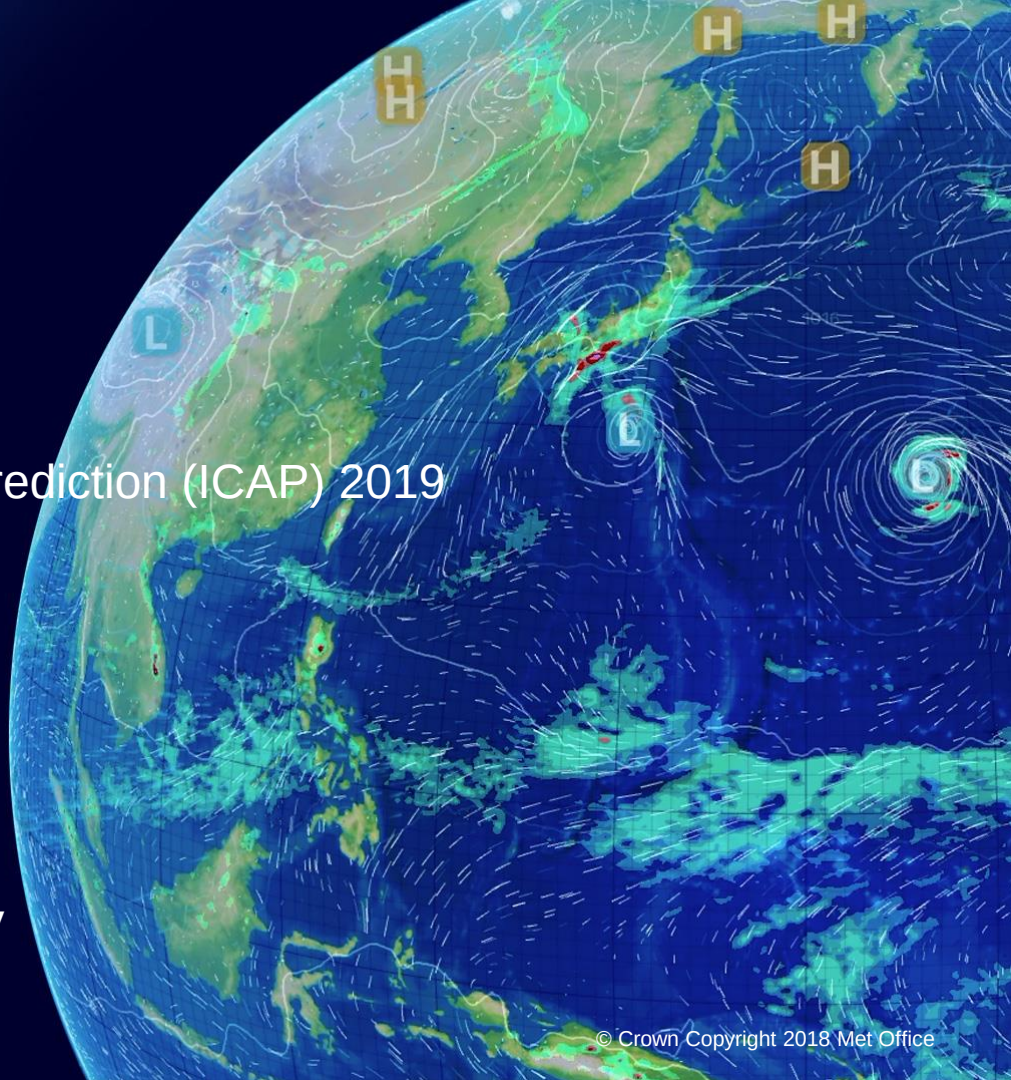
Met Office Update

International Cooperative for Aerosol Prediction (ICAP) 2019
Tsukuba, Japan.

Malcolm Brooks, Yaswant Pradhan,
Sandra LeGrande (US Army ERDC)

Ben Shipway, Adrian Hill, Jane Mulcahy



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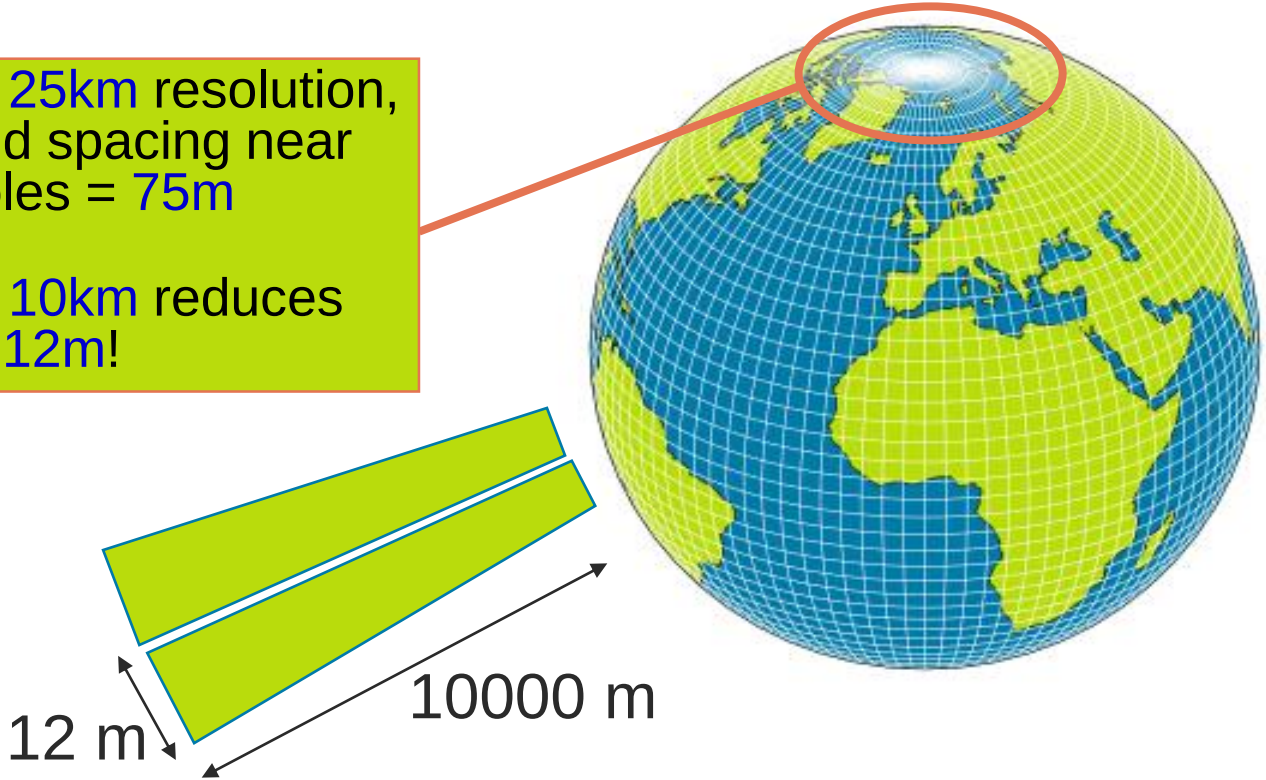
Outline:

1. Met Office migration to LFRic
   a) New model details
   b) Optimisation and technical aspects
   c) Progress
2. Aerosols within LFRic
   a) Migration for climate applications
   b) NWP system outline
   c) Supporting that migration
3. Updates to the current system
   a) Satellite data assimilation
   b) Development work on surface erodibility.

