Using Data Assimilation to Improve Climate Models - Troposphere

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Rodwell and Palmer, 2007: *Q. J. R. Meteorol. Soc.*, **133**, 129-146

Parameter Uncertainties in Climate Sensitivity

Parameter	Physics	Low	Middle	High
Droplet to rain conversion rate (s^{-1})	Cloud	$0.5x10^{-4}$	$1.0x10^{-4}$	$4.0x10^{-4}$
Relative humidity for cloud formation	Cloud	0.6	0.7	0.9
Cloud fraction at saturation (free trop.)	Cloud	0.5	0.7	0.8
Entrainment rate coefficient	Convection	0.6	3.0	9.0
Time-scale for destruction of CAPE (h)	Convection	1.0	2.0	4.0
Effective radius of ice particles (μm)	Radiation	25	30	40
Diffusion e-folding time (h)	Dynamics	6	12	24
Roughness length parameter (Charnock)	Boundary	0.012	0.016	0.02
Stomatal conductance dependent on CO_2	Land	Off	-	On
Ocean-to-ice heat transfer ($m^{-2}s^{-1}$)	Sea Ice	$2.5x10^{-5}$	$1.0x10^{-4}$	$3.8x10^{-4}$

MANY UNCERTAINTIES ARE ASSOCIATED WITH "FAST PHYSICS".
… WHICH IS ALSO IMPORTANT IN NWP

Representative selection of parameters and uncertainties used by Murphy et al., 2004: *Nature*, **430**, 768-772.

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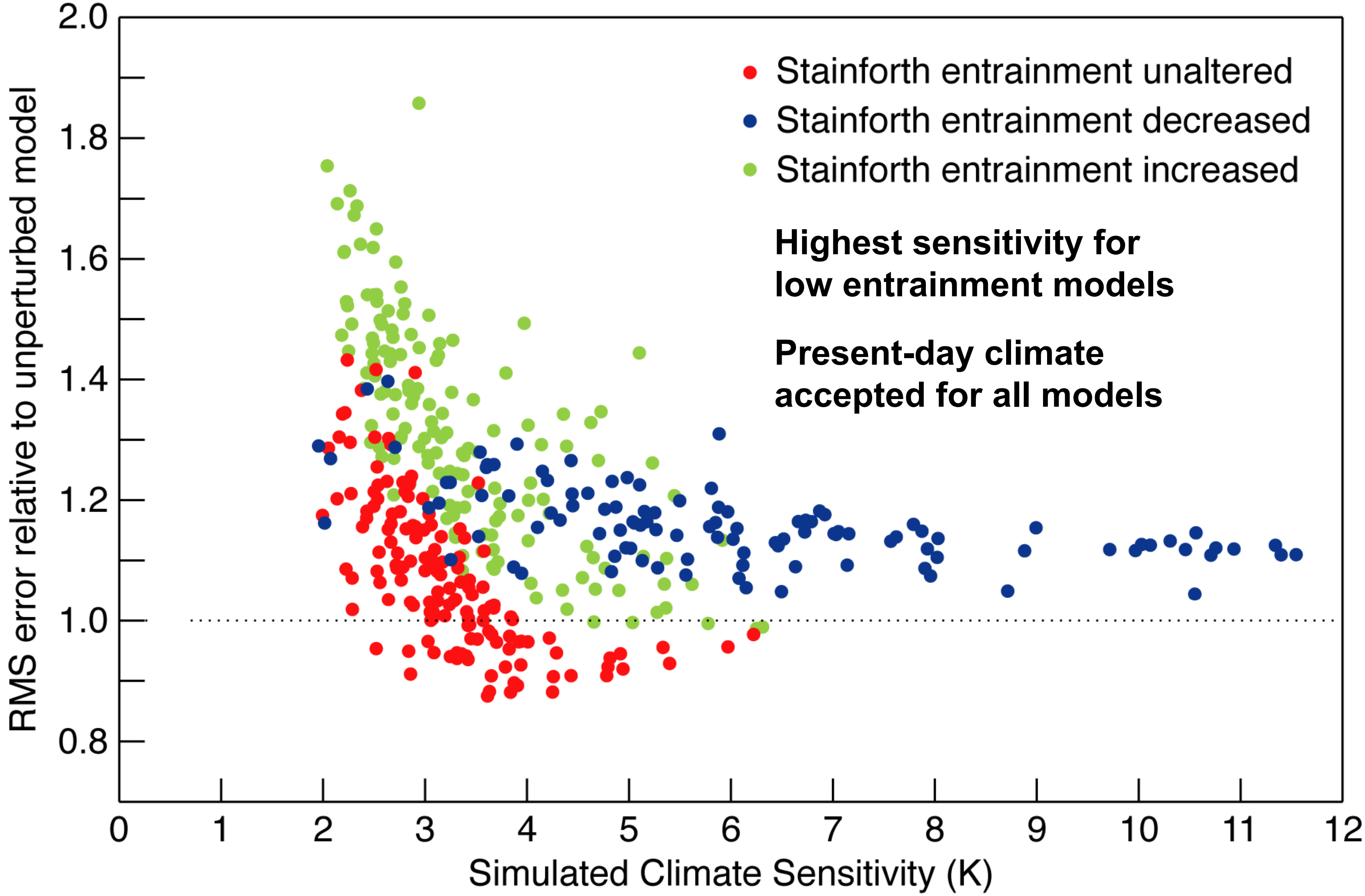
Climate: Error vs Sensitivity to CO_2 doubling



*Combined RMSE of 8 year mean, annual mean T_{2m}, SLP, precipitation and ocean-atmosphere sensible+latent heat fluxes (equally weighted and normalised by the control). Stainforth et al., 2005, Nature, **433**, 403-406.*

