OSSE - based Mission and Instrument Concept Exploration

Meemong Lee, PhD
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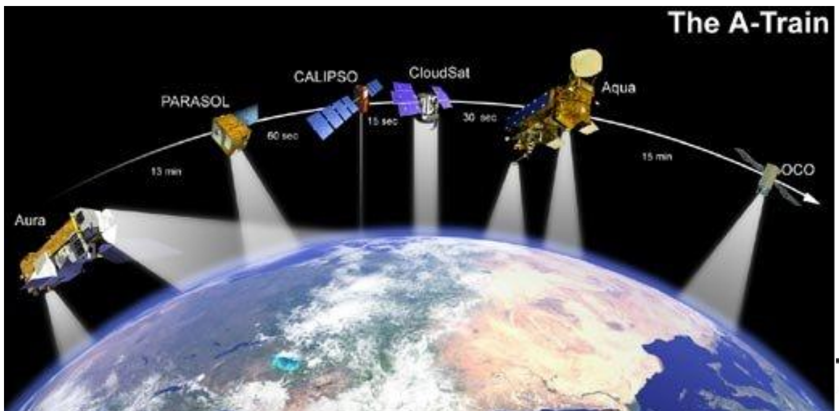
Kevin Bowman, PhD

Jet Propulsion Laboratory
California Institute of Technology

❖Background

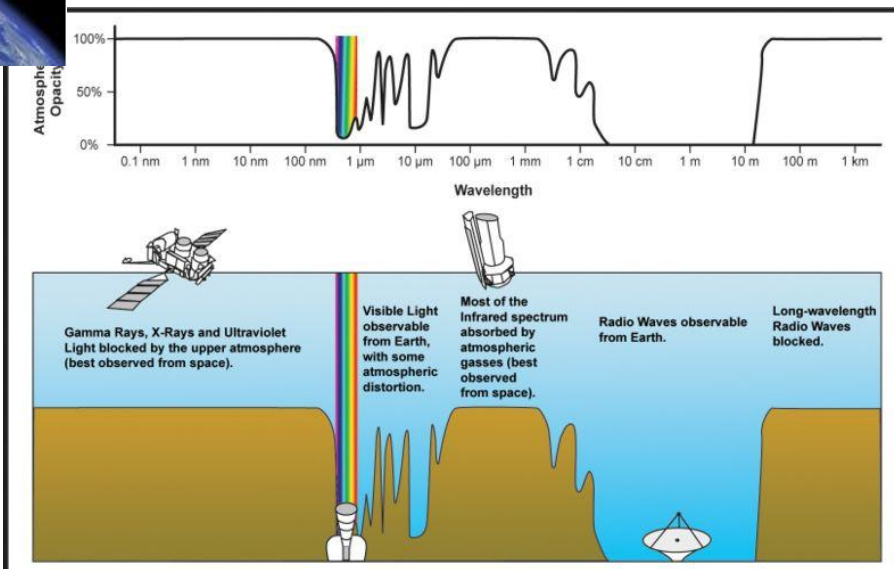
SOX

Atmospheric sounding



Spectral lines are highly atom-specific, and can be used to identify the chemical composition of any medium capable of letting light pass through it.

An **atmospheric sounding** is a measurement of vertical distribution of physical properties of the atmospheric column such as pressure, temperature, wind direction, liquid water content, ozone concentration, pollution, and other properties.



Measurement Physics

Satellite instruments (active and passive) simply measure the RADIANCE *L* that reaches the top of the atmosphere at given frequency *v* . The measured radiance is related to geophysical atmospheric variables (T,Q,O_3) by the radiative transfer equation

$$L(\nu) = \int_0^{\infty} B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots$$

$$L(\nu) \approx \int_0^{\infty} B(\nu, T(z)) \left[\frac{dTR(\nu)}{dz} \right] dz$$

B : *Planck function*
TR : *transmittance*
T(z) : *temperature*
Z : *altitude*

SOX

Atmospheric state modeling

GEOSChem

Emissions

Aircraft emissions
Anthropogenric emissions
Biofuel emissions
Biogenic emissions
Biomass burning emissions
Lightning NOx emissions
Ship emissions
Soil NOx emissions
Volcanic emissions

Aerosols

Sulfate aerosols
Sea salt aerosols
Mineral dust aerosols
Cabonaceous aerosols
Aerosol optical properties
Aerosol microphysics

Deposition

Dry deposition
Wet deposition

MET fields

GMAO GEOS-4
GMAO GEOS-5
GMAO MERRA

Chemistry

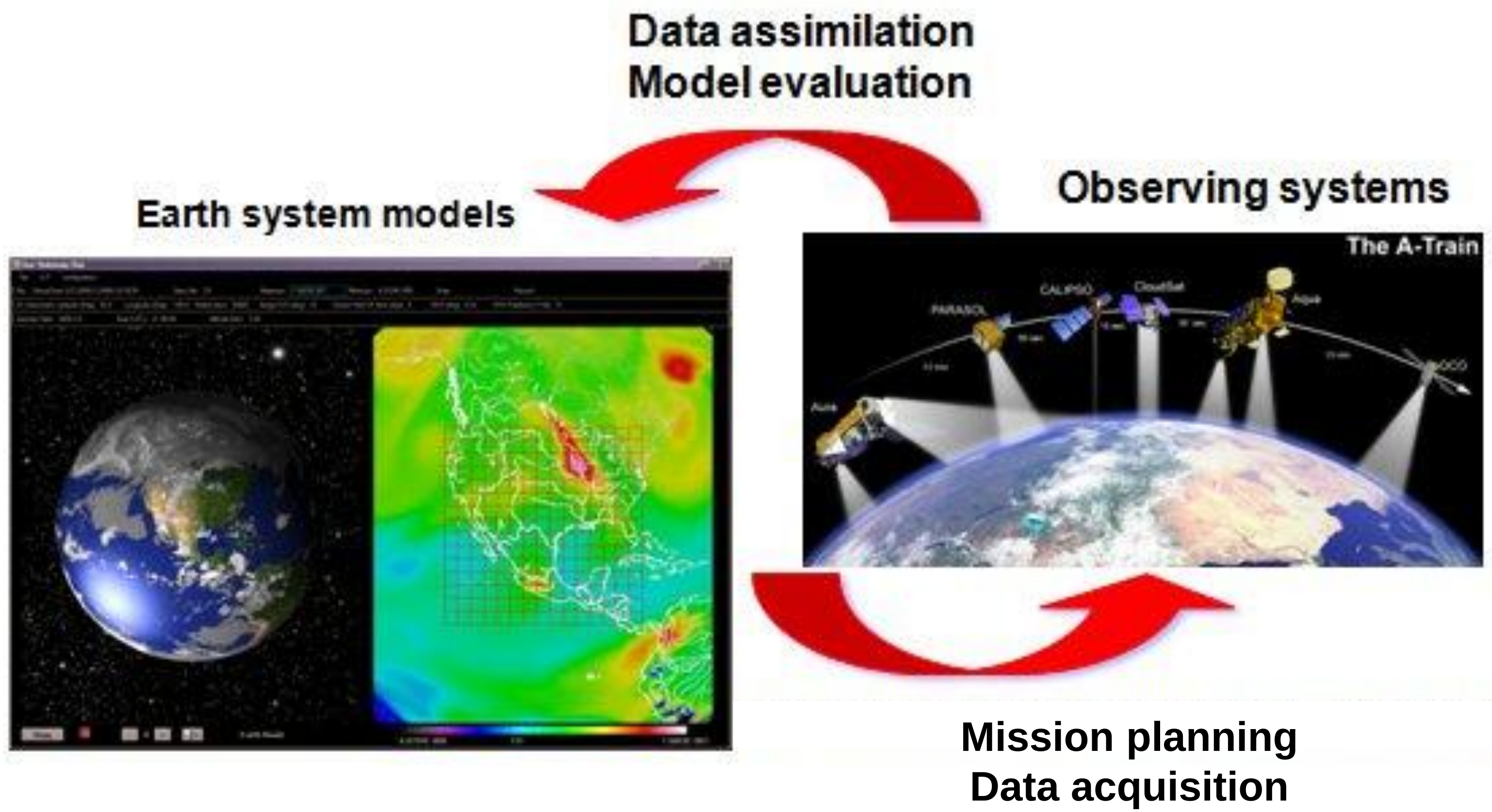
Nox-Ox-hydrocarbon-aerosol
KPP chemical solver
Linoz stratospheric ozone chemistry
FAST-J photolysis mechanism
Dicarbonyls simulation
Bromine chemistry mechanism
CMAQ inteface

