ENDGame, a Tropical Tropopause warm bias, and Lagrange vs Hermite

Chris Smith, John Thuburn and Nigel Wood

Outline of Presentation

- ENDGame
- Symptoms of problem
- Analysis of problem
- Solution
- Summary

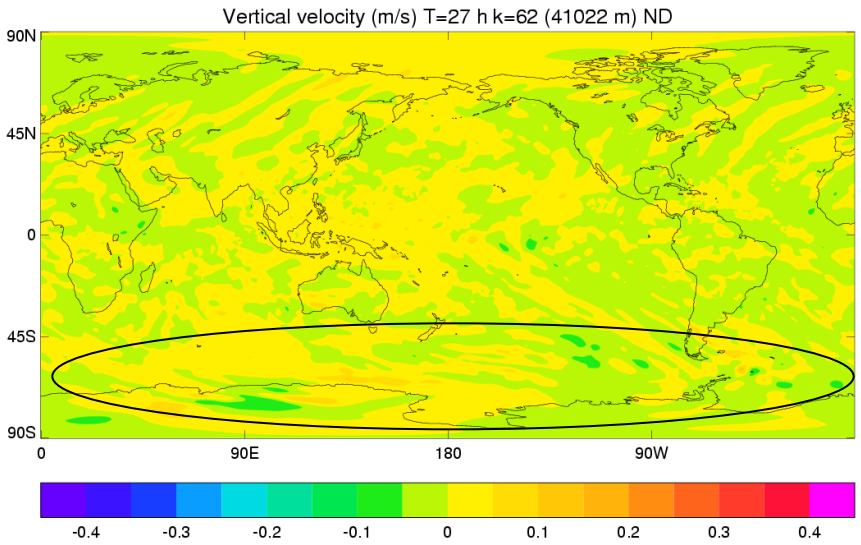
ENDGame

- New Dynamics:
  - Current operational core of Unified Model (Unified ⇒ same model for NWP and climate)
  - SISL, FD, C-grid Charney-Phillips
- ENDGame = Even Newer Dynamics:
  - Improved (iterative) solution procedure
  - Similar approach to GEM: Côté et al. (1998)
  - More centred, approaching second-order in time

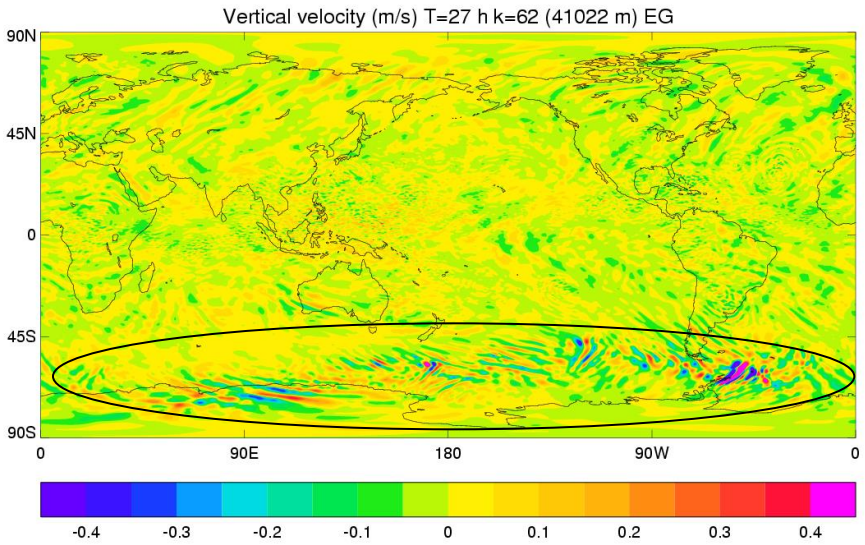
⇒ Improved accuracy, stability and scalability

An example: stratospheric gravity waves

Vertical velocity at 41km



New Dynamics



ENDGame

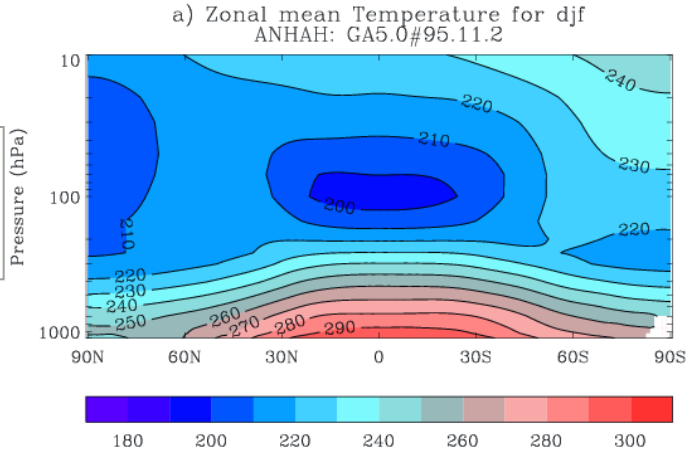
Simon Vosper

ENDGame

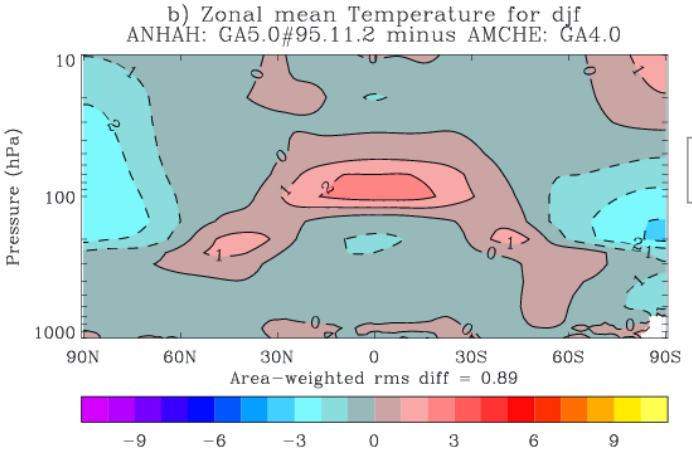
- Undergone two years of extensive testing and trialling for both NWP and Climate
- Currently being run in parallel with operational model
- Targeted at replacing operational model in June
- En route…

