

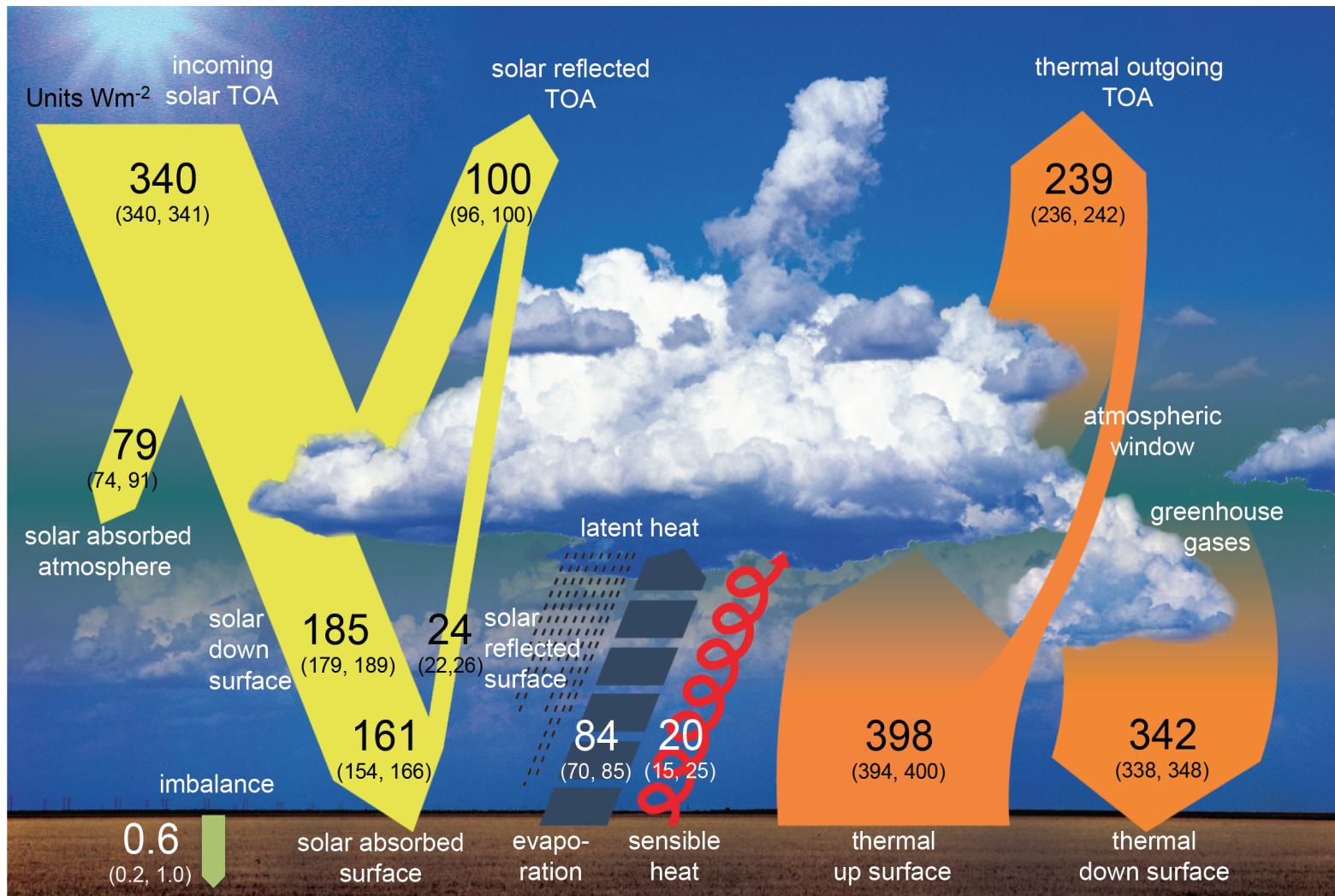
The surface radiation budget and its representation in CMIP5 models

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Global Mean Energy Balance

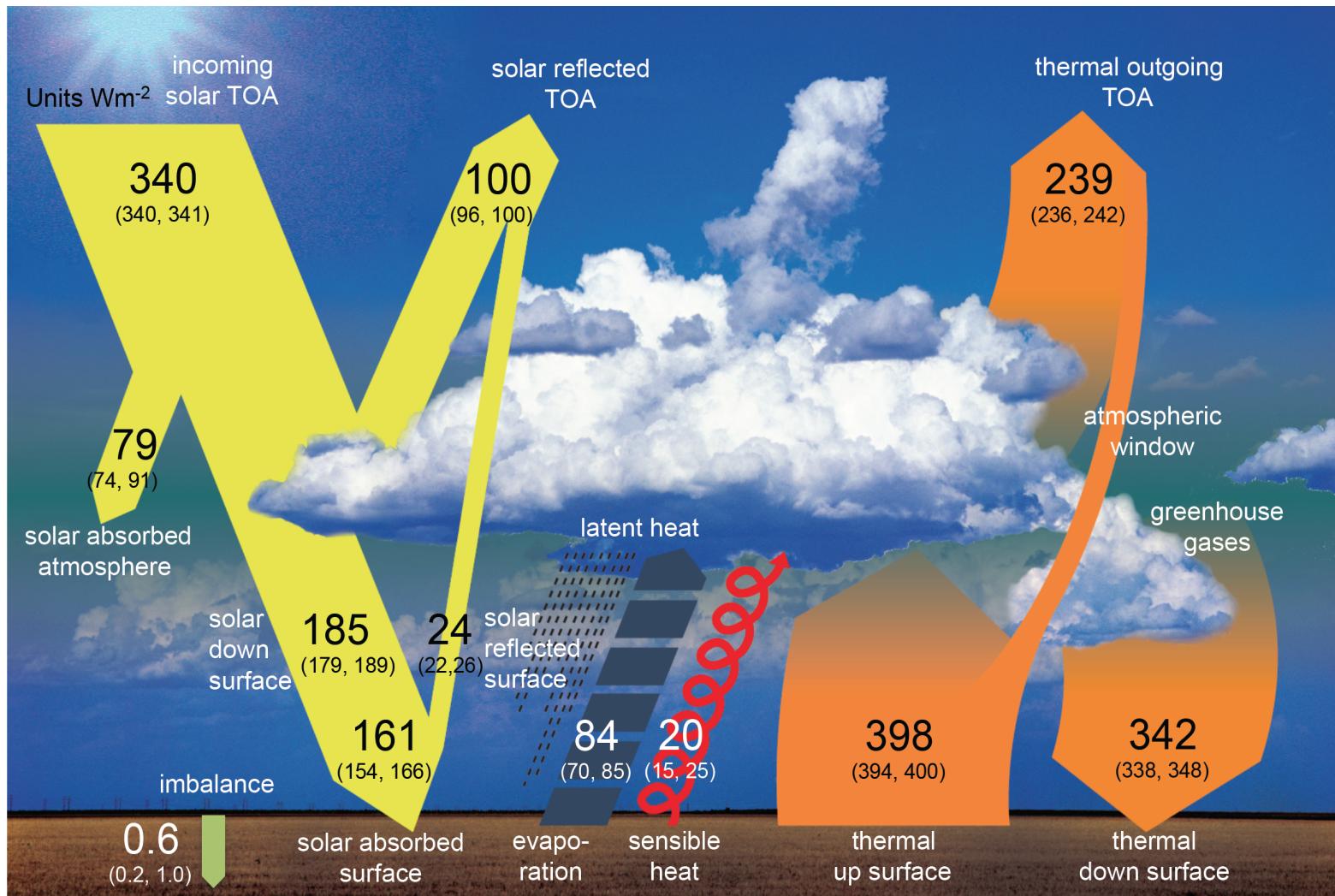
Units Wm⁻²



Global Mean Energy Balance

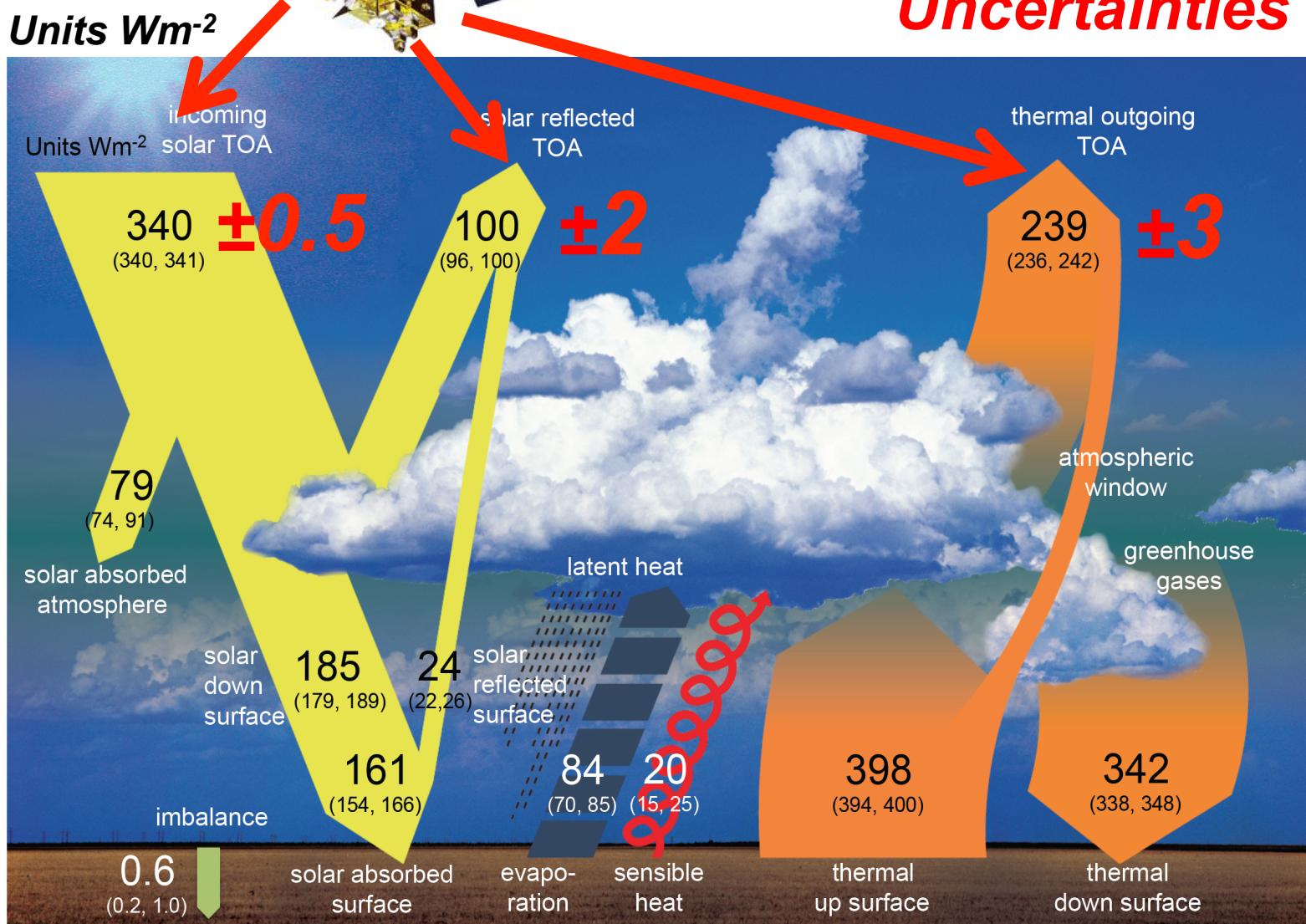
Units Wm⁻²

Uncertainties



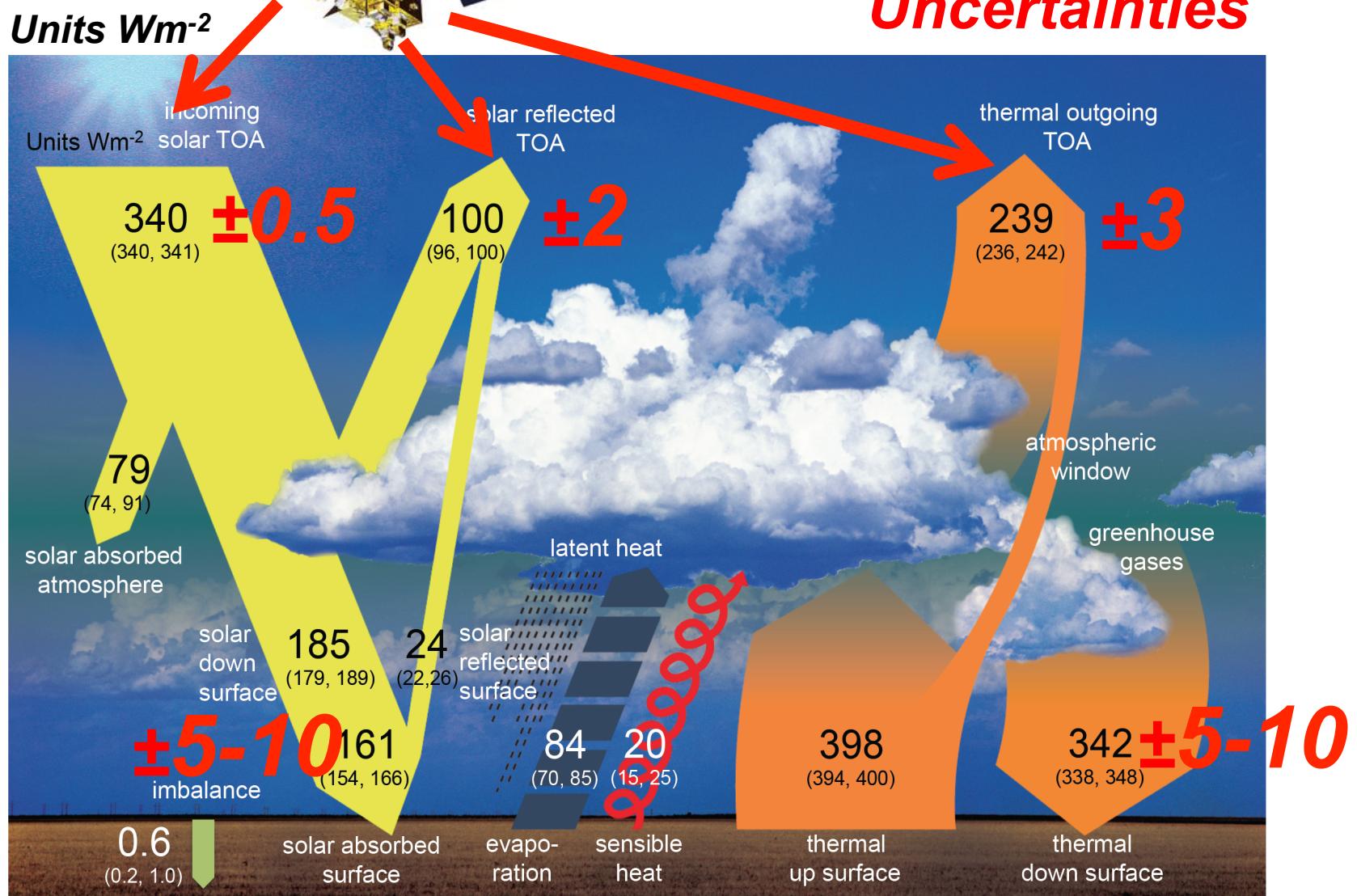
Satellite missions
CERES
SORCE

Energy Balance



Satellite missions
CERES
SORCE

Energy Balance

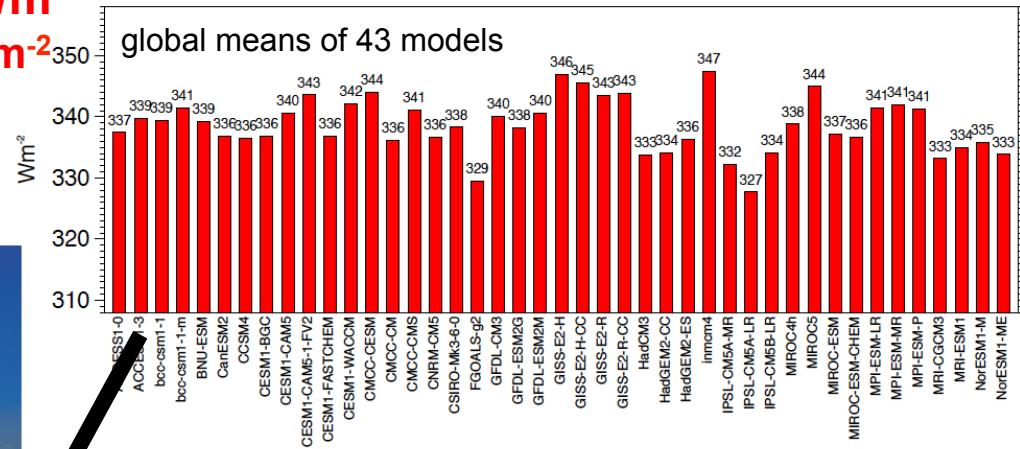
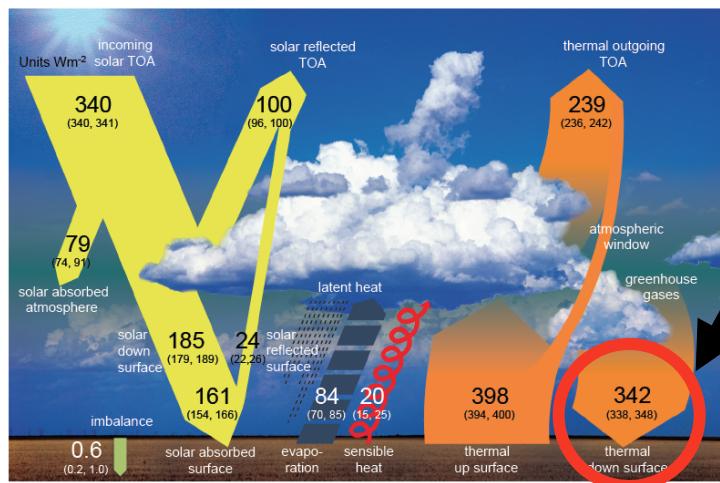


