Experiences from tuning and high-resolution climate modelling with EC-Earth 3

EC EARTH 3

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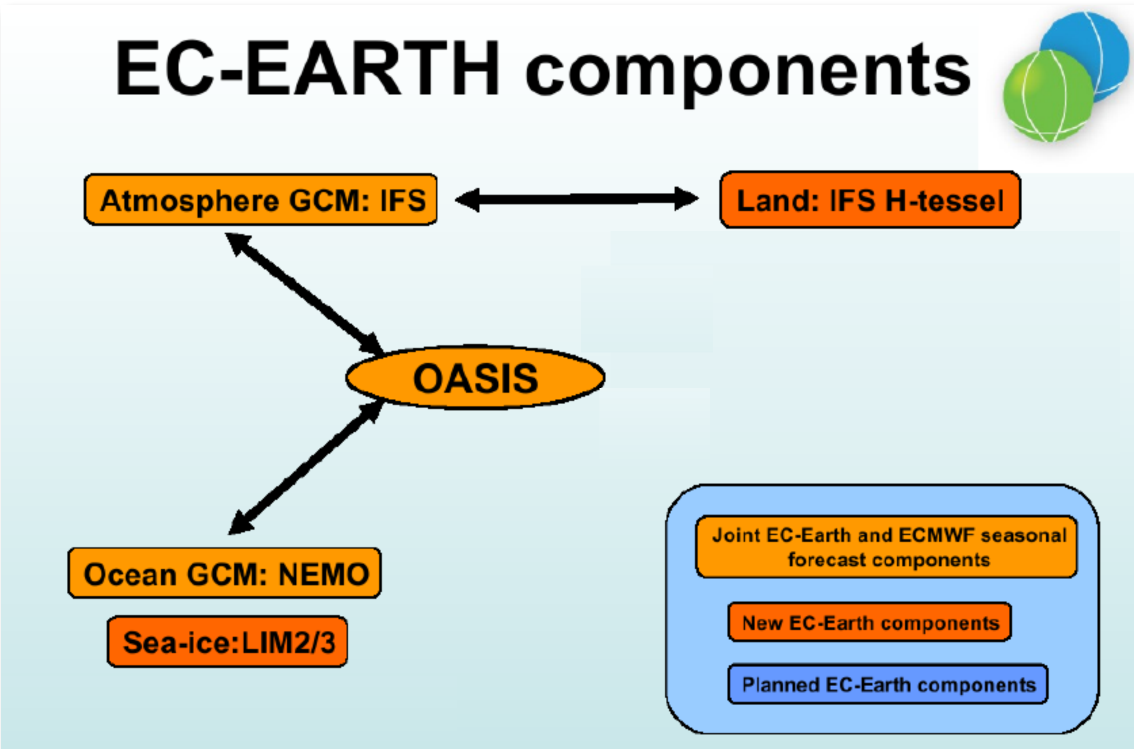
ISAC

EC EARTH3 is a Global Climate Model

ECMWF IFS atmosphere (cy 36r4)+ H-Tessel Land/veg module
+ NEMO 3.6 ocean (ORCA1 L) (will be 3.6) + LIM 3 sea ice



Integrated
Forecast
System
ECMWF

NEMO

Louvain La Neuve Ice Model
LIM3 (ECE v3)

H-Tessel Land-surface model

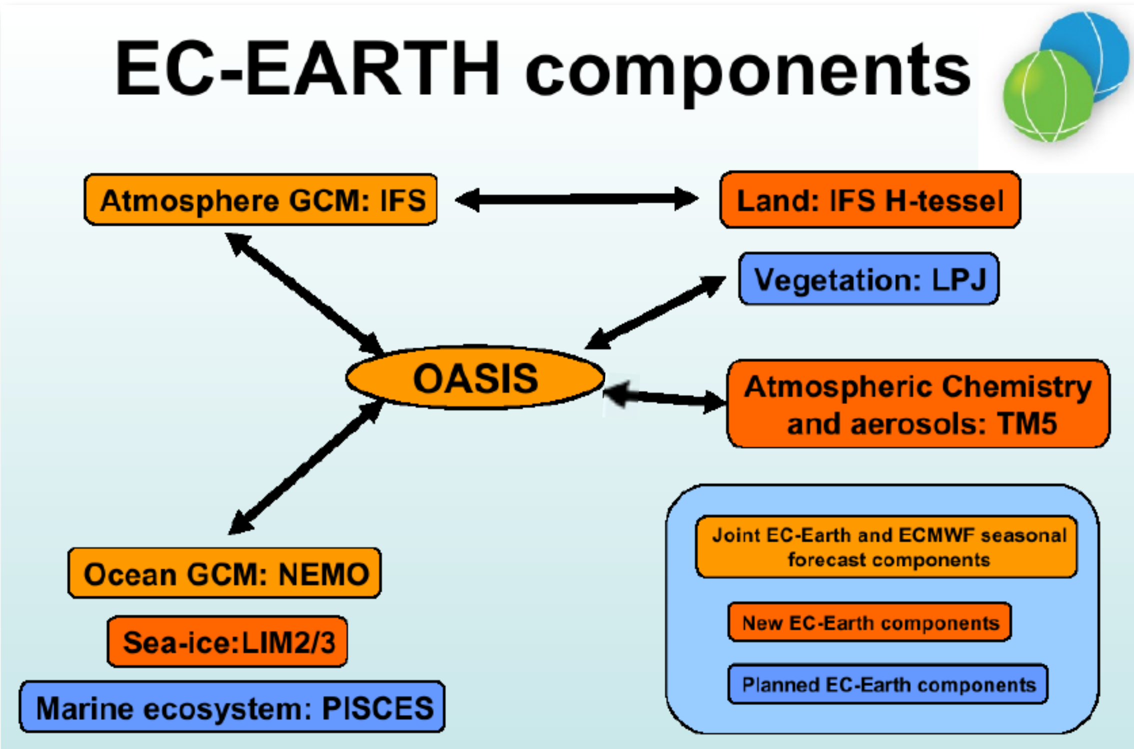
EC-Earth v3 under development since 2009

(release of EC-Earth 3.0 on 19/10/12)

Ref.: Hazeleger, W. et al., 2009. EC-Earth: A Seamless Earth System Prediction Approach in Action. *Bull. Amer. Meteor.*

EC-EARTH3 is an Earth-System Model

ECMWF IFS atmosphere (cy 36r4)+ H-Tessel Land/veg module
+ NEMO 3.6 ocean (ORCA1 L) (will be 3.6) + LIM 3 sea ice + LPJ-GUESS DGVM
+ TM5 chemistry/aerosols (6°x4° / 3°x2°) + PISCES (biogechemistry)



Integrated Forecast System ECMWF

NEMO

Louvain La Neuve Ice Model LIM3 (ECE v3)

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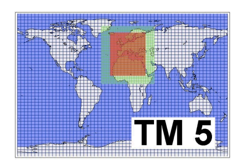

TM5 atmospheric chemistry and transport model

LPJ-Guess dynamic vegetation

Ref.: Hazeleger, W. et al., 2009. EC-Earth: A Seamless Earth System Prediction Approach in Action. *Bull. Amer. Meteor. Soc.*

… is a consortium

The Netherlands
KNMI, Utrecht Univ., WUR, VU, SURFSARA

Ireland
MetEireann, UCD, ICHEC

Denmark
DMI, Copenhagen Univ.

Finland
FMI

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SMHI, Lund Univ., Stockholm Univ., IRV, NSC

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KIT

Belgium
UCL

From a weather model to a climate model and model tuning

- Goals of tuning → to improve:
  - **Energy:** Radiative fluxes
    (Net SFC, Net TOA, LW, SW, LHFL, SHFL, cloud forcing)
  - **Mass:** P-E and SSH changes
- Specific fields, e.g. t2m temperatures
- model variability
- Performance indices (Reichler and Kim 2008)
- Regional properties of specific fields
- Model tuning necessary for CMIP6 or other experiments with specified forcing fields

