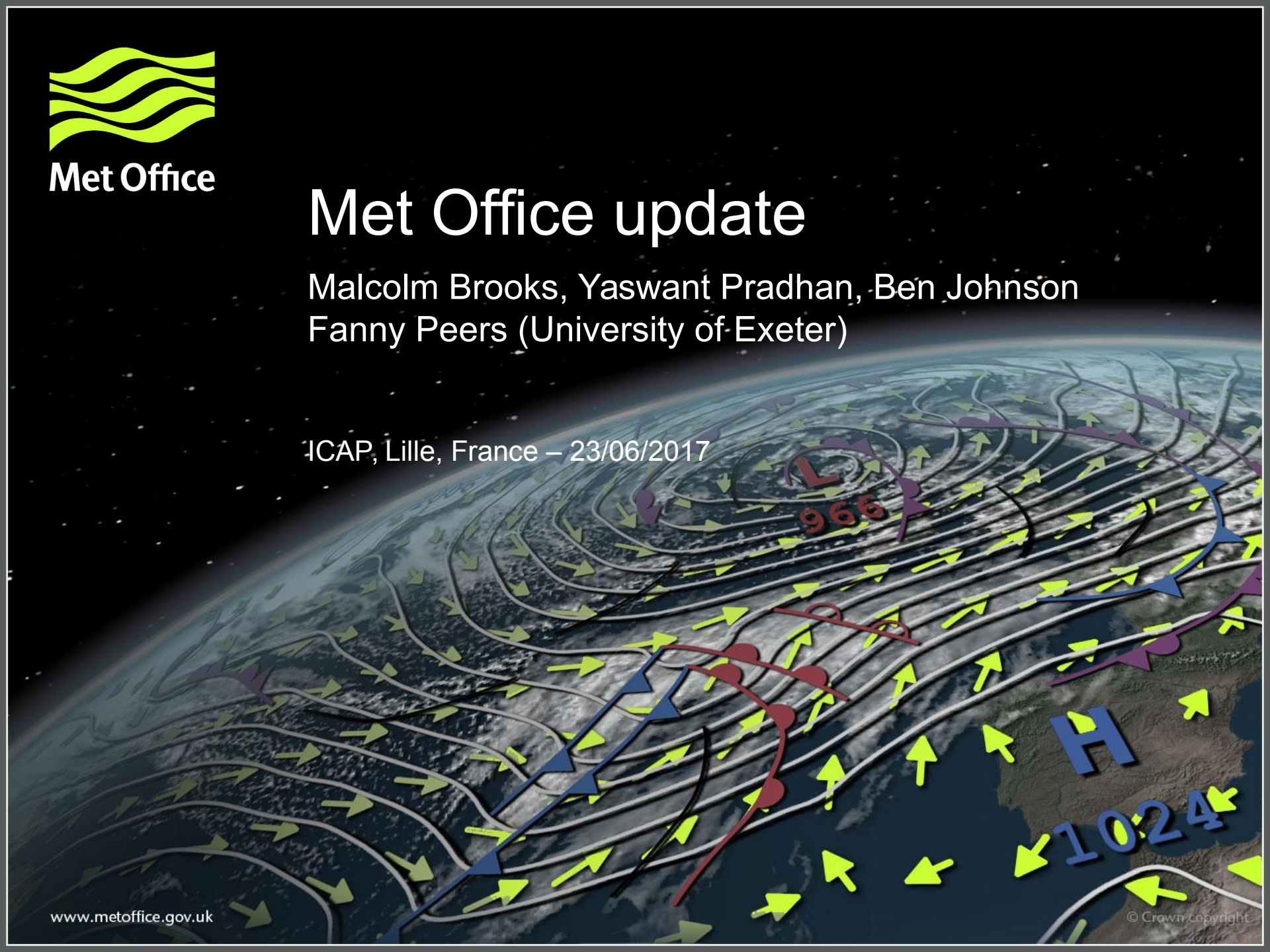


Met Office

# Met Office update

Malcolm Brooks, Yaswant Pradhan, Ben Johnson  
Fanny Peers (University of Exeter)

ICAP, Lille, France – 23/06/2017





Met Office

# Contents

1. Upcoming changes
  - a. Dust assimilation changes for MODIS.
  - b. Forecast model resolution.
2. Other aerosol forecasts
  - a) Field campaigns.
  - b) Other applications?
3. Summary

# Aerosol in the Met Office NWP models

## Dust:

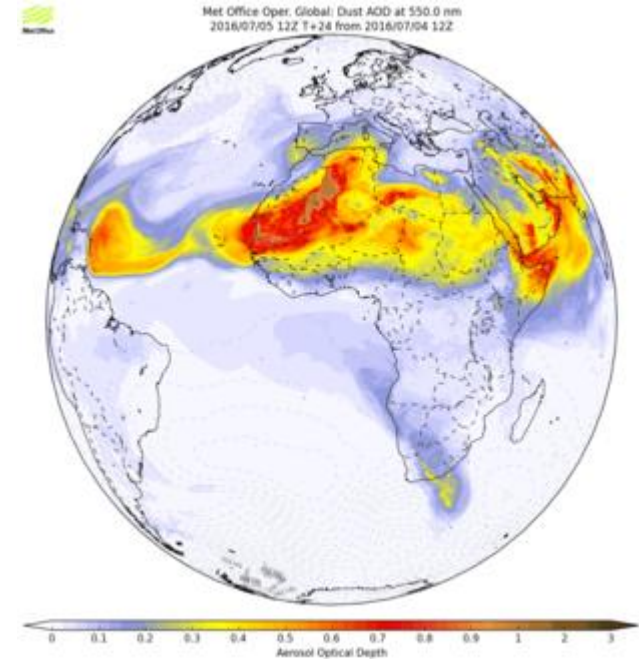
Operational global model:

- Deterministic at  $0.23^\circ \times 0.15^\circ$   
(~17 km)
- Ensemble at  $0.45^\circ \times 0.4^\circ$   
(~30 km)

Assimilates dust AOD from MODIS

Assimilation: Hybrid 4D-VAR

Static (clim) Error Covariances + ensemble for flow dependent Error Covariances





# Aerosol in the Met Office NWP models

## Dust:

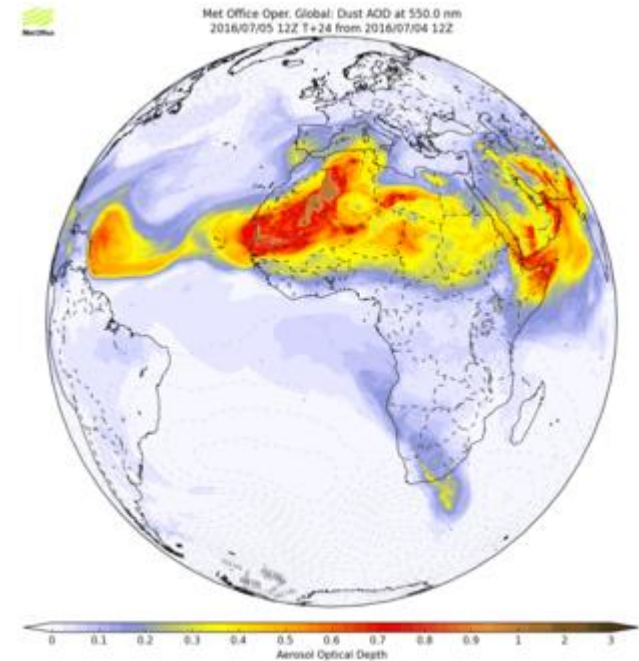
Operational global model:

- Deterministic at  $0.23^\circ \times 0.15^\circ$   
(~17 km)
- Ensemble at  $0.45^\circ \times 0.4^\circ$   
(~30 km)

Assimilates dust AOD from MODIS

4 km LAMs covering hot dusty places of interest

Based on Woodward 2001, with 2 bins (global) and 6 regional models, with prescribed emission size distribution

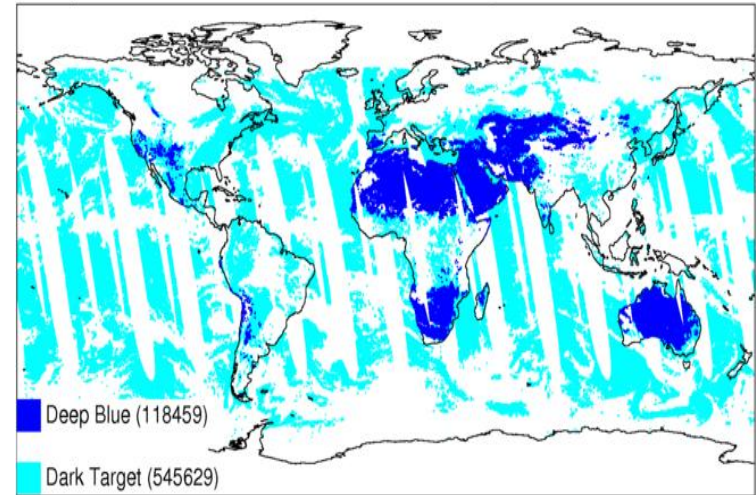


# Migration to MODIS C6.0 in global DA

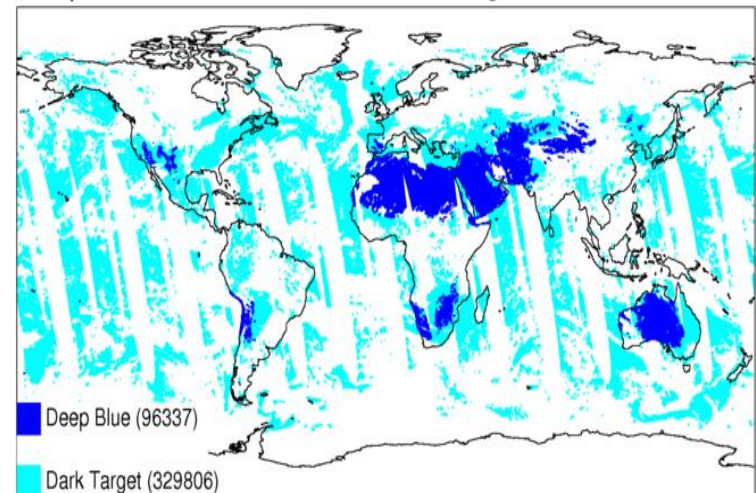
## Data coverage

Yaswant Pradhan

Aqua-MODIS C5.1 AOD retrieval algorithm - 20161006



Aqua-MODIS C6.0 AOD retrieval algorithm - 20161006



- Collection 5.1 (top) vs 6.0 (bottom)

- Coverage qualitatively similar:

- Fewer obs being used (~60%)

- More use of quality flags



# Migration to MODIS C6.0 in global DA

## Updated dust/coarse filtering criteria

FineModeFraction	$\leq$	0.4
AngstromExponent	$\leq$	<del>0.5</del> 0.6
EffectiveRadius	$>$	$1.0 \mu m$
MassConcentration	$\geq$	$1.2e - 4 kg/m^2$
AOD ( $\tau_{550}$ )	$\geq$	0.1 or
		$\tau_{Bg} \geq 0.1$ and $\tau_{Ob} < 0.1$

+

Deep\_Blue\_Spectral\_Single\_Scattering\_Albedo\_Land threshold  
(Müller et al., 2011):

$$0.878 > w_0(470) > 0.955$$



# Migration to MODIS C6.0 in global DA Winter 2016 Trials against dust denial

## Global NWP index: Aggregates and weighted skill score metric

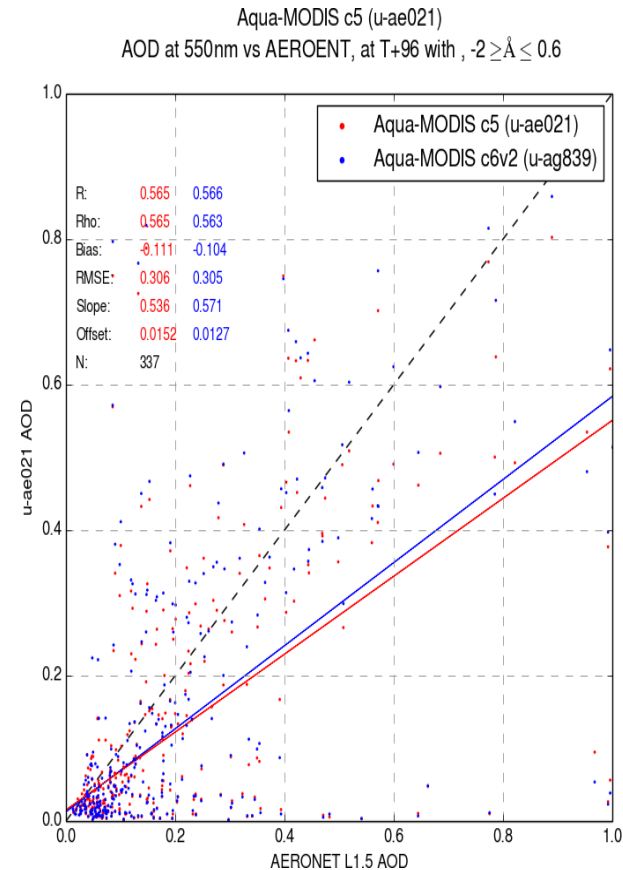
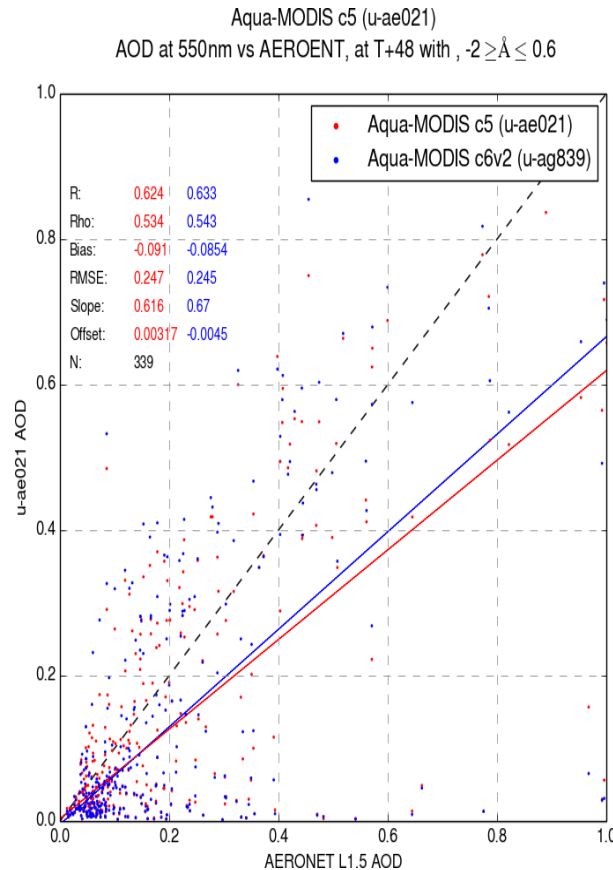
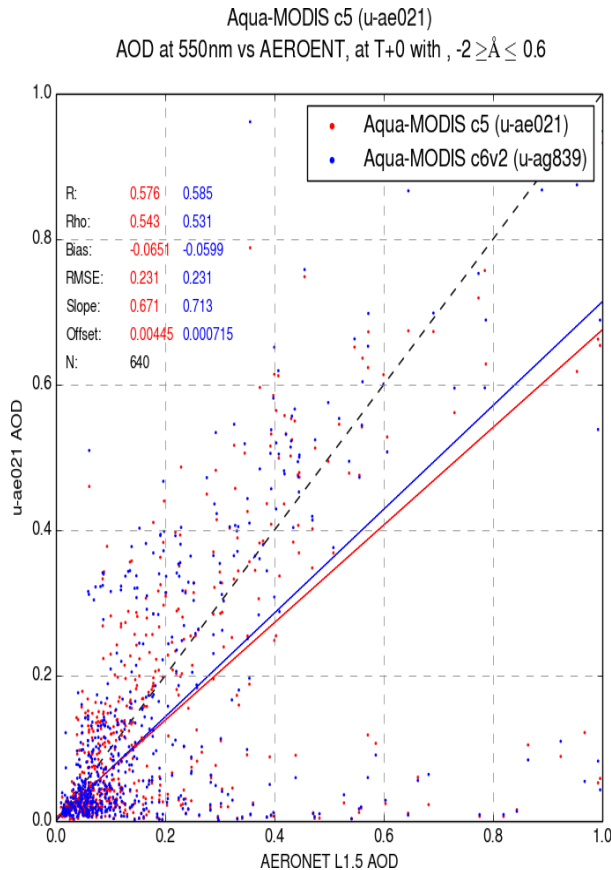
DA experiments with	Vs Observation	Vs Analysis
MYD C5.1 (old)	0.093	0.155
MYD C6.0 (current)	0.043	0.112
(MYD + MOD) C6.0	0.187	0.256

- Measures large scale forecast performance (Pmsl,  $Z_{500}$ )
- Neutral (slightly positive) against dust denial
- Aqua/Terra C6 was better but Terra not implemented at this time (calibr. bias)



