Tuning the Planet Simulator Earth system Model of Intermediate Complexity for climate sensitivity studies

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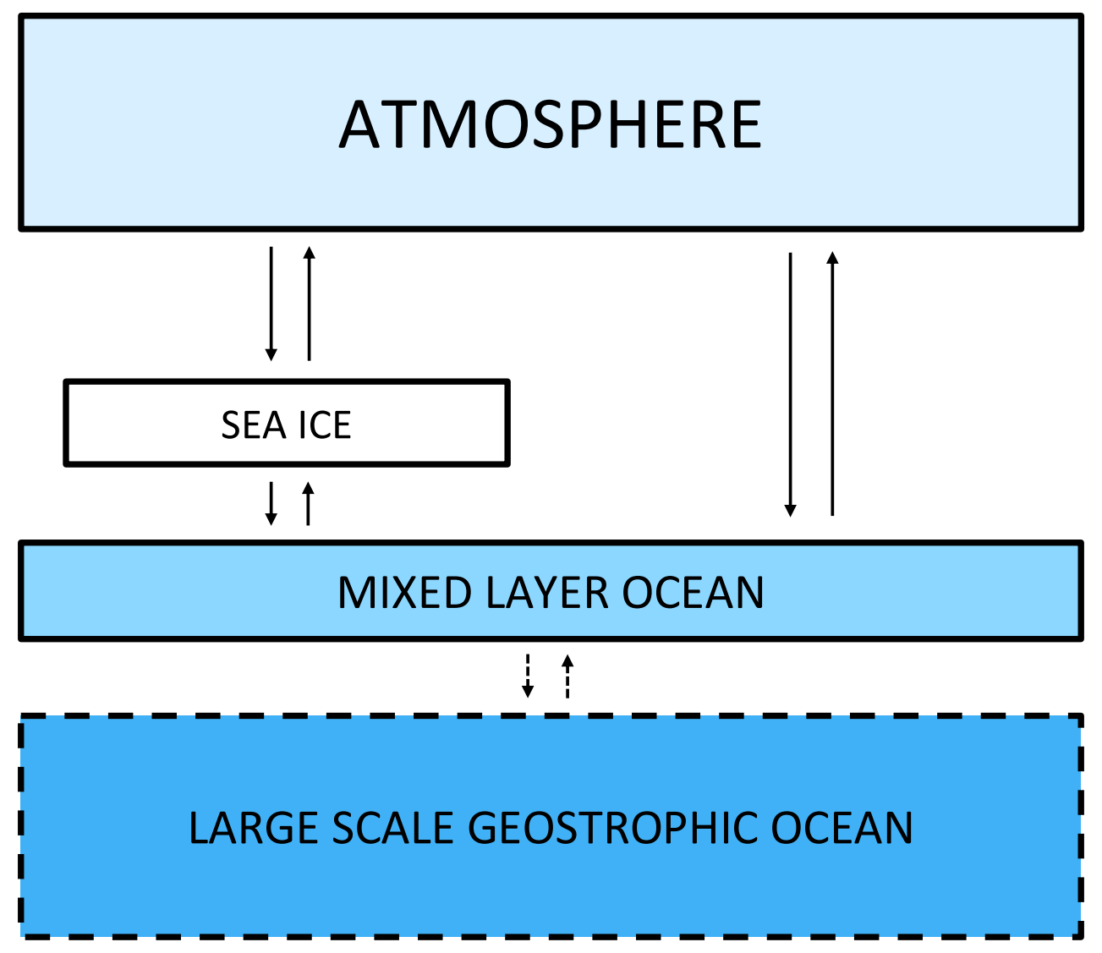
A state-of-the-art Earth system Model of Intermediate Complexity, the **Planet Simulator (PlaSim)**, is used to determine its **equilibrium climate sensitivity**, comparing it with results from more complex models. Fixed-forcing runs have been performed coupling the atmospheric model of PlaSim with a simple Mixed Layer (ML) ocean model and with the Large Scale Geostrophic (LSG) oceanic circulation model, at two horizontal resolutions (*600 km* and *300 km*). The study has required a preliminary **tuning** of specific model parameters, under different model configurations, such as the horizontal and vertical oceanic diffusion coefficient, in order to identify the set-up which better reproduced the characteristics of present climate, by comparing the model's outputs to satellite and reanalysis datasets. Sensitivity experiments with doubled CO_2 concentrations were run, in order to assess the equilibrium climate sensitivity of the model. In the case of PlaSim coupled with a Mixed Layer ocean, a quite high climate sensitivity of **6.3 K** is found, while when PlaSim is coupled with LSG the value is **4.3 K**. The latter is more in agreement with the range of climate sensitivity values which are known from the literature and other models and, in particular, found in the latest IPCC Fifth Assessment Report. The simplified and highly parameterized form of the PlaSim EMIC makes it easier to identify and disentangle fundamental processes and interactions at work, making this model also a suitable tool to study the characteristics of the transitions occurring in one or more Earth system components in presence of **tipping points** and to identify possible **early warning signals**.