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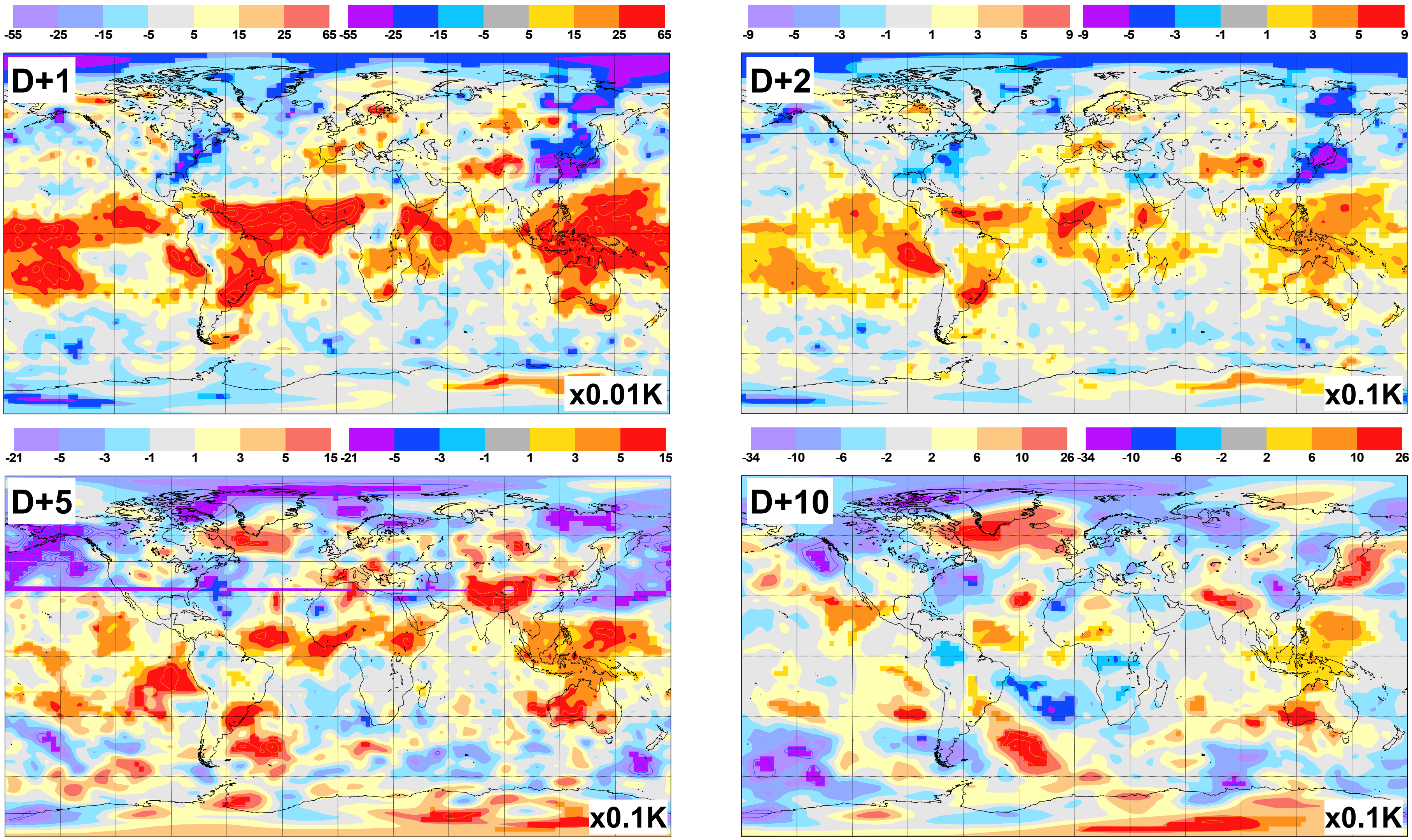
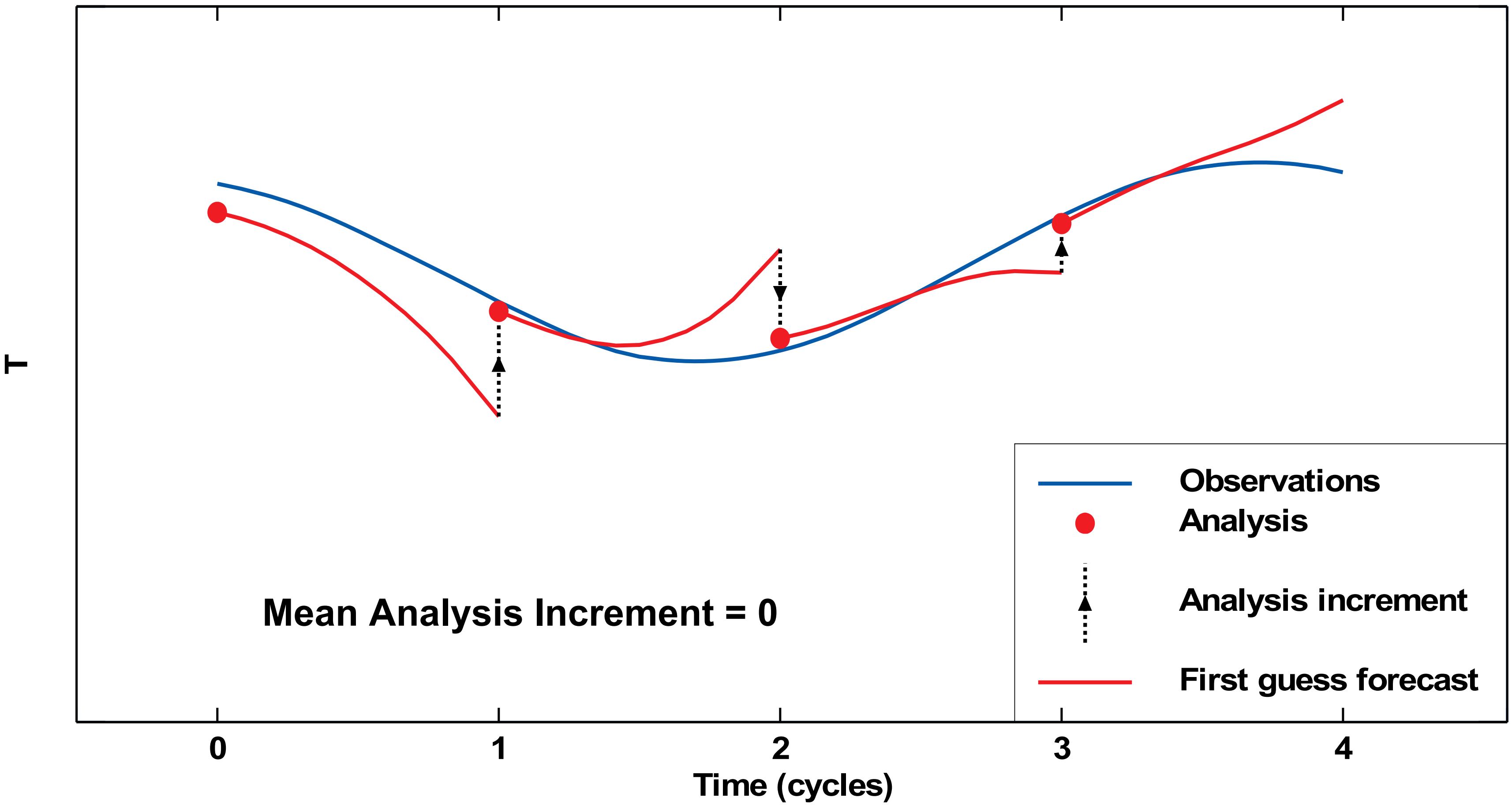
T500 Forecast Error as function of lead-time