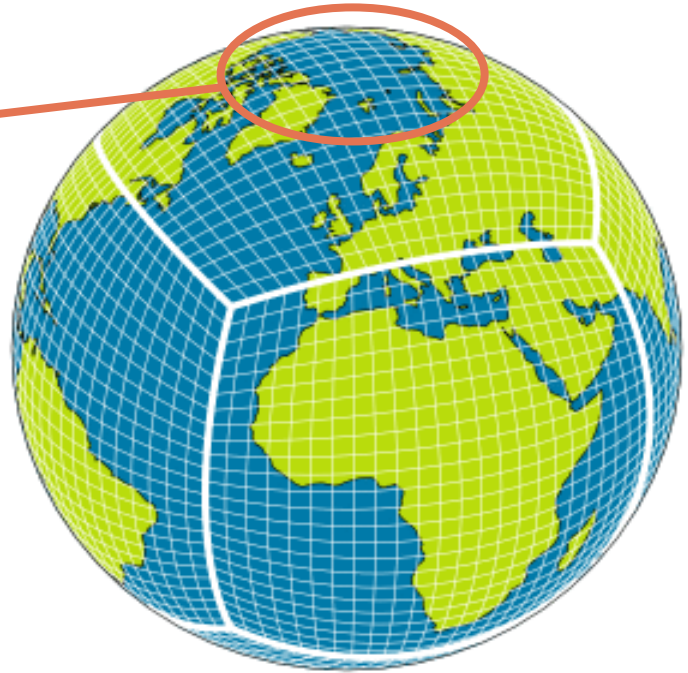
1. Met Office migration to LFRic - motivation

- At 25km resolution, grid spacing near poles = 75m
- At 10km reduces to 12m!



1. Met Office migration to LFRic - motivation

- A new grid is essential or any resolution increase
- Migration to a cubed-sphere
- New dynamical core: ‘GungHo’



	ENDGame	GungHo
Grid	Lat-Long	Cubed-Sphere
Prognostic Variables	ρ, θ, Π, u, v, w	ρ, θ, Π, **u**
Prognostics Equations	Advective form	Flux/Advective/Vector Invariant form
Spatial Discretisation	2nd Order FD	Mixed FEM
Temporal Discretisation	Iterative Semi-Implicit	Iterative Incremental Semi-Implicit
Advection	Semi-Lagrangian	COSMIC (Dimensionally split, Eulerian)

ENDGame (UM) vs GungHo

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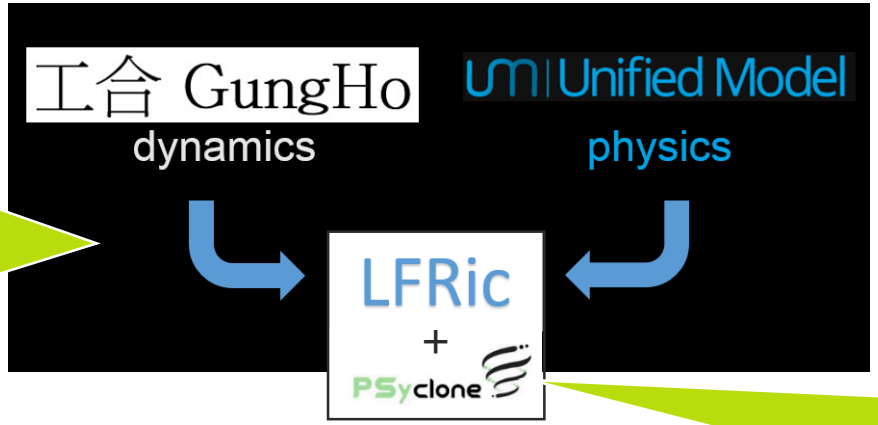
1. Met Office migration to LFRic – Optimisation and technical aspects

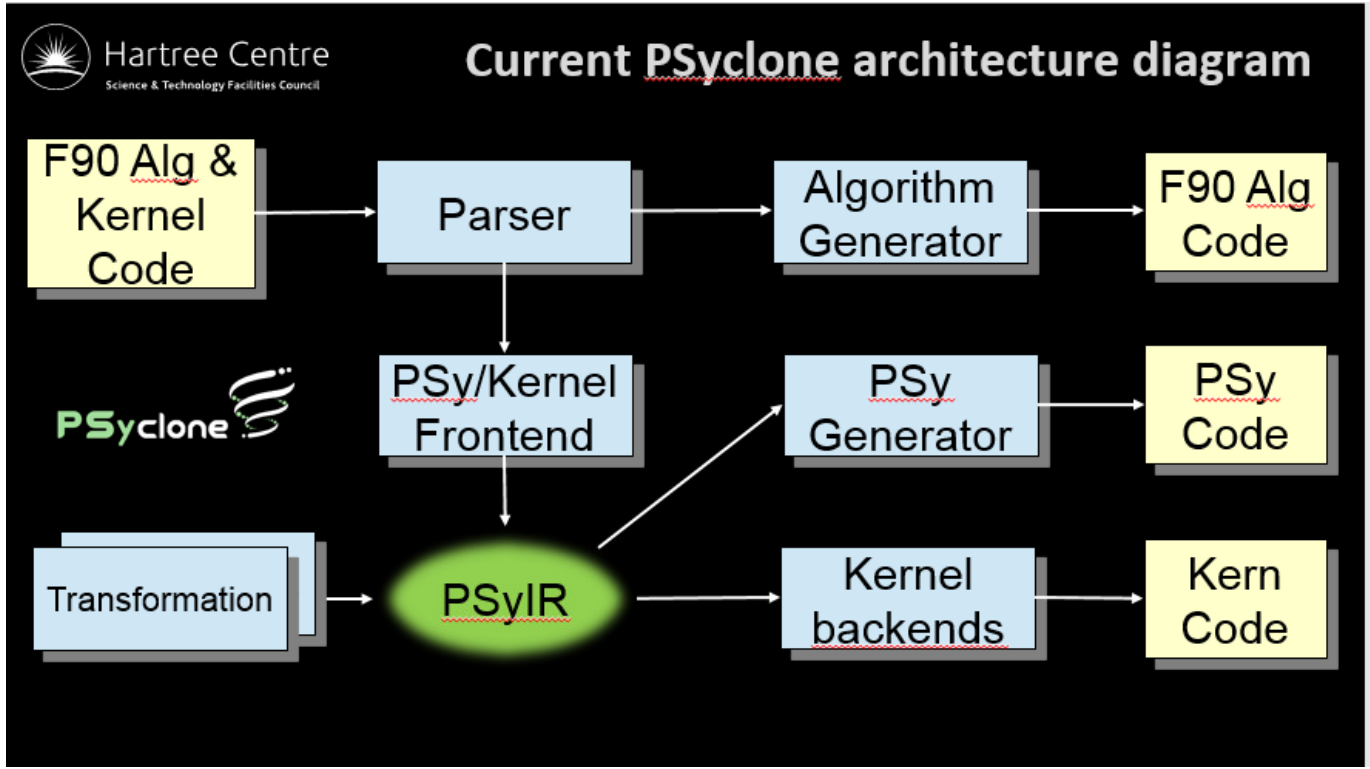
A coupling infrastructure between dynamics and physics schemes.

