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In this Issue

A Note From the IGAC Chair

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Refocussing IGAC and Integration of Results

Since its origin, IGAC has been structured around mostly "geographic" foci (e.g., tropical, mid-latitude, polar atmospheric processes). The structure served well for a time, but was also increasingly becoming a barrier system for scientists working on similar issues in different geographic locations. The IGAC Council has therefore decided to revise the entire structure of the Project, and to establish a new model that would eliminate these barriers and address contemporary scientific issues more directly. I am pleased to announce that this new structure is now in place and should soon become operational. The Council tried to simplify and consolidate where possible, but also added a few new Activities to fill gaps when necessary. More importantly, the new structure will allow more emphasis to be placed on integration and synthesis of the results of IGAC research.

Figure 1 shows that the 3 major scientific themes of IGAC are: (1) Biosphere-Atmosphere Interactions, (2) Oxidants and Photochemistry, and (3) Atmospheric Aerosols. In addition, IGAC will host several fundamental and cross-cutting activities, and will continue to put emphasis on education and capacity building. A new team will be responsible for integration and synthesis of the scientific work conducted in the framework of IGAC over the last 10 years. The overall guidance of IGAC will continue to be provided by the IGAC Scientific Steering Committee, with general oversight by the Commission on Atmospheric Chemistry and Global Pollution (CACGP) and the Scientific Committee for the International Geosphere Biosphere Program (SC-IGBP).

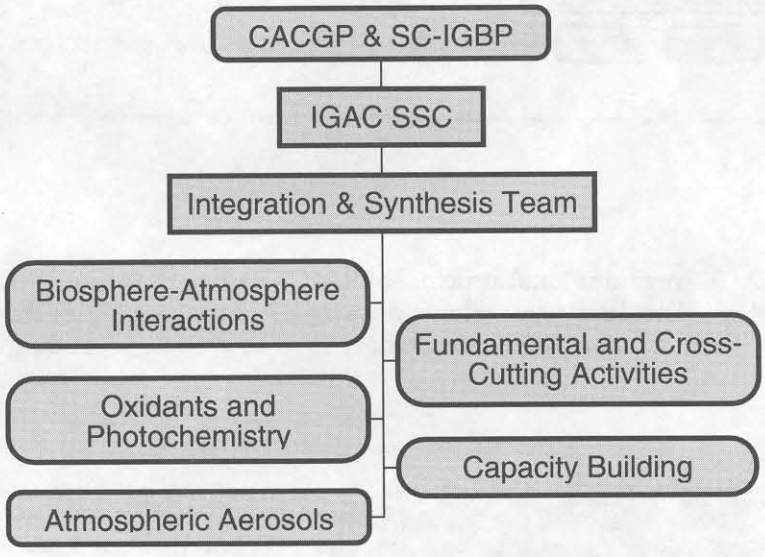

Figure 1. The new overall organizational structure of IGAC

GLOBAL CHANGE IGBP

The detailed structures of the IGAC Foci are shown in Figures 2 and 3. In the case of the Biosphere-Atmosphere Interactions Focus, emphases will be on Ocean-Atmosphere coupling (MAGE), and Terrestrial Biosphere-Atmosphere Interactions (BIBEX, DEBITS, and an Activity representing a merger of several ongoing ones concerning trace gas emissions from terrestrial ecosystems). The Focus on Oxidants and Photochemistry highlights intercontinental transport and chemical transformations (APARE and NARE) and global ozone and its precursors (GLONET and GTOP). The Atmospheric Aerosols Focus is unchanged, and includes 4 Activities (ACAPS, DARF, ACI, and SUTA). Each of these Foci will have its own integration and synthesis group which will "feed" the team described above. Cross-cutting activities include mostly global modeling work (GIM), laboratory studies, calibration of chemical measurements (ICIC), production of global emission inventories (GEIA), and studies of polar atmospheric and snow chemistry (PASC). Finally, IGAC's activities related to capacity building will continue under ACE[ED].

Through 1995, the IGAC Council directed most of its attention to the definition and implementation of international projects such as large field campaigns. Since then, attention has shifted toward developing a framework for integrating scientific findings. Time has come for IGAC (and for the larger scientific community) to answer the following questions: What have we really learned in the last 10 years, especially from the IGAC-sponsored field campaigns? What are the remaining questions related to global atmospheric-biospheric chemistry, and what are the best approaches to solve them? The integration and synthesis teams recently created by the IGAC Council will lead this effort over the next 2 years. The effort will involve a large fraction of our community and will culminate with the publication of a synthesis book in year 2000. We are beginning to plan a meeting involving a large number of scientists for the September-October 1999 time frame to address these questions and to discuss how IGAC should evolve further in the future. I will keep you posted on developments in upcoming issues of this newsletter.

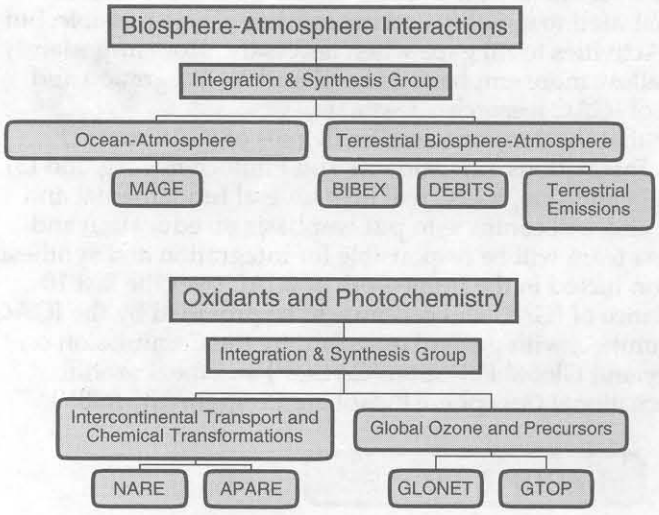

Figure 2. The organizational structure of IGAC's new Foci on "Biosphere-Atmosphere Interactions" and "Oxidants and Photochemistry".

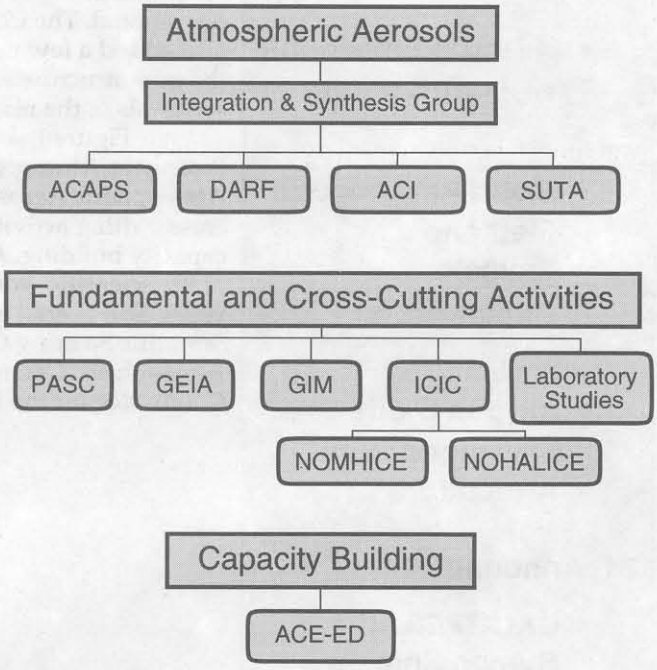

Figure 3. The organizational structure of IGAC's Foci on "Atmospheric Aerosols", "Fundmental and Cross-Cutting Activities", and "Capacity Building".

THE BUDGET OF METHANE FROM RICE FIELDS

Contributed by H.-U. Neue, Umweltforschungszentrum, Bad Lauchstädt, Germany and R. Sass, Rice University, USA

Methane (CH_4) is an important greenhouse gas. The present atmospheric CH_4 concentration is more than double its preindustrial level of about 0.8 ppmv. The current burden of CH_4 in the atmosphere is approximately 4700 Tg (1 Tg = 1 million tons), and the global annual emission is about 500 Tg with an apparent net flux of 40 Tg y^{-1} (Cicerone & Oremland, 1988). Isotopic measurements of atmospheric CH_4 show that 70-80% is of biogenic origin (Wahlen et al., 1989). Flooded rice fields are a significant source of atmospheric CH_4. The emission is the net result of opposing bacterial processes, production in anaerobic microenvironments, and consumption and oxidation in aerobic microenvironments, both of which can be found side by side in flooded rice soils. Flooding cuts off the soil's oxygen supply, causing anaerobic fermentation of organic matter and concomitant CH_4 formation. CH_4 transport to the atmosphere takes place by ebullition of gas bubbles from the soil and through the gas-conduit system of rice plants that supply atmospheric oxygen to the submerged roots. As long as rice was originally grown on soils that were naturally flooded, the associated CH_4 emission may partly be classified as a natural source. However, increased production, the bunding of rice fields, concomitant water harvesting, and artifical flooding have added an anthropogenic CH_4 source. Given the further required increase in rice production from 520 million tons today up to 1 billion tons in the next century, a further increase in CH_4 emission will occur if current technologies are continued.

Comprehensive reviews on CH_4 emission from rice fields have recently been published (Neue and Sass, 1994; Neue, 1997) and various technical papers in national and international journals have contributed to the understanding of the relationships between CH_4 fluxes, agronomic practices and biogeochemical processes and factors. Still disputed is the regional and global source strength of CH_4 emission from rice fields. This paper updates these budget efforts. The presented assessments are based upon the Guidelines of OECD/IPCC revised in 1996 (IPCC, 1997) and on recently reported flux measurements.

Natural wetlands (105 ± 55 Tg) and wetland rice fields (60 ± 40 Tg) account for about one third of the total global estimated annual CH_4 source strength of 515 ± 75 Tg (IPCC, 1992). Methane fluxes in rice fields are the result of production, oxidation and transport. Various abiotic, biotic and management and cultivation factors affect the fluxes. The high variation of natural and cultural components affecting rice growth and CH_4 fluxes from rice fields make it extremely difficult to accurately calculate regional and global emissions. Today many of the processes controlling CH_4 fluxes are understood in detail, but respective integrated mechanistic modeling and the required geographic information of important factors are still lacking. A major shortcoming is also the insufficient time resolution of many flux measurements to achieve representative mean seasonal fluxes.