(1) The Planet Simulator model

PlaSim is an Earth system Model of Intermediate Complexity developed at the University of Hamburg (*Fraedrich et al., 2005*).

- The dynamical core is a simplified General Circulation Model, the **Portable University Model of Atmosphere (PUMA)**
- The oceanic component can be prescribed by sea surface temperature climatology, introduced by a simple **Mixed Layer (ML) ocean model** or coupled as a dynamical model such as the **Large Scale Geostrophic (LSG) Ocean Circulation Model** (*Maier-Reimer et al., 1993*)
- Sea ice distributions can either be prescribed by climatology or simulated by a **thermodynamic sea ice model**

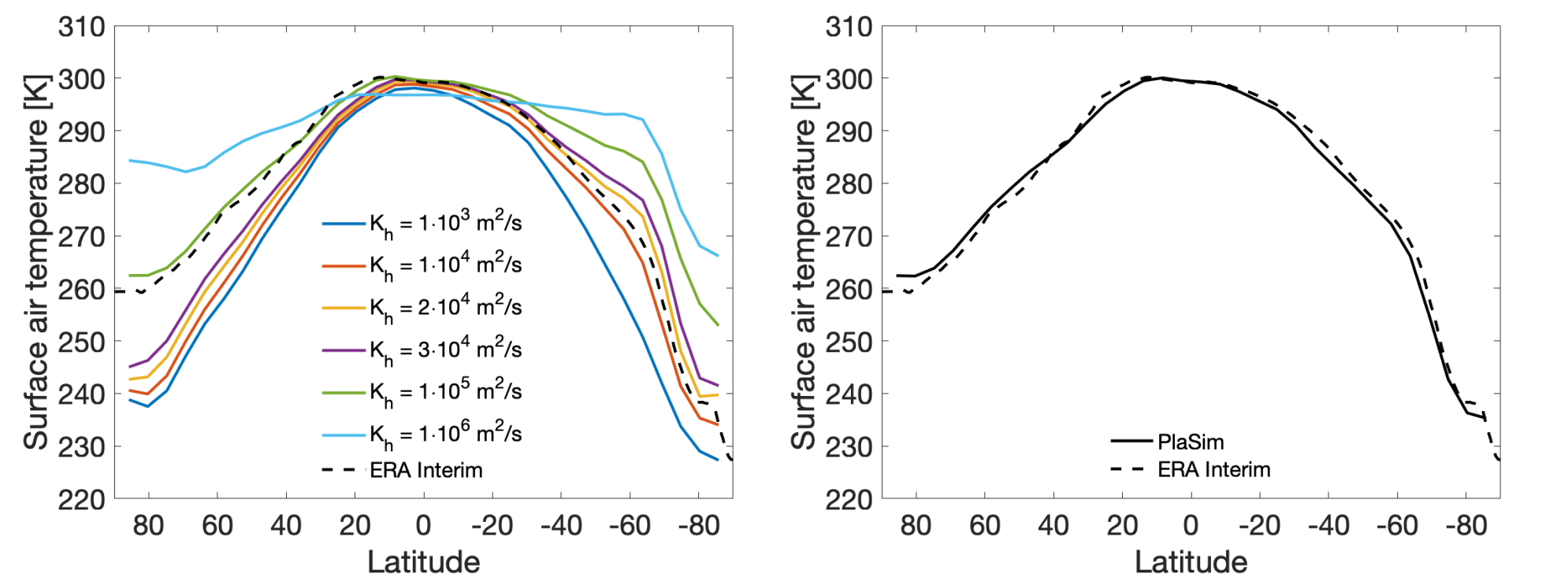

ATMOSPHERE
SEA ICE
MIXED LAYER OCEAN
LARGE SCALE GEOSTROPHIC OCEAN

(2) Tuning

✓ perennial runs (CO_2 = 354 ppm)
✓ dynamic sea ice

T21 + ML

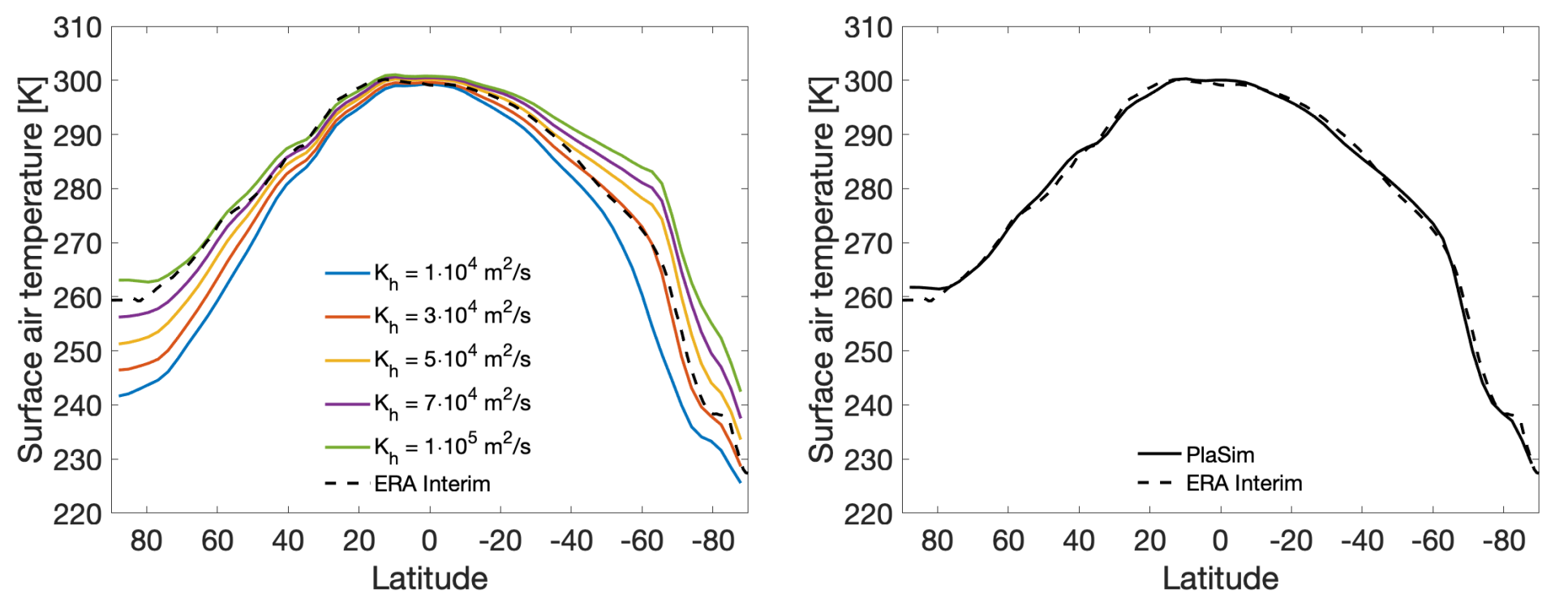
Mixed Layer ocean
T21 (~ 600 km) resolution
Tuned parameter:
horizontal oceanic diffusion coefficient K_h



K_h = 1·10⁵ m²/s (Northern hemisphere)
K_h = 1·10⁴ m²/s (Southern hemisphere)