Two main target resolutions: T255L91 ORCA1 and T511L91 ORCA025

From a weather model to a climate model and model tuning

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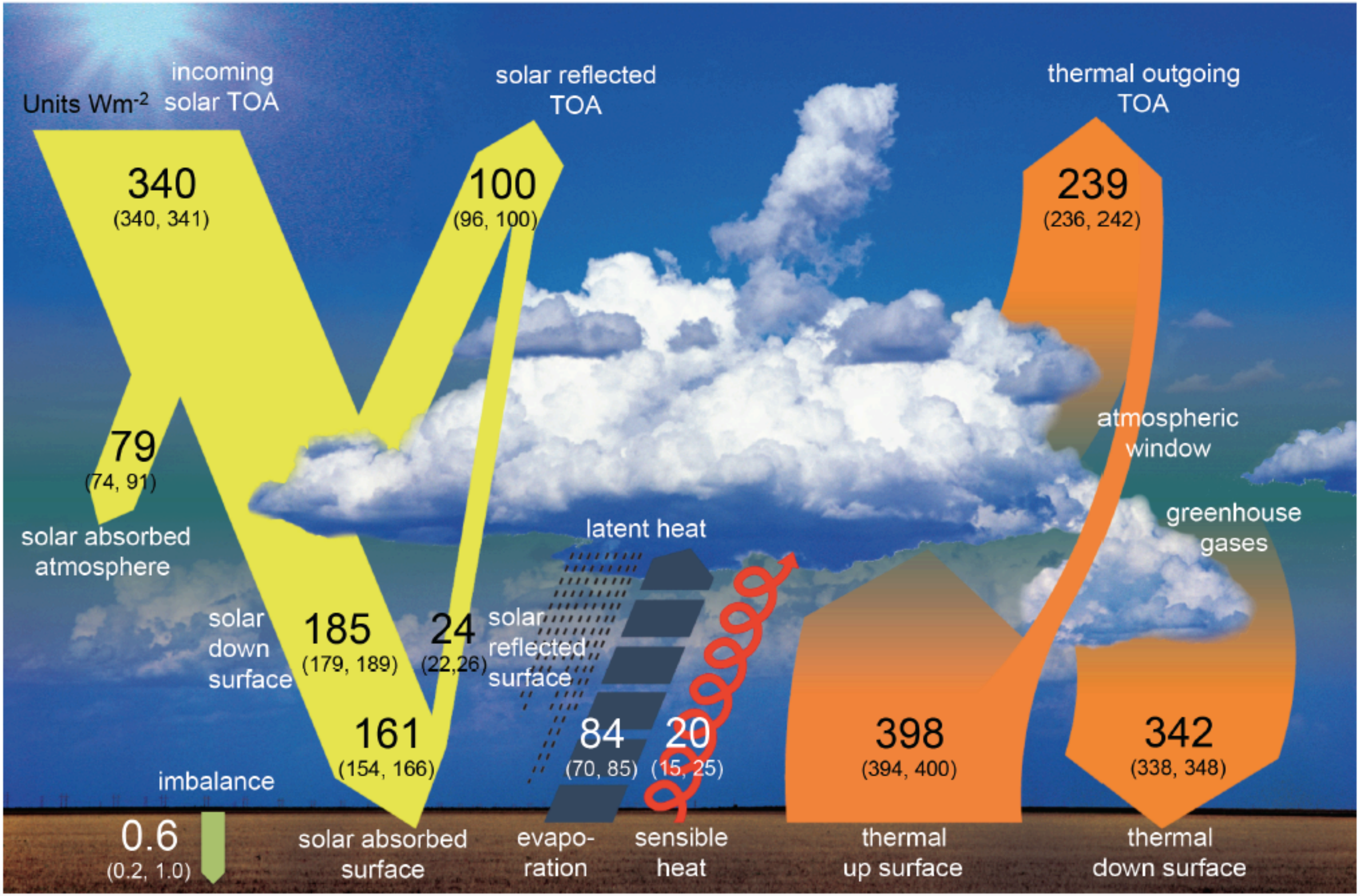
  - **Energy:** Radiative fluxes
    (Net SFC, Net TOA, LW, SW, LH ...)
  - **Mass:** P-E and SSH change...
- Specific field...
- ...
- ...
- R ... ields
- M... ...ssary for CMIP6 or other experiments with spe... ...orcing fields

Tuning a climate model (long integration times) may be very different than what is needed for weather prediction!

E.g. Energy and mass conservation become important since they affect equilibrium temperatures, SSH etc.

Two main target resolutions: T255L91 ORCA1 and T511L91 ORCA025



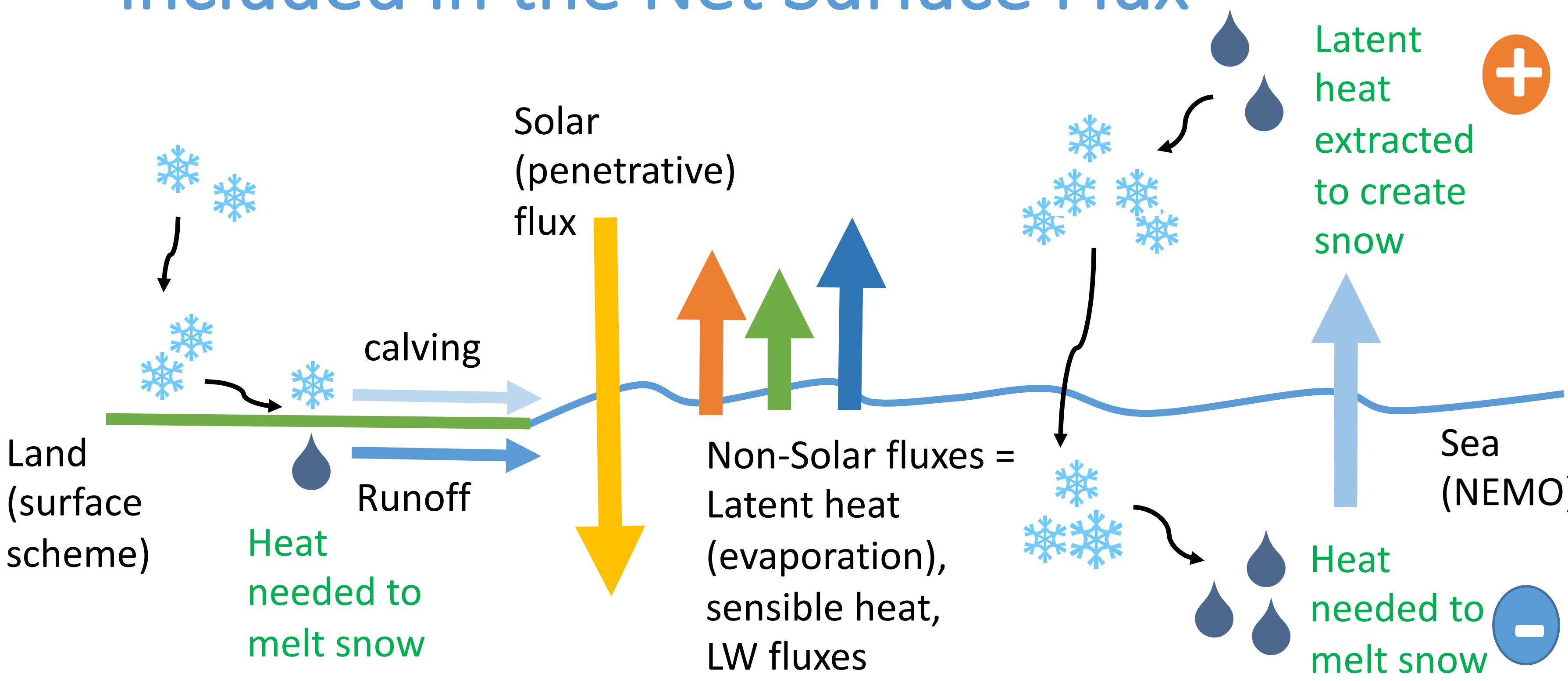
Wild et al. 2013

TOA – SFC radiative imbalance

- **All** simulations (T255L91) with standard ECE 3.0.1 presented a net TOA Net flux –SFC Net flux **radiative imbalance** of ~ **-2.5 W/m^2**
- Tested for coupled and uncoupled runs, different GHG forcings, changing surface albedo. Long runs (> 30 yr)
- This imbalance may be distributed differently: (e.g. some runs had SFC=2.15 W/m^2, TOA=0.35 W/m^2, others had SFC=+0.5 W/m^2, TOA=-2.0 W/m^2)
- **No significant atmospheric cooling** associated with this apparent heat loss

→Suggests presence of **an internal heat source**

Latent heat from snowfall has to be included in the Net Surface Flux



Snowfall in EC-Earth ~ 0.23 mm/day → (* L=334 KJ/Kg) → **-0.88 W/m2**

Explains part of the TOA-SFC imbalance!

Advection mass fixing

- The model is not mass-conservative (P-E is positive, 0.030 mm/day).
- In fact, IFS advection is not conservative (Diamantakis & Flemming 2013)
- The condensation of 0.03 Kg/m^2/day of water → 0.9 W/m^2 of latent heat release
- Significant source of heat, same order of TOA-SFC imbalance and of anthropogenic forcing

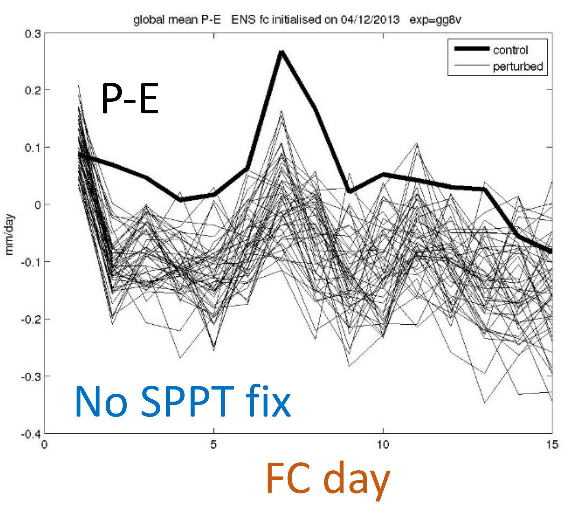
Solution:

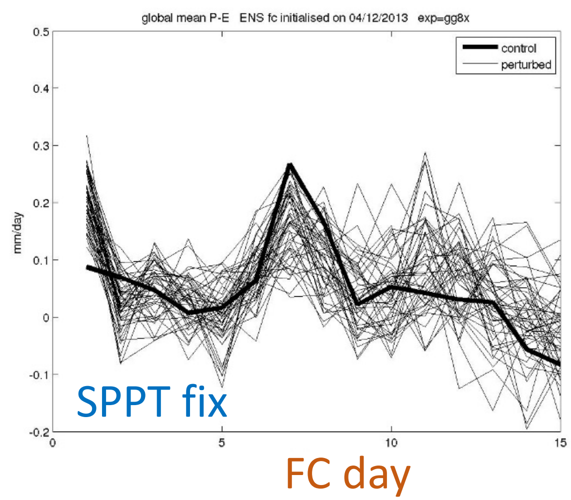
- Backported proportional advection mass fixer from C38r4
- P-E reduced to -0.016 mm/day (indicates presence of another water sink in the atmosphere, not associated with advection)
- In all runs→ TOA-SFC reduced to -0.27 W/m^2
  (a 1.4 W/m^2 improvement)
- P-E becomes -0.016 mm/day (so the mass imbalance was actually 0.046 mm/day)
- Tested IFS c40r1 (ECMWF) with and without the Barnejo & Conde mass-fixer provides similar results
- More refined advection mass fixers from IFS c40r1 (Diamantakis 2014) could not be implemented due to significant changes in IFS code since cy36r4

