

# Evaluation of Cloud Feedback Components in Observations and Their Representation in Climate Models

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CERES Science Team Meeting

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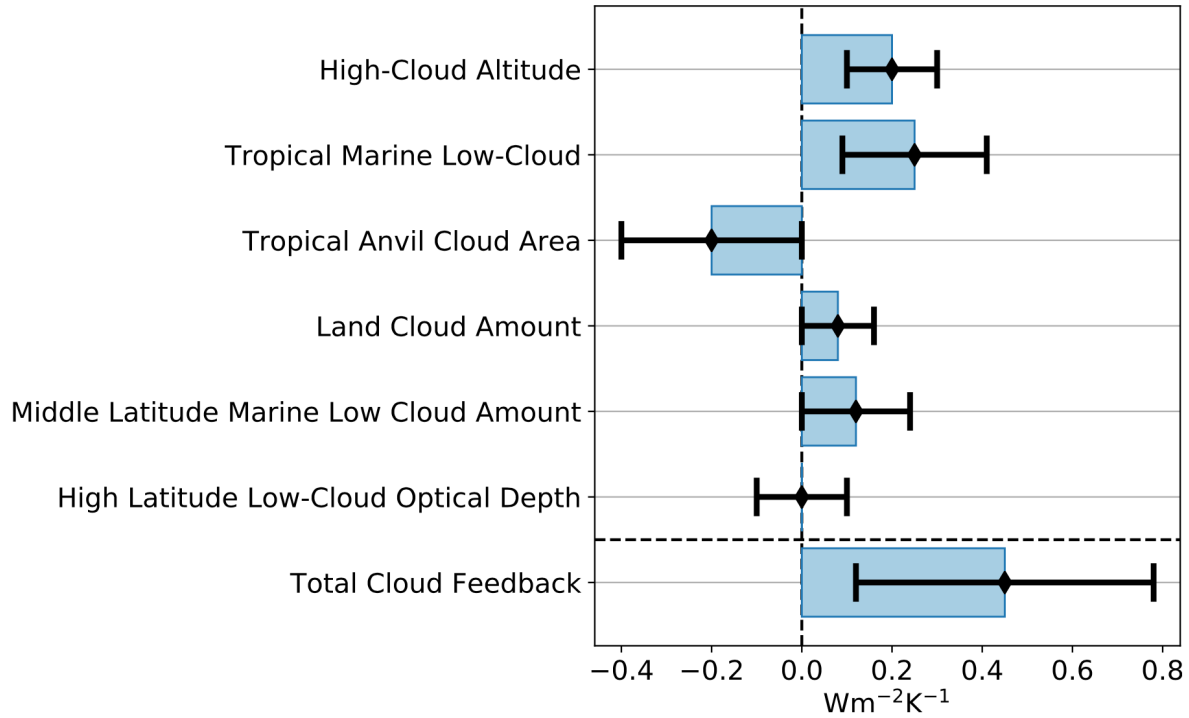
We gratefully acknowledge support from DOE's Regional and Global Model Analysis Program Area



# Process understanding of cloud feedback

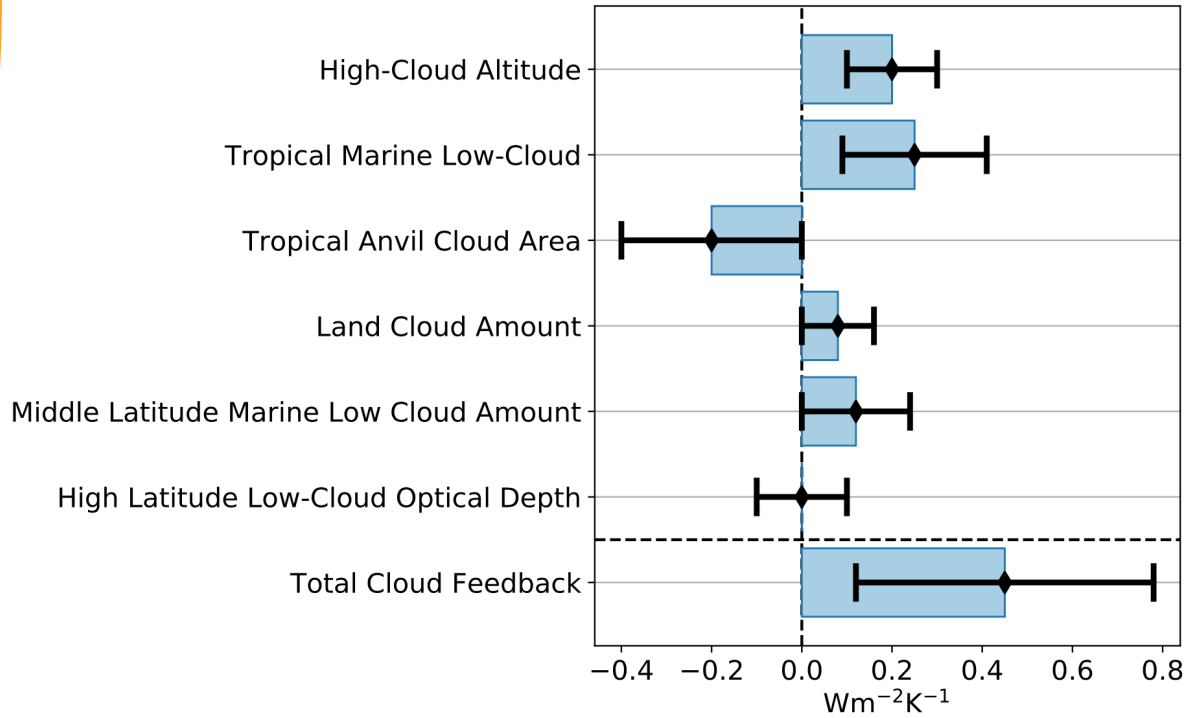
# Process understanding of cloud feedback

## Expert Assessment (Sherwood et al., 2020)



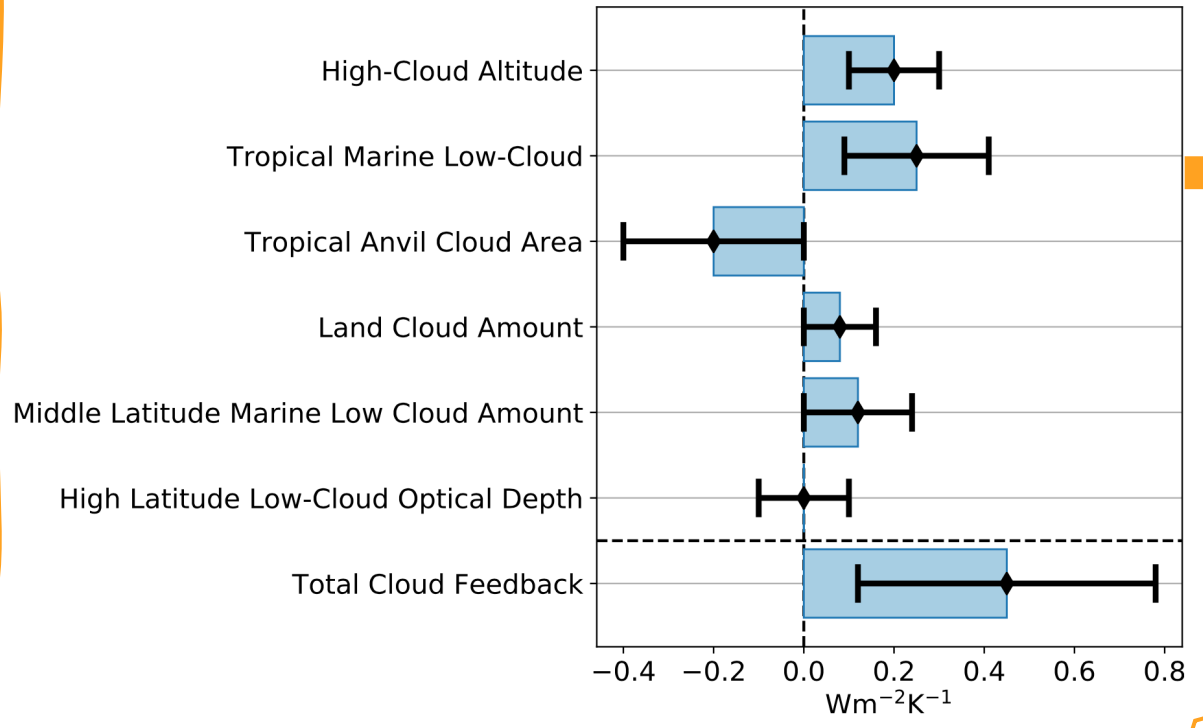
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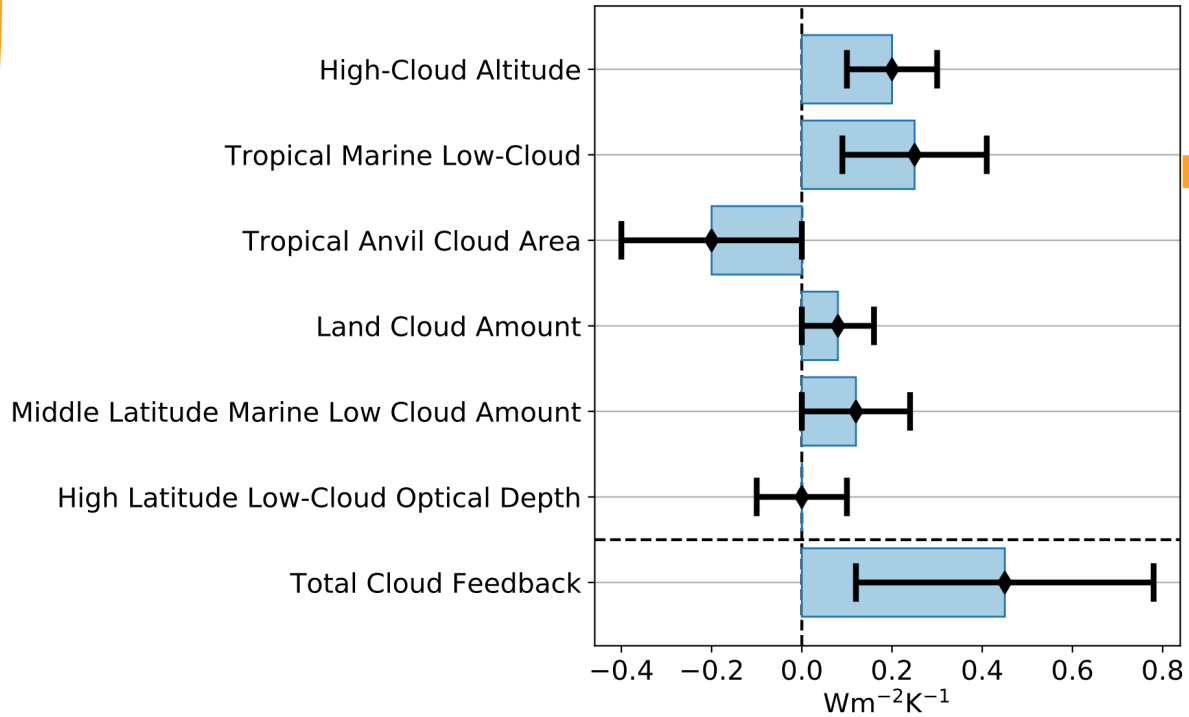
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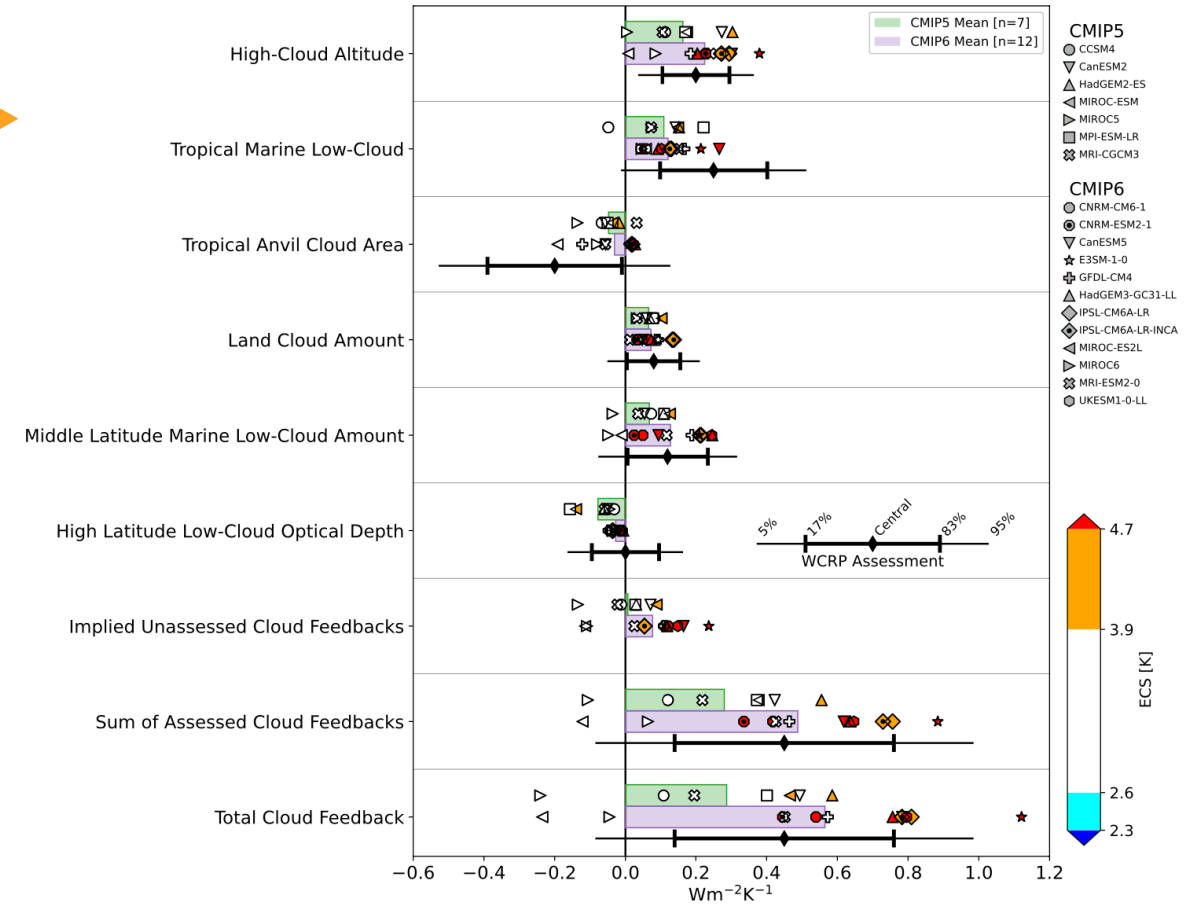


# Process understanding of cloud feedback

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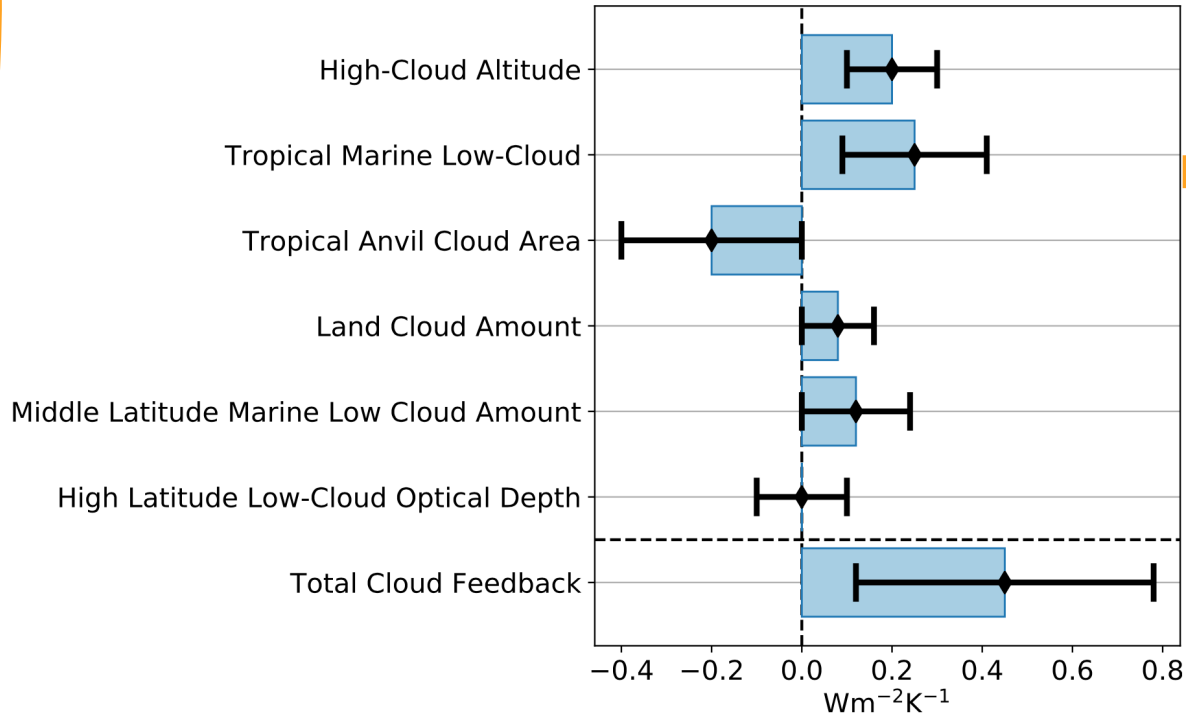


## Long-term cloud feedback in GCMs (Zelinka et al., 2022)

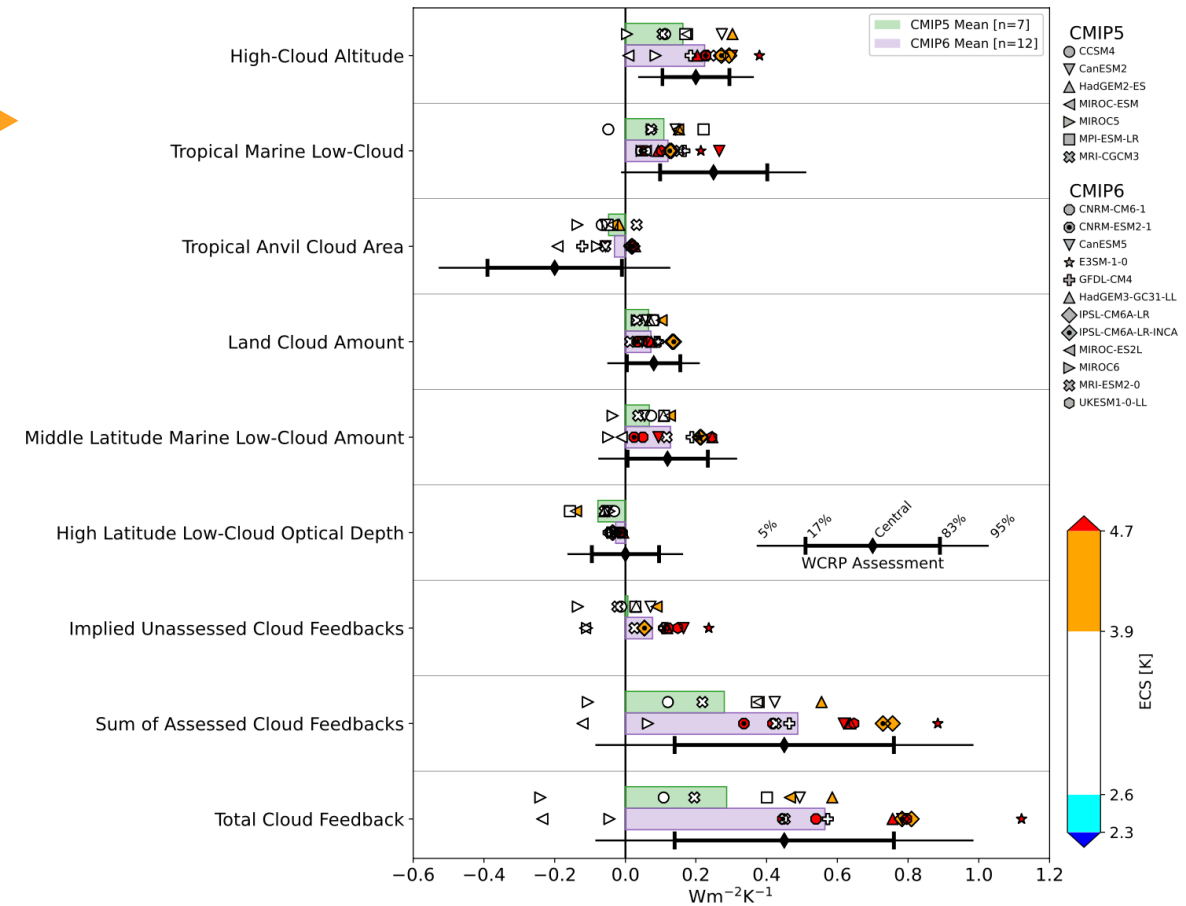


# Process understanding of cloud feedback

## Expert Assessment (Sherwood et al., 2020)



## Long-term cloud feedback in GCMs (Zelinka et al., 2022)



- (1) Other cloud feedback = ?
- (2) Multiple lines of evidence, not independent from GCM outputs
- (3) Values based on available studies till 2020

