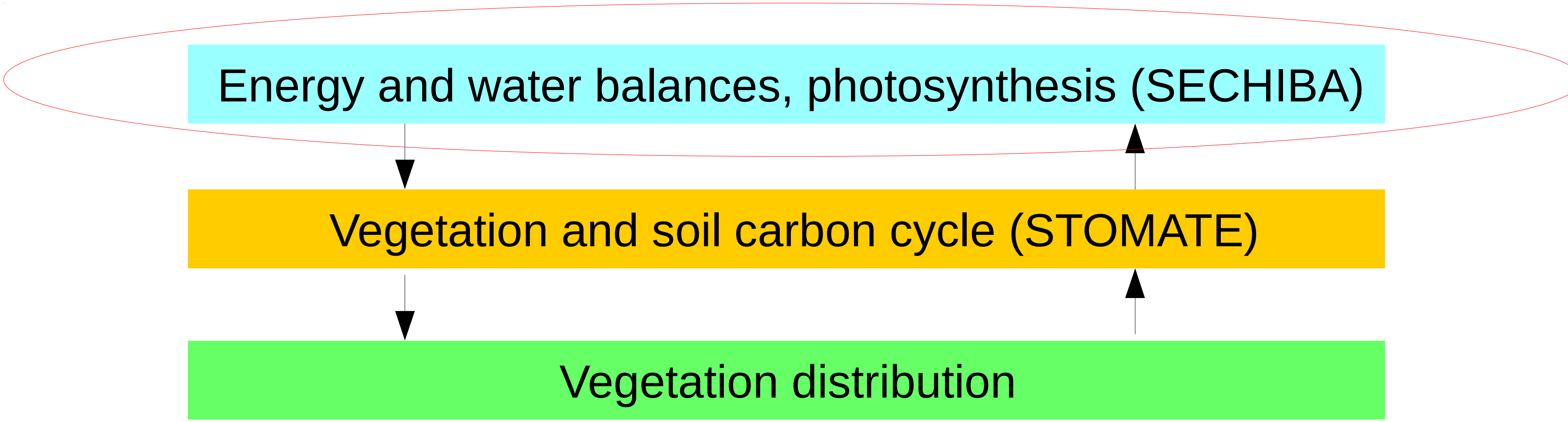
Validation and evaluation of ORCHIDEE hydrological component (SECHIBA) using various data sources

30 01 2018, Hiroki Mizuochi

Structure of ORCHIDEE



Various validations have been done.
However,
quantitative/comprehensive evaluation is still not sufficient.

Factor analysis by using various data sources
would extend our knowledge about
controlling factor of uncertainty in SECHIBA.

Structure of ORCHIDEE

Energy and water balances, photosynthesis (SECHIBA)

Vegetation and soil carbon cycle (STOMATE)

Vegetation distribution

Simulation version: revision 4438 (used in IPSL6.0.11)
- 13 PFT maps
- zobler soil map (3 textures)
- OK_FREEZE = y
- OK_EXPLICITSNOW = y
- DO_RSOIL = y
- ALB_BG_MODIS = y

Two simulations

offline simulation: FG3 reference, created on 23 Jun, 2017
- forced by WFDEI (WATCH-Forcing-DATA-ERA-Interim)

online simulation: CL5 reference, created on 22 Jun, 2017
- coupled with LMDZ; NPv5.67 with nudging

Evaluated values

SSM, ET, albedo

- 0.5deg × 0.5deg or 1deg × 1deg (depends on simulation), monthly time step
- temporal (long-term/seasonal) change
- spatial pattern
- pixel-based statistics (mean bias, *r*, RMSE and NSE to reference data)

Reference data

SSM:	CCI SSM version 3.2 (Liu et al., 2012) SMOS IC version 1.0 (initial version; Fernandez-Moran et al., 2017)
ET:	MPI (Jung et al., 2011); GLEAM (Miralles et al., 2011); NTSG (Zhang et al., 2010); PKU (Zeng et al., 2014)
Albedo:	MODIS albedo product (provided by Ghattas, J.)

Factor analysis criteria

PFT:	ORCHIDEE input (13 categories)
Topography:	ORCHIDEE reinfiltration ratio (reinf_slope)
LAI:	GIMMS 3G (Zhu et al., 2013; gap-filled by Druel, A.)
Irrigation:	GMIA (Siebert et al., 2013; Siebert et al., 2010)

1. Soil Moisture

Pre-processing (quality check, co-masking, spatiotemporal aggregation and normalization)
- remove unreliable observation data
- mitigate inconsistency (data availability and systematic bias) among data

CCI_SSM — 0.25deg × 0.25deg, 1979–2015, VWC [m^3/m^3]
- uncertainty [m^3/m^3] < 0.06 — (Al-Yaari et al., 2016)
- VWC [m^3/m^3] > 0 && < 0.6 — (Fernandez-Moran et al., 2017; Drigo et al., 2013)
- Flag = 0 — exclude snow, dense vegetation, other unreliable region
- only used after 1987 — after "uncertainty" value being assigned

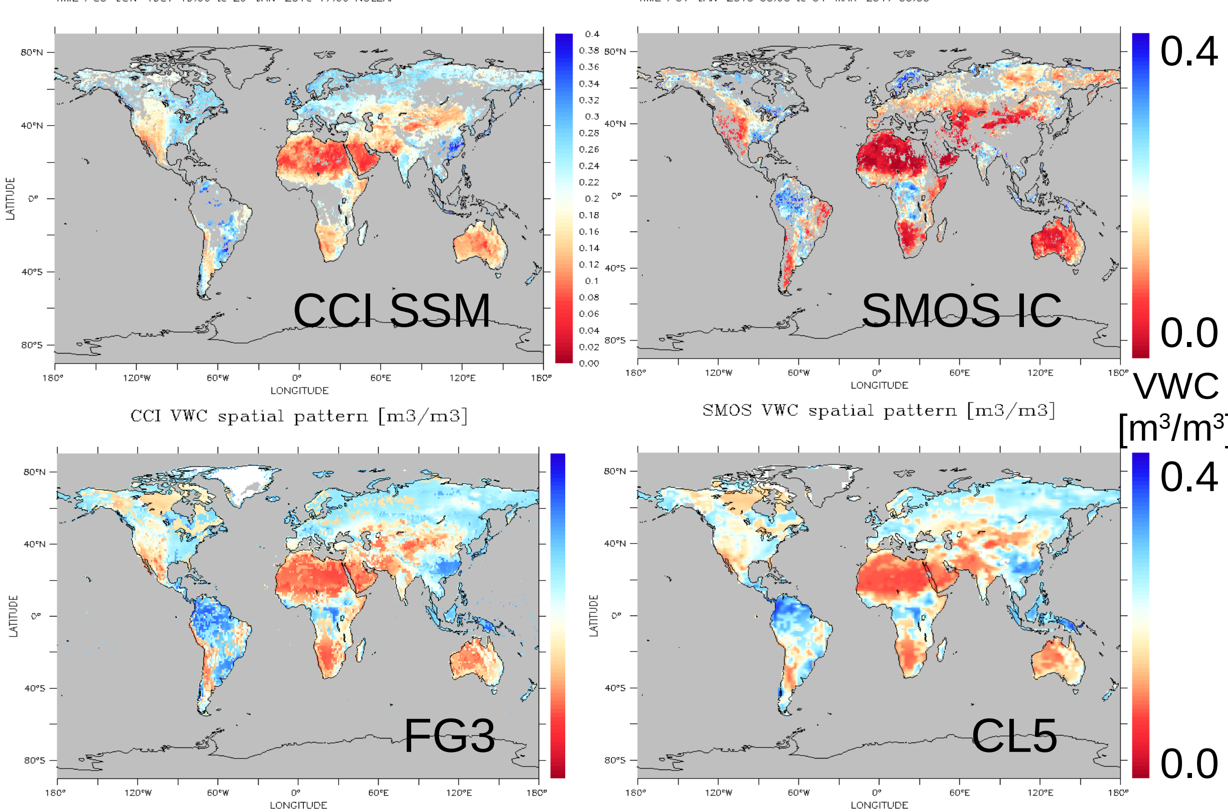
SMOS IC — 0.25deg ×0.25deg, 2010–2017, VWC [m^3/m^3]
- quality flag = 0 — data OK
- VWC [m^3/m^3] > 0 && < 0.6 — (Fernandez-Moran et al., 2017; Drigo et al., 2013)

FG3 — 0.5deg × 0.5deg, 1979–2009, kg/m^2 ▶ VWC [m^3/m^3]
- SWE [mm] < 48 — exclude snowy/frozen region
- only used after 1981 — to avoid initialization error

CL5 — 143pixel × 144pixel, 1985–2014, kg/m^2 ▶ VWC [m^3/m^3]
- SWE [mm] < 48 — exclude snowy/frozen region

※SWE threshold was set by trial and error referring to seasonal cycle of boreal region.

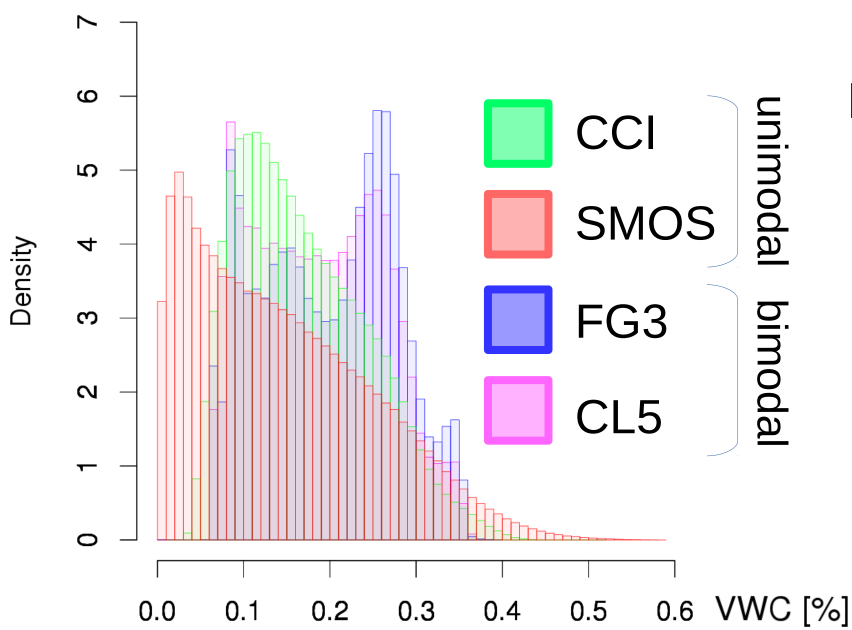
All data were aggregated into 0.5deg × 0.5deg. ▶ co-masking, normalization



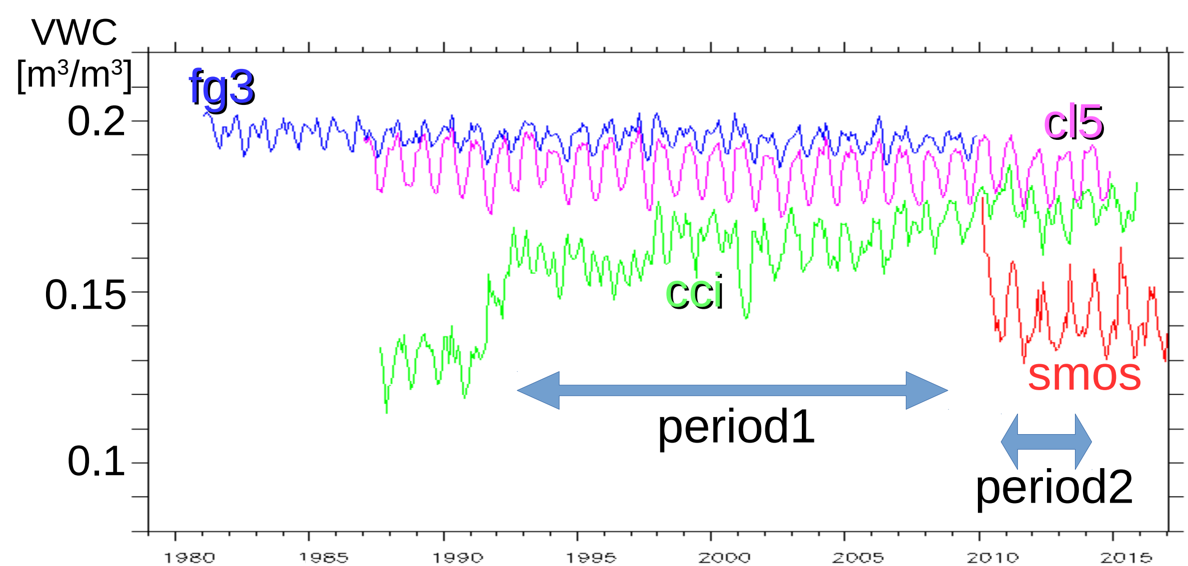
Spatial pattern of temporal average of each SSM

- Spatial patterns are basically similar among datasets.
- FG3/CL5 seem to show lower contrast than observations.
- SMOS IC data is available over tropical regions, but largely missed over China and some other regions (radio frequency interference).
- large discrepancy was observed in PDF and temporal change.

▶ Split into specific periods, co-masking & normalization



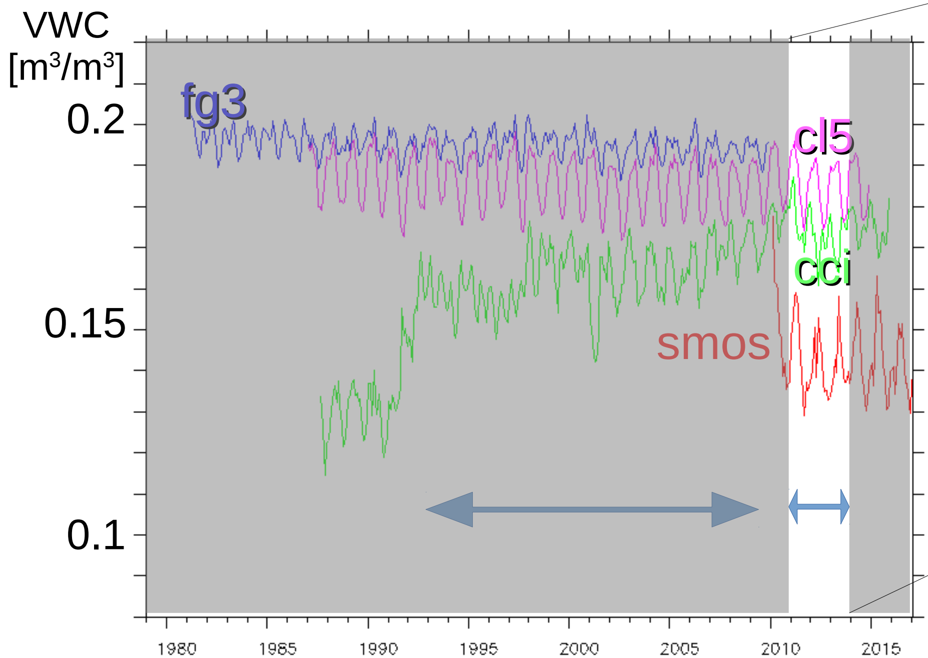
PDF of each SSM (all spatiotemporal pixels)



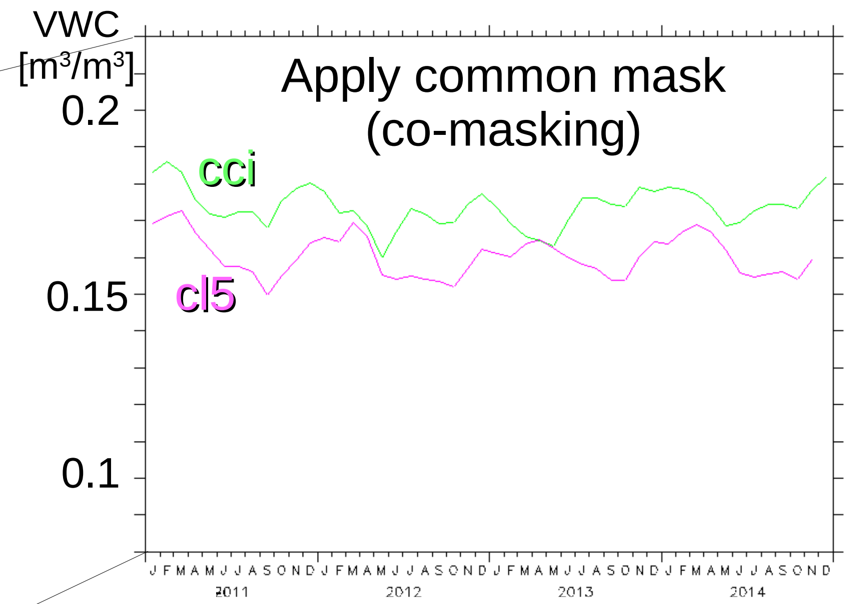
Temporal change of spatial average of each SSM

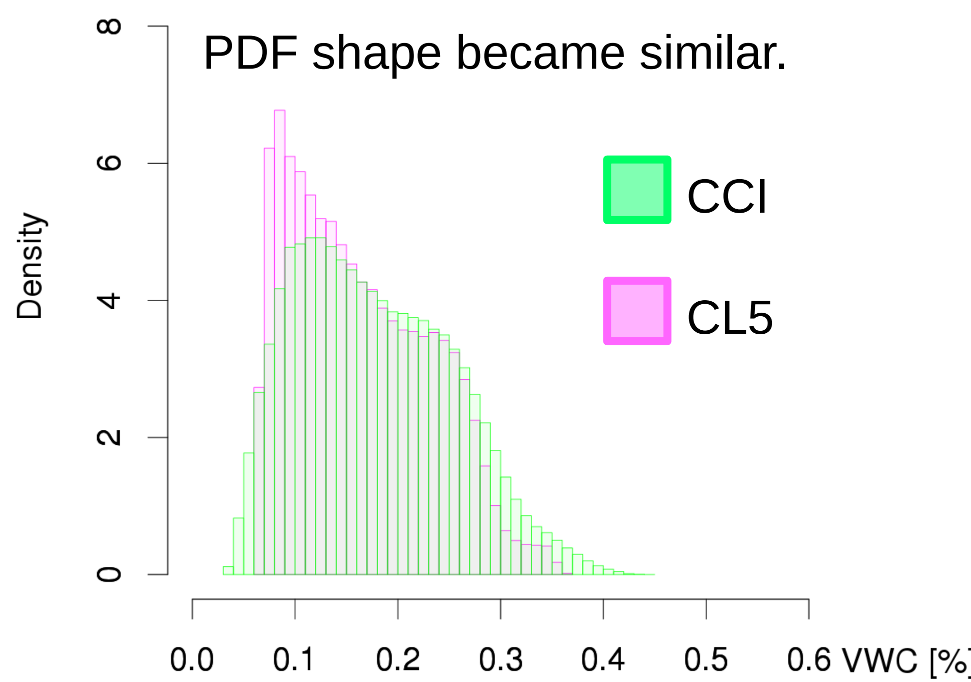
Co-masking is important to avoid “dummy” temporal trend (especially when using CCI: Loew et al., 2013)

ex) co-masking between CCI and CL5



Temporal change of spatial average of each SSM

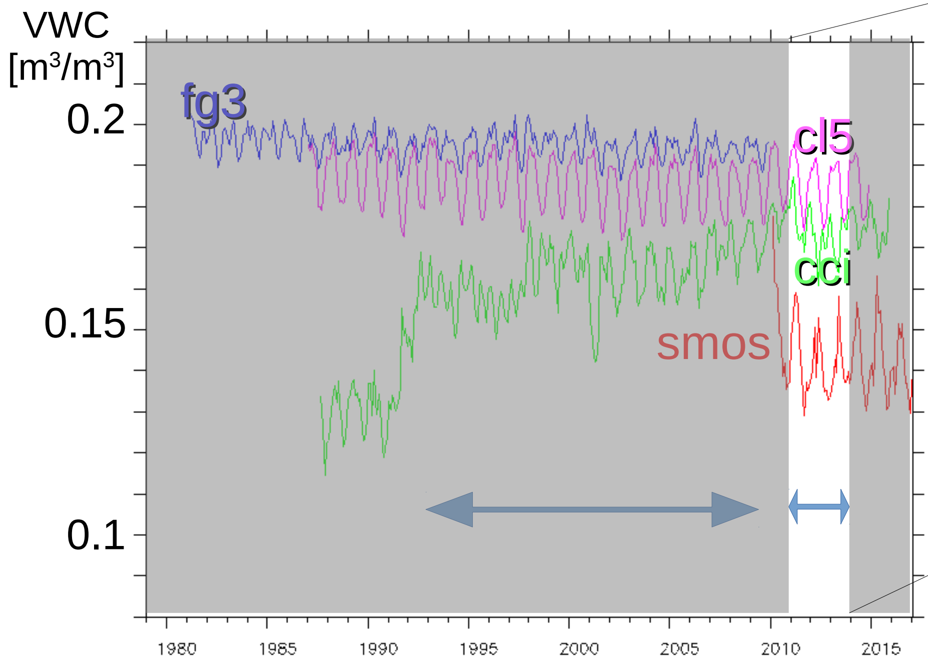




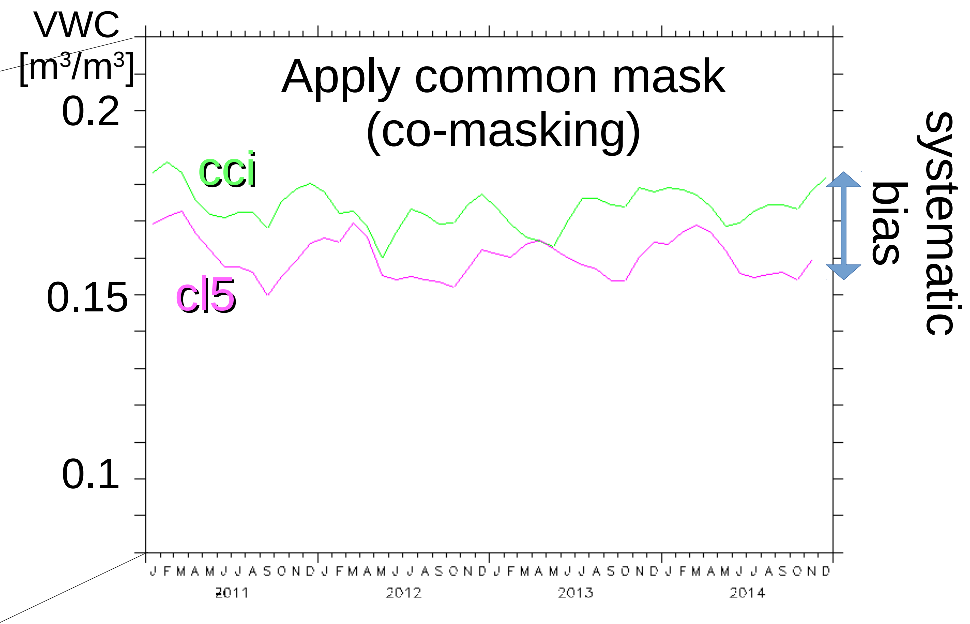
SSM PDF of CCI and CL5

Co-masking is important to avoid “dummy” temporal trend (especially when using CCI: Loew et al., 2013)

ex) co-masking between CCI and CL5

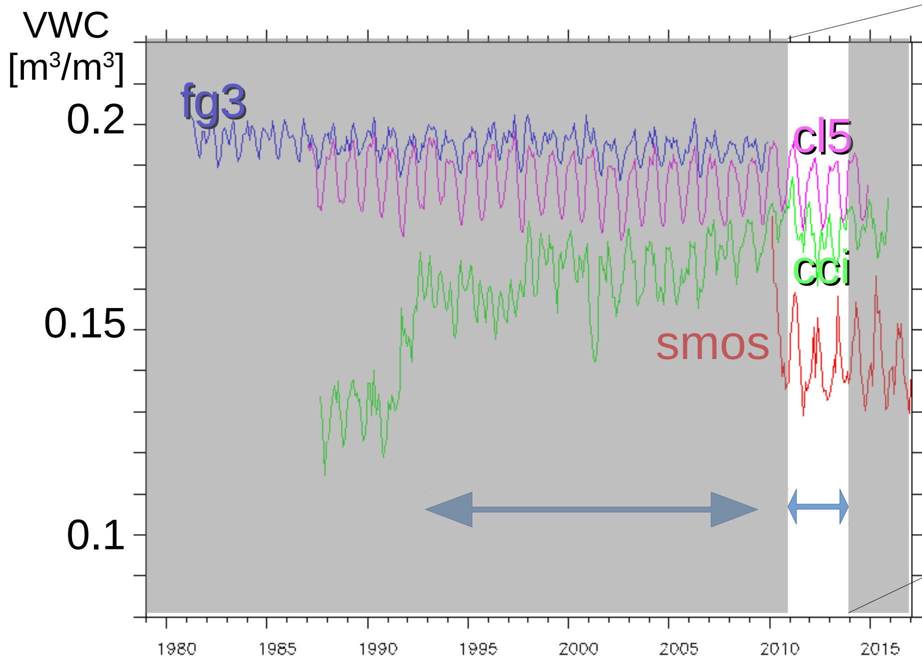


Temporal change of spatial average of each SSM

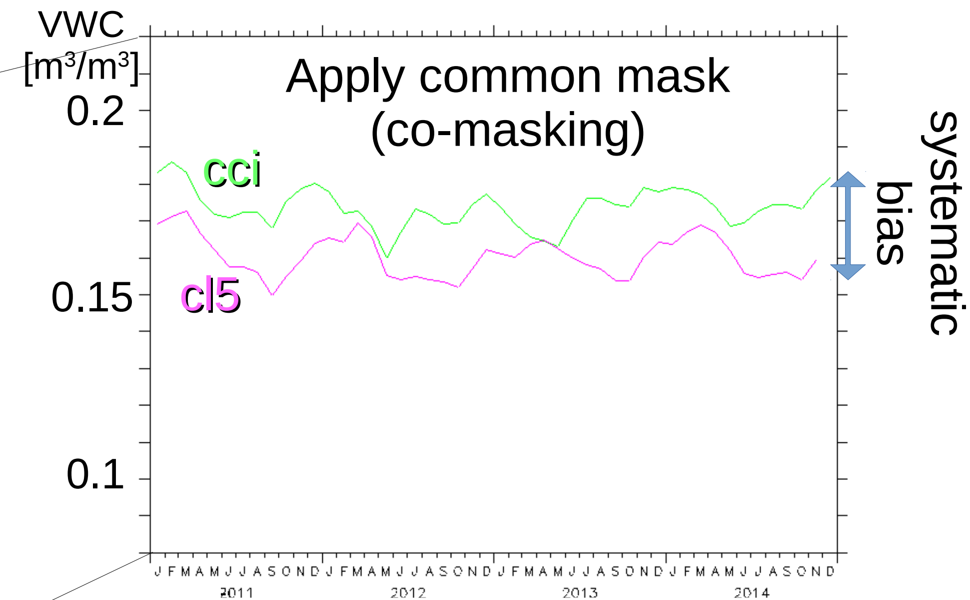


Co-masking is important to avoid "dummy" temporal trend (especially when using CCI: Loew et al., 2013)

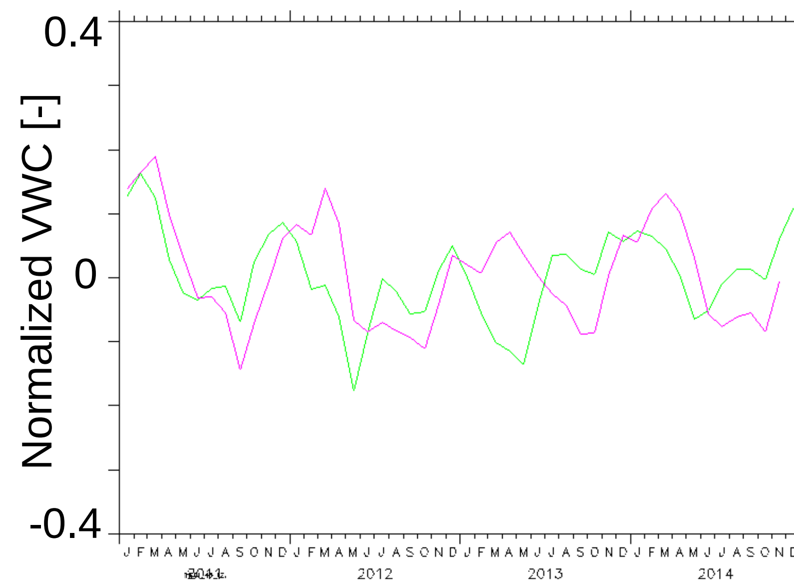
ex) co-masking between CCI and CL5



Temporal change of spatial average of each SSM



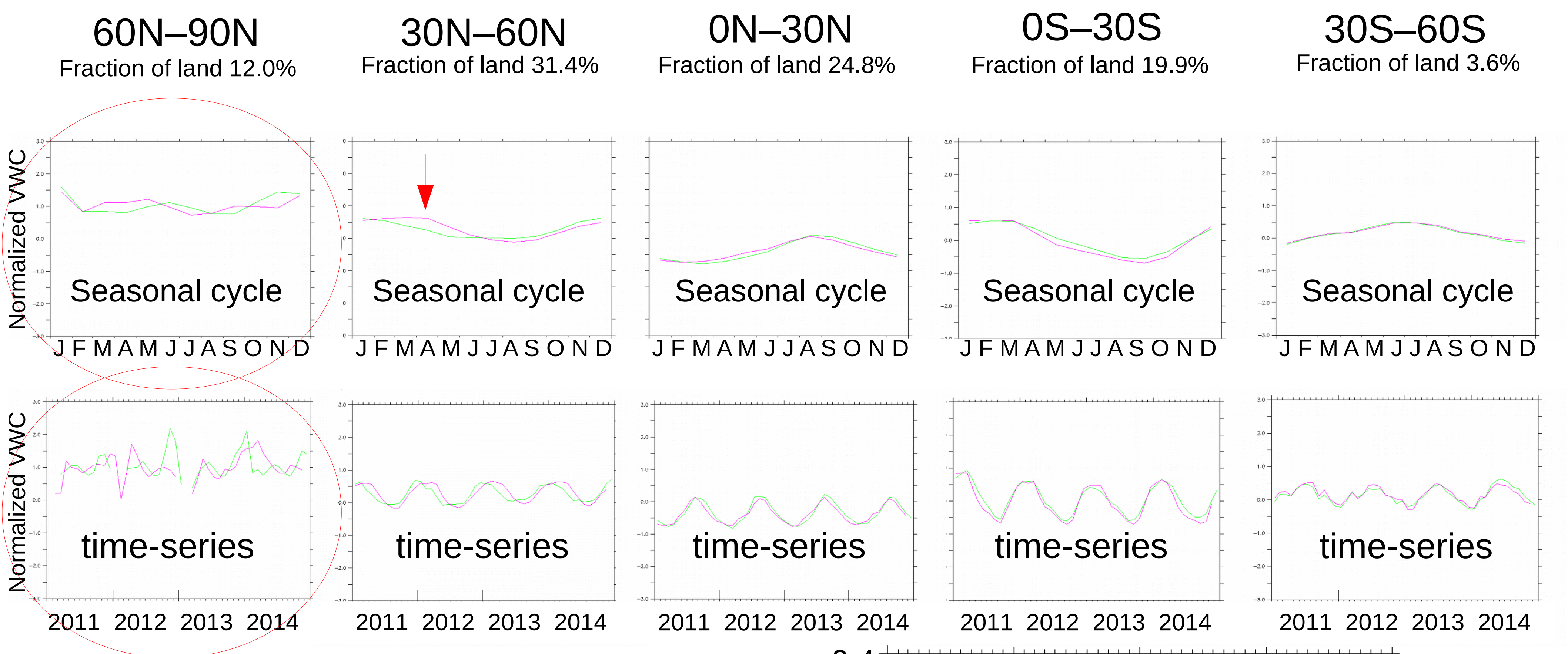
normalization $SSM_{nor} = \frac{SSM - ave(SSM)}{sd(SSM)}$



Temporal change of CCI, CL5 after normalization

We focus on this pair
(CCI-CL5 period2) hereafter.
(the other pairs showed similar results)

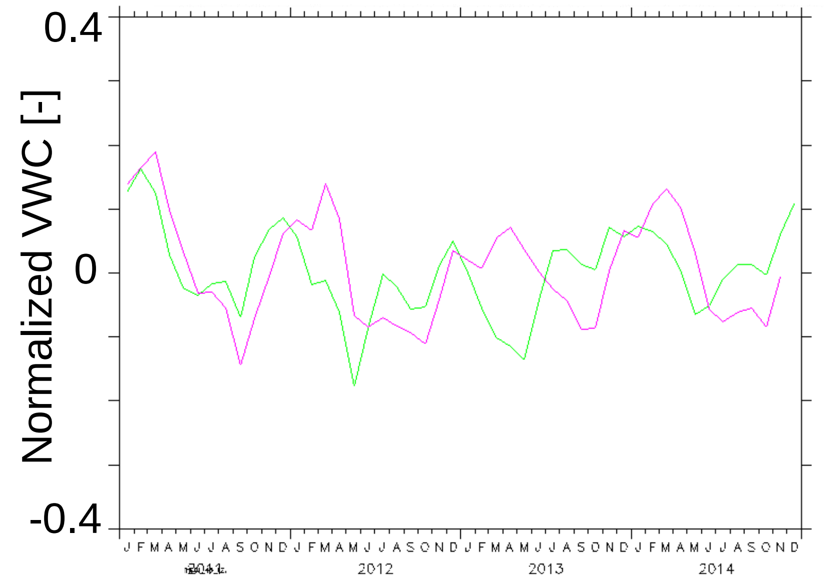
Discrepancy in seasonal cycle.
▶Plot time-series for each zone



Discrepancy in seasonal cycle is from discrepancy in boreal region.

