0. Creator

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1. Inversion system and settings

System name

NISMON-CO_2 ver.2021.1

Transport model

NICAM-TM (Niwa, Tomita et al., 2011; Niwa, Tomita et al., 2017)
Horizontal resolution: glevel-5 (~223 km)
Vertical layers: 40 (up to ~45km)
Meteorological data: horizontal winds are nudged towards JRA-55 (Kobayashi et al., 2015)
See more references listed below for transport performances.

Flux model

The surface CO_2 fluxes that are input to NICAM-TM can be described as

$$f_{\mathrm{CO_2}}(x,t) = f_{\mathrm{fos}}(x,t) - \beta_{\mathrm{GPP}}\,(f_{\mathrm{GPP}}(x,t) + \Delta f_{\mathrm{GPP}}(x,t)) + \beta_{\mathrm{RE}}(f_{\mathrm{RE}}(x,t) + \Delta f_{\mathrm{RE}}(x,t)) + \big(1 + \Delta\alpha_{\mathrm{LUC}}(x,t)\big) f_{\mathrm{LUC}}(x,t) + \big(1 + \Delta\alpha_{\mathrm{fire}}(x,t)\big) f_{\mathrm{fire}}(x,t) + f_{\mathrm{ocn}}(x,t) + \Delta f_{\mathrm{ocn}}(x,t),$$

where x and t represent flux location and time, respectively. Fluxes from fossil fuel use and cement production, gross primary production (GPP) and respiration (RE) of terrestrial biospheres, land use change (LUC), biomass burning, and oceans are denoted as f_{fos}, f_{GPP}, f_{RE}, f_{LUC}, f_{fire}, and f_{ocn}, respectively; they are prescribed by flux datasets prepared in advance and have monthly temporal resolution here. The above Δ variables are optimized in the inversion; their temporal resolutions are all set monthly except for the ocean flux Δf_{ocn}. The coefficients β_{GPP} and β_{RE} are scaling factors that reproduce diurnal variations; they distribute fluxes at 3-hourly resolution from the monthly fluxes.

Optimization method

POpULar (Fujii and Kamachi, 2003; Fujii, 2005; Niwa, Fujii et al., 2017)
a quasi-Newton BFGS method

Prescribed flux

fossil fuel: GCP-GridFEDv2021.2 (Jones et al., 2021)
https://zenodo.org/record/5565199
terrestrial biosphere (GPP, RE, LUC): VISIT (Ito and Inatomi, 2012; Ito, 2019)
air-sea exchange: JMA air-sea flux data (Iida et al., 2015; Takatani et al., 2014)
https://www.data.jma.go.jp/gmd/kaiyou/english/co2_flux/co2_flux_data_en.html
biomass burning: GFEDv4.1s (van der Werf et al., 2017)
Note: For the years GFED does not cover (i.e., 1990-1996), the climatological data were used.

Analysis period

Jan 1990 – Dec 2020
(one year spin-up of Jan 1989 – Dec 1989 and three month spin-down of Jan 2021 – Mar 2021)

