Nudging to reanalyses: a tool to evaluate model process realism (and later study predictability issues)

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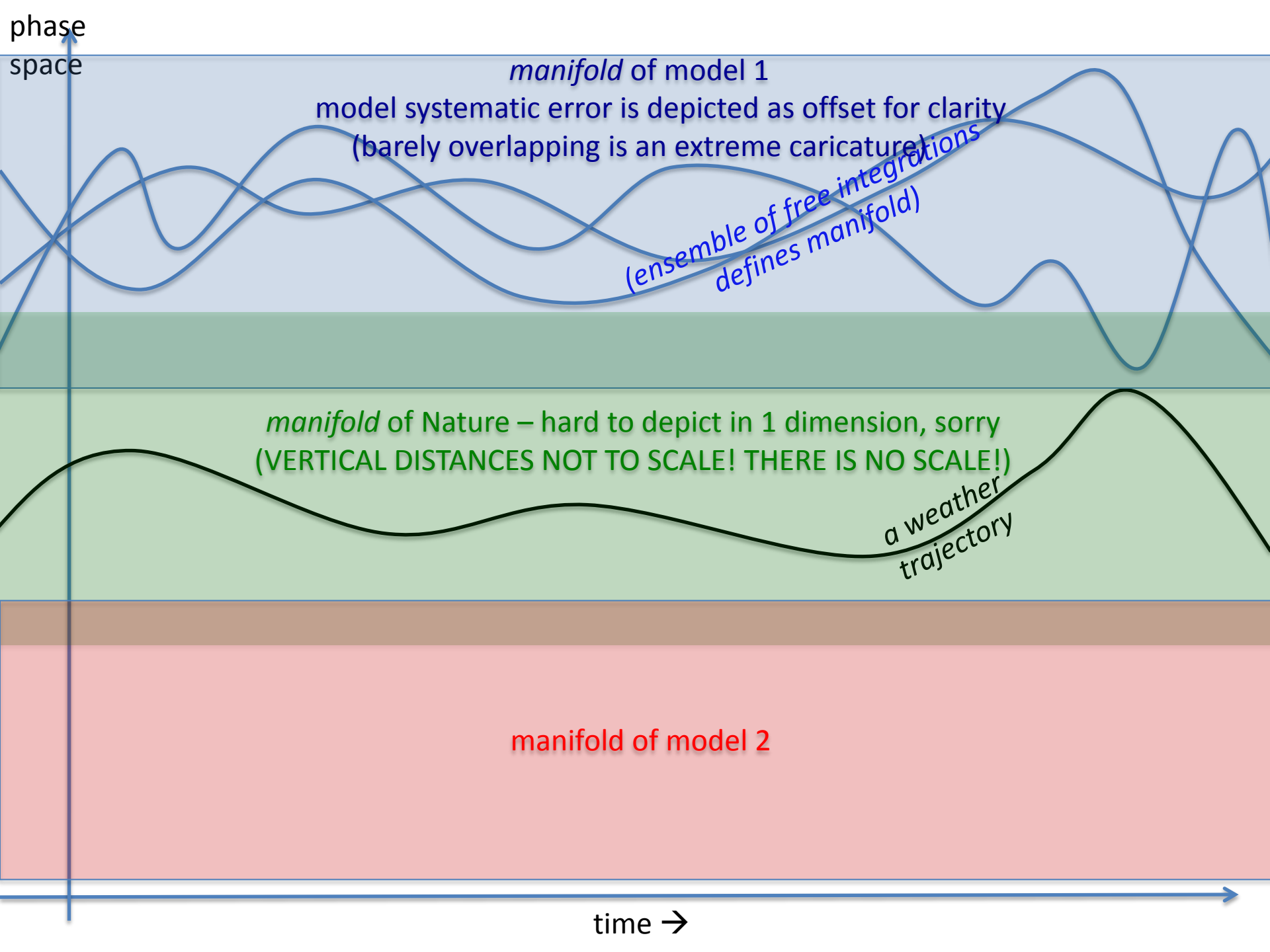
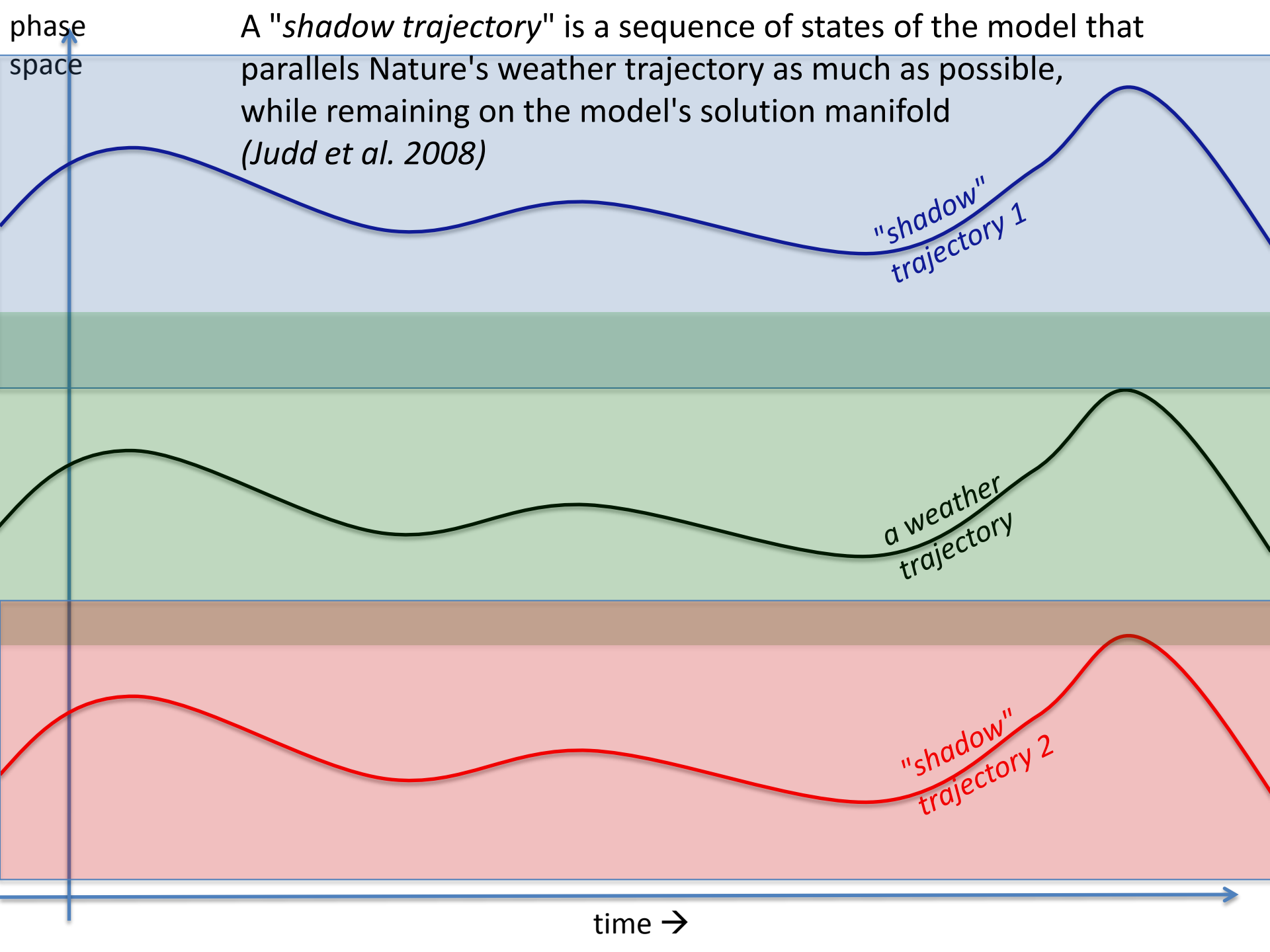
Huge thanks for can-do:

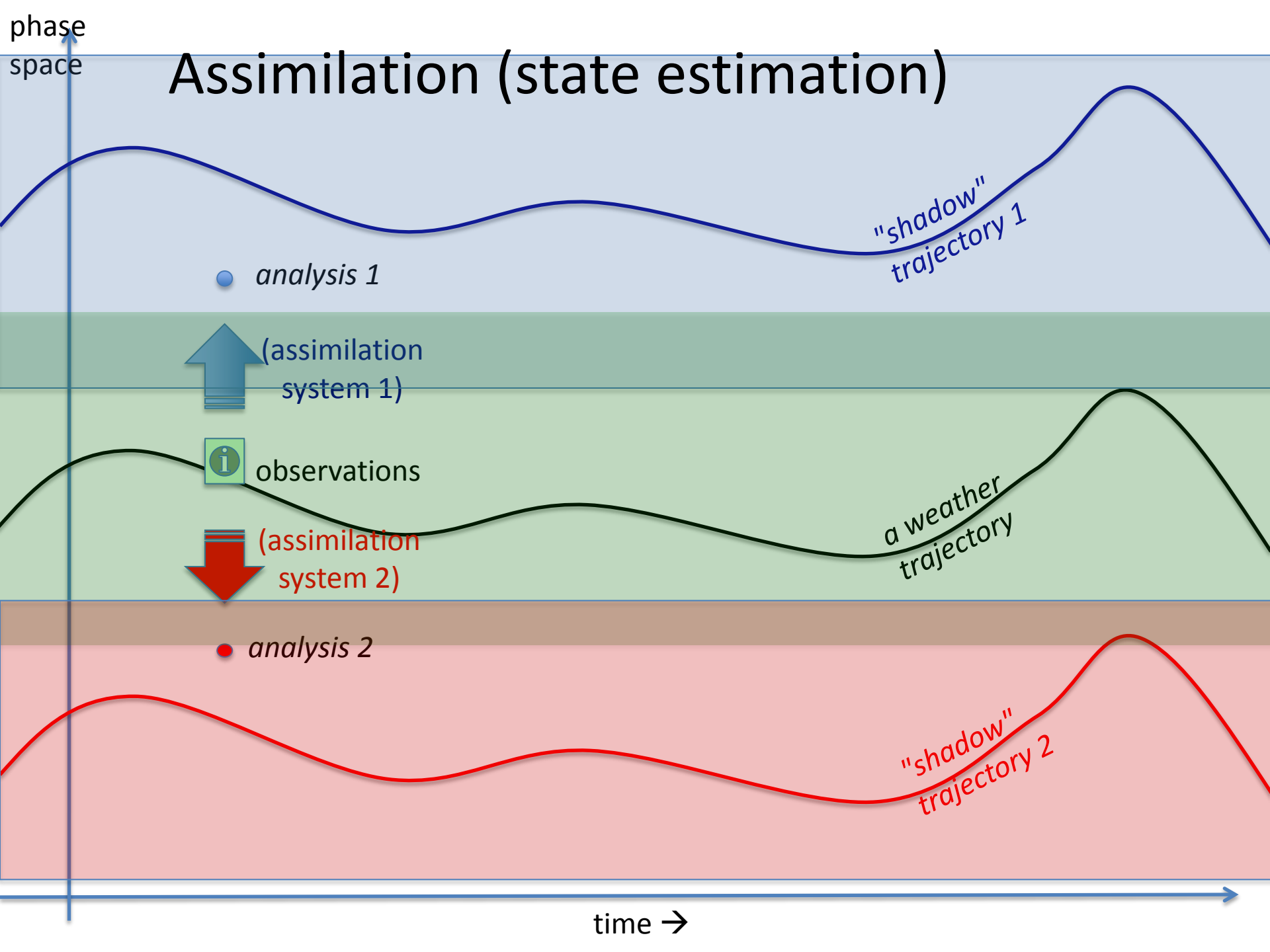
Patrick Callaghan, Julio Bacmeister, Jerry Olson

