The impact of rain on global and regional air-sea CO_2 fluxes: a 10 year time series analysis

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OceanFlux GHG is funded by: esa and affiliated to: solas

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Introduction

- Rain impacts air-sea gas exchange through a number of mechanisms.
  - Enhancing k, wet deposition of DIC, chemical dilution, SST
- Rain intensity and frequency varies considerably throughout the globe.

  - Can rain have a significant impact on global and regional net air-sea fluxes ?
- What are the ranges of these impacts on regional and global net air-sea fluxes ?
  - Are some regional fluxes impacted more than others?

Introduction

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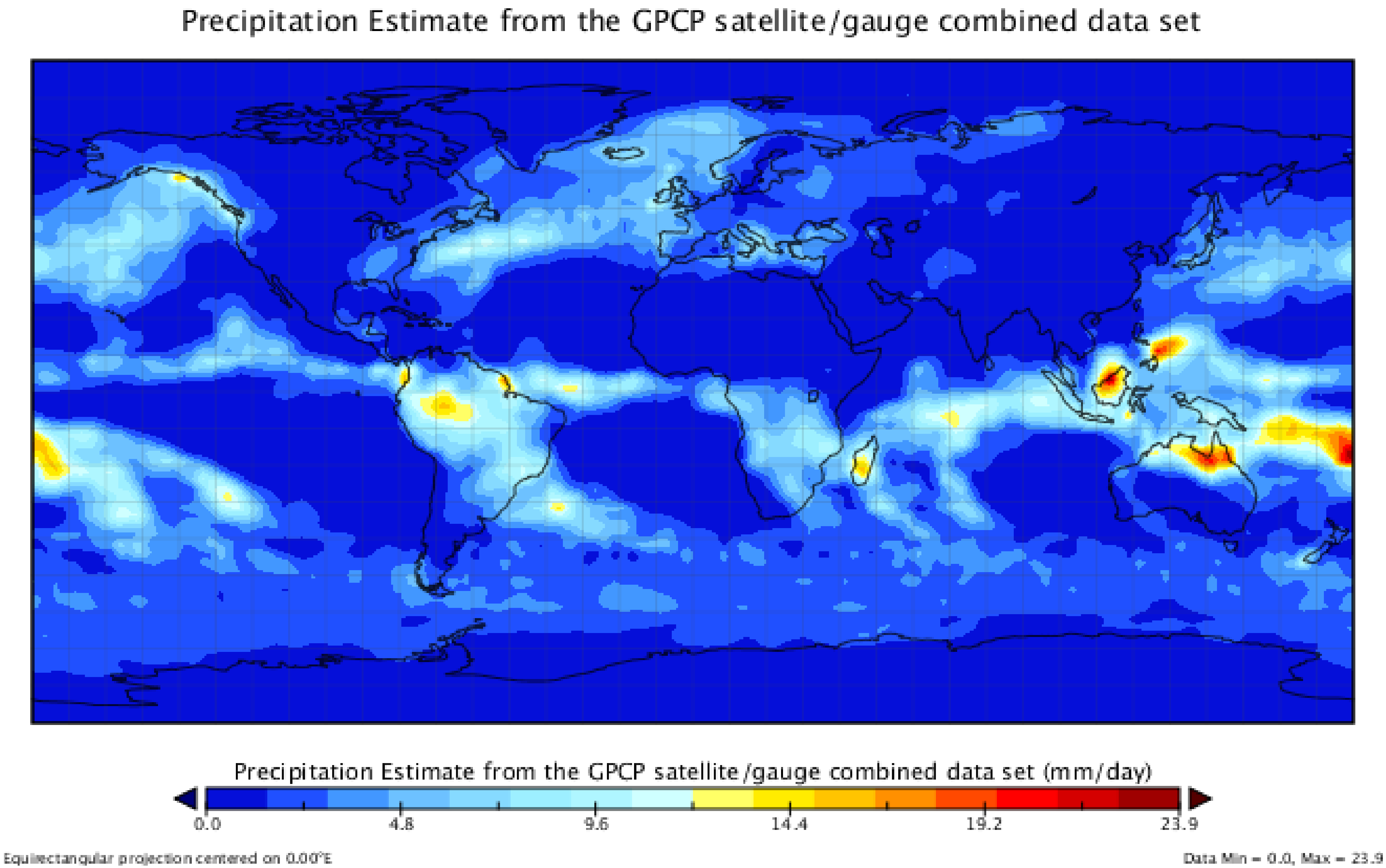

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Methods

1. Global rain fluxes:

- Baseline flux – default data and a wind k.
- Parameterise wet deposition flux (Fw) and rain k flux (Fk) based on previous in situ work.

- Run 10 year time series
- Calculate global and regional Fw, Fk and compare with the baseline.

Methods

Rn = rain rate in mm h^{-1}

Fk : Rain gas transfer (Ho *et al.*, 1997)

$$k(rain) = [0.929 + 0.679\ Rn - 0.0015\ Rn^2]\ (600/Sc)^{0.5}$$

Fw : Rain wet deposition (Komori *et al.*, 2007)

