Atmosphere Monitoring

ECMWF operational aerosol update

Zak Kipling

With thanks to: Mel Ades, Anna Agusti-Panareda, Jerome Barre, Angela Benedetti, Nicolas Boussarez, Alessio Bozzo, Richard Engelen, Johannes Flemming, Vincent Huijnen, Antje Inness, Mark Parrington, Luke Jones, Julie Letertre-Danczak, Mark Parrington, Vincent-Henri Peuch, Samuel Remy, Roberto Ribas.

ICAP workshop, 22–24 July 2019, Tsukuba, Japan

Copernicus Europe's eyes on Earth | European Commission | ECMWF

Overview of aerosol activities at ECMWF

Atmosphere Monitoring

CAMS

(Copernicus Atmosphere Monitoring Service)

Operational forecasting and reanalysis

Aerosol modelling
Zak Kipling

Data assimilation
Mel Ades, Antje Inness, Jerome Barre

Chemical modelling
Johannes Flemming

Emissions
Mark Parrington

Forecast Department
Juan-Jose Dominguez, Luke Jones, Miha Razinger, Roberto Ribas, Martin Suttie

Management
Richard Engelen, Vincent-Henri Peuch

+ external partners: Samuel Remy, …

Other aerosol research activities:

Aerosols in (sub-)seasonal weather forecasting

Aerosol Reflectance Assimilation Study (ARAS)

Aeolus/EarthCARE aerosol assimilation

FRAMES proposal: fires/biomass-burning aerosol

DACCIWA (dynamics/aerosol/chemistry/cloud)

EUNADICS-AV (volcanic aerosol & aviation)

ACTRIS-2

Angela Benedetti, Samuel Quesada Ruiz, Julie Letertre-Danczak

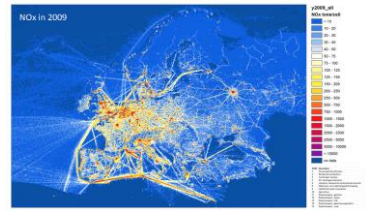
ECMWF Copernicus Europe's eyes on Earth European Commission

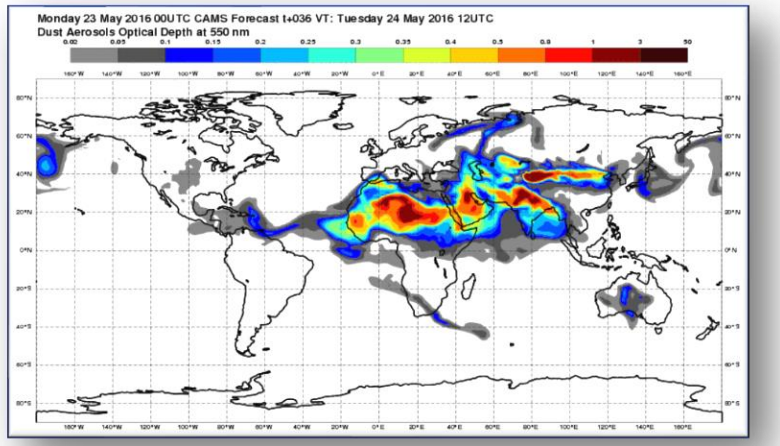
The CAMS system

Atmosphere Monitoring

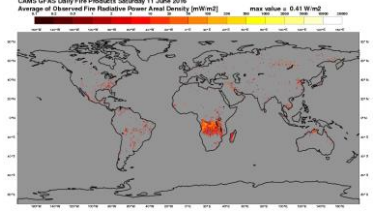
Observations

Anthropogenic emissions

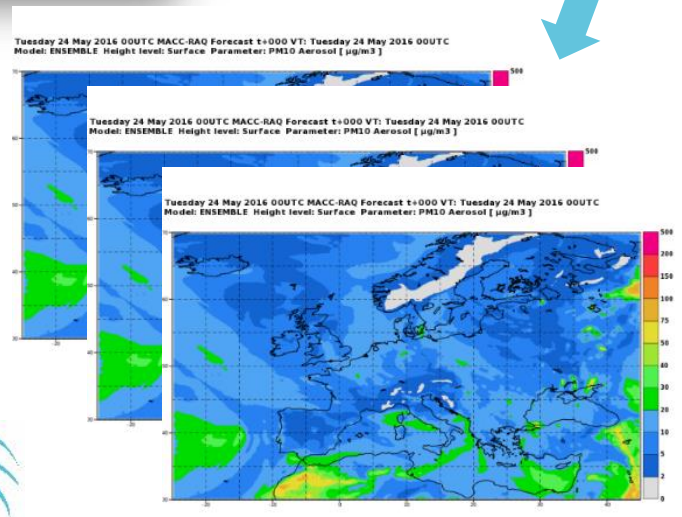




Global (ECMWF IFS)

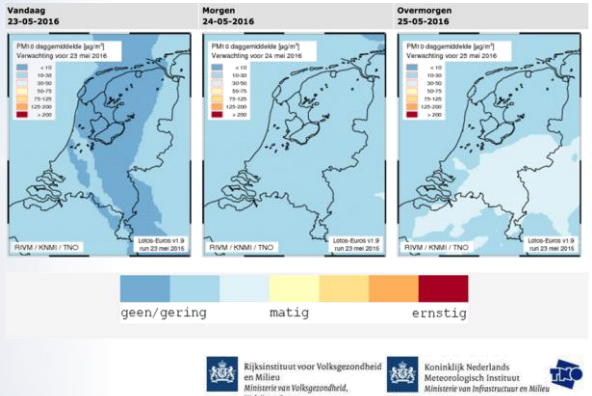


Fire emissions (GFAS)



Regional (multi-model ensemble)

National scale



Rijksinstituut voor Volksgezondheid en Milieu
Ministerie van Volksgezondheid, Welzijn en Sport

