Verification of radiation in large scale climate models

Martin Wild
ETH Zürich, Switzerland

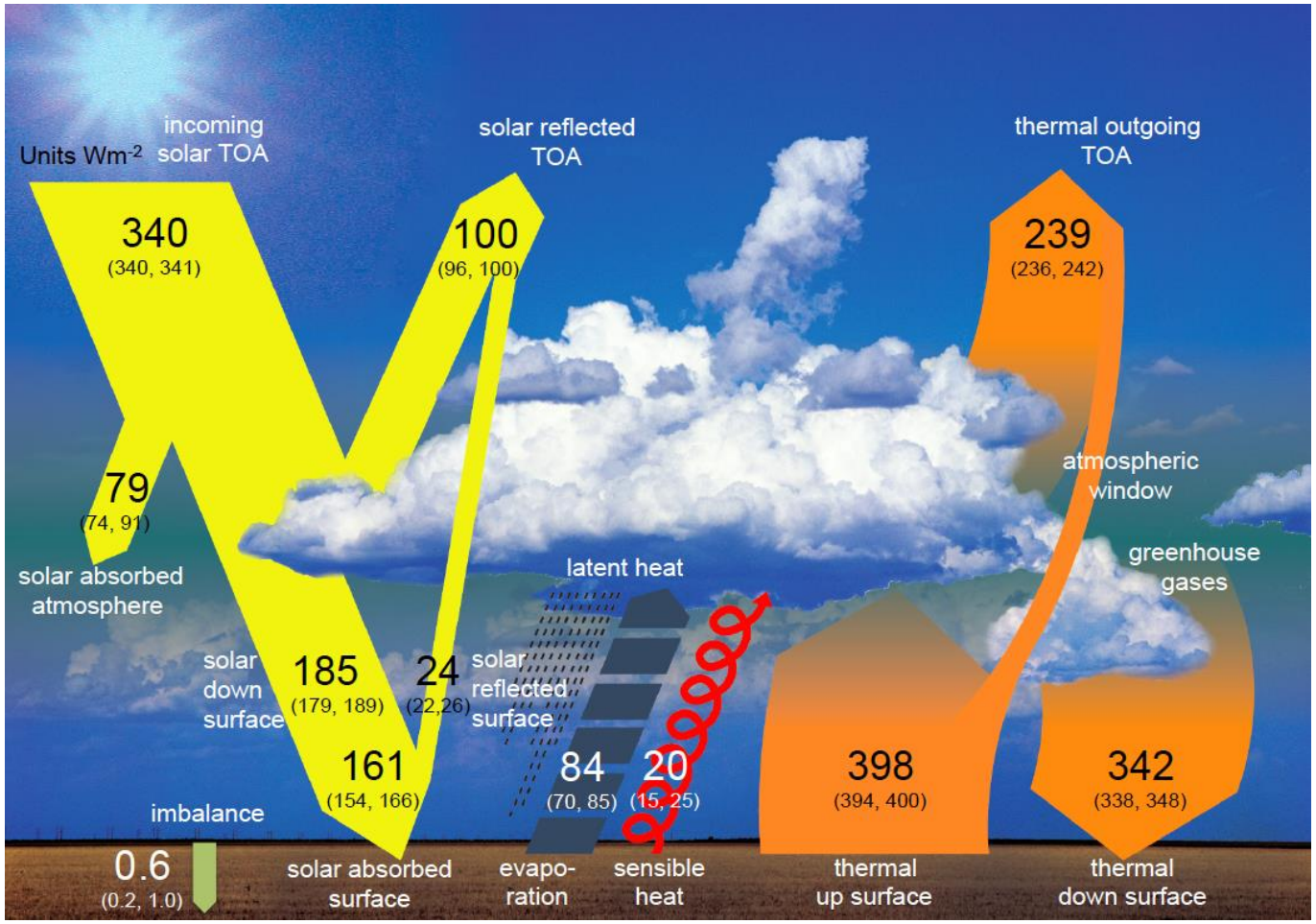
martin.wild@env.ethz.ch

ETH Institute for Atmospheric and Climate Science

Content

- ***What is the role of Earth radiation budget in the global climate system?***
- ***How is it reproduced in climate models****? > focus on Earth‘s surface*
- ***How do the surface radiative components change over time?***
- ***Are climate models able to reproduce these changes?***
- ***What are the implications for simulated climate change?***

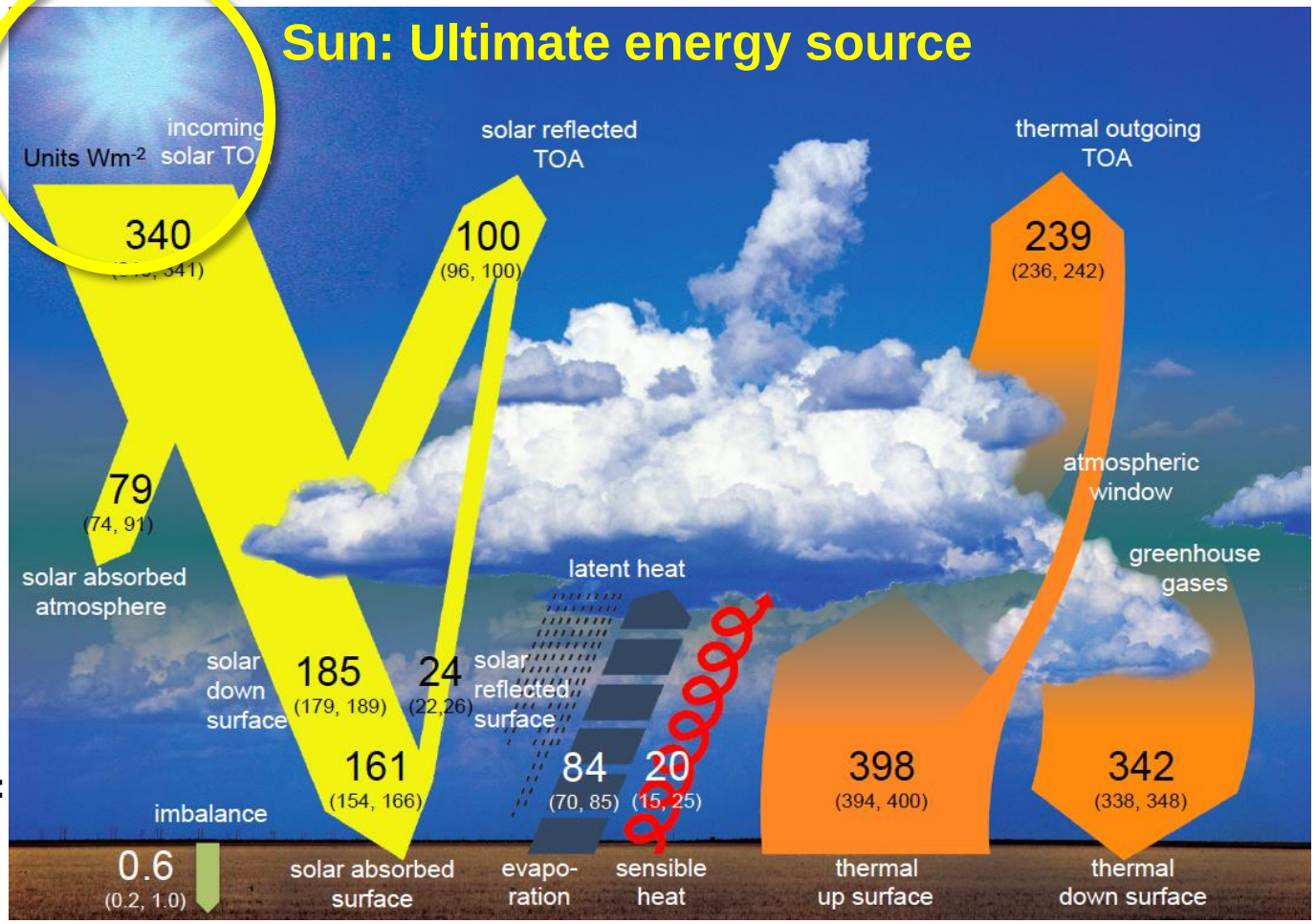
Earth radiation budget



Units: Wm^{-2}

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

Earth radiation budget



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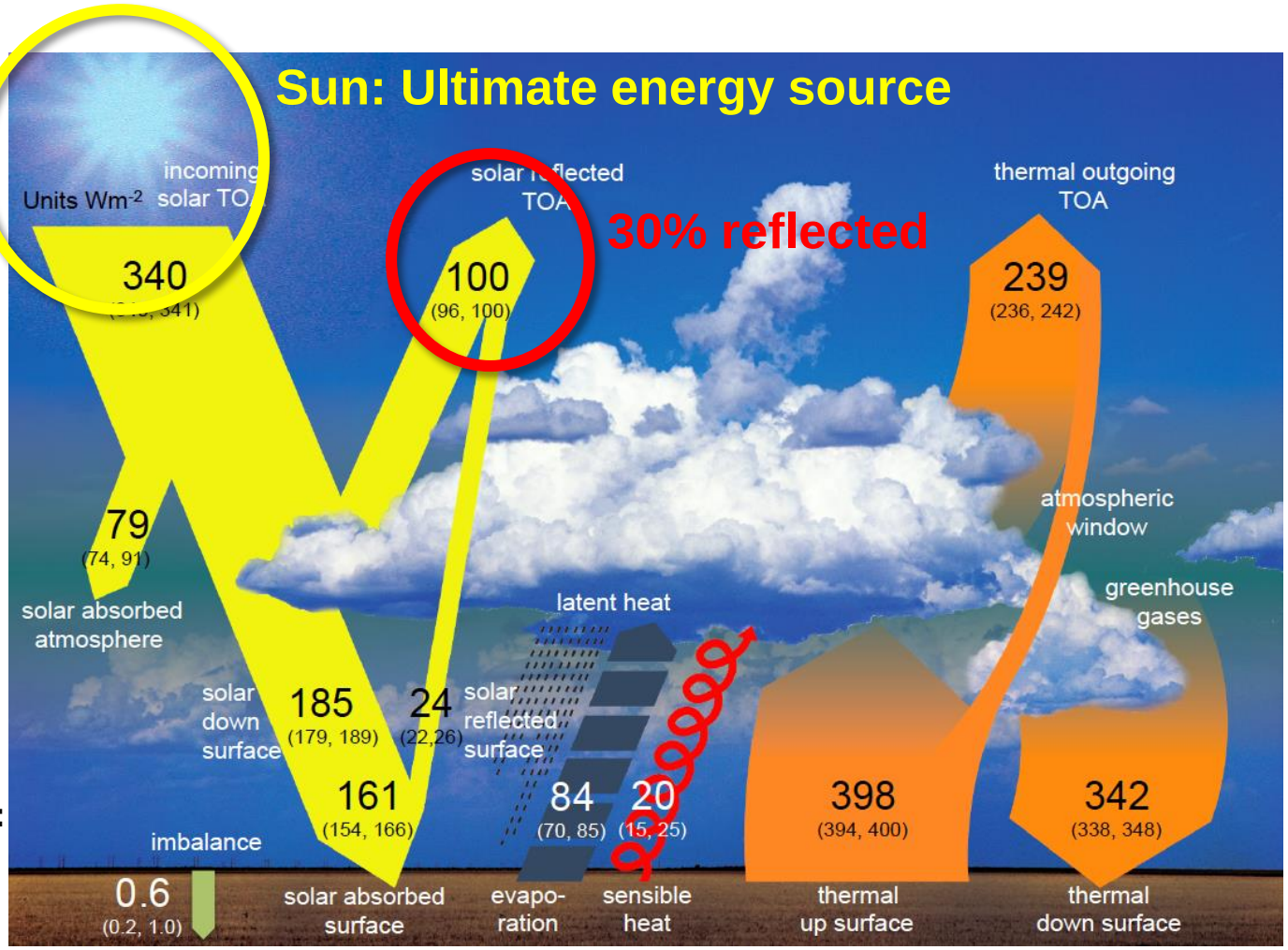
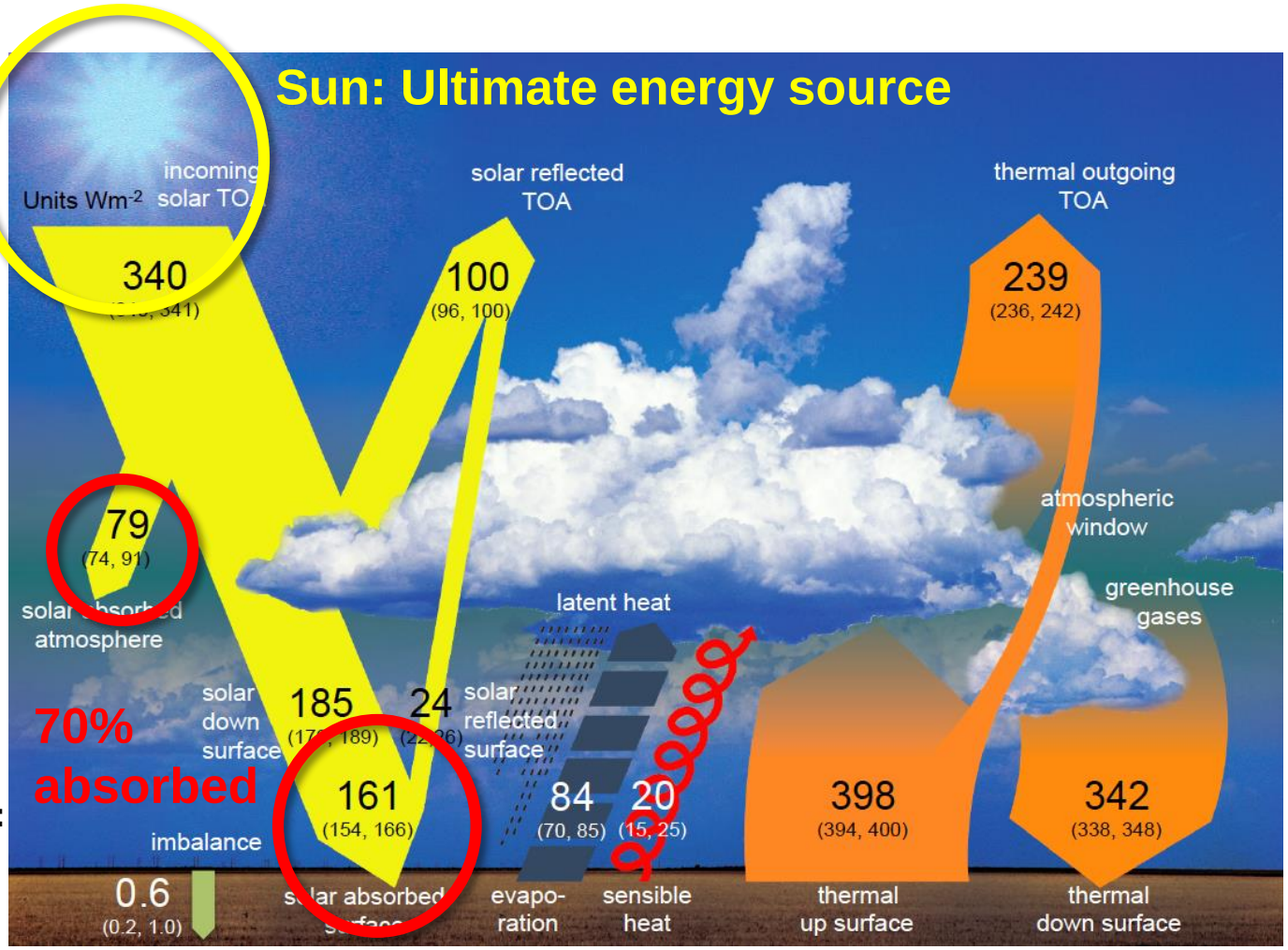


Units: Wm^{-2}

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

Earth radiation budget



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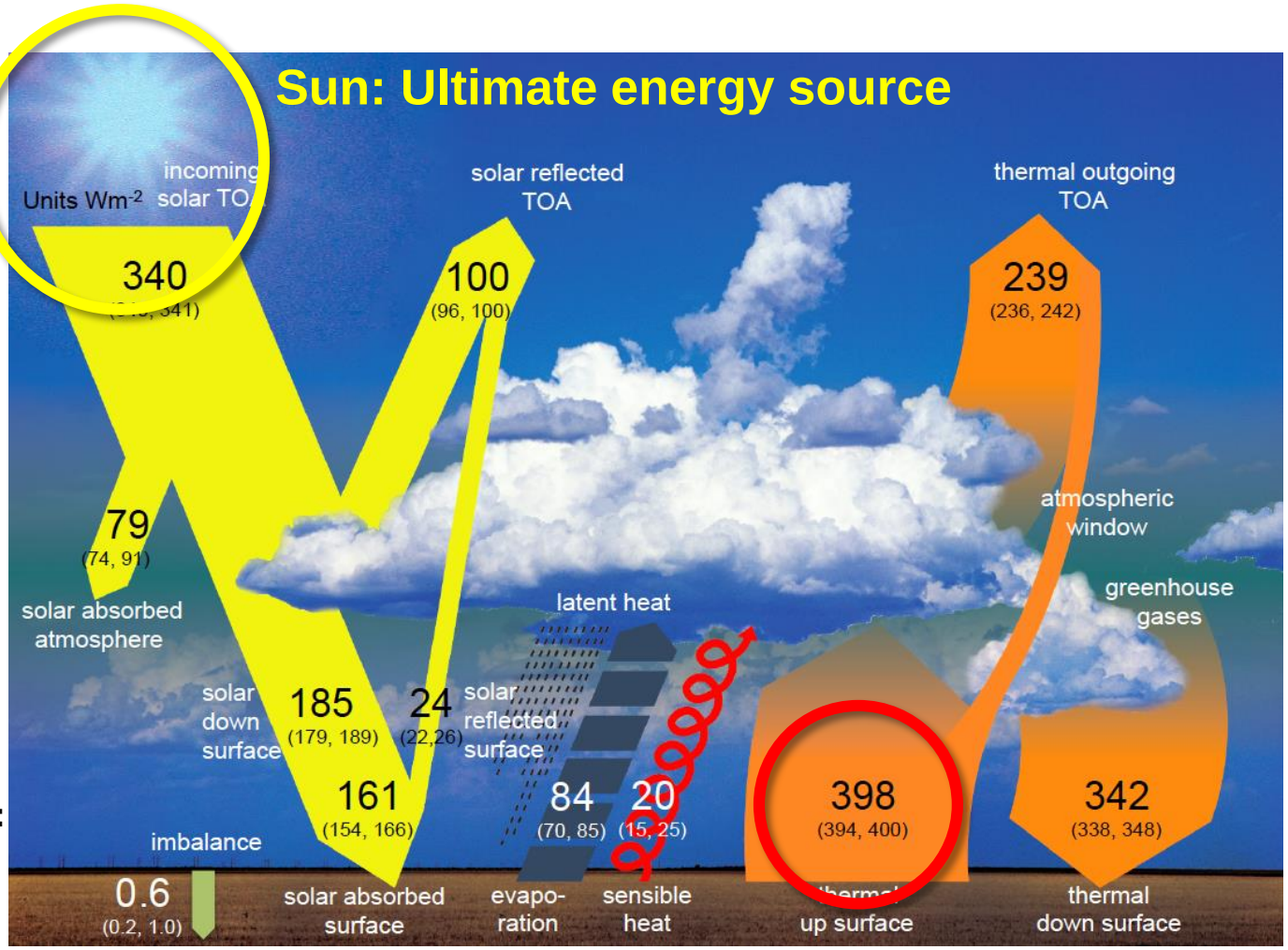
Earth radiation budget

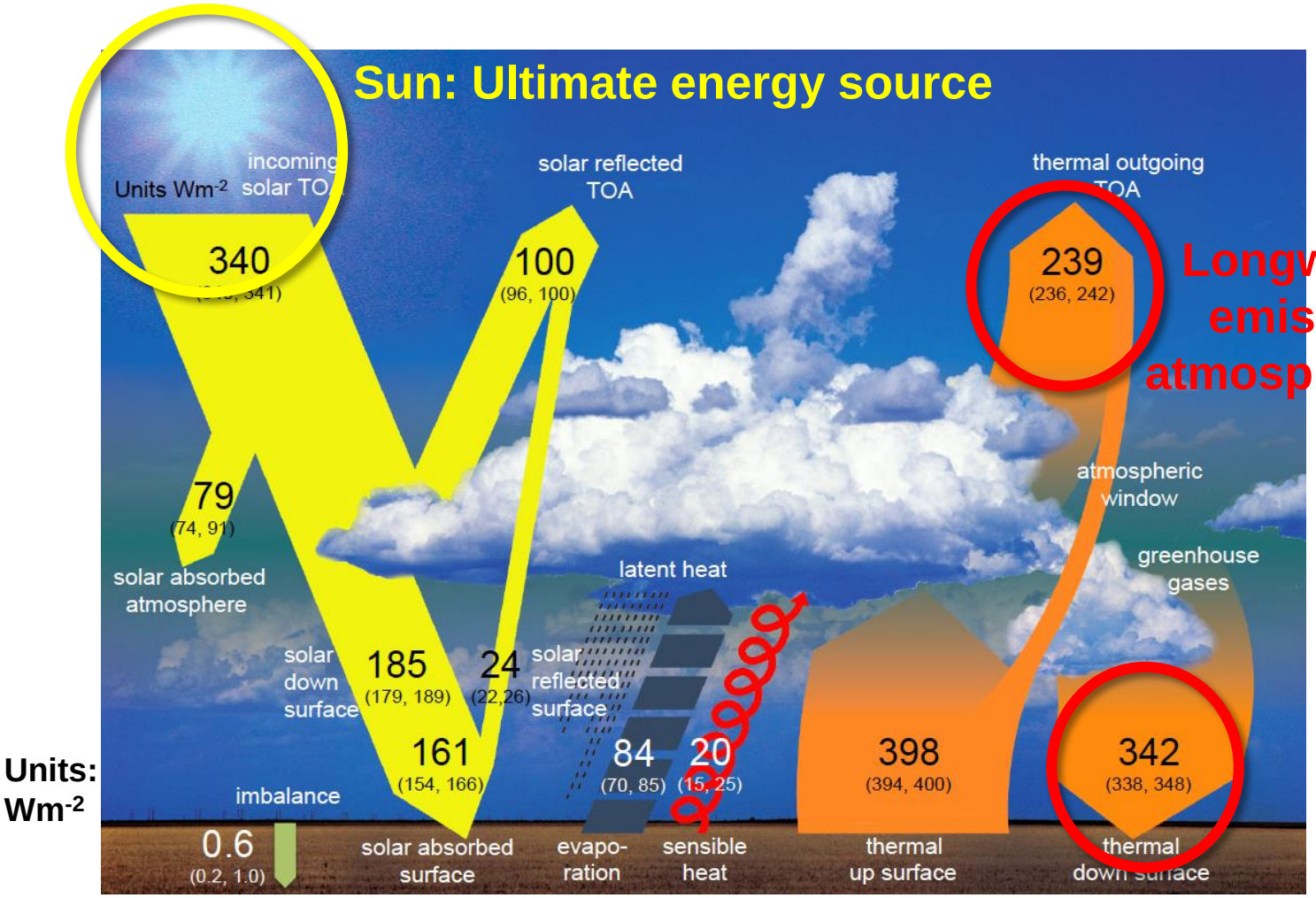


Units: Wm^{-2}

Longwave emission

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

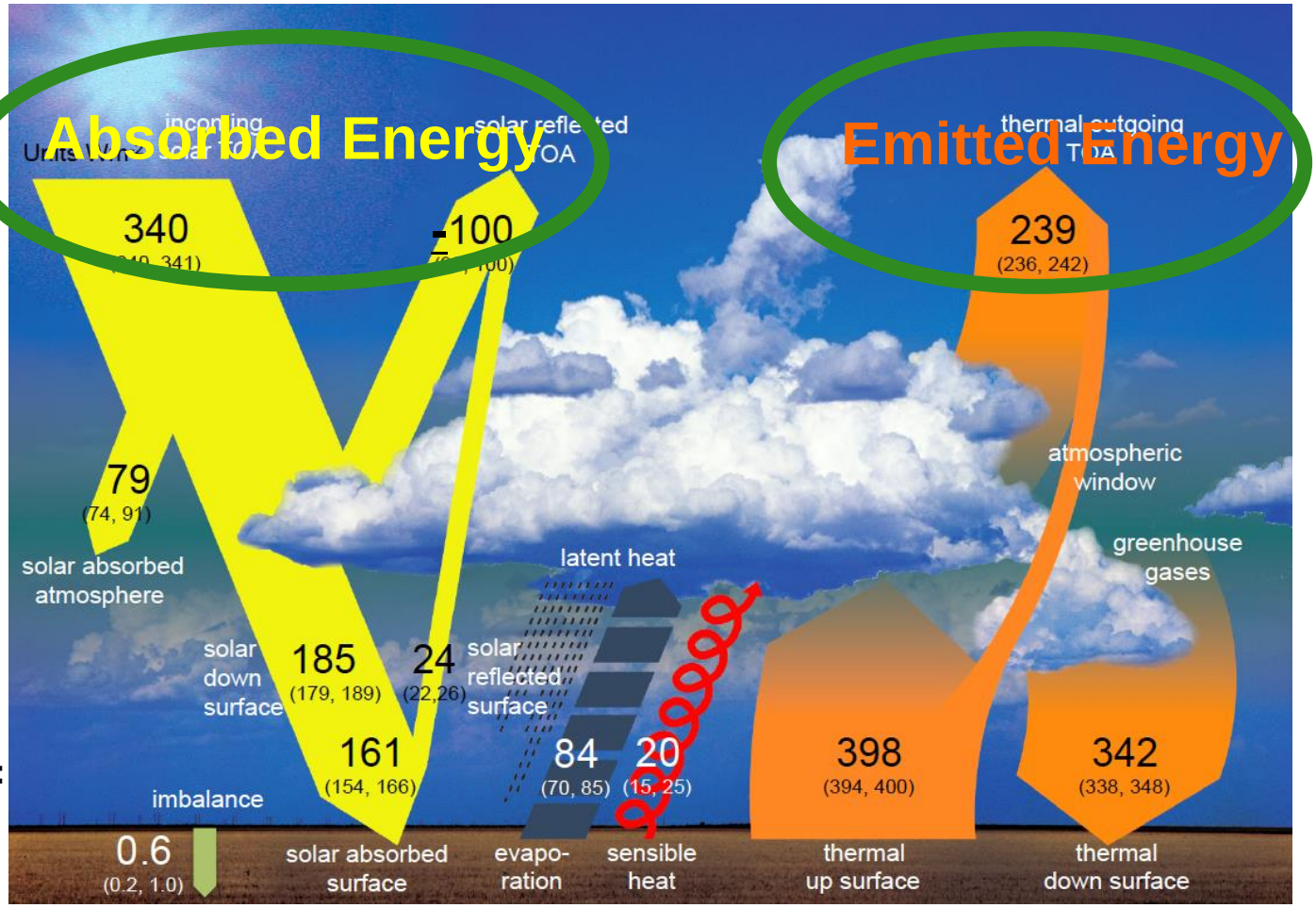
Earth radiation budget



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

Earth radiation budget

Radiation balance at the Top of Atmosphere

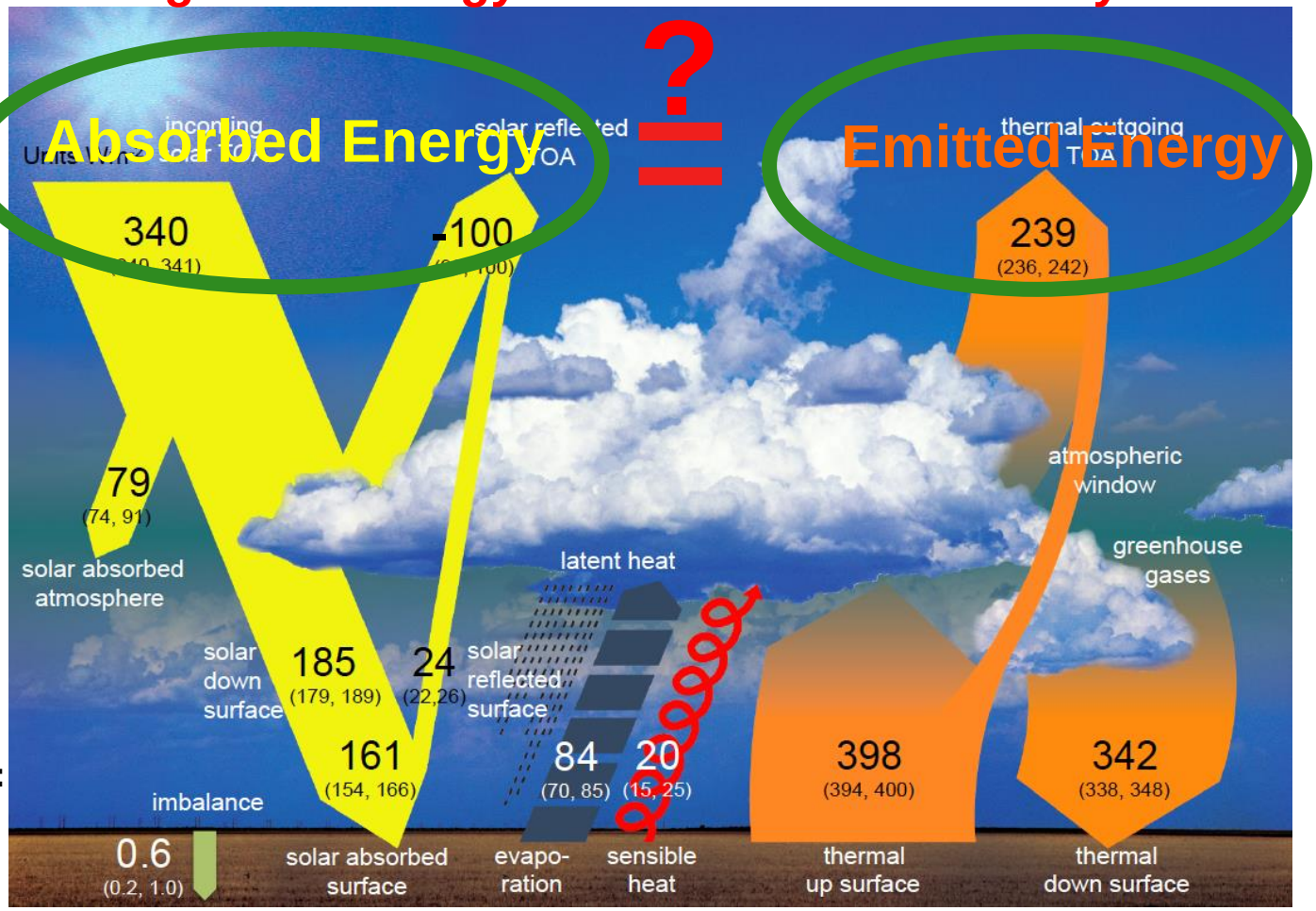


Units: Wm^{-2}

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

Earth radiation budget

Radiation balance at the Top of Atmosphere regulates energy content of the climate system



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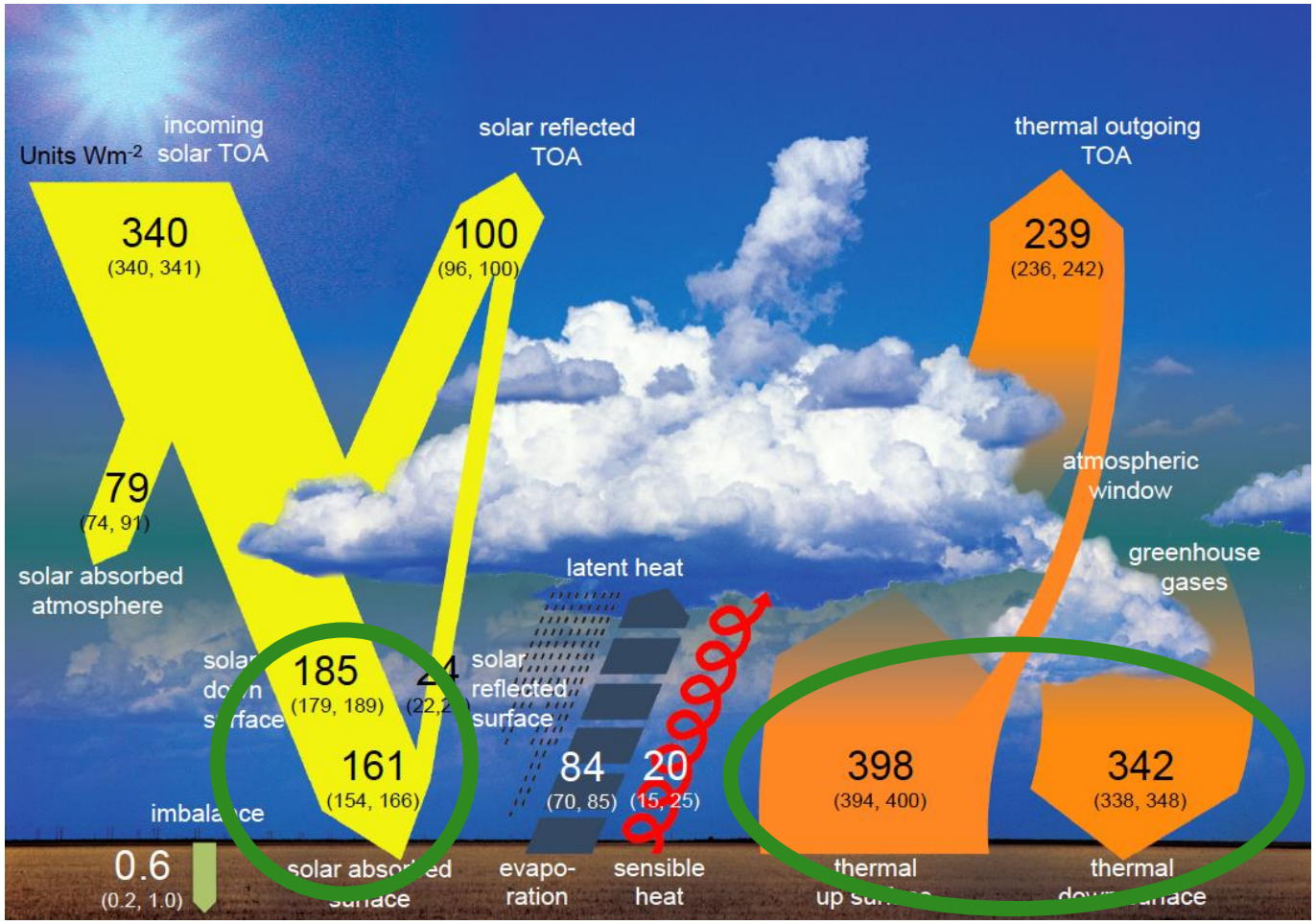
Wild et al. 2013 Clim.Dyn. / IPCC AR5

Earth radiation budget

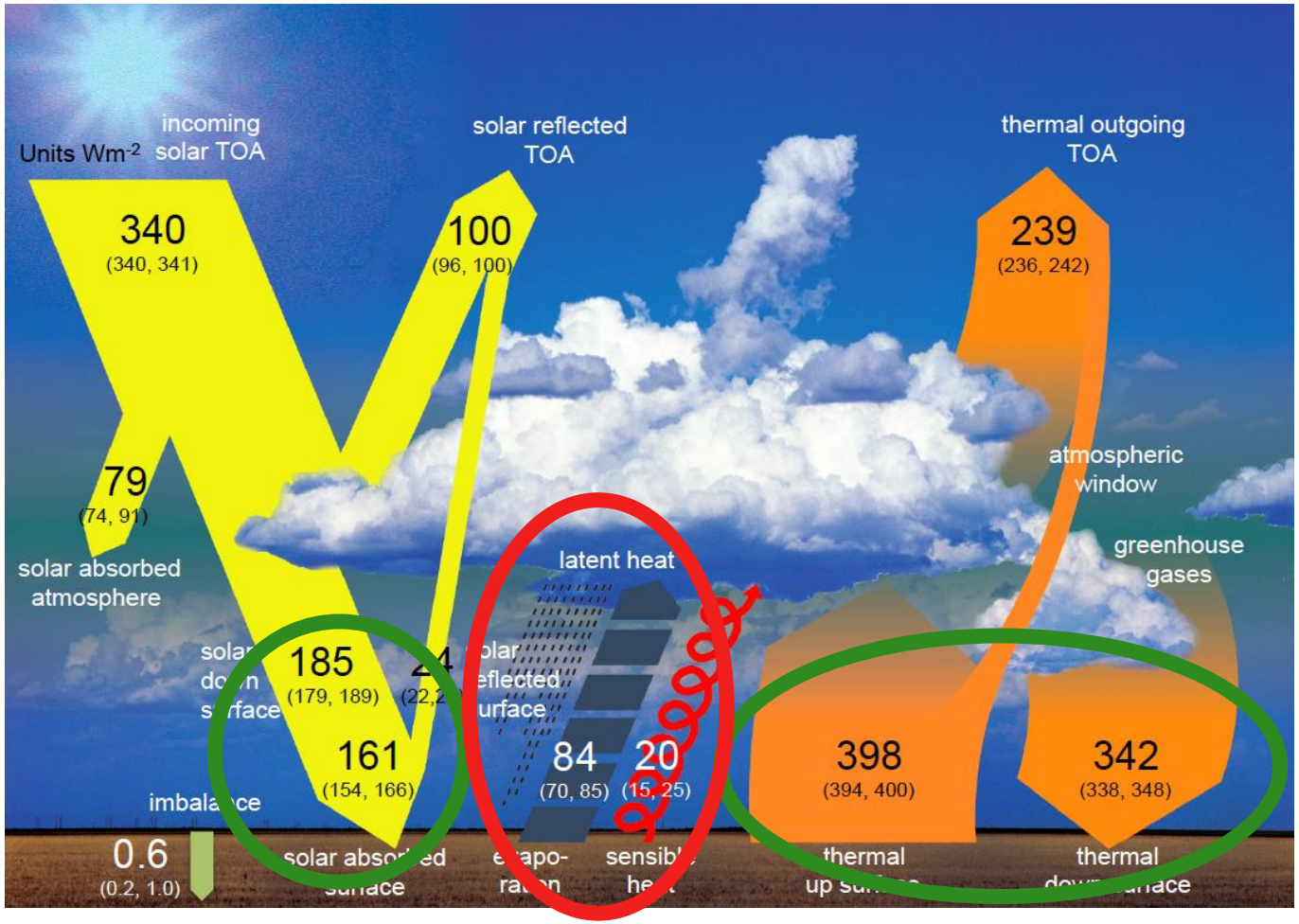


Units: Wm^{-2}

Radiation balance at the surface:

