Met Office

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

Toward Sun-Earth coupled modelling

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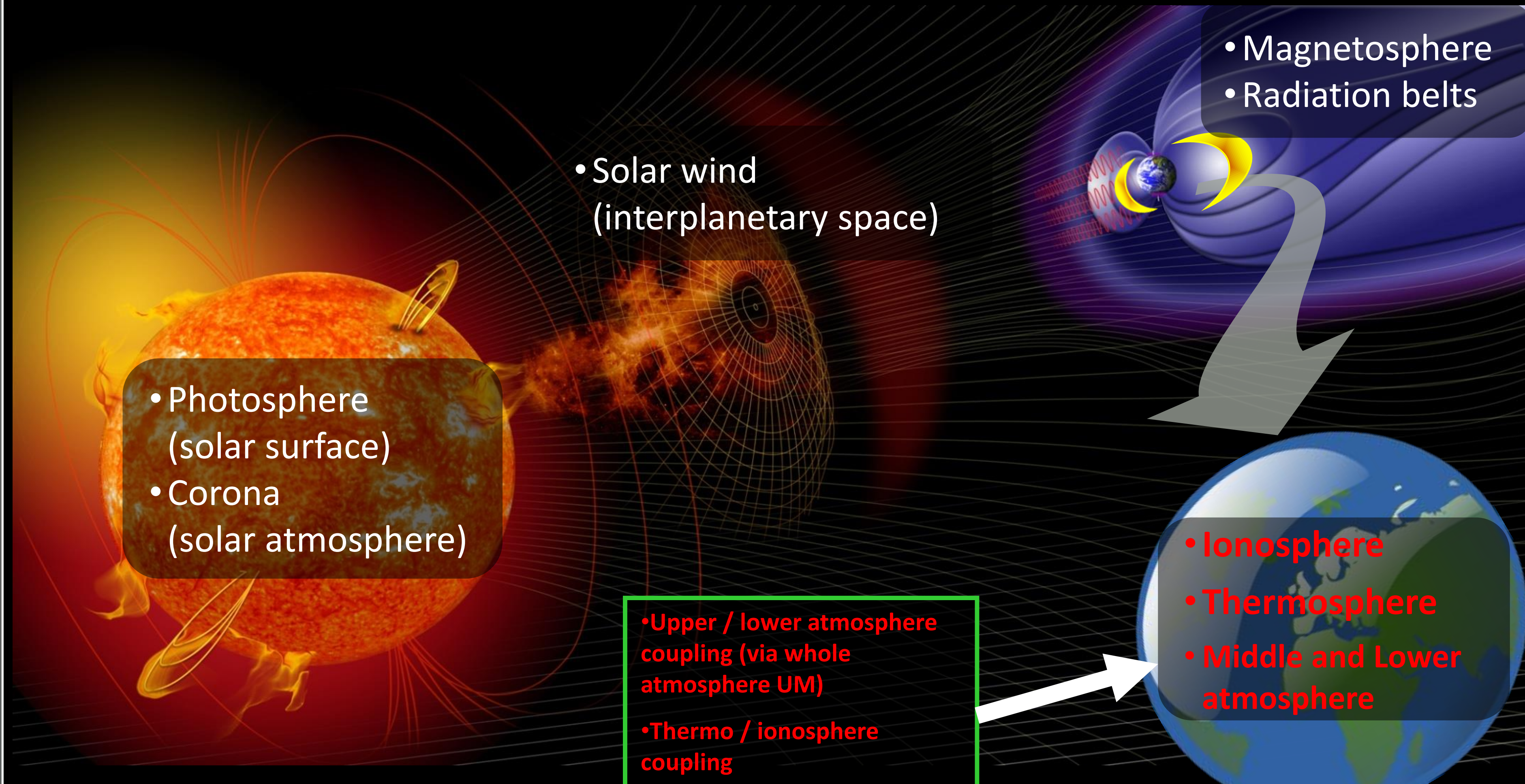

