Evaluation of HadGEM3 Southern Ocean cloud using observations and reanalyses

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Introduction

Shortwave radiation (SW) bias in the Southern Ocean (SO) is present in multiple general circulation models due to cloud representation.

Possible causes:

- Cyclones (cold sectors)
- Boundary layer stability/thermodynamics
- Cloud-aerosol interaction / ice nuclei
- Cloud (in)homogeneity
- Cloud phase – supercooled liquid
- Sub-gridscale cloud parametrisation

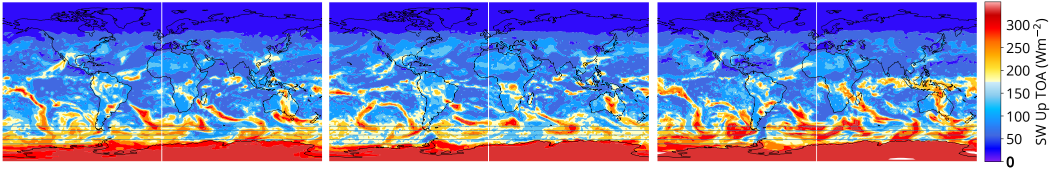
SO view from space

3 December 2018, DSCOVR/EPIC, https://epic.gsfc.nasa.gov.

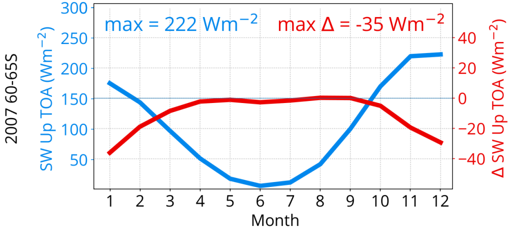
Models and reanalyses

- NZESM (NIWA version of HadGEM3) – GA7.0 and GA7.1 atmospheric model
  - 1980–89 run (non-nudged)
  - 2007 run (nudged)
- MERRA-2 reanalysis
  - years 2015–2018

