PFC emissions from Australian & global aluminium production

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CSIRO Marine and Atmospheric Research: Light Metals Flagship

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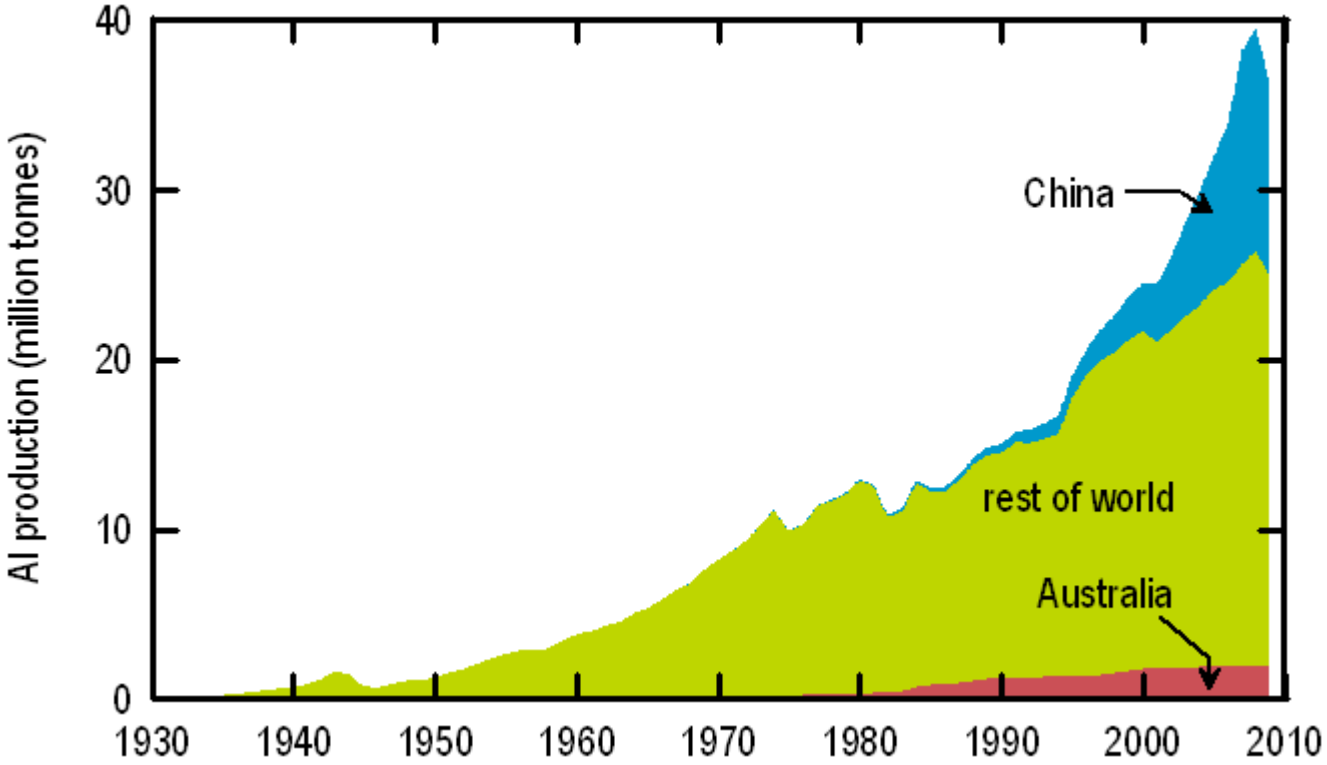
Perfluorocarbons (PFCs) from aluminium production

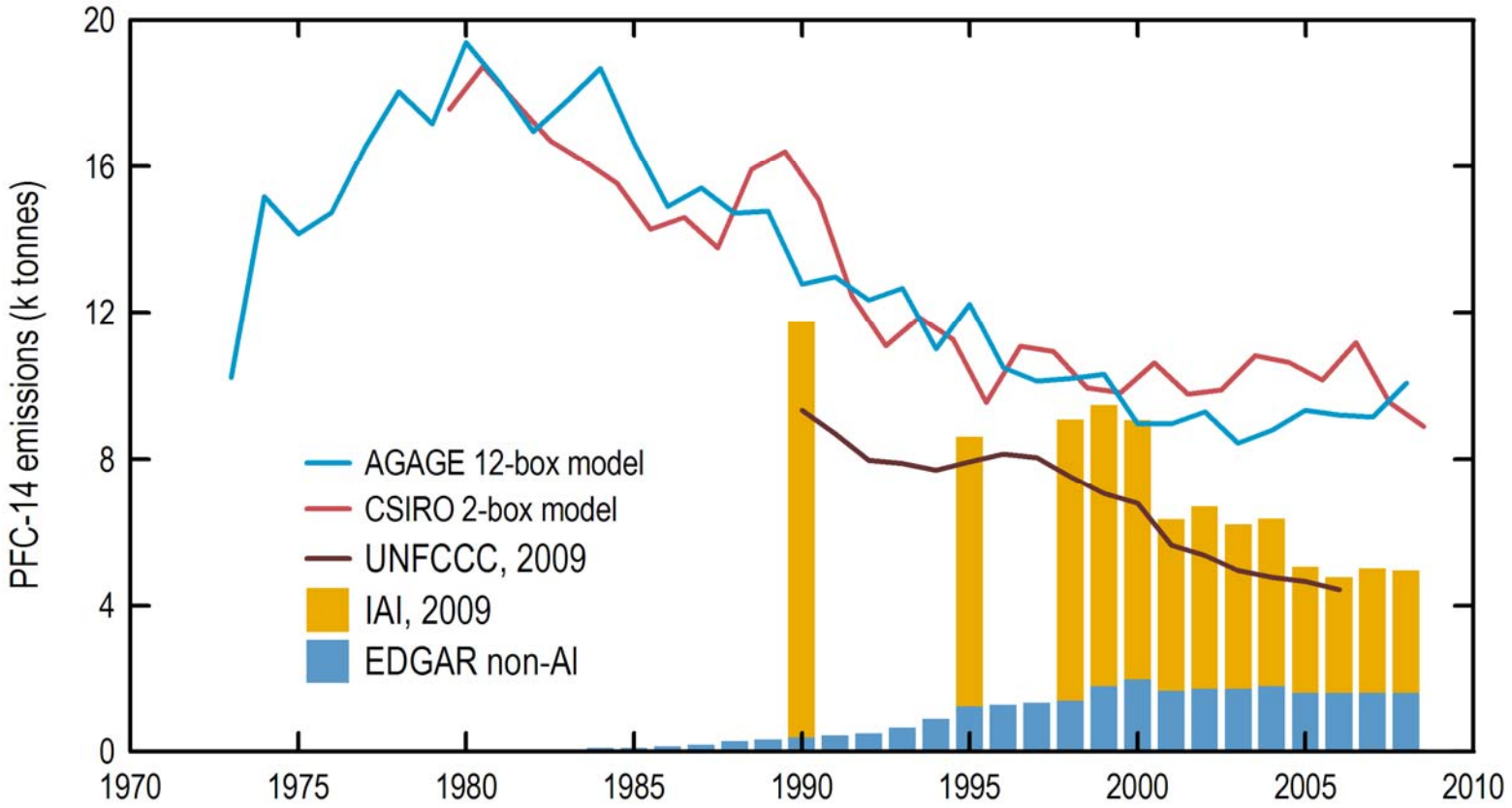
- PFCs (CF_4, C_2F_6) are released to the atmosphere from aluminium production (during anode events) & by the electronics industry (plasma etching, cleaning etc)
  - normal operation: $2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$
  - anode event (AE): $Na_3AlF_6 + nC \rightarrow (CF_2)_n \rightarrow CF_4, C_2F_6 \ldots$
  - typical AE frequency: 0.2-1.5 per cell per day (150-300 cells/smelter)
  - typical AE duration: 2 minutes
  - Al_2O_3 feed control technology critical in determining anode event frequency
- Direct CO_2-e emissions from aluminium smelting: 2-4 tonnes CO_2-e/tonne Al
  - PFCs account for ~20%
  - CO_2 from anode consumption accounts for 65%, CO_2 from anode baking 15%
  - CO_2-e emissions from electricity generation: 14-19 tonnes CO_2/tonne Al (coal)

Global aluminium production (IAI 2009, ABARE 2009)



