Climate and Computational Savings of the Lower Resolution Physics Grid in CESM

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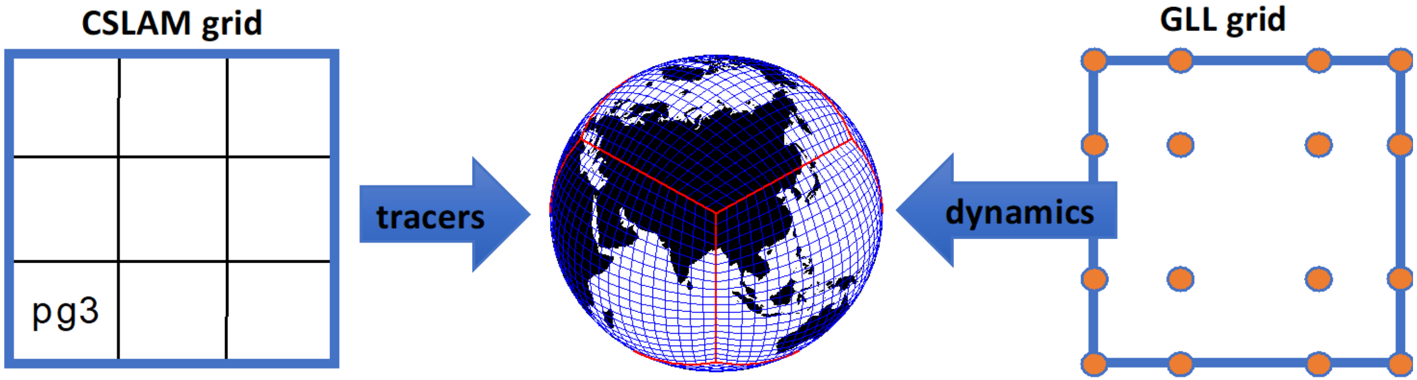
Winter AMWG Meeting, 2020

CAM-SE-CSLAM

Conservative **S**emi-**La**grangian **M**ulti-tracer Transport



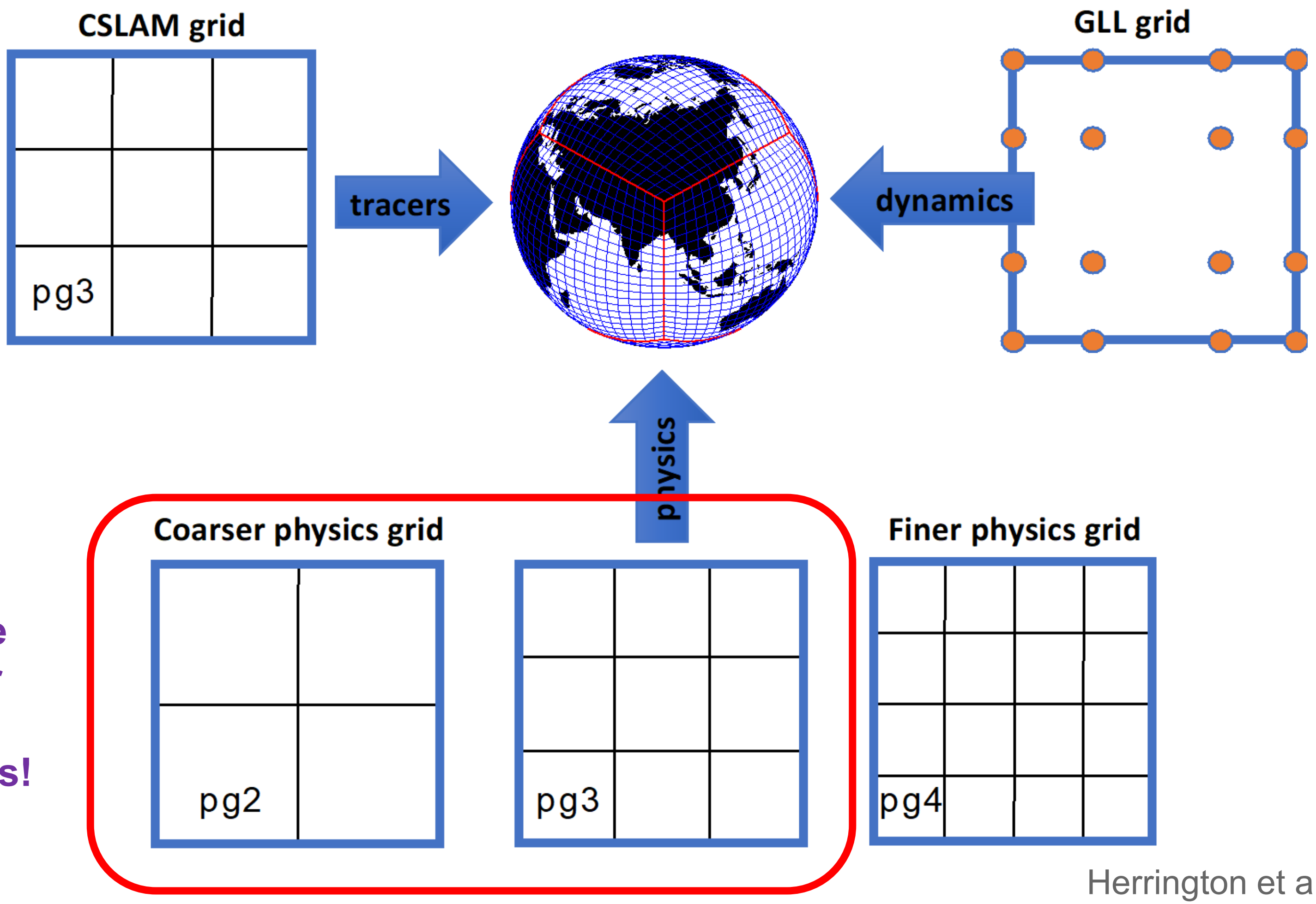
Improvements over CAM-SE:

- Accelerated multi-tracer transport
- Preserves linear correlations between two (2) reactive species
- Mitigates against spectral-element grid-imprinting
- Model "state" lives on finite-volume CSLAM grid, rather than the GLL grid (consistent with physics / coupler)

Lauritzen et al. 2017, many more … ; Herrington et al. 2018; 2019

CAM-SE-CSLAM

Conservative **S**emi-**La**grangian **M**ulti-tracer Transport



4/9th the number of grid columns!

Herrington et al. 2018; 2019

4 Questions

1.) Does the pg2 configuration lower the effective resolution?

2.) Is the solution aliased to the pg2 physics forcing?

3.) Is the solution aliased to the pg2 topography (forcing)?

4.) What are the cost savings of the pg2 configuration?

Numerical hogwash and the effective resolution

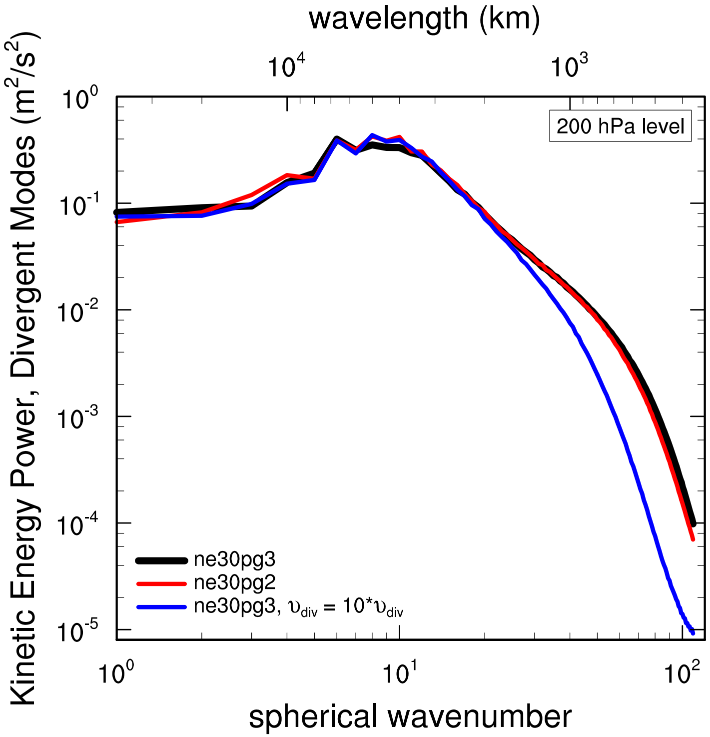
Numerical errors accumulate at the grid-scale, i.e., ***the grid scale contains unpleasantries that need to be disposed of.***

***Note**

Discretization errors grow with increasing grid spacing. Requires adjusting two (2) aspects of the model when increasing grid spacing:

1.) Increase numerical dissipation to rid the now larger pile of garbage.

2.) Smooth the topography so as to not excite grid-scale features. CESM2 uses a ~2dx smoothing radius.

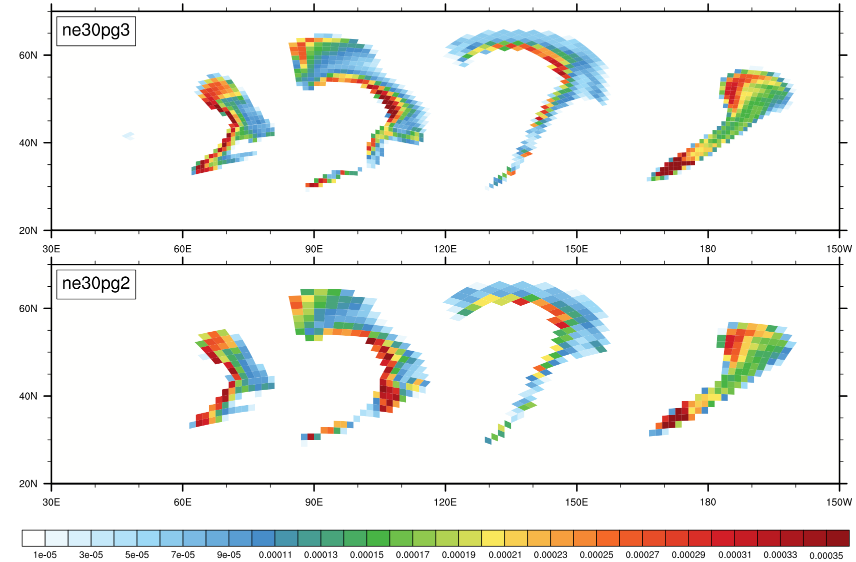


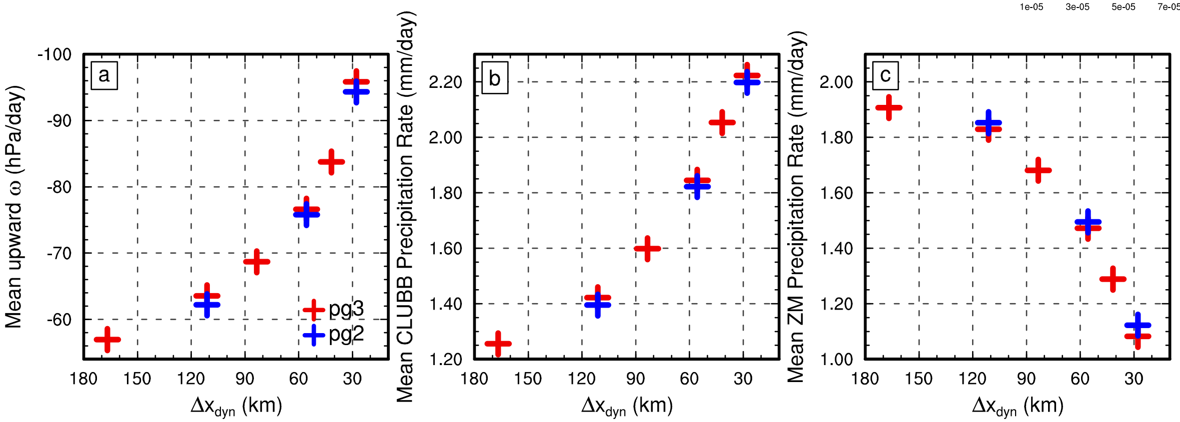
We speak of the ***effective resolution***, i.e., ***scale of the finest feature in the model that can be trusted*** ("believable scales" of Lander and Hoskins)

Does pg2 lower the effective resolution?

