Image courtesy of
http://qldplanespotting.blogspot.com/
Air New Zealand Boeing777 at Brisbane
Sept 2009

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Aircraft Engine Dust Ingestion at Major Global Airports

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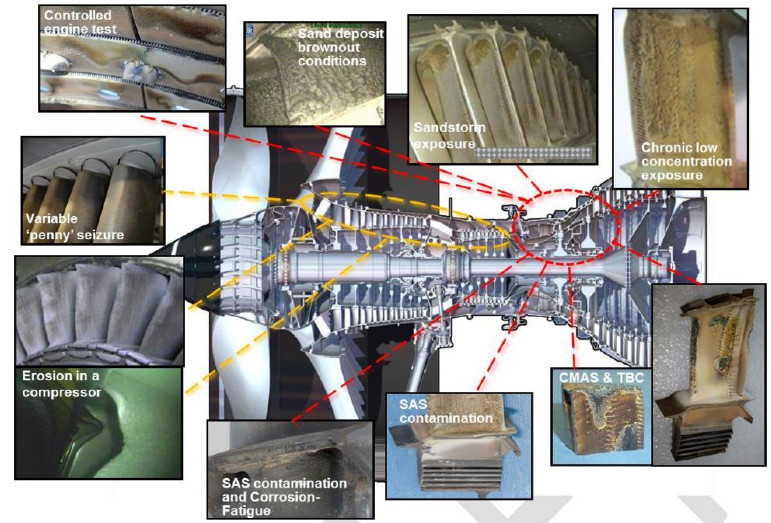
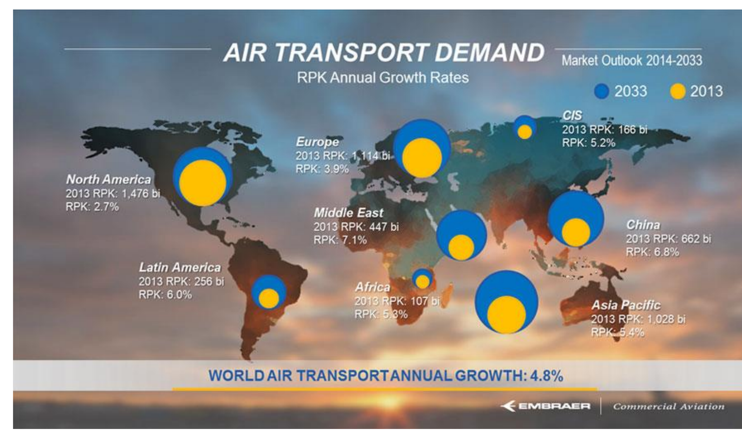
Motivation

- Technological developments in aircraft engines → less tolerant to dust
    - Quieter, more fuel/weight efficient, more complex and intricate cooling systems, vulnerable materials and coatings
- Increased air traffic in dusty areas
    - Middle East, Northern India, Central Asia
- Change in Airlines' economic models
    - Airlines have service contracts with engine suppliers; Financial risk passed to supplier; airlines pressurized to maximize operation
- Dust does not (mostly) cause short term threats to safety; long term engine wear



Engine damage mechanisms from sand and dust: SAS – secondary Air System, CMAS – Calcium Magnesium Alumino-Silicate, TBC – Thermal Barrier Coating (a thin layer of ceramic)

