THE DEEP SOUTH | Te Kōmata o Te Tonga | National Science Challenges

UC University of Canterbury, Te Whare Wānanga o Waitaha, Christchurch New Zealand | Gateway Antarctica | NIWA Taihoro Nukurangi

Shipborne and ground-based observations of clouds in the Southern Ocean

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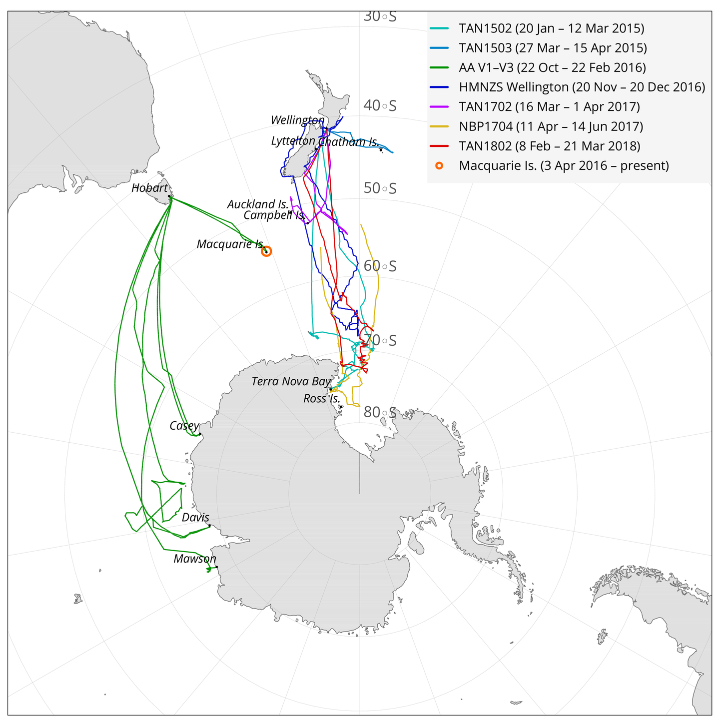
1 Abstract

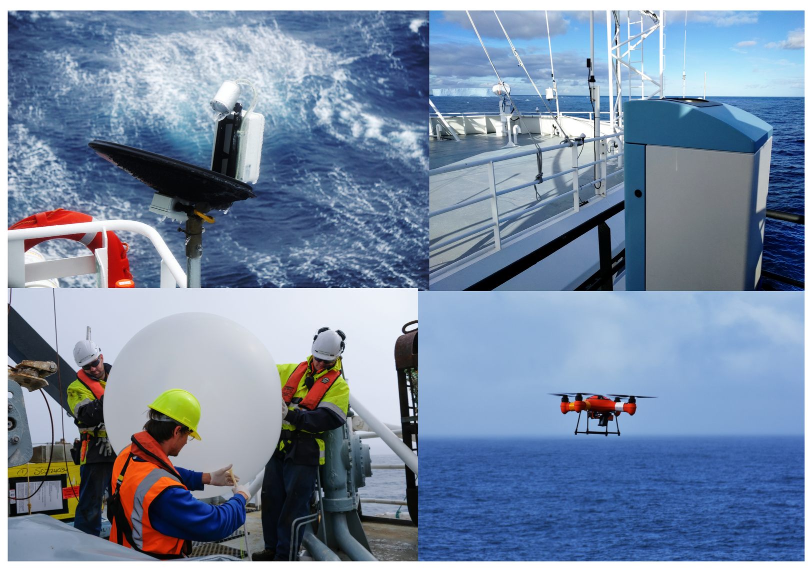
Satellites provide unprecedented spatial and temporal coverage of cloud and aerosol observations in inaccessible regions such as the Antarctic. However, their view is hindered by overlapping cloud, reducing their applicability in the Southern Ocean, where cloud fraction can reach 90%. We present a collection of Southern Ocean ground-based observatons made on voyages and Subantarctic islands. Our primary aim is to identify processes in general circulation models (especially HadGEM/GA7) which lead to underestimation of cloud in the region and the resulting shortwave radiation bias of up to 30 W/m². Using ceilometer measurements and a newly-made ceilometer simulator based on the CFMIP Observation Simulator Package (COSP) lidar simulator we identified strong deficiencies of simulated cloud in the first 500 m above sea level. Colocated radiosonde observations suggest convection due to relatively warm ocean surface (relative to sub-zero surface air temperature) is a strong driver of cloud formation in the region.



▲ Map showing the voyage tracks.

