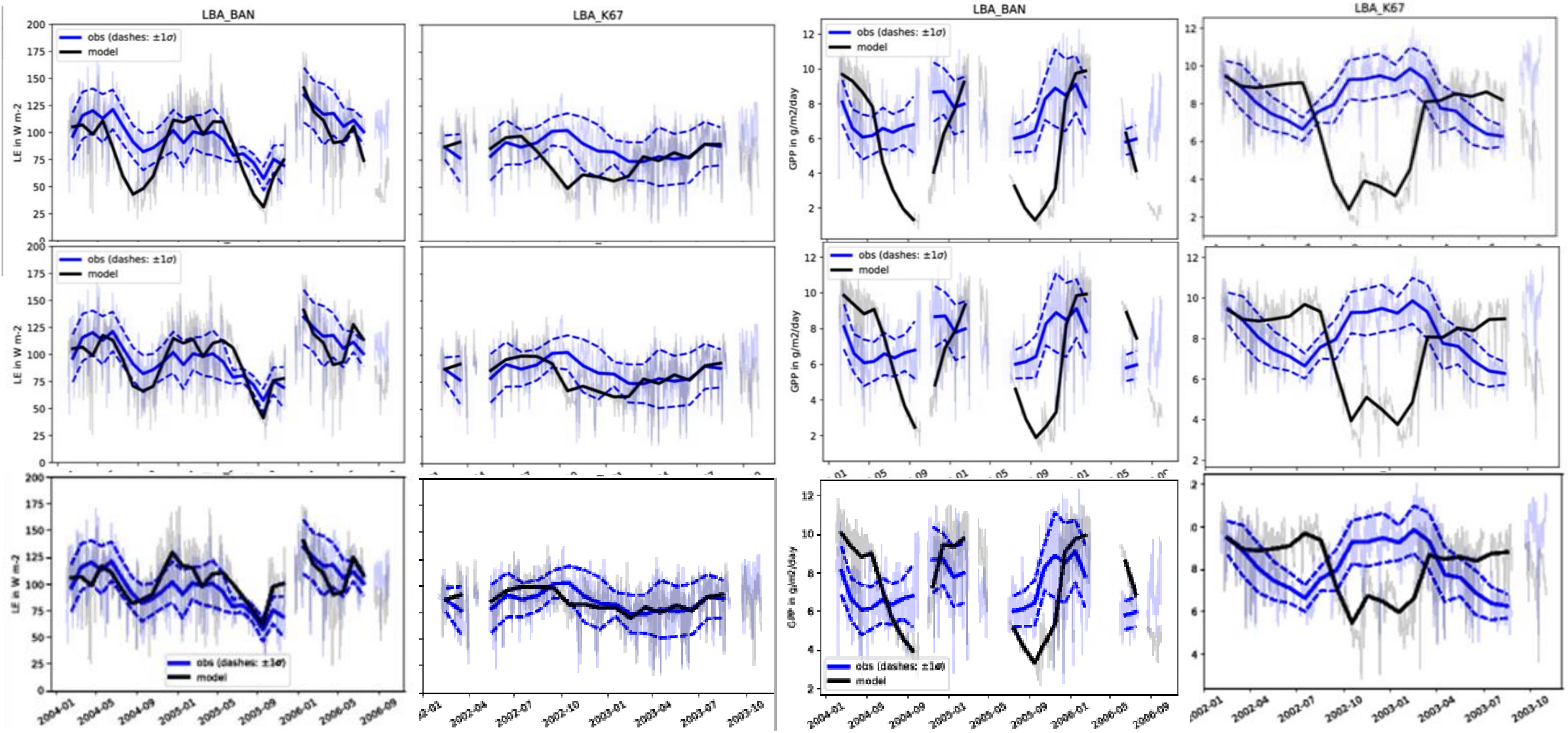
Uncertainty in the future water budget of the Amazon basin due to land parameter and climate uncertainty - Nic Gedney (Met Office)

- **Objectives:**
  - Reduce land surface uncertainty using data assimilation
  - Assess remaining uncertainty in future projections

- **Approach:**
  - Assess modelled river flow & land water storage
  - Optimise JULES parameters which affect seasonal water budget
    - Implement 4D ensemble variational data assimilation (LAVENDAR)
  - Ensemble of very high emission transient simulations

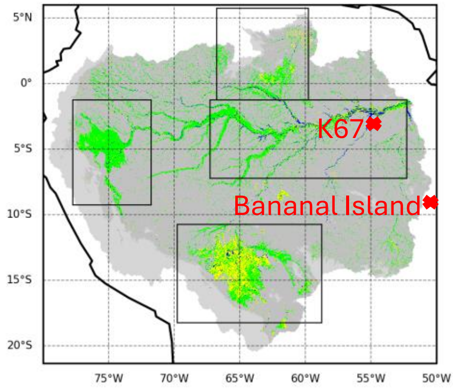
Comparison against Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)



