REVIEW OF THE OPERATION OF THE CAP

RESPONSE SHEET FOR COMMENTS ON DRAFT REPORT

The March 2000 draft report on the **Review of the Operation of the Cap** by the Cap Project Board to the Murray-Darling Basin Ministerial Council is now available for public comment. Comments on the draft report are due by **10 July 2000**.

The draft report, and further copies of this response sheet, is available from the Murray-Darling Basin Commission and from the Commission's web site:
www.mdbc.gov.au

If you wish, you may use this form to tell us what you think about the position of the Cap Project Board in their report on the Review of the Operation of the Cap. If there is insufficient space on the form, you may add additional sheets or write a separate submission.

The draft report will be modified to reflect comments received and a final report on the Review of the Operation of the Cap will be presented to Ministerial Council Meeting 29 in August 2000.

Those who provide comments will receive a copy of the final Report once it has been approved by the Ministerial Council.

COMMENTS BY: The Australian Management Consolidated Pty. Ltd.

CONTACT DETAILS: Aron Gingis, Managing Director,
2A Walker Grove Cheltenham Victoria 3192
Phone: (03) 95845690, Fax: (03) 95845625
Email: amc21@hotmail.com

DATE: 7 July 00

The deadline for comment is **10 July 2000.**

Comments (by e-mail if possible – this response sheet is available electronically on the Commission's web site) should be directed to:

Review of the Operation of the Cap
Murray-Darling Basin Commission
GPO Box 409
CANBERRA ACT 2601

Attn: Dr Tony McLeod, Project Manager
Tel: 02 6279 0144
Fax: 02 6230 7579
Email: tony.mcleod@mdbc.gov.au

or your local member of the Community Advisory Committee (CAC). Those comments made via the CAC that are received prior to **Friday 16 June 2000** will be considered at CAC Meeting 24 – 27 June 2000.

	Cap Project Board Position	Comment

Ecological Sustainability of Rivers	The Project Board has concluded that the Cap has been an essential first step in providing for the environmental sustainability of the river system of the Basin. Without the Cap, there would have been a significantly increased risk that the environmental degradation of the river system of the Murray-Darling Basin would have been worse.	This conclusion is correct, but it also should be based on solid scientific evidence or reasonable consideration of the other issues involved with the environmental sustainability of the river system of the Basin. Recent scientific discovery of Prof. Daniel Rosenfeld in association with Australian Management Consolidated Pty. Ltd. (AMC) that urban and industrial air pollution suspected to cause substantial reduction of natural rainfall in the Snowy Mountains and Victorian Alps and possibly in other important catchments of MDBC was not considered by the Cap Project Board. These findings were published on 10 March 2000 in the “Science” journal, titled “Suppression of Rain and Snow by Urban and Industrial Air Pollution” and were available to the Cap Project Board for consideration. (See Attachment 1, ”Suppression of Rain and Snow by Urban and Industrial Air Pollution.”). That paper focuses on southeastern Australia and provides direct physical evidence that: 1. Pollution tracks are seen very clearly in the clouds, and could be pinpointed to individual pollution sources, such as power stations. 2. The precipitation from clouds impacted by the air pollution is inhibited, to the point of total suppression in some cases. 3. The pollution inhibits also the production of snow in the clouds and it is suspected reducing amount of precipitation in the Snowy Mountains and Victorian Alps. We suspect that the average losses of winter precipitation over these areas could be accounted for about 25-30% of the natural precipitation on average year, which estimated by our company at about 5,000,000 ML. The Regional Rainfall Data purchased by us from the Bureau of Meteorology was not of sufficient quality to confirm these calculations with required level of certainty. AMC and Prof. Rosenfeld have proposed a 6 month project to MDBC to conduct quantitative assessment of the potential environmental damage that is already occurring, and potential ways for rectify the situation. However, to date MDBC, NSW, Queensland and South Australian Governments have not committed to any action to follow on that. MDBC has been briefed on this issue in August 1999.