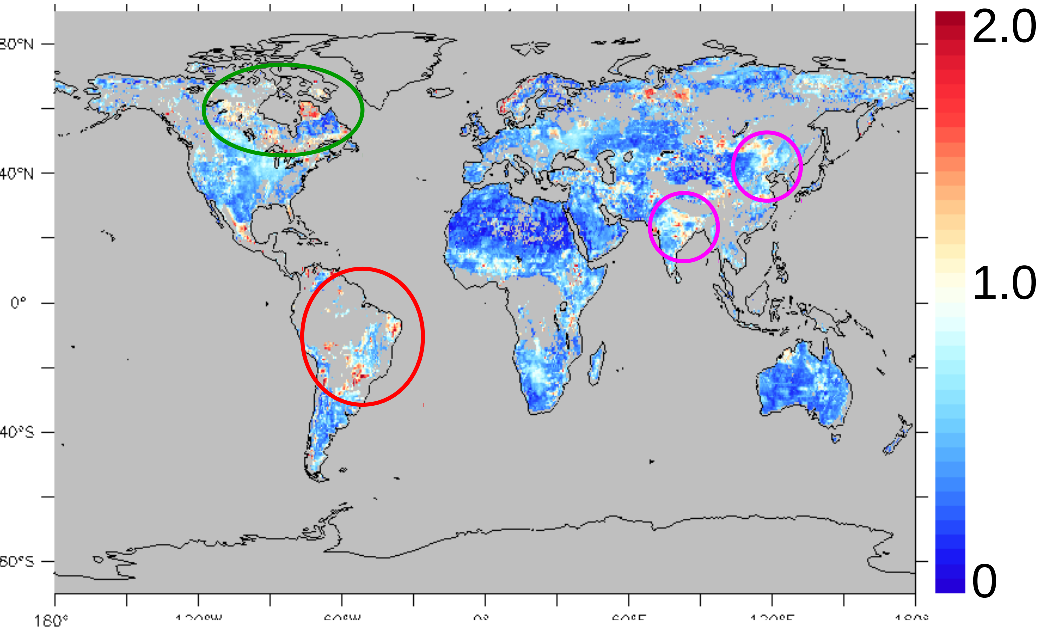
▶Snowmelt effect in model ?

The other region showed good consistency in seasonal cycle.

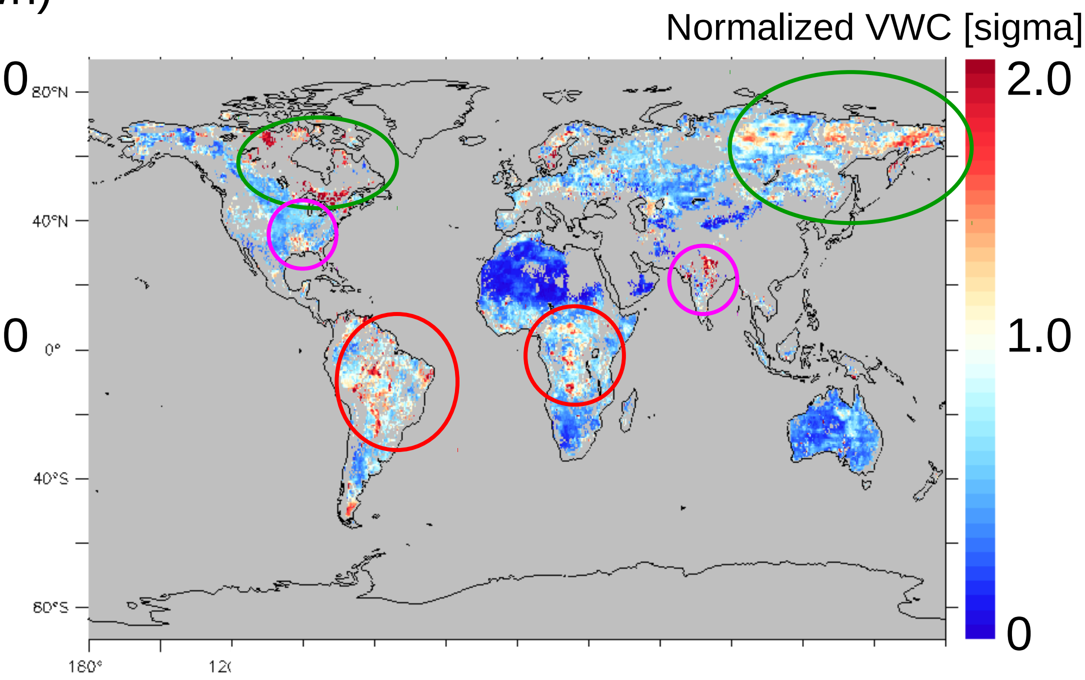


Temporal change of CCI, CL5 for all zones

Pixel-based statistics (only RMSE was shown)



RMSE between CCI and CL5 (period2)



RMSE between SMOS and CL5 (period2)

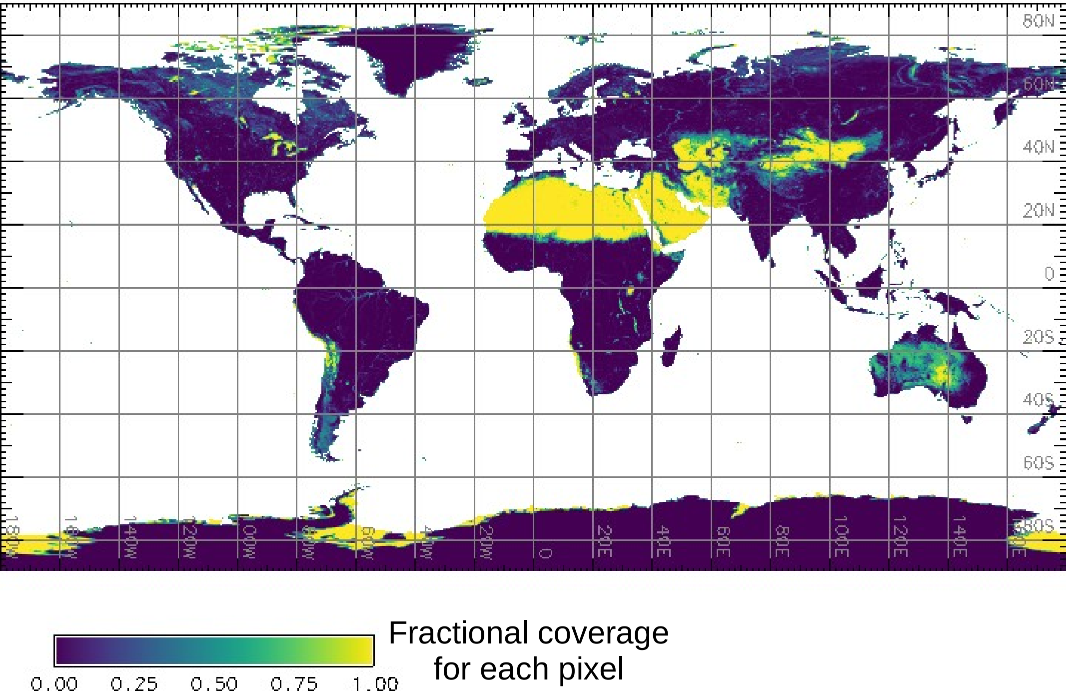
Basically good accuracy in many region (0–1.0)

Uncertain region
- Boreal region
  Snow-melting/freezing effect

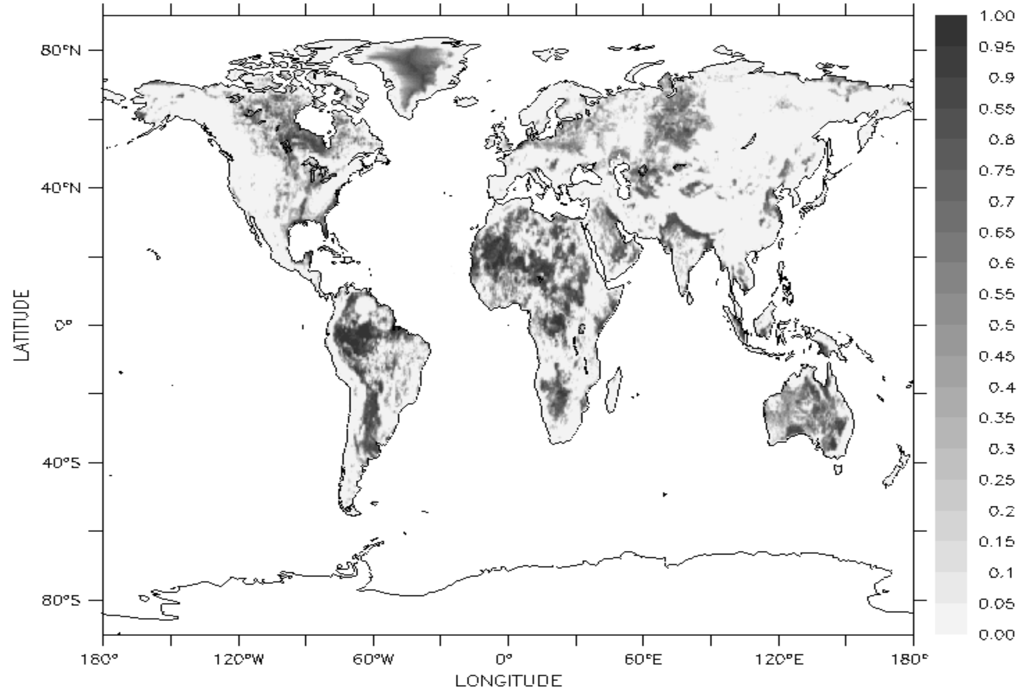
- some tropical rainforest (Congo, Amazon)
  Less reliability in SMOS?

- Largely irrigated region (North America, Indo-Gangetic Plain):

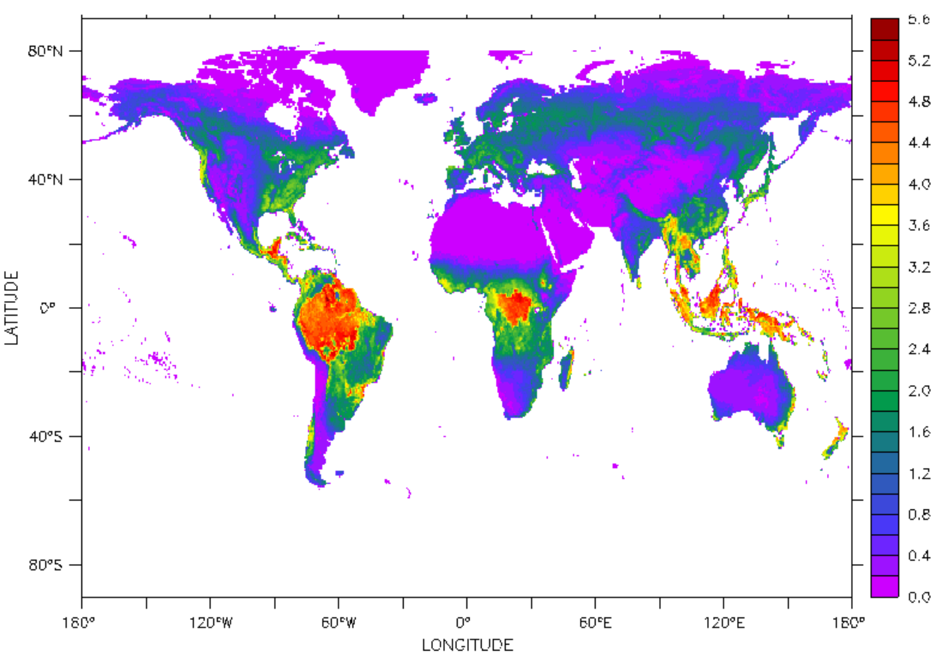
▶Add factor analysis to see irrigation and LULC effects



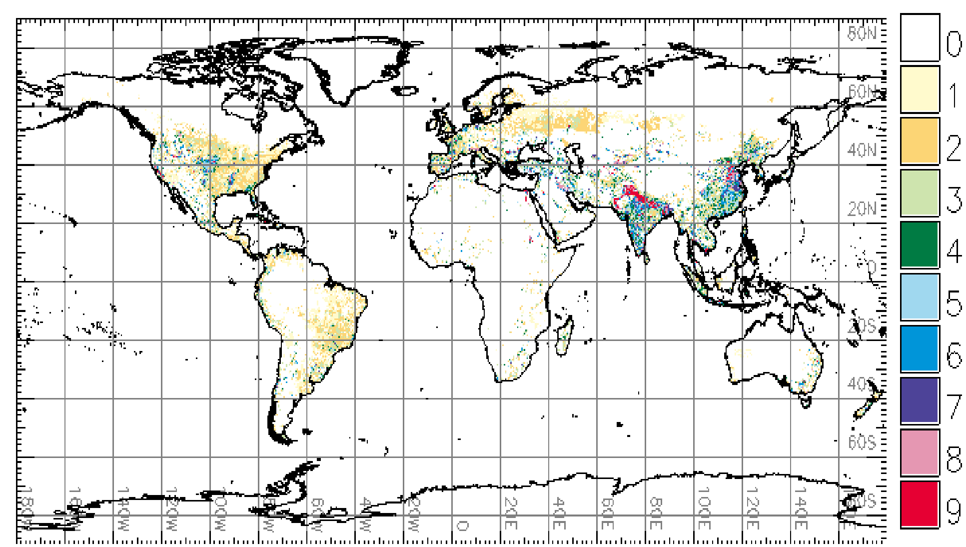
PFT maps (ex. PFT1: bare soil fraction)



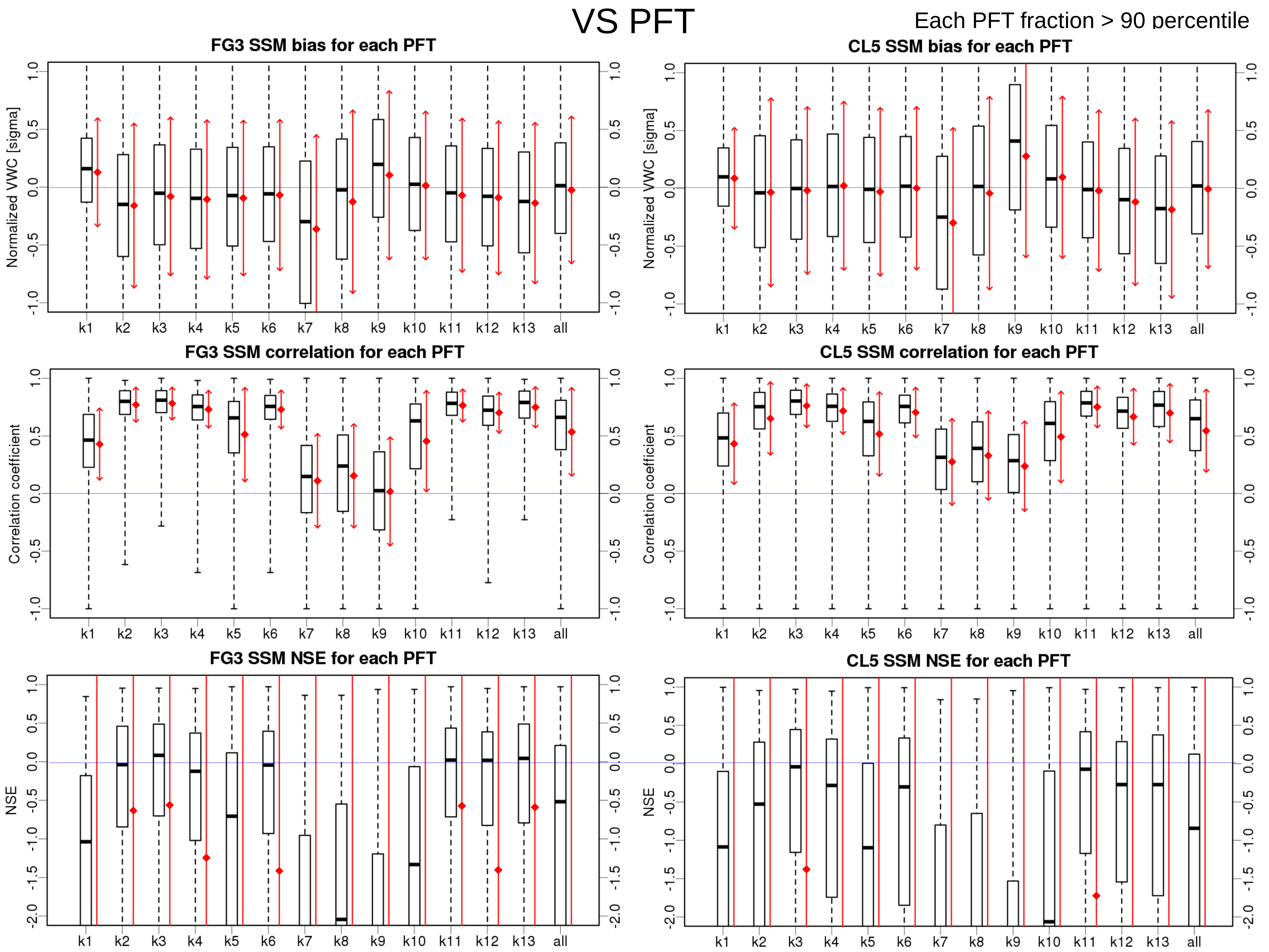
Reinfiltration ratio (from FG3)



Temporally averaged LAI [m^2/m^2]

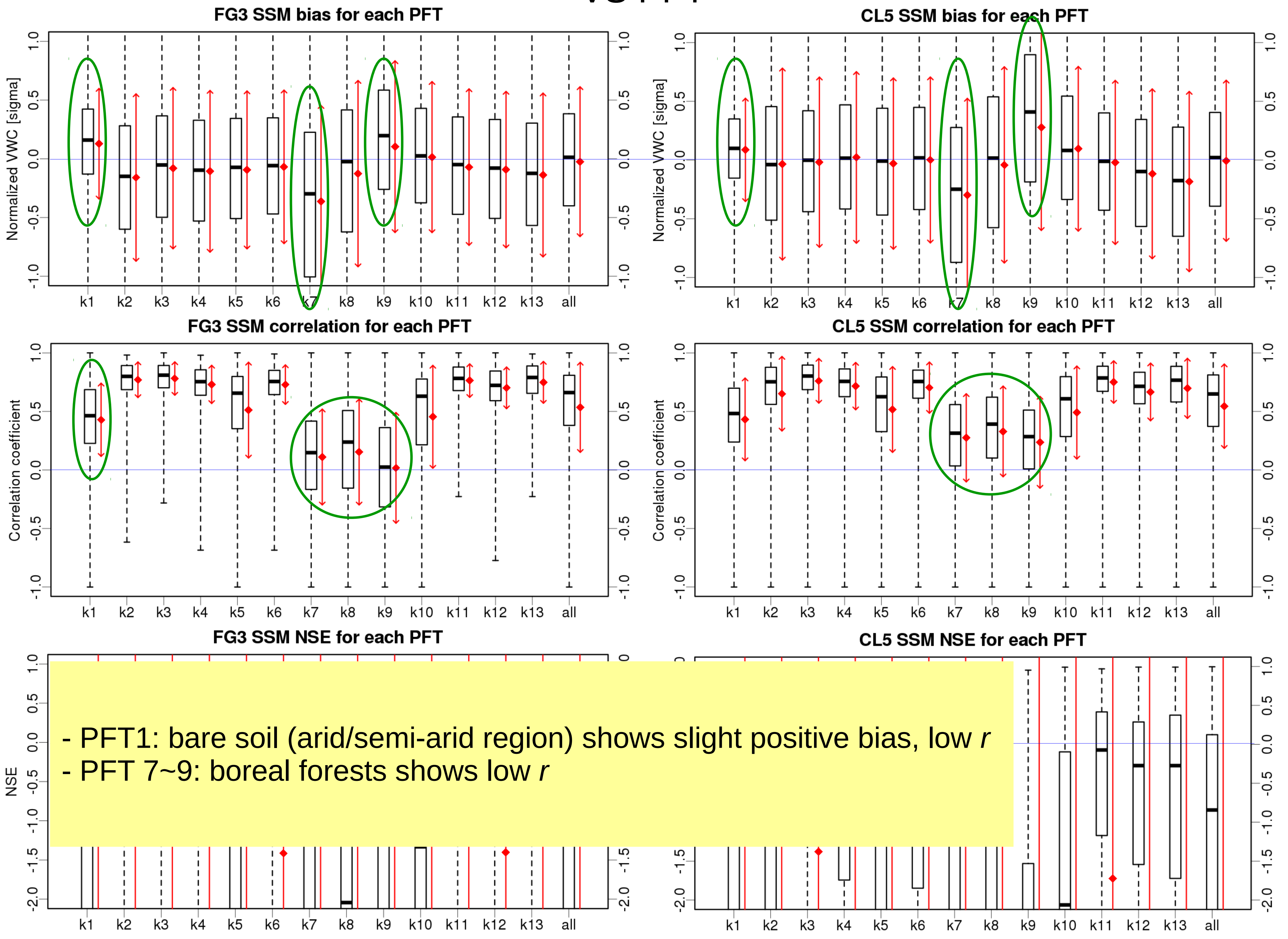


Fractional area equipped for irrigation
0: =0, 1: <0.1, 2: <1, 3: <5, 4: <10,
5: <20, 6: <35, 7: <50, 8: <75, 9: <100


VS PFT
Each PFT fraction > 90 percentile
FG3 SSM bias for each PFT
CL5 SSM bias for each PFT
Normalized VWC [sigma]
FG3 SSM correlation for each PFT
CL5 SSM correlation for each PFT
Correlation coefficient
FG3 SSM NSE for each PFT
CL5 SSM NSE for each PFT
NSE
k1
k2
k3
k4
k5
k6
k7
k8
k9
k10
k11
k12
k13
all

VS PFT

Each PFT fraction > 90 percentile



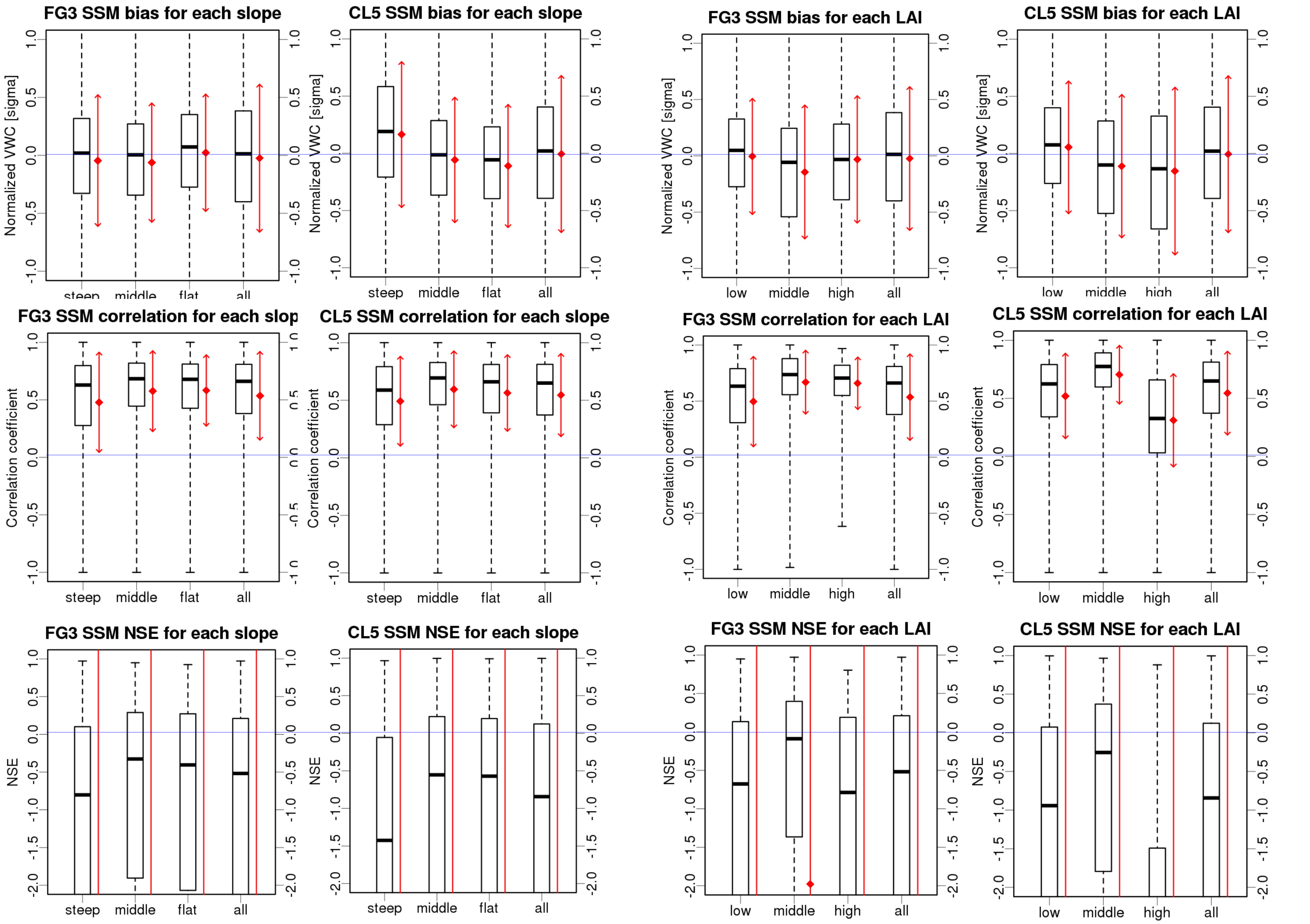
- PFT1: bare soil (arid/semi-arid region) shows slight positive bias, low *r*
- PFT 7~9: boreal forests shows low *r*

VS slope

FG3 reinf_slope data used
steep: 0 middle: 0~0.5 flat: 0.5~1.0

VS LAI

low: 0~1.0 middle: 1.0~3.0 high: 3.0~

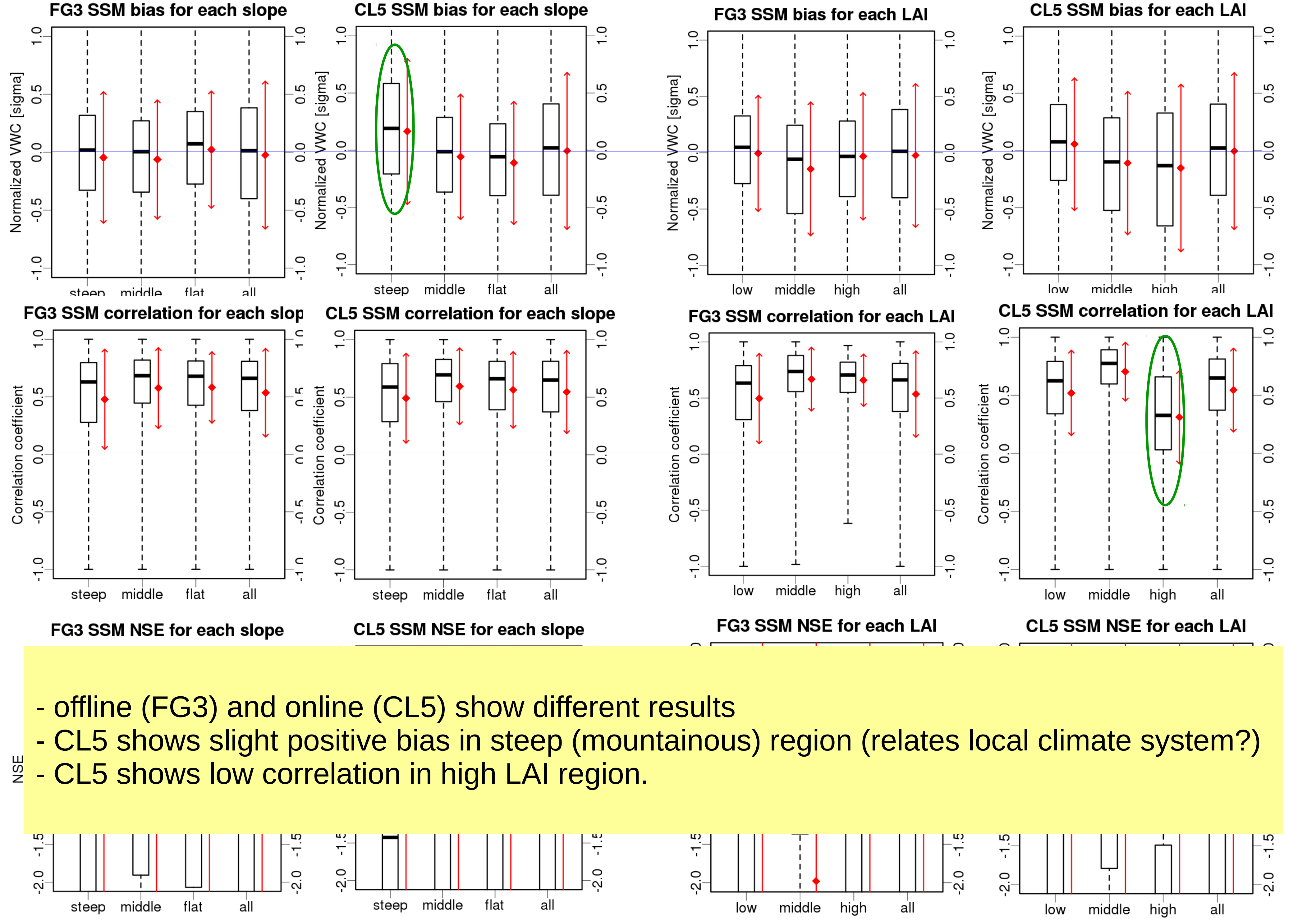


VS slope

FG3 reinf_slope data used
steep: 0 middle: 0~0.5 flat: 0.5~1.0

VS LAI

low: 0~1.0 middle: 1.0~3.0 high: 3.0~

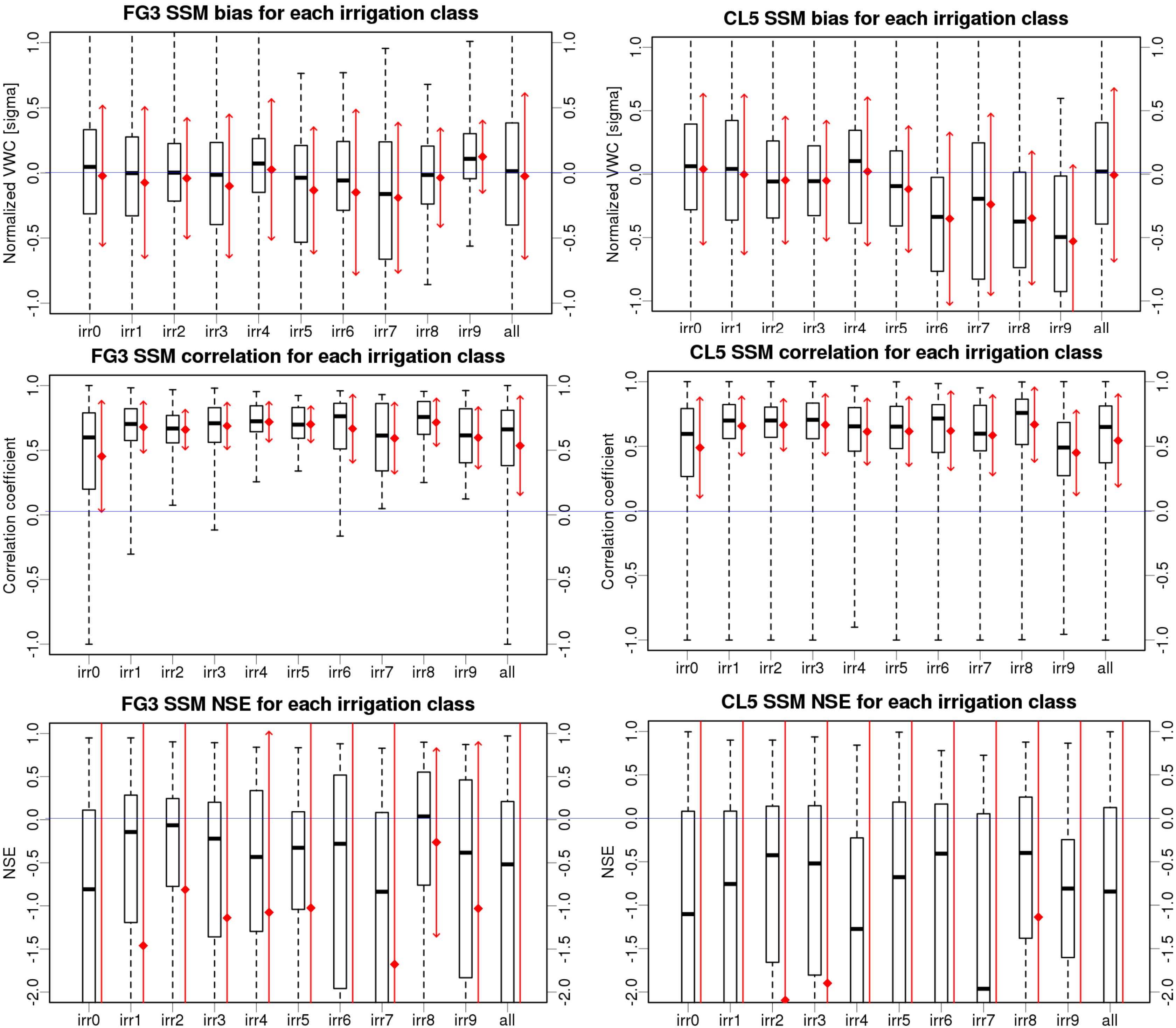


- offline (FG3) and online (CL5) show different results
- CL5 shows slight positive bias in steep (mountainous) region (relates local climate system?)
- CL5 shows low correlation in high LAI region.

