Results of a new methodology for the analyze the climate change uncertainty on a high step mountain range. Application at the Andes

A methodology with independence of model resolution and following criteria

L. Fita[1,3], A. F. Carril[1,3], P. Flombaum[1,3,4], C. Menéndez[1,2,3], R. Ruscica[1,3], A. Sörensson[1,3], P. Zaninelli[1,3,5]

[1] *Centro de Investigaciones del Mar y la Atmósfera (CIMA), CONICET-UBA, C. A. Buenos Aires, Argentina*

[2] *Departamento de Ciencias de la Atmósfera y los Océanos (DCAO), UBA - FCEyN, C. A. Buenos Aires, Argentina*

[3] *Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos (IFAECI), CNRS UMI-3351, C. A. Buenos Aires, Argentina*

[4] *Departamento de Ecología, Genética y Evolución (DEGE), FCEyN-UBA, C.A. Buenos Aires, Argentina*

[5] *Facultad de Ciencias Astrónomicas y Geofísicas, Universidad Nacional de La Plata (UNLP), La Plata, Argentina*

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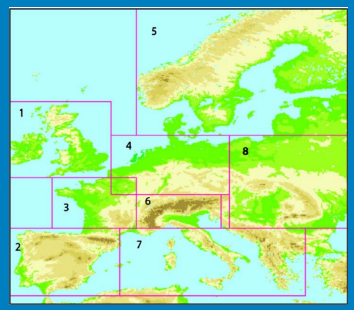
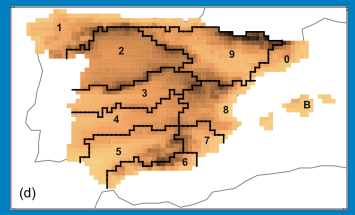
Currently

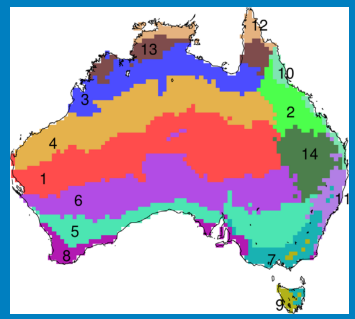
- **Space averaging:** comparison of different data-sets by spatial averaging over areas
- Definition of spatial areas different possibilities:



lon,lat boxes: artificial 'mathematical' boundaries *[Christensen, 2007, Climatic Change]*



orography: river basins *[Herrera, 2010, J. Geophys. Res.]*

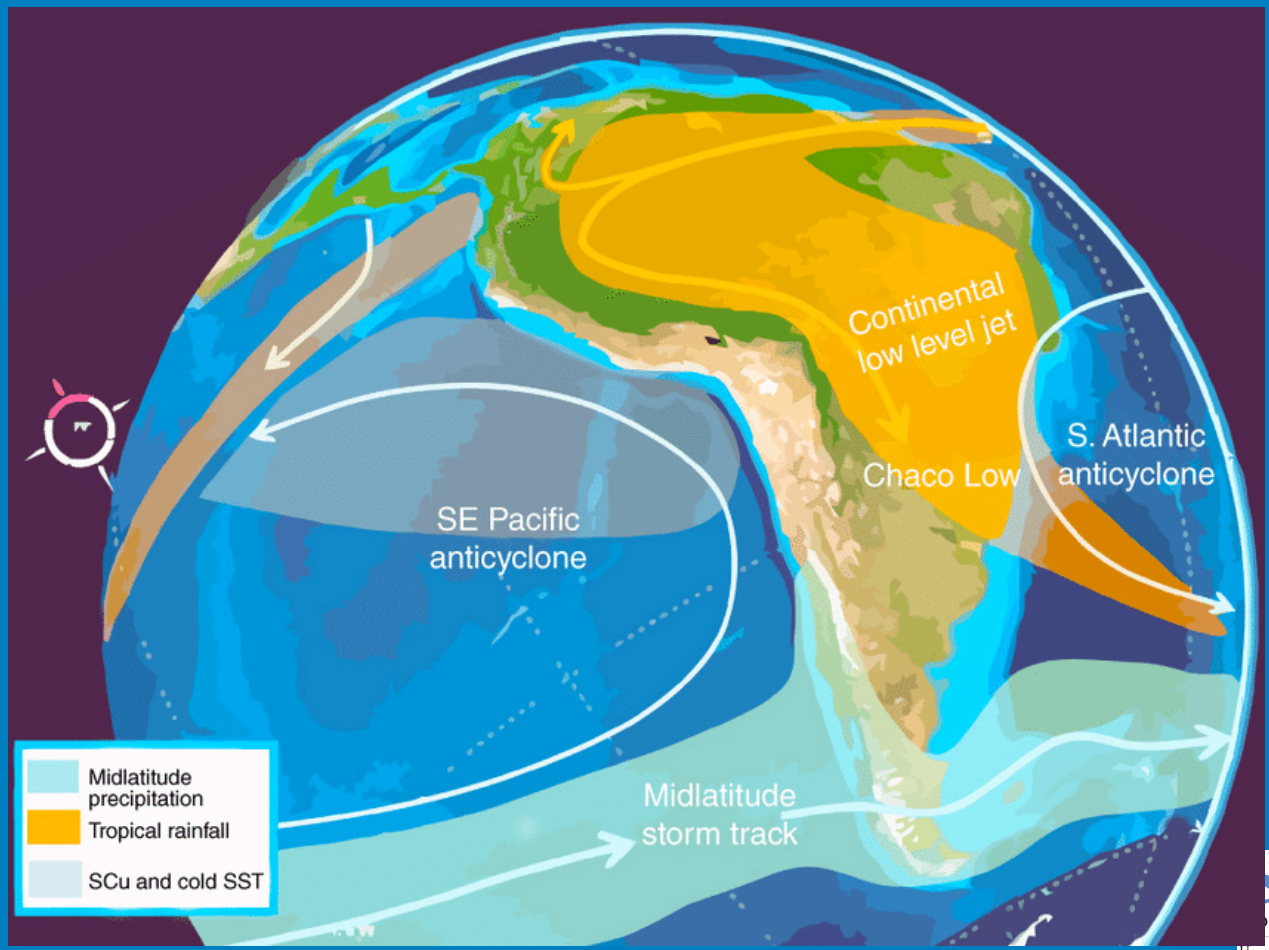


climate: climate coherence of regions *[Fita, 2016, Clim. Dyn.]*

- Following only one criteria
- **spatial incoherence** mixture of: different climates, atmospheric-dynamics, morphological characteristics...