Clarkson, 2019

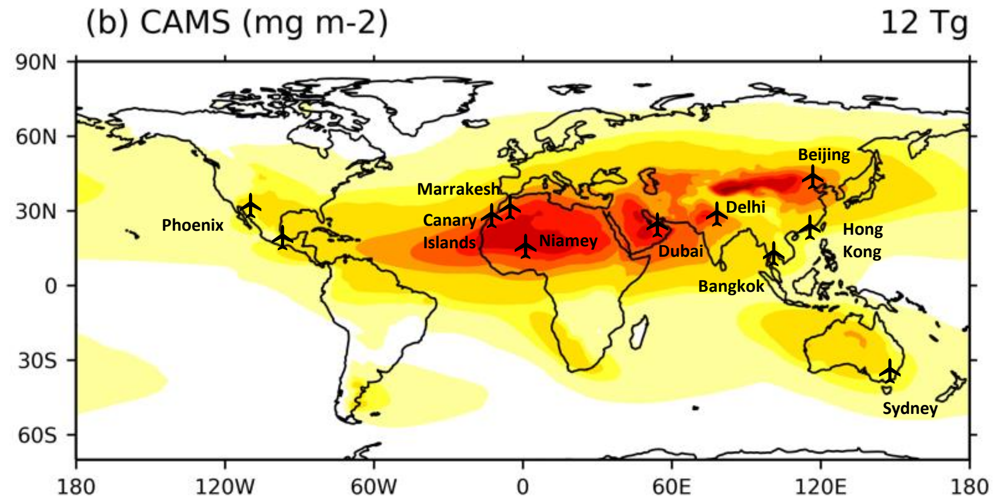


Regional growth in air traffic 2013-2033 (www.airlines.iata.org)

Key Questions

- Dust is degrades engine performance:
  - Where, when, how much?
- What is the vertical distribution of dust at major airports?
- How does this vary seasonally and diurnally?
- How much dust is ingested into engines? (Dust dose)
  - Which portions of the vertical profile of dust contribute most?
- How similar is model dose to observations?
- What can be done to reduce dust ingestion?

Global Dust Distribution and Airport Locations



CAMS Climatological Global mean dust load, A. Zhao et al. (2021), ACP

Data

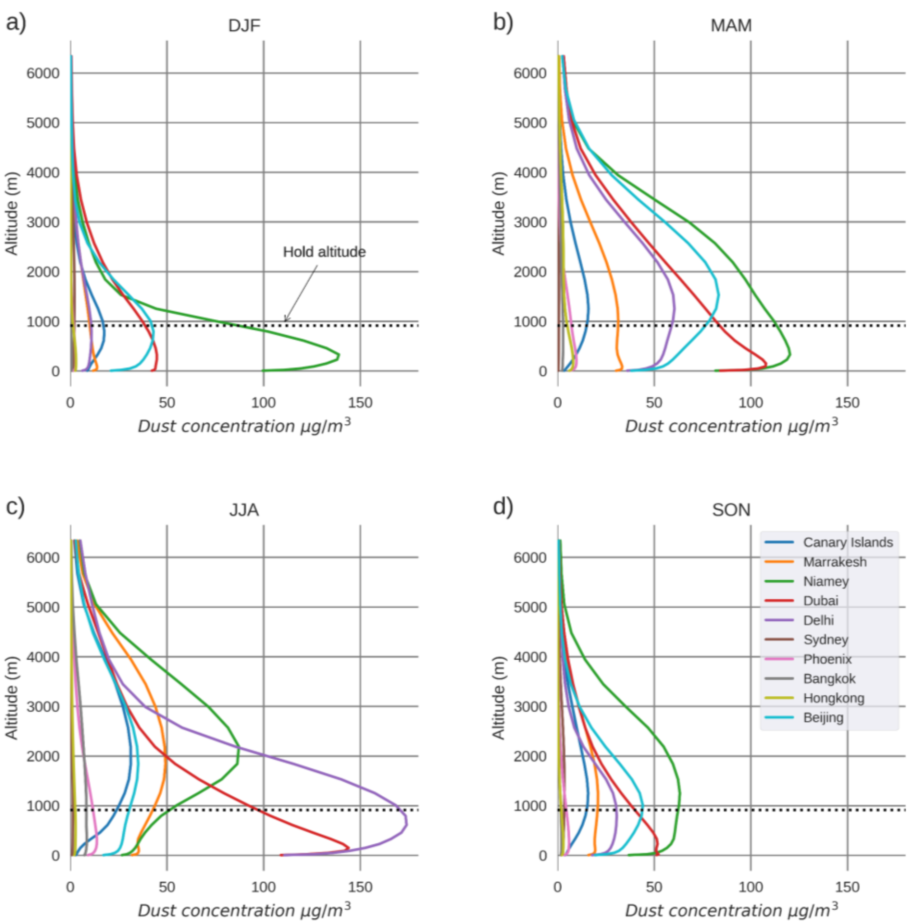
CAMS Reanalysis
- 2003-2020
- Vertically resolved mass concentration
- ~80km spatial resolution

