Systematic Errors in parametrisations in Global NWP: evaluation against observational data and budget studies

Sean Milton, Glenn Greed, Malcolm Brooks, Paul Earnshaw, Martin Willett, David Walters

Introduction

There are key advantages to using the Numerical Weather Prediction (NWP) framework to investigate systematic errors in model formulation.

1. Individual **weather systems** and physical processes can be evaluated against detailed both in-situ (ARM, AMMA, TOGA-COARE…) and satellite (GERB, ISCCP, Cloudsat…) observational datasets.
2. Systematic drifts of forecasts from analyses can be studied in terms of **heat, momentum, moisture and potential vorticity (PV) budgets and radiative and hydrological balance**.
3. The **Errors from remote forcing (e.g. tropical – extra tropical interactions)** have no time to impact on 'local errors' making error attribution to a given physical process more tractable.
4. In short-range forecasts (00-36 hours) **parametrisations are driven by reasonably accurate dynamical fields of mass, wind and temperature**. We investigate errors in the parametrisations themselves rather than the errors in 'inputs' to parametrisations. Less clear with moisture due to considerable uncertainty in the moisture analyses.
5. Use **NWP Verification Metrics** (RMSE, Bias) to evaluate any parametrisation improvements.

Unified Modelling approach – seamless prediction

The **Met Office Unified Model (UM)** consists of a non-hydrostatic, fully compressible, deep atmosphere dynamical core with semi-implicit semi-Lagrangian time integration and physical parametrisations as at HadGAM1/1a (Martin et. al. (2005)). The UM is used across a range of prediction timescales from short-range NWP (1-6 days), THORPEX (1-15d), seasonal, decadal, and climate change prediction. Physical formulations are very similar for **NWP** and **climate** model and routine NWP forecasts can be used to inform climate model errors and vice-versa. Aim to bring seasonal and decadal prediction systems up to latest model versions (SISL dynamical core & HadGAM1a) and move towards a **seamless prediction system**.

Systematic Errors Across prediction timescales

Striking degree of similarity between Systematic Errors in short-range NWP (d1-5), medium range (THORPEX) timescales (d11-15), and 20 year AMIP runs of climate configuration (HadGAM1a). This appears to be true for errors in the mean circulation (see opposite), clouds (see poster by K.Williams) and in some aspects of variability (e.g. equatorial waves & MJO – see poster by G.Yang).

Common circulation errors include (opposite)

- Westerly (easterly) bias polewards (equatorwards) of subtropical jets.
- Westerly bias in equatorial upper tropospheric winds @300hPa – conv. momentum transport?
- Warm bias in NH mid-latitudes in summer (see discussion of land surface biases over SGP).
- Tropical mid-trop. warm bias and upper trop. cold bias.

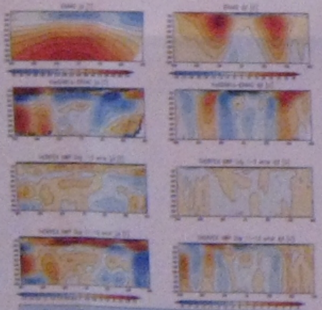


Fig 1. Zonally averaged JJA [T] and DJF [U] biases for predictions at Climate, NWP(D1-5) and THORPEX (D11-15) timescales.

Improving tropical performance – convection and BL processes

Temperature, Humidity & Precipitation Biases: ARM Manus Island (2S, 147E)

- **Dry/Warm bias** in mid-upper troposphere (Fig. 2) – too little moisture detrained from convection – massflux too large?
- **moist/cold bias** at level of convective termination – convective parcel detrains all water here. LW cooling from anvil & LS cloud.
- Too **moist** at cloud base and too dry in boundary layer
- Too **moist** at freezing/melting level.
- **Convection too shallow** – hydropause too low.
- **Lack of variability** in RH and precipitation (Fig.3)).

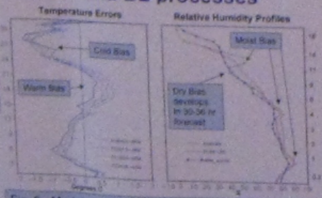


Fig. 2 - Model vs. ARM Manus Is. Sonde - JAS 2003

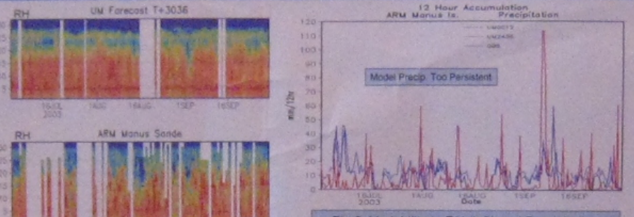


Fig.3: Variability in RH (left) and Precipitation (above) for JAS 2003 - Model vs. ARM

Improvements to convection and BL processes – New Physics package

- Adaptive Detrainment (Maidens & Derbyshire (2007)) – detrainment profile based on local bouyancy giving smoother and more active detrainment in upper troposphere – improves model mass flux profiles vs CRM.
- Marine BL Changes (Brown et. al. (2007)) – 'SHARP' tails over sea; non-local momentum mixing; modified scalar transfer over sea – reduced LH flux at higher wind speeds (see poster by A. Brown et. al.).

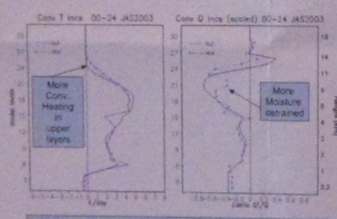


Fig 4 : Impact of New Physics on the Model Convective T & q Inc. - Warm Pool (5S-15N,120-180E).