VS irrigation

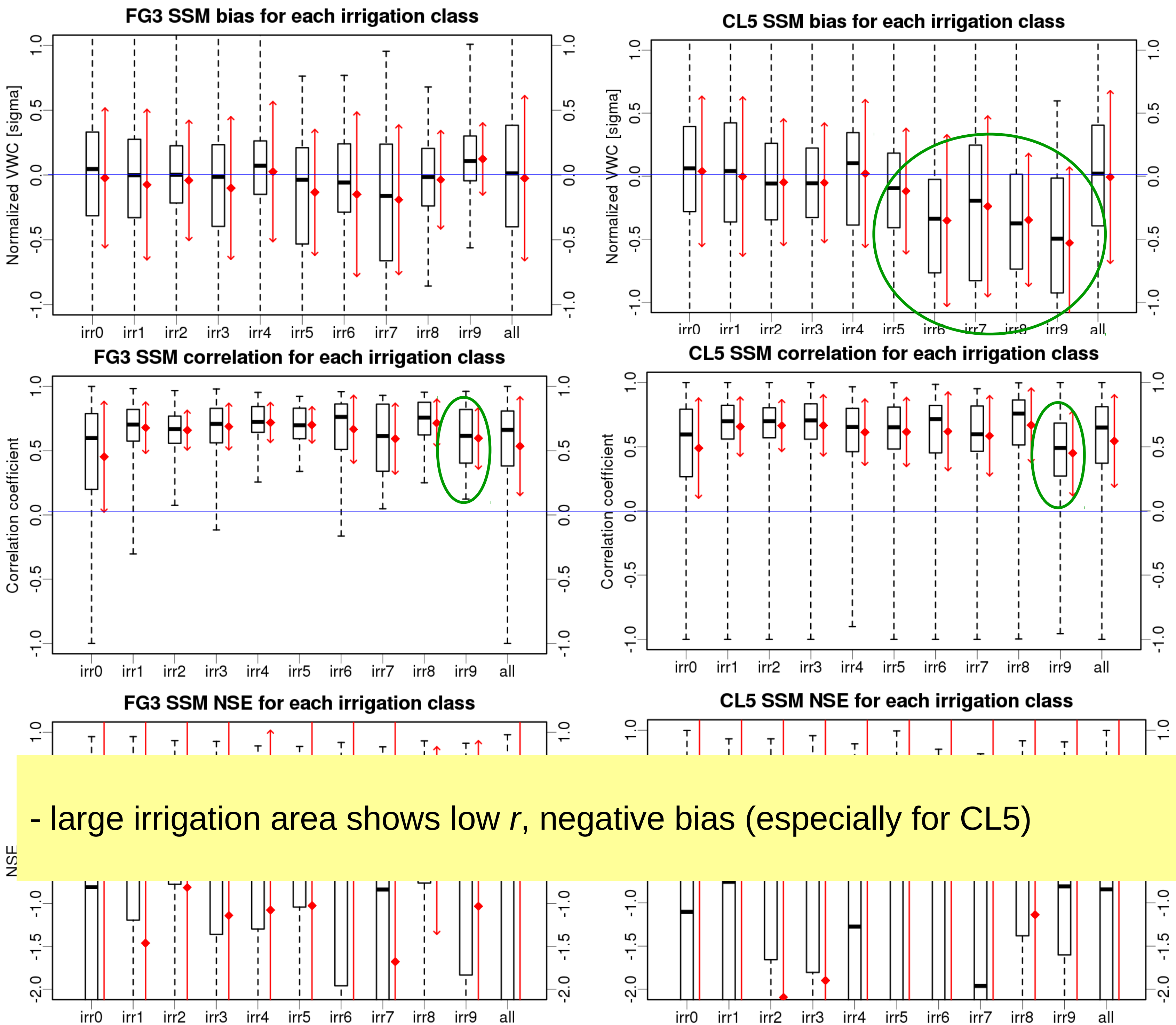
Fractional area equipped for irrigation

Irr0: 0 **irr1**: 0~0.1 **irr2**: 0.1~1 **irr3**: 1~5 **irr4**: 5~10 **irr5**: 10~20 **irr6**: 20~35 **irr7**: 35~50 **irr8**: 50~75 **irr9**: 75~100



VS irrigation

Fractional area equipped for irrigation
Irr0: 0 **irr1**: 0~0.1 **irr2**: 0.1~1 **irr3**: 1~5 **irr4**: 5~10 **irr5**: 10~20 **irr6**: 20~35 **irr7**: 35~50 **irr8**: 50~75 **irr9**: 75~100



- large irrigation area shows low *r*, negative bias (especially for CL5)

Summary for SSM

- ORCHIDEE basically shows satisfactory consistency with observations.
- Discrepancy was observed in
  Boreal region: snowmelt effect and observation uncertainty
  Arid regions: low r seems to be from less temporal variability (not fault of ORCHIDEE), but slight positive bias was also observed.

- offline (FG3) and online (CL5) show different results
  suggest climate model uncertainty in steep region, high LAI region

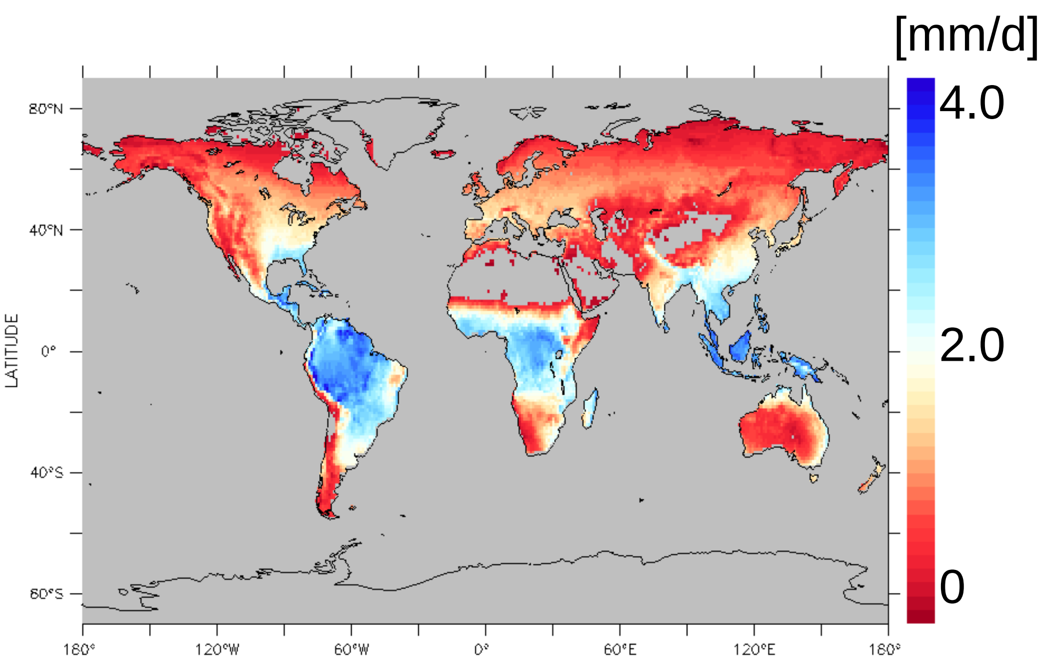
- large irrigation area shows low *r*, negative bias (especially for CL5)
  ORCHIDEE does not implements irrigation scheme.

2. Evapotranspiration

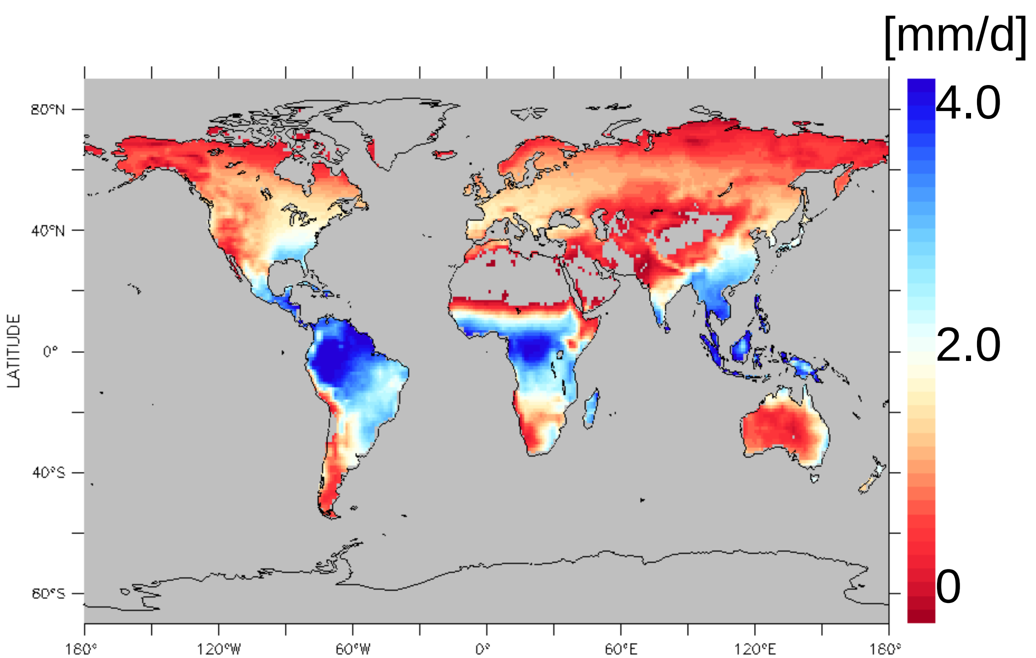
Average of 4 reference data 1deg × 1deg, 1984–2006, [mm/d]
- MPI, GLEAM, NTSG, PKU
- spatially interpolated by Juan-Pablo Boisier

FG3 0.5deg × 0.5deg, 1979–2009, [mm/d]
- used only 1986–2006

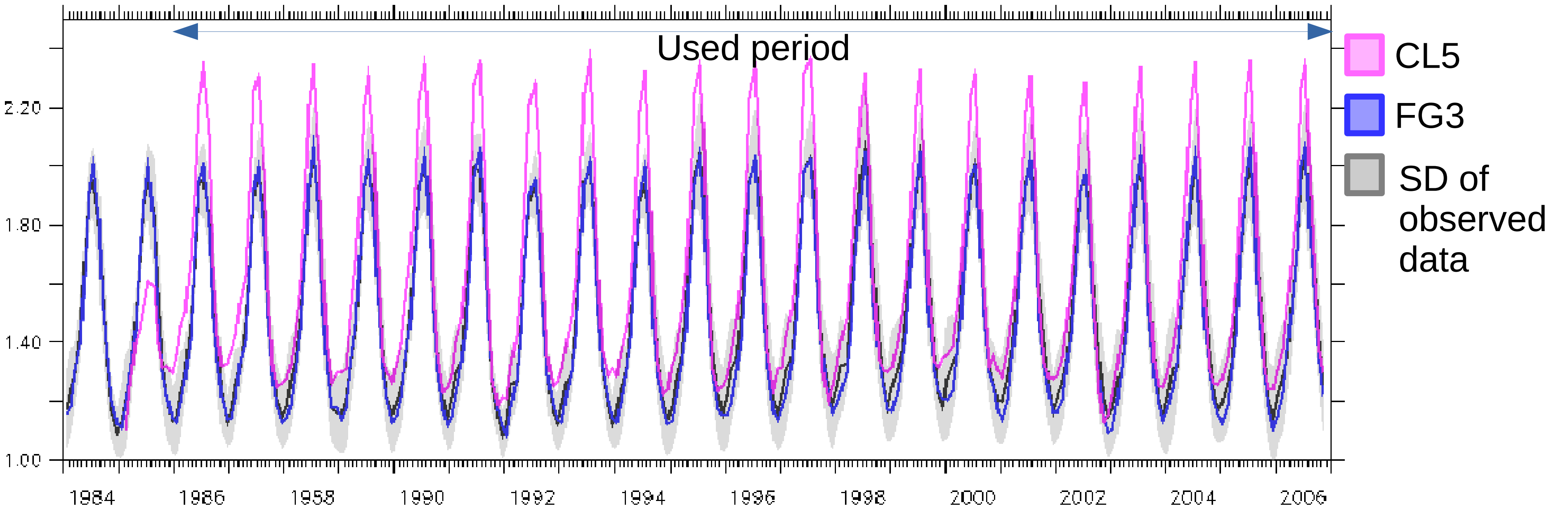
CL5 143pixel × 144pixel, 1985–2014, [mm/d]
- used only 1986–2006



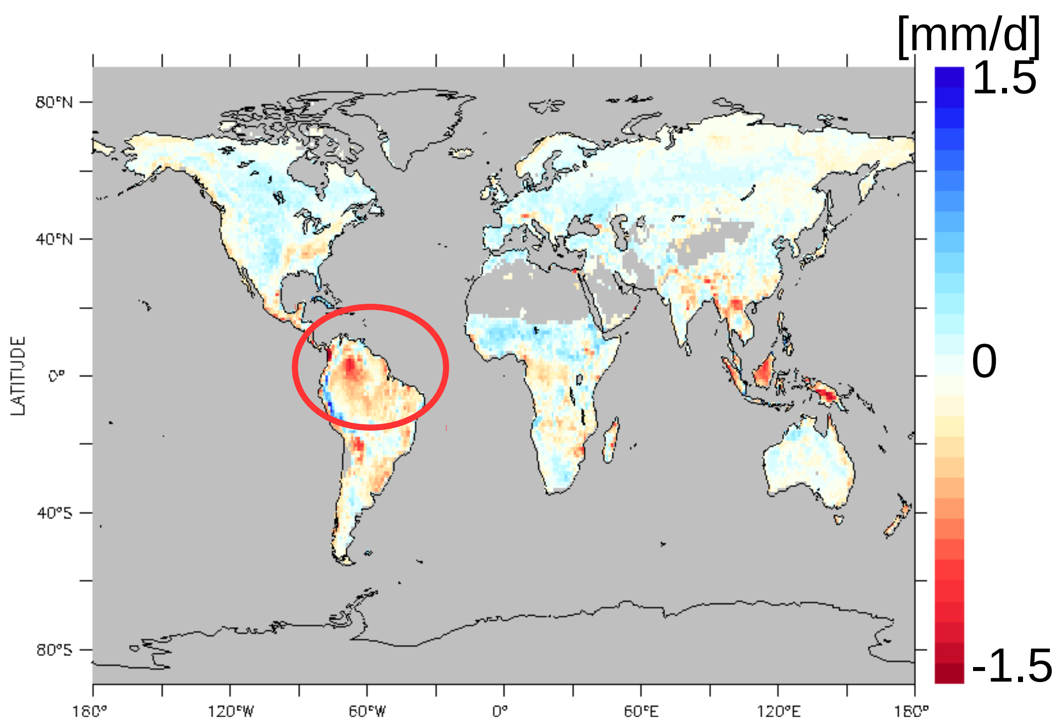
Spatial pattern of FG3 ET



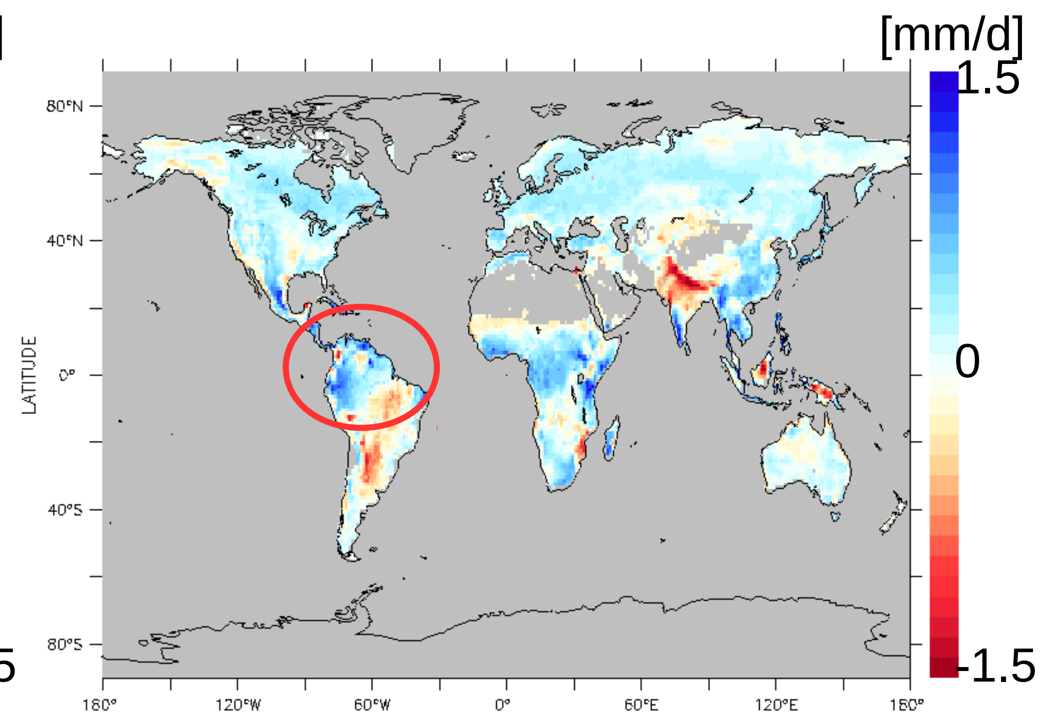
Spatial pattern of CL5 ET



Time-series of FG3, CL5 and observations.



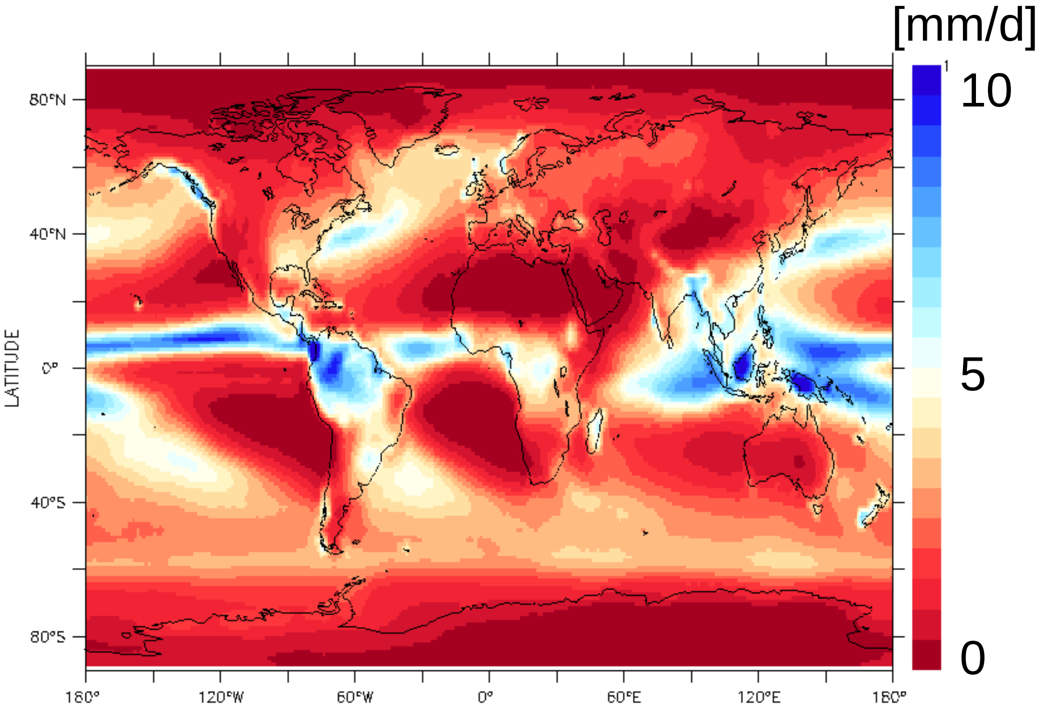
ET bias of FG3 – observation



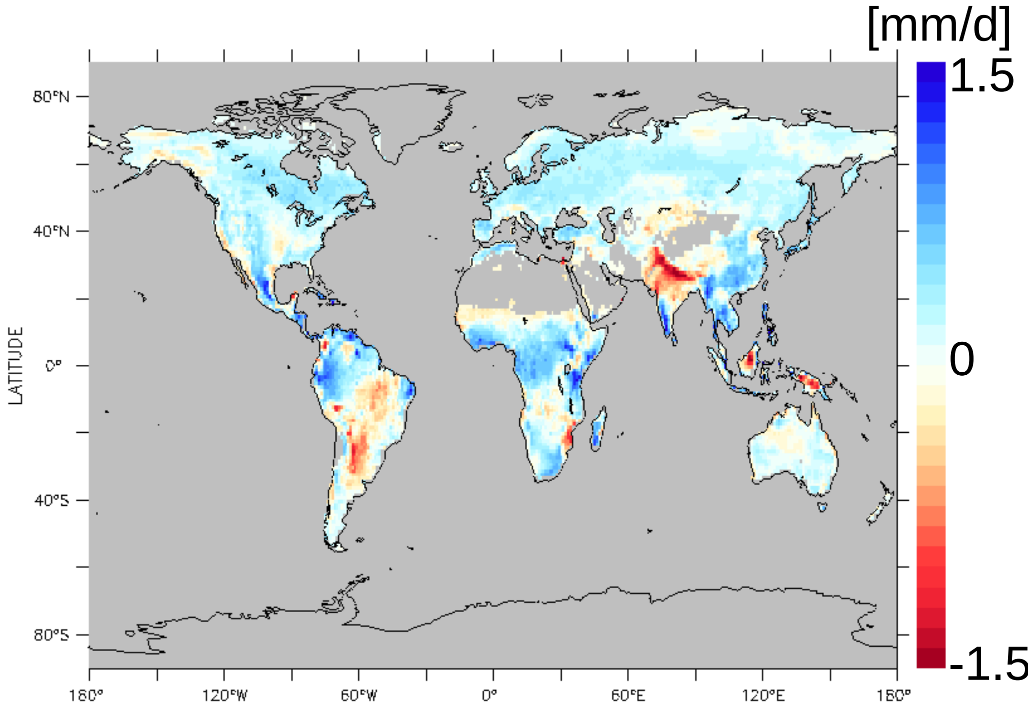
ET bias of CL5 – observation

- FG3 temporal pattern was good.
- CL5 temporal pattern has positive systematic bias.
- Opposite bias patterns in tropical Africa and south America between FG3 and CL5. seems to relate to atmospheric component such as precipitation in CL5.
- substantial underestimation was observed in India and Indonesia (irrigation?)

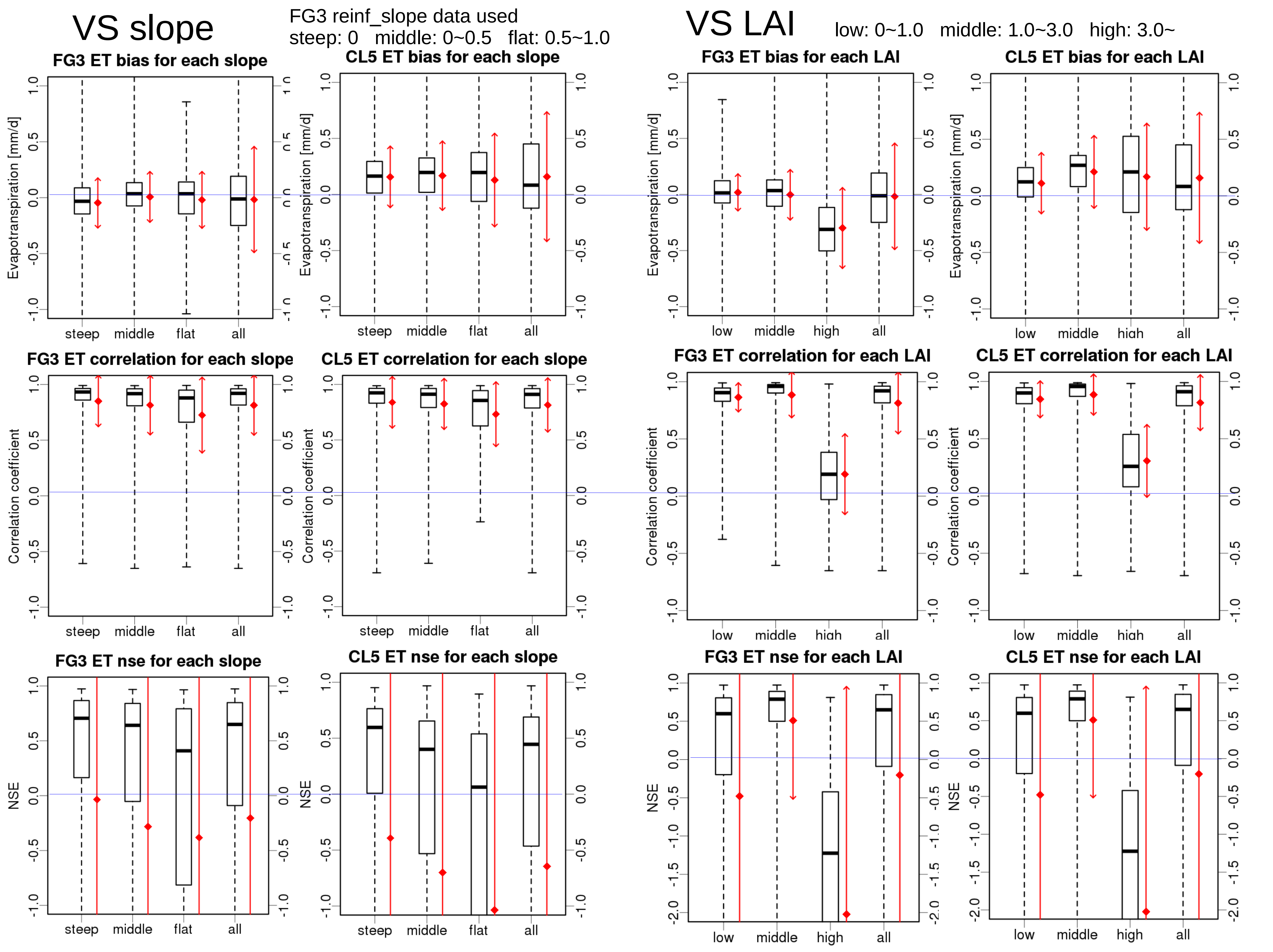
▶ factor analysis



Annual mean precipitation



ET bias of CL5 – observation



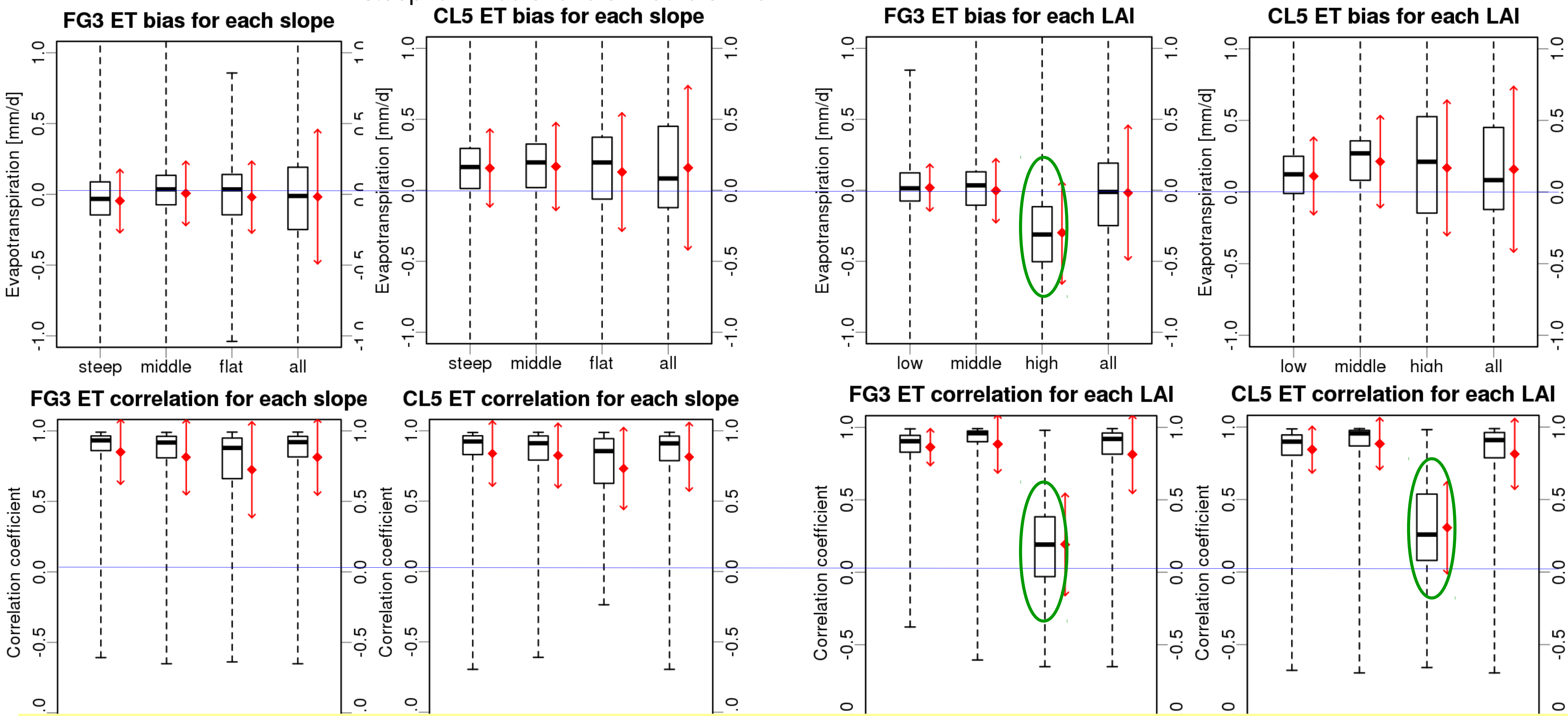
VS slope
FG3 reinf_slope data used
steep: 0 middle: 0~0.5 flat: 0.5~1.0
VS LAI
low: 0~1.0 middle: 1.0~3.0 high: 3.0~
FG3 ET bias for each slope
CL5 ET bias for each slope
FG3 ET bias for each LAI
CL5 ET bias for each LAI
Evapotranspiration [mm/d]
FG3 ET correlation for each slope
CL5 ET correlation for each slope
FG3 ET correlation for each LAI
CL5 ET correlation for each LAI
Correlation coefficient
FG3 ET nse for each slope
CL5 ET nse for each slope
FG3 ET nse for each LAI
CL5 ET nse for each LAI
NSE
steep
middle
flat
all
low
high

VS slope

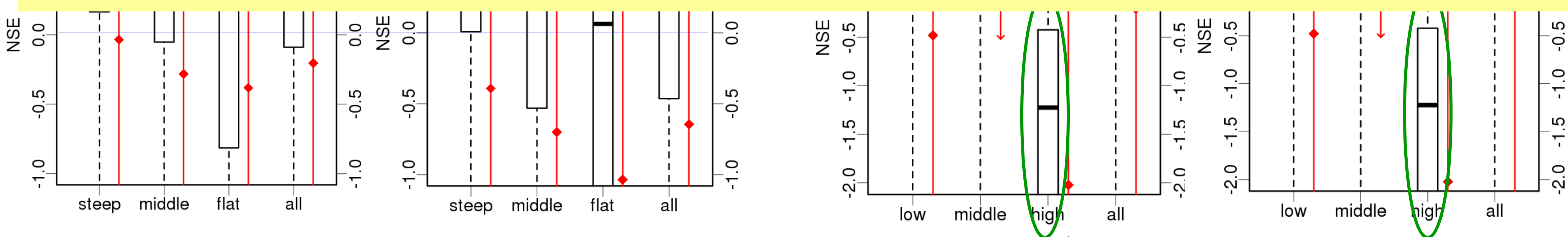
FG3 reinf_slope data used
steep: 0 middle: 0~0.5 flat: 0.5~1.0

VS LAI

low: 0~1.0 middle: 1.0~3.0 high: 3.0~

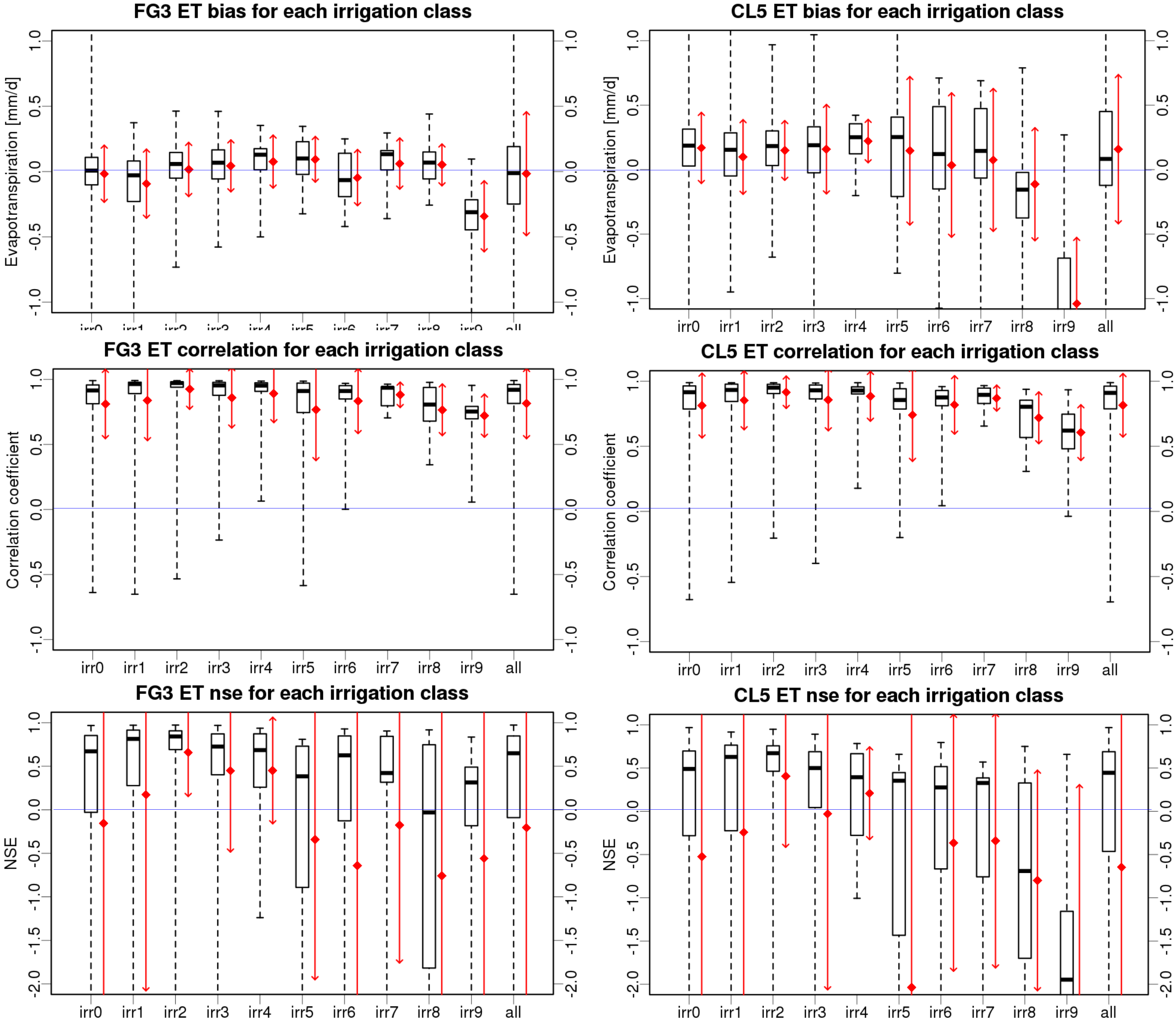


- not obvious pattern for slope
- low~middle LAI show good consistency
- high LAI region shows low *r*, negative bias in FG3
  too much water stress in high LAI region ?



