Using Initial State and Forecast Temporal Variability to Evaluate Model Behavior

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Forecast error attribution useful for system development. Methods to characterize forecast error include:

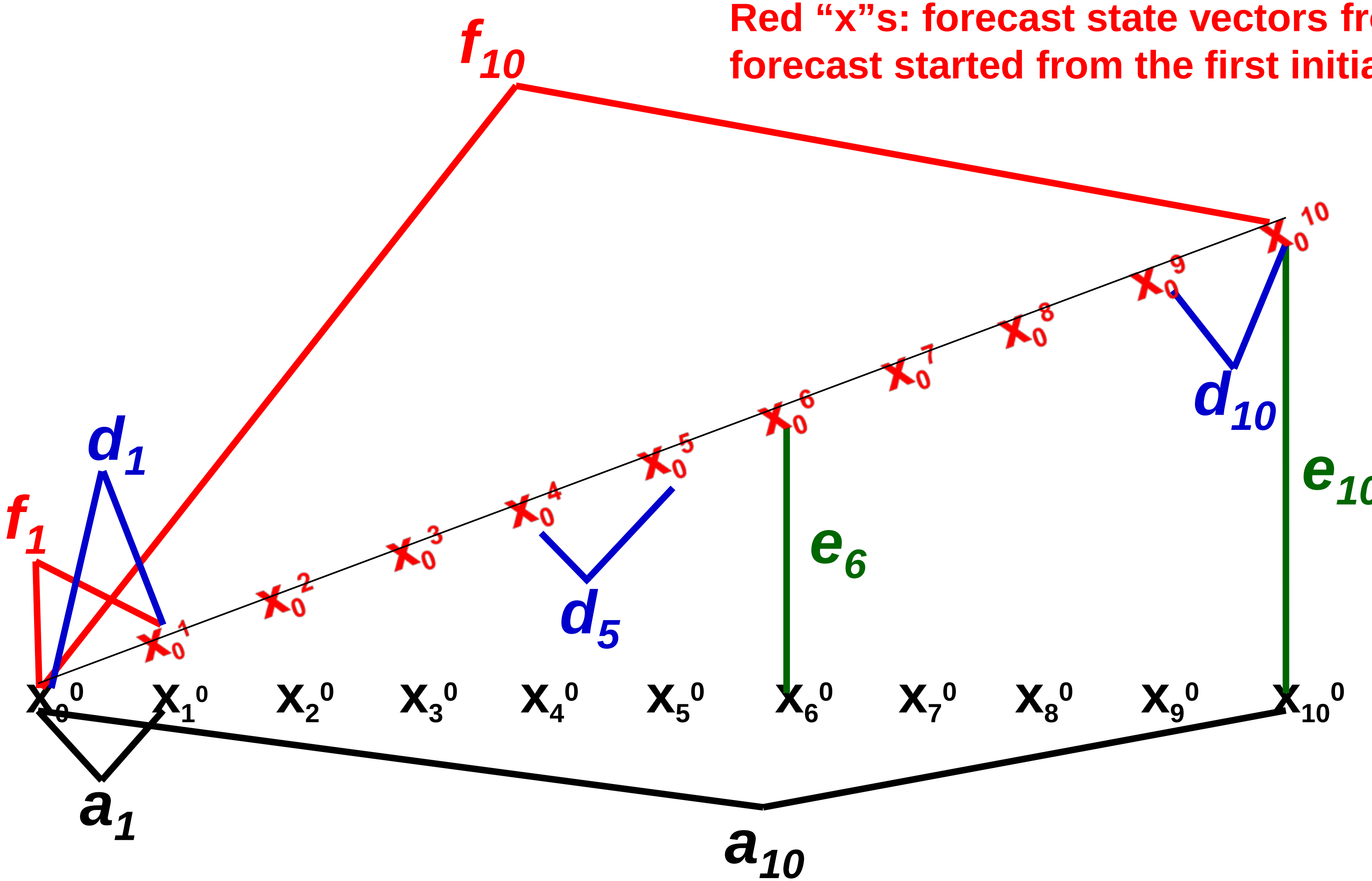
- **Assume exponential (linear) forecast error component due to initial (model) errors: Leith (1978), Dalcher and Kalnay (1987) and many follow-on studies.**
- **Time-mean biases (short and long integrations, e.g. Klocke and Rodwell 2014)**
- **Energy spectra of forecasts compared to obs. (e.g., Skamarock 2004).**
- **Geometric/shadowing techniques (Judd et al. 2008), mapping techniques (Toth and Pena 2007)**
- **Compare variability of long forecast integrations to long time series of analyses (e.g., Lau and Nath, 1987), relate to time-mean biases (e.g. Reynolds and Gelaro, 1997).**

Goal: Demonstrate utility of simple diagnostics of temporal variability to characterize and quantify aspects of model error.

Diagnostic Relationships for a Forecast and Sequence of Initial States

Black "x"s: series of initial states.

Red "x"s: forecast state vectors from forecast started from the first initial state.



Diagnostics are RMS Differences for Different Quantities

$$\left(a_i^{exper}\right)^2 = \frac{1}{n_t}\sum_{j=1}^{n_t}\left(x_{j+i}^0 - x_j^0\right)^2$$

***a**$_i$*: **RMS differences for initial states that are *i* days apart. Error of a persistence forecast.**

$$\left(f_i^{exper}\right)^2 = \frac{1}{n_t}\sum_{j=1}^{n_t}\left(x'^{i}_{j} - x_j^0\right)^2$$

***f**$_i$*: **RMS differences within forecast that are *i* days apart. In a perfect model, we expect $f_i < a_i$ because a_i contains independent errors.**

$$\left(e_i^{exper}\right)^2 = \frac{1}{n_t}\sum_{j=1}^{n_t}\left(x'^{i}_{j} - x_{j+i}^0\right)^2$$

***e**$_i$*: **RMS errors for forecasts of length *i* days. Should be smaller than a_i.**

$$\left(d_i^{exper}\right)^2 = \frac{1}{n_t}\sum_{j=1}^{n_t}\left(x'^{i}_{j} - x'^{i-1}_{j}\right)^2$$

***d**$_i$*: **RMS differences within forecast that are 1 day apart. In a perfect model, expect $d_i < a_1$.**

Time mean forecast bias removed. Calculated for each grid point at 850, 500 and 200 hPa, for U, V, T, Z (height), and Q (specific humidity).

Data Sets: NCEP and CMC Control and Perturbed Ensemble Members from TIGGE Archive

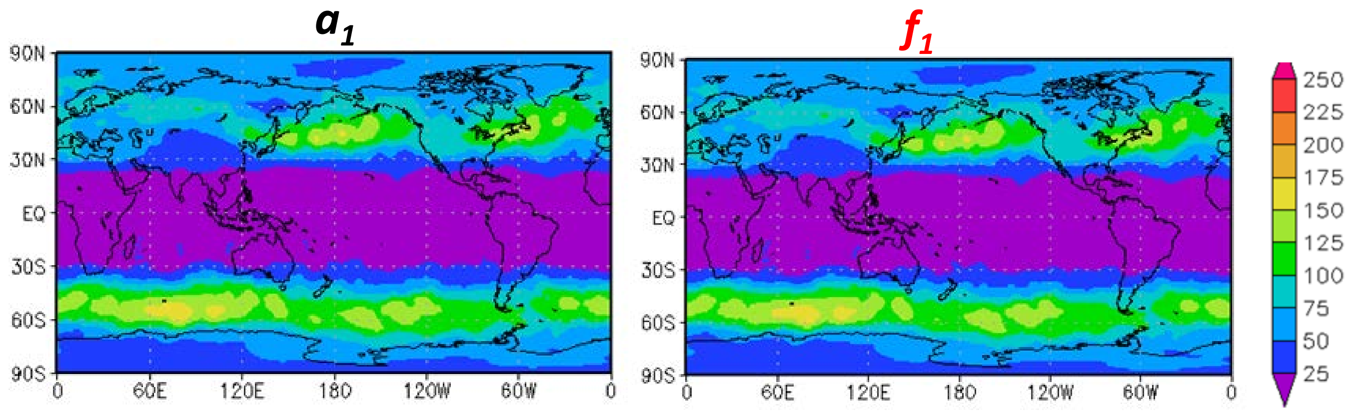
Experiment Name (exper)		Date range	Resolution	Initial Perturbations	Model Perturbations
ncepctl	NCEP control member	2013010100-2013033100	T254–52km (0-192h) T190--68km (192-384 h)	None	None
nceprt	NCEP perturbed member	2013010100-2013033100	T254--52km (0-192h) T190—68km (192-384 h)	ET with rescaling	Stochastic forcing
cmcctl	CMC control member	2013010100-2013033100	100 km/66 km	None	None
cmcprt	CMC perturbed member	2013010100-2013033100	100 km/ 66 km	EnKF	Stochastic forcing and parameterization modification

CMC system change on 13 FEB: Upgrades to model, DA, increased resolution, *improvements to physics tendency perturbations reduce spuriously high precip. rates, particularly in tropics (Gagnon et al. 2013).*

Showing results for the control forecasts for full period, and control and perturbed forecasts before and after upgrade.

NCEP Control Member: 500-hPa Z

a_1 and f_1 almost identical. Consistent with close match between 1-day 500-hPa forecast and verifying analyses. Maxima in storm tracks.



