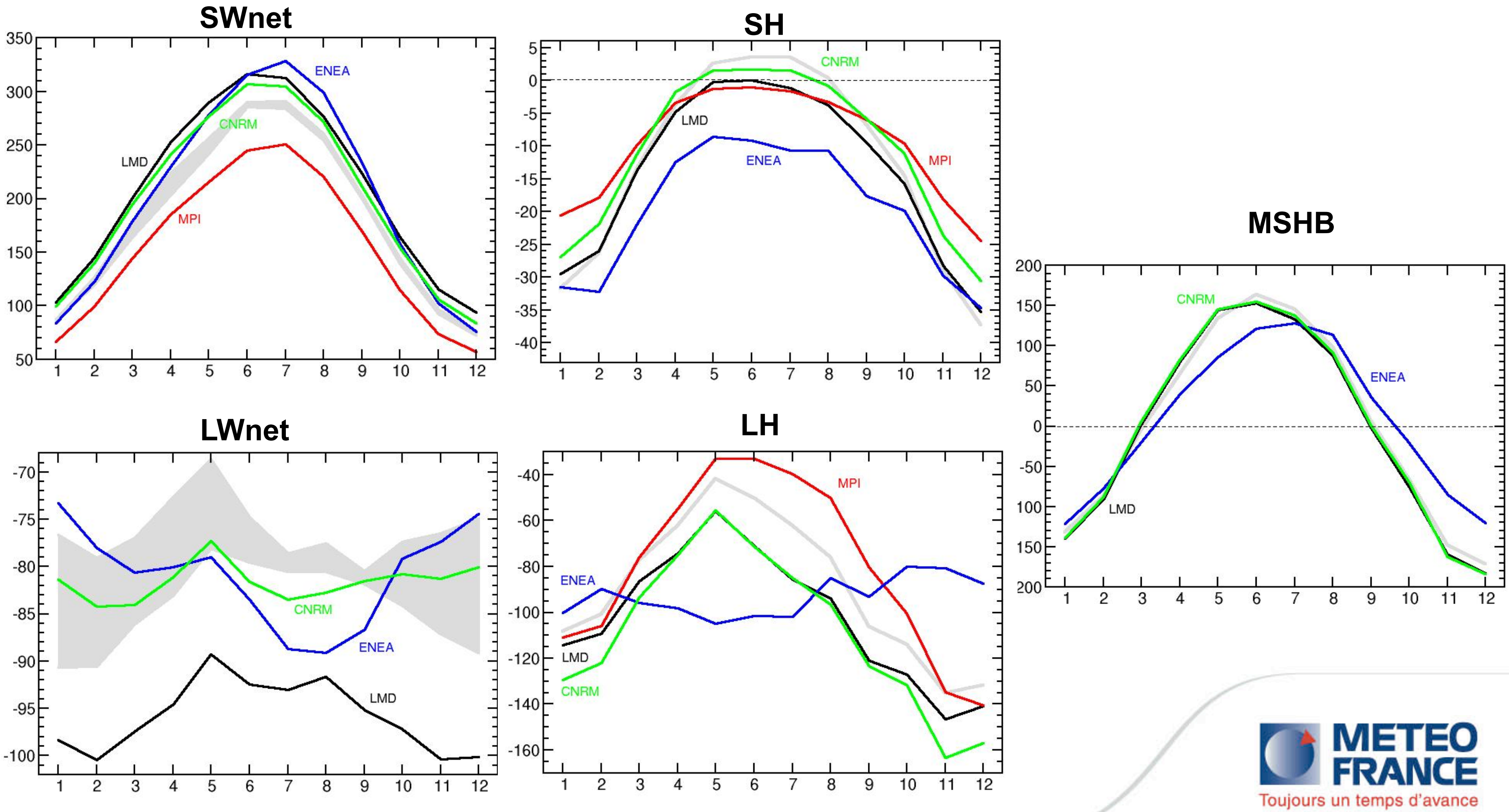
RCMs to evaluate: CIRCE

Mean seasonal cycle



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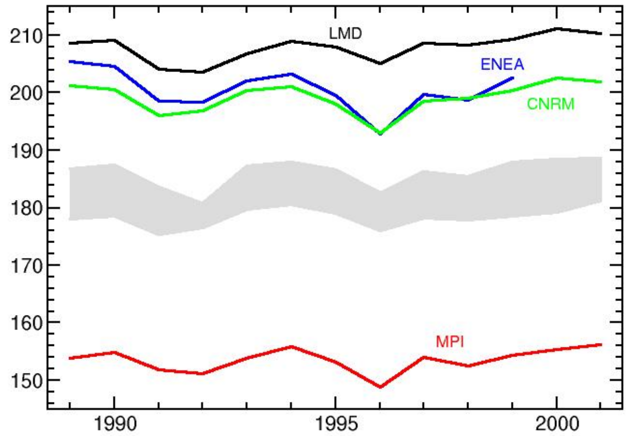
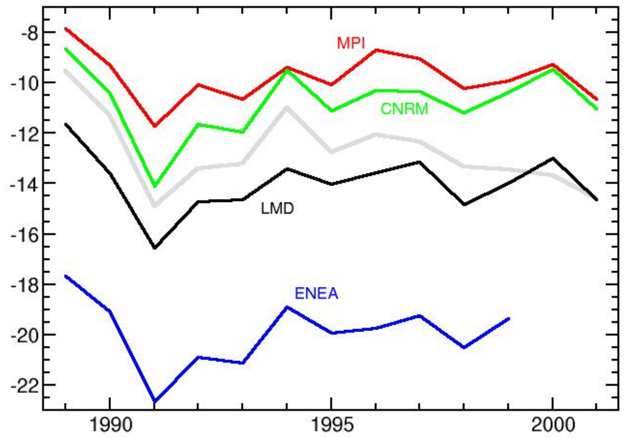
RCMs to evaluate: CIRCE

