MOVES Light-Duty Emission Rate Evaluation in the Context of Reconciling Modeled and Ambient NOx

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Background

- Studies suggested that NOx is overestimated in the 2011 National Emissions Inventory (NEI) and proposed reducing the mobile sector by 30-70% [1,2] to improve the agreement between modeled and measured NOx.

- The development of NEI is a complex process where State, Local and Tribal (SLT) air agencies provide local information to generate the inventory.

  – For SLTs that do not provide local information, EPA generates county inputs using updated national datasets for the corresponding NEI calendar year obtained from commercial sources.

  – These EPA-developed county inputs are **not equivalent** to MOVES defaults

Objective

- Evaluation of MOVES light-duty defaults used in NEI calculations
  - In the NEI, MOVES defaults (e.g., emission rates, relative mileage accumulation rates) are never replaced by local inputs, thus potentially contributing to discrepancies with ambient NOx levels.
  - We focus on sensitivity exercises to understand the impact of evaluation findings

- This presentation provides an overview* of evaluation and sensitivity results for:
  - High-power gaseous emission rates
  - Preliminary adjustment of base rates
  - Deterioration trends for start and running emissions (NOx only)

*More technical detail is provided in our MOVES Review Work Group presentations
https://www.epa.gov/moves/moves-model-review-work-group

High-power gaseous emission rates in MOVES2014

- MOVES divides the VSP* range into different bins defined by speed and acceleration

- High-power emission rates refer to 6 bins (or operating modes) that represent high speed and high acceleration

- MOVES2014 assumes that the Emission Rate vs VSP trend is steeper at higher power

Example for speed range 25-50mph:

*VSP = Vehicle Specific Power

High-power gaseous emission rates in MOVES2014

NOx, Cars, Age 0-3, LOG SCALE

- Larger reductions, "FTP drive cycle"
- Smaller reductions, "US06 drive cycle"

Legend: 2000, 2005, 2010
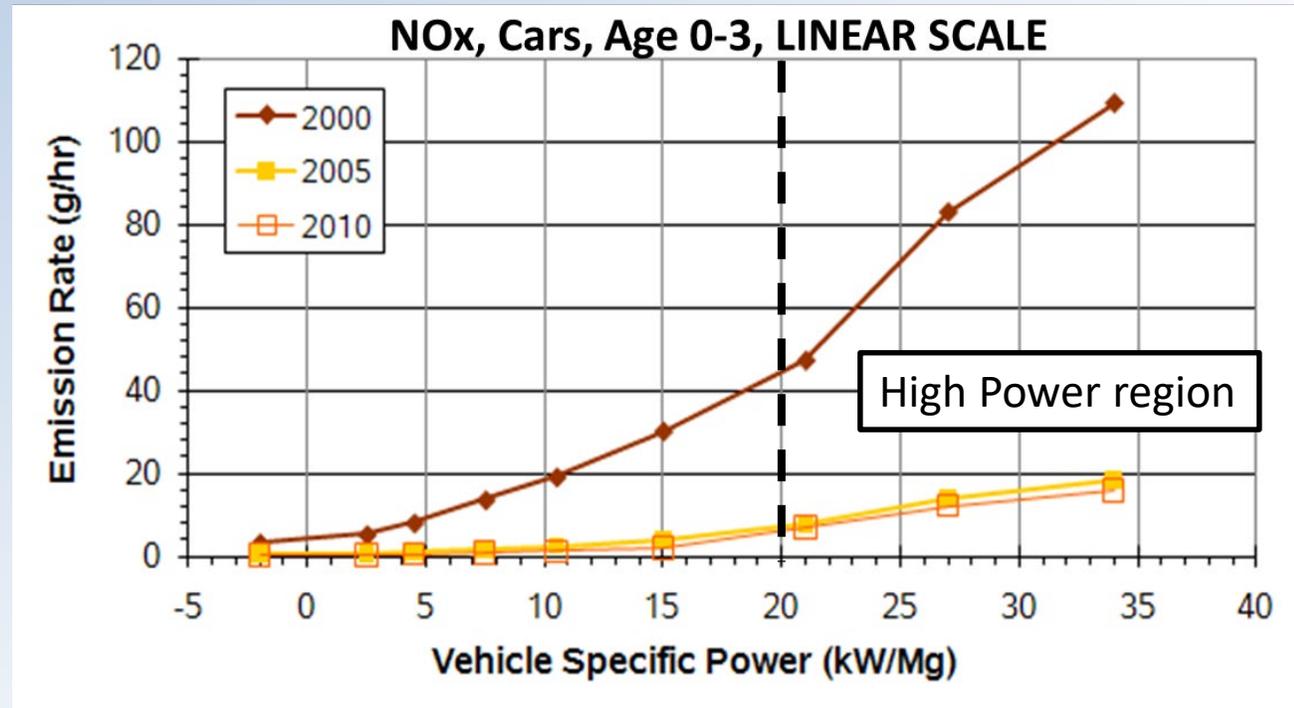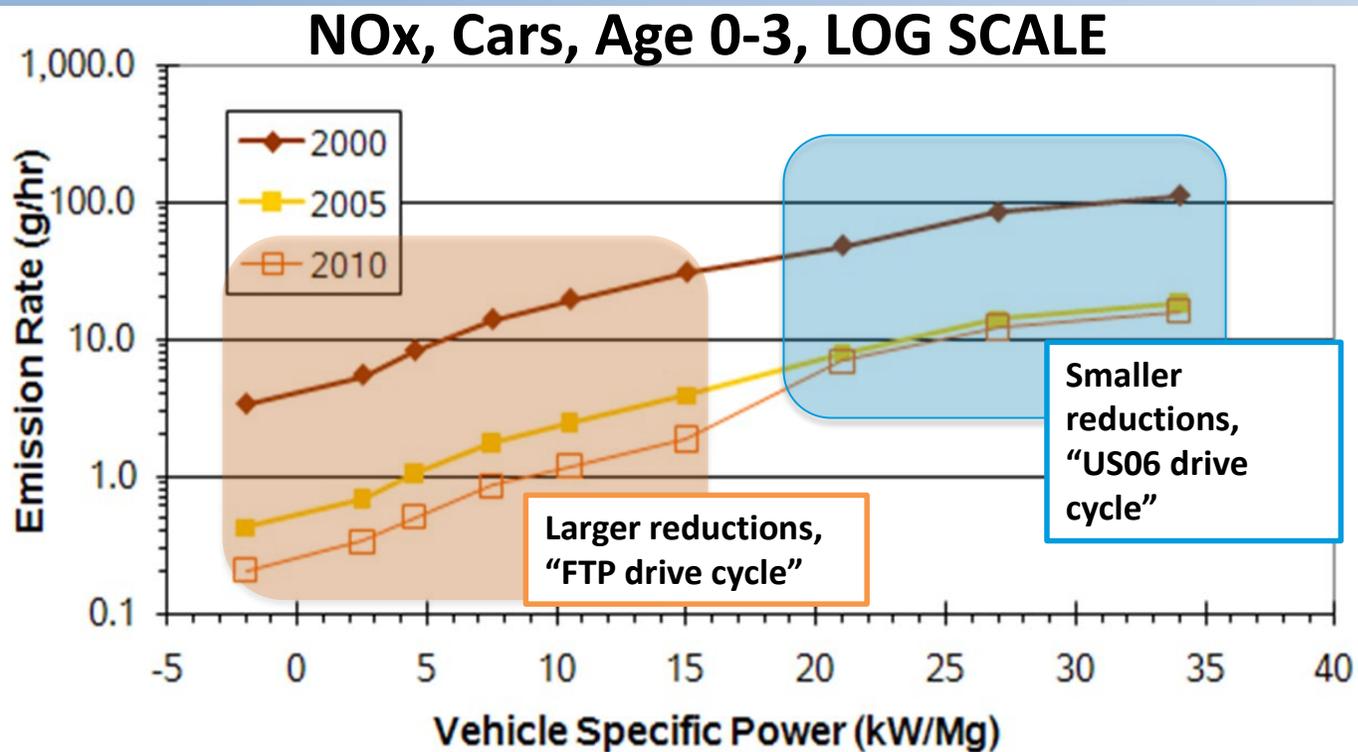
- **EPA expected that at high power, less effective control would result in higher emissions**

