# Curved Ray Propagation Kernel - Theory and Implementation in NAF and ANOPP2

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# Outline

- New propagation capabilities have been added to NAF and ANOPP2 Codes to integrate realistic atmosphere affects (i.e., wind and temperature gradients).
- This is a two-part presentation
  1. Propagation Theory and Method (Stephanie Heath)
  2. Implementation and Usage (Leonard Lopes)
- First half of presentation explains the theory and methods implemented in the curved ray algorithm.
- Second half of presentation explains how algorithm is implemented in the Curved Ray Kernel (CRK) and used with NASA's Auralization Framework (NAF) and the second-generation Aircraft NOise Prediction Program (ANOPP2) acoustic codes.

# Why Enhance Propagation Capabilities?

- Previous studies of wind and temperature effects on measured helicopter noise show that the propagation effects can be significant.

- Reference “Validation of Ray Tracing Code Refraction Effects”, Heath, McAninch, Smith and Conner, AIAA-2008-2994.

- UAM vehicle operating environments (in relation to communities) require accurate prediction methods of noise over long distances, more accurate community impact.

# Curved Ray Algorithm

- Curved ray algorithm includes refractive effects of wind and temperature gradients not currently available using traditional straight line propagation techniques

- Algorithm is based on the Ray Tracing Propagation (RTP) code
  - "Propagation Effects of Wind and Temperature on Acoustic Ground Contour Levels", Heath and McAninch, AIAA-2006-411

- Ray equations use the Eikonal Equation and require point to point ray tracing (i.e., point and shoot rays and iterate launch angles until the ray connects the source and the observer)

# Curved Ray Equations for Stratified Media

Algorithm is based on the Ray Tracing Propagation (RTP) code. Reference AIAA-2006-411. This code is based on the Eikonal Equation using the slowness vector.

$$\bar{s}^2 = \frac{\Omega^2}{c^2}$$

where the slowness vector, $\bar{s}$, the ray wave front normal, $\bar{n}$, and $\Omega$, the ratio of sound speed to effective sound speed are defined as,

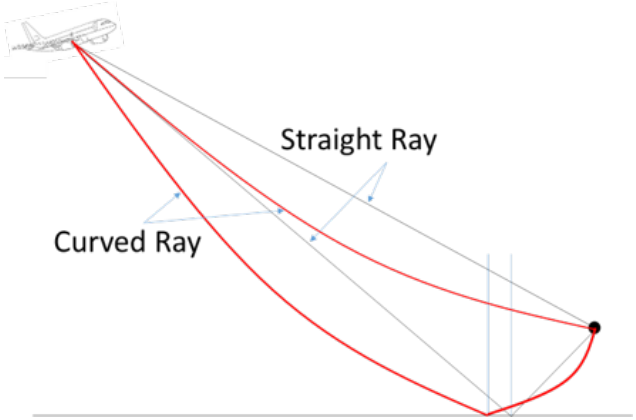
$$\bar{s} = \frac{\bar{n}}{c + \bar{w} \cdot \bar{n}} \qquad \bar{n} = \frac{c\,\bar{s}}{\Omega} \qquad \Omega = \frac{c}{c + \bar{w} \cdot \bar{n}}$$

In stratified atmospheric layers with linearly varying properties of z, and constant x and y slowness vector components, $s_x$ and $s_y$, along each ray, the z component of the slowness vector may be traced along the path defined by,

$$s_z = \pm \left[ \left( \frac{\Omega}{c} \right)^2 - s_x^2 - s_y^2 \right]^{1/2}$$

# What propagation rays are included at the observer?

- Currently two rays are calculated at the observer
  - Direct ray between source and observer
  - Shortest indirect ray from the source to the observer
- Iterate over both azimuthal and elevation angles to find both ray paths



