Cloud Effects

on the Earth's radiation budget

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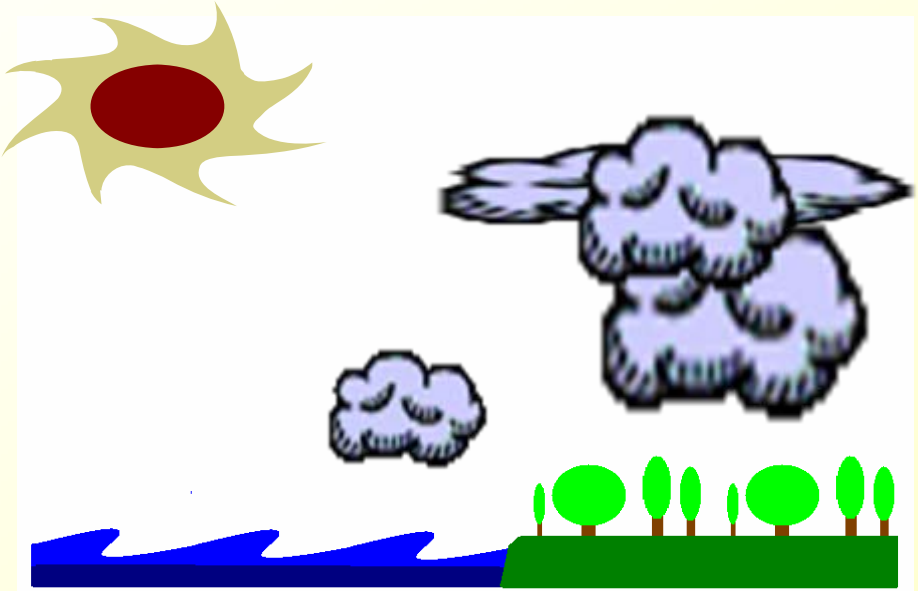
clouds impact …

- … on radiative energy budget determined by
  - cloud cover
  - altitude
  - microphysics
  - concentrations
  - phase



- details from
  - in-situ sampling *(e.g. aircraft)*
  - sub-spectral remote sensing *(e.g. satellite)*

sat. remote sensing - why ?

- +
  - global coverage *(almost, at least for LEO)*
  - good statistics over time *(still samples)*

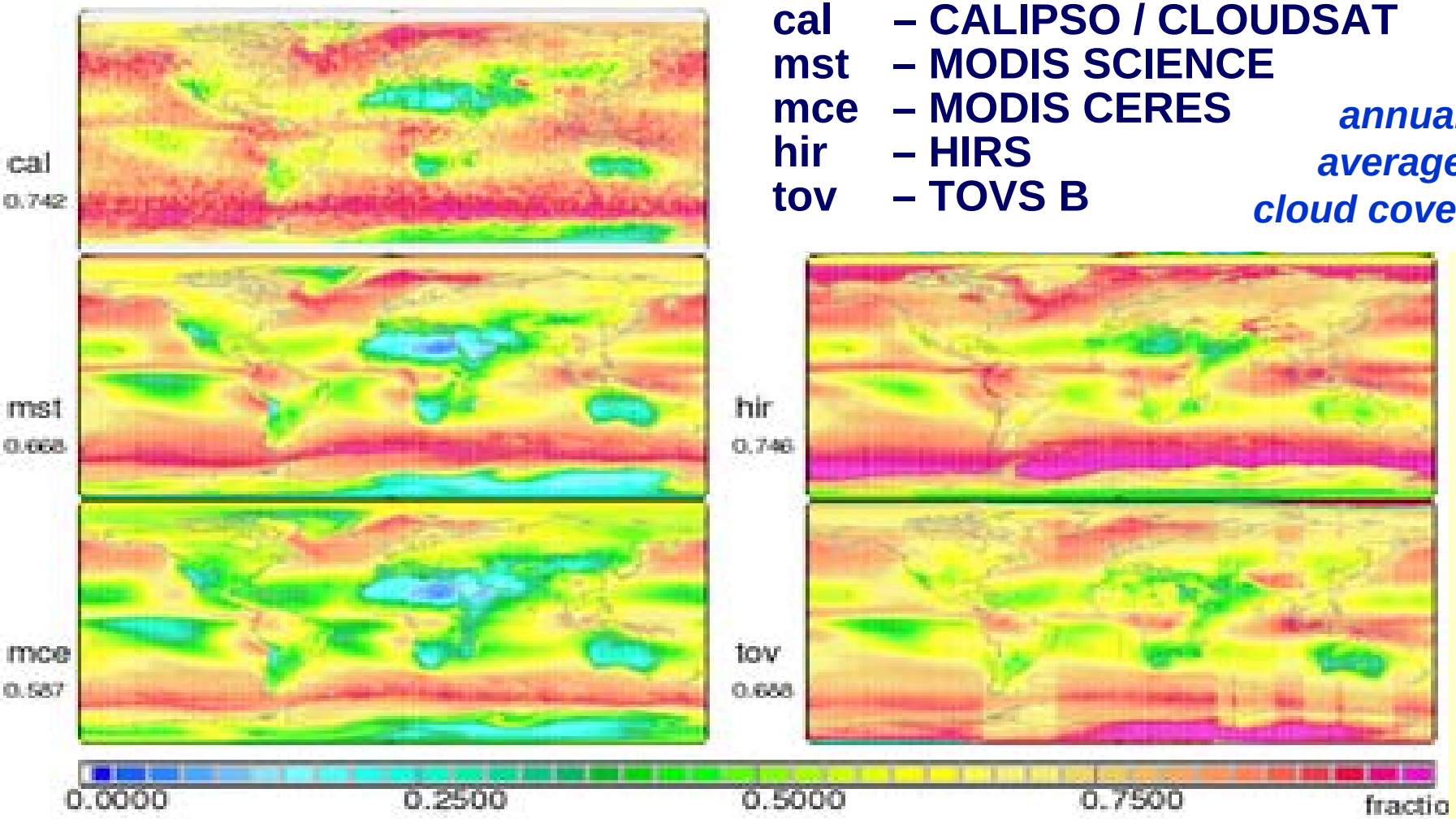
- -
  - ambiguity on detection thresholds
    - different sensor sensitivity → what is a cloud?
  - different penetration depth into a cloud

what is a cloud ?

- **total cloud cover … is a function of sensor**

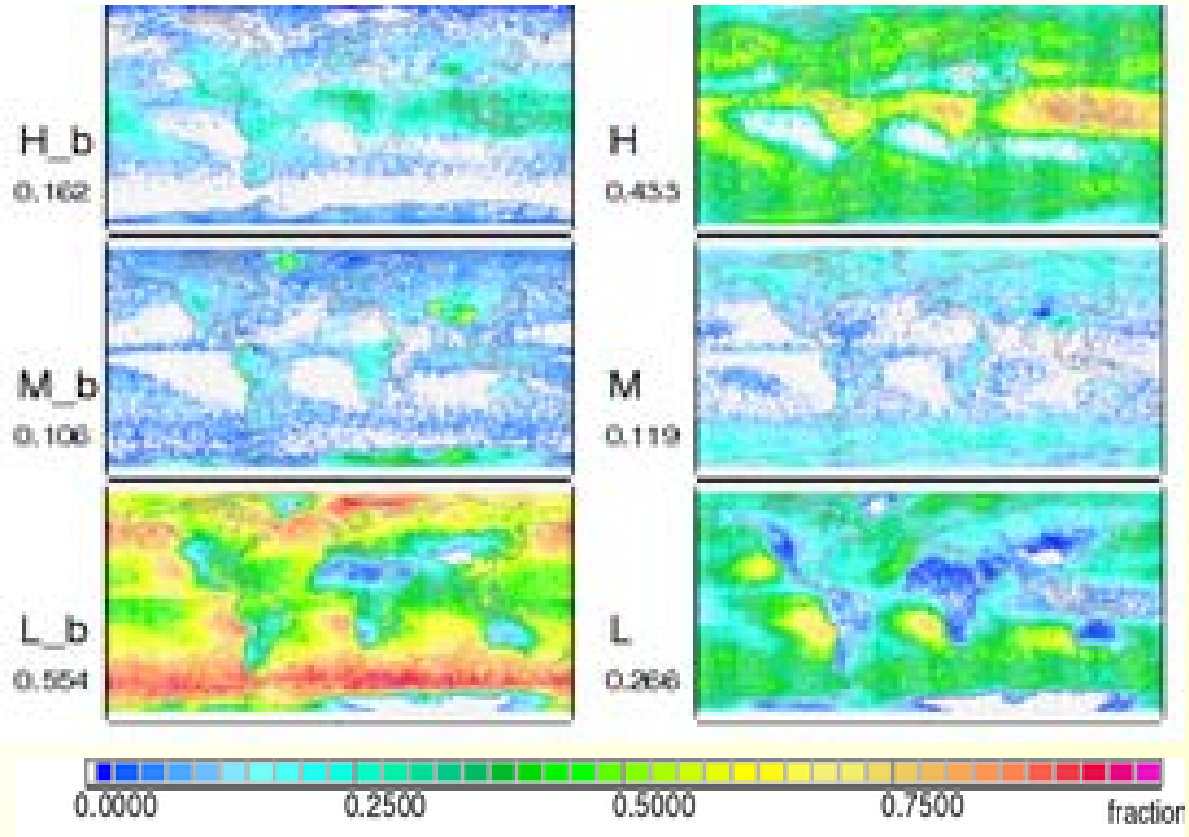
cal – CALIPSO / CLOUDSAT
mst – MODIS SCIENCE
mce – MODIS CERES
hir – HIRS
tov – TOVS B

annual average cloud cover



cloud altitude ?

- **limited penetration leads to different data**



bottom - up view (ground-view)

top - down view (satellite sensor)

sat. remote sensing – how?