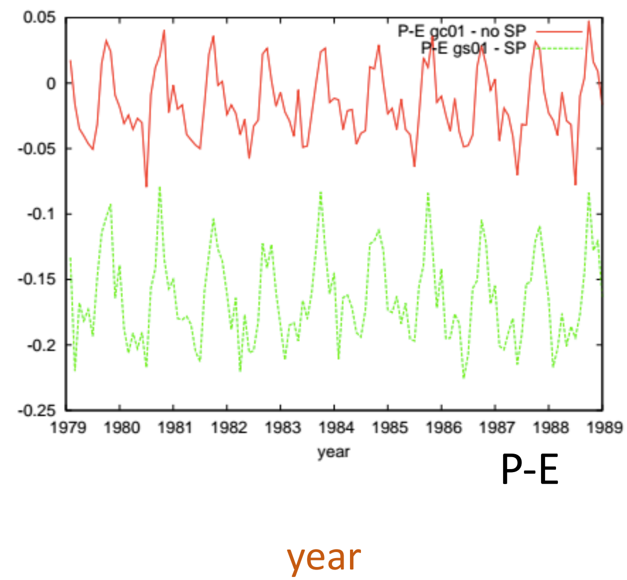
** Ref: Diamantakis, M. and J. Flemming (2013): Global mass fixer algorithms for conservative tracer transport in the ECMWF mode, ECMWF Technical Memoranda, 713.*

TENDENCY CONSERVATION IN THE STOCHASTIC PHYSICS (SPPT) SCHEME

- The **SPPT scheme** was found not to be conservative in water vapour and energy
  → Leading to strongly negative Precip.-Evap. (P-E) imbalance
  (-0.16 mm/day) and Top of Atmosphere - Surface net fluxes = 1.5 W/m2
- Implementation of a scheme enforcing (proportional) conservation of T, Q, U and V tendencies before and after SPPT
- → leads to P-E=0.016 mm/day (like base physics) and
  TOA-SRF=-0.58 W/m2







In collaboration with Antje Weisheimer (Oxford Univ.), Simon Lang (ECMWF), Linus Magnusson (ECMWF), Massimo Bonavita (ECMWF)
ECMWF RD memo on 17/05/2016

AMIP sensitivity tests to convection and precipitation parameters

Investigation of the sensitivity of the EC-Earth radiative fields and PIs to different parameters that affect convection, entrainment rates, precipitation, and other water-cycle-related features:

1. **ENTRORG** : organized entrainment in deep convection
2. **RPRCON** : rate of conversion of cloud water to rain
3. **DETRPEN** : detrainment rate in penetrative convection
4. **ENTRDD** : average entrainment rate for downdrafts
5. **RMFDEPS** : fractional massflux for downdrafts
6. **RVICE** : fall speed of ice particles
7. **RLCRITSNOW** : critical autoconversion threshold for snow in large scale precipitation
8. **RSNOWLIN2** : snow autoconversion constant in large scale precipitation.
9. **RTAUMEL** : relaxation time that affects the melting of falling solid particles for large scale precipitation
10. **RALBSEAD** : albedo for diffusive radiation over the ocean
11. **RCLDIFF :** Mixing coefficient for turbulence , controls cloud cover
12. **COND-LIMITER** : a code modification suggested by Richard Forbes at ECWMF that affects the vertical humidity distribution.

- 40 short AMIP runs - 6 years each, using standard climatological SSTs and with perennial present day forcing. Averages over years 2-6.

Condensation limiter in cloudsc

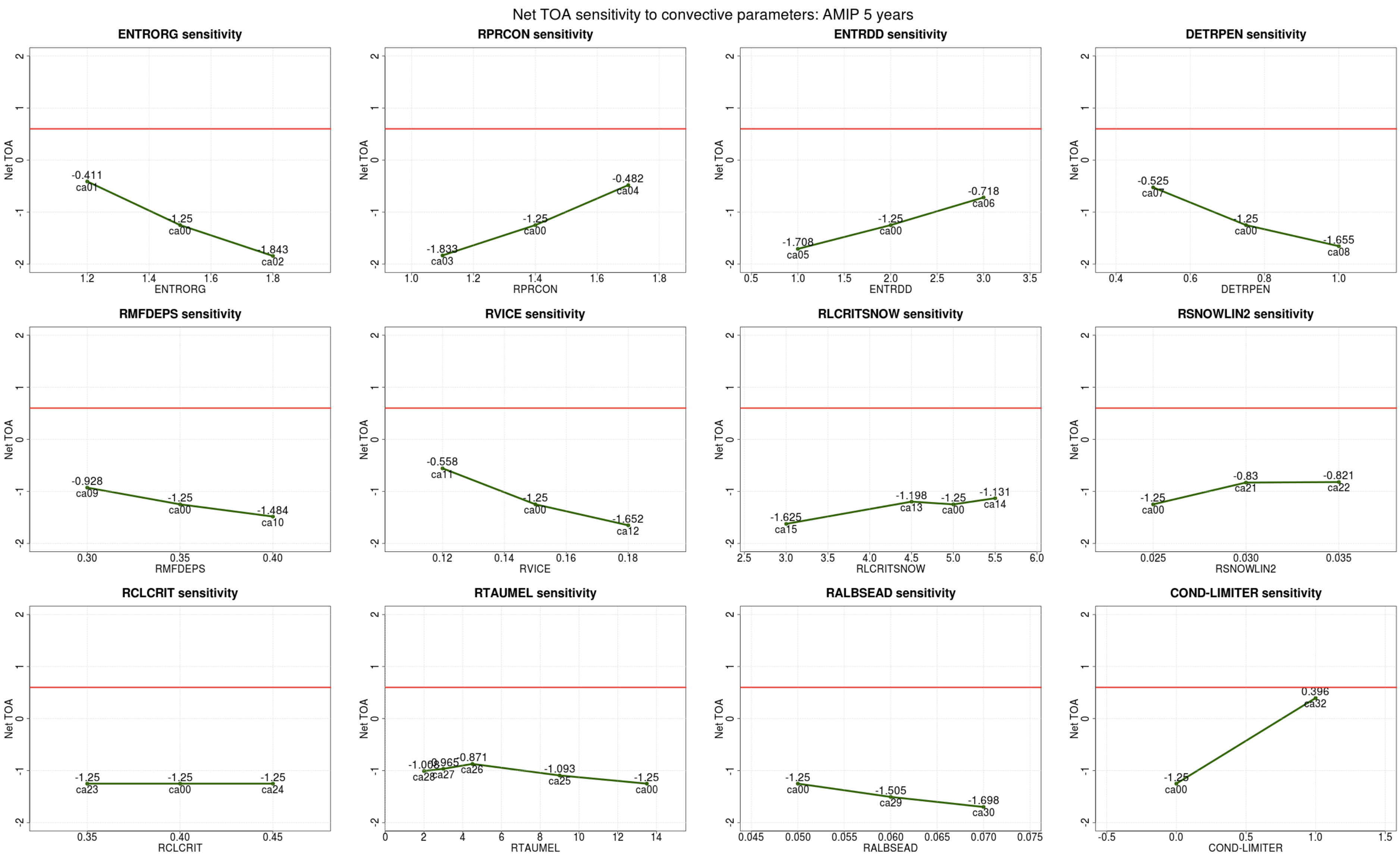
- EC-Earth is based on cy36r4
- In that cycle a new condensation limiter for the increase of cloud water in existing clouds was used
- The old limiter has then been reintroduced in later cycles
- Reintroducing the “old” limiter also in EC-Earth has a strong effect on the NET TOA fluxes in AMIP runs:

	Cy36r4 limiter	”old” limiter	Diff. [W/m2]
Net TOA (A)	-1.02	0.47	1.49
Net TOA (B)	-2.83	-1.05	1.78
SWCF (B)	-47.11	-45.46	1.65
LWCF (B)	26.75	26.41	-0.34
TCC	0.656	0.651	-0.005

Useful tool to shift TOA net fluxes by >+1.5 W/m2 !

Suggested by R. Forbes, ECMWF

AMIP sensitivity tests to convection and precipitation parameters



(linear) Sensitivity of radiative fluxes to parameters from AMIP experiments

	Toa Net LW	TOA Net Sw	LWCF	SWCF	NetSFC
RPRCON	-4.70	6.96	-3.59	7.30	2.24
RVICE	-36.17	18.03	-35.28	19.83	-18.40
RLCRITSNOW	0.56	-0.37	0.61	-0.39	0.19
RSNOWLIN2	140.00	-97.00	148.50	-101.90	40.00
ENTRORG	-0.55	-1.84	-0.25	-1.80	-2.47
DETRPEN	1.14	-3.40	1.23	-3.30	-2.21
ENTRDD	0.02	0.48	0.00	0.44	0.50
RMFDEPS	0.80	-6.39	0.20	-6.46	-5.52
CONDLIM	1.18	0.47	0.89	0.34	1.63

[W/m^2 per unit parameter change]

