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Human-caused increases in humidity-related compound extremes constrained by homogenized observations

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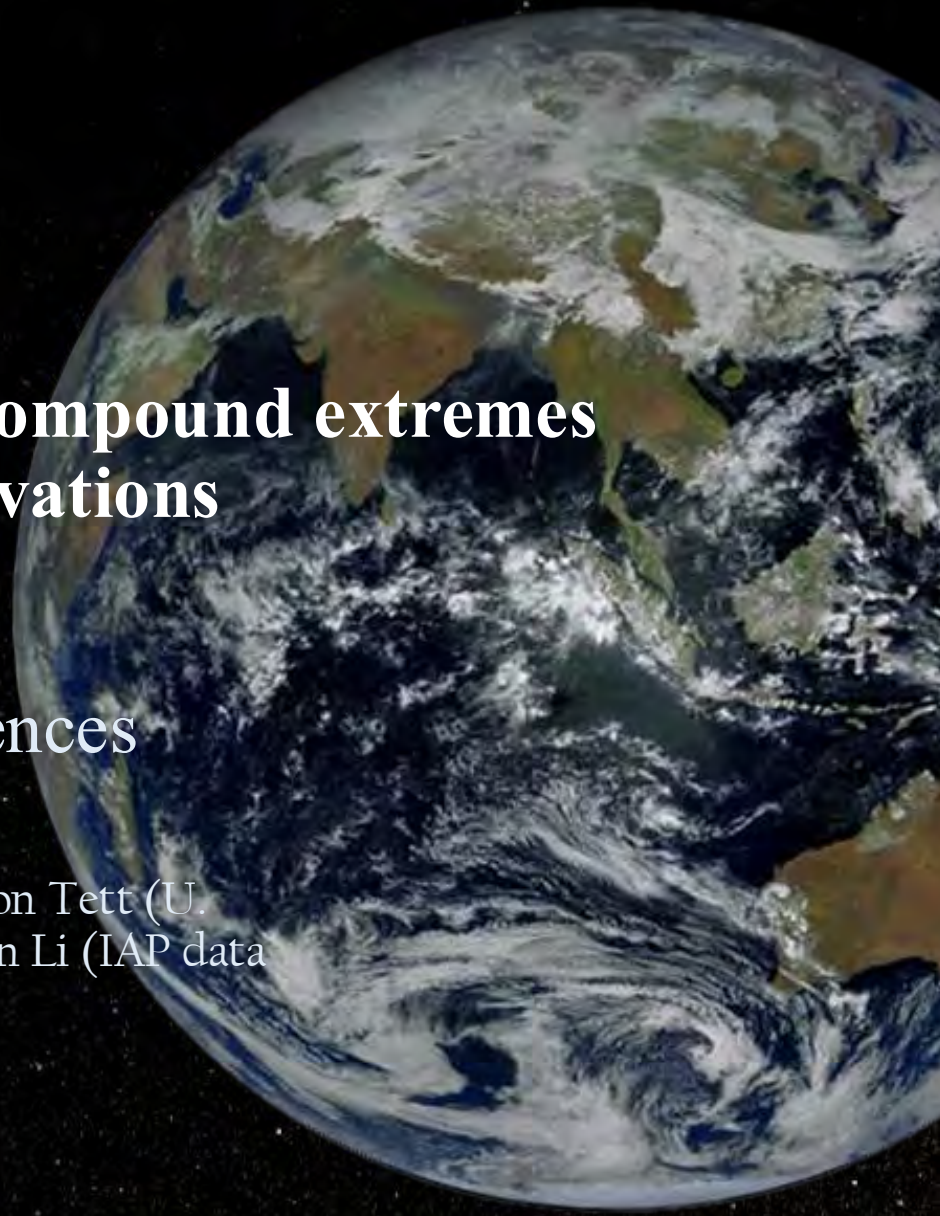