- … depends on the application

- process understanding requires high spatial resolution in time and space *(GEO sufficient?)*
- evaluation requires global fields for all seasons *(as spatial and seasonal patterns are strong constrains)*

- … how to deal with sensor data limitations

- data ‘redundancy’: use different sensors to address the same property at the same time
  - this redundancy helps sensor data interpretation
- ground monitoring to complement satellite data
  - learn about senor / sensor product deficiencies

data for model evaluations

- **global modeling needs data constrains !**
  - **seasonal cycle, global coverage … preferably as extension to historic data for 'trends'**
- **sub-sample modeling to mimic satellite sensor capabilities *(sensor simulators)***
- **compare to long-term climatologies … … here for broadband radiative flux maps**
  - **what is the impact of clouds on solar/IR flux ?**
  - **are spatial patterns reproduced by modeling ?**
  - **are data of different climatologies consistent ?**
  - **where are regions of major disagreement ?**

the players

- ISCCP (1984 …)
  - usually a 12 year avg is used (1984-1995)
- SRB (1984 …)
  - usually a 12 year avg is used (1984-1995)
- CERES (2000 …)
  - usually a 4 year avg is used (2000-2003)

- IPCC model median fields (of 20 models) … to represent typical values of modeling
  - usually a 12 year avg is used (1984-1995)

top of atmosphere

- there … the ‘integral’ cloud impact can be detected with satellite remote sensing … by the difference between clear-sky and all-sky cases

cloud-effect = ‘all-sky’ *minus* ‘clear-sky’

… specifically at the top of atmosphere (ToA):

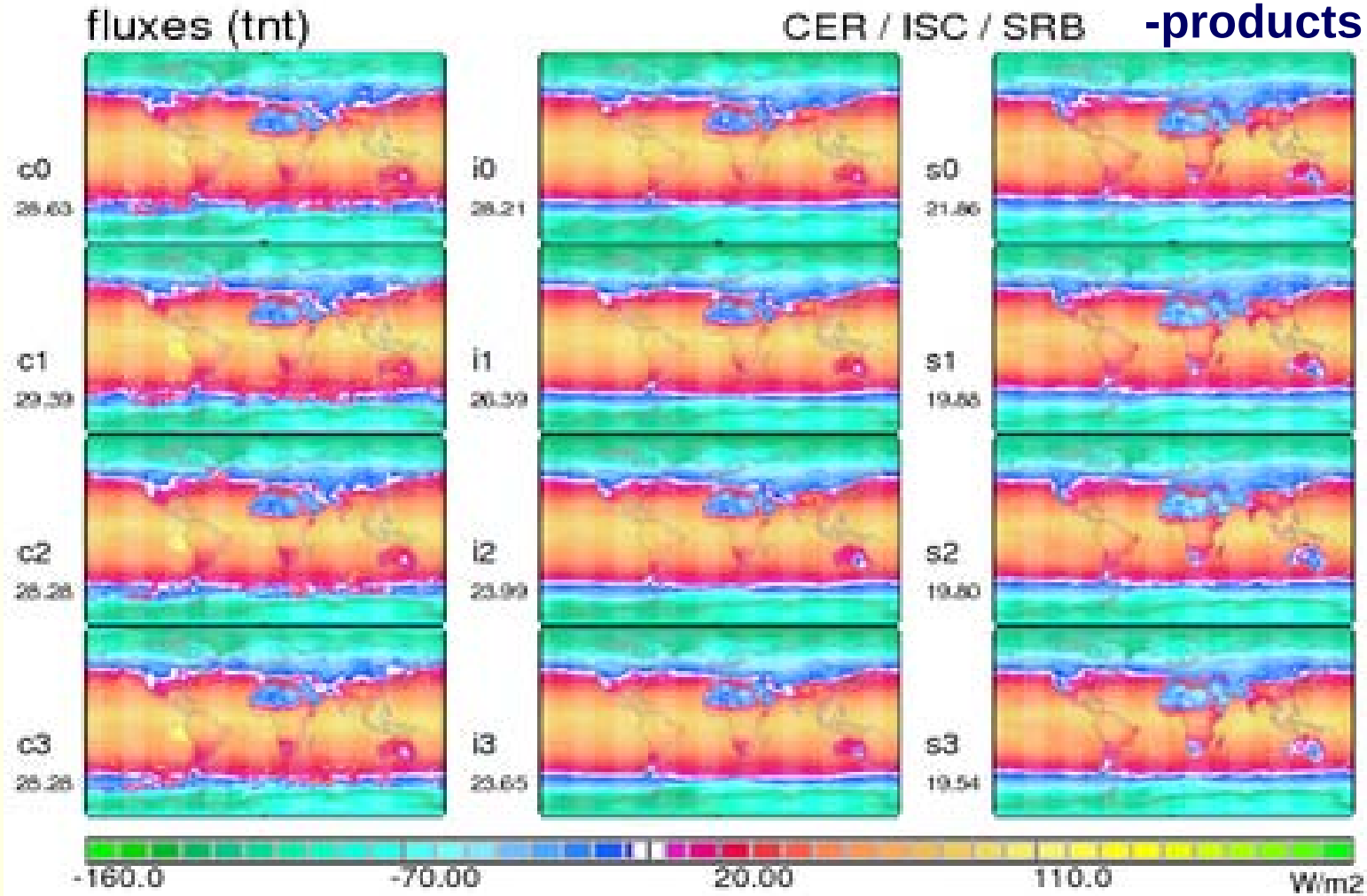
- how much solar radiation is reflected ?
- how much terrestrial radiation is trapped?

‘data’ – consistency ?

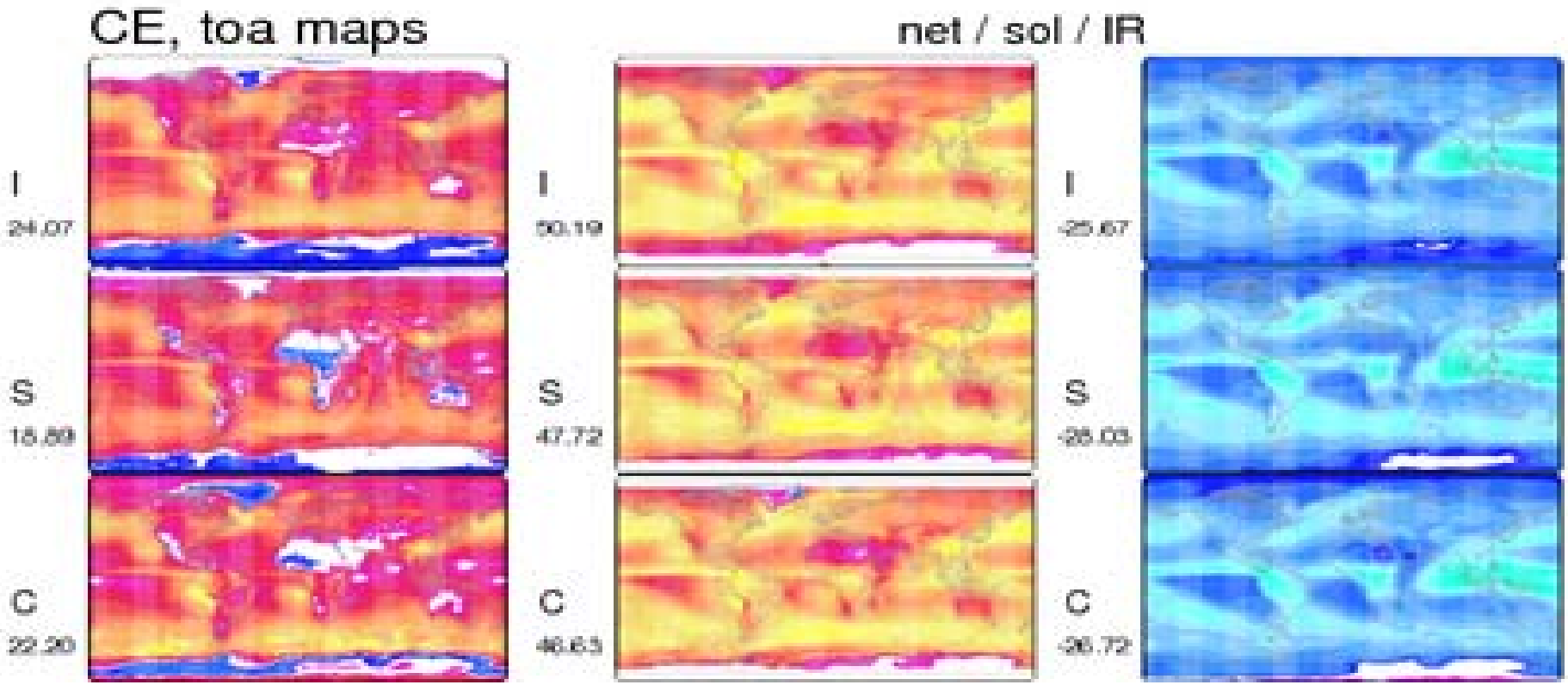
- yes at ToA *(solar and IR net all-sky fluxes)*