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

Earth radiation budget



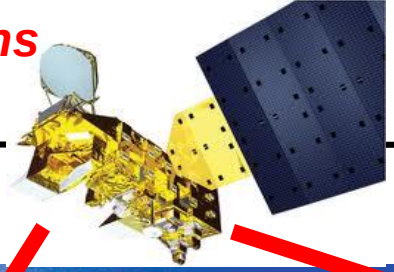
Units: Wm^{-2}

Radiation balance at the surface:
drives the global water cycle

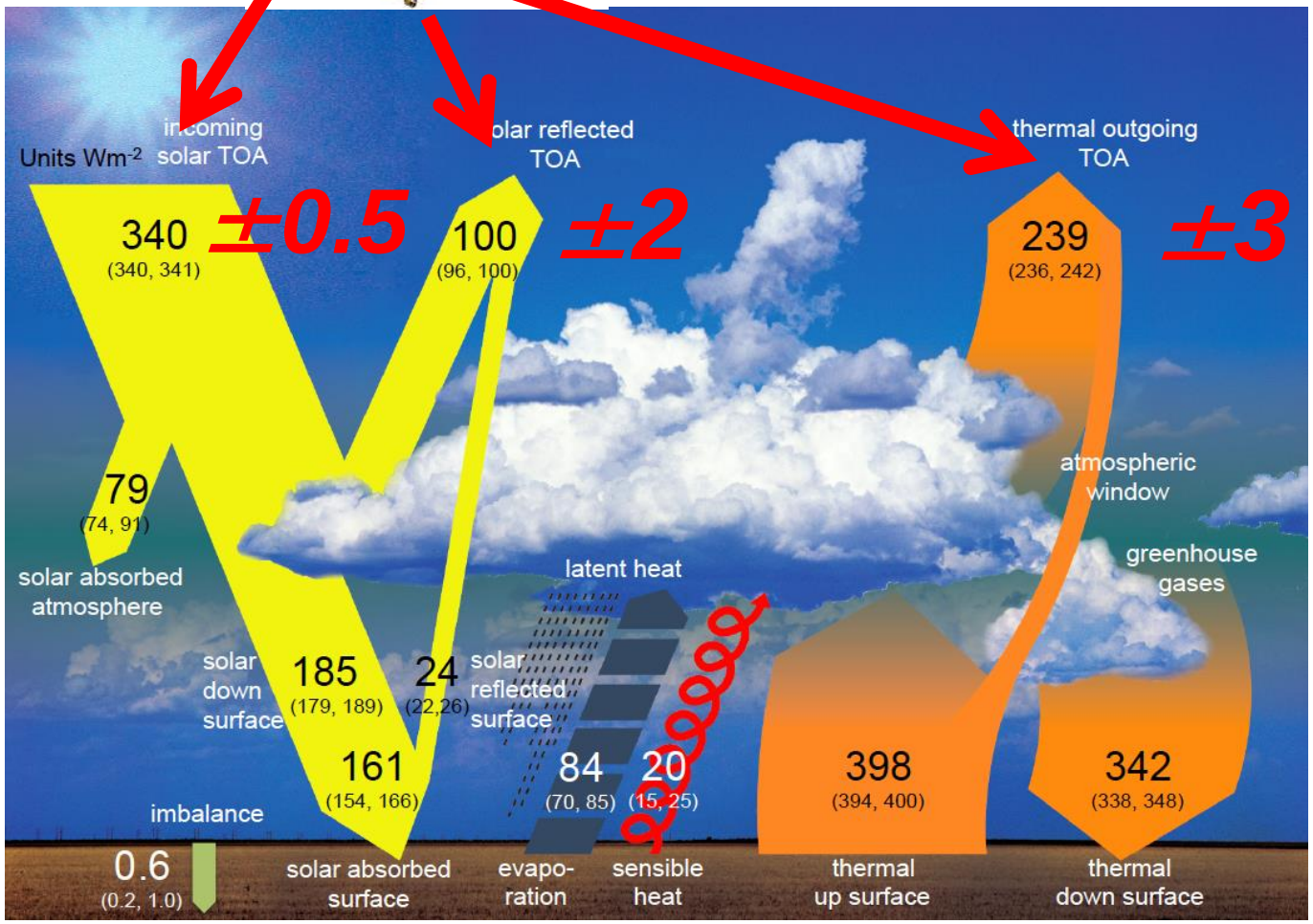
Wild et al. 2013 Clim.Dyn. / IPCC AR5

Satellite missions
CERES
SORCE

iation budget



Uncertainties



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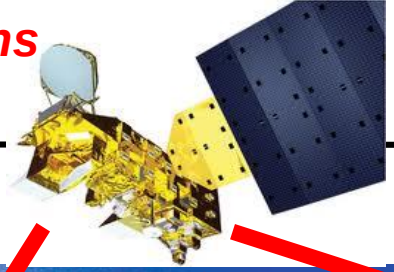
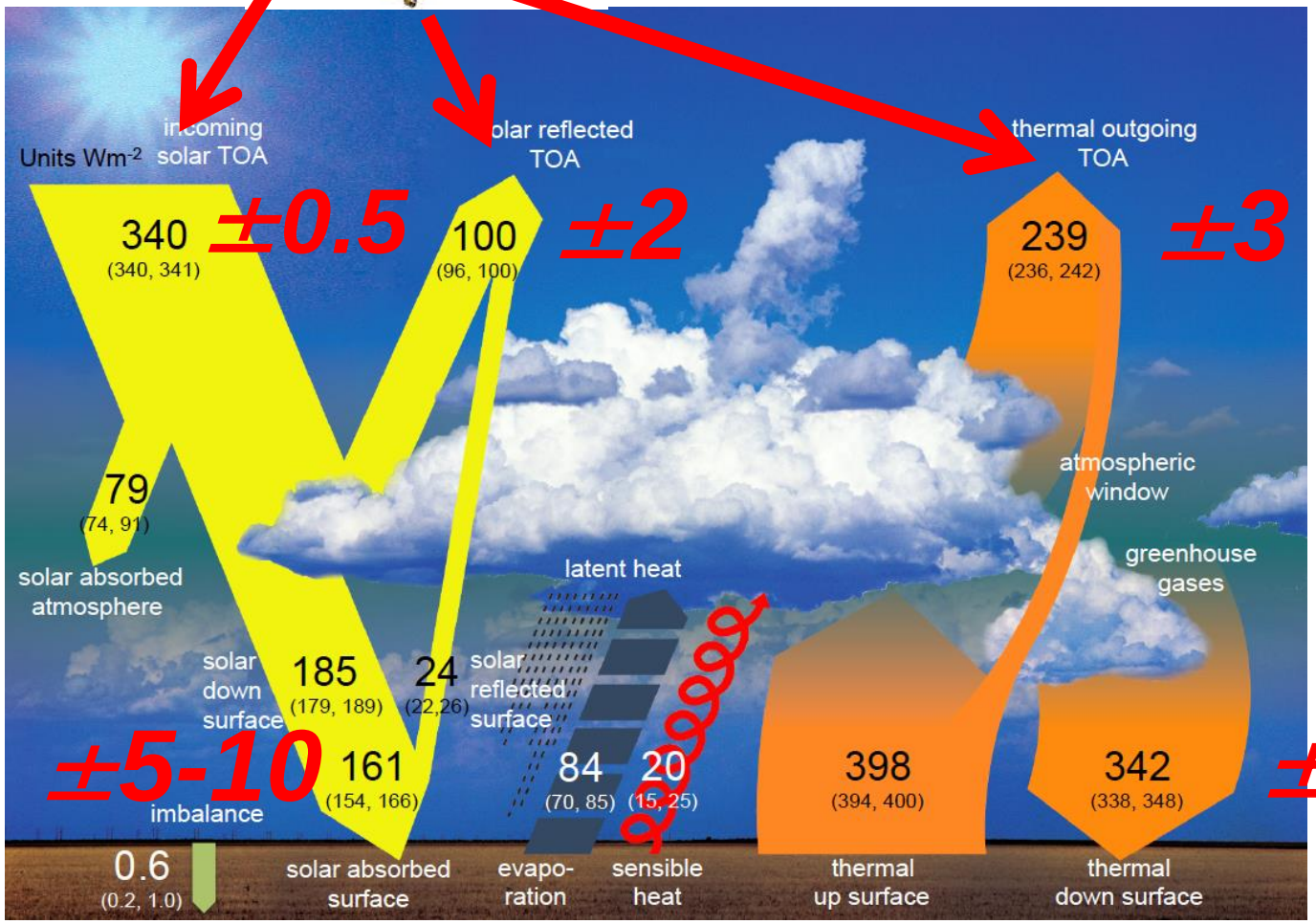
Wild et al. 2013 Clim.Dyn. / IPCC AR5

iation budget

Satellite missions
CERES
SORCE



Uncertainties



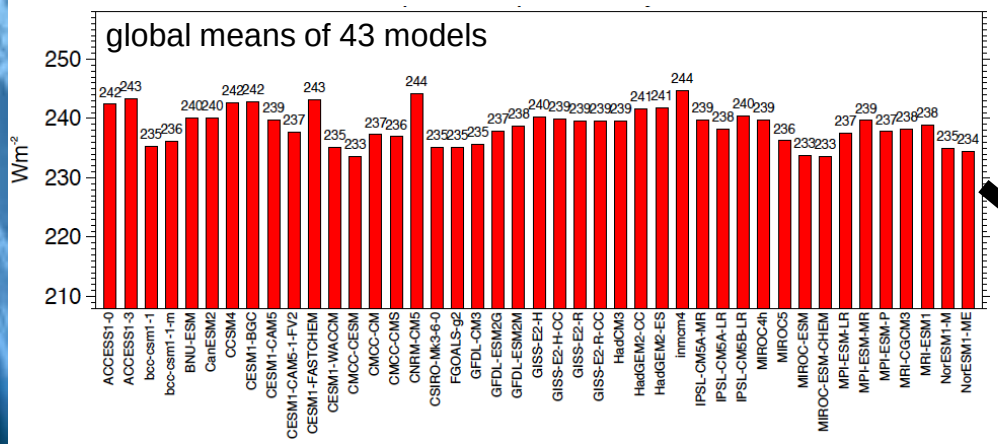
Units: Wm^{-2}

Surface radiation budget traditionally more uncertain than TOA budget

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

Shortwave radiation budgets in CMIP5 GCMs

Absorbed shortwave radiation
top of atmosphere

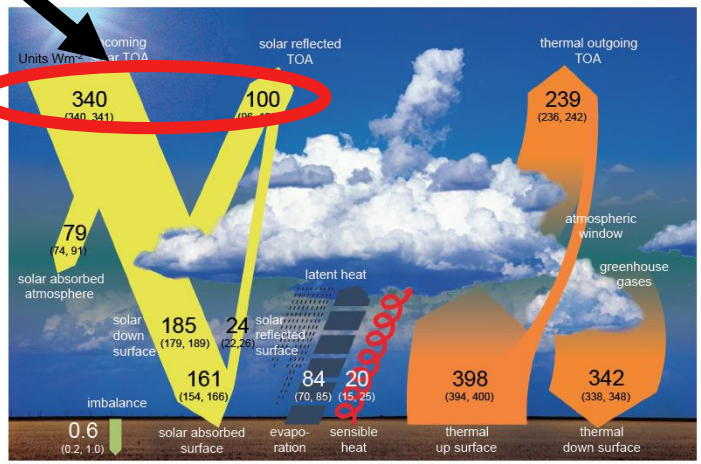


Model mean: 239 Wm^{-2}

Model range: 11 Wm^{-2} (4%)

Standard dev.: 3.0 Wm^{-2}

Reference Satellite Value (CERES EBAF): 240 Wm^{-2}



Wild et al. 2013, Climate Dynamics

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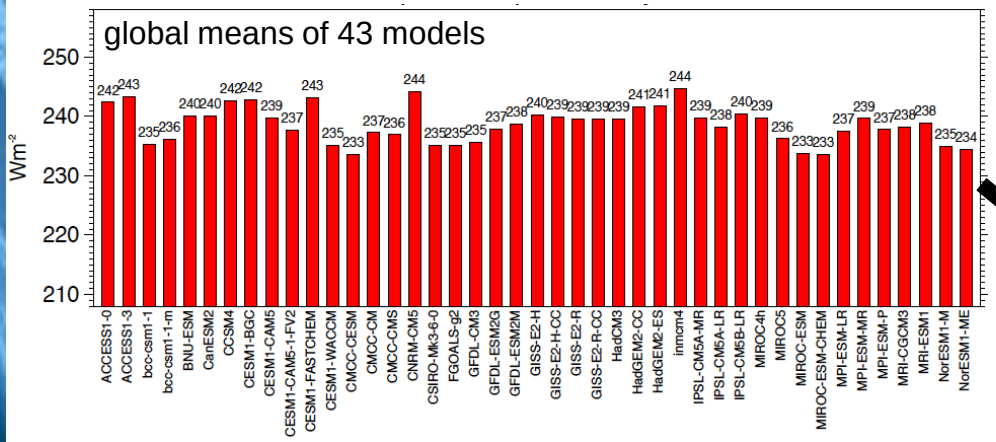
Shortwave radiation budgets in CMIP5 GCMs

Absorbed shortwave radiation
top of atmosphere



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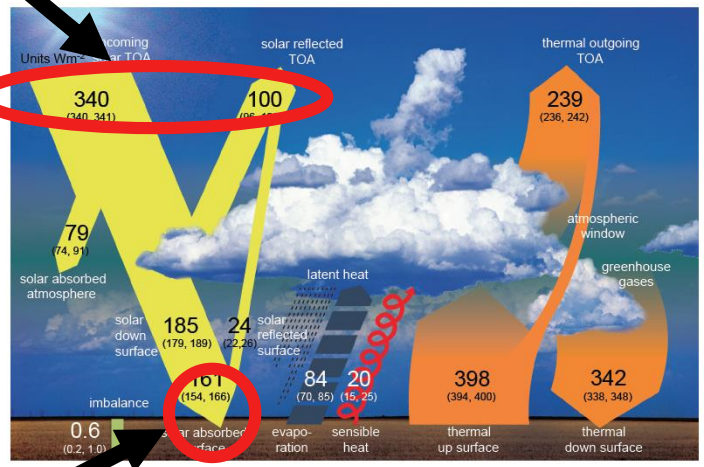
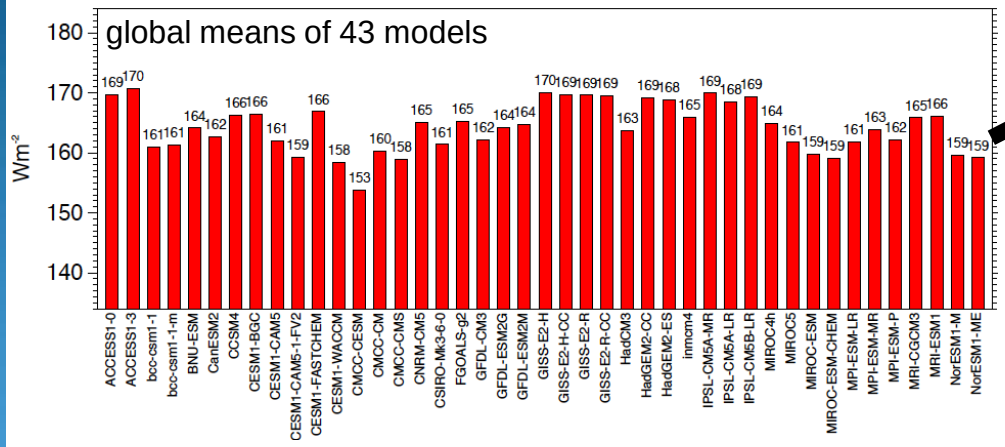


Absorbed shortwave radiation
surface



Model mean: 164 Wm^{-2}
Model range: 17 Wm^{-2} (10%)
Standard dev.: 4.1 Wm^{-2}

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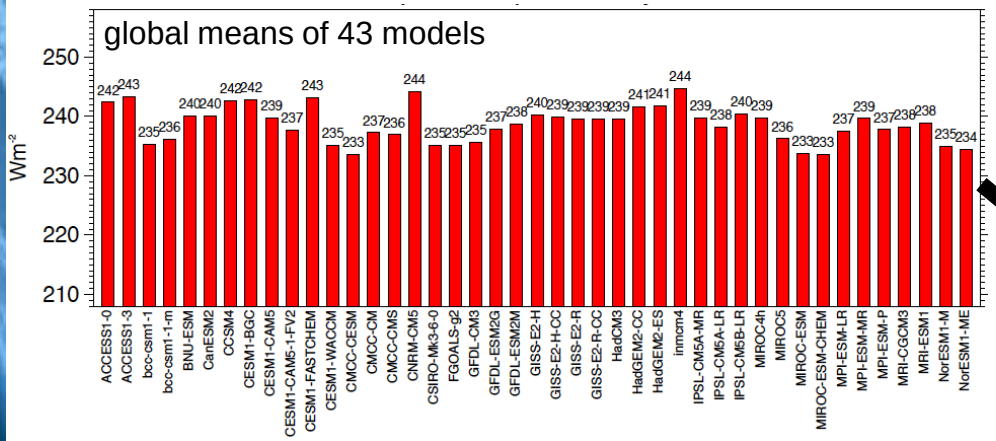
Shortwave radiation budgets in CMIP5 GCMs

Absorbed shortwave radiation
top of atmosphere



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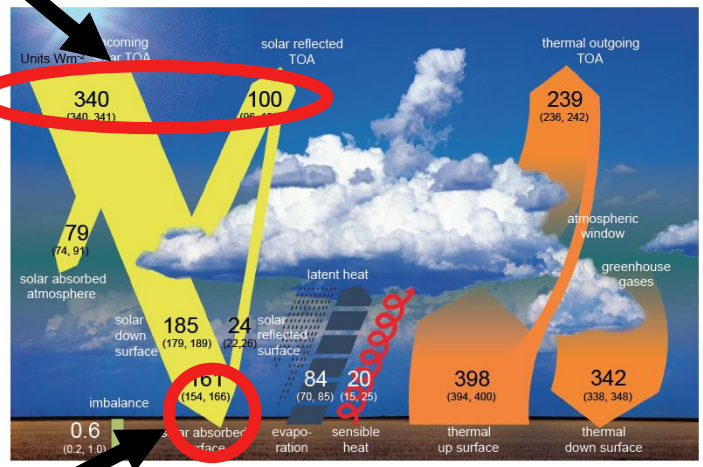
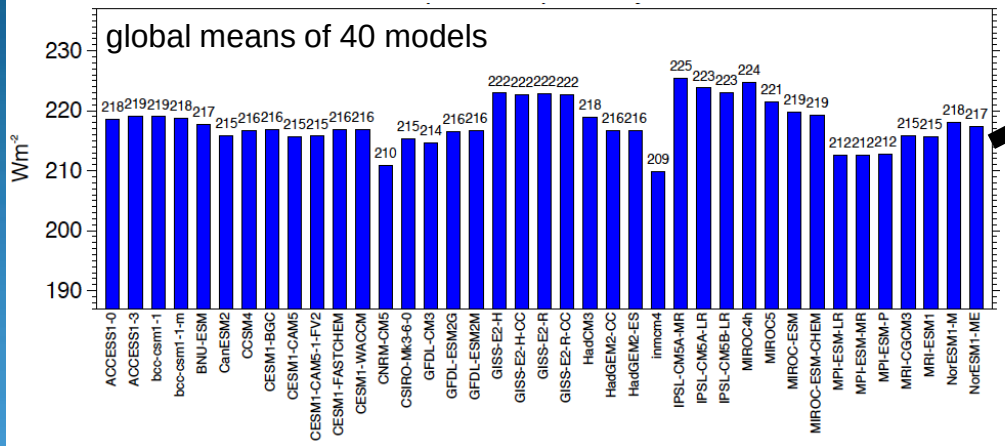


Absorbed shortwave radiation
surface cloud free



Model mean: 218 Wm^{-2}
Model range: 16 Wm^{-2}
Standard dev.: 3.7 Wm^{-2}

Wild et al. 2013, Climate Dynamics

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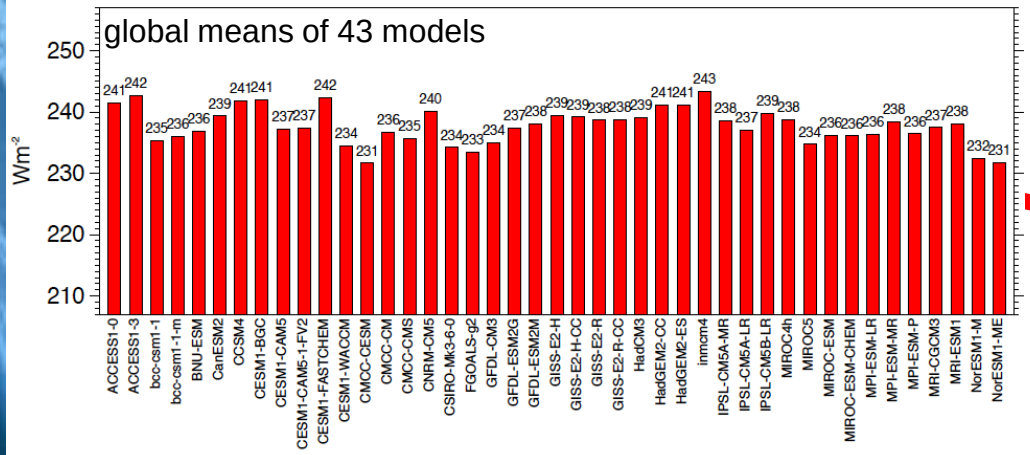
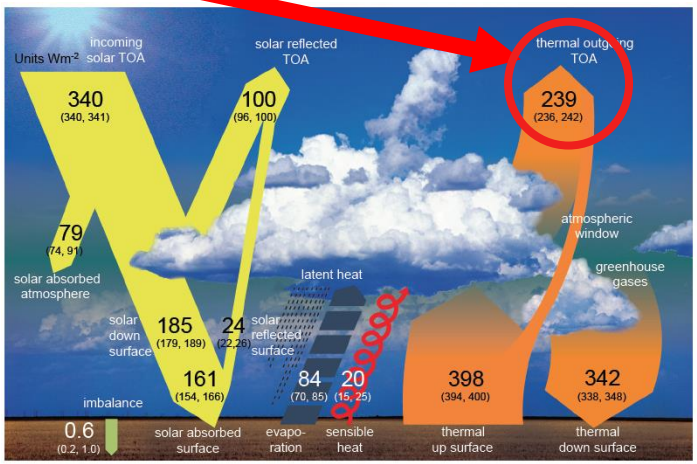
Longwave radiation budgets in CMIP5 GCMs

Outgoing longwave radiation
top of atmosphere



Multimodel mean 238 Wm^{-2}
Model range: 12 Wm^{-2}
Standard dev.: 2.9 Wm^{-2}

Reference Satellite Value (CERES EBAF): 239.8 Wm^{-2}



Wild et al. 2013, Climate Dynamics

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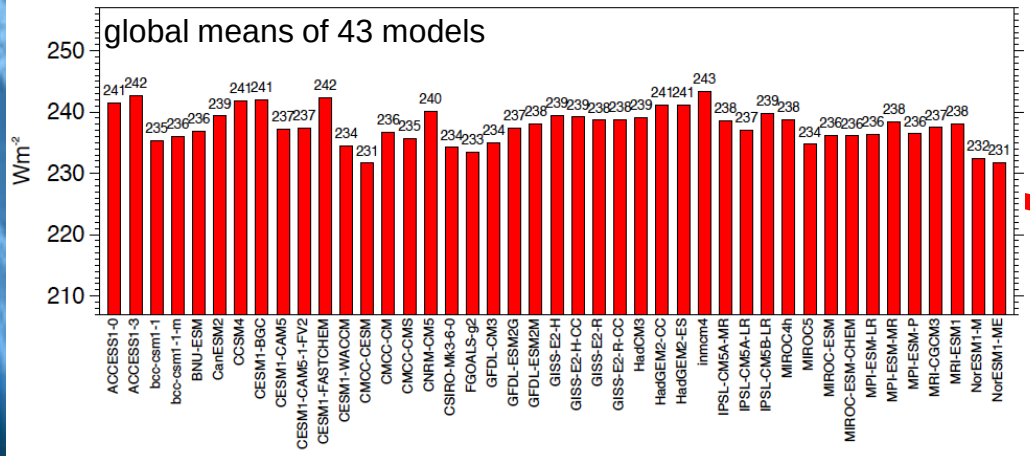
Longwave radiation budgets in CMIP5 GCMs

Outgoing longwave radiation
top of atmosphere



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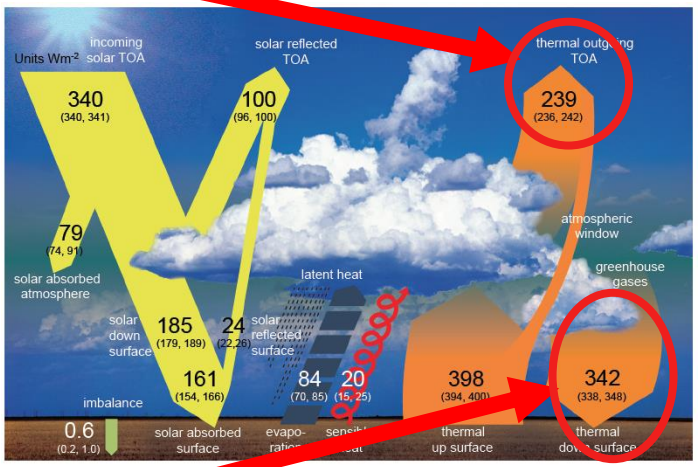
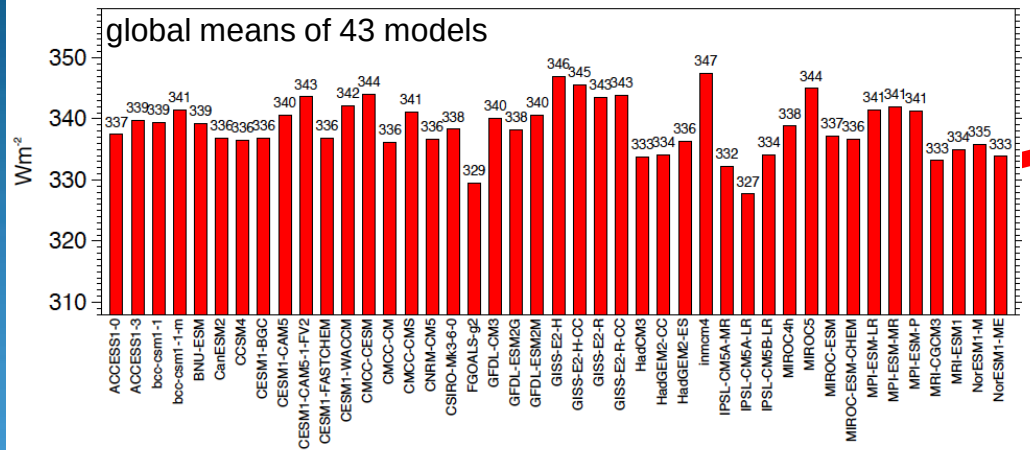


Downward longwave radiation
surface



Multimodel mean 339 Wm^{-2}
All sky model range: 20 Wm^{-2}
Standard dev.: 4.4 Wm^{-2}

Wild et al. 2013, Climate Dynamics

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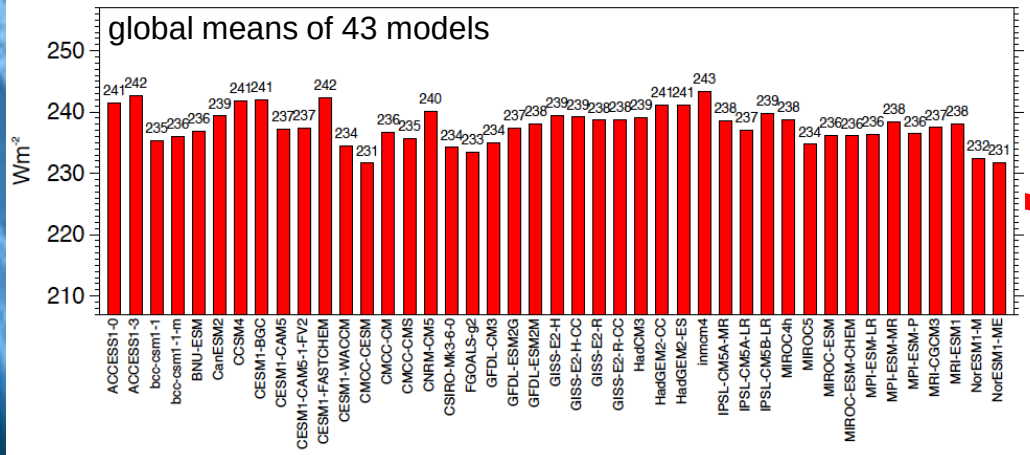
Longwave radiation budgets in CMIP5 GCMs

Outgoing longwave radiation
top of atmosphere



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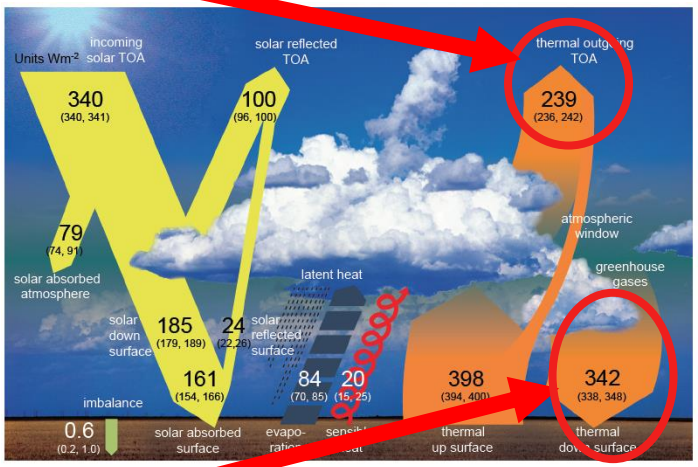
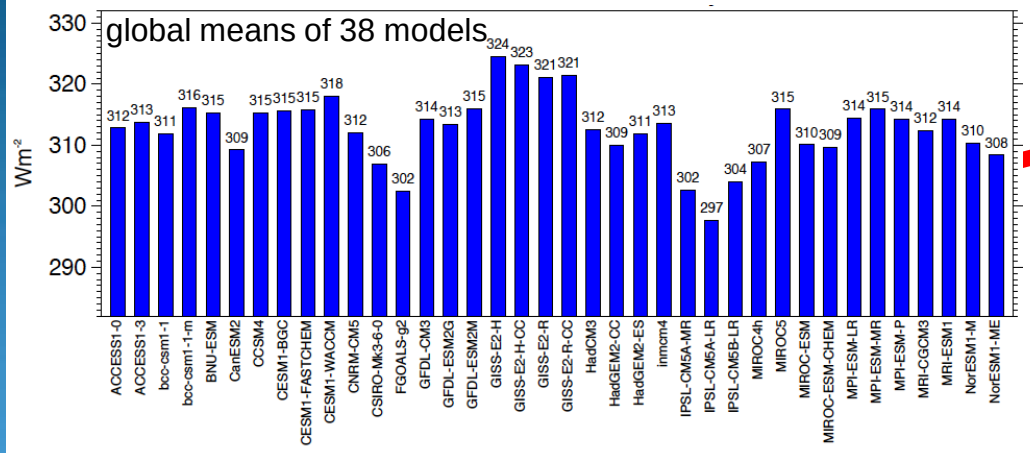


Downward longwave radiation
surface cloud free



Multimodel mean 313 Wm^{-2}
All sky model range: 27 Wm^{-2}
Standard dev.: 5.6 Wm^{-2}

Wild et al. 2013, Climate Dynamics

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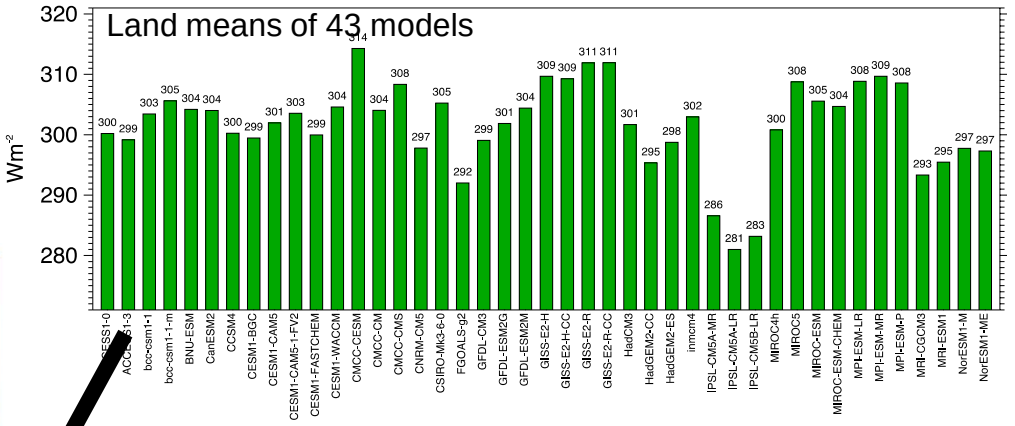
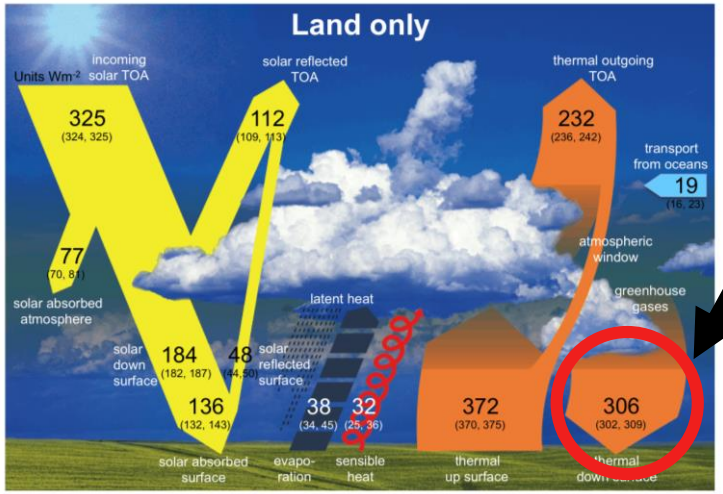
Land mean surface energy fluxes in CMIP5 GCMs

Model mean 302 Wm^{-2}
Model range: 33 Wm^{-2}
Standard dev.: 7.2 Wm^{-2}

Downward longwave radiation surface





Wild et al. 2015, Climate Dynamics

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Land mean surface energy fluxes in CMIP5 GCMs

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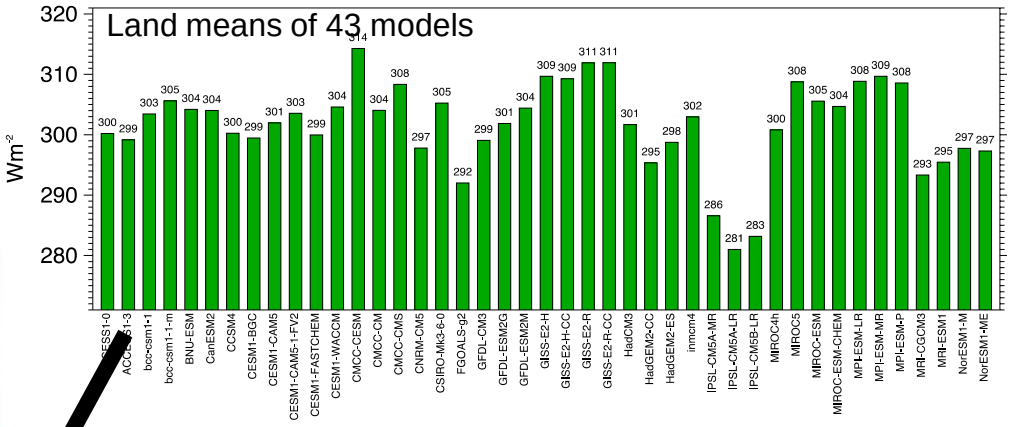
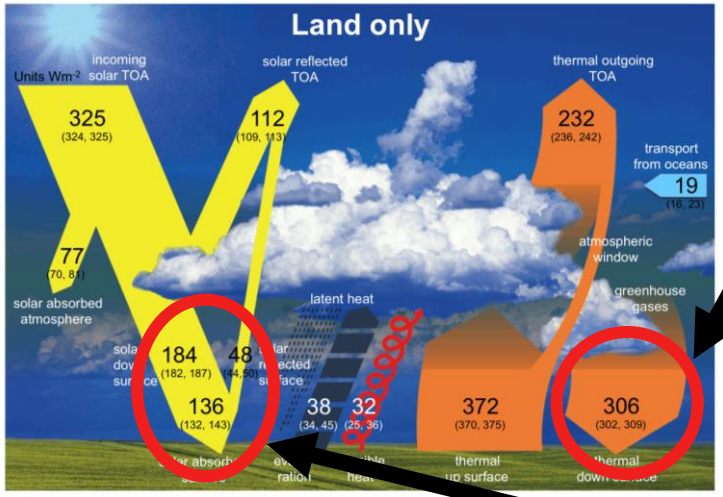
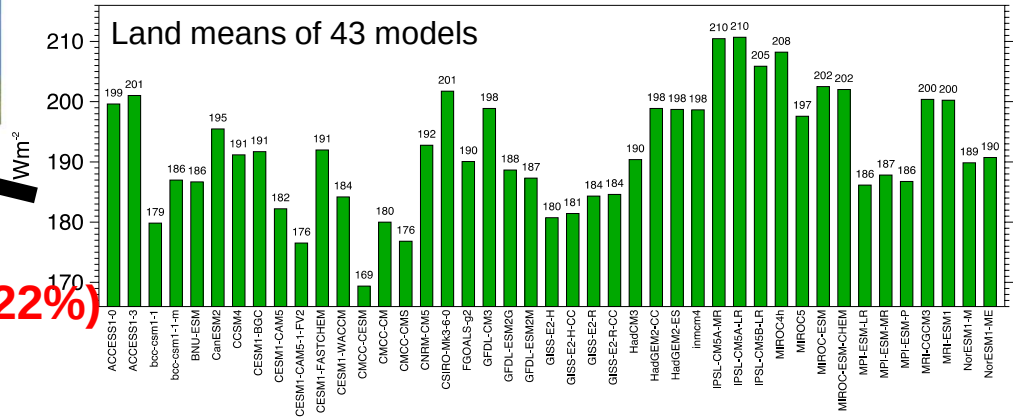




Downward shortwave radiation surface



Model mean: 192 Wm^{-2}
Model range: 42 Wm^{-2} (22%)
Standard dev.: 10 Wm^{-2}

⇒ ***Particularly large discrepancies in land mean downward radiative fluxes in CMIP5 models*** Wild et al. 2015, Climate Dynamics

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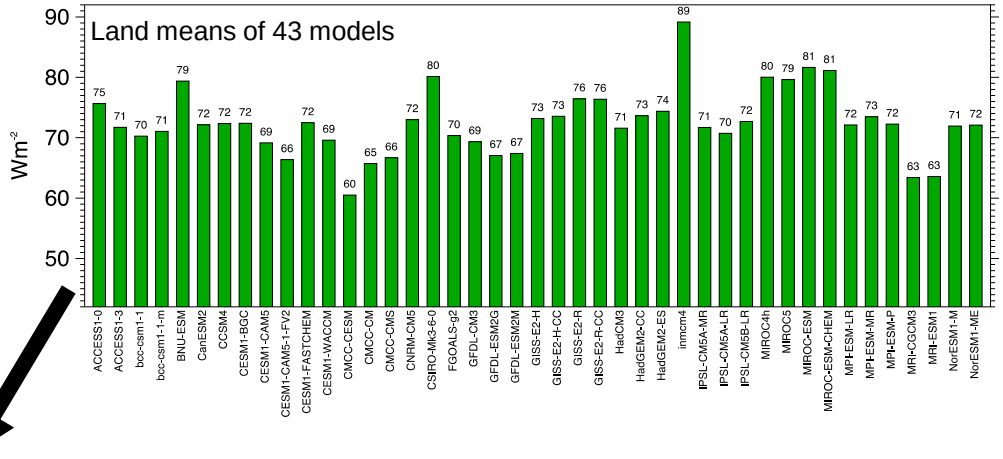
Land mean surface energy fluxes in CMIP5 GCMs

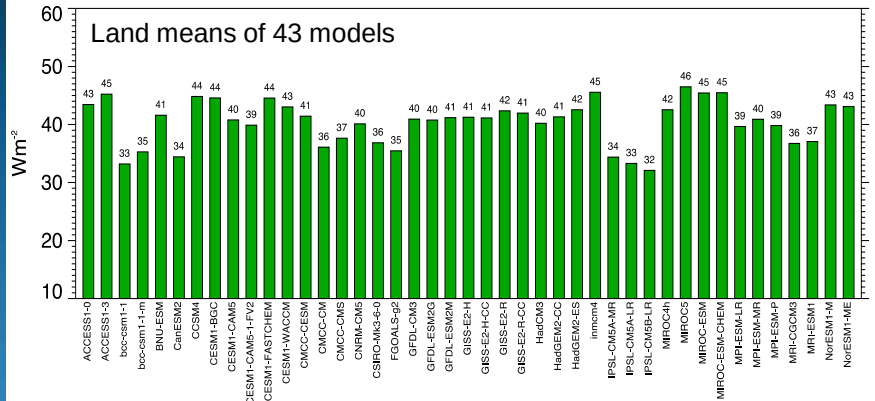
Wild et al. 2015, Climate Dynamics

Land mean surface net radiation



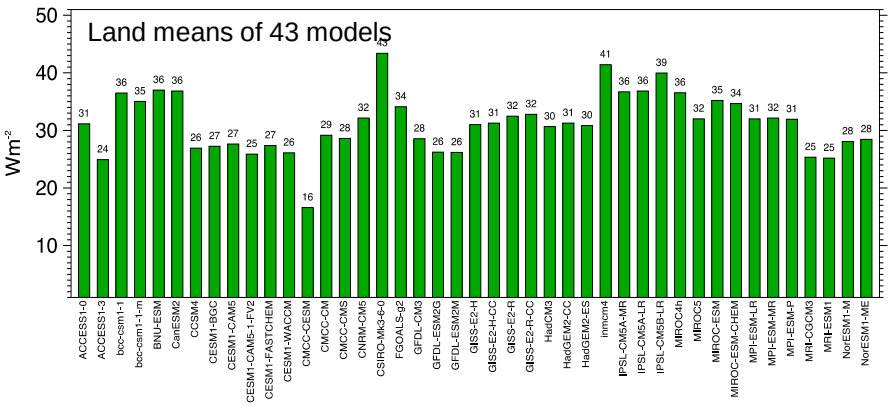
Model mean 73 Wm^{-2}
Model range 29 Wm^{-2} (40%)

Land mean latent heat flux



Model mean 40 Wm^{-2}
Model range 14 Wm^{-2} (36%)

Land mean sensible heat flux



Model mean 31 Wm^{-2}
Model range 27 Wm^{-2} (86%)

=> Uncertainties in radiative fluxes in CMIP5 models affects energy available for sensible and latent heat fluxes

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Implications

Discrepancies in surface radiation budget components of state of the art climate models (CMIP5) still large
e.g. land mean downward solar radiation differs by more than 40 Wm^{-2}

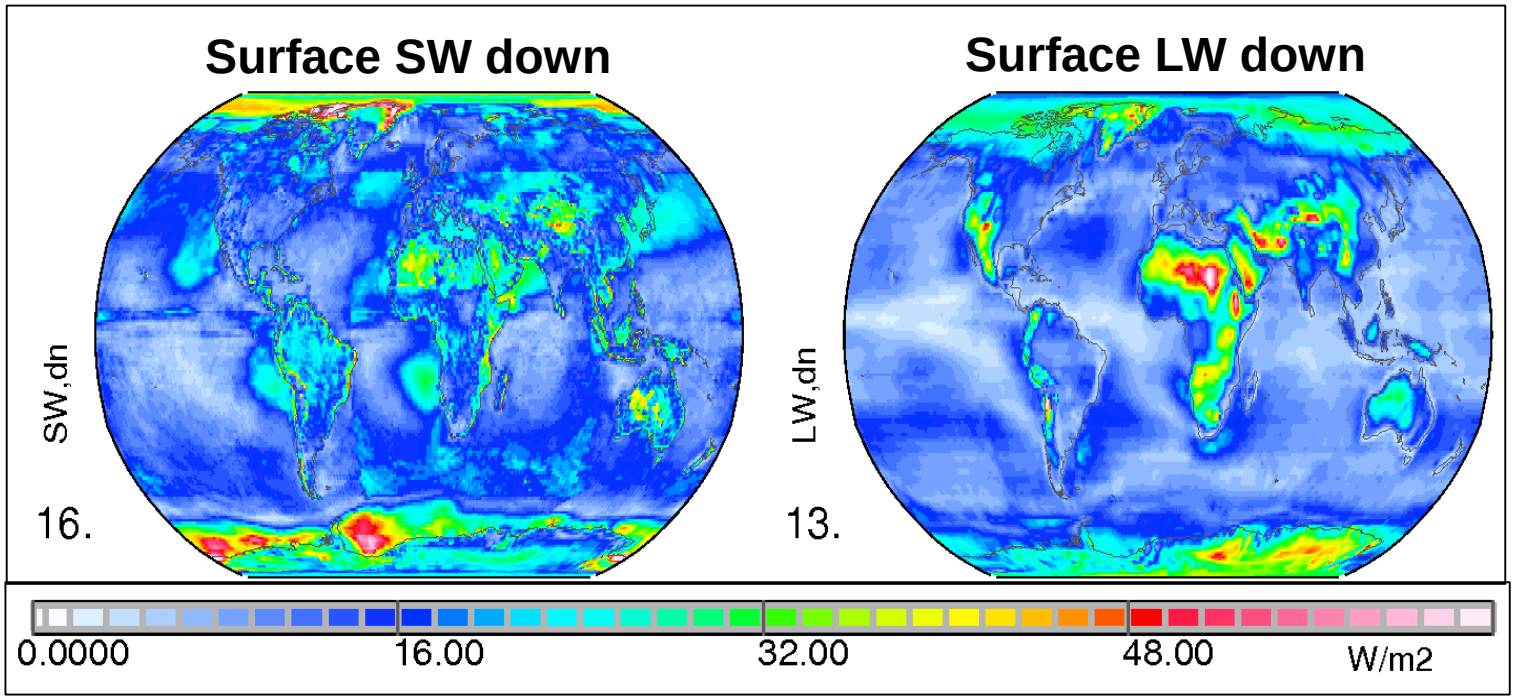
=> hampers realistic simulation of surface climates and adequate energy exchanges with other climate system components (e.g., oceans, biosphere, cryosphere)

=> observational references required to better constrain these fluxes:

- satellite-derived products
- direct surface observations (focus of this presentation)

Constraints from satellite-derived surface products

Range of 3 satellite-derived products (SRB, ISCCP, CERES)