Dynamics

Advection (TPCORE).
Boundary layer mixing
Cloud convection,
Dynamic tropopause

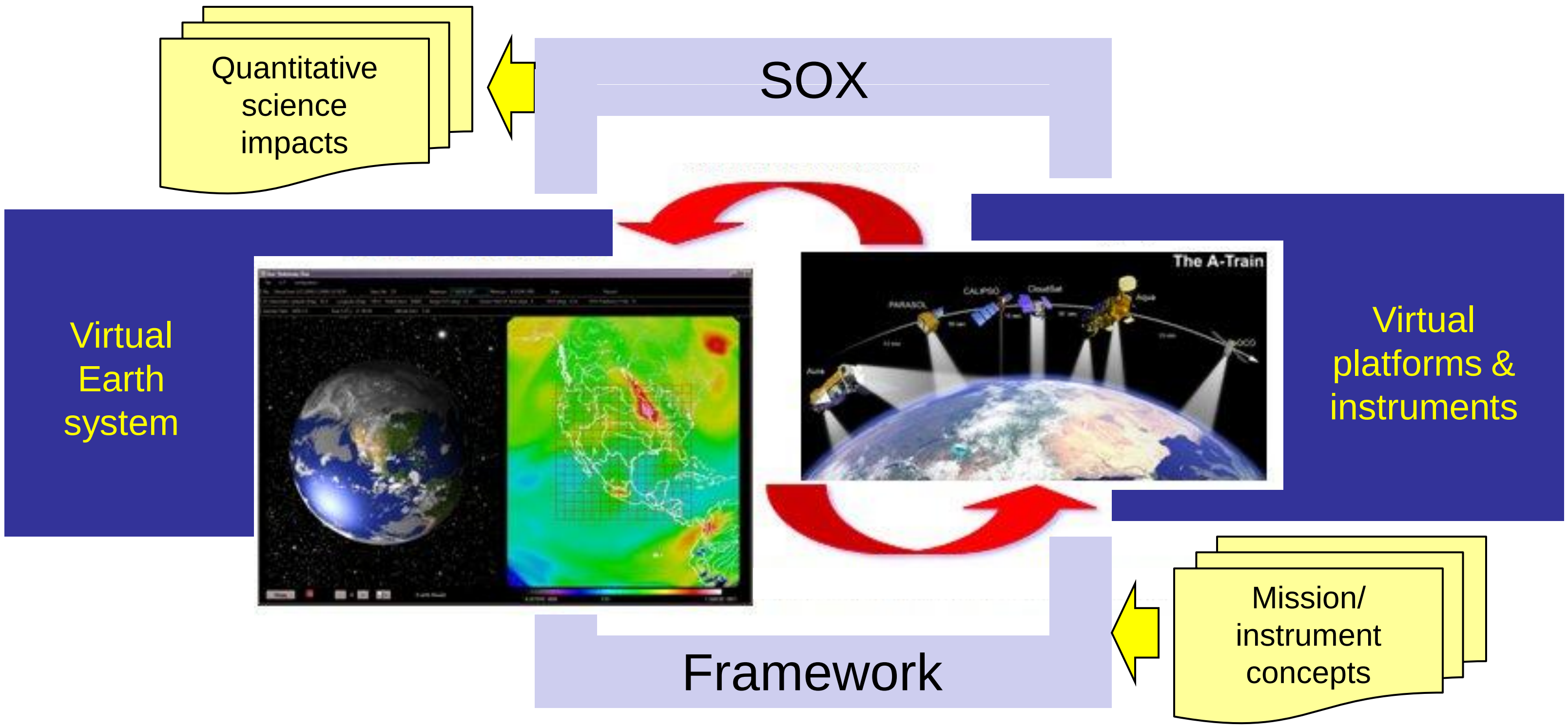
SOX

Emerging paradigm



❖SOX framework

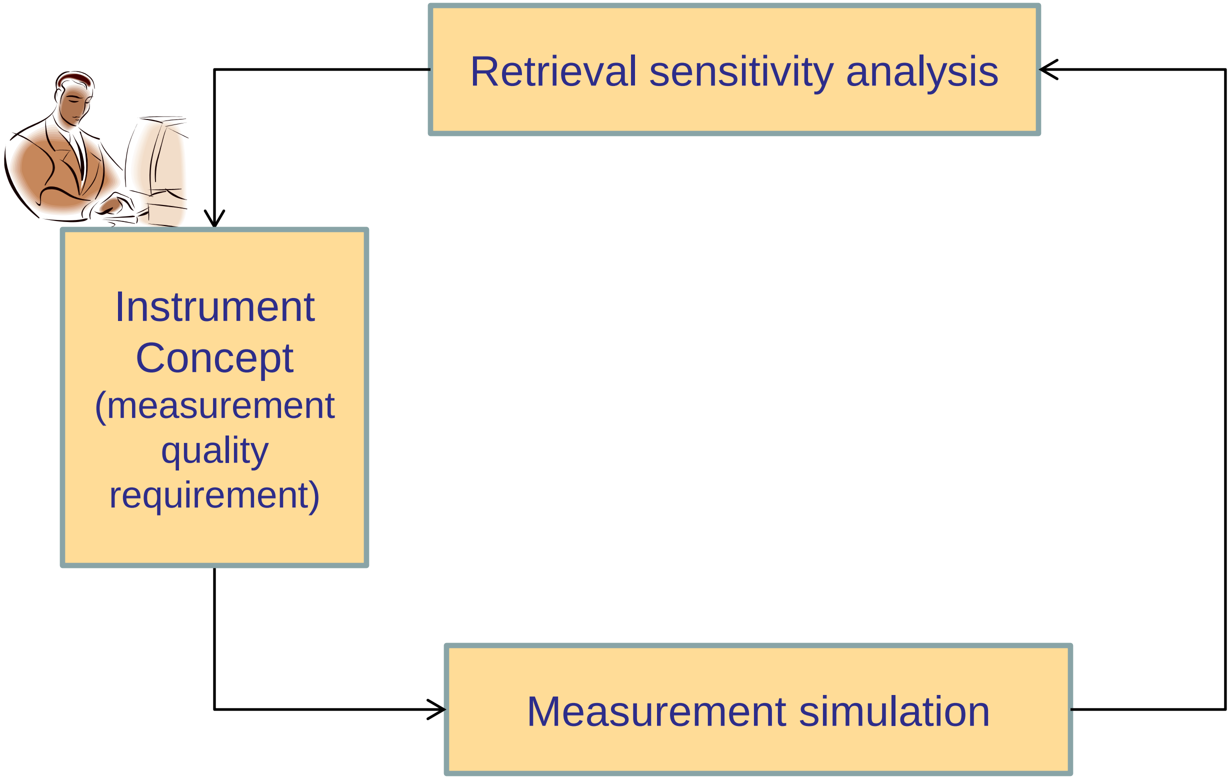
Observing system simulation experiment (OSSE)



