

Measurements of the partial pressure of CO₂ in near-surface seawater and in marine boundary air

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Ships:

Measurements have been made on onboard the following ships:
RV Hakuho Maru I and II, Ocean Research Institute, the University of Tokyo
RV Ryofu Maru II, Japan Meteorological Agency
RV Natsushima, Japan Marine Science and Technology Center
RV Kaiyo Maru, Japan Fisheries Agency
MS Wellington Maru, Mitsui O.S.K. Lines
RV Sogen Maru, Marine Biotechnology Institute
TS Hokuto Maru, National Institute of Sea Training
TS Taisei Maru, National Institute of Sea Training
RV Kaiyo, Japan Marine Science and Technology Center
RV Mirai, Japan Marine Science and Technology Center
(see cruise list)

Variables:

Variable_Name: mixing ratio of CO₂ in dry air ($x\text{CO}_2$)
Description_of_Variable: $x\text{CO}_2$ in marine boundary air ($x\text{CO}_2\text{Air}$) and $x\text{CO}_2$ in air equilibrated with near-surface seawater ($x\text{CO}_2\text{Sea}$).

Equilibrator_Design:

Equilibrator_Type: shower-head
Equilibrator_Volume: 1.5 dm³
Water_Flow_Rate: ca. 6 – 10 dm³ min⁻¹
Headspace_Gas_Flow_Rate: ca. 500 – 700 cm³ min⁻¹
Vented: Yes.

Calibration_Gas:

Four cylinders of reference gases have been used to calibrate the output voltage of NDIR every 60 or 90 minutes. All reference gases used onboard underwent a pre- and post-cruise calibration against MRI-87 CO₂ concentration scale of which primary standards consists of a series of primary standard gases made at Nippon Sanso Co. with a gravimetric method following the procedure reported by [Tanaka, M., T. Nakazawa and S. Aoki (1987): Time and space variations of tropospheric carbon dioxide over Japan. *Tellus*, **39B**, 3-12.]. The difference in CO₂ concentration scale between WMO mole-fraction and MRI87 has tentatively been determined as Eq.(1):

$$\begin{aligned} & (x\text{CO}_2^{\text{WMO}} - x\text{CO}_2^{\text{MRI87}}) / \text{ppm} \\ &= -0.015 - 0.569 \cdot (x\text{CO}_2^{\text{MRI87}} - 370) \cdot 10^{-2} + 0.237 \cdot (x\text{CO}_2^{\text{MRI87}} - 370)^2 \cdot 10^{-4} \\ &+ 0.341 \cdot (x\text{CO}_2^{\text{MRI87}} - 370)^3 \cdot 10^{-6} \quad (271 < x\text{CO}_2^{\text{MRI87}} / \text{ppm} < 405) \end{aligned}$$

CO₂_Sensor: Non-Dispersive Infrared (NDIR) Gas Analyzer

Model: Beckman315A, 864, 865, 880, Rosemount Binos 4.1, LI-COR6251

Environmental_Control: Temperature controlled within the instrument around the cell of the NDIR.

CO₂_Sensor_Calibration: Once per hour or once per 1.5 hours using four standard gases.

Warming_correction:

Correction of $p\text{CO}_2w$ in the equilibrator to the in situ $p\text{CO}_2sw$ for seawater warming (typically $0.0 < \Delta t / ^\circ\text{C} < 1.0$ depending on the ship and location) was made using the equation given by [Gordon and Jones (1973): The effect of temperature on carbon dioxide partial pressure in seawater. *Marine Chemistry*, **1**, 317 - 322, 1973] or [Copin-Montegut, C. (1988): A New formula for the effect of temperature on the partial pressure of CO₂ in seawater. *Marine Chemistry*, **25**, 29-37, and Copin-Montegut, C. (1989): A new formula for the effect of temperature on the partial pressure of CO₂ in seawater. Corrigendum. *Marine Chemistry*, **27**, 143 - 144.] after mid-1990s.

Method_References:

Inoue, H.Y., CO₂ exchange between the atmosphere and the ocean: carbon cycle studies of the Meteorological Research Institute since 1968, *In: Dynamics and Characterization of Marine Organic Matter.*, Eds. N. Handa, E. Tanoue and T. Hama., TERAPUB/Kluwer, Tokyo, 509-53, 2000.

See also the references in the cruise list.

For at-sea intercomparison exercise, see Körtzinger, A., Mintrop, L., Duinker, J. C., The international intercomparison exercise of underway $f\text{CO}_2$ systems

during the R/V *Meteor* cruise 36/1 in the North Atlantic Ocean. Environmental Science Division Publication No.4844, NDP-067, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., 1999.

Data_Set_References:

Data_Set_Link:

Majority of the data in this data set have been archived at WMO's World Data Center for Greenhouse Gases: URL: http://gaw.kishou.go.jp/wdcgg_j.html.
Data taken on board JAMSTEC's R/V Mirai are available from JAMSTEC's MIRAI DATA WEB: URL:<http://www.jamstec.go.jp/mirai/>

