Comments from Public Consultation on ECV Requirements 13/01 – 13/03 2020 for:

# Precursors for Aerosols and Ozone

## ECV Product: CO Total Column e

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | CO Total Column | | | | |
| **Definition** | 2D field of total amount of CO molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 |  |
| B | 30 |
| T | 200 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.02 |  |
| B | 1 |
| T | 7 |
| **Timeliness** | year |  | G | 0.01 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G |  | number of CO molecules per unit area |
| B |  |
| T |  |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
| --- | --- |
| Author: MRI Scnatweb | Email: mountainresearchinitiative@gmail.com |
| Important for gas and aerosol transport in mountain areas, but remote sensing or modelling cannot reproduce local aspects to important in mountain context. Network of in situ measurements needed to provide adequate spatial resolution.  Based on discussions and preliminary outcomes of the GEO GNOME workshop for identifying ECVs to monitor and understand mountain climate change. More information on the workshop here: LINK. | |

## ECV Product: CO Mole fraction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | CO Mole fraction | | | | |
| **Definition** | 3D field of amount of CO (Carbon monoxide, expressed in moles) divided by the total amount of all constituents in dry air (also expressed in moles) | | | | |
| **Unit** | ppb | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 200 |  |
| B | 1000 |
| T | 10000 |
| **Vertical Resolution** | m |  | G | 25 |  |
| B | 100 |
| T | 1000 |
| **Temporal Resolution** | days |  | G | 0.04 |  |
| B | 1 |
| T | 7 |
| **Timeliness** | year |  | G | 0.01 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | ppb |  | G | 2 | number of CO molecules per unit area |
| B | 5 |
| T | 10 |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
| --- | --- |
| Author: Martin Steinbacher | Email: martin.stonycreek@gmail.com |
| Required Measurement Uncertainty - Goal and Breakthrough: G = 2 ppb, B = 5 ppb, add reference to GAW report #242 as it is done for CO2, CH4 and N2O mole fraction | |

## ECV Product: CO Total Column

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Name** | CO Total Column | | | | | | **Definition** | 2D field of total amount of CO molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | | | **Unit** | Molecules/cm2 | | | | | | **Note** |  | | | | | | **Requirements** | | | | | | | **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** | | **Horizontal Resolution** | km |  | G | 10 |  | | B | 30 | | T | 200 | | **Vertical Resolution** | N/A |  | G |  | Column Integrated | | B |  | | T |  | | **Temporal Resolution** | days |  | G | 0.02 |  | | B | 1 | | T | 7 | | **Timeliness** | year |  | G | 0.01 |  | | B | 0.5 |  | | T | 1 |  | | **Required Measurement Uncertainty** | Molecules/cm2 |  | G |  | number of CO molecules per unit area | | B |  | | T |  | | **Stability** | Molecules/cm2 /decade |  | G |  |  | | B |  | | T |  | | **Standards and References** |  | | | | | | **Adaptation and Extremes** | | | | | | |  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | | | **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | | | **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |     [1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)  [2] Is the ECV Product directly relevant to support Climate Adaptation?  [3] Can the ECV Product be used to monitor climate extremes or aspects of extremes? | | | | |
| **Definition** | 2D field of total amount of CO molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 |  |
| B | 30 |
| T | 200 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.02 |  |
| B | 1 |
| T | 7 |
| **Timeliness** | year |  | G | 0.01 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G |  | number of CO molecules per unit area |
| B |  |
| T |  |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

NO COMMENT

## ECV Product: HCHO Total Column

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | HCHO Total Column | | | | |
| **Definition** | 2D field of total amount of HCHO molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 |  |
| B | 30 |
| T | 200 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.02 |  |
| B | 1 |
| T | 1 |
| **Timeliness** | year |  | G | 0.01 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G | max(5x10^15, 10%) | number of HCHO molecules per unit area |
| B | max(1x10^16, 20%) |
| T | max(2x10^16, 50%) |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
| --- | --- |
| Author: Paul Wennberg and Josh Laughner | Email: Click here to enter text. |
| Temporal resolution:  Currently data with a temporal resolution of one day is available, but is not useful due to large random uncertainties due to low signal-to-noise, which necessitate averaging ~ one month of data to achieve useful uncertainty.  Unclear if the "temporal frequency" line in the ECV document is the frequency of the physical measurement or of the "logical" (i.e. useful) measurement. | |