Fundamentally **more modular design**

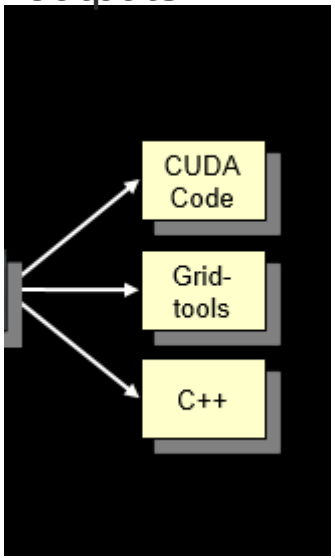


PSyclone:
Separates the Natural Science from the Computational Science (performance)

1. Met Office migration to LFRic – Optimisation and technical aspects



Other/future outputs



FPGA being worked on

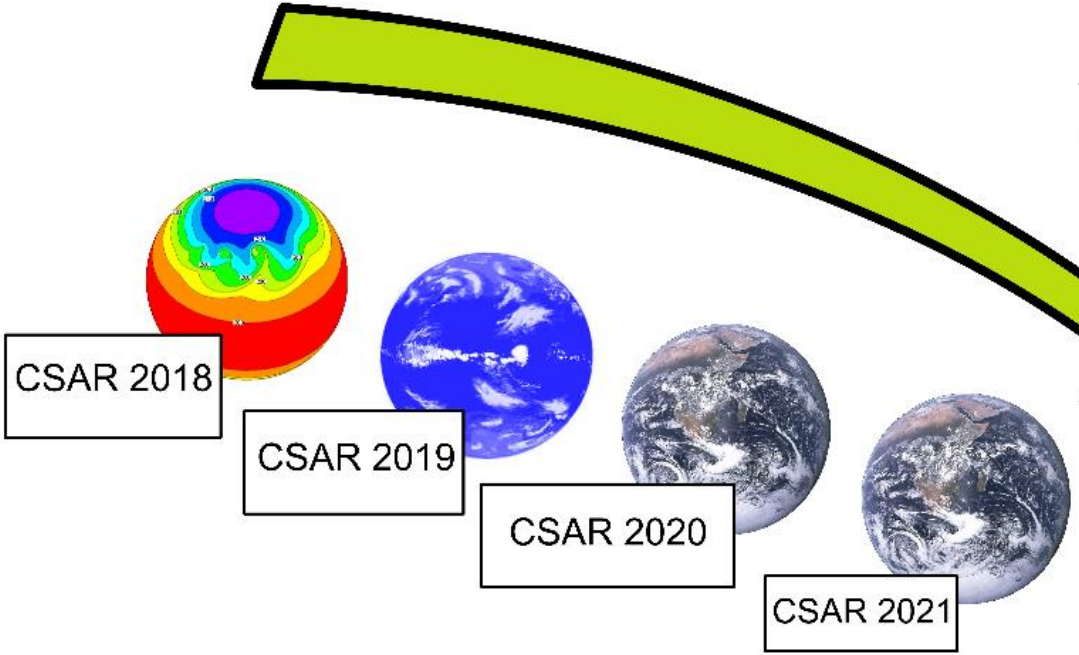
1. Met Office migration to LFRic – Optimisation and technical aspects

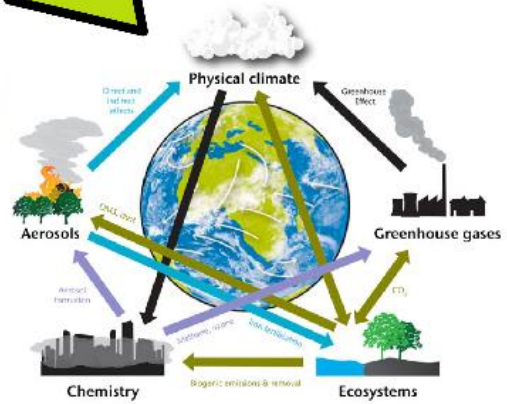
Other/future

- PSyclone optimisation works on current architecture.
- New and future architectures can be optimised in a modular way.
- Gives future flexibility of hardware.
- LFRic investing in this complexity for long term benefits.

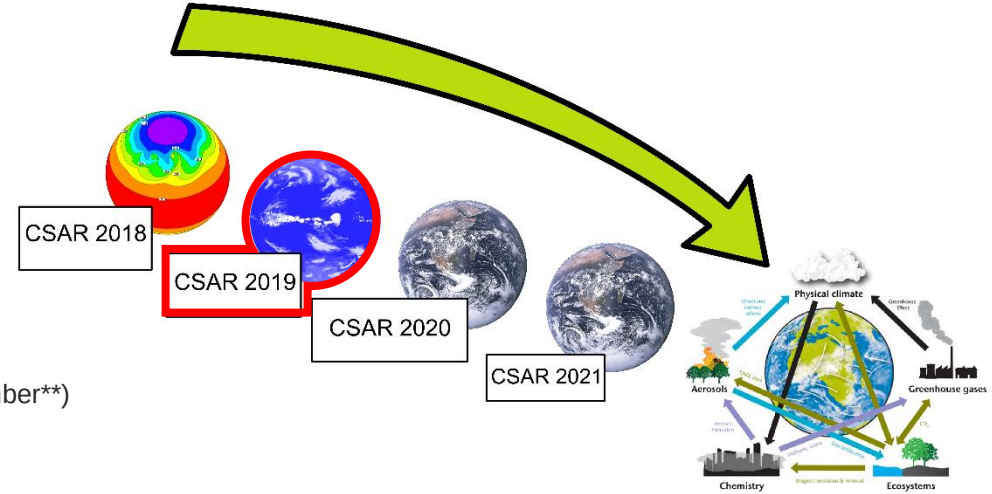
1. Met Office migration to LFRic – Progress

Step by step approach of increasing complexity.





Aquaplanet



Target aquaplanet defined by:

- Dynamical core
  - GungHo semi-implicit timestepping (c.f. ENDGame)
  - Transport (timestep limited by advective Courant number**)
  - Vertically stretched mesh
- Physics (GA configurations unless stated)
  - Boundary Layer scheme
  - Smith Cloud scheme
  - W-B microphyiscs
  - L-L convection scheme**
  - SOCRATES radiation
- Physics Coupling
  - Spatial mappings from FE to FD and back again
  - Temporal SI coupling as ENDGame
- Infrastructure
  - Build system to bring in Physics source codes
  - UM2LFRic reconfiguration
  - Initialize capability from startdump
  - Checkpoint-restart capabilities
  - Basic UGRID diagnostic capabilities