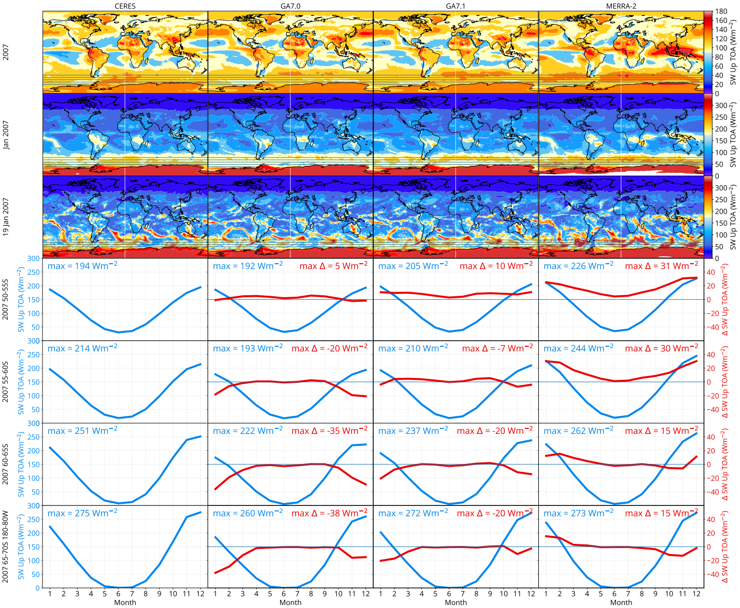
SW radiation bias



CERES (Satellite) GA 7.0 MERRA-2



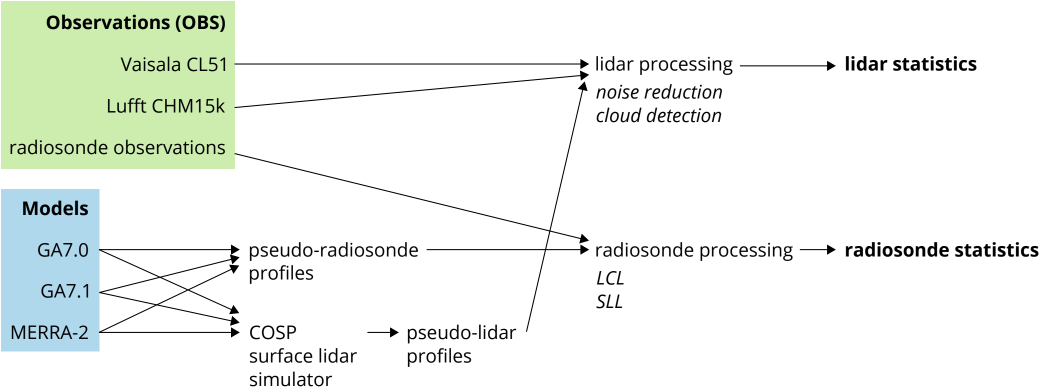
GA 7.0 vs. CERES


CERES
GA7.0
GA7.1
MERRA-2
2007
Jan 2007
19 Jan 2007
SW Up TOA (Wm^{-2})
2007 50-55S
2007 55-60S
2007 60-65S
2007 65-70S 180-80W
max = 194 Wm^{-2}
max = 192 Wm^{-2}
max Δ = 5 Wm^{-2}
max = 205 Wm^{-2}
max Δ = 10 Wm^{-2}
max = 226 Wm^{-2}
max Δ = 31 Wm^{-2}
max = 214 Wm^{-2}
max = 193 Wm^{-2}
max Δ = -20 Wm^{-2}
max = 210 Wm^{-2}
max Δ = -7 Wm^{-2}
max = 244 Wm^{-2}
max Δ = 30 Wm^{-2}
max = 251 Wm^{-2}
max = 222 Wm^{-2}
max Δ = -35 Wm^{-2}
max = 237 Wm^{-2}
max Δ = -20 Wm^{-2}
max = 262 Wm^{-2}
max Δ = 15 Wm^{-2}
max = 275 Wm^{-2}
max = 260 Wm^{-2}
max Δ = -38 Wm^{-2}
max = 272 Wm^{-2}
max Δ = -20 Wm^{-2}
max = 273 Wm^{-2}
max Δ = 15 Wm^{-2}
Δ SW Up TOA (Wm^{-2})
Month