### Comment 2

|  |  |
| --- | --- |
| Author: Glenn M. Wolfe | Email: Click here to enter text. |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | HCHO Total Column | | | | |
| **Definition** | 2D field of total amount of HCHO molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 | (T) The threshold value is based on recent model-based inversions of HCHO columns to infer hydrocarbon emissions, which are nominally at a geospatial resolution of ~0.5 degrees (Chaliyakunnel et al., 2019; Kaiser et al., 2018; Stavrakou et al., 2018).  (B) The breakthrough value is based on the fact that most HCHO in the atmosphere is produced and lost via chemistry (rather than directly emitted). A reasonable lower limit for the HCHO lifetime due to oxidation and photolysis is ~2 hours. For a nominal lower-limit wind speed of ~4 m/s, the expected e-fold timescale for HCHO to approach chemical steady state is 2h x 4 m/s x 3600 s/h \* 0.001 km/m = 29 km.  (G) The goal value would be sufficient to observe fine-scale horizontal structure in emission regions (such as cities) without oversampling (Zhu et al., 2014), assuming the goal uncertainty was also achieved. |
| B | 30 |
| T | 100 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.04 | (T) The minimum sampling resolution required to obtain statistically-meaningful averages, given the need for cloud-filtering and typically large random uncertainties. (B) The timescale over which it would be possible to observed diurnal variability in concentrations (morning, midday, afternoon). (G) The timescales over which it would be possible to observe small-scale variability due to changes in emissions (e.g., wildfires, traffic conditions). |
| B | 0.2 |
| T | 1 |
| **Timeliness** | year |  | G | 0.02 | (T) Sufficient for climate monitoring. (B) Permits timely analysis of seasonal phenomena. (C) Allows for rapid analysis of extreme events, such as wildfires. |
| B | 0.1 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G | max(5x10^15, 10%) | Typical atmospheric column concentrations for HCHO range from 1 - 40 x 1015 molecules cm-2. (T) is based on current uncertainties in hydrocarbon emission inventories (Cao et al., 2018; Kaiser et al., 2018). (B) is based on typical variability over continental regions (Zhu et al., 2016). (G) is based on variability in the remote atmosphere (Wolfe et al., 2019).  The specification of requirements for uncertainty ranges is somewhat misleading in the case of HCHO, as much of the uncertainty is random (e.g. fitting errors) and is rapidly reduced with signal averaging (Smedt et al., 2018). |
| B | max(1x10^16, 20%) |
| T | max(2x10^16, 50%) |
| **Stability** | % of annual mean |  | G | 1 | Stability requirements are based on (T) strong, (B) moderate, and (G) weak trends as recently reported in the literature (Stavrakou et al., 2018). |
| B | 3 |
| T | 6 |
| **Standards and References** | Typical scientific uses for total-column HCHO include 1) evaluation of hydrocarbon emission inventories (Chaliyakunnel et al., 2019; Kaiser et al., 2018; Stavrakou et al., 2018); 2) assessment of near-surface ozone production via ratios with tropospheric total-column NO2 (Jin et al., 2017); and 3) constraining atmospheric oxidizing capacity (Wolfe et al., 2019). Measurement requirements are defined within this context. Requirements refer to native instrument performance (e.g., pixel-level (L2) information). In most applications, data are averaged spatially and/or temporally to obtain useful L3 or L4 products. | | | | |

