The history of ECMWF radiation schemes

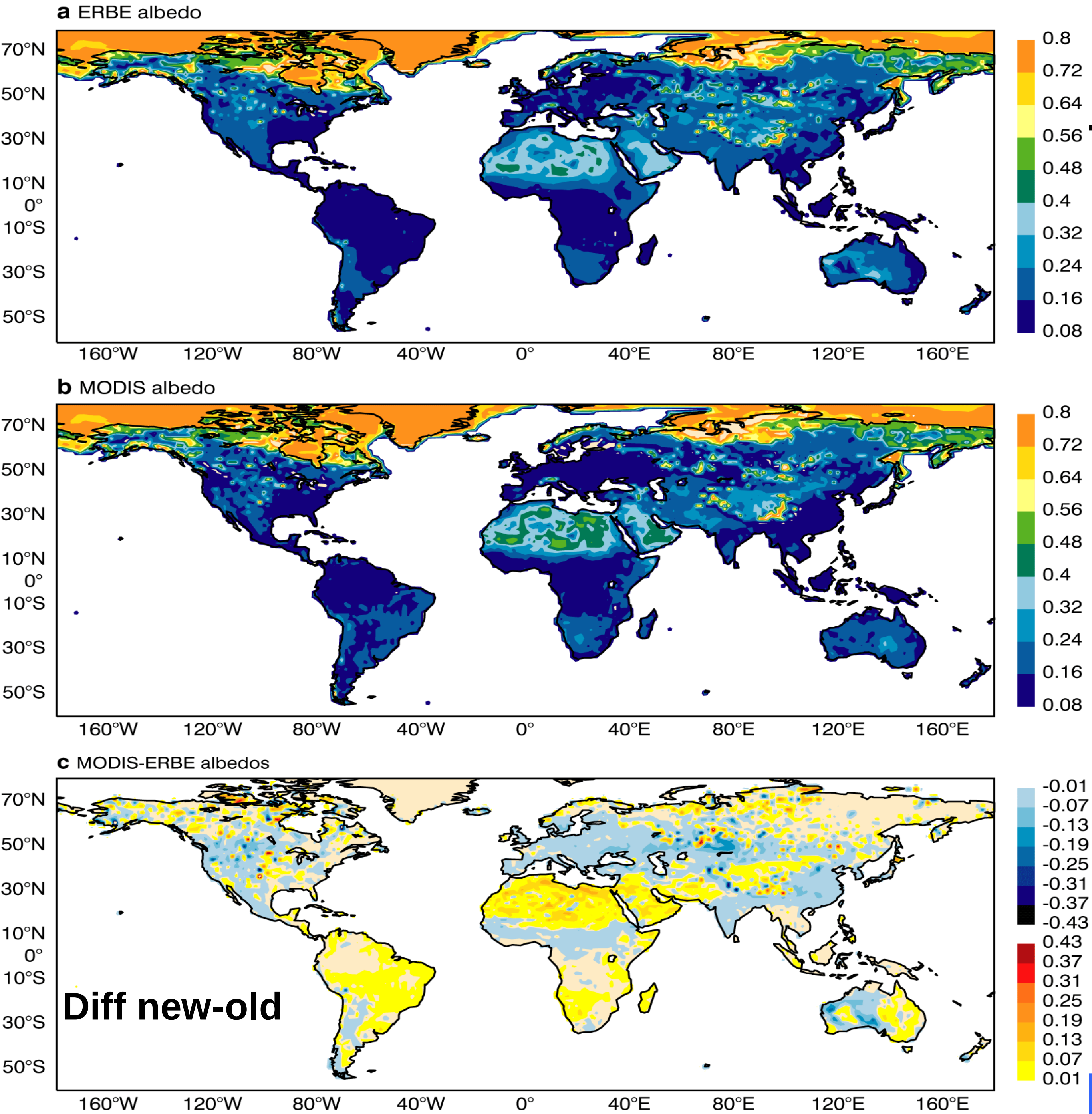
Cycle	Implementation date	Description
SPM 32	02/05/1989	RT schemes from Univ.Lille
SPM 46	01/02/1993	Optical properties for ice and mixed phase clouds
IFS 14R3	13/02/1996	Revised LW and SW absorption coefficients from HITRAN'92
IFS 16R2	15/05/1997	Voigt profile in long-wave RT scheme
IFS 16R4	27/08/1997	Revised ocean albedo from ERBE
IFS 18R3	16/12/1997	Revised LW and SW absorption coefficients from HITRAN'96
IFS 18R5	01/04/1998	Seasonal land albedo from ERBE
IFS 22R3	27/06/2000	$RRTM_{LW}$ as long-wave RT scheme short-wave RT scheme with 4 spectral intervals
IFS 23R4	12/06/2001	Hourly, instead of 3-hourly, calls to RT code during data assimilation cycle
IFS 25R1	09/04/2002	Short-wave RT scheme with 6 spectral intervals
IFS 26R3	07/10/2003	New aerosol climatology adapted from Tegen et al. (1997), new radiation grid
IFS 28R3	28/09/2004	Radiation called hourly in high resolution forecasts
IFS 32R2	05/06/2007	McICA approach to RT with $RRTM_{LW}$ and $RRTM_{SW}$ revised cloud optical properties, MODIS-derived land albedo

The ECMWF radiation schemes

- A number of radiation schemes are in use at ECMWF. Since January 2011, have been active
  - McRad including RRTM_LW and RRTM_SW is used in the forward model for operational 10-day forecasts at T_L1279L137, EPS 15-day forecasts at T_L639 L91, and seasonal forecasts at T_L159 L62.
  - The tangent linear and adjoint of the "old" SW radiation scheme in a 2-spectral interval version
  - The tangent linear and adjoint of the "old" LW radiation scheme with 6 spectral intervals,
  - These last two schemes are used in the assimilation (cf. P.Lopez's presentation in TC PA module)
  - … and all the dedicated RT scheme used to simulate radiances (RTTOV-based) in the analysis of satellite data (cf. TC DA module)
  - A dedicate RT code to compute spectral irradiance in the UV spectrum (a modified version of RRTM-SW)

McRad, a new radiation package for the ECMWF IFS

- McRad (operational with CY32R2, 5 June 2007)
- Includes MODIS land surface albedo
- A new SW radiation transfer scheme (RRTMG_SW) consistent with RRTMG_LW introduced in June 2000
- McICA: Monte-Carlo Independent Column Approximation: a new treatment of clouds in RT schemes
- Revised cloud optical properties
- More extensive use of the flexible radiation grid



31R1: "old" surface albedo: one component only (0.3-5.0 microns)

32R2: equivalent surface albedo from F_{up}/F_{down}

2 components (0.3-0.7 and 0.7-5.0 microns), diffuse and direct

Impact: it depends on which SW RT scheme is used: Slightly negative with SW6, slightly positive with RRTM_SW

ECMWF

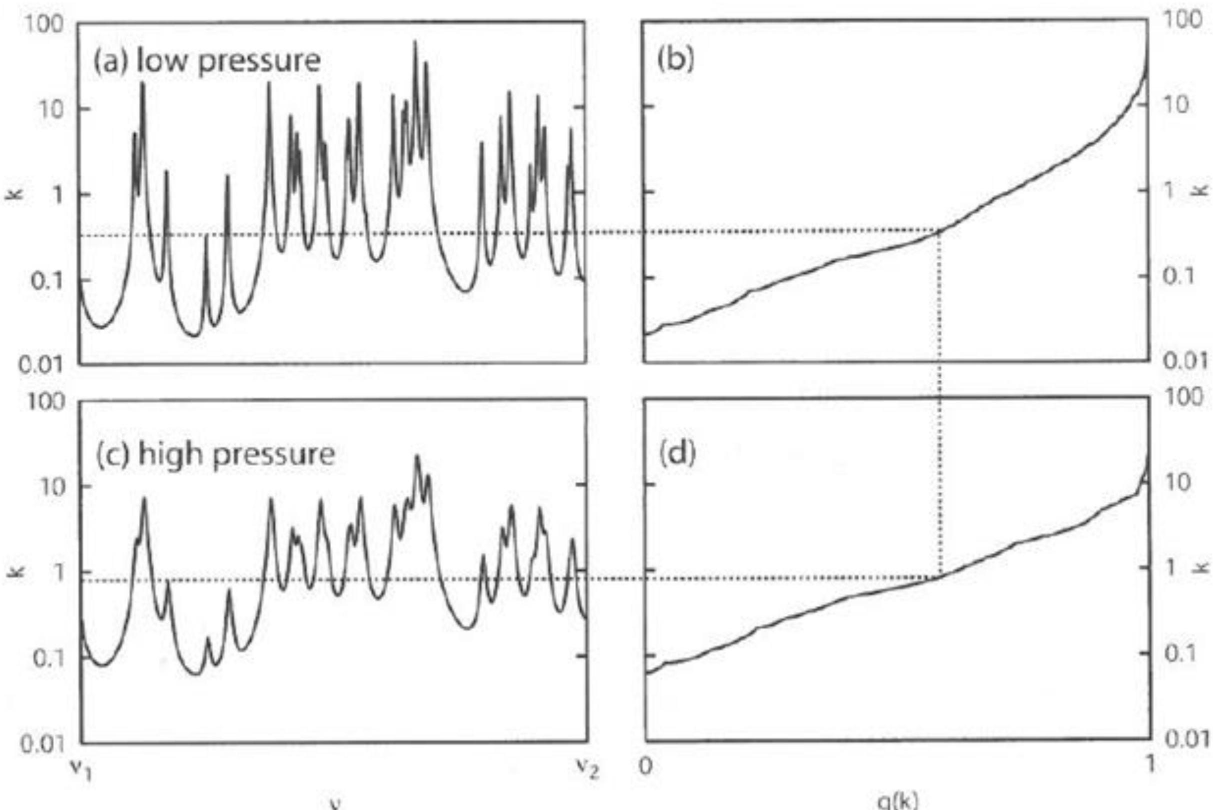
RRTM

Aer Inc.

Mlawer et al., 1997: JGR, 102D, 16663-16682

Morcrette et al., 1998: ECMWF Tech.Memo., 252

- The use of the correlated-k method (mapping k(v) ->g(k)) allows radiative transfer to be performed as a monochromatic process



The original RRTM integrates each of the LW and SW bands with 16 pseudo-monochromatic channels (g-points)

The ECMWF model uses a version with less g-points RRTMG

A two stream algorithm performs the vertical radiative transfer

$$T(z) \approx \sum_{i=1}^{N} w_i \exp\left[-k(\nu_i)z\right] \Rightarrow T(z) \approx \sum_{i=0}^{M} c_i \exp\left[-k(g_i)z\right]$$

M<N

ECMWF

RRTMG-LW configuration

Spectral intervals cm^{-1}	Number of g-points	Gases included: Troposphere	Gases included: Stratosphere
10–250	8	H_2O	H_2O
250–500	14	H_2O	H_2O
500–630	16	H_2O, CO_2	H_2O, CO_2
630–700	14	H_2O, CO_2	O_3, CO_2
700–820	16	H_2O, CO_2, CCl_4	O_3, CO_2, CCl_4
820–980	8	H_2O, CFC11, CFC12	CFC11, CFC12
980–1080	12	H_2O, O_3	O_3
1080–1180	8	H_2O, CFC12, CFC22	O_3, CFC12, CFC22
1180–1390	12	H_2O, CH_4	CH_4
1390–1480	6	H_2O	H_2O
1480–1800	8	H_2O	H_2O
1800–2080	8	H_2O	
2080–2250	4	H_2O, N_2O	
2250–2380	2	CO_2	CO_2
2380–2600	2	N_2O, CO_2	
2600–3000	2	H_2O, CH_4	