T42 + ML

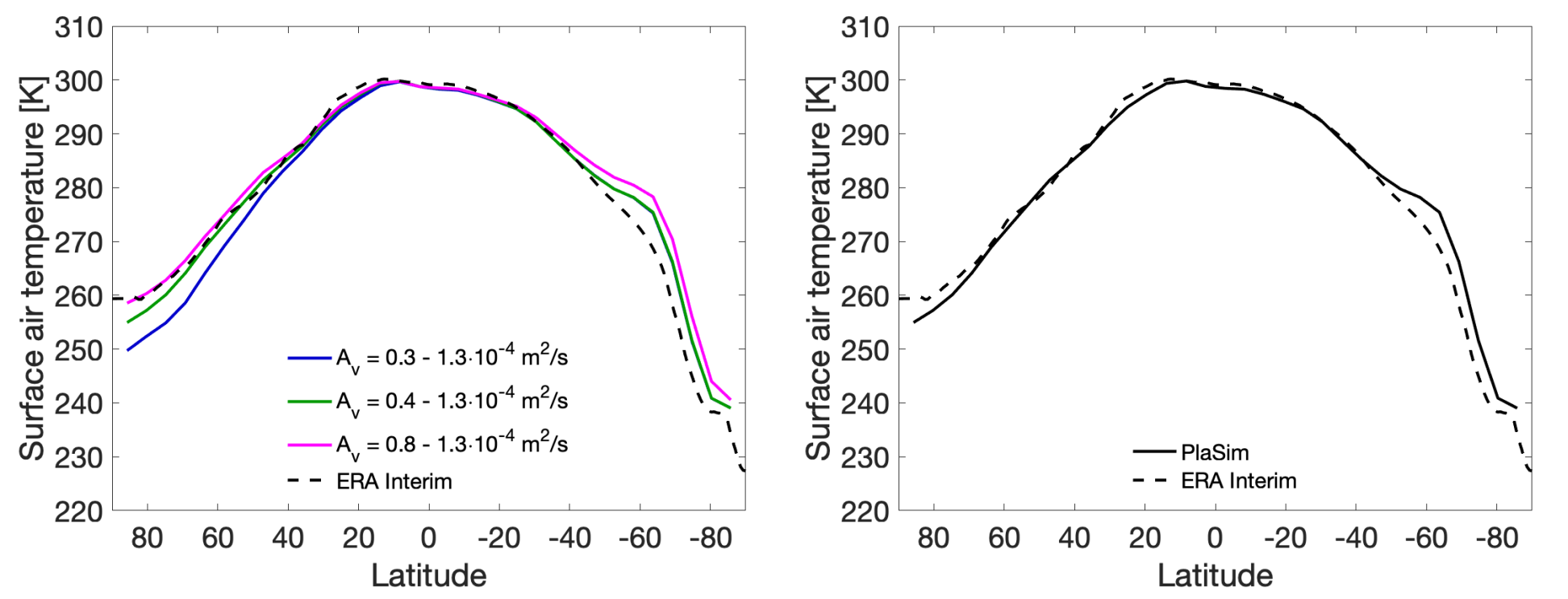
Mixed Layer ocean
T42 (~ 300 km) resolution
Tuned parameter:
horizontal oceanic diffusion coefficient K_h



K_h = 1·10⁵ m²/s (Northern hemisphere)
K_h = 3·10⁴ m²/s (Southern hemisphere)

T21 + LSG

Large Scale Geostrophic ocean
T21 (~ 600 km) resolution
Tuned parameter:
vertical oceanic diffusion coefficient A_v

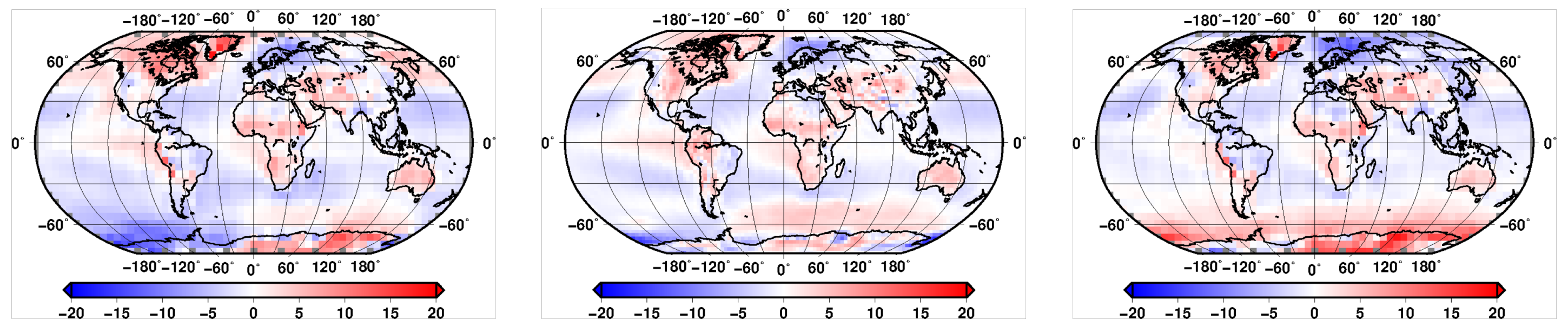


A_v from **0.4·10⁻⁴ m²/s** (top) to **1.3·10⁻⁴ m²/s** (bottom)
to reduce the Southern Ocean bias

