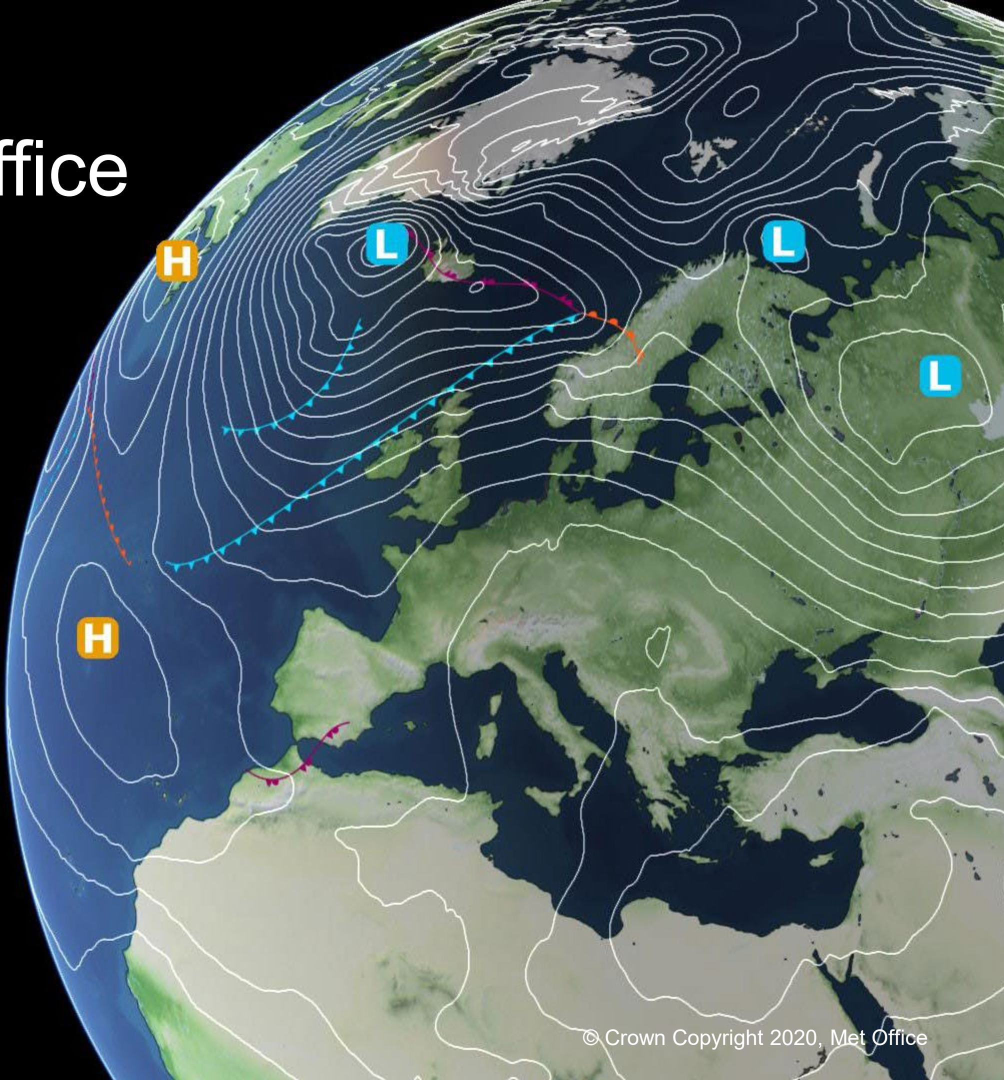
An Update on the Met Office dust assimilation and forecasting system

Heather Lawrence, Alex Paterson,
Anthony Jones, Melissa Brooks



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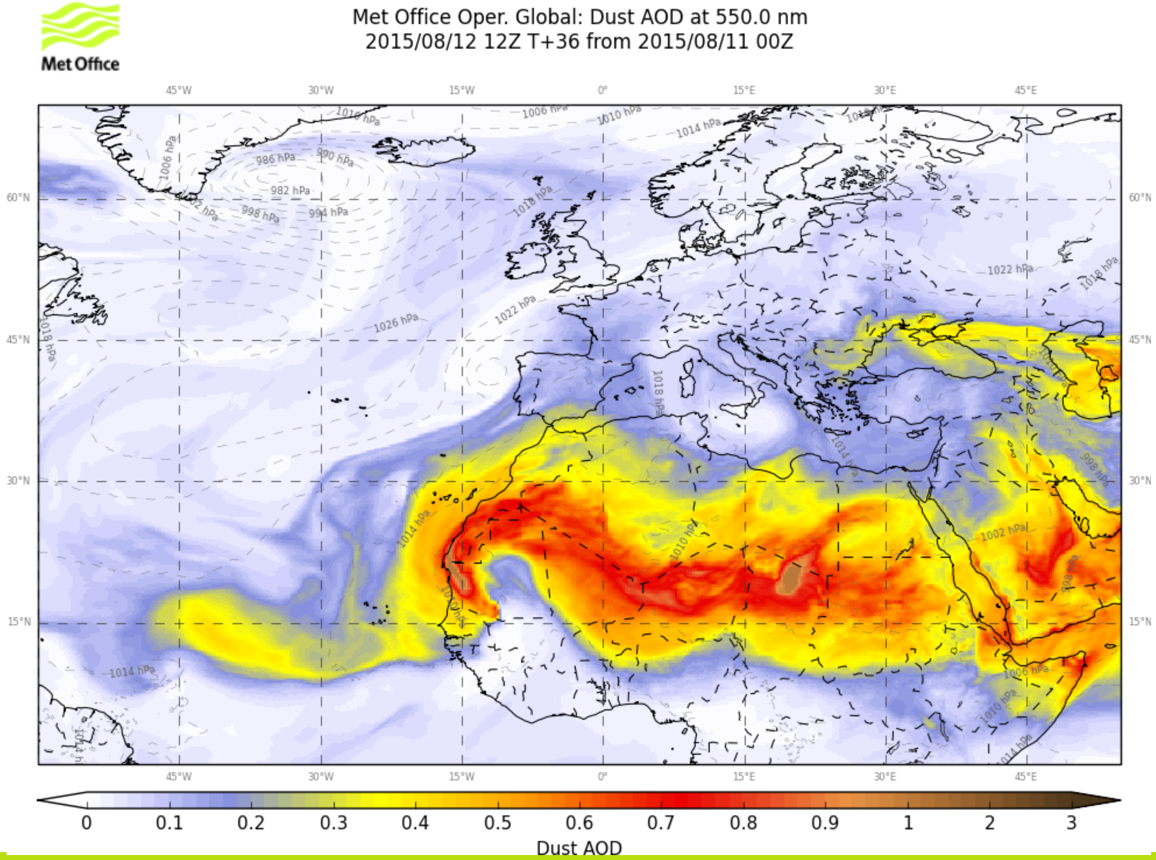
1. NWP: improved use of observations