EPESC—LEADER Science Meeting

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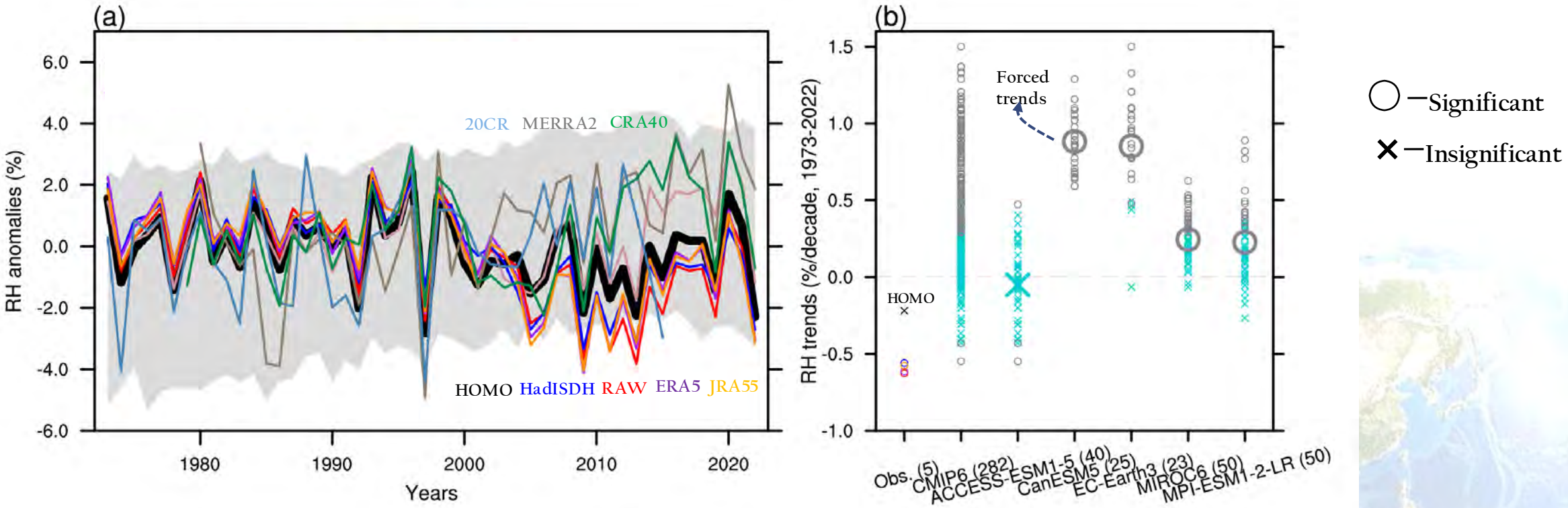
RH data inhomogeneity

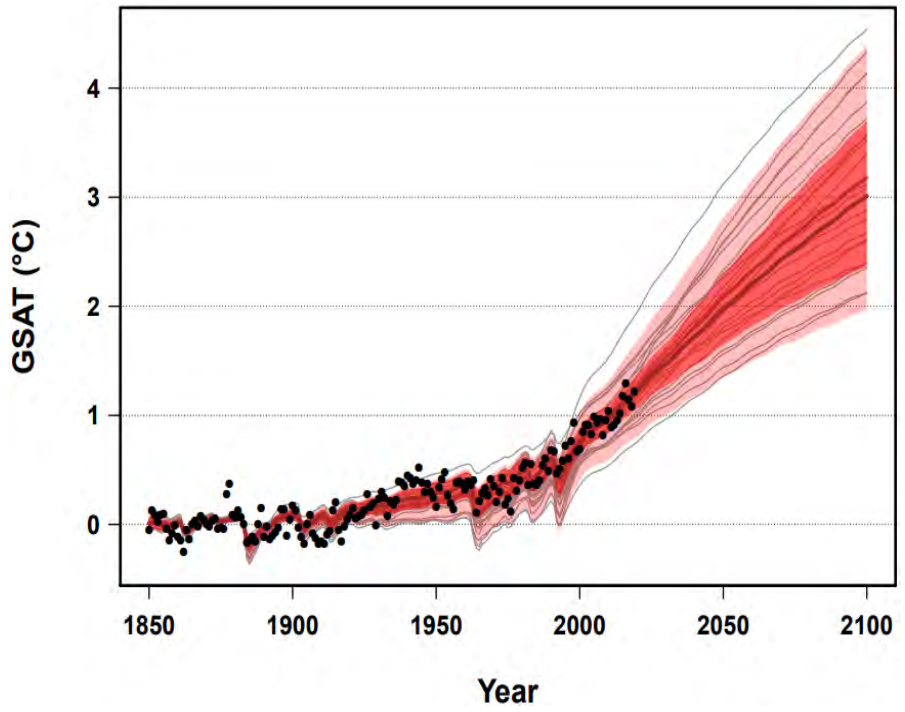
- Improved model—observation consistency