Done: FKESSLER
FHSTOPO
QPC6
F2000climo

Todo: B-Compset
BG-Compset





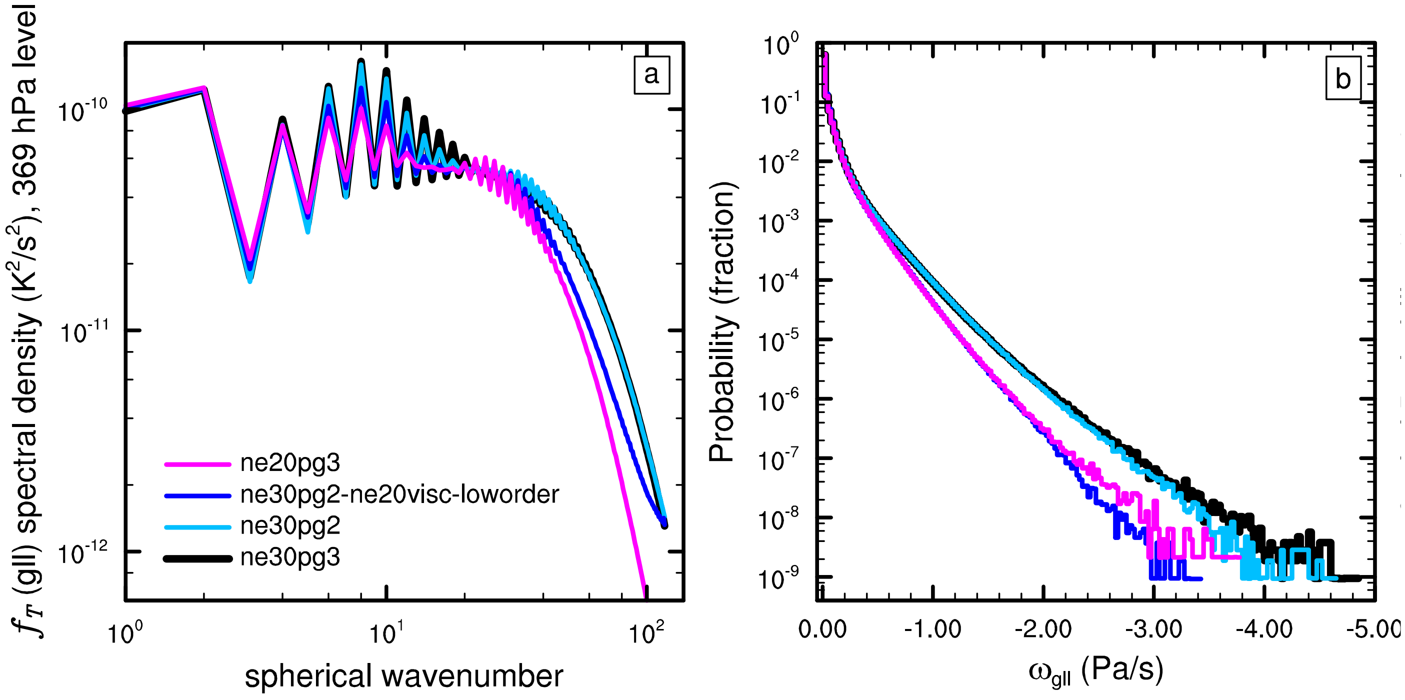
Herrington et al. 2019

The experiments indicate that the answer is: not really.
There is a modest diffusive effect, but this is un-important for most purposes.

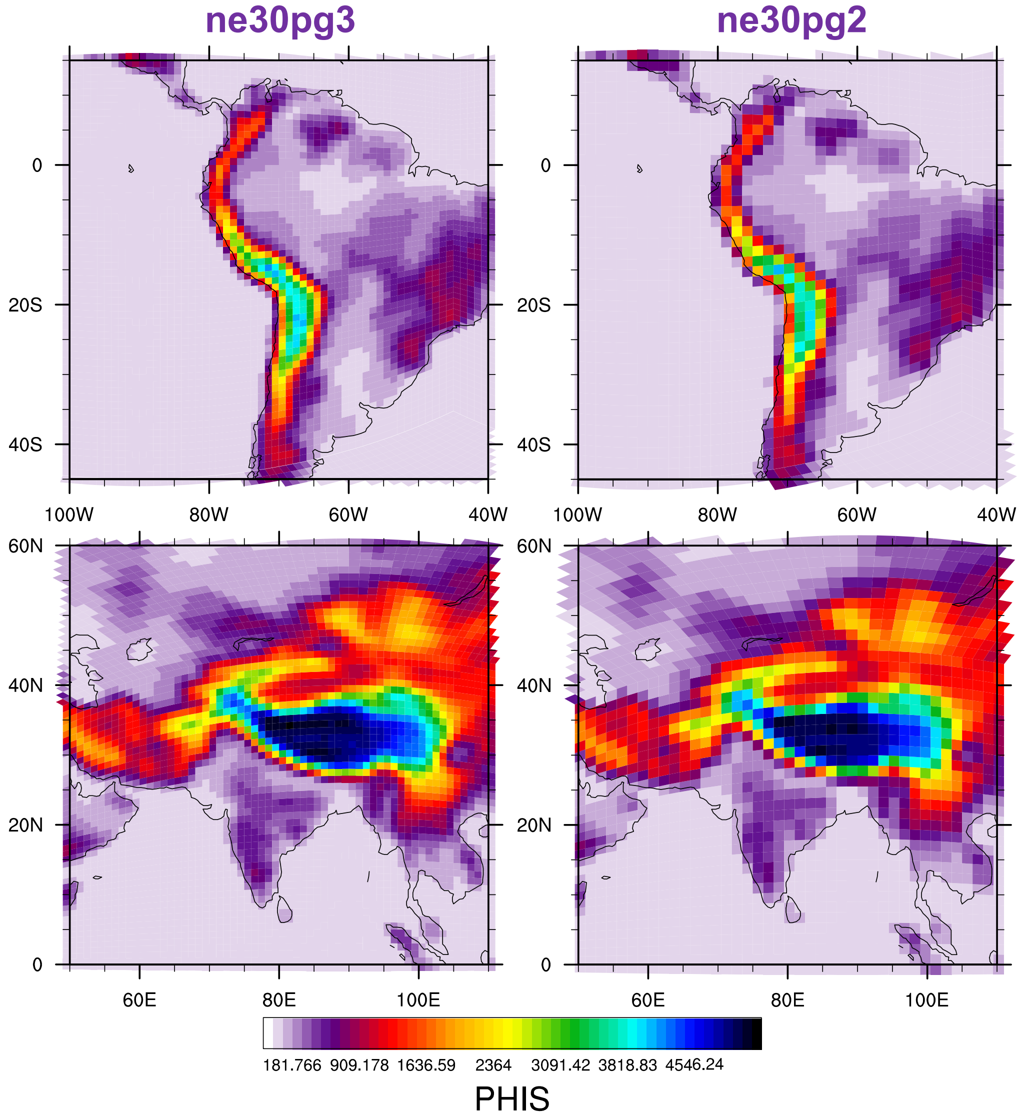
Aliasing from the lower resolution physics forcing?
(the importance of high-order mapping)

1 yr QPC6 (aqua-planet)

Grid name	Δx_{dyn}	Δt_{dyn}	Δx_{phys}	Δt_{phys}
ne20pg3	166.8km	300s	166.8km	1800s
ne30pg2	111.2km	300s	166.8km	1800s
ne30pg3	111.2km	300s	111.2km	1800s