Circulation patterns over South America

- Climate in South America dominated by Andes mountain range, with tropical precipitation North, and storm tracks South



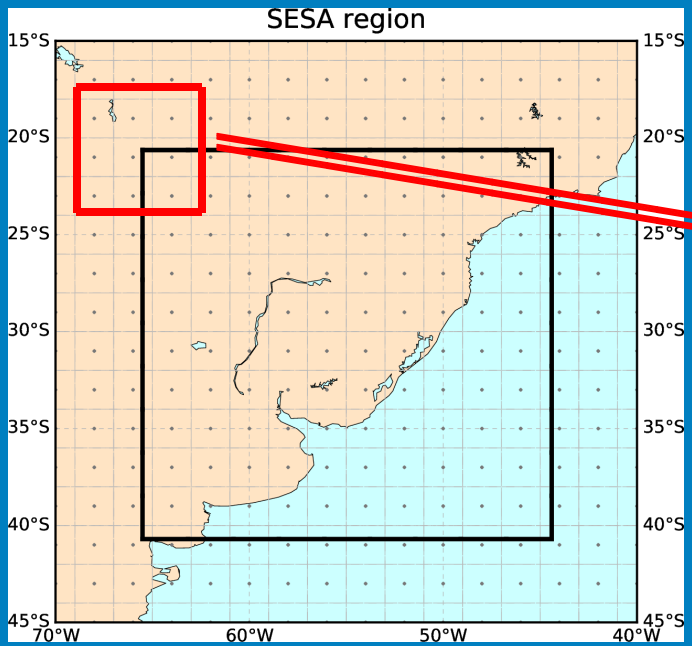
[Rusticucci et al., 2016, Int. J. Climate]

Proposal

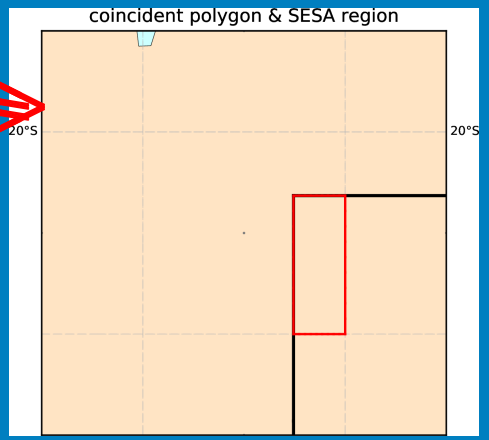
- Reduction of **spatial incoherence:** definition of regions using combination of different objective criteria
- Example on Andes study (3 criteria):
  1. **latitudinal bands**: climate coherence
  2. **orographic height**: climate coherence
  3. **mountain range face**: atmospheric-dynamics coherence
- Simultaneous application of 3 criteria to define spatial regions to spatially average model output
- Definitions:
  - criteria: definition of categories to select grid points
  - slice: union of criteria
- **spatial average**: spatial weighted average by **areal overlapping** of **slice** (as a polygon) and model **grid cell** (as lon,lat box)

Polygonal overlapping area

- Polygonal area overlapping: grid selection by spatial criteria.
- e.g. slice: SESA area
- $\forall$ grid cell $((i,j))$ area $(\mathcal{P}_g)$ within slice $(\mathcal{P}_S)$:



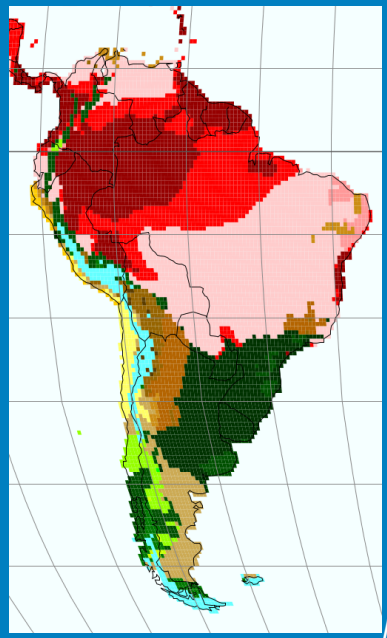
1. Overlaping of polygons: individual grid cells and slice. Take cell **fractions**



2. spatial averaging **weights** for grid cell as covered fraction of the total area of the slice $\mathcal{W}_g = \frac{\mathcal{A}_g^g}{\mathcal{A}_S}$

1st criteria: Latitudinal bands

- General climate latitudinal dependence (dist. from Equator & Poles)
- South American climate N-S bands:

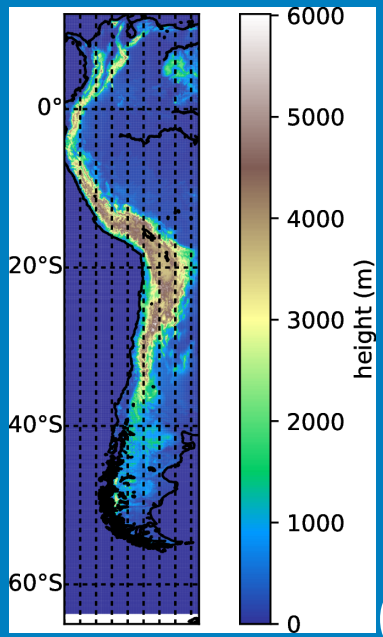


[Kottek, 2006, Meteorol. Z.]

- **criteria:** bands of latitude, from S 63.° to N 19."° every 2.° [41 categories]

2nd criteria: Topographical height

- Climate dependence on topographical height
- South American orography:

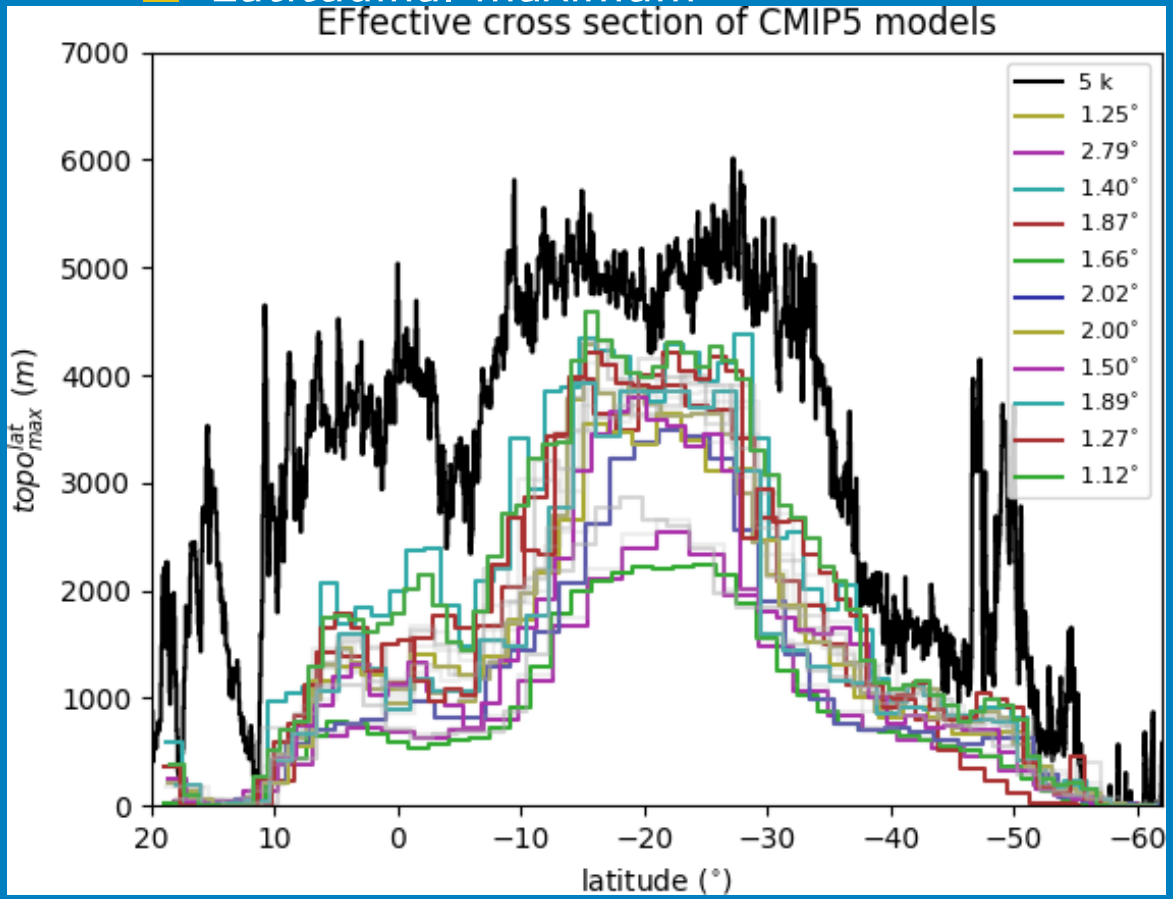


(3 *km* resolution)

- **criteria:** height ranges of orography from 500. to 7000. *m* every 500. *m* [13 categories]

Topographycal representation CMIP5 models

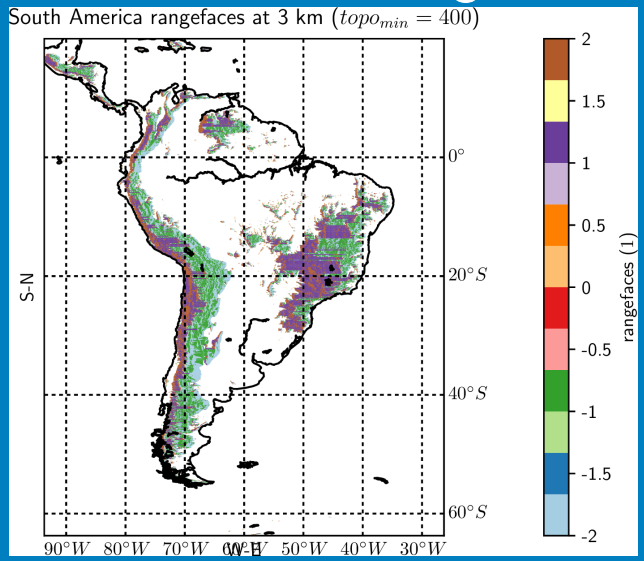
- **Challenge**: results using CMIP5 data at various poor resolutions
- Latitudinal maximum



Loss of main peaks
Differences about 2000 *m*

3rd criteria: mountain face

- Atmospheric dynamics dependence on wind/lee-ward side of the Andes mountain range
- Use new diagnostic **rangefaces** to define west, peak and east regions along a mountain range
- South American 'rangefaces':



(3 *km* resolution)

$$\begin{cases} 2 & \textit{uphill} \\ 1 & \textit{uphill valley} \\ 0 & \textit{peak} \\ -1 & \textit{downhill valley} \\ -2 & \textit{downhill} \end{cases}$$

- Use only Andes range (single 'range' value)
- **criteria:** grid point 'uphill', 'peak' or 'downhill' [3 categories]

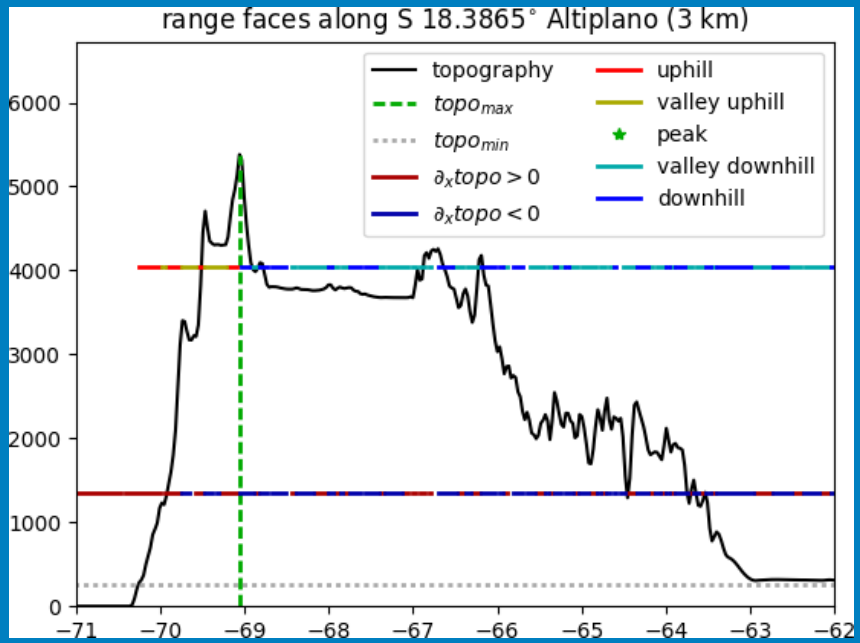
rangefaces: mountain range face diagnostics

