Using NWP to assess climate models

(Harnessing the power of data assimilation)

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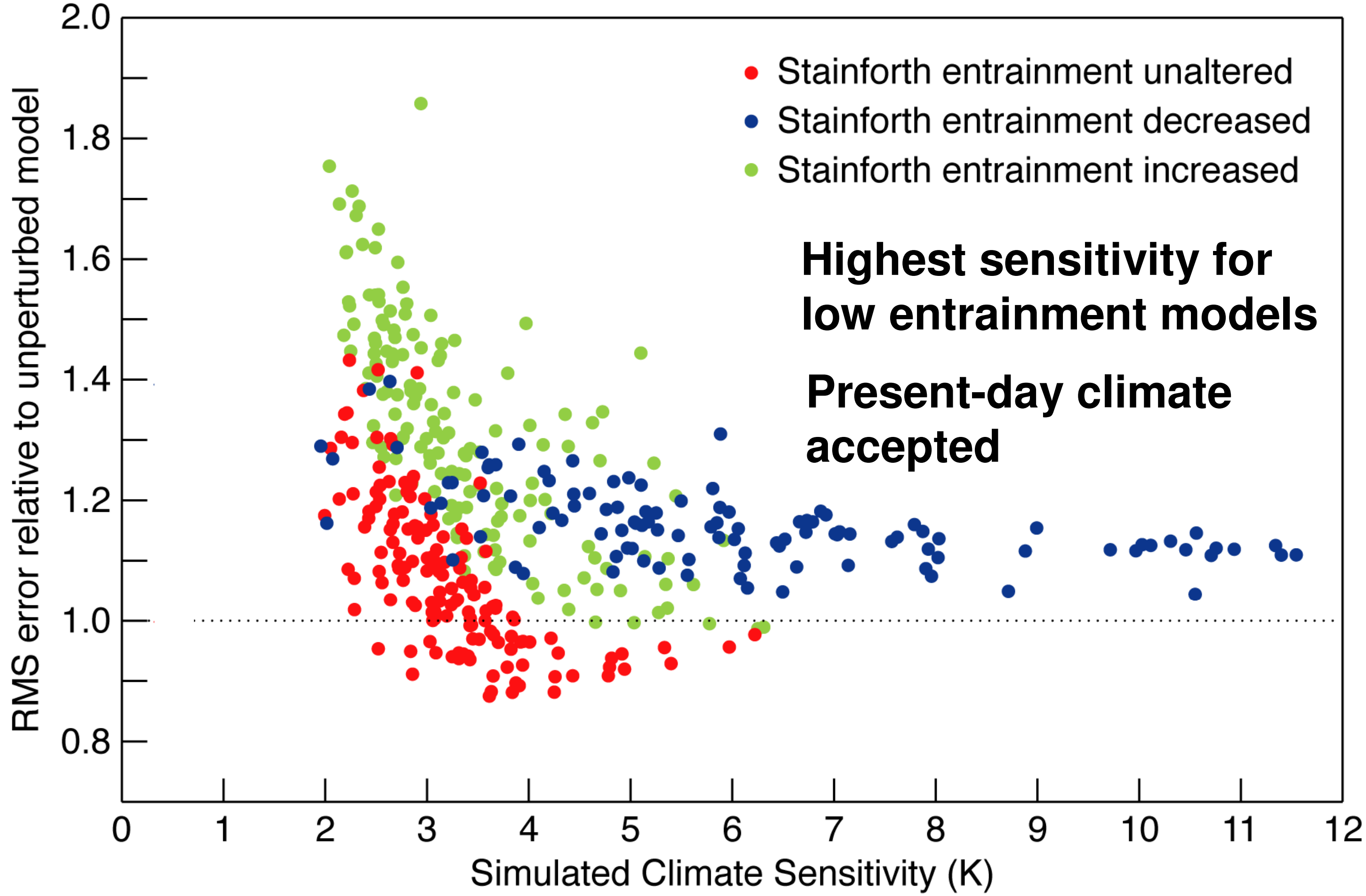
Parameters & Uncertainties (HadAM3)

