Producing a “Nudged” version of the UKCA CCM

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Motivation

• **GCM** produces reasonable agreement over long timescales
• Doesn’t reproduce day to day **weather**
• Still a few **biases**
• Complicates the study of **chemistry**
• Assimilate **ERA-40** to reproduce observations
• Allow chemistry to be studied in ‘**isolation**’
• Increases data sets available for **validation**
Introduction

• Introduce model & nudging
• Demonstrate that nudging works
• Compare to some ‘real’ data
• Describe some applications for nudging
• Talk about prospects for the work
Model

- Model is Met Office GCM: ‘Unified Model’
- Resolution $3.75^\circ \times 2.5^\circ$ horizontally and 60 levels from 0 to 80 km vertically.
- **UKCA** new (aerosol)-chemistry climate model
- Collaboration between NCAS & Met Office
- Tropospheric & stratospheric flavours
- Concentrate on **stratospheric** model
Specimen UKCA Results

- Plot some UKCA results
- Plot $O_3$ zonal mean in model & UARS climatology
- In general agree, but too small hole
- Examine ClO
- In general good, but too little over Antarctica
History of Nudging

- Nudging is a weak form of data assimilation on global scales.
- Constrain GCMs using meteorological analyses.
- Developed by ECHAM to validate chemistry.
- Used in Old UM to study clouds and QBO.
- We introduce to new UM comprehensively.

(Ozone "profiles")

EQ total ozone anomalies

Model Observations

(image courtesy of P. Braesicke)
Set-up of Nudging

- Data from ERA-40
- Adjust $u$, $v$, $T$ ($\theta$)
- Interpolated onto model grid, levels, time
- Introduce as extra term
  \[ X \times X_{MOD} \times a(X_{DAT} \times X_{MOD}) \]
- Small relaxation parameter ($a=0.056$)
- Limited height range
Validation of the Nudging

- Compare to ERA-40 data
- Use model w & w/o nudging
- Evaluate biases
- Calculate absolute differences & variability
- Study variables directly ($\theta, u$) & indirectly ($P_s, \text{precip.}$) adjusted
- Sensitivity studies to chosen parameters
- Fuller description in ACPD
Potential Temperature ($\theta$) Biases

- Bias in model (free and nudged) wrt data
- Warm biases in model disappear
Differences & Variability

• Examine **differences** and **correlations** in time and space.

![Graph showing differences and correlations in time and space with and without nudging for different months.](image)
Surface Pressure

- Look at a variable that we *don’t adjust*
- Make **snapshot** comparisons between **models** (with & w/o nudging) and **data**
- Synoptic systems reproduced in **S Ocean**

![Diagram showing surface pressure comparisons between free and nudged models](image)
Precipitation

- More complicated variable to model
- Plot differences (RMSE) between model & ERA-40
- See large improvements in extra-tropics
- Reduced improvement in tropics
Spatial Variation

- Look at surface differences & correlation in $\theta$
- Prescribing SSTs constrains surface
- Correlations best in extra-tropics
- Errors still small in tropics though correlation lower
Nudging for Model Validation

• Improved correspondence to ERA-40 demonstrates that nudging works
• Allows us to represent instantaneous weather
• Can compare to episodic data (satellites, campaigns..)
• Provide examples to demonstrate this
• Start using to examine chemistry
Comparing to Satellite Data

- Compare to HALOE Profiles ($T$, $O_3$, $CH_4$)
- Concentrate on $T$ as simpler
- Show example from Sep 1999 at 50°S
- Without nudging large tropopause difference
- Differences still above nudging (40-50 km+)
Quantitative Assessments

- Make quantitative comparisons with HALOE
- Use bias, RMSE and correlation
- Compare PDFs for T at 30 hPa (Sep-Dec ‘99) for greater than 30° N

Nudged: Correlation 0.96

Free: Correlation 0.67
Comparing to Campaign Data

• Look at NASA ER-2 aircraft in campaign (THESEEO/SOLVE)
• Compare flight data to nudged & free models
• Nudging captures large scale structure
• The chemistry is more complicated
Chemistry Profiles

- Look at O$_3$ profile early Nov ’99 65° N
- For reference include T profile
- Nudging produces better agreement
- Still some differences
- Other factors at play (eg NOx, initialisation)
Chemistry Profiles

- Nudging doesn’t always improve
- Look at quantitative assessment (Sep thru Dec 1999)
Modelling Episodic Data

• Nudging allows GCM to be compared to episodic data
• Compare to campaign data (Theseo/SOLVE)
• Gives data greater statistical power
• Study specific events (e.g. Pinatubo, 2003 summer)
Pinatubo Eruption

- Erupted 15\textsuperscript{th} June 1991
- Largest stratospheric aerosol loading in C20\textsuperscript{th} (30Tg)
- Heated stratosphere
- Record lows of Ozone
- Cooled troposphere
- Change in rate of methane increase
- Changes in CO\textsubscript{2} increase as well
Stratospheric Ozone

- Record lows in extra-polar region
- Preliminary results
- Caused by
  - Higher Aerosol loading
  - Hotter stratosphere
  - More uplift
  - Also QBO effects
- Investigate split
- Interesting test of UKCA chemistry

Nudged Nov '91-'90 (from Randel et al 1995)
Earth System Modelling

- Earth system model QUEST
- Pinatubo interesting test
- Nudge to constrain atmospheric response
- Test effect on other parts of model
- Try with biosphere
- Consider feedbacks

(image courtesy of U. Bristol)

T, rain, SW, humidity  VOCs

(image courtesy of P. Young)
Surface Effects

- Surface where atmosphere interacts with biosphere
- Radiative effects moderate surface \( T \)
- Compare ERA-40 with Nudging for DJF post Pinatubo
- Both show winter warming/ tropical cooling
Nudging vs Analyses

• Why use nudging rather than analyses?
  • More comprehensive output
  • Same set-up as ‘finished ’model
  • Eg Look at SW Flux
  • Can test feedbacks (biogenic emissions etc) in same model
Prospects

- Model works, beginning to apply
- Shown preliminary studies of some effects of Pinatubo, finish these studies
- Use model to help validate UKCA
- Allows us to make direct comparisons with other NGCMs/CTMs (ECHAM, TOMCAT..)
- And hopefully many other uses....
Summary

• Nudging has been added to UKCA model
• Improves agreement with ERA-40 analyses
• Full evaluation complete & published
• Allows study of chemistry in isolation
• Allows use of episodic datasets