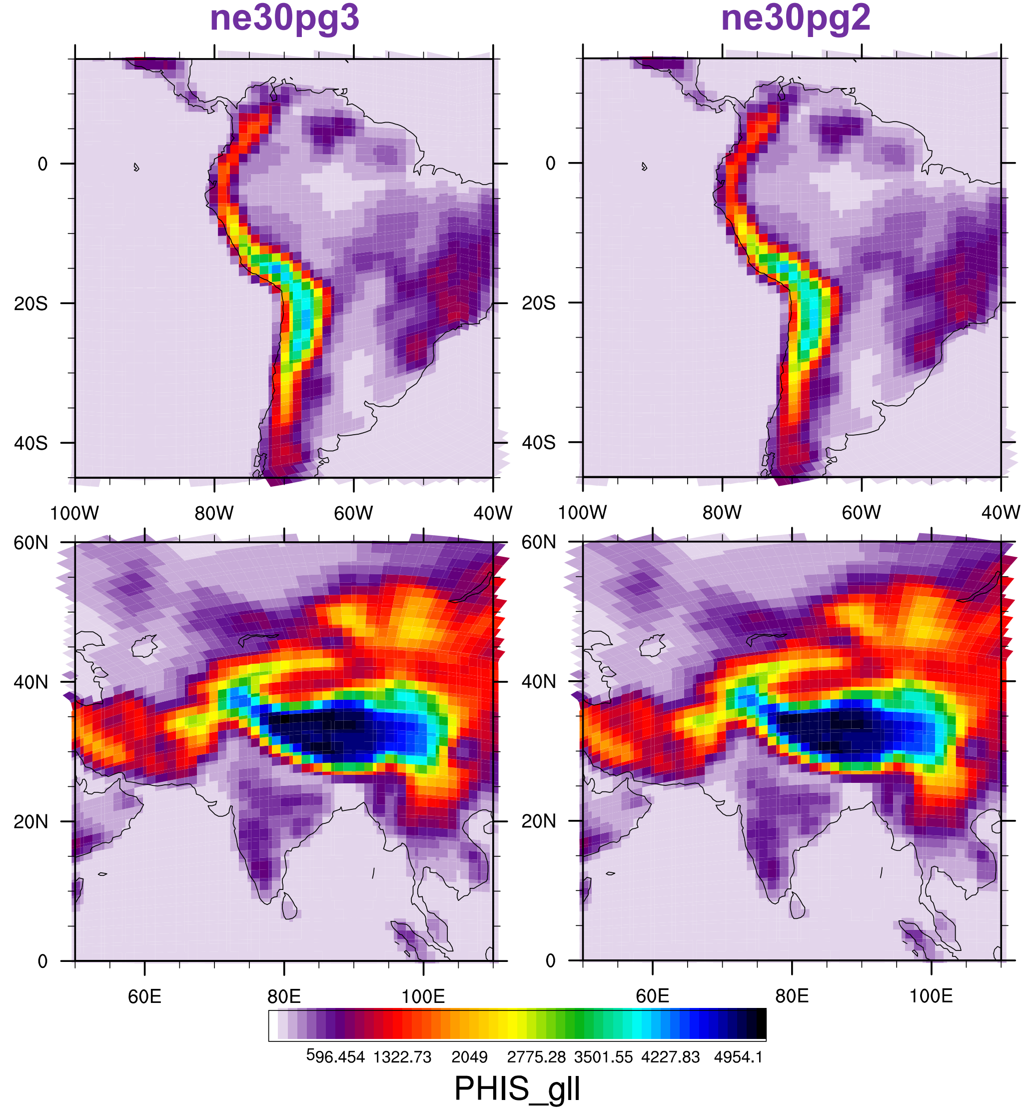


Aliasing from the lower resolution topography?



Topography "lives" on the physics grid

Aliasing from the lower resolution topography?

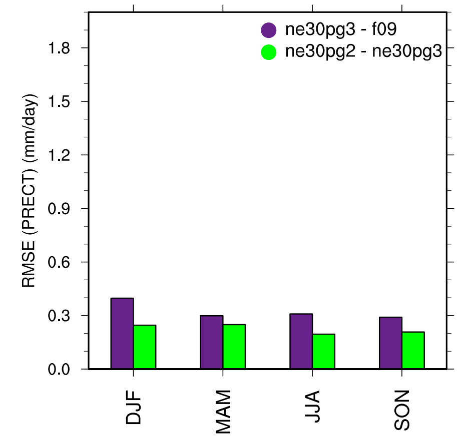


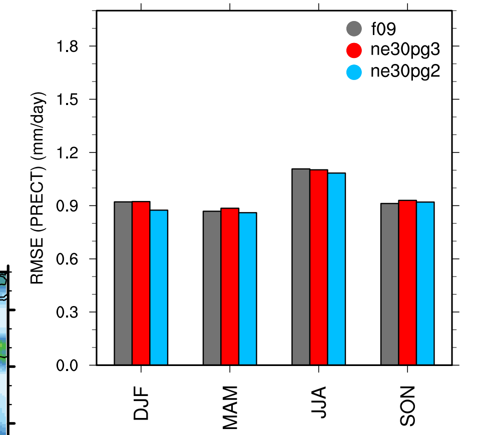
…But dry dynamics "sees" it on the GLL grid

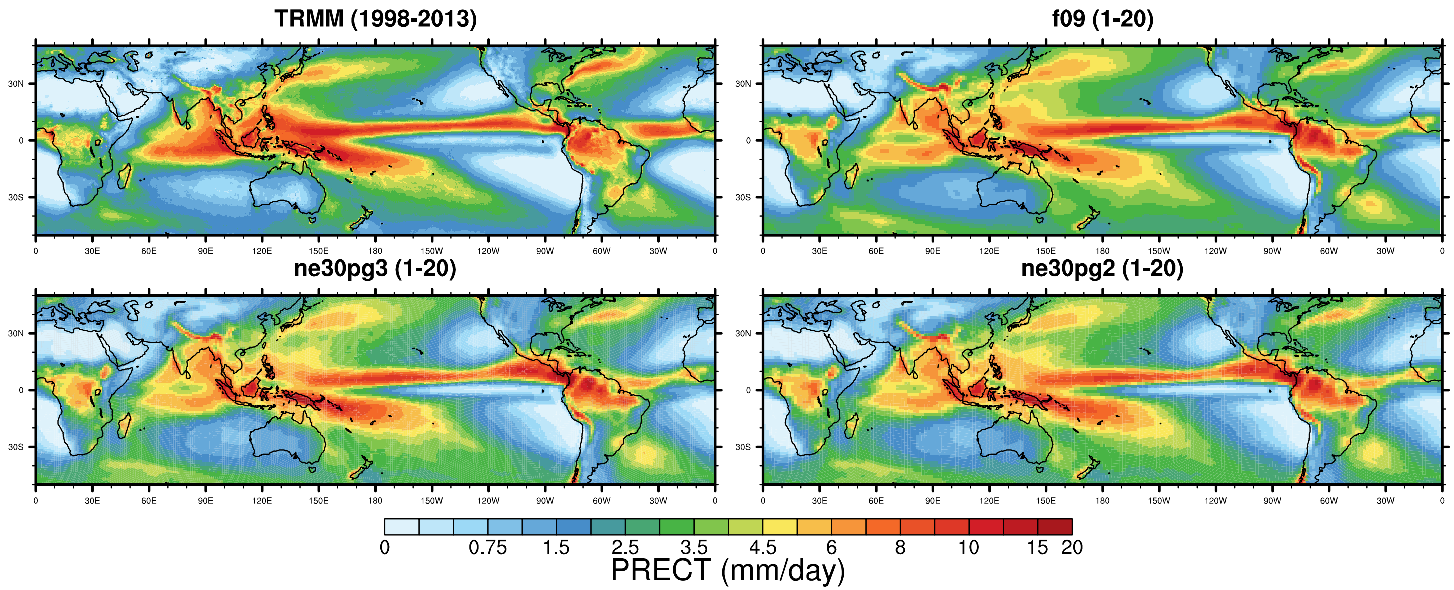
F2000 runs (20 yrs)
(f09, ne30pg3, ne30pg2)

1.) Are differences due to changing dynamical core (i.e., **ne30pg3 and f09**) larger than differences due to changing physics resolution (i.e., **ne30pg2 and ne30pg3**)?

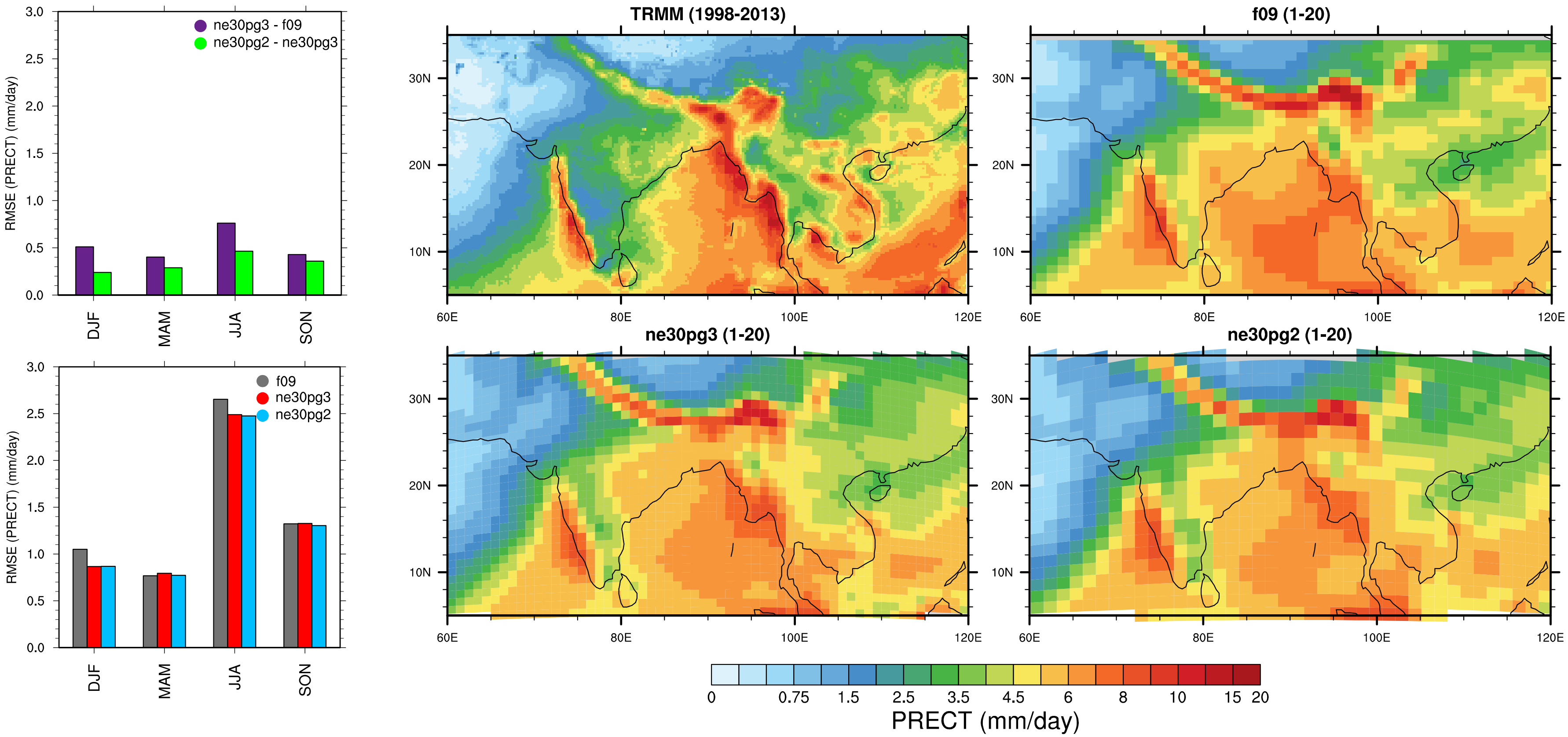
2.) Does **ne30pg2** deteriorate skill relative to observations?