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

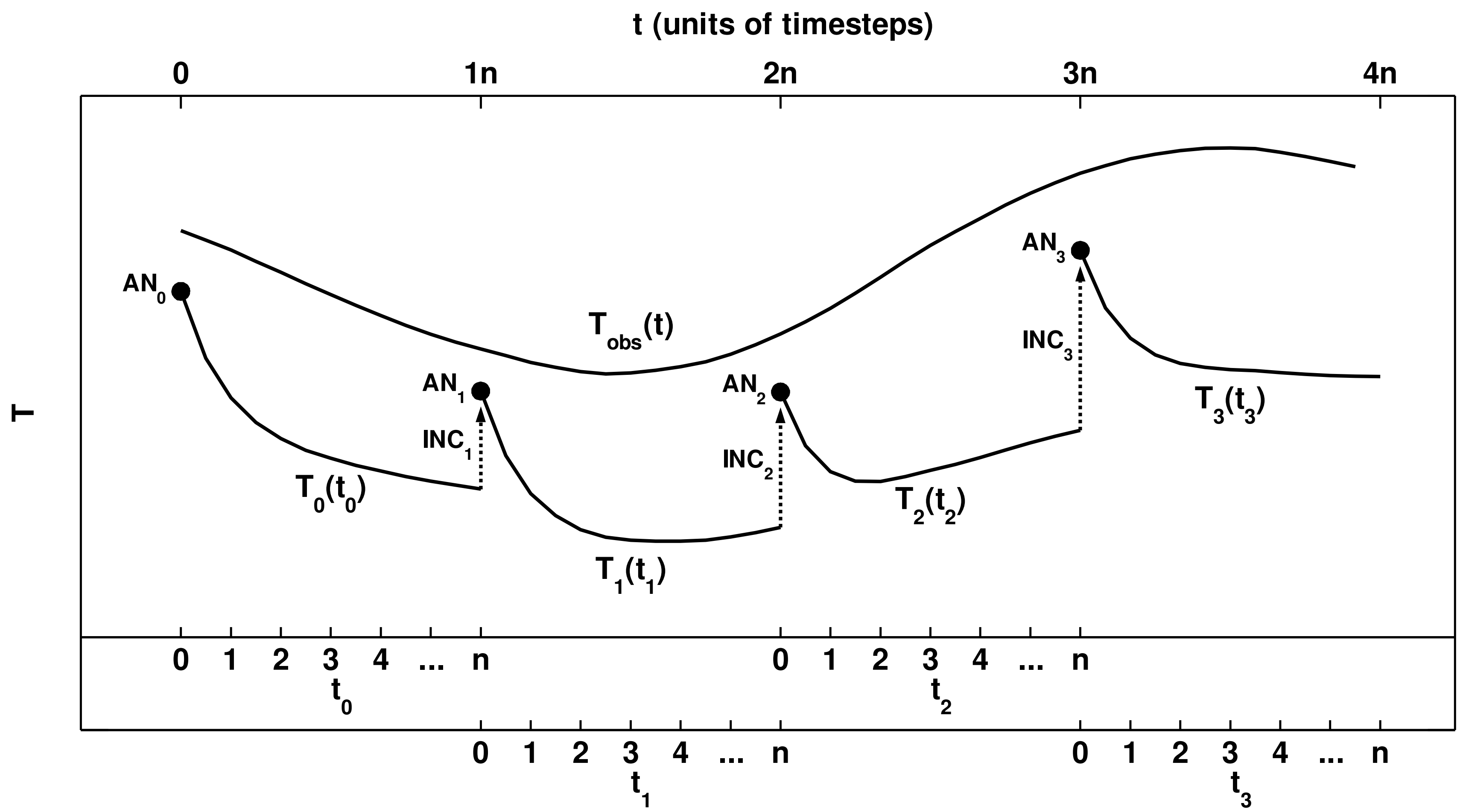
Representative selection of parameters and uncertainties used by Murphy et al., 2004: *Nature*, **430**, 768-772.