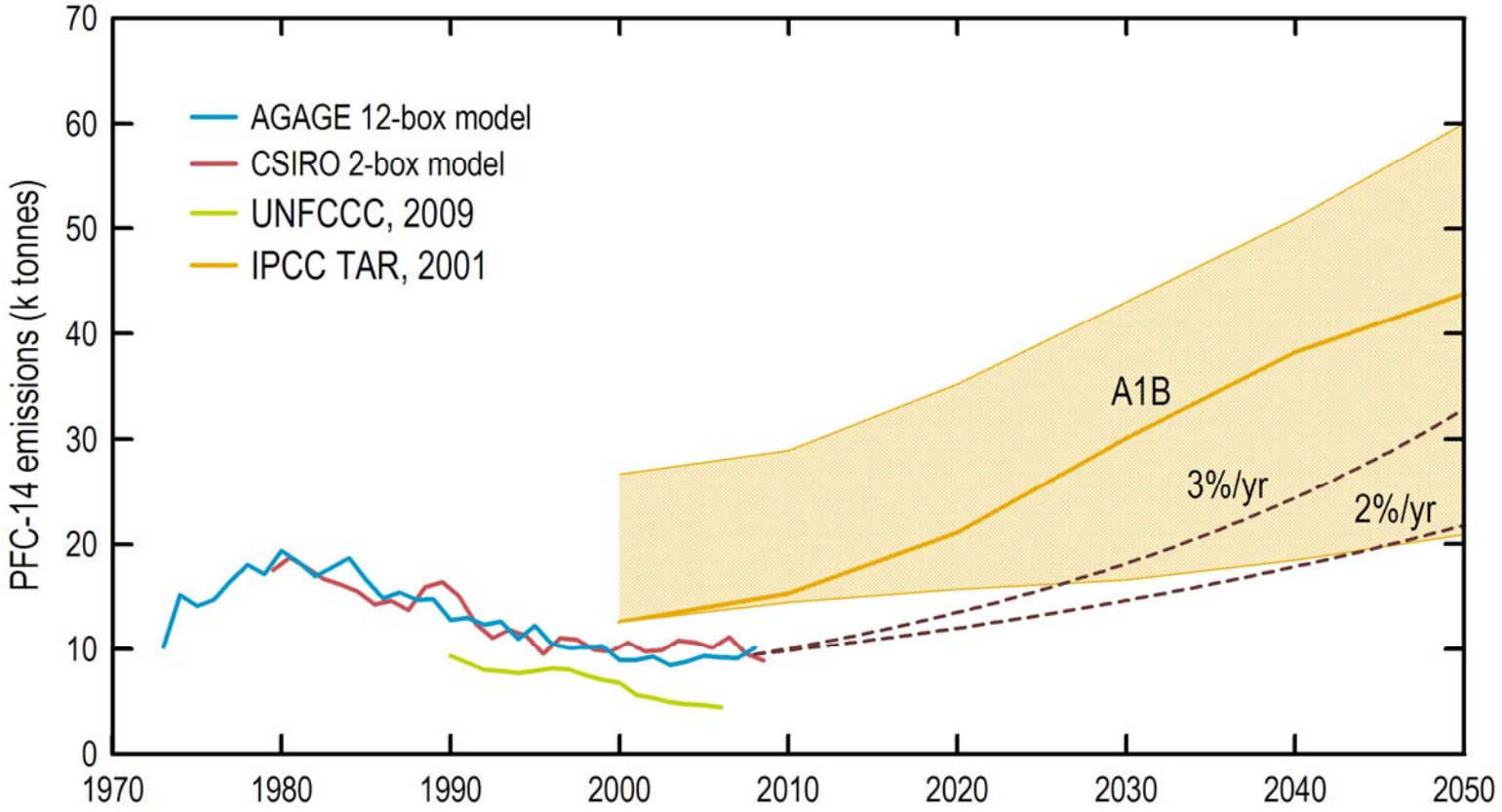
- Global aluminium production 2009 will likely decline 9% from 2008
- Significant zonal change (Europe, N. America →Asia) in PFC emissions pattern
  - 1990: Asia 5%, EU, N. America 50%; 2007: Asia 40%, EU, N. America 25%

PFC-14 (CF_4) emissions from atmospheric observations



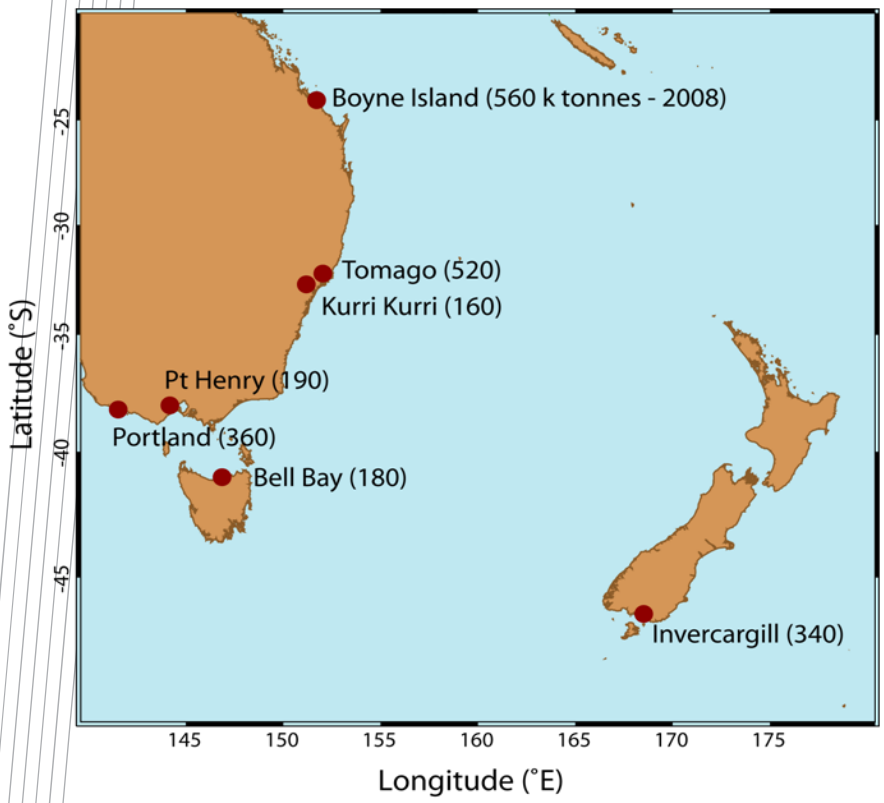
- UNFCCC data: 40% of aluminium smelting in countries not reporting to UNFCCC
- CF_4 emissions (UNFCCC Tier 2) from aluminium, electronics: ~50% of global emissions
- Missing CF_4 source(s)?

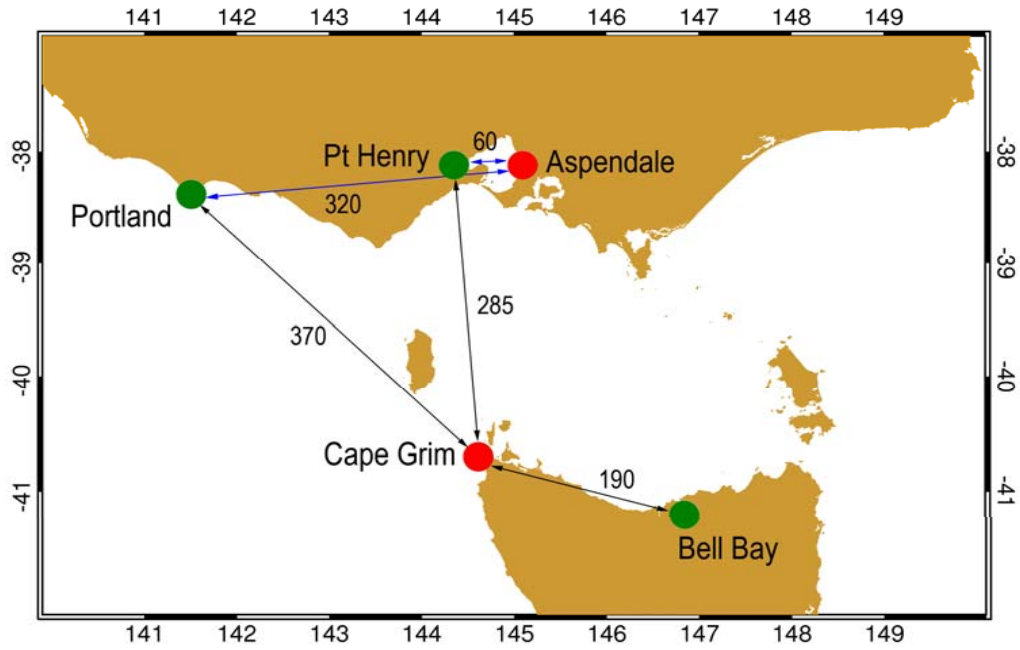
Future global PFC-14 (CF_4) emissions



- CF_4 emissions set to rise again: unlikely to follow the current IPCC scenarios
- industry estimates & IPCC scenarios are 50% lower,100% higher than actual emissions