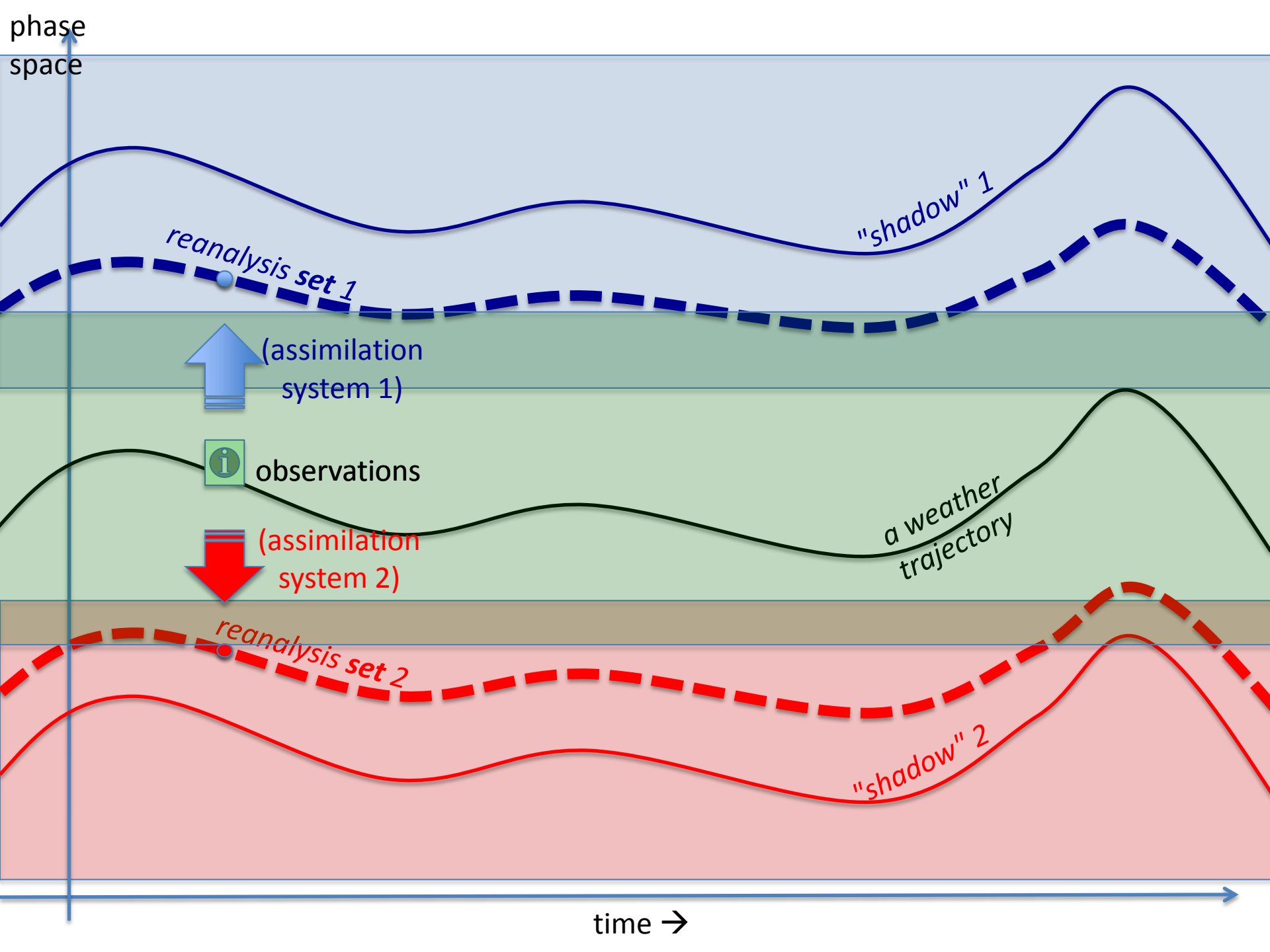
Outline

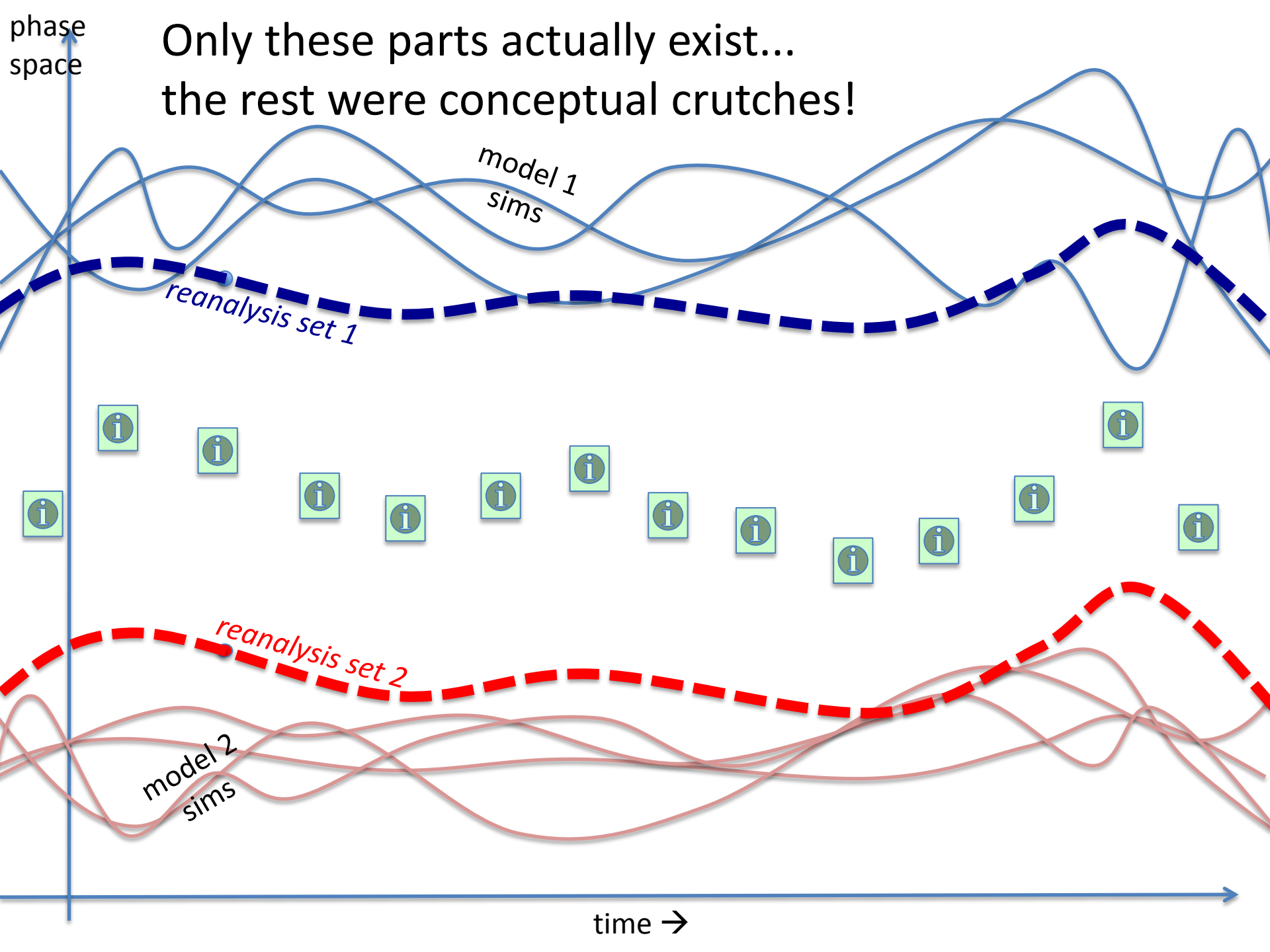
- A flurry of conceptual orientation slides
- Some results from nudging {u,v,T} in CAM5-UWens-org-SE toward 3 reanalyses (MERRA, ERAI, JRA)
- Conclusions and a plea for sensible CAM tendency outputs

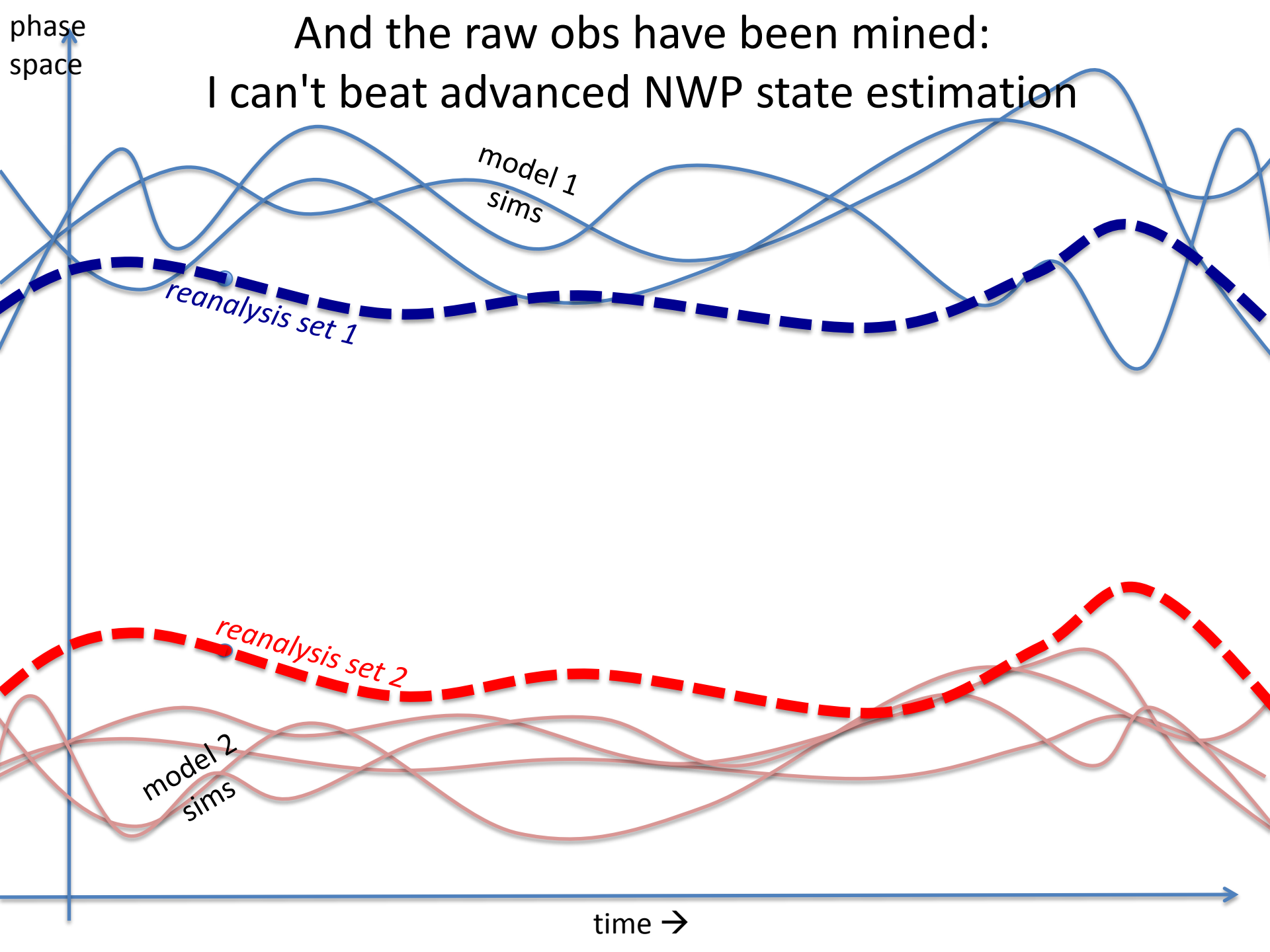

phase space
manifold of model 1
model systematic error is depicted as offset for clarity
(barely overlapping is an extreme caricature)
(ensemble of free integrations defines manifold)
manifold of Nature – hard to depict in 1 dimension, sorry
(VERTICAL DISTANCES NOT TO SCALE! THERE IS NO SCALE!)
a weather trajectory
manifold of model 2
time →

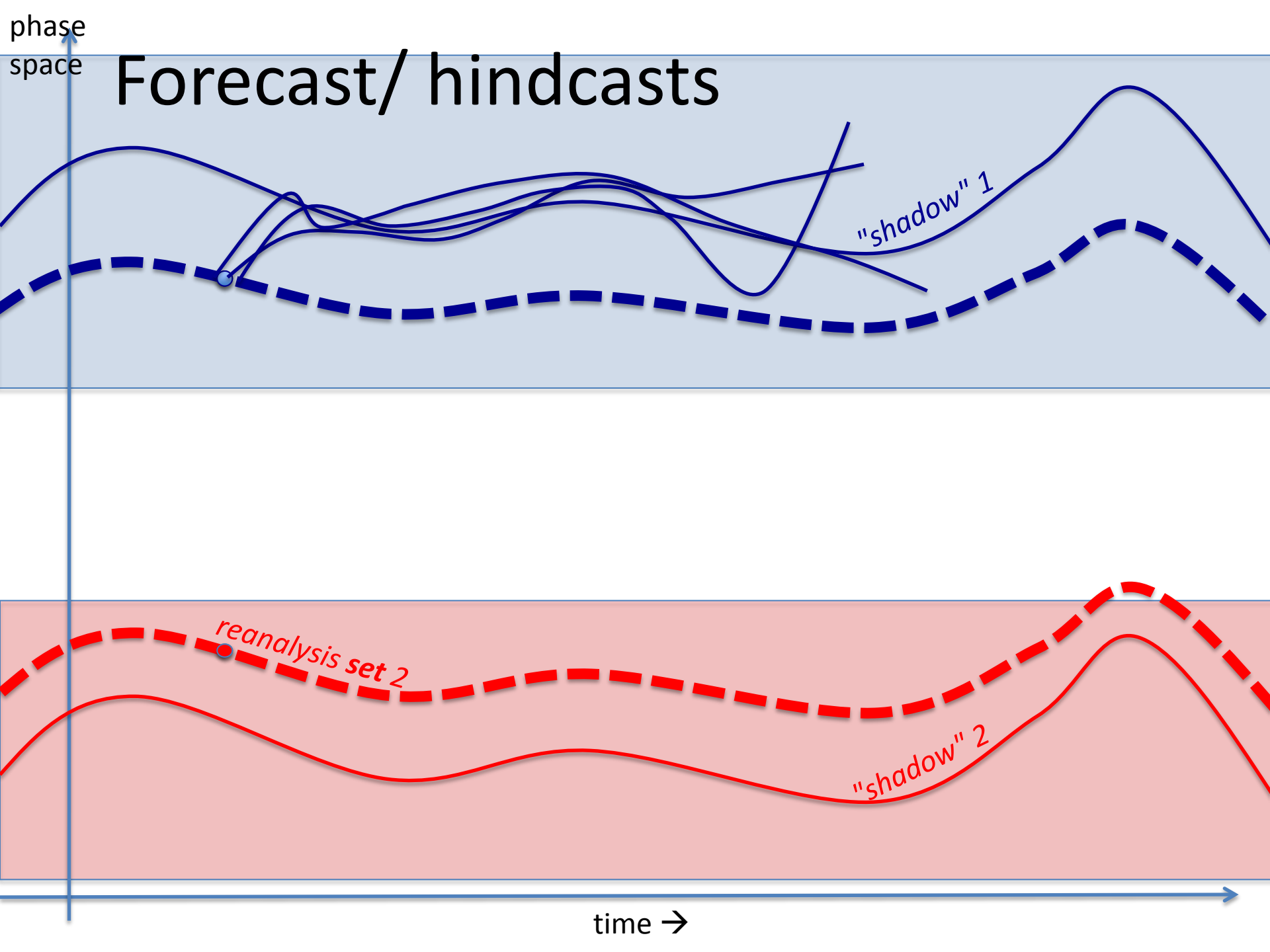

phase space
A "*shadow trajectory*" is a sequence of states of the model that parallels Nature's weather trajectory as much as possible, while remaining on the model's solution manifold
(Judd et al. 2008)
"shadow" trajectory 1
a weather trajectory
"shadow" trajectory 2
time →

