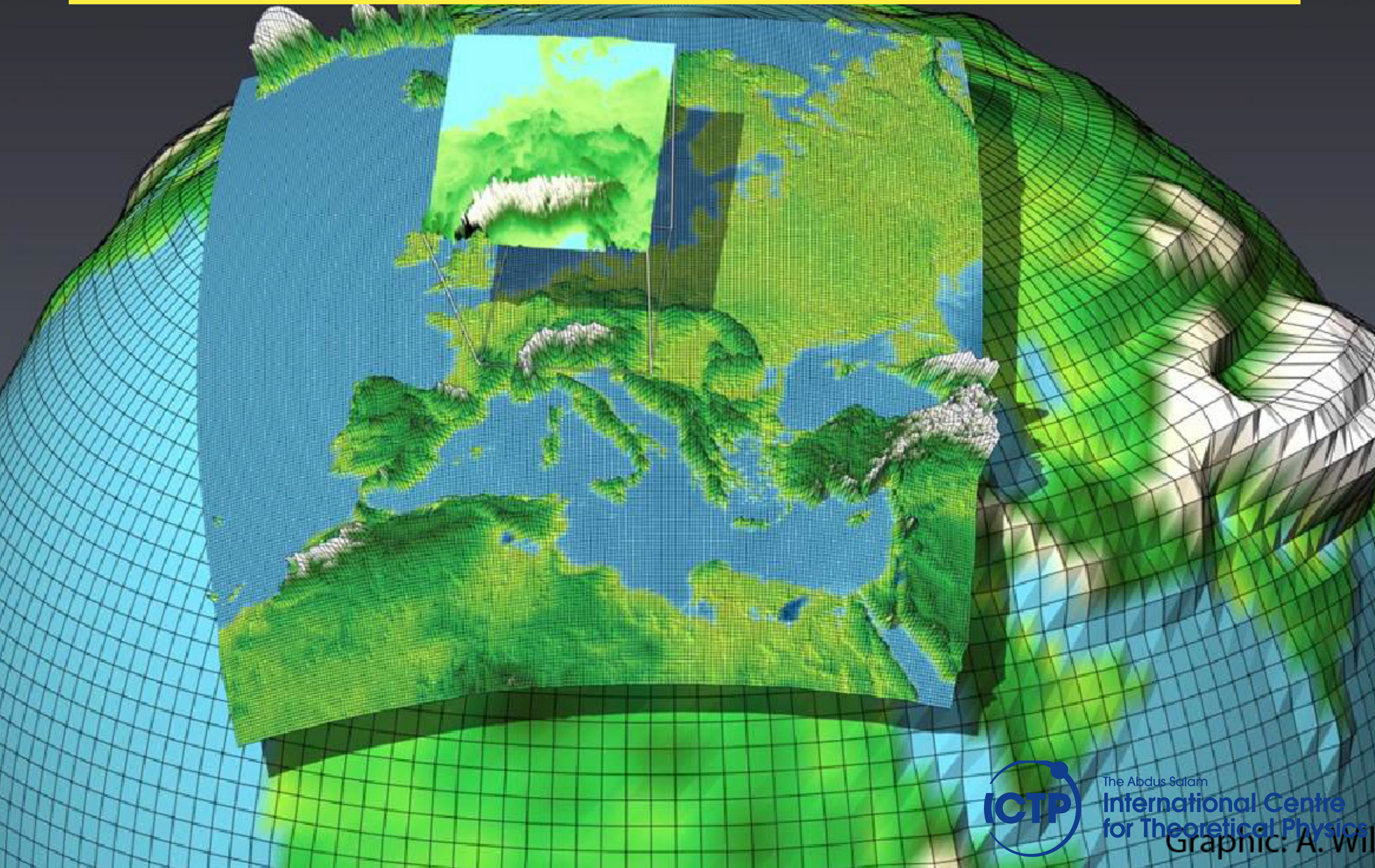
Recent development – RegCM4.7-non hydrostatic version-evaluation metrics

Erika Coppola and the ICTP-RegCM team



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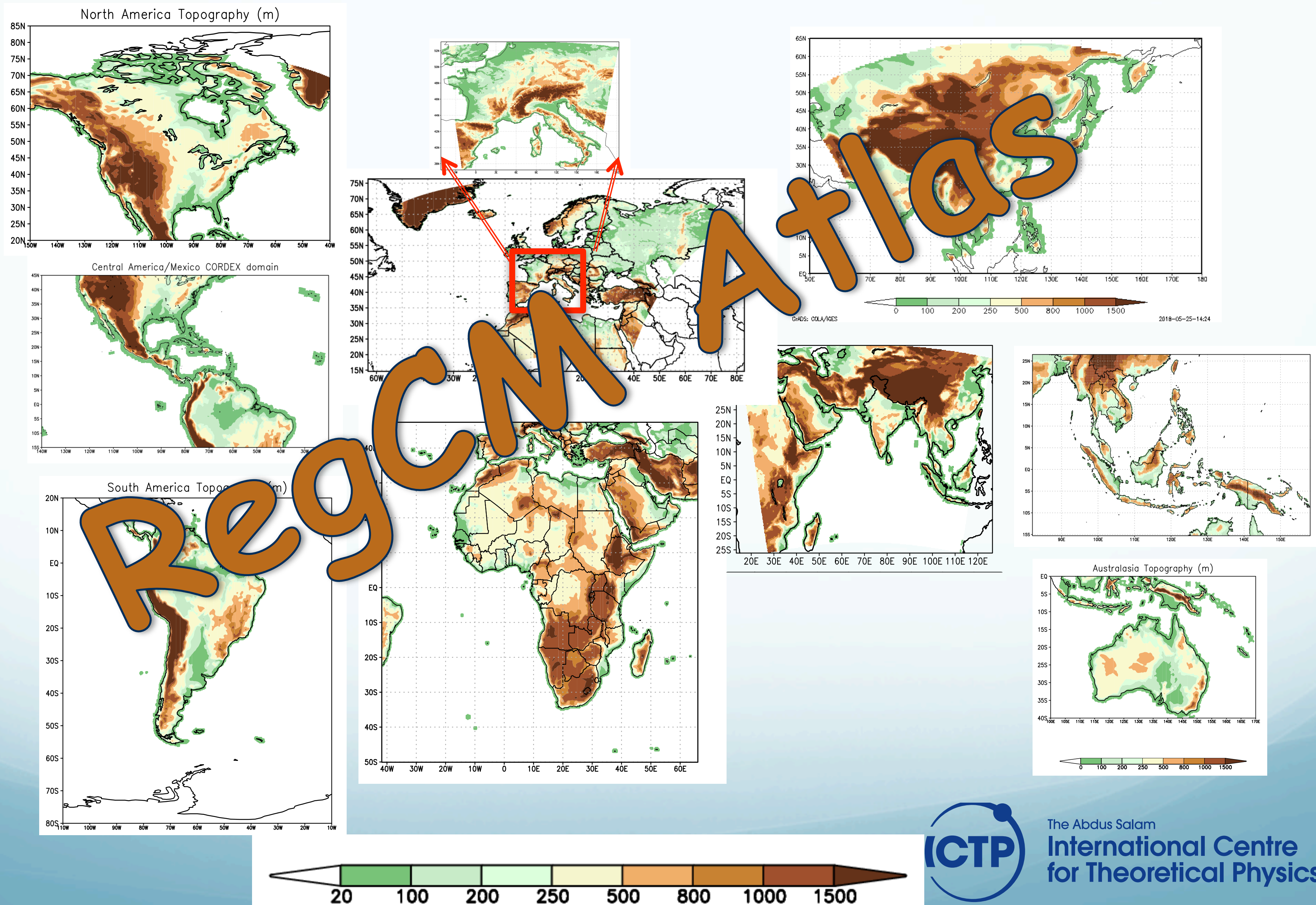
RegCM4.7 tested domain available and long scenario simulations available



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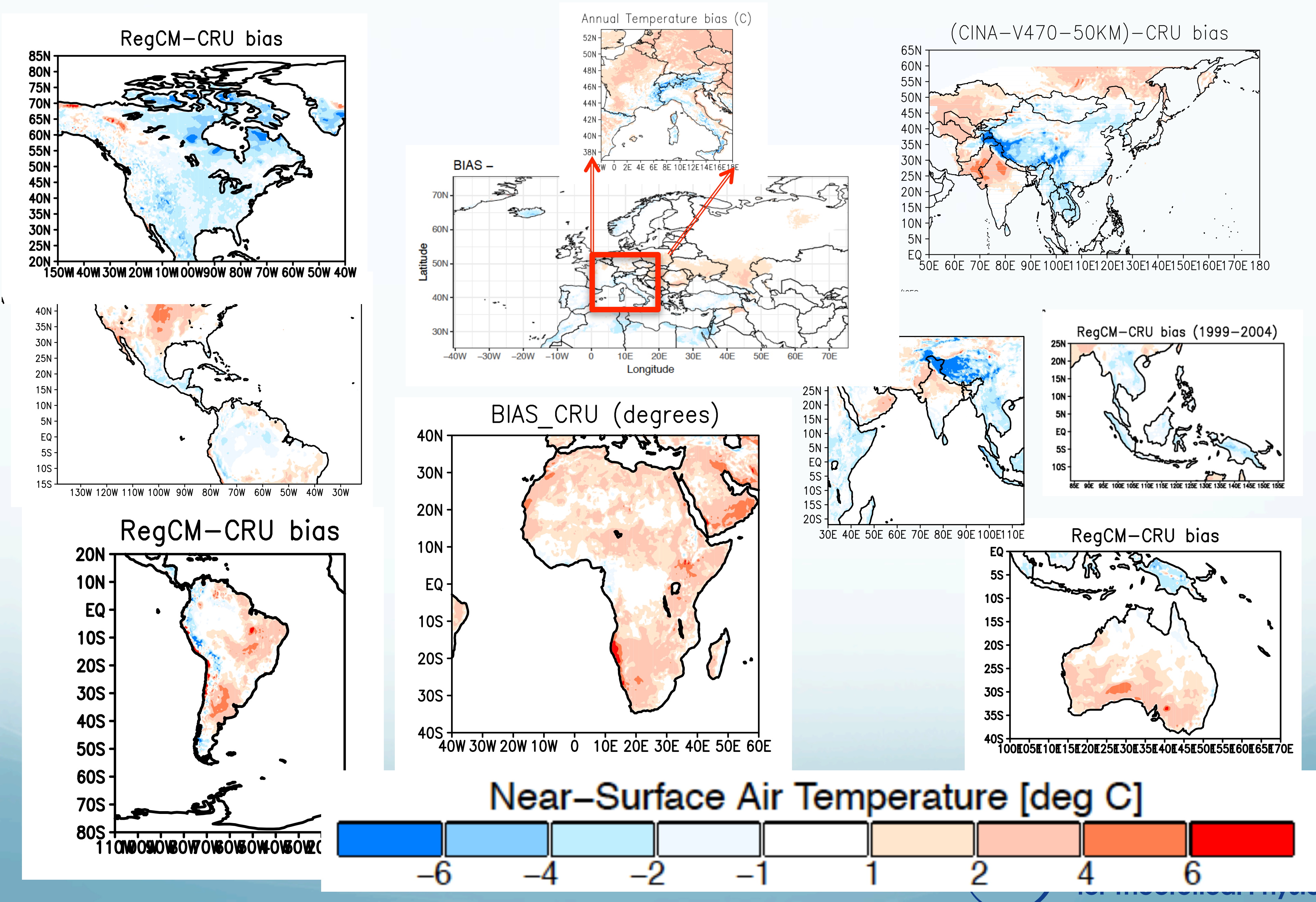
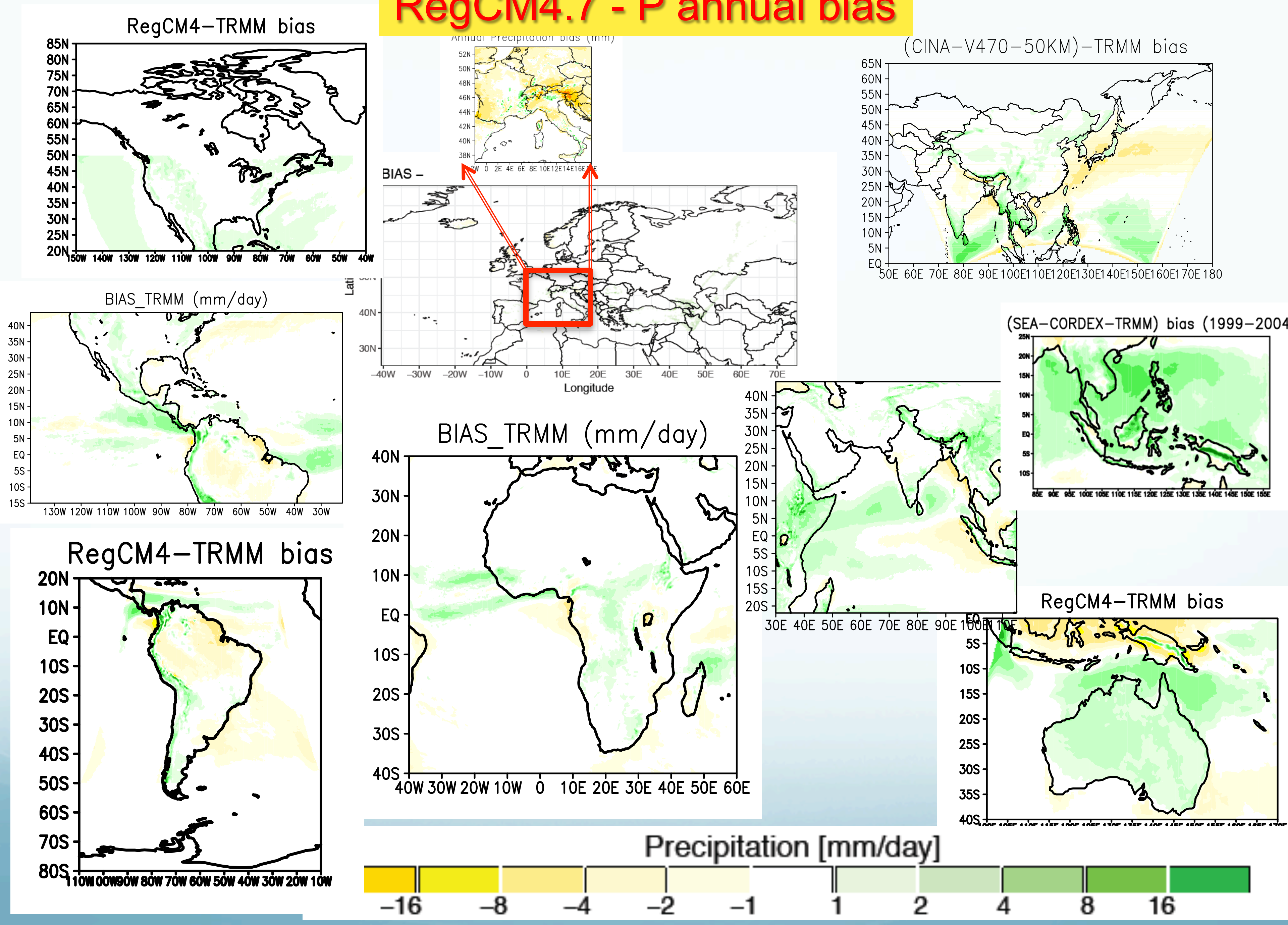
RegCM4.7 -T annual bias



RegCM4.7 - P annual bias



From RegCM4.5 to RegCM4.7 through 4.6.1

G. Giuliani

Infrastructure:

- Cressman interpolation with KDTree point locator
- Date from -9999 to 9999 with offsetting possible in range 10^-6 - 10^6
- CF-1.7 compliant output format
- MPI communication optimization

PreProcessing:

- New interfaces:
  - - MPI-ESM-LR
  - - NorESM1-M
  - - MIROC5
  - - CCSM4
- Dataset changes for CLM 4.5
- Chemistry and aerosol nesting option

From RegCM4.5 to RegCM4.7 through 4.6.1

G. Giuliani

Model:

- Aerosol input for radiative effect without transport
- Climatological Ozone input corrected
- Constant greenhouse gas concentration option
- CORDEX variable names, units and time conventions
- Solar constant can be set to arbitrary values
- Fix cross/dot point tendencies from cumulus schemes
- Revert all cumulus schemes parametrizations to default as in papers
- Automatic timestep selection reviewed
- Non Hydrostatic:
  - Rayleigh damping at model top relaxing to ICBC
  - Advection limiters and upstream weight
  - Fix errors in equations and configurable standard atmosphere
  - MM5 shallow convection scheme
  - Fix Top Radiative BC
  - Fix chemical tracers interpolation on non-hydrostatic levels

From RegCM4.5 to RegCM4.7 through 4.6.1

- Hydrostatic:
    - Advection limiters and upstream weight
    - Mean state instead of standard atmosphere configurable as MM4
- CAPE and CIN, wind at 100 m and potential evaporation computation
- Dry and total water mass check
- Mean Sea level pressure computed by the model
- Fix sea ice model for Era Interim SST input.
- Fix Nogherotto-Tompkins scheme
- Add WRF 5 hydrometeor class scheme
- Add implicit diffusion of ice in PBL
- Add Gultepe-Isaac and Thompson cloud fraction schemes
- Use 9-point laplacian as in LeVeque diffusion stencil
- RAW timefilter for tracers
- Output soil moisture on land model levels
- Partial CLM 4.5 emissions support
- Convective cloud fraction using Xu and Krueger parametrization

PostProcessing:

- Grads interpolation not requested at higher resolution
- Pycordexer script updated and enhanced to produce Core Cordex

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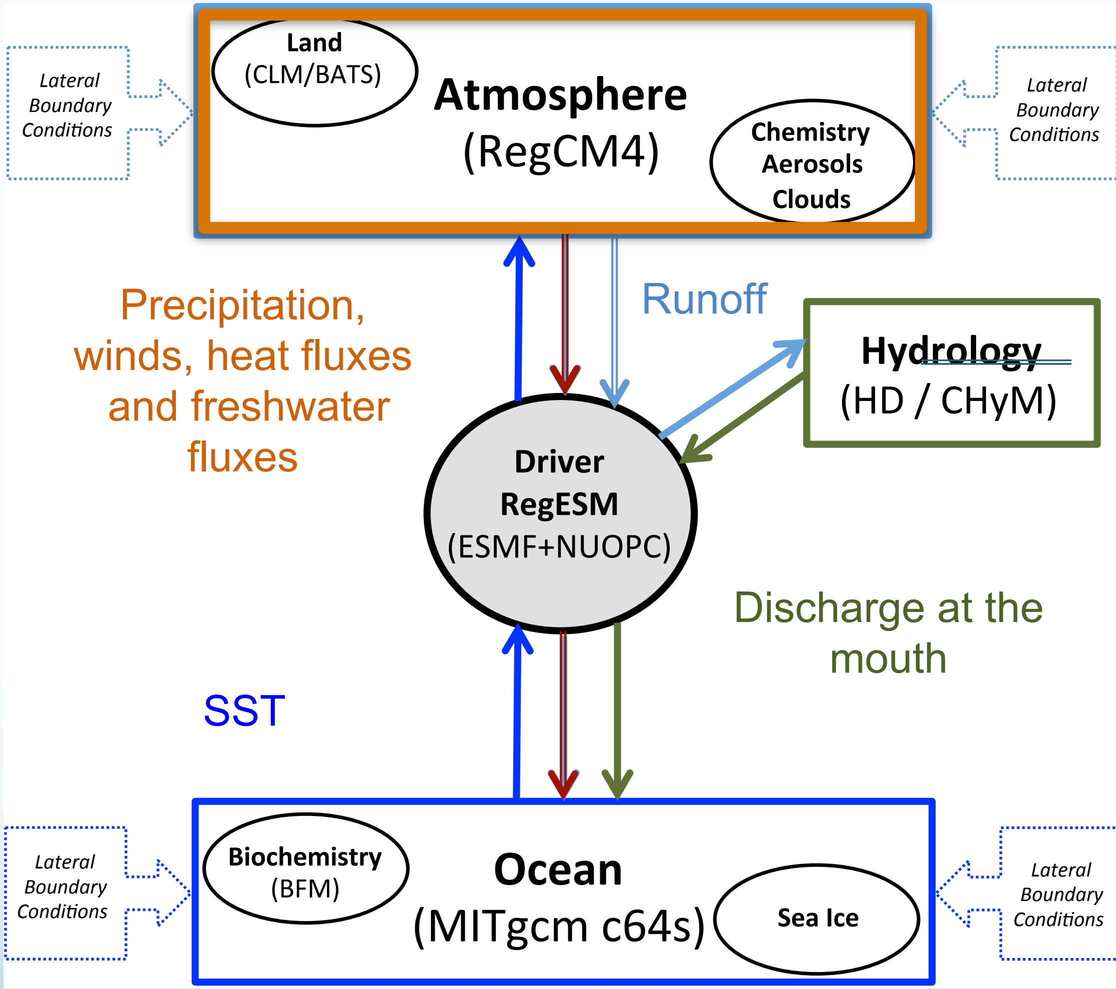
RegCM-ES (4.6.1)



Sitz, L. E., **Di Sante, F.**, Farneti, R., Fuentes-Franco, R., Coppola, E., Mariotti, L., Reale, M., Sannino, G., Barreiro, M., Nogherotto, R., Giuliani, G., Graffino, G., Solidoro, C., Cossarini, C., and Giorgi, F. (2017). Description and evaluation of the eart system regional climate model (regcm-es). J. Adv. Model. Earth Syst.

