What we can learn about ECS from short-term climate variations

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\[ \Delta R_{\text{total}} - \Delta F = + \lambda_{\text{total}} \Delta T \]
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**CERES**

**MERRA**

**climate sensitivity**
Global, monthly avg., 2000-2014

\[ \lambda_{\text{total}} = -1.08 \pm 0.89 \text{ W/m}^2/\text{K} \]
Global, monthly avg., 2000-2014

\[ \lambda_{\text{total}} = -1.08 \pm 0.89 \text{ W/m}^2\text{K} \]

due to short-term variations
$\lambda_{total} = -1.23 \pm 0.60 \text{ W/m}^2/\text{K}$
\lambda_{\text{total}} = -1.23 \pm 0.60 \text{ W/m}^2/\text{K} \quad \text{ECS} = 3.0 \pm 1.4 \text{ K}
\( \lambda_{\text{total}} = -1.23 \pm 0.60 \text{ W/m}^2\text{/K} \quad \text{ECS} = 3.0 \pm 1.4 \text{ K} \)

- **doesn’t** require estimates of forcing or OHC
- **does** require model-derived relation between short- and long-term \( \lambda_{\text{total}} \)
\[ \Delta R_{\text{total}} = \Delta F + \lambda_{\text{total}} \Delta T \]
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\[ \Delta R_{\text{temp}} + \Delta R_{\text{wv}} + \Delta R_{\text{clouds}} + \ldots \]

Estimate \( \Delta R_x \) using radiative kernels
Regress $\Delta R_x$ vs. $\Delta T_s$

$x = \text{Planck, lapse rate, cloud, etc.}$
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Slope = feedback $\lambda_x$ (W/m$^2$/K)
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\[ \Delta R_{\text{temp}} + \Delta R_{\text{wv}} + \Delta R_{\text{clouds}} + \ldots \]

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Estimate \( \Delta R_x \) using radiative kernels

\[ \lambda_{\text{total}} = \lambda_{\text{temp}} + \lambda_{\text{wv}} + \lambda_{\text{clouds}} + \ldots \]

examine \( \lambda_{\text{total}} \) budget for in control and RCP8.5 models & obs.
Feedbacks

• Held and Shell decomposition
  [J. Climate, 2012]
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  – $\Delta$RH: change in RH
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  – Lapse-rate: differential warming of the surface and atmosphere, *constant RH*
  – \( \Delta \text{RH} \): change in RH
  – albedo & clouds: change due to changing surface albedo and clouds
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We should have confidence in models’ ability to simulate these feedbacks in response to long-term warming.
• Planck+LR+RH+albedo = Fixed-cloud $\lambda_{\text{total}}$
• RCP8.5 $\lambda_{\text{total, fixed-cloud}} = -1.87 \pm 0.20$ W/m$^2$/K
• translates to ECS of 1.8-2.2°C $\approx 2°C$
• clouds add on to this …
Chen Zhou et al., in prep.
cloud feedback

RCP8.5 $\lambda_{cloud}$ (W/m$^2$/K)

control $\lambda_{cloud}$ (W/m$^2$/K)
• good agreement between ensemble avg. of control models and observations of $\lambda_{\text{cloud}}$. 

**Cloud Feedback**

![Graph showing relationship between RCP8.5 $\lambda_{\text{cloud}}$ (W/m^2/K) and control $\lambda_{\text{cloud}}$ (W/m^2/K). The graph displays a scatter plot with black dots and a red cross indicating a point of interest.]
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cloud feedback

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• arguments exist why individual elements of cloud feedback should be positive

• long-term cloud feedback very likely positive; best estimate $\approx 0.7 \text{ W/m}^2/\text{K}$
Back of envelope calculation
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- $\lambda_{\text{total}} = \lambda_{\text{total, fixed cloud}} + \lambda_{\text{cloud}}$
Back of envelope calculation

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- Translates to ECS of $1.8$-$2.2^\circ\text{C}$
- $\lambda_{\text{total}} = \lambda_{\text{total, fixed cloud}} + \lambda_{\text{cloud}}$
- If $\lambda_{\text{cloud}} = +0.7 \, \text{W/m}^2/\text{K}$, then ECS $\approx 3.5 \pm 1.6^\circ\text{C}$
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- if \( \lambda_{\text{cloud}} = +0.7 \ \text{W/m}^2/\text{K} \), then ECS \( \approx 3.5 \pm 1.6°C \)
- if \( \lambda_{\text{cloud}} > 0 \ \text{W/m}^2/\text{K} \), then ECS > 2°C
Back of envelope calculation

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- translates to ECS of 1.8-2.2°C
- $\lambda_{total} = \lambda_{total, fixed \ cloud} + \lambda_{cloud}$
- if $\lambda_{cloud} = +0.7 \text{ W/m}^2\text{/K}$, then ECS $\approx 3.5 \pm 1.6°C$
- if $\lambda_{cloud} > 0 \text{ W/m}^2\text{/K}$, then ECS $> 2°C$

This is at least “likely” and perhaps “very likely”
Conclusions

• analysis of CERES TOA flux & models implies ECS of 3.0±1.4°C (very likely range)

• With fixed clouds, we can have high confidence in ECS of 1.8-2.2°C

• Evidence of positive cloud feedback is at least _likely_, suggesting in turn that ECS > 2°C is also at least _likely_
Fig. 1. Scatterplot of the temperature ($\Delta R_T$), water vapor ($\Delta R_v$), albedo ($\Delta R_{alb}$), and cloud ($\Delta R_{cloud}$) flux anomalies vs surface temperature anomaly in the observations (using the ERA-Interim reanalysis). Also shown are a linear fit to the data and the 95% confidence intervals.

Dessler, J. Climate, 2013
Fig. 3. The zonal average temperature (bottom curves) and water vapor feedbacks (top curves). Observations are the solid lines (black is ERA-Interim and red is MERRA) and the models are dashed (black dashed is the control ensemble and red dashed is the A1B ensemble). The shading indicates one standard deviation about the average of the control ensemble. Error bars indicate the 2σ uncertainty of the fit for the ERA-Interim calculation at selected latitudes.
FIG. 4. The zonal average Planck–RH, lapse-rate–RH, and ΔRH feedbacks (these are from an alternative decomposition of the feedbacks in which the Planck and lapse-rate feedbacks also include changes in water vapor needed to maintain constant RH). Observations are the solid lines (black is ERA-Interim and red is MERRA) and the models are dashed (black dashed is the control ensemble and red dashed is the A1B ensemble). The shading indicates one standard deviation about the average of the control ensemble. Error bars indicate the 2σ uncertainty of the fit for the ERA-Interim calculation at selected latitudes.
\[ \lambda_{\text{total}} = -1.06 \pm 0.49 \text{ W/m}^2/\text{K} \]
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