References

- Fujii, Y.: Preconditioned Optimizing Utility for Large-dimensional analyses (POpULar), J. Oceanogr., 61, 167–181, https://doi.org/10.1007/s10872-005-0029-z, 2005.
- Fujii, Y. and Kamachi, M.: A nonlinear preconditioned quasi-Newton method without inversion of a first-guess covariance matrix in variational analyses, Tellus A, 55, 450–454, https://doi.org/10.1034/j.1600-0870.2003.00030.x, 2003.
- Iida, Y., Kojima, A., Takatani, Y., Nakano, T., Sugimoto, H., Midorikawa, T., and Ishii, M.: Trends in pCO_2 and sea–air CO_2 flux over the global open oceans for the last two decades, J. Oceanogr., 71, https://doi.org/10.1007/s10872-015-0306-4, 2015.
- Ito, A.: Disequilibrium of terrestrial ecosystem CO_2 budget caused by disturbance-induced emissions and non-CO_2 carbon export flows: a global model assessment, Earth System Dynamics, 10, 685–709, https://doi.org/10.5194/esd-10-685-2019, 2019.
- Ito, A. and Inatomi, M.: Use of a process-based model for assessing the methane budgets of global terrestrial ecosystems and evaluation of uncertainty, Biogeosciences, 9, 759–773, https://doi.org/10.5194/bg-9-759-2012, 2012.
- Jones, M.W., Andrew, R.M., Peters, G.P., Janssens-Maenhout, G., De-Gol, A. J., Ciais, P., Patra, P. K., Chevallier, F., and Le Quéré, C.: Gridded fossil CO_2 emissions and related O_2 combustion consistent with national inventories 1959–2018, *Sci Data* 8, 2, https://doi.org/10.1038/s41597-020-00779-6, 2021.
- Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K. and Takahashi, K.: The JRA-55 Reanalysis: General Specifications and Basic Characteristics, J. Meteor. Soc. Japan, 93, 5–48, https://doi.org/10.2151/jmsj.2015-001, 2015.
- Niwa, Y., Tomita, H., Satoh, M., and Imasu, R.: A Three-Dimensional Icosahedral Grid Advection Scheme Preserving Monotonicity and Consistency with Continuity for Atmospheric Tracer Transport, J. Meteor. Soc. Japan, 89, 255–268, https://doi.org/10.2151/jmsj.2011- 306, 2011.
- Niwa, Y., Fujii, Y., Sawa, Y., Iida, Y., Ito, A., Satoh, M., Imasu, R., Tsuboi, K., Matsueda, H., and Saigusa, N.: A 4D-Var inversion system based on the icosahedral grid model (NICAM-TM 4D-Var v1.0) – Part 2: Optimization scheme and identical twin experiment of atmospheric CO_2 inversion, Geosci. Model Dev., 10, 2201–2219, https://doi.org/10.5194/gmd-10-2201-2017, 2017.
- Niwa, Y., Tomita, H., Satoh, M., Imasu, R., Sawa, Y., Tsuboi, K., Matsueda, H., Machida, T., Sasakawa, M., Belan, B., and Saigusa, N.: A 4D-Var inversion system based on the icosahedral grid model (NICAM-TM 4D-Var v1.0) – Part 1: Offline forward and adjoint transport models, Geosci. Model Dev., 10, 1157–1174, https://doi.org/10.5194/gmd-10-1157-2017, 2017.
- Takatani, Y., Enyo, K., Iida, Y., Kojima, A., Nakano, T., Sasano, D., Kosugi, N., Midorikawa, T., Suzuki, T., and Ishii, M.: Relationships between total alkalinity in surface water and sea surface dynamic height in the Pacific Ocean, J. Geophys. Res., 119, 2806–2814, https://doi.org/10.1002/2013jc009739, 2014.
- van der Werf, G. R., Randerson, J. T., Giglio, L., van Leeuwen, T. T., Chen, Y., Rogers, B. M., Mu, M., van Marle, M. J. E., Morton, D. C., Collatz, G. J., Yokelson, R. J., and Kasibhatla, P. S.:

Global fire emissions estimates during 1997–2016, Earth Syst. Sci. Data, 9, 697–720, https://doi.org/10.5194/essd-9-697-2017, 2017.

2. Main changes from NISMON-CO2 ver.2020.1

- Increased prior land/ocean uncertainties
  global total uncertainty: 1.0 => 2.1 Pg C yr^{-1} (land), ocean: 0.13 => 0.17 Pg C yr^{-1}

- Obs-model mismatch uncertainty
  Constant => depending on prior concentration variations

- Observations
  NOAA Tower sites, NIES Shipboard data, and other several sites are added

- Optimization
  Although the same resolution (~223km) was used for the transport simulations, the optimization was performed on 1x1 lat-lon grid dimension, instead of the model grid dimension (icosahedral grids).

3. Observations

See observation_list.ver.2021.1.csv.
Basically, all the ObsPack data (obspack_co2_1_GLOBALVIEWplus_v6.1_2021-03-01 & obspack_co2_1_NRT_v6.1.1_2021-05-17) (Schuldt et al., 2021a,b) provided from CSIRO, EC, Empa, FMI, IPEN, JMA, LSCE, NCAR, NIES, NILU, NIWA, NOAA, SIO, and TU/NIPR with obs_flag=1 were used. In addition, the NIES data, which are available from the NIES database NIES-GED, were also used.