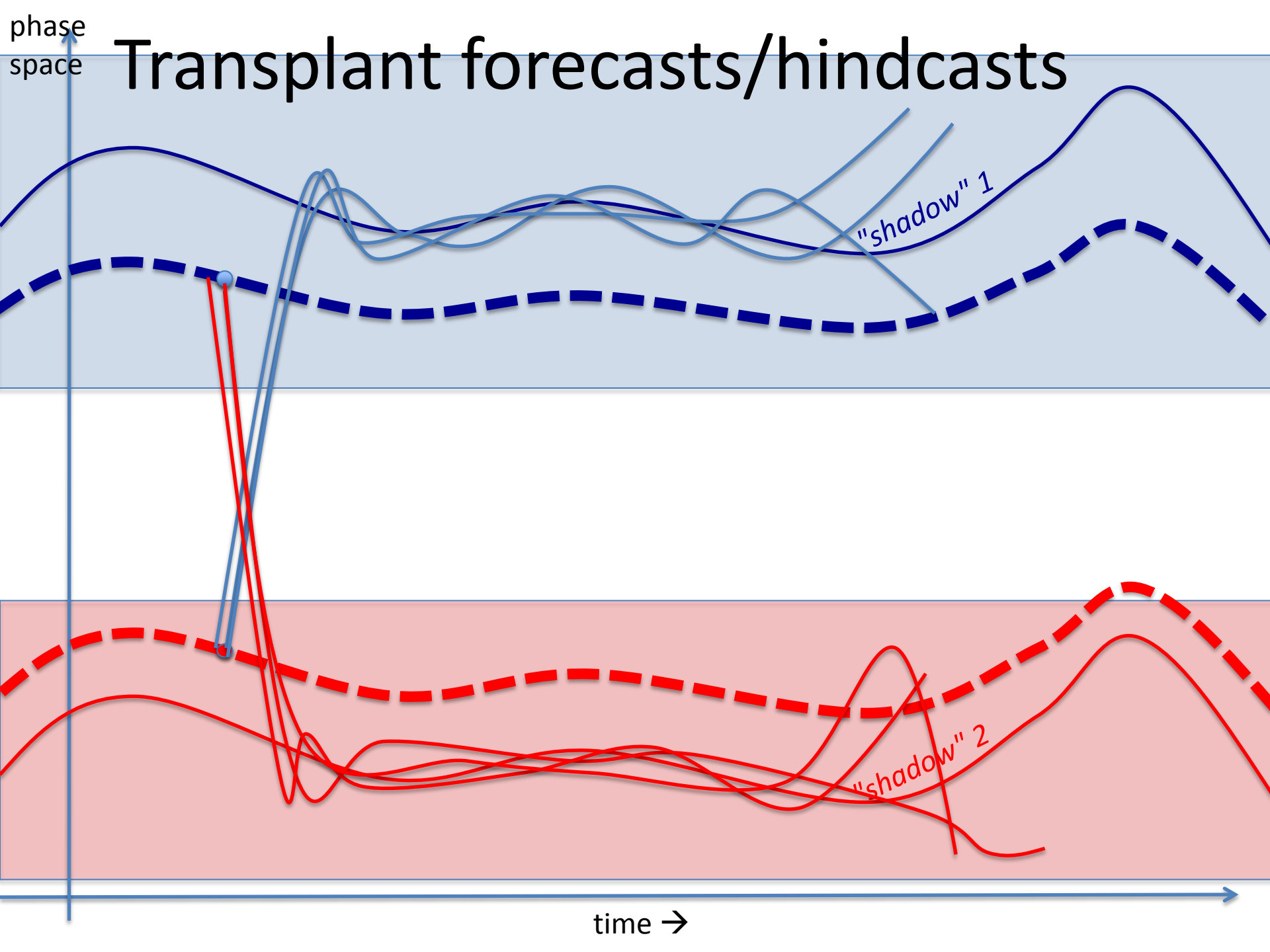

phase space
Assimilation (state estimation)
"shadow" trajectory 1
analysis 1
(assimilation system 1)
observations
a weather trajectory
(assimilation system 2)
analysis 2
"shadow" trajectory 2
time →

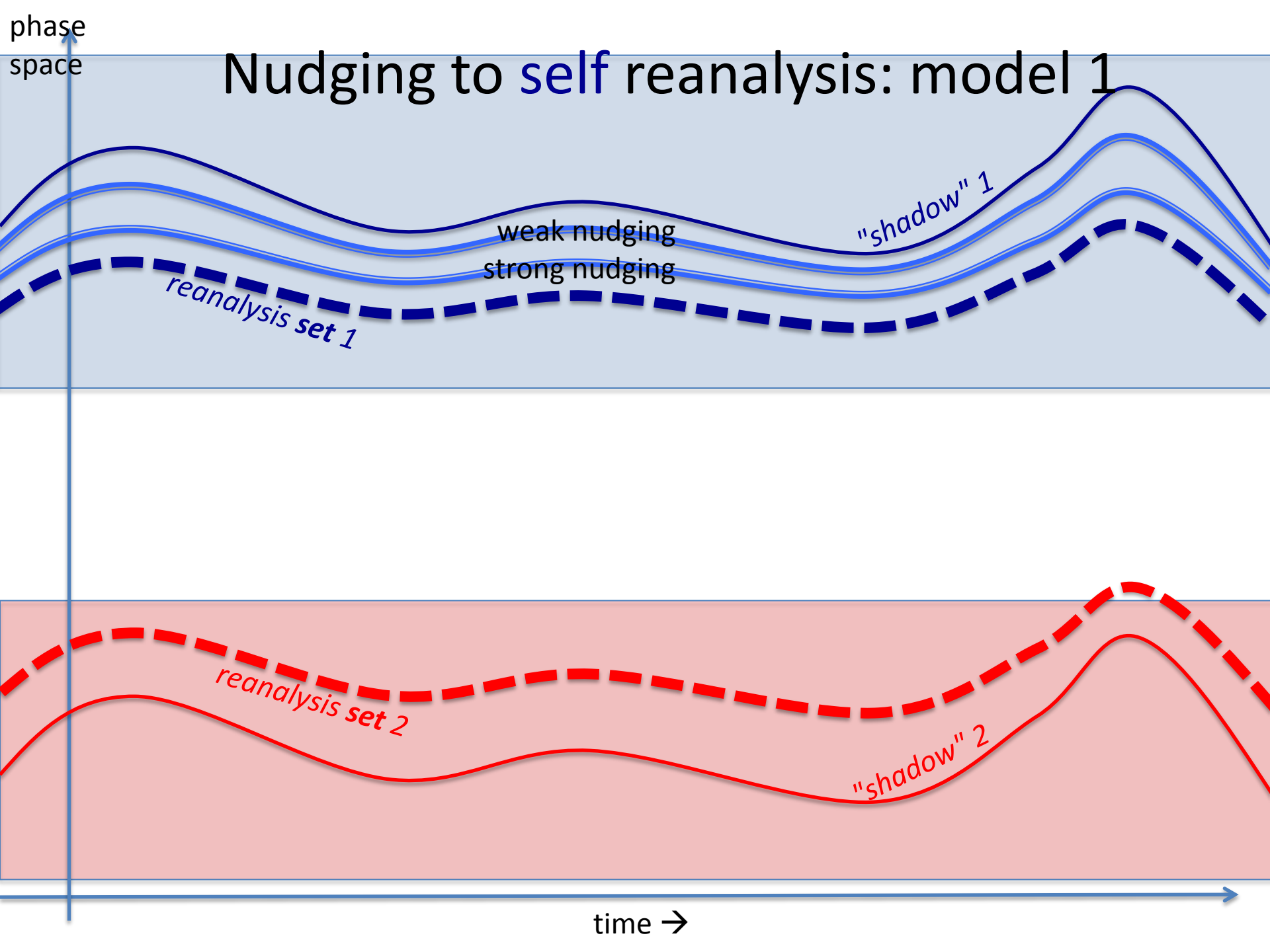

phase space
"shadow" 1
reanalysis set 1
(assimilation system 1)
observations
(assimilation system 2)
a weather trajectory
reanalysis set 2
"shadow" 2
time →

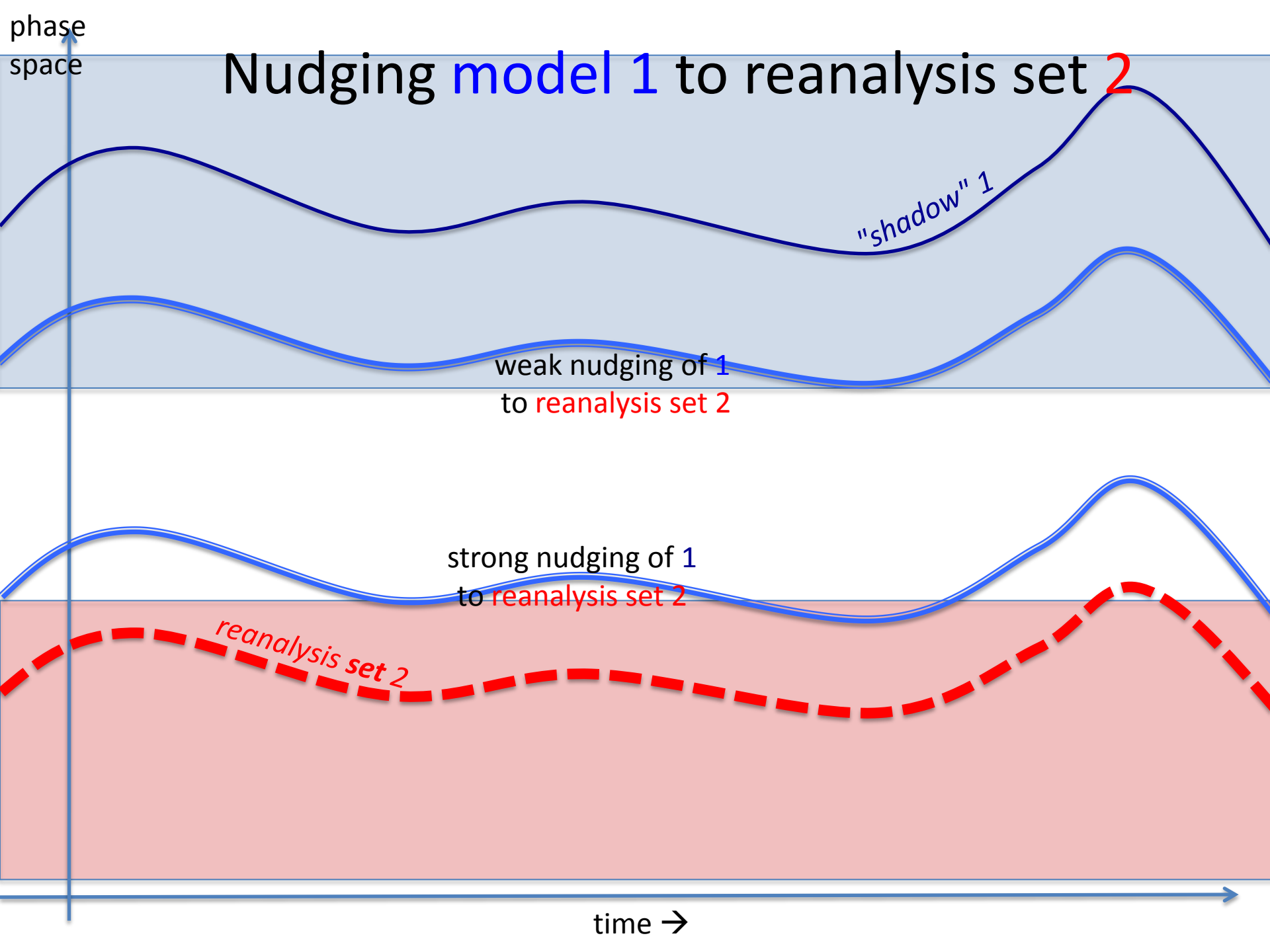

phase space
Only these parts actually exist...
the rest were conceptual crutches!
model 1 sims
reanalysis set 1
reanalysis set 2
model 2 sims
time →