16 BANDS

~100 microns

~3 microns

~100 hPa

140 g-points

ECMWF

RRTMG-SW configuration

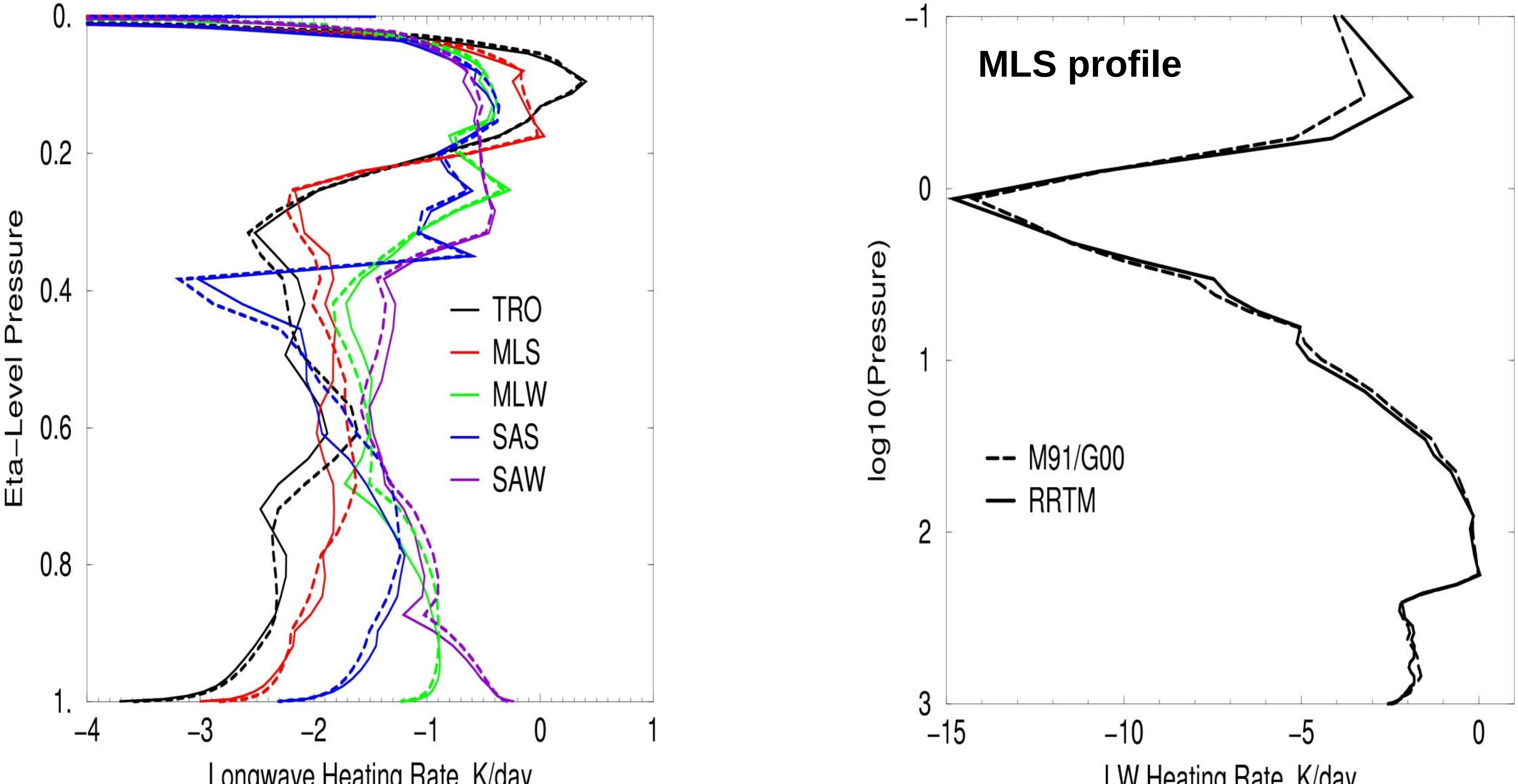
Spectral intervals cm^{-1}		Number of g-points	Gases included: Troposphere	Gases included: Stratosphere
800–2600	~3 microns	12	H_2O	CO_2
2600–3250		6	H_2O, CH_4	
3250–4000		12	H_2O, CO_2	H_2O, CO_2
4000–4650		8	H_2O, CH_4	CH_4
4650–5150		8	H_2O, CO_2	CO_2
5150–6150		10	H_2O, CH_4	H_2O, CH_4
6150–7700		10	H_2O, CO_2	H_2O, CO_2
7700–8050		2	H_2O, O_2	O_2
8050–12850		10	H_2O	
12850–16000		8	H_2O, O_2	O_2
16000–22650		6	H_2O	
22650–29000		6		
29000–38000		8	O_3	O_3
38000–50000	0.2 microns	2	O_3, O_2	O_3, O_2

14 BANDS

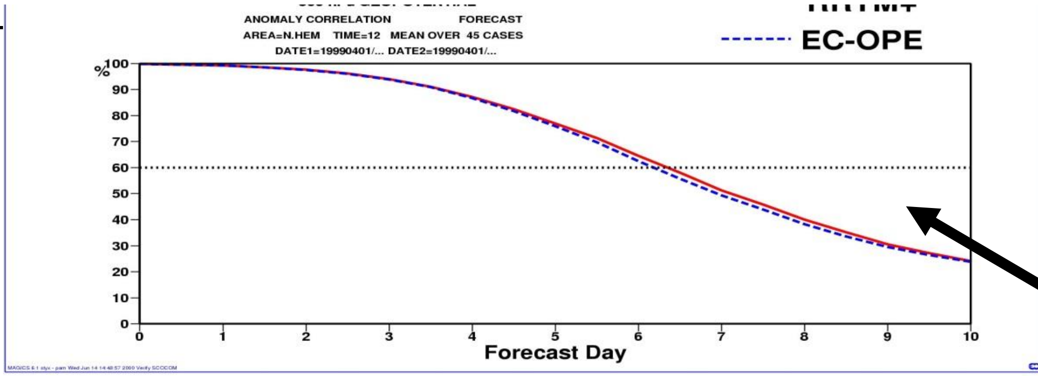
112 g-points

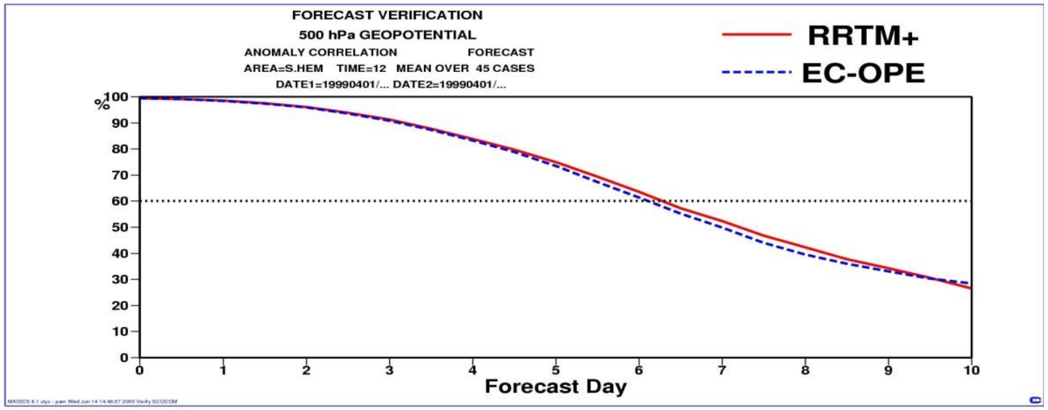
ECMWF

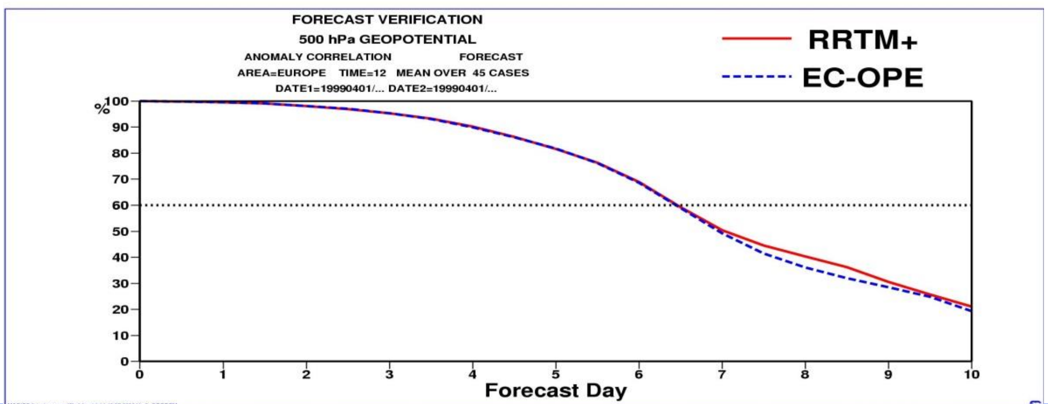
RRTM_LW vs. M91/G00:
Impact when operationally introduced in 2000