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

ECMWF Copernicus Europe's eyes on Earth

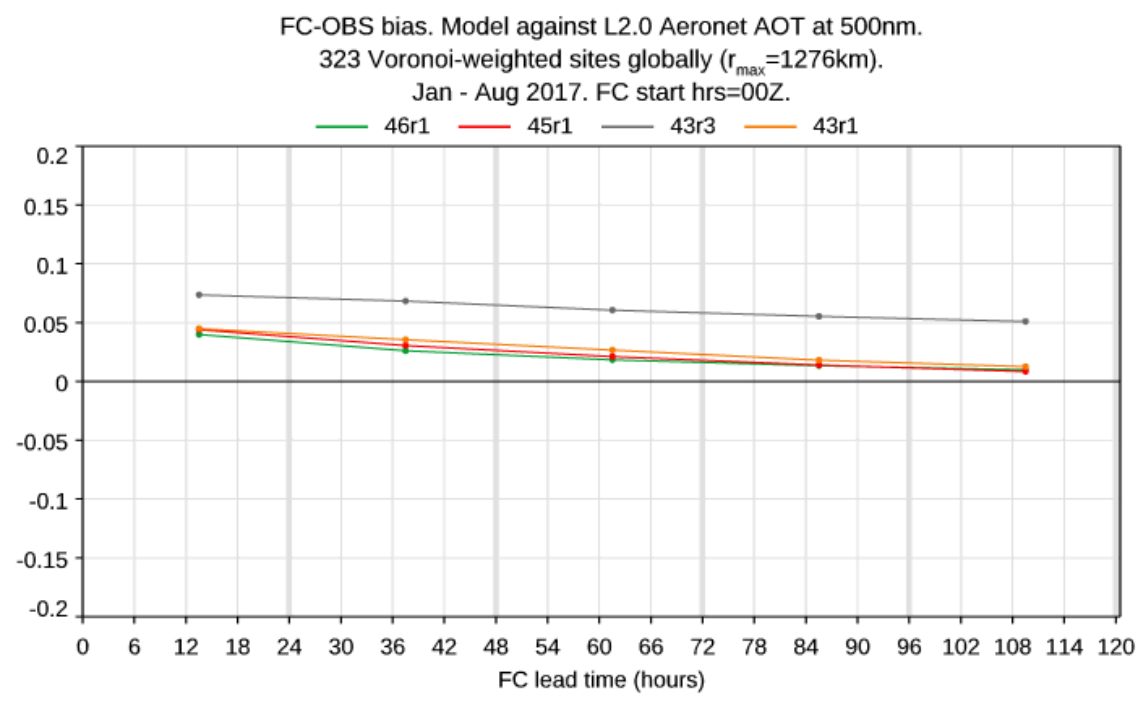
European Commission

Evolution of CAMS global system performance

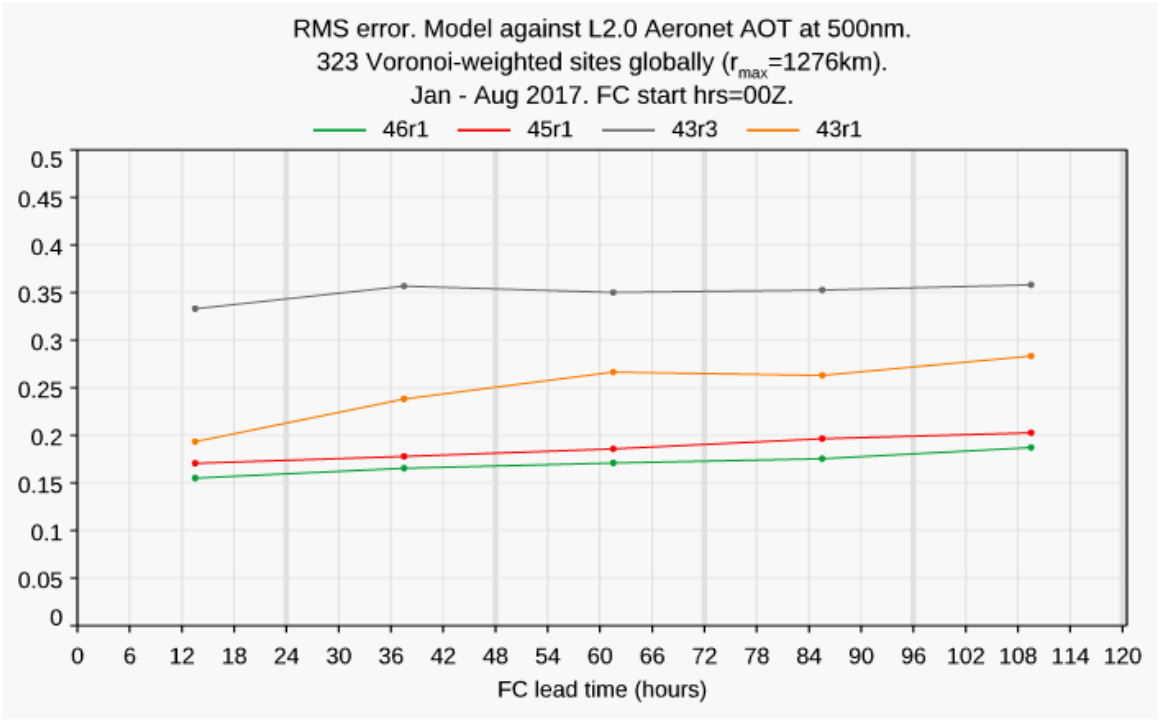
Atmosphere Monitoring

500nm AOD vs Aeronet (L2 V3)

Bias



RMSE



Jan–Aug 2017

AERONET verification tool: *Luke Jones*

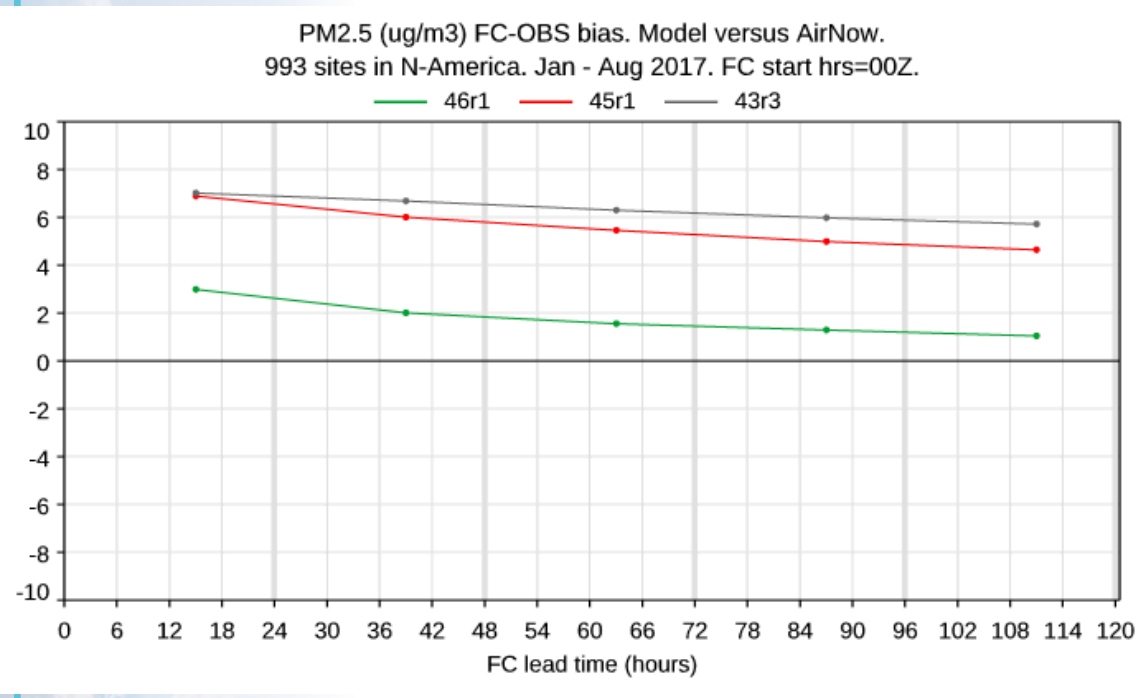
ECMWF Copernicus Europe's eyes on Earth European Commission

Evolution of CAMS global system performance

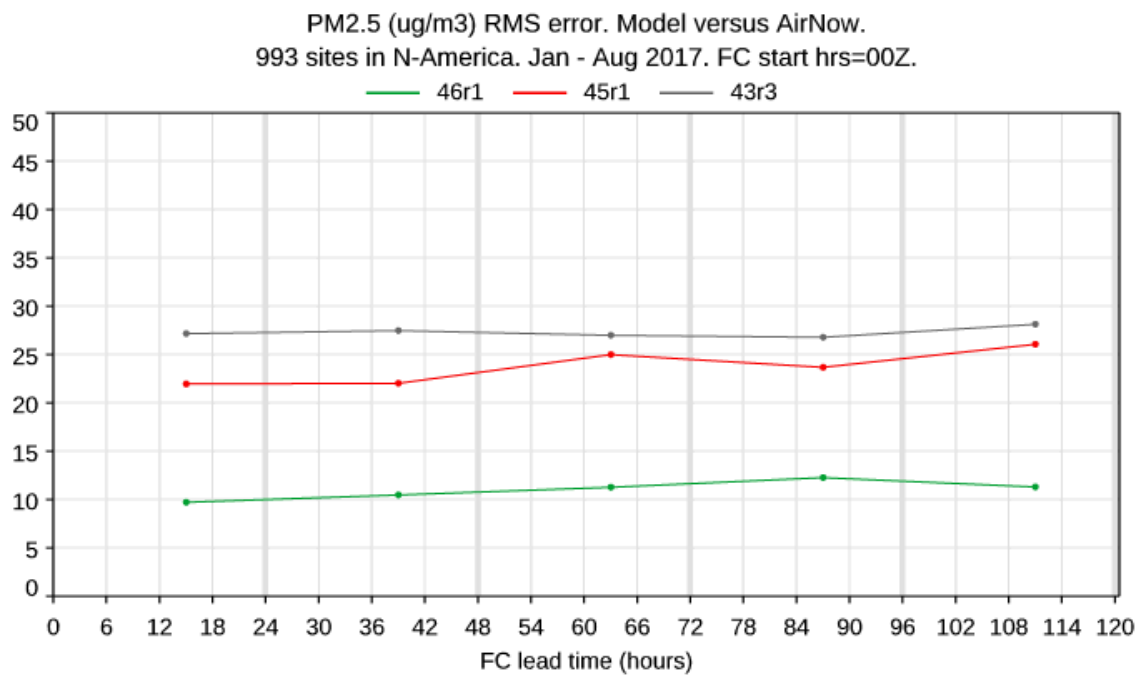
Atmosphere Monitoring

PM2.5 vs AirNow (North American stations, mostly in USA)

Bias



RMSE



Jan–Aug 2017

PM verification tool: *Luke Jones*

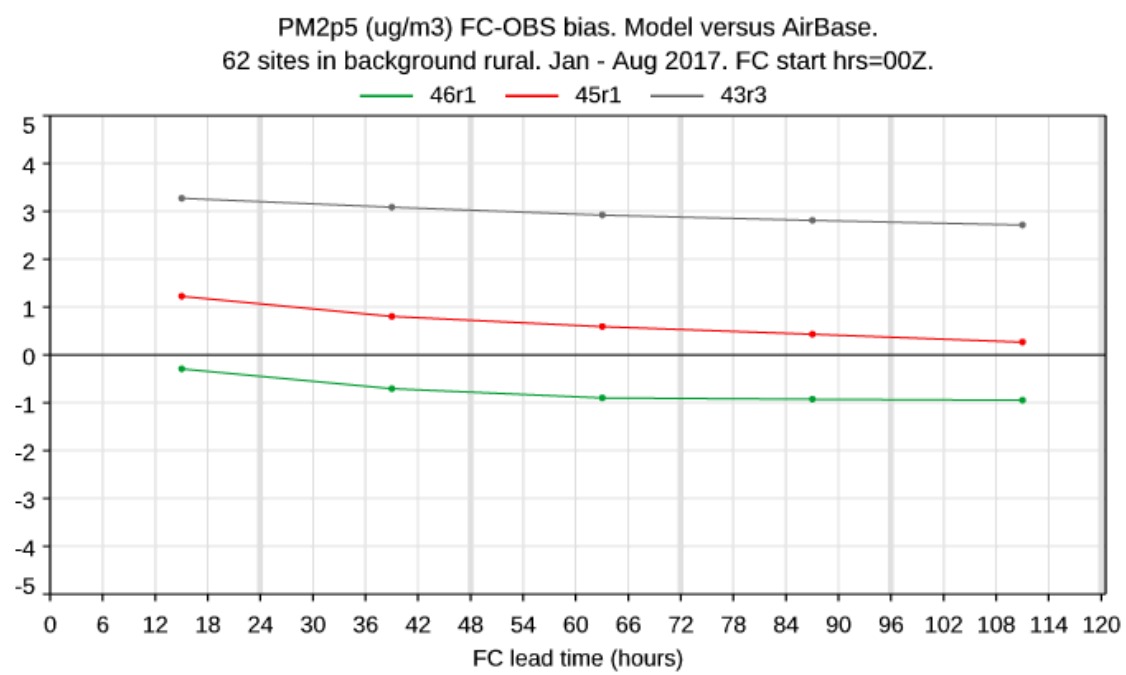
ECMWF Copernicus Europe's eyes on Earth European Commission