Variabilities and trends of RH over Eastern China.

Constrained projection of forced changes

- Bayesian observational constraint (Ribes et al., Sci. Adv. 2021)



$$\boldsymbol{x} = \begin{pmatrix} x^{all}_{1850} \\ \vdots \\ x^{all}_{2100} \end{pmatrix}, \qquad \boldsymbol{y} = \begin{pmatrix} y_{1850} \\ \vdots \\ y_{2019} \end{pmatrix}.$$

Prior: $\boldsymbol{x} \sim N(\boldsymbol{\mu}, \boldsymbol{\Sigma}_{\text{mod}})$,

Obs: $\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{\varepsilon}$, with $\boldsymbol{\varepsilon} \sim N(\boldsymbol{0}, \boldsymbol{\Sigma}_{\text{obs}})$,

We compute: $p(\boldsymbol{x}|\boldsymbol{y})$

$\boldsymbol{x}$: total forced response, 1850–2100,
$\boldsymbol{\Sigma}_{\text{mod}}$: model error covariance,
$\boldsymbol{H}$: observation operator,

$\boldsymbol{y}$: observations, 1850–2019,
$\boldsymbol{\Sigma}_{\text{obs}}$: observation error covariance,
$\boldsymbol{\varepsilon}$: error in observations (i.v. + meas.),

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There are 4 inputs: $\boldsymbol{y}, \boldsymbol{\mu}, \boldsymbol{\Sigma}_{\text{mod}}, \boldsymbol{\Sigma}_{\text{obs}}$. *#Kriging, #KalmanFiltering*