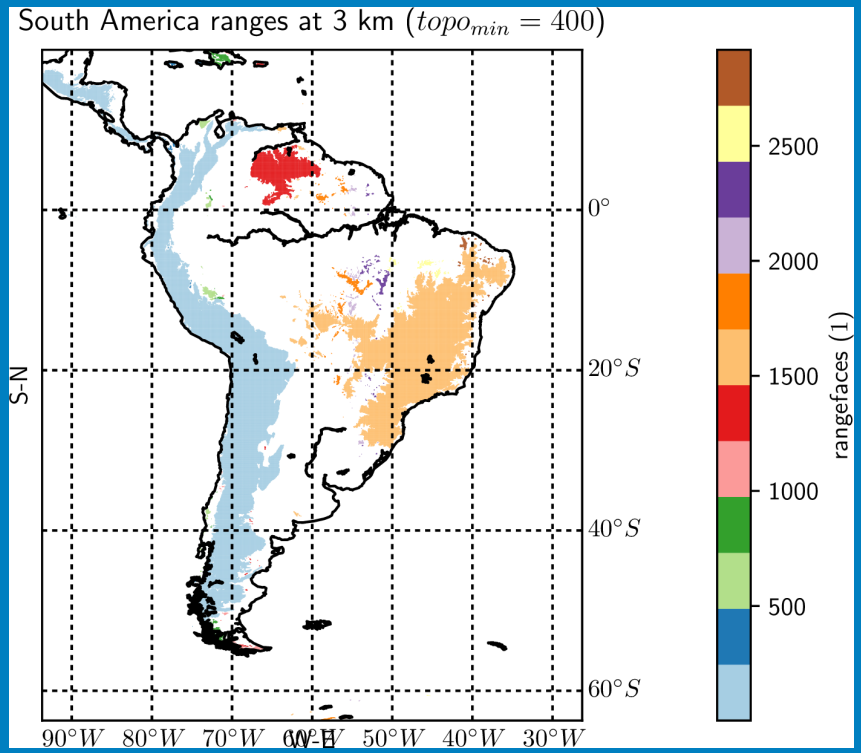
- Grid point side along longitudinal/meridional sections. e.g. Andes: latitudinal sections
  1. *range*: grid point as part of a mountain range if it is above 400 m ($topo_{min}$)
  2. *West/East*: 'x' derivative of the topography: West (**uphill**, [2]), East (**downhill**, [-2])

$$\partial_x topo(i,j) = \frac{topo(i+1,j) - topo(i,j)}{\delta x} \begin{cases} > 0. & uphill\ (2) \\ < 0. & downhill\ (-2) \end{cases}$$

  3. $topomax(j)$: topo. max along lat section. Defines the two major areas: uphill (before), downhill (after)
  4. **peak** [0]: grid point $imax$ where $topomax(j)$
  5. *valleys*: local minimums: **uphill valleys** [1] and **downhill valleys** [-1]
  6. Repeated along all meridional sections per mountain range (contiguous grid points above $topo_{min}$)
  7. Unique identification per mountain range

rangefaces: mountain range face diagnostics





(e.g. section lat. S 18.3865°, 3 *km res.*)

rangefaces

$$\begin{cases} 2 & \textit{uphill} \\ 1 & \textit{uphill valley} \\ 0 & \textit{peak} \\ -1 & \textit{downhill valley} \\ -2 & \textit{downhill} \end{cases}$$

Result on:

- 3km resolution topography
- y-axis section
- $topo_{min} = 400\ m$

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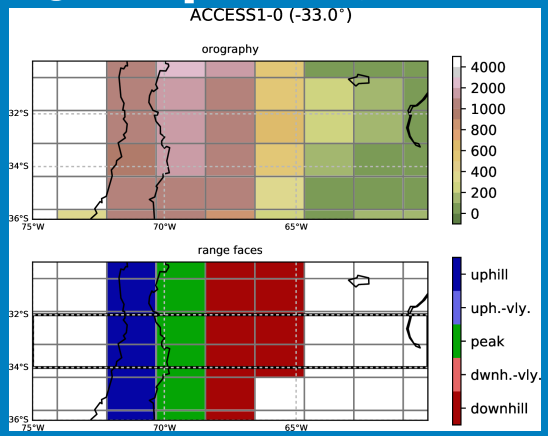
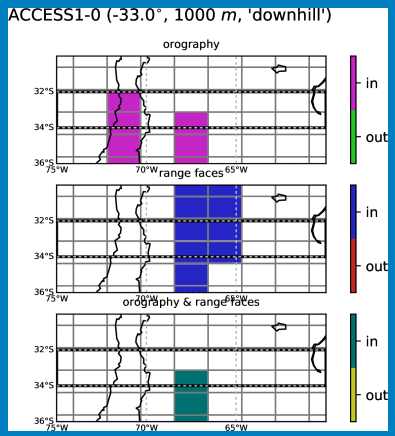
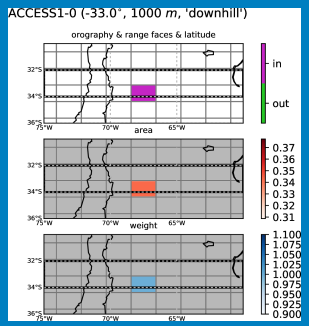
Slicing: regions following different criteria

- e.g. Andes mountain range following: lat. bands, orog. and range-face. Total pot. slices: $41 \times 13 \times 3 = 1599$
- e.g. CMIP5 ACCESS1.0 for: latitudinal band=[S 34°, S 32°], height= [750. m, 1250. m] and 'downhill' range face: $[-2.5, -0.5]$