$$F_{DIC} = R_n\ \alpha\ p(CO_2)_{air}$$

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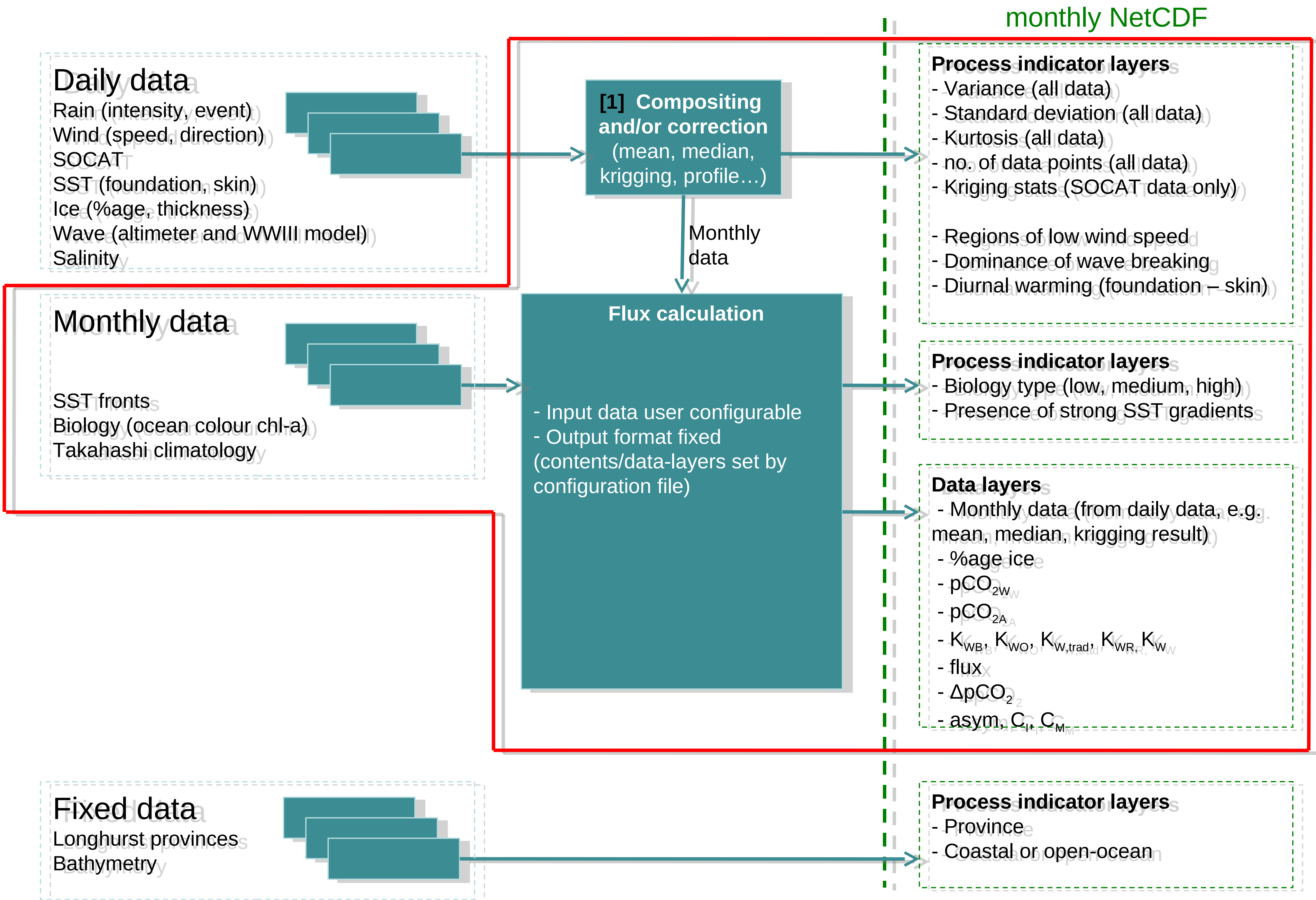
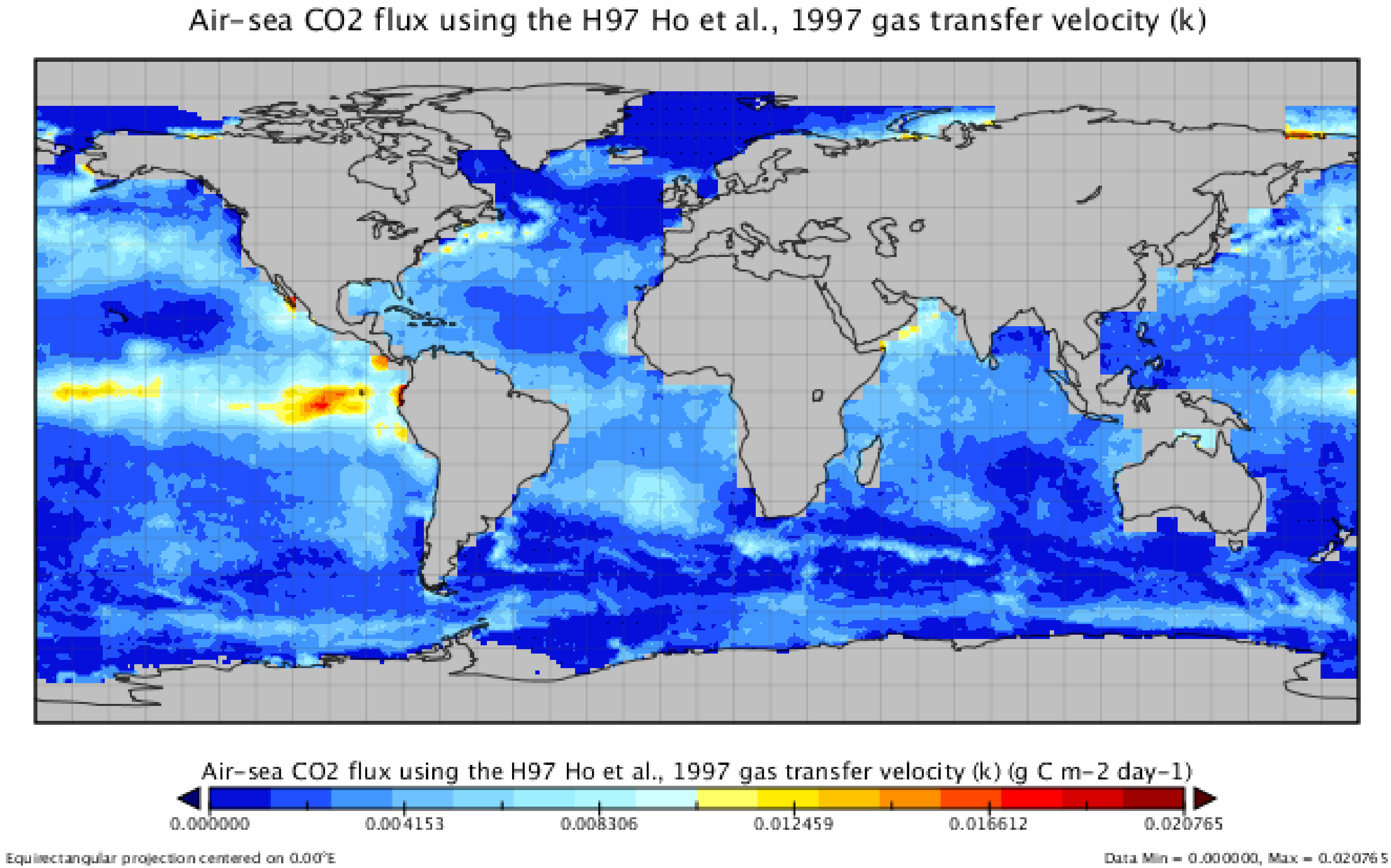
Input Data