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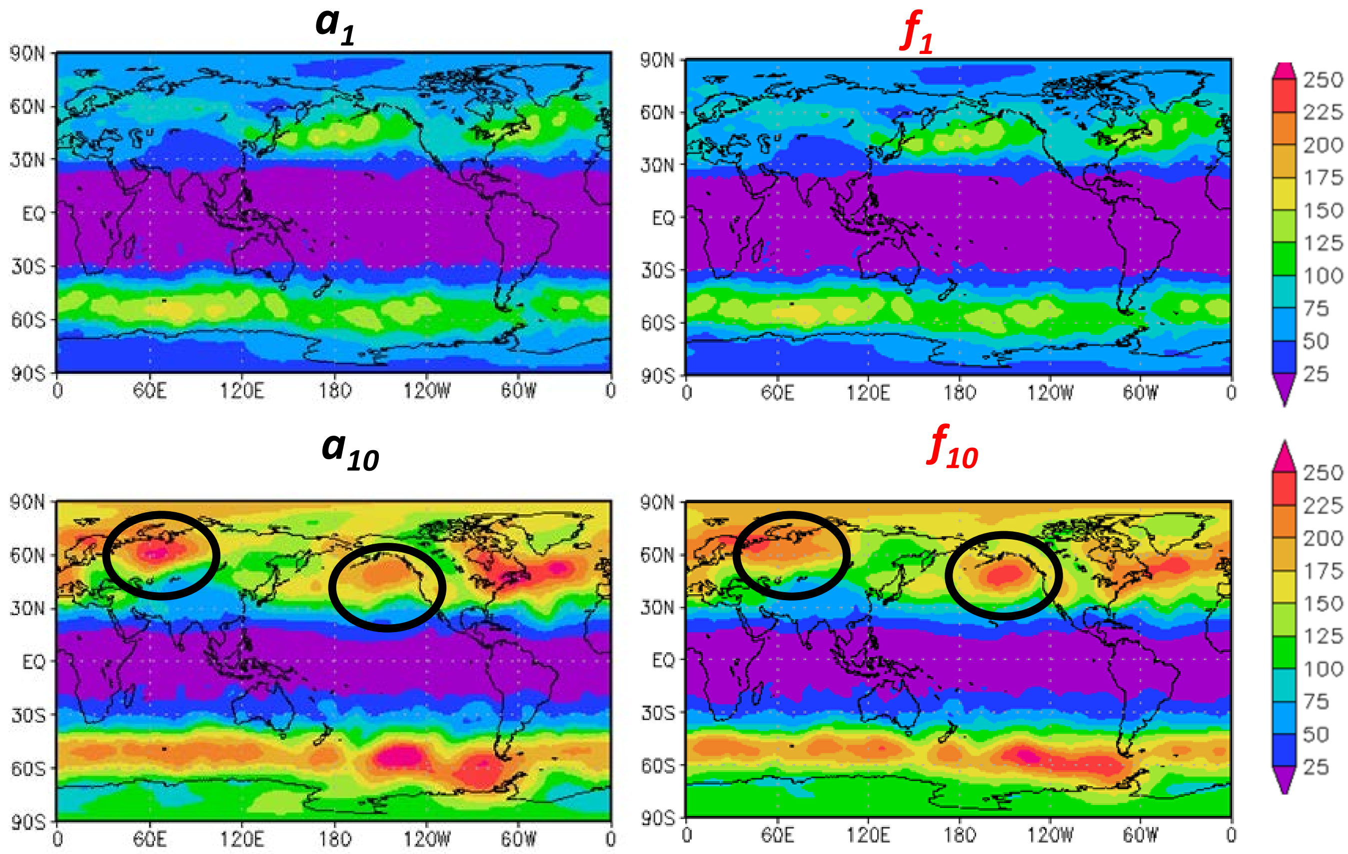
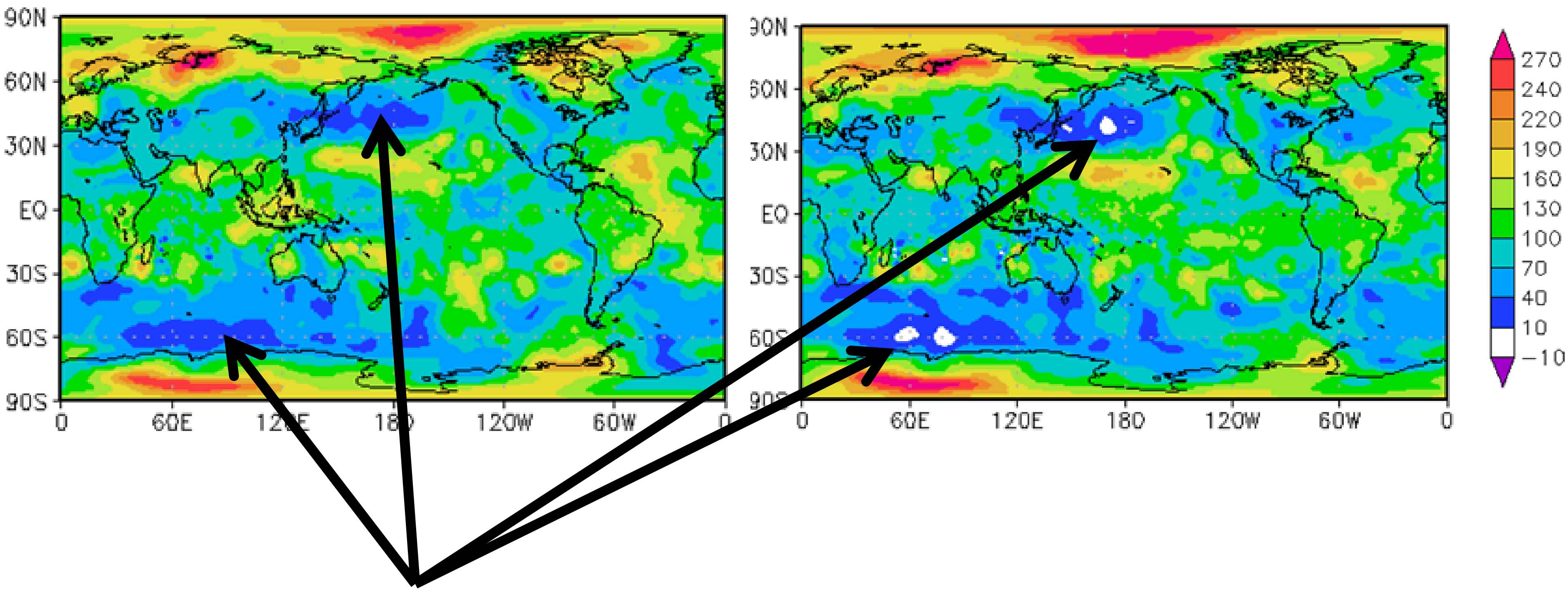


a_{10} and f_{10} mostly similar, but *differ in detail*. Maxima extend/shift downstream (blocking regions). Patterns similar to high and band-pass filtered results from previous studies *without the need for a multi-year forecast integration*.

NCEP Control Member: 500-hPa Z

% diff between a_{10} and a_1 (f_{1o} and f_1). Warm colors indicate regions where there is more variability on longer time scales than on shorter time scales.

$100*(a_{10}-a_1)/a_1$ $\quad$ $100*(f_{10}-f_1)/f_1$



North Pacific and SH storm tracks dominated by 1-d variability.

NCEP Control Member: 500-hPa Z

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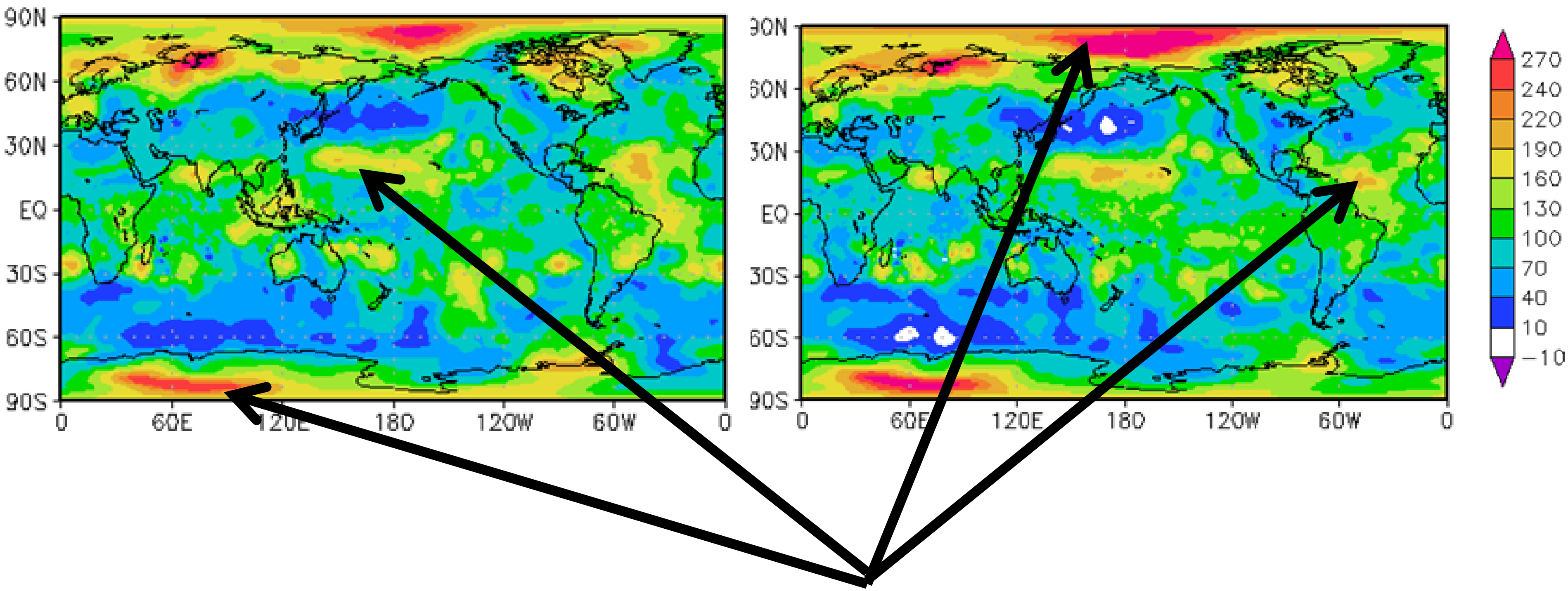
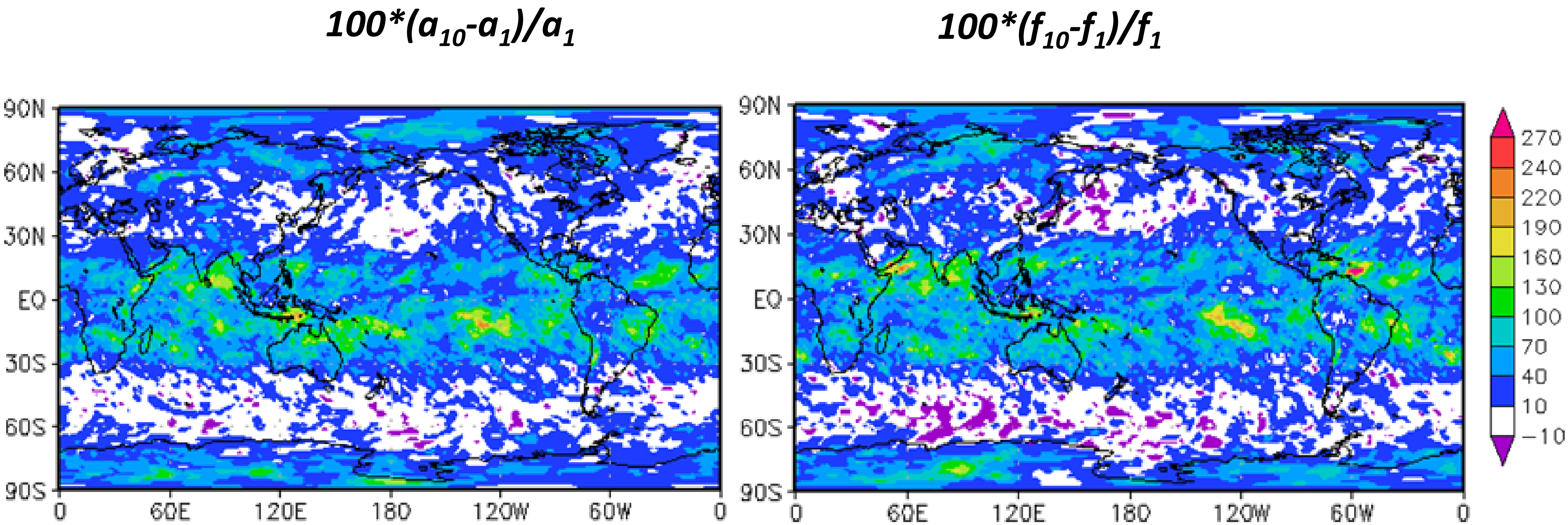


North Pacific and SH storm tracks dominated by 1-d variability.