	However, the Project Board has concluded that there is no certainty that the Cap on diversions at its current level represents a sustainable level of diversions – the level at which it is set being that which existed at the time when it was decided to introduce a Cap. Further, the Project Board recommends that as better information informs our management of the Basin's resources, the level at which the Cap is set should continue to be refined to reflect our increased understanding. It is likely that such refinements may lead to the lowering of the level of the Cap in some valleys. Indeed, some jurisdictions have already increased the environment's share, via access restrictions in addition to that required by the Cap, as part of their longer-term direction of improved water management.	Better information is available to MDBC and Cap Project Board from "Draft EIS May 1993, Snowy Precipitation Enhancement Project, Proposal to Evaluate Feasibility of Increasing Precipitation on the Snowy Mountains Area. SMHEA report found (see Page 8-25) that there are strong indications that the amount of snow has decreased substantially in the Snowy Mountains during the last century and suggested that there are other management initiatives that could be utilized to restore natural precipitation there. The Board must properly explore and consider information available and strong evidence to suspect that at least 1,000,000 ML of water lost in the Snowy Mountains area alone per average year due to air pollution by human activities which is not related to agriculture or irrigation. MDBC and AMC can jointly take immediate action to quantify losses caused by air pollution to the natural precipitation in the Snowy Mountains and Victorian Alps. Restore to the maximum possibly available natural rainfall and snowfall, increase environmentally necessary minimum flow to Murray, Murrumbidgee and Snow Rivers and than the Cap Project Board could recommend what changes needed to be implemented to the present level of the Cap, taking into consideration increase amount of water resources, environmental, economic and social implications of the Cap levels for individual valleys and even individual farmers. There is also a strong potential that the impacts of air pollution originated from Sydney, Woollongong, Newcastle and power stations in Hunter Valley, SE QLD and Gladstone could be affecting the natural rainfall in Central and NW NSW and SE QLD, between Brisbane and Rockhampton. All of that possibly lost natural precipitation, if recovered, could create those additional water resources and subsequent economic and environmental benefits to all MD Basin communities without the lowering of the level of the Cap, which the Cap Project Board is presently considering to implement.
	Cap Project Board Position	Comment
Economic and Social Impacts	The Project Board considers that there is compelling evidence that the Cap has already delivered significant economic and social benefits to the Basin community and that the net benefit will increase over time.	Substantial reduction of water allocation in most Basin communities could not bring any economic and social benefits as claimed by Cap Project Board. In contrary it has brought substantial losses of productivity, reduction of irrigation farm production, financial hardship and increase in unemployment of younger generation of irrigation farmers and seriously affecting economic development of rural Australia. The argument presented by Marsden Jacob Ass. that there are many other external factors causing social and economic demise of rural communities does not stand, since the beginning of civilization more water available for irrigation in an arid country, like Australia, always created more life and prosperity regardless of climate variability or shifts in commodity prices.

	The results of research conducted for the Review make it clear that, in the absence of the Cap, the erosion of security of supply for irrigators and other users would have been significant. These analyses were performed on several systems across the Basin reflecting diverse agricultural practices and climatic conditions.	Security of supply is indeed a very serious problem and more specifically when surface and ground water levels in majority of MDBC valleys is at the record low levels. Furthermore, there is observed reduction of precipitation due to air pollution, which yet remains to be quantified properly around the whole MD Basin. Therefore, MDBC must vigorously support every legitimate scientific research that may lead to quantify the precipitation reduction and use the finding for restoring the natural rainfall and snowfall in all-important locations within MD Basin.
	Through guaranteeing security of water supply at the valley level, the Project Board views the Cap as having provided a more certain climate for long-term investment and development, particularly in high value agriculture and value adding processing, as well as providing benefits to the environment.	The guarantee of security of water supply could only be achieved by increase of water available for distribution and not by unjustified reductions of water allocations. When the reservoirs are empty Cap Project Board could not guarantee security of supply anyhow and the high value agriculture and value adding processing developments are only market driven and could only sustained reductions of production efficiency as the result of reduction of water allocations. The efficiency of water usage on the farm level could be planned and regulated in relation to crop/industry standards and local conditions of the growing season. Security of water supply could be only guaranteed if increased allocations of water can be made in exceptionally dry years when demand for water is larger and additional water is available from the long term storage reservoirs, in opposite to the current MD Basin situation.
	The Project Board considers that the Cap has provided a mechanism for restraining, in an orderly fashion, growth in diversions while enabling economic development to proceed.	The Cap certainly provided mechanism for water restraining. Since reduction of water available to individual farmers directly impacting on their ability to produce, it should be seriously taken in consideration reduction of economic viability and competitiveness of every farming unit and subsequent economic decline of rural communities in MD Basin. The reduction of certain agricultural produce available for domestic and export markets impacting on Australian economic growth. How can the economic development growths to proceed when less water can be available for allocation with time? The basic economy of irrigation agriculture is directly related to the amount of water available to the farmers, as there is plenty of land available to be irrigated within MD Basin.
	The Project Board recognizes that this strong positive conclusion will not be the perception of every stakeholder in the Basin. However, the Project Board concludes that the overall benefit of the Cap, especially from ensuring security of supply at a valley level and providing an environment within which water trading and related reforms could be developed, has been a positive one.	We appreciate that the Project Board conclusion will not be recognized or agreed with by the majority of stakeholders in the Basin. We can understand the rationale behind justified and rational cuts in water allocations and why Cap Project Board relates those restrictions to security of supply to valley level. If the natural rainfall in the catchments could be restored the security of supply to valley level would be much easier to manage.

