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**Results from the LLNL Eulerian GRANTOUR Model
for the WCRP '93 Workshop on the
Parameterization of Sub-Grid Scale Tracer Transport**

**D. Bergmann, J. Dignon, J. Penner and J. Walton
Global Climate Research Division**

April 1994

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Results from the LLNL Eulerian GRANTOUR Model for the WCRP '93 Workshop on the Parameterization of Sub-Grid Scale Tracer Transport

D. Bergmann, J. Dignon, J. Penner, and J. Walton
Global Climate Research Division
Lawrence Livermore National Laboratory

GRANTOUR is a 3D chemical transport model (CTM) developed at LLNL (Walton et al., 1988) which has been applied to a diverse set of problems in the troposphere including the transport and chemistry of smoke (Ghan et al. 1988; Penner et al. 1991b), asteroid impact generated aerosols (Covey et al., 1990) sulfate aerosols (Erickson et al., 1991; Penner et al., 1993a), NO_x (Penner et al. 1991a), ozone (Atherton 1993; Atherton et al. 1993; Penner et al. 1993a), CFC-11 (Penner, 1990), ^7Be (in progress), and ^{222}Rn with decay to ^{210}Pb (Dignon et al., 1993). GRANTOUR uses fields supplied by a GCM (General Circulation Model) and calculates the advection of inert or chemically reactive trace species in a Lagrangian scheme. The model can be run either as an off-line model which uses fields precalculated by a GCM or in a coupled mode where the results from the CTM are used in the radiation calculations of the GCM. The atmosphere is divided into "parcels" of equal mass and the center of mass of each of these parcels is accurately advected in a Lagrangian manner with little or no numerical diffusion. The advantage of this approach is the accuracy of the advection, while the disadvantages of this scheme are the difficulties in resolving the stratosphere and accurately inferring fluxes from the movements of the center of masses of the parcels.

An Eulerian option has recently been implemented in GRANTOUR which uses a second order Van Leer scheme to transport inert or reactive trace species through a fixed three dimensional grid. Although this new model introduces a small amount of numerical diffusion which the Lagrangian approach did not have, it provides the potential to accurately resolve the stratosphere and to diagnose important quantities such as fluxes across the equator or the tropopause.

Both sets of GRANTOUR radon calculations performed for the WCRP workshop used time averaged 12 hour fields from the CCM1 model in an uncoupled mode. The Lagrangian results were obtained from a resolution of 50,000 parcels, while the Eulerian results used the CCM1 resolution of approximately 7.5° (longitude) by 4.5° (latitude) and 13 sigma levels.

Mixing is calculated on a fixed grid for both the Lagrangian and Eulerian versions, and includes both convection and diffusion. Convection is identical in each version and the convective mass flux is diagnosed from the CCM1 model (Penner et al., 1991). Large scale diffusion uses a set of fixed eddy coefficients in the stratosphere ($\sigma < 0.2$) and a second set in the troposphere. A horizontal diffusion coefficient of $1 \times 10^5 \text{ cm}^2/\text{sec}$ was used in the stratosphere while a value of $1 \times 10^8 \text{ cm}^2/\text{sec}$ was used in the troposphere. Vertical diffusion coefficients of $1 \times 10^2 \text{ cm}^2/\text{sec}$ in the stratosphere and $1 \times 10^4 \text{ cm}^2/\text{sec}$ in the troposphere were used. An additional mixing term is used in the Lagrangian version to simulate inter-parcel mixing.

The chemistry model for these radon calculations is a simple exponential decay of ^{222}Rn into ^{210}Pb with an e-folding lifetime of 5.5 days. The ^{210}Pb produced from this decay is tracked as a second species.

Deposition models for both wet and dry scavenging of ^{210}Pb are included in both versions. Wet scavenging is proportional to the precipitation rate obtained from the CCM1, while dry scavenging uses a fixed deposition velocity of 0.1 cm/sec.

Some minor differences exist between the radon problem specifications and their implementation in the two GRANTOUR versions. For the natural radon calculation (case A) the Lagrangian version injected radon into all parcels located between sigma values of 0.9 and 1.0, while the Eulerian version injected into grid boxes between sigma values of 0.926 and 1.0. The height of the aircraft and lightning injections is between 200 and 400 mb in the Lagrangian version. In the Eulerian version we injected the material between sigma coordinates of 0.165 and 0.355. The precise horizontal locations of the aircraft and lightning sources differs very slightly between the two versions and is explained in the data package submitted to the workshop. Output from the Lagrangian version labeled *mixed layer* is actually at 977 mb, while in the Eulerian version it is at $\sigma=0.965$.