# Migration to MODIS C6.0 in global DA Winter 2016 Trial

## AOD Validation Vs AERONET

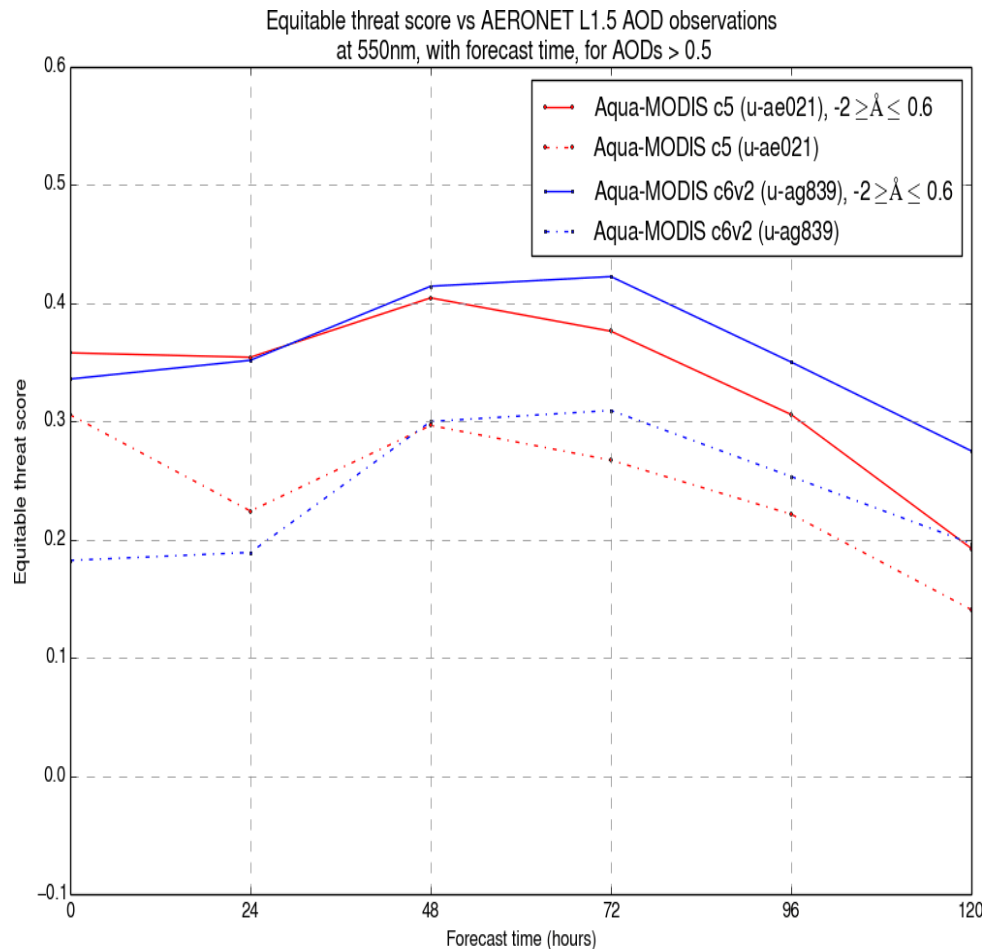






# Migration to MODIS C6.0 in global DA Winter 2016 Trial

## AOD forecast skill Vs AERONET



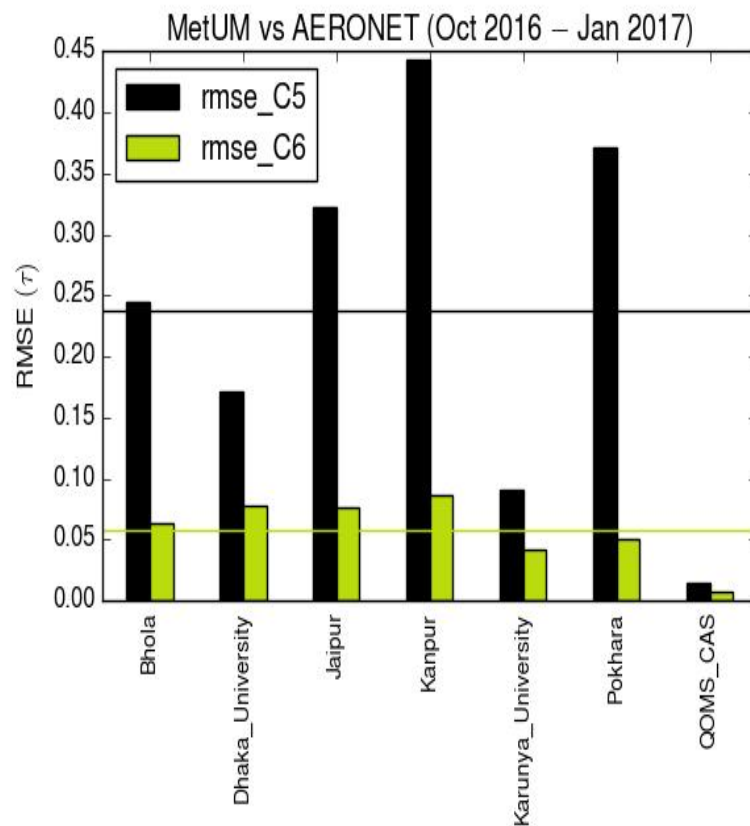
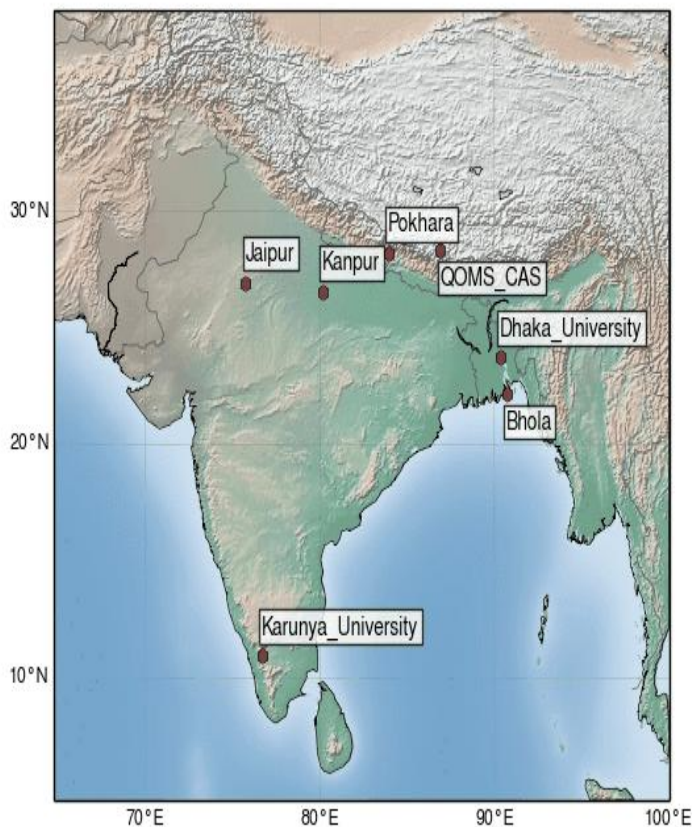
ETS  
slightly  
better  
(worse)  
w/C6 at  
>T+48  
(T+0)

Mixed Site-  
specific  
details.



# Migration to MODIS C6.0 in global DA Improvements to dust forecast w/ MYD C6

T+6 forecasts vs. AERONET SDA (v2 NRT) coarse mode AOD<sub>500</sub>.  
MODIS C6 in DA: reduces wintertime bias and RMSE over India,





# Horizontal resolution

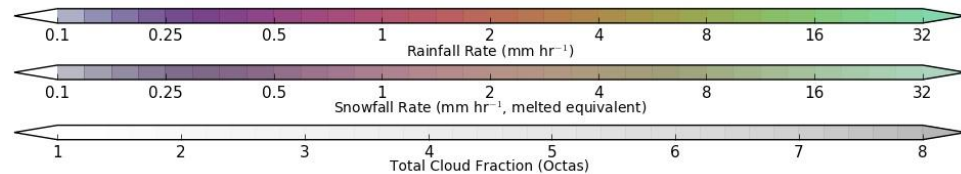
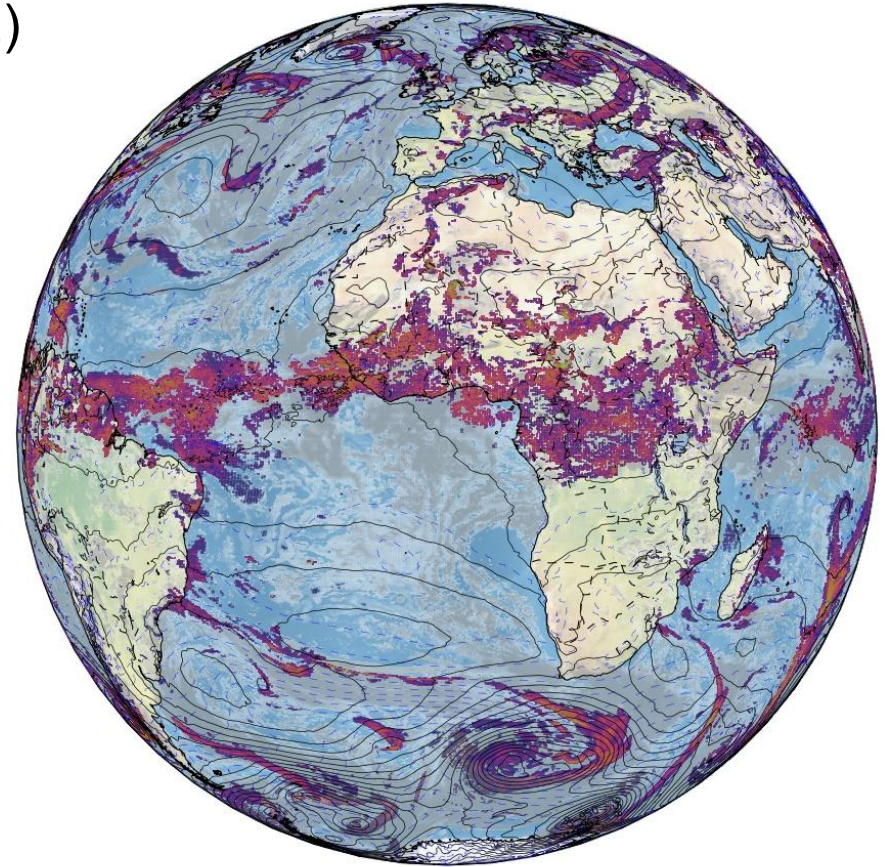
Regular latt/long grid at N768 to N1280



Met Office Oper. Global: P<sub>msl</sub>, 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z

• N768: 17km, 0.23x0.15°(1536x1152)

- E-W details: 26km EQ, 15km 55N, 36m by poles.
- Timestep: 7.5 minutes
- Runtime ~50 minutes







# Horizontal resolution

## Regular latt/long grid at N768 to N1280

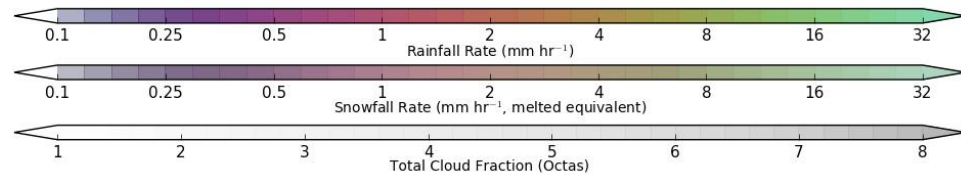
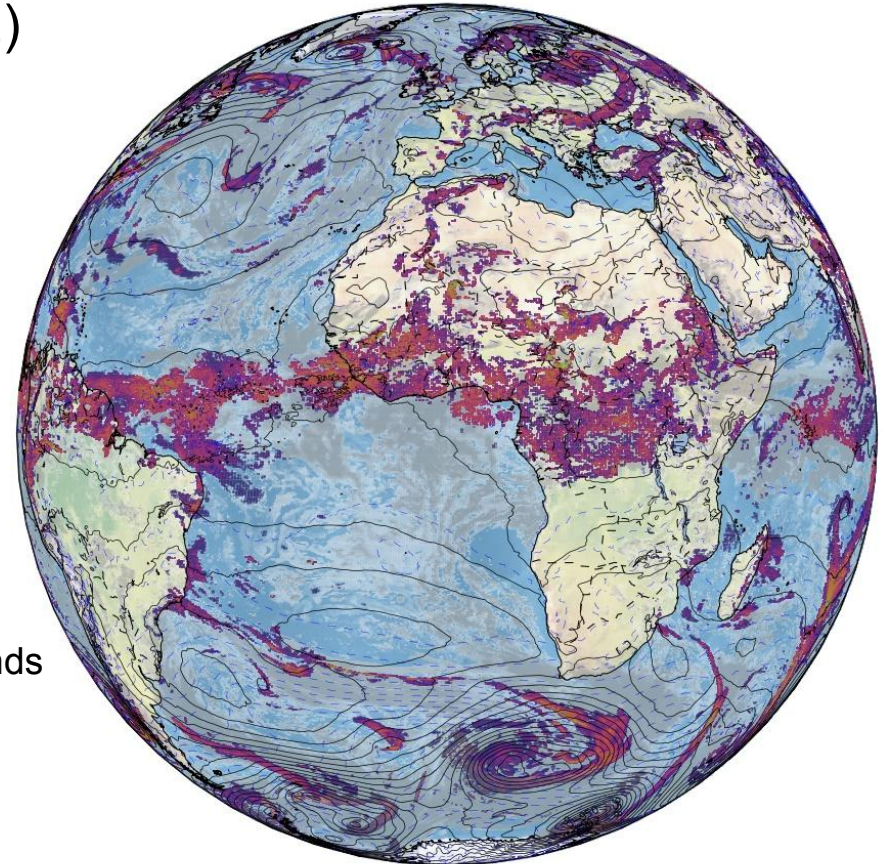


Met Office Oper. Global: P<sub>msl</sub>, 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z

- N768: 17km, 0.23x0.15°(1536x1152)

- E-W details: 26km EQ, 15km 55N, 36m by poles.
- Timestep: 7.5 minutes
- Runtime ~50 minutes

- Paul Earnshaw, David Walters and a cast of thousands





# Horizontal resolution

## Regular latt/long grid at N768 to N1280



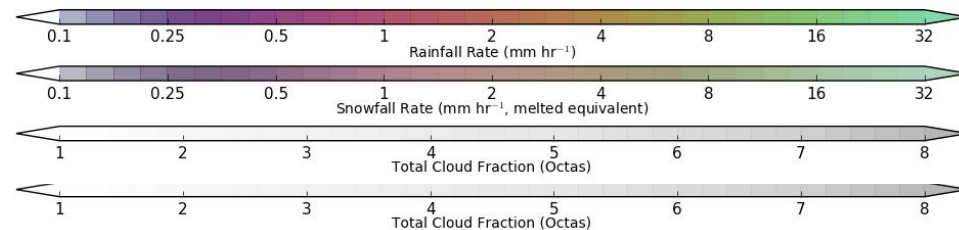
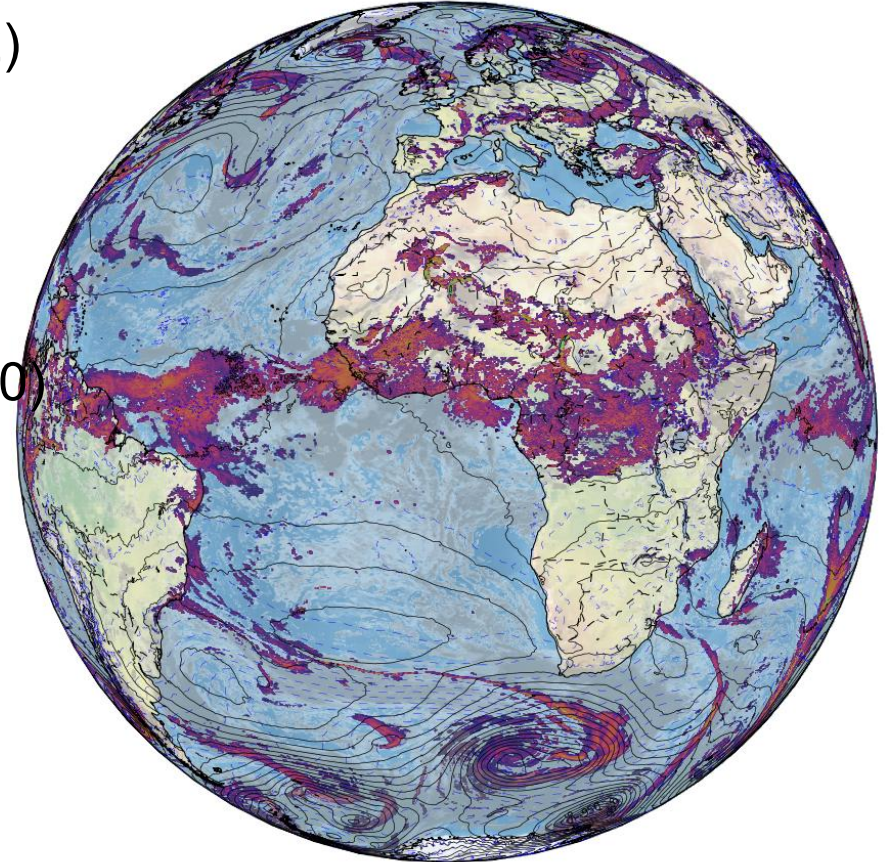
Met Office Para. Global:  $P_{mod}$ , 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z

- **N768: 17km,  $0.23 \times 0.15^\circ$  (1536x1152)**

- E-W details: 26km EQ, 15km 55N, 36m by poles.
- Timestep: 7.5 minutes
- Runtime ~50 minutes

- **N1280: 10km,  $0.14 \times 0.09^\circ$  (2560x1920)**

- E-W details: 15km EQ, 9km 55N, 13m by poles.
- Timestep: 4 minutes
- Runtime: ~50 minutes



# Horizontal resolution

Regular latt/long grid at N768 to N1280



Met Office Para. Global:  $P_{total}$ , 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z