VS irrigation

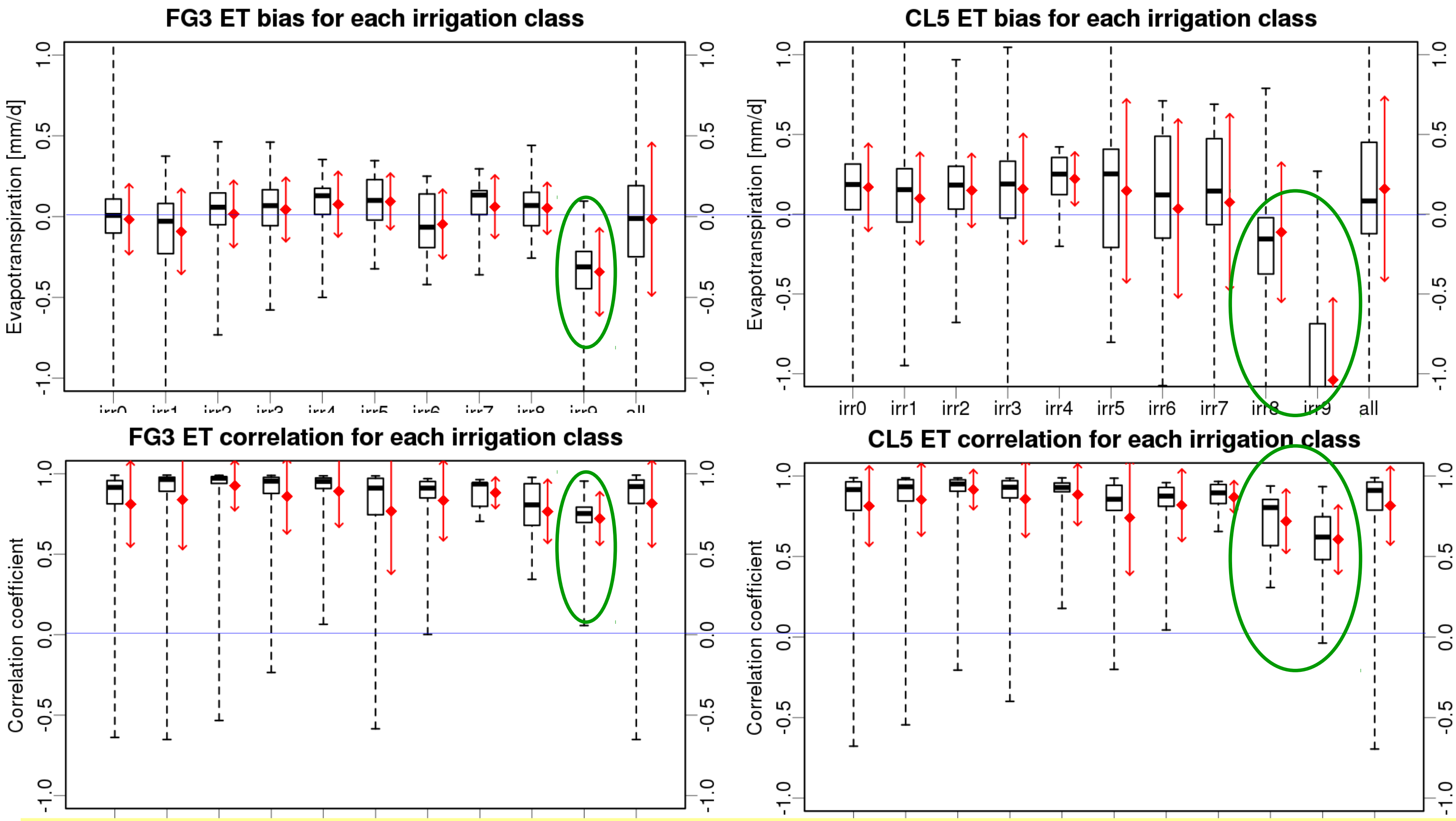
Fractional area equipped for irrigation
Irr0: 0 **irr1**: 0~0.1 **irr2**: 0.1~1 **irr3**: 1~5 **irr4**: 5~10 **irr5**: 10~20 **irr6**: 20~35 **irr7**: 35~50 **irr8**: 50~75 **irr9**: 75~100



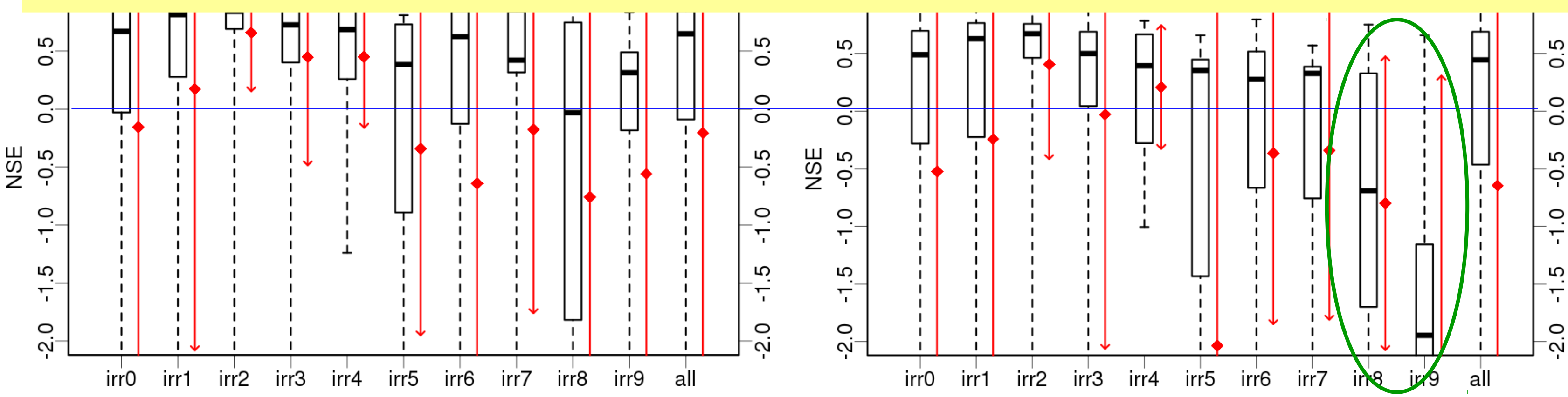
VS irrigation

Fractional area equipped for irrigation

Irr0: 0 **irr1**: 0~0.1 **irr2**: 0.1~1 **irr3**: 1~5 **irr4**: 5~10 **irr5**: 10~20 **irr6**: 20~35 **irr7**: 35~50 **irr8**: 50~75 **irr9**: 75~100



- obvious negative bias in largely irrigated area



Summary for ET

- FG3 temporal change was good, CL5 has positive bias
  relates to precipitation in CL5.

- LAI affects ET accuracy.
  Low~middle LAI is good (boreal, arid/semiarid, temperate)
  high LAI leads high uncertainty. FG3 shows negative ET bias in high LAI region
  (too much water stress?)

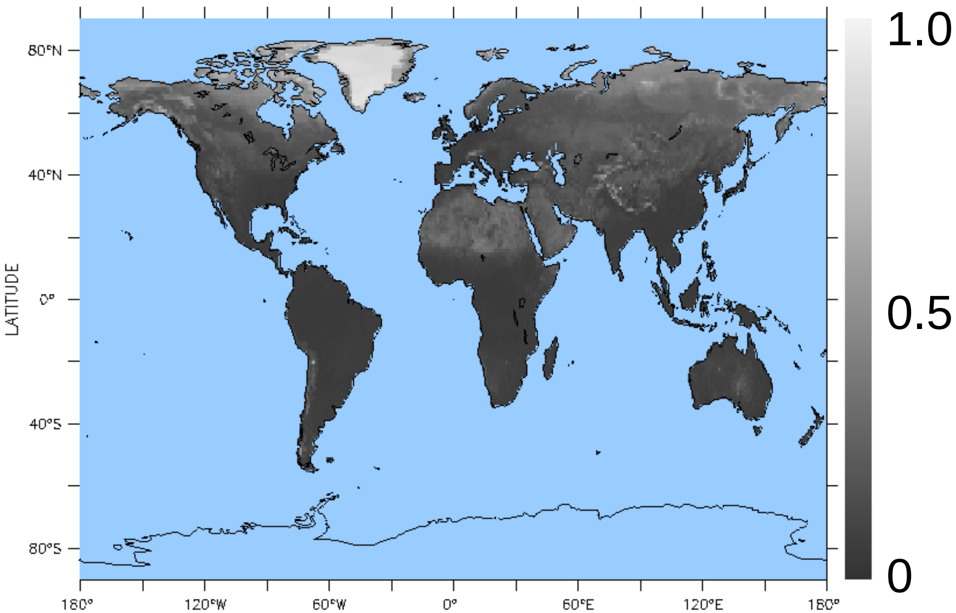
- obvious negative bias in largely irregated region

3. Albedo

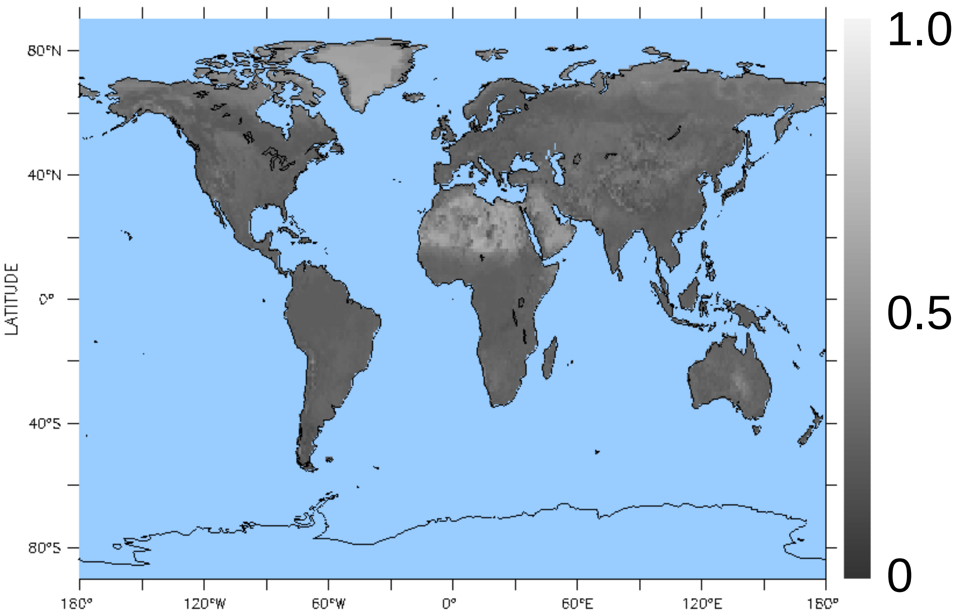
MODIS albedo (VIS, NIR) — 1deg × 1deg (aggregated), 2001–2010
- used only 2001–2009

FG3 (VIS, NIR) — 0.5deg × 0.5deg, 1979–2009
- used only 2001–2009

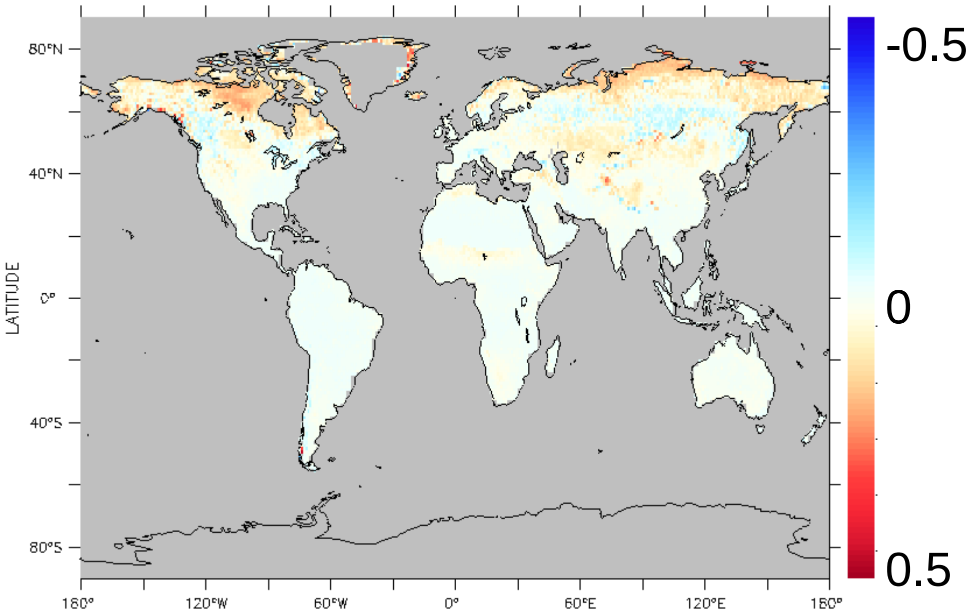
CL5 (VIS, NIR) — 143pixel × 144pixel, 1985–2014
- used only 2001–2009



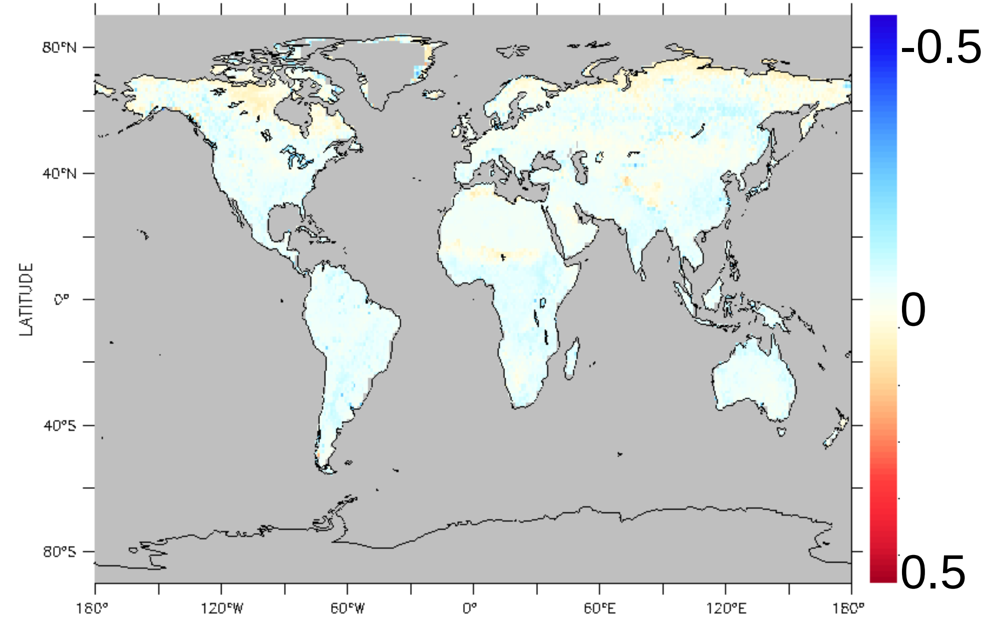
Temporally averaged FG3 VIS albedo



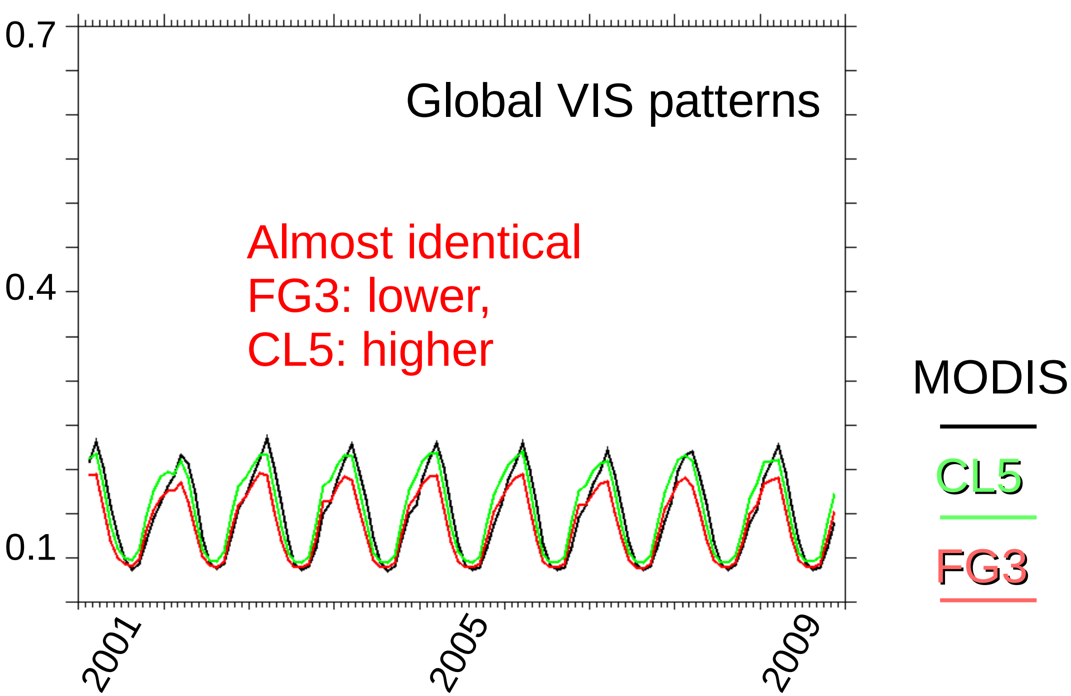
Temporally averaged FG3 NIR albedo



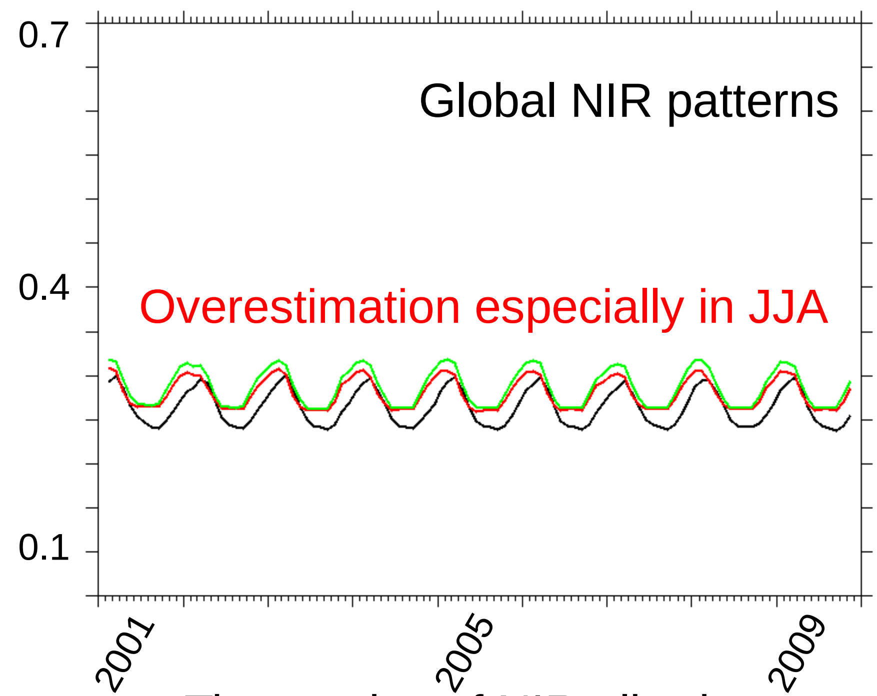
VIS albedo bias FG3 - MODIS



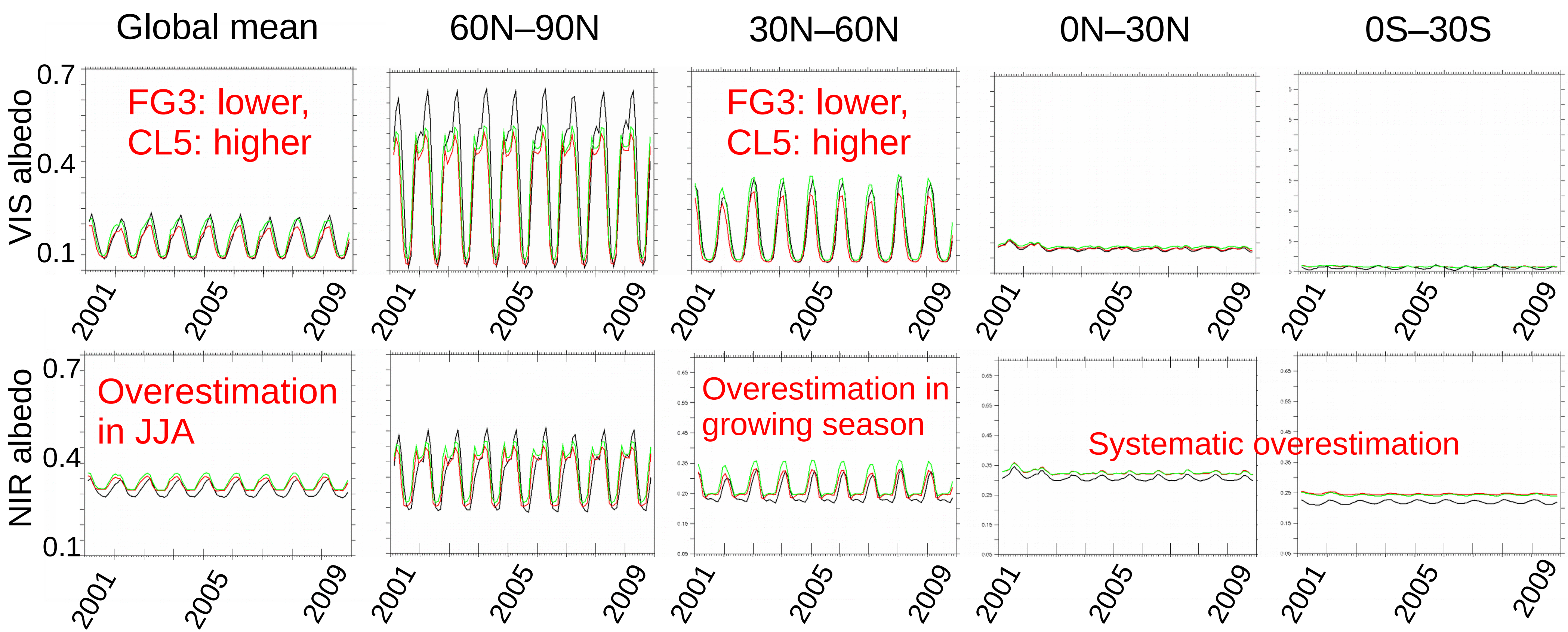
NIR albedo bias FG3 - MODIS



Time series of VIS albedo



Time series of NIR albedo



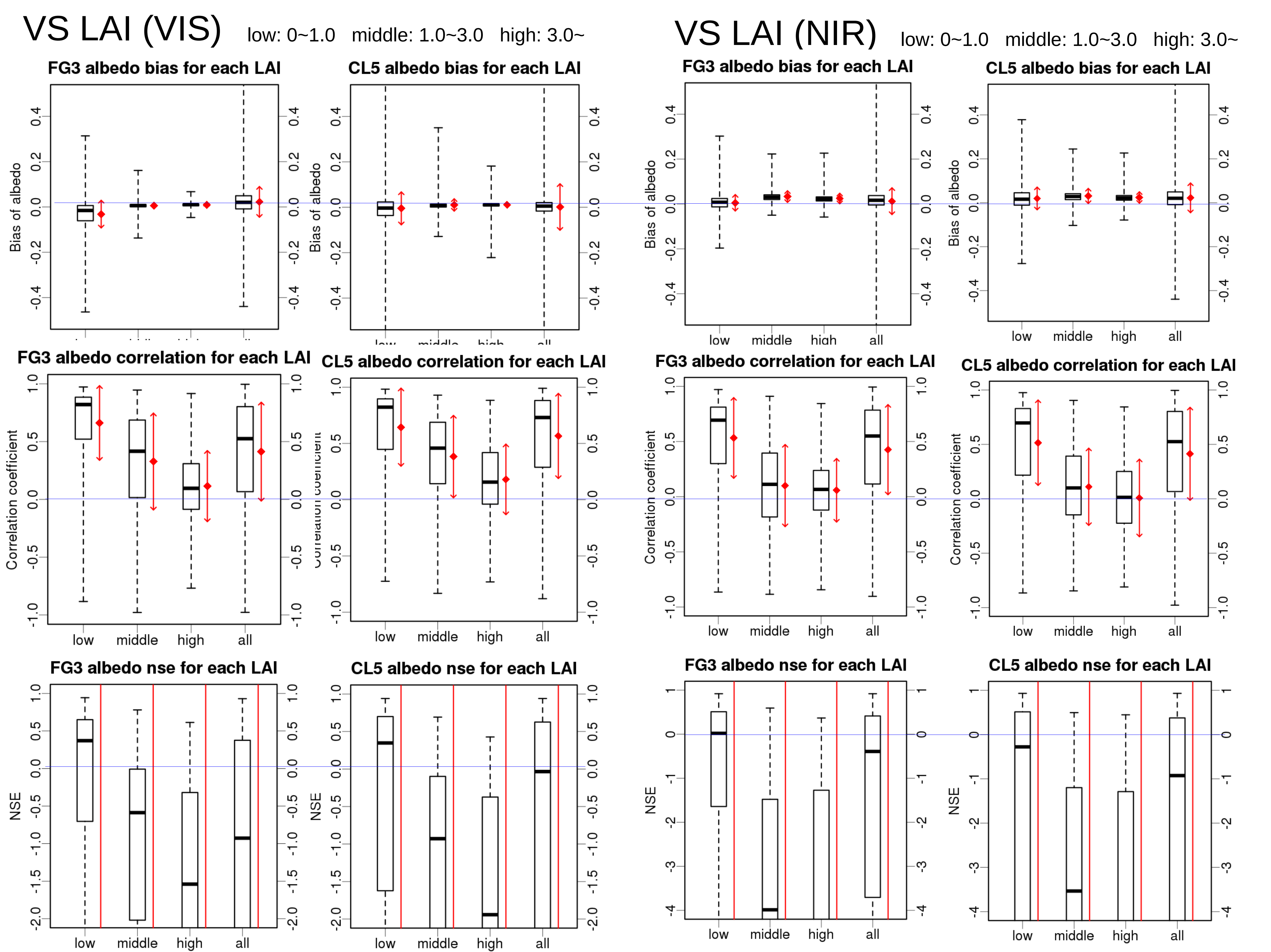
MODIS

CL5

FG3

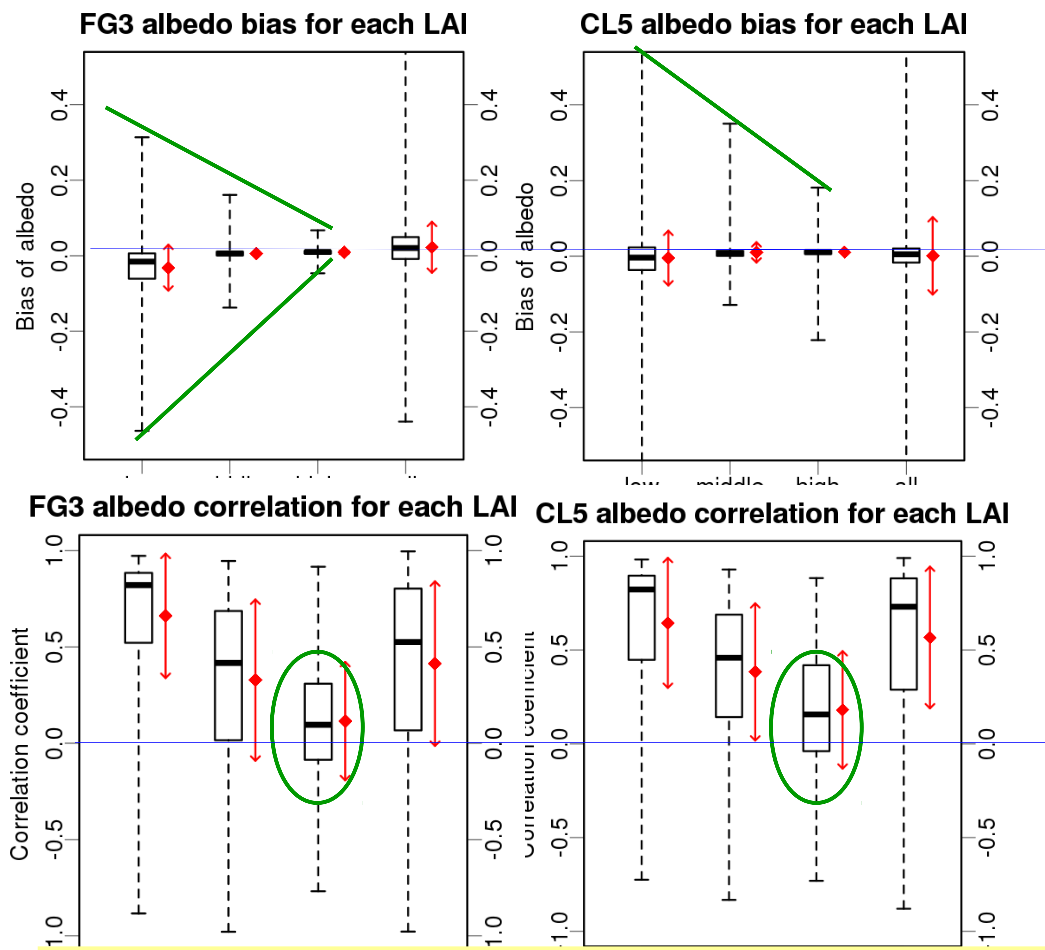
- underestimation of VIS/NIR albedo in winter~spring of boreal region
  Likely to be snow albedo effect
- Global pattern is primary controlled by 30N-60N region
  (largest land pixels)

- NIR global overestimation is related to systematic overestimation in equatorial region and overestimation in growing season at temperate zone


VS LAI (VIS)
low: 0~1.0 middle: 1.0~3.0 high: 3.0~
VS LAI (NIR)
low: 0~1.0 middle: 1.0~3.0 high: 3.0~
FG3 albedo bias for each LAI
CL5 albedo bias for each LAI
Bias of albedo
FG3 albedo correlation for each LAI
CL5 albedo correlation for each LAI
Correlation coefficient
FG3 albedo nse for each LAI
CL5 albedo nse for each LAI
NSE
low
middle
high
all

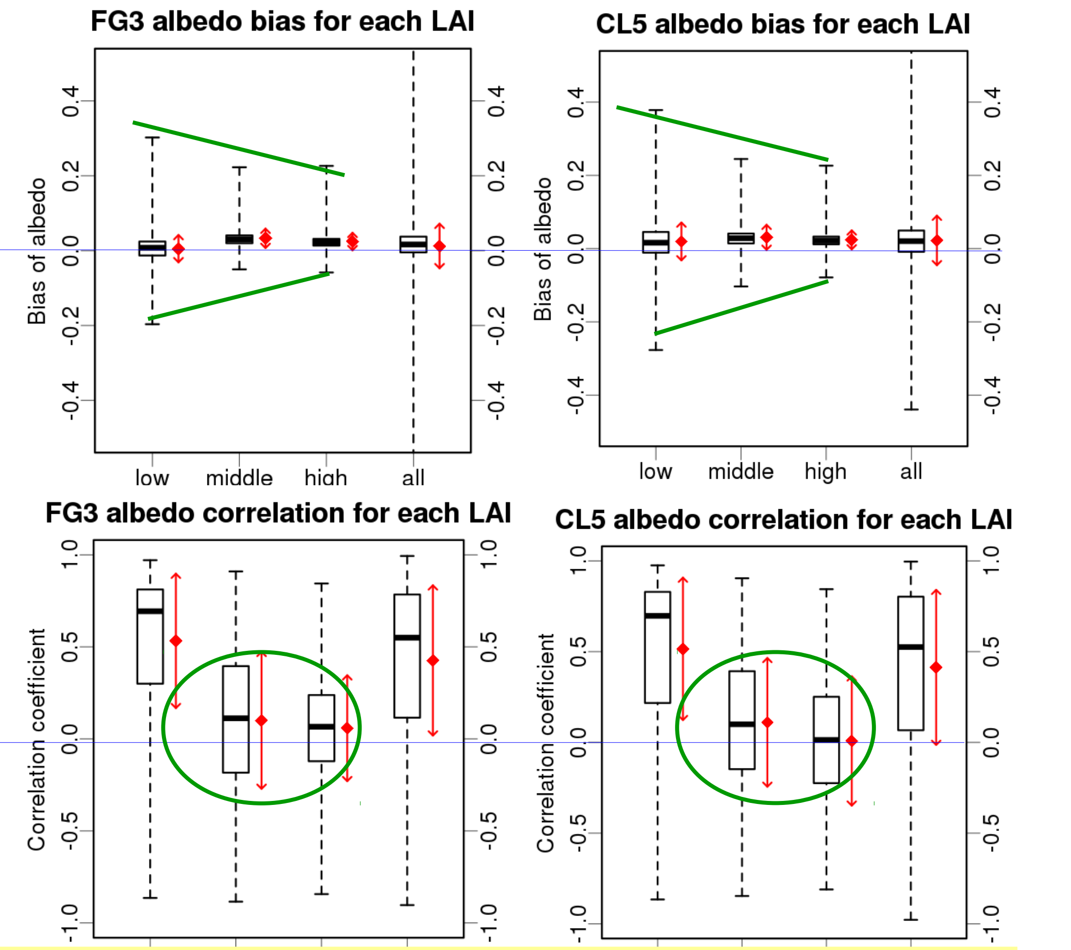
VS LAI (VIS)

low: 0~1.0   middle: 1.0~3.0   high: 3.0~



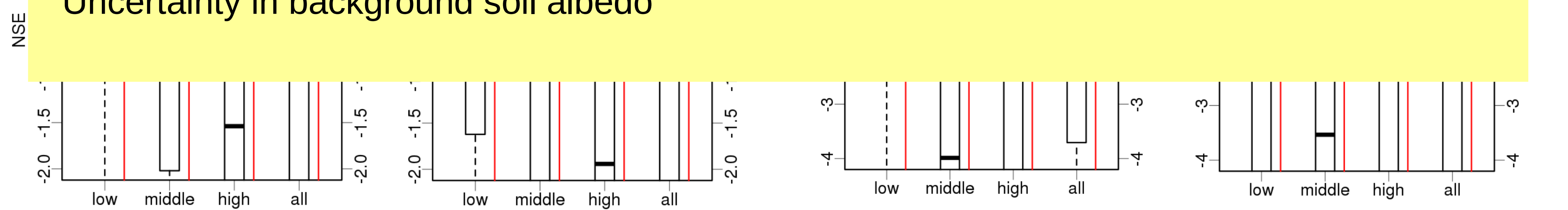
VS LAI (NIR)

low: 0~1.0   middle: 1.0~3.0   high: 3.0~



- middle~high LAI region show low r for both VIS and NIR in spite of small mean bias.
  Suggest incomplete vegetation seasonality in ORCHIDEE

- low LAI region has high dispersion in bias (especially for VIS)
  Uncertainty in background soil albedo



Summary for albedo

- VIS/NIR albedo in winter~spring of boreal region (or mountainous region) are likely to be affected by snow

- NIR global overestimation is related to systematic overestimation in tropical zone And overestimation in growing season at temperate zone.

- Seasonality of VIS/NIR albedo of vegetation should be carefully considered in ORCHIDEE.

- bias of background soil albedo (especially for VIS) shows large dispersion.

Summary

ORCHIDEE hydrological component (SECHIBA) was evaluated in the aspect of:

SSM

- ORCHIDEE shows basically good result, but some uncertainty was observed in boreal region, arid region and irrigated area.