CERES
ISCCP
SRB
-products

- 2000
- 2001
- 2002
- 2003



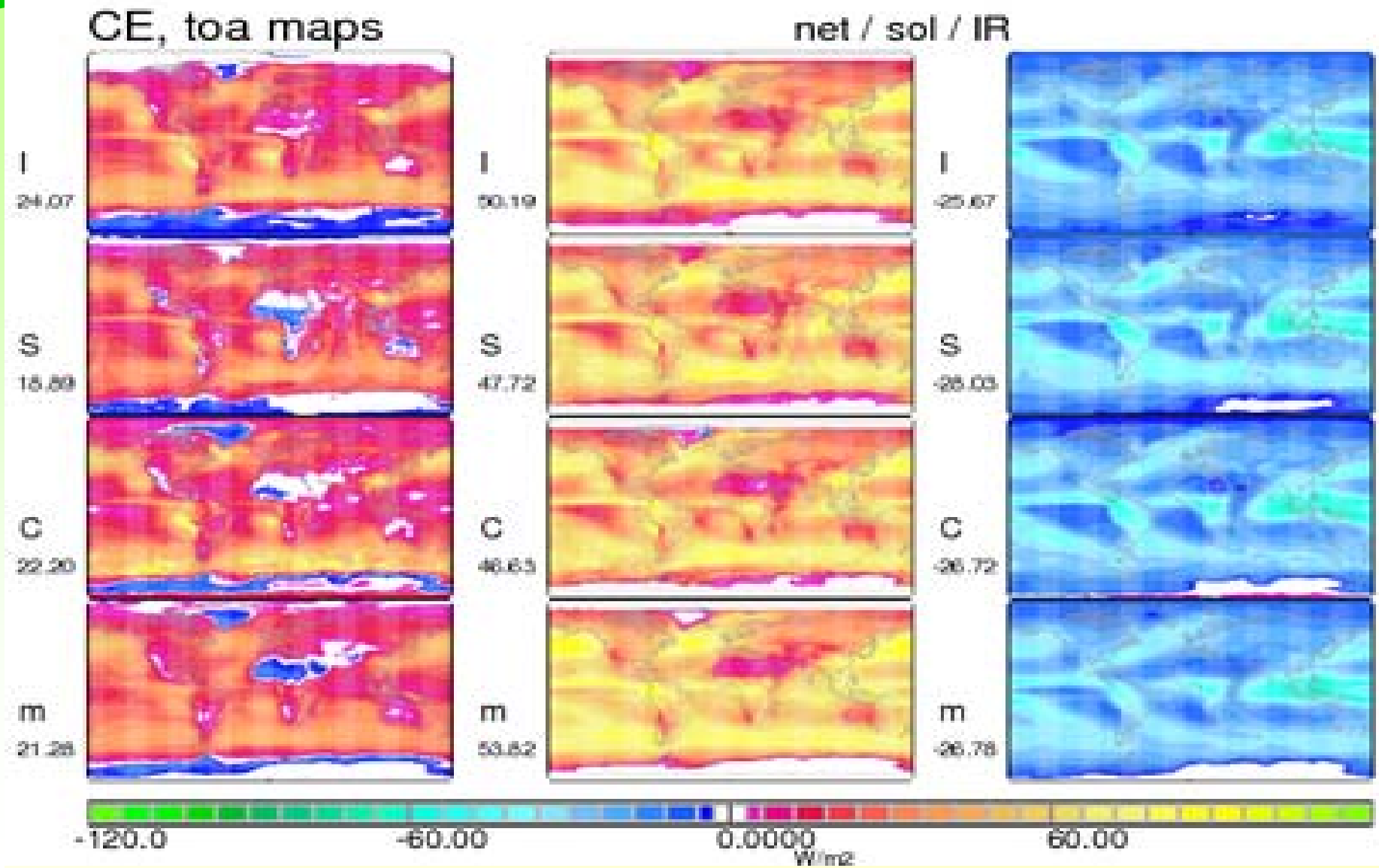
cloud effects on ToA-net (1)



fair agreement in patters among ISCCP, SRB and CERES

clouds increase planetary albedo (+) more than their ability to trap IR radiation (-), except over deserts and polar ice

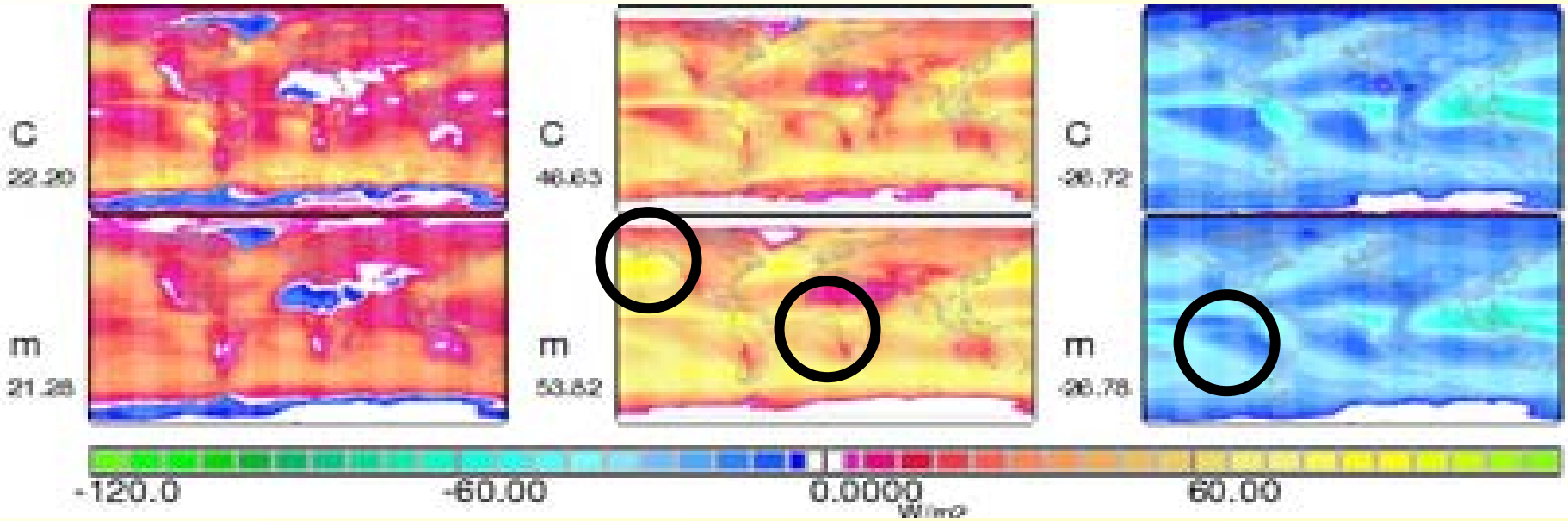
cloud effects on ToA-net (1)



cloud effects on ToA-net (2)

- **typical modeling patters differ most**
  - **too solar reflective over mid-latitude oceans**
  - **lack of solar reflection for off coastal stratus**
  - **lack of altitude over eastern SH Pacific**

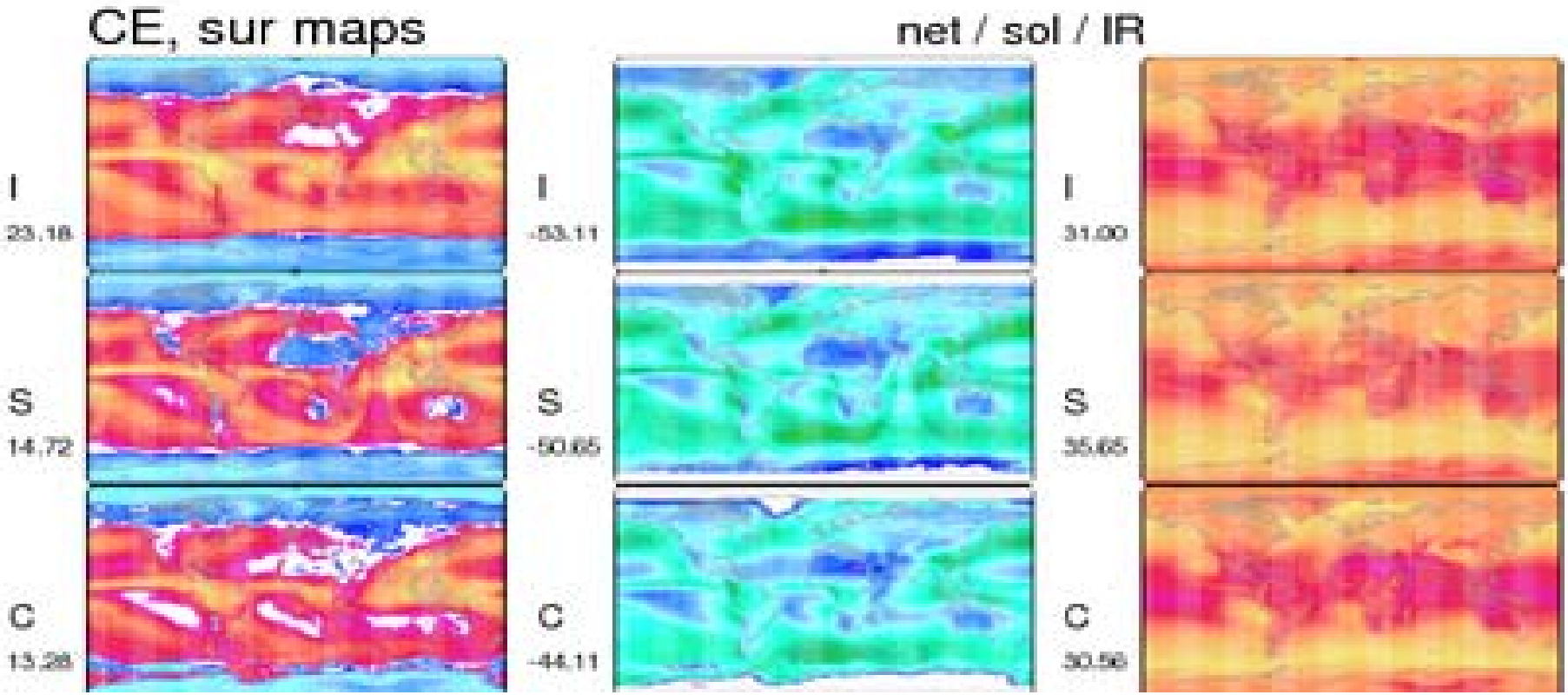
overall: **global CE average is close**



surface

- getting the surface radiative budget correct … is a much tougher challenge
- surface ‘data’ constrains are few and weak
  - sampling of quality surface data is still in its infancy (e.g. currently ~ 40 BSRN stations)
  - site’s regionality is under-investigated
- for global coverage: satellite climatologies
  - + they are tied to TOA radiances and to added info on microphysics, structure and altitude …
  - - necessity to use ancillary data and assumptions introduces errors