SOX: Sensor-web Observation Explorer

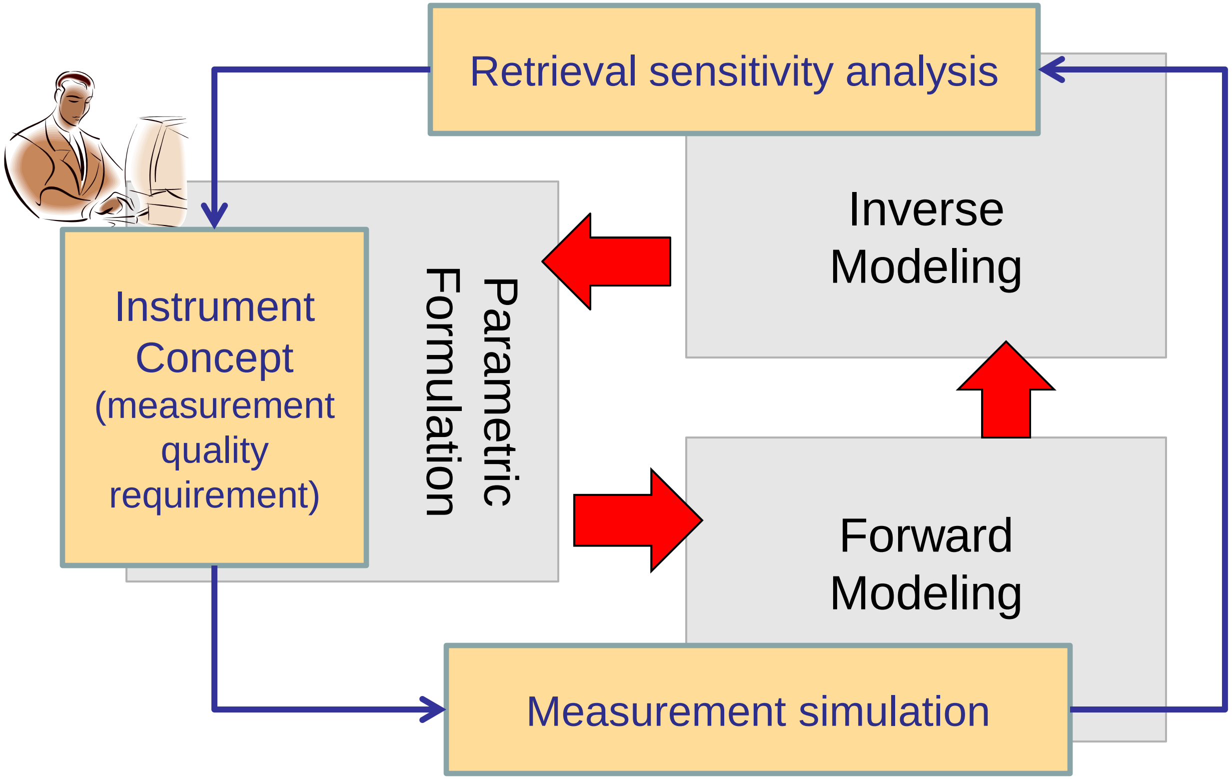
SOX

Instrument concept exploration



SOX

Instrument concept exploration



Parametric Formulation

What to measure?

Spectral coverage (IR, UV, IR+UV)

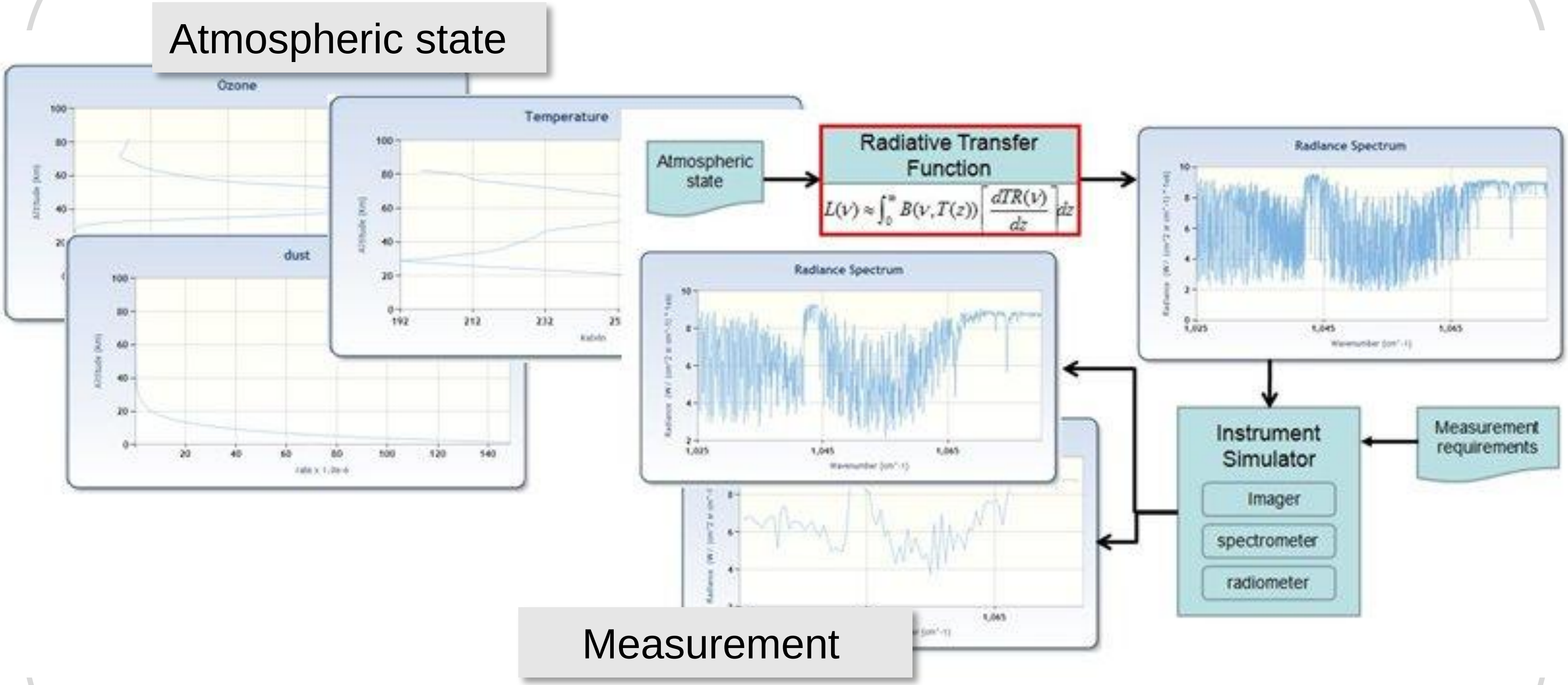
How precisely?

Spatial & spectral resolution

How accurately?

