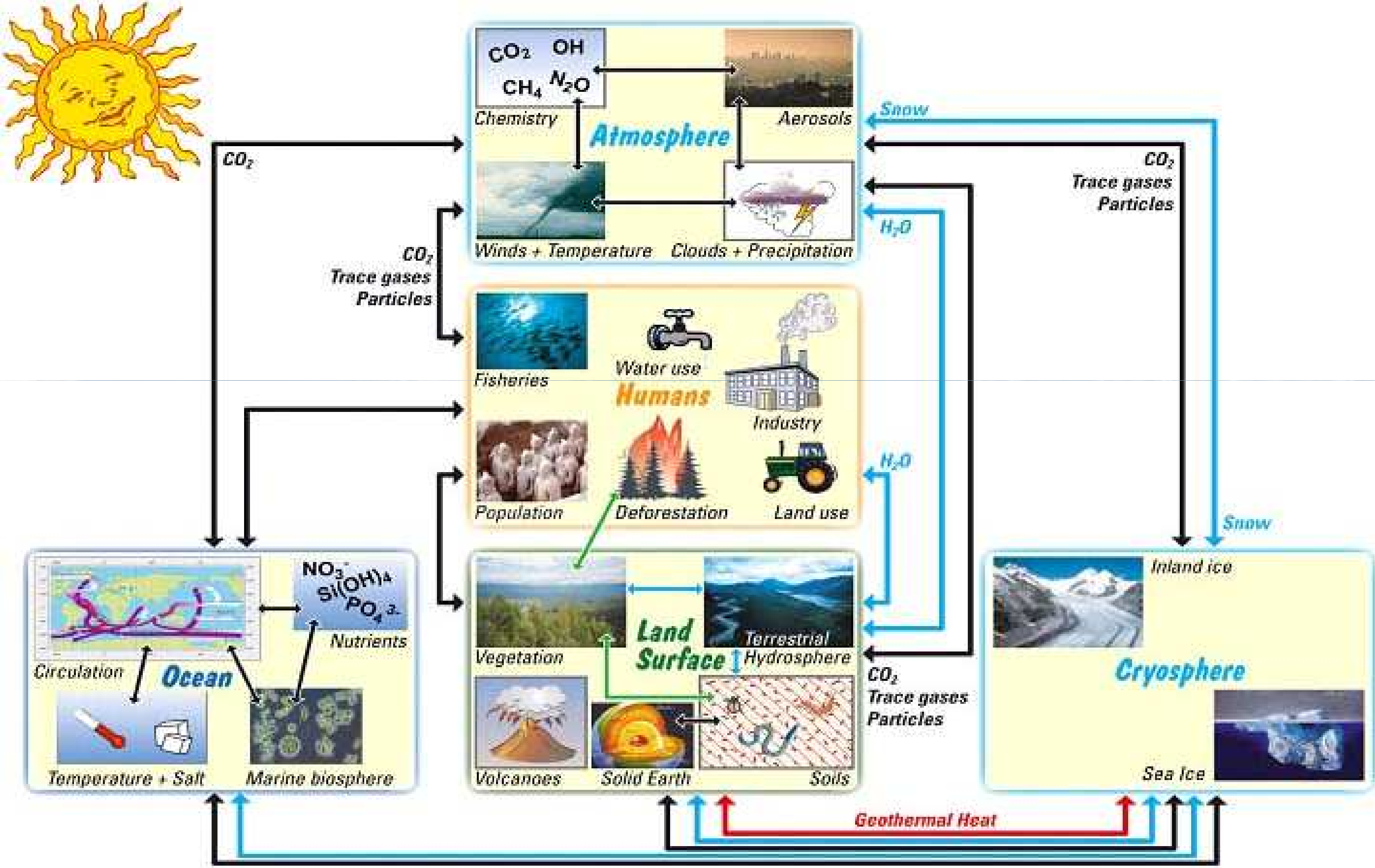
The Earth System



Earth System Models
what role for Observations?

Colin Jones

Head Rossby Centre SMHI (departing..)

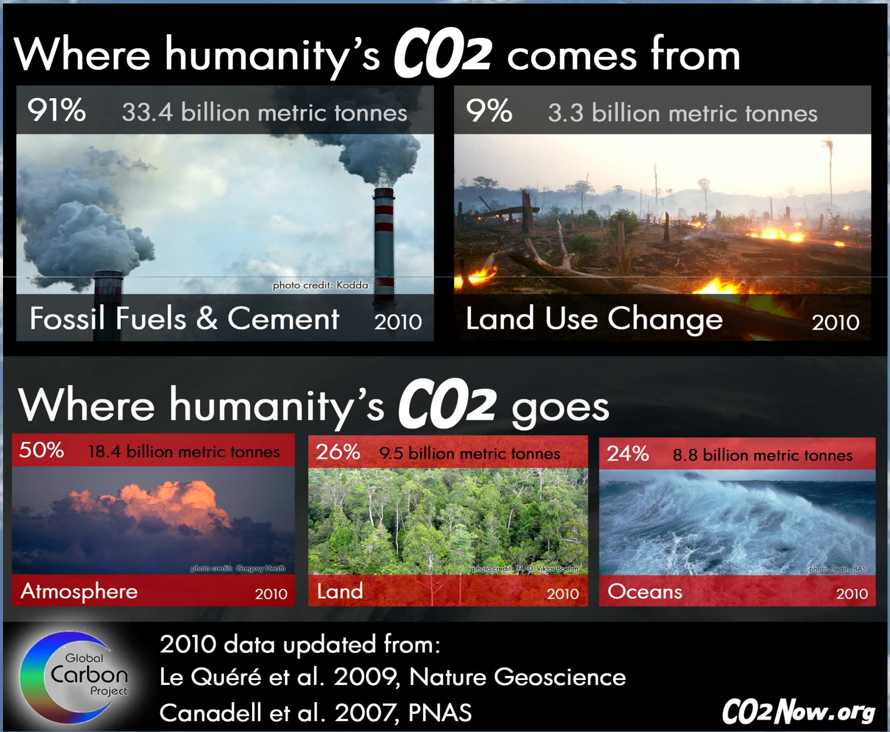
Head UK Earth System Modeling Project (arriving…)

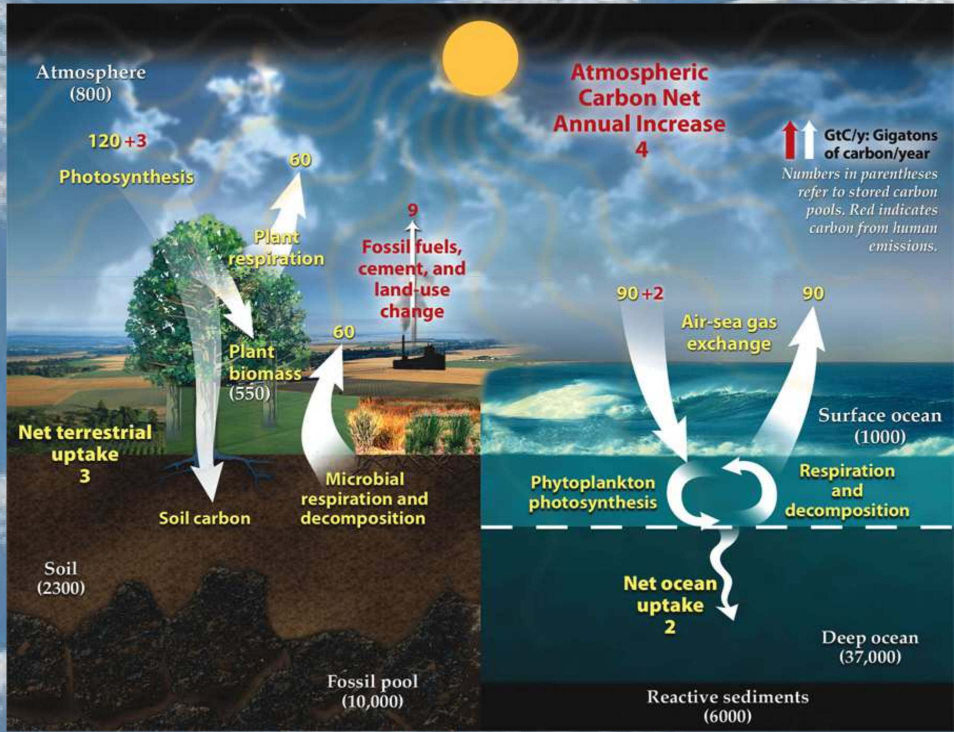
Coordinator EU FP7 EMBRACE (remaining…..)

Earth systeM Bias Reduction and Abrupt Climate changE

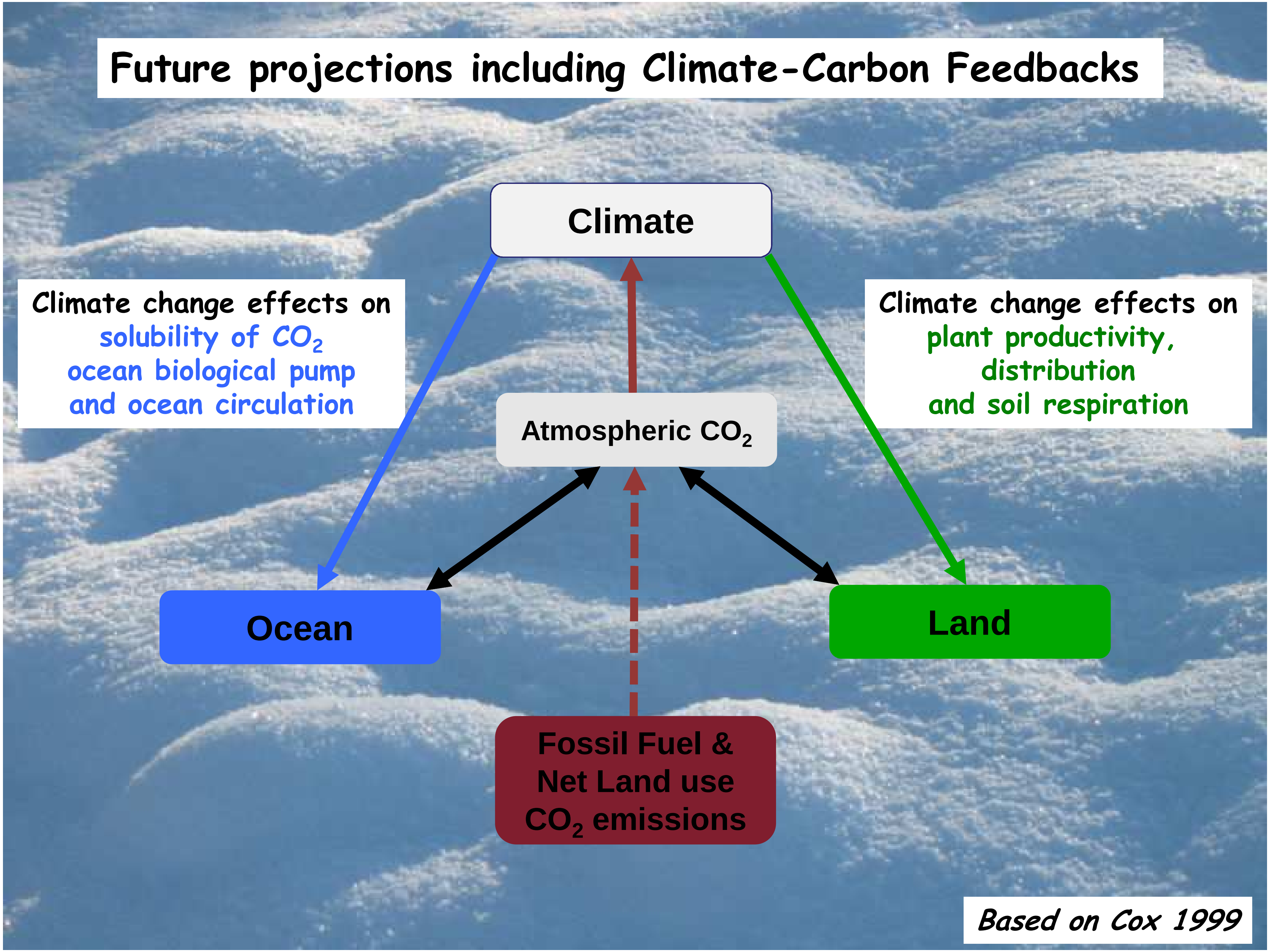
ESMs 1st steps : Coupled Climate-Carbon Cycle Models

came from concerns the Earth's carbon sources/sinks may be sensitive to climate change or increased CO_2 loading, potentially changing the rate of uptake of (emitted) CO_2 from the atmosphere by the global biosphere

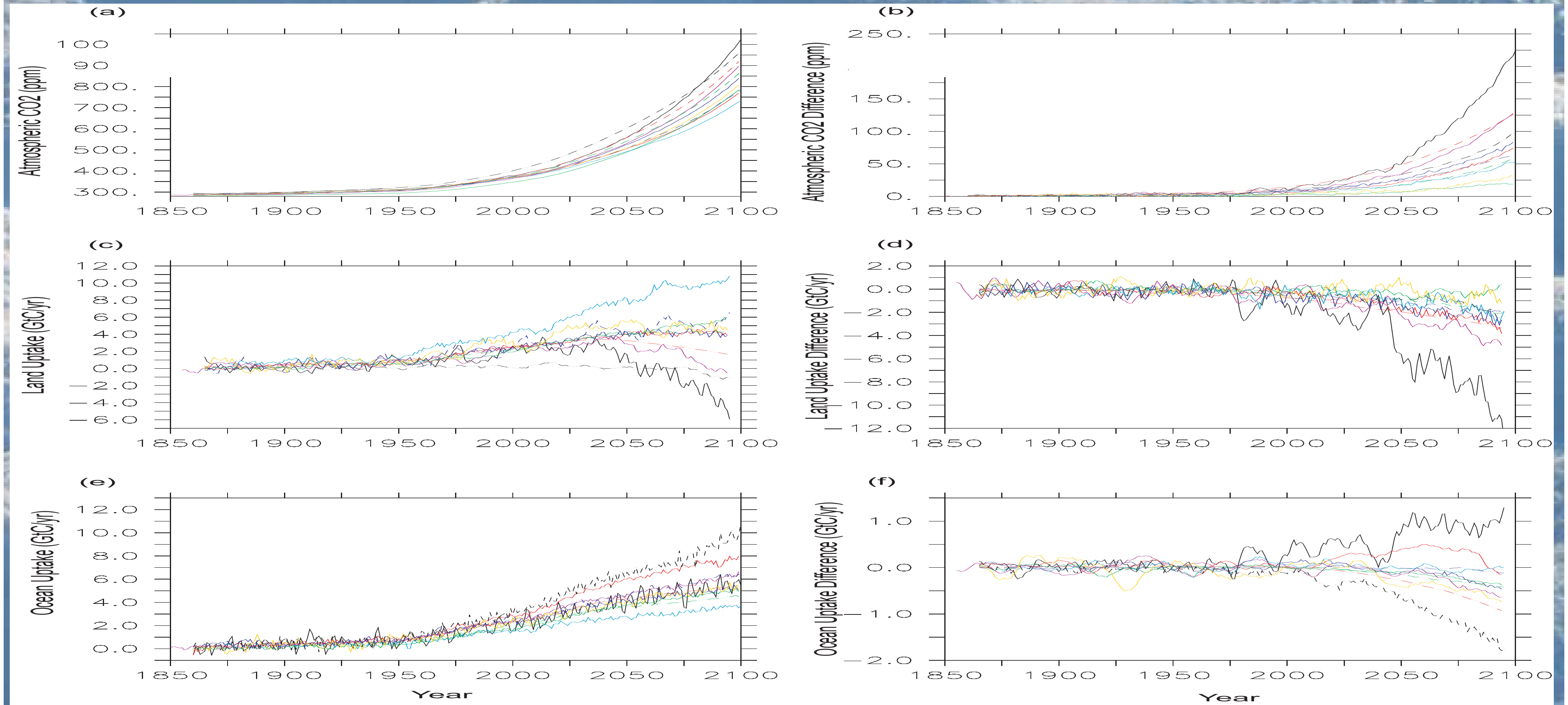




The carbon cycle is intimately linked to the physical climate system and may also require accurate simulation of associated biogeochemical cycles (e.g. H_2O, N_2, O_2)