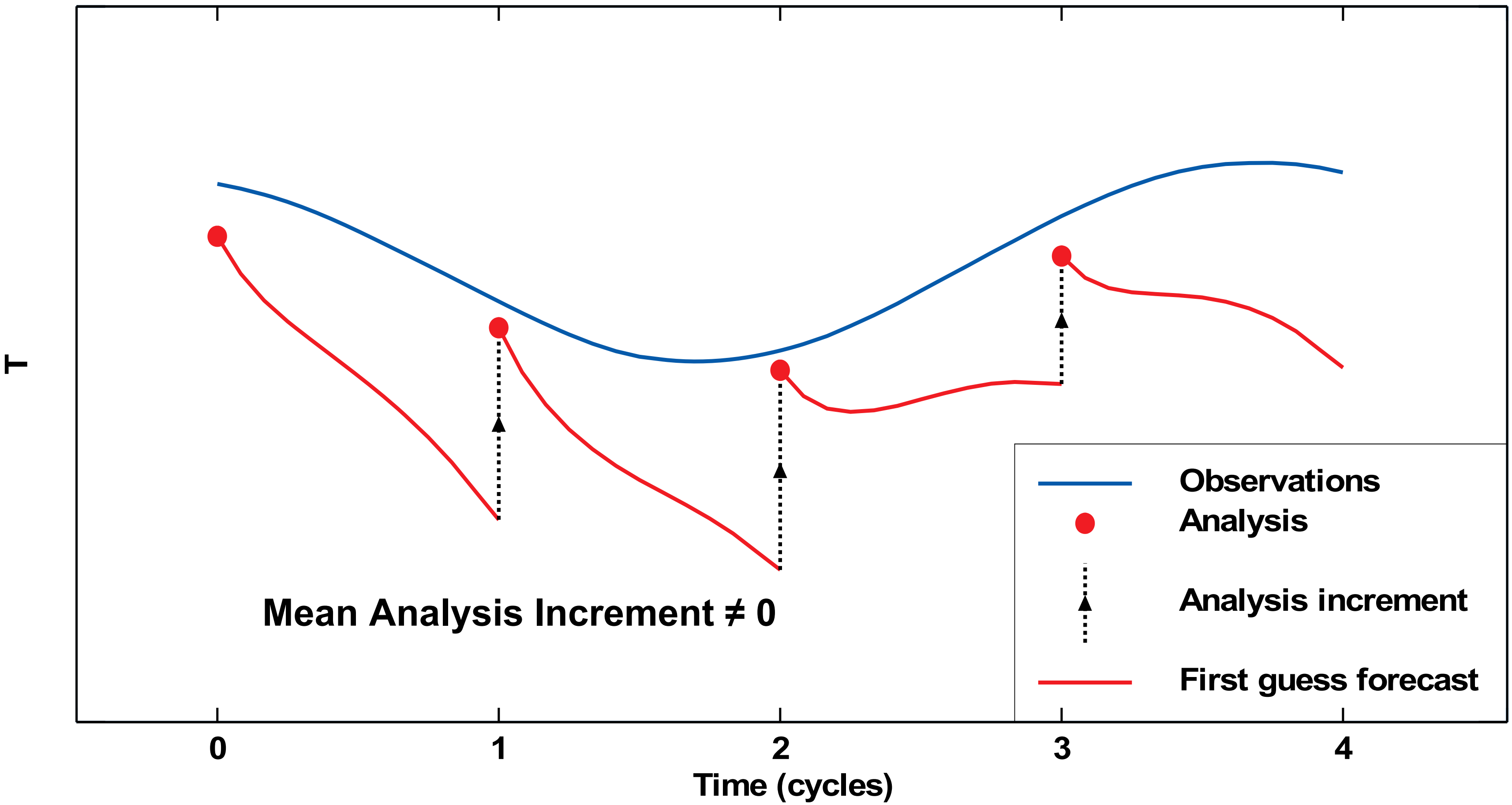
Based on DJF 2007/8 operational analyses and forecasts. Significant values (5% level) in deep colours.

Data Assimilation Cycle: Perfect Model



(Imperfect, unbiased observations)

Data Assimilation Cycle: Imperfect Model



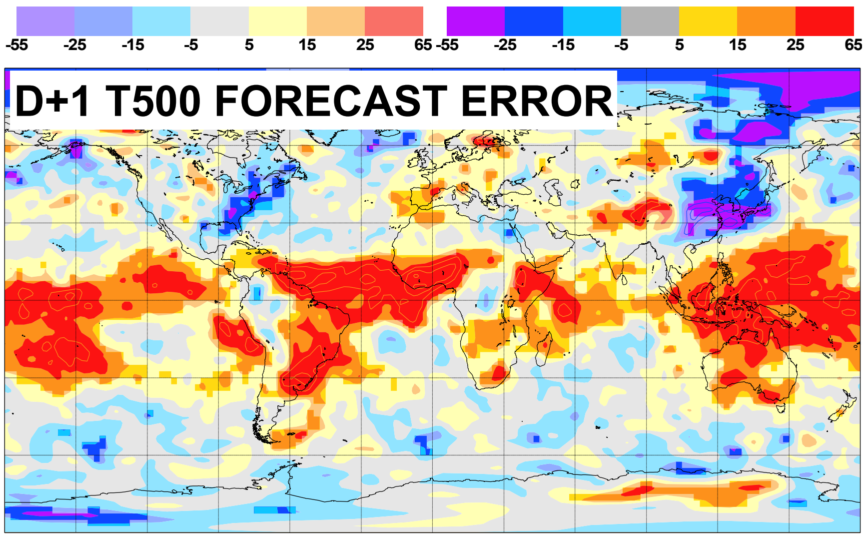
−Mean Analysis Increment = Mean Net Initial Tendency ("I.T." in, *e.g.*, Kcycle^{-1})

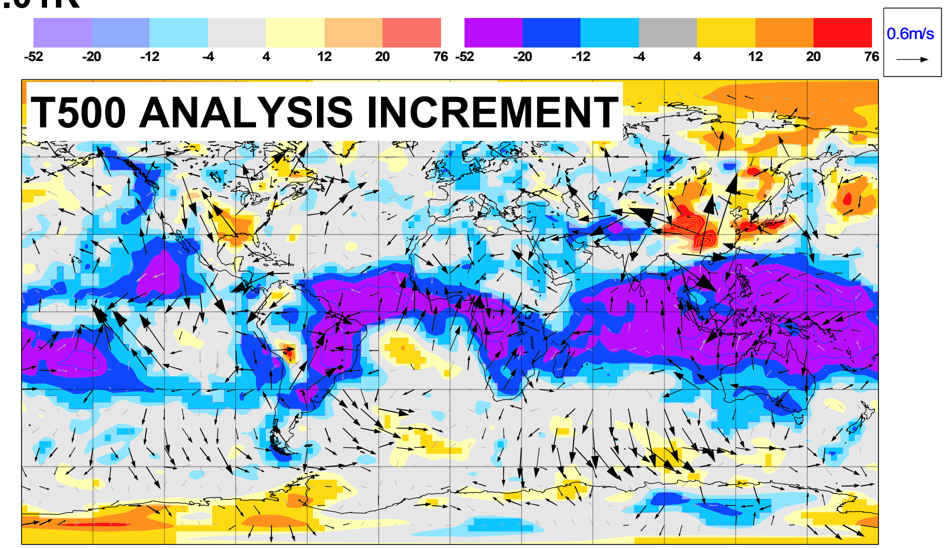
= Mean: Convective I.T. + Radiative I.T. + … + Dynamical I.T.