|  |  |  |  |
| --- | --- | --- | --- |
| References  Cao, H., Fu, T.-M., Zhang, L., Henze, D. K., Miller, C. C., Lerot, C., Abad, G. G., De Smedt, I., Zhang, Q., van Roozendael, M., Hendrick, F., Chance, K., Li, J., Zheng, J. and Zhao, Y.: Adjoint inversion of Chinese non-methane volatile organic compound emissions using space-based observations of formaldehyde and glyoxal, Atmos. Chem. Phys., 18(20), 15017–15046, doi:10.5194/acp-18-15017-2018, 2018.  Chaliyakunnel, S., Millet, D. B. and Chen, X.: Constraining Emissions of Volatile Organic Compounds Over the Indian Subcontinent Using Space-Based Formaldehyde Measurements, J. Geophys. Res. Atmos., 124(19), 10525–10545, doi:10.1029/2019JD031262, 2019.  Jin, X., Fiore, A. M., Murray, L. T., Valin, L. C., Lamsal, L. N., Duncan, B., Folkert Boersma, K., De Smedt, I., Abad, G. G., Chance, K. and Tonnesen, G. S.: Evaluating a Space-Based Indicator of Surface Ozone-NOx-VOC Sensitivity Over Midlatitude Source Regions and Application to Decadal Trends, J. Geophys. Res. Atmos., 122(19), 10,410-439,461, doi:doi:10.1002/2017JD026720, 2017.  Kaiser, J., Jacob, D. J., Zhu, L., Travis, K. R., Fisher, J. A., Abad, G. G., Zhang, L., Zhang, X. S., Fried, A., Crounse, J. D., St Clair, J. M. and Wisthaler, A.: High-resolution inversion of OMI formaldehyde columns to quantify isoprene emission on ecosystem-relevant scales: application to the southeast US, Atmos. Chem. Phys., 18(8), 5483–5497, doi:10.5194/acp-18-5483-2018, 2018.  Smedt, I. De, Theys, N., Yu, H., Danckaert, T., Lerot, C., Compernolle, S., Roozendael, M. Van, Richter, A., Hilboll, A., Peters, E., Pedergnana, M., Loyola, D., Beirle, S., Wagner, T., Eskes, H., Geffen, J. Van, Boersma, K. F., Veefkind, P., De Smedt, I., Theys, N., Yu, H., Danckaert, T., Lerot, C., Compernolle, S., Van Roozendael, M., Richter, A., Hilboll, A., Peters, E., Pedergnana, M., Loyola, D., Beirle, S., Wagner, T., Eskes, H., van Geffen, J., Boersma, K. F. and Veefkind, P.: Algorithm theoretical baseline for formaldehyde retrievals from S5P TROPOMI and from the QA4ECV project, Atmos. Meas. Tech., 11(4), 2395–2426, doi:10.5194/amt-11-2395-2018, 2018.  Stavrakou, T., Müller, J.-F., Bauwens, M., De Smedt, I., Van Roozendael, M. and Guenther, A.: Impact of Short-Term Climate Variability on Volatile Organic Compounds Emissions Assessed Using OMI Satellite Formaldehyde Observations, Geophys. Res. Lett., 45(16), 8681–8689, doi:10.1029/2018GL078676, 2018.  Wolfe, G. M., Nicely, J. M., St. Clair, J. M., Hanisco, T. F., Liao, J., Oman, L. D., Brune, W. B., Miller, D., Thames, A., González Abad, G., Ryerson, T. B., Thompson, C. R., Peischl, J., McCain, K., Sweeney, C., Wennberg, P. O., Kim, M., Crounse, J. D., Hall, S. R., Ullmann, K., Diskin, G., Bui, P., Chang, C. and Dean-Day, J.: Mapping hydroxyl variability throughout the global remote troposphere via synthesis of airborne and satellite formaldehyde observations, Proc. Natl. Acad. Sci., 116(23), 11171 – 11180, doi:10.1073/pnas.1821661116, 2019.  Zhu, L., Jacob, D. J., Mickley, L. J., Marais, E. A. E. A., Cohan, D. S., Yoshida, Y., Duncan, B. N., Abad, G. G. and Chance, K. V: Anthropogenic emissions of highly reactive volatile organic compounds in eastern Texas inferred from oversampling of satellite (OMI) measurements of HCHO columns, Environ. Res. Lett., 9(11), doi:10.1088/1748-9326/9/11/114004, 2014.  Zhu, L., Jacob, D. J., Kim, P. S., Fisher, J. A., Yu, K., Travis, K. R., Mickley, L. J., Yantosca, R. M., Sulprizio, M. P., Smedt, I. De, Gonzalez, G., Chance, K., Li, C., Ferrare, R., Fried, A., Hair, J. W., Thomsa, F., Richter, D., Scarino, A. J., Walega, J., Weibring, P. and Wolfe, G. M.: Observing atmospheric formaldehyde ( HCHO ) from space : validation and intercomparison of six retrievals from four satellites ( OMI , GOME2A , GOME2B , OMPS ) with SEAC 4 RS aircraft observations over the Southeast US, , (March), 1–24, doi:10.5194/acp-2016-162, 2016. | | | |
|  | | | |
| **Adaptation and Extremes** | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