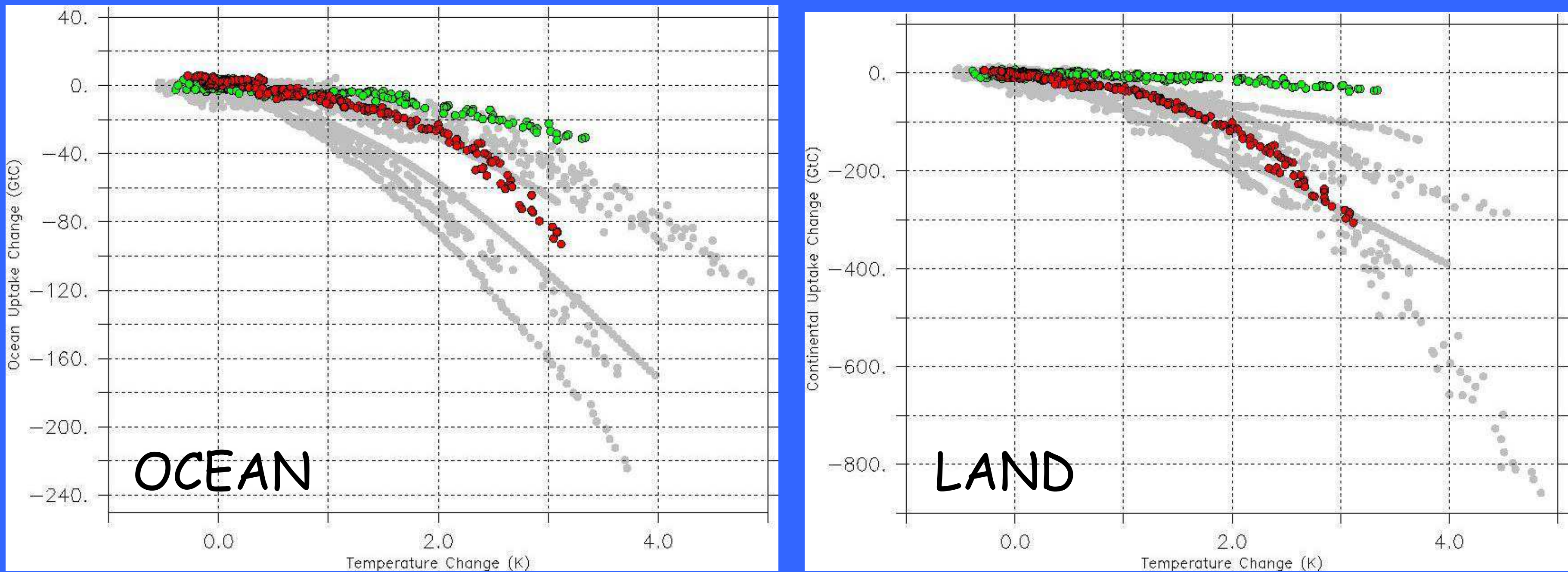

Future projections including Climate-Carbon Feedbacks
Climate
Climate change effects on
solubility of CO_2
ocean biological pump
and ocean circulation
Climate change effects on
plant productivity,
distribution
and soil respiration
Atmospheric CO_2
Ocean
Land
Fossil Fuel &
Net Land use
CO_2 emissions
Based on Cox 1999

Coupled Carbon-Climate Models in C4MIP indicate a possible increase in the amount of carbon staying in the atmosphere in the future of ~5-20% due to the Earth's carbon sinks **slowing down in response to climate change**



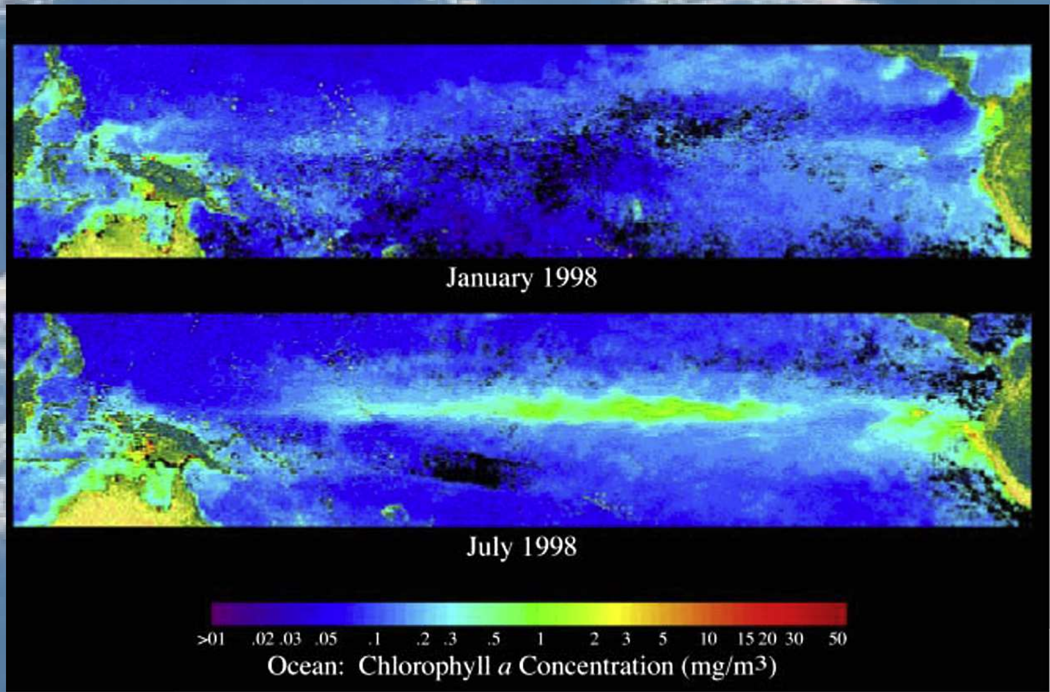
Uncertainty is large; depending on the physical climate change, increasing CO_2 other gas concentrations and the carbon cycle response to these change

Changes in both Ocean and Terrestrial Carbon uptake with climate warming are highly uncertain

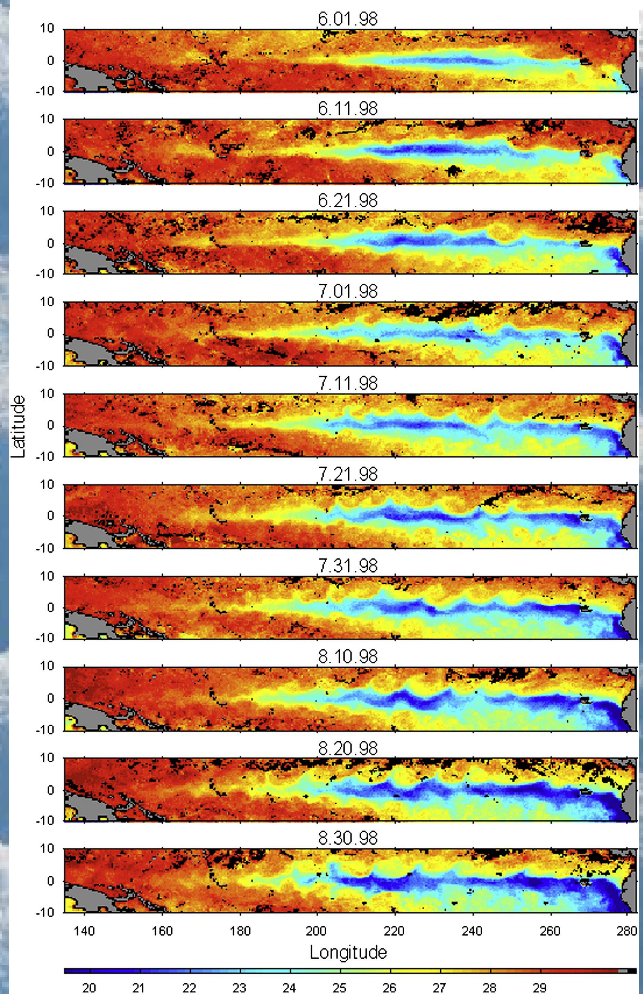


Physical climate variability and the carbon cycle interact strongly

Ocean biological activity, upwelling, carbon outgassing and nutrient transport

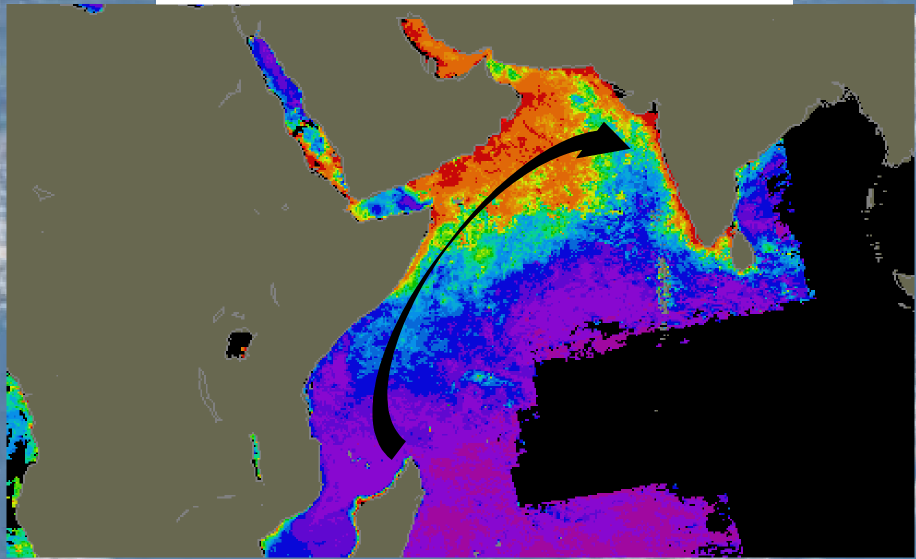


Evolution of summer 1998 La Nina

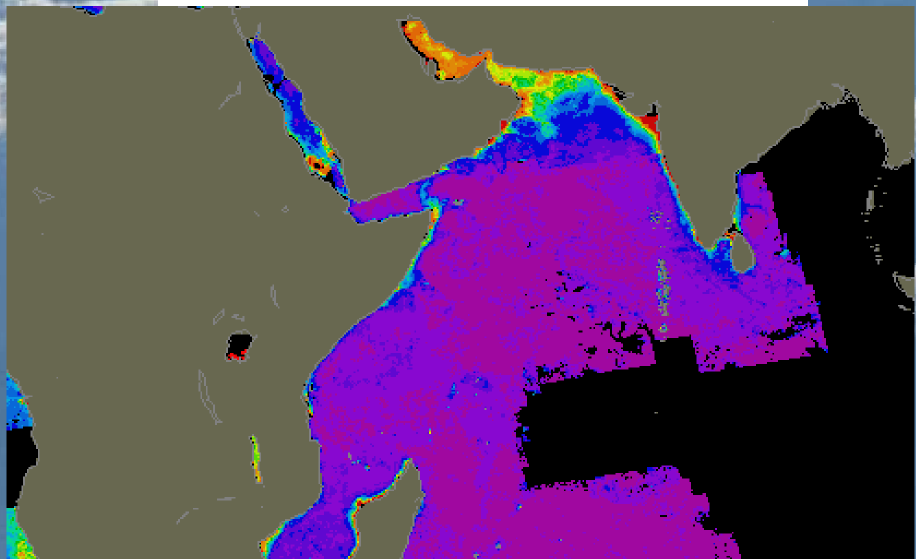


Critical that physical climate processes and their two-way interaction with the global carbon cycle are accurately represented in ESMs

JJA Biological Activity

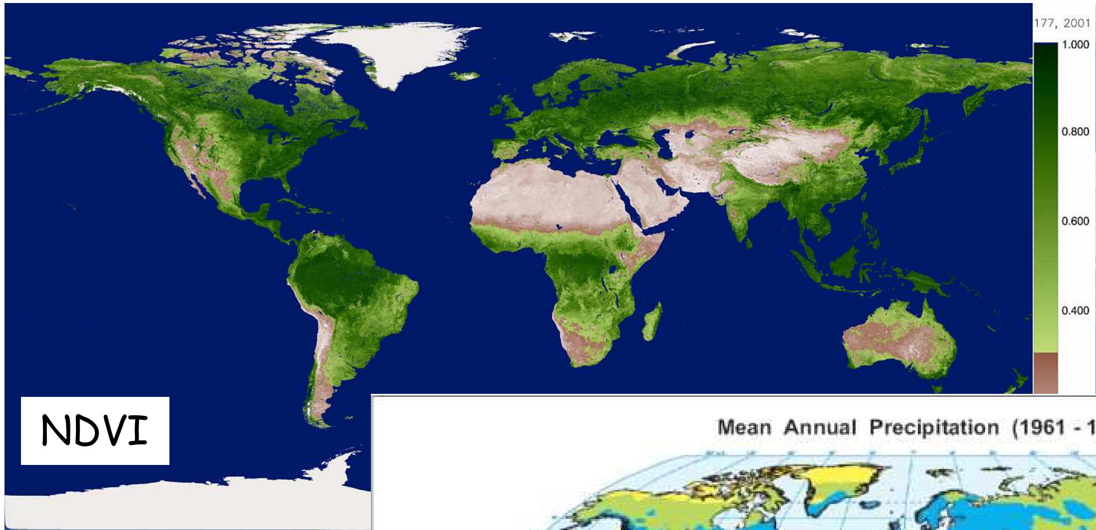


SON Biological Activity

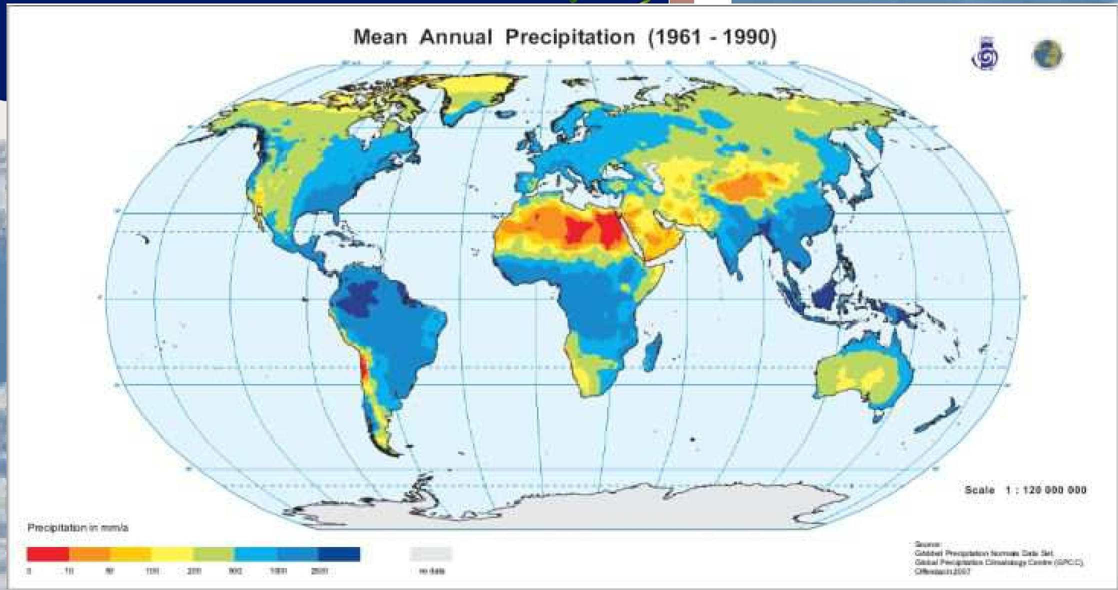


South Asian monsoon winds generate oceanic upwelling off Arabian Peninsula with nutrient rich waters reaching the sunlit surface layer, leading to enhanced biological activity and uptake of CO_2

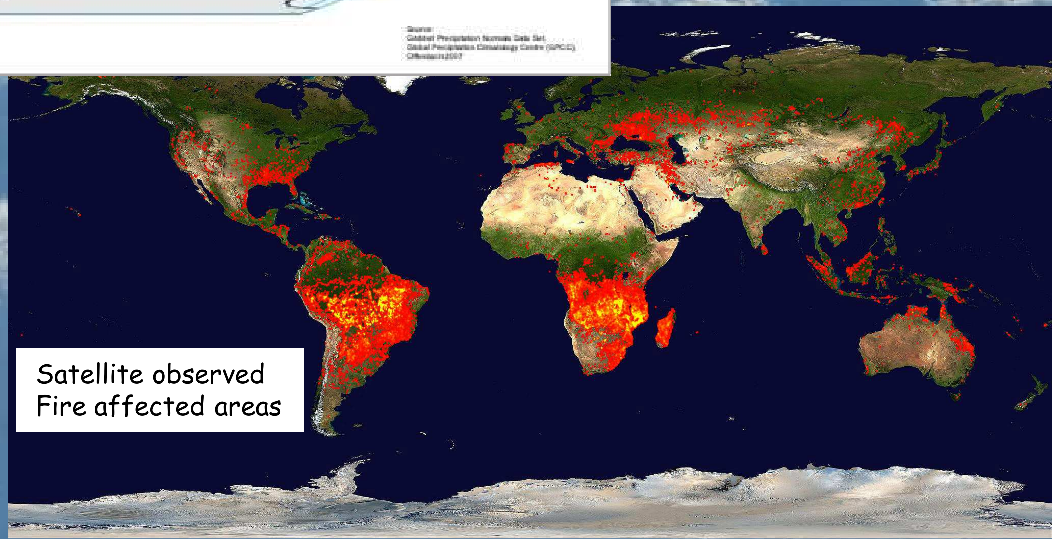
The strong dependence of the carbon cycle on the state and circulation of the physical climate means we need to evaluate both components and their interactions/covariability