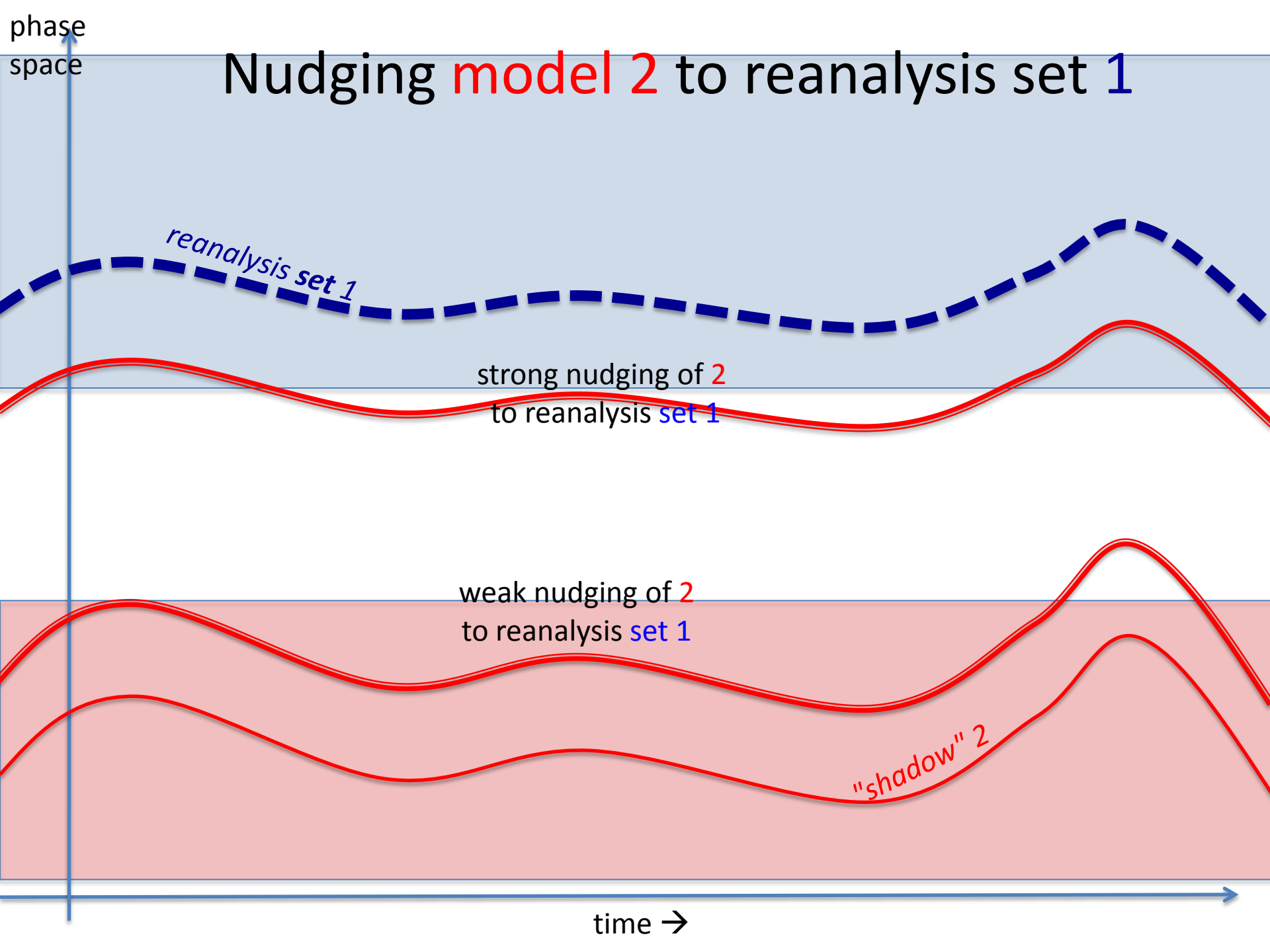

phase space
And the raw obs have been mined:
I can't beat advanced NWP state estimation
model 1 sims
reanalysis set 1
reanalysis set 2
model 2 sims
time →

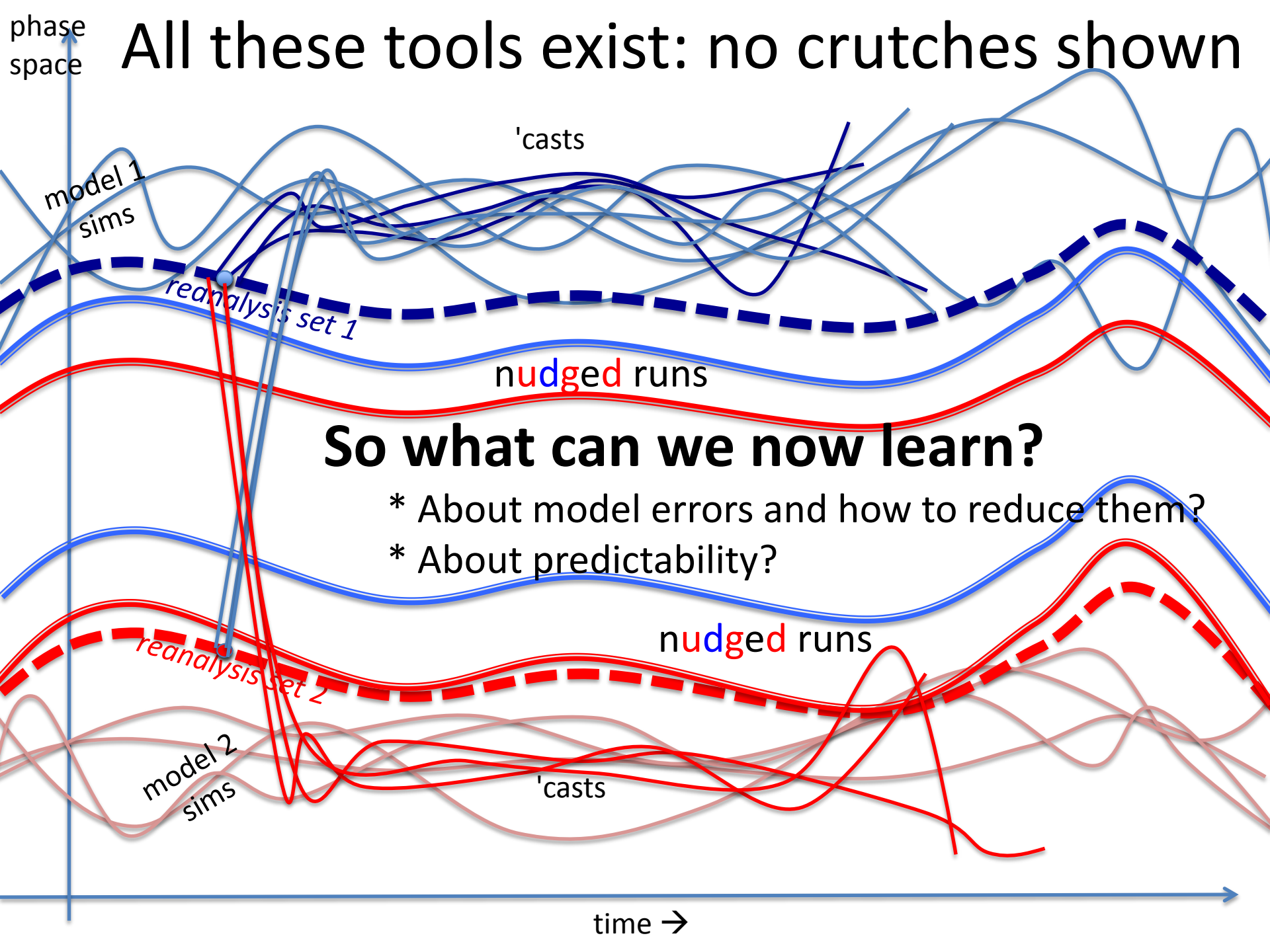

phase space
Forecast/ hindcasts
"shadow" 1
reanalysis set 2
"shadow" 2
time →


phase space
Transplant forecasts/hindcasts
"shadow" 1
"shadow" 2
time →


phase space
Nudging to self reanalysis: model 1
weak nudging
strong nudging
"shadow" 1
reanalysis set 1
reanalysis set 2
"shadow" 2
time →


phase space
Nudging model 1 to reanalysis set 2
"shadow" 1
weak nudging of 1
to reanalysis set 2
strong nudging of 1
to reanalysis set 2
reanalysis set 2
time →

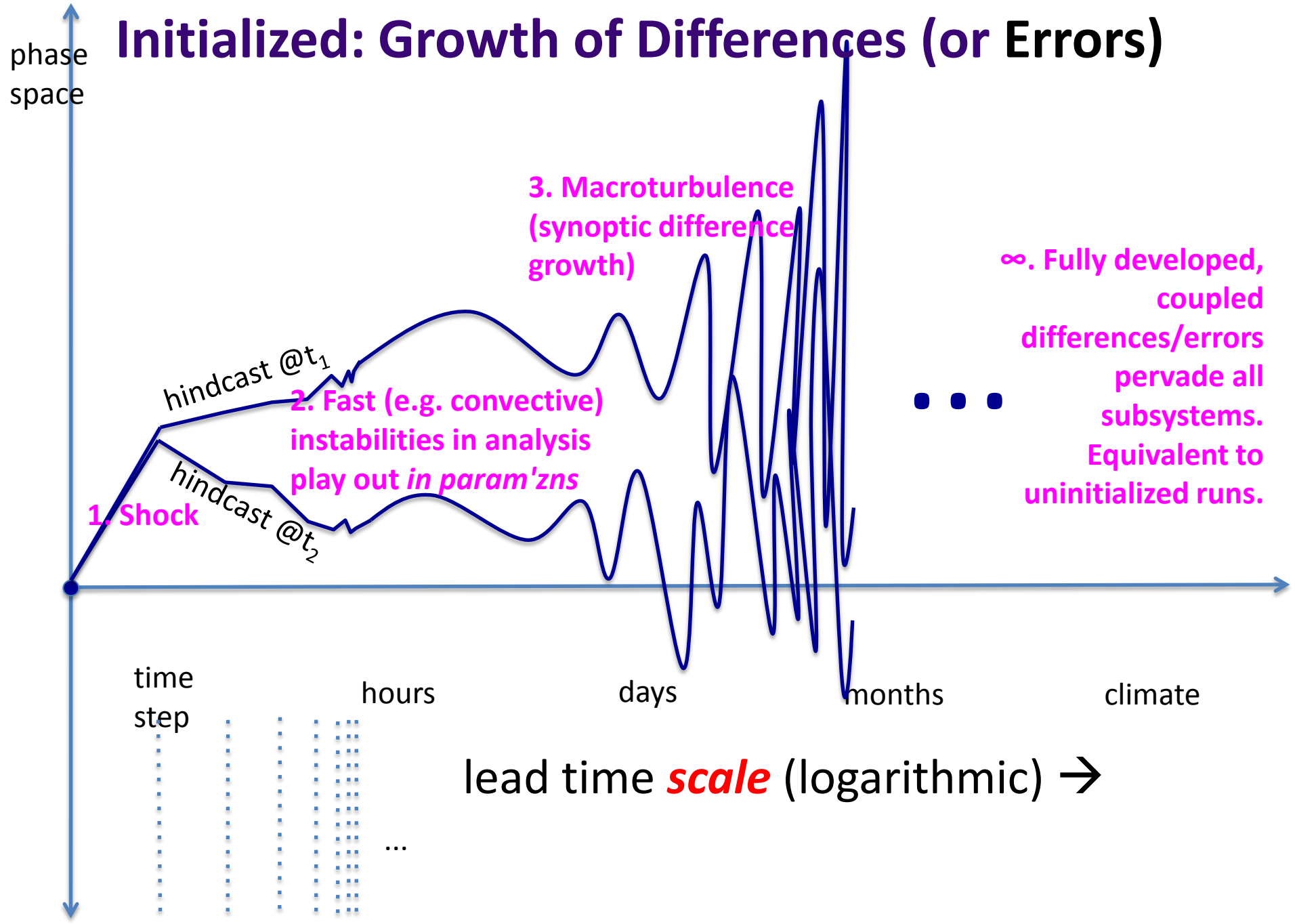

phase space
Nudging model 2 to reanalysis set 1
reanalysis set 1
strong nudging of 2 to reanalysis set 1
weak nudging of 2 to reanalysis set 1
"shadow" 2
time →


phase space
All these tools exist: no crutches shown
'casts
model 1 sims
reanalysis set 1
nudged runs
So what can we now learn?
* About model errors and how to reduce them?
* About predictability?
nudged runs
reanalysis set 2
model 2 sims
'casts
time →