SNR/ NESR, channel linearity

Forward Modeling

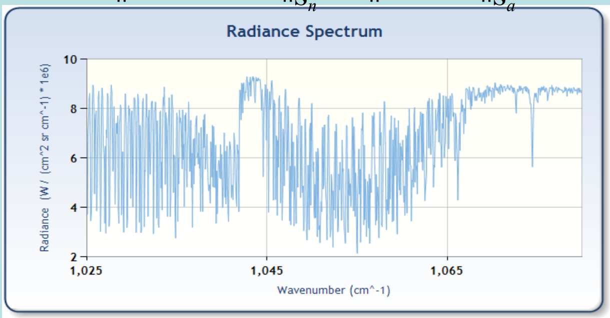


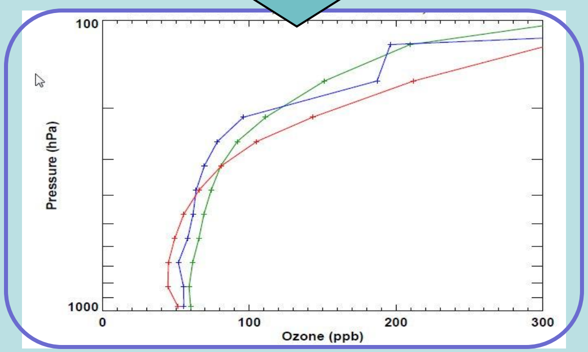
SOX

Inverse Modeling

Retrieval analysis

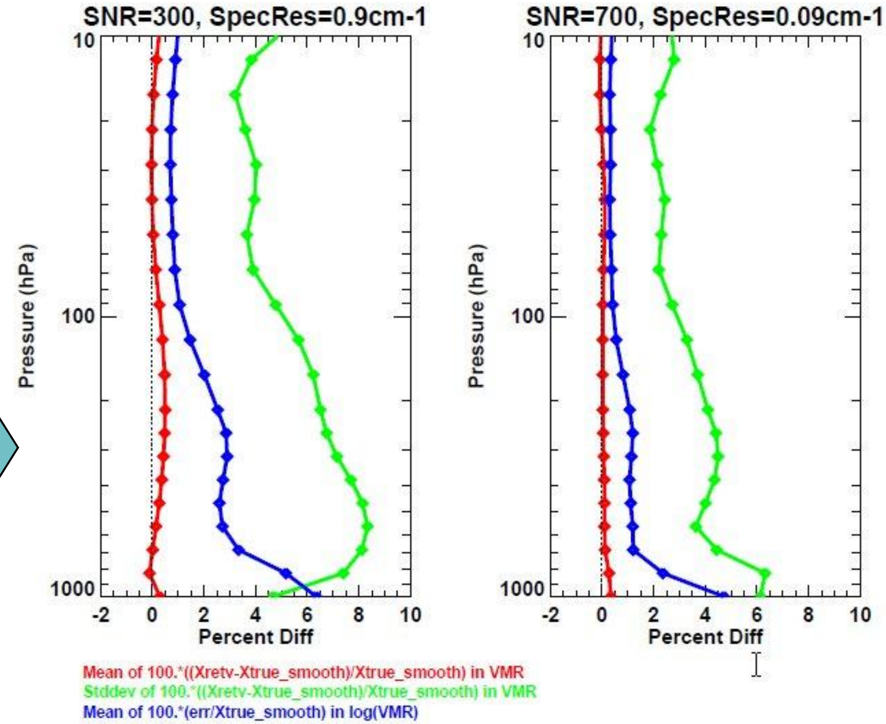
$$\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\|^2_{\mathbf{S}_n^{-1}} + \|\mathbf{x}-\mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$$



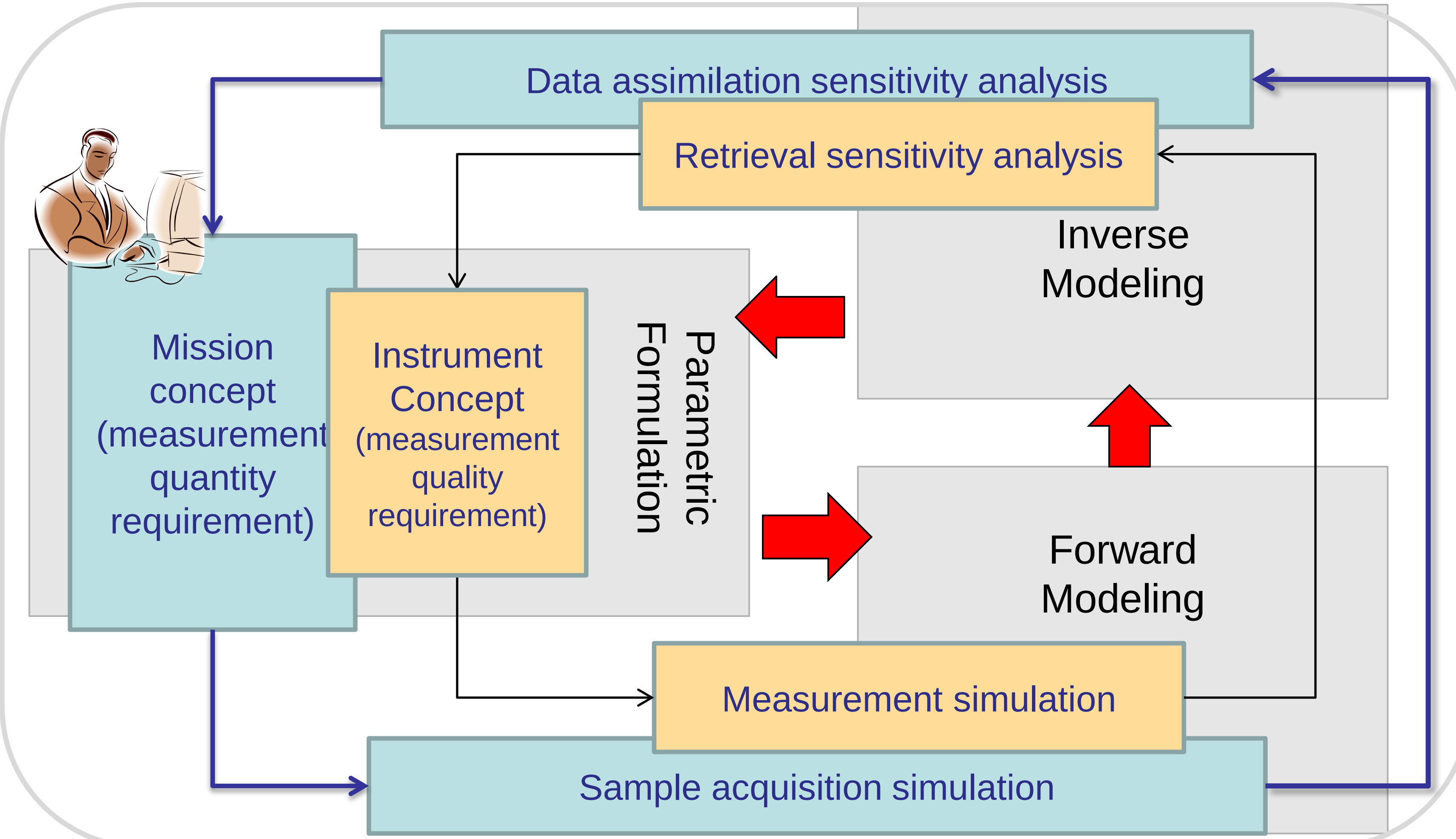


$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}(\mathbf{x}-\mathbf{x}_a) + \mathbf{Gn}$$

O3 retrieval performance sensitivity



Mission concept exploration



Parametric Formulation

What to measure?

O_3, CO, CO_2

Where?