	Cap Project Board Position	Comment
Equity	The Project Board identified several equity issues (notably Cap arrangements for Queensland and the ACT) of longstanding duration that require urgent resolution. In addition there are several more recently identified equity issues (floodplain and overland flows and diversions, farm dams and tree plantations) also requiring attention. The effective management of these issues will necessitate a total catchment management approach to water management that embraces both surface and groundwater resources.	
	The Project Board focused on equity issues arising from the implementation of the Cap between jurisdictions and between river valleys within States. In several cases, the submissions received by the Review of the Operation of the Cap raised equity issues that are about the details of implementation within valleys which are outside the jurisdiction of the Murray-Darling Basin Commission and Ministerial Council processes. The vast majority of such issues related to the recognition of licensed entitlement versus history of use, specifically in New South Wales (the "sleeper/dozer" issue). Such issues need to be dealt with by the particular jurisdiction concerned. In order that all submissions receive appropriate attention, these submissions and that of the CAC have been referred to the appropriate Government for consideration and reply.	

	Cap Project Board Position	Comment
Implementation and Compliance	The work of the Independent Audit Group (IAG) on the ongoing implementation of the Cap and compliance of actual diversions with Cap target diversions has provided a clear direction for the finalisation of the implementation phase of the Cap. The Project Board generally supports the IAG recommendations.	
	Significantly, effective compliance tools (computer simulation models used to determine Cap target diversions) have not yet been developed and the Project Board recommends that a high priority be given to the finalization of these models.	
	The Review has found that Victoria and South Australia have complied with the Cap, while Queensland and ACT are yet to complete the establishment of their respective Caps. Nevertheless, it is apparent that in Queensland there has been significant growth in storage which will impact on the water available for alternative consumptive and environmental uses. In New South Wales, the Cap has been breached in the Barwon-Darling system, with other valleys being within Cap limits.	

	Cap Project Board Position	Comment
Schedule F to the *Murray-Darling Basin Agreement*	The most important challenge in Cap implementation is to finalize the arrangements under "Schedule F – Cap on Diversions" to the *Murray-Darling Basin Agreement*. This schedule is the primary tool for defining Cap arrangements especially those concerned with assessing compliance and its consequences.	

	Cap Project Board Position	Comment
	With the intent of improving the operation of the Cap through the development of fair and meaningful compliance arrangements, the Project Board invites comments on the following modifications to Schedule F which have been recommended by the IAG:	
	Removal of references to end-of-valley flows as a method for Cap compliance.	
	Arrangements for remedial actions in the case of Cap exceedence. The recommendation of the IAG is that States be required "*to ensure that cumulative diversions are brought back into balance with the cap*".	
	re-setting the commencement date for accounting for diversions under the Cap to start with the 2000/01 water year.	
	Cap Project Board Position	Comment
Sustainable Rivers Audit	With the implementation of the Cap nearing completion in most jurisdictions, there is now the opportunity to take the "next step" and to consider the environmental outcomes of the Cap from a whole of Basin perspective. The Project Board supports the introduction of a regular Sustainable Rivers Audit, which would cast the Cap as an input to Basin health, rather than an outcome in itself. Whereas the Cap is seen as the first step towards achieving the longer-term objective of the *Initiative*, a Sustainable Rivers Audit can be viewed as the next step in the process of achieving this objective.	The Sustainable River Audit must take in consideration the latest scientific findings discovered by Prof. Rosenfeld and AMC and utilize it to urgently conduct quantitative assessment of the potential environmental damage that is already occurring, and potential ways for rectify the situation by restoring natural precipitation as the most important input to MD Basin environmental health and economic prosperity.
	Cap Project Board Position	Comment
Any Other Issues	Are there any other issues raised in the draft report that you wish to comment upon?	

Suppression of Rain and Snow by Urban and Industrial Air Pollution

Daniel Rosenfeld

Inst. of Earth Sciences, The Hebrew University of Jerusalem, Israel

Direct evidence demonstrates that urban and industrial air pollution can shut off precipitation completely from clouds with tops of about -10°C over large areas. Satellite data reveal plumes of reduced cloud particle size and suppressed precipitation, originating from major urban areas and industrial facilities such as power plants. Measurements obtained by the Tropical Rainfall Measuring Mission (TRMM) satellite reveal that both cloud droplet coalescence and ice precipitation formation are inhibited in polluted clouds.

The precipitation forming processes in clouds depend to a large extent on the presence of aerosols, namely cloud condensation nuclei (CCN) and ice nuclei. The large concentrations of small CCN in the smoke from burning vegetation nucleate many small cloud droplets (*1,2*), which coalesce very inefficiently into raindrops (*3,4*). Although suspected for many years (*5,6*), conclusive evidence that smoke from burning vegetation suppresses precipitation was obtained just recently, using the observations of the Tropical Rainfall Measuring Mission (*7*) (TRMM) satellite (*8*).

Much less is known, however, about the impact of aerosols from urban and industrial air pollution on precipitation. It was assumed initially that industrial and urban pollution inhibited precipitation, as was the case with the smoke from burning vegetation, (*9*). However, later reports of enhanced rainfall downwind of paper-mills (*10*) and over major urban areas (*11*) suggested that giant CCN caused enhancement of precipitation (*12*), but attempts to correlate the urban-enhanced rainfall to the air pollution sources failed to show any relationship (*13*). Another explanation for the urban rain enhancement invoked the heat-island effect and increased friction, both of which would tend to increase the surface convergence, resulting in more cloud growth and rainfall over and downwind of the urban areas (*14*). Furthermore, the recent suggestion (*15*) that air pollution might enhance precipitation on the large scale in northeastern America, and the accompanying speculative explanations, demonstrate how little is known about the subject.