Dataset	Parameter	Uncertainty (precision, bias)	Reference
ESA SST CCI	SST_{skin}, ^oC	0.14, < 0.1^oC	Merchant *et al.*, JGR,2013
ESA GlobWave	U10, m s^{-1}		www.globwave.org
Global Precipitation Climatology Project	Rain rate, mm h^{-1}	0.05, 0.01 mm h^{-1}	Huffman and Bolvin, 2013
Takahashi	pCO_2, µatm SST, ^oC	0.2 µatm, 0.0 (air) 3 µatm, 0.0 (water)	Takahashi *et al.*, DSRII, 2009
NCEP CSFR	Air pressure		Saha *et al.*, 2010



monthly NetCDF
Daily data
Rain (intensity, event)
Wind (speed, direction)
SOCAT
SST (foundation, skin)
Ice (%age, thickness)
Wave (altimeter and WWIII model)
Salinity
[1] Compositing and/or correction
(mean, median, krigging, profile…)
Monthly data
Process indicator layers
- Variance (all data)
- Standard deviation (all data)
- Kurtosis (all data)
- no. of data points (all data)
- Kriging stats (SOCAT data only)
- Regions of low wind speed
- Dominance of wave breaking
- Diurnal warming (foundation – skin)
Monthly data
SST fronts
Biology (ocean colour chl-a)
Takahashi climatology
Flux calculation
- Input data user configurable
- Output format fixed (contents/data-layers set by configuration file)
Process indicator layers
- Biology type (low, medium, high)
- Presence of strong SST gradients
Data layers
- Monthly data (from daily data, e.g. mean, median, krigging result)
- %age ice
- pCO_{2W}
- pCO_{2A}
- K_{WB}, K_{WO}, $K_{W,trad}$, K_{WR}, K_W
- flux
- ΔpCO_2
- asym, C_I, C_M
Fixed data
Longhurst provinces
Bathymetry
Process indicator layers
- Province
- Coastal or open-ocean

Example results – max Fk across all years



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Initial yearly results –global for 1999-2009

Component	Flux (Tg C yr^{-1})
Rain	
Rain k (Fk)	0.01 – 0.05 (into water)
DIC wet deposition (Fw)	0.06 - 0.07 (into water)
Rain total (Fr = Fk + Fw)	0.08 – 0.11 (into water)
Rain impact on Net global fluxes (fixed 1.402)	5 - 8 %
Rain impact on Net global fluxes (variable)	5 - 6 %

Komori *et al.*, (2007) estimated <5 % for 2001, we estimate 5.8 % (0.085 Tg C yr^{-1})