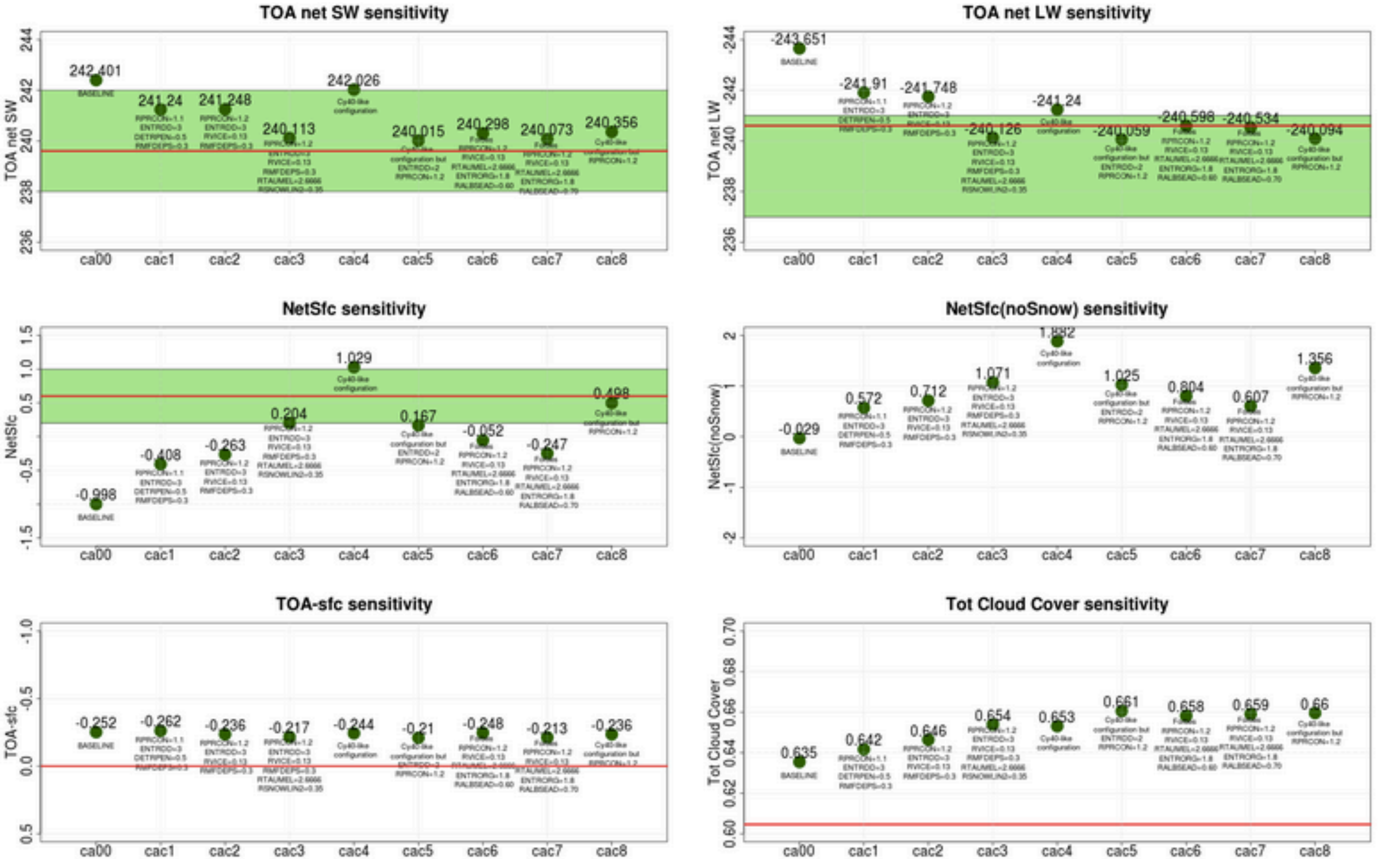
With these sensitivities we can estimate the impact of possible parameter changes and plan new tuning parameter sets starting from an existing experiment (we have a **‘tuning simulator’** to compute the effect of new configurations)

AMIP sensitivity tests to convection and precipitation parameters

- We combined together parameters in order to improve the representation of the main radiative fluxes. 3 main goals:
  - EC-Earth 3 had an unrealistic high net TOA shortwave and longwave fluxes (about 243 W/m^2 vs. observed of about 240 W/m^2).
  - LW cloud forcing shows unrealistic low values (about 24 W/m^2 vs. observed about 26 W/m^2).
  - Too low net surface flux. The PD flux is estimated about 0.6 W/m^2

- The goal was to improve these while mantaining similar Performance Indices

Tuning the model: Sensitivity to cloud and convective parameters



AMIP sensitivity tests to convection and precipitation parameters

- We were successful in reducing the net TOA LW and SW fluxes, and this can be achieved in different ways. The most efficient knobs are RPRCON and RVICE, since they operate on the high cloud cover.

- Interestingly a combination with values similar to those used in IFS cy40r1 provided very good results.

- When net surface flux is computed as the sum of the net shortwave, net longwave, sensible heat and latent heat flux plus the contribution of snowfall a cy40-like combination with reduced ENTRORG works best to achieve realistic current-day values.

EC-Earth 3.2.1 TOA fluxes in AMIP runs

Experiment	Description	Net TOA	Net SFC	R&K PI3
tag1	CMIP5 G,S	-1.92	-1.61	
tag0	CMIP6 G,S	-1.84	-1.55	0.254
taj1	CMIP6 G,S+MacSP (M)	**-2.97**	-2.65	0.278
taj2	CMIP6 G,S,M + cond. lim. (C)	**-1.20**	-0.92	0.248
taj3	CMIP6 G,S,M,C+ T1	0.12	0.43	0.258
taj4	CMIP6 G,S,M,C+ T2	0.30	**0.60**	0.264

TUNED

* 1991-1995 averages

Forcings:

G: GHGs
S: Solar
M: MacSP

Tuning:

C: Condensation limiter

T1: RPRCON=1.45E-3 RVICE=0.13 RLCRITSNOW=4.1E-5 RSNOWLIN2=0.035 ENTRORG=1.45E-4 DETRPEN=0.7E-4 ENTRDD=3.5E-4 RMFDEPS=0.3

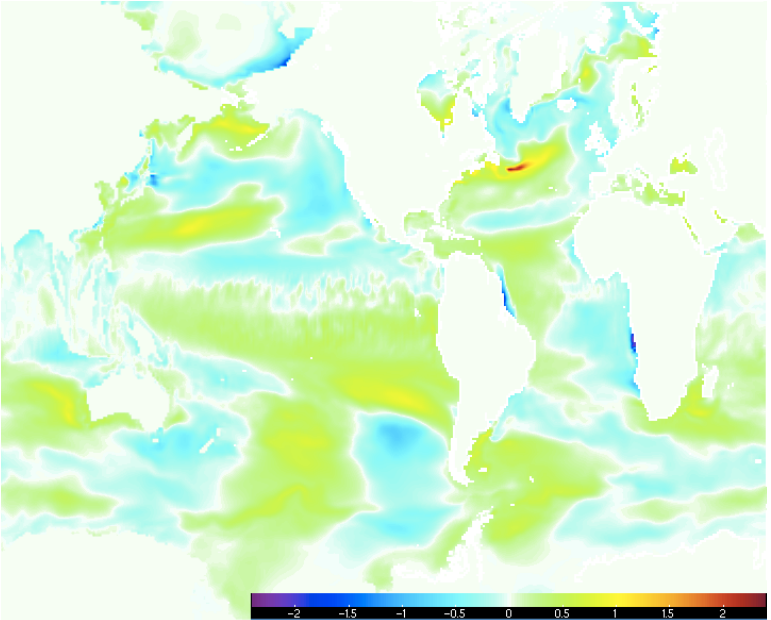
T2: RPRCON=1.49E-3 RVICE=0.125 RLCRITSNOW=4.0E-5 RSNOWLIN2=0.035 ENTRORG=1.4E-4 DETRPEN=0.7E-4 ENTRDD=3.5E-4 RMFDEPS=0.3

Ocean temperature changes due to dilution effects

- NEMO takes into account the temperatures of incoming and outgoing mass fluxes to represent dilution effects → it adds an energy flux corresponding to the the internal energy (Cp*dT) of rainfall, snowfall, evaporation and runoff fluxes
- This is physical: warm water evaporates in the tropics and cold runoff and calving water enter the ocean at high latitudes.
- Problem: for IFS rainfall has no temperature, it did not spend energy to, e.g., warm up the rainfall !

→Not energy conserving in the system

SST differences if constant temperature is assumed for all mass fluxes



The imbalance due to this effect has been estimated to be of the order of

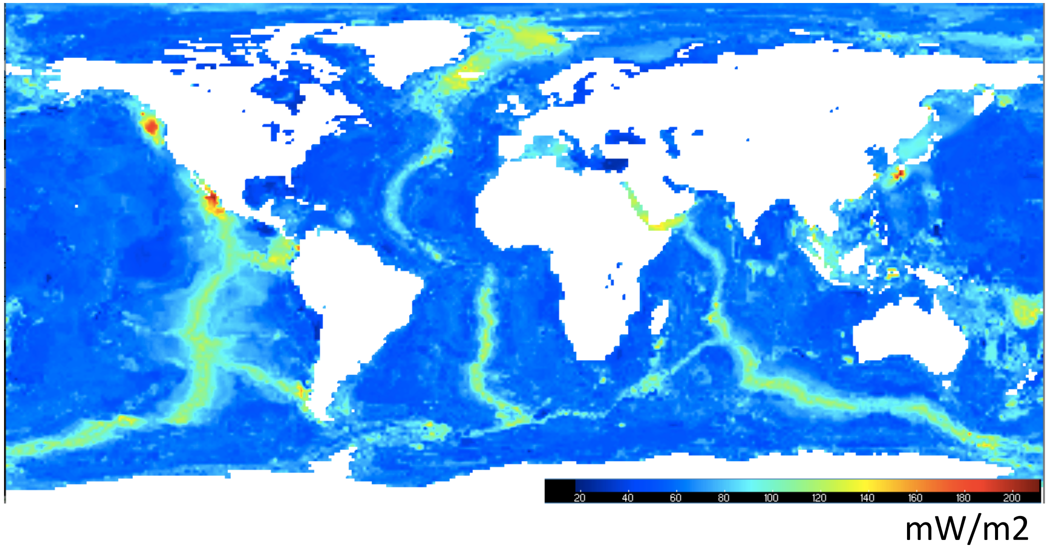
-0.23 W/m2 (averaged over the ocean = -0.16 W/m2 globally)

(an energy sink in the ocean)

Geothermal heating

- A geothermal heating source is added as a bottom BC for NEMO → 0.0655 W/m2 (over the ocean = 0.0465 W/m2 globally)