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RegCM4.7 non-hydrostatic

hydrostatic

Horizontal momentum

$$\frac{\partial p^*u}{\partial t} = -m^2\left[\frac{\partial p^*uu/m}{\partial x} + \frac{\partial p^*vu/m}{\partial y}\right] - \frac{\partial p^*u\dot{\sigma}}{\partial \sigma} - mp^*\left[\frac{\sigma}{\rho}\frac{\partial p^*}{\partial x} + \frac{\partial \phi}{\partial x}\right] + p^*fv + D_u$$

$$\frac{\partial p^*v}{\partial t} = -m^2\left[\frac{\partial p^*uv/m}{\partial x} + \frac{\partial p^*vv/m}{\partial y}\right] - \frac{\partial p^*v\dot{\sigma}}{\partial \sigma} - mp^*\left[\frac{\sigma}{\rho}\frac{\partial p^*}{\partial y} + \frac{\partial \phi}{\partial y}\right] - p^*fu + D_v$$

Temperature

$$\frac{\partial p^*T}{\partial t} = -m^2\left[\frac{\partial p^*uT/m}{\partial x} + \frac{\partial p^*vT/m}{\partial y}\right] - \frac{\partial p^*T\dot{\sigma}}{\partial \sigma} + p^*\frac{\omega}{\rho c_p} + p^*\frac{\dot{Q}}{c_p} + D_T,$$

Surface pressure

$$\frac{\partial p^*}{\partial t} = -m^2\left[\frac{\partial p^*u/m}{\partial x} + \frac{\partial p^*v/m}{\partial y}\right] - \frac{\partial p^*\dot{\sigma}}{\partial \sigma},$$

non-hydrostatic

Horizontal momentum

$$\frac{\partial p^*u}{\partial t} = -m^2\left[\frac{\partial p^*uu/m}{\partial x} + \frac{\partial p^*vu/m}{\partial y}\right] - \frac{\partial p^*u\dot{\sigma}}{\partial \sigma} + uDIV - \frac{mp^*}{\rho}\left[\frac{\partial p'}{\partial x} - \frac{\sigma}{p^*}\frac{\partial p^*}{\partial x}\frac{\partial p'}{\partial \sigma}\right] + p^*fv + D_u$$

$$\frac{\partial p^*v}{\partial t} = -m^2\left[\frac{\partial p^*uv/m}{\partial x} + \frac{\partial p^*vv/m}{\partial y}\right] - \frac{\partial p^*v\dot{\sigma}}{\partial \sigma} + vDIV - \frac{mp^*}{\rho}\left[\frac{\partial p'}{\partial y} - \frac{\sigma}{p^*}\frac{\partial p^*}{\partial y}\frac{\partial p'}{\partial \sigma}\right] - p^*fu + D_v$$

Vertical momentum

$$\frac{\partial p^*w}{\partial t} = -m^2\left[\frac{\partial p^*uw/m}{\partial x} + \frac{\partial p^*vw/m}{\partial y}\right] - \frac{\partial p^*w\dot{\sigma}}{\partial \sigma} + wDIV + p^*g\frac{\rho_0}{\rho}\left[\frac{1}{p^*}\frac{\partial p'}{\partial \sigma} + \frac{T'_v}{T} - \frac{T_0p'}{Tp_0}\right] - p^*g\left[(q_c + q_r)\right] + D_w$$

Temperature

$$\frac{\partial p^*T}{\partial t} = -m^2\left[\frac{\partial p^*uT/m}{\partial x} + \frac{\partial p^*vT/m}{\partial y}\right] - \frac{\partial p^*T\dot{\sigma}}{\partial \sigma} + TDIV + \frac{1}{\rho c_p}\left[p^*\frac{Dp'}{Dt} - \rho_0 g p^* w - D_{p'}\right] + p^*\frac{\dot{Q}}{c_p} + D_T,$$

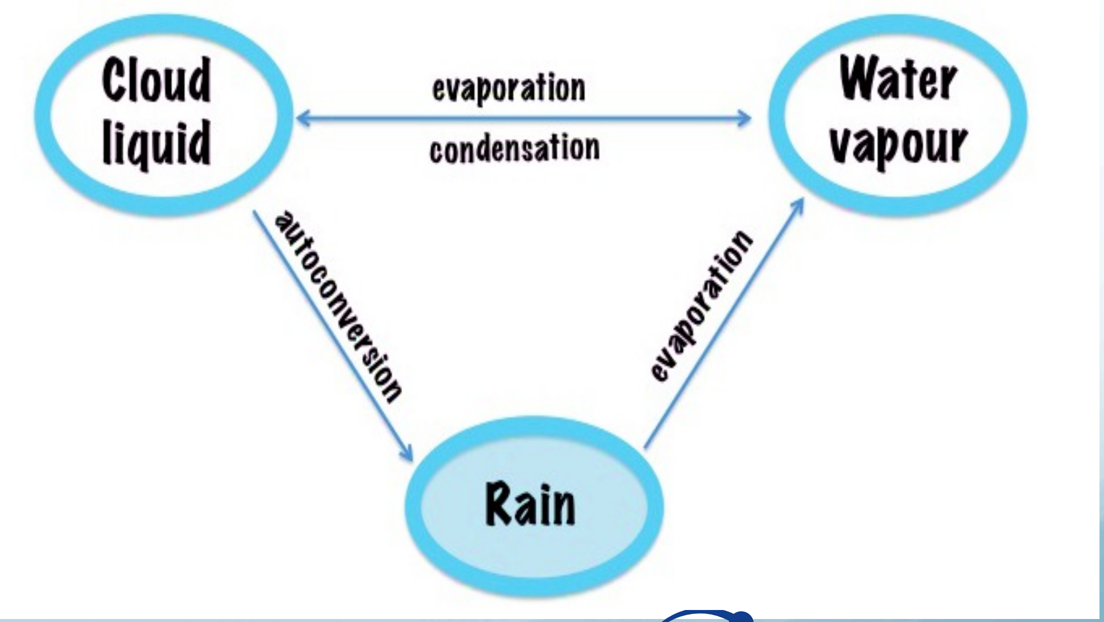
Pressure

$$\frac{\partial p^*p'}{\partial t} = -m^2\left[\frac{\partial p^*up'/m}{\partial x} + \frac{\partial p^*vp'/m}{\partial y}\right] - \frac{\partial p^*p'\dot{\sigma}}{\partial \sigma} + p'DIV - m^2p^*\gamma p\left[\frac{\partial u/m}{\partial x} - \frac{\sigma}{mp^*}\frac{\partial p^*}{\partial x}\frac{\partial u}{\partial \sigma} + \frac{\partial v/m}{\partial y} - \frac{\sigma}{mp^*}\frac{\partial p^*}{\partial y}\frac{\partial v}{\partial \sigma}\right] + \rho_0 g\gamma p\frac{\partial w}{\partial \sigma} + p^*\rho_0 g w$$

RegCM4.7 microphysic scheme

SUBEX scheme

- Pal et al 2000.
- Kessler scheme
- Warm rain – no ice



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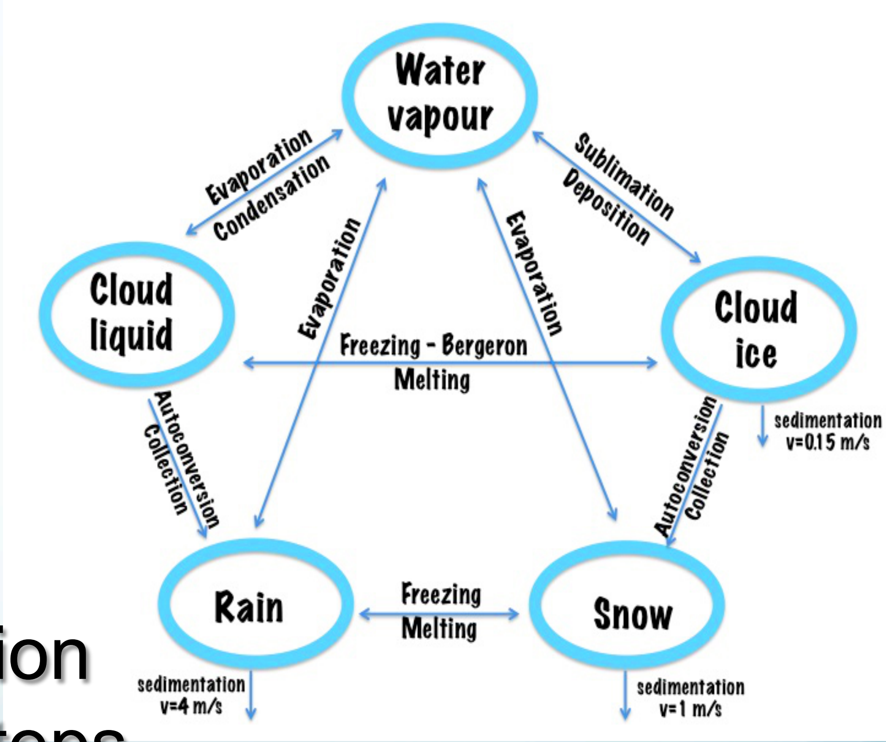
RegCM4.7 microphysic scheme

NOGTOM microphysics scheme

- Nogherotto et al 2016.
- one-moment scheme
- 5-class microphysics

(water vapor, cloud liquid, rain, snow, ice)

- Mixed-phase clouds
- Ice, snow and precip. advection
- Implicit solver – longer timesteps
- Flexibility for inserting new variables (i.e. graupel)



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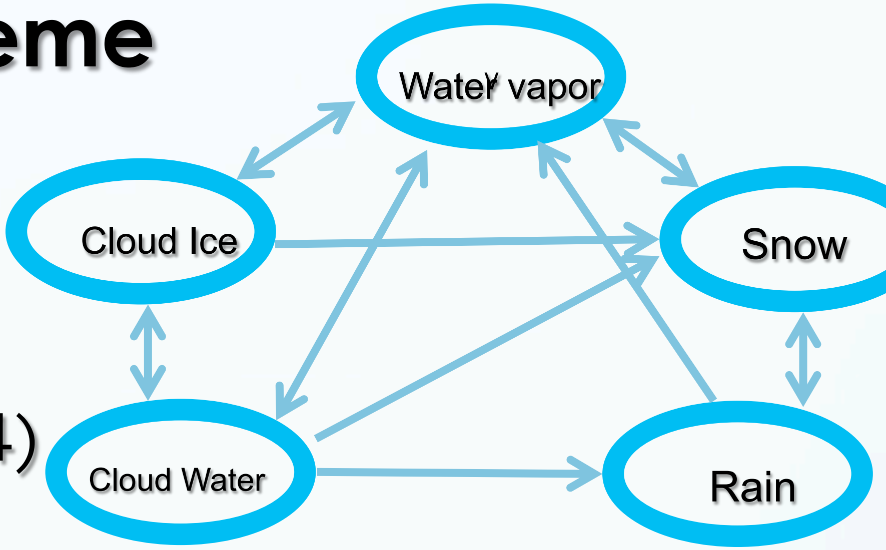
RegCM4.7 microphysic scheme

WSM5 microphysics scheme



WSM 5-class scheme

- Hong, Dudhia and Chen (2004)
- one-moment scheme
- 5-class microphysics (It includes vapor, rain, snow, cloud ice, and cloud water)
- Represents condensation, precipitation and thermodynamics effects of latent heat release
- It allows supercooled water to exist, and a gradual melting of snow falling below the melting layer.
- Explicit solver

$$\sigma = \frac{p - p_t}{p_s - p_t},$$

$$p^* = p_s - p_t.$$

$$\sigma = \frac{p_0 - p_t}{p_s - p_t},$$

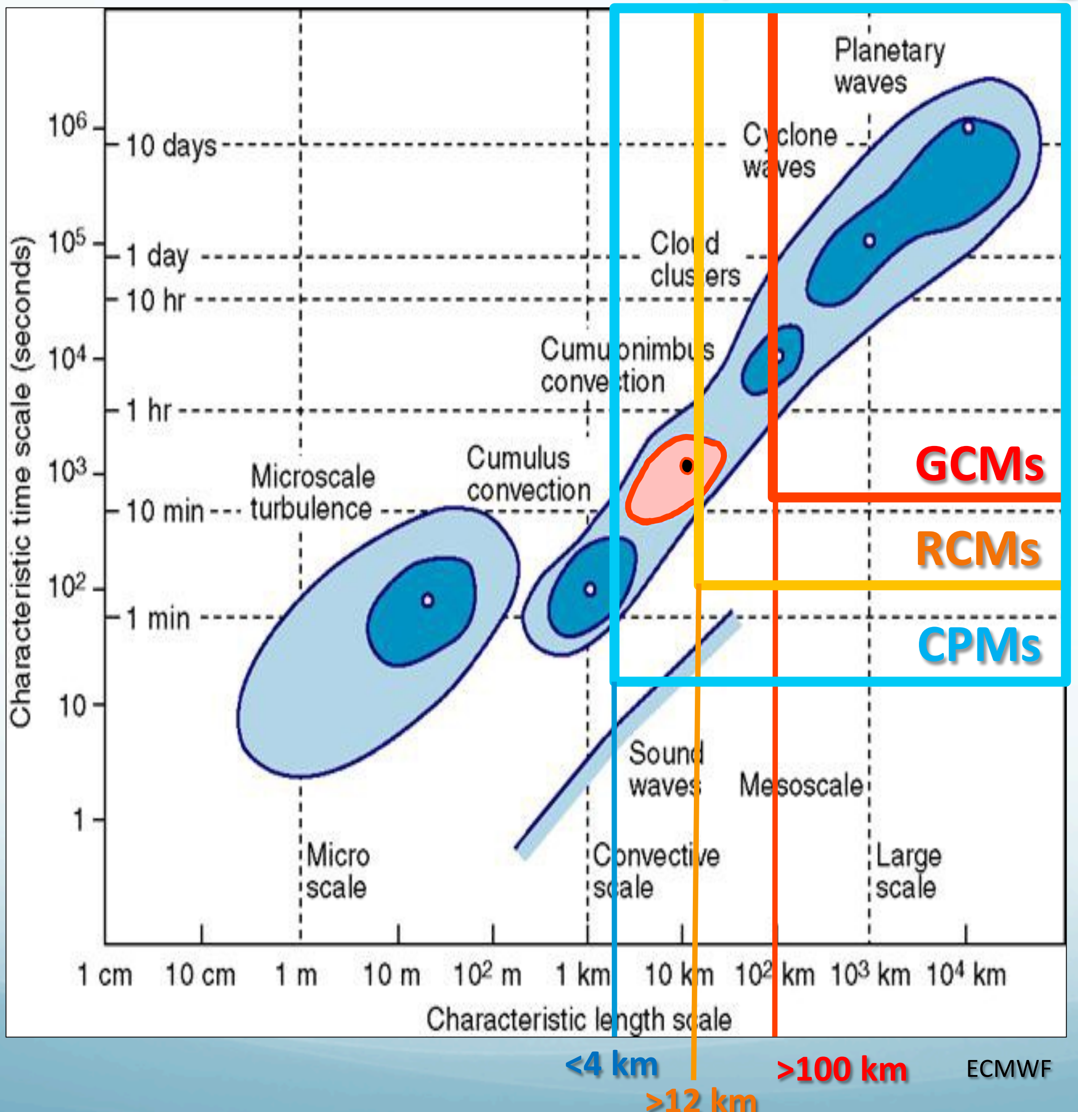
$$p = p^*\sigma + p_t + p',$$

$$p^*(x, y) = p_s(x, y) - p_t.$$

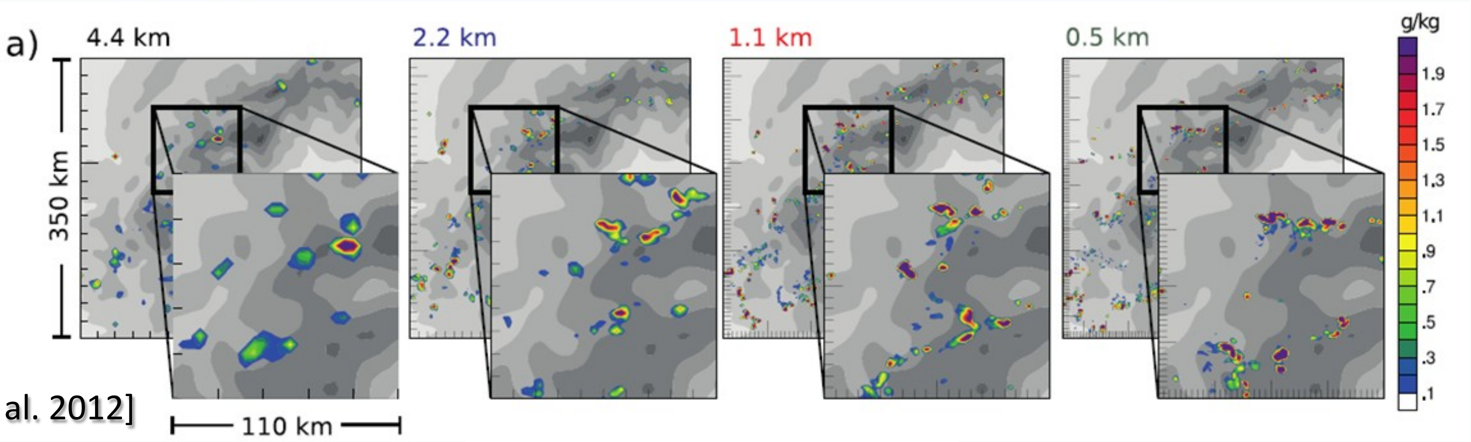
$$DIV = m^2 \left[\frac{\partial p^* u/m}{\partial x} + \frac{\partial p^* v/m}{\partial y} \right] + \frac{\partial p^* \dot{\sigma}}{\partial \sigma},$$

