Dust forecasting at the Met Office – recent developments

Yaswant Pradhan Satellite Applications Malcolm Brooks Global Modelling

6th ICAP meeting, NCAR, Boulder. 21-24 Oct 2014.

More on Wednesday...

- 11:00 am (call-in): Marion's talk on “Current Operational Verification Practices”

- 05:30 pm onwards: Jane's poster on “Impacts of Increasing Aerosol Complexity in the Met Office Global NWP Model”

Recap - Evolution of dust forecasting in the Met Office NWP system

	Mar 2010	Jul 2011	Apr 2013	PS34	PS35
Area	LAM (SAM)	Global	Global (cut-outs for LAMs)	Global	Global
Resolution	12 km	25 km	25 km (GA3.1)	17/33 km (Gl/ MOGREPS-G)	⏪ +GA6.1
FC lead to	6 days	6 days	6 days	6/7 days	⏪
Dust scheme	• 6-bin (spectral) after *Woodward (2001)* • advection and (wet + dry) deposition • direct radiative effect	• 2-bin (0.1-2, 2-10um) version after *Woodward (2001, 2011)* • advection and deposition • no interaction with radiation (prescribed DOD climatology)	⏪	⏪	⏪ +interactive dust (direct)
DA	• *3D-Var (Benedetti 2009)* • *Obs: MSGAOD over land (Brindley & Russell 2009)* • *Obs var: AOD* • *Ctrl var: Dust MMR*	No dust assimilation	• 4D-Var (*Rawlins, 2007*) • Obs: MODIS/Aqua over land • Obs var: AOD • Ctrl var: Dust MMR	⏪	⏪ +MODIS/Aqua over ocean

Progress since 5th ICAP

1. Model changes - impacts

2. Observation changes

3. DA trials
   - One season (Summer 2013, 38.5 days) with different configurations
   - Verification
   - Impact on NWP

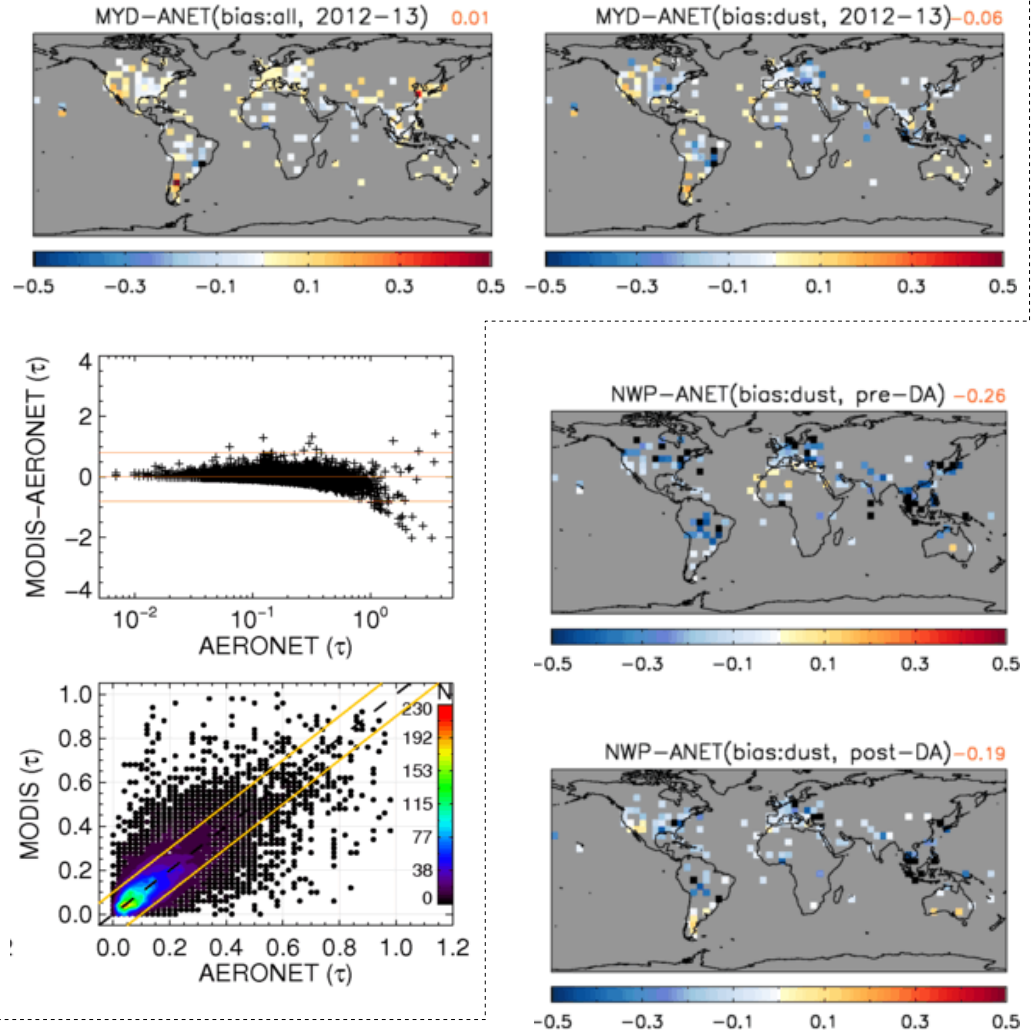
4. Future plan

1. Model changes (D. Walters)

- Major changes in model physics and dynamical core (ENDGame)
- Enhanced horizontal resolution to deterministic global NWP model
- Impacts:
  - Improved tropical/extra-tropical variability (storm system/location)
  - **Reduced NH PMSL RMS errors at longer forecast ranges**
  - Improved structure to frontal rain and trough-like features
  - Reduced wind-speed bias in the troposphere
  - Reduced US summer warm bias
  - Increased model stability, and many more..
  - Increased errors in upper-level tropical winds (partly due to the removal of tropical vertical diffusion)
  - Worse SH PMSL on day 5
- Interactive dust in global NWP (prognostic dust replaces prescribed aerosol climatology)

2. Obs changes (pre-2014)

Impact of DA – an example (2012-13)



- No SEVIRI
- Aqua/MODIS over land (DB+DT)
  - Neutral (-ve) bias overall (dust, filtered using α) against AERONET
  - -ve bias for ($\tau_{AERONET} > 0.3$)
  - Without DA, high model bias over Saharan (more emission, less transport)
  - DA improves the overall low bias in model forecast and analysis (still -ve though)

2. Obs changes

Include MYDAOD over ocean (dust only)

- Dust qualifying criteria based on *Bellouin et al* (*2005*) and *Jones & Christopher* (*2011*):
  - FMF <= 0.4
  - α <= 0.5
  - Effective radius > 1 μm
  - τ >= 0.1
  - Mass concentration >= 1.2e-4 kg/m^2;
  - Retrieval error < 0.4 and Confidence = 3 "best"
  - Dust homogeneity test
  - Regional mask over ocean (see trial results)

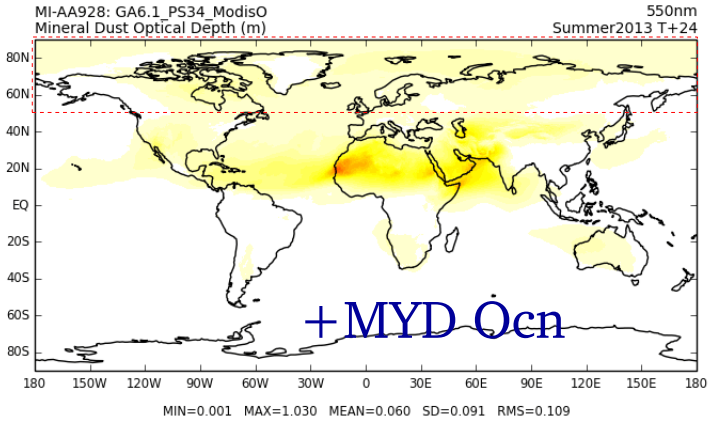
3. Trials

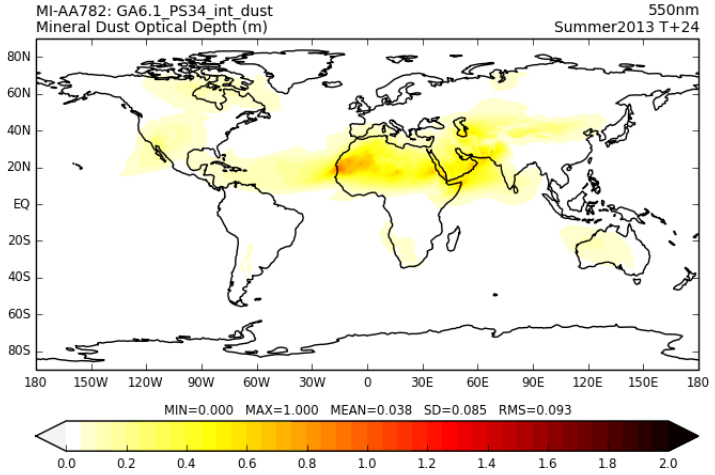
between 1st Jul and 8th Aug 2013

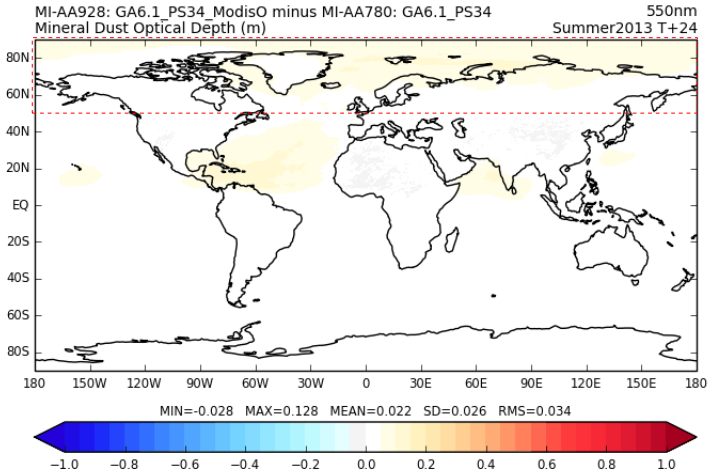
ID	Experiment	Description
mi-aa780	CTRL	Non-interactive dust; MYD Land (DB, DT)
mi-aa782	EXPT-1	Interactive dust; MYD Land (DB, DT)
mi-aa928	EXPT-2	mi-aa782 + MYD Ocean (global)
mi-ab262	EXPT-3	mi-aa782 + MYD Ocean (trop; τ>0.1)
mi-ab850	EXPT-4	mi-ab262 + relax τ>0.1 criterion

3. Trials

MYDAOD over global ocean



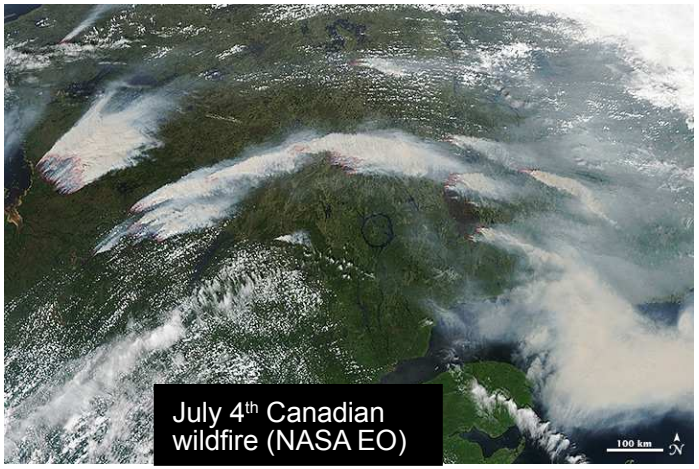


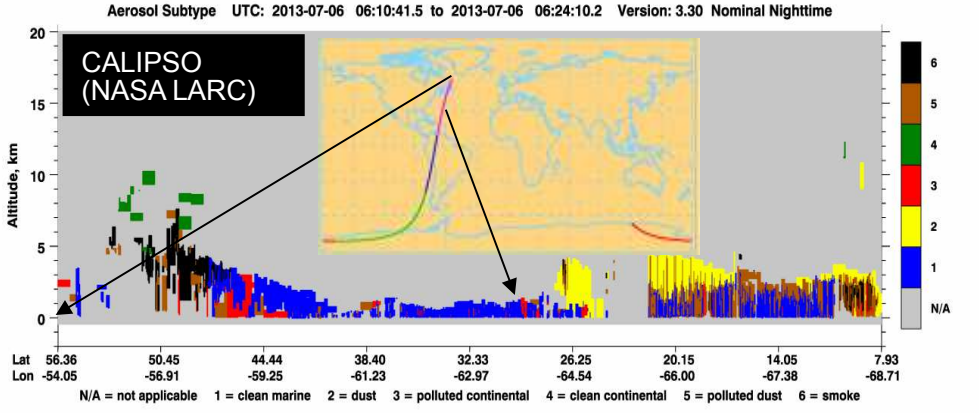


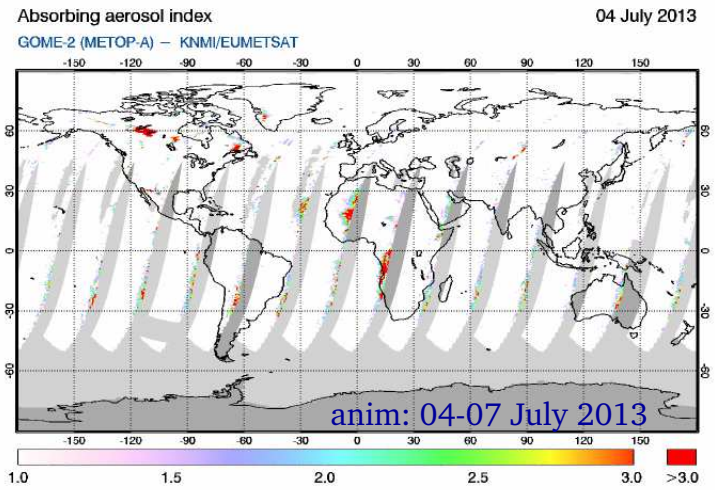
too much dust in NH high latitudes at T+0 and short range forecast times