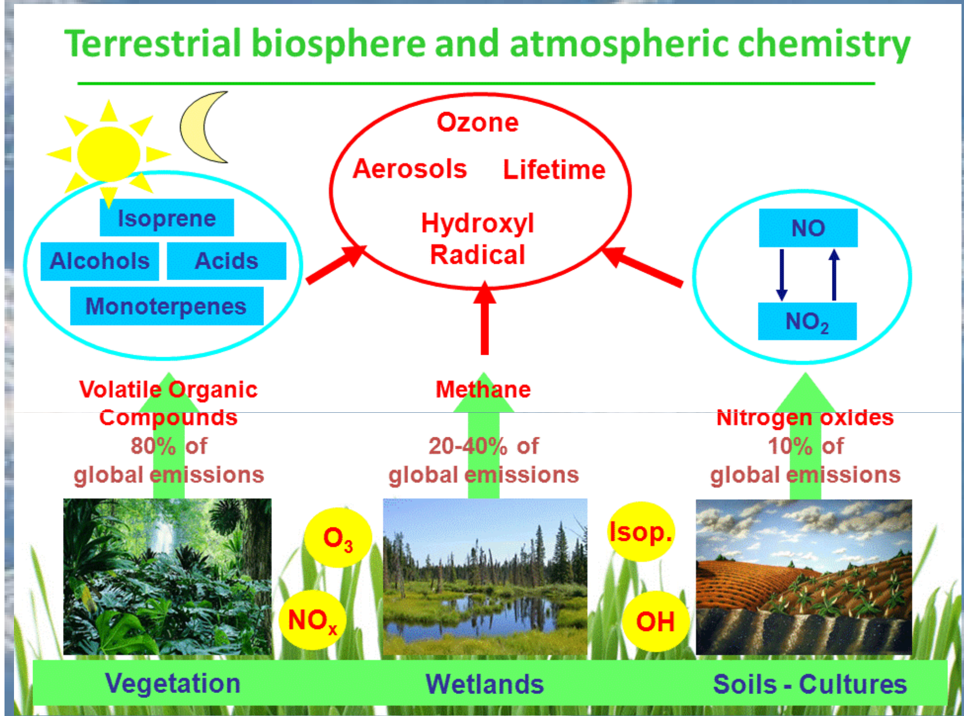
The land biosphere is also tightly coupled with the physical climate, particularly the water cycle

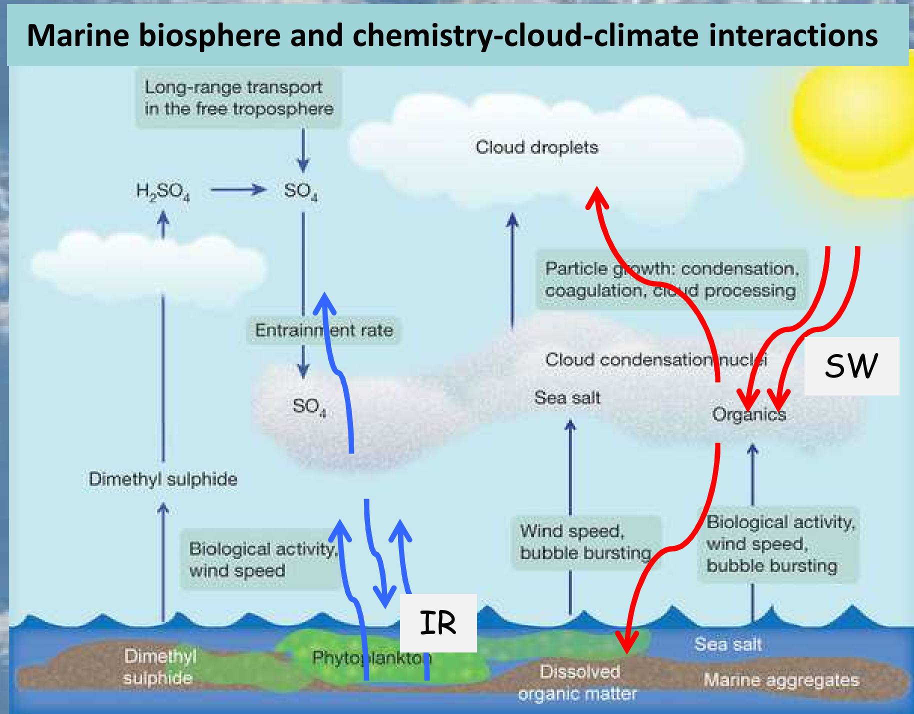


Fires play an important role in vegetation dynamics, are a source of biogenic aerosol precursors and are strongly influenced by physical climate variability. They therefore need to be included in ESMs



Both the terrestrial and marine biosphere are important emission sources for the atmosphere and interact with chemical and physical climate processes



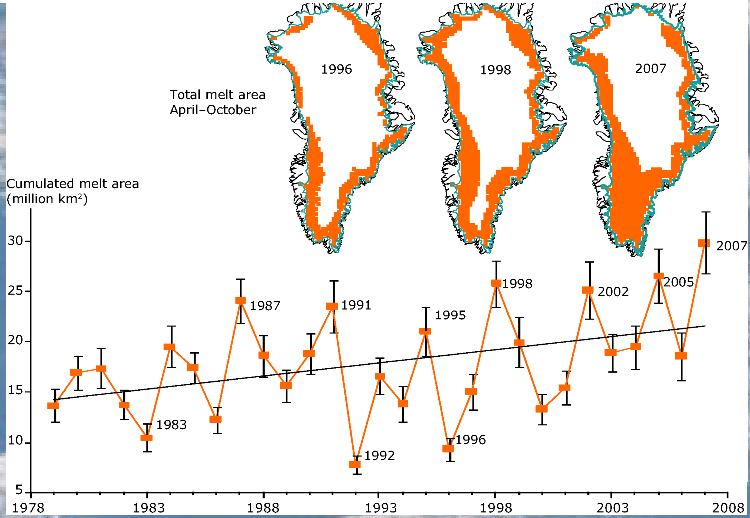


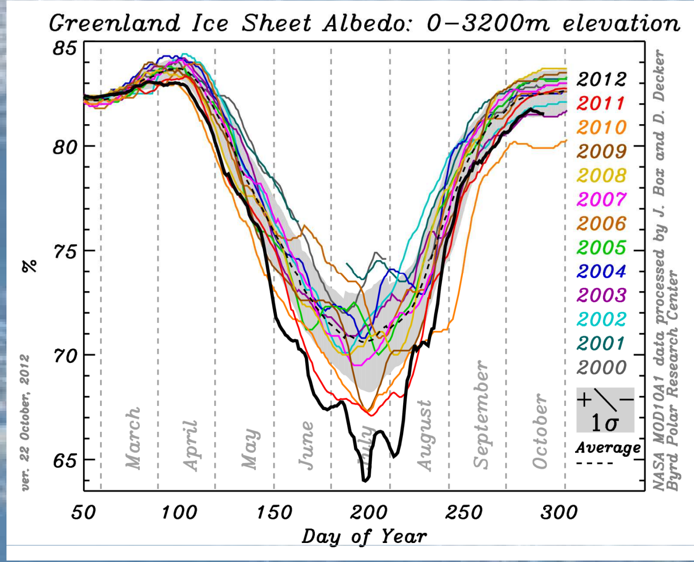
ESMs need to represent the important process interactions between global biogeochemistry, atmospheric chemistry and the climate system

Processes and their multi-directional interactions require careful evaluation both the basic variables and perhaps more importantly their covariability

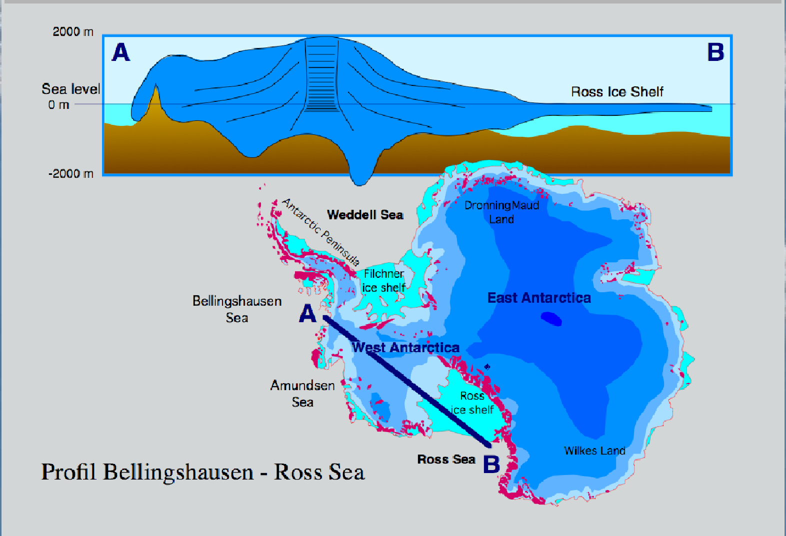
Ice Sheets & Sea Level Rise important to model on longer timescales

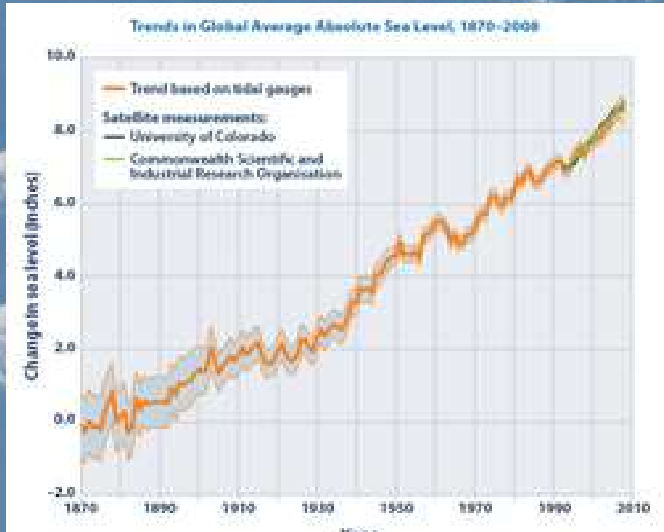
Greenland melt rates and melt area





West Antarctic Ice Shelf stability

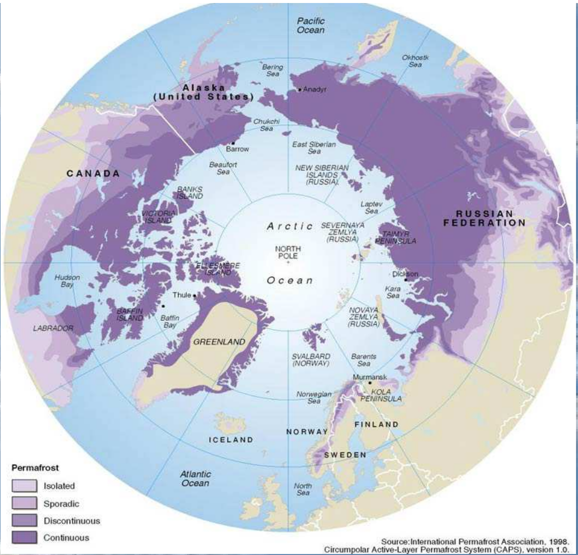


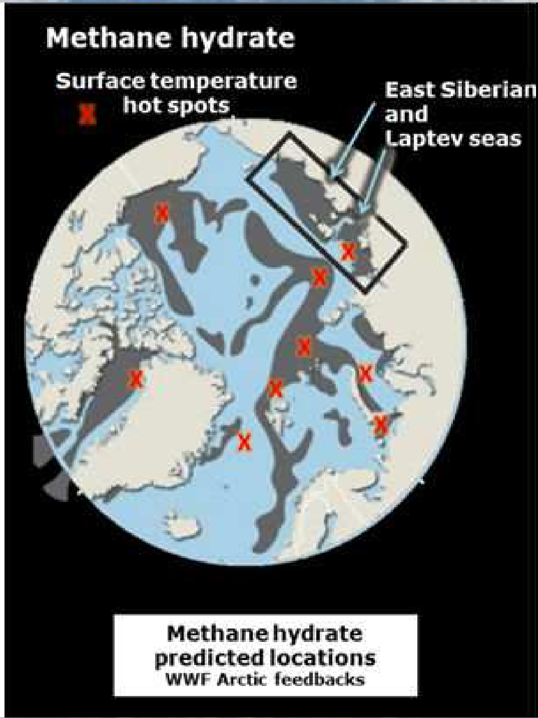


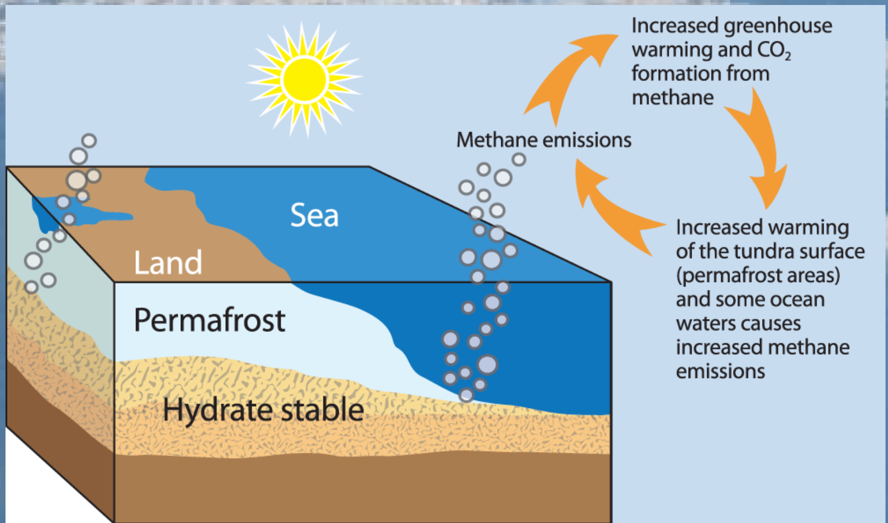
Observed Sea Level increase 1870-present

Arctic Warming: Risk for carbon and methane release from permafrost and warming ocean and methane hydrates: Potential Earth System Tipping Points

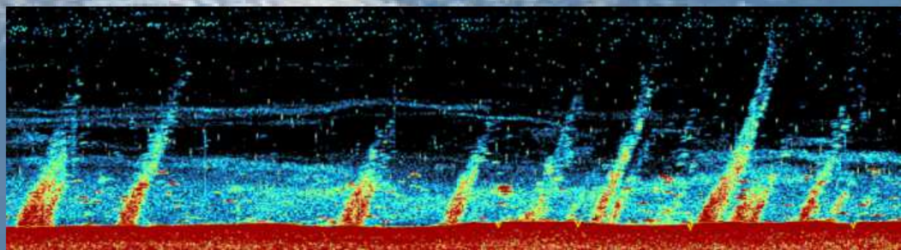
Permafrost areas in the Arctic

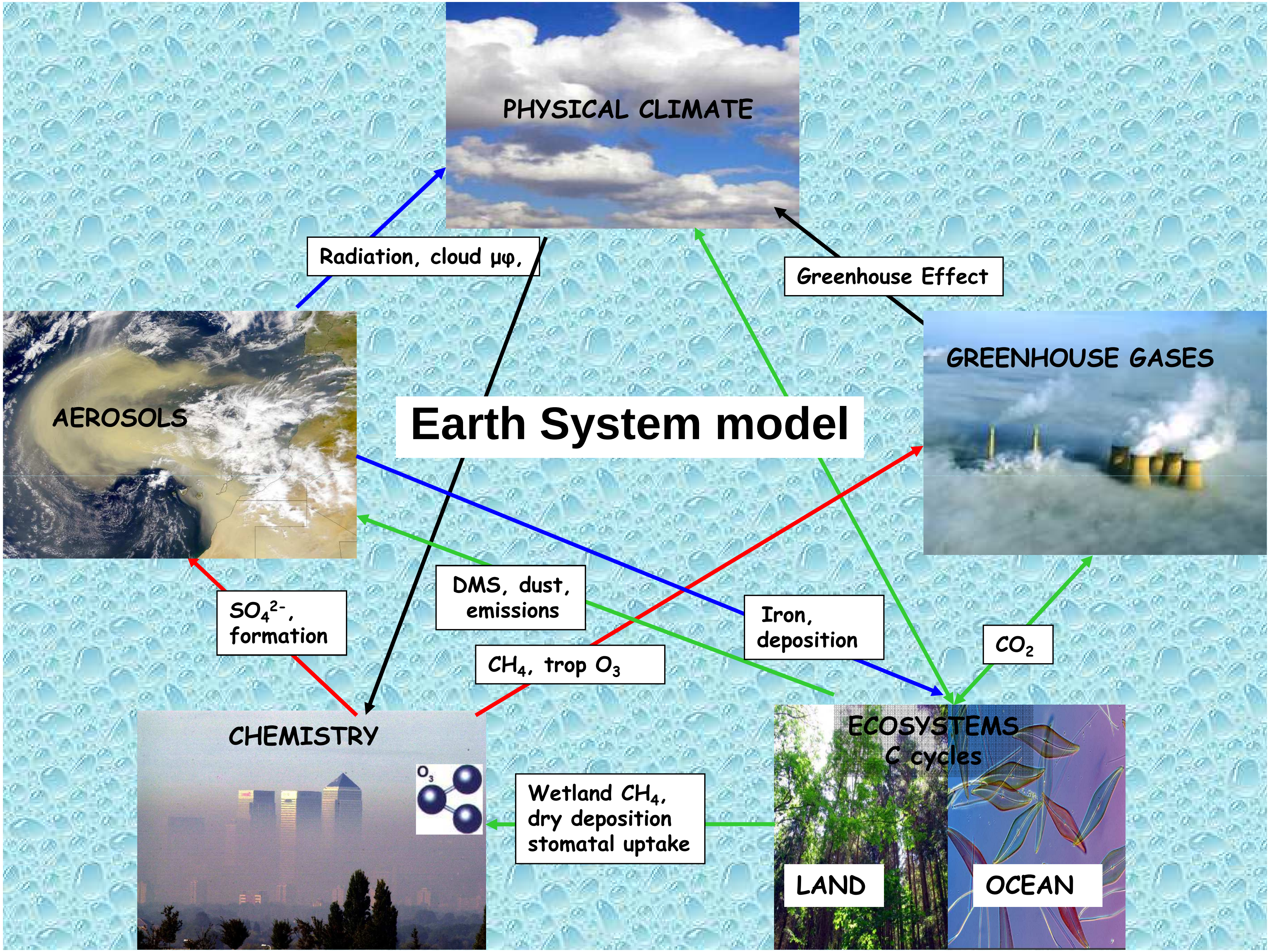






Observed methane plumes in the Arctic Ocean





PHYSICAL CLIMATE
Radiation, cloud μφ,
Greenhouse Effect
GREENHOUSE GASES
AEROSOLS
Earth System model
DMS, dust, emissions
Iron, deposition
SO_4^{2-}, formation
CH_4, trop O_3
CO_2
CHEMISTRY
O_3
Wetland CH_4, dry deposition stomatal uptake
ECOSYSTEMS
C cycles
LAND
OCEAN