Interannual variability 1989-2001

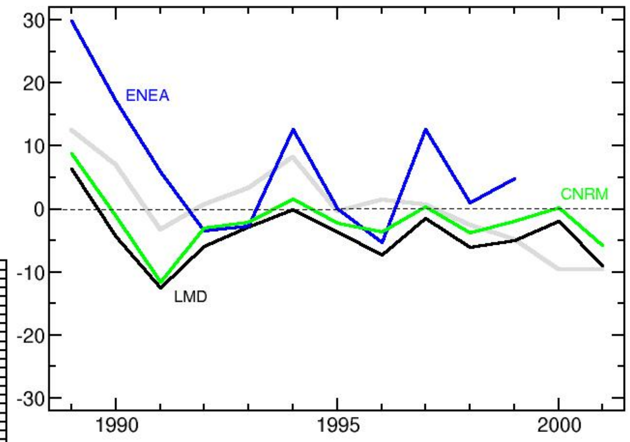
SWnet



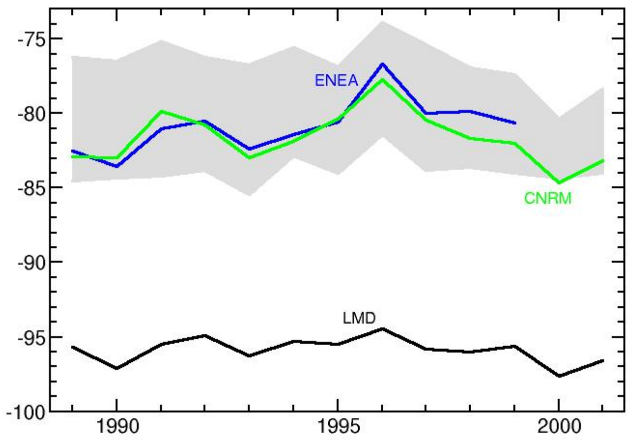
SH



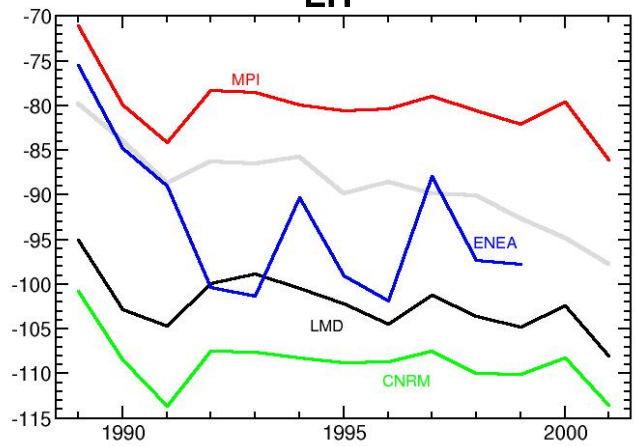
MSHB



LWnet



LH



Tests with ALADIN-Climate: 1989-2001

Working on improving the MSHB of ALADINv5.1

(HyMeX version but not the same as in ENSEMBLES)

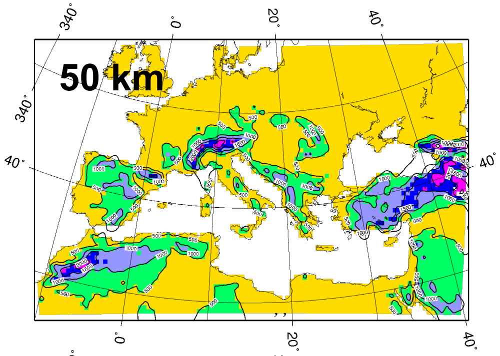
- ALADIN vs ALADIN/NEMOMED8/TRIP
- ERA40 vs ERAInterim
- Use of the spectral nudging
- 50 and 12 km
- Change in the parameterizations:

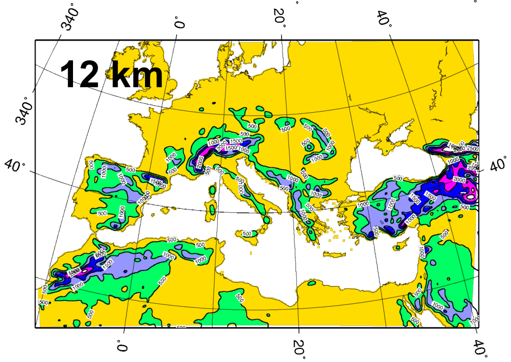
    Radiative code: RRTM vs FMR15

    Bulk formula: ECUME vs Louis 1979

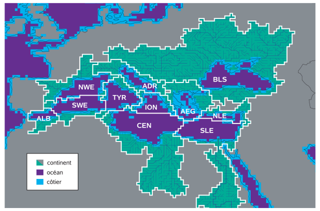
    Prognostic physics vs diagnostic (TKE, water)