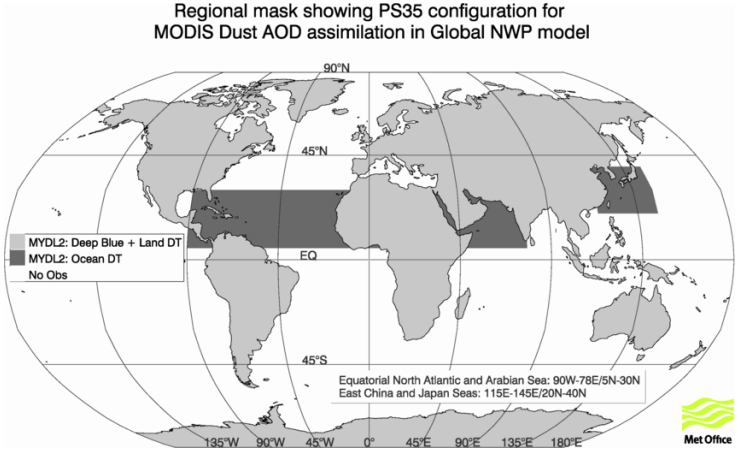
3. Trials

unable to separate out BB aerosol





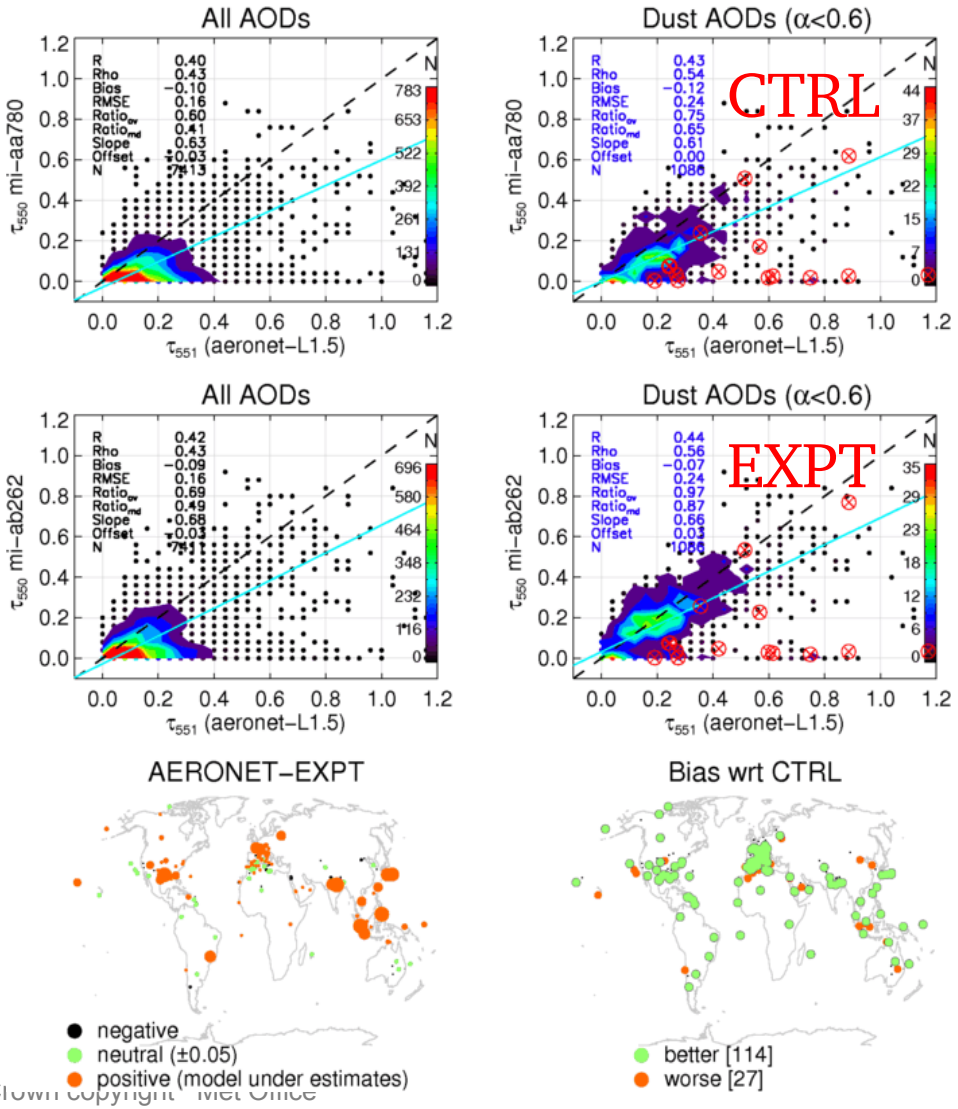




Verification – 1. Impact on dust

Analysis vs. AERONET L1.5

mi-ab262 / CTRL



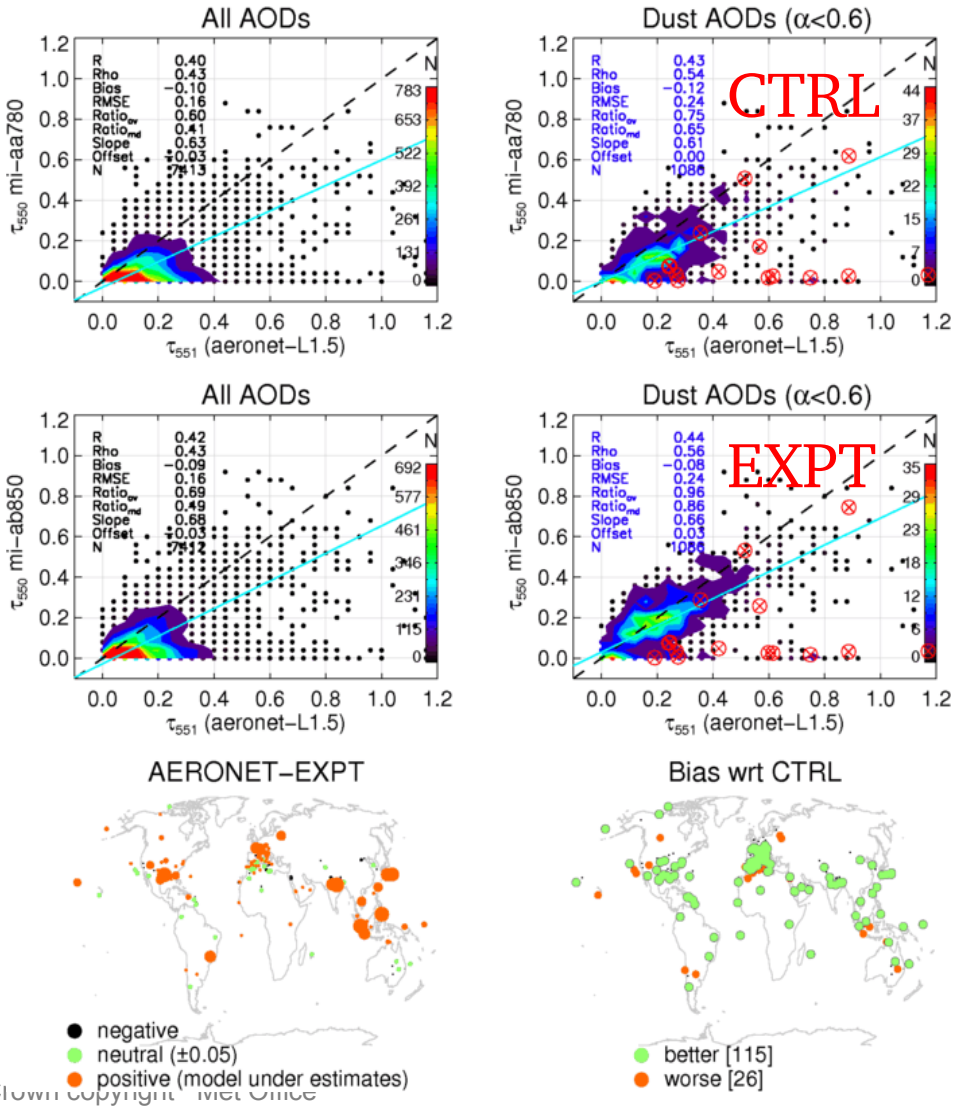
⊗ high variance in AERONET samples

<u>mi-ab262</u>

- Overall reduction in bias, better ratio and slope (still low bias)
- Generally improves analysis in most AERONET location (Better/Worse: 114/27)

Analysis vs. AERONET L1.5

mi-ab850 / CTRL



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<u>mi-ab850</u>

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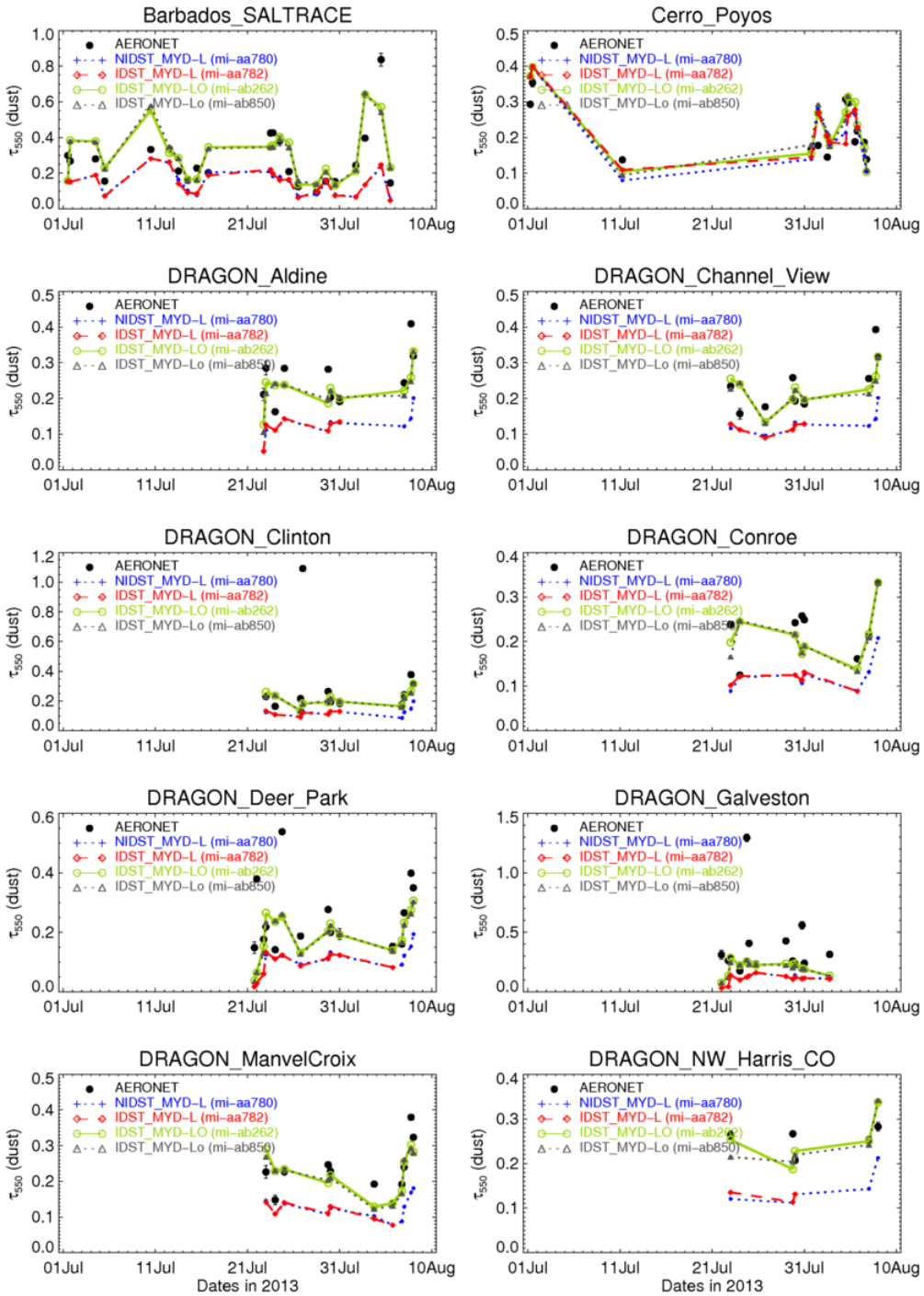
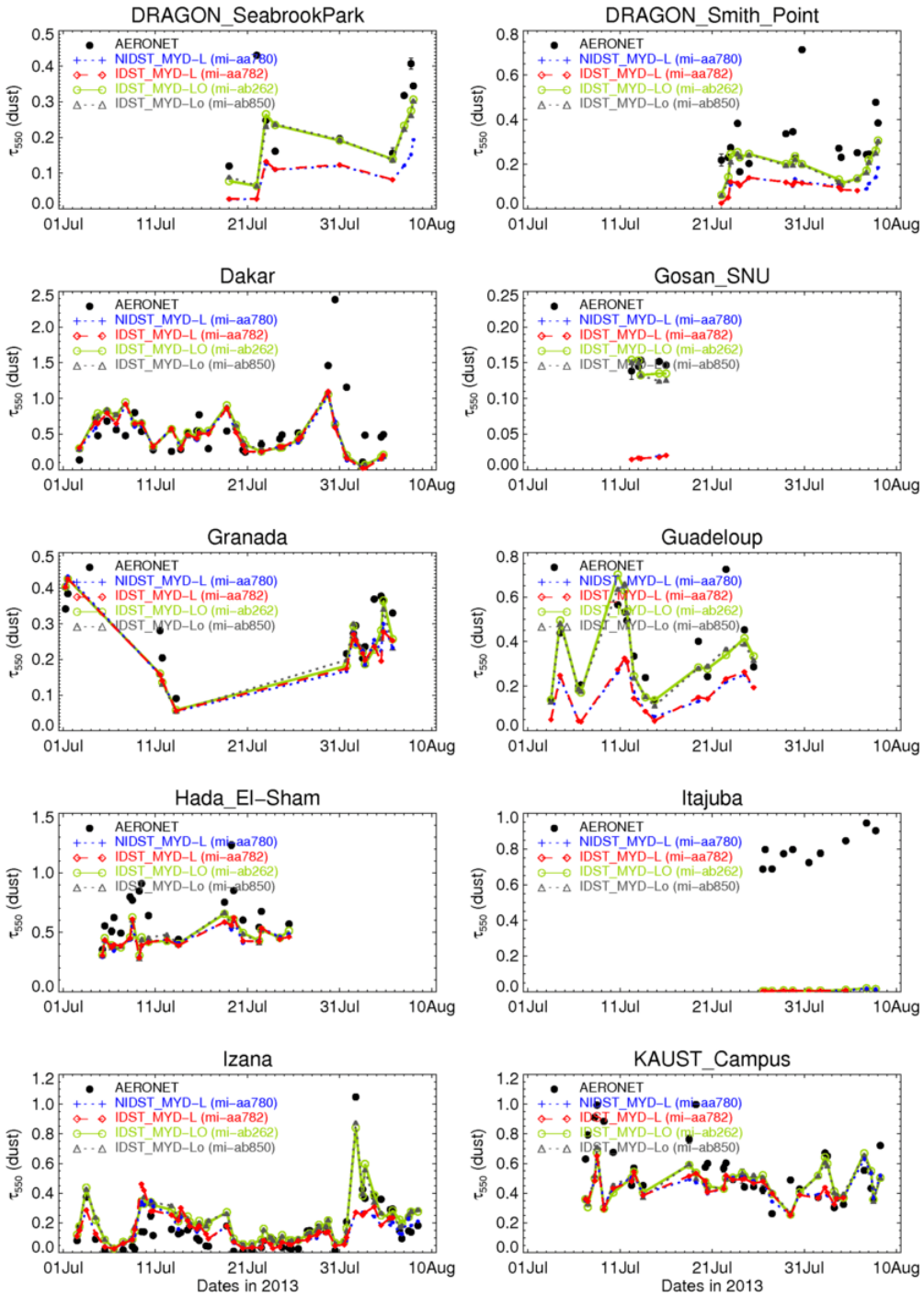
- Generally improves analysis in most AERONET location, esp. over M. East and E. Asia (Better/Worse: 115/26)