- **N768: 17km, 0.23x0.15°(1536x1152)**

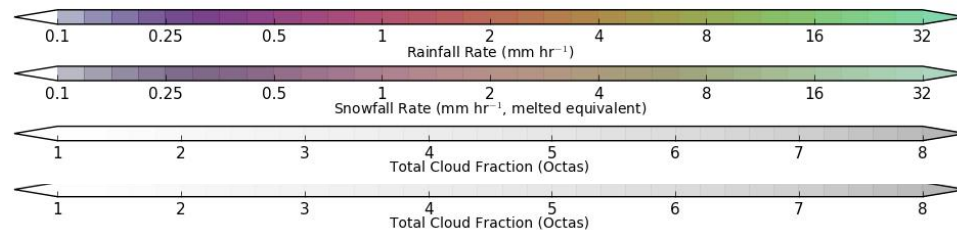
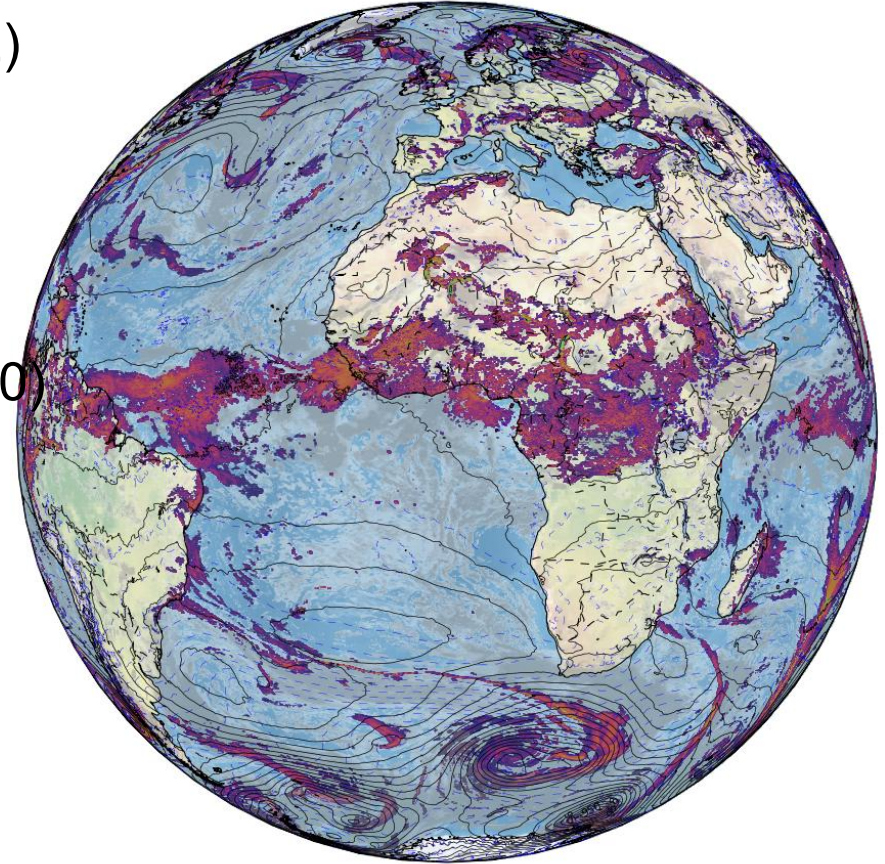
- E-W details: 26km EQ, 15km 55N, 36m by poles.
- Timestep: 7.5 minutes
- Runtime ~50 minutes

- **N1280: 10km, 0.14x0.09°(2560x1920)**

- E-W details: 15km EQ, 9km 55N, 13m by poles.
- Timestep: 4 minutes
- Runtime: ~50 minutes

- **x points = 2.7, x timesteps = 1.75, x runtime = 1.0**

- Perfect scaling would require: 4.725 x cores
- Actual: 5.4 x cores.
- Scaling ~OK~ to N1280







# Horizontal resolution

## Regular latt/long grid at N768 to N1280



Met Office Para. Global:  $P_{mod}$ , 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z

- N768: 17km,  $0.23 \times 0.15^\circ$  (1536x1152)

- E-W details: 26km EQ, 15km 55N, 36m by poles.
- Timestep: 7.5 minutes
- Runtime ~50 minutes

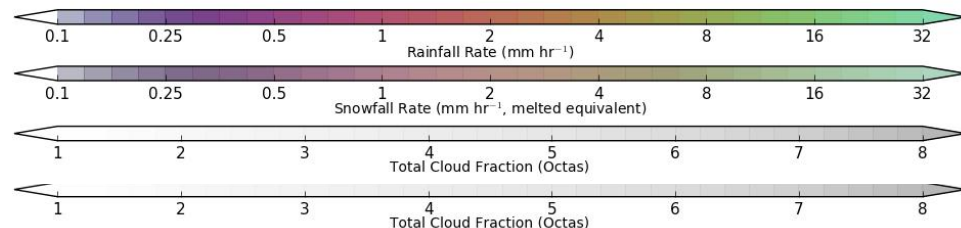
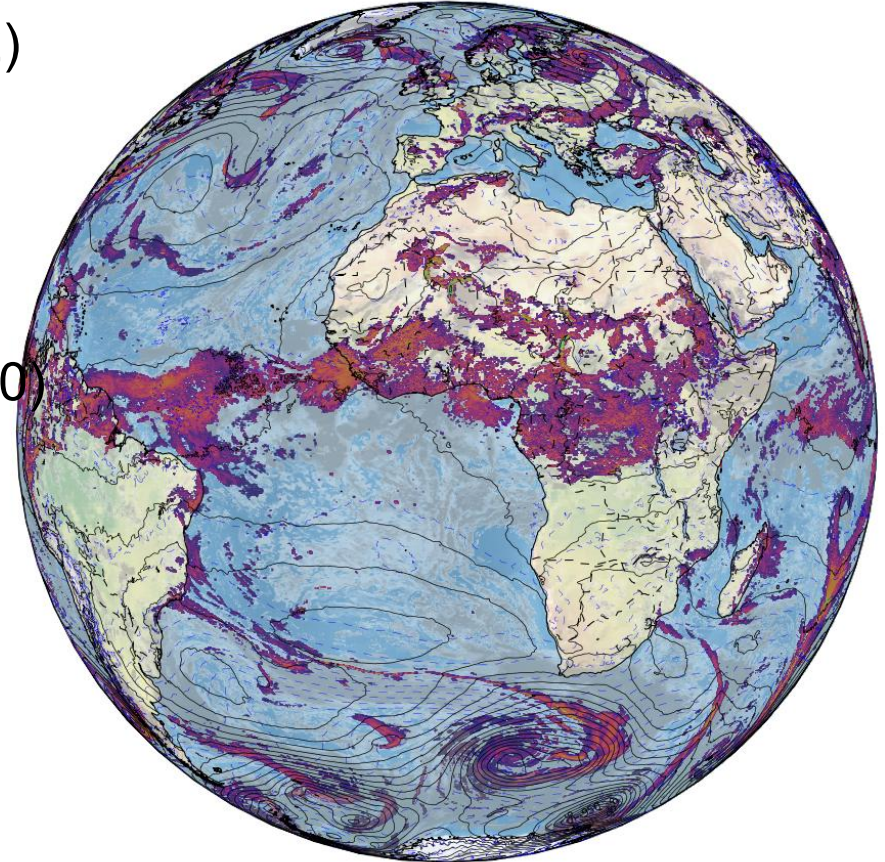
- N1280: 10km,  $0.14 \times 0.09^\circ$  (2560x1920)

- E-W details: 15km EQ, 9km 55N, 13m by poles.
- Timestep: 4 minutes
- Runtime: ~50 minutes

- x points = 2.7, x timesteps = 1.75, x runtime = 1.0

- Perfect scaling would require: 4.725 x cores
- Actual: 5.4 x cores.
- Scaling ~OK~ to N1280

- Implementation: 4<sup>th</sup> July 2017.







Met Office

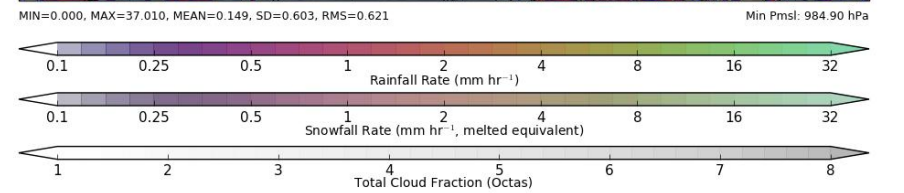
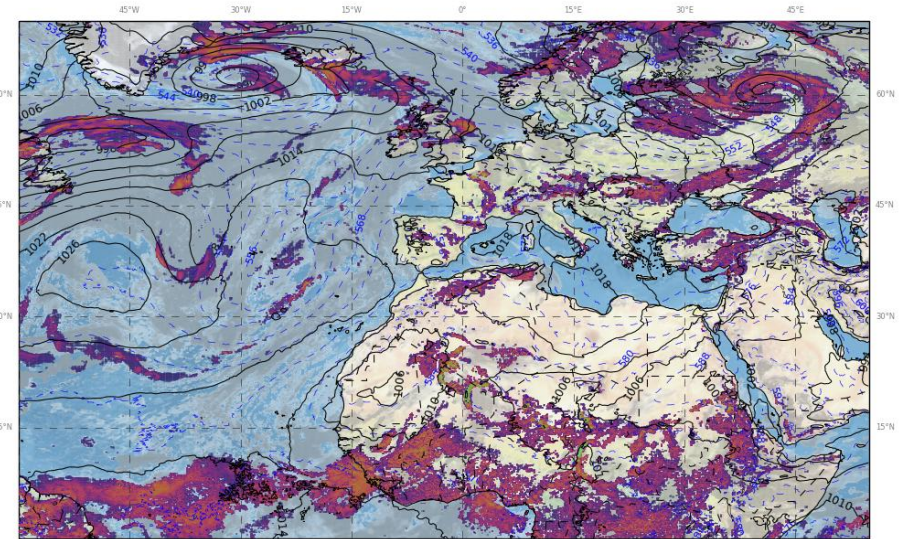
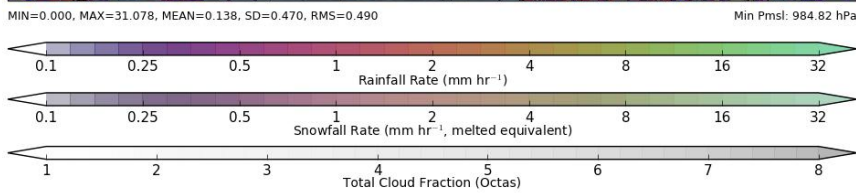
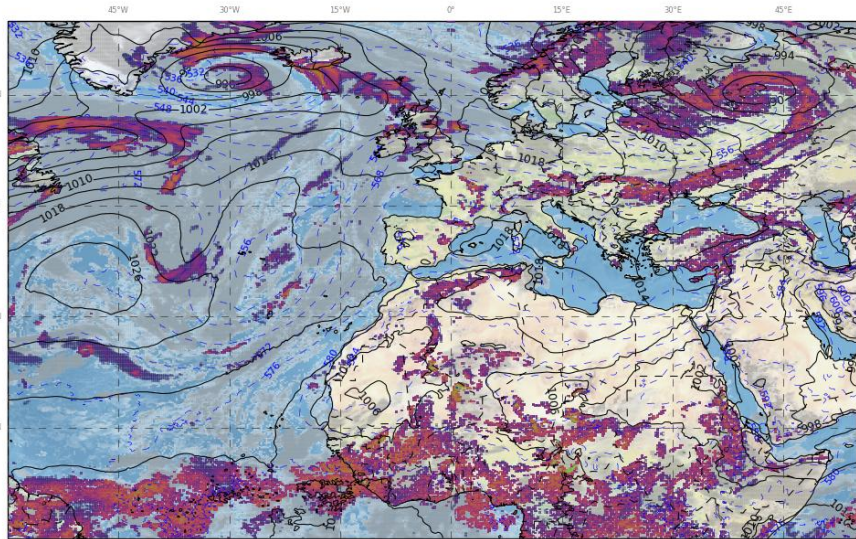
# Horizontal resolution

## Regular latt/long grid at N768 to N1280

Met Office Oper. Global:  $P_{msl}$ , 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



Met Office Para. Global:  $P_{msl}$ , 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



In more detail, in a single forecast:





# Horizontal resolution

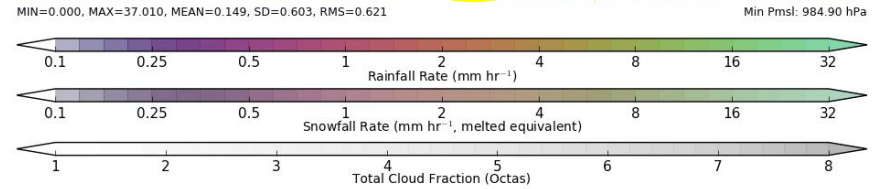
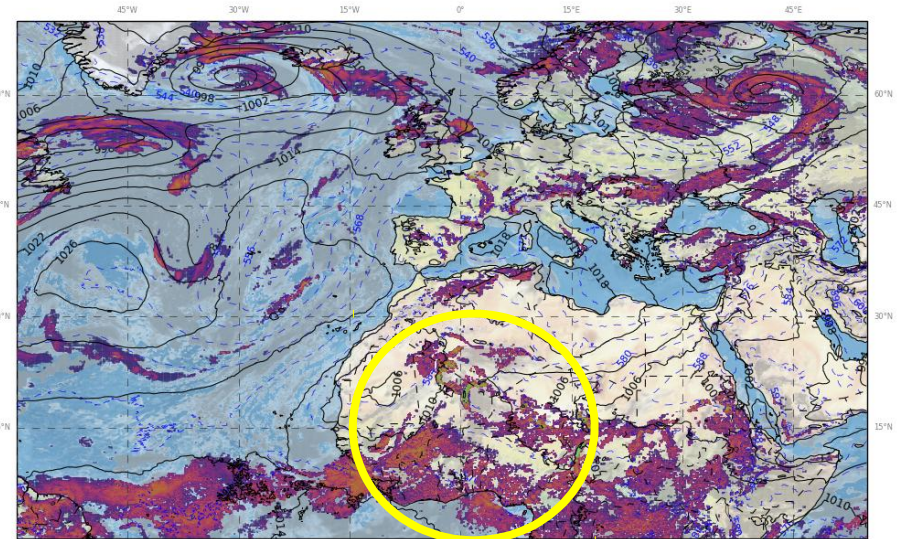
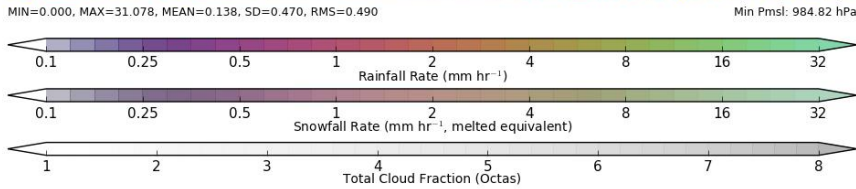
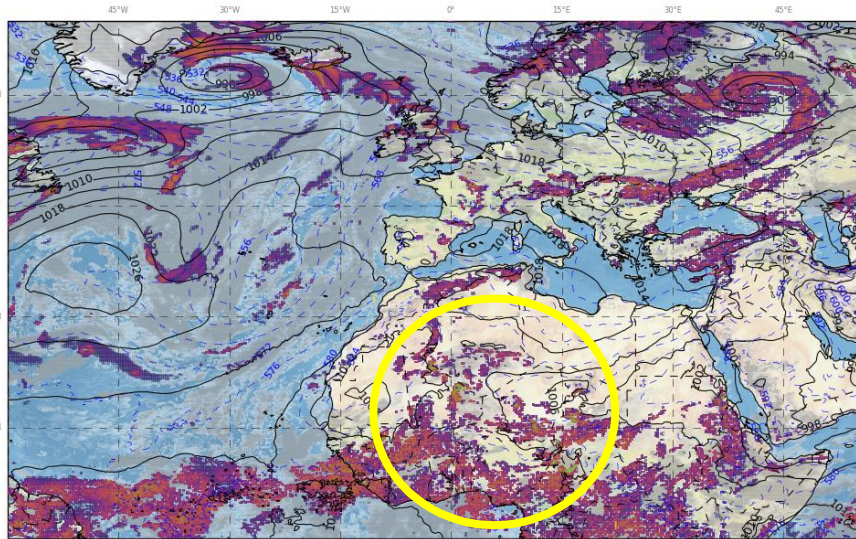
## Regular latt/long grid at N768 to N1280



Met Office Oper. Global: P<sub>msl</sub>, 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



Met Office Para. Global: P<sub>msl</sub>, 500hPa Thickness, Precip Rates, Cloud  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



In more detail, in a single forecast:

- Tropical squall lines look more 'squally'/organised (convection parameterisation unchanged).



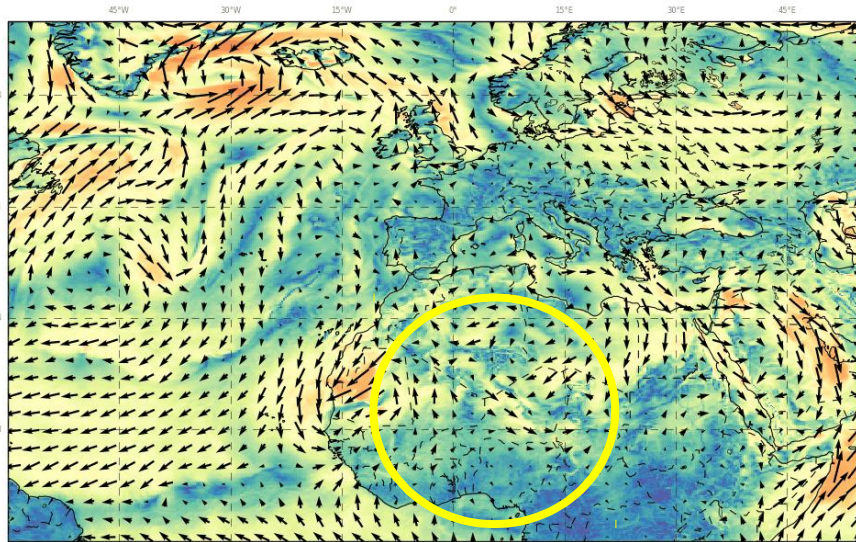


# Horizontal resolution

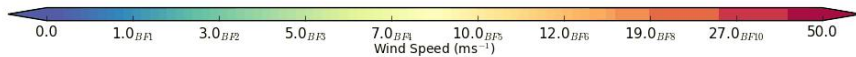
## Regular latt/long grid at N768 to N1280



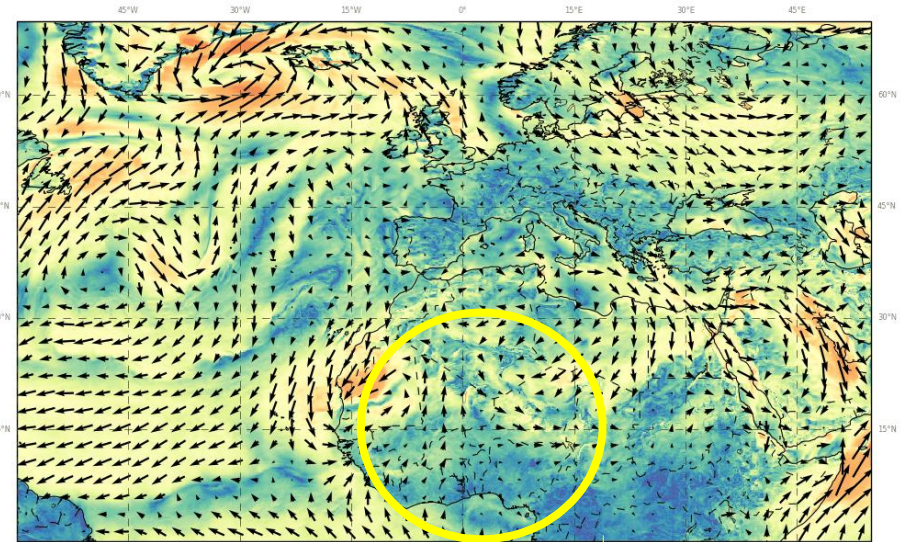
Met Office Oper. Global: Wind speed and direction ( $\text{ms}^{-1}$ ) at 10 m  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



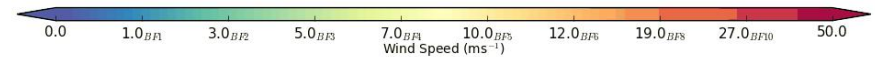
MIN=0.000, MAX=19.243, MEAN=5.289, SD=2.751, RMS=5.962



Met Office Para. Global: Wind speed and direction ( $\text{ms}^{-1}$ ) at 10 m  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



MIN=0.000, MAX=20.075, MEAN=5.320, SD=2.767, RMS=5.997



In more detail, in a single forecast:

- Tropical squall lines look more 'squally'/organised (convection parameterisation unchanged), stronger gusts.