Climate: Error vs Sensitivity

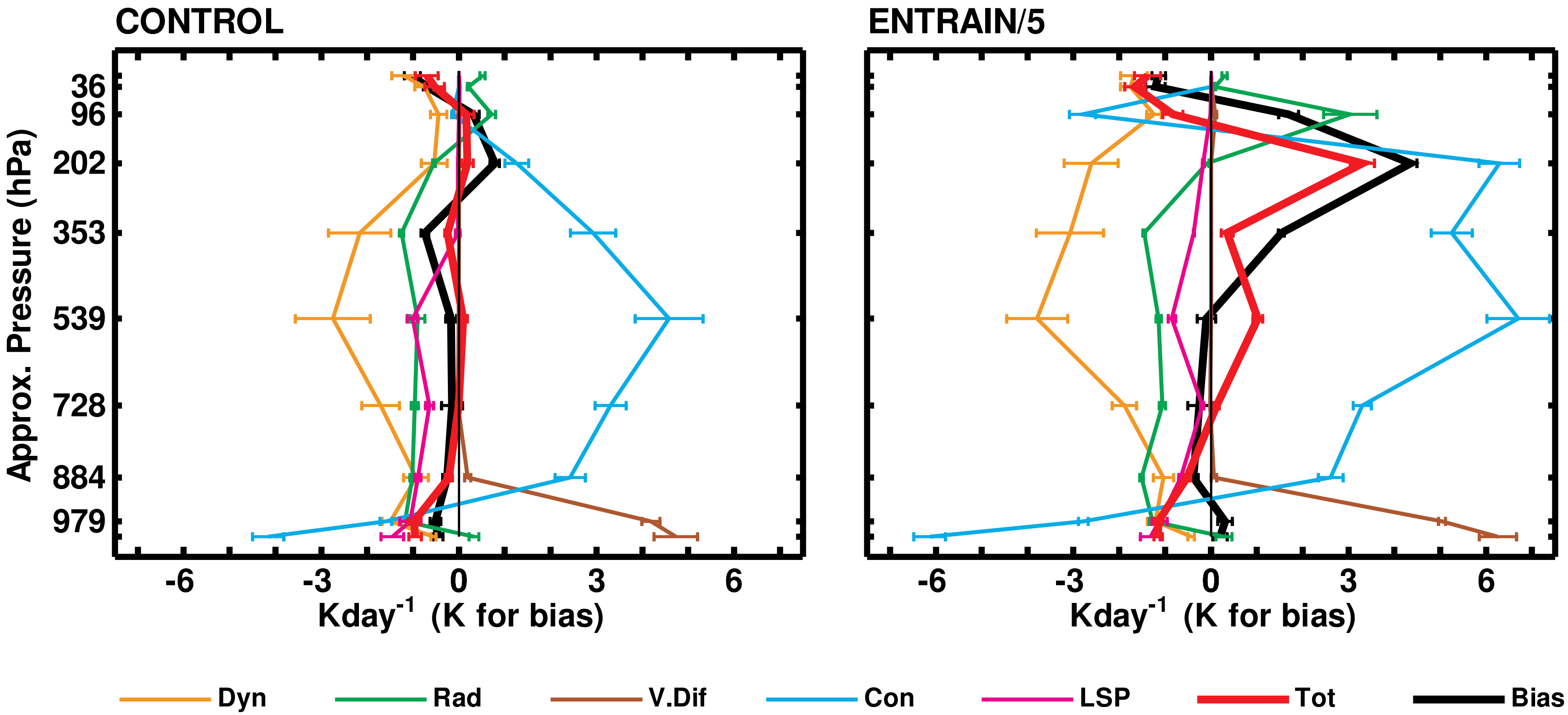


Combined RMSE of 8 year mean, annual mean T_{2m}, SLP, precipitation and ocean-atmosphere sensible+latent heat fluxes (equally weighted and normalised by the control). Stainforth et al., 2005, *Nature*, **433**, 403-406.

