Extending the UM into the thermosphere

SWAMI – a project to develop a European whole atmosphere model for improved satellite operations

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Contents

• Met Office Space Weather Operations Centre (MOSWOC)
  • Ambition for Sun to Earth modelling & motivation for a Whole Atmosphere Model
• Extending the Met Office UM into the lower thermosphere
  • SWAMI project
  • Radiation, chemistry and dynamics
• Road map towards a coupled S2E models and whole atmosphere model
Met Office Space Weather Operations Centre (MOSWOC)

- 24/7 Operations
- Fully integrated within Met Office Operations Centre
- National capability supporting government, military, and critical sectors
- Team includes
  - Space Weather Operational Meteorologists
  - Scientists
  - Programme managers
  - IT developers
- Set up in response to NRR: Met Office owns risk
- UK Government (BEIS funds) operations and associated research via rolling programme
- This funding is for R2O so **does not** include Whole Atmos modelling

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Toward Sun-Earth coupled modelling

GOAL: Coupled Sun-to-Earth models with DA for much-enhanced forecast capacity

- Photosphere (solar surface)
- Corona (solar atmosphere)
- Solar wind (interplanetary space)
- Magnetosphere
- Radiation belts
- Ionosphere
- Thermosphere
- Upper / lower atmosphere coupling (via whole atmosphere UM)
- Thermo / ionosphere coupling
- Middle and Lower atmosphere

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A Whole Atmosphere Model

Reasons:

• Important role of lower level driving in thermospheric state – improved mean state and better representation of variability
• Lack of thermosphere obs means that lower level driving could be like “free DA”
• State of the thermosphere important for ionospheric evolution
• Impacts of space weather on tropospheric weather and climate

Immel et al, (2006l)

Chartier et al (2013)
Whole Atmosphere Modelling
The Unified Model (UM)

- All WA / thermos models (except GITM) use hydrostatic dynamical cores.
- Hydrostatic assumption assumes vertical velocity is negligible – poor assumption in the thermosphere (e.g. Larsen and Meriwether, 2012)
- Most other models also use a shallow atmosphere approximation ($g \neq g(z)$, $r=a$)
- The UM has a deep atmosphere, non-hydrostatic dynamical formulation. This should lead to
  - considerably more accurate modelling of vertical velocities (and air density) in the thermosphere than existing, hydrostatic, models.
  - Different interaction between dynamics, radiation and chemistry (possibly benefiting the more accurate dynamics)
- This non-hydrostatic formulation will also make the UM unique amongst surface to thermosphere-spanning models.
Extending the UM

• Aim is Whole Atmosphere UM (+ ionosphere) as part of coupled S2E modelling system

• Huge task, so focus first on UM to ~120-170 km (“Extended UM”)
  • Add relevant physics & chemistry
  • Dynamical robustness
  • Verification.
  • Enable coupling with TIEGCM (~97-600 km) – pushes any ionospheric development to later
  • Meet goals of Met Office and SWAMI project
Towards Extended UM building blocks

- In SWAMI project aim is to blend Extended UM with DTM around ~150-170 km
- We will
  - Add non-LTE to fix too-large UM heating rates above 70 km
  - Add FUV/EUV radiation schemes for chemical scheme photolysis rates
  - Enhance chemistry scheme => exothermic chemical heating for large rise in T in MLT
  - Dynamics - stability
  - Build all these changes into a stable version
Blending heating rates

The longwave (LW) heating rates are combined as

\[ p_x < 0.1 \quad \text{Fomichev NLTE scheme} \]
\[ \text{Height} < 65\text{km} \]

\[ p_x \geq 0.1 \quad \text{UM LTE scheme} \]
\[ \text{Height} \geq 65\text{km} \]

Status:

• recoding to meet UM coding standards
• IR nearly done; NIR to follow
• Will be made widely available via SOCRATES
Need to derive Socrates spectral files for the FUV/EUV (0.05 – 200nm)