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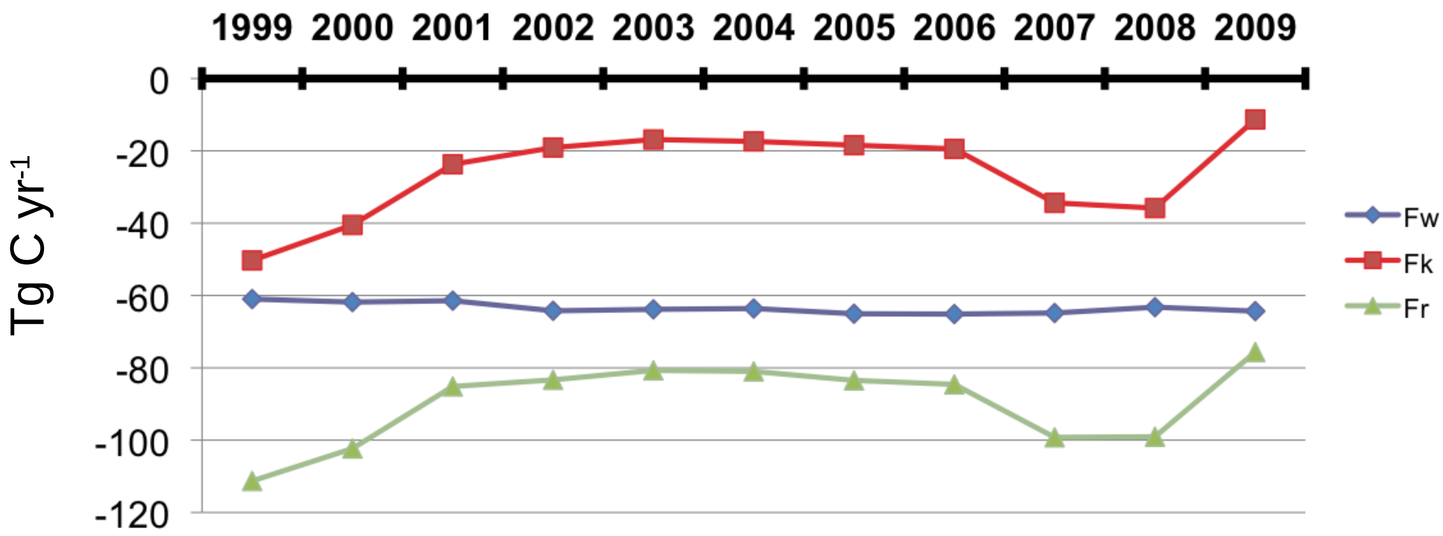
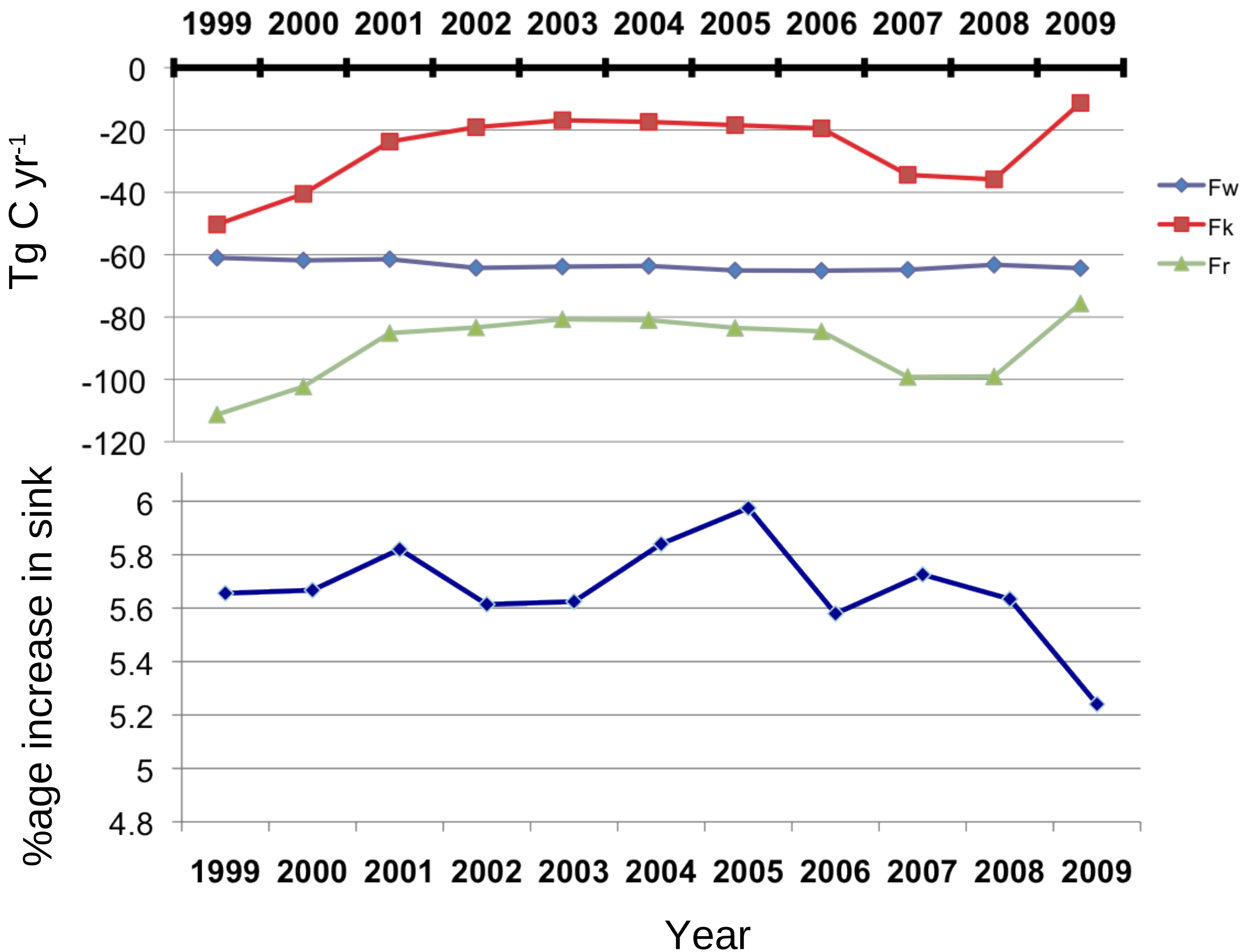
Initial yearly results – Global



Initial yearly results – Global



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Initial yearly results – oceanic regions for 1999-2009

	%age impact (min to max)
Rain	
Global	5 - 6 increase in sink
Atlantic	5 - 6
Pacific	5 - 7
Indian	5 - 6
Southern	6 - 13

Initial yearly results – oceanic regions for 1999-2009

	%age impact (min to max)
Rain	
Global	5 - 6 increase in sink
Atlantic	5 - 6
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Indian	5 - 6
Southern	6 - 13

Greatest impact in the Southern ocean and slightly elevated in Pacific

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Initial monthly results – Oceanic regions for 1999-2009

	%age impact	Flux (Tg C yr^{-1})
Rain		
Global	4 to 11 increase in sink	-11 to -4
Atlantic	4 to 12 increase in sink	-4.23 to -0.5
Pacific	-31 to +23 (6 months much greater)	-6 to +0.2
Indian	4 to 8 increase in sink	-3 to -0.3
Southern	±15 (5 months much greater)	-1.6 to +0.2

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Rain increases sink in Atlantic and Indian oceans