Heather Lawrence, Alex Paterson

Dust in the NWP model

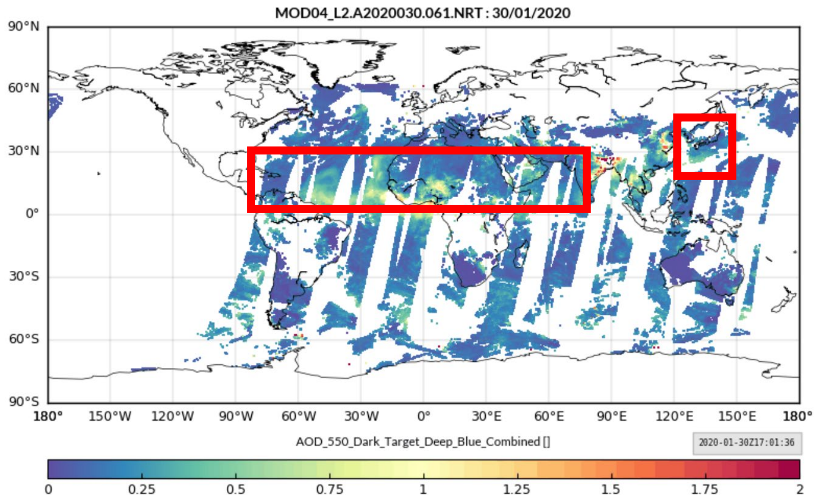


- CLASSIC dust forecast model with 2 bin setup
- Other aerosols are not included (smoke, pollution, sea salt, etc.)
- Interactive dust (direct radiative effect) since 2015
- Forecasts are initialised using MODIS satellite observations (2 instruments)

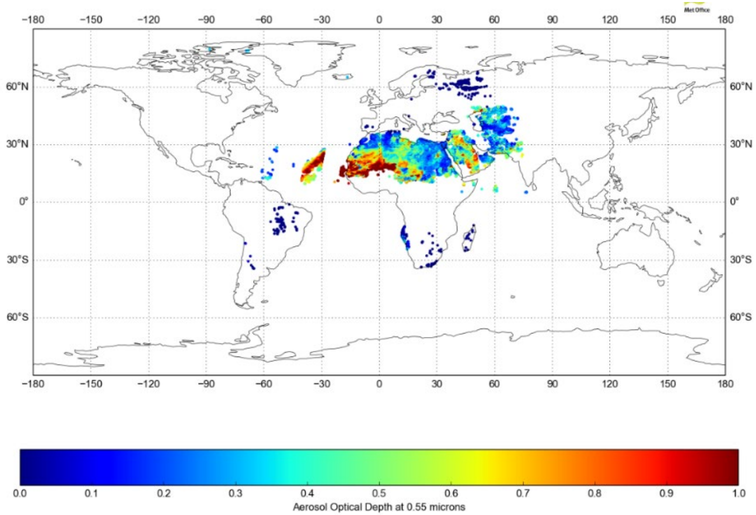
MODIS Assimilation: Dust Filtering

Filtering is needed to remove non-dust aerosol and may introduce errors

Rely on a geographical ocean check + secondary retrieval products



QC



Development of the dust assimilation system

Maintenance activities (high priority) to evaluate more AOD products for assimilation

- Suomi-NPP VIIRS: NASA product v1
- Metop-B/C PMAp v 2.1& 2.2

PMAp & VIIRS Evaluation

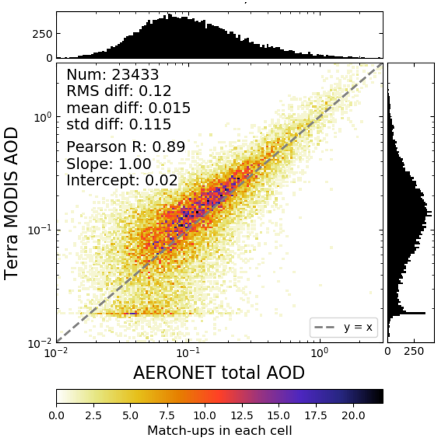
Check the performance of PMAp/VIIRS relative to MODIS:

1. Compare to ground-based AERONET data
2. Compare directly to Aqua/Terra MODIS

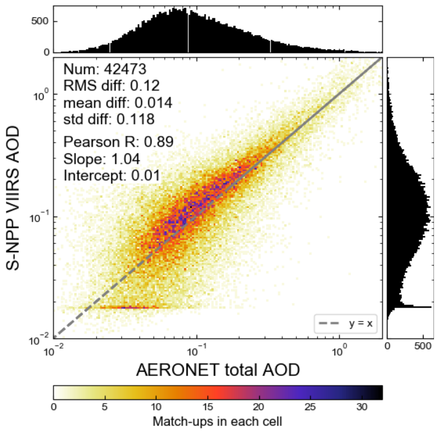
Comparison to AERONET: all data

1 year: Dec 2019 – Dec 2020

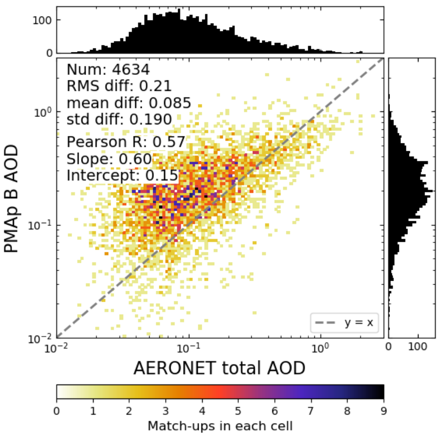
Terra MODIS DB/DT



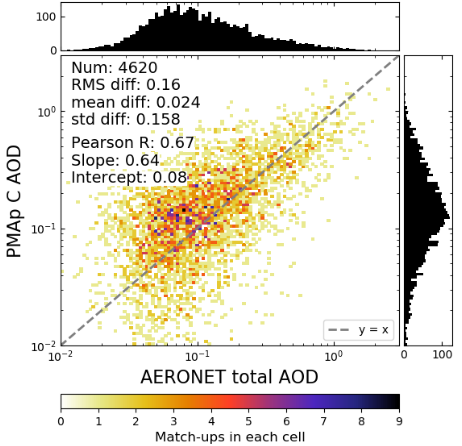
VIIRS DB



Metop-B PMAp v2.1



Metop-C PMAp v. 2.1



	Terra MODIS DB/DT	VIIRS DB	Metop-B PMAp v2.1	Metop-C PMAp v. 2.1
R:	0.89	0.89	0.57	0.67
RMS:	0.12	0.12	0.21	0.16

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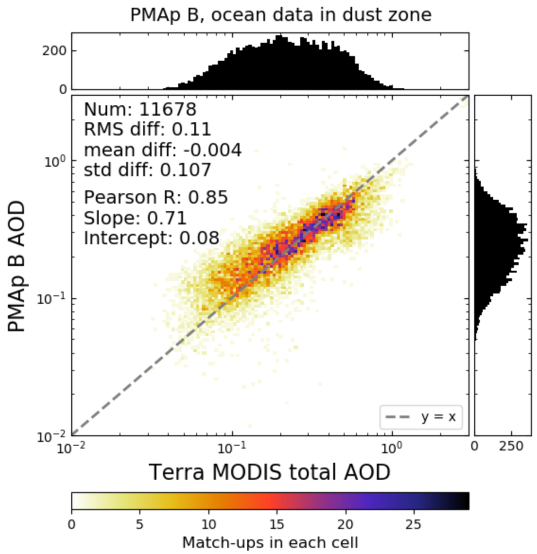
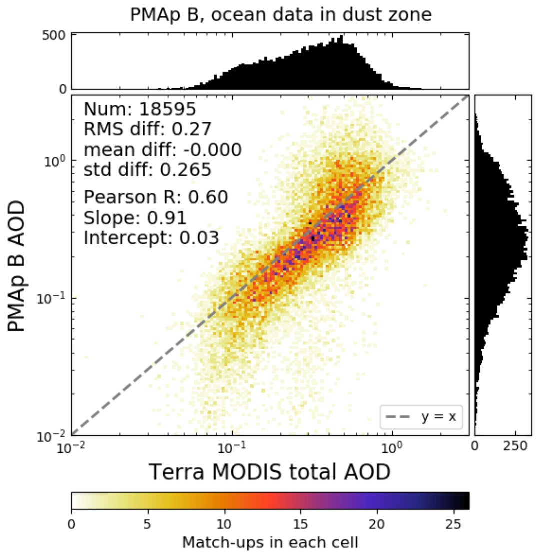
PMAp over ocean

PMAp v2.1 ocean



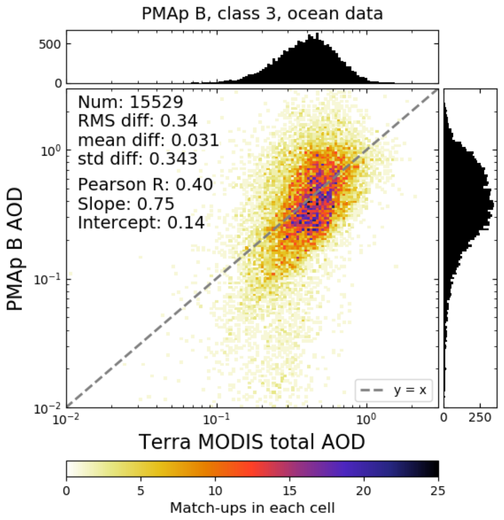
R = 0.85
RMS = 0.11

PMAp v2.2 ocean



R = 0.60
RMS = 0.27

PMAp v2.2 ocean dust



R = 0.40
RMS = 0.34

Evaluation summary

- VIIRS looking promising – generally similar quality to MODIS
- PMAp does not perform as well as MODIS. It shows some promise over ocean.