JULES

JULES + LSH (simple groundwater)

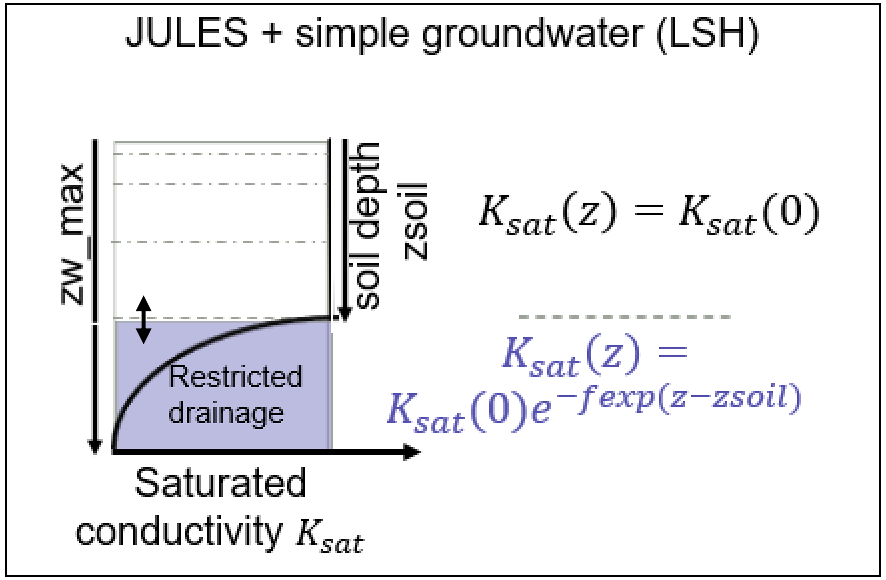
JULES + LSH + full hydraulic connectivity



- Too much seasonal water stress in regions of Amazonia (Harper et al 2022)
- Improvement with JULES+LSH+full connectivity (+ other errors – Harper et al 2022)

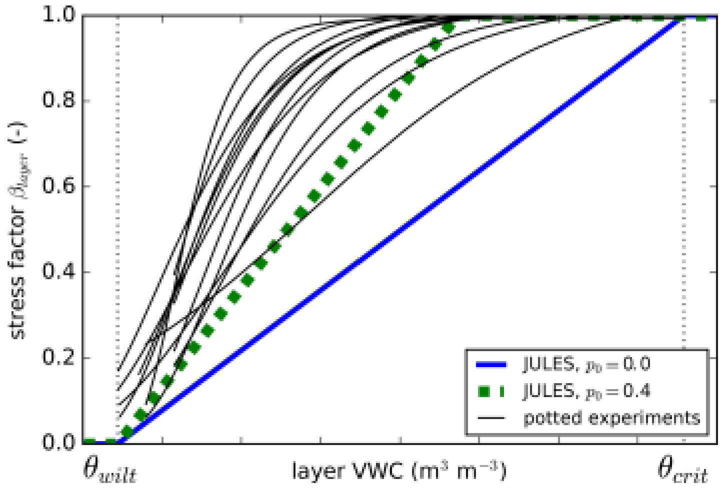
- Can we utilise basin-scale observations to optimise parameters which affect the land water budget?

JULES set up



- full hydraulic connectivity between all layers
- new water table calculation
- Soil ancils include oxisols and ultisols

(From Harper et al 2022)



$\beta = \Theta_{wilt} + (\Theta_{crit} - \Theta_{wilt}) * (1 - fsmc\_p0\_io)$

Parameters to be optimised which affect water budget:

- **zw_max**: total model depth
- **fexp**: restricted drainage in deepest layer factor
- **fsmc_p0_io**: soil moisture content when vegetation starts to be stressed