Geothermal heating flux



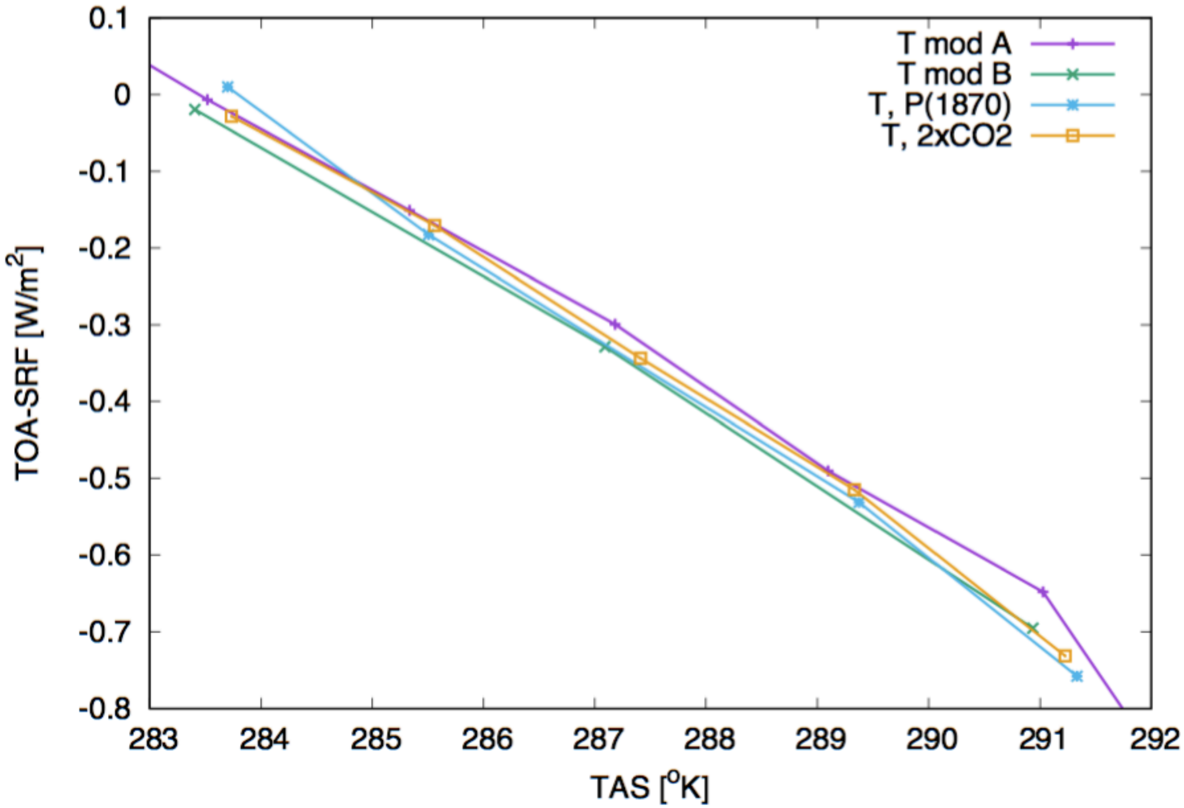
What average NetSurface flux do we expect in a long run with constant forcing driven to equilibrium (such as a preindustrial fixed-1850 run) ?

Geoth. Heating + "Temperature of rain" additions by NEMO → +0.12 W/m2

Since IFS has a TOA-SFC=-0.27 W/m2 (an internal energy production, for T255L91) → -0.15 W/m2 at TOA

Caveats: TOA-SRF imbalance

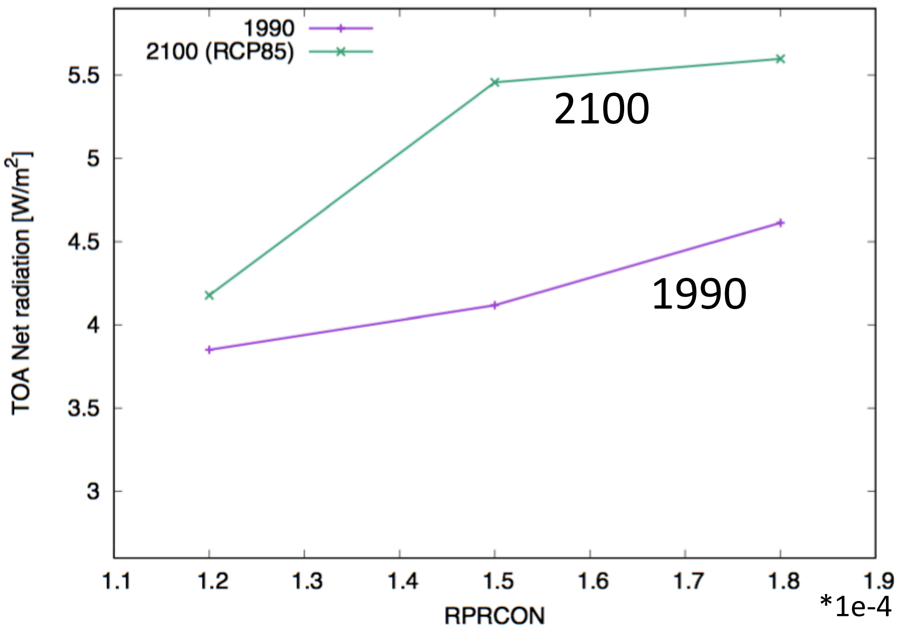
- EC-Earth IFS has a TOA-SRF net energy flux imbalance of about -0.3 W/m^2 under PD conditions* (an internal energy source)
- This imbalance is state dependent!

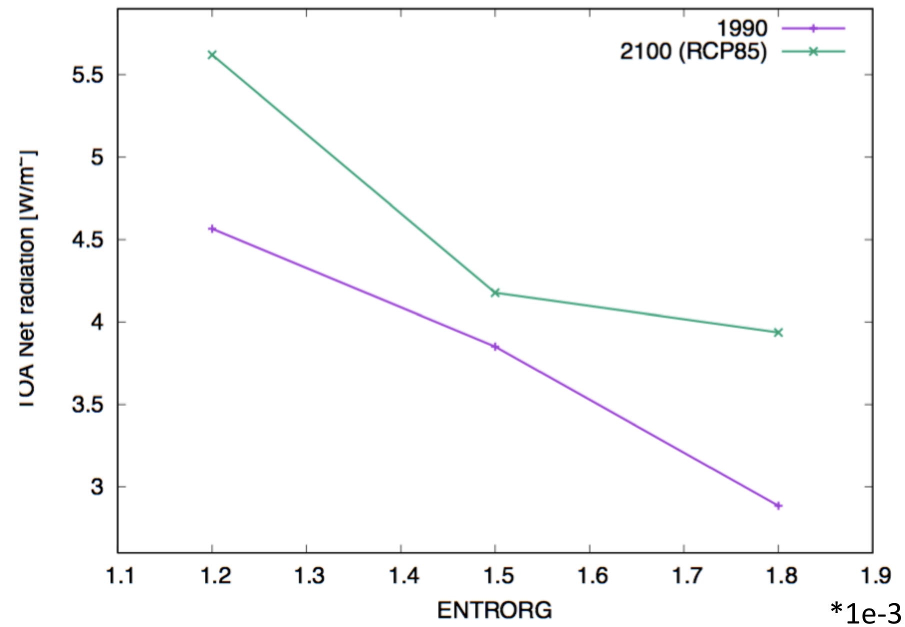


*) If we take into account also -0.88 W/m^2 associated with snowfall.

Caveats: parameter sensitivity

- The sensitivity of radiative fluxes to parameters is state dependent!





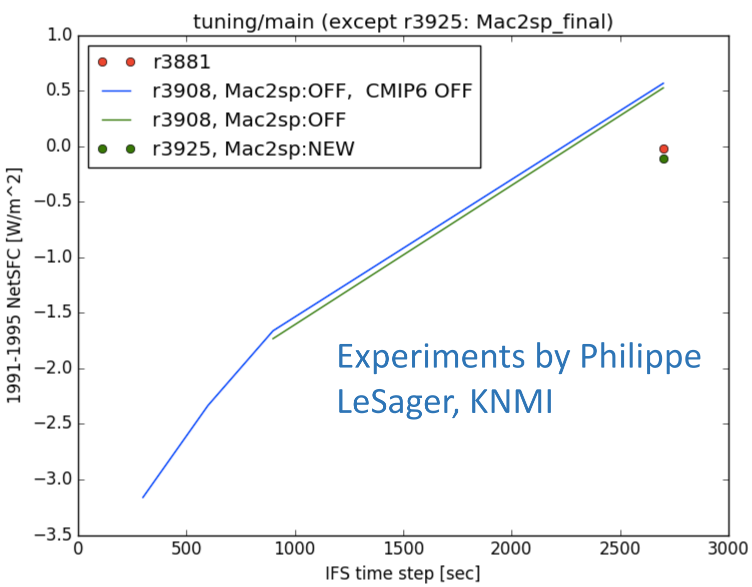
ENTRORG (entrainment in deep convection) and and RPRCON (controls rate of conversion of cloud water to rain) are two relevant tuning parameters

→ Tuning a model for different climates will not lead to the same parameter choices
→ Different tuning sets may lead to different model climate sensitivities (see also Mauritsen et al. 2012)

Ref: Mauritsen, T., et al. (2012), Tuning the climate of a global model, J. Adv. Model. Earth Syst., 4, M00A01, doi:10.1029/2012MS000154.