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Case A: Surface (natural radon)

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case A: Time series statistics (E-21 v/v) Dec-Jan-Feb									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	1.51	0.83	0.69	0.68	0.97	1.32	1.72	5.67
	600 mb	5.94	3.62	13.09	1.87	3.70	5.06	7.19	23.42
	mixed	129.40	24.38	594.54	55.92	113.13	136.82	151.27	159.75
	surface	138.03	24.03	577.39	64.76	122.23	144.85	158.70	169.22
Cincinnati	300 mb	1.68	0.67	0.45	0.81	1.22	1.56	1.83	5.28
	600 mb	5.12	2.78	7.74	1.76	3.26	4.69	6.04	14.26
	mixed	123.07	15.90	252.80	70.79	113.34	124.20	132.77	158.20
	surface	133.13	16.36	267.65	76.59	123.82	132.99	143.86	167.83
Socorro	300 mb	1.61	0.48	0.23	0.86	1.24	1.49	1.90	3.05
	600 mb	5.27	3.60	12.96	1.72	2.84	4.06	5.87	21.10
	mixed	106.51	27.29	744.66	46.87	86.56	104.50	123.68	162.91
	surface	118.90	25.83	667.17	64.63	100.76	115.38	137.83	173.79
Hawaii	300 mb	1.60	0.47	0.22	0.99	1.23	1.52	1.77	2.95
	600 mb	2.15	0.59	0.35	1.10	1.65	2.20	2.59	3.26
	mixed	2.84	0.91	0.83	1.57	2.02	2.75	3.55	4.86
	surface	2.90	0.93	0.87	1.63	2.03	2.75	3.62	4.85
Samoa	300 mb	1.22	0.28	0.08	0.76	1.02	1.20	1.35	2.33
	600 mb	1.31	0.31	0.09	0.73	1.12	1.30	1.43	2.38
	mixed	1.62	0.58	0.33	0.79	1.29	1.52	1.83	3.68
	surface	1.67	0.57	0.33	0.84	1.30	1.56	1.91	3.56
Crozet	300 mb	0.89	0.43	0.18	0.24	0.63	0.79	1.00	3.22
	600 mb	1.16	0.69	0.48	0.22	0.72	0.92	1.42	3.81
	mixed	1.95	0.95	0.91	0.67	1.21	1.73	2.52	5.11
	surface	1.98	0.96	0.92	0.74	1.22	1.77	2.55	5.18
Ferraz	300 mb	0.45	0.44	0.19	0.11	0.21	0.28	0.50	2.30
	600 mb	0.84	0.87	0.76	0.14	0.23	0.43	1.23	4.22
	mixed	2.34	1.68	2.81	0.80	1.16	1.67	2.96	8.19
	surface	2.28	1.56	2.44	0.82	1.16	1.67	2.93	7.67

EULERIAN GRANTOUR-LLNL

DJF

A: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: 600 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: 300 mb

RADON-222 Mixing Ratio [$\times 10^2$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: OEW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: Zonal Avg

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: OEW

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: 180EW

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: Mixed Layer

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: 600 mb

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

A: 300 mb

LEAD-210 Mixing Ratio [$\times 10^2$ v/v]

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case A: Time series statistics (E-21 v/v) Jun-Jul-Aug									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	2.34	2.16	4.67	0.66	1.21	1.70	2.56	16.98
	600 mb	6.95	5.36	28.74	1.41	3.47	5.49	8.16	29.70
	mixed	81.46	24.89	619.35	30.20	60.70	83.36	100.05	126.94
	surface	88.40	24.18	584.67	46.05	68.77	88.06	107.36	131.42
Cincinnati	300 mb	3.10	2.05	4.20	0.64	1.62	2.38	4.37	10.82
	600 mb	8.73	4.50	20.24	2.25	5.48	8.20	10.84	30.02
	mixed	107.63	16.30	265.58	51.35	98.84	109.90	116.87	142.76
	surface	118.22	16.60	275.40	73.86	108.22	118.66	129.22	155.09
Socorro	300 mb	1.77	1.14	1.31	0.64	1.05	1.40	1.84	6.01
	600 mb	6.42	3.38	11.43	2.37	4.10	5.42	7.87	18.83
	mixed	138.12	22.32	498.31	80.58	129.14	144.28	155.57	171.08
	surface	147.47	21.96	482.18	92.72	134.32	153.12	164.91	180.42
Hawaii	300 mb	0.99	0.46	0.21	0.43	0.64	0.80	1.30	2.15
	600 mb	0.62	0.29	0.08	0.27	0.41	0.51	0.81	1.34
	mixed	2.44	0.93	0.87	1.01	1.66	2.43	2.97	4.93
	surface	2.61	1.01	1.02	1.09	1.79	2.62	3.17	5.34
Samoa	300 mb	0.71	0.30	0.09	0.33	0.53	0.66	0.77	2.05
	600 mb	0.80	0.25	0.06	0.44	0.61	0.77	0.92	1.50
	mixed	1.66	0.88	0.78	0.75	1.06	1.35	1.94	4.78
	surface	1.79	0.95	0.91	0.82	1.18	1.44	2.07	4.97
Crozet	300 mb	0.77	0.48	0.23	0.30	0.50	0.64	0.84	3.58
	600 mb	1.54	0.81	0.66	0.59	1.02	1.37	1.82	5.96
	mixed	2.82	1.52	2.30	1.26	1.64	2.20	3.68	7.84
	surface	2.87	1.54	2.38	1.27	1.66	2.27	3.73	7.75
Ferraz	300 mb	0.34	0.14	0.02	0.18	0.25	0.30	0.37	0.87
	600 mb	0.86	0.64	0.41	0.23	0.43	0.67	1.04	3.61
	mixed	3.80	3.37	11.35	0.66	1.48	2.51	4.54	15.53
	surface	3.79	3.33	11.08	0.77	1.41	2.51	4.62	15.49

