Setting highest_state_pressure_Pa with a New Innovation Damping Algorithm

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Background

CESM's atmospheric components have a "sponge" region at the top of the model to reduce noise, reflection of vertically propagating waves off of the model top, and/or excessive jets. There is a selection of algorithms available in CAM-FV (controlled by div24del2flag in dynamics/fv/cd_core.F90), but diffusion in each scheme increases with height. CAM-SE has "regular diffusion" added in the top 3 layers (controlled by nu_top in dynamics/se/share/prim_advance_mod.F90), which also increases with height.

The model state does not respond well to being modified by data assimilation at the damped levels.

Goal

There is an algorithm in cam/model_mod to reduce the influence of observations on state variables in those layers. This is accomplished by increasing the distance between the observation and the state variable in model_mod:get_close_obs. The levels subject to this damping are controlled by the namelist variable highest_state_pressure_Pa (H_{Pa}). The higher above this level the state variable is, the more distance is added to the actual distance. At some height the new distance is larger than 2×cutoff (normalized by vert_normalization_YYY) and the state variable will not be affected by the observation. The recommended value of H_{Pa} will make this happen in all the CAM layers which are damped, but all state variables below CAM's damped layers will be impacted to some extent by the observations. Users are free to choose another value, but should compare the results with an assimilation using the recommended value of H_{Pa}.

Algorithms: CAM's 2nd Order Divergence Damping Coefficient

Div2 Damping:

$$\left.\begin{aligned} &\tau = 8\{1+\tanh[\ln(p_{top}/p_k)]\} \\ &\tau_k = \max(1, \tau) \end{aligned}\right\} \quad \text{(PHL* Eq (14) without spurious } \mu_2\text{)} \qquad (2)$$

Layers k are subject to this damping if $\tau_k > 1$

p_{top} = pressure at model top (hyai(1))
p_k = pressure at "mid-point" level k

So for what k is $\tau_k > 1$?

$$p_k < p_{top} e^{\left[\tanh^{-1}(1-1/8)\right]} < 3.87\, p_{top} \qquad (3)$$

*Peter H. Lauritzen, et al., 2011: **Implementation of new diffusion/filtering operators in the CAM-FV dynamical core**
Int. J. High. Perform. C., Vol. 26 (Issue 1), pp. 63–73. DOI:10.1177/1094342011410088 (June 2, 2011)

Algorithms: CAM's "Laplacian" Damping Coefficient

Del2 Damping*:

Layers k are subject to this damping if $\tau \geq 0.3$, (PHL Eq (21))

So

$$p_k < p_{top} e^{\left[\tanh^{-1}(1-0.3/8)\right]} < 7.234\, p_{top} \qquad (4)$$

*__Peter H. Lauritzen__, et al., 2011: **Implementation of new diffusion/filtering operators in the CAM-FV dynamical core**
Int. J. High. Perform. C., Vol. 26 (Issue 1), pp. 63–73. DOI:10.1177/1094342011410088 (June 2, 2011)

Algorithms: CAM's Advection Operator Damping

The advection operator goes to first order in the top levels where $k \le klev/8$.
So far we have not found the need to set H_{Pa} based on this algorithm.
Since H_{Pa} is set below the div2 and/or del2 levels, there will be some damping of obs impacts at most, maybe all, of the levels where the advection operator is first order.

DART's highest_state_pressure_Pa

So we want an algorithm which increases the distance from an ob to a state variable smoothly from its nominal distance lower down to something larger than twice the cutoff at the lowest level where CAM is damped. After some experimentation we currently add a weighted distance given by (if vert_coord = 'log_invP' = scale height):

$$\Delta d = \left[\frac{(g-H)}{(H_{top}-H)}\right]^n (g-H) \quad (5)$$

g = the scale height of the level of interest (in this case the lowest damped level in CAM)