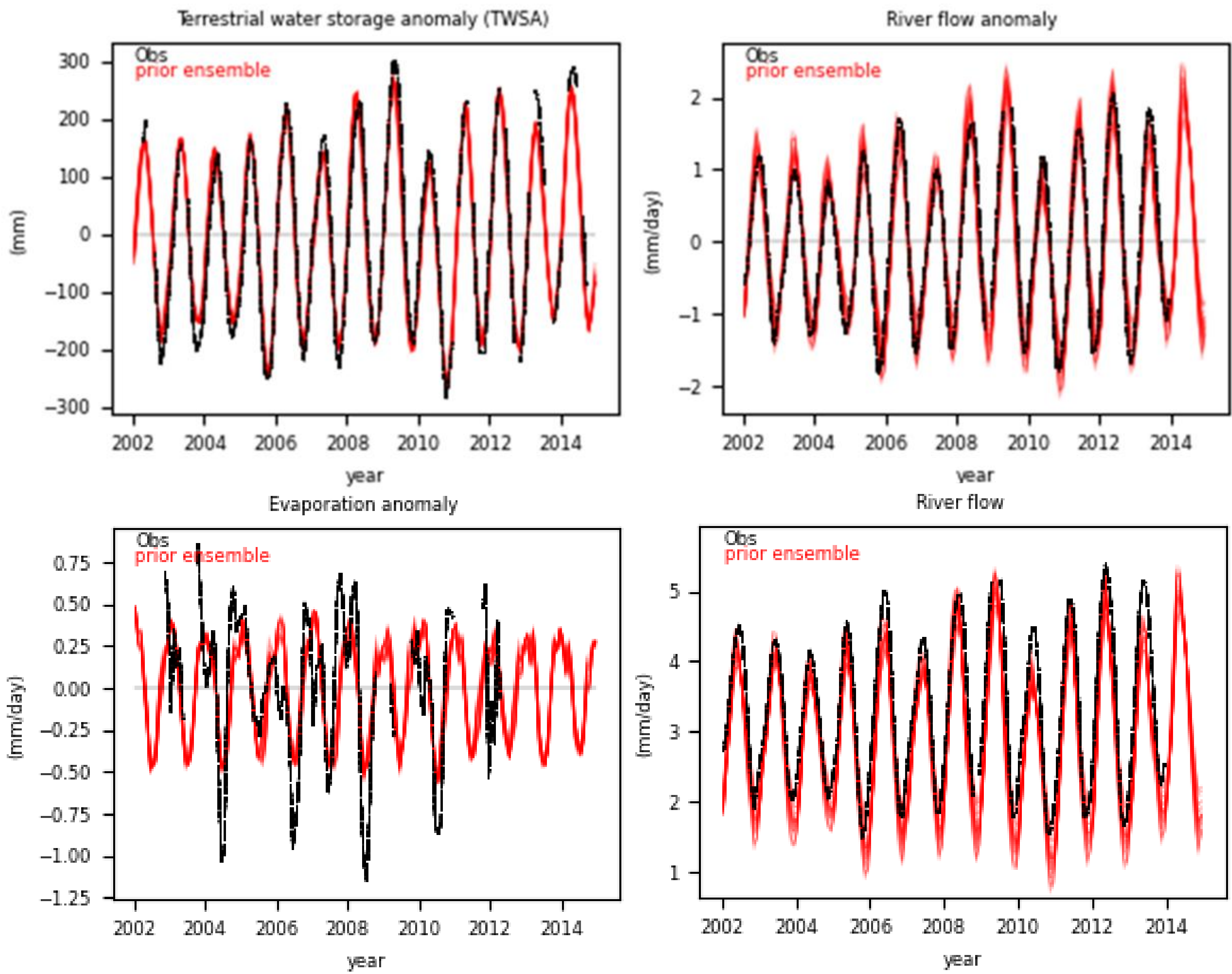
Provide a prior ensemble of parameter vectors
Run JULES for each unique parameter vector:
Historical run with obs met driving data (GSWP3)

Use of basin-wide observations to calibrate JULES

TWSA = anom total water stored in/on land
(Obs: GRACE satellite)
dTWSA = (Precip-Evap-River Flow)△t

Evap ~ Precip-River Flow -dTWSA/△t

River flow (Obidos)



- TWSA relatively little impact due to parameter values:
- Runoff/river flow changes ⟷ evaporation changes (for most ensemble)
- Evaporation estimate more uncertain
- Interested in seasonal water budget → Utilise TWSA and River flow anomaly

Land Variational Ensemble Data Assimilation Framework (LAVENDAR): Optimising JULES parameters

LAVENDAR implements four-dimensional ensemble variational (4D-En-Var) data assimilation (DA) for land surface models.

Method:

Provide a prior ensemble of parameter vectors
Run JULES for each unique parameter vector