EULERIAN GRANTOUR-LLNL

JJA

A: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 600 mb

RADON-222 Mixing Ratio [$\times 10^2$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 300 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: OEW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 180EW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: Zonal Avg

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: OEW

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 180EW

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: Mixed Layer

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 600 mb

LEAD-210 Mixing Ratio [$\times 10^2$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

A: 300 mb

LEAD-210 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL	Scenario A: Lead Loading in kg	
	Dec-Jan-Feb	Jun-Jul-Aug
<300 mb	0.199	0.220
<600 mb	0.379	0.417
Total in Atmosphere	0.617	0.670

Case B: Aircraft

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case B: Time series statistics (E-21 v/v) Dec-Jan-Feb									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	74.65	35.44	1256.58	13.03	45.36	73.38	101.16	159.74
	600 mb	6.04	2.40	5.76	2.61	4.24	5.46	7.86	13.81
	mixed	1.29	0.50	0.25	0.56	0.81	1.27	1.65	2.35
	surface	1.25	0.49	0.24	0.55	0.77	1.24	1.61	2.31
Cincinnati	300 mb	218.51	51.16	2617.52	126.25	179.07	214.86	256.54	366.17
	600 mb	8.02	3.14	9.87	3.77	5.79	7.24	9.74	19.07
	mixed	1.41	0.33	0.11	0.81	1.15	1.39	1.61	2.50
	surface	1.33	0.31	0.10	0.78	1.07	1.31	1.54	2.32
Socorro	300 mb	67.68	24.84	616.98	20.37	48.12	70.54	86.95	117.80
	600 mb	7.46	2.11	4.46	3.49	6.01	7.18	8.66	14.97
	mixed	2.08	0.44	0.19	1.33	1.75	2.02	2.30	3.38
	surface	1.97	0.42	0.17	1.29	1.66	1.92	2.24	3.25
Hawaii	300 mb	20.39	7.55	56.95	5.11	14.64	19.47	24.59	39.04
	600 mb	6.75	2.88	8.29	2.76	4.78	5.83	7.60	17.34
	mixed	1.97	0.65	0.42	0.99	1.31	1.95	2.46	3.60
	surface	1.85	0.60	0.36	0.94	1.23	1.83	2.34	3.19
Samoa	300 mb	0.29	0.22	0.05	0.07	0.16	0.24	0.31	1.46
	600 mb	0.21	0.09	0.01	0.06	0.13	0.20	0.25	0.55
	mixed	0.18	0.10	0.01	0.04	0.11	0.15	0.23	0.51
	surface	0.17	0.10	0.01	0.04	0.10	0.14	0.21	0.48
Crozet	300 mb	3.3e-2	1.4e-2	2.1e-4	9.3e-3	2.2e-2	2.9e-2	4.0e-2	1.0e-1
	600 mb	1.1e-2	4.9e-3	2.4e-5	3.1e-3	7.0e-3	1.0e-2	1.4e-2	2.8e-2
	mixed	4.6e-3	3.1e-3	9.4e-6	1.0e-3	2.3e-3	3.9e-3	6.3e-3	1.6e-2
	surface	4.5e-3	3.0e-3	9.0e-6	9.9e-4	2.2e-3	3.8e-3	6.1e-3	1.5e-2
Ferraz	300 mb	1.1e-2	5.9e-3	3.5e-5	2.9e-3	7.0e-3	9.5e-3	1.3e-2	2.9e-2
	600 mb	4.4e-3	3.2e-3	1.0e-5	9.0e-4	2.2e-3	3.4e-3	5.5e-3	1.5e-2
	mixed	1.6e-3	1.0e-3	1.1e-6	3.0e-4	7.3e-4	1.2e-3	2.4e-3	4.4e-3
	surface	1.5e-3	9.9e-4	9.8e-7	2.8e-4	7.0e-4	1.1e-3	2.3e-3	4.0e-3