Many estimates are based on simple extrapolations of a time and space limited number of flux measurements to areas and time spans for which they may not necessarily be representative. Most estimates are based on an area weighted summation of CH_4 emission measurements at a few periods and sites from transplanting to harvest only.

Despite these shortcomings most reported CH_4 fluxes for different rice ecosystems are of reasonable magnitudes (Table 1). The relative source strength of rice ecosystems follows the order: irrigated rice > favorable rainfed rice > flood prone rainfed rice > deepwater rice > drought prone rainfed rice > tidal wetland rice. Upland rice is not a source of CH_4, since it is grown like wheat in aerated soils that never become flooded for a significant period of time. Irrigated rice has the highest CH_4 source strength because of the assured water supply and the area planted. Differences in residue recycling, organic amendments, scheduled short aeration periods, soils, fertilization, and rice cultivars are major causes for variations of CH_4 fluxes in irrigated rice. Highest CH_4 fluxes are observed in fields receiving organic amendments. Lowest CH_4 fluxes are recorded in fields with low residue recycling, multiple aeration periods, poor soils and low fertilization with resulting poor rice growth and low yields. The source strength of rainfed rice, planted on 39 million ha, is most uncertain because of its high variability in all factors controlling CH_4 emission. CH_4 fluxes are generally lower from rainfed rice because of drought periods and low rice yields. Residue recycling and organic amendments are also generally less in rainfed rice compared to irrigated rice. CH_4 fluxes may match those of irrigated rice in some favorable as well as floodprone rainfed rice areas. Future improvements of rice production in these areas through partial irrigation, higher fertilizer input, increasing organic recycling and manuring will likely enhance CH_4 emission if not combined with mitigation technologies.

Table 1. Minimum, maximum and median of reported CH_4 fluxes from rice fields from seeding or transplanting to harvest (adapted from Neue, 1997).

Country	No of observations		Mean emission rate ($g\ CH_4\ m^{-2}\ day^{-1}$)			Seasonal emission ($g\ CH_4\ m^{-2}$)			Reference
			min.	median	max.	min.	median	max.	
China									Wang M. X. et al. 1993, Wang M.X. 1995; Lu et al. 1995
irrigated	74		0.06	0.34	1.41	5	34	155	
India									
irrigated	7				0.02	0.06	0.74	2	Mitra 1992
irrigated	25		0.09	0.24	0.41	6	20	39	Adhya et al. 1994, CRRC 1996
rainfed	8					5	17	60	Mitra 1992
deepwater	7					14	19	24	Mitra 1992
Indonesia									Nugroho et al. 1994; Makarim et al. 1995
irrigated	10		0.16	0.52	0.78	14	31	47	
rainfed	4		0.01	0.06	0.10	4	8	10	
Italy									Schütz et al. 1989; Holzapfel-Pschorn & Seiler 1986
irrigated	22		0.10	0.29	0.68	12		77	
Japan									Yagi & Minami 1990,1991; Kimura & Minami 1995
irrigated	28		0.01		0.39	1		45	
Korea (ROK)									
irrigated	4		0.07	0.24	0.46	9	33	63	Shin Y. K. et al 1995
Philippines									IRRI 1996; Metra-C. et al. 1995
irrigated	56		0.09	0.25	0.79	10	27	87	
rainfed	1		0.09			7			
Spain									Seiler et al. 1984
irrigated	1		0.10			12			
Thailand									Jermsawatdipong et al. 1994 a,b,; Chairoj, 1994; Kimura & Minami 1995
irrigated	27		0.38	0.48	0.72	34	48	86	
rainfed	4		0.02	0.15	0.45	1	15	68	
deepwater	2		0.09		0.17	12		32	Charoensilp et al. 1995; Siriratpiriya 1994
USA									Lindau et al 1991; Cicerone et al. 1992; Sass & Fisher 1995
irrigated	41	0.05	0.27	0.55	1	25	48		

Some of the 11.5 million hectares (Mha) planted to deepwater rice may even have a higher source strength than irrigated rice because of long flooded growing periods and high rice biomass production, even though grain yields are low. The source strength of tidal wetland rice is small because of its area (5 Mha) and because it is affected by salt water high in sulfate.

Extrapolating results of a national measurement campaign in India 1991, Mitra (1992) estimated a total emission of about 3 Tg yr^{-1} from the 42 Mha harvested rice area in India. This is 3 - 10 times less than reported by various other authors. While rainfed and deepwater rice fields revealed similar emission rates found in other countries, rice fields classified as irrigated rice in the Indian campaign emitted almost no CH_4 (mean seasonal emission rate of less than 1g m^{-2}). During the 1991 kharif (wet) season CH_4 fluxes were monitored on 34 fields/plots at 14 sites (irrigated rice at 4 sites, deepwater rice at 3 sites, and rainfed rice at 7 sites). CH_4 flux measurements (two replicates) were generally done weekly at 10 and 16 hrs from transplanting to harvest. According to Mitra (1992), the rainfed waterlogged and deepwater rice fields which constitute 40% of the 42 Mha harvested rice area in India (IRRI, 1995) contribute 94%, while the 45% irrigated rice contributes only 6% to the total emission. Mitra's extrapolation does not comprise a consistent and realistic estimate of CH_4 emission from irrigated rice fields in India. It appears that the fields and plots that were claimed to represent irrigated rice in India have not grown to rice before. Irrigating once a week and using up to 3.5 m of water per season, the experimental plots were flooded only for 1-2 days per week because percolation rates were mostly >20 mm d^{-1}. More than 6.5 meters of water would have been needed to keep these fields flooded during the growing season. These fields even became a sink for atmospheric CH_4, indicating fully aerated soils for most of the growing season, which is also supported by the low total dry plant biomass (3 to 9 t ha^{-1}) at N-fertilizer rates of up to 120 kg ha^{-1}. The high percolation should have also leached much of the small amounts of the CH_4 still produced under these conditions.

Expanding irrigation systems have increasingly assured water supply in irrigated rice in India, raising the harvested irrigated rice area to 19 Mha (45% of the total) in the past two decades, and contributing 61% to the total rice yield harvested. Assured water control has also led to higher inputs and input efficiency. In some areas, such as Punjab, Haryana, and Tamil Nadu, yields have increased by 55 - 98% (IRRI, 1993). The average yield level of irrigated rice in India is now, at 3.6 t ha^{-1}, similar to that of Thailand (4.0 t ha^{-1}), Sri Lanka (3.7 t ha^{-1}), the Philippines (3.4 t ha^{-1}), and Malaysia (3.0 t ha^{-1}) (IRRI, 1993), indicating that average water regimes, input levels, cultural practices and resulting CH_4 fluxes should not be expected to be very different. Indeed, except for Mitra's (1992), reported emission rates for irrigated rice fields in India (Adhya et al., 1994), are similar to those found in other countries.

Discriminating results that have emerged from flux measurements in the field according to rice ecologies show remarkable consistency (Table 2) in spite of the complexity and variability of methane fluxes discussed above. Existing model approaches are still very crude, with low resolution, but provide quite good regional estimates within the range of observed and extrapolated fluxes. Since most measurements have covered only the growing season of rice and missed the time of initial flooding, land preparation and post harvest periods as well as cultural practices, current annual CH_4 emissions from rice fields are probably higher than the median fluxes but much lower than the maximum fluxes given in Table 2. The proposed OECD/IPCC guidelines discriminate rice fields and respective CH_4 emissions according to rice ecologies and introduce factors for organic amendments and water regimes. Sass (1997) applied the proposed OECD/IPCC guidelines (IPCC, 1997) to available data from the world rice statistics (Table 3). He varied an assumed basic CH_4 flux within the range of most observed fluxes from irrigated rice fields without any organic amendment except recycling of roots and stubbles. Because of lack of data he used a stable fraction of farmers using organic amendments and a stable reduction-factor for rice grown under rainfed condition (rainfed rice and deepwater rice). Upscaling the median of all reported seasonal CH_4 fluxes or applying proposed OECD/IPCC default values resulted in a best estimate ranging between 30 and 50 Tg of the annual world CH_4 emission from rice fields.

The global and regional source strength of rice fields will retain this level of uncertainty as long as mechanistic information on CH_4 fluxes and respective geographic information of controlling factors is not sufficiently established for more reliable modeling. Understanding and modeling of processes has progressed well and large-scale information on rice growing areas, growing seasons, temperature regimes, and soil types is available. Essential geographic information on water regimes, organic recycling and amendments, controlling soil properties, rice cultivars, and cultural practices are still insufficient or not available at present. The high spatial and temporal variability, even within small scales, of each of these factors as well as their interrelations and feedback limits further fast improvements in defining the source strength. Merely increasing the number of sites of CH_4 flux measurements will not reduce uncertainties. Sound upscaling and verification methods, for example downscaling of atmospheric measurements, have to be established.

Table 2. Estimated annual CH_4 fluxes from rice fields based on observed seasonal emissions (adapted from Neue, 1997).