ET

- ORCHIDEE offline simulation (FG3) describes good temporal change. Online simulation (CL5) has positive bias, relating to precipitation.
- In high LAI region, high uncertainty
- obvious negative bias in large irrigated area

Albedo

- snow may affects both VIS/NIR albedo
- vegetation (middle~high LAI) seasonality in VIS/NIR albedo should be considered.
- background soil albedo also leads diverged bias

Future work:

- Do the analysis for the recent ORCHIDEE trunk (CMIP6 simulation)
- Add evaluation on LAI, total water storage
- Careful selection of observation data (SMOS IC recent version etc...)


Thank you for your attention!!
Contact: hiroki.mizuoti@gmail.com

Citations

Global Map of Irrigation Areas (GMIA)
Siebert, S., Henrich, V., Frenken, K., Burke, J. (2013): Update of the Global Map of Irrigation Areas to version 5. Project report, 178 p. [Download pdf, 4 MB]
Siebert, S., Burke, J., Faurès, J.-M., Frenken, K., Hoogeveen, J., Döll, P., Portmann, F.T. (2010): Groundwater use for irrigation - a global inventory. Hydrology and Earth System Sciences, 14, 1863-1880. [Download pdf, 3 MB, and Download zip, 11 MB]

Koppen-Geiger map http://koeppen-geiger.vu-wien.ac.at/shifts.htm
university of Bern, Institute for Veterinary Public Health
Rubel, F., and M. Kottek, 2010: Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. Meteorol. Z., 19, 135-141. DOI: 10.1127/0941-2948/2010/0430.

Soil Moisture

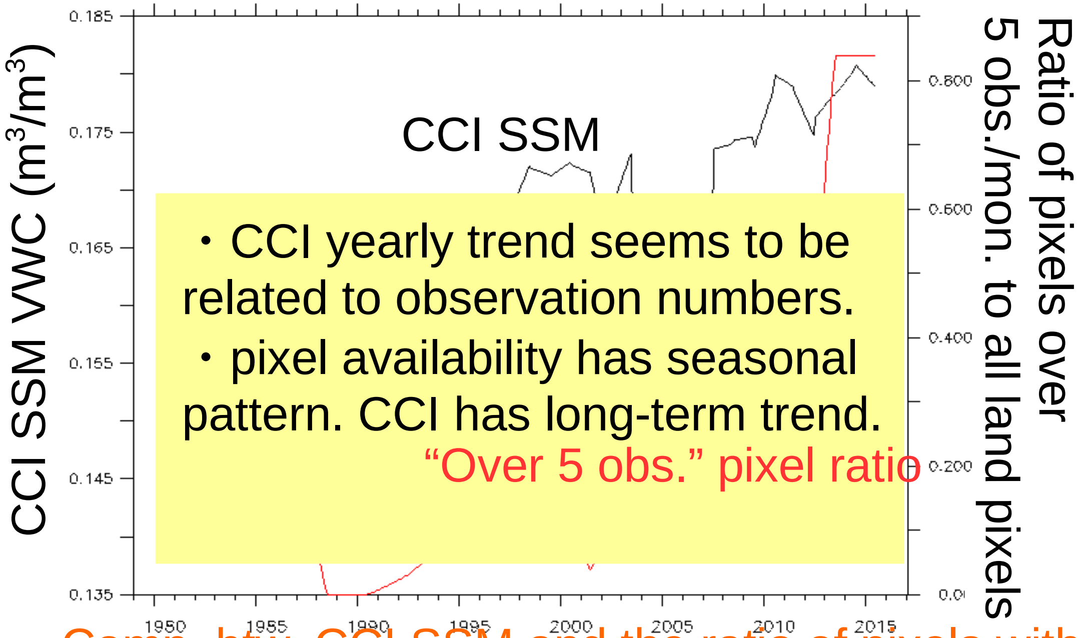
Masking process

<CCI_SSM>
82.8% of data remained; mean available land area 3.52×10^{13} m^2
Data range after masking and monthly aggregation: 0.016–0.511 (VWC)

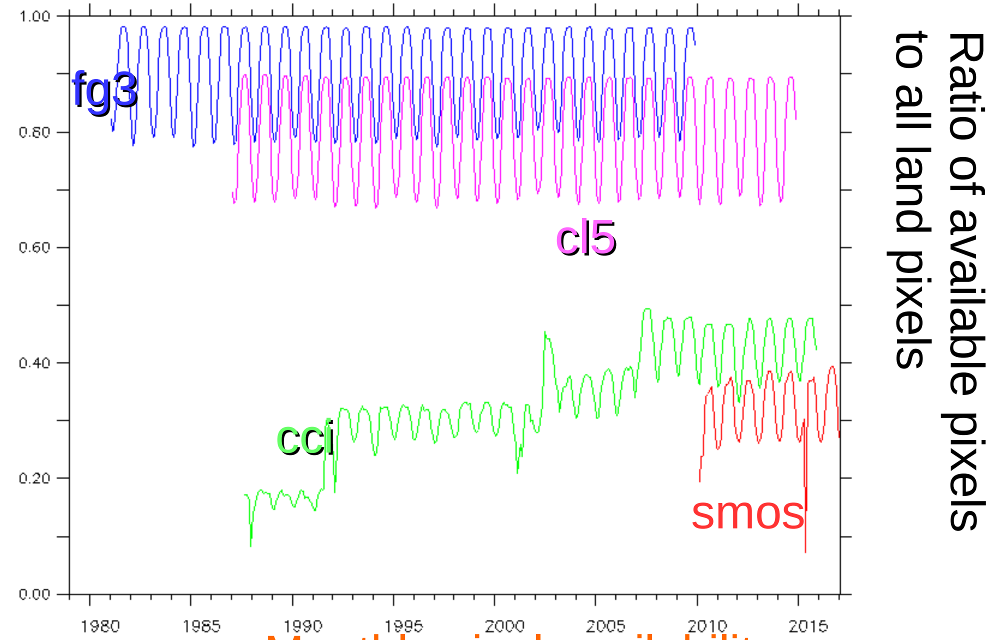
<SMOS IC>
80.9% of data remained; mean available land area 1.48×10^{13} m^2
Data range after masking and monthly aggregation: 0.000–0.587 (VWC)

<FG3> FG3.4438z_19790101_20091231_1M_mrsos.nc
90.1% of data remained; mean available land area 1.33×10^{14} m^2
Data range: 0.002–0.400

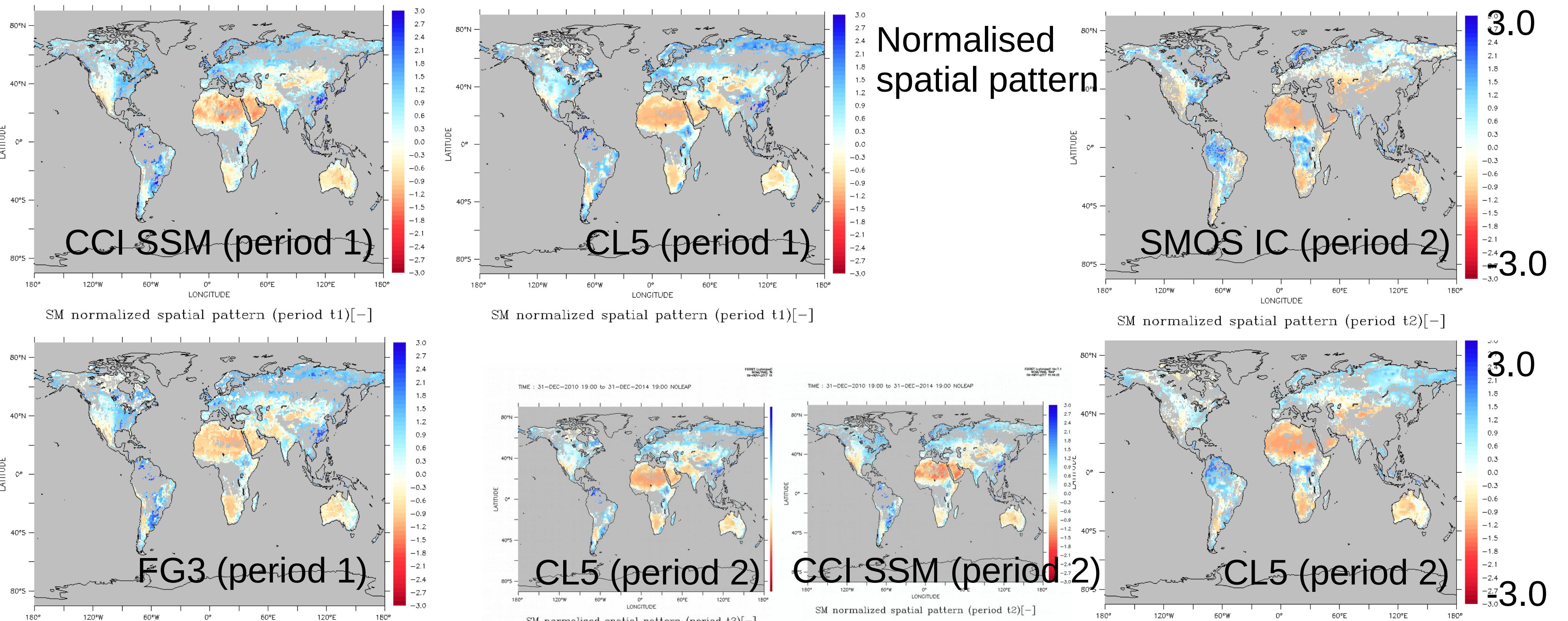
<CL5> CL5.4438.L6010.ref_19850101_20141231_1M_mrsos.nc
87.4% of data remained; mean available land area 1.18×10^{14} m^2
Data range: 0.060–0.389

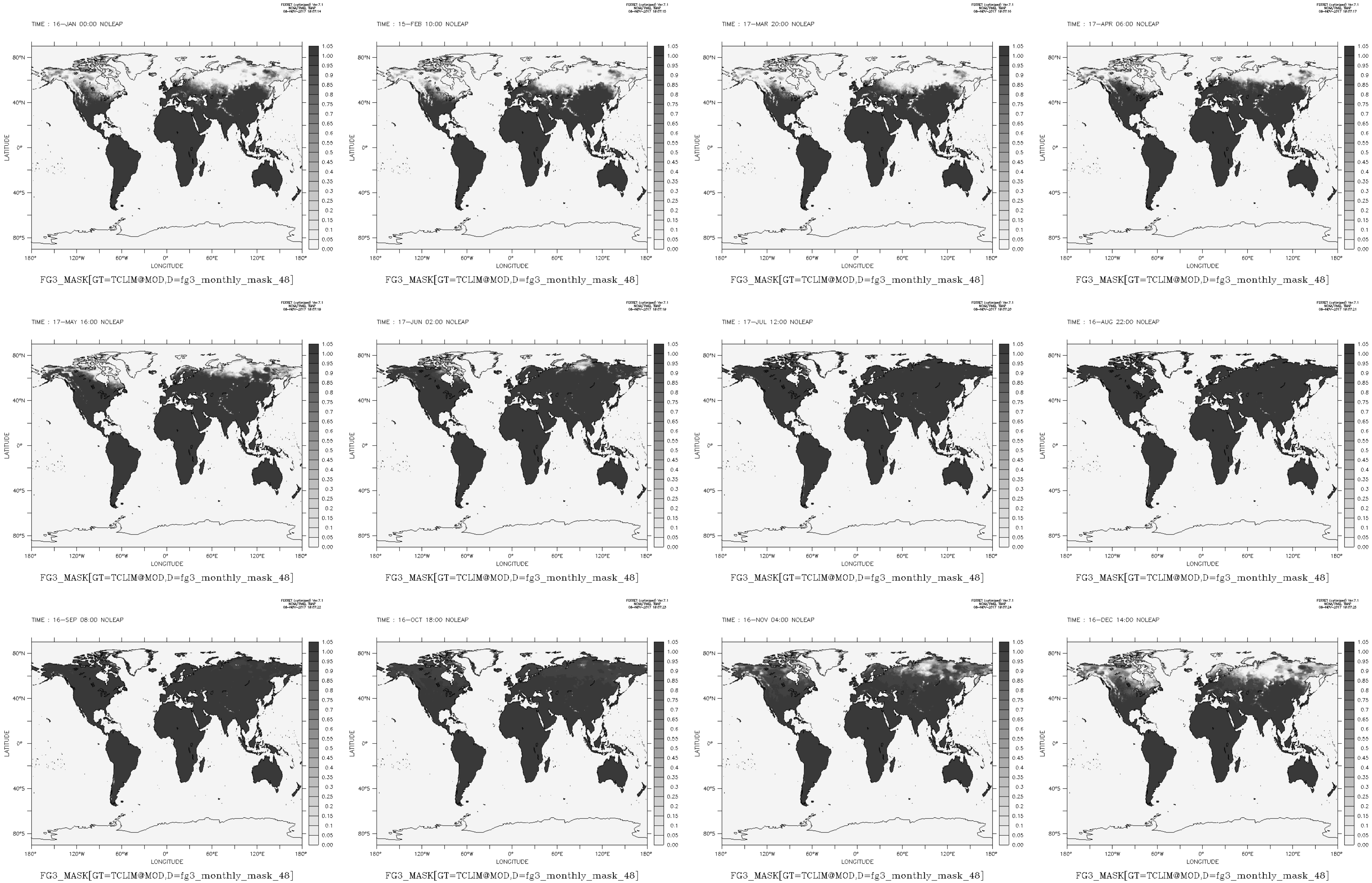


Comp. btw. CCI SSM and the ratio of pixels with large observation number (< 5 obs. per month)

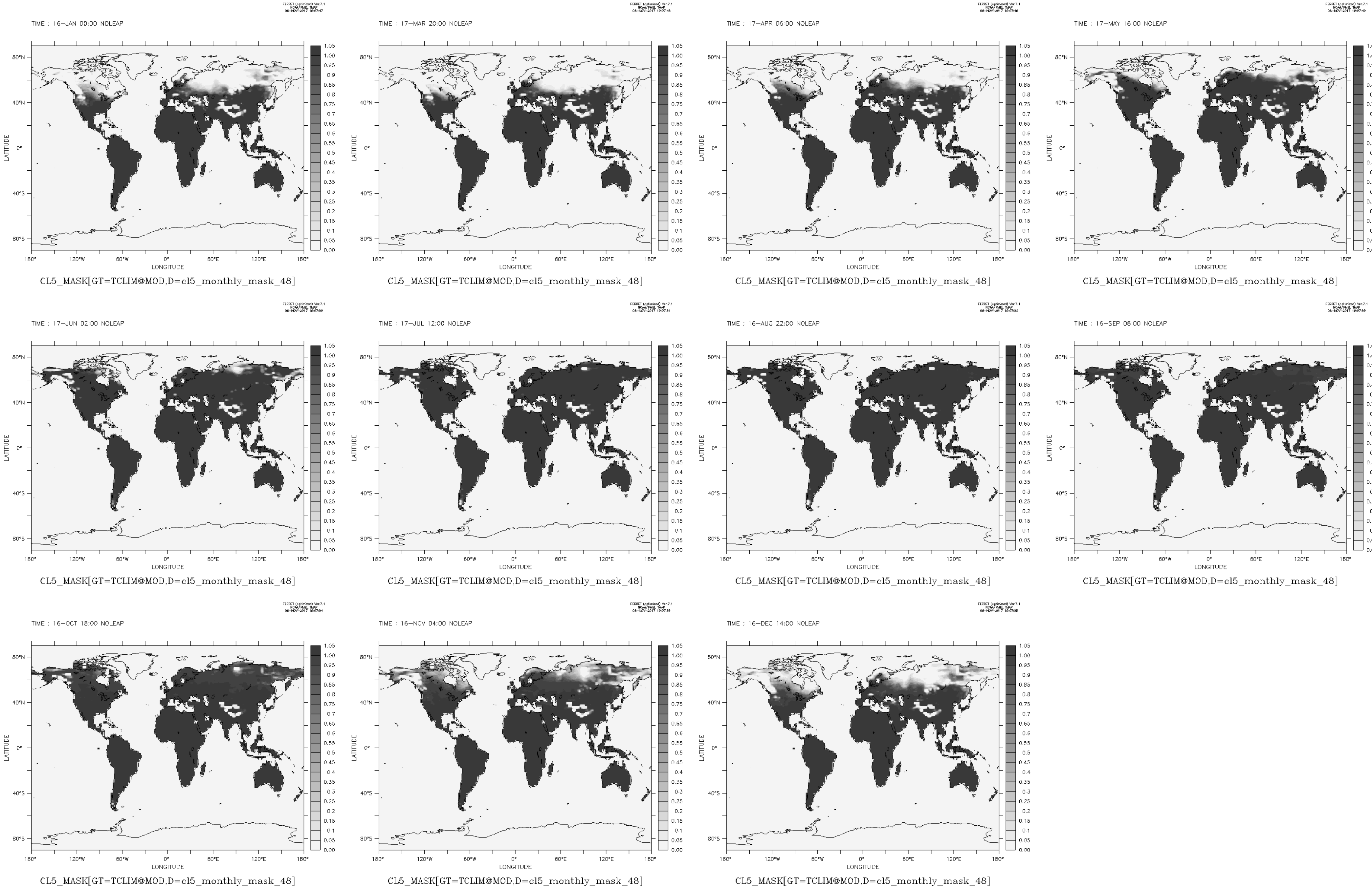


Monthly pixel availability (ratio to all lands)

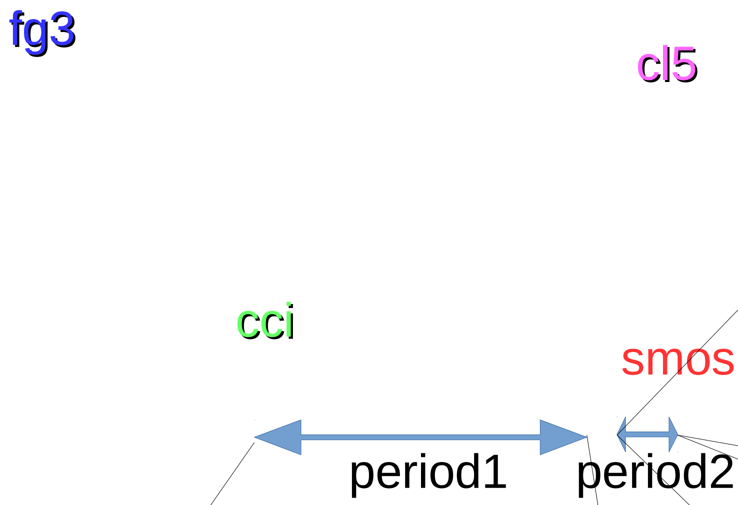


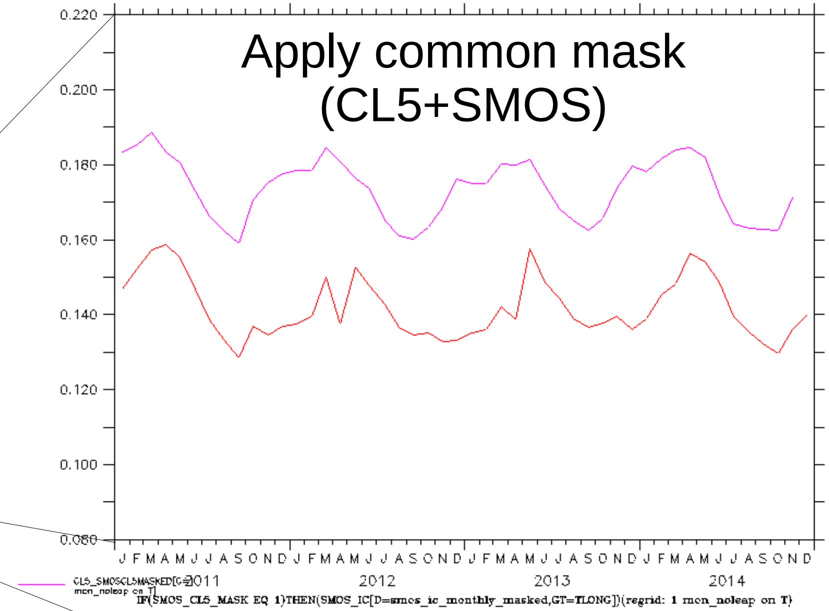


FG3 (SWE < 48 mm) seasonal availability

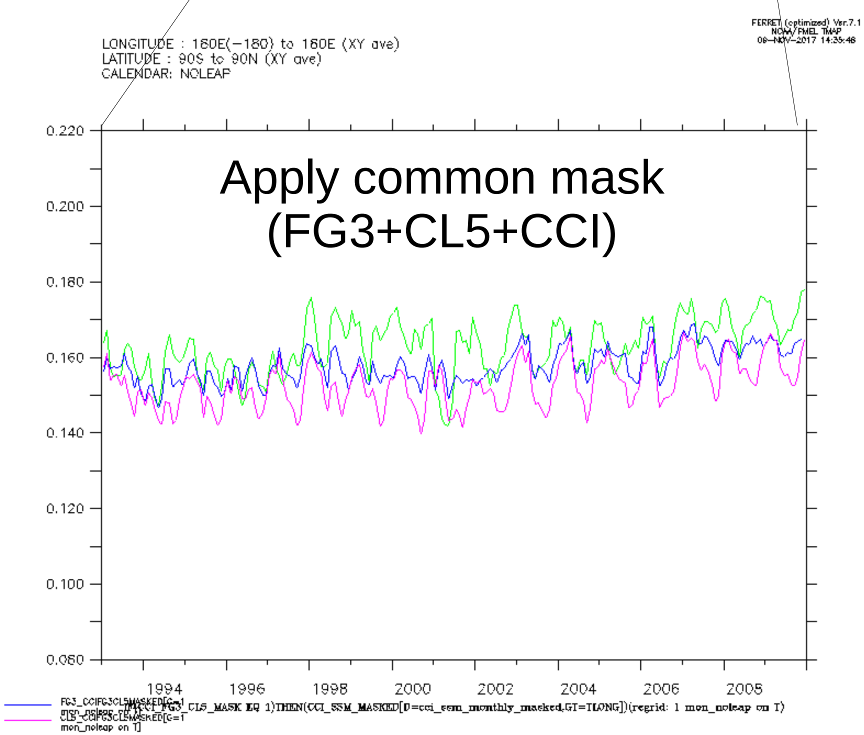


CL5 (SWE < 48 mm) seasonal availability



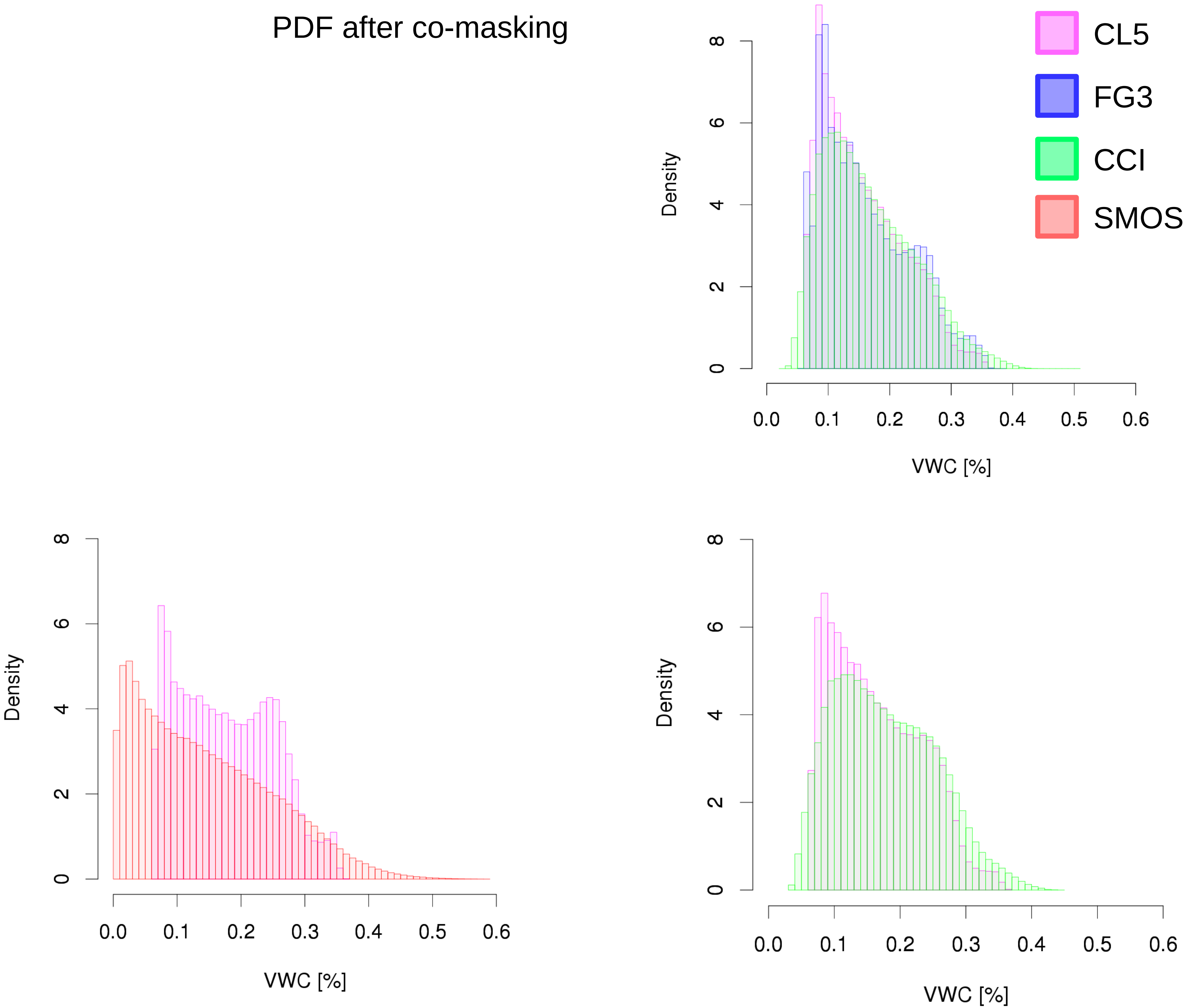


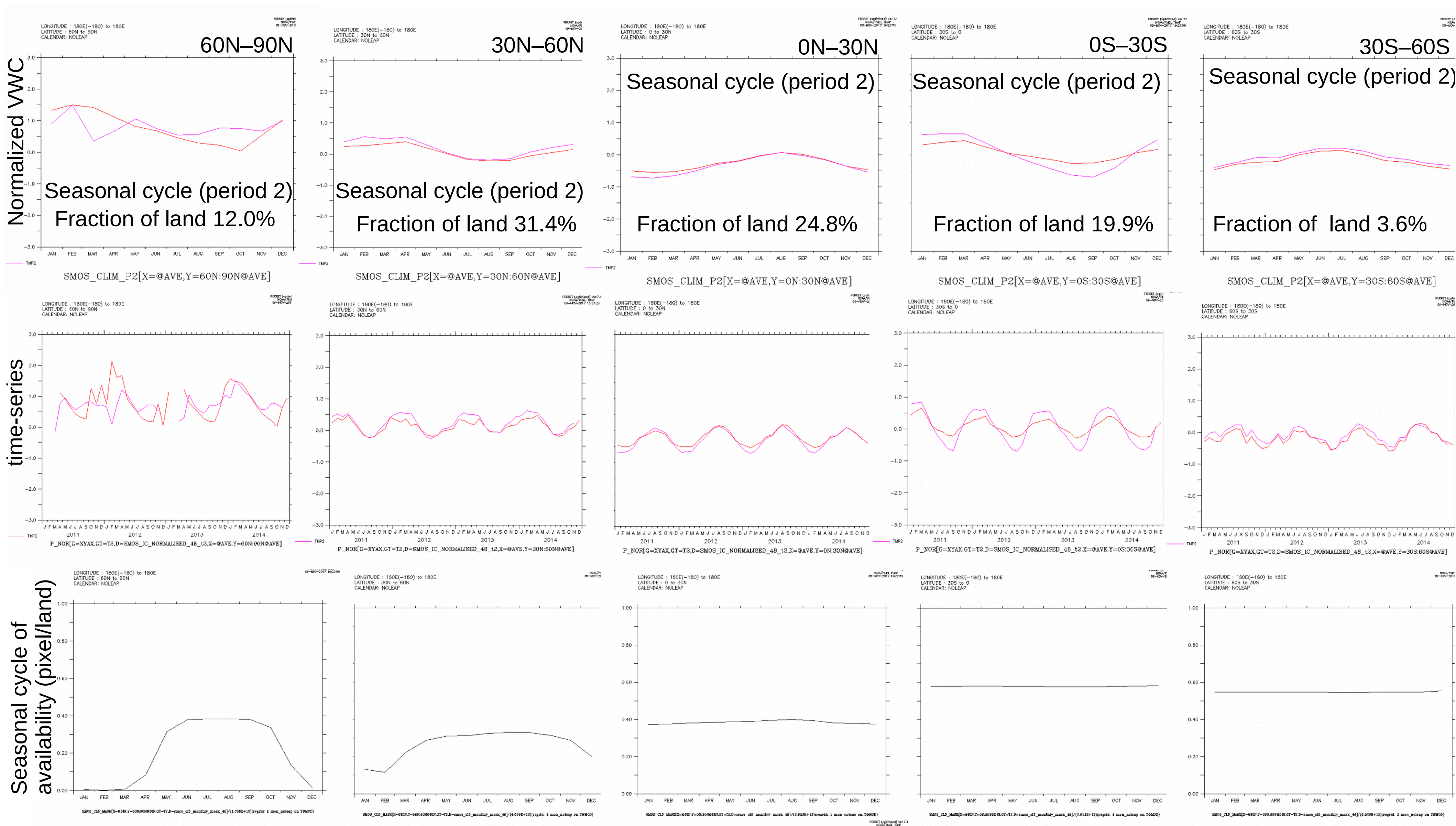
Monthly time series for data with each mask



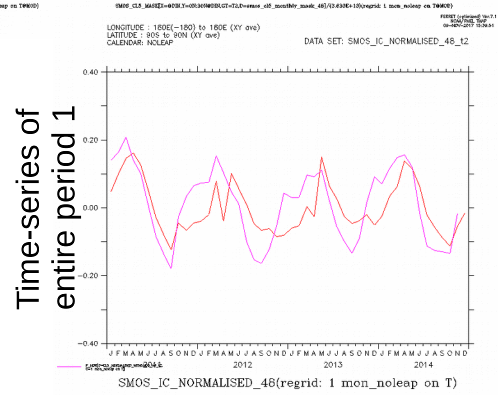
Apply common mask
(CL5+CCI)

Co-masking is important to avoid “dummy” temporal trend (especially when using CCI: Loew et al., 2013)


PDF after co-masking
CL5
FG3
CCI
SMOS
Density
VWC [%]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
2
4
6
8



Slight gap in seasonal change
Snowmelt in boreal region?



Normalized VWC

time-series

60N–90N

Seasonal cycle (period 2)

Fraction of land 12.0%

30N–60N

Seasonal cycle (period 2)

Fraction of land 31.4%

0N–30N

Seasonal cycle (period 2)

Fraction of land 24.8%

0S–30S

Seasonal cycle (period 2)

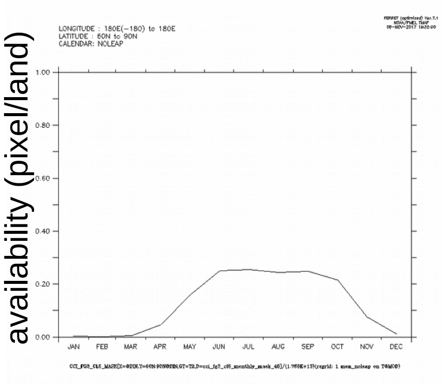
Fraction of land 19.9%

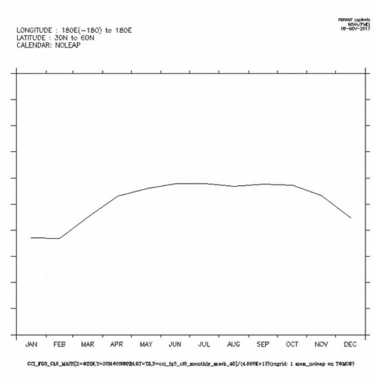
30S–60S

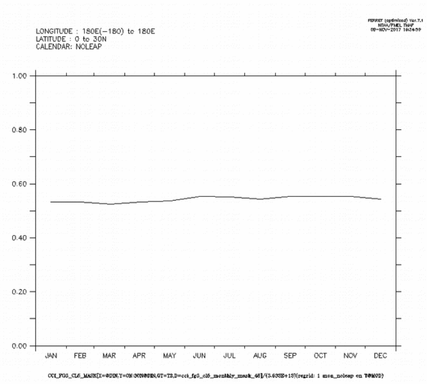
Seasonal cycle (period 2)

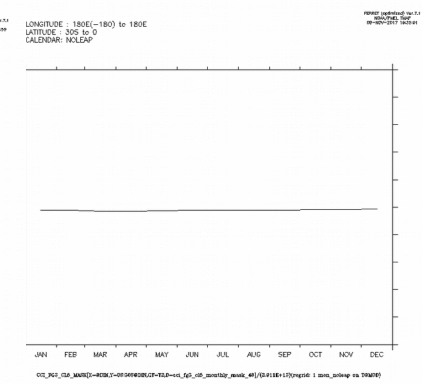
Fraction of land 3.6%

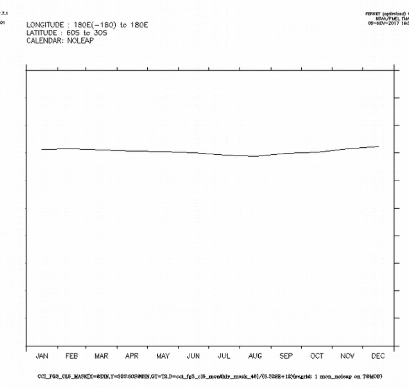
Seasonal cycle of availability (pixel/land)







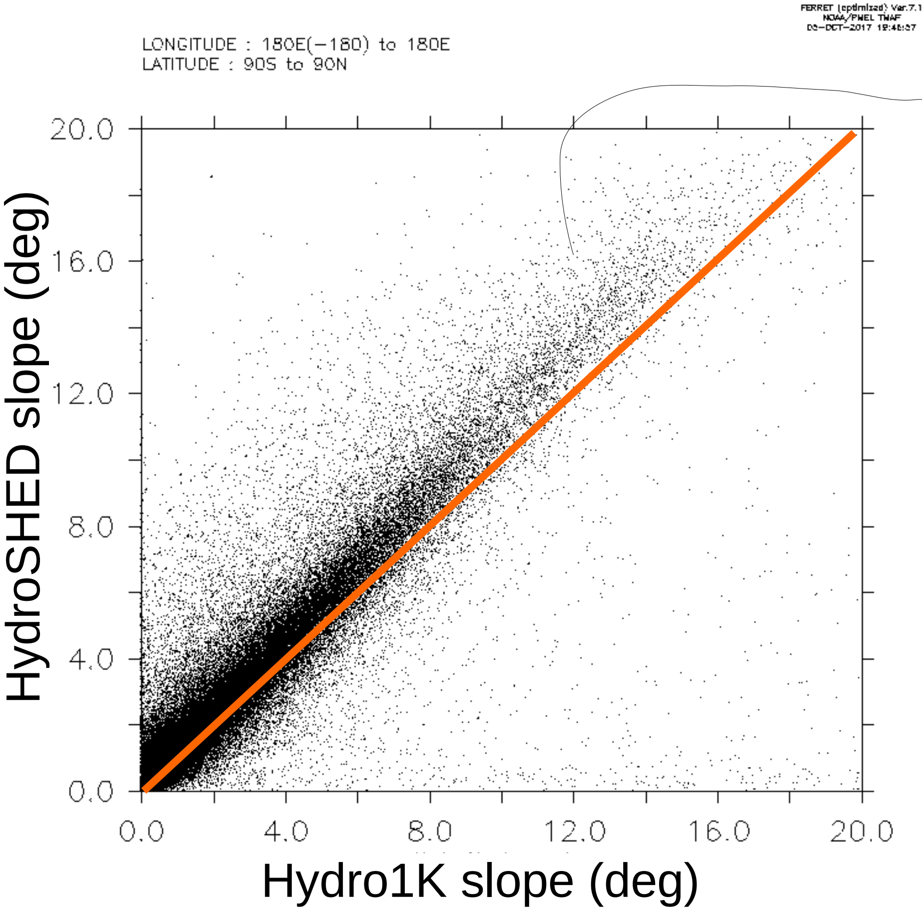




Slight gap in seasonal change
Snowmelt in boreal region?