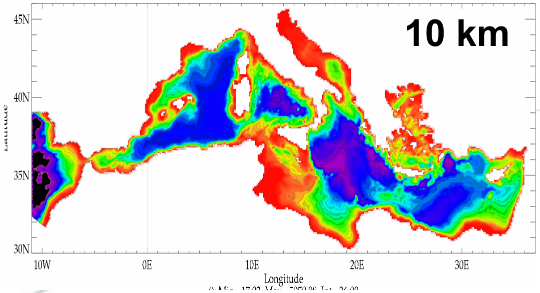
    others (to be done)





50 km





Tests with ALADIN-Climate 1989-2001: MED50

W/m2	SW	LW	SH	LH	MSHB	
Obs range	**[178;186]**	**[-77;-84]**	**[-6;-13]**	**-89**	**[-8;-1]**	
MED50-ERA40 (M15)	196	-81	-11	-109	-5	REF
MED50-ERA40-SN (M16)	195	-81	-12	-119	-17	SN
MED50-ERA40-AOR (CBNT2)	199	-81	-11	-109	-2	AOR
MED50 – ERAI (M10)	197	-81	-12	-104	0	ERAI
MED50 – ERAI - ECUME (M11)	200	-86	-13	-88	+13	ECUME
MED50 – ERAI - RRTM (M12)	199	-81	-8	-104	+6	RRTM
MED50 – ERAI – PROG (M13)	196	-85	-13	-104	-6	PROG
MED12 – ERAI (MB1)	202	-85	-10	-111	-4	12km

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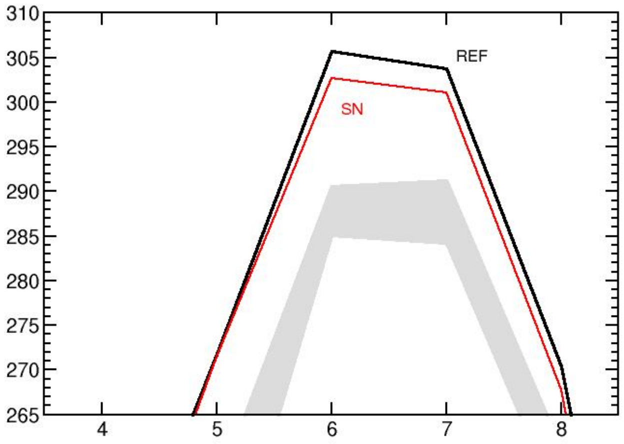
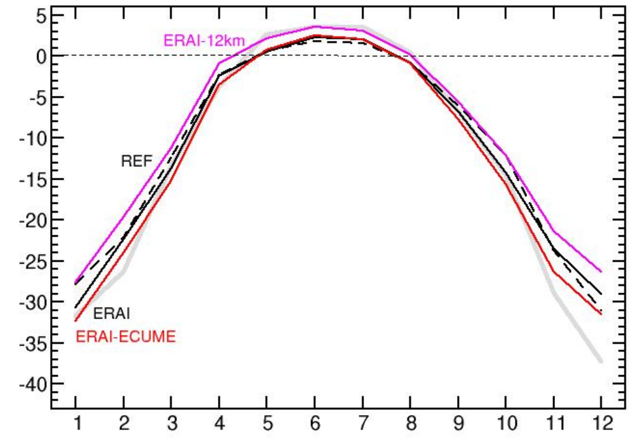
Tests with ALADIN-Climate

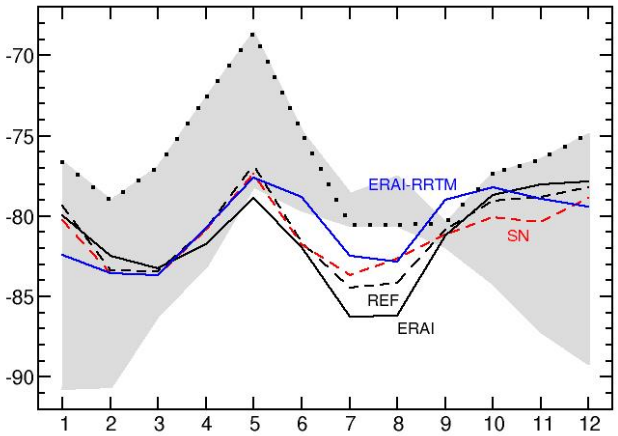
SWnet



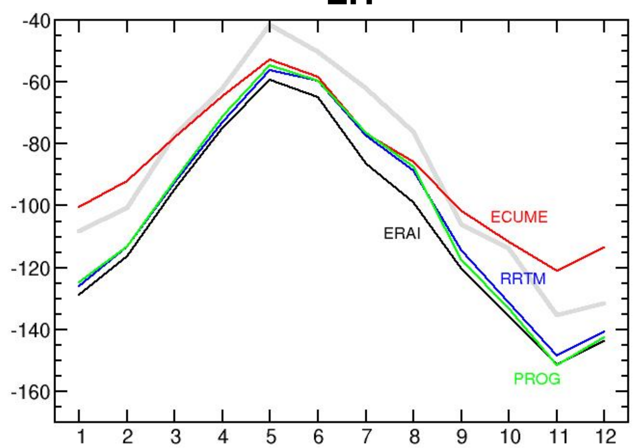
SH



LWnet



LH



Conclusion on the evaluation

Conclusion :

-Observations: problem with SH in NOCS (personal feeling), satellite data not always homogeneous in time, still big problem and large range of uncertainty (178;186 W/m2 for SW and -84;-77 W/m2 for LW), but we closed the budget with surface in-situ and satellite data (for the first time ?!)