RegCM4.7 non-hydrostatic

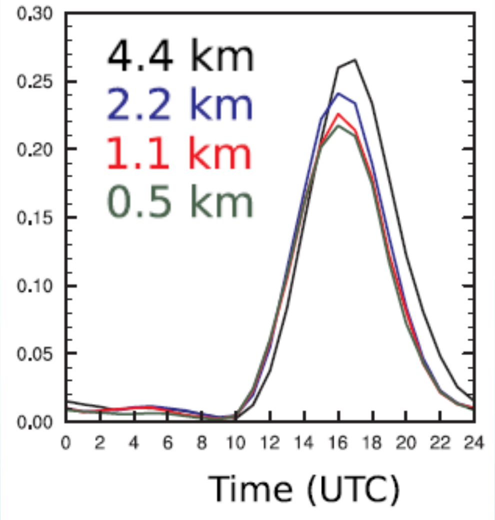
Convection permitting



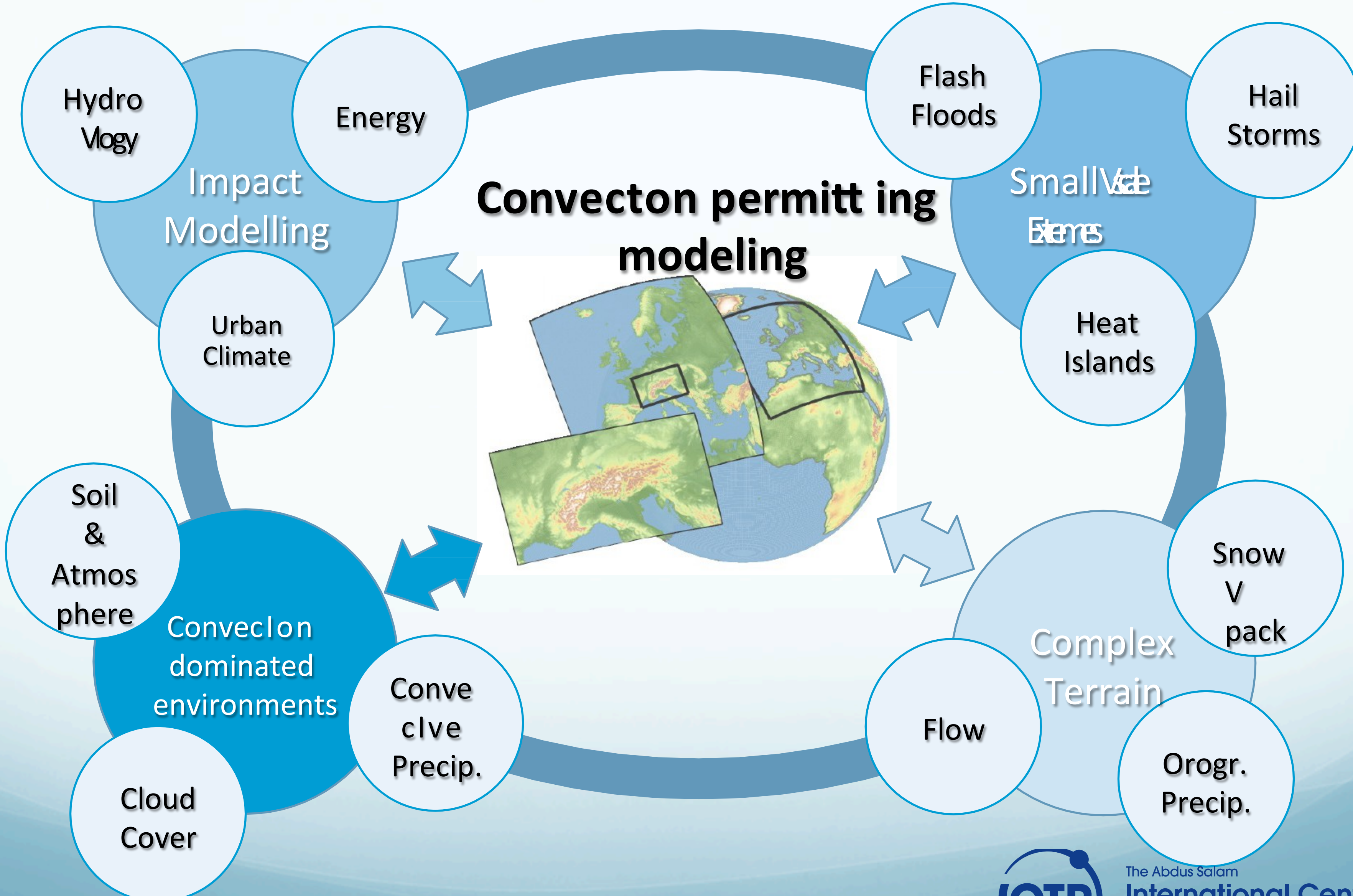
CPM grid spacing



[Langhans et al. 2012]



Where we expect the added Value



Courtesy By Prei A.

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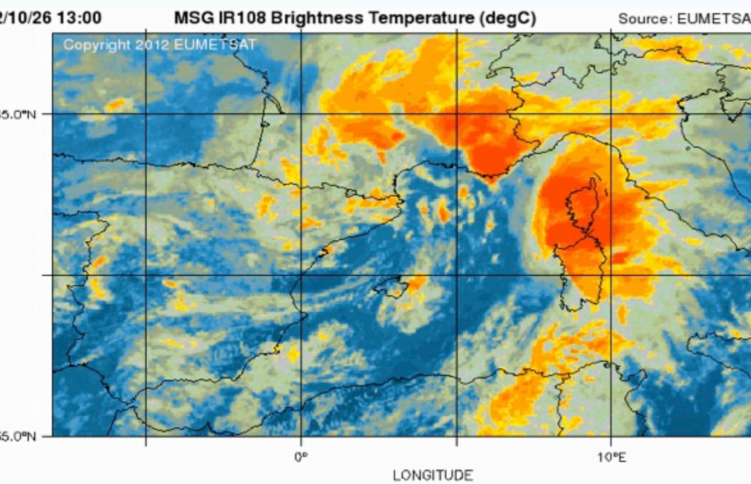
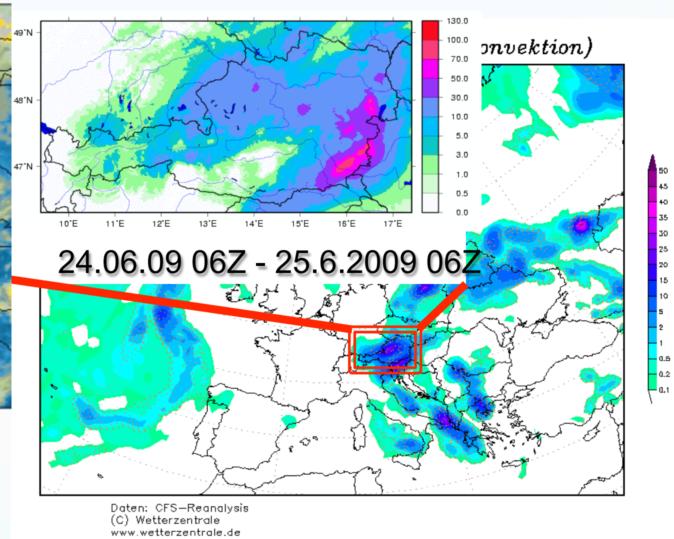
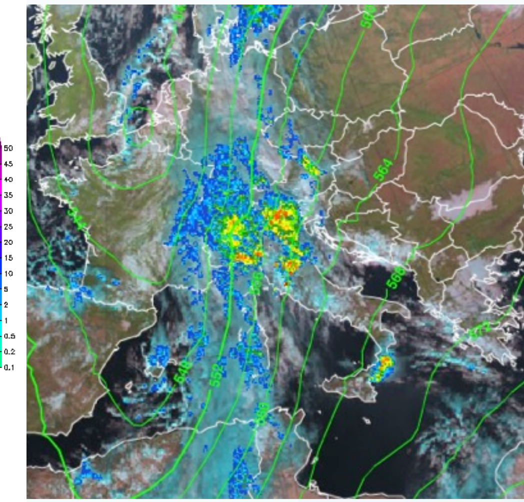
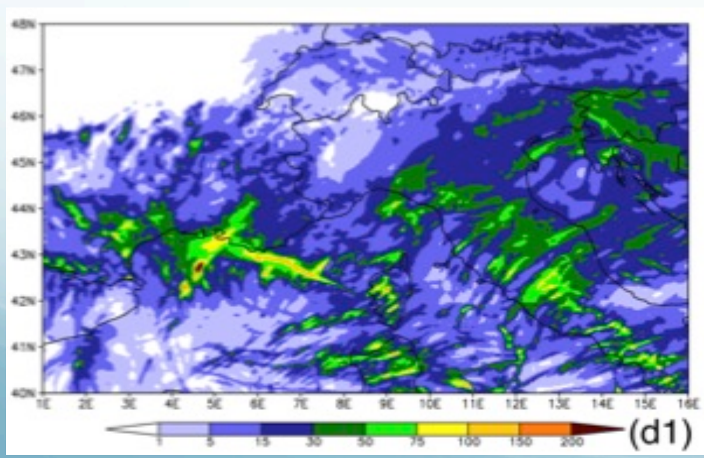
RegCM4.7 non-hydrostatic

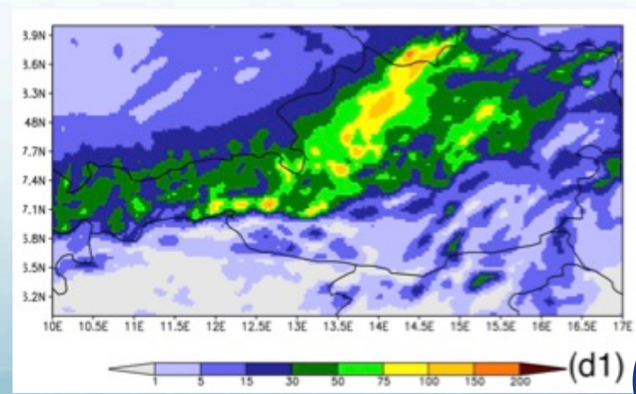
Convection permitting

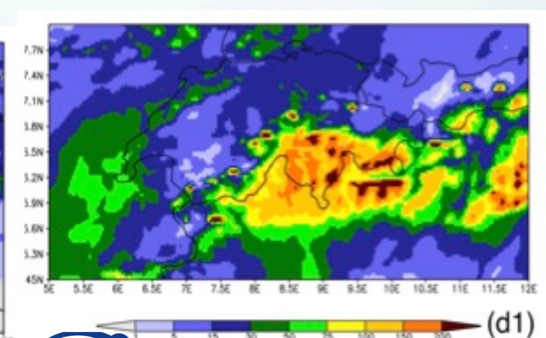












Coppola et al., 2018

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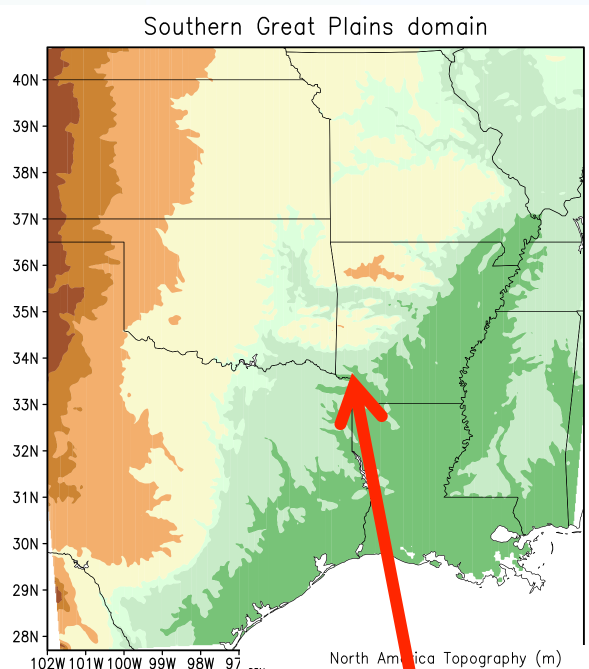
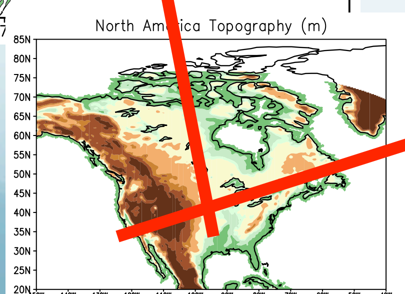
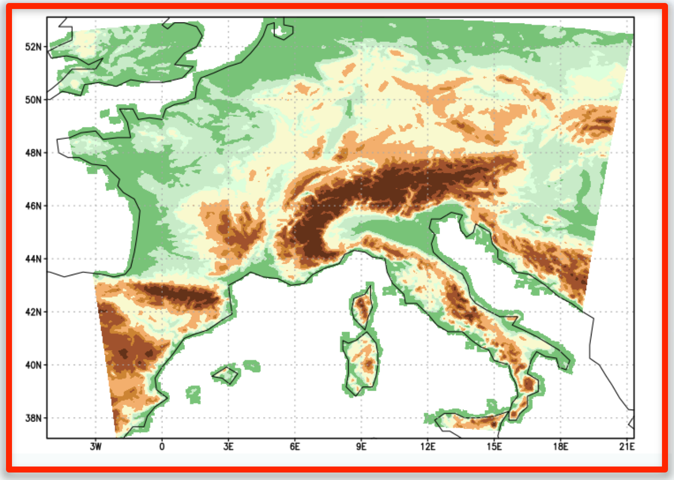
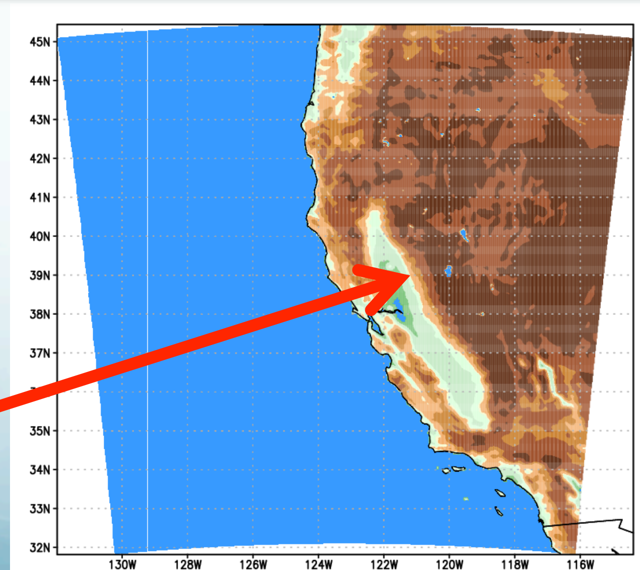
RegCM4.7 non-hydrostatic

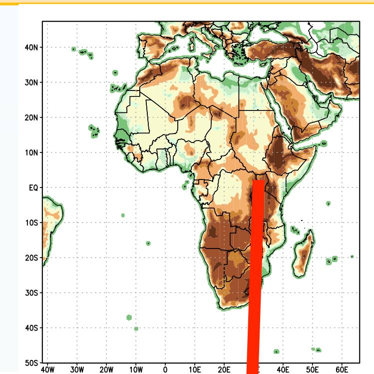
Convection permitting: domain tested so far...