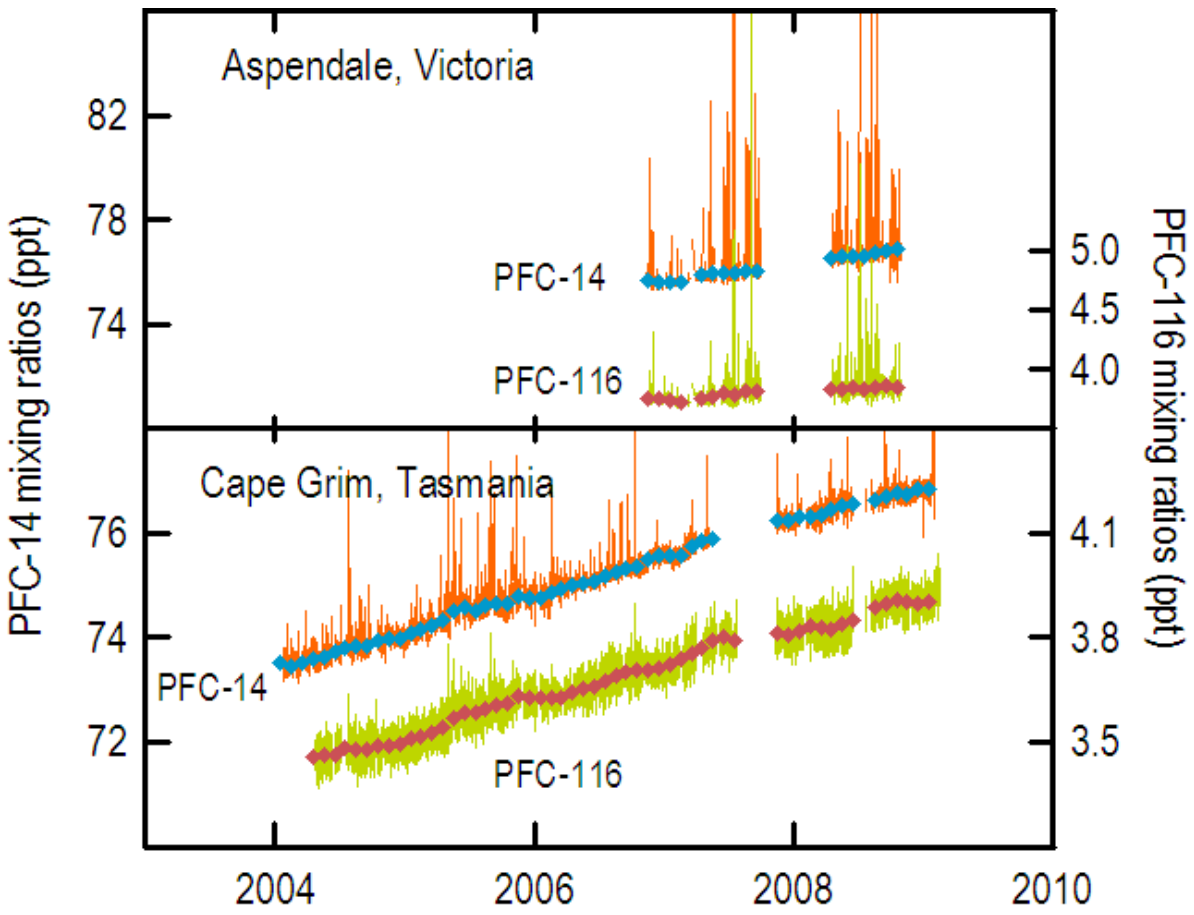
Australia/NZ smelters & AGAGE PFC monitoring sites (Cape Grim, Aspendale)





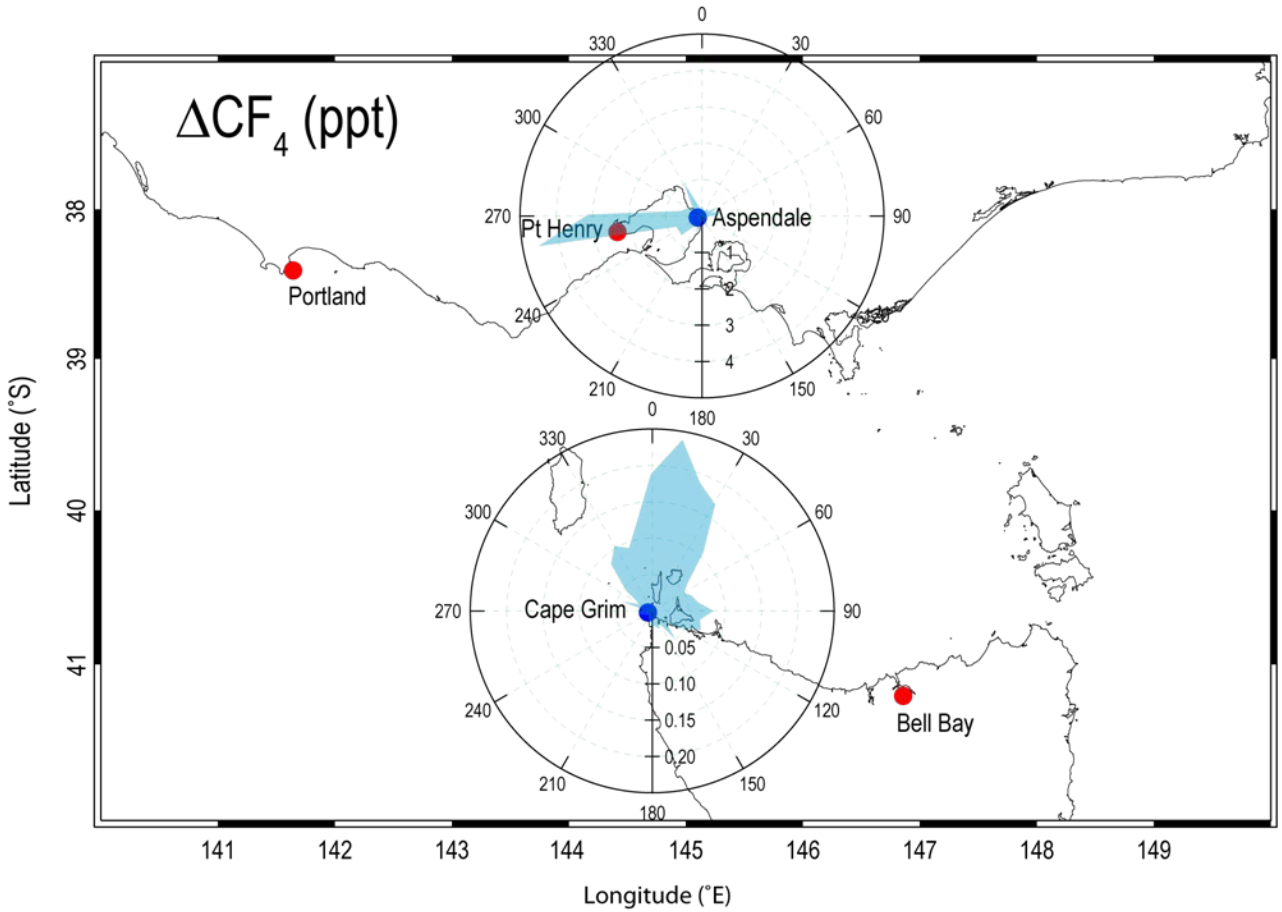
- Australian/NZ smelters: 2.3 M tonnes aluminium/year, 6% of global production
- Portland/Pt Henry/Bell Bay: 0.8 M tonnes/year, 40% of Australia's production
- PFC plumes (Portland, Pt Henry & Bell Bay) observed regularly at Cape Grim & Aspendale

PFC observations at Cape Grim & Aspendale



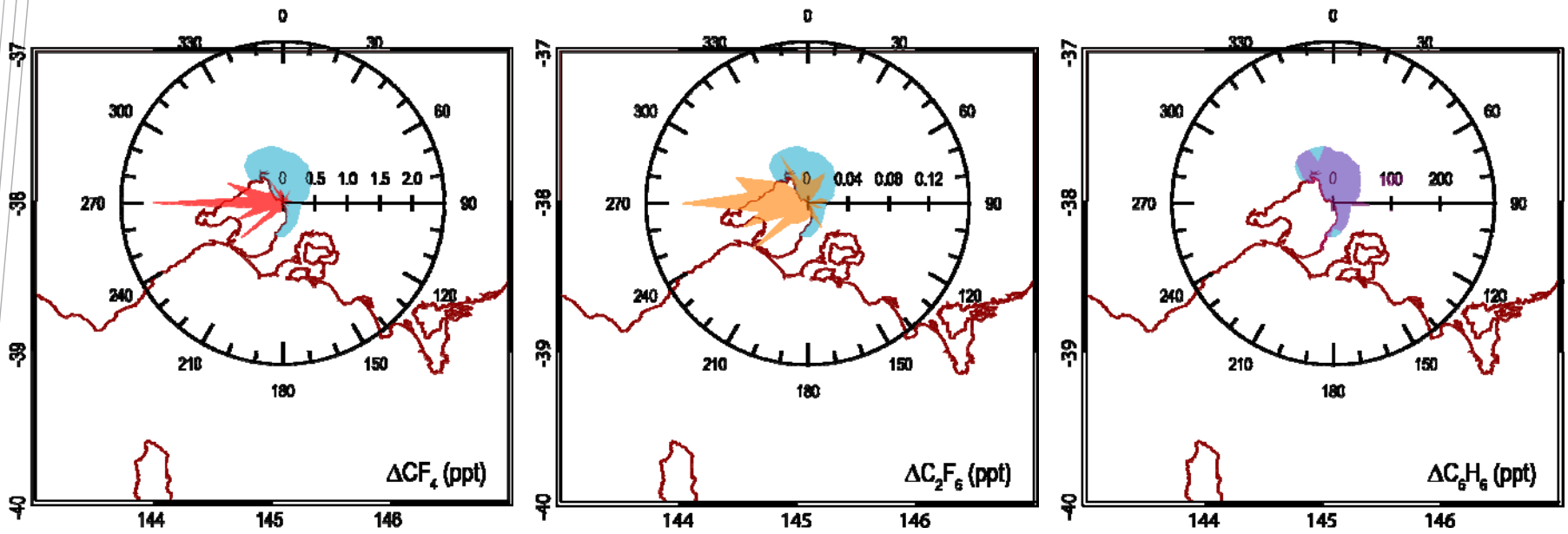
- PFC-14 ~1%/year (2%/year above background); PFC-116 ~3%/year