The data assimilation / forecast cycle



Amazon January 2005 Initial T Tendencies

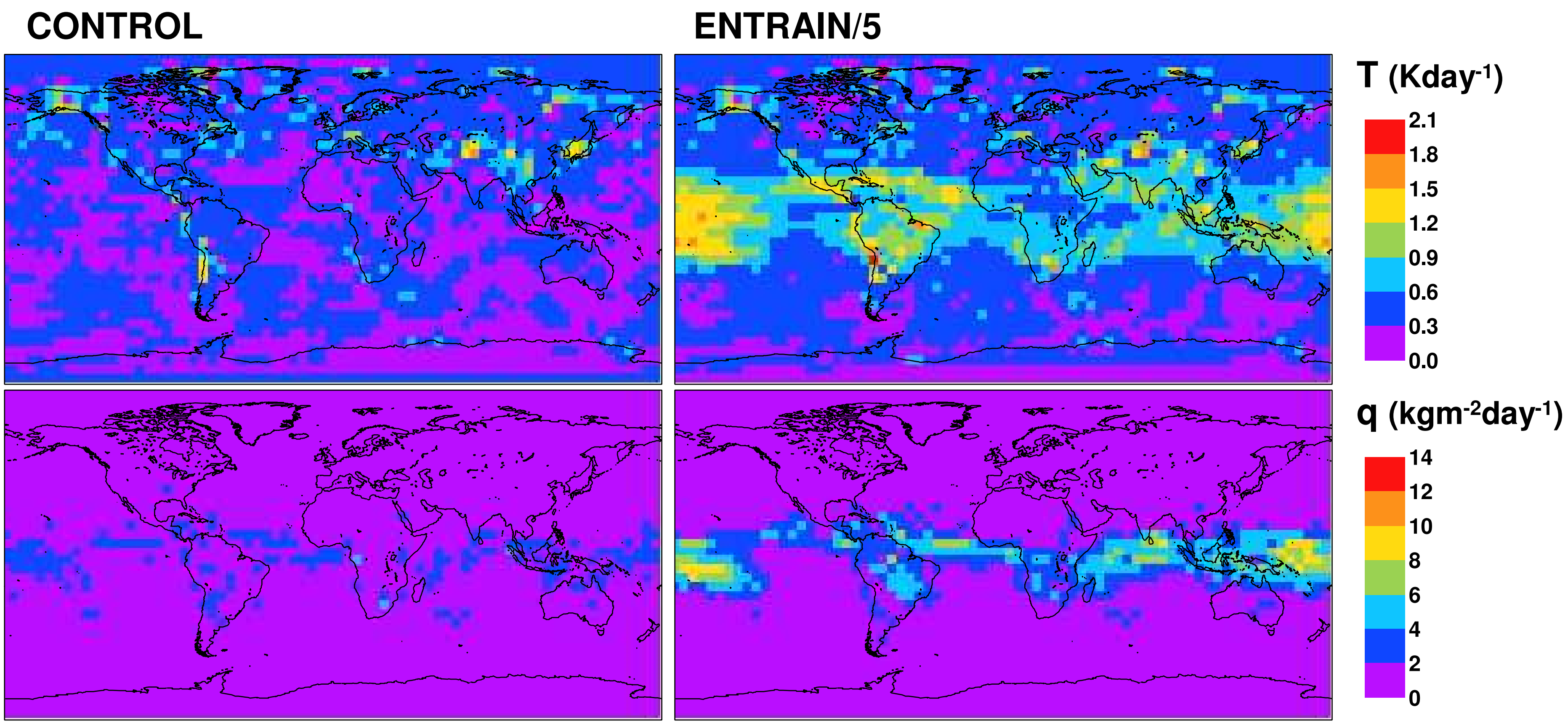


ENTRAIN/5 out of balance: reject or down-weight?

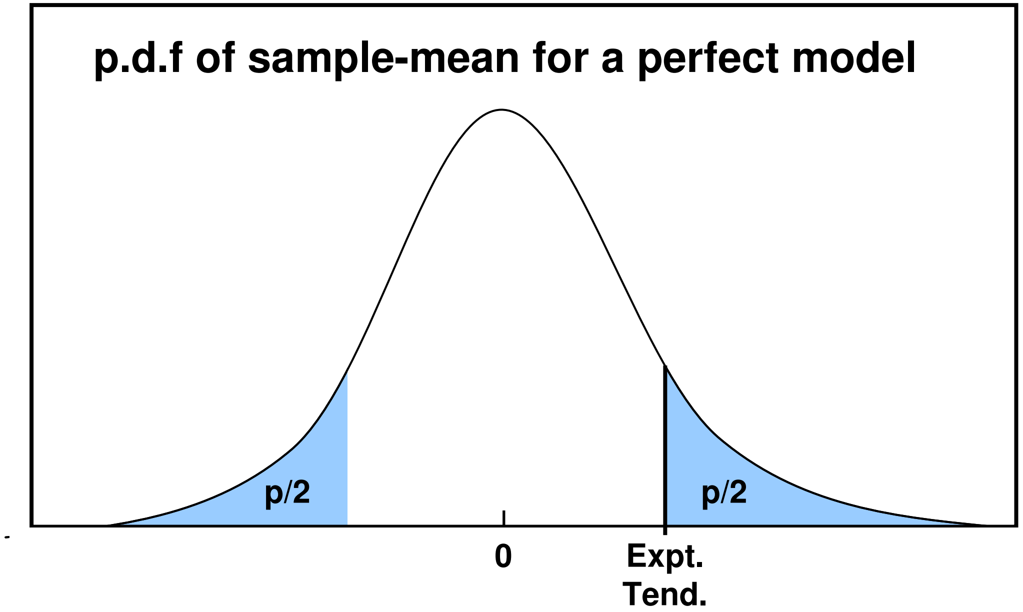
By D+5 balance is restored but it is complicated by interactions between processes (non-linearity)