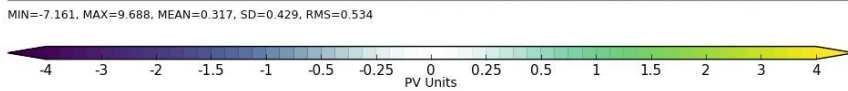
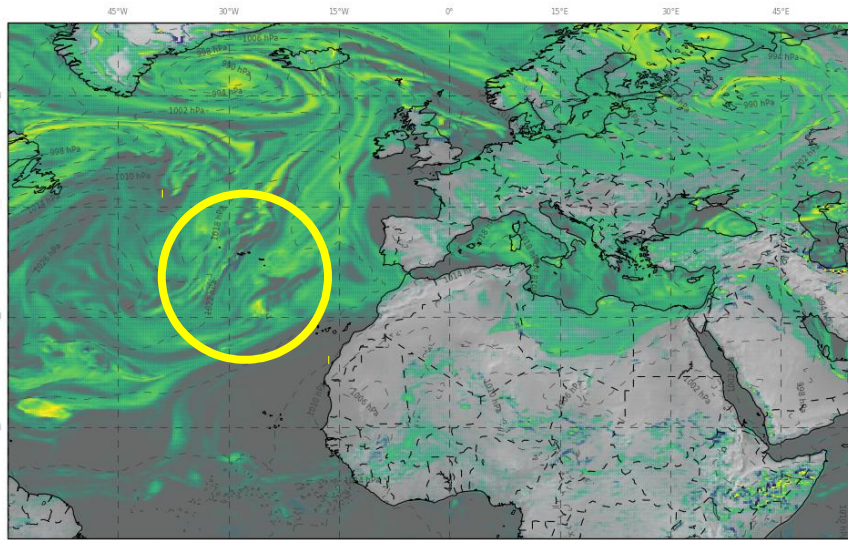


Met Office

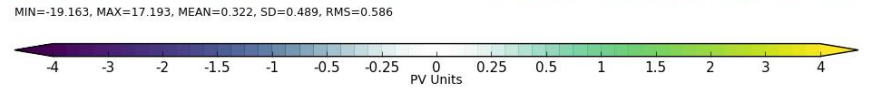
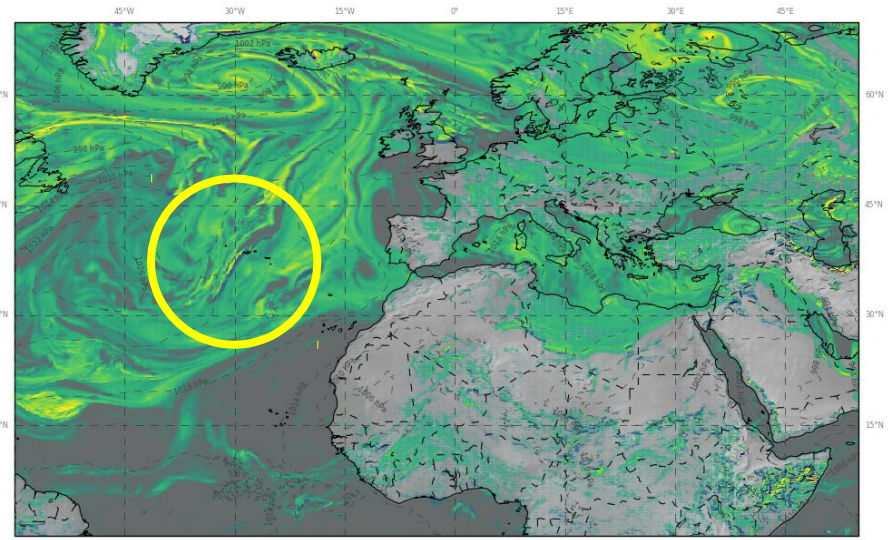
# Horizontal resolution

## Regular latt/long grid at N768 to N1280

Met Office Oper. Global: Potential Vorticity ( $10^6 \text{ m}^2 \text{ kg}^{-1} \text{ K s}^{-1}$ ) at 700 hPa  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



Met Office Para. Global: Potential Vorticity ( $10^6 \text{ m}^2 \text{ kg}^{-1} \text{ K s}^{-1}$ ) at 700 hPa  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



In more detail, in a single forecast:

- Tropical squall lines look more 'squally'/organised (convection parameterisation unchanged).
- Resolving small scale features in the large scale dynamics: diabatic cooling causing PC anomaly ahead of cold fronts?

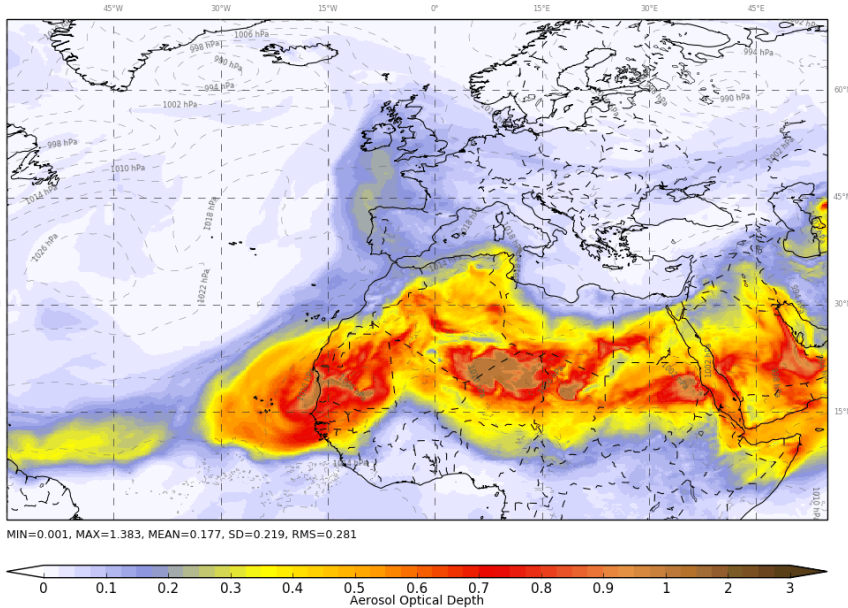


# Horizontal resolution

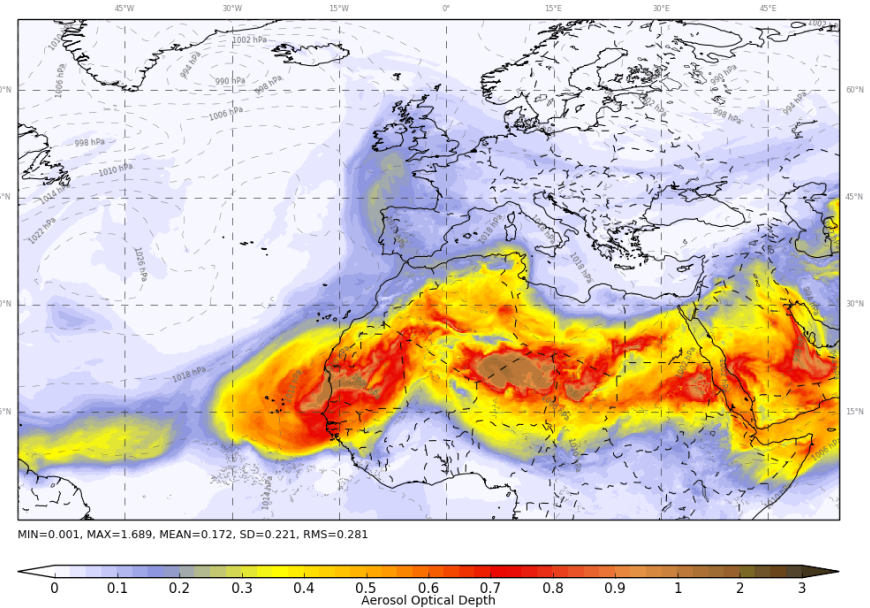
## Regular latt/long grid at N768 to N1280



Met Office Oper. Global: Dust AOD at 550.0 nm  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



Met Office Para. Global: Dust AOD at 550.0 nm  
Wed 2017/06/21 12Z T+6 from 2017/06/21 06Z



In more detail, in a single forecast:

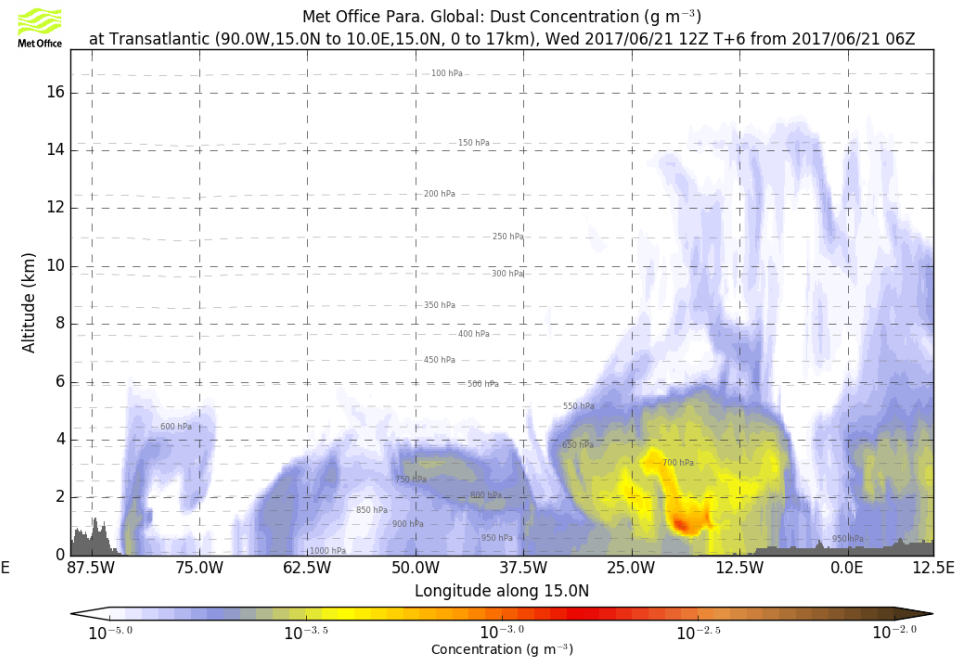
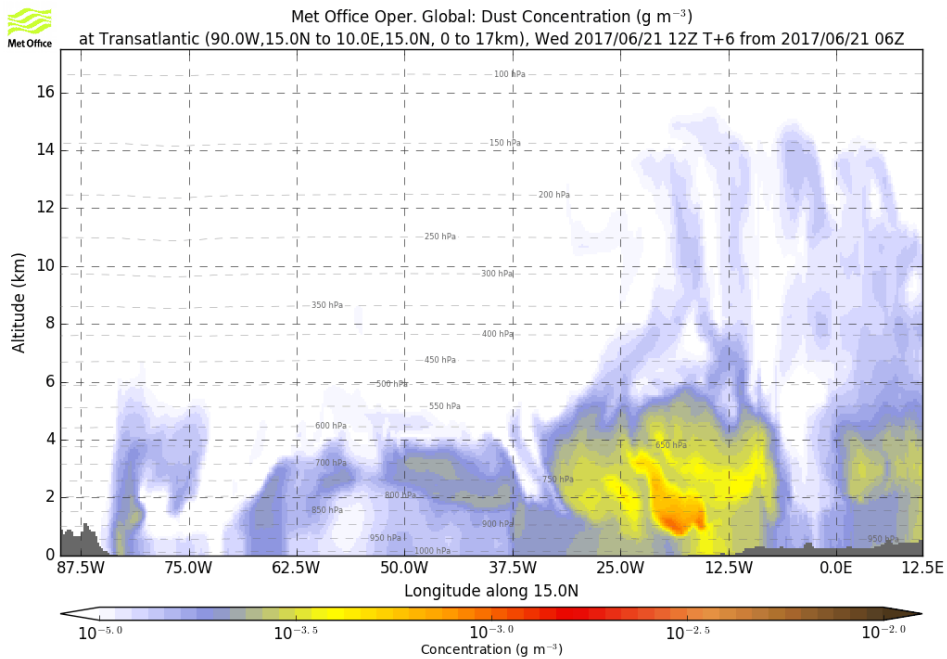
- Tropical squall lines look more 'squally'/organised (convection parameterisation unchanged).
- Resolving small scale features in the large scale dynamics: diabatic cooling causing PC anomaly ahead of cold fronts?
- Dust impact, more coherent high AOD structures?





# Horizontal resolution

## Regular latt/long grid at N768 to N1280



In more detail, in a single forecast:

- Tropical squall lines look more 'squally'/organised (convection parameterisation unchanged).
- Resolving small scale features in the large scale dynamics: diabatic cooling causing PC anomaly ahead of cold fronts?
- Dust impact, more coherent high AOD/concentration structures?





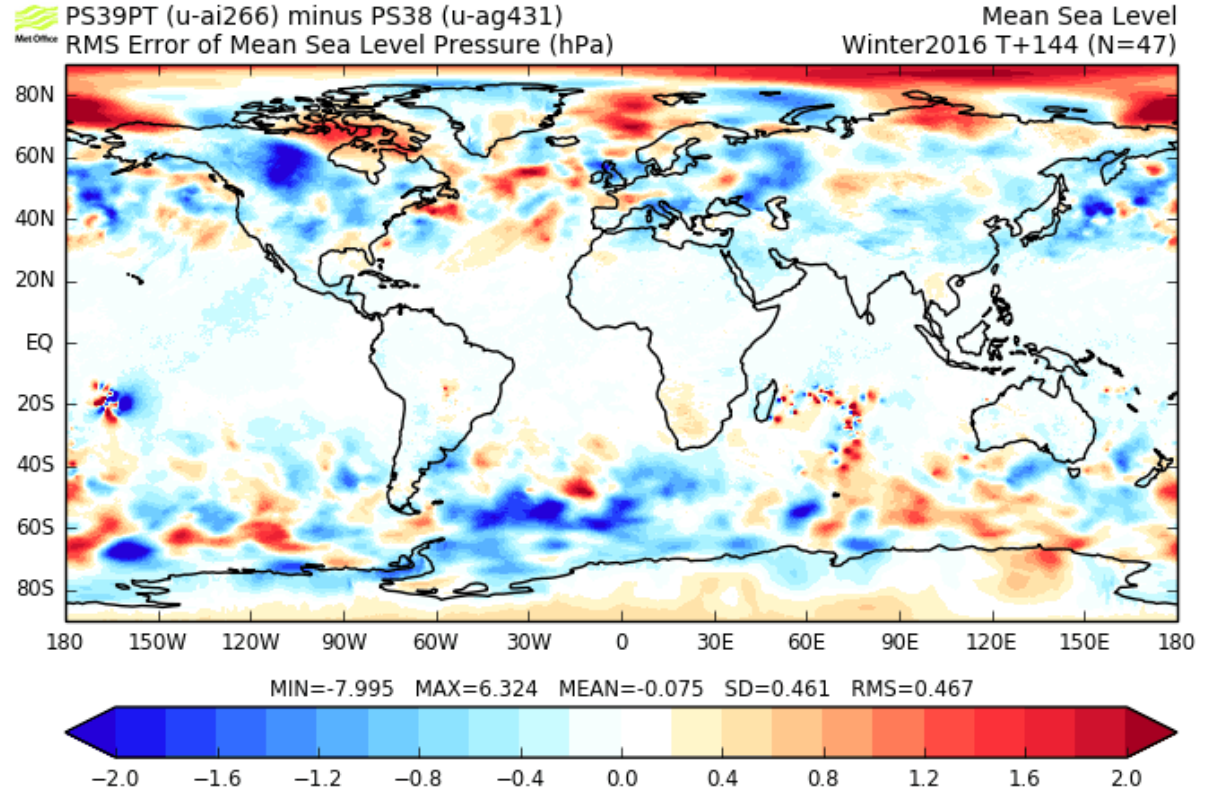


# Horizontal resolution

## Large scale verification: Winter trial

Time mean RMS error differences, against analysis at T+144:

- Pmsl improvements
  - (more blue than red)





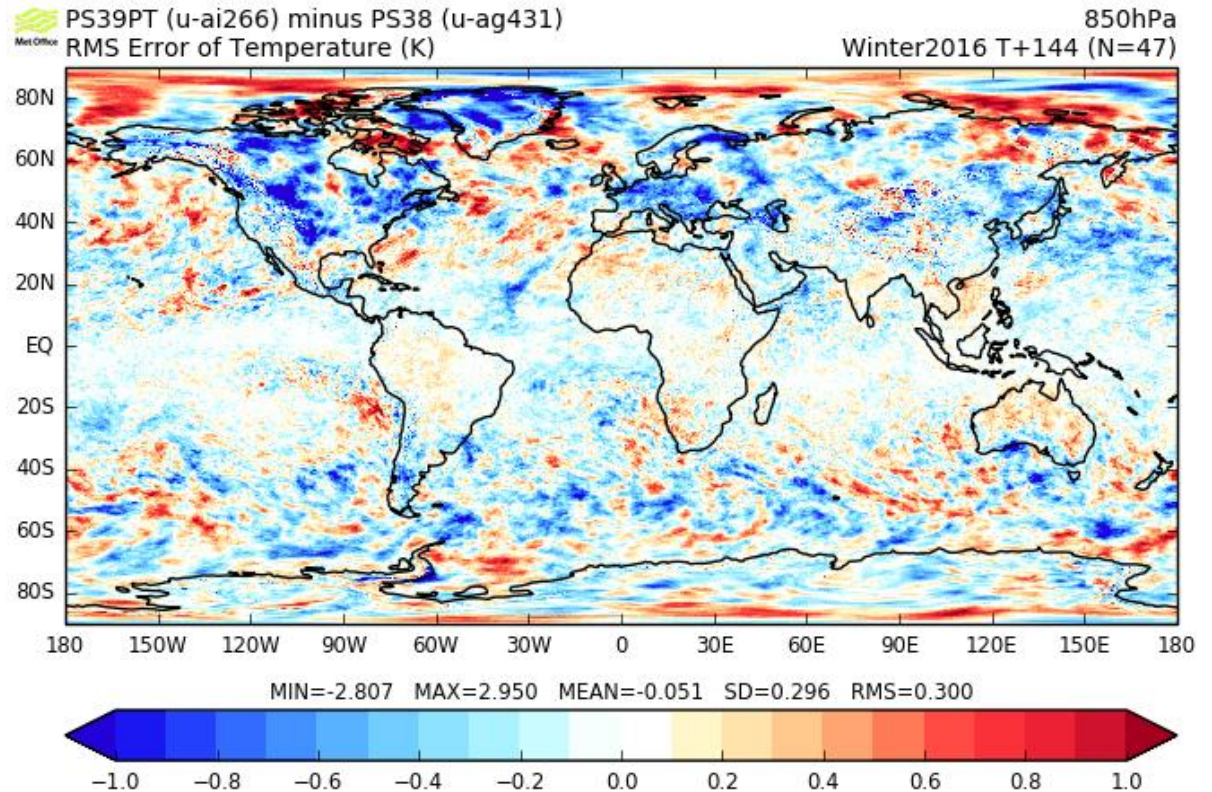


# Horizontal resolution

## Large scale verification: Winter trial

Time mean RMS error differences, against analysis at T+144:

- Pmsl improvements
  - (more blue than red).
- T(850) improvements.