# Process understanding of cloud feedback

Expert Assessment



Long-term cloud feedback in GCMs



# Process understanding of cloud feedback

Expert Assessment



Long-term cloud feedback in GCMs

Short-term cloud feedback in observations



Short-term cloud feedback in GCMs

# Process understanding of cloud feedback

Expert Assessment

Long-term cloud feedback in GCMs

Short-term cloud feedback in observations

Short-term cloud feedback in GCMs

$$\text{Cloud feedback} = \frac{\Delta R}{\Delta T_s}$$

# Process understanding of cloud feedback

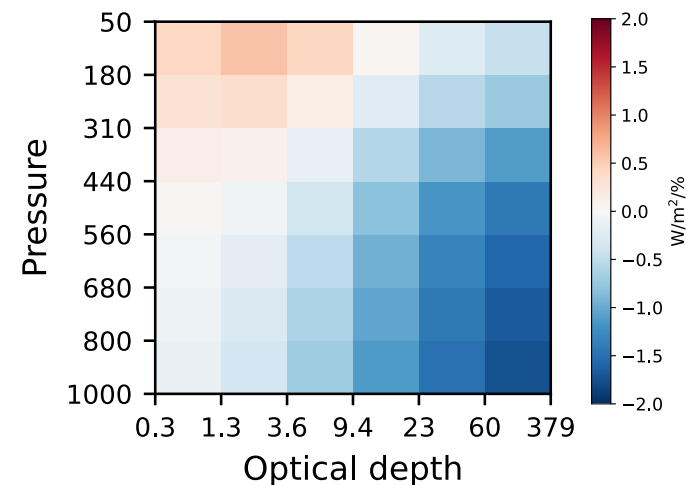
Expert Assessment

Long-term cloud feedback in GCMs

Short-term cloud feedback in observations

Short-term cloud feedback in GCMs

$$\begin{aligned} \text{Cloud feedback} &= \frac{\Delta R}{\Delta T_S} \\ &= \frac{\text{Cloud radiative kernels} \times \Delta \text{cloud fraction}}{\Delta T_S} \end{aligned}$$



# Process understanding of cloud feedback

Expert Assessment

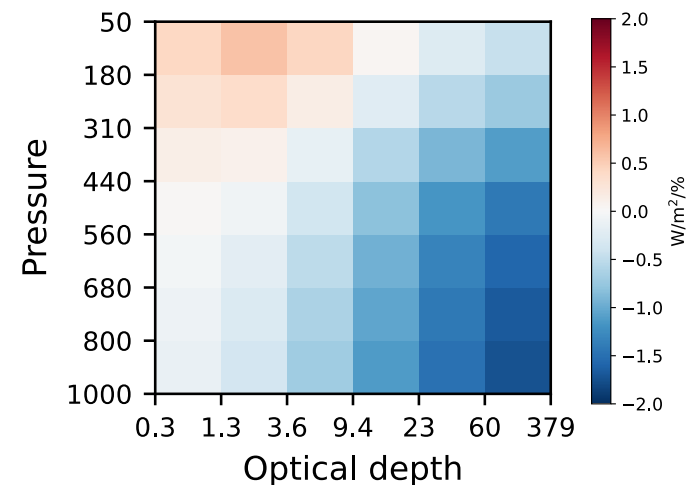
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$$\text{Cloud feedback} = \frac{\Delta R}{\Delta T_s}$$
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= changes in cloud amount + changes in cloud altitude  
+ changes in cloud optical depth + residual



# Process understanding of cloud feedback

Expert Assessment

Long-term cloud feedback in GCMs

**Short-term cloud feedback in observations**

- Period: 2002/07-2014/12

**Short-term cloud feedback in GCMs**

- Period: 2002/07-2014/12

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Long-term cloud feedback in GCMs

Short-term cloud feedback in observations

- Period: 2002/07-2014/12
- Cloud radiative kernels: Zhou et al. (2013) following the methods in Zelinka et al. (2012)
- Cloud fraction: **CERES FluxByCloudType, MODIS-COSP**

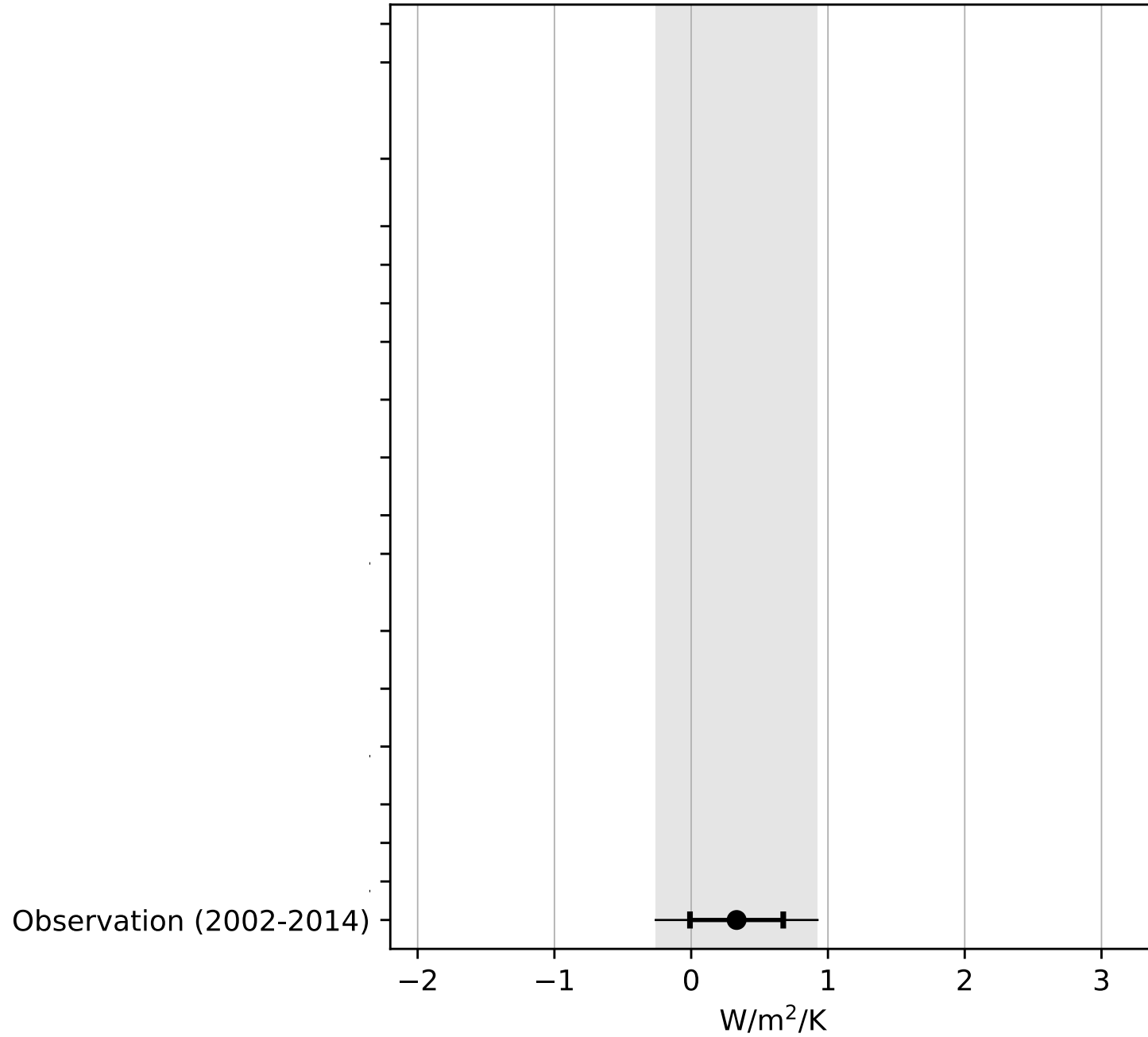
Short-term cloud feedback in GCMs

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- Cloud fraction: **CMIP6 AMIP simulations**

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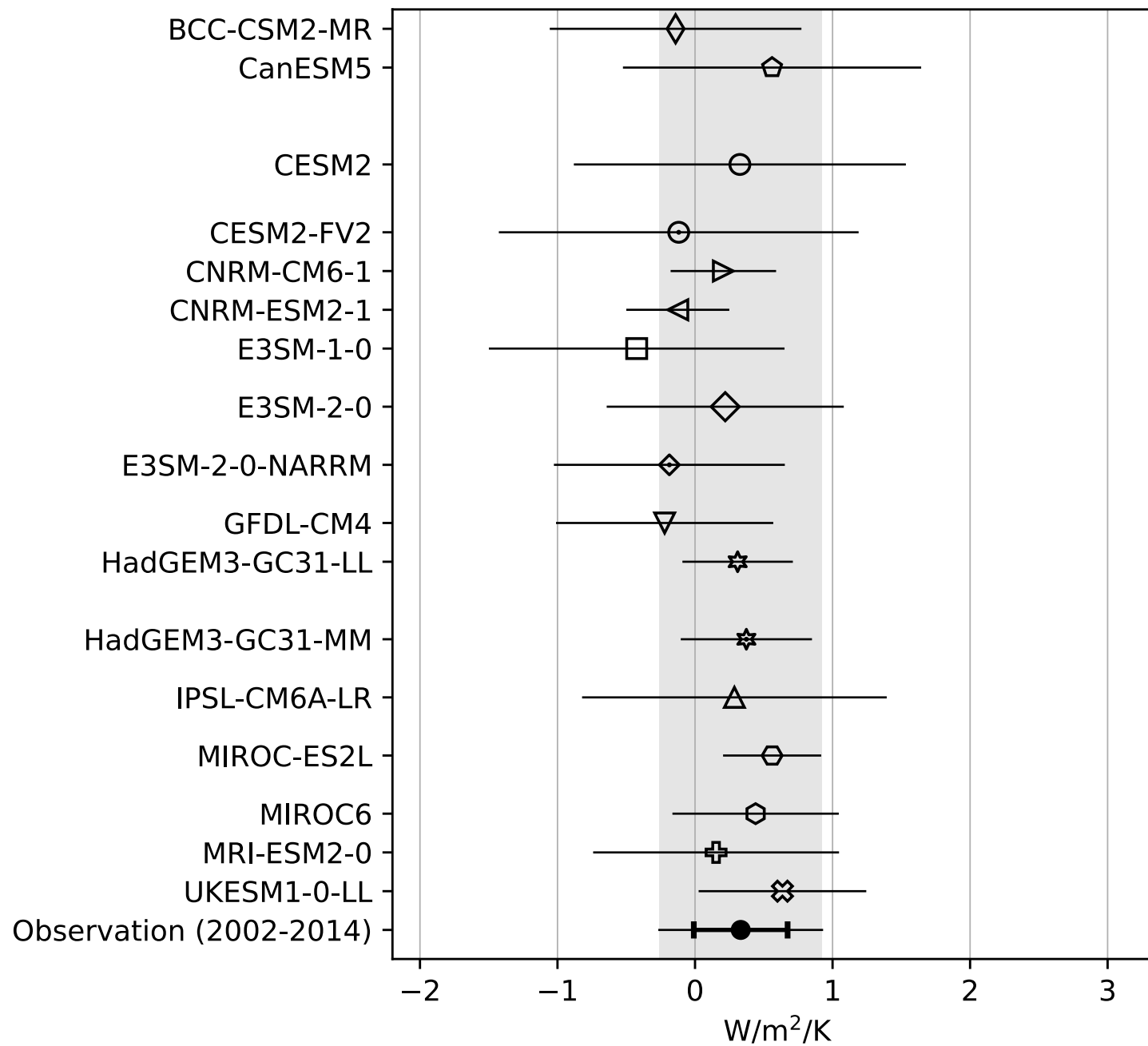
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# Results - Total cloud feedback

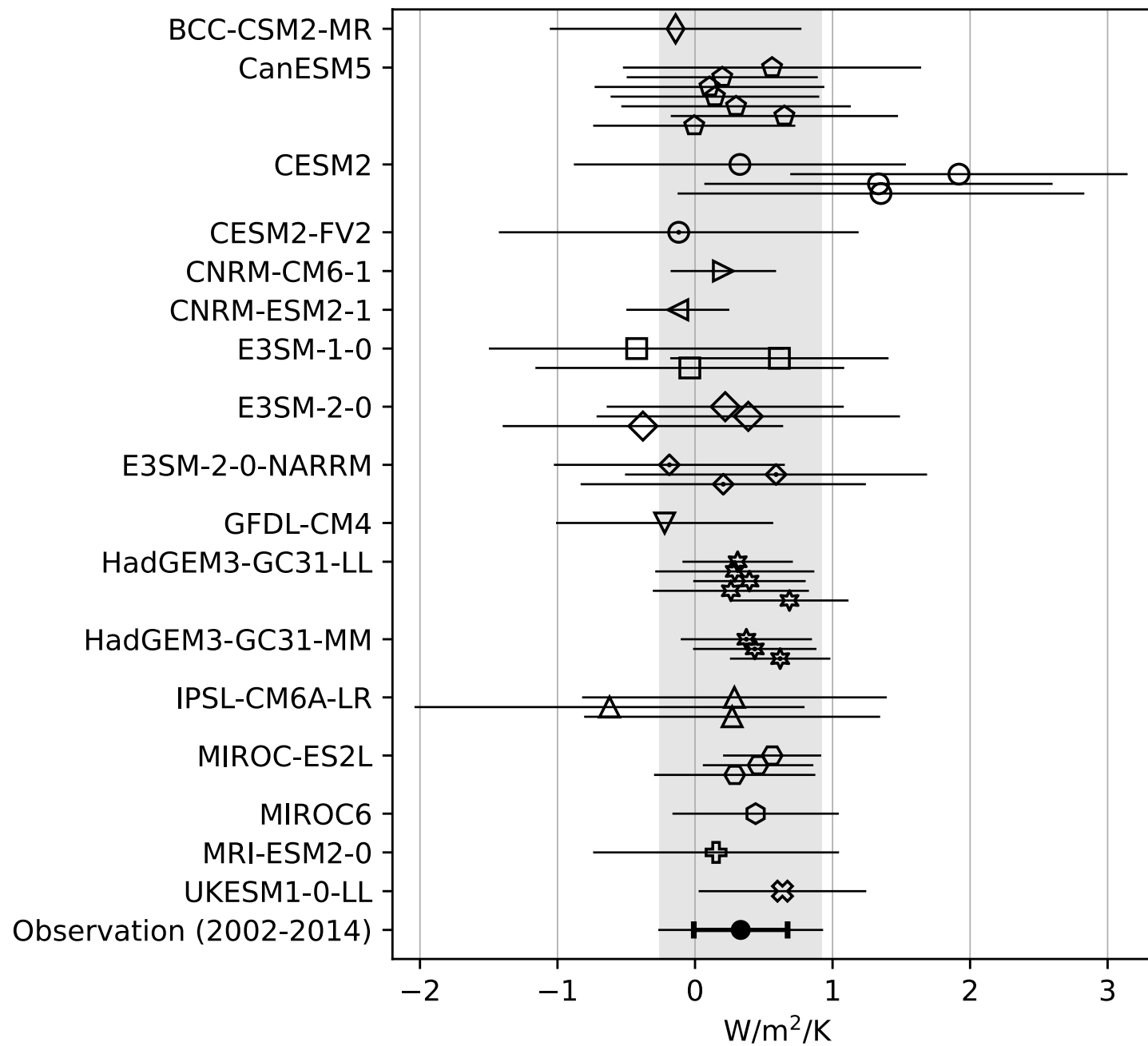




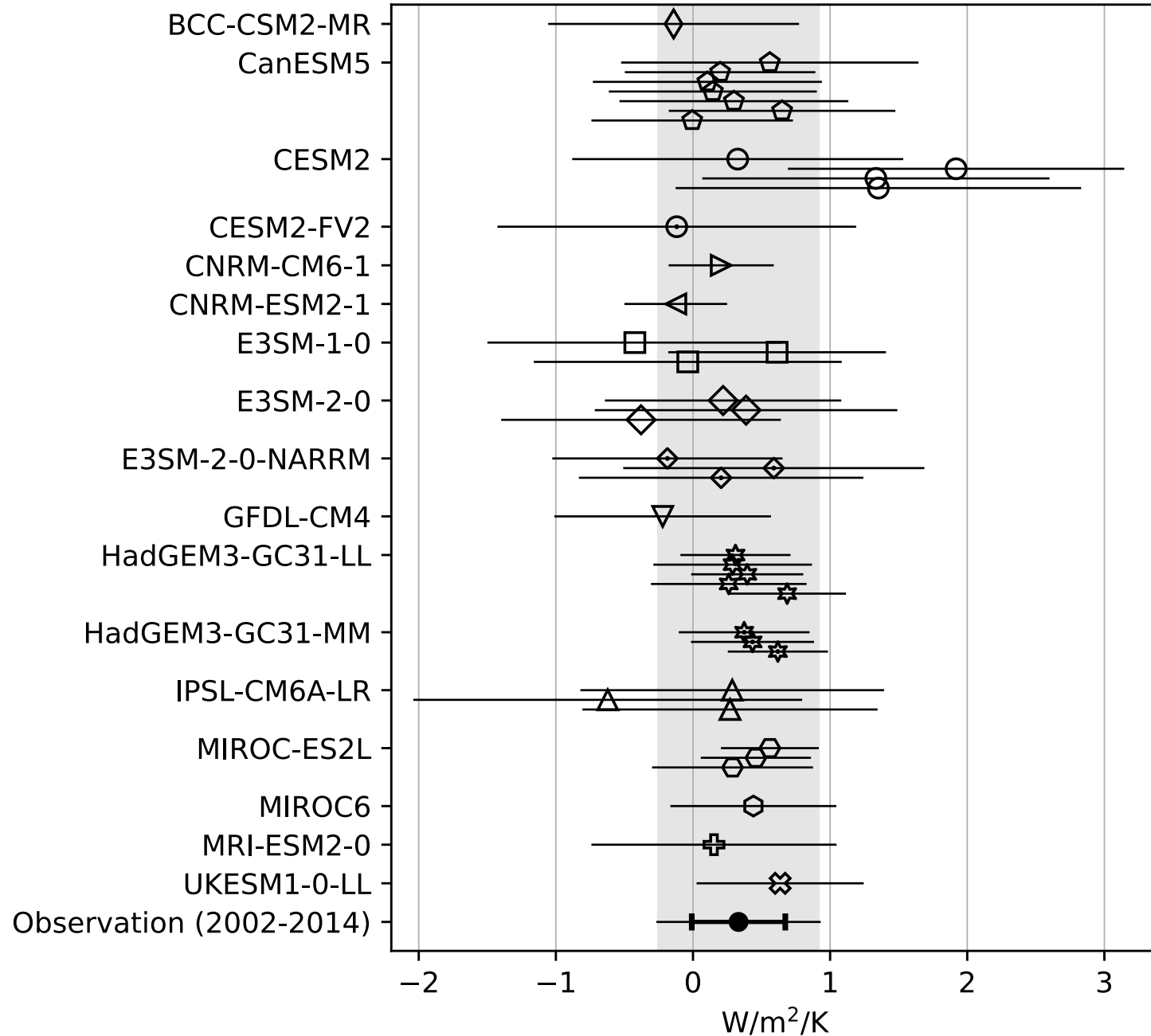
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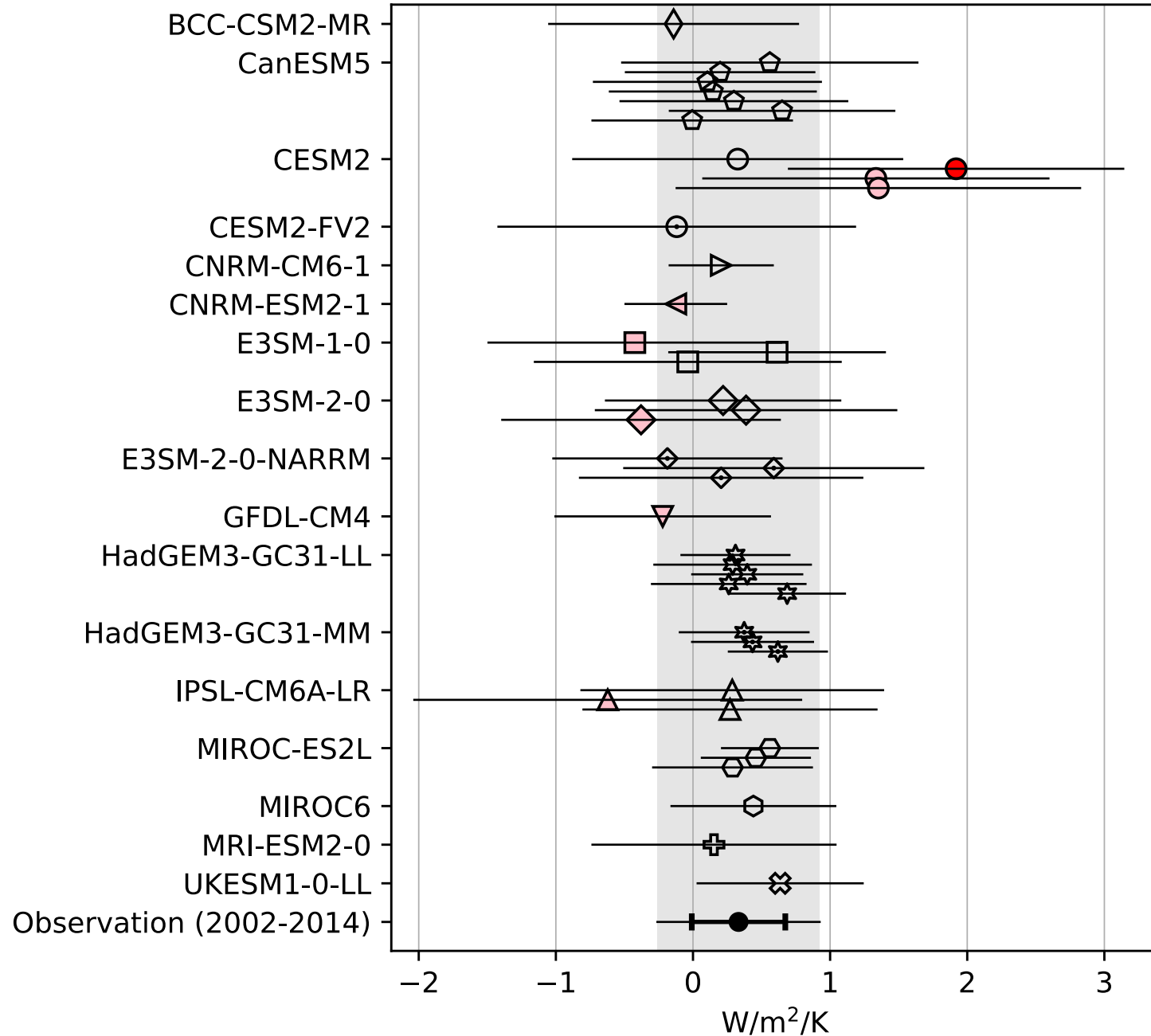
# Results - Total cloud feedback