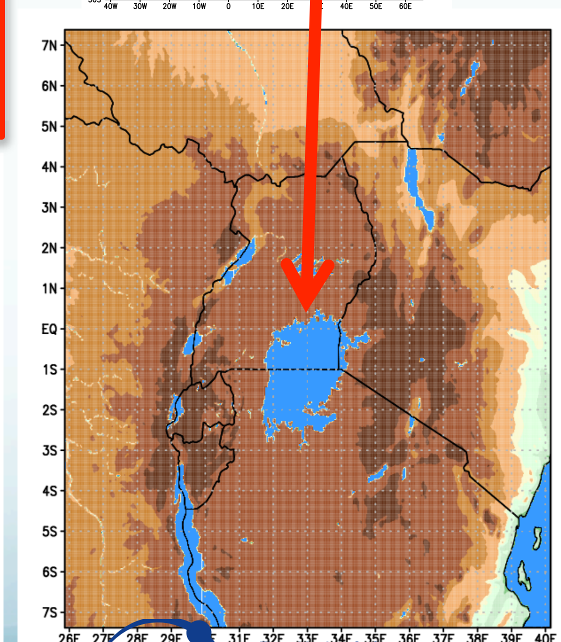












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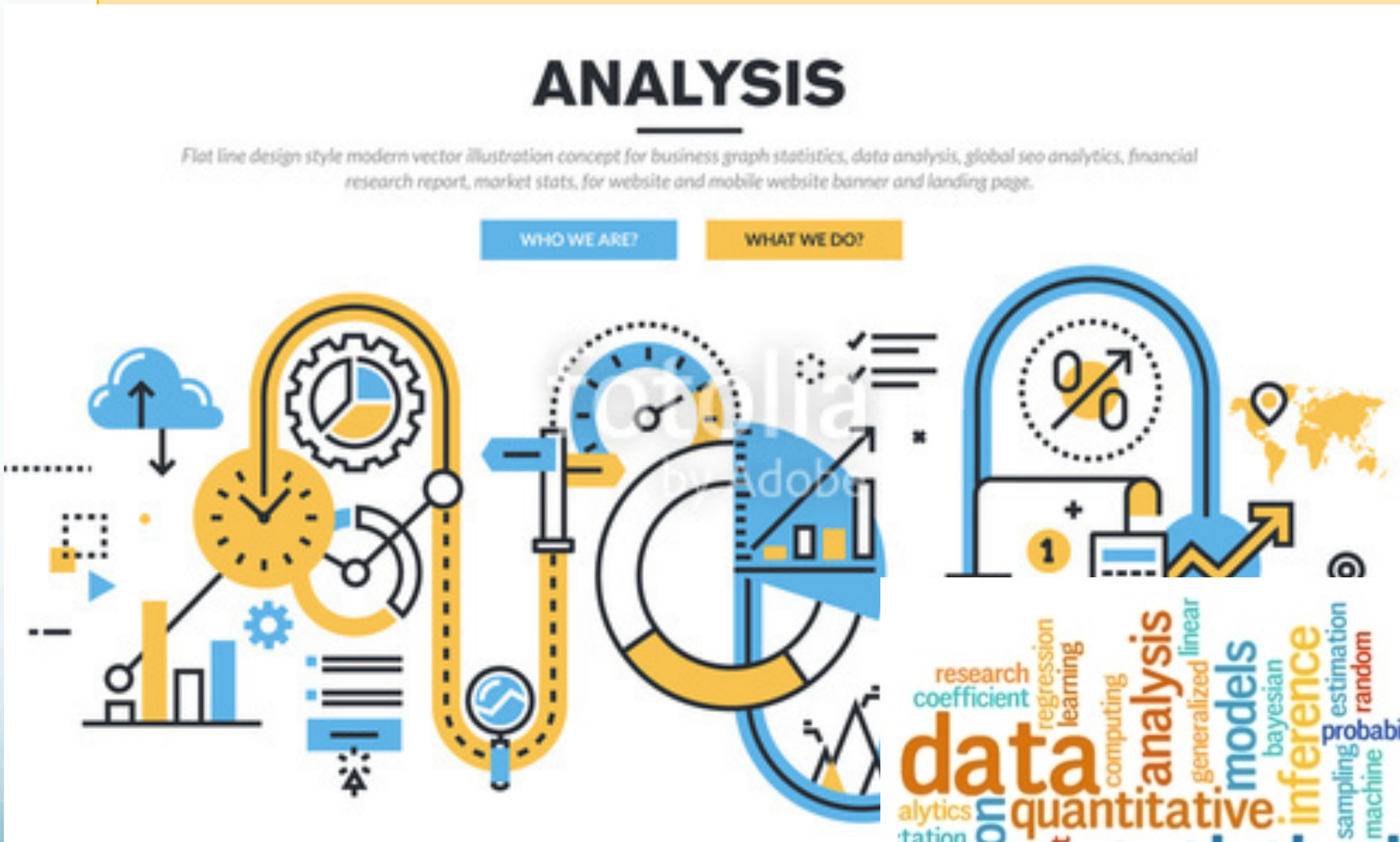
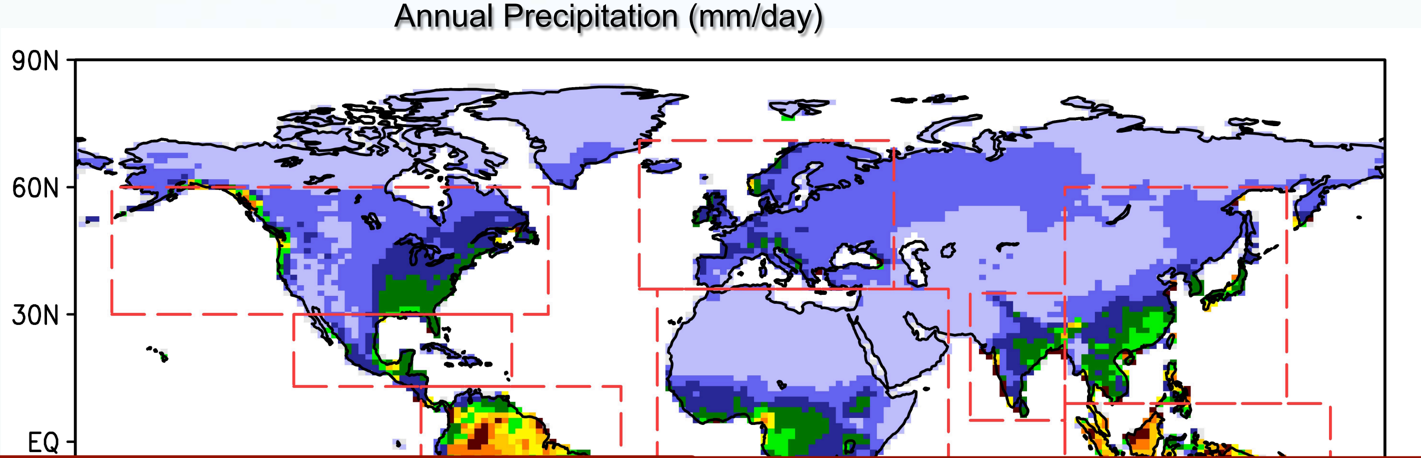
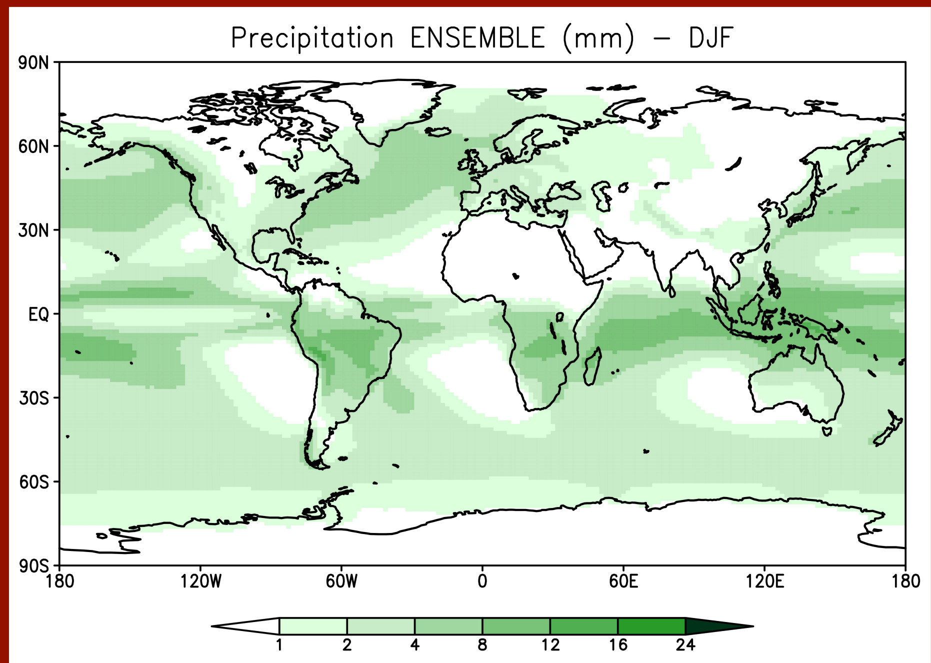
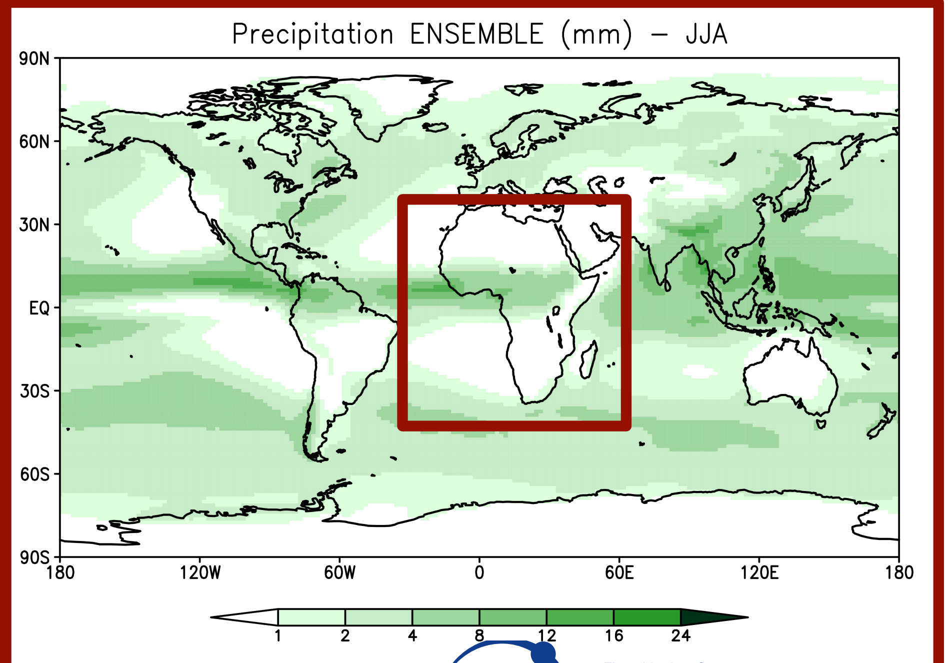
Evaluation metrics



Mean state validation







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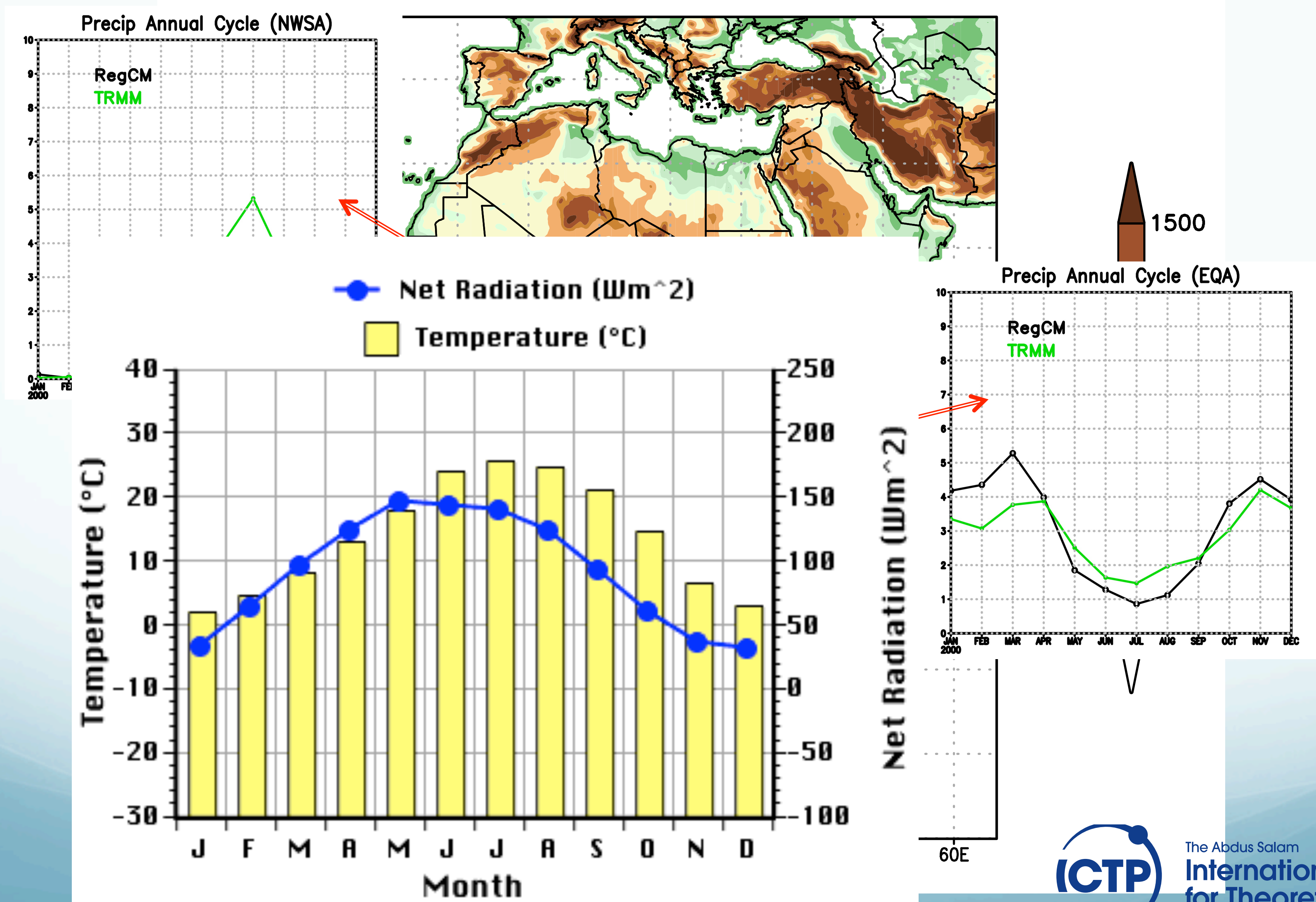
Example of definition of sub-domains representing different climatic regions



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The Taylor Diagrams: information on spatial correlation and signal variability

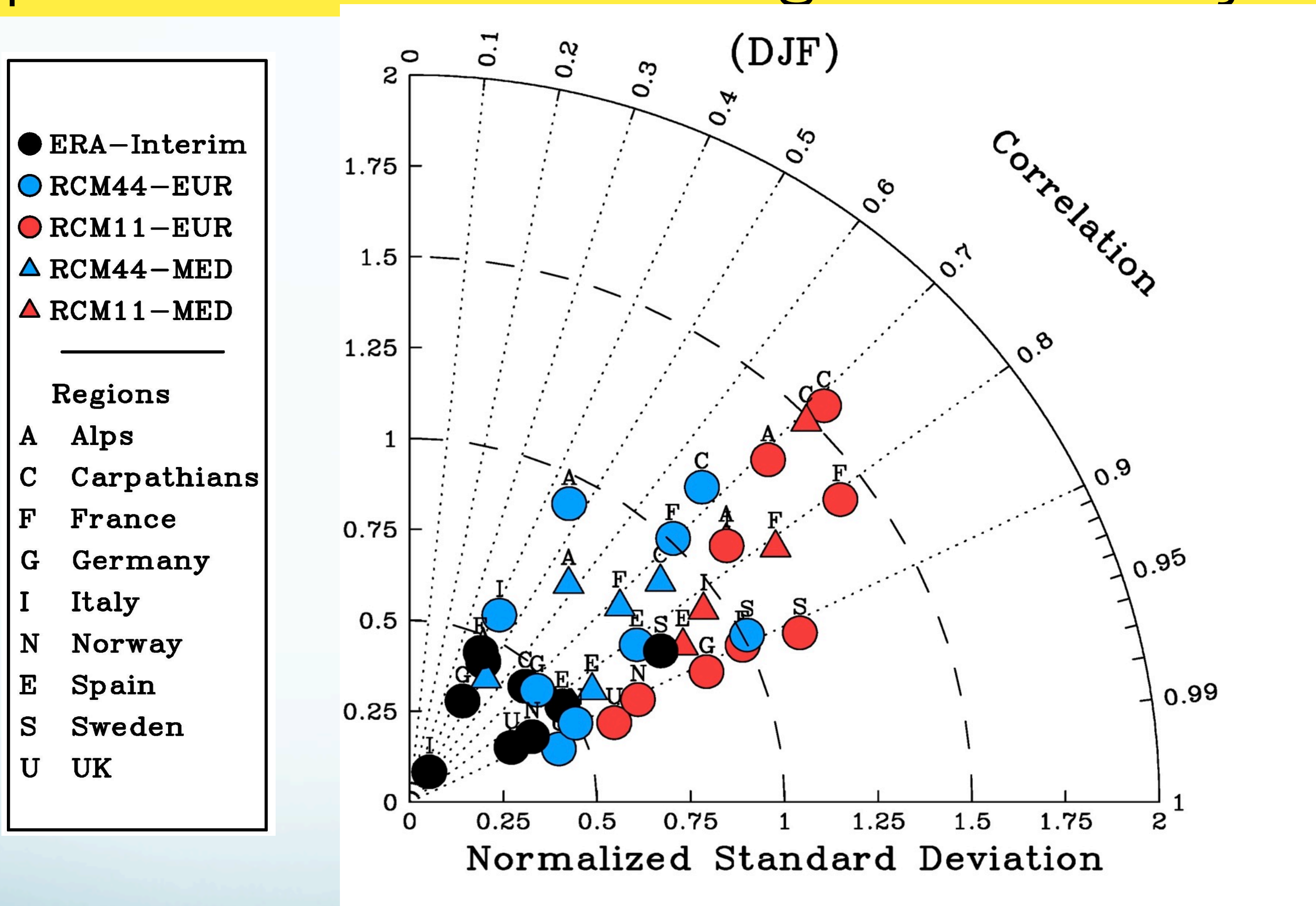
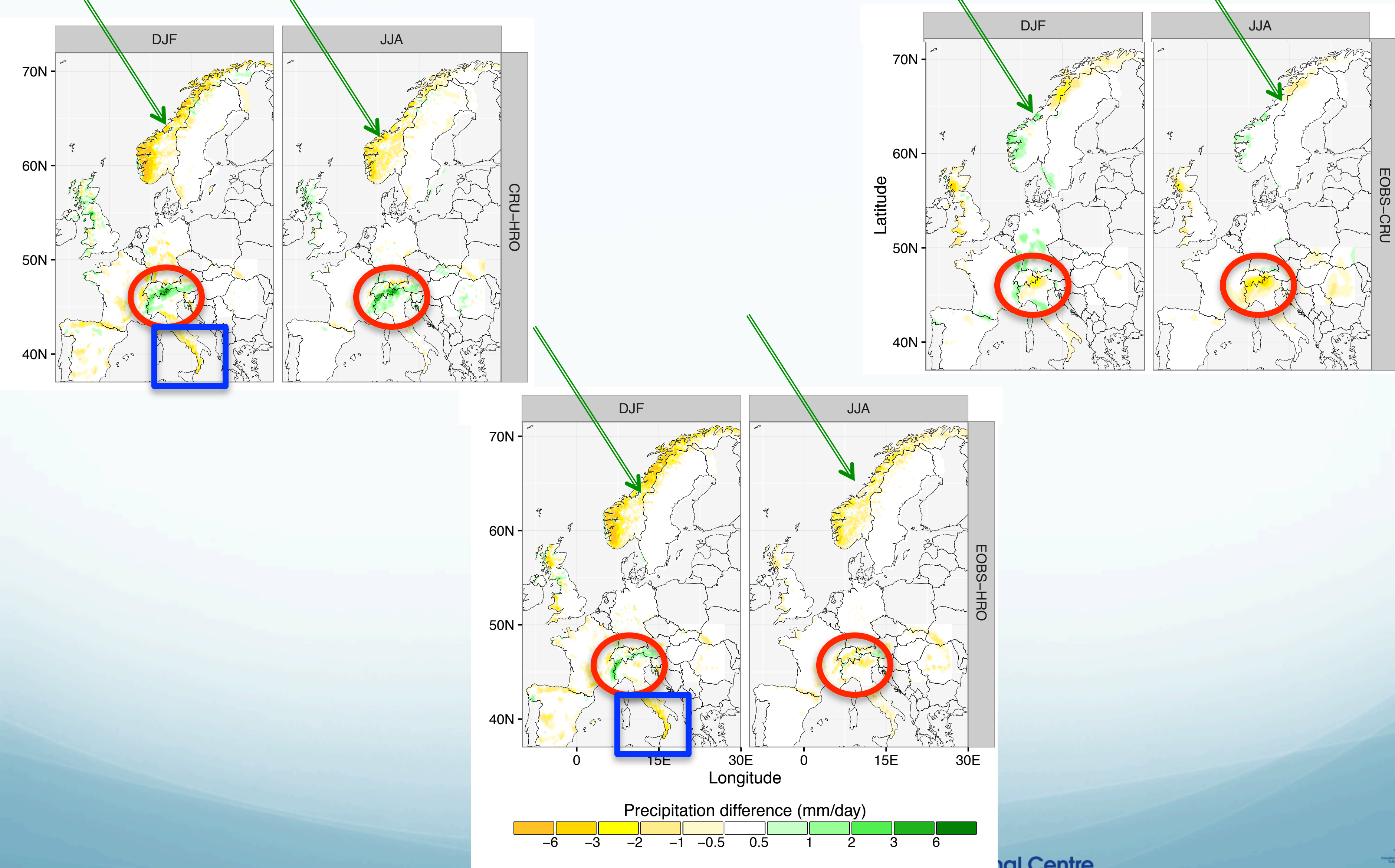
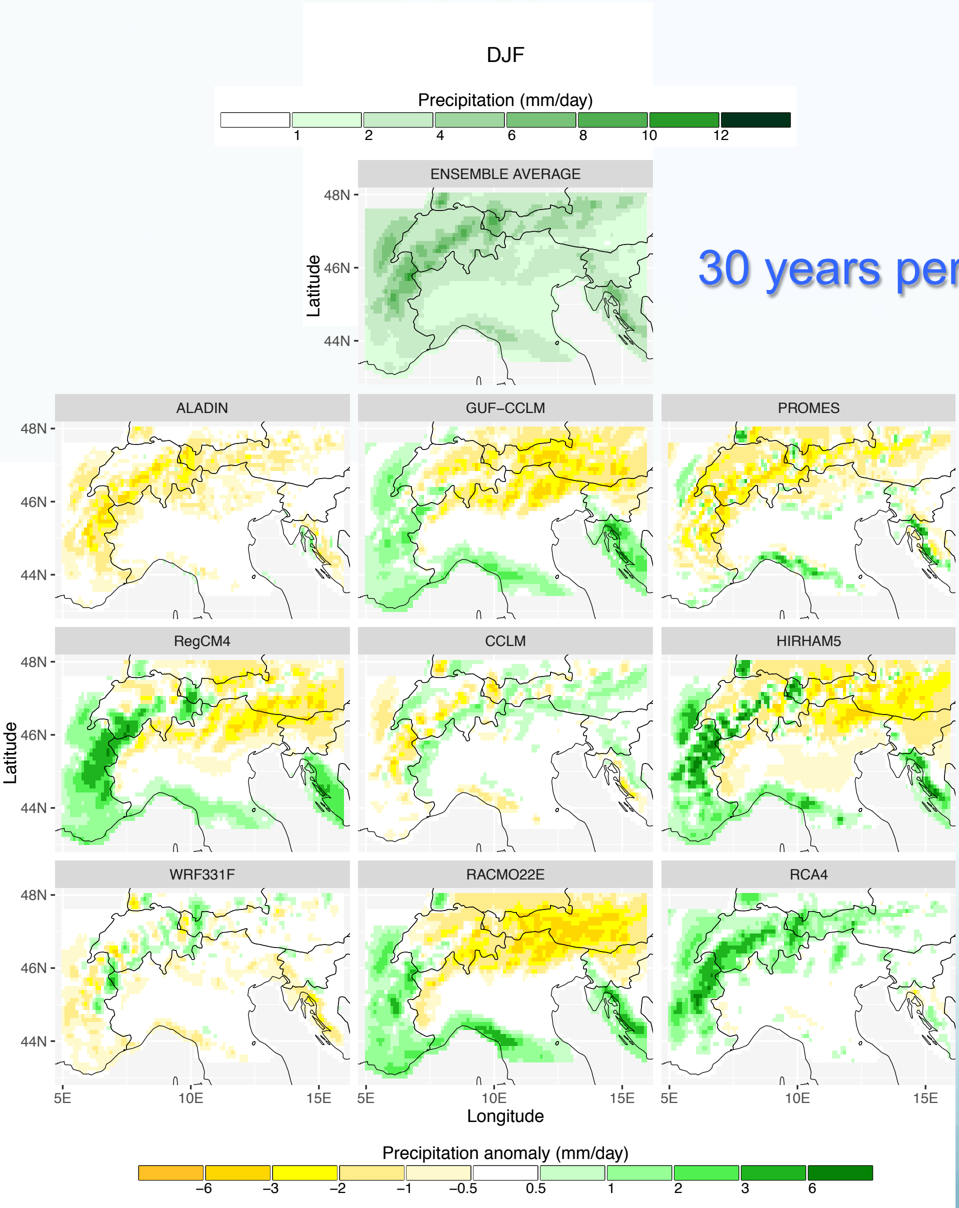