Rain can modulate monthly fluxes in Pacific and Southern oceans

Initial monthly results – Oceanic regions for 1999-2009

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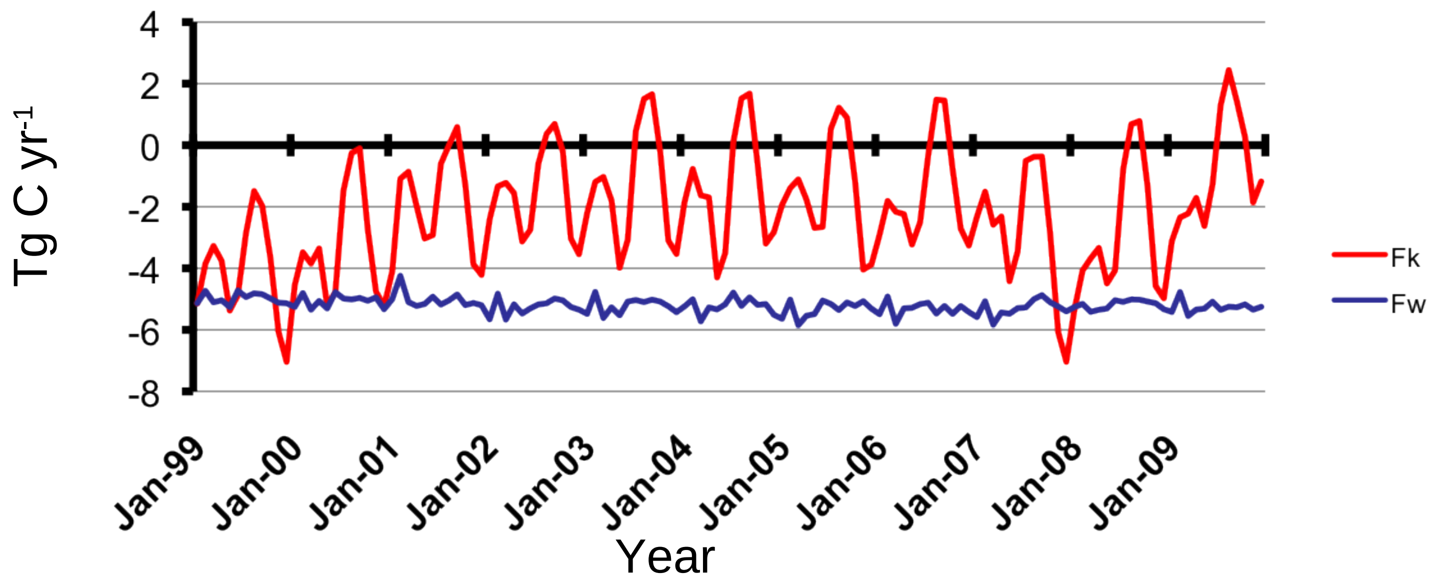
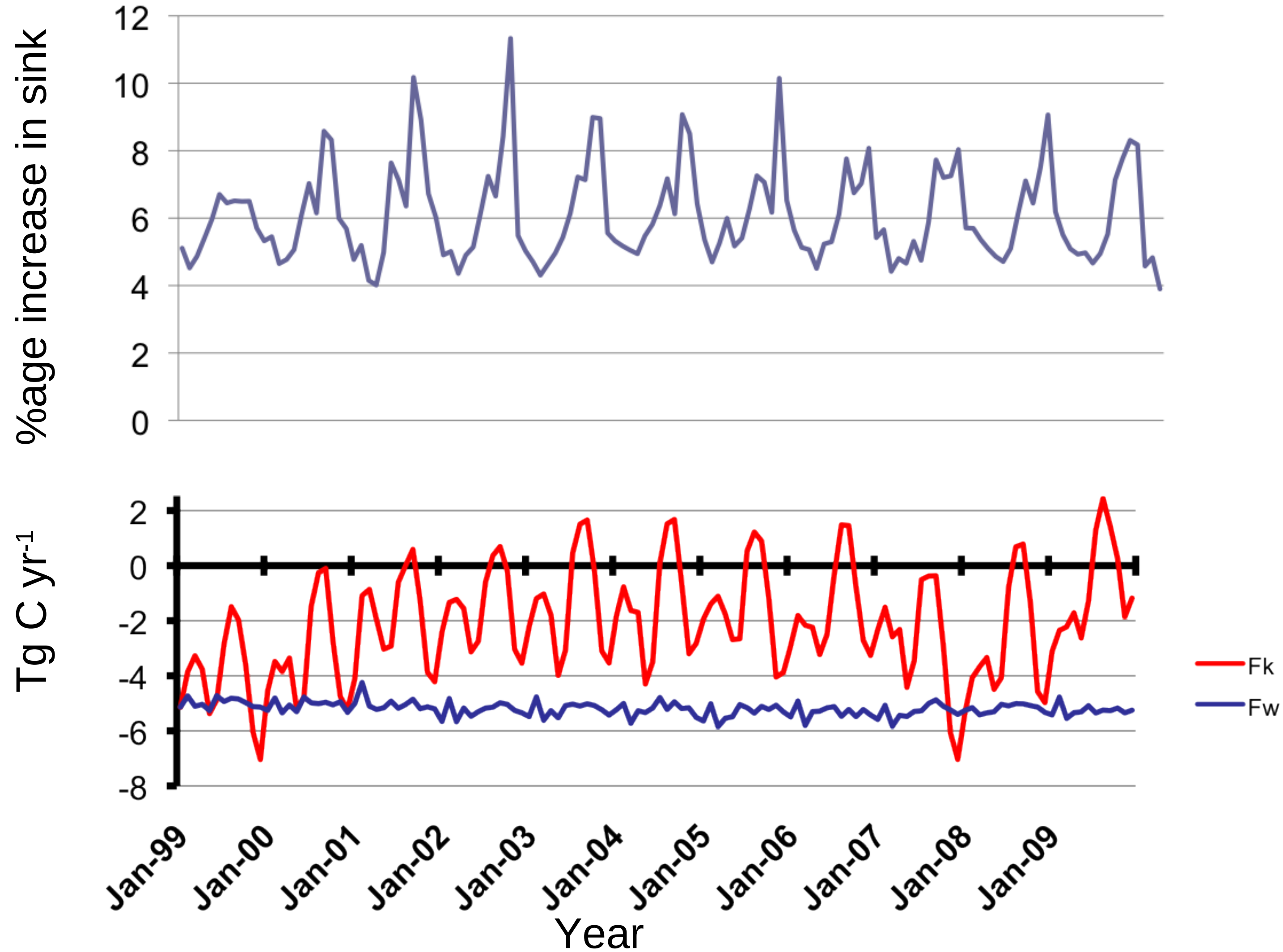
Initial monthly results – Global



Initial monthly results – Global



Largest increase in sink is generally during August and September

- Storm and hurricane season in North Atlantic ?
- East Asian monsoon ?