VIIRS Assimilation

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VIIRS Assimilation: Dust Filtering

MODIS filtering

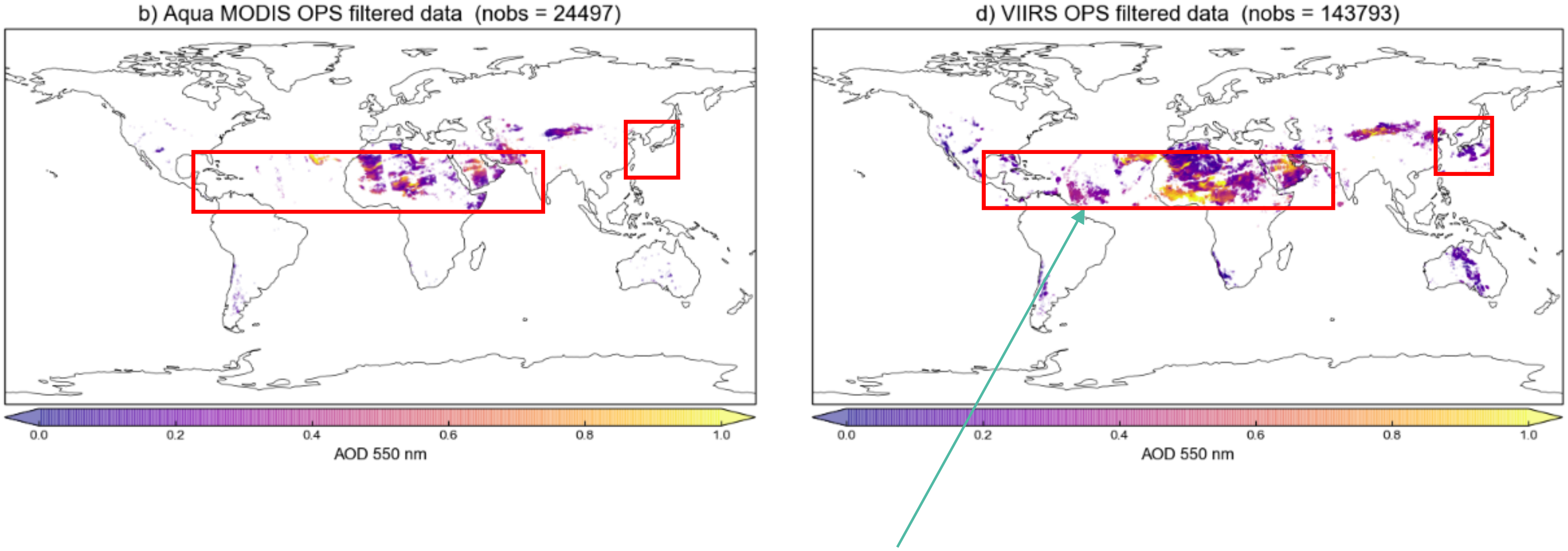
Surface	Aerosol filters
Ocean	Geographical filter
	Aerosol Fine Mode Fraction $\leq$ 0.4
	Ångstrom Exponent $\leq$ 0.5
	Aerosol Effective Radius $>$ 1.0 μm
	Aerosol Mass Concentration $\geq$ 1.2 x 10^{-4} kg/m^2
	AOD $\geq$ 0.1 or (AOD $<$ 0.1 & Background AOD $\geq$ 0.1)
Land: DB retrievals	0.878 $<$ SSA $<$ 0.955
	Ångstrom Exponent $<$ 0.6
Land: DT retrieval	Ångstrom Exponent $<$ 0.45

Not available for VIIRS Deep Blue, replace with aerosol type check:

- *maritime (low AOD)*
- *dust (AOD > 0.15)*

Assimilation set-up: Dust Filtering

Apply similar filtering to MODIS based on secondary products…:



Not all fields available for VIIRS over ocean, less data removed

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Assimilation set-up: Check Dust Filtering

Angstrom Exponent:

$$\frac{AOD_\lambda}{AOD_{\lambda_0}} = \left(\frac{\lambda}{\lambda_0}\right)^{-\alpha}$$

Identify Dust: AERONET Angstrom Exponent < 0.6
Identify Non-dust: AERONET Angstrom Exponent >= 0.6

	Dust Nobs	Non-dust Nobs	**Dust %**	**Non-Dust %**
VIIRS ocean dust-filtered, AOD > 0.2	442	56	**91%**	**9%**
VIIRS land filter, AOD > 0.2	674	931	**43%**	**57%**
MODIS land filter, AOD > 0.2	250	351	**38%**	**62%**
VIIRS land aerosol type filter, AOD > 0.2	376	244	**61%**	**39%**