Figure 3. Taylor diagrams of the ensemble mean seasonal precipitation in the different analysis regions for the ERA-Interim, RCM44 and RCM11 (both All Models and Med-CORDEX models) ensembles with respect to the corresponding regional observation datasets. The distance from the point 1 measures the centered (bias removed) RMSE and the mean is taken over the different regional analysis periods.

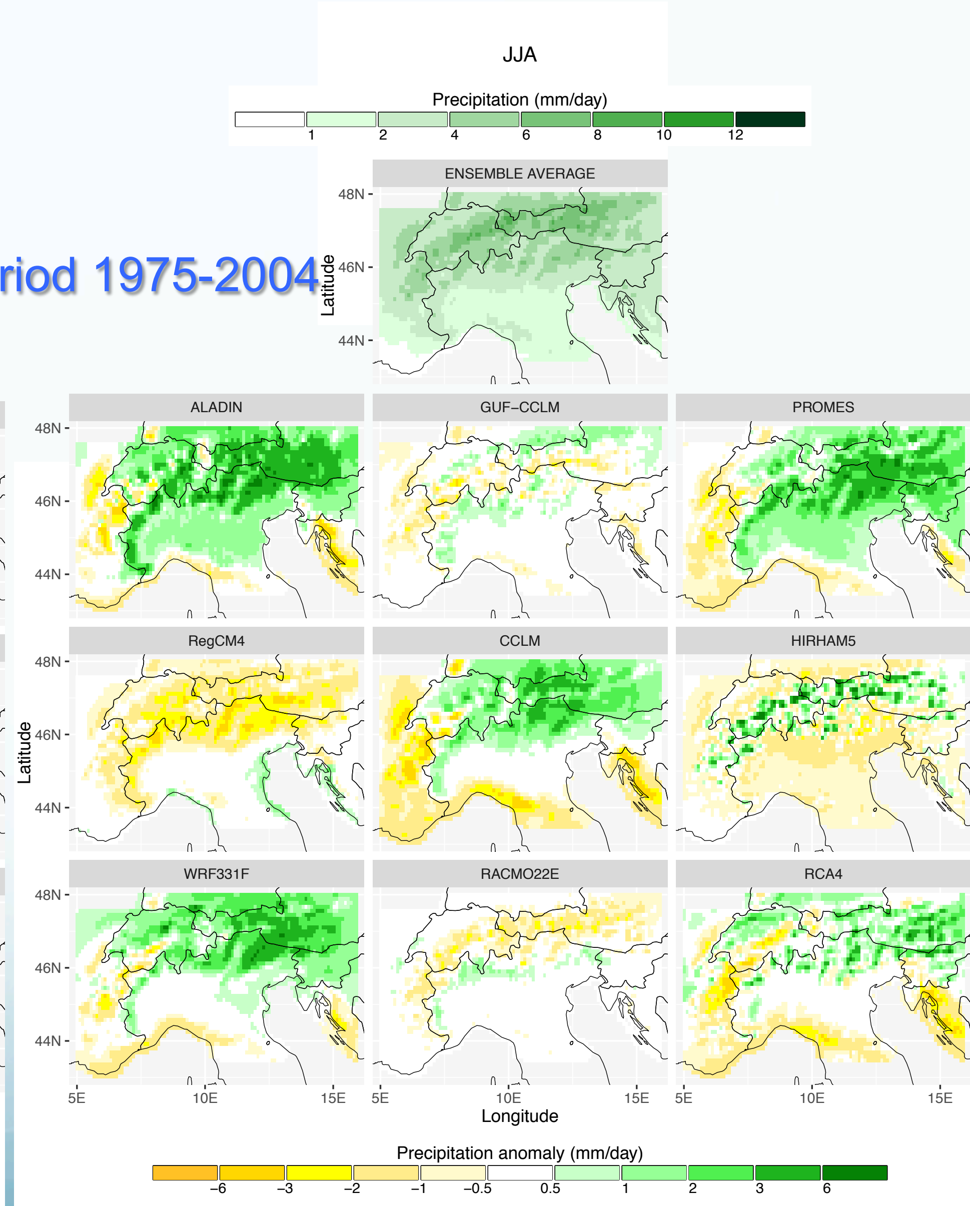
Observation Uncertanty



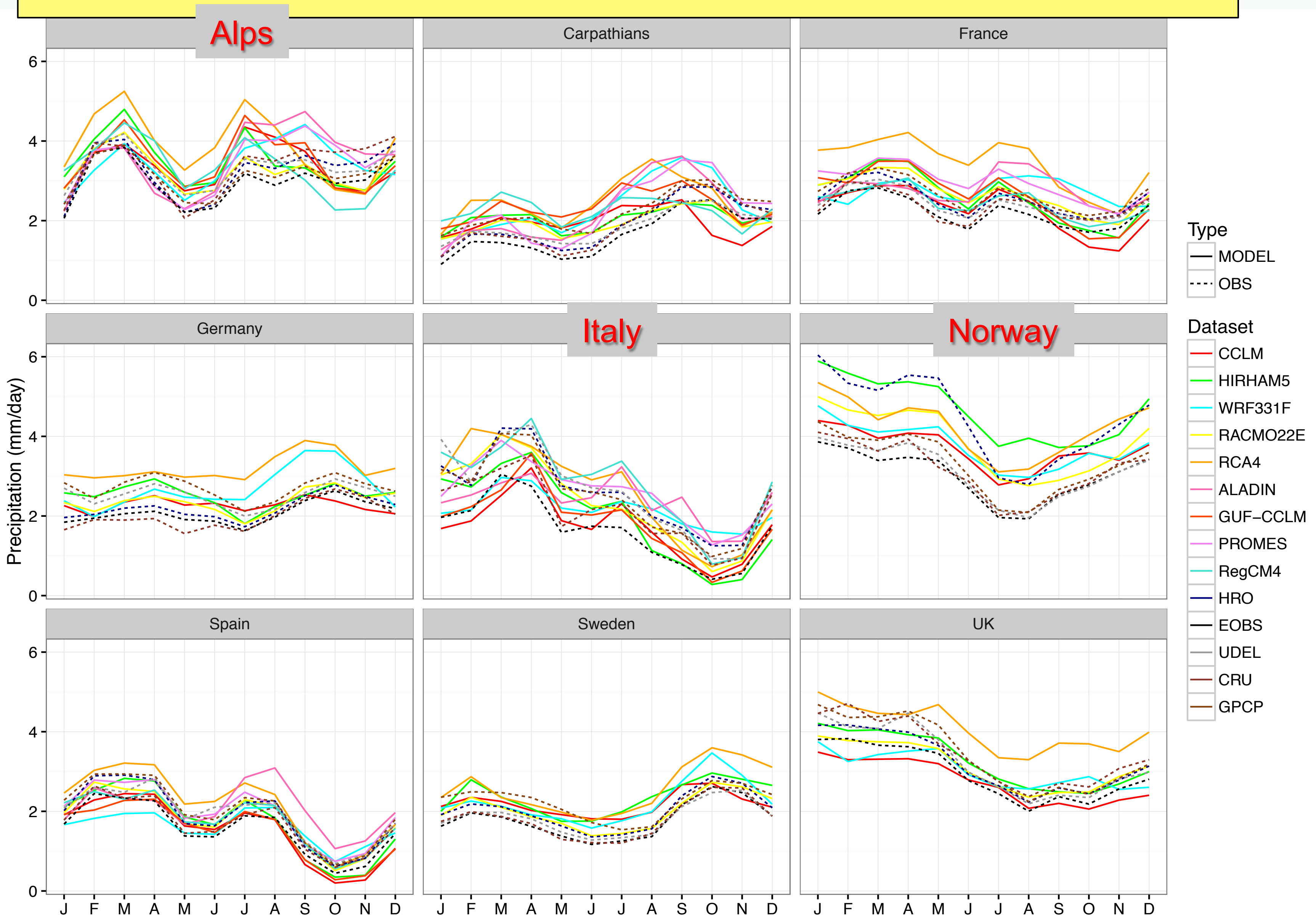
Model Uncertanty



30 years period 1975-2004



Observation+Model Uncertanty



Beniston M,..., **Coppola E**,. The European mountain cryosphere: A review of past, current and future issues, *The Cryosphere Discuss*., doi:10.5194/tc-2016-290, in review, 2017.

The interannual variability

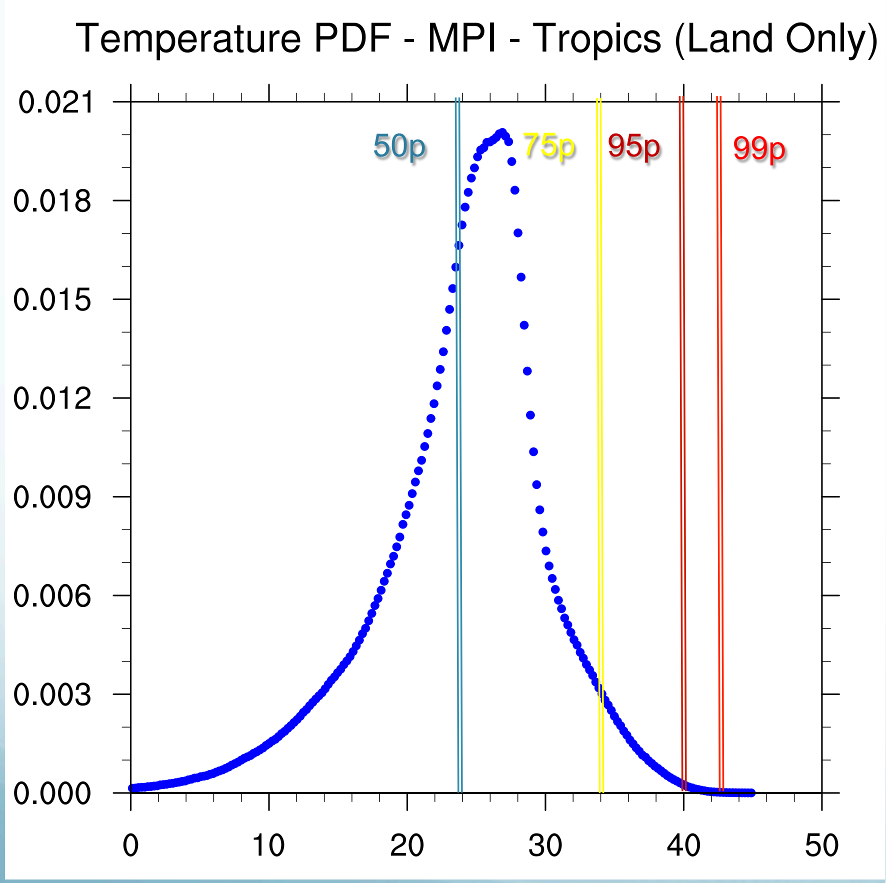
- **<u>The interannual variability</u>** (for temperature): it is a measure of how much a model is able to reproduce the year by year variability of temperature compared for example to the observations. It is calculated as standard deviation.

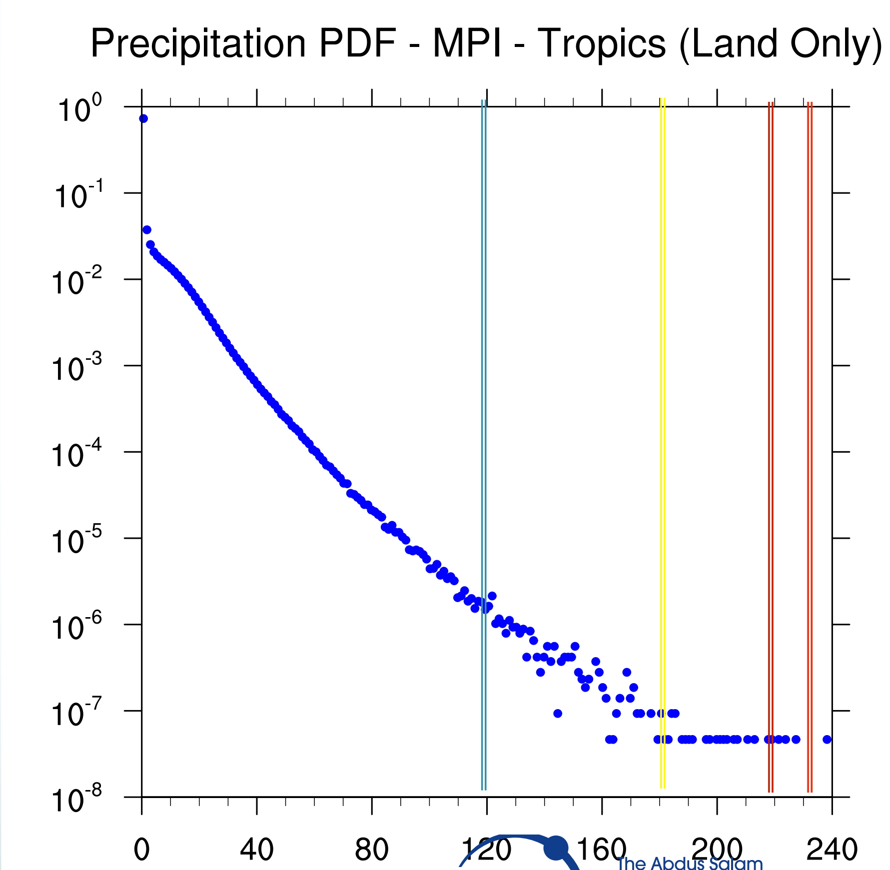
- **<u>The coefficient of variation</u>** (for precipitation): it is a measure of relative **variability**. It is the ratio of the standard deviation to the mean (average):

Coefficient of Variation = (Standard Deviation / Mean) * 100

The coefficient of variation is useful because the standard deviation of precipitation data must always be compared to the mean value.
Moreover, the actual value of the CV is a dimensionless number, thus it's perfect for comparison between data sets with different units or widely different means.