-Reanalyse: problem with the SW due to cloud cover

-SDS et DDS: Pettenuzzo's data agree well, ARPERA: problem with the LH term

-ARCM: no one perfect, large spread

-RCSM: always a good MSHB (but the components and SST)

-ALADIN tests: ERAInterim forcing and the new bulk formulae improve LH

-No positive impact of SN, RRTM, 12km, Prognostic physics, coupling

Advices:

-For observations and satellites: Higher resolution, better taking into account the land-sea contrast, check and remove breaks

-For SDS: better check the reference data, more complex correction (quantile)

-For modellers, careful look at the air-sea fluxes, check in non-coupled and coupled mode, work on the parameterizations

-For the rest of the community: help us for validation and valorisation (ENSEMBLES, HyMeX, MedCORDEX, MedCLIVAR databases)

Climate change scenario

ENSEMBLES runs: A1B, 1950-2100, 13 models:

Most of the ENSEMBLES RCMs lead to an increased cooling of the Med Sea by the air-sea fluxes along the 21st century (The RCMs react to the SST increase). The design RCM+forcing by SST is not adapted to the study of the MSHB under climate change as, in reality, the SST reacts to the atmosphere warming and not the opposite

CIRCE runs: A1B, 1950-2050, ENEA, INGV, MPI, CNRM, LMDZglo, (LMDZreg)

The 5 models give a qualitatively similar response between the period 2021-2050 and the period 1961-1990 with:

- an increase in SW heat gain: less cloud as Med area dries.
- a decrease in the LW loss: the GHG effect wins against the SST increase
- a decrease in the SH loss: the air-sea temperature gradient decrease as the land and the atmosphere warms faster that the ocean (land-sea contrast increase). And wind decrease.
- an increase in the LH heat loss: increase of the humidity gradient as the atmosphere can contain more humidity with a warmer SST and the Med area becomes drier.

Finally the surface net heat loss decreases during the 21st century leading to a weaker cooling of the ocean by the atmosphere or even a warming

Climate change scenario

Difference 2021-2050 vs 1961-1990, A1B	SW	LW	SH	LH	MSHB	
Ensemble Mean	**+2.2**	**+1.9**	**+1.5**	**-2.5**	**+3.1**	
ENEA	+2.3	+1.7	+0.9	-3.0	+1.9	
INGV	+1.5	+1.8	+1.5	-2.0	+2.8	
MPI	+0.8	+1.2	+0.9	-0.8	+2.1	
CNRM	+2.4	+1.9	+0.7	-3.4	+1.6	
LMDZglo	+2.6	+2.8	+2.9	-2.8	+5.5	

