

## Extending the Met Office Weather and Climate Model into the Thermosphere

**David Jackson** 

david.jackson@metoffice.gov.uk

Emily Down, Dan Griffin<sup>(1)</sup>, Matt Griffith<sup>(2)</sup>, Chris Kelly<sup>(3)</sup>, Sean Bruinsma<sup>(4)</sup>, Sandra Negrin<sup>(5)</sup> and Claudia Stolle<sup>(6)</sup>

<sup>(1)</sup>Exeter, <sup>(2)</sup>Bath, <sup>(3)</sup>Leeds, <sup>(4)</sup>CNES, <sup>(5)</sup>Deimos-Space, <sup>(6)</sup>GFZ Potsdam

Spring MIST, Southampton, 26 March 2018





- Met Office Space Weather Operations Centre (MOSWOC)
- Sun to Earth modelling & motivation for a Whole Atmosphere Model
- Extending the Met Office UM into the lower thermosphere
  - Radiation, chemistry and dynamics
- Dynamics for the whole thermosphere 1<sup>st</sup> steps
- SWAMI H2020 project

## Met Office Met Office Space Weather Met Office Operations Centre (MOSWOC)

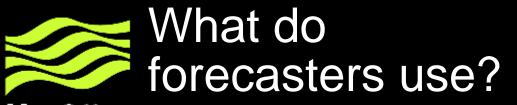
#### • 24/7 Operations

- 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 on behalf of UK Government (Dept of Business, Energy and Innovation Strategy (BEIS))
- BEIS funds operations and associated research via rolling programme

www.metoffice.gov.uk



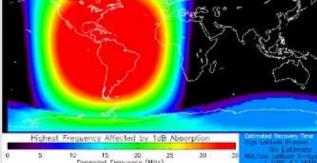
#### Met Office Observations

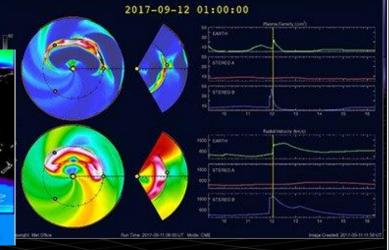
- Solar and corona images and maps (eg SDO, STEREO, SOHO)
- Solar wind on S2E line (ACE, DSCOVR)
- E, p and X-rays at GEO (GOES)
- magnetometers, GPS coes x - Ray Flux



16:36 UTC (10 Sec

13.373.9410<sup>-4</sup> W m





#### Models

- WSA Enlil: solar wind prediction model; CME predictions
- RÉFM:/>2MeV electron fluence at GEO
- D-RAP: HF absorption due to flares, SEPs
- Bernese: TEC (ionosphere)

•Statistics (eg flares); solar wind persistence model, knowledge

© Crown copyright



## Toward Sun-Earth coupled modelling

 Solar wind (interplanetary space) MagnetosphereRadiation belts

Photosphere (solar surface)
Corona (solar atmosphere)

> •Upper / lower atmosphere coupling (via whole atmosphere UM)

•Thermo / ionosphere coupling • Thermosphere • Middle and Lower atmosphere

lonosp

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

www.metoffice.gov.uk



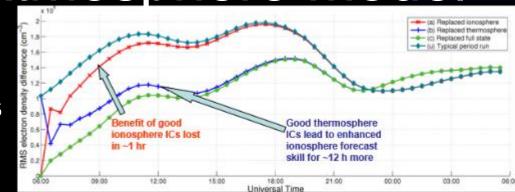
## Whole Atmosphere Modelling

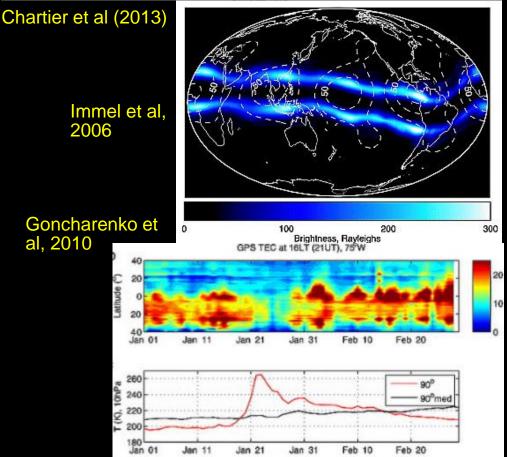
© Crown copyright Met Office

## A Whole Atmosphere model

### Met Office

- One model from the Earth's surface to exobase
- Motivation:
  - Thermosphere state important for ionospheric evolution
  - Important role of lower level driving in thermos / ionospheric state (convection/tides; SSWs)
  - Lack of thermosphere obs means that lower level driving could be like "free DA"
  - Self-consistent representation of dynamics across whole atmosphere
  - Solar / SEP impact on weather and climate