Extremes Validation: the Probability Distribution Function





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Other relevant extremes indexes:

- **R95 and R99** = precipitation percent due to the sum of those days > 95th (or 99th) percentile of the daily precipitation amount at WET days (precip >= 1 mm) for any period used as reference. (%)
- **CDD** = Consecutive dry days (precip < 1 mm) index per time period (No. days)
- **SDII** = Simple daily intensity index per time period, that is the mean precipitation amount at wet days (precip >= 1 mm) (mm/day)
- **WET/DRY** days frequency = the number of wet (or dry) days are summed up and divided for the total number of days in the period considered. (%)
- **HY-int** = normalized Dry Spell Lengh X normalized SDII
- **Heat waves** = Heat wave duration index, that is the number of days where, in intervals of at least *nday* consecutive days, the daily maximum temperature exceeds the mean (TXnorm) of daily maximum temperatures (for any period used as reference) of at least *T* (a user-defined Temperature offset, in Celsius degrees).
- **Return period** = the probability that the flood event will be equalled or exceeded in any one year

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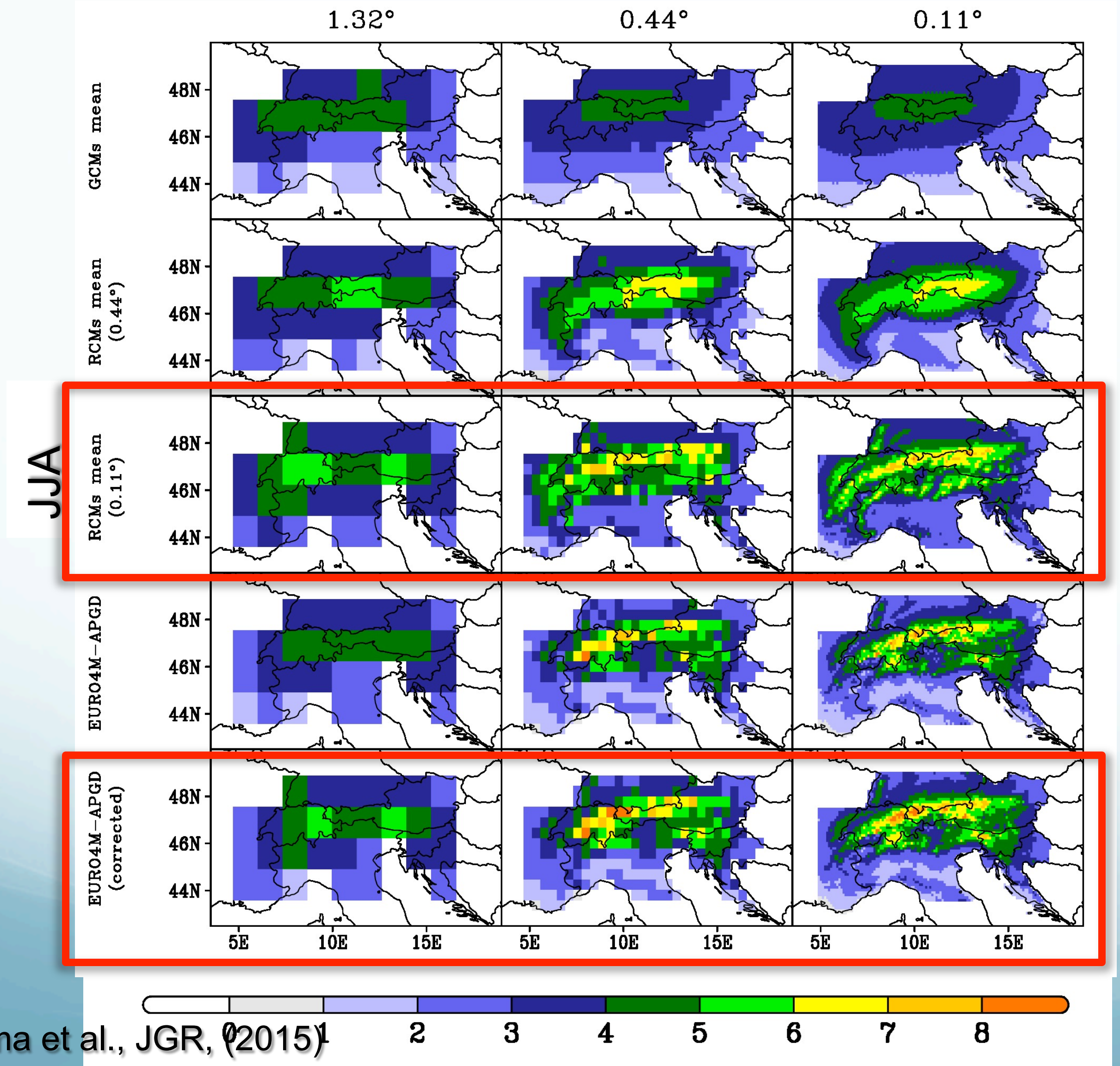
The Added Value: where can I find it?
1. in the spatial patterns of summer precipitation



Higher resolution

Increasing details in precipitation spatial distribution

Fine scale AV

Torma et al., JGR, (2015)

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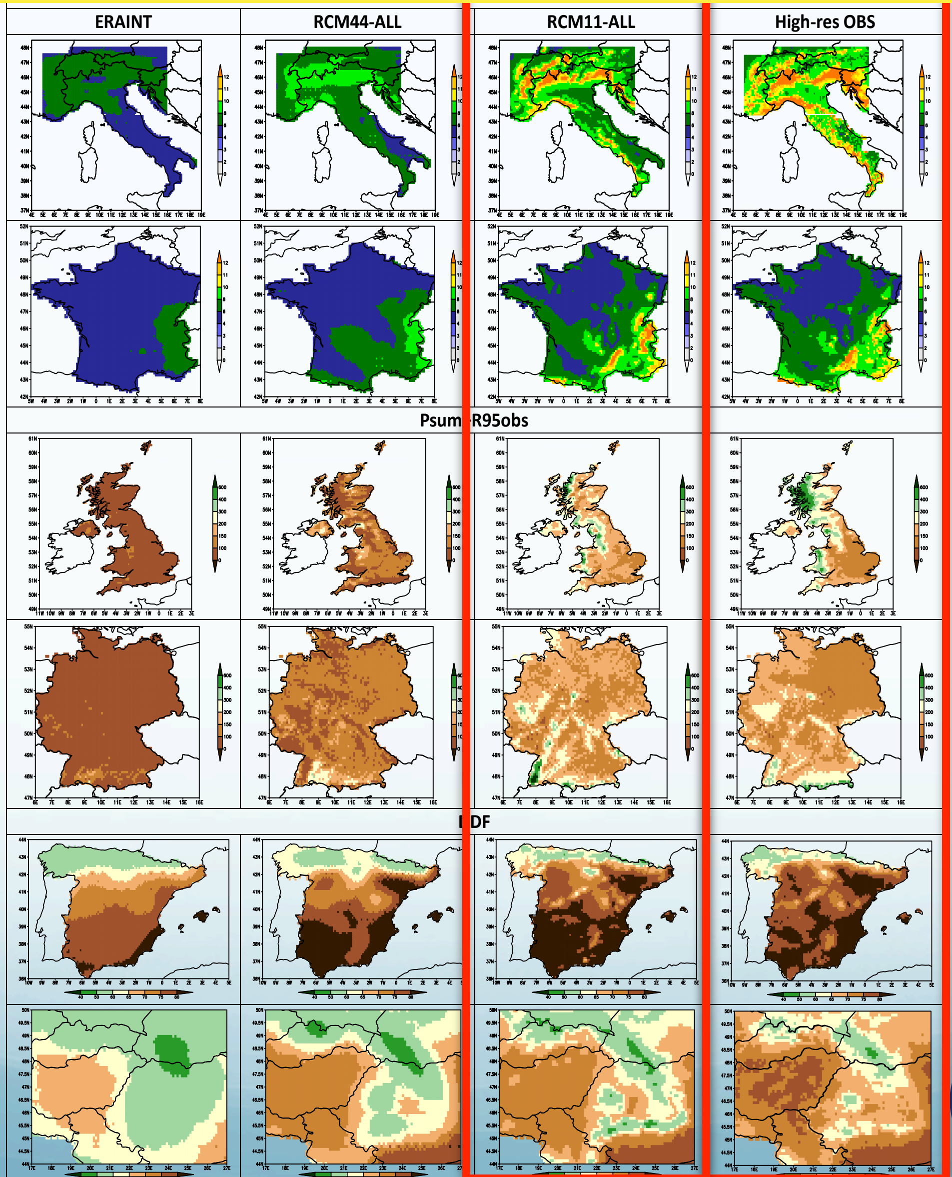
The Added Value: where can I find it?
1. in the spatial patterns of extreme precipitation indices



Fantini et al., Cli. Dyn., (2017)

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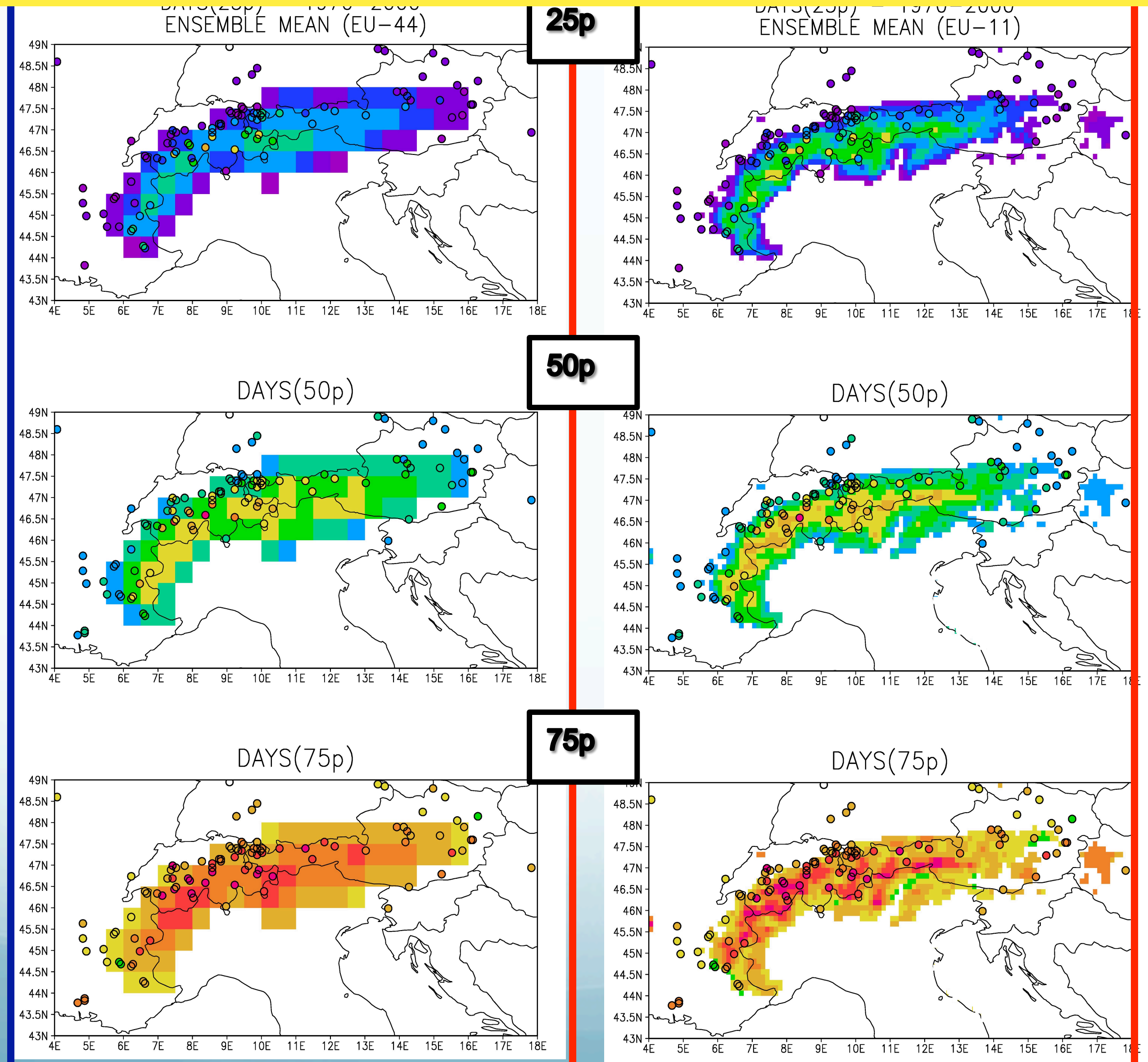
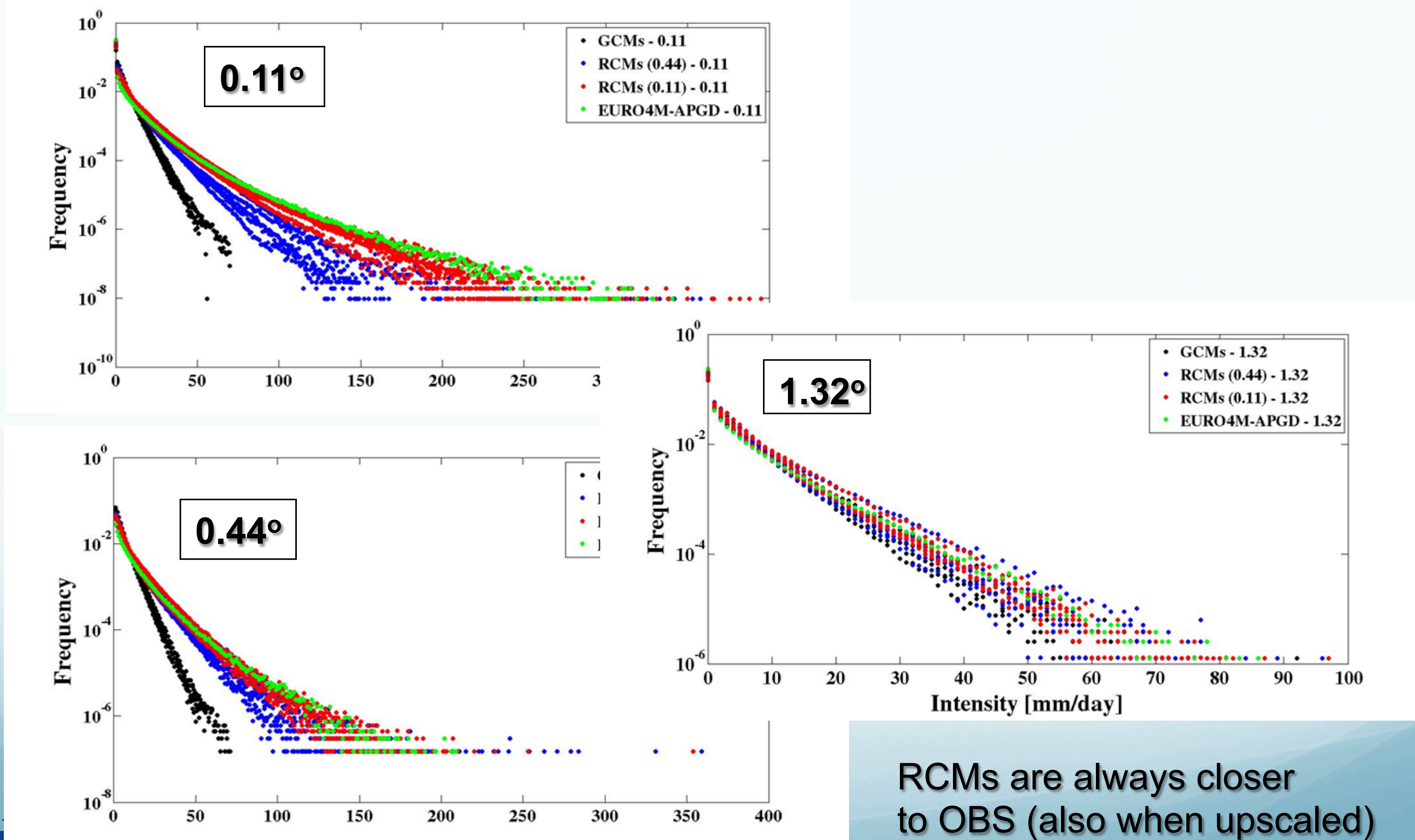
The Added Value: where can I find it?
2. Impacts - SDR change signal -Validation

0.44



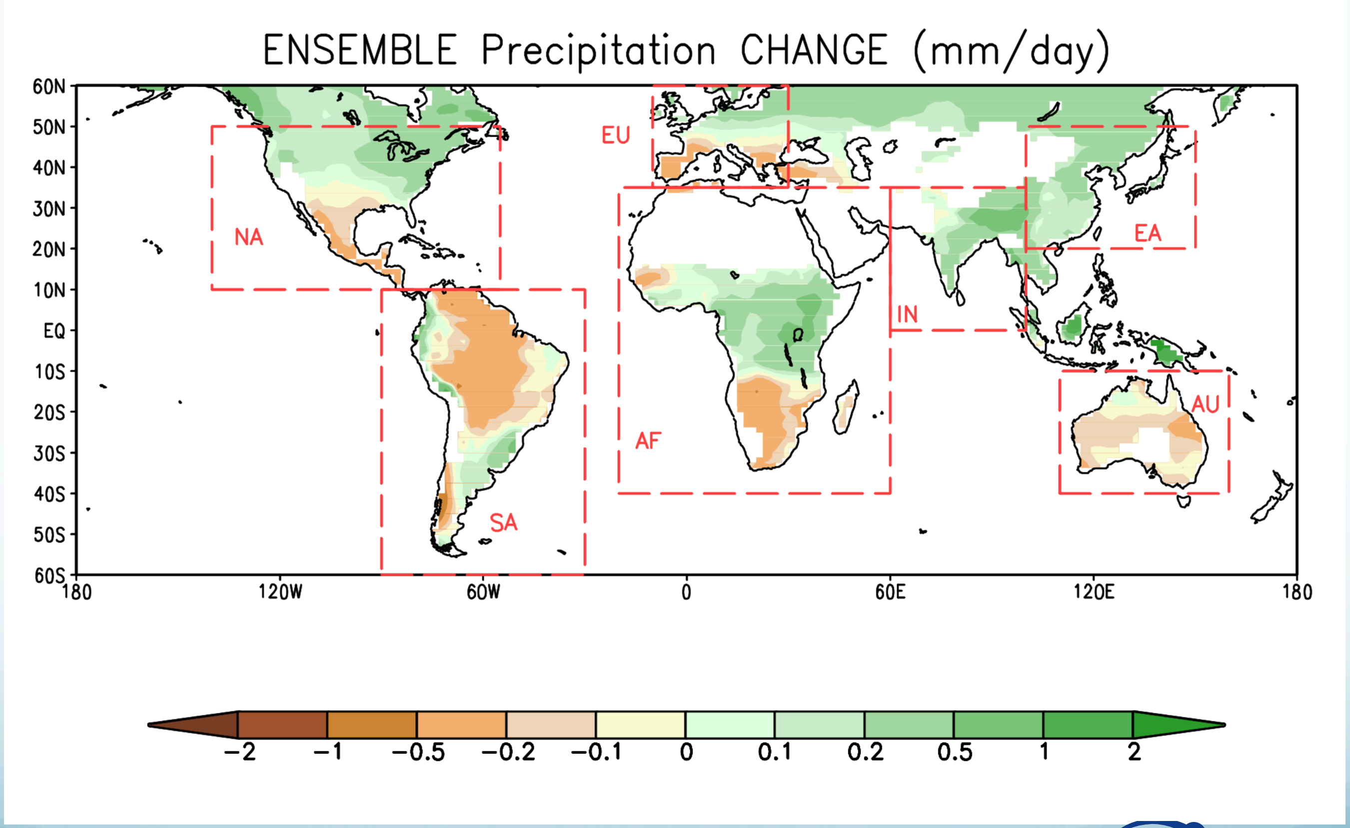
0.11

The Added Value: where can I find it?
3. in the daily precipitation intensity PDF



RCMs are always closer
to OBS (also when upscaled)

