Impacts of Wildfires on Boreal Forest Ecosystem Carbon Dynamics

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Summary

This dataset contains simulations of net primary production (NPP), heterotrophic respiration (RH), net ecosystem production (NEP), and soil temperature data in North American boreal forests for the period 1986-2020. Data sources included historical fire sources and Landsat data. The delta Normalized Burn Ratio (dNBR), which can be used to represent burn severity for a fire, was calculated for each individual fire over the time period. The interactions between canopy, fire and soil thermal dynamics were modelled using a soil surface energy balance model incorporated into a previous Terrestrial Ecosystem Model (TEM). Using the revised TEM, two regional simulations were conducted with and without fire disturbance. Fire polygons were dissected into each unit with unique fire history and then intersected with each grid cell to measure fire impacts. The output values for each grid cell are the area-weighted mean of each fire polygon and unburned area within the cell. Two extra simulations without a canopy energy balance scheme were also conducted to quantify the impact of the canopy. Soil temperature was simulated with and without the canopy energy balance scheme in the model in addition to considering fire impacts.

There are three files in comma separated values (CSV) format.

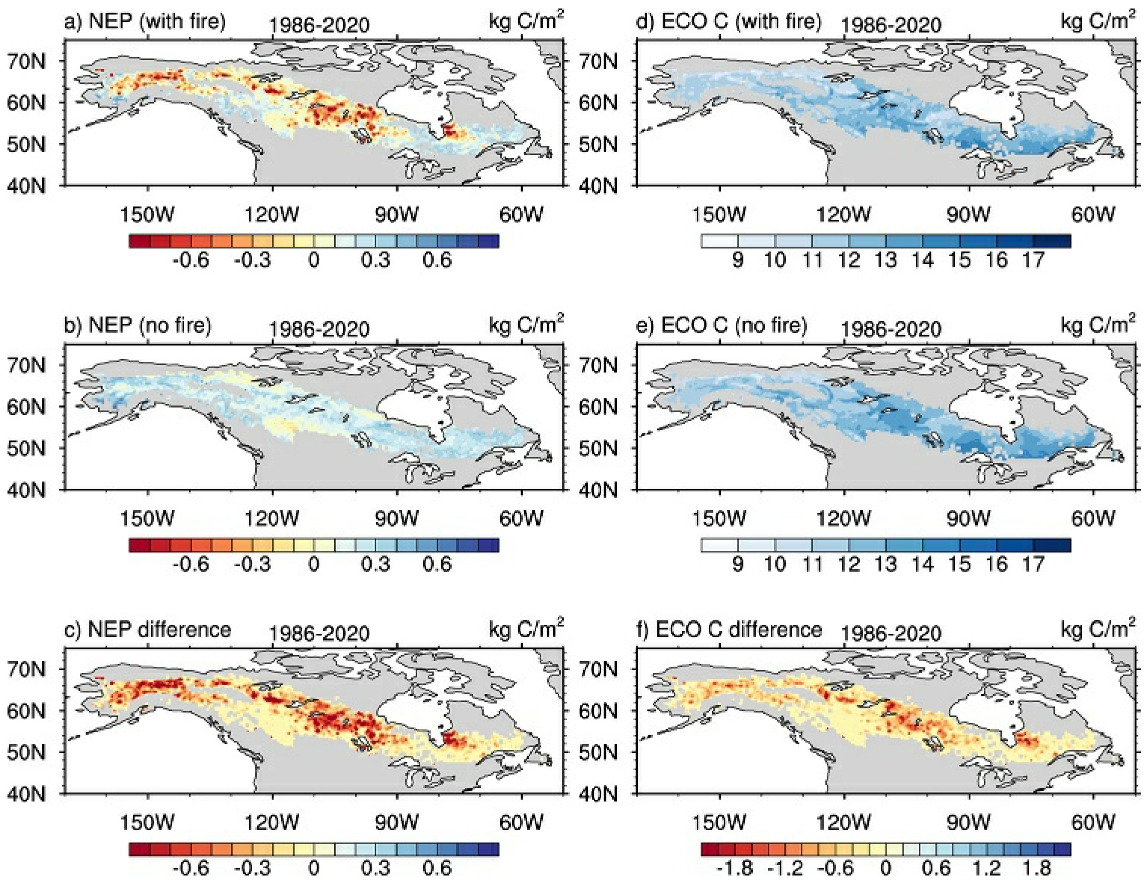

Figure 1. Spatial pattern of carbon dynamics during 1986-2020: (a) cumulative net ecosystem productivity (NEP) considering fires; (b) cumulative NEP without considering fires; (c) differences of NEP with and without considering fires (a minus b); (d) time-mean ecosystem carbon storage (vegetation carbon plus soil carbon) considering fires; (e) ecosystem carbon storage without considering fires; (f) differences of carbon storage with and without considering fires (d minus e).

Citation

Xu, Y., Q. Zhuang, B. Zhao, M. Billmire, C. Cook, J.A. Graham, N.H.F. French, and R. Prinn. 2024. Impacts of Wildfires on Boreal Forest Ecosystem

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1. Dataset Overview

This dataset contains simulations of net primary production (NPP), heterotrophic respiration (RH), net ecosystem production (NEP), and soil temperature data in North American boreal forests for the period 1986-2020. Data sources included historical fire sources and Landsat data. The delta Normalized Burn Ratio (dNBR), which can be used to represent burn severity for a fire, was calculated for each individual fire over the time period. The interactions between canopy, fire and soil thermal dynamics were modelled using a soil surface energy balance model (Xu and Zhuang, 2023) incorporated into a previous Terrestrial Ecosystem Model (TEM) (Zhao et al., 2021). Using the revised TEM, two regional