Cruise List

Ship	Cruise	Place	Period	PIs	References
RV Hakuho Maru I	KH68-4	N.Pac, eqPac, S.Pac, Southern	Nov. 16, 1968 – Feb. 28, 1969	Inoue, H. Y.*	1, 11,18
	KH70-1	N.Pac	Feb. 6, 1970 – Mar. 2, 1970	Inoue, H. Y.*	1, 11
	KH70-2	N.Pac	Apr. 15, 1970 – Jun. 17, 1970	Inoue, H. Y.*	1, 11
	KH83-4	N.Pac, eqPac, S.Pac, Southern	Nov. 23, 1983 – Feb. 22, 1984	Inoue, H. Y.	2, 4, 6, 11,18
	KH85-3	N.Pac	May. 31, 1985 – Jun. 30, 1985	Inoue, H. Y.	
	KH88-1	N.Pac, eqPac, S.Pac,	Jan. 22, 1988 – Mar. 23, 1988	Inoue, H. Y.	7
RV Hakuho Maru II	KH90-2	N.Pac, eqPac, S.Pac,	Sep. 3, 1990 – Oct. 25, 1990	Inoue, H. Y. Ishii, M.	8
	KH90-3	N.Pac, eqPac	Oct. 31, 1990 – Dec. 13, 1990	Ishii, M.	8
	KH94-4	N.Pac, eqPac, S.Pac, Southern	Nov. 23, 1994 – Feb. 13, 1995	Ishii, M.	11, 13, 15,18
	KH01-3	N.Pac, eqPac, S.Pac, Southern	Nov. 28, 2001 – Jan. 21, 2002	Ishii, M.	18
RV Ryofu Maru II	RY8301	N.Pac, eqPac	Jan. 19, 1983 - Feb. 5, 1983	Inoue, H. Y.	3, 4, 9, 19
	RY8401	N.Pac, eqPac	Jan. 21, 1984 - Feb. 8, 1984	Inoue, H. Y.	4, 6, 9, 19
	RY8501	N.Pac, eqPac	Jan. 18, 1985 - Feb. 6, 1985	Inoue, H. Y.	4, 9, 19
	RY8601	N.Pac, eqPac	Jan. 19, 1986 - Feb. 7, 1986	Inoue, H. Y.	9, 19
	RY8701	N.Pac, eqPac	Jan. 14, 1987 - Feb. 2, 1987	Inoue, H. Y.	5, 7, 9, 19
	RY8706	N.Pac, eqPac	Jun. 9, 1987 - Jul. 25, 1987	Inoue, H. Y.	7, 9, 19
	RY8801	N.Pac, eqPac	Jan. 16, 1988 - Feb. 4, 1988	Inoue, H. Y.	7, 9, 19
	RY8901	N.Pac, eqPac	Jan. 19, 1988 - Feb. 6, 1989	Inoue, H. Y.	7, 9, 19
RV Natsushima	Na8701	N.Pac, eqPac	Jan. 24, 1987 - Feb. 22, 1987	Inoue, H. Y.	5, 7

	Na8901	N.Pac, eqPac	Dec. 28, 1988 - Feb. 21, 1989	Inoue, H. Y.	6
	Na9001	N.Pac, eqPac	Jan. 12, 1990 - Feb. 28, 1990	Inoue, H. Y., Ishii, M.	9
	Na9101	N.Pac, eqPac	Dec. 28, 1990 - Mar. 10, 1991	Inoue, H. Y., Ishii, M.	9
RV Kaiyo Maru	Ki87	N.Pac, eqPac, S.Pac	Oct. 28, 1987 - Dec. 5, 1987	Inoue, H. Y.	6
MS Wellington Maru	We8811	N.Pac, eqPac, S.Pac	Nov. 4, 1988 - Nov. 13, 1988	Inoue, H. Y.	6
RV Sogen maru	9110	N.Pac	Oct. 8, 1991 - Dec. 31, 1990	Inoue, H. Y.	
TS Hokuto maru	9207	N.Pac, eqPac, S.Pac	Jul. 4, 1992 - Aug. 19, 1992	Inoue, H. Y.	
	9407	N.Pac	Jul. 9, 1994 - Aug. 28, 1994	Inoue, H. Y.	
	9601	N.Pac, Indian	Jan. 20, 1996 - Feb. 29, 1996	Inoue, H. Y.	
	9607	N.Pac	Jul. 6, 1996 - Aug. 27, 1996	Inoue, H. Y.	
TS Taisei maru	9301	N.Pac, eqPac, S.Pac	Jan. 25, 1993 - Mar. 6, 1993	Inoue, H. Y.	
	9307	N.Pac, eqPac, S.Pac	Jul. 5, 1993 - Aug. 27, 1993	Inoue, H. Y.	15
	9501	N.Pac, eqPac, S.Pac, Indian	Jan. 23, 1995 - Mar. 8, 1995	Inoue, H. Y.	
	9801	N.Pac, eqPac, S.Pac	Jan. 23, 1998 - Mar. 7, 1998	Inoue, H. Y.	
RV Kaiyo	KY9307	eqPac	Jan. 6, 1994 - Feb. 17, 1994	Inoue, H. Y., Ishii, M.	9,13,16
	KY9406	N.Pac, eqPac	Nov. 9, 1994 - Jan. 31, 1995	Inoue, H. Y.	9,13,16
	KY9511	eqPac	Dec. 23, 1995 - Jan. 19, 1996	Inoue, H. Y.	
	KY9601	eqPac	Jan. 24, 1996 - Feb. 24, 1996	Inoue, H. Y.	
	KY9701	eqPac	Dec. 15, 1996 - Jan. 22, 1997	Inoue, H. Y.	
	KY9702	eqPac	Jan. 26, 1997 - Feb. 27, 1997	Inoue, H. Y.	
	KY9714	eqPac	Dec. 7, 1997 - Dec. 24, 1997	Ishii, M.	11,16
	KY9801	eqPac	Jan. 3, 1998 - Jan. 31, 1998	Ishii, M.	11,13
	KY9901	eqPac	Jan. 26, 1999 - Feb. 28, 1999	Inoue, H. Y.	