Country	Harvested area (Mha)	Seasonal emission (kg CH_4 m^{-2})		Annual CH_4 emission (Tg)		Bachelet & Neue (1993) (Tg)
		median	max.	median	max.	
China				10.5	47.7	14.7
irrigated	30.8	340	1550	10.5	47.7	
India				6.8	16.4	14.5
irrigated	19.0	200	390	3.8	7.4	
rainfed	13.9	170	600	2.4	8.3	
deepwater	3.0	190	240	0.6	0.7	
Indonesia				2.4	3.5	3.5
irrigated	7.3	310	470	2.3	3.4	
rainfed	0.7	80	100	0.06	0.07	
Italy					0.02	
irrigated	0.2		770		0.02	
Japan					0.9	0.8
irrigated	2.0		450		0.9	
Korea (ROK)				0.4	0.7	0.6
irrigated	1.1	330	630	0.4	0.7	
Philippines				0.7	1.9	0.8
irrigated	2.1	270	870	0.6	1.8	
rainfed	2.0		70		0.1	
Spain					0.006	
irrigated	0.05		120		0.006	
Thailand				1.8	6.7	2.2
irrigated	0.7	480	860	0.3	0.6	
rainfed	8.6	150	680	1.3	5.9	
deepwater	0.7		320		0.2	
USA				0.3	0.5	
irrigated	1.1	250	480	0.3	0.5	
World				31.7	104.0	46.7 (Asia only)
irrigated	79.2	312	983	24.7	77.9	
rainfed	40.6	153	571	6.2	23.2	
deepwater	11.5	214	255	0.8	2.9	

Table 3. Annual World Rice Field Methane Emission by Country (adopted from Sass, 1997, unpublished)

Country Methane = (Fraction inorganic+2*fraction organic)*(irrigated area+rainfed factor* rainfed area)*world methane constant

World methane (g/m^2), 100% irrigated, no organic ammendments	20,0	25,0	30,0
Fraction of farmers using organic ammendments	0,4	0,4	0,4
Factor for rainfed rice	0,7	0,7	0,7
Factor for upland rice	0,0	0,0	0,0

	1990 Area .000 ha		world (%)	irrigated (%)	rainfed (%)	upland (%)	irrigated .000 ha	rainfed .000 ha	upland .000 ha	Tg CH_4 for above param.	Tg CH_4 for above param.	Tg CH_4 for above param.	Tg CH_4 for country reports
ASIA	**133.328**		**89,94**	**59**	**33**	**8**	**78.615**	**44.199**	**10.514**	**30,68**	**38,34**	**46,01**	
Afghanistan	173		0,12	100	0	0	173	0	0	0,05	0,06	0,07	
Bangladesh	10.435		7,04	22	70	8	2.296	7.305	835	2,07	2,59	3,11	
Bhutan	25		0,02	50	46	4	13	12	1	0,01	0,01	0,01	
Brunei	1		0,00	79	0	21	1	0	0	0,00	0,00	0,00	
China	33.265		22,44	93	5	2	30.936	1.663	665	8,99	11,24	13,48	13-17
Hong Kong	0		0,00	100	0	0	0	0	0	0,00	0,00	0,00	
India	42.321		28,55	53	32	15	22.430	13.543	6.348	8,93	11,17	13,40	2.4-6.0
Indonesia	10.502		7,08	72	17	11	7.561	1.785	1.155	2,47	3,08	3,70	4,0
Iran	570		0,38	100	0	0	570	0	0	0,16	0,20	0,24	
Iraq	78		0,05	100	0	0	78	0	0	0,02	0,03	0,03	
Japan	2.074		1,40	99	0	1	2.053	0	21	0,57	0,72	0,86	.02-1.04
Kampuchea	1.800		1,21	8	90	2	144	1.620	36	0,36	0,45	0,54	
Korea, DPR	670		0,45	67	20	13	449	134	87	0,15	0,19	0,23	
Korea, Republic	1.242		0,84	100	0	0	1.242	0	0	0,35	0,43	0,52	0,44
Laos	638		0,43	2	61	37	13	389	236	0,08	0,10	0,12	
Malaysia	639		0,43	66	22	12	422	141	77	0,15	0,18	0,22	
Myanmar	4.760		3,21	18	76	6	857	3.618	286	0,95	1,19	1,42	
Nepal	1.445		0,97	23	74	3	332	1.069	43	0,30	0,38	0,45	
Pakistan	2.113		1,43	100	0	0	2.113	0	0	0,59	0,74	0,89	
Philippines	3.319		2,24	61	37	2	2.025	1.228	66	0,81	1,01	1,21	0.31-0.70
Sri Lanka	828		0,56	37	56	7	306	464	58	0,18	0,22	0,26	
Syria	0		0,00	100	0	0	0	0	0	0,00	0,00	0,00	
Taiwan	700		0,47	97	0	3	679	0	21	0,19	0,24	0,29	
Thailand	9.650		6,51	7	92	1	676	8.878	97	1,93	2,41	2,89	0.47-8.77
Turkey	52		0,04	100	0	0	52	0	0	0,01	0,02	0,02	
Vietnam	6.028	4,07	53	39	8	3.195	2.351	482	1,36	1,69	2,03		
PACIFIC	**115**		0,08	**94**	**0**	**6**	**109**	**0**	**7**	**0,03**	**0,04**	**0,05**	
Australia	102		0,07	100	0	0	102	0	0	0,03	0,04	0,04	
Fiji	13		0,01	50	0	50	7	0	7	0,00	0,00	0,00	
Solomon Islands	0		0,00	38	62	0	0	0	0	0,00	0,00	0,00	
Papua/New Guinea	0		0,00	38	62	0	0	0	0	0,00	0,00	0,00	

Table 3. (Continued)

	1990 Area .000 ha	world (%)	irrigated (%)	rainfed (%)	upland (%)	irrigated .000 ha	rainfed .000 ha	upland .000 ha	Tg CH $_4$ for above param.	Tg CH $_4$ for above param.	Tg CH $_4$ for above param.	Tg CH $_4$ for country reports
AFRICA	**6.499**	**4,38**	**18**	**33**	**49**	**1.197**	**2.133**	**3.169**	**0,75**	**0,94**	**1,13**	
Algeria	1	0,00	100	0	0	1	0	0	0,00	0,00	0,00	
Angola	18	0,01	100	0	0	18	0	0	0,01	0,01	0,01	
Benin	7	0,00	10	0	90	1	0	6	0,00	0,00	0,00	
Birkina Faso	19	0,01	89	0	11	17	0	2	0,00	0,01	0,01	
Burundi	12	0,01	25	0	75	3	0	9	0,00	0,00	0,00	
C. African Rep;	10	0,01	25	0	75	3	0	8	0,00	0,00	0,00	
Cameroon	15	0,01	25	0	75	4	0	11	0,00	0,00	0,00	
Chad	39	0,03	25	0	75	10	0	29	0,00	0,00	0,00	
Comoros	13	0,01	100	0	0	13	0	0	0,00	0,00	0,01	
Congo	4	0,00	25	0	75	1	0	3	0,00	0,00	0,00	
Egypt	436	0,29	100	0	0	436	0	0	0,12	0,15	0,18	
Gabon	0	0,00	25	0	75	0	0	0	0,00	0,00	0,00	
Gambia	14	0,01	90	0	10	13	0	1	0,00	0,00	0,01	
Ghana	85	0,06	24	0	76	20	0	65	0,01	0,01	0,01	
Guinea	608	0,41	8	45	47	49	274	286	0,07	0,08	0,10	
Guinea Bissau	57	0,04	25	0	75	14	0	43	0,00	0,00	0,01	
Ivory Coast	583	0,39	6	7	87	35	41	507	0,02	0,02	0,03	
Kenya	15	0,01	25	0	75	4	0	11	0,00	0,00	0,00	
Liberia	168	0,11	0	6	94	0	10	158	0,00	0,00	0,00	
Madagascar	1.160	0,78	10	76	14	116	882	162	0,21	0,26	0,31	
Malawi	29	0,02	25	0	75	7	0	22	0,00	0,00	0,00	
Mali	222	0,15	25	0	75	56	0	167	0,02	0,02	0,02	
Mauritania	14	0,01	100	0	0	14	0	0	0,00	0,00	0,01	
Morocco	6	0,00	100	0	0	6	0	0	0,00	0,00	0,00	
Mozambique	109	0,07	25	0	75	27	0	82	0,01	0,01	0,01	
Niger	29	0,02	35	0	65	10	0	19	0,00	0,00	0,00	
Nigeria	1.567	1,06	16	33	51	251	517	799	0,17	0,21	0,26	
Rwanda	3	0,00	25	0	75	1	0	2	0,00	0,00	0,00	
Senegal	73	0,05	25	0	75	18	0	55	0,01	0,01	0,01	
Sierra Leone	339	0,23	1	32	67	3	108	227	0,02	0,03	0,03	
Somalia	5	0,00	50	0	50	3	0	3	0,00	0,00	0,00	
South Africa	1	0,00	100	0	0	1	0	0	0,00	0,00	0,00	
Sudan	1	0,00	50	0	50	1	0	1	0,00	0,00	0,00	
Swaziland	0	0,00	25	0	75	0	0	0	0,00	0,00	0,00	
Tanzania	375	0,25	3	75	22	11	281	83	0,06	0,07	0,09	
Togo	21	0,01	4	0	96	1	0	20	0,00	0,00	0,00	
Uganda	37	0,02	25	0	75	9	0	28	0,00	0,00	0,00	
Zaire	393	0,27	5	5	90	20	20	354	0,01	0,01	0,01	
Zambia	11	0,01	25	0	75	3	0	8	0,00	0,00	0,00	
Zimbabwe	0	0,00	25	0	75	0	0	0	0,00	0,00	0,00	

Table 3. (Continued)