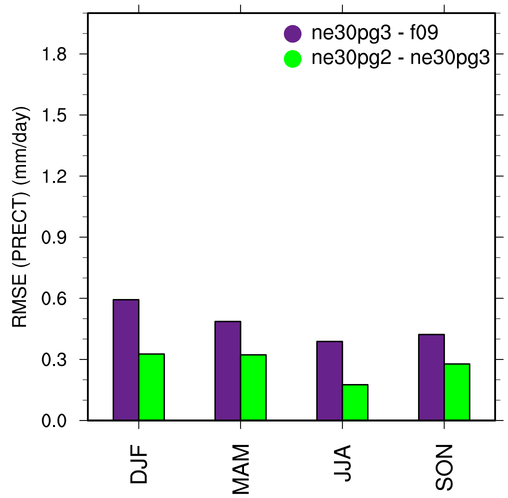


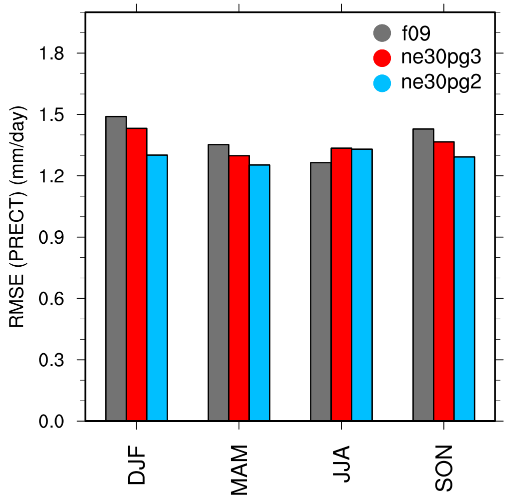
HIMALAYAS

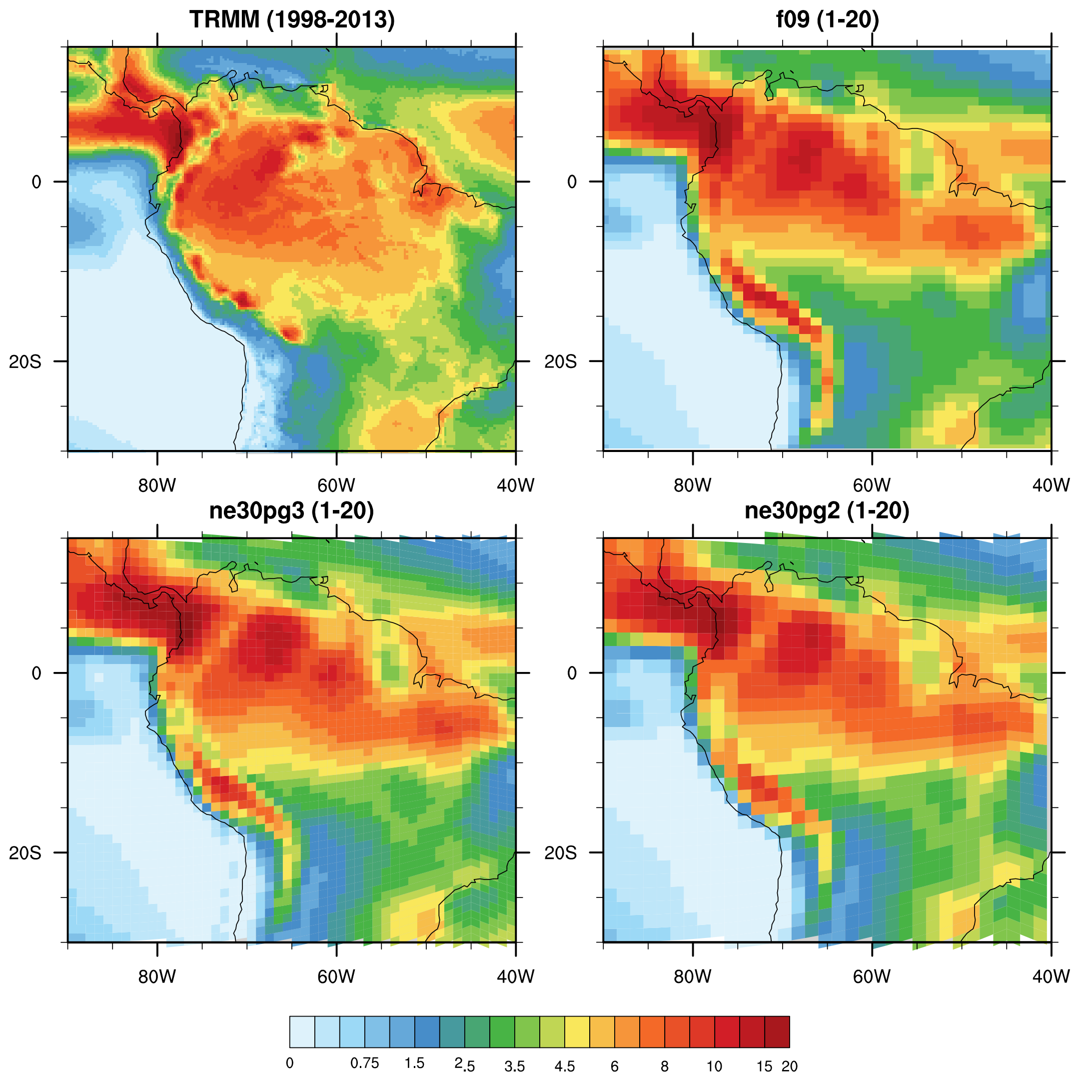


ne30pg3 - f09
ne30pg2 - ne30pg3
RMSE (PRECT) (mm/day)
DJF
MAM
JJA
SON
f09
ne30pg3
ne30pg2
TRMM (1998-2013)
f09 (1-20)
ne30pg3 (1-20)
ne30pg2 (1-20)
30N
20N
10N
60E
80E
100E
120E
0
0.75
1.5
2.5
3.5
4.5
6
8
10
15
20
PRECT (mm/day)

ANDES

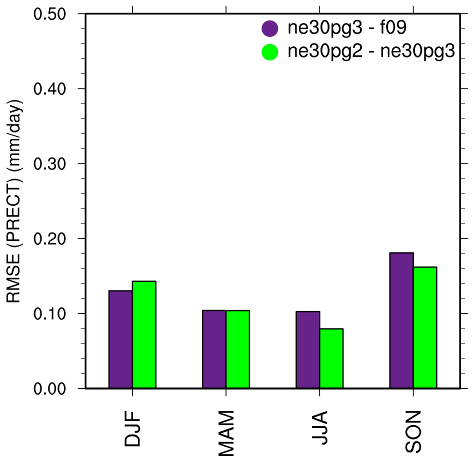


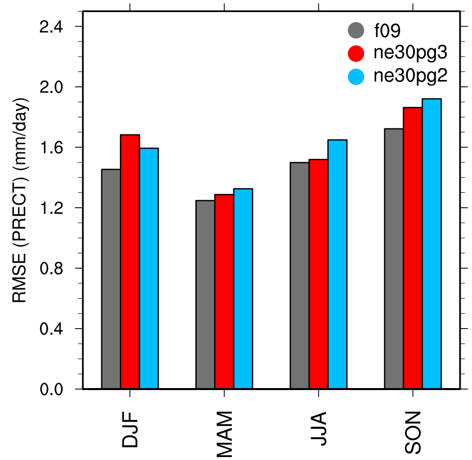


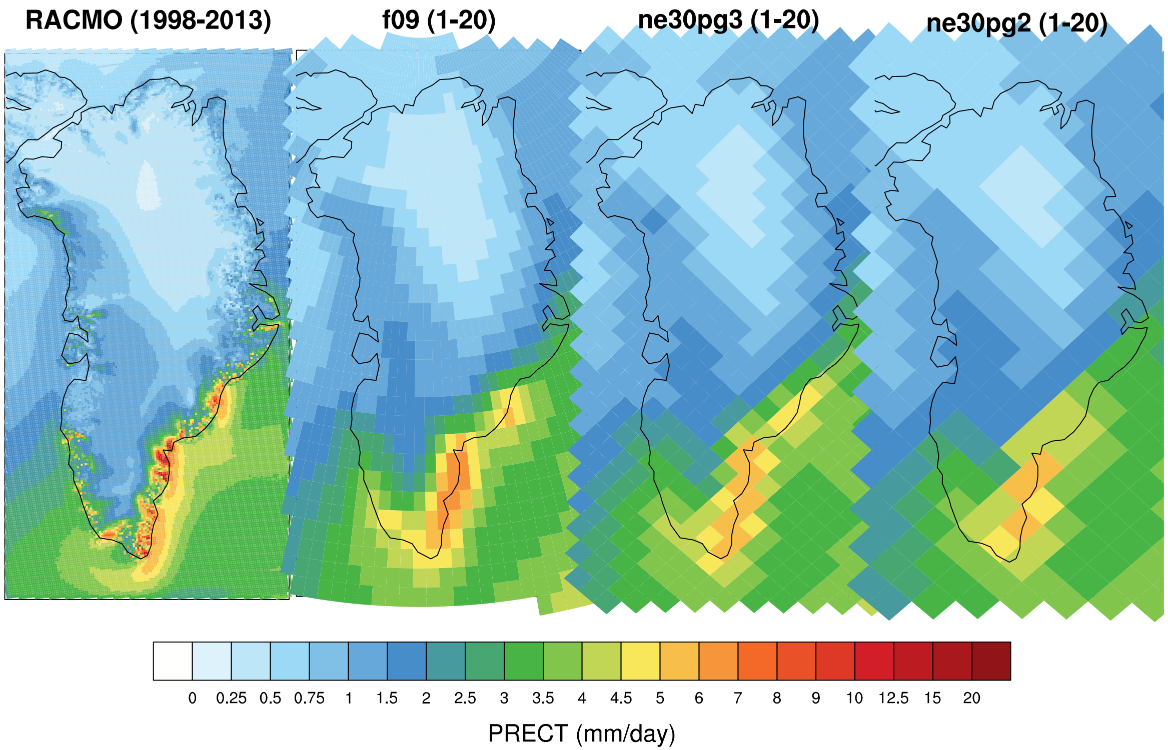


NCAR
UCAR

GREENLAND (vs. RACMO2.3)

