Current work to improve convection and tropical performance in the UM

Steve Derbyshire, Roy Kershaw
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Thanks to..

Anna Maidens, Rachel Stratton, Ricky Wong, Jon Petch, Adrian Lock, Martin Willett, Jose Rodriguez, Manoj Joshi, William Ingram, Chris Dearden, Tim Hinton, Cath Senior, Sean Milton, Gill Martin … a cross-cutting team from NWP and Climate Research.

- Plus academic groups (esp. CGAM) for very useful inputs and advice.

Some climate results included, as they shed light on NWP (a payoff from “keeping the UM Unified”)
Outline (as per paper)

1. Introduction
2. Summary of identified problems
3. Mechanisms for parametrization impacts on circulations
4. Parametrization changes
5. Results in the full Unified Model
6. Conclusions and future work
1. Introduction
Importance of tropical performance

- Direct tropical predictions, including crisis-area modelling, aviation and climate
- Extratropical impacts at extended NWP, seasonal and climate ranges, e.g.
  - Wave-like teleconnections
  - Impacts of “nonlinear events”
  - Radiation balance

- MOSAC-9 specifically flagged tropical performance concerns re THORPEX and seasonal predictions
2. Summary of problems identified
Known problems identified in systematic NWP verification can be illustrated in small sample used for preliminary testing of changes:

- Humidity biases
- Temperature biases
- Excessive tropical circulations

(Following plots from Sean Milton/Martin Willett)
Substantial dry bias in inner-tropical upper troposphere (up to 10% RH in places)
Warm bias in most of tropical troposphere but cold bias at the top of convection (top too low?)
Extensive past NWP validation (e.g. presentation by Sean Milton to MOSAC-9) shows signals including:

- Convecting regions show warm, dry bias in mid-troposphere
- Signs of cold and moist biases around top of convecting layer, probably associated with convection not going high enough.
- Overactive broad-scale convective circulations in both zonal and meridional directions
Wind spin-up in 5-day forecasts

U Winds 5N–5S  JJA 2004
Precipitation and wind spinup

(b) UM 0–24 hours – GPCP Precipitation JJA 2004  Mean=1.0333
Winds @850 T+24–T+00 (suppressed <0.6 m/s)
GCSS NWP model comparison (M.Willett/P.Bechtold/D.Williamson under working group chaired by J.Petch) shows revealing difference between models (also time-development of forecast errors) in the key Tropical West Pacific region.

An adequate account of the exciting developments in GCSS (joining up process studies with large-scale model performance) would be another talk in itself. Direct inclusion of full NWP models (alongside SCMs and CRMs) is a major step forward in GCSS methodology.
3. Mechanisms for parametrization impacts on circulations
Simple arguments:

- T, q biases seen in NWP and SCM results must have some impacts on dynamics and hydrological cycle
  - E.g. 0.5K convective warm bias cf. SST+0.5K?
- Various other impacts
  - convective momentum transport
  - cloud-radiative effects
Total heat thinking (Emanuel-Neelin): tropical convection broadly response to accumulation of \( h = c_p T + Lq + gz \), exported largely via \( \int \omega \left( \frac{\partial h}{\partial p} \right) dp \)

Possible explanations for excessive convection:

- Convection exports insufficient \( h \) for given mass-flux (cf. Neelin’s Gross Moist Stability)?
- DD too weak? Or carry insufficiently low \( h \) back into the BL (because saturated)? (cf. Raymond)
- Winds too strong? \( c_h \) too high?
- Sea too warm? (cf. Emanuel)
4. Parametrization changes
1. Changes to adaptive detrainment and entrainment
2. Use of Emanuel downdraughts
3. Change to microphysics in the convection scheme
4. Detailed changes to the BL coupling (initial convective parcel excesses; mixing of cloud-base increments
5. Change to mid-level convection closure
EUROCS humidity case/motivation for adaptivity

Mass flux profiles in a range of free-tropospheric humidities

Cloud-Resolving Model

SCM (UM4.5)

Derbyshire et al., QJRMS (2004) – EUROCS Special Issue

[Numbers are for “humidity parameter RHt”]
In CRM study of deep convection Swann (QJ 2001) found:

Plume excess buoyancy $\sim$ half adiabatic value

Seems to imply entrainment and detrainment adapt to control $\theta_v^{ex}$
Specific changes

1. Adaptive forced detrainment as extension of Gregory-Rowntree forced detrainment
   - Replace 0.2K threshold by more interactive scaling
2. Adaptive entrainment using moist static energy h to predict buoyancy excesses
   - Again basically a simplified implementation of Swann’s CRM result
Adaptive mass fluxes in EUROCS framework