Cautions are needed when evaluating short-term cloud feedbacks in models and observations

→ Focus on biases that are systematic across models and realizations

# Results - Total cloud feedback



Significantly different from the observed feedback at **90% (red)** or **66% (pink)** confidence intervals



Cautions are needed when evaluating short-term cloud feedbacks in models and observations

→ Focus on biases that are systematic across models and realizations

# Quantifying the models' performance


**6 components**  
**(same as Expert Assessment)**

**7 components**

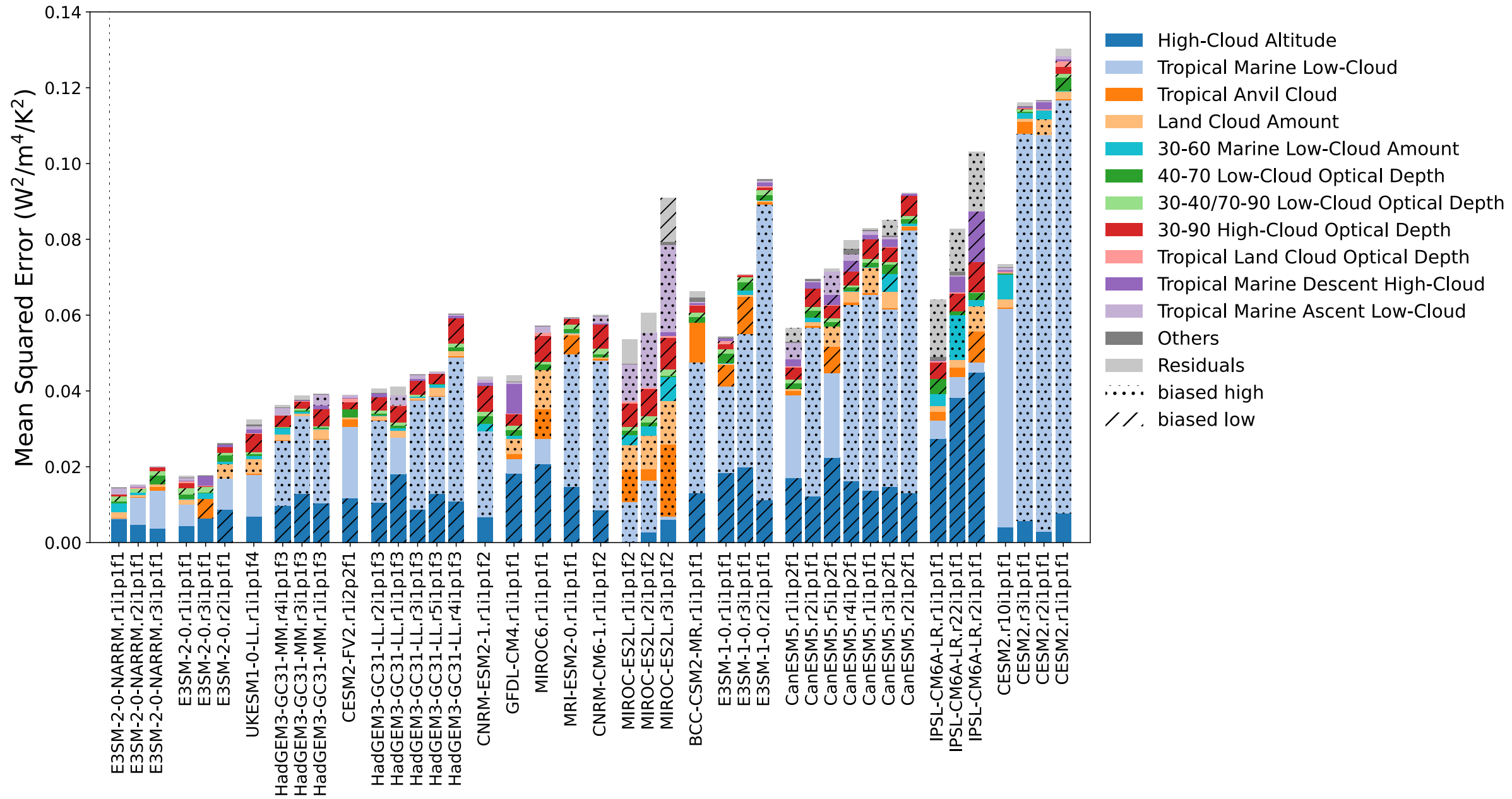
- High-Cloud Altitude
- Tropical Marine Low-Cloud
- Tropical Anvil Cloud
- Land Cloud Amount
- 30-60 Marine Low-Cloud Amount
- 40-70 Low-Cloud Optical Depth
- 30-40/70-90 Low-Cloud Optical Depth
- 30-90 High-Cloud Optical Depth
- Tropical Land Cloud Optical Depth
- Tropical Marine Descent High-Cloud
- Tropical Marine Ascent Low-Cloud
- Others
- Residuals

# Quantifying the models' performance

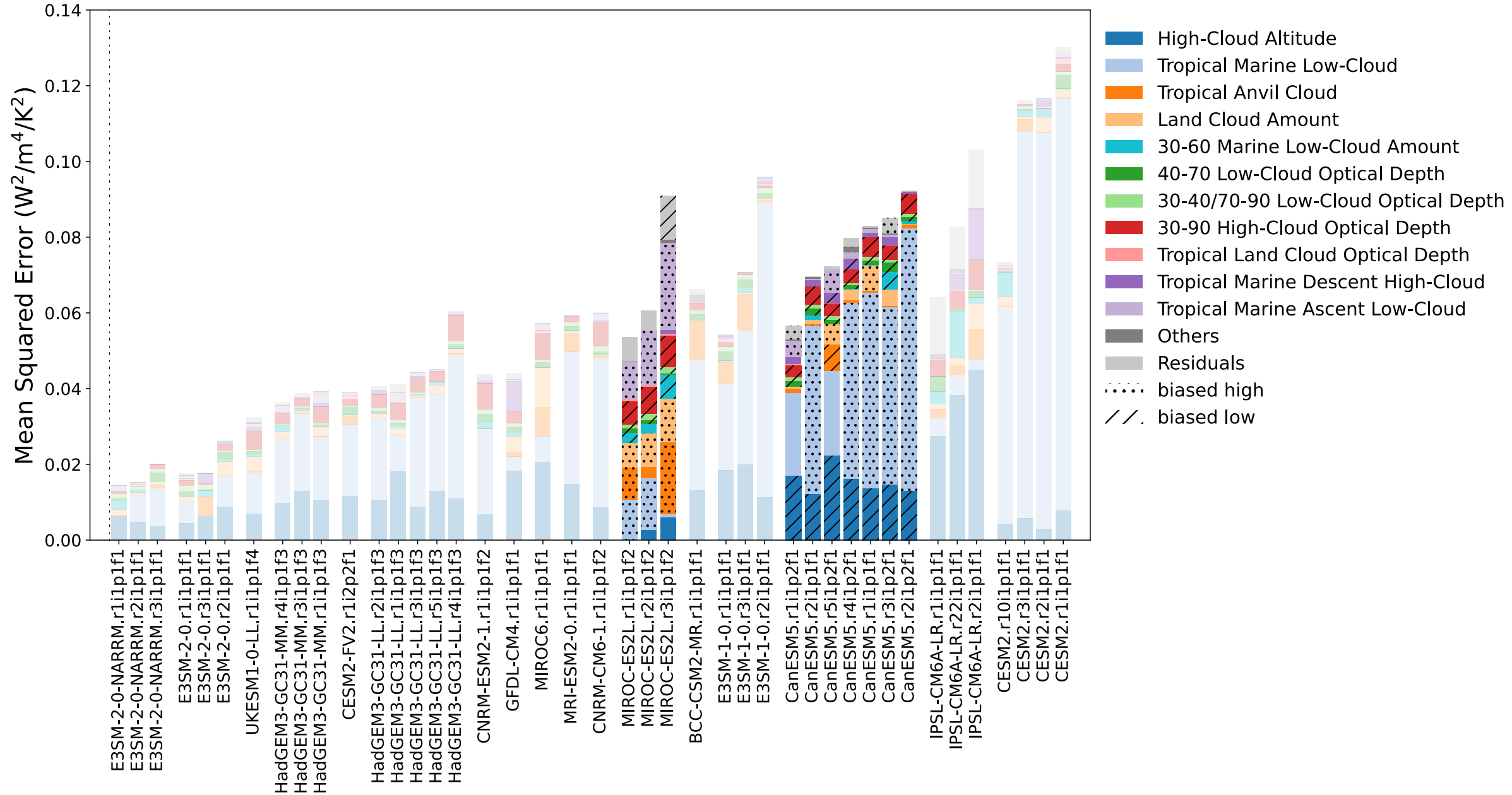
$$\text{Mean Squared Error} = \sum (\lambda_{model} - \lambda_{obs})^2$$

- 
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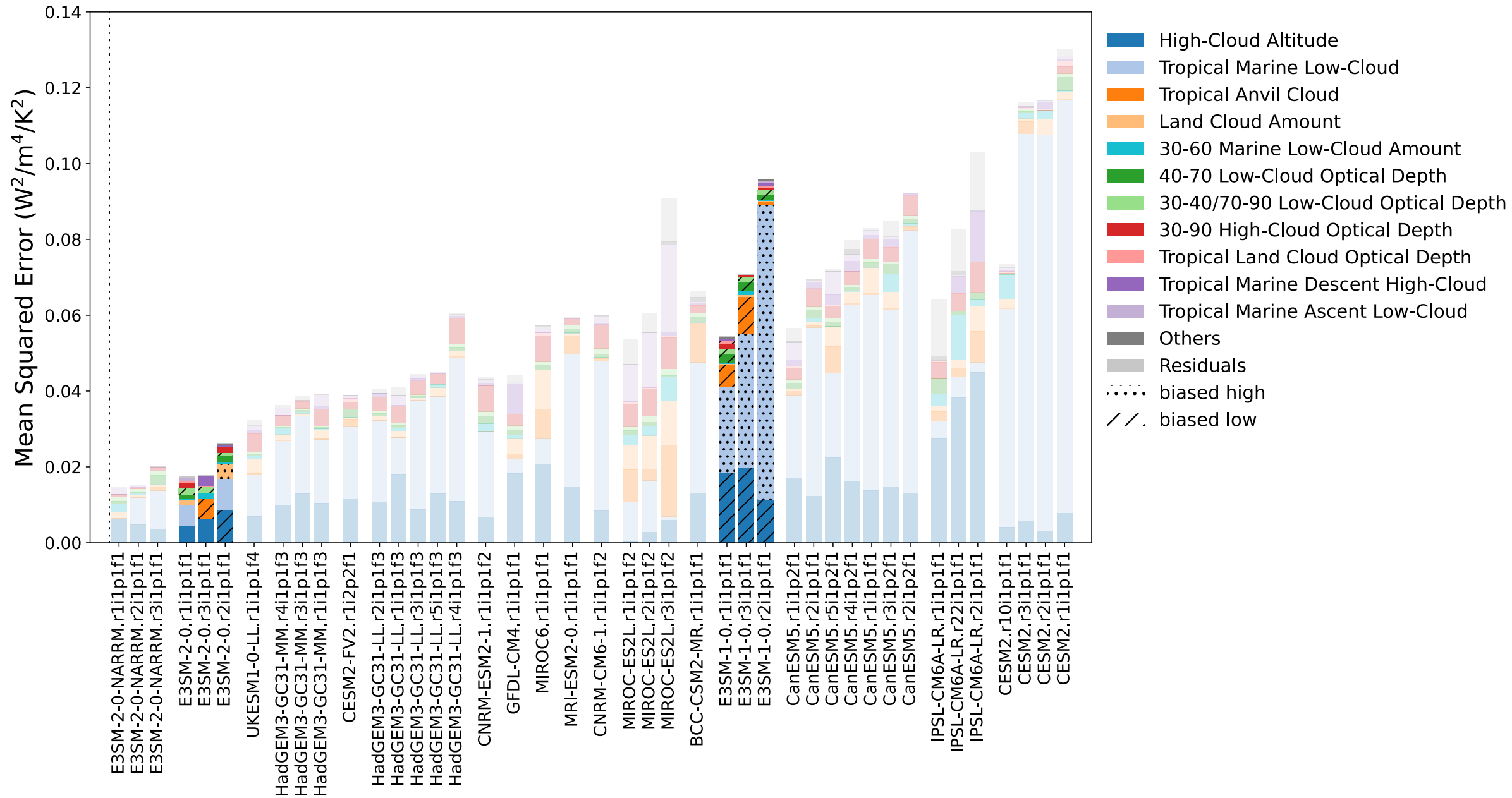