	KY9909	eqPac	Oct. 10, 1999 – Nov. 21, 1999	Inoue, H. Y.	
RV Mirai	MR98test	N.Pac, eqPac	Jan. 31, 1998 – Feb. 9, 1998	Inoue, H. Y.	11,16
	MR98K2	N.Pac, eqPac	Dec. 24, 1998 – Jan. 30, 1999	Ishii, M.	13,15,16
	MR99K1	N.Pac, eqPac	Feb. 8, 1999 – Mar. 30, 1999	Inoue, H. Y.	
	MR99K6	N.Pac, eqPac	Oct. 15, 1999 – Nov. 18, 1999	Ishii, M.	
	MR99K7	N.Pac, eqPac	Nov. 21, 1999 – Dec. 25, 1999	Ishii, M.	15,16
	MR00K8	N.Pac, eqPac	Dec. 27, 2000 – Feb. 6, 2001	Ishii, M.	15,16
	MR01K1	N.Pac, eqPac	Feb. 15, 2001 – Mar. 21, 2001	Inoue, H. Y.	
	MR02K1	N.Pac, eqPac	Jan. 7, 2002 – Feb. 14, 2002	Inoue, H. Y.	16
	MR02K2	N.Pac, eqPac	Feb. 22, 2002 – Mar. 29, 2002	Inoue, H. Y.	
	MR02K6	N.Pac, eqPac	Nov. 14, 2002 – Feb. 12, 2003	Ishii, M.	16

N.Pac: the North Pacific,

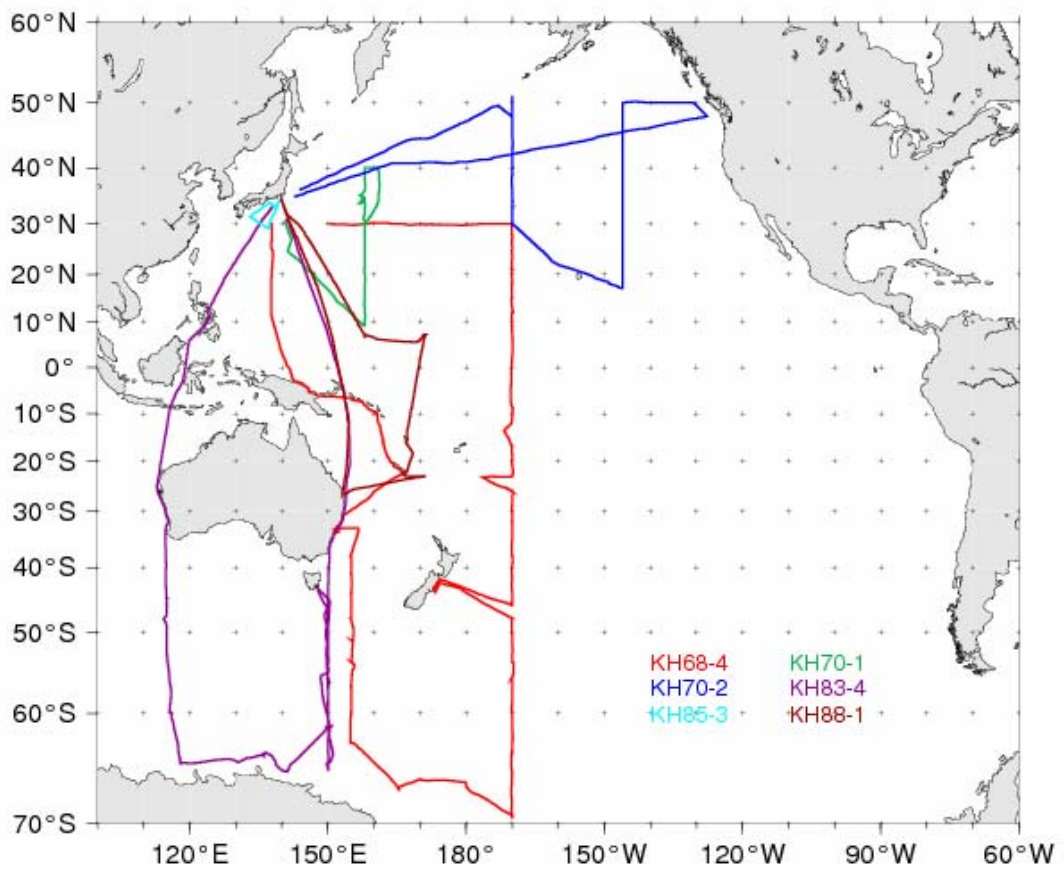
eqPac: the equatorial Pacific (10°S – 10°N)