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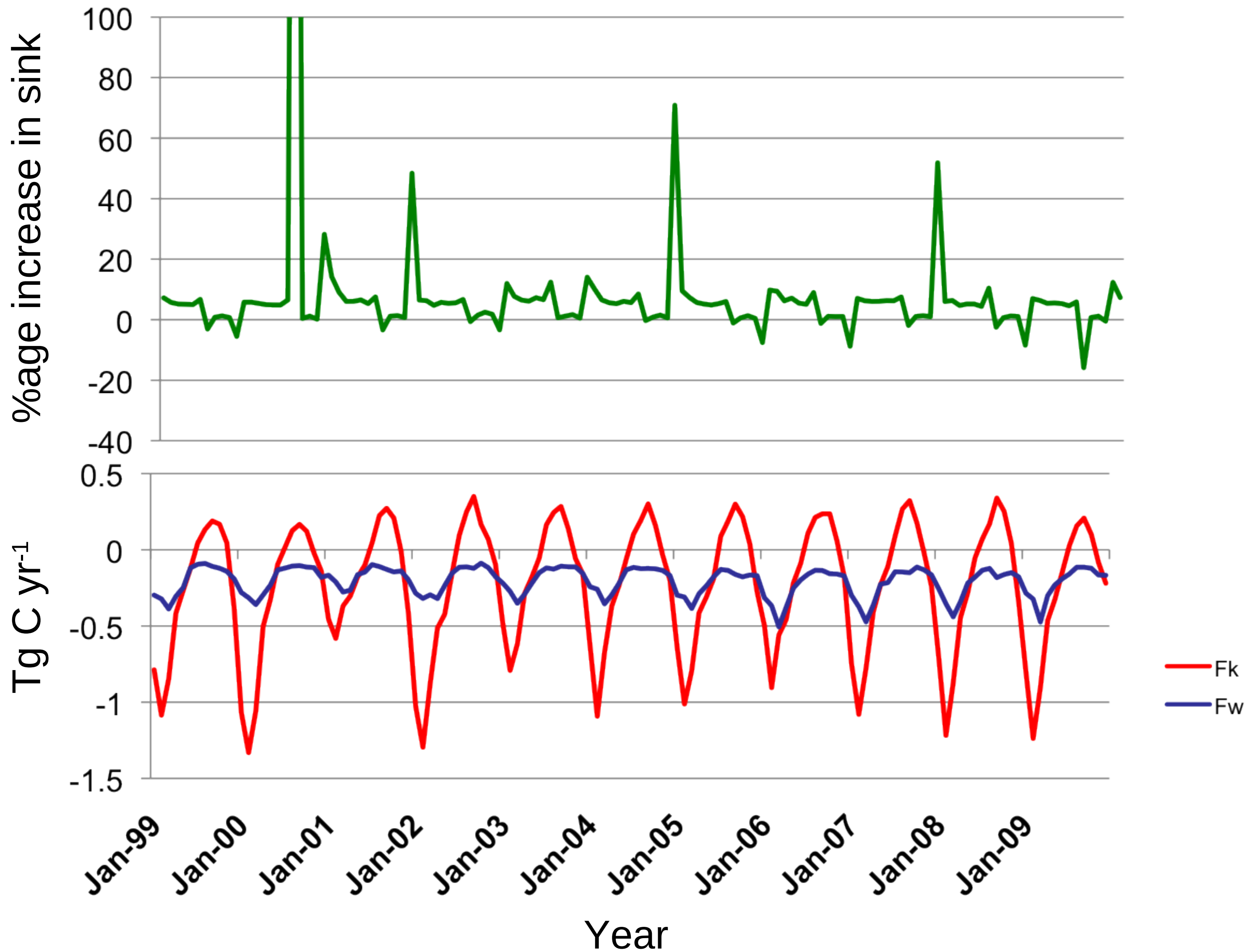
Initial monthly results – Southern Ocean