Polar regions and subtropics indicate substantial increases in variability at longer time scales.

NCEP Control Member: 500-hPa Q

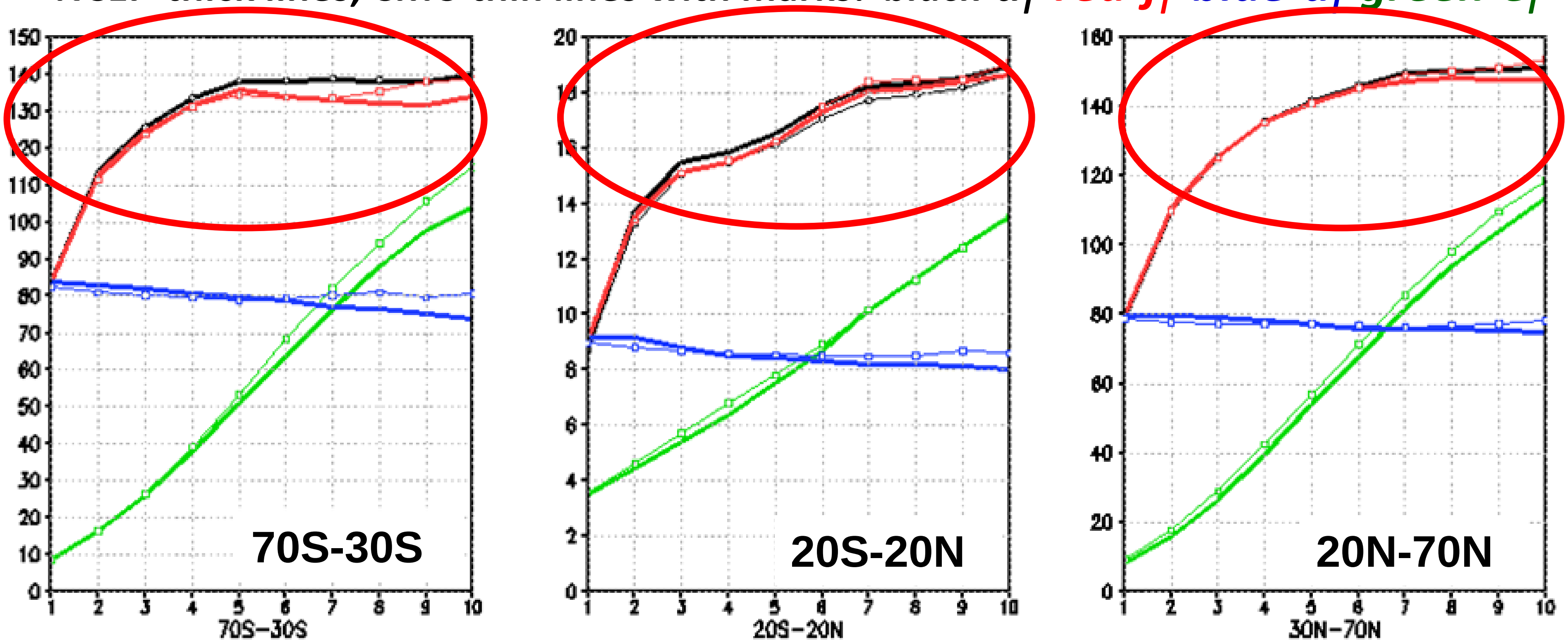
% diff between a_{10} and a_1 (f_{1o} and f_1) indicate regions where there is more variability on longer time scales than on shorter time scales.



For most mid-latitude regions, 1-d variability as large as 10-d variability. In tropics and subtropics, 10-d variability substantially larger than 1-d variability (equatorial waves?).

NCEP and CMC Control Members: 500-hPa Z

NCEP-thick lines, CMC-thin lines with marks: ***black-a_i*** ***red-f_i*** ***blue-d_i*** ***green-e_i***

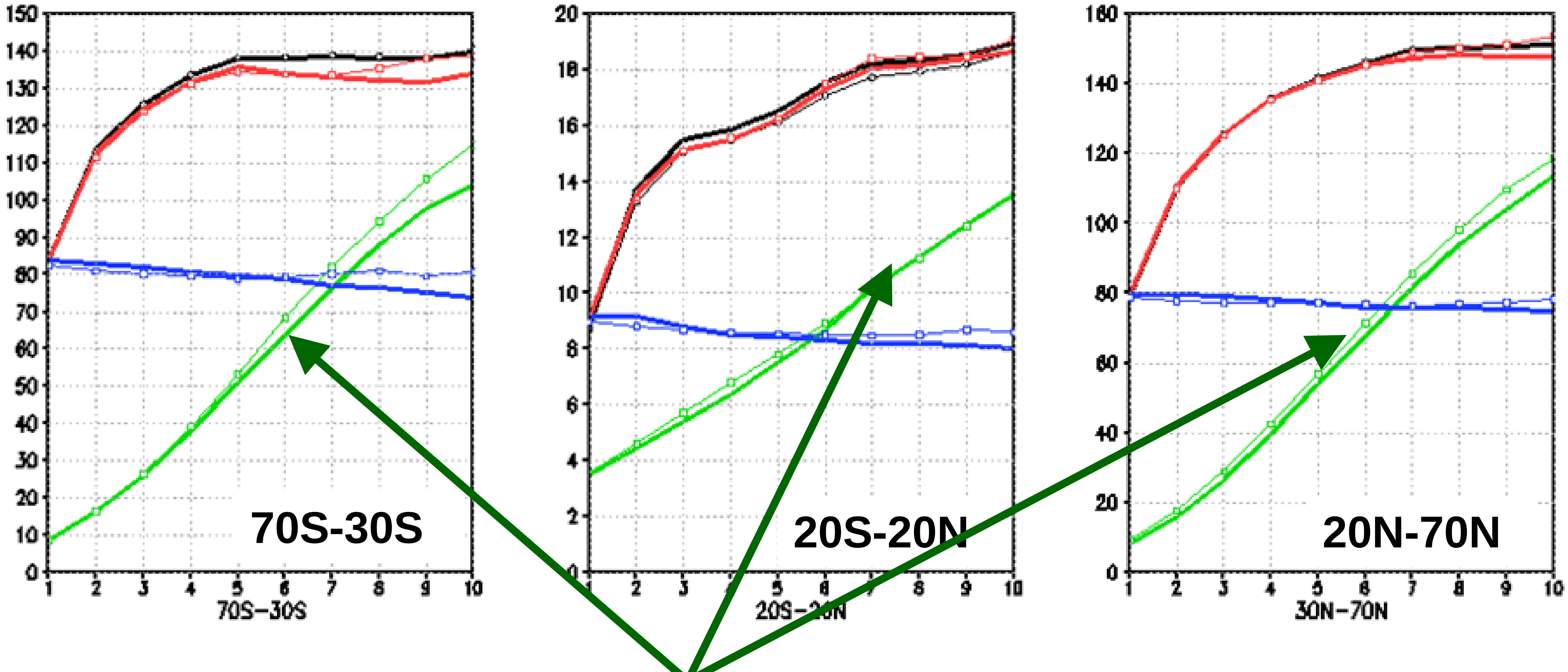


NCEP and CMC a_i, f_i similar: Small uncertainties in 500-hPa Z analyses, similar temporal behavior in forecasts and analyses.

f_i, a_i saturate in 5-7 d in mid-latitudes, after 10 d in tropics: larger fraction of temporal variability on longer timescale in tropics than in mid-latitudes.

NCEP and CMC Control Members: 500-hPa Z

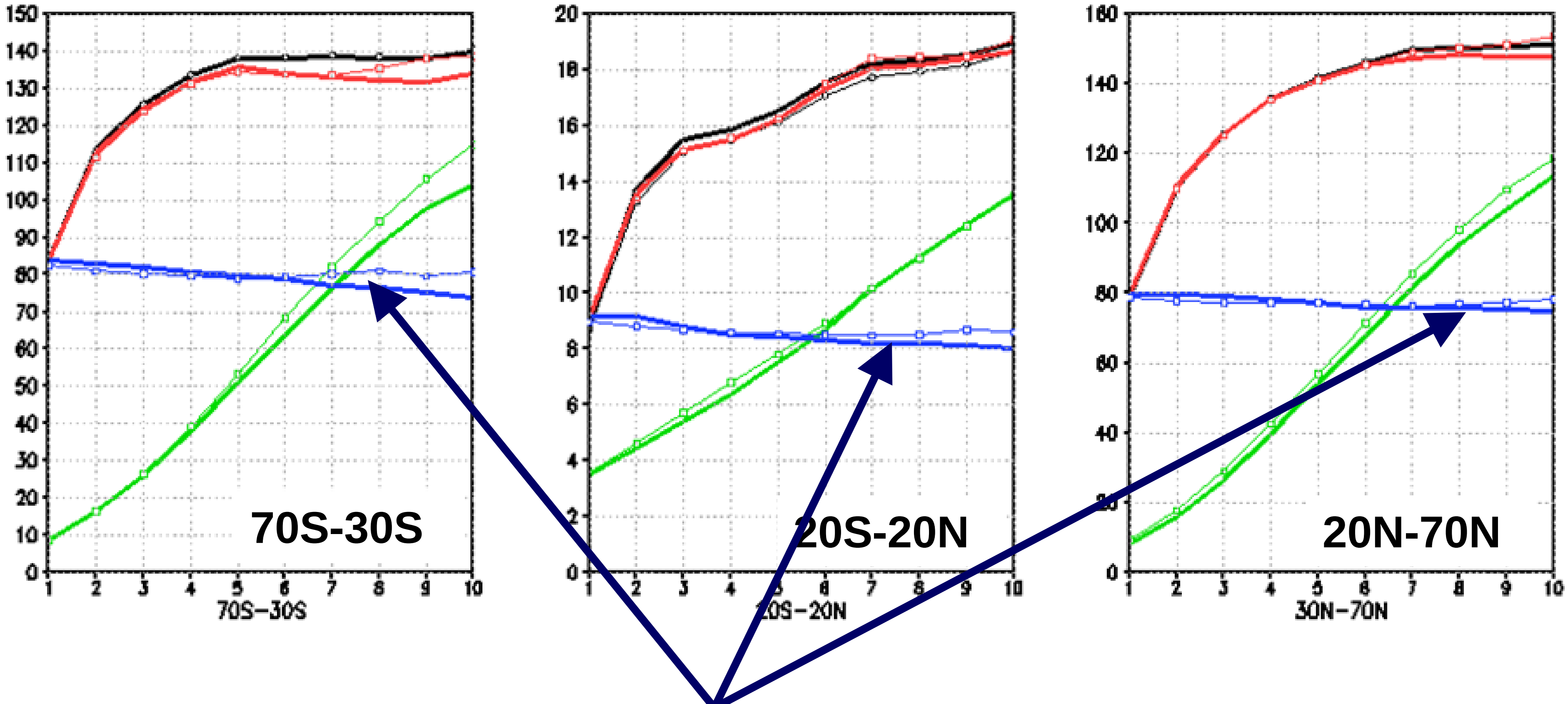
NCEP-thick lines, CMC-thin lines with marks: *black-a_i* *red-f_i* *blue-d_i* *green-e_i*