S.Pac: the South Pacific

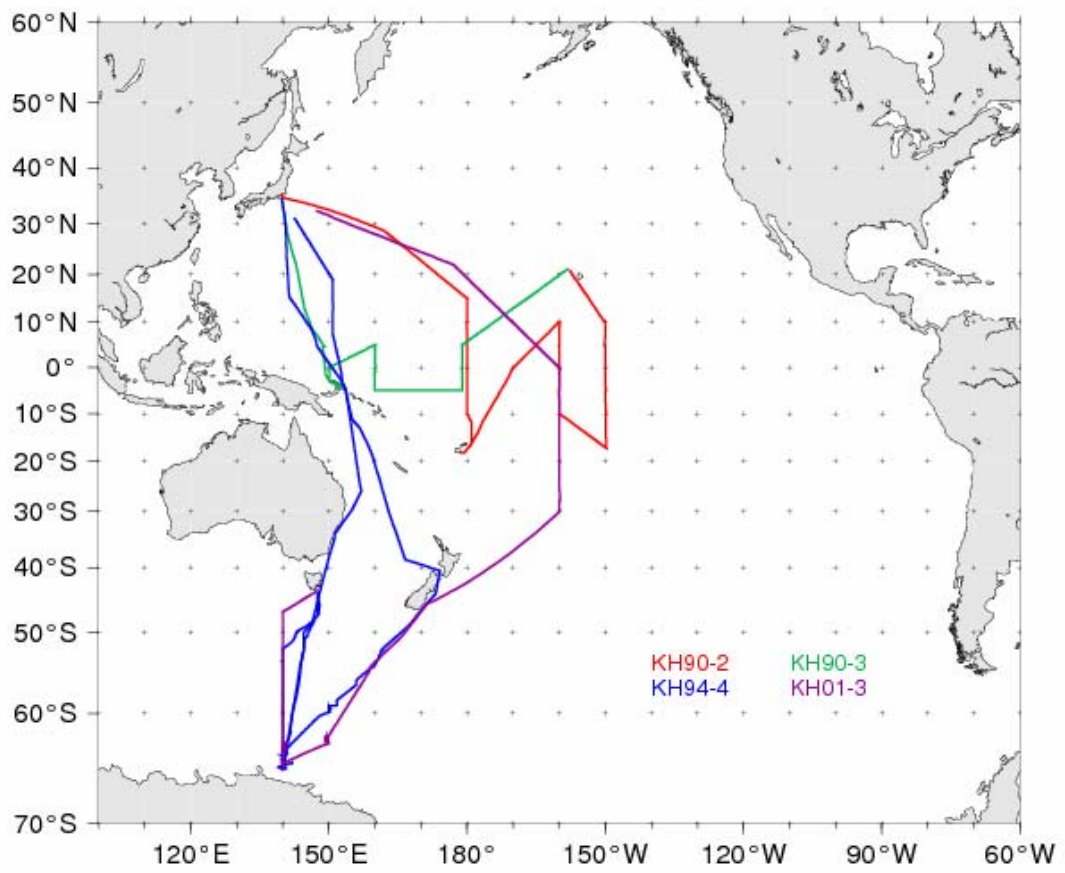
Southern : the Southern Ocean

* Reanalyzed from original data charts in 1998.

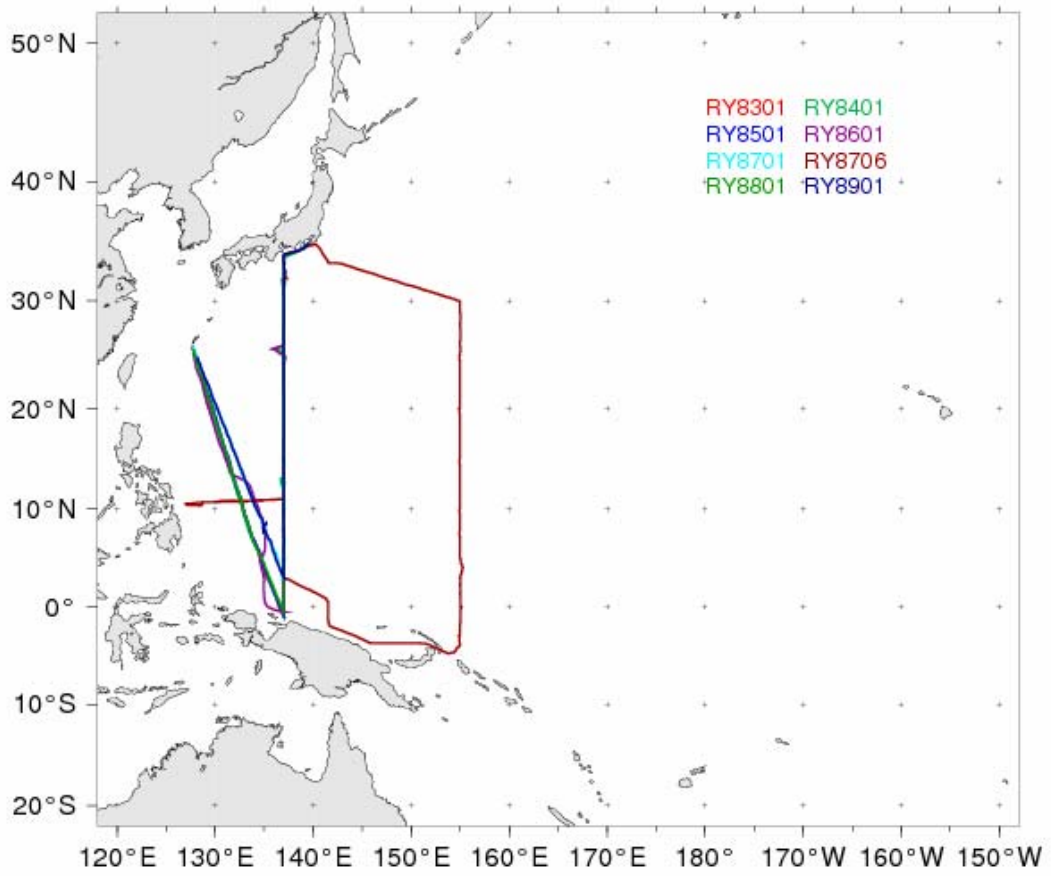
RV Hakuho Maru I (ORI, Univ.Tokyo)