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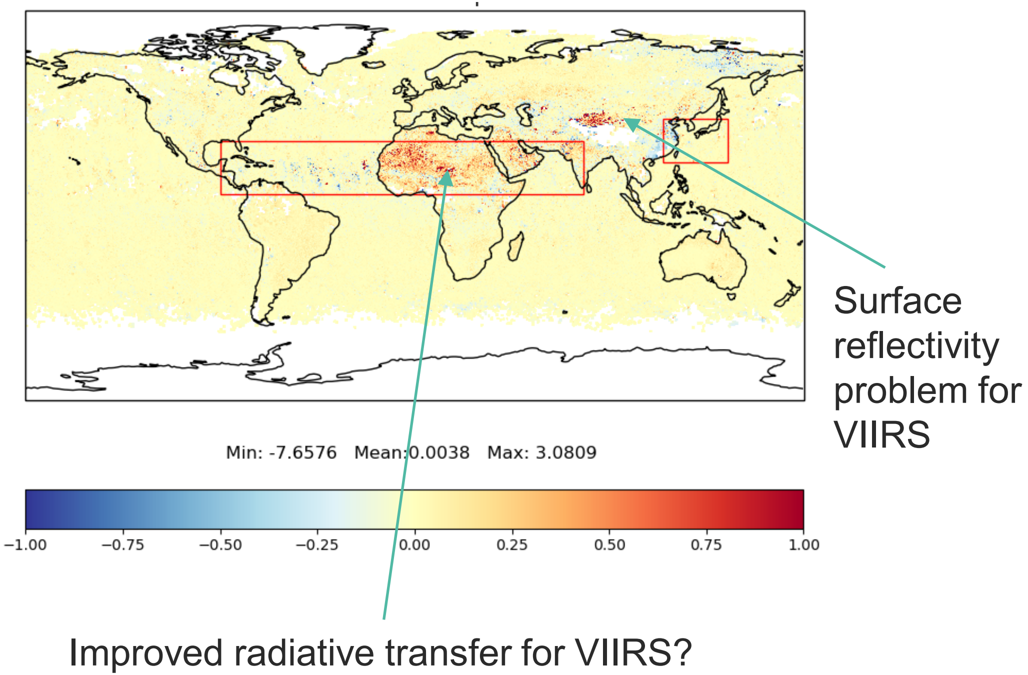
Assimilation set-up

Set-up:

- Apply dust filtering
- Blacklist over Taklamakan desert
- 10 km thinning to replicate MODIS
- Apply same observation error covariances as MODIS (R = 0.222)
- No bias correction

Mean VIIRS – MODIS AOD



Assimilation of VIIRS: experiment set-up

Assimilation trials:

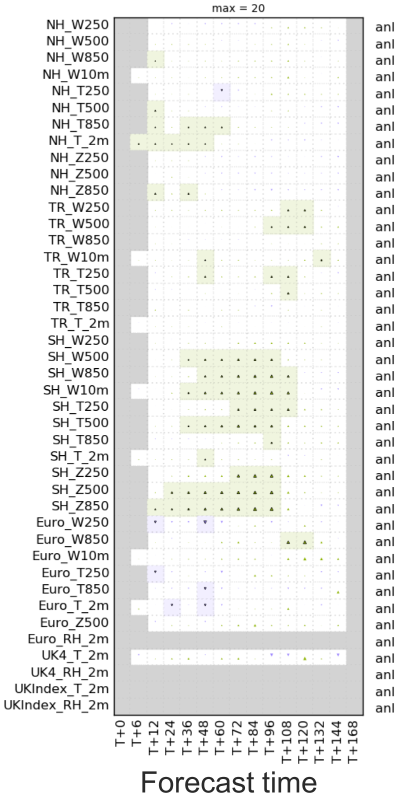
Winter: Dec 2019 – Feb 2020
Summer: May – June 2020

1. VIIRS + MODIS
2. Add VIIRS with no MODIS

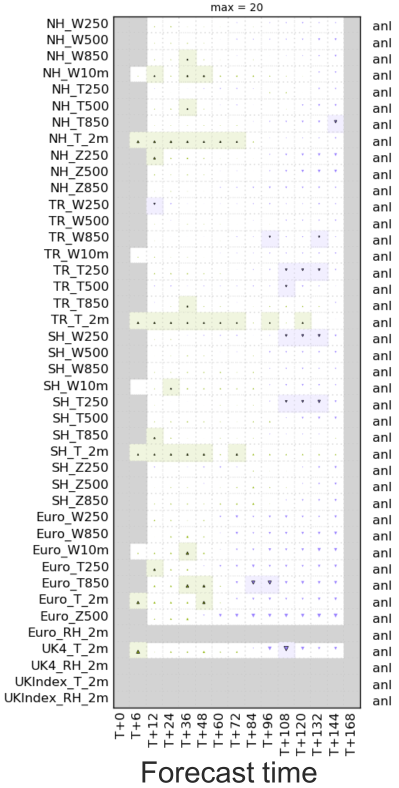
Results: VIIRS + MODIS Assimilation

Meteorological variables

Winter



Summer



Green = lower RMSE

Verification: EC Analysis

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Analysis Statistics against AERONET: selected sites, ***VIIRS + MODIS - MODIS***

	Total AOD	Coarse AOD	Coarse AOD AE<0.6
All sites	**0.0002 +/- 0.0014**	**0.0056 +/- 0.0015**	**-0.0029 +/- 0.0050**
Sahara + middle East + Caribbean	**-0.0096 +/- 0.0086**	**-0.0052 +/- 0.0054**	**-0.0115 +/- 0.0083**
Australia	-0.0017 +/- 0.0084	0.0027 +/- 0.0119	-0.0004 +/- 0.0101
S. Africa	0.0004 +/- 0.0013	0.0016 +/- 0.0010	0.0076 +/- 0.0163
S. America	-0.0038 +/- 0.0034	0.0045 +/- 0.0052	0.0056 +/- 0.0134
N. America	0.0016 +/- 0.0016	0.0048 +/- 0.0022	-0.0054 +/- 0.0128
Europe	0.0039 +/- 0.0017	0.0098 +/- 0.0025	0.0066 +/- 0.0056
Asia	-0.0012 +/- 0.0039	0.0072 +/- 0.0043	0.0063 +/- 0.0184