	1990 Area .000 ha	world (%)	irrigated (%)	rainfed (%)	upland (%)	irrigated .000 ha	rainfed .000 ha	upland .000 ha	Tg CH$_4$ for above param.	Tg CH$_4$ for above param.	Tg CH$_4$ for above param.	Tg CH$_4$ for country reports
EUROPE	**1.050**	**0,71**	**100**	**0**	**0**	**1.050**	**0**	**0**	**0,29**	**0,37**	**0,44**	
Albania	2	0,00	100	0	0	2	0	0	0,00	0,00	0,00	
Bulgaria	11	0,01	100	0	0	11	0	0	0,00	0,00	0,00	
France	20	0,01	100	0	0	20	0	0	0,01	0,01	0,01	
Greece	15	0,01	100	0	0	15	0	0	0,00	0,01	0,01	
Hungary	11	0,01	100	0	0	11	0	0	0,00	0,00	0,00	
Italy	208	0,14	100	0	0	208	0	0	0,06	0,07	0,09	
Portugal	33	0,02	100	0	0	33	0	0	0,01	0,01	0,01	
Romania	37	0,02	100	0	0	37	0	0	0,01	0,01	0,02	
Spain	81	0,05	100	0	0	81	0	0	0,02	0,03	0,03	
Former USSR	624	0,42	100	0	0	624	0	0	0,17	0,22	0,26	
Former Yugoslavia	8	0,01	100	0	0	8	0	0	0,00	0,00	0,00	
AMERICAS	**7.247**	**4,89**	**45**	**6**	**49**	**3.264**	**413**	**3.570**	**0,99**	**1,24**	**1,49**	
USA	1.114	0,75	100	0	0	1.114	0	0	0,31	0,39	0,47	0.04-0.47
Argentina	103	0,07	100	0	0	103	0	0	0,03	0,04	0,04	
Belize	2	0,00	10	0	90	0	0	2	0,00	0,00	0,00	
Bolivia	110	0,07	25	0	75	28	0	83	0,01	0,01	0,01	
Brazil	3.945	2,66	19	6	75	750	237	2.959	0,26	0,32	0,38	
Chile	35	0,02	79	0	21	28	0	7	0,01	0,01	0,01	
Columbia	435	0,29	67	10	23	291	44	100	0,09	0,11	0,14	
Costa Rica	53	0,04	10	0	90	5	0	48	0,00	0,00	0,00	
Cuba	150	0,10	100	0	0	150	0	0	0,04	0,05	0,06	
Dominican Rep	93	0,06	98	0	2	91	0	2	0,03	0,03	0,04	
Ecuador	266	0,18	40	50	10	106	133	27	0,06	0,07	0,08	
El Salvador	15	0,01	10	0	90	2	0	14	0,00	0,00	0,00	
Guatemala	15	0,01	10	0	90	2	0	14	0,00	0,00	0,00	
Guyana	68	0,05	95	0	5	65	0	3	0,02	0,02	0,03	
Haiti	52	0,04	40	0	60	21	0	31	0,01	0,01	0,01	
Honduras	19	0,01	10	0	90	2	0	17	0,00	0,00	0,00	
Jamaica	0	0,00	40	0	60	0	0	0	0,00	0,00	0,00	
Mexico	123	0,08	41	0	59	50	0	73	0,01	0,02	0,02	
Nicaragua	48	0,03	10	0	90	5	0	43	0,00	0,00	0,00	
Panama	92	0,06	5	0	95	5	0	87	0,00	0,00	0,00	
Paraguay	34	0,02	50	0	50	17	0	17	0,00	0,01	0,01	
Peru	185	0,12	84	0	16	155	0	30	0,04	0,05	0,07	
Puerto Rico	0	0,00	75	0	25	0	0	0	0,00	0,00	0,00	
Surinam	58	0,04	100	0	0	58	0	0	0,02	0,02	0,02	
Trinidad & Tobago	5	0,00	45	0	55	2	0	3	0,00	0,00	0,00	
Uruguay	108	0,07	100	0	0	108	0	0	0,03	0,04	0,05	
Venezuela	119	0,08	90	0	10	107	0	12	0,03	0,04	0,04	
TOTAL	148.239	100,00	56,8	31,5	11,6	84235	46744	17260	32,8	40,9	49,1	

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GLOBAL ANTHROPOGENIC METHANE EMISSION COMPARISONS

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1. Introduction

For national anthropogenic greenhouse gas inventories for the Climate Convention, the IPCC developed a default methodology and a reporting framework (IPCC/OECD/IEA, 1995). This methodology was adopted at the first conference of the parties (CoP1) to the Climate Convention in Berlin. The IPCC recently revised the methodology for national greenhouse gas inventories (IPCC/OECD/IEA, 1997). The updated methodology is adopted for use during the CoP3 in December 1997 in Kyoto. For the moment no future updates for the methodology are planned within five years, but still the uncertainties in the inventories using the latest methodology are around 30% in methane and more than 50% in all other sources, except for the largest anthropogenic source: namely CO_2 emissions from fossil fuel combustion (in which the uncertainty is around 10% globally and around 5% in some OECD countries). This raises the question how the uncertainty ranges can be reduced for the sake of verifying compliance with the Kyoto protocol. The reduction of uncertainties in emission inventories is a scientific undertaking. In the Netherlands an initiative was started to compare top-down with bottom-up emission inventories with the aim of improving national inventories. A GEIA Meeting and an IPCC expert meeting on the subject were organized at RIVM, Bilthoven, the Netherlands, 3-7 November 1997. Results of these meetings will be published in proceedings. In this paper some highlights are given, with emphasis on methane.

2. Comparison

2.1 Results of comparisons of national inventories with budgets and models

In national emission inventories total emissions are given for different sectors in the economy for one year, e.g., 1990 or 1995. Can model results be used to reduce the uncertainties in national inventories? Model results are given as concentrations for a grid over the globe for any period between one hour and a year, based on an *a priori* emission estimate, concentration measurements and meteorology. To compare the two is difficult because of the different space and time dimensions. In a background study (Van Amstel et al., 1997), methodology is developed for this kind of comparison. It is recommended to make comparisons at the national, zonal and global levels based on aggregated national inventories. The comparison for CO_2 however is hampered by the uncertainty in the partitioning of the extra fossil fuel related CO_2 emissions over the most important global sinks, namely the biosphere and the oceans. More measurements are needed to resolve this problem. The GEIA and IPCC expert meeting participants concluded that the uncertainty in the uptake by the oceans is approximately 1 Gt C per year.

For methane and nitrous oxide, three dimensional models of the troposphere to obtain atmospheric concentration fields of greenhouse gases

at different levels above the earth are using *a priori* greenhouse gas emission estimates on a grid of one by one degree longitude and latitude. Some atmospheric chemistry models can calculate in the forward and in the inverse mode. In the forward mode emission estimates are the input variables and greenhouse gas concentrations are the output. In the inverse mode concentration fields are the input variables and greenhouse gas emissions are the output.

National inventories can be used as new *a priori* estimates in the forward mode. In the inverse mode measurements of concentrations can be used to improve the emission estimates. For methane in an inverse modeling exercise Hein et al. (1997) concluded that a higher tropical wetland source is needed to explain the high concentrations measured at tropical latitudes and to close the budgets. In trajectory models methane concentration measurements can be used to validate the national emission inventories in the surrounding countries within 500 km distance (Fowler et al., 1996; Vermeulen et al., 1997; Stijnen et al., 1997).

2.2 *Comparisons of national inventories with EDGAR: Methane as an example*

A detailed comparison was made of national inventories (UNFCCC, 1996) and US country study results (Braatz, 1996) with the EDGAR database (Emissions Database for Global Atmospheric Research, Olivier et al., 1996). Preliminary results of this comparison have been published in the report: "Greenhouse Gas Emission Accounting" (Van Amstel et al., 1997). The purpose of this study was to investigate the possibilities of comparing different types of emissions inventories; to develop a methodology for this comparison and to use the results in an analysis to identify areas for improvement of the IPCC methodology and data quality.

Van Amstel et al. (1997) presented the differences between national total emissions and EDGAR totals for CO_2, CH_4 and N_2O emissions. In the following for methane some of the most important differences found are highlighted. The reasons for these differences are discussed and a comparison is made with top-down budget results according to IPCC (1994).

2.2.1 *Global emissions of methane*

Global total methane emissions can be calculated using the National Communications, the US country study results and EDGAR data for the missing countries (Table 1). From this Table it is clear that these totals are sometimes lower than the IPCC 1994 central budget estimates, although often still within the uncertainty ranges. For instance, the world total anthropogenic emissions according to national estimates (including EDGAR estimates for missing countries) is 295 Tg, while IPCC estimates total anthropogenic methane emissions at 375 Tg. Thus national totals are about 30% lower than the IPCC global budget. The difference, although considerable, is within the IPCC 's uncertainty range.

Even with EDGAR data included for the countries that have not yet reported their emissions, estimates fall short of the world totals per sector from IPCC. This is especially the case for methane emissions from biomass combustion, oil and gas production and distribution, animal manure, and waste handling. Natural wetland and swamp emissions are not discussed in this paper. The IPCC budget is still under discussion, as illustrated by the article by Hein et al. (1997), who introduce a new large tropical wetland source. So final conclusions can not be made here.

2.2.2 *Comparison of national anthropogenic methane inventories: National estimates versus EDGAR*

In the following, differences between national and EDGAR data are given in absolute amounts (Gigagrams or 10^9 grams CH_4) and in percentages, taking the official national total of all methane sources as 100%. Differences between official national totals and EDGAR were found to be large for emissions from fossil fuel combustion, biofuel combustion, fugitive coal, fugitive oil and gas, enteric fermentation, manure management and landfills (solid waste disposal). In this section the larger differences of all relevant sectors are given (>10% of the national total methane emissions from all sources or large in absolute amounts, see also Table 2).

Methane from coal

The global total methane emission from coal is estimated at 30 (range 15-45) Tg (IPCC, 1994). The USA estimate is about 7 Tg lower than the EDGAR estimate (see Table 2). This difference is substantial on a world scale. The reason for the difference is a different emission factor. The EDGAR emission factor for underground hard coal from the IEA study of Smith and Sloss (1992) was used. The IPCC default value is lower. Recently an update was made of the IEA study on coal emission factors by Smith (1997).

Methane from oil and gas

The global total methane emission from oil and gas is estimated at 55 (range 30-80) Tg (IPCC, 1994). For oil it is 15 (range 5-30) Tg, for natural gas it is 40 (range 25-50) Tg. The USA estimate is 6 Tg lower than the EDGAR estimate. Again the difference is due to use of diferent emission factors. The EDGAR emission factors were taken from the Arthur D. Little study (1989). The default emission factors recommended in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1995) are low

Table 1. Total methane emissions in 1990 for world regions (in Gg or 10^9 grams). The sum of National Communications, US Country Studies and EDGAR data for missing countries is given.

Region	Fossil	Biomass	Coal	Oil&Gas	Enteric	Manure	Animals	Rice	Agr. waste	Savanna	Land use	Waste	Total
	1A1-5	1A6	1B1	1B2	4A	4B	4A+B	4C	4E	4F	5	6	
EU15	734	86	2945	1499	6732	2626		103	0	146	14	8052	23262
OECD Europe	72	130	105	39	932	177		21	0	369	0	775	2058
E-Eur+CIS	129	26	6496	21792	6718	494		191	0	45	8	4898	48863
OECD-North Am.	655	772	4491	4472	6460	2520		429	0	79	38	10945	30861
OECD Pacific	60	13	854	296	4795	285		276	370	22	379	2395	9770
Latim America	368	927	484	4402	19634	888		2480	1498	967	3101	3282	38067
Africa	618	3081	1448	954	8050	516	1909	1696	4848	794	1278	3362	28553
Middle East	63	177	39	4309	1203	147		391	0	521	1	1388	8238
India region	67	3709	865	436	13194	1024		20935	23	2701	397	1848	45216
China region	94	3064	10775	397	6445	2963	301	15853	37	170	185	234	40525
E-Asia	183	1519	190	2022	1411	477		11560	43	431	621	779	19263
Small Islands	6	10	0	7	6	1		3	0	0	0	13	46
Total of regions	3049	13515	28692	40624	75584	12120	2210	53938	6819	6246	6022	37980	295354
Total acc. to IPCC		40000	30000	55000	80000	25000		60000				55000	375000
Total difference		26485	1308	14376	4416	12880		6062				17020	79646

compared to these. Some countries (like Mexico and Venezuela) used emission factors that were even higher than from the Arthur D. Little study.