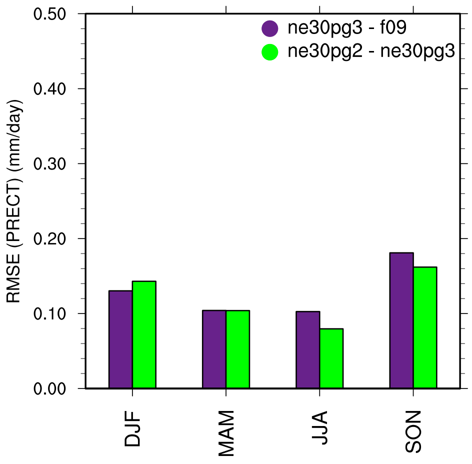


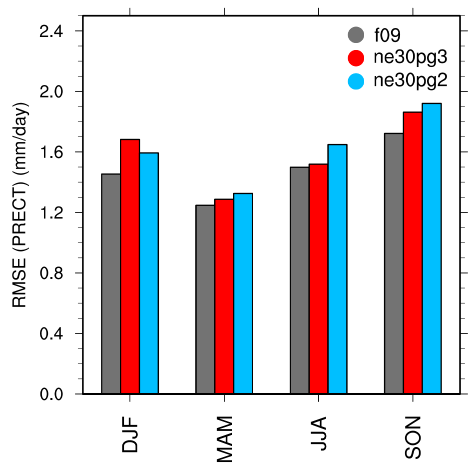


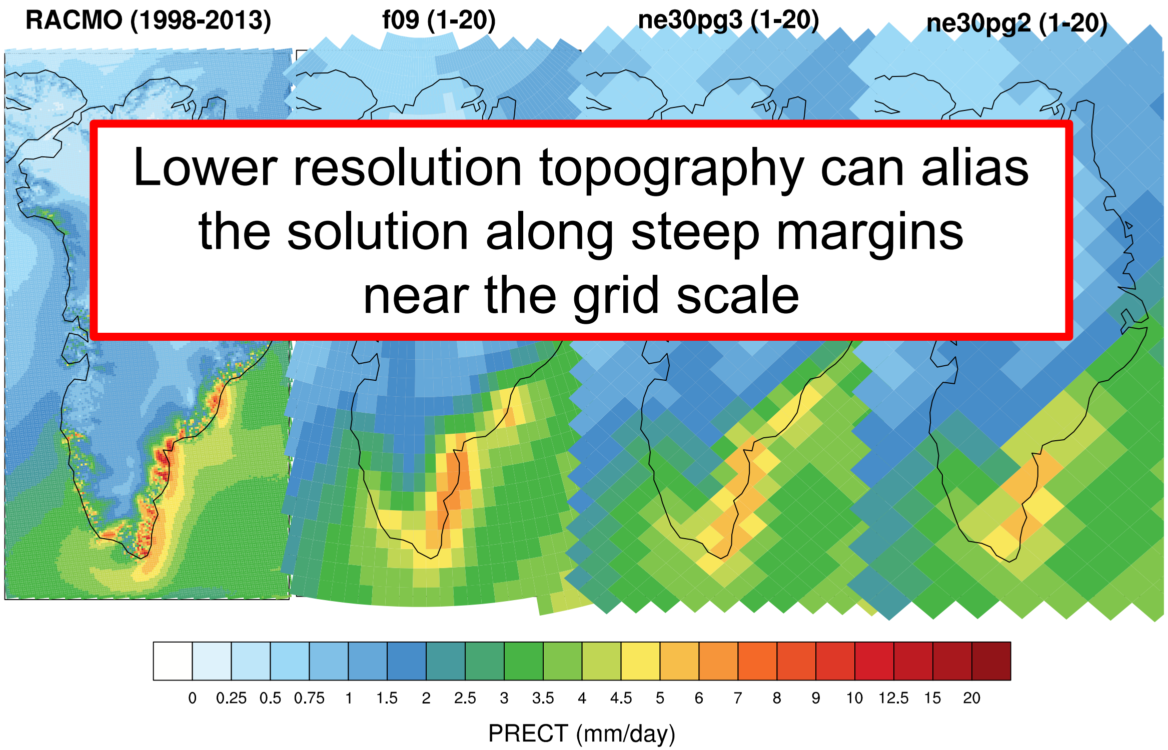


Diffs	RMSE (TOPO)	GLL RMSE (TOPO)
ne30pg3 – f09	14.26 m	
ne30pg2 – ne30pg3	37.5 m	19.54 m

GREENLAND (vs. RACMO2.3)

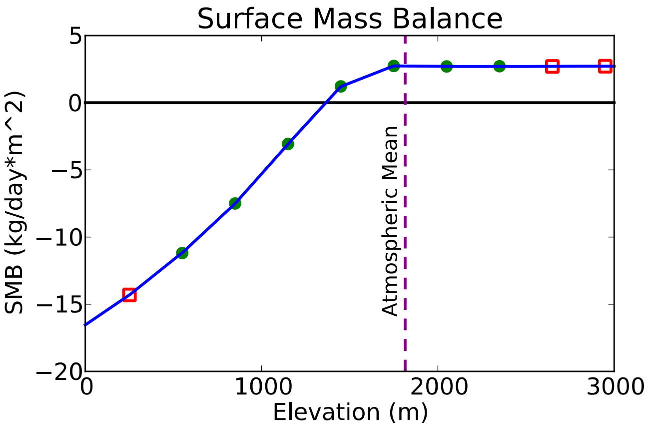




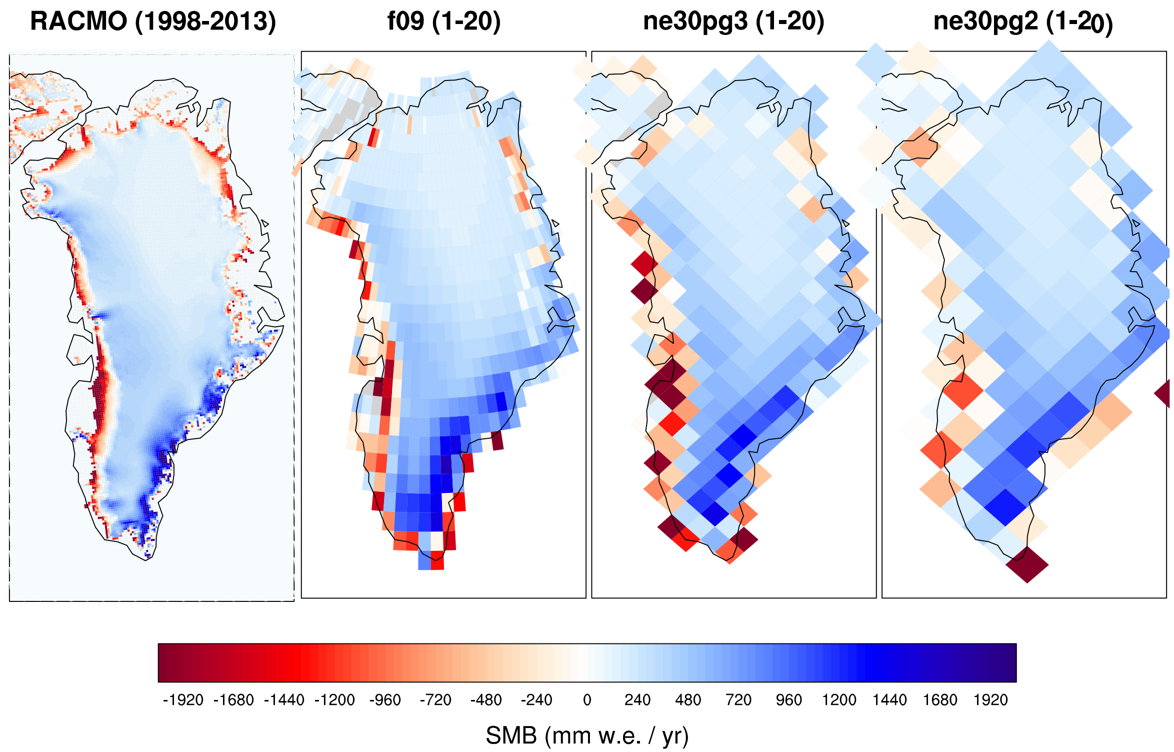


Diffs	RMSE (TOPO)	GLL RMSE (TOPO)
ne30pg3 – f09	14.26 m	
ne30pg2 – ne30pg3	37.5 m	19.54 m

Can CLM/CISM downscaling mitigate topo aliasing?