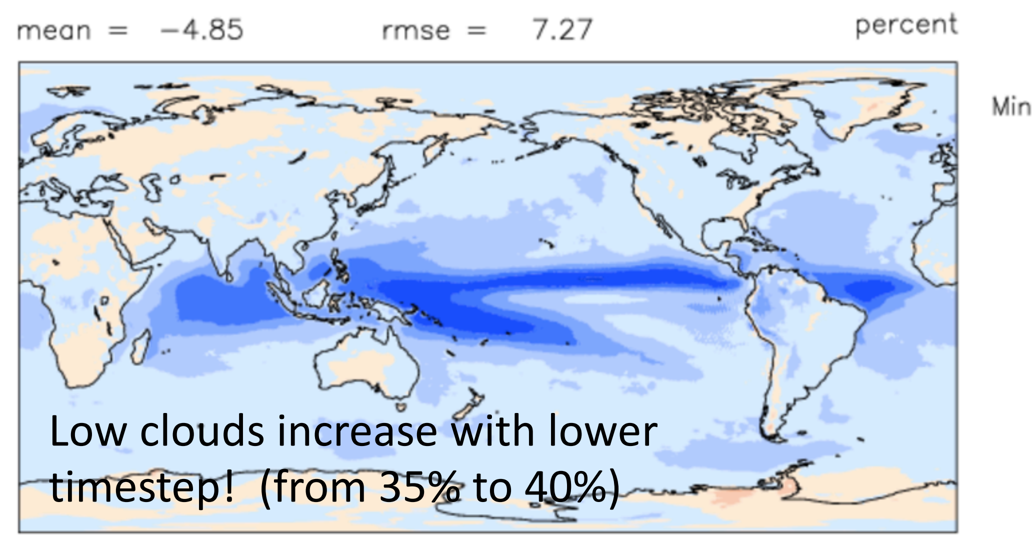
Caveats: time-step dependency

- Changing timestep (std res) from 2700s to 900s changes Netsfc fluxes by -2 W/m2 ! Due to increase in low-level clouds.



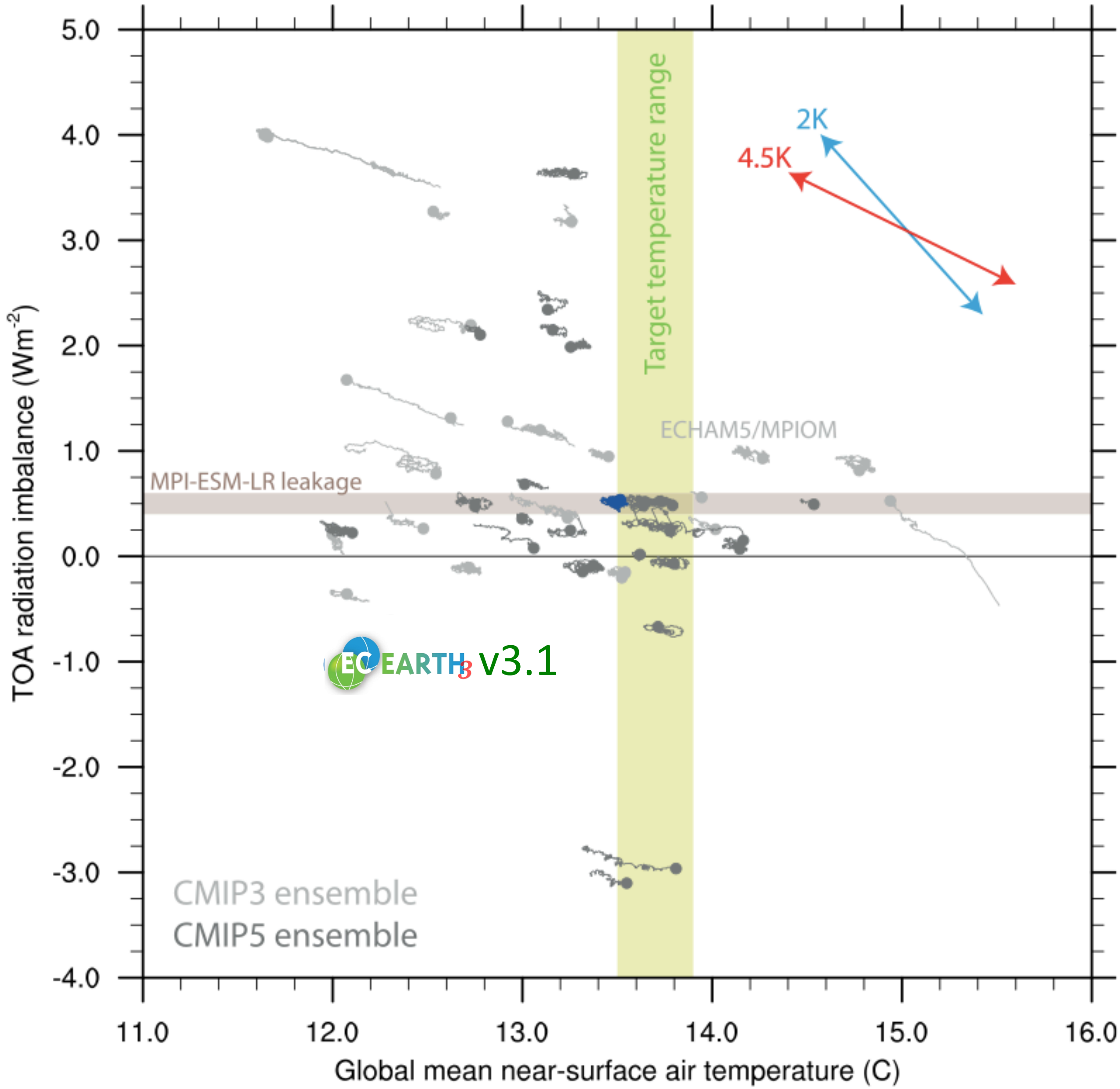
LCC change 2700s-900s

Difference in low clouds dt=2700s – dt=900s



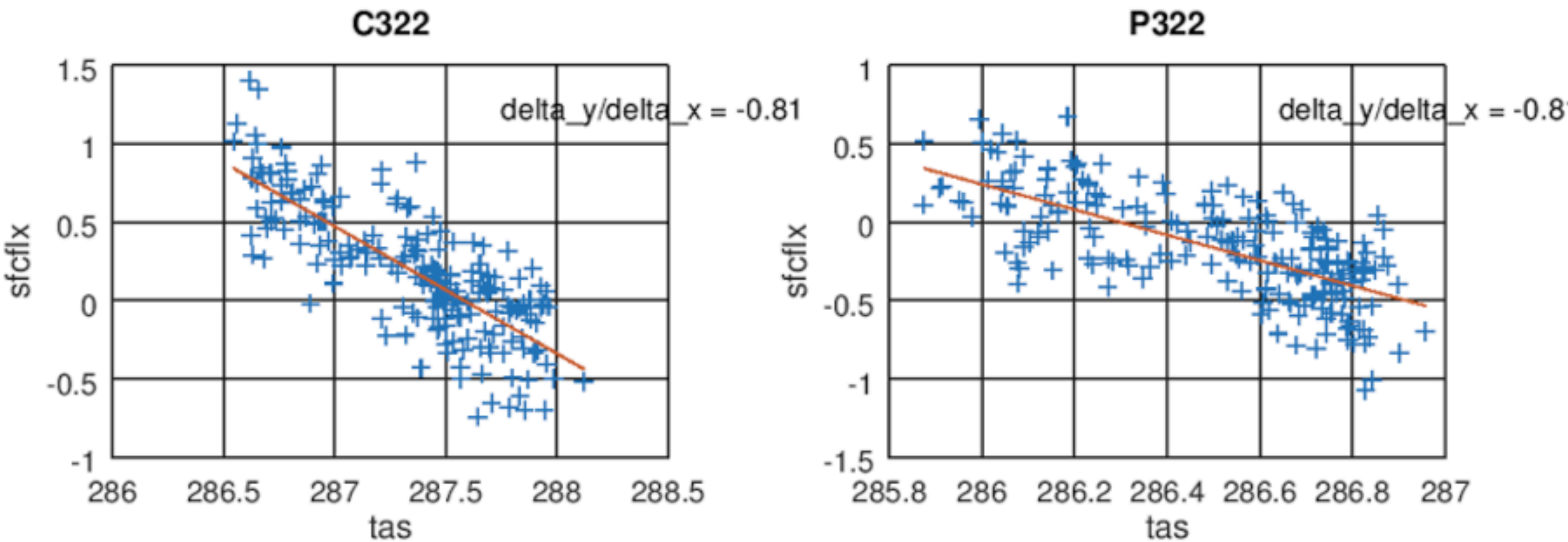
Problem well known to ECMWF (R. Forbes), is under investigation,
Is being solved for next cycles of IFS