Forecast error (e_i) substantially smaller than persistence error (a_i), even at 10 days, NCEP and CMC comparably skillful.

NCEP and CMC Control Members: 500-hPa Z

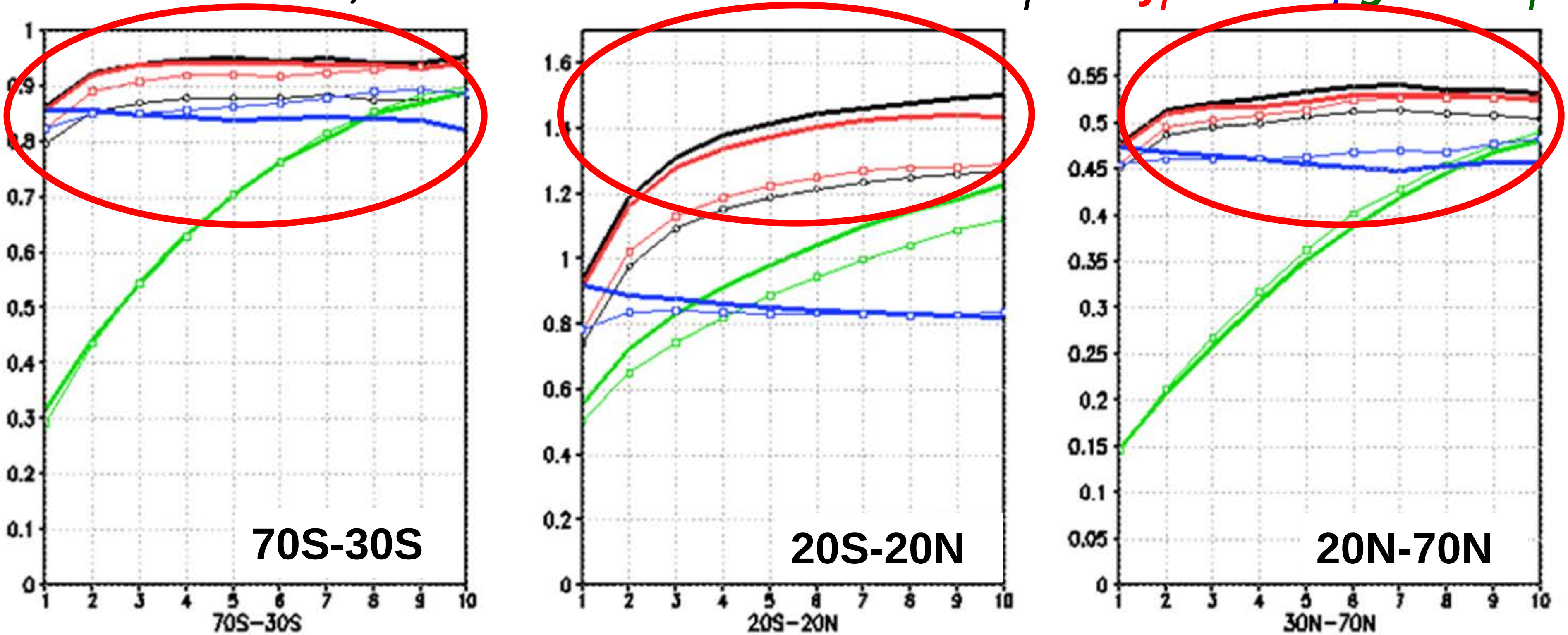
NCEP-thick lines, CMC-thin lines with marks: ***black-a_i*** ***red-f_i*** ***blue-d_i*** ***green-e_i***



NCEP d_i decreases fairly consistently in time (by up to 13%). CMC d_i changes are smaller (<3%).

NCEP and CMC Control Members: 500-hPa Q

NCEP-thick lines, CMC-thin lines with marks: ***black-a_i*** ***red-f_i*** ***blue-d_i*** ***green-e_i***



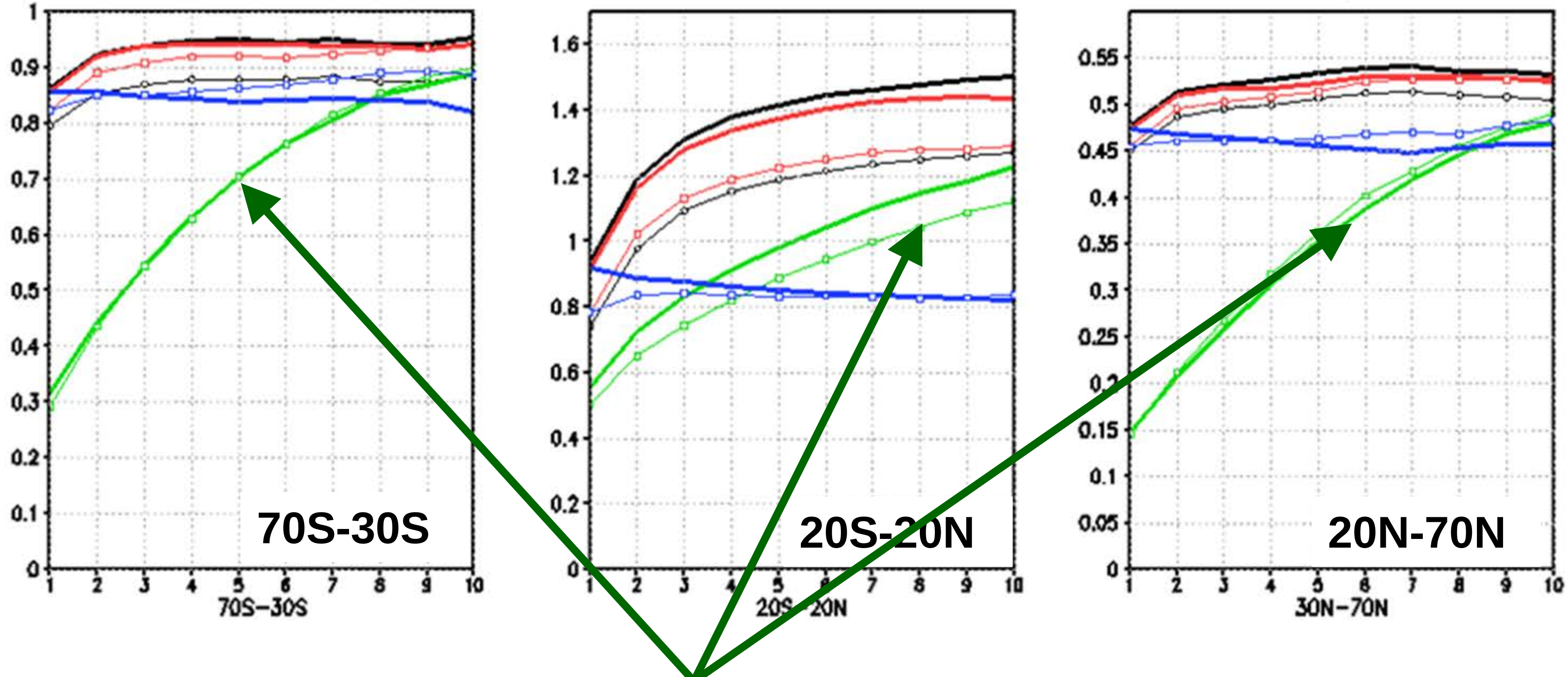
Larger NCEP-CMC differences in Q than in Z, esp. in tropics (16%).

$f_i < a_i$ for NCEP, while $f_i > a_i$ for CMC (*not expected in perfect system*).

f_i, a_i saturate after few days in mid-lats, after 10 d in tropics.

