Consistency and robustness of selected emergent constraints for equilibrium climate sensitivity

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Equilibrium climate sensitivity (ECS)

Definition
Projected equilibrium change in global annual mean surface temperature following a doubling of the atmospheric CO$_2$ concentration.
Emergent constraints are a relationship across an ensemble of models, between some aspect of Earth system sensitivity and an observable trend or variation in the current climate.

- A necessary property of emergent constraints is a physical basis for the relation.
- Offer the potential to reduce uncertainty in climate feedbacks and projections.
- Can help guiding model development onto processes crucial to the magnitude and spread of future climate change and to guide future observations.
Selected published emergent constraints for equilibrium climate sensitivity

Test consistency among different proposed emergent constraints and their sensitivity to:

- Model ensemble (CMIP3, CMIP5)
- Observational dataset(s)

Selected published emergent constraints for ECS

1) **Precipitation** – Southern ITCZ index (Tian, 2015)
2) **Humidity** – Tropical mid-tropospheric humidity asymmetry index (Tian, 2015)
3) **Mixing** – Lower tropospheric mixing index (LTMI) (Sherwood et al., 2014)
4) **Clouds** – Covariance of deseasonalized tropical low cloud (TLC) shortwave reflection with SST (Brient and Schneider, 2016)
ESMValTool version 1.1.0

http://www.esmvaltool.org/
Eyring et al., Geosci. Model Dev., 2016

- Community diagnostics and performance metrics tool for the evaluation of Earth System Models (ESMs)
- Standardized model evaluation can be performed against observations, against other models or to compare different versions of the same model
- many diagnostics and performance metrics covering different aspects of the Earth System (dynamics, radiation, clouds, carbon cycle, chemistry, aerosol, sea-ice, etc.) and their interactions
- Well-established analysis based on peer-reviewed literature
- Currently ≈ 70 developers from 28 institutions and > 100 users

GitHub: https://github.com/ESMValGroup/ESMValTool
Southern ITCZ index (Tian, 2015)

Southeastern Pacific
30°S-0°, 150°W-100°W

- Climatological annual mean precipitation bias
- Model – observation (mm day\(^{-1}\))
- Averaged over southeastern Pacific

Observational data

1) Global Precipitation Climatology Project (GPCP, 1980-2005)
2) CPC Merged Analysis of Precipitation (CMAP, 1980-2005)
Southern ITCZ index (Tian, 2015)

TRMM, CMIP5

- ECS [K]
- Southern ITCZ index [mm day$^{-1}$]
Southern ITCZ index (Tian, 2015)

TRMM

GPCP

CMAP

CMIP3

CMIP5

ECS [K]

Southern ITCZ index [mm day$^{-1}$]

4.1 K

3.8 K

3.7 K

4.0 K

3.8 K

3.7 K
Southern ITCZ index (Tian, 2015)
Tropical mid-tropospheric humidity asymmetry index (Tian, 2015)

- Climatological annual mean mid-tropospheric specific humidity relative bias
- \( \frac{\text{model} - \text{observation}}{\text{observation}} \) (in %)
- SH tropical Pacific \( (120^\circ\text{E}-80^\circ\text{W}, \ 30^\circ\text{S}-0^\circ) \) – NH tropical Pacific \( (120^\circ\text{E}-80^\circ\text{W}, \ 0^\circ-20^\circ\text{N}) \)

Observationally based data

1) Atmospheric Infrared Sounder (AIRS, 2003-2010)
2) ERA-Interim Reanalysis (1980-2005)
Tropical mid-tropospheric humidity asymmetry index (Tian, 2015)
Lower tropospheric mixing index (LTMI) (Sherwood et al., 2014)

- Averaged over tropical ocean region of mean ascent (upper 25%)
- Small-scale mixing \( S = (\Delta R_{700-850}/100\% - \Delta T_{700-850}/9K) / 2 \)
- Large-scale component of mixing = ratio of shallow to deep overturning
  \( D = \frac{\langle \Delta H(\Delta)H(-\omega_1) \rangle}{\langle -\omega_2 H(-\omega_2) \rangle} \)
- Lower tropospheric mixing index \( \text{LTMI} = S + D \)

Observationally based data

1) ERA-Interim Reanalysis (1980-2005)
2) NCEP/NCAR Reanalysis 1 (1980-2005)
Lower tropospheric mixing index (LTMI) (Sherwood et al., 2014)
Covariance of tropical low cloud (TLC) shortwave reflection with SST (Brient and Schneider, 2016)

- Mean over TLC regions: 25% of tropical ocean area (30°S-30°N) with lowest 500 hPa relative humidity
- TLC reflection (at TOA) = -⟨S_c⟩ / ⟨I⟩ (in %)
- Regression coefficients: deseasonalized variations of TLC shortwave reflection and sea surface temperature (in % per K)

Observationally based data

1) Relative humidity: ERA-Interim Reanalysis, NCEP/NCAR Reanalysis 1
2) TOA radiative fluxes: CERES, SRB, ISCCP-FD
3) SST: HadISST
Covariance of tropical low cloud (TLC) shortwave reflection with SST (Brient and Schneider, 2016)
Southern Hemisphere Hadley cell extent (Lipat et al., 2017)
Conclusions and outlook

- All four of the tested emergent constraints are sensitive to the model ensemble and/or the observational datasets used.
- Estimated ECS range in the original four studies: 3.8 – 4.0 K (2.4 – 4.3 K)
- Robustness estimates obtained here (additional observations and ensembles): 2.9 K – 4.1 K
- Applying compilation of current emergent constraint studies (for ECS) do not allow to narrow range of ECS significantly

<table>
<thead>
<tr>
<th>Emergent constraint</th>
<th>Original range</th>
<th>This study</th>
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</thead>
<tbody>
<tr>
<td>ITCZ bias</td>
<td>4.1 K</td>
<td>2.7 – 4.1 K</td>
</tr>
<tr>
<td>Humidity asymmetry index</td>
<td>3.8 K</td>
<td>3.3 – 3.8 K</td>
</tr>
<tr>
<td>LTMI</td>
<td>4.0 K (3.0 –)</td>
<td>2.9 – 3.6 K</td>
</tr>
<tr>
<td>TLC reflection</td>
<td>4.0 K (2.4 – 4.3 K)</td>
<td>3.3 – 3.7 K</td>
</tr>
</tbody>
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Outlook

- Further selection based on physical mechanisms and fundamental processes
- Focus on individual feedbacks to constrain ECS/TCR/TCRE (e.g. carbon cycle)
- Accounting for observational uncertainties
- Investigation of additional published emergent constraints
- Development of new emergent constraints