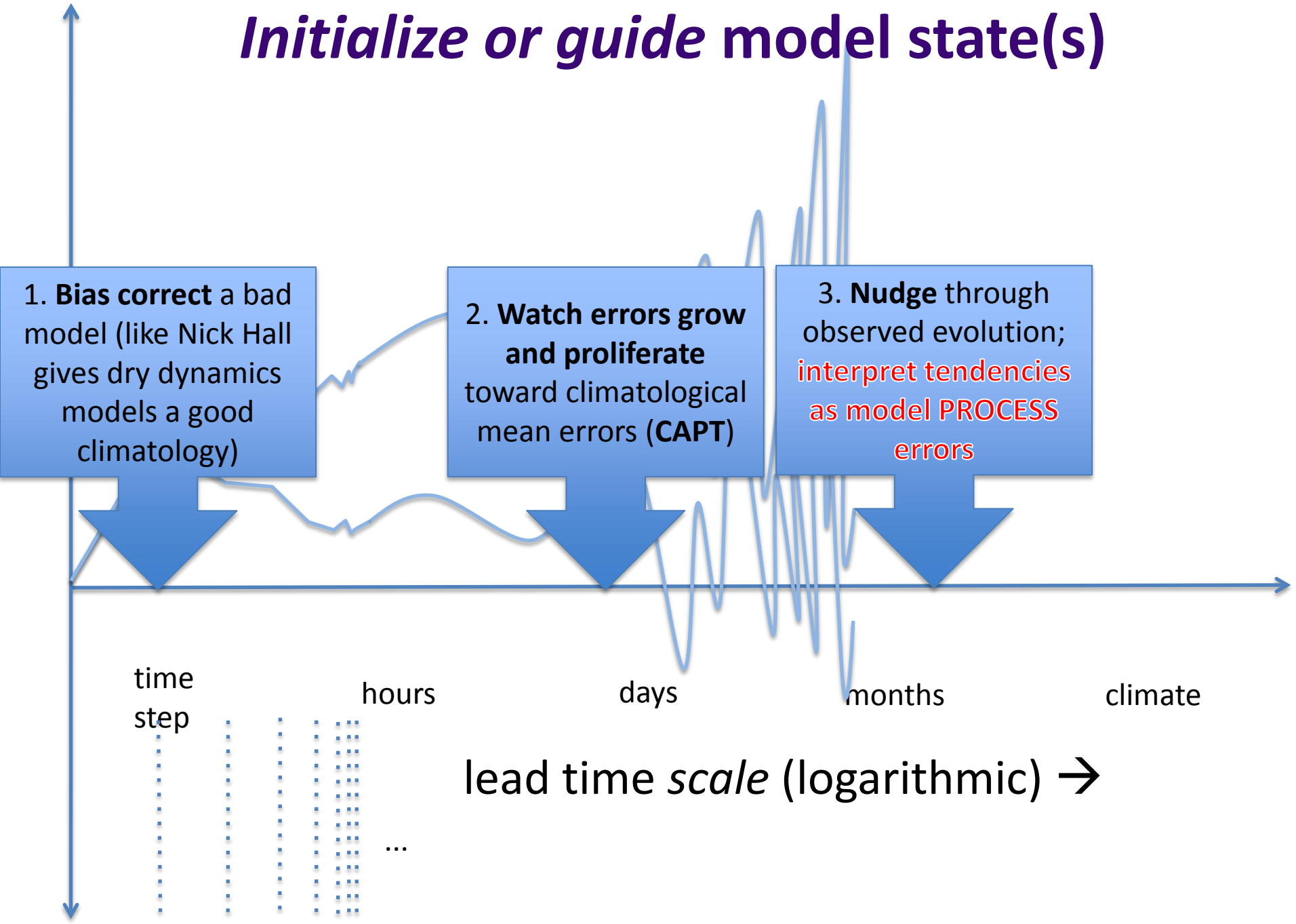
Opportunities for (analyzed) observations

Beyond **comparing state variables**
to model outputs

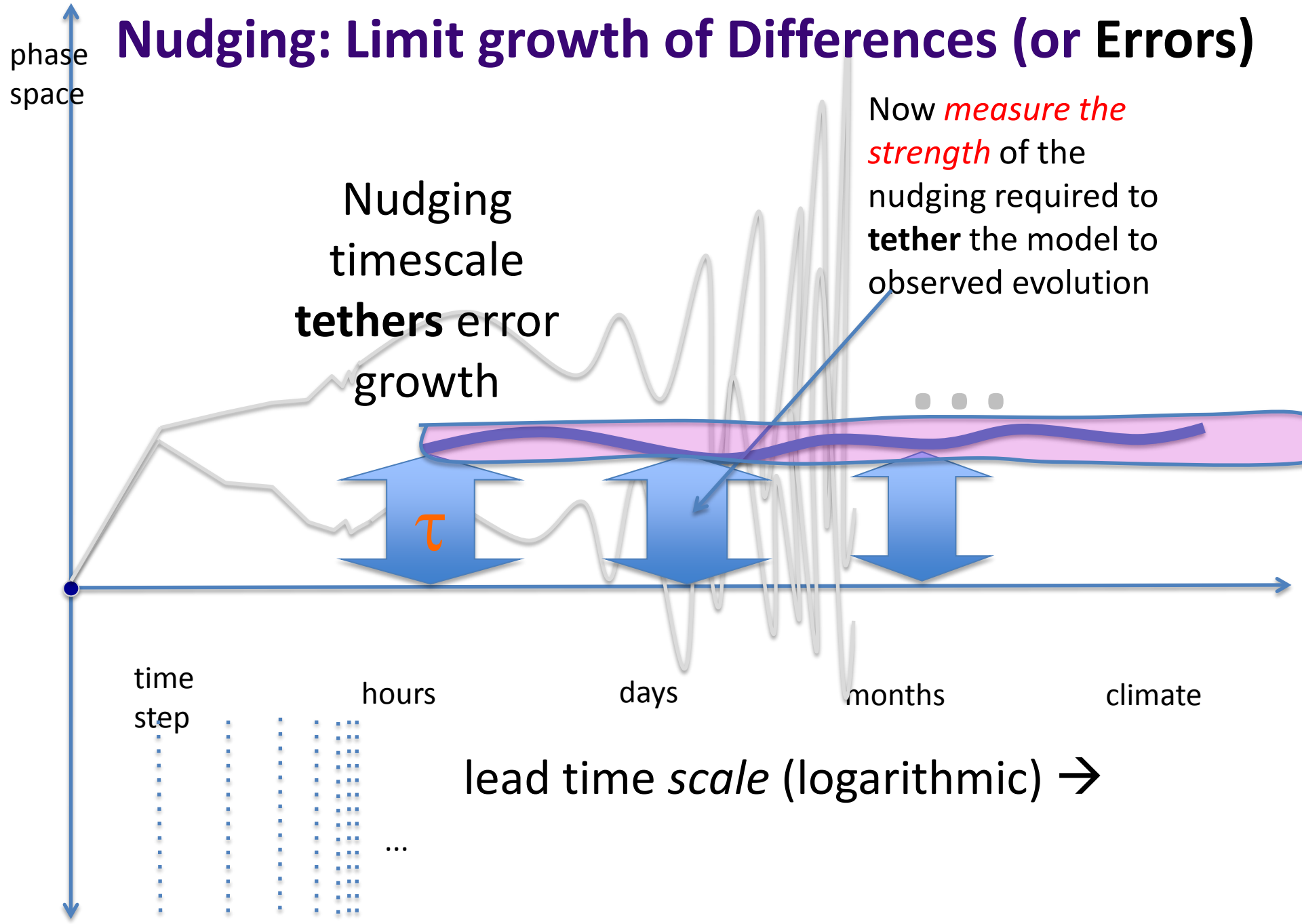
(e.g. AMWG SD sets)


Initialized: Growth of Differences (or Errors)
phase space
3. Macroturbulence (synoptic difference growth)
∞. Fully developed, coupled differences/errors pervade all subsystems. Equivalent to uninitialized runs.
hindcast @t1
2. Fast (e.g. convective) instabilities in analysis play out in param'zns
hindcast @t2
1. Shock
time step
hours
days
months
climate
...
lead time scale (logarithmic) →

Initialize or guide model state(s)



Nudging: Limit growth of Differences (or Errors)



I like NASA '*tendency*' nomenclature

- The model is a PDE solver
- Time rate of change = Σ (tendencies)

Time rate of change of ψ =

= model_error

+ model

$\psi = \{u,v,T,q_v,...\}$

Time rate of change of ψ =

= model_error

+ $d\psi$dt_dyn

+ $d\psi$dt_phy

$\psi = \{u,v,T,q_v,...\}$

Time rate of change of ψ =

= $d\psi dt\_ana$

+ $d\psi dt\_dyn$

+ $d\psi dt\_phy$

$\psi = \{u,v,T,q_v,...\}$

Time rate of change of T =

= dTdt_ana

+ dTdt_dyn

+ dTdt_rad + dTdt_mst +

dTdt_trb + dTdt_gwd + dTdt_dis

Time rate of change of T =

= dTdt_ana

+ dTdt_dyn

+ (dTdt_swr + dTdt_lwr)

+ (dTdt_cnv + dTdt_lsc) +

+ dψdt_trb + …

etc… *breaking down a sensible whole*

resemblance tests for interpretation of error = dψdt_ana. Try to reduce by adjusting ("improving!") physics.

NASA tendency-of-ψ datasets

- All tendencies evaluated *at realistic state*
- Time axis is real-world time, not model time

- *Analyze* your flow phenomenon!
  - e.g. MJO composites (Mapes & Bacmeister 2012)
- *Closed* model budgets: a firm framework
  - 3D, plus vertically integrated (2D fields)
  - Variable names clear
  - model errors glimpsed through ddt_ana

- **Makes me *want* to look at model output!**

- DTCOND = [DRYADJDT] + [ZMTOTDT] + [CMDTOTDT] + MACPDT/CPAIR + MPDT/CPAIR
- [ZMTOTDT] = ZMDT + EVAPTZM + ZMMTT + DPDLFT
- [CMDTOTDT] = CMFDT + SHDLFT
- [EVRNTZM] = EVAPTZM - FZSNTZM – EVSNTZM
- [DTCONV] = ZMDT + EVAPTZM + ZMMTT + CMFDT + DPDLFT + SHDLFT
- MACPDT =
- + L_v*CMELIQ + L_v*CLDLIQADJ + L_v*CLDLIQLIM (liquid <--> vapor)
- + (L_v+L_i)*CLDICEADJ + (L_v+L_i)*CLDICELIM (ice --> vapor)
- MPDT =
- - L_v*QCSEVAP + L_v*QCRESO (liquid <--> vapor)
- - (L_v+L_i)*QISEVAP + (L_v+L_i)*QIRESO + (L_v+L_i)*CMEIOUT
- - L_v*[EVAPRAIN] (rain --> vapor)
- - (L_v+L_i)*EVAPSNOW (snow --> vapor)
- - L_i*MPDW2I (liquid --> ice)
- + L_i*(PSACWSO + BERGSO) (liquid --> snow)
- + L_i*MNUCCRO (heterogeneous freezing of rain --> snow)
- + L_i*PRACSO (accretion of rain by snow)
- + MELTSDT (melting of snow to rain - W/Kg)
- + FRZRDT (Homogeneous freezing of rain to snow - W/Kg)
- [NONPHYSDT] = L_v*CLDLIQADJ + (L_v+L_i)*CLDICEADJ
- + (L_v+L_i)*CLDICELIM + L_v*QCRESO + (L_v+L_i)*QIRESO
- - prevent nonphysical states by making arbitrary corrections,

CAM5: ...better triple check your code & final budgets, at the end of adding up this heap of historically named partial tendencies!

CAM Time rate of change of ψ

Makes me *want* to look at model output…

…From NASA!

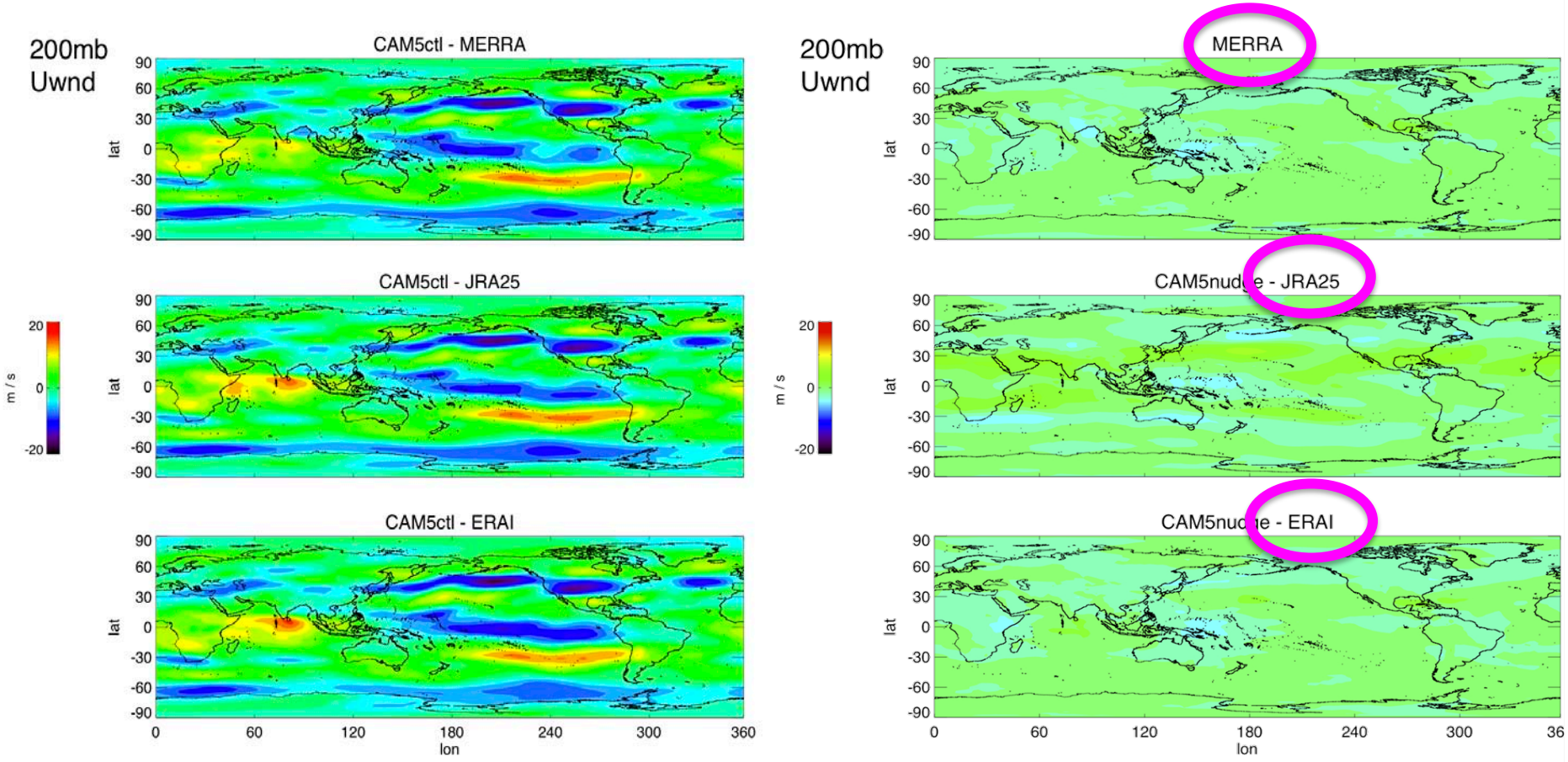
Nudging CAM5-SE

- CAM5 with HOMME (SE) DyCore
- Mapes-Neale (2 PB plumes w/ORG) convection
  - ZM scheme disabled; plume2 is "deep" (low ε)
- 4-member ensemble run for JJA 2008
- CTL run compared to runs Nudged to Various Reanalyses (MERRA, JRA, ERAI)
  - U, V, and T nudging tendencies added
  - nudging time scale = 6 hrs