Time-series of entire period

CL5
FG3
CCI
SMOS



There seems to be slight bias?

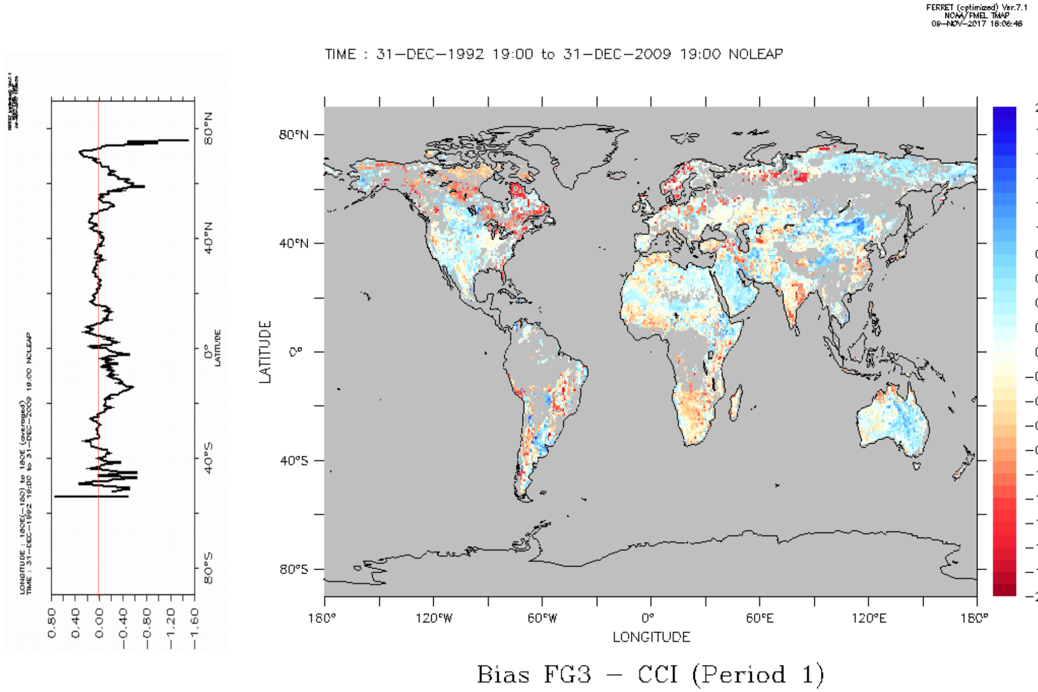
→use only Hydro1K to keep the consistency within dataset

→but Hydro1K has no data over Australia ()

→use HydroSHED only for Australia

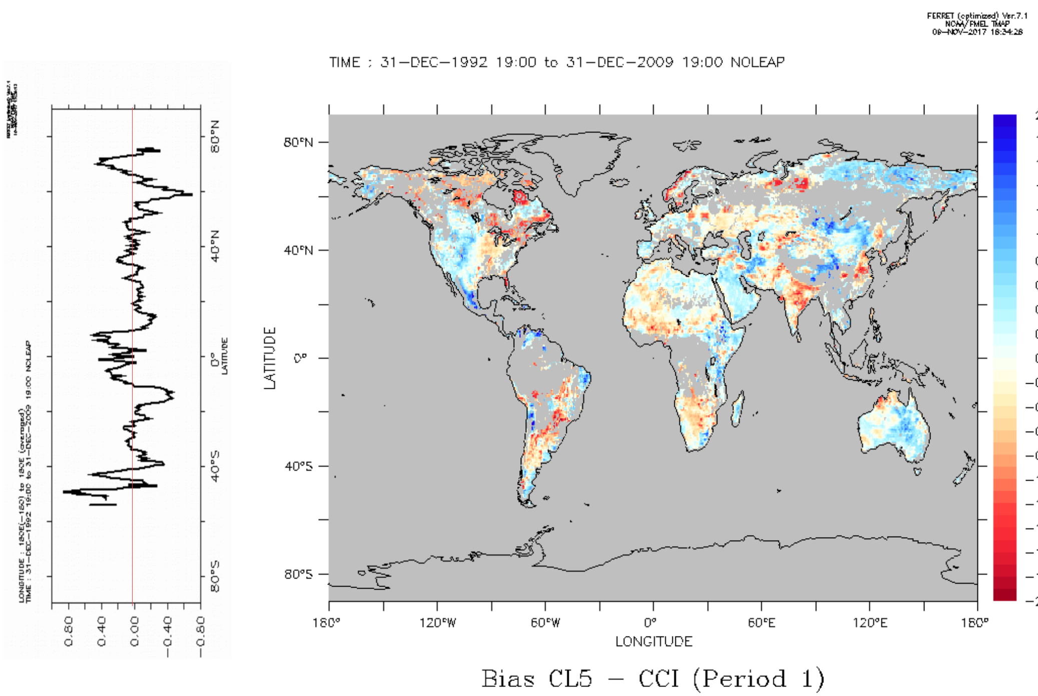
ETOPO: 1.922×10^{12} m^2 (1.3%) were removed
Range: 0 – 73.6 (%), mean 1.50

Hydro1K: 1.922×10^{12} m^2 (1.3%) were removed
Range: 0.00 – 47.3 (%), mean 2.81

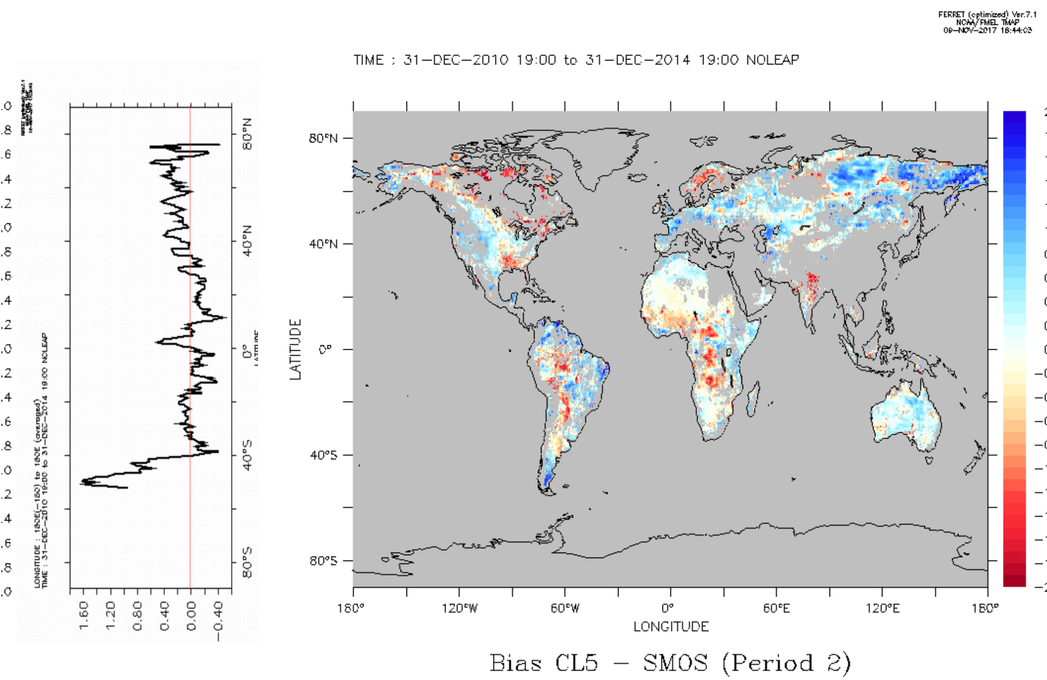


Mean bias of FG3 - CCI over period 1 (monthly time steps).

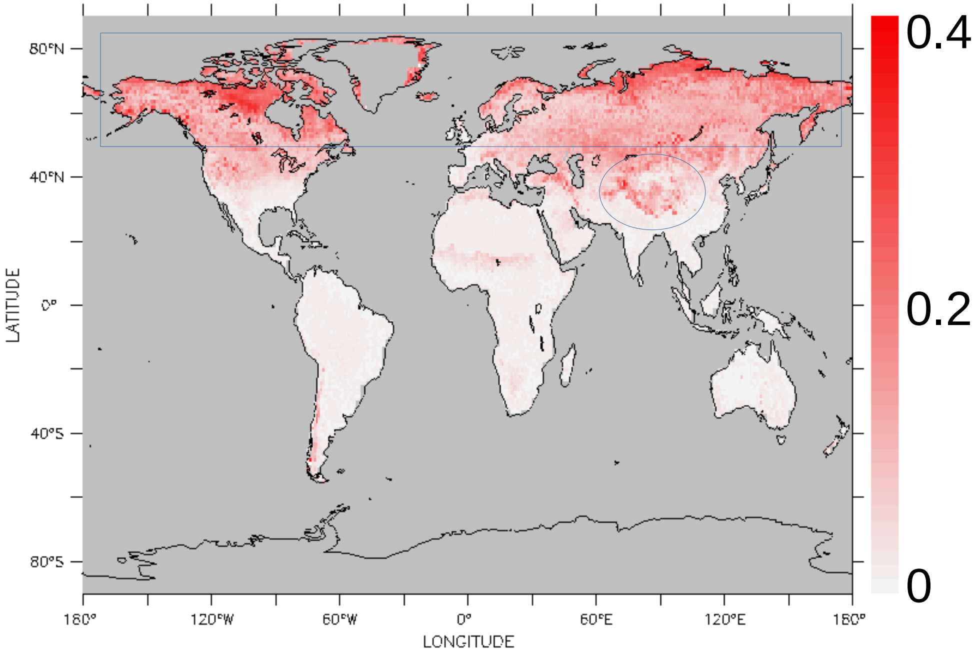
Mean bias of CL5 - CCI over period 2 (monthly time steps).



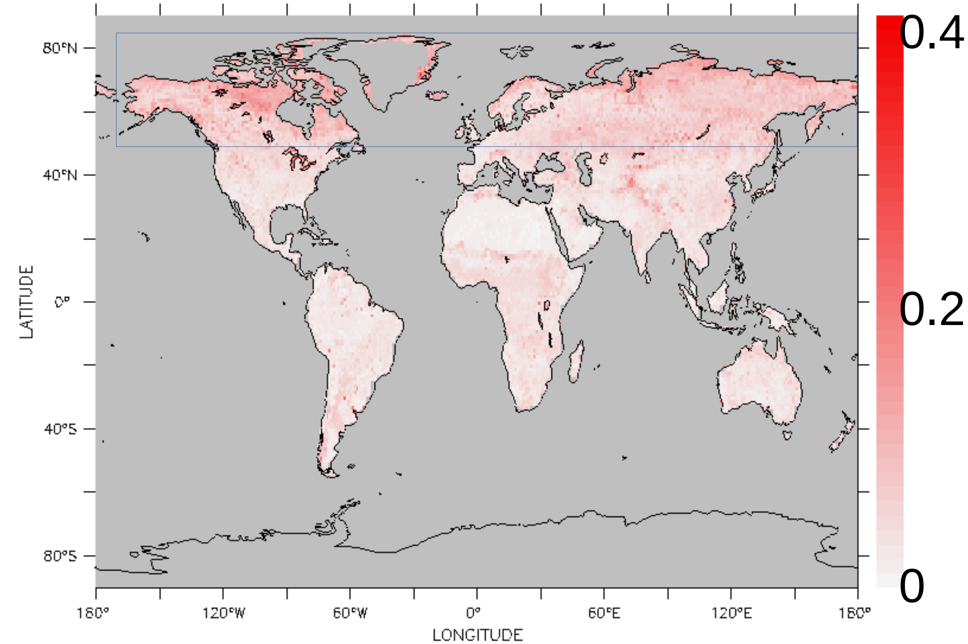
Mean bias of CL5 - CCI over period 1 (monthly time steps).



Mean bias of CL5 - SMOS over period 2 (monthly time steps).

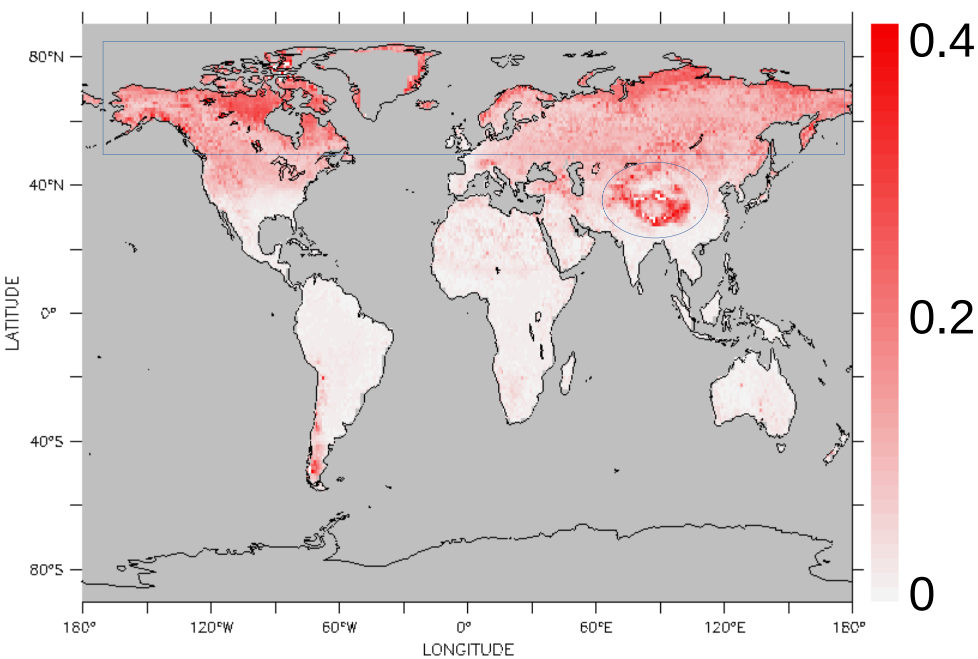


Albedo RMSE between FG3 and MODIS (VIS)

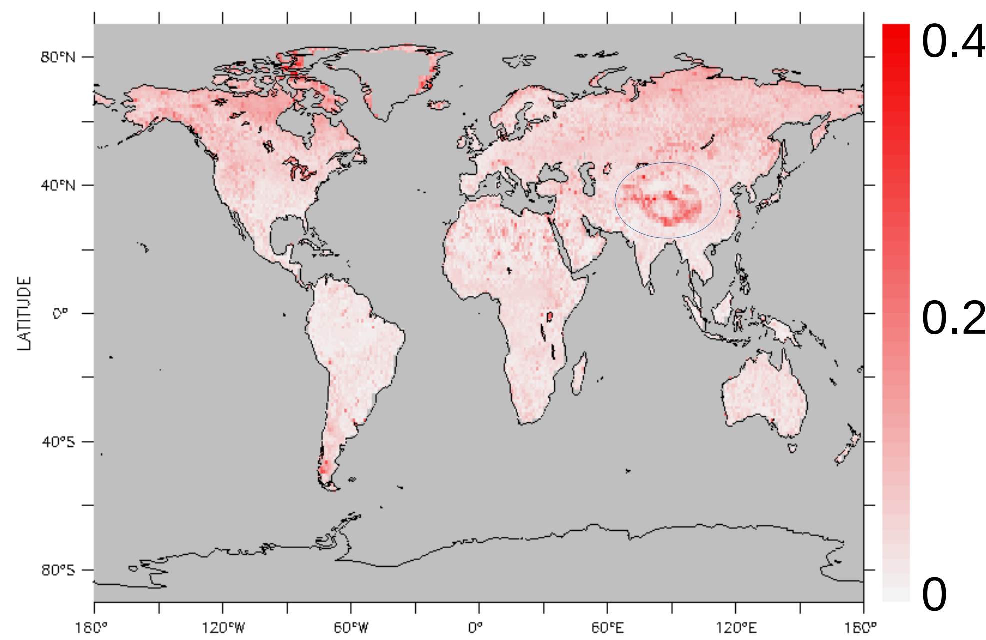


Albedo RMSE between FG3 and MODIS (NIR)

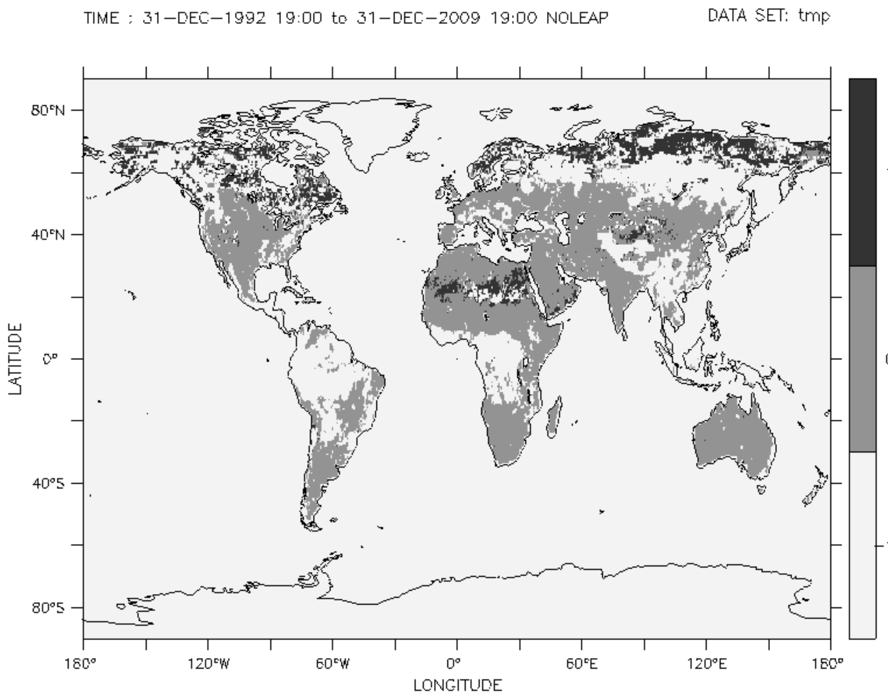
Large inconsistency occurs in boreal & mountainous region (snow)



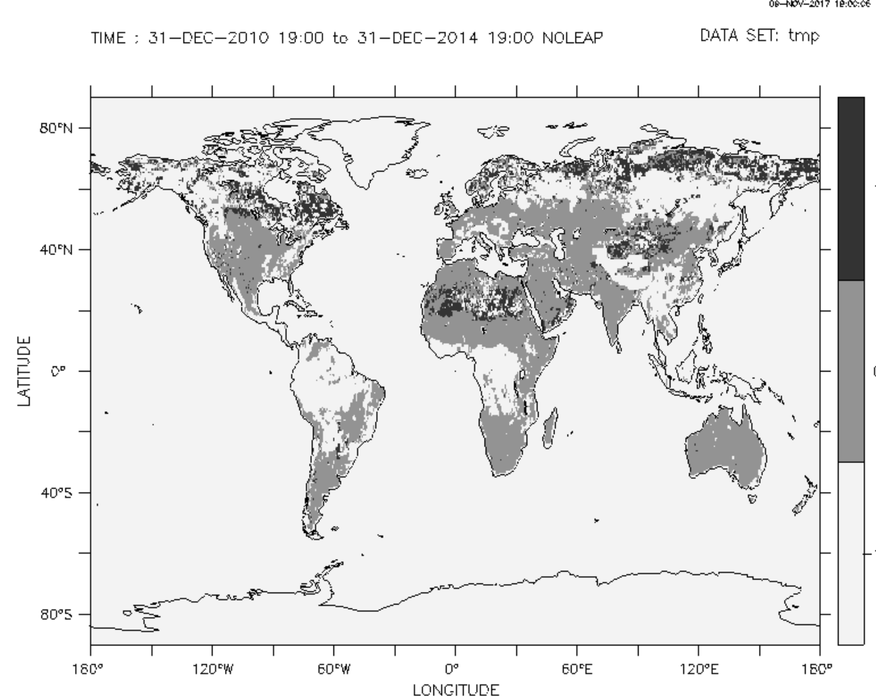
Albedo RMSE between CL5 and MODIS (VIS)



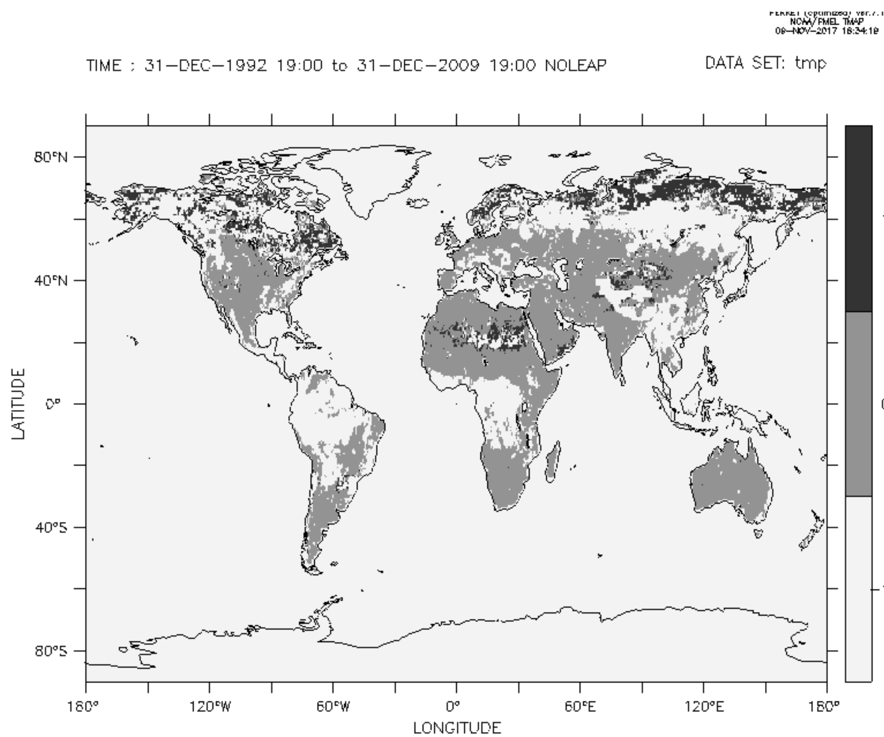
Albedo RMSE between CL5 and MODIS (NIR)



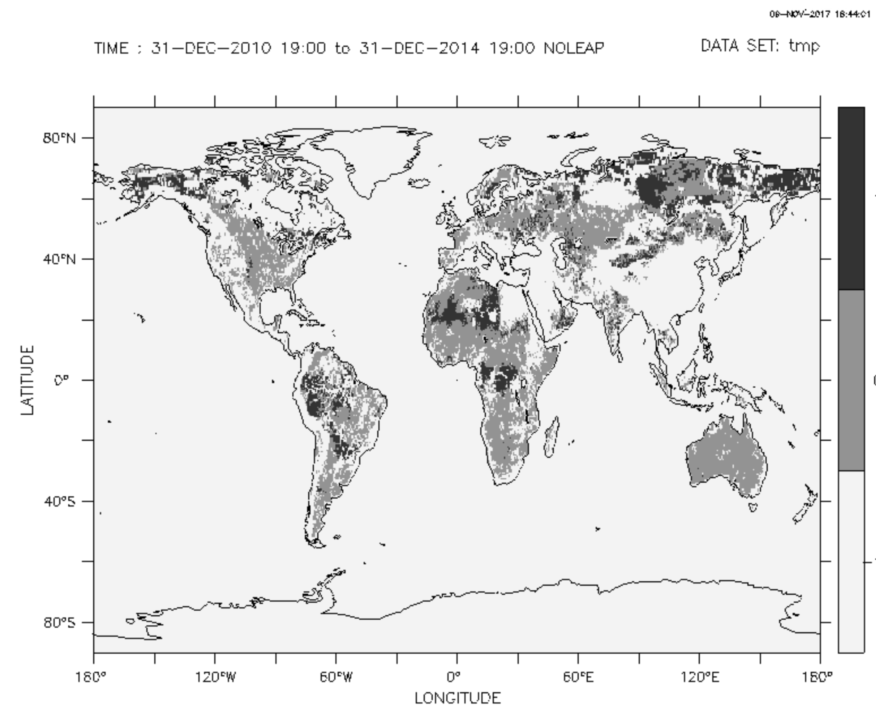
Correlation significance between CCI/FG3 (period 1).



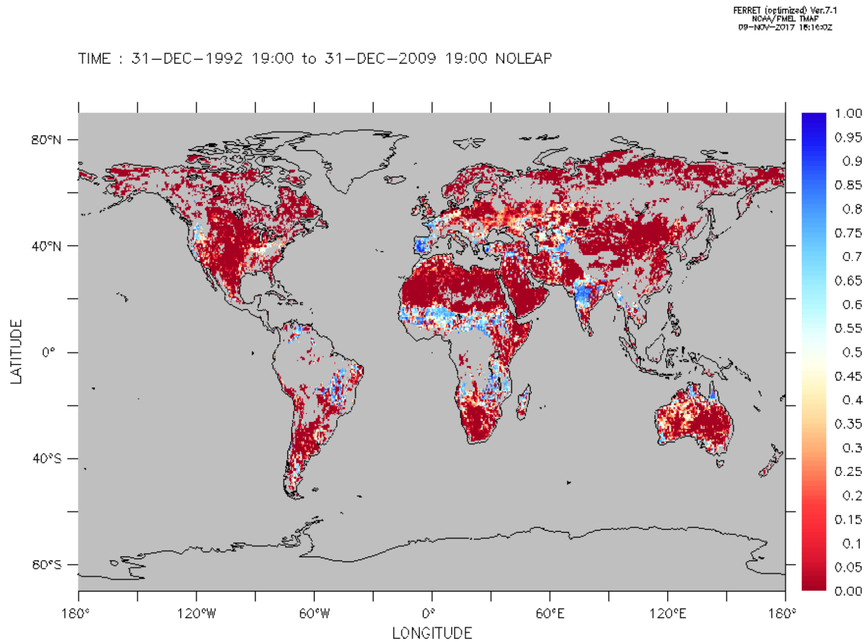
Correlation significance between CCI/CL5 (period 2).



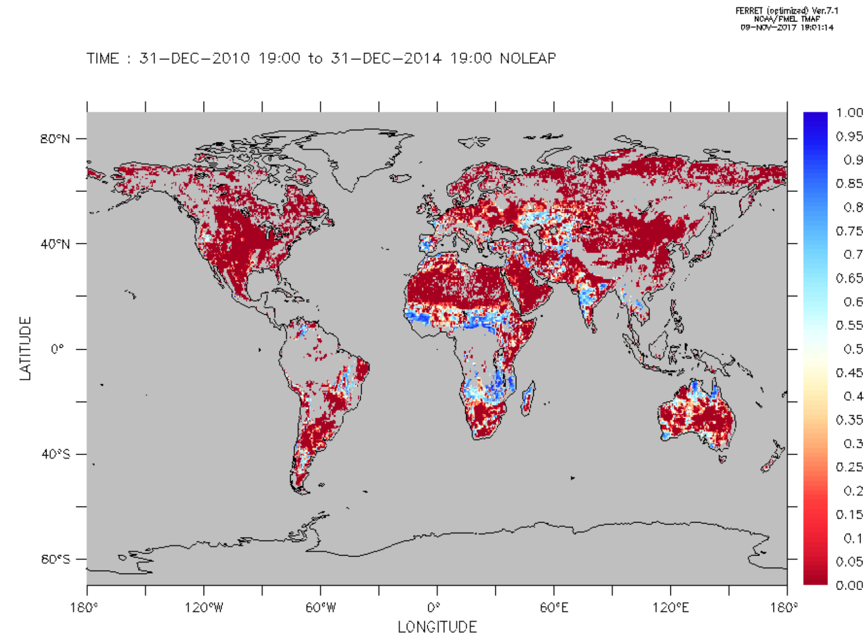
Correlation significance between CCI/CL5 (period 1).



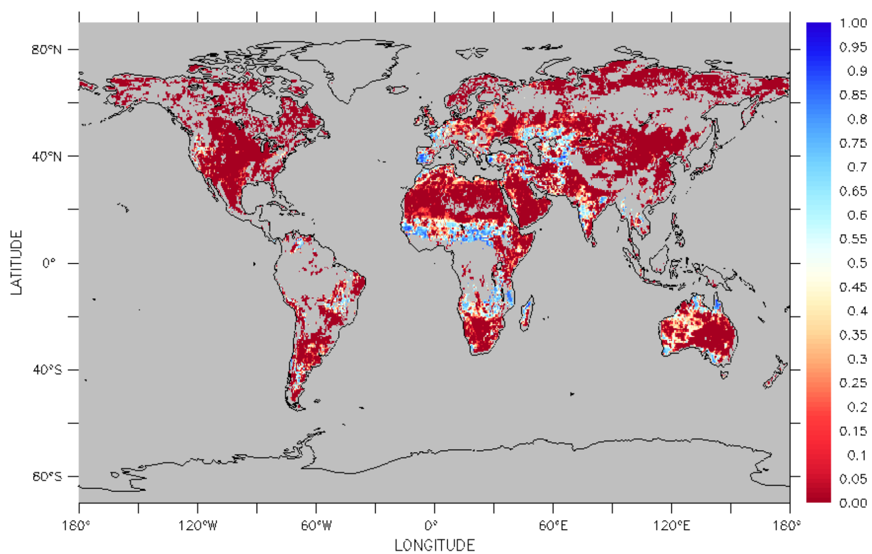
Correlation significance between CCI/SMOS (period 2).



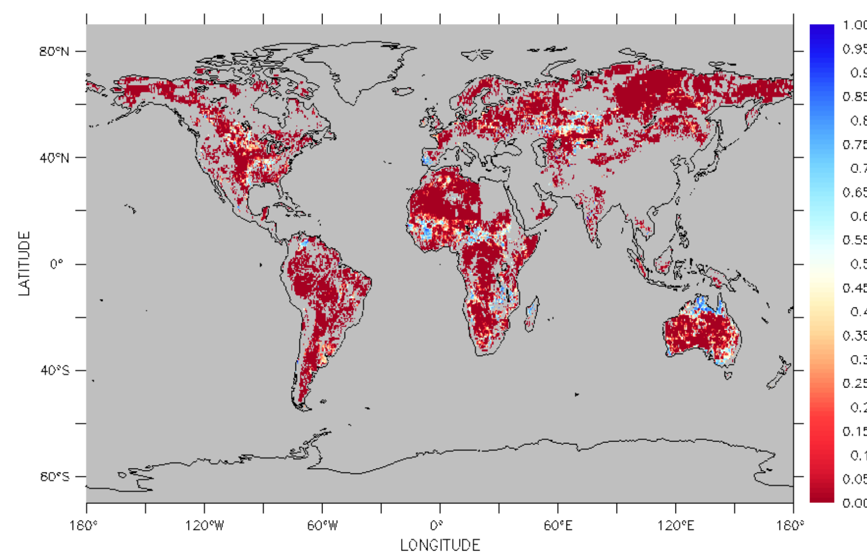
NSE of CCI/FG3 over period 1.



NSE of CCI/CL5 over period 2.



NSE of CCI/CL5 over period 1.



NSE of SMOS/CL5 over period 2.