Implement LAVENDAR => posterior parameter vectors

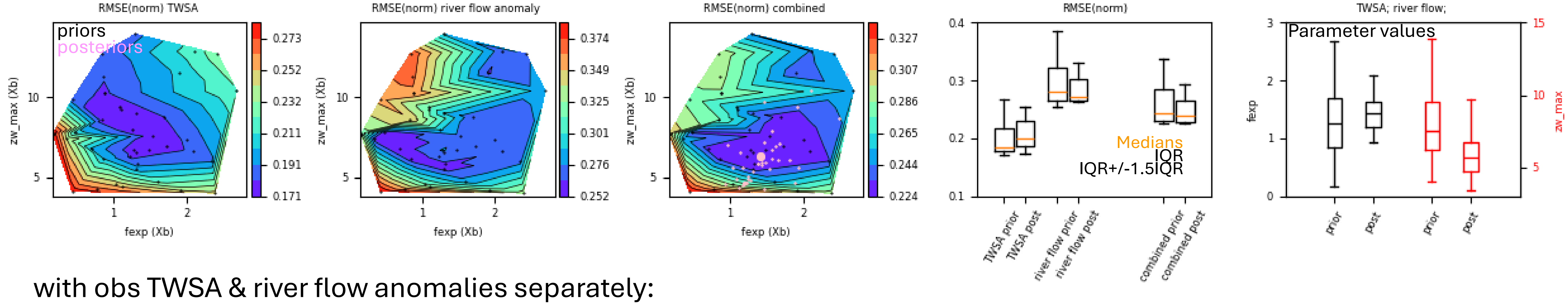
Here we consider 2 sets of experiments with 2 different parameters optimised:

- **fexp** & **zw_max** (restricted drainage in deepest layer & total model depth)
- **fexp** & **fsmc_p0_io**(restricted drainage in deepest layer & soil moisture at stress onset)

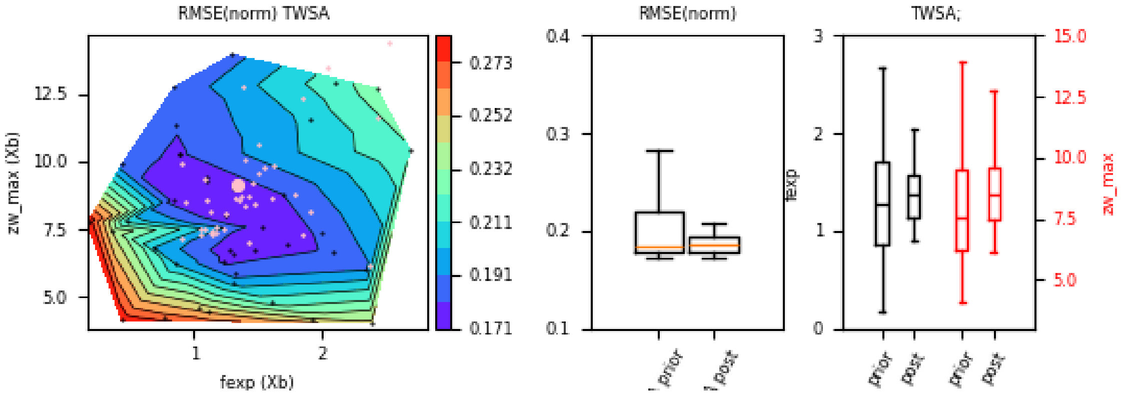
Constraining fexp & zw_max JULES parameters

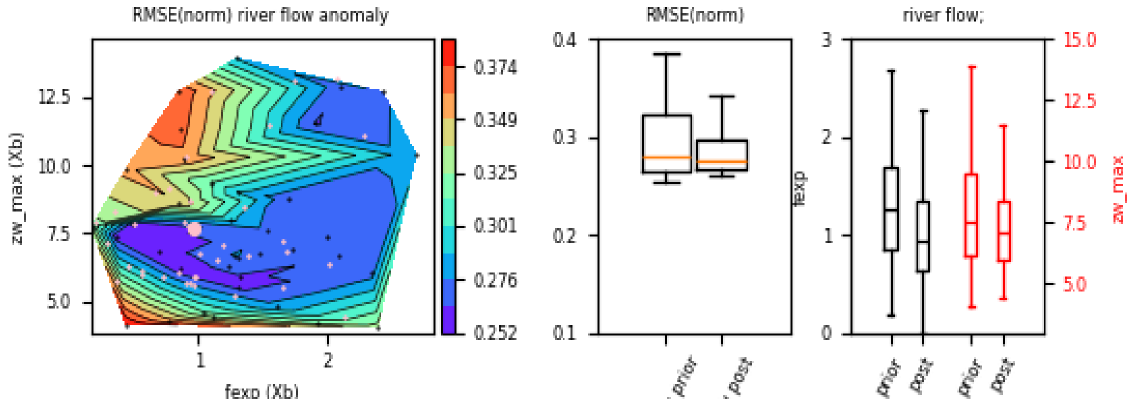
zw_max: total model depth
fexp: restricted drainage
fsmc_p0_io: soil moisture for veg stress

with both obs TWSA and river flow anomalies (=>normalise RMSE = RMSE/σ(obs)):



with obs TWSA & river flow anomalies separately:





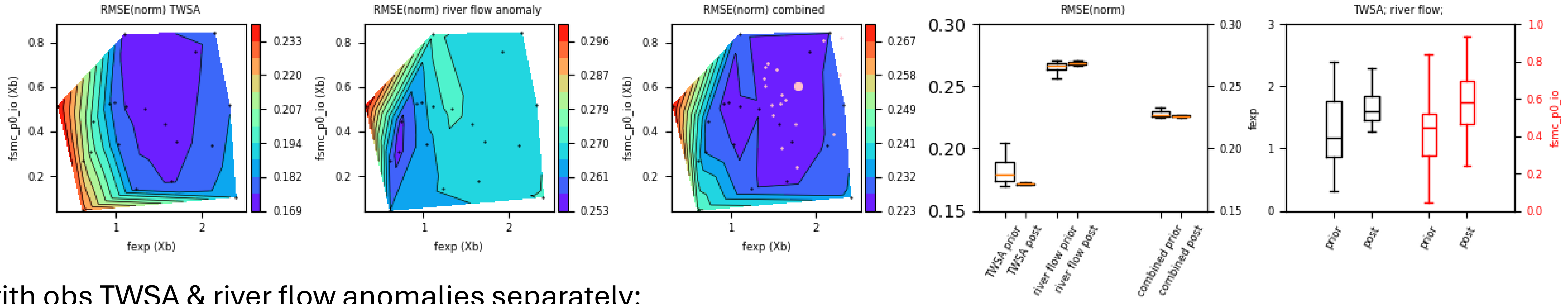
- Using both TWSA and river flow:
  - reduces parameter value spread
  - doesn't reduce both median RMSE's

- Different obs datasets give different optimised parameter values
- All DA's give a reduced parameter spread

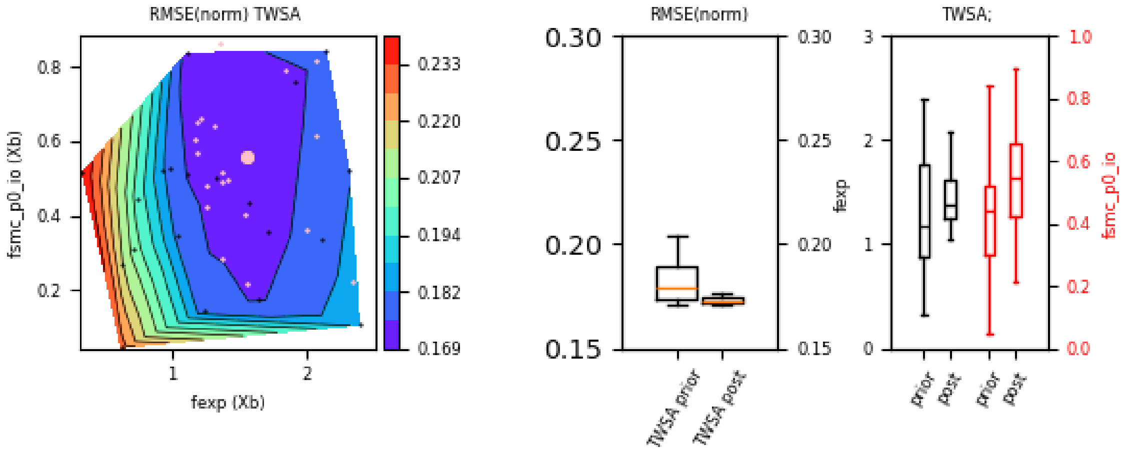
Constraining fexp & fsmc_p0 JULES parameters

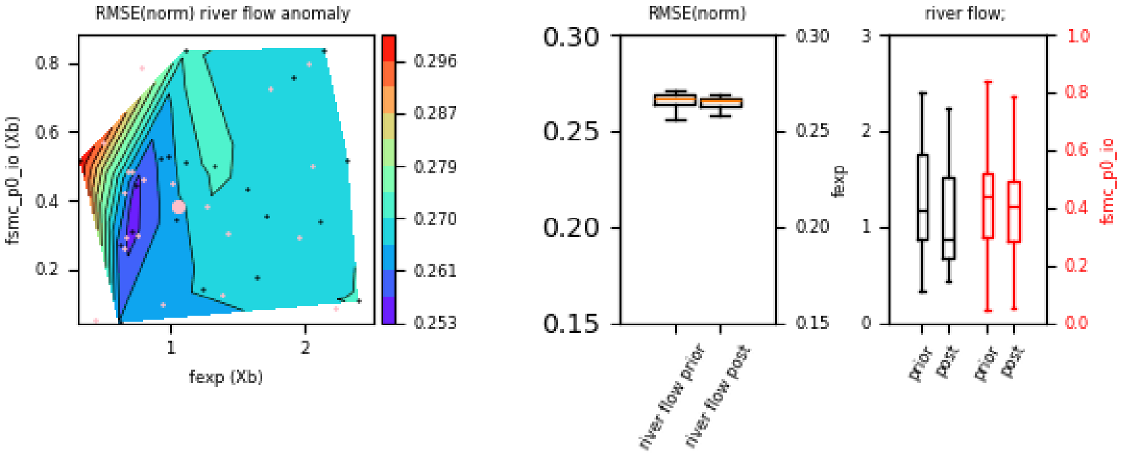
zw_max: total model depth
fexp: restricted drainage
fsmc_p0_io: soil moisture for veg stress

with both obs TWSA and river flow anomalies (=>normalise RMSE = RMSE/σ(obs)):



with obs TWSA & river flow anomalies separately:



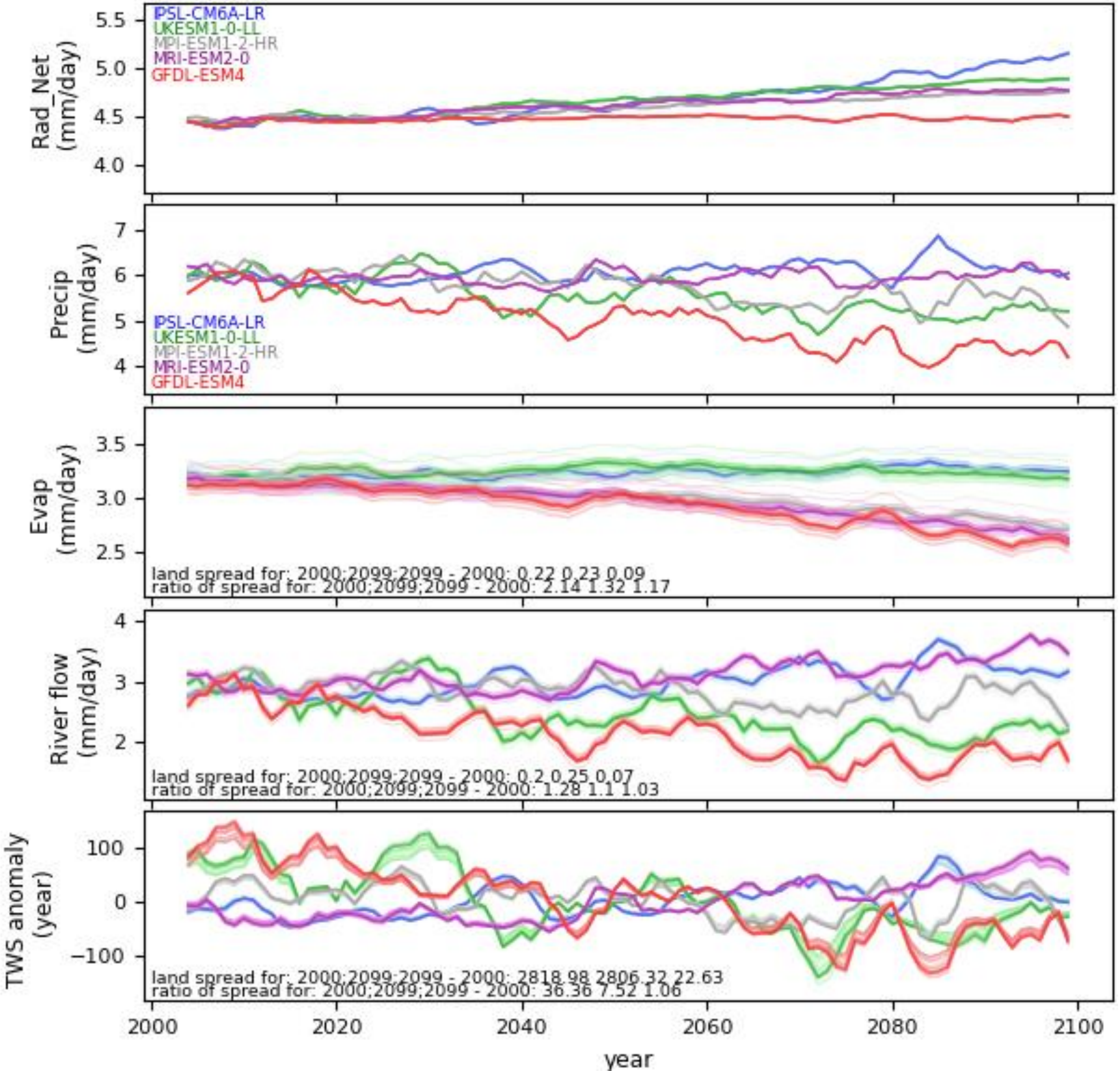


- Relatively little reduction in spread fsmc_p0 – due to JULES being mainly unstressed over the basin as whole