The difference between national data and EDGAR for Eastern Europe and Russia is also about 6 Tg and once again the default emission factors recommended in the Guidelines are low compared to the Arthur D. Little study. The reasons for differences within the countries in this region are various. Some new independent states are missing. In Algeria the reason for the difference may be a mistake or gap in reporting.

Methane from fossil fuel combustion

The global total methane emission from fossil fuel combustion is 15 (range 1-30) Tg according to budget studies (IPCC, 1994). China's estimate is 1.5 Tg lower than the EDGAR estimate. The IPCC default emission factor for residential coal combustion is 10 g/GJ, a factor from the RADIAN Corporation study used for boilers. EDGAR used 300 g/GJ for residential coal combustion, a factor from Berdowski et al. (1993). Mexico used an even higher emission factor than that from Berdowski et al. Algeria may have made a mistake in reporting under this sector.

Methane from enteric fermentation

The global total methane emission from enteric fermentation is 85 (range 65-100) Tg according to budget studies (IPCC, 1994), and is in reasonable agreement with the total in EDGAR (80 Tg). The difference in Eastern Europe and the former Soviet Union between national data and EDGAR is 5 Tg. Some new independent states are missing in EDGAR. In addition emission factors and activity levels are different.

The EDGAR estimate for the OECD Pacific is 1.6 Tg lower than the total from the National Communications. This is substantial. The difference is a result of different emission factors used: EDGAR uses a regional-specific factor, while Australia and New Zealand use animal-specific factors for their national inventories.

The difference in Africa between US country study results and EDGAR for methane estimates from enteric fermentation is 1 Tg. The reason is that the African countries use lower emission factors than EDGAR. Actually the difference is somewhat smaller. Some countries have given the total for enteric plus manure. These are not taken into account in the totals of each separate category: enteric and manure.

Methane from animal manure

The global total methane emission from animal manure is 25 (range 20-30) Tg according to budget studies (IPCC, 1994), while the EDGAR estimate is 14 Tg. For Eastern Europe and Russia the difference between national data and EDGAR for methane emission estimates for manure systems is 2 Tg. The reason is that the Russian Federation did not give an estimate for manure.

The difference for China between the US country study result and EDGAR for methane emissions from manure is nearly 1 Tg. EDGAR is lower because other emission factors were used.

Methane emission from rice

The global total methane emission from rice is 60 (range 20-100) Tg according to budget studies (IPCC, 1994). The EDGAR total is 60 Tg. The total of national studies with EDGAR for missing countries is, however, lower than 60 Tg. Thus national studies tend to report lower estimates than EDGAR.

Significant differences were found between the US country study results and the EDGAR estimates for methane emission from rice, for Bangladesh (4 Tg), China (3 Tg), and the Philippines (1 Tg). The reason is that EDGAR used different emission factors and different activity levels.

Only for Thailand was the US country study estimate higher than the EDGAR estimate. The difference is about 2.5 Tg. Thailand used higher emission factors and activity levels.

Methane emission from solid waste

The global total methane emission from solid waste is 40 (range 20-70) Tg according to budget studies (IPCC, 1994). The EDGAR estimate for the European Union is lower than the sum of national inventories: 6101 Gg against 8052 Gg. This difference is 2 Tg and significant on a world scale. The difference for the region is 9%. The reason for the differences are that EDGAR used a direct method and national estimates are based on first order degradation models in some cases (Netherlands, UK, Germany). EDGAR used different activity data and different emission factors. Differences were more than 10% in most European countries.

The EDGAR estimate for methane from solid waste disposal in Africa is much lower than the national totals for the region: 924 against 2562 Gg. This difference of 1.6 Tg is significant on a world scale. The difference is 13%. Also for the separate countries EDGAR is consistently much lower: 10 to 20%. Probably the national reports have used the same method but different emission factors.

The EDGAR estimate for methane from solid waste disposal in China is 2346 Gg while the national report has zero emissions. This difference of 2.3 Tg matters on a world scale. The difference is 7% of the national methane emission. The reason for the difference is that China assumes total use of the methane from disposal.

2.2.3 Discussion and conclusions on methane comparisons.

National methane inventories as reported to the Climate Convention Secretariat and US country study results have been compared with EDGAR methane data. The reasons for differences are described. Eventually, this kind of comparison with semi-independent scientific database results contribute to the validation and verification of both national inventories and EDGAR and contribute to improvement of methodologies to estimate emissions.

Three types of differences were found when emission estimates from national inventories and EDGAR were compared:

1. Differences as a result of different emission factors: These differences can be relatively large, for instance in the case of methane emissions from manure, rice and waste. Measurements may be needed to improve emission factors. This information may be needed for the development of new IPCC default emission factors.
2. Differences because of the use of different activity levels: These differences point to the fact that EDGAR uses internationally available activity data, which in some cases differ from national data. Also EDGAR used available approximations. For example, the methane emissions from rice are different because it is hard to find data on areas planted and flooded each year.
3. Differences due to gaps in national data or EDGAR: Various National Communica

Table 2. Overview of large differences (>10% or large in absolute methane emission) between official national emission estimates from National Communications, US country studies and EDGAR data (in Gg and as % of national total).

	National Gg	EDGAR Gg	Difference[1] Gg	Difference[2] % of national total
Coal				
USA	4400	11969	7569	27
Oil and gas				
USA	3241	9430	6189	22
Mexico	969	821	-148	-4
Venezuela	1823	651	-1172	-37
E-Eur+fUSSR	21686	27394	5708	14
Algeria	0	458	458	33
Fossil combustion				
China	73	1529	1456	4
Mexico	247	41	-206	-5
Algeria	537	6	-531	-39
Enteric fermentation				
E-Eur+fUSSR	6278	11357	5079	13
OECD-Pacific	4768	3132	-1636	-17
Africa	3275	4239	964	8
Manure				
E-Eur+fUSSR	350	2527	2177	5
China	2850	1958	-892	-2
Rice				
Bangladesh	439	4131	3692	379
China	11800	14869	3069	9
Philippines	367	1314	947	92
Thailand	6290	3820	-2470	-35
Solid waste				
European Union	8052	6101	-1951	-9
Africa	2562	924	-1638	-13
China	0	2346	2346	7
Total EDGAR higher			39654	
Total EDGAR lower			-10644	
NET TOTAL OF LARGE DIFFERENCES			**29010**	

[1] Difference between national estimate and EDGAR

[2] Difference between National % of total methane and EDGAR % of total methane for a country.

tions and US country study reports are not complete or not yet available. When compared with EDGAR these gaps come out very distinctly. US country studies were made for capacity building and to learn about IPCC methodology. We expect a more complete reporting when more official National Communications are due. EDGAR showed gaps, for example, in methane emissions from waste water treatment. EDGAR missed some of the new independent states in Eastern Europe. No comparison was possible of methane emission estimates for the following agriculture and land use sectors: agricultural waste burning, savanna burning, deforestation and biomass burning, because the reporting is very scattered in the national estimates for these sectors.

The analysis indicates that review and evaluation of emission inventories of greenhouse gases can be useful because:

1. The use of both bottom-up and top-down emission data improves the scientific understanding of the global and regional budgets, it increases the quality of emission data and improves methodologies to compile national emissions inventories;
2. The exchange, review and comparison of data promotes dialogue, the sharing of data and consensus about the data among scientists and policy-makers, and
3. The comparison of national inventories with EDGAR data has identified potential areas for future improvement in the methodology to estimate emissions (Van Amstel et al., 1997).

The comparison of national methane emissions with (semi) independent scientific database results can contribute to verification of the emission inventories and to the reduction of the uncertainty in the emission estimates. In the national communications however, only summaries of emissions are published. The transparency of the emissions inventory is reduced this way, because not all data is available for a third party to review. Often a reference is made to a background report with the more complete emission inventory. These background documents are crucial in a review procedure, but they are not always readily available. It is recommended that countries publish standard data tables for reporting and that countries improve the reporting on emission factors and activity data in the national communications.

When comparing national inventories and EDGAR data for 1990, the net large differences are 29 Tg. This may be interpreted as the uncertainty of the methane emission inventories. The world total methane emissions estimated from national data, US country studies and EDGAR to fill in the missing countries, fall short of the IPCC budget as published in 1994. This may mean that IPCC default emission factors and emission factors used in national communications are generally too low.

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A NEW APPROACH TO ESTIMATE EMISSIONS OF NITROUS OXIDE FROM AGRICULTURE AND ITS IMPLICATIONS TO THE GLOBAL N_2O BUDGET

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1. Introduction

During the past decade attempts to define budgets for global atmospheric N_2O suggested that the strength of known N_2O sources is underestimated or that unidentified sinks exist (IPCC, 1990; 1992; Robertson, 1993). In these budgeting efforts anthropogenic N_2O emissions due to agricultural activities were considered to be relatively small (Table 1). These assessments were based upon a few reviews and interpretations that needed further examination (IPCC, 1992; Mosier, 1994; Bouwman, 1996). Questions to these interpretations were beginning to be raised during the development of national inventory methodologies for N_2O in agriculture (IPCC, 1995b; Bouwman, 1995; Duxbury and Mosier, 1993; Mosier and Bouwman, 1993). Before that time N_2O emissions from agricultural systems were only considered from the aspect of direct N_2O emissions from agricultural fields (OECD/OCDE, 1991) that had been fertilized with synthetic nitrogen (N) fertilizer. The estimates used tended to underestimate total agricultural emissions (Mosier, 1994; Bouwman, 1996) since only part of the N input into crop production was considered and the animal production portion of agriculture was not included and needed to be considered along with the rest of the agricultural N cycle.