EULERIAN GRANTOUR-LLNL

DJF

B: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

B: 600 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

B: 300 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

B: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

B: OEW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

B: 180EW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case B: Time series statistics (E-21 v/v) Jun-Jul-Aug									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	97.85	40.08	1606.91	23.54	66.34	95.38	126.08	218.26
	600 mb	10.49	4.37	19.06	3.64	7.51	9.80	12.68	26.74
	mixed	2.23	1.42	2.01	0.52	1.19	1.89	2.83	8.09
	surface	1.98	1.14	1.30	0.51	1.16	1.71	2.58	6.41
Cincinnati	300 mb	292.15	74.17	5501.63	142.60	238.65	283.49	335.62	532.77
	600 mb	12.47	5.58	31.10	3.89	8.63	10.73	15.39	27.59
	mixed	2.79	2.71	7.36	1.08	1.68	2.24	2.67	22.03
	surface	2.45	1.99	3.96	1.01	1.61	1.98	2.50	16.11
Socorro	300 mb	69.88	29.12	848.13	25.54	46.07	67.99	88.19	151.99
	600 mb	13.86	4.61	21.22	6.52	10.74	13.29	16.50	26.68
	mixed	3.16	1.60	2.57	1.92	2.29	2.64	3.33	10.41
	surface	2.96	1.55	2.40	1.83	2.15	2.47	3.07	9.92
Hawaii	300 mb	18.89	9.20	84.66	7.15	11.98	16.23	24.11	48.53
	600 mb	5.04	1.73	2.98	2.68	3.85	4.63	5.65	11.71
	mixed	1.27	0.36	0.13	0.54	1.06	1.27	1.46	2.03
	surface	1.19	0.34	0.12	0.51	1.01	1.24	1.40	1.94
Samoa	300 mb	0.40	0.21	0.05	0.15	0.25	0.33	0.48	1.15
	600 mb	0.16	0.05	0.00	0.09	0.12	0.15	0.19	0.34
	mixed	0.06	0.03	0.00	0.03	0.04	0.05	0.06	0.15
	surface	0.05	0.03	0.00	0.02	0.03	0.04	0.06	0.14
Crozet	300 mb	4.7e-2	2.1e-2	4.6e-4	1.6e-2	3.0e-2	4.1e-2	6.3e-2	1.1e-1
	600 mb	1.6e-2	6.8e-3	4.6e-5	6.2e-3	1.1e-2	1.5e-2	2.0e-2	5.0e-2
	mixed	6.1e-3	3.2e-3	1.1e-5	2.4e-3	3.8e-3	5.4e-3	7.6e-3	2.7e-2
	surface	5.8e-3	3.1e-3	9.4e-6	2.3e-3	3.6e-3	5.2e-3	7.5e-3	2.5e-2
Ferraz	300 mb	2.1e-2	1.1e-2	1.2e-4	7.8e-3	1.1e-2	1.8e-2	2.8e-2	5.6e-2
	600 mb	7.2e-3	4.0e-3	1.6e-5	2.4e-3	4.1e-3	6.4e-3	9.4e-3	2.2e-2
	mixed	2.9e-3	1.9e-3	3.8e-6	8.8e-4	1.4e-3	2.6e-3	3.6e-3	1.0e-2
	surface	2.8e-3	1.9e-3	3.5e-6	6.9e-4	1.3e-3	2.5e-3	3.4e-3	1.0e-2

EULERIAN GRANTOUR-LLNL

JJA

B: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

B: 600 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

B: 300 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

B: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

B: OEW

RADON-222 Mixing Ratio [$\times 10^{-11}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