Observations and Earth System Modeling

Process understanding to improve models (parameterizations)

Evaluation of simulated present climate and climate variability

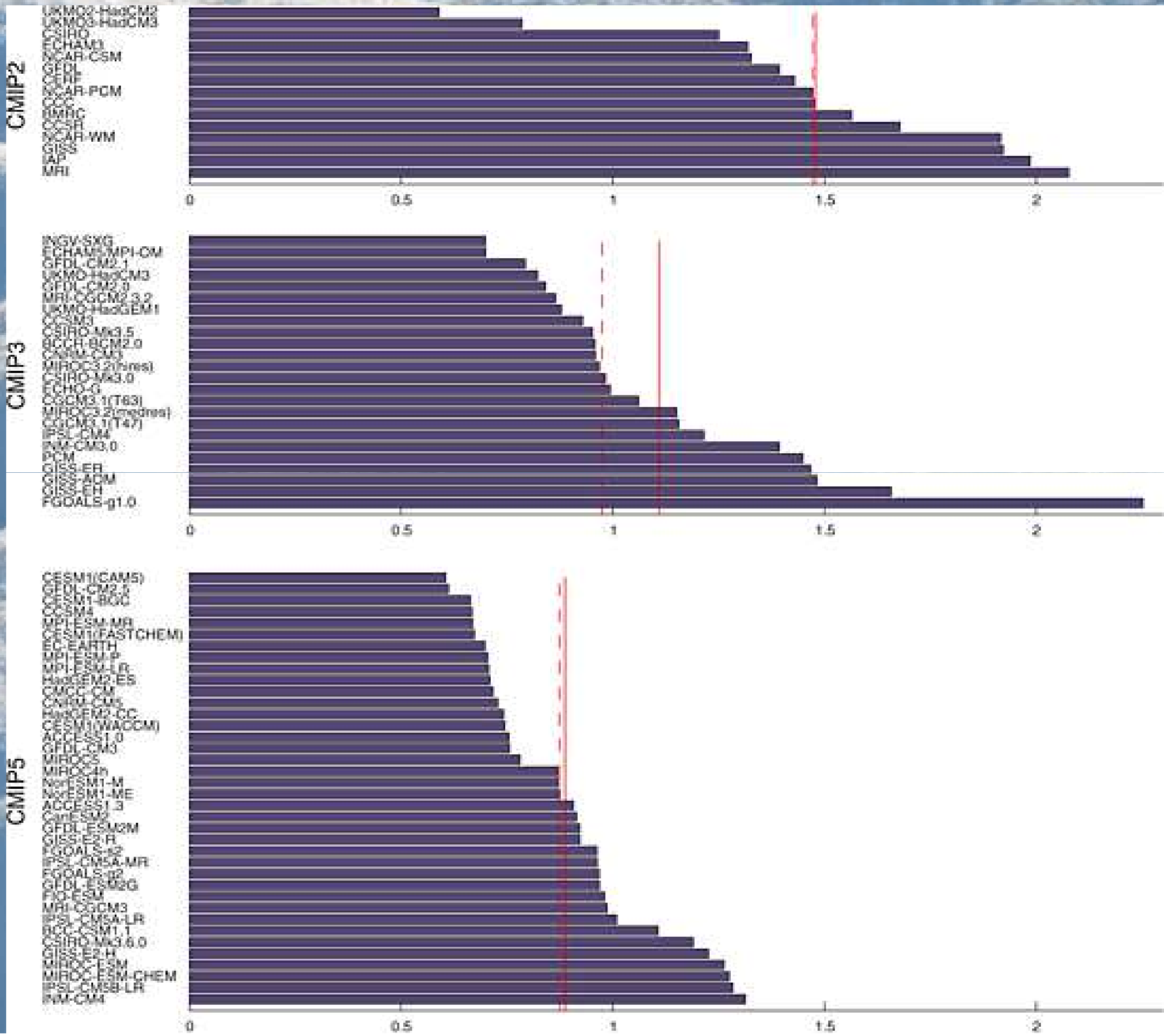
Evaluation of simulated parameter co-variability/sensitivity

Evaluation of simulated trends against observed trends

Help to constrain future climate change feedbacks by constraining key model variability: Emergent constraints

Documenting model improvement (with time) and perhaps for ranking model reliability/suitability for climate projection

Observations allow evaluation of model accuracy against past climate variability, allowing (attempts) to rank model quality and assess improvements over time



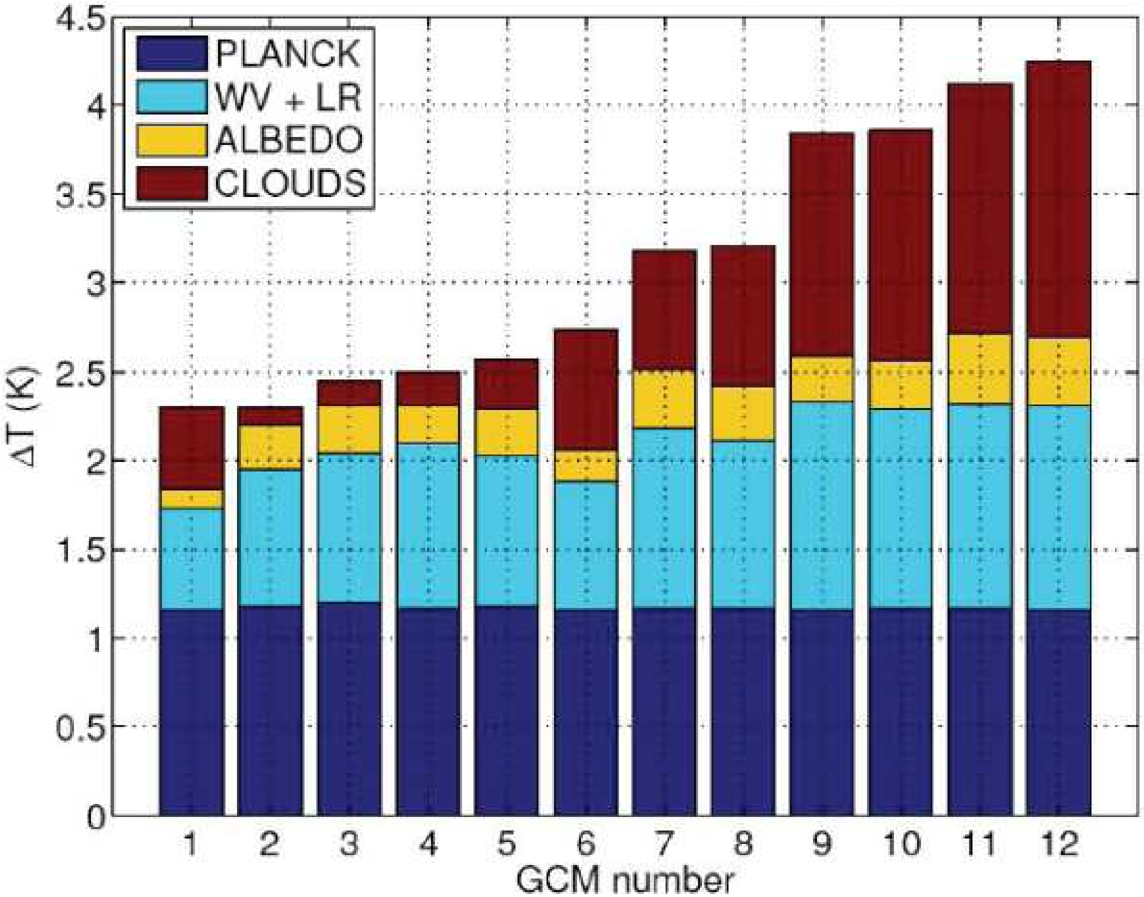
Normalized distance from observations for temperature and precipitation

Identify the largest sources of uncertainty in estimating future climate response to increased greenhouse gas loading

Equilibrium/transient (global) climate sensitivity

Cloud Feedbacks remain the main uncertainty in estimating Global Climate Sensitivity

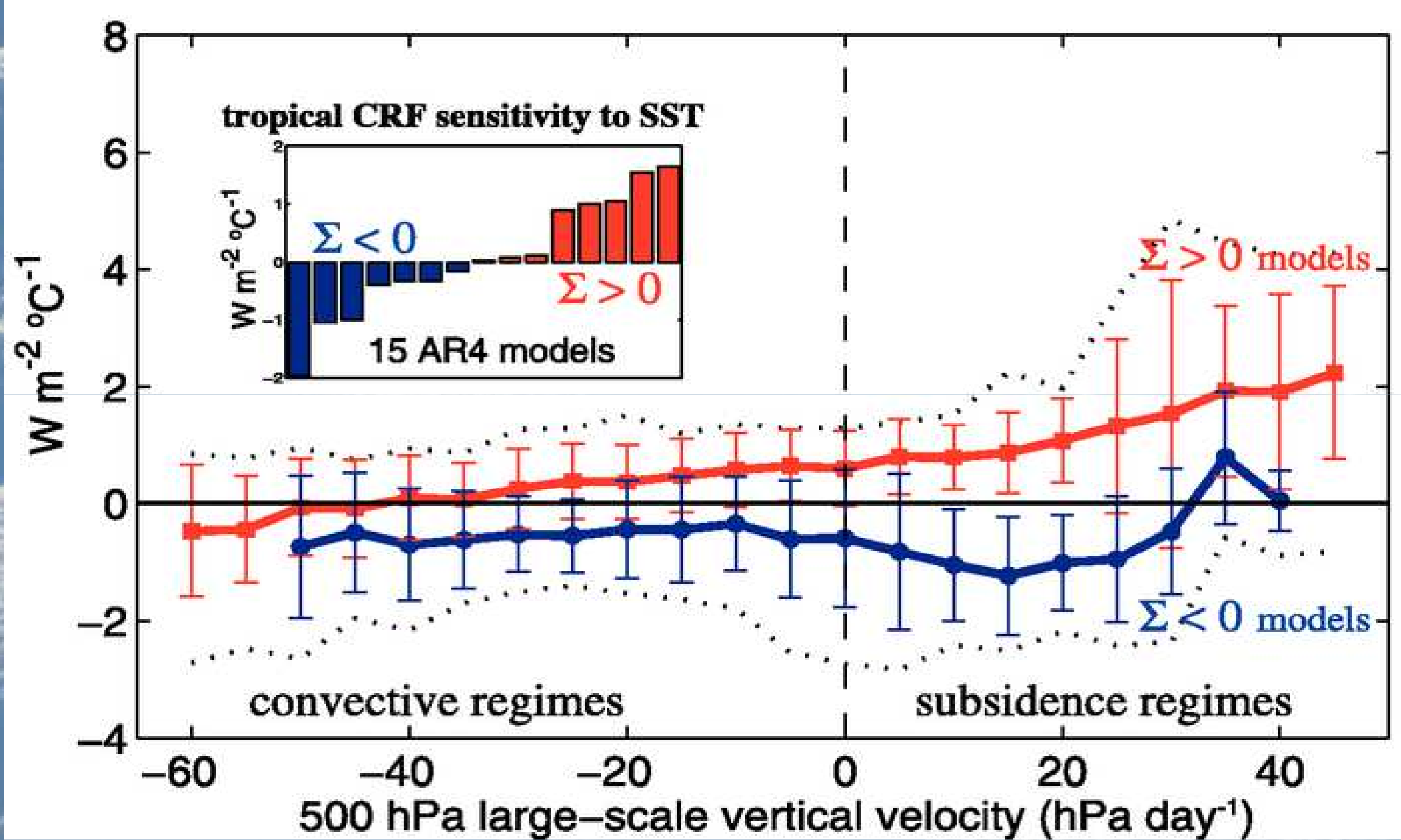
Equilibrium temperature change decomposition, for 2xCO2



With feedback parameters from (Soden and Held, 2006)

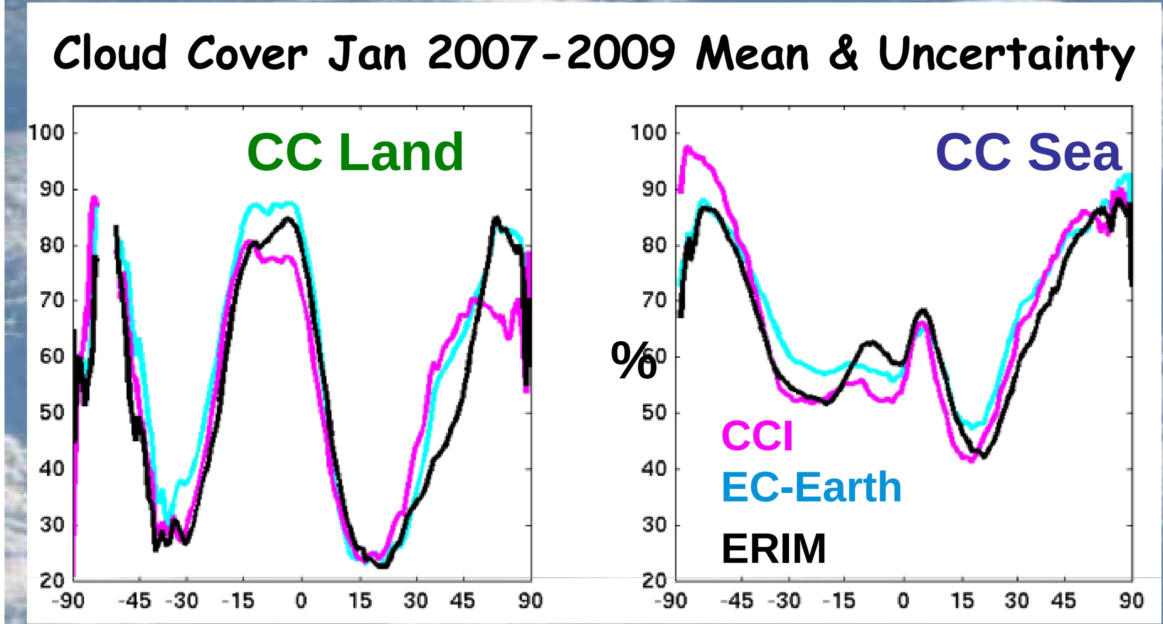
[Dufresne and Bony, 2007]

Change in TOA Cloud Radiative forcing with increased tropical SST as a function of 500hpa vertical motion. Red Lined models exhibit a feedback to warming tropical SST, blue models a negative feedback

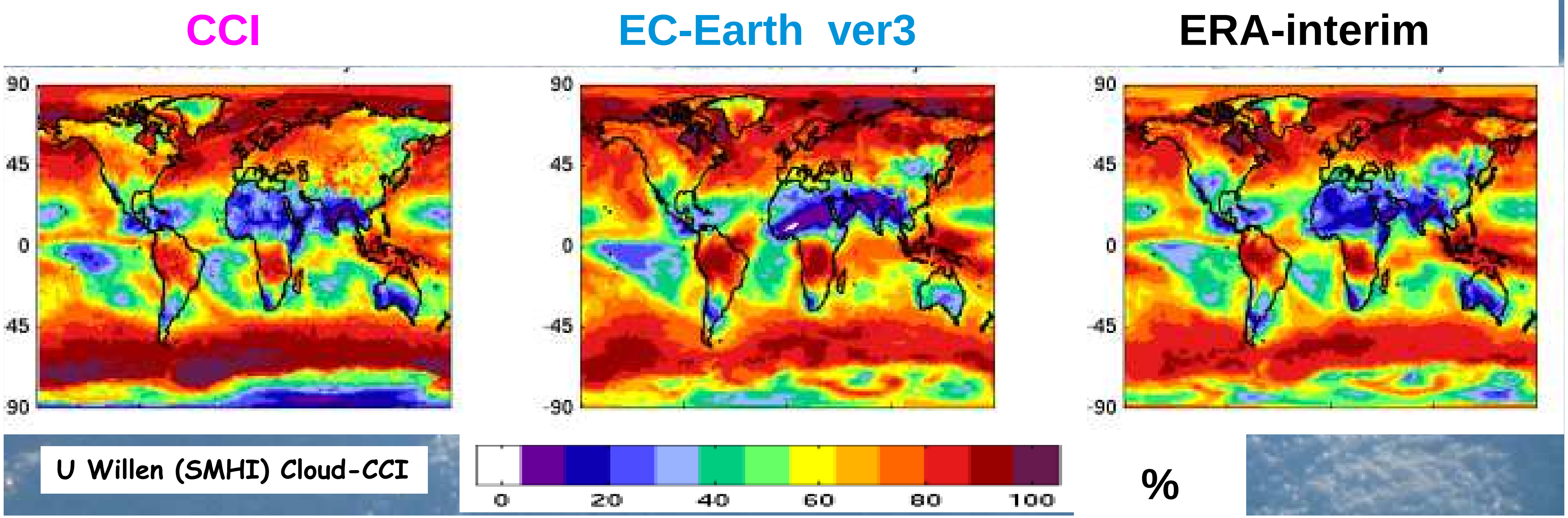


Largest inter-model differences occur in areas of large scale subsidence Regions of boundary layer trade cumulus and stratocumulus clouds