# Quantifying the models' performance

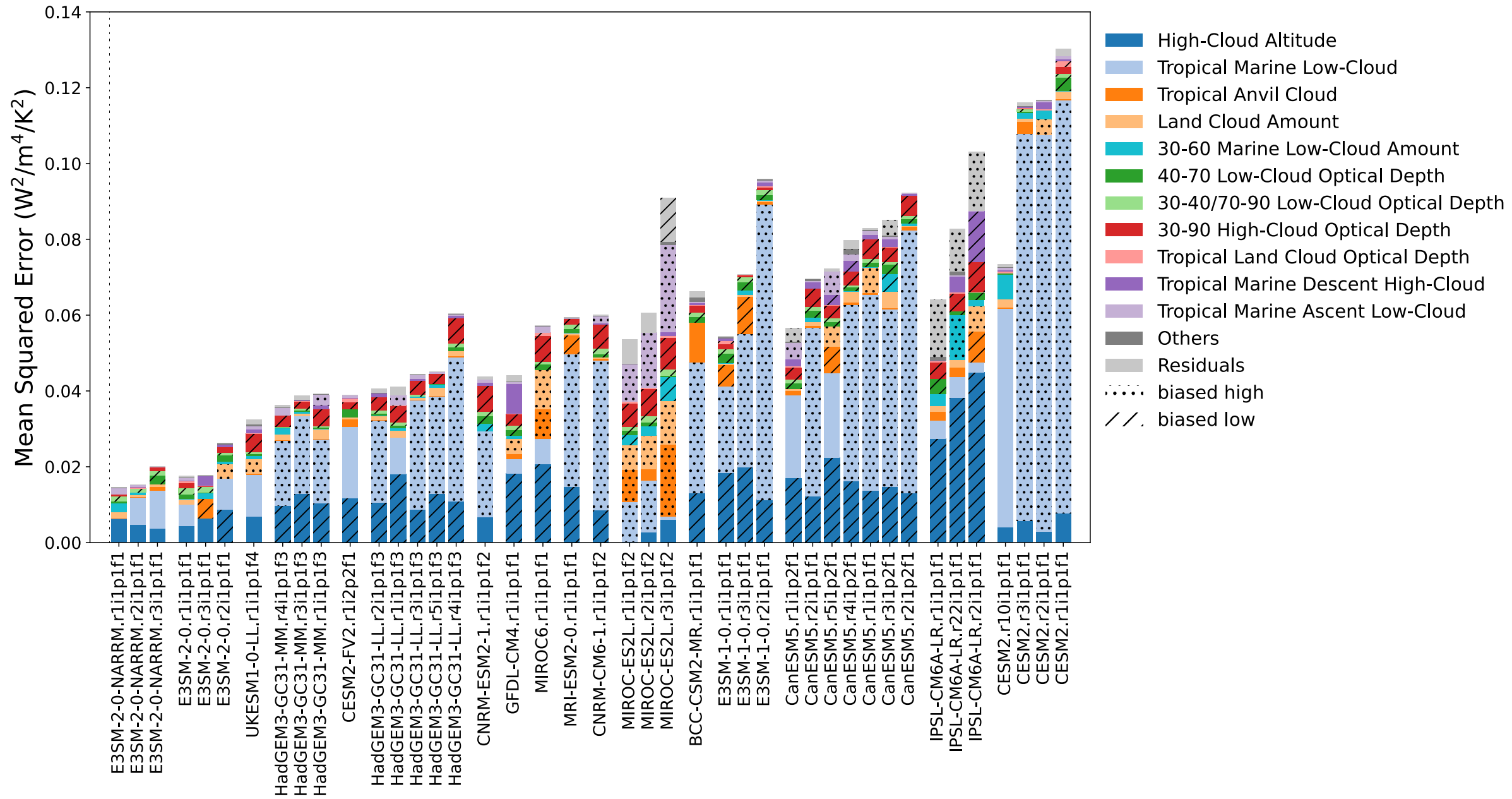




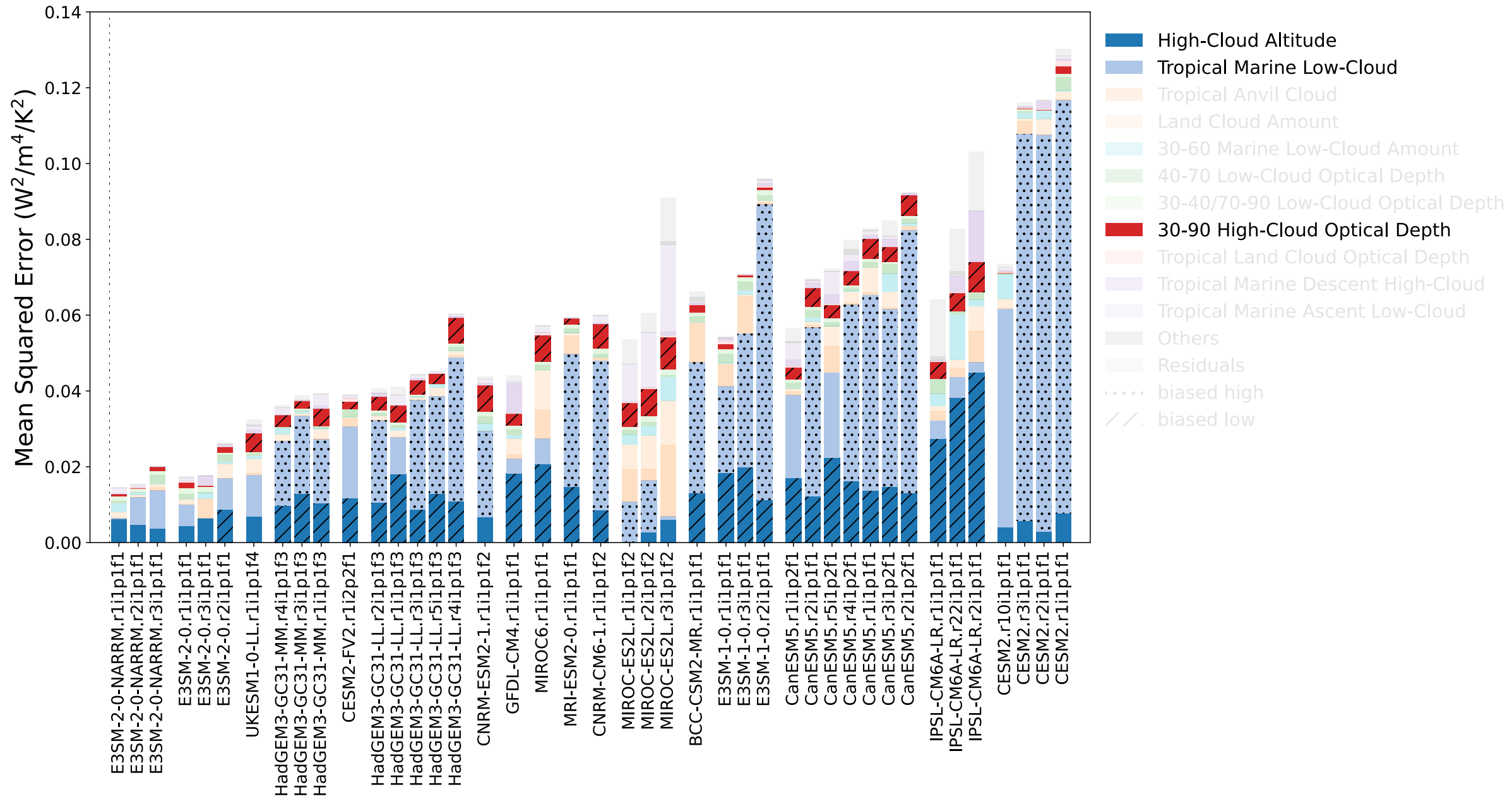
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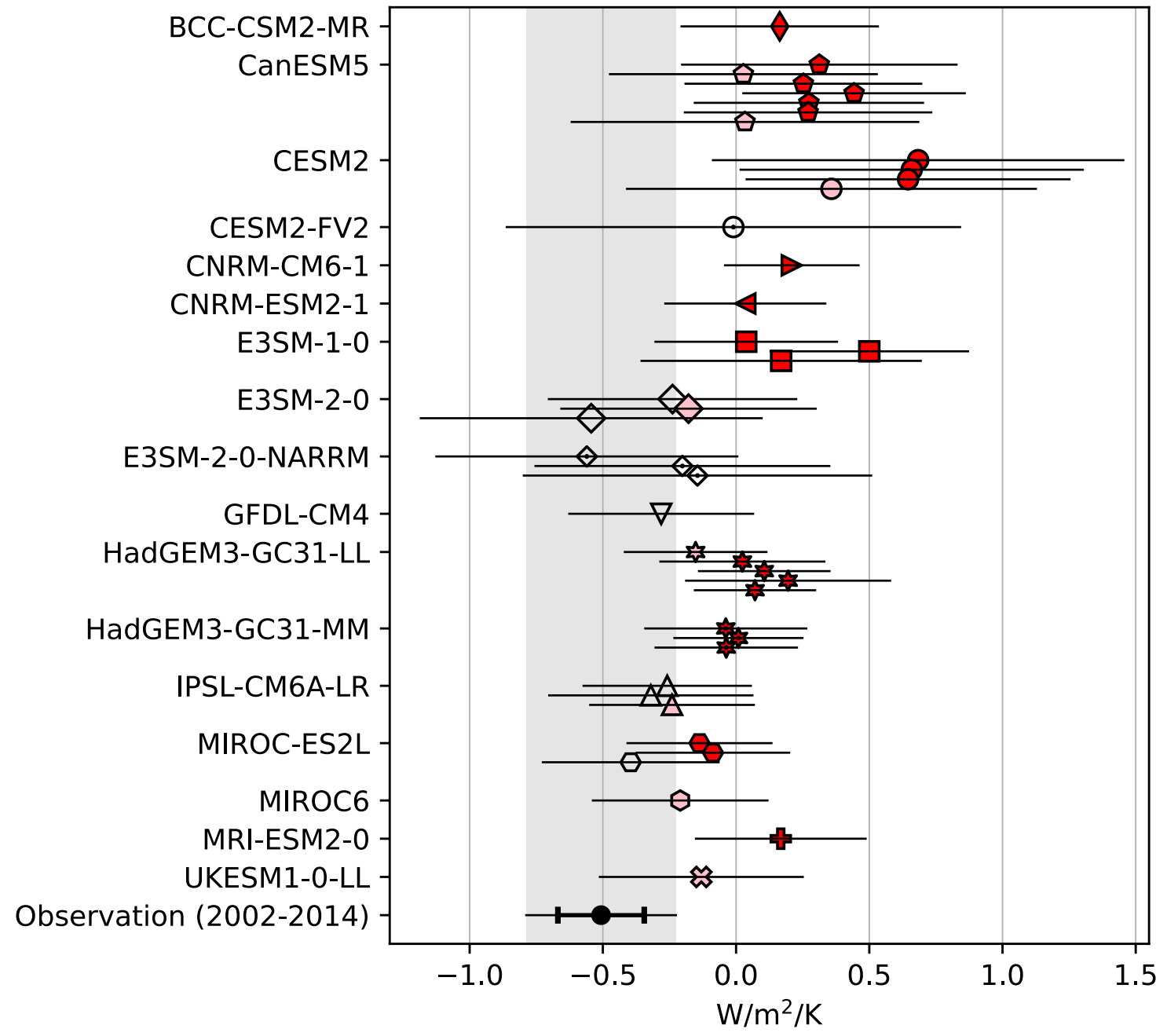
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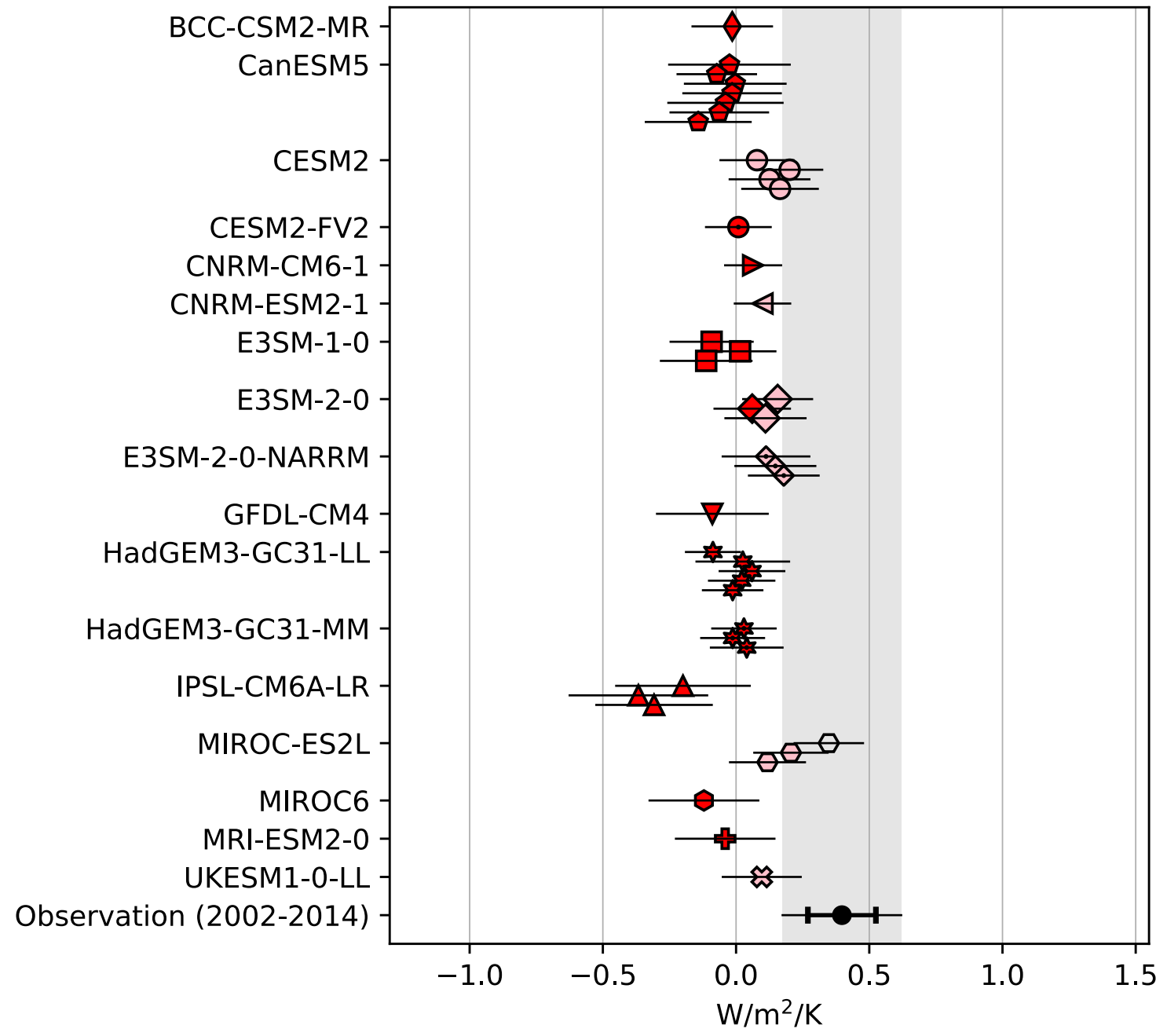


# Model-obs discrepancies - (1) Tropical Marine Low Cloud



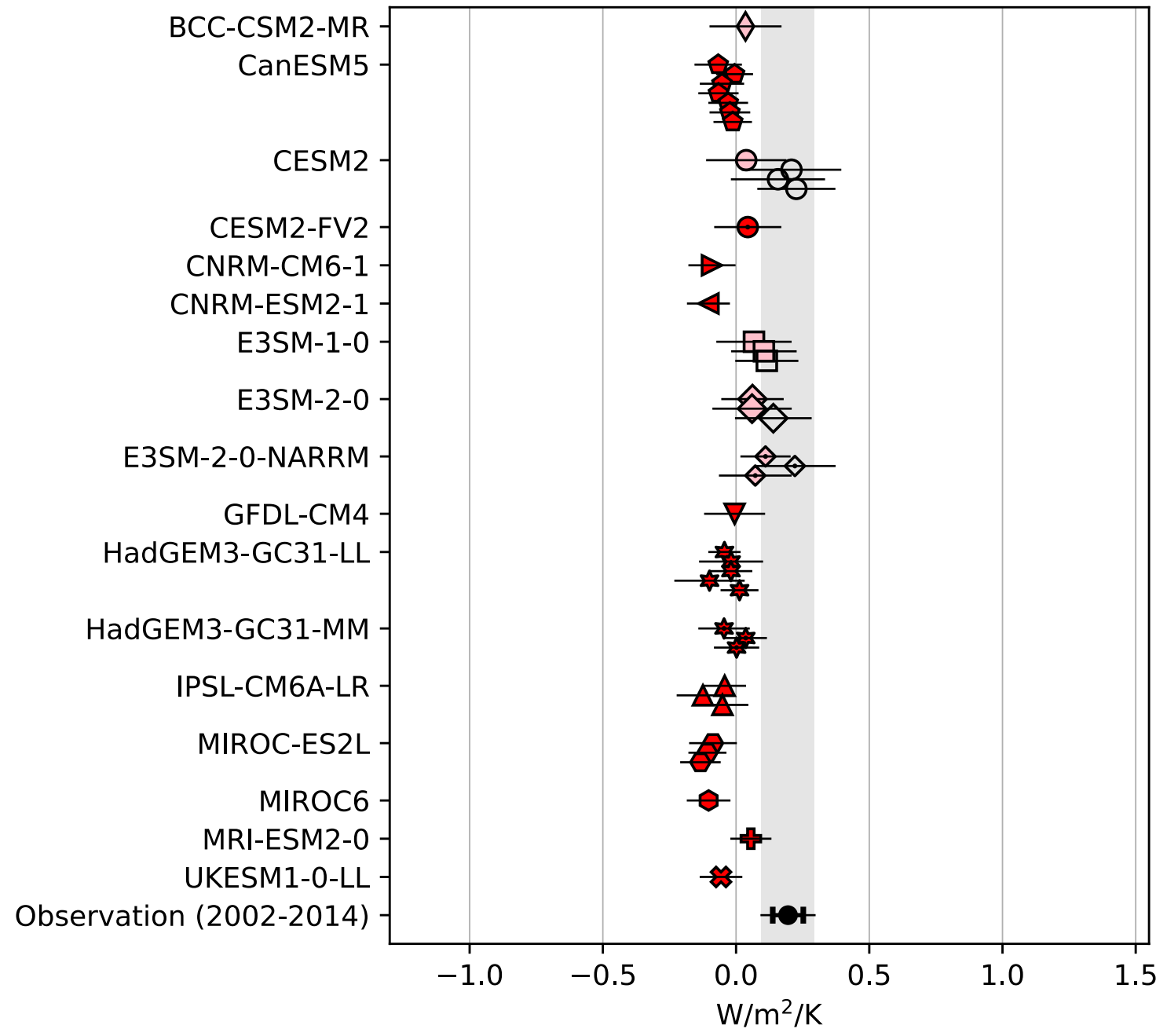
14 of 17 model has at least one realization that is **biased high** at 66% CI, with many at 90% CI

# Model-obs discrepancies - (2) High-cloud Altitude



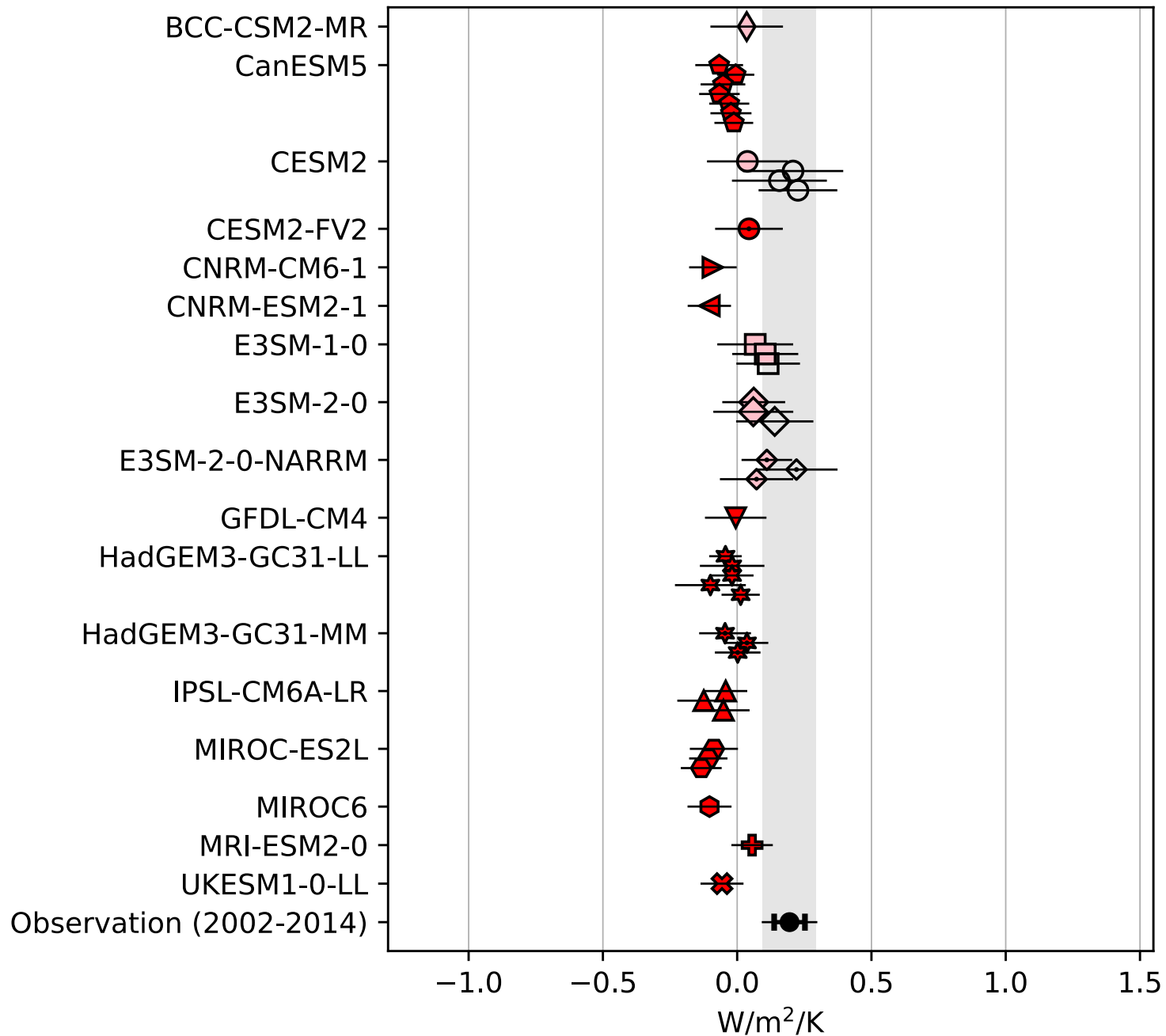
Every model has at least one realization that is **biased low** at 66% CI, with many at 90% CI

# Model-obs discrepancies - (3) 30-90 High-cloud Optical Depth



Every model has at least one realization that is **biased low** at 66% CI, with many at 90% CI

# Model-obs discrepancies - (3) 30-90 High-cloud Optical Depth



Every model has at least one realization that is **biased low** at 66% CI, with many at 90% CI

Not included in the expert assessment of Sherwood et al. (2020)

- Evaluate climate models' performance in simulating cloud feedbacks:



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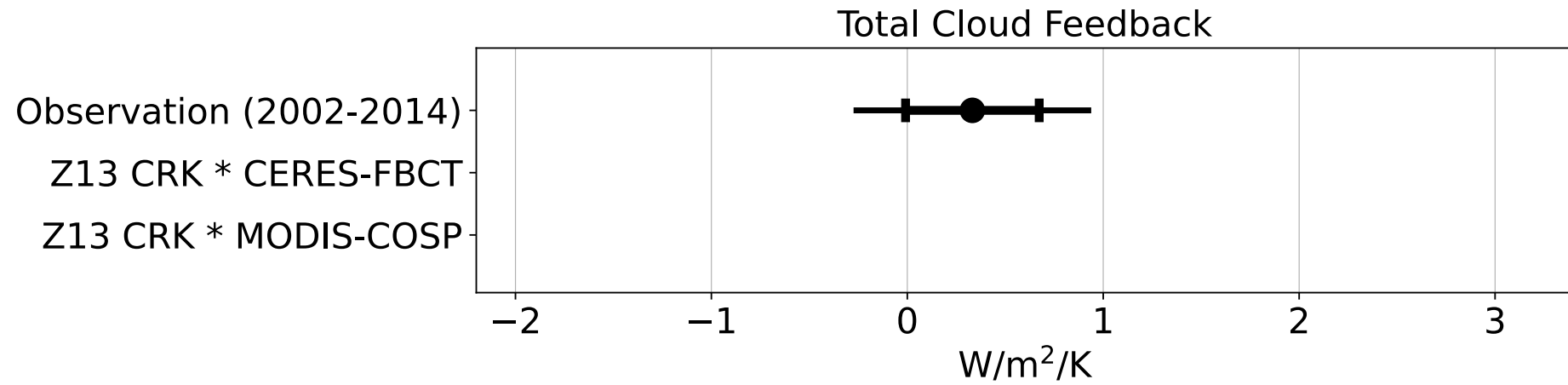
Compared to satellite observations, CMIP6 models exhibit systematic high biases in **tropical marine low cloud feedback** and systematic low biases in **high-cloud altitude** and **extratropical high-cloud optical depth feedbacks**

- Evaluate climate models' performance in simulating cloud feedbacks:

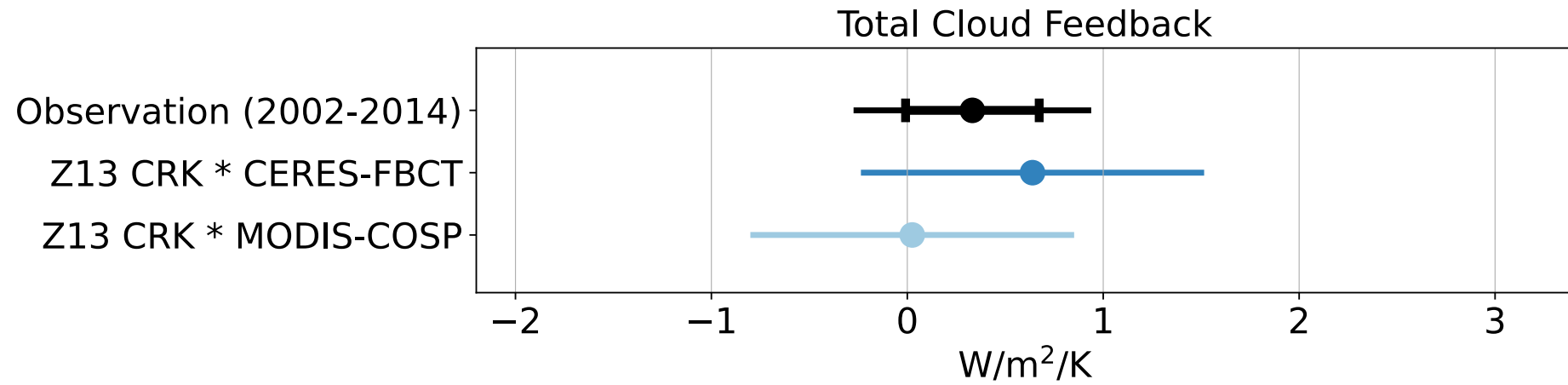
Compared to satellite observations, CMIP6 models exhibit systematic high biases in **tropical marine low cloud feedback** and systematic low biases in **high-cloud altitude** and **extratropical high-cloud optical depth feedbacks**

- The values of short-term cloud feedback depend on:
  - 1) different realizations within one model
  - 2)
  - 3)
  - 4)