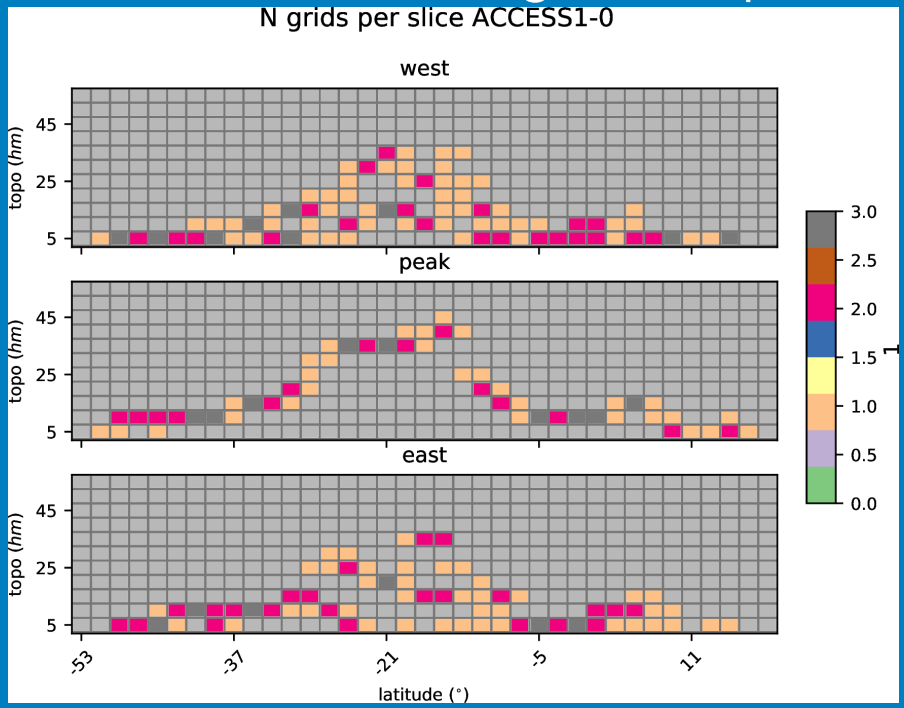


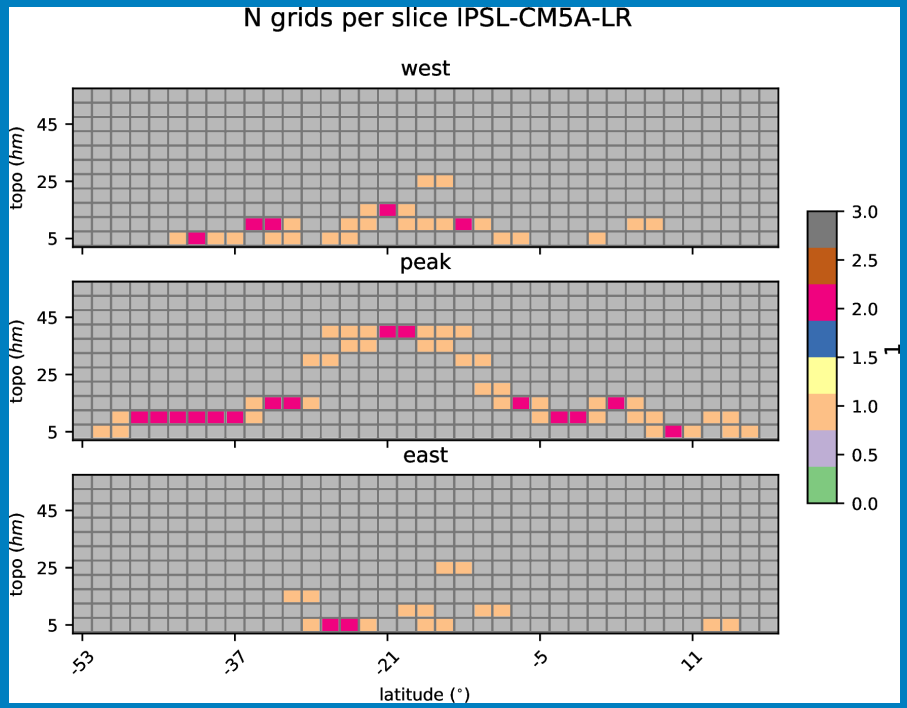
1. Final area ($\mathcal{A}_{C1,C2,C3}$); acc. product of area of each criteria
2. weights ($\mathcal{W}$): fraction of slice area ($\mathcal{A}_{C1,C2,C3}$) covered by each grid point $\mathcal{A}^{g}_{C1,C2,C3}[k]$

$$\mathcal{W}[k] = \frac{\mathcal{A}^{g}_{C1,C2,C3}[k]}{\mathcal{A}_{C1,C2,C3}}, \qquad \mathcal{A}_{C1,C2,C3} = \sum_{k=1}^{N_{1,2,3}} \mathcal{A}^{g}_{C1,C2,C3}[k]$$

Slicing: description

- Number of grid cells per slices: ACCESS 1.0 & IPSL-CM5A-LR



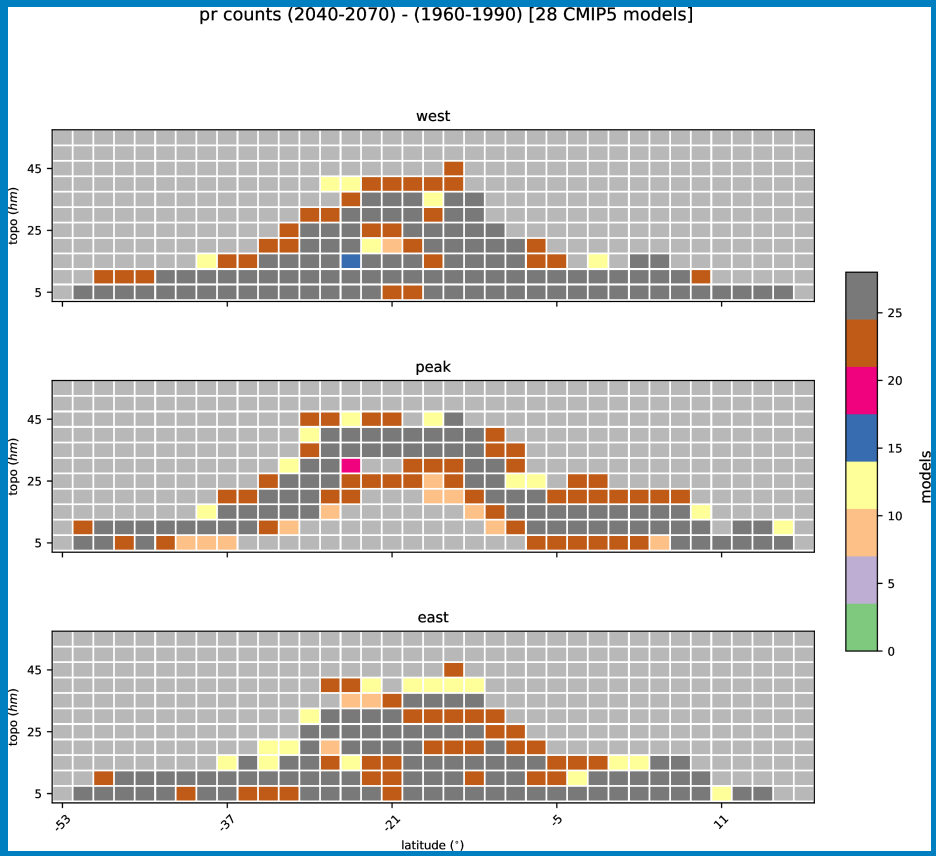


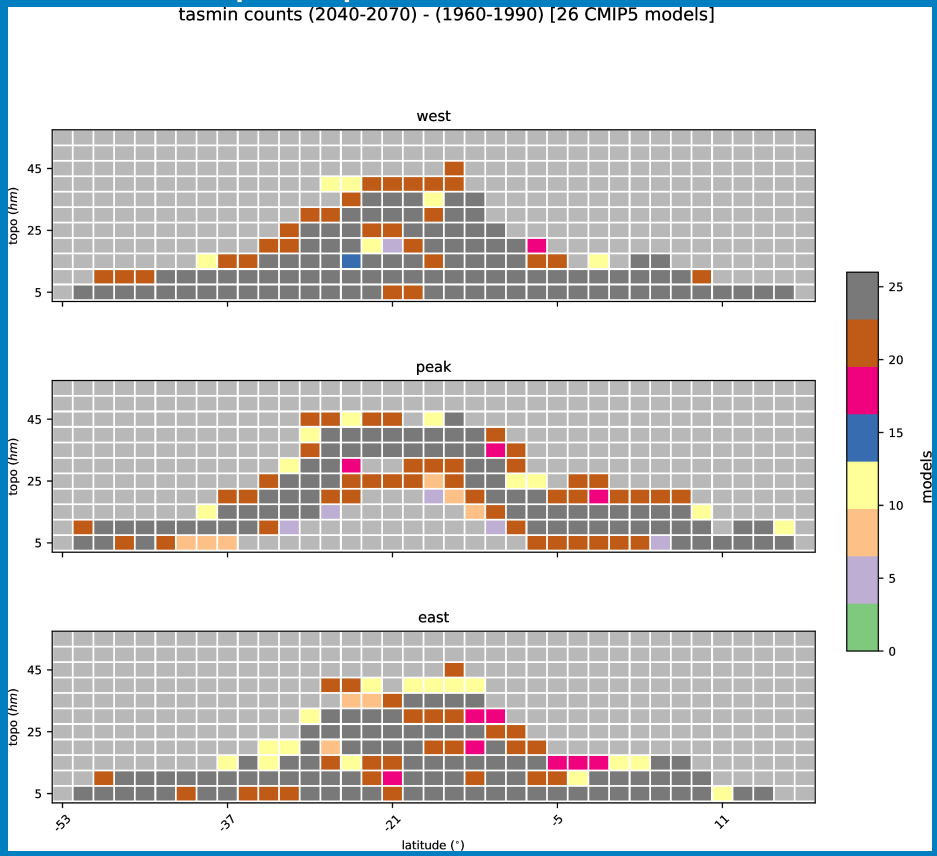
Number of grid cells per slice depend on model resolution:

- ACCESS 1.0: $1.875 \times 1.25°$
- IPSL-CM5A-LR: $3.75 \times 1.895°$

Slicing: description (cont. ii)

- Number of models with data per slice for precipitation and tasmin





Each slice with different models and ensemble size

Uncertainty of climate change signal

- For each slice, response to climate change (*fut*, 2040-2070 vs *hist*, 1960-1990) for: pr, tasmin, tasmax is computed. ESGF monthly data (28 models pr, 26 models tasmin/tasmax)
- Uncertainty of response is computed as in *[Kendon et al., 2008, J. Climate]* (after *[Storch and Zwiers, 1999,]*)
  1. signal-to-noise-ratio: $SNR = \frac{<ENSresp>}{\left(\frac{\sqrt{(\sigma^{hist}_{yrvar})^2+(\sigma^{fut}_{yrvar})^2}}{2}\right)}$
  2. significance at 5 % by two-tailed T-student:
     1. equivalent T-student: $t_{equiv} = SNR\sqrt{\frac{Nmod}{2}}$
     2. γ-degrees of freedom: $\gamma = (Nmod - 1)\left[\frac{\left(1+\left(\frac{\sigma^{fut}_{yrvar}}{\sigma^{hist}_{yrvar}}\right)^2\right)^2}{1+\left(\frac{\sigma^{fut}_{yrvar}}{\sigma^{hist}_{yrvar}}\right)^4}\right]$
     3. finally, significance: $\begin{cases} t < t_{theo}(\gamma, 0.025) \\ t > t_{theo}(\gamma, 0.975) \end{cases}$

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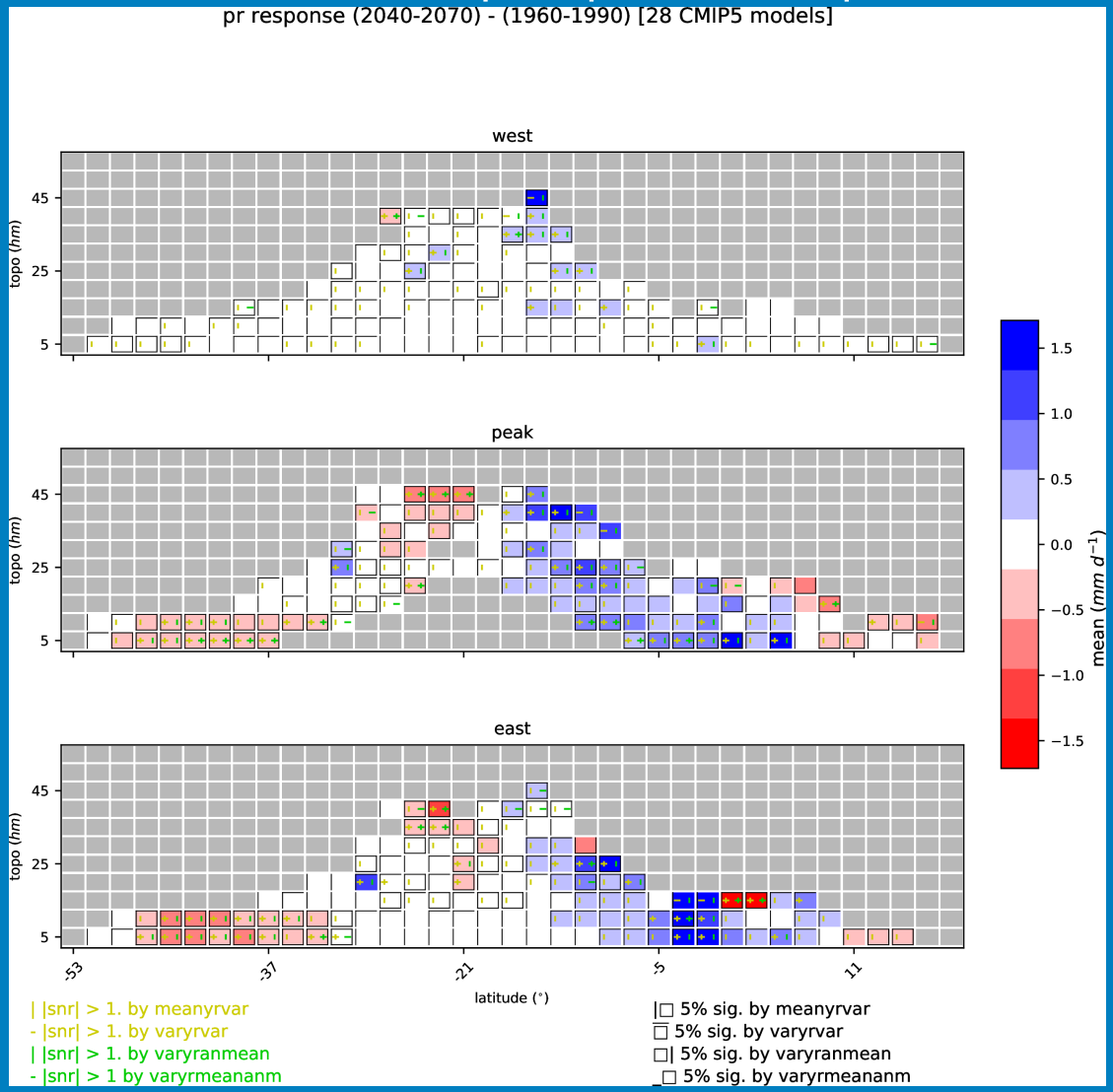
Uncertainty of climate change signal (cont.)