Analysis vs. AERONET time-series

- Including AOD over ocean (green and grey) better captures the day-to-day variability of AOD, and improves dust AOD at T+0
- AOD analyses are similar for both Interactive and non-interactive cases (when dust DA over ocean are excluded)
- Relaxing AOD threshold over ocean (grey) doesn't show much difference (in dust analysis) to the fit against AERONET, during the trial period



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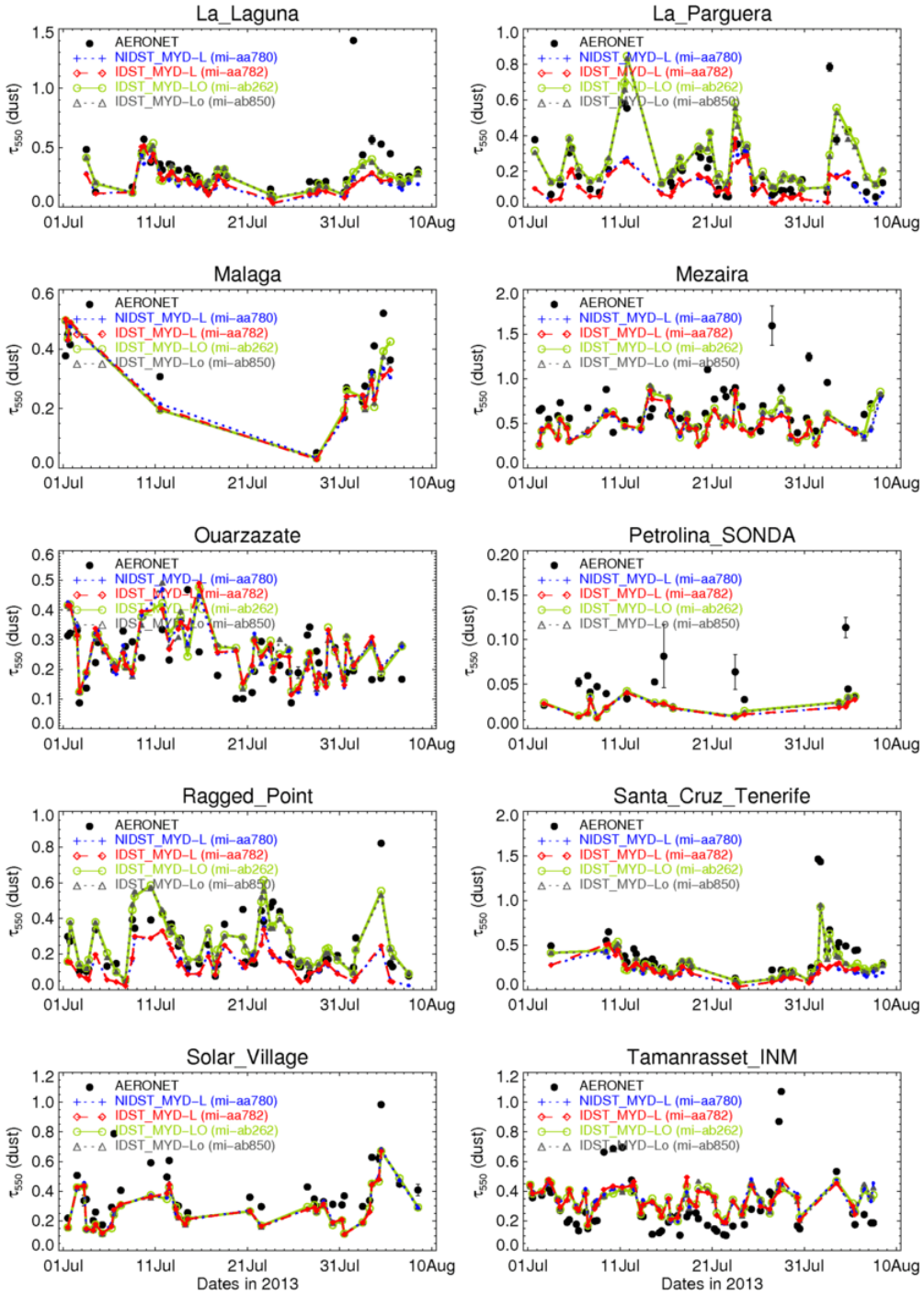

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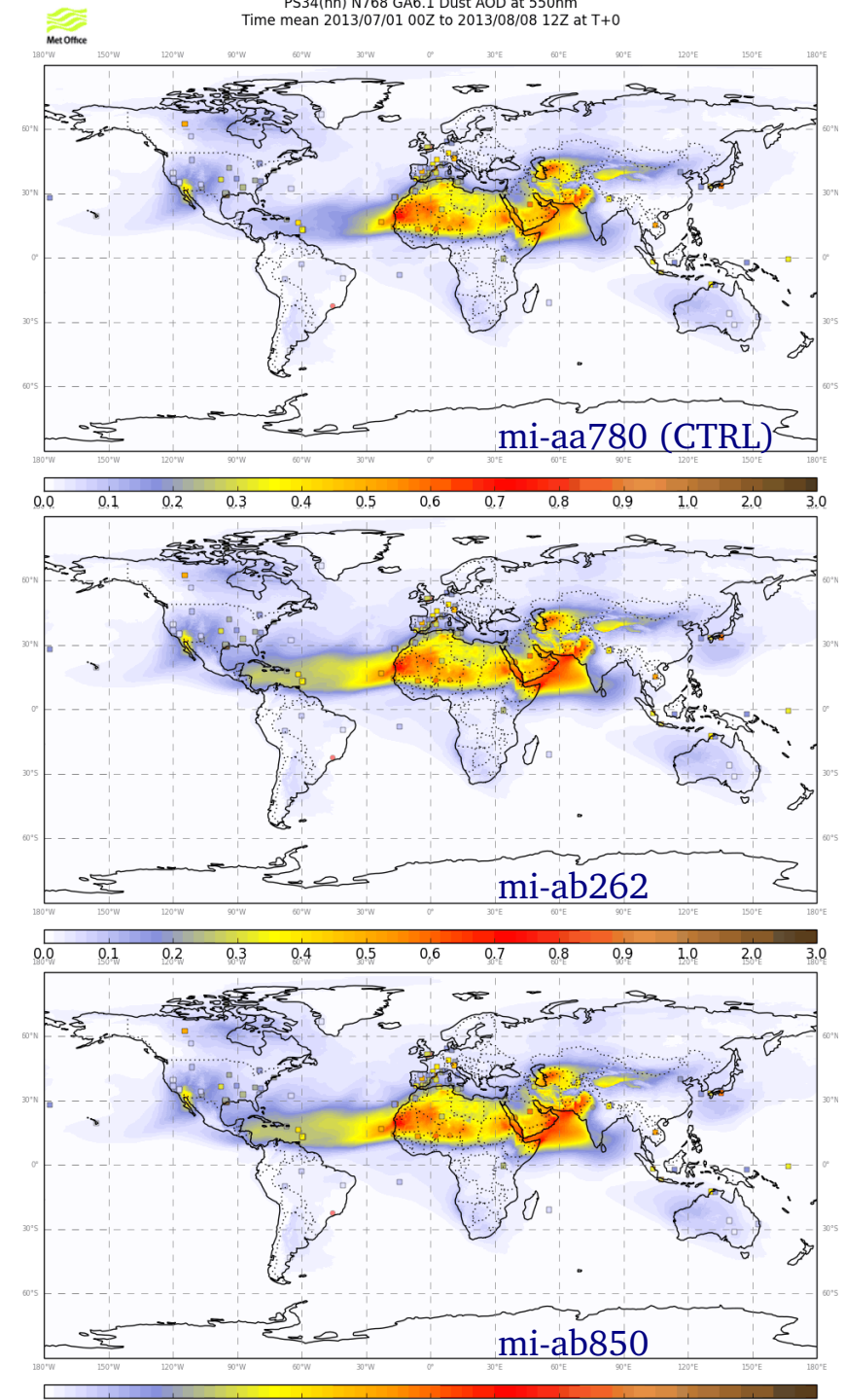
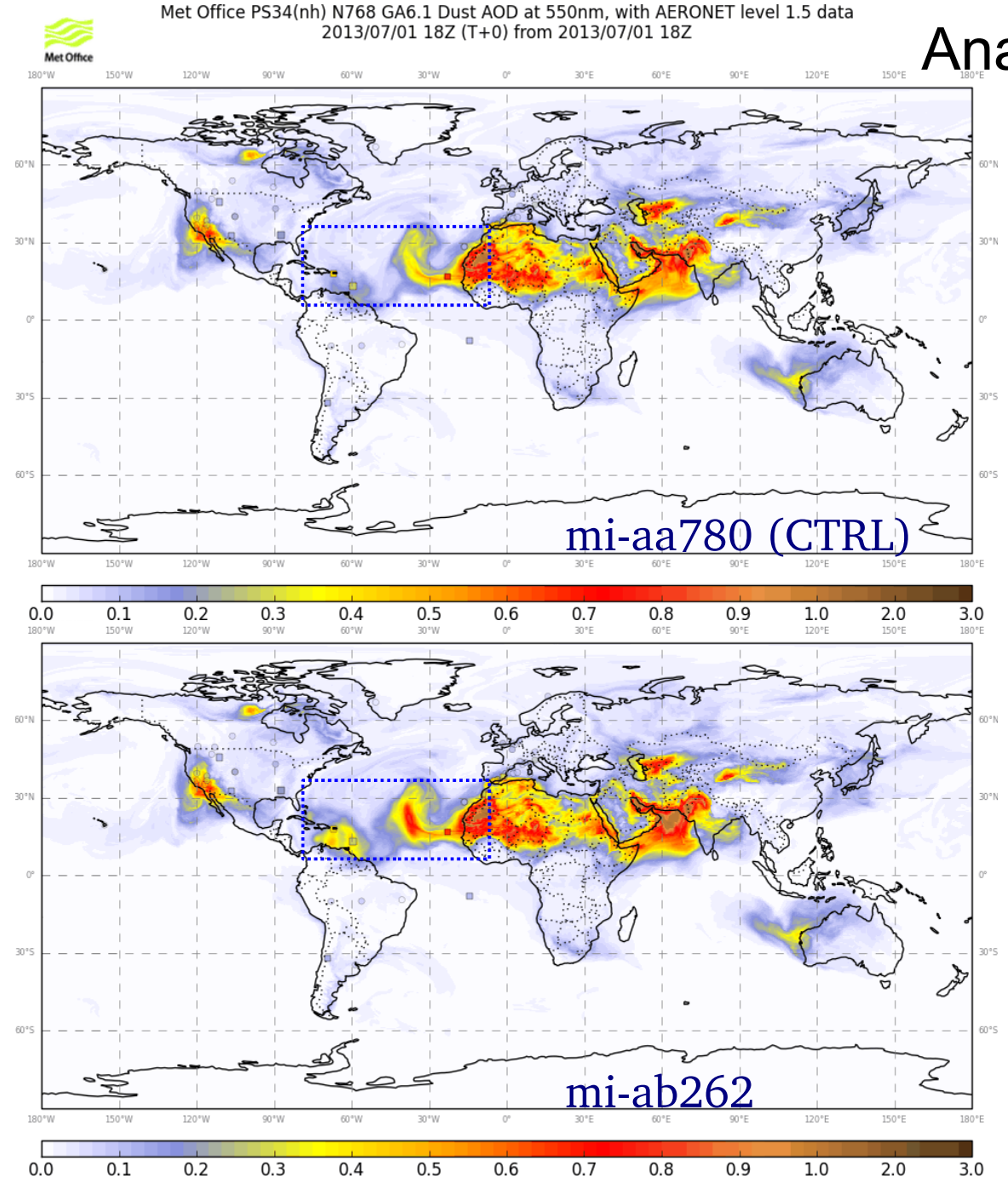
- Relaxing AOD threshold over ocean (grey) doesn't show much difference (in dust analysis) to the fit against AERONET, during the trial period, but indicates better NWP skill score (next section)