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



How to weight each model



Calculate the probability that each model is "perfect"

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

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

Possible methodology:

Average 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

Linearity and Cost

31 day Initial Tendencies ≡ 5 years CGCM

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

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

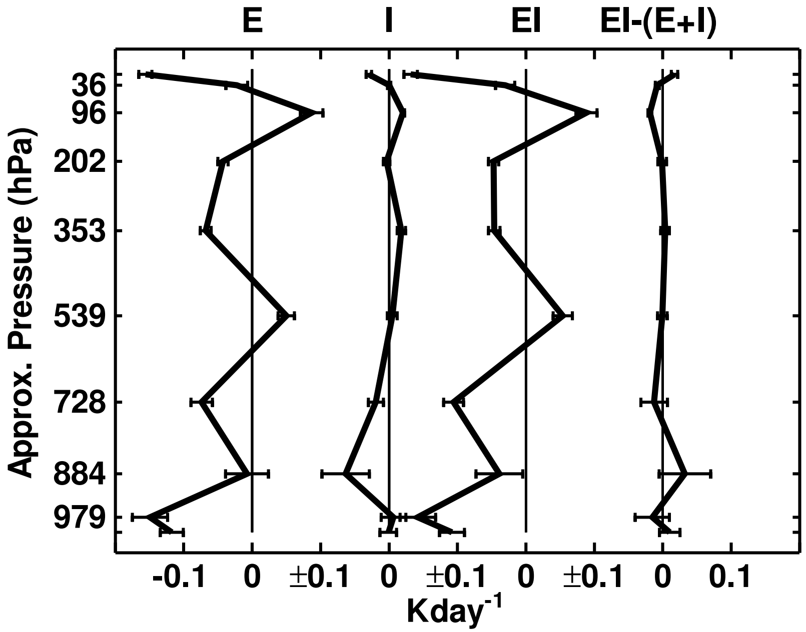
$$\frac{\partial M_{p_1,p_2,\ldots,p_n}}{\partial t} = \frac{\partial M_{p_1}}{\partial t} + \frac{\partial M_{p_2}}{\partial t} + \ldots + \frac{\partial M_{p_n}}{\partial t} \quad ?$$