H = scale height of H_{Pa}

H_{top} = scale height of the model top

n = some power of the weighting function, currently 1.0

We require that $\Delta d > 2\,c\,v$, where c = cutoff, v = vert_normalization_scale_height. Solving the quadratic equation yields

$$H = g - cv\left\{1 + \sqrt{1 + \frac{2(H_{top}-g)}{cv}}\right\} \quad (6)$$

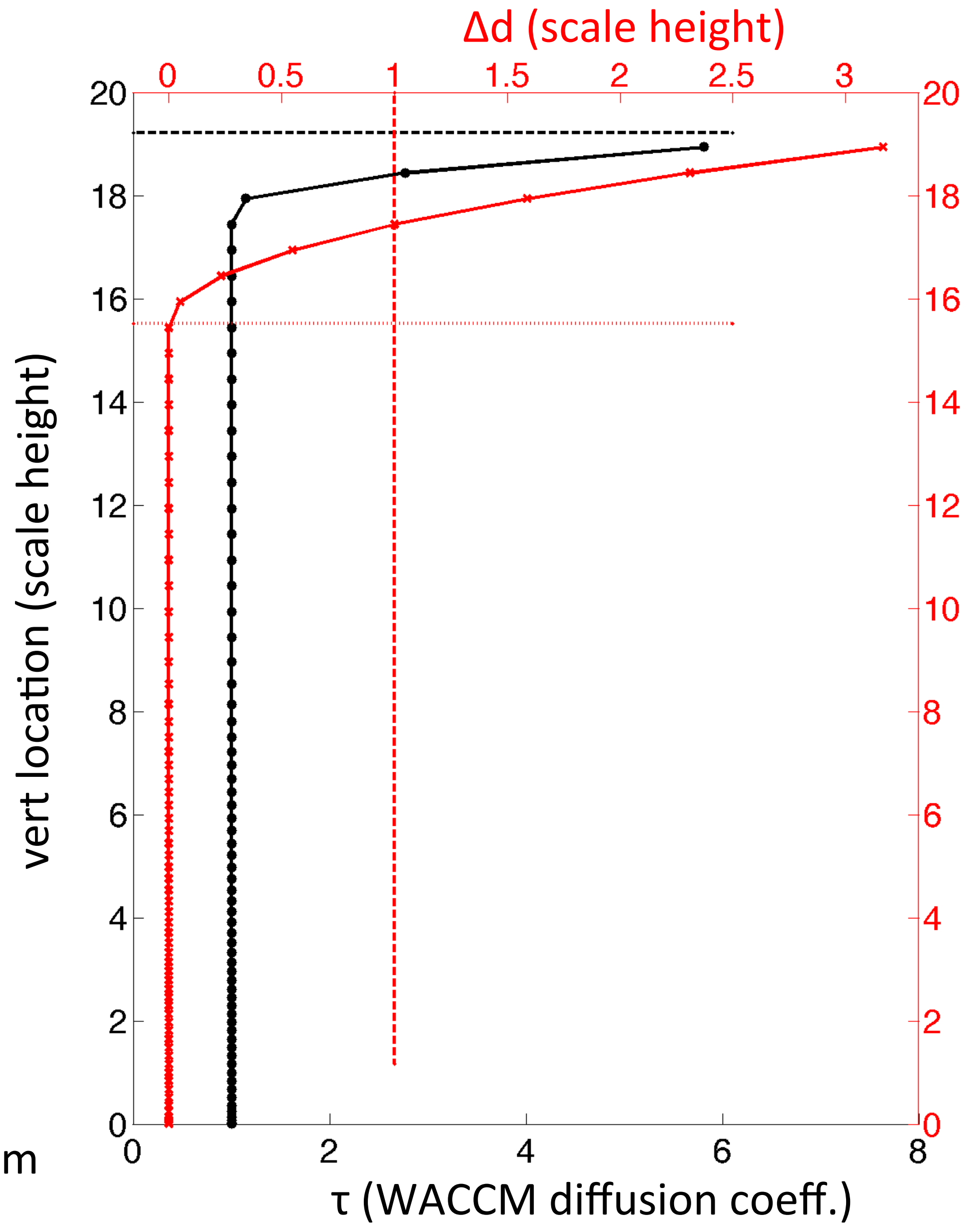
The negative root has been chosen based on it yielding H_{Pa} below CAM's damped levels (g). Then H_{Pa} can be found from the definition of scale height ($\ln(p_{surf}/p)$): $H_{Pa} = 10^5 \mathrm{Pa} \times e^{-H}$