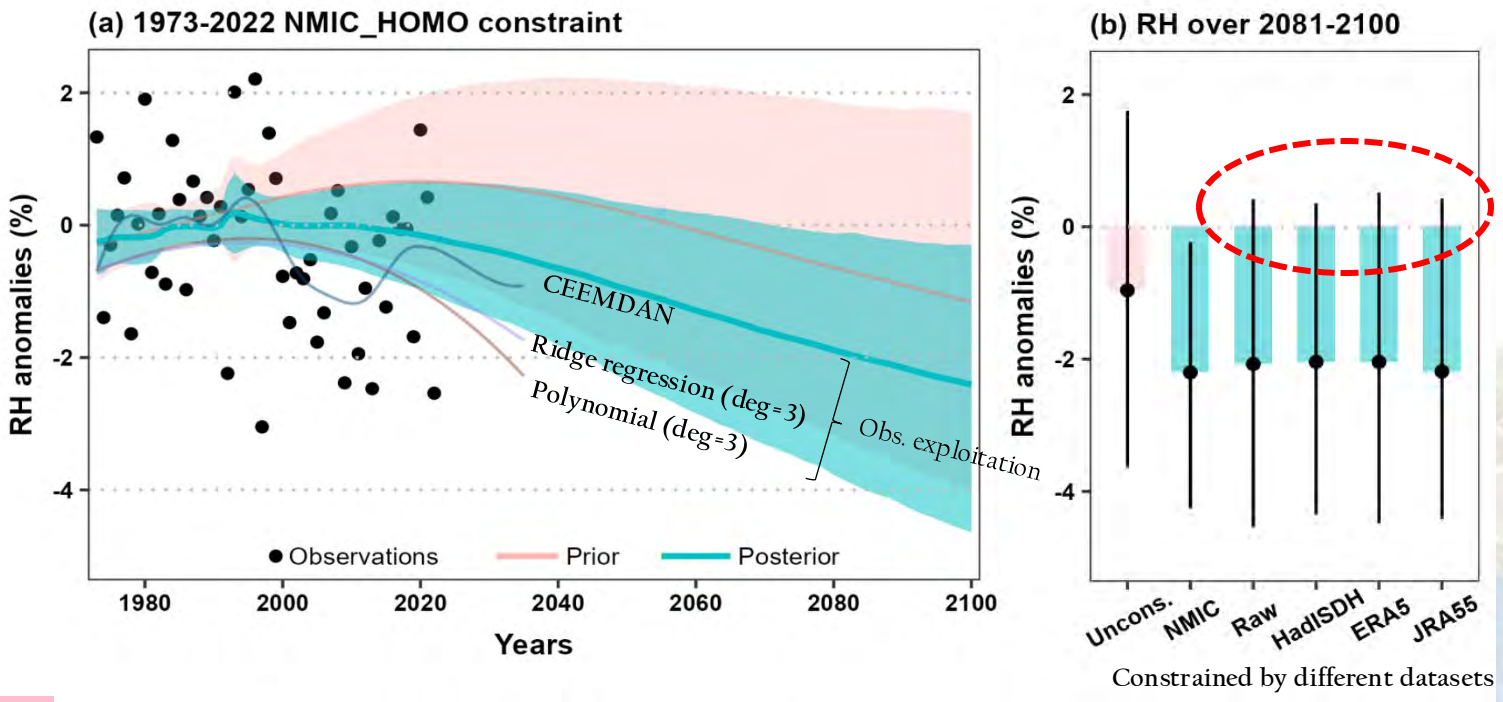
Gaussian conditioning theorem

$$\begin{pmatrix} \boldsymbol{x} \\ \boldsymbol{y} \end{pmatrix} = \begin{pmatrix} \boldsymbol{I} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{H} \end{pmatrix} \begin{pmatrix} \boldsymbol{x} \\ \boldsymbol{x} \end{pmatrix} + \begin{pmatrix} \boldsymbol{0} \\ \boldsymbol{\varepsilon} \end{pmatrix} \sim N\left(\begin{pmatrix} \boldsymbol{\mu} \\ \boldsymbol{H}\boldsymbol{\mu} \end{pmatrix}, \begin{pmatrix} \boldsymbol{\Sigma}_{\text{mod}} & \boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}' \\ \boldsymbol{H}\boldsymbol{\Sigma}_{\text{mod}} & \boldsymbol{H}\boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}' + \boldsymbol{\Sigma}_{\text{obs}} \end{pmatrix} \right)$$

$$p(\boldsymbol{x}|\boldsymbol{y} = \boldsymbol{y}_0) \sim N\left(\boldsymbol{\mu} + \boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}'\left(\boldsymbol{H}\boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}' + \boldsymbol{\Sigma}_{\text{obs}}\right)^{-1}(\boldsymbol{y}_0 - \boldsymbol{H}\boldsymbol{\mu}), \boldsymbol{\Sigma}_{\text{mod}} - \boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}'\left(\boldsymbol{H}\boldsymbol{\Sigma}_{\text{mod}}\boldsymbol{H}' + \boldsymbol{\Sigma}_{\text{obs}}\right)^{-1}\boldsymbol{H}\boldsymbol{\Sigma}_{\text{mod}}\right)$$