simulations were conducted with and without fire disturbance. Fire polygons were dissected into each unit with unique fire history and then intersected with each grid cell to measure fire impacts. The output values for each grid cell are the area-weighted mean of each fire polygon and unburned area within the cell (Zhao et al., 2021). Two extra simulations without a canopy energy balance scheme were also conducted to quantify the impact of the canopy. Soil temperature was simulated with and without the canopy energy balance scheme in the model in addition to considering fire impacts.

This study uses a process-based biogeochemistry model to simulate the impacts of both fires and their induced changes in canopy on soil thermal and carbon dynamics in North American boreal forests during 1986-2020 based on satellite-derived burn severity data.

Project: North American Carbon Program

The North American Carbon Program (NACP) is a multidisciplinary research program designed to improve understanding of North America's carbon sources, sinks, and stocks. The central objective is to measure and understand the sources and sinks of Carbon Dioxide (CO2), Methane (CH4), and Carbon Monoxide (CO) in North America and adjacent oceans. The NACP is supported by a number of different federal agencies.

Related Publication

Xu, Y., Q. Zhuang, B. Zhao, M. Billmire, C. Cook, J. Graham, N.H. French, and R. Prinn. 2024. Impacts of wildfires on boreal forest ecosystem carbon dynamics from 1986 to 2020. Environmental Research Letters 19:064023. https://doi.org/10.1088/1748-9326/ad489a

Acknowledgement

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2. Data Characteristics

Spatial Coverage: North American boreal forests

Spatial Resolution: 0.5 degree x 0.5 degree

Temporal Coverage: 1986-01-01 to 2020-12-31

Temporal Resolution: Annual

Study Area: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Southwestern Alaska	-166.0	-53.0	70.0	43.5

Data File Information

There are three data files with this dataset in comma-separated values (.csv) format described below.

NPP_NEP_RH_Boreal_Ecosystems_FireConsidered.csv: Provides simulated net primary production (NPP), net ecosystem production (NEP), and heterotrophic respiration (RH) with fire disturbance considered and with and without the effect of the canopy.

NPP_NEP_RH_Boreal_Ecosystems_WithoutFire.csv: Provides simulated net primary production (NPP), net ecosystem production (NEP), and heterotrophic respiration (RH) without fire disturbance considered and with and without the effect of the canopy.

Soil_Temps_Boreal_Ecosystems.csv: Provides simulated soil temperatures at 5 and 20 cm depth with and without fire disturbance considered and with and without the effect of the canopy.

Table 1. Variables in *NPP_NEP_RH_Boreal_Ecosystems_FireConsidered.csv* and *NPP_NEP_RH_Boreal_Ecosystems_WithoutFire.csv*.