Analysis vs. AERONET spatial distribution

Trial mean at T+0

- Mean change in analysis over trial: Generally extends dust from outflow further from N. Africa (+Somalia and China)
- Improved analysis (cf. AERONET) over Caribbean (over the tropical N. Atlantic in general)
- The τ threshold relaxation scheme reduces dust over Bay of Bengal and East China Sea



Analysis vs. AERONET spatial distribution

1 Jul 2013 18Z snapshot

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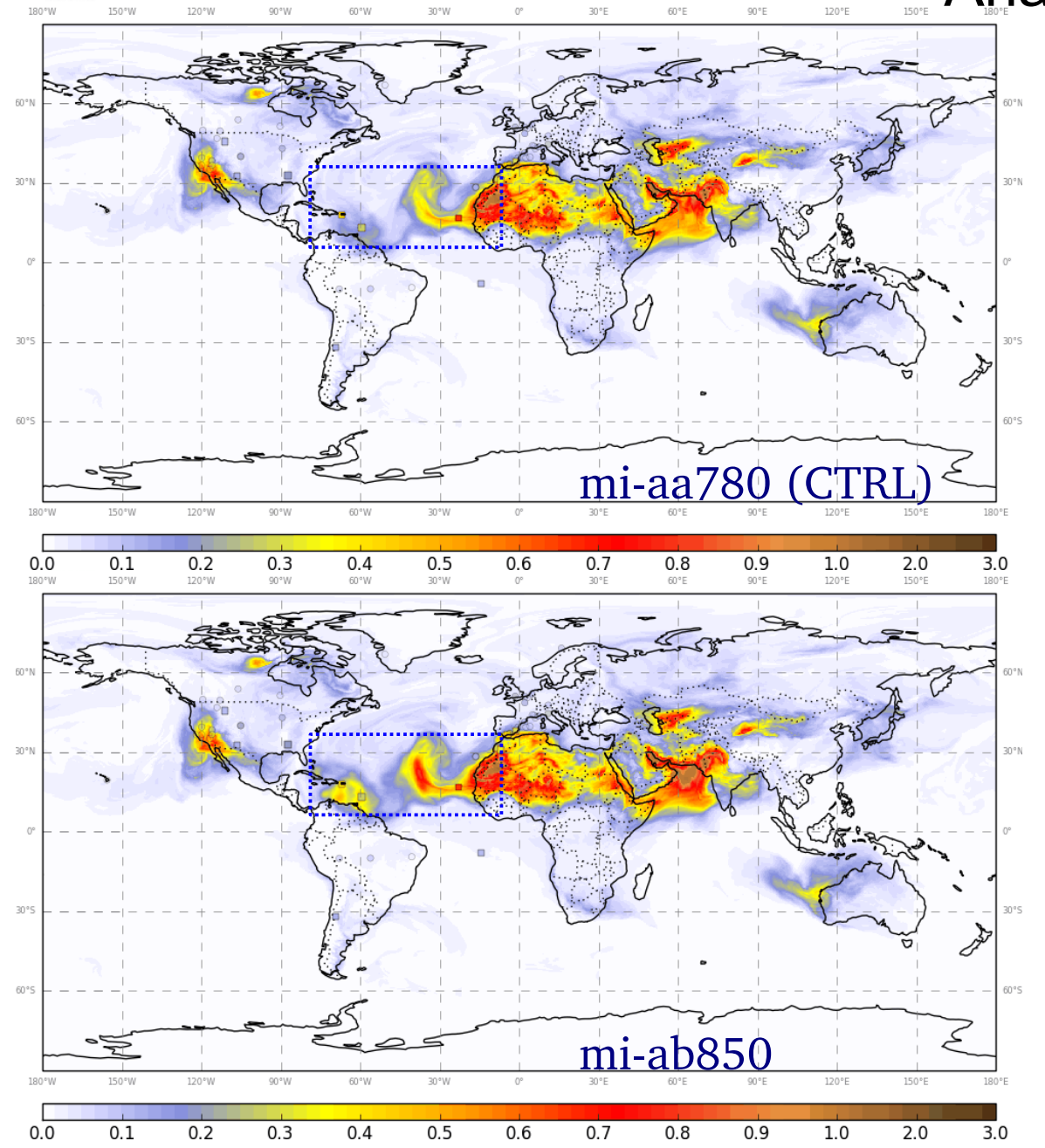
Analysis vs. AERONET spatial distribution



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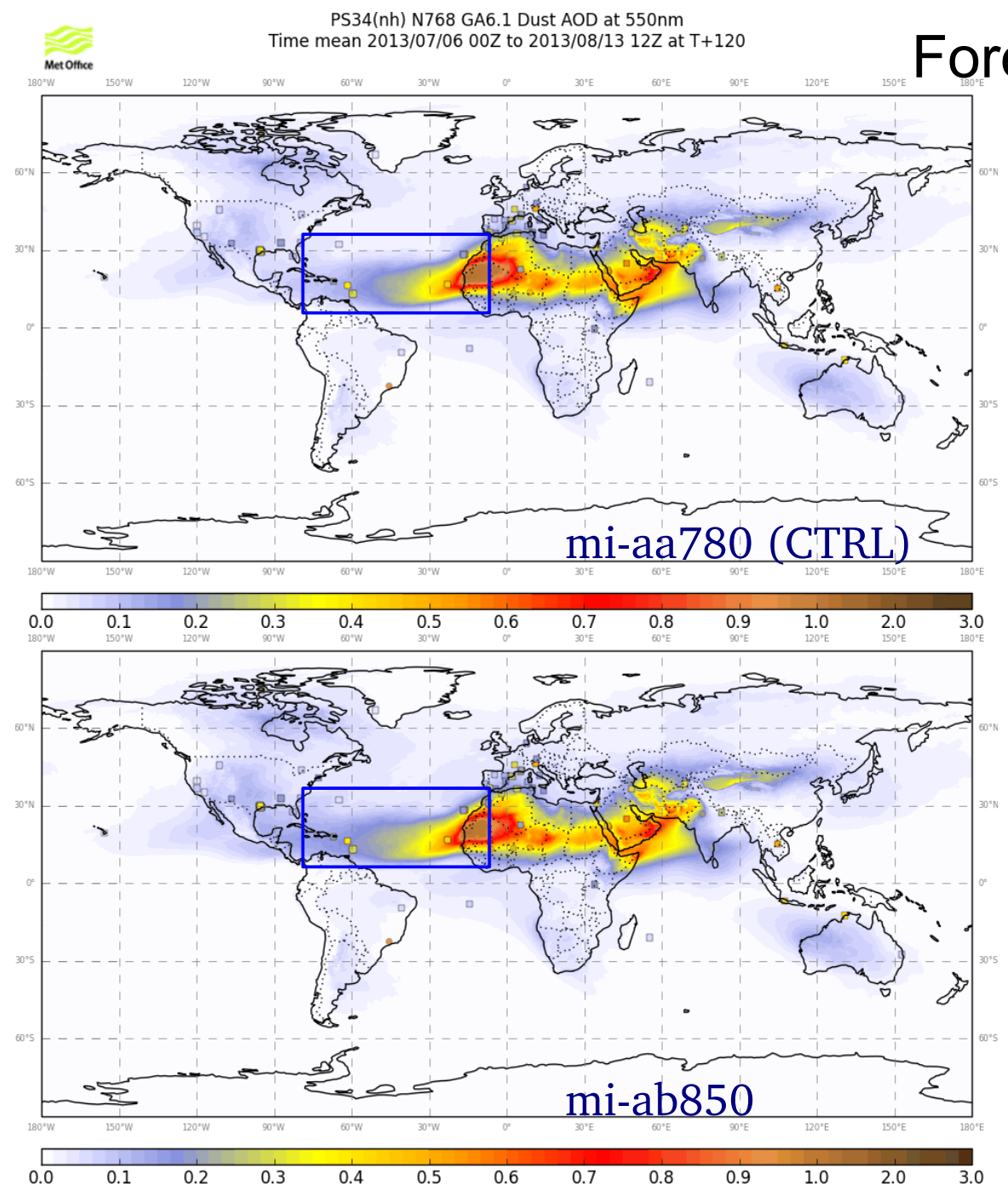


Forecast vs. AERONET spatial distribution

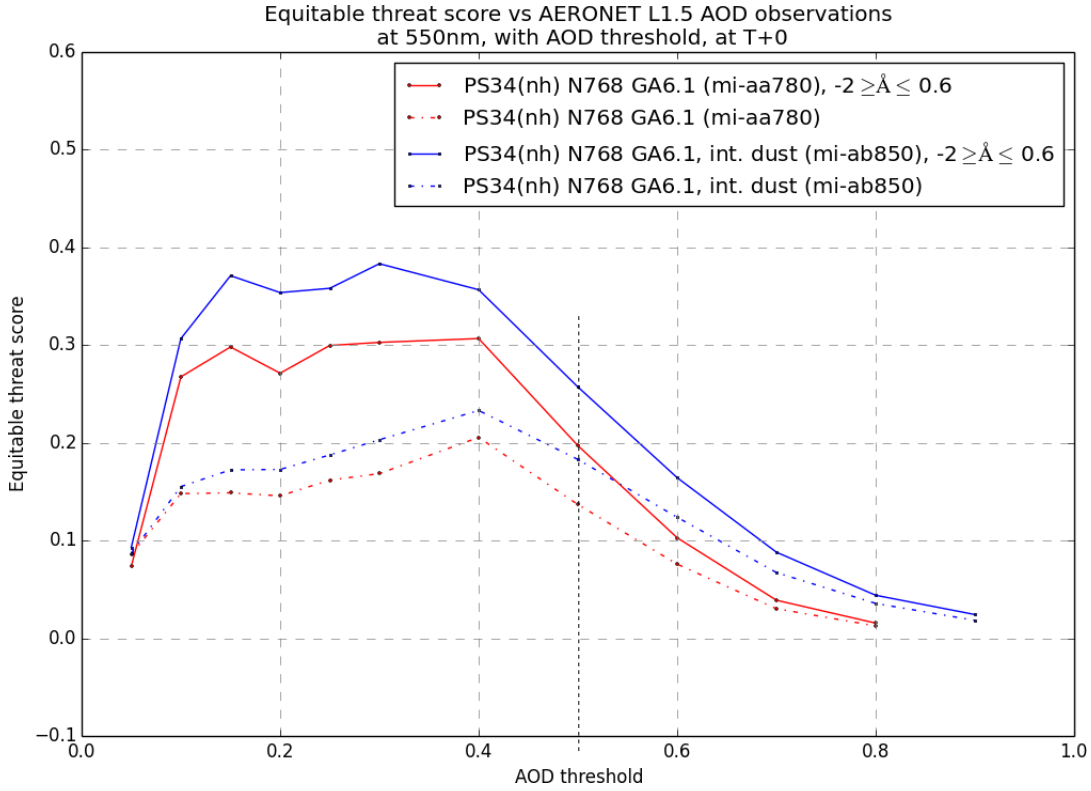
Trial mean at T+120

- As forecast evolves, the model is unchanged, so the DA impact is lessened

Q: Is the forecast better?

'Standard' Forecast verification

Equitable Threat Score (ETS)

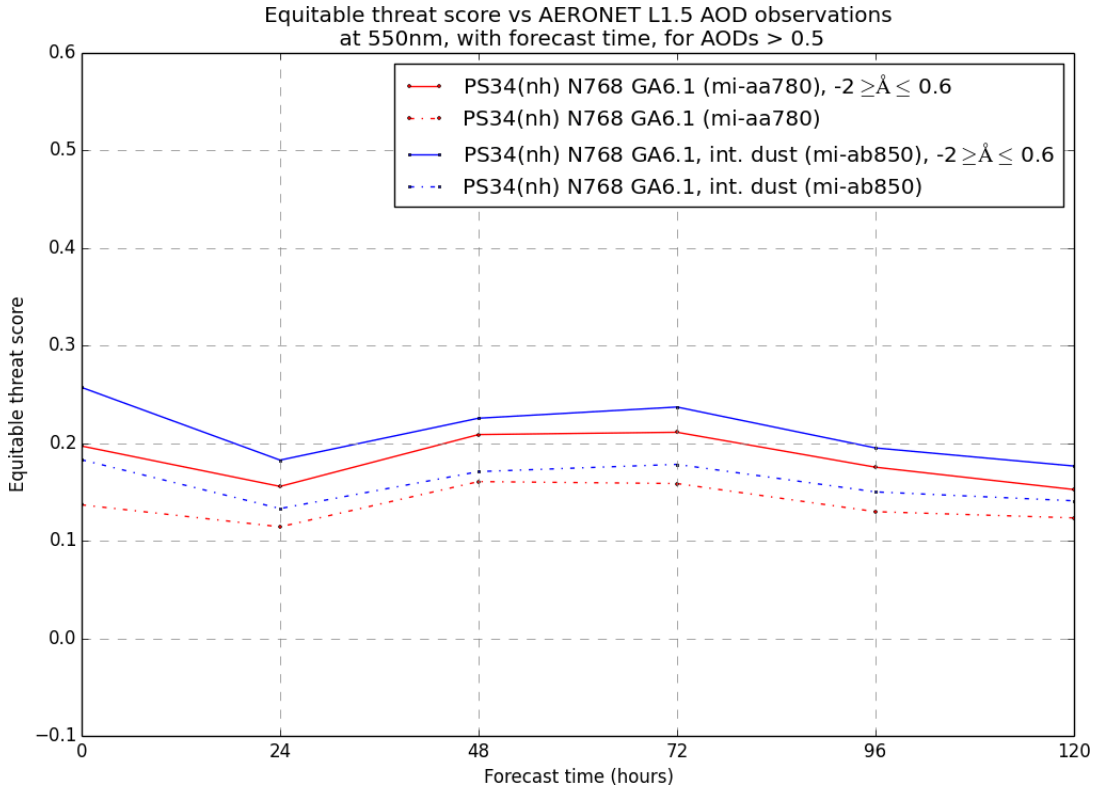


AOD at T+0 skilful vs AERONET at all thresholds

- Uses a categorical method, with skill scores of exceeding, or not, a given threshold.
- The "Equitable Threat Score" is our most standard score.
- The ETS measures the fraction of observed and/or forecast events that were correctly predicted, adjusted for hits associated with random chance.
- A perfect forecast has an ETS of 1.
- An ETS of 0 indicates the forecast has no skill.