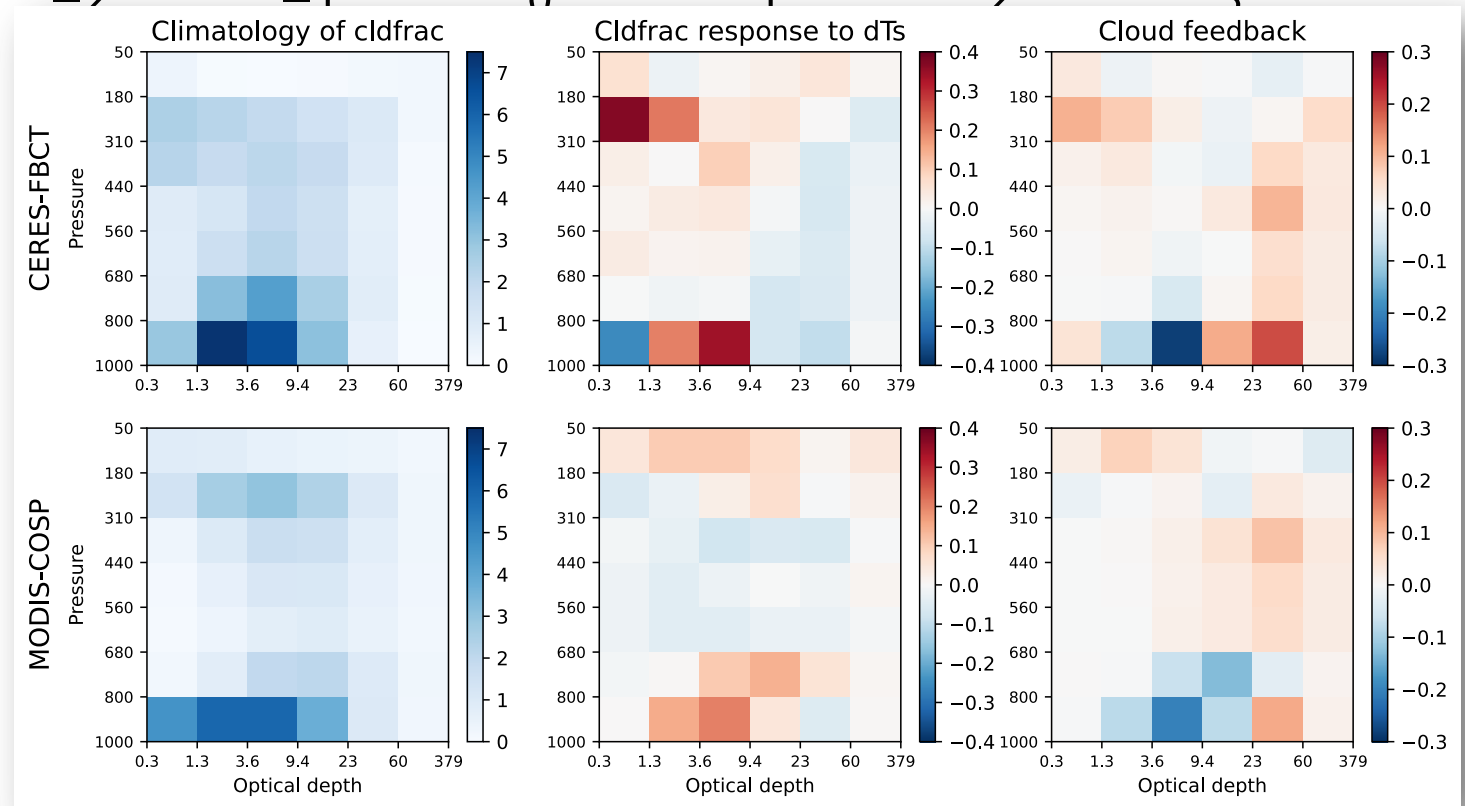
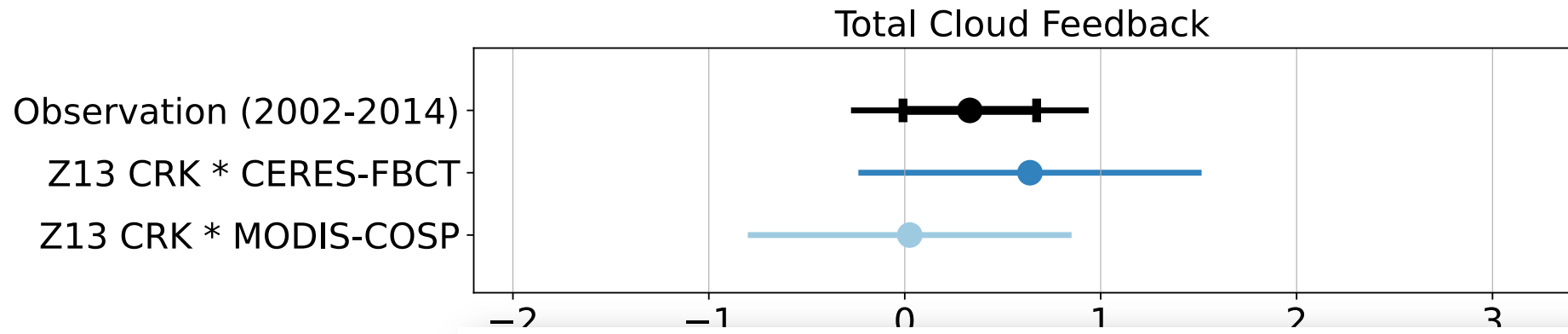
# The sensitivity of cloud feedback values to choice of (1) cloud fraction product



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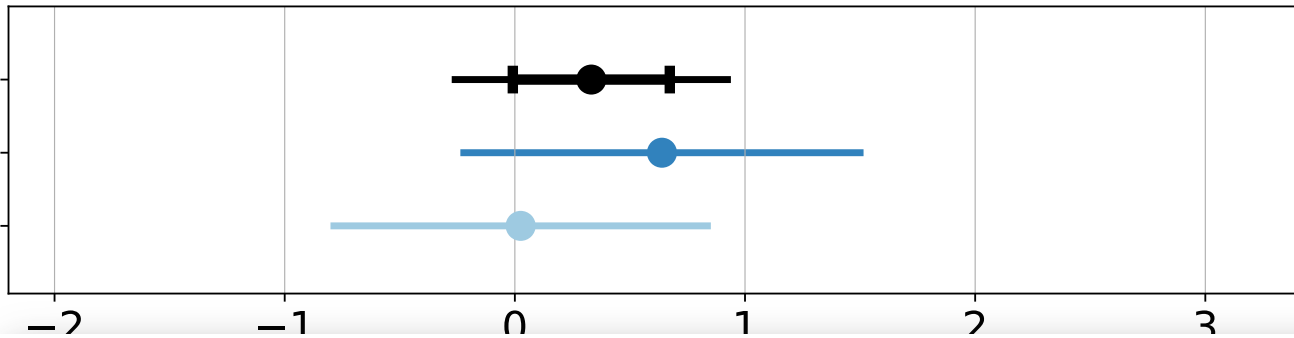
# The sensitivity of cloud feedback values to choice of (1) cloud fraction product

Observation (2002-2014)

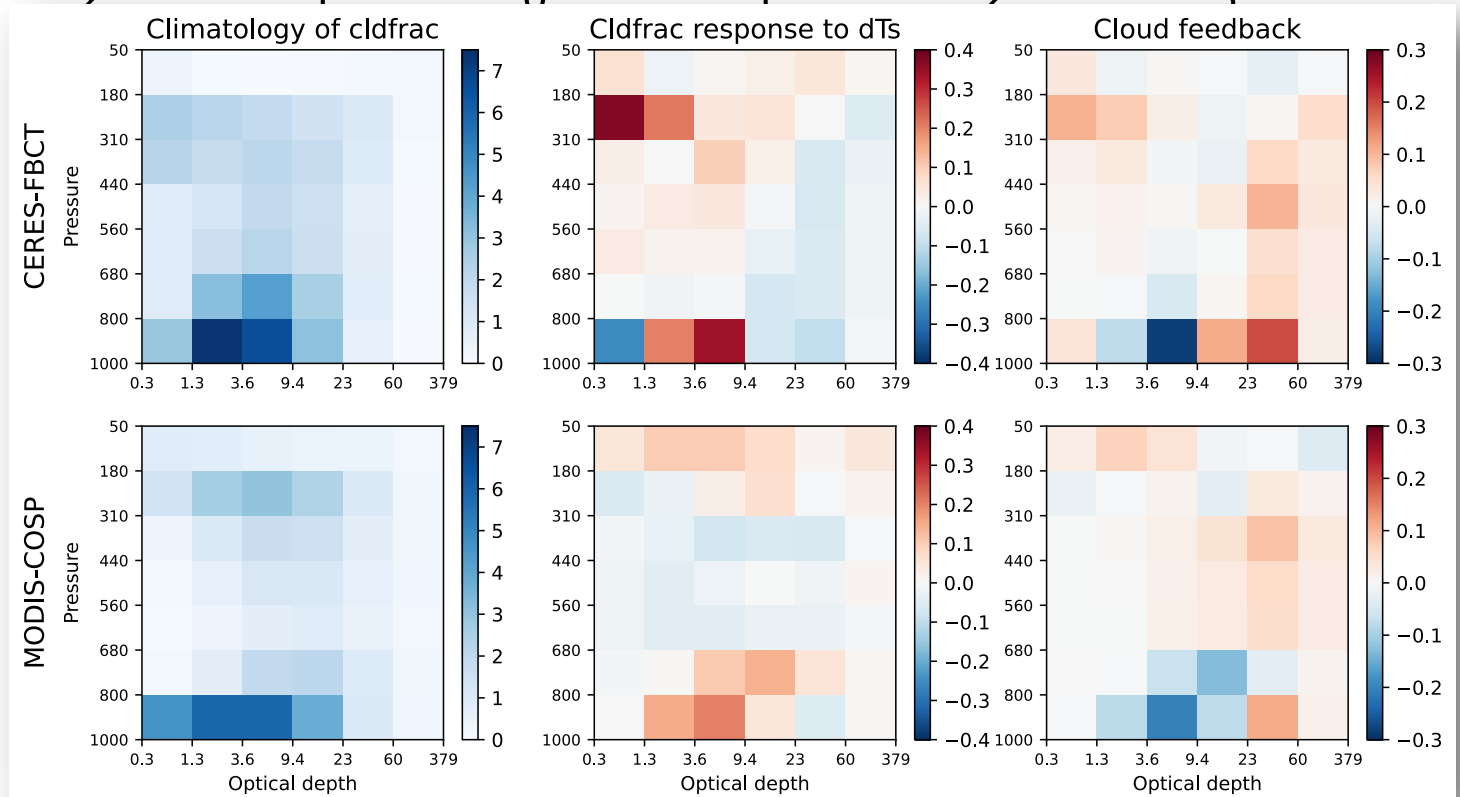
Z13 CRK \* CERES-FBCT

Z13 CRK \* MODIS-COSP

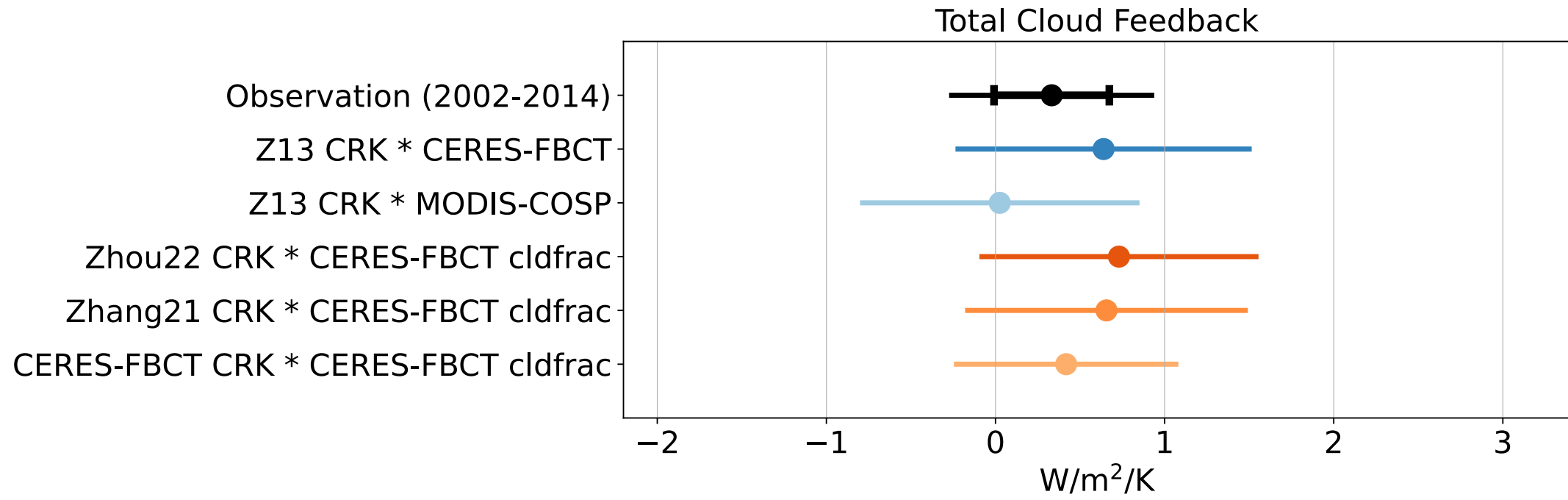
### Total Cloud Feedback



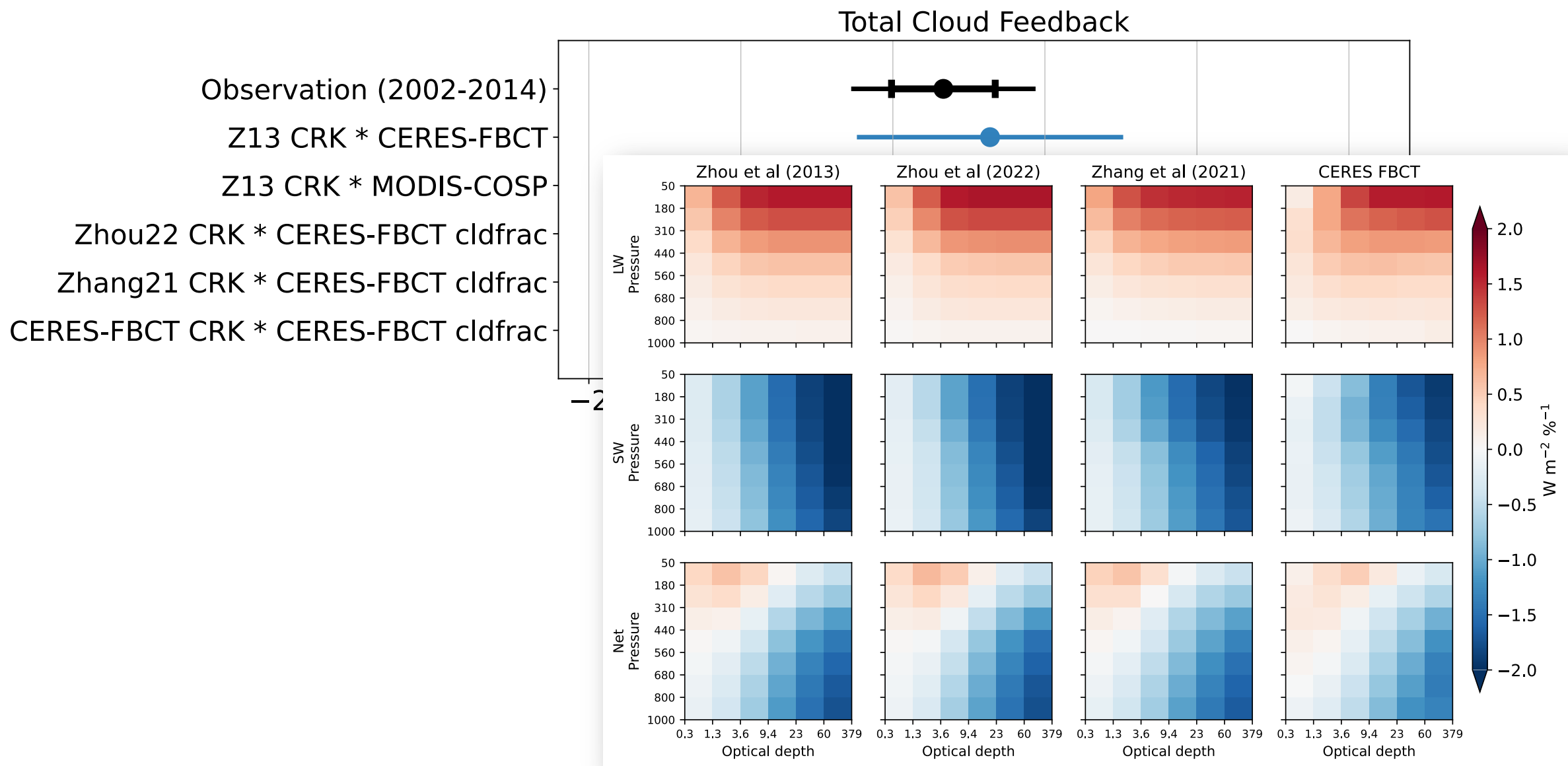
**None** of the differences between FBCT- and MODIS-derived cloud feedback components are statistically significant at 90% confidence



# The sensitivity of cloud feedback values to choice of (2) cloud radiative kernel



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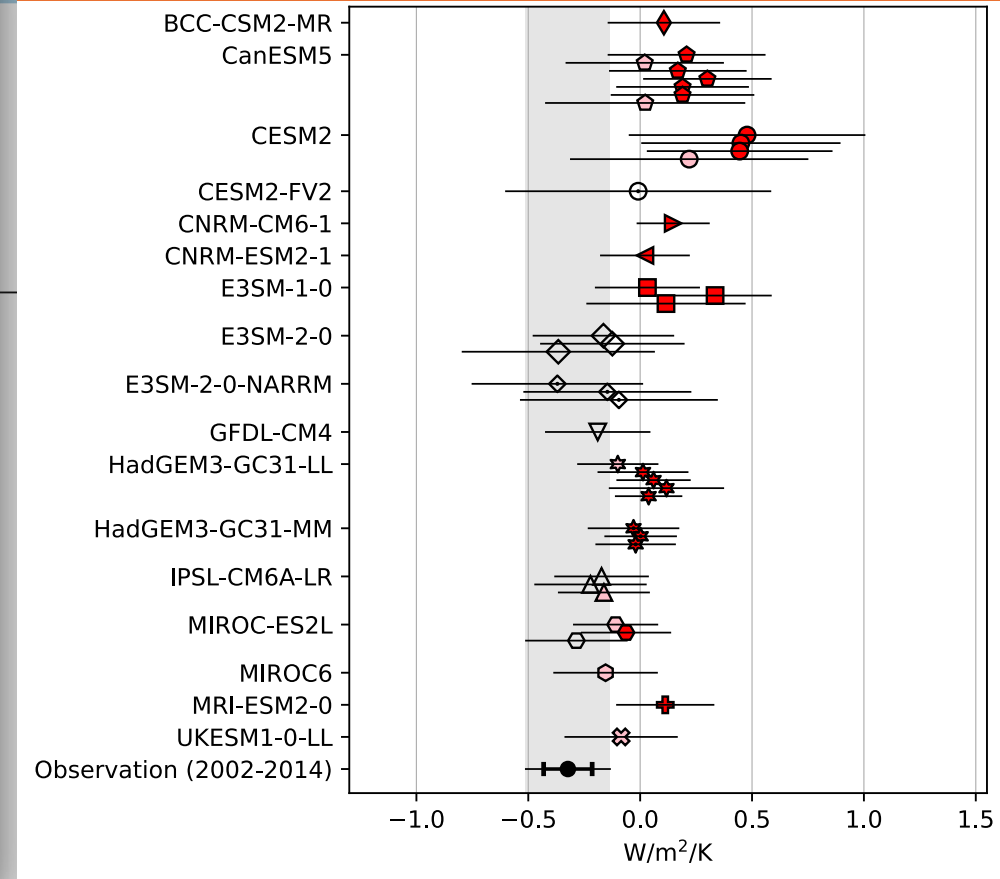
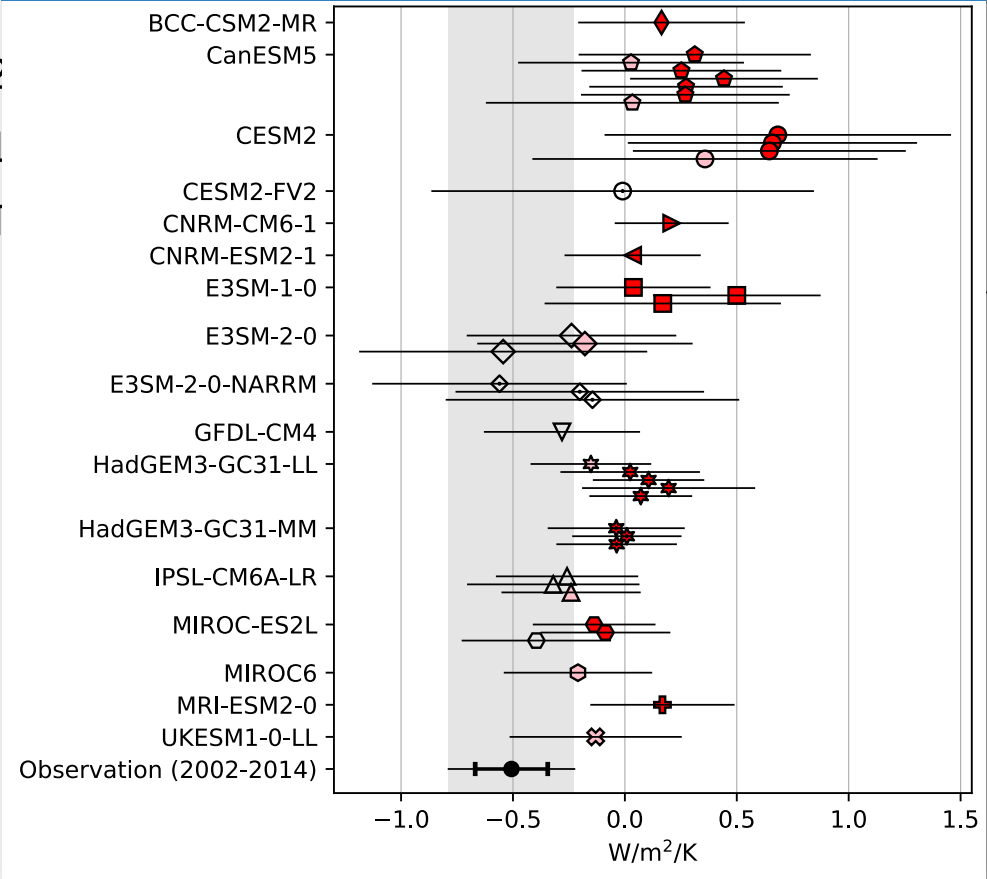
## Total Cloud Feedback

Observation (2002-2014)