Surface radiation budget has larger uncertainties than TOA budget

Global mean surface energy balance in CMIP5 GCMs

Model mean **339 Wm⁻²**
Model range: **20 Wm⁻²**
Standard dev.: **4.4 Wm⁻²**

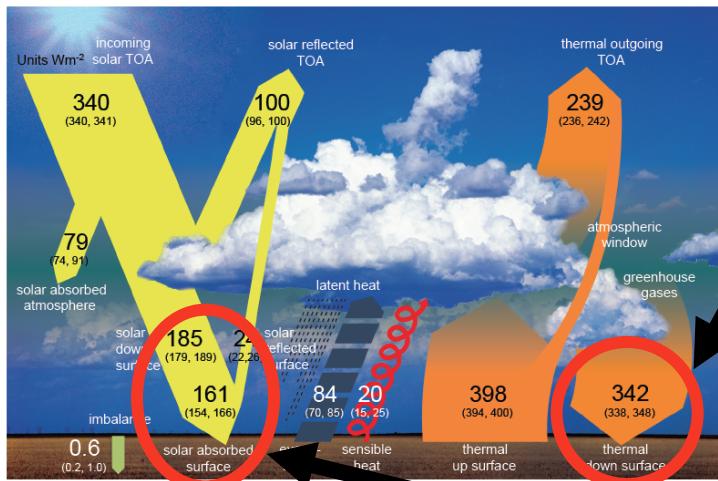
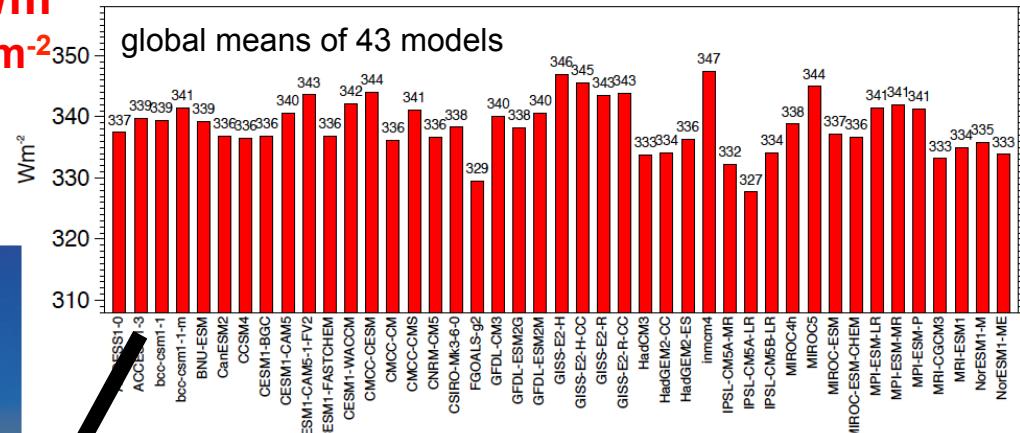
Downward longwave radiation
surface



Global mean surface energy balance in CMIP5 GCMs

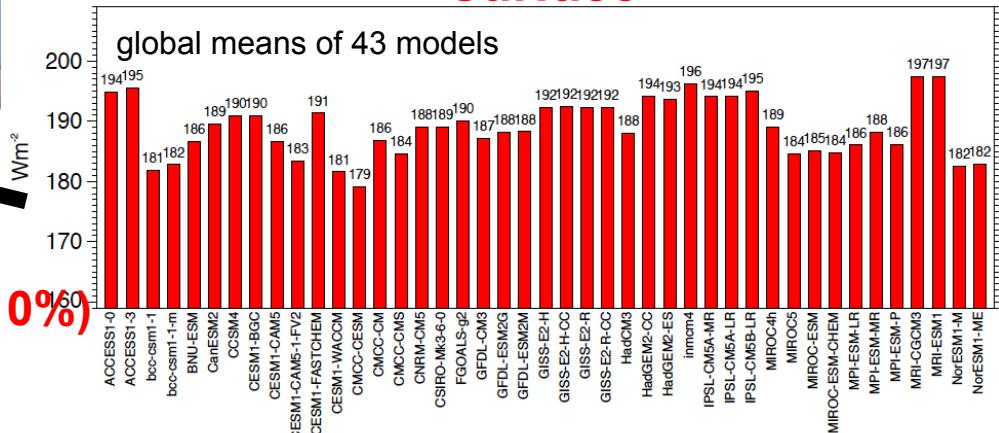
Model mean 339 Wm^{-2}
Model range: 20 Wm^{-2}
Standard dev.: 4.4 Wm^{-2}

Downward longwave radiation surface



Model mean: 189 Wm^{-2}
Model range: $18 \text{ Wm}^{-2} (10\%)$
Standard dev.: 4.7 Wm^{-2}

Downward shortwave radiation surface

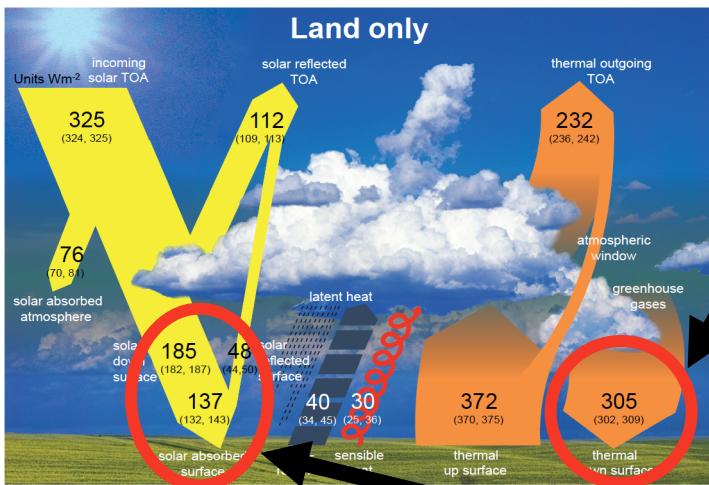


=> Large discrepancies in global mean downward radiative fluxes in CMIP5 models

Wild et al. 2013, Climate Dynamics

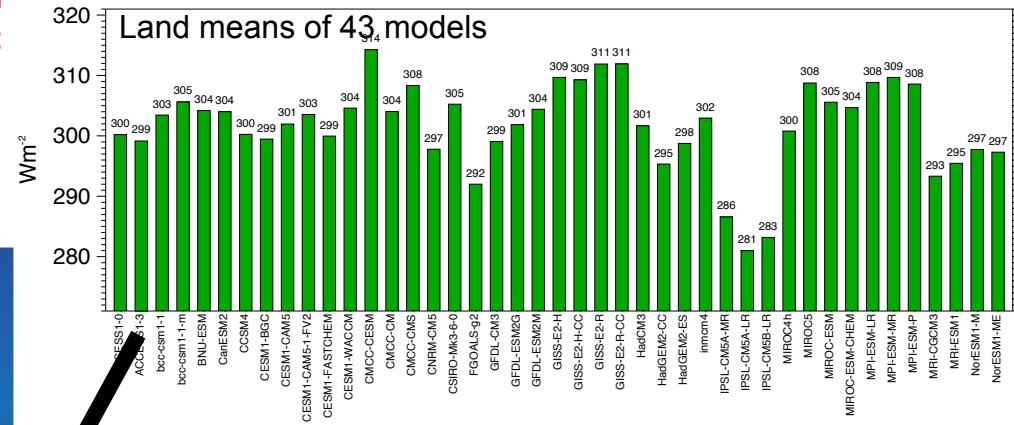
Land mean surface energy balance in CMIP5 GCMs

Model mean **302 Wm⁻²**
 Model range: **33 Wm⁻²**
 Standard dev.: **7.2 Wm⁻²**

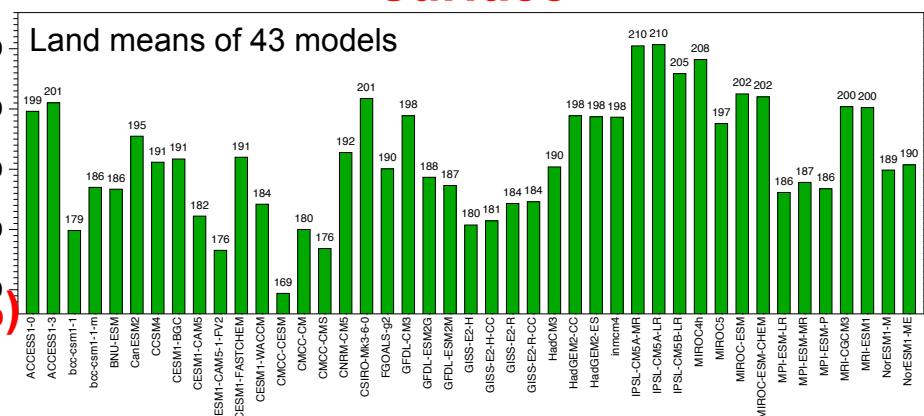


Model mean: **192 Wm⁻²**
 Model range: **42 Wm⁻² (22%)**
 Standard dev.: **10 Wm⁻²**

Downward longwave radiation surface

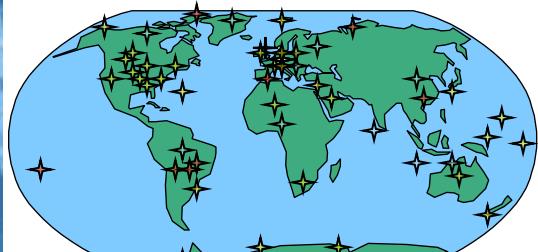


Downward shortwave radiation surface



=> **Particularly large discrepancies in land mean downward radiative fluxes in CMIP5 models**

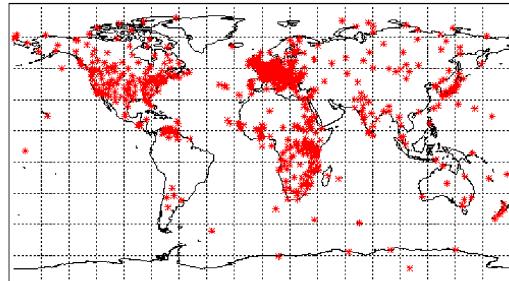
Constraints from surface observations



Ohmura et al. 1998



BSRN site Payerne



Ohmura, Gilgen, Wild 1989

BSRN Baseline Surface Radiation Network

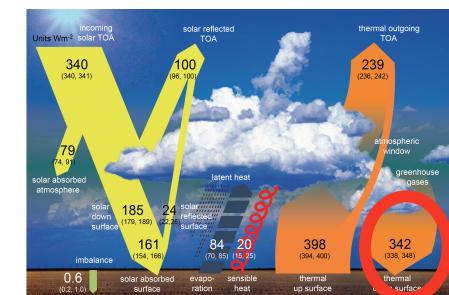
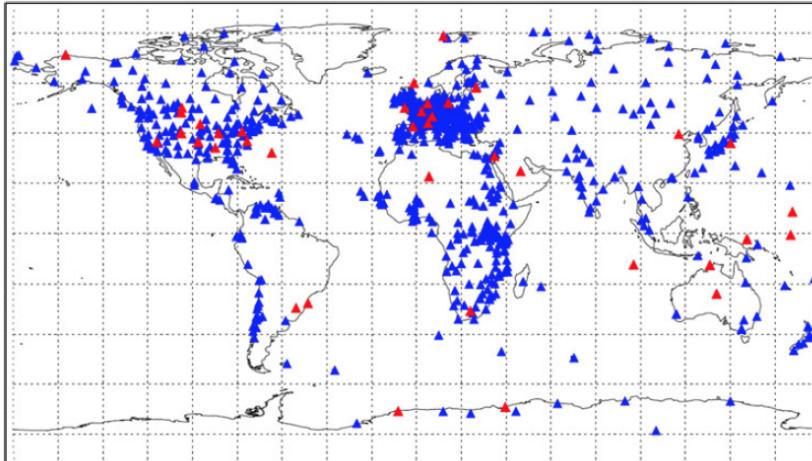
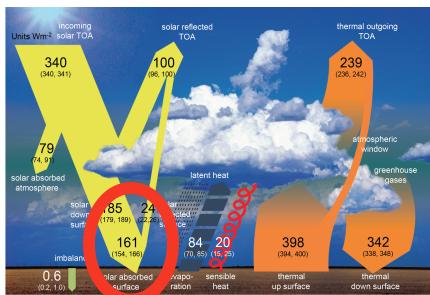
- WCRP initiative, starting in 1992
- Highest measurement quality at selected sites worldwide (currently 51 anchor sites)
- Minute values
- Ancillary data for radiation interpretation

GEBA Global Energy Balance Archive

- Worldwide measurements of historic energy fluxes at the surface (2500 sites)
- Solar radiation data at many sites since 1950s, some back to 1930s
- Monthly mean values

Evaluation of CMIP5 surface radiation balance

Long-term observation sites from **GEBA** and **BSRN**

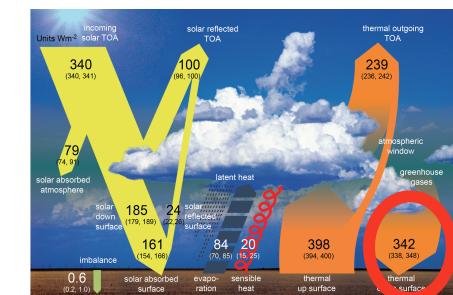
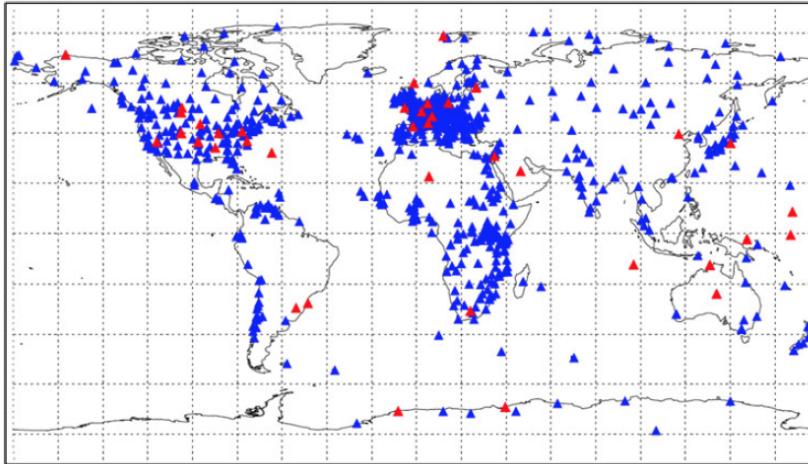
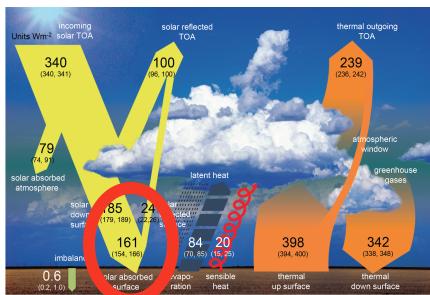


SW_{down} against 760 GEBA sites
42 BSRN sites

LW_{down} against 41 BSRN sites

Evaluation of CMIP5 surface radiation balance

Long-term observation sites from **GEBA** and **BSRN**



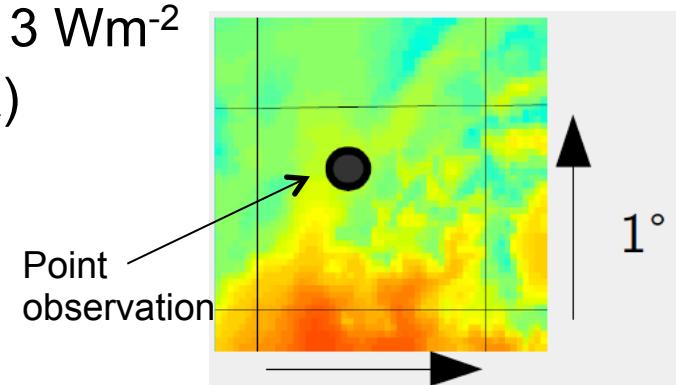
SW_{down} against 760 GEBA sites
42 BSRN sites

LW_{down} against 41 BSRN sites

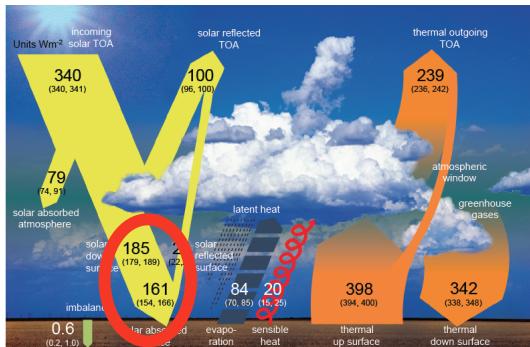
Using point observations to assess gridded datasets:

Estimated error due to subgrid variability $\sim 3 \text{ Wm}^{-2}$
at individual sites (Hakuba et al. 2013 JGR)