GOAL: Coupled Sun-to-Earth models with DA for much-enhanced forecast capacity

A Whole Atmosphere Model

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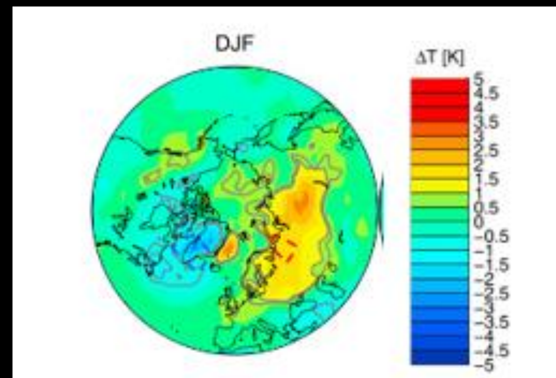
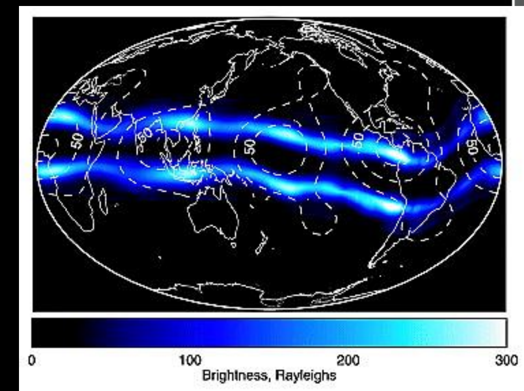
Reasons:

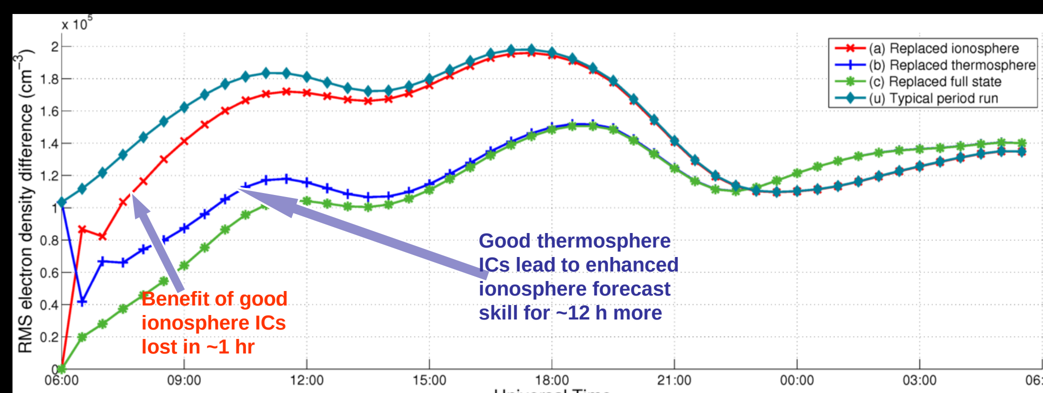
- Important role of lower level driving in thermospheric state – improved mean state and better representation of variability
- Lack of thermosphere obs means that lower level driving could be like "free DA"
- *State of the thermosphere important for ionospheric evolution*
- *Impacts of space weather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



Surface T (high Kp – low Kp) from Seppala et al (2009)



Immel et al, (2006l)



Chartier et al (2013)