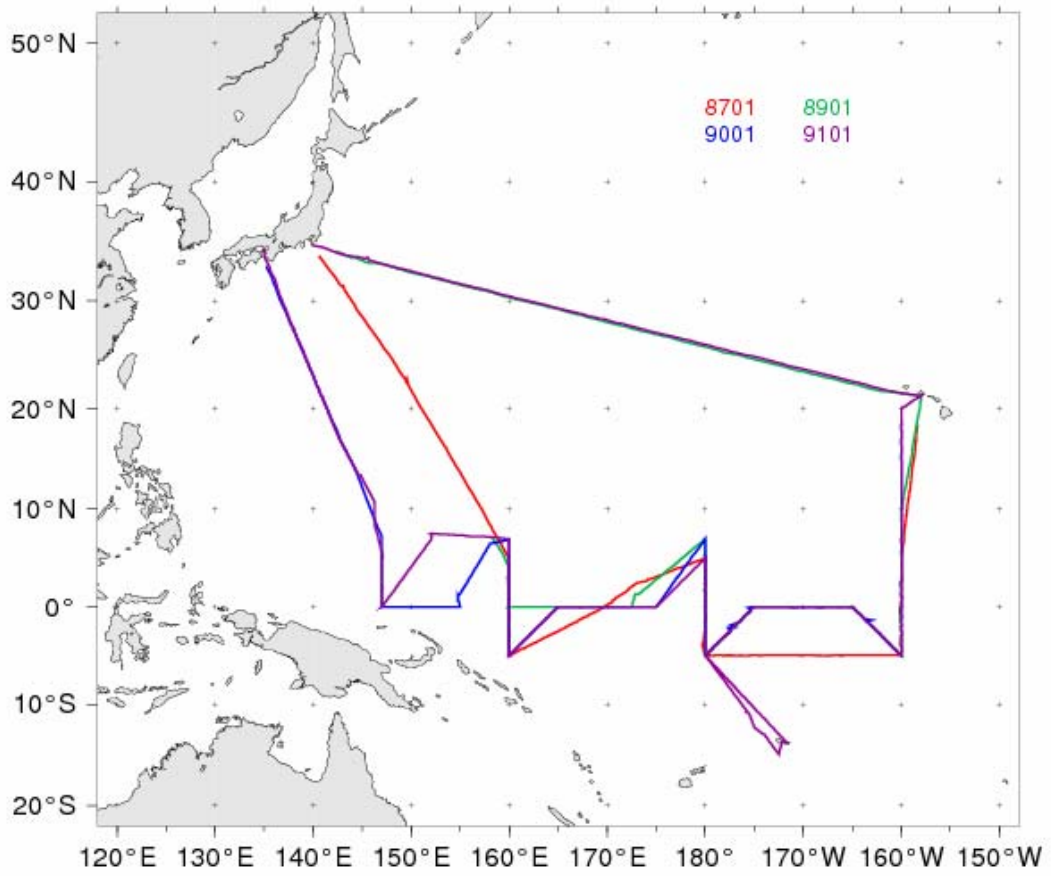
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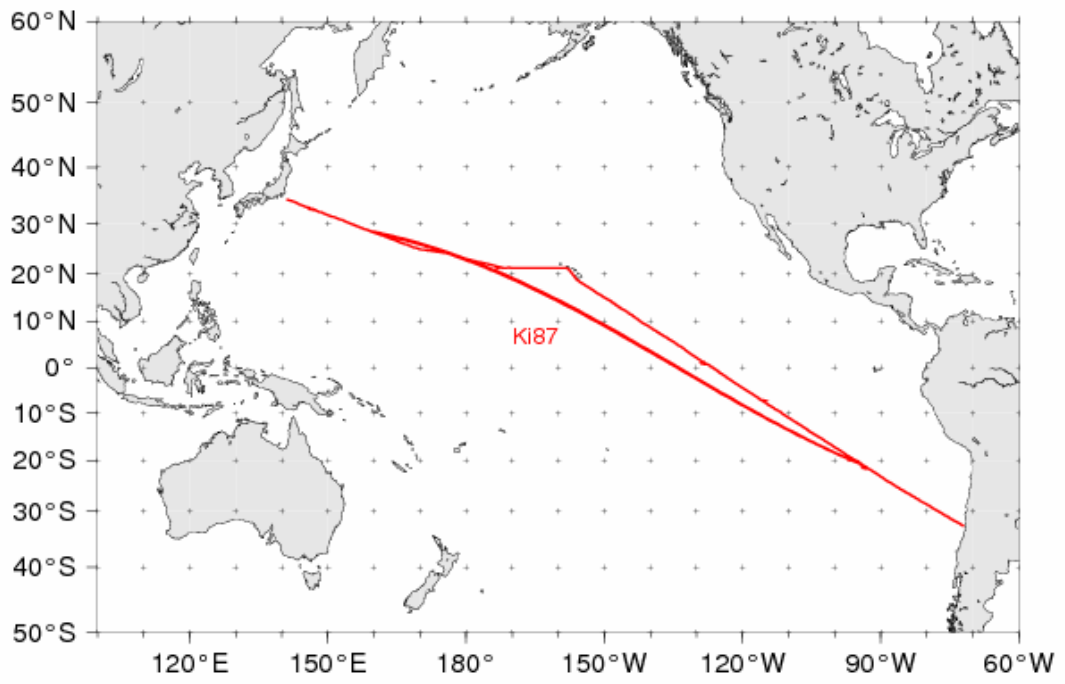
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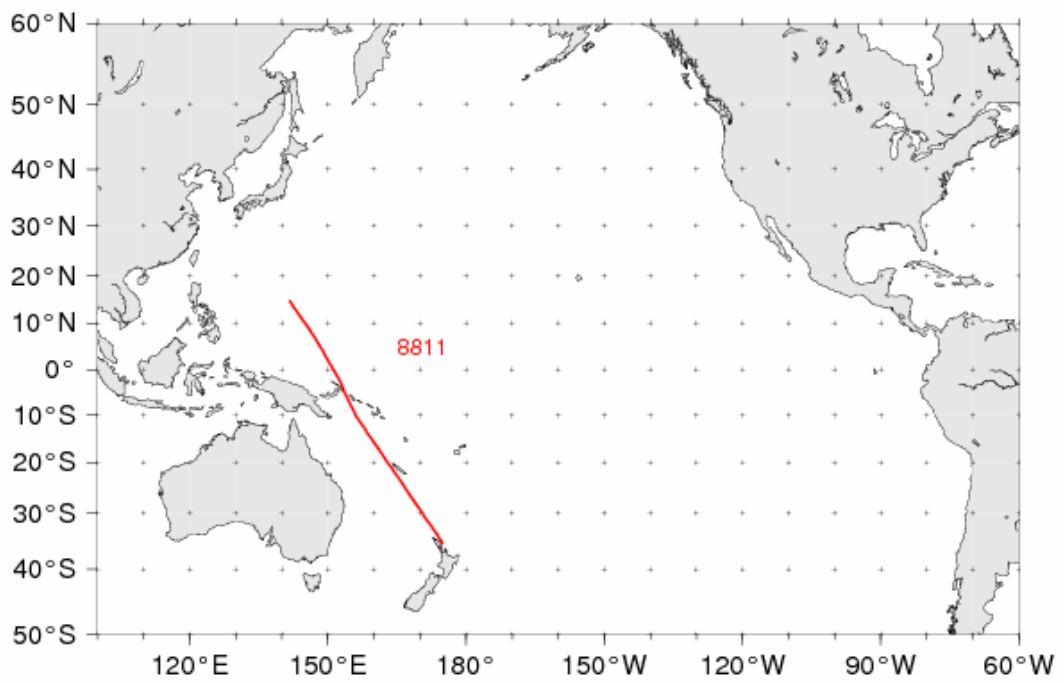