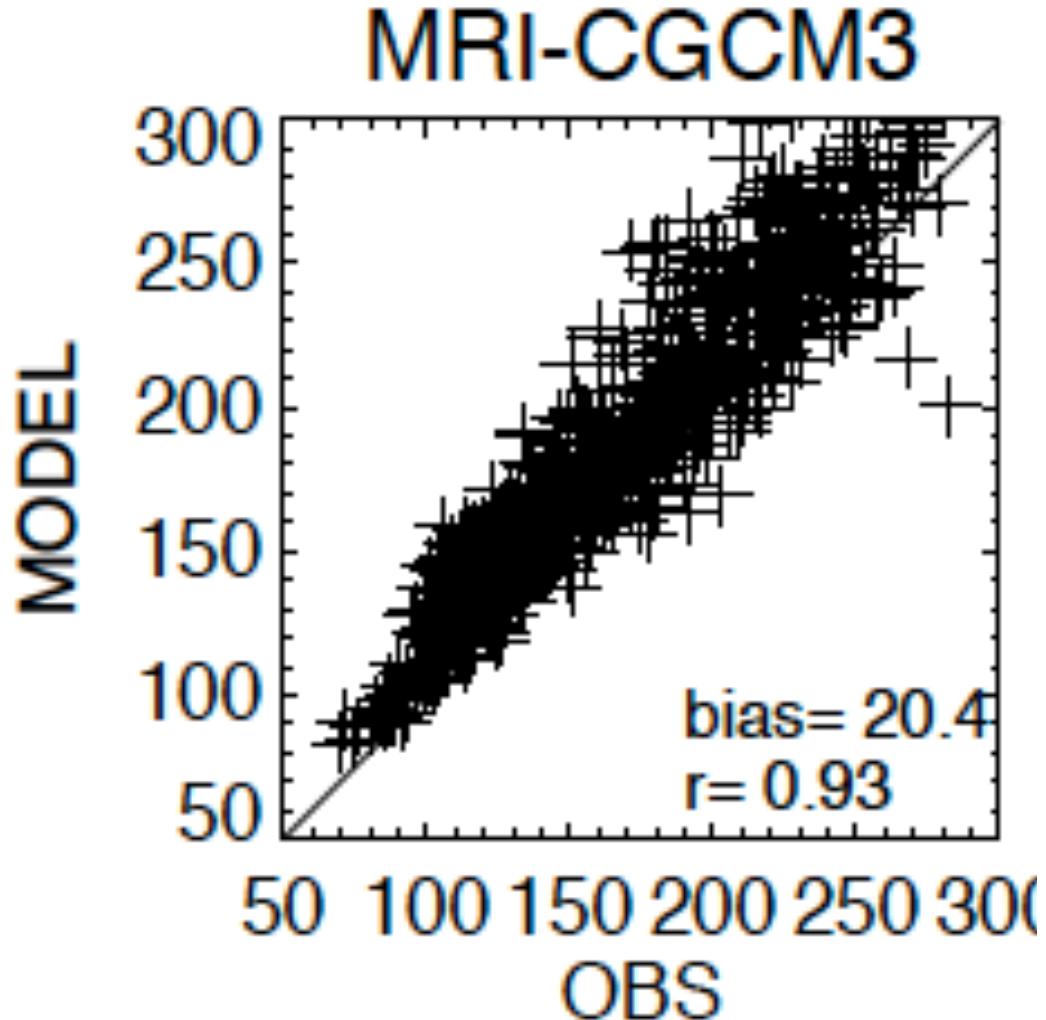
=> Poster 146 tonight



Evaluation of CMIP5 surface radiation balance

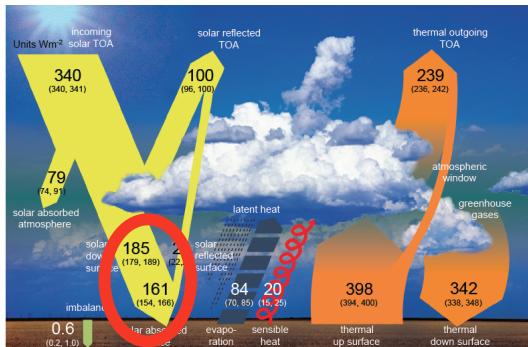


SW down
760 **GEBA sites**

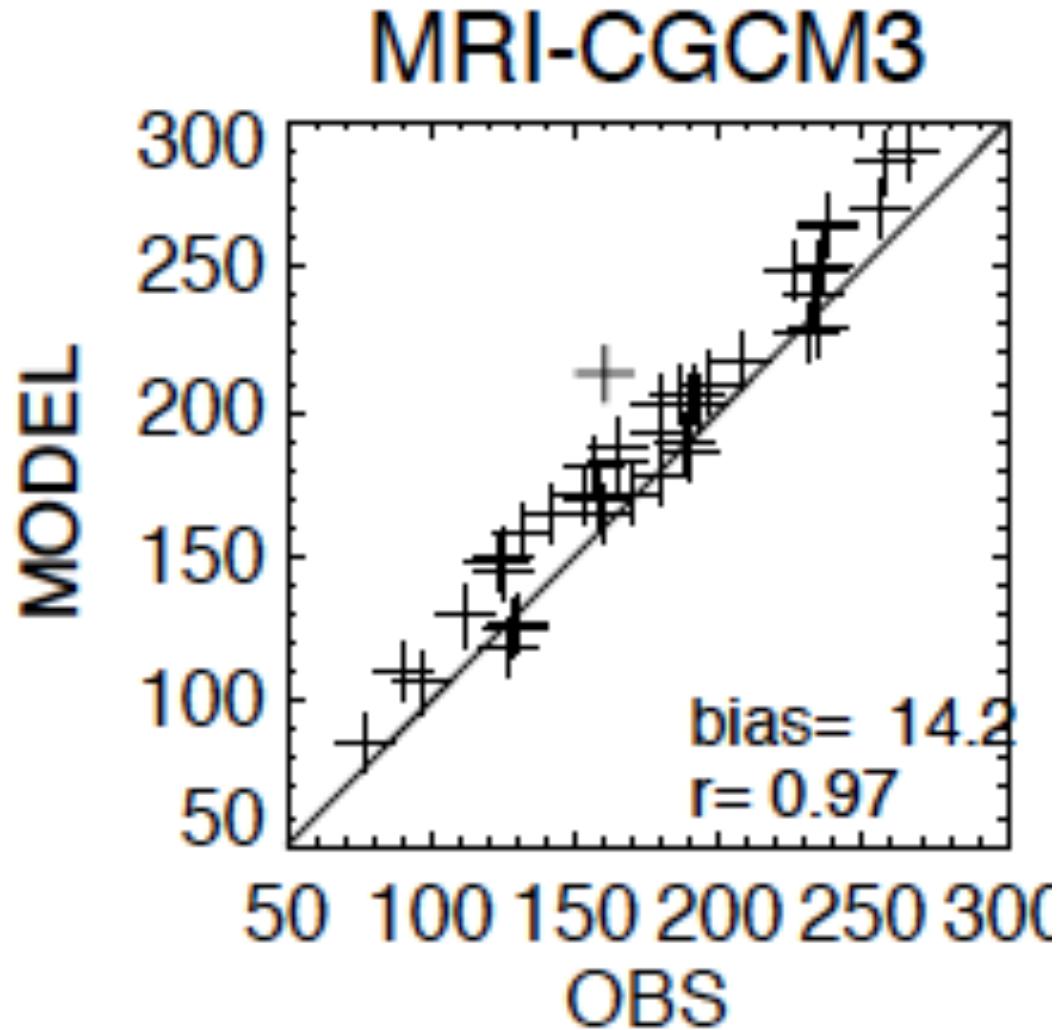


**Constraining surface fluxes with GEBA obs:
Most models overestimate surface SW down**

Evaluation of CMIP5 surface radiation balance

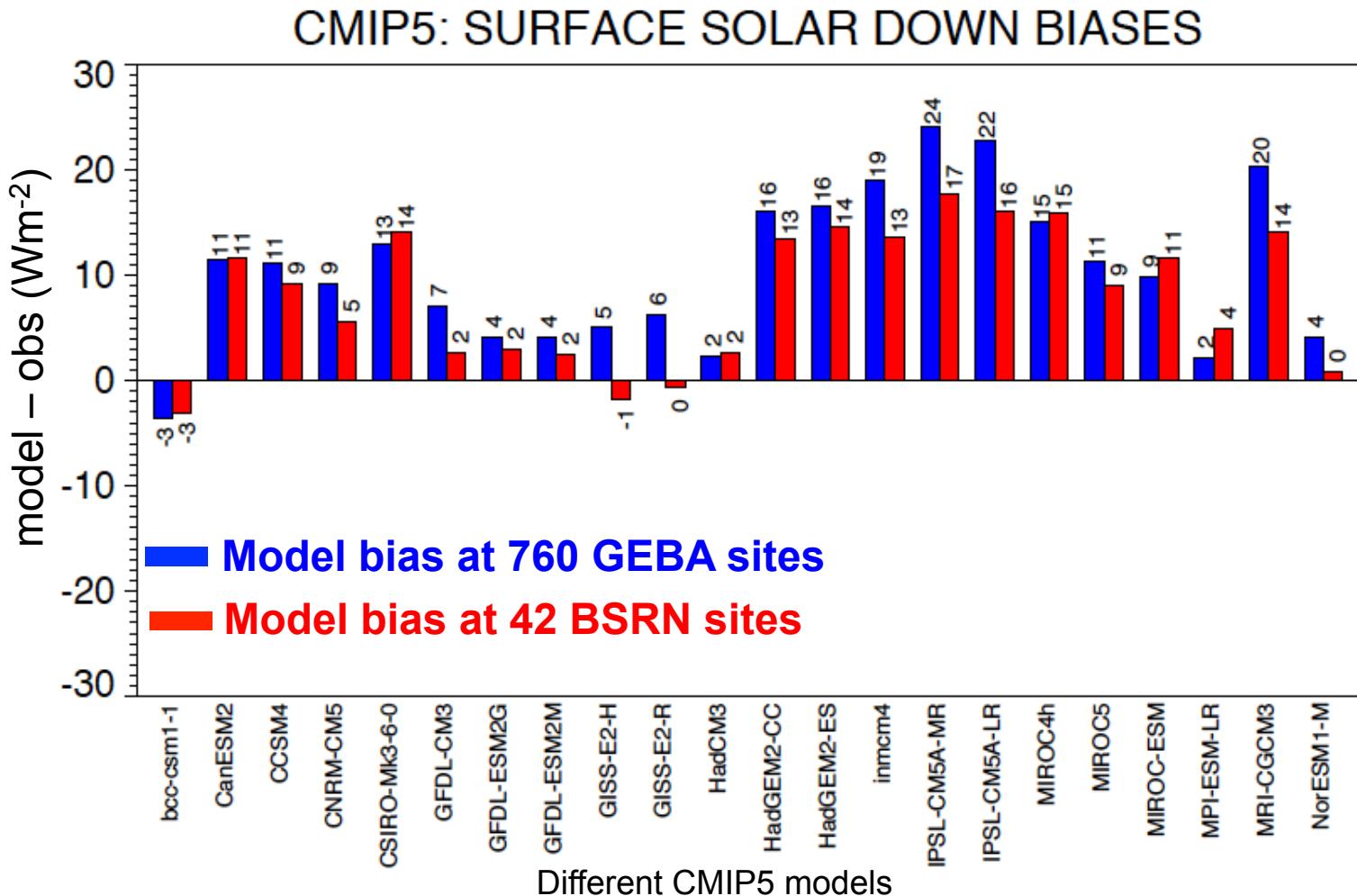


SW down
42 **BSRN** sites



Constraining surface fluxes with **BSRN obs:
Most models overestimate surface SW down**

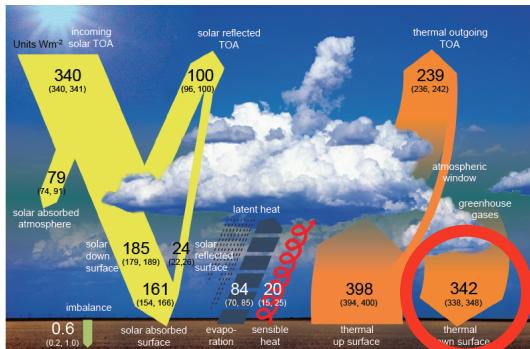
Evaluation of CMIP5 surface radiation balance



Multimodel mean bias SWdown at 760 GEBA sites: +10 W m^{-2}

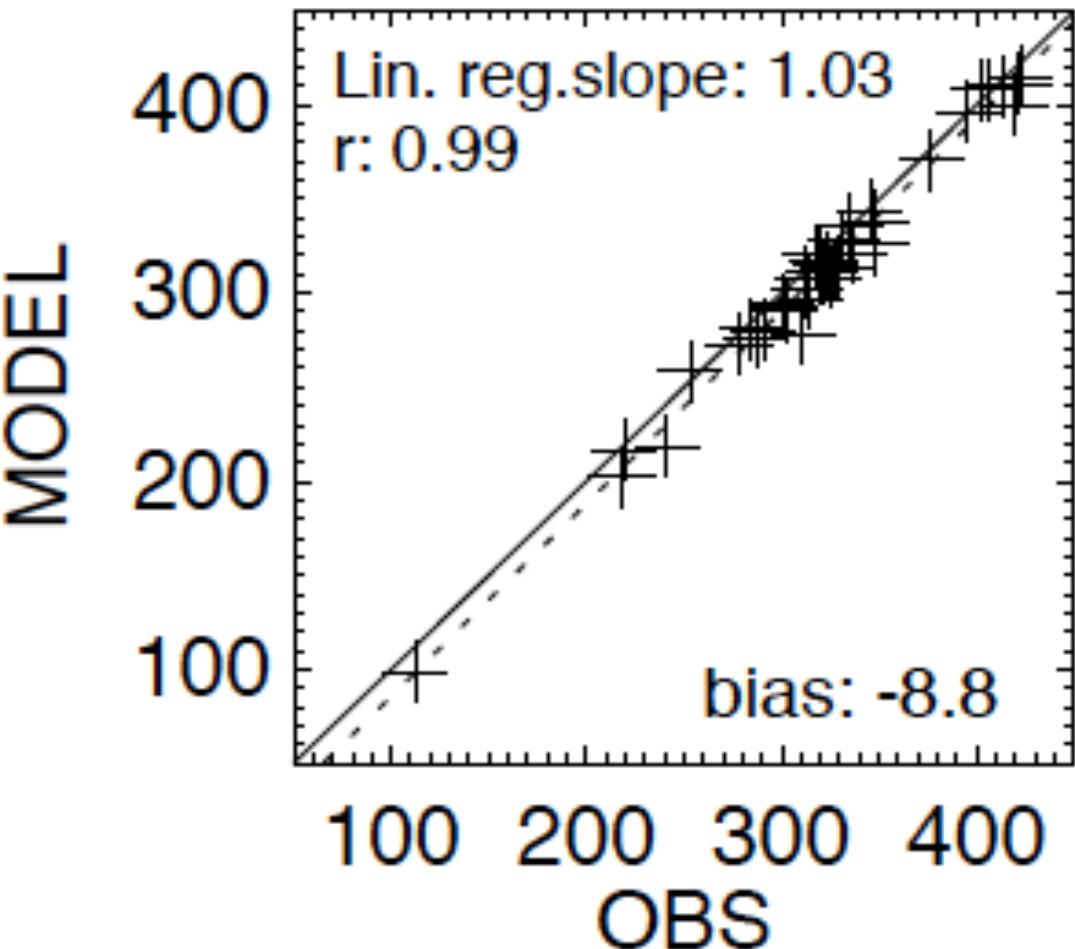
Multimodel mean bias SWdown at 42 BSRN sites: +8 W m^{-2}