CALIPSO spaceborne lidar observations
- NASA CALIOP L3
- LIVAS dataset
- Night time observations, ‘pure’ dust datasets
- Vertically resolved backscatter (calculate extinction, mass concentration)

Dust Dose Calculations
- Typical aircraft altitude & engine data provided by Rolls-Royce
- w_{core}=mass flow of air entering engine core, varies with engine operation (& therefore altitude)
- k_f=fan concentration/dilution factor
- CAMS vs CALIPSO

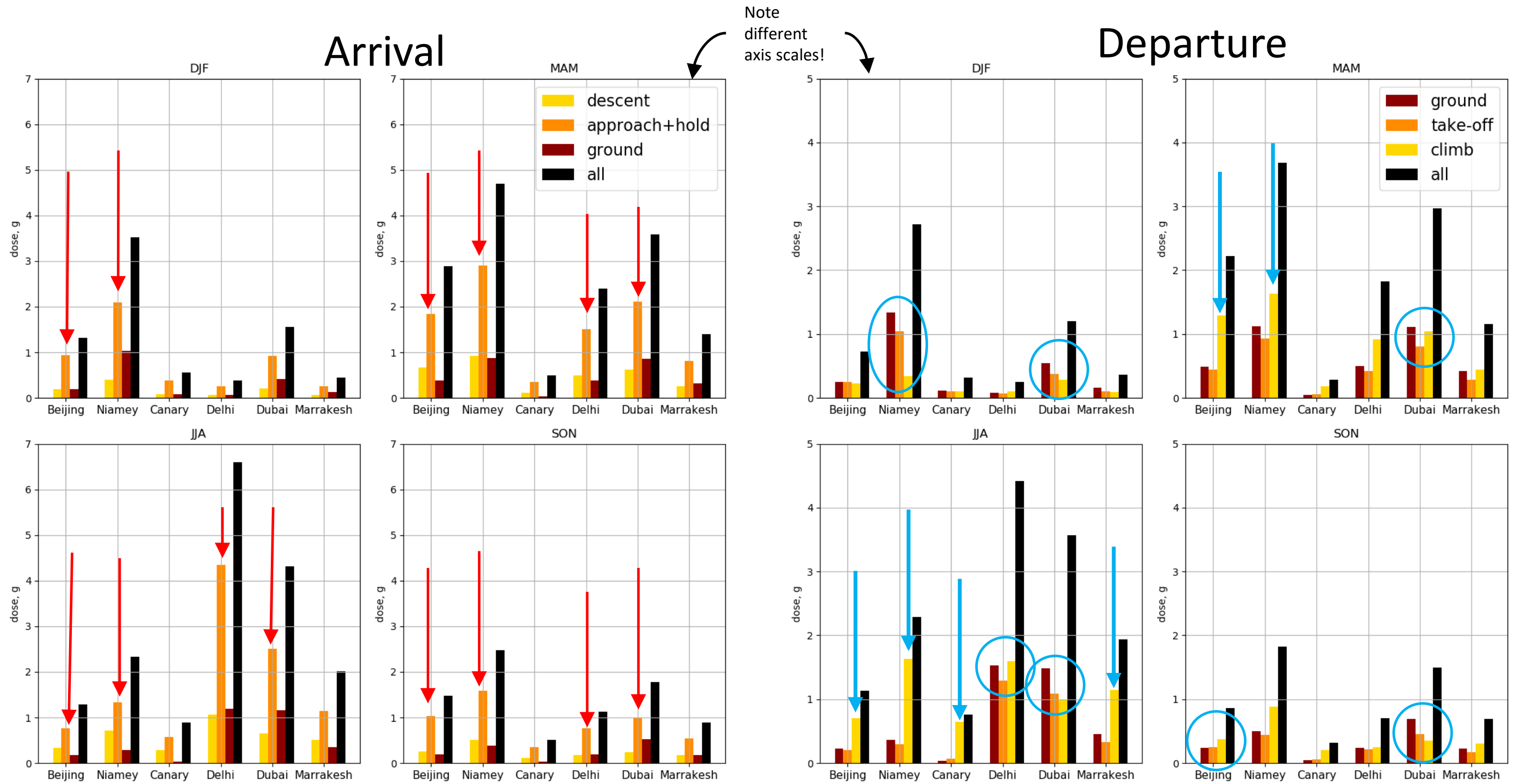
DEPARTURE	t (s)	alt (ft)	w (kg/s)	kf
Taxi	890	0	19.23	0.9
Take-Off	10	0	111.76	0.7
	60	35	113.76	0.7
	60	1500	110.99	0.7
	3	1500	98.88	0.8