CLMs multiple elevation classes for downscaling to 4km CISM

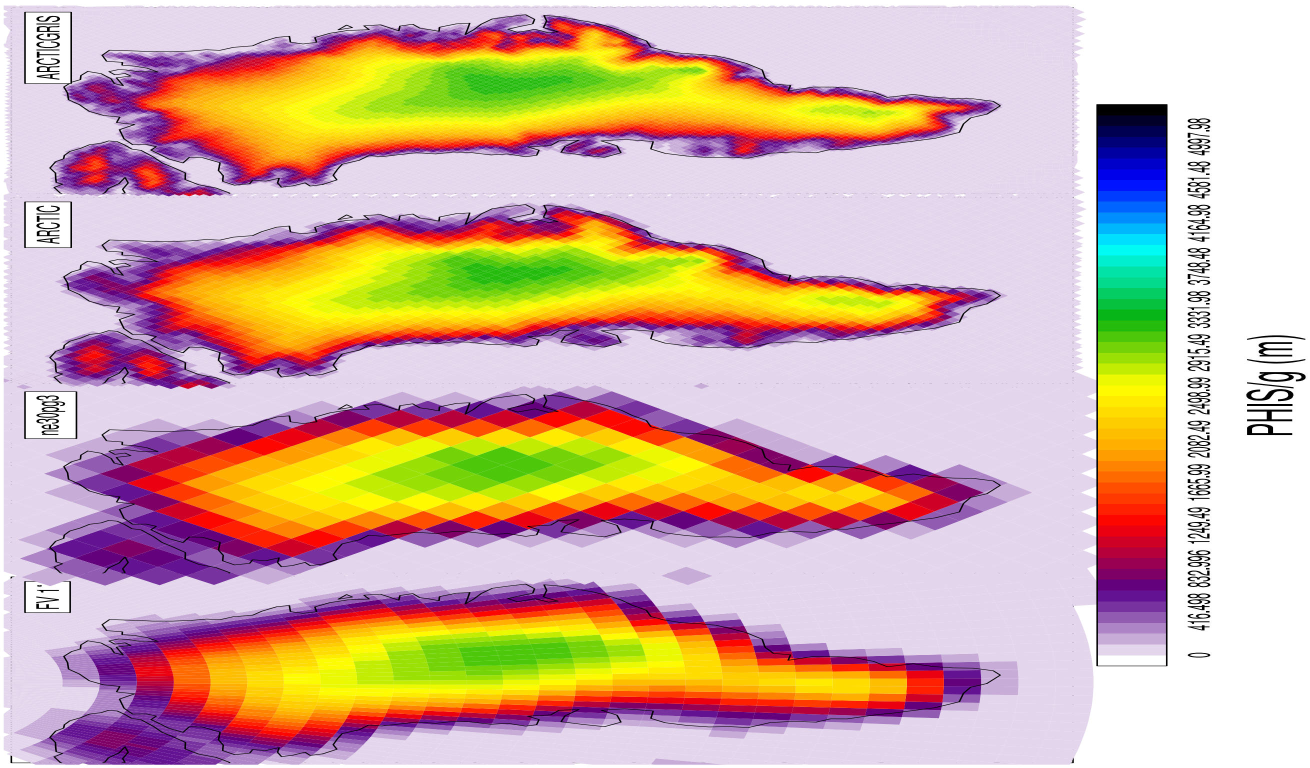


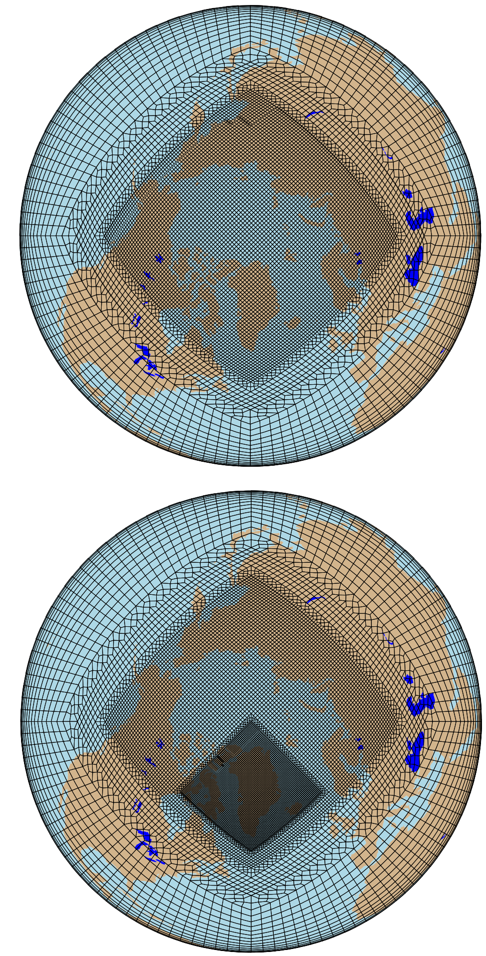
Diffs	CLM RMSE (SMB)	CISM RMSE (SMB)
ne30pg3 – f09	120.24 mm w.e. / yr	109.18 mm w.e. / yr
ne30pg2 – ne30pg3	72.88 mm w.e. / yr	60.47 mm w.e. / yr

Historical F-compset (data ocn) simulations

Substantial improvement in GrIS SMB over the standard 1º model
(van Kampenhout et al. 2019)

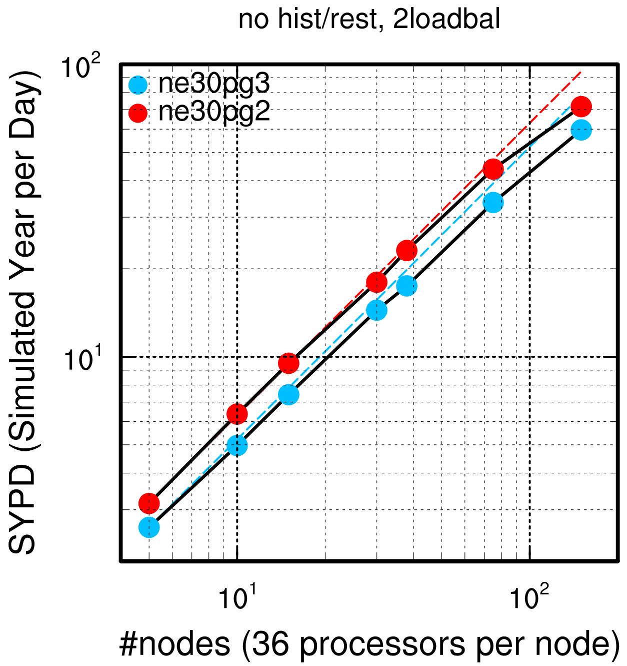
Greenland Ice Sheet (GrIS) Topography



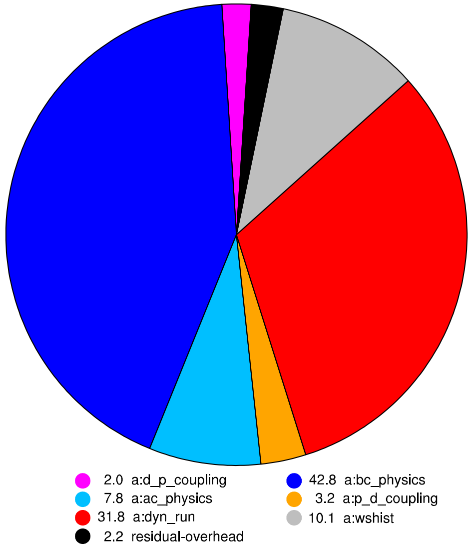


Cost Savings and Performance of pg2

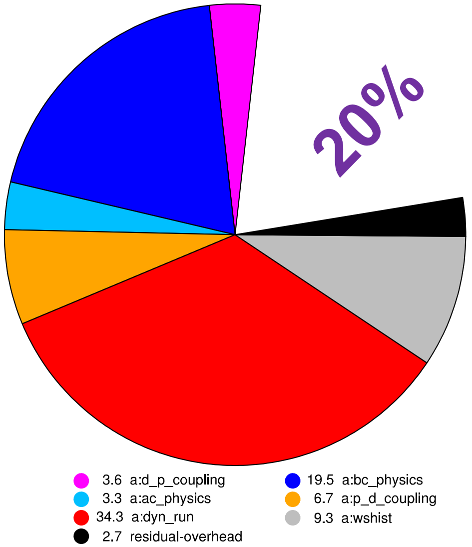
(Cheyenne, no threading)



ne30pg3-F2000climo



ne30pg2-F2000climo



The costs of increasing horizontal resolution in CAM

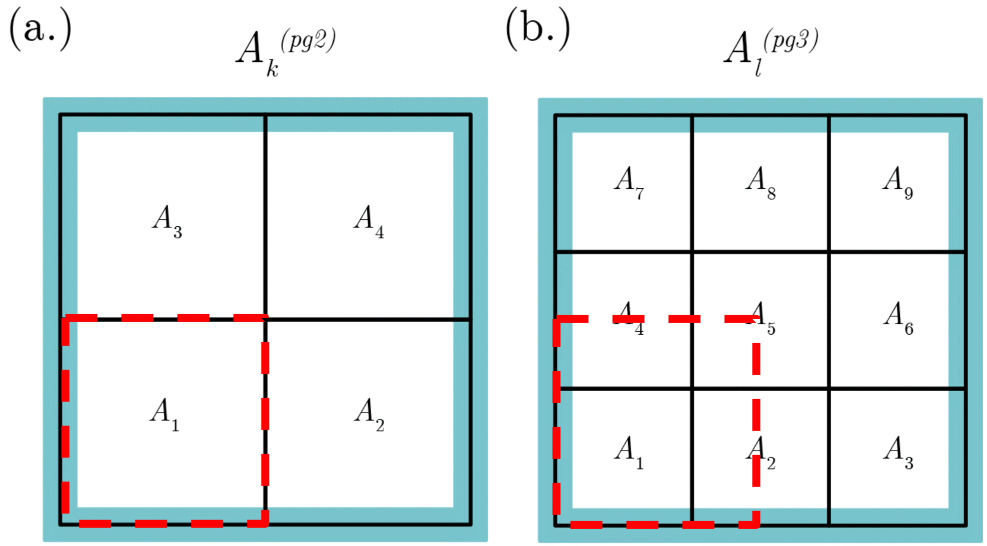
leveraging savings of the lower-resolution physics grid

1 month QPC6, daily i/o

	f09	ne30pg2	ne45pg2	ne60pg2
dx_eq	138 km	111.1 km	74.1 km	55.6 km
sypd@1800pes	21.87	26.93	9.38	4.15
core-hrs/syr	1975.66	1604.41	4604.76	10412.46
fv-factor	**1**	**0.812**	**2.33**	**5.27**

Factor increase in core-hours (per syr) over standard 1 degree FV

Mapping tracer tend from pg2 to CSLAM



$\Delta m_k^{(excess)} = \overline{m}_k - \overline{m}_k^{(min)}$, excess mixing ratio such that no local minima is produced

Amount of mass that can be removed on overlap grid per $A_k^{(pg2)}$: $\Delta m_k^{(excess)} \overline{\Delta p}_k \delta A_k$.

To ensure the mass removed by physics does not exceed this amount, solve for γ_k:

$$\Delta A_k^{(pg2)} \overline{\Delta p}_k^{(pg2)} \overline{f}^{(pg2)} = \gamma_k \sum_\ell \Delta m_{k\ell}^{(excess)} \overline{\Delta p}_{k\ell} \delta A_{k\ell},$$

The physics mass increment on overlap grid: $\gamma_k \Delta m_{k\ell}^{(excess)} \overline{\Delta p}_{k\ell} \delta A_{k\ell},$

Mapping tracer tend from pg2 to CSLAM

In an aqua-planet simulation, mass leaks of water vapor improve from 10^{-7} to 10^{-16} Pa per time-step (i.e., within machine-precision)

errors computed after Lauritzen and Williamson (2019)

$\Delta m_{k\ell}^{(excess)} = \overline{m}_{k\ell} - \overline{m}_{k\ell}^{(min)}$, excess mixing ratio such that no local minima is produced

Amount of mass that can be removed on overlap grid per $A_k^{(pg2)}$: $\Delta m_{k\ell}^{(excess)} \overline{\Delta p}_{k\ell} \delta A_{k\ell}$.