Evaluation of CMIP5 surface radiation balance



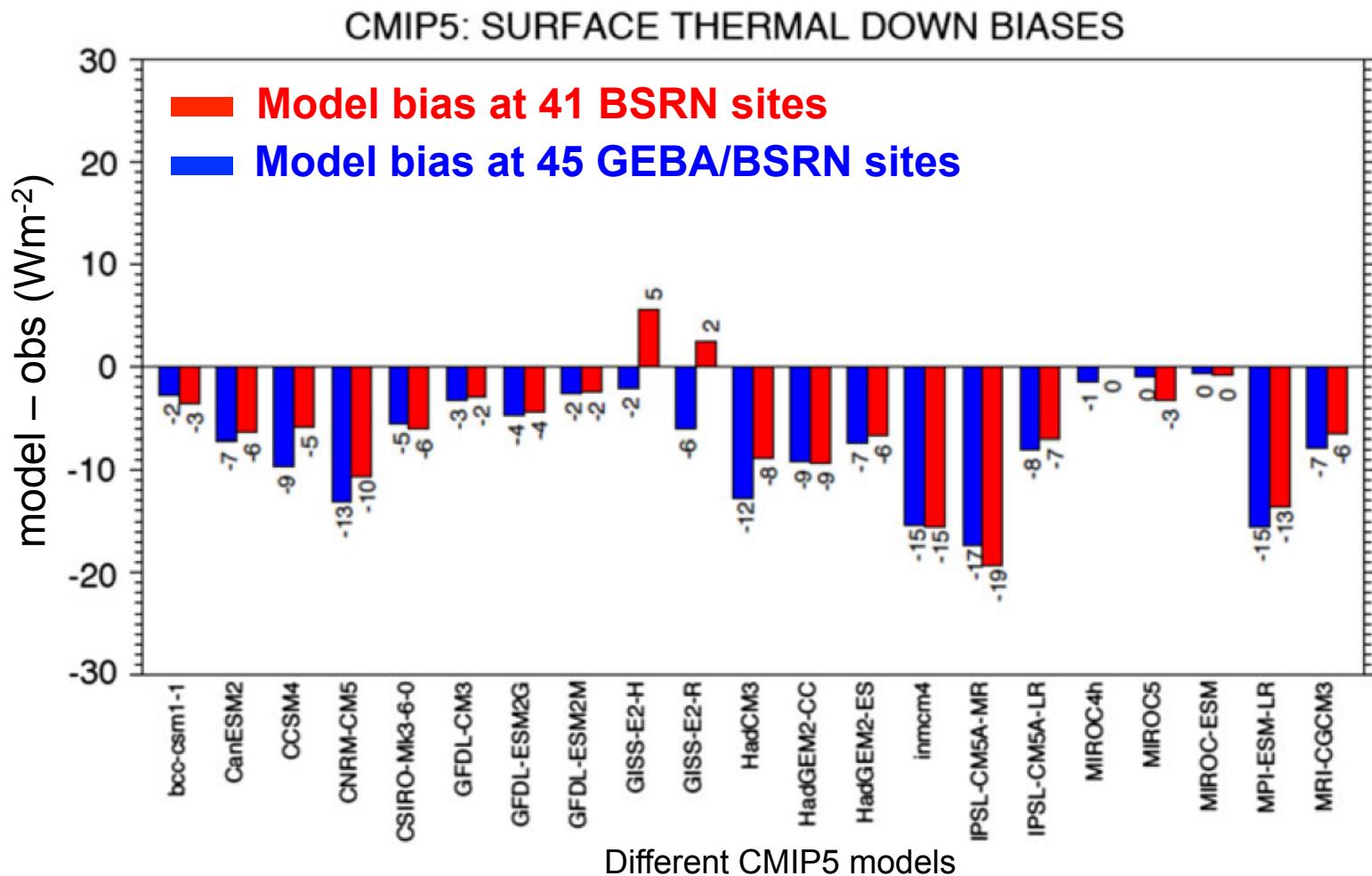
LW down
41 BSRN sites

HadCM3



**Constraining surface fluxes with BSRN observations:
CMIP5 models typically underestimate LW down**

Evaluation of CMIP5 surface radiation balance



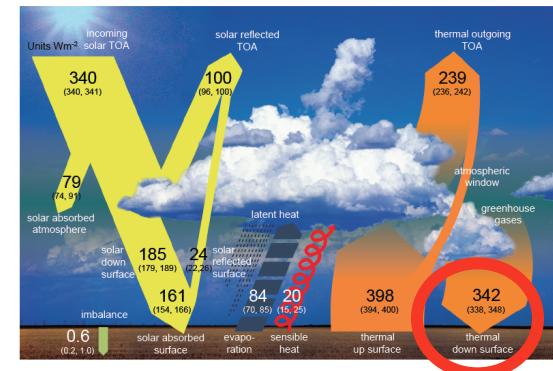
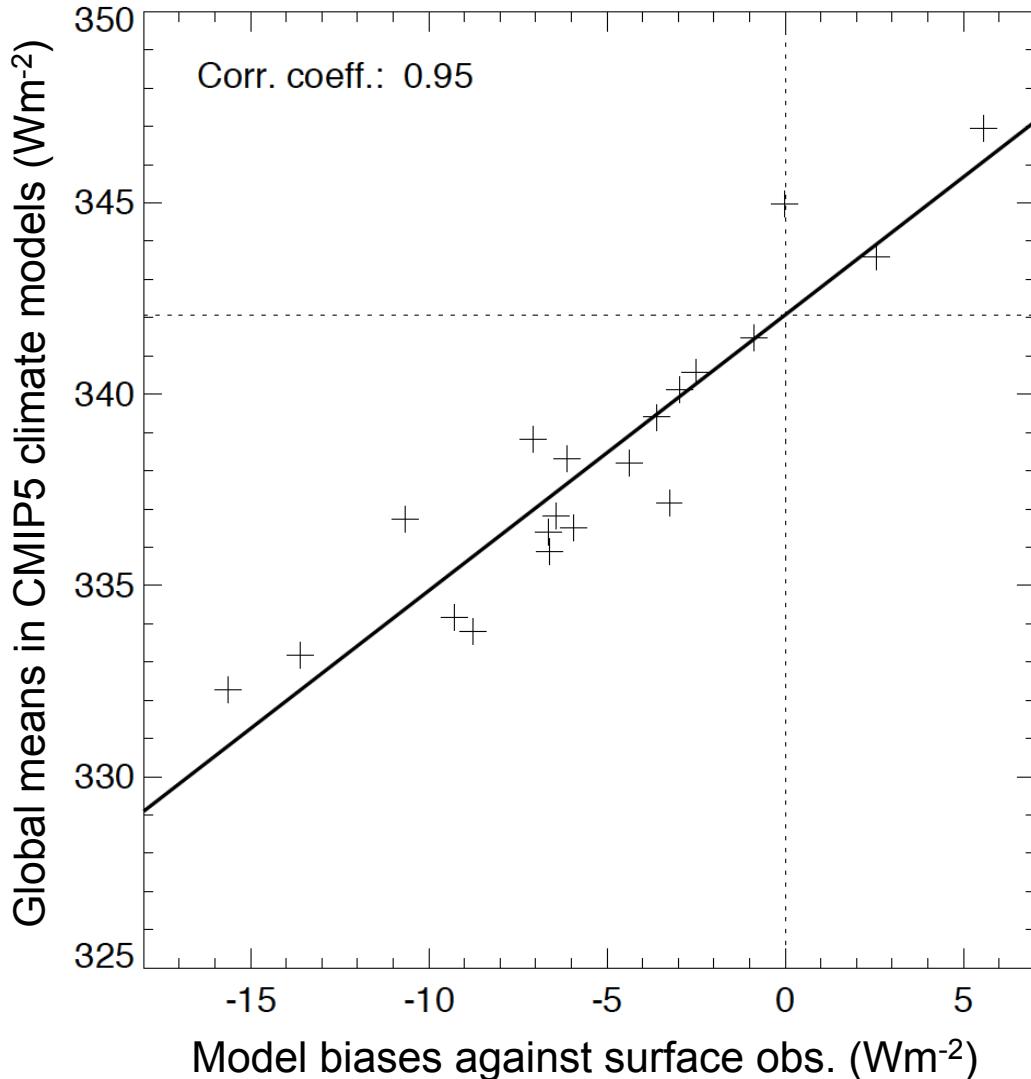
Multimodel mean bias LWdown at 41 BSRN sites: -6 W m^{-2}

Multimodel mean bias LWdown at 45 GEBA/BSRN sites: -7 W m^{-2}

Constraining LW surface fluxes in CMIP5 models

Surface LW down

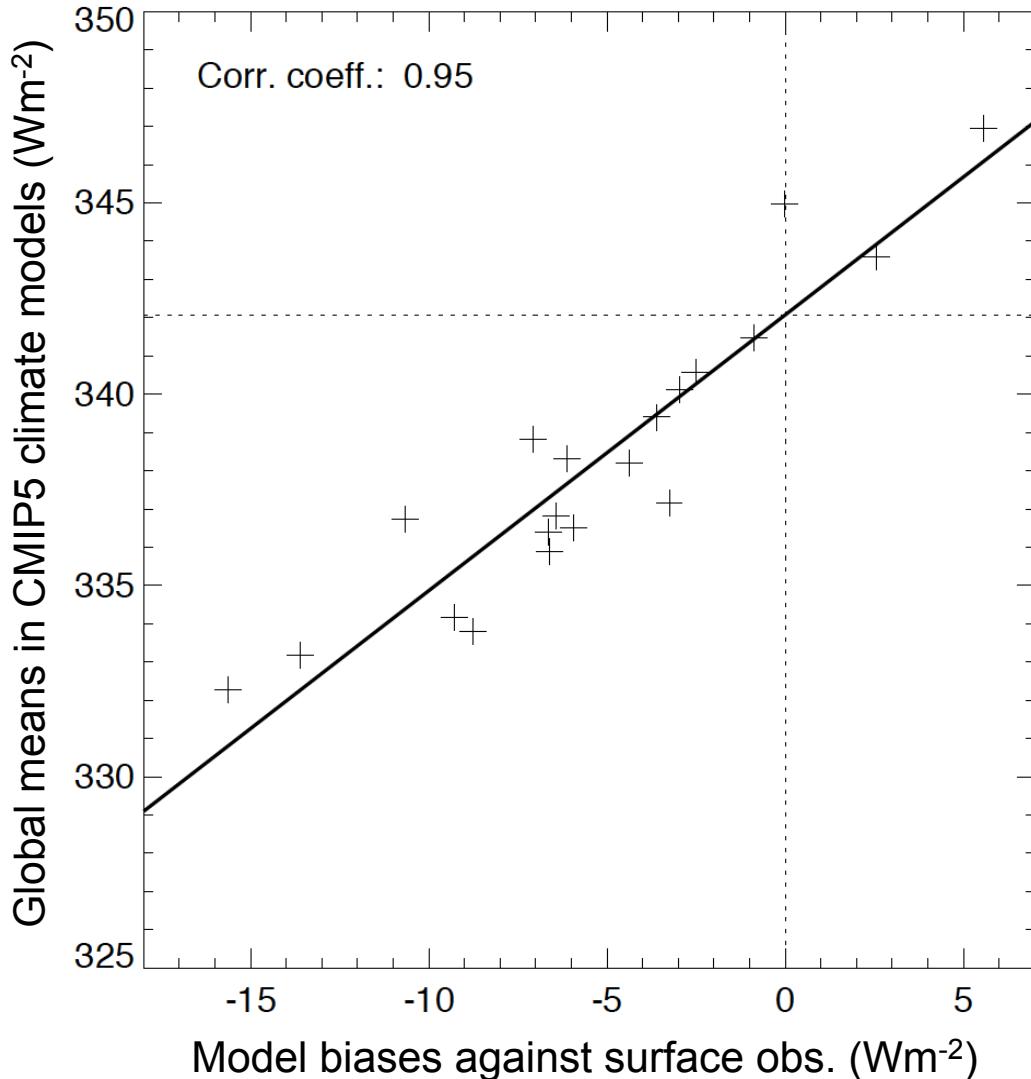
GCM global means versus their biases averaged over 41 BSRN sites



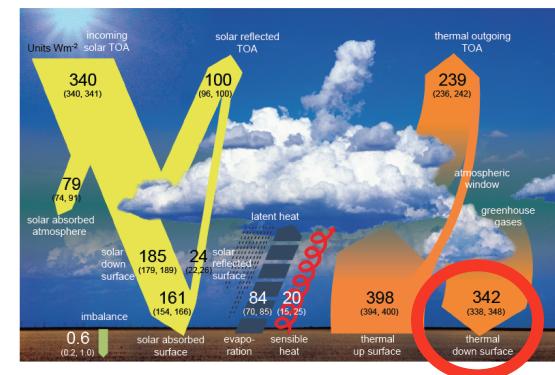
Constraining LW surface fluxes in CMIP5 models

Surface LW down

GCM global means versus their biases averaged over 41 BSRN sites



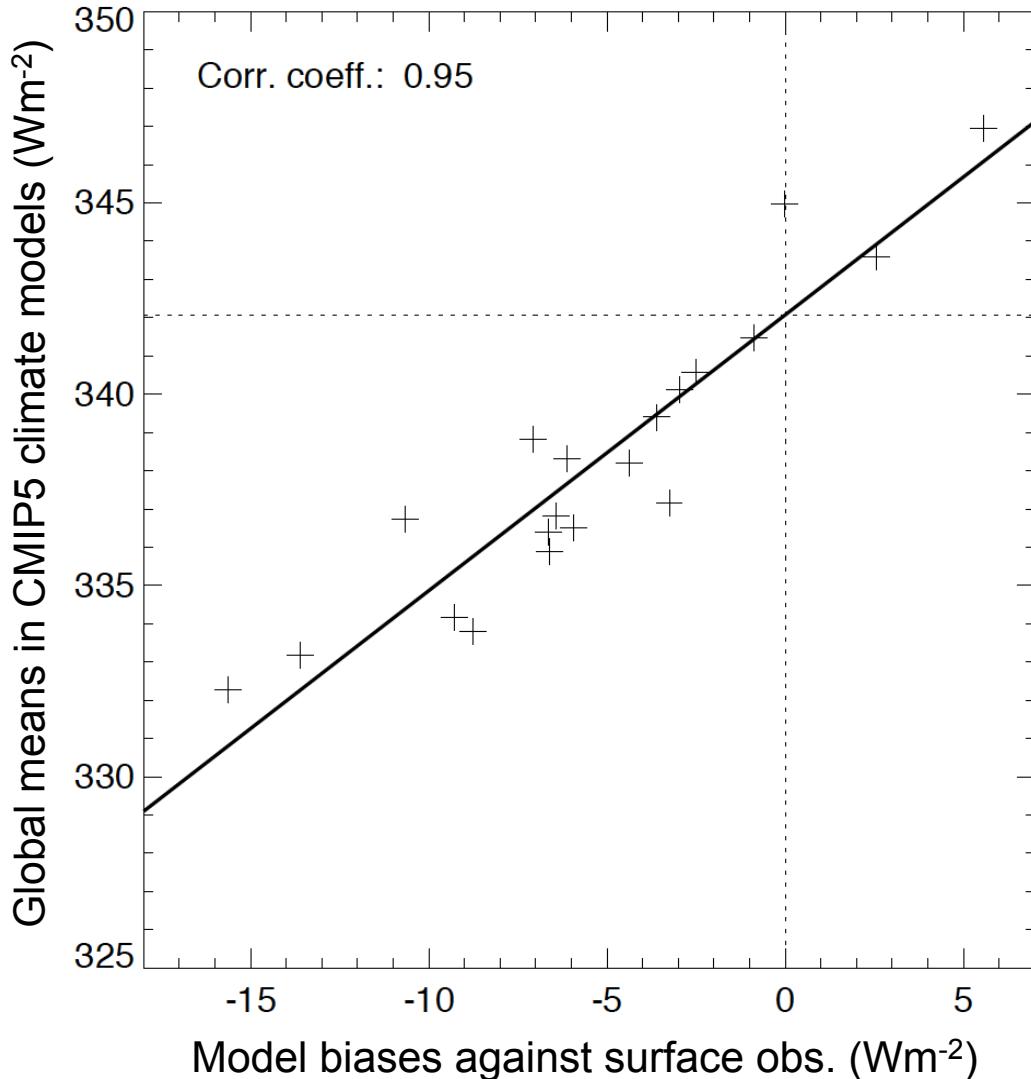
**Best estimate
surface LW down:**
342 Wm^{-2}



Constraining LW surface fluxes in CMIP5 models

Surface LW down

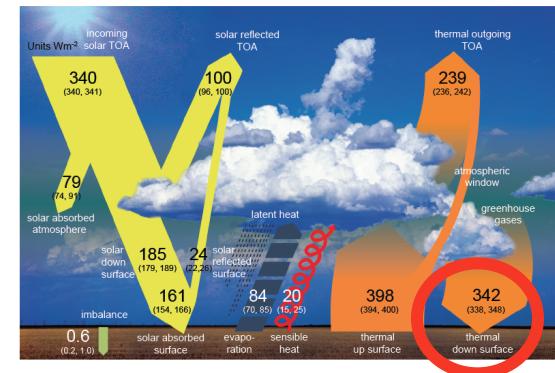
GCM global means versus their biases averaged over 41 BSRN sites



Best estimate surface LW down:
342 Wm^{-2}

c.f.

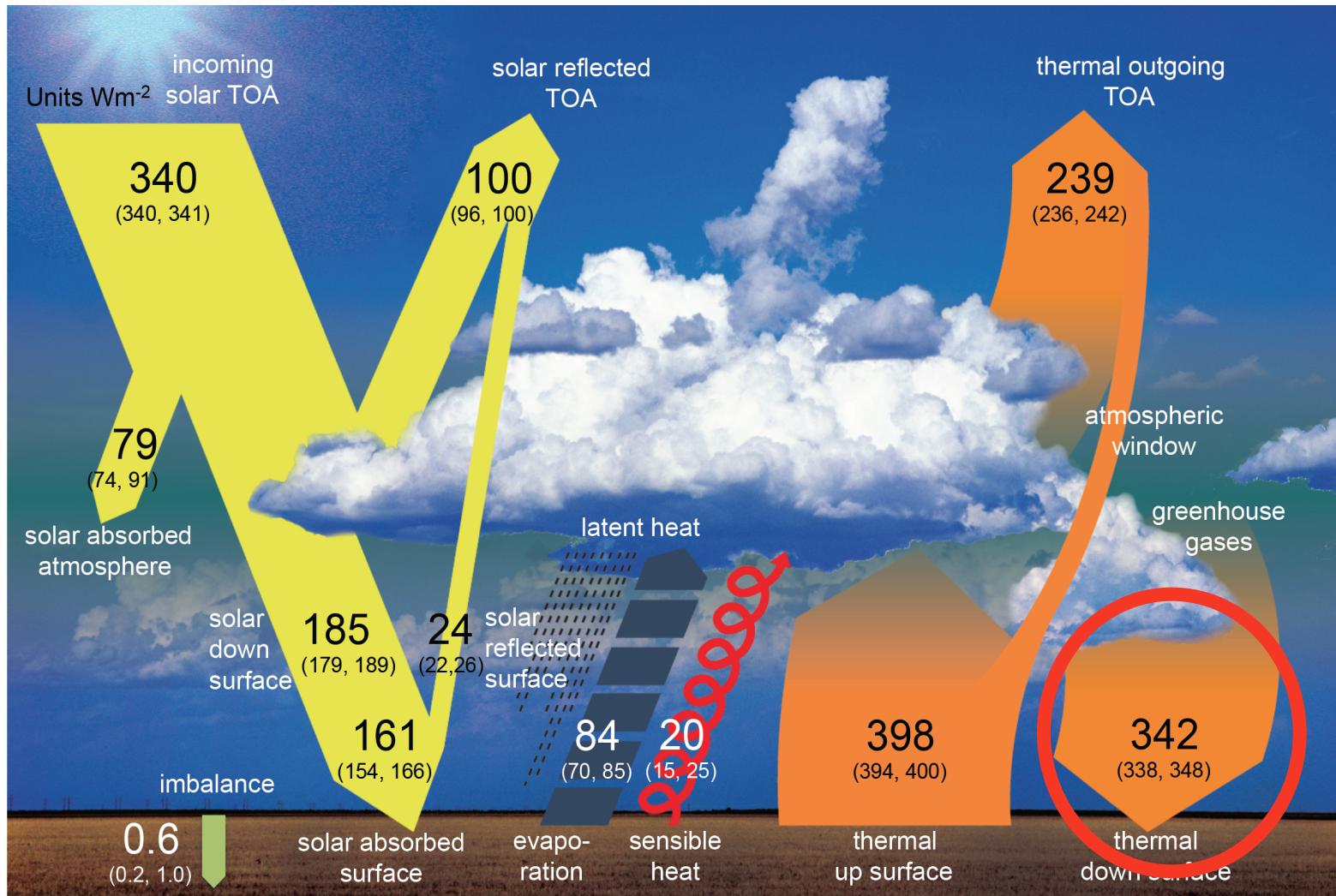
Kato et al. 2013: 344 Wm^{-2}
Stephens et al. 2013: 345 Wm^{-2}
Wang, Dickinson 2013: 342 Wm^{-2}
Wild et al. 1998, 2001: 344 Wm^{-2}