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°S

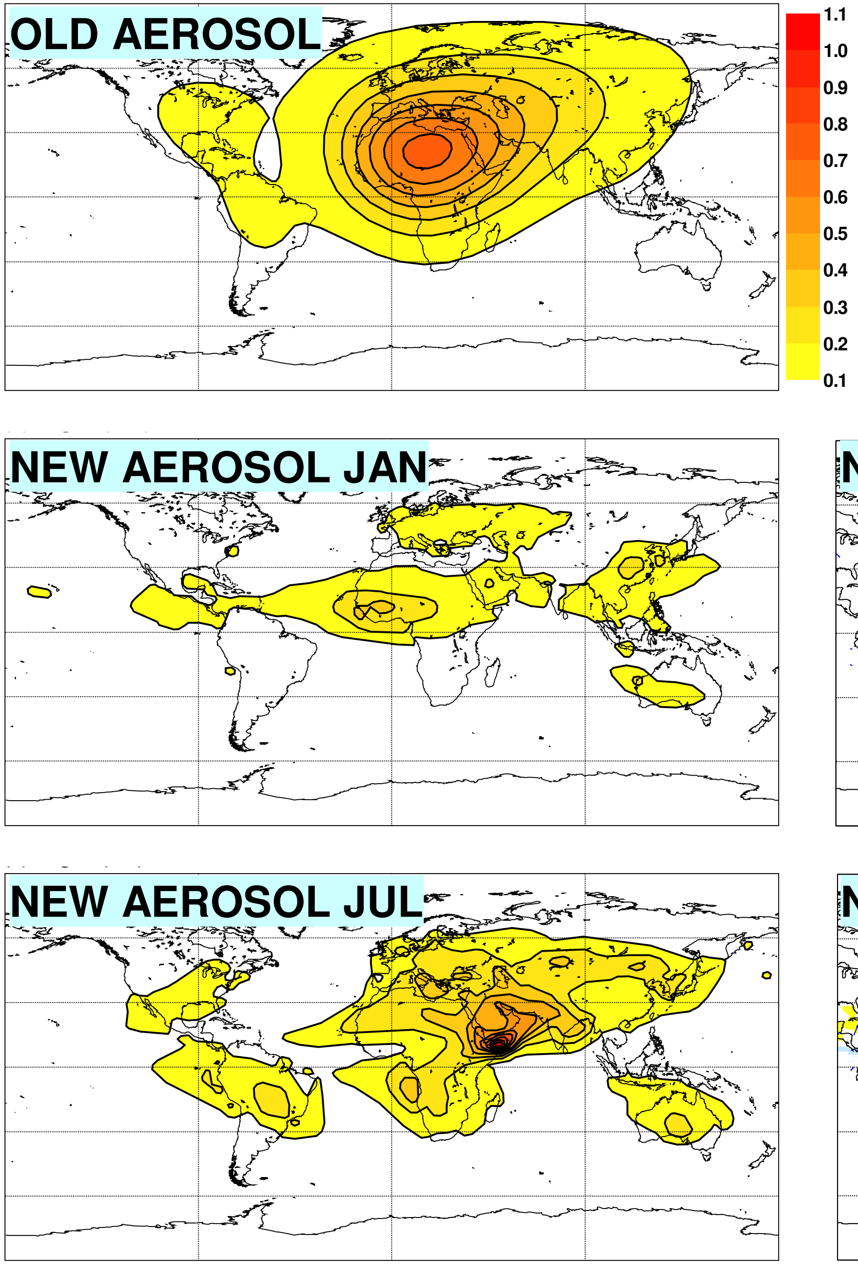


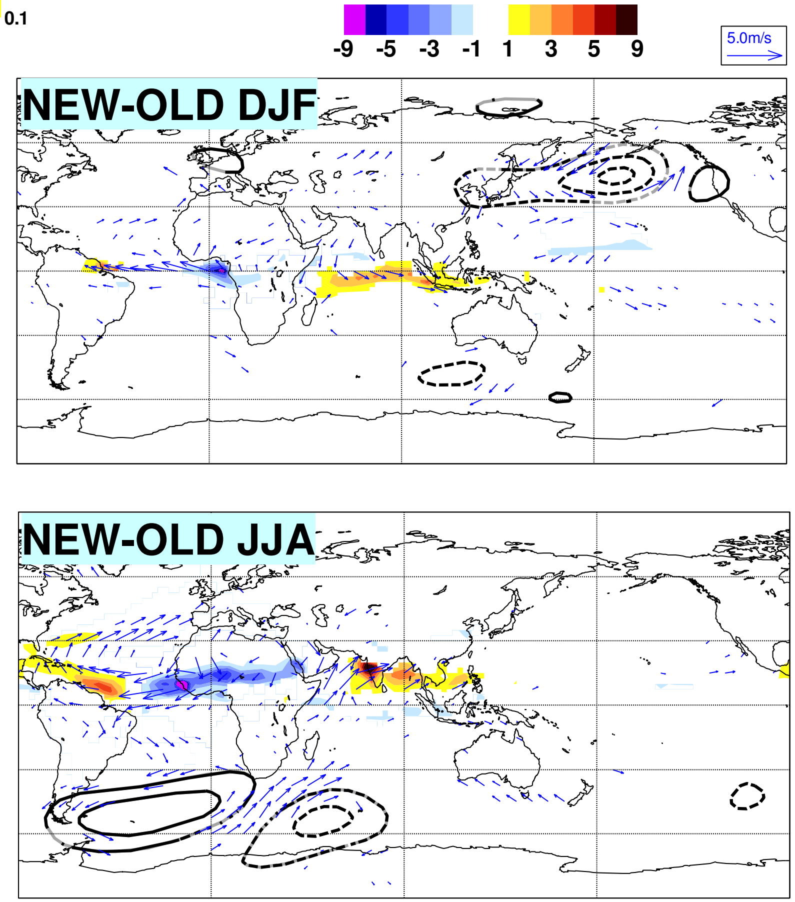
70% confidence intervals shown
E = ENTRAINX3 - CONTROL
I = ICE SIZE X 2 – CONTROL
EI = (ENTRAINX3 & ICE SIZE X 2) – CONTROL