NCEP and CMC Control Members: 500-hPa Q

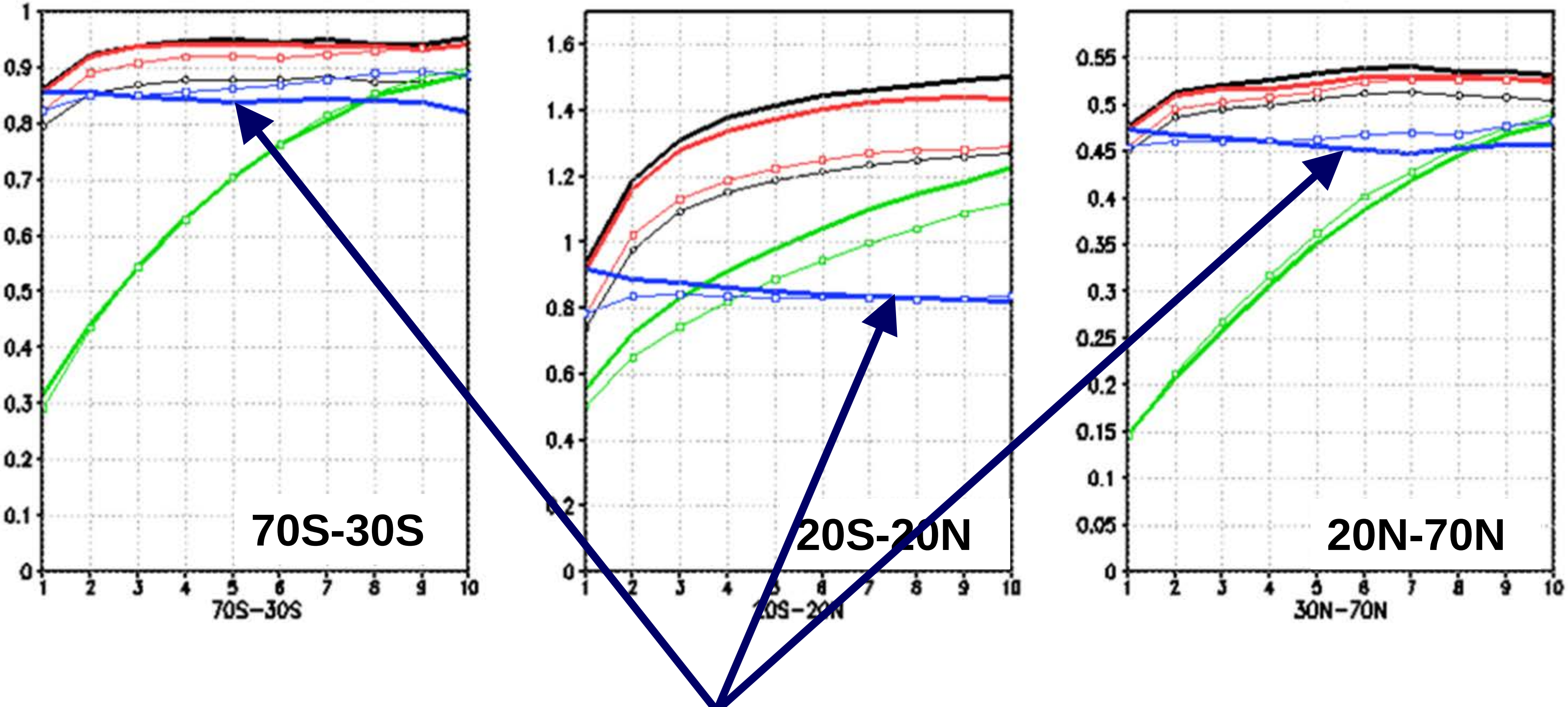
NCEP-thick lines, CMC-thin lines with marks: ***black-a_i*** ***red-f_i*** ***blue-d_i*** ***green-e_i***



Forecast error (e_i) smaller than persistence error (a_i), but gap between the two is smaller for Q than for Z after 10 days.

NCEP and CMC Control Members: <u>500-hPa Q</u>

NCEP-thick lines, CMC-thin lines with marks: ***black-a_i red-f_i blue-d_i green-e_i***

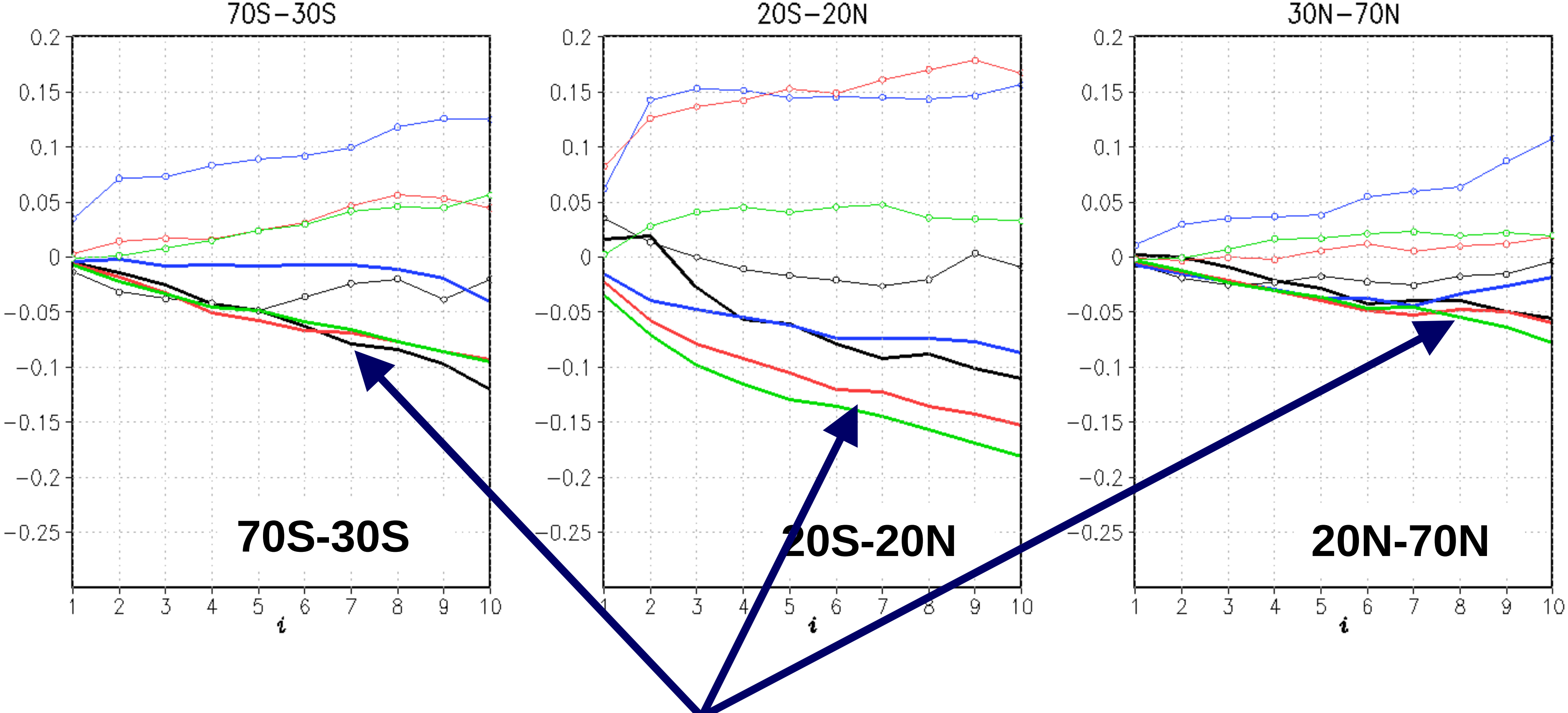


NCEP d_i decreases fairly consistently in time (by up to 8%). CMC d_i shows increase in time (by up to 9% in SH mid-lats.)

Trends in d_i illustrate model behavior dependence on forecast lead time.

NCEP and CMC Control Members
$(d_i - a_1)/a_1$ for 500-hPa Z, Q, T, and U

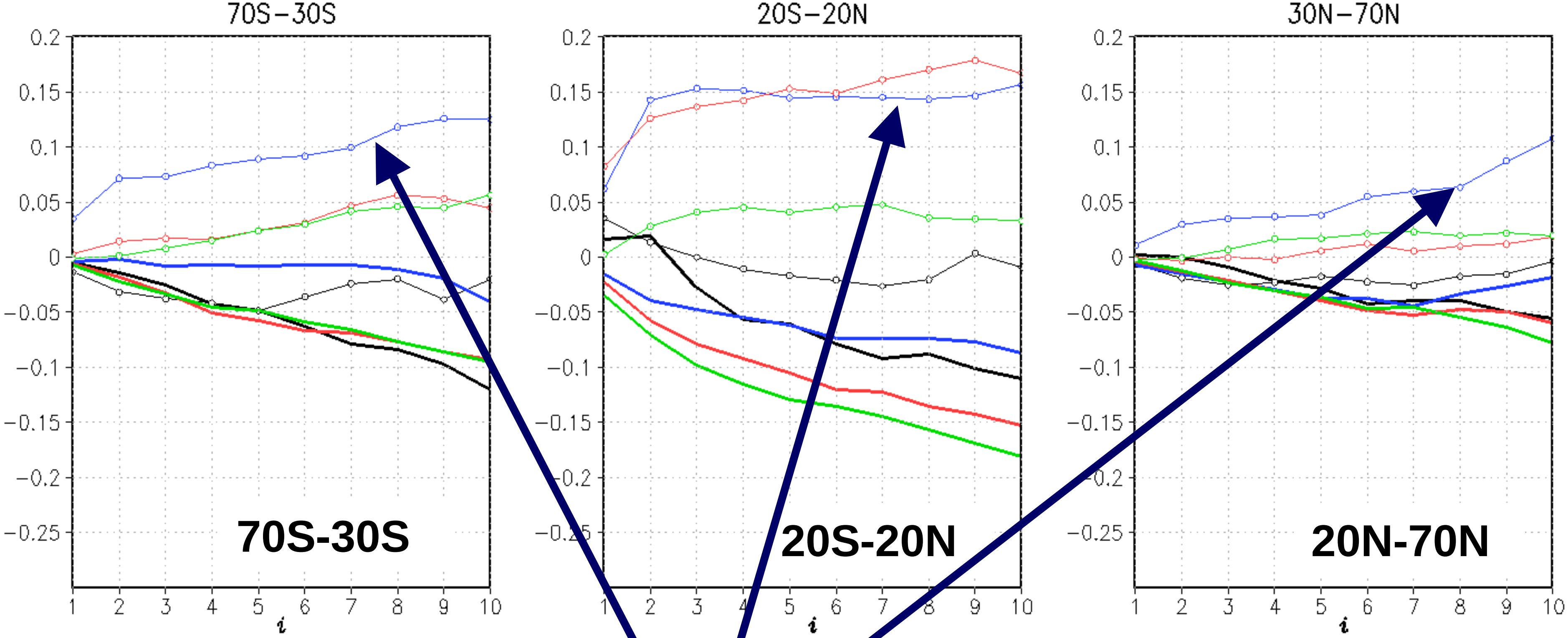
NCEP-thick lines, CMC-thin lines with marks



NCEP: d_i decreases in time (all three regions and all 4 variables).