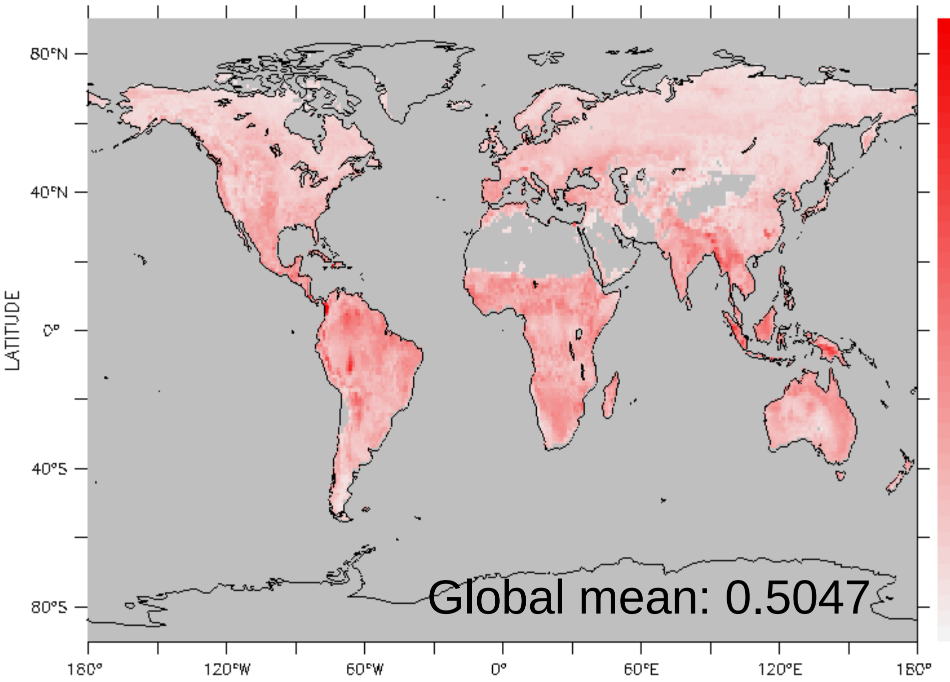
$$NSE \equiv 1 - \frac{\sum_t (Q_{0,t} - Q_{m,t})^2}{\sum_t (Q_{0,t} - Q_{0,ave})^2}$$

$Q_{0,t}$: observed time series

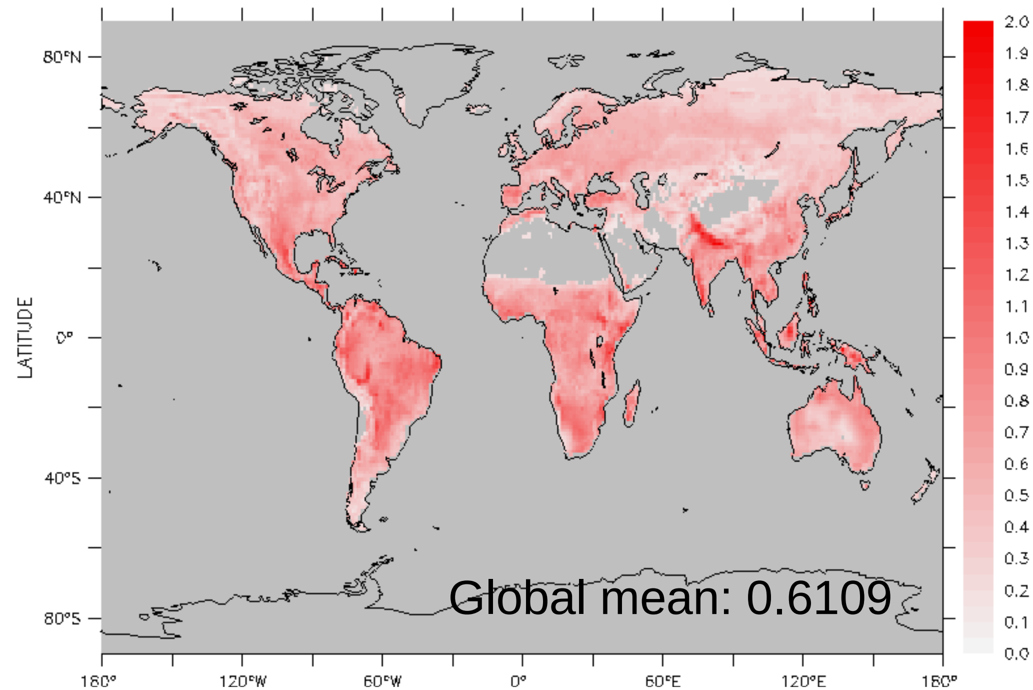
$Q_{m,t}$: simulated time series

$Q_{0,t}$: temporal average of observation

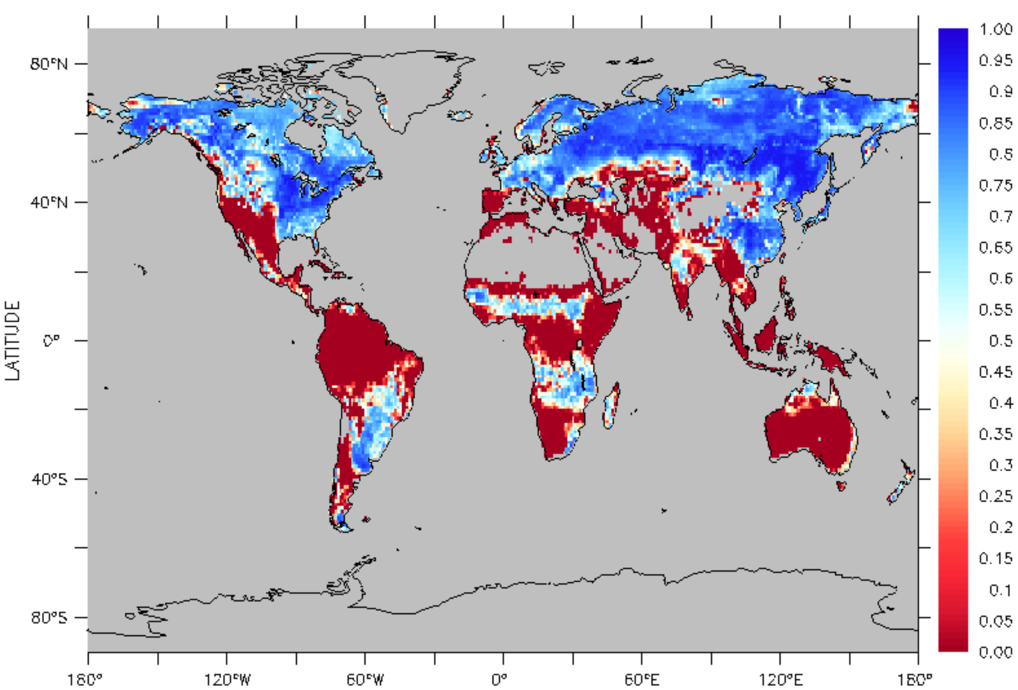
※ NSE < 0 is also shown as 0.0 in the colorscale.



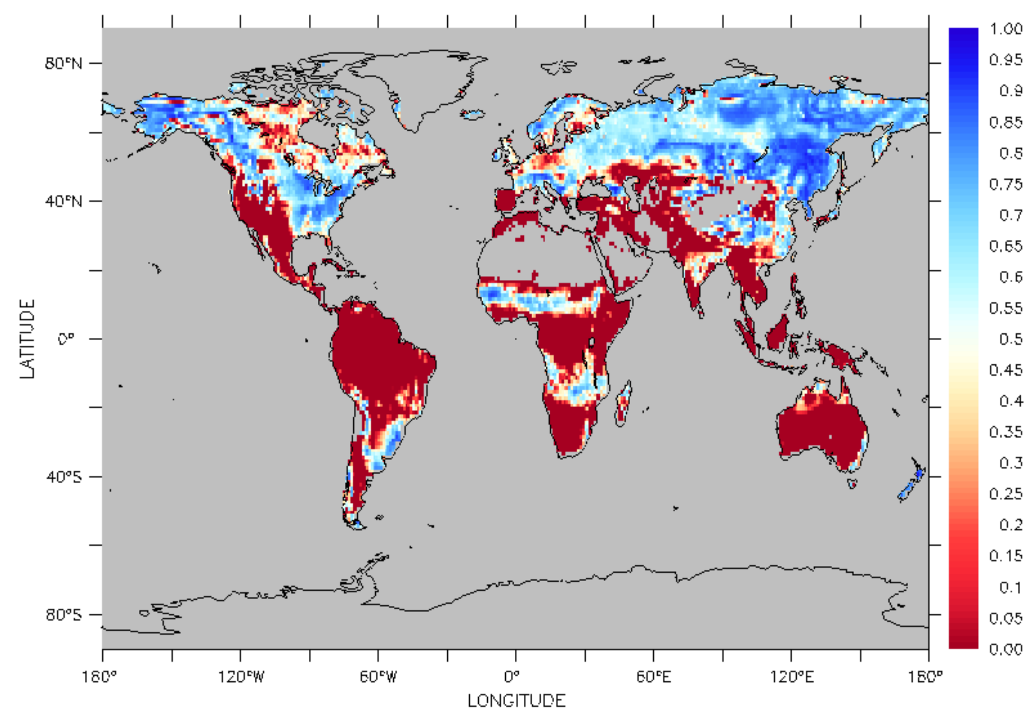
RMSE btw. FG3 and observation ave. (mm/d)



RMSE btw. CL5 and observation ave. (mm/d)



NSE btw. FG3 and observation ave.

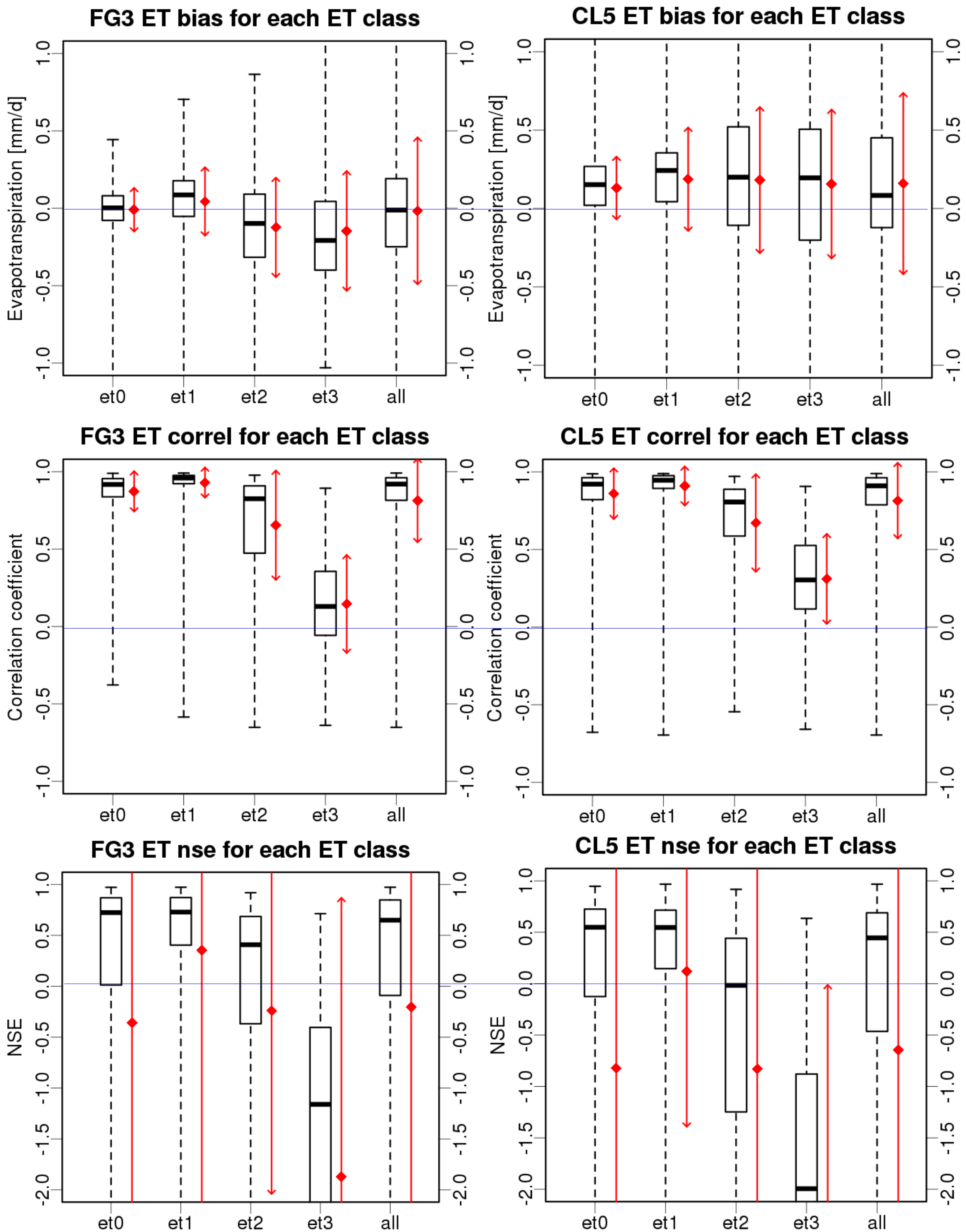


NSE btw. CL5 and observation ave.

Small ET region: positive bias
Large ET region: negative bias

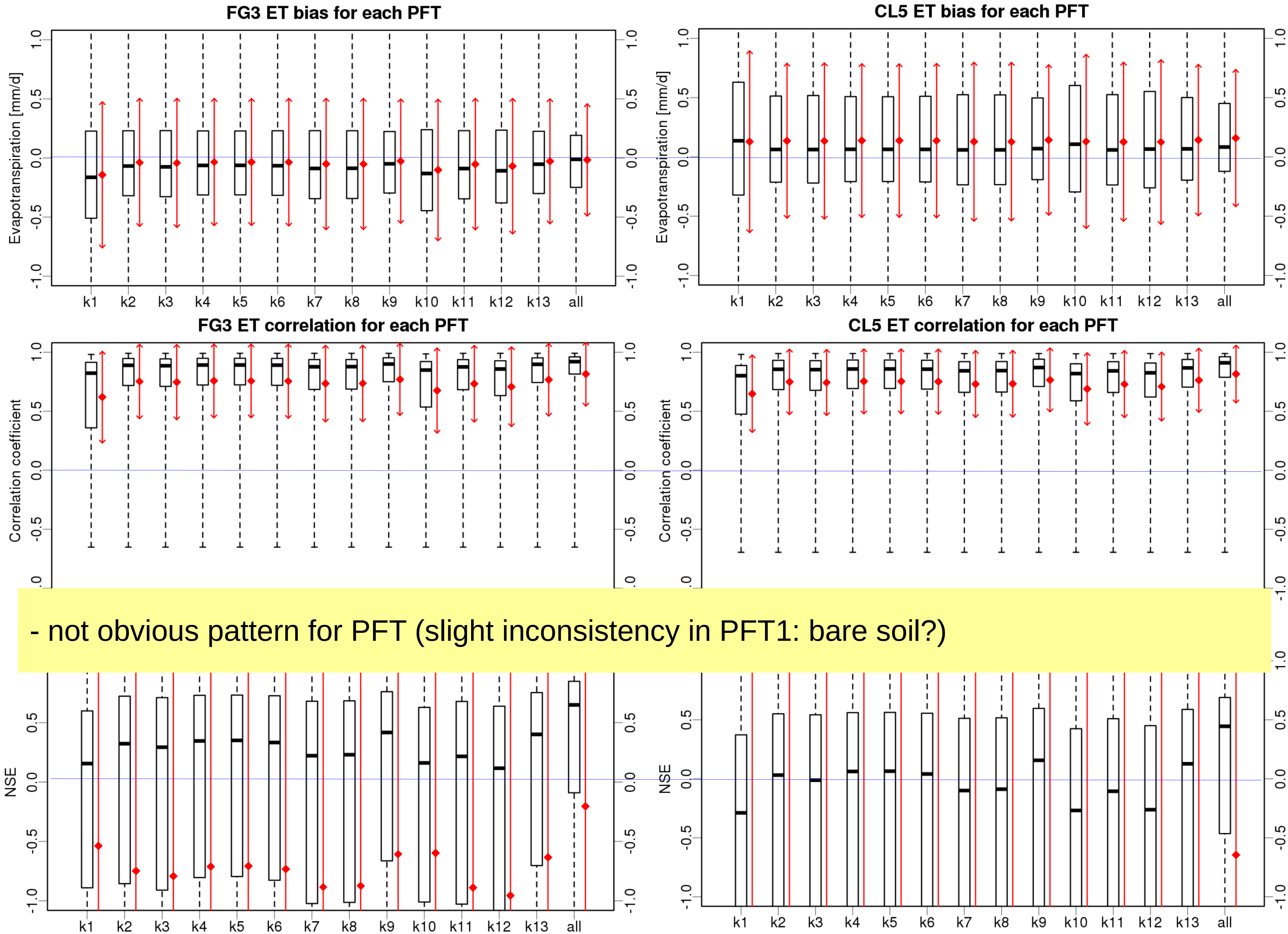
VS ET (mm/d) itself

ET ≦ 1.0: et0
1.0 < ET ≦ 2.0: et1
2.0 < ET ≦ 3.0: et2
3.0 < ET ≦ 4.0: et3



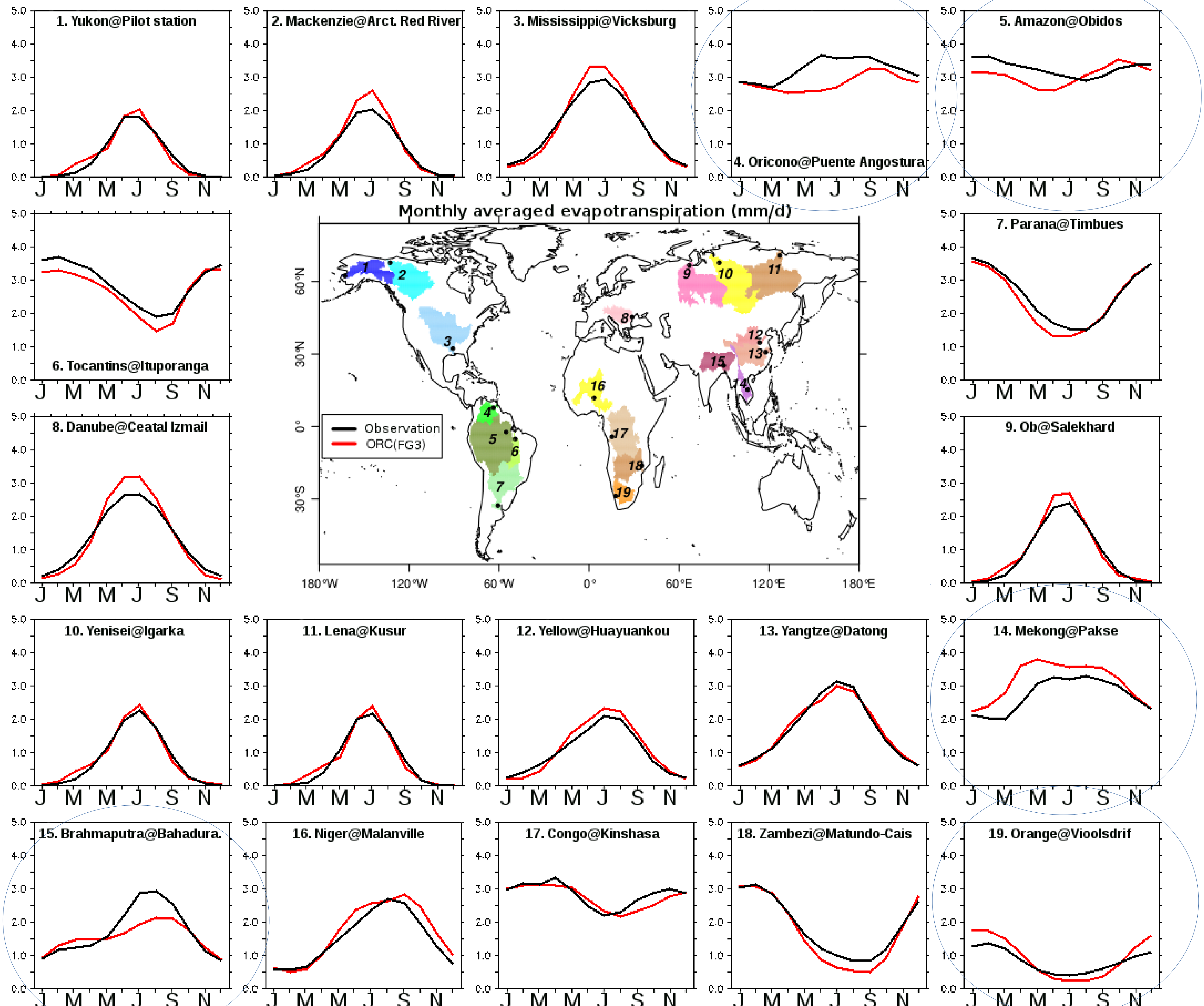
VS PFT

Each PET fraction > 90 percentile

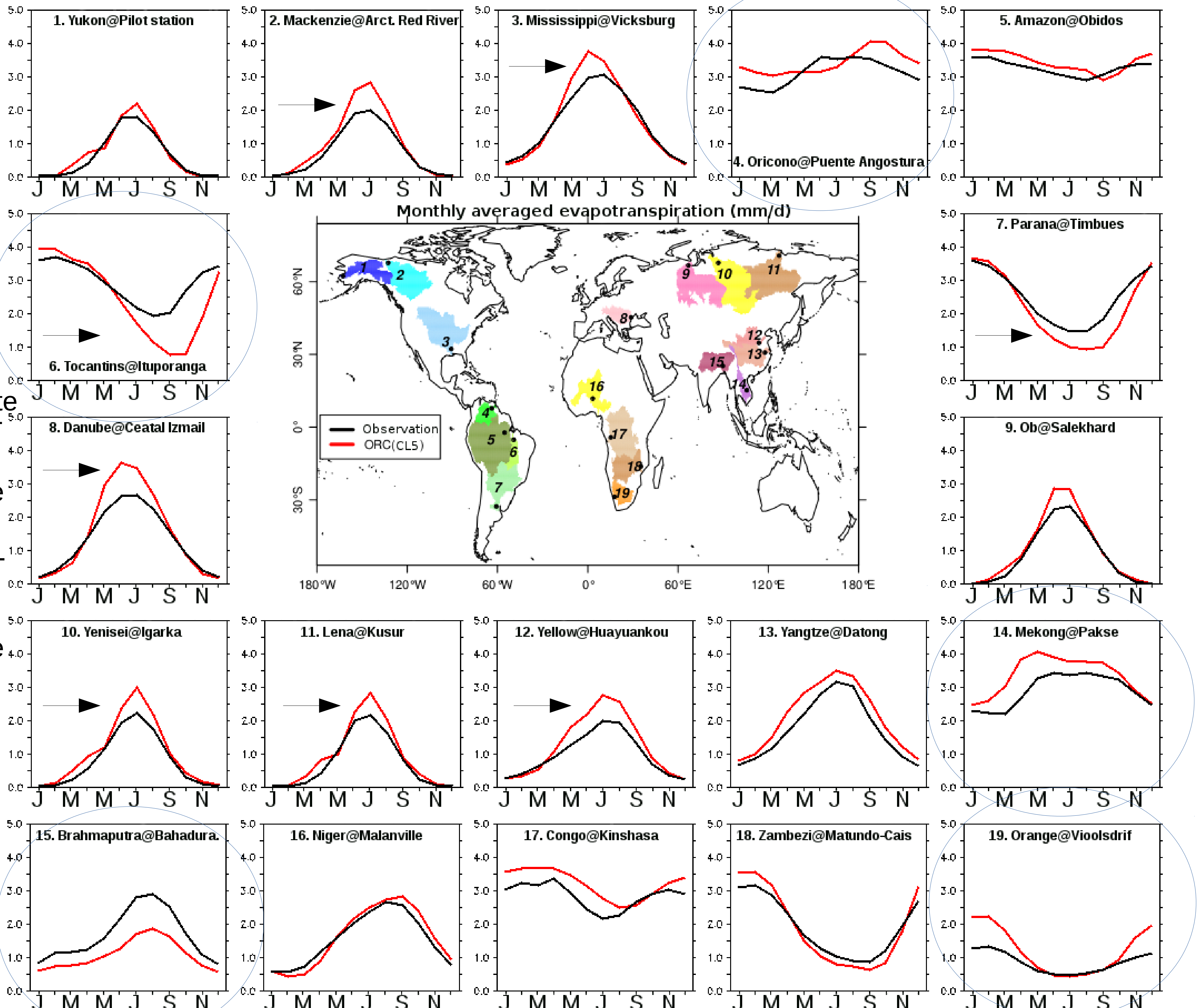


- not obvious pattern for PFT (slight inconsistency in PFT1: bare soil?)

FG3

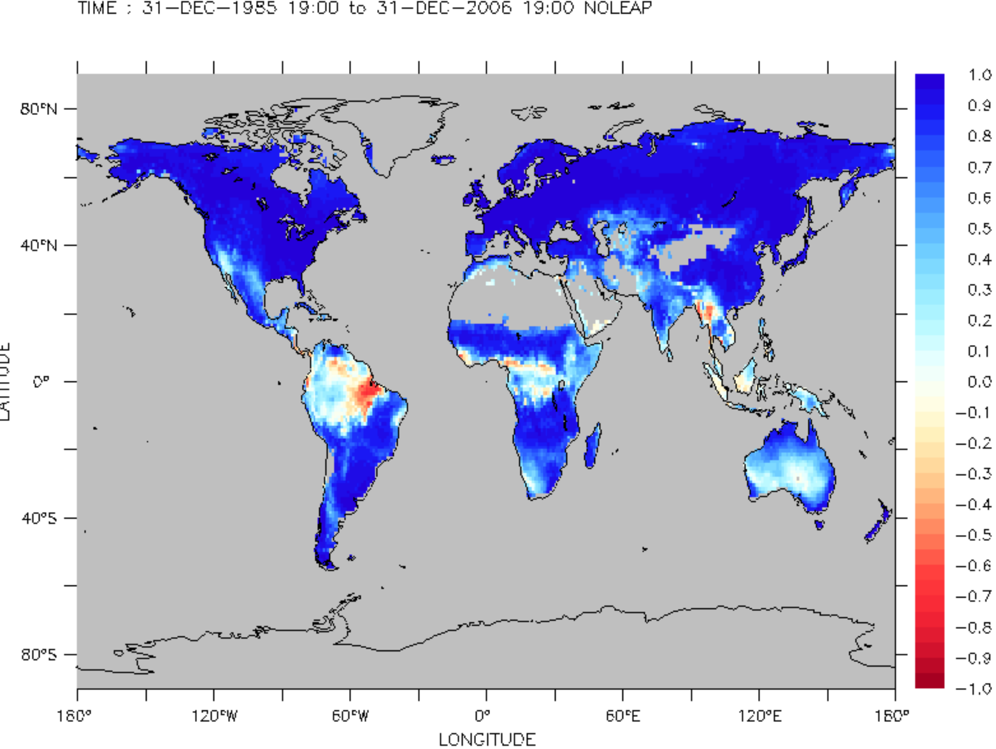

1. Yukon@Pilot station
2. Mackenzie@Arct. Red River
3. Mississippi@Vicksburg
4. Oricono@Puente Angostura
5. Amazon@Obidos
6. Tocantins@Ituporanga
7. Parana@Timbues
8. Danube@Ceatal Izmail
9. Ob@Salekhard
10. Yenisei@Igarka
11. Lena@Kusur
12. Yellow@Huayuankou
13. Yangtze@Datong
14. Mekong@Pakse
15. Brahmaputra@Bahadura.
16. Niger@Malanville
17. Congo@Kinshasa
18. Zambezi@Matundo-Cais
19. Orange@Vioolsdrif
Monthly averaged evapotranspiration (mm/d)
Observation
ORC(FG3)
60°N
30°N
0°
30°S
180°W
120°W
60°W
0°
60°E
120°E
180°E
J M M J S N
0.0
1.0
2.0
3.0
4.0
5.0

CL5

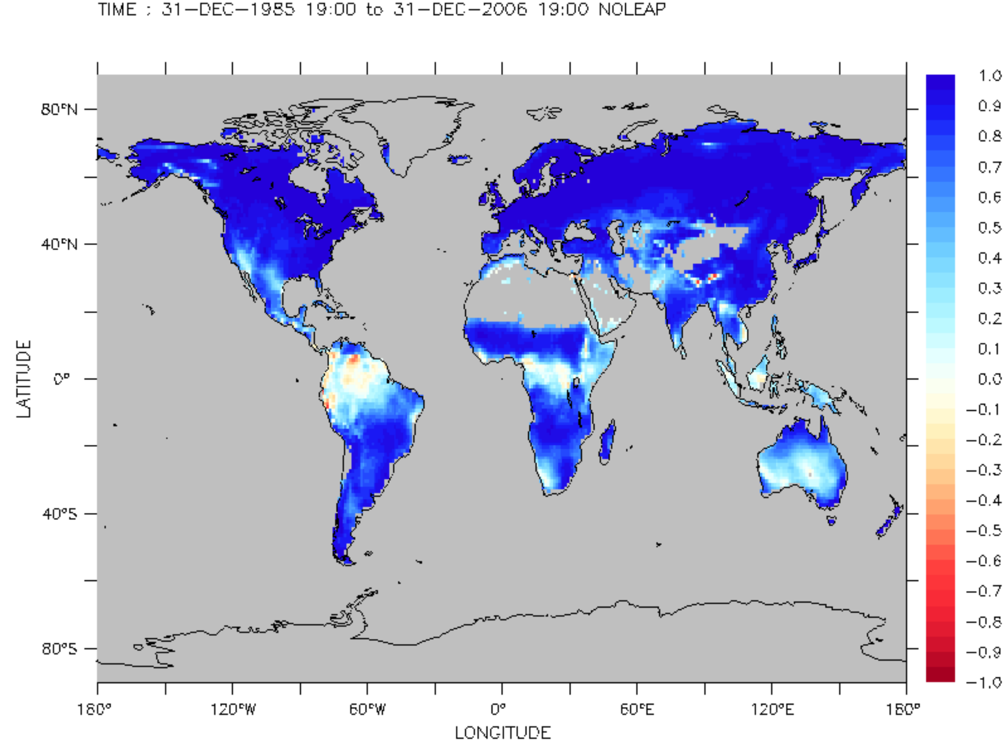


Tends to overestimate summer ET In northern hemisphere

underestim-ate in sorthen hemisphere



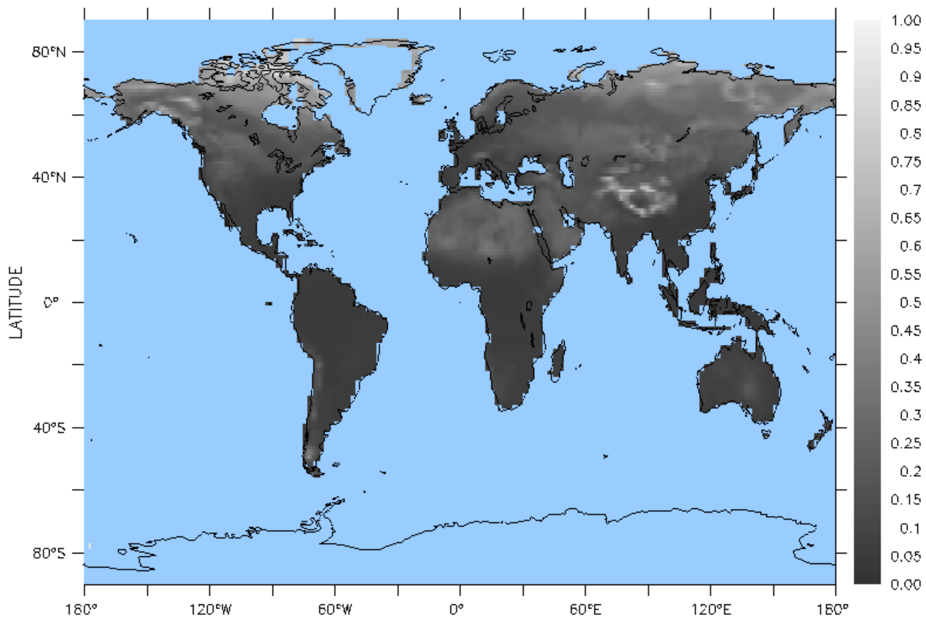
Correlation between CCI and FG3



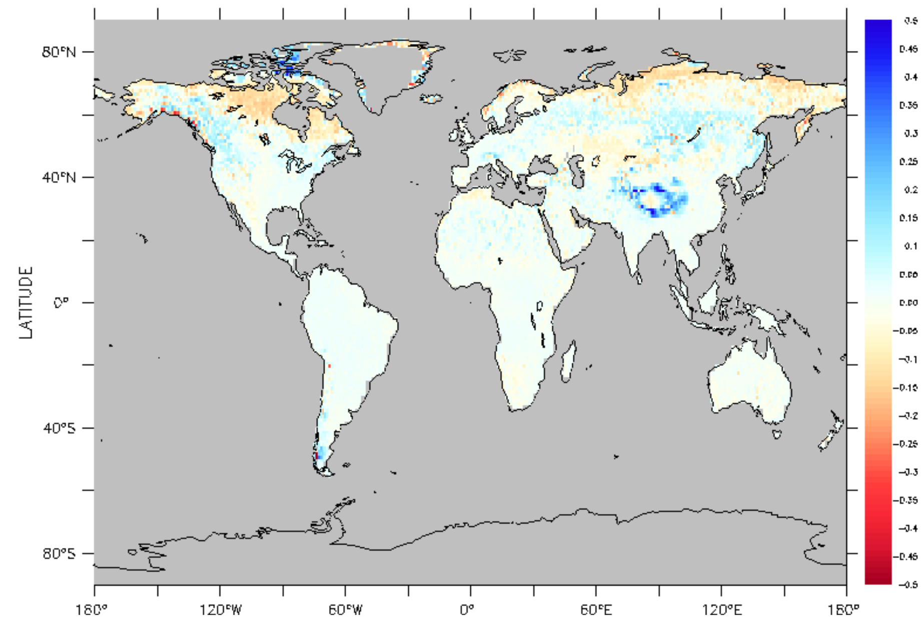
Correlation between CCI and CL5

Significantly correlated area btw. FG3 and obs.

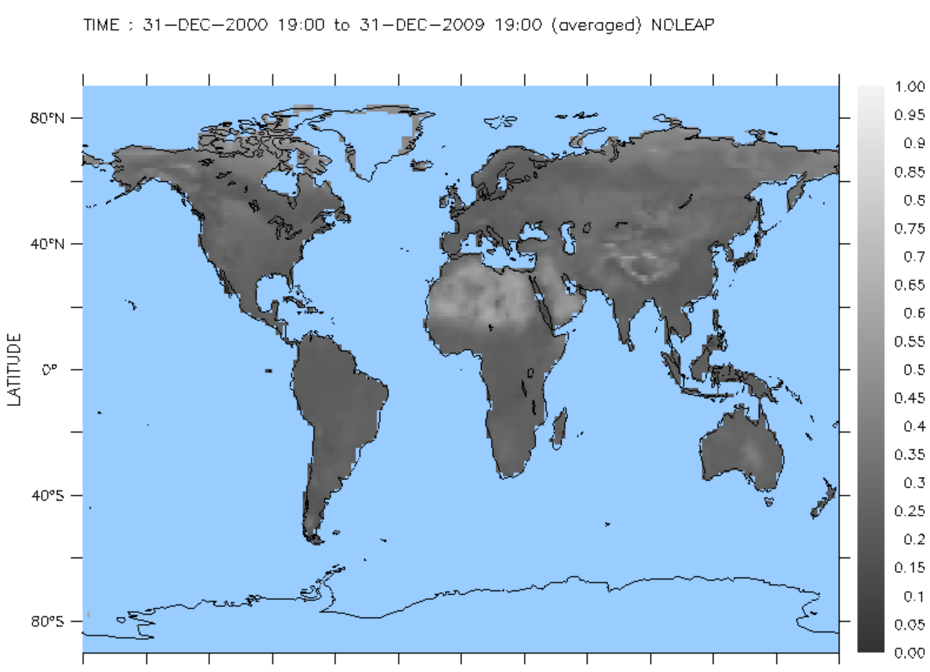
Significantly correlated area btw. CL5 and obs.