Variable	Units	Description
year	YYYY	Year
NPP	Tg y^{-1}	Net Primary Production (NPP) simulations without canopy's effect considered in teragrams of carbon per year (Tg C y^{-1})
NPP_canopy_effect	Tg y^{-1}	NPP simulations with canopy's effect considered in Tg C y^{-1}

RH	Tg y^{-1}	Heterotrophic respiration (RH) simulations without canopy's effect considered in Tg C y^{-1}
RH_canopy_effect	Tg y^{-1}	RH simulations with canopy's effect considered in Tg C y^{-1}
NEP	Tg y^{-1}	Net Ecosystem Production (NEP) simulations without canopy's effect considered in Tg C y^{-1}
NEP_canopy_effect	Tg y^{-1}	NEP simulations with canopy's effect considered in Tg C y^{-1}

Table 2. Variables in the file *Soil_Temps_Boreal_Ecosystems.csv*.

Variable	Units	Description
year	YYYY	The year of data
5cm_fire	degrees C	Simulated mean soil temperature at 5 cm depth, with fire simulation
20cm_fire	degrees C	Simulated mean soil temperature at 20 cm depth, with fire simulation
5cm_canopy	degrees C	Simulated mean soil temperature at 5 cm depth, with canopy's influence
20cm_canopy	degrees C	Simulated mean soil temperature at 20 cm depth, with canopy's influence

3. Application and Derivation

This study highlights the importance of considering burn severity and fire-induced canopy changes in regional carbon dynamics in boreal forests of North America.

4. Quality Assessment

Using delta Normalized Burn Ratio (dNBR) to represent burn severity to estimate fire impacts on carbon might have resulted in uncertainties of carbon dynamics since other factors such as moisture, elevation and time of burn are not considered in this study (Kasischke and Hoy, 2012; Tan et al., 2007; Zhao et al., 2021). Additionally, the relationship between dNBR and combustion proportion is established based on black spruce dominated forests while North American boreal forests also include white spruce or pines and other forest types. This might bias burn severity estimations.

The model was originally calibrated with field data from forests in Alaska. It might also induce uncertainties when the parameters are applied to boreal forests across the whole of North America (Zhao et al., 2021).

5. Data Acquisition, Materials, and Methods

Historical fire burn areas were retrieved from 1986 to 2020 for 45 degrees latitude northward in North America, based on the data from the Bureau of Land Management (BLM) and Alaska Fire Service Alaska Interagency Coordination Center (AICC), the Canadian National Fire Database (CNFDB), and the United States Geological Survey (USGS) combined wildfire dataset (Welty and Jeffries, 2020). The Alaska, Canada, and contiguous U.S. perimeters were created by their respective agencies through a combination of methods over the period of interest, with older fires (pre-Landsat) typically requiring field data and aerial imagery, and more recent fires being satellite-derived. All fire perimeters were standardized through a series of sequential dissolves to fix issues regarding fire ID uniquity using GIS-based tools available in QGIS or ArcGIS Pro. Fire perimeters were then simplified to a 60-meter resolution to improve run time of subsequent processing steps.

A Google Earth Engine (GEE) script was developed to calculate a pre- and post- Normalized Burn Ratio (NBR) value (Miller and Thode, 2007) from within each perimeter, as well as from within a 300-m buffer ring offset 1.5 km from the perimeter. Because Landsat Collection 2 was not yet available on GEE at time of analysis, data were sourced from Landsat Collection 1. Use of Landsat Collection 2 GEE product in a future data product release should provide image calibration and other improvements relative to Collection 1 (Crawford et al., 2023). Landsat sensors 4-8 were used after applying a cloud, cloud shadow, snow, and water mask. Normalized burn ratio (NBR) for each fire was calculated as the ratio between the near infrared (NIR) and short-wave infrared (SWIR) bands for the available Landsat mission.