Control, u.d. mass flux

Adapt en/detrainment, u.d. mass flux

Adapt detrainment, u.d. mass flux

Adapt en/detrainment, with GR, u.d. mass flux

“original”

+ adaptive detrainment

+ full adaptive

+ hybrid adaptive
5. Results in the full UM
Adaptive Detrainment – Relative Humidity impacts

(Preliminary NWP tests by Sean Milton/Martin Willett)
Observations

Preliminary climate tests – J. Rodriguez

1-year annual mean precipitation (1990)

Adaptive mod seems to improve Tropical W. Pacific with benefits to Pacific wind-stress
Impact on wind-stresses

Annual mean U wind stress 5N–5S for the Pacific

Meridional mean

acagi = HadGAM1  5yr
acuob = adaptive detrainment, RDET=0.75
Southampton climatology

(Rachel Stratton)
Aquaplanet impacts (3KW1 case of APE)

- 3KW1 case (equatorial SST perturbed by 3 cos longitude) mimics Eq. Pacific
- Adaptive detrainment consistently shows wind-stress reductions around 90°E
- Longer runs (15month) in progress for statistical robustness (these are 3-month)

(Anna Maidens)
(1) “No shallow” test: treat as deep convection
(2) “Shallow precip” test: reduce precipitation threshold from 1 g/kg to 0.5 g/kg
• Similar impacts in NWP tests
• Seems to explain some past experience with convection changes via side-effects on shallow-Cu precipitation

(A.Lock; similar impact shown in aquaplanet by J.Petch)
NWP tests of shallow-Cu precip change

Adrian Lock, using NWP Case Study Suite
Summary of work so far

- Significant impacts shown from adaptive detrainment (reduction in Pacific windstresses ~30% and reductions in tropical oceanic precipitation; profile biases appear better)
  - ENSO appears better in coupled climate runs
- Additional windstress reductions from use of Emanuel DD scheme
- Signs that enhanced precipitation in shallow convection could reduce Hadley-type circulations by ~10%
- Various other tests give smaller impacts
- Use of SCM and aquaplanet (aligned where possible with IC projects) as well as full UM
Further work

- Finalize package for operational NWP subject to current trials (+HadGEM1a)
- Examine performance of current package (and incremental improvements to it) in more detail in:
  - GCSS Case 5 (intercomparison with ECMWF etc.)
  - 70-level NWP and next (HadGEM2) climate model.
  - Representing moderate convection/congestus (consider Indian Ocean and RICO area)
- Further research
  - develop more components of turbulence-based convection parametrization
  - Consider other ideas, e.g. arising from stochastic physics work (G. Shutts).
Questions?
Supplementary slides
Further analysis of EUROCS CRM results

Detrainment in particular varies with humidity
Some versions of the adaptive detrainment give significant reductions in diagnosed deep-convective frequency.

This is still under examination but probably reflects pre-existing problems in the coupling to the boundary layer (we have some ideas about how to address this).

How well-posed is the evaluation of deep convective frequency in a multi-scale (fractal?) system?

Plots: Anna Maidens
Emanuel DD impacts combined with ad det

U stress 5N–5S

-0.15  -0.10  -0.05  0.00  0.05

-0.15  -0.10  -0.05  0.00  0.05

Meridional mean

Longitude

0  30  60  90  120  150  180  210  240  270  300  330

aerhg  – Eman DD 3 yr

aerhb  – control fast phys 1yr
Issues with the Emanuel DD option

- Shown to decrease Pacific windstress in full climate model (and gives additional reduction in combination with adaptive detrainment), but…
- Could not replicate this in aquaplanet (even 3KW1 test)
- Impacts on precipitation distribution more questionable
- Somewhat similar comments to original Emanuel scheme impacts in old climate model tests.
Precipitation in APE

Extracted by R. Stratton from APE 3KW1 results (intercomparison of a range of global models in idealized aquaplanet configurations).

$\text{SST}' \sim 3K \cos(\text{longitude}) \cdot f(\text{latitude})$
Representation of Andes (N512 unsmoothed; N96 and N48 smoothed as in climate model)

Significant loss of Barrier height from 10S-10N at N96
Impact of Andes on Pacific wind stress

**CONTROL**

- N96 test of impact of increasing mean height of Andes from 10S-10N
- Decrease in 5S-5N wind stress this JJA
- Other seasons and years give signal in the same sense but generally smaller

**HIGH ANDES**

**SUMMARY**

- Stress shows some sensitivity to representation of Andes
- But sensitivity is much weaker than that to convection changes