EC-Earth compared to Cloud-CCI



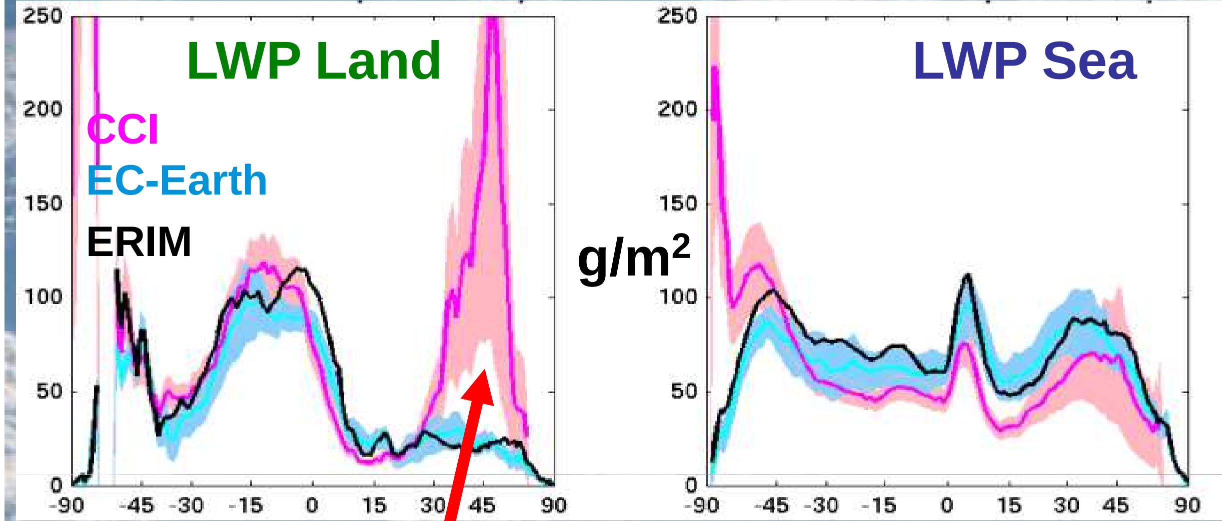
Some CCI problems over Snow covered regions And subtropical/arid areas



U Willen (SMHI) Cloud-CCI

EC-Earth compared to Cloud-CCI

Liquid Water Path Jan 2007-2009 Mean & Uncertainty



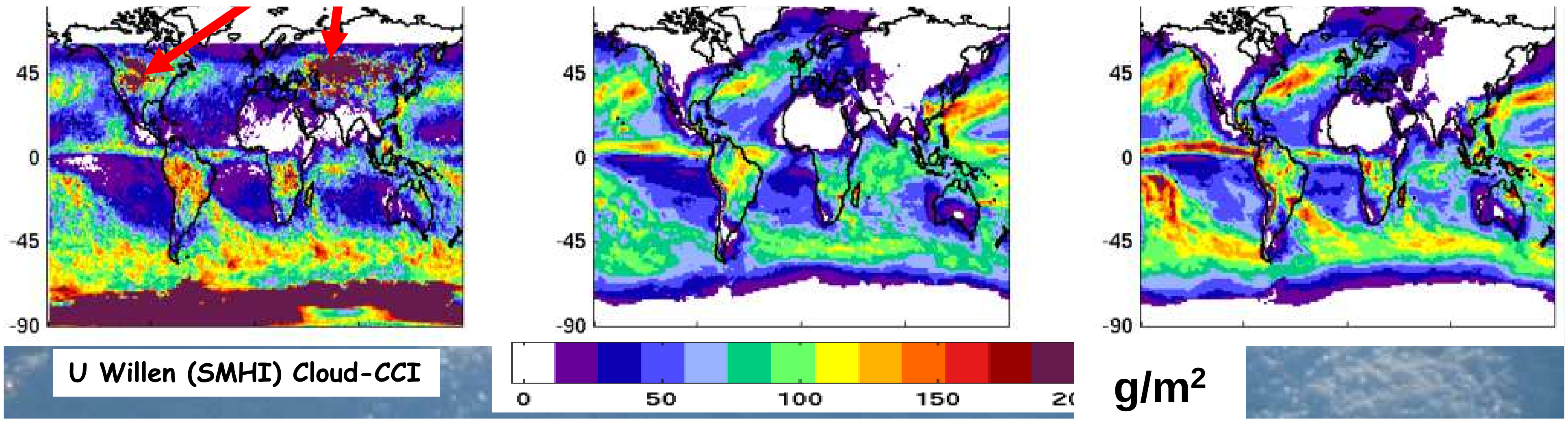
Good agreement except over snow & stratocumulus regions

Good with modeller/observational interactions – finding problem regions, how to use data and uncertainties

CCI

EC-Earth ver3

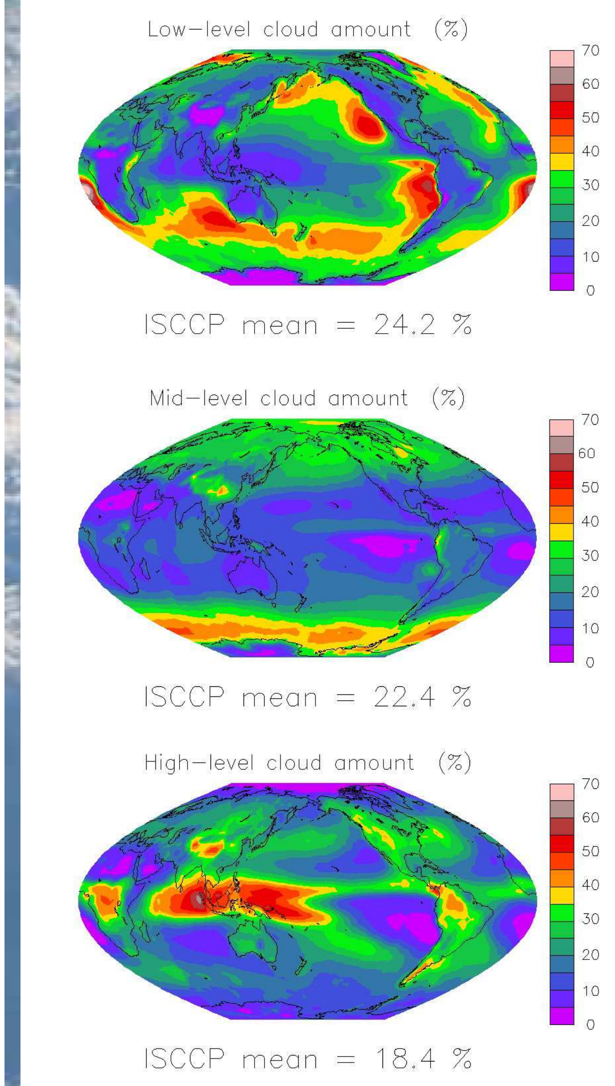
ERA-interim



U Willen (SMHI) Cloud-CCI

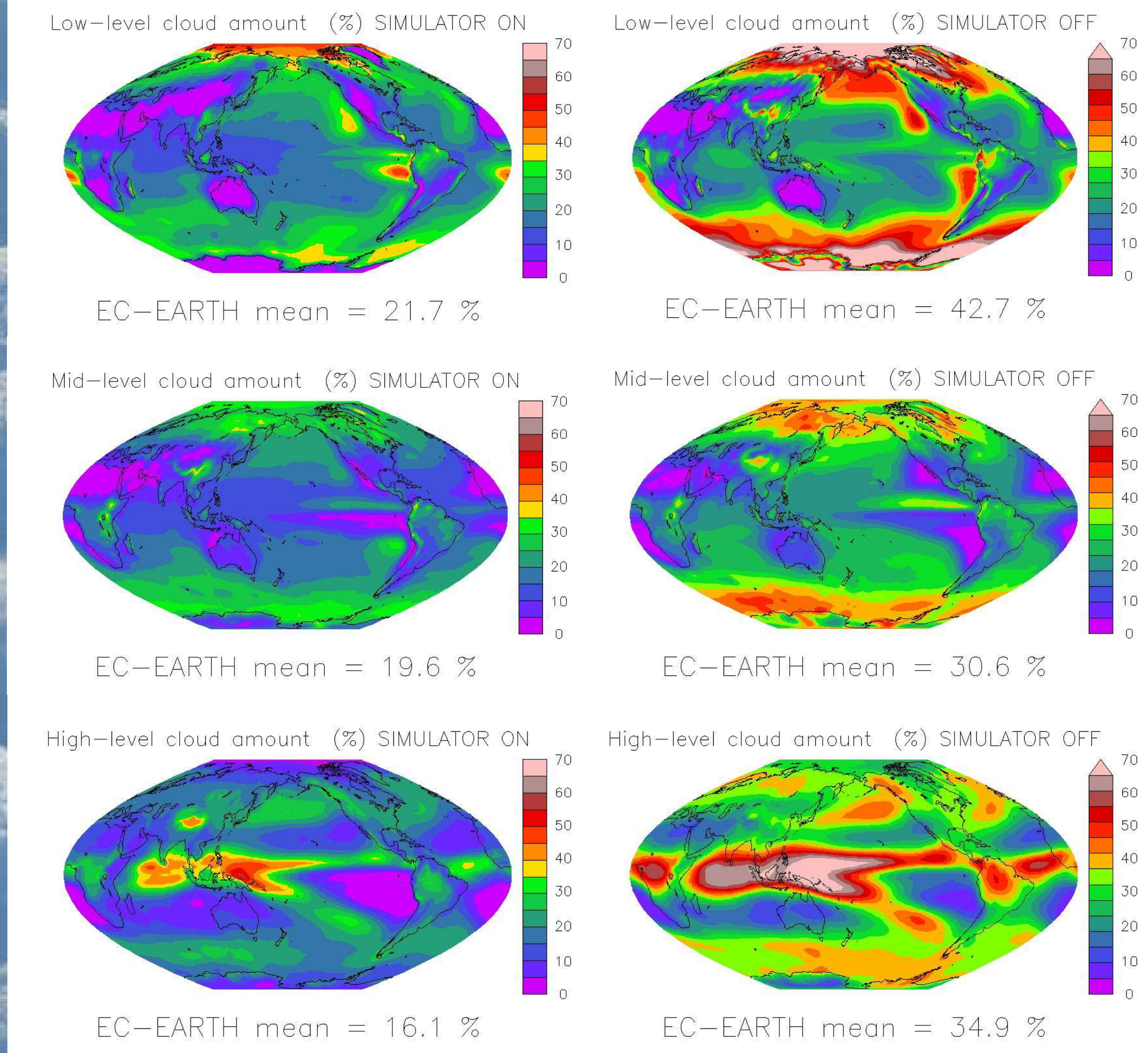
Satellite simulators: Comparing Like with Like

OBSERVATIONS: ISCCP



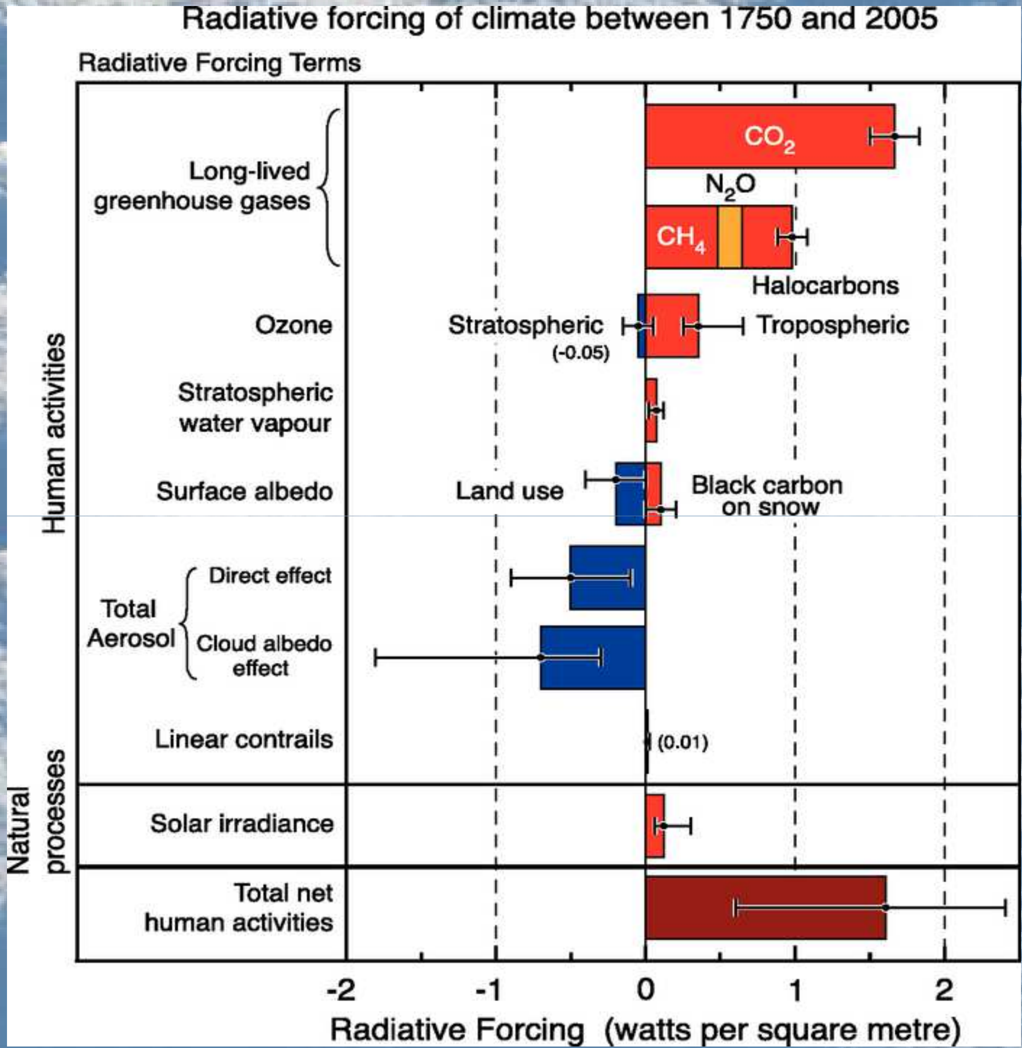
EC-EARTH SIMULATOR ON

EC-EARTH SIMULATOR OFF



(Lacagnina and Selten, submitted)

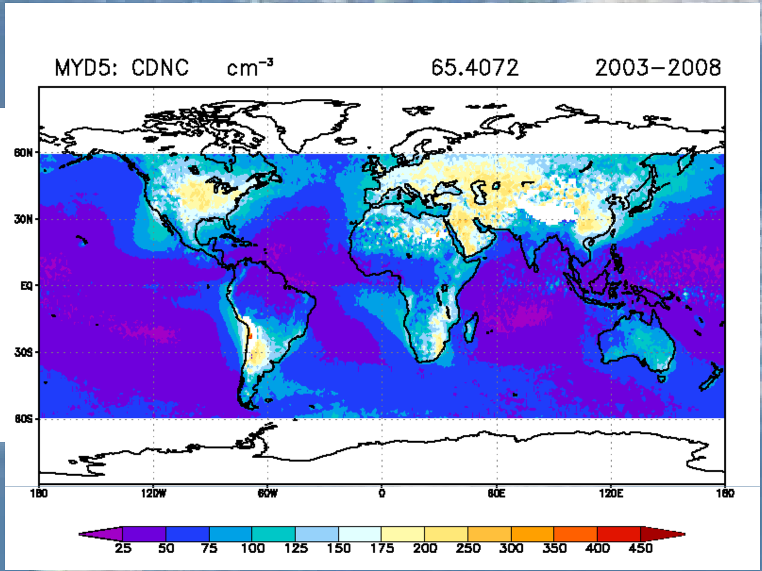
Changes in radiative forcing of the Earth System are the physical driver of climate change



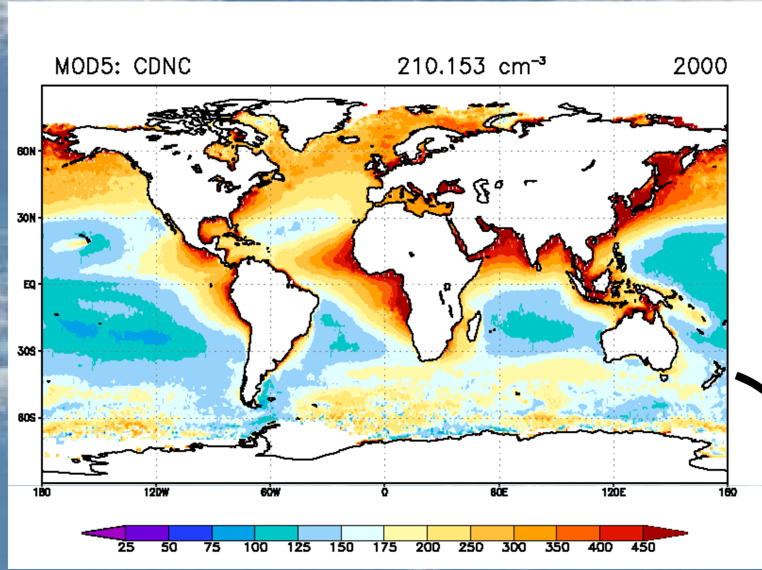
Aerosol-(cloud/precipitation)-radiation effects on climate are highly Uncertain and limit our ability to estimate global climate sensitivity