Transient ISIMIP3b SSP585 high emissions scenario: ensemble simulations with **posterior fexp, zw_max** values

zw_max: total model depth
fexp: restricted drainage

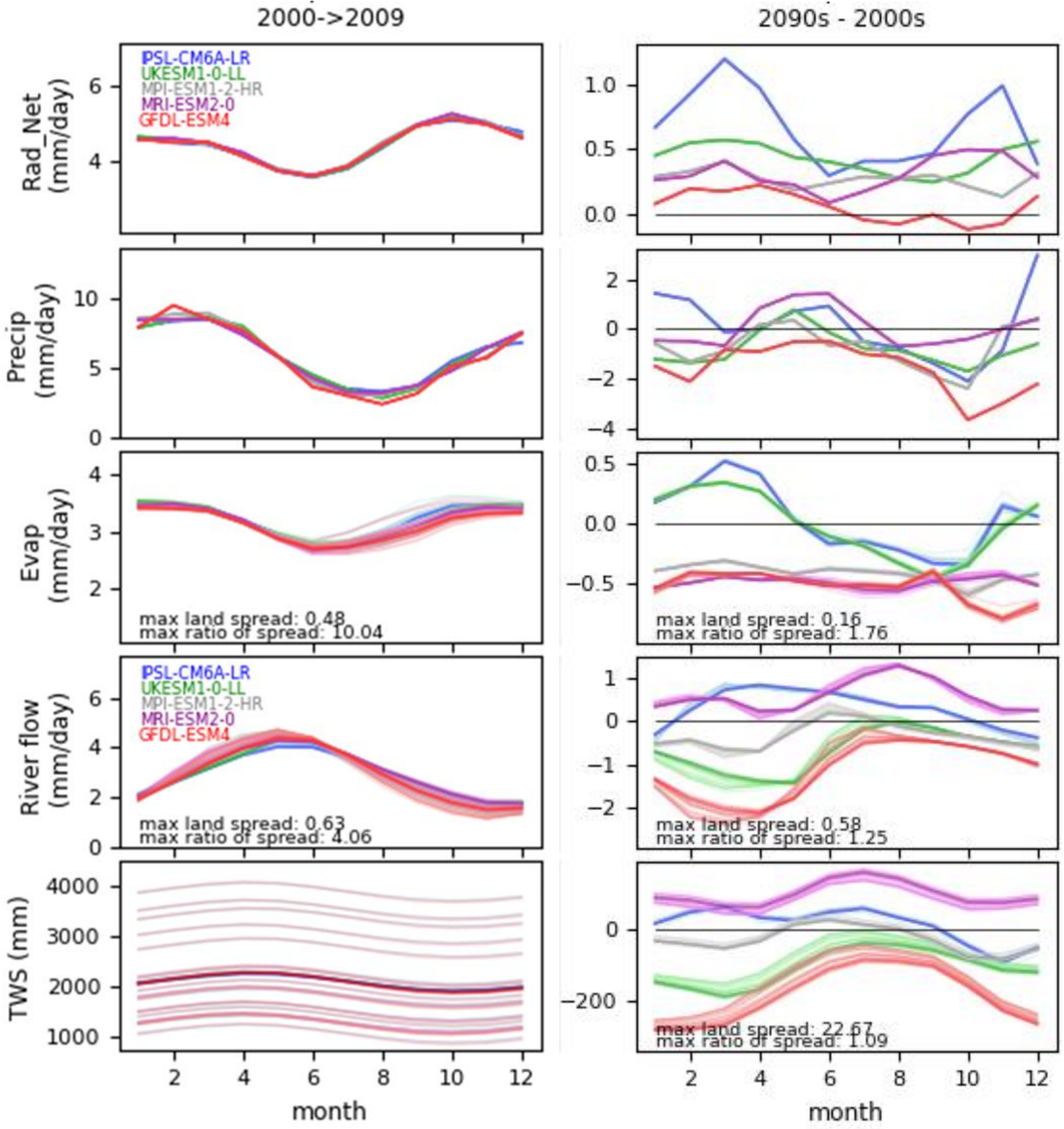
- Annual mean river flow and TWSA mainly driven by precip
- Projected uncertainty due to fexp, zw_max is small compared to from climate forcing
- fexp, zw_max has comparable impact on long term evaporation & river flow



Transient ensemble simulations with **posterior fexp**, **zw_max** values: Seasonal changes

zw_max: total model depth
fexp: restricted drainage
fsmc_p0_io: soil moisture for veg stress