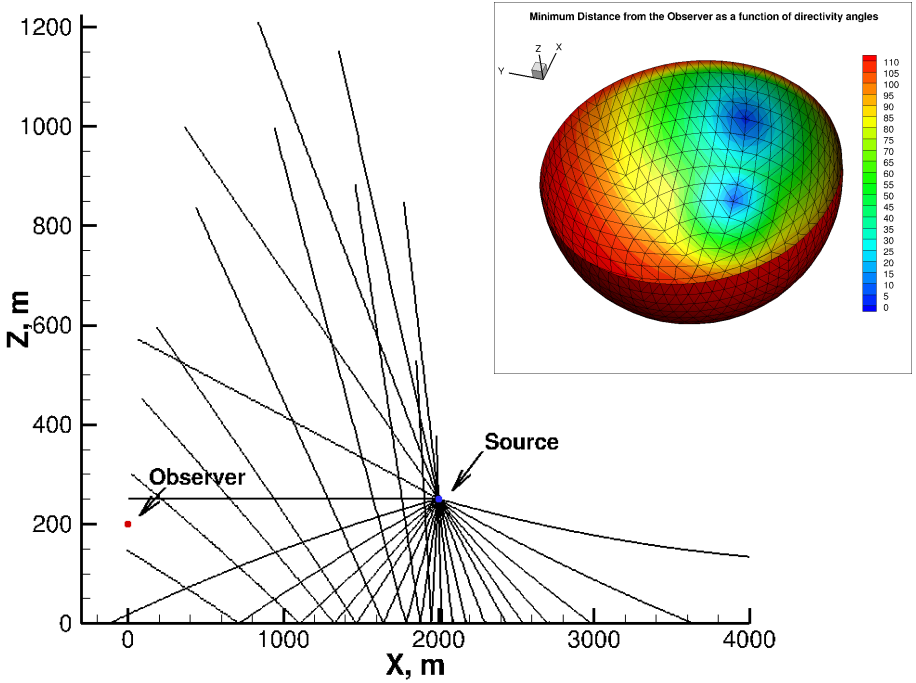
# Part 2: Implementation of Curved Ray Algorithm

- Two frameworks under development and supported by NASA
  - NASA's Auralization Framework (NAF) (POC Steve Rizzi)
  - Second Generation Aircraft NOise Prediction Program (ANOPP2) (POC Leonard Lopes)
- Each framework has different audience and application but relies on common algorithms
  - Acoustic analysis metrics such as EPNL
  - ANOPP-based source noise
- Inefficient to implement curved ray algorithm in both codes
- Common code base that is used by both frameworks
  - Concurrent development
  - Reduce code base and testing requirements
  - Reduce errors and faster debugging

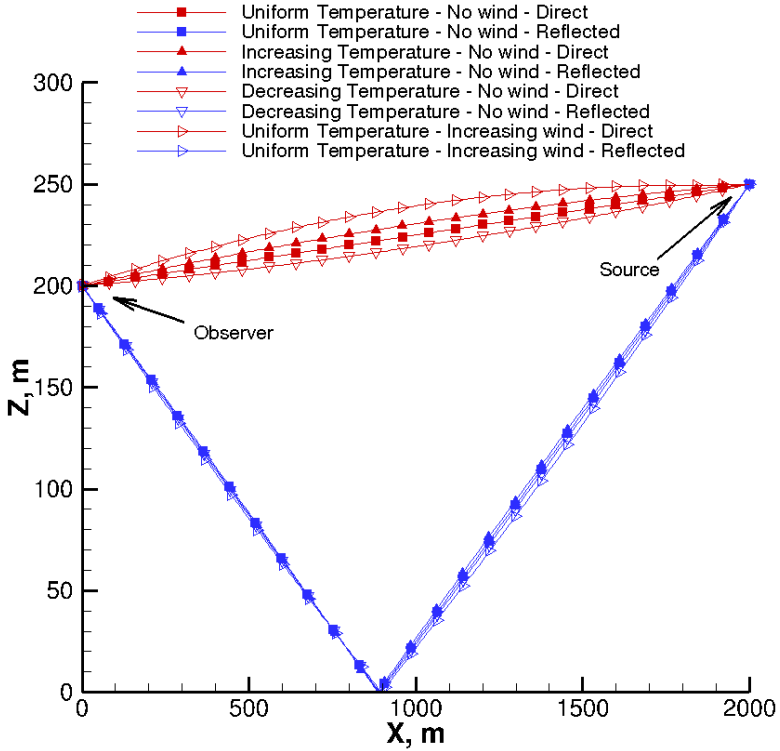
1. Algorithm implemented in Curved Ray Kernel (CRK)
2. CRK is used by NAF and ANOPP2's Curved Ray Module (ACRPIFM)