**Interim solutions while target schemes are in development

Aquaplanet

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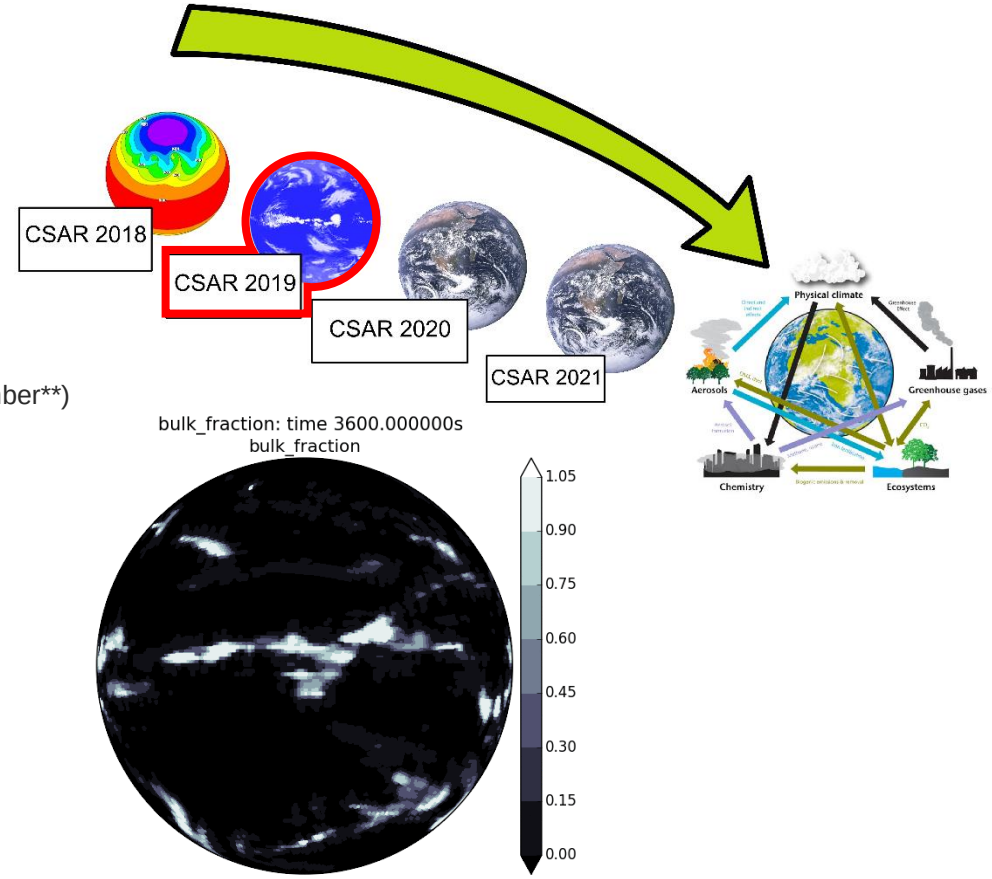
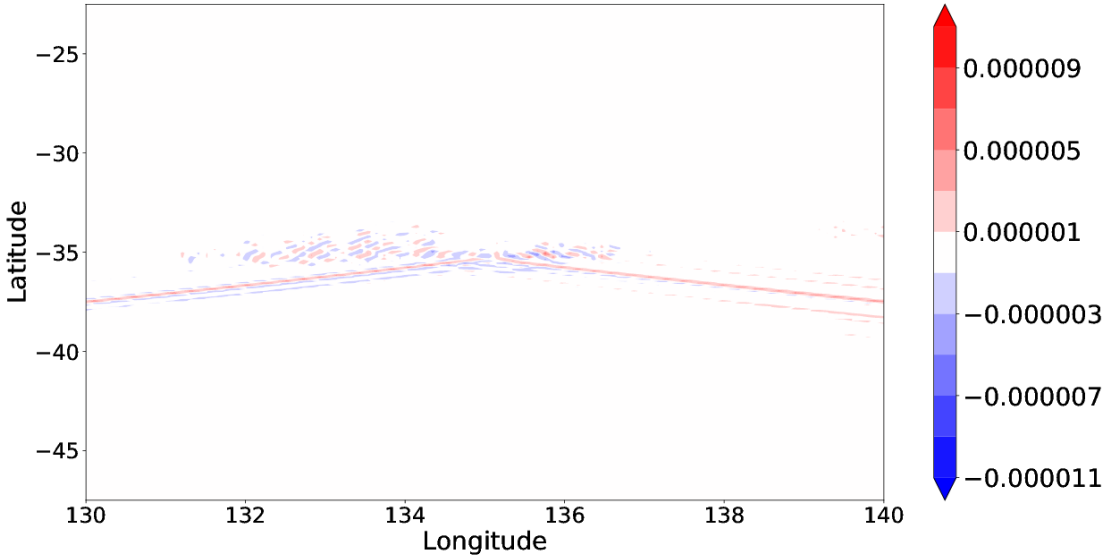


**Interim solutions while target schemes are in development

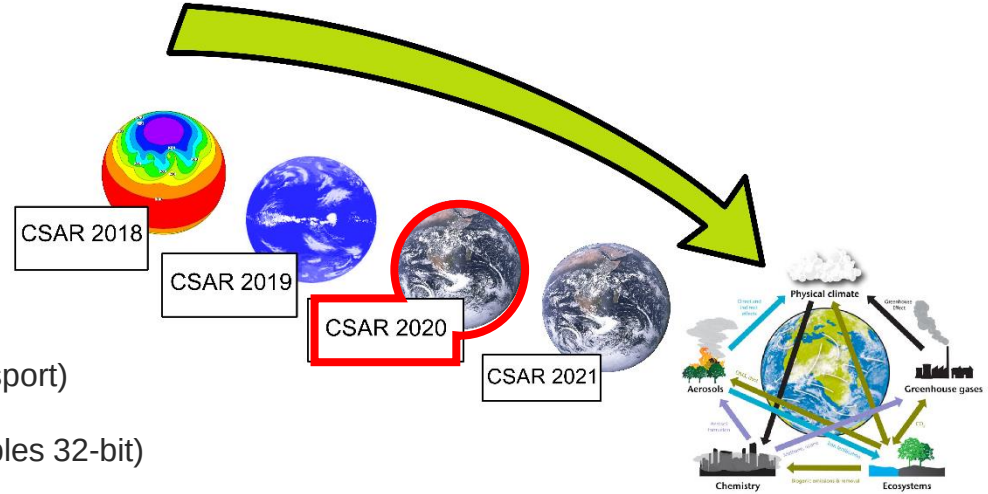
Grid Imprinting ☺

Vertical velocity over a corner of the cubed sphere after 1 day

Zoom in on corner
C768 ~ 13km



Towards full physics



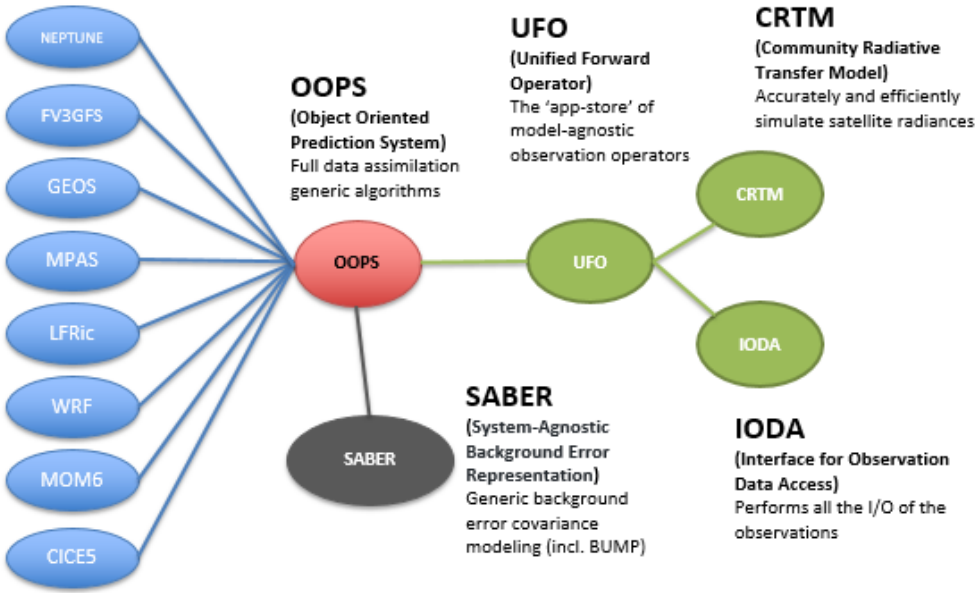
Developments:

- Dynamical core
  - Improvements to accuracy (Momentum transport)
  - Real orography
  - Move to a spherical coordinate system (enables 32-bit)
- Additional Physics
  - Gregory-Rowntree (6A) convection
  - Non-orographic GWD
  - Orographic GWD
  - JULES surface exchange
  - PC2 clouds
  - Basic cloud-aerosol interactions from climatological aerosol
- Infrastructure
  - Ancillary generation
  - Higher resolution reconfiguration of startdumps from UM
  - Move to unified (decomposition-independent) UGRID file format
  - Refactoring to bring in new LFRic infrastructure when it comes on line

1. Met Office migration to LFRic – Data assimilation

JEDI Separation of Concerns/Flexible Infrastructure

Joint Effort for Data assimilation Infrastructure



- Different concepts are treated in different parts of the code. Nobody can know it all
- Abstract interfaces are the most important aspect of the design
- The end of the monolithic gigantic jumble of code…

https://www.jcsda.org/software

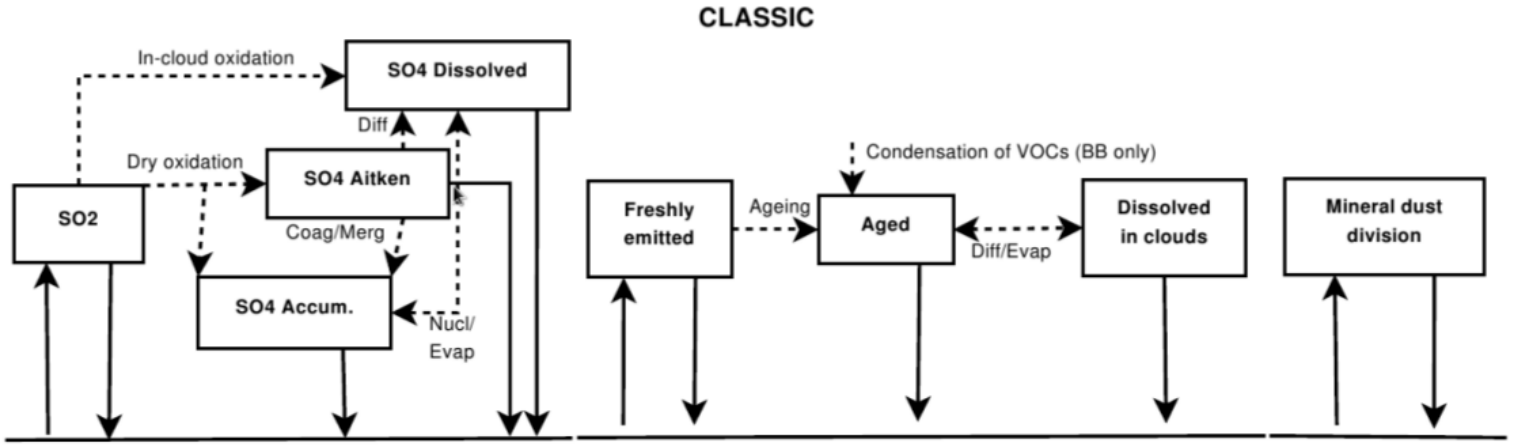
Yannick Tremolet, JCSDA

2. Aerosols within LFRic

- The current UM has 2 aerosol models
  - CLASSIC: single moment, mass based. Operational NWP for dust. Research NRT for other aerosols.
  - GLOMAP MODE: 2 moment Used in climate model config, using full complexity

Met Office

Aerosol in the UM - Classic



Sulphur cycle

BB, soot, OCFF

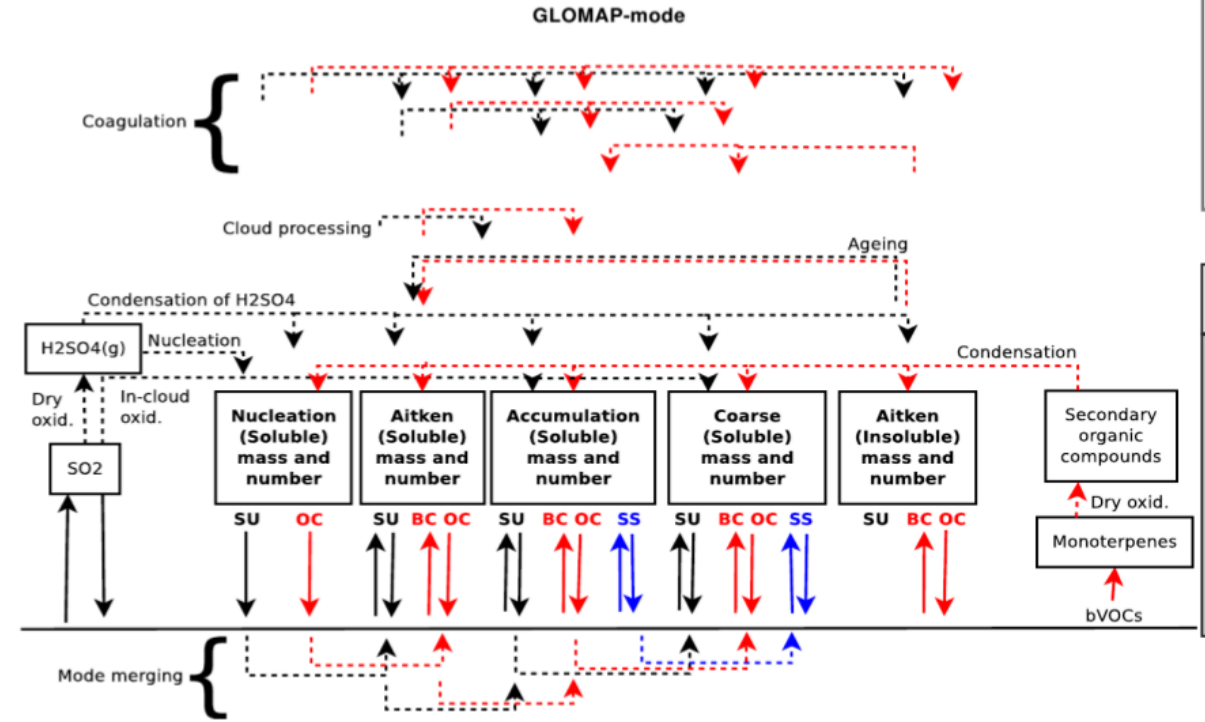
Dust

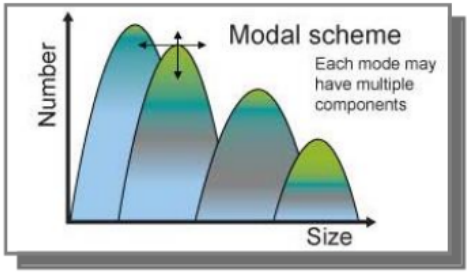
- Single moment scheme, mass-based
- Diagnostic Sea Salt, climatological SOA
- Externally mixed aerosol particles
- CDNC diagnosed using Jones et a. (2001)

Adrian Hill, Jane Mulcahy

Met Office

Aerosol in the UM – UKCA-MODE





GLOMAP-mode (Mann et al. 2011)

- Online calculation of aerosol optical properties (RADAER)
- Online aerosol activation to cloud droplets (UKCA-Activate, West et al. 2014)
- GLOMAP climatologies currently being developed for NWP

Adrian Hill, Jane Mulcahy

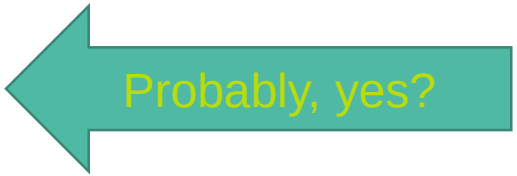
2. Aerosols within LFRic

- The current UM has 2 aerosol models
  - CLASSIC: single moment, mass based. Operational NWP for dust. Research NRT for other aerosols.
  - GLOMAP MODE: 2 moment Used in climate model config, using full complexity.