JJA U 200mb

Mean Bias CTL

Mean Bias w/ Nudging

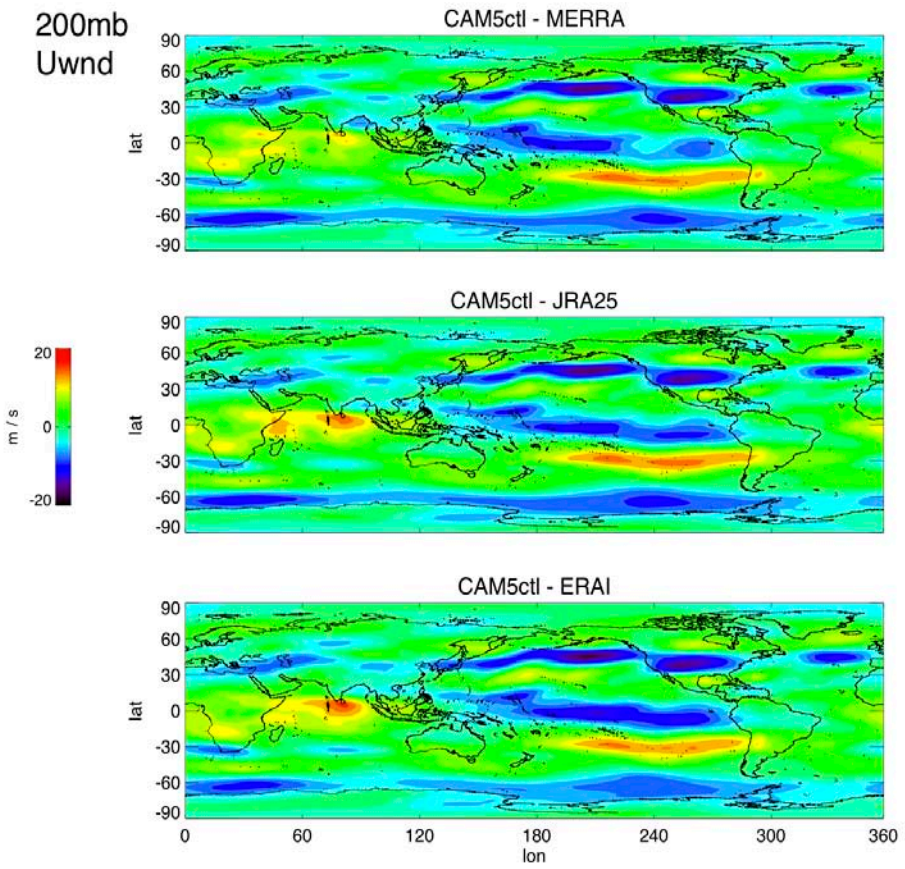


Any reanalysis will do!

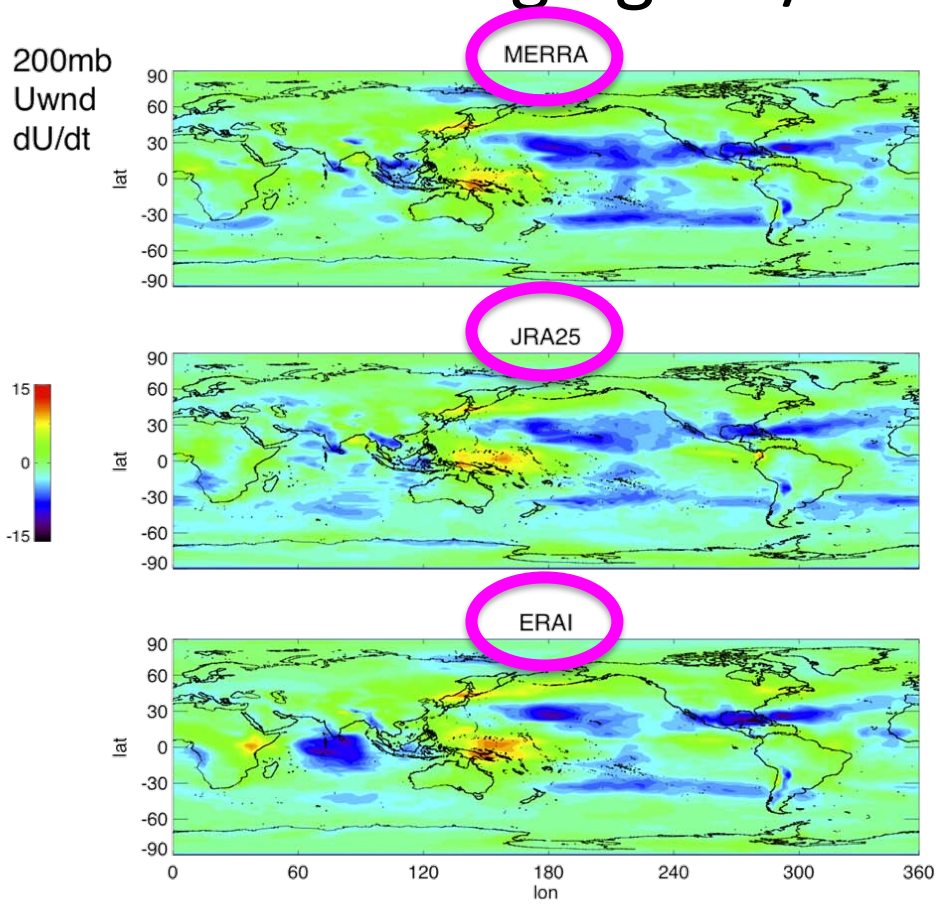
(at least for such a bad model version as ours...)