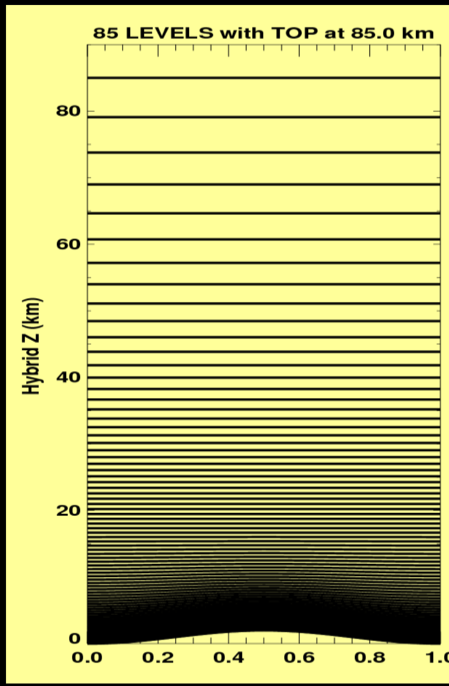
Whole Atmosphere Modelling

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.**

Vertical levels: 0-~85 km

resolution: ~100m near surface; 4-8 km at top



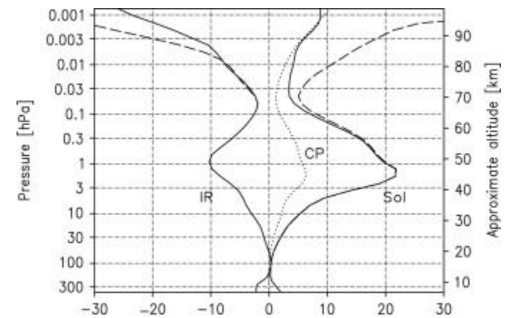
Extending the UM

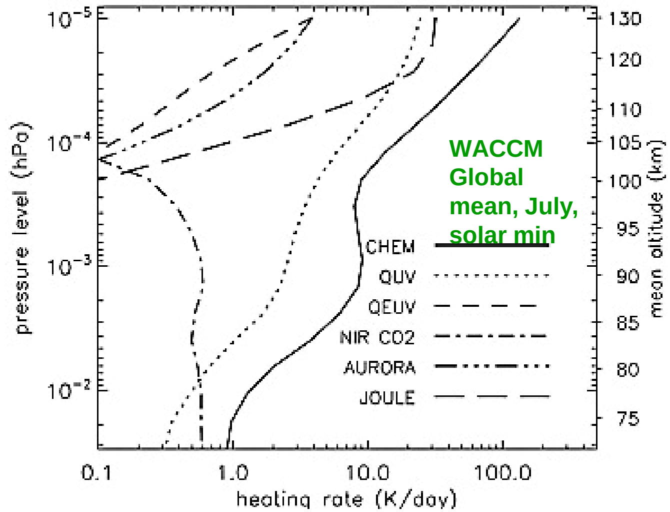
- Aim is Whole Atmosphere UM (+ ionosphere) as part of coupled S2E modelling system
- Huge task, so focus first on UM to ~120-170 km ("Extended UM")
  - Add relevant physics & chemistry
  - Dynamical robustness
  - Verification.
  - Enable coupling with TIEGCM (~97-600 km) – pushes any ionospheric development 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

Zonal mean SW and LW heating – Fomichev (2009)