Space-borne (*16*) and in situ aircraft (*17*) measurements of ship tracks in marine stratocumulus clouds provided the first evidence that effluents from ship stacks change cloud microstructure such that their water is redistributed into a larger number of smaller droplets. Albrecht (*18*) suggested that the drizzle, which normally occurs in marine stratocumulus clouds in clean air, would be inhibited from the clouds with reduced droplet size, thereby increasing the cloud water content and longevity. Extrapolation to clouds that are sufficiently thick for raining (i.e., at least 2 km from base to top) would mean that the effluents have the potential to suppress precipitation over ocean and over land. However, pollution tracks in any clouds over land were not reported in previous studies. Application of the imaging scheme of

Rosenfeld and Lensky (*6*) to the Advanced Very High Resolution Radiometer (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) orbiting weather satellites revealed numerous "ship-track" like features in clouds over land, emanating from major urban and industrial pollution sources. Illustrations of such tracks from Turkey (Figure 1A), Canada (Figure 1B), and Australia (Figure 1C) are shown here. Because the tracks clearly originate from pollution sources, they will be called hereafter "pollution tracks".

The pollution tracks in Turkey (Figure 1A) originate from several sources in and near the cities of Istanbul, Izmit and Bursa.

The pollution track in Canada (Figure 1B) originates from Flin-Flon, Manitoba, the home of the Hudson Bay Mining and Smelting Company. That location has been a frequent source for such tracks. Other sources in Canada have been observed, but not reported here.

Study of the pollution tracks emanating from the region of Adelaide, South Australia, is especially interesting. They received special attention because of their intensity and frequent occurrence. These pollution tracks were identified in the clouds of all 47 AVHRR images on different days that were examined in which stratocumulus and cumulus clouds with tops warmer than about $-12^{o}C$ existed over the region. The pollution tracks in Figure 1C coincide with these major industrial and urban areas:

- Port Augusta (marked as PA in Figure 1C) has a 520 megawatt power plant operating on brown coal, providing electricity to the mines in the vicinity and to the adjacent large steel industry in Whyalla. Port Pirie (PP) is the home of the world's largest lead smelter and refinery.

- Adelaide (AD) has industry for processing minerals mined in the vicinity. Among these are Australia's largest cement plant, located on the Port Adelaide River. A major oil refinery and a power plant are located 20 km to the south of the city near the origin of the strongest pollution track in Figure 1C.

The 1998/99 annual average effluents from the stack of Port Augusta power plant were 43 kg hr^{-1} of sub-micron ash particles with modal diameter of 0.14 μm pass the electrostatic precipitator. The gaseous annual average effluents are 1108 kg hr^{-1} of SO_2 and 1655 kg hr^{-1} of NO_x (*19*). Apparently part of the ash particles act as CCN at short range, and chemical reactions of the gases produce additional CCN hundreds of km further downwind of the pollution source, mainly in the form of sulfates.

The AVHRR data were used to retrieve the dependence of the indicated effective radius ($r_e=\langle r^3\rangle/\langle r^2\rangle$, where r is the radius of the cloud droplets in the measurement volume) on cloud temperature, T. The method of Rosenfeld and Lensky (*6*) was used to derive the T-r_e relations for inference of the precipitation forming processes in the clouds.

The median r_e of the cloud tops in the pollution plumes (Figures 1-3) was considerably less than the precipitation threshold of 14-μm (*20*). Outside the plumes, however, r_e increased steeply with decreasing T to more than 25 μm, indicating that the cloud droplets in the general area were coalescing into precipitation. At the same time, little growth of r_e with decreasing T was indicated within the pollution plumes, indicating a lack of coalescence and, thus, suppressed precipitation.

These inferences are validated using the additional sensors onboard the TRMM satellite. The TRMM instruments used here are:

- Visible and Infra Red Sensor (VIRS): Similar to the NOAA/AVHRR, but with a 2-km sub-satellite resolution instead of the 1.1 km resolution of the AVHRR. The VIRS is used to obtain the T-r_e relations, as done with the NOAA/AVHRR.
- Precipitation radar (PR): 2.2 cm radar, with a sub-satellite resolution of 250 m vertically by 4 km horizontally. The minimum detectable signal is about 17 dBZ, equivalent to about 0.7 mm/hr. The PR is used to measure the precipitation which forms in the clouds.
- TRMM passive Microwave Imager (TMI): The 85-GHz vertical polarization brightness temperature (T_{85}) is used here to detect the water in non-precipitating clouds.

The TRMM measurements are validated by an extensive ground validation program (*21*), with preliminary results showing variability of about 25% between rain gauges and TRMM rainfall over large areas, with some TRMM underestimate at the heavier rainfall (*22*). The simultaneous space-borne measurements of cloud microphysics (VIRS), cloud water (TMI) and precipitation (PR), makes it possible to relate the precipitation to cloud microstructure.