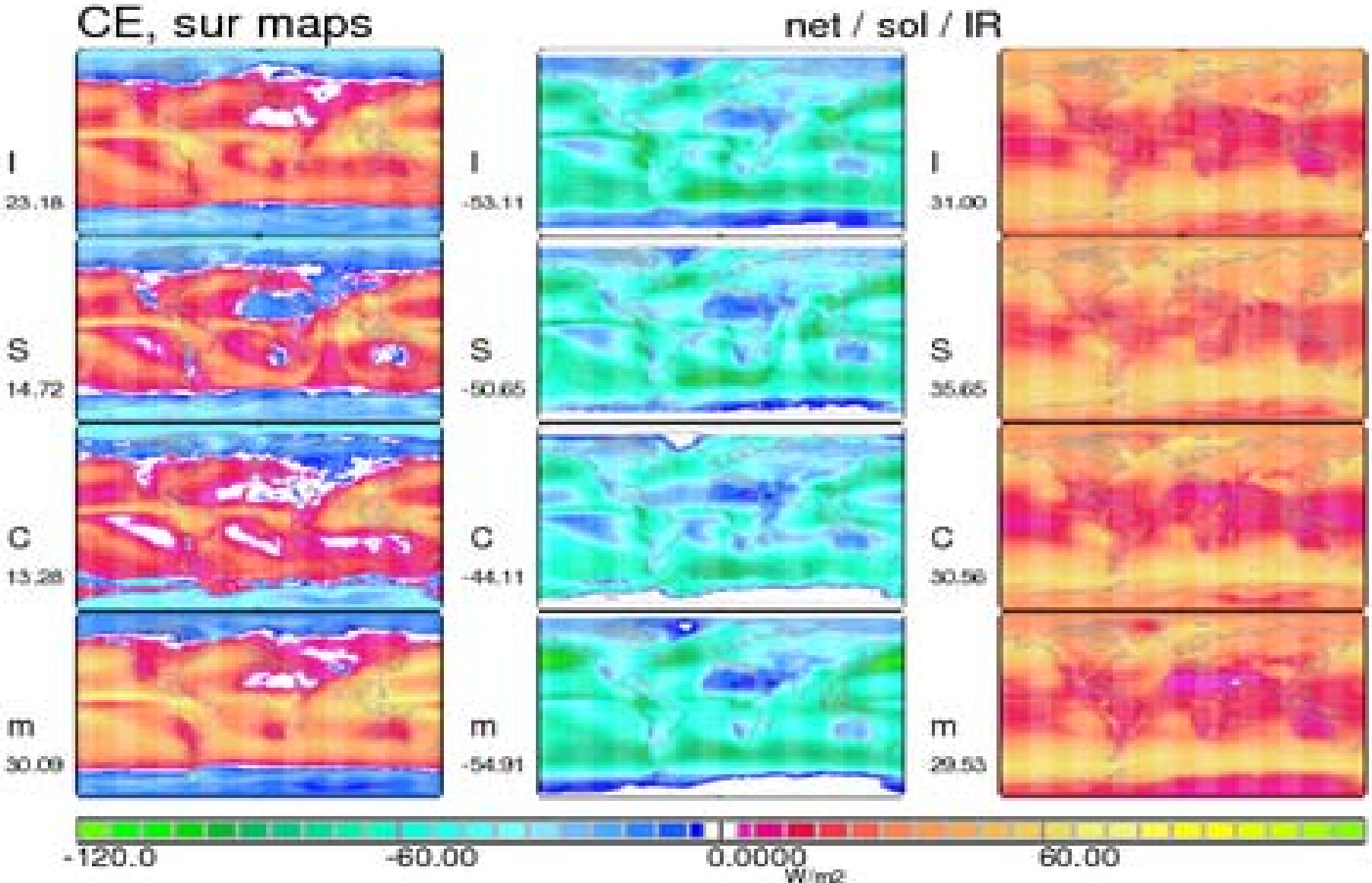
cloud effect on surf-net (1)



diff. in magn. and patters among ISCCP, SRB and CERES

ISCCP/SRB reflect more solar radiation (e.g. mid-lat. ocean)
CERES has a stronger lat. low-cloud altitude contrast

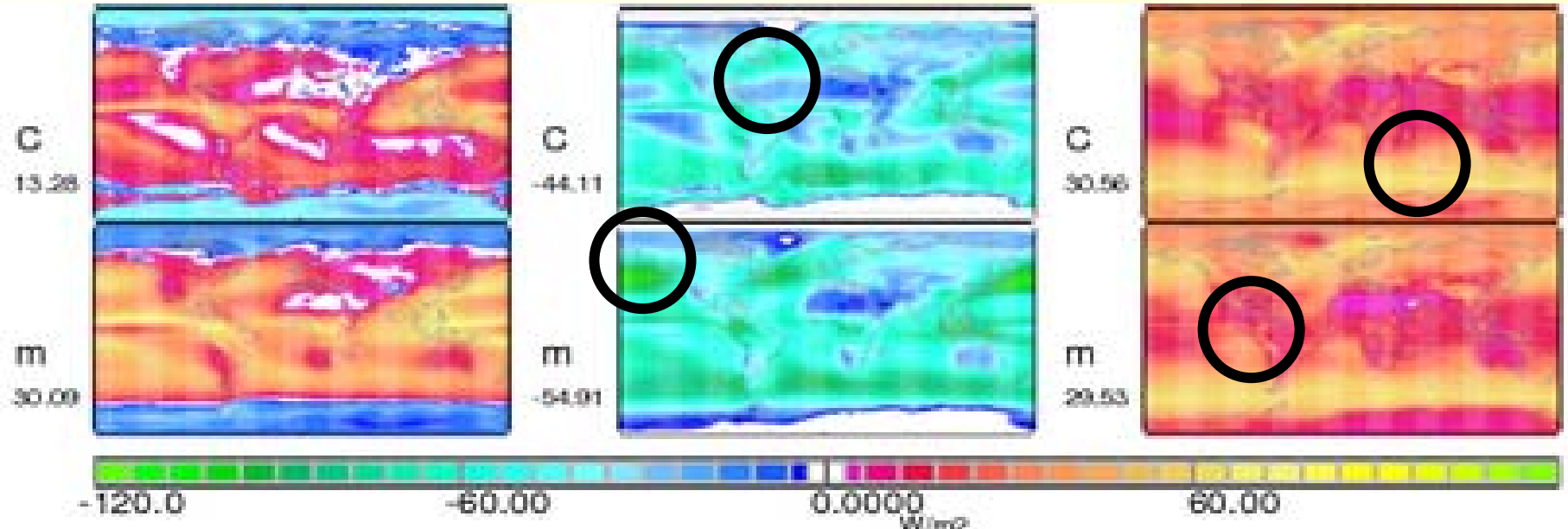
cloud effect on surf-net (1)



cloud effect on surf-net (2)

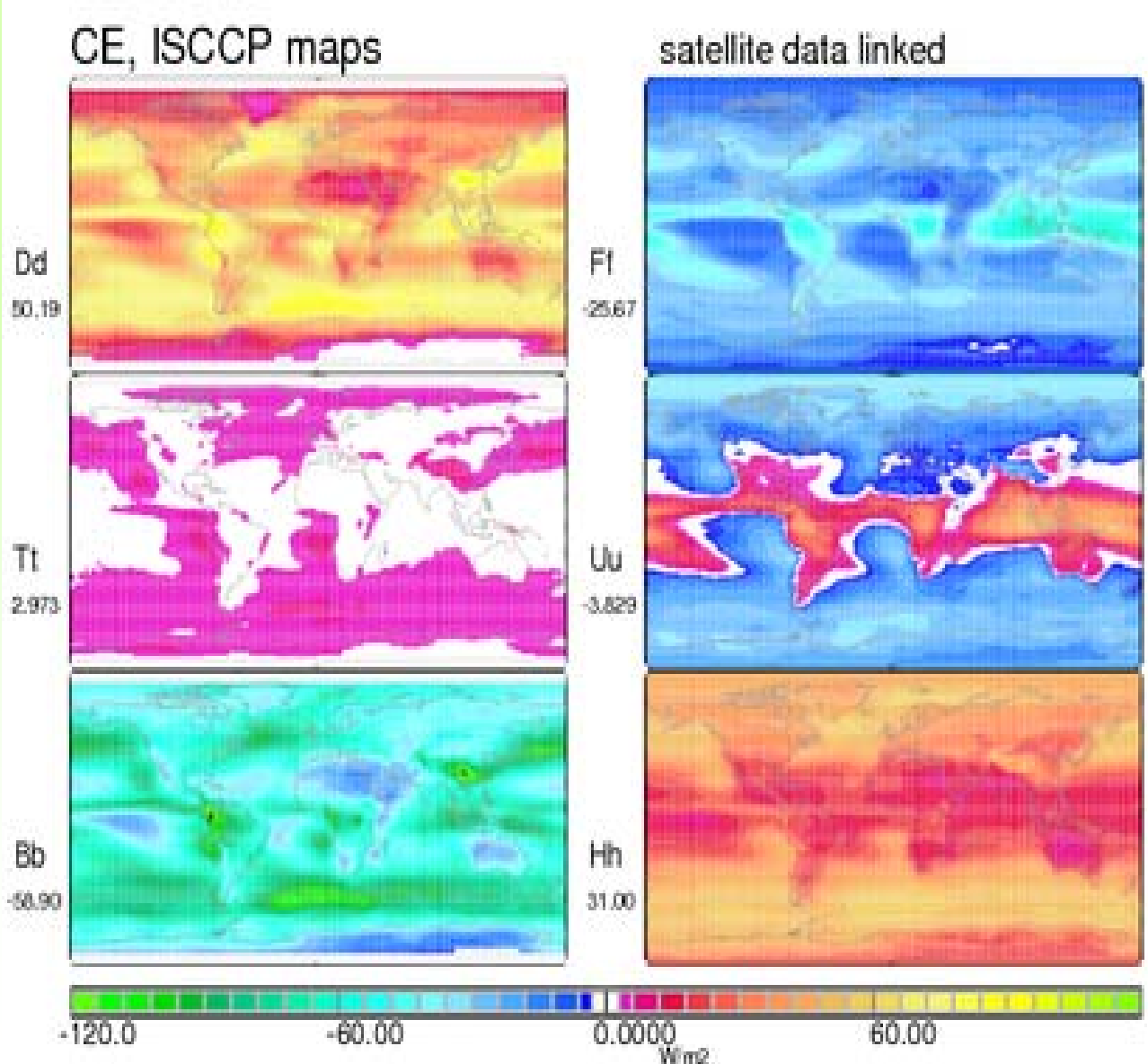
- modeling suggest higher solar losses …
  … especially over all oceans
- re-radiation is lacking for off-coastal stratus and mid-latitude clouds