'Standard' Forecast verification

Equitable Threat Score



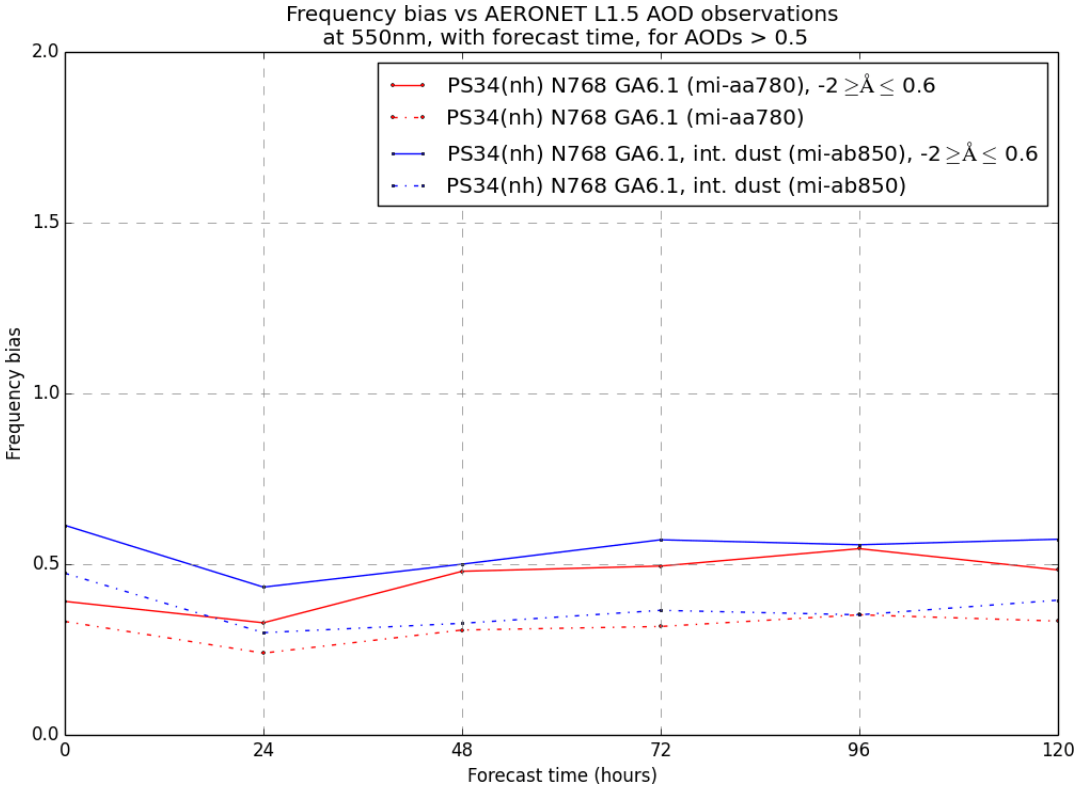
AOD threshold of 0.5 with forecast time shows:

- Forecast maintains skill, compared to analysis (better than precip does)
- The experiment (blue) has higher ETS than control (red)
- Changes should be considered 'good'

Comparable skill to short range precip forecasts (see later)

'Standard' Forecast verification

Frequency bias

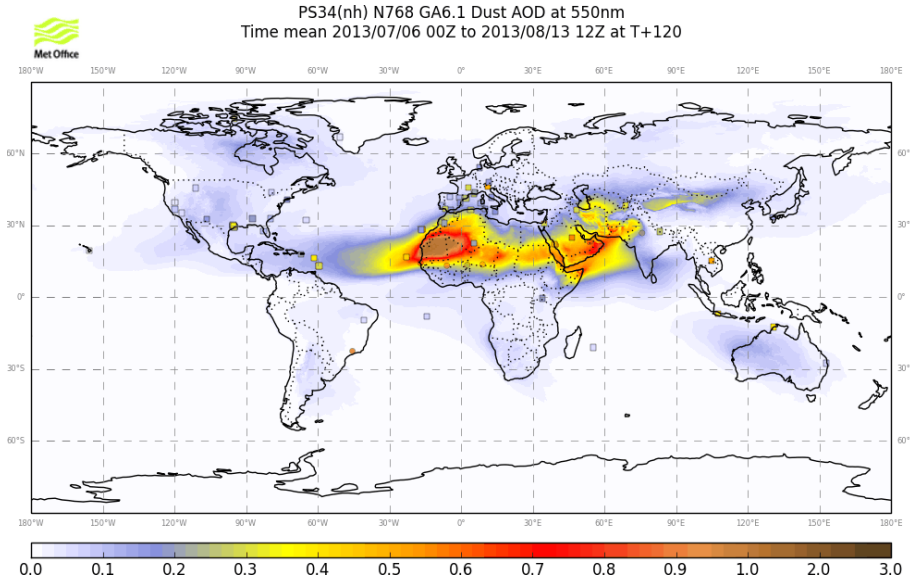


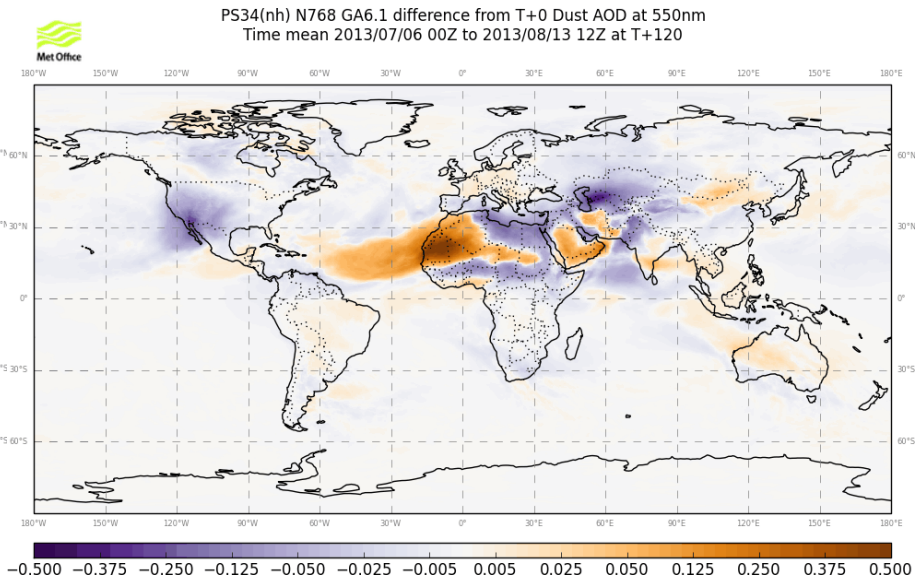
- Uses a categorical method, with skill scores of exceeding, or not, a given threshold.
- The "frequency bias" indicates whether the event is predicted more or less often than observed.
- **Bias = 1** is good.
- **Bias < 1** indicates under-prediction.
- **Bias > 1** indicates over-prediction.

AOD threshold of 0.5 with forecast time shows an under-prediction of dust events with AOD>0.5 at AERONET sites

'Standard' Forecast verification

vs Analysis at T+120

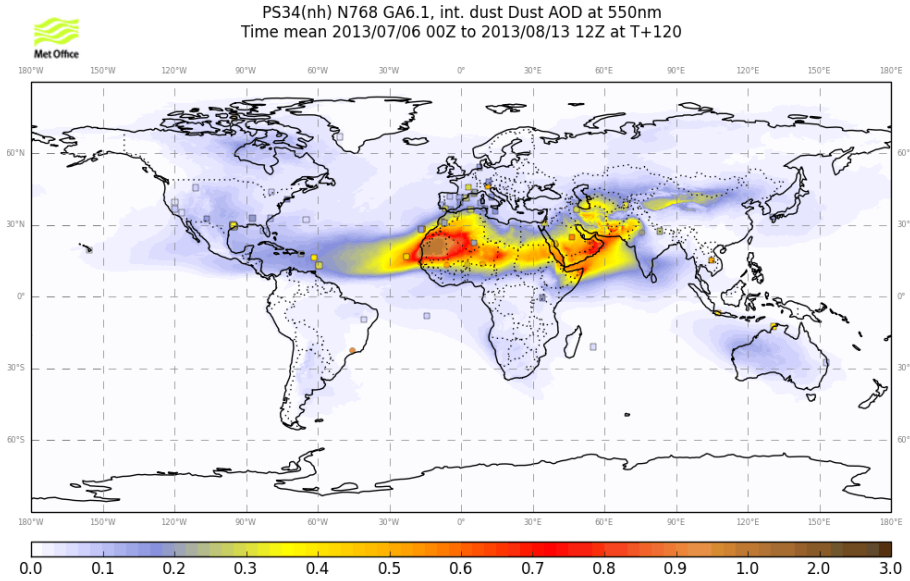


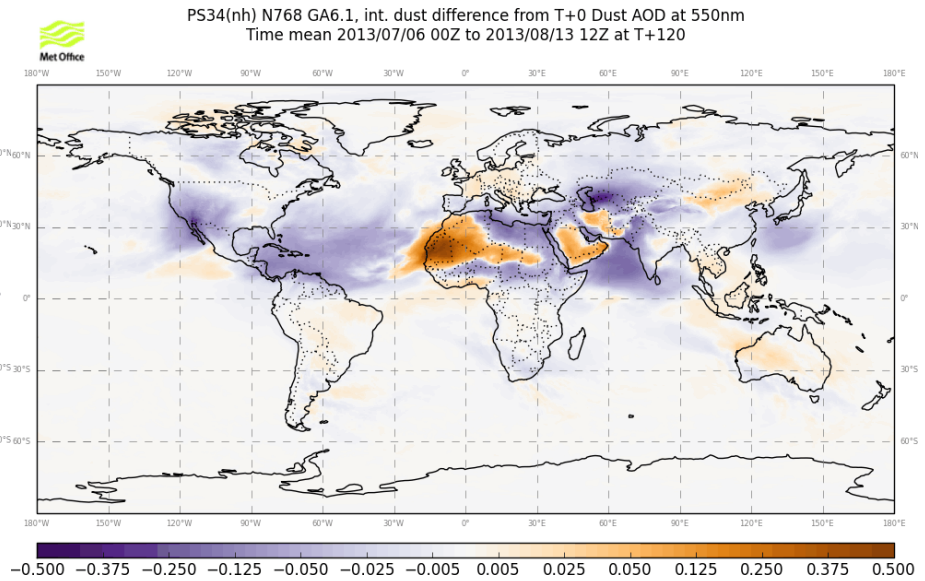


- Without MODIS obs over ocean the positive bias vs analysis over Land is believable
- The bias over the ocean is just the advection of the biases over land – the analysis has no obs here to be of use
- The positive bias over Land could imply we need to reduce dust emission in the forecast model
- This is the opposite of what the AERONET frequency bias suggests. Why!?