Evolution of CAMS global system performance

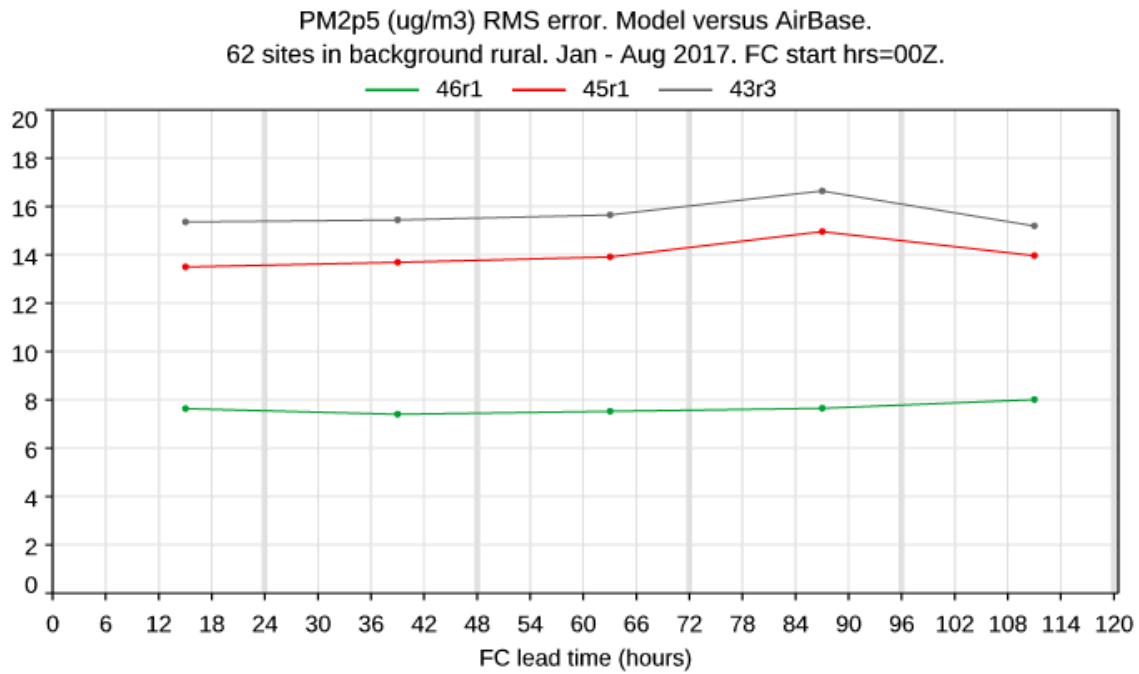
Atmosphere Monitoring

PM2.5 vs AirBase (European stations classified “background rural”)

Bias



RMSE



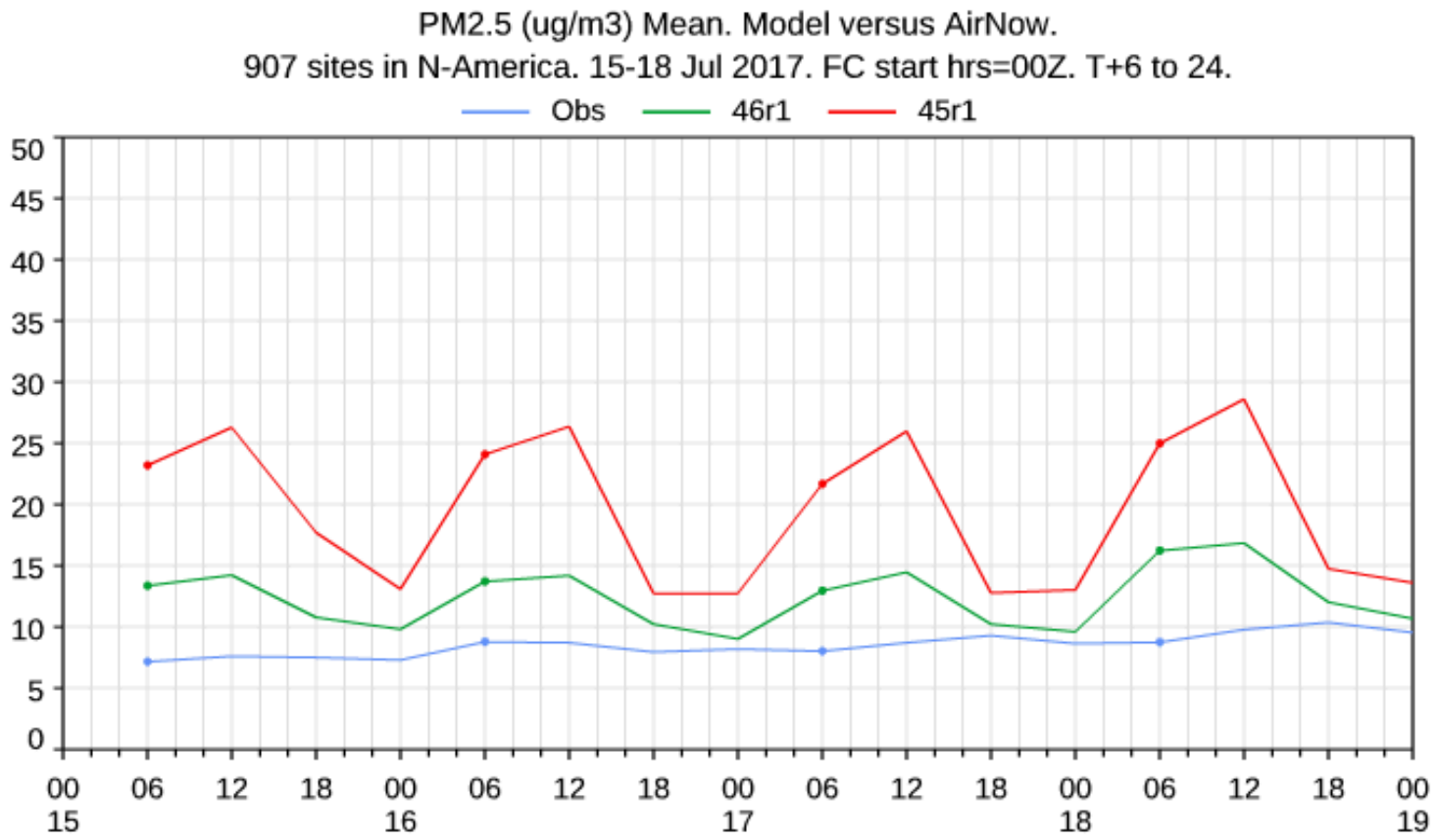
Jan–Aug 2017

PM verification tool: *Luke Jones*

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

Improvement in PM diurnal cycle



(Mostly related to OM, via changes to SOA production)

Atmosphere Monitoring

Changes in 46r1

- New nitrate and ammonium species
- Coupling with chemistry scheme
- Increased vertical resolution
- New prescribed emissions inventories
- New online dust emission scheme
- Emission diurnal cycles and injection heights

ECMWF Copernicus Europe's eyes on Earth European Commission

Coupling aerosol and chemistry: sulphate, nitrate and ammonium

Atmosphere Monitoring

Aerosol (LOA/LMD-Z)

SS_{small}	SS_{mid}	SS_{large}
DU_{small}	DU_{mid}	DU_{large}
OM_{hphob}	OM_{hphil}	
BC_{hphob}	BC_{hphil}	
SO_2	SO_4	
$NO_{3\ fine}$	$NO_{3\ coarse}$	NH_4

Chemistry (CB05)

O_3	NO_x	H_2O_2	CH_4	CO	HNO_3
CH_3OOH	CH_2O	PAR	C_2H_4	OLE	ALD_2
PAN	ROOH	ONIT	C_5H_8	SO_2	DMS
NH_3	SO_4	NH_4	MSA	CH_3COCHO	$O_{3\ (strat)}$
Rn	Pb	NO	HO_2	CH_3O_2	OH
NO_2	NO_3	N_2O_5	HO_2NO_2	C_2O_3	ROR
RXPAR	XO_2	XO_2N	NH_2	CH_3OH	HCOOH
MCOOH	C_2H_6	C_2H_5OH	C_3H_8	C_3H_6	C_10H_16
ISPD	$NO_{3\ (aerosol)}$	CH_3COCH_3	ACO_2	$IC_3H_7O_2$	$HYPROPO_2$
NO_xA	PSC				

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

Coupling aerosol and chemistry: sulphate, nitrate and ammonium

Aerosol (LOA/LMD-Z)

SS_{small}	SS_{mid}	SS_{large}
DU_{small}	DU_{mid}	DU_{large}
OM_{hphob}	OM_{hphil}	
BC_{hphob}	BC_{hphil}	
SO_2 →	SO_4	
$NO_{3\ fine}$	$NO_{3\ coarse}$	NH_4

Chemistry (CB05)

O_3	NO_x	H_2O_2	CH_4	CO	HNO_3
CH_3OOH	CH_2O	PAR	C_2H_4	OLE	ALD_2
PAN	ROOH	ONIT	C_5H_8	SO_2	DMS
NH_3	SO_4	NH_4	MSA	CH_3COCHO	$O_{3\ (strat)}$
Rn	Pb	NO	HO_2	CH_3O_2	OH
NO_2	NO_3	N_2O_5	HO_2NO_2	C_2O_3	ROR
RXPAR	XO_2	XO_2N	NH_2	CH_3OH	HCOOH
MCOOH	C_2H_6	C_2H_5OH	C_3H_8	C_3H_6	C_10H_16
ISPD	$NO_{3\ (aerosol)}$	CH_3COCH_3	ACO_2	$IC_3H_7O_2$	$HYPROPO_2$
NO_xA	PSC				

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

Coupling aerosol and chemistry: sulphate, nitrate and ammonium

Aerosol (LOA/LMD-Z)