Gregory plots: CMIP3 and CMIP5 pre-industrial runs

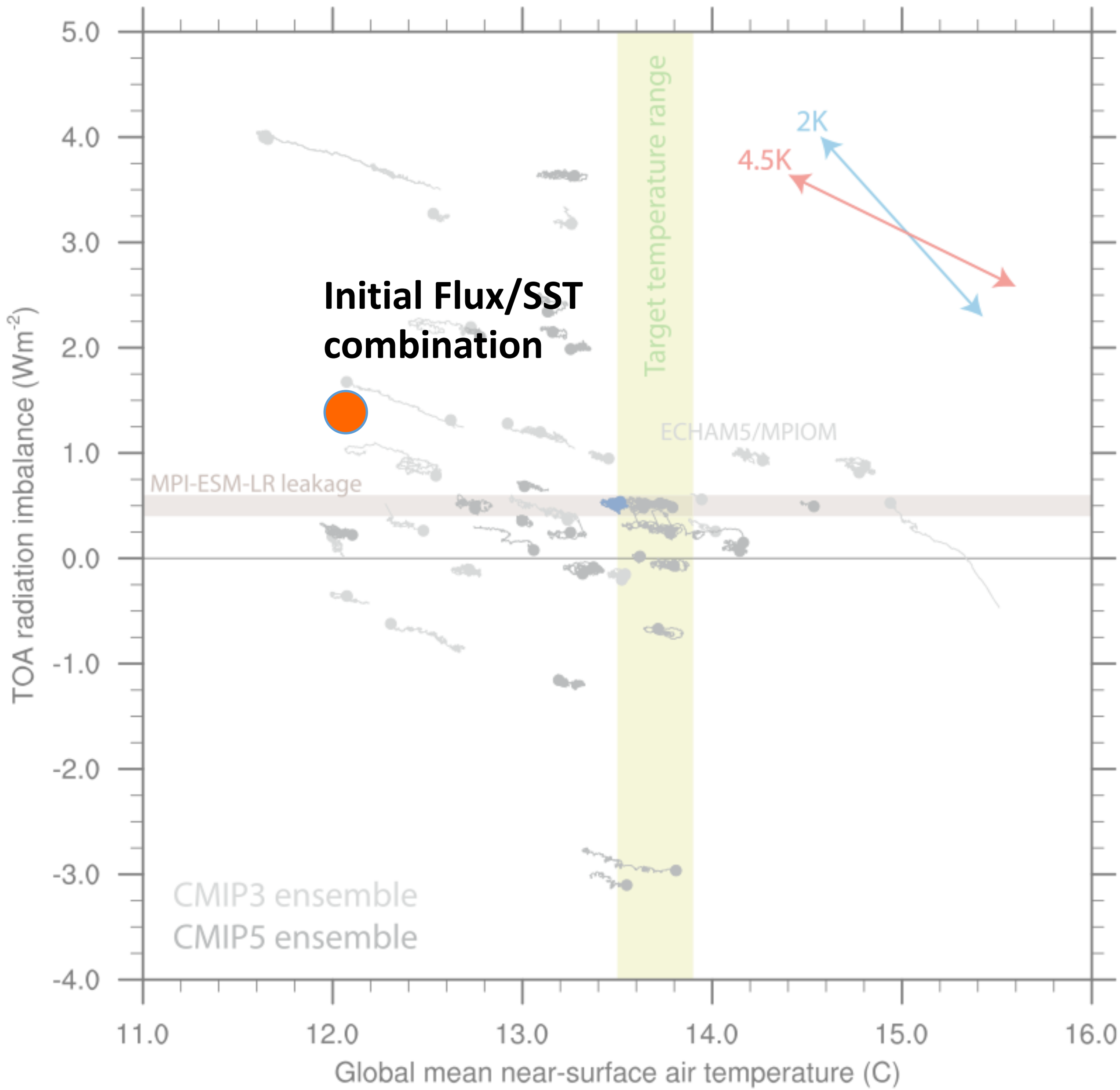


T. Mauritsen, et al. (2012): Tuning the climate of a global model, *J. Adv. Model. Earth* Syst., 4, M00A0.

Gregory plots for 200y-long experiments with EC-Earth 3.2 (K. Wyser)



A strategy for coupled EC-Earth tuning (hires and low res)



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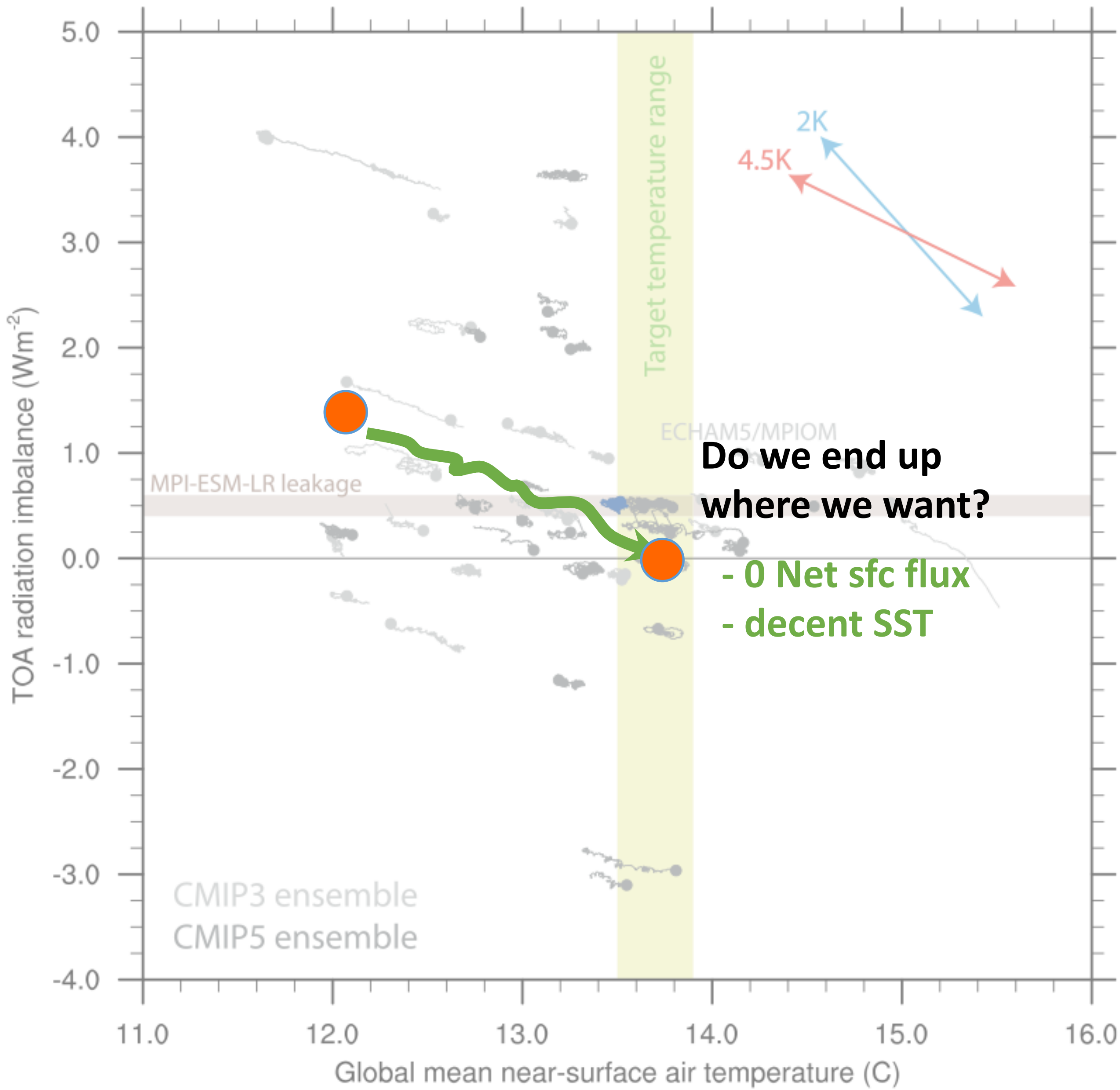
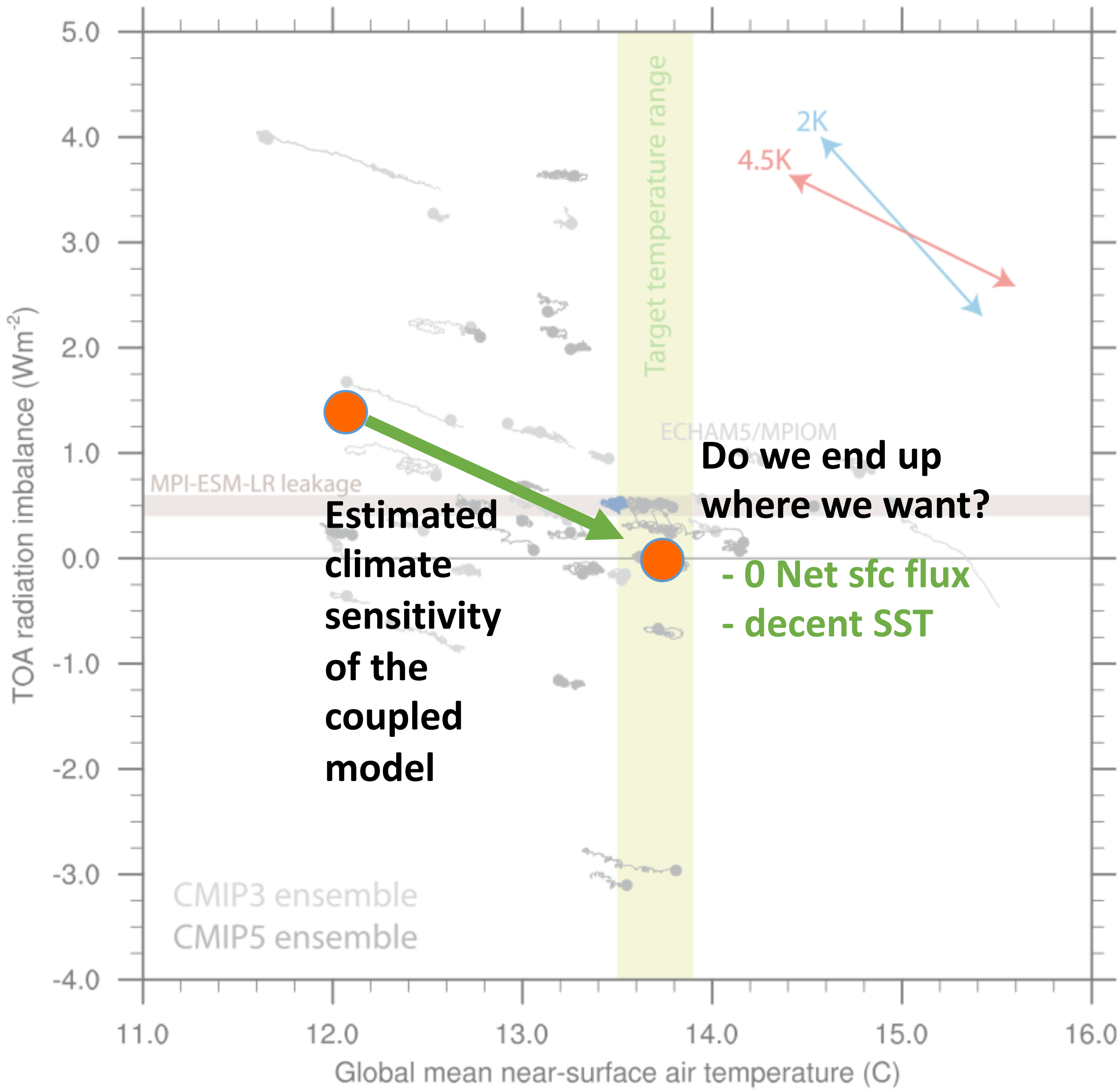