B: 180EW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

Case C: Lightning

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Dec-Jan-Feb

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case C: Time series statistics (E-21 v/v) Dec-Jan-Feb									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	0.56	0.28	0.08	0.23	0.39	0.47	0.70	1.39
	600 mb	0.19	0.11	0.01	0.08	0.13	0.16	0.22	0.72
	mixed	0.09	0.05	0.00	0.03	0.54	0.07	0.11	0.26
	surface	0.08	0.04	0.00	0.03	0.54	0.07	0.11	0.23
Cincinnati	300 mb	2.29	0.68	0.47	1.19	1.80	2.15	2.52	4.53
	600 mb	0.90	0.23	0.05	0.50	0.71	0.89	1.02	1.69
	mixed	0.27	0.09	0.01	0.09	0.20	0.27	0.32	0.52
	surface	0.26	0.09	0.01	0.08	0.19	0.26	0.31	0.50
Socorro	300 mb	3.05	0.99	0.98	1.66	2.32	2.87	3.61	6.35
	600 mb	1.19	0.35	0.12	0.68	0.91	1.14	1.36	2.35
	mixed	0.48	0.16	0.02	0.24	0.36	0.45	0.58	0.90
	surface	0.46	0.15	0.02	0.23	0.34	0.43	0.56	0.86
Hawaii	300 mb	8.22	2.56	6.53	4.60	6.30	7.96	10.12	16.54
	600 mb	3.55	0.97	0.95	1.92	2.84	3.55	4.04	6.55
	mixed	0.86	0.26	0.07	0.43	0.67	0.84	1.03	2.20
	surface	0.80	0.24	0.06	0.41	0.62	0.78	0.92	2.11
Samoa	300 mb	6.24	2.03	4.12	2.51	4.98	6.11	7.50	12.54
	600 mb	2.56	0.71	0.51	1.11	1.97	2.48	3.05	4.23
	mixed	0.68	0.24	0.06	0.34	0.49	0.64	0.77	1.52
	surface	0.62	0.21	0.04	0.33	0.47	0.59	0.73	1.32
Crozet	300 mb	0.94	0.59	0.35	0.27	0.54	0.80	1.15	3.58
	600 mb	0.26	0.14	0.02	0.08	0.15	0.23	0.31	0.86
	mixed	0.10	0.06	0.00	0.03	0.05	0.08	0.12	0.29
	surface	0.10	0.06	0.00	0.02	0.05	0.08	0.12	0.27
Ferraz	300 mb	0.33	0.11	0.01	0.14	0.26	0.34	0.38	0.71
	600 mb	8.9e-2	3.2e-2	1.0e-3	3.9e-2	6.8e-2	8.8e-2	1.0e-1	1.9e-1
	mixed	2.4e-2	1.0e-2	1.0e-4	8.7e-3	1.6e-2	2.2e-2	3.0e-2	5.6e-2
	surface	2.3e-2	9.8e-3	9.7e-5	8.4e-3	1.5e-2	2.0e-2	2.9e-2	5.5e-2

EULERIAN GRANTOUR-LLNL

DJF

C: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

C: 600 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

C: 300 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

C: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

C: OEW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

DJF

C: 180EW

RADON-222 Mixing Ratio [$\times 10^{-11}$ v/v]

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

AIM

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Centimeter

Inches

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BY APPLIED IMAGE, INC.

2 of 2

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL

Jun-Jul-Aug

RADON-222 Mixing Ratio

EULERIAN GRANTOUR-LLNL Case C: Time series statistics (E-21 v/v) Jun-Jul-Aug									
site	level	mean	stdv	var*E-42	min	1/4	median	3/4	max
Kirov	300 mb	0.53	0.36	0.13	0.10	0.25	0.42	0.71	1.75
	600 mb	0.14	0.07	0.01	0.03	0.08	0.12	0.20	0.36
	mixed	0.05	0.03	0.00	0.01	0.02	0.03	0.06	0.24
	surface	0.04	0.03	0.00	0.01	0.02	0.03	0.05	0.13
Cincinnati	300 mb	0.31	0.12	0.01	0.15	0.23	0.26	0.36	0.76
	600 mb	0.19	0.10	0.01	0.07	0.13	0.16	0.21	0.57
	mixed	0.19	0.19	0.04	0.03	0.05	0.13	0.27	0.77
	surface	0.19	0.19	0.03	0.03	0.05	0.12	0.27	0.76
Socorro	300 mb	0.51	0.20	0.04	0.27	0.36	0.47	0.59	1.27
	600 mb	0.28	0.16	0.02	0.08	0.18	0.24	0.33	0.87
	mixed	0.18	0.20	0.04	0.04	0.07	0.08	0.19	0.85
	surface	0.17	0.19	0.04	0.04	0.06	0.08	0.19	0.80
Hawaii	300 mb	0.69	0.45	0.20	0.22	0.31	0.48	0.95	2.07
	600 mb	0.34	0.27	0.07	0.09	0.15	0.25	0.43	1.03
	mixed	0.10	0.10	0.01	0.03	0.04	0.05	0.08	0.48
	surface	0.09	0.10	0.01	0.03	0.04	0.05	0.08	0.44
Samoa	300 mb	11.00	5.69	32.39	2.21	6.26	10.65	14.62	30.90
	600 mb	5.70	2.30	5.31	1.98	4.28	5.56	6.78	14.86
	mixed	1.31	0.36	0.13	0.77	1.07	1.23	1.44	2.36
	surface	1.23	0.33	0.11	0.74	1.01	1.12	1.33	2.17
Crozet	300 mb	1.48	0.91	0.82	0.50	0.89	1.16	1.77	4.95
	600 mb	0.48	0.23	0.05	0.20	0.30	0.43	0.56	1.32
	mixed	0.17	0.08	0.01	0.06	0.12	0.14	0.20	0.60
	surface	0.16	0.08	0.01	0.06	0.11	0.14	0.18	0.54
Ferraz	300 mb	0.84	0.39	0.15	0.29	0.52	0.72	1.15	1.78
	600 mb	0.29	0.15	0.02	0.11	0.17	0.23	0.39	0.74
	mixed	0.10	0.07	0.00	0.03	0.05	0.09	0.14	0.31
	surface	0.10	0.06	0.00	0.03	0.05	0.08	0.13	0.30