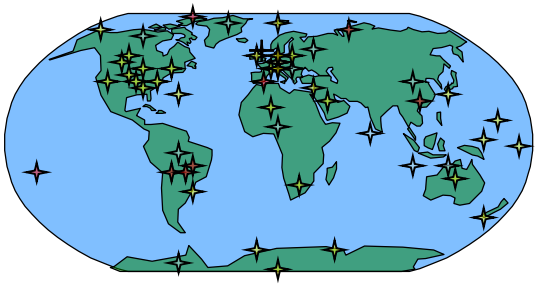


Courtesy of E. Raschke, S. Kinne 2014

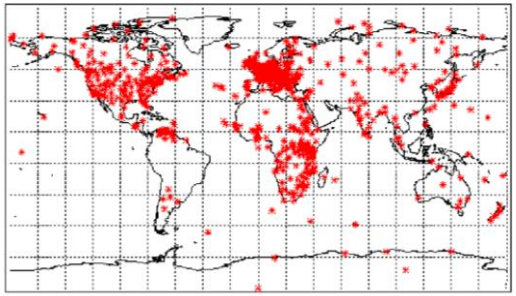
Outcome from GEWEX radiative flux assessment (RFA, P. Stackhouse et al.):

- Satellite-derived surface downward radiation products of SRB, CERES, ISCCP (not latest versions!) differ considerably (> 10% at many locations)
- Necessity for direct observations as anchor sites

Constraints from surface radiation observations



Ohmura et al. 1998



Ohmura, Gilgen, Wild 1989

BSRN
Baseline Surface Radiation Network

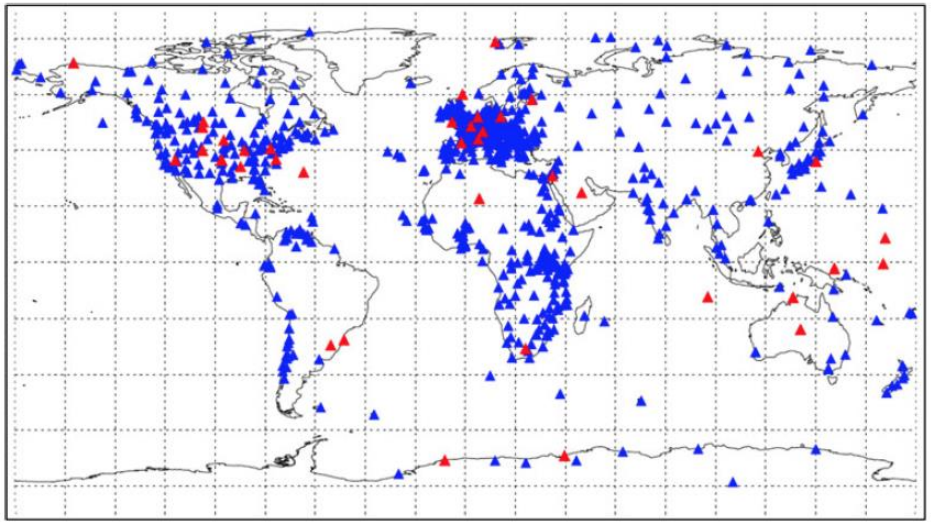
- WCRP initiative, starting in 1992
- Highest measurement quality at selected sites worldwide (currently 51 anchor sites)
- network-wide calibration standards and standardized operating procedures
- Minute values
- Ancillary data for radiation interpretation

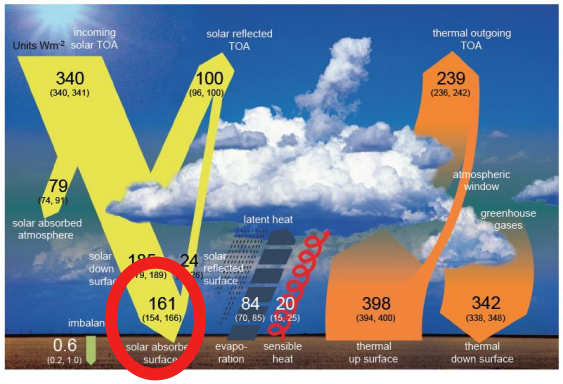
GEBA
Global Energy Balance Archive

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

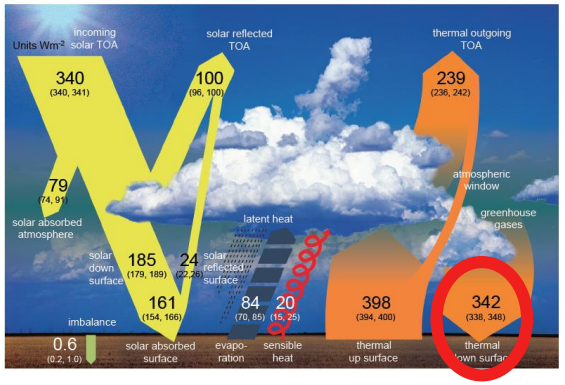
Evaluation of CMIP5 surface radiation balance

Long-term observation sites from GEBA and BSRN





SW_{down} against 760 GEBA sites
42 BSRN sites



LW_{down} against 41 BSRN sites

Wild et al. 2013, Climate Dynamics

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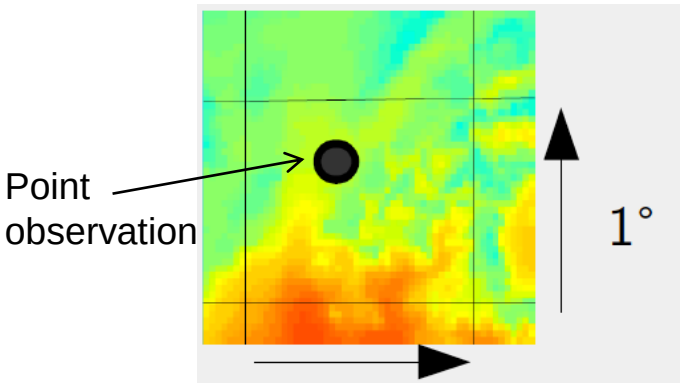
Comparing point observations with gridded data

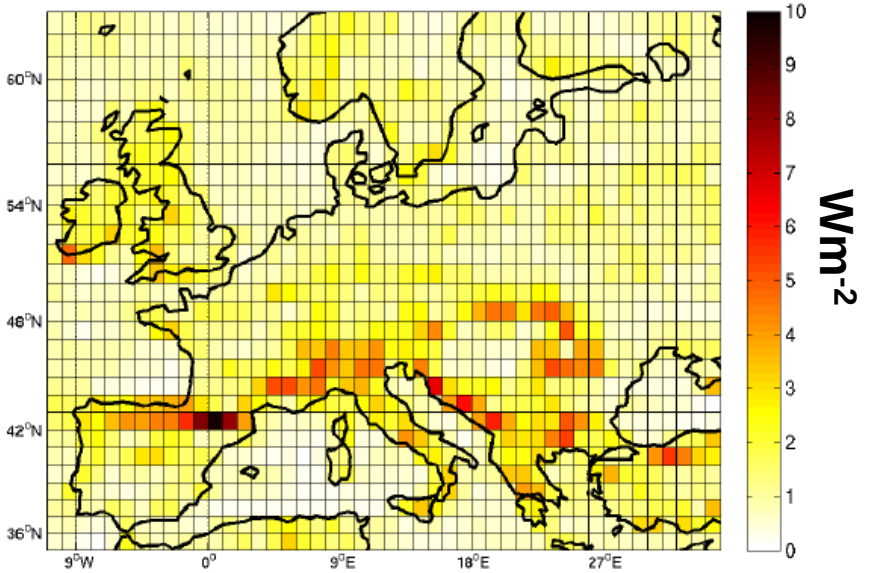
- ***Challenge:*** ***What is the error when comparing point observations and gridded datasets?***

  => requires knowledge on subgrid variability within gridbox



How representative is a point observation for an entire gridbox?

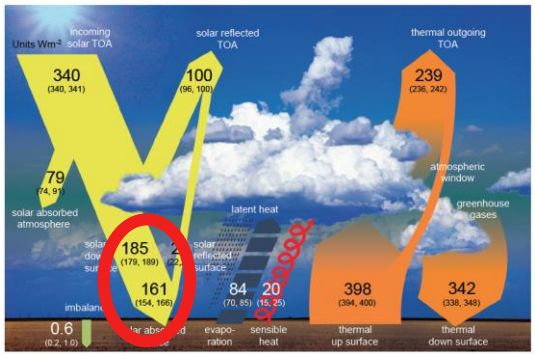
Subgrid variability in 1° solar radiation dataset



Use of high resolution (0.03°) CMSAF/Meteosat surface solar radiation product to estimate spatial subgrid variability in coarser grids (e.g. CERES 1° grid) => Estimated clim. mean absolute bias (deviation of local point observation from 1° grid mean) is **~3 Wm^{-2}**
(Hakuba et al. 2013)

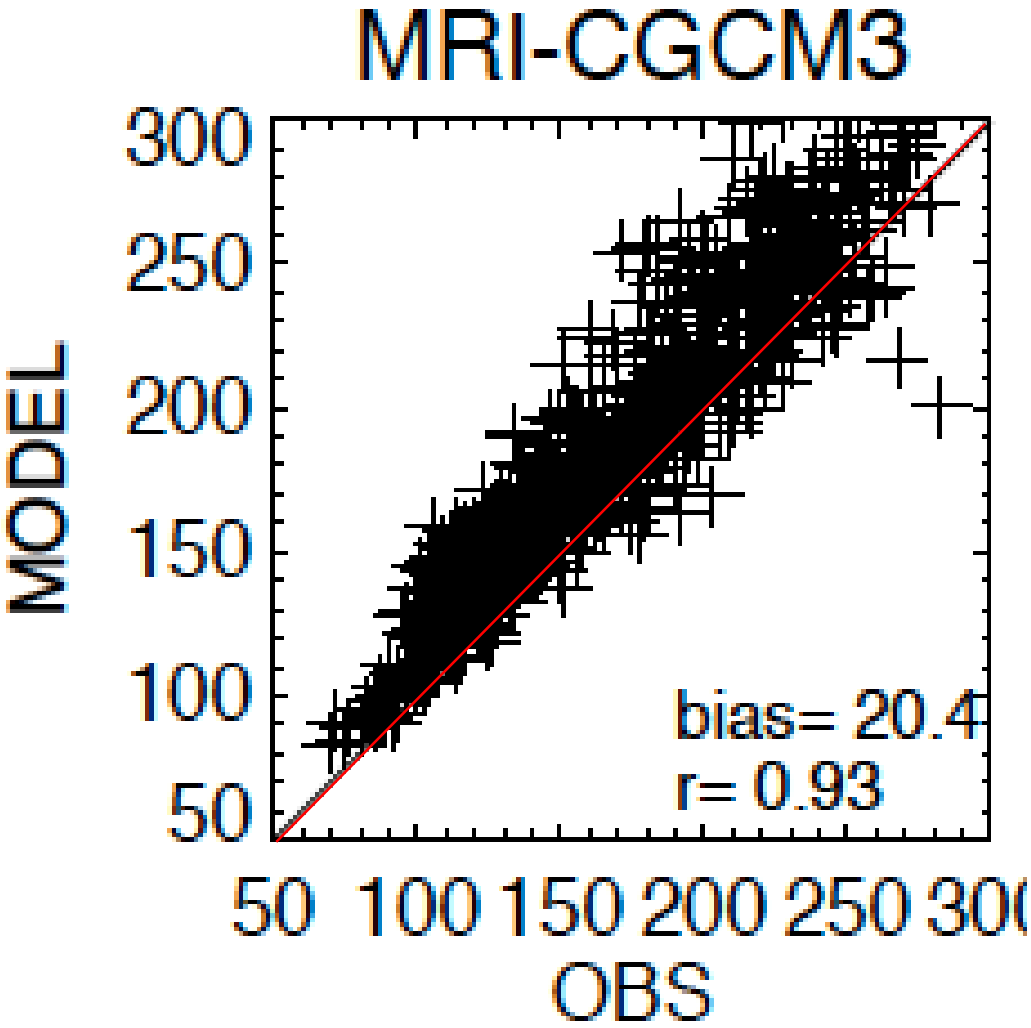
Hakuba, Folini, Sanchez-Lorenzo, Wild, 2013: Spatial representativeness of ground-based solar radiation measurements, *J. Geophys. Res.,* 118.

Evaluation of CMIP5 surface radiation balance



SW down

760 GEBA sites

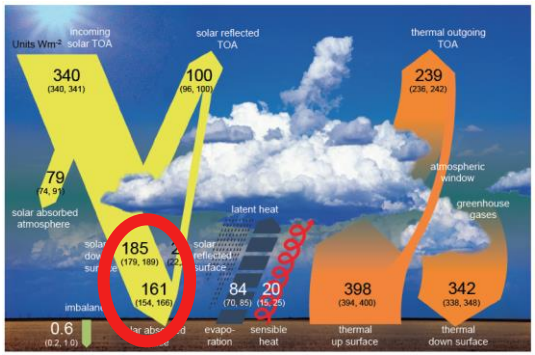


Constraining surface fluxes with GEBA obs:

Most models overestimate surface SW down

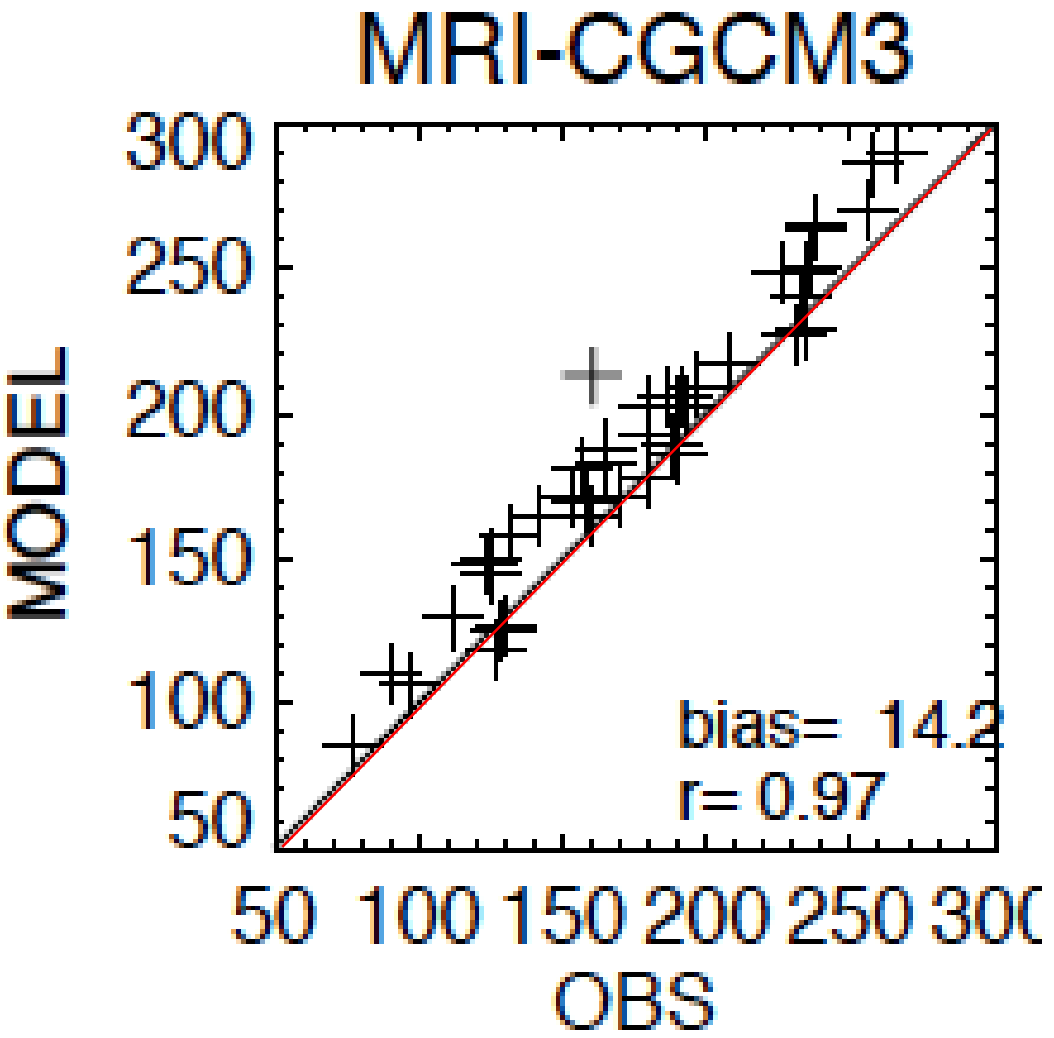
Wild et al. 2013, Climate Dynamics

Evaluation of CMIP5 surface radiation balance



SW down

42 BSRN sites

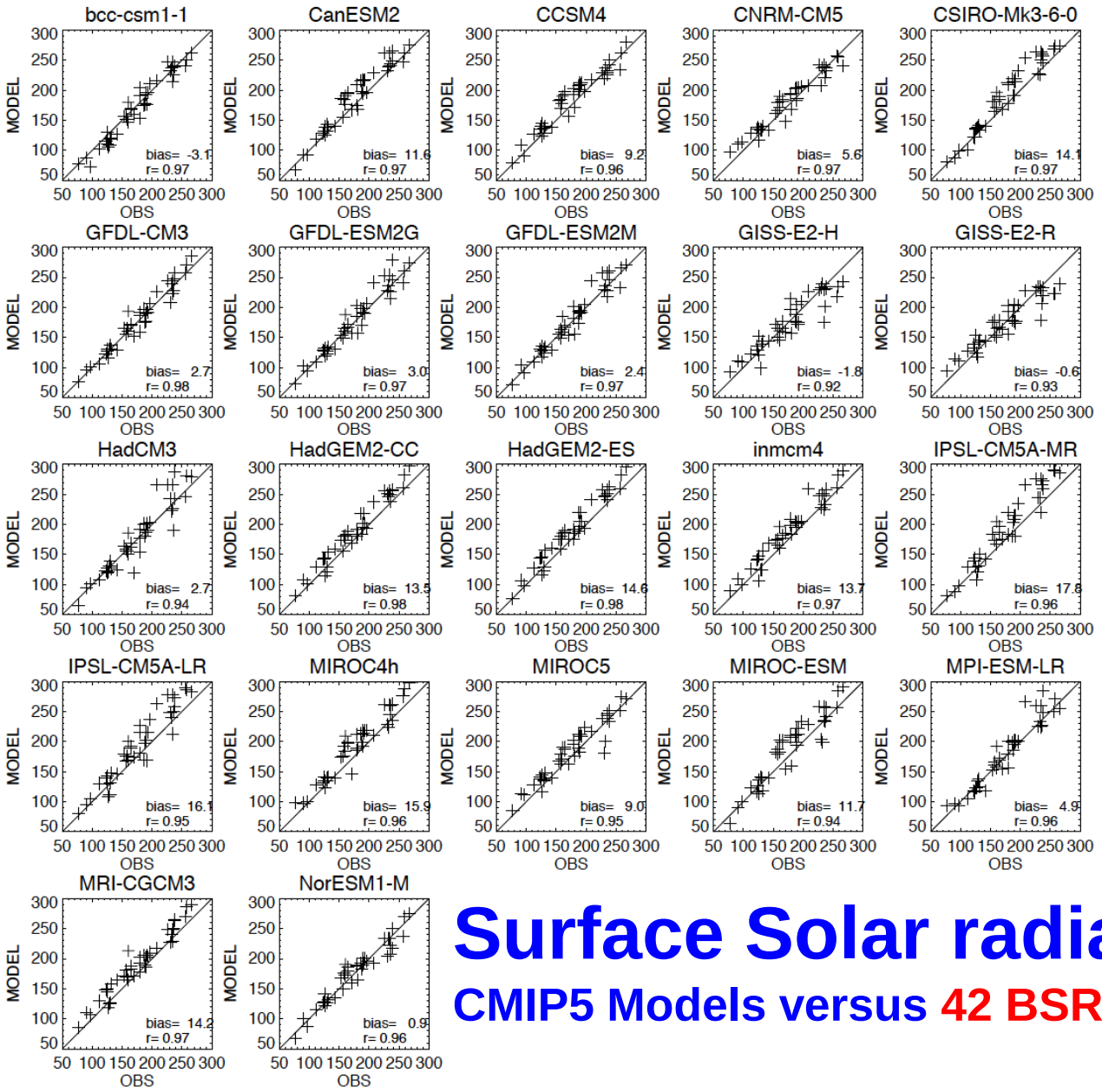


Constraining surface fluxes with BSRN obs:

Most models overestimate surface SW down

Wild et al. 2013, Climate Dynamics

Evaluation of CMIP5 surface radiation balance

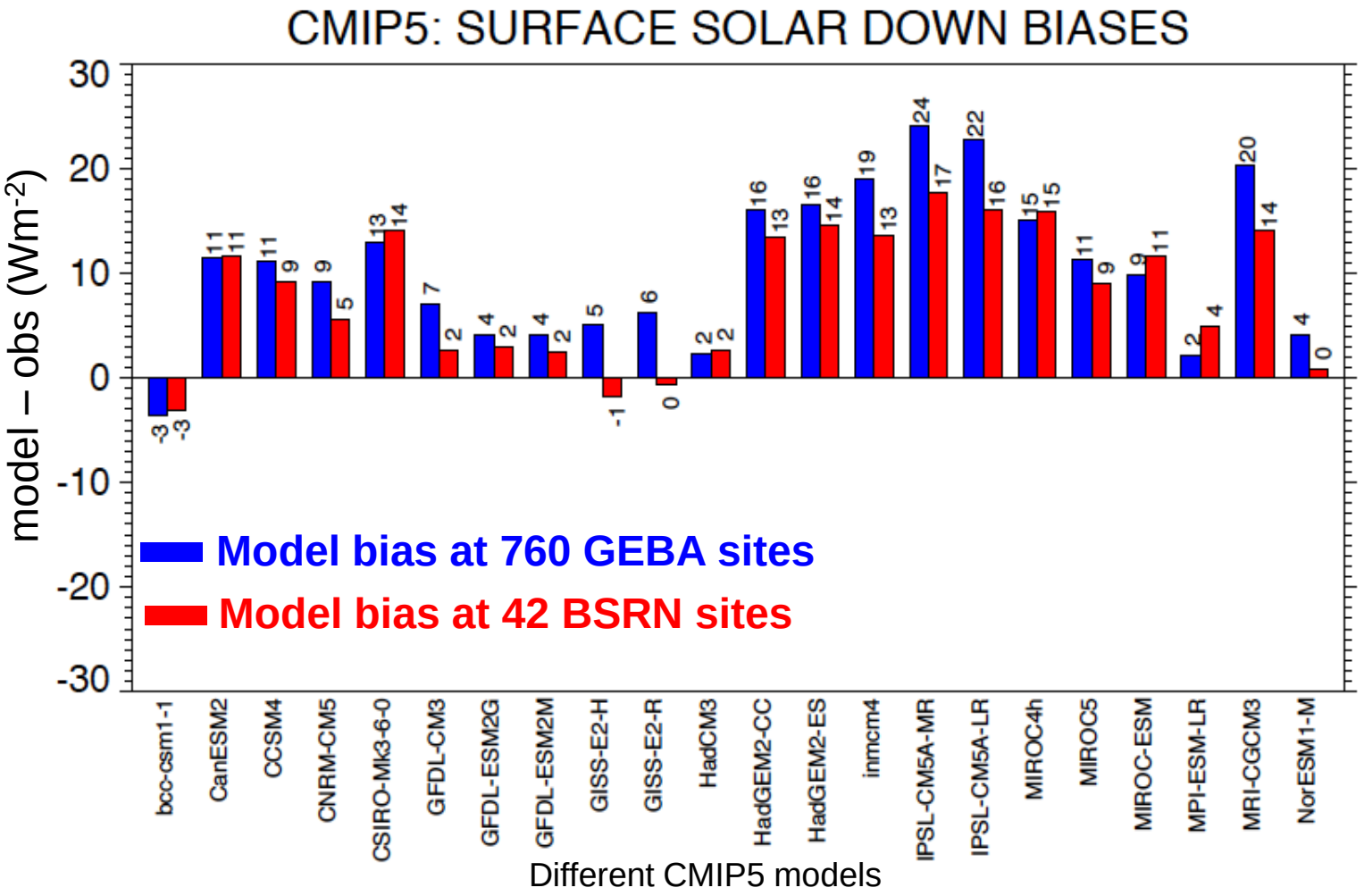


Surface Solar radiation:

CMIP5 Models versus 42 BSRN stations

ETH Institute for Atmospheric and Climate Science

Evaluation of CMIP5 surface radiation balance



Multimodel mean bias SW_{down} at 760 GEBA sites:+10 Wm^{-2}

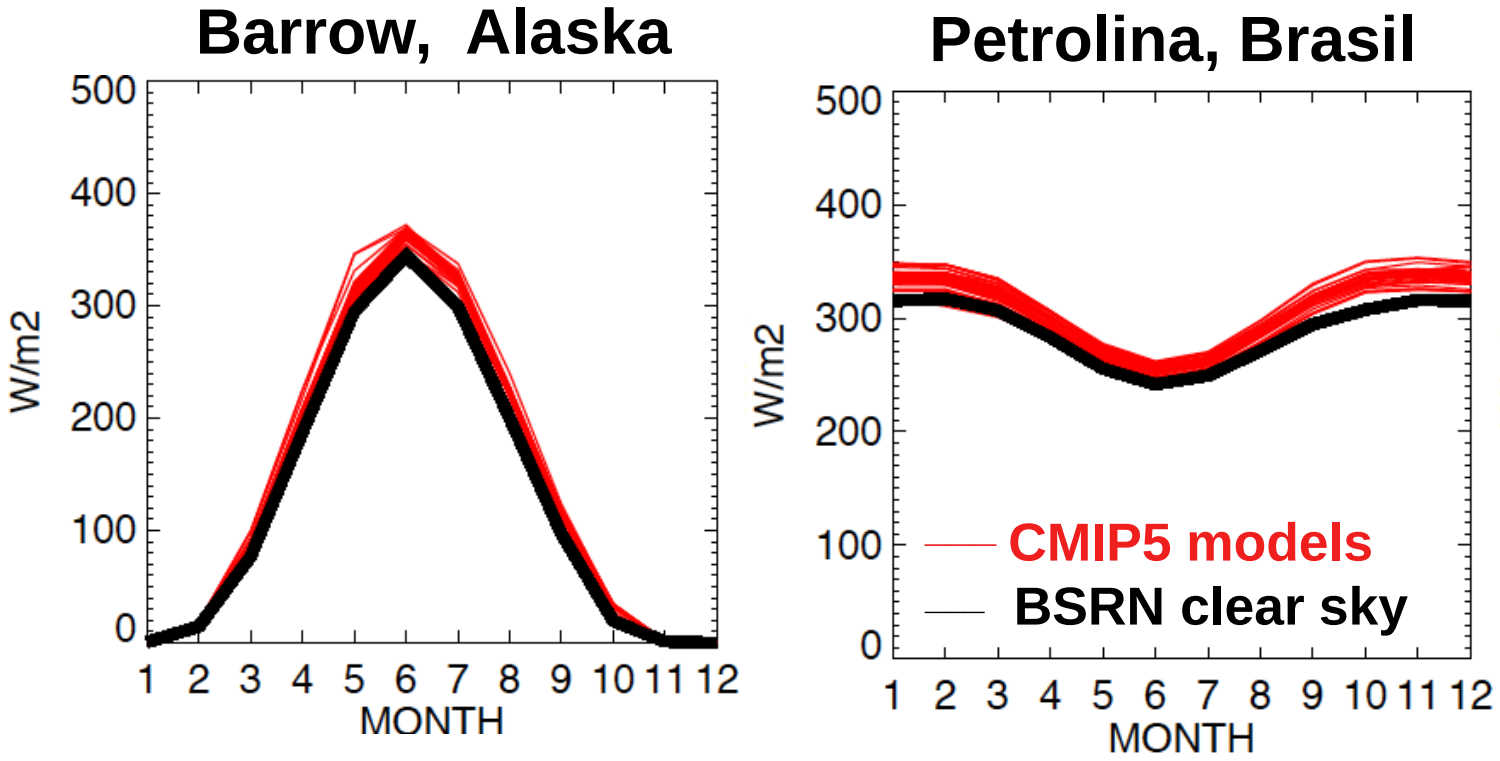
Multimodel mean bias SW_{down} at 42 BSRN sites:+8 Wm^{-2}

Wild et al. 2013, Climate Dynamics

Evaluation of surface SW clear sky fluxes

Analysis of SW clear sky fluxes:

Clear sky SW reference climatologies determined from BSRN minute data using Long and Ackermann (2000) clear sky detection algorithm



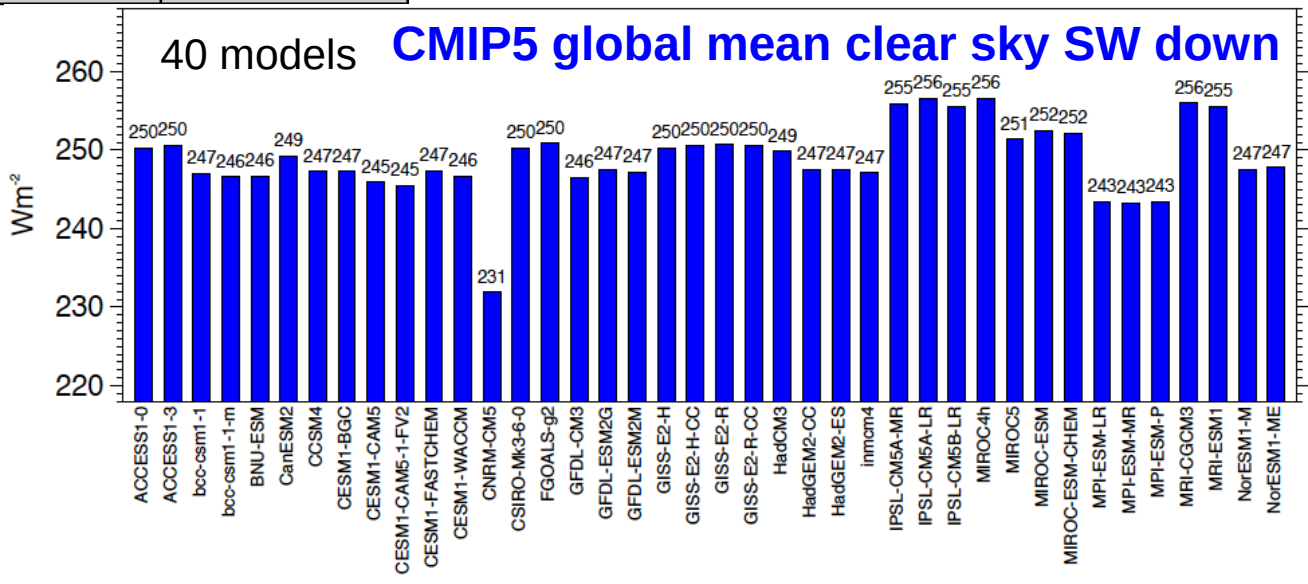
- ***Clear sky SW_{down} traditionally overestimated in climate models***
- ***caused by too transparent cloud-free atmospheres***

Updated from Wild et al. 2006, *JGR*

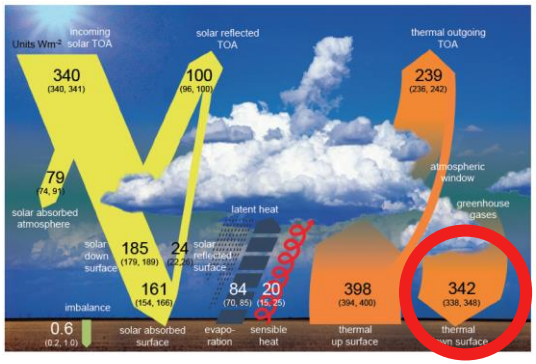
Evaluation of surface SW clear sky fluxes

Model Generation	Multimodel global mean $SW_{down\ clearsky}$	Overall bias at BSRN sites
AMIP II (representing 1990s)	**255** Wm^{-2}	**+7** Wm^{-2}
CMIP3 (early 2000s)	**253** Wm^{-2}	**+5** Wm^{-2}
CMIP5 (2010s)	**250** Wm^{-2}	**+2** Wm^{-2}

Tendency towards reduced SW_{down} under cloud-free conditions in newer model generations, in better agreement with surface observations

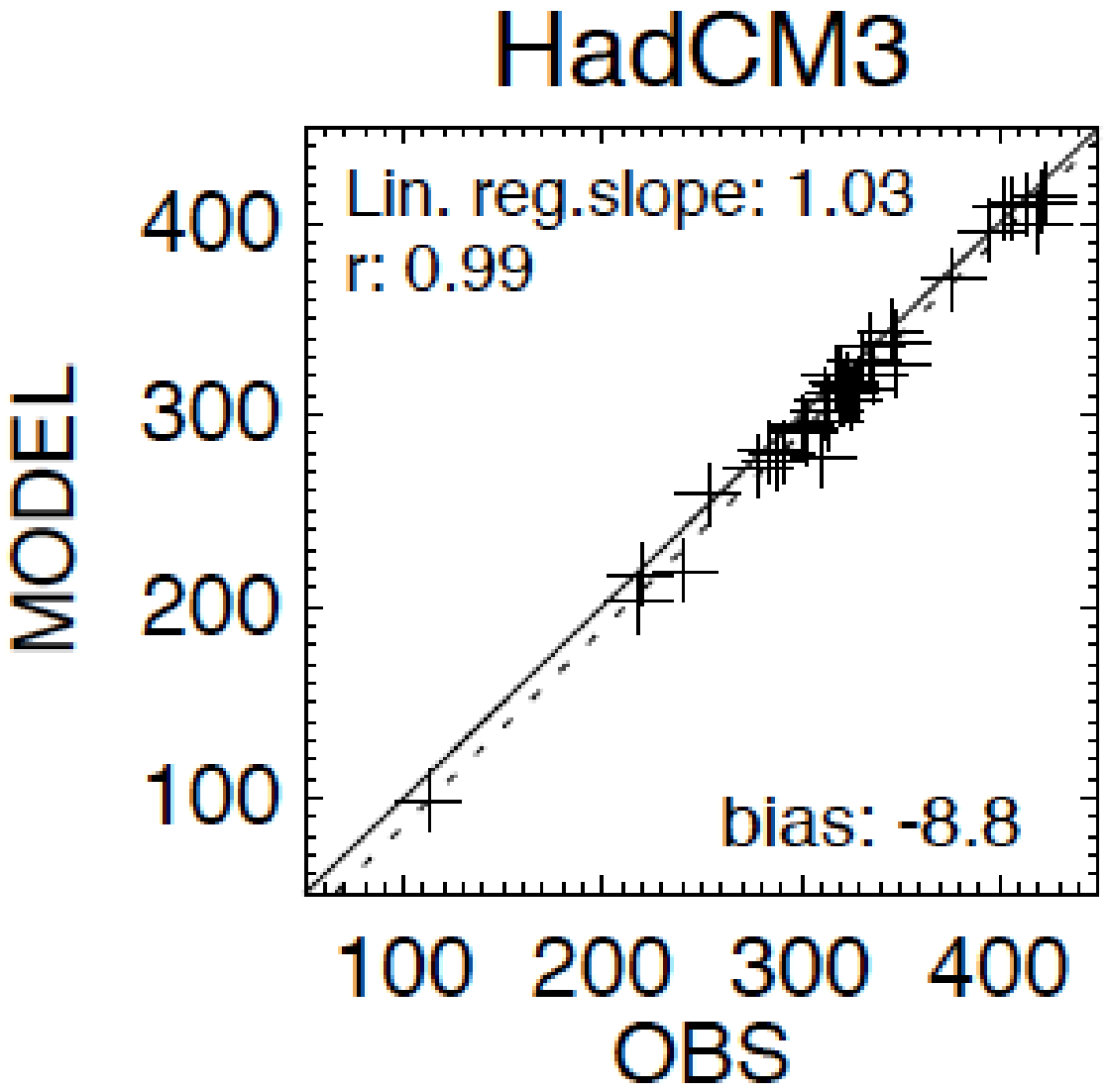


Evaluating LW surface fluxes in CMIP5 models



LW down

41 BSRN sites

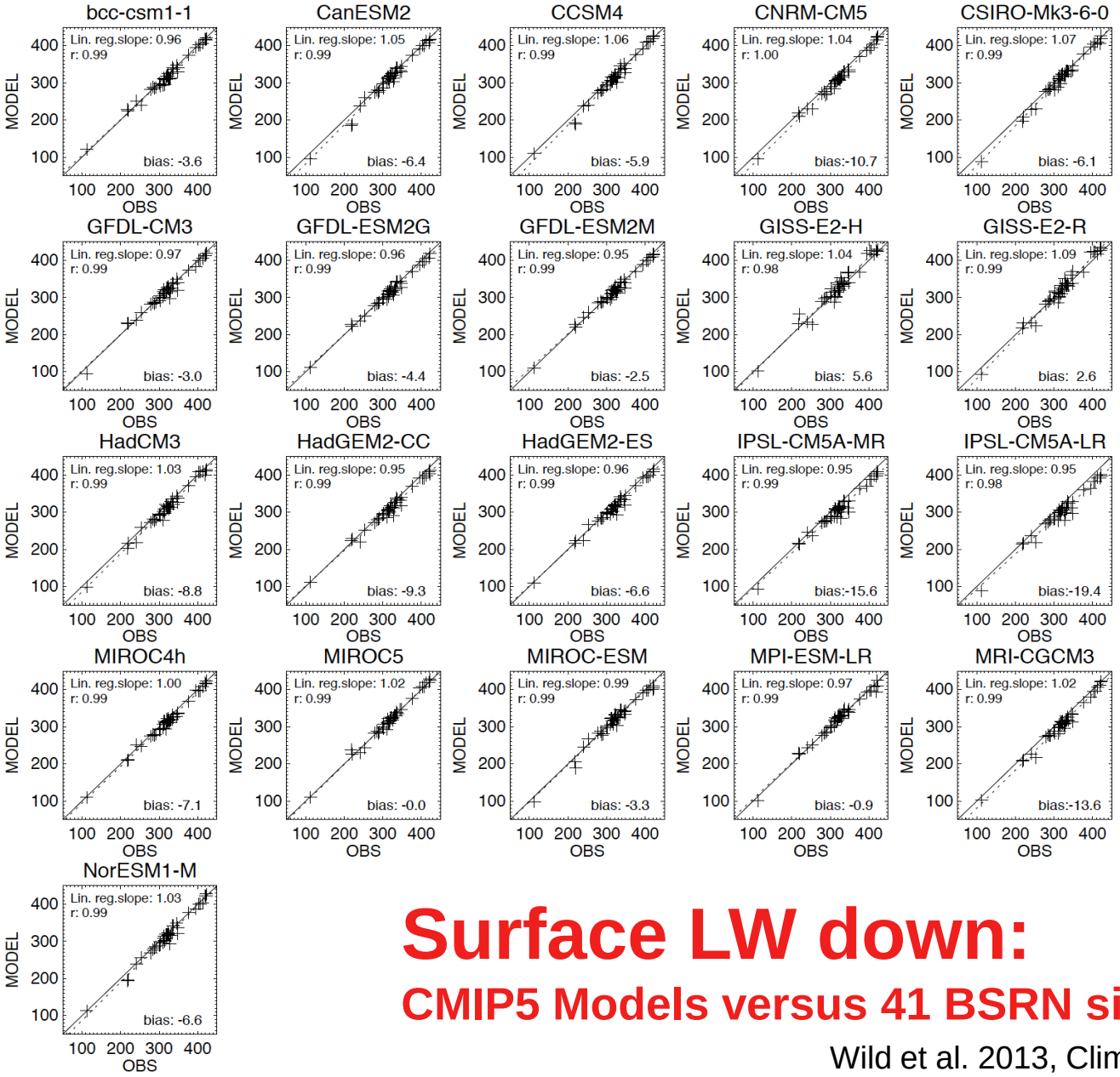


Constraining surface fluxes with BSRN obs.