CF_4 enhancements above 'baseline' at Cape Grim & Aspendale



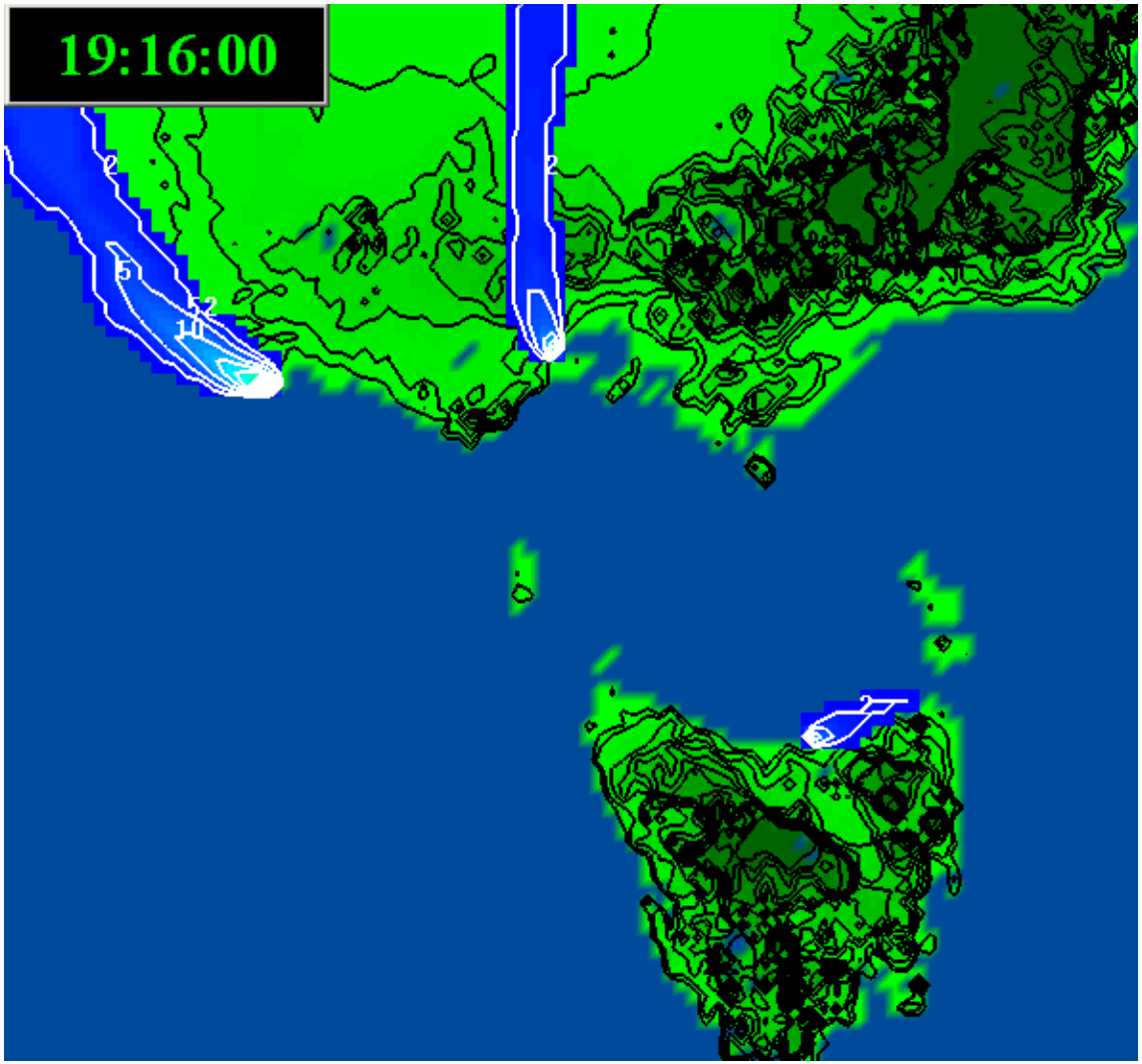
- PFC 'events' at Aspendale embedded in clean westerlies
- PFC 'events' at Cape Grim embedded in polluted (by Melbourne) northerlies

PFC-14, PFC-116, benzene enhancements at Aspendale

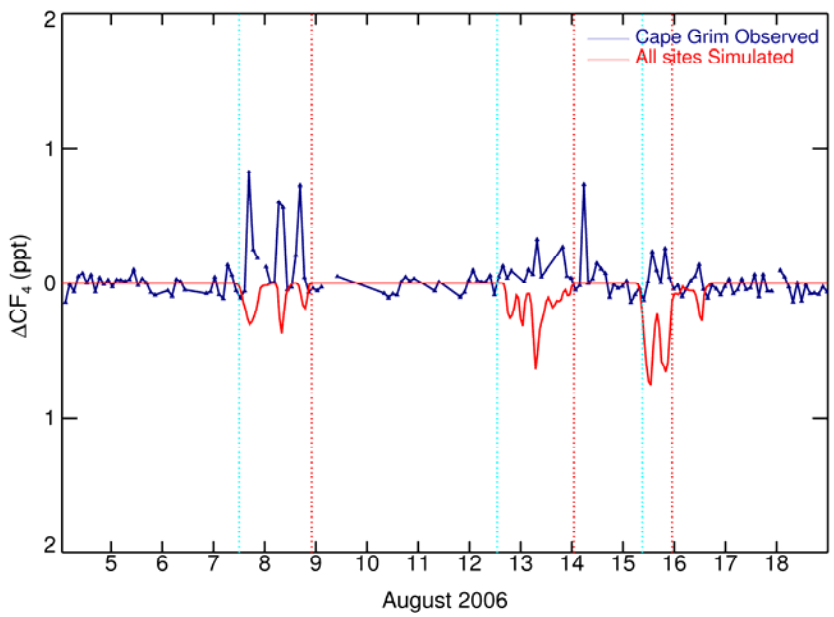


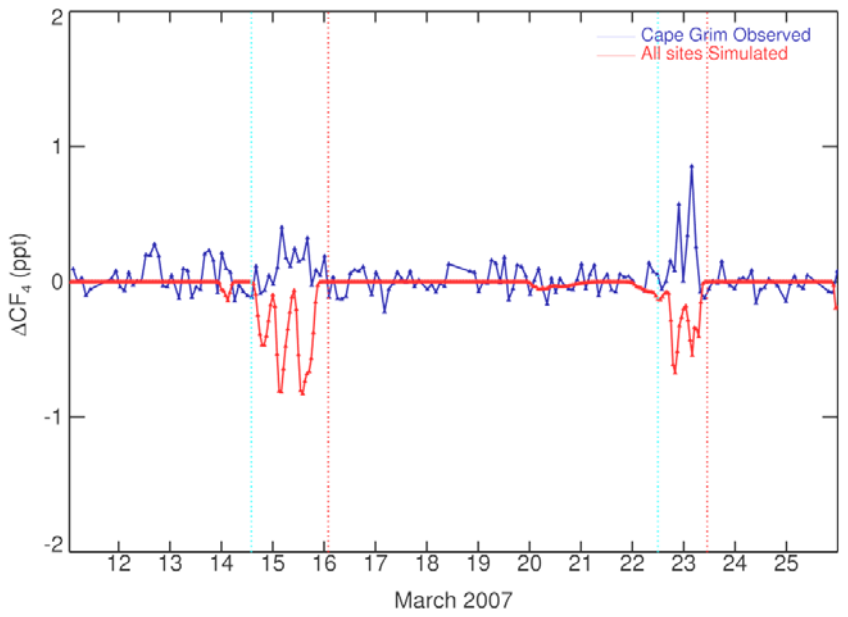
- C_2F_6/CF_4 mass emission ratio: 0.10±0.03 (IPCC 0.12±0.01)
- No CHF_3 emissions observed