EULERIAN GRANTOUR-LLNL

JJA

C: Mixed Layer

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

C: 600 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

C: 300 mb

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

C: Zonal Avg

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

C: OEW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

EULERIAN GRANTOUR-LLNL

JJA

C: 180EW

RADON-222 Mixing Ratio [$\times 10^{21}$ v/v]

APPENDIX A

Specifications for the three radon simulations

Sep 24 08:52 1993 standard input Page 1

From prather@halo.ps.uci.edu Thu Sep 23 17:03:42 1993
Date: Fri, 24 Sep 93 00:11:03 GMT
From: Michael Prather <prather@halo.ps.uci.edu>
To: jane@scuba.llnl.gov (Jane Dignon)
Subject: Re: WCRP '93 Workshop
Content-Length: 14665

observations still being prepared
comparison not done model-by-model, but across all models by topic,

michael

=====#5
WCRP '93 WORKSHOP ON THE
PARAMETERIZATION OF SUB-GRID SCALE TRACER TRANSPORT
30 Nov - 3 Dec 1993, Virginia Beach, VA

A Radon/Lead Simulation to Test Boundary-Layer & Cumulus Transport
in Global Chemical Models --- REVISED 7 Sep 93
boville@ncar.ucar.edu, mprather@uci.edu, jacob(djj@hera.harvard.edu)

=====NEW: TABLE & PLOT SPEC'S=====

SEE LAST PAGES

=====Rn/Pb Experiment===== (13 Jul 93)=====

This WCRP workshop includes tutorials and discussion about how to represent subgrid-scale transport of trace species in global models (i.e., boundary exchange between surface & free troposphere and cloud convection; transport of water vapor, heat, reactive and unreactive chemicals). This writeup defines the numerical simulation of ²²²Rn (and the extension to ²¹⁰Pb).

The PRIMARY GOAL of this workshop is to develop global chemical transport models (CTMs) in conjunction with numerical weather prediction models and general circulation models of the atmosphere. Attendance at the workshop will be limited, and preference will be given to those groups developing high resolution 4-D (i.e., spatial and temporal) CTMs. This goal is met by the tutorials, discussions with the NWP modelers, and the Case A simulation of radon and lead deposition compared with observations.

A SECONDARY GOAL of this workshop is to understand how current CTMs transport short-lived trace species. The key element in model predictions of chemical change in the troposphere (i.e., ozone, OH) is the distribution of tropospheric NO_x (=NO+NO₂). NO_x is short-lived (hours to days), has highly non linear chemistry, and has a wide variety of sources whose roles are not yet quantified. Cases B-C of the radon simulations are intended to give a standardized "first-look" at atmospheric distributions predicted for different source terms known to be important in the global NO_x budget:

A=surface (natural radon), B=aircraft, C=lightning

This 2nd goal of the workshop is important to IPCC Climate Assessments, and will provide a necessary yardstick for interpreting the different model predictions of tropospheric chemistry that hinge on NO_x distributions from different sources. Current CTMs include 2-D and coarse 3-D (e.g., monthly averaged) models, and we anticipate representation of some of these models at the Workshop.

SOURCE: TOTAL = 16 kg/yr of ²²²Rn

Case A - radon is emitted ubiquitously by decay of radium in soils:

70 - 90 degrees latitude (N & S): no emissions (all surfaces)

60 - 70 degrees latitude (N & S): 1.6E-18 kg/m2/day (all surfaces)
60S- 60N degrees latitude ocean: 1.6E-18 kg/m2/day
60S- 60N degrees latitude land: whatever to get 16 kg/yr*
*this land source depends on model geography, about 3.3E-16 kg/m2/day

Case B - aircraft source of "radon":

Put emissions along 4 flight routes: (constant latitude OR longitude)
Japan-Calif (34N, 120E-120W), Calif-NY (40N, 120W-75W)
Boston-Rome (42N, 75W-10E), Rome-Oslo (42N-60N, 10E)
Emit EQUAL amounts on each leg (4 kg/yr/route = 16 kg/yr total)
Emit uniformly with air mass (pressure) between 200-400 mb.