In this paper, we summarize the background of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) for N_2O from agriculture and its implications for the global N_2O budget as described in Mosier et al. (1998a; 1998b). The United Nations Framework Convention on Climate Change requires that all parties periodically update and publish national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies. In response to this mandate the Intergovernmental Panel on Climate Change (IPCC), through the Office of Economic Cooperation and Development (OECD) and International Energy Agency (IEA) has been coordinating the development and updating of national inventory methodologies for various greenhouse gases. The first Phase of methodology development was published in the 1995 IPCC

Guidelines for National Greenhouse Gas Inventories (IPCC, 1995b). In Phase II a working group of 32 persons from 18 countries was assembled in December, 1995 at the request of OECD/IPCC/IEA to revise the IPCC Guidelines for National Greenhouse Gas Inventories for N_2O from Agricultural Soils (IPCC, 1997).

The IPCC 1995 Guidelines (IPCC, 1995b) included only N_2O emissions occurring directly from agricultural fields. The N sources in this calculation were expanded to include synthetic fertilizers, organic N from animal excreta and crop residue and the amount of biological N fixation. This basic formula equating direct N_2O emissions from agricultural soils to the N input multiplied by a conversion factor of 1.25 ± 1.0 % was used in the Cole et al. (1996) Climate Change 1995 assessment of mitigation options for N_2O emissions from agriculture. Values from these estimates were included in the Climate Change 1994 (IPCC, 1995a) report. Cole et al. (1996) included an additional factor of 0.75% of N applications to provide some accounting for indirect N_2O emissions that eventually evolved back to the atmosphere from N leaching or runoff from agricultural fields as well as NO_x and NH_3 volatilization (Cole et al., 1996) (Table 1).

TABLE 1. Global N_2O budgets: IPCC (1992), IPCC (1994) and from the N_2O methodology presented in this paper for N_2O from cultivated soils (IPCC, 1997)

Sources	IPCC, 1992	IPCC, 1995a	IPCC, 1997
		Tg N y^{-1}	
Natural			
ocean	1.4-2.6	3 (1-5)	3.0 (1-5)
tropical soils			
wet forest	2.2-3.7	3 (2.2-3.7)	3.0 (2.2-3.7)
dry savanas	0.5-2.0	1 (0.5-2.0)	1.0 (0.5-2.0)
temperate soils			
forests	0.5-2.0	1 (0.1-2.0)	1.0 (0.1-2.0)
grasslands	?	1 (0.5-2.0)	1.0 (0.5-2.0)
Subtotal	4.6-8.3	9 (4.3-14.7)	9.0 (4.3-14.7)
Anthropogenic			
agricultural soils	0.03-3.0	3.5 (1.8-5.3)	3.3 (0.6-14.8)
biomass burning	0.2-2.1	0.5 (0.2-1.0)	0.5 (0.2-1.0)
industrial sources	0.8-1.8	1.3 (0.7-1.8)	1.3 (0.7-1.8)
cattle and feedlots	?	0.4 (0.2-0.5)	2.1 (0.6-3.1)
Subtotal	1.0-6.9	5.7 (3.7-7.7)	7.2 (2.1-19.7)
Total Sources	5.6-15.2	14.7 (8-22.4)	16.2 (6.4-34.4)
Sinks			
Atmospheric Increase	3-4.5	3.9 (3.1-4.7)	3.9 (3.1-4.7)
Soils	?	?	?
Stratospheric Sink	7-13	12.3 (9-16)	12.3 (9-16)

[#] The 3.3 shown here is 0.8 lower than the total in Table 2, because we assume that part of the natural soil and ocean emissions estimates include part of the indirect N_2O that we calculate from emissions of NH_3 and NO_x from fertilization of agricultural soils and from nitrate leaching and runoff from these soils (Kroeze et al., 1998).

[*] For IPCC 1997 estimates of natural N_2O sources we use the values from IPCC 1995a. The values in parenthess in this column represent the range of estimates for each category.

The IPCC 1995 Guidelines still lacked mechanisms for estimating N-fixation and crop residue input and a quantifiable method for calculating N_2O productions following N leaching and runoff. N applied to agricultural soils may be lost from the fields through surface erosion or leaching (Duxbury and Mosier, 1993). This leached N continues recycling in the soil-water-air system and eventually is denitrified and converted to N_2O and N_2 and released back to the atmosphere (Figure 1; Nevison et al., 1996), or buried in sediments. All of these pathways and factors needed to be included in the anthropogenic agricultural soil N_2O source. Additionally, in the IPCC 1995 Guidelines animal production systems were not included in the agricultural anthropogenic N_2O production guidelines. As a start in overcoming these deficiencies in national emission inventories, we developed a revised method for estimating country-scale anthropogenic N_2O emissions from agricultural soils which is described in detail in the 1996 IPCC National Inventory Methodology Guidelines (IPCC, 1997) and in Mosier et al. (1998a). The result of using the new calculations suggests that an underestimation of total anthropogenic N_2O emissions from agricultural systems is likely responsible for the previous imbalanced global N_2O budgets (Table 1).

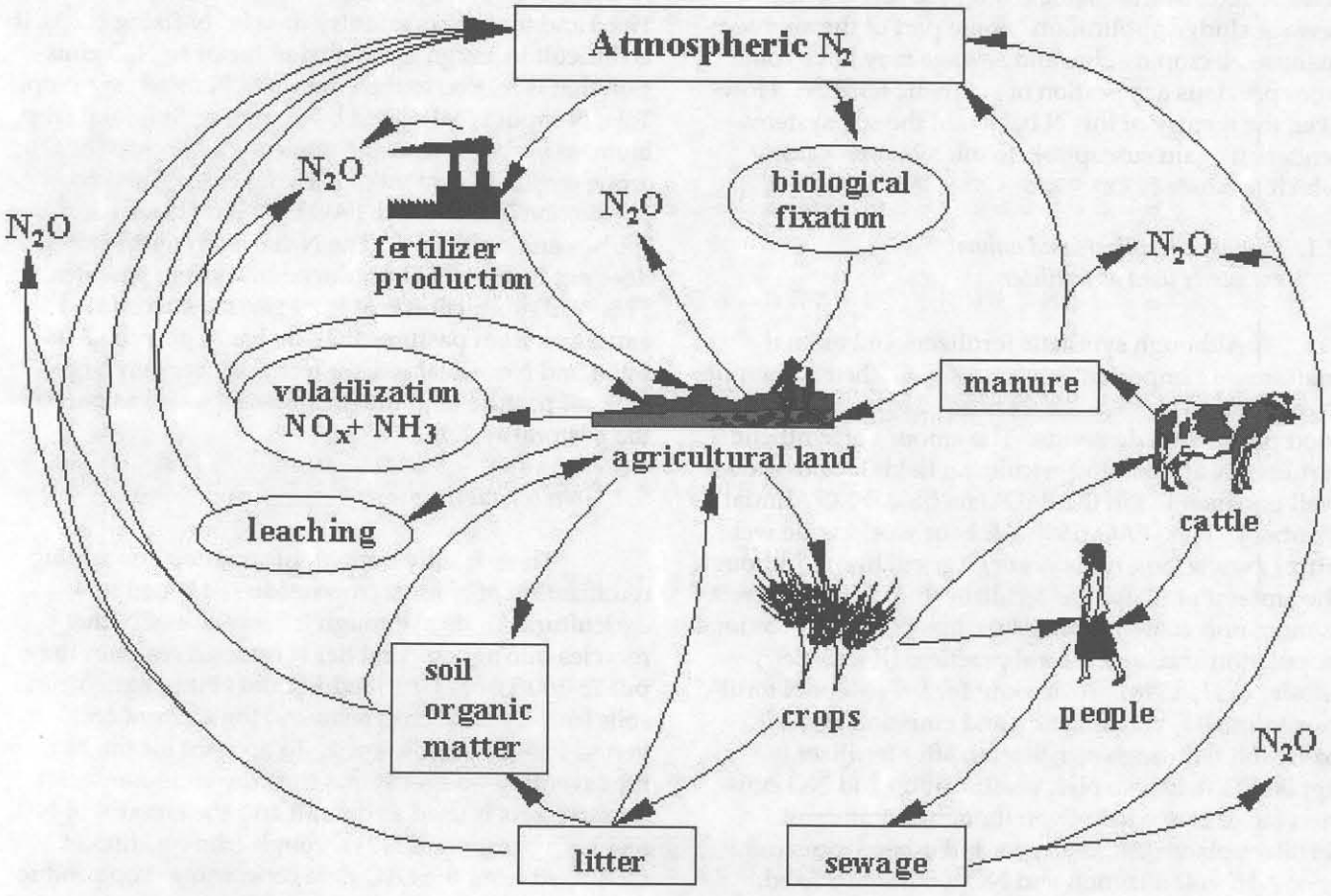

Figure 1. Diagram of agricultural soil N cycle and N_2O production (concept from Nevison et al., 1996; Mosier el al., 1998a).

2. Sources of N_2O directly related to N input into agricultural soils

In most agricultural soils biogenic formation of N_2O is enhanced by an increase in available mineral N which, in turn, increases nitrification and denitrification rates. Addition of fertilizer N, therefore, directly results in extra N_2O formation (Figure 1). In addition, these inputs may lead to indirect formation of N_2O after N leaching or runoff, or following gaseous losses and consecutive deposition of NO_x and NH_3. We term a variety of sources of N in agricultural systems as anthropogenic; including synthetic fertilizers, animal manures (urine and feces), N derived from enhanced biological N-fixation through N_2-fixing crops, crop residue returned to the field after harvest and human sewage sludge application. Some part of the animal manure N, crop residue and sewage may have come from previous application of synthetic fertilizer. However, the reentry of this N back into the soil systems renders it again susceptible to microbial processes which produce N_2O.