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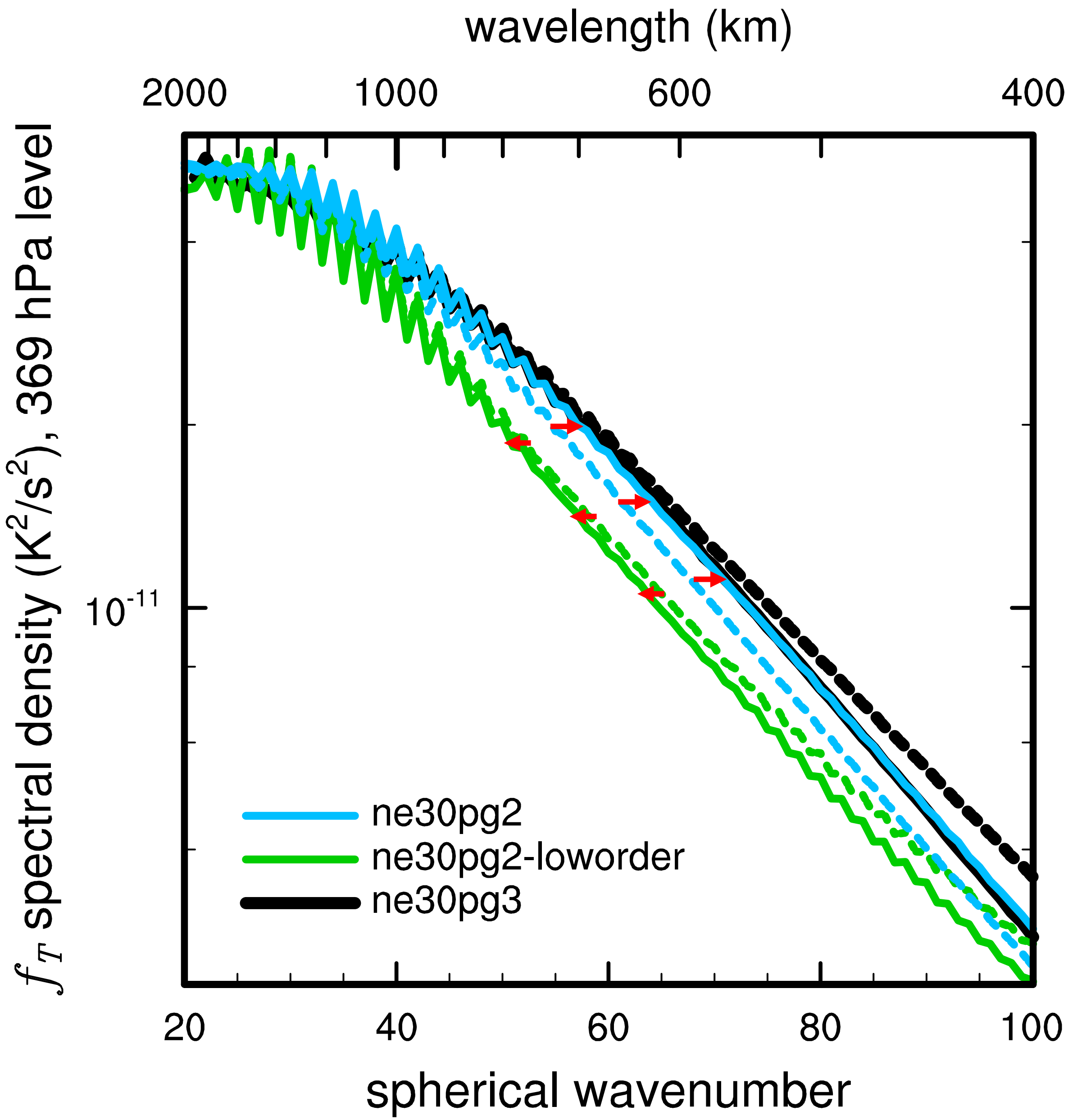
The physics mass increment on overlap grid: $\gamma_k \Delta m_{k\ell}^{(excess)} \overline{\Delta p}_{k\ell} \delta A_{k\ell}$,

Herrington et al, 2019, JAMES

Importance of high-order mappings



Dotted Lines

– phys tend on pgX grid

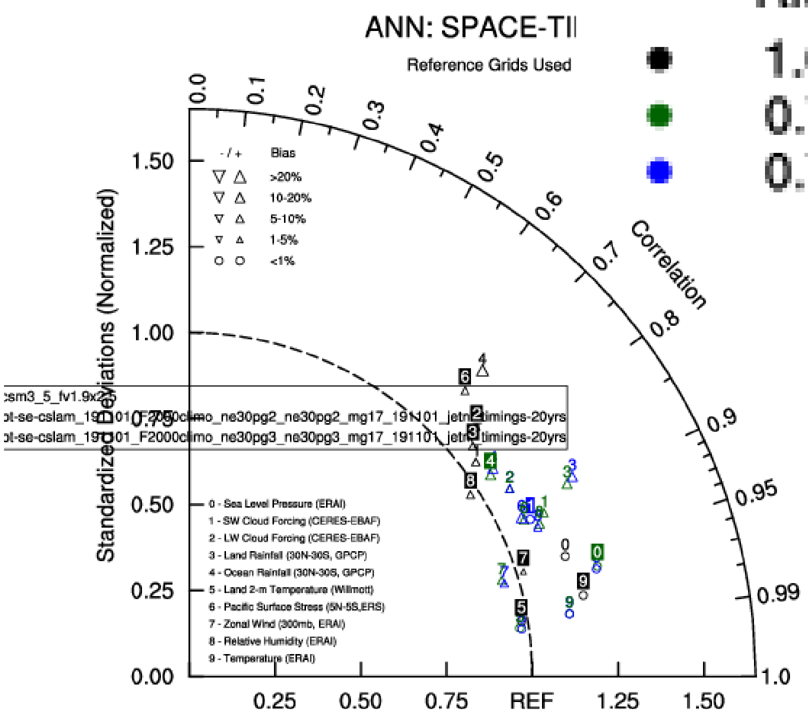
Solid Lines

– phys tend on GLL grid

F2000 Simulations (20 yrs)
(f09, ne30pg3, ne30pg2)

1.) Are the differences between **ne30pg3 and f09** (i.e., changing dycore) larger than the differences between **ne30pg3 and ne30pg2** (i.e., physics resolution)?

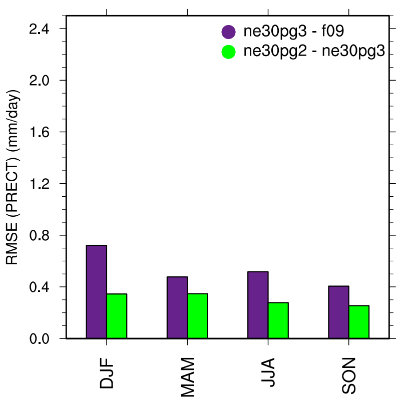
2.) Does **ne30pg2** deteriorate skill relative to observations?

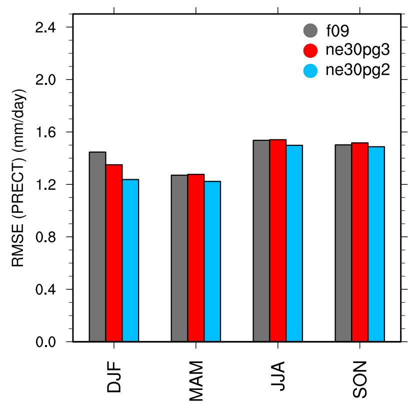


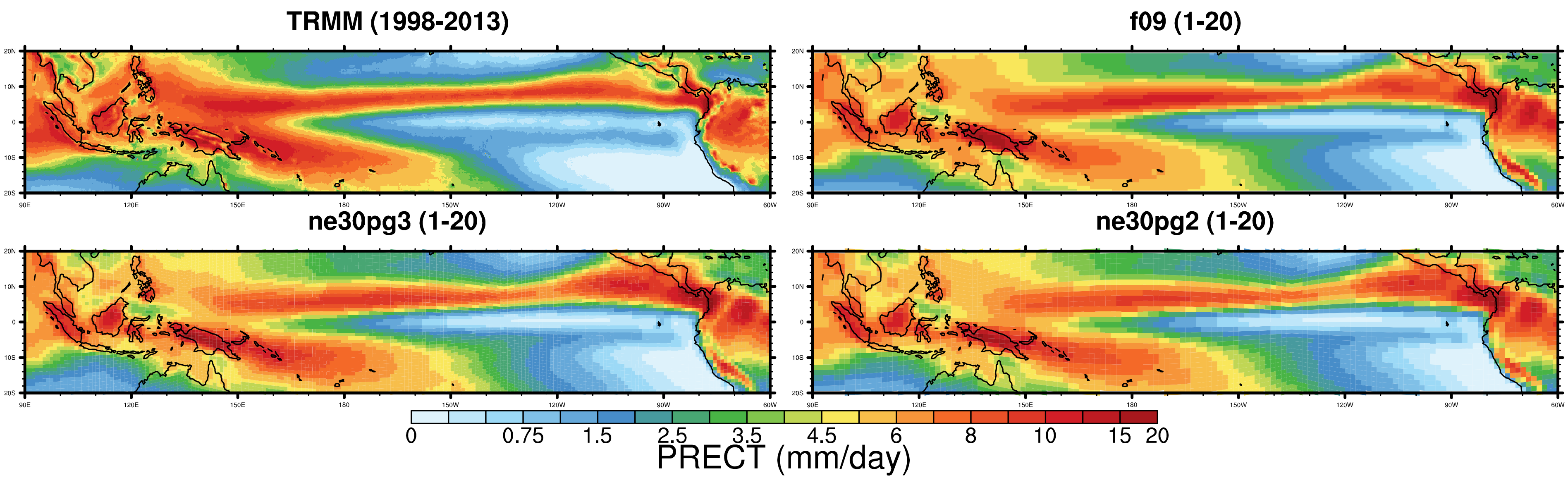
	RMSE	Bias	
●	1.000	1.000	
●	0.749	1.305	ne30pg2
●	0.747	1.182	ne30pg3

Do both box plots over entire trmm domain here

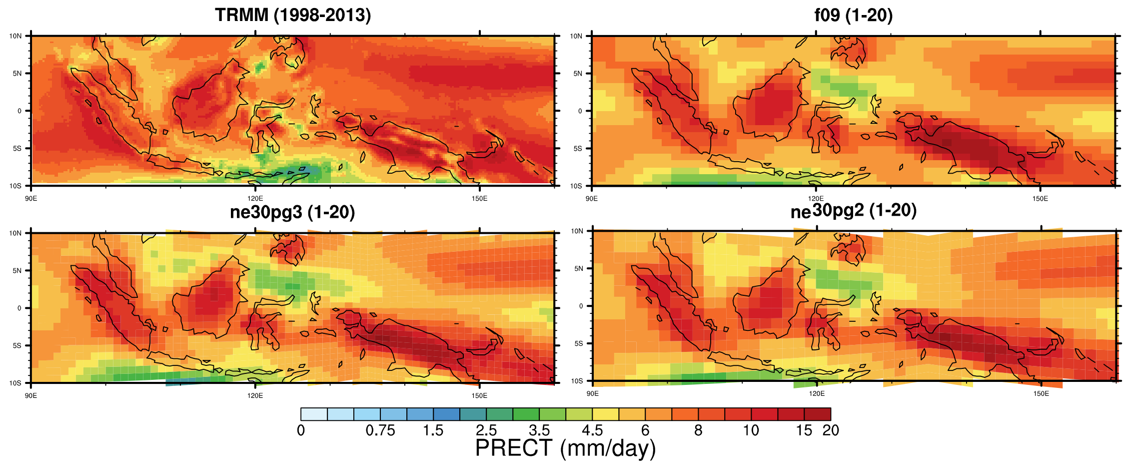
PACIFIC

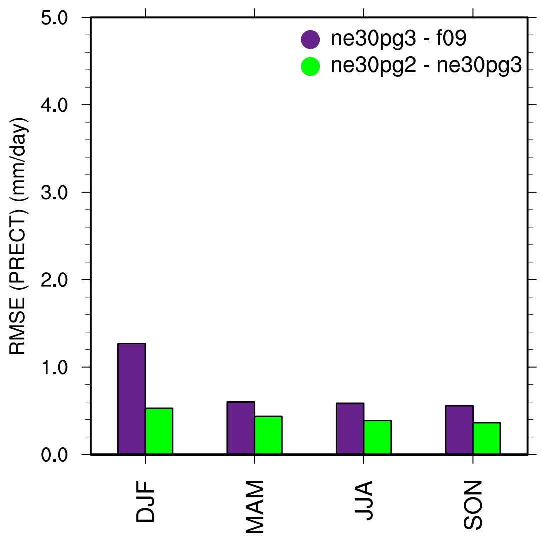

ne30pg3 - f09
ne30pg2 - ne30pg3
RMSE (PRECT) (mm/day)
2.4
2.0
1.6
1.2
0.8
0.4
0.0
DJF
MAM
JJA
SON