# CRK Finds The Rays

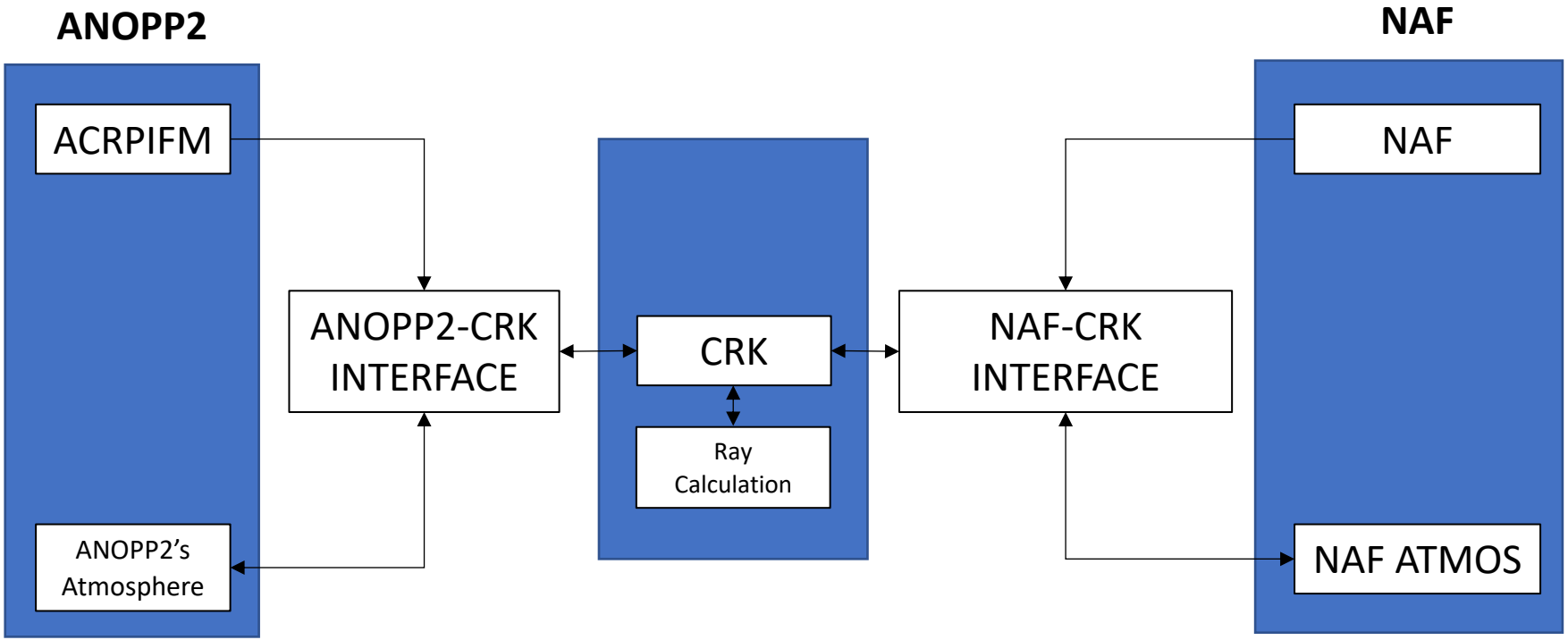
## Distance Between Ray And Observer



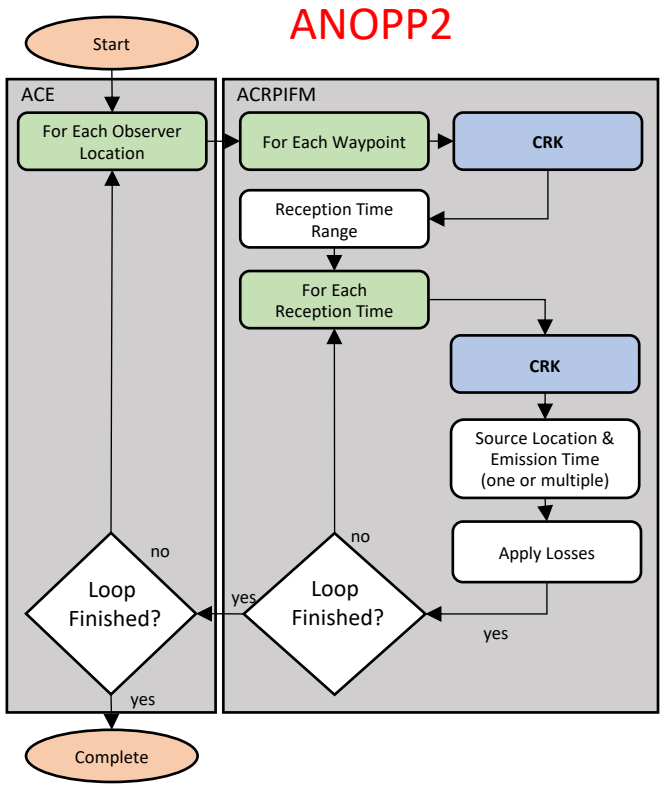

## Iterates To Find The Eigen Rays

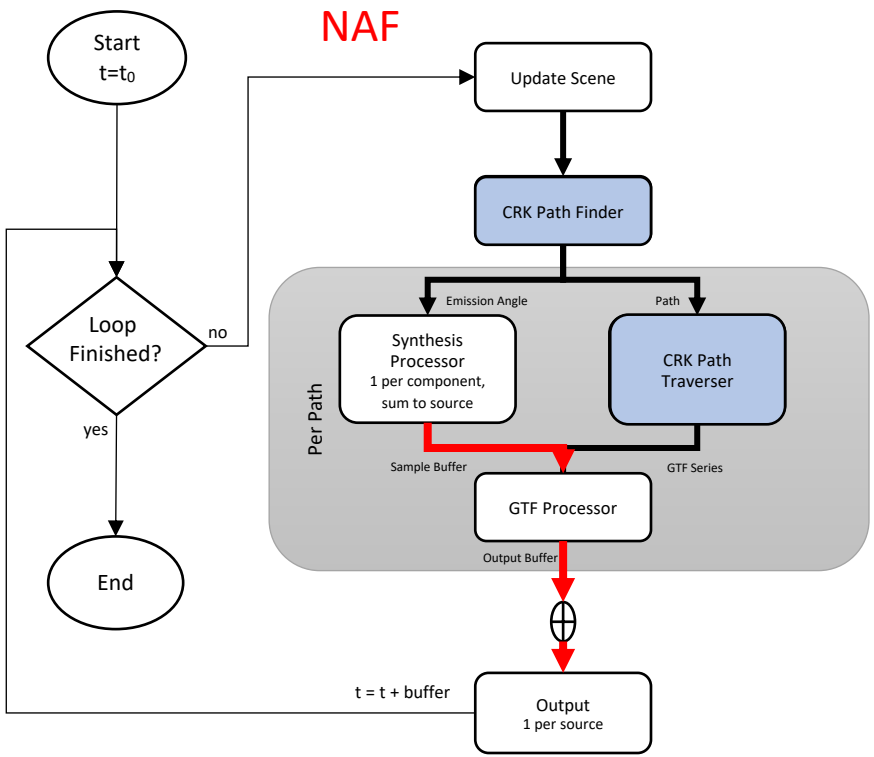


# Leveraging the Common Kernel



# Usage of CRK in ANOPP2 and NAF



# Loss Calculations

- NAF and ANOPP2 have each retained their own version of atmospheric absorption and ground loss
  - Very similar, nearly identical operations
  - NAF is applied in time domain via GTF operation and ANOPP2 is applied in frequency domain via ΔdB