## ECV Product: SO2 Total Column

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | SO2Total Column | | | | |
| **Definition** | 2D field of total amount of SO2 molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 |  |
| B | 30 |
| T | 200 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.02 |  |
| B | 1 |
| T | 7 |
| **Timeliness** | year |  | G | 0.01 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G | max(1x10^16, 10%) | number of SO2 molecules per unit area |
| B | max(2x10^16, 20%) |
| T | max(3x10^16, 50%) |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

NO COMMENT

## ECV Product: NO2 Total Column

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | NO2 Total Column | | | | |
| **Definition** | 2D field of total amount of NO2 molecules per unit area in an atmospheric column extending from the Earth’s surface to the upper edge of the atmosphere | | | | |
| **Unit** | Molecules/cm2 - | | | | |
| **Note** |  | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km |  | G | 10 |  |
| B | 30 |
| T | 200 |
| **Vertical Resolution** | N/A |  | G |  | Column Integrated |
| B |  |
| T |  |
| **Temporal Resolution** | days |  | G | 0.02 |  |
| B | 1 |
| T | 7 |
| **Timeliness** | year |  | G | 0.02 |  |
| B | 0.5 |  |
| T | 1 |  |
| **Required Measurement Uncertainty** | Molecules/cm2 |  | G | 10% | number of NO2 molecules per unit area |
| B | 20% |
| T | 50% |
| **Stability** | Molecules/cm2 /decade |  | G |  |  |
| B |  |
| T |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** |  |  | Reviewers are invited to suggest answers for these fields | | |
| **Extremes[3]** |  |  | Reviewers are invited to suggest answers for these fields | | |