'Standard' Forecast verification

vs Analysis at T+120

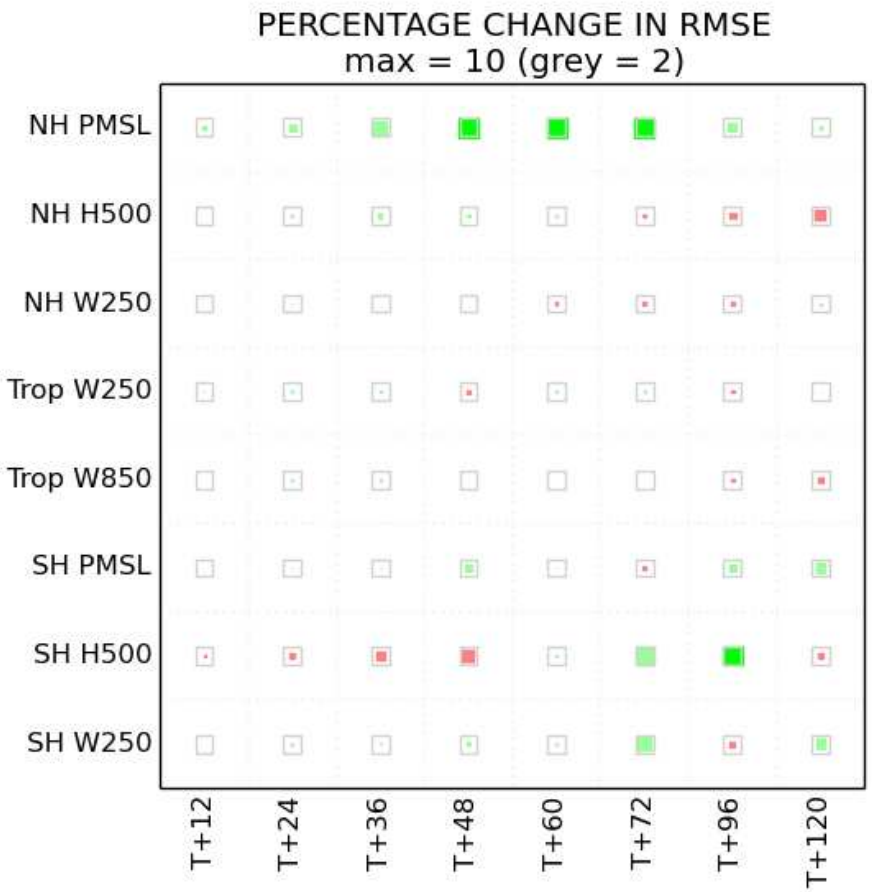


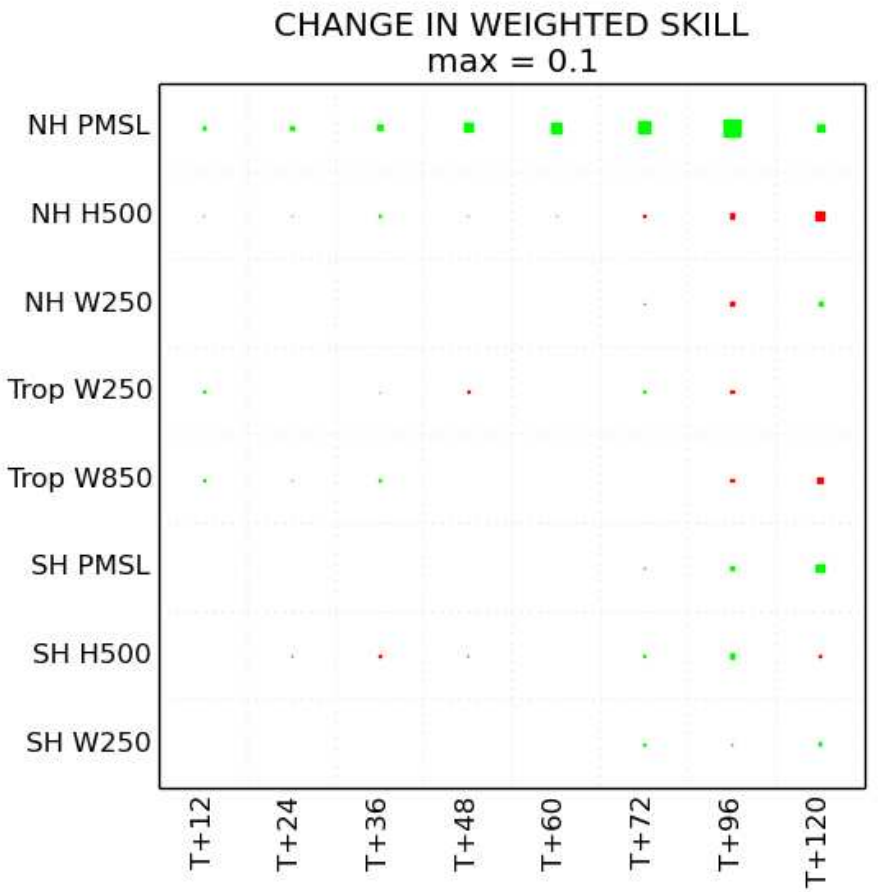


- With MODIS Ocean obs, the analysis is extending dust much further out of the outflow regions
- Coupled with the high bias over land, this implies we need less emission and more long range transport
- Consistent with tentative SAMUN, SALTRACE, FENNEC obs - dust ageing is shorter process, and aged dust has a larger size distribution, stays aloft for longer. Further field campaigns required to understand the process

Verification – 2. Impact on NWP skill

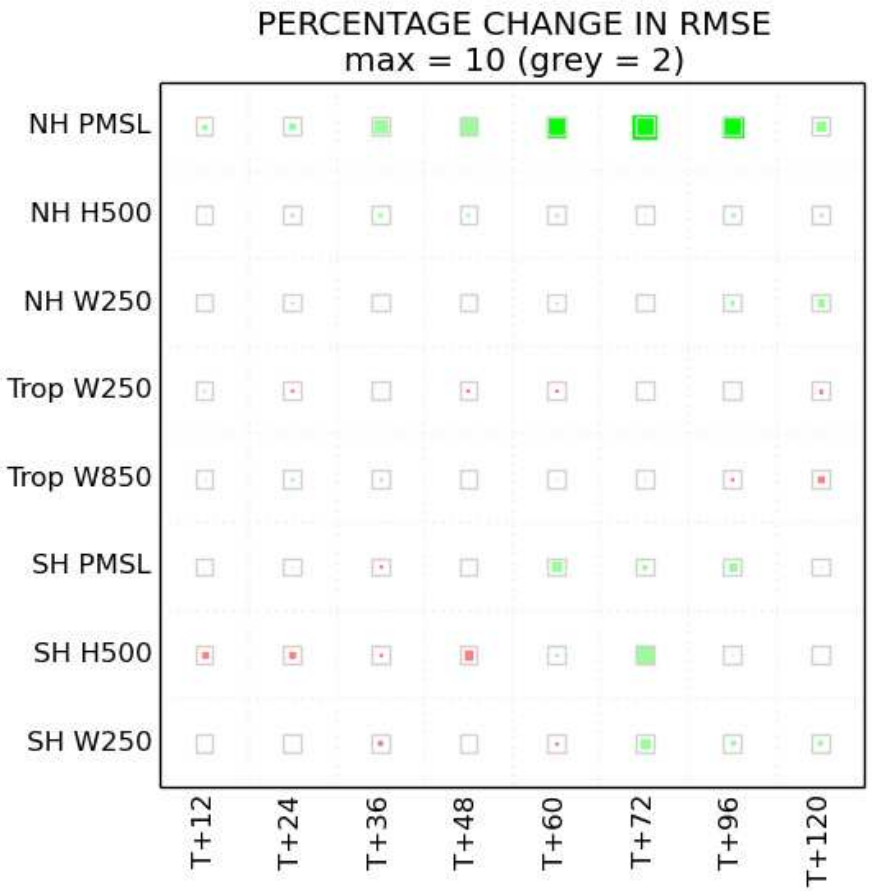
VAR TRIAL: Non Interactive Dust v Int. Dust + ModisOcnLrg (Summer2013)
VERIFICATION VS OBSERVATIONS
FROM 20130701 TO 20130808
OVERALL CHANGE IN NWP INDEX = 0.228

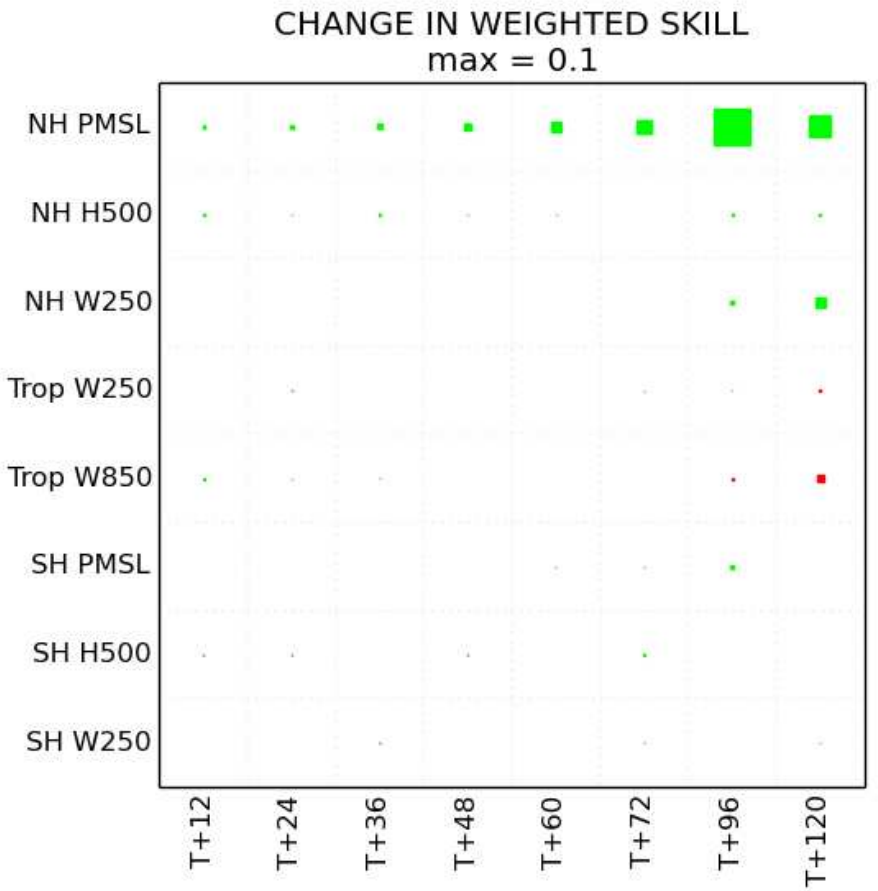




mi-aa780 v mi-ab262: Verification against Obs

VAR TRIAL: Non Interactive Dust v Int. Dust + ModisOcnAll (Summer2013)
VERIFICATION VS OBSERVATIONS
FROM 20130701 TO 20130808
OVERALL CHANGE IN NWP INDEX = 0.425

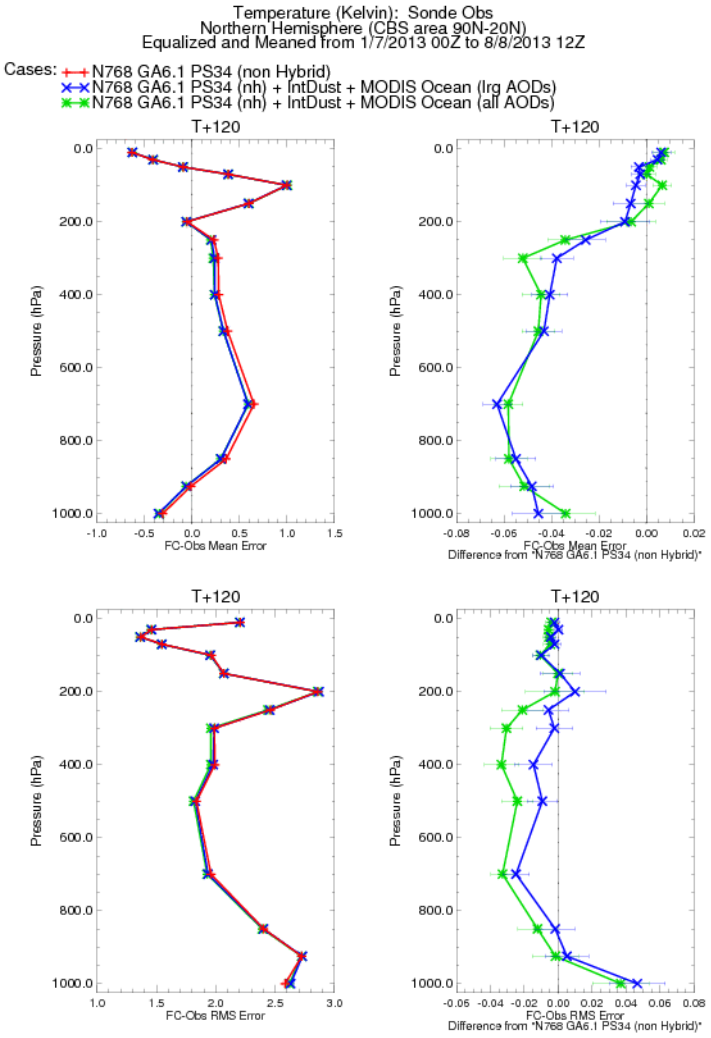


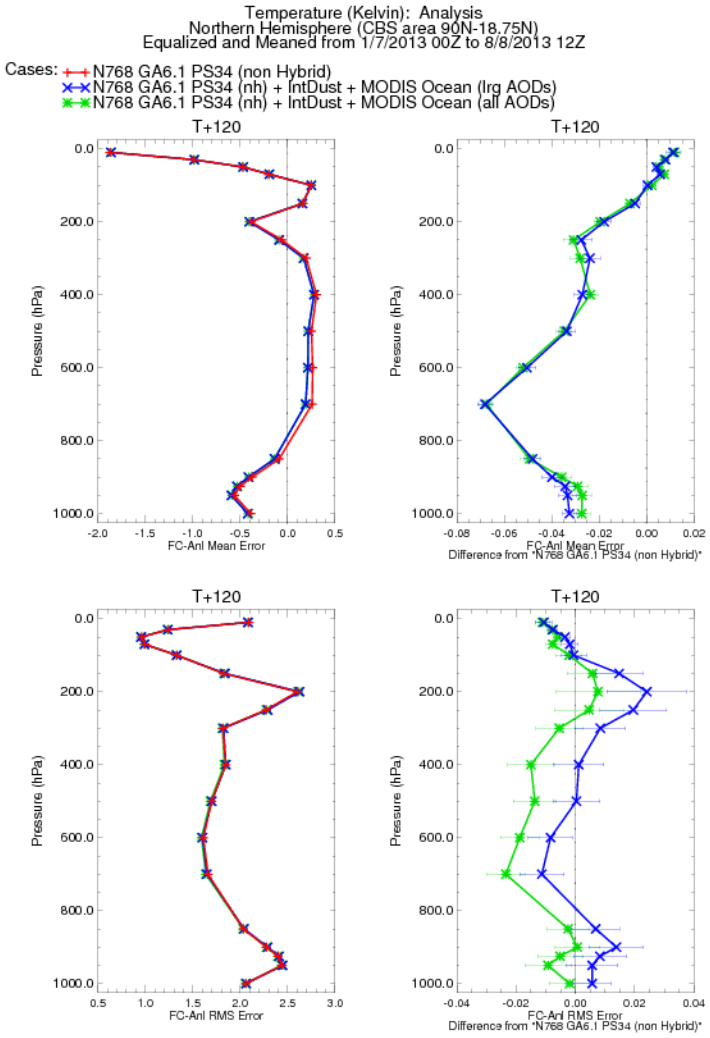


mi-aa780 v mi-ab262: Verification against Obs

Impacts on meteorology (NH)