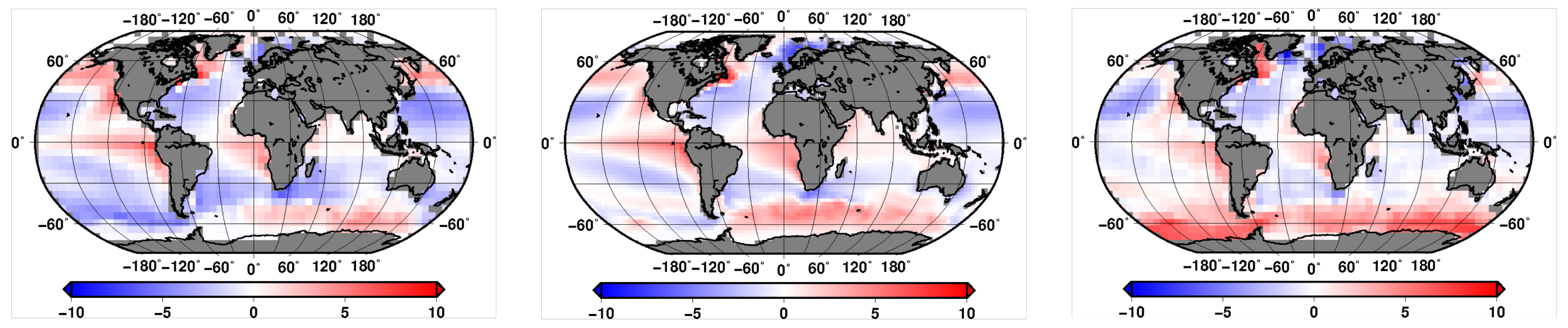
(3) Simulated climate

T21 + ML | T42 + ML | T21 + LSG

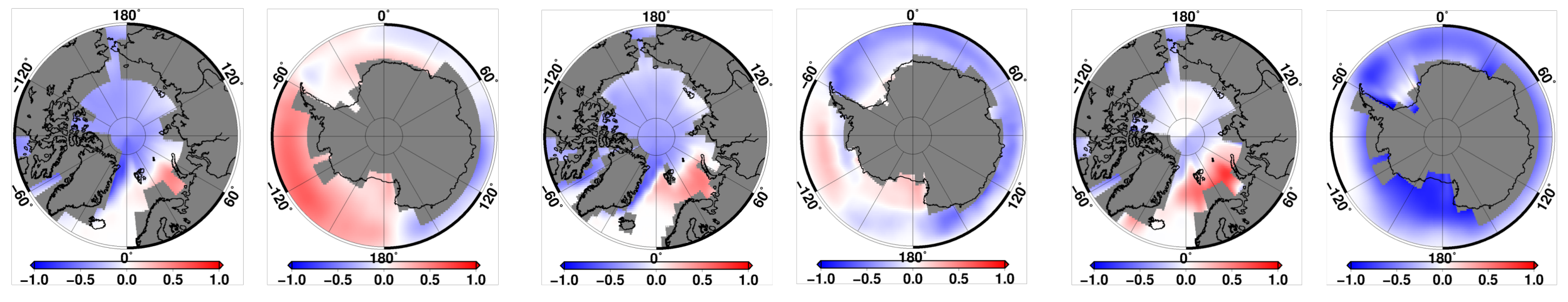
Surface air temperature anomaly [K] with respect to the ERA Interim reanalysis dataset (2005-2015 average) (*Dee et al., 2011*)



Sea surface temperature anomaly [K] with respect to the HadISST dataset (2005-2015 average) (*Titchner & Rayner, 2014*)