PFC plumes from Portland, Pt Henry and Bell Bay smelters: TAPM 3D transport model simulation May 2004



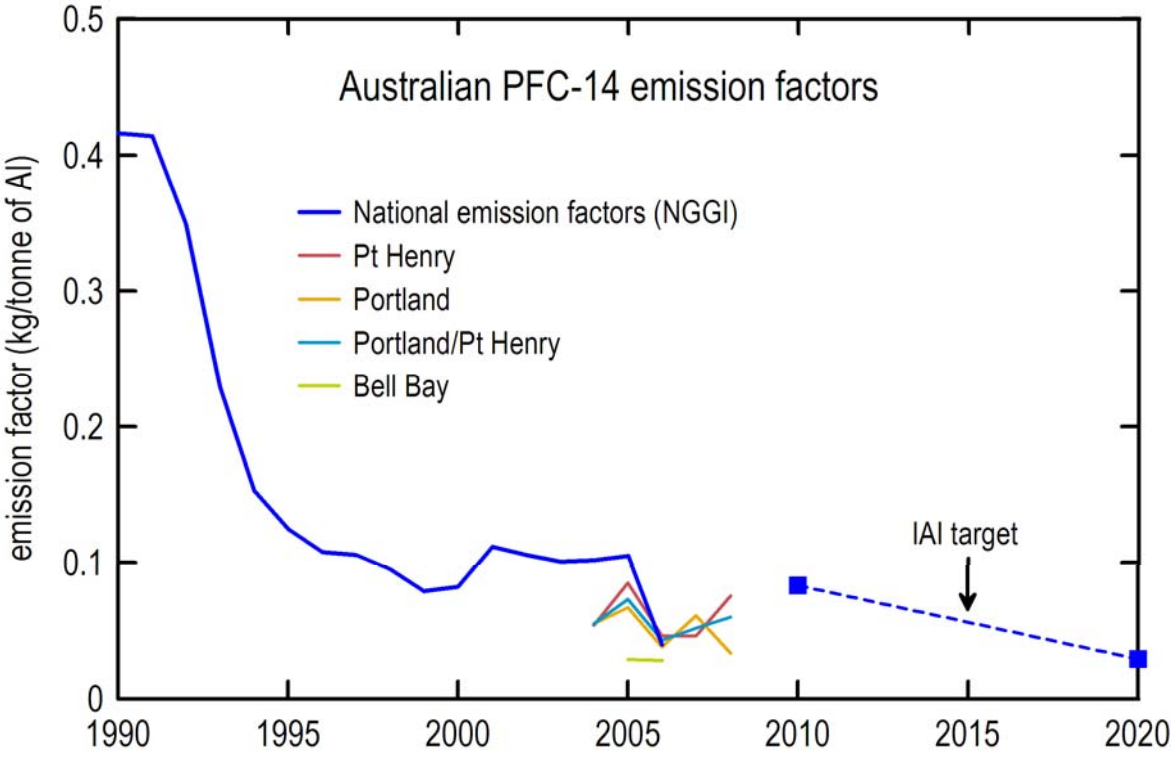
PFC-14 pollution events at Cape Grim: observed & modelled





- Model CF_4 annual emissions from Portland/Pt Henry/Bell Bay smelters scaled to match observations

Australian PFC-14 emission factors (kg CF_4/tonne Al)



- Significant technology changes in early 1990s and 2005/2006
- IAI targets: EF reductions from 1990 by 2010 (80%) and by 2020 (93%)

Kurri Kurri smelter, Hydro Aluminium, Hunter Valley, NSW

- Time-integrated air samples collected from exhaust stack line

PFC, CO_2 & other emissions at Kurri Kurri, April 2008

concentration		**CF_4**	**C_2F_6**	**C_3F_8**	**COS**	**HF**	**CO_2**
		ppt	ppt	ppt	ppm	ppm	ppm
Kurri Kurri	pot line exhaust	16300	250	44	2.4	3.1	4920
	pot line shed	130	8.3	1.1	0.002		416
	smelter ambient	81	4.2	0.6	0.001		383
Cape Grim	Apr 2008	77	3.8	0.5	0.001		382

emission factors		**CF_4**	**C_2F_6**	**C_3F_8**	**COS**	**HF**	**CO_2**
		g/tonne Al					t/tonne Al
Kurri Kurri		18	0.43	0.10	63	30	0.96
SE Australian smelters		53	5.3				
IAI (PFPB, CWPB)		38-64	4.5-7.7				1.59
NGGI (2006)		40	5				1.59

Conclusions

- global CF_4 emissions peaked in the 1980s at close to 20 k tonnes per year, then declined & stabilised at 10 k tonnes per year since the early 2000s
- bottom-up estimates of emissions from the aluminium (IAI) and electronics (EDGAR) industries underestimate total current CF_4 emissions by a factor of 2
- UNFCCC underestimates global CF_4 emissions because 40% of aluminium producing countries do not report to UNFCCC
- global CF_4 emissions set to rise again, but unlikely to follow IPCC-TAR scenarios (100% higher than actual emissions)
- aluminium smelter PFC emissions & emission factors can be derived from strategically located atmospheric monitoring stations or by exhaust gas sampling at smelters
- aluminium smelters emit at least 3 PFCs: CF_4, C_2F_6, C_3F_8, but no HFCs, c-C_4F_8?
- at Kurri Kurri, the exhaust gas extraction system collects >95% of PFCs produced
- in 2006 Australian aluminium smelters emitted ~120 tonnes PFCs (800 k tonnes CO_2-e) and 3100 k tonnes CO_2 (PFCs: 20%) ($27M @ $25/tonne C)
- Australian smelters should meet the 2010 IAI target for reduced emission factors
- the 2020 target presents a significant challenge for aluminium producers

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This paper is dedicated to the memory of Derek Cunnold – thank you

A new method for determining PFC emission factors

$\Delta PFC = PFC\ (downwind) - PFC\ (upwind)$

$\Delta CO_2 = CO_2\ (downwind) - CO_2\ (upwind)$

$E_{PFC} = k_{PFC} * \Delta PFC$

$E_{CO2} = k_{CO_2} * \Delta CO_2$

since the sources of CO_2 & PFCs are co-located, $k_{PFC} = k_{CO_2}$, therefore

$E_{PFC}/E_{CO_2} = \Delta PFC/\Delta CO_2$

$E_{CO_2} = f_{CO_2} * P_{Al}$, $E_{PFC} = f_{PFC} * P_{Al}$, therefore

$E_{PFC}/E_{CO_2} = f_{PFC}/f_{CO_2}$

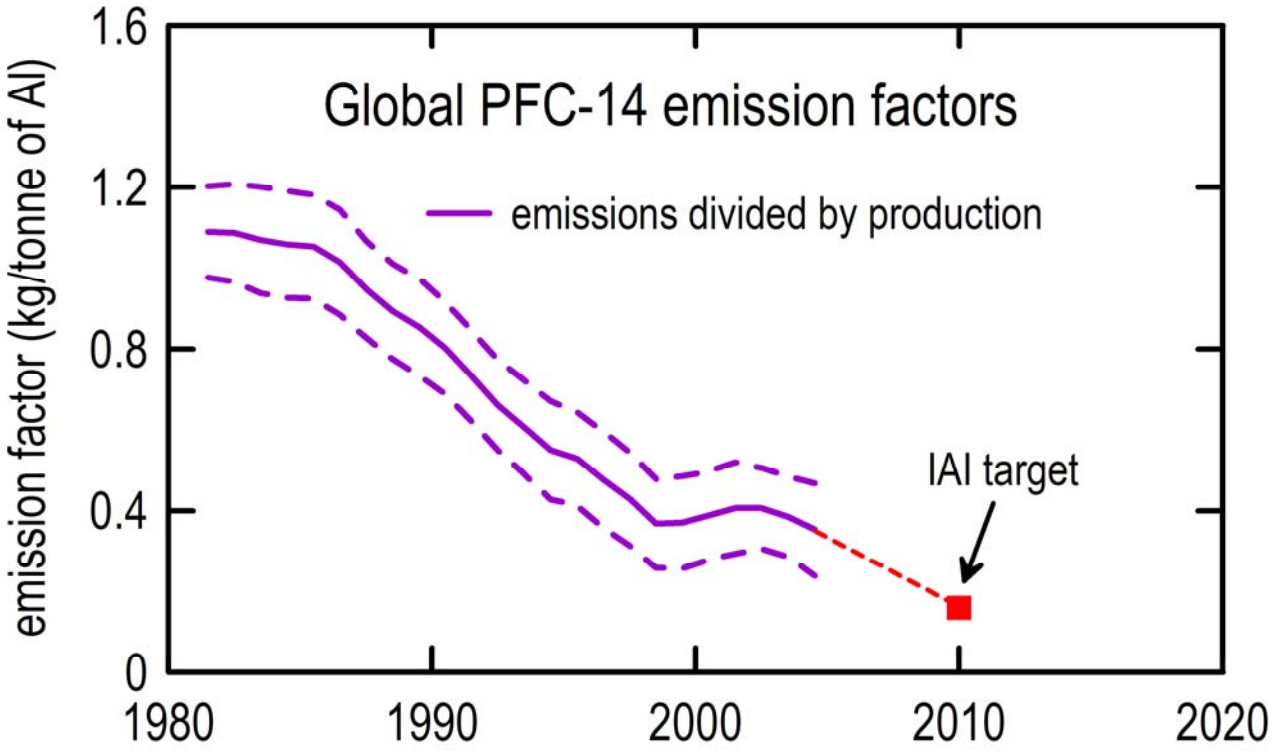
$f_{PFC} = f_{CO_2} * \Delta PFC/\Delta CO_2$