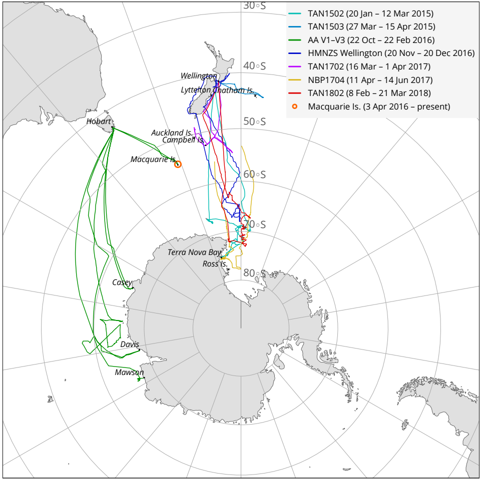
Methods

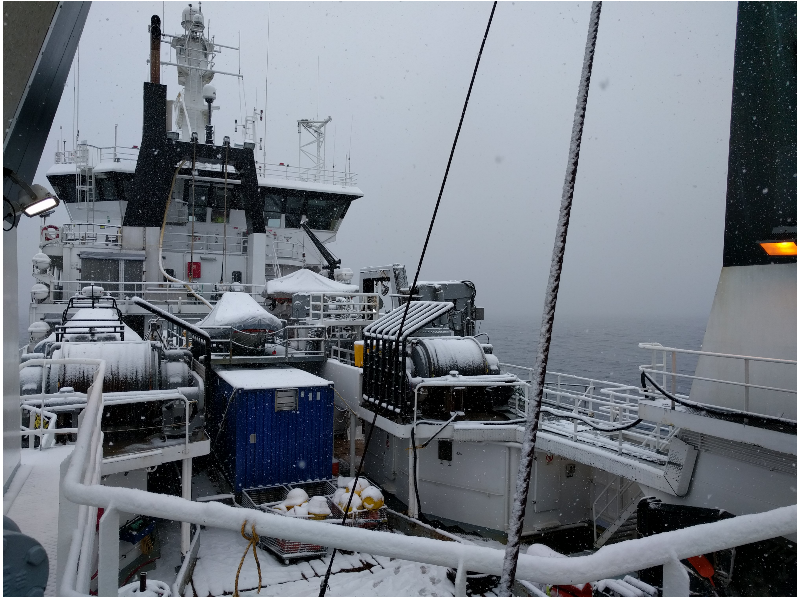
- Comparison:
  - GA7.0, GA7.1, MERRA-2 models
  - ship observations (OBS)
- COSP simulator:
  - ground-based lidar simulator based on ACTSIM (CALIPSO lidar sim.)
  - reversal of layers
  - account for different Mie and Rayleight scattering (wavelength dependence)
- Derived quantities:
  - lidar cloud detection, noise removal
  - cloud occurrence statistics
  - model “pseudo-radiosoundings”, lifting levels

Processing pipeline – lidar and radiosoundings / model & OBS



Southern Ocean voyages (1/2)





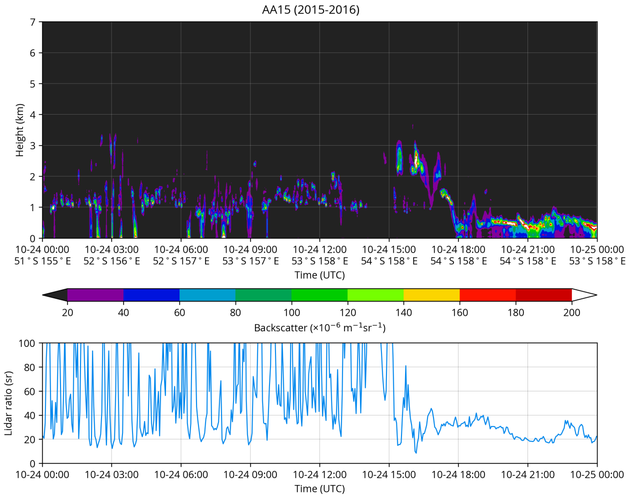
How to defend yourself against a penguin (with a broom)

TAN1802, 2018, Ross Sea. Photo by Amelia Connell.

Southern Ocean voyages (2/2)

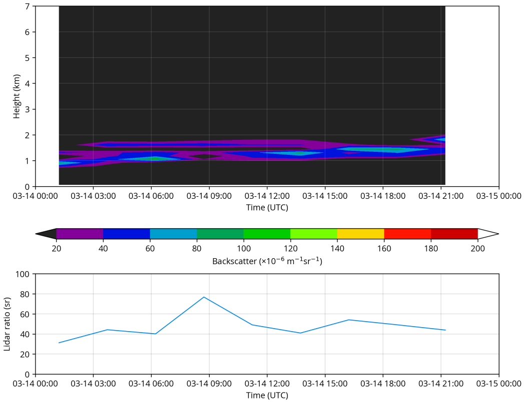
- Instruments:
  - ceilometer – Vaisala CL51 & Lufft CHM 15k
  - radiosondes
  - AWS
- Voyages:
  - TAN1802 – RV Tangaroa, NIWA, Ross Sea, 2018
  - TAN1502 – RV Tangaroa, NIWA, Ross Sea, 2015
  - HMNZSW16 – HMNZS Welligton, Royal New Zealand Navy, Ross Sea, 2016
  - NBP1704 – Nathaniel B. Palmer, NSF, Ross Sea, 2017
  - AA15 – Aurora Australis, AAD, 2015–2016
- Subsets:
  - by season: December–January–February (DJF), March–April–May (MAM)
  - by latitude: 55–60°S, 60–65°S, 65–70°S

Ceilometer



Vaisala CL51 backscatter, 24 hours. Aurora Australis ("AA15"), Davis Sea, 2015.