NCEP and CMC Control Members
$(d_i - a_1)/a_1$ for 500-hPa Z, Q, T, and U

NCEP-thick lines, CMC-thin lines with marks

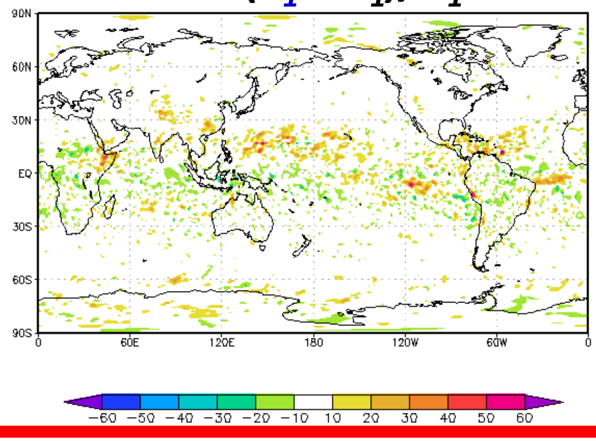


NCEP: d_i decreases in time (all three regions and all 4 variables).
CMC: d_i increases for Q, T, and U. ***Steady increase in Q, T in mid-latitudes; immediate increase, then leveling off, in tropics: Indicative of different types of model errors*.**

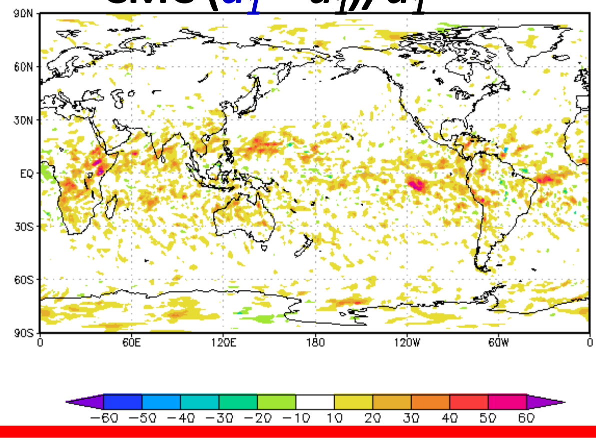
NCEP and CMC Control Members: 500-hPa Q

$100*(d_1 - a_1)/a_1$ (top) ***$100*(d_{10} - a_1)/a_1$ (bottom)***

NCEP $(d_1 - a_1)/a_1$



CMC $(d_1 - a_1)/a_1$

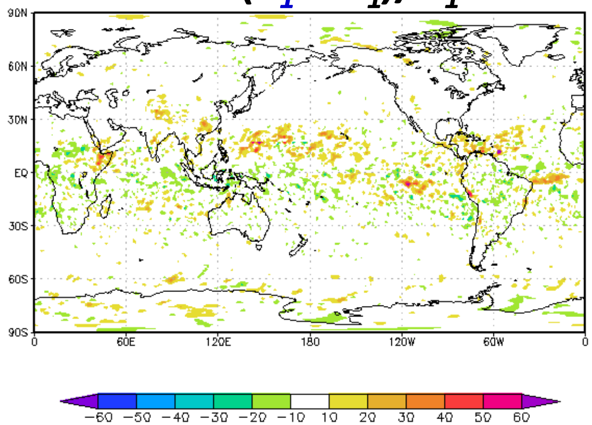


Day 1: NCEP shows mix of small values. CMC mostly positive.

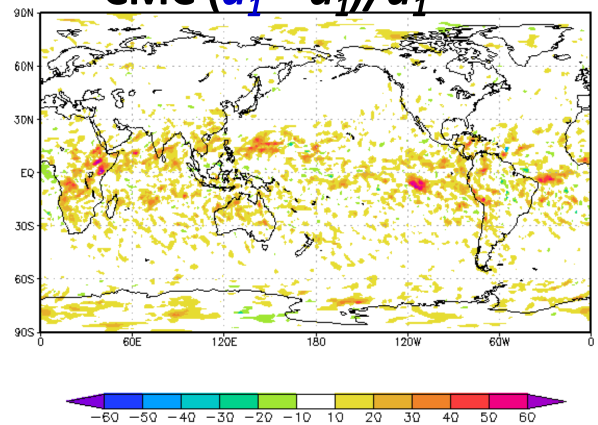
NCEP and CMC Control Members: 500-hPa Q

$100*(d_1 - a_1)/a_1$ (top) $100*(d_{10} - a_1)/a_1$ (bottom)

NCEP $(d_1 - a_1)/a_1$



CMC $(d_1 - a_1)/a_1$



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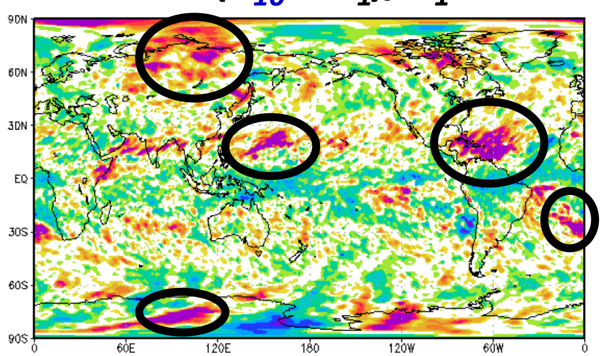
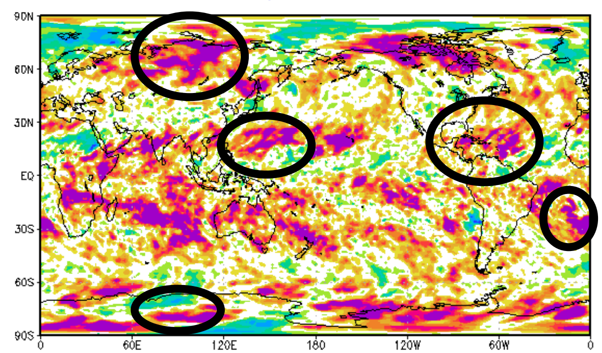


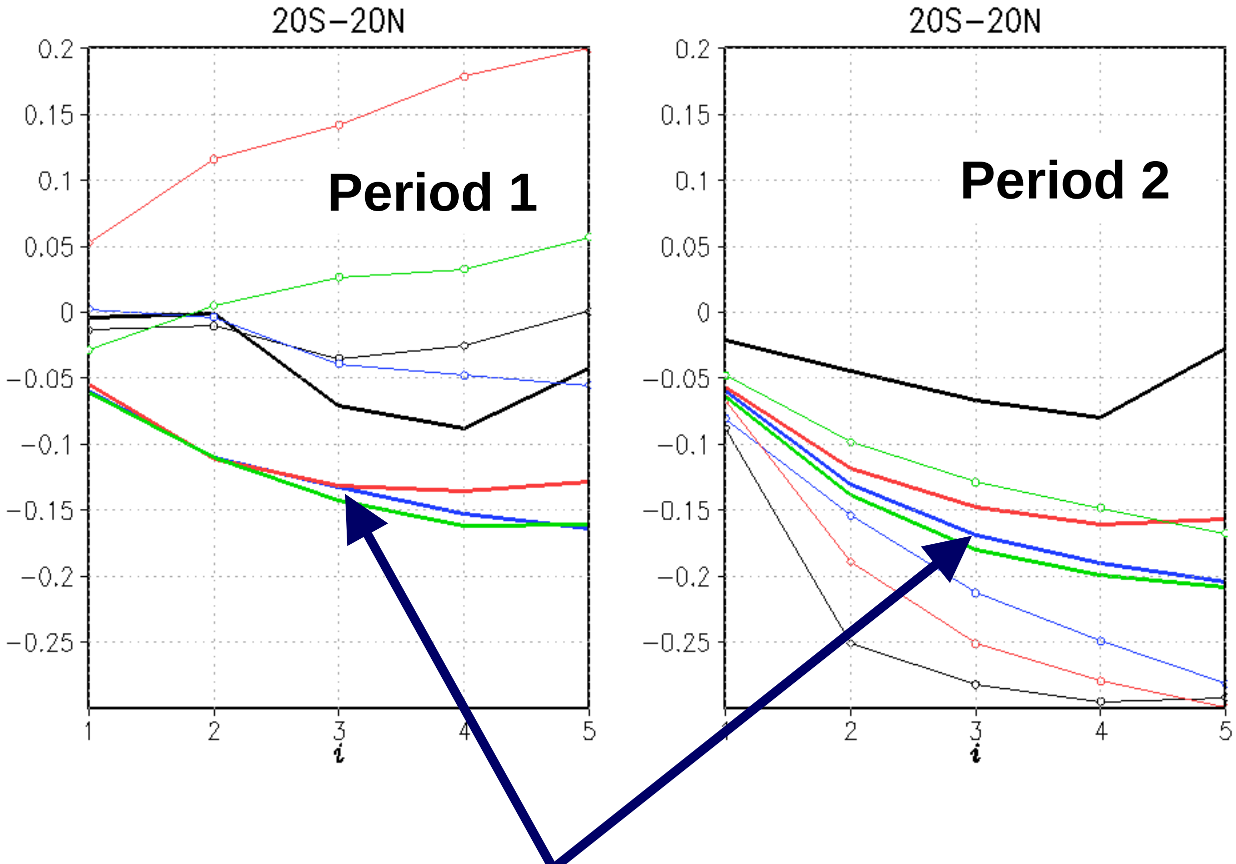
CMC $(d_{10} - a_1)/a_1$



Day 10: NCEP negative in tropics, with isolated positive regions in subtropics. CMC positive in many regions. ***Shared regions of positive values may indicate common traits/sources of model error.***

NCEP, CMC Perturbed Members before/after 13 FEB.
$(d_i - a_1)/a_1$ for 500-hPa Z, Q, T, and U