SS_{small}	SS_{mid}	SS_{large}
DU_{small}	DU_{mid}	DU_{large}
OM_{hphob}	OM_{hphil}	
BC_{hphob}	BC_{hphil}	
SO_2	SO_4	
$NO_{3\ fine}$	$NO_{3\ coarse}$	NH_4

Chemistry (CB05)

O_3	NO_x	H_2O_2	CH_4	CO	HNO_3
CH_3OOH	CH_2O	PAR	C_2H_4	OLE	ALD_2
PAN	ROOH	ONIT	C_5H_8	SO_2	DMS
NH_3	SO_4	NH_4	MSA	CH_3COCHO	$O_{3\ (strat)}$
Rn	Pb	NO	HO_2	CH_3O_2	OH
NO_2	NO_3	N_2O_5	HO_2NO_2	C_2O_3	ROR
RXPAR	XO_2	XO_2N	NH_2	CH_3OH	HCOOH
MCOOH	C_2H_6	C_2H_5OH	C_3H_8	C_3H_6	C_10H_16
ISPD	$NO_{3\ (aerosol)}$	CH_3COCH_3	ACO_2	$IC_3H_7O_2$	$HYPROPO_2$
NO_xA	PSC				

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

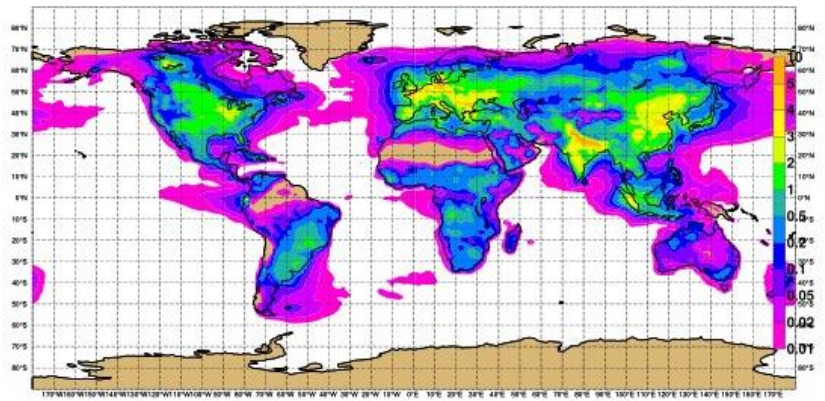
Recap: Introducing nitrate and ammonium aerosol (Hauglustaine et al., 2014)

- Three new aerosol bins:
  - Fine mode nitrate, partitioned with gas phase: $HNO_3 + NH_3 \leftrightarrow NH_4NO_3$.
  - Coarse mode nitrate from heterogeneous reactions of HNO_3 over calcite (dust) and sea-salt particles: $HNO_3 + NaCl \rightarrow NaNO_3 + HCl$,
  - Ammonium $2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + H_2CO_3$.

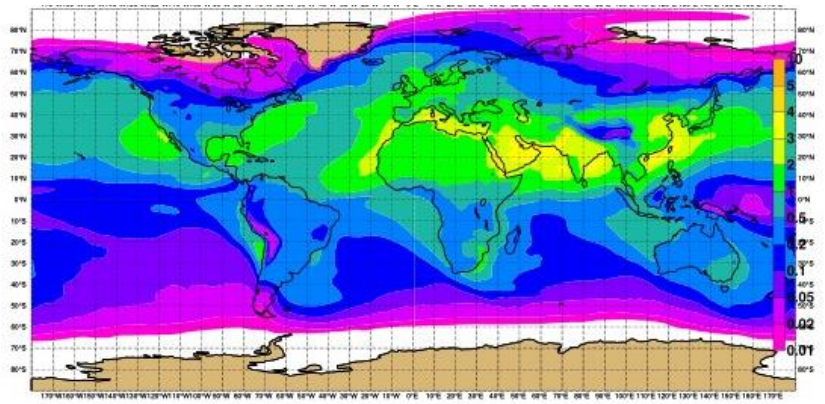
- Improved PM and AOD scores over Europe, especially when combined with coupled sulphur cycle.

Samuel Remy

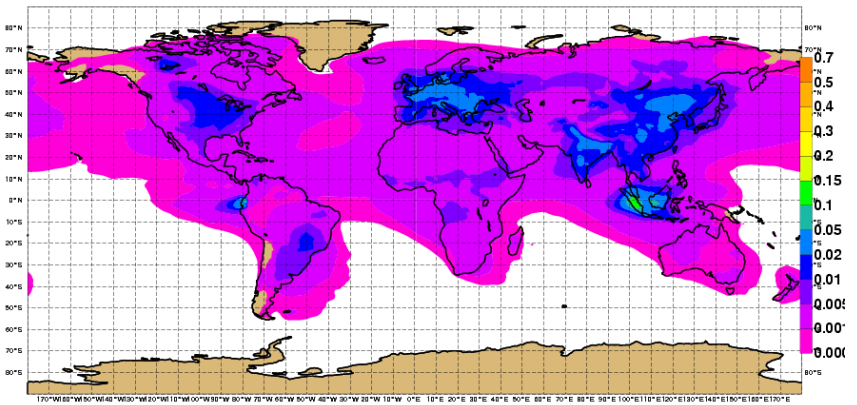
Fine NO_3^- concentration



Coarse NO_3^- concentration



Nitrate AOD



Atmosphere Monitoring

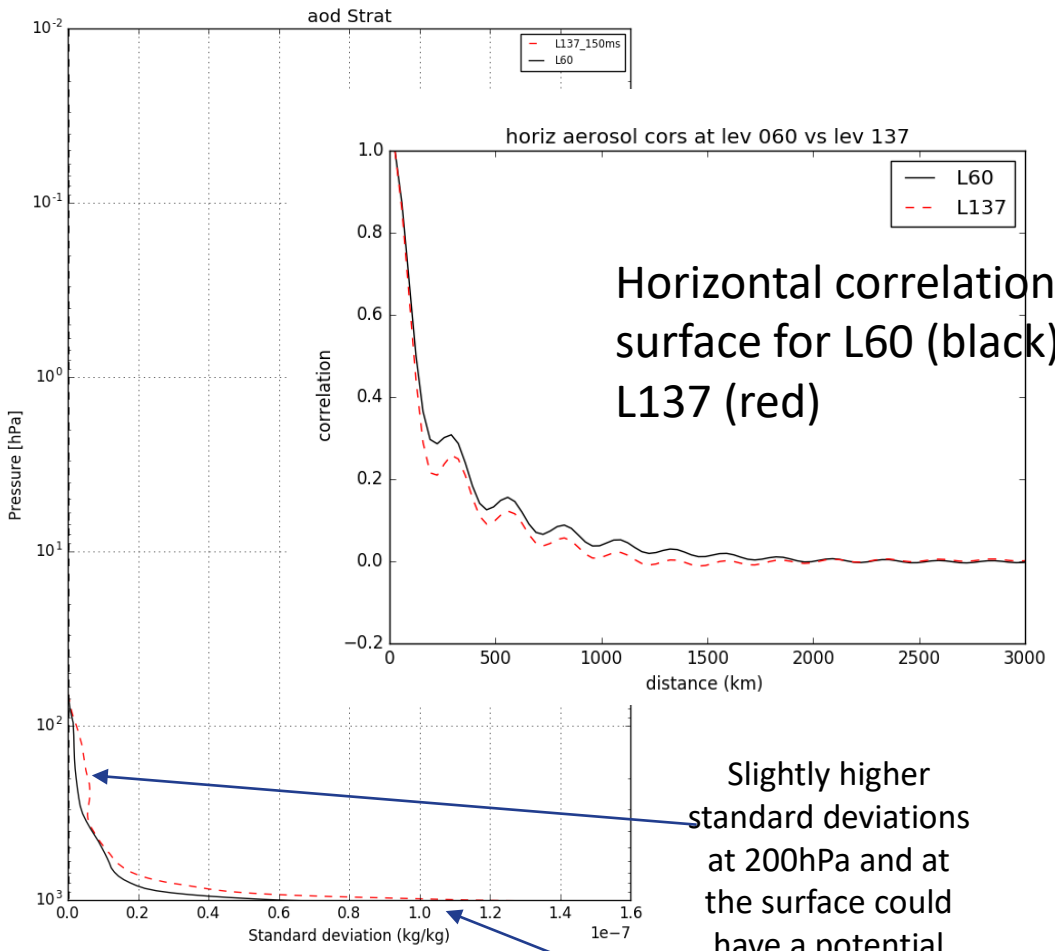
Increased vertical resolution

- Increased from 60 to 137 hybrid model levels
- Model top raised from 10 Pa to 1 Pa
- Brings CAMS into line with ECMWF NWP
- New $\boldsymbol{J}_B$ (model error covariance) matrix generated by NMC method
- More impact for chemistry than aerosol