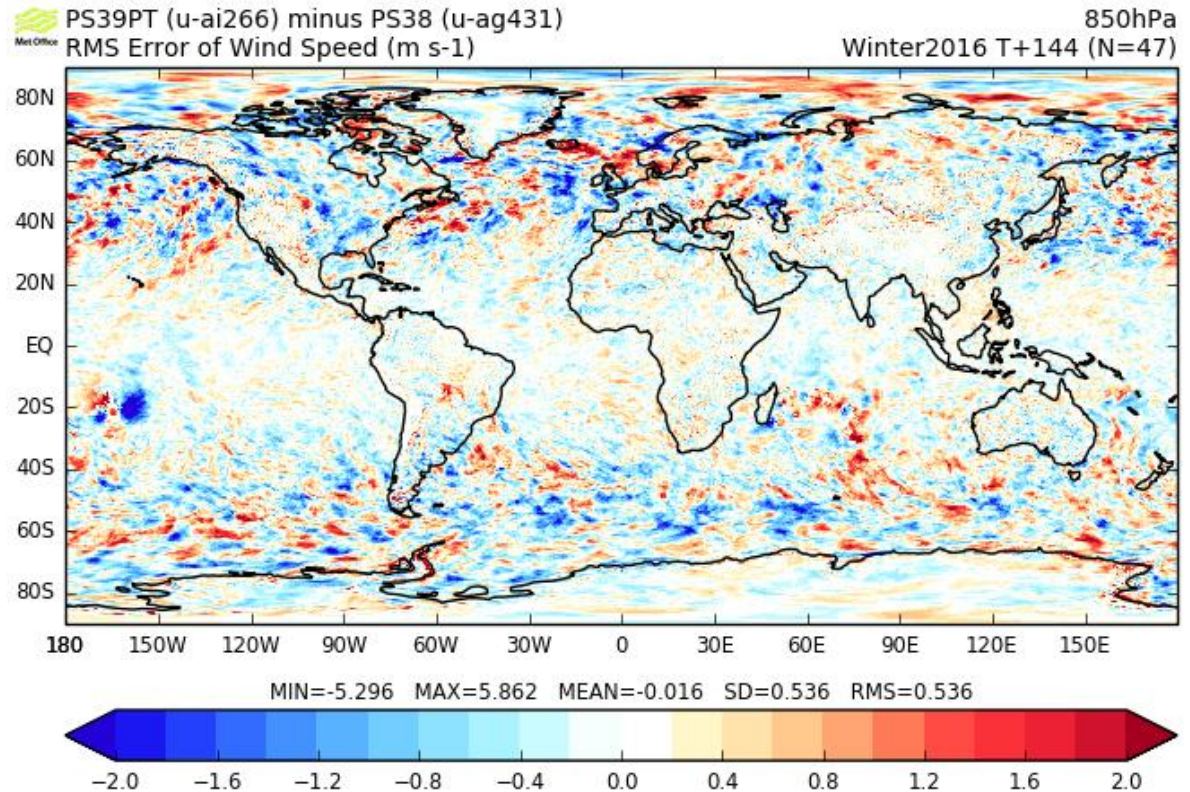


# Horizontal resolution

## Large scale verification: Winter trial

Time mean RMS error differences, against analysis at T+144:

- Pmsl improvements
  - (more blue than red).
- T(850) improvements.
- Wind speed improvements



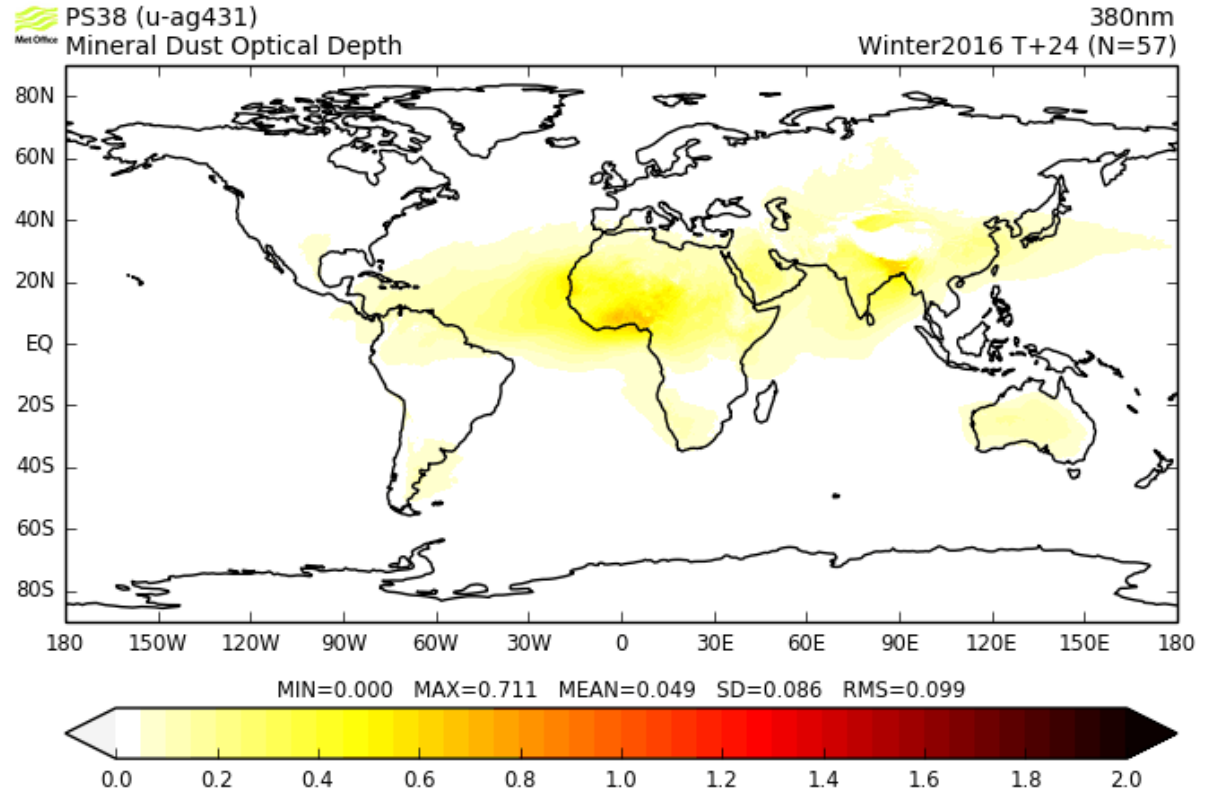


# Horizontal resolution

## Dust impact: Winter trial

Time mean dust AOD at T+24:

- From current system.





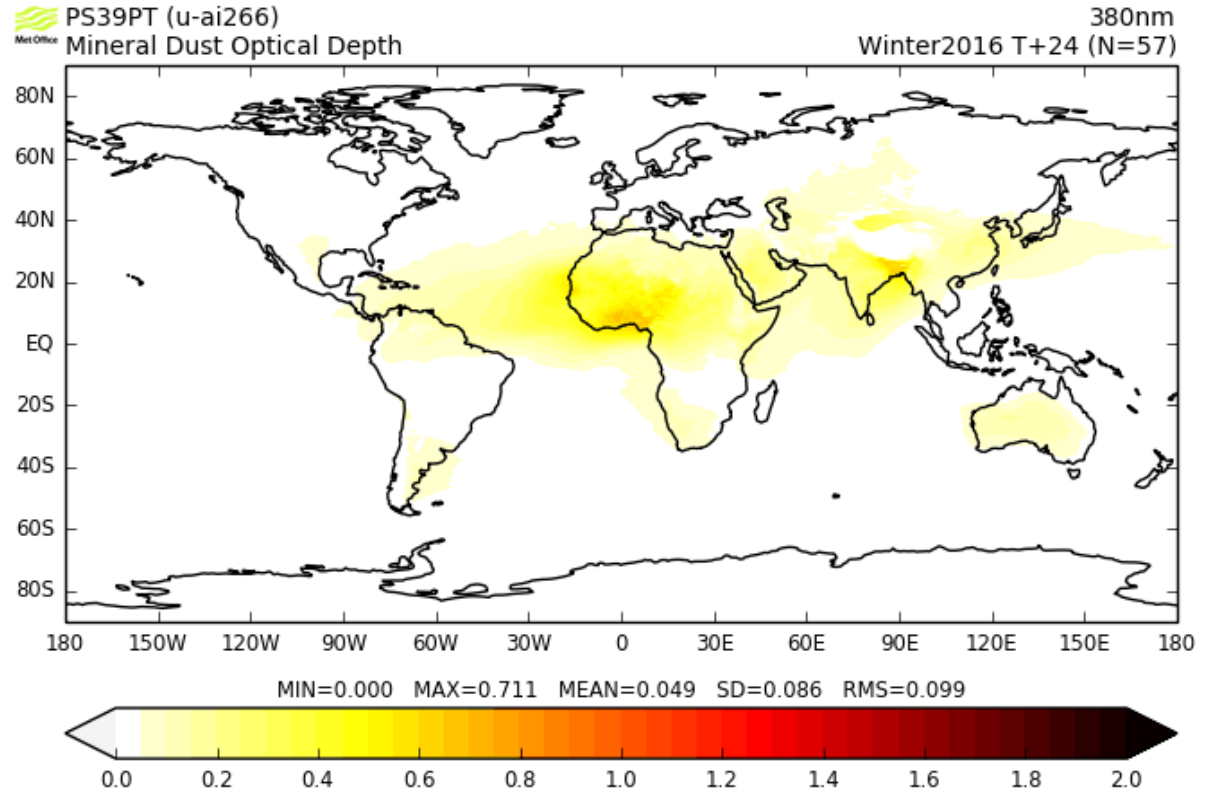


# Horizontal resolution

## Dust impact: Winter trial

Time mean dust AOD at T+24:

- From current system.
- From final winter trial.



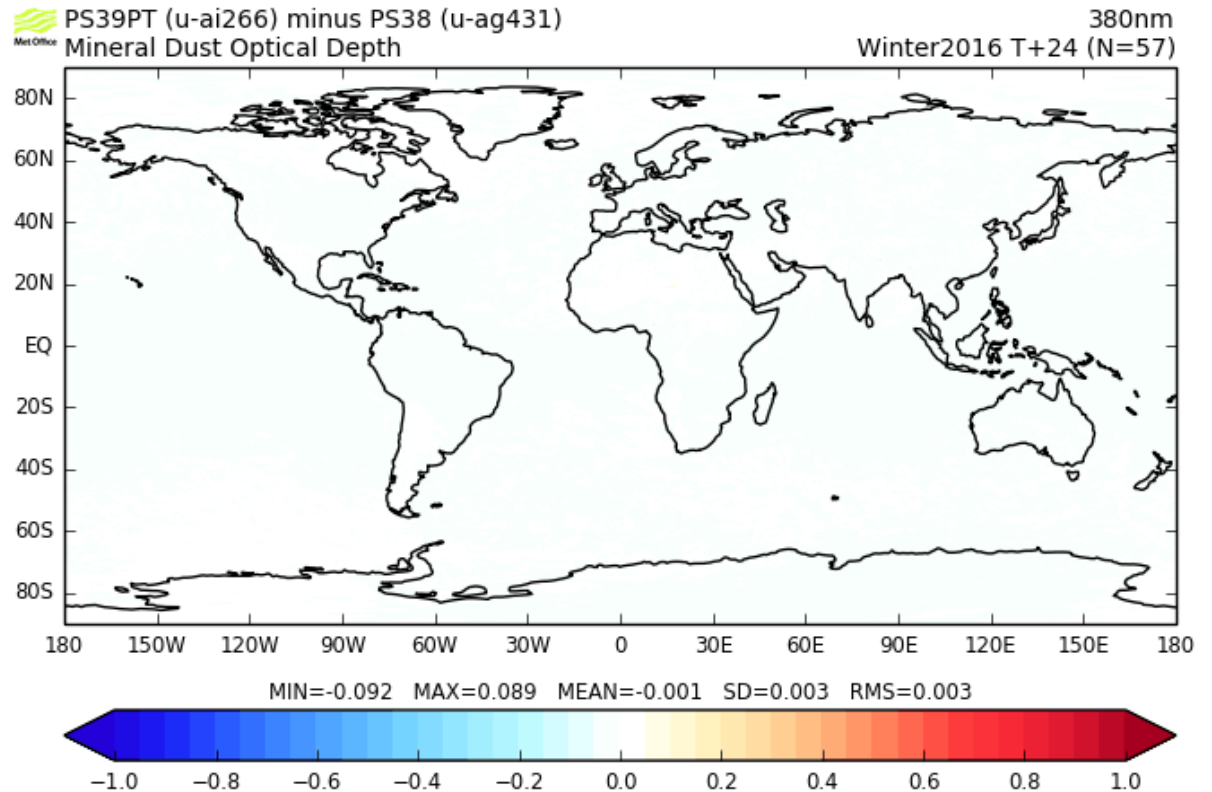


# Horizontal resolution

## Dust impact: Winter trial

Time mean dust AOD at T+24:

- From current system.
- From final winter trial.
- and the difference
  
- No noticeable change.





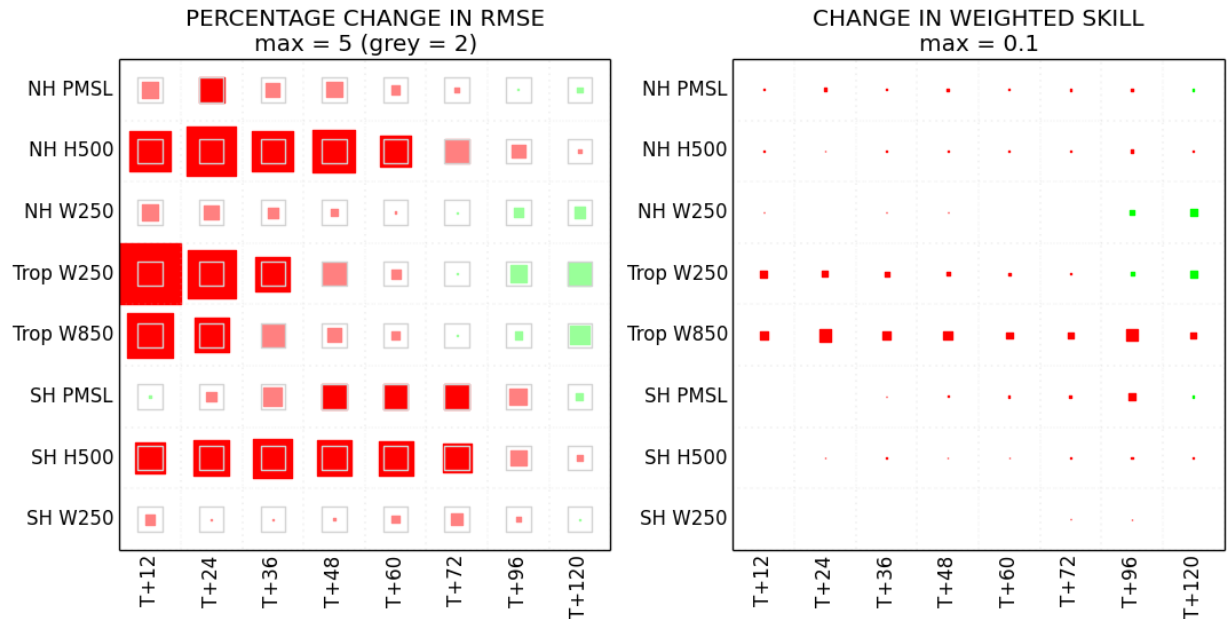
# ICAP 2016 slides: physics and resolution.