The TRMM overpass selected for analysis in this study is for 21 October 1998 at 04:41 UT during a time of strong pollution-track signatures in the clouds throughout southeastern Australia (Figure 2). Seven boxes within the image were delimited for analyses of the dependence of r_e (Figure 3) and the PR reflectivities (Figure 4) as a function of T. Box 2 encloses a pollution plume, which is clearly visible by the yellow coloring indicating the small r_e of the cloud particles downwind of Adelaide. According to the T-r_e relations, presented in Figure 3A, the clouds in the plume had little coalescence, had not glaciated and were without precipitation, whereas the unpolluted clouds in boxes 1 and 3, side wind of box 2, had strong coalescence and were precipitating. That inference is corroborated by the PR, which observed precipitation echoes in the clouds outside the plume, but not in the plume. The PR-measured rain intensities exceeded 10 mm/hr. Another large area of clouds with extremely small r_e existed in the Melbourne area and extended downwind to the northeast (box 4). The r_e increased gradually further downwind but did not reach the precipitation threshold. Further downwind and to the east of the plume (box 5) only a few isolated showers had formed in some of the clouds that reached the $-9^{o}C$ isotherm and barely exceeded the 14-μm precipitation threshold.

Clouds over the Sydney area (box 6) also had much reduced r_e, apparently due to the pollution there. Clouds over the sea some 150 km away from

Sydney (box 7) had much large r_e, indicative of strong coalescence and precipitation, apparently in the pristine maritime air. The TMI-based TRMM rainfall algorithm identified those clouds as precipitating.

The vertical cross sections (Figure 5), cutting through the plumes, show no obvious differences in the cloud top heights and horizontal dimensions in and outside the areas of suppressed precipitation. Furthermore, the depression of the TMI measured T_{85} in the non-precipitating clouds indicates that lack of cloud water was not the reason for the lack of precipitation from these clouds. The vertical profile of the precipitation echoes, as measured by the PR, has a distinct maximum near the 0^oC isotherm, between 2 and 2.5 km above sea level (Figure 4). This maximum is caused by the enhanced radar returns from melting snowflakes, known as the “bright band”. The existence of the bright band shows that much of the precipitation was initiated as snow in the upper parts of the clouds. That means that the pollution suppressed the precipitation not only by inhibiting the coalescence of the cloud droplets into raindrops but also by preventing the formation of ice particles and cold precipitation processes in clouds. A likely explanation is that the pollution reduces the radius of the largest cloud droplets below the threshold of 12 μm, which is required for both primary and secondary ice generation in clouds (*23,24*). In view of the observations that most of the winter precipitation events in the Snowy Mountains (east of box 4 in Figure 2) come from clouds with tops between -4^o and -13^oC (*25*), air pollution must be a significant factor in determining the precipitation amounts in the region. Interestingly, a decreasing trend of the snow cover in the Snowy Mountains was suspected for the period 1897-1991 (*25*). However, a trend analyses for 1910-1991 of snow, winter temperature and total winter rainfall showed that the decreases in all three parameters were statistically insignificant (*26*).

The satellite data provide evidence connecting urban and industrial air pollution to the reduction of the precipitation, pinpointing both the sources and the affected clouds. This has become possible with the newly acquired capabilities to observe both cloud microstructure and precipitation over large areas, using the TRMM satellite observations. It might be seen strange that some of the most obvious pollution signatures occur in Australia, which is probably the least polluted inhabited continent. The pollution is evident best in Australia perhaps because it is seen against a background of pristine clouds, whereas in most other places the clouds are already polluted on a very large scale. That might serve as a preliminary indication that human activity may be altering clouds and natural precipitation on virtually a global scale.

References and Notes

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27. The author is grateful to all the members of the TRMM team, too numerous to mention individually, for all their hard work to make the satellite a reality and the data of such high quality. The NOAA AVHRR data were obtained from NOAA Satellite Active Archive. The author thanks Mr. Aron Gingis of Australian Management Consolidated Pty. Ltd. for assisting in this study. Thanks are also due to Dr. W. L. Woodley for his help with the manuscript.

Figure Captions:

Figure 1: Satellite visualization of NOAA/AVHRR images, showing the microstructure of clouds with streaks of visibly smaller drops due to ingestion of pollution, for three cases over three continents, originating from known pollution sources, marked by white numbered asterisks. The yellow streaks in panel A (about 300 x 200 km) originate from the urban air pollution of Istanbul (*1), Izmit (*2) and Bursa (*3), on 25 Dec 1998 12:43 UT. Panel B (about 150 x 100 km) shows the impact of the effluents from the Hudson Bay Mining and Smelting compound at Flin Flon (*4), Manitoba, Canada (54:46N 102:06W), on 4 June 1998 20:19 UT. Panel C (about 350 x 450 km) shows pollution tracks over South Australia on 12 Aug 1997, 05:26 UT, originating from Port Augusta power plant (*5), Port Pirie lead smelter (*6), Adelaide port (*7) and the oil refineries (*8). All images are oriented with north at the top. The images are color composites, where the red is modulated by the visible channel, blue by the thermal IR, and green is modulated by the solar reflectance component of the 3.7 μm channel, where larger (greener) reflectance means smaller droplets. That determines the color of the clouds, where red represents clouds with large drops, and yellow clouds with small drops. The blue background is the ground surface below the clouds. A full description of the color pallets and their meaning was provided in the Bulletin of the American Meteorological Society (*6*).