Wild et al. 2013, Climate Dynamics

ETH Institute for Atmospheric and Climate Science

Evaluating LW surface fluxes in CMIP5 models



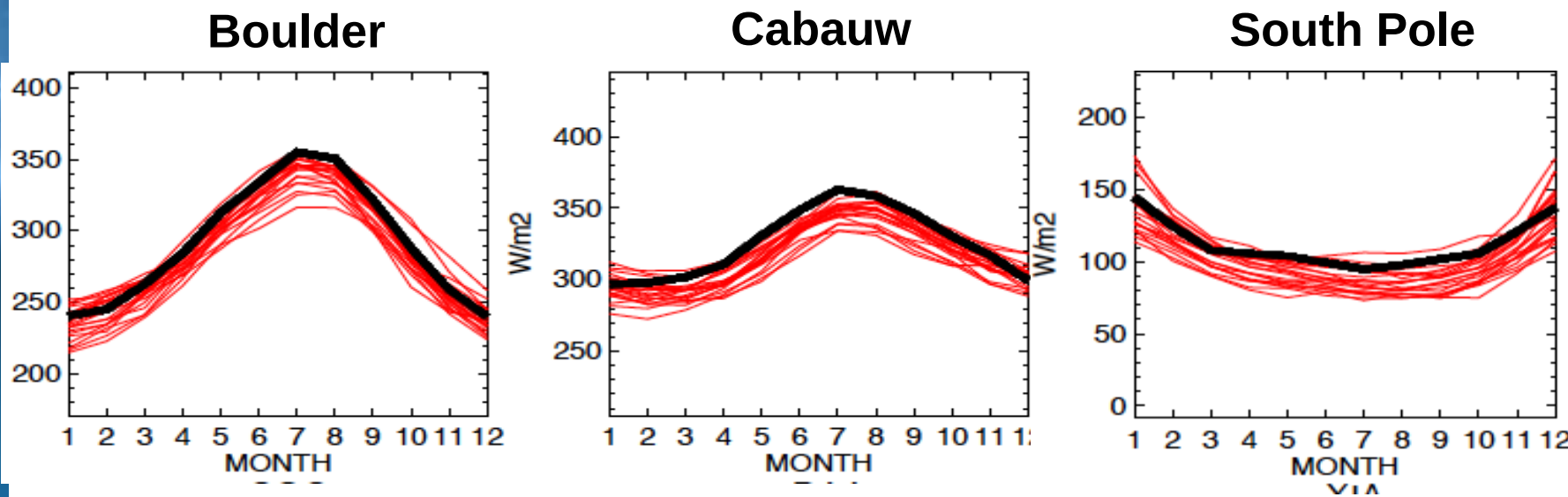
Surface LW down:

CMIP5 Models versus 41 BSRN sites

Wild et al. 2013, Climate Dynamics

Evaluating LW surface fluxes in CMIP5 models

Surface LW down: example sites



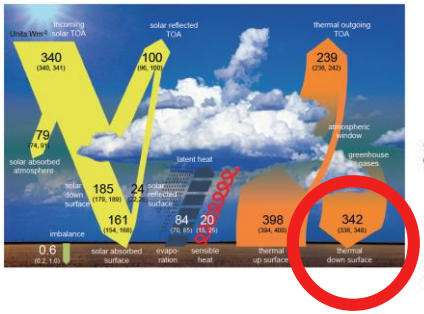
CMIP5 Models

BSRN observations

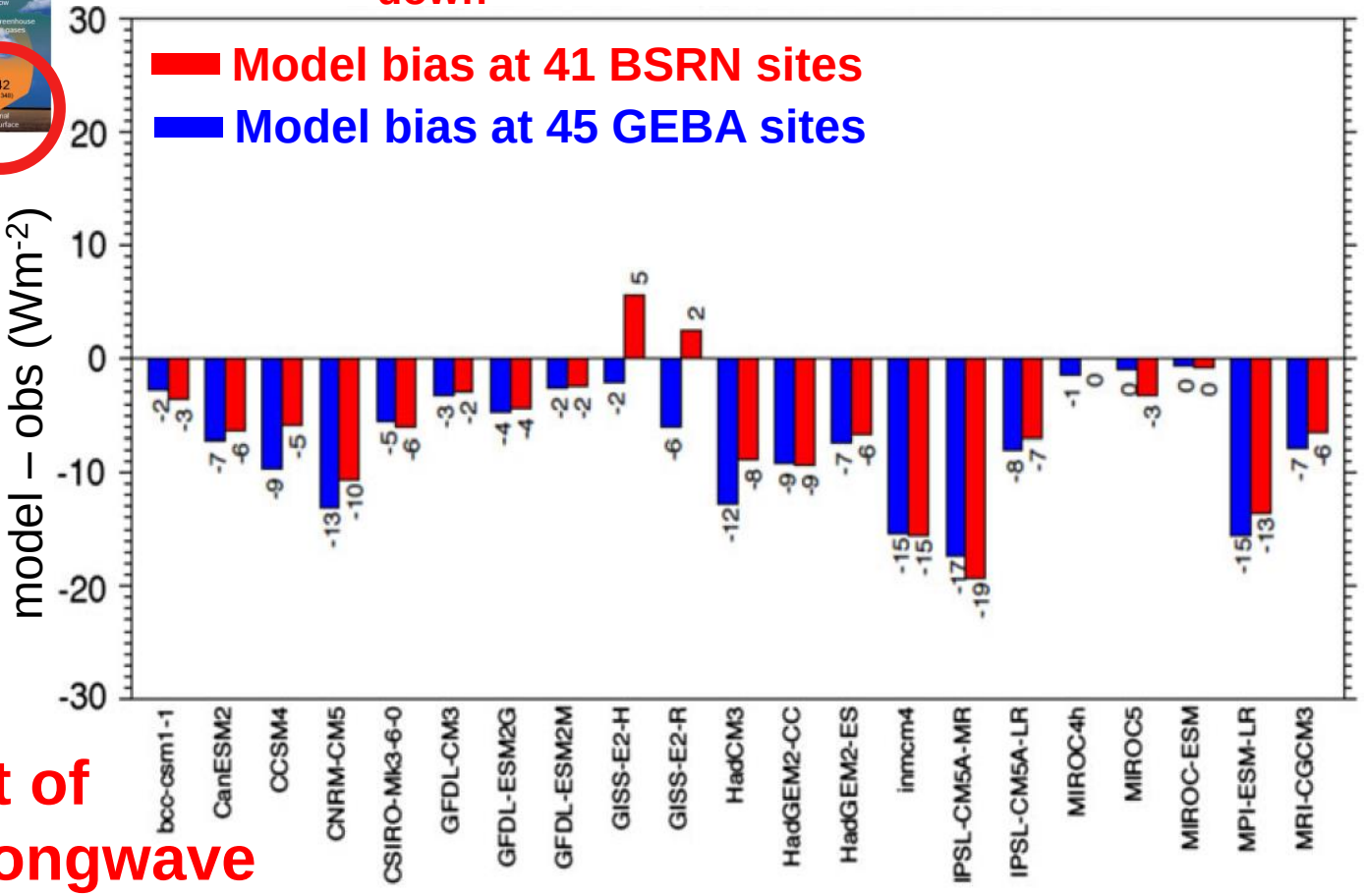
Underestimation in LW down throughout the year

Wild et al. 2013, Climate Dynamics

Evaluating LW surface fluxes in CMIP5 models



LW_{down} biases in CMIP5 models



Assessment of downward longwave radiation

Multimodel mean bias LW_{down} at 41 BSRN sites: -6 Wm^{-2}

Multimodel mean bias LW_{down} at 45 GEBA sites: -7 Wm^{-2}

Wild et al. 2013, Climate Dynamics

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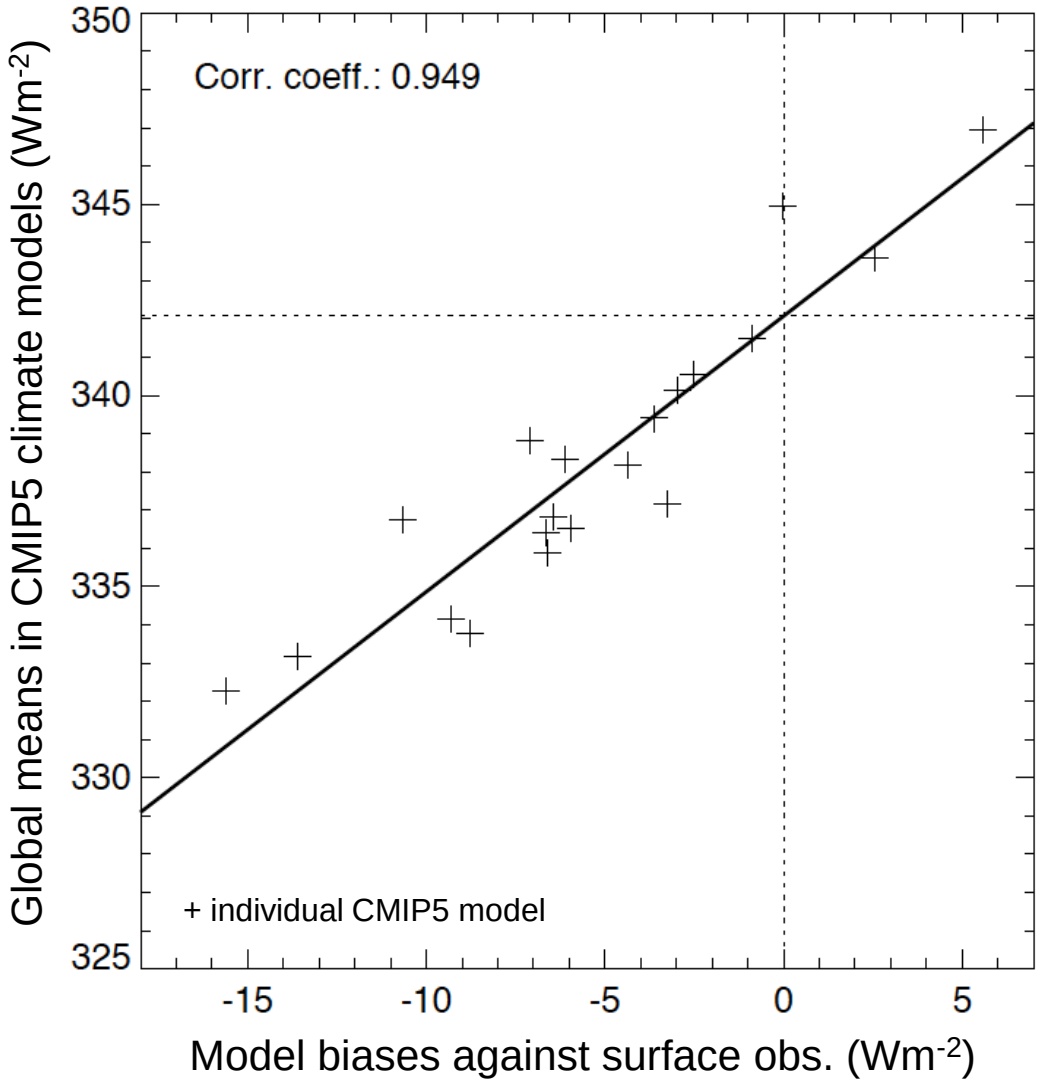
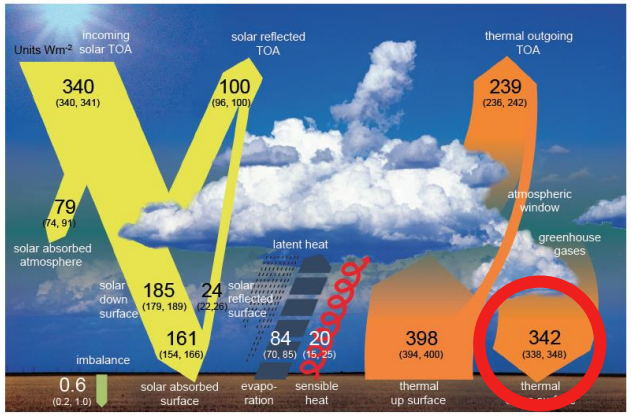
Best estimates for global mean radiation fluxes

Surface LW down

GCM global means versus their biases averaged over 41 BSRN sites





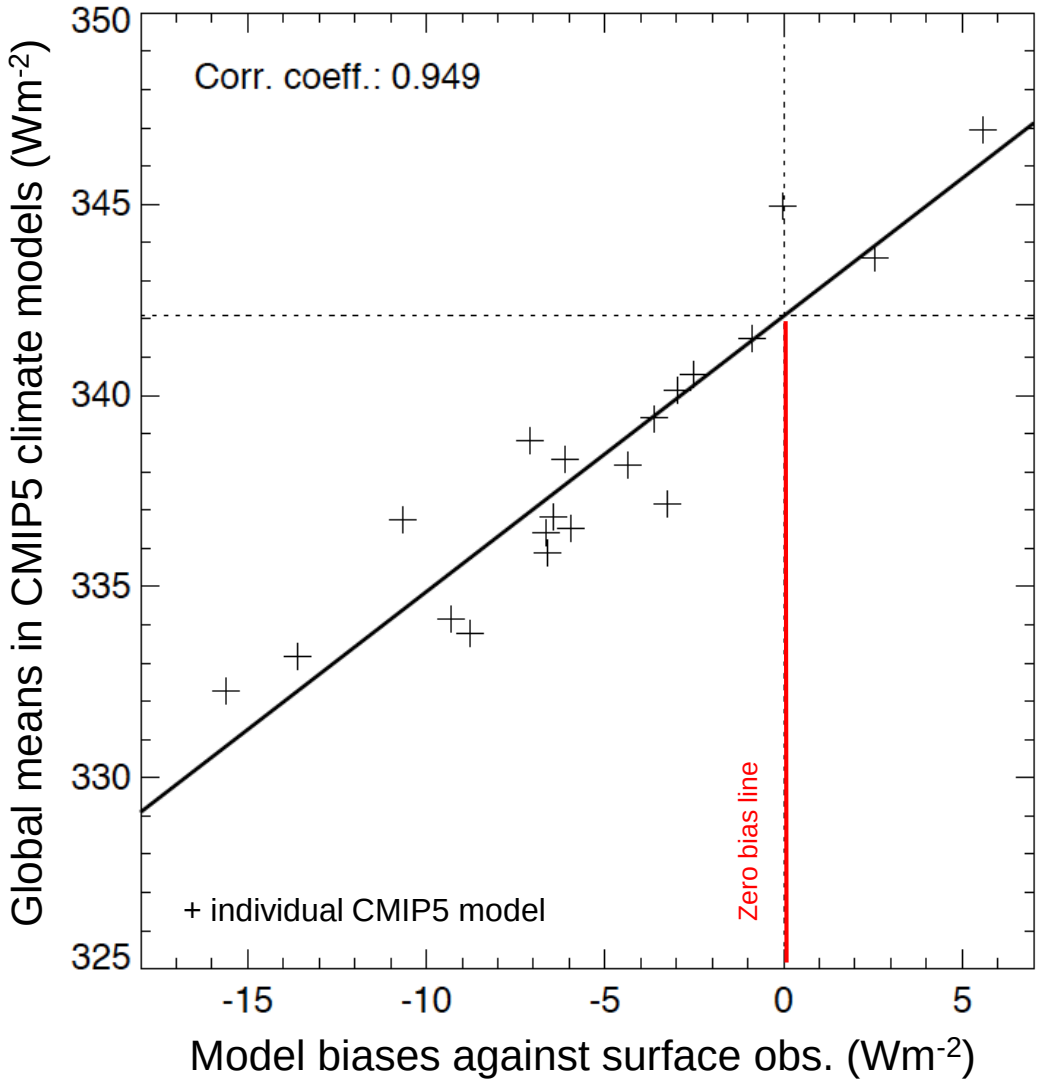
Wild et al. 2013, Climate Dynamics

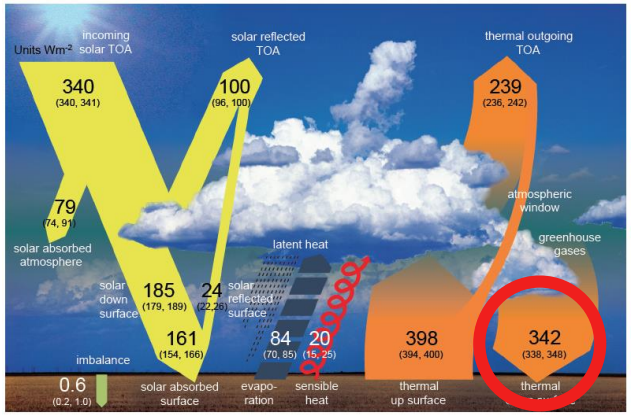
ETH Institute for Atmospheric and Climate Science

Best estimates for global mean radiation fluxes

Surface LW down

GCM global means versus their biases averaged over 41 BSRN sites





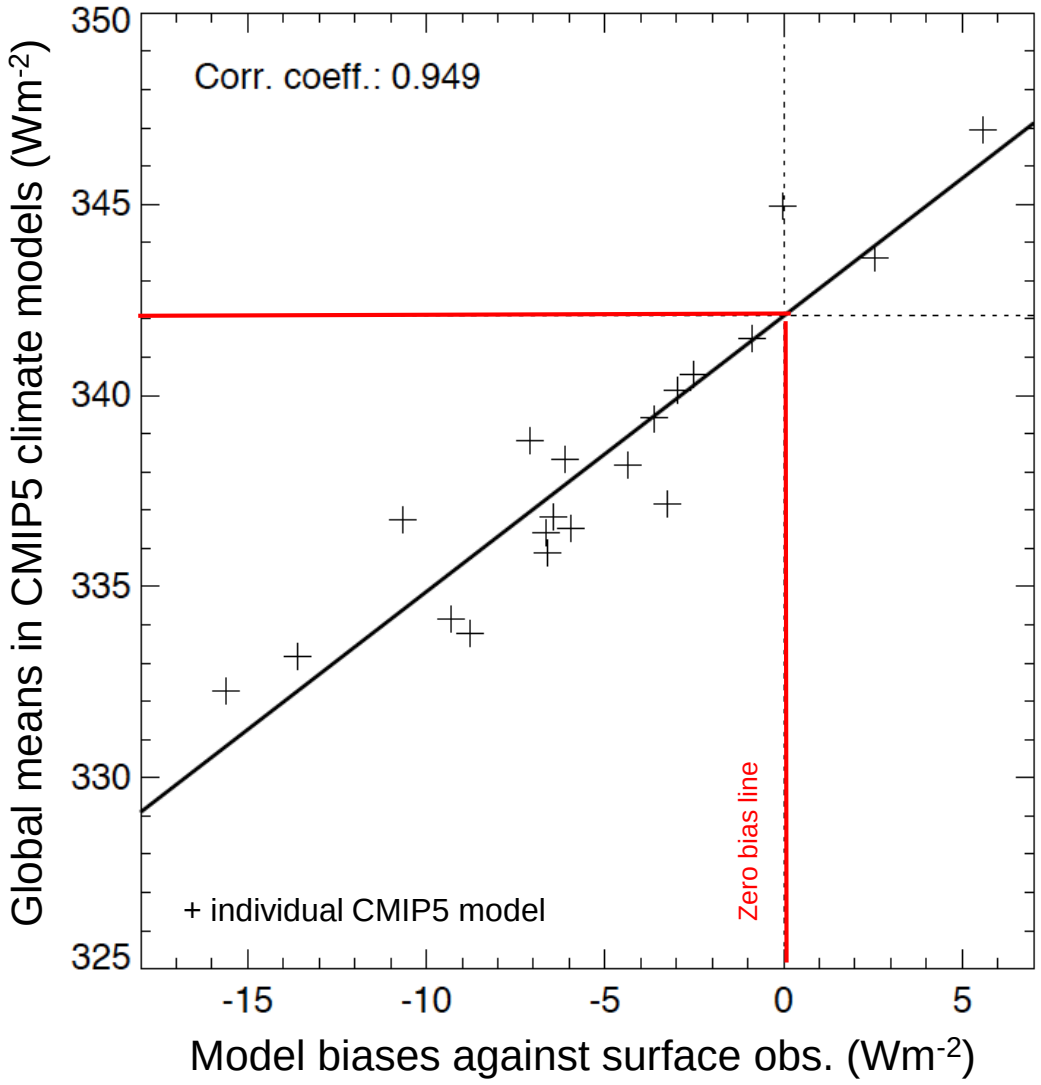
Wild et al. 2013, Climate Dynamics

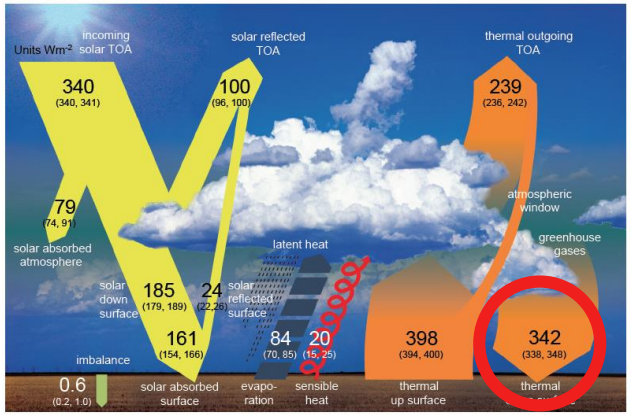
ETH Institute for Atmospheric and Climate Science

Best estimates for global mean radiation fluxes

Surface LW down

GCM global means versus their biases averaged over 41 BSRN sites





Wild et al. 2013, Climate Dynamics

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Surface LW down

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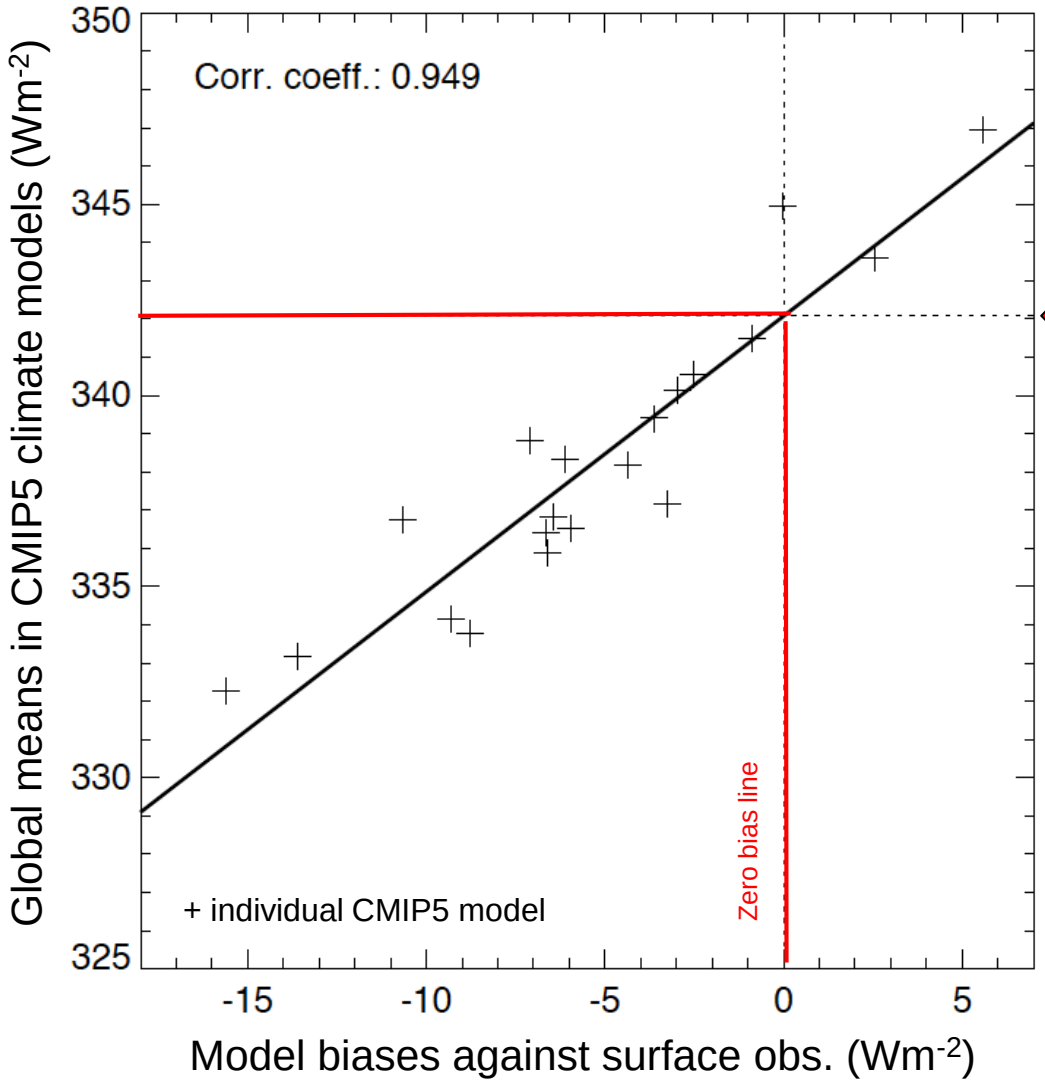
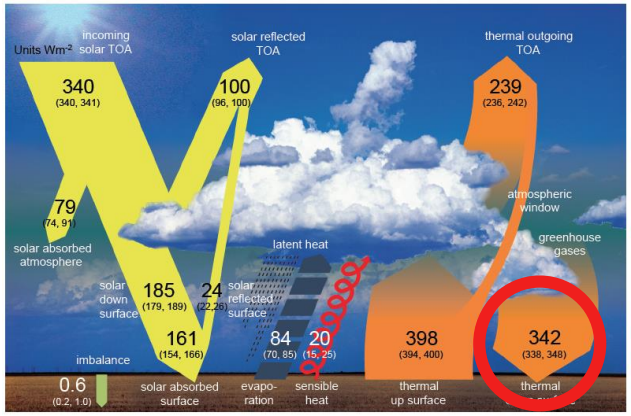


Best estimate surface LW down:
342 Wm^{-2}



Wild et al. 2013, Climate Dynamics

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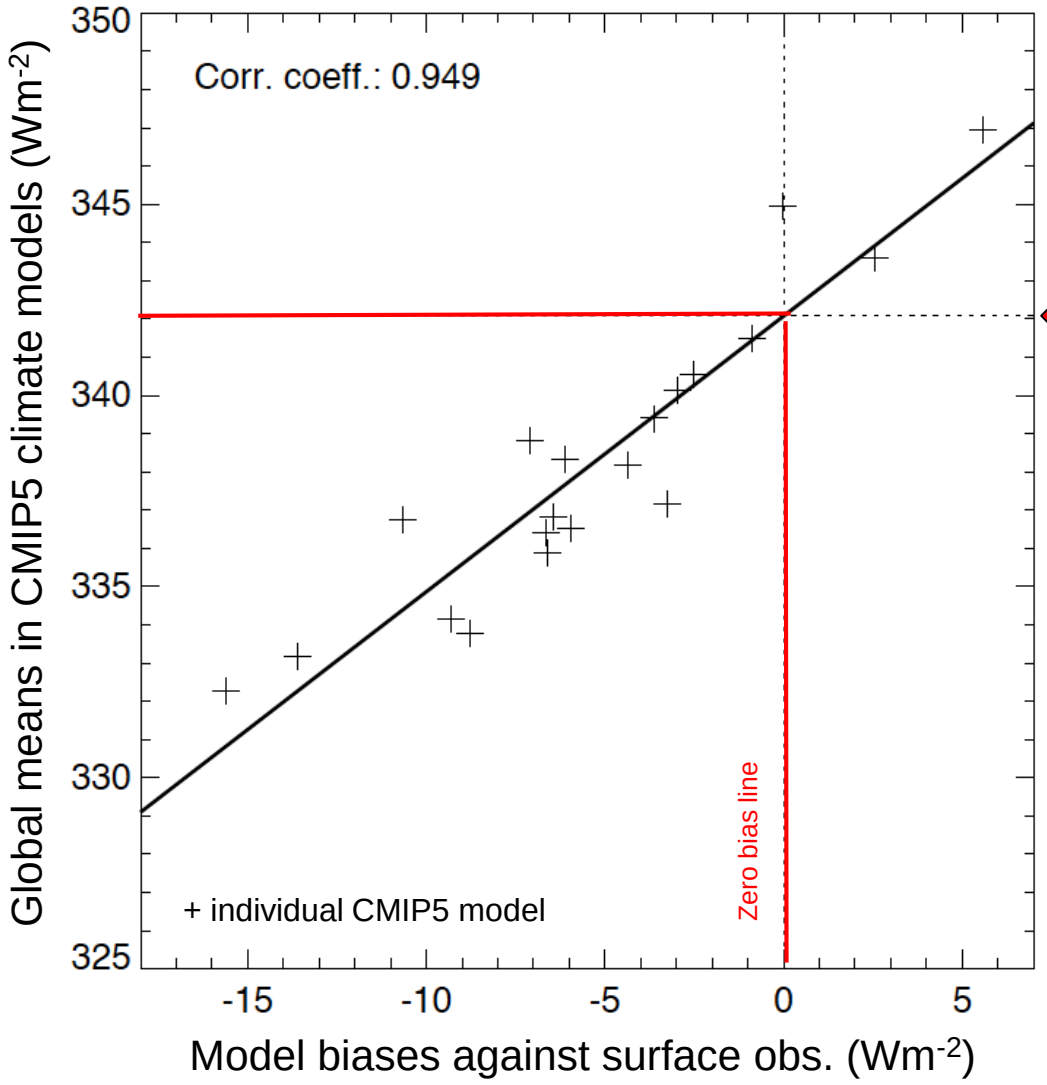
Best estimates for global mean radiation fluxes

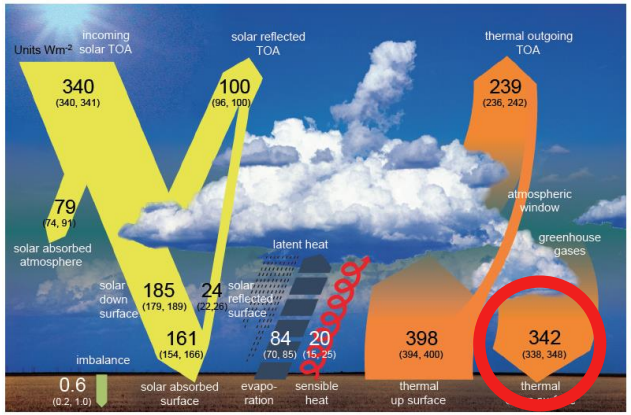
Surface LW down

GCM global means versus their biases averaged over 41 BSRN sites



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

c.f. CERES/EBAF satellite-derived estimate: *344 Wm^{-2}* (Kato et al. 2012)



Wild et al. 2013, Climate Dynamics

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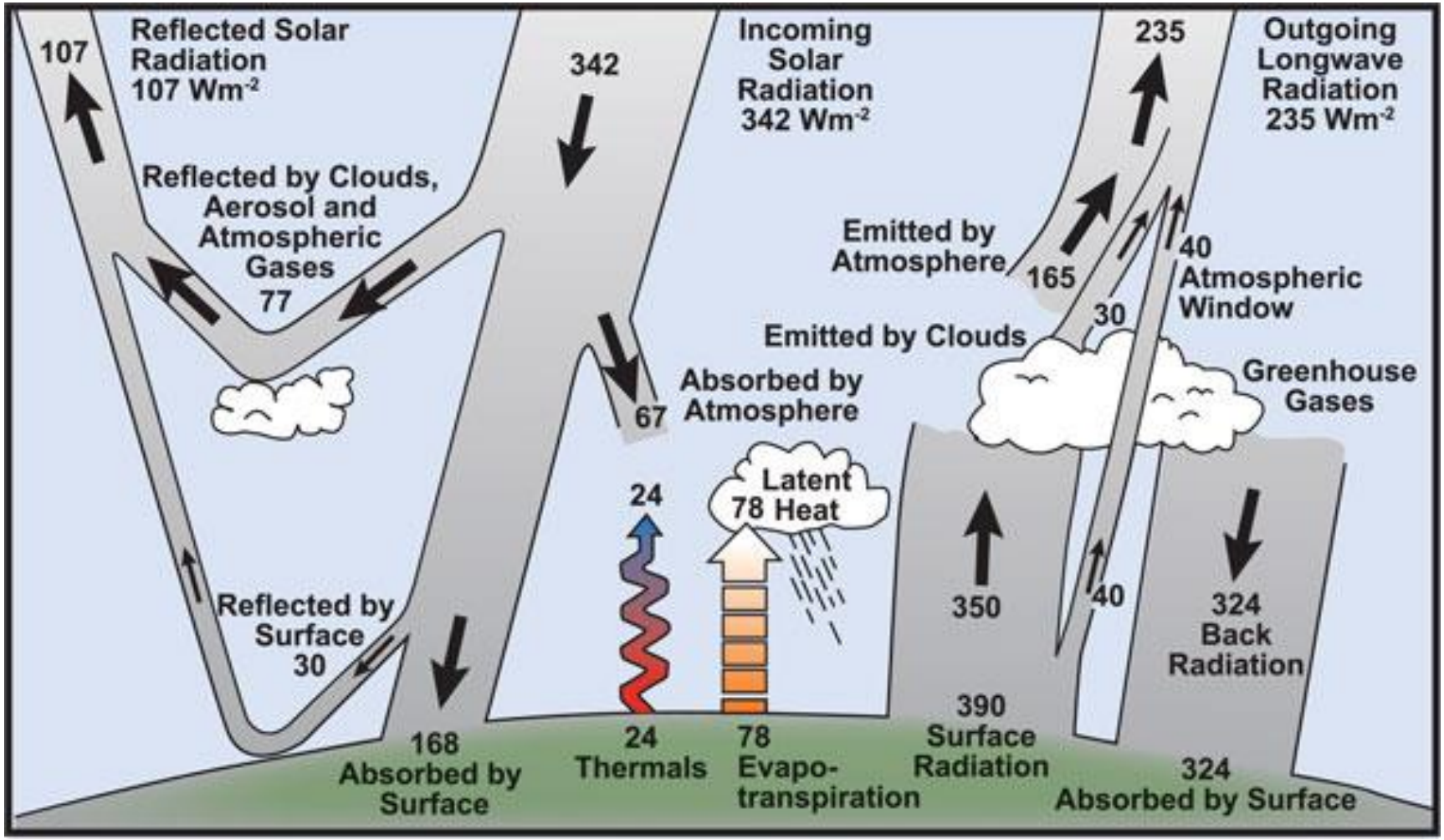
Revision of IPCC AR4 Energy Balance Figure

Units Wm^{-2}

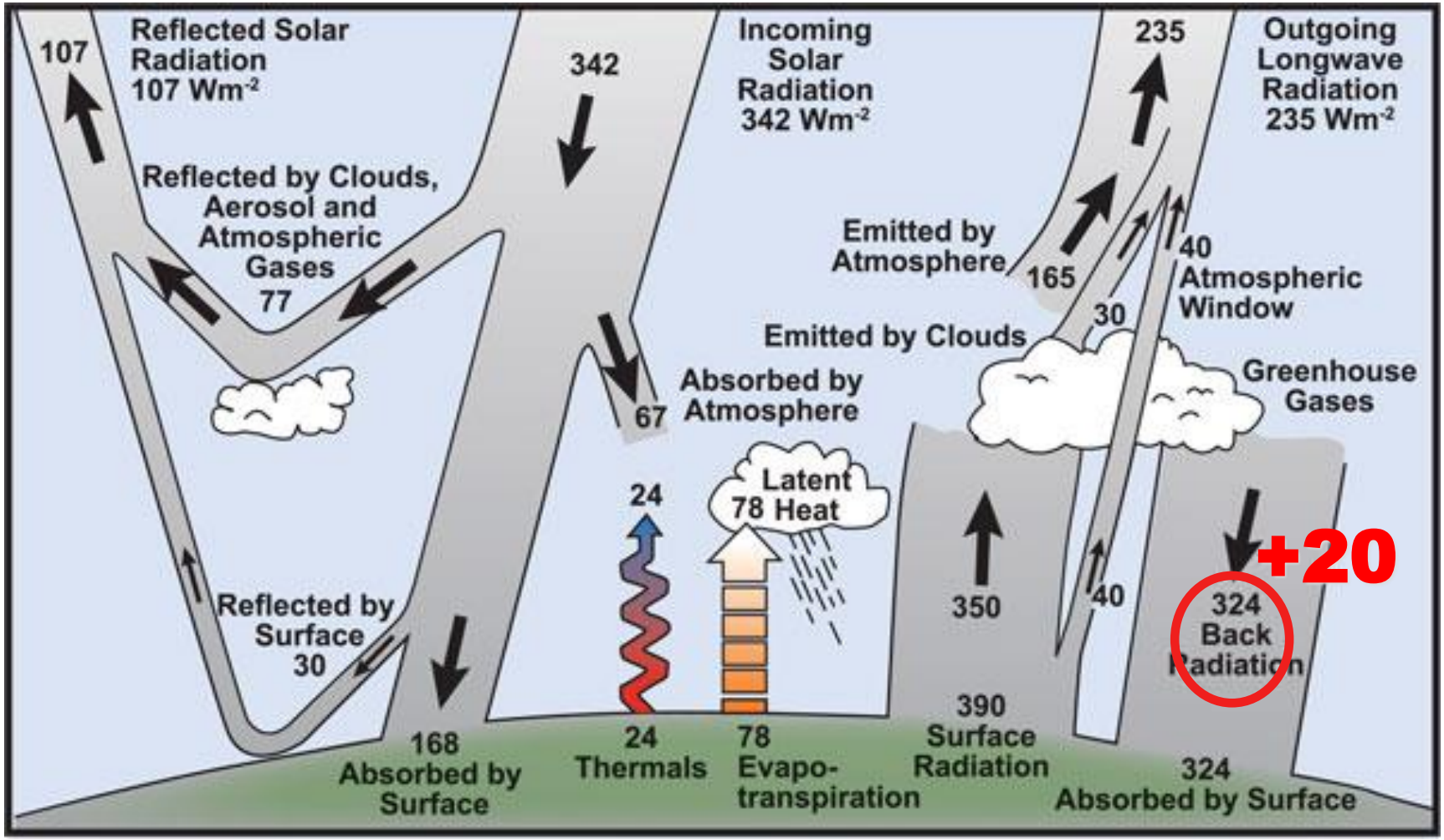


IPCC AR4, based on Kiehl and Trenberth

Wild 2012: A facelift for the picture of the global energy balance, *Atmos. Environ.* **55**

Revision of IPCC AR4 Energy Balance Figure

Units Wm^{-2}



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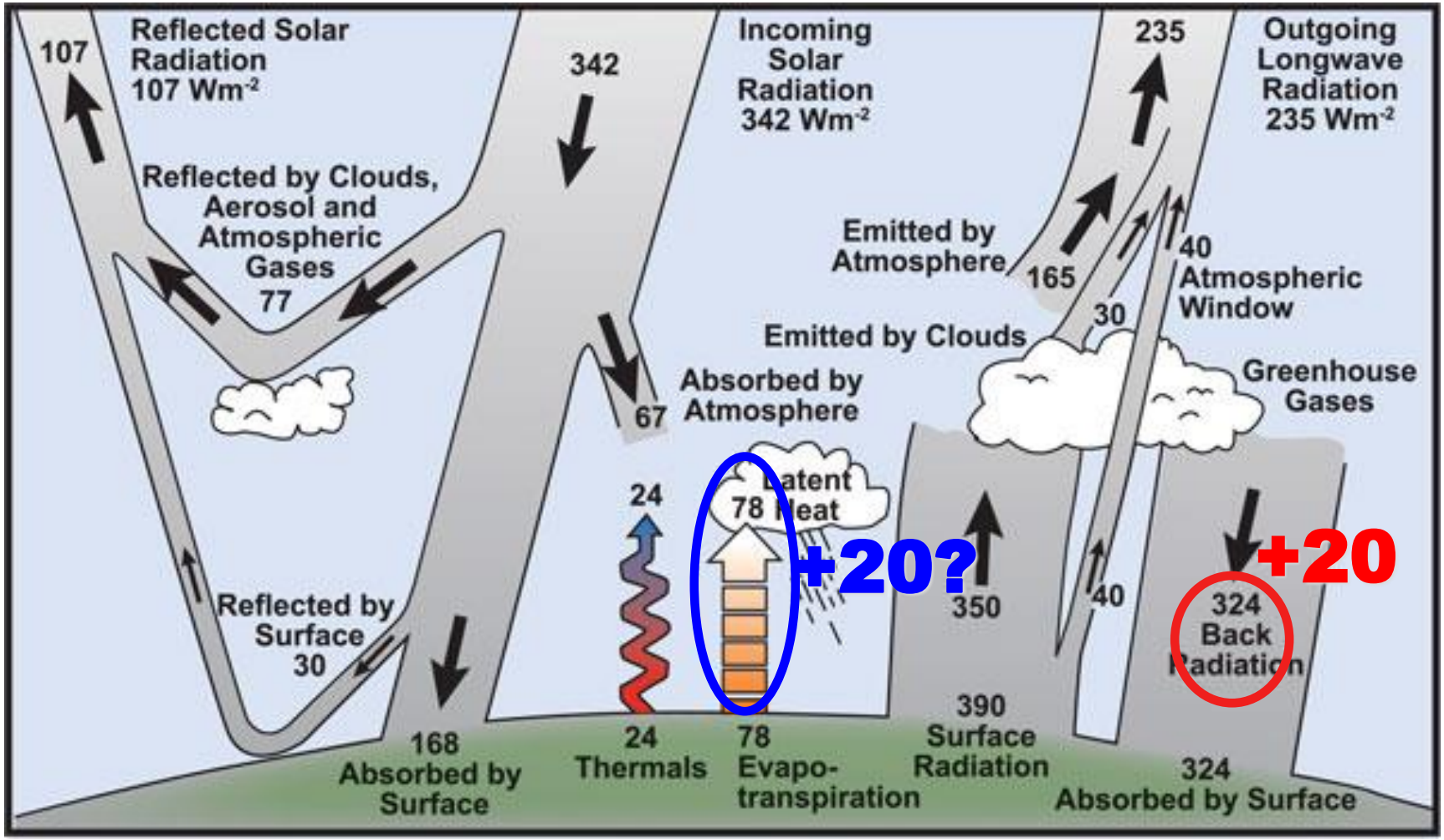

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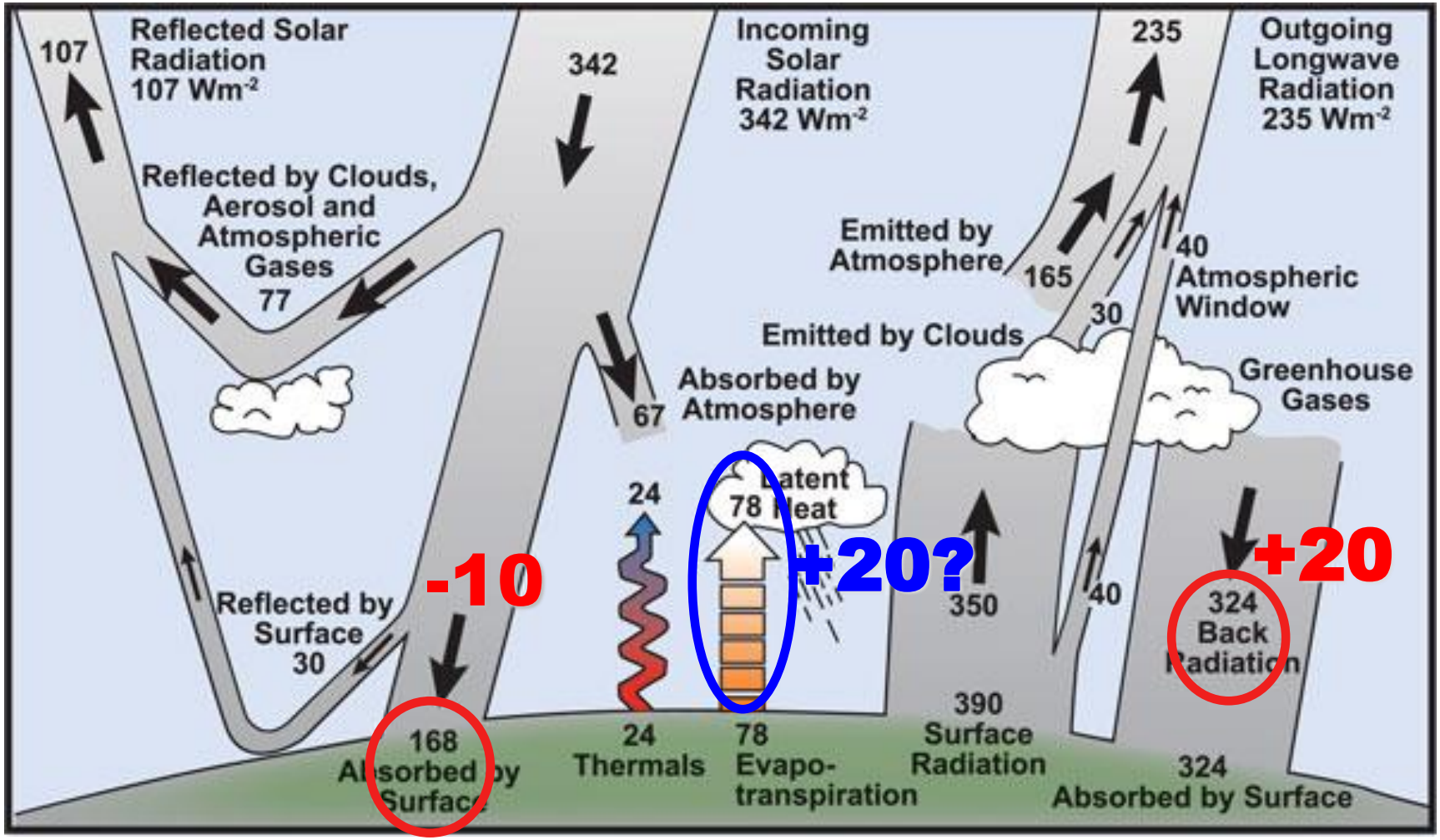