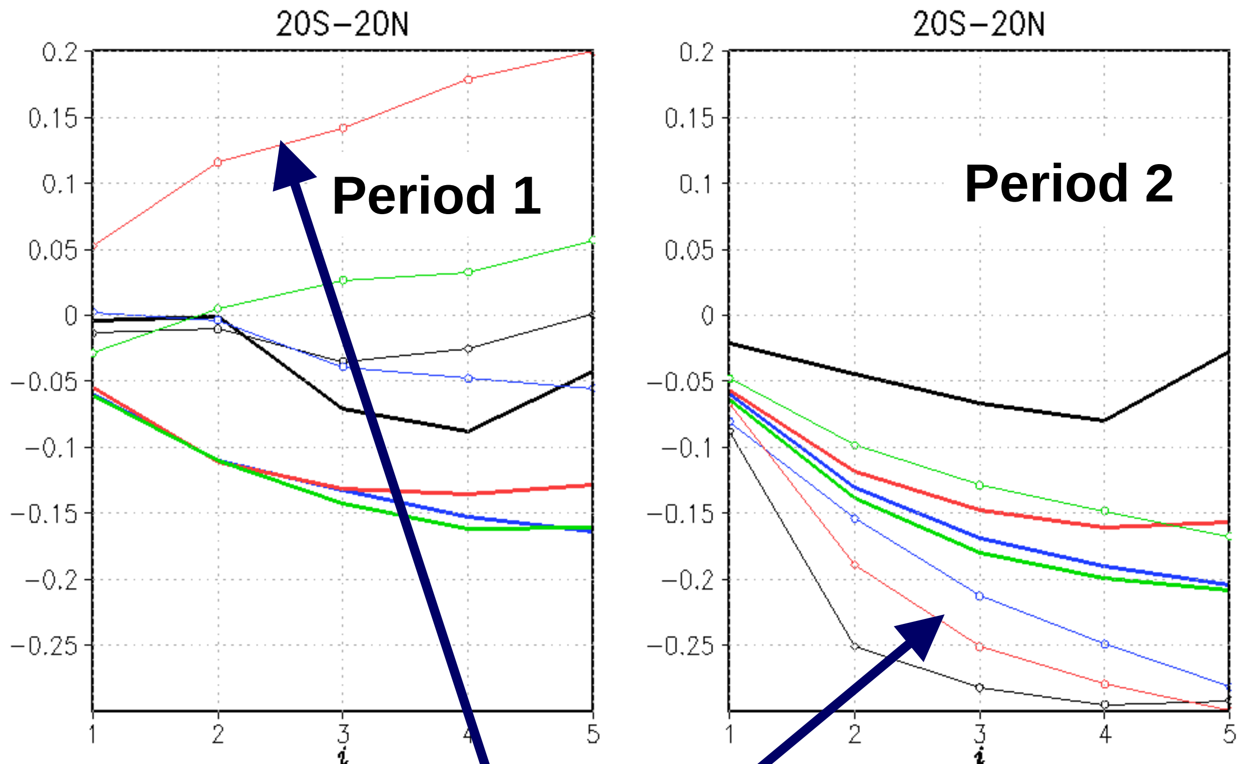
NCEP-thick lines, CMC-thin lines with marks



NCEP: d_i decreases in both periods (consistent with stable system).

NCEP, CMC Perturbed Members before/after 13 FEB.
$(d_i - a_1)/a_1$ *for 500-hPa Z,* *Q*, *T*, *and U*

NCEP-thick lines, CMC-thin lines with marks

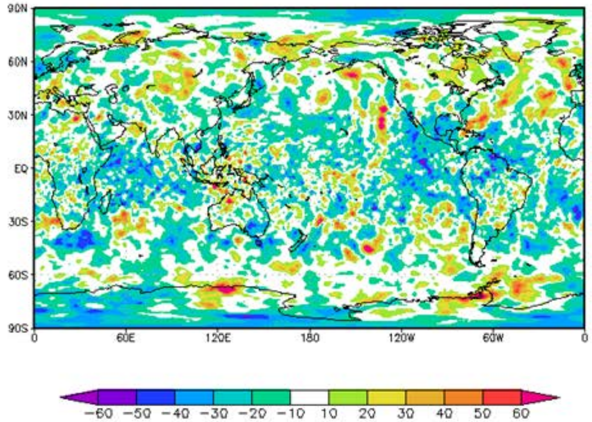


NCEP: d_i decreases in both periods (consistent with stable system).
CMC: *substantial changes after upgrade, consistent with PTP modification that decreases spurious large precipitation rates*.

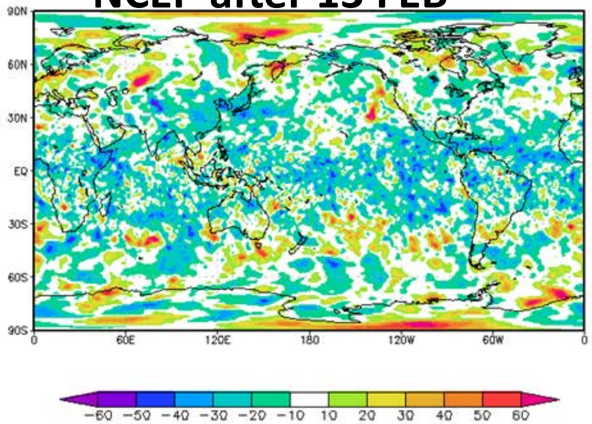
NCEP, CMC Perturbed Members Before/After 13 FEB. 500-hPa Q

100*(d$_5$ – a$_1$)/a$_1$

NCEP before 13 FEB



NCEP after 13 FEB



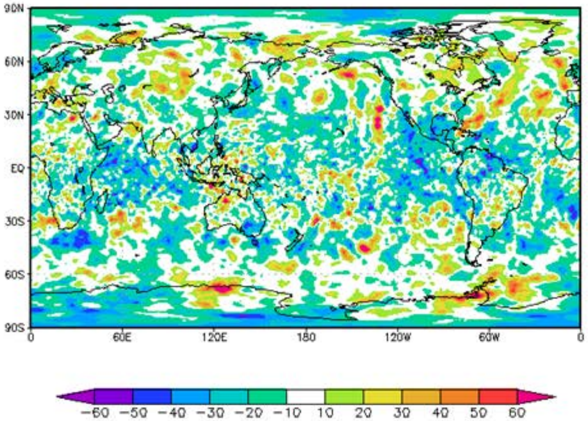
NCEP: Relatively small differences, mix of positive and negative values.

NCEP, CMC Perturbed Members Before/After 13 FEB. 500-hPa Q

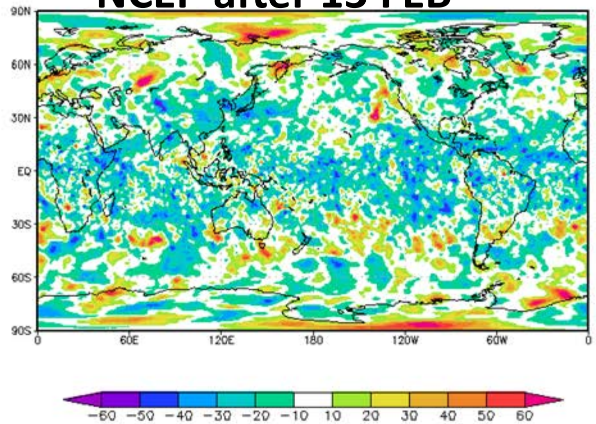
100*(d₅ – a₁)/a₁

$100*(d_5 - a_1)/a_1$

NCEP before 13 FEB



NCEP after 13 FEB



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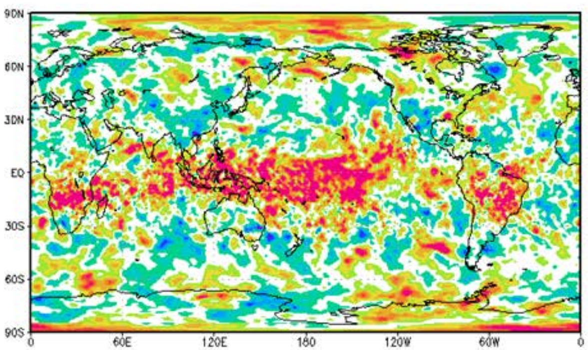
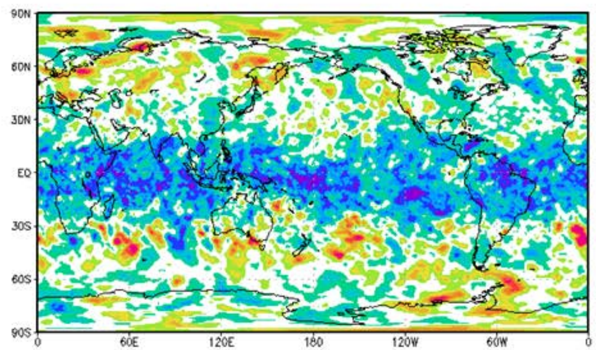
CMC before 13 FEB



CMC after 13 FEB



CMC: Large positive values substantially reduced after upgrade. *Consistent with improvements to physics tendency perturbations that reduced spurious tropical precipitation (Gagnon et al. 2013).*

Summary

- **Simple diagnostics based on temporal variability provide framework to assess forecast variability on varying time scales without the need for AMIP-type integrations.**
- **The diagnostics show, in some cases, significant changes in forecast variability with increasing forecast time.**
- **The diagnostics are clearly able to discern impact of CMC ensemble upgrade, consistent with documented impacts of that upgrade.**
- **We recommend adding these diagnostic to suite of established diagnostics to assess forecast model characteristics. Would complement assessment of spatial variability and provide utility for tuning of stochastic forcing.**

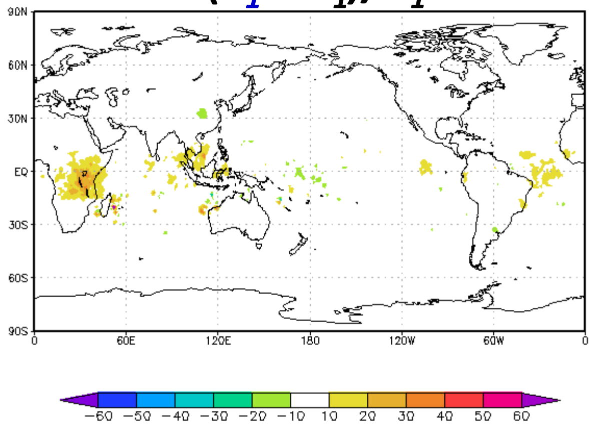
Reynolds, C. A., E. A. Satterfield, and C. H. Bishop, 2015: Using initial state and forecast temporal variability to evaluate model behavior. Mon. Wea. Rev., 143, 4785-4804.

Extra Slides

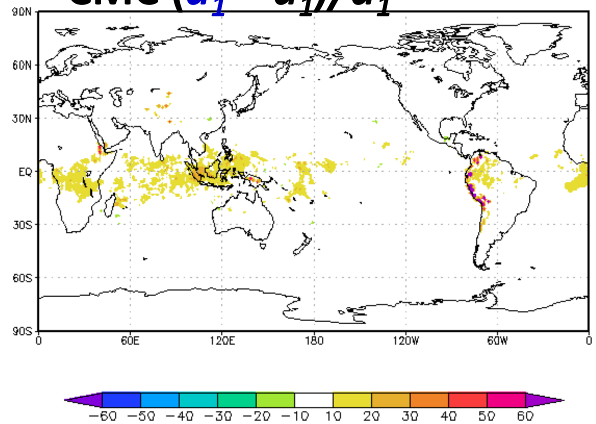
NCEP and CMC Control Members: 500-hPa Z

$100*(d_1 - a_1)/a_1$ (top) ***$100*(d_{10} - a_1)/a_1$ (bottom)***

NCEP $(d_1 - a_1)/a_1$



CMC $(d_1 - a_1)/a_1$



Day 1: Both NCEP and CMC show slightly positive values in tropics.