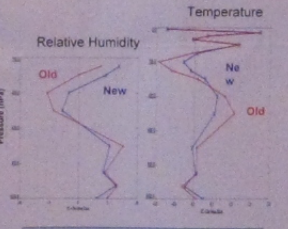


Fig.5 : NWP Metrics Improved Reduced T & RH biases vs.Tropical Sondes.

Conclusions

1. **Similarity in Systematic Errors across prediction timescales**. NWP forecasts combined with detailed observations (ARM & satellite data (e.g. GERB)), and drift in budgets of temperature, moisture, momentum, radiative/hydrological balance, can be used to detect systematic biases in physical parametrisations.
2. **Examples**
   a) Recent improvements in tropical performance via changes to convection and BL processes – improved diabatic heatening/moistening and reduction in mean circulation biases. Improvements in tropical variability less obvious.
   b) Ongoing investigation of summertime biases over land using data from ARM SGP site highlighted lack of cloud cover contributing to near surface warm bias and slow evolution of convective mixed layer.
3. **Unified model approach** - parametrisations developed for climate prediction can be developed quickly for NWP applications and evaluated against observations for individual weather systems. Mineral dust tested in NWP points to important missing process in radiative balance over west Africa – more work on circulation impacts of including dust in NWP underway.

References

Brown, A. et. al. (2007). Upgrades to the boundary layer scheme in the Met Office NWP model. (submitted to MWR)
Haywood, J. et al. (2005) Can desert dust explain the OLR radiation anomaly over the Sahara during July 2003. JGR,110, D05105, doi: 10.1029/2004JD005232
Martin, G. et. al (2005). The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model. Part I. J. Clim.,19, 1274-1301
Maidens, A. and Derbyshire D. (2007). Improving mass-flux profiles in the Gregory-Rowntree convection scheme using adaptive detrainment (submitted to QJ)
Woodward, S. (2001) Modelling the atmospheric life cycle and radiative impact of mineral dust in the Hadley Centre climate model. JGR, 106, 18,155-18,166

Evaluating dust in NWP – aerosols and radiation

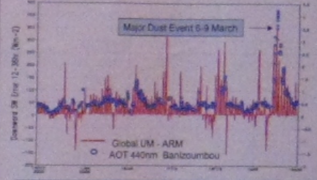


Fig 6 : Positive biases in down. SW at ARM Niamey site (Dec 05-Mar 06) of +50-300 Wm^{-2} correlated with AOT from AERONET Banizoumbou – lack of dust and biomass.

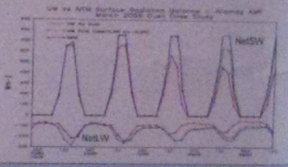
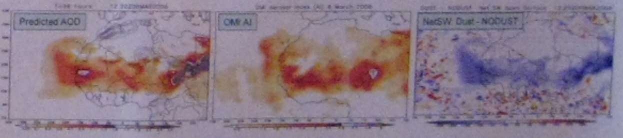


Fig 7: 8th March Saharan dust outbreak - Large radiative perturbation, 200 Wm^{-2} reduction in net SW at surface and 40 Wm^{-2} net LW. Predicted dust gives half observed surface radiative forcing at ARM -Niamey site.

Originally developed for climate applications the dust parametrisation (Woodward, 2001) is run in a 5-day global NWP forecast of major Saharan Dust outbreak. Day 4 forecasts (valid 12UTC 8 March 2006) show (below)

- Dust distribution compares well with Ozone Measuring Instrument (OMI) Aerosol Index (AI)
- Reductions in net SW at surface (left) up to 100-200 Wm^{-2} for aerosol optical depths (AOD) > 0.7

Uncertainties remain in dust prediction with (i) Soil moisture state (ii) Soils datasets for dust production, and (iii) Radiative properties of dust.



Summer Biases at ARM SGP – (Transpose AMIP, CEOP)

IOP June-July 1997 – WGNE **Transpose AMIP** project
JJA 2003 & 2004 – GEWEX/WCRP **CEOP** project

1. Too little cloud cover (Fig.9) -> too much down. SW radiation -> warm bias in 1.5m temp (Fig. 8).
2. Night-time temperatures too warm -> (downward) SH fluxes too large in stable BL – "long-tail" stability functions in model.
3. Evolution of the **convective mixed layer** too slow. Linked to excessive cooling overnight above surface layer - excessive mixing in stable BL.

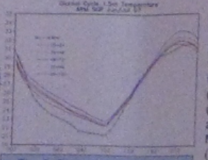


Fig. 8: Diurnal cycle of 1.5m temperatures from IOP97 shows warm bias at night and day compared to ARM

Improvements to warm bias made in **climate model** through changes to:
(i) surface runoff,
(ii) surface albedo using MODIS data,
(iii) use of biogenic aerosol.

These are being tested in NWP.

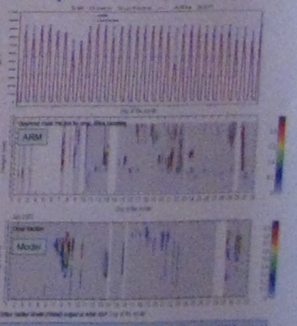


Fig 9: ARM-SGP site cloud radar and lidar derived cloud fractions from the CloudNET show lack of shallow cloud (3-5km on 24-29 July) and mid level cloud (19-22 July) -> overestimate in model down. SW (top)

Met Office Hadley Centre FitzRoy Road Exeter Devon EX1 3PB United Kingdom
Tel: 01392 886081 Fax: 01392 885681
Email: sean.milton@metoffice.gov.uk