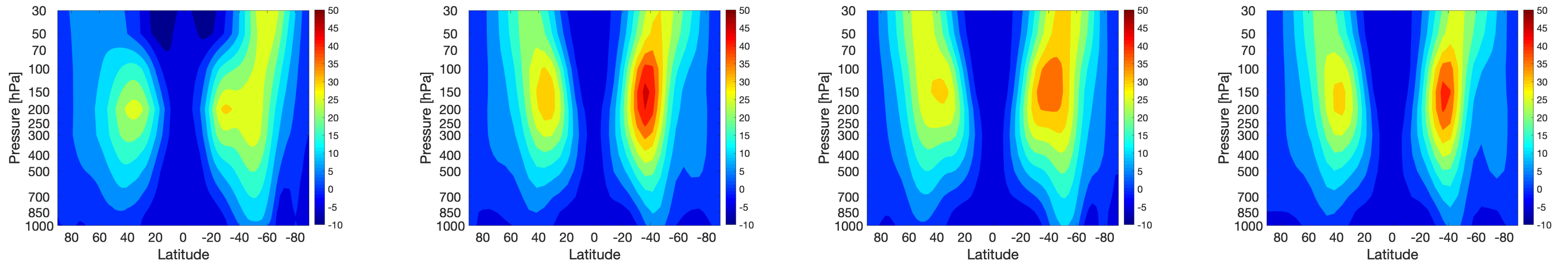


Sea ice cover anomaly with respect to the HadISST dataset (2005-2015 average) (*Titchner & Rayner, 2014*)



Mean zonal wind [m/s]

ERA Interim (1990-2009 average)



(4) Equilibrium climate sensitivity and feedback parameter

EQUILIBRIUM CLIMATE SENSITIVITY (ECS)

Equilibrium (steady state) change in the annual global mean surface temperature following a **doubling** of the atmospheric equivalent carbon dioxide (CO_2) concentration (*IPCC*)

Range of ECS in *CMIP5* models:
2.1 – 4.7 K (*Andrews et al., 2012*)