Airport Dust Climatology: CAMS



- Seasonal cycles evident
- Vertical structure varies between airports and season
- Dustiest airports: Dubai, Delhi, Niamey, Beijing, Marrakesh, Canaries
- Elevated peaks notable for:
  - Niamey, Marrakesh, Beijing, Canaries (JJA)
  - Beijing, Delhi (MAM)
- Trends & patterns consistent with literature & known seasonality of dust

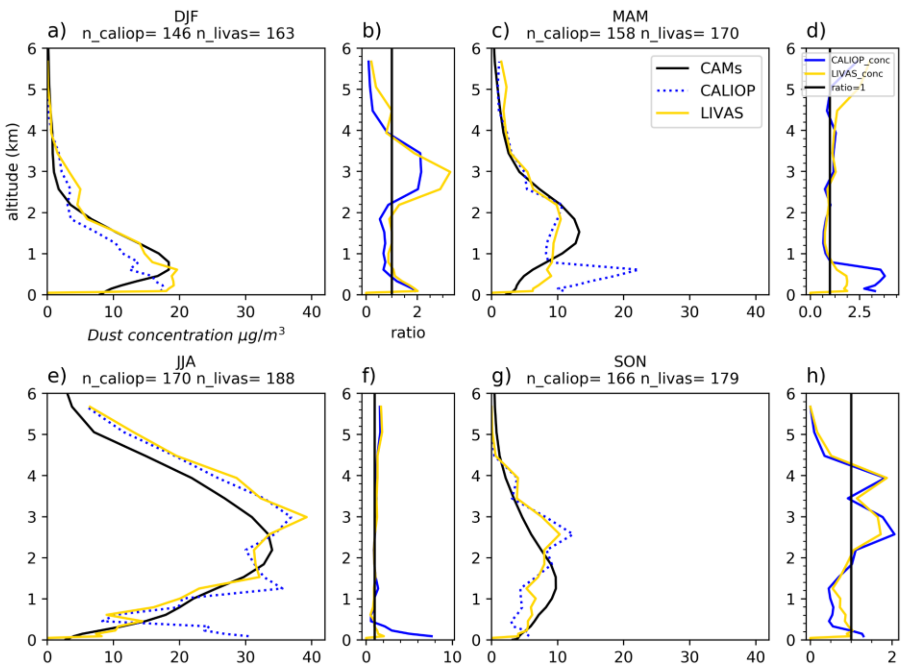
Airport Dose: Arrival vs Departure



- Highest dose in MAM & JJA: dustiest seasons, for both arrival and departure
- Arrival: strong contribution from holding phase
- Departure:
  - Strong contribution from climb in MAM & JJA for elevated dust plume airports
  - Otherwise ground/take-off/climb contribute equally, despite disproportionate short time spent in take-off, potential dose is high due to engine mass flow rate: influence of low altitude dust
- Arrival dose higher than departure; due to holding pattern
- Seasonal dust profile strongly affects dust dose