Vertical Profiles for Scale Height vert_coord

τ (WACCM div2 diffusion coeff.)
model top (ptop)
distance increment
highest_state_scale_height
vert_normalization_scale_height *2*cutoff

This shows how the distance (which is added to the nominal distance between an ob and gridpoint) is 0 below highest_state_scale_height, and increases smoothly upwards until it is larger than 2*cutoff*vert_norm at the lowest level where CAM's extra diffusion is active. So there are no innovations at and above that level, even if the ob and grid point are co-located (the nominal distance is 0).

Similar plots can be generated using models/cam/matlab/highest_state_scale_h.m



Code version

As implemented in the code, Δd has units of radians, not scale height as derived above. The 3 factors in () are distances, which are derived in radians using get_dist, which applies the correct vert_normalization to the vertical component of distance.

Alternative to H_{top}

If I use $H_{lowest\_damped\_level}$ instead of H_{top} then H reduces to?

$$H = g - 2cv$$

which is higher, so more levels feel more impact of observations. It makes little difference near H because of the quadratic formula, and may not make much qualitative difference near the lowest damped level, because the tail of the Gaspari-Cohn function is also reducing the innovations there. But the weighting would be smoother there, approaching as $\sim 1^2$ rather than $\sim .8^2$.

DART's highest_state_pressure_Pa

If vert_coord = 'pressure', then the signs of all 3 factors in Δd are reversed (because pressure increases downwards, instead of upwards) and the resulting expression for H_{Pa} is

$$H_{Pa} = g + cv\{1 + \mathrm{sqrt}[1 + 2(g - H_t)/(cv)]\} \quad (7)$$

Vertical Profiles for Pressure vert_coord

———	τ (CAM div2 diffusion coeff.)
- - - - -	model top (ptop)
——— (red)	distance increment
········ (red)	highest_state_pressure_Pa
- - - - - (red)	vert_normalization_pressure *2*cutoff

This shows how the distance (which is added to the nominal distance between an ob and gridpoint) is 0 below highest_state_pressure_Pa, and increases smoothly upwards until it is larger than 2*cutoff*vert_norm at the lowest level where CAM's extra diffusion is active. So there are no innovations at and above that level, even if the ob and grid point are co-located (the nominal distance is 0).