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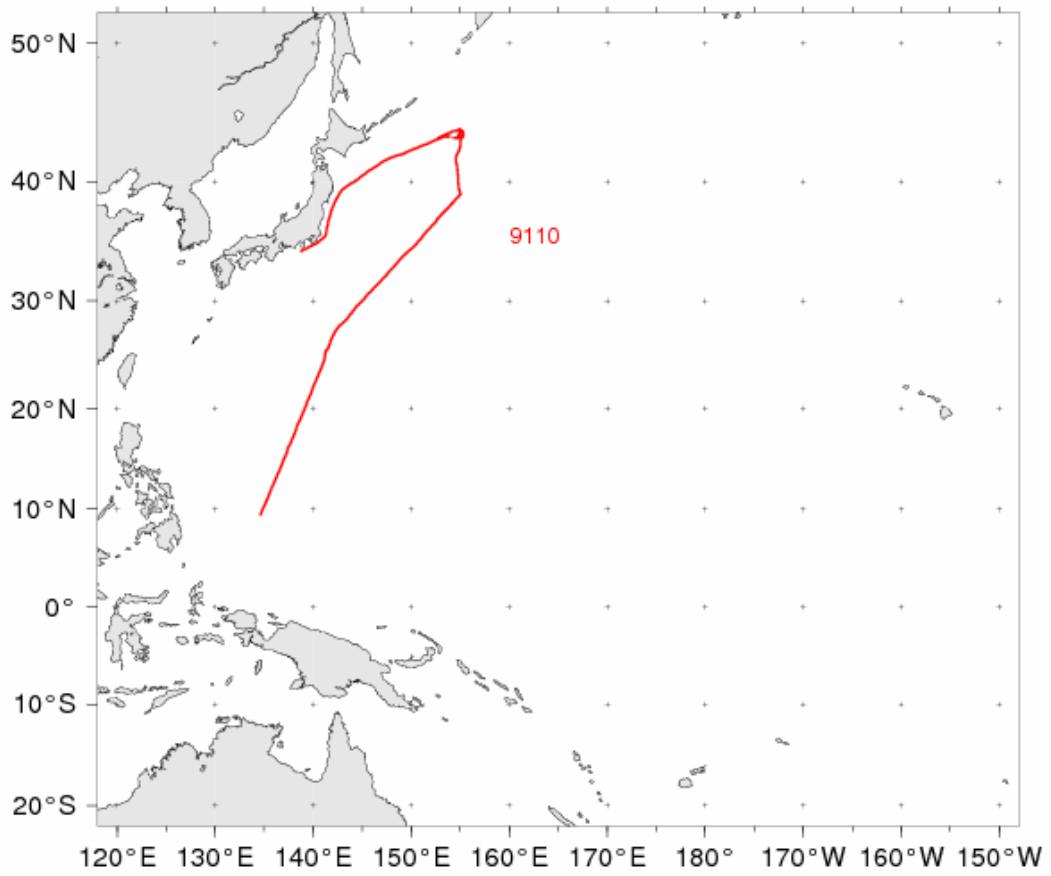
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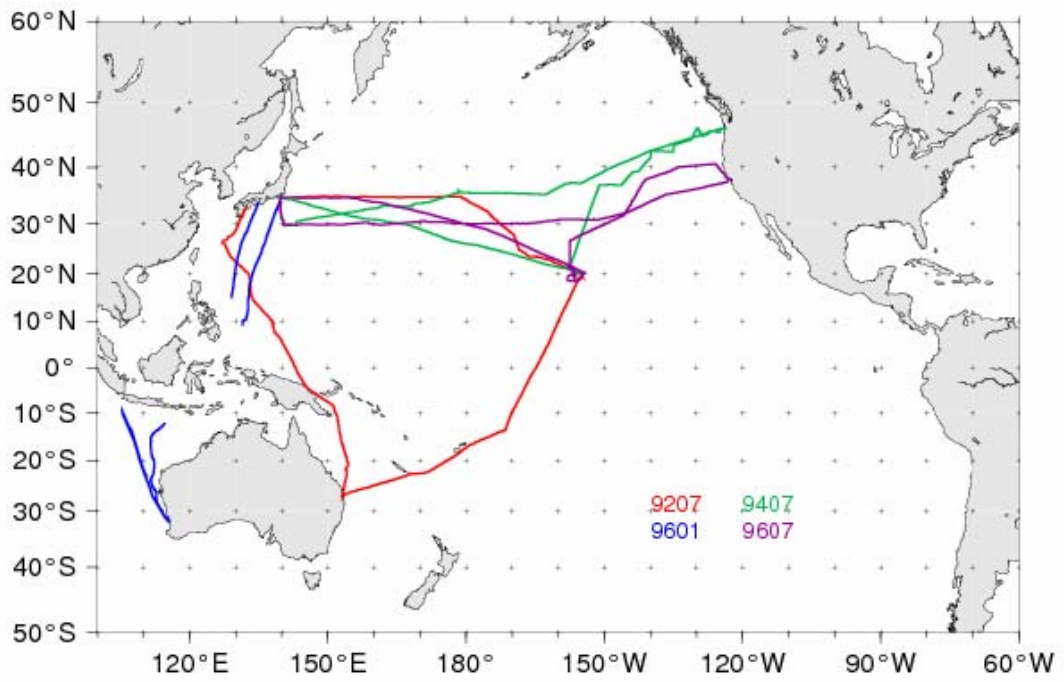
