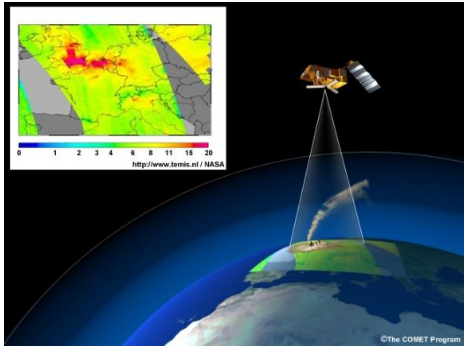
Environment and Climate Change Canada | Environnement et Changement climatique Canada

University of Saskatchewan

TEMPO



Some TEMPO-related updates from Canada

1. **Chris McLinden**, Environment & Climate Change Canada

2. **Lukas Fehr**, University of Saskatchewan

TEMPO Science Team Meeting · 05 June 2019 · Madison, WI

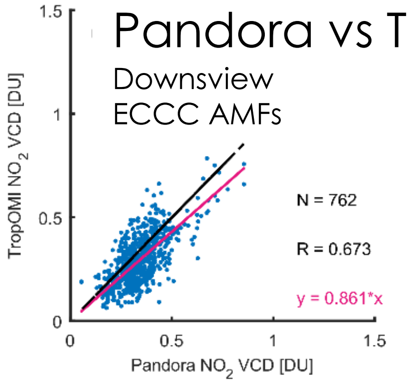
Canada

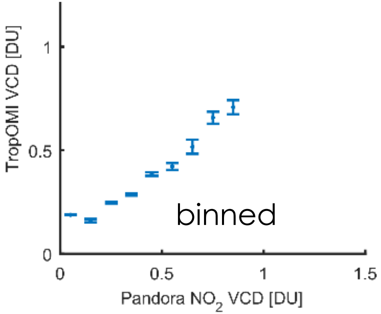
Some ECCC activities

- Expansion of Cdn Pandora network

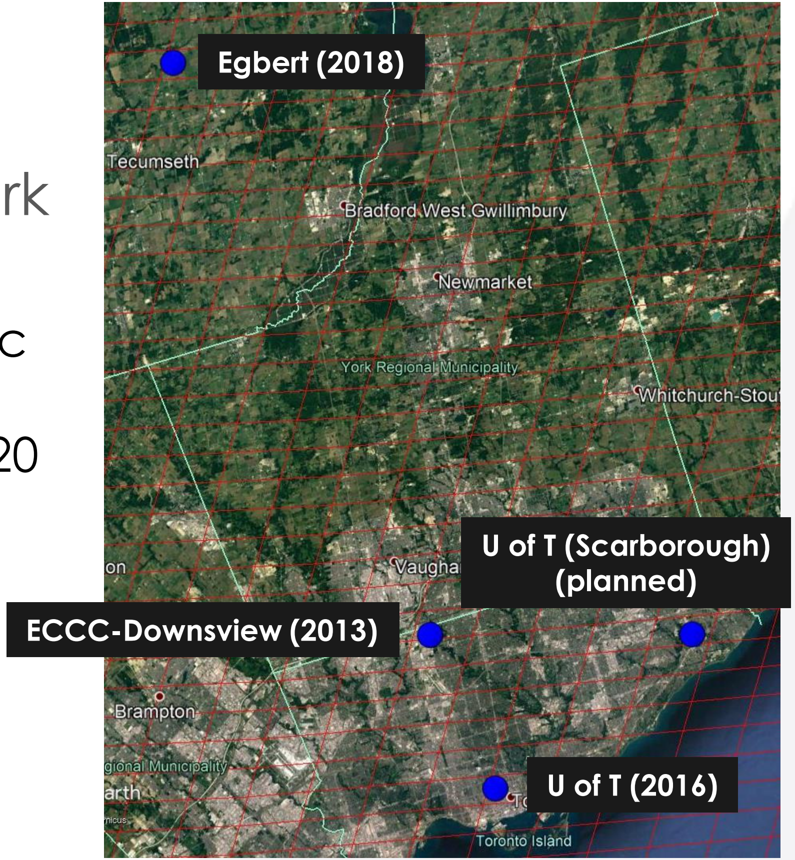
Current status: 8 Pandoras at 6 sites
- 3 in GTA, oil sands, Vancouver Island, Arctic
- Two additional sites planned
- Two Pandoras to be purchased in 2019-2020

Pandora vs TROPOMI NO_2



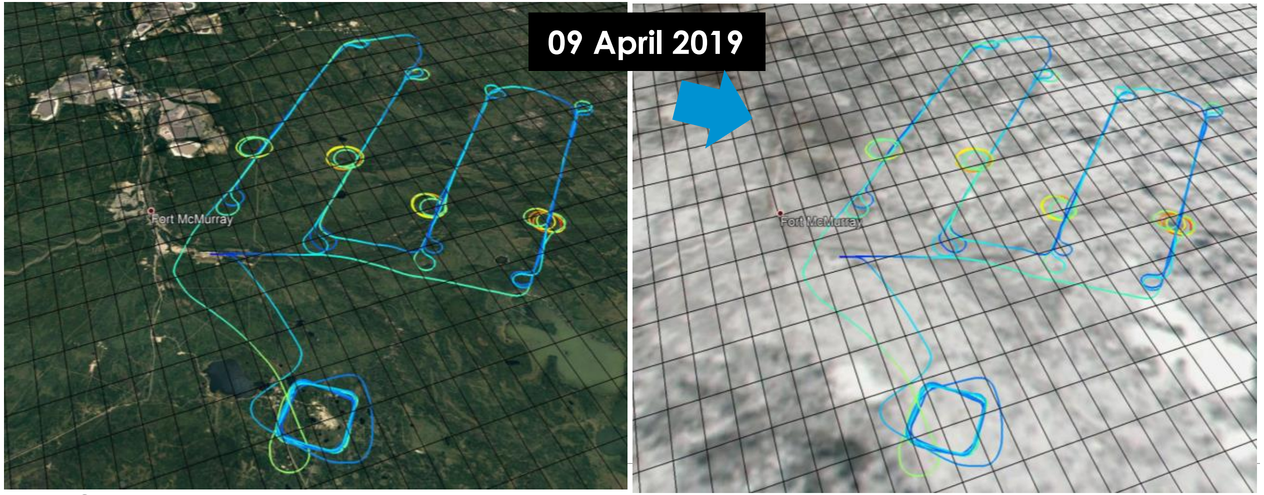


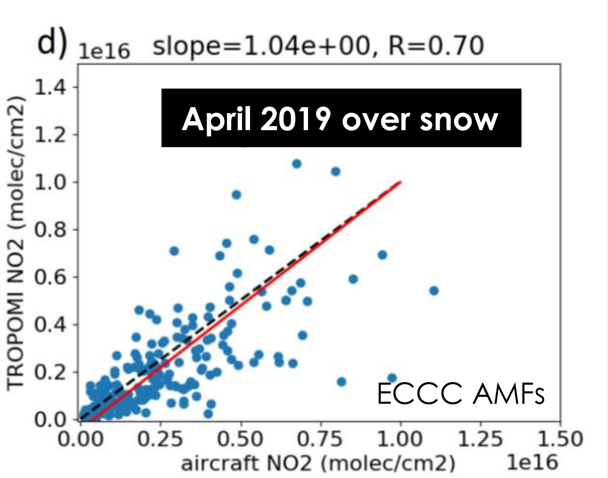
Courtesy X. Zhao, ECCC



Some ECCC activities

- Aircraft campaigns:
  - 2018 spring / summer in Alberta – oil sands, fracking, forest fire flights – used for TROPOMI validation, including observations over snow
  - Next flight ≥2021, proposal for forest fire flights to be submitted