Climate Change Signal (ensemble of models): 1. the mean change



Coppola et al., 2014

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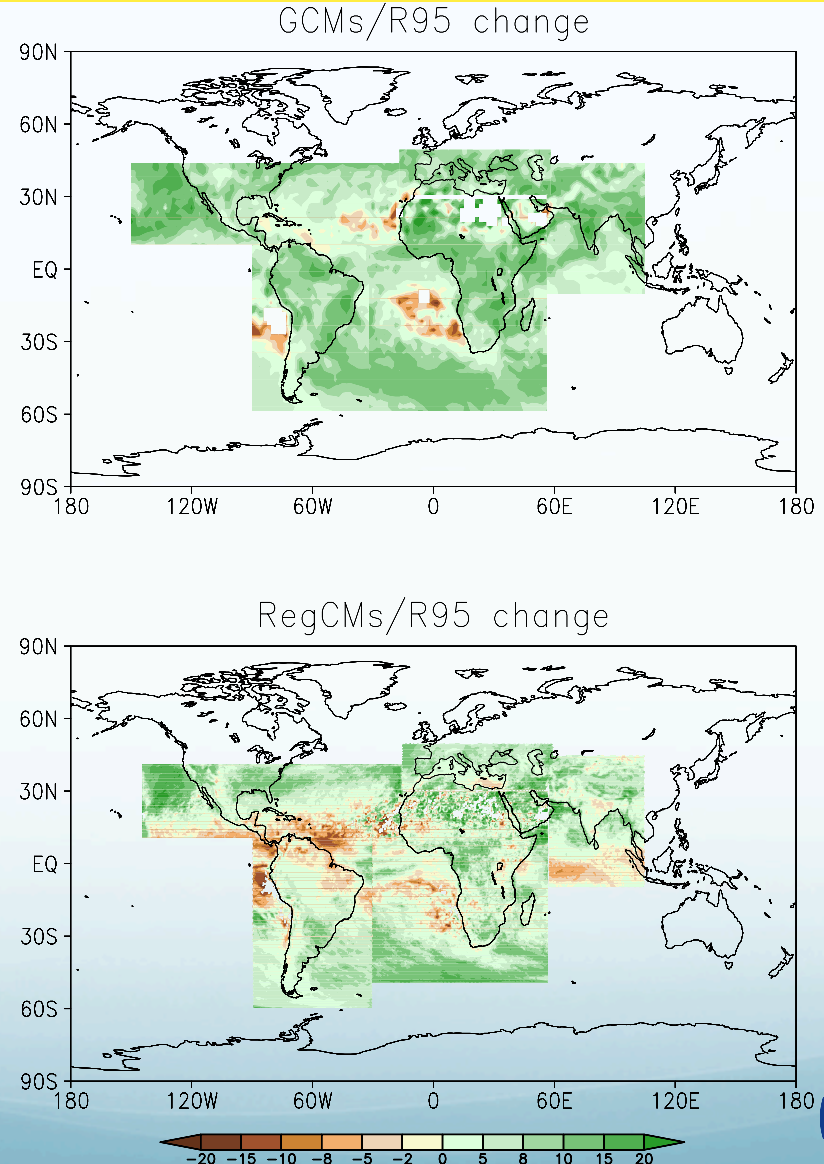
Climate Change Signal (ensemble of models): 2. the change in the extreme indices



Giorgi et al., 2014

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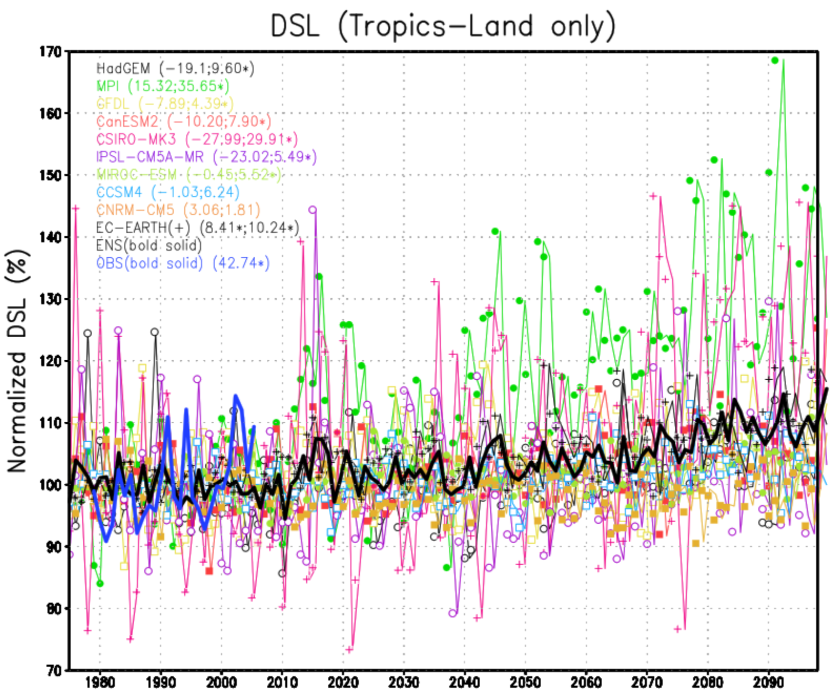
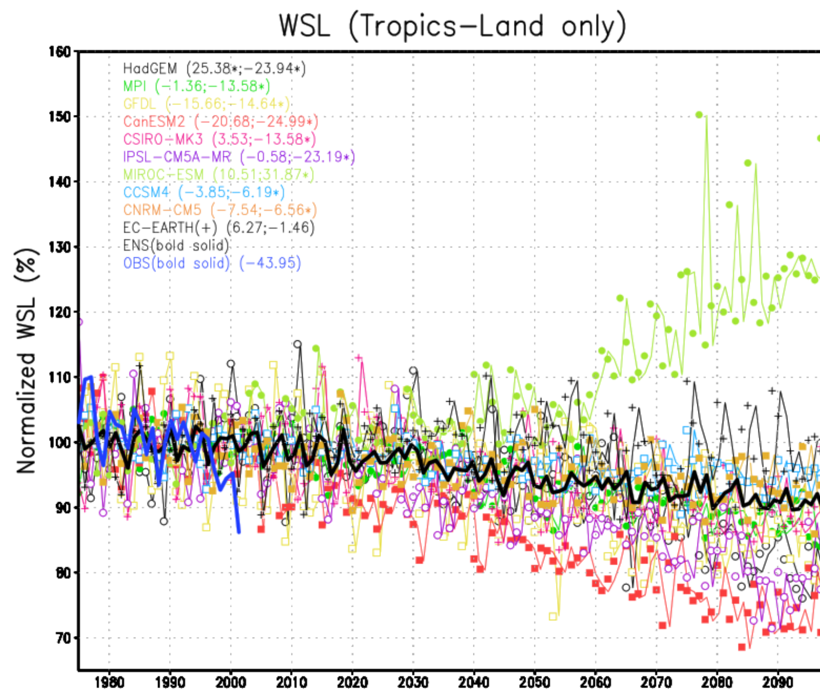
Climate Change Signal (ensemble of models): 3. Spaghetti plots





Time evolution of annual values of the 2 hydroclimatic indices considered averaged over tropical land areas for 10 GCM and their ensemble mean. Also shown for the historical period are the corresponding values for the CPC_GLOBAL observations. The two values in parentheses are the linear trends for the 1976-2005 and 2006-2100 periods, respectively and an asterisk indicates that the trend in statistically significant at the 95% confidence level. Units are % / 100 yrs.

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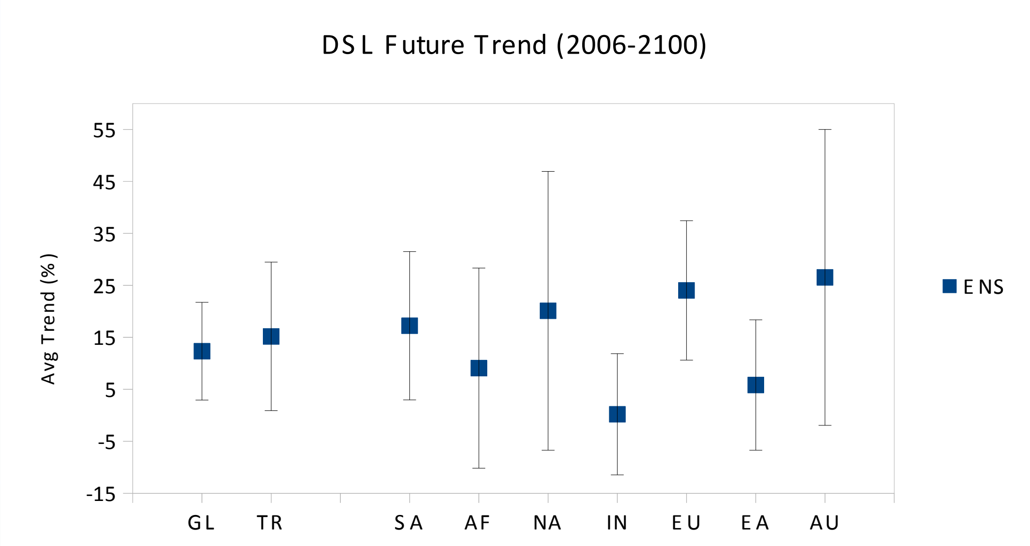
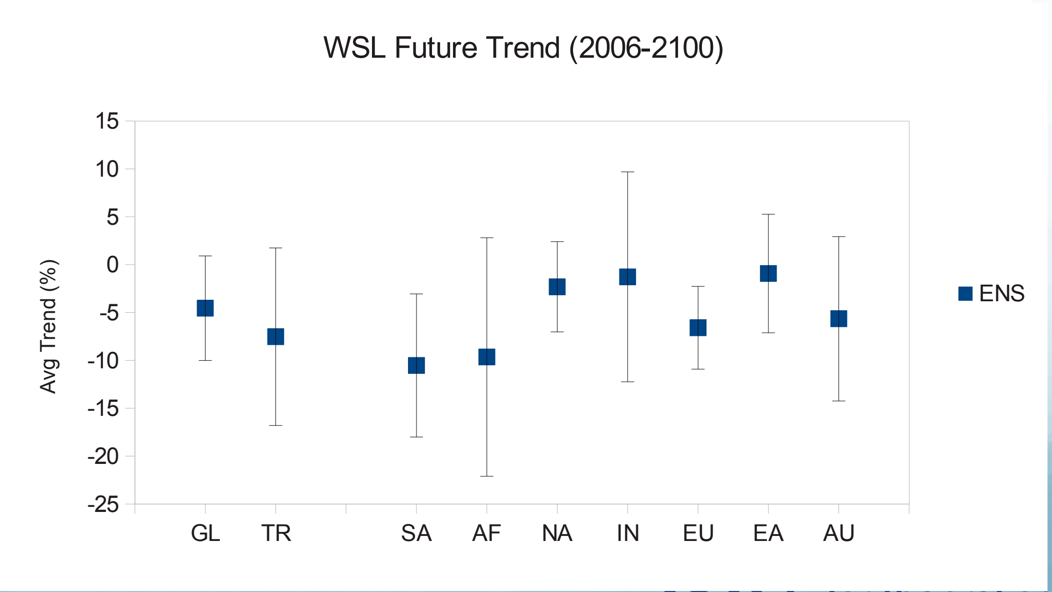
Giorgi et al., 2014

Climate Change Signal (ensemble of models):
4. Model consensus

Ensemble mean and inter-model 90% significance range of the linear trend values for the period 2006-2100, averaged over global (60 S - 60 N) and tropical (30 S - 30 N) land areas and over 7 continental regions. Units are % / 100 yrs





Giorgiet al., 2014

Centre for Theoretical Physics

Climate Change Signal (ensemble of models): 5. Inter-annual variability

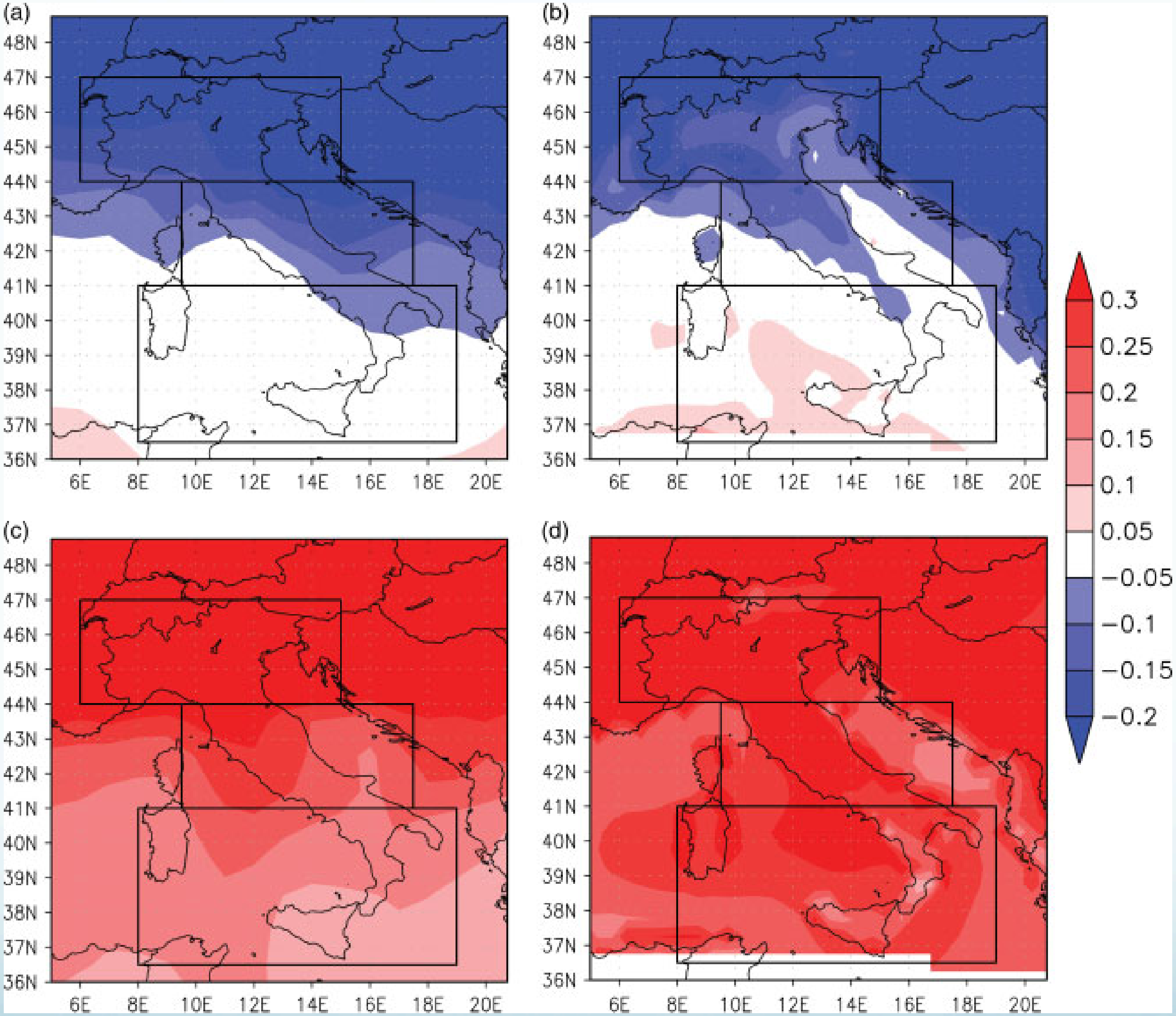


Figure 9. Ensemble average change in surface air temperature inter-annual variability (A2 scenario, 2071–2100 minus 1961–1990) for the CMIP3 AOGCMs [panels (a), (c)] and the PRUDENCE RCMs [panels (b), (d)] for winter (DJF, top panels) and summer (JJA, bottom panels). Units are % of 1961–1990 values. The inter-annual variability is measured buy the inter-annual standard deviation. This figure is available in colour online at www.interscience.wiley.com/ijoc

Coppola et al., 2014

Climate Change Signal (ensemble of models): 5. Inter-annual variability

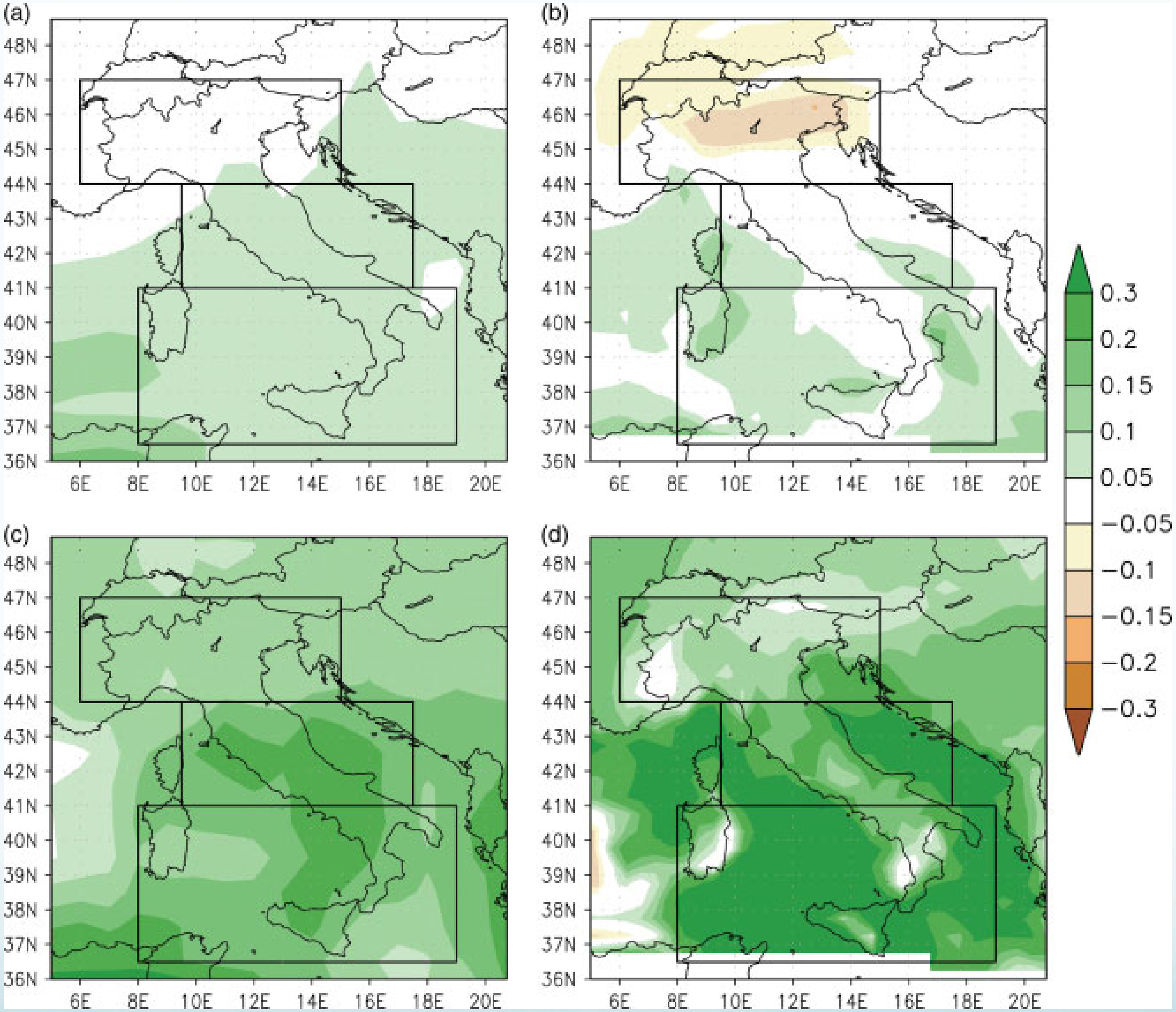
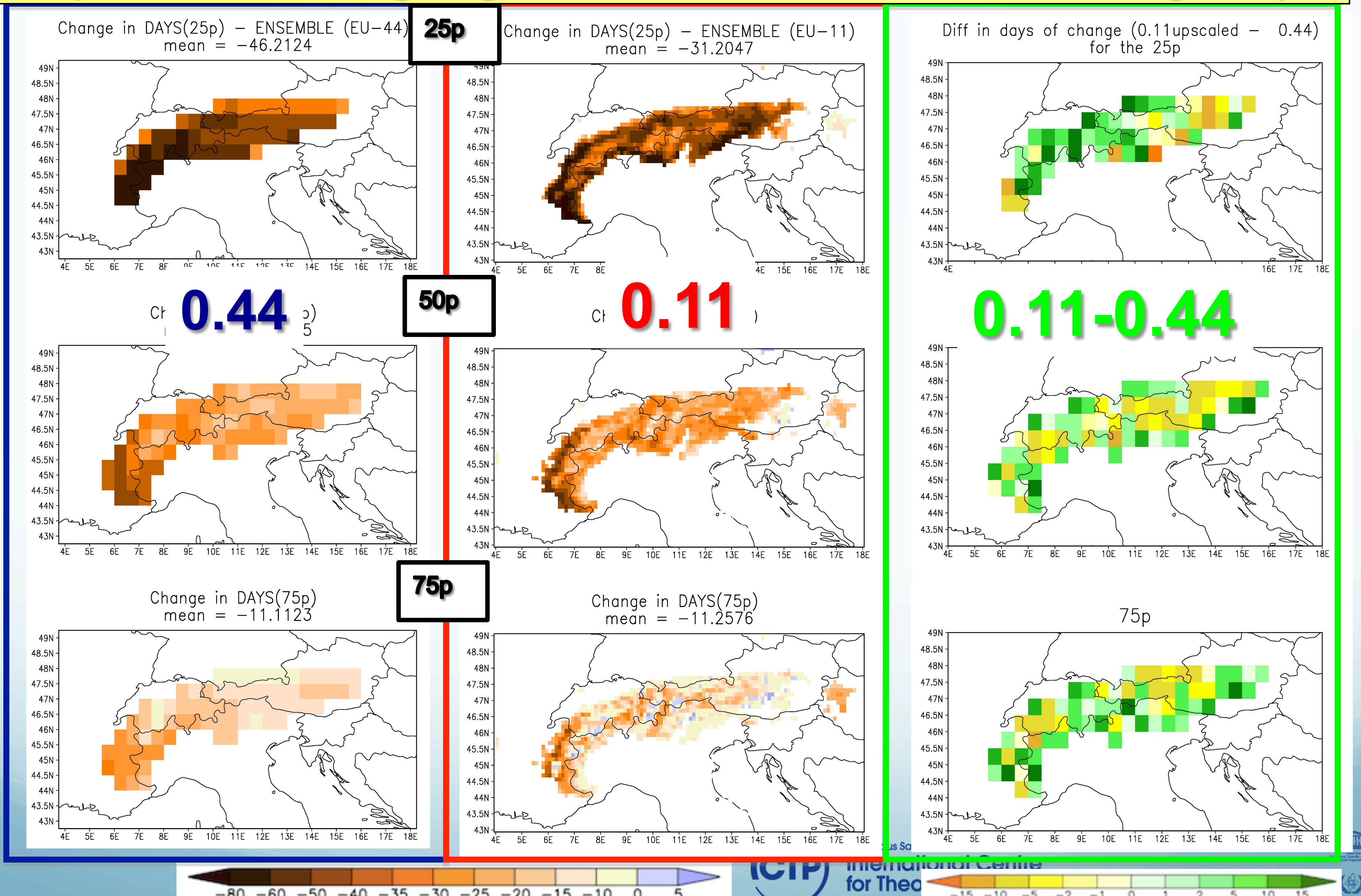