Case C - tropical lightning source of "radon":

Put total source (16 kg/yr) EQUALLY into three tropical hot spots -
(10S - 10N) x 3 longitude belts: (45W-75W), (10E-40E), and (100E-130E).
Emit uniformly with air mass (pressure) between 200-400 mb (assumes
lightning source has been deposited aloft by cumulus transport).

CHEMISTRY:

Remove Rn with a constant loss frequency of $2.10\text{E-}6$ /sec (about 5.5 days)

****Case A only**** assume each ^{222}Rn loss = instantaneous production of ^{210}Pb . Apply a wet deposition sink to ^{210}Pb using any scheme by which a highly water-soluble, submicron aerosol is removed in your model. Include a dry deposition velocity of 0.1 cm/sec (referenced to 10 m altitude) for ^{210}Pb over all surfaces.

N.B. The focus of this workshop is on transport of radon, the lead experiment is included as an example of possible directions for future workshops. Therefore it is not so constrained as the radon experiment, and we leave the Pb results for an open discussion at the end of the workshop, comparing approaches on heterogeneous removal processes.

INITIALIZE with near-zero levels of Rn and Pb on NOV 1 and on MAY 1, RUN for 4 months, REPORT statistics for final 3: DEC-JAN-FEB & JUN-JUL-AUG.

UNITS: at 16 kg/yr, the global mean mixing ratio is thus $6.5\text{E-}21$ v/v, thus report all concentrations as mixing ratios in units of $1\text{E-}21$ v/v.

PERIOD: all statistics (means, rms, medians, q-tiles, fluxes) based on the full three month period June 1 - August 31 and December 1 - Feb 28.

=====

MODEL DIAGNOSTICS & COMPARISON with MEASUREMENTS:

^{222}Rn DIAGNOSTICS (Cases A-D, except surface times series for Case A only):

3-Month (!) averages or times series requested for both DJF and JJA

(1) At the following geographic sites, record modeled time series of radon:

8 SITES:

3 ALTITUDES:

a Kirov, Russia 58N 49E "mixed" layer = 300m above surface

b Cincinnati, Ohio 40N 84W 600 mb (true pressure, not sigma)

c Socorro, N. Mexico 34N 107W 300 mb (true pressure)

d Hawaii **** 20N 155W 1 PLOT per site & season, 3 altitude on page):

e Samoa **** 14S 171W time series, sub-select surface @ 1400H

f Crozet Isl. **** 46S 51E TABULATED values (site x season x alt)

g Ferraz, Antarct 62S 58W means, rms, min, 1/4, median, 3/4, max

(2) latitude x pressure (linear) of v/v 3-month means at DATELINE (180EW) and GREENWICH (0EW), and v/v 3-month zonal mean - [THREE PLOTS per season].

(3) latitude x longitude of v/v 3-month means at "mixed" layer (300 m), at 600 mb and at 300 mb - [THREE PLOTS per season].

^{210}Pb DIAGNOSTICS (Case A only):

(4) latitude x pressure (linear) of v/v 3-month means at DATELINE (180EW) and GREENWICH (0EW), and v/v 3-month zonal mean - [THREE PLOTS per season].

(5) table of amount of Pb (kg): (a) total in atmosphere, (b) $p < 600$ mb (altitudes above), and (c) $p < 300$ mb integrated over all latitudes & longitudes at the end of each of 3-month simulation (Feb 28 & Aug 31).

THE MEASUREMENTS (Rn/Pb) TO BE COMPARED WITH WILL BE DEVELOPED OVER THE SUMMER, AND THESE "DATA" PLOTS WILL BE SENT OUT TO ALL WHO CONTRIBUTE TO THE WORKSHOP BY GETTING THEIR RESULTS (PLOTS & TABLES) IN TO THE ORGANIZERS.

=====

RESULTS DUE in by 1 NOV 93

=====

WE PLAN TO HAVE 'TOPICAL' DISCUSSION LEADERS WHO WILL TAKE A SPECIFIC DIAGNOSTIC FROM ALL PARTICIPATING MODELS AND CROSS-COMPARE.