RRTM_LW vs. M91/G00 - 4

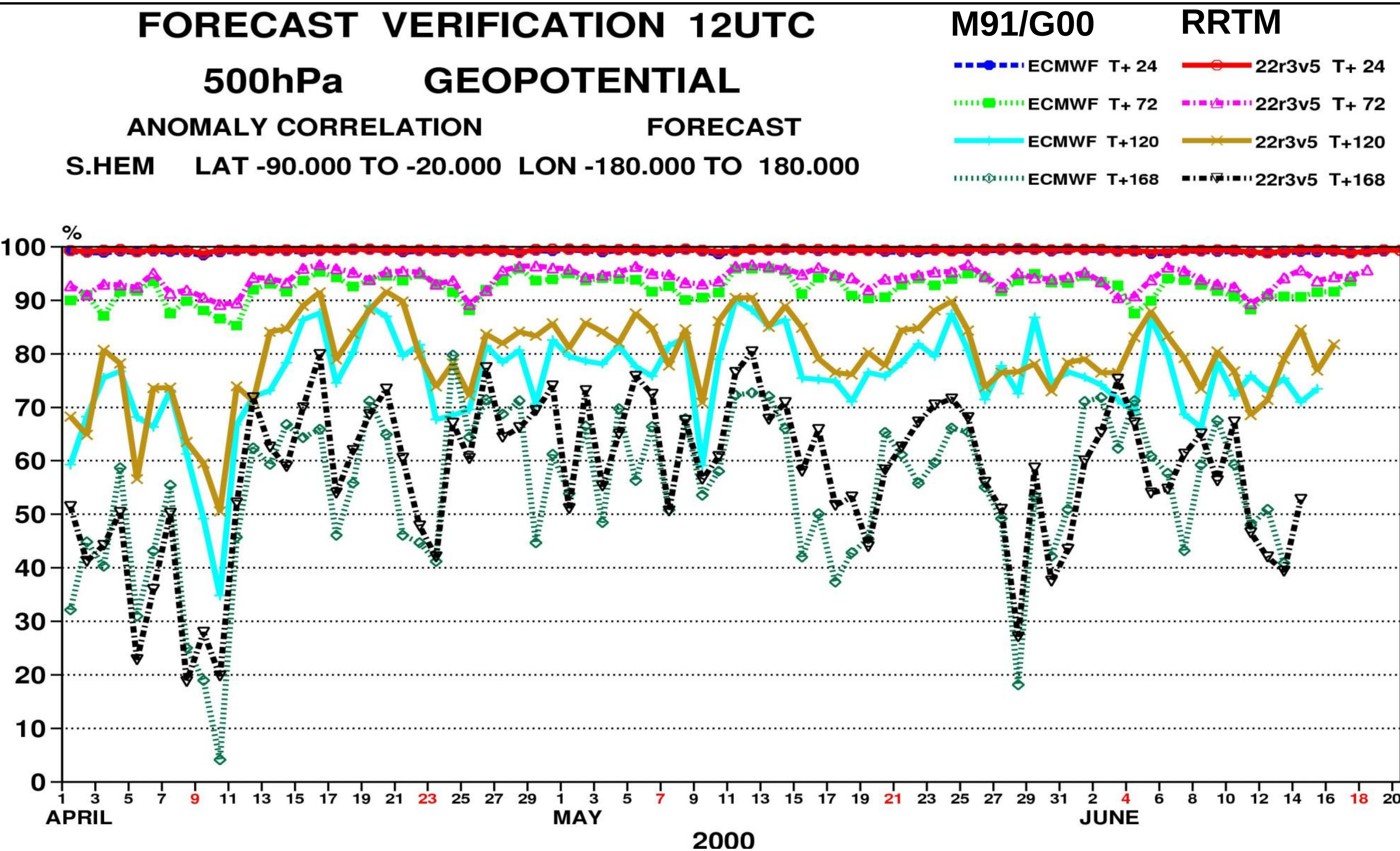






Objective scores: RRTM vs. M91/G00

RRTM vs. M91/G00 - 5



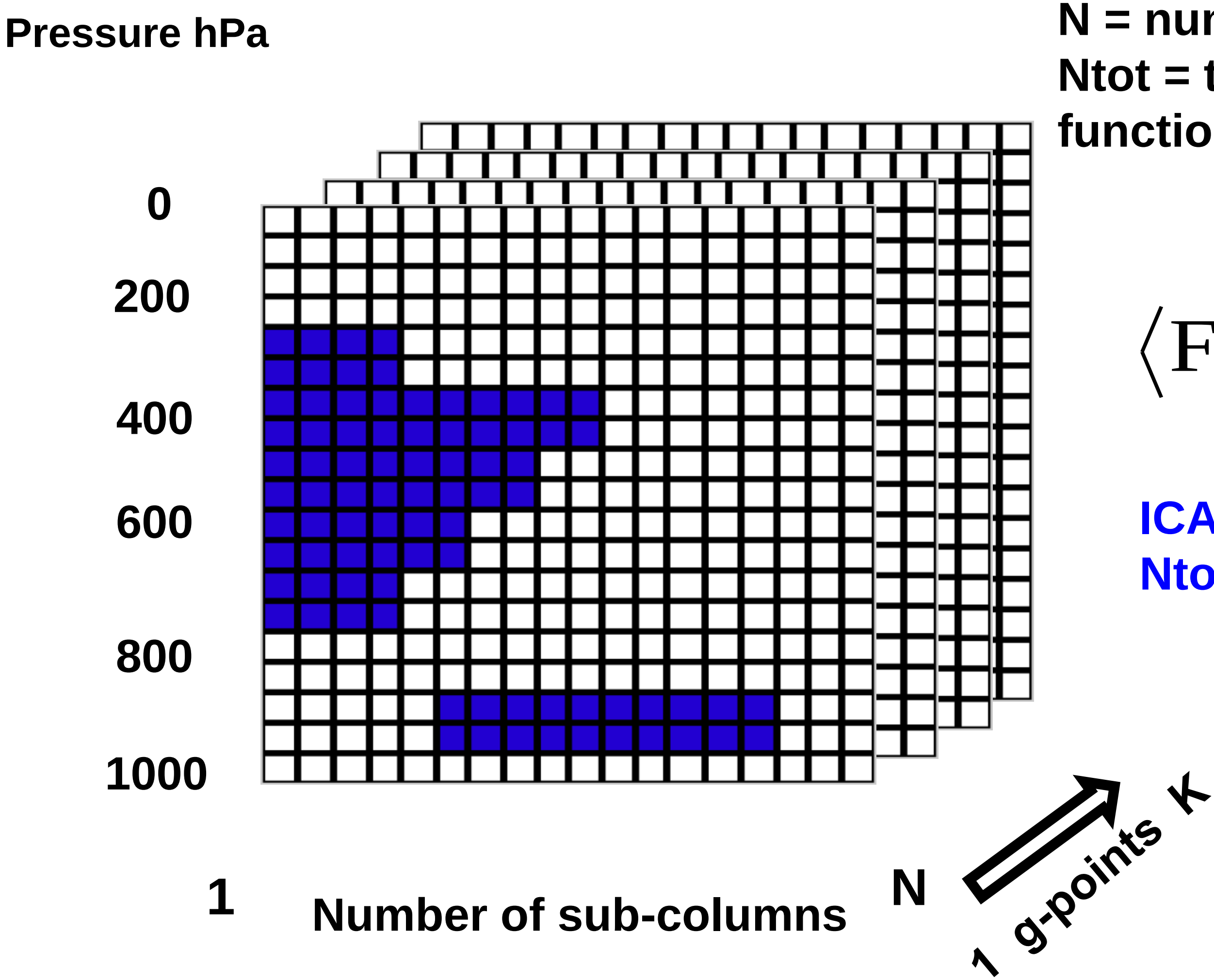
ECMWF

McICA in 2 figures

Barker et al. (2003),
Pincus et al. (2003)

K = number of spectral intervals (g-points)

N = number of independent sub-columns
Ntot = total number of transmission function computations



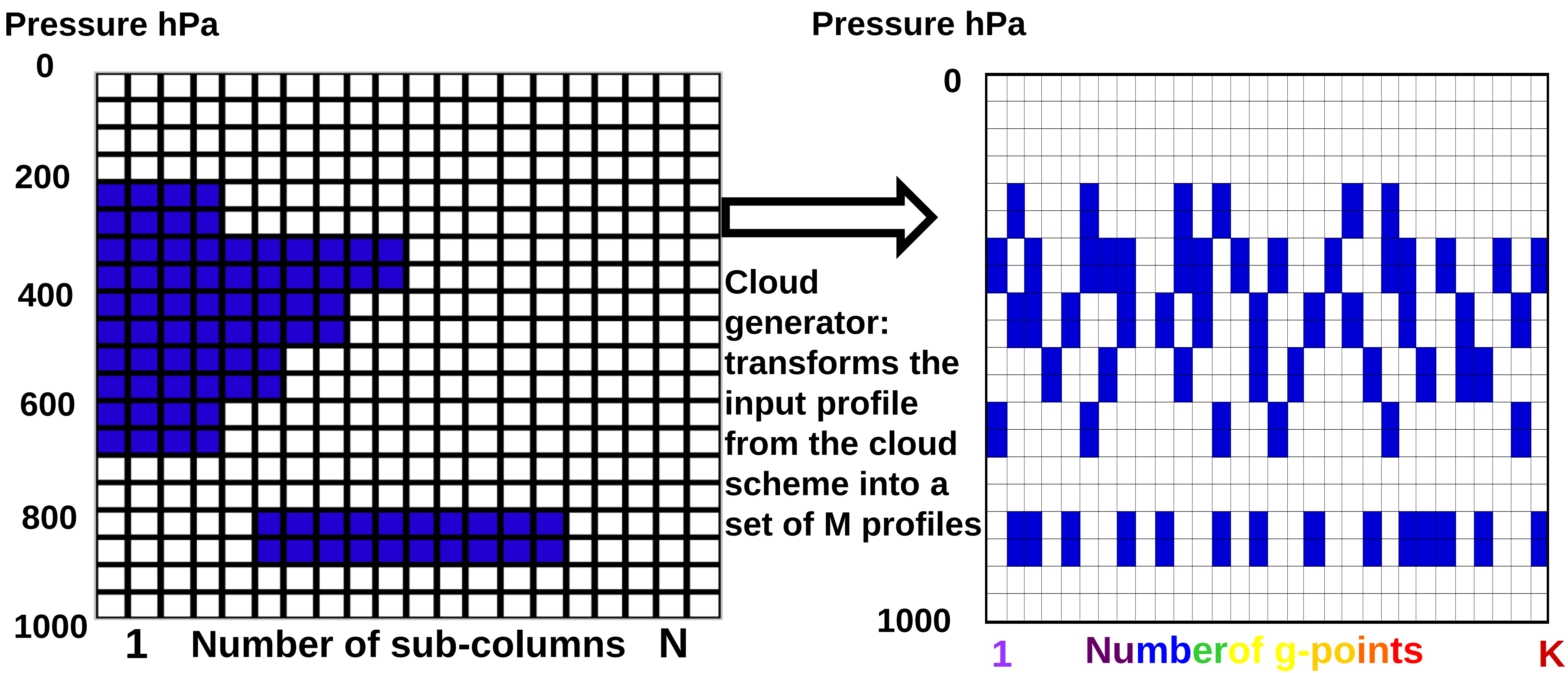
$$\langle \mathrm{F} \rangle = \frac{1}{N} \sum_{n=1}^{N} \sum_{k=1}^{K} c_k F_n$$

ICA RT scheme:
Ntot = N * K ~ O(10^3)

ECMWF

McICA in 2 figures

Cloud generator:
Raisanen et al. (2004)



McICA: approximates $< F > = \frac{1}{N} \sum_{n=1}^{N} \sum_{k=1}^{K} c_k F_{n,k}$ into $< F > \sim \sum_{k=1}^{K} c_k F_{n_k,k}$

ECMWF

ECMWF+McICA - configuration

- Random errors are a consequence of the incomplete pairing of sub-columns and spectral intervals.
- The errors are unbiased with sufficiently large samples (140+112 for RRTMG)
- No explicit need for cloud fraction: at each level the cloud, if present, fills the whole layer. Cloud overlap assumption in the cloud generator as in Hogan and Illingworth (2000,2003)
- A way to deal with uncertainty in sub-grid cloud distribution

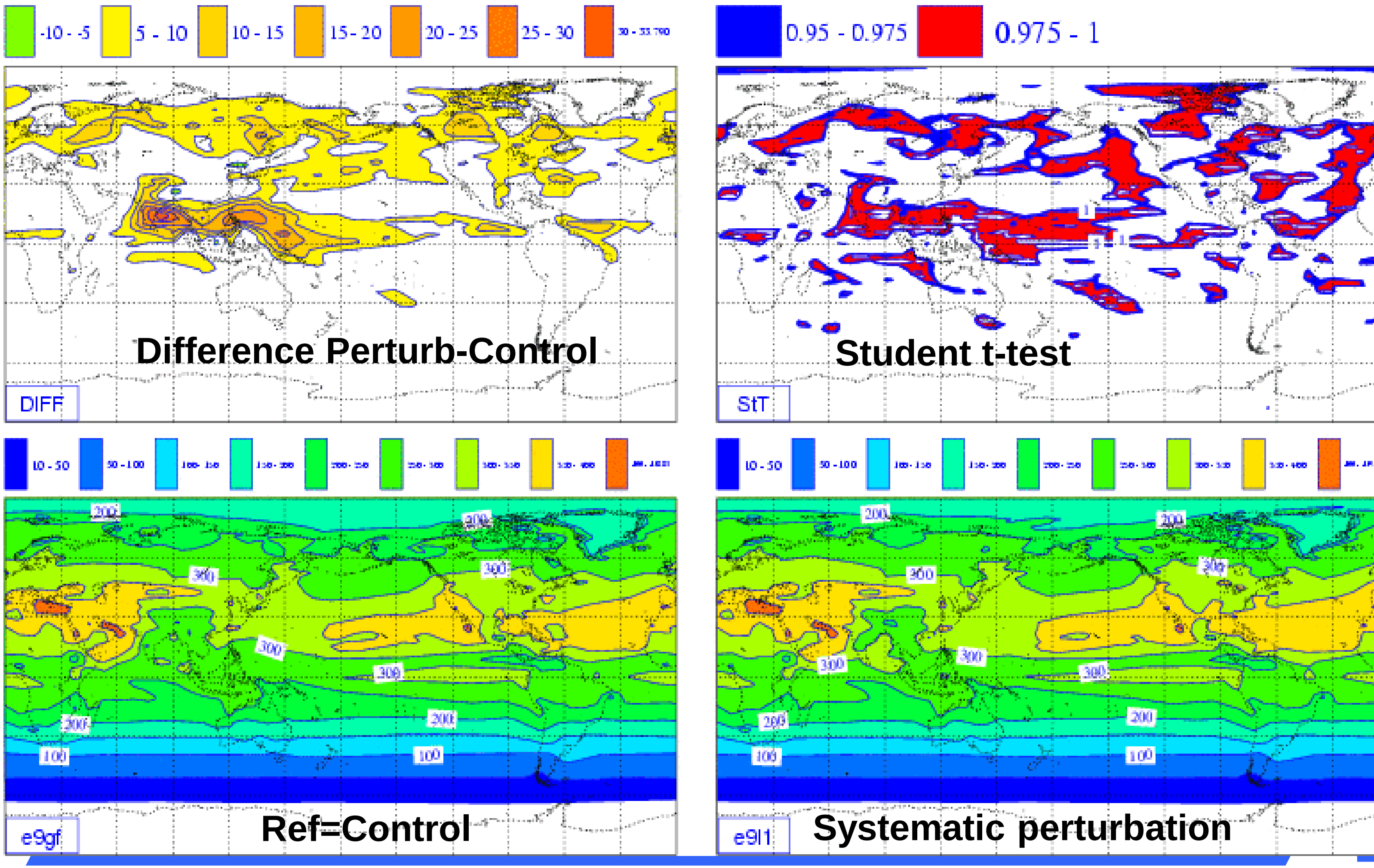
McICA: A state-of-the-art method for representing cloud-radiation interactions?

- In long seasonal runs and high-resolution 10-day forecasts
  - How does the model survive noise in radiative heating rate?
  - How does the model survive noise in layer cloud fraction?

- Tests with 31x10-day FC at T_L319L60 from 20010401 to 20010501
- Tests with 4-month simulations at T_L95 L60 for same period
  - control (control)
  - random perturbation within Gaussian distribution (the relevant quantity x -> x (1+σ*ran)
    - ➔ σ=2 CF (1-CF) applied on x = CF (random1) (cloud fraction)
    - ➔ σ=1.5 CF $|HR_{tot}|$ applied on x = HR (random2) (heating rate)
    - ➔ σ=2 CF sqrt $(HR_{LW}^2+HR_{SW}^2)$ applied on x = HR (random3) (heating rate)

McICA: Hoes does the model deal with radiative noise?