Blending heating rates

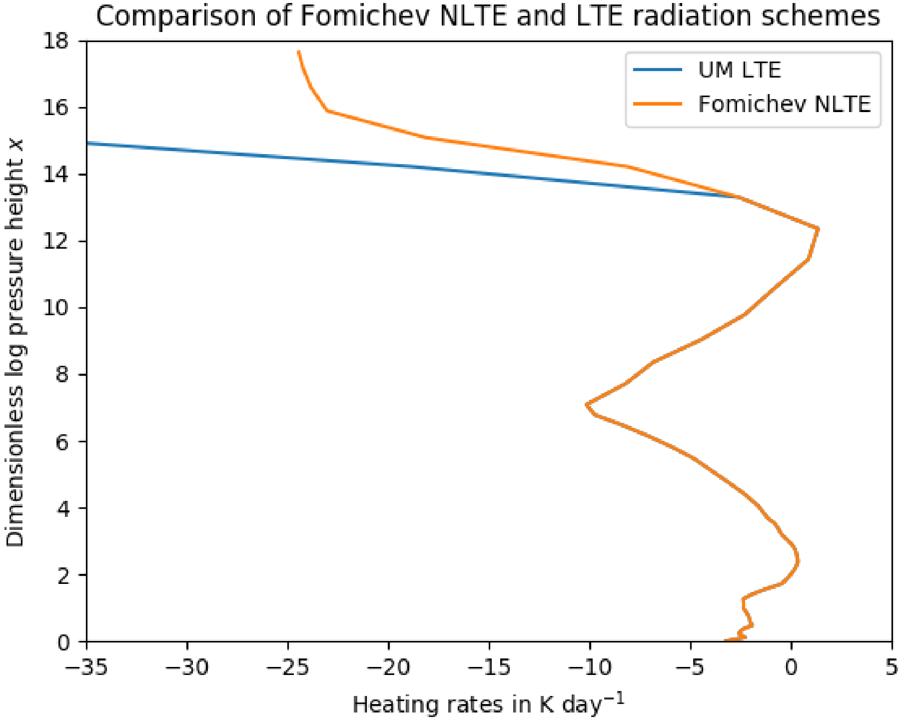
The longwave (LW) heating rates are combined as

$p_x < 0.1$ Fomichev NLTE scheme
Height $< 65\text{km}$

$p_x \geq 0.1$ UM LTE scheme
Height $\geq 65\text{km}$

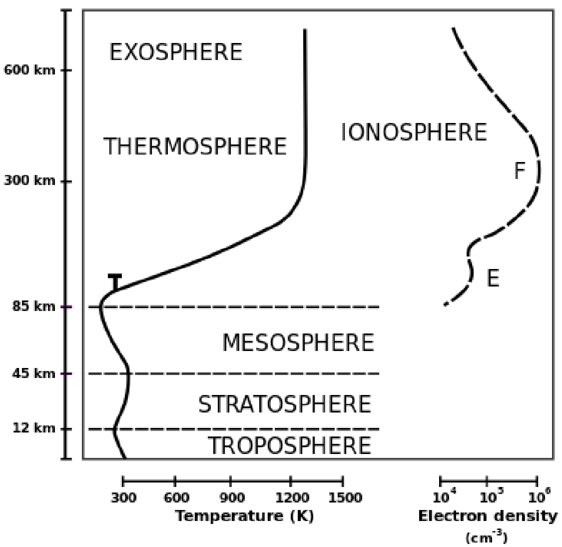
Status:

- recoding to meet UM coding standards
- IR nearly done; NIR to follow
- **Will be made widely available via SOCRATES**



NLTE plot from Fomichev's original code.

Need to derive Socrates spectral files for the FUV/EUV (0.05 – 200nm)



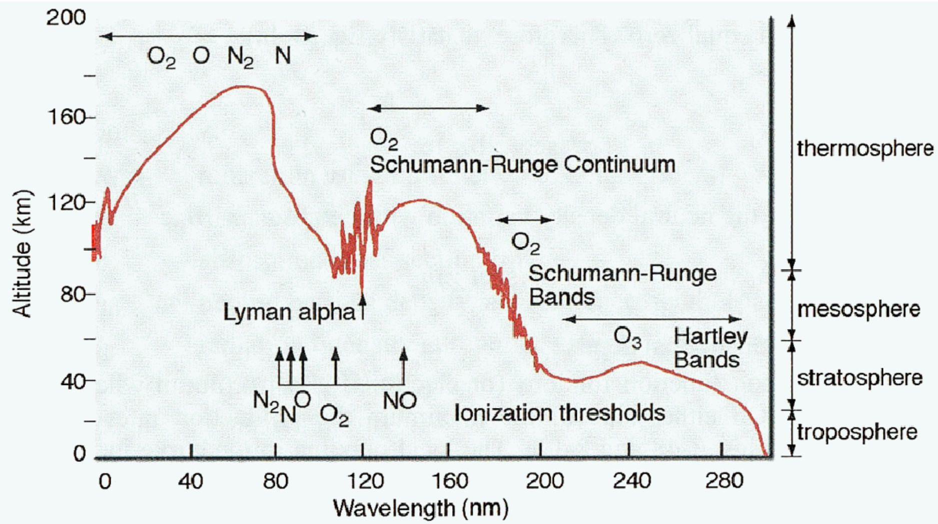


Fig. 5 Solar irradiance atmospheric penetration depth, unitary optical depth, for photons from hard X-rays to 300 nm (from Chamberlain 1978)