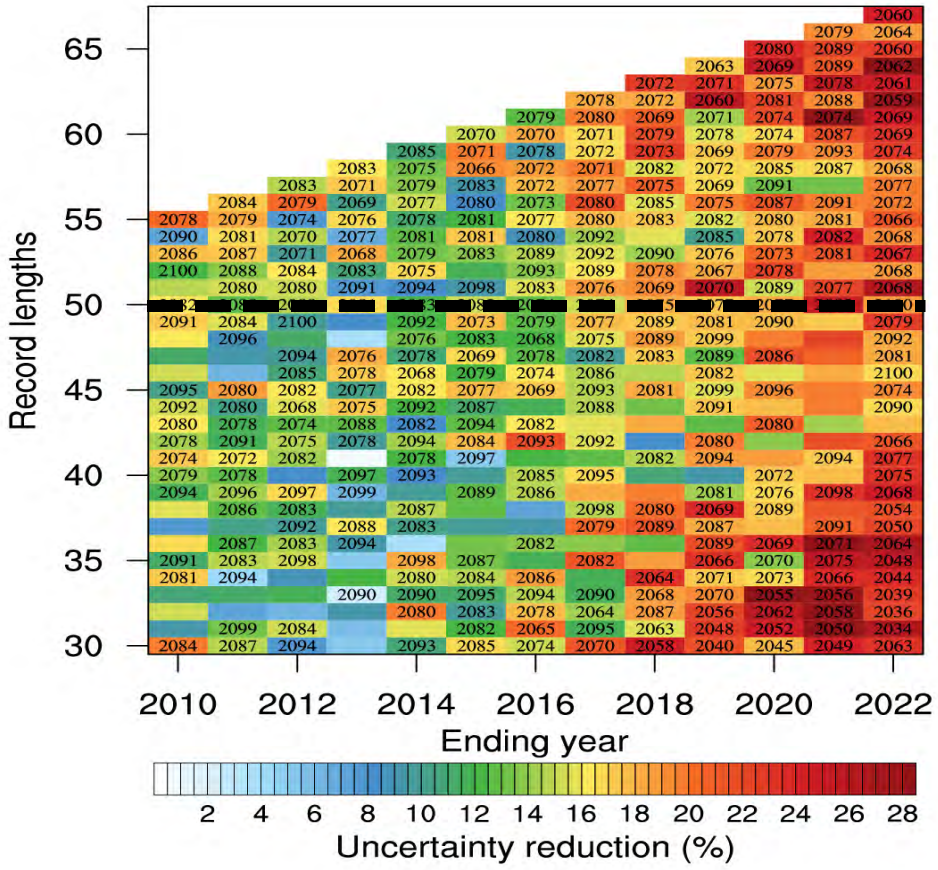
Constrained projection of forced changes

- Compared to inhomogeneous observational constrains:
  Greater narrowing of uncertainty range (~26%)
  Exclusion of wetting response (not until end—of—century)



Constrained Raw projection

Constrained projection of forced changes



Shading	Reduction of uncertainty range
Number	Year for robust drying

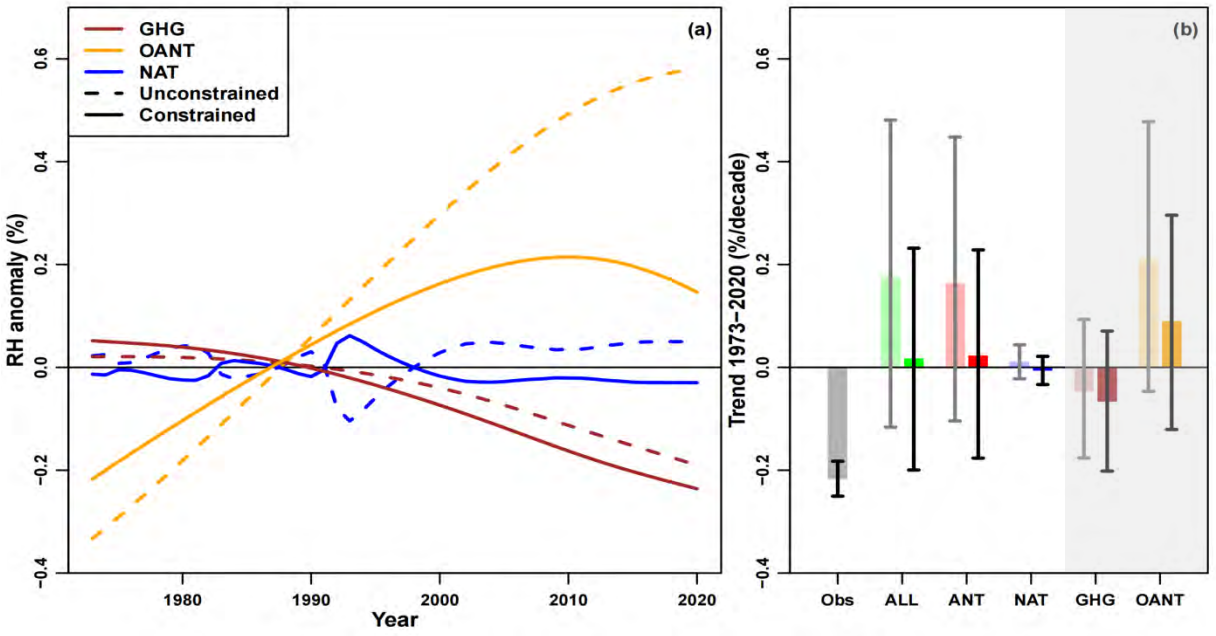
Does longer records add value to constraining?