## So what happened to all the physics?

Full trials (with full ensemble):

- Poor performance vs analyses
- short range

**VAR TRIAL: GA7 #170.2 vs GA6.1 (JJA2015)**  
**VERIFICATION VS ANALYSIS**  
**FROM 20150601 TO 20150831**  
**OVERALL CHANGE IN NWP INDEX = -0.979**







# ICAP 2016 slides: physics and resolution.

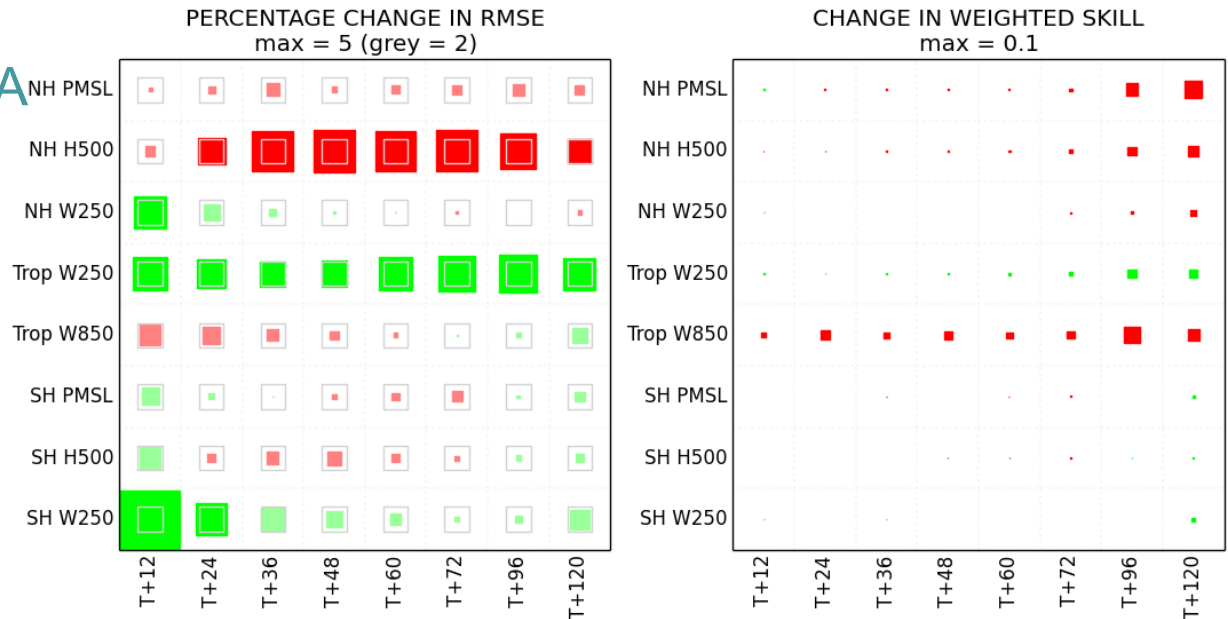
## So what happened to all the physics?

Full trials (with full ensemble):

- Poor performance vs analyses
- short range

- Tests with consistent DA covariance stats
- totally different,
- NH warming signal
- cloud retune?

**VAR TRIAL: GA7 #170.2 vs GA6.1: both consistent COV (JJA2015)**  
**VERIFICATION VS ANALYSIS**  
**FROM 20150601 TO 20150831**  
**OVERALL CHANGE IN NWP INDEX = -0.948**





# ICAP 2016 slides: physics and resolution.

So what happened to all the physics?

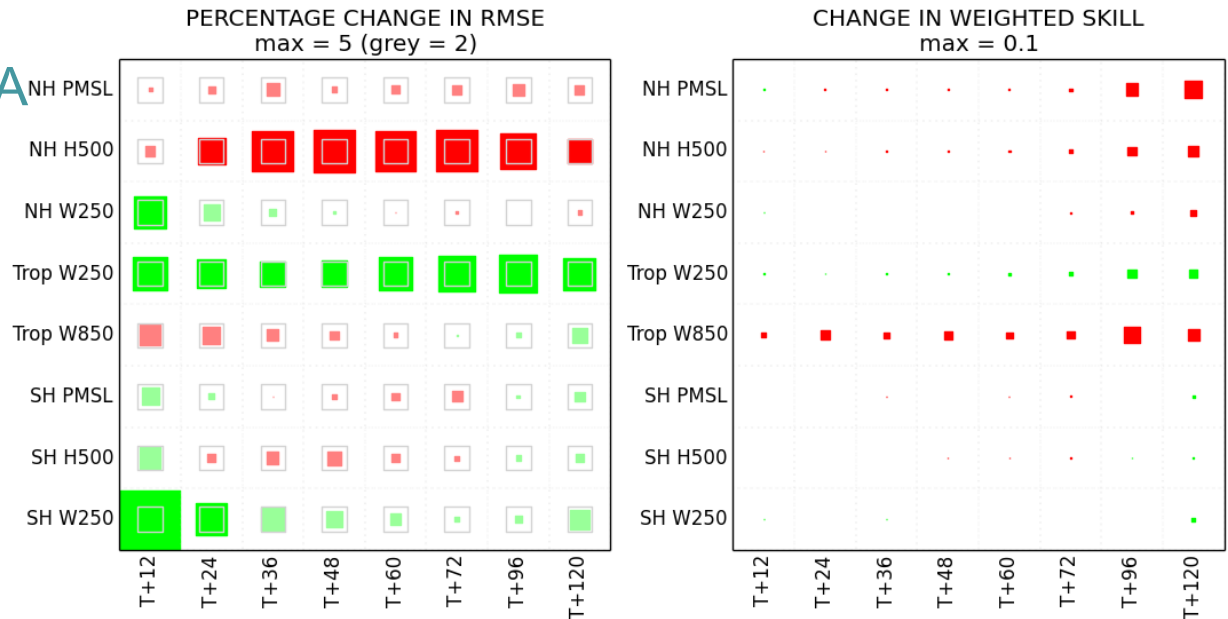
Full trials (with full ensemble):

- Poor performance vs analyses
- short range

**VAR TRIAL: GA7 #170.2 vs GA6.1: both consistent COV (JJA2015)**  
**VERIFICATION VS ANALYSIS**  
**FROM 20150601 TO 20150831**  
**OVERALL CHANGE IN NWP INDEX = -0.948**

- Tests with consistent DA covariance stats
- totally different,
- NH warming signal
- cloud retune?

- COV stats need full ensemble to make.
- Iterative process
- Slow.
- Missed deadlines.



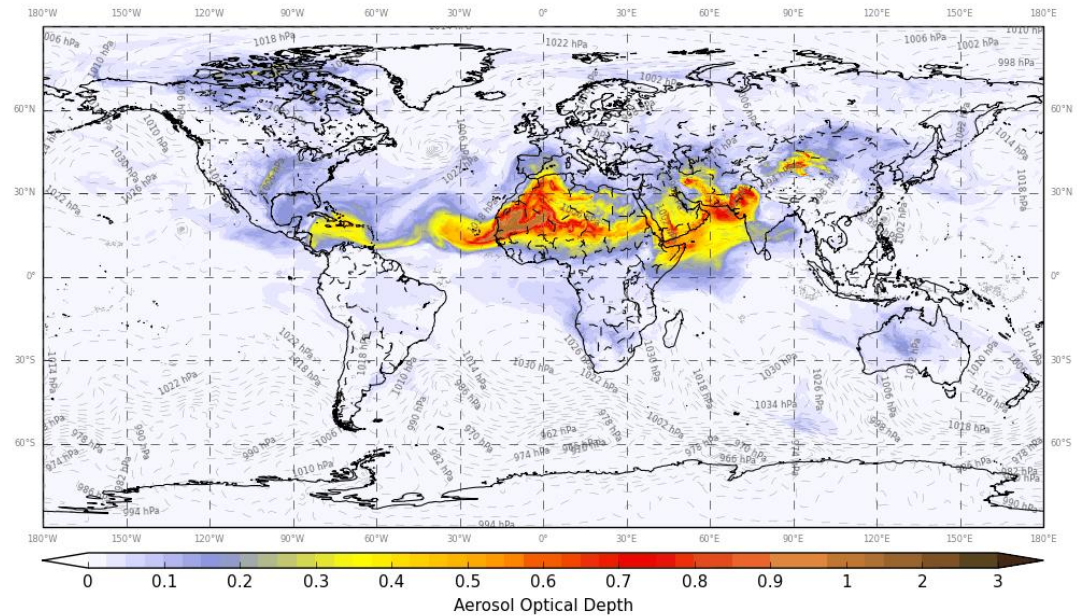


# Other aerosol work, flight campaign support

A lot of aerosol research campaigns this year:



Met Office Res. Global: Dust AOD at 550.0 nm  
2016/07/07 18Z T+72 from 2016/07/04 18Z





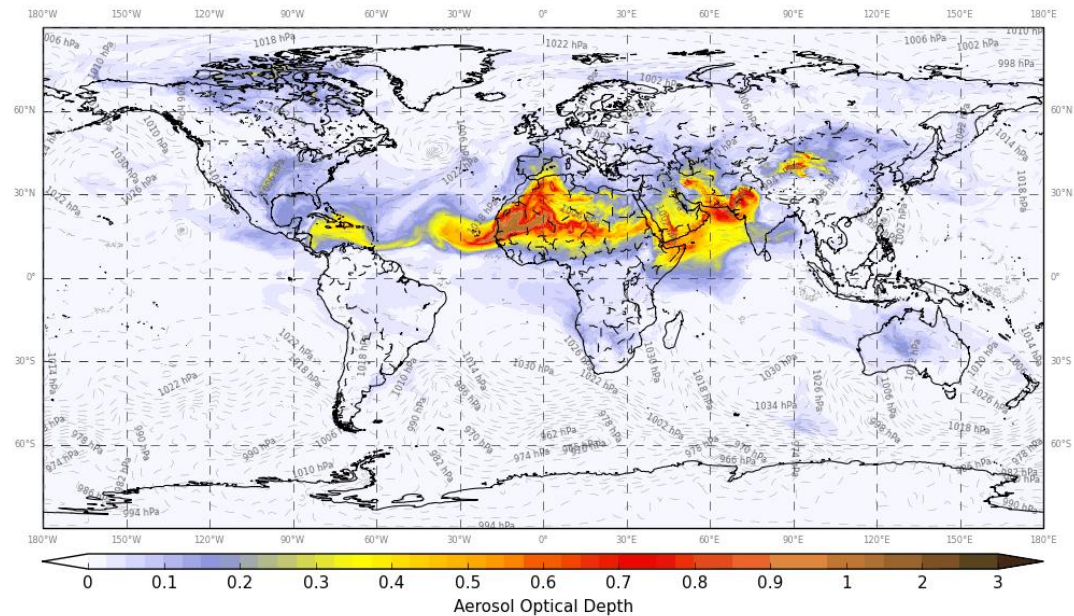
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- INCOMPASS, SWAMMI, MONSOON: over India pre/during the monsoon, 2016.
- Detailed evaluation underway (U. Reading)



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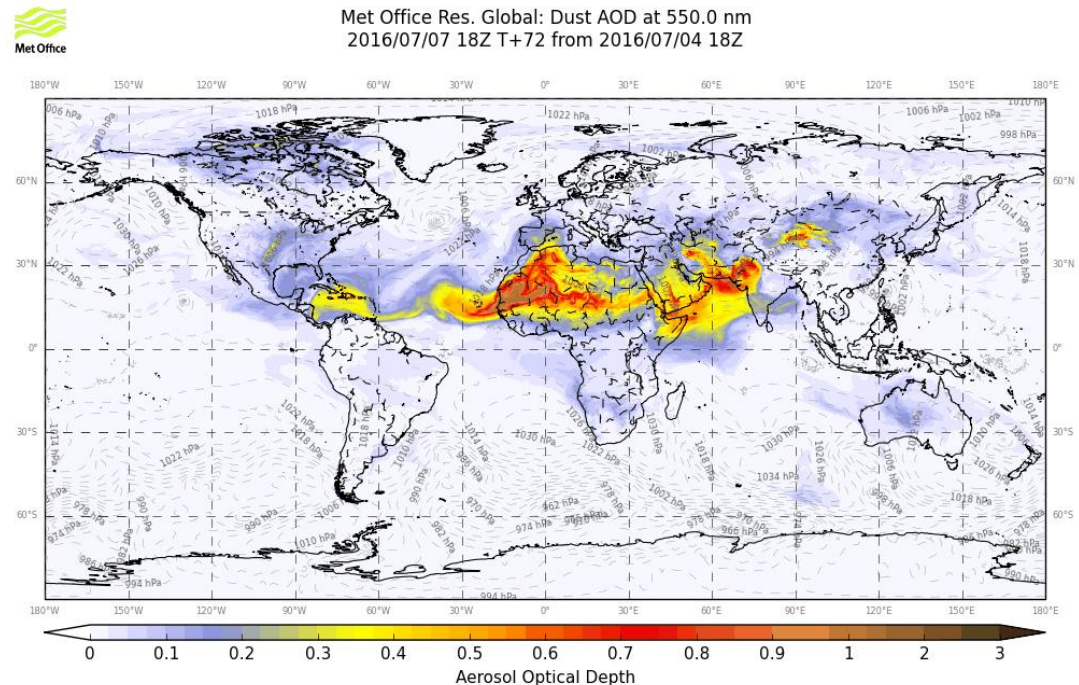
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- INCOMPASS, SWAMMI, MONSOON: over India pre/during the monsoon, 2016.

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- CLARIFY: aerosol cloud interaction over Tropical South Atlantic. Aug 2017.



A need for increased aerosol modelling support: **not just dust**

<http://www.metresearch.com/flyingforecasts>

[http://gws-access.ceda.ac.uk/public/mo\\_forecasts/](http://gws-access.ceda.ac.uk/public/mo_forecasts/)



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# Other aerosol work, flight campaign support (Ben Johnson)

Carbonaceous aerosol,  
CLASSIC:

- fossil fuel
- bio-fuel
- biomass burning



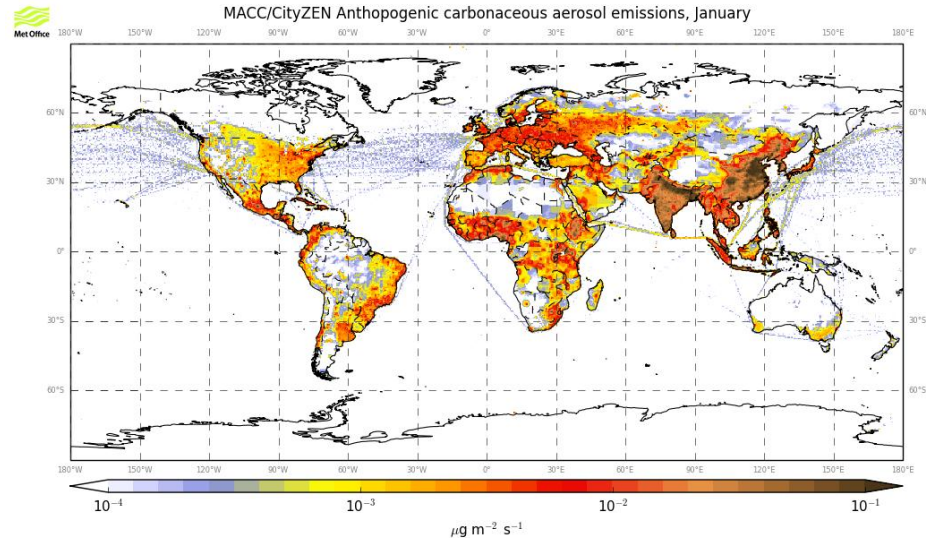
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## Anthropogenic emissions:

- 2014 monthly mean
- MACC/CityZen



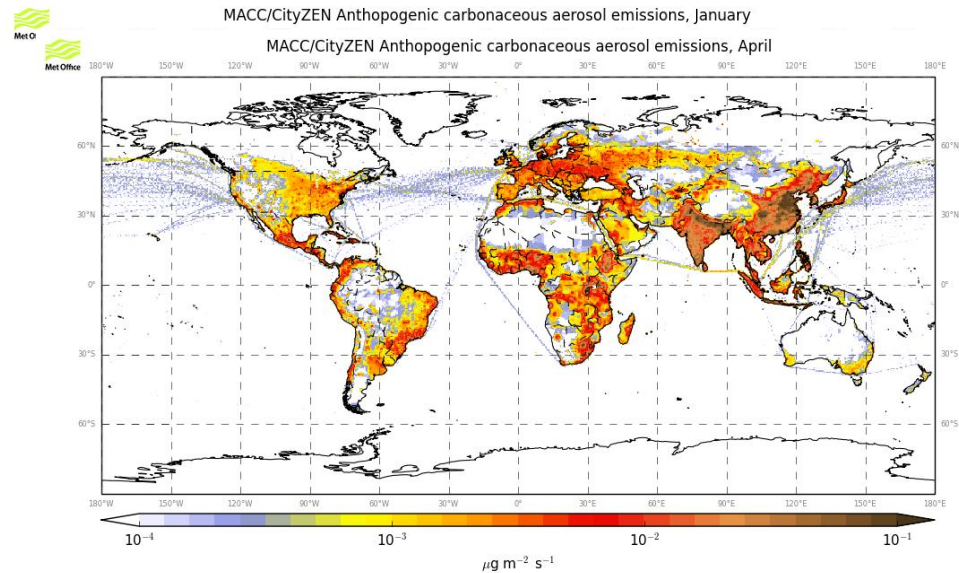
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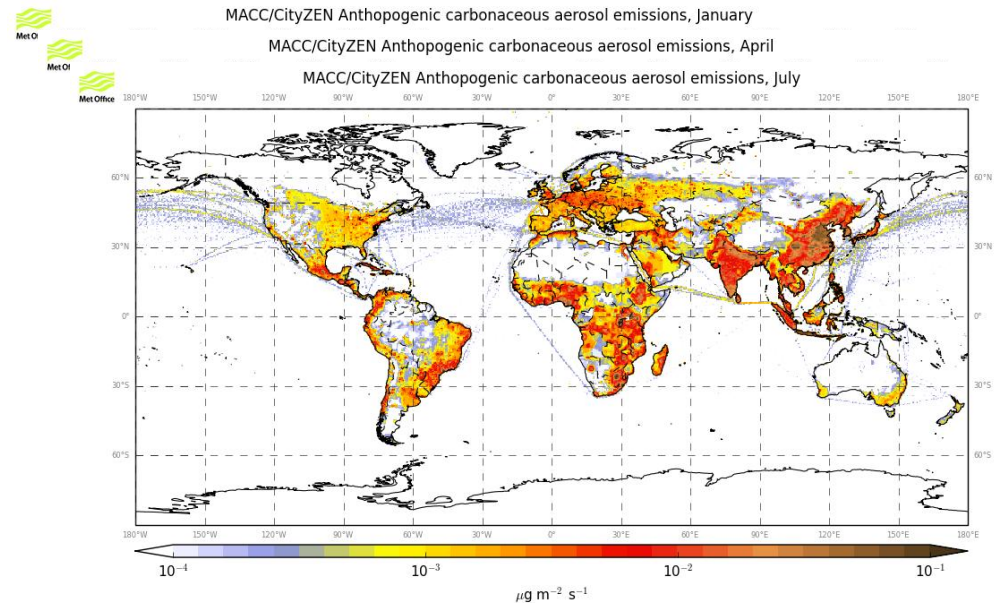
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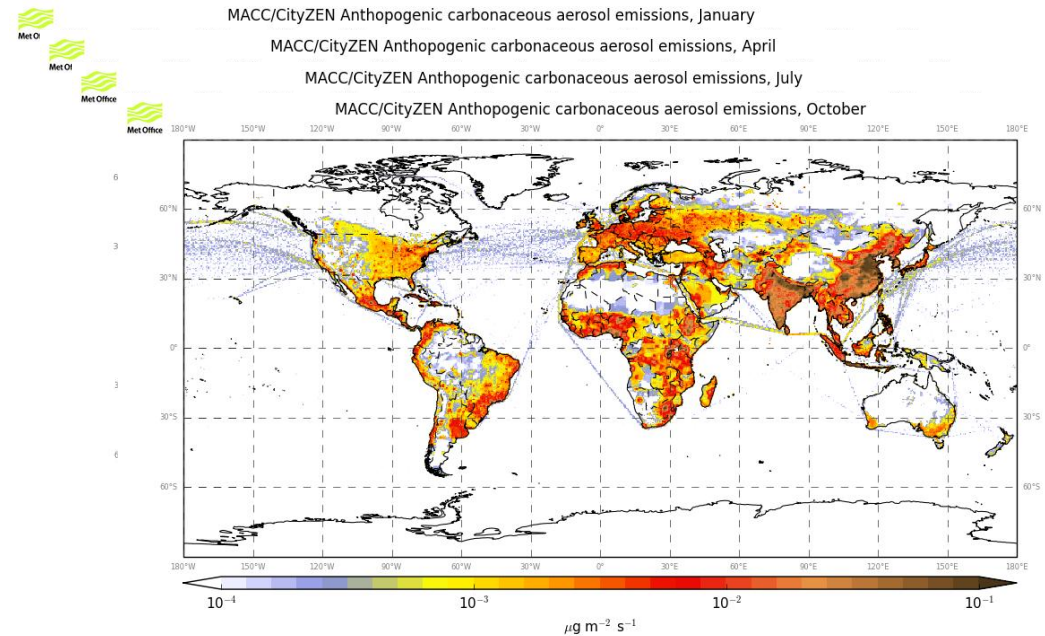
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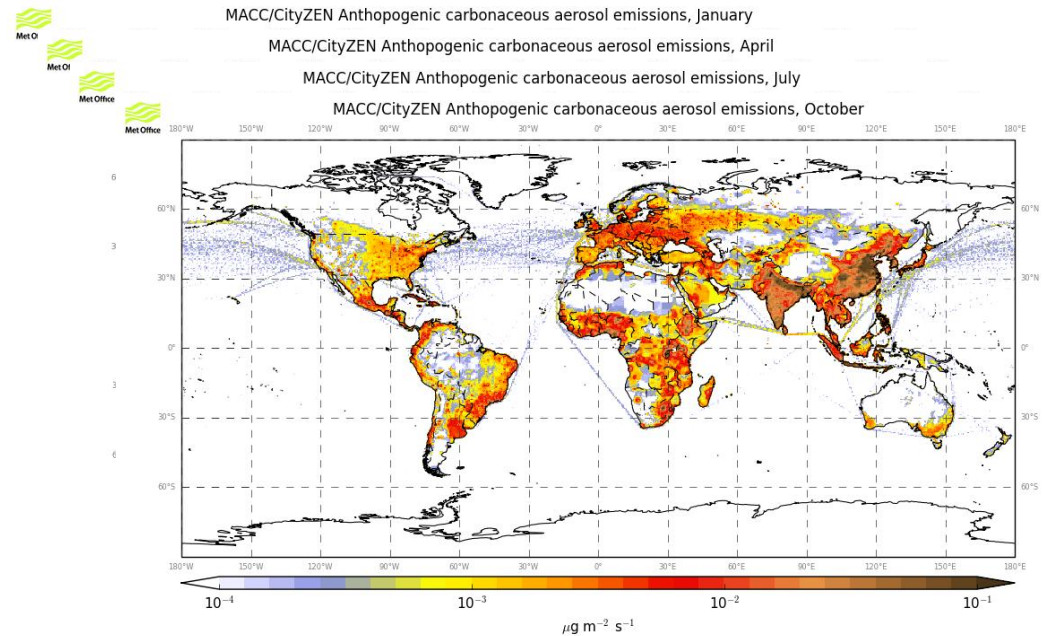
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- 1 day lagged from GFAS
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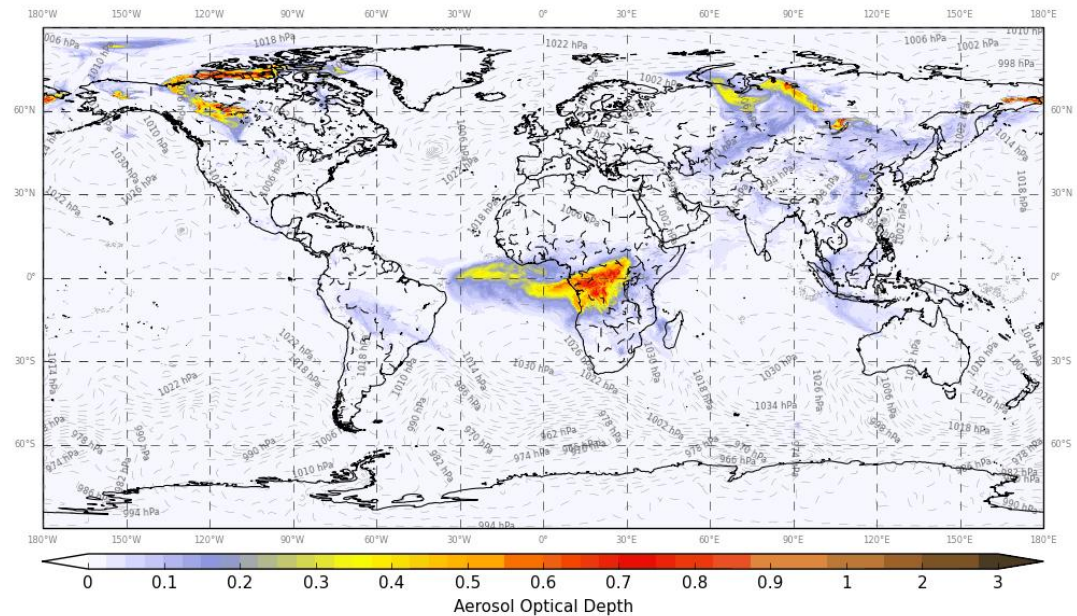
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Met Office Res. Global: Carbonaceous AOD at 550.0 nm  
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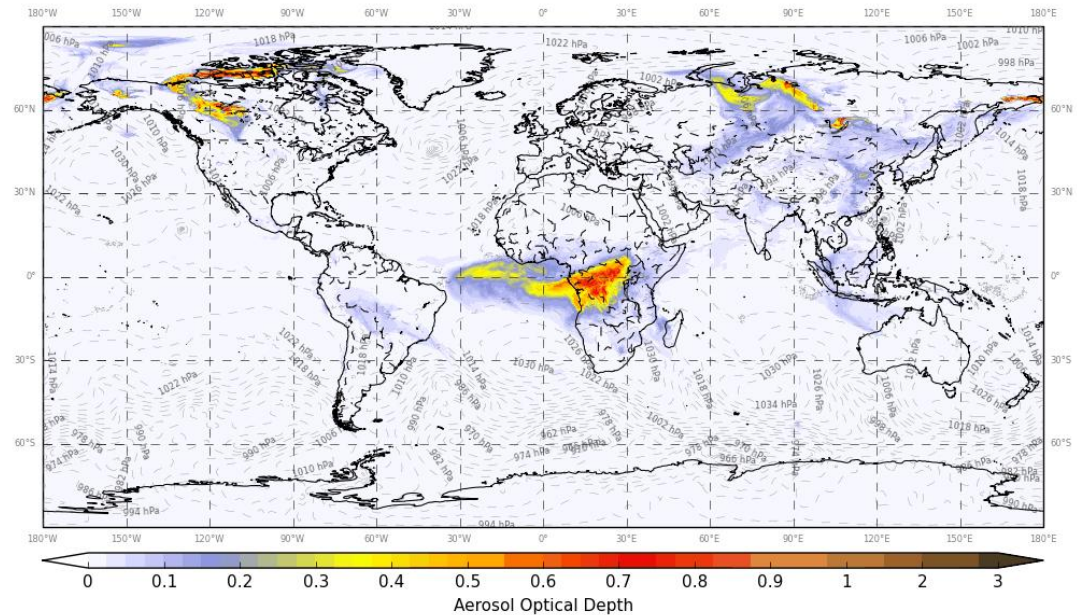
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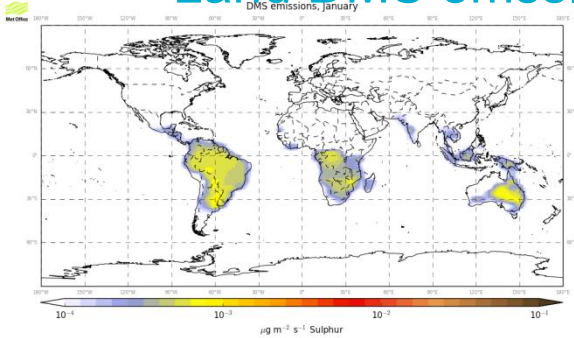
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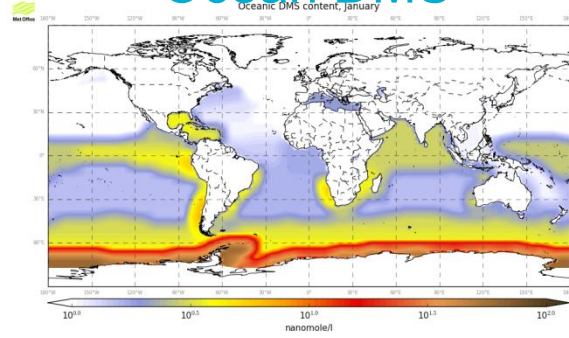
Once airborne, only dust assimilated in these runs!

# Other aerosol work, flight campaign support

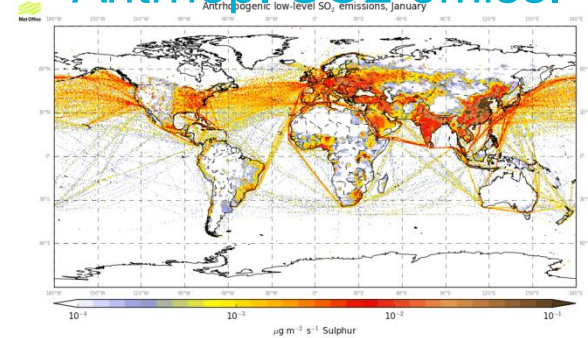
Land DMS emss.



Ocean DMS



Anthrop. SO2 emiss.

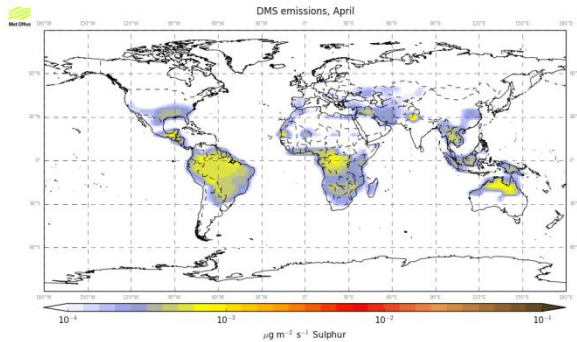


## Sulphate aerosol forecasts with CLASSIC:

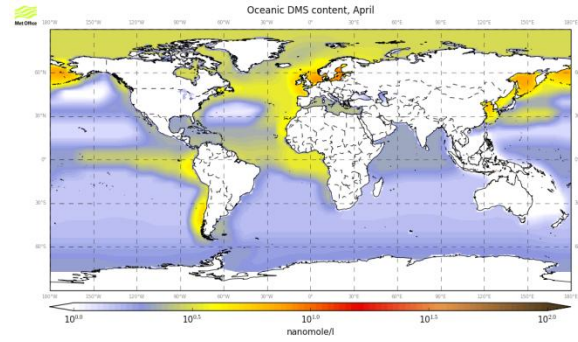
- Anthropogenic SO<sub>2</sub> (MACC/CityZen)
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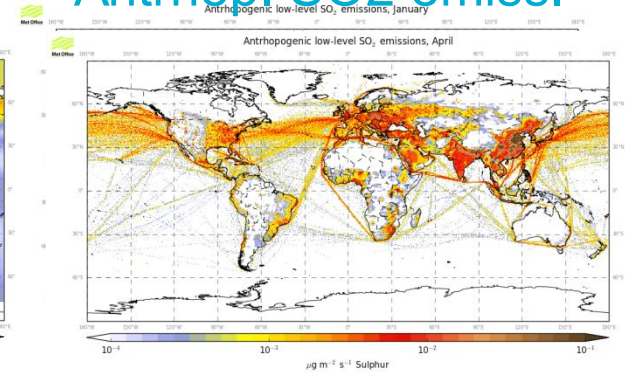
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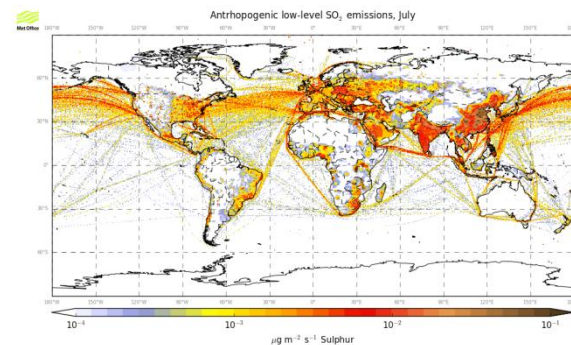
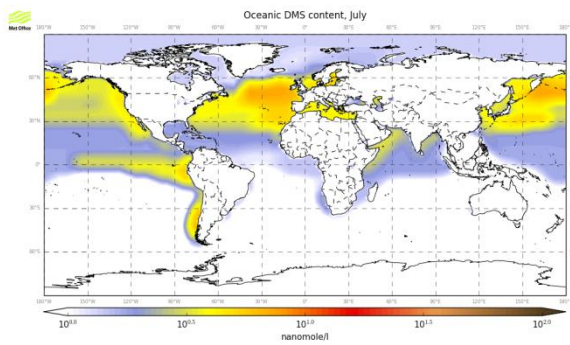
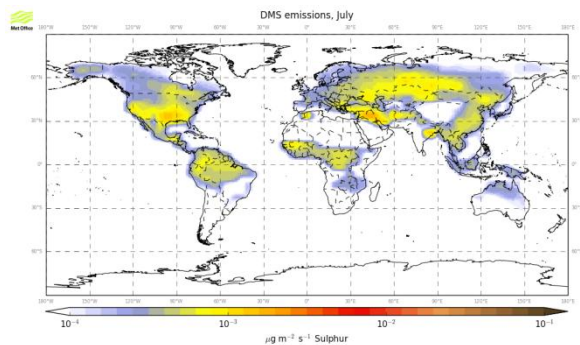