2 Voyages and Instruments

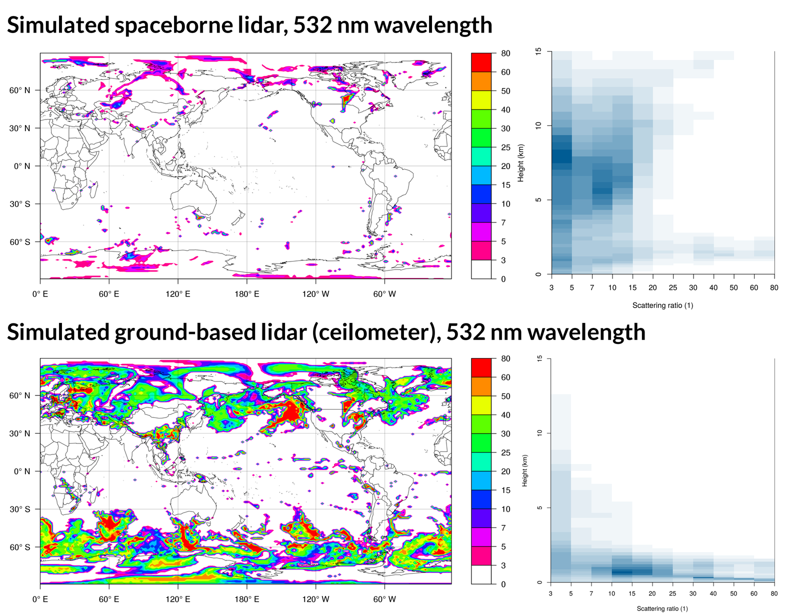
Overall, we deployed our instruments on 7 Southern Ocean voyages and one Subantarctic island over the period of 4 years. These included ceilometers (Lufft CHM 15k, Vaisala CL51), rain radar (Metek MRR-2), micropulse lidar (MiniMPL), radiosondes and aerosol optical particle counters. Supplementary data from ship automatic weather stations is available. Optical particle counters were also deployed on a UAV and helikite flights to altitude of up to 200 m above sea level.



▲ Instruments deployed on the TAN1802 voyage.

3 Ceilometer and Ceilometer Simulator

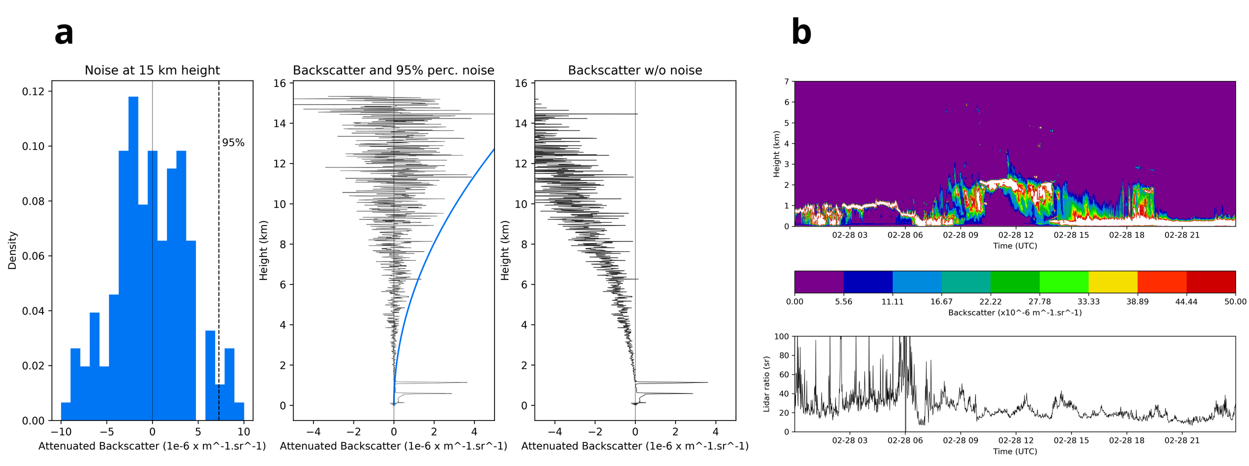
Ceilometers are ground-based low-power lidars, capable of measuring the cloud base and 2-dimensional profile of backscatter. Identifiable features include cloud layers, precipitation and the boundary layer. This is similar to the satellite lidar CALIPSO, but allows us to observe cloud from below. Lidar pulses are quickly attenuated by thick cloud, and this affects how cloud is seen from the ground and from space. Due to attenuation, cloud layers identified by a lidar cannot be compared directly with model clouds, a lidar simulator is required to produce pseudo-observations. We have modified the COSP/ACTSIM space lidar simulator to account for a different viewing geometry and wavelength of the ceilometer.