Ocean e9gf Control 214.7 e9l1 PertRe1/10. 217.4 Diff= 2.7
3-Month Mean 2880_720 ToA Net SW Rad. W/m2
Global e9gf Control 226.5 e9l1 PertRe1/10. 229.4 Diff= 3.0
Area 95%: 24.02 area >97.5%: 18.35 cases: 10 nexp: 30



Systematic perturbation:

Re +1 μm
De +10 μm

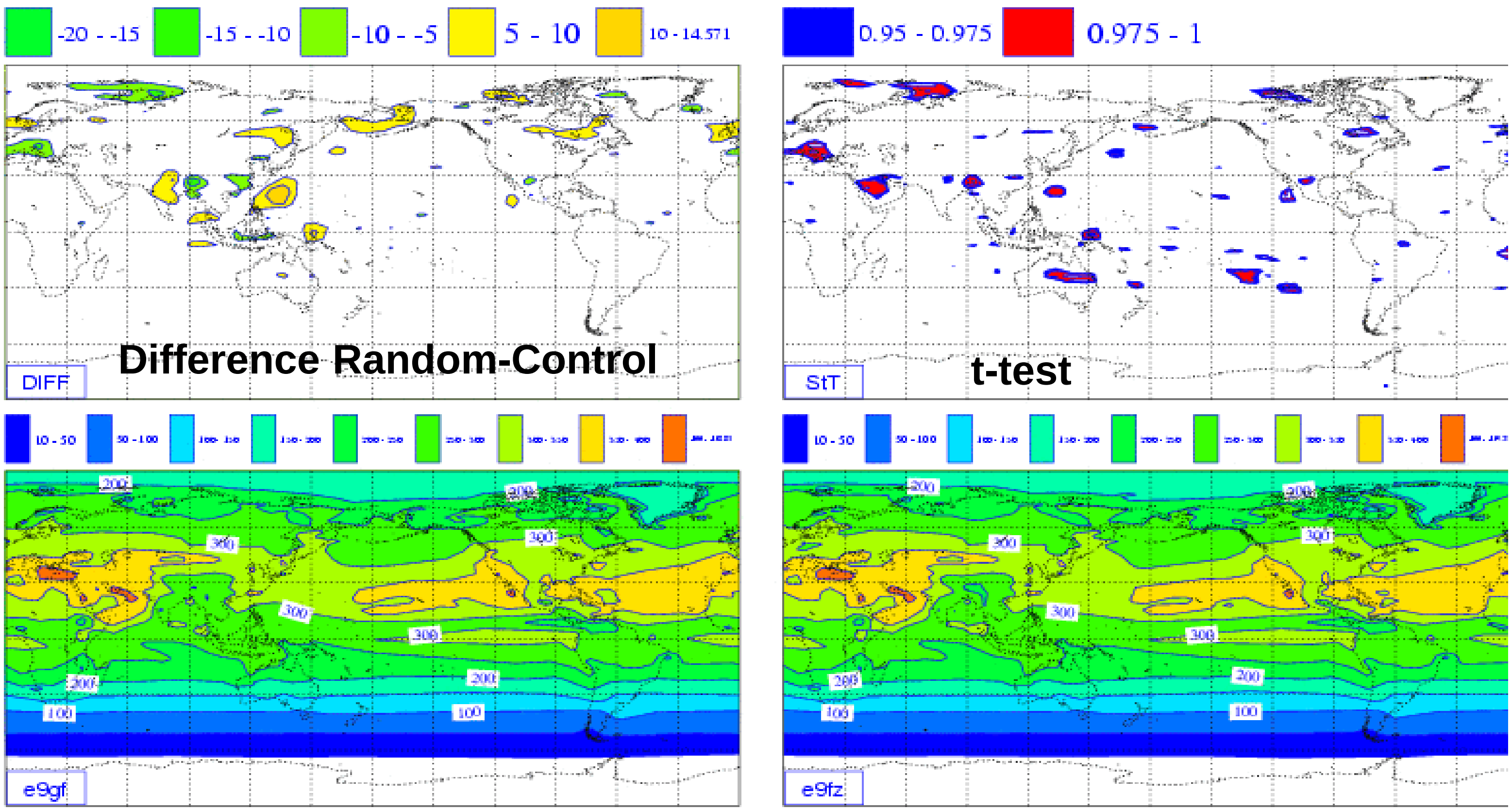
T_L95 L60 starting 24-hour apart from 20010401 to 20010430

Results averaged over JJA

ECMWF

McICA: Hoes does the model deal with radiative noise?

Ocean e9gf Control 214.7 e9fz PertRan 214.5 Diff= -0.2
3-Month Mean 2880_720 ToA Net SW Rad. W/m2
Global e9gf Control 226.5 e9fz PertRan 226.6 Diff= 0.1
Area 95%: 2.73 area >97.5%: 1.43 cases: 10 nexp: 30



Random perturbation:

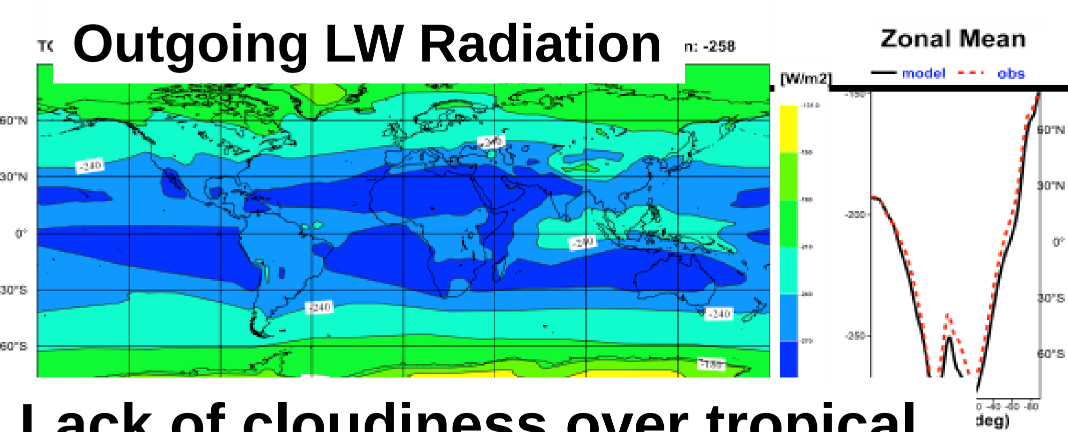
random3

Results

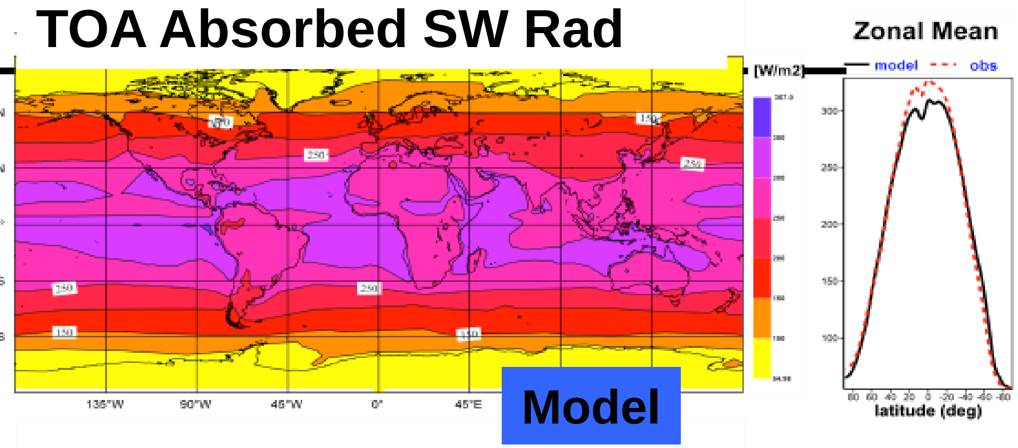
- Impact in sets of 13-month runs at T_L159 L91
- Impact in 10-day forecasts at T_L799 L91

The problem in ECMWF model "climate" runs? Example from 31R1

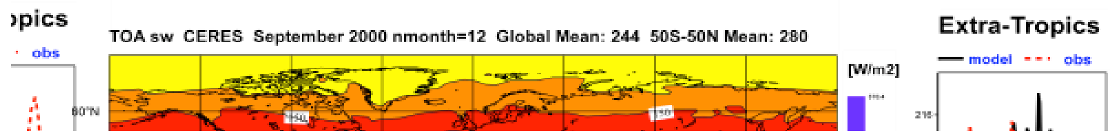
Outgoing LW Radiation



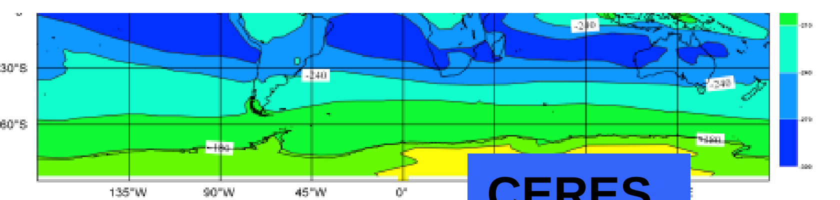
TOA Absorbed SW Rad



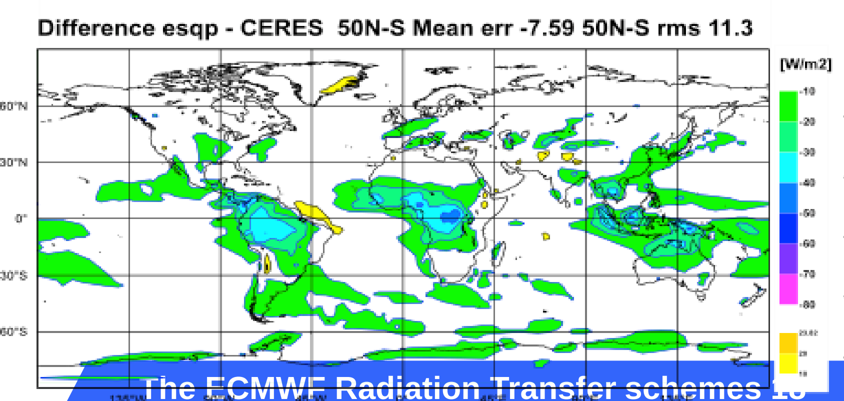
Model



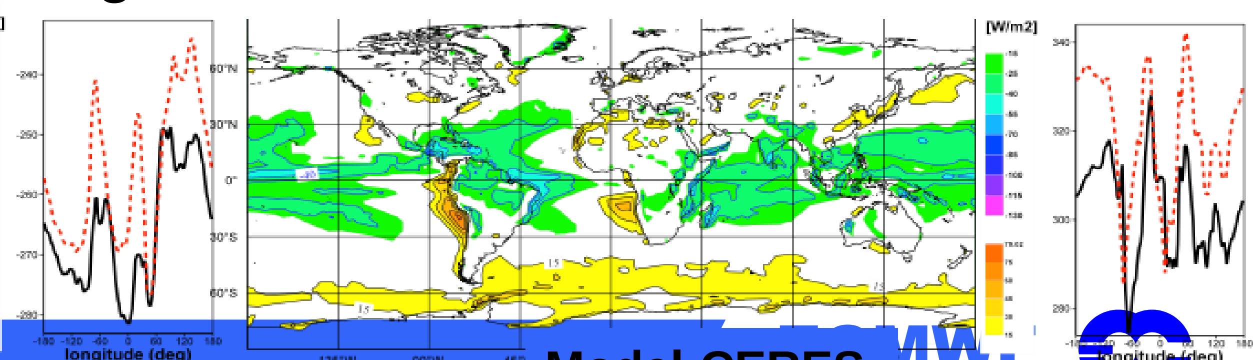
Lack of cloudiness over tropical continents:
Too large OLR over Africa, South America



CERES

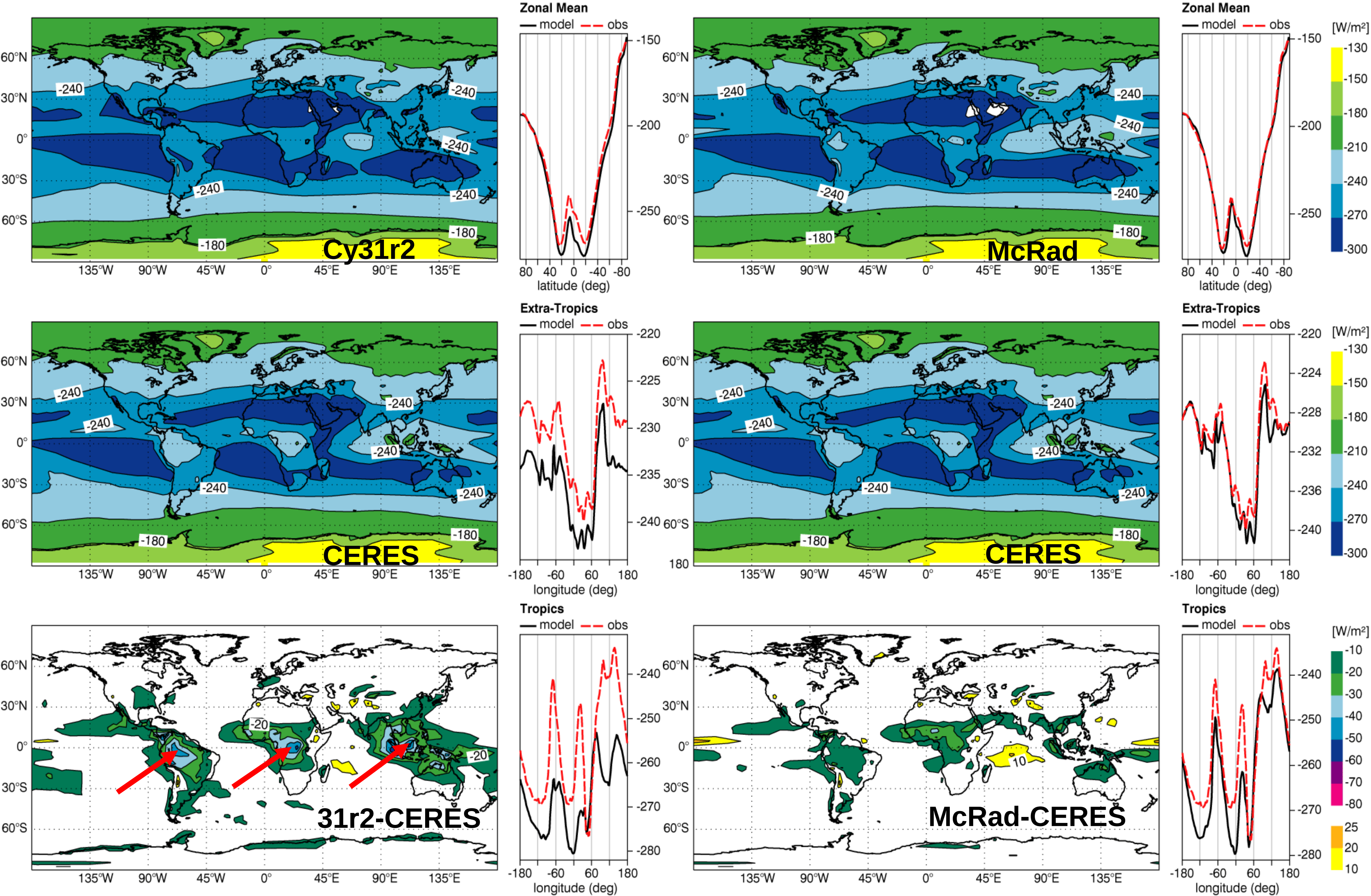


Too much cloudiness over tropical oceans
Too much reflection at TOA, too little downward SW radiation at the ocean surface. Little reflection in stratocumulus regions and close to Antarctica