ECMWF Copernicus Europe's eyes on Earth European Commission

Assimilation on 137 levels: new J_B matrix

Atmosphere Monitoring

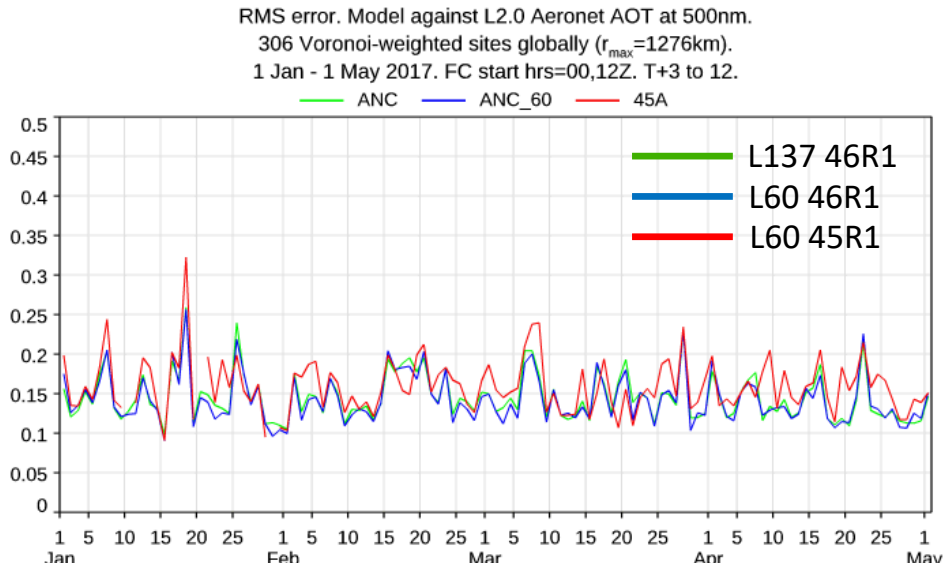


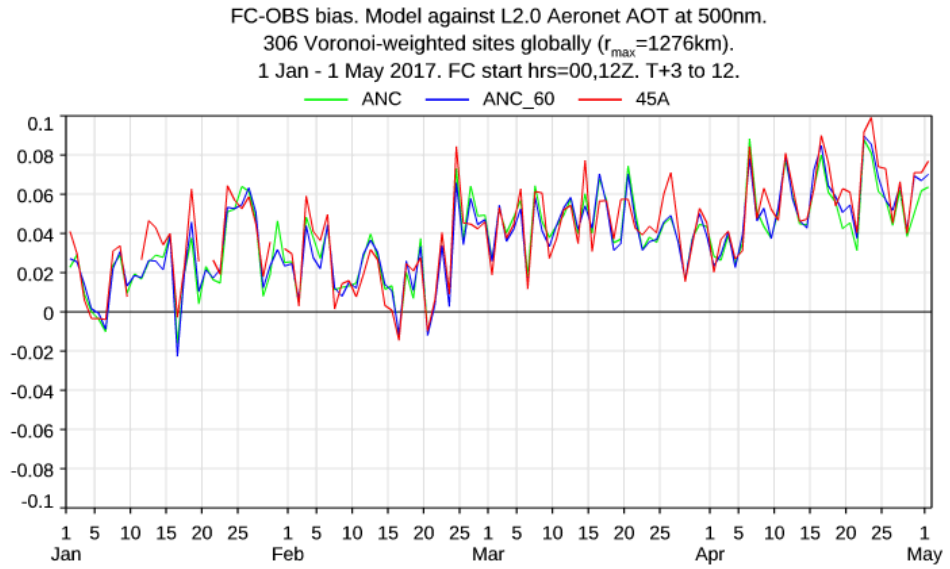
Horizontal correlations at the surface for L60 (black) and L137 (red)

Slightly higher standard deviations at 200hPa and at the surface could have a potential impact but verification results don't show any issues.

Standard deviations over pressure levels for L60 (black) and L137 (red)

Verification results against L2 Aeronet





ECMWF Copernicus Europe's eyes on Earth — European Commission

Mel Ades

New emissions inventories

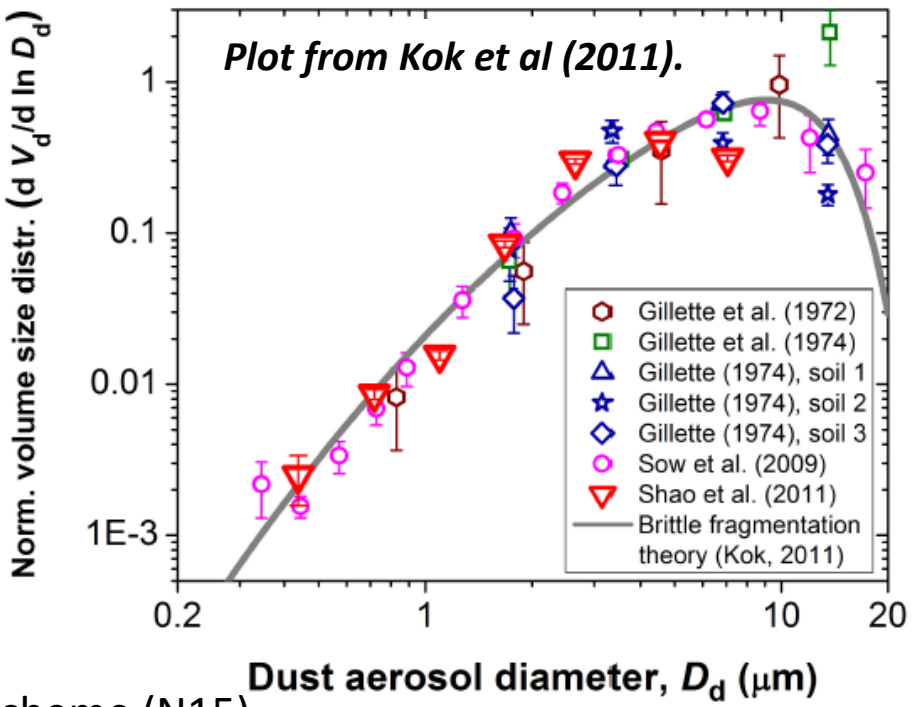
- New inventories for anthropogenic and biogenic emissions (CAMS_GLOB_ANT v2.1, CAMS_GLOB_BIO v1.1)

- Customised anthropogenic SOA “emission” dataset based on regionally-tuned scaling of CO emissions (replaces existing fixed scaling).
  - ***This is a large contributor to the reduced PM2.5 RMSE***

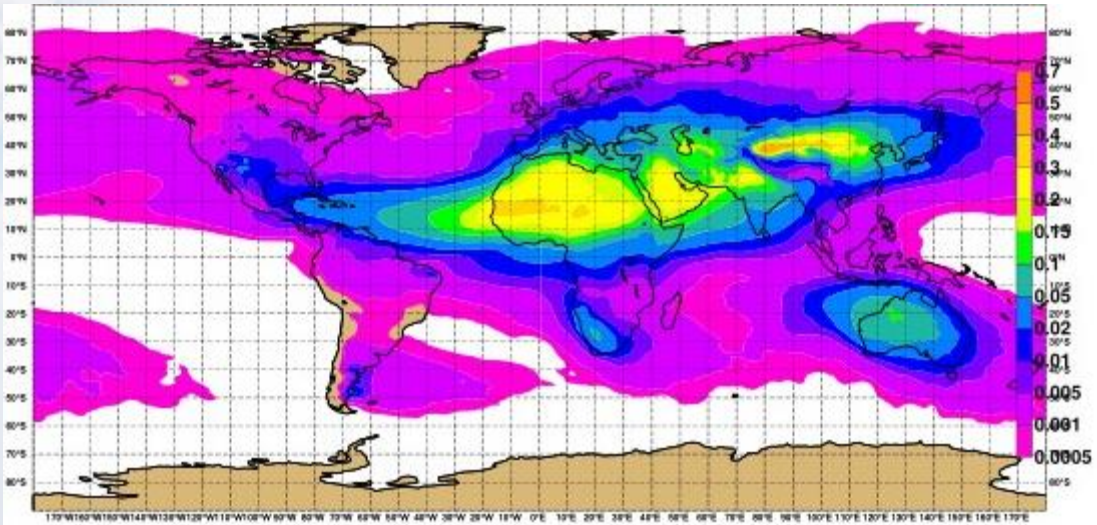
Atmosphere Monitoring

Recap: new dust scheme: Nabat et al. (2015)

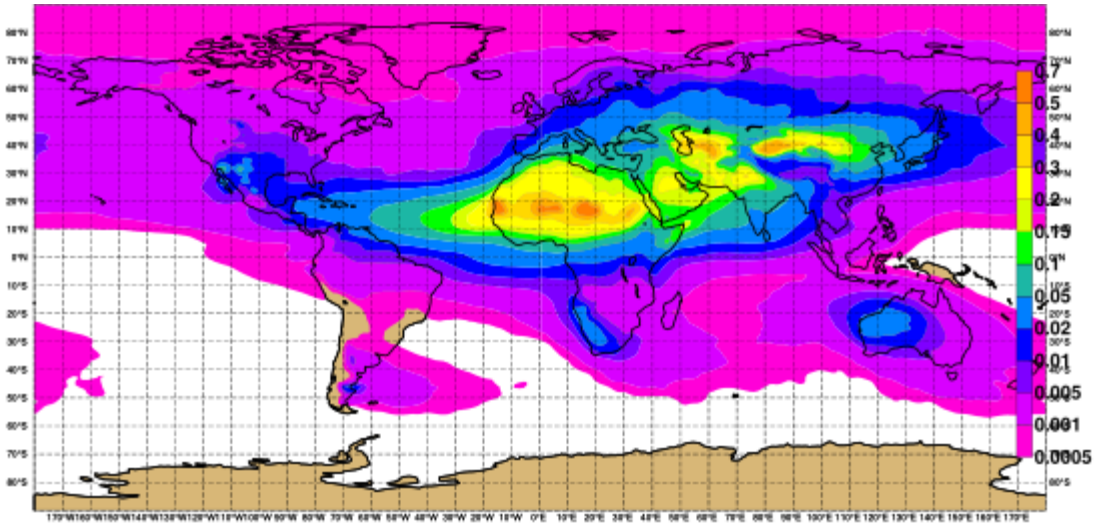
- Replaces older Ginoux et al. (2001).
- Marticorena and Bergametti (1995) saltation
- Kok et al. (2011) size distribution at emission
- Sand and clay fraction from SURFEX (Météo-Fr)
  (recently updated)
- 4-fold increase in super-coarse particles
- Greater total emissions
  - Possibly now *TOO* high…



