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

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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
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!)

manifold of model 2

a weather trajectory
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).
Assimilation (state estimation)

- **analysis 1**
- **observations**
- **analysis 2**

(assimilation system 1)

(assimilation system 2)

"shadow" trajectory 1

"shadow" trajectory 2

a weather trajectory

phase space

time
phase space
time →

(reanalysis set 1)
(assimilation system 1)

observations

(assimilation system 2)

(reanalysis set 2)

"shadow" 1

"shadow" 2
Only these parts actually exist... the rest were conceptual crutches!
And the raw obs have been mined:
I can't beat advanced NWP state estimation
Forecast/ hindcasts

phase space

time →

"shadow" 1

reanalysis set 2

"shadow" 2
Transplant forecasts/hindcasts
Nudging to self reanalysis: model 1

phase space

strong nudging
weak nudging

"shadow" 1

reanalysis set 1

reanalysis set 2

"shadow" 2

time →
Nudging model 1 to reanalysis set 2

- weak nudging of 1 to reanalysis set 2
- strong nudging of 1 to reanalysis set 2

"shadow" 1

phase space
Nudging model 2 to reanalysis set 1

- Strong nudging of 2 to reanalysis set 1
- Weak nudging of 2 to reanalysis set 1

```
time \rightarrow
debug

phase space

reanalysis set 1

"shadow" 2
```
All these tools exist: no crutches shown

So what can we now learn?

* About model errors and how to reduce them?
* About predictability?
Opportunities for (analyzed) observations

Beyond comparing state variables to model outputs

(e.g. AMWG SD sets)
Initialized: Growth of Differences (or Errors)

1. Shock
2. Fast (e.g. convective) instabilities in analysis play out in param'zns
3. Macroturbulence (synoptic difference growth)
∞. Fully developed, coupled differences/errors pervade all subsystems. Equivalent to uninitialized runs.

lead time scale (logarithmic) →
1. **Bias correct** a bad model (like Nick Hall gives dry dynamics models a good climatology)

2. **Watch errors grow and proliferate** toward climatological mean errors (**CAPT**)

3. **Nudge** through observed evolution; interpret tendencies as model PROCESS errors

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**Initialize or guide model state(s)**

Lead time _scale_ (logarithmic) →
Now measure the strength of the nudging required to tether the model to observed evolution.
I like

NASA 'tendency' nomenclature

- The model is a PDE solver
- Time rate of change = $\sum$ (tendencies)
Time rate of change of $\psi =$

$= \text{model\_error} + \text{model}$

$
\psi = \{u, v, T, q_v, \ldots\}$
Time rate of change of $\psi =$

\[ = \text{model\_error} + d\psi dt_{\text{dyn}} + d\psi dt_{\text{phy}} \]

$\psi = \{u, v, T, q_v, \ldots\}$
Time rate of change of $\psi = $

$$= d\psi dt_{\text{ana}} + d\psi dt_{\text{dy}} + d\psi dt_{\text{phy}}$$

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

$= dT dt_{ana}$

$+ dT dt_{dyn}$

$+ (dT dt_{swr} + dT dt_{lwr})$

$+ (dT dt_{cnv} + dT dt_{lsc}) +$

$+ d\psi dt_{trb} + ...$

etc... breaking down a sensible whole

resemblance tests for interpretation of error $= d\psi dt_{ana}$. Try to reduce by adjusting ("improving!") physics.
NASA tendency-of-$\psi$ 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!
...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 $\psi$

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

CAM5ctl - MERRA

CAM5ctl - JRA25

CAM5ctl - ERAI

200mb Uwnd

0 60 120 180 240 300 360

lon

200mb dU/dt

0 60 120 180 240 300 360

lon

lat

lat
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

Unbalanced Coriolis force on u budget overpowers v nudging?
DeWeaver and Nigam 2000
JJA Temp 850mb

Mean Bias CTL

Nudging DT/Dt

NH land too Hot

SH ocean too Cold

Nudging directly opposes the pattern of errors
But Marginal improvement of $T_{850\text{mb}}$ 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**

- CAM5ctl - MERRA
- CAM5ctl - JRA25
- CAM5ctl - ERAI

**Mean Bias w/ Nudging**

- CAM5nudge - MERRA
- CAM5nudge - JRA25
- CAM5nudge - ERAI
Nudging greatly improves large-scale divergent flow ($\chi_{200}$)

**Mean Bias CTL**

**Mean Bias w/Nudging**

Too little Upper-level Divergence due to weak monsoon heating
All 3 Nudgings of \{u,v,T\} only reduce precip errors

← Control error in precipitation

All 3 similar
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 $d\psi dt_{ana}$ 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.
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