THIS IS THE TYPE MODEL COMPARISONS DONE FOR STRATOSPHERE OVER THE
PAST SEVERAL YEARS. THEREFORE, PLEASE SUBMIT COPIES OF YOUR FIGURES
AND TABLES IN THE FORMAT (INCLUDING SCALE) DESCRIBED BELOW.
ALSO, PLEASE BRING TRANSPARENCIES (ONE SET) TO THE MEETING, WE WILL NOT BE
ABLE TO MAKE THAT MANY TRANSPARENCIES AT THE MEETING.
MANY OF YOU WILL BE ASKED TO LEAD THE COMPARISON ON A SPECIFIC TOPIC:
e.g. REMOTE SITES, FREE TROP, LAT/LONG GRADIENTS, TIME SERIES,...

=====

=====

DIAGNOSTICS SPECS: PLEASE PREPARE THESE SO THAT YOU CAN BRING TRANSPARENCIES
TO THE MEETING SO THAT THE TOPICAL DISCUSSION LEADERS CAN DO THEIR JOB

=====

	X-Model	A: Time Series Stats		(E-21	v/v)	Jun-Jul-Aug		
		mean	var	min	1/4	median	3/4	max
Kirov	300 mb	---	---	---	---	---	---	---
	600 mb	---	---	---	---	---	---	---
	mixed	---	---	---	---	---	---	---
Cincinnati	300 mb	---	---	---	---	---	---	---
	600 mb	---	---	---	---	---	---	---
	mixed	---	---	---	---	---	---	---
Socorro	300 mb	---	---	---	---	---	---	---
	600 mb	---	---	---	---	---	---	---
	mixed	---	---	---	---	---	---	---

Hawaii same for remaining 4 stations, all on one page,
 Samoa use whatever decimal accuracy you deem appropriate
 Crozet
 Ferraz NEW PAGE for the Dec-Jan-Feb run

=====

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and the same for Dec-Jan-Feb (NEW PAGE)

WE NEED TO BE ABLE TO PLAN A BALANCE BETWEEN THE DIFFERENT
SCIENTIFIC GROUPS NEEDED FOR A SUCCESSFUL WORKSHOP.
SO PLEASE SEND IN A NOTICE OF INTENTION TO PARTICIPATE IN
THE MODEL COMPARISON AS SOON AS POSSIBLE TO
Byron Boville and myself with copy to
WCRP: V.Savtchenko, WCRP c/o WMO, Cass Postale 2300,
CH-1211 Geneva 2, Switzerland, fax=41 22 734 0357
IF YOU DID NOT RECEIVE THE WCRP ANNOUNCEMENT, PLEASE FAX V.SAVTCHENKO
INCLUDE: name / address / tele & fax # / e-mail and the
reason for attendance (abstract or description).

Appendix B

**Differences between the Lagrangian and Eulerian Grantour
simulations**

**A list of the minor differences between the implementation of the
Lagrangian Grantour (LG) radon simulations and the Eulerian
Grantour (EG) radon simulations.**

1) For case A: (natural radon) LG injects radon between sigma coordinates 0.9 to 1.0 while EG injects between sigma coordinates 0.926 and 1.0 .

2) For case B: (aircraft) LG injects according to the specifications but in a corridor with width of five degrees. EG injects between sigma levels of 0.165 and 0.355 rather than between 200 and 400 mb. Horizontally the EG injections are into the following grid boxes:

Specifications		EG Approximation	
longitude	latitude	longitude	latitude
120E - 120W	34N	120E - 120W	32.9 - 37.3
75W - 10E	42N	75W - 7.5E	41.7 - 46.1
120W - 75W	40N	120W - 75W	37.3 - 41.7
10E	42N - 60N	7.5E - 15E	41.7 - 59.2

3) For case C: (lightning) LG injects according to the specifications. EG injects between sigma levels of 0.165 and 0.355 rather than between 200 and 400 mb. Horizontally the EG injections are into the following grid boxes:

Specifications		EG Approximation	
longitude	latitude	longitude	latitude
45W - 75W	10S - 10N	45W - 75W	11S - 11N
10E - 40E	10S - 10N	7.5E - 37.5E	11S - 11N
100E - 130E	10S - 10N	97.5 - 127.5	11S - 11N

4) LG biases all its injections by surface pressure. In areas of high local surface pressure one expects to find more parcels, thus there is a slightly larger source term there. In areas of low surface pressure, one expects to find fewer parcels, thus there is slightly reduced injection there. The total amount injected is correct.

5) LG reports results every 12 hours. EG reports results every 24 hours.

6) Data from LG labeled "mixed layer" is actually at 977 mb. At locations where the surface pressure is less than 977 mb, the surface values are reported. Data from EG labeled "mixed layer" is actually at 0.965 in sigma coordinates.

**DATE
FILMED**

6 / 30 / 94

END