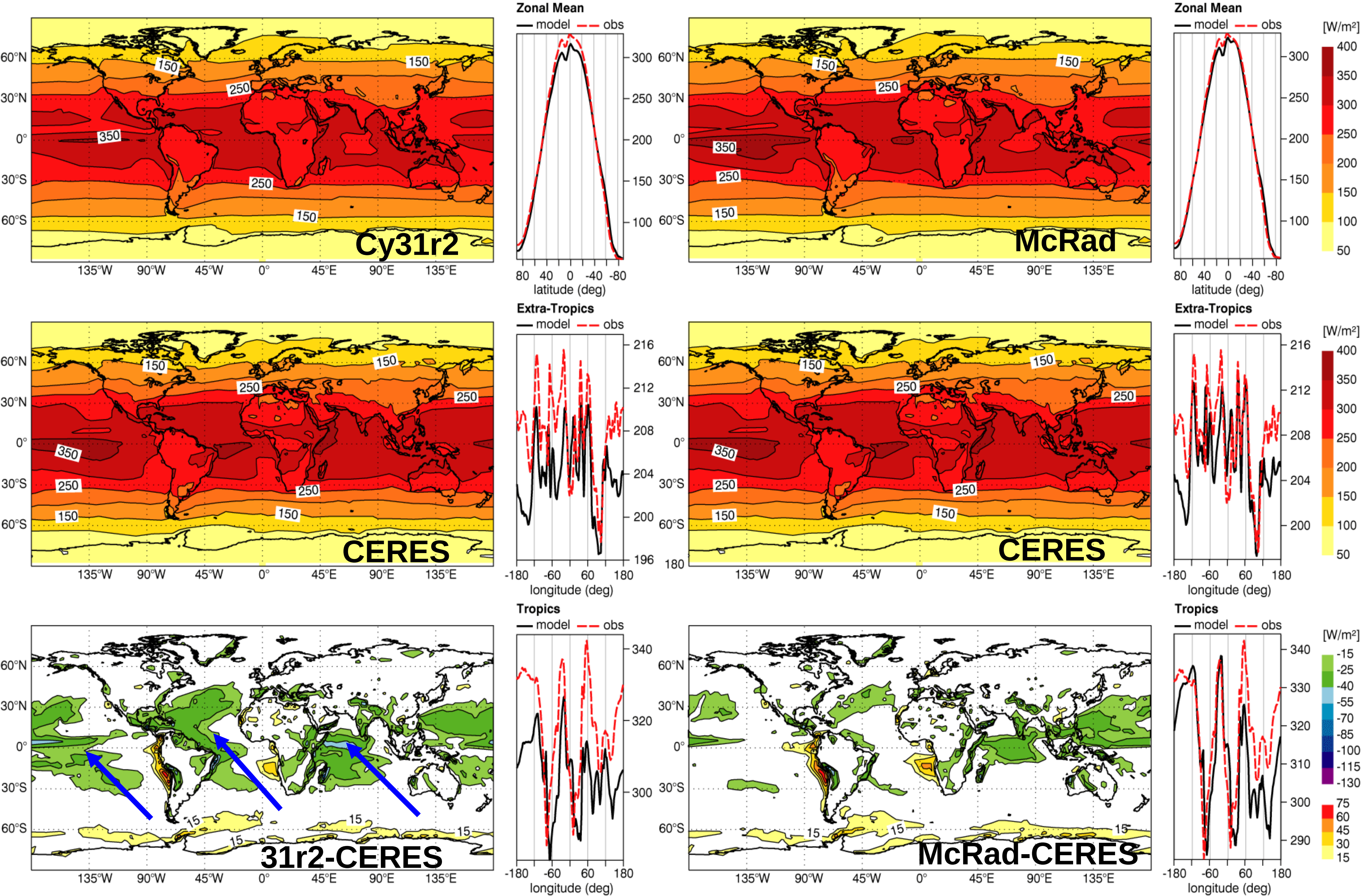


Model-CERES

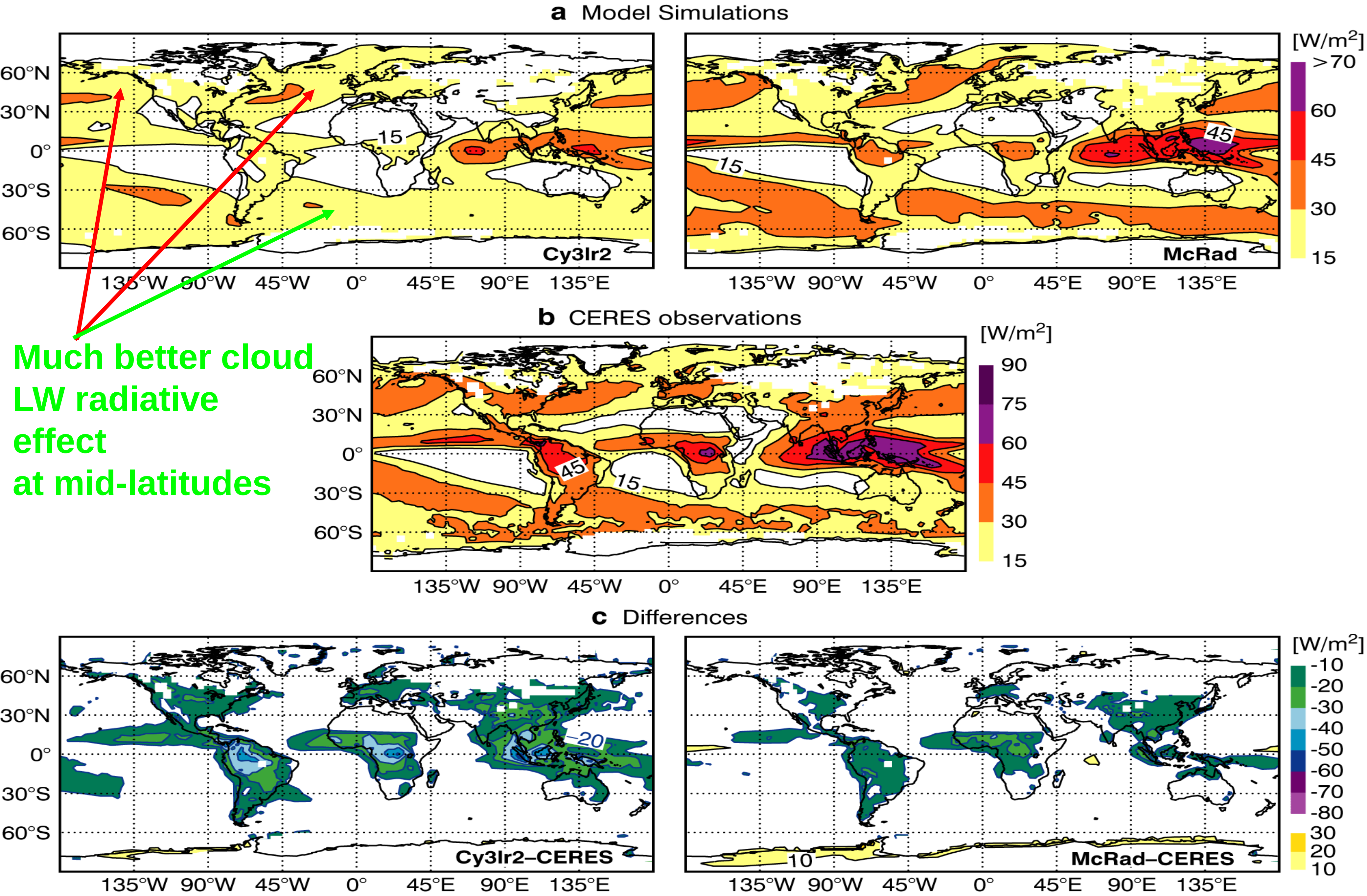
Impact on OLR in ensembles of 1-year simulations



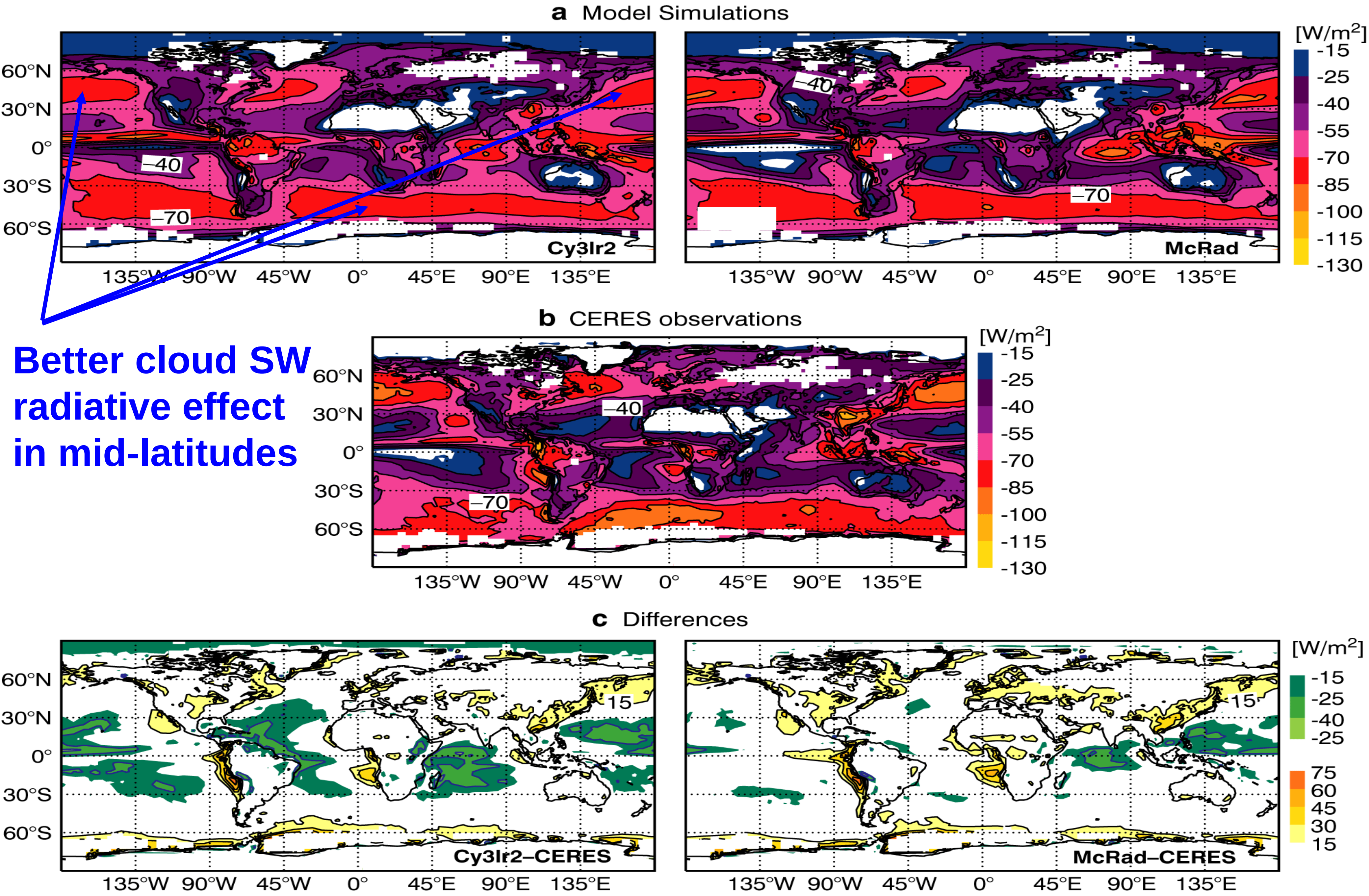
Impact on TOA absorbed SW radiation in ensembles of 1-year simulations