(summed over all processes in the model)

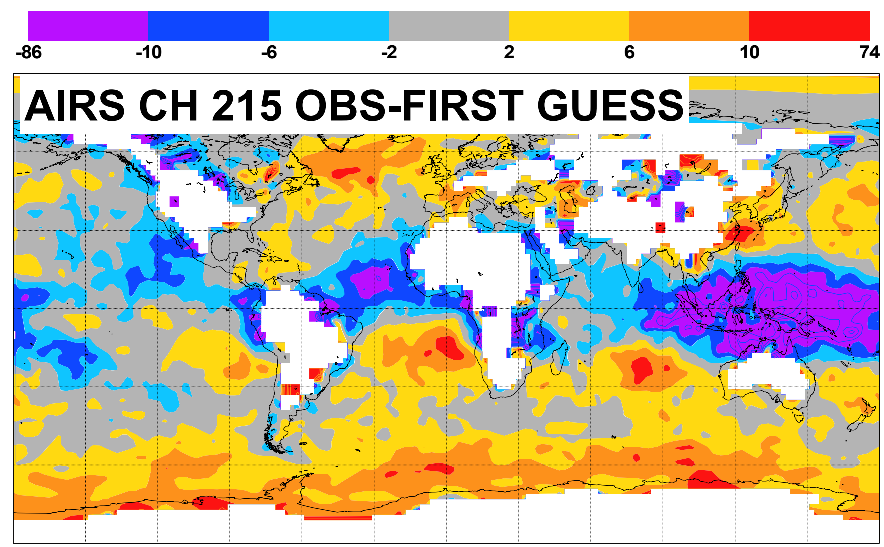
Confronting Models with Observations

UNIT=0.01K





- **Every 1° square has data every cycle**
  - **~6 Million data values**
- **Independent vertical modes of information:**
  - **IASI / AIRS: ~ 15**
  - **HIRS / AMSUA: ~ 5 (~ 2 IN TROP)**
- **Anchors (not bias corrected):**
  - **Radiosonde**
  - **AMSUA-14**
  - **Radio Occultation**



Based on DJF 2007/8 operational analyses and forecasts. Significant values (5% level) in deep colours.
AIRS CH 215 BRIGHTNESS TEMPERATURE ~T500

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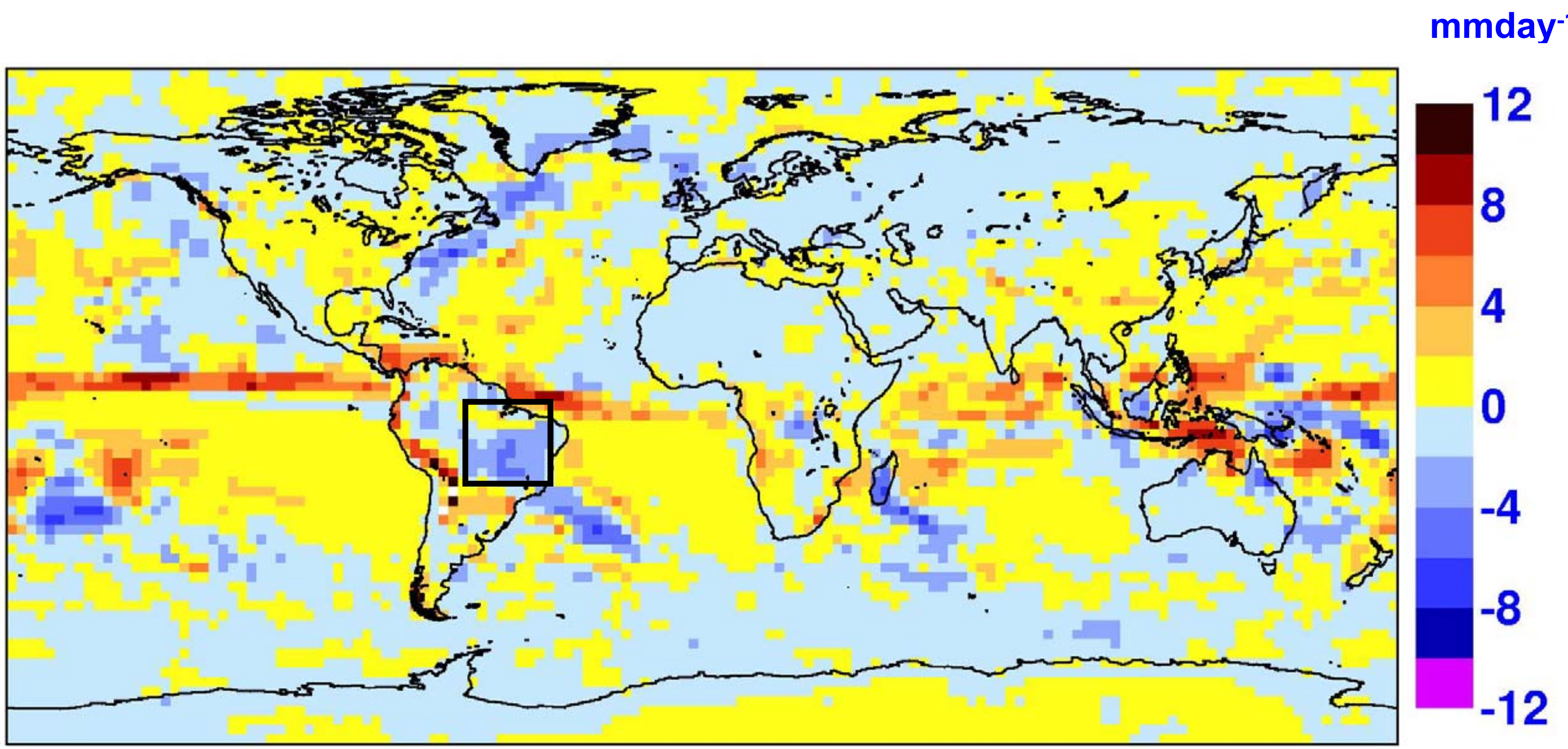
Mean Precipitation Error at Day+5 (Jan 2005)