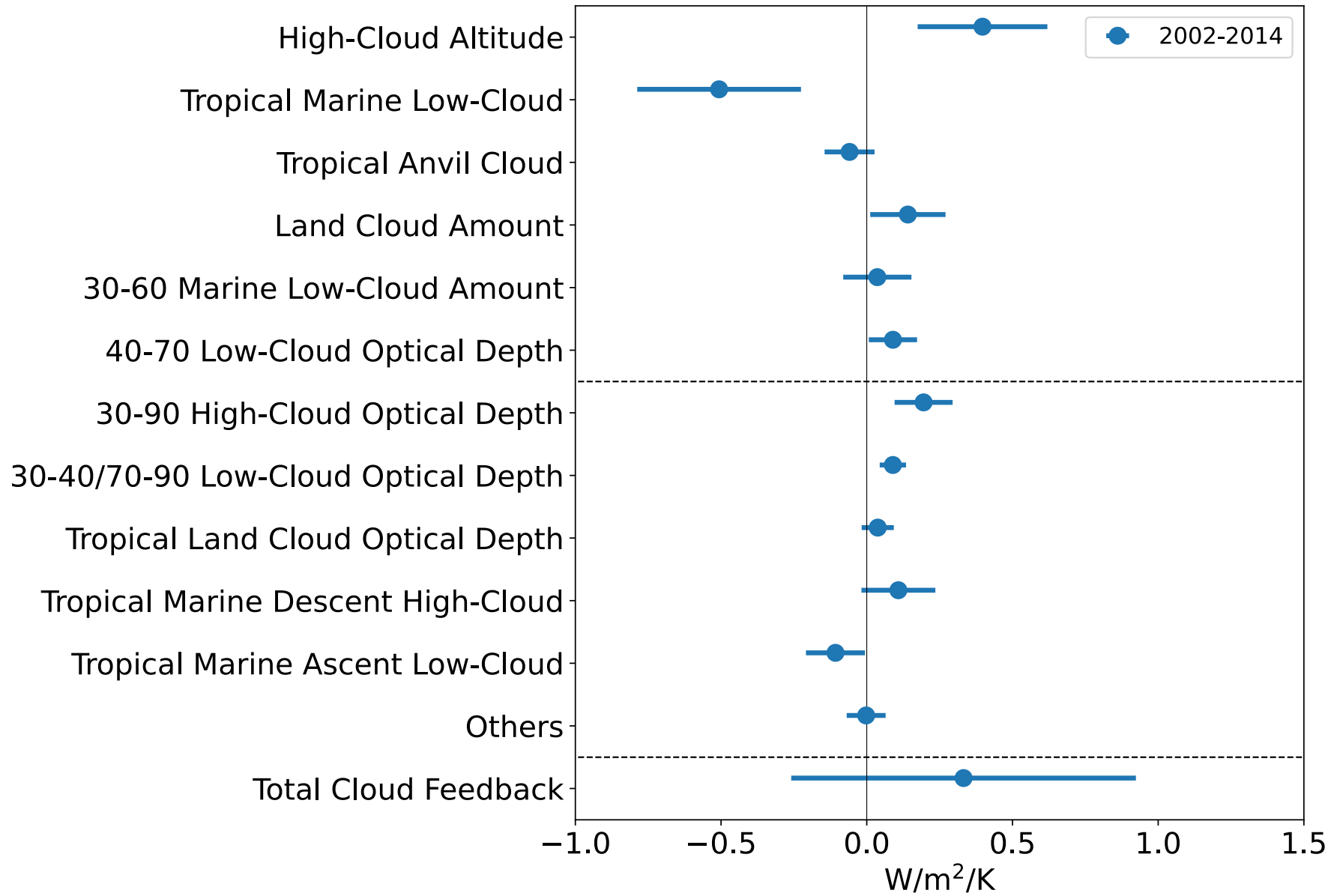
**Z13 CRK:**  
14 of 17 models are biased high

**CERES-FBCT CRK:**  
13 of 17 models are biased high

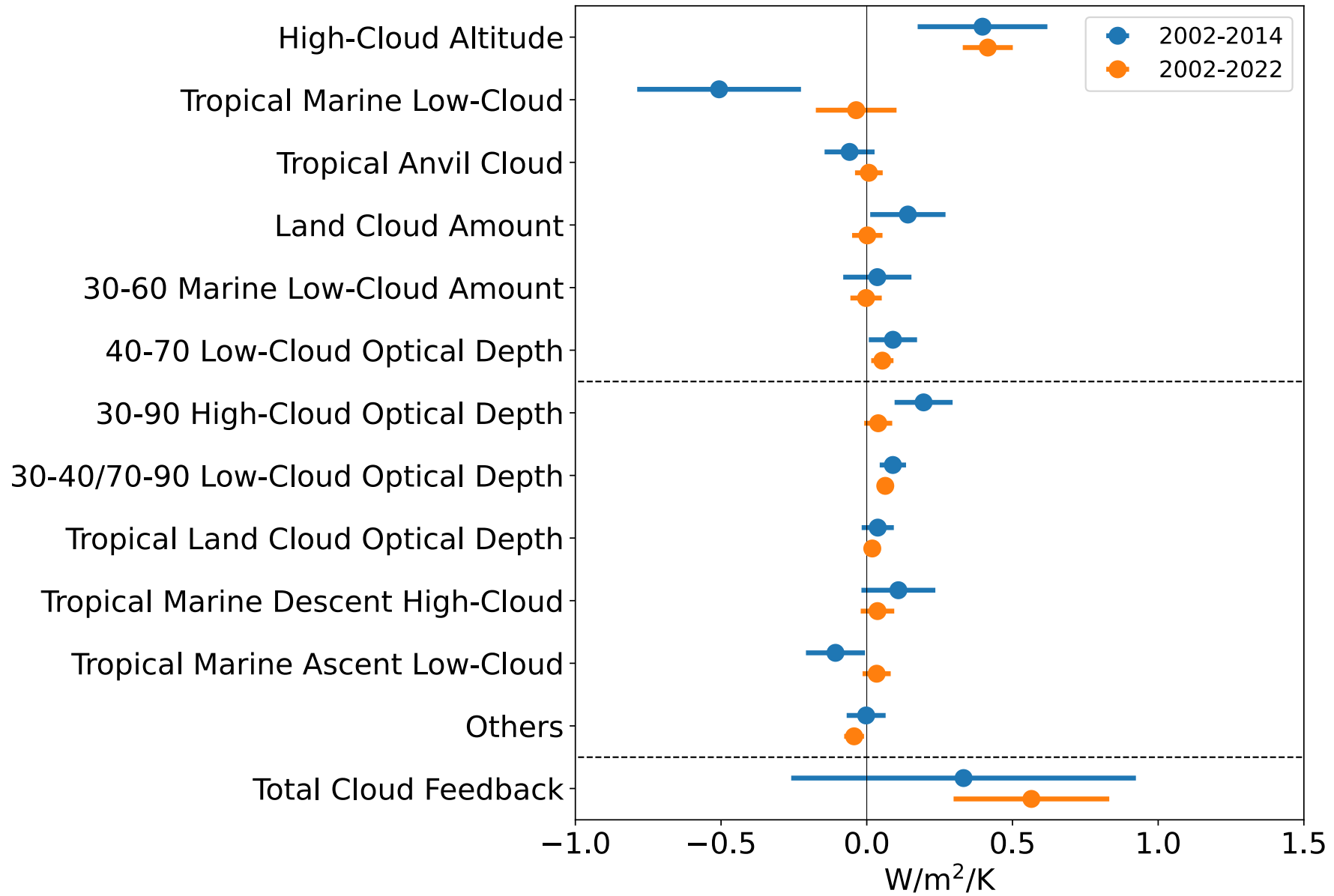
Zhou22  
Zhang21  
CERES-FBCT



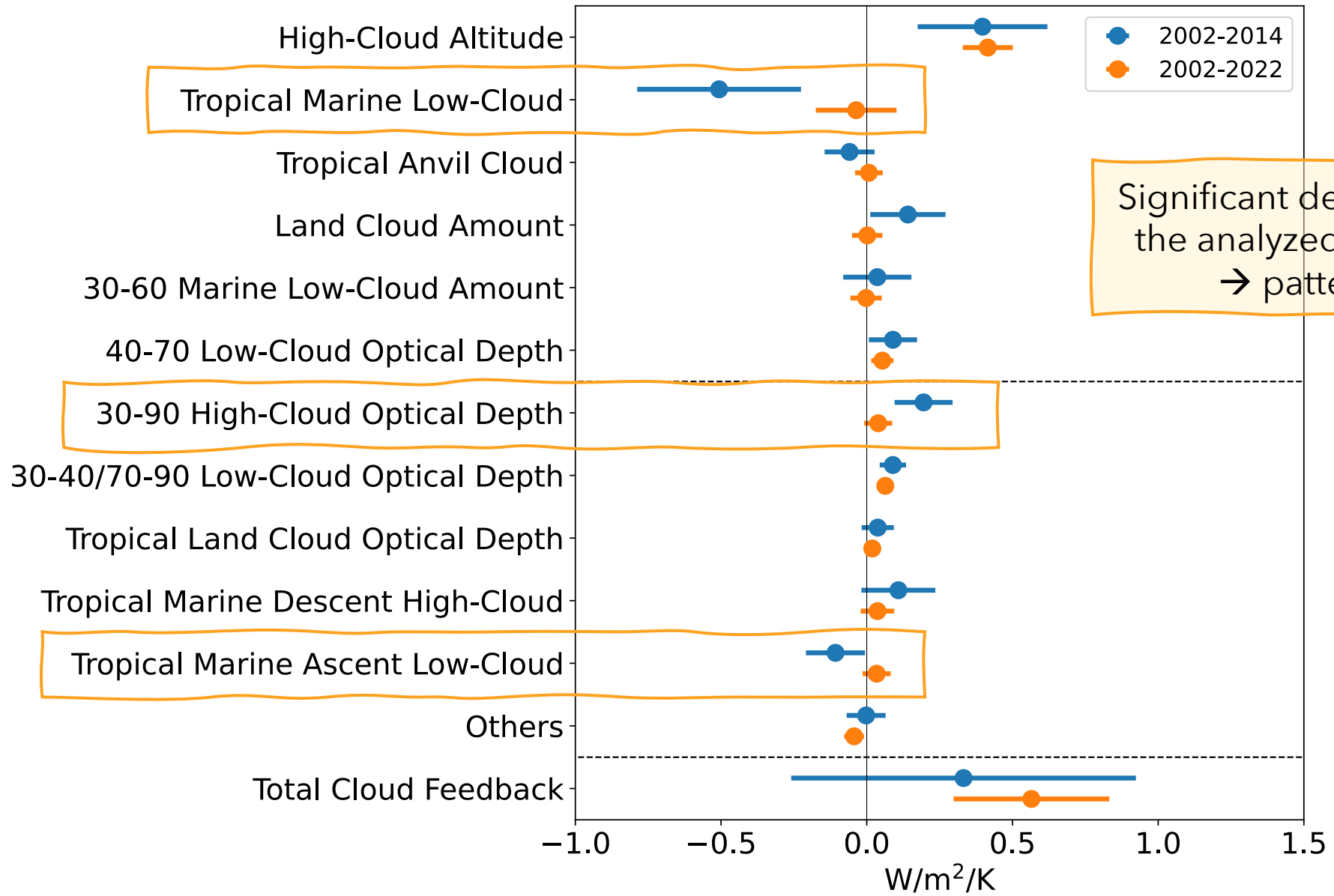
# The sensitivity of cloud feedback values to choice of (3) time periods



# The sensitivity of cloud feedback values to choice of (3) time periods



# The sensitivity of cloud feedback values to choice of (3) time periods



Significant dependence on the analyzed time period  
→ patten effect

# Cloud feedbacks across different time scales

Expert Assessment



Long-term cloud feedback in GCMs

Short-term cloud feedback in observations



Short-term cloud feedback in GCMs

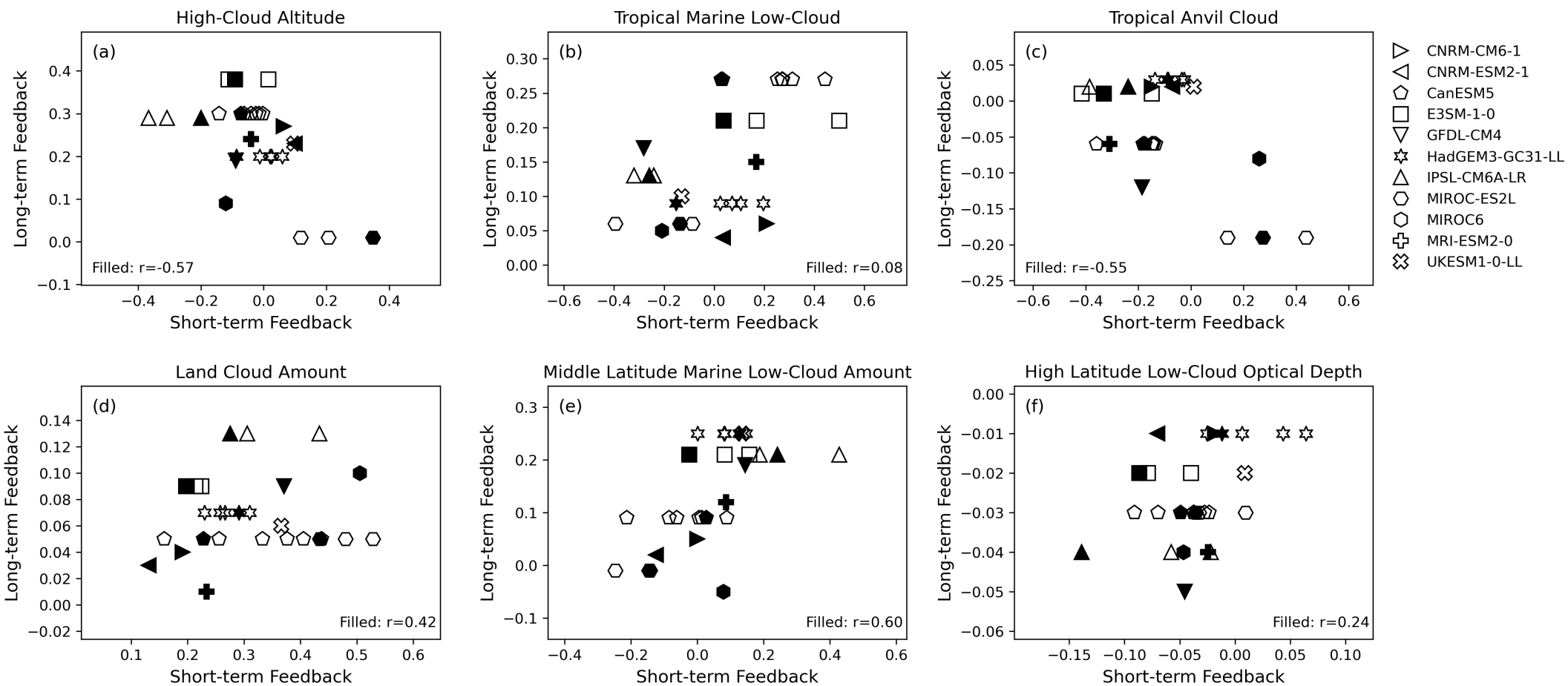
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Short-term cloud feedback in observations

Short-term cloud feedback in GCMs



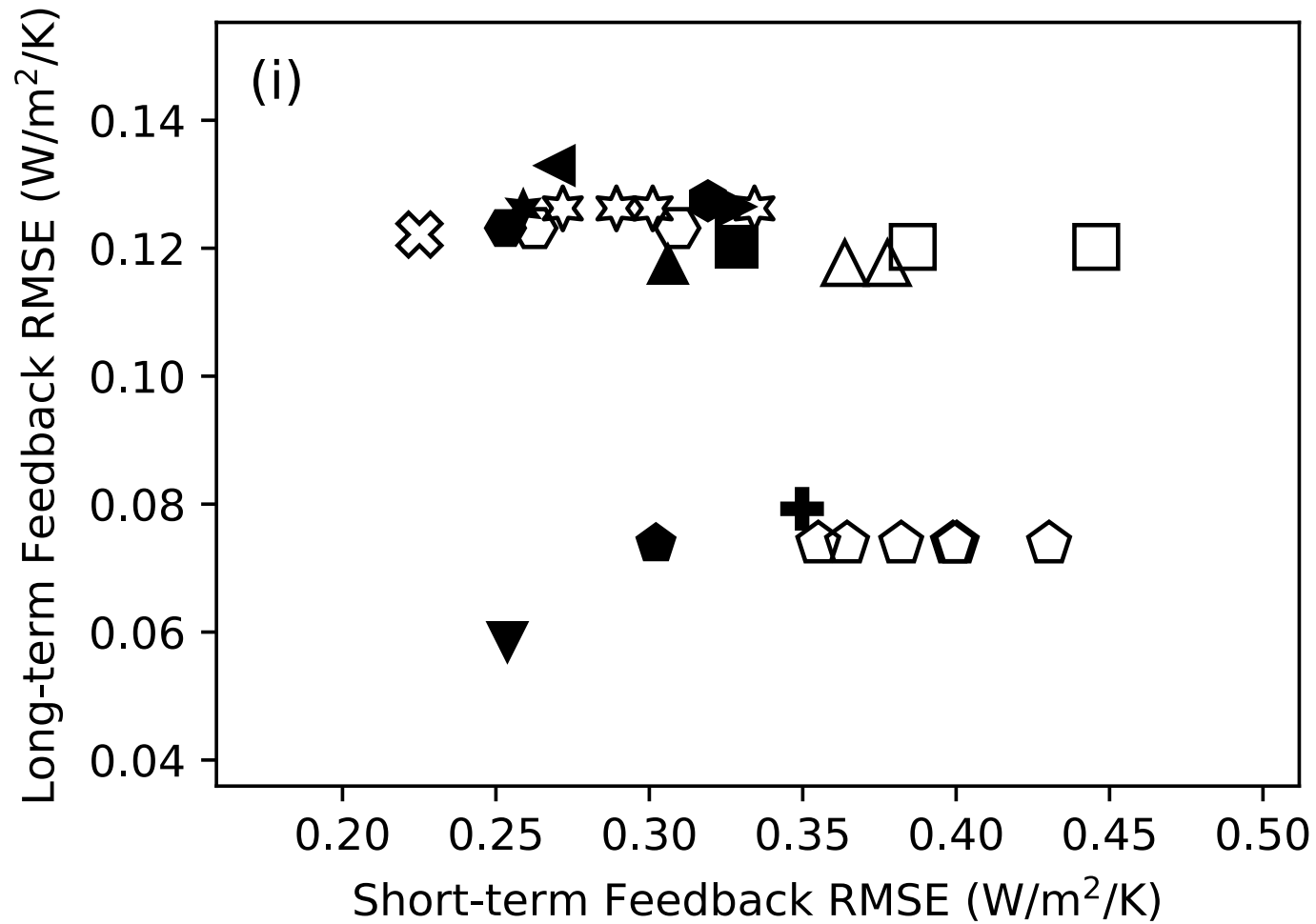
# Cloud feedbacks across different time scales

Skills in  
simulating  
long-term  
feedback

Skills in simulating short-term feedback

# Cloud feedbacks across different time scales

Skills in  
simulating  
long-term  
feedback



- ▽ CNRM-CM6-1
- △ CNRM-ESM2-1
- ◇ CanESM5
- E3SM-1-0
- ▽ GFDL-CM4
- ☆ HadGEM3-GC31-LL
- △ IPSL-CM6A-LR
- ◇ MIROC-ES2L
- ◇ MIROC6
- ⊕ MRI-ESM2-0
- ⊗ UKESM1-0-LL

Skills in simulating short-term feedback



- Compared to satellite observations, CMIP6 models exhibit systematic high biases in **tropical marine low cloud feedback** and systematic low biases in **high-cloud altitude** and **extratropical high-cloud optical depth feedbacks**
- Cautions are needed during evaluation since the values of short-term cloud feedback depend on:
  - different realizations within one model
  - choice of cloud fraction products
  - choice of cloud radiative kernels
  - choice of time periods
- A better skill in simulating short-term cloud feedback may not indicate a better skill in simulating long-term cloud feedback. Alternative approach to constraint long-term cloud feedback may be via cloud controlling factors