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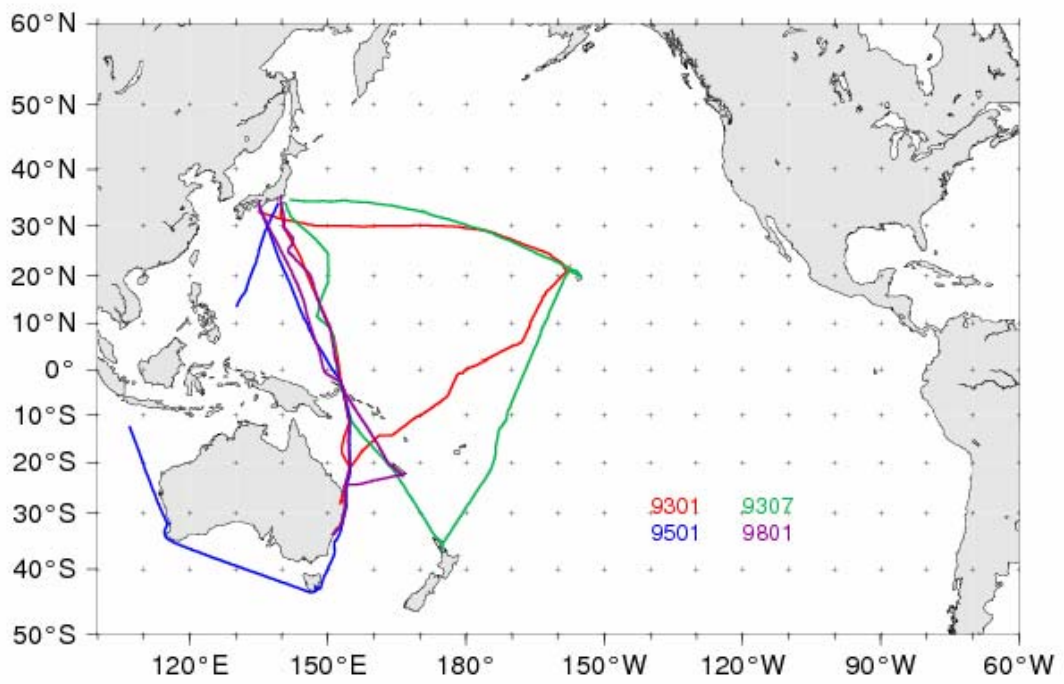
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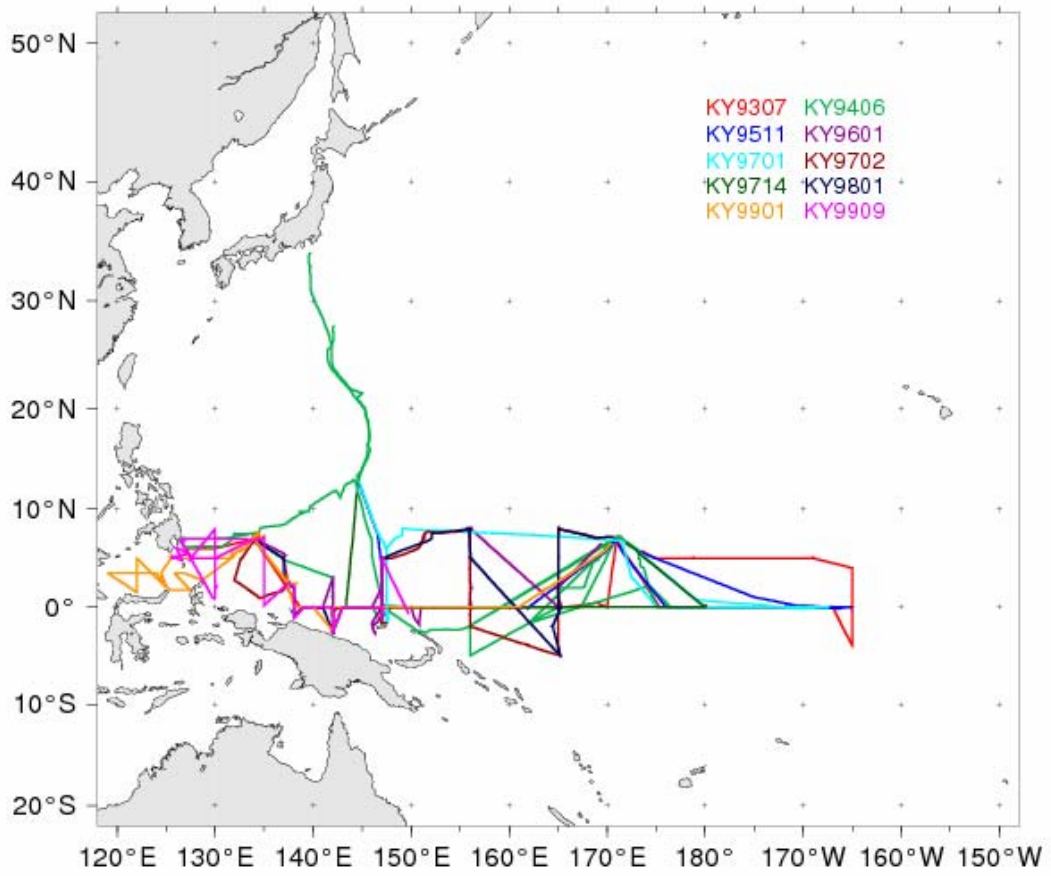
TS Hokuto Maru (NIST)