Changes in STDEV(Analysis – AERONET)

Red: negative statistically significant

Blue: positive statistically significant

VIIRS Assimilation Conclusions

- S-NPP VIIRS shows good impact in assimilation:

  - Improvements to near-surface temperature
  - Small (tiny) improvements to total AOD over the Sahara against AERONET

2. ERDC collaborative project: improved mapping of dust emissions

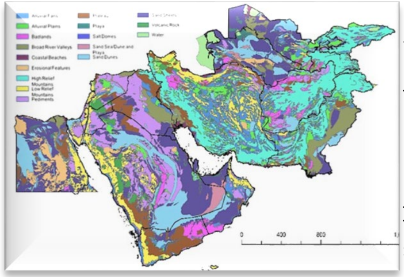
Melissa Brooks

ERDC lead:
Sandra LeGrand - US Army Engineer Research and Development Center

Dust Sources: ERDC-GEO

ERDC-GEO

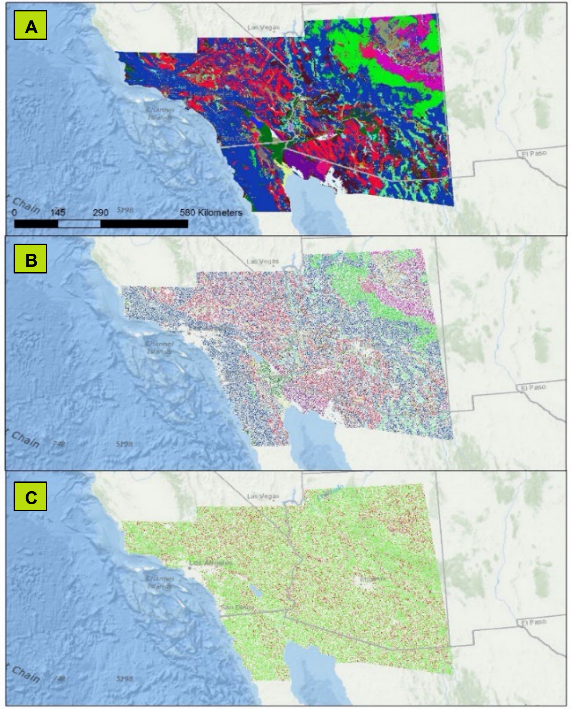
- A 3 year joint project between the US Army ERDC, US Air Force and the Met Office



Hand drawn map used to train and test a ML algorithm

- This high resolution emission potential is averaged to the model grid and compared to the model's idealized emissions to produce a correction factor.
- Dust emission is highly non-linear; small scale features can produce very large emissions.
- Previous maps (e.g. SW Asia and Middle East are difficult to make:
  - Meticulously hand drawn by trained analysts
  - Expensive / time consuming (~ £3M over 6+ years)
- Using a machine learning approach to generate these maps from a wide range of inputs, satellite imagery, topography etc. is scalable and aims to have a datasaet suitable for global dust modelling by completion of the project.

- Takes high resolution geomorphological landform maps and estimates an idealized 'dust emission potential'



Hand drawn map used to train and test a ML algorithm

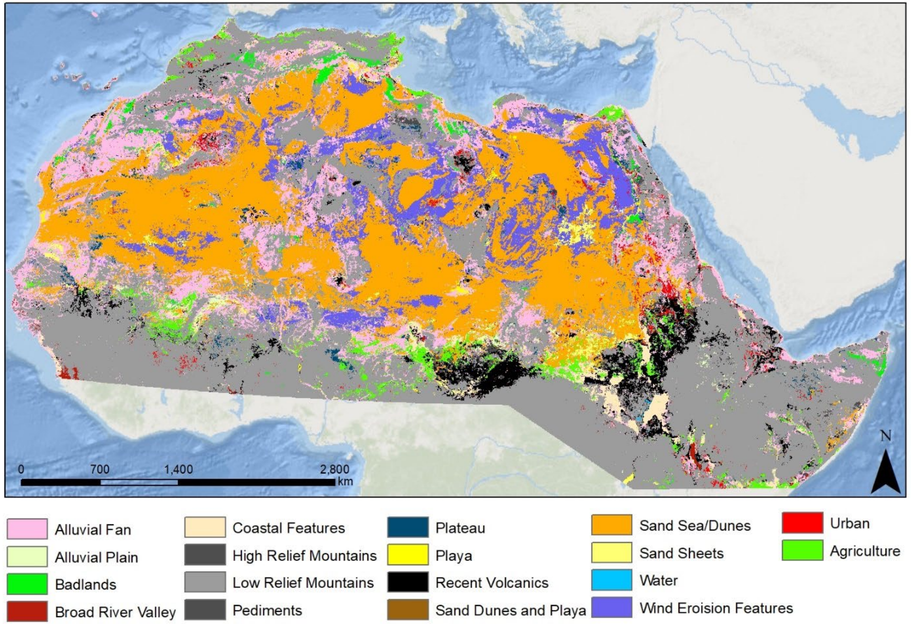
ML output for test points

ML - accuracy (green = correct)

GOAL: Better represent major high impact dust events

North Africa, Australia, Asia, mapped.