overall: **modeled cloud effect is too strong**



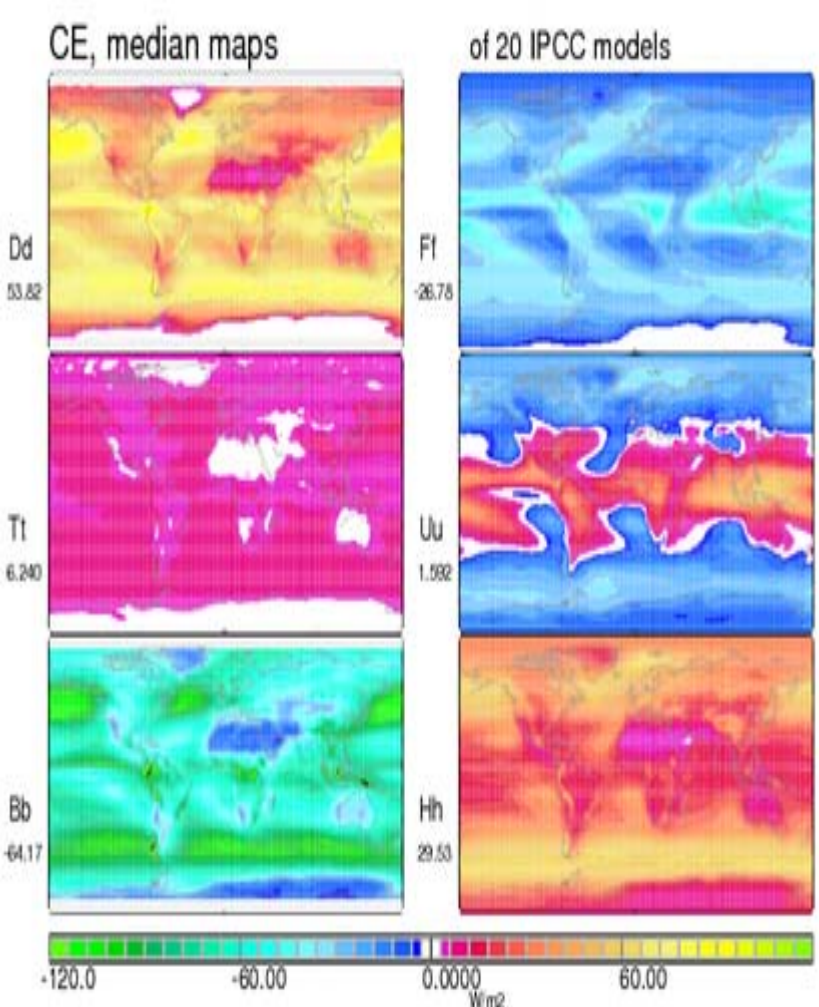
atmospheric cloud effects

- Dd: CE on solar up flux
- Ff: CE on IR up flux
- Tt: CE on sol absorption
- Uu: CE on IR atmos. diver
- Bb: CE on dn solar flux
- Hh: CE on up IR flux

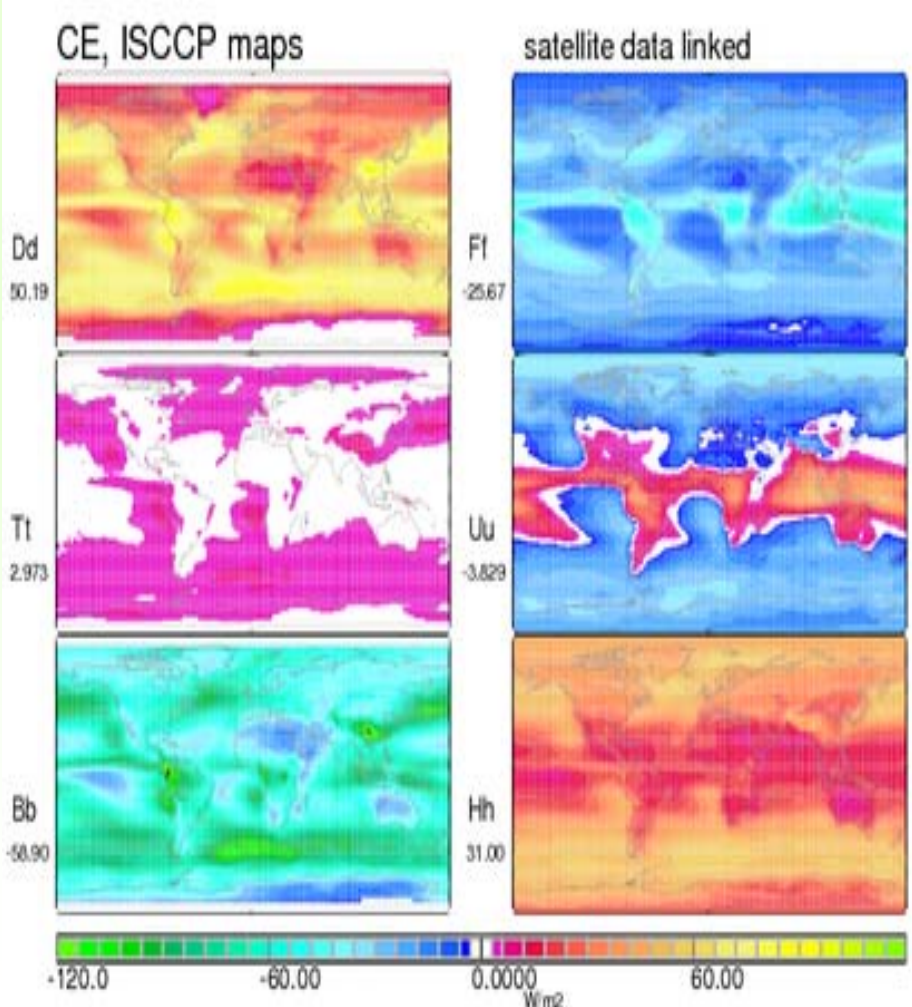


model vs ‘data’

- **IPCC model median**



- **ISCCP**



(annual) modeling biases

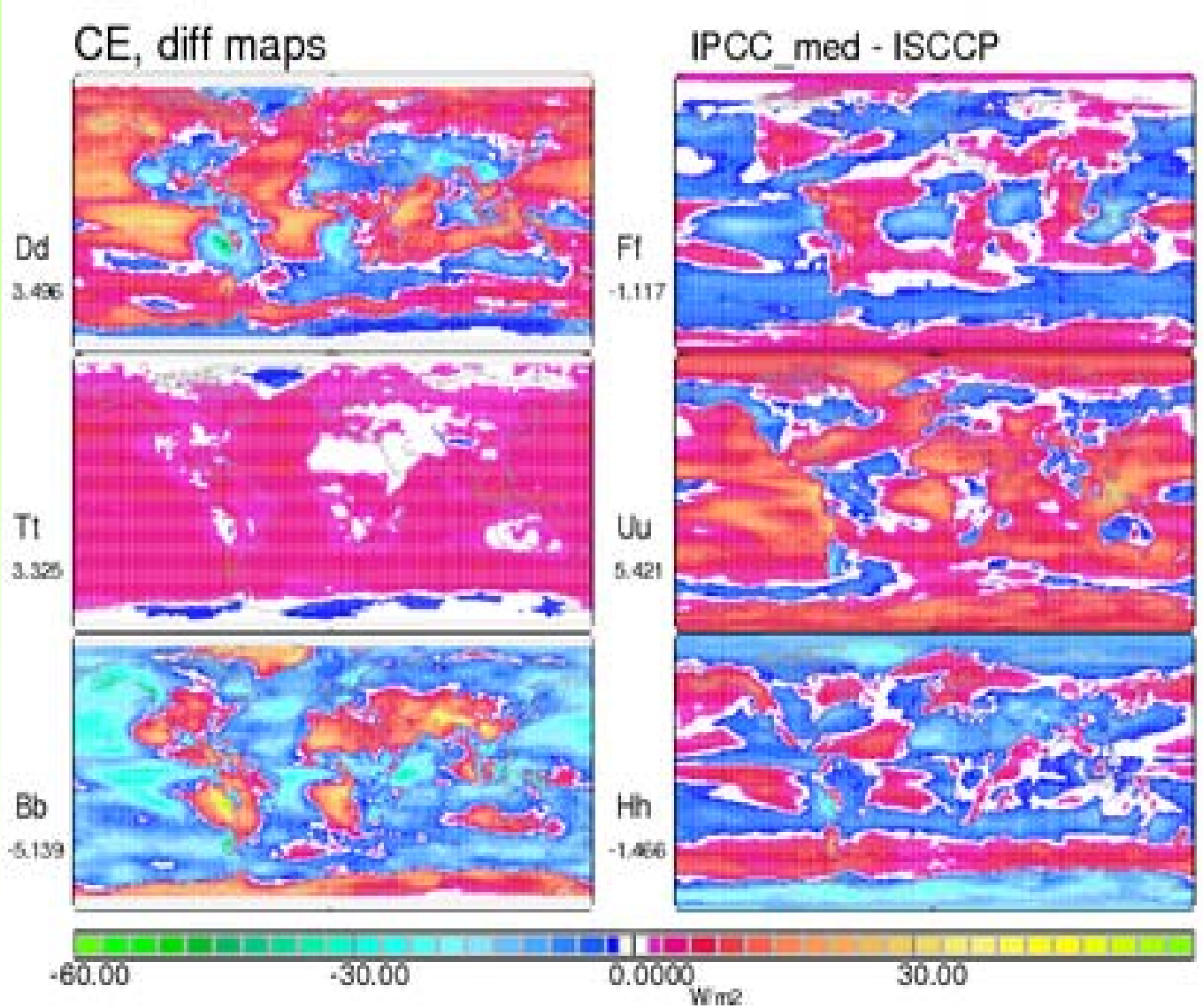
note sign !
Bb, Ff: neg

modeling:
distinct diff patterns !