Large uncertainty in remote-sensing retrievals of CCN

Bennardz et al. (2007)



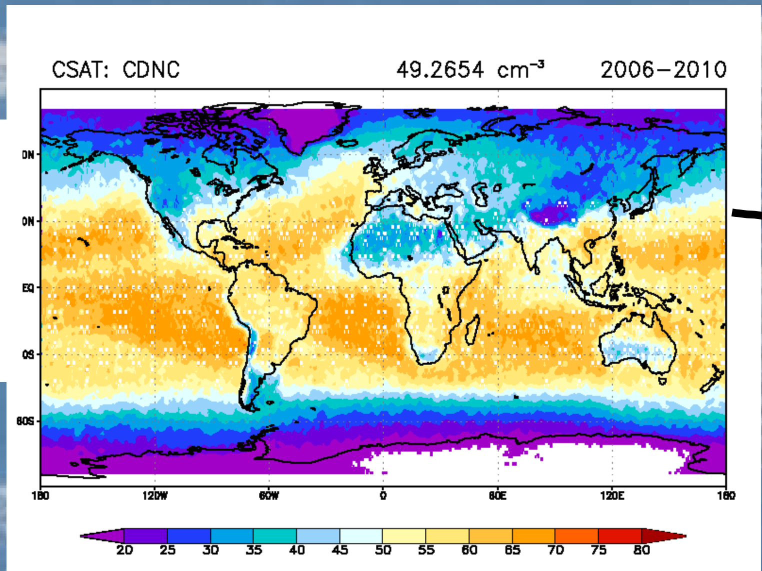
MODIS-Aqua



MODIS-Aqua:
- Liquid clouds T>268K
- Warm cld fac> 0.4
- CCN at cloud top

MODIS-Terra/Aqua:
- CCN at cloud top

CloudSat



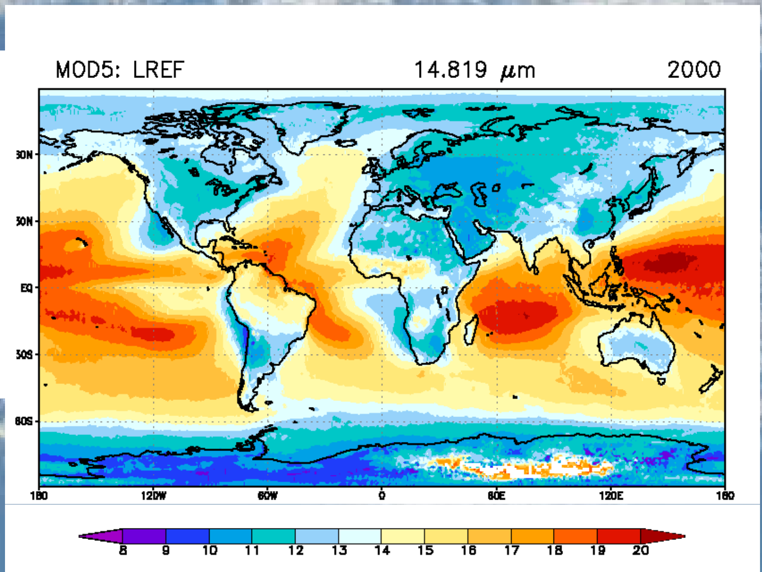
CloudSat screened for:
- Uncertainty < 200%
- Represents CCN averaged through the cloud depth

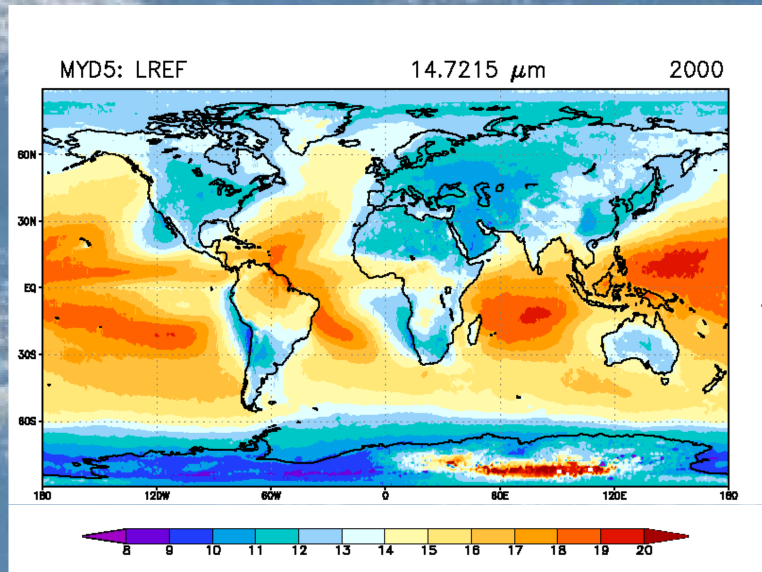
Cloud simulator needed for proper comparison!

I. Ivanova SMHI

Large uncertainty in remote-sending retrievals of effective radius

MODIS-Terra

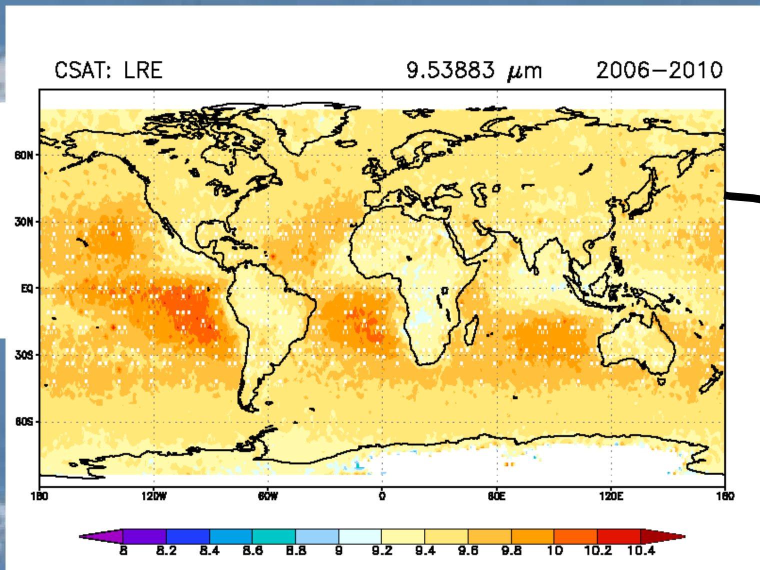




MODIS-Aqua

MODIS-Terra/Aqua
Liquid Reff at
cloud top

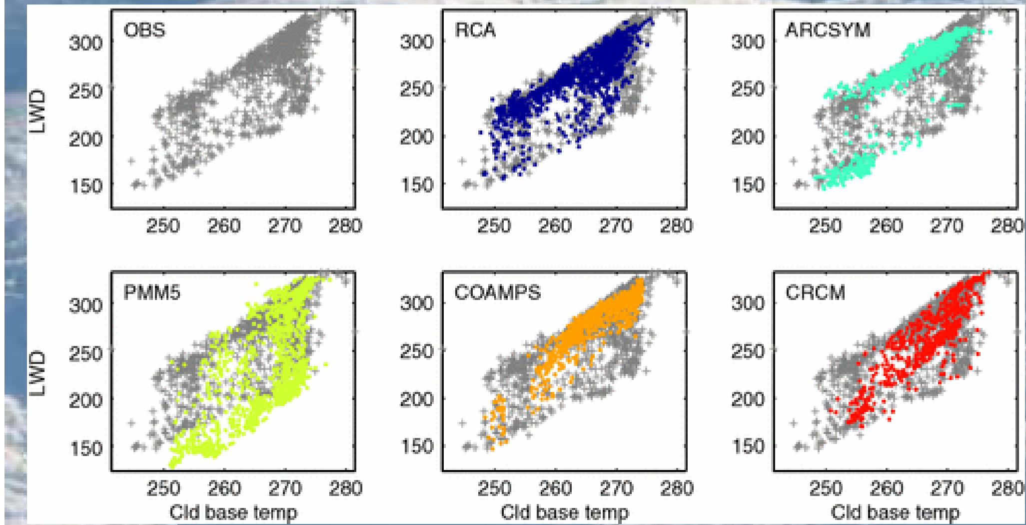
CloudSat



CloudSat screened for:
-Uncertainty < 200%
-Average liquid Reff
through the cloud depth

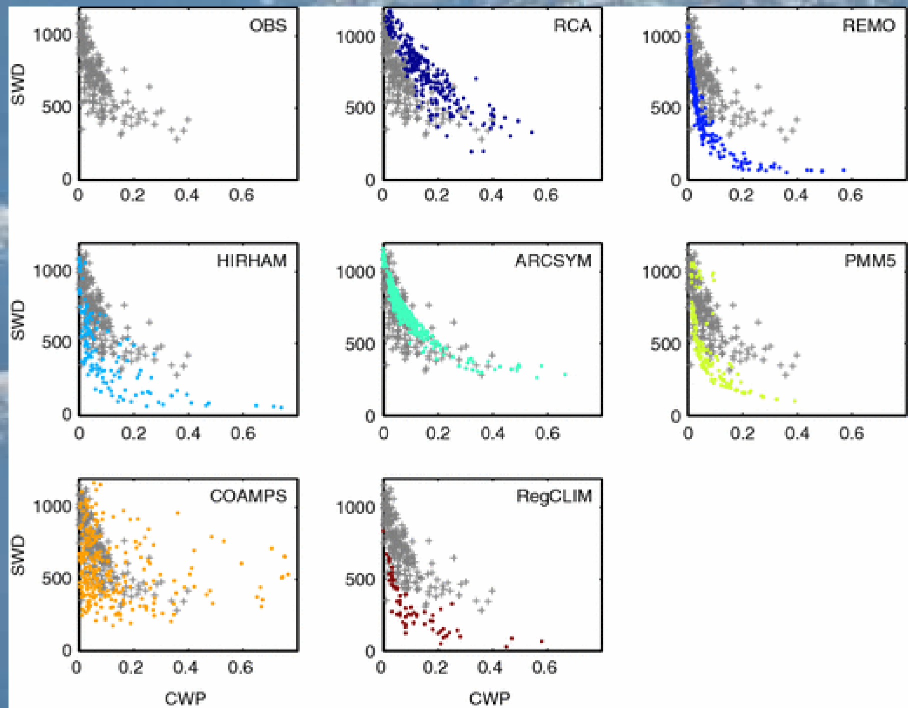
I. Ivanova SMHI

It is important to evaluate process controlling cloud-radiation interactions



Arctic SHEBA/RCM comparison

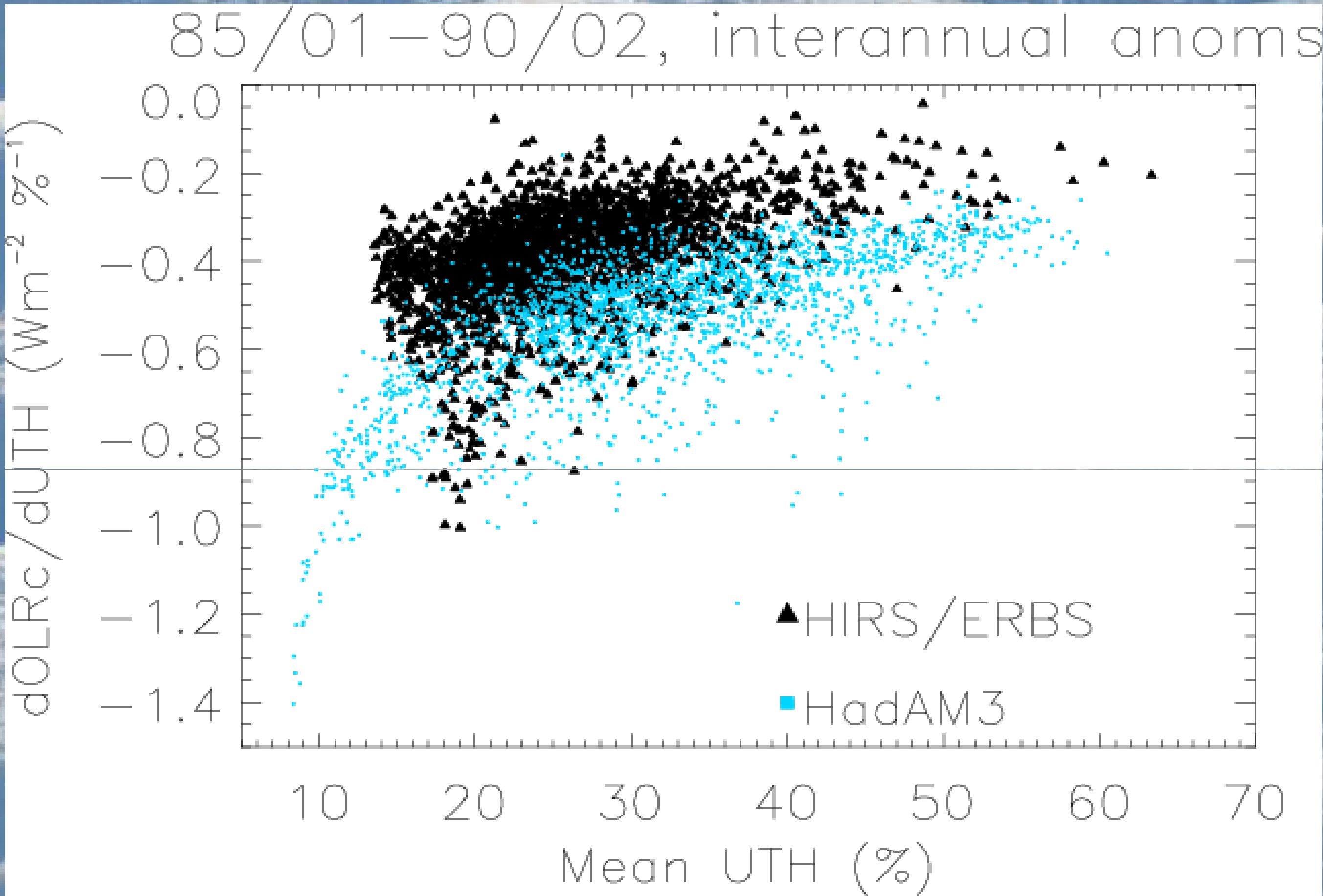
covariability between surface downwelling longwave radiation and cloud base temperature



Arctic SHEBA/RCM comparison

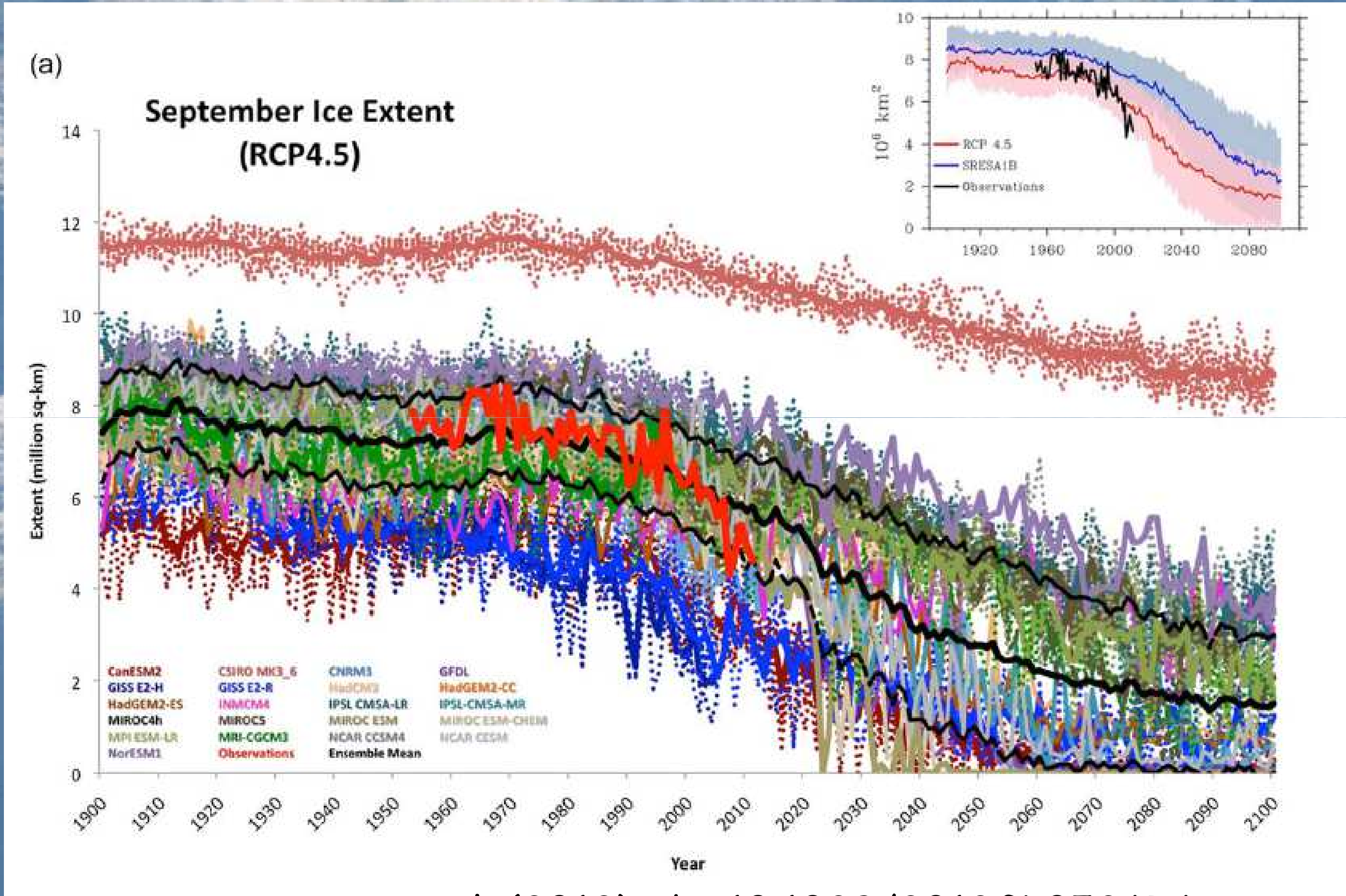
covariability between surface Downwelling solar radiation and Cloud liquid water path (CWP)