References

- Schuldt, K. N., Multi-laboratory compilation of atmospheric carbon dioxide data for the period 1957-2019; obspack_co2_1_GLOBALVIEWplus_v6.1_2021-03-01; NOAA Global Monitoring Laboratory, http://doi.org/10.25925/20201204, 2021a.

- Schuldt, K. N., Multi-laboratory compilation of atmospheric carbon dioxide data for the period 2020-2021; obspack_co2_1_NRT_v6.1.1_2021-05-17; NOAA Earth System Research Laboratory, Global Monitoring Laboratory, http://doi.org/10.25925/20210517, 2021b.

4. Transport model performances

Advection scheme, radon simulation

- Niwa, Y., Tomita, H., Satoh, M., and Imasu, R.: A Three-Dimensional Icosahedral Grid Advection Scheme Preserving Monotonicity and Consistency with Continuity for Atmospheric Tracer Transport, J. Meteor. Soc. Japan, 89, 255–268, https://doi.org/10.2151/jmsj.2011- 306, 2011.

SF6 simulation

- Niwa, Y., Machida, T., Sawa, Y., Matsueda, H., Schuck, T. J., Brenninkmeijer, C. A. M., Imasu, R., and Satoh, M.: Imposing strong constraints on tropical terrestrial CO_2 fluxes using passenger aircraft based measurements, J. Geophys. Res., 117, https://doi.org/10.1029/2012JD017474, 2012.

Model intercomparison

- Patra, P. K., Law, R. M., Peters, W., Rödenbeck, C., Takigawa, M., Aulagnier, C., Baker, I., Bergmann, D. J., Bousquet, P., Brandt, J., Bruhwiler, L., Cameron-Smith, P. J., Christensen, J.

H., Delage, F., Denning, A. S., Fan, S., Geels, C., Houweling, S., Imasu, R., Karstens, U., Kawa, S. R., Kleist, J., Krol, M. C., Lin, S.-J., Lokupitiya, R., Maki, T., Maksyu- tov, S., Niwa, Y., Onishi, R., Parazoo, N., Pieterse, G., Rivier, L., Satoh, M., Serrar, S., Taguchi, S., Vautard, R., Vermeulen, A. T., and Zhu, Z.: TransCom model simulations of hourly atmospheric CO_2: Analysis of synoptic-scale variations for the period 2002–2003, Global Biogeochem. Cy., 22, doi:10.1029/2007GB003081, 2008.

- Law, R. M., Peters, W., Rödenbeck, C., Aulagnier, C., Baker, I., Bergmann, D. J., Bousquet, P., Brandt, J., Bruhwiler, L., Cameron-Smith, P. J., Christensen, J. H., Delage, F., Denning, A. S., Fan, S., Geels, C., Houweling, S., Imasu, R., Karstens, U., Kawa, S. R., Kleist, J., Krol, M. C., Lin, S.-J., Lokupitiya, R., Maki, T., Maksyutov, S., Niwa, Y., Onishi, R., Parazoo, N., Patra, P. K., Pieterse, G., Rivier, L., Satoh, M., Serrar, S., Taguchi, S., Takigawa, M., Vautard, R., Vermeulen, A. T., and Zhu, Z.: TransCom model simulations of hourly atmospheric CO_2: Experimental overview and diurnal cycle results for 2002, Global Biogeochem. Cy., 22, GB3009, doi:10.1029/2007GB003050, 2008.

- Niwa, Y., Patra, P. K., Sawa, Y., Machida, T., Matsueda, H., Belikov, D., Maki, T., Ikegami, M., Imasu, R., Maksyutov, S., Oda, T., Satoh, M., and Takigawa, M.: Three-dimensional variations of atmospheric CO_2: aircraft measurements and multi-transport model simulations, Atoms. Chem. Phys., 11, 13 359–13 375, https://doi.org/10.5194/acp-11-13359-2011, 2011.