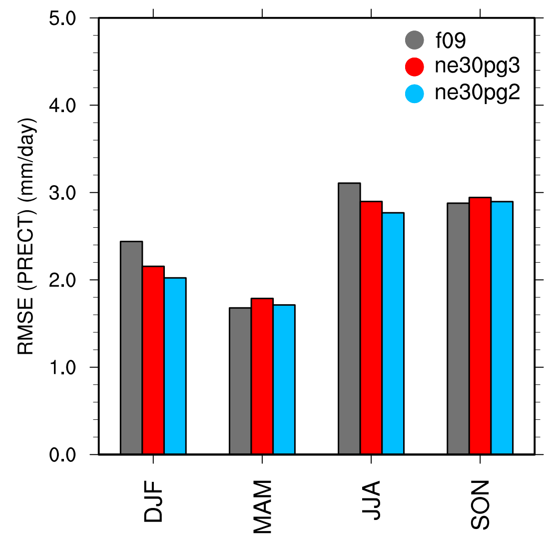

f09
ne30pg3
ne30pg2
RMSE (PRECT) (mm/day)
2.4
2.0
1.6
1.2
0.8
0.4
0.0
DJF
MAM
JJA
SON


TRMM (1998-2013)
f09 (1-20)
ne30pg3 (1-20)
ne30pg2 (1-20)
0
0.75
1.5
2.5
3.5
4.5
6
8
10
15
20
PRECT (mm/day)

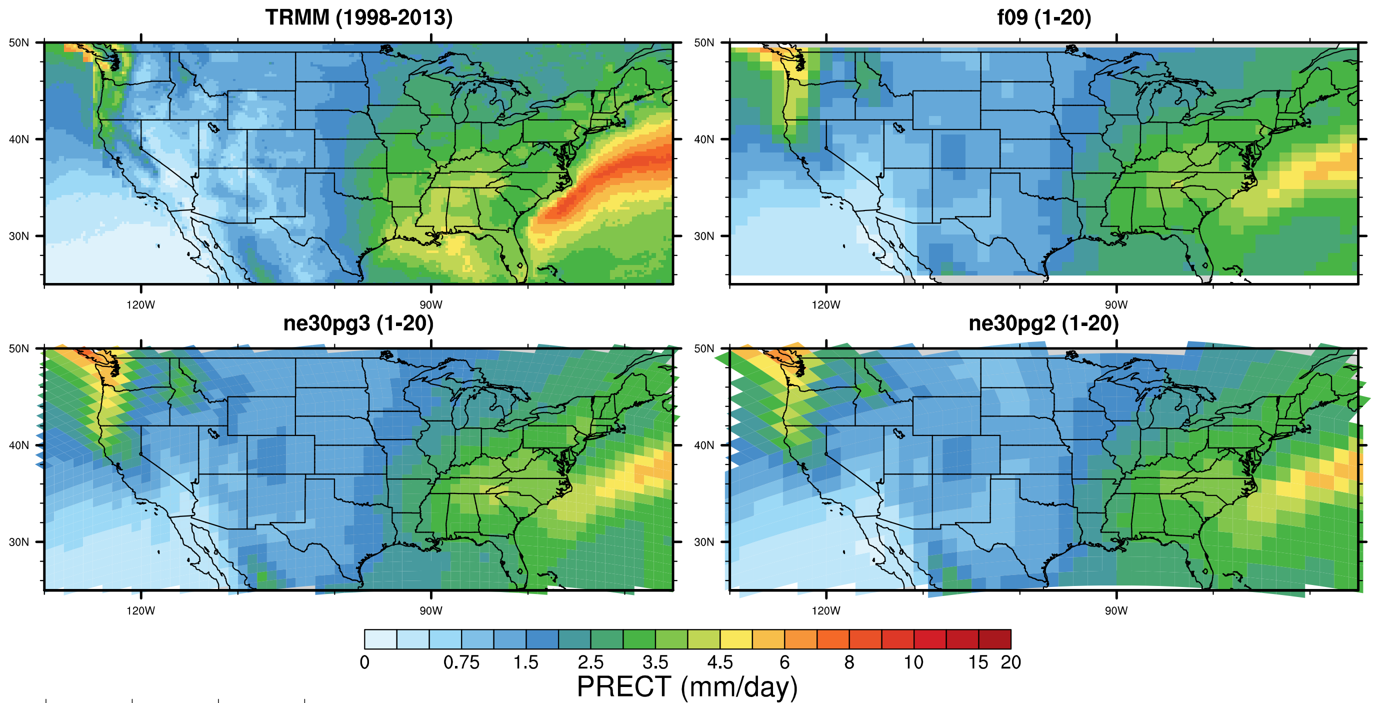
INDONESIA (Maritime Continent)

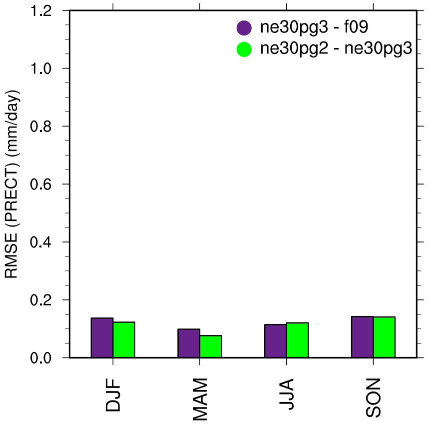


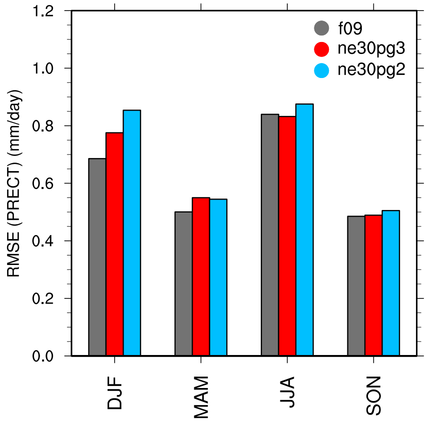




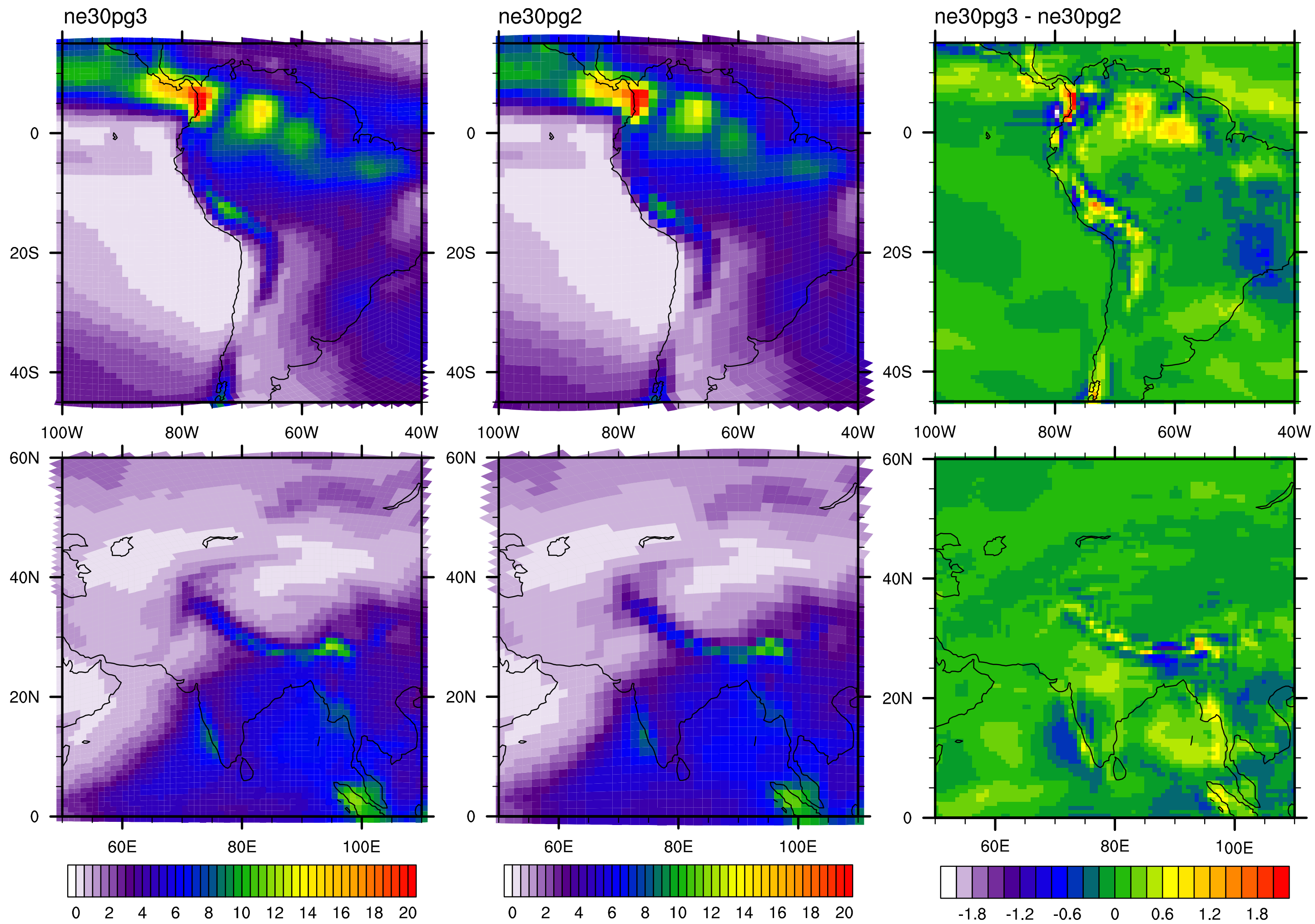
CONUS


TRMM (1998-2013)
f09 (1-20)
ne30pg3 (1-20)
ne30pg2 (1-20)
50N
40N
30N
120W
90W
0
0.75
1.5
2.5
3.5
4.5
6
8
10
15
20
PRECT (mm/day)


ne30pg3 - f09
ne30pg2 - ne30pg3
RMSE (PRECT) (mm/day)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DJF
MAM
JJA
SON


f09
ne30pg3
ne30pg2
RMSE (PRECT) (mm/day)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DJF
MAM
JJA
SON

Climatological PRECT



PRECT (mm/day)
20 yrs of F2000