Pre-fire data use the median pixel values of the image collection, with images filtered to the approximate snow-free fire season of June 15 to September 15, from the two years before the fire. Post-fire data use the median pixel values from the image collection June 15 to September 15 the year following the fire. The median pixel values from within the perimeter and buffer ring averaged to create a pre-fire NBR and post-fire NBR for each perimeter and buffer ring. These NBR values were written out of GEE along with each unique fire ID. Methods in the GEE code for masking and pooling the Landsat 4-8 data were sourced from Holsinger et al. (2021).

The values in the buffer ring are used to correct for differences between the imagery not related to the fire (e.g., phenology, plant health), as this land area is assumed to have not burned. One caveat is that in some areas that had nearby fires within the same year, there may be some overlap between the buffer ring and another fire perimeter; however, these cases are uncommon. The difference between the pre-fire NBR and the post-fire NBR is known as the delta NBR (dNBR) and can be used to represent burn severity for a fire.

In addition to calculating dNBR for each individual fire over 1986-2020, data were aggregated at a $0.5^{\circ} \times 0.5^{\circ}$-grid cell for each year in order to incorporate these data into Terrestrial Ecosystem Model (TEM) simulations.

Model description

The Terrestrial Ecosystem Model is a process-based biogeochemical model (Zhuang et al., 2002) that quantifies carbon and nitrogen dynamics in terrestrial ecosystems. TEM has been used to simulate fire disturbance impacts on carbon dynamics in North America (Zhuang et al., 2002; Zhao et al., 2021). In addition to the direct combustion emission, TEM can also estimate carbon dynamics during post-fire recovery (Zhao et al., 2021). In this study, a surface energy balance scheme was incorporated into TEM by considering the influences of plant canopy on soil surface temperature. The model is then used to evaluate the impacts of fire disturbance on regional carbon dynamics.

The calculated dNBR, representing burn severity for fires, is used to estimate the proportion of vegetation and soil carbon consumption in TEM. In the model, fires remove vegetation and soil carbon based on the burn severity (Zhuang et al., 2002; Zhao et al., 2021). Fires with greater burn severity remove more carbon and nitrogen from the ecosystem. Following fire, soil organic carbon composition can vary more drastically than vegetation carbon due to reduction in litterfall while the vegetation recovers. This reduced vegetation carbon and soil nitrogen storage results in lower ecosystem production during the recovery phase. In addition, fires impact soil thermal dynamics (i.e., soil temperature), together with the canopy's influence on soils, further changing carbon and nitrogen dynamics, such as RH and vegetation nitrogen uptake.

Regional input data and simulation protocols

Data required to drive TEM (not included in this dataset) includes monthly mean surface air temperature, cloudiness, precipitation, vapor pressure, and surface wind speed, which are from ERA5 from 1986 to 2020 (Hersbach et al., 2020). Spatially-explicit soil texture (percentage of silt, clay and sand), elevation, plant function types and annual CO_2 concentrations of the atmosphere are also used (Melillo et al., 1993; Zhuang et al., 2002). The model is spun-up for 120 years before 1986 with cyclic climate data from 1986 to 2000 to achieve an equilibrium state. Then transient simulations from 1986 to 2020 are conducted for each grid cell at a spatial resolution of $0.5^{o} \times 0.5^{o}$ for the North American boreal forests.

Two regional simulations were conducted, with and without fire disturbance considered, respectively. Fire polygons are dissected into each unit with unique fire history and then intersected with each grid cell when considering fire impacts. The output values for each grid cell are area-weighted mean of each fire polygon and no- burn area within the cell (Zhao et al., 2021). An extra simulation with fire considered but without a canopy energy balance scheme is also conducted for quantifying the impact of the canopy.

Impacts of fire-induced canopy changes on soil thermal regime and carbon dynamics

The fire-induced changes in canopy can significantly influence ecosystem carbon dynamics (Martin Belda et al., 2022; von Oppen et al., 2022; Xu and Zhuang, 2023). Soil temperature was simulated with and without the canopy energy balance scheme in the model in addition to considering fire impacts.