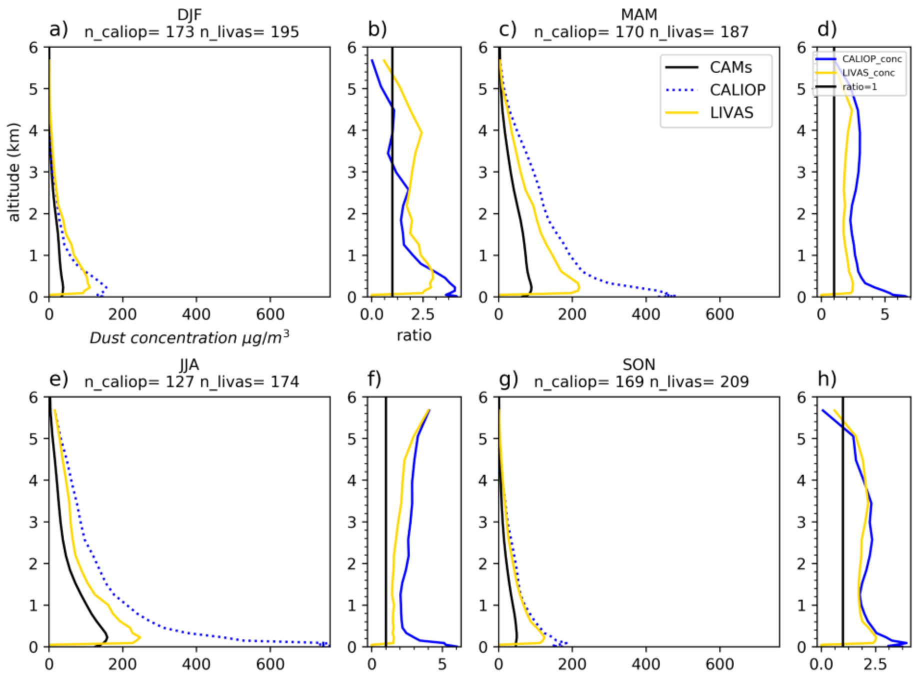
How does this compare to observational data?

CAMS vs CALIPSO: Canary Islands



- Example of good agreement between CAMS & CALIPSO with elevated dust
- Use CAMS dust optical properties to convert CALIPSO extinction to mass concentration