Pseudo-lidar (COSP)

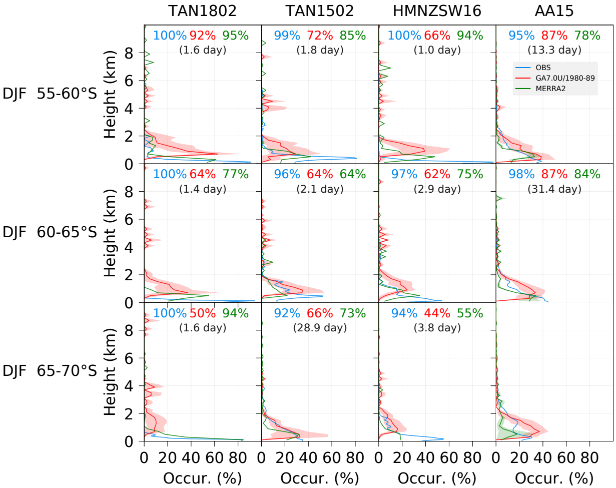


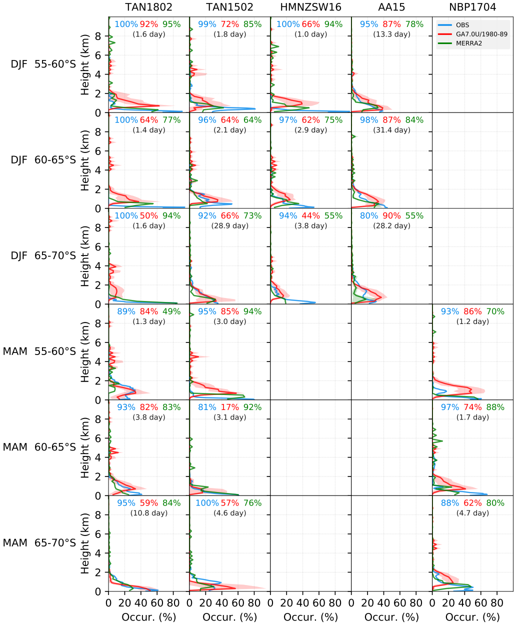
MERRA-2 (1 × 1 °), TAN1802 track, Ross Sea, 14 March 2018.

Results

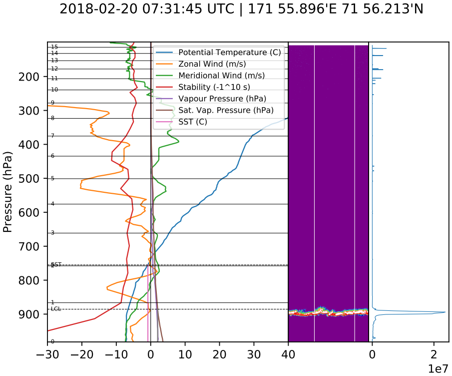
- GA7.0 vs. MERRA-2 vs. ship observations
  - Cloud occurrence
  - SST lifting level
  - Zonal plane plots
- TAN1802 human & AWS observations