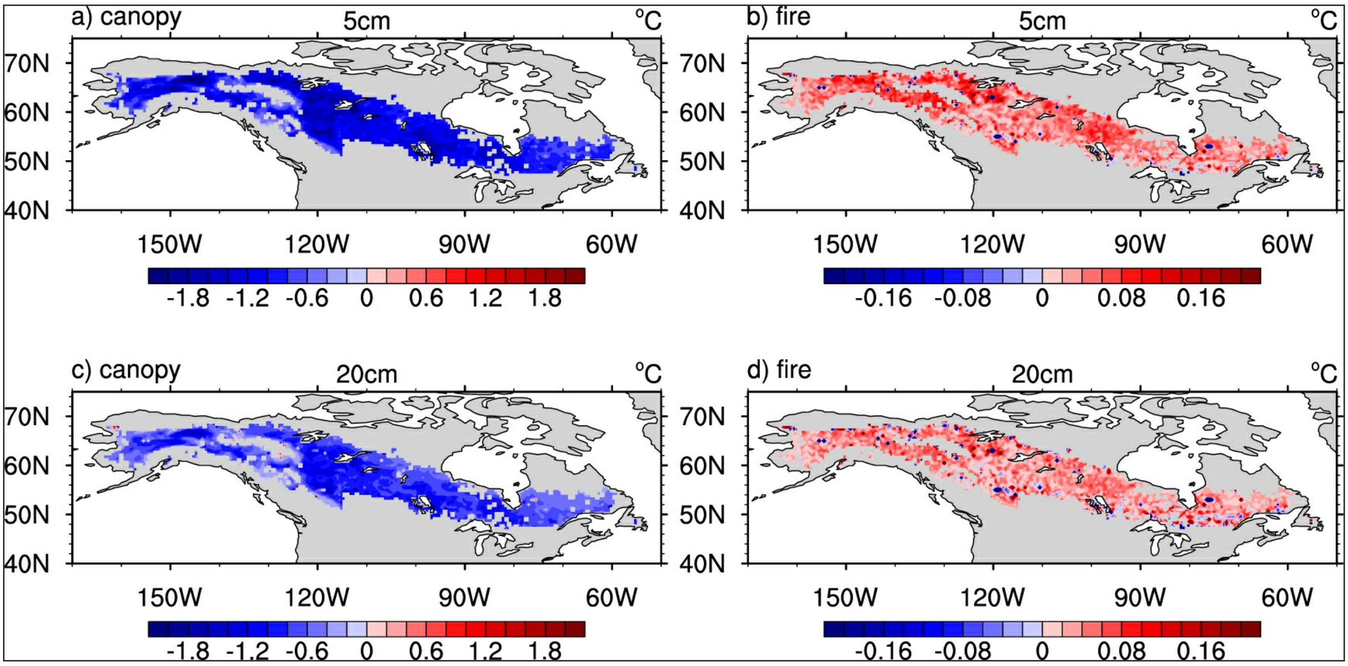

Figure 2. Differences of the simulated mean soil temperature with and without canopy's influence in July (with canopy simulation minus without canopy simulation) and fire (with fire simulation minus without fire simulation) at 5cm depth (a, b) and 20cm depth (c, d) from 1986 to 2020.

Refer to Xu et al. (2024) for additional details.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Impacts of Wildfires on Boreal Forest Ecosystem Carbon Dynamics

Contact for Data Center Access Information:

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7. References

Crawford, C.J., D.P. Roy, S. Arab, C. Barnes, E. Vermote, G. Hulley, A. Gerace, M. Choate, C. Engebretson, E. Micijevic, G. Schmidt, C. Anderson, M. Anderson, M. Bouchard, B. Cook, R. Dittmeier, D. Howard, C. Jenkerson, M. Kim, T. Kleyians, T. Maiersperger, C. Mueller, C. Neigh, L. Owen, B. Page, N. Pahlevan, R. Rengarajan, J.-C. Roger, K. Sayler, P. Scaramuzza, S. Skakun, L. Yan, H.K. Zhang, Z. Zhu, and S. Zahn. 2023. The 50-year Landsat collection 2 archive. Science of Remote Sensing 8:100103. https://doi.org/10.1016/j.srs.2023.100103