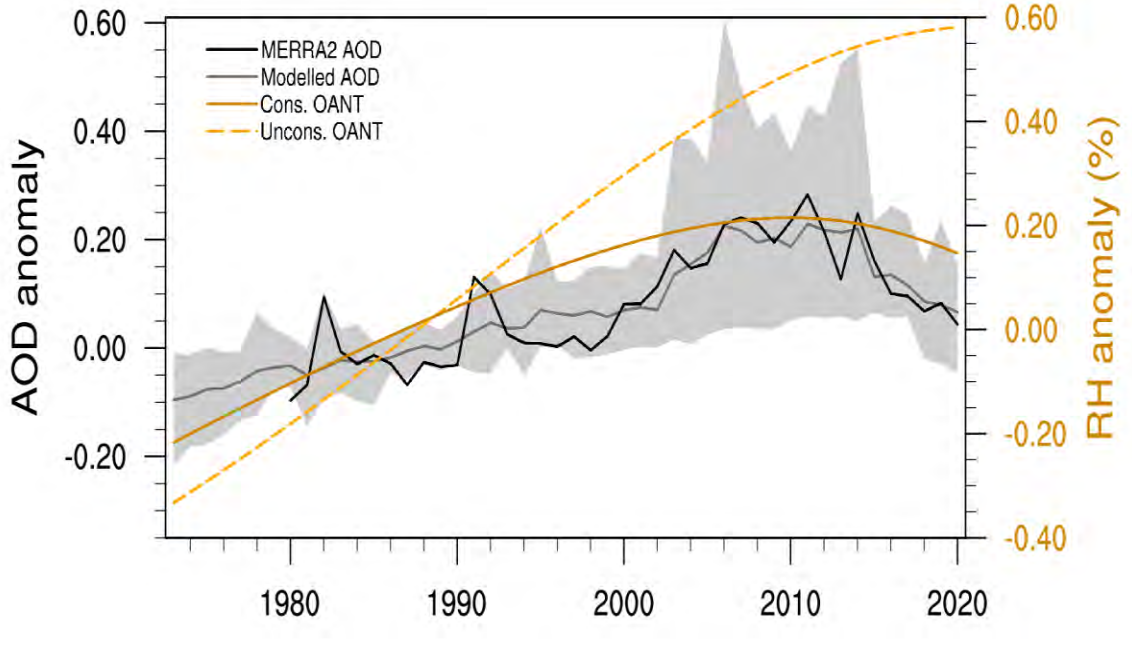
- ✓ Not necessarily, but the inclusion of recent records matters
- ✓ Longer records add chance to see robust drying before 2100 (96% for 50 year+ constraints vs. 72% for shorter constraints)
- ✓ More than 80% (52%) predicted the time for the certain response to be no earlier than the 2070s (2080s).