Temperature bias in 20 year AMIP run

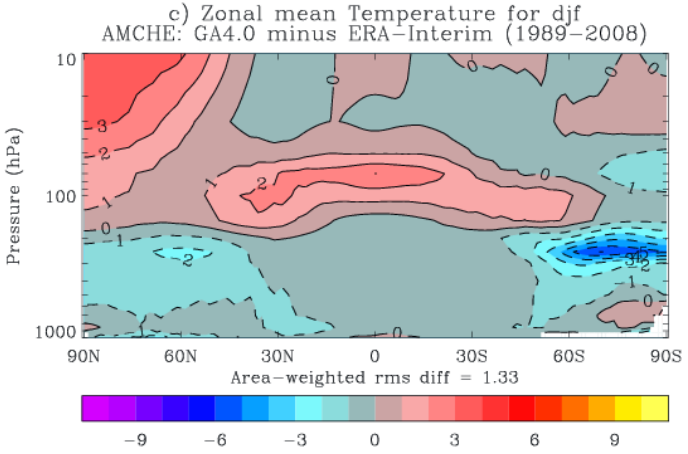
ENDGame zonal mean temperature



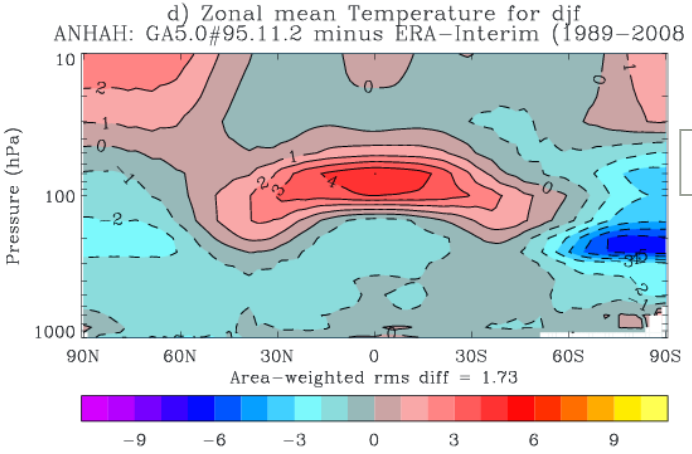
EG - ND



ND - ERA



EG - ERA



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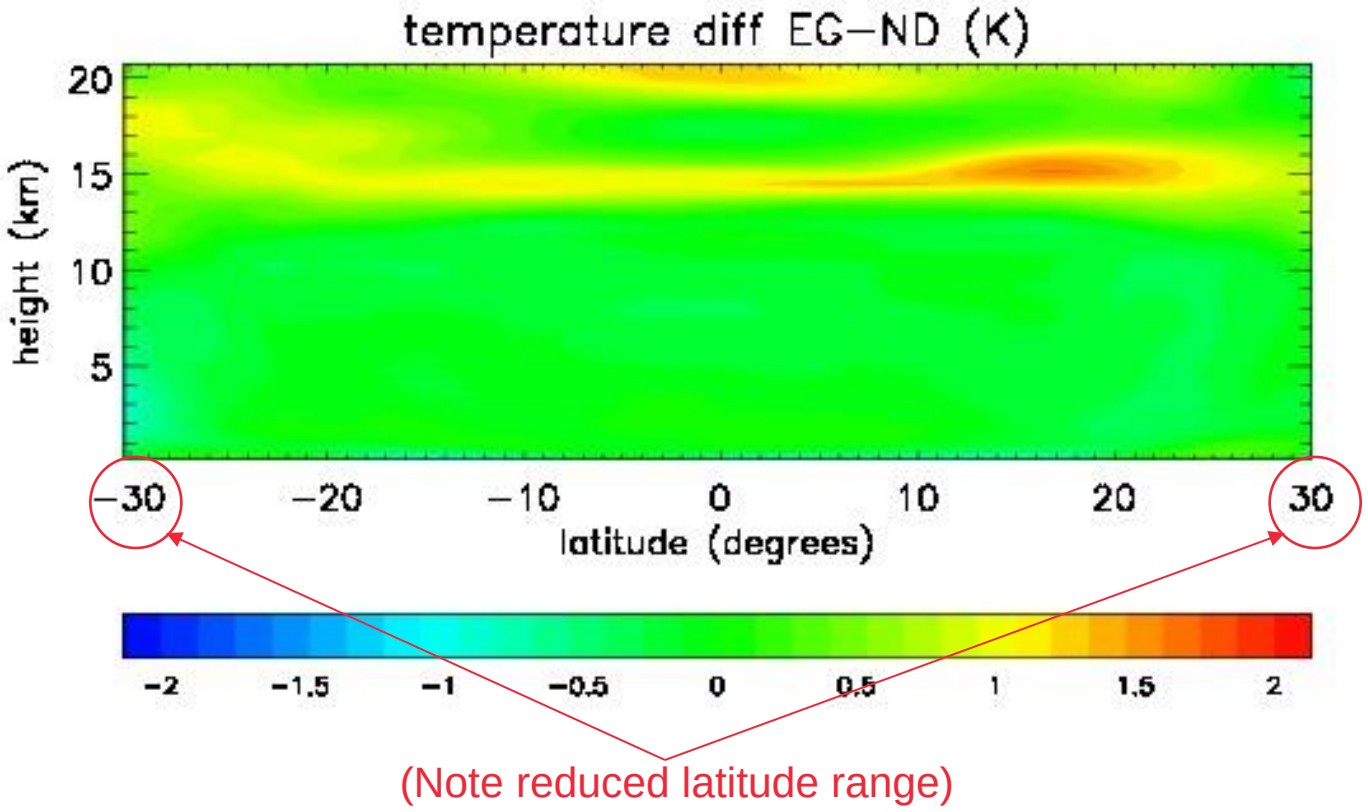
(ND=New Dynamics; EG=ENDGame; ERA=ERA-Interim)