Sensitivity of clear sky OLRc to Upper Tropospheric Humidity

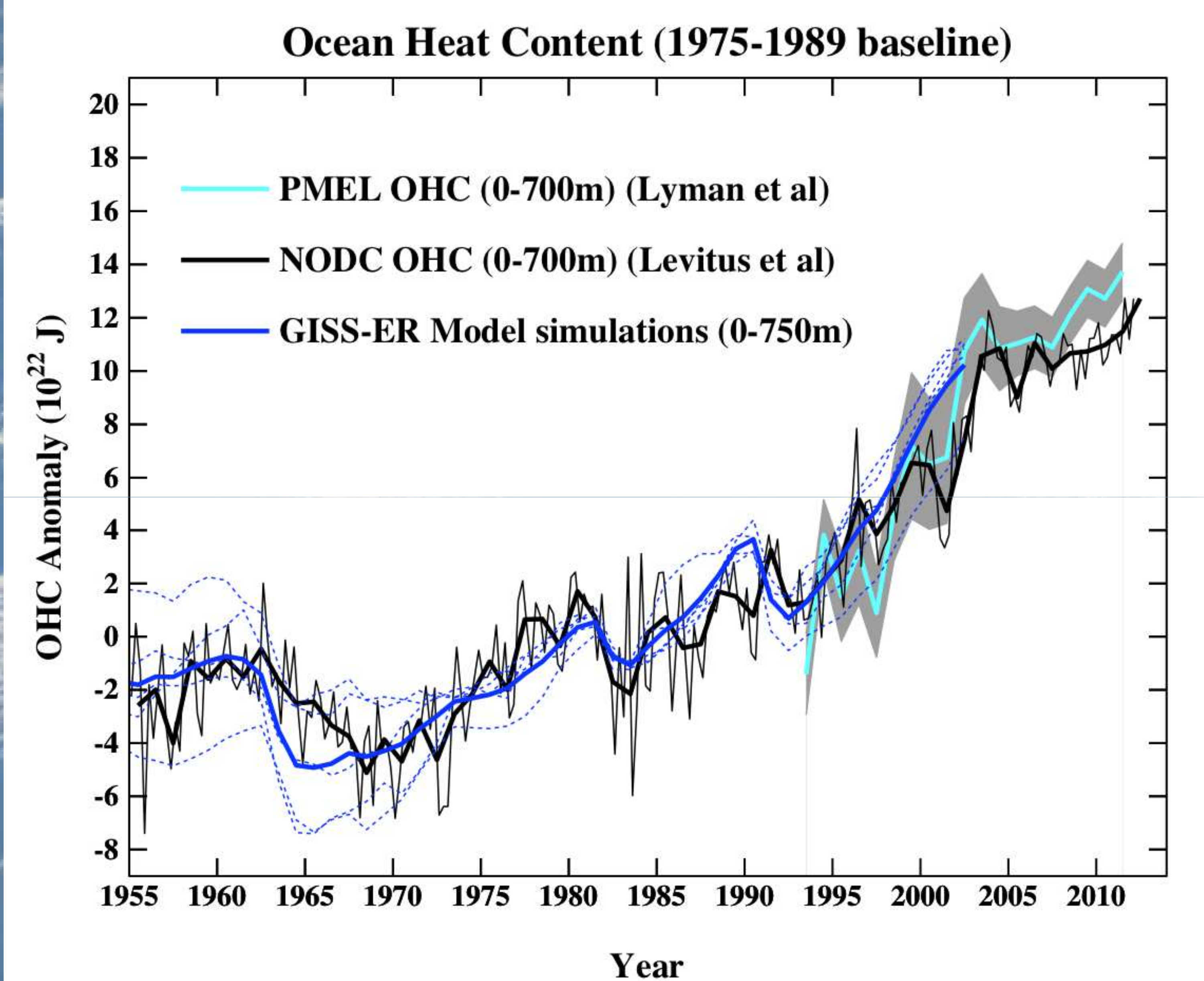


Reduction in OLRc for a 1% increase in UTH is larger where the mean UTH is low (e.g ~4Wm^{-2} for a 10% increase)

Trends in simulated and observed sea ice extent



Stroeve et al. (2012), doi:10.1029/2012GL052676



Ocean Heat Content (1975-1989 baseline)
PMEL OHC (0-700m) (Lyman et al)
NODC OHC (0-700m) (Levitus et al)
GISS-ER Model simulations (0-750m)
OHC Anomaly (10^{22} J)
Year
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

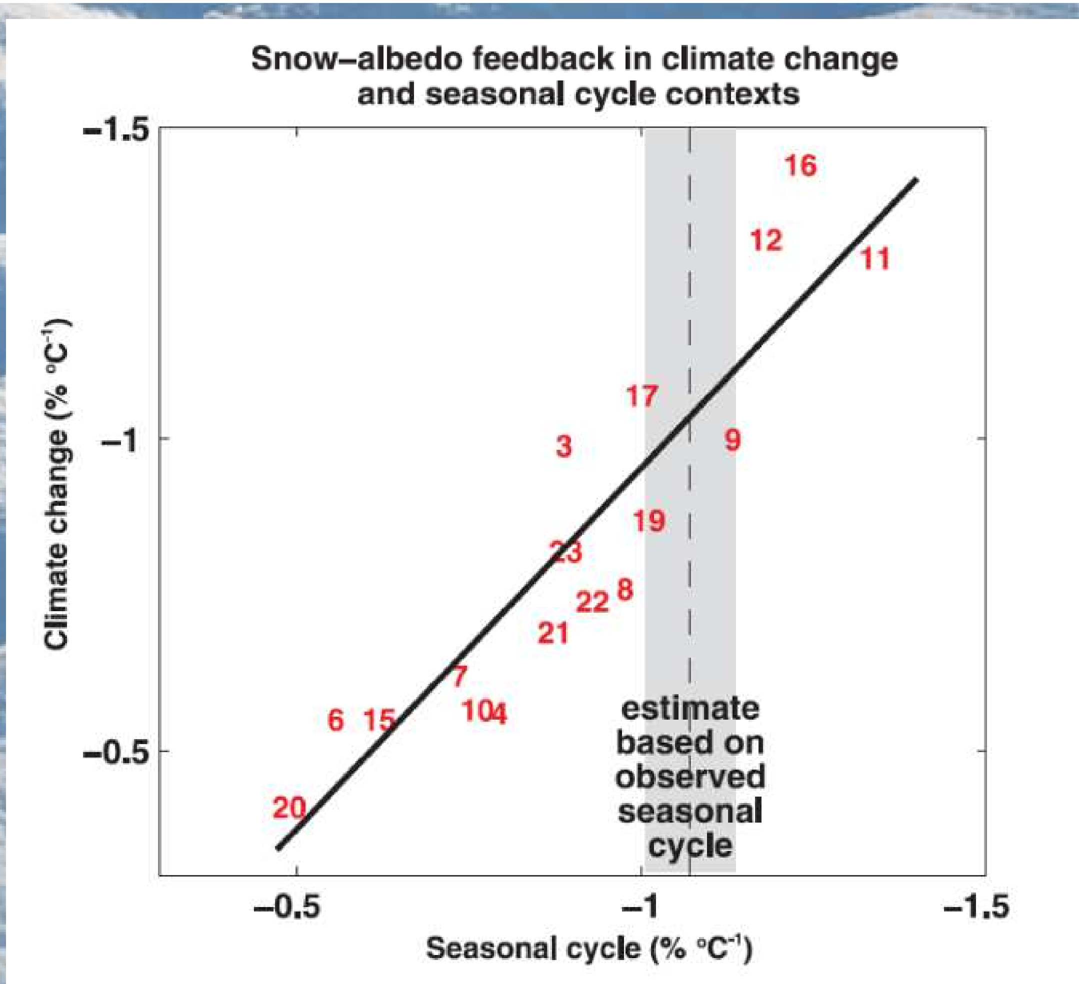
Emergent Constraints

We wish to find constraints on potential changes in the Earth System over the next century. The observational data records we have relate to shorter timescales.

- Emergent Constraint : a relationship between an Earth System sensitivity to anthropogenic forcing and an observable (or already observed) feature of the ES.
- Emergent because it emerges from an ensemble of ESMs
- Constraint because it allows an observational constraint on estimates of the ES sensitivity in the real world.

After P.Cox et al. 2012

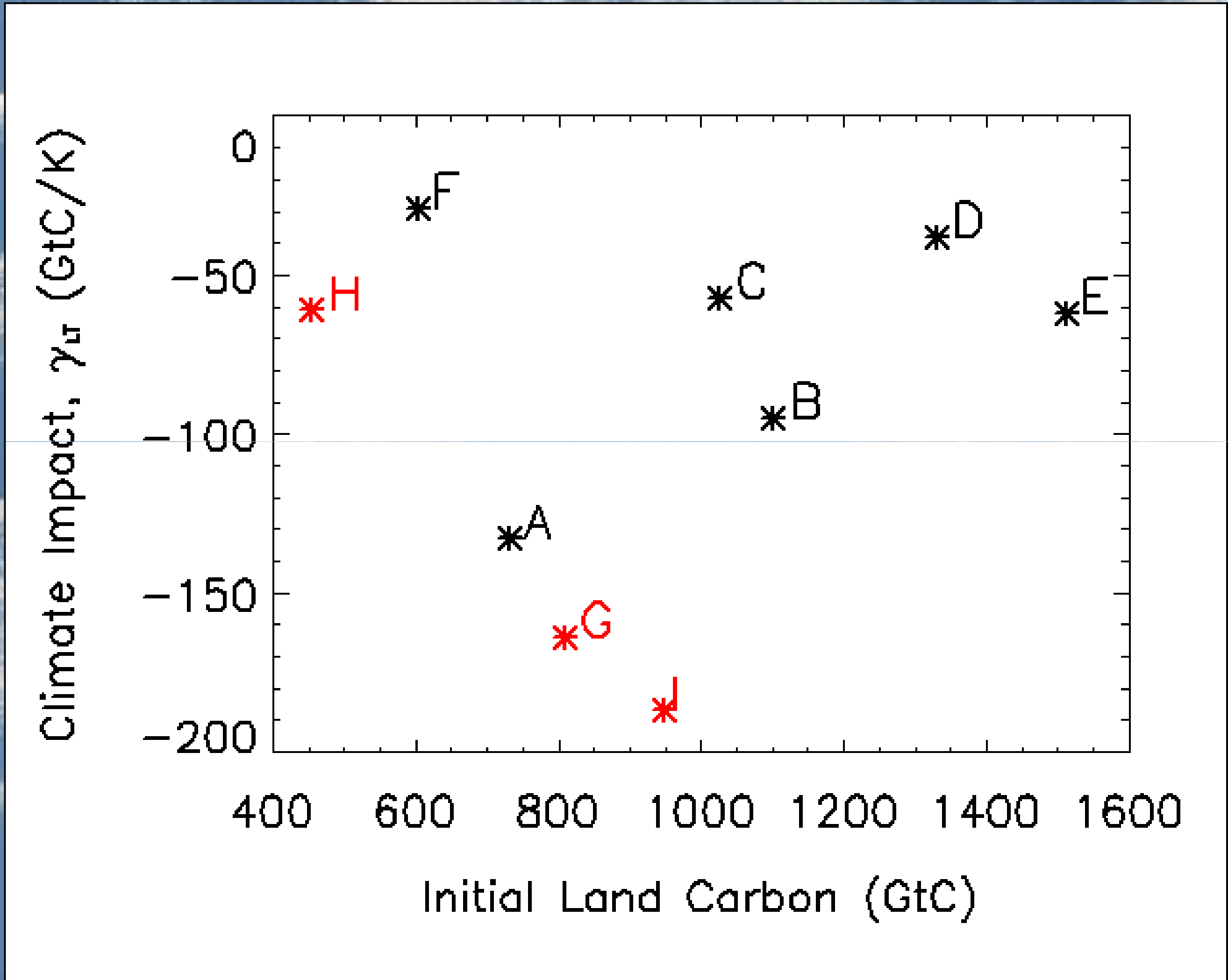
An example of an Emergent Constraint



Sensitivity of the seasonal cycle of fractional snow cover to surface temperature in GCMs strongly correlated with amplitude of snow-albedo feedback in climate change simulations with the same GCMs

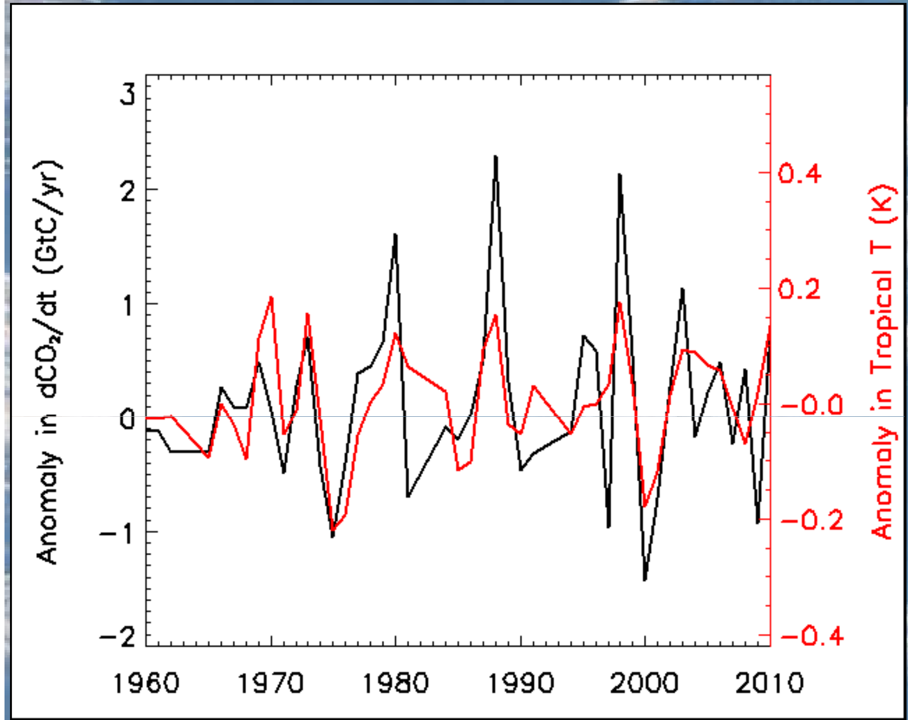
Hall & Qu (2006)

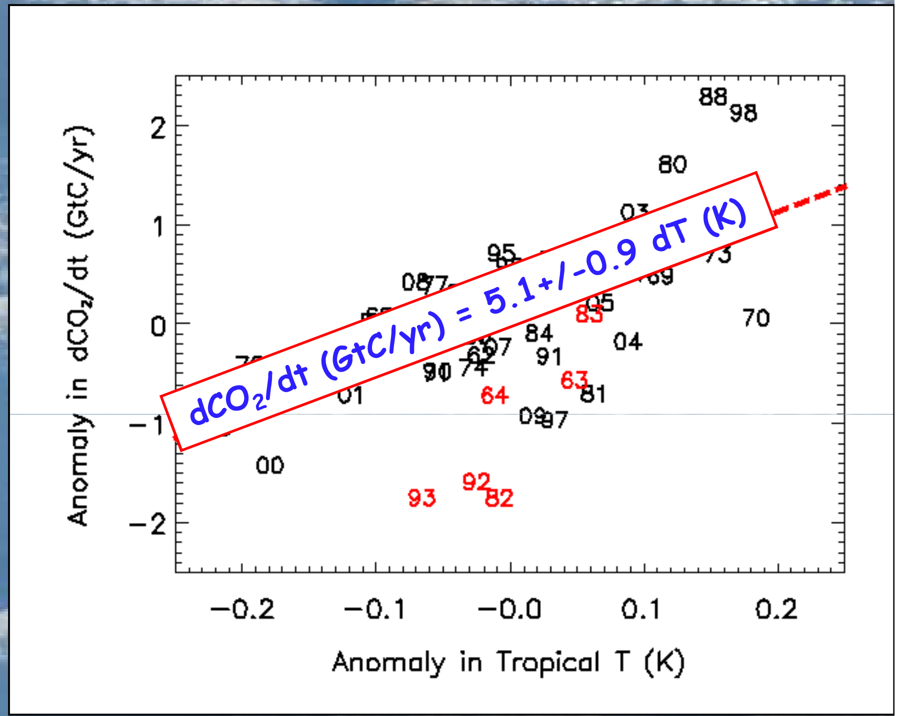
Control climate Carbon Content: Poor Predictor of future sensitivity of land carbon uptake/release to climate change: Can we do better ?