Temperature at T+120





68% error bars calculated using $S/(n-1)^{1/2}$

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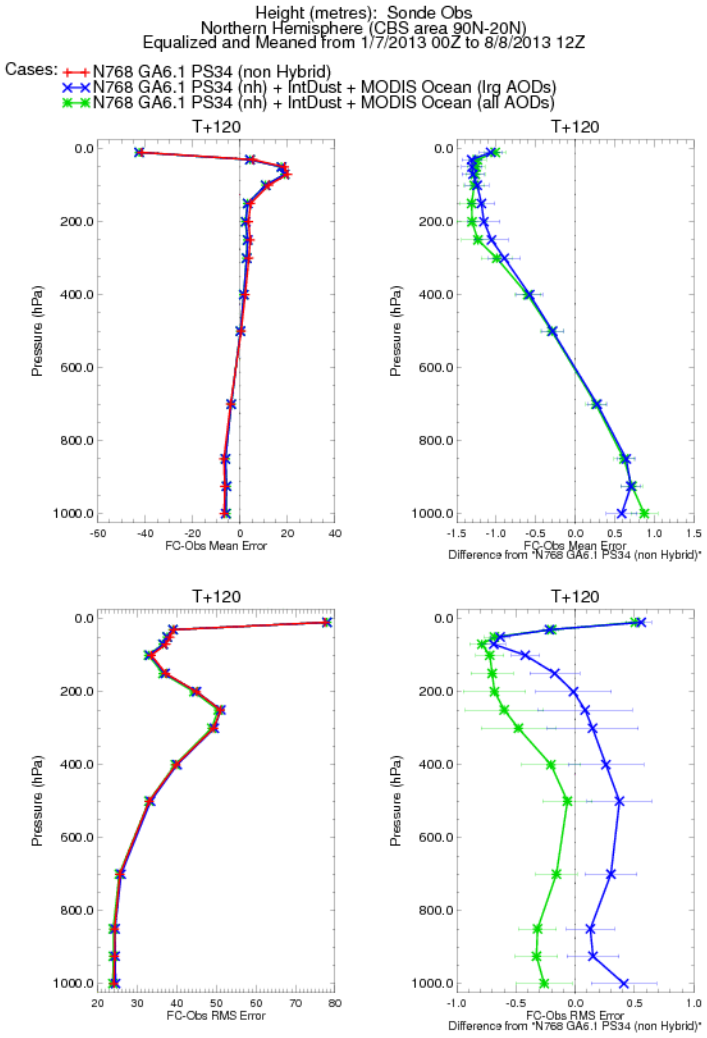
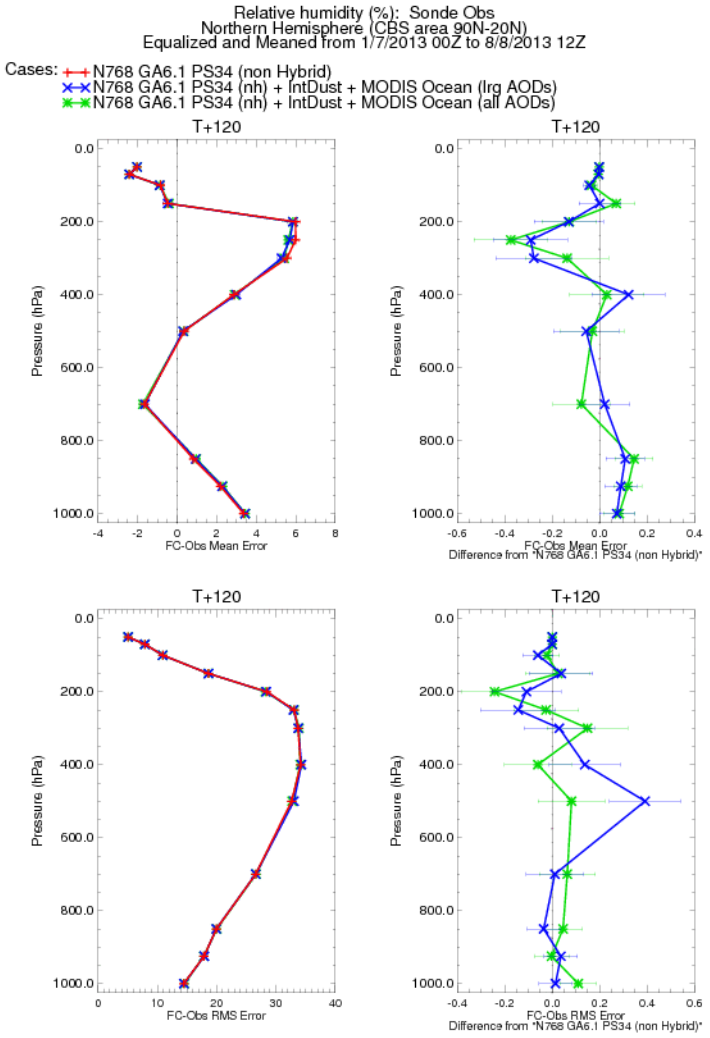
Impacts on meteorology (NH)

Height and Rel. Humidity at T+120





68% error bars calculated using $S/(n-1)^{1/2}$

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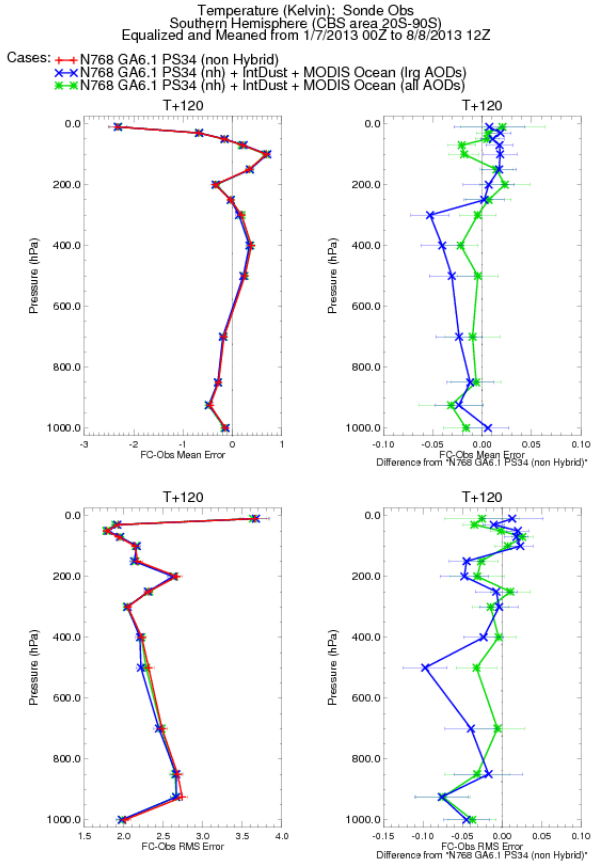
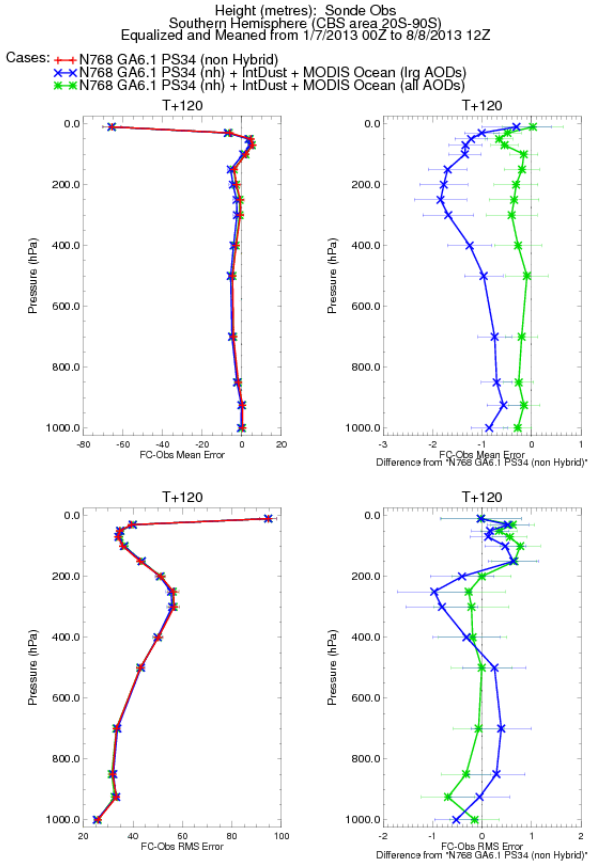
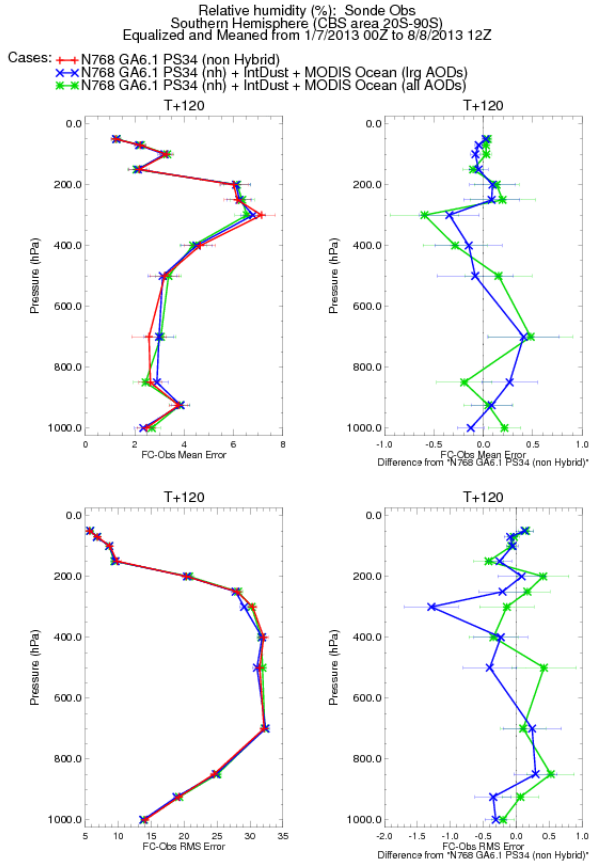
Impacts on meteorology (SH)

Temperature, Height and Rel. Humidity at T+120

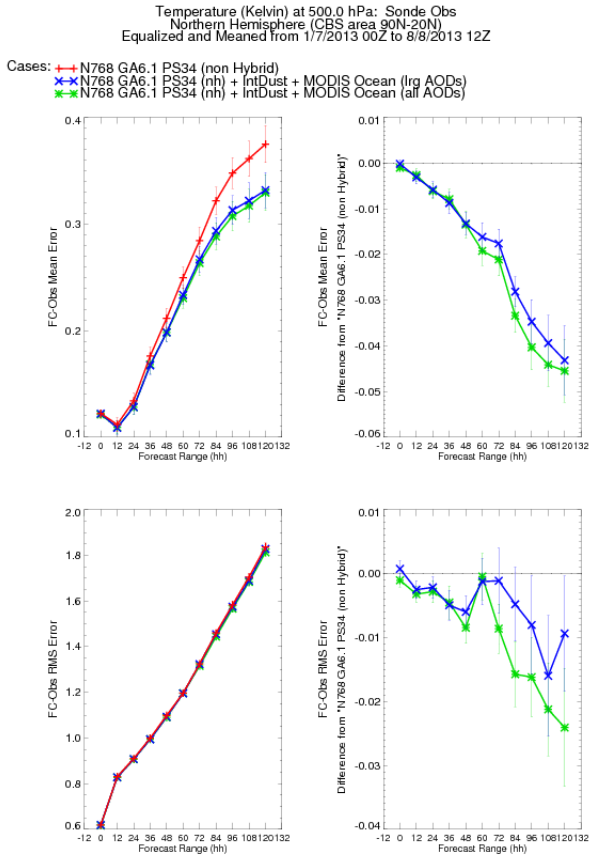


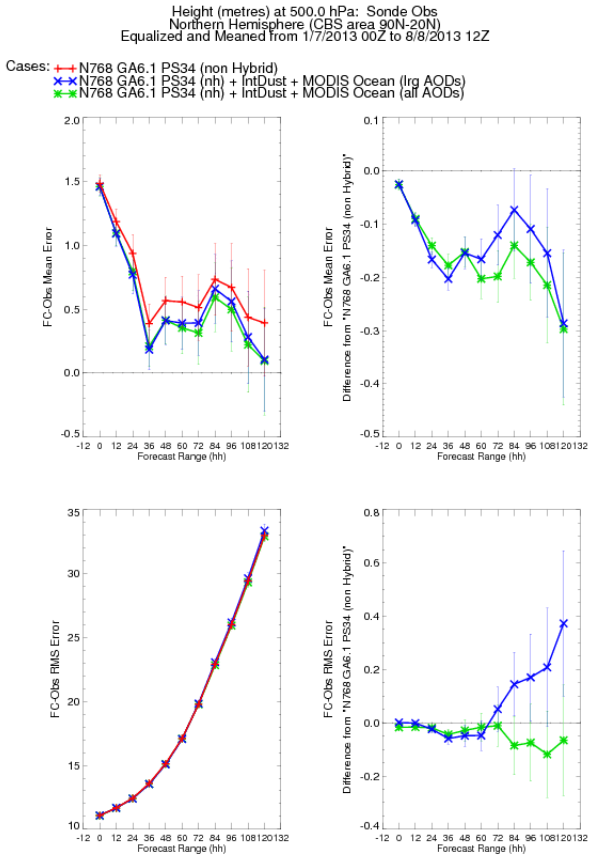


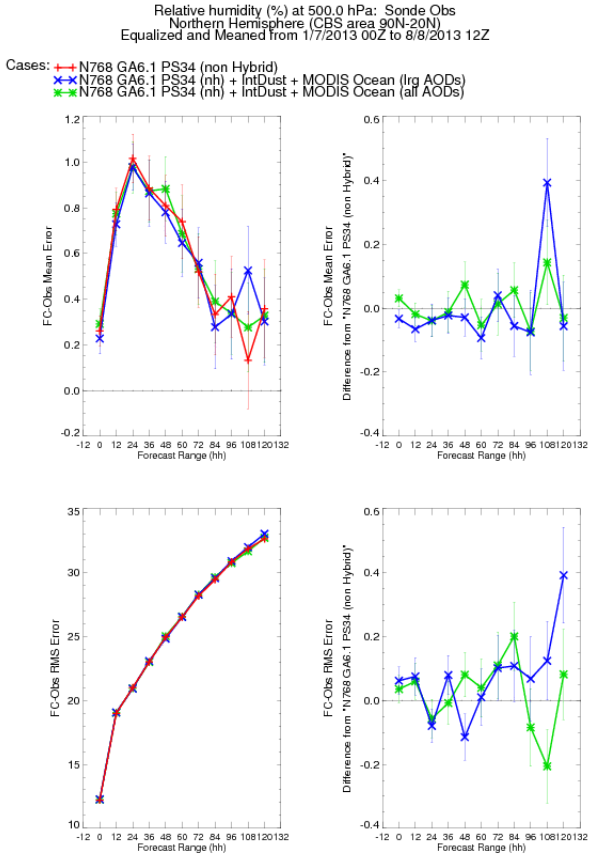


Impacts on meteorology (NH)