**JGR Atmospheres**

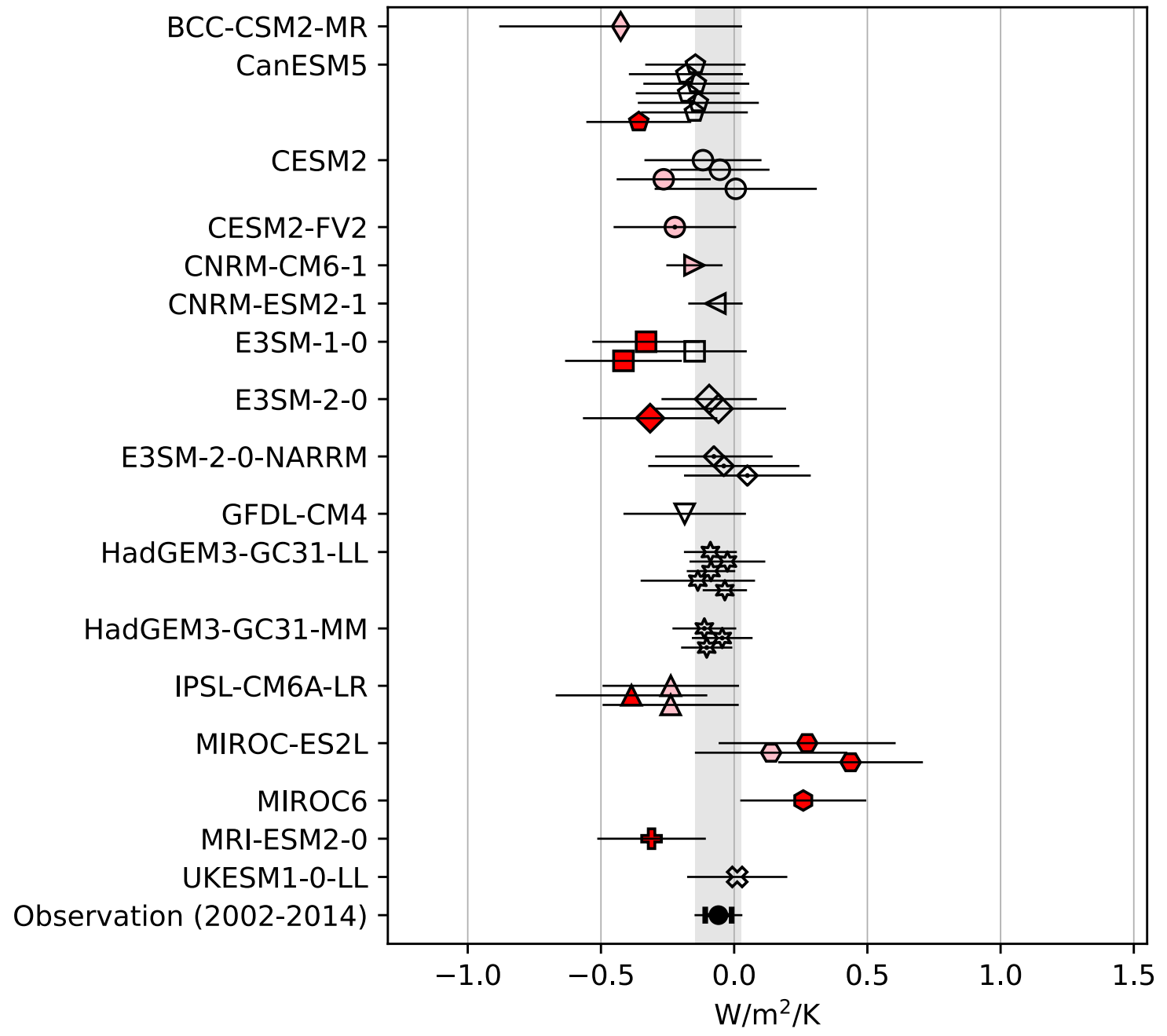
Research Article | [Open Access](#) |  

**Evaluating Cloud Feedback Components in Observations and Their Representation in Climate Models**

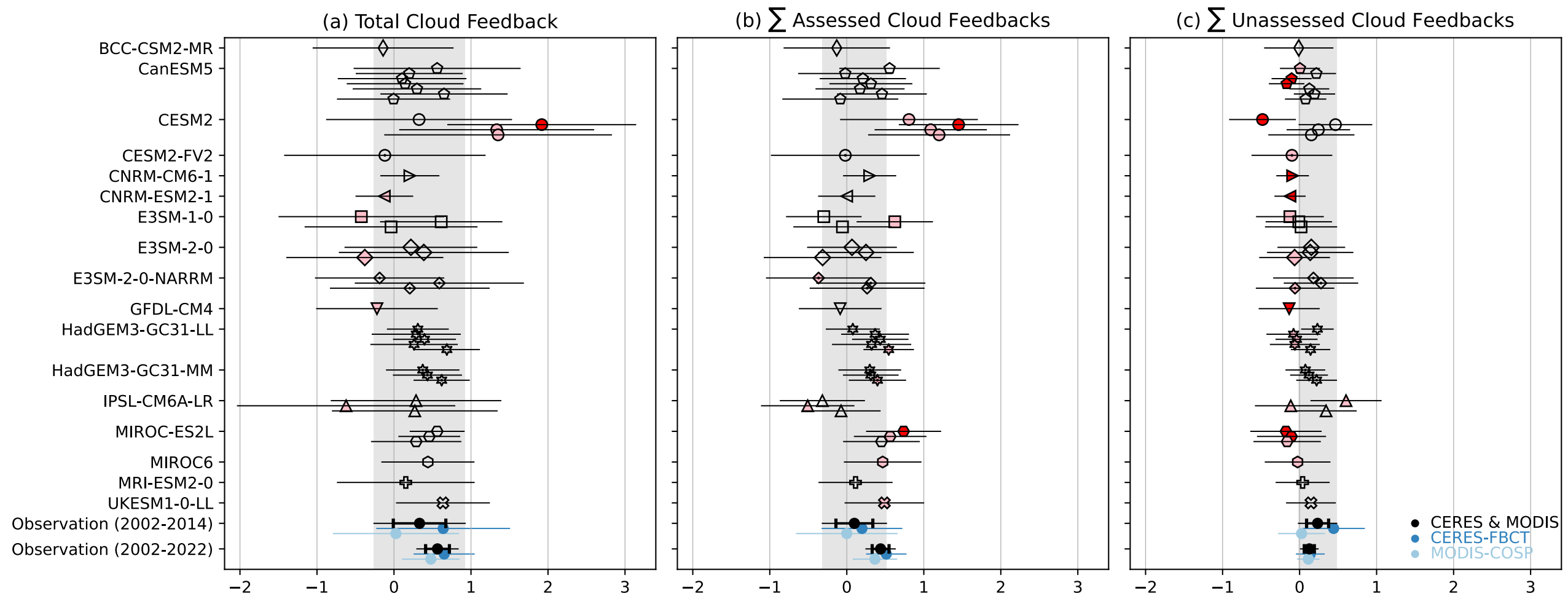
Li-Wei Chao , Mark D. Zelinka, Andrew E. Dessler

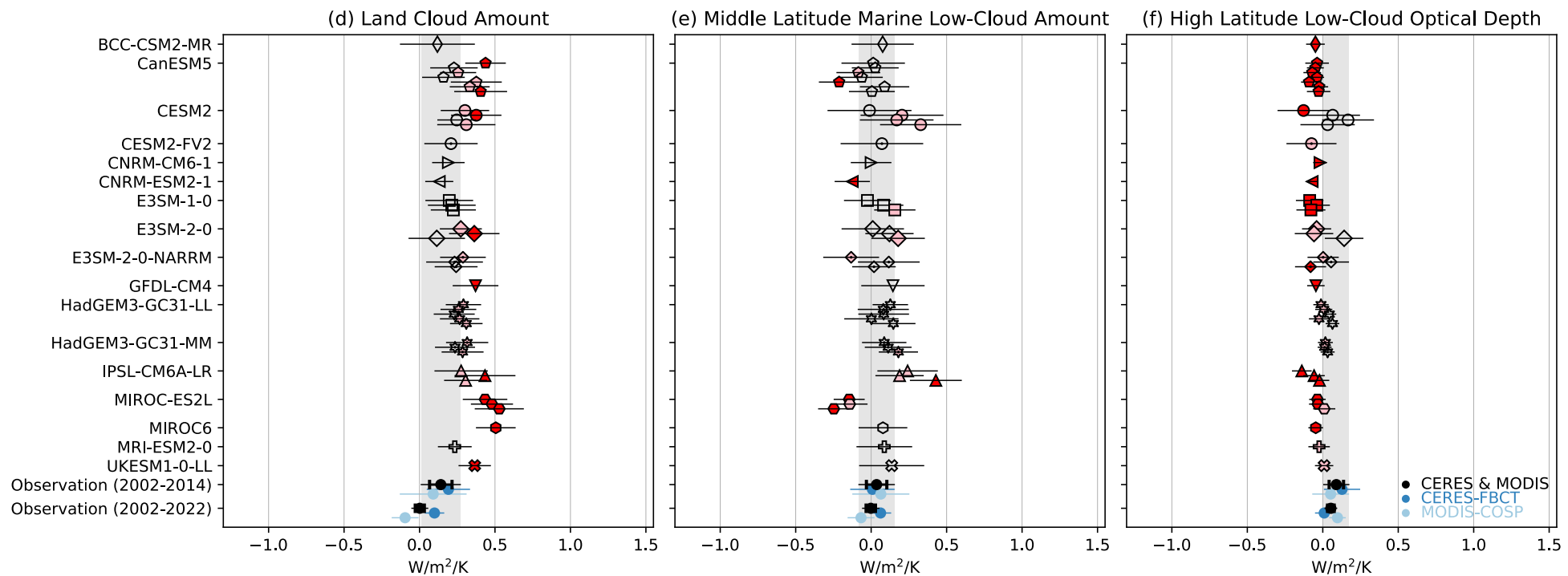
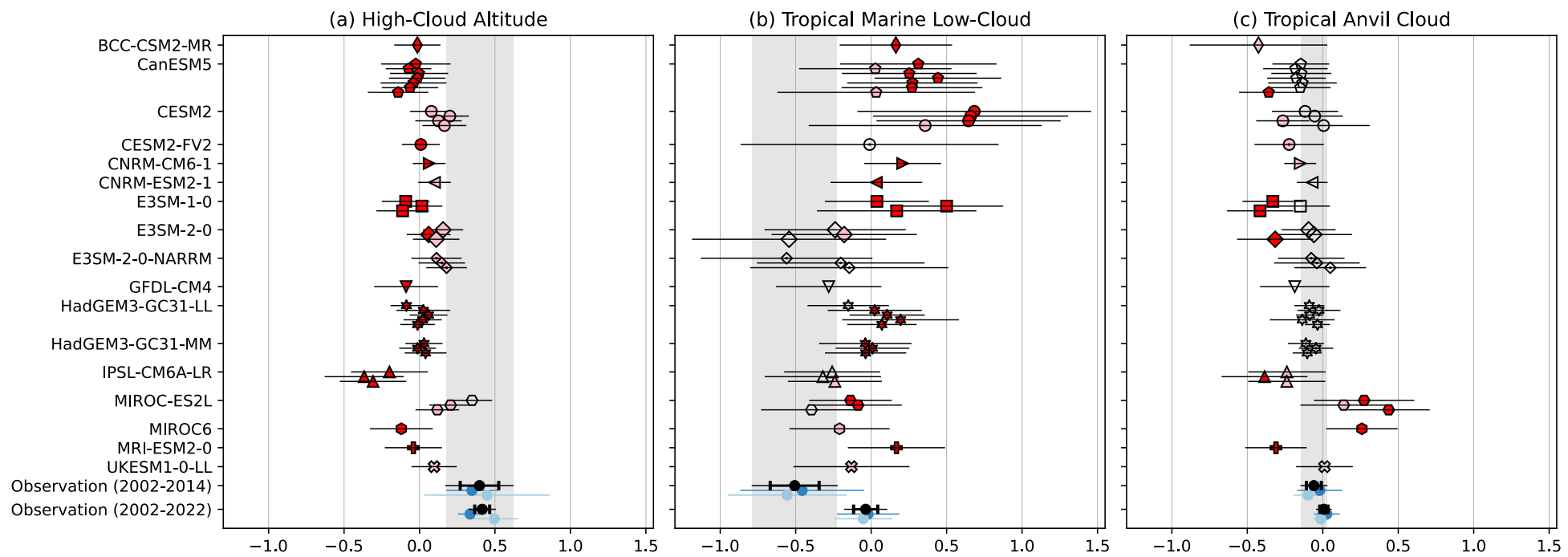
Supplement

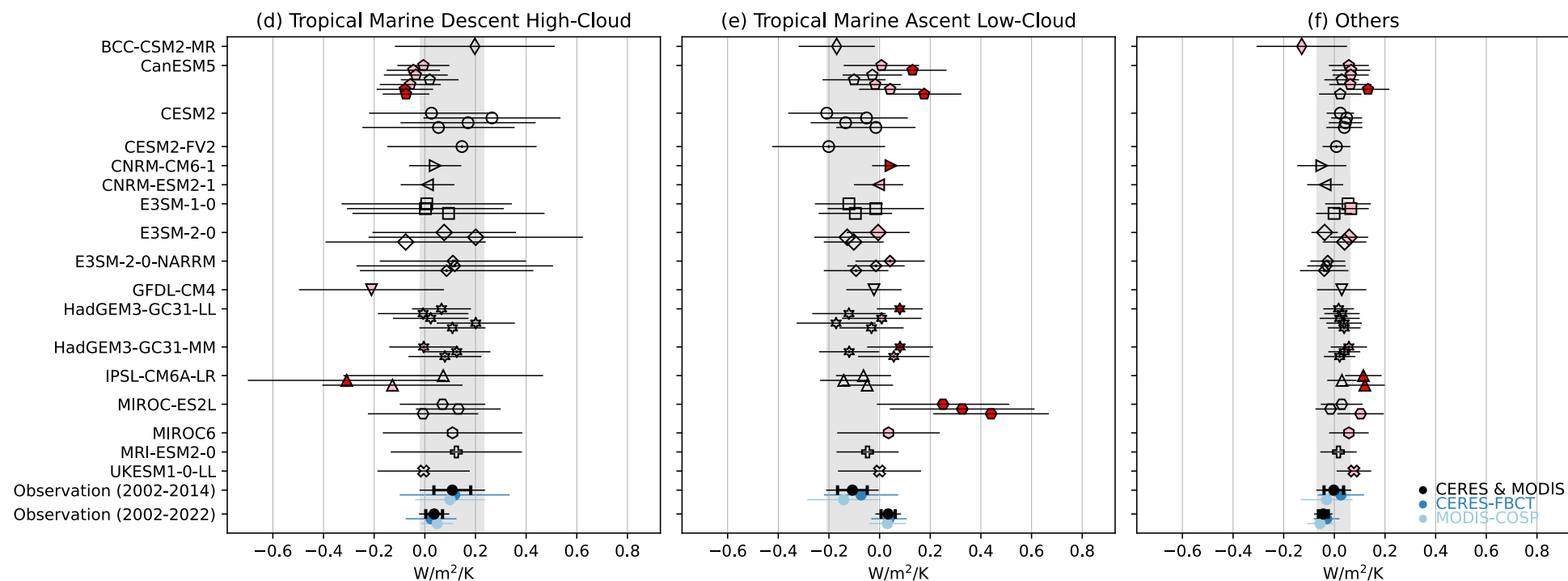
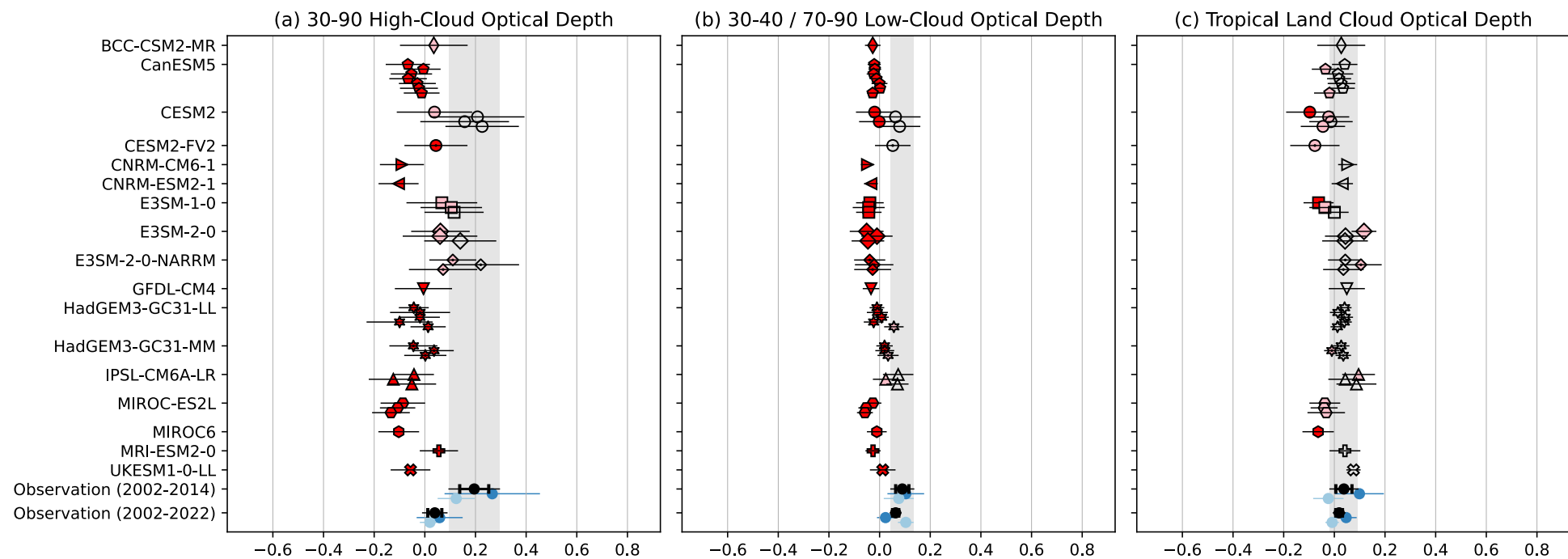
# Tropical anvil cloud

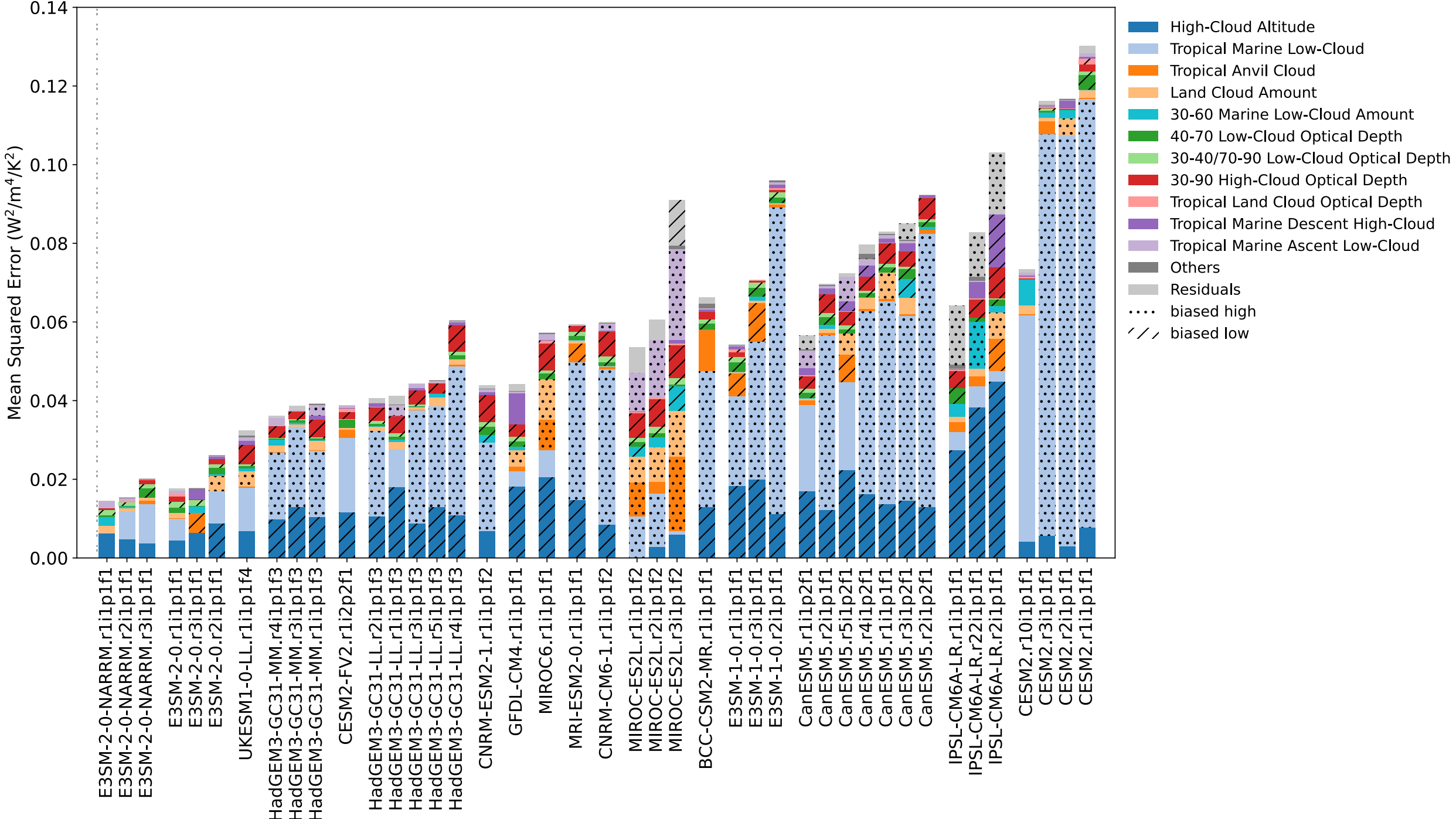


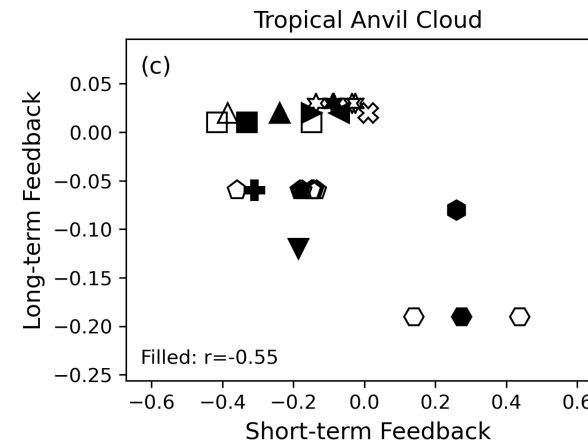
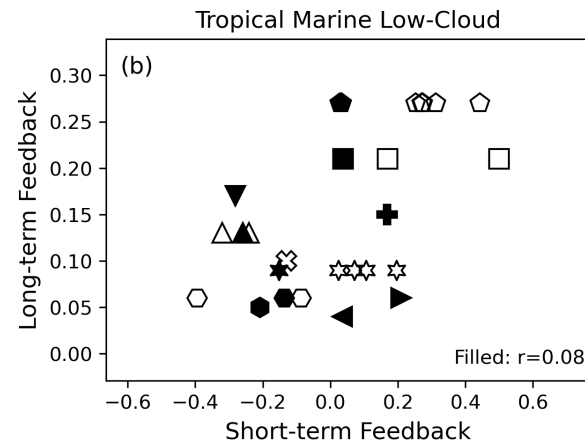
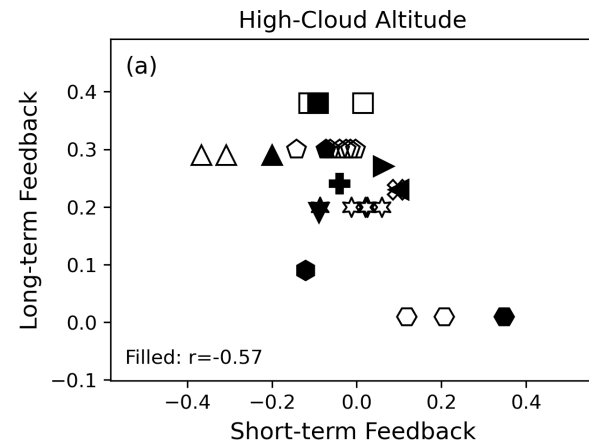
- Less negative than suggested in Sherwood et al. (2020)
- No systematic bias