Global Mean Energy Balance

Estimates consistent with direct observations

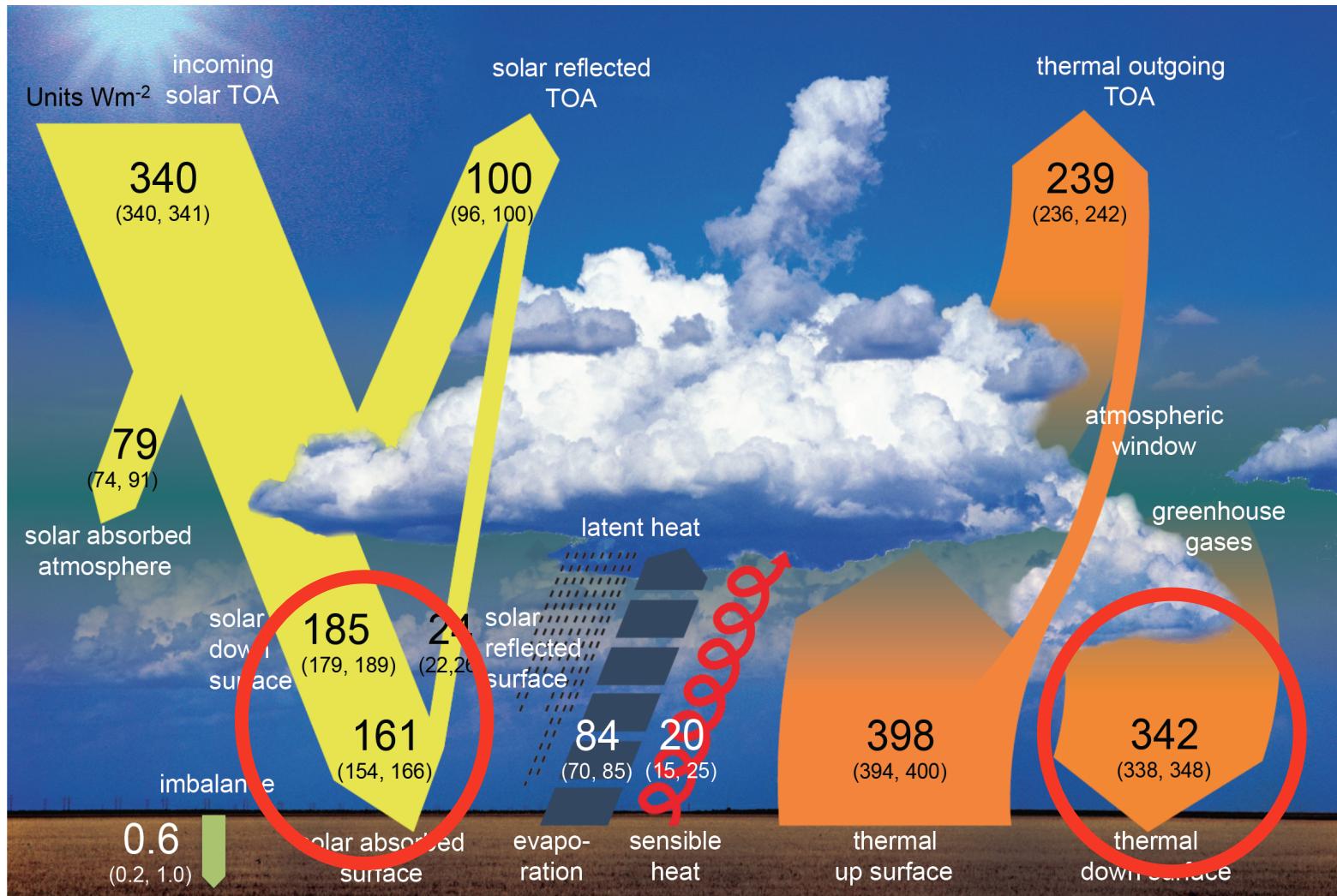
Units Wm^{-2}



Global Mean Energy Balance

Estimates consistent with direct observations

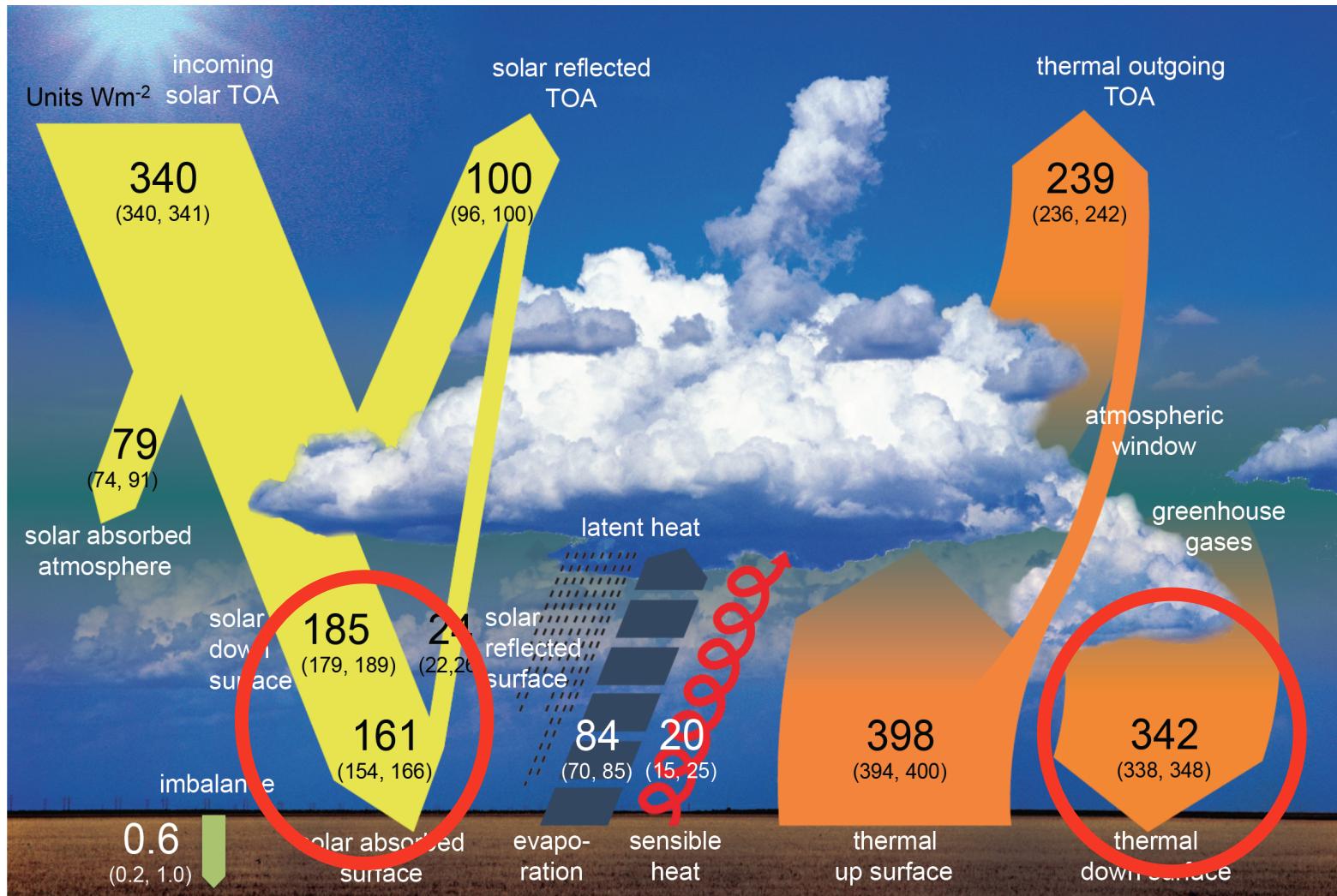
Units Wm^{-2}



Global Mean Energy Balance

Estimates consistent with direct observations

Units Wm^{-2}



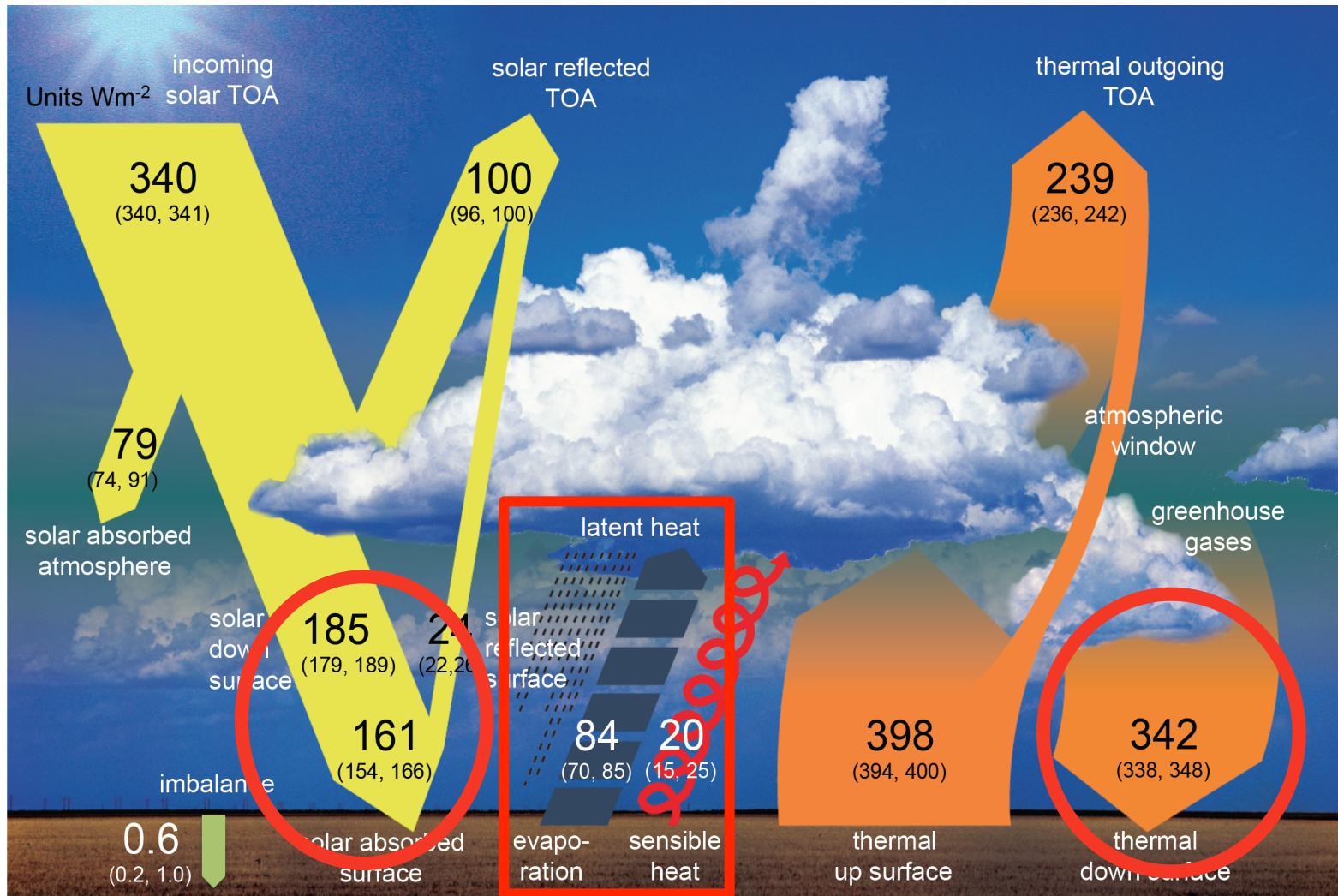
Surface net radiation: 105 Wm^{-2}

IPCC AR5 Fig. 2.11 / Wild et al. 2013 Clim. Dyn.

Global Mean Energy Balance

Estimates consistent with direct observations

Units Wm^{-2}



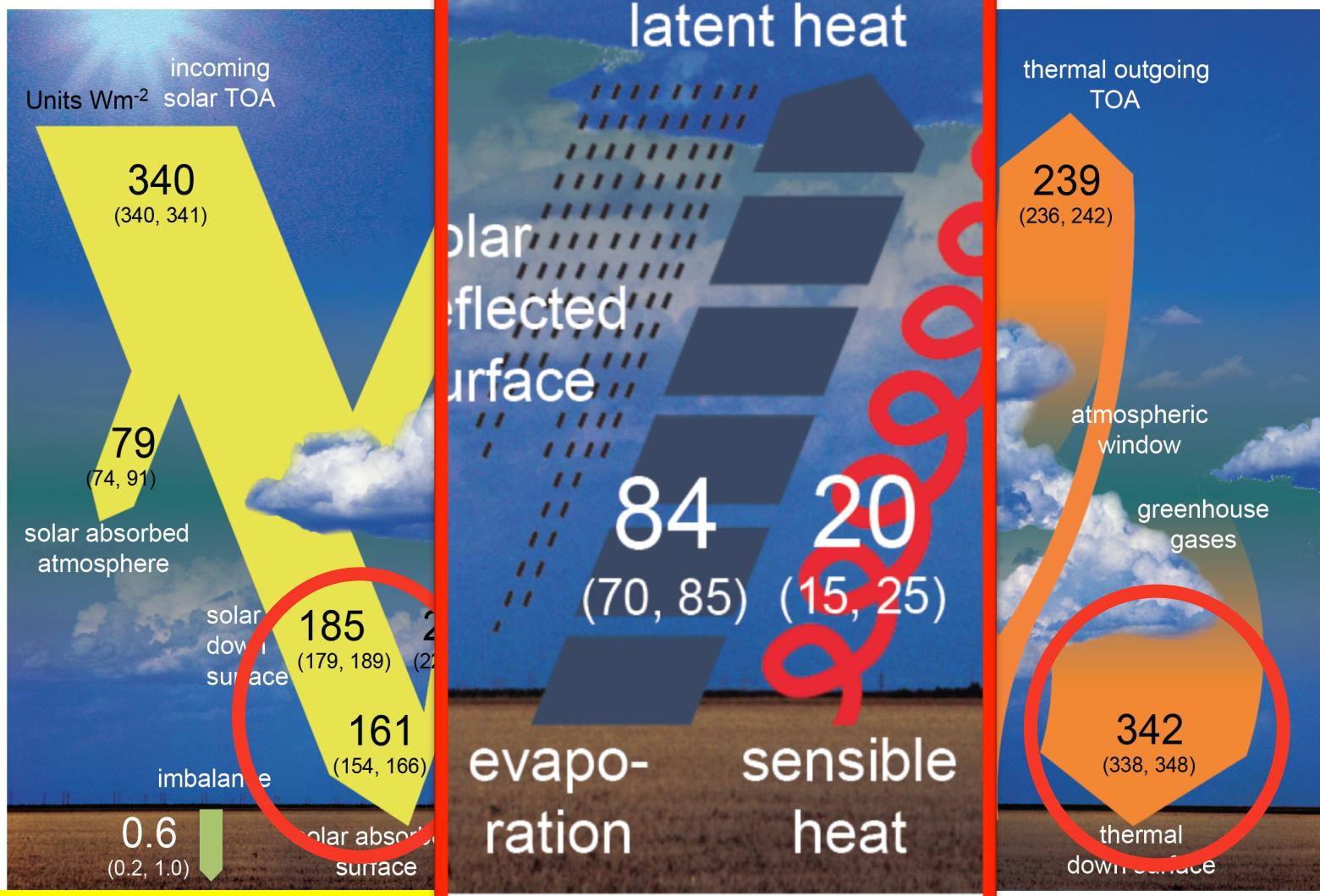
Surface net radiation: 105 Wm^{-2}

IPCC AR5 Fig. 2.11 / Wild et al. 2013 Clim. Dyn.