More warming

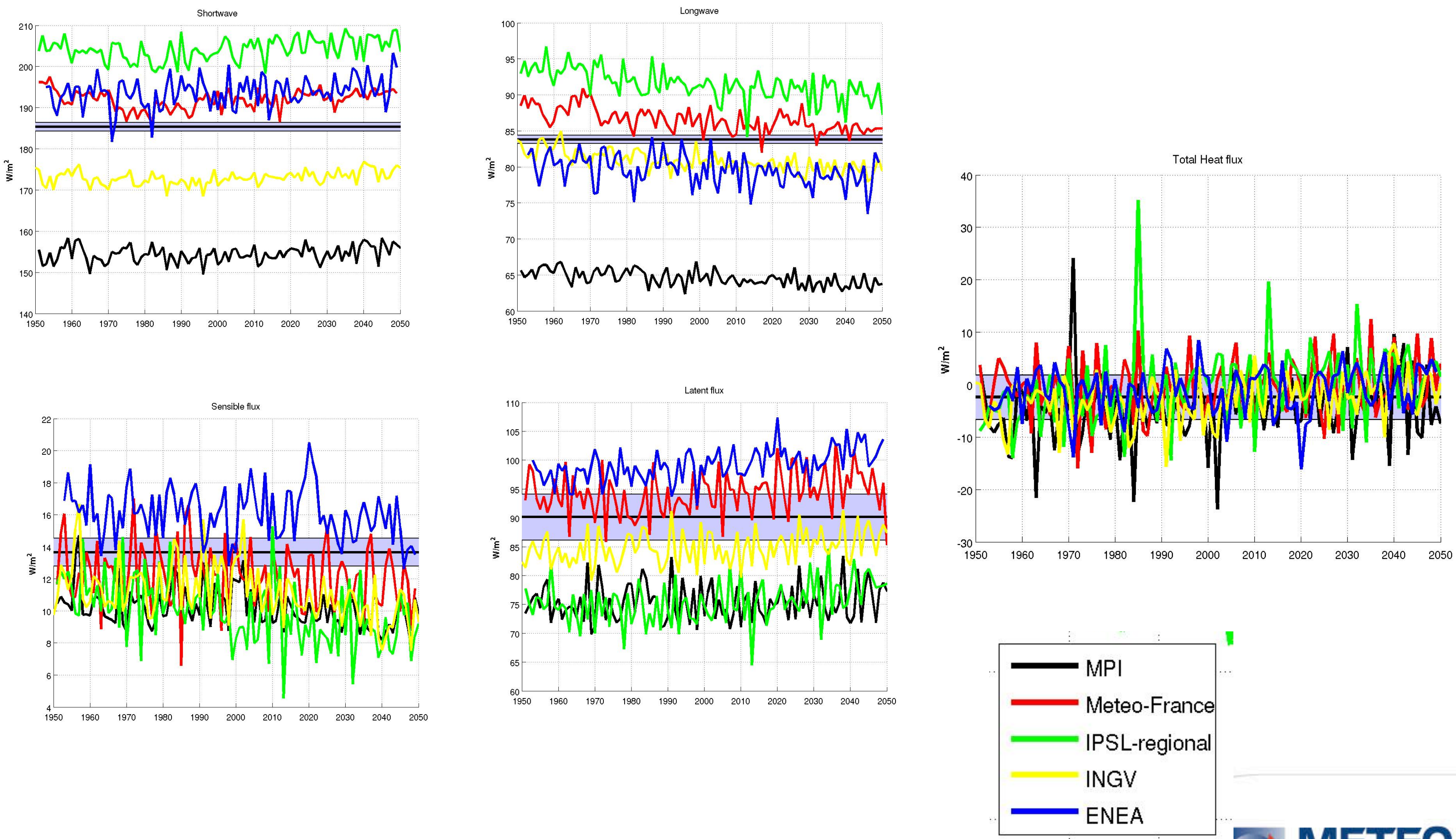
Less cooling

Less cooling

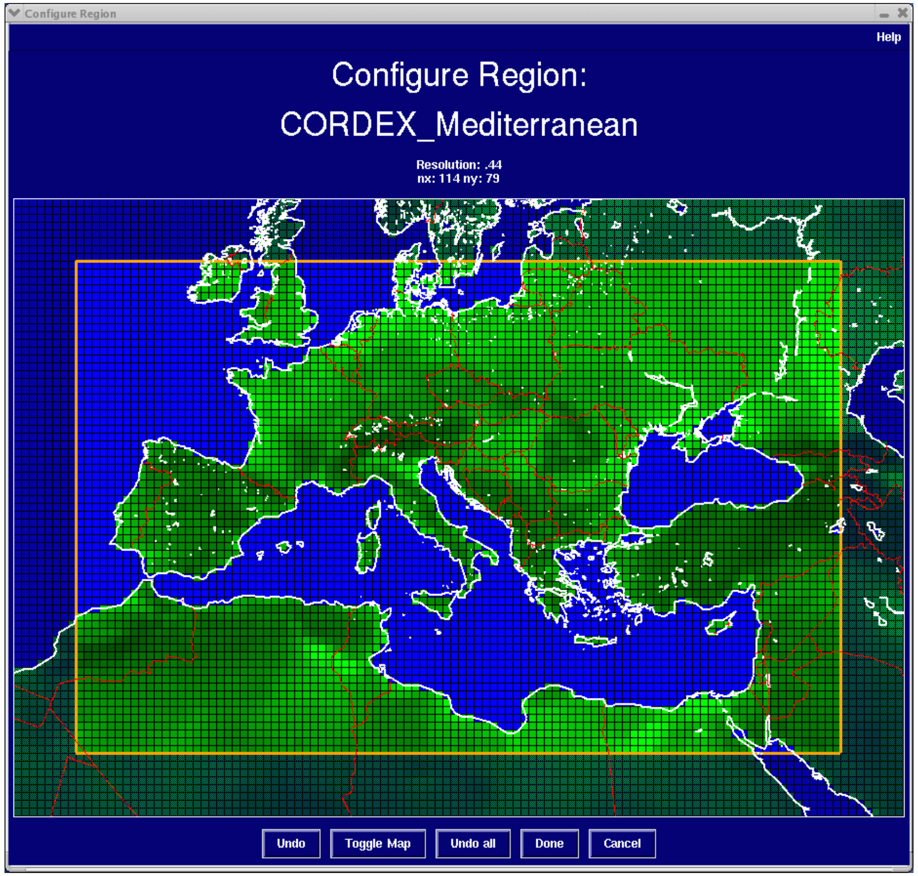
More cooling

Less cooling

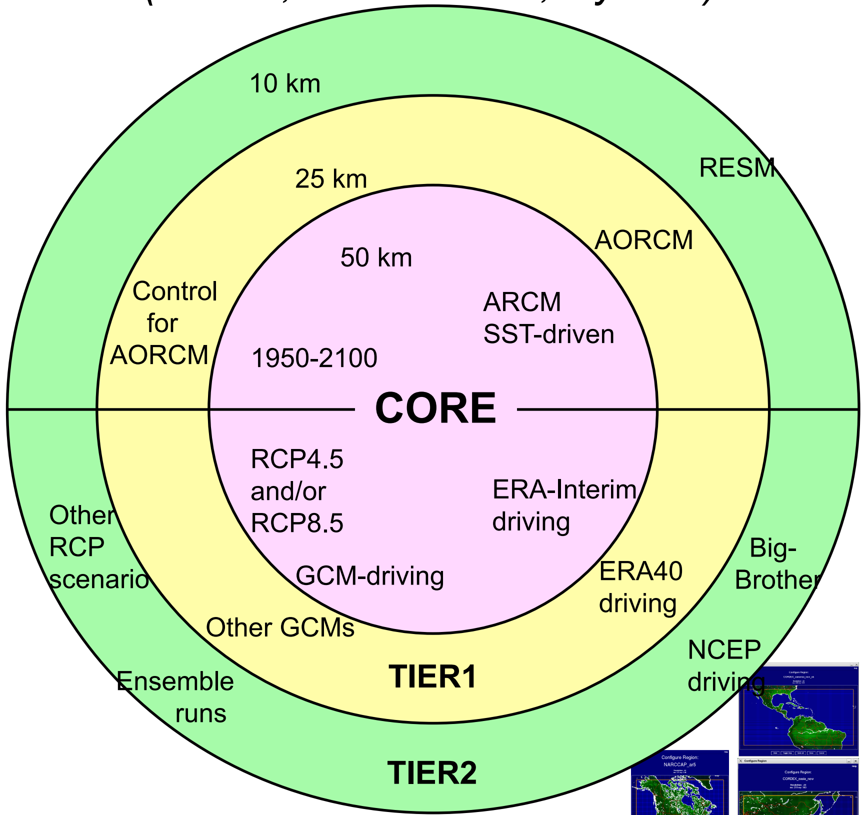
Climate change scenario

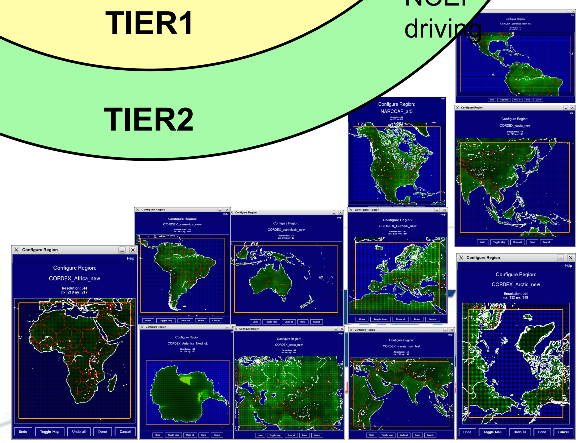


Towards a regional climate system model intercomparison: HyMeX MedCORDEX (www.hymex.org)



Design of the Med-CORDEX exercise (WCRP, MedCLIVAR, HyMeX)