- Portability: ideally there should be only one.
  - CLASSIC code is distributed through the UM.
  - GLOMAP MODE code is modular with a defined interface.

  - GLOMAP will have to be ported for climate applications.

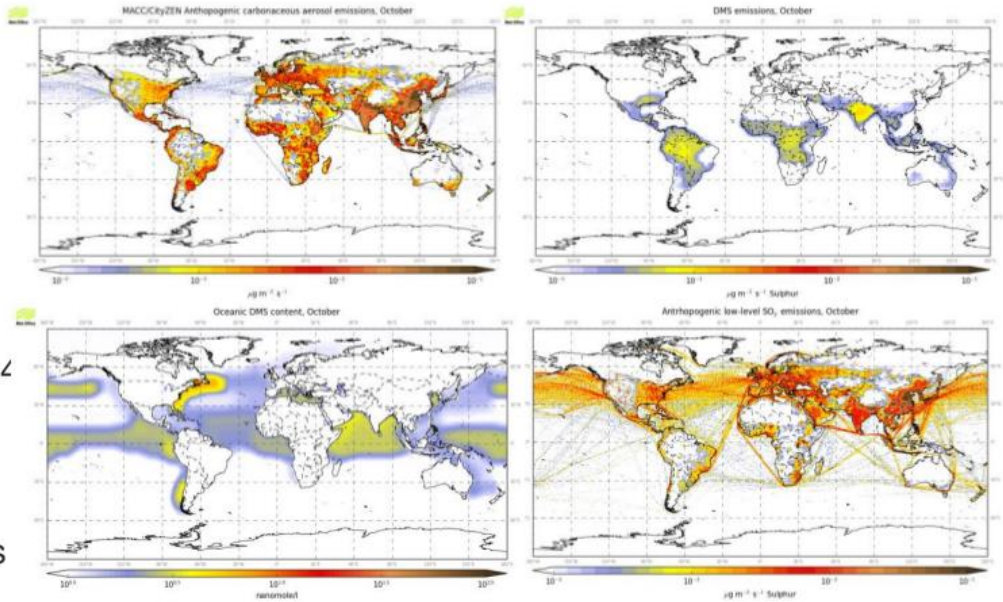
  - Can GLOMAP MODE meet NWP needs?



2. Aerosols within LFRic

- Can GLOMAP MODE meet NWP needs?
  - Current active area of work.
  - Dust forecast comparisons between CLASSIC and GLOMAP MODE underway.
  - Setting up a NRT forecast using CLASSIC from 1 global ensemble member

- prognostic, single moment aerosol representation, used to support research campaigns
  - INCOMPASS, SWAMMI, MONSOON - over India, pre/during monsoon 2016
  - CLARIFY – Aerosol-cloud interaction over the tropical south Atlantic
- Carbonaceous aerosol
  - Fossil fuel, biomass burning, bio-fuel
  - Anthropogenic emissions - MACC/CityZEN, 201
    monthly mean
- Sulphate aerosol forecasts
  - Anthropogenic SO_2 (MACC/CityZen), Volcanic SO_2, Land based DMS Ocean DMS conc (fluxes wind based)



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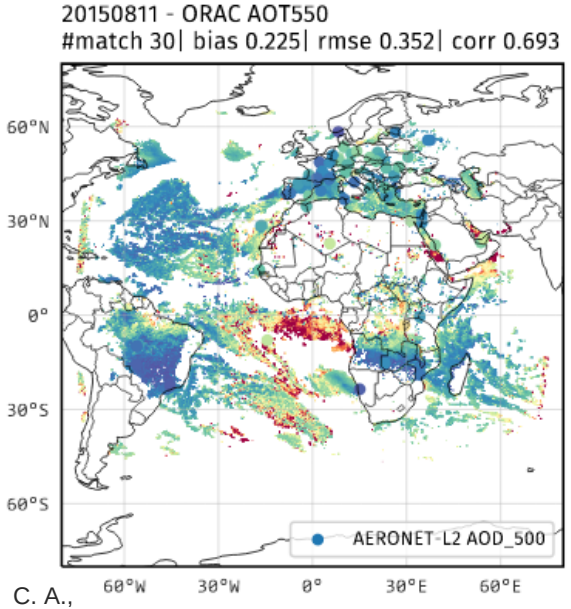
- Can GLOMAP MODE meet NWP needs?
  - Current active area of work.
  - Dust forecast comparisons between CLASSIC and GLOMAP MODE underway.
  - Setting up a NRT forecast using CLASSIC from 1 global ensemble member
    - Gives a spun-up aerosol setup to initialise GLOMAP MODE test runs.
    - Allow comparisons between full complexity version of GLOMAP MODE and CLASSIC
    - Simplified (cheaper!) versions of GLOMAP MODE in early development.
- Aim: GLOMAP MODE as single LFRic aerosol model, with complexity for climate and simplifications for NWP.
- Not fully “unified modelling”, but “tracable” is the next best thing.

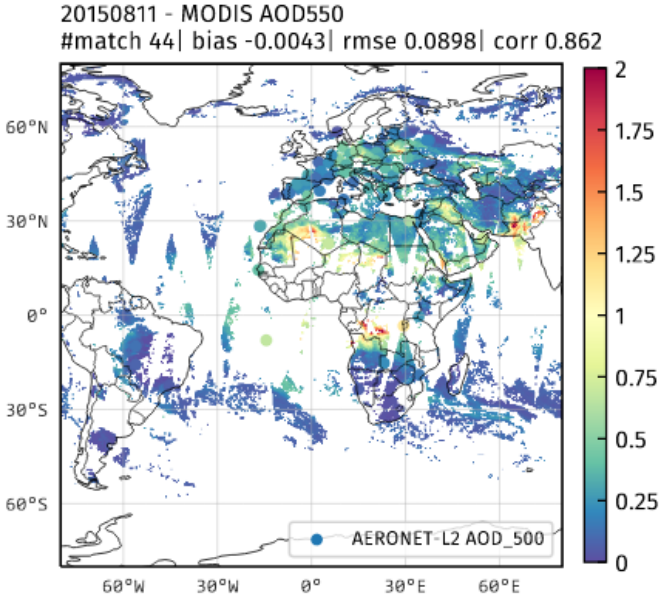
3. Updates to the current system

Satellite and Data Assimilation updates:

- Currently assimilate only MODIS AOD (Aqua and Terra)

- Investigation of Optimal Retrieval of Aerosol and Cloud (ORAC*) from IR SEVIRI
  - Uses optimal estimation of radiances to give cloud and aerosol properties.
  - Daily mean AOT
  - ORAC coverage good
  - Large differences, especially on boundaries





* Thomas, G. E., Carboni, E., Sayer, A. M., Poulsen, C. A., Siddans, R., & Grainger, R. G. (2009a).Oxford-RAL Aerosol and Cloud (ORAC): aerosol retrievals from satellite radiometers. Satellite Aerosol Remote Sensing over Land, (pp. 193–225).