## What model to use?

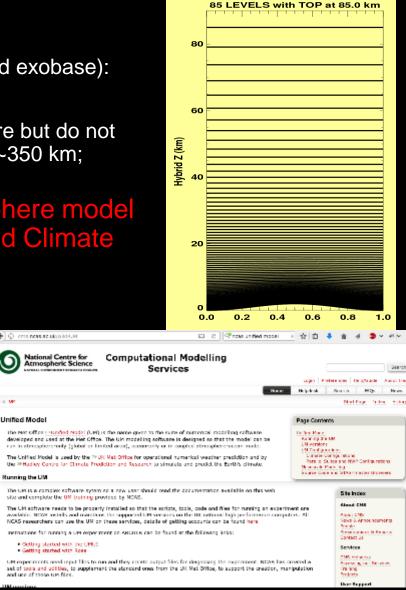
#### **Met Office**

Current whole atmosphere models (surface to around exobase): WAM, WACCM-X, GAIA

Models that include the thermosphere and ionosphere but do not extend all the way down to the surface: CMAT2: 15-~350 km; TIEGCM and GITM – both ~97-~600-700 km

Thanks, but no thanks! – our whole atmosphere model will be based on the Met Office Weather and Climate model (Unified Model – UM)

- Why UM instead of another model?:
  - All other models (except GITM) use hydrostatic dynamics
  - ...assumes vertical velocity is negligible poor in thermosphere
- Its non-hydrostatic formulation will make the UM unique amongst surface to thermospherespanning models.
- Should lead to
  - more accurate modelling of vertical velocities (and air density) in thermosphere
  - Different interaction between dynamics, radiation and chemistry (possibly benefiting from more accurate dynamics)



Also a UK Community model – hosted by NCAS (NERC)

Vertical levels: 0-~85 km

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

## Extending the UM to the thermosphere

## Met Office

#### Huge task - split into 2 strands:

- 1. Upward extension ~120-170 km ("Extended UM").
  - Add relevant physics & chemistry; examine dynamical robustness
  - Couple with TIEGCM (LB ~97 km) – pushes ionosphere development to later
- 2. Develop dynamical core fast waves (acoustic), new eqns, etc

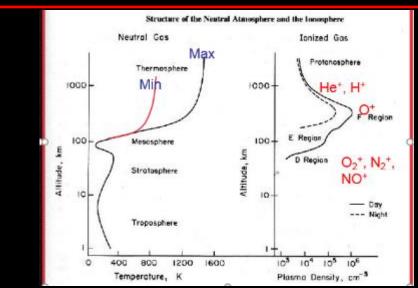
## Eventually blend 1 + 2 => whole atmosphere UM with exobase UB

• Radiation scheme – no non-LTE (less accurate MLT heating rates). No scheme in short UV and EUV (photolysis rates for new chemistry)

•Add thermosphere chemistry – for the large rise in T in the MLT,

•No idea how dynamics will work in less dense atmosphere, and above turbopause (~110-120 km)

#### No electrodynamics (ionosphere)

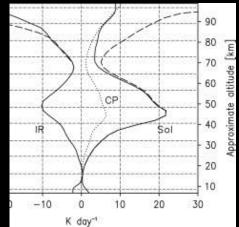


#### Chemical heating dominant in MLT in determining T structure

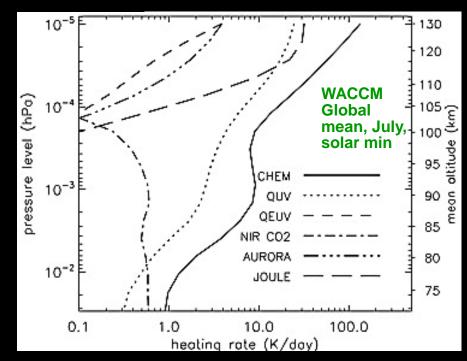
- Current UM chemistry (UKCA) runs up to mesopause but with trop / stratosphere focus
- Chris Kelly (Leeds PhD) developing neutral and ion chemistry for UKCA (based on WACCM). Motivations:
  - Can study impact of EPP on stratosphere and troposphere
  - Will improve MLT simulation (exothermic heating)
  - Examining N2O in WACCM (possible new source)
  - Starting UKCA work with 5 species Na ion chemistry (data for validation available)

## schemes for chemical scheme photolysis rates

 Need exothermic chemical heating to model large rise in T in MLT



SW and LW heating – Fomichev (2009)

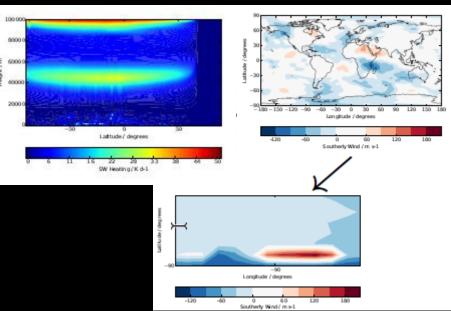


## Dynamical Stability – just raise the lid!



- With 100 km stable climatology but fails after a few months – unless timestep is halved
  - 105-120 km lids fails after days/weeks even with extra diffusion, short timesteps, etc

SW heating looks too large: due to non-LTE effects being omitted (actually in NIR)
Could adding non-LTE to UM radiation scheme fix stability issues?