Temperature, Height & Rel. Humidity at 500hPa

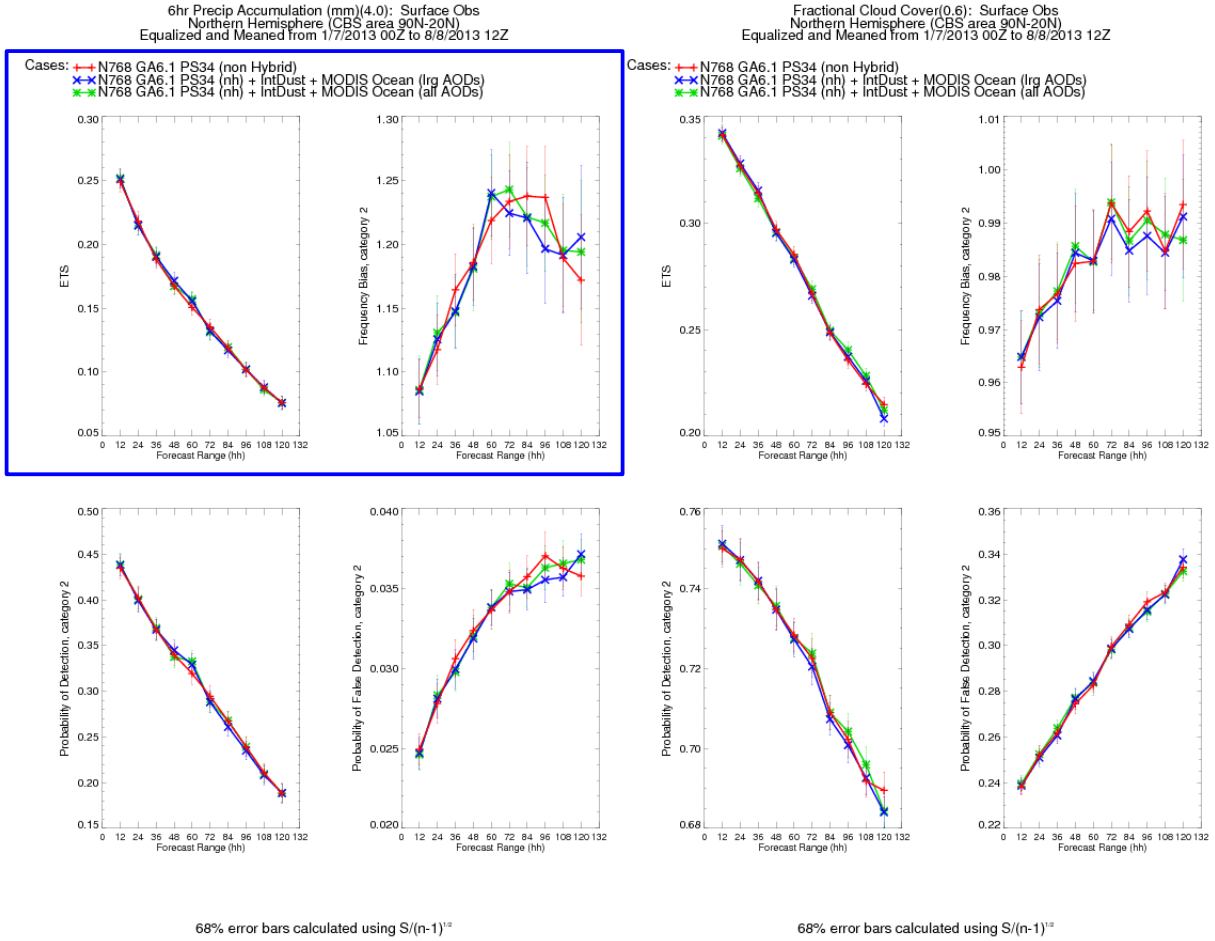






Impacts on meteorology (NH)

Precipitation & Cloud vs surface SYNOP obs



Short-range precip skill comparable to AOD forecasts

Adding MODIS over ocean doesn't degrade the system

Summary

- The inclusion of “interactive dust” in the UM forecast has been tested alongside changes to the “dust DA” system. In these trials it has been shown to give small benefits to long range predictability
- Without the inclusion of interactive dust, the impact on the forecast model would be negligible (leaving only small changes to the analysis increments to account for the dust obs).
- With the inclusion of interactive dust and assimilation of MODIS obs over ocean, there is a small benefit to the NWP system.

Future plan

- Model and DA changes
  - Dust tunings of the UM forecast using lower res (N320)
  - Adopt GLOMAP-mode in global NWP
  - Possible inclusion of other aerosol species
- Observation changes
  - Include VIIRS and/or MetOP and/or SEVIRI optimal estimation AOD
  - Longer trials (more seasons) with dust denial experiment

Impacts of aerosol complexity in the UM

Jane Mulcahy Earth System Science

Atmos. Chem. Phys., 14, 4749–4778, 2014
www.atmos-chem-phys.net/14/4749/2014/
doi:10.5194/acp-14-4749-2014

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Met Office

Impacts of increasing the aerosol complexity in the Met Office global numerical weather prediction model

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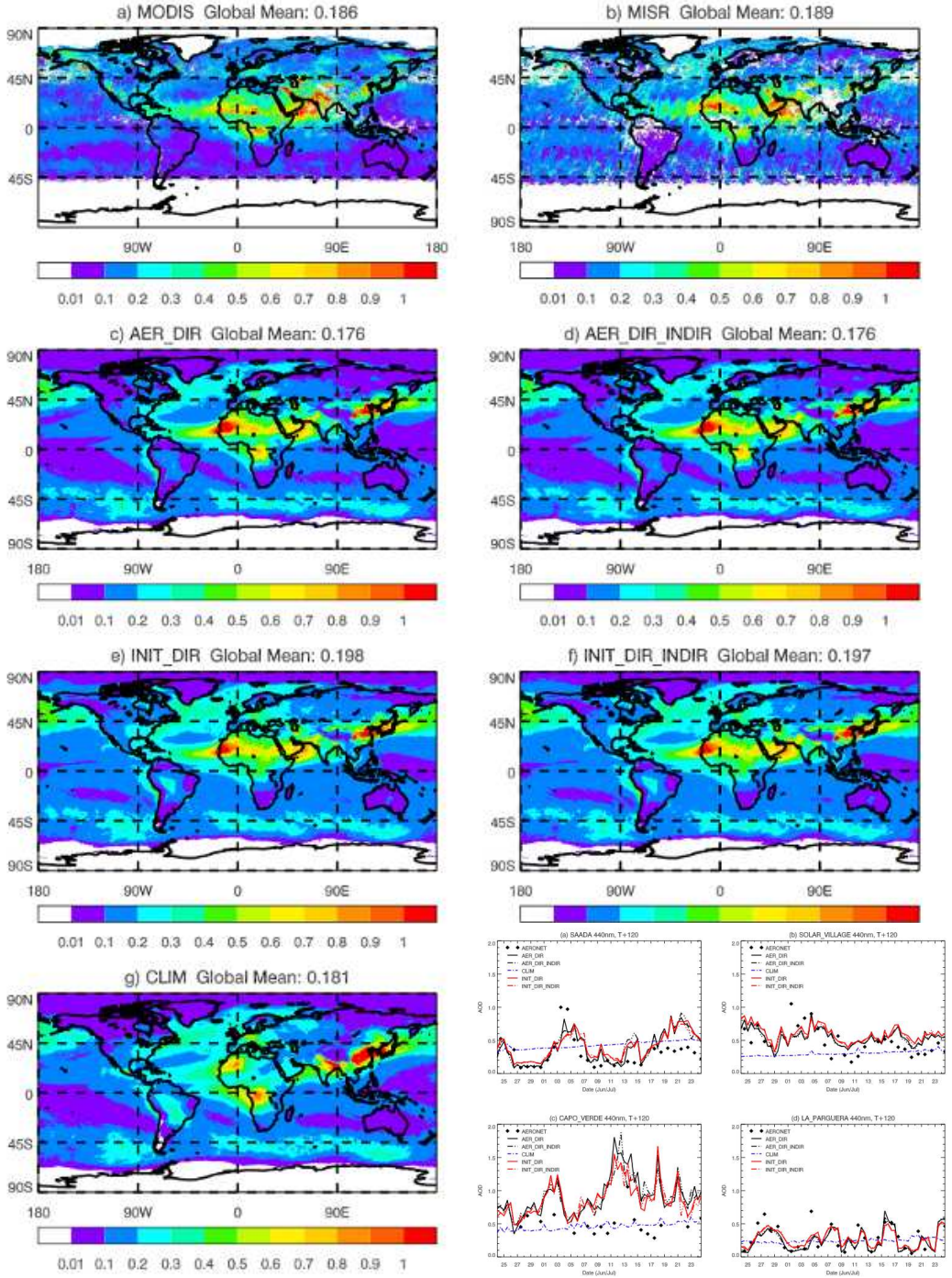
51-day Summer trial (03 Jun – 24 Jul, 2009)

N512L70 (~40 km)

Since July 2010

Experiment	Aerosol representation	Direct Effect	Indirect Effect
CNTRL:	"Historical" aerosol climatology (Cusack et al. 1998)	Yes	No
CLIM (current NWP config.):	Monthly mean speciated climatologies derived from HadGEM2 simulations.	Yes	No
AER_DIR:	Fully prognostic CLASSIC aerosol	Yes	No
AER_DIR_INDIR:	Fully prognostic CLASSIC aerosol	Yes	Yes
INIT_DIR:	GEMS Initialised CLASSIC aerosol	Yes	No
INIT_DIR_INDIR:	GEMS Initialised CLASSIC aerosol	Yes	Yes

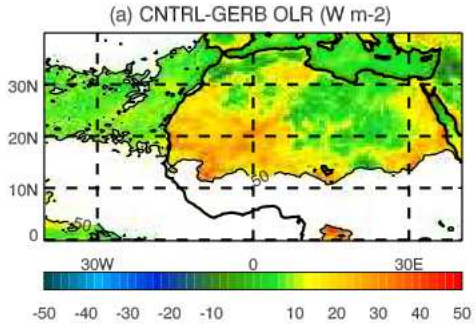


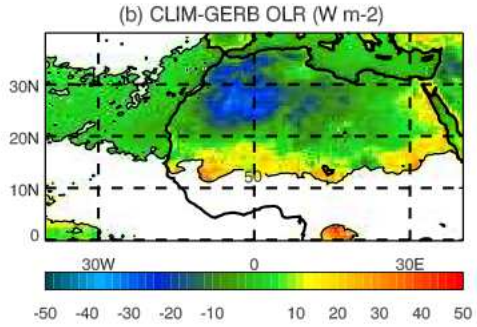
Aerosol FC

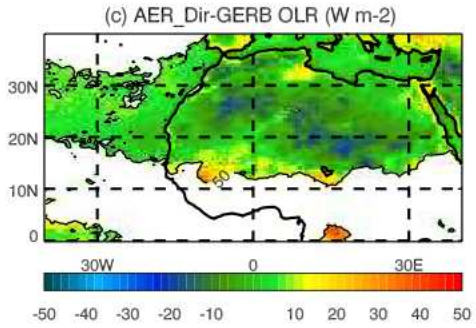
- AER/INIT: simulations decrease/increase AOD in NH high latitudes
- CLIM:
  - higher AOD in NH
  - doesn't represent dust loading over the AS
  - doesn't capture diurnal variability of AOD
- Prognostic aerosol (AER) scheme better predicts the spatio-temporal variation of AOD

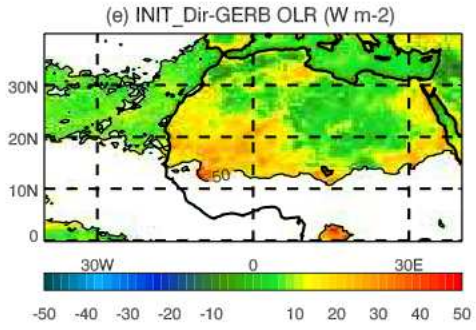
Radiation & meteorology

direct/indirect aerosol effect







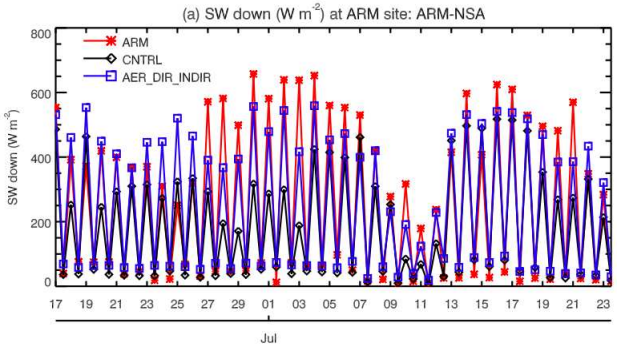


Aerosol direct effect:

- AER improves model biases in OLR over West Africa (due to better representation of mineral dust)
- Smaller improvement in INIT due to smaller dust loadings in the initialised simulations at short forecast lead times

Aerosol indirect effect:

- Improves surface SW↓ biases in NH high latitudes



- Improves T and Height forecasts
- Small impact on hydrological cycle/ circulation pattern
- Leads to a strengthening of low-level monsoon flow over the Indian monsoon region and increase in precip in SE Asia

Questions and answers

Useful references

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