- ΔPFC, ΔCO_2 can be measured directly, f_{CO_2} is a well constrained factor, therefore f_{PFC} can be estimated

Emission factors for SE Australian smelters: 2004-2008

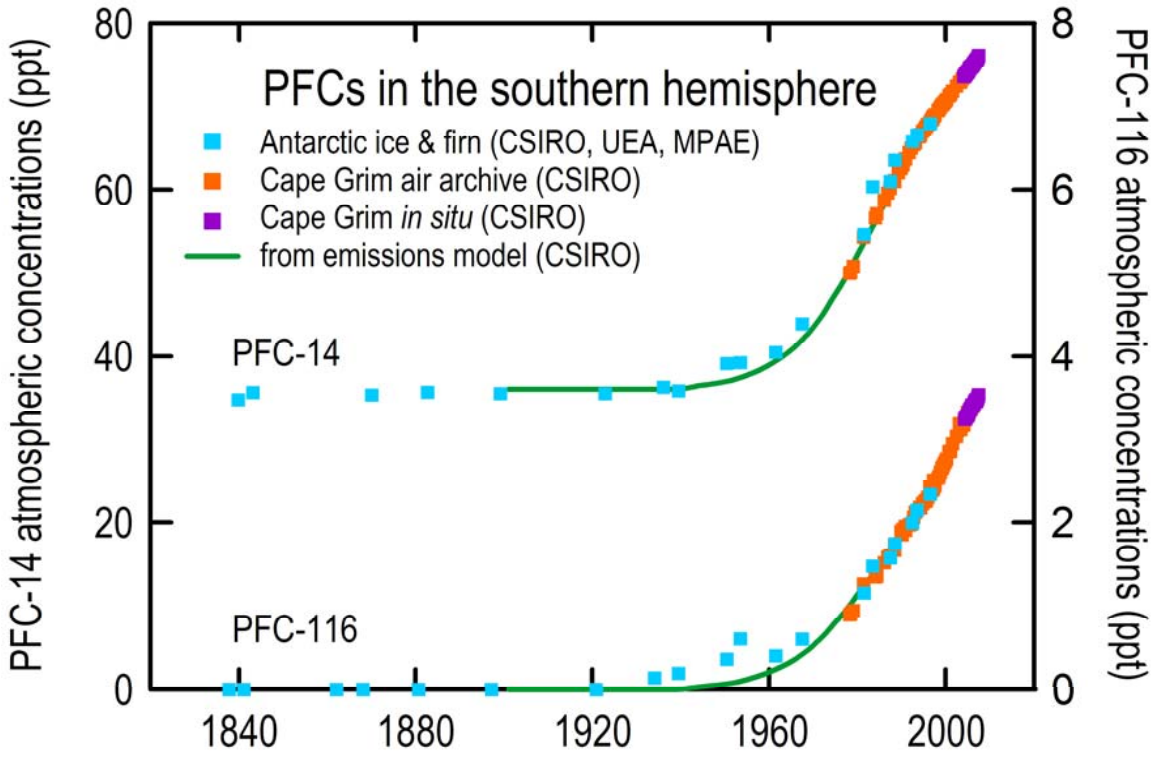
	Emission factor (kg/tonne Al) (n)	
Smelter	PFC-14	PFC-116
Pt Henry	0.071±0.035 (59)	0.013±0.006 (18)
Portland	0.055±0.027(18)	
Bell Bay	0.032±0.016 (8)	
All	0.053±0.026 (85)	
National average 2004-2005 (NGGI)	0.106	0.014

Global PFC-14 emission factors from global PFC emissions and aluminium production



- 1980s emission factor 1.1 kg PFC per tonne of Al
- current factor 0.35 kg PFC per tonne of Al

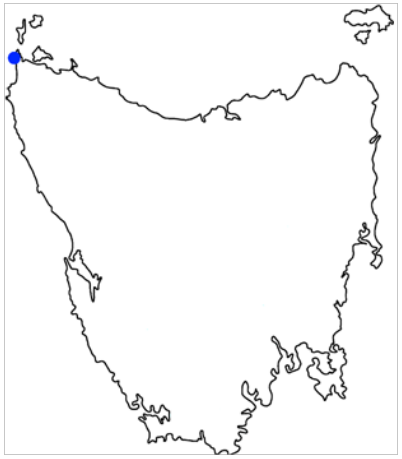
PFCs in the southern hemisphere



- PFC-14 concentration doubled since aluminium first produced
- PFC-14 growth rate slowed after 1980
- PFC-116 first appeared in the atmosphere in the 1930s

Cape Grim, Tasmania (40° 41’ 00” S; 144 ° 41’ 22” E)