2.1. Synthetic fertilizers and animal excreta N used as fertilizer

Although synthetic fertilizers and animal manures are important sources of N_2O, their soil input is required to provide the N needed to meet global food production demands. The amount of synthetic fertilizer N applied to agricultural fields world-wide is well documented in the FAO data base (FAO Annual Yearbooks (e.g., FAO, 1990 a & b; or world wide web: http://www.fao.org/waicent/Agricul.htm). Although the amount of N used as fertilizer from animal excreta is more uncertain, estimates are made, based on animal population and agricultural practices (IPCC, 1997; Mosier et al., 1998). To account for the loss of N fertilizer from NH_3 volatilization and emission of nitric oxide (NO) through nitrification after fertilizer is applied to fields, an NH_3 volatilization and NO emission factor is needed. Even though climate, soil, fertilizer placement and type, and other factors influence NH_3 volatilization and NO_x emission a fixed, default emission factor of 0.1 kg NH_3-N + NO_x-N emitted/kg N excreted is used for synthetic fertilizers and 0.2 kg NH_3-N + NO_x-N emitted/kg N applied for animal waste fertilizer. The amount of N from these sources available for conversion to N_2O is therefore equal to 90% of the synthetic fertilizer N applied and 80% of the animal waste N applied (Schepers and Mosier, 1991).

2.2. Biological N fixation

Both the amount of N fixed by biological N fixation in agricultural systems and the N_2O conversion coefficient are uncertain. Biological nitrogen fixation (BNF) supplies globally some 90 to 140 Tg N y^{-1} to agricultural systems (Peoples et al., 1995). Although more verification on these figures is necessary, most indications are that BNF contributes more N for plant growth than the total amount of synthetic N fertilizers applied to crops each year (Danso, 1995). The Phase I IPCC Guidelines (IPCC, 1995b) mention about equal rates. On average, BNF supplies 50-60% of the N harvested in grain legumes, 55-60% of the N in nitrogen fixing trees and 70-80% of the N accumulated by pasture legumes (Danso, 1995). Cultivation of grain legumes, however, often results in net soil N depletion.

Because of the uncertainty in knowing the amount of N_2 fixed during N-fixation (Peoples et al., 1995) and the lack of country data on N-fixing crops, it is difficult to assign a conversion factor to N_2O emission that is related to the amount of N fixed by a crop. Total N input is estimated by assuming that total crop biomass is about twice the mass of edible crop (FAO), and a certain N content of N fixing crop. This crop production is defined in FAO crop data bases as "pulses and soybeans". The N-fixation contribution does not include N_2O produced in legume pastures. This N_2O production is at least partially accounted for emissions from pastures that are being grazed. Australia and New Zealand, for example, contain large areas of pasture land that includes legumes as part of the pastoral system.

2.3. Crop residue

There is only limited information concerning reutilization of N from crop residues applied to agricultural lands. Although the amount of N that recycles into agricultural fields through residues may put 25-100 Tg of N y^{-1} of additional N into agricultural soils (mainly from crop residues) the amount converted to N_2O is not known. To account for the N_2O in the inventory budget at this time the emission factor for fertilizers is used as default and the amount of N reentering cropped fields through crop residues is calculated from the FAO data concerning crop production.

Nitrous oxide emissions associated with crop residue decomposition are calculated here by estimating the amount of N entering soils as crop residue. The amount of nitrogen entering the crop residue pool is calculated from crop production data. Since FAO data only represent the edible portion of the crop, these must be roughly doubled to estimate total crop biomass. We assume a nitrogen percentage to convert from kg dry biomass y^{-1} to kg N y^{-1} in crops. We distinguish between N-fixing crops (pulses and soybeans) and non-N-fixing crops. Some of the crop residue is removed from the field as crop (approxi-

mately 45%), and some may be burned (approximately 25% of the remaining residue in developing countries), or fed to animals. The amount of N in crop residue actually returned to a field is uncertain, as is the amount of time required for the N to mineralize. We assume here that input and impact on N_2O production occur annually. Neither the amount of root biomass remaining in the soil nor the amount of plant residue fed to animals is accounted for in this crop residue estimate.

3. Revised IPCC guidelines for estimating N_2O emissions from agriculture

This new approach to estimating N_2O emissions from agricultural systems includes: (1) direct emissions of N_2O from agricultural fields; (2) direct emissions of N_2O in animal production systems and, (3) some of the indirect emissions of N_2O that are derived from N that originated from agricultural systems. Elements (2) and (3) were not previously included in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). These guidelines provide default emission factors that can be applied to readily available databases, thus the method is applicable to any world country.

3.1. Direct emissions of N_2O from agricultural soils

Formation of N_2O in agricultural soils is a biogenic process and primarily results from nitrification and denitrification. Simply defined, nitrification is the aerobic microbial oxidation of ammonium to nitrate and denitrification is the anaerobic microbial reduction of nitrate to dinitrogen gas. Nitrous oxide is an intermediate in the reaction sequences of both processes which leaks from microbial cells into the soil atmosphere (Firestone and Davidson, 1989).

The revised IPCC Guidelines estimate direct emissions of N_2O from agricultural soils as a fixed percentage, 1.25 (0.25 - 2.25)% of the additional N inputs. This recognizes that in most agricultural soils biogenic formation of N_2O is enhanced by an increase in available mineral N which, in turn, increases nitrification and denitrification rates (Mosier et al., 1998a). Addition of fertilizer N, therefore, directly results in extra N_2O formation.

The IPCC Guidelines also provide an estimate of enhanced background emissions (2-5 kg N_2O-N ha^{-1} y^{-1}) from cultivated organic soils. Many studies on N_2O emissions from agricultural soils investigate the difference in N_2O production between fertilized and unfertilized fields. Emissions from unfertilized fields are considered background emissions. However, actual background emissions from agricultural soils may be higher than historic natural emissions as a result of enhanced mineralization of soil organic matter due to previous agricultural activities. This is particularly observed in organic soils (Bouwman and van der Hoek, 1991; Kroeze, 1994). Background emissions may also be lower than historic emissions due to depletion of soil organic matter (Groffman et al., 1993).

3.2. N_2O emissions in animal production systems

The IPCC 1995 Guidelines, as most earlier estimates of N_2O emission from agriculture and other sources (IPCC, 1990; 1992), did not include N_2O emission from animal production. Recent studies (e.g. Bouwman, 1996; Jarvis and Pain, 1994; Mosier et al., 1996) indicate that emissions from animal wastes can be significant. Therefore, the revised IPCC Guidelines include two potential sources of N_2O in animal production (i) wastes from confined animals and (ii) dung and urine deposited on the soil by grazing animals. Emissions induced by use of manure N as fertilizer applied to agricultural fields are considered direct N_2O emissions from agricultural fields. The revised method assumes that N_2O emissions can be calculated as a function of the N excretion and the type of animal waste management system (AWMS) (Mosier et al., 1998a). Therefore, default N excretion factors were defined (in kg N per animal) for several animal types in different world regions. In addition, N_2O emission factors (as fraction of the amount of manure-N) are given for different AWMS. Thus, the calculation estimates N_2O produced from animal production systems (AWMS) separately from the N from animal wastes that is used as fertilizer.

3.3. Indirect N_2O emissions from N used in agriculture

The revised methodology includes indirect N_2O formation induced by (i) emissions and consecutive deposition of NO_x and NH_3, (ii) nitrogen leaching and runoff, and (iii) sewage (Mosier et al., 1998a). Thus the method recognizes that annual N input into agricultural systems for crop production is only partly utilized by crops. Generally, less than 70% of N applied, and frequently as little as 20%, is taken up by the crop (Meisinger and Randall, 1991). The added fertilizer N that is not utilized by the crop is either stored in the soil profile of the field or is lost from the system through leaching of nitrate to groundwaters, runoff of soil ammonium or nitrate to surface waters, or volatilized through ammonia volatilization or nitrification/denitrification as NO_x, N_2O or N_2. The N that leaves the agricultural system is, over the long term, either denitrified to N_2 with a small fraction of N_2O produced (IPCC, 1997) or stored in sediments of aquatic systems.

To summarize the aspects of indirect N_2O emissions, the major pathways for synthetic fertilizer

and manure nitrogen input that give rise to indirect emissions are:

A. Volatilization and subsequent atmospheric deposition of NH_3 and NO_x
B. Nitrogen leaching and runoff
C. Human consumption of crops followed by municipal sewage treatment

The IPCC Guidelines provide default factors to estimate the N_2O emissions related to these fluxes on a national scale. In short, the method assumes that 1 (0.2 - 2)% of the NO_x and NH_3 emitted from agricultural fields is converted to N_2O elsewhere. Indirect emissions following N leaching and runoff are estimated as 2.5 (0.2 -12)% of the amount of N lost from the fields. And an estimated 1 (0.2 - 12)% of N in sewage is estimated to be lost as N_2O. Thus these N_2O-N emissions are calculated from a country's NO_x and NH_3 emissions and N transported in leaching and runoff, so that all N_2O formed as a result of NO_x and NH_3 emissions and leaching and runoff in country Z are assigned to country Z, even if the actual N_2O formation takes place in another country (Mosier et al., 1998a).

4. Global Emissions of N_2O from Agriculture 1960 - 1994

Following the IPCC (1997) methodology the total global emissions of N_2O from agricultural source in 1990 were 6.2 (1.2 - 16.9) Tg N_2O-N y^{-1}. The estimated direct emissions from agricultural soils totaled 2.1 Tg N, direct emissions from animal production totaled 2.1 Tg N and indirect emissions resulting from agricultural N input into the atmosphere and aquatic systems totaled 2.0 Tg N_2O-N (Table 2). These estimates show that each of the three components of agriculture considered contribute about the same amount of N_2O to the global atmospheric budget. Moreover, the estimates indicate that the N_2O input to the atmosphere from agricultural production as a whole has apparently been previously underestimated (Table 1). We also estimated global agricultural N_2O emissions for each fifth year from 1960 through 1994, to observe temporal emission trends (Fig. 2, Mosier et al., 1998b). Considering only N_2O emitted directly from agricultural fields, these emissions increased 2.6 times over the 35 year period while total global agricultural emissions increased by about 1.8 times. The larger increase from direct emissions is due, mainly, to increased synthetic fertilizer input. Synthetic fertilizer comprised about 15% of total N input (about 64 Tg) into agriculture in 1960 compared to about 44% of total N input (about 167 Tg) in 1994 we

TABLE 2. Global N_2O emissions from agricultural soils calculated with the IPCC (1997) methodology (Tg N y^{-1}) for 1990.