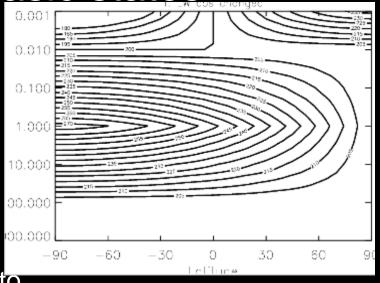
Zonal mean SW heating – lat/pressure section (left). Lat/lon fields meridional winds (right and bottom)

## Dynamical Stability – Basic states

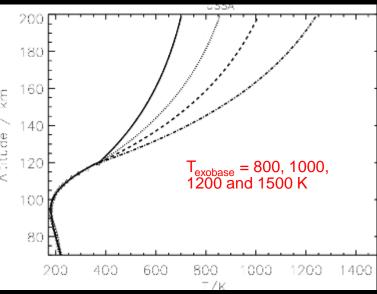
#### **Met Office**

- Try stripped down dynamics only tests
  - Impose climatological T structure
  - Clears out unidentified problems with parametrization schemes (eg gravity waves, diffusion, even convection)
- Builds on well used Held-Suarez tests relax to Lin-Williamson basic state up to m/pause (radiative timescales)
- Add tidally-locked state for thermosphere in development – but already applied to exoplanets! (eg Mayne et al, 2014)

```
For "full" UM – relaxation to give realistic basic state while awaiting radiation / chemistry devs (eg in SWAMI)
Global mean T based on USSA/CIRA and asymptotic relaxation to specified exobase T
Follows nudging approach (eg Telford et al, 2008)
```



Lin-Williamson (Jan)

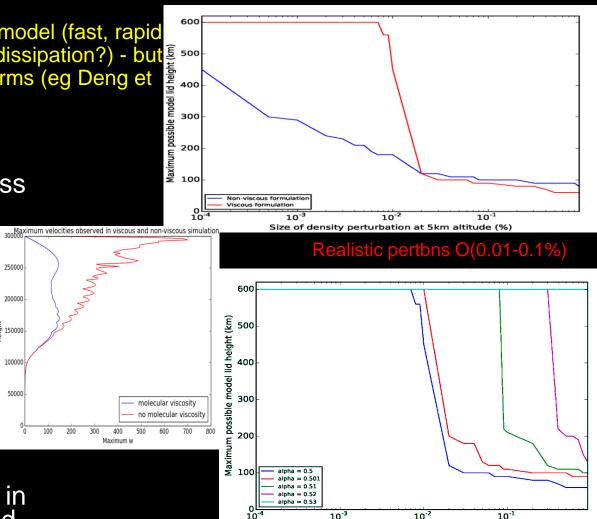


## Dynamical stability high higher up damping via molecular viscosity

#### Met Office

Acoustic waves most challenging to model (fast, rapid amplitude growth, how to represent dissipation?) - but can be important in geomagnetic storms (eg Deng et al)

- Initial simulations with acoustic waves not stable above ~100-120 km (unless amplitude unrealistically small)
- Molecular viscosity is realistic wave damping mechanism important >~ 130 km (t/scale < wave growth t/scale)
- Addition of molecular viscosity into solver (plus use of α≥0.52) appears to decrease wave amplitude in a realistic manner and lead to more stable simulations



Dan Griffin and John Thuburn: Numerical Effects on Vertical Wave Propagation in Atmospheric Models. QJRMS in prep.

Size of density perturbation at 5km altitude (%

© Crown copyright Met Office



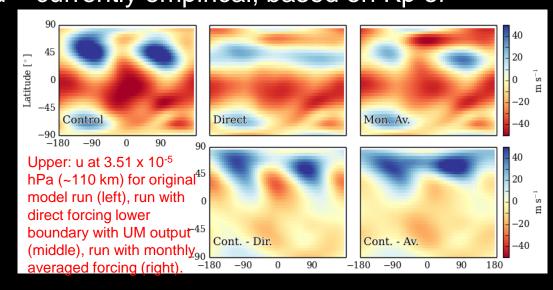
## What about the ionosphere?