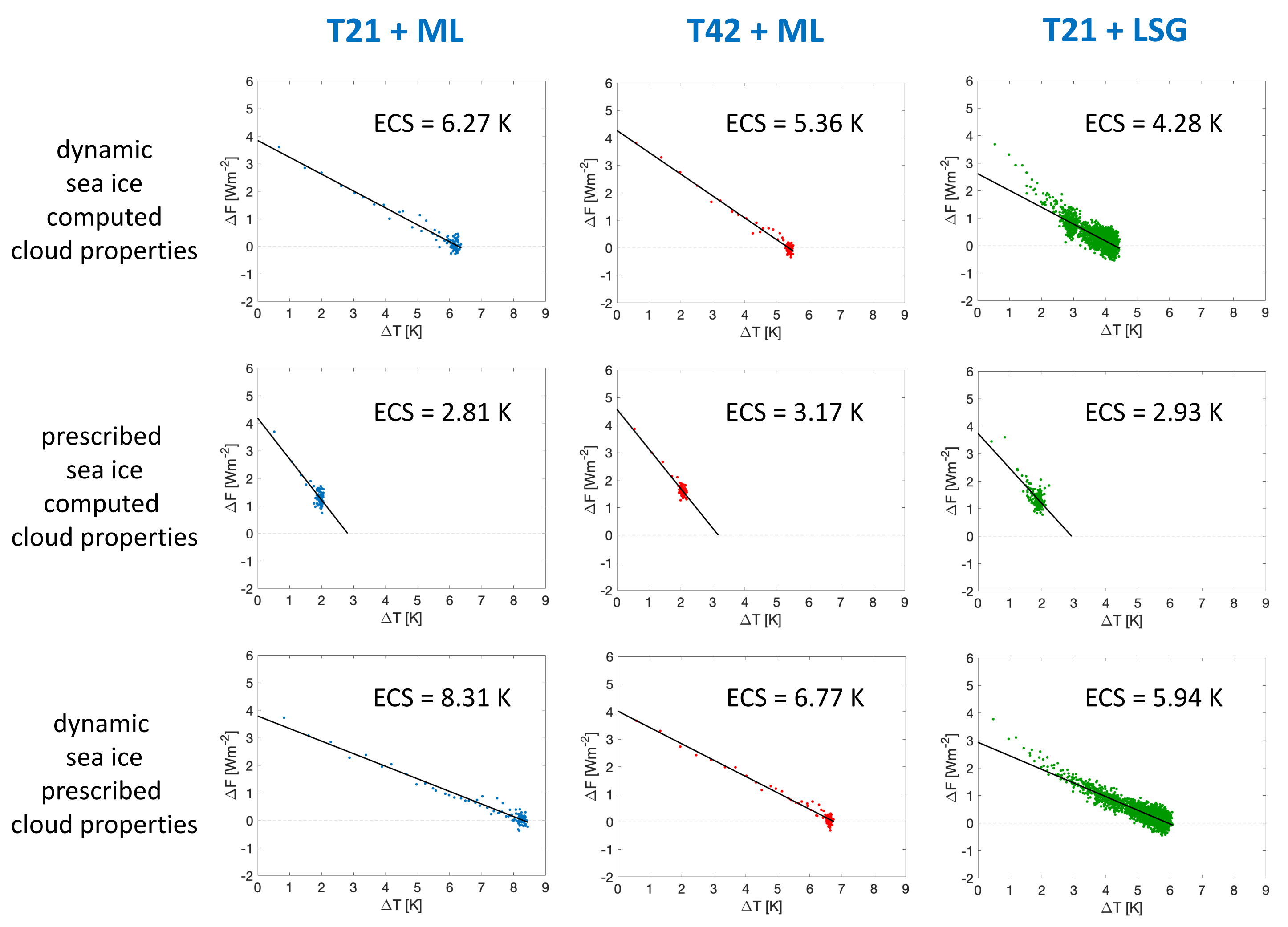
Feedback parameter λ

$$\Delta F = -(\lambda_I + \lambda_C + \lambda_X)\,\Delta T$$

ΔF = radiative forcing
λ_I = sea ice albedo feedback par.
λ_C = cloud properties feedback par.
λ_X = other feedback parameters
ΔT = equilibrium change in T

ECS and λ calculated as in *Gregory et al. (2004)*

✓ CO_2 doubling experiments (285 ppm → 570 ppm)
✓ dynamic or prescribed sea ice
✓ computed or prescribed cloud properties



T21 + ML	T42 + ML	T21 + LSG
$\lambda_I = -0.88\ Wm^{-2}K^{-1}$	$\lambda_I = -0.64\ Wm^{-2}K^{-1}$	$\lambda_I = -0.67\ Wm^{-2}K^{-1}$
$\lambda_C = 0.15\ Wm^{-2}K^{-1}$	$\lambda_C = 0.21\ Wm^{-2}K^{-1}$	$\lambda_C = 0.12\ Wm^{-2}K^{-1}$
$\lambda_X = 1.34\ Wm^{-2}K^{-1}$	$\lambda_X = 1.23\ Wm^{-2}K^{-1}$	$\lambda_X = 1.16\ Wm^{-2}K^{-1}$
$\lambda_{TOT} = 0.61\ Wm^{-2}K^{-1}$	$\lambda_{TOT} = 0.80\ Wm^{-2}K^{-1}$	$\lambda_{TOT} = 0.61\ Wm^{-2}K^{-1}$

(5) Energy balance

✓ perennial runs (CO_2 = 354 ppm)
✓ dynamic sea ice

Simulated and observed energy fluxes (Wm^{-2}) at the top of the atmosphere and at the surface

	T21 + ML	T42 + ML	T21 + LSG	Stephens et al. (2012)
Top net shortwave	231.6	235.9	233.0	240.2
Top net longwave	-232.3	-236.0	-233.1	-239.7
Top budget	-0.8	-0.1	-0.2	0.6
Surface net shortwave	163.2	169.4	163.9	165