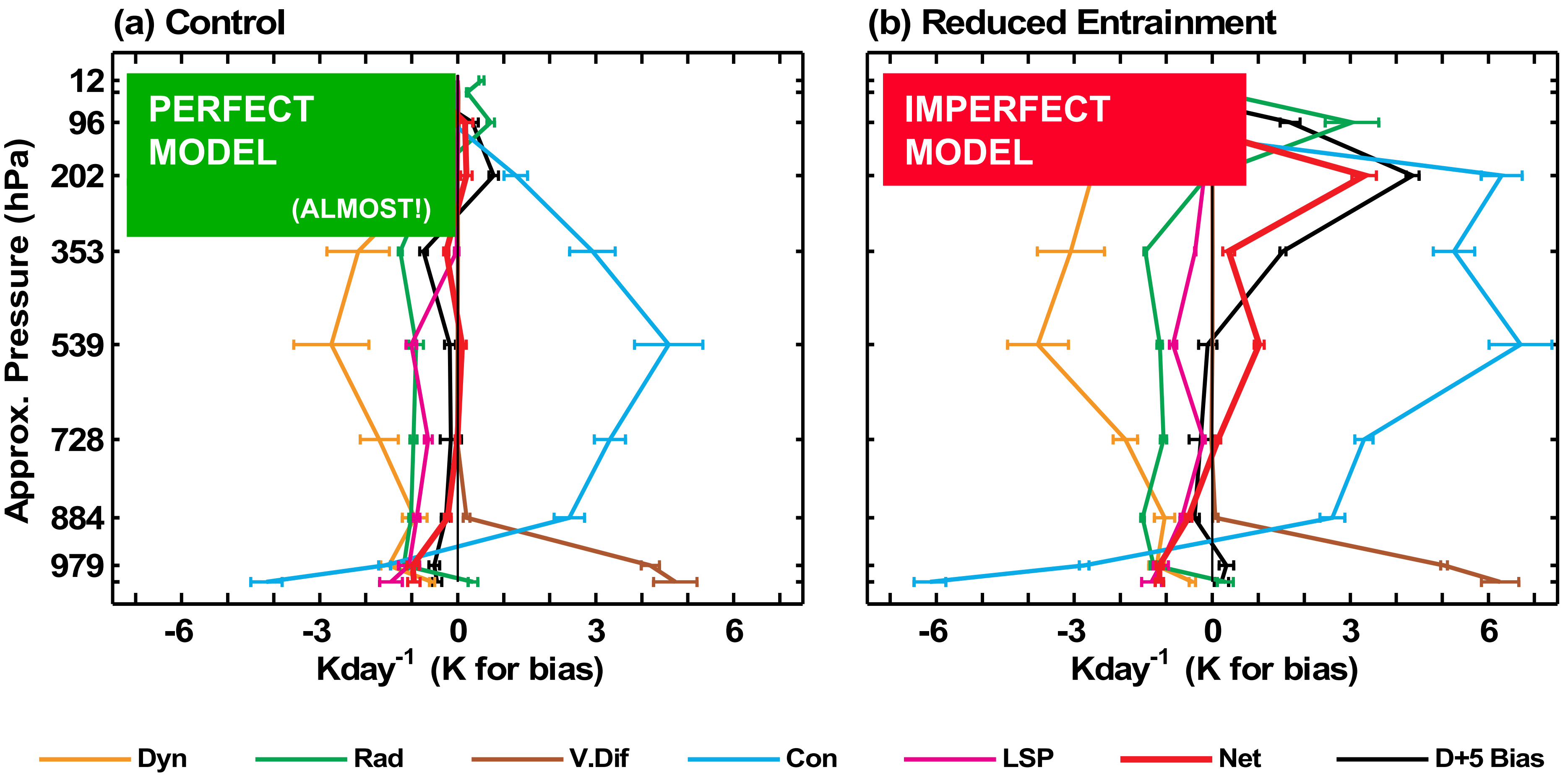


Focus on Amazon/Brazil region (300°E-320°E, 20°S-0°N) as it should not favor the CONTROL model

The Amazonian precipitation deficit exists at medium and seasonal ranges

Modelled precipitation is accumulated over 31x4 integrations with start times 2004/12/27 0Z to 2005/01/26 18Z. It actually represents precipitation between D+5 and D+5 ¼. Analysis (4D VAR, 6h window) is consistent with forecast model (CY29R1 T159 L60 TS=1800s).

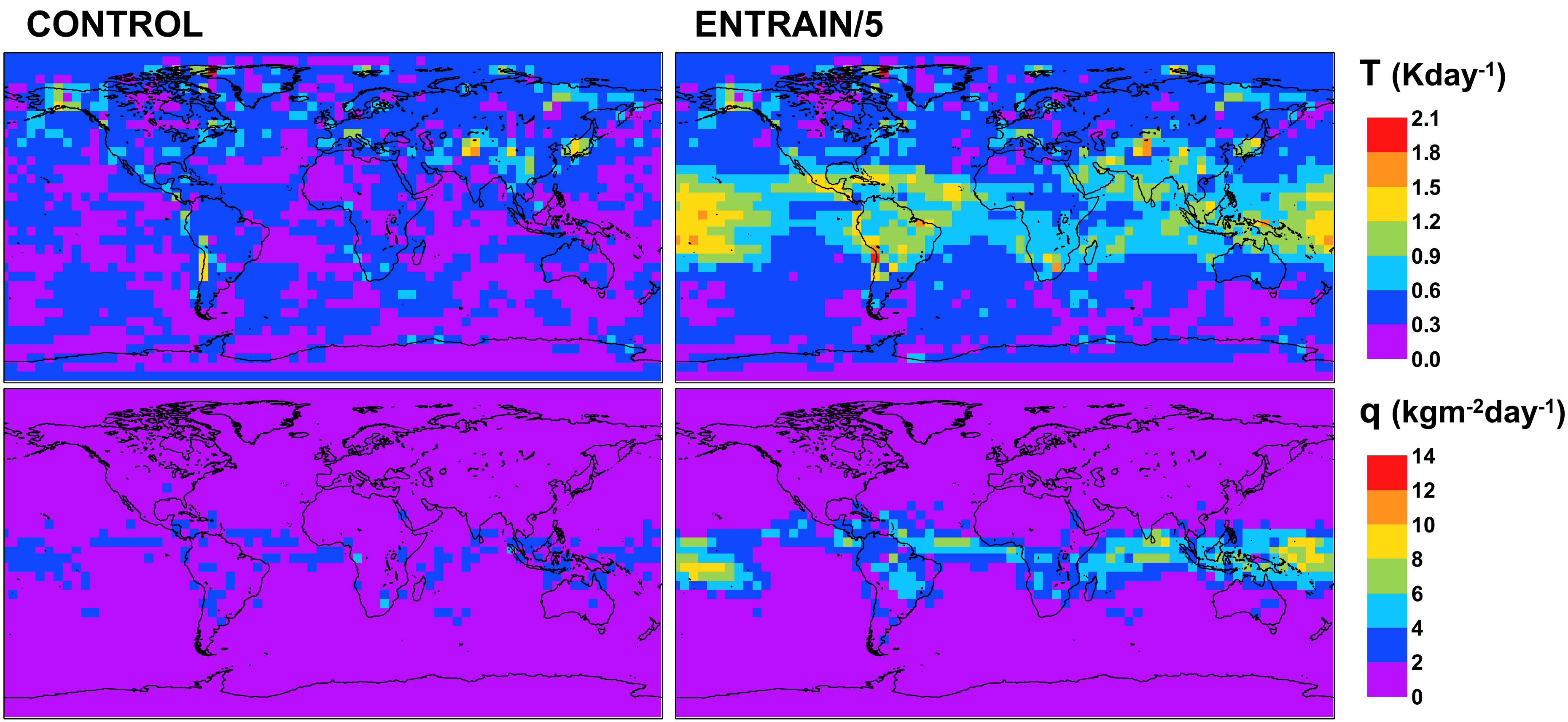
Amazon January 2005 Initial T Tendencies