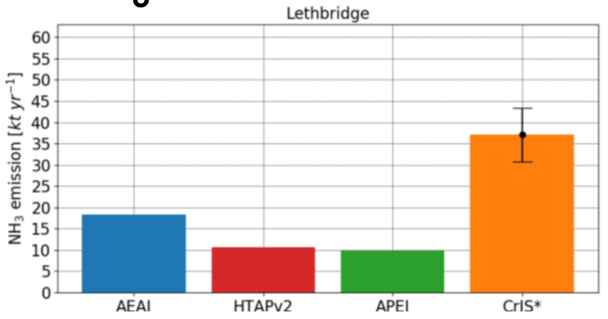


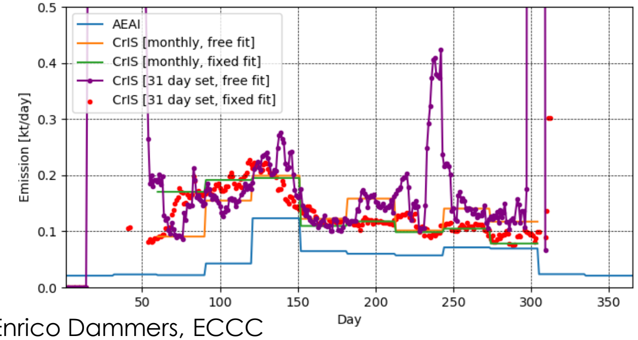
Griffin et al., 2019

Some ECCC activities

- Emissions – NO_x, SO_2, NH_3, CO; anthropogenic, wildfires
  - Satellite observations + winds

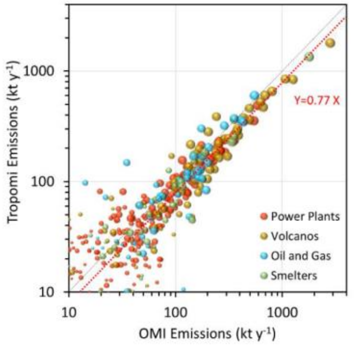
NH_3 emissions from CrIS





Enrico Dammers, ECCC

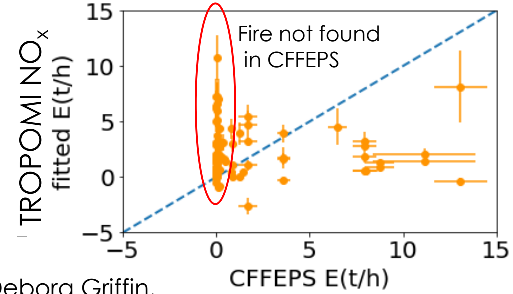
TROPOMI SO_2 emissions



Vitali Fioletov, ECCC

Wildfire emissions

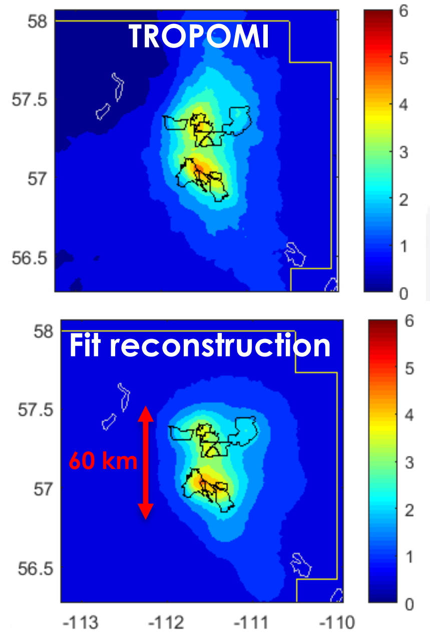
Fires in June 2018

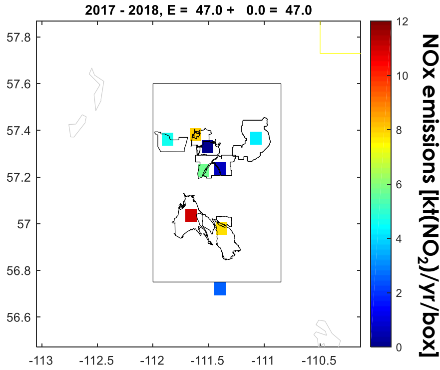


Bottom-up model

Debora Griffin, ECCC

NO_x Area Sources using TROPOMI





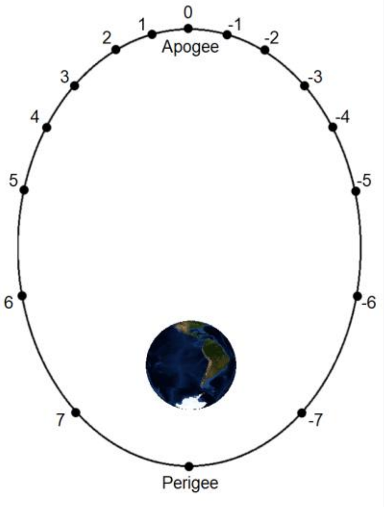
www.aim-north.ca

	2019	2021	2022	...	...	*2026 ?*		
CSA Phase Names	**Phase 0 (Pre-Phase A)**	**Phase A**	**Phase B**	**Phase C**	**Phase D**	**Phase E**	**Phase F**
Description	Mission Definition	System Definition	Preliminary Design	Detailed Design	Manufacturing, Assembly, Integration, Testing, Launch, Commissioning	Operations	Disposal

AIM-North (Atmospheric Imagining Mission for the North)

Concept: Two satellites in highly-elliptical orbits (HEO) provide geostationary-like coverage of Northern-latitudes

- New incarnation of defunct PCW concept
- would carry AQ (UV-visible) and GHG (solar-IR) imagers; 4 x 4 km pixels
- Currently in Phase 0; Users Requirement Document being developed
- Instrument simulators and OSSEs being developed
- TBD: Imaging FTS vs. Dispersive spectrometer for GHGs, met imager
- International collaborations sought

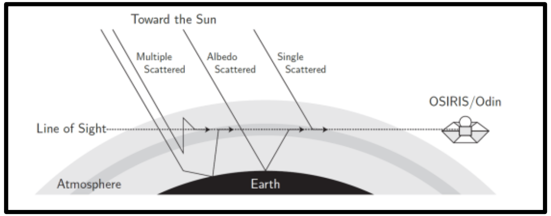


Some ECCC activities

- Work developing system for assimilation of TEMPO + surface observations in Canadian AQ forecast model ongoing
- Support to University research groups
  - Dalhousie University – R. Martin group
  - University of Saskatchewan – A. Bourassa group

University of Saskatchewan Introduction

- SASKTRAN
  - Radiative transfer model framework
  - Two fully spherical methods: successive orders and Monte Carlo
  - One plane-parallel method: DISORT replication
- Experience with limb instruments and retrievals
  - Odin-OSIRIS limb scattering
  - OMPS-LP tomographic



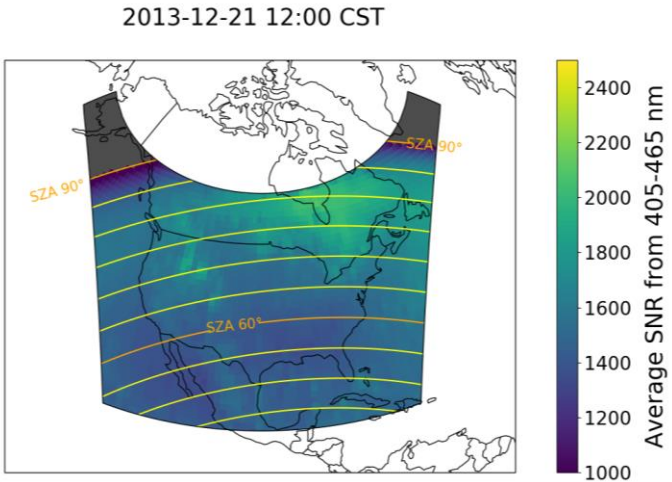
TEMPO Study Objectives

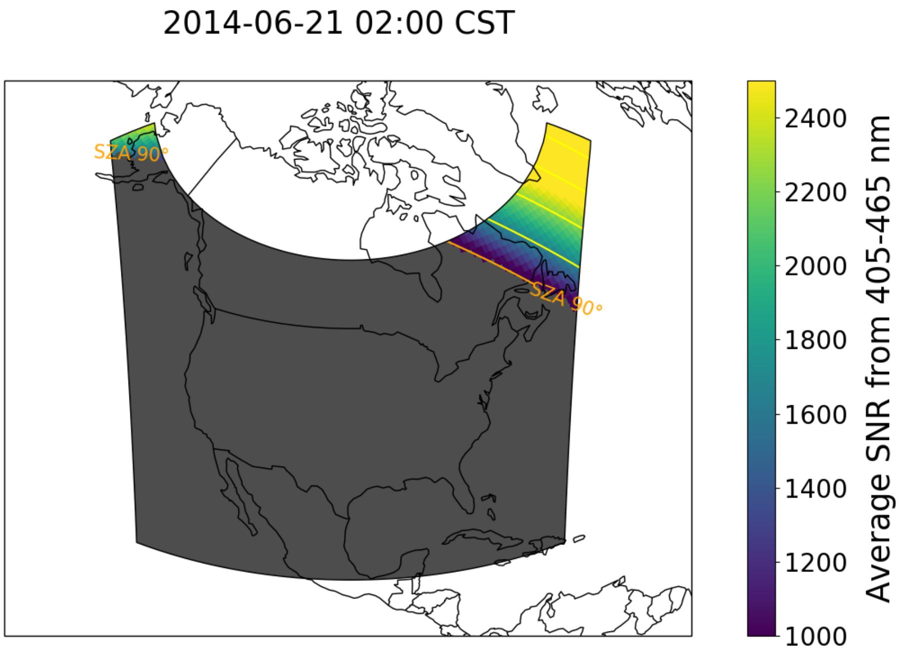
- Use SASKTRAN to investigate high latitude retrievals
    - Large zenith angles
    - Snow
    - Horizontal variability
- Understand distribution of retrieval uncertainties over Canada
- Scope:
    - radiance simulation over TEMPO's FOR
    - Simulate daylit hours on each solstice/equinox
    - Cloud-free
    - Apply OMI NO_2 retrieval error analysis [1]

Radiance Simulations

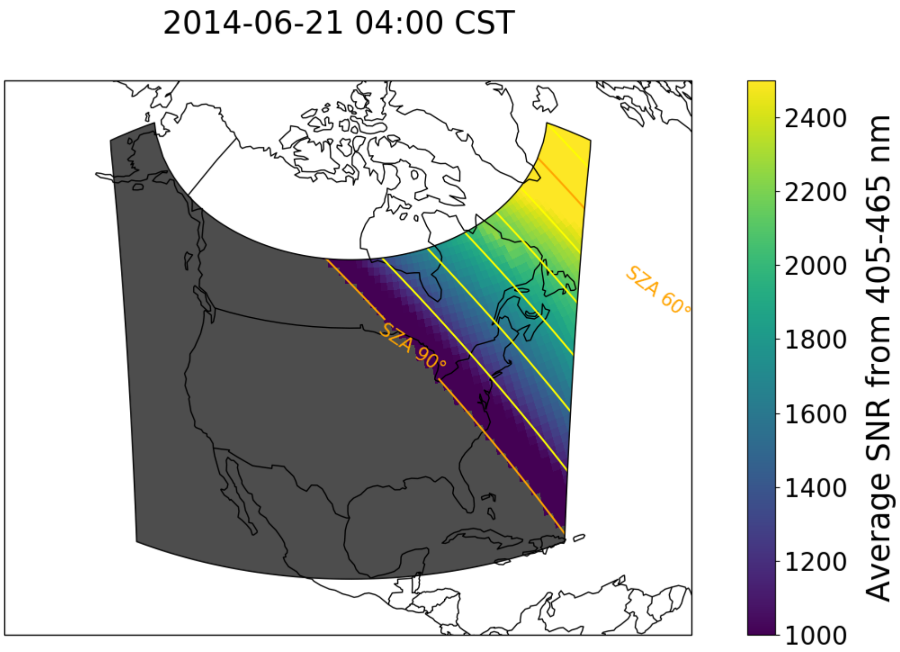
Radiance Simulations:

- Simulate radiance with no absorber with SASKTRAN
- Surface albedo from GOME LER product [2]
- Add absorption using AMF lookup table
- NO_2 profiles taken from the 2013-14 GEOS-5 Nature Run with GEOS-Chem chemistry [3]
- Noise estimation:
  – Assume SNR is entirely shot noise
  – Calculate radiance for nominal conditions (midday, 36.5N 100W), compare with reported nominal TEMPO SNR
  – Extend to other scenes

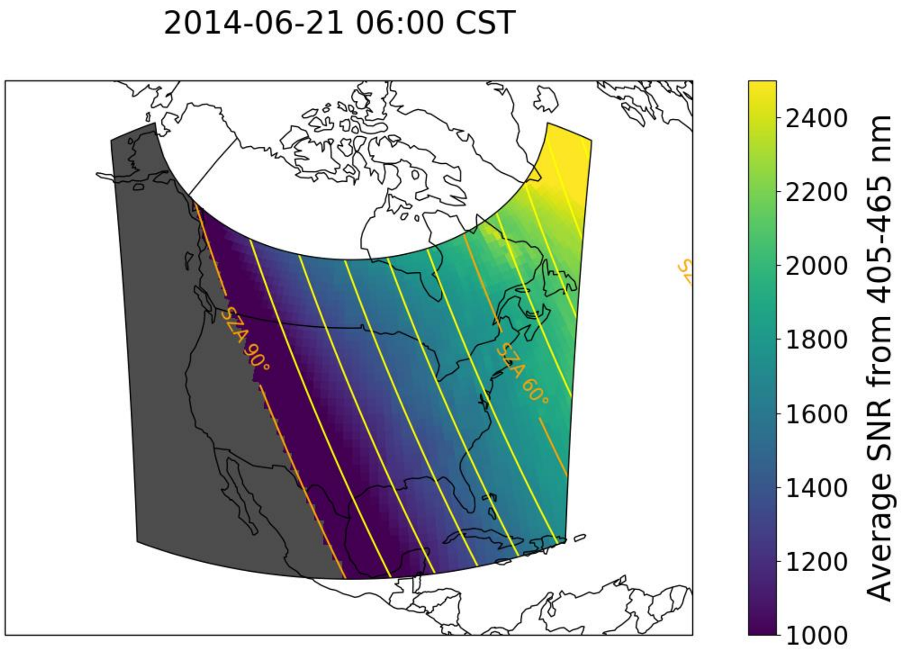




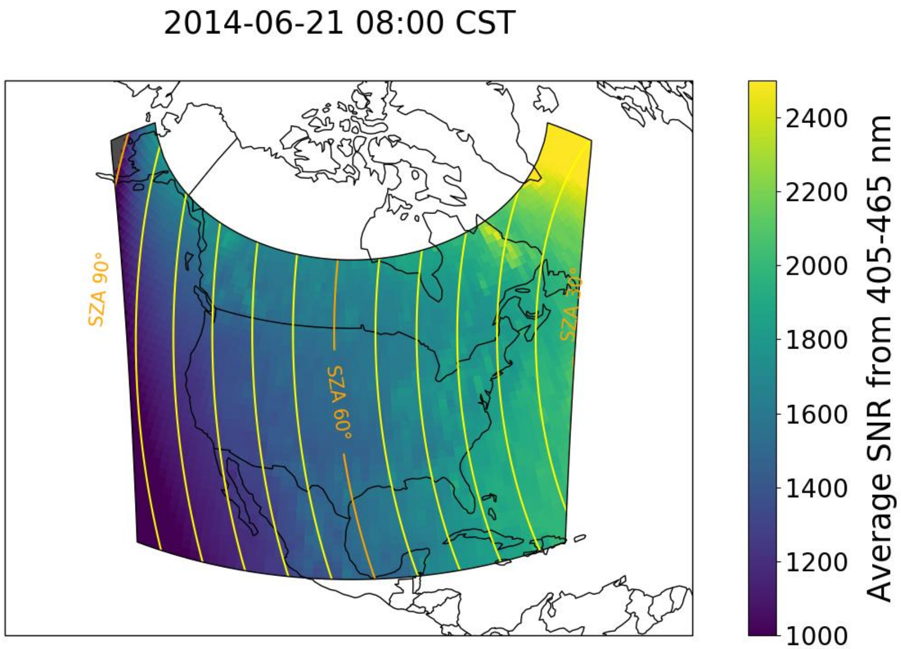
Summer Solstice



Summer Solstice



Summer Solstice



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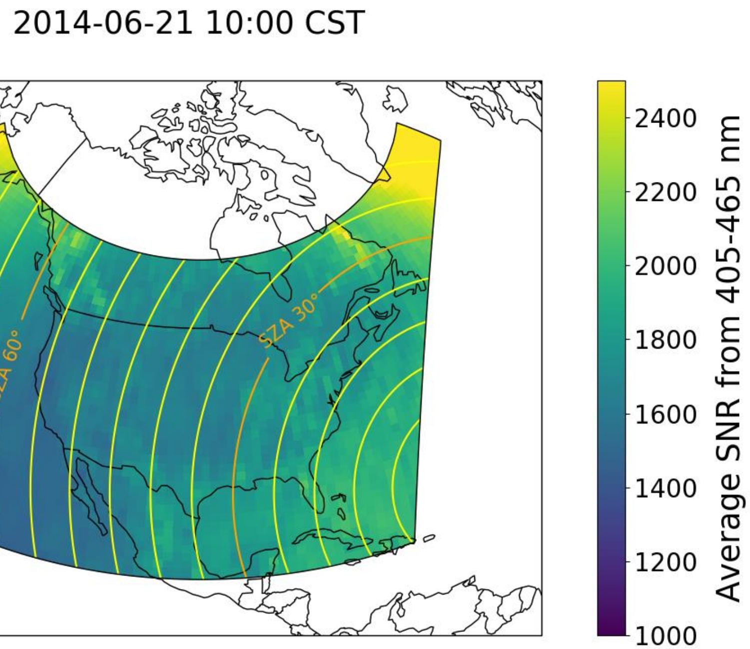
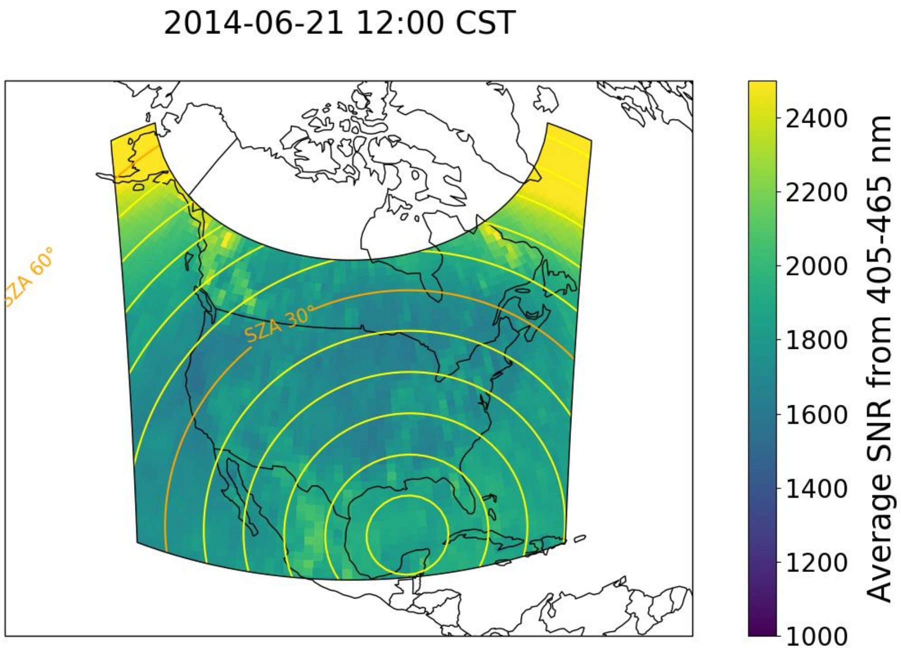


Summer Solstice



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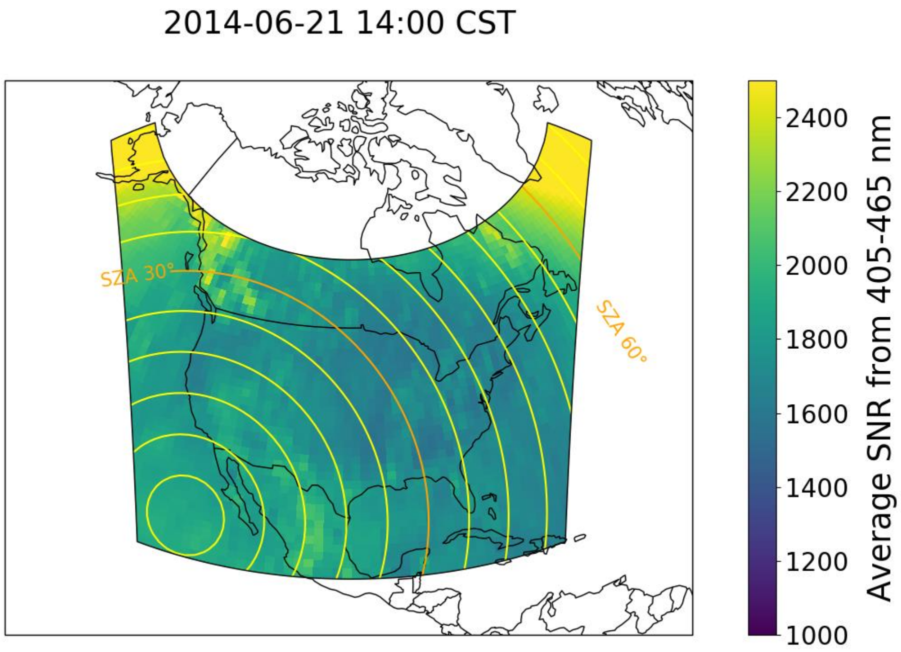

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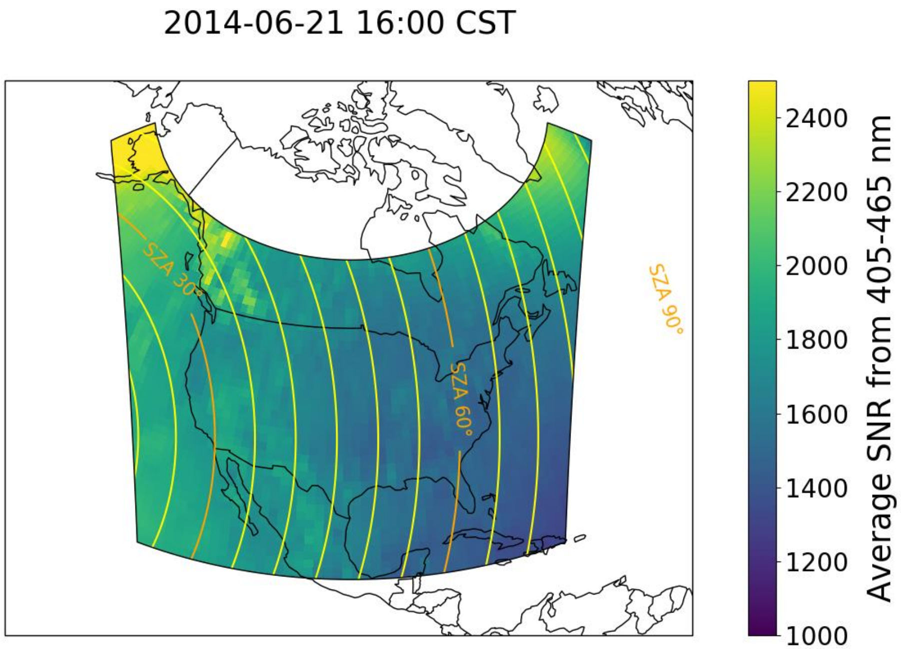

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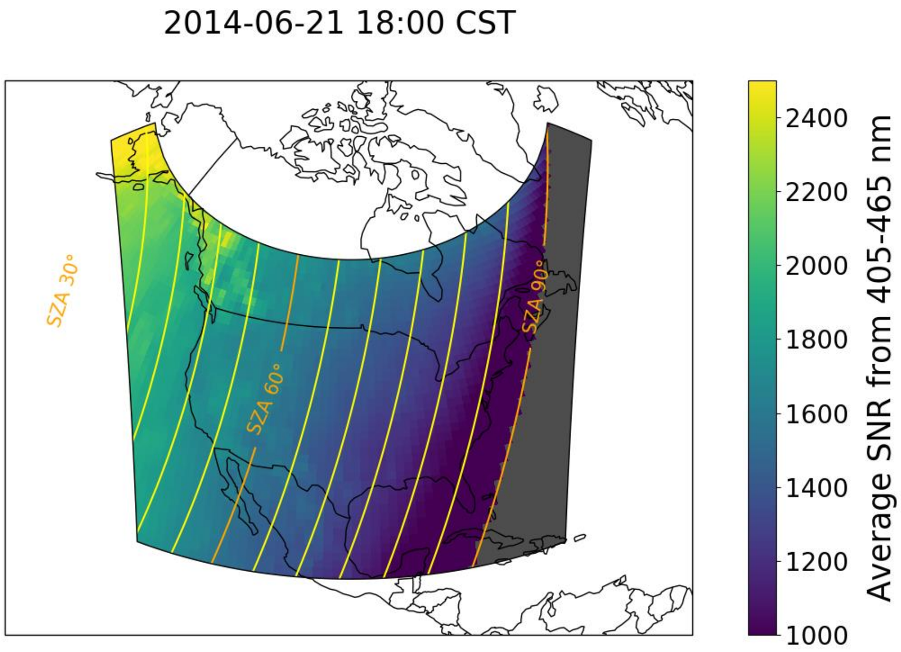

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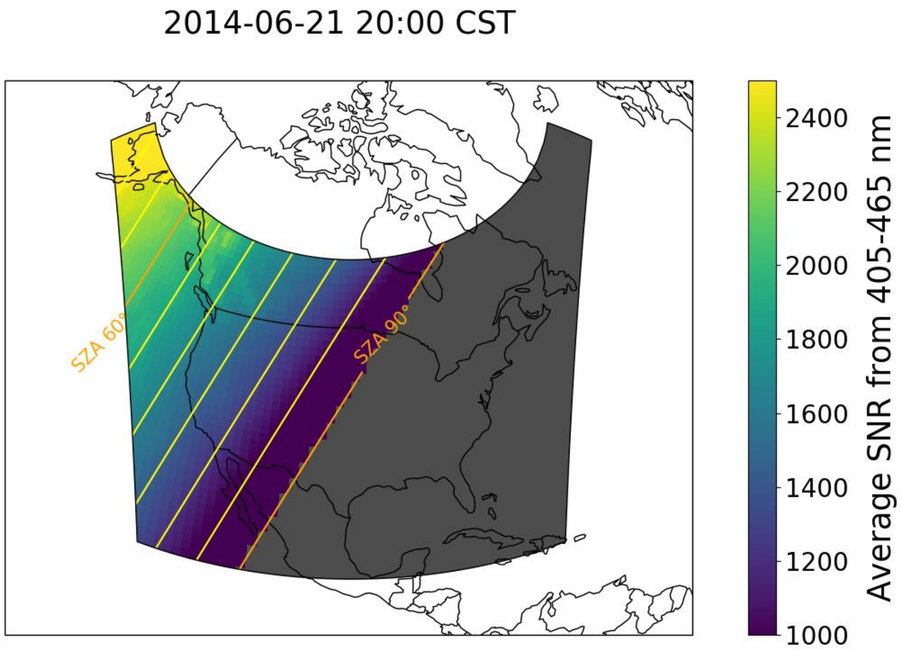

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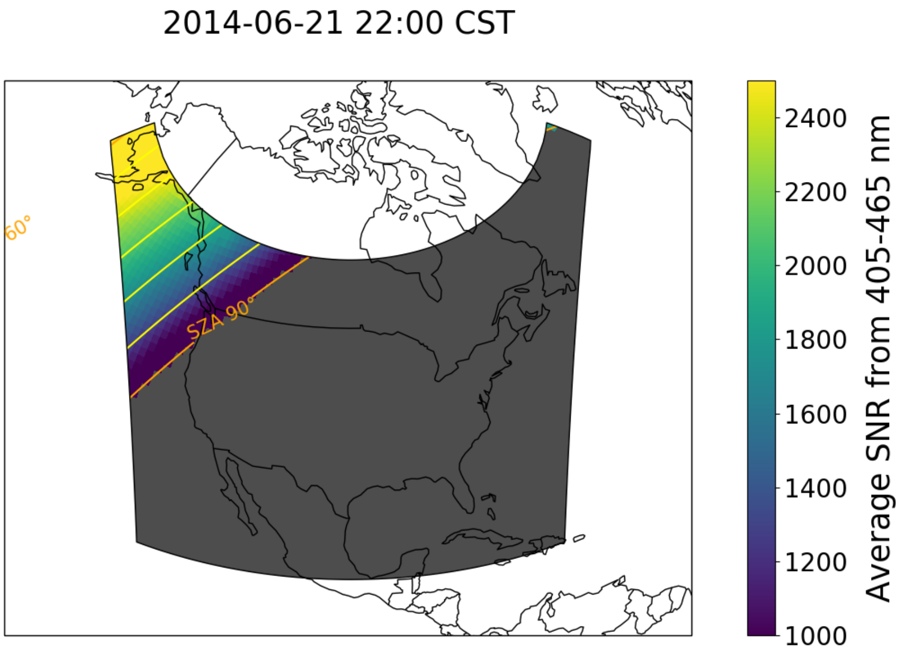
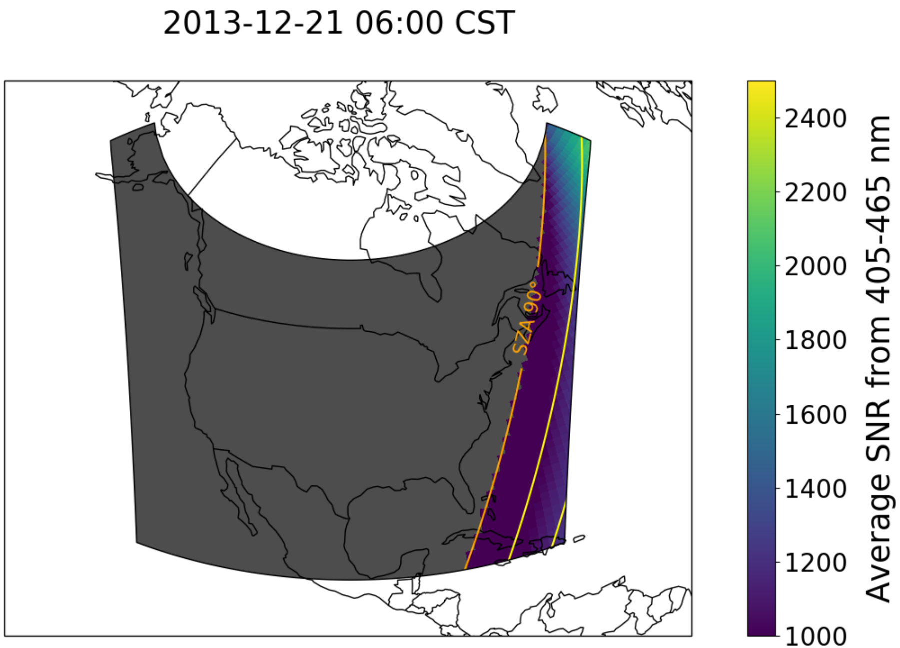
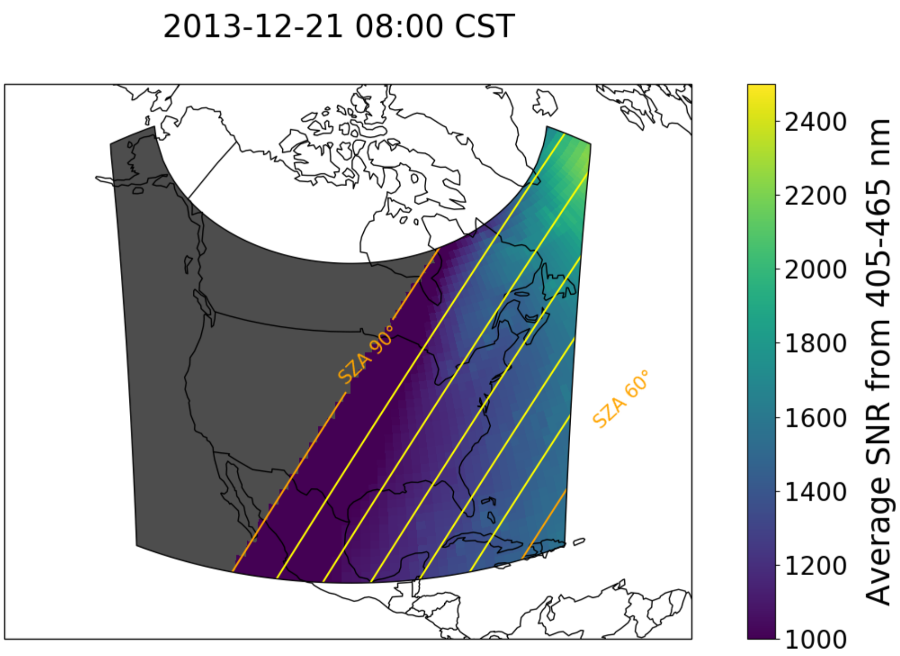


Summer Solstice

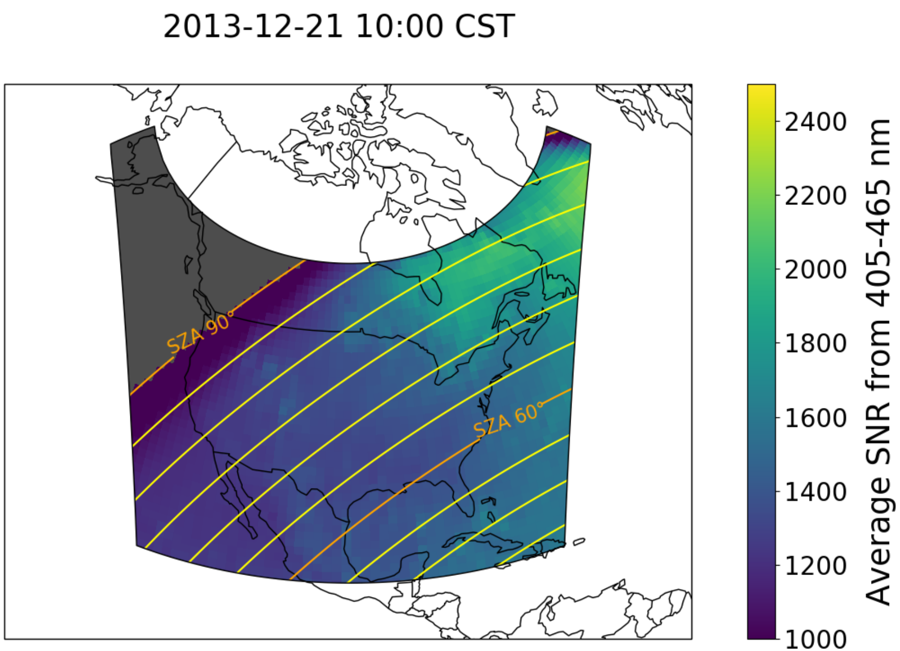
Winter Solstice



Winter Solstice



Winter Solstice



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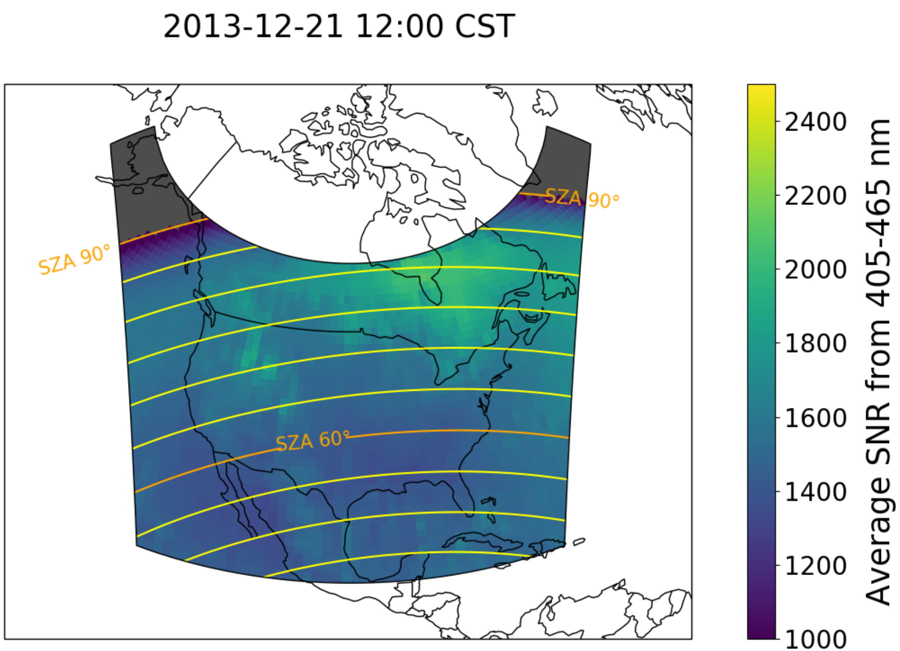

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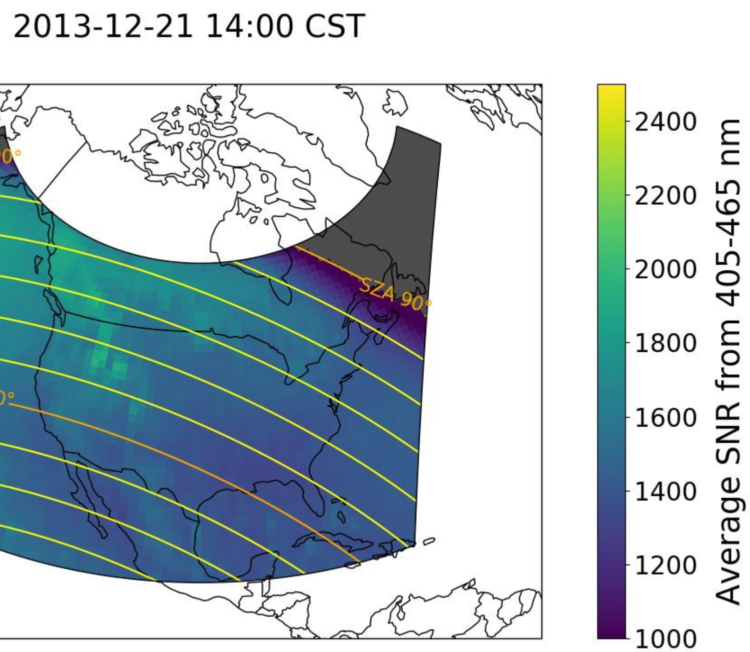

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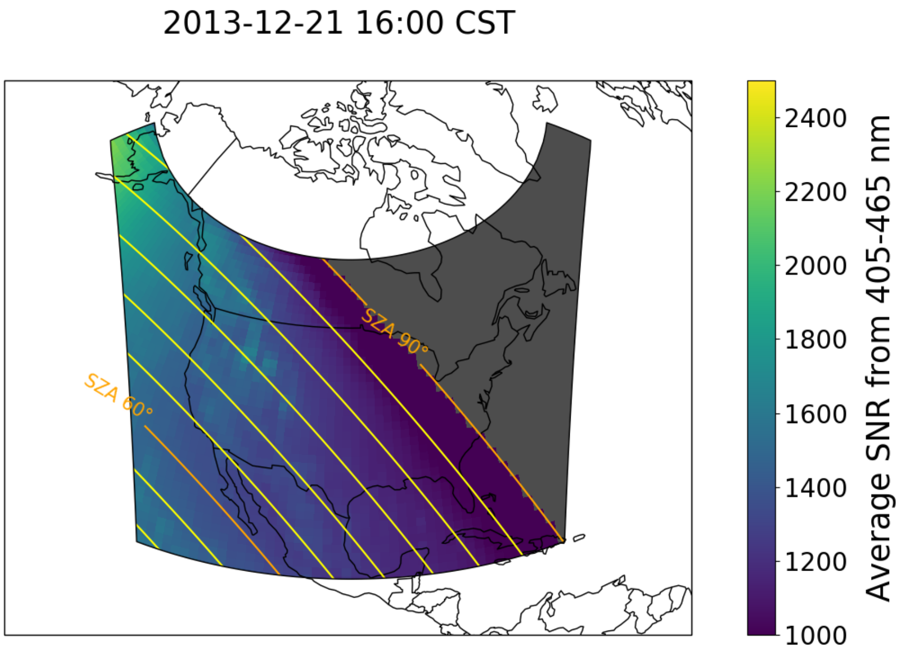

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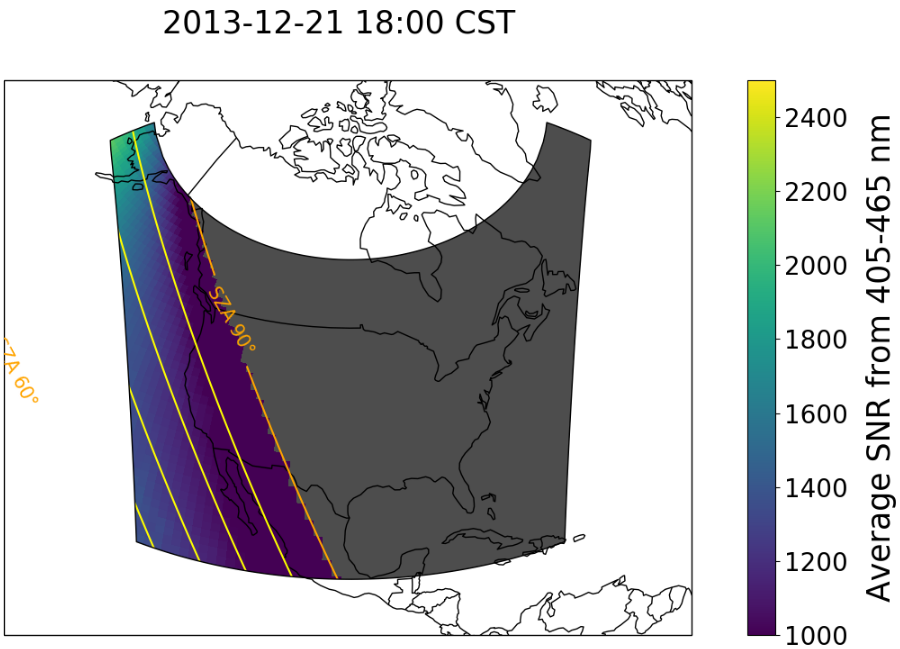


Winter Solstice

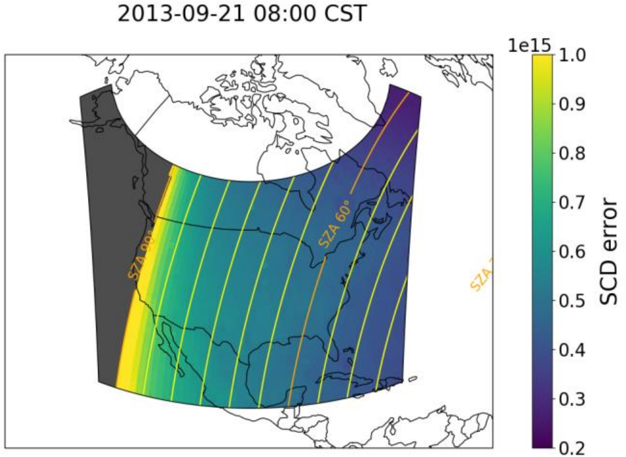
Retrieval

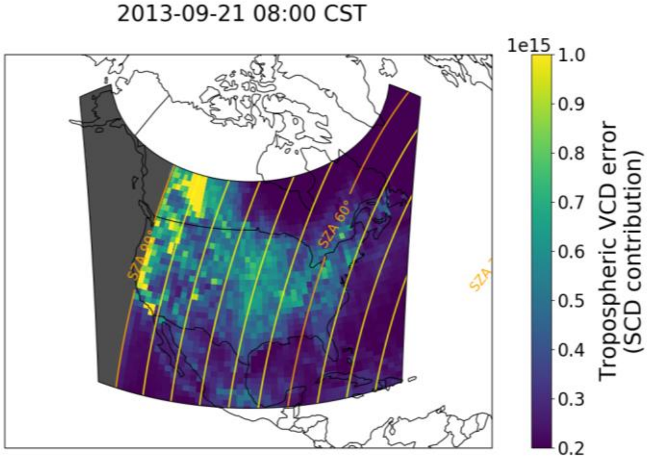
- SCD from spectral fitting in the 405-465 nm window
- Calculate 3 key contributors to tropospheric VCD variance following Bucsela et al. (2013) [1]
  - SCD fitting
  - Surface albedo variance
  - NO_2 profile variability

$$\sigma_{V_{trop}}^2 = \left(\frac{\sigma_S}{A_{trop}}\right)^2 + \left(\frac{A_{strat}\sigma_{V_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{strat}\sigma_{A_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{trop}\sigma_{A_{trop}}}{A_{trop}}\right)^2$$

$$\sigma_A^2 = \boldsymbol{J}_{\boldsymbol{R}}^{\boldsymbol{T}}(\boldsymbol{U} \cdot \sigma_R^2)\boldsymbol{J}_{\boldsymbol{R}} + J_w^T(U \cdot \sigma_w^2)J_w + J_{P_c}^T(U \cdot \sigma_{P_c}^2)J_{P_c} + \boldsymbol{J}_{\xi}^{\boldsymbol{T}}\boldsymbol{S}_{\xi}\boldsymbol{J}_{\xi}$$

SCD Variance

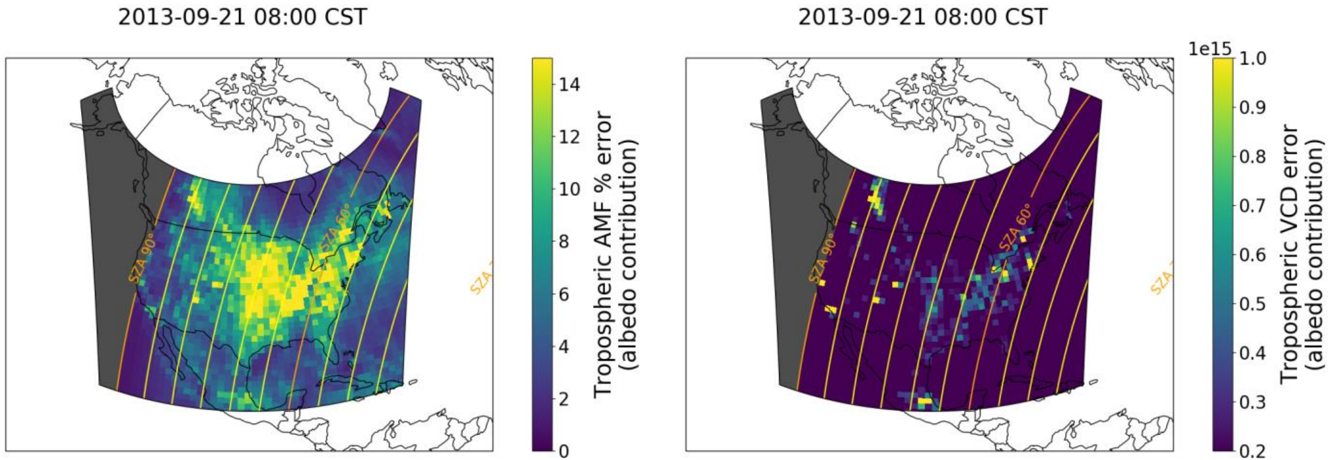




$$\sigma_{V_{trop}}^2 = \left(\frac{\sigma_S}{A_{trop}}\right)^2 + \left(\frac{A_{strat}\sigma_{V_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{strat}\sigma_{A_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{trop}\sigma_{A_{trop}}}{A_{trop}}\right)^2$$

$$\sigma_A^2 = \boldsymbol{J}_R^T(\boldsymbol{U}\cdot\sigma_R^2)\boldsymbol{J}_R + \boldsymbol{J}_w^T(\boldsymbol{U}\cdot\sigma_w^2)\boldsymbol{J}_w + \boldsymbol{J}_{P_c}^T(\boldsymbol{U}\cdot\sigma_{P_c}^2)\boldsymbol{J}_{P_c} + \boldsymbol{J}_\xi^T\boldsymbol{S}_\xi\boldsymbol{J}_\xi$$

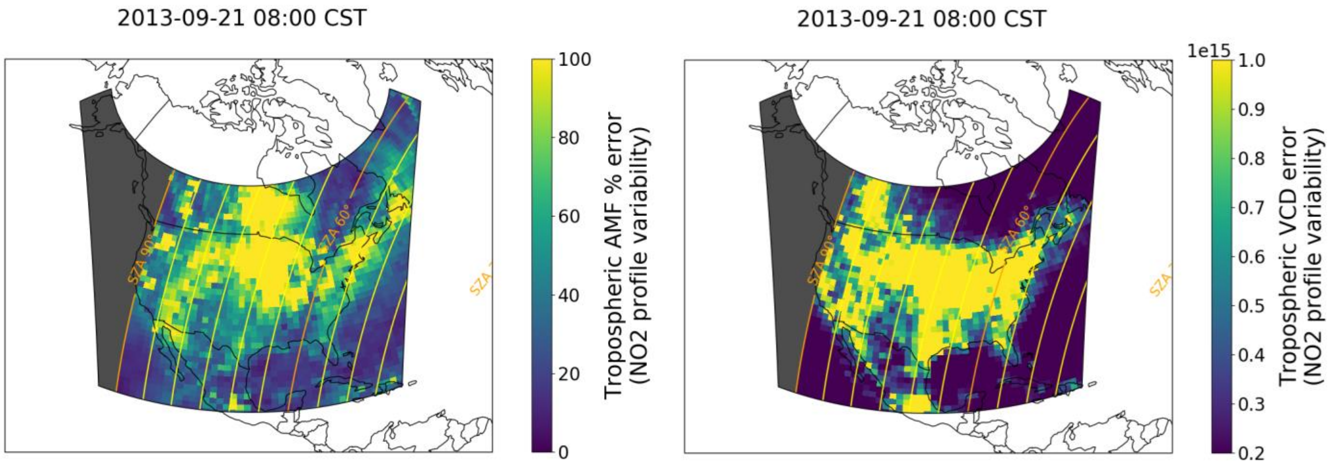
Albedo Variance



$$\sigma_{V_{trop}}^2 = \left(\frac{\sigma_S}{A_{trop}}\right)^2 + \left(\frac{A_{strat}\sigma_{V_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{strat}\sigma_{A_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{trop}\sigma_{A_{trop}}}{A_{trop}}\right)^2$$

$$\sigma_A^2 = \boldsymbol{J}_{\boldsymbol{R}}^{\boldsymbol{T}}(\boldsymbol{U}\cdot\sigma_R^2)\boldsymbol{J}_{\boldsymbol{R}} + \boldsymbol{J}_w^T(\boldsymbol{U}\cdot\sigma_w^2)\boldsymbol{J}_w + \boldsymbol{J}_{P_c}^T(\boldsymbol{U}\cdot\sigma_{P_c}^2)\boldsymbol{J}_{P_c} + \boldsymbol{J}_\xi^T\boldsymbol{S}_\xi\boldsymbol{J}_\xi$$

NO2 Profile Variability



$$\sigma_{V_{trop}}^2 = \left(\frac{\sigma_S}{A_{trop}}\right)^2 + \left(\frac{A_{strat}\sigma_{V_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{strat}\sigma_{A_{strat}}}{A_{trop}}\right)^2 + \left(\frac{V_{trop}\sigma_{A_{trop}}}{A_{trop}}\right)^2$$

$$\sigma_A^2 = J_R^T(U \cdot \sigma_R^2)J_R + J_w^T(U \cdot \sigma_w^2)J_w + J_{P_c}^T(U \cdot \sigma_{P_c}^2)J_{P_c} + \boldsymbol{J_\xi^T S_\xi J_\xi}$$

Conclusions

- All three major sources of NO_2 VCD uncertainty are on the order of 10^{15} cm^{-2} in polluted, low albedo areas
  - Trade-off between spatial resolution, precision, number of measurements per day
- Fewer daylit hours in winter is countered by increased albedo
  - Retrievals with SZA above 80 are more important and more feasible in winter
  - Only possible if snow-related issues can be dealt with

Future Work

- Continue to add details
  - Clouds
  - Stratospheric-tropospheric separation
- Look into effects of horizontal variability
- Investigate feasibility of different algorithms
  - Optimal estimation approach
  - Simultaneous 2D retrieval

References

[1] E. J. Bucsela, N. A. Krotkov, E. A. Celarier, L. N. Lamsal, W. H. Swartz, P. K. Bhartia, K. F. Boersma, J. P. Veefkind, J. F. Gleason, and K. E. Pickering. A new stratospheric and tropospheric NO2 retrieval algorithm for nadir-viewing satellite instruments: applications to OMI. Atmospheric Measuring Techniques, 6, 2607-2626, 2013.

[2] R. B. A. Koelemeijer, J. F. de Haan, and P. Stammes. A database of spectral surface reflectivity in the range 335–772 nm derived from 5.5 years of GOME observations. Journal of Geophysical Research, 108 (D2), 2003.

[3] Lu Hu, Christoph A. Keller, Michael S. Long, Tomas Sherwen, Benjamin Auer, Arlindo Da Silva, Jon E. Nielsen, Steven Pawson, Matthew A. Thompson, Atanas L. Trayanov, Katherine R. Travis, Stuart K. Grange, Mat J. Evans, and Daniel J. Jacob. Global simulation of tropospheric chemistry at 12.5 km resolution: performance and evaluation of the GEOS-Chem chemical module (v10-1) within the NASA GEOS Earth system model (GEOS-5 ESM). Geoscientific Model Development, 11, 4603-4620, 2018.