Surface net longwave	-62.8	-62.3	-62.9	-52.1
Sensible heat flux	-18.9	-20.8	-18.3	-24
Latent heat flux	-81.4	-86.0	-82.1	-88
Surface budget	-0.6	-0.2	0.1	0.6
Top-surface budget	**-0.2**	**0.1**	**-0.3**	**0**

Please notice that the estimates from *Stephens et al. (2012)* are only reported for reference, since we are comparing **equilibrium model results** with the **current observed transient**.

(6) Conclusions

The tuning of PlaSim with the ML ocean suggests the use of two different values for the oceanic horizontal diffusion coefficient, **10⁵ m²/s** in the Northern hemisphere and **10⁴ m²/s** (T21) or **3·10⁴ m²/s** (T42) in the Southern hemisphere. The tuning of the coupled PlaSim-LSG model recommends an oceanic vertical diffusion ranging from **0.4·10⁻⁴ m²/s** (top) to **1.3·10⁻⁴ m²/s** (bottom). The climatic variables are well simulated but there is a warm bias in the Southern Ocean and the Antarctic sea ice is underestimated using T21 + LSG. The ECS is estimated from CO_2 doubling experiments and is generally higher than the range of values found in the literature. Sea ice plays a fundamental role in determining the ECS. The λ parameters are indicators of the contribution of different **feedback mechanisms**.

Bibliography

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