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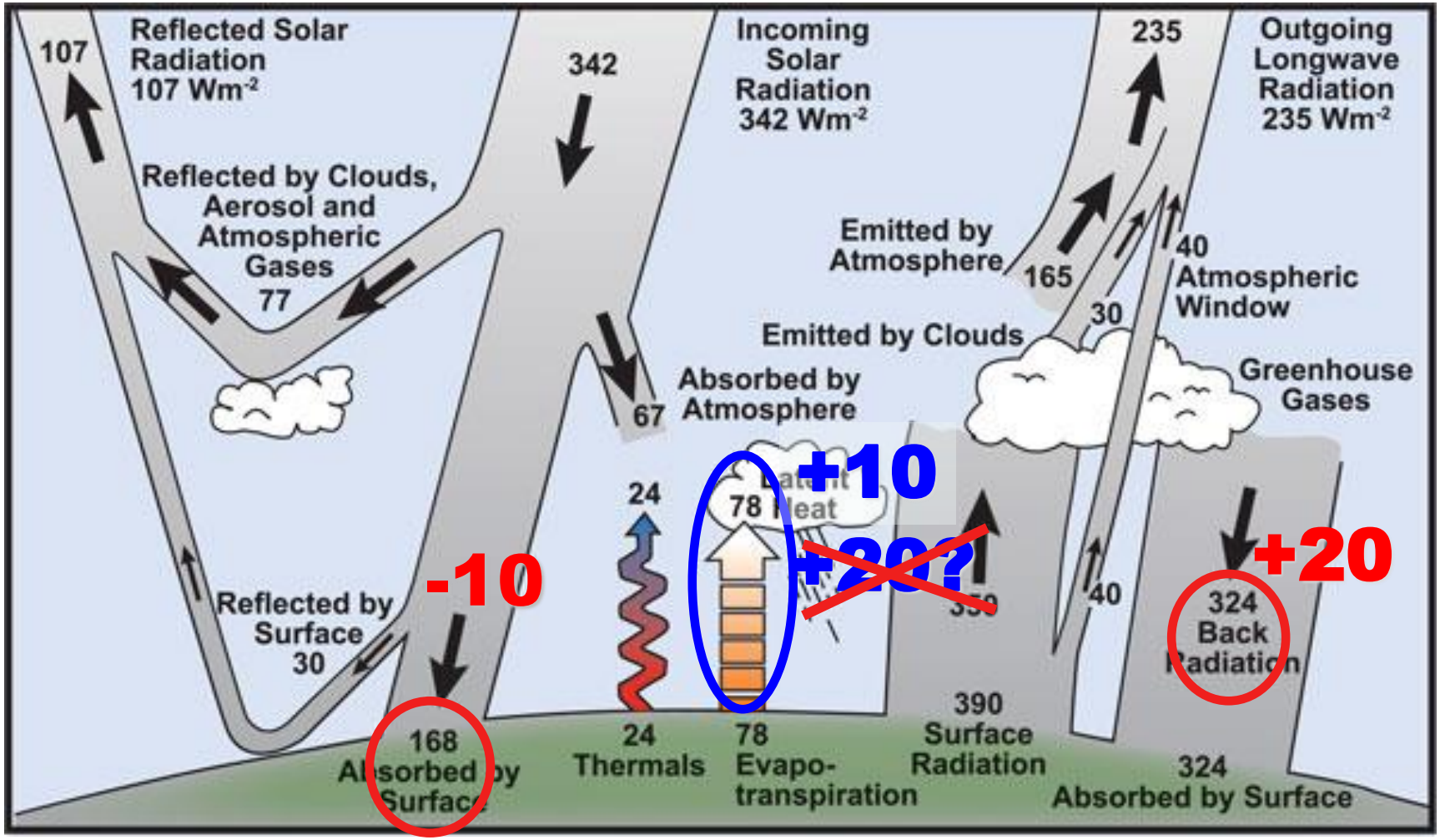

IPCC AR4, based on Kiehl and Trenberth

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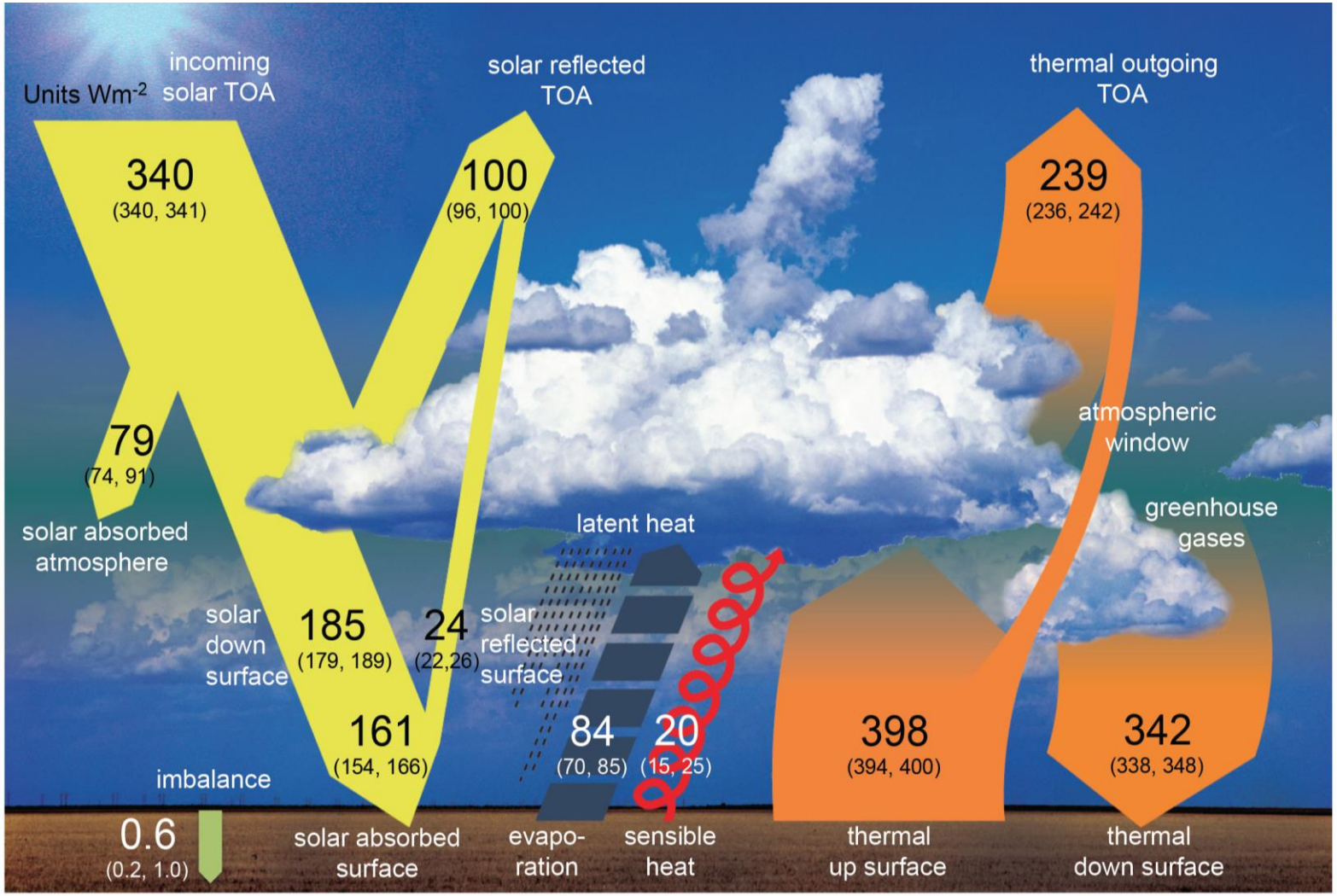
Revision of IPCC AR4 Energy Balance Figure

Revised estimates for AR5 consistent with observations

Units Wm^{-2}



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

Revision of IPCC AR4 Energy Balance Figure

Revised estimates for AR5 consistent with observations

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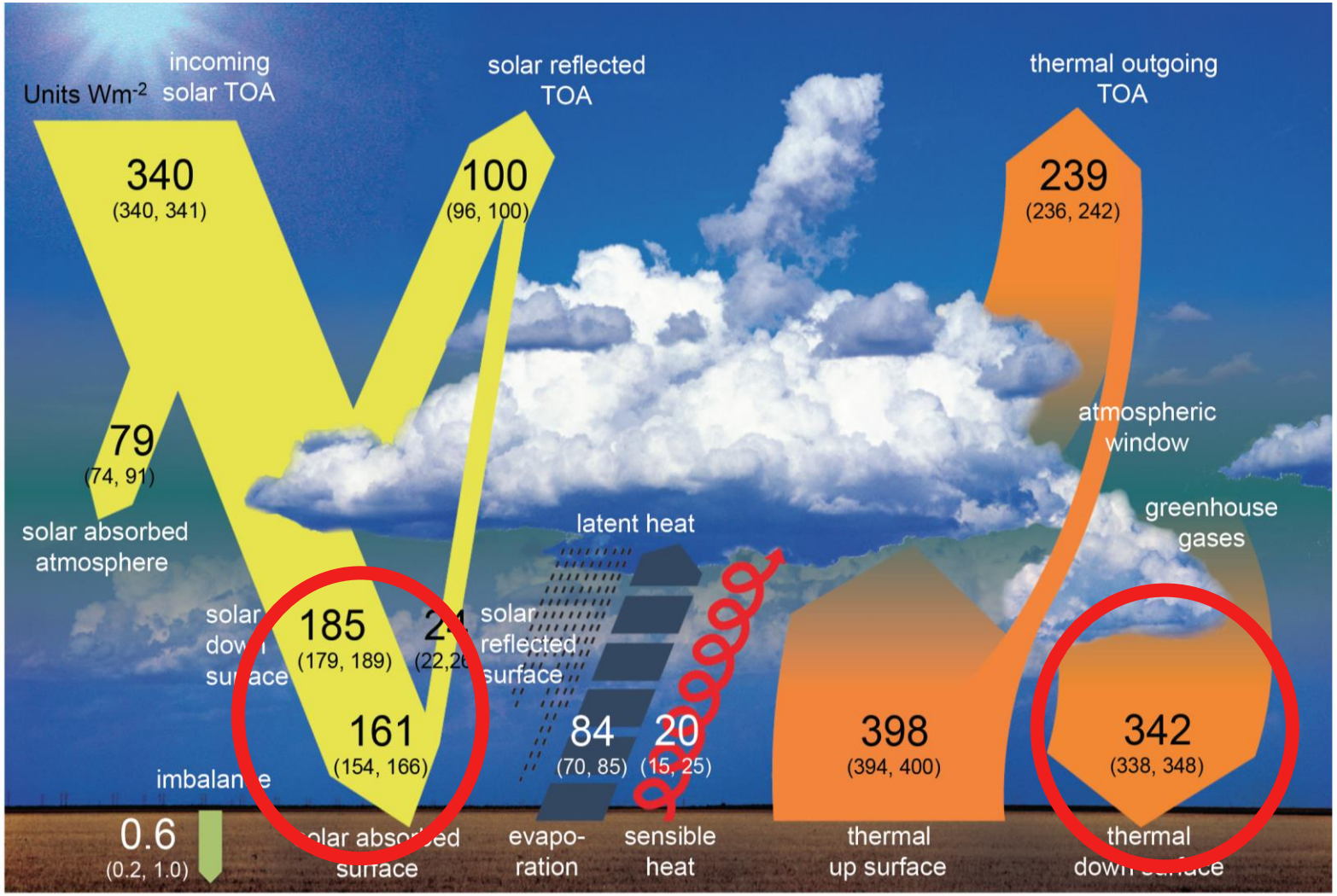


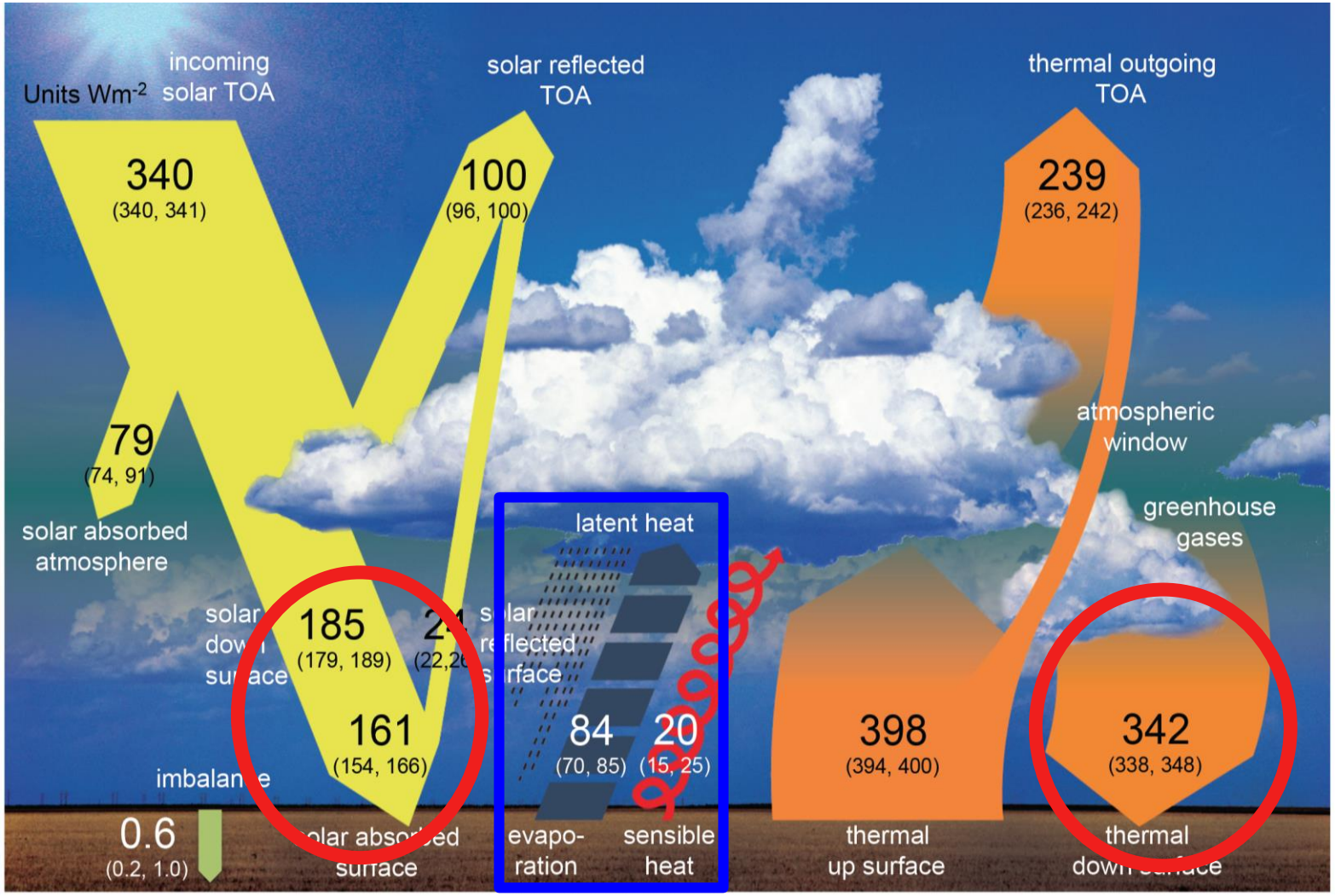
Surface net radiation: 105 Wm^{-2}

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

Revision of IPCC AR4 Energy Balance Figure

Revised estimates for AR5 consistent with observations

Units Wm^{-2}



Surface net radiation: 105 Wm^{-2} consistent with global water cycle

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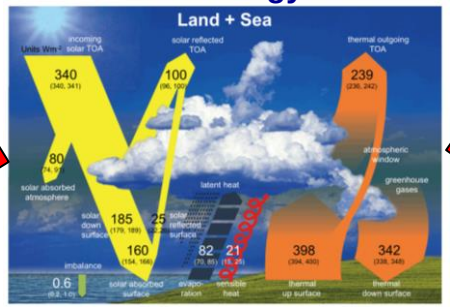
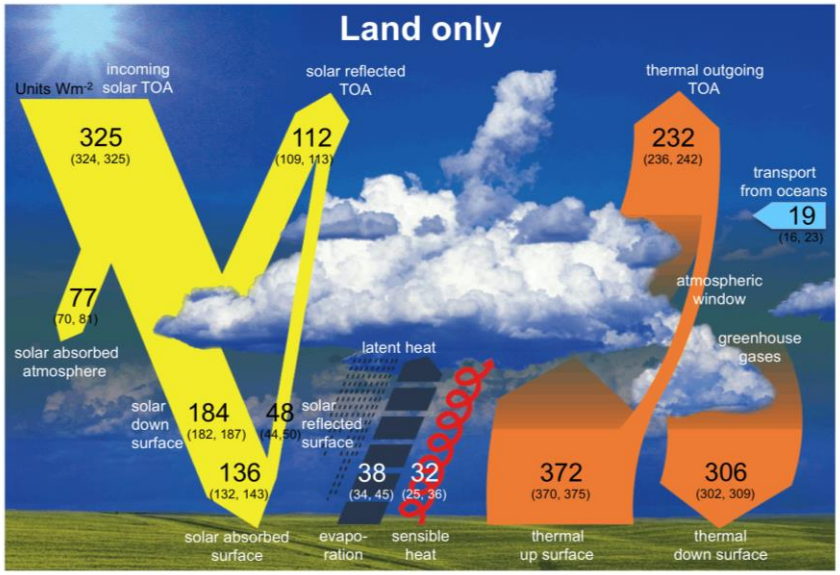
Land and sea mean energy balance

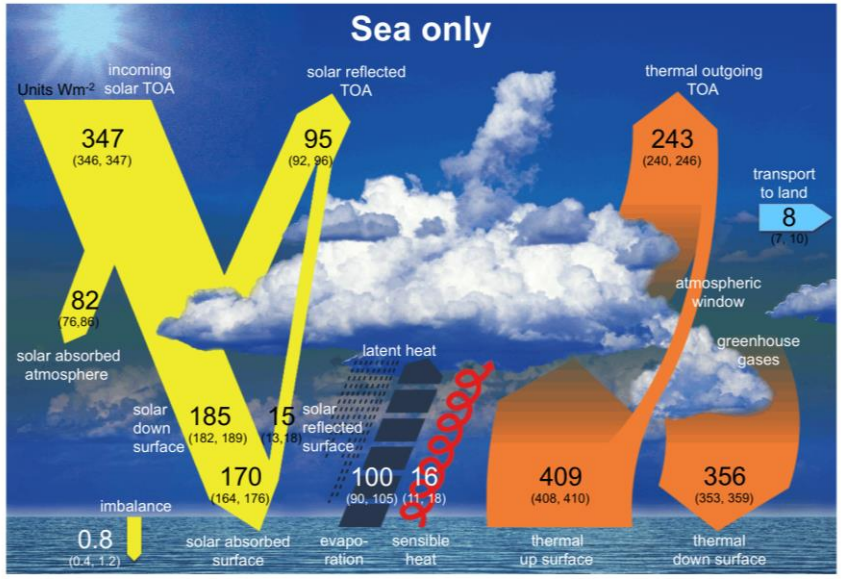
Global mean energy balance



Land mean energy balance



Ocean mean energy balance



New estimates for land and ocean mean energy budgets
based to the extent possible on direct observations from surface and space, and climate models.

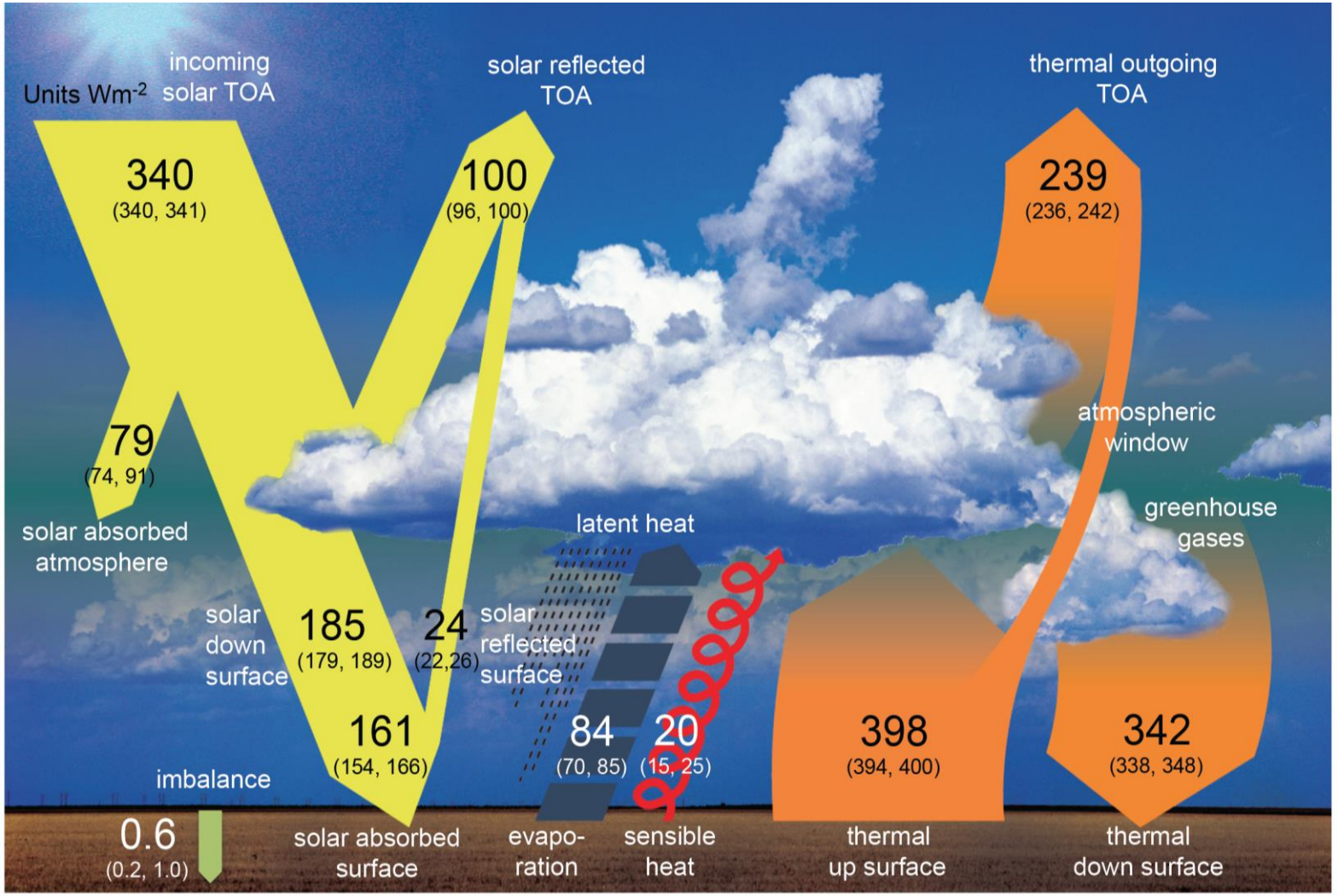
=> SEE POSTER

Wild et al. 2015, Climate Dynamics

Changes in the Earth radiation budget

Anthropogenic Perturbations

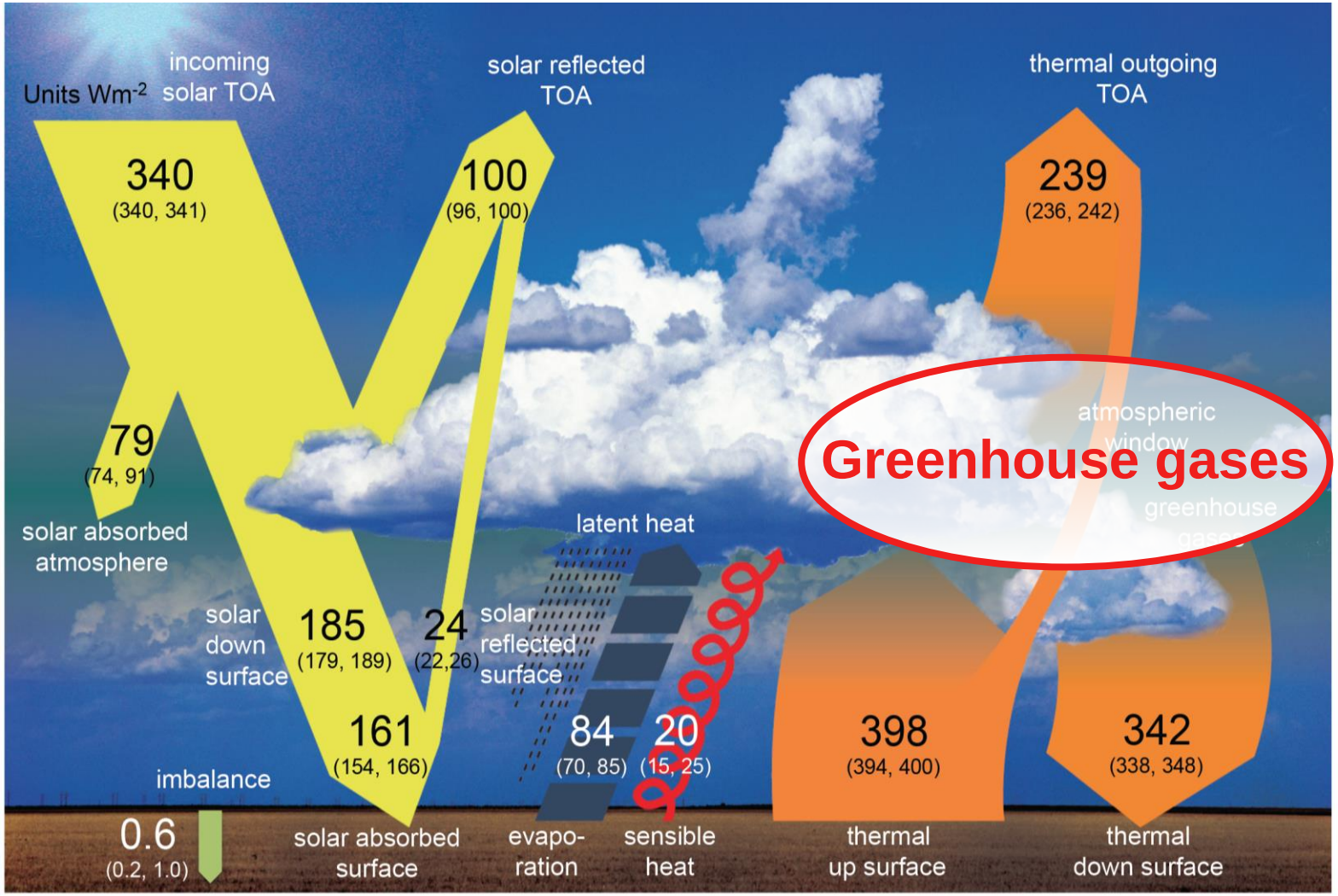
Units Wm^{-2}



Changes in the Earth radiation budget

Anthropogenic Perturbations

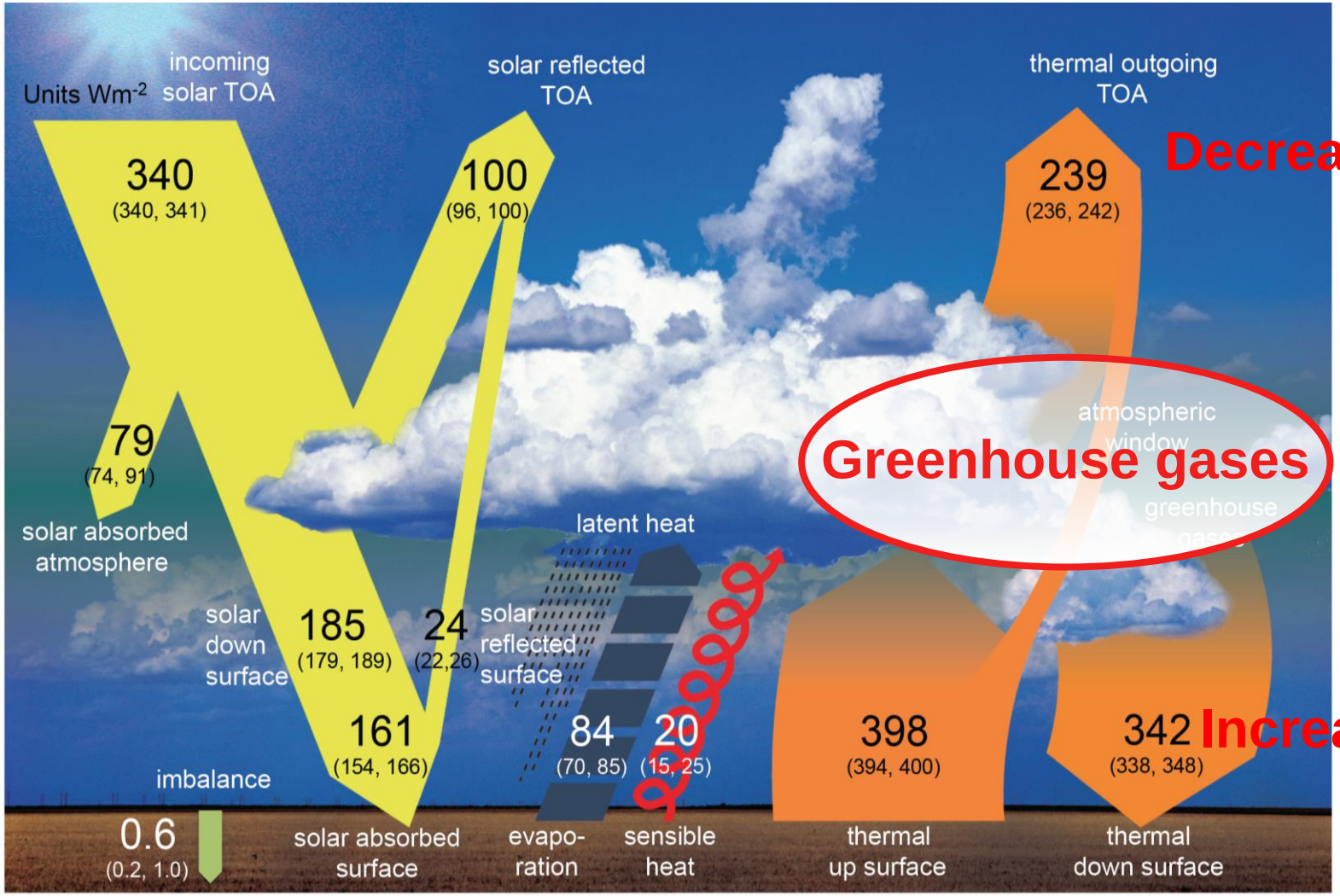
Units Wm^{-2}



Changes in the Earth radiation budget

Units Wm^{-2}

Anthropogenic Perturbations



Changes in the Earth radiation budget

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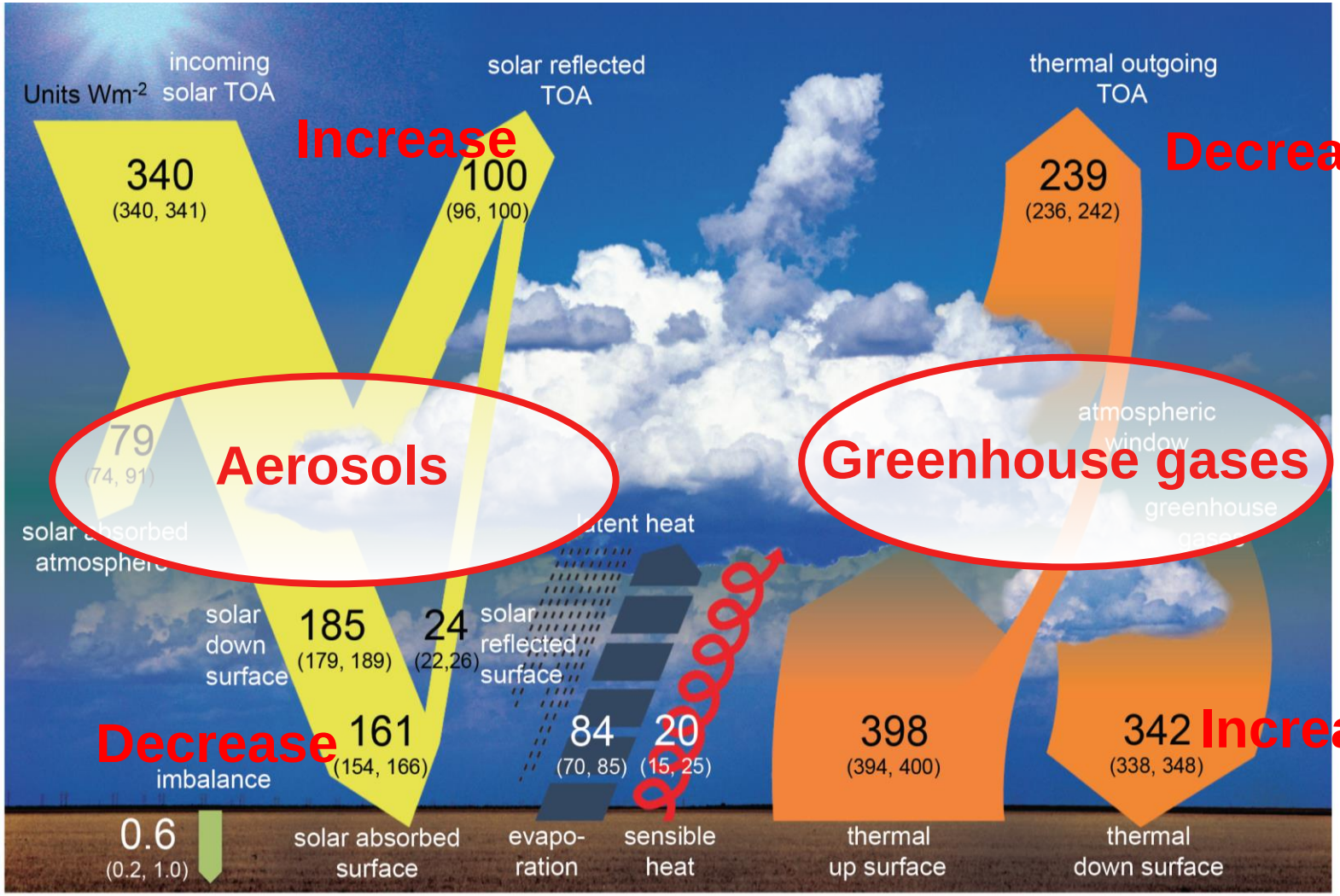
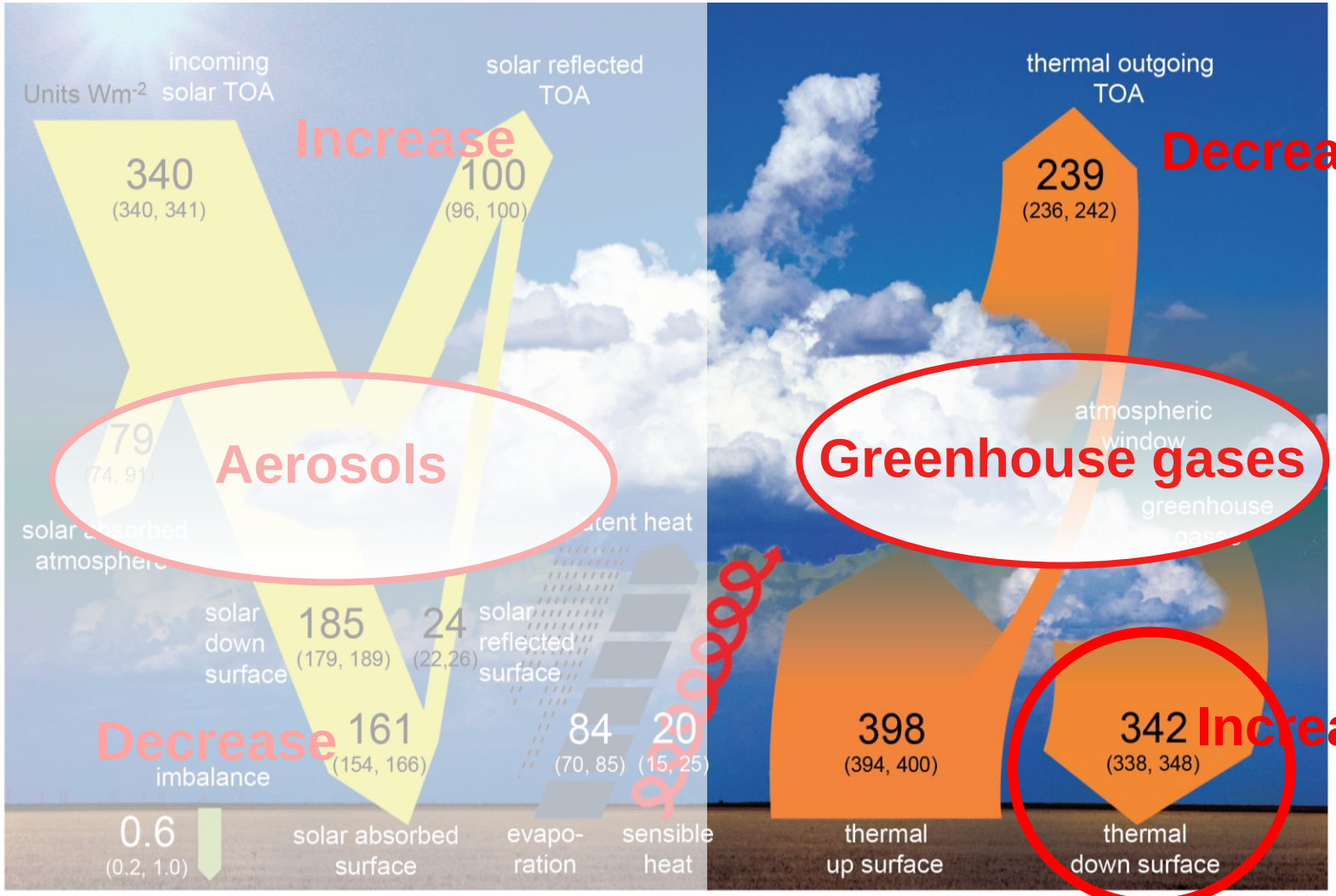


Changes in the Earth radiation budget

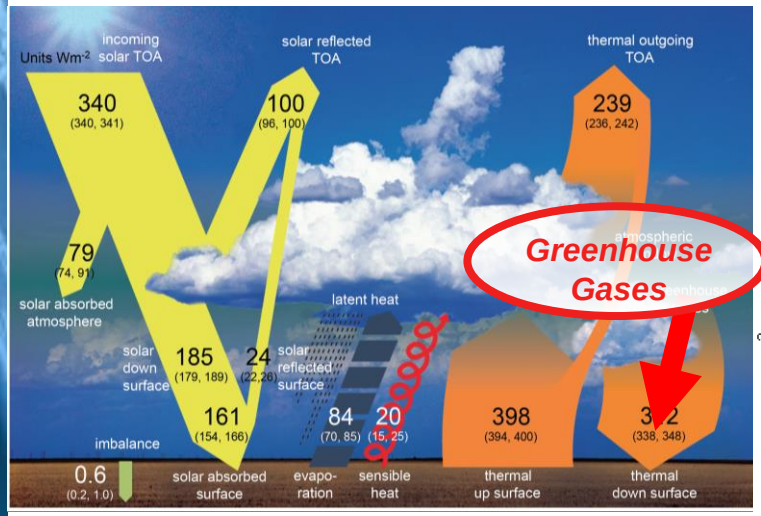
Units Wm^{-2}

Anthropogenic Perturbations



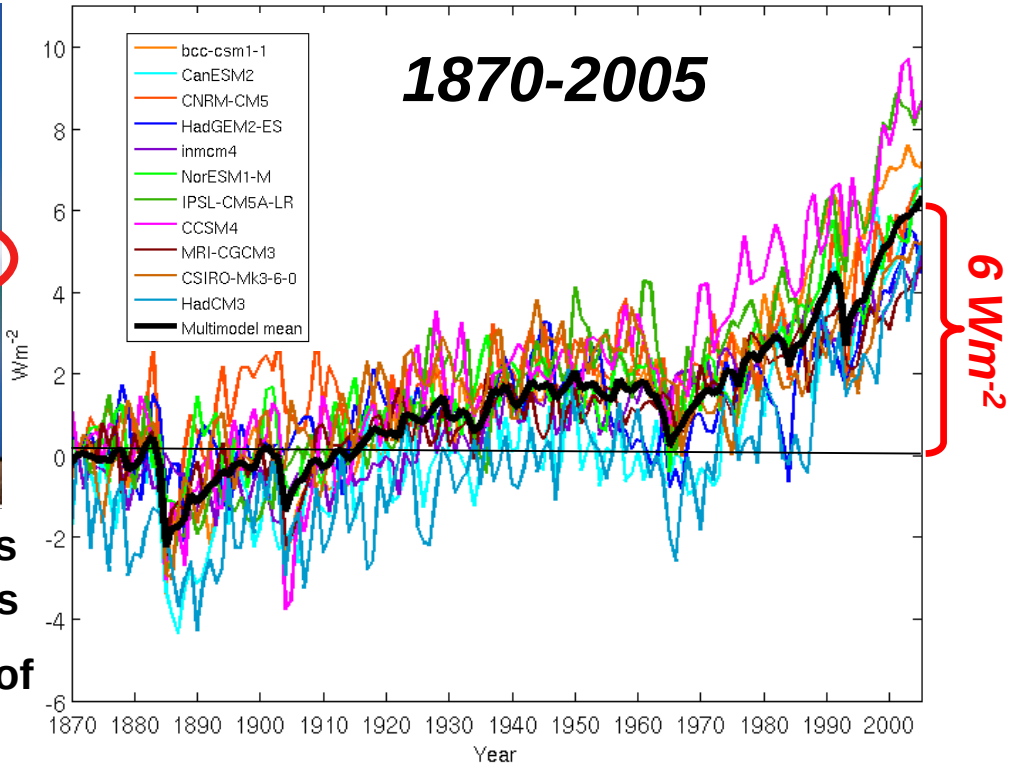
Changes in downward LW radiation

Changes in downward longwave radiation



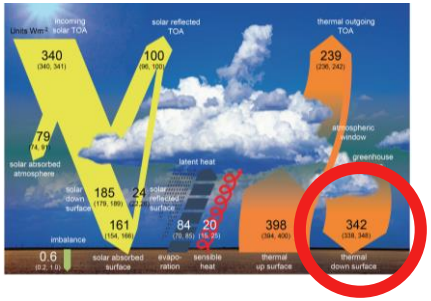
- most directly affected by changes in atmospheric greenhouse gases
- CMIP5 models suggest increase of 6 Wm^{-2} since 1870
- expected to undergo largest change of all energy balance components in coming decades
- Only monitored since the initiation of BSRN early 1990s