Cape Grim



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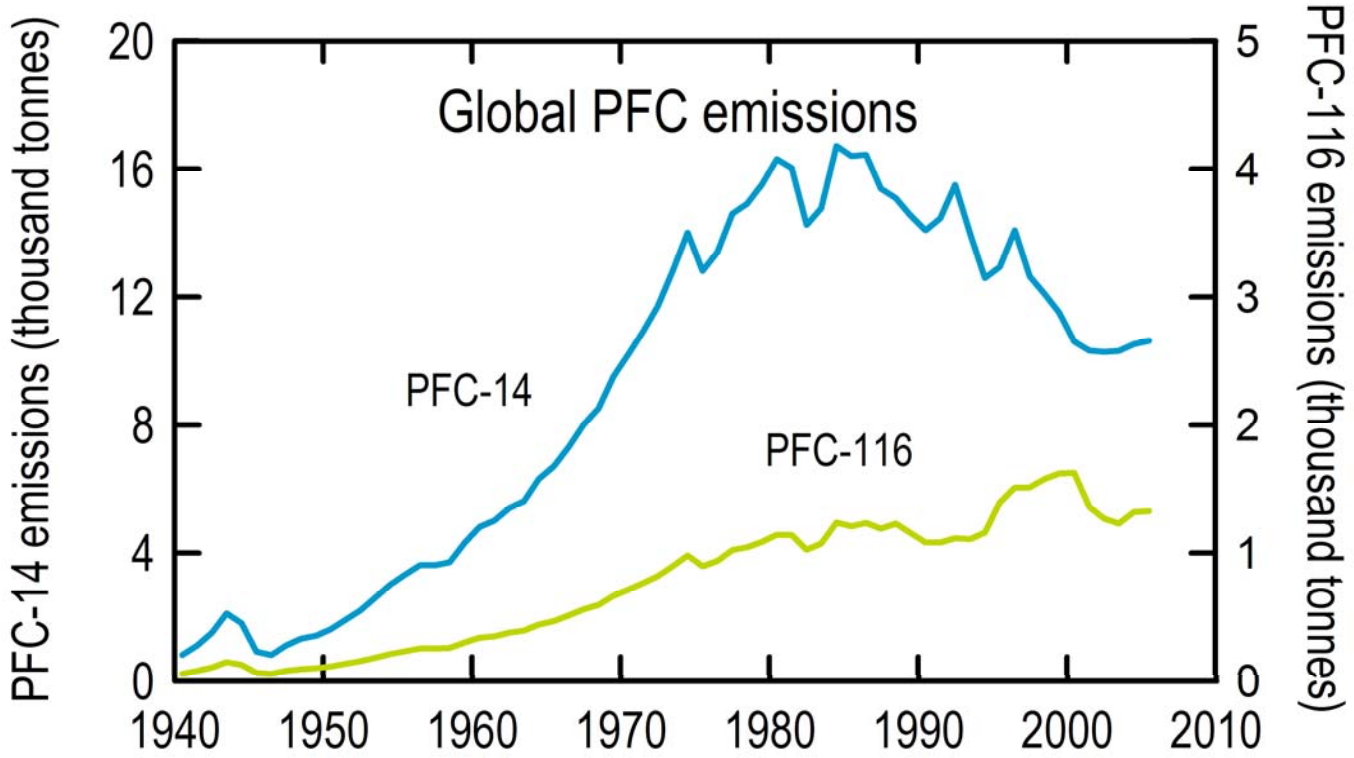
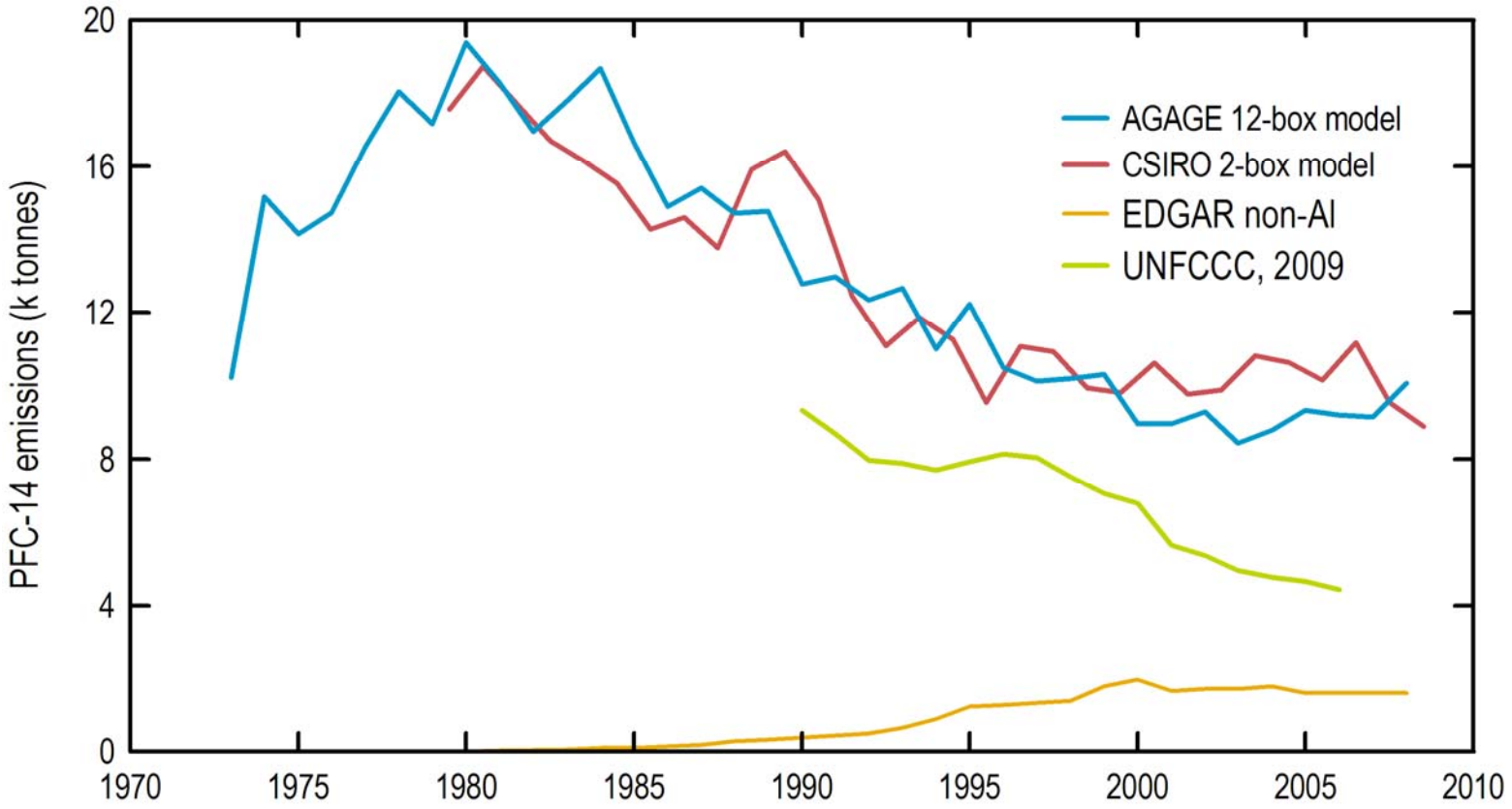
Global PFC emissions from atmospheric observations using inverse modelling



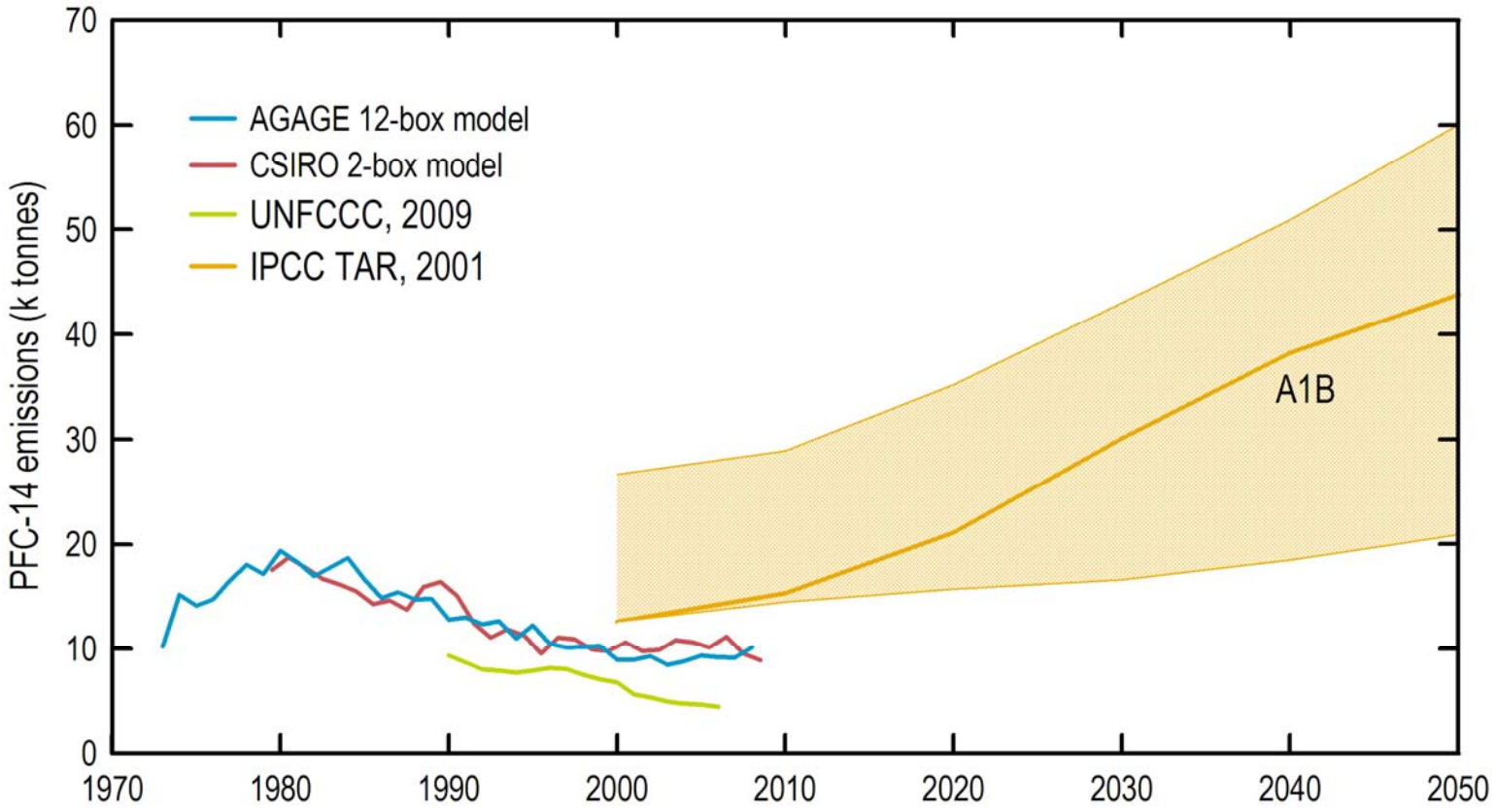
- PFC-14 emissions peaked at 16.7 k tonnes mid-1980s and stabilised at 10.3 k tonnes in the early 2000s.
- PFC-116 emissions reached 1.5 k tonnes in the early 2000s.