Old scheme (G01)



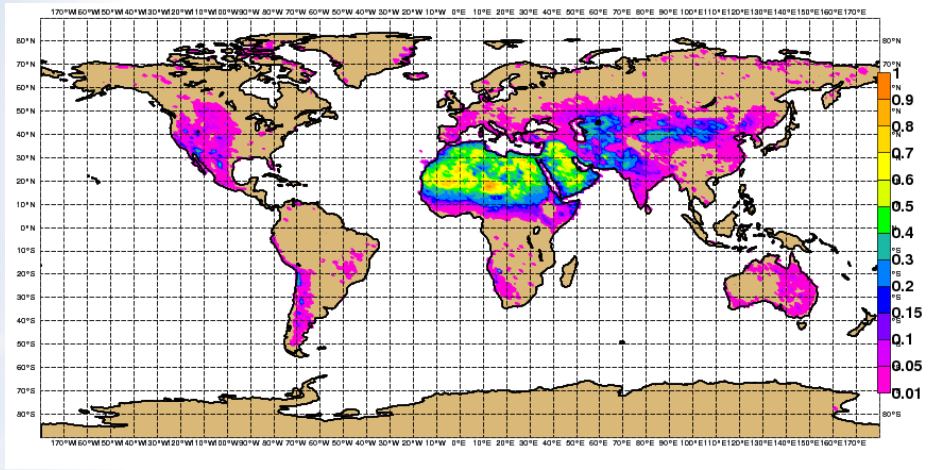
New scheme (N15)



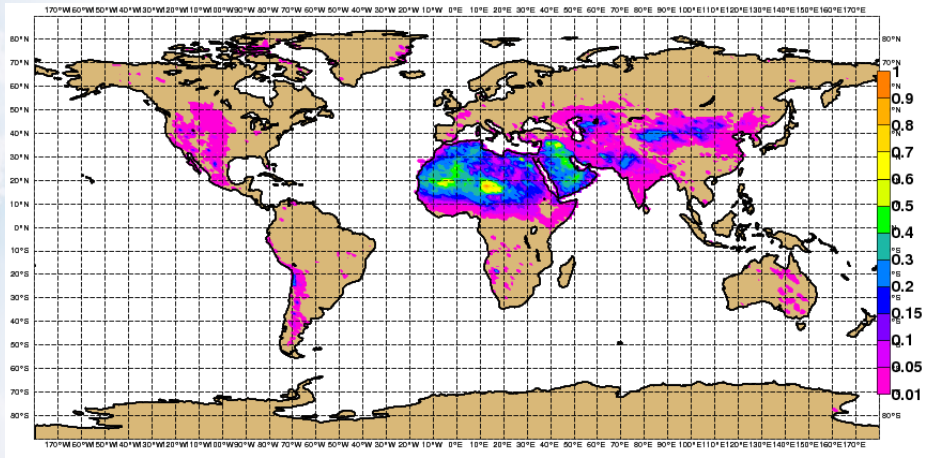
Recap: Dust Source Function

Atmosphere Monitoring

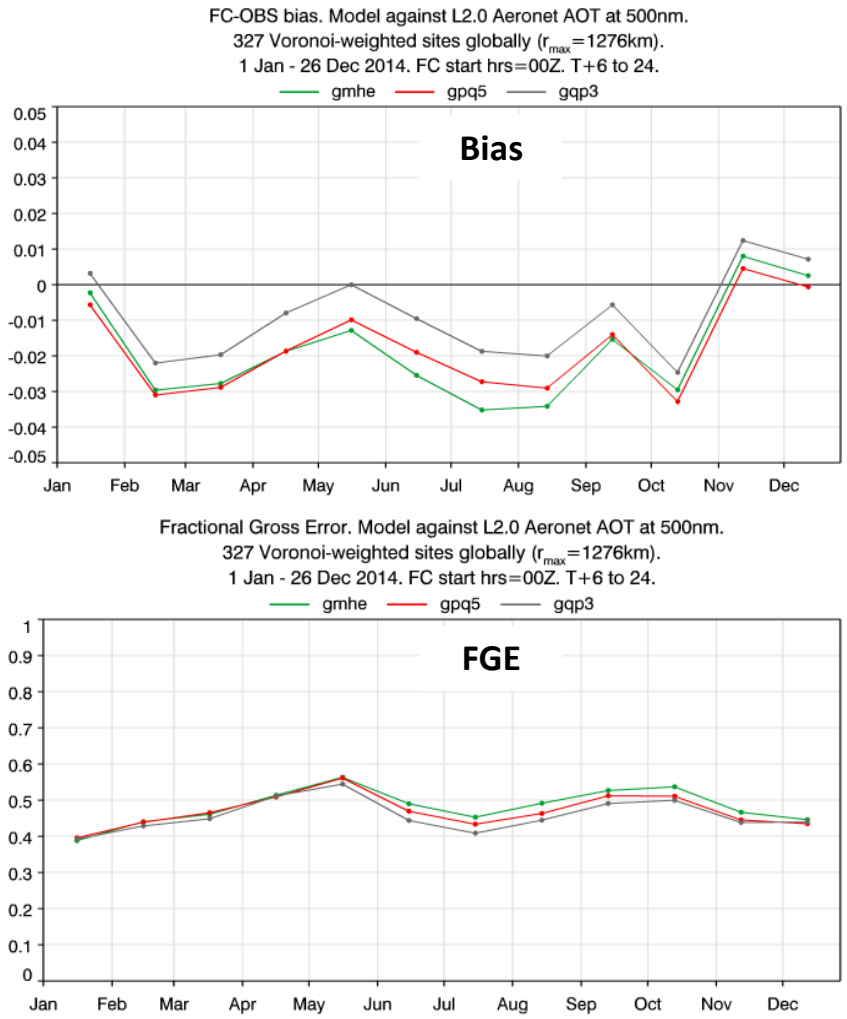
Freq (DOD > 0.2)



Freq (DOD > 0.4)



— Ref (43r1, G01) — N15+DSF — N15+DSF+largebins



DSF based on AquaMODIS DOD 2003–14 (P. Ginoux) to replace empirical local dust emission criteria

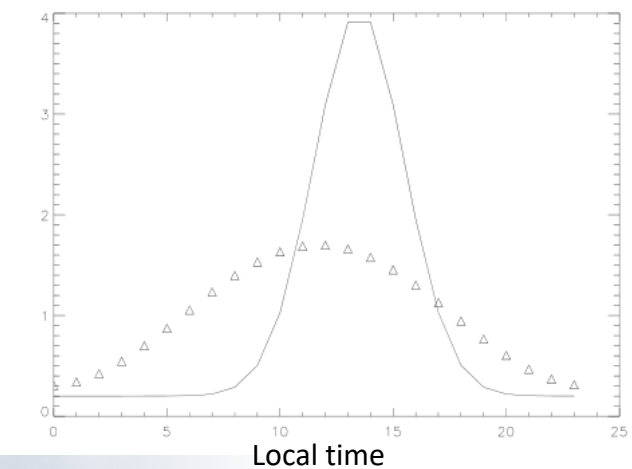
- *May need adjusting to reduce excesses*

Samuel Remy

ECMWF Copernicus Europe's eyes on Earth European Commission

Emission diurnal cycle and injection heights

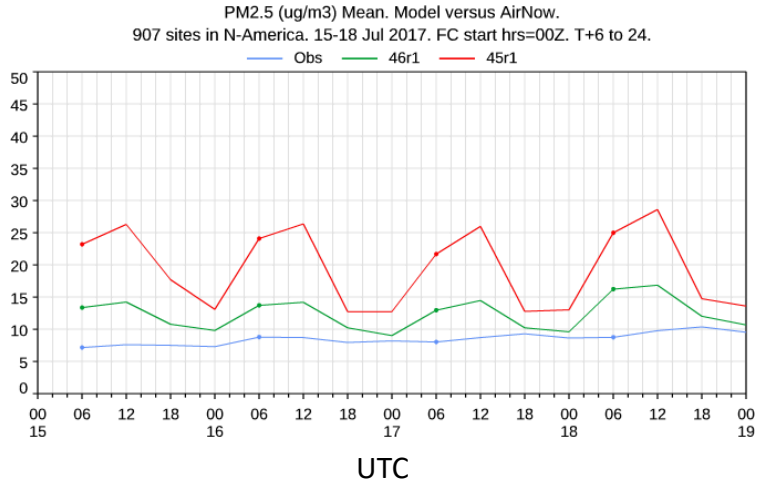
- Biomass-burning diurnal cycle brought in line with GFAS assumptions
- Biomass-burning injection heights from GFAS rather than at surface
  - Major contribution to improved PM in fire episodes
- SOA production diurnal cycle narrowed to eliminate night-time peaks
  - Major contribution to improved PM in polluted areas



Local time

Triangles: old SOA diurnal cycle
Line: GFAS diurnal cycle
(new SOA cycle is same but centred at noon)