Reduced Entrainment model is out of balance: reject or down-weight?

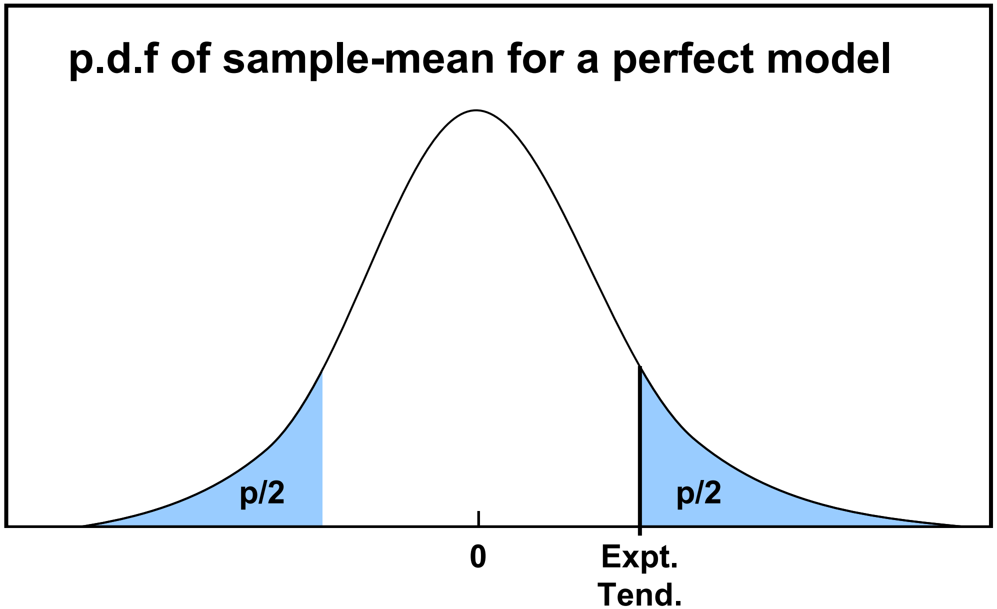
Amazon = [300°E-320°E, 20°S-0°N]. Mean of 31 days X 4 forecasts per day X 12 timesteps per forecast. 70% confidence intervals are based on daily means. CONTROL model = 29R1,T159,L60,1800S.

Vertically Integrated Absolute Tendencies



Mean of 31 days X 4 forecasts per day X 12 timesteps per forecast. Mass-weighted vertical integrals.
CONTROL model = 29R1,T159,L60,1800S.

How to Weight Models in Perturbed Ensemble



Calculate the probability that a given model is “perfect”

p = p(param,x,y,z)

= probability that a zero population-mean tendency cannot be rejected

Possible methodology:

Average p over parameters (T,q,u,v)

Vertically integrate

Integrate over tropics and extra-tropics

$p_{PERF} \equiv p_{TROP} \times p_{EX\text{-}TR}$

	Probability that model fast physics is perfect
CONTROL	0.20
ENTRAIN/5	0.12

Cost of Assessing Models with Multiple Pert^{n}s

31 day Initial Tendencies ≡ 5 years CGCM

Assessment of Coupled Climate

$$C'_{p_1,p_2,\ldots,p_n} = C'_{p_1} + C'_{p_2} + \ldots + C'_{p_n} \quad ?$$

Murphy et al. (2004): 23 "fast physics" parameters over 5 processes, 2 to 4 values

Linear: 24 models to assess

Non-linear: 15,000,000,000 models to assess

Assessment of Initial Tendencies

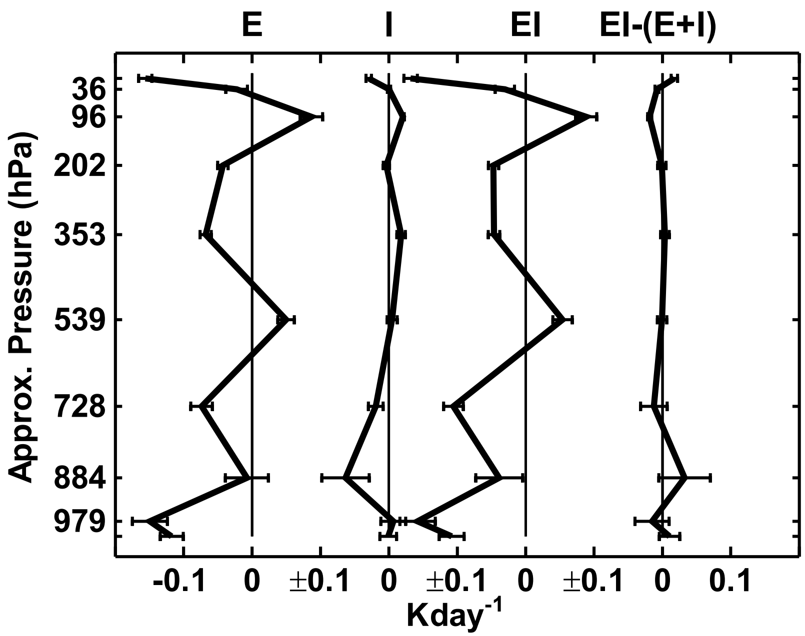
$$\frac{\partial M_{p_1,p_2,\ldots,p_n}}{\partial t} = \frac{\partial M_{p_1}}{\partial t} + \frac{\partial M_{p_2}}{\partial t} + \ldots + \frac{\partial M_{p_n}}{\partial t} \quad ?$$