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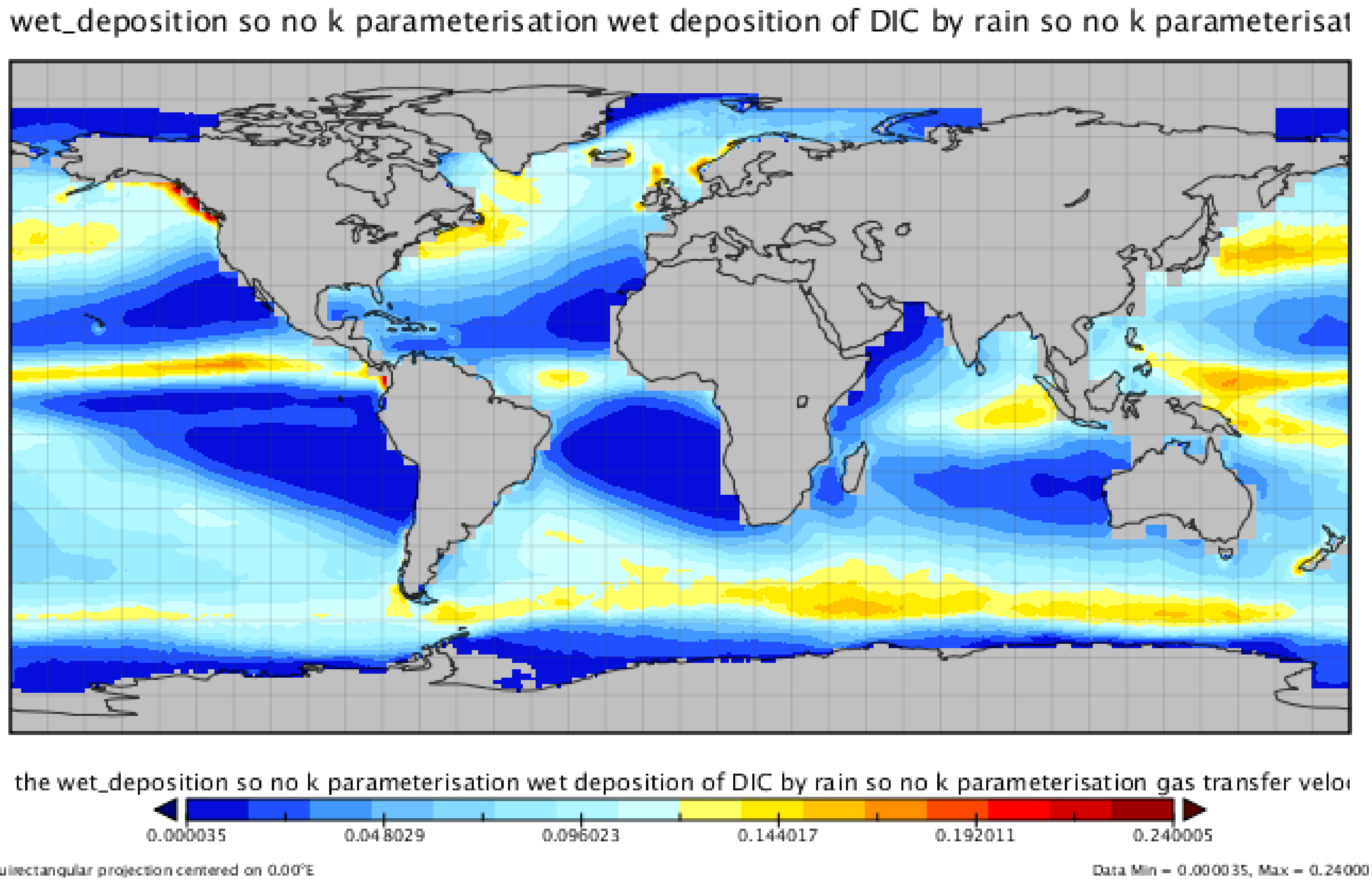
Initial results – total wet deposition all years



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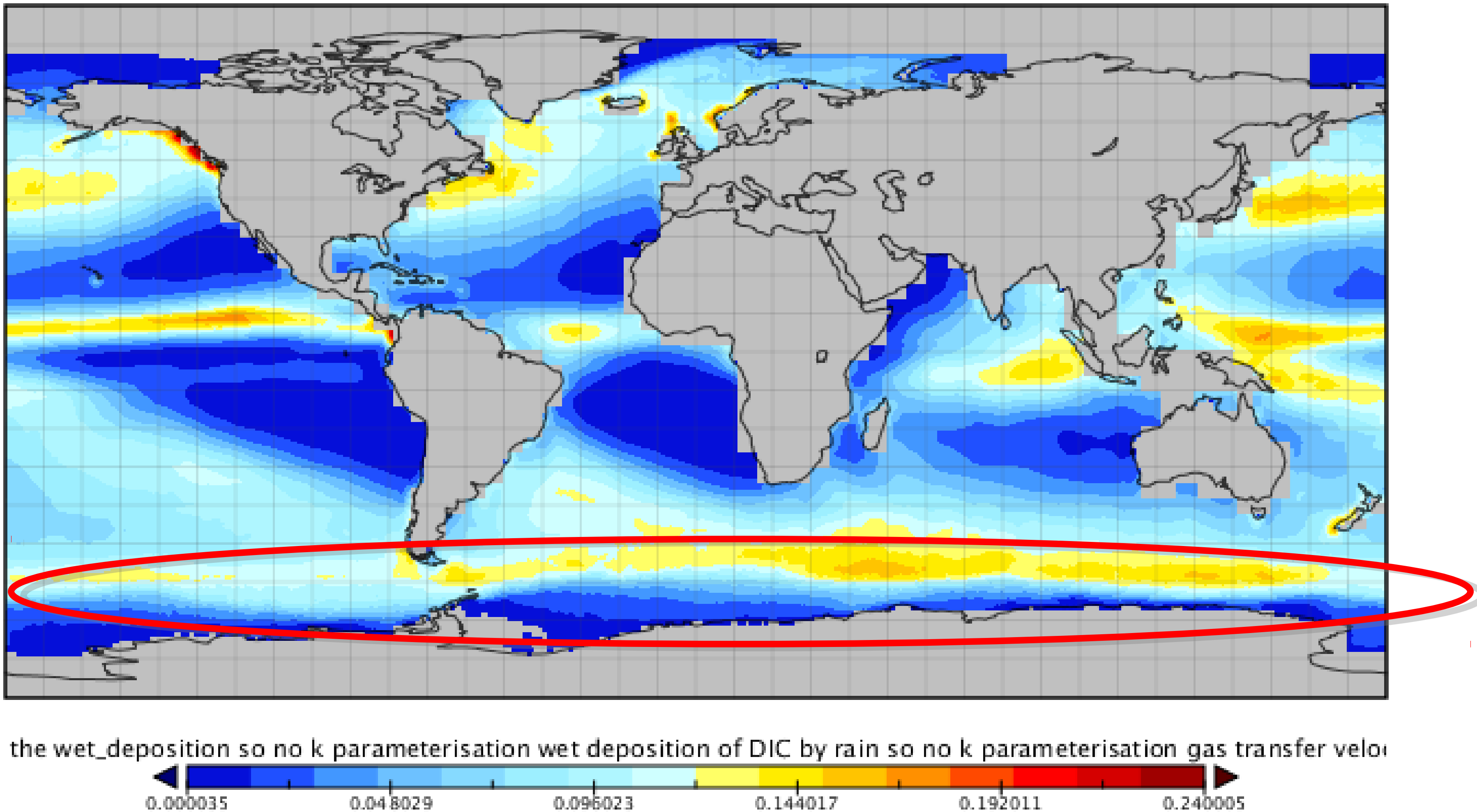
Initial results – total wet deposition all years

wet_deposition so no k parameterisation wet deposition of DIC by rain so no k parameterisat