Initial investigations

- ENDGame uses less off-centring (EG=0.55 cf. ND=0.7/1.0)
- More accurate cubic Lagrange interpolation for θ
  (cf. second-order scheme in New Dynamics)
- More accurate ∴ focused on physical parametrizations
- Changes impact bias, but none made significant changes
- Forced to consider the possibility that it could be the dynamics…

Held-Suarez results

ENDGame – New Dynamics

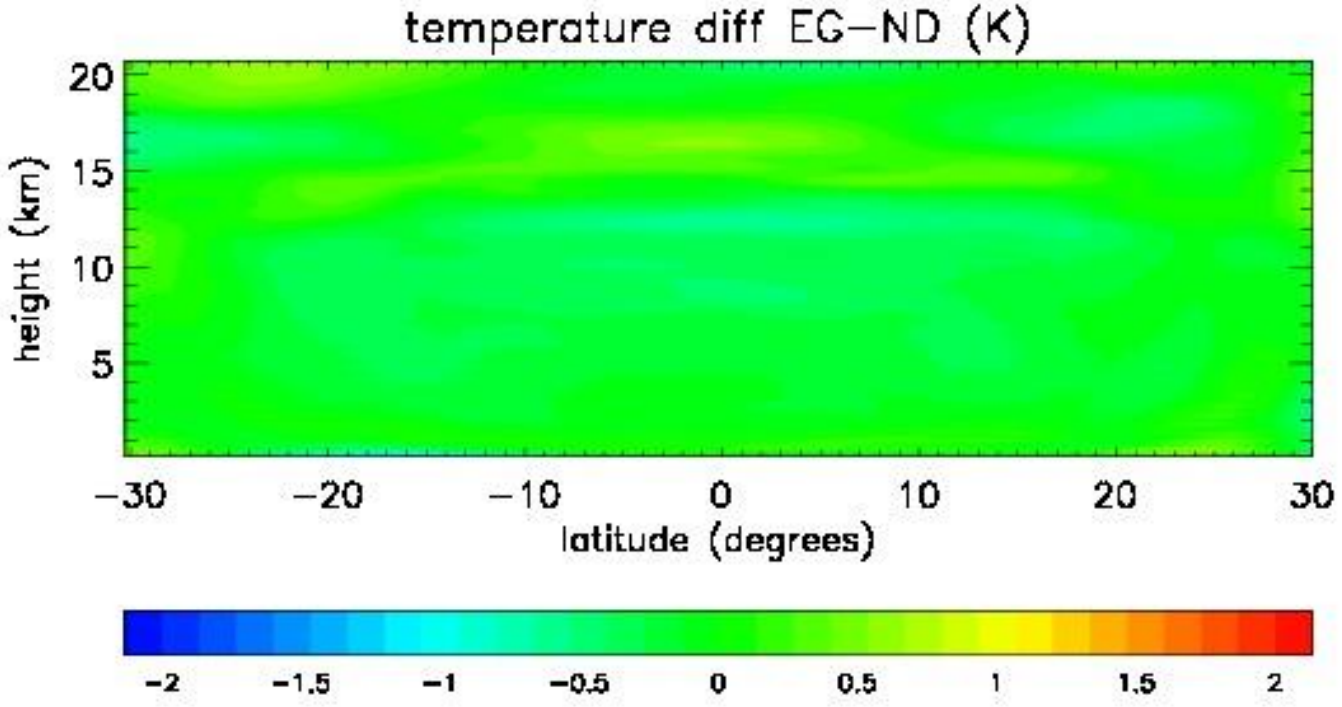


(Note reduced latitude range)