- Extension to spherical geometry already done

To do
- Cross-section data from JPL
- Construct reference file with resolution of 0.1 - 1nm
- Construct broadband file using correlated-\(k\) technique
- Calculate actinic fluxes => photolysis rates

See James Manners’ talk
Chemistry

Chemical heating dominant in MLT in determining T structure

- Current UM chemistry (UKCA) runs up to mesopause but with trop / stratosphere focus

- Chris Kelly (Leeds) developing neutral and ion chemistry for UKCA. Motivations:
  - Can study impact of EPP on stratosphere and troposphere
  - Will improve MLT simulation (exothermic heating)
  - Examining new source of NOx in WACCM MLT
  - Starting UKCA work with 5 species Na ion chemistry (data for validation available)

See Chris Kelly’s talk
Dynamical Stability – simply lift the lid and go..

- If we lift the lid of the full UM to 100 km it can run OK for a few months (or for > 1 year if timestep halved), but issues appear
  - Unrealistic local wind structure
  - Issue with lack of non-LTE?
  - Issue with GW parametrization?
- With lid in 105-120 km region, UM fails in days to weeks

See Matt Griffith’s talk
Acoustic waves are most challenging to model - but can be important

In its current form, ENDGame becomes unstable if the top model boundary is lifted above ~120 km (idealised tests)

- **Molecular viscosity** is realistic wave damping mechanism important >~ 130 km (t/scale < wave growth t/scale)
- Its addition reduces acoustic wave amplitude above ~130 km (resolved GWs at sl lower levels)

![Latitude-Altitude plots](image)

See Dan Griffin’s talk
Other Considerations

- Joule heating (NOx cooling) also important for high latitude thermospheric $T$, especially when there are very strong geomagnetic storms
  - For this we need electric field model. But outside SWAMI project scope / resources
  - We can include this by coupling to TIEGCM (UM / TIEGCM coupling code already there).

- GWs need to be parametrized, since UM horizontal resolution used here will be too coarse ($O(100-200\text{km})$).
  - Existing UM GW scheme (USSP) may need to be tuned – lower level simulations can be sensitive to scheme settings.
  - May experiment with switching off or strongly damping the scheme near / around turbopause ($\sim100-120\text{ km}$) instead of applying it right to the top of UM.
Going beyond the lower thermosphere

Longer term plans

Spring 2021: Stable Extended UM (post SWAMI) - necessary rad/dyn/chem

Early 2021 – Roadmap for WA UM, building on extended UM, including new dynamical equations, decision on ionosphere model, implications of even newer DyCore

2023 – Coupled Sun to Earth modelling system (Ext UM / TIEGCM / magnetosphere)
Conclusions

• Whole Atmosphere UM important part of coupled Sun to Earth system:
  • better lower / upper atmosphere coupling => improved thermosphere / ionosphere

• Initial focus on Extended UM:
  • Range of projects on dynamics, chemistry and radiation
  • SWAMI provides resources and focus leading to 1st stable, verified Extended UM version

• Pathway to Whole Atmosphere (full thermosphere / ionosphere) UM and coupled S2E modelling system.
Extra slides
Basic states in absence of radiation and chemistry

- First cut at blending UM and DTM (to create MOWA) will be summer 2019
- By then we should have completed
  - Non-LTE radiation
  - Molecular viscosity re-coding into full UM
  - Some tuning of USSP / other parameters for better model stability
- However, FUV / EUV not likely to be complete
- Chemistry changes may not be complete
- So we have written code to relax UM to a realistic basic state while awaiting radiation / chemistry devs
- Also provides more accurate basic state for testing
  - Global mean T based on USSA/CIRA and asymptotic relaxation to specified exobase T
  - Follows nudging approach (eg Telford et al, 2008)

\[ T_{\text{exobase}} = 800, 1000, 1200 \text{ and } 1500 \text{ K} \]