Equirectangular projection centered on 0.00°E

Data Min = 0.000035, Max = 0.240005

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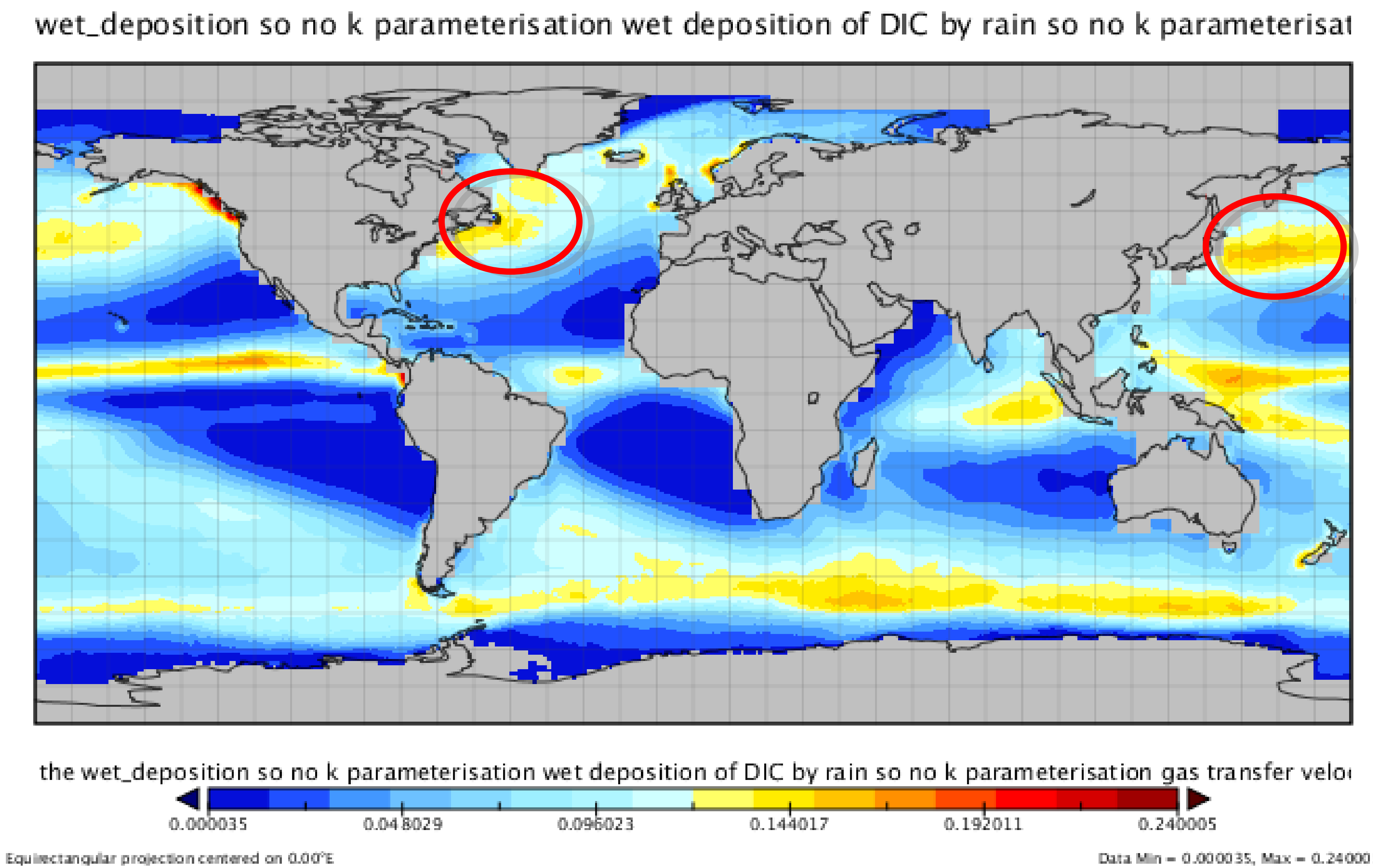
Initial results – total wet deposition all years



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Conclusions

- 10 year global analysis
- Global annual results are comparable to Komori *et al.,* 2007 which focused on 2001.
- Wet deposition appears fairly consistent between years (k rain is more variable).

- Rain increases the annual global oceanic net sink of CO_2 by up to 6 %.
  - This can be used as the estimate of rain uncertainty in annual global net fluxes.
- Regional annual variations
  - Rain can increase the Southern ocean net sink by up 13 %
- Regional monthly variations
  - Pacific and Southern ocean monthly fluxes can be significantly modulated by rain (ie > ± 15%)
  - Instances of very large modulation (ie > ± 50%)

To complete:

- Inclusion of a dilution model.
- 19 year run (1992-2010).
- Range of SST impacts (curves of possible impacts).
- Wave and rain correlations.

Shutler, J. D., Woolf, D. K., Quartly, G., Land, P. E., (in-prep) Quantifying the impact of rain on global and regional air-sea CO_2 fluxes, *to be submitted to OceanFlux GHG workshop special issue (for ACP).*

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