solar maps indicate OT issue

more + sol atm abs

IR div map



model certainty ? NO

- **large diversity … even limited data help!**

- **Dd: CE on solar up flux**
- **Ff: CE on IR up flux**
- **Tt: CE on sol absorption**
- **Uu: CE on IR atmos. diverg**
- **Bb: CE on dn solar flux**
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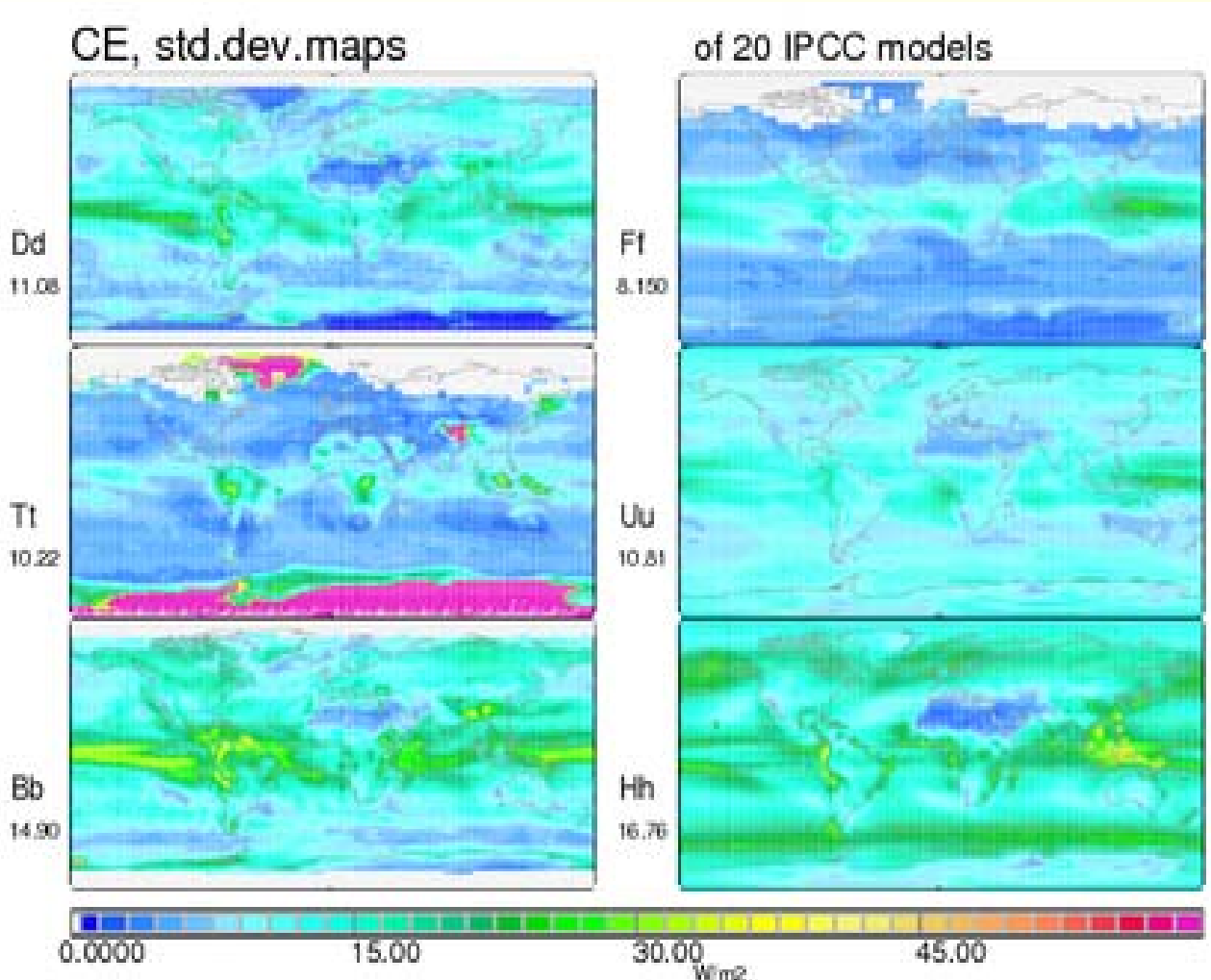

summary

- **satellite remote sensing gives insights into global property patterns** ***(spatially, seasonally)***
- **satellite monitoring provides info on changes / trends** ***(abs. accuracy not required)***
- **divergence among satellite data-sets …** ***(especially, if judged in the proper context of their capabilities – what needs to be done !)*** **… is small compared to difference in glob. modeling**
- **(cloud) evaluation requirements: 1. spatial** ***(to resolve clouds)*** **, 2. spectral** ***(for spec. properties),*** **3. global, 4. annual cycle** ***(duration),*** **5. time**

analysis of cloud-aerosol interactions

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satellite statistics ?

- **MODIS**
  - **(anthrop.) aod, cld cover, LW-path, # drops**
- **CERES**
  - **planetary albedo**
  - **based on association of 1x1deg averages:**
- **maritime clouds (droplet numbers) are more susceptible to aerosol**
- **data-based first indirect effect *(smaller r_{eff} with aerosol)* is only between 0 and -.5 W/m^2**
  - **this is much smaller than in modeling**

indirect effect modeling

model	forcing*	status	institution
GFDL GCM	-2.1 Wm^{-2}	submitted	GFDL Princeton
GISS	-0.6 Wm^{-2}	submitted	LBL / GISS
SPRINTARS	-1.0 Wm^{-2}	submitted	Univ Kyushu
CCM	-1.9 Wm^{-2}	submitted	Univ Michigan
CAM3.5	-2.6 Wm^{-2}	submitted	NCAR Boulder
ECHAM5-et	-1.4 Wm^{-2}	submitted	ETH Zürich
HadGEM	-1.5 Wm^{-2}	submitted	Met Office Exeter
ECHAM5-rh	-1.1 Wm^{-2}	submitted	MPI Met, Hamb.
ECHAM5-lc	-1.6 Wm^{-2}	submitted	MPI Met, Hamb.
LMDZ-INCA	-0.6 Wm^{-2}	submitted	LSCE Gif sur Y.
CCM-Oslo	-1.9 Wm^{-2}	submitted	Univ Oslo
CAM	-2.1 Wm^{-2}	submitted	PNNL
CCCma		running	EC, Downsview
EC-Earth		in prep	ETH Zürich
GMI		in prep	Georgia Tech

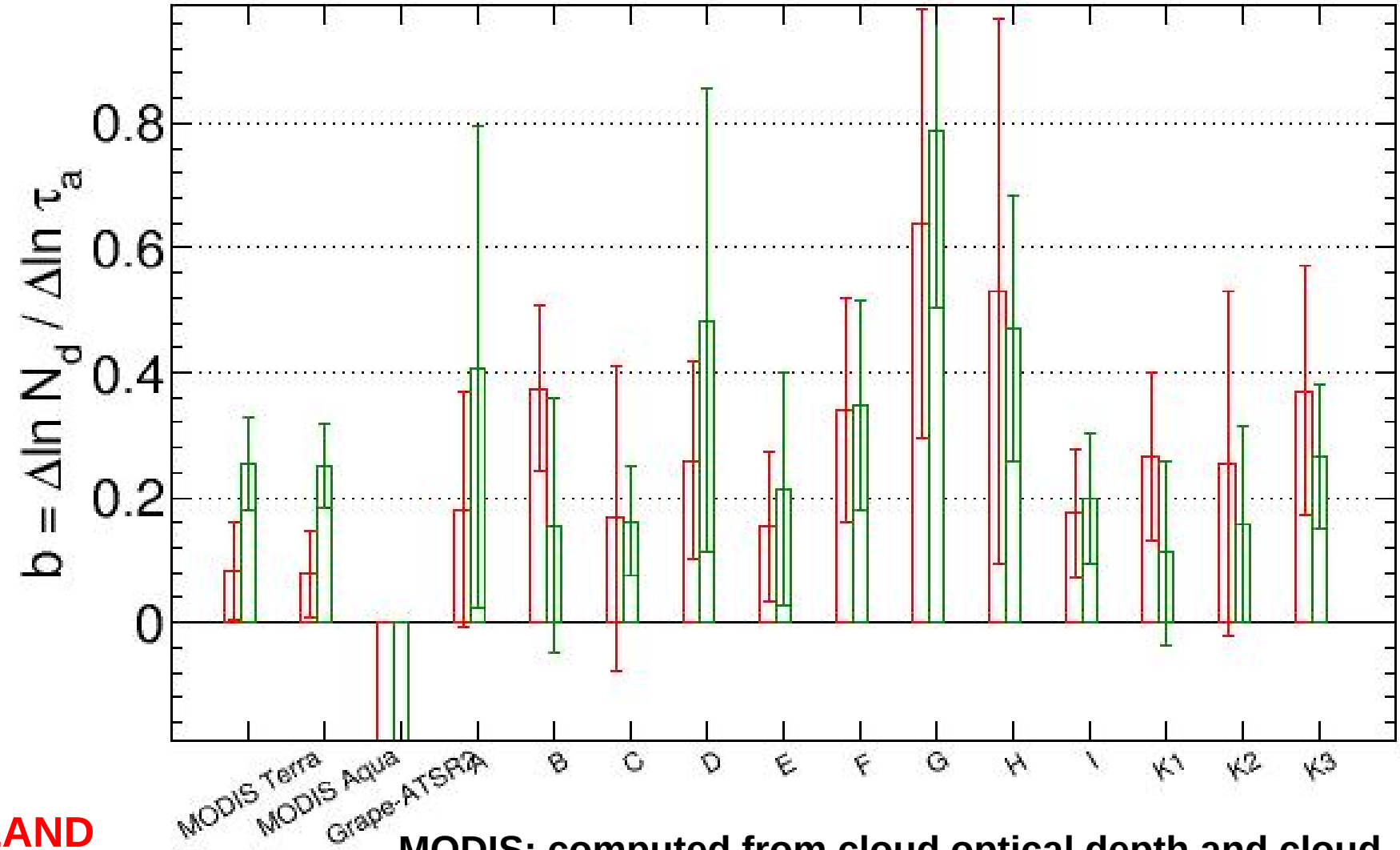
http://wiki.esipfed.org/index.php/Indirect_forcing