Seasonal Impact of Aerosol Change:

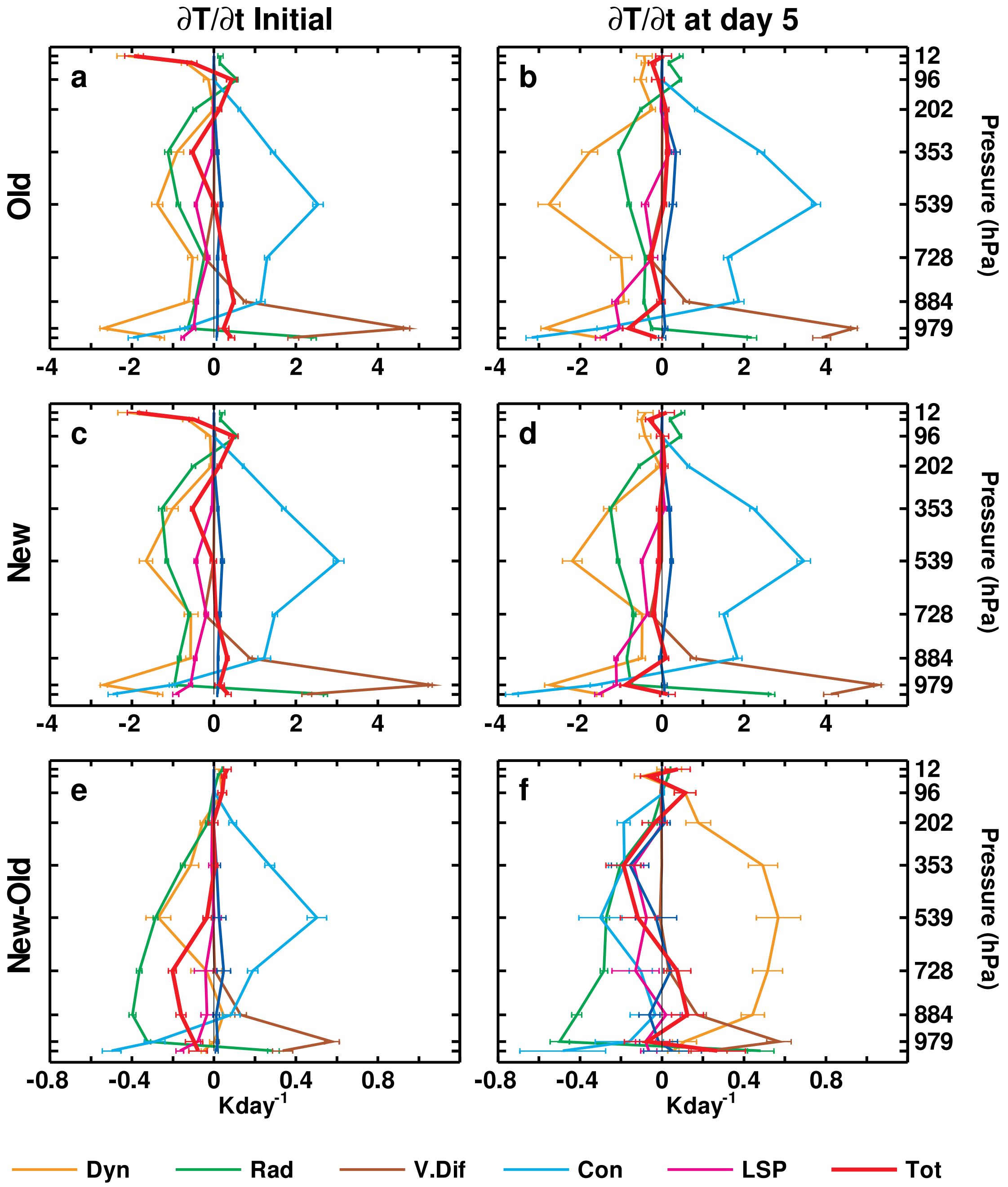
Precipitation coloured in mmday^{-1}
Z_{500} contour interval 2 dam
$\underline{v}_{925}$ vectors

Optical Depth @ 550nm





Local Response: Tendencies over N. Africa (Jul 2004)