Global Mean Energy Balance

Estimates consistent with direct observations

Units Wm^{-2}



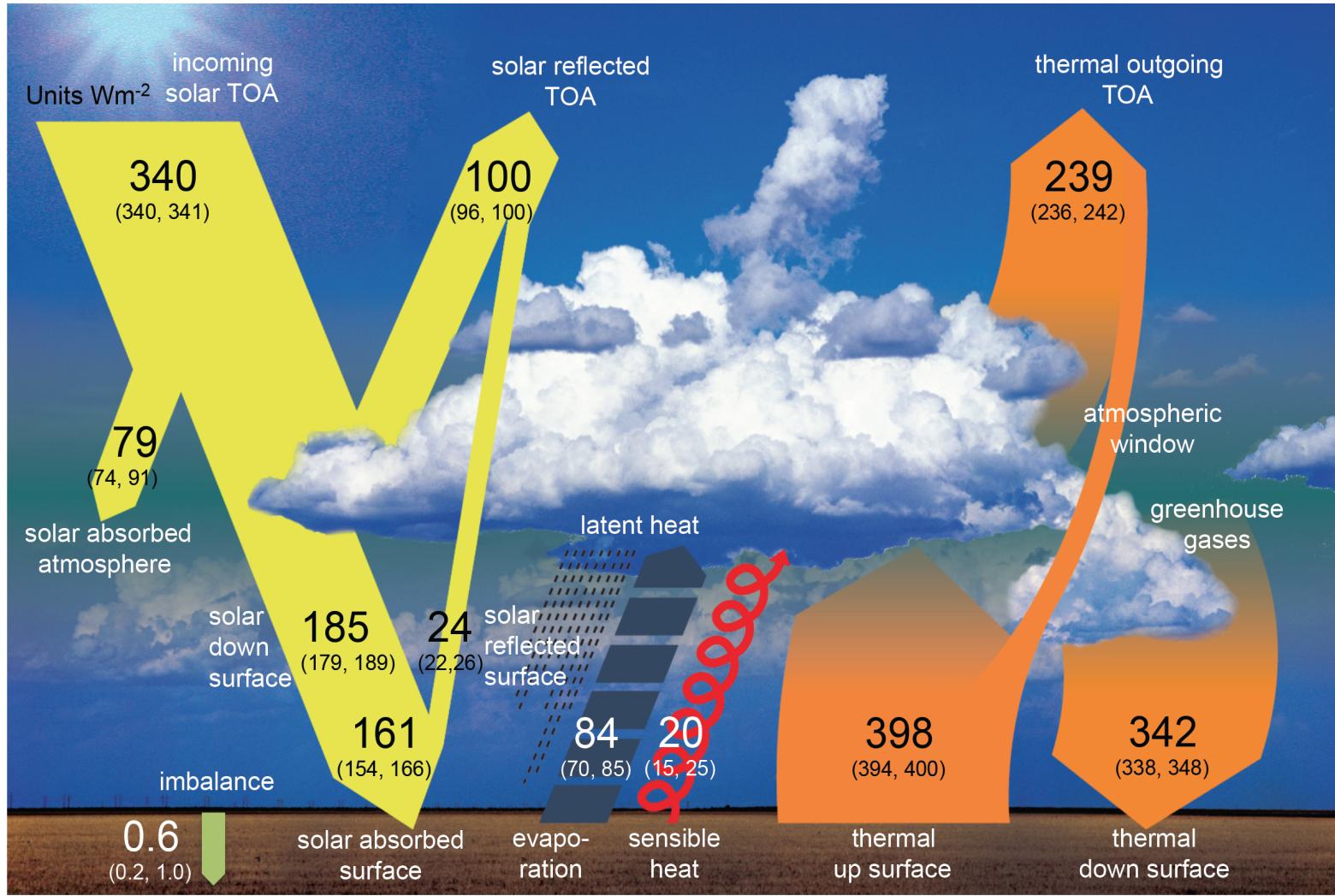
Surface net radiation: 105 Wm^{-2}

IPCC AR5 Fig. 2.11 / Wild et al. 2013 Clim. Dyn.

Global Mean Energy Balance

Units Wm^{-2}

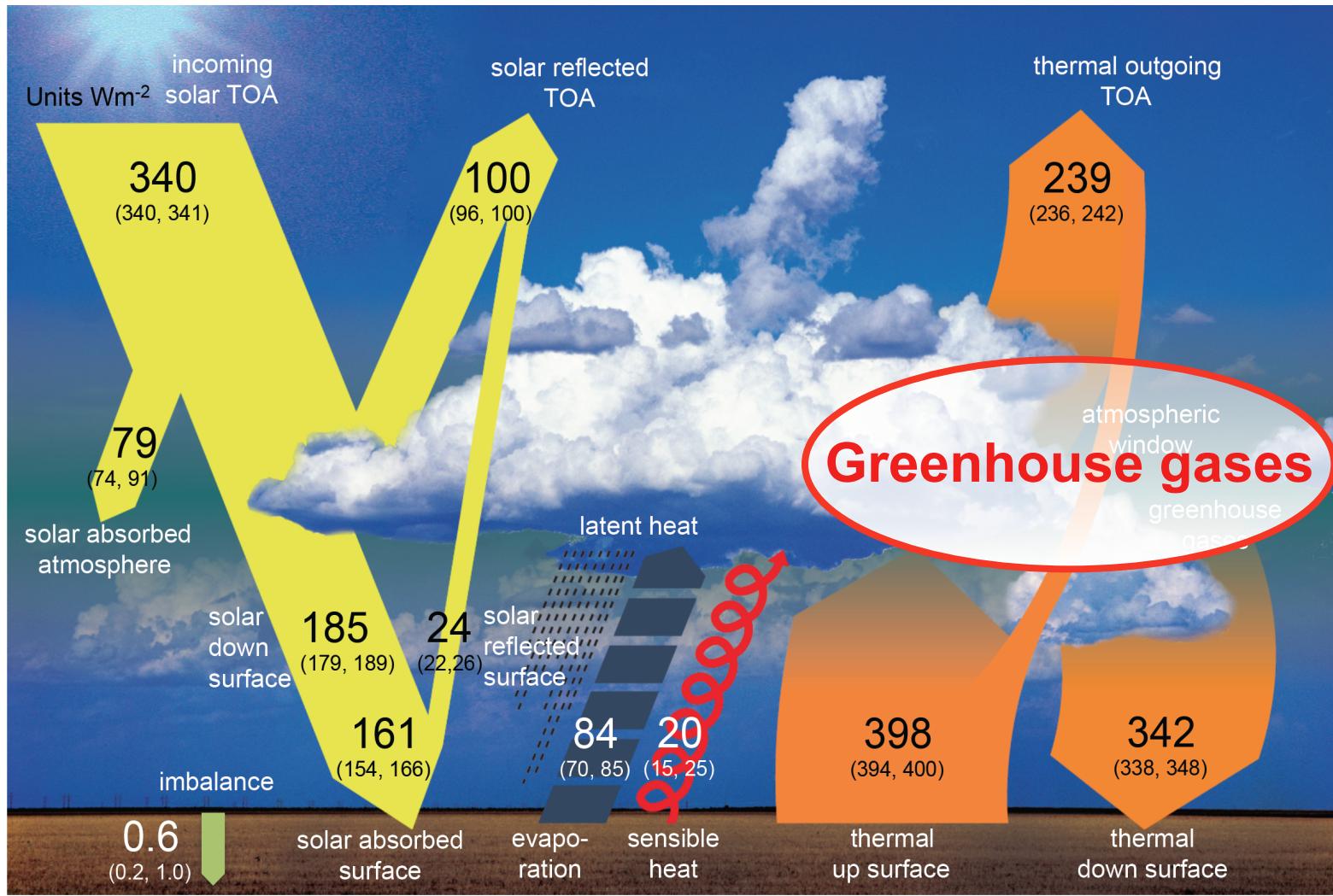
Perturbations



Global Mean Energy Balance

Units Wm^{-2}

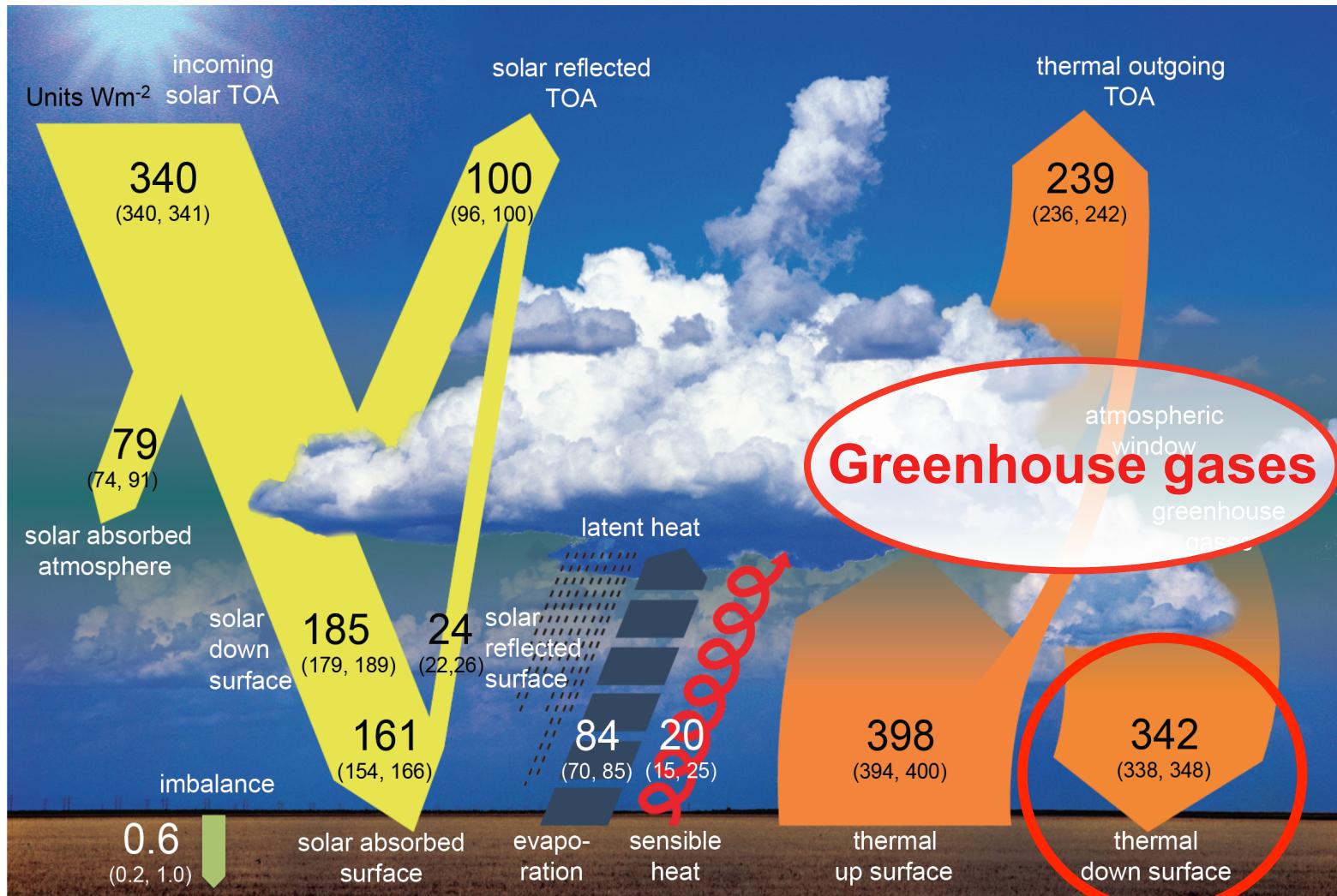
Perturbations



Global Mean Energy Balance

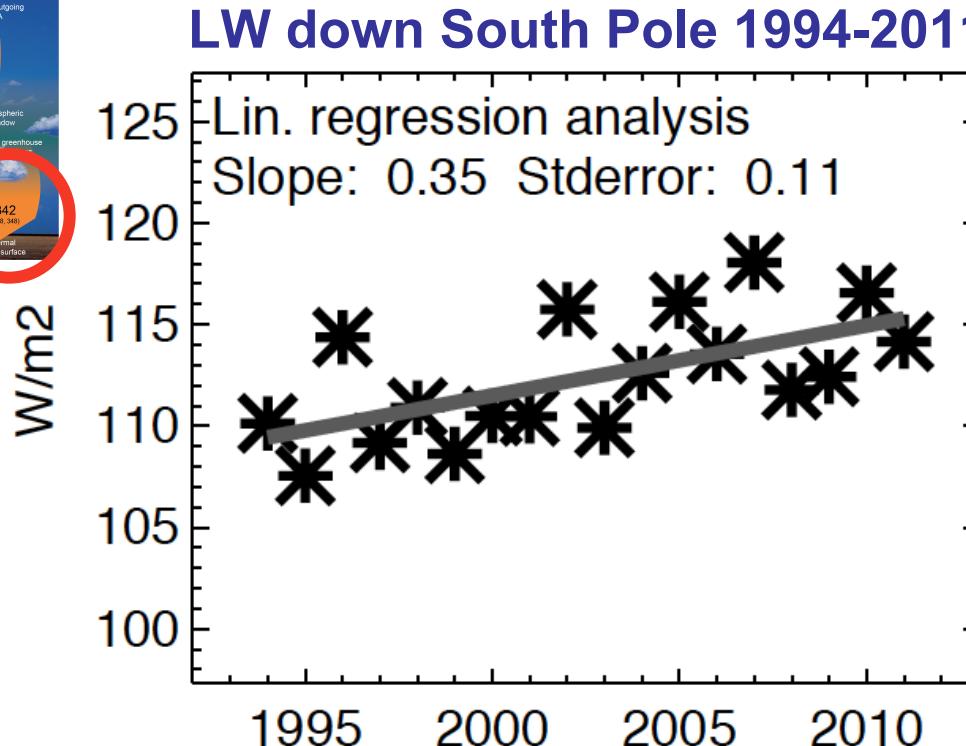
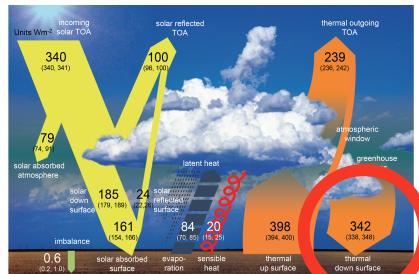
Units Wm^{-2}

Perturbations



Changes in downward LW radiation

Observed changes downward longwave radiation



Observed changes at BSRN sites since early 1990s:

25 longest BSRN records (totally 353 years): **+2.0 $\text{Wm}^{-2}\text{dec}^{-1}$**

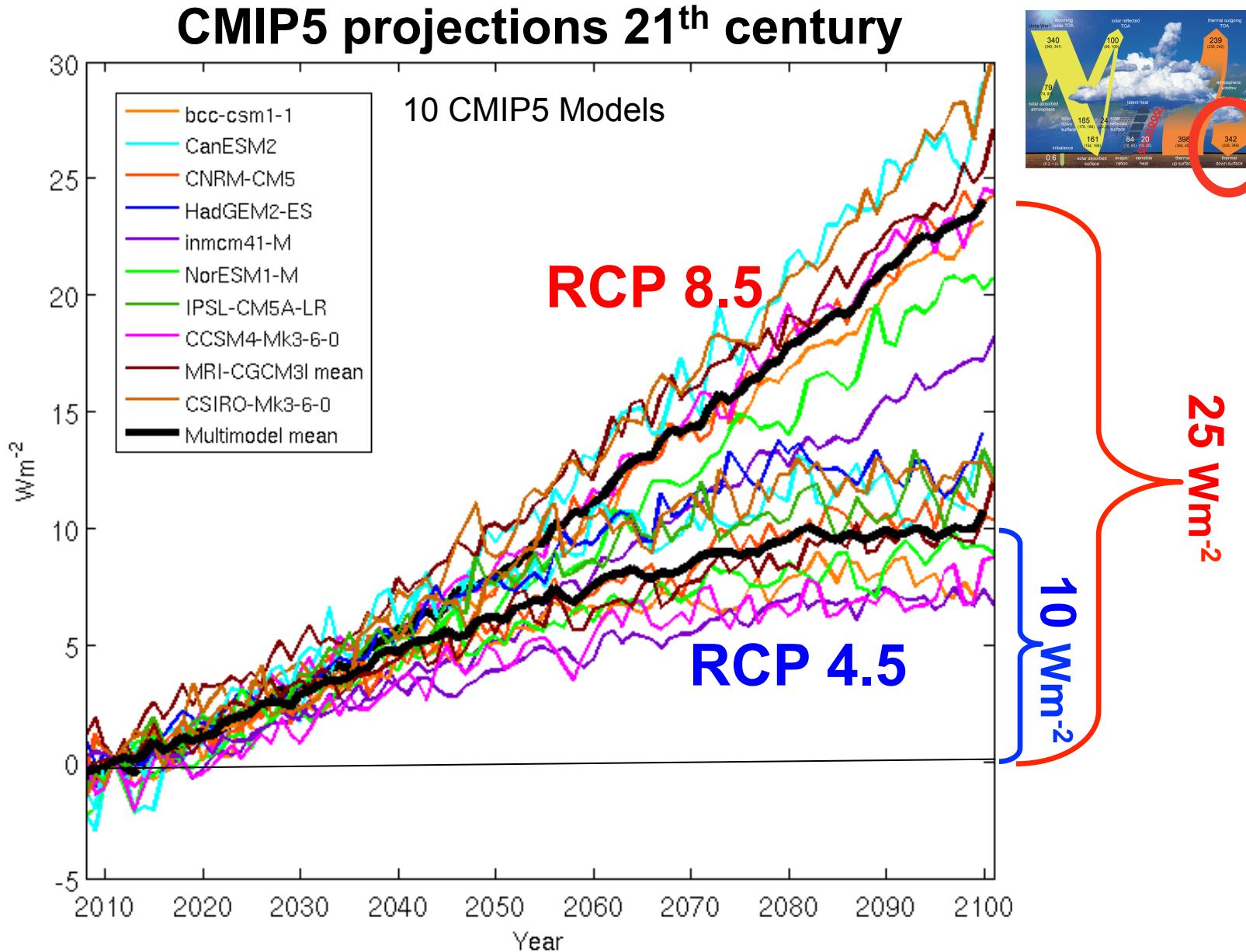
cf. Philipona et al. (2009): **+ 2.4-2.7 $\text{Wm}^{-2}\text{dec}^{-1}$** (Europe, 1981-2005)