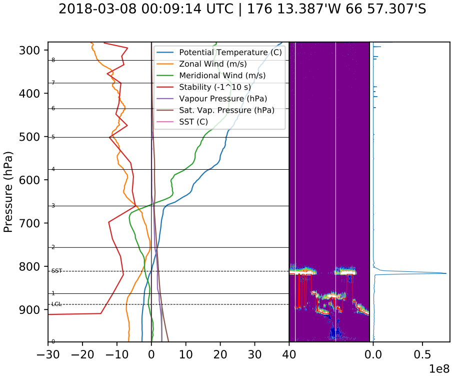
Cloud occurrence




TAN1802
TAN1502
HMNZSW16
AA15
NBP1704
OBS
GA7.0U/1980-89
MERRA2
DJF 55-60°S
DJF 60-65°S
DJF 65-70°S
MAM 55-60°S
MAM 60-65°S
MAM 65-70°S
Height (km)
Occur. (%)
100% 92% 95% (1.6 day)
99% 72% 85% (1.8 day)
100% 66% 94% (1.0 day)
95% 87% 78% (13.3 day)
100% 64% 77% (1.4 day)
96% 64% 64% (2.1 day)
97% 62% 75% (2.9 day)
98% 87% 84% (31.4 day)
100% 50% 94% (1.6 day)
92% 66% 73% (28.9 day)
94% 44% 55% (3.8 day)
80% 90% 55% (28.2 day)
89% 84% 49% (1.3 day)
95% 85% 94% (3.0 day)
93% 86% 70% (1.2 day)
93% 82% 83% (3.8 day)
81% 17% 92% (3.1 day)
97% 74% 88% (1.7 day)
95% 59% 84% (10.8 day)
100% 57% 76% (4.6 day)
88% 62% 80% (4.7 day)

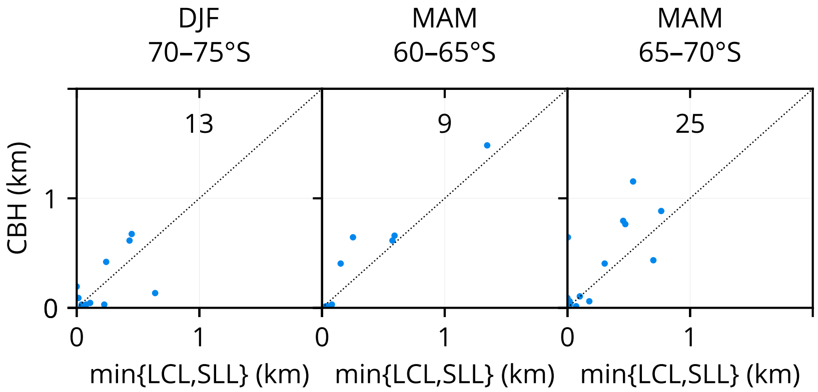
Lifting level / cloud base height (1/2)





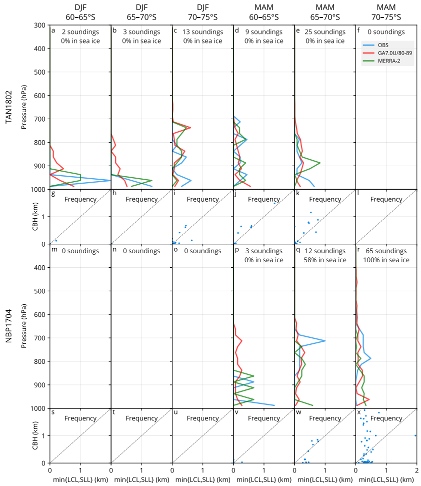
TAN1802, RV Tangaroa, Ross Sea, 2018.

Lifting level / cloud base height (2/2)