- SNR and significance test computed from variances ($\sigma_{yrvar}^{hist/fut}$):
  - interanual variability of the ENS:
    $\frac{1}{Nmod} \sum_{imod=1}^{Nmod} (yrvar_{imod}^{hist/fut})$
  - ENS spread of the interannual variability:
    $\sigma(yrvar_{imod}^{hist/fut})$
  - ENS spread of the annual mean:
    $\sigma(yranmean_{imod}^{hist/fut})$
  - ENS spread of the interannual anomalies:
    $\sigma(yrmeananom_{imod}^{hist/fut})$

Results

- ENSmean precipitation response



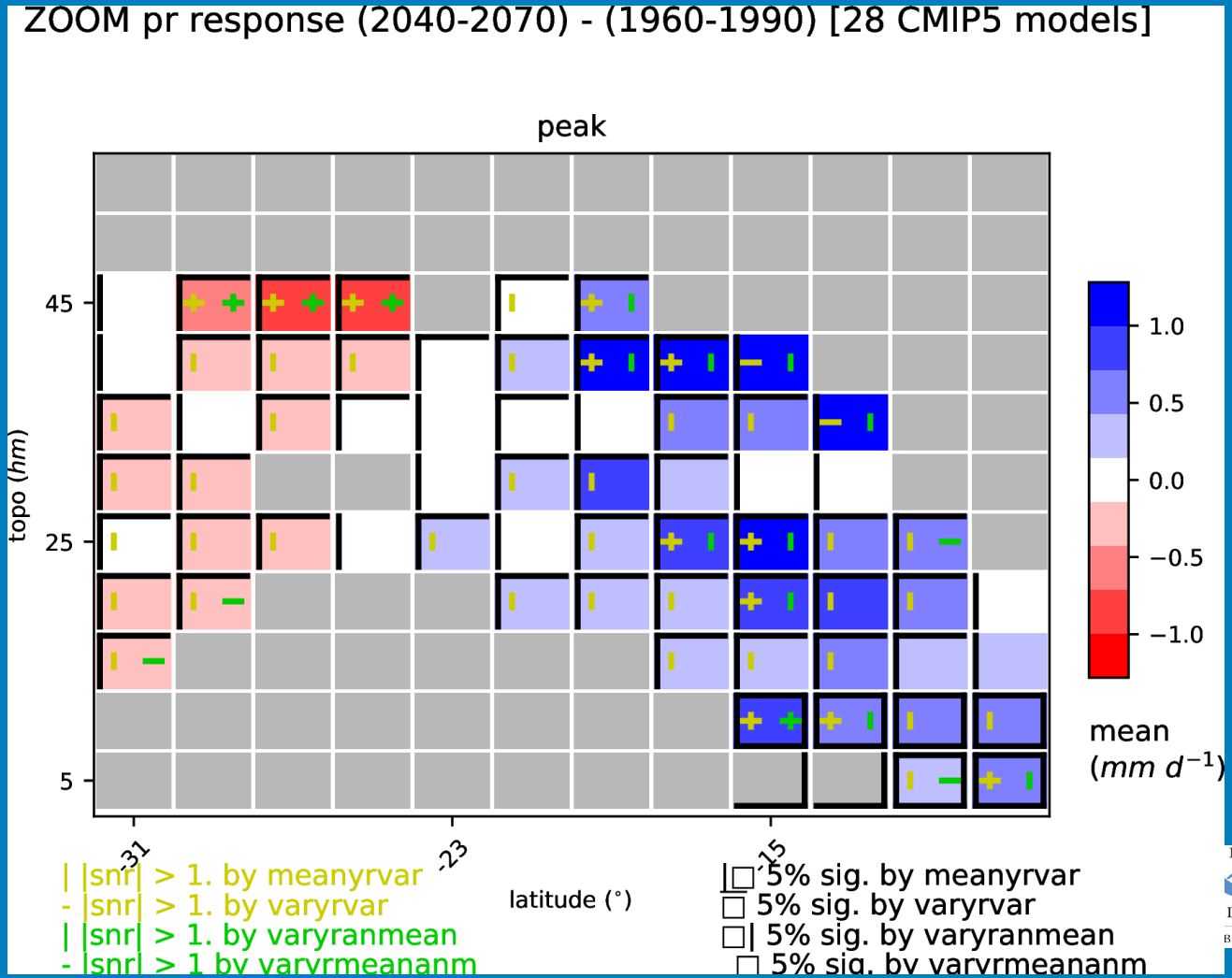
- Precpitation increase mostly East-tropical regions
- pr decrease everywhere else
- certainty and significance slice and variance dependency

'+': certain by $|SNR| > 1$

'□': T-student sig.