* all aerosol effects

understanding modeling

- **modeling of aerosol-cloud interactions is largely based on small scale processes**
- **how do simulations compare to ‘data’ ?**
- **AeroCom (international mod. community) indirect experiment … analysis lead by J.Quaas**
  - **http://wiki.esipfed.org/index.php/Indirect_forcing**
- **next: some comparisons for associations between *(anthropogenic)* aerosol optical depth and cloud properties**

(water) cloud droplet



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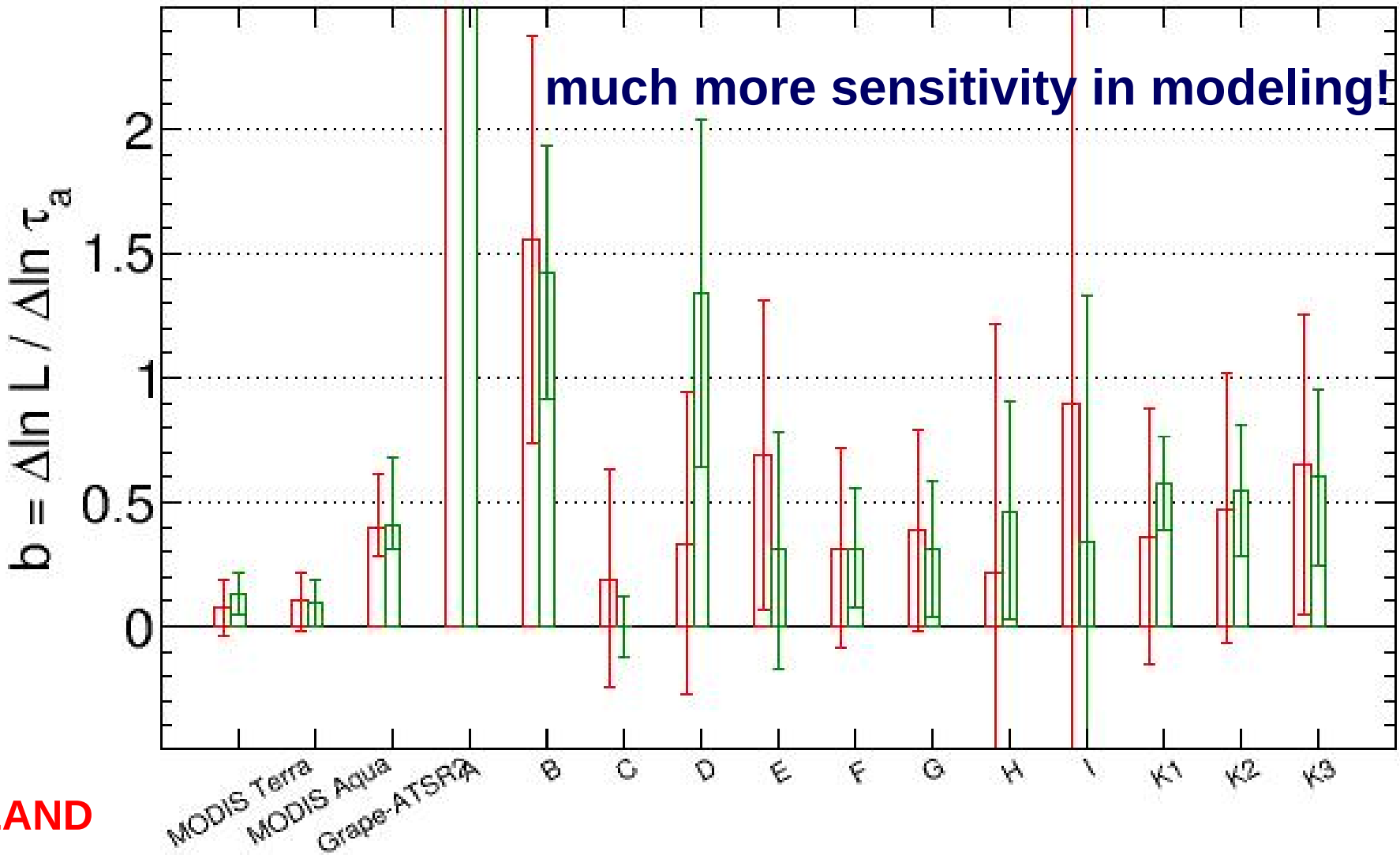
MODIS: computed from cloud optical depth and cloud-top droplet effective radius assuming adiabatic clouds

liquid water path



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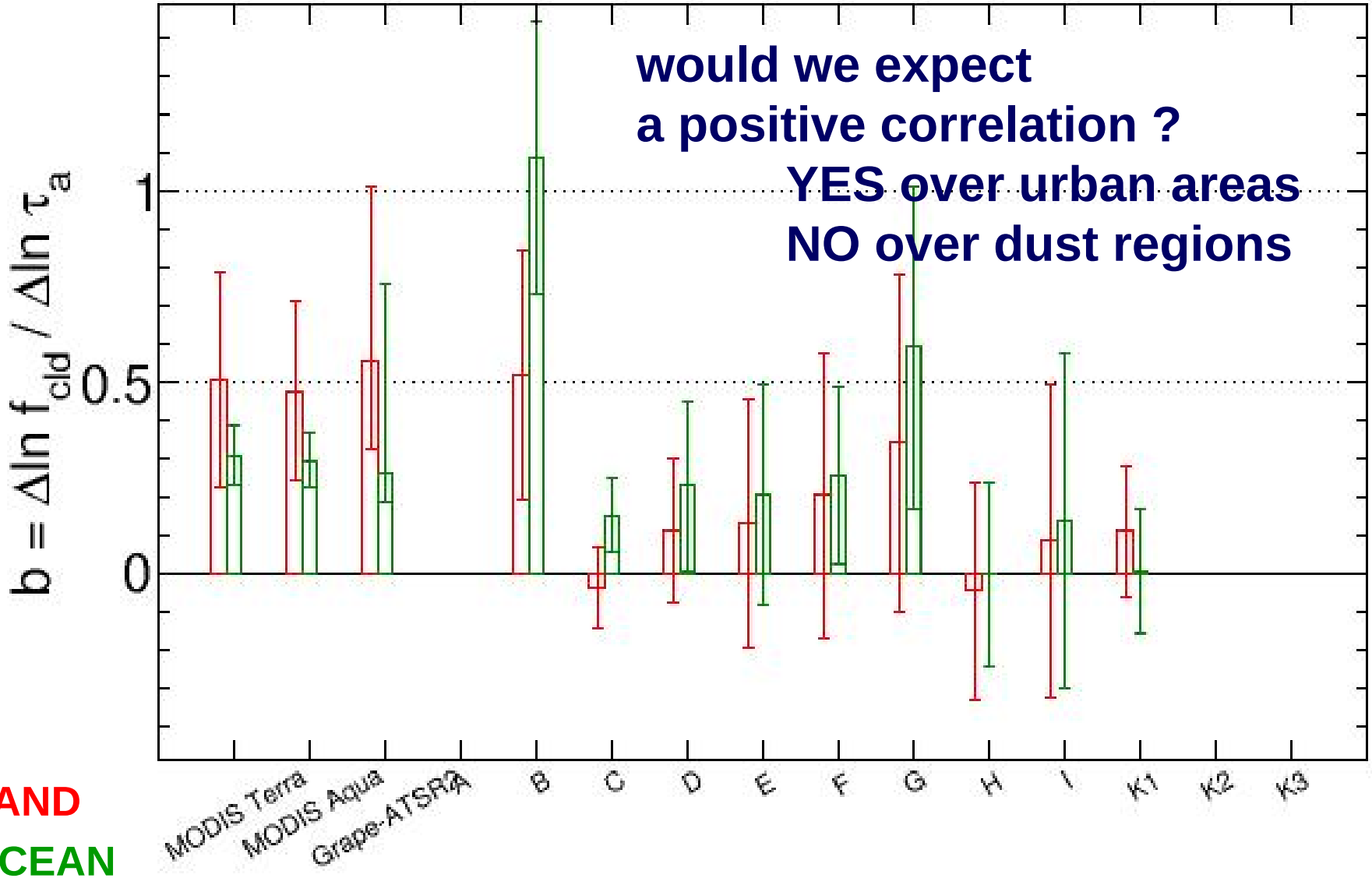
total cloud cover