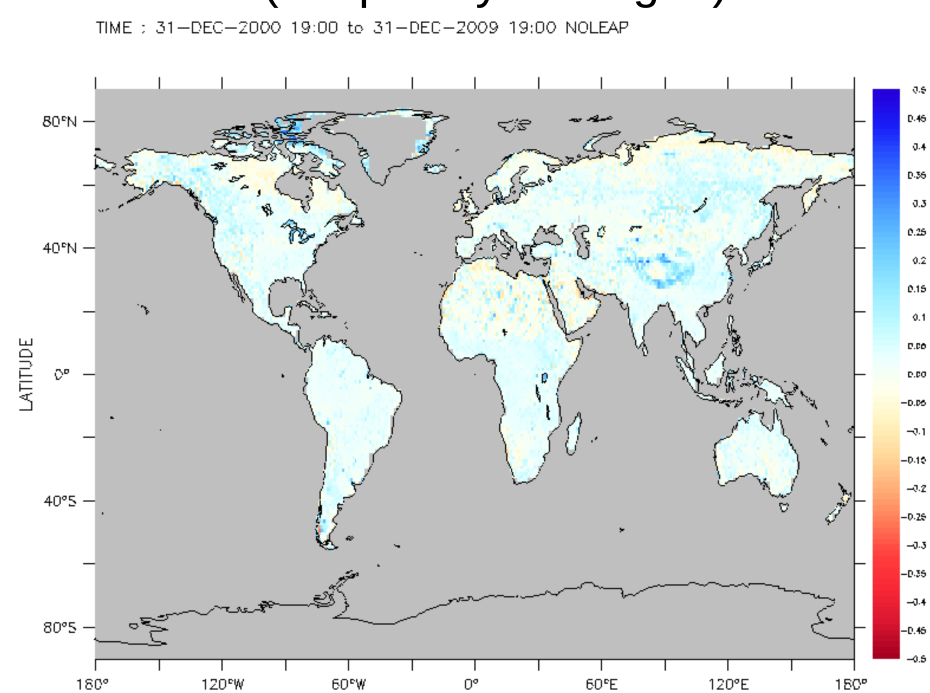
CL5 VIS albedo (temporally averaged)



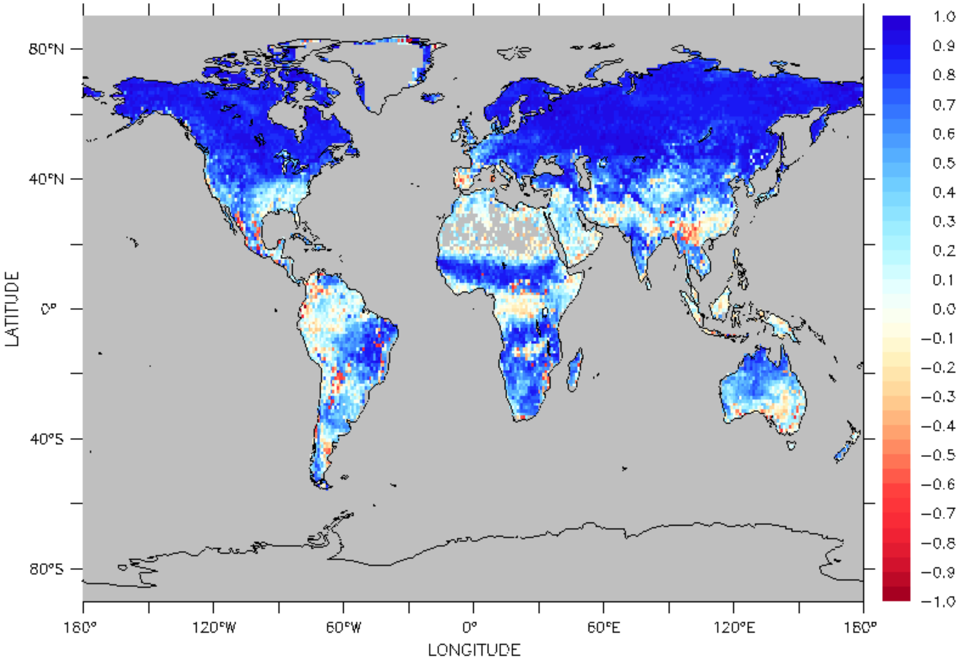
VIS albedo bias FG3 - MODIS
(temporally averaged)



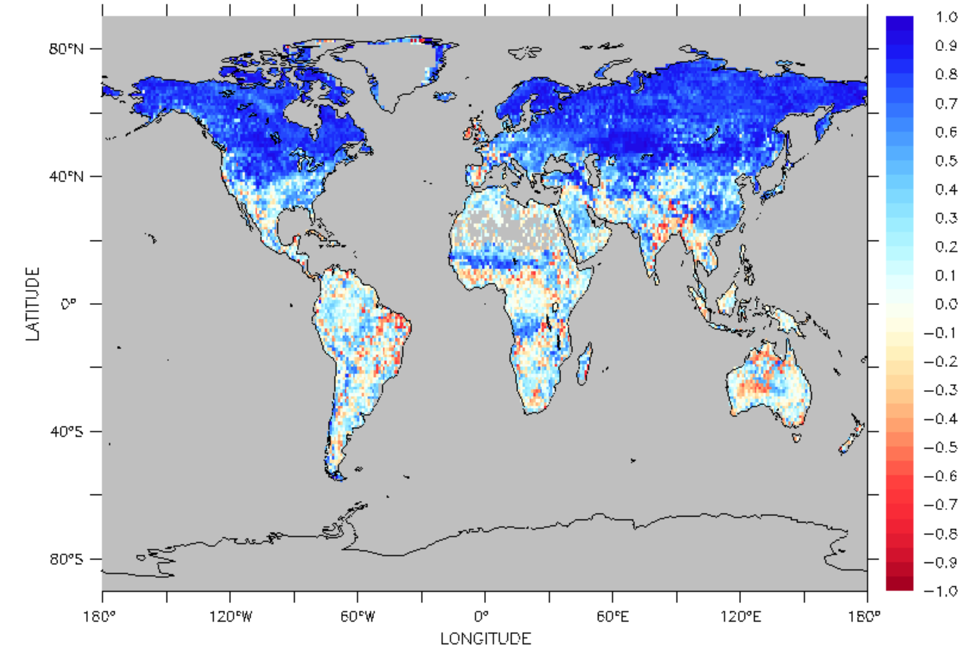
CL5 NIR albedo (temporally averaged)



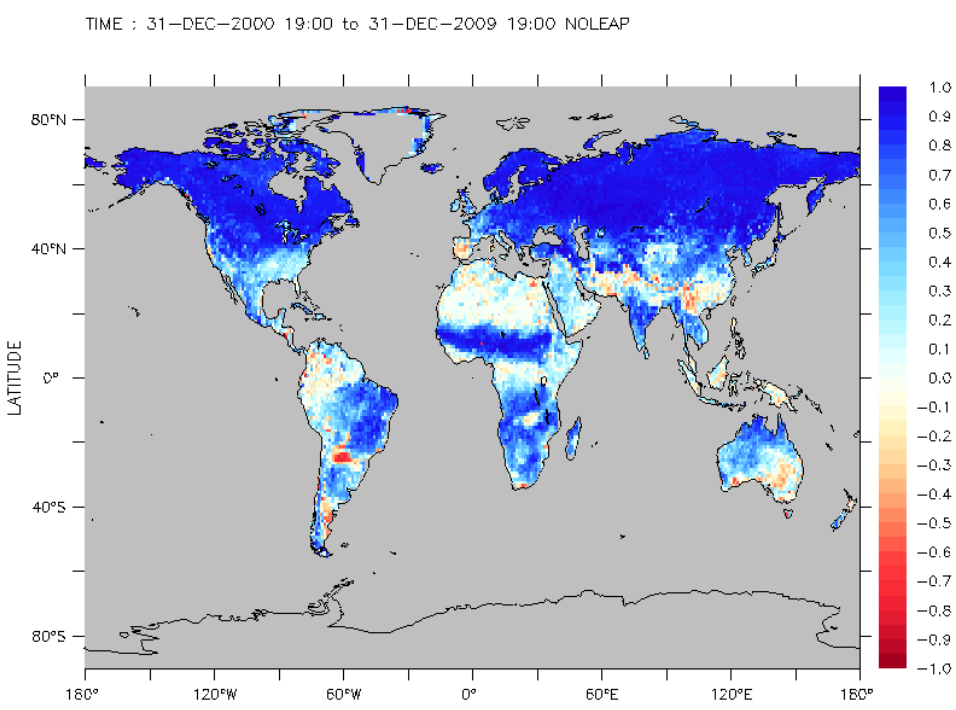
NIR albedo bias FG3 - MODIS
(temporally averaged)



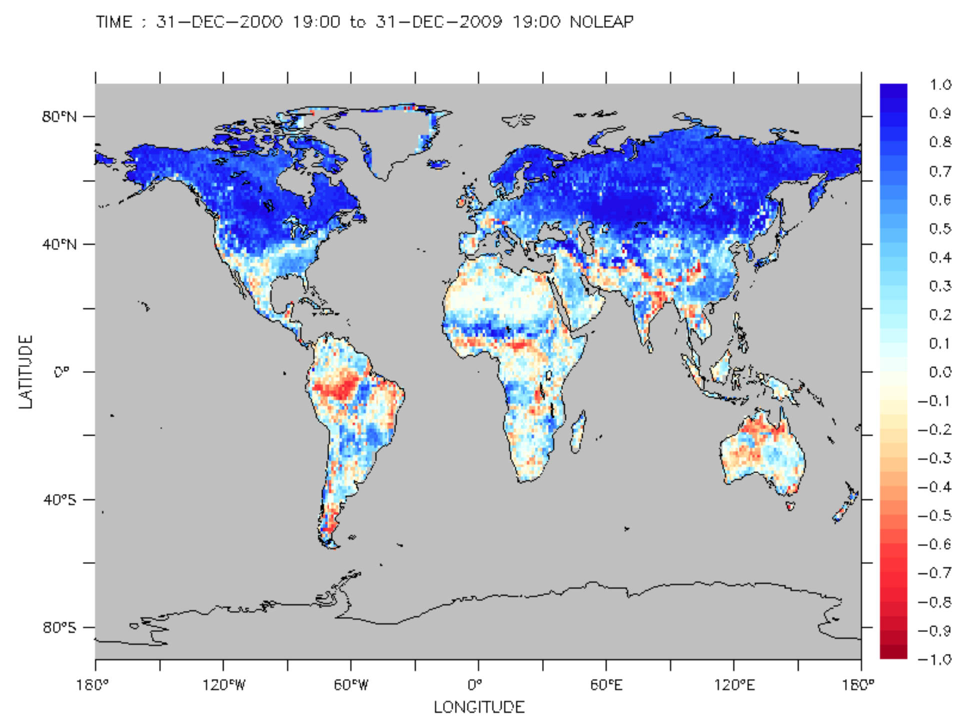
Correlation between FG3 and MODIS in VIS



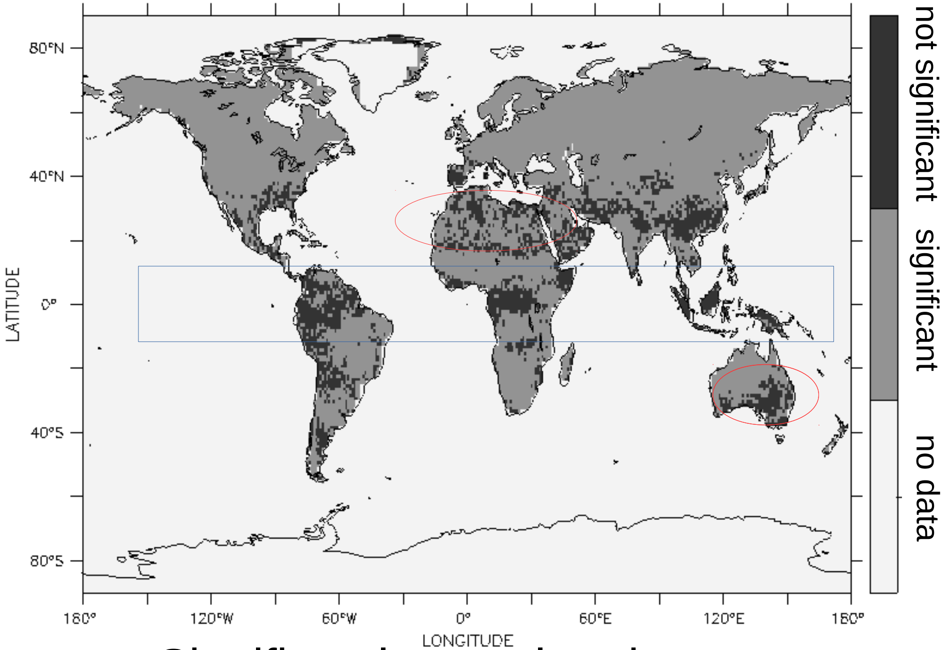
Correlation between FG3 and MODIS in NIR



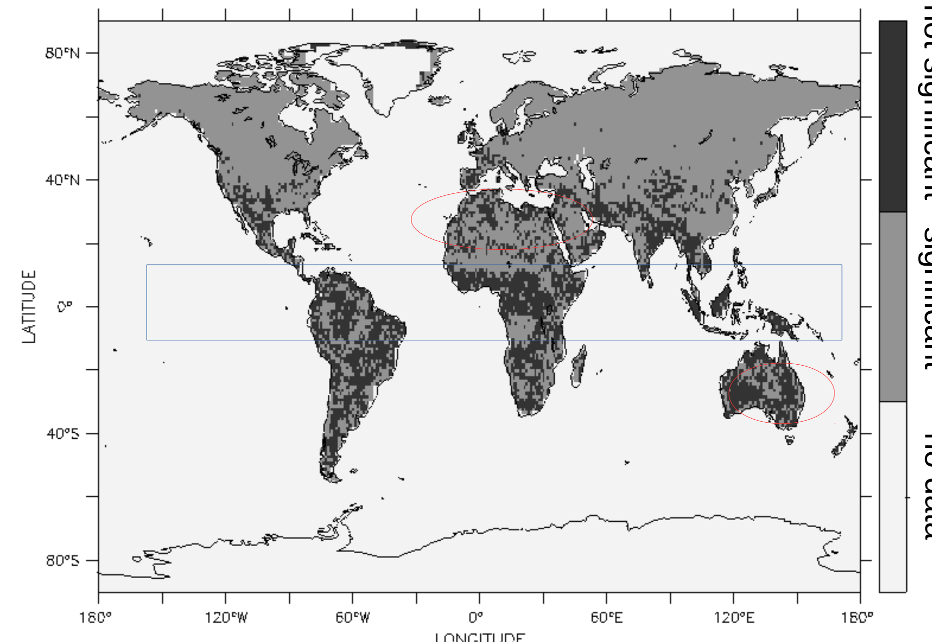
Correlation between CL5 and MODIS in VIS



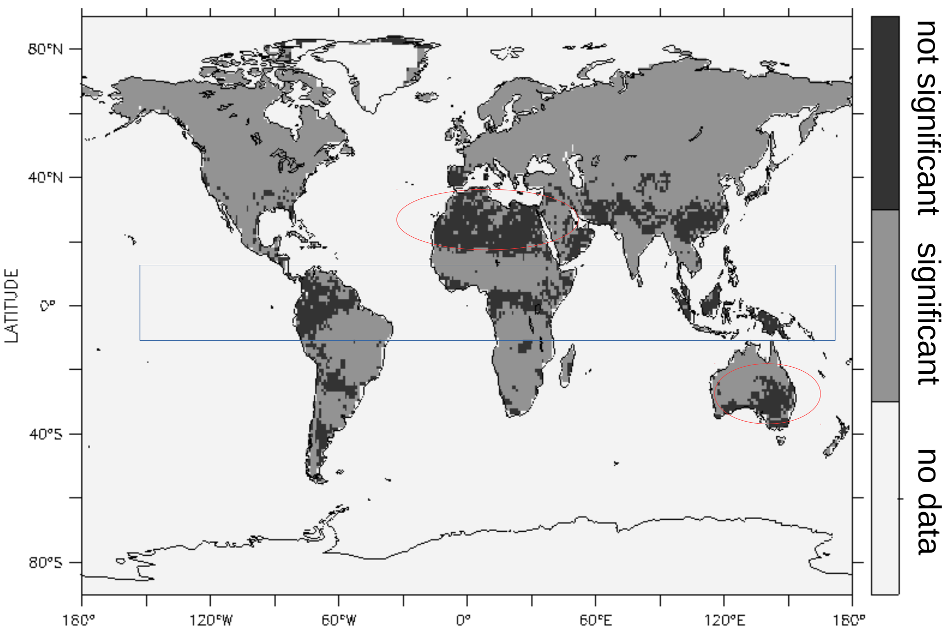
Correlation between CL5 and MODIS in NIR



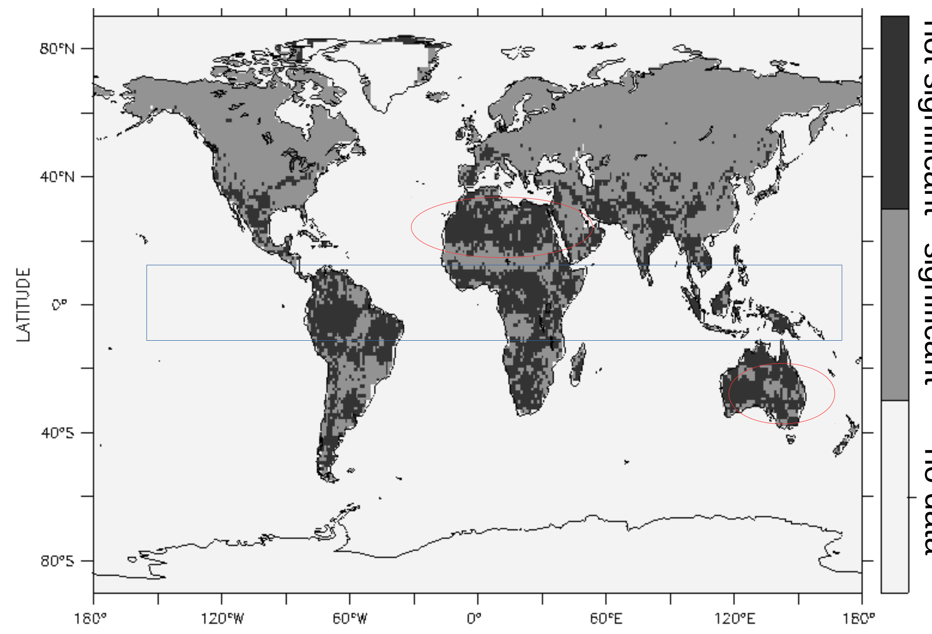
Significantly correlated area
Between FG3 and MODIS (VIS)



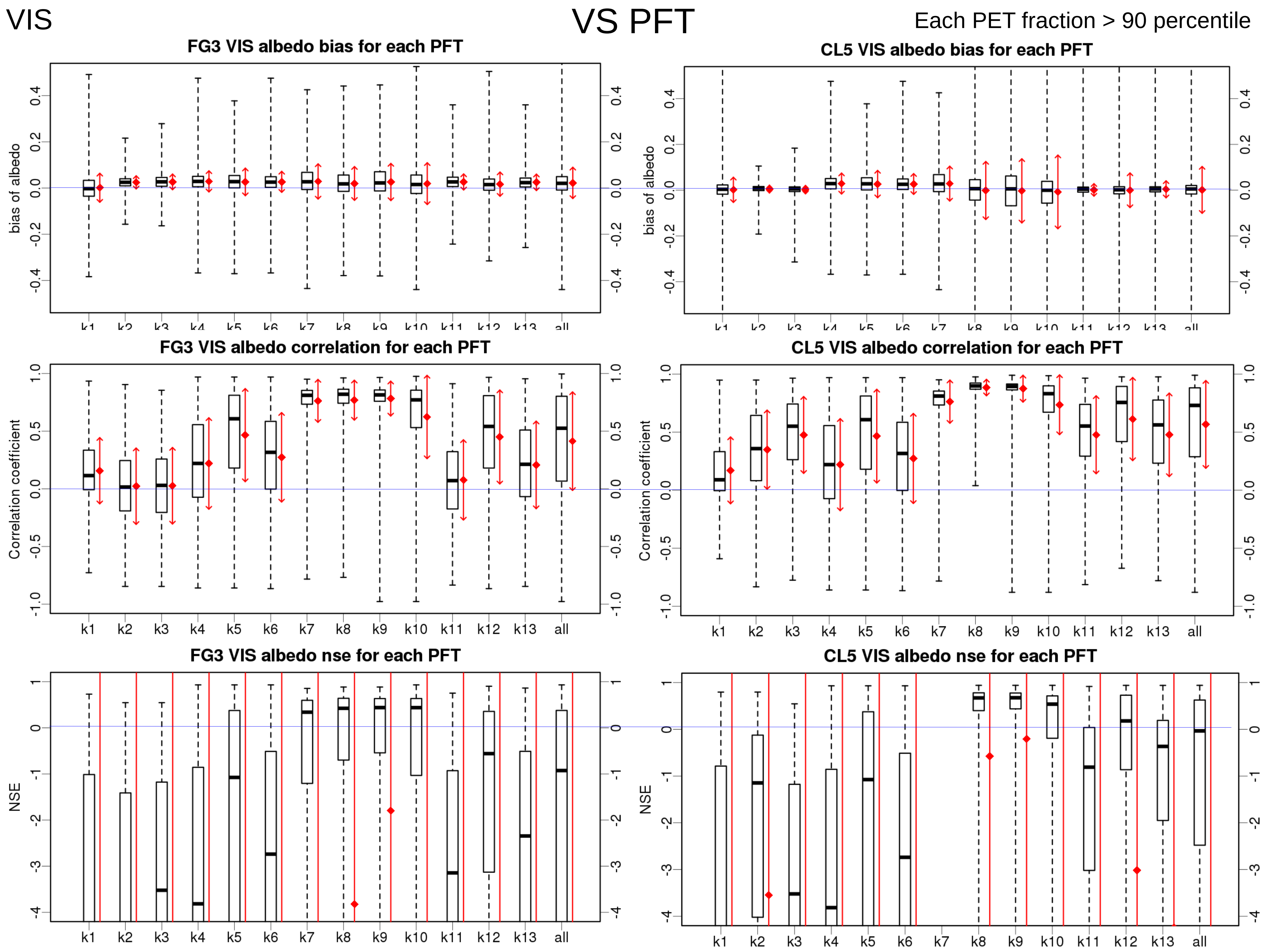
Significantly correlated area
Between FG3 and MODIS (NIR)



Significantly correlated area
Between CL5 and MODIS (VIS)



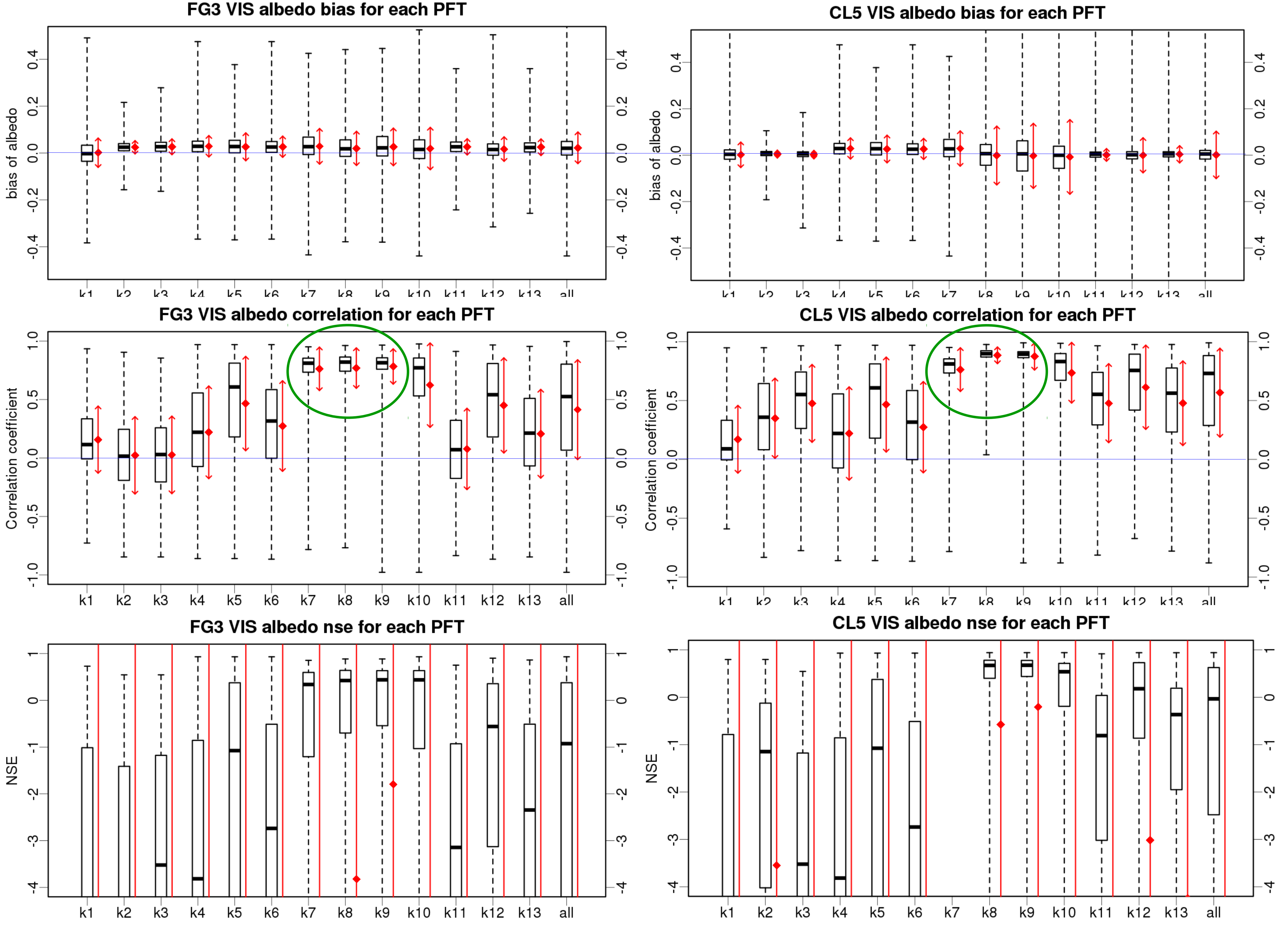
Significantly correlated area
Between CL5 and MODIS (NIR)

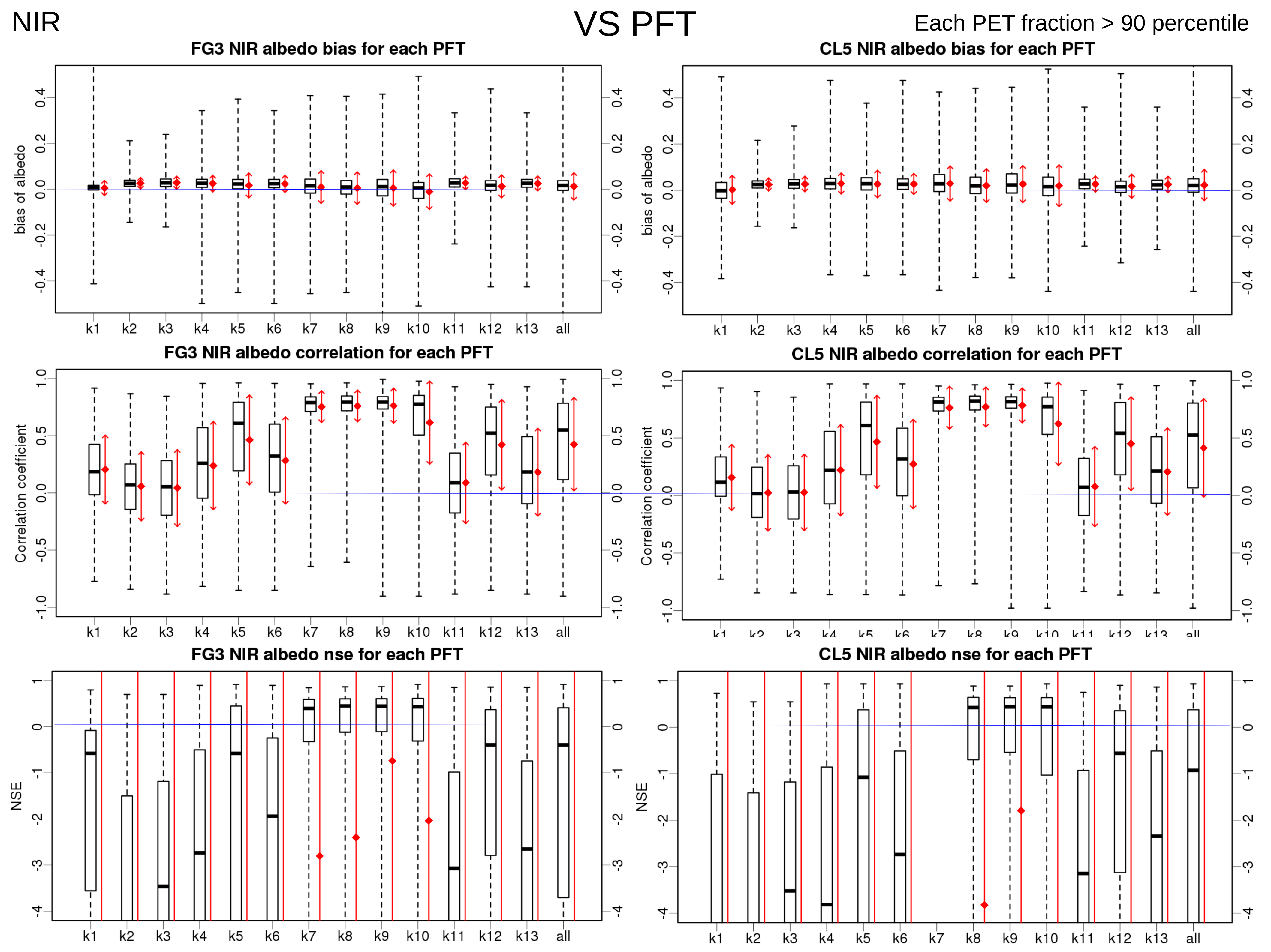

VIS
VS PFT
Each PET fraction > 90 percentile
FG3 VIS albedo bias for each PFT
CL5 VIS albedo bias for each PFT
bias of albedo
FG3 VIS albedo correlation for each PFT
CL5 VIS albedo correlation for each PFT
Correlation coefficient
FG3 VIS albedo nse for each PFT
CL5 VIS albedo nse for each PFT
NSE
k1 k2 k3 k4 k5 k6 k7 k8 k9 k10 k11 k12 k13 all

VIS

VS PFT

Each PFT fraction > 90 percentile

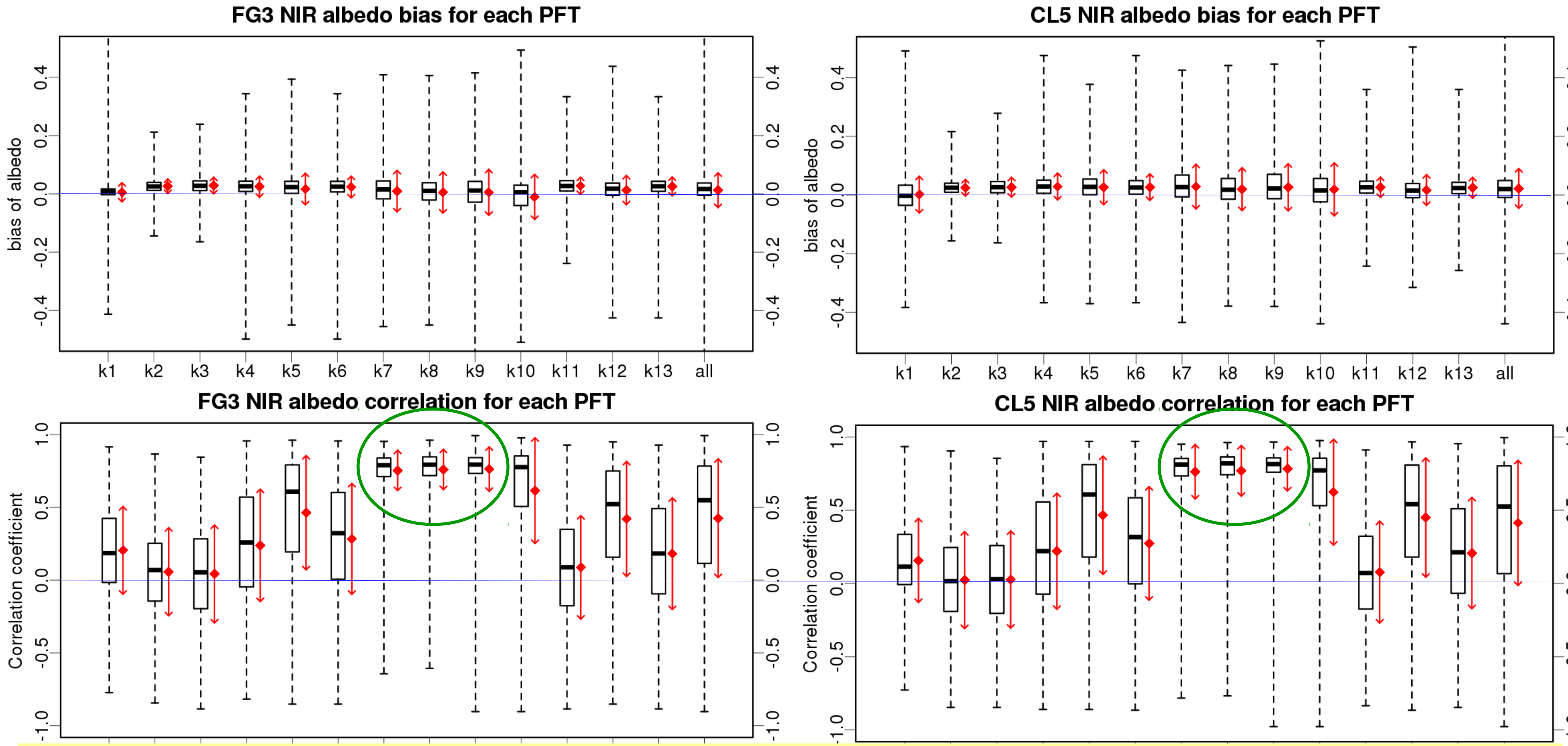



NIR
VS PFT
Each PET fraction > 90 percentile
FG3 NIR albedo bias for each PFT
CL5 NIR albedo bias for each PFT
bias of albedo
FG3 NIR albedo correlation for each PFT
CL5 NIR albedo correlation for each PFT
Correlation coefficient
FG3 NIR albedo nse for each PFT
CL5 NIR albedo nse for each PFT
NSE
k1 k2 k3 k4 k5 k6 k7 k8 k9 k10 k11 k12 k13 all

NIR

VS PFT

Each PET fraction > 90 percentile



- PFT7~9 (boreal forest) show good *r* in both VIS and NIR bands