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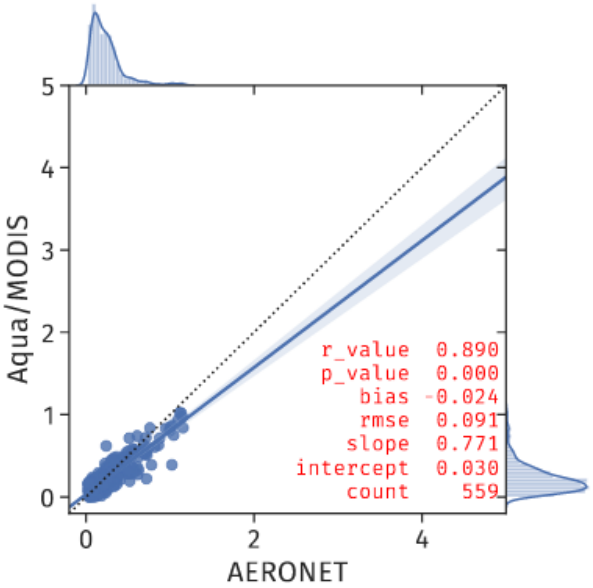
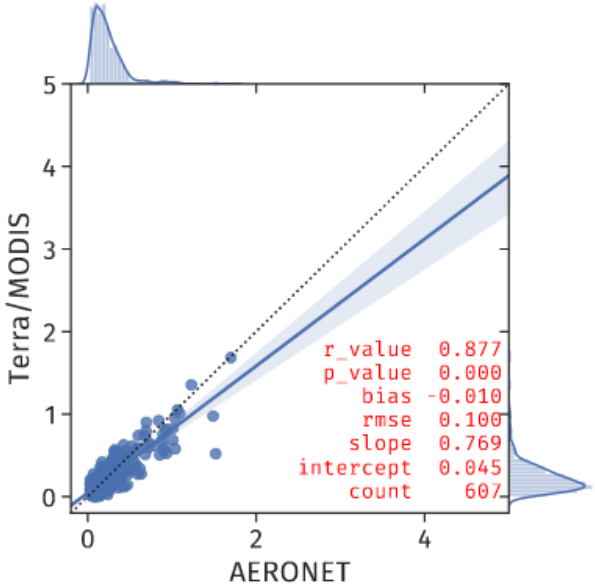
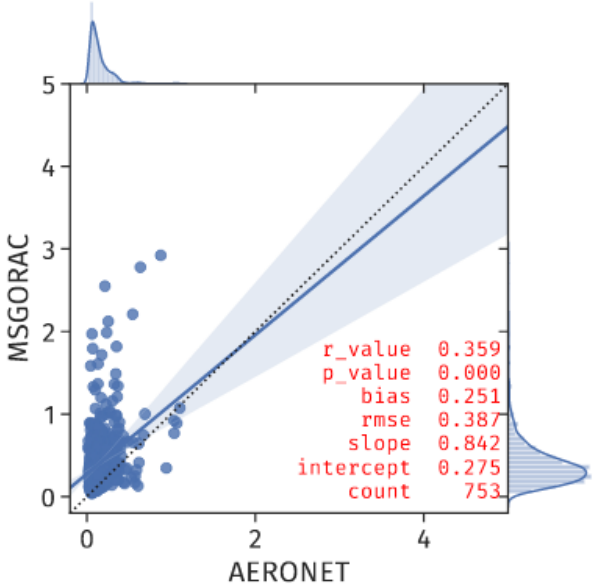




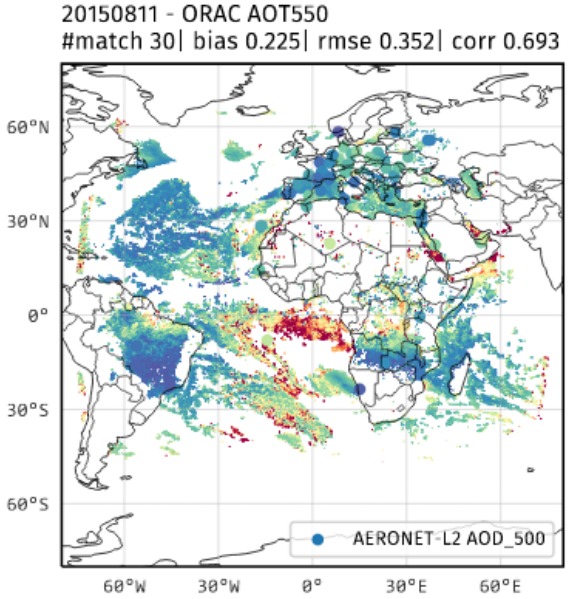


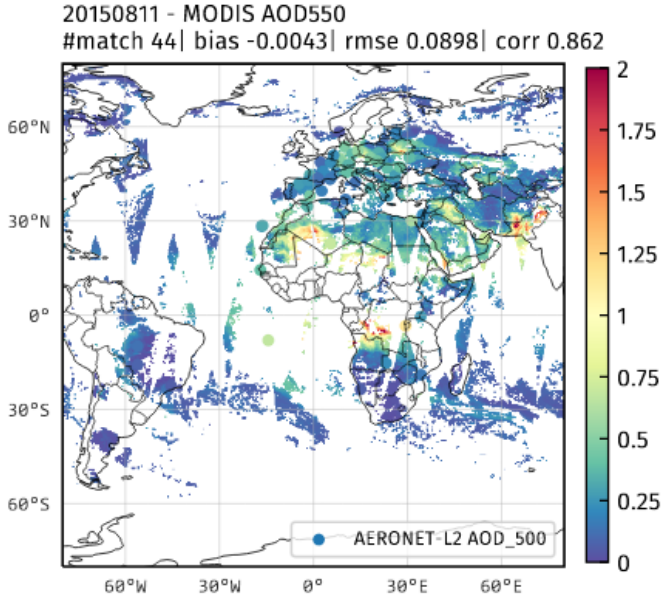
3. Updates to the current system

Satellite and Data Assimilation updates:

- Currently assimilate only MODIS AOD (Aqua and Terra)

- Investigation of Optimal Retrieval of Aerosol and Cloud (ORAC) from IR SEVIRI channels
  - Daily mean AOT
  - ORAC coverage good
  - Large differences, especially on boundaries
  - On average, comparison shows more work needed before can be used.





Collaborative Efforts to Improve Unified Model Dust and Visibility Forecasts with the ERDC-Geo Surface Erodibility Parameterization for Dust Source Characterization

- Sandra (Jones) LeGrand
- US Army Engineer Research & Development Center (ERDC)
- June 2019
- Sandra.L.LeGrand@usace.army.mil

Distribution A: Approved for public release

CRREL COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

CAPABILITY GAP

- **Current UM** dust emission configuration **struggles to simulate individual dust events**
- Especially:
  - Significant dust outbreaks
  - Surface visibility
  - Location/time specific extinction coefficients
- UM code **originally designed for** large scale atmospheric patterns and **climate applications**
- Produces **widespread dust emission** to achieve atmospheric aerosol loads

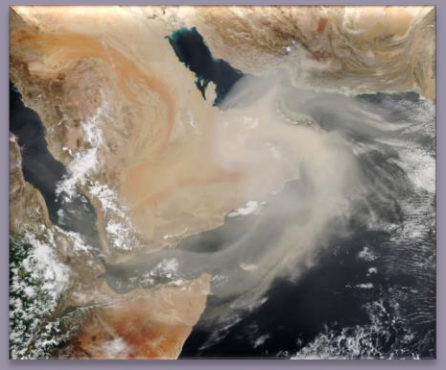


Figure 1. July 20, 2018 VIRS true color satellite image of a strong dust storm over the Arabian Peninsula, Arabian Sea, and Persian Gulf.