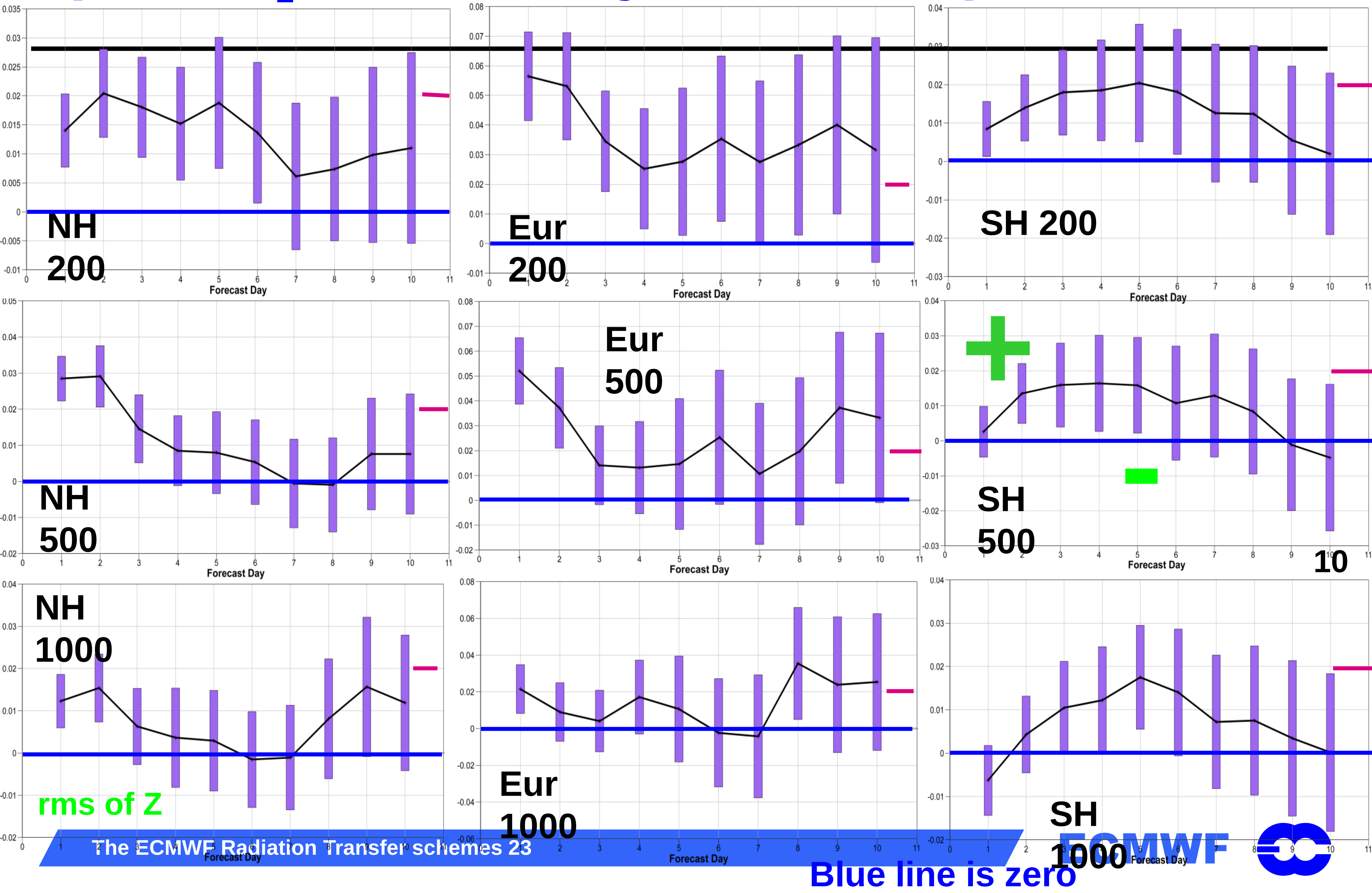
Impact on long-wave cloud forcing in ensembles of 1-year simulations



Impact on short-wave cloud forcing in ensembles of 1-year simulations



Impact in T_L799 L91 10-day FCs Dec'06-Apr'07



ECMWF

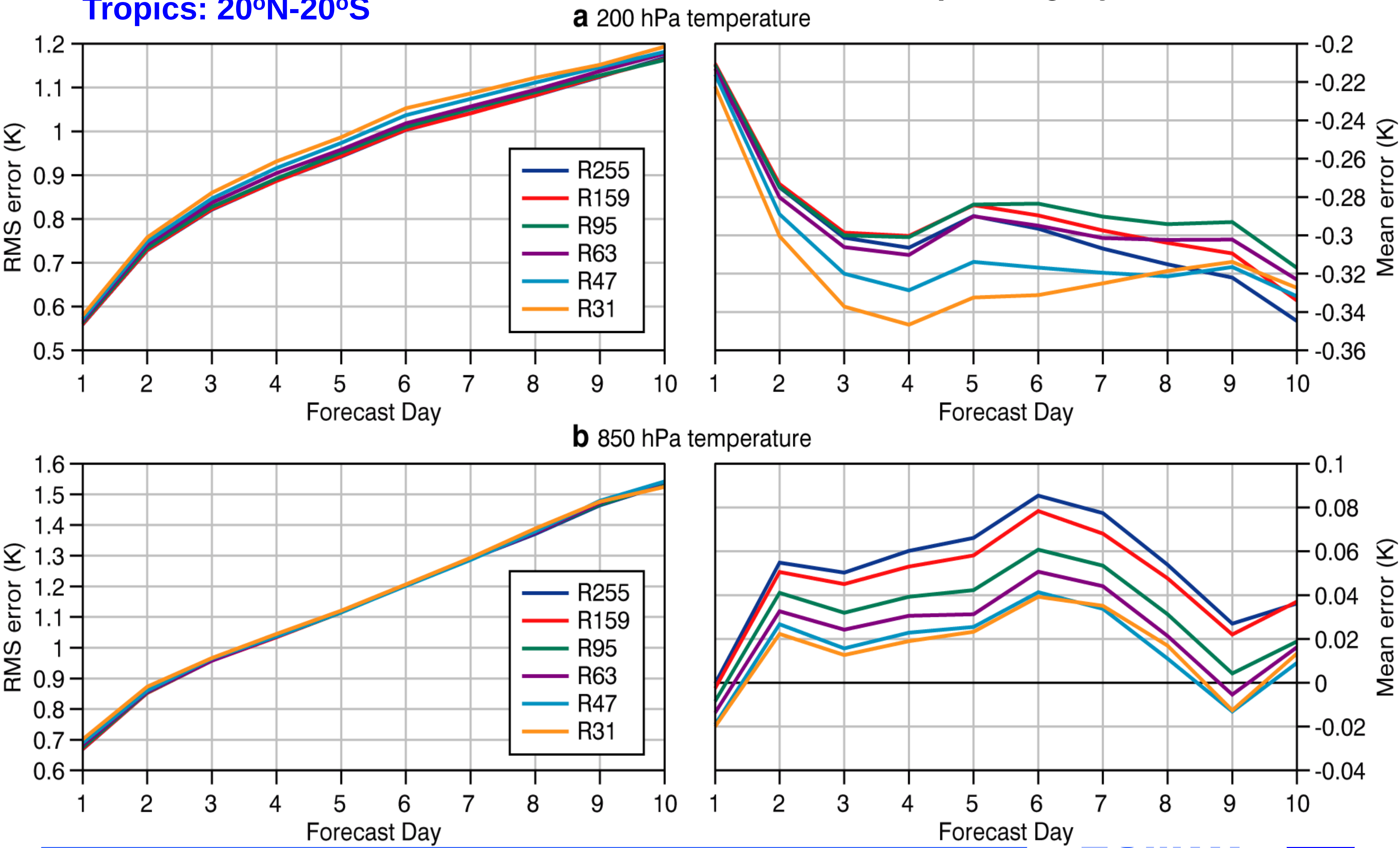
McRAD spatio-temporal resolution

- Even if optimised, McRAD is computationally expensive (mostly due to the SW scheme)
- Operationally, the RT code runs on a spatial grid coarser than the rest of the physics and with a longer time step
  - HiRes 10 day forecasts: model T1279 (~16 km at the equator) McRAD T511 (~40 km). Model time step 10 min, McRAD 1h
  - Ensemble forecasts: model T639 (~30 km), McRAD T255 (~70 km). Model time step 20min, McRAD 3h
- LW flux constant between radiation calls, SW adjusted with the solar zenith angle. Minor impact on diurnal cycle, larger for the 3h time step

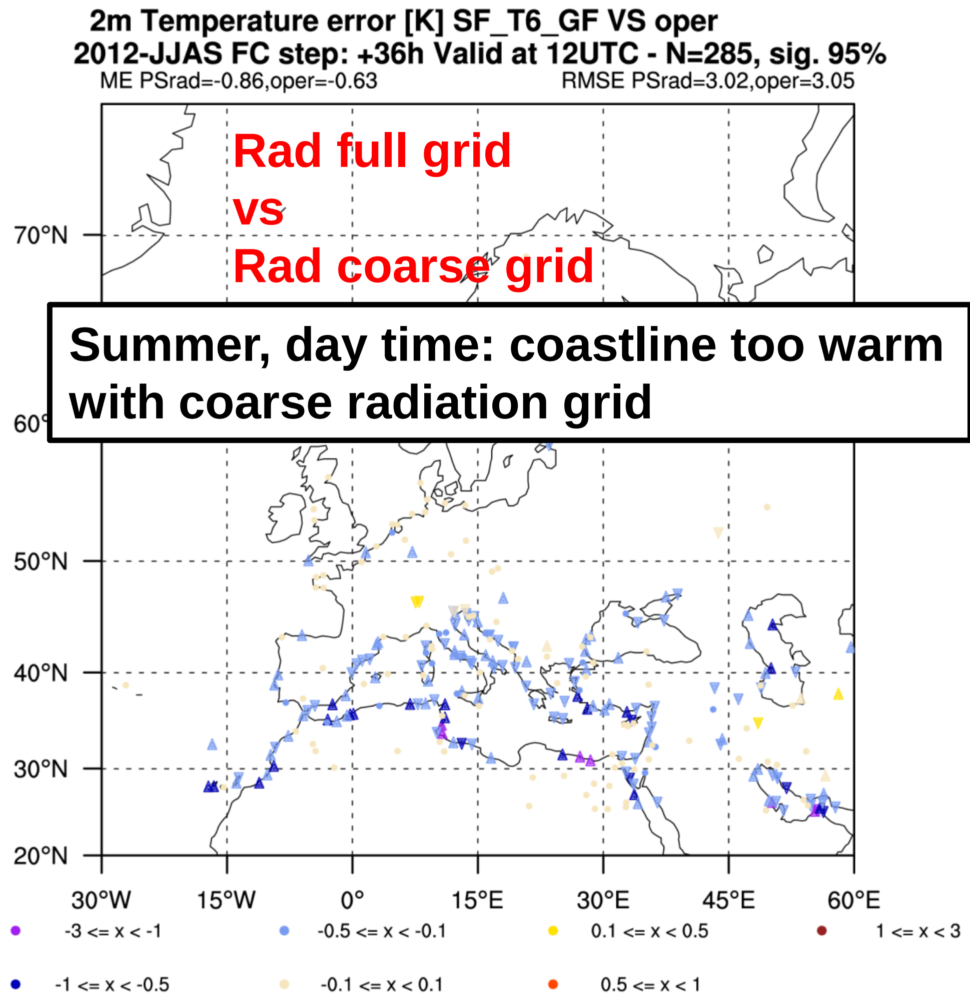
Impact of reduced radiation grid

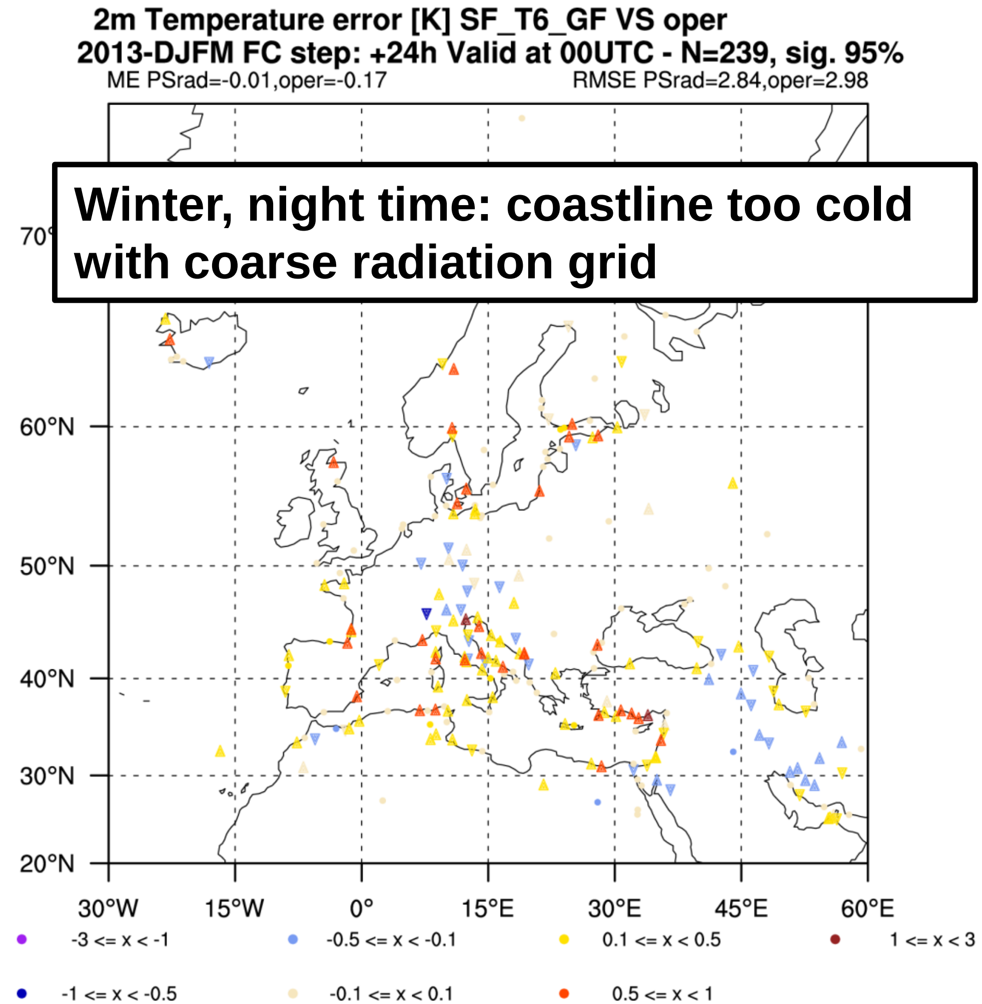
For 93 FCs at T_L399 L62 spanning a year