Similar amplitude and height, somewhat different structure

Damp w in ENDGame

ENDGame (w≈0) – New Dynamics

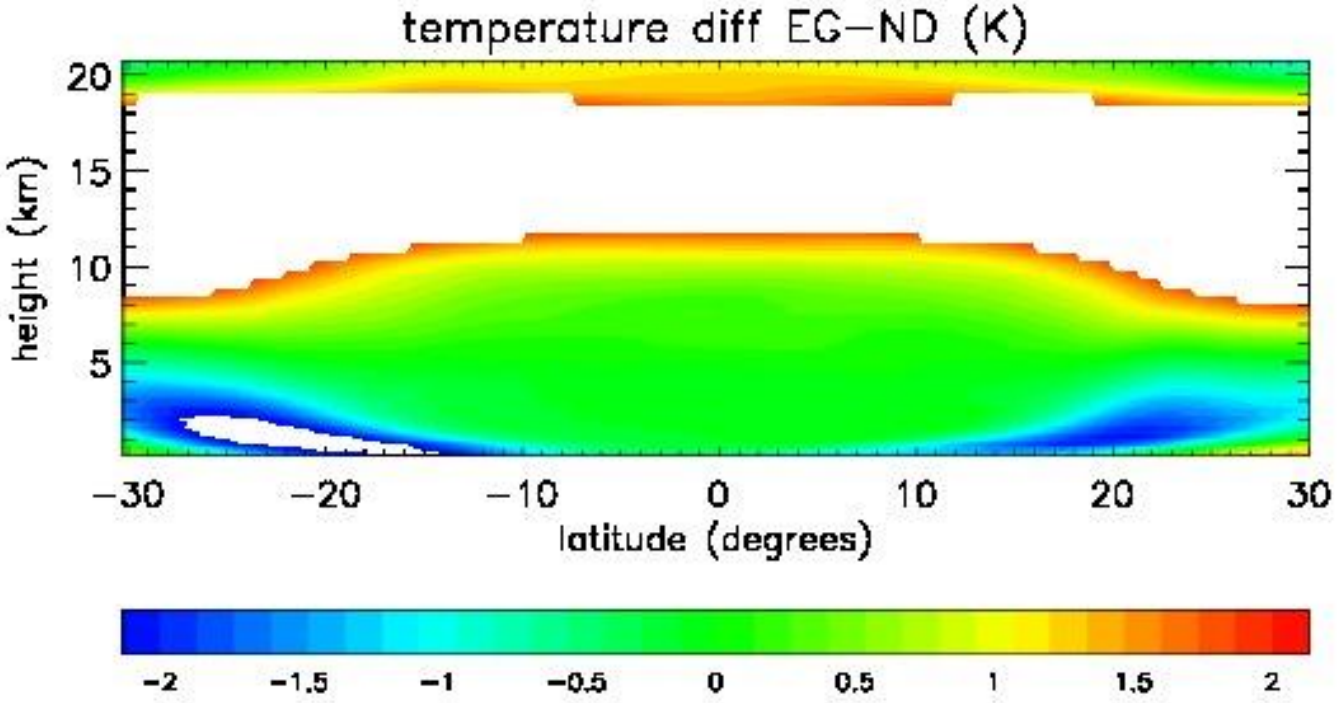


Bias directly linked to vertical advection

⇒ Experiment with ENDGame interpolation of θ

Trilinear θ interpolation

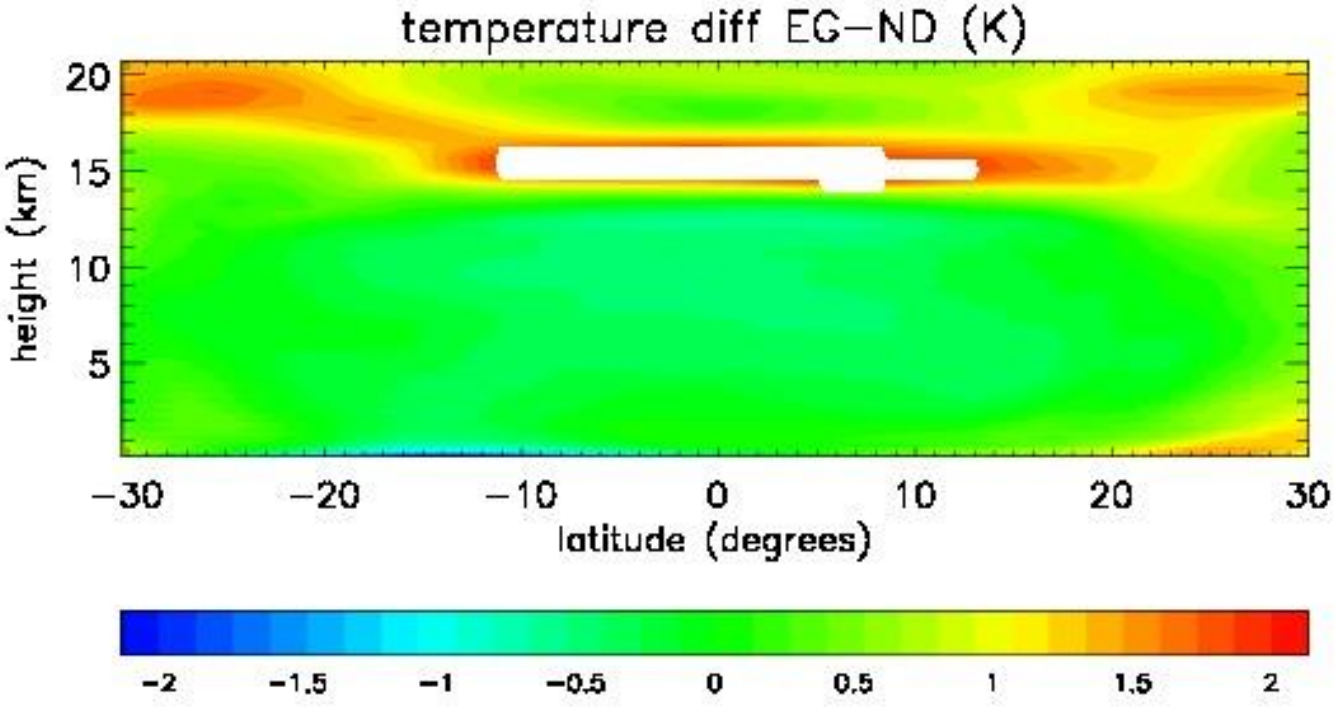
ENDGame (Trilinear) – New Dynamics



Bias worse!