[1]Goal (G); Breakthrough (B) (not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
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| Author: Paul Wennberg and Josh Laughner. | Email: Click here to enter text. |
| NO2  Use NO2 tropospheric, not total, columns  • Far from sources, the stratosphere makes up 90% of the total column (Krotkov et al., 2017)  • Even just the free tropospheric background column can complicate interpretation of NOx emission trends (Silvern et al., 2019)  • Therefore, avoiding the additional background column of the stratosphere will improve estimates of tropospheric processes.  – The standard NO2 retrievals (Krotkov et al., 2017; Zara et al., 2018) have well established and independent methods to remove the stratospheric column (see Bucsela et al. 2013 and Boersma et al. 2011, respectively).  – Because these methods are established and verified, and especially as the two methods are independent and can be compared to estimate uncertainty, using the tropospheric columns produced by these methods simplifies studies looking at tropospheric processes, since individual studies will not need to implement their own approaches to estimating the stratospheric background.  • Tropospheric columns have been used in numerous studies to constrain anthropogenic (e.g. Lu et al., 2015; Miyazaki et al., 2012, 2017; Russell et al., 2012) and natural NOx emissions (Hudman et al., 2012; Huijnen et al., 2012; Martin et al., 2007; Mebust and Cohen, 2014; Nault et al., 2017; Pickering et al., 2016; van Marle et al., 2017; van der A et al., 2008; Z¨orner et al., 2016) and lifetime (e.g. Beirle et al., 2011; Laughner and Cohen, 2019; Liu et al., 2016, 2017; Valin et al., 2013)  • Additionally, the interpretation of the tropospheric component of the column (par- ticularly in the conversion from slant to vertical columns, of which the latter more naturally compare with other observations and models) is particularly sensitive to the a priori information.  – Because NO2 has strong spatial gradients near sources, increasing the resolution of the a priori NO2 profile from 100s of kilometers (i.e. 1° to 2°) to of order 10 kilometers can increase the retrieved NO2 by as much as a factor of two (e.g. McLinden et al., 2014; Laughner et al., 2016)  – Until computing power makes 10 km global CTMs practical, such profiles will need to be simulated in region CTMs, such as WRF-Chem or CMAQ, which focus on tropospheric processes.  NO2 uncertainty  • Uncertainty in tropospheric NO2 columns typically arises from three sources (Boersma et al., 2004):    1. The spectral fitting, which yields slant columns  2. The tropospheric-stratospheric separation  3. The air mass factor (AMF) calculation which converts slant columns to vertical columns  • #1 and #2 typically do not depend on the SCD magnitude (Zara et al., 2018; Bucsela et al., 2013) while #3 does, since the AMF is a multiplicative factor. Therefore, relative or absolute uncertainty may both dominate, depending on the conditions.  • Uncertainty limits should be given both as an absolute and relative threshold to avoid underestimating the uncertainty requirement. Recommendations:  – Threshold: max(40%, 1 × 1015 molec. cm−2).  ∗ This level of uncertainty is typically calculated for current retrievals (Boersma et al., 2004, 2011; Bucsela et al., 2013; Lorente et al., 2017; Zara et al., 2018) which have already been effective at constraining climate-relevant variables.  – Breakthrough: max(< 30%, 5 × 1014 molec. cm−2):  ∗ Understanding the effect of NOx on climate in the future is going to demand understanding the chemistry in remote areas as NOx levels reduce enabling greater formation of alkyl nitrates (ANs)  ∗ Browne and Cohen (2012) show formation of ANs varies with changes in NOx concentration of order 50 pptv in the boundary layer. For changes of this magnitude, we expect the absolute error to dominate (Boersma et al., 2018).  ∗ Assuming a 50 pptv background concentration (SEAC4RS campaign, Silvern et al., 2019), a typical remote NO2 column is ≈ 8 × 1014 molec. cm−2. A change of 50 pptv NO2 in a 1 km boundary layer 1 1014 molec. cm−2 in the tropospheric column.  ∗ Assuming error reduces by √n and no data lost to clouds or other screening  concerns, resolving changes at this level with 30 days of observations requires an absolute error of ∼ 5 × 1014 molec. cm−2  ∗ In polluted areas, the relative error tends to dominate.  ∗ Currently, uncertainties in NOx emission inventories are of order 30–40% (Kurokawa et al., 2013; Travis et al., 2016; Zhang et al., 2009; Zhao et al., 2011).  ∗ Errors in assimilated retrievals of 40% lead to uncertainties in posterior emissions of 5–45% (Miyazaki et al., 2012, 2017).  ∗ Therefore, pushing relative uncertainties below 30% will help improve un- certainty in emissions.  • Goal: 5 × 1013 molec. cm−2  – Following the logic for the breakthrough criterion, to measure changes in remote areas of order 1 1014 molec. cm−2 with single measurements at S/N = 2 requires this absolute precision.    – At this level, relative errors due to the AMF are small compared to the absolute errors from spectral fitting and stratospheric separation (Boersma et al., 2018), so a relative criterion does not make sense.  Stability  • Jiang et al. (2018) report United States NO2 trends of −7 %/yr before 2010; Lu et al. (2015) report United States NO2 trends of 7 %/yr for 2005 to 2014 under slow wind conditions (which would tend to lessen the effect of changing lifetime)  • Curier et al. (2014) report −5 %/yr to −6 %/yr in Europe  • Qu et al. (2019) report ∼4 %/yr for China  • A 4 %/yr trend = 40 %/decade.  • In Jiang et al. (2018), the difference between the bottom-up and top-down emissions was 20% by the end of the record. Distinguishing which inventory is correct would require knowing the trends to better than 10% to avoid overlapping uncertainties. Therefore I’d recommend a stability requirement of 0.1 × 40 %/decade = 4 %/decade  Reference  • NO2 columns are not tied back to a single reference standard the same way XCO2 is  • The usual approach is to validate NO2 columns against either ground based column measurements (i.e. Pandora) or integrated aircraft columns  – Validation against aircraft: Bucsela et al. (2008); Hains et al. (2010); Lamsal et al. (2014); Laughner et al. (2019); Russell et al. (2011)  – Validation against Pandora: Goldberg et al. (2017); Ialongo et al. (2016); Krotkov et al. (2017); Laughner et al. (2019)  • Both approaches have limitations  – Aircraft profiles usually miss the bottom 500 m to 1000 m due to flight altitude restrictions and may miss a significant part of the top of the profile depending on the operational ceiling.  – Aircraft profiles from campaigns not geared for satellite validation will have pro- files taken in a straight line, not a spiral, so the horizontal extent of the profile is large and a decision must be made about how to match it up to pixels.  – Ground based column measurements report total, not tropospheric, column, so accounting for the stratosphere when comparing tropospheric retrievals means the stratospheric error can’t be readily quantified.    – The averaging kernel will differ between the ground and satellite column, but often it is assumed that the vertical columns are directly comparable (i.e. the air mass factor corrects for the sensitivity). Also I believe the ground-based NO2 column retrievals may just use a geometric AMF (assume no altitude/profile dependence) but I remember that detail being difficult to find in the literature.  HCHO  Temporal resolution  • Currently data with a temporal resolution of one day is available, but is not useful due to large random uncertainties due to low signal-to-noise, which necessitate averaging  ∼ one month of data to achieve useful uncertainty.  • Unclear if the “temporal frequency” line in the ECV document is the frequency of the physical measurement or of the “logical” (i.e. useful) measurement.  Appendix - Calculations  Remote NO2 columns  Assume a 12 km troposphere with scale height (H) = 7.4 km and lapse rate (Γ) = 6 K/km. If [NO2](z) = 50 pptv for all z then  p(z) = p0 exp (−z/H)  T (z) = T0 − Γ · z  p(z) nd(z) = R · T (z)  / 12 km − −  ≈ 8 × 1014 molec. cm−2  for p0 = 101 325 Pa and T0 = 298 K. Similarly, for the change in column from a change of 50 pptv NO2 in the PBL, replace 12 km with 1 km in Eq. (1).  References  Beirle, S., Boersma, K., Platt, U., Lawrence, M., and Wagner, T.: Megacity Emissions and Lifetimes of Nitrogen Oxides Probed from Space, Science, 333, 1737–1739, 2011.  Boersma, K. F., Eskes, H. J., and Brinksma, E. J.: Error analysis for tropospheric NO2 retrieval from space, J. Geophys. Res. Atmos., 109, n/a–n/a, https://doi.org/10.1029/ 2003jd003962, URL https://doi.org/10.1029/2003jd003962, 2004.    Boersma, K. F., Eskes, H. J., Dirksen, R. J., van der A, R. J., Veefkind, J. P., Stammes, P., Huijnen, V., Kleipool, Q. L., Sneep, M., Claas, J., Leit˜ao, J., Richter, A., Zhou, Y., and Brunner, D.: An improved tropospheric NO2 column retrieval algorithm for the Ozone Monitoring Instrument, Atmospheric Measurement Techniques, 4, 1905–1928, https://doi.org/10.5194/amt-4-1905-2011, URL https://www.atmos-meas-tech.net/4/ 1905/2011/, 2011.  Boersma, K. F., Eskes, H. 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### Comment 2

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| Author: MRI Scnatweb | Email: mountainresearchinitiative@gmail.com |
| Important for gas and aerosol transport in mountain areas, but remote sensing or modelling cannot reproduce local aspects to important in mountain context. Network of in situ measurements needed to provide adequate spatial resolution.  Based on discussions and preliminary outcomes of the GEO GNOME workshop for identifying ECVs to monitor and understand mountain climate change. More information on the workshop here: LINK. | |