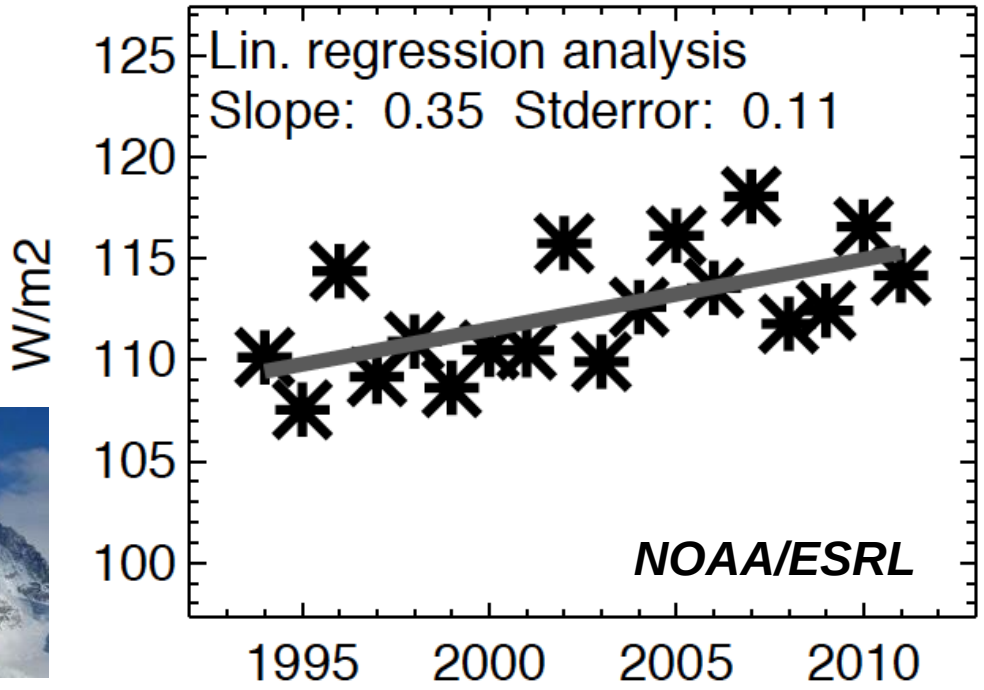
Downward longwave radiation in CMIP5 models



"Greenhouse effect at the Earth surface"

Changes in downward LW radiation: observations





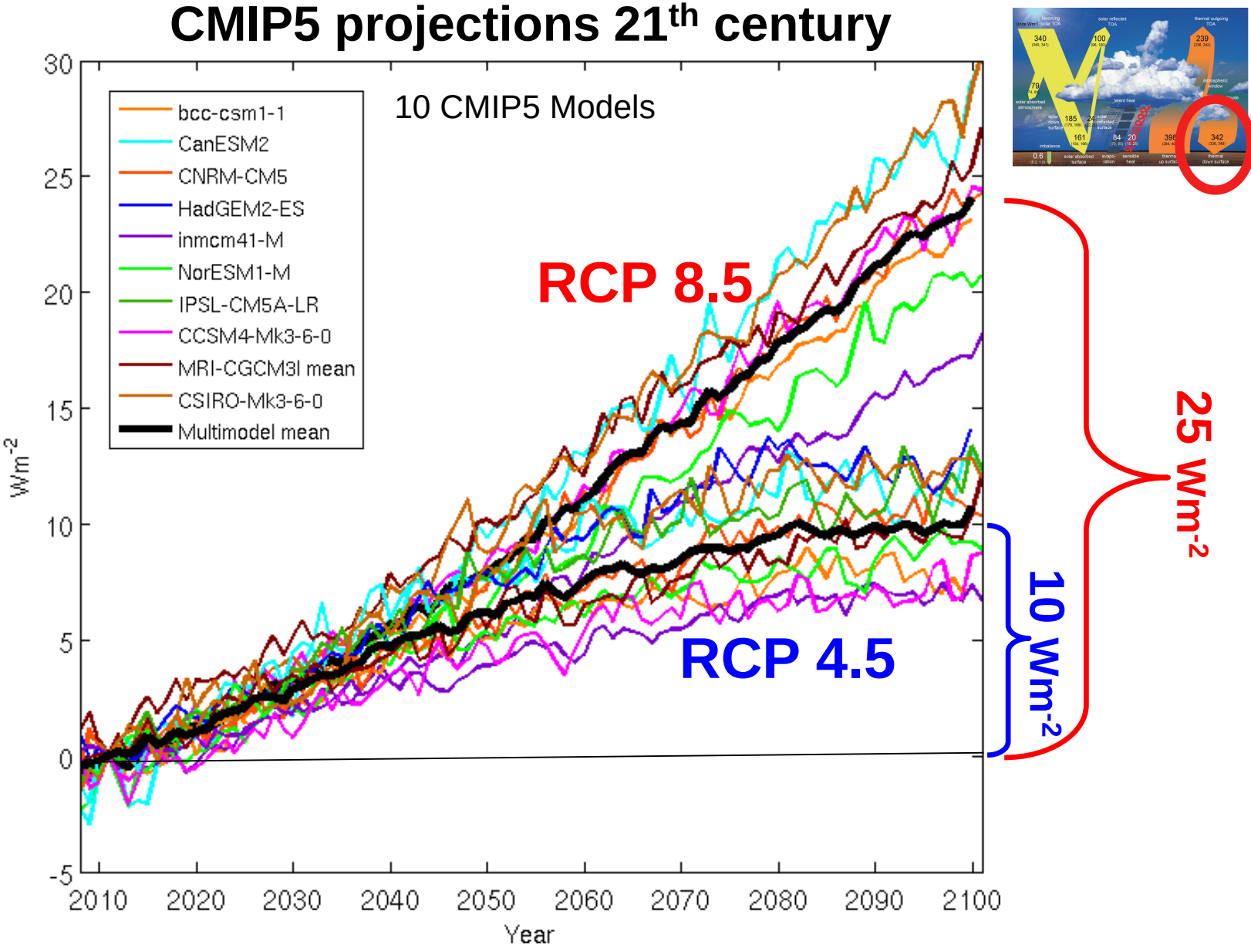
Observed changes at BSRN sites since early 1990s:

25 longest BSRN records (totally 353 years)

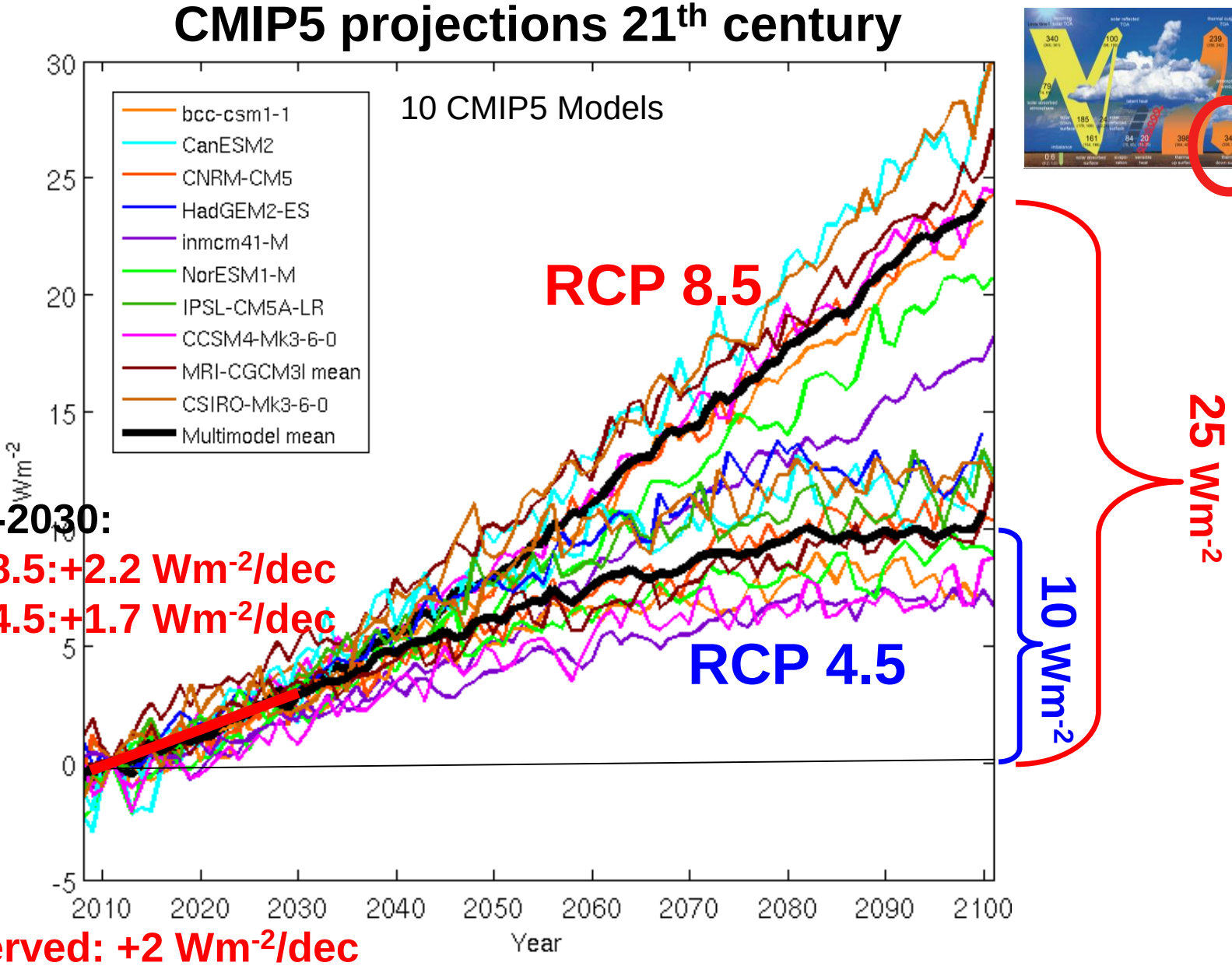
- ***19 stations (76%) with increase*** *in LW down (9 significant)*
- ***6 stations (24%) with decrease*** *in LW down (3 significant)*
- ***Average change all sites: +2.0 $Wm^{-2}dec^{-1}$***

Wild 2015 in press

Downward longwave radiation in RCP scenarios



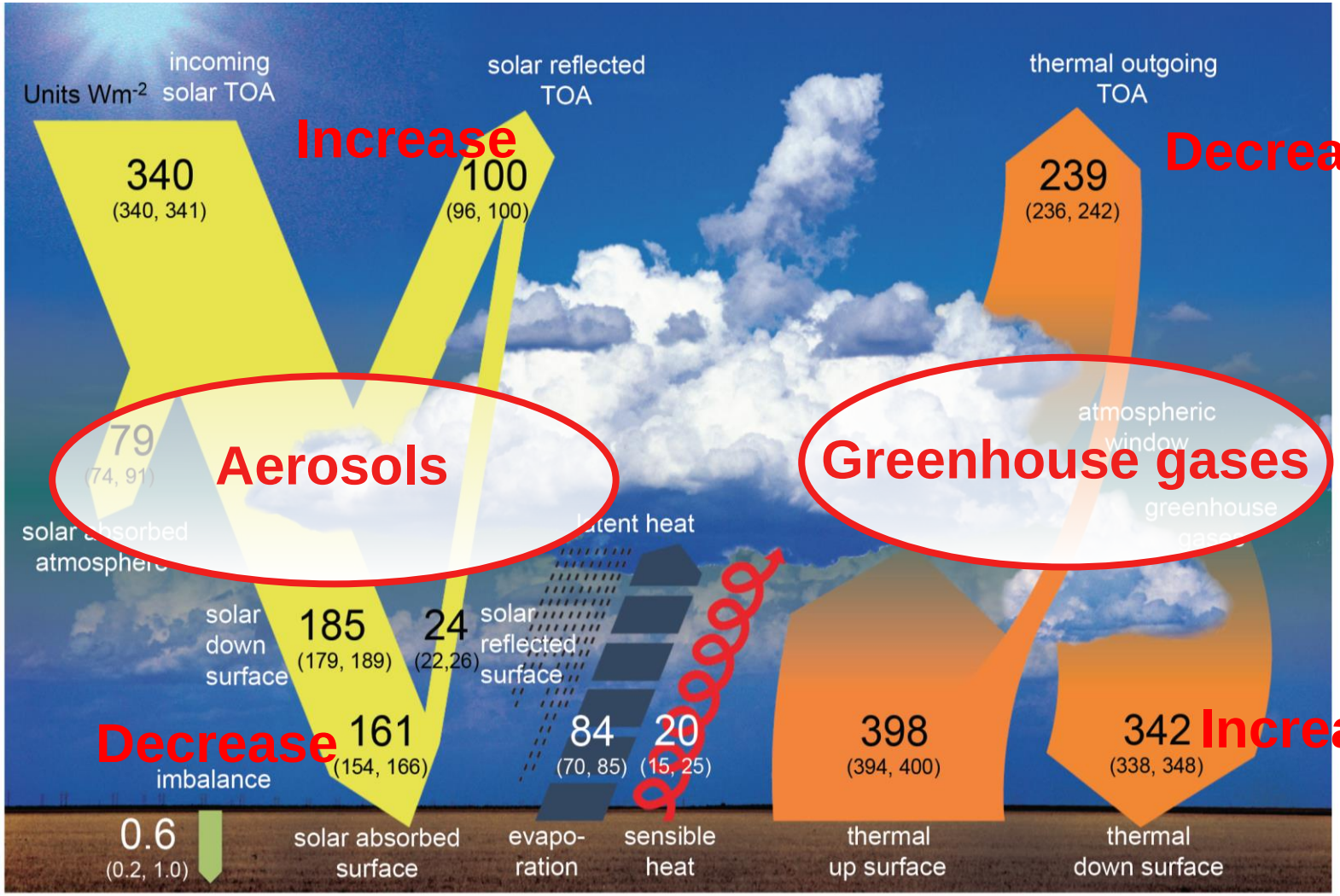
Downward longwave radiation in RCP scenarios



Changes in the Earth radiation budget

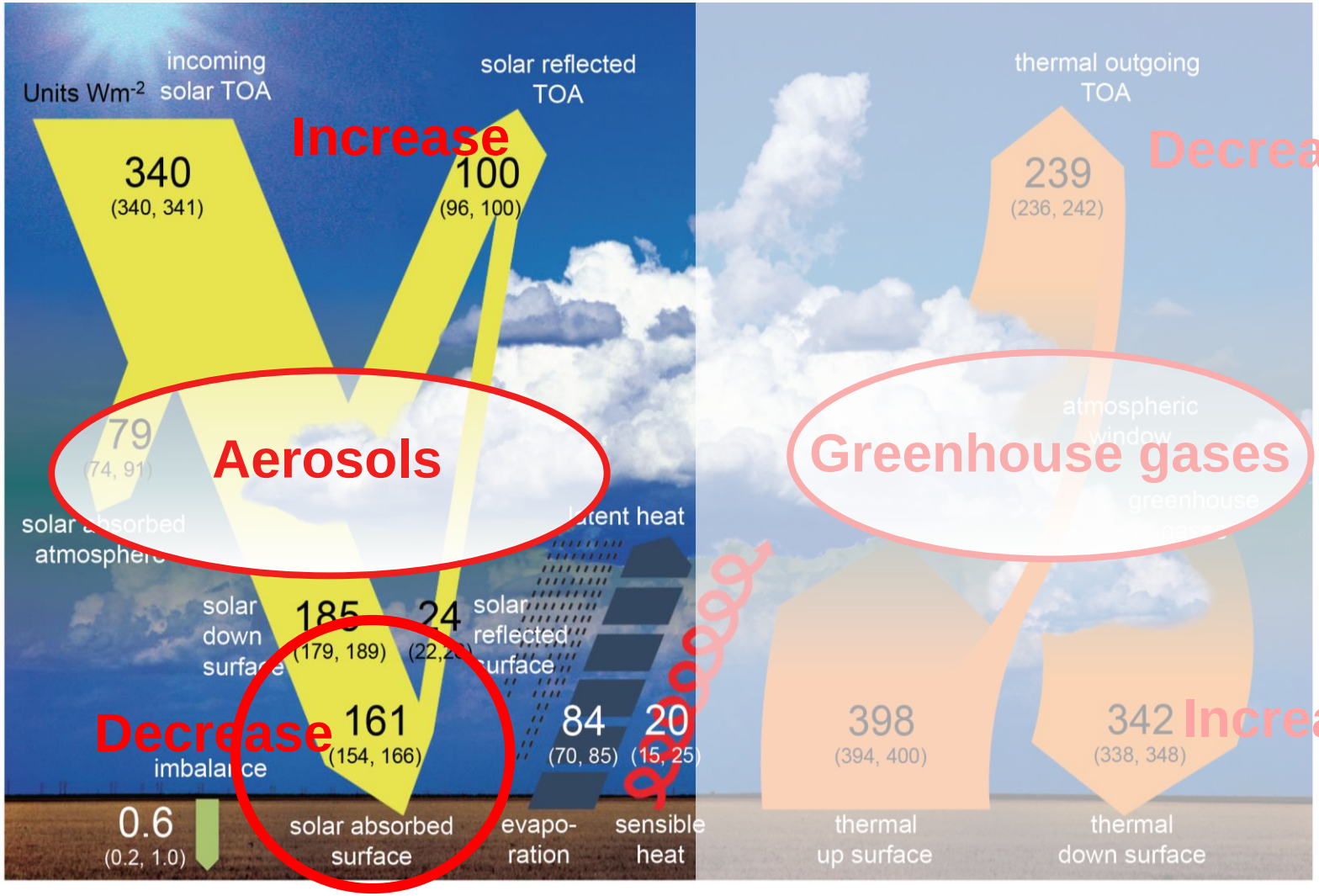
Anthropogenic Perturbations

Units Wm^{-2}



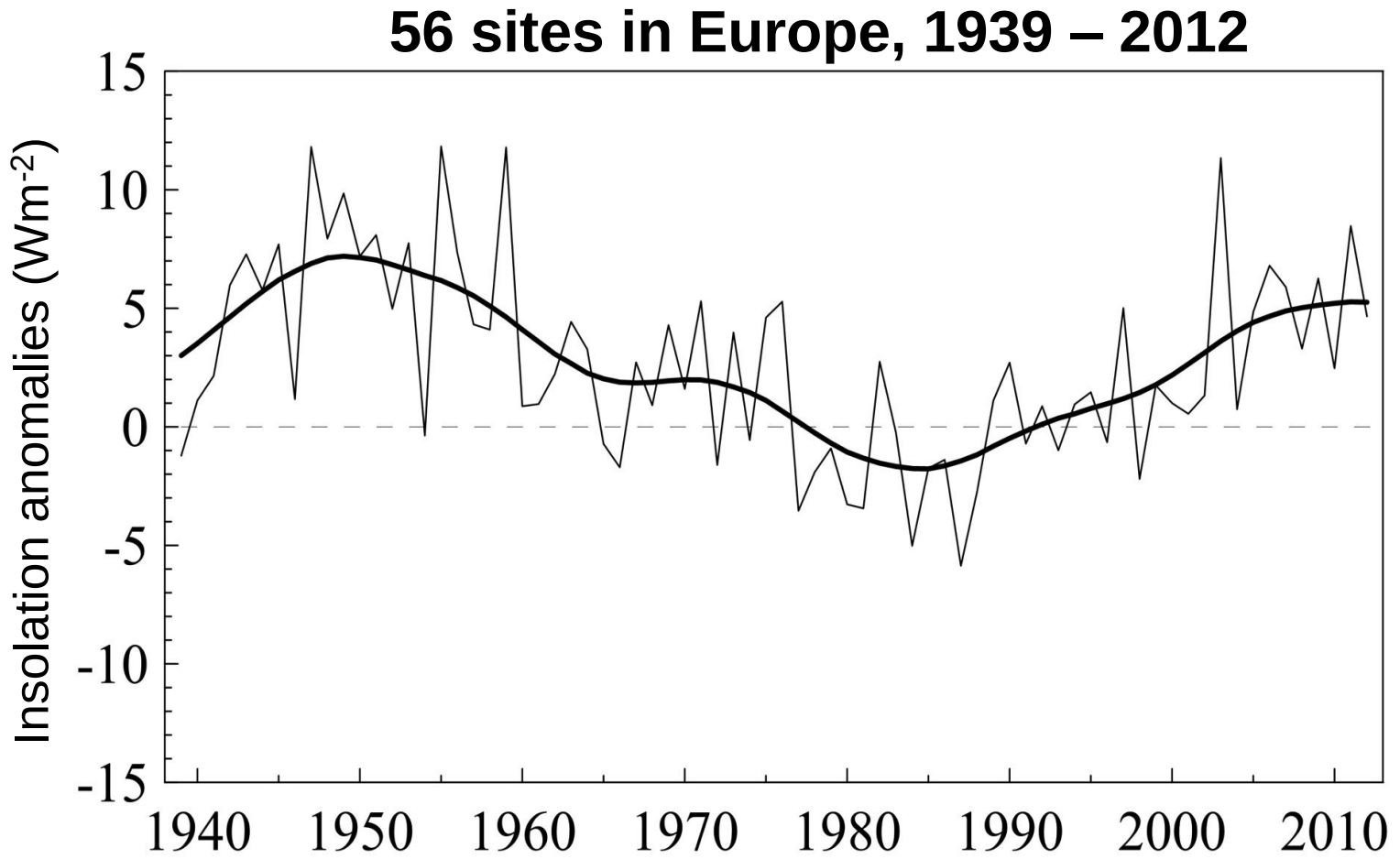
Changes in the Earth radiation budget

Anthropogenic Perturbations

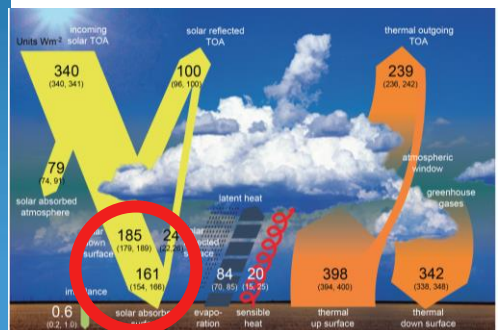


Changes in surface solar radiation

Decadal changes in surface solar radiation

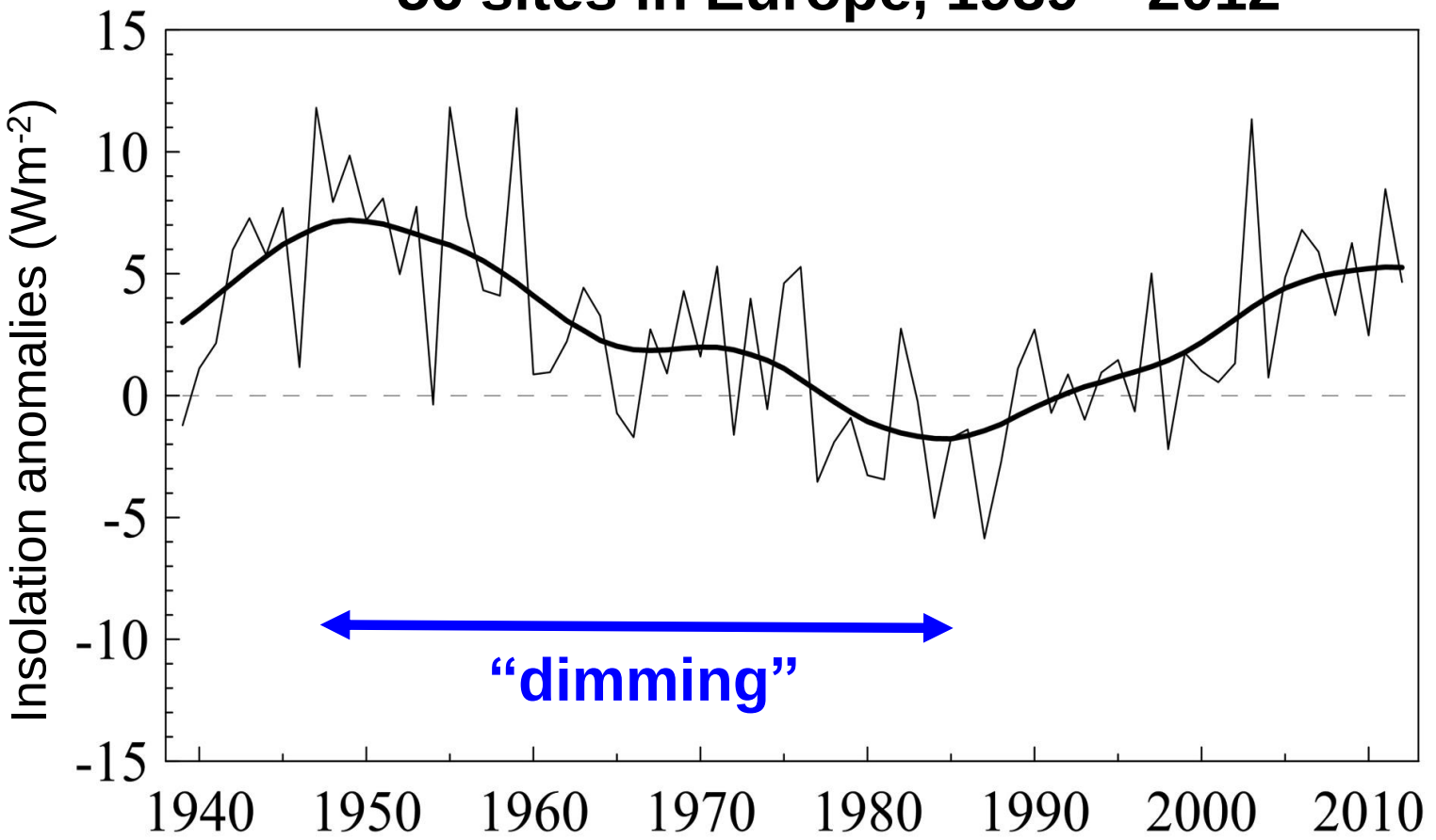


Data from Global Energy Balance Archive (GEBA)

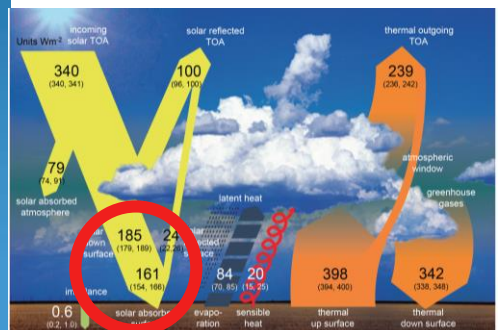


Wild et al. (2005) *Science*
Wild (2012) *BAMS*
Sanchez et al. (2015) *JGR*

Decadal changes in surface solar radiation



Data from Global Energy Balance Archive (GEBA)



Wild et al. (2005) *Science*
Wild (2012) *BAMS*
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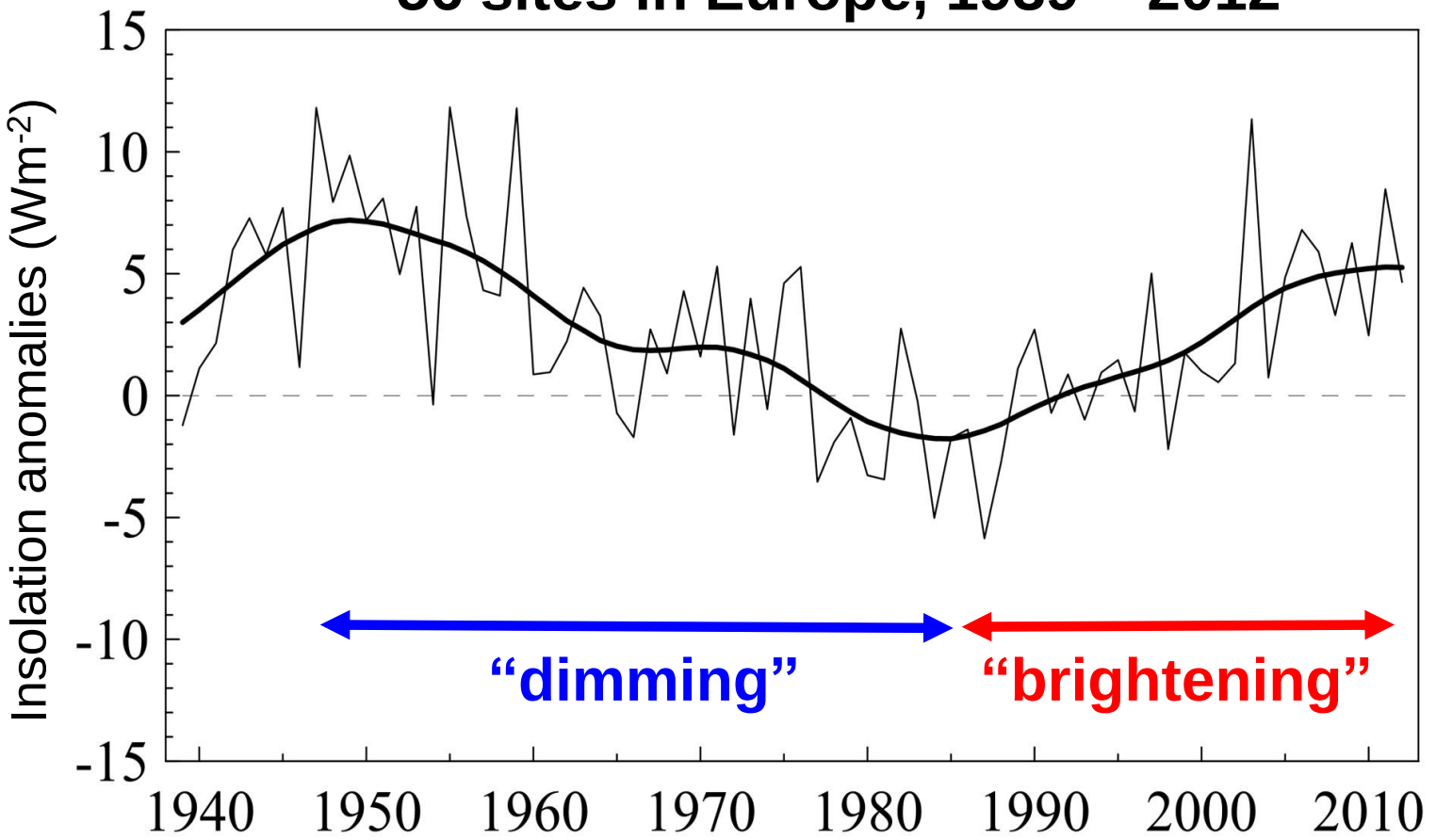
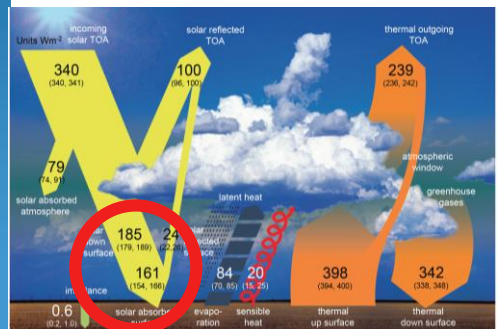
Decadal changes in surface solar radiation



Data from Global Energy Balance Archive (GEBA)



Wild et al. (2005) *Science*
Wild (2012) *BAMS*
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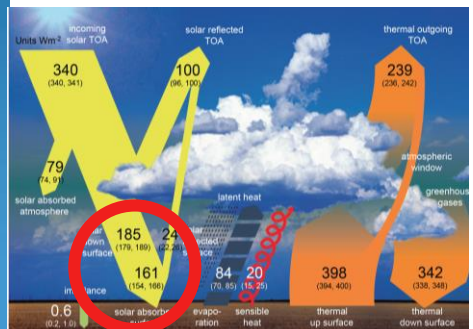
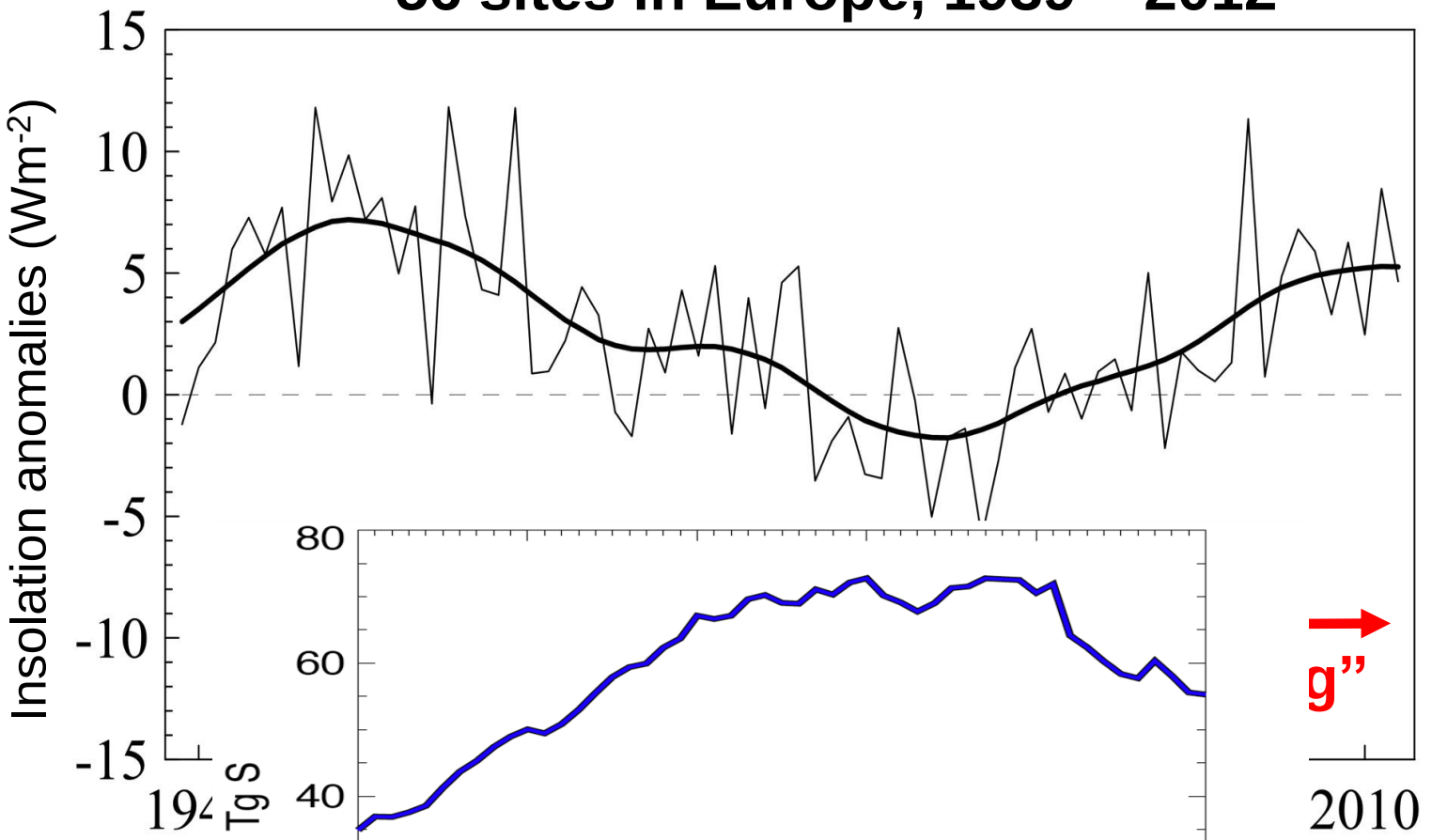
Decadal changes in surface solar radiation



56 sites in Europe, 1939 – 2012

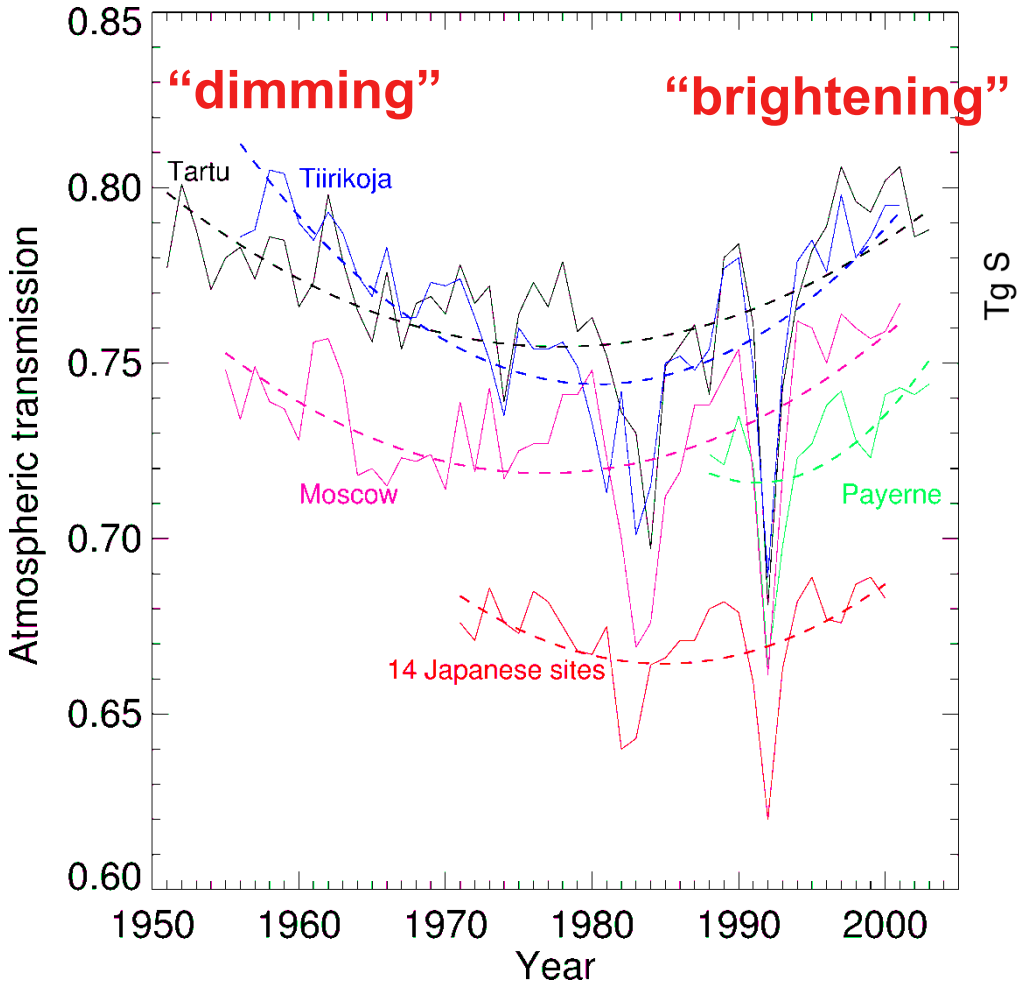


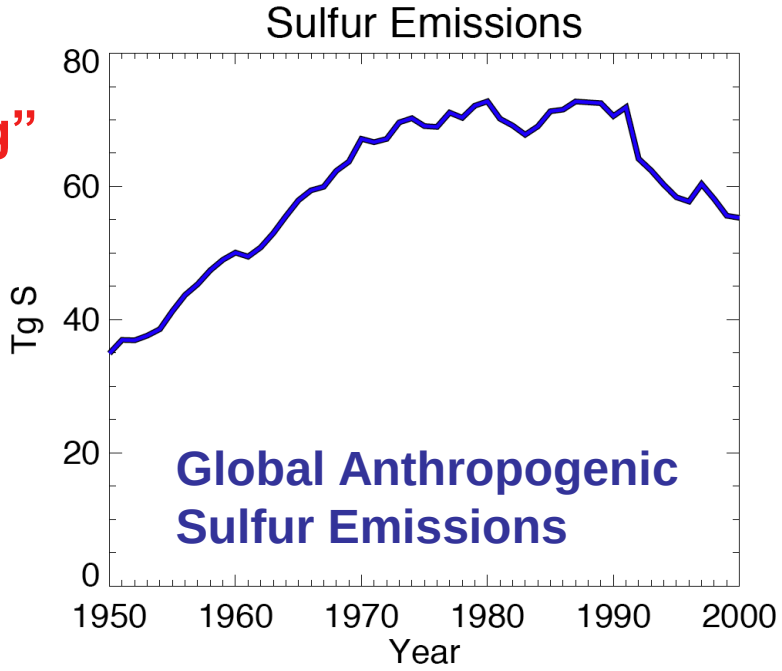
g”

:BA)

Changes in cloud-free atmosphere since 1950s

Atmospheric clear-sky transmission





Data source: Stern, 2005

Recent recovery in atmospheric transmittance in line with reduced emissions

Wild et al, 2005, *Science*

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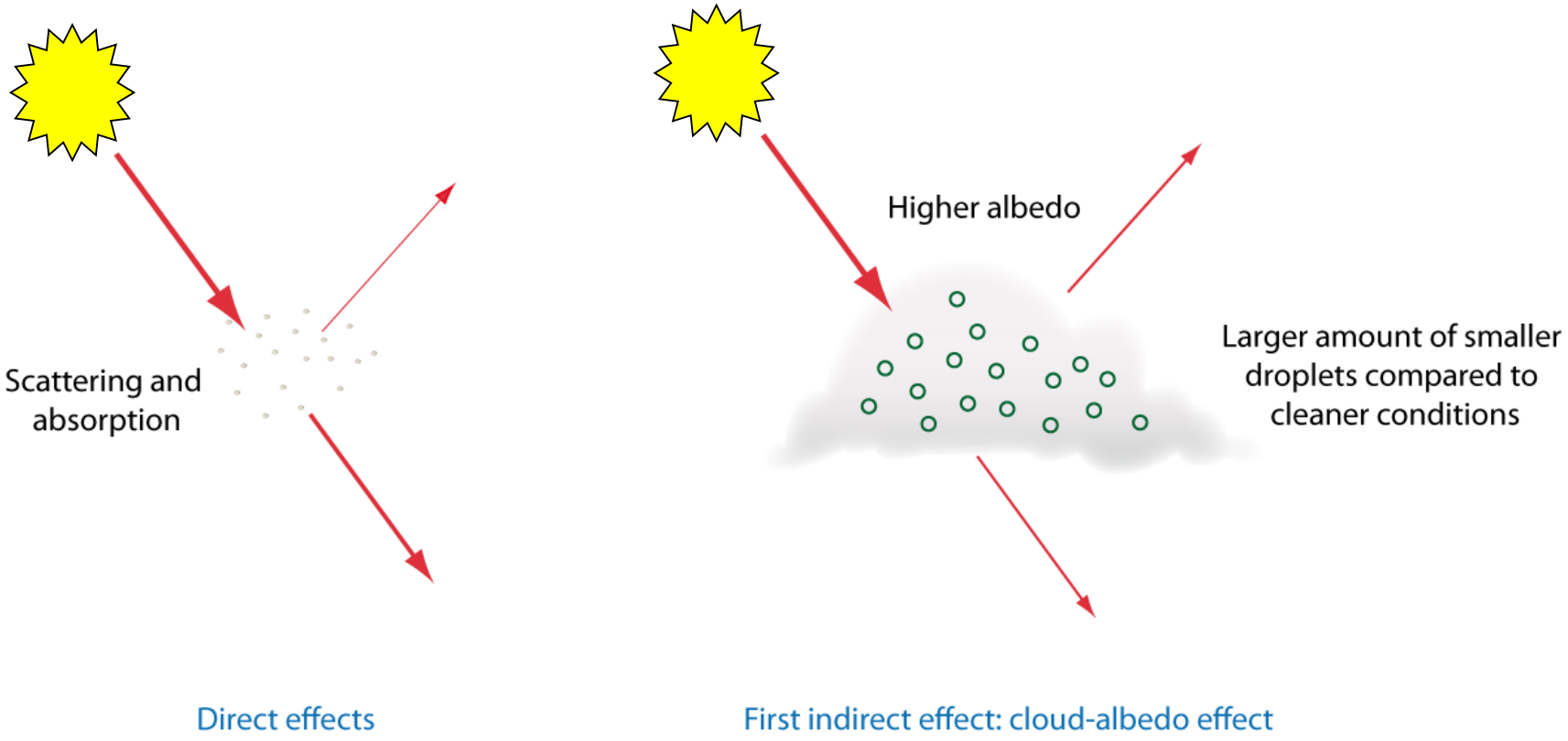
Potential causes for the surface solar variations