Non-linear tendency term not significantly different from zero in troposphere

Initial Tendencies may be "linear enough"

Linearity between processes: 1275 models to assess

Anomalous T Tendencies at 60^{o}S



70% confidence intervals shown
E = ENTRAINX3 - CONTROL
I = ICE SIZE X 2 – CONTROL
EI = (ENTRAINX3 & ICE SIZE X 2) – CONTROL

Conclusions

Analysis Increments and Initial Tendencies

- **Assesses model 'fast physics' (NWP physics)**
  - Unlike forecast skill which is complicated by unknown inherent predictability
- **Assesses model processes when they are acting on atmospheric states close to reality**
  - Single column models: Atmospheric state inconsistent with model physics
  - AGCM climate simulations: Atmospheric state has drifted towards model manifold
- **Can be applied to Climate Models**
  - Majority of climate model perturbations are associated with fast physics
  - Weight each model by the probability that it is 'perfect' (?)
  - More powerful than assessing annual-mean climates
  - Big computational cost savings: Can be devoted to 'slow physics'
  - Part of a more seamless approach

Implications of Variational Bias Correction

- May attribute some large-scale model bias to observations. However …
- There are anchor points: Radiosonde, AMSUA-14, Radio Occultation
- Any bias left is more likely to be due to model error
- VARBC is good for a fair comparison of models

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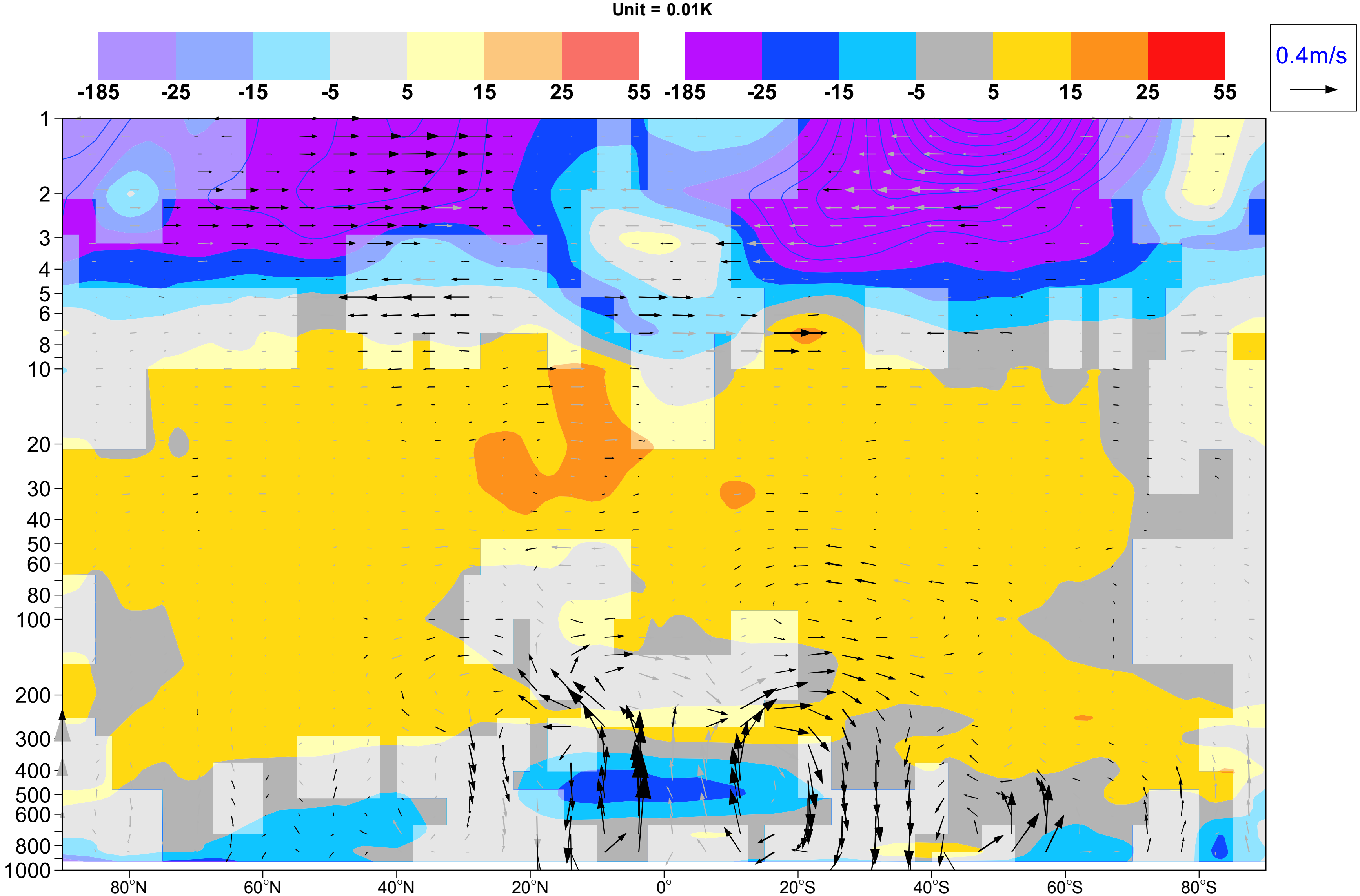
T and (v,ω) Analysis Increments MAM09



Based on MAM 2009 0 & 12 UTC operational analyses. Significant values (5% level) in deep colours.