- **MOVES2014 applies this assumption to NLEV*, Tier 2 and Tier 3 vehicles**

Note: High-power emission rates are also referred to as "US06 rates" since they are represented by the US06 driving cycle

*NLEV = National Low Emission Vehicle

Validation of high-power gaseous emission rates

- Previous NOx evaluation work determined that high-power operation contributes significantly to LD NOx emissions in the NEI[3]

- Our evaluation of PEMS data suggests that real world emissions do not increase with power as steeply as MOVES predicts, especially for passenger trucks

- We observed similar results with a larger dataset from NCSU* and for other gaseous pollutants[4,5]
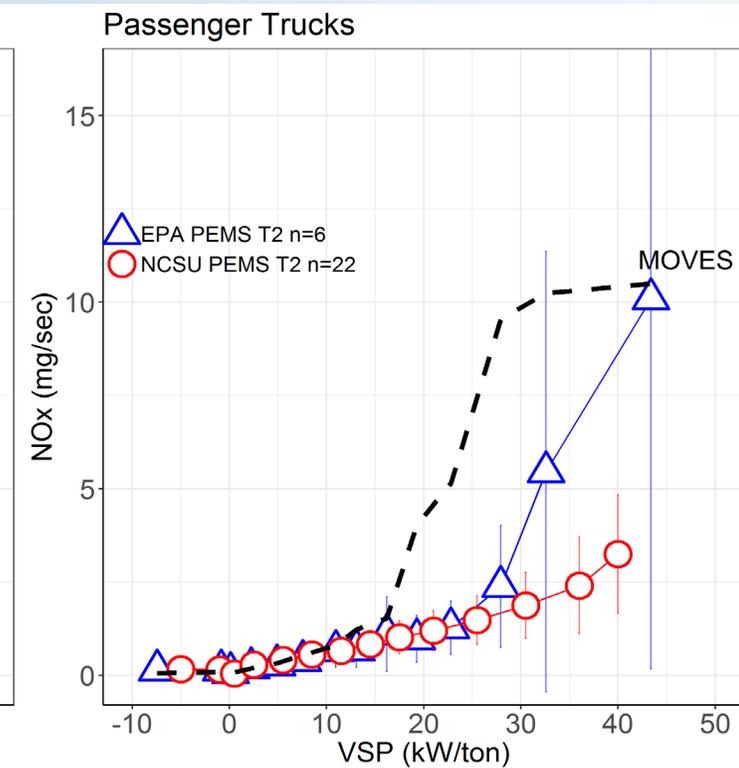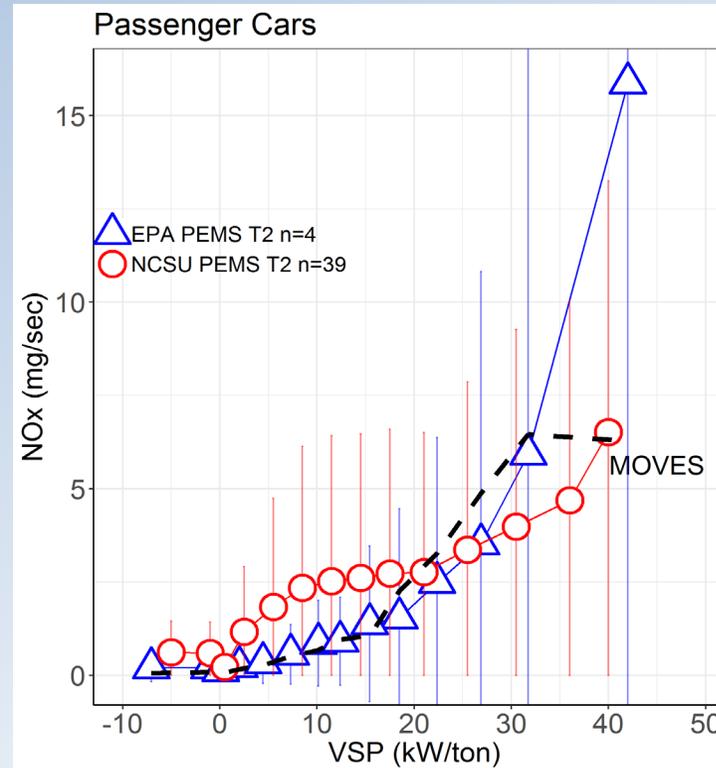
*NCSU = North Carolina State University