Figure 10. Ensemble average change in precipitation inter-annual variability (A2 scenario, 2071–2100 minus 1961–1990) for the CMIP3 AOGCMs [panels (a), (c)] and the PRUDENCE RCMs [panels (b), (d)] for winter (DJF, top panels) and summer (JJA, bottom panels). Units are % of 1961–1990 values. The inter-annual variability is measured buy the inter-annual coefficient of variation. This figure is available in colour online at www.interscience.wiley.com/ijoc

Coppola et al., 2014

Added value for climate change signal

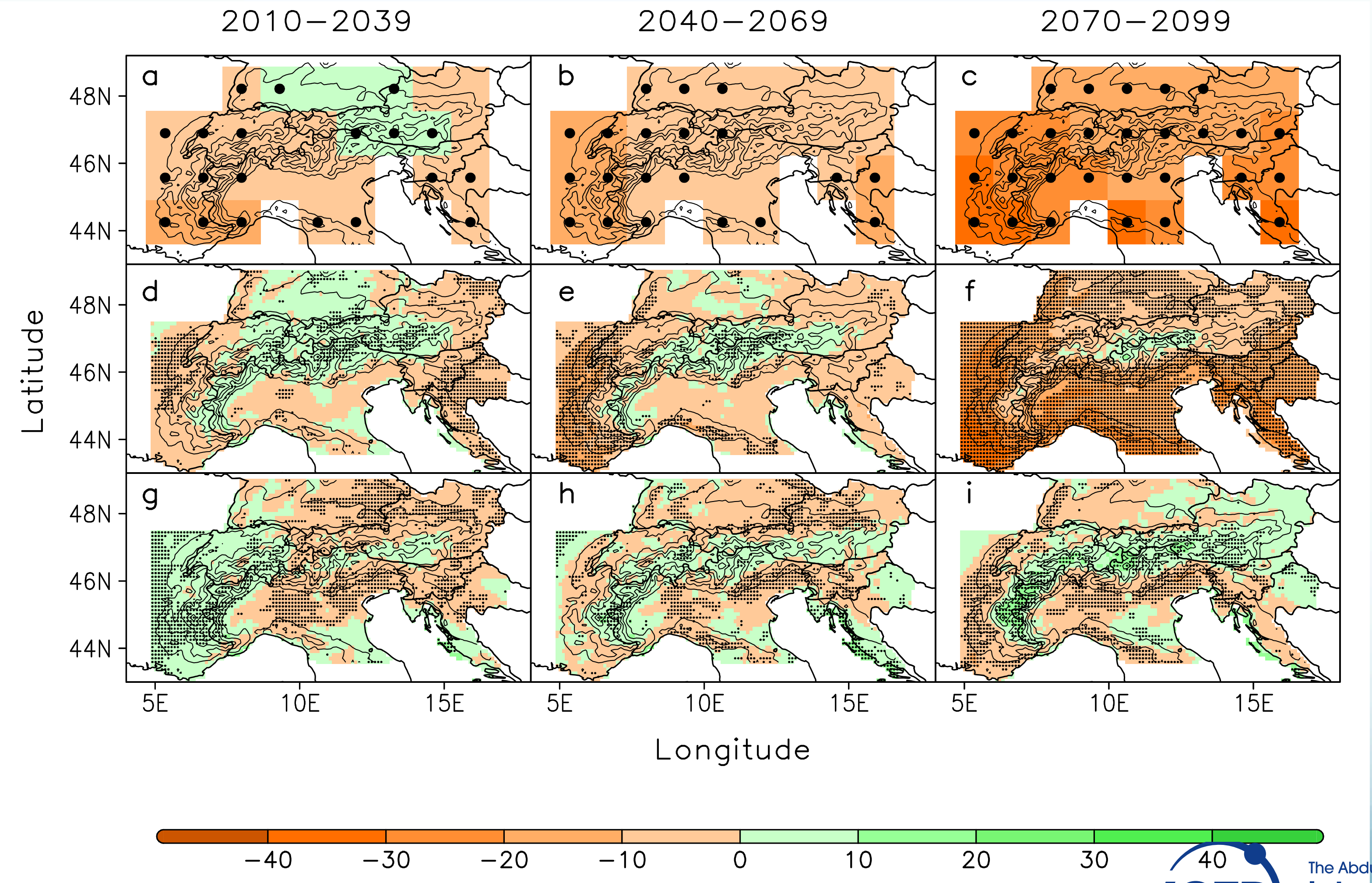
Impacts - SDR change signal- Results-Model ensemble change-days



Coppola E, **Raffaele F**, **Giorgi F**, Impact of climate change on runoff timing over the Alpine region.
Climate Dynamics, DOI: 10.1007/s00382-016-3331-0

Added value for climate change signal

Summer precipitation change (%)

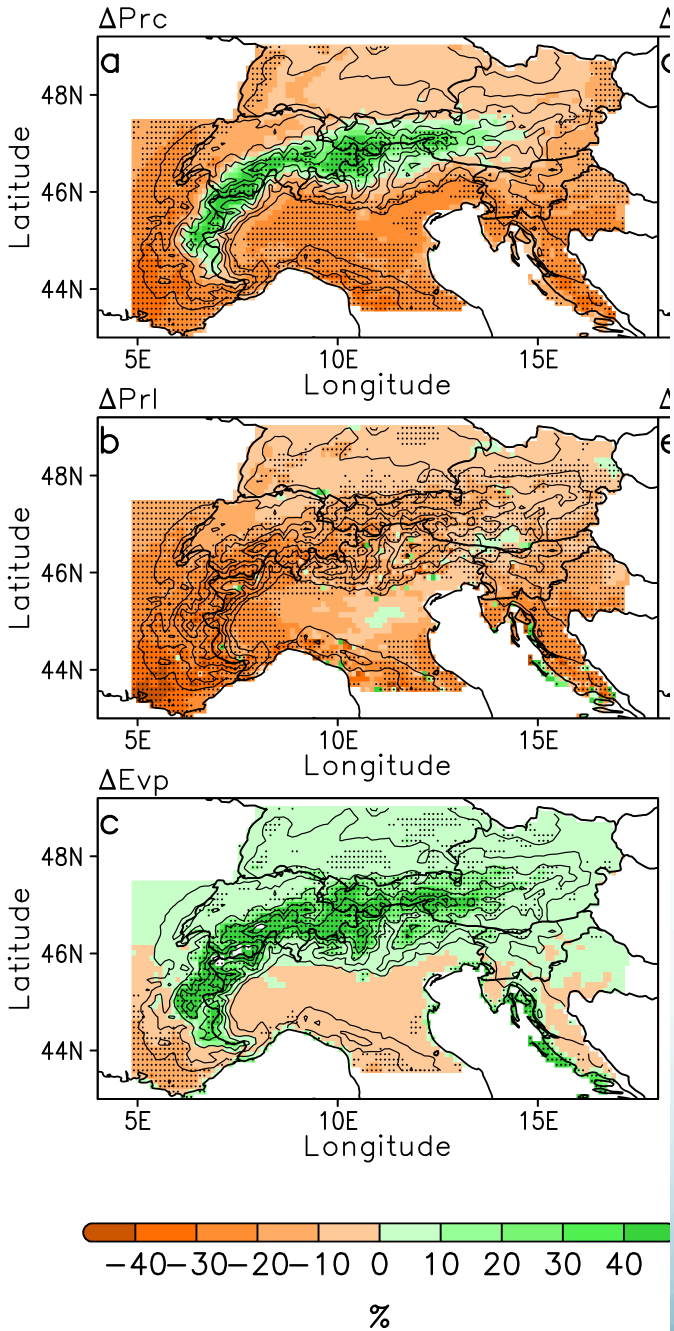


GCMs

RCMs 0.11°

Downscal. Signal

Giorgi et al., 2016



Convective

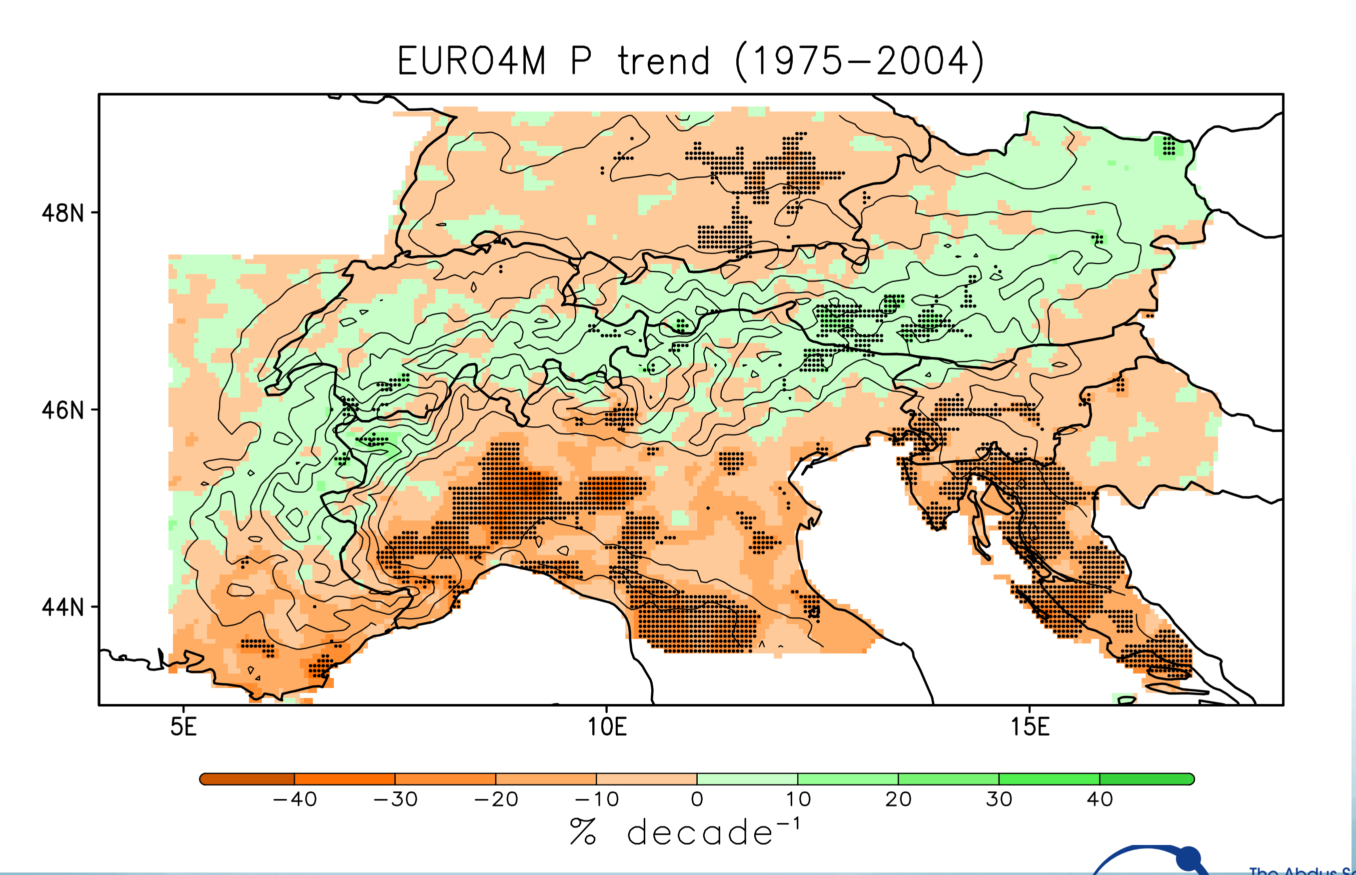
Non Convective

Evaporation

Summer precipitation change

Giorgi F, Torma C, Coppola E, Ban N, Schar C, Somot S, 2016. Enhanced summer convective rainfall at Alpine high elevations in response to climate warming. *Nature Geoscience*, **9:8**, DOI: 10.1038/NGEO2761

Observed summer precipitation trend during 1975-2004



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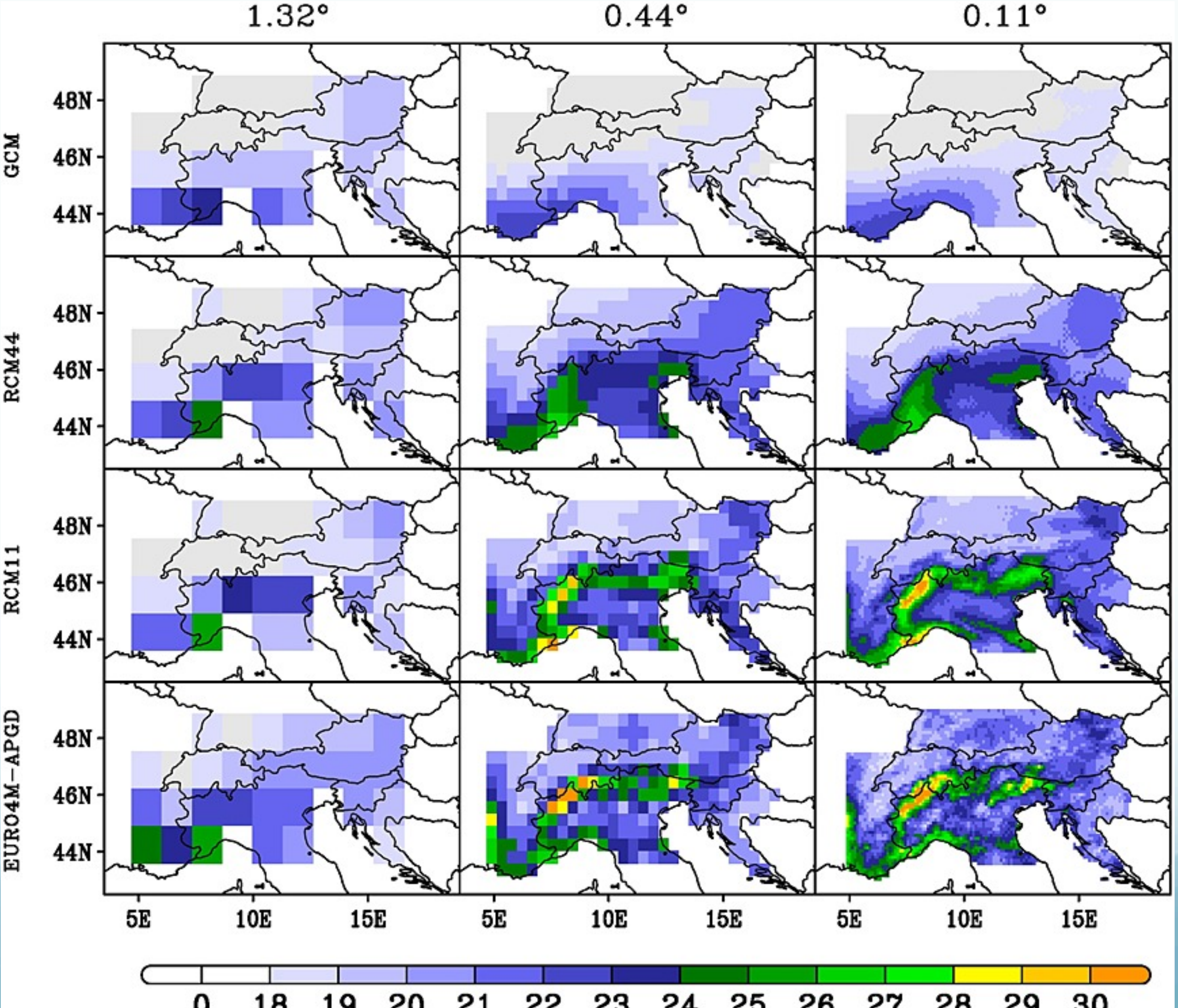
Added Value: R95 change for the historical period 1976–2005 and the three resolution gri
Units are in percent of total precipitation accounted for by events above the 95th percenti



Ensemble mean linear trend values for the future period 2006-2100