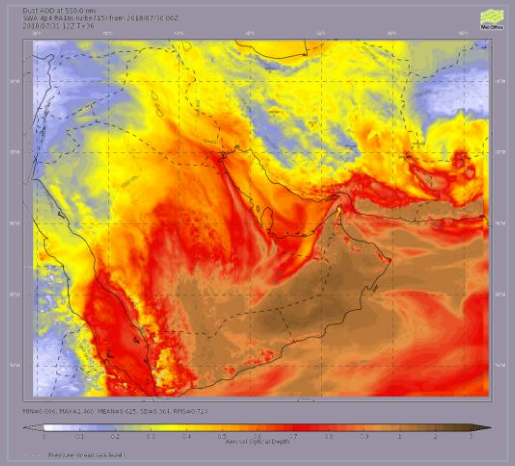


Figure 2. 36 hour 4.4 km 550 nm Aerosol Optical Depth (AOD) forecast generated via the current UM configuration. Model produces widespread dust with "excessive tails."

GOAL: **Resolve widespread dust emission issues in the UM** through **improved dust emission characterization techniques.**

ERDC-Geo

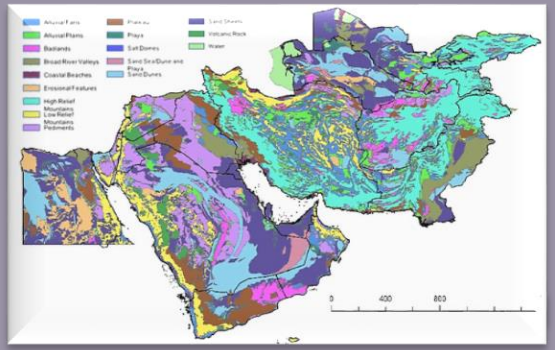


Figure 3. 16-class geomorphic landform dataset at 1:750,000 map-scale for Southwest Asia.

Dust producing Regions are mapped into a series of preselected geomorphic classifications using satellite imagery and GIS

Figure 4. Karen Foley collecting samples in the Mojave Desert and a wind shear chamber device used for measuring landscape dust emission potential.

Wind shear chamber devices are used to create landform-based dust emission potential look-up tables

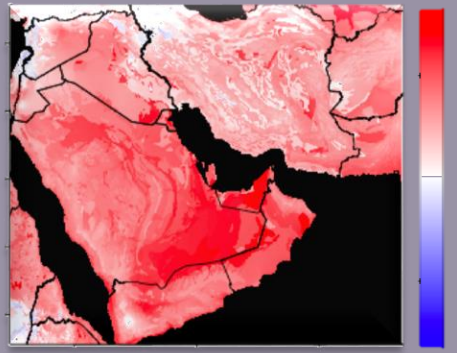


Figure 5. Idealized dust emission flux (g m^{-2} s^{-1}) for Southwest Asia produced by physical equations from the UM dust emission scheme and prescribed environmental conditions.

Idealized dust emission potential values produced using physically-based algorithms with environmental conditions prescribed to match the wind shear chamber

ERDC-Geo

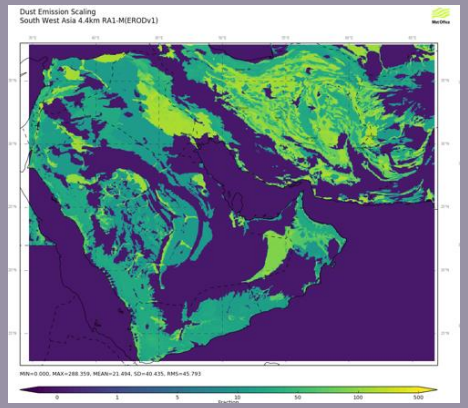
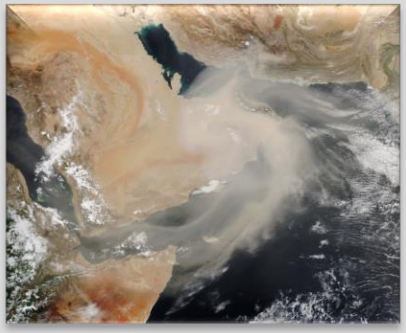
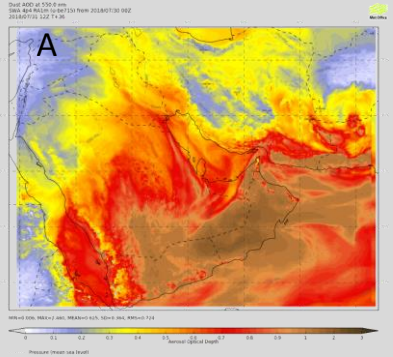


Figure 6. Dust emission scaling factor for 4.4 km Southwest Asia produced for UM domain/dust emission module. Note, this field does not represent dust source strength.

Ratio of physically-modeled to analog-based dust emission potential used to generate a **spatially varying dust emission flux multiplier** field





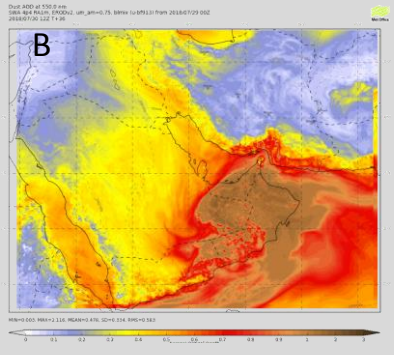


Figure 7. July 20, 2018 dust event and 36 hour 550nm AOD forecasts produced by the A) original UM configuration and B) UM with ERDC-Geo.

Initial qualitative assessment suggests **ERDC-Geo will greatly improve** spatial accuracy of **UM dust products**

FUTURE RESEARCH

Collaborative quantitative assessment of UM/ERDC-Geo model performance for Southwest Asia

ERDC / 557 WW / Met Office

Expand spatial coverage of the ERDC-Geo geomorphic landform dataset to global coverage for desert regions

ERDC / UCLA / USDA-ARS

Demonstrate global UM/ERDC-Geo dust, surface visibility, and air quality forecast capability

ERDC / UCLA / USDA-ARS / Uni. of Cardiff (UK)

GOAL: **Expand** required **ERDC-Geo input datasets** to **global coverage** to improve UM simulated **surface visibility** and **extreme dust events** on the global domain

Met Office Summary

- The Met Office is in the process of building a new model, LFRic
  - A new dynamical core, on a new grid.
  - A more modular design.
  - Initially will interface with current physics.
  - Design includes a separation of ‘natural’ and ‘computational’ science layers (Psclone) to give flexibility to work on current, new and future hardware.
  - Working for an aquaplanet, moving towards a fully functional atmosphere model.
  - Data assimilation work underway through collaboration (JEDI)
- Migrating aerosol codes to LFRic
  - Ideally only GLOMAP MODE aerosols will be migrated.
  - Evaluating GLOMAP MODE against CLASSIC in NWP.
- ORAC/SEVIRI AOT retrievals evaluated for assimilation
  - Not currently suitable.
- Dust emission
  - Collaboration with Sandra LeGrande (US Army) to include a dust emission potential in the UM.
  - Demonstration project successful, useful in bidding for money for expanding obs.

Extra slides