Tropics: 20ºN-20ºS



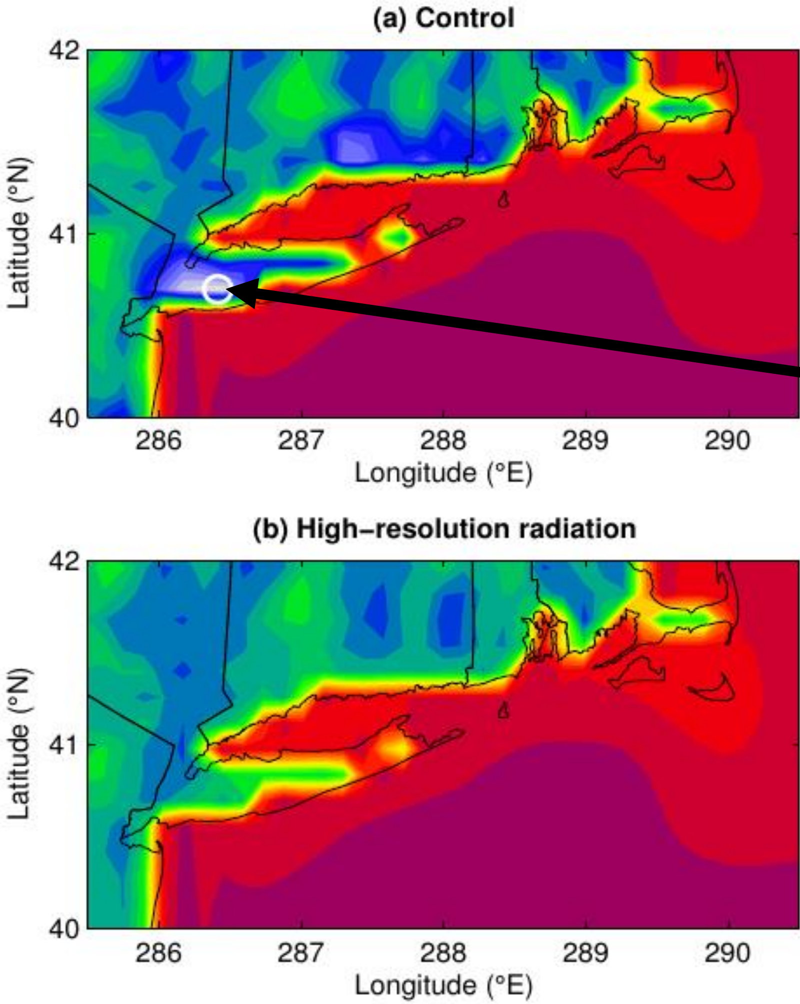
Reduced radiation grid: 2m temperature



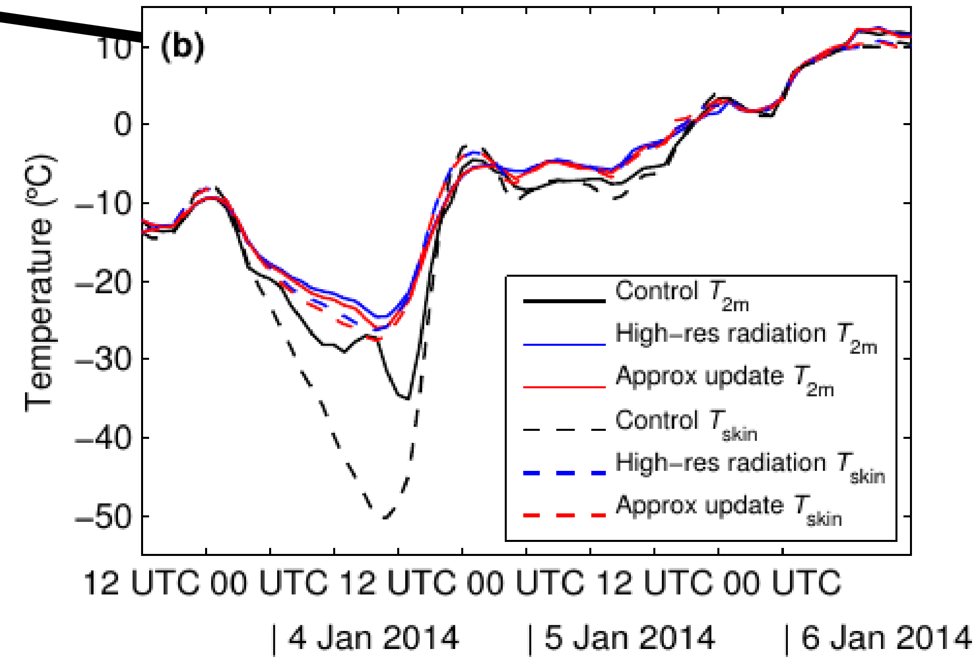


Bozzo et al., 2014

Extreme cases at coastlines

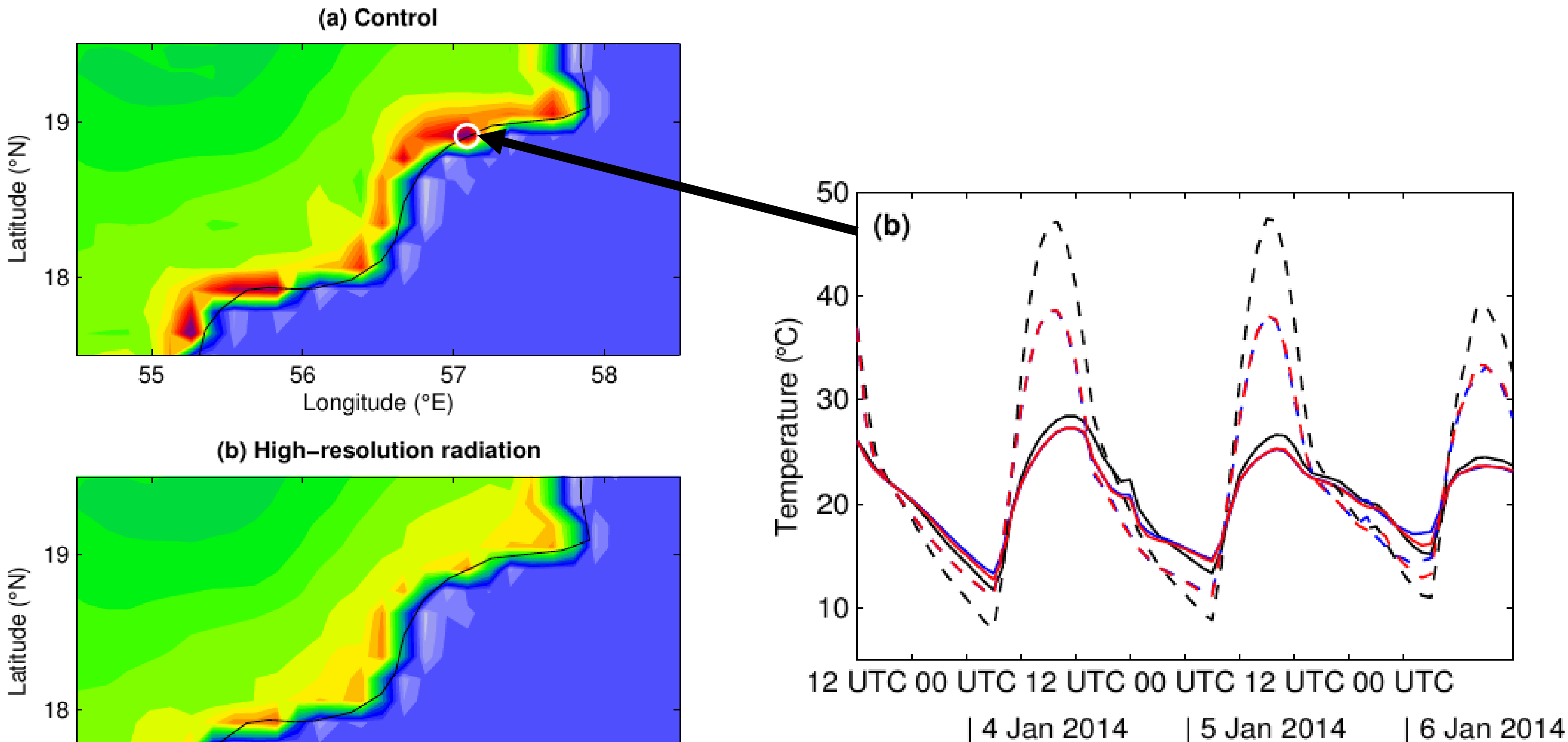


Approximate solution of the surface energy balance taking into account local albedo and changes in the skin temperature reduces the impact of the coarse radiation grid and time step



Hogan&Bozzo 2015

Extreme cases at coastlines



Hogan&Bozzo 2015

Conclusions on McRad

- As McRad modifies the cloud-radiation interactions, its impact is felt right from the start of the model integrations.

- Thanks to McICA and the revised cloud optical properties, improvements in TOA radiation is seen both in the tropics and at higher latitudes.

- Whereas McICA does not increase the computational burden, RRTM_SW does. But RRTM_SW and RRTM_LW share the same heritage: based on the same state-of-the-art line-by-line model (LBLRTM), same database of spectroscopic parameters, and both extensively validated as part of the ARM program.

- Going for a slightly lower resolution for full radiation computations does not affect the quality of the high-resolution 10-day forecasts. A lower resolution radiation grid neither degrades the quality of the EPS. But biases are introduced in surface fields and these can lead to large errors occasionally

Conclusions on McRad (continued)

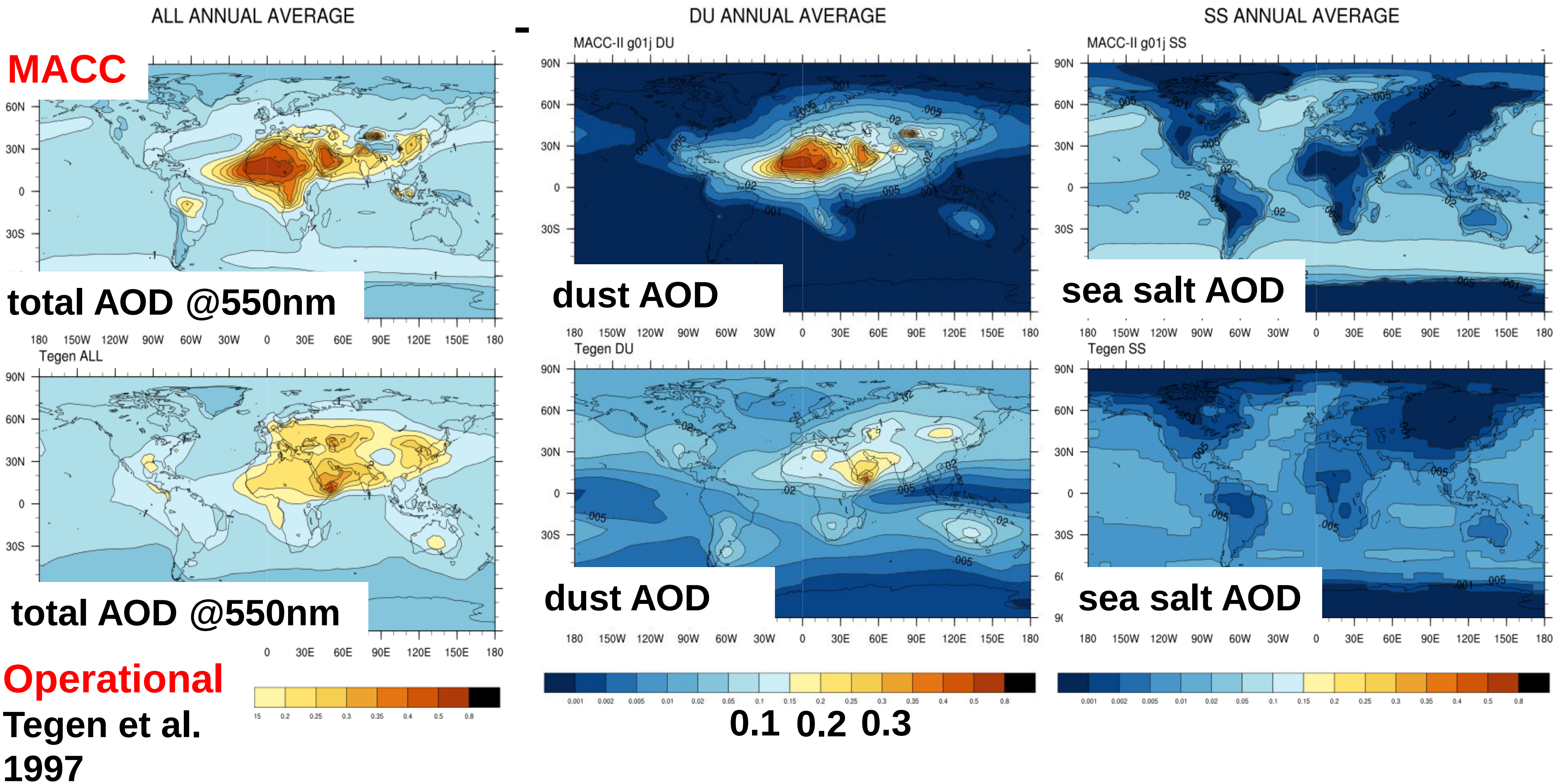
- The model shows little dependence on the decorrelation length used for cloud fraction and cloud water. But this formulation will allow further developments once information on these quantities becomes available from cloud/cloud water profiles derived from CLOUDSAT/CALIPSO measurements.