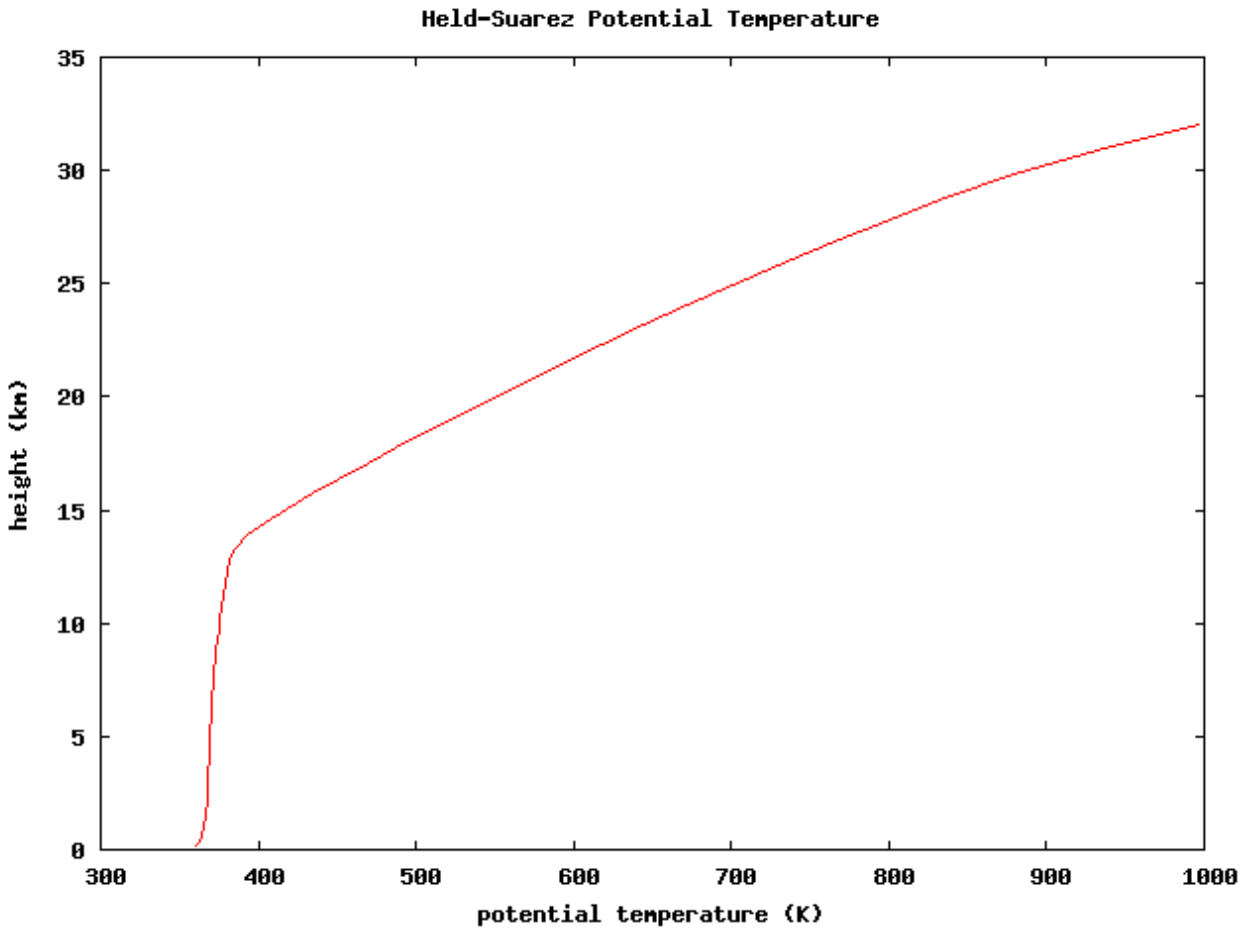
Quintic θ interpolation in vertical

ENDGame (Quintic) – New Dynamics



Bias also worse!

Held-Suarez profile



Z (km)

θ (K)

Advect vertically with oscillatory motion …

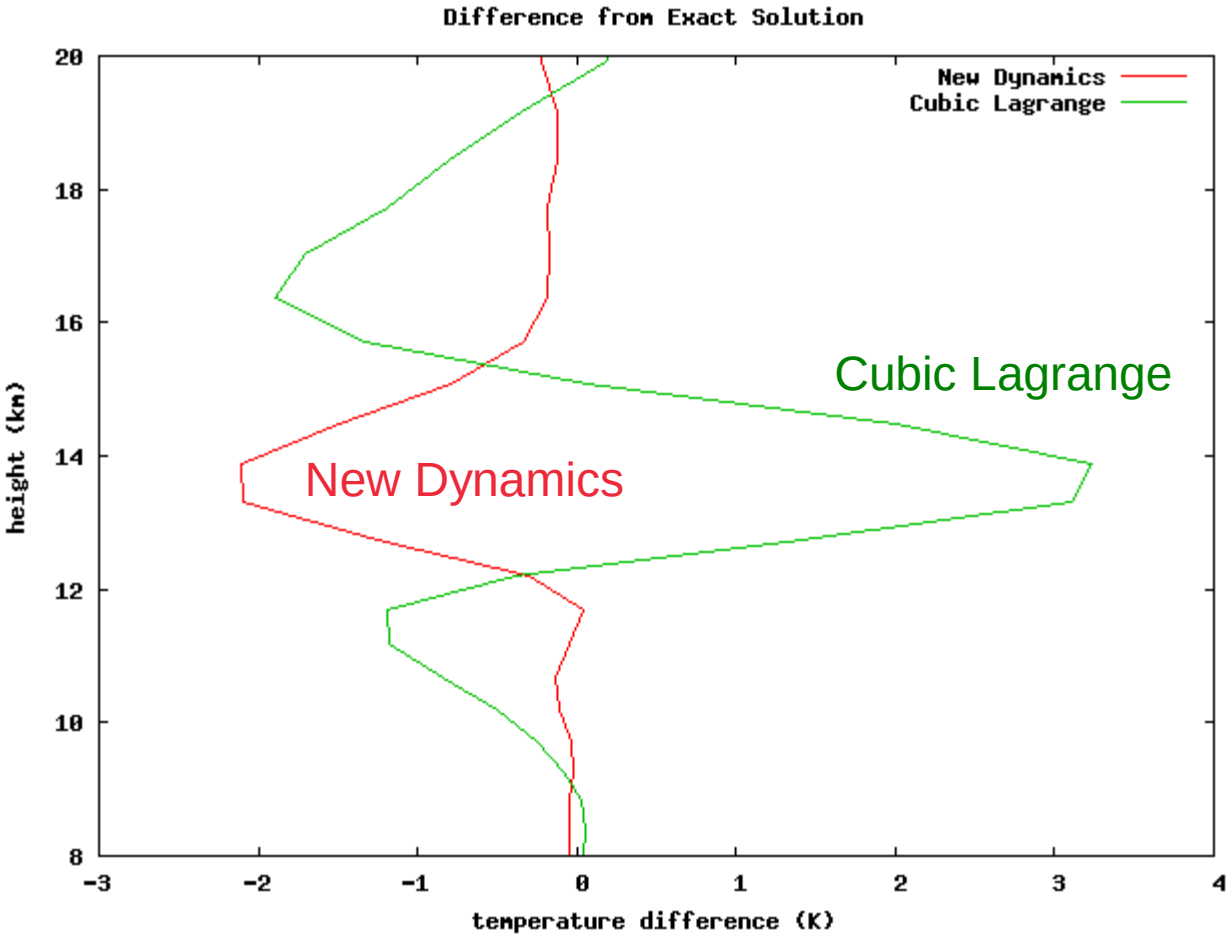
Vertical wind: $w(t) = w_{\max} \sin\left(\frac{2\pi t}{\tau}\right)$

where $w_{\max} = 10\mathrm{cm/s}$

$\Delta t = 900\mathrm{s}$

$\tau > 2\Delta t$

Error after 100 days



Z (km)