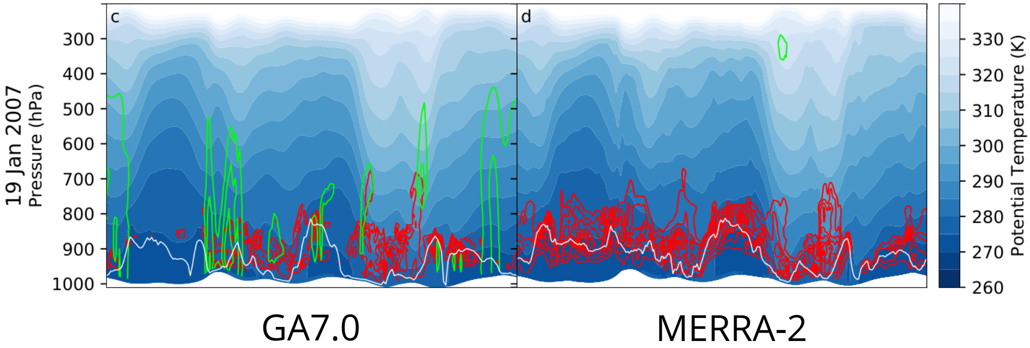


TAN1802, RV Tangaroa, Ross Sea, 2018.

SST lifting level

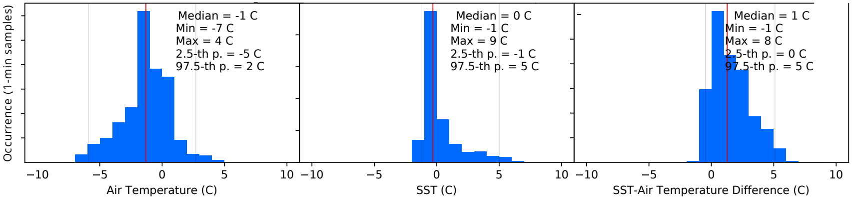


Zonal plane - GA7.0 vs. MERRA-2



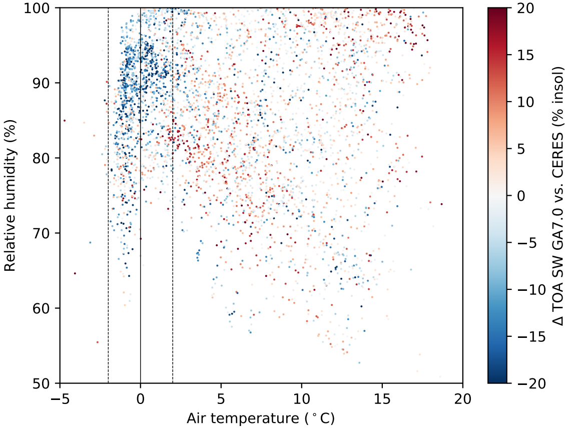
Daily average, latitude: 60°S, cloud liquid (red), cloud ice (green), potential temperature (blue).

TAN1802 human & AWS observations



Cloud Type/Cloud Cover	0	1	2	3	4	5	6	7	8	All
Stratus	0	0	0	0	0	0	0	3	49	52
Nimbostratus	0	0	0	0	0	0	2	0	21	23
Stratocumulus	0	2	0	0	0	0	5	13	8	30
Cumulus	0	0	0	0	0	0	1	1	0	2
Altostratus	0	0	0	0	0	1	0	3	1	5
Altocumulus	0	0	0	0	0	1	2	3	1	7
Cirrus	0	0	0	0	0	0	0	2	0	2
All	0	2	0	0	0	1	5	16	75	100

GA7.0 vs. CERES, where is the SW bias?



GA7.0 grid cells *40–70°S*, 19 January 2007.

Conclusion

- Cloud cover is near 100% in the SO, with predominant low cloud (Sc, St).
- Cloud cover is underestimated in GA7.0 and MERRA-2 relative to ship observations by approximately 20% and 10%, respectively.
- There is close correspondence between lifting levels (min{SLL,LCL}) and cloud base height observed by ceilometer, suggesting role of boundary layer thermodynamics/stability.
- SLL does not appear to differ significantly between radiosonde observations and GA7.0 and MERRA-2.
- MERRA-2 simulates much more liquid content than GA7.0. GA7.0 simulates some ice content, but not enough to compensate.
- Synoptic scale structures and thermodynamics do not appear to be different enough between GA7.0 and MERRA-2 to explain the difference in cloud.

Acknowledgments