Similar plots can be generated using models/cam/matlab/highest_state_p_Pa.m

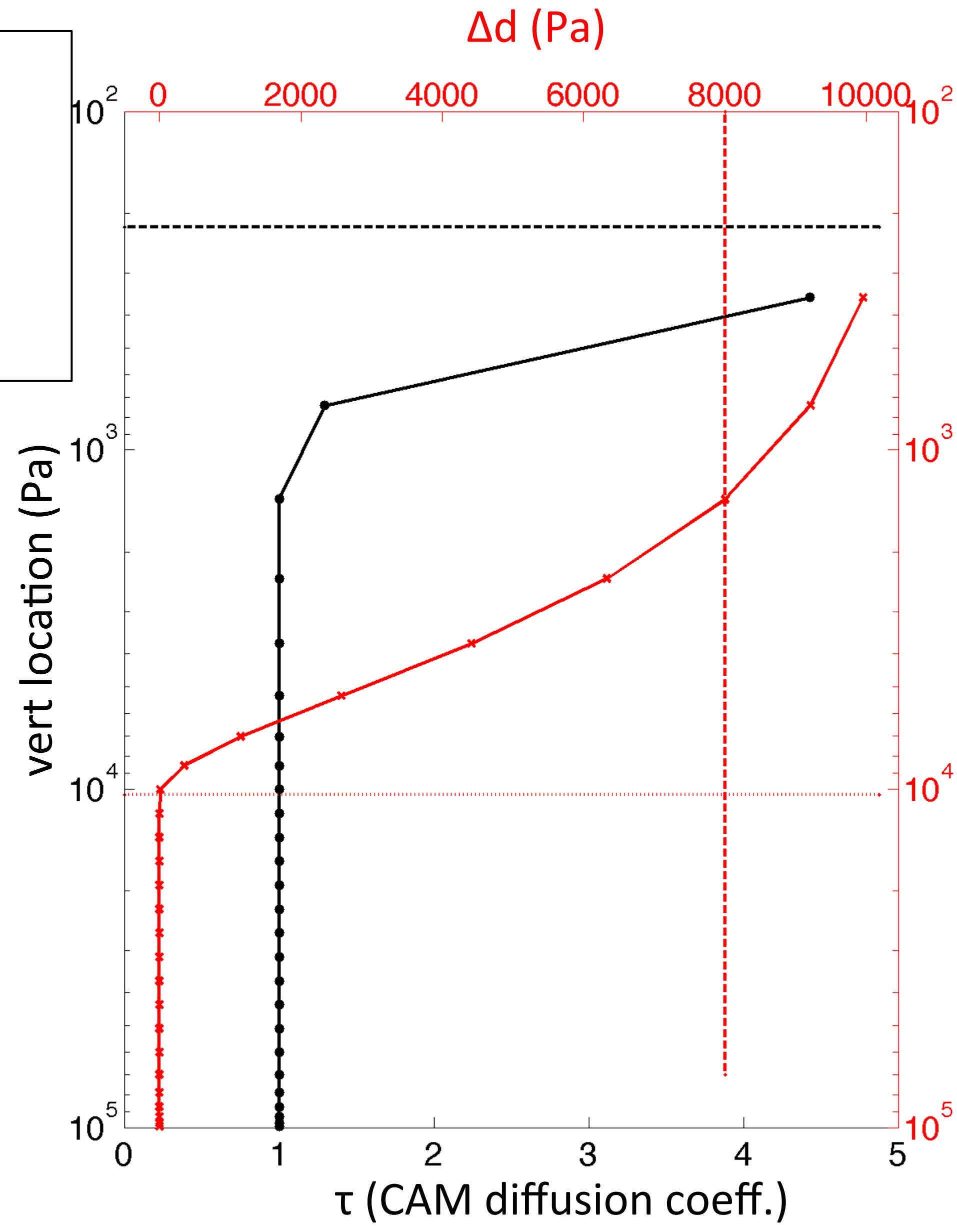


Table of Common Vertical Coordinate Data

Using typical values of c = 0.2 and
v = 2.5 scale heights/radian (WACCM) or
v = 2×10^4 Pa/radian (FV and SE)*,

*With the old damping formula I've used v = 10^5 Pa and $H_{Pa}=10^4$ Pa, which yielded 0 innovations at levels ~1-7. That v, and making 0 innovations at levels 1-2, yields H_{Pa}(div2) = 41300 Pa in the new formula, which is too low.

Model	# levels	p_{top}	div2 damped levels	H_{Pa} div2	del2 damped levels	H_{Pa} del2
CAM4-FV CAM5-FV	26 30,32	220 Pa	1,2	9370 Pa (8 levels)	1,2,3	10500 Pa (9 levels)
WACCM4-FV WACCM5	66 70	4.5×10^{-4} Pa 19.22 s.h.	1,2,3	9.2×10^{-3}Pa 16.2 s.h.(6 lvls)	1,2,3,4	0.0183 Pa 15.5 s.h.(7 lvls)
CAM6	46? 60? 70?					
CAM-SE	26,30	220 Pa	X	X	1,2,3	10500 Pa