Project outputs so far

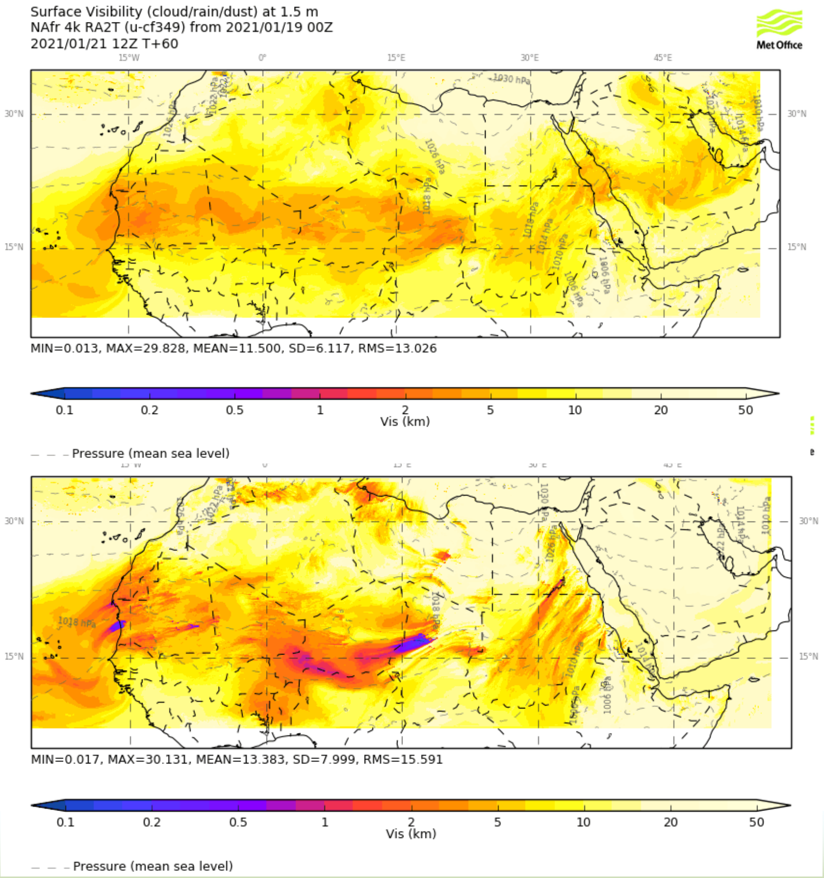


- Implementation and evaluation work is ongoing over North Africa on test cases.
- Maps for Australia and Asia are very new and modelling work about to commence on identified test cases.

- Dust source identification seem to handle salt crust formation well. The training data had these features identified by hand and the ML &multi-sensor approach seems to produce something sensible. In Australia we are trying to specify these as a seasonal climatology.
- ML approach gives diagnostics on what is important for the method: vegetation dominated channels are not very important, so it is likely to robust to future changes in vegetation cover in semi-arid regions.

North Africa, Australia, Asia, mapped.

Project outputs so far



- Modelling work is underway using these maps and being evaluated
- In this case we have visibility diagnostic maps from a 4km regional model over N. Africa showing standard control and test with ERDG-GEO
- On course to have a dataset for a global model by the end of 2023 or soon after, and implementation testing is already underway.