Direct soil emissions	
- synthetic fertilizer	0.87 (0.18-1.6)[1]
- animal waste	0.63 (0.12-1.1)
- biological N_2 fixation	0.12 (0.02-0.2)
- crop residue	0.37 (0.07-0.7)
- cultivated Histosols	0.1 (0.02-0.2)
- subtotal	2.1 (0.4-3.8)
Animal production[2]	
- animal waste management systems	2.1 (0.6-3.1)
Indirect emissions	
- atmospheric deposition	0.36 (0.07-0.7)
- nitrogen leaching and runoff	1.4 (0.11-6.7)
- human sewage	0.22 (0.04-2.6)
- subtotal	1.98 (0.22-10.0)
Total	6.2 (1.2-16.9)

[1]Values in parentheses indicate estimated range which is derived from emission factor range.
[2]Animal production includes grazing animals.

found that the total global N_2O budget is reasonably in balance if we use the N_2O emission estimate for agricultural soils calculated by the IPCC (1997) methodology. Incorporating the above estimate into an atmospheric model, Kroeze et al. (1998) suggest that the increases in atmospheric N_2O that have occurred during the past century can be mainly attributed to changes in food production systems.

5. Future needs for methodology development

The methodology for country-based N_2O emissions described above is a rough, generalized approach which treats all agricultural systems as being the same under all climates, in all soils, in all crops and in all management systems. The ranges of conversion factors, however, provide for direct emissions calculations which cover much of the potential N_2O emissions from each country, whatever climate, soils and set of crops is involved. Some recent studies in temperate (e.g., Thornton and Valente, 1996) and tropical (Veldkamp and Keller, 1997) systems show very high direct N_2O emissions while other studies (Corrie et al., 1996; Flessa et al., 1995; Wagner-Riddle and Thurtel, 1998) demonstrate that significant N_2O emissions commonly occur during thaw periods in early spring and winter or through snow-covered agricultural soils (Van Bochove et al., 1996). Thus, annual emission factors used may underestimate direct annual N_2O emissions from agricultural fields.

To make significant improvement in inventory methodologies for N_2O, we think that the next step is to utilize process-based models to produce country inventories for direct emissions from agricultural soils (e.g., Li et al., 1992; Potter et al., 1996; Parton et al., 1996), appropriate animal management models for N_2O from animal production, simulation models which more effectively represent N transformations in aquatic systems, including riparian areas, wetlands, rivers estuaries, continental shelves and the deep ocean (e.g., Seitzinger and Kroeze, 1998). The soil C and N cycles are tightly integrated and we think that both C and N should be considered together so that various aspects of the C and N cycle and CO_2 and N_2O production can be more accurately defined. The accuracy of N fraction prediction is closely tied to C turnover in the soil as it controls N mineralization and immobilization. The turnover and retention of N and consumption of methane in all soils is also intimately linked with the C cycle. Conversely, C retention in soils is directly tied to mineral N availability. These models must, however, include adequate flexibility to predict cold soil emissions as well as emissions under tropical conditions.

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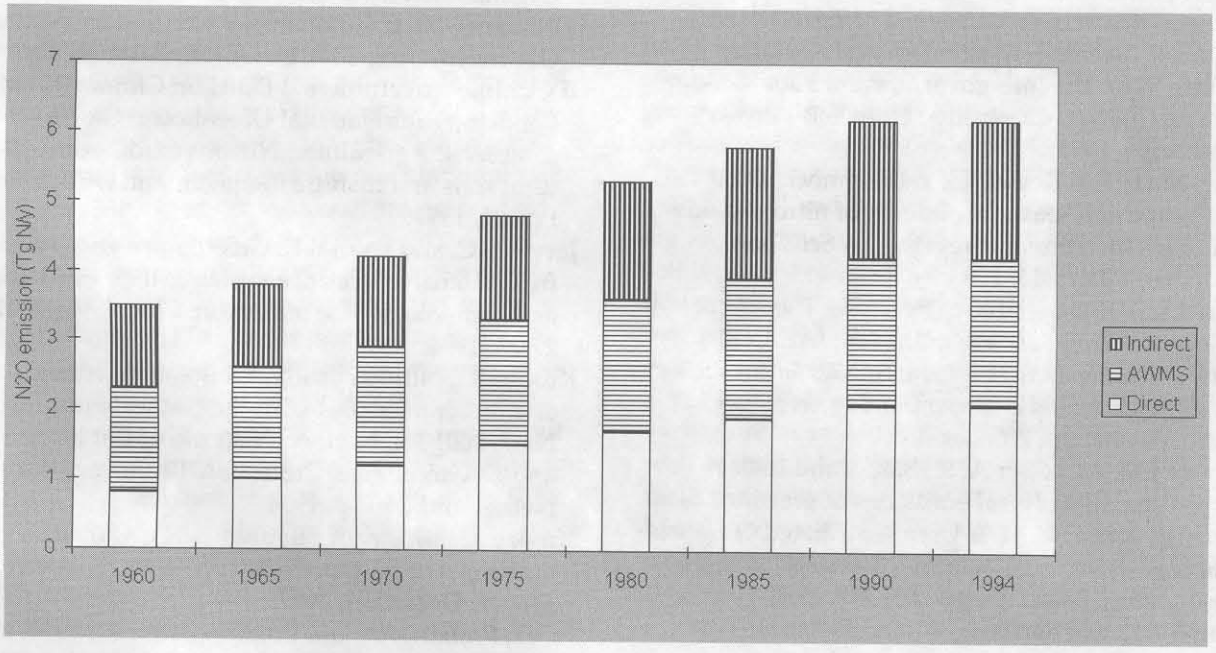

Figure 2. Estimates of N_2O emissions from agricultural systems worldwide, directly from agricultural fields (direct) from animal waste management systems (AWMS) and from indirect sources (indirect).

R. A. Dentener, R. Francisco, J. Freney, S. Frolking, P. Groffman, O. Heinemeyer, R. Karaban, L. Klemedtsson, P. Leffelaar, E. Lin, K. Minami, D.C. Parashar, R. Sherlock, K. Smith, H.G. Van Faassen, E. Veldkamp, G.L. Velthof, G.X. Xing, in generating the concepts presented in this paper.

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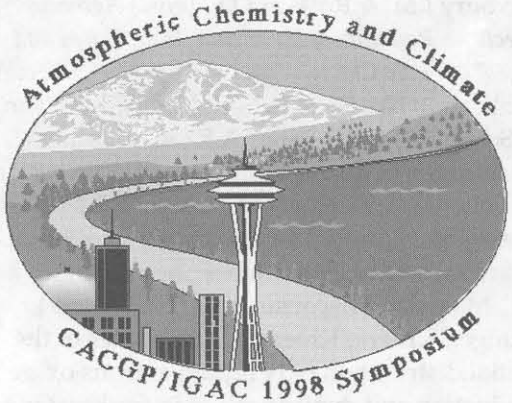
Announcements

Joint International Symposium on Global Atmospheric Chemistry and Climate Change



Ninth Symposium of the IAMAS Commission on Atmospheric Chemistry and Global Pollution (CACGP)

and

Fifth Scientific Conference of the International Global Atmospheric Chemistry Project (IGAC)

Seattle, Washington, USA
19-25 August 1998

OBJECTIVES AND DISCUSSION THEMES

The focus of the Symposium is "Atmospheric Chemistry and Climate Change". Papers on relevant field and modeling studies of tropospheric chemistry in non-urban regions will be presented. Papers will address four main themes relating human-induced changes in the chemistry of the troposphere to changes in climate. These themes are:

Aerosol, Clouds, and Climate: Results of recent IGAC field studies, Effects of organic aerosols, Direct and indirect climate forcing by aerosols

Human Impact on Atmospheric Chemistry and Climate: Biomass burning, Effect of urban and industrial emissions on global atmospheric climate, Land use changes, Effects of aircraft emissions

Greenhouse Gases: The Cycling of Carbon Dioxide and Other Greenhouse Gases Over the Past 1000 Years: Chemistry of the past atmosphere as observed in ice cores, Distributions and fluxes of greenhouse gases, Radiative forcing of greenhouse gases

Remote Sensing: Studies Related to Atmospheric Chemistry and Climate: Remote sensing of chemical and climate-related processes, Estimates of parameters that affect radiative forcing, Emerging technologies to address atmospheric chemistry and climate change

In addition, two panel discussions will take place during the symposium. The first will focus on Atmospheric Chemistry and Climate—Science and Public Policy and the second on Atmospheric Chemistry and Climate—Looking Ahead to the Next Decade.

GENERAL INFORMATION

The symposium will be held at the University of Washington. The registration fee is $400 if received on or before June 1 and $425 if received after June 1. Early registration is encouraged as registration is limited to 400 participants.

For further information contact:

Dr. Patricia Quinn
CACGP/IGAC Meeting—1998
NOAA/PMEL/OCRD
7600 Sand Point Way NE
Seattle, WA 98115 USA
Fax (+1-206) 526-6744
Email: quinn@pmel.noaa.gov

Or access the Symposium web site at:

http://saga.pmel.noaa.gov/cacgp98/

JOINT SPARC/IGAC PROJECT ON LABORATORY STUDIES OF ATMOSPHERIC PROCESSES

IGAC and SPARC (a component of the World Climate Research Program, WCRP) have decided to institute a new joint project on "Laboratory Studies of Atmospheric Processes". On the SPARC side, this project will be a component of the *Chemistry and Microphysics in the Lower Stratosphere and the Upper Troposphere* initiative. In IGAC it will be an Activity within the new Focus on *Fundamental and Cross-Cutting Activities*. This new project will center around chemical, photochemical, and heterogeneous/multiphase processes of relevance to the chemistry of Earth's troposphere and stratosphere. In addition, acquisition of spectroscopic parameters needed to evaluate the interaction of radiation with atmospheric constituents and for the measurements of the constituents, in the atmosphere or the laboratory, will be addressed.

This project will aim to bring together various laboratory investigators to provide improved data and knowledge relating to atmospheric processes and enhance their interactions with those involved in field measurements and modeling, both in IGAC and SPARC. The inaugural Co-Conveners of this project are Dr. R.A. Cox of the Atmospheric Chemistry Center, University of Cambridge, UK, on the IGAC side and Dr. A.R. Ravishankara of the NOAA Aeronomy Laboratory, Boulder, CO, USA, on the SPARC side. Drs. Cox and Ravishankara are beginning to develop the plan of action for the project and welcome input by all interested parties (Cox: rac26@cam.ac.uk; Ravishankara: ravi@al.noaa.gov).

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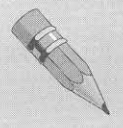

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