Land, Ocean, Coast, Globe, N. America

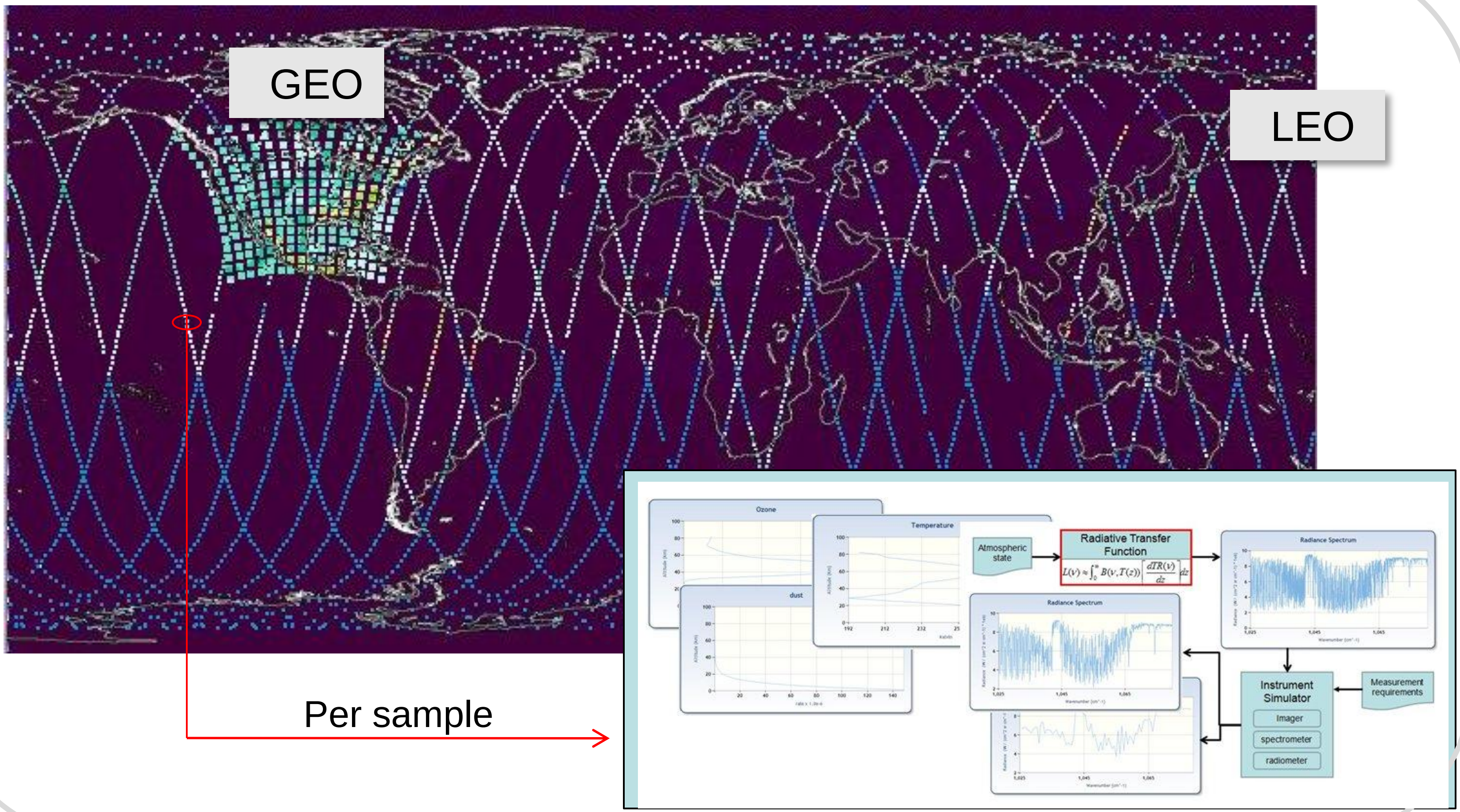
When?

Day, Night, anytime

How often?

hourly, daily, monthly

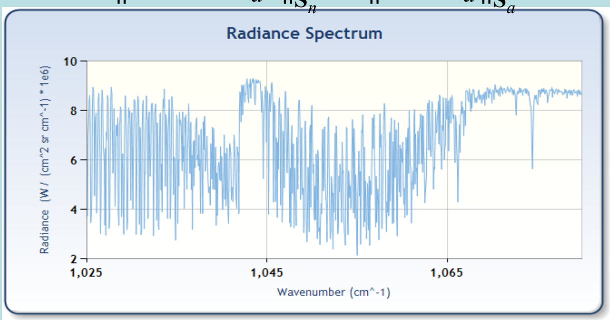
Forward Modeling

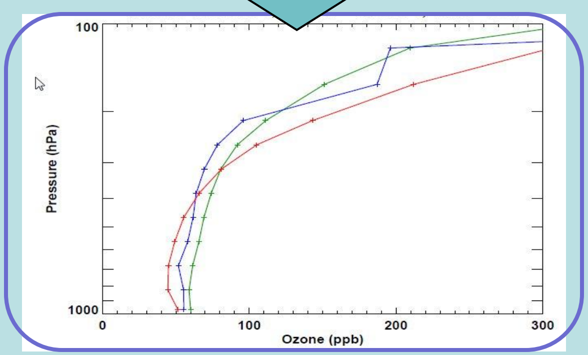


Inverse Modeling

Retrieval analysis

$$\left\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\right\|^2_{\mathbf{S}_n^{-1}}+\left\|\mathbf{x}-\mathbf{x}_a\right\|^2_{\mathbf{S}_a^{-1}}$$



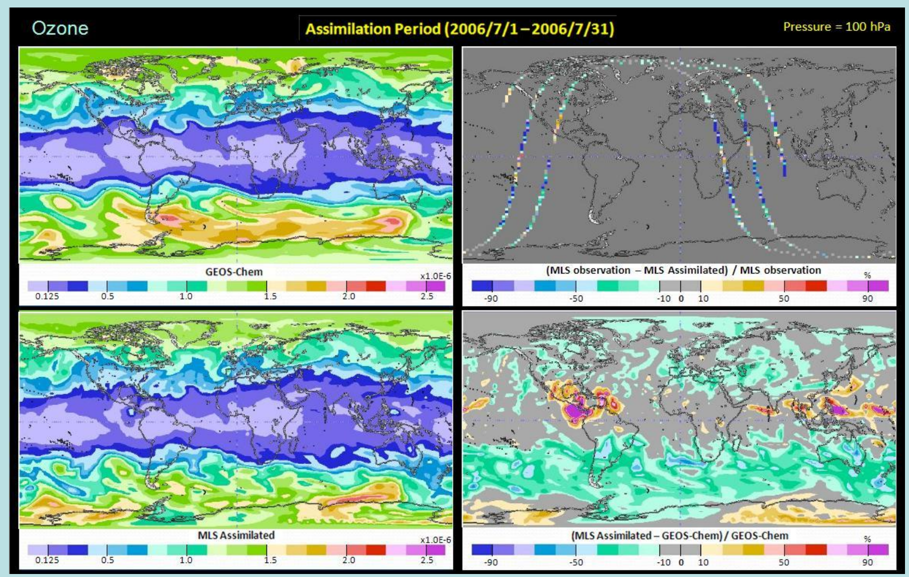


$$\hat{\mathbf{x}}=\mathbf{x}_a+\mathbf{A}(\mathbf{x}-\mathbf{x}_a)+\mathbf{G}\mathbf{n}$$

Assimilation analysis

$$\mathbf{H}_i(\bullet)=\mathbf{x}_a+\mathbf{A}_i(\bullet-\mathbf{x}_a)$$

$$\sum_i\left\|\hat{\mathbf{x}}_i-\mathbf{H}_i(\mathbf{x})\right\|^2_{(\mathbf{G}_i\mathbf{S}_n^i\mathbf{G}_i^T)^{-1}}+\left\|\mathbf{x}_0-\mathbf{x}_B\right\|^2_{\mathbf{B}^{-1}}$$