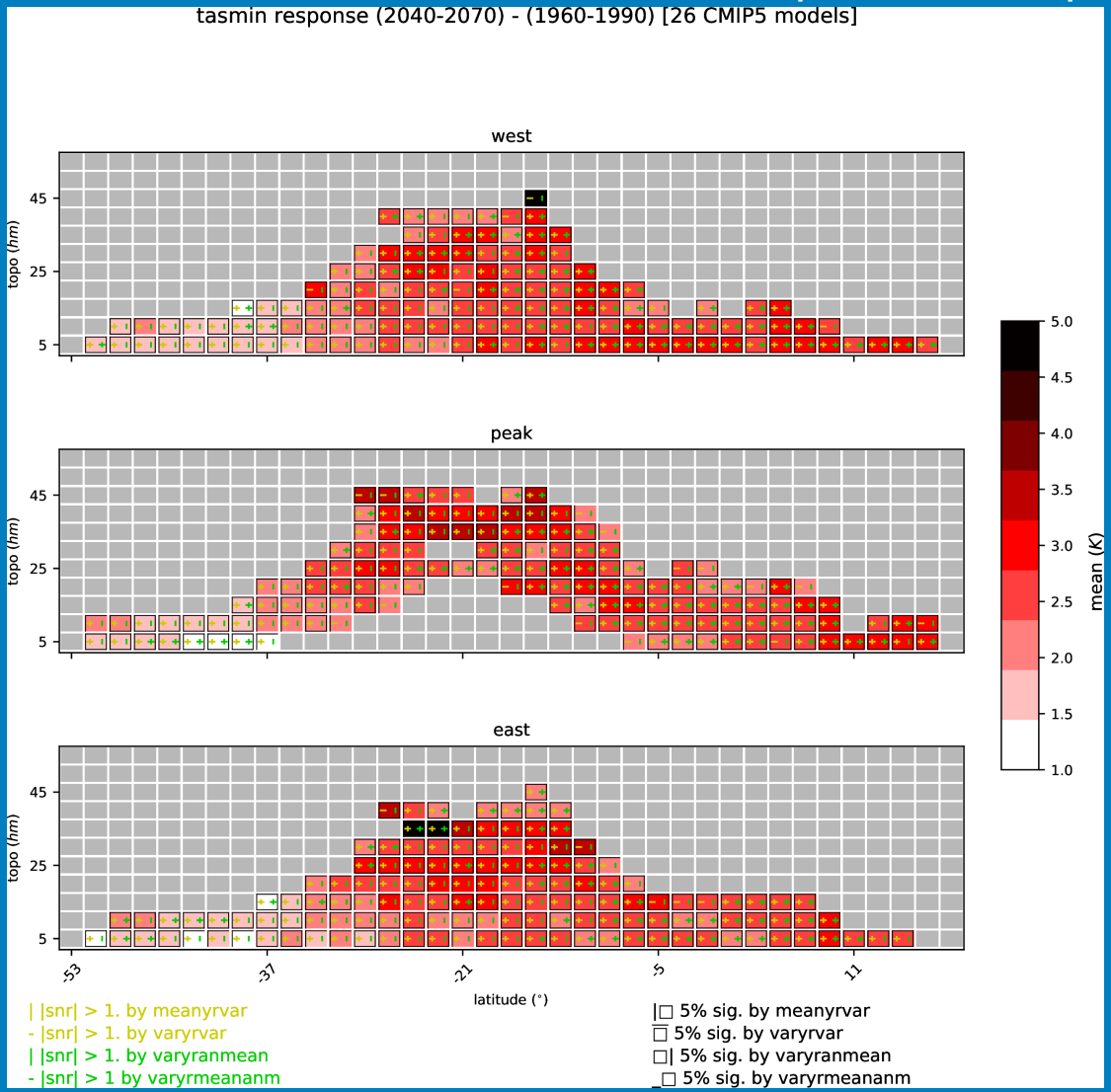
Results

- Zoomed example on slicing for pr: 'peak'



Results

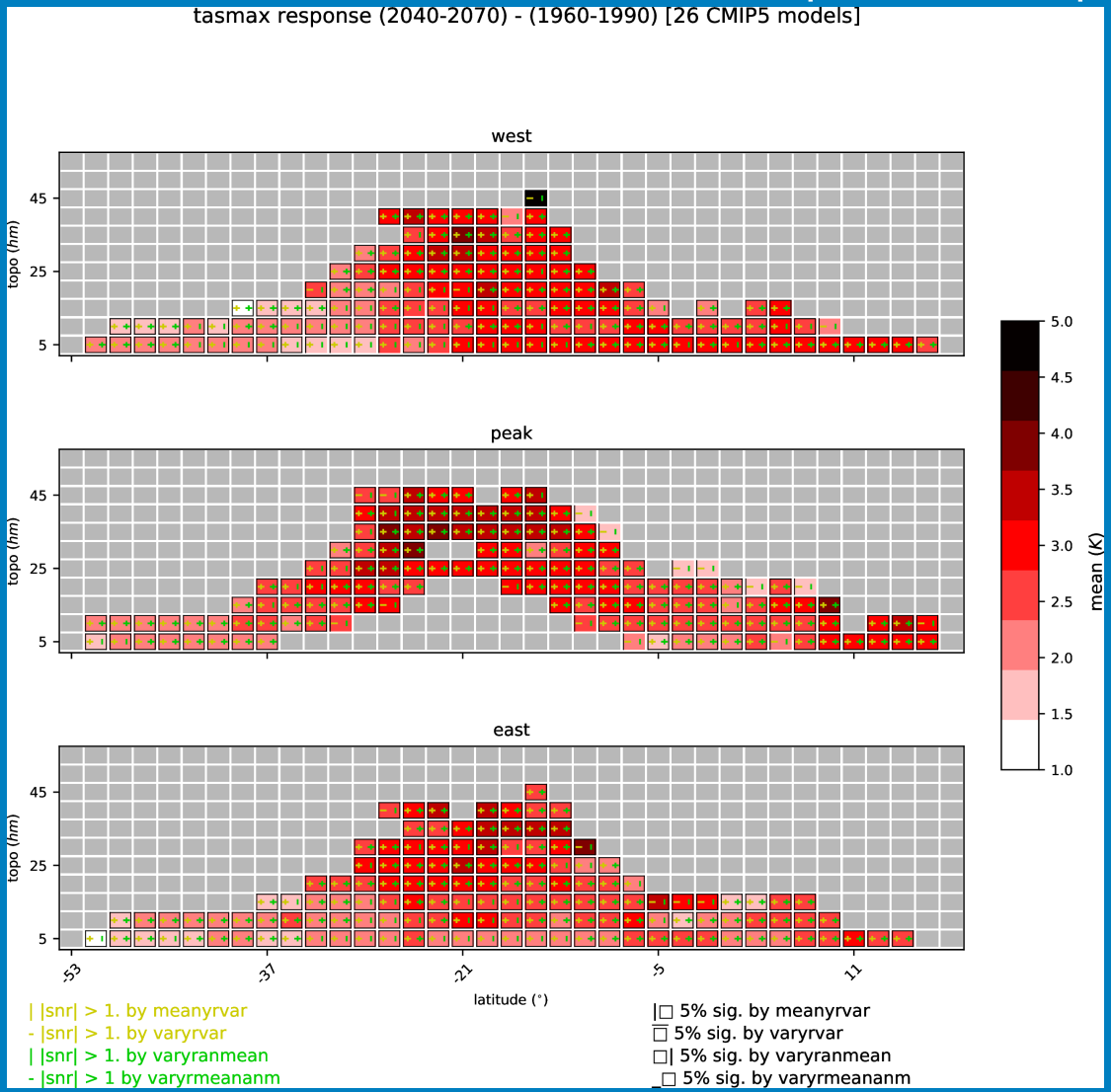
- ENSmean minimum temperature response



- stronger increase at higher altitudes, 'peak' and 'east' areas
- no signal at high latitudes
- certainty and 5% significance slice and variance dependency

Results

- ENSmean maximum temperature response



- Stronger increase that tasmin
- Increase also at high latitudes
- Slight decrease in certainty and significance

Conclusions

- Analysis of climate change signal of CMIP5 by **slices** (latitude, orography and mountain side) over the Andes
- Objective definition of **coherent** spatial areas **no-interpolation**
- latitudinal, height and mountain side **dependency** of climate signal on **precipitation**
- **Wider thermal** response, stronger at higher altitudes
- Stronger response of **tasmax**
- Strong **dependency** of signal certainty and significance on **slice** and method estimation of uncertainty

Thank you for your attention !!

Scripts available from: `www.xn--llusfb-5va.cat/python/PyNCplot`

The Andes - South America's backbone for interdisciplinary studies

- Andes comprise a heterogeneous territory in which ***climate variations affect socio-economic activities and could endanger vulnerable communities***

- The Andes are a biodiversity hotspot hosting 10% of the world's plant species, and providing ***critical ecosystem services*** as water provision, soil protection, carbon storage

- Vulnerability of the Andean population is high and therefore ***increasing knowledge of climate change is crucial to guide adaptation policies***

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ANDES are a gap! and an opportunity to CORDEX

→linking with Andex community under the umbrella of GEWEX

Thank you!

carril@cima.fcen.uba.ar