Revised high-power gaseous emission rates
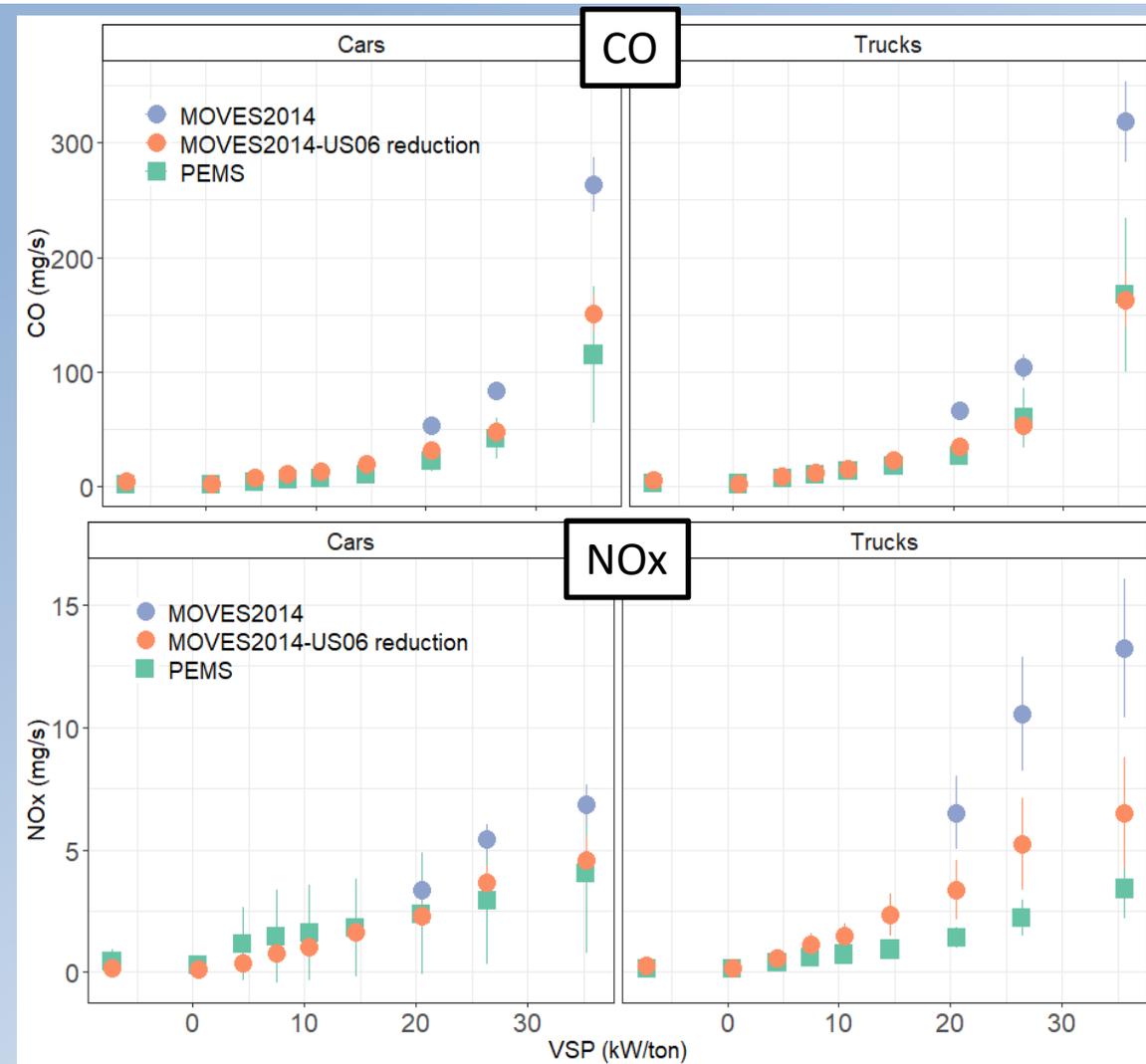
- Removing the high-power assumption results in better agreement with observations[5]
  - Orange circles correspond to revised rates

- Currently, we plan to revise the high-power assumption for future versions of MOVES
  - However, we continue evaluating emissions behavior at high power

Adjusting rates of youngest age group for sensitivity analysis

Comparison between MOVES2014 with Denver I/M for LDV at age 2

- MOVES: based on Phx I/M
- MOVES: Projected
- Denver IM240
- Denver IM240: MY 96-98
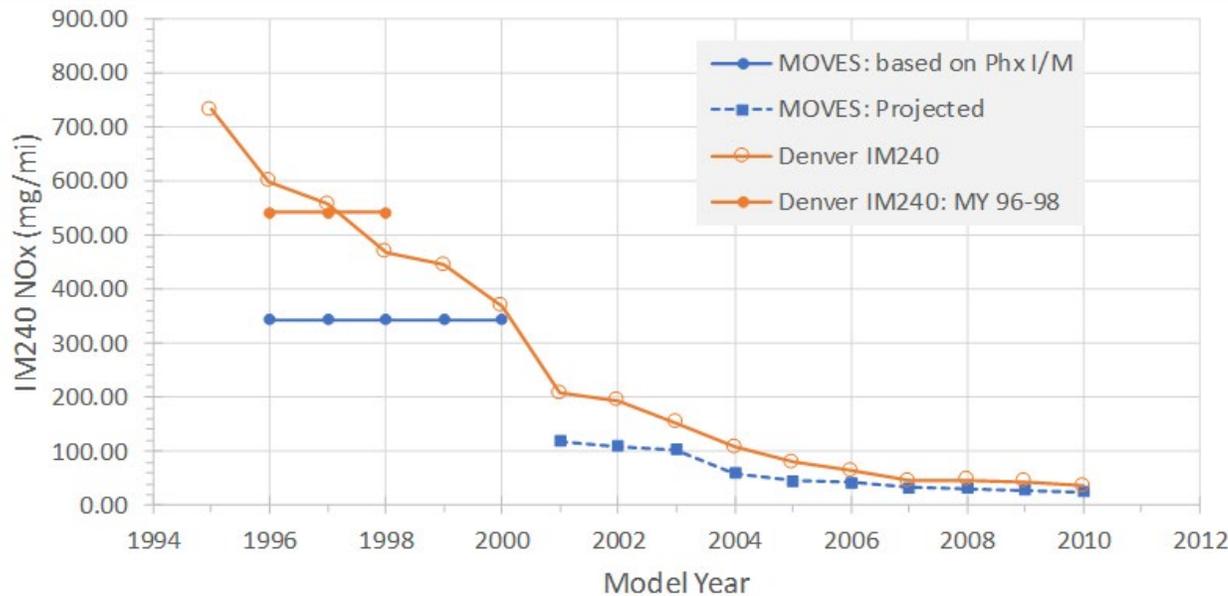
- MOVES2014 rates are based on data from the Phoenix I/M program and projected for later MYs