▲ Geographical distribution of low-level cloud as seen by a ground-based and spaceborne ceilometer simulator.

4 Noise Estimation and Backscatter Calibration

Unlike the ceilometer simulator, backscatter measured by a ceilometer is affected by noise and imprecise calibration constant. Noise can be determined by the highest measured level of 15 km where no cloud is present. Calibration can be performed thanks to the fact that the lidar ratio in fully opaque cloud scenes tends to be close to a known constant. Noise estimation and calibration allows us to determine confidence bands on measured backscatter.

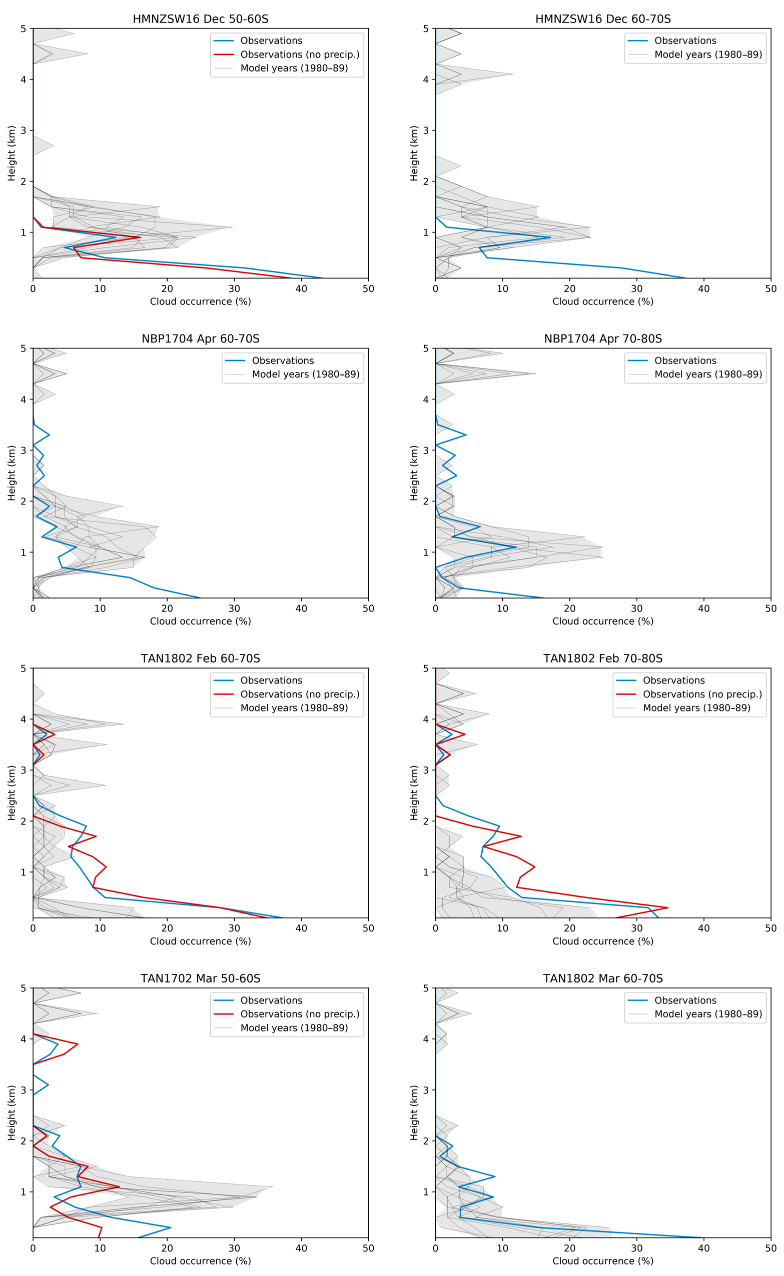


▶ **a, Noise reduction based on noise at 15 km. b, Backscatter profile and lidar ratio.**

5 Cloud Occurrence

We compared vertical distribution of cloud occurrence from model output and observations from 3 different voyages. Model data was selected from grid cells along voyage tracks and divided by months and latitude bands. Model vertical distribution of cloud occurrence was determined based on the ceilometer simulator, and cloud layers were identified using a backscatter threshold. We found that the model underestimates low cloud or fog, especially in the bottom 500 m. This is not possible to assess with current spaceborne instruments: passive instruments such as MODIS can only observe cloud top of thick clouds, CALIPSO spaceborne lidar cannot see through thick clouds and CloudSat spaceborne radar is affected by ground clutter. Co-located voyage automatic weather station (AWS) and radiosonde measurements will allow us to further identify conditions leading to this cloud bias.