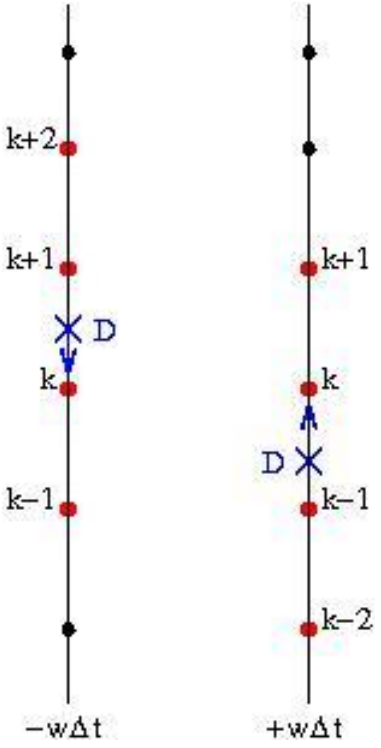
Δθ (K)

Symptoms of problem

- Sharp change in gradient
- Small amplitude wave motion
- Semi-Lagrangian advection of potential temperature is part of problem

Analysis of problem

Consider what happens when vertical wind flips sign every time step



- Write cubic Lagrange in Hermite form:

$$-w\Delta t \quad : \quad \theta_D = H_1\theta_k + H_2\theta_{k+1} + H_3 d_k^+ + H_4 d_{k+1}^-$$
$$+w\Delta t \quad : \quad \theta_D = H_1\theta_{k-1} + H_2\theta_k + H_3 d_{k-1}^+ + H_4 d_k^-$$

where $d_k = \left.\dfrac{\partial\theta}{\partial z}\right|_{z=z_k}$

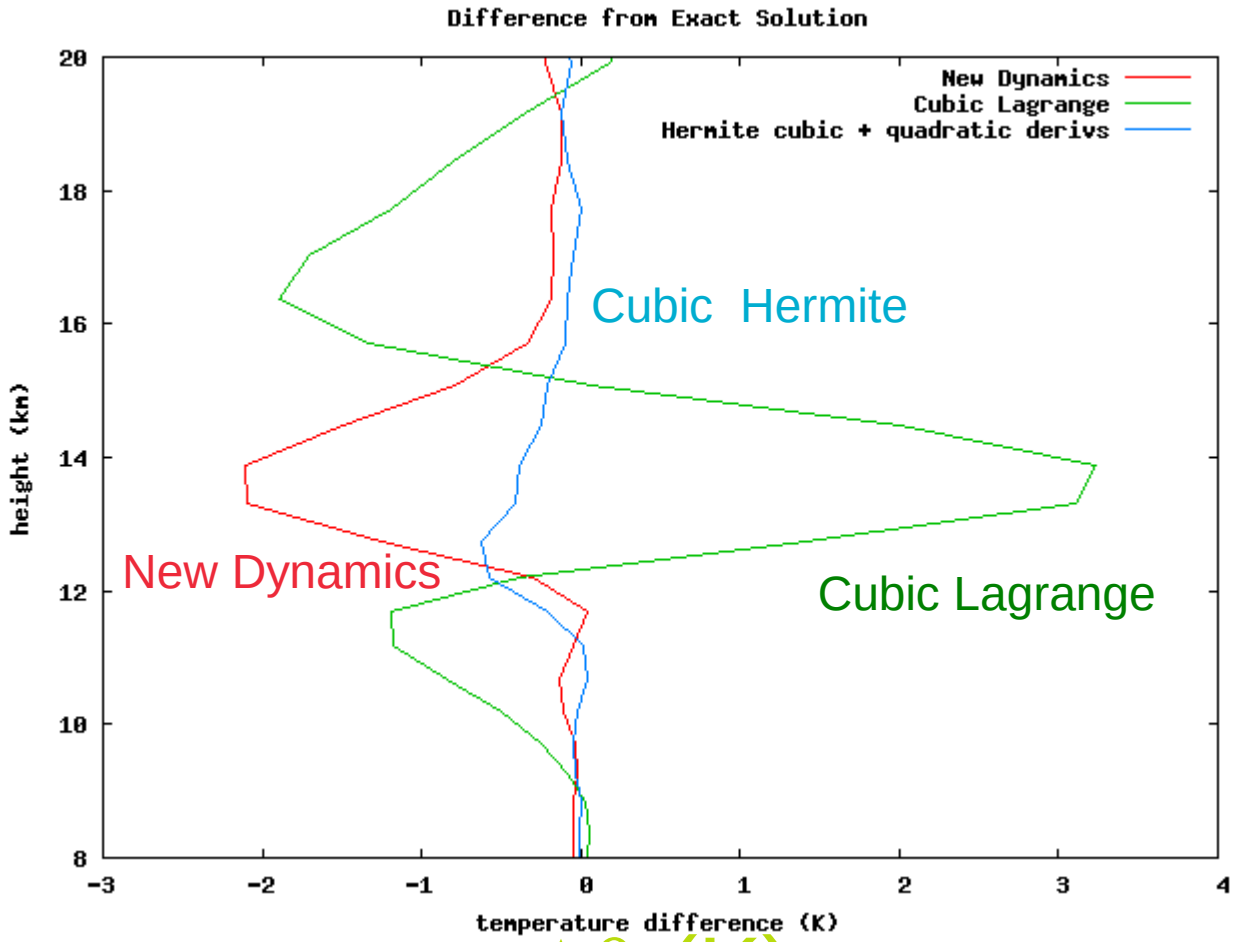
- Error after 2 steps:

$$\text{error} \propto \boxed{\left(d_k^+ - d_k^-\right)}\Delta t + \mathrm{O}\left(\Delta t^2\right)$$