❖OSSE PROCESS

SOX

Service-oriented process

❖Linear

designed as a series of steps

❖Chronological

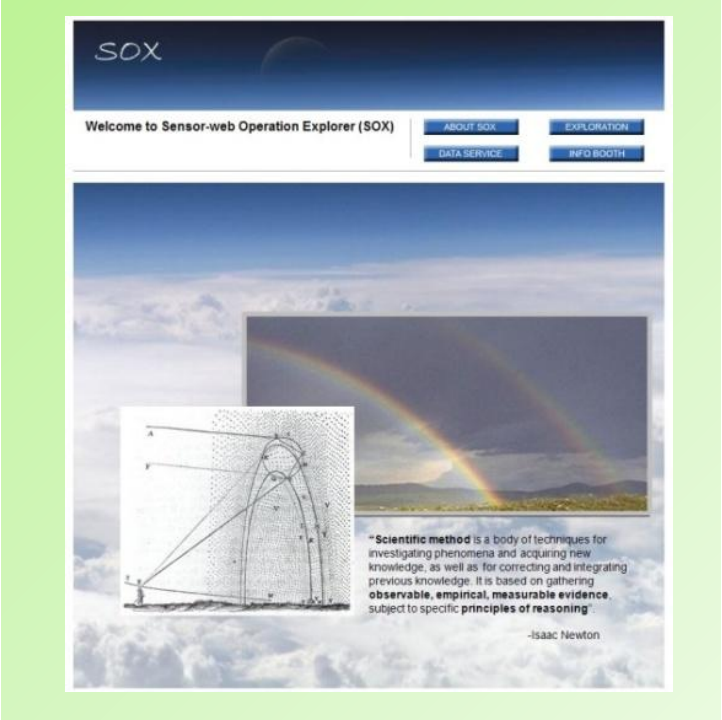
steps executed in time-sequence

❖Cumulative

adding value at each step

❖Synchronous

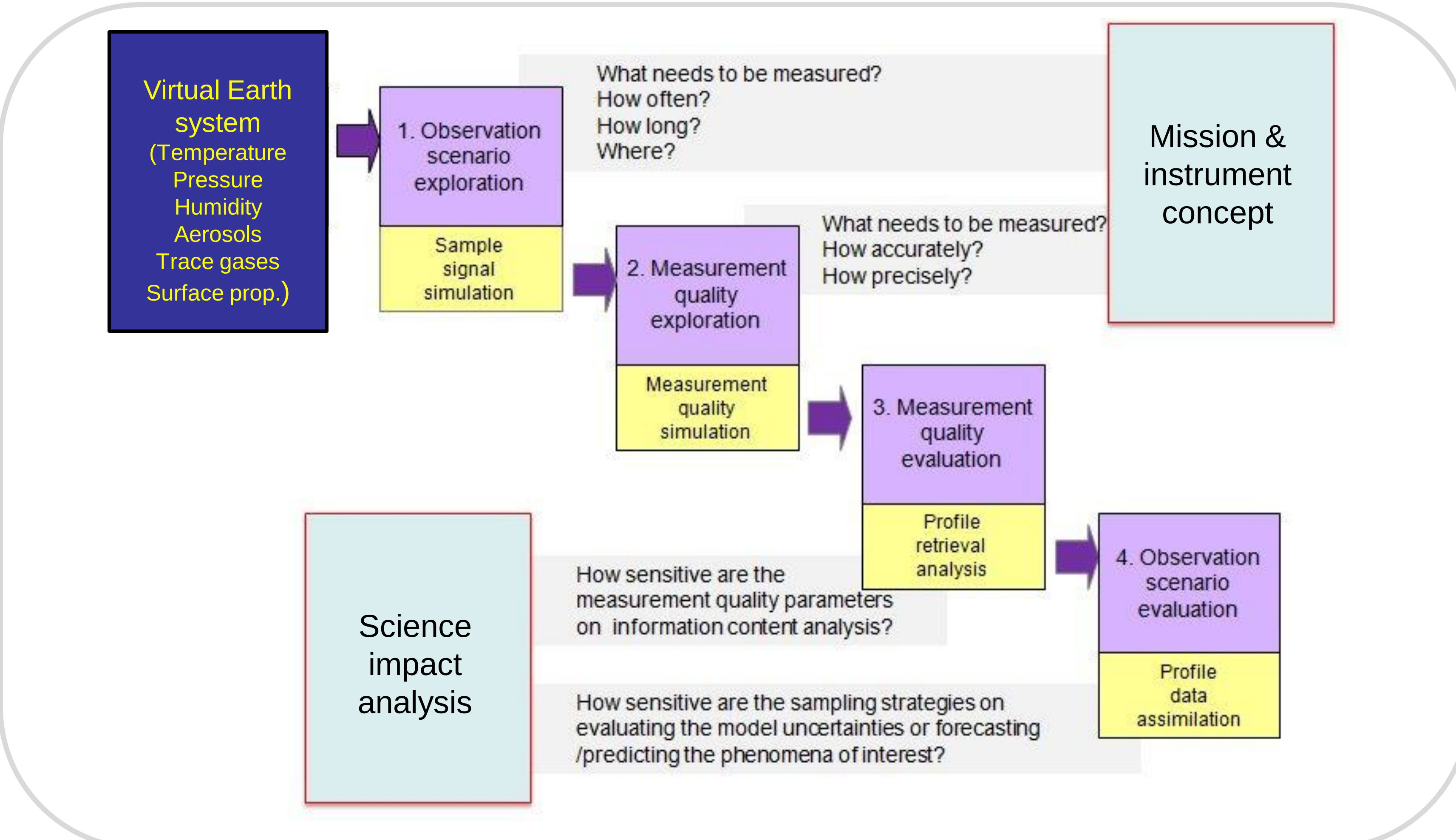
each step dependent and waiting upon the previous steps.



- Henry Ford

SOX

OSSE process flow



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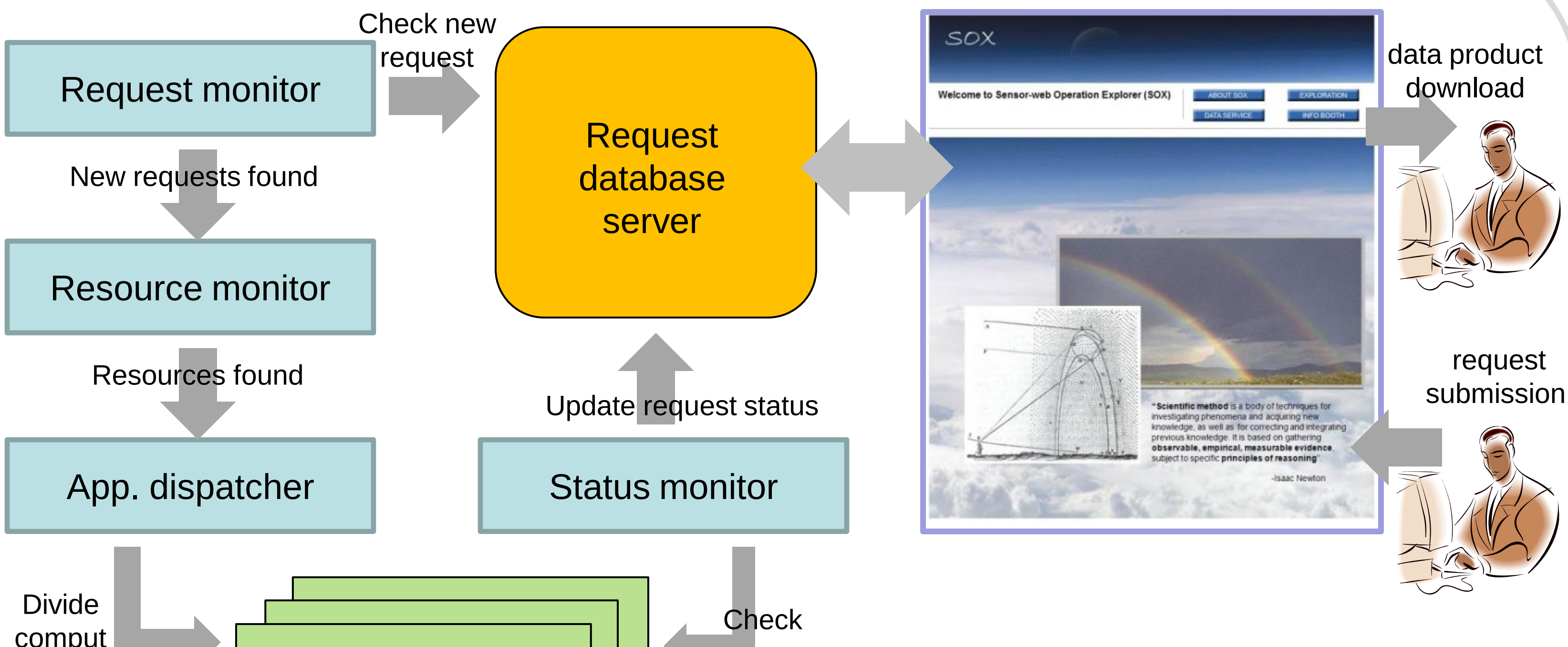
Process flow



Applications include:
- Atmospheric state generator
- Radiative transfer model
- Multi-instrument retrieval analysis
- GeosChem-3Dvar assimilation

❖**Technology infusion**

GEOCAPE - OSSE

Annmarie Eldering (JPL)
Susan kalaweik (JPL)
Ming Luo (JPL)
Meemong Lee (JPL)
Zheng Qu (Raytheon)

Technology Infusion

GEOCAPE mission study team led by Dr. Annmarie Eldering utilized the SOX framework for validating instrument concepts and exploring alternative observation scenarios.