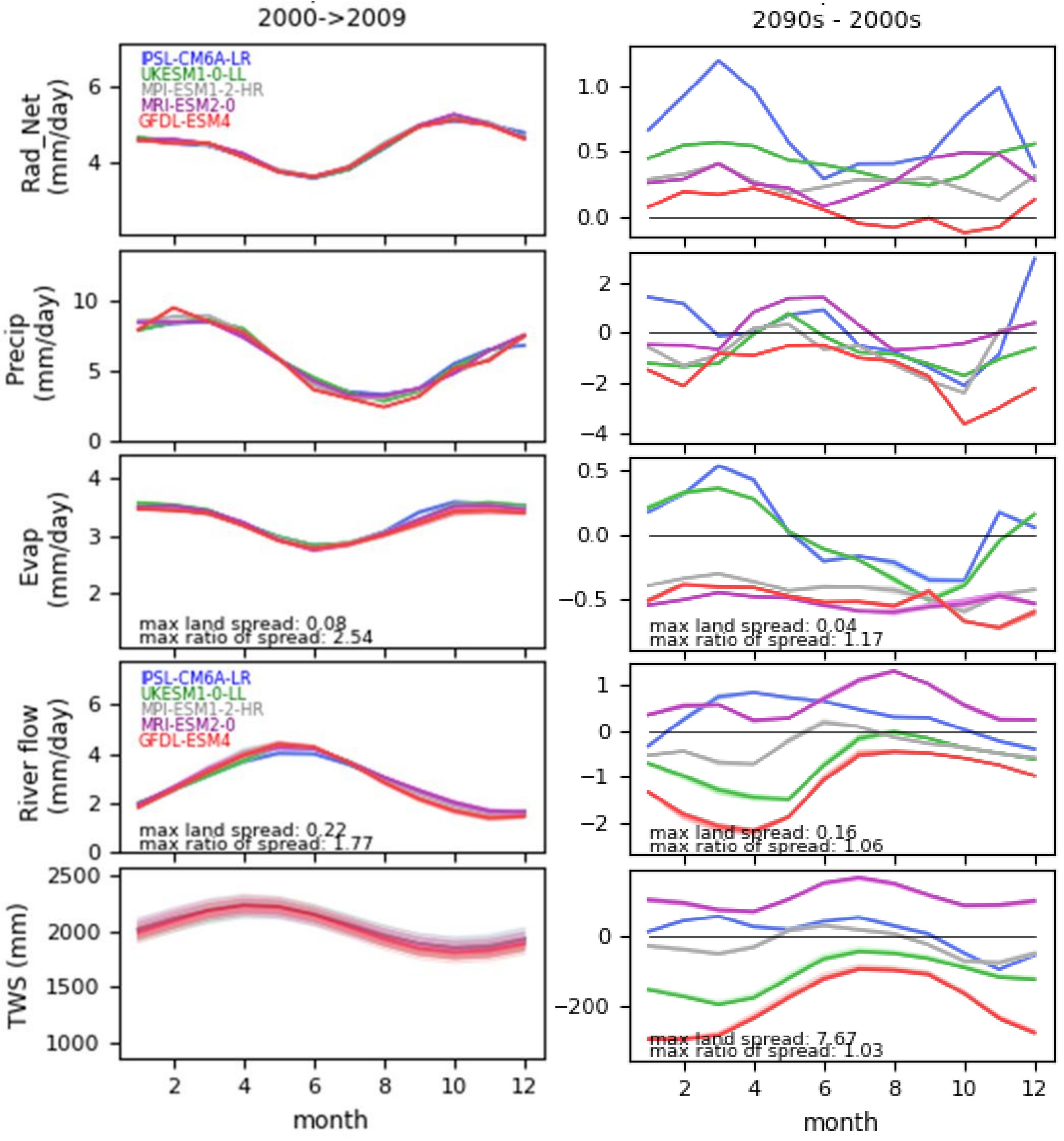
- 2000s seasonal more energy than water limited
- Projected future drop in rainfall at the start of the rainy season
- Projected change uncertainty due to posterior fexp, zw_max is small compared to from climate forcing
- fexp, zw_max has more impact on long term monthly river flow change than evaporation: (as zw_max, fexp more directly impacts seasonal runoff/river flow)



Transient ensemble simulations with **posterior fexp**, **fsmc_p0** values: Seasonal changes

zw_max: total model depth
fexp: restricted drainage
fsmc_p0_io: soil moisture for veg stress

- Projected change uncertainty due to fexp, fsmc_p0 is much smaller than that due to from climate forcing
- => **zw_max** is the cause of most of **remaining** uncertainty of parameters considered



Conclusions

- Including deeper model layer and groundwater improves modelled evaporation at seasonally water stressed sites.

- LAVENDAR can reduce parameter value uncertainty but results are observation dataset dependant.

- Simulated climate change water budget uncertainty driving more uncertainty than (considered) constrained land parameters

- Land parameters relatively more important for seasonal than annual mean change.

Further work

- Redo 4D-En-Var with adjusted state parameters & larger parameter ensemble.

- Geographical regions within Amazon basin.

- Consider other JULES parameters & parameterisations.