- 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

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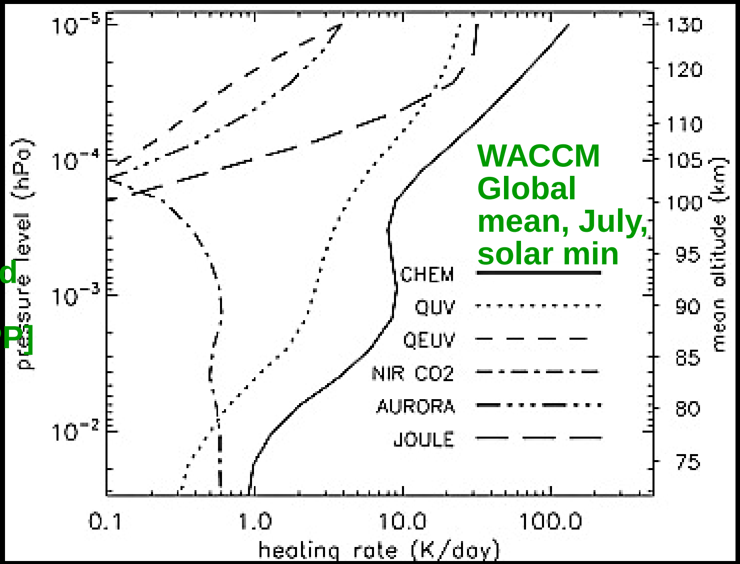
Chemical heating dominant in MLT in determining T structure

[QUV and QEUV: thermalized radiation, AURORA: thermalized energy from EPP] (Marsh et al, 2007)

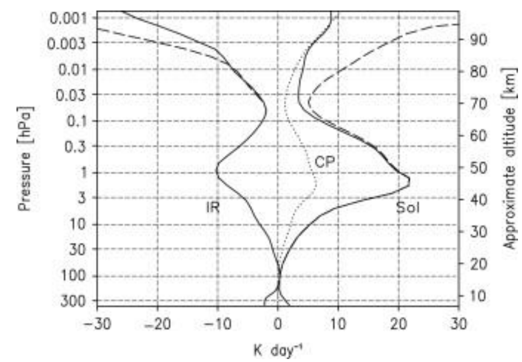


- Current UM chemistry (UKCA) runs up to mesopause but with trop / stratosphere focus
- Chris Kelly (Leeds) developing neutral and ion chemistry for UKCA. Motivations:
  - Can study impact of EPP on stratosphere and troposphere
  - Will improve MLT simulation (exothermic heating)
  - Examining new source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