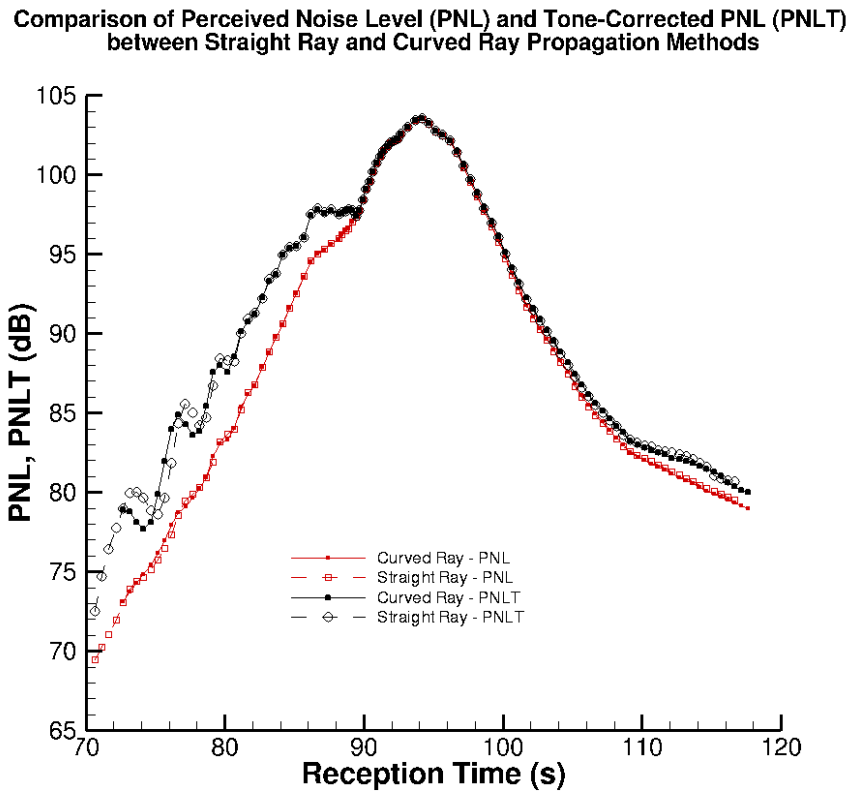
- These losses include the following
  - Conventional spreading based on area ratios
  - Atmospheric absorption
  - Ground impedance
  - Doppler shifts

- Time and distance are tracked consecutively along the ray, providing accurate location and phase information at the observer.

# ANOPP2 Example PNL/PNLT for Representative Vehicle

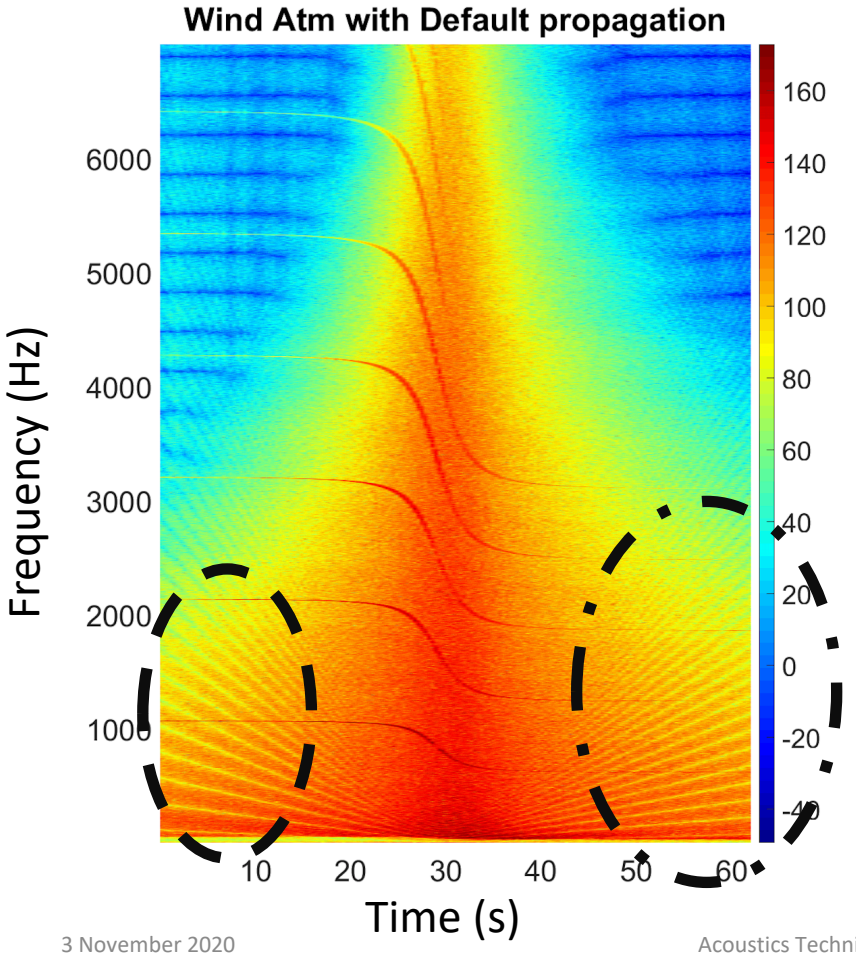
Representative 737-like vehicle undergoing takeoff (microphone underneath)