PM diurnal cycle improvement compared to previous cycle



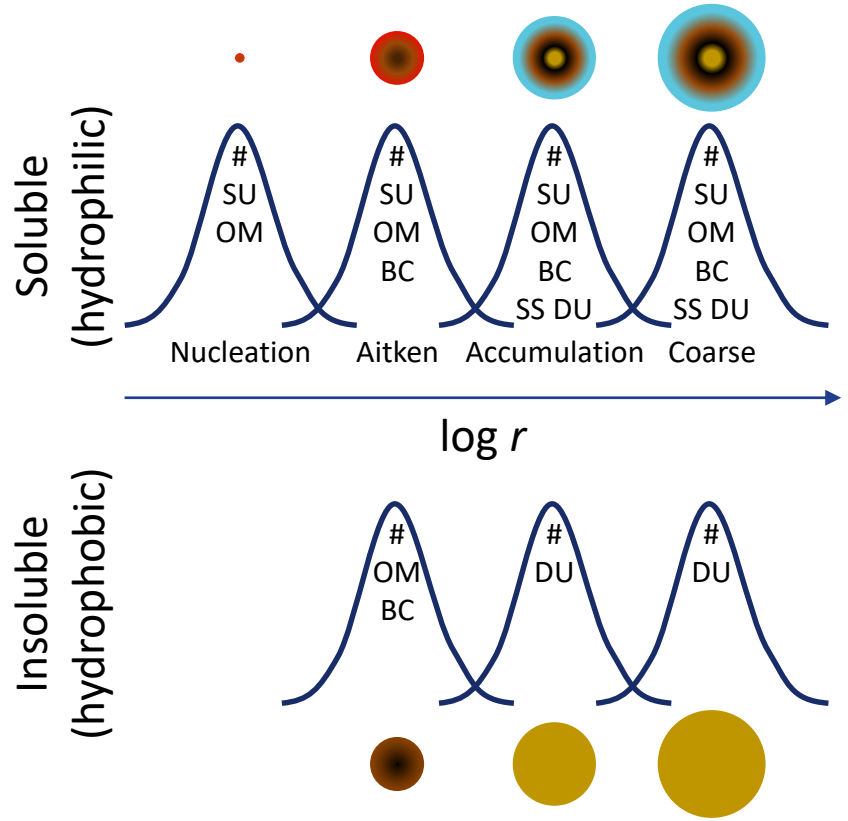
UTC

In development: IFS–GLOMAP

- GLOMAP-mode (Mann et el., 2010) introduced as alternative aerosol scheme in 46r1, based on work begun by Matt Woodhouse under MACC.

- Two-moment modal scheme combining M7-like size modes with microphysical parameterisations from GLOMAP-bin (Spracklen et al., 2005).

- Coupled with whole atmosphere chemistry as “IFS-CB05-BASCOE-GLOMAP”.



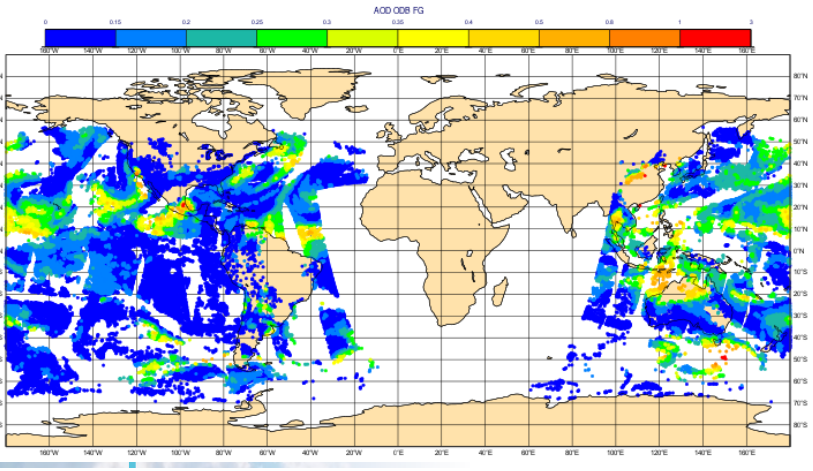
In development: IFS–GLOMAP assimilation

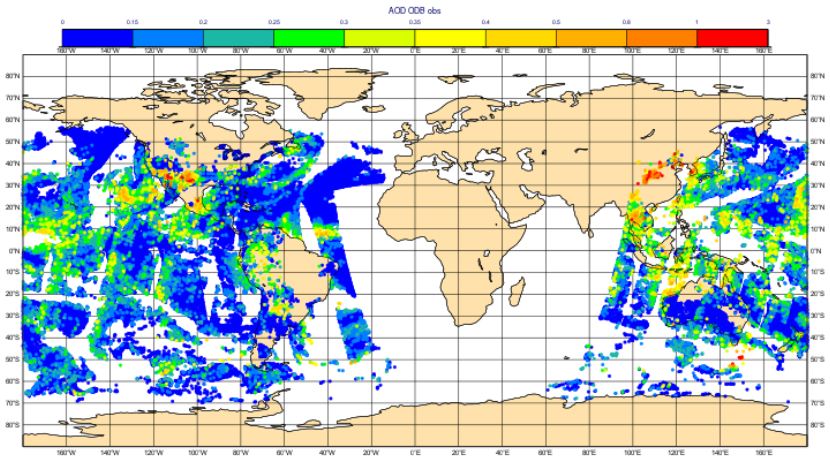
Atmosphere Monitoring

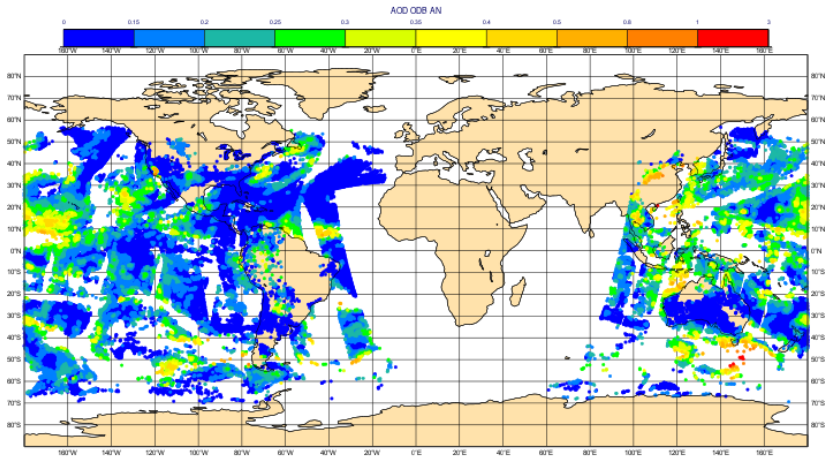
First Guess

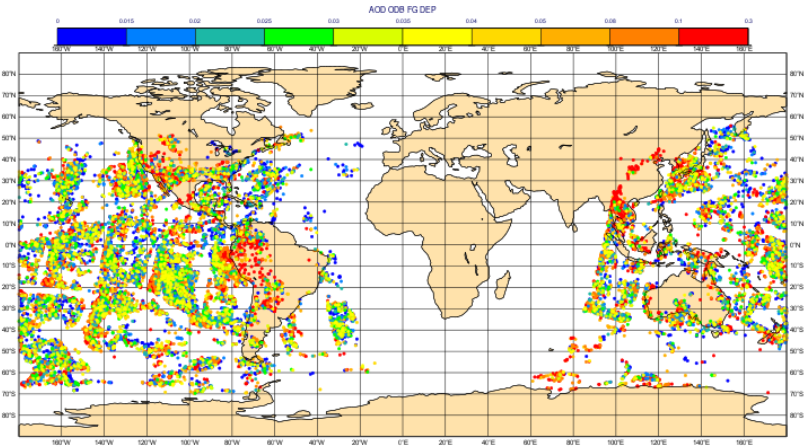
Observations

Analysis



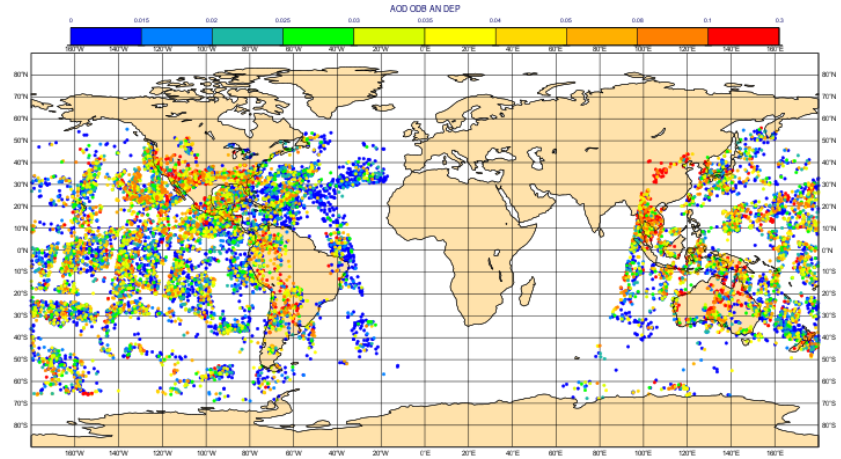






First Guess departures

The top left plot shows the first guess equivalent to the observations in the centre and the top right shows the analysis. The bottom row shows the difference between the first guess and the observations and the analysis and the observations. As you would hope the analysis shows a better match to the observations than the first guess, so the data assimilation is performing as expected.