- cf. New Dynamics: $d_k^+ = d_k^-$

Mitigating the impact

Use continuous first derivative in vertical $\Rightarrow$ cubic Hermite $d_k^+ = d_k^-$

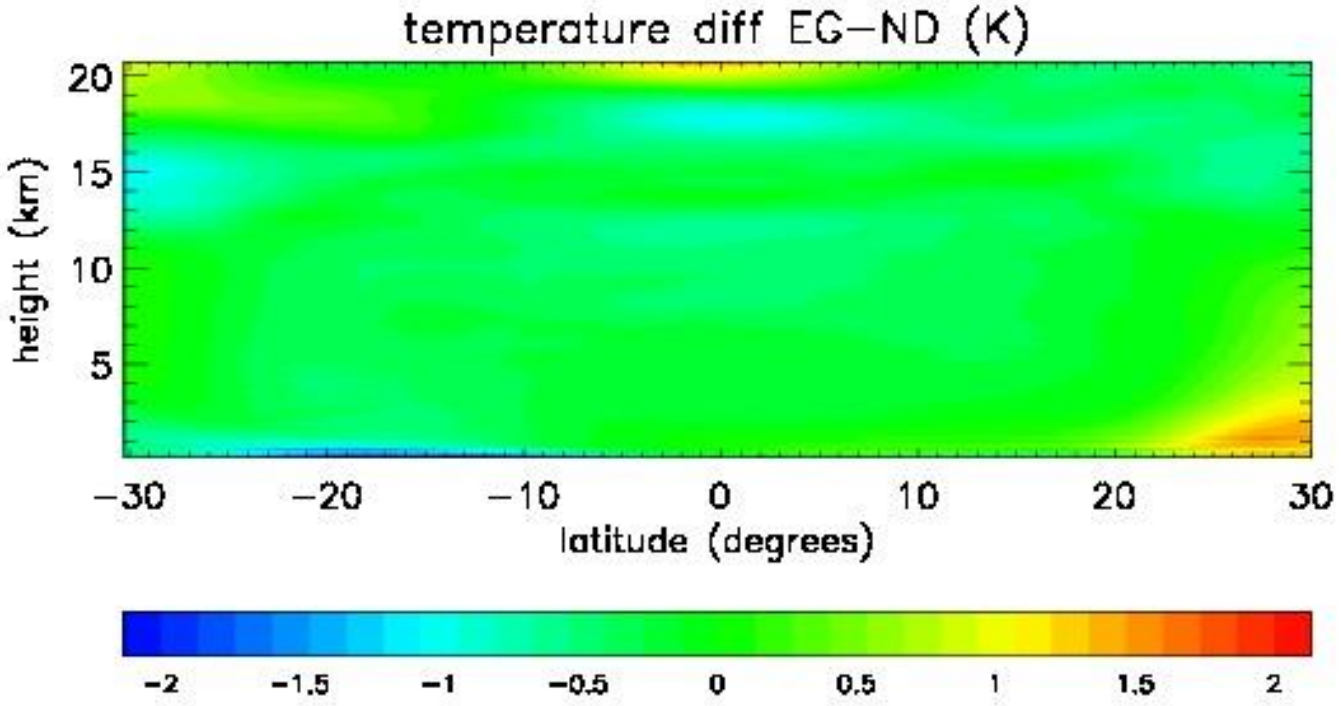


Z (km)

$\Delta\theta$ (K)