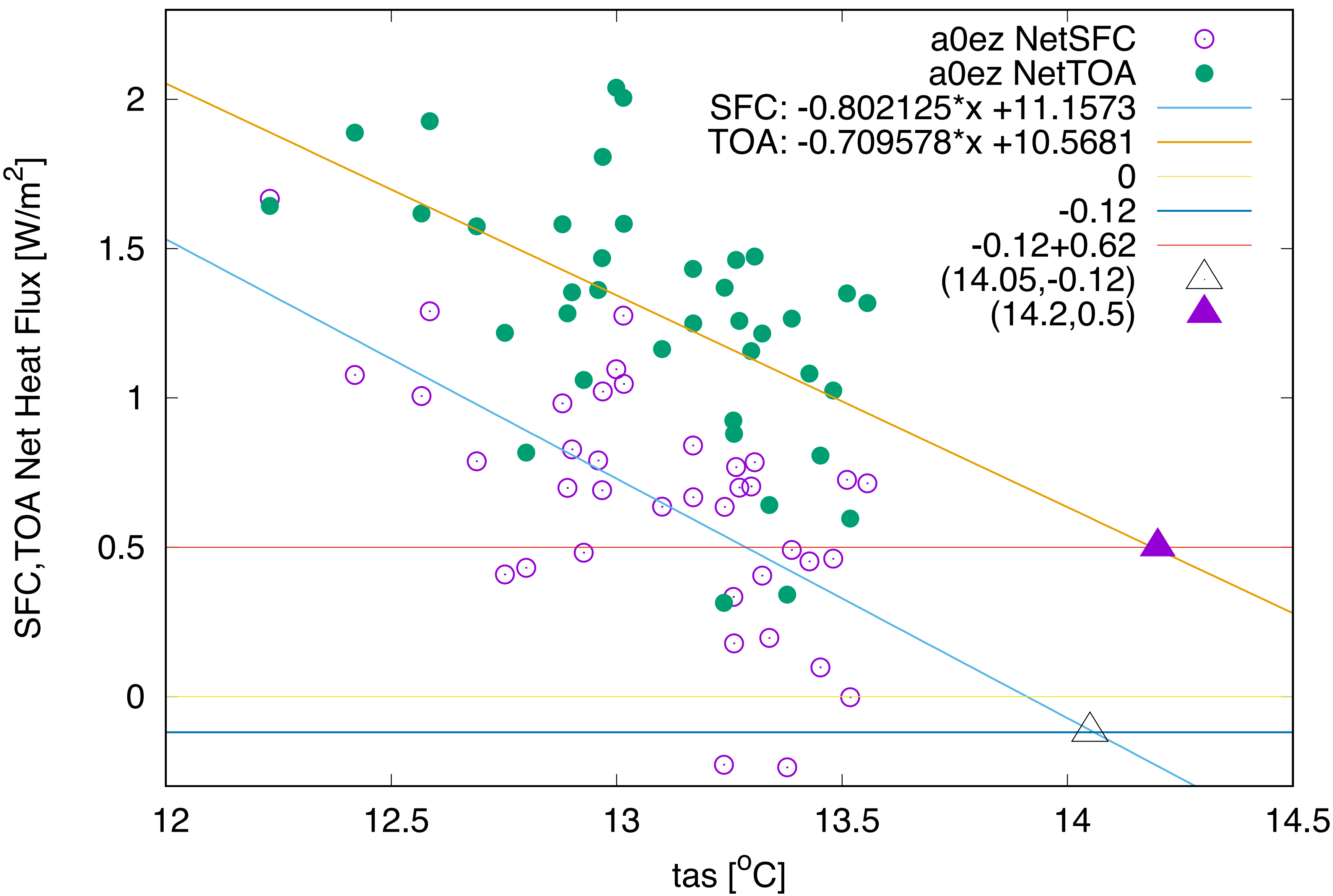
Do we end up where we want?

- 0 Net sfc flux
- decent SST

A strategy for coupled EC-Earth tuning (hires and low res)



Example: tuning T511L91 - ORCA025 runs (1950 spinup)



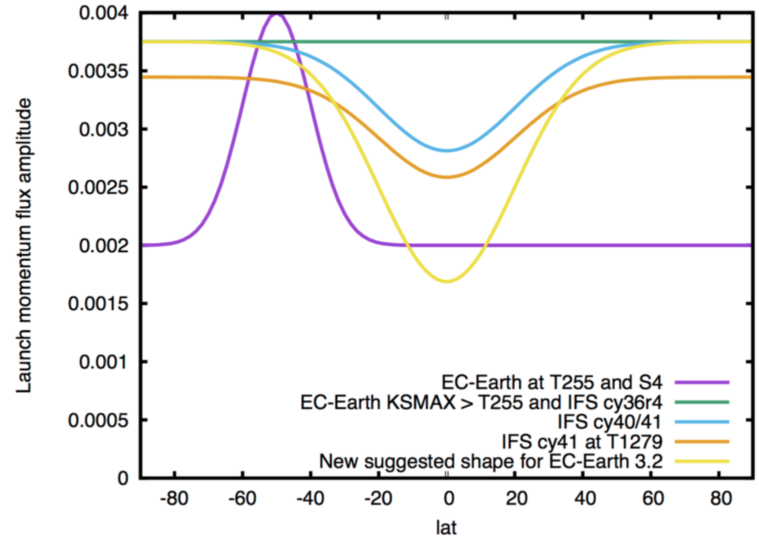
Improved non-orographic Gravity Wave drag parameterization

- The Quasi-biennial oscillation is an oscillation of equatorial zonal average winds with a period of about 28 months.

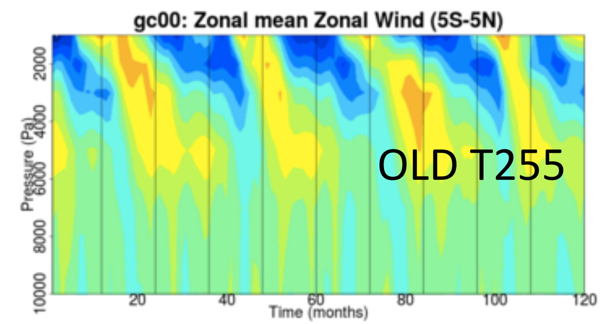
Original model
→ No Quasi-Biennial Oscillation (QBO) at higher res

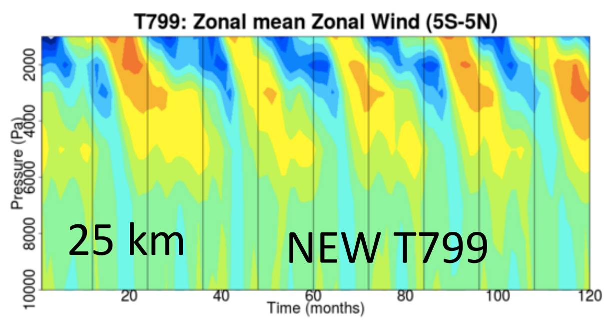
- We adopt a different recent IFS shape
- Resolution-dependent parameterization of non-orographic gravity waves

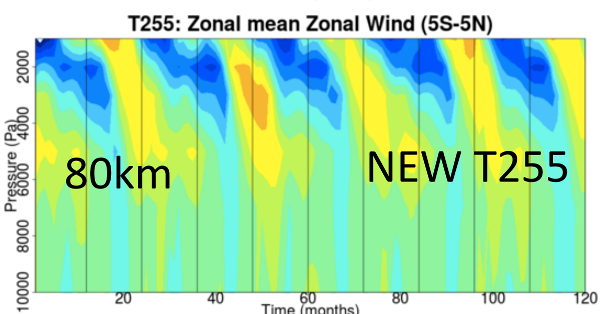
→ Improved representation of QBO also at hi-res

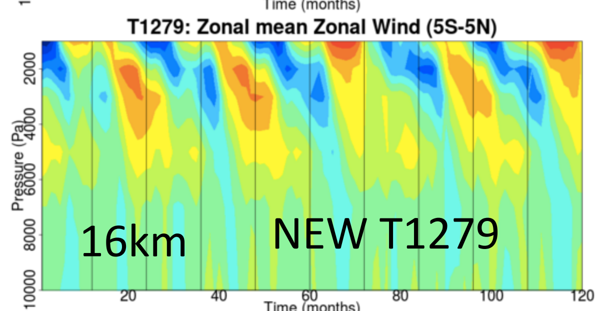


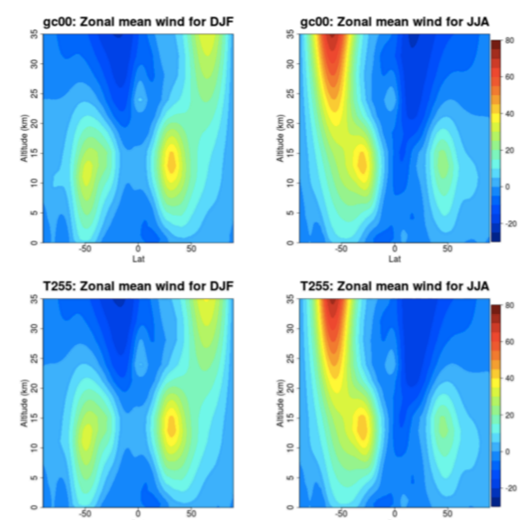
GFLUXLAUN = momentum flux launched in mid-troposphere to simulate the effects of gravity waves.











Thanks to
Tim Stockdale and Peter Bechtold