JJA U 200mb

Mean Bias CTL

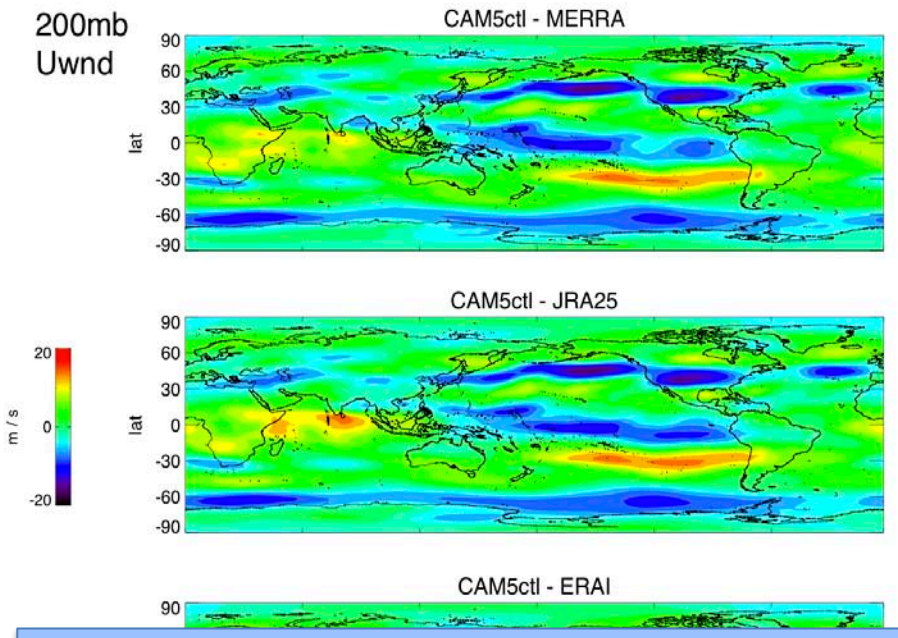


Mean nudging DU/DT

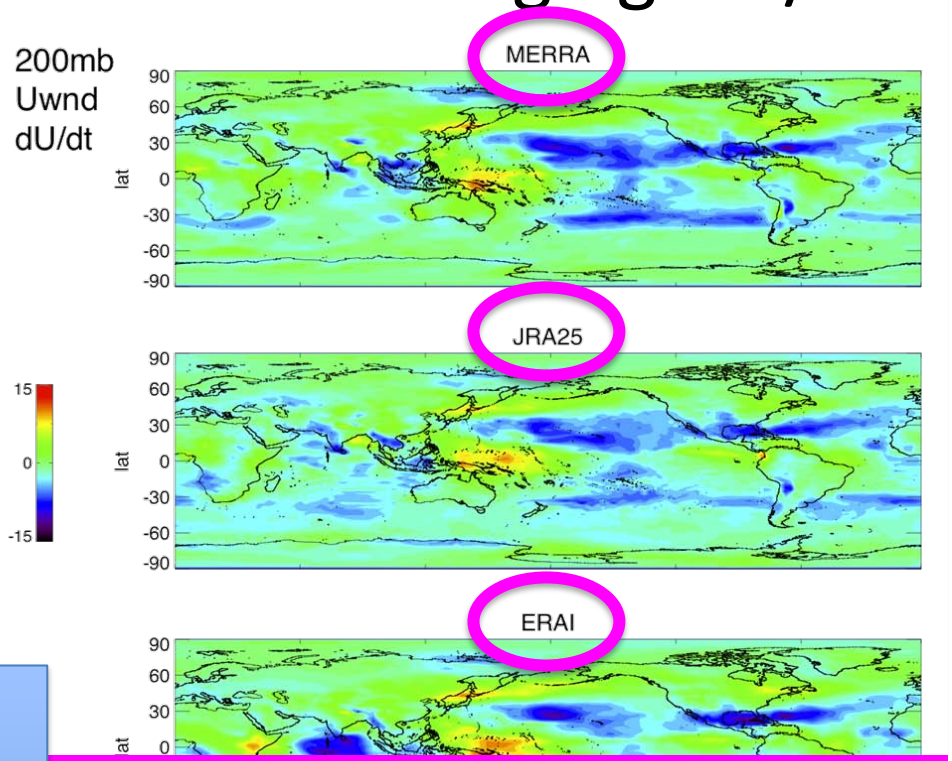


JJA U 200mb

Mean Bias CTL



Mean nudging DU/DT



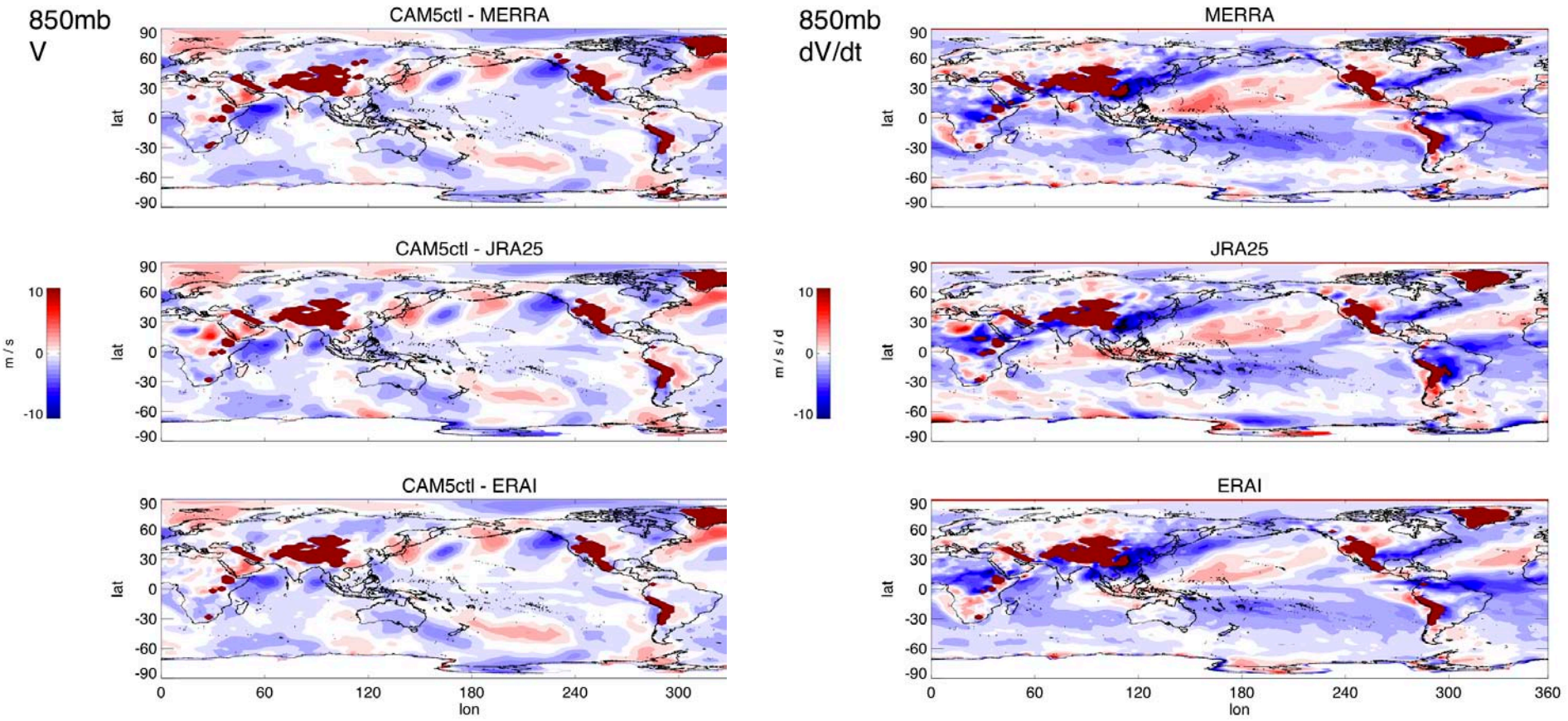
Mean model bias is a compounded, coupled complex of process errors and all the feedbacks they excite. Easy to see (e.g. AMWG Std Diags) but hard to interpret & know how to fix!

But these (model *process or tendency* errors) contain clearer clues how to go try and fix it!

V-wnd errors not as well constrained

Mean Bias CTL

Mean Bias w/Nudging

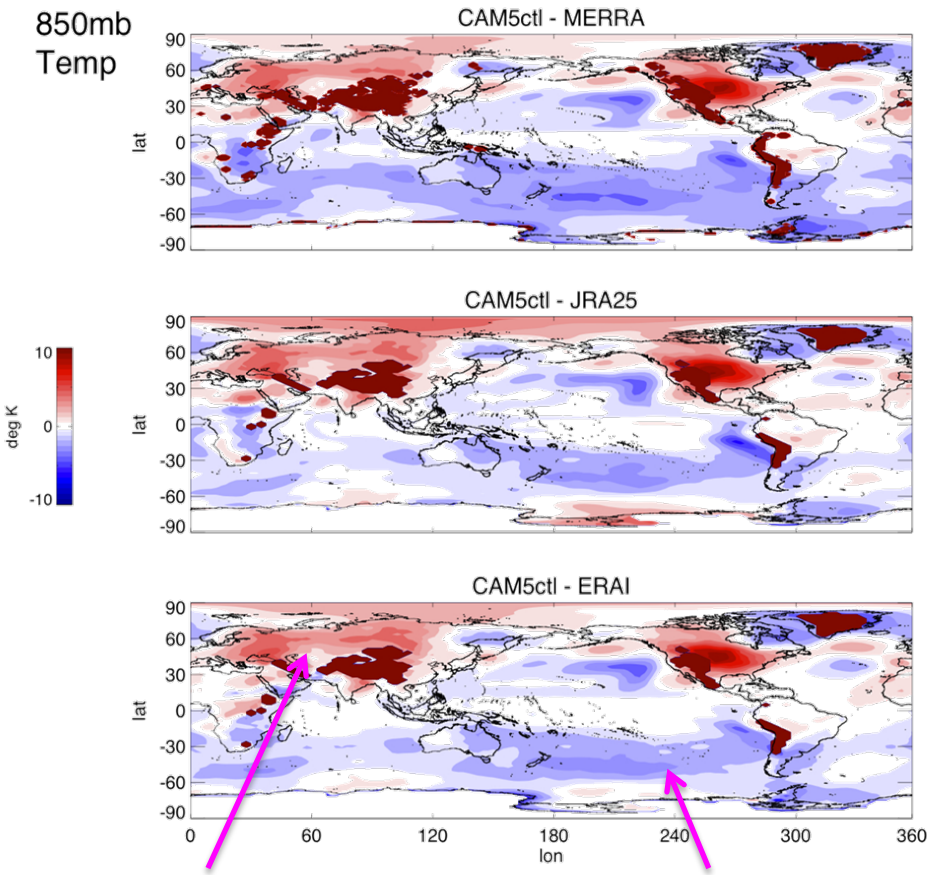


(Unbalanced Coriolis force on u budget overpowers v nudging?

DeWeaver and Nigam 2000)