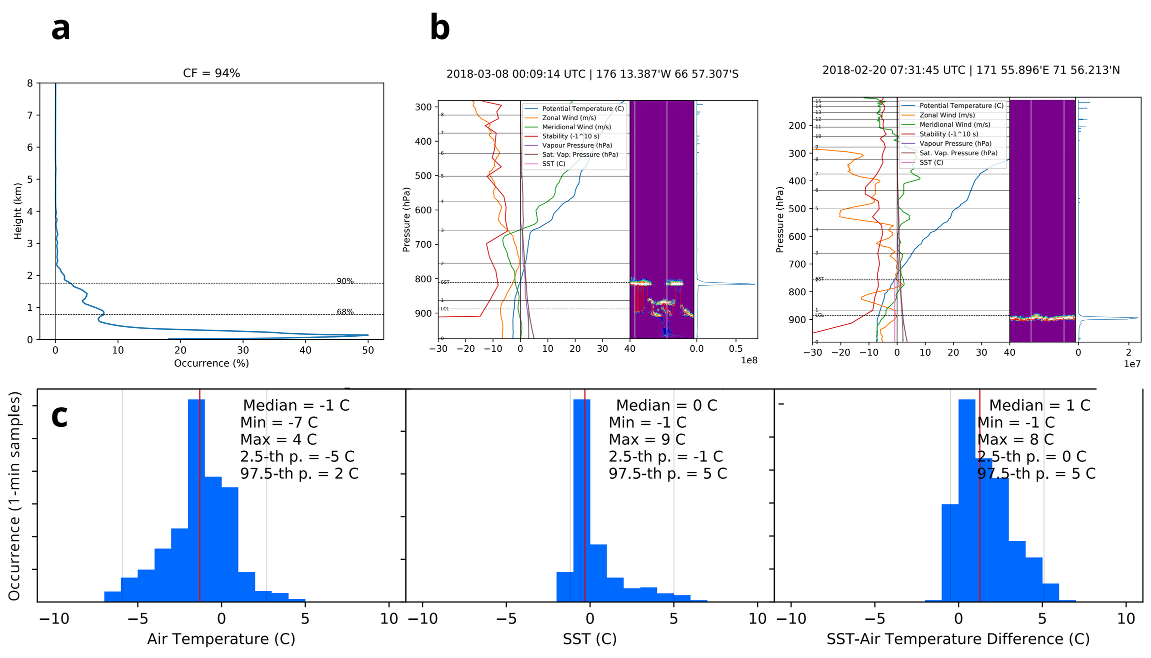
Vertical distribution of cloud occurrence derived from 10 years of HadGEM/GA7.0 data using the ceilometer simulator applied on grid cells selected along voyage tracks and the actual cloud occurrence measured by a ceilometer. ▶



6 Shallow Convection Over Warm Water

The TAN1802 voyage involved 30 days between 60 and 73° S in the Ross Sea. We observed cloud occurrence of 94% and cloud types mostly stratus (52%), nimbostratus (23%), stratocumulus (30%) covering 8 octas (75%) and 7 octas (16%). Surface air temperature was mostly sub-zero, while sea surface temperature (SST) was mostly close to 0 °C. We observed good correlation between cloud layers as seen by a ceilometer and the derived lifting levels (lifting condensation level (LCL) and lifting level of air parcels with temperature equal to SST). This suggest thermodynamics was an important driver of low cloud formation.

▶ **a, Vertical distribution of cloud base measured by a ceilometer. b, Radio soundings colocated with backscatter profiles. c, Distribution of air and sea temperature south of 60 °S.**



▶ **Frequencies of cloud types and cloud cover.**

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

We assessed AWS, radiosonde and ceilometer observations from the TAN1802 R/V Tangaroa voyage to the Ross Sea in February and March 2018. Cloud occurrence was characterised by highly predominant low stratus, stratocumulus and nimbostratus. We found good correlation between vertical distribution of cloud occurrence, thermodynamic profile of the atmosphere and sea surface temperature. Sea surface temperature was generally higher than the surface air temperature, triggering convection and condensation in the lower part of the troposphere. This suggest that biases in model surface air temperature over the high-latitude Southern Ocean might be partly responsible for the model cloud bias and resulting shortwave radiation bias.

7 Acknowledgements

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