Direct and indirect aerosol effects

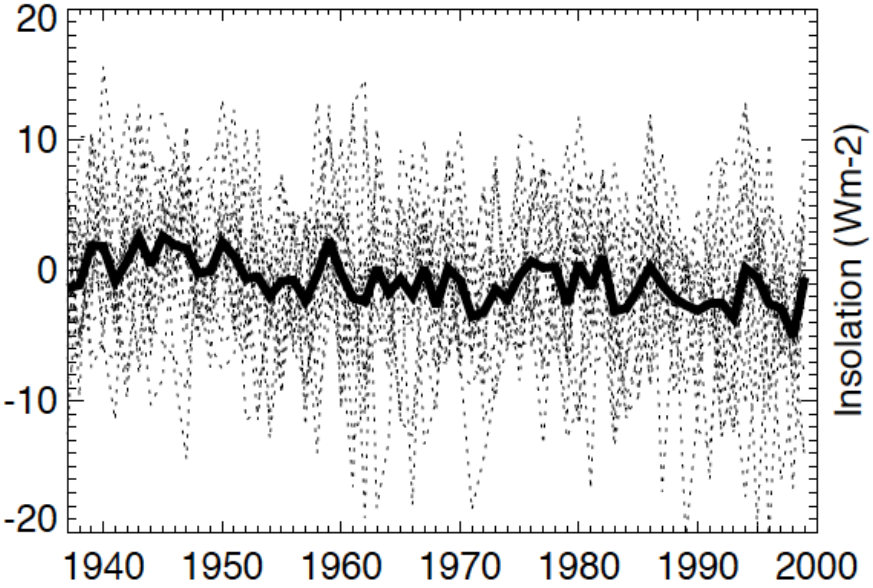


Both direct and indirect aerosol effects (cloud albedo/cloud lifetime) reduce the amount of solar radiation reaching the ground

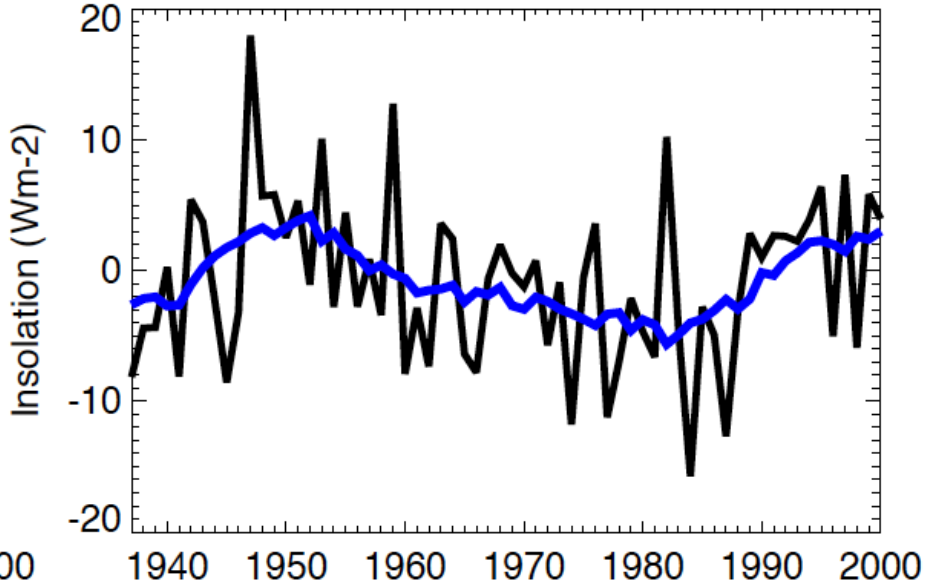
Surface solar radiation changes in climate models

Surface solar radiation Potsdam 1937-2000

Climate models



observed

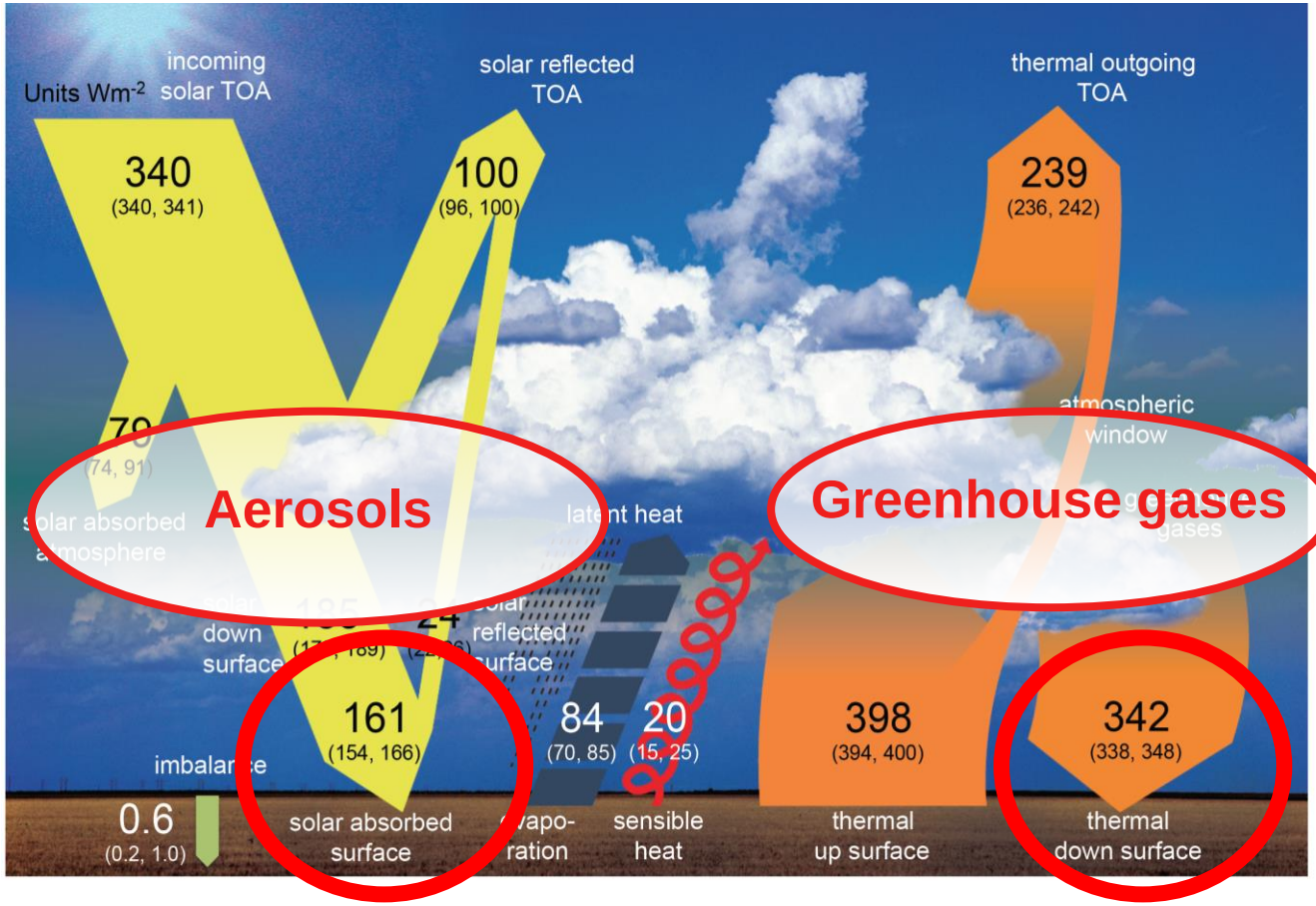


Lack of decadal variations in surface solar radiation simulated by climate models

Wild 2009 *JGR*

Changes in the Earth radiation budget

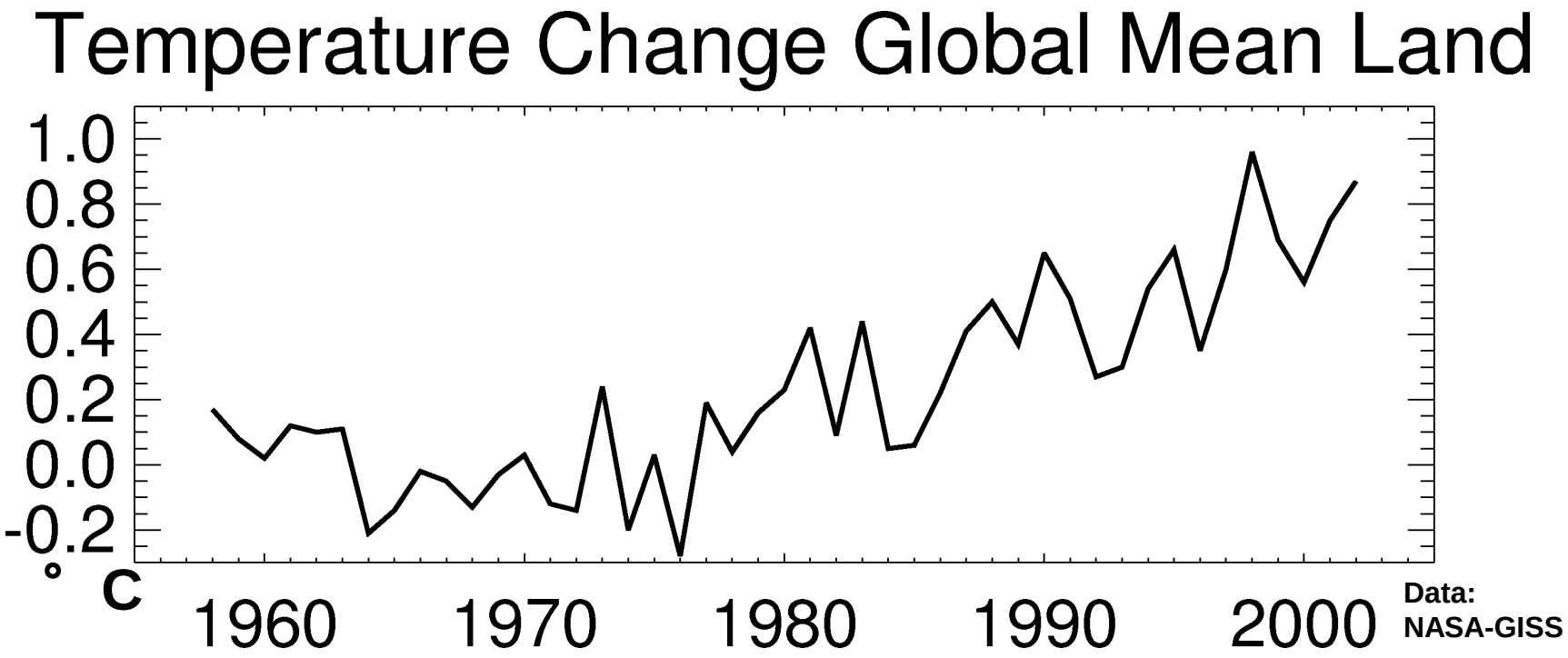
Implications for global warming



Multidecadal variations

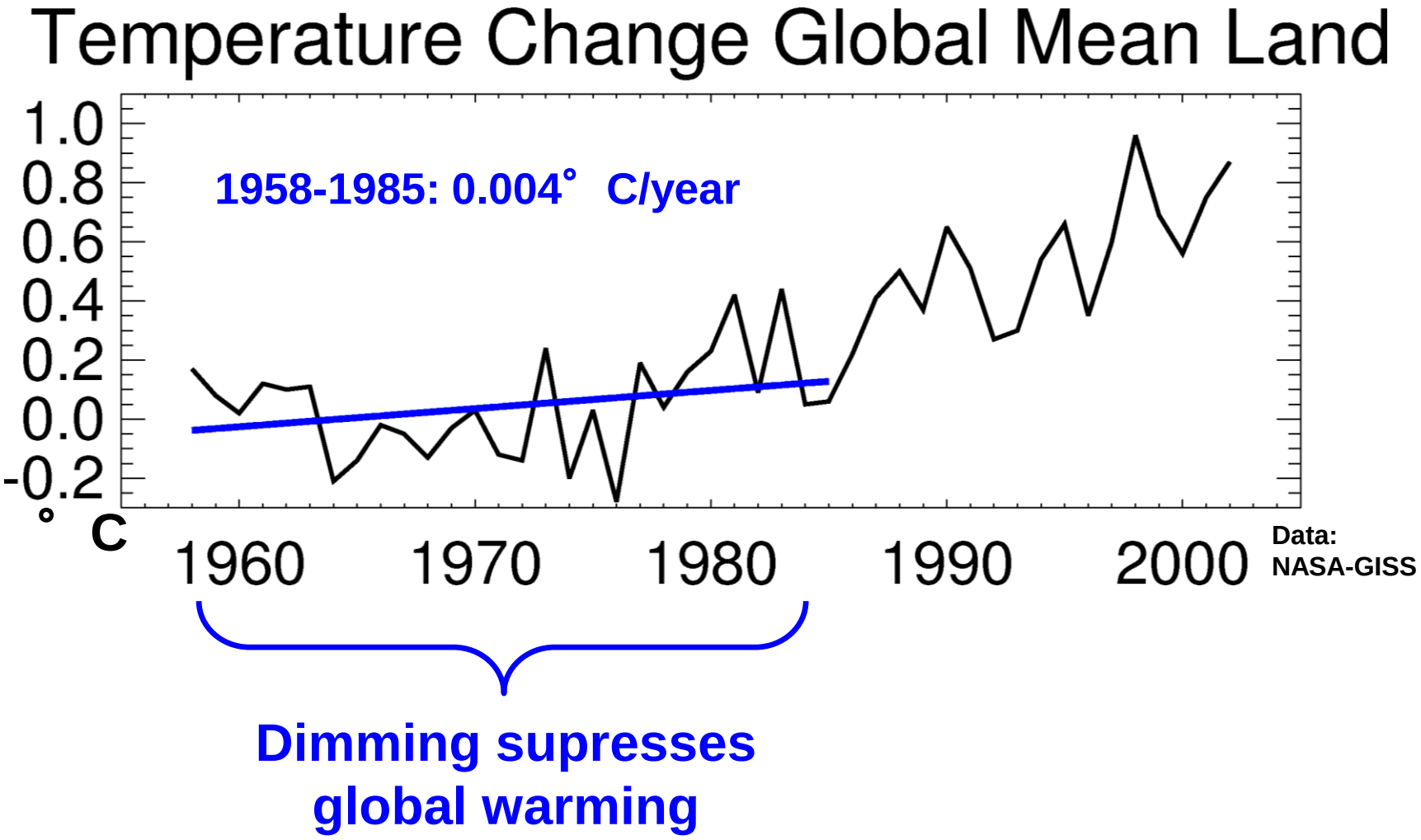
Increase

Solar dimming versus greenhouse warming



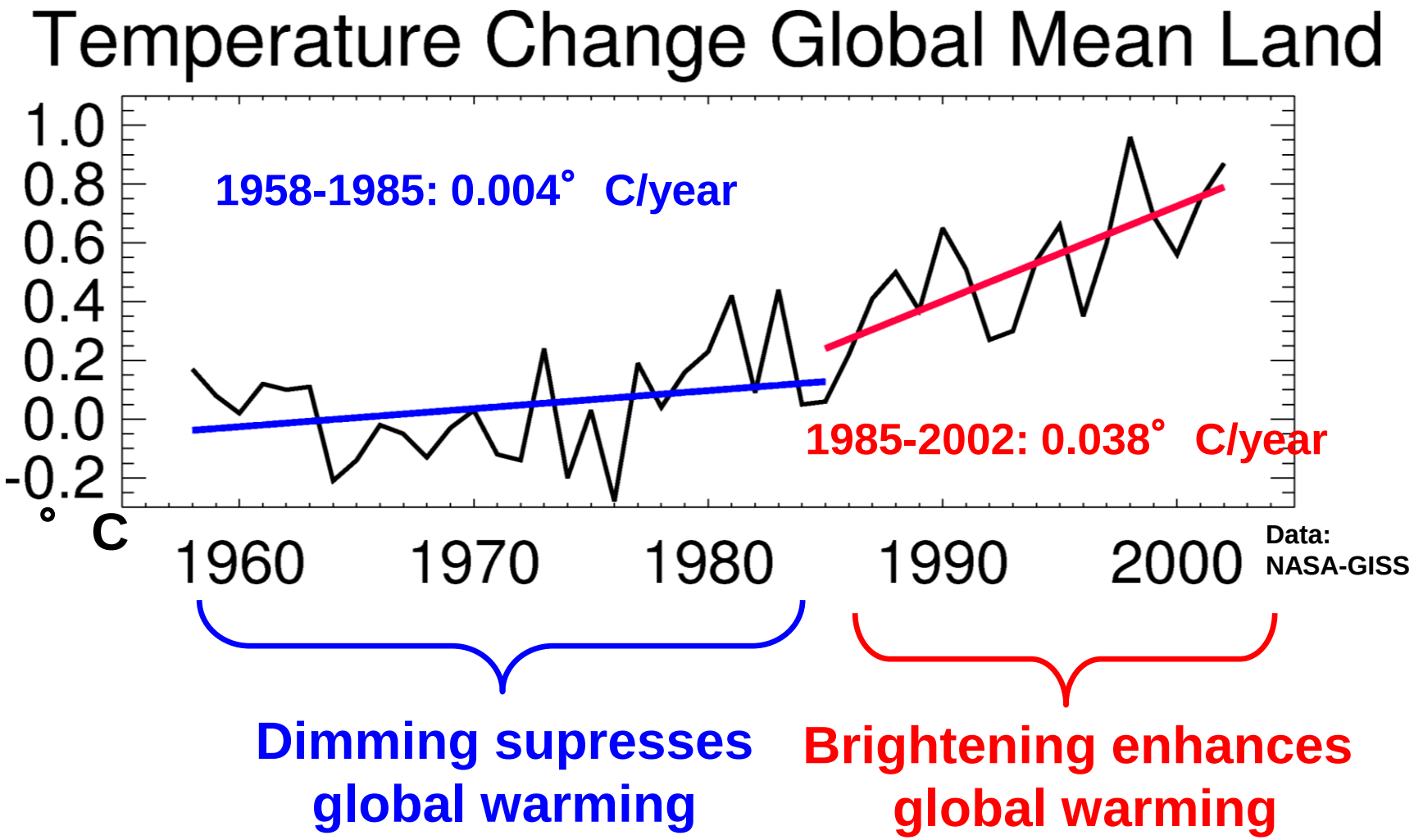
Wild et al. 2007 GRL 34

Solar dimming versus greenhouse warming



Wild et al. 2007 GRL 34

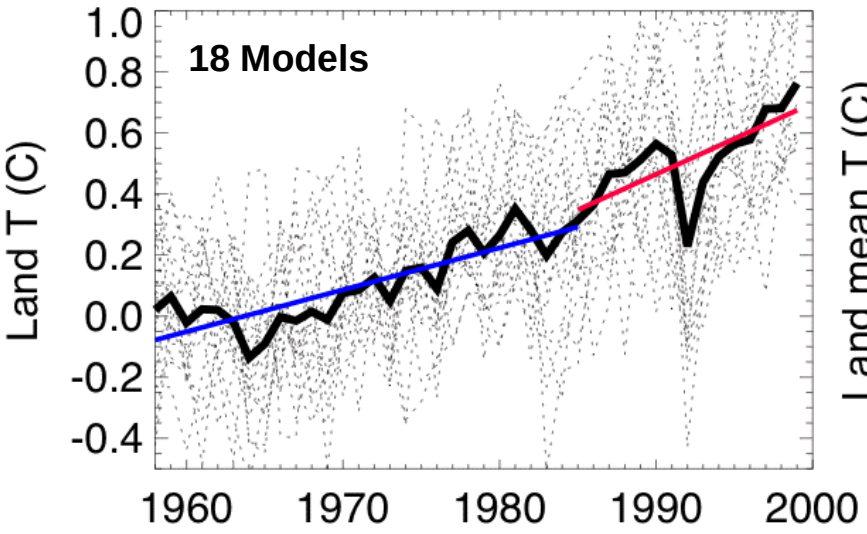
Solar dimming versus greenhouse warming



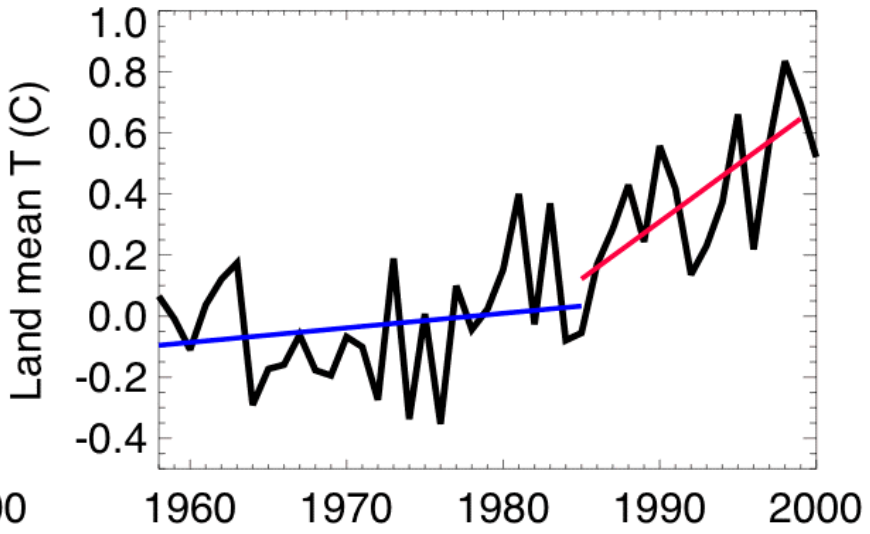
Wild et al. 2007 GRL 34

Decadal warming rates in climate models

Model-calculated land mean T



Observed land mean T



Linear regression slopes land mean temperature

Units ° C per decade	Dimming period 1958-85	Brightening period 1985-99	Change in slope	Total period 1958-99
Model mean	**+0.14**	**+0.23**	**+0.09**	**+0.18**
Observed	**+0.04**	**+0.38**	**+0.34**	**+0.17**

- **GCM overestimate warming in dimming phase** (1950s to 1950s)
- **GCMs underestimate warming in brightening phase** (since 1980s)

Wild 2009 *JGR*

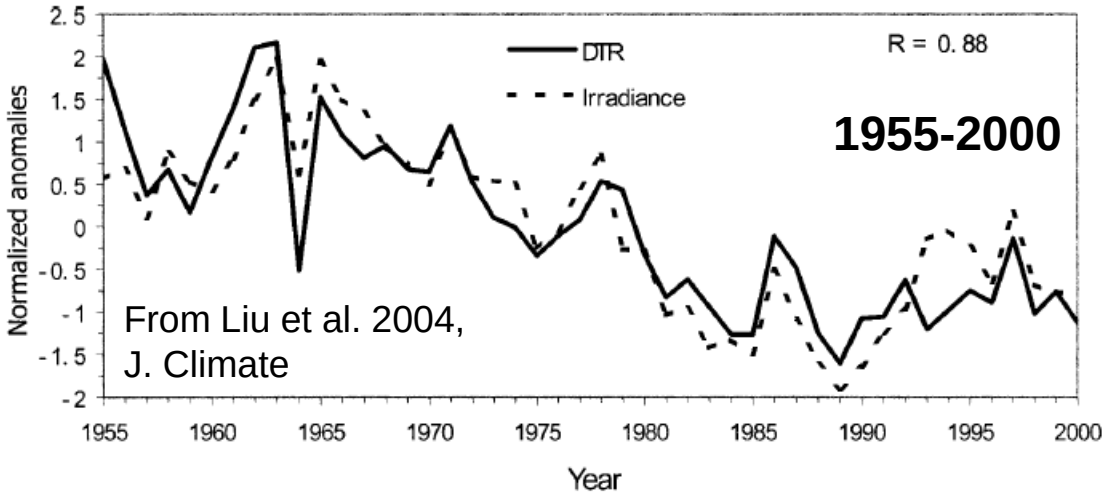
Impact of dimming/brightening on DTR

DTR:

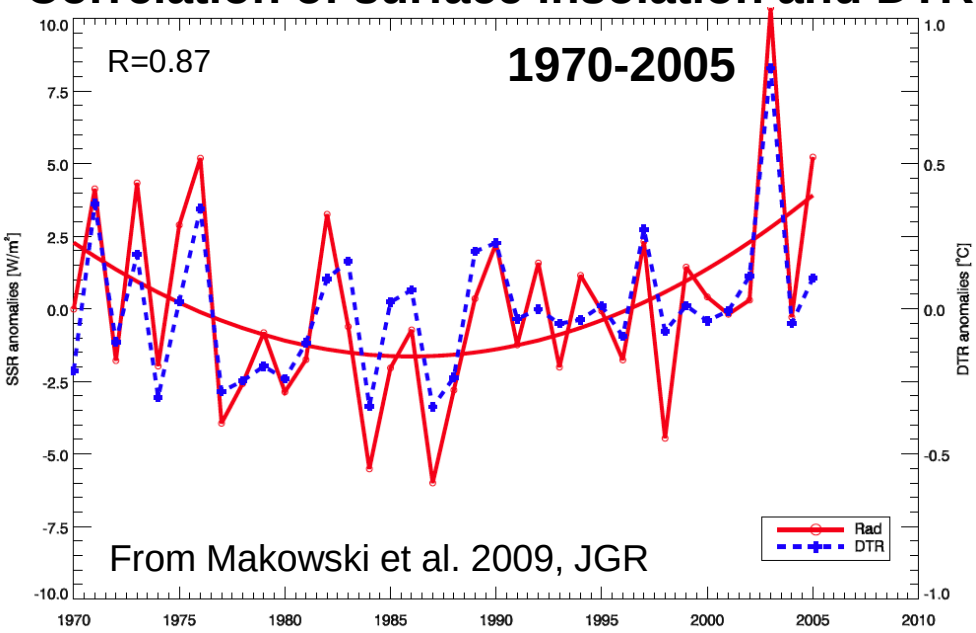
Diurnal Temperature Range

= T max – T min

Correlation of surface insolation and DTR in China



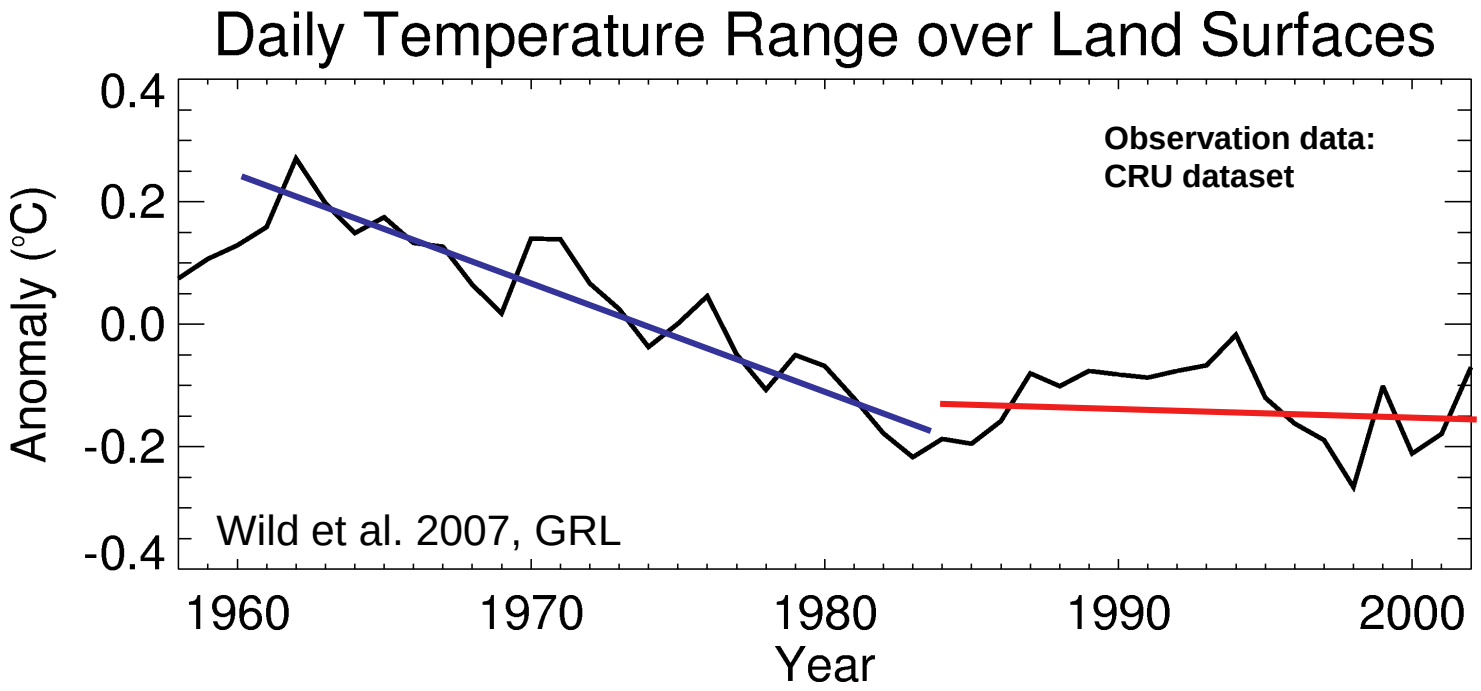
Correlation of surface insolation and DTR in Europe



Daily maximum temperature dominated by surface solar radiation

Daily minimum temperature dominated by thermal radiation

Observed DTR global land 1958-2000



Linear regression slopes land mean DTR

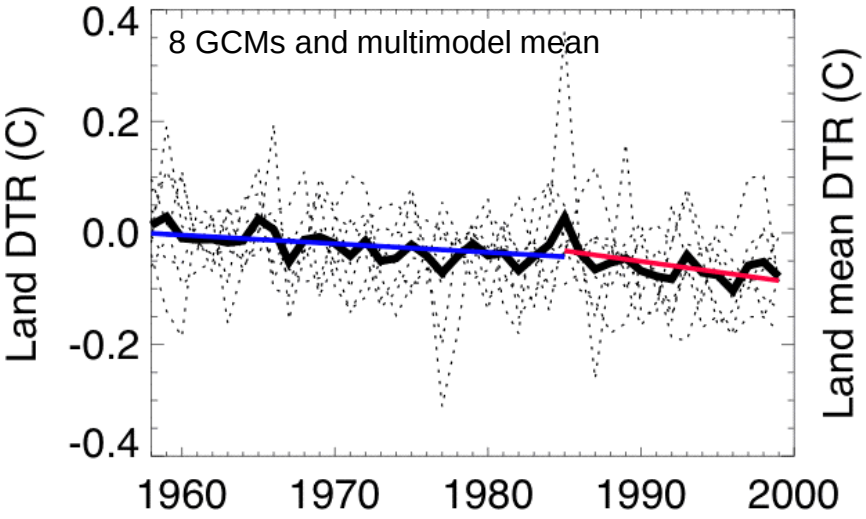
Units ° C/decade	1958-1985 "dimming"	1985-2002 "brightening"
T max	**-0.04**	**+0.37**
T min	**0.11**	**+0.40**
DTR	**-0.15**	**-0.03**

Evidence for large scale change in surface radiative forcings

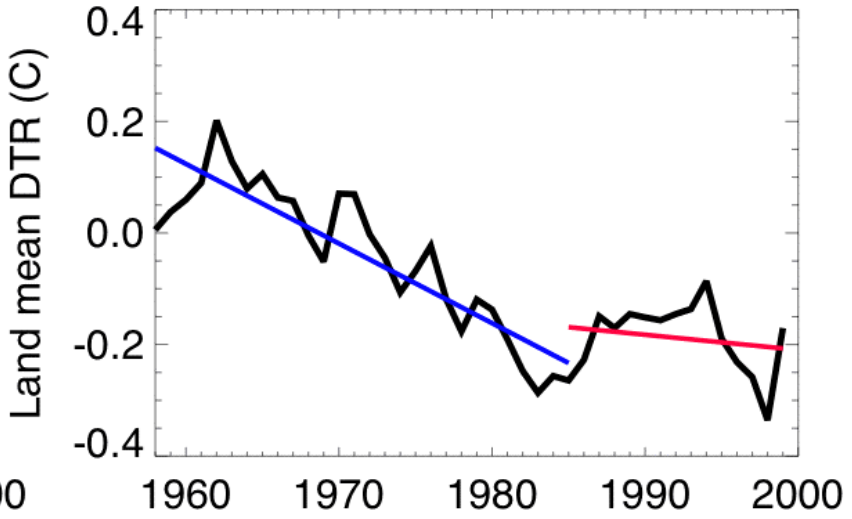
Wild et al. 2007, *Geophys. Res. Lett.*

DTR in global climate models

Model-calculated land mean DTR



Observed land mean DTR



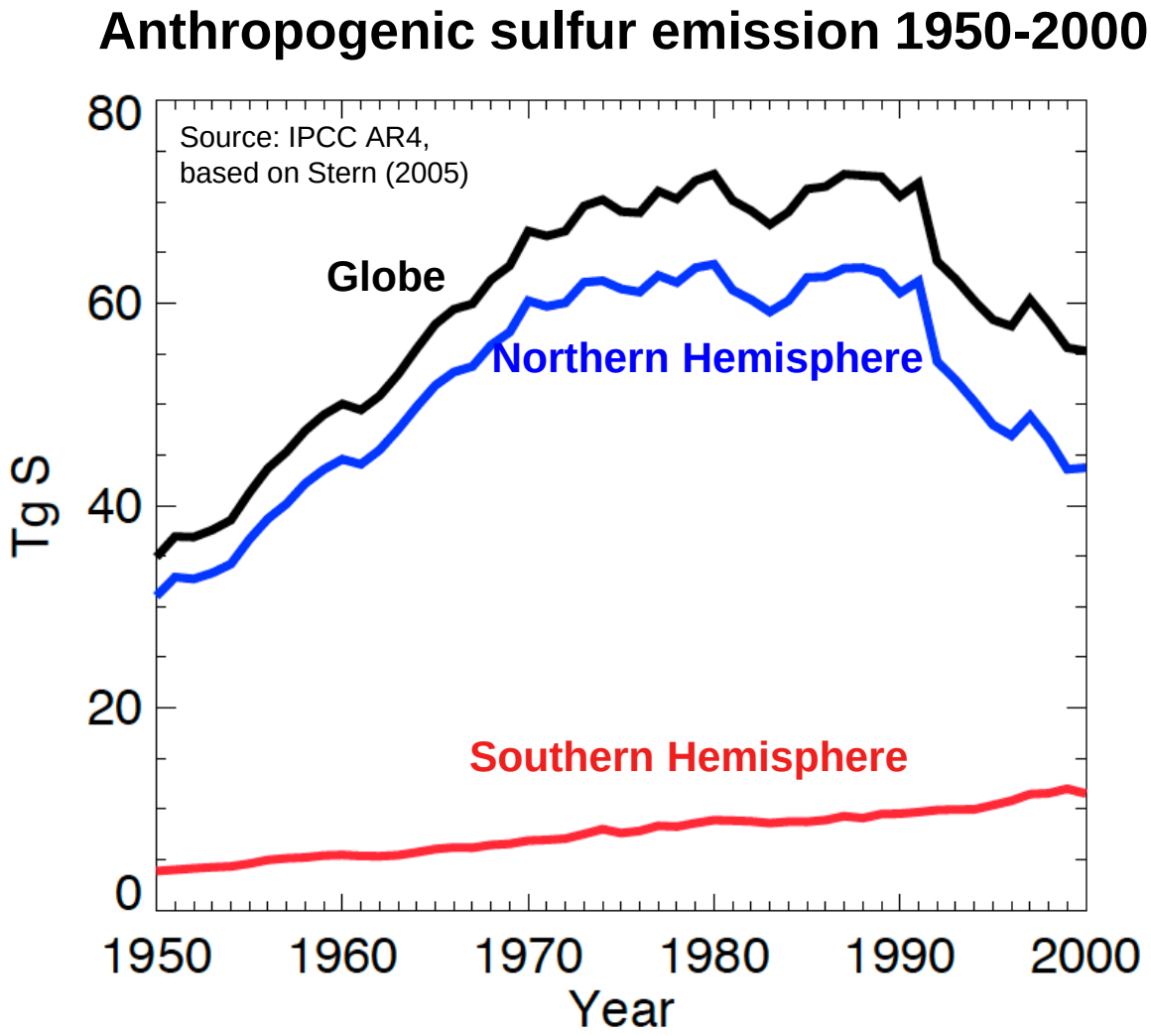
Linear regression slopes land mean DTR

Units ° C per decade	dimming phase 1958-85	brightening phase 1985-99	Change dimming > brightening
Model mean (8 GCMs)	**-0.02**	**-0.04**	**-0.02**
Observed	**-0.15**	**-0.03**	**+0.12**

GCMs do not show strong decrease in DTR during dimming phase and leveling off in brightening phase > indication for lack of dimming/brightening in GCMs

Wild 2009 *JGR*

Asymmetric hemispheric pollution

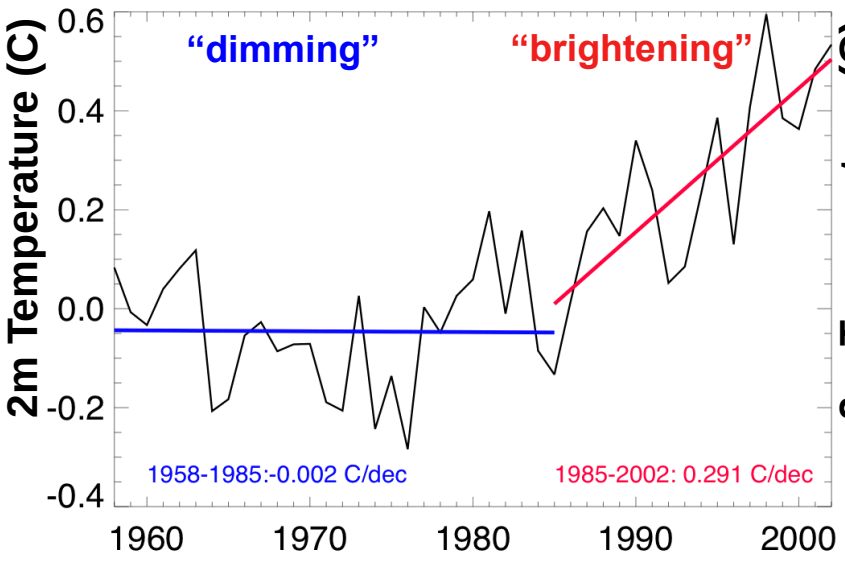


Emissions show trend reversal in NH, but not in SH

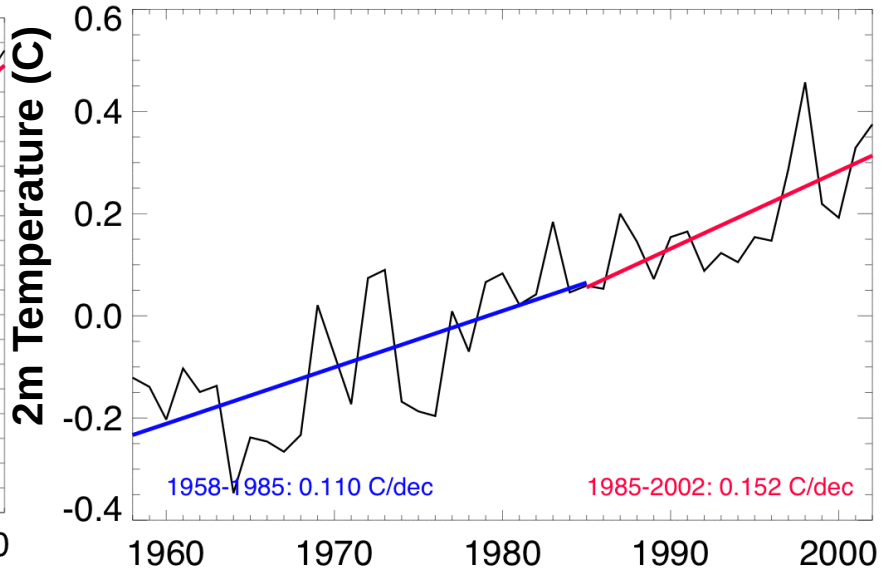
Wild 2012, *Bull. Amer. Meteor. Soc.*

Asymmetric hemispheric warming

T observed Northern Hemisphere



T observed Southern Hemisphere



Obsdata: CRU

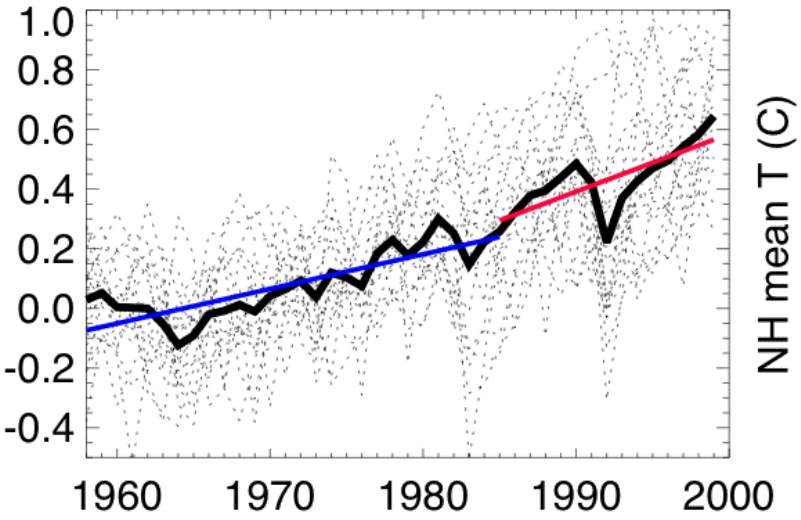
Linear regression slopes observed 2m T

Units ° C/decade	1958-2002	1958-1985 "dimming"	1985-2002 "brightening"
NH	**+0.10**	**-0.002**	**+0.29**
SH	**+0.12**	**0.11**	**+0.15**

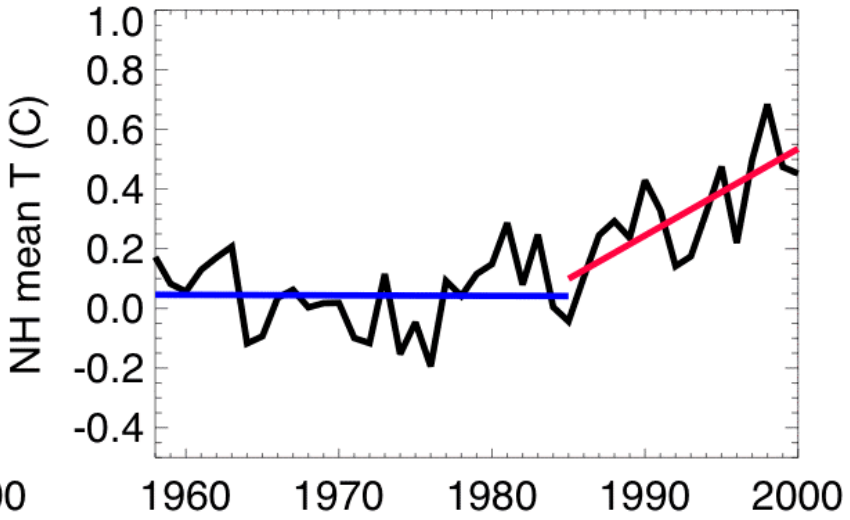
Wild 2012, *Bull. Amer. Meteor. Soc.*

Northern Hemisphere warming

Model-calculated NH warming



Observed NH warming



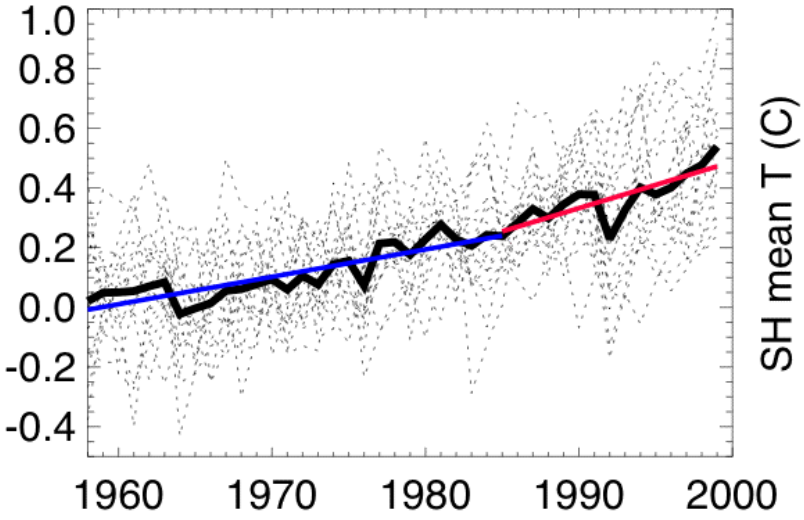
Linear regression slopes: Northern Hemisphere 2m T

Units ° C per decade	dimming phase 1958-85	brightening phase 1985-99	Change dimming > brightening
Model mean (18 GCMs)	**+0.12**	**+0.19**	**+0.07**
Observed	**-0.002**	**+0.29**	**+0.31**

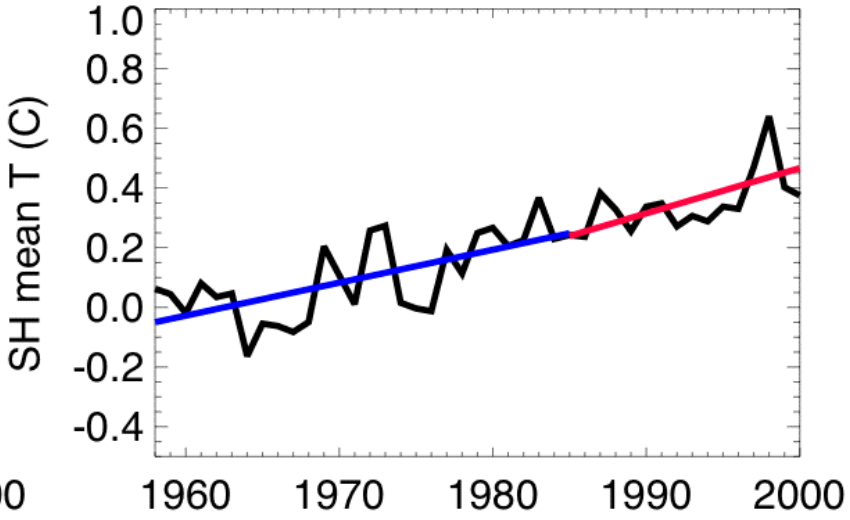
Wild 2012, *Bull. Amer. Meteor. Soc.*

Southern Hemisphere warming

Model-calculated SH warming



Observed SH warming



Linear regression slopes: Southern Hemisphere 2m T

Units ° C per decade	dimming phase 1958-85	brightening phase 1985-99	Change dimming > brightening
Model mean (18 GCMs)	**+0.09**	**+0.15**	**+0.06**
Observed	**0.11**	**+0.15**	**+0.04**

GCMs reproduce decadal warming in unpolluted SH better than in polluted NH

Wild 2012, BAMS

Summary

- Still large uncertainties in Earth radiation budget of the latest (CMIP5) climate models, particularly at the surface

  => Direct surface observations can provide some constraints
- CMIP5 models tend to overestimate surface downward shortwave and underestimate downward longwave radiation compared to surface obs
  => long standing issue in climate models (AMIPI, II, CMIP3)
- Biases also seen under cloud-free conditions
- Biases generally smaller than in earlier model generations, but not completely removed
- Bias structure may be used to infer best estimates of the global mean Surface Radiation Budget
- Decadal changes observed in both surface SW and LW fluxes
- Observations indicate an increase of downward longwave radiation of 2 Wm^{-2} per decade, in line with CMIP5 simulations and expectations from an increasing greenhouse effect
- Surface shortwave radiation also undergoes strong decadal changes ("dimming/brightening"), not adequately represented in GCMs
  =>implications for the simulation of global warming.