Figure 2. The same as Figure 1, but for the TRMM VIRS, with the added information of precipitation, in the white overlay. The white patches denote precipitation echoes, as observed by the TRMM Precipitation Radar (PR).

The two parallel lines delimit the PR swath of 230 km. The swath is oriented from west (left of the image) to east. The image shows pollution plumes in the clouds over southeastern Australia, from 21 Oct 1998, 04:44 UT. The lines AB and CD show the locations of the vertical cross sections, presented in Figure 5.

Figure 3: Analysis of the T-r_e relations, where T is the temperature and r_e is the cloud particle effective radius, for the clouds in the seven boxes in Fig. 2, respectively. Plotted are the 15% (long dashed line) 50% (solid line) and 85% (short dashed line) percentiles of the r_e for each 1^oC interval. The black lines correspond to the polluted boxes. The vertical green line marks the 14-µm precipitation threshold. A full description of the meaning of the T-r_e charts was provided in the Bulletin of the American Meteorological Society (*6*).

Figure 4: Vertical profiles of the precipitation echo intensities as measured by the TRMM Precipitation Radar for the various boxes in Figure 2. The peak near 2 km corresponds to enhanced echoes from snowmelt just below the 0^oC isotherm. Box 2 had no detectable precipitation. Boxes 4 and 7 are outside of the radar swath.

Figure 5. Vertical cross section along the lines AB and CD in Fig. 2. The gray areas represent clouds. The vertical extent of the clouds is converted from the VIRS measured top temperatures. The colors represent the precipitation reflectivity, in dBZ, as measured by the TRMM radar. The

white line is the brightness temperature of the TRMM Microwave Imager 85 GHz vertical polarization (T_{85}), plotted at the altitude of that temperature. Lower T_{85} (represented as larger height of the white line) in non-precipitating clouds means larger cloud water content. Please note that the T_{85} and actual cloud top temperature have different physical meanings.