3. Next Generation modelling: from CLASSIC to UKCA

Anthony Jones, Adrian Hill

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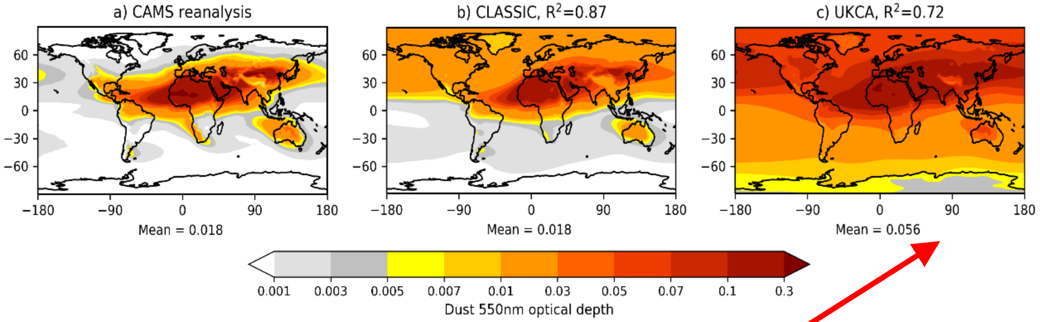
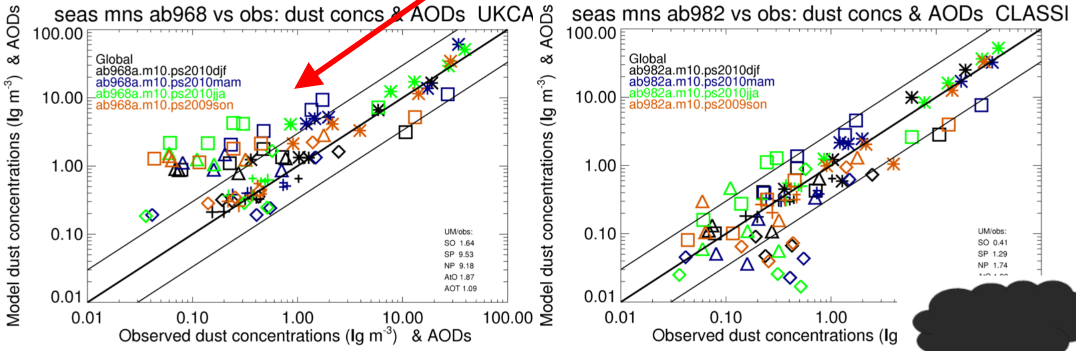
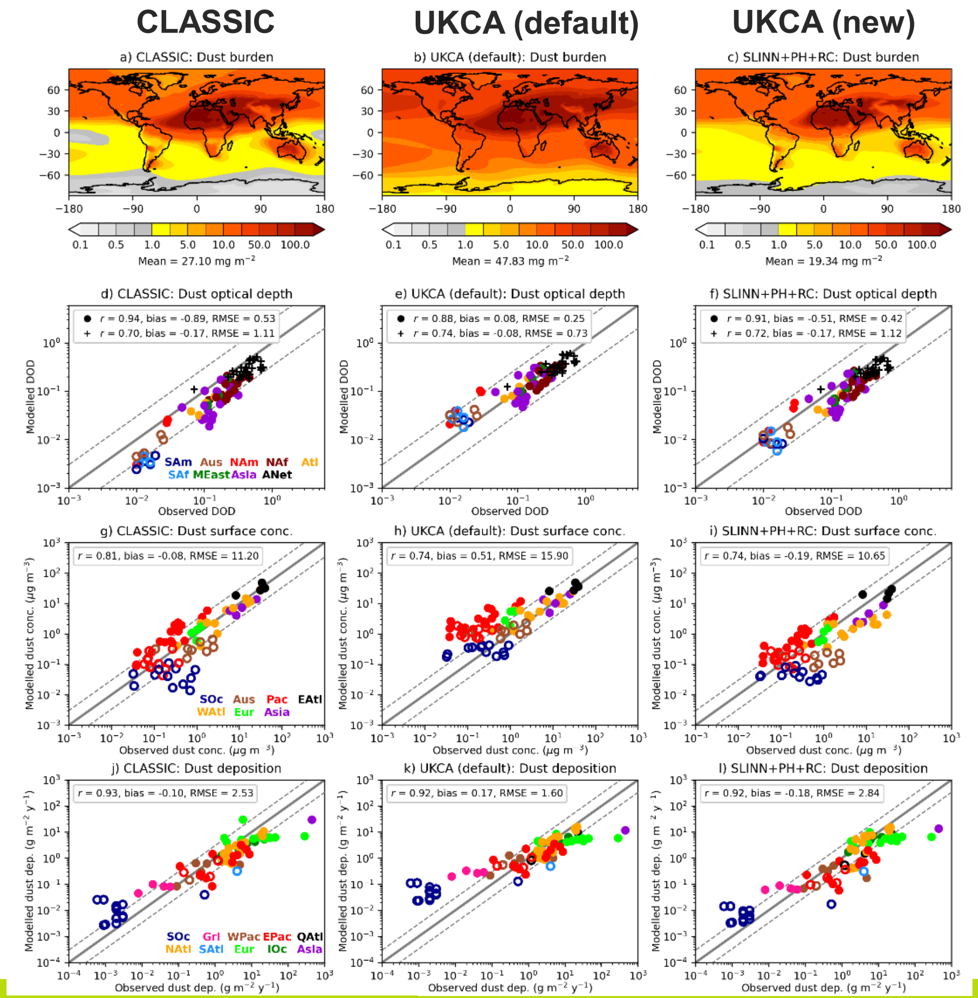
Improvements to UKCA dust
A new Below-Cloud Scavenging (BCS) scheme

- UK climate model has changed aerosol scheme (CLASSIC to UKCA)
- CLASSIC dust, currently the default in the UK climate model, has 6 bins and has high skill in simulating dust compared to obs
- UKCA dust (2 modes) travels too far from source regions
- UKCA dust bias could be due to the use of a single-moment below cloud scavenging (BCS) scheme
- Aim: improve BCS by liquid rain (no change to snow) by adding a double-moment scheme accounting for rain-rate and aerosol size properties



Too much dust in UKCA





Results compared to UKCA (default) and CLASSIC

- A significant improvement to simulated dust compared to UKCA (default) and now comparable to CLASSIC
- However, dust optical depth is worse near source regions possibly owning to missing dust mass associated with 6th bin
- Still deposition biases over Southern Ocean – too much dust emission in southern hemisphere?
- New scheme on the trunk since UM12.2 (ticket 6544) and available by setting l_dust_slinn_impc_scav = True

Figure 11 from Jones et al. (2022)
https://doi.org/10.5194/acp-22-11381-2022

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Summary: Ongoing work

- Maintain current assimilation system by preparing replacements for MODIS
- Port dust assimilation and forecasting/climate system to the next generation models
- Ongoing collaborative project to improve dust emissions in the forecast model

Summary: planned developments

Next Generation modelling:

- Continuing development of Next Generation modelling & data assimilation
  - E.g. developing the use of UKCA for NWP

Improved use of Observations:

- Making Suomi-NPP VIIRS AOD operational
- Testing new datasets for assimilation:
  - NOAA-20 VIIRS (NOAA or NASA product?)
  - Investigating use of infrared data e.g. SEVIRI 1D-Var retrievals, IASI MAPIR dust product

Improved forecasts:

- Ongoing testing/development of more realistic dust emission (aiming for operations 2025)
- Opportunities for all-aerosol modelling are being considered as the new system is being developed