Hersbach, H., B. Bell, P. Berrisford, S. Hirahara, A. Horányi, J. Muñoz-Sabater, J. Nicolas, C. Peubey, R. Radu, D. Schepers, A. Simmons, C. Soci, S. Abdalla, X. Abellan, G. Balsamo, P. Bechtold, G. Biavati, J. Bidlot, M. Bonavita, G. De Chiara, P. Dahlgren, D. Dee, M. Diamantakis, R. Dragani, J. Flemming, R. Forbes, M. Fuentes, A. Geer, L. Haimberger, S. Healy, R.J. Hogan, E. Hólm, M. Janisková, S. Keeley, P. Laloyaux, P. Lopez, C. Lupu, G. Radnoti, P. de Rosnay, I. Rozum, F. Vamborg, S. Villaume, and J. Thépaut. 2020. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society 146:1999–2049. https://doi.org/10.1002/qj.3803

Holsinger, L.M., S.A. Parks, L.B. Saperstein, R.A. Loehman, E. Whitman, J. Barnes, and M. Parisien. 2021. Improved fire severity mapping in the North American boreal forest using a hybrid composite method. Remote Sensing in Ecology and Conservation 8:222–235. https://doi.org/10.1002/rse2.238

Kasischke, E.S., and E.E. Hoy. 2011. Controls on carbon consumption during Alaskan wildland fires. Global Change Biology 18:685–699. https://doi.org/10.1111/j.1365-2486.2011.02573.x

Loboda, T.V., D. Chen, J.V. Hall, and J. He. 2018. ABoVE: Landsat-derived Burn Scar dNBR across Alaska and Canada, 1985-2015. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1564

Martín Belda, D., P. Anthoni, D. Wårlind, S. Olin, G. Schurgers, J. Tang, B. Smith, and A. Arneth. 2022. LPJ-GUESS/LSMv1.0: a next-generation land surface model with high ecological realism. Geoscientific Model Development 15:6709–6745. https://doi.org/10.5194/gmd-15-6709-2022

Melillo, J.M., A.D. McGuire, D.W. Kicklighter, B. Moore, C.J. Vorosmarty, and A.L. Schloss. 1993. Global climate change and terrestrial net primary production. Nature 363:234–240. https://doi.org/10.1038/363234a0

Tan, Z., L.L. Tieszen, Z. Zhu, S. Liu, and S.M. Howard. 2007. An estimate of carbon emissions from 2004 wildfires across Alaskan Yukon River Basin. Carbon Balance and Management 2. https://doi.org/10.1186/1750-0680-2-12

von Oppen, J., J.J. Assmann, A.D. Bjorkman, U.A. Treier, B. Elberling, J. Nabe-Nielsen, and S. Normand. 2022. Cross-scale regulation of seasonal microclimate by vegetation and snow in the Arctic tundra. Global Change Biology 28:7296–7312. https://doi.org/10.1111/gcb.16426

Welty, J.L., and M.I. Jeffries. 2020. Combined wildfire datasets for the United States and certain territories, 1878-2019. U.S. Geological Survey. https://doi.org/10.5066/P9Z2VVRT

Xu, Y., Q. Zhuang, B. Zhao, M. Billmire, C. Cook, J. Graham, N.H. French, and R. Prinn. 2024. Impacts of wildfires on boreal forest ecosystem carbon dynamics from 1986 to 2020. Environmental Research Letters 19:064023. https://doi.org/10.1088/1748-9326/ad489a

Xu, Y., and Q. Zhuang. 2023. The importance of interactions between snow, permafrost and vegetation dynamics in affecting terrestrial carbon balance in circumpolar regions. Environmental Research Letters 18:044007. https://doi.org/10.1088/1748-9326/acc1f7

Zhuang, Q., A.D. Mcguire, K.P. O'Neill, J.W. Harden, V.E. Romanovsky, and J. Yarie. 2002. Modeling soil thermal and carbon dynamics of a fire chronosequence in interior Alaska. Journal of Geophysical Research Atmospheres 107:FFR 3-1-FFR 3-26. https:/doi.org/10.1029/2001JD001244

Zhao, B., Q. Zhuang, N. Shurpali, K. Köster, F. Berninger, and J. Pumpanen. 2021. North American boreal forests are a large carbon source due to wildfires from 1986 to 2016. Scientific Reports 11:7723. https://doi.org/10.1038/s41598-021-87343-3