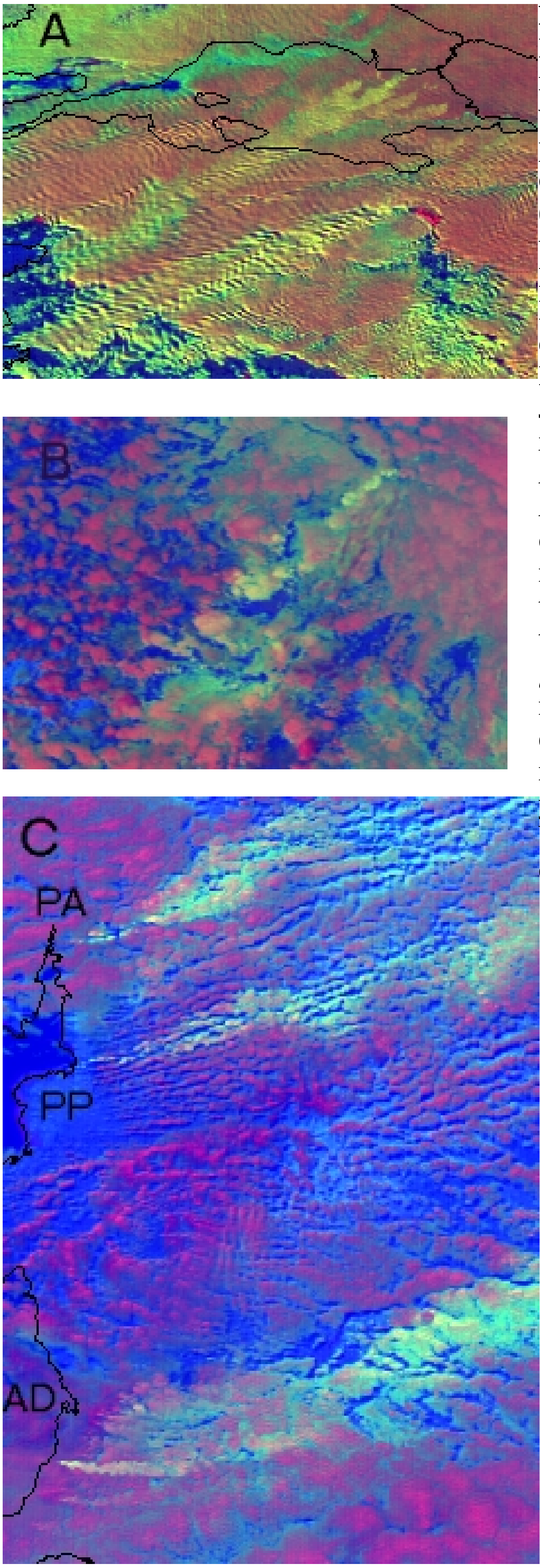


Figure 1: Satellite visualization of NOAA/AVHRR images, showing the microstructure of clouds with streaks of visibly smaller drops due to ingestion of pollution, for three cases over three continents. . The yellow streaks in panel A (about 300 x 200 km) originate from the urban air pollution of Istanbul, Ismit and Bursa, on 25 Dec 1998 12:43 GMT. Panel B (about 150 x 100 km) shows the impact of unknown source on clouds over Manitoba, Canada (54:46N 102:06W), on 4 June 1998 20:19 GMT. Panel C (about 350 x 450 km) shows three sources in the Adelaide area of South Australia, on 12 Aug 1997, 05:26 GMT. The images are color composites, where the red is modulated by the visible channel, blue by the thermal IR, and green is modulated by the solar reflectance component of the 3.7 μm channel, where larger (greener) reflectance means smaller droplets. That determines the color of the clouds, where red represents clouds with large drops, and yellow clouds with small drops. The blue background is the ground surface below the clouds.

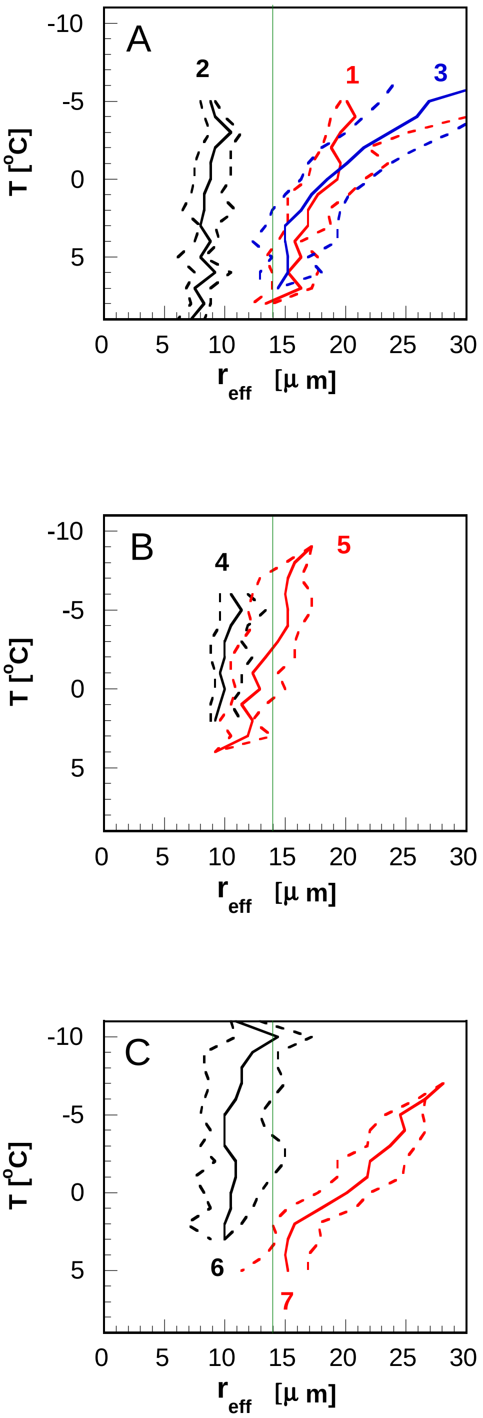


Figure 3: Analysis of the temperature (T) – cloud particle effective radius (r_e) relationship, for the clouds in the seven boxes in Fig. 2, respectively. Plotted are the 15% 50% and 85% percentiles of the r_e for each 1^{o}C interval. The medians are indicated by the solid lines. The vertical green line marks the 14-µm precipitation threshold.