- The model assumes constant emissions during periods where standards are stable (e.g. 1996-2000)

- However, Denver I/M data suggests that emissions decreased during 1996-2000, despite stable (Tier 1) standards

- **For youngest age:**
  - MY1996-2000: Denver I/M shows a consistent decrease (also observed for LDT).
  - MY2001-2010: MOVES projections compared to Denver I/M are lower for cars and higher for trucks.

*IM240: dynamometer driving cycle used during LD inspection & maintenance emissions testing. Based on FTP, running only and lasting 240 seconds.

Adjusting rates of youngest age group for sensitivity analysis

Denver/MOVES ratios for youngest age
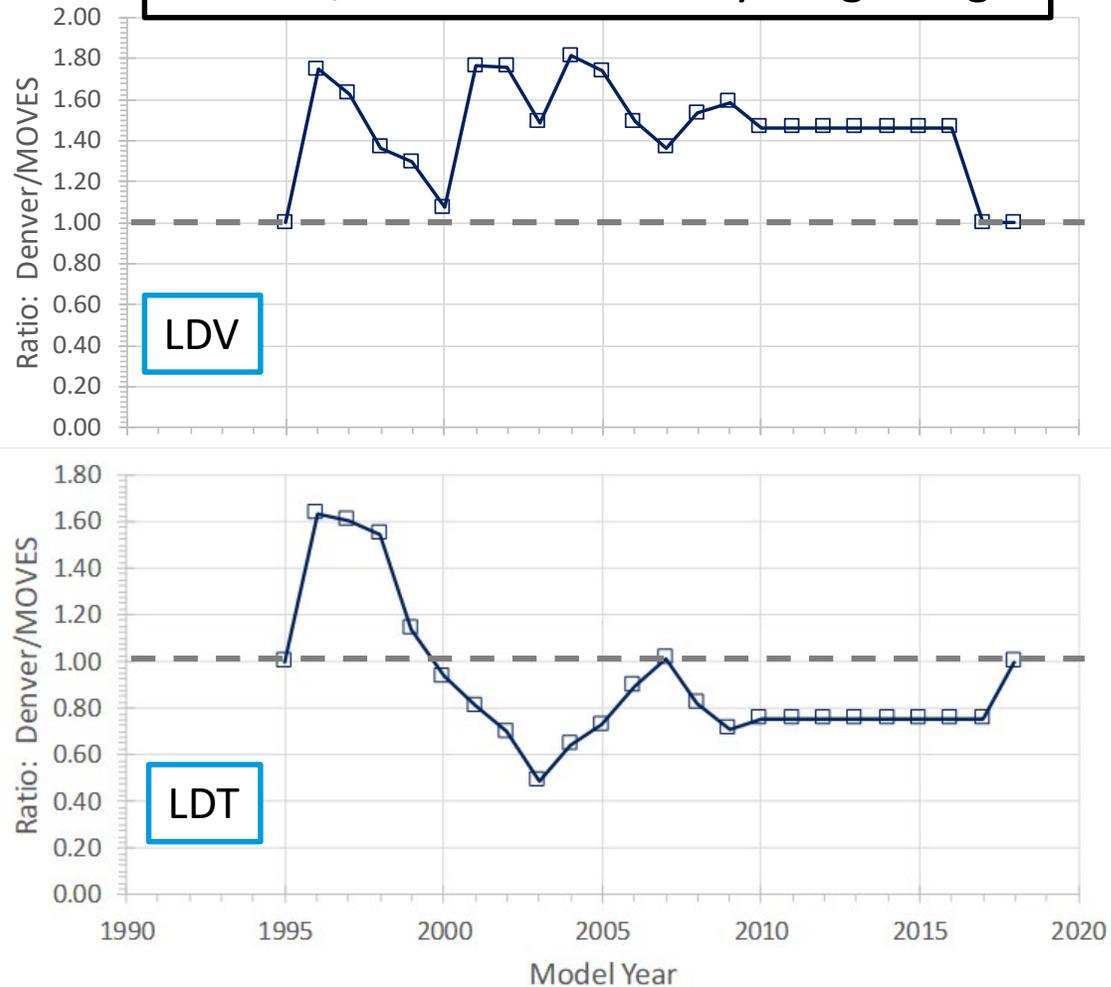
- **Denver I/M to MOVES ratios vary by vehicle type and by model year**
  - Denver I/M higher than MOVES for LDV
  - Denver I/M higher for pre-2000 LDT
  - MOVES higher for post-2000 LDT

Deterioration Trends – Running Emission Rates (NOx)

- Deterioration trends of running emissions in MOVES2014 are based on data from the Phoenix I/M program (CY 1996-1998; 2002-2005)

- Previous evaluations of deterioration were based on grouping by emission standards[6]

- These results suggested that deterioration trends were consistent with observations

Comparison of MOVES and Denver IM240 for Tier 2 cars
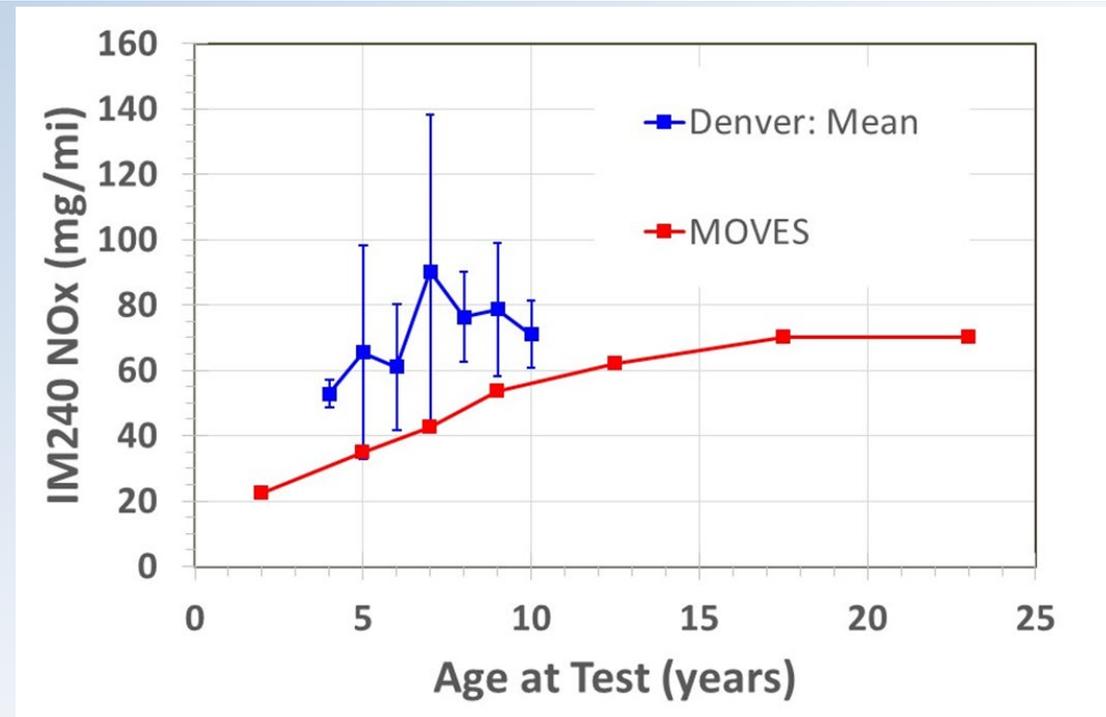
Deterioration Trends – Running Emission Rates (NOx)

Comparison of MOVES and Sensitivity case informed by Denver IM for an LDV (MY 2008)

pollutant=NOx, process=Running, regClassName=LDV, modelYearID=MY2008 opModeID=27

MOVES2014

Sensitivity Case (Denver IM based)
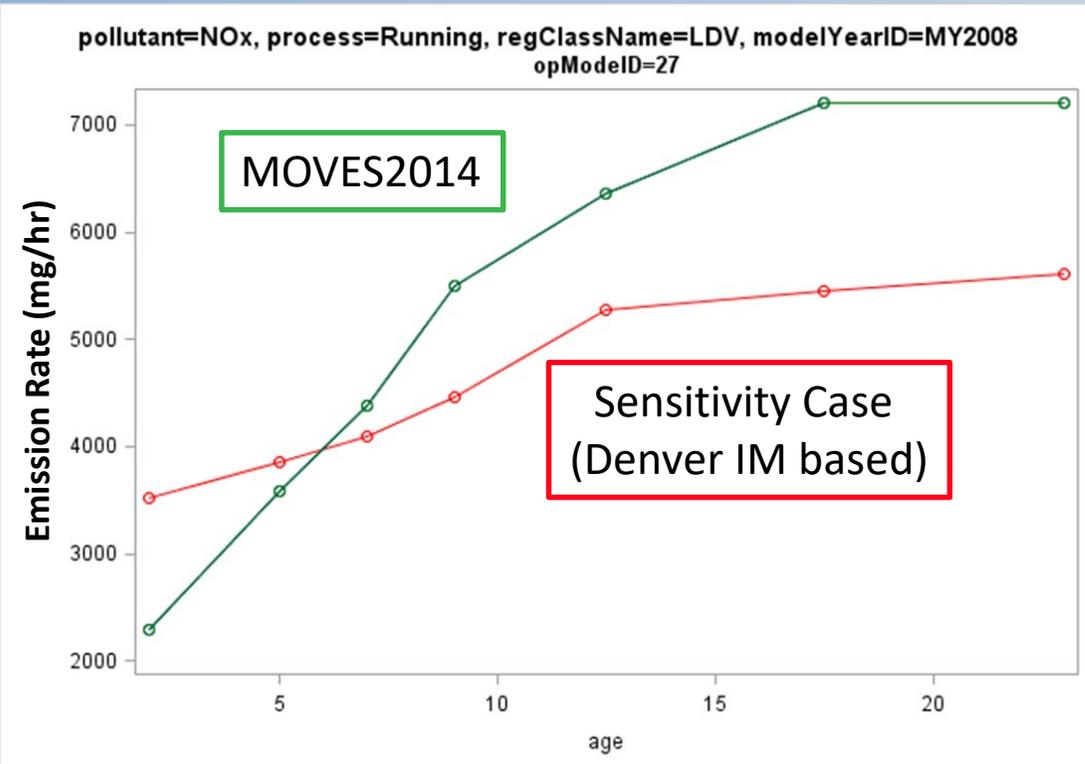
- This evaluation is based on data from the Denver I/M program (MY 1995-2010) and focuses on trends for individual MY

- Revised results show a more gradual deterioration trends than MOVES2014
  - It also shows steeper trends for trucks than cars

- Our sensitivity exercise covers two aspects based on Denver I/M data:
  - Adjustment of rates for youngest age group
  - New running deterioration trends

NOx Start Deterioration Trend in MOVES 2014

Relative deterioration in MOVES2014
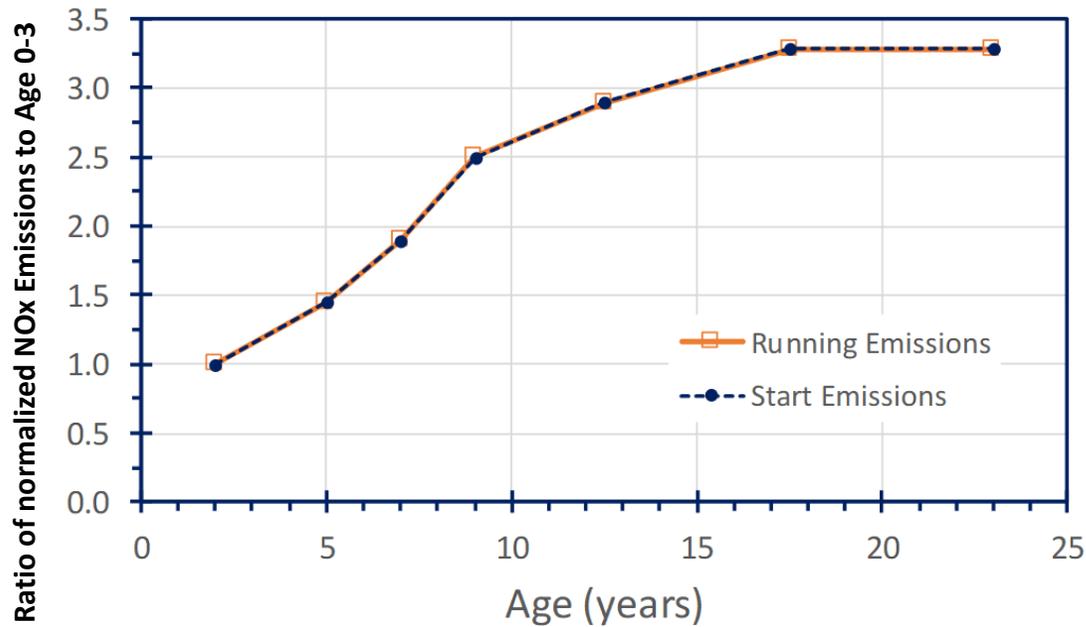
- MOVES2014 deterioration is based on Phoenix I/M

- For NOx, in MOVES2014, we use the same relative deterioration for starts and running (in the figure, the curves representing Start and Running are the same).

NOx Start Deterioration Trend Data

- Is MOVES2014 assumption on identical deterioration for starts and running correct?

  - Data are sparse

  - I/M* dataset behind MOVES2014 provides information for running emissions, but not for starts

- In Use Verification Program (IUVP)

  - Run by manufacturers and designed to verify compliance. Vehicles are recruited from the public and required to be well maintained.

  - Used to determine start deterioration trend relative to running deterioration trend (well-maintained vehicles might not fully represent deterioration in real-world vehicles).

NOx vs mileage from IUVP program

*I/M = Inspection/Maintenance
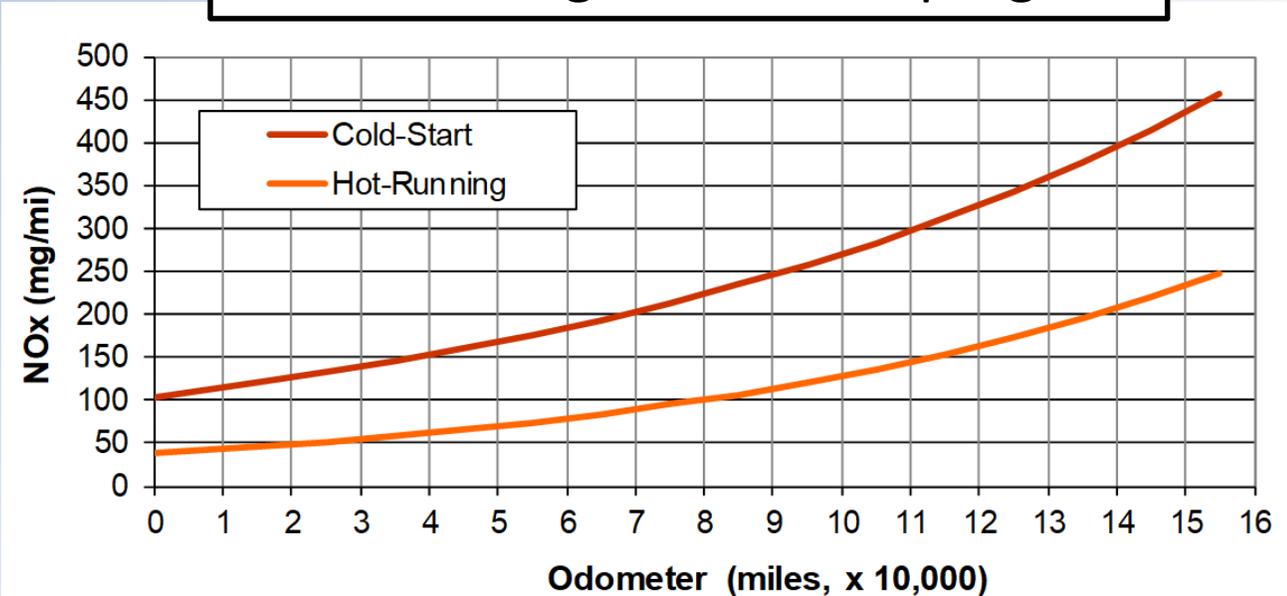
Normalized IUVP Emissions at Zero Miles

- We normalize at 0 miles to model on a comparable basis.

- When normalized, start emissions deteriorate *slower* than running emissions

Normalized Emissions at 0 miles from IUVP data
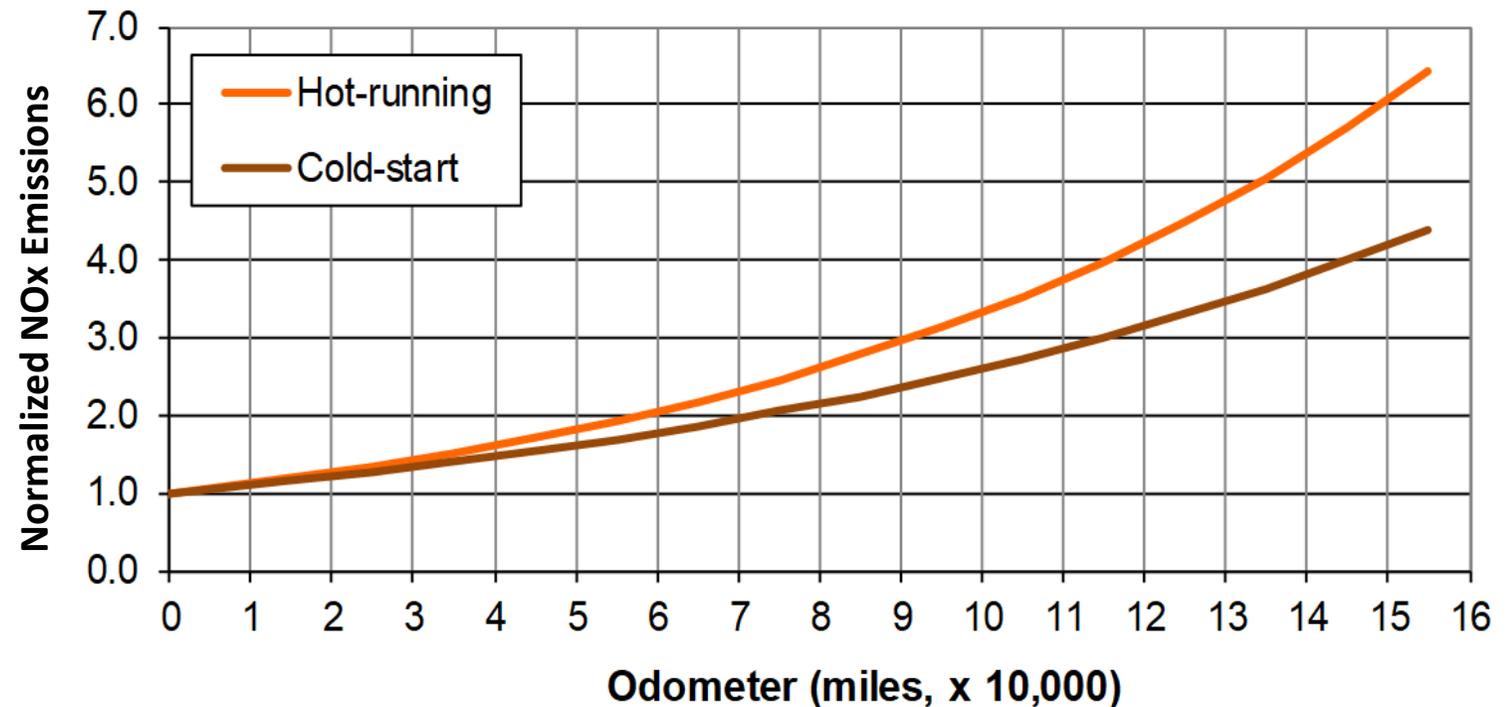
New Start Deterioration Trend from IUVP

- Our reassessment used multiplicative factors derived from IUVP for start emissions, different than those used for running[5]

- As result, we obtain a slower deterioration for starts emissions relative to that for running emissions

Sensitivity Case Evaluated
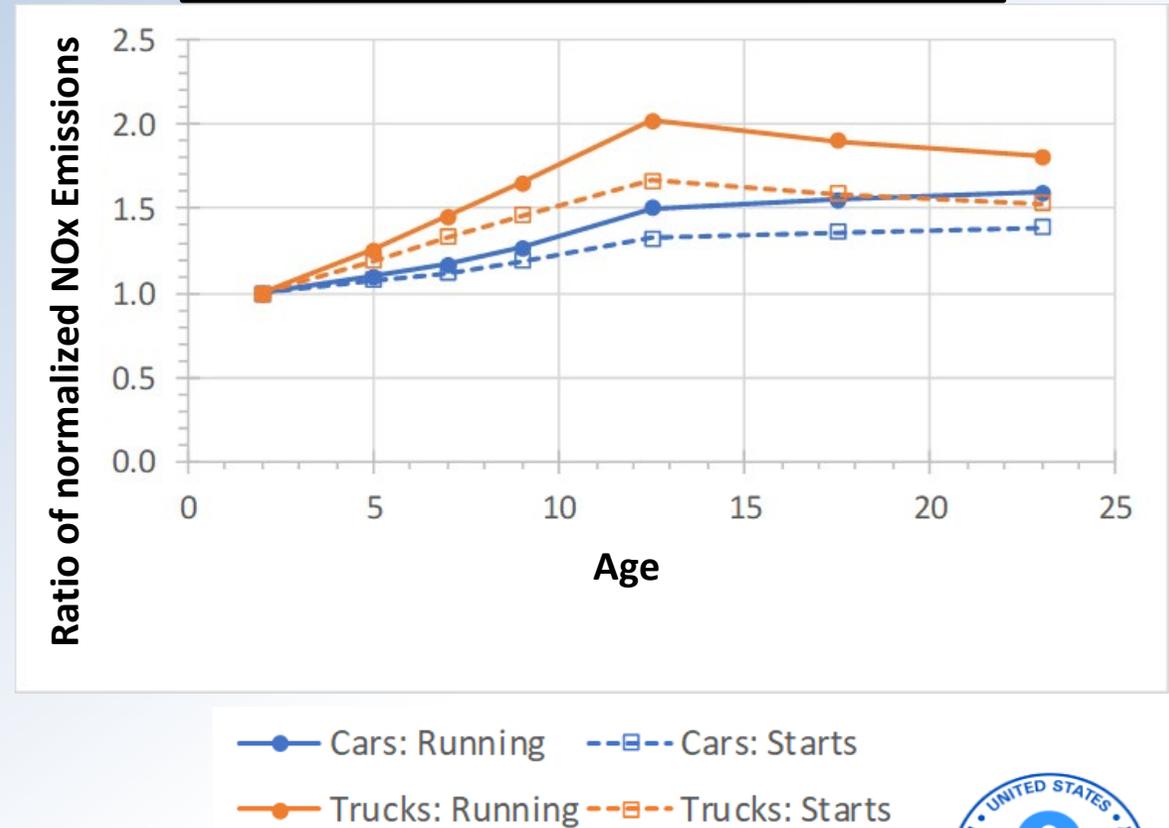
Sensitivity Cases Summarized

- Model version used: MOVES2014b

Case	Description
Baseline	National run, all vehicles, fuels and roadtypes
US06 change	Revised assumptions on high power gaseous emission rates.
New Start Deterioration	Informed by IUVP data. Different trend for starts and running; different trend for cars and trucks. At this point, only NOx.
New Running Deterioration	Informed by Denver I/M data. Adjusted rates for younger vehicles. Slower running deterioration than MOVES2014b. At this point, only NOx.

Preliminary Emission Impact – Sensitivity on LD NOx

Impact by sensitivity case on LD NOx

Legend: New Running Det | New Starts Det | US06 Change
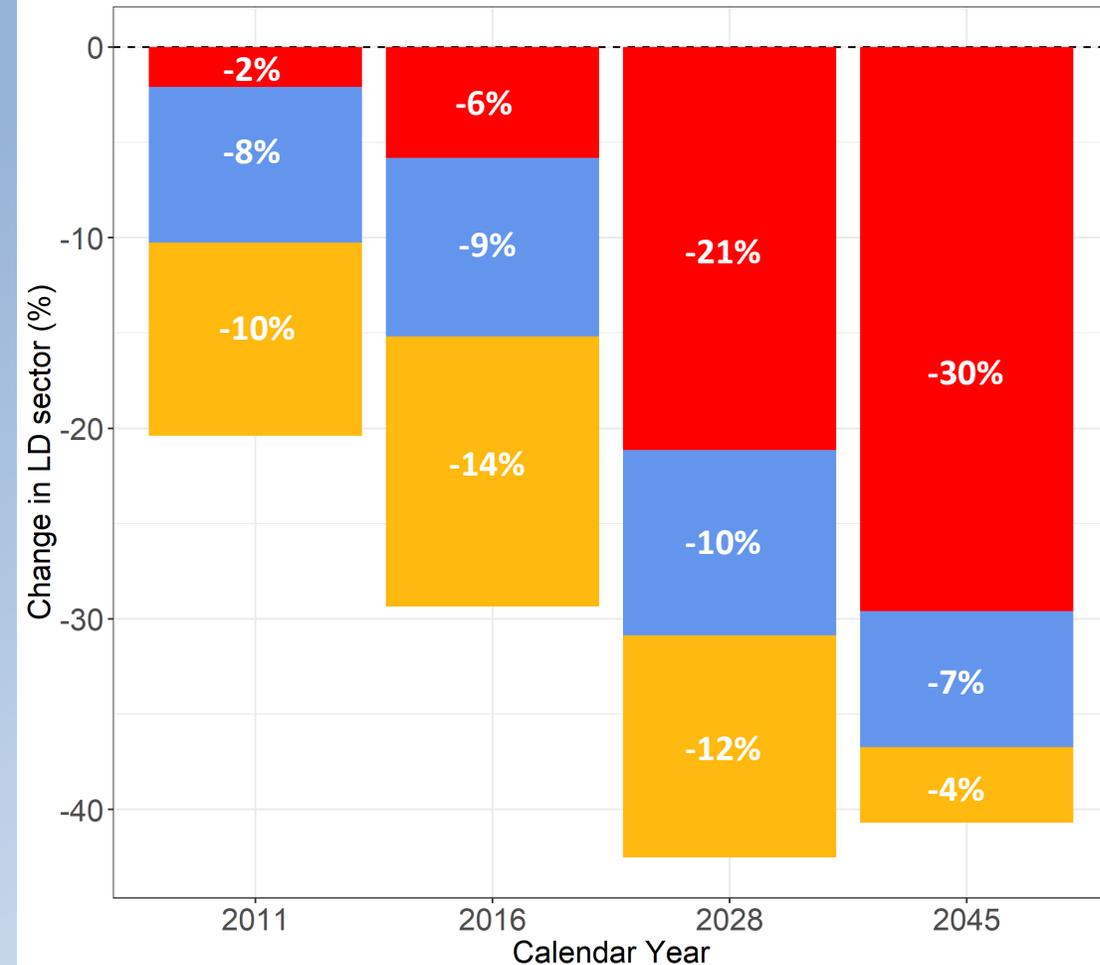
- Overall impact of these sensitivity exercises is more important for the future (i.e. largest overall impact in 2028)
  - Sensitivity cases impact vehicles under Tier 1, NLEV, Tier 2 and Tier 3 standards
  - Larger impact observed when running emissions from Tier 2 vehicles are still an important part of the inventory
- Reduction for CY2011 is estimated as ~20%

Caveats of this sensitivity exercise

1. The impact estimated is preliminary as we continue to work on remaining questions and expand to other gaseous pollutants.

2. The impact estimated cannot be used as an 'adjustment' to onroad emissions because many other aspects of the model continue to be evaluated and will impact the onroad sector (e.g. HD sector, see *Han et al.*[7]).

3. The impact estimated is only an approximation at a national level; results will differ when using local inputs (e.g. NEI development, modeling platform development).

Reconciling modeled and measured NOx

- Our evaluation of the LD sector in MOVES suggests important reductions to the LD NOx inventory, although not to the degree recommended by some studies.

- The context for this evaluation is changing:

  - For example, improvements in modeling meteorology within the CMAQ model have resulted in better agreement between measured ambient NOx concentrations and CMAQ predictions on a national basis using inventories developed with MOVES2014 (Appel et al. 2017[8], Toro et al. *in progress*).

Summary and Next Steps

- Our evaluation of LD modeling in MOVES suggests important reductions to the LD NOx inventory

- We continue to work on remaining questions from the current evaluation

  - Further evaluation of high power emission rates

  - A/C effects on NOx emissions

  - Relative Mileage Accumulation Rates

- Future work: explore impact of revised LD input on air quality through air quality modeling sensitivity exercises

References

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4. Sonntag et al., (2018) *Updated Evaluation of MOVES Light-duty Gasoline NOx Emission Rates with Real World Measurements*, 28th CRC Real World Emissions Workshop, Garden Grove, CA
5. Toro et al., (2019) *Updates to high-power emission rates and start deterioration for light-duty vehicles*, MOVES Review Workgroup, Ann Arbor, MI
6. Warila et al. (2017) *Evaluation of NOx Emissions Projected by MOVES2014 Using Dynamometer, Remote-Sensing and Tunnel Data*, 27th CRC Real World Emissions Workshop, Long Beach, CA
7. Han et al. (2019), *Planned updates to EPA MOVES Emission Model for Heavy-duty Onroad Vehicles*, 2019 International Emissions Inventory Conference, Dallas, TX
8. Appel KW, et al. (2017) *Description and evaluation of the Community Multiscale Air Quality (CMAQ) modeling system version 5.1.* Geosci. Model Dev. 10(4):1703–1732.