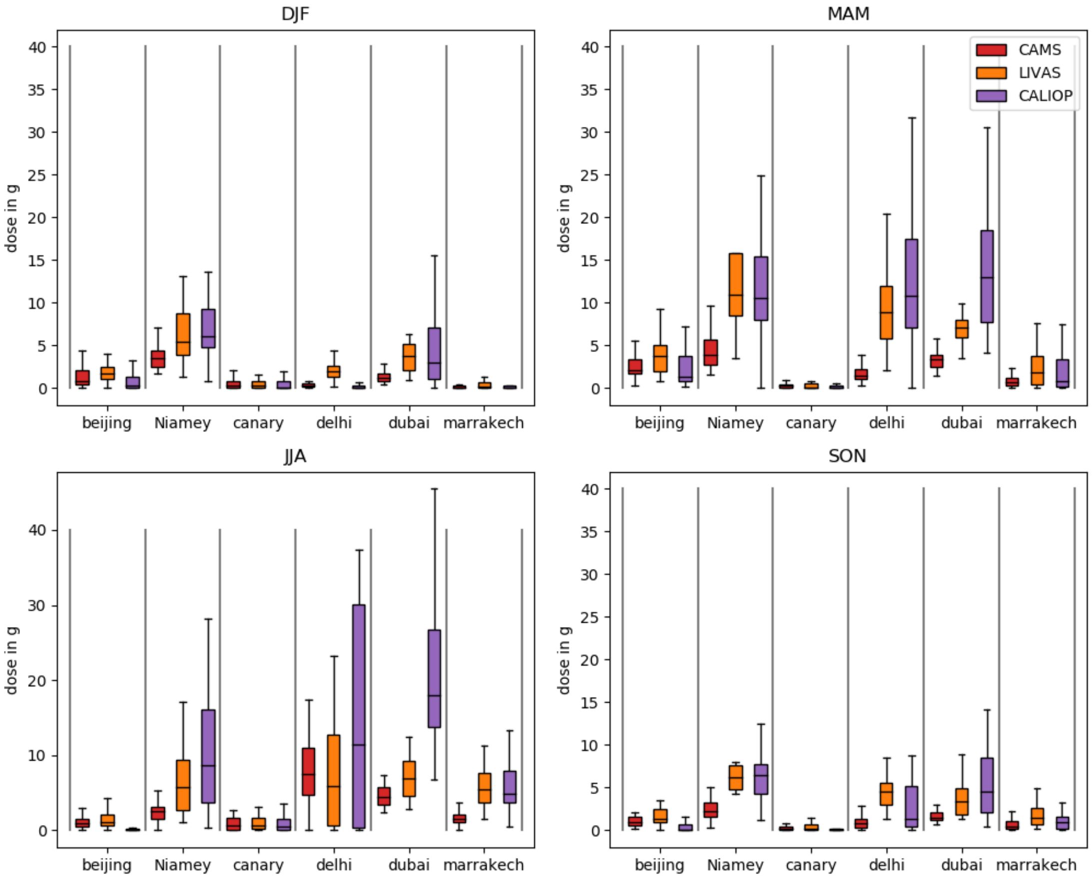
CAMS vs CALIPSO: Dubai



- Agreement worse at Dubai
- Better for LIVAS than CALIOP L3
- CAMS gets vertical structure and seasonal cycle correct
- Multiple explanations for differences…
  - Resolution, coverage, aerosol type DA, lidar signal strength close to surface in thicker dust, optical props, size distribution, lidar aerosol type ID… to name a few
- Other airports sit between Dubai & Canaries in terms of agreement between lidar & CAMS

Dose: Model vs Satellite Observations; Arrival

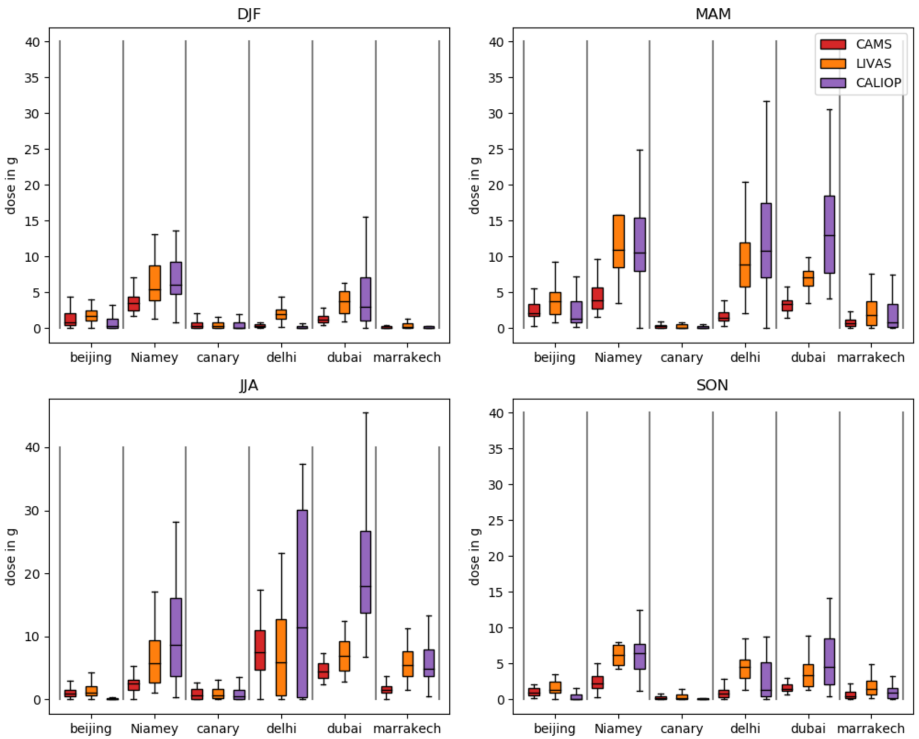
CAMS vs CALIPSO (CALIOP L3 & LIVAS)