Instrument concept →

	coverage (wn)	resolution (wn)	SNR
IR (6)	970-1080	0.6, 0.06	300,500,700
UV (3)	29000-37200	82	300,500,700
IR+UV (18)	All combinations of the above		

wn: wave number (1/wave length in cm)

Observation scenario →

Orbit : GEO stationary
Target area: O_3 over North America
Footprint coverage : 16 x 16 (~2deg x 2 deg)
Sampling frequency : 3 hours
No. of instruments: IR only, UV only, and IR+UV
Experiment duration : July/1 – July/7

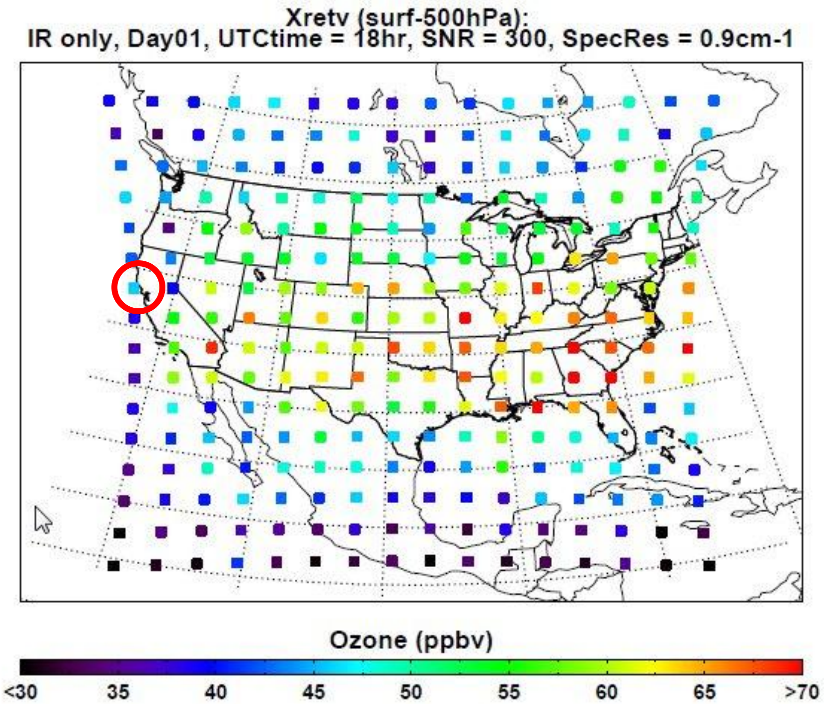
RTMs →

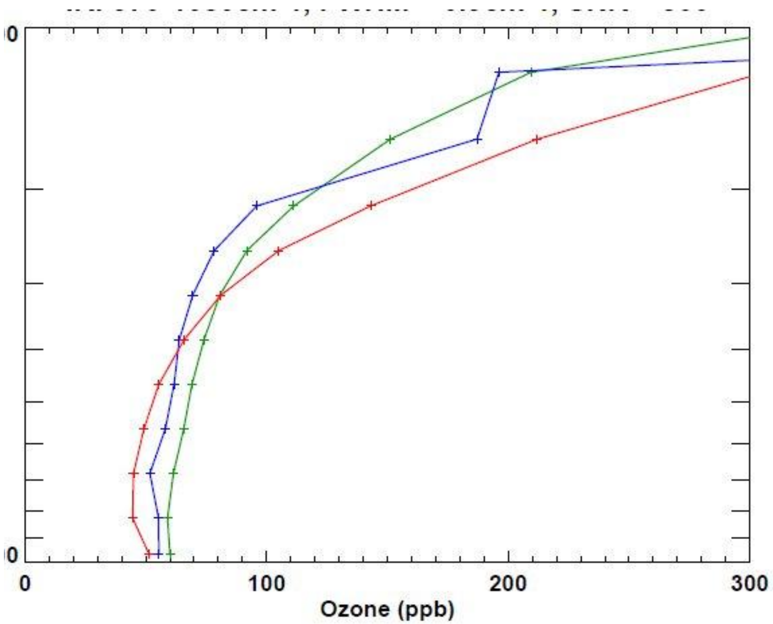
IR : LBLRTM (Line by line radiative transfer model)
UV: LIDORT (linearized discrete ordinate radiative transfer model)