Cox et al. Nature 2013

Relationship between annual CO_2 Growth-rate and annual Tropical Temperature anomalies - Observations

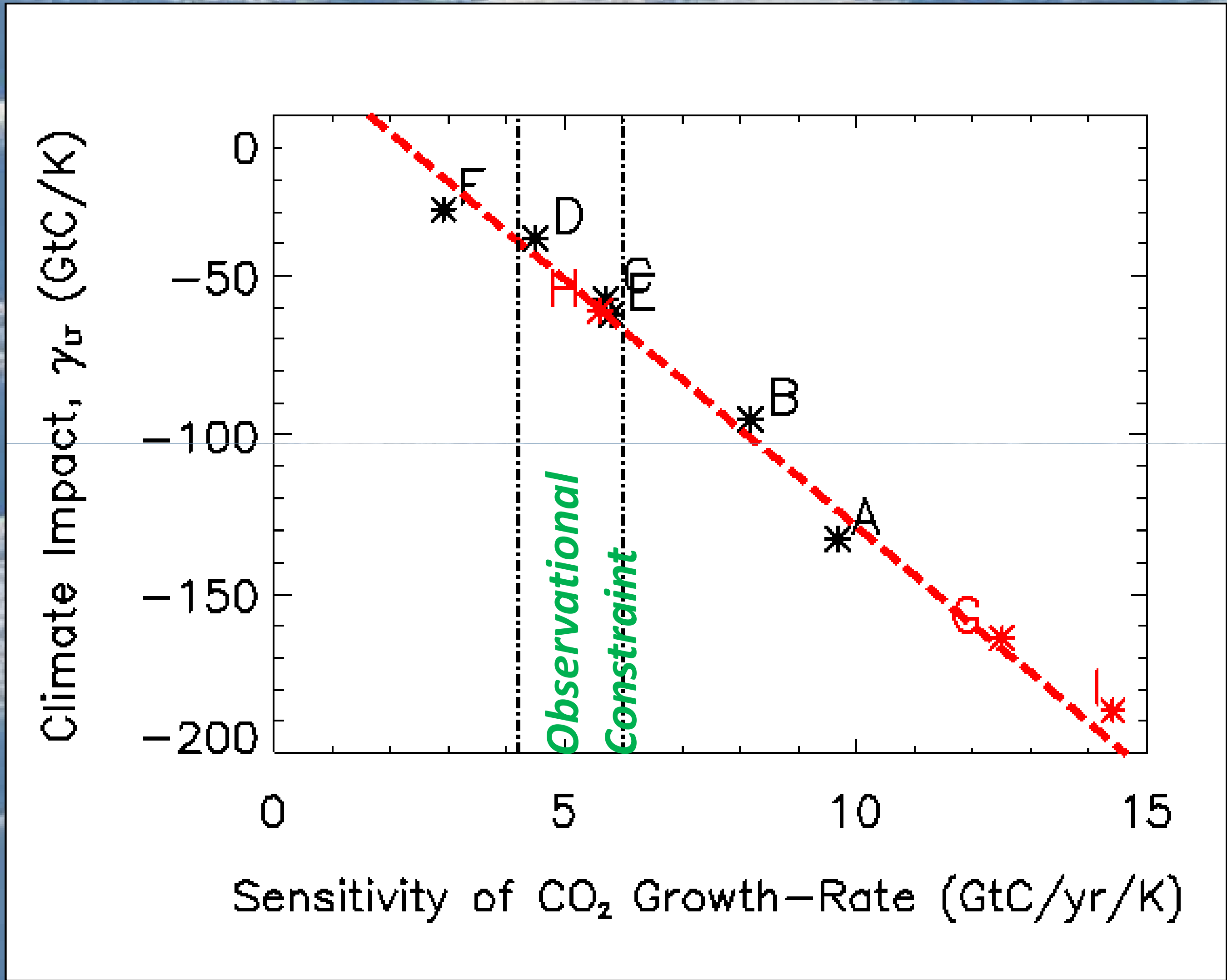




Correlation between annual growth rate in tropical CO_2 (proxy For tropical Land uptake/release) and annual mean anomalies in tropical Temperatures Very high in all C4MIP GCMs

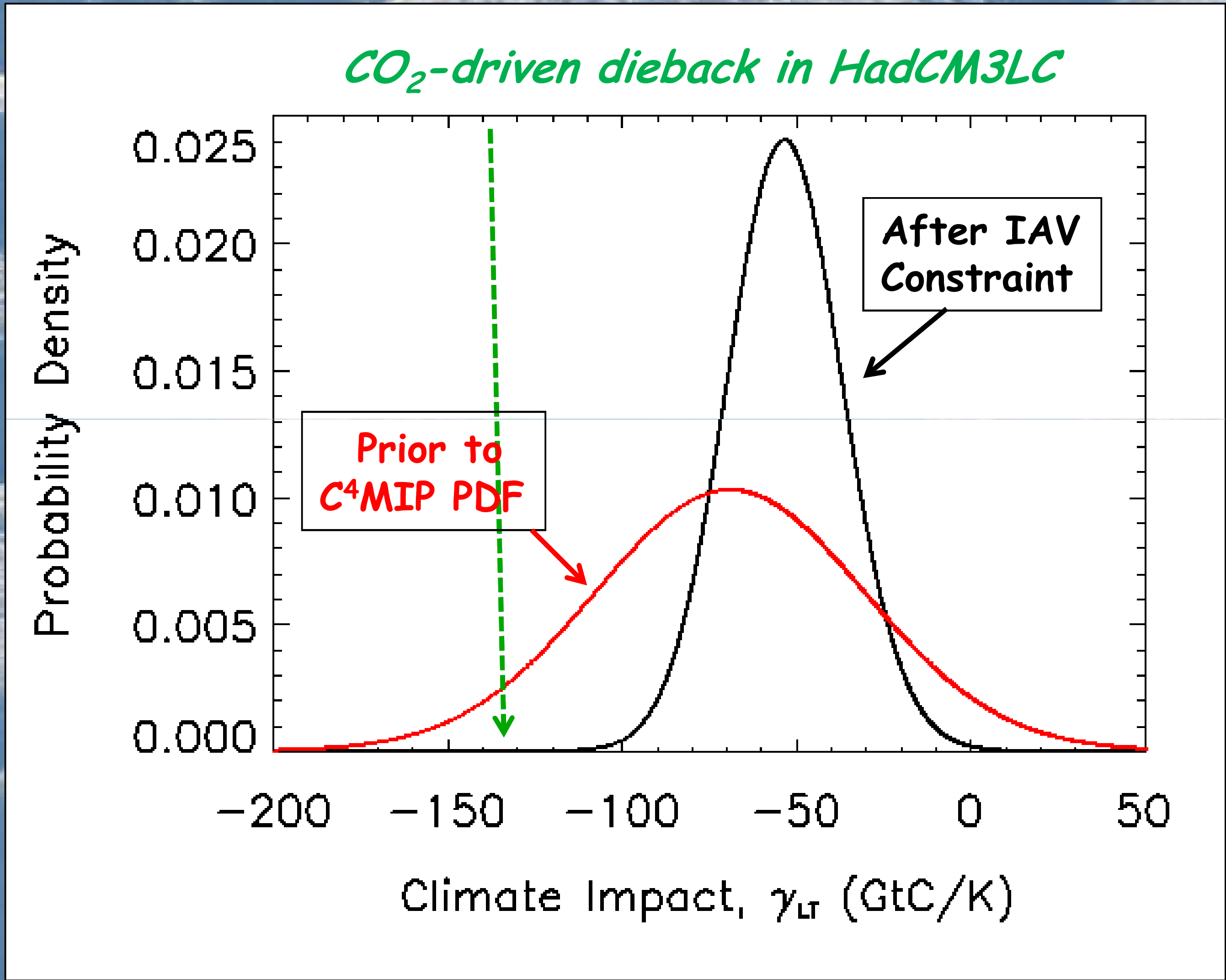
Cox et al. Nature 2013

Model IAV of dCO_2/dt – Excellent Predictor of Future Sensitivity of model land carbon uptake to climate change



Cox et al. Nature 2013

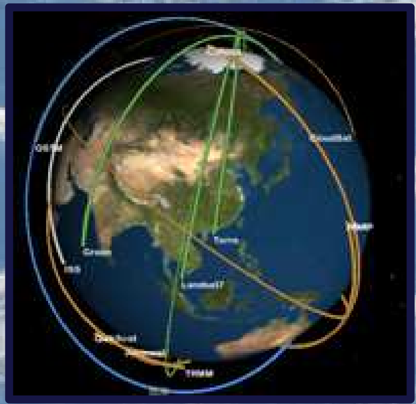
Probability Density Function for Climate Sensitivity of Tropical Forest



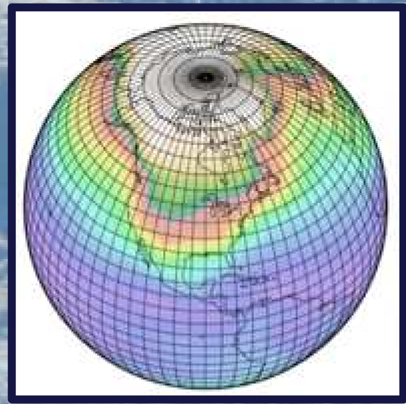
Cox et al. Nature 2013

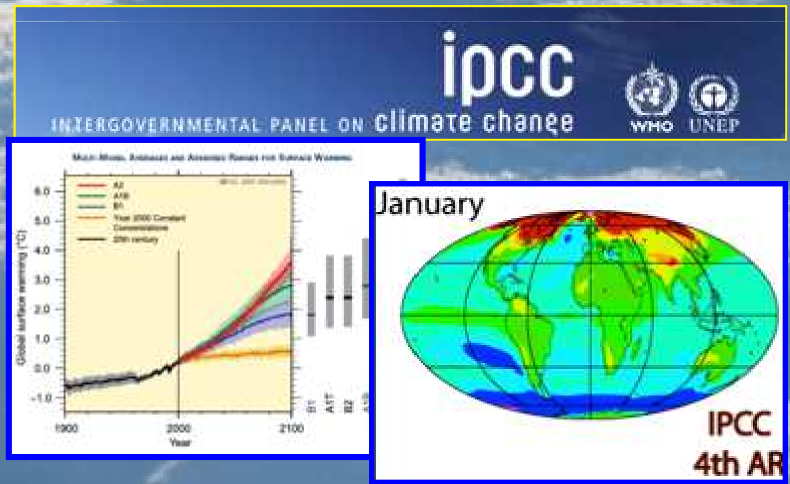

Tools for model observation comparison
Making people's lives a little easier

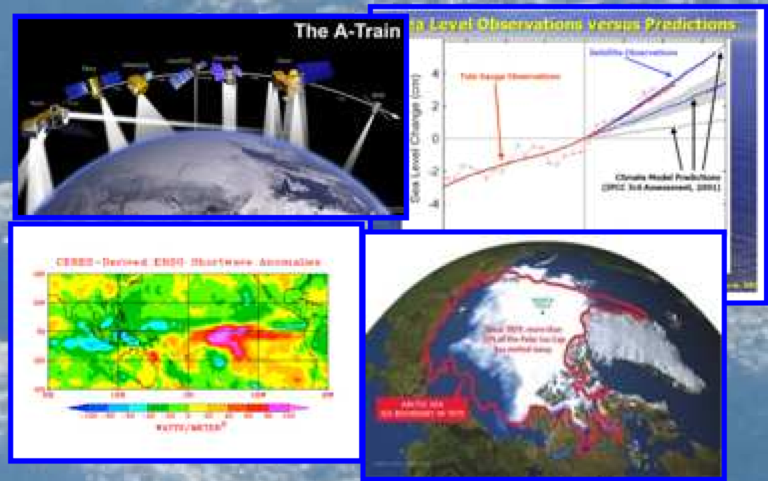
NASA-JPL: Observations for Model Intercomparison Project (obs4MIP)
Facilitating the use of Satellite Data to Evaluate Climate Models



Obs4MIPs







How to bring as much observational scrutiny as possible to the IPCC process?

How to best utilize the wealth of satellite observations for the IPCC process?

Some Basic Tenets of OSB4MIP

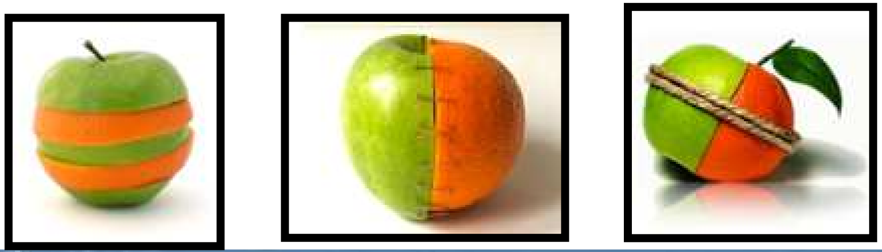
Use CMIP5 simulation protocol to guide which observations to stage in parallel to model simulations. Target: monthly mean products on 1°x1° grid

Convert Satellite Observations to be formatted exactly same as CMIP Model output: CMOR output, NetCDF files, CF Convention Metadata

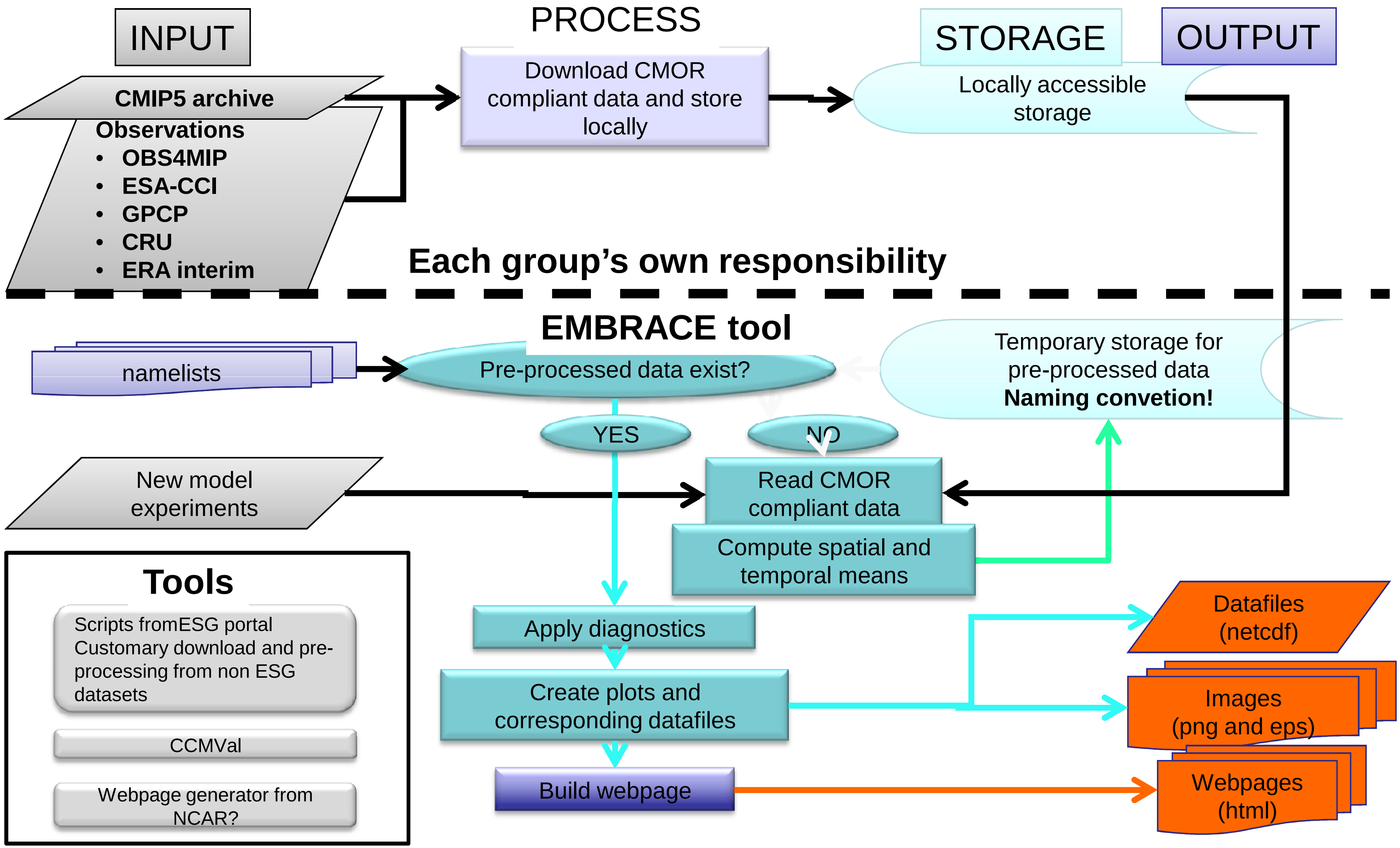
Includes a 6-8 page Technical Note describing strengths/weaknesses, uncertainties, dos/don'ts regarding interpretations comparisons with models. (at graduate student level)

Hosted side by side on the ESG with CMIP5 model data.

Advertise availability of observations for use in CMIP5 analysis.



EMBRACE FP7 evaluation tool (*under development: See V. Eyring talk Weds*)



Observations are fundamental for improving Earth System Models

Process understanding ….. model development
Global Coverage ………… model evaluation
Homogeneous over time …. model evaluation,
…. detection & attribution / monitoring

High accuracy needed, uncertainty estimates & guidance required

Ease of use & continuous modeler/observationalist dialogue essential