Analysis departures

ECMWF Copernicus Europe's eyes on Earth European Commission

Mel Ades

Atmosphere Monitoring

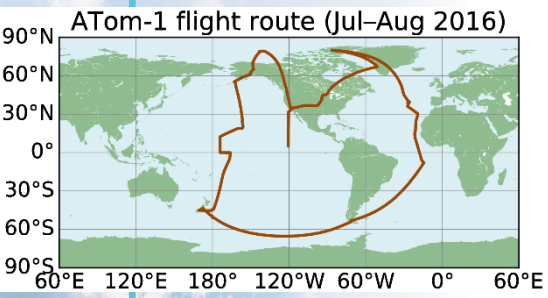
Developing evaluation strategy

- Move to AERONET v3 brings greater consistency between L1.5 and L2
- More emphasis on surface PM10 and PM2.5 in addition to AOD
- Use of flight campaigns (e.g. ATom) for 3D evaluation
- Use of CASTNET in-situ measurements

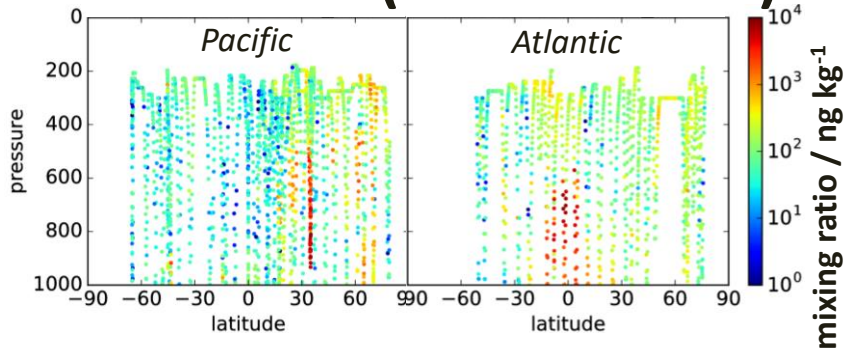
ECMWF Copernicus Europe's eyes on Earth European Commission

New evaluation approaches: large-scale flight campaigns

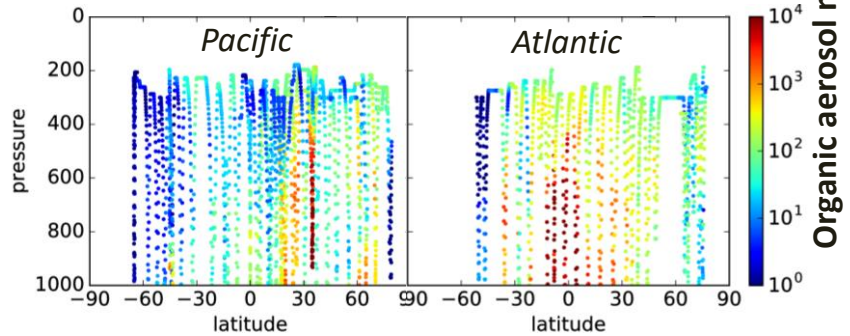
Atmosphere Monitoring



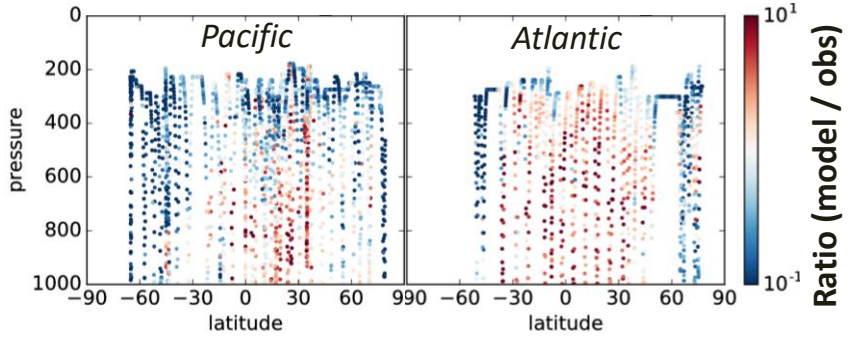
ATom-1 obs (HR-ToF-AMS)



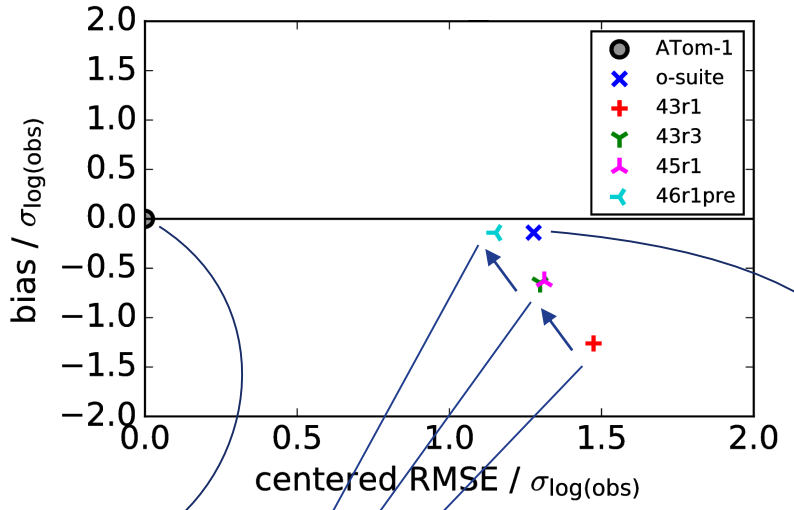
IFS 45r1



IFS 45r1 / obs



Normalised bias & RMSE of log(*OM MMR*) across IFS cycles



A perfect match would sit here

o-suite at this time was older (41r1), and also assimilating MODIS AOD

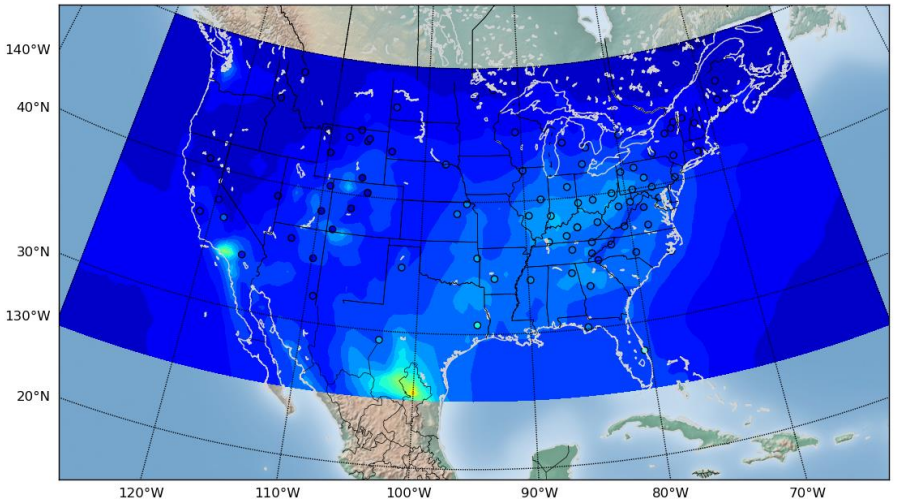
Improving from 43r1 to 46r1 in fc-only mode

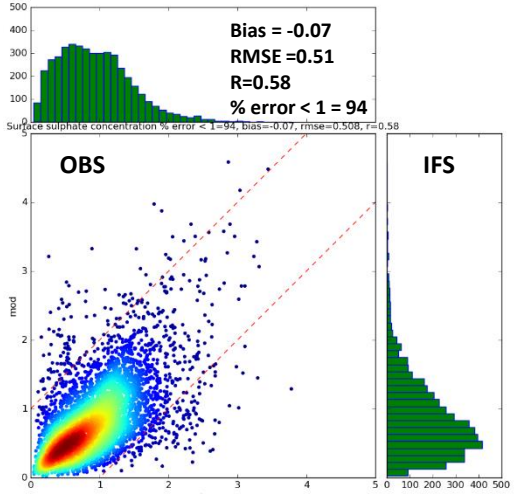
ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

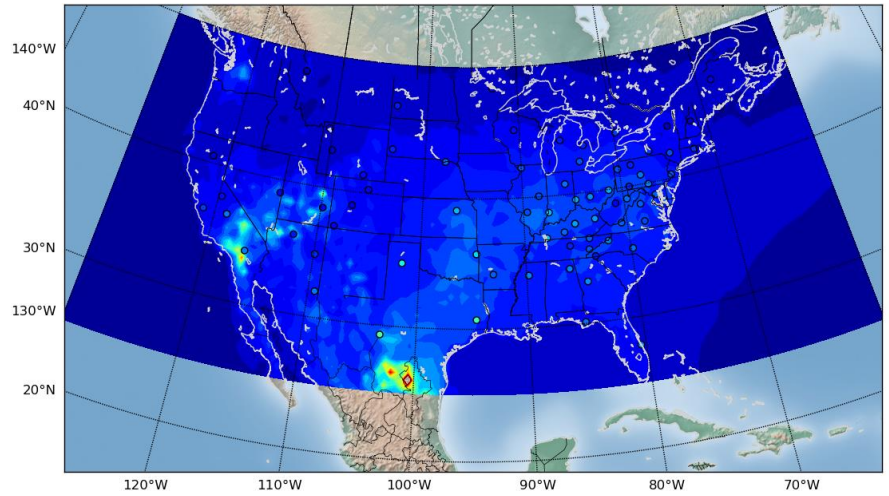
Use of CASTNET ground-based in-situ observations

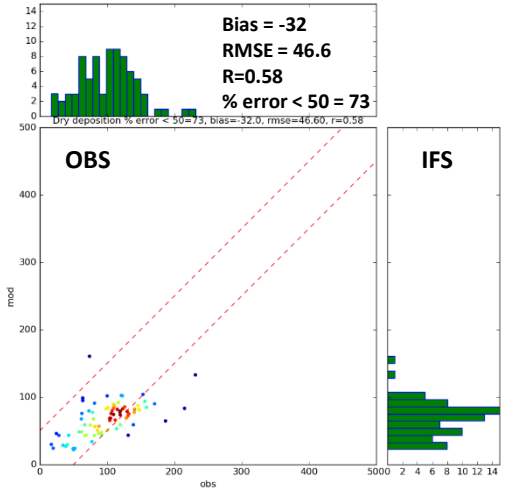
Sulphate concentrations





Sulphate dry deposition fluxes





ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

For the future

- Precursor-driven SOA
- Sea-salt coupling to wave model
- Brown carbon
- More evaluation of speciation, deposition and absorption

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

And now…

… over to Julie!

ECMWF Copernicus Europe's eyes on Earth European Commission