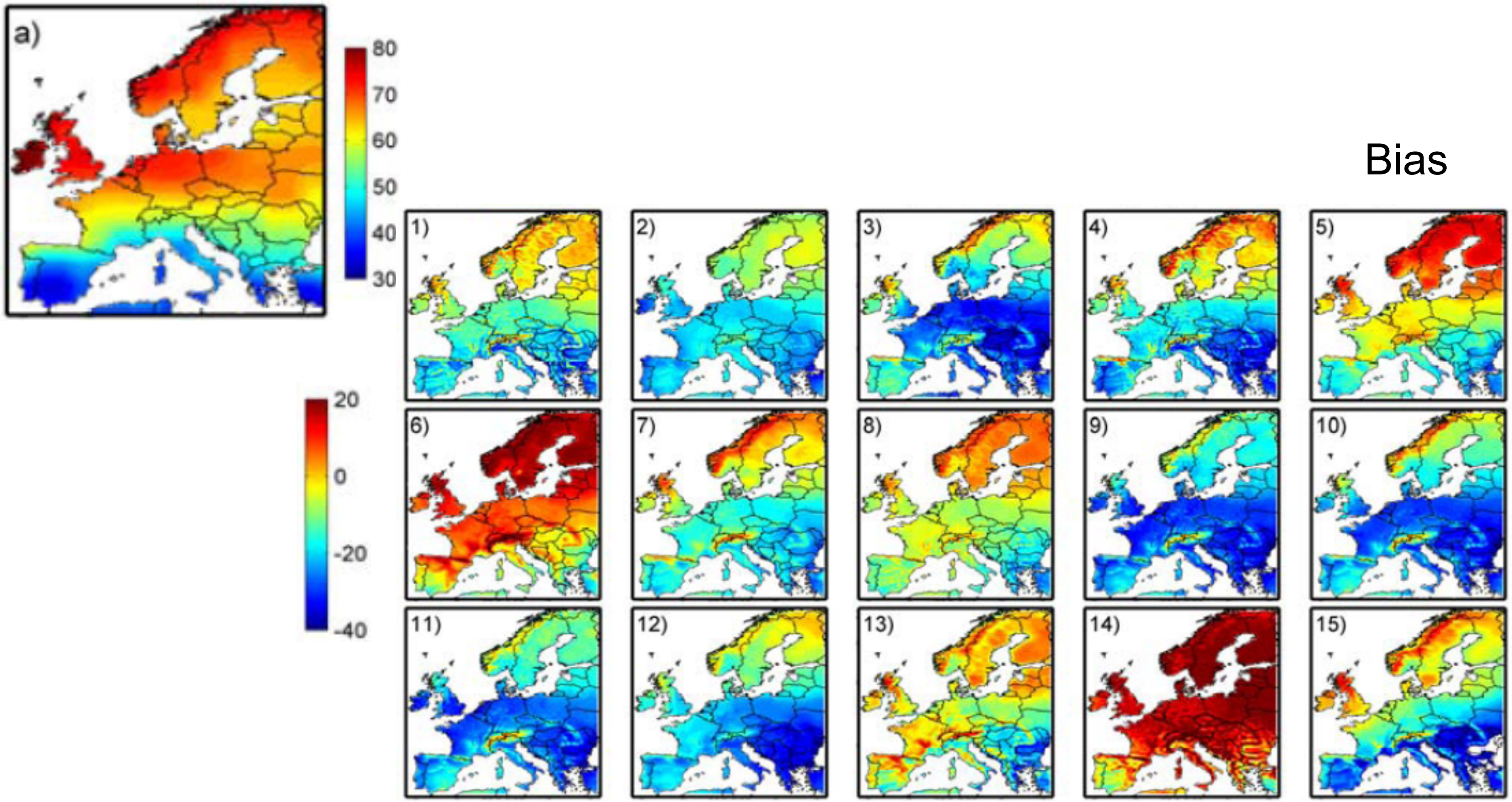




To register, just send an email to hymex-TTM3@cnrm.meteo.fr

Examples: Med Sea Heat Budget

ISCCP-D2 cloud fraction dataset for SW flux in Summer (W/m2)
Christensen et al. 2010, accepted



Forcing for a Med Sea Model

Surface fluxes (see also talk by E. Tragou):

T evolution: $$\frac{\partial T}{\partial t} \propto \frac{Q}{\rho . C_p}$$

$Q = Q_{SW} + Q_{LW} + Q_S + Q_L$

Q_{SW}: from the radiative scheme of the atmosphere model + albedo

Q_{LW}: downward (atm. model radiative)
upward : $\varepsilon.\sigma.T_o^4$

Q_S = sensible heat flux
$-\rho_a.C_p.C_S(u).(T_O-T_A)$

Q_L = latent heat flux
$-\rho_a.L.C_e(u).(q_S(T_o)-q_A)$

$$\frac{\partial S}{\partial t} \propto \frac{(E-P-R)}{h}.S$$

E: evaporation from Q_h
P: precipitation
R: river + Black Sea

$$\frac{\partial \vec{V}}{\partial t} \propto \frac{rot(\vec{\tau})}{\rho}$$

$$\tau = \rho_a C_d(u).u^2$$

SST coupling

METEO FRANCE
Toujours un temps d'avance

Forcing for a Med Sea Model

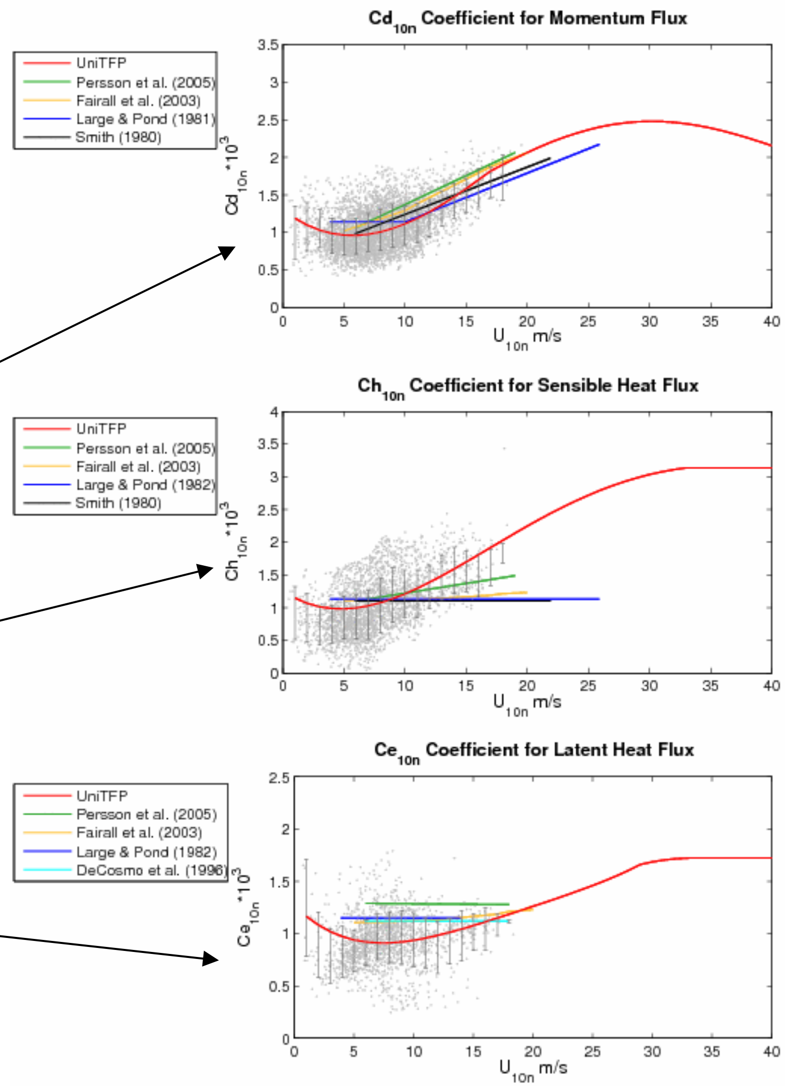
Turbulent fluxes (Latent, Sensible, Wind stress) are computed through the « bulk formula »:

$\tau \;\; = -\rho_a C_d(u).u^2$

$Q_L = -\rho_a.L.C_e(u).(q_S(T_o)-q_A)$

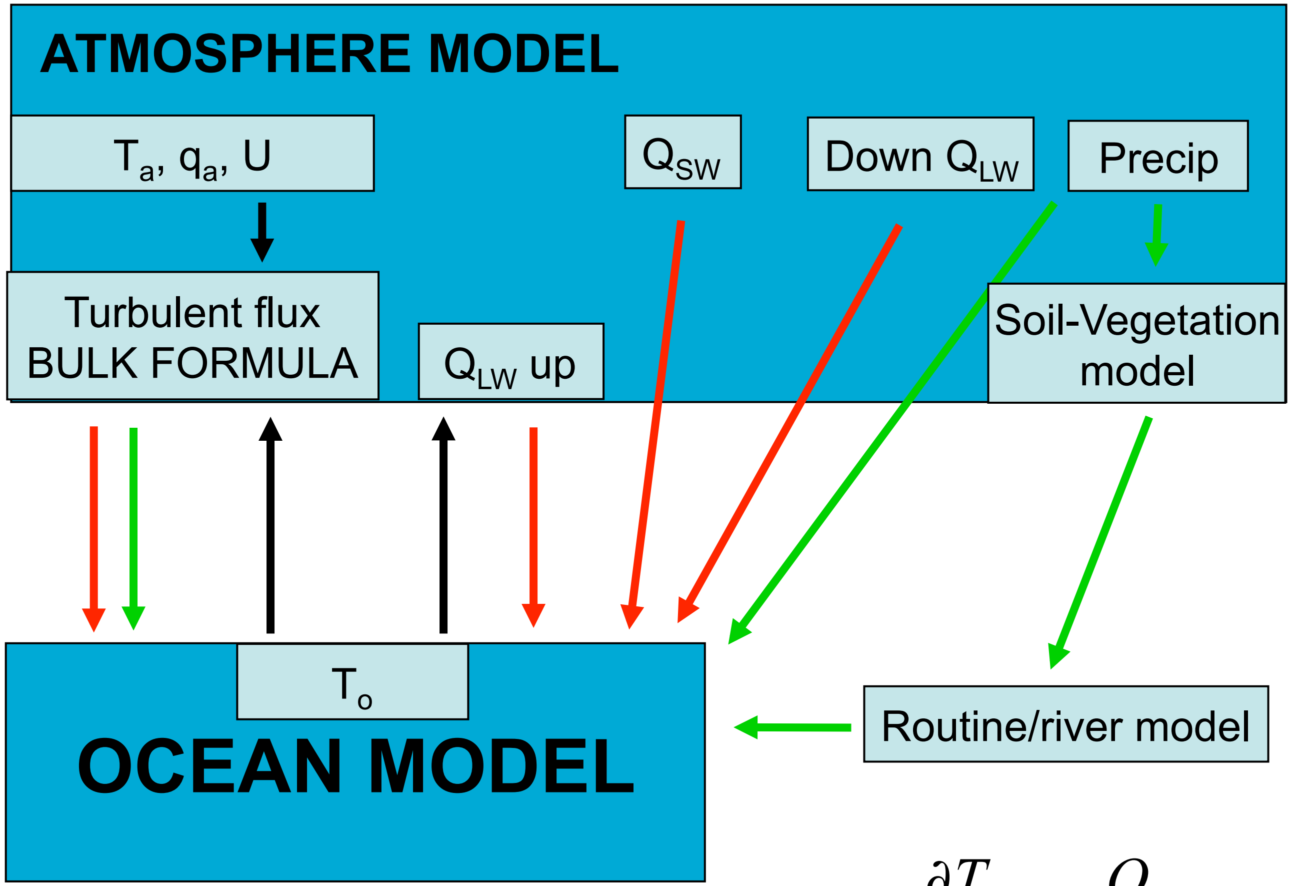
$Q_S = -\rho_a.C_p.C_S(u).(T_O-T_A)$

C_d ,C_S ,C_e are the tranfer coefficient computed from empirical formula based on in-situ measurment (depend on the wind, neutral atmosphere)



Forcing for a Med Sea Model

The (high-frequency) on-line coupled approach



Bulk formula and Q_{LW} up are inside the atmosphere model. They are computed every time step (30 min) and the fluxes are cumulated over the coupling frequency (1 day)

$$\frac{\partial T}{\partial t} \propto \frac{Q}{\rho . C_p}$$