- The McICA approach appears particularly adapted to pdf-based cloud schemes.

Ongoing development

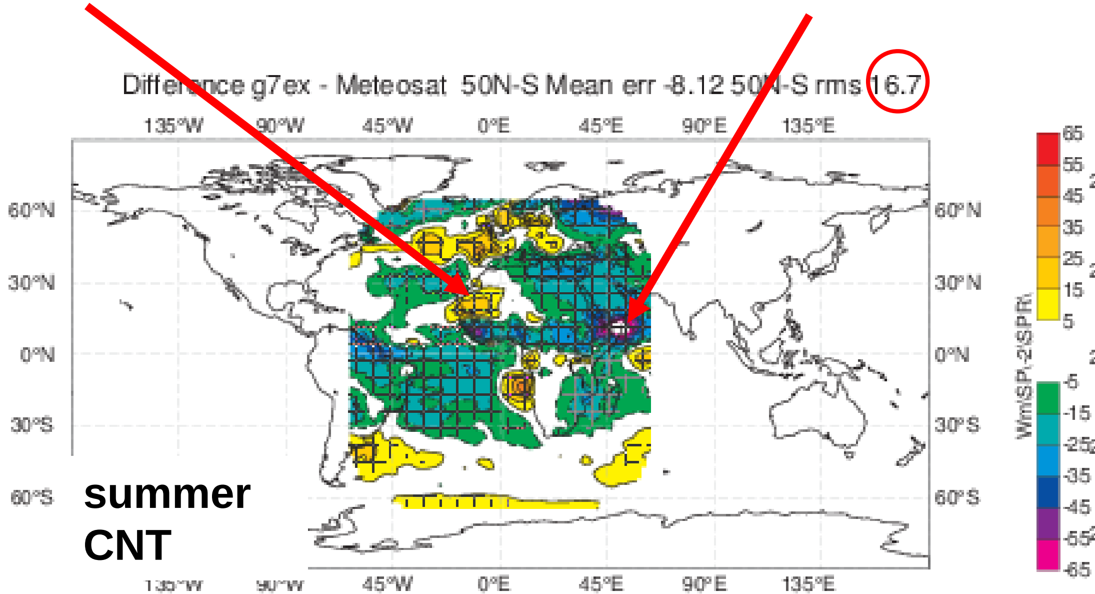
- Revision of the current aerosol climatology (Tegen et al. (1997), 5 species sea salt,dust,organic,black carbon and sulphates) -> towards interactive aerosols?
- Interactive radiatively active gases (e.g. Ozone -> Johannes Flemming lecture)?
- Code efficiency improvements. Number of g-points maybe over-dimensioned ? Will need to reduce at least 10x to improve the efficiency. Positive tests with stochastic spectral integration (Pincus and Stevens 2009,2013, Bozzo et al. 2014). Other options -> see Robin's lecture on Friday
- 3D radiation, long wave scattering

Climatological aerosol distribution – MACC vs operational

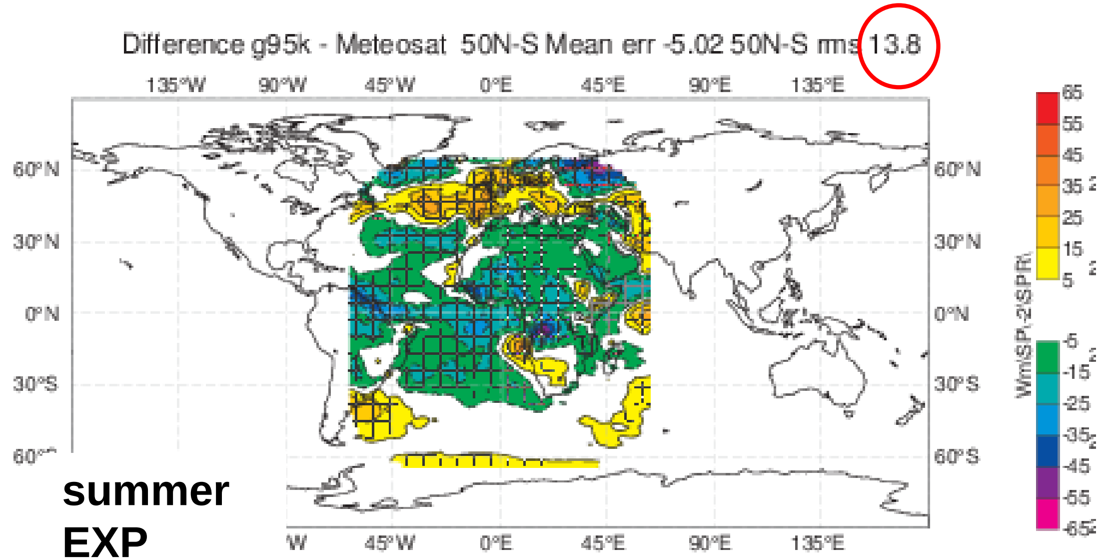


- Large differences in total AOD distribution for Sea salt, Organic, Black Carbon, Dust.

Biases in surface solar radiation (against geostationary sat product CM SAF)



Large bias in the current climatology in dust regions in summer

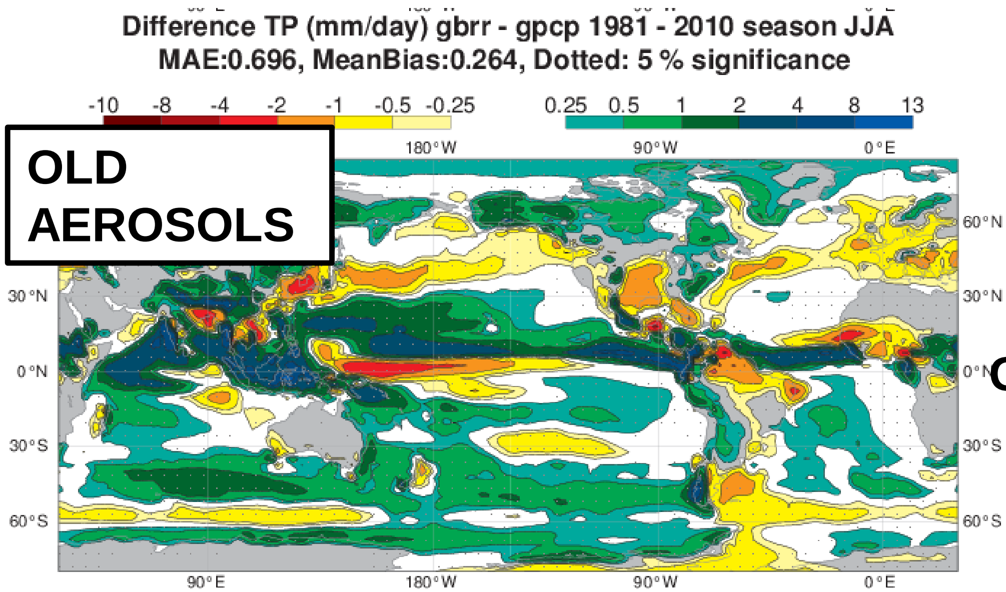


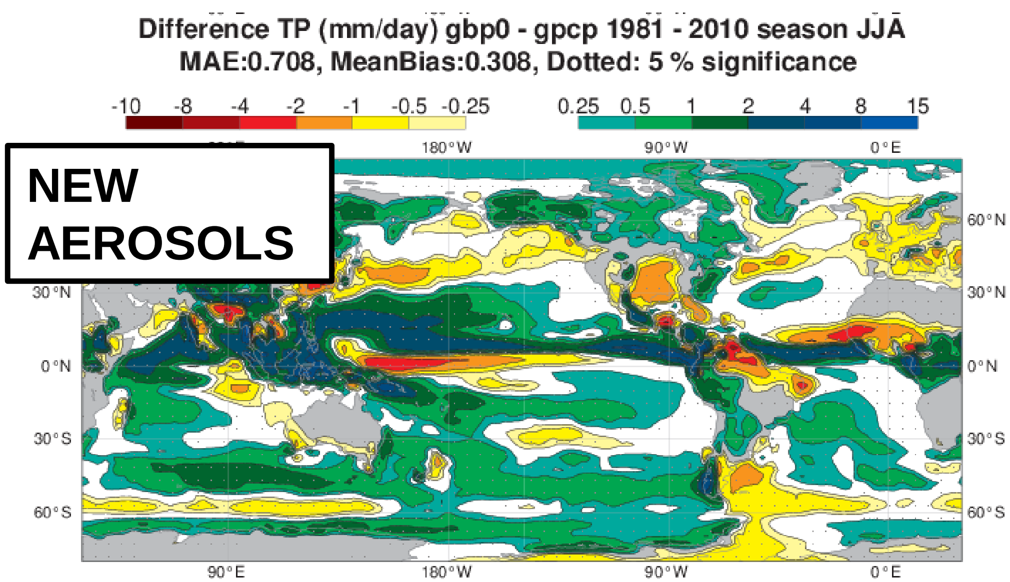
AOD from MACC reduces the bias

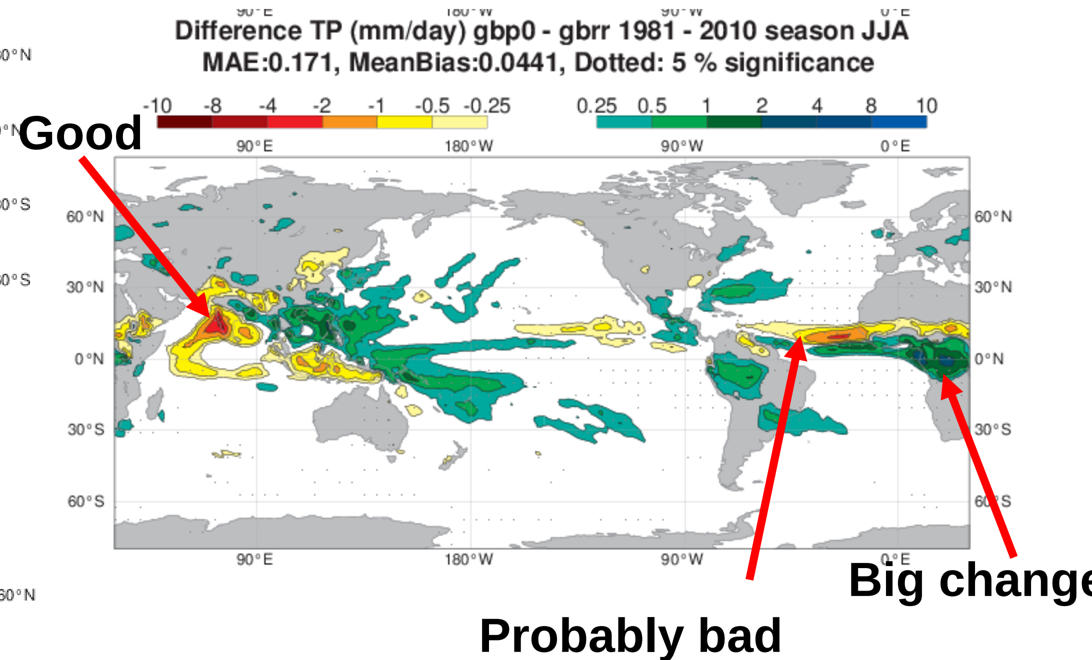
ECMWF

Impact on large scale circulation in coupled climate simulations

JJA precipitations







ECMWF