JJA Temp 850mb

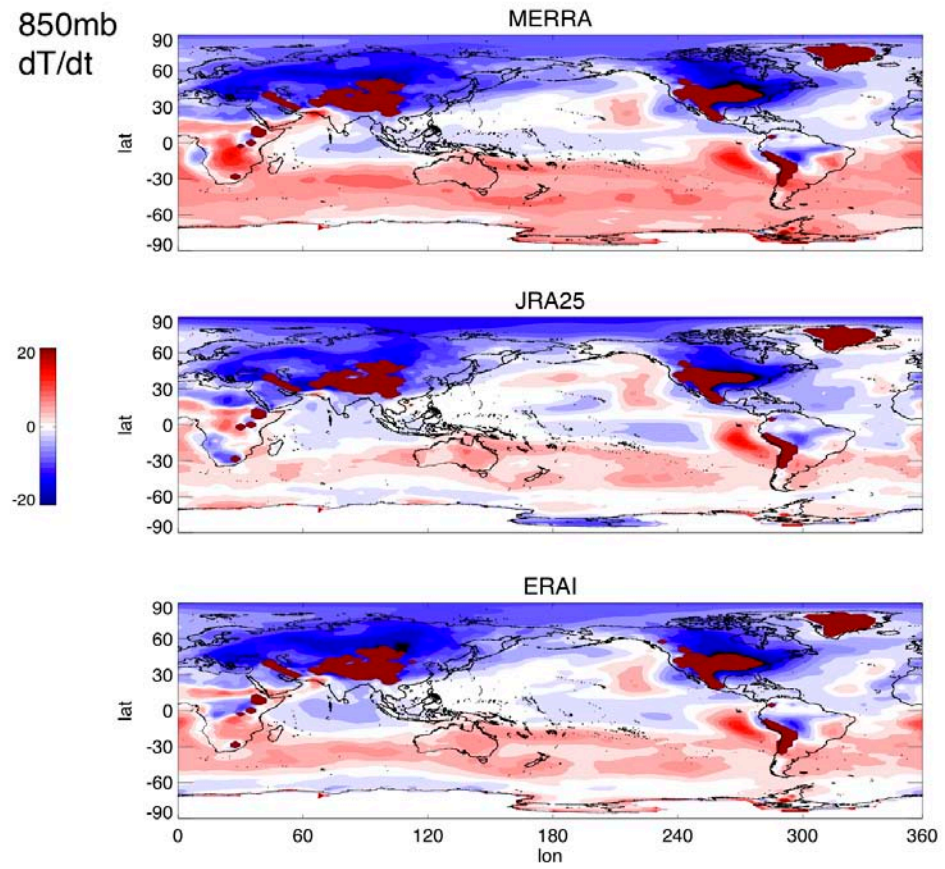
Mean Bias CTL



NH land too Hot

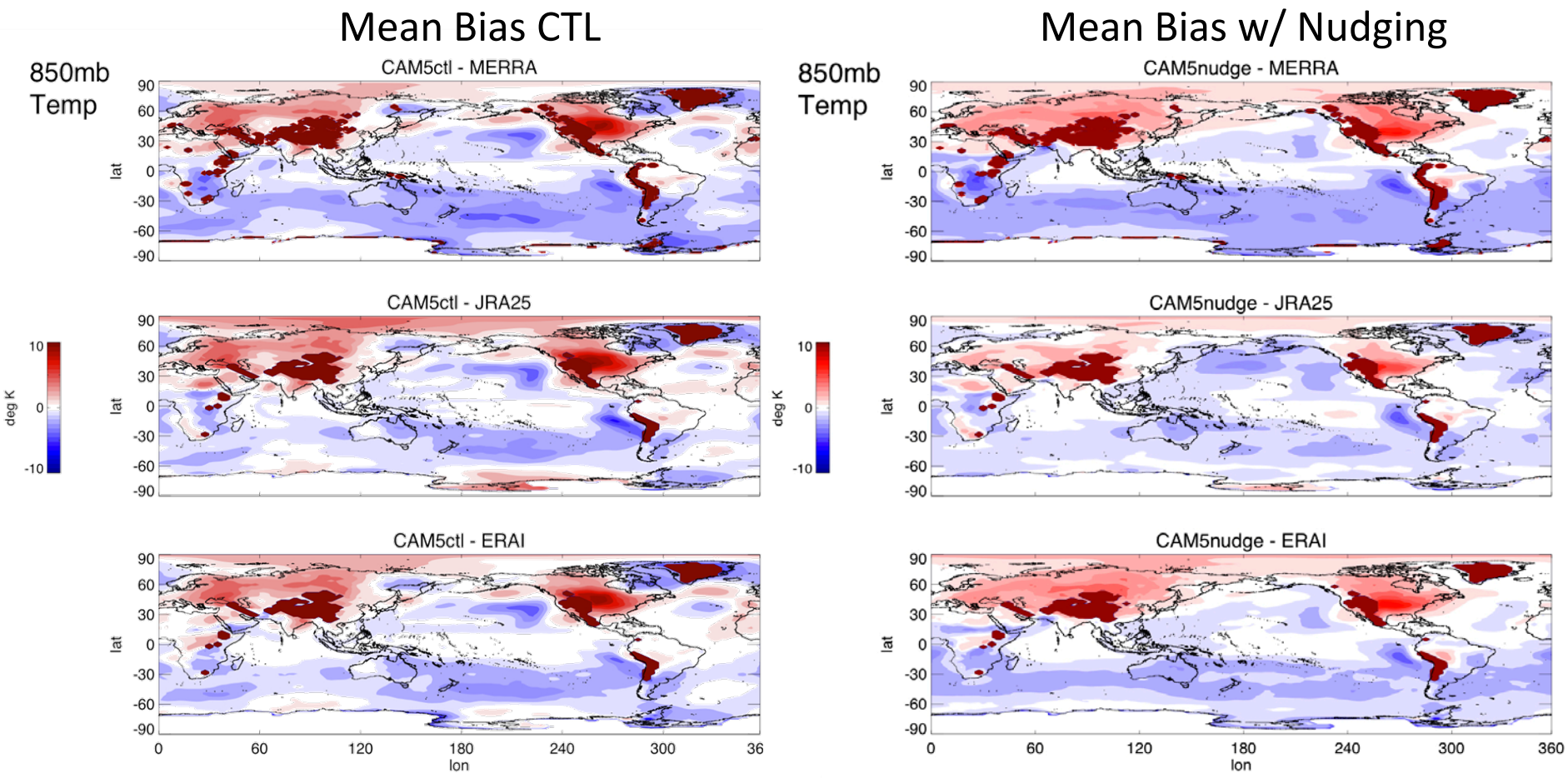
SH ocean too Cold

Nudging DT/Dt



Nudging directly opposes the pattern of errors

But Marginal improvement of T_{850mb} errors

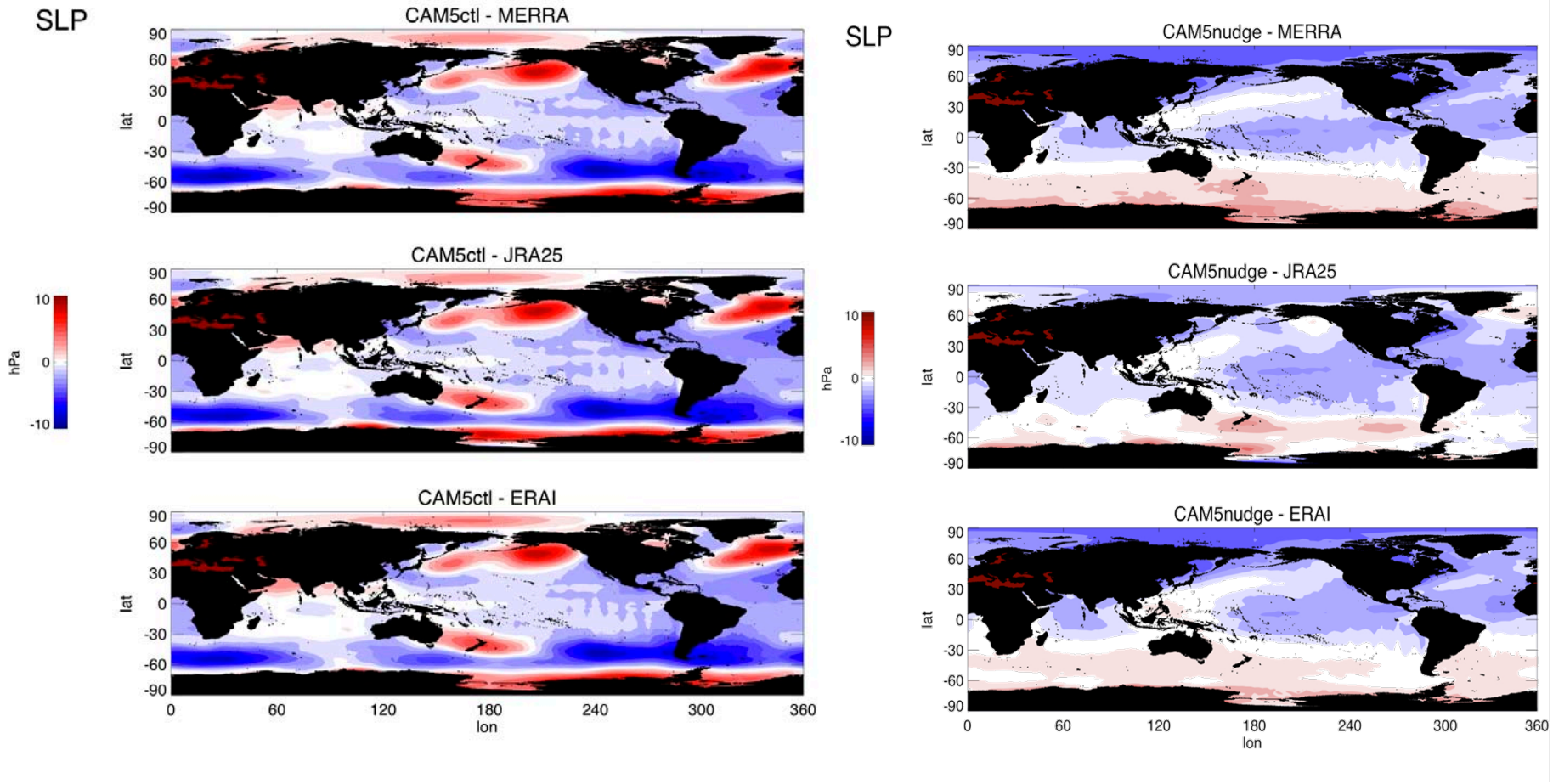


Some stronger tendencies overpower nudging:
(*from surface? from imbalance like in v wind?*)

Nudging {u,v,T} has profound effect on SLP

Mean Bias CTL

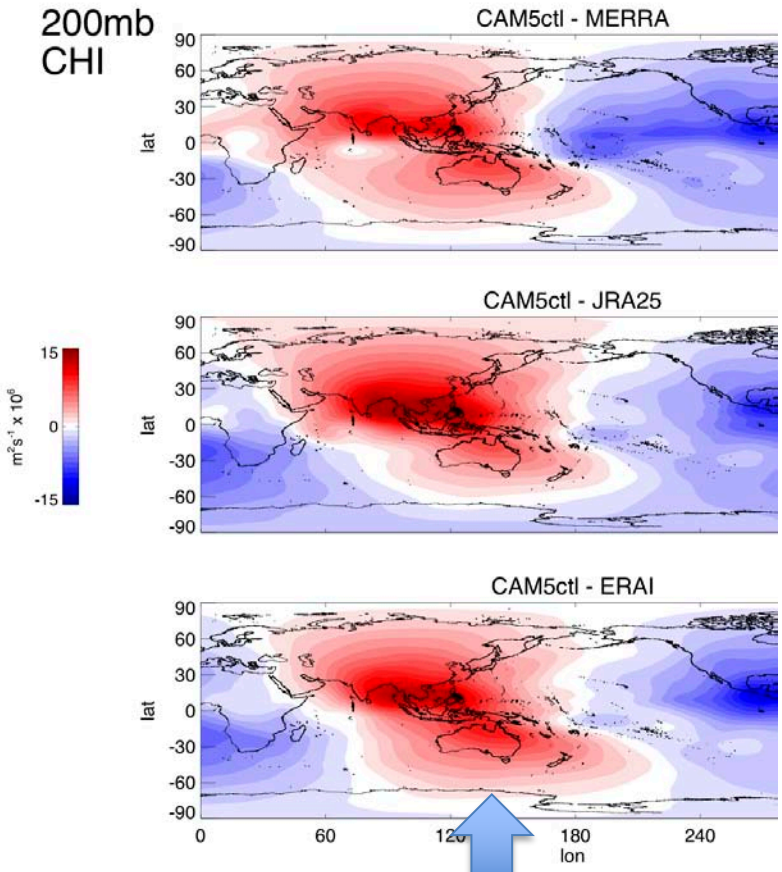
Mean Bias w/ Nudging

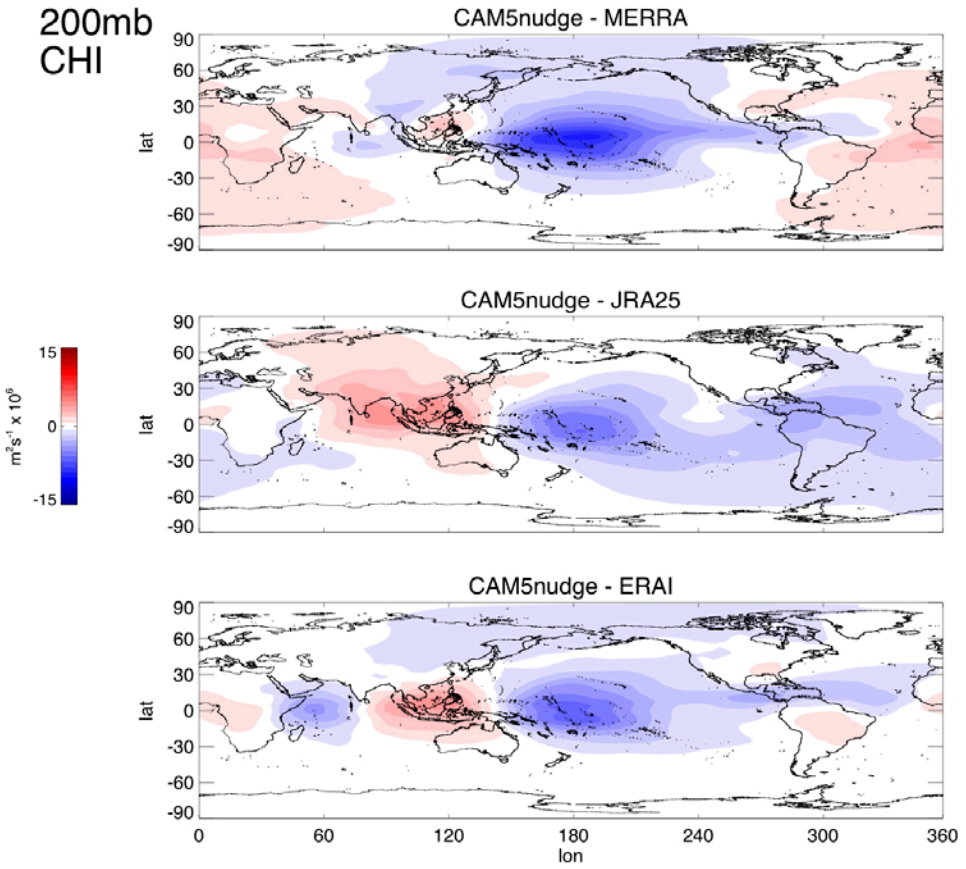


Nudging greatly improves large-scale divergent flow (χ_{200})

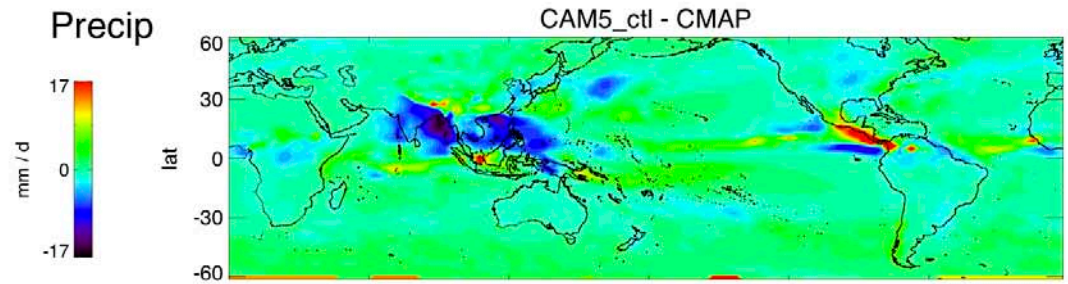
Mean Bias CTL

Mean Bias w/Nudging

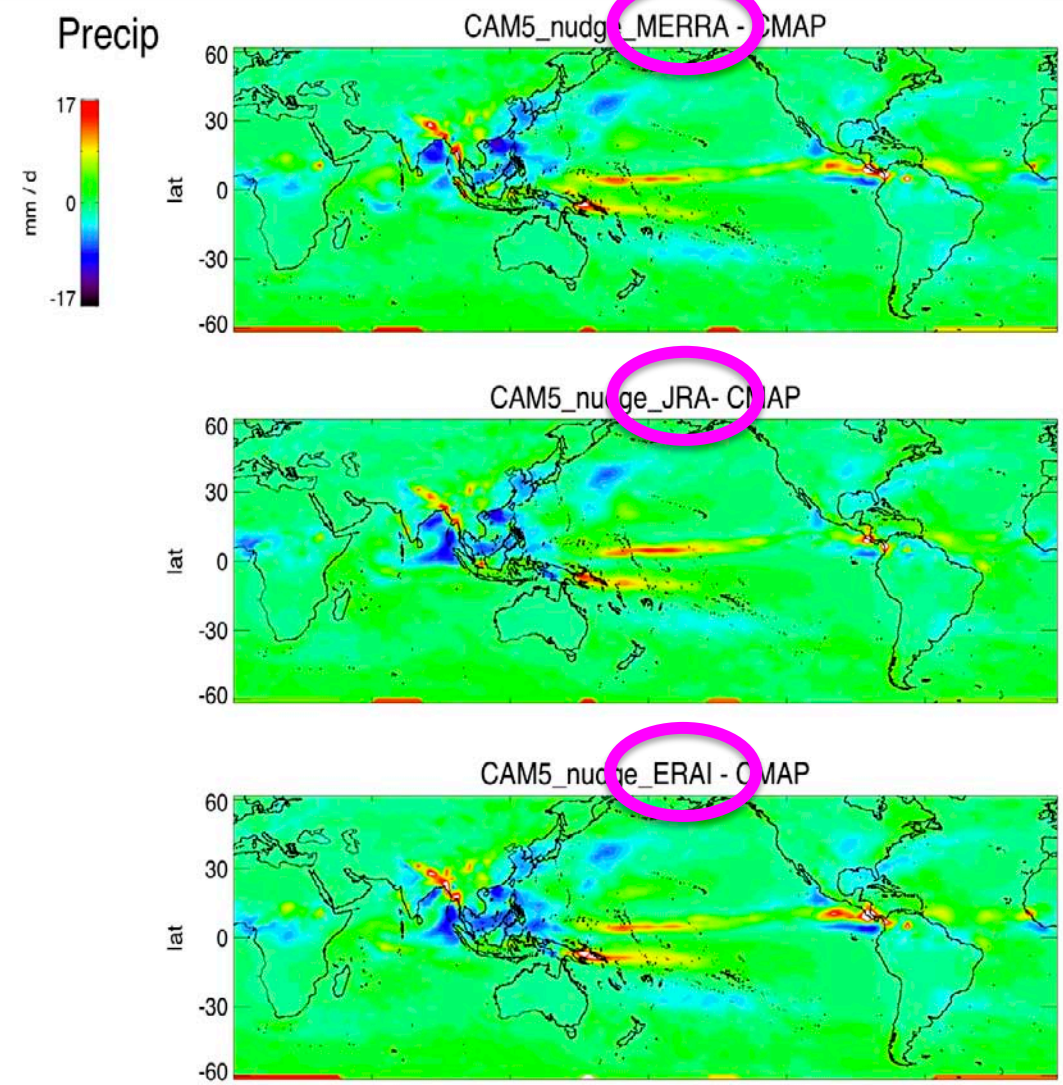




Too little Upper-level Divergence due to weak monsoon heating



←Control error in precipitation



All 3 Nudgings of {u,v,T} only reduce precip errors

<u>All 3 similar</u>

Conclusions

- Nudging-to-reanalysis escorts model processes through 'realistic' states
  - albeit pulled a bit off its attractor/manifold
- After the run, nudging tendencies are essentially a data set of model process (tendency) errors
  - on real time axis: easy to composite flow dependences
  - multi-reanals bracket uncertainties: *< signal, hooray!*
- Comparing dψdt_ana to model tendencies a promising path to interpreting & reducing errors at their process source
- A plea for budget outputs as central CAM code!
  - *additional* sensibly-named hierarchy of tendencies
    - total & breakdowns – not a heap of scheme-specific scraps!
    - nothing historical is lost. No threat, pure opportunity.

Special thanks

- NCAR/CISL for computing resources
- Julio Bacmeister
- Patrick Callaghan
- Jerry Olson