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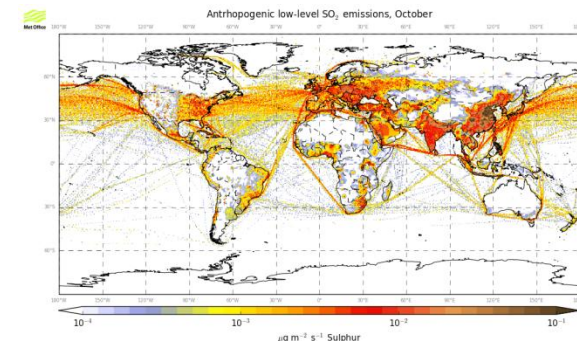
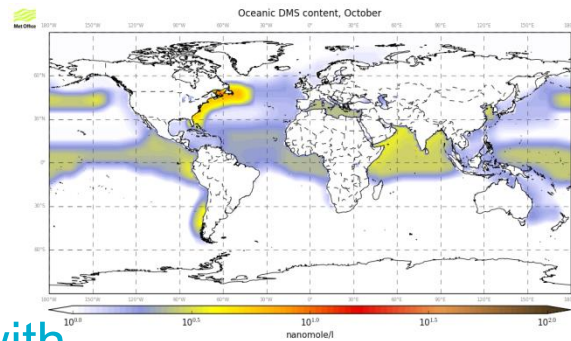
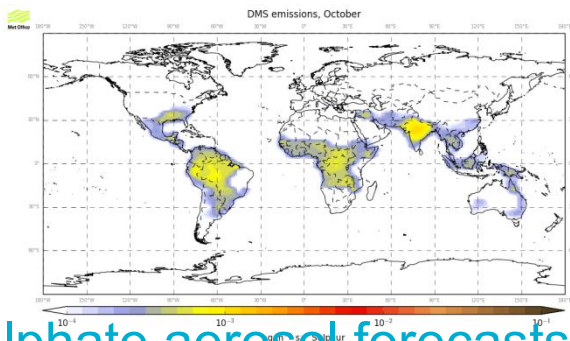
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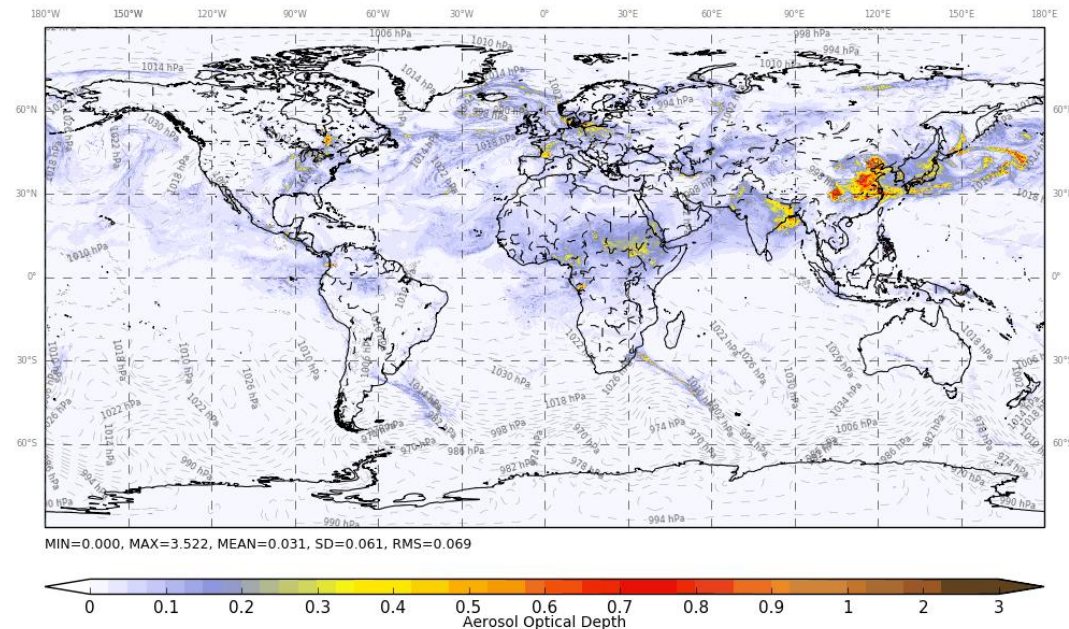
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Met Office Res. Global: Sulphate AOD at 550.0 nm  
Fri 2017/06/23 06Z T+6 from 2017/06/23 00Z





# Other aerosol work, flight campaign support

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Ocean DMS

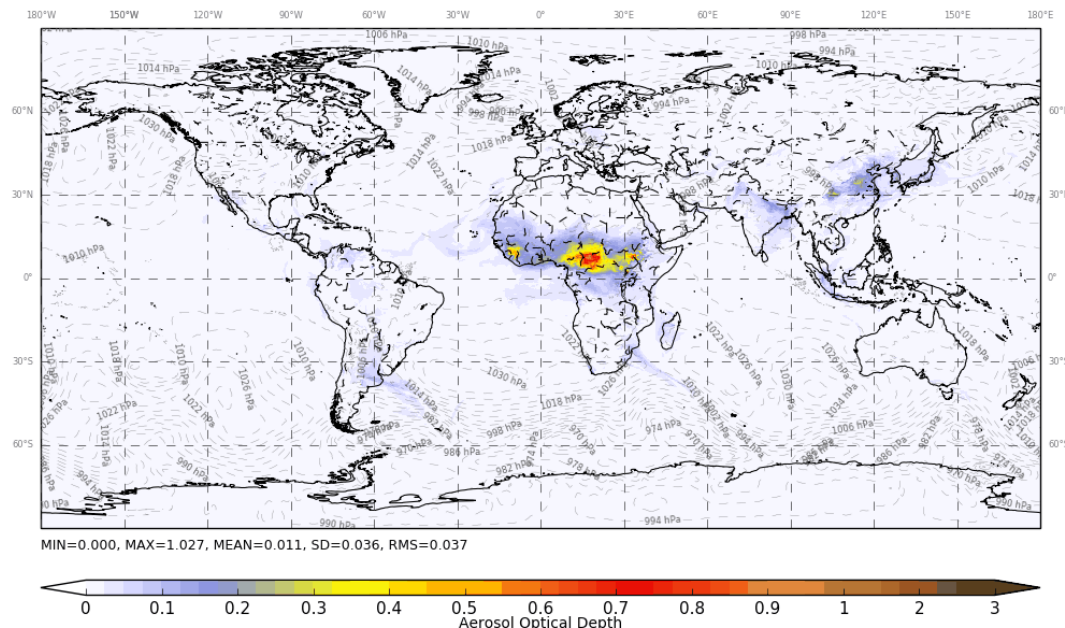
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Met Office Res. Global: Carbonaceous AOD at 550.0 nm  
Fri 2017/06/23 06Z T+6 from 2017/06/23 00Z



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Ocean DMS

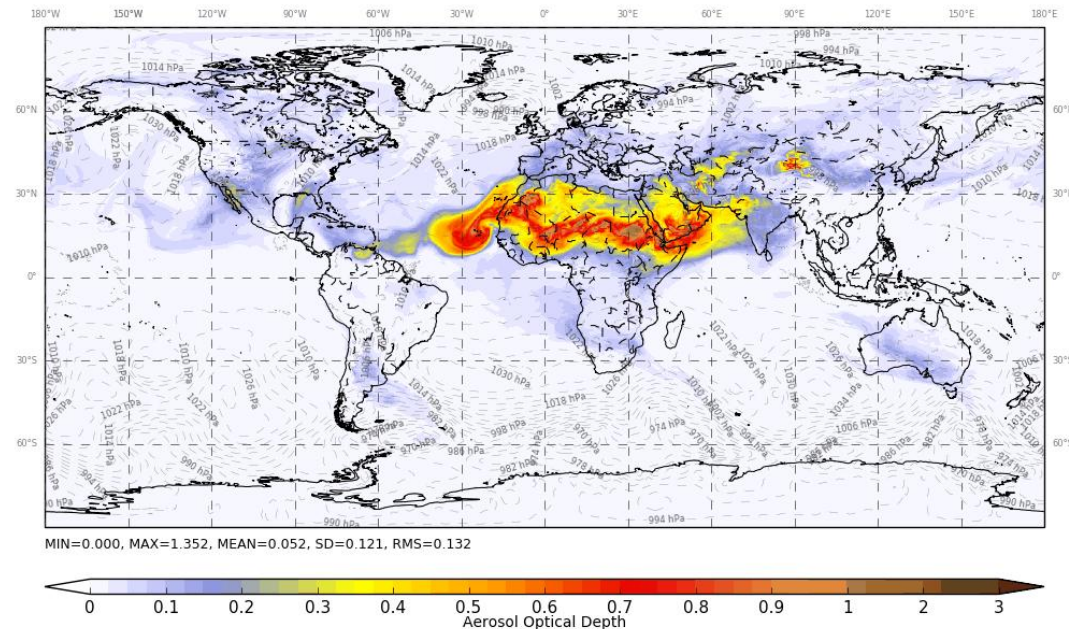
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Fri 2017/06/23 06Z T+6 from 2017/06/23 00Z



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Ocean DMS

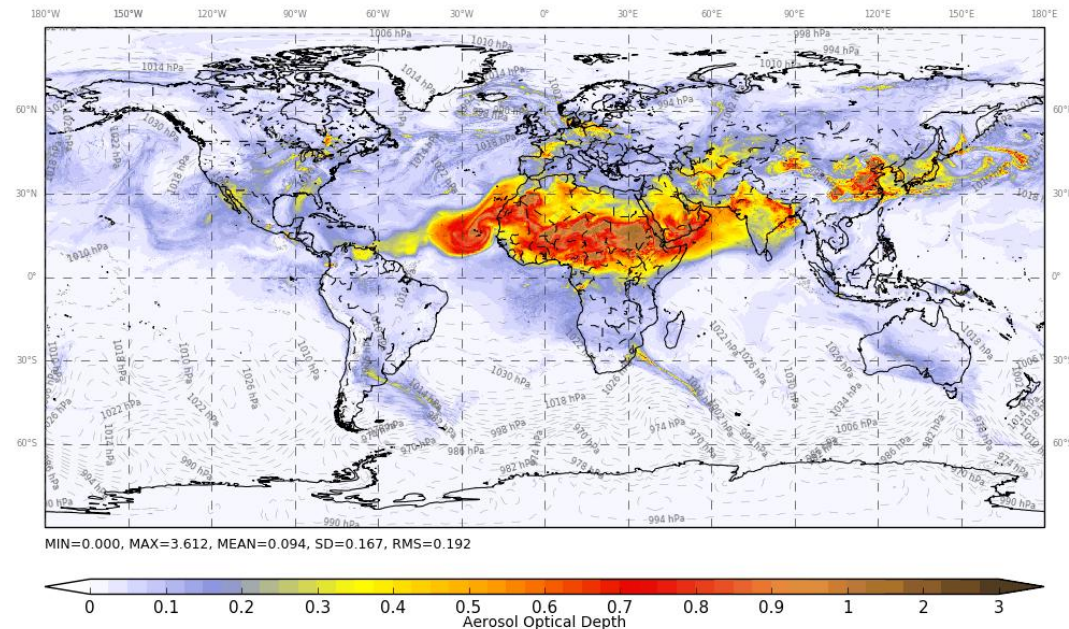
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Met Office Res. Global: Total Prognostic AOD at 550.0 nm  
Fri 2017/06/23 06Z T+6 from 2017/06/23 00Z





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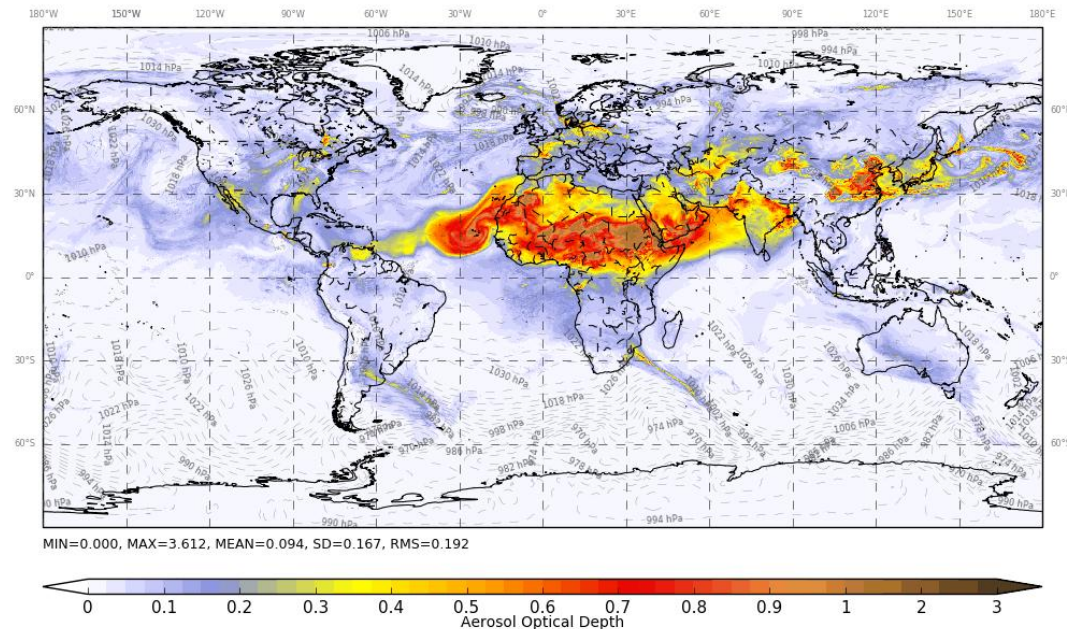
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Dust, carbonaceous, sulphate  
Just missing nitrate and sea salt?



Met Office Res. Global: Total Prognostic AOD at 550.0 nm  
Fri 2017/06/23 06Z T+6 from 2017/06/23 00Z



Cost increase ~30% to ~40%

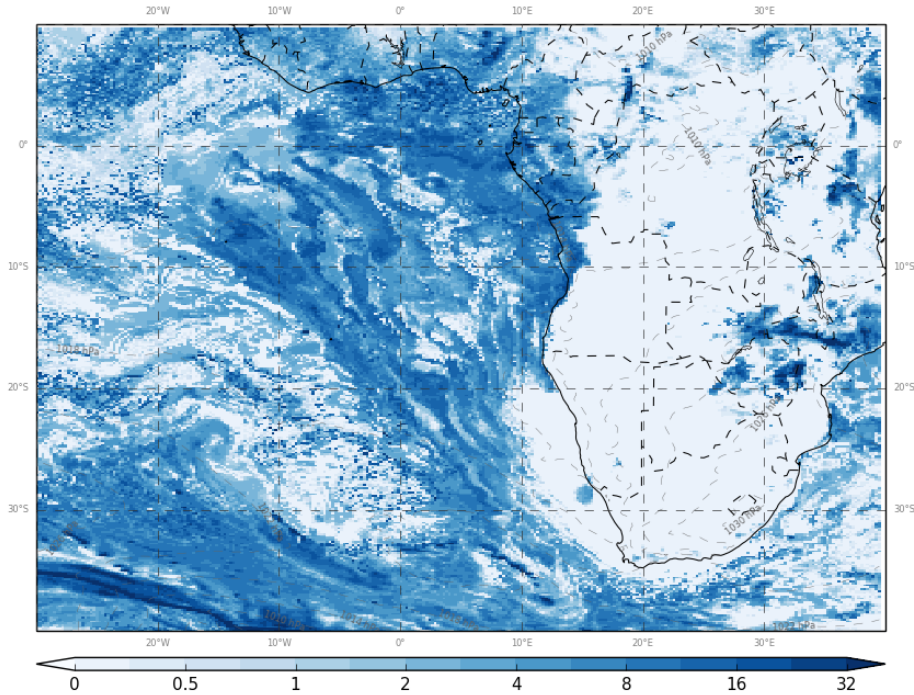


# CLARIFY: aerosol cloud interactions

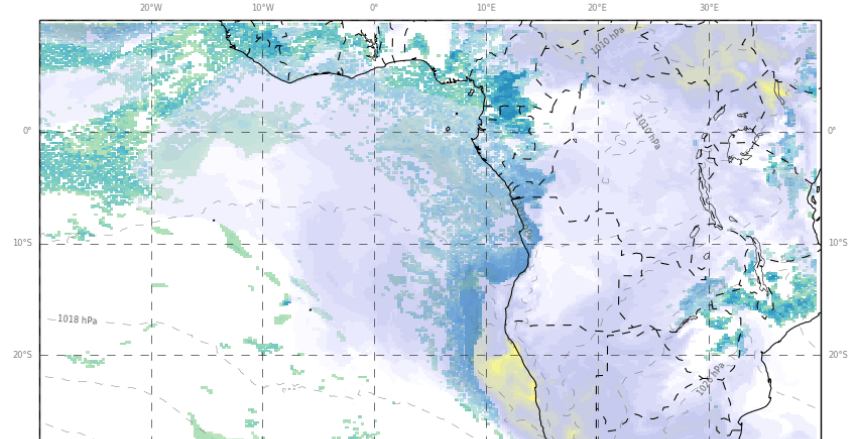
## From Ascension Island



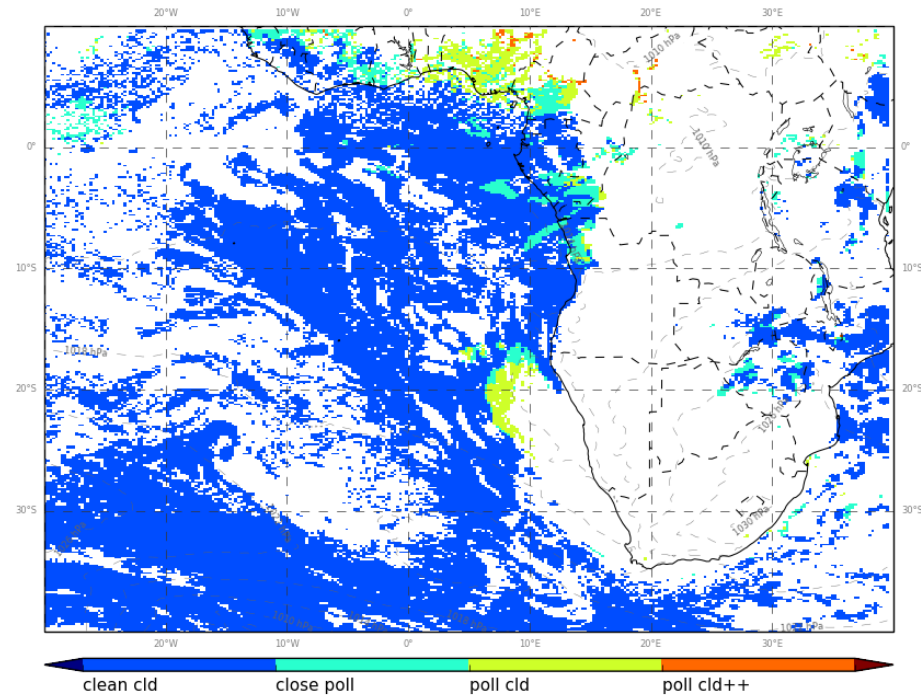
Met Office Res. Global: Liquid Cloud Optical Depth  
Mon 2017/06/26 06Z T+72 from 2017/06/23 06Z

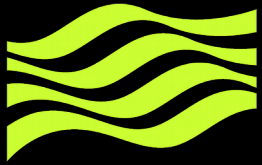


Met Office Res. Global: Cloud spec. humidity, Total Aerosol Conc. (g kg-1)  
at Model level 8 (533 m), Mon 2017/06/26 06Z T+72 from 2017/06/23 06Z



Met Office Res. Global: Clarify Polluted Cloud Diag.  
Mon 2017/06/26 06Z T+72 from 2017/06/23 06Z





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# Summary

1. MODIS used in DA from collection 5.1 to 6.0:
  - Fewer obs (higher QC)
  - Aqua+Terra promising.
  - Significant reduction in India dust biases.
2. Resolution (only) upgrade for global NWP, July 2017:  
17km to 10km global.  
Improvements for NWP  
Negligible for dust.
3. Additional aerosol forecasts still running:  
Dust + Carbonaceous + sulphate  
Detailed evaluation underway  
Demonstration and campaign support only.





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# Questions and answers