PFC-14 emissions from atmospheric observations



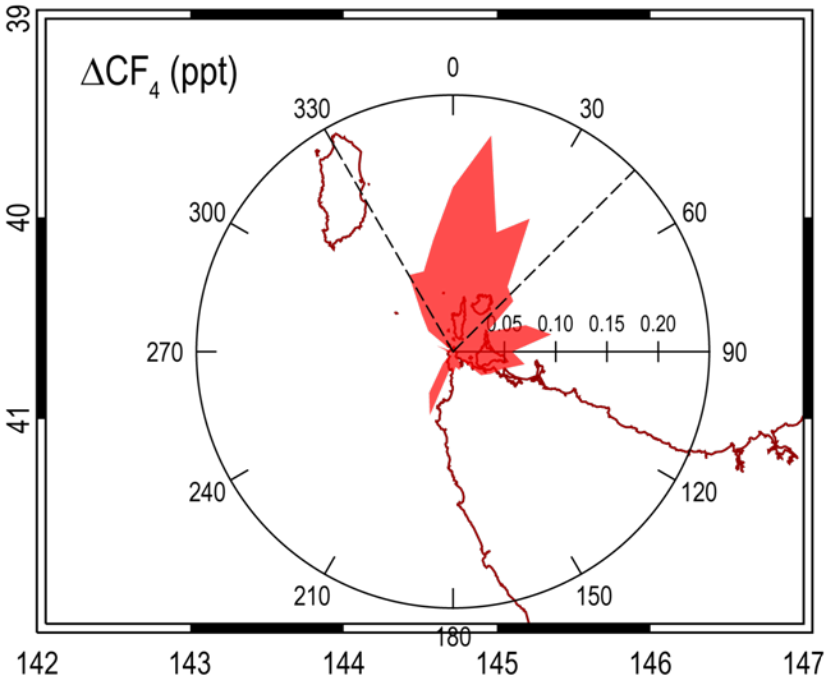
- Emissions calculated by inverse methods from AGAGE *in situ* and archive data
- UNFCCC data: 40% of Al smelting in countries not reporting to UNFCCC
- PFC-14 emissions from Al smelting: subtract EDGAR non-Al emissions

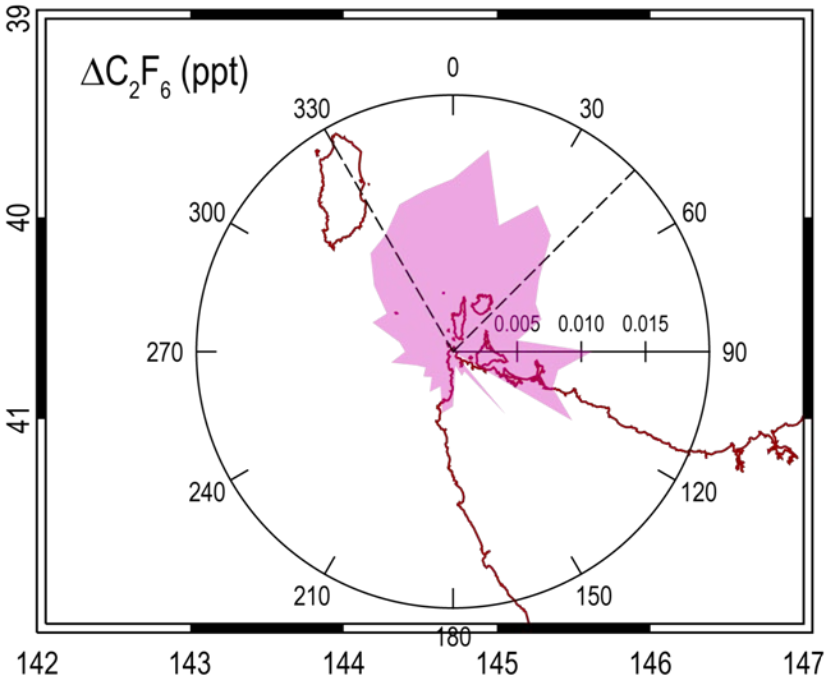
Future global PFC-14 emissions



- PFC-14 emissions set to rise again?
- Unlikely to follow the current IPCC scenarios

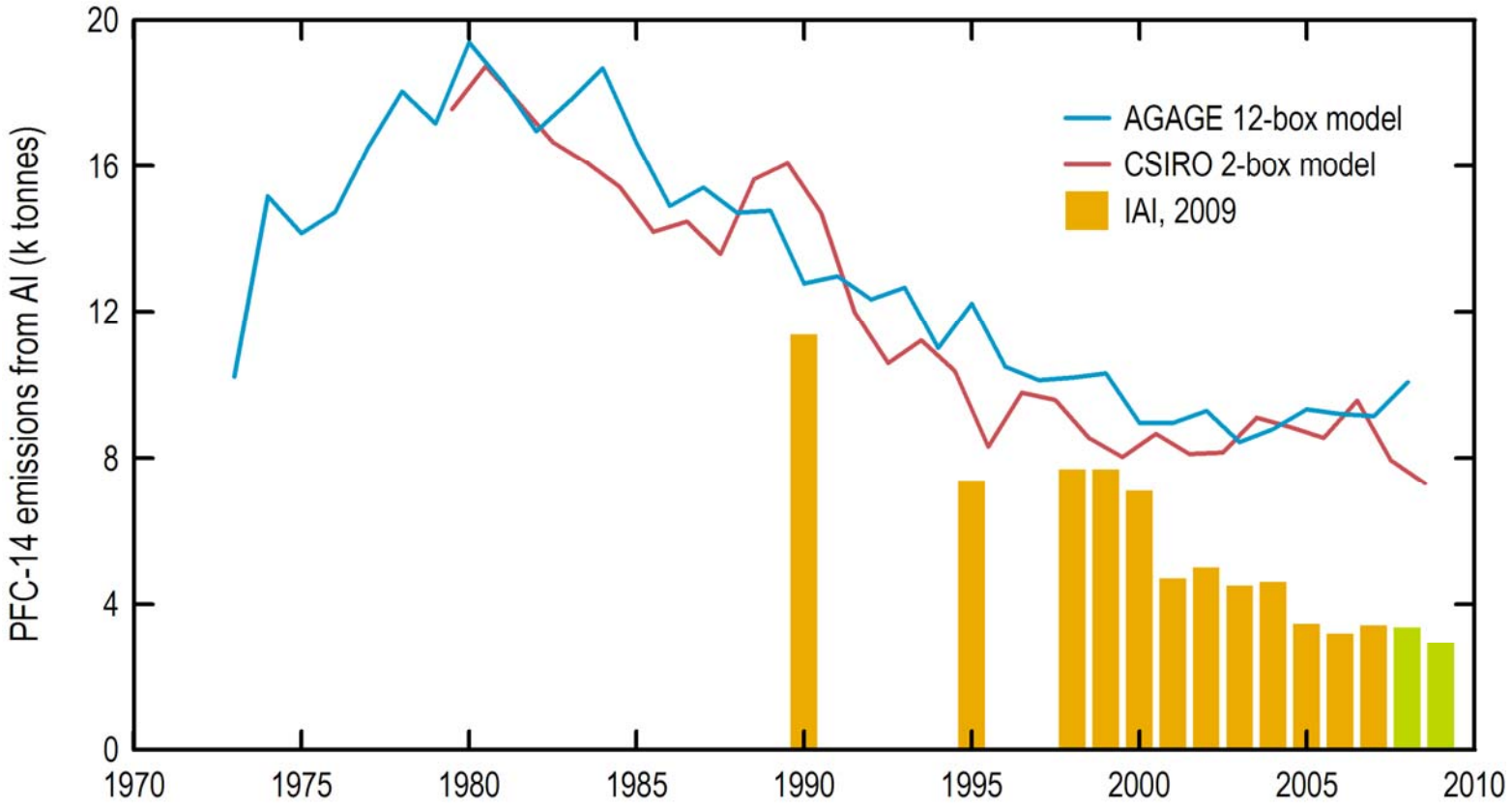
PFC-14, PFC-116 enhancements at Cape Grim





north	0.14±0.06
east	0.13±0.08

Global PFC-14 emissions from aluminium smelting



- Emissions from atmospheric data are now significantly higher than those obtained from the IAI Anode Effect Survey (May 2009)
- Has the IAI Anode Effect Survey captured the emissions from China?

PFC-14 (CF_4) annual emissions & emission factors

Aluminium production (k tonnes)	2004	2005	2006	2007	2008	2004-2008
Bell Bay	162	174	176	176	176	864
Portland	355	346	340	358	358	1757
Pt Henry	192	187	190	190	190	950
Pt Henry/Portland	546	534	530	548	548	2707
All	708	707	707	725	725	3571

CF_4 annual emissions (tonnes)

Bell Bay		5	5			25±14
Portland	19	23	13	22	12	90±37
Pt Henry	10	16	9	9	14	58±19
Pt Henry/Portland	30	39	23	29	41	161±53
all	39	48	28	36	39	191±41

CF_4 emission factors (kg/tonne)

Bell Bay		0.03	0.03			0.03±0.02 (8)
Portland	0.06	0.07	0.04	0.06	0.03	0.05±0.02 (47)
Pt Henry	0.05	0.09	0.05	0.05	0.08	0.06±0.02 (68)
Pt Henry/Portland	0.06	0.07	0.04	0.05	0.08	0.06±0.02 (36)
all	0.06	0.07	0.04	0.05	0.05	0.05±0.01 (159)
Australia NGGI	0.10	0.11	0.04			