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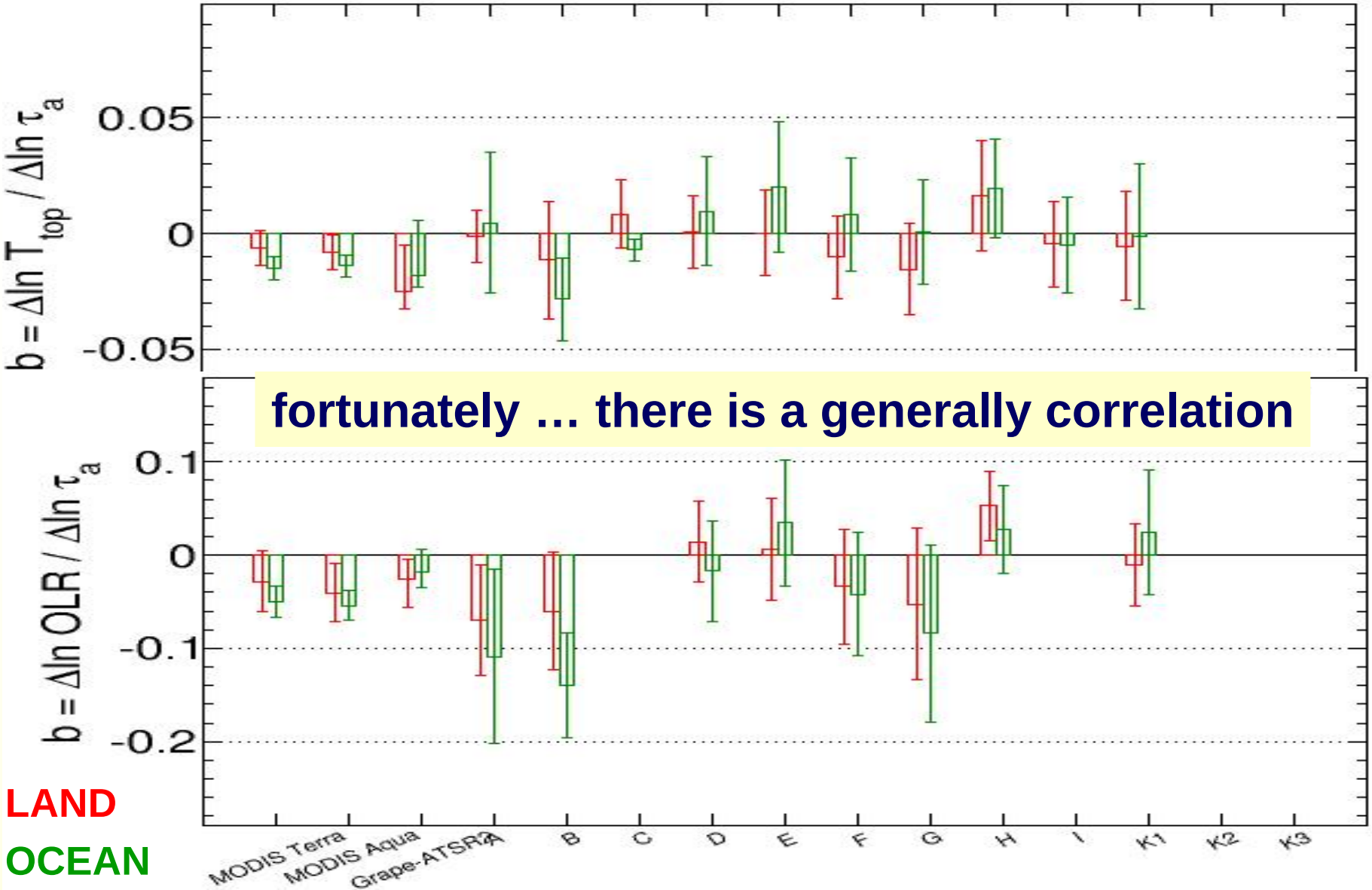
top Temp and OLR



fortunately … there is a generally correlation

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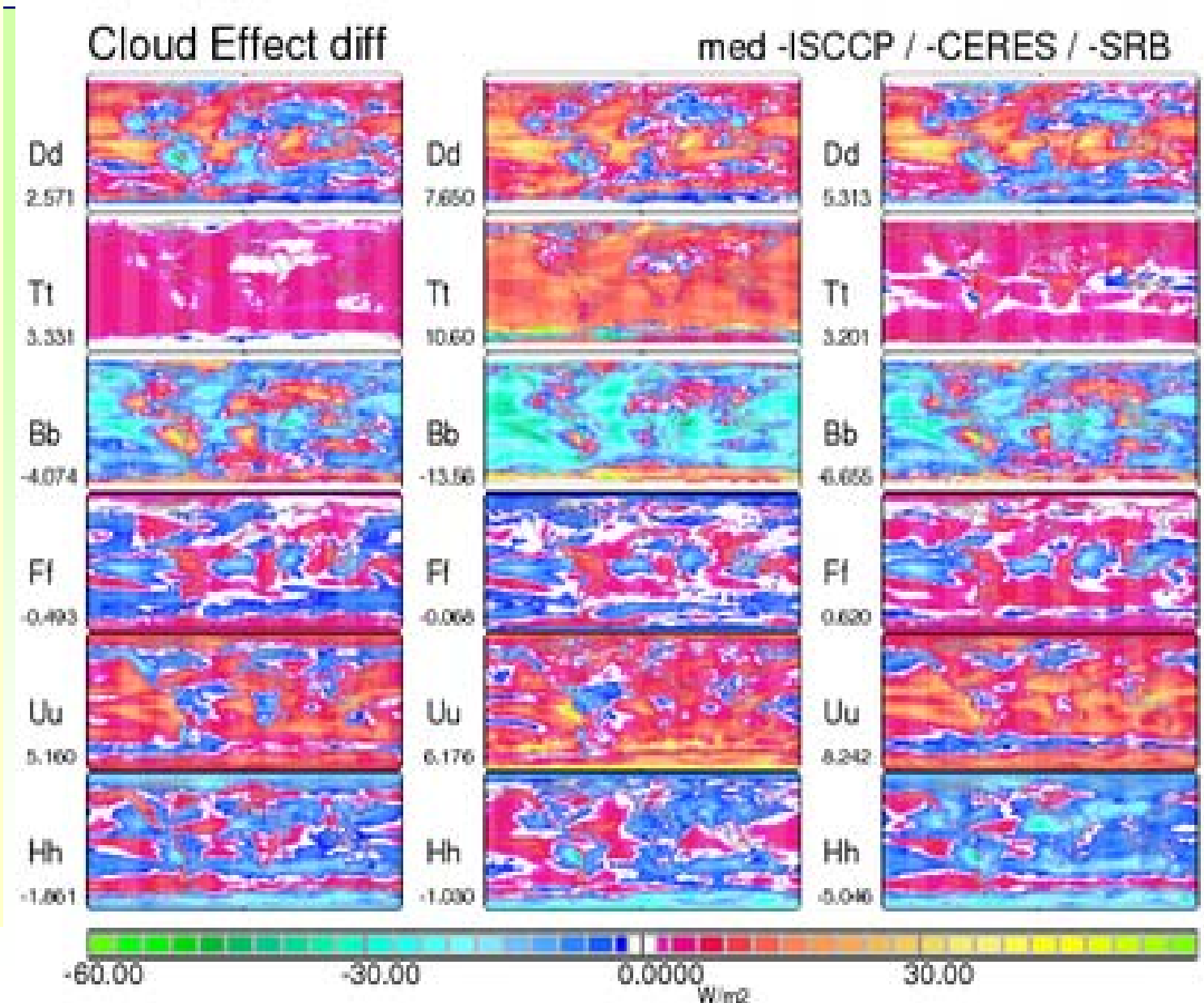
conclusion

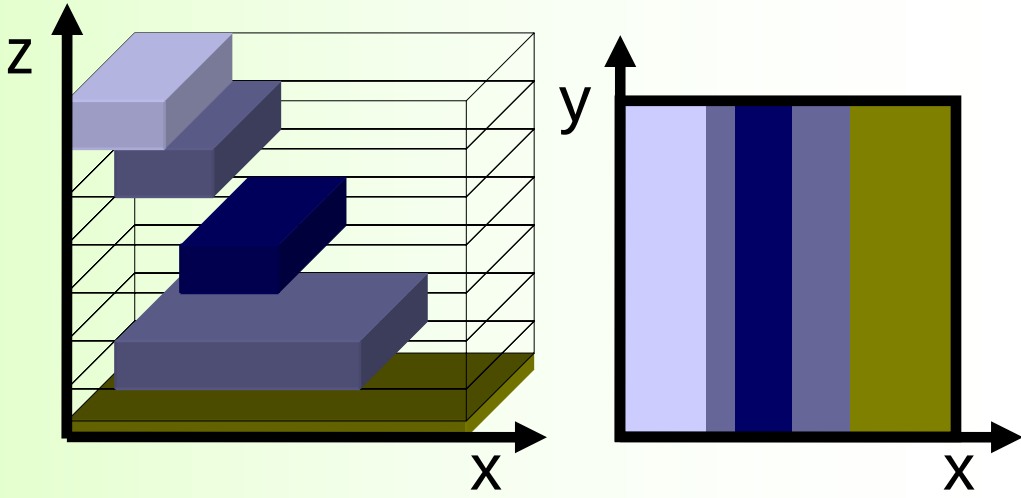
- **indirect effect estimates with satellite data**
  - **estimate only near -0.2 W/m^2 ... much less than in modeling**
- **AEROCOM model inter-comparison**
  - **CDNC – AOD relationship relatively well simulated**
  - **strong overestimation of LWP sensitivity in modeling *(lack of processes in modeling ?)***
  - **LW effect consistent with data … but not in all models**

extras

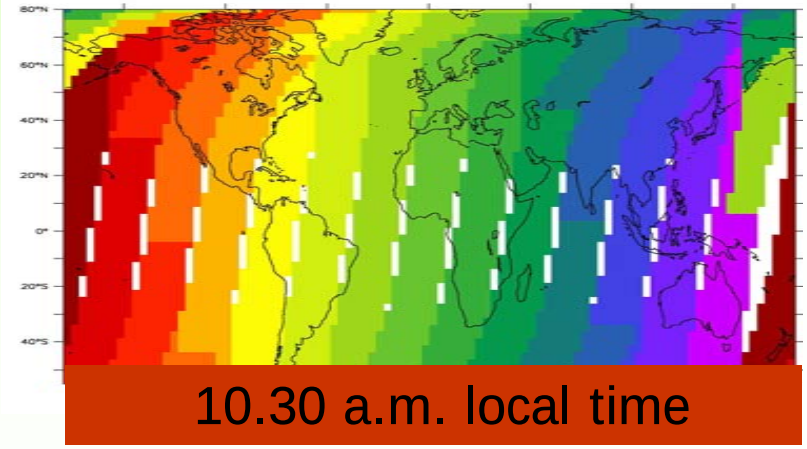
- sol up at TOA
- solar atmos
- sol dn at surf
- IR up at ToA
- IR atmos
- IR dn at surf



‘satellite simulator’



- sample cloud top quantities

- sample model at overpass time

- use same assumptions