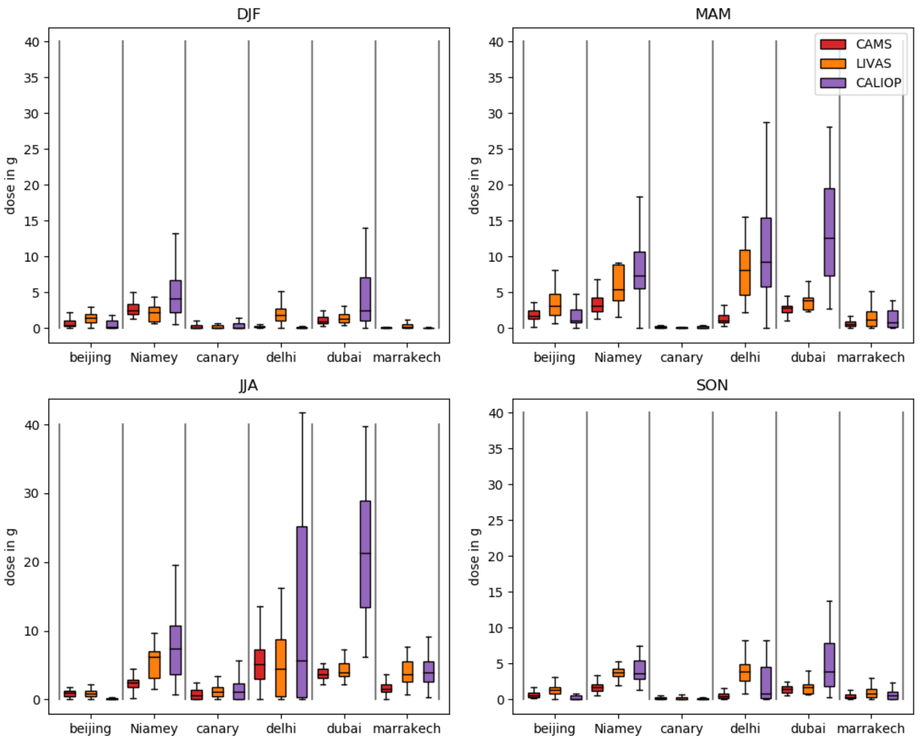
- CAMS dose generally lower than satellite-calculated dose
  - Generally lower values for LIVAS & better overlap with CAMS (19/24 vs 13/24 for CALIOP L3)
- More variability in lidar data
- Airports which have elevated dust year round (Canaries, Marrakesh, Beijing) have similar seasonal cycles for CAMS & lidar
- Lidar data strongly influenced by airports which have large surface concs (Niamey DJF/SON; Dubai; Delhi MAM)
- Niamey doses vastly different: CAMS has significantly lower mass concs in all seasons; even when elevated.
- **Caveats:** optical vs mass quantities; different vertical/spatial resolution; night time only; temporal sampling co-located; dust identification method