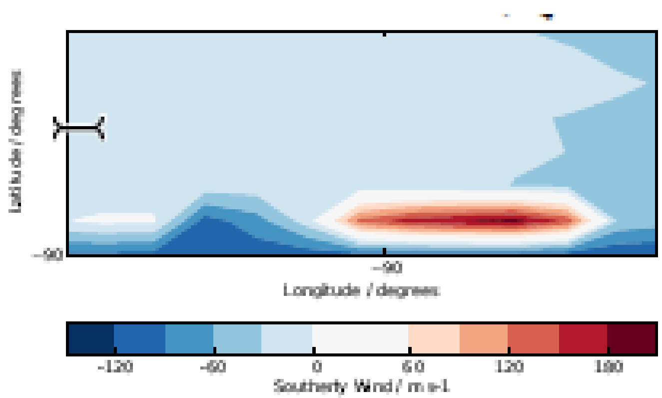
See Chris Kelly's talk

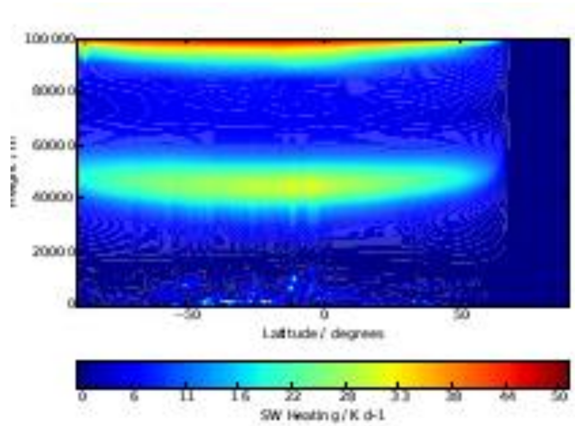
Dynamical Stability – simply lift the lid and go..

- 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



Zonal mean SW and LW heating – Fomichev (2009)





Zonal mean SW heating in UM

See Matt Griffith's talk

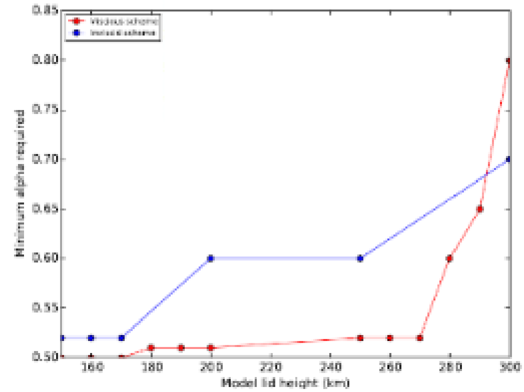
Dynamical Stability – modification of ENDGame dynamical core

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)

Little off-centring needed for stability



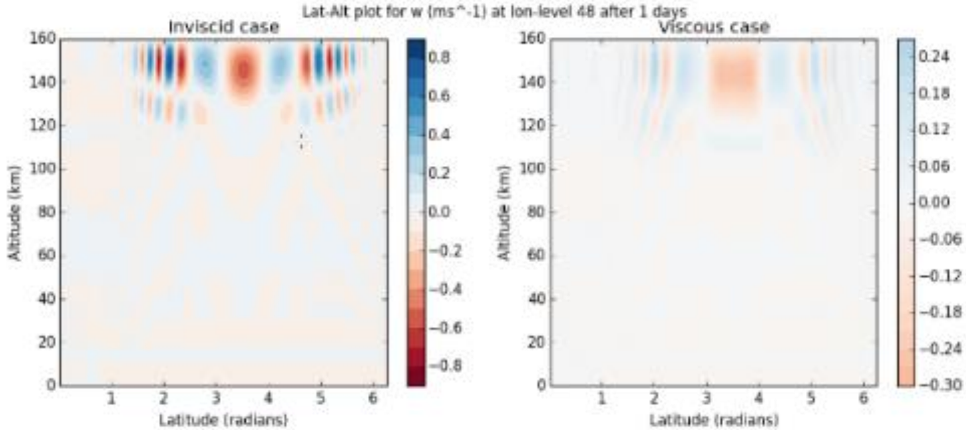
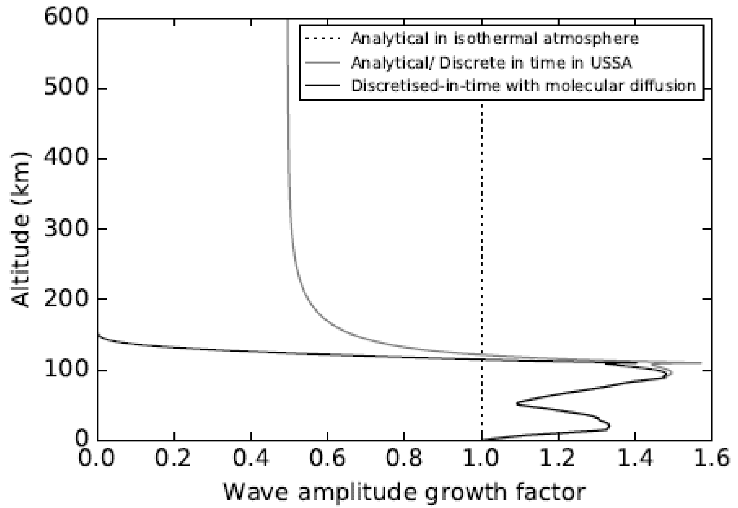