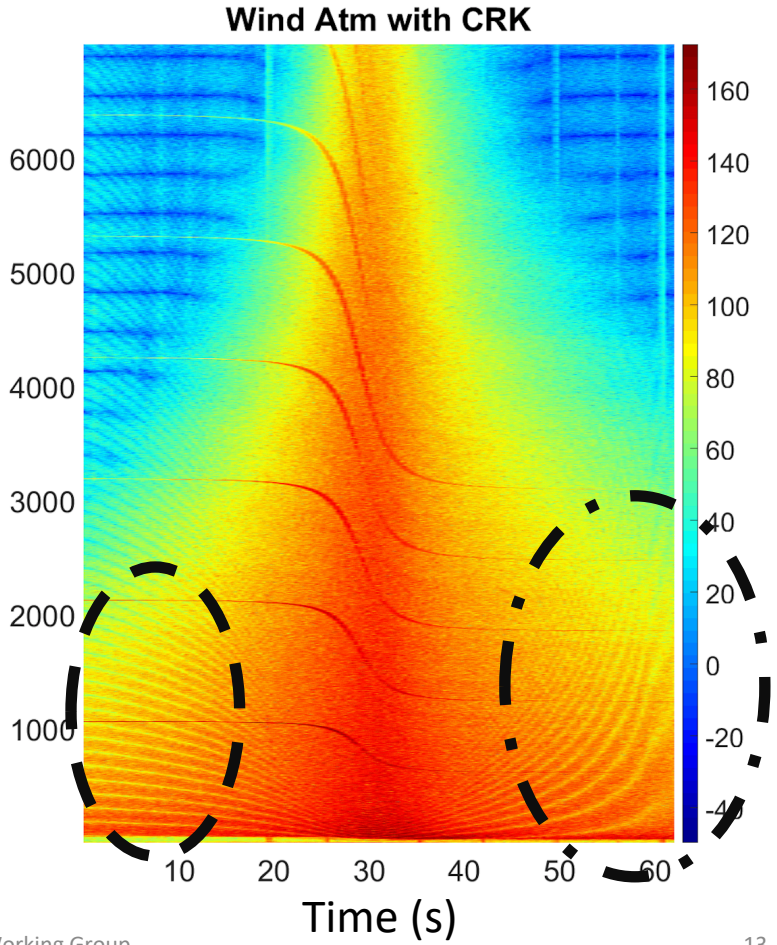
Differences between curved and straight ray at extreme emission angles (as expected)



# NAF Example Prediction

https://stabserv.larc.nasa.gov/flyover/



# Summary, Future Work, and Release Dates

Summary

- Added the Curved Ray Kernel (CRK) to the NAF and ANOPP2 propagation capabilities
- Combined wind and temperature propagation effects are calculated at the observer
- Turning rays are accounted for using closed form solutions for quick and easy ray tracing
- Preliminary demonstrations showing temperature and wind cases in both the NAF and ANOPP2 codes

Future Work

- Future work will further simplify the ray tracing method by connecting the source to the observer through mathematics
  - This will eliminate the need to iterate on a point and shoot method to find the connecting ray
  - Identify and address caustics and shadow regions
- Further applications of curved ray propagation to understand impact and importance

Preliminary Release Dates

- NAFv1.2 around 6/30/2021
- ANOPP2v1.4 around 6/30/2022 (Beta available now to NASA personnel)
- CRKv1.0 embedded within NAF (potentially in 2021) and ANOPP2 distributions

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