Dose: CAMS vs CALIPSO; Arrival vs Departure

Arrival



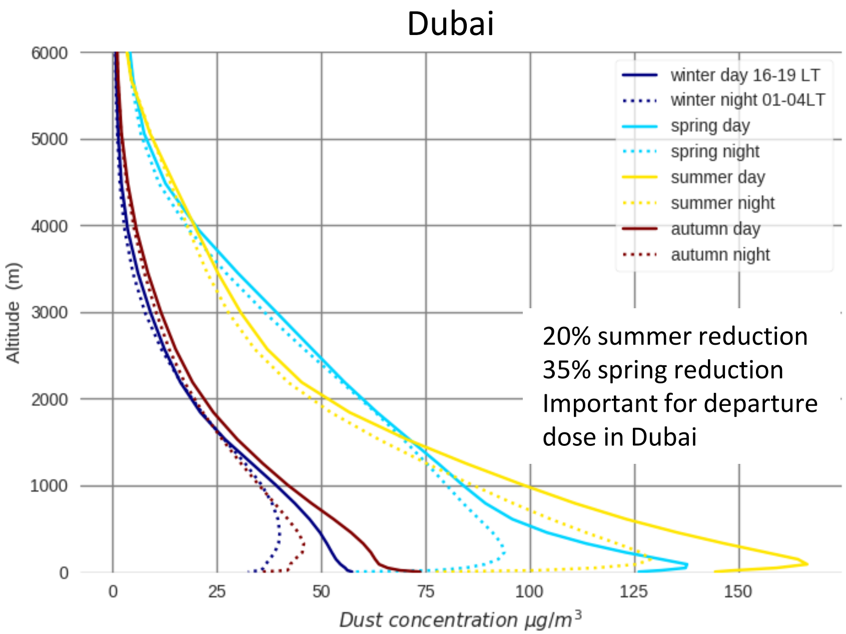
Departure

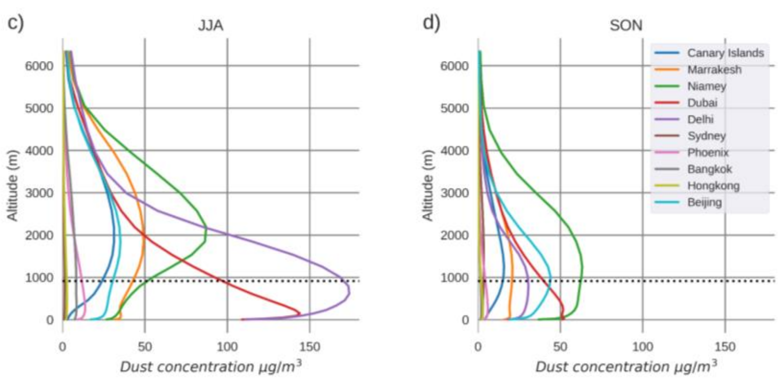


- For Departure:
  - CAMS vs lidar dose differences even larger where profiles peak near surface (e.g. Dubai) since surface contribution more important for departure
  - Niamey: overall conc differences are more important than vertical profile differences

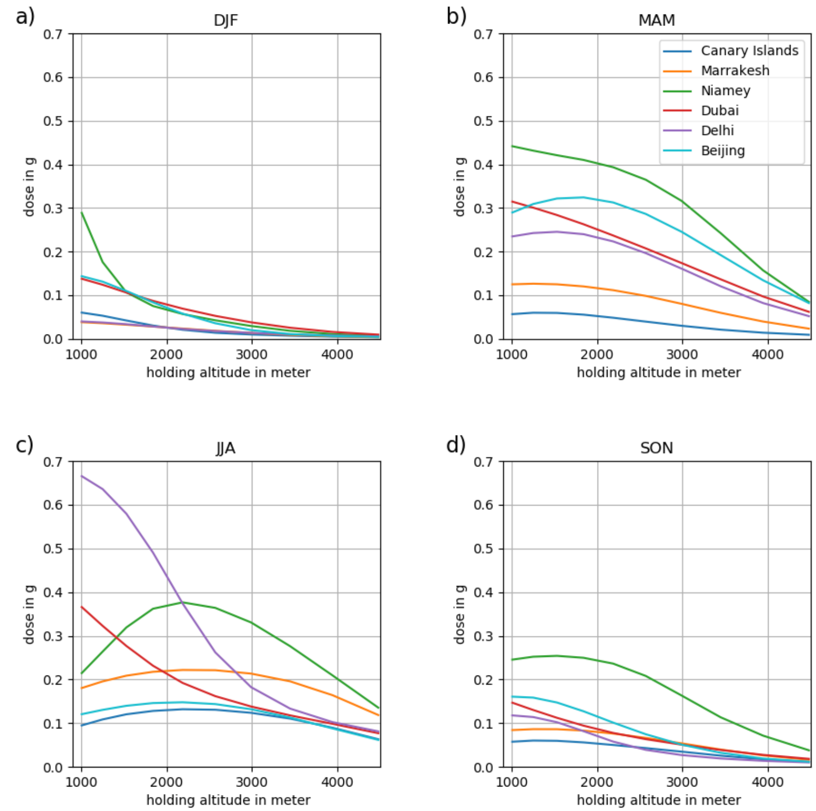
Mitigation

Time of Day





Altitude of Holding Pattern



- Hold altitude can be varied to reduce dust dose
- Raising or lowering benefits depend on the vertical profile of dust

Conclusions

- Dust Dose higher for arrival than departure (hold pattern); low-level dust important for departure dose
- CAMS reanalysis vs spaceborne lidars
  - Seasonal cycle well-represented
  - Magnitude: in many cases CAMS appears to underestimate dust dose
  - Underestimation due to differing vertical profiles, especially near surface (important for departure dose)
  - Caveat: large uncertainties
- Recommendations for avoiding dust ingestion: adjust time of day and holding pattern altitude