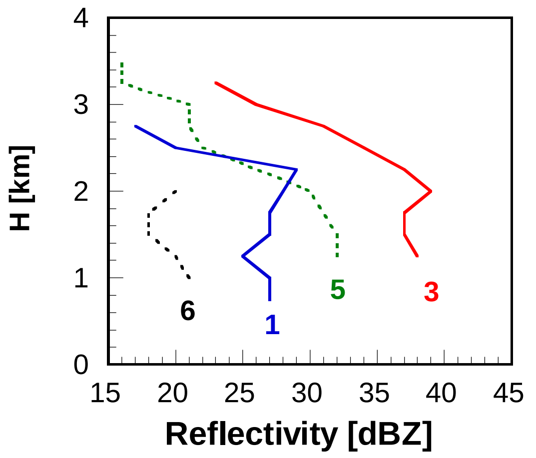
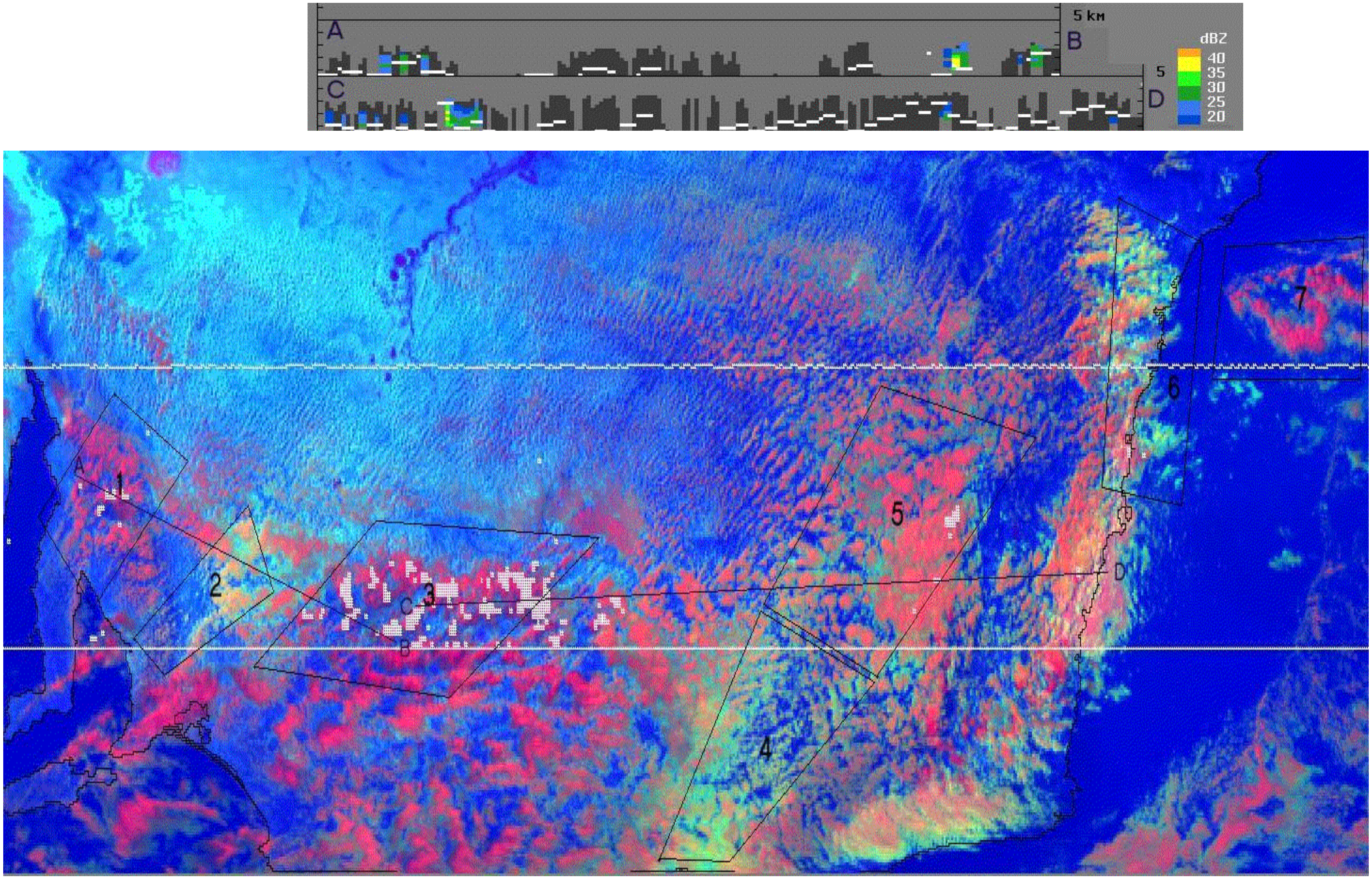


Figure 4: Vertical profiles of the precipitation echo intensities as measured by the TRMM Precipitation Radar, at the various boxed in Figure 2. The peak near 2 km corresponds to the enhanced echoes from snowmelt just below the 0^{o}C isotherm. Box 2 had no detectable precipitation. Boxes 4 and 7 are outside of the radar swath.

Figure 2. The same as Figure 1, but for the TRMM VIRS, with the added information of precipitation, in the white overlay. The two parallel lines delimit the TRMM Precipitation radar swath of 230 km. The swath is oriented from west (left of the image) to east. The image shows pollution plumes in the clouds over southeastern Australia, from 21 Oct 1998, 04:44 UT. The lines AB and CD show the locations of the vertical cross sections, presented in Figure 5.

Figure 5. Vertical cross section along the lines AB and CD in Fig. 2. The gray area is the clouds, as measured by their top temperature. The colors represent the precipitation reflectivity, in dBZ, as measured by the TRMM radar. The white line is the brightness temperature of the TRMM Microwave Imager 85 GHz vertical polarization, plotted at the altitude of that temperature. Please note that the 85 GHz brightness temperature and actual cloud top temperature have different physical meanings.


5 km
A
B
C
D
5
dBZ
40
35
30
25
20
1
2
3
4
5
6
7