Wang and Liang (2009): **+ 2.2 $\text{Wm}^{-2}\text{dec}^{-1}$** (1973-2008)

Wild et al. (2008): **+ 2.6 $\text{Wm}^{-2}\text{dec}^{-1}$** (BSRN sites 1990s)

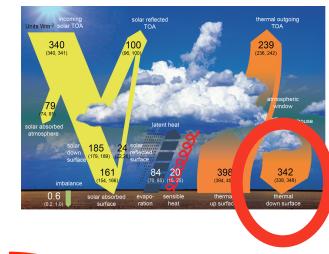
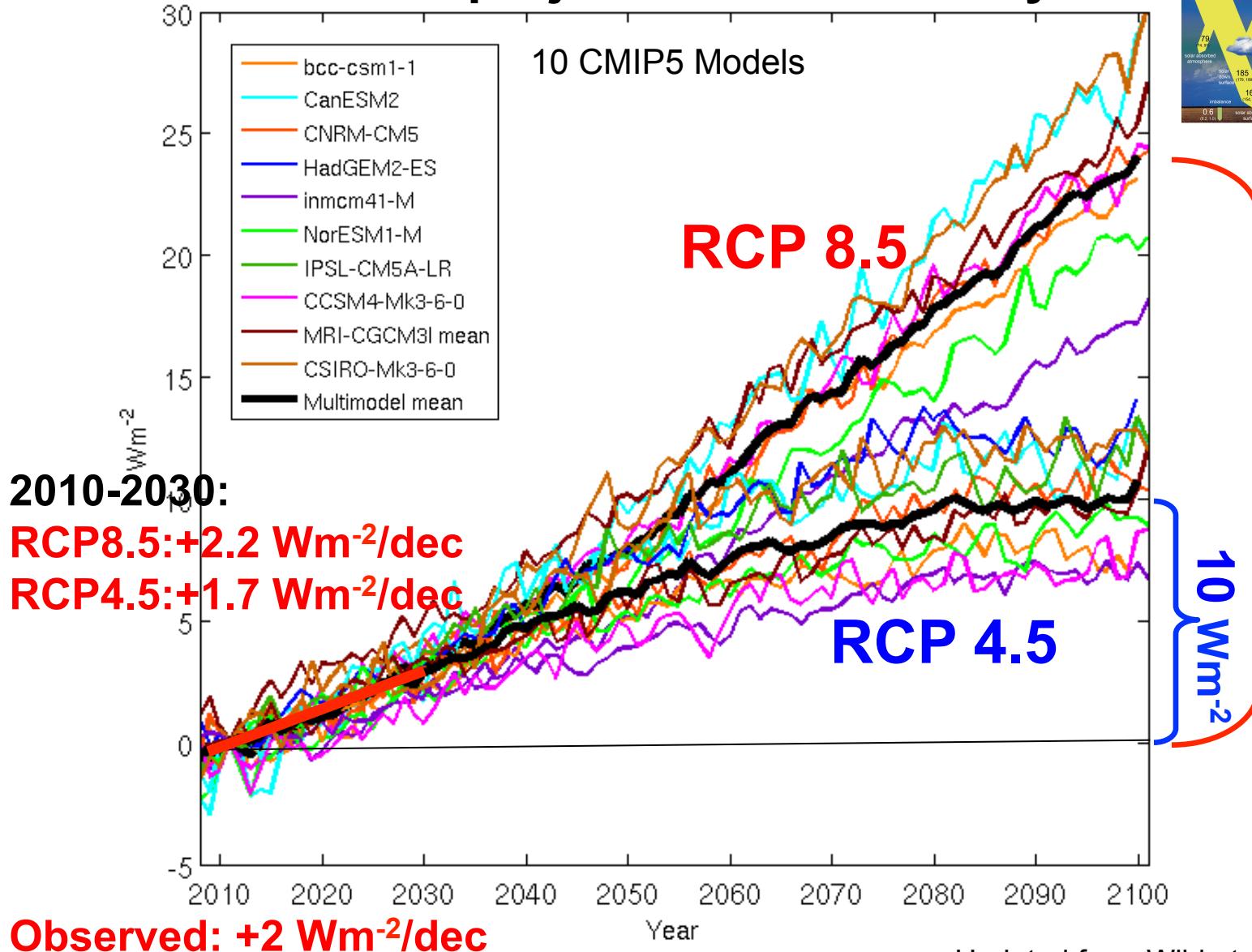
Prata (2008): **+ 1.7 $\text{Wm}^{-2}\text{dec}^{-1}$** (clear sky, 1964-1990)

Downward longwave in RCP scenarios



Downward longwave in RCP scenarios

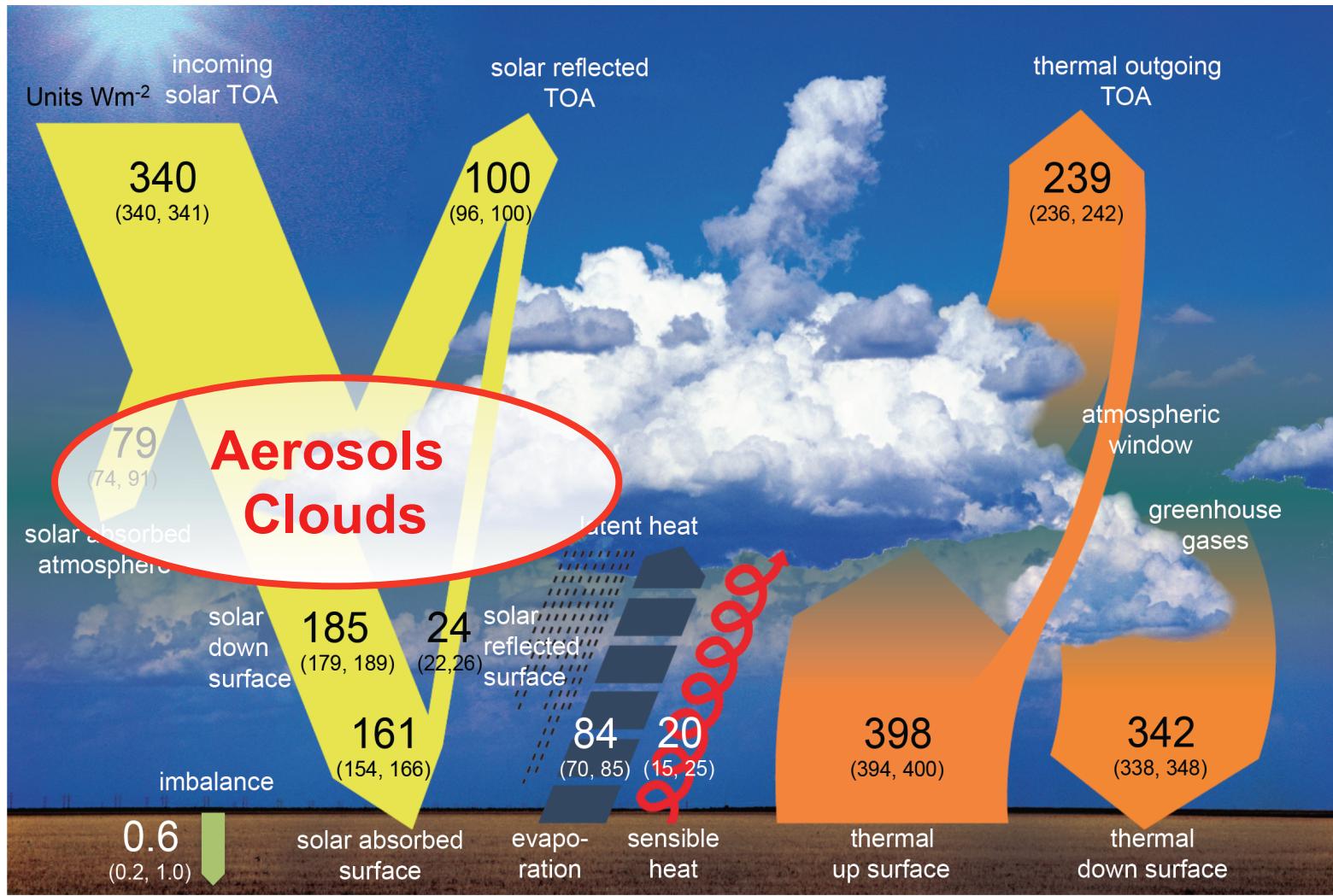
CMIP5 projections 21th century



Global Mean Energy Balance

Units Wm^{-2}

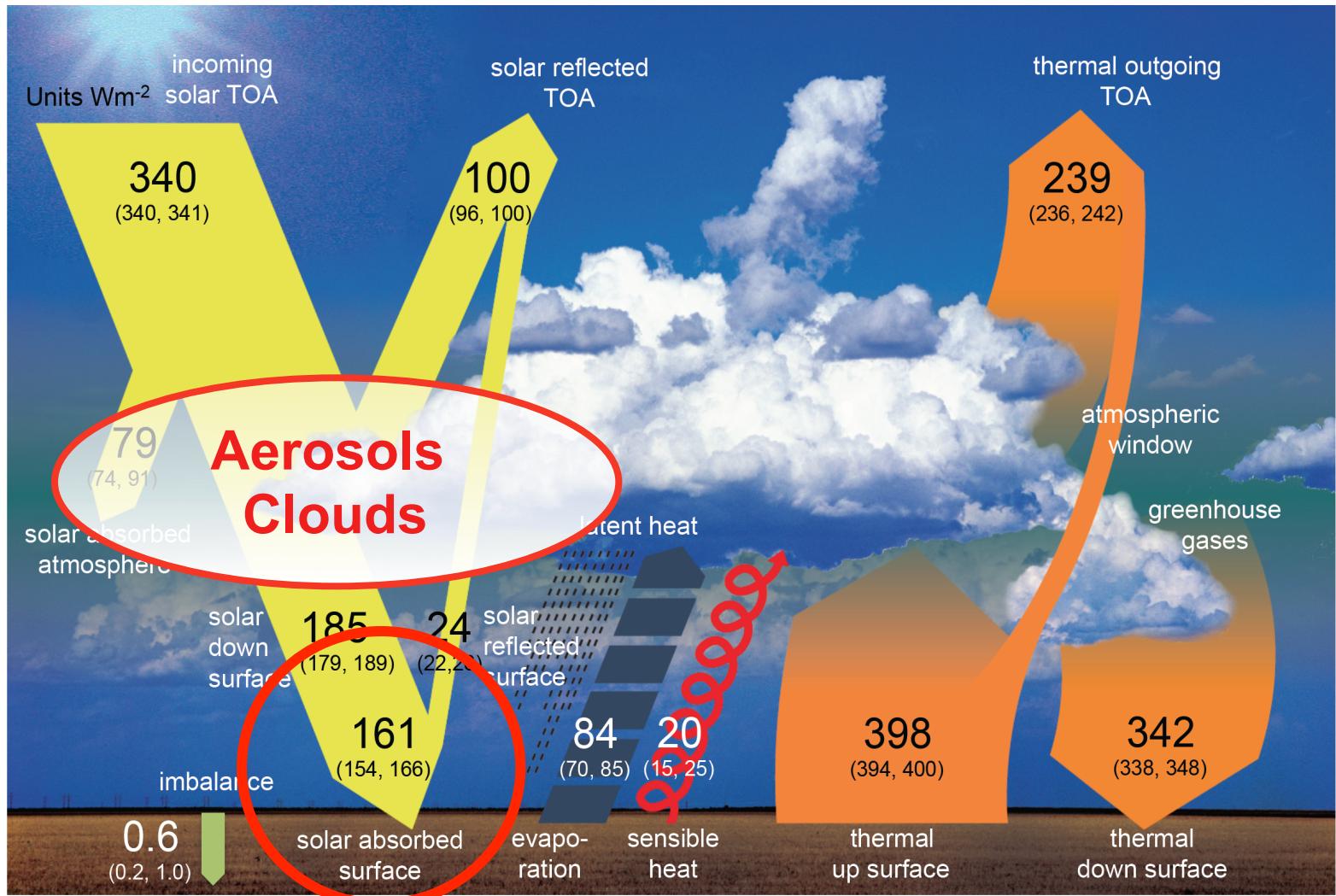
Perturbations



Global Mean Energy Balance

Units Wm^{-2}

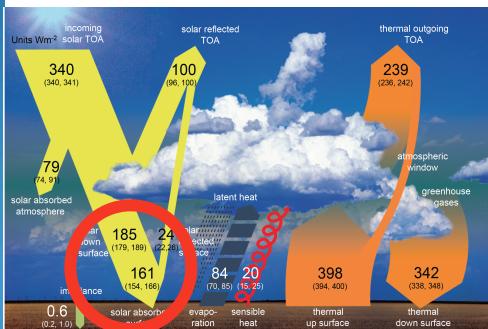
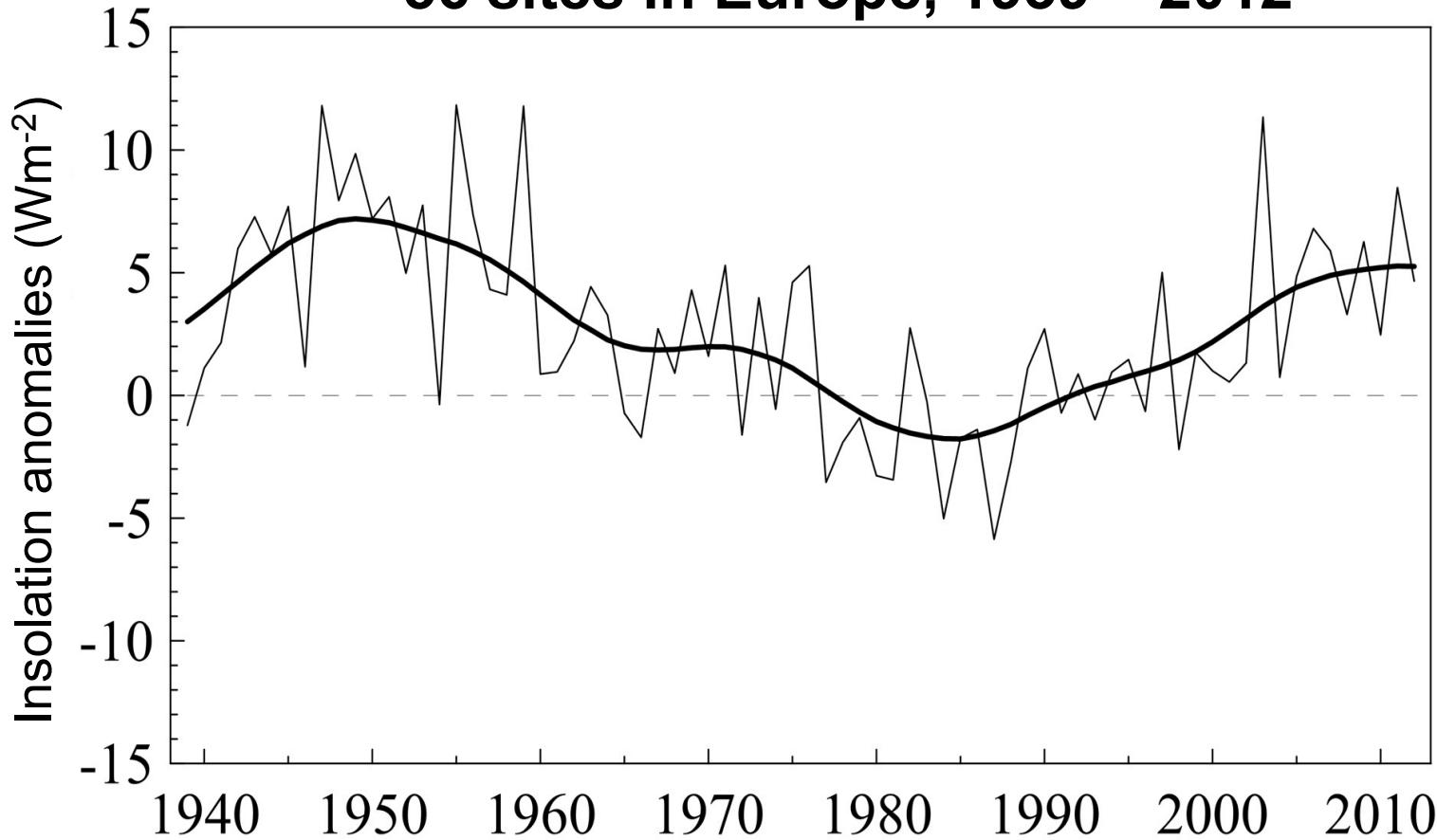
Perturbations