Figure 9: Latitude-Altitude plots at 45° longitude of vertical velocity w after 1 day for a baroclinic wave test with (left) the original formulation and (right) the new formulation with molecular viscosity and diffusion.

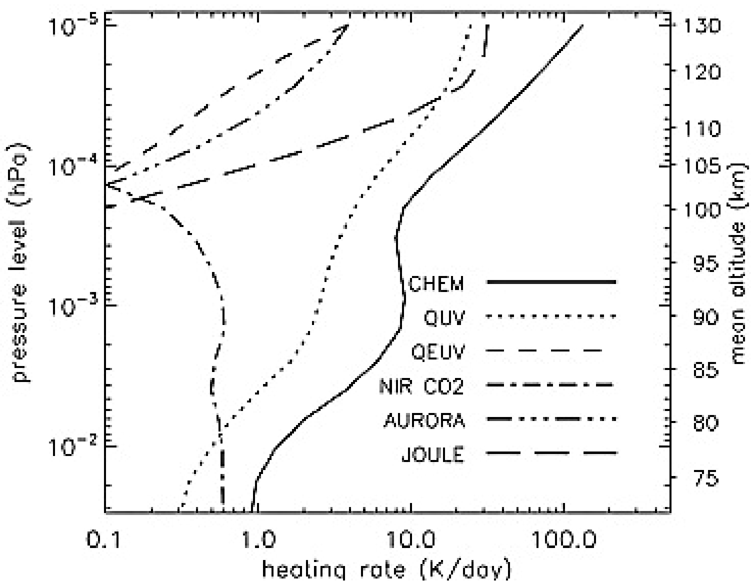


See Dan Griffin's talk

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(100-200km)).
  - 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 (~100-120 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

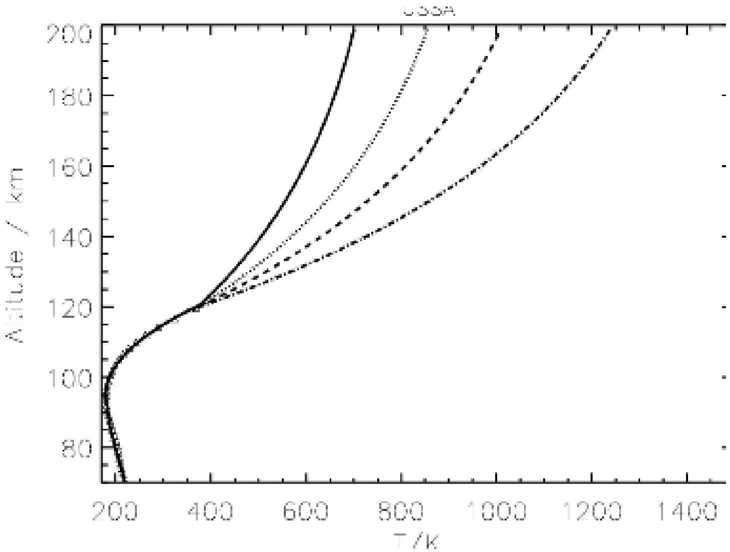
•However, FUV / EUV not likely to be complete

•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)



$T_{exobase}$ = 800, 1000, 1200 and 1500 K