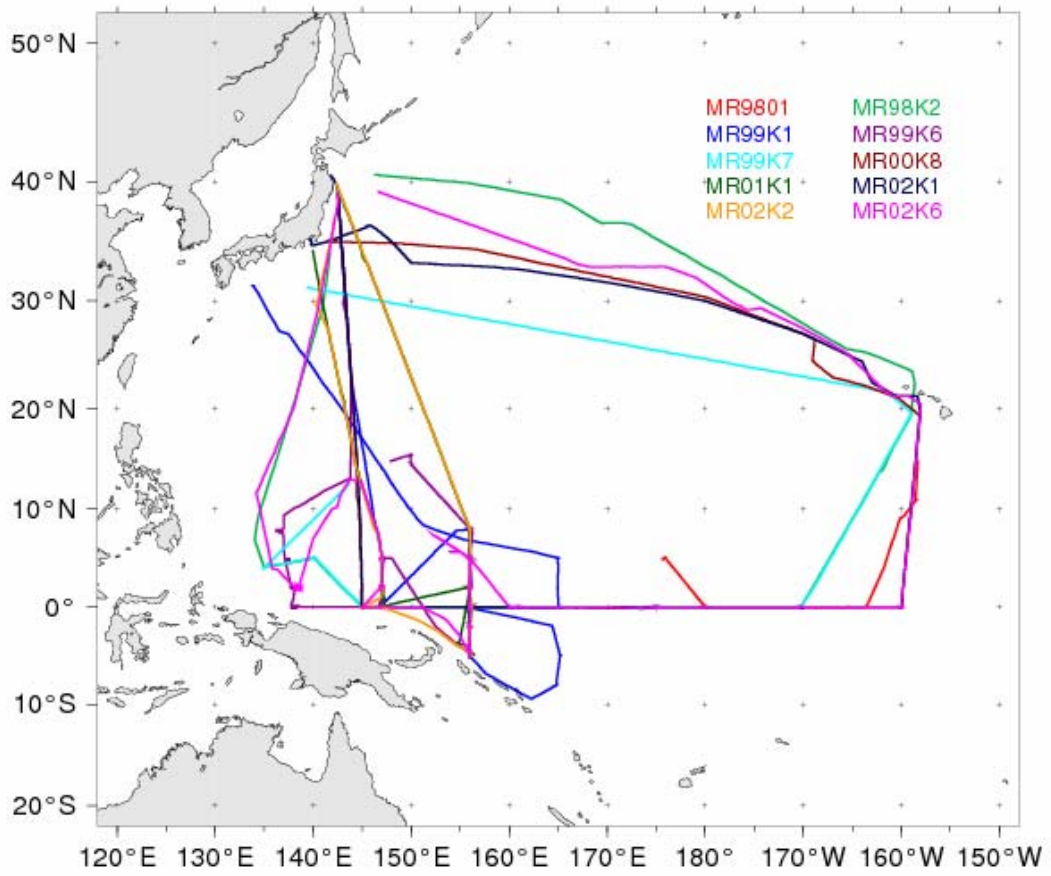
TS Taisei Maru (NIST)



RV Kaiyo (JAMSTEC)



RV Mirai (JAMSTEC)



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