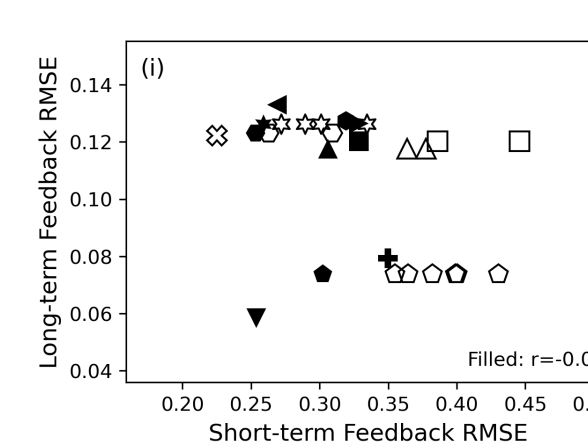
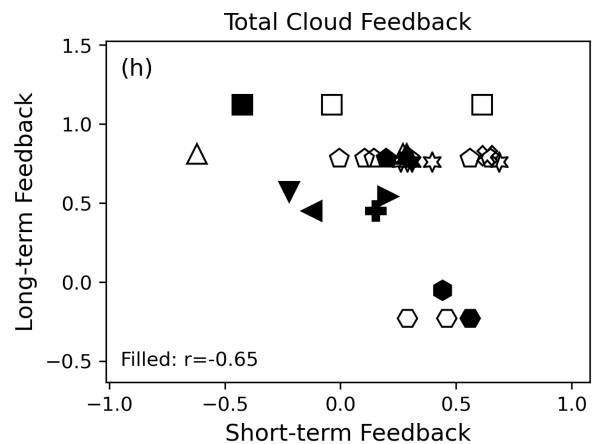
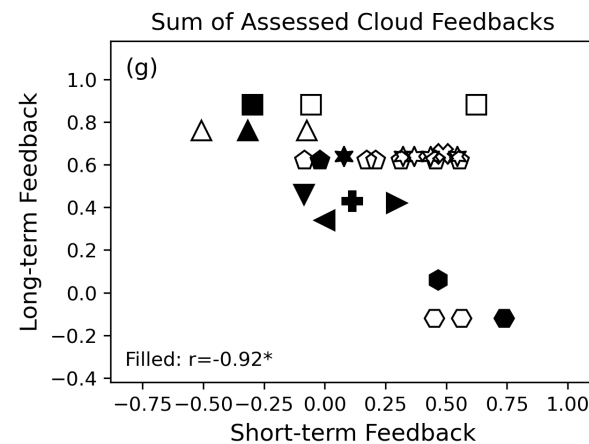
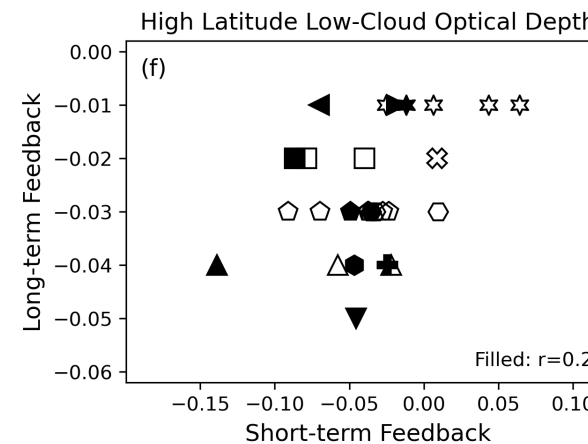
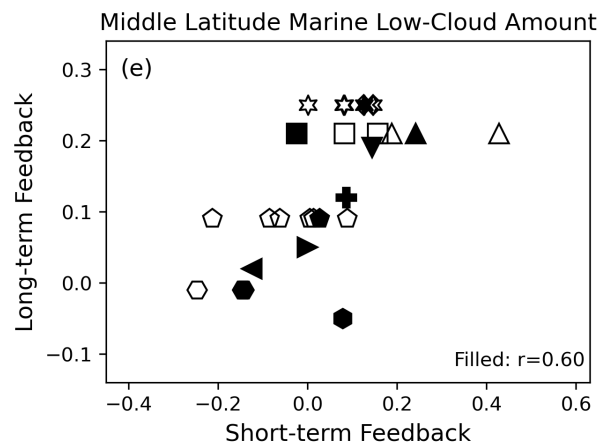
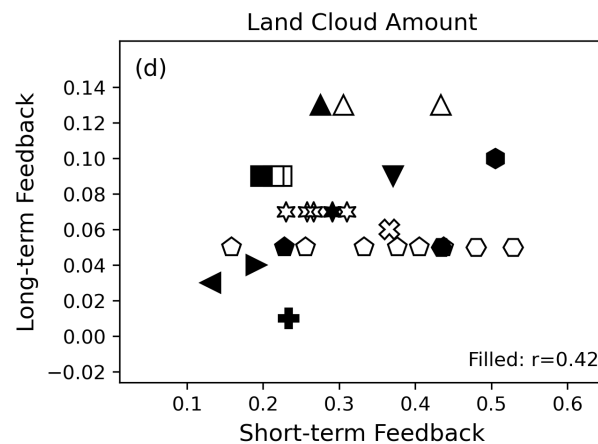






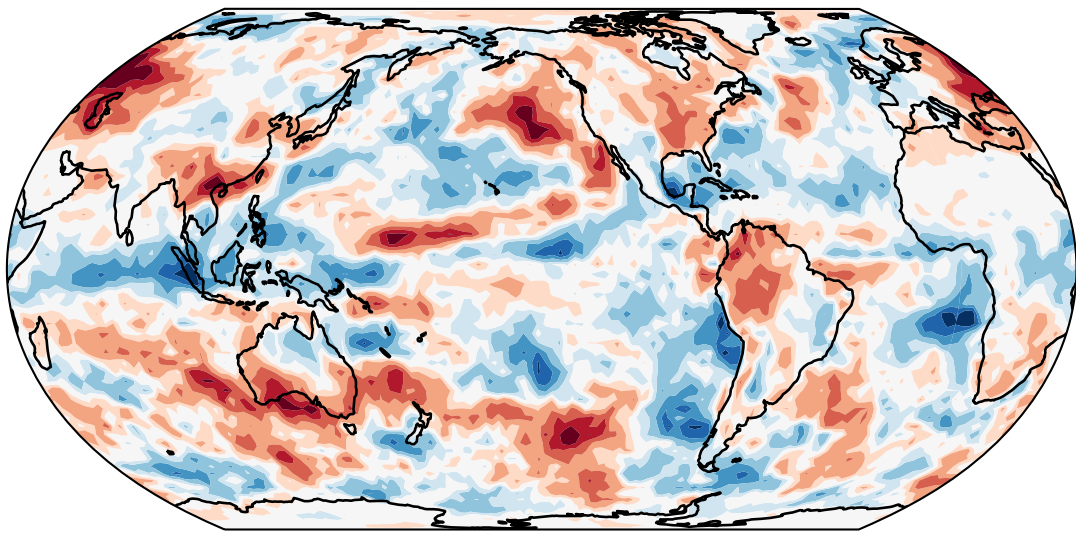


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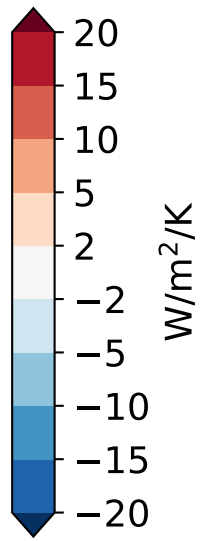
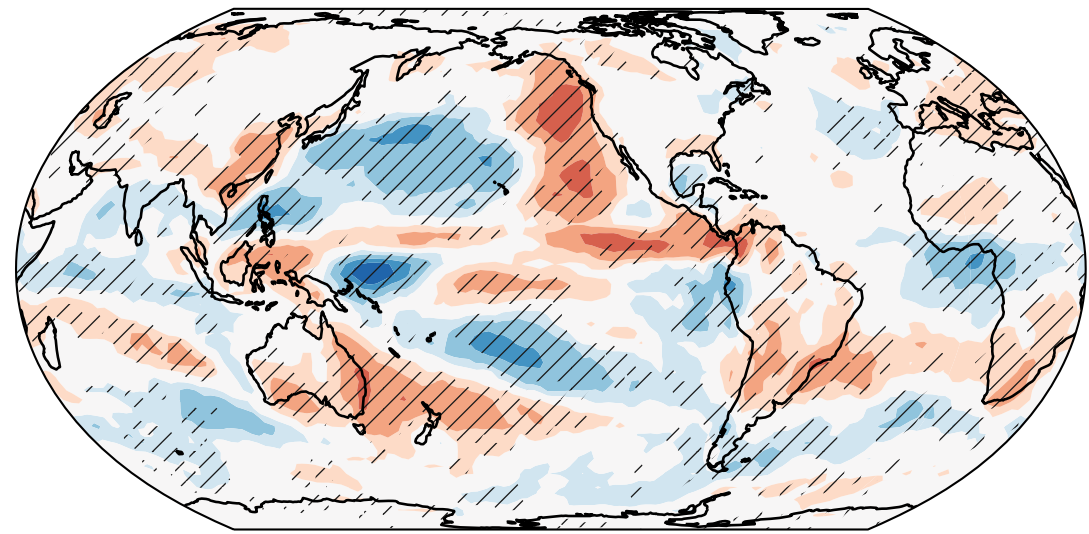


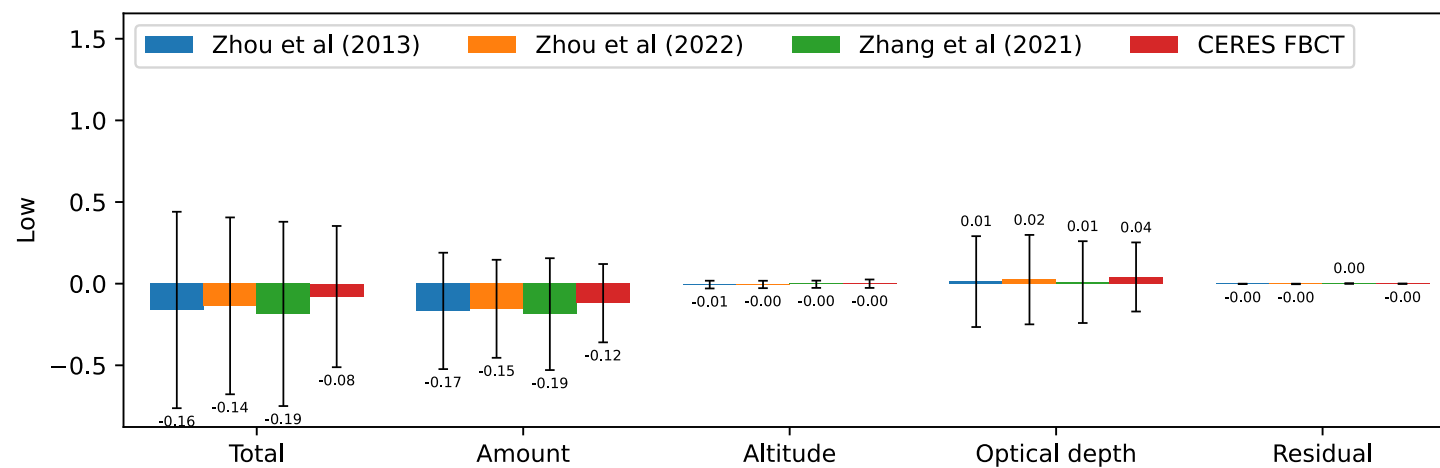
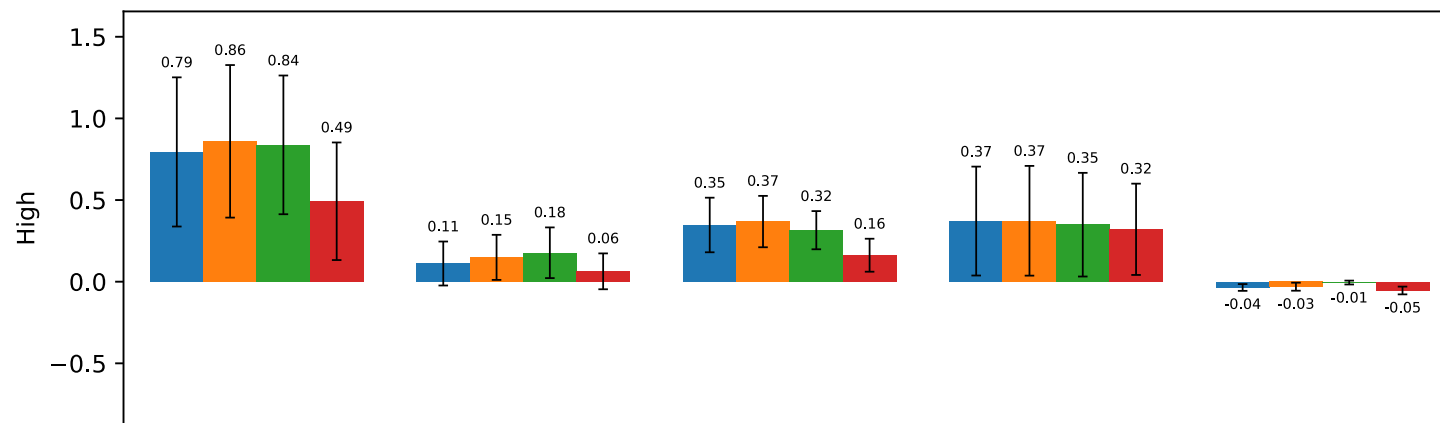
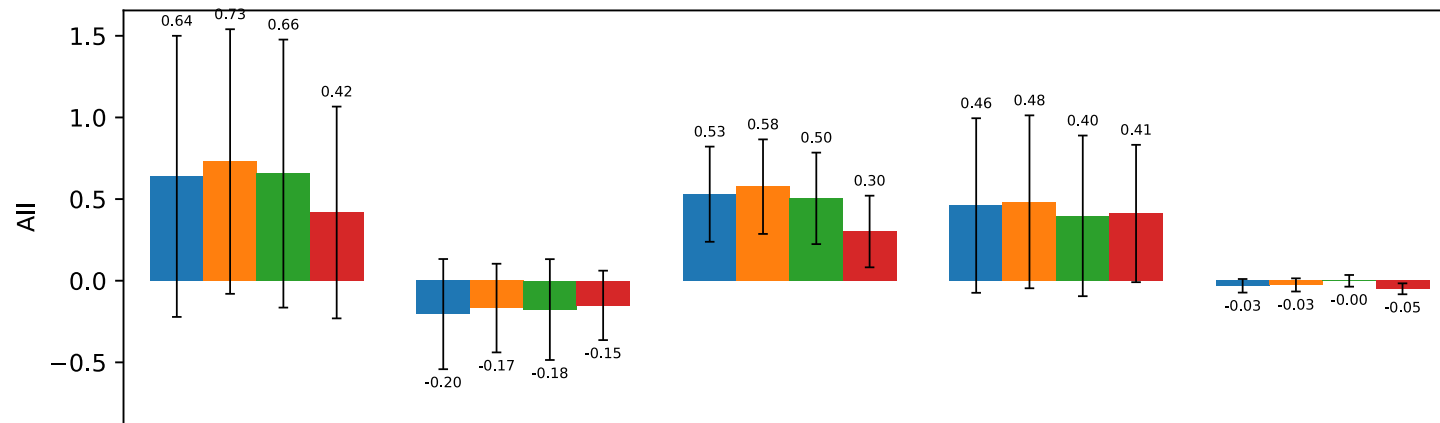


Observations  
(a) Total Cloud Feedback

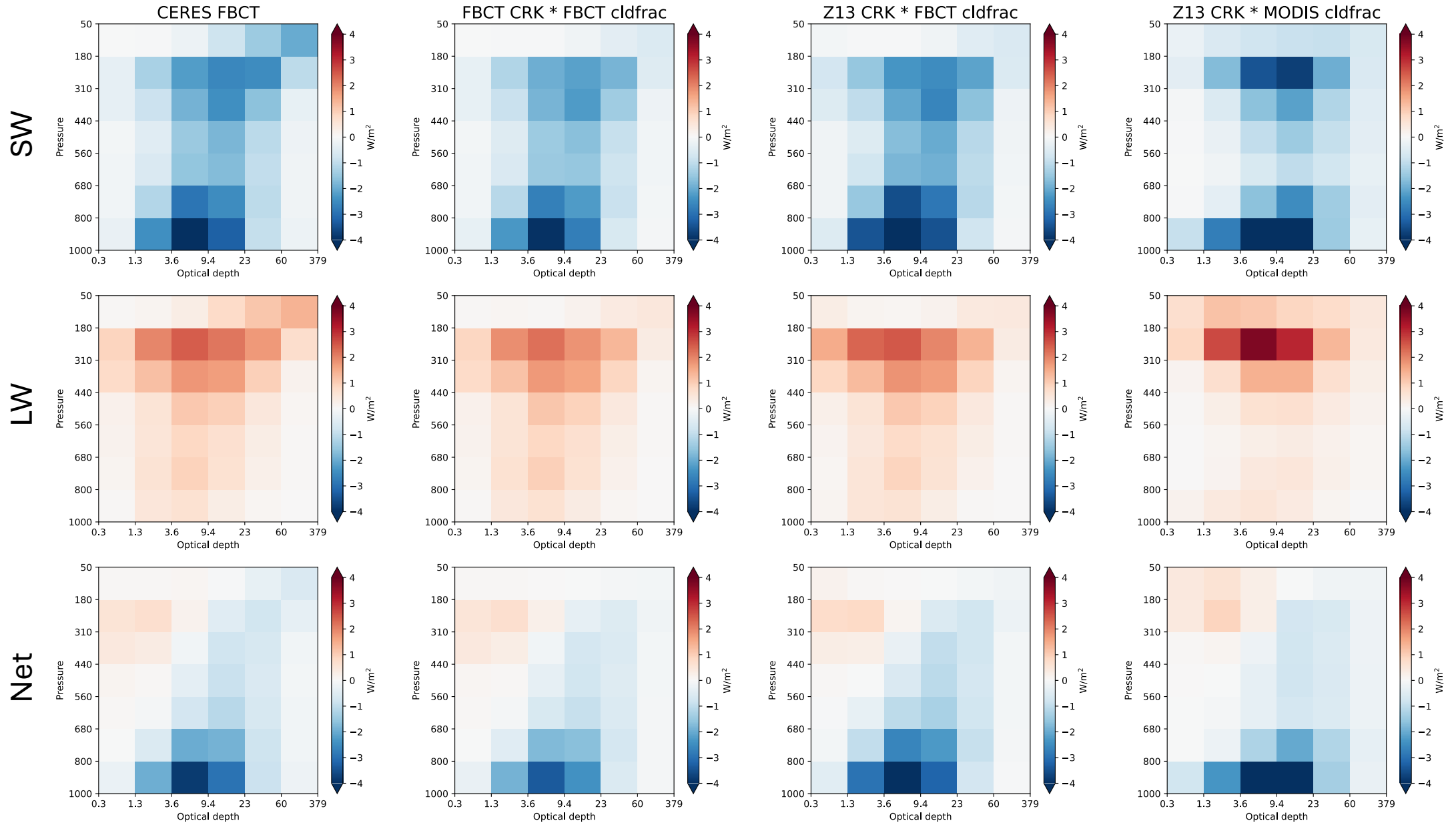


CMIP6 Mean  
(b) Total Cloud Feedback





# Comparison of p-tau distribution (near-global average, SZA<82°)



# Comparison of CRE anomaly

- CERES EBAF and FBCT are consistent in general; CRE inferred directly from FBCT and from FBCT CRK\*cldfrac have good agreement
- Kernels from radiative transfer models tend to overestimate the mean-state SW CRE but **underestimate the trend of CRE anomaly**
- Among different CRK methods, the mean-state LW CRE is consistent, but **the anomaly of LW CRE shows larger deviations; vice versa for SW CRE**