Impact in Held-Suarez

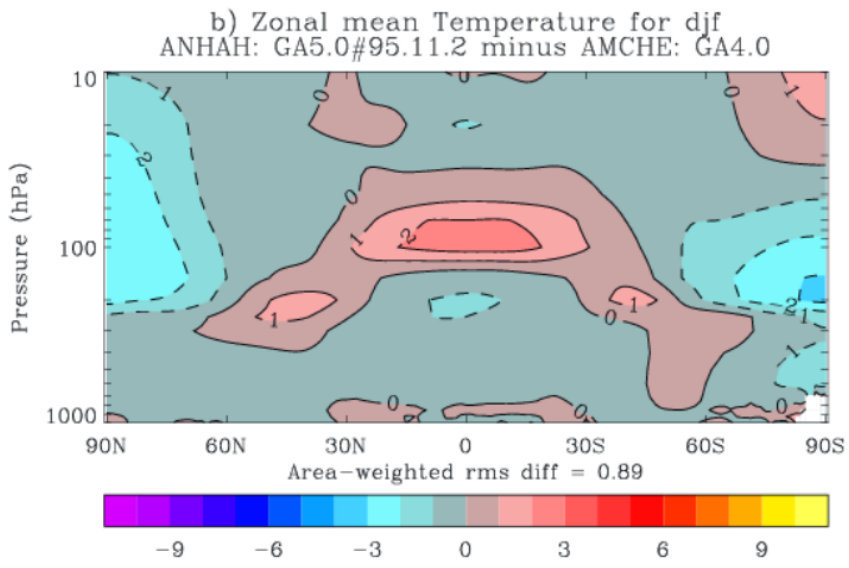
ENDGame (cubic Hermite) – New Dynamics



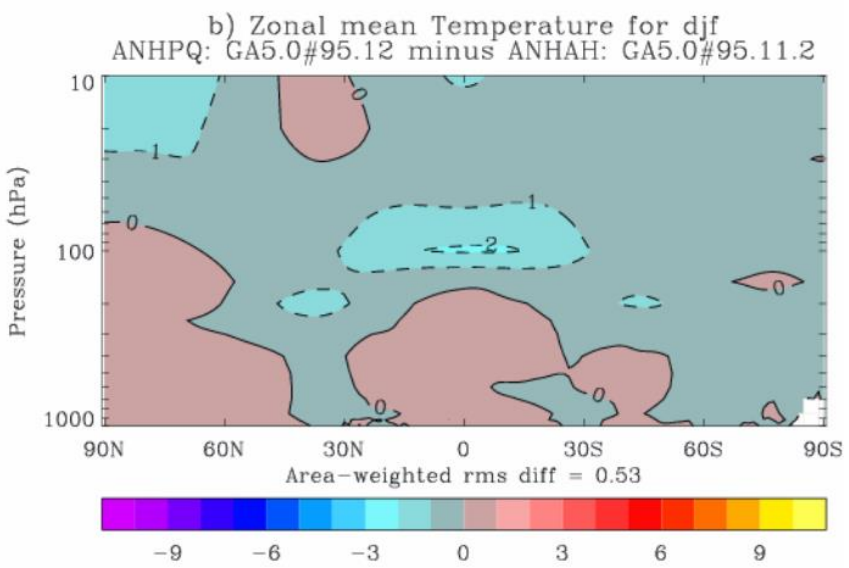
Bias vanishes!

Impact in AMIP

ENDGame minus New Dynamics



ENDGame cubic Hermite minus ENDGame cubic Lagrange

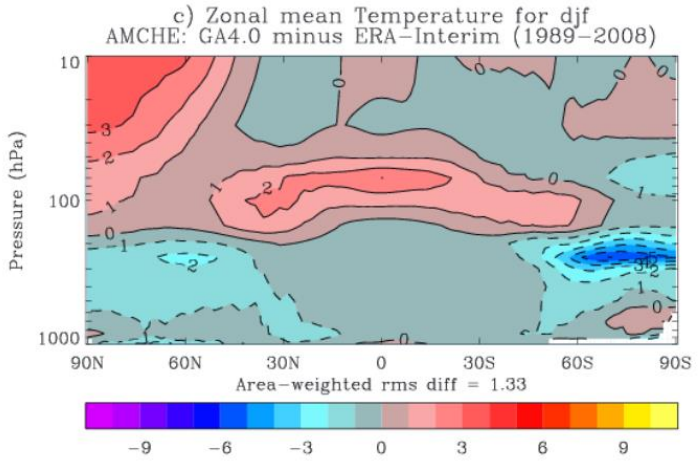


Opposite sign, similar pattern

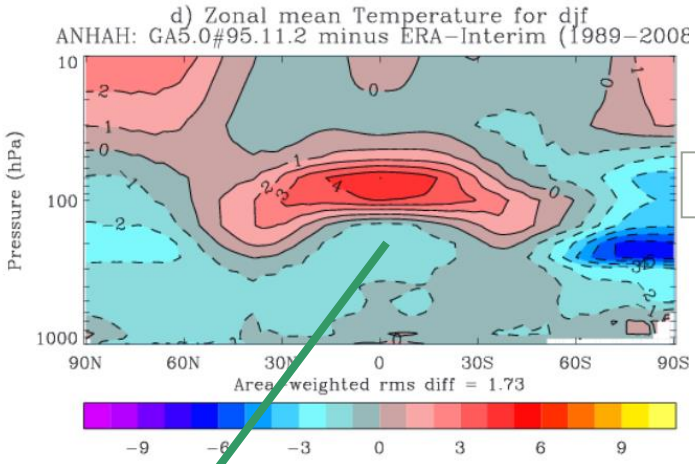
Impact of cubic Hermite

Second-order centred → **Cubic Lagrange**

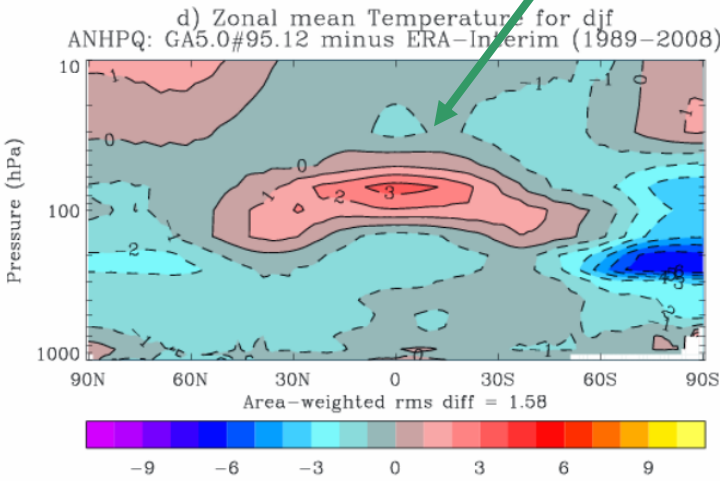
ND bias



EG bias



Cubic Hermite



With thanks to David Walters

Summary

- A more accurate scheme can $\Rightarrow$ significantly worse results!
- Need to capture wave like aspects of advection of θ
- Key feature of scheme is reversibility
- Recover this by ensuring continuity of derivative

Pros

- Bias in tropical tropopause bias reduced by ~2˚C
- Derivatives estimated using quadratics: no change to stencil
- Hermite interpolation offers new options for monotonicity

Cons

- Order of accuracy reduced by cubic Hermite –
  Perhaps use quartic polynomials for derivatives and extend stencil

Thank you!

Questions?

Parameters for Held-Suarez

- Original paper: Held & Suarez (1994), *BAMS* **75**, 1825--1830
- N216 horizontal resolution
- 15 minute timestep
- 32km deep domain
- 63 levels, geometrically stretched, ratio=1.03
- 400 day integration sufficient to show effect

Diagnostic: zonal mean temperature, averaged over final 50 days