Old aerosol

- Initial lower-tropospheric heating error (red)
- At D+5, increased convection (blue) & ascent (orange)

New aerosol

- Initial & day 5 profiles more stable

Difference

- Reflects radiative changes (green)

D+5 Precipitation

Old: 5.8mmday^{-1}

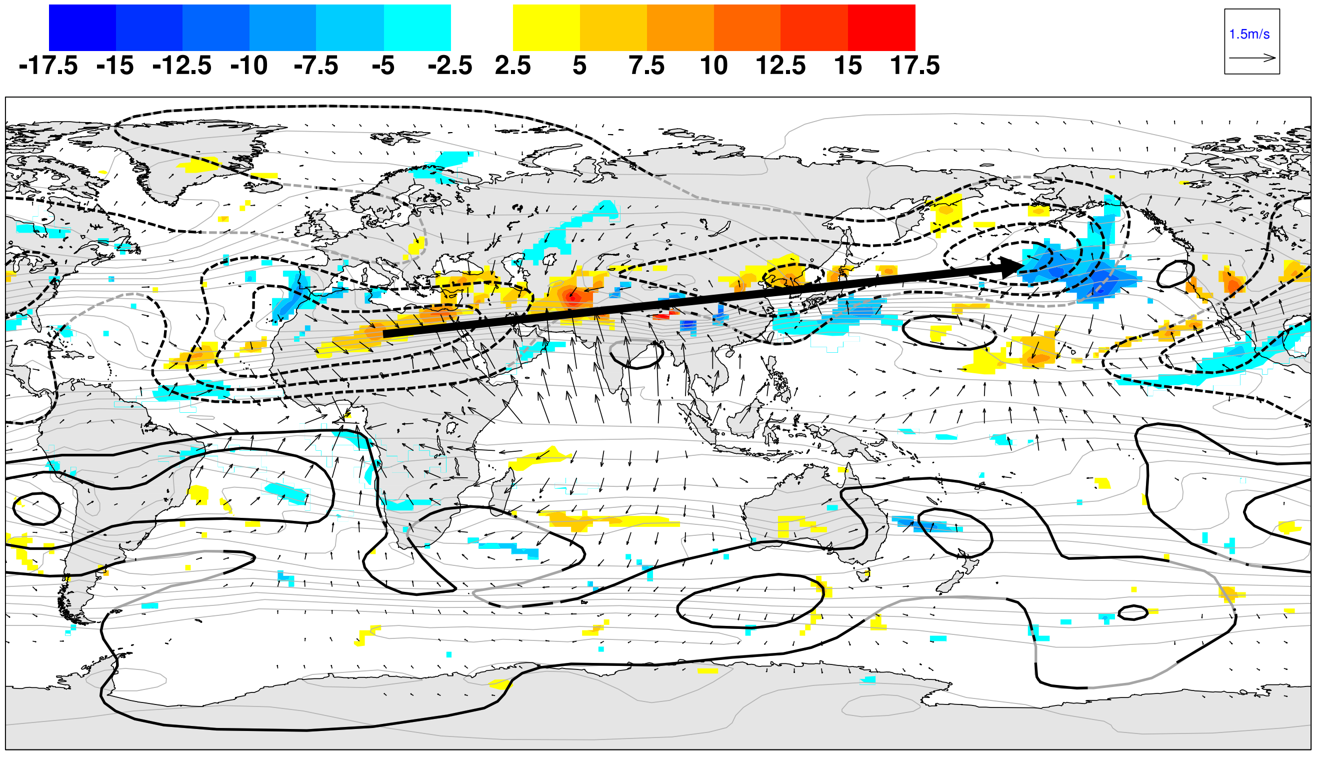
New: 4.8mmday^{-1}

GPCP: 4.7mmday^{-1}

Region = 20^{o}W-40^{o}E, 5^{o}N-15^{o}N

70% confidence intervals shown

Remote Response: 250hPa Streamfunction, Divergent Wind and Rossby-Wave-Source



Aerosol Change → **Local Convection Improvement**
→ **Remote Tropical Convection Improvement (via equatorial waves)**
→ **Changes in Extratropical Vorticity Forcing**
→ **North Pacific Bias Improvement**

RWS coloured with contour $2.5x10^{-11}s^{-2}$. Streamfunction thick contours with interval $2x10^{6}m^{2}s^{-1}$. Mean absolute vorticity thin grey with interval $10^{-5}s^{-1}$