NCEP and CMC Control Members: 500-hPa Z

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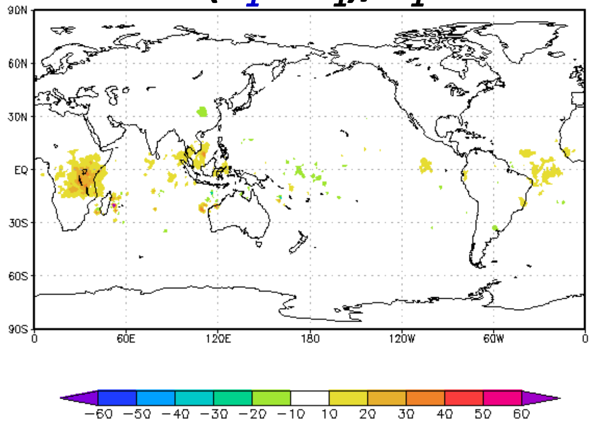
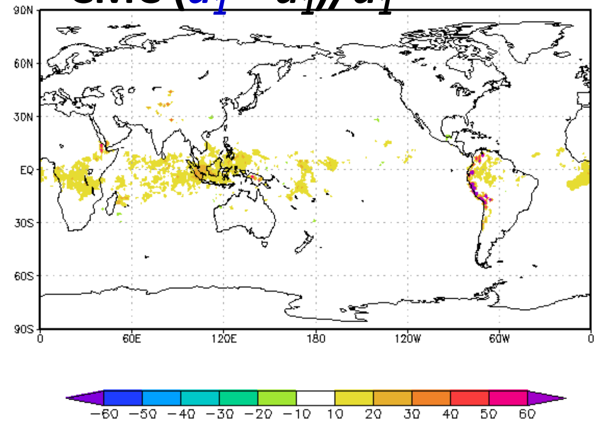
NCEP $(d_1 - a_1)/a_1$



CMC $(d_1 - a_1)/a_1$



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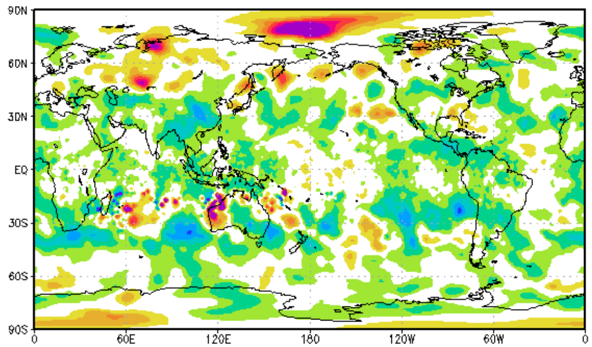
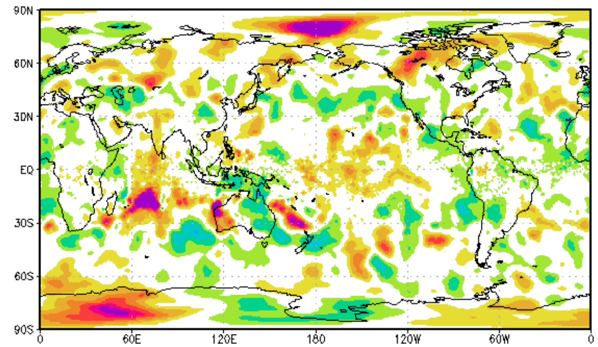


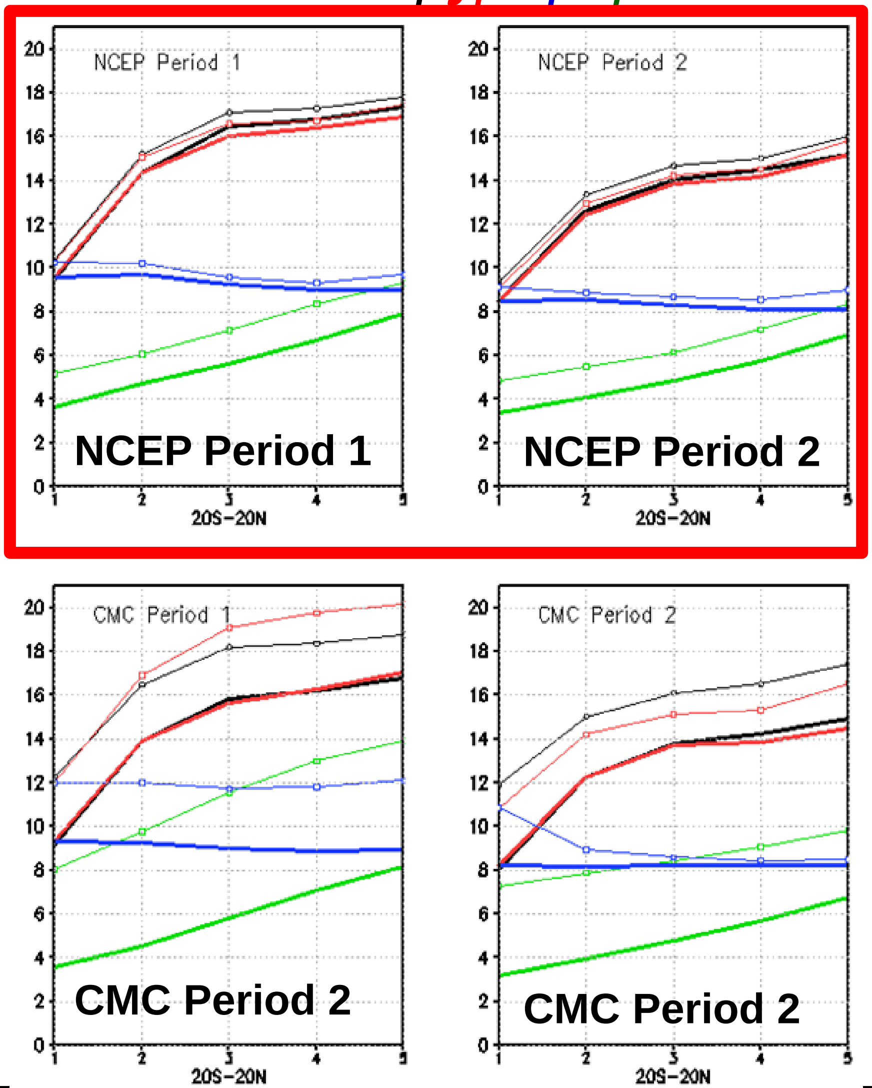
CMC $(d_{10} - a_1)/a_1$



Day 10: NCEP mostly negative. CMC mix of positive and negative.

NCEP and CMC Control and Perturbed Ensemble Members 20S-20N: 500-hPa z

Control-thick lines, Perturbed- thin lines with marks: *a_i* *f_i* *d_i* *e_i*

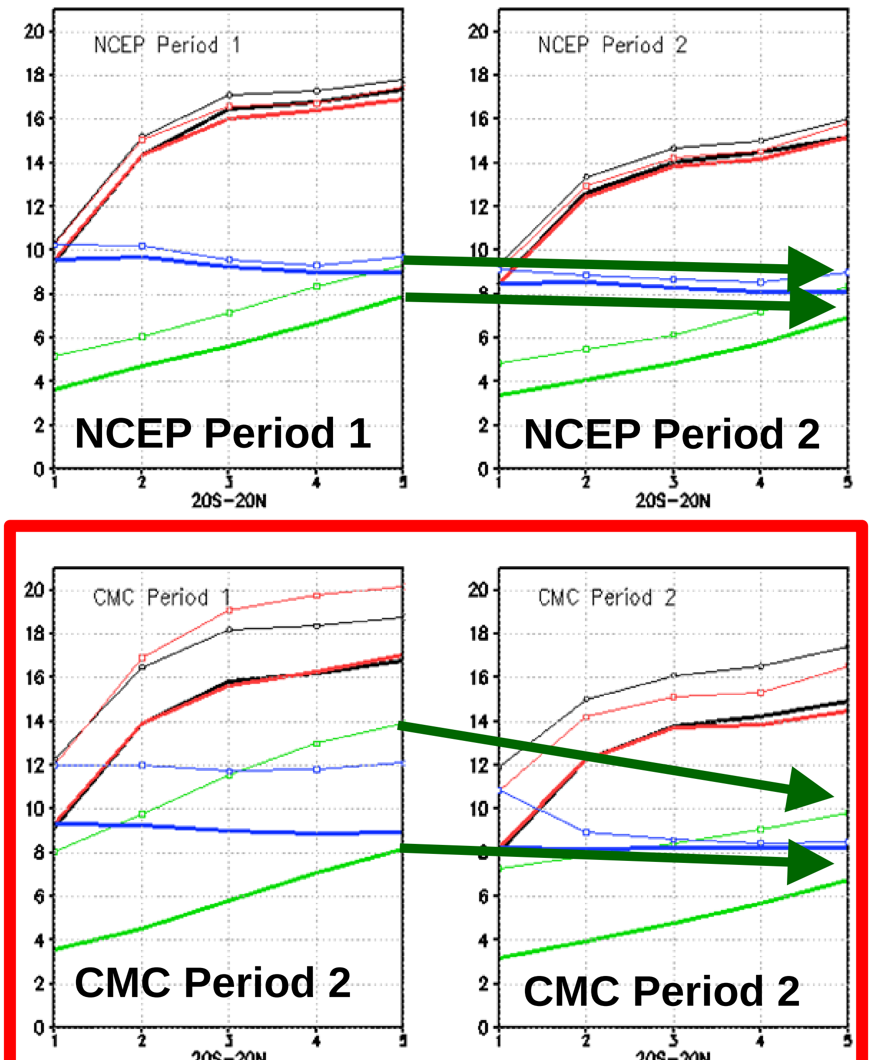


For NCEP, behavior before and after 13 FEB very similar, consistent with stable system.

- ***f_i* slightly (3%) smaller than *a_i*. Values slightly (3-5%) larger for perturbed member (thin) than for control member (thick).**
- ***d_i* decreases similarly with time for both control and perturbed members.**
- ***e_i* larger for perturbed member than control member for both periods.**

NCEP and CMC Control and Perturbed Ensemble Members 20S-20N: 500-hPa z

Control-thick lines, Perturbed- thin lines with marks: a_i f_i d_i e_i



For CMC, Notable change in behavior consistent with system upgrade.

- **$f_i > a_i$ before upgrade, and $f_i < a_i$ after upgrade, for perturbed member.**
- **Larger differences (up to 18%) between perturbed and control members (parameterization differences, stochastic forcing). Difference decreases after upgrade.**
- **20% decrease in d_i between i=1, and i=2 after upgrade (initial adjustment).**
- **Decrease in e_i after upgrade larger for CMC perturbed member (40%) than for CMC control member or NCEP (20%).**