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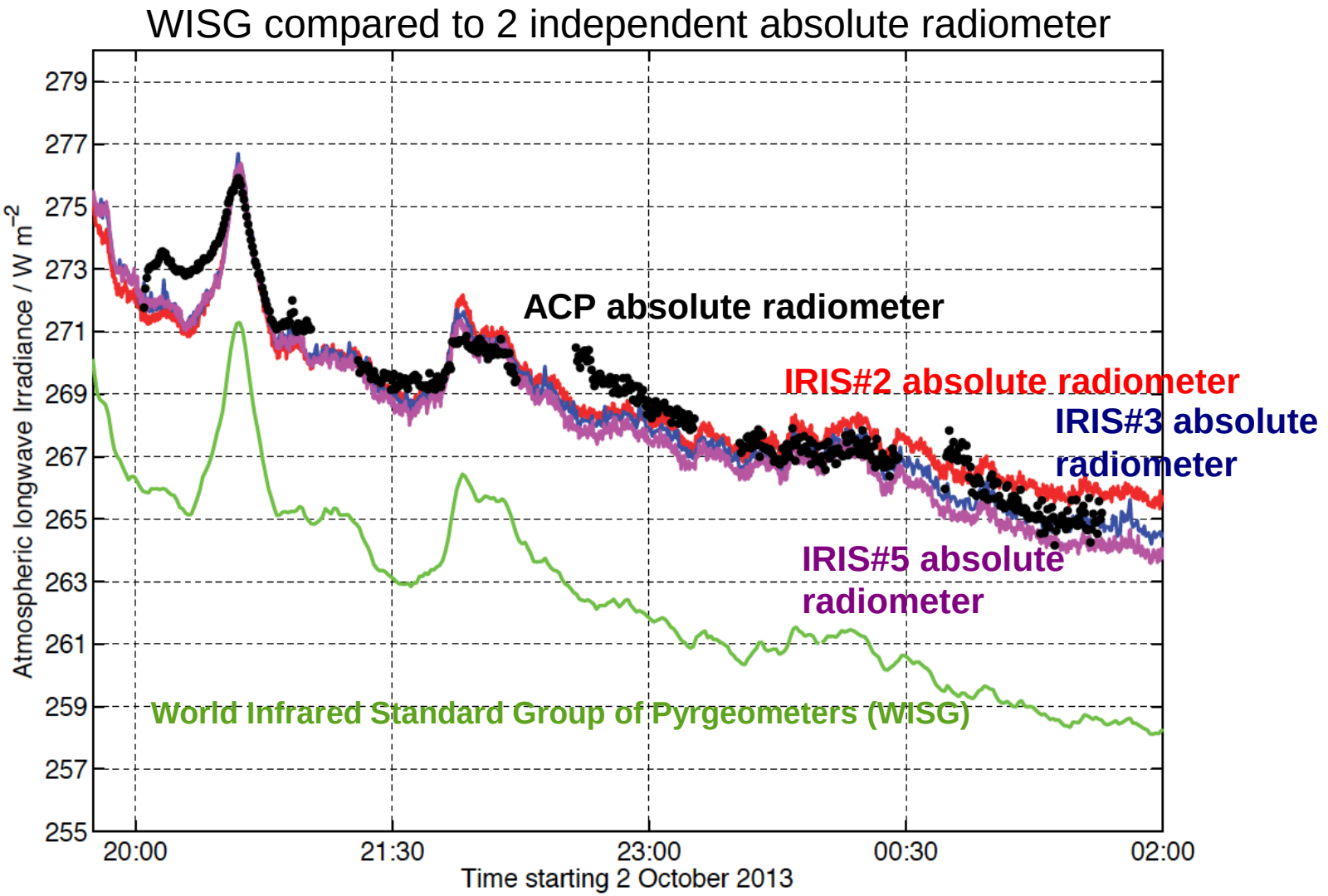
  =>implications for the simulation of global warming.

Mesurement issues

BSRN Measurement Accuracy Target

- **Direct SW radiation: 1% or 2 Wm-2 (normal incidence pyrheliometer)**
- **Diffuse radiation: 4 % or 5 Wm-2 (ventilated pyranometer)**
- **Global Radiation 2% or 5 Wm-2 (ventilated pyranometer)**
- **Reflected SW radiation: 5% (ventilated pyranometer)**
- **Downwelling longwave radiation +/ - 2 Wm-2 (pyrgeometer)**

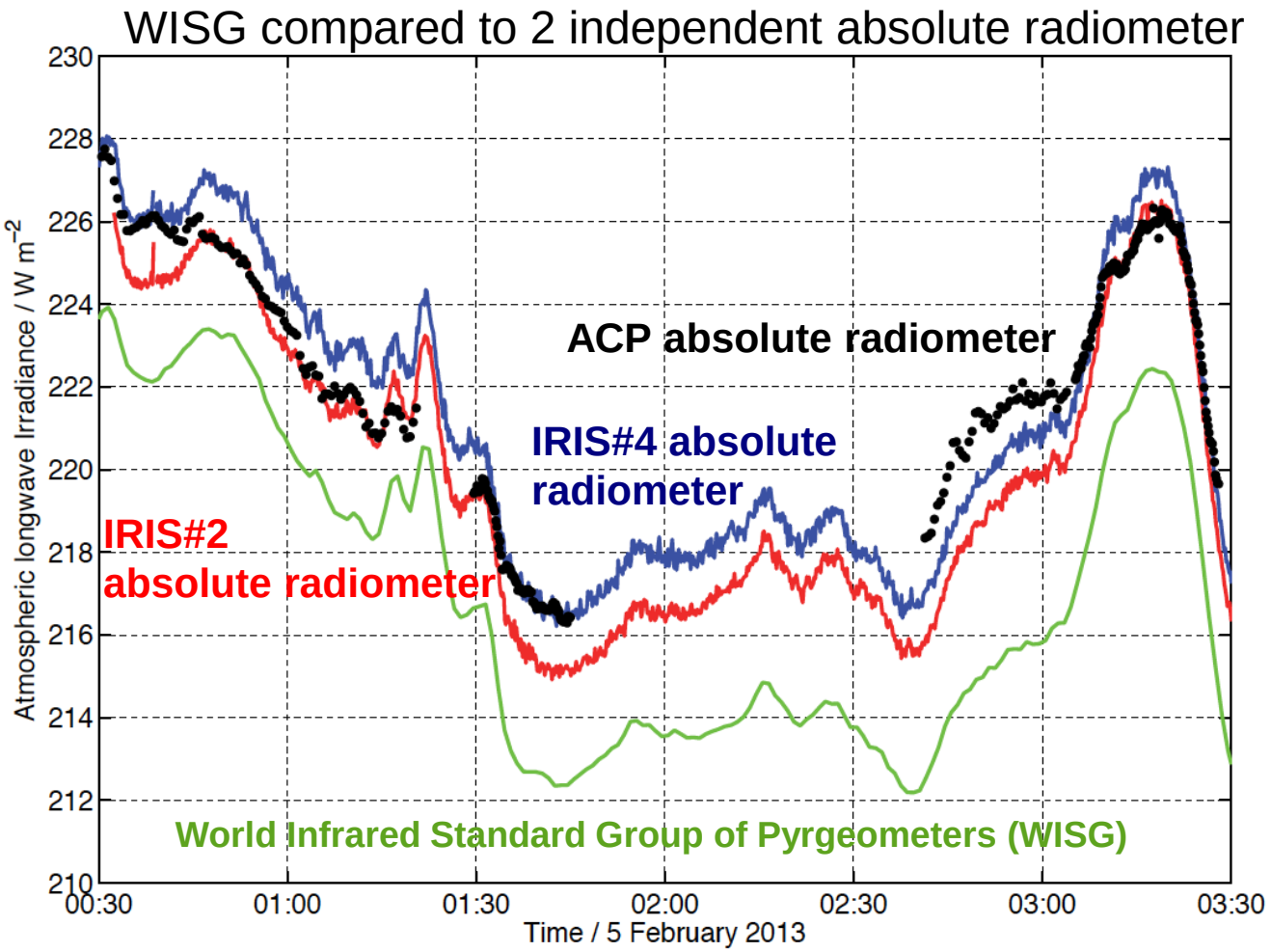
Underestimation of LW_{down} by World Infrared Standard Group?



Current standard group may underestimate LW_{down} by 2 - 5 Wm^{-2} depending on IWV

Gröbner et al., JGR (2015)

Underestimation of LW_{down} by World Infrared Standard Group?



Current standard group may underestimate LW_{down} by 2 - 5 Wm^{-2}

Gröbner et al., JGR (2015)

Identification of clear sky periods

Long and Ackerman (2002), JGR 105 (D12), 15609-15626

- **Based on 1 minute data of downwelling total and diffuse shortwave irradiance**
- **4 tests applied:**

A) Normalized total shortwave magnitude test Normalized with solar zenit angle, nominal range of values for clear sky

B) Maximum diffuse shortwave test

clear sky diffuse irradiance below a certain threshold

C) Change in magnitude with time test

compares temporal change in total irradiance, small for clear periods compared to cloudy periods over short timescales

D) Normalized diffuse ratio vatiability test

diffuse divided by total irradiance,smooth timeseries for clear skies, variability below threshold

Measurement uncertainty: single measurement

Kurzwellig:

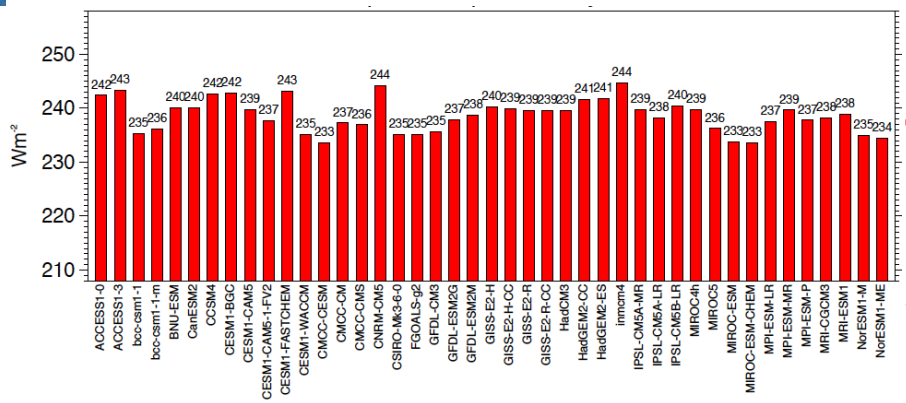
- Pyranometer:
  2% (Ohmura and Gilgen 1993)
  4 Wm^{-2} bei guter Wartung der Instrumente (Konzelmann und Ohmura 1995)

Langwellig:

- Pyrgeometer: +/- 2 Wm^{-2} (R. Phillipona, Pers. Mitteilung)
- Pyrradiometer:
  Belüftet, mit Schattenscheibe: +/- 10 Wm^{-2}

Global mean radiation budgets in CMIP5

Global mean solar radiation budgets in IPCC AR5 GCMs

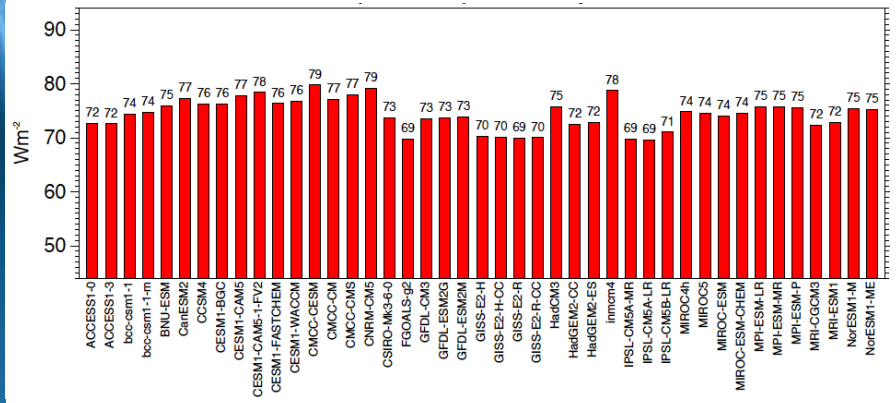


Absorbed SW all sky top of atmosphere

Multimodel mean: 239 Wm^{-2}

Range of models: 11 Wm^{-2}

Standard deviation: 3.0 Wm^{-2}

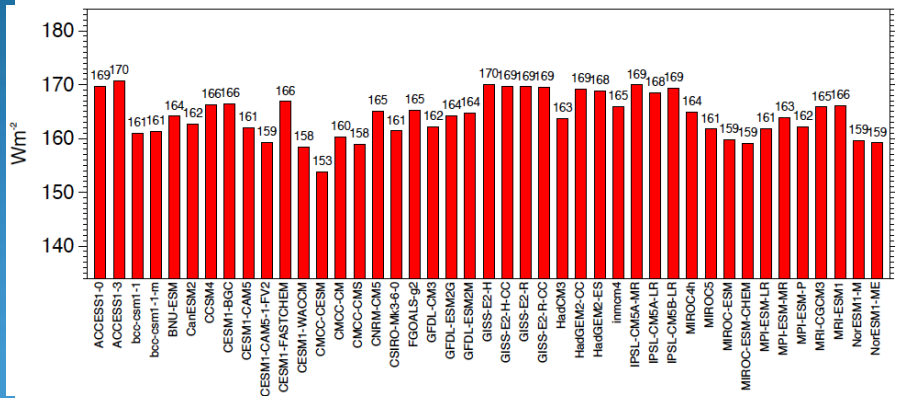


Absorbed SW all sky in the atmosphere

Multimodel mean: 74 Wm^{-2}

Range of models: 10 Wm^{-2}

Standard deviation: 2.8 Wm^{-2}



Absorbed SW all sky at the surface

Multimodel mean: 164 Wm^{-2}

Range of models: 17 Wm^{-2}

Standard deviation: 4.1 Wm^{-2}

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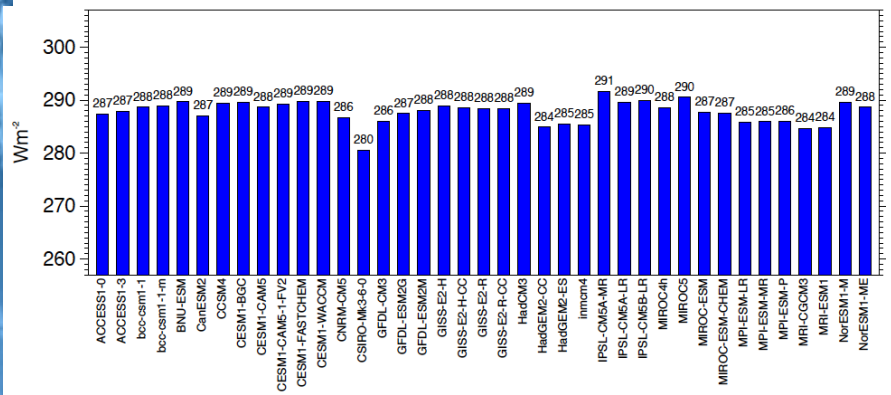
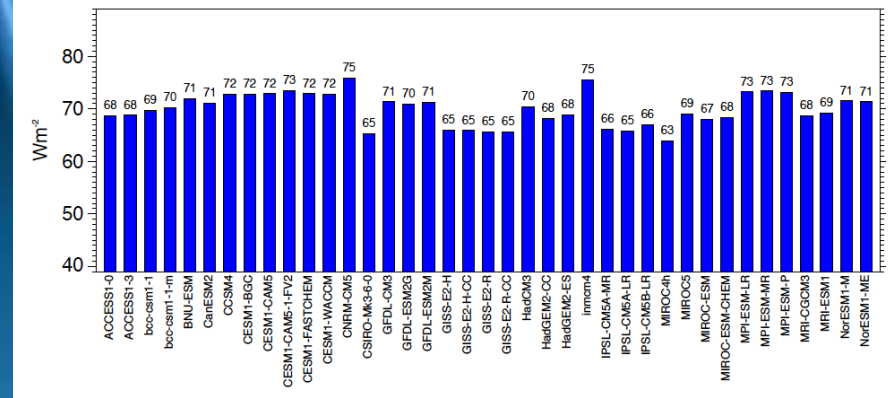
Global mean solar radiation budgets in IPCC AR5 GCMs



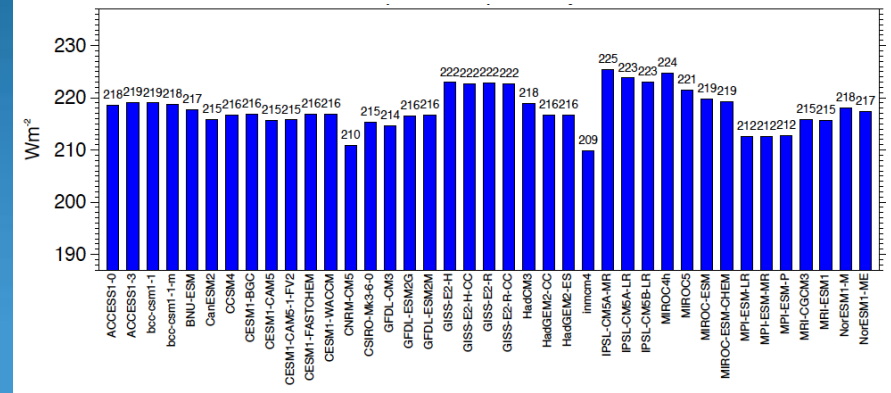
Absorbed SW clear sky top of atmosphere

Multimodel mean: 288 Wm^{-2}
Range of models: 11 Wm^{-2}
Standard deviation: 2.1 Wm^{-2}



Absorbed SW clear sky in the atmosphere

Multimodel mean: 70 Wm^{-2}
Range of models: 12 Wm^{-2}
Standard deviation: 3.0 Wm^{-2}



Absorbed SW clear sky at the surface

Multimodel mean: 218 Wm^{-2}
Range of models: 16 Wm^{-2}
Standard deviation: 3.7 Wm^{-2}

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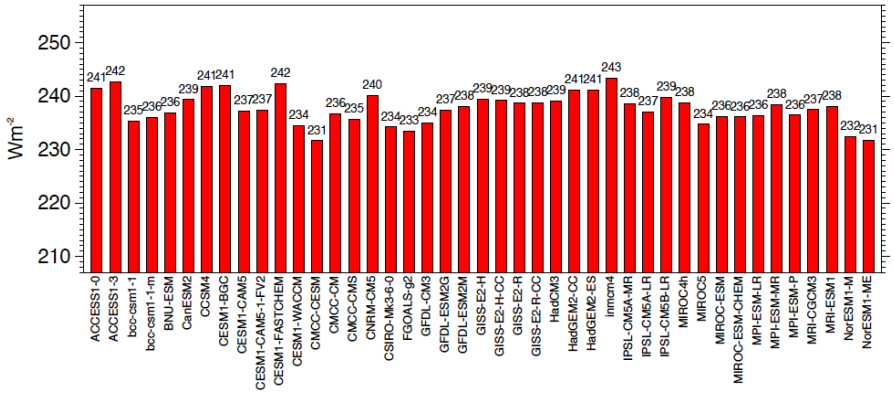
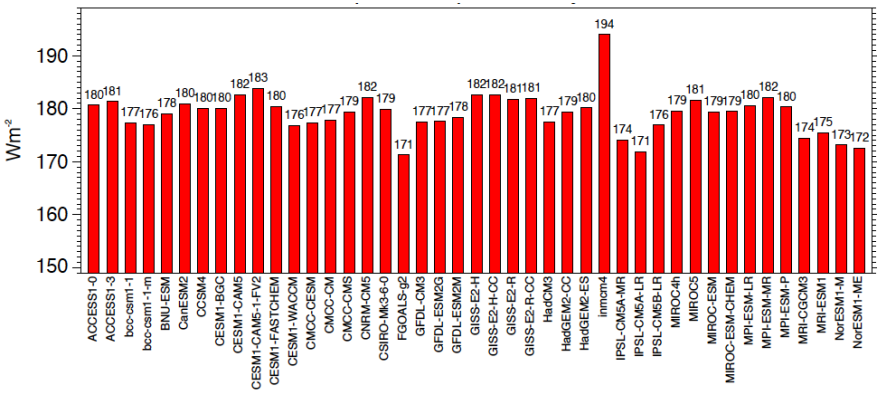
Global mean LW radiation budgets in IPCC AR5 GCMs



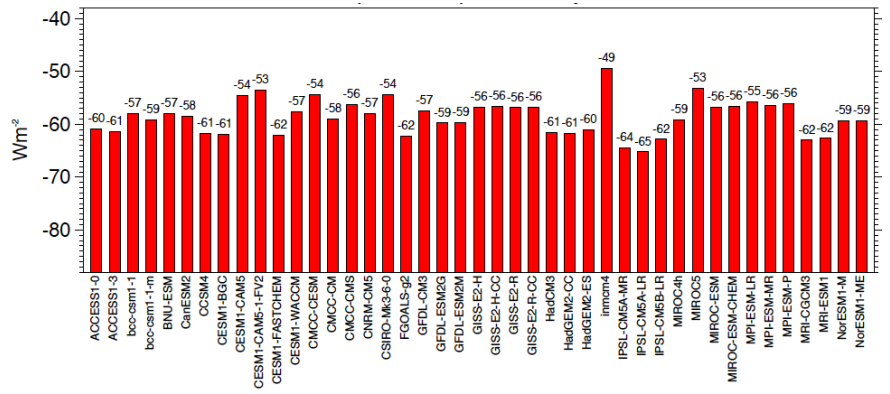
Outgoing LW all sky **top of atmosphere**

Multimodel mean: -238 Wm^{-2}
Range of models: 12 Wm^{-2}
Standard deviation: 2.9 Wm^{-2}



Absorbed LW all sky **in the atmosphere**

Multimodel mean: -179 Wm^{-2}
Range of models: 23 Wm^{-2}
Standard deviation: 3.9 Wm^{-2}



Absorbed LW all sky **at the surface**

Multimodel mean: -59 Wm^{-2}
Range of models: 16 Wm^{-2}
Standard deviation: 3.3 Wm^{-2}

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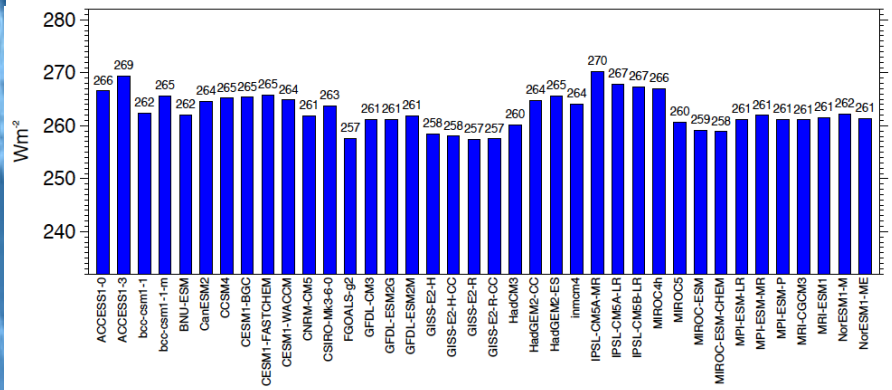
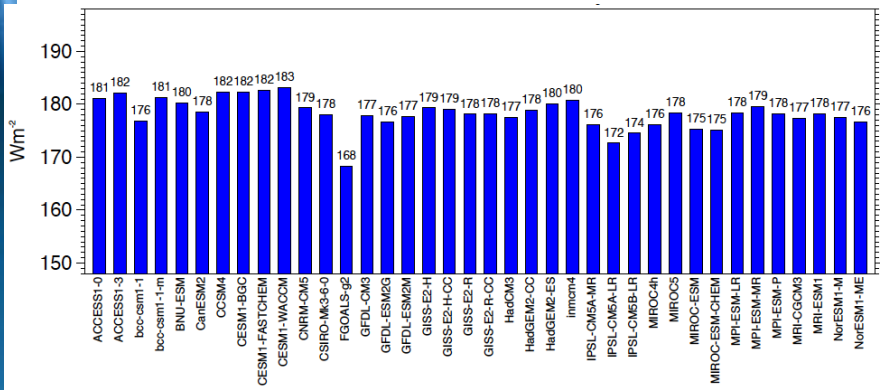


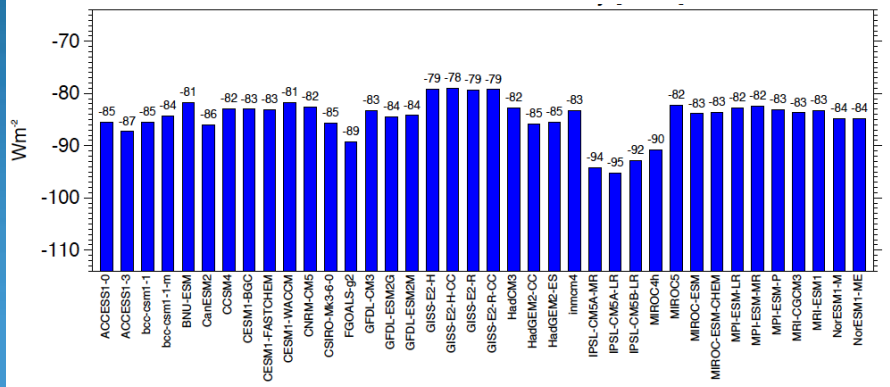
Outgoing LW clear sky **top of atmosphere**

Multimodel mean: -263 Wm^{-2}
Range of models: 13 Wm^{-2}
Standard deviation: 3.3 Wm^{-2}



Absorbed LW clear sky **in the atmosphere**

Multimodel mean: -178 Wm^{-2}
Range of models: 15 Wm^{-2}
Standard deviation: 2.9 Wm^{-2}



Absorbed LW clear sky **at the surface**

Multimodel mean: -85 Wm^{-2}
Range of models: 16 Wm^{-2}
Standard deviation: 3.8 Wm^{-2}

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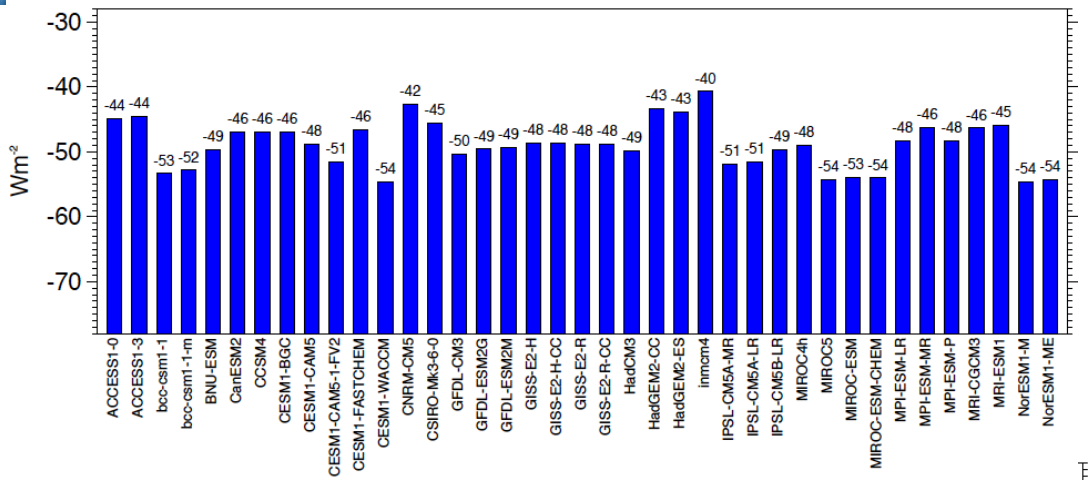
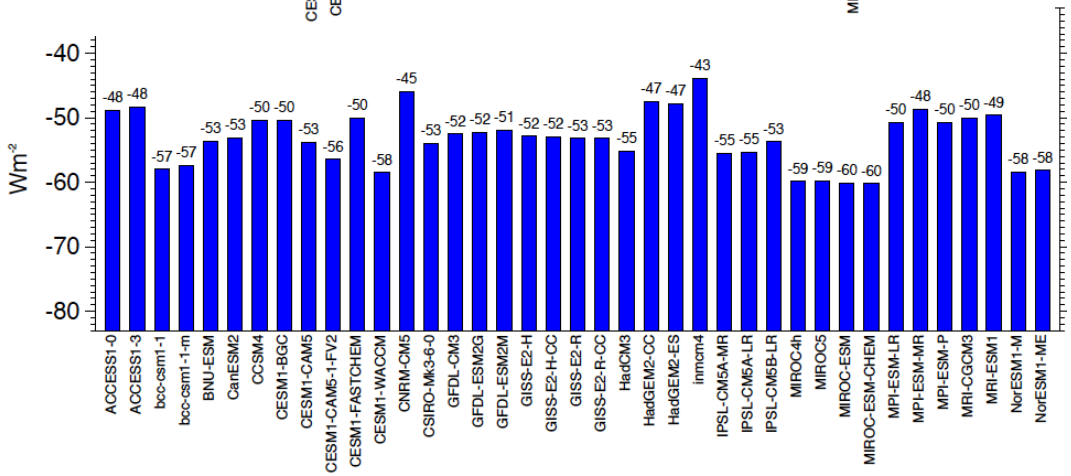
SW CRF in IPCC AR5 GCMs



SW CRF
top of atmosphere

Multimodel mean: -49 Wm^{-2}
Range of models: 14 Wm^{-2}
Standard deviation: 3.6 Wm^{-2}



SW CRF
at the surface

Multimodel mean: -53 Wm^{-2}
Range of models: 16 Wm^{-2}
Standard deviation: 4.2 Wm^{-2}

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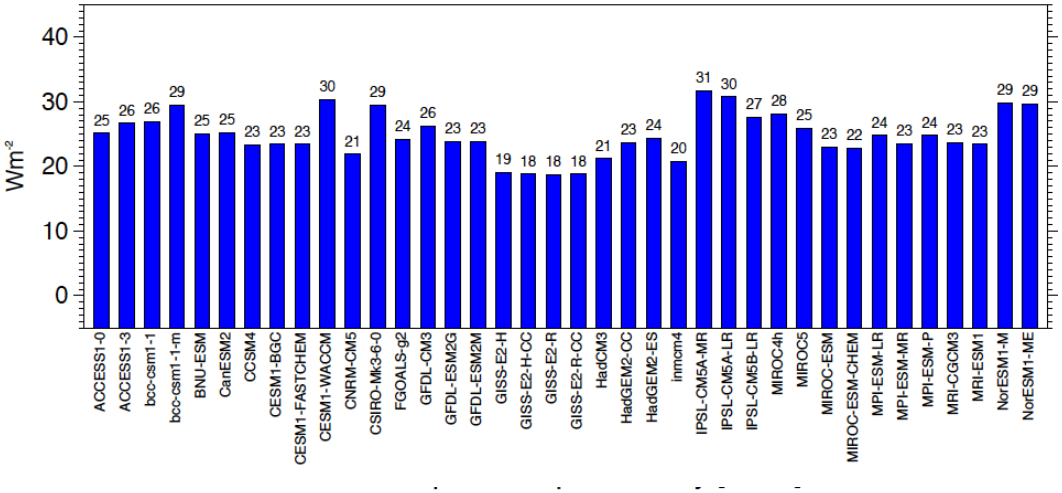
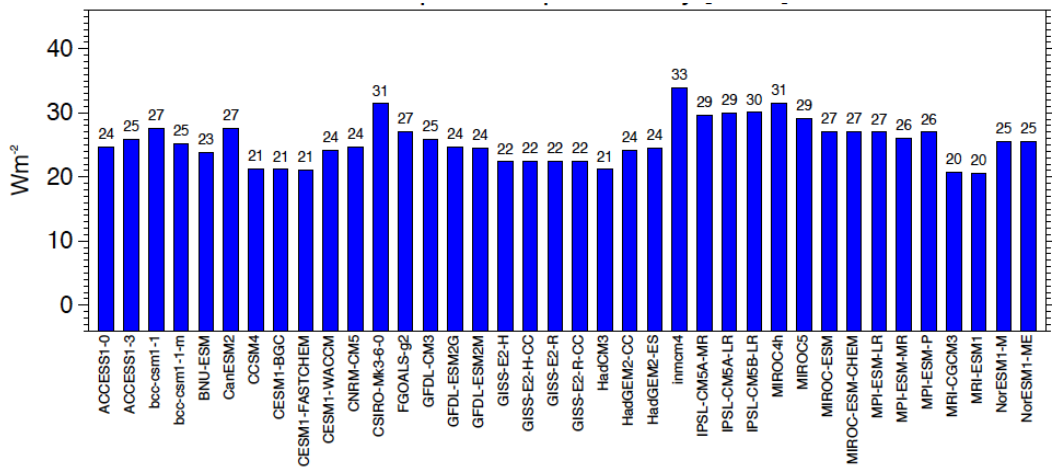
LW CRF in IPCC AR5 GCMs



LW CRF
top of atmosphere

Multimodel mean: 25 Wm^{-2}
Range of models: 13 Wm^{-2}
Standard deviation: 3.5 Wm^{-2}



LW CRF
at the surface

Multimodel mean: 26 Wm^{-2}
Range of models: 13 Wm^{-2}
Standard deviation: 3.3 Wm^{-2}

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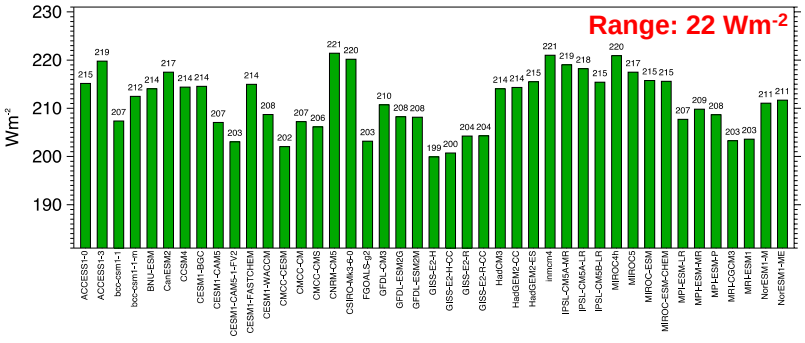
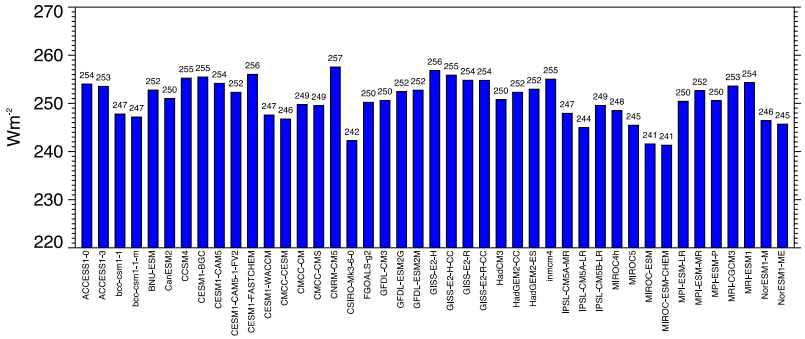
CMIP5 SW radiation budgets over land and ocean

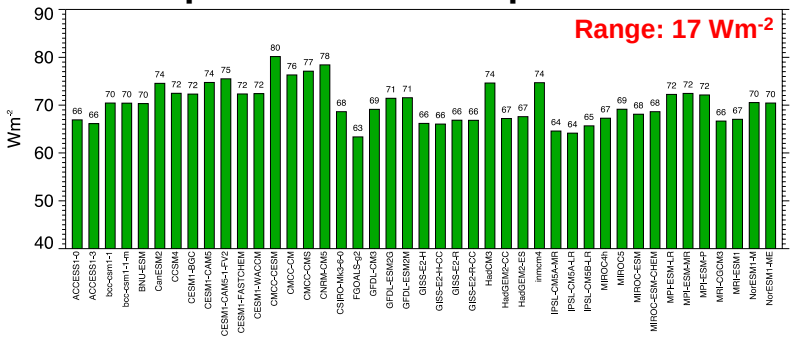
Total (TOA) solar absorption over land



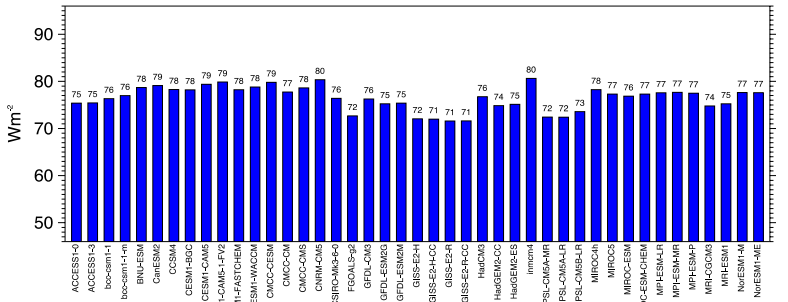
Total (TOA) solar absorption over oceans



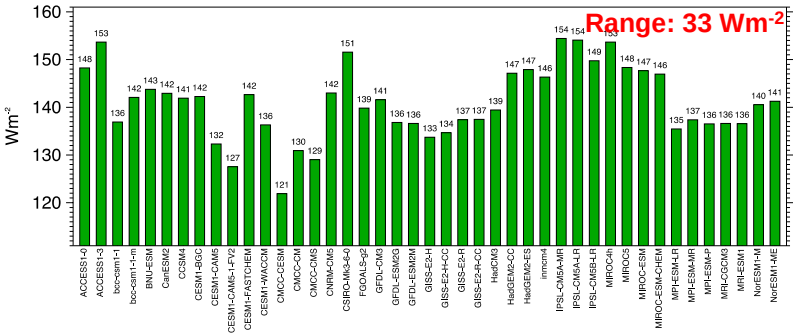
Atmospheric solar absorption over land



Atmospheric solar absorption over oceans



Surface solar absorption over land



Surface solar absorption over oceans