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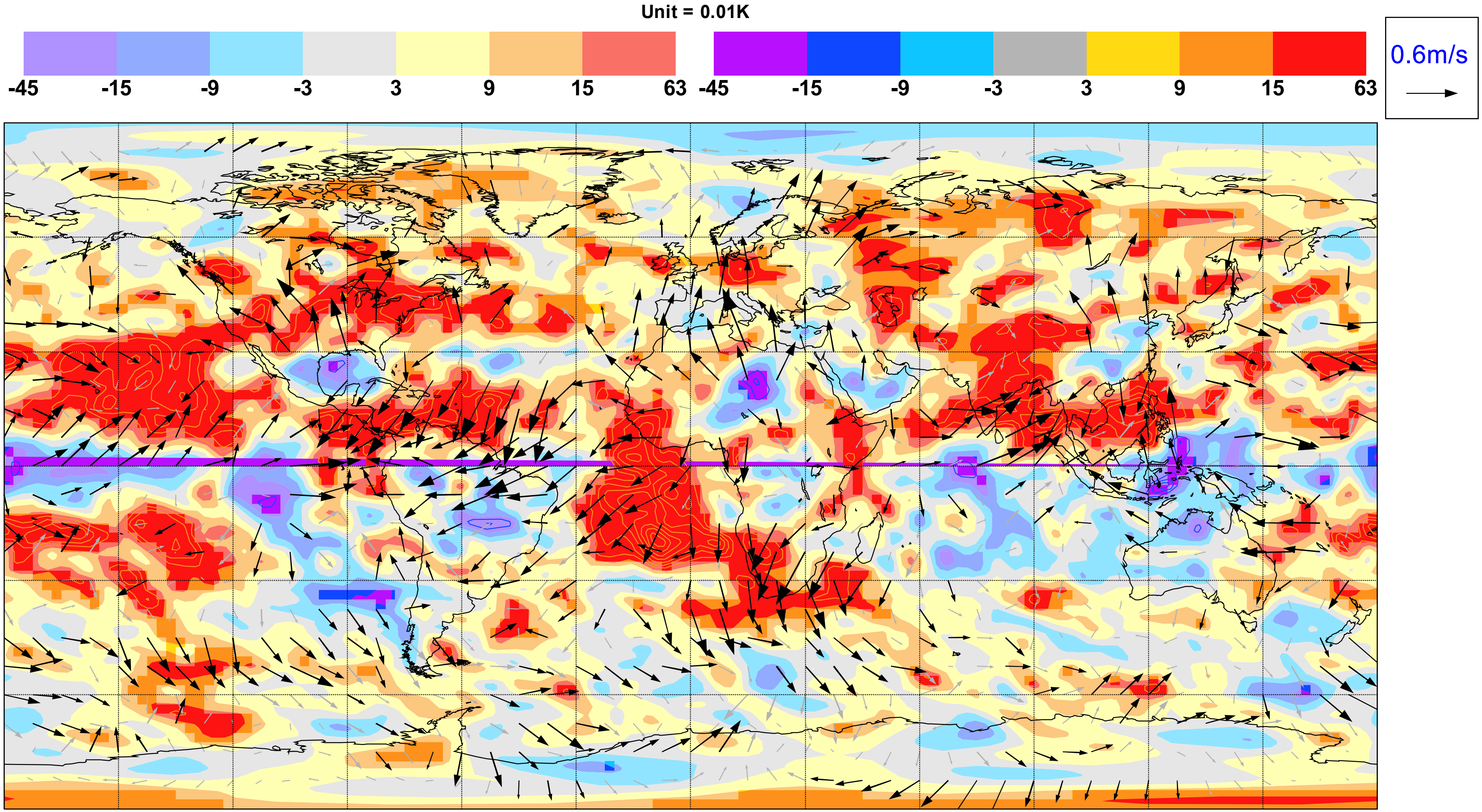
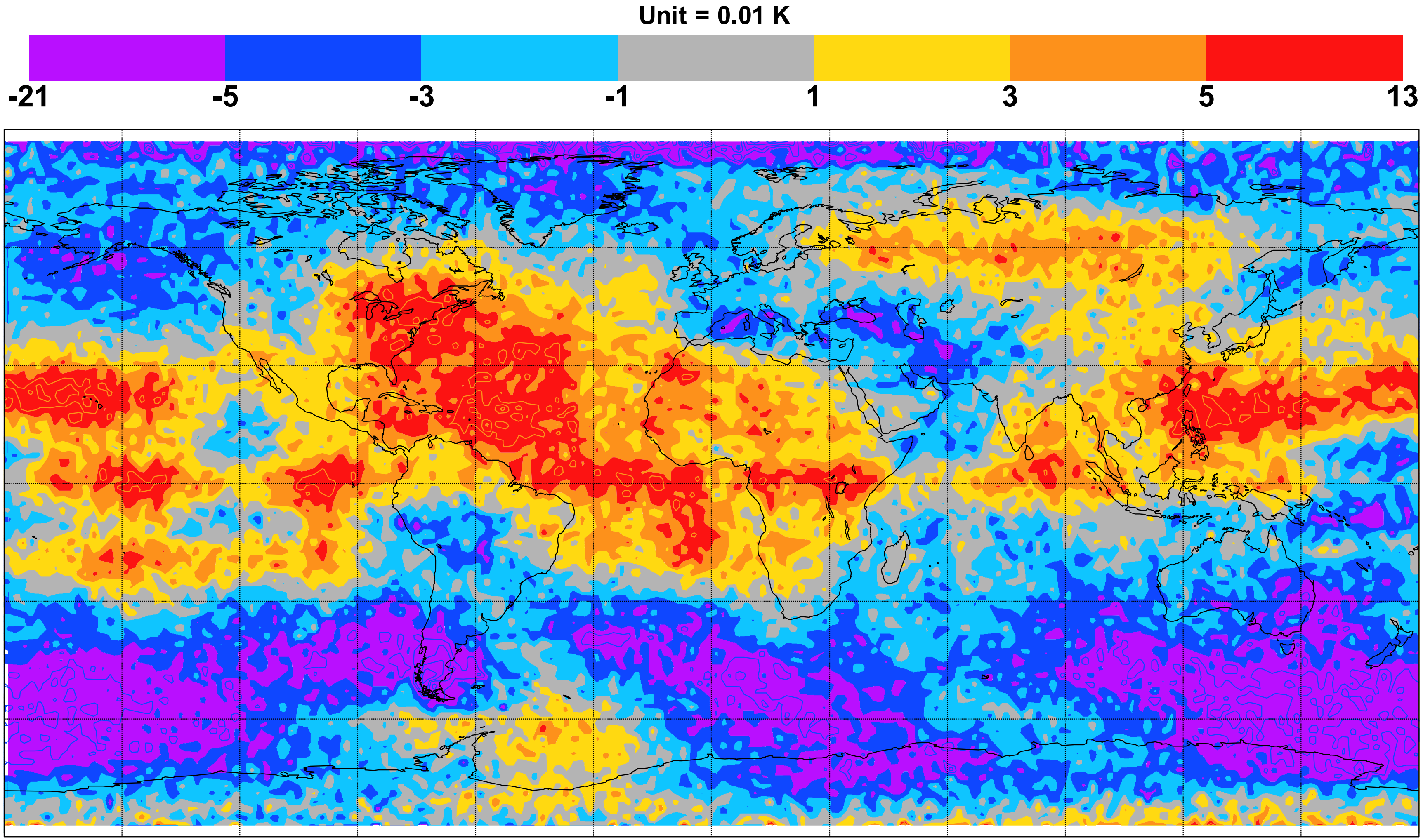
T and (u,v) An. Incs. at 10hPa MAM09



Based on MAM 2009 0 & 12 UTC operational analyses. Significant values (5% level) in deep colours.

AMSUA Channel 12 (~T10) Obs-F.G. MAM09



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