Changes in surface solar radiation

Decadal changes in surface solar radiation

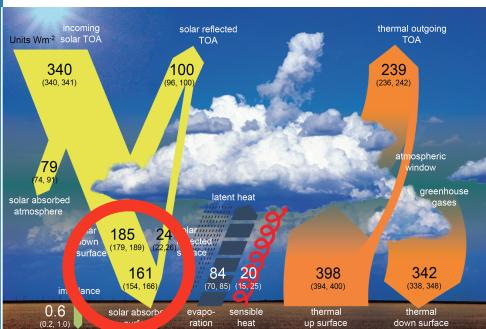
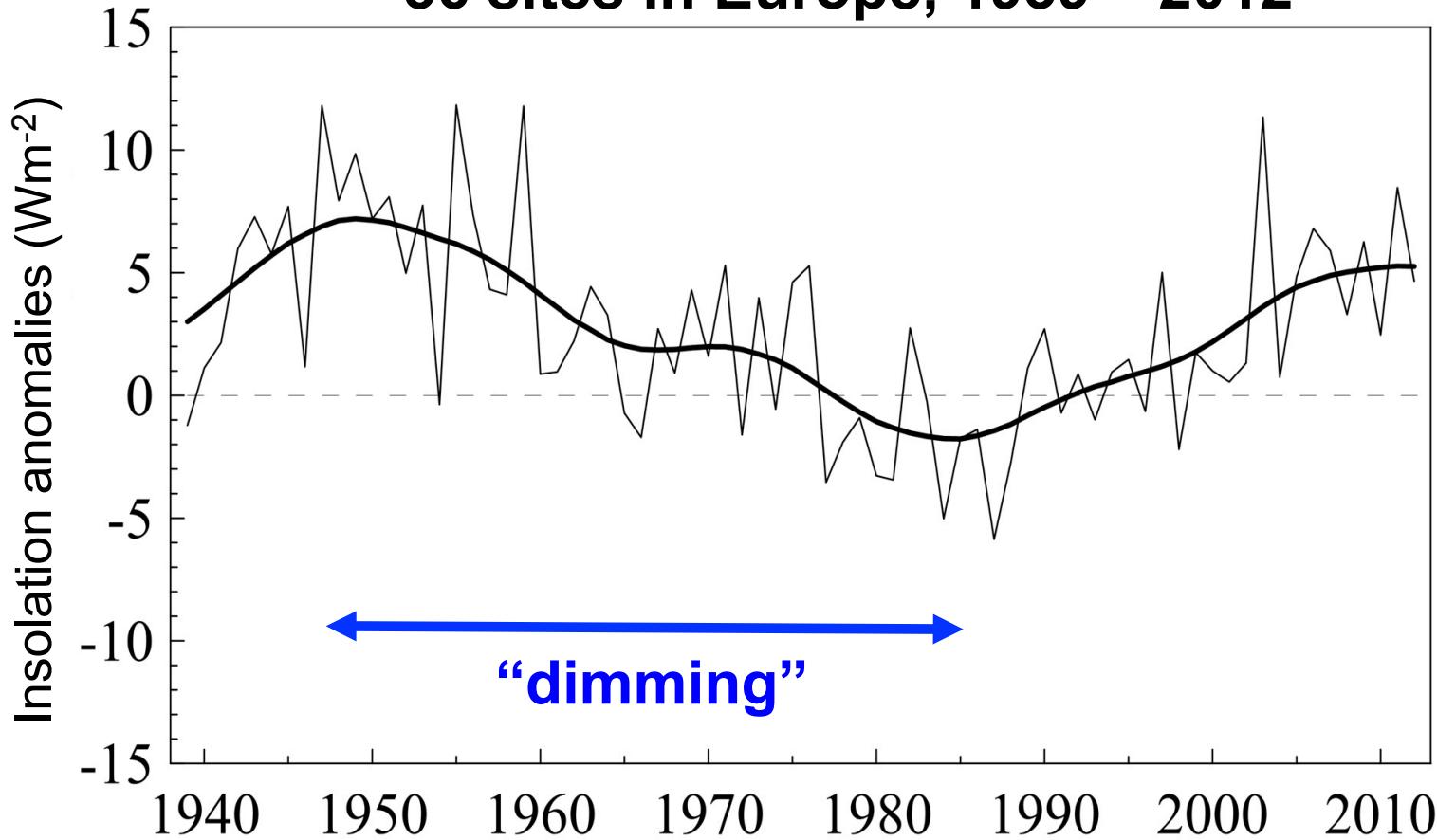
56 sites in Europe, 1939 – 2012



Updated from GEBA, Sanchez- Lorenzo et al. in prep.

Decadal changes in surface solar radiation

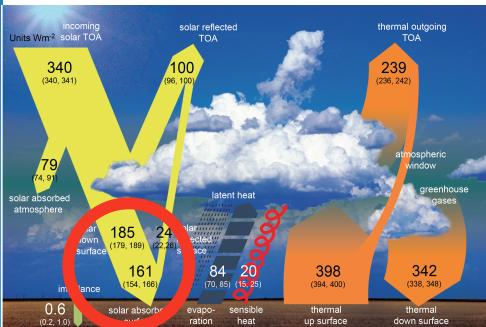
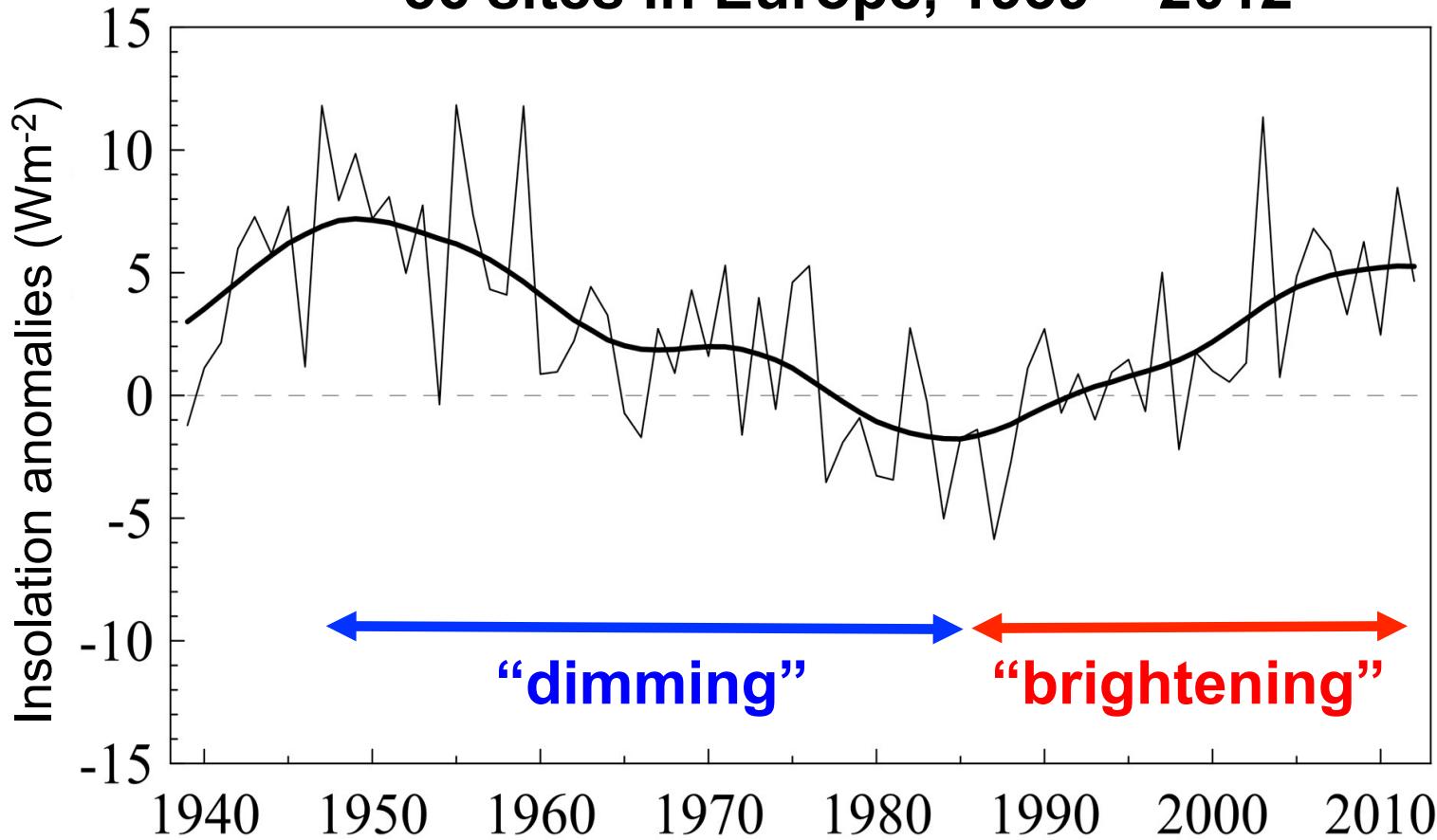
56 sites in Europe, 1939 – 2012



Updated from GEBA, Sanchez- Lorenzo et al. in prep.

Decadal changes in surface solar radiation

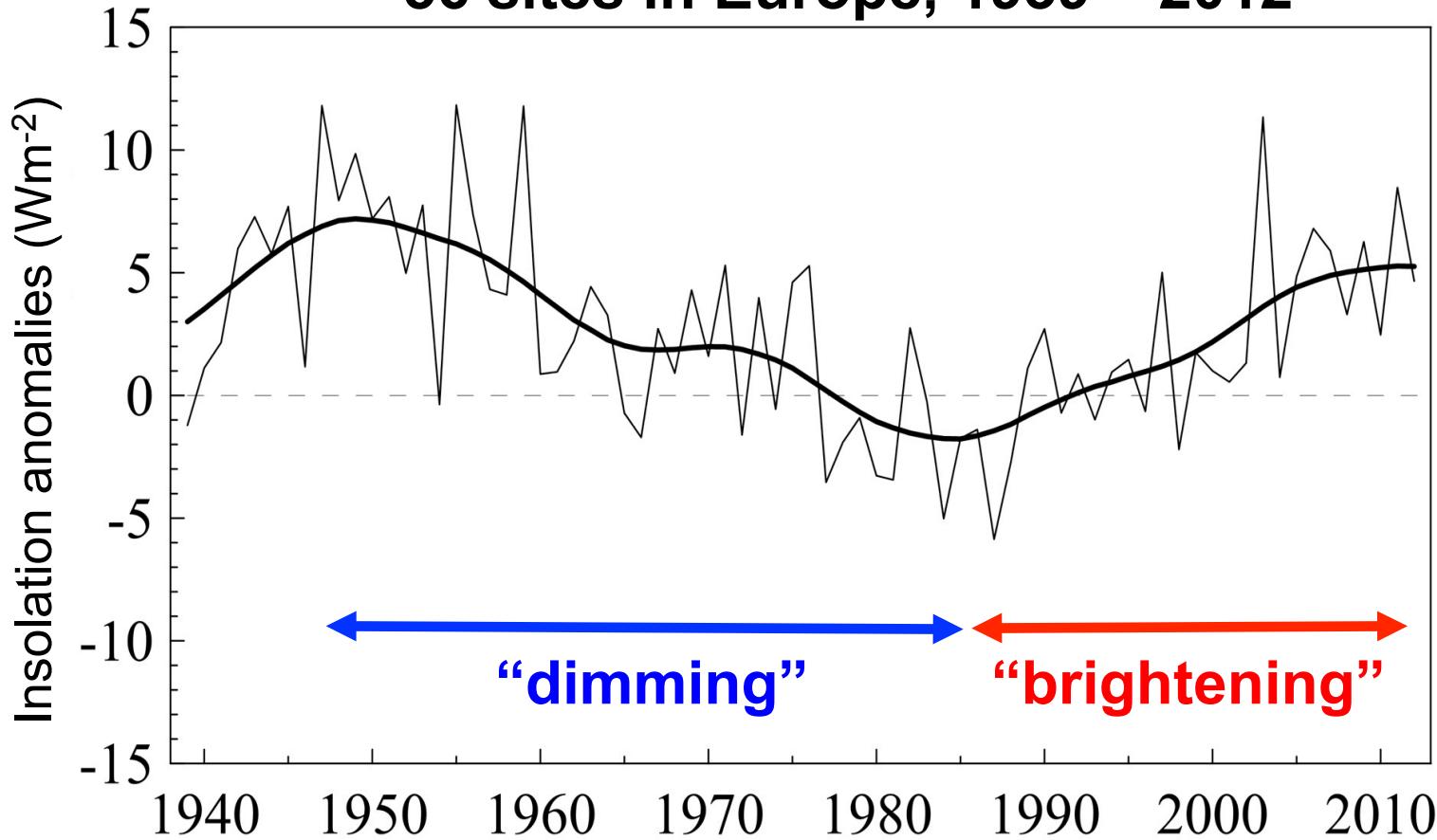
56 sites in Europe, 1939 – 2012



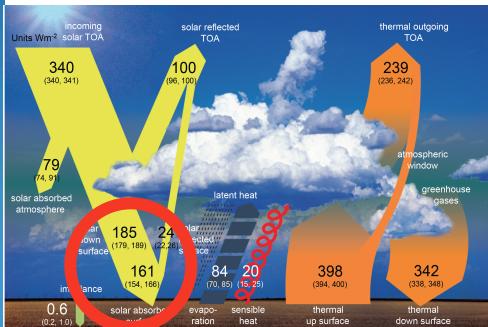
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Decadal changes in surface solar radiation

56 sites in Europe, 1939 – 2012



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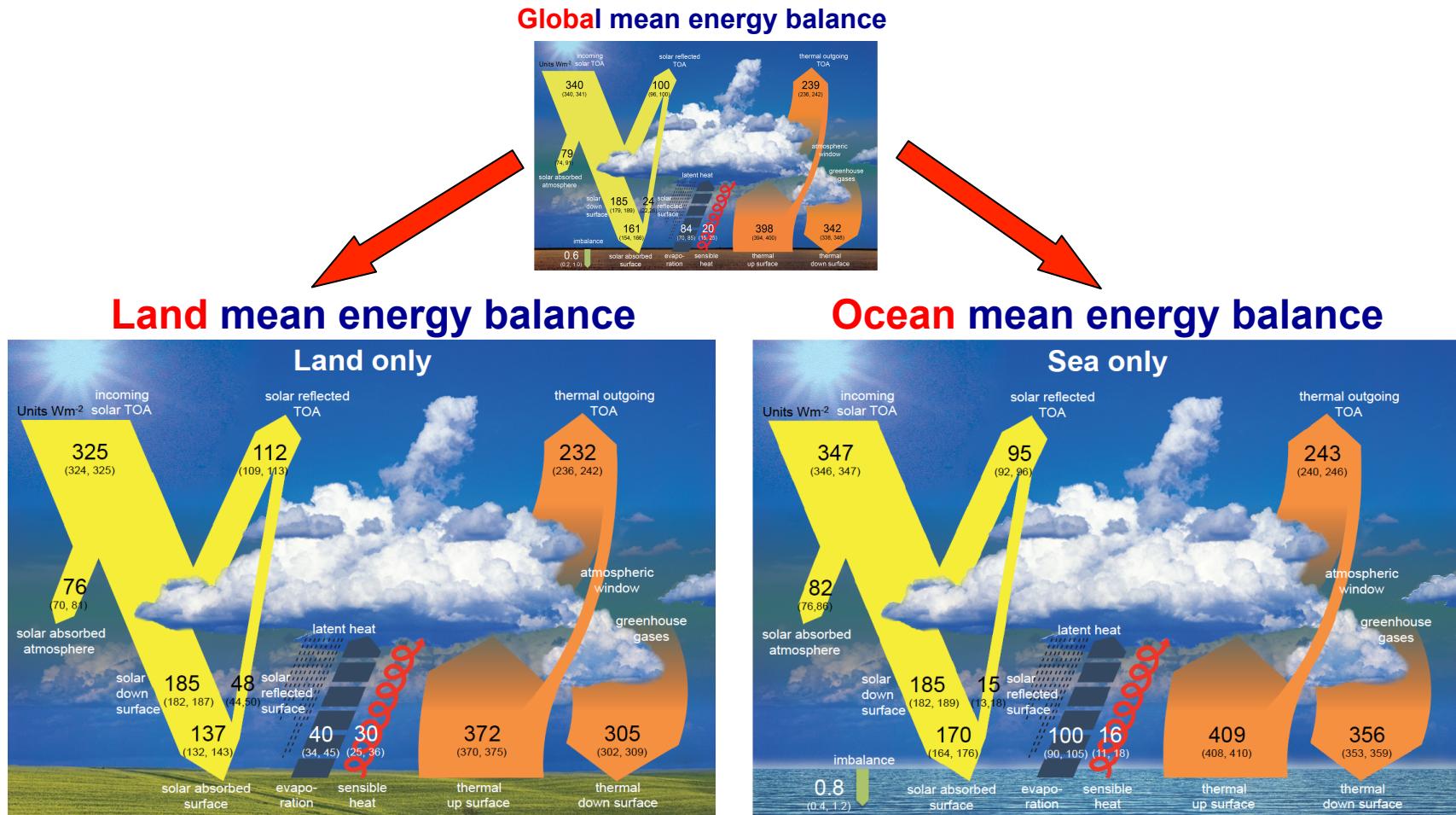


=> Not adequately reproduced in CMIP5 models

Summary

- Still large uncertainties in global mean radiation budgets in CMIP5 models, particularly at the surface.
=> Direct observations can provide additional constraints.
- CMIP5 models tend to overestimate surface downward shortwave and underestimate downward longwave radiation compared to surface obs.
> long standing issue in climate models (AMIP1, II, CMIP3).
- Global mean budget: estimated downward longwave is higher / downward shortwave is lower than in some of the previous estimates.
- Global surface energy and water budgets consistent within error bars.
- Significant decadal changes observed in both surface longwave and shortwave fluxes.
- Observations indicate increase of downward longwave radiation of 2 Wm^{-2} per decade, in line with CMIP5 simulations and expectations from increasing greenhouse effect.
- Surface shortwave radiation also undergoes strong decadal changes (“dimming/brightening”), not fully captured in CMIP5 Models.

Separation in land and ocean energy balance



Separation into land and ocean mean budgets
based on CERES EBAF (TOA), BSRN/GEBA /CMIP5 (surface)

Poster 125 tonight

Related references

Wild, M. et al. 2013a: The global energy balance from a surface perspective, *Climate Dynamics*, 40, 3107-3134, doi:10.1007/s00382-012-1569-8.

Wild, M. et al. 2013b: A new diagram of the global energy balance, *AIP Conf. Proc.*, 1531, 628-631, doi: 10.1063/1.4804848.

Wild, M. et al. 2014: The energy balance over land and sea: An assessment based on direct observations and CMIP5 models (submitted).