#### Met Office

- For now, couple extended UM and TIEGCM
  - Global 3-D physics-based model of thermo/ionosphere (~97 ~600 km). Used at Met Office in thermosphere DA and ionosphere nowcasts
  - Provides contribution to MLT budget via Joule heating (collisions between ions and neutral gases)
- Electric field model required solar wind at high latitudes)
   Coupling extended UM with TIEGCM (direct or "nudging") already coded

## New developments:

- Improved JH and E field model
- Ionospheric DA and low level coupling © Crown copyright Met Office

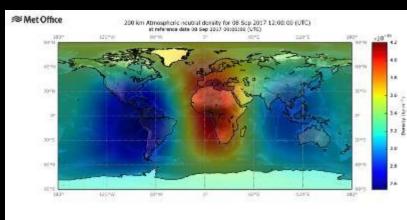






## New Horizon 2020 project (Jan 2018 – Dec 2020)

- Met Office aims
  - Add new radiation schemes to UM
  - Build and test (+ dynamics and chemistry changes) => stable, validated Extended UM
- Blend with DTM => "whole atmosphere" model with quick use option for satellite launch and reentry
- Driven by higher cadence Kp nowcasts & improved Kp forecasts
   © Crown copyright Met Office





- 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 dynamics, chemistry and radiation, coupled UM / TIEGCM
  - SWAMI provides resources and focus leading to 1<sup>st</sup> stable, verified Extended UM version
- Pathway to Whole Atmosphere (full thermosphere / ionosphere) UM and coupled S2E modelling system.

#### Extended UM

To Jump to ...

R New Threads

Starred = general

# talks-and-posters

#### Extended **UM Slack** group

(Met Office, Bath, Exeter, Leeds, UCL, Lancaster, B'ham..)

#general \$ 16 % 0 Company-wide announcements and work-based matters.

E Eventbrite

0 @ Q Thursday, February 8th

deimos

#### System-Scale Data Analysis to Resolve Thermospheric Joule Heating

About the workshop: The 1-day workshop "System-Scale Data Analysis to Resolve Thermospheric Joule Heating", will be held at the Aurora Centre in the British Antarctic Survey (Cambridge, UK) on Friday 27th April 2018. It is sponsored by the Royal Astronomical Society. The aim of this workshop is to give a forum for discussing of the interdisciplinary utility of data-driven analytical techniques, and the best ways to harness the potential of the available large datasets which are driving advances in near-Earth space research. The specific focus of the workshop is on the

intrinsically interdisciplinary problem of resolvi energy from electrical currents in the i... Show r Where Whe Madingley Road, Cambridge, CB3 0ET, Fri. 2

United Kingdom



Google Docs Abstract Upload Form Please complete the fields below to upload you

Come and join us!

Projects

Products & Services

#### WHOLE ATMOSPHERE MODELLING WORKSHOP.

About us 🐱

What we dot w

Developments in the context of Space Weather

#### f 🕑 in 😳 🤊 🕊

Careers

News

Contact

ABSTRACTS & POSTERS	PROGRAMME	TRAVEL

This workshop is intended to focus on the scientific and technical issues associated with developing atmospheric models that extend from the ground up to and including the thermosphere at about 600km. The goal of this effort is to develop models for improved ionospheric and thermospheric space weather forecasting, which include comprehensive representations of forcing from the lower atmosphere, as well as solar and geomagnetic forcing. Themes of the workshop shall include:

- Atmospheric models: capabilities and limitations
- Developing whole atmosphere model building blocks
- · Dynamic drivers of the thermosphere and ionosphere
- Data assimilation and model validation
- Ionosphere and magnetosphere interactions

## WA Modelling Workshop: Madrid, 13-15/06/18

http://www.elecnor-deimos.com/wam-workshop-2018/

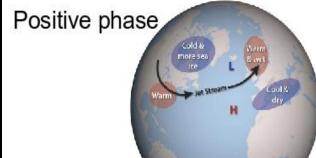


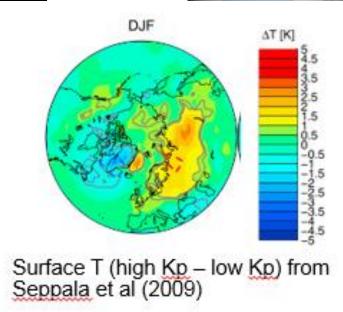
## Extra slides

# Met Office Motivation: Impact on tropospheric climate & seasonal forecasts?

- Solar cycle in UV => increased heating via o3 (at solar max) =>stronger meridional T gradient and stronger polar vortex
- EPP reduces strat O3 (NOx + t/port) and meso O3 (HOx) -> warming (cooling) in

level pressure difference (hPa





Solar min – Solar max for near-surface temperature for UM left) ERA (right) Ineson et al (2011)

© Crown copyright Met Office

Model temperature difference