Source of the constraining power

- Attribution within the same framework

  calibration of overestimated AER–forced wetting & underestimated GHG–caused drying



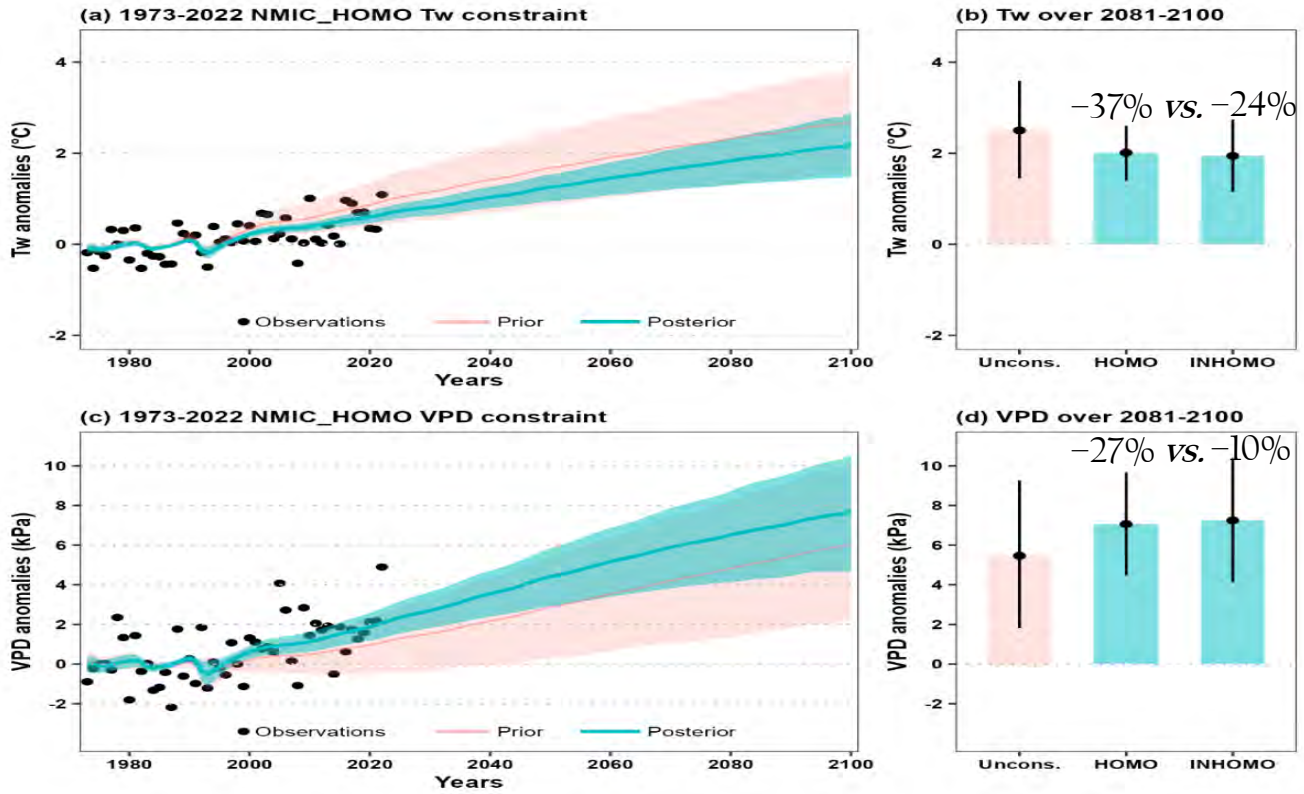


Constrained projection of compound extremes

- Subject to the constraint (summertime maxima—daily):

  20% smaller increases in Tw extremes, 40% reduction in uncertainty range

  30% larger increases in VPD extremes, 30% reduction in uncertainty range



HOMO: homogenized T &RH
INHOMO: homogenized T & raw RH

Constrained

Raw projection

Constrained projection of human—caused changes in regional Tw and VPD extremes

Summaries

- ✓ The theoretical atmospheric drying would be much stronger, more robust, but decades later than expected;
- ✓ The constrained projections call for enhanced preparedness against atmospheric aridity risks (fire, tree dieback, harvest failure) in the humid region.

- ✓ Chen, Y.*, Liao, Z., Zhu, Y. et al., Homogenized observations—informed responses of relative humidity and compound extremes to future climate change. *(In Review @Sci. Adv.).*

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