Daily samples: 16x16x8 = 2048 Daily measurements: 2048*(6+3+18) = 55296

GEOCAPE-OSSE

IR: 970-1080 cm-1, FWHM = 0.9 cm-1, SNR = 300

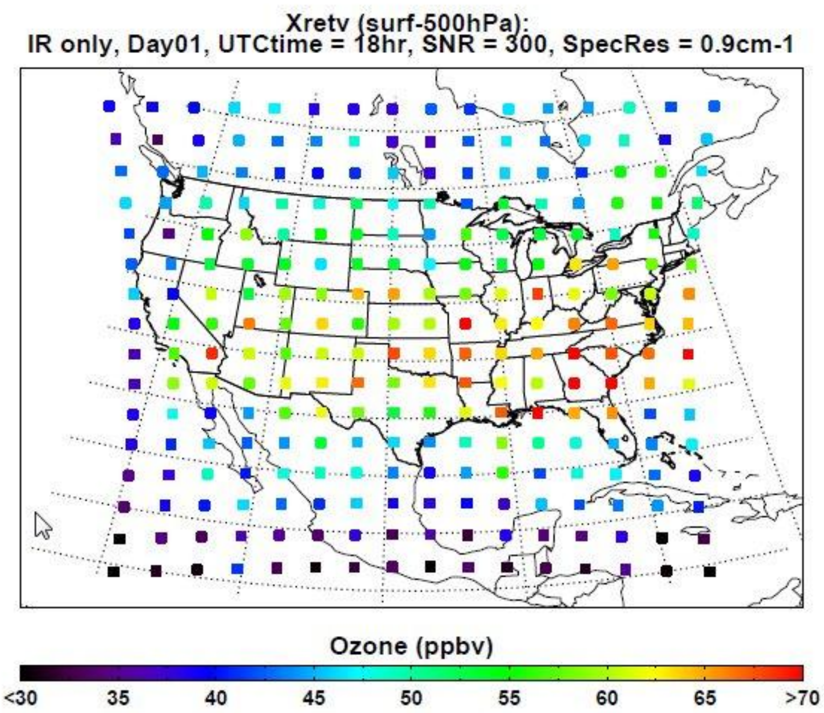


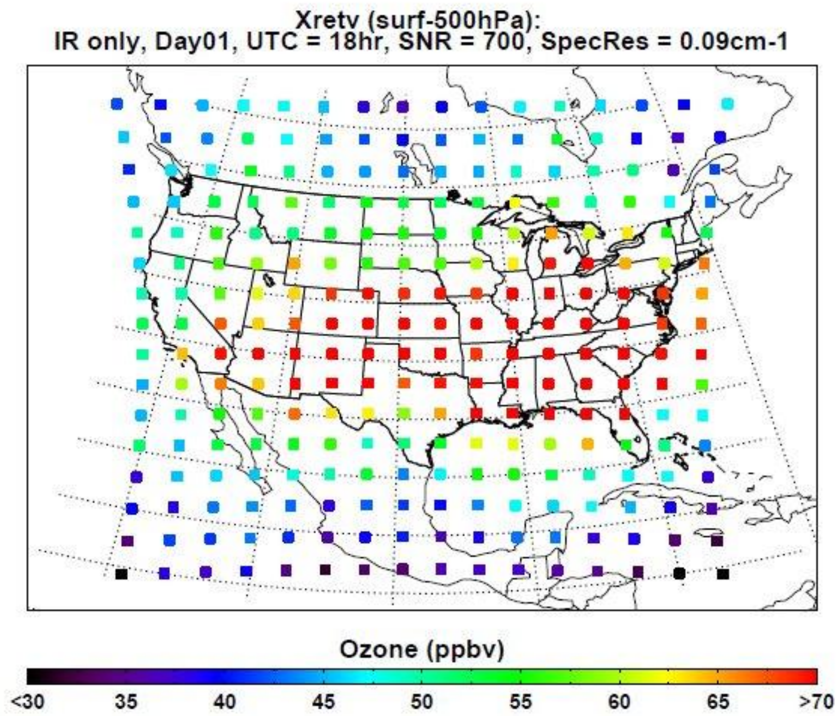


retrieved, a priori, truth

SOX

GEOCAPE-OSSE

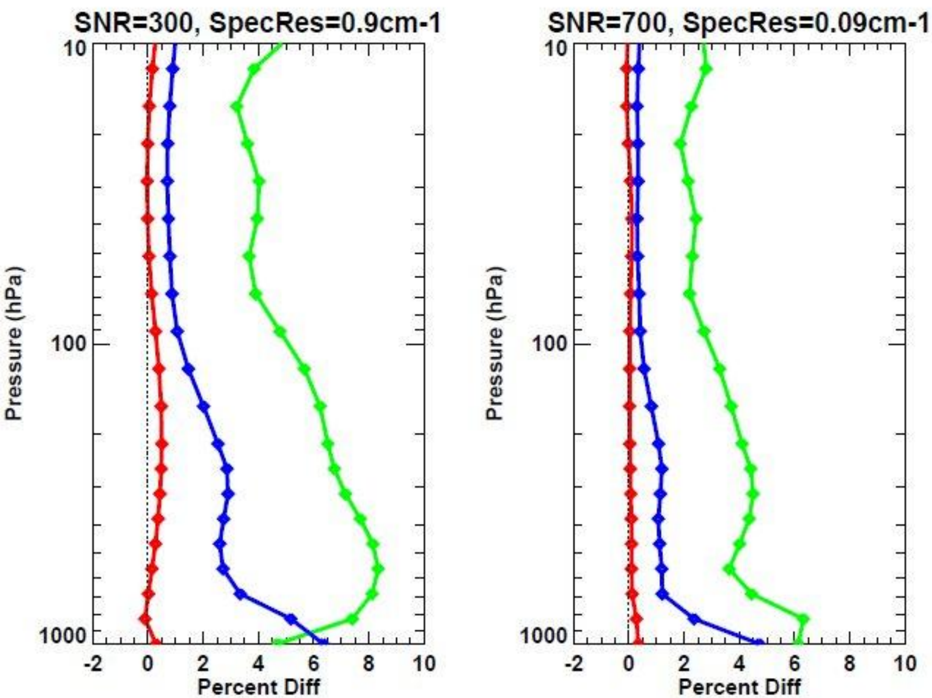




SOX

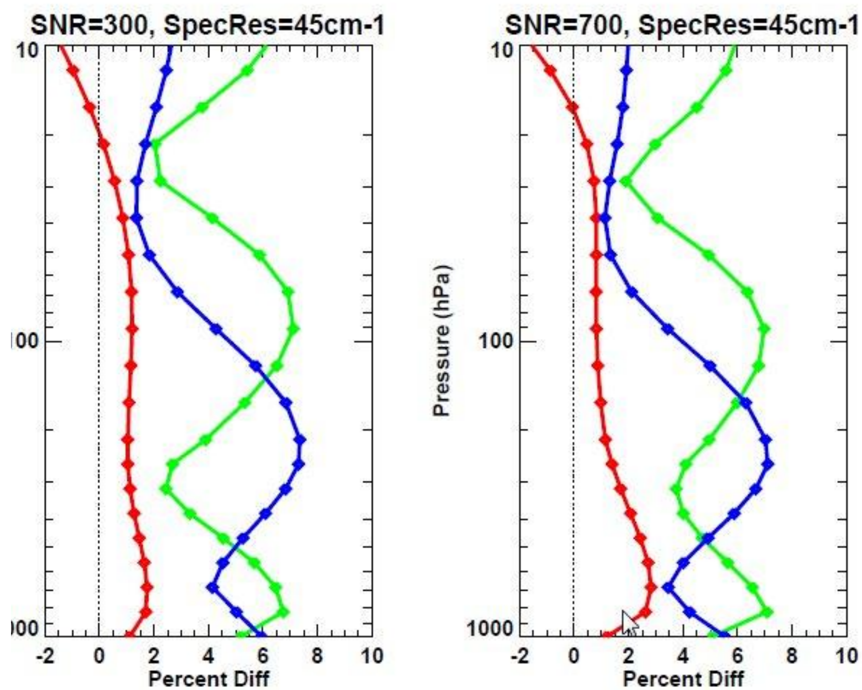
GEOCAPE-OSSE

IR: 970-1080 cm-1



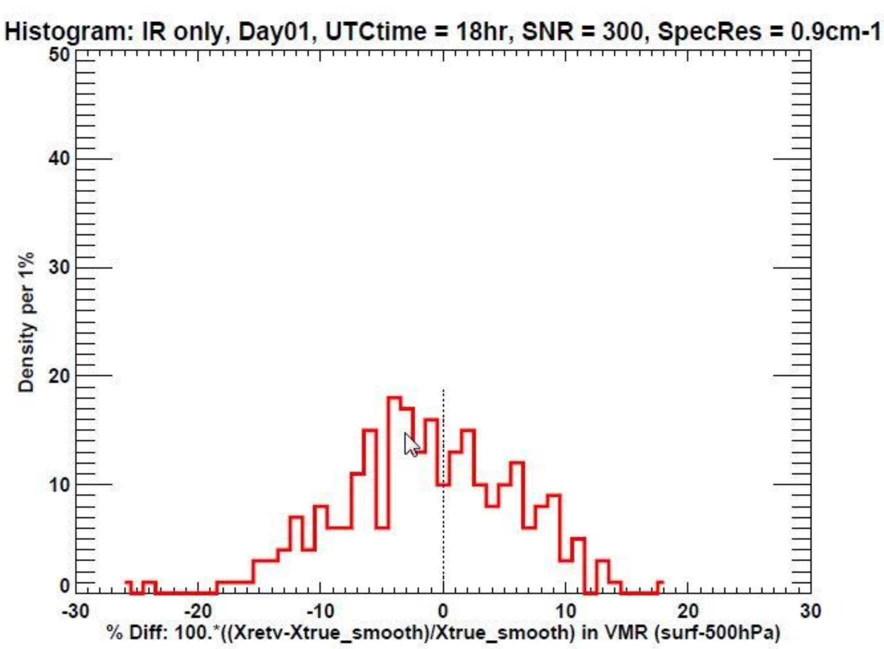
Mean of 100.*((Xretv-Xtrue_smooth)/Xtrue_smooth) in VMR
Stddev of 100.*((Xretv-Xtrue_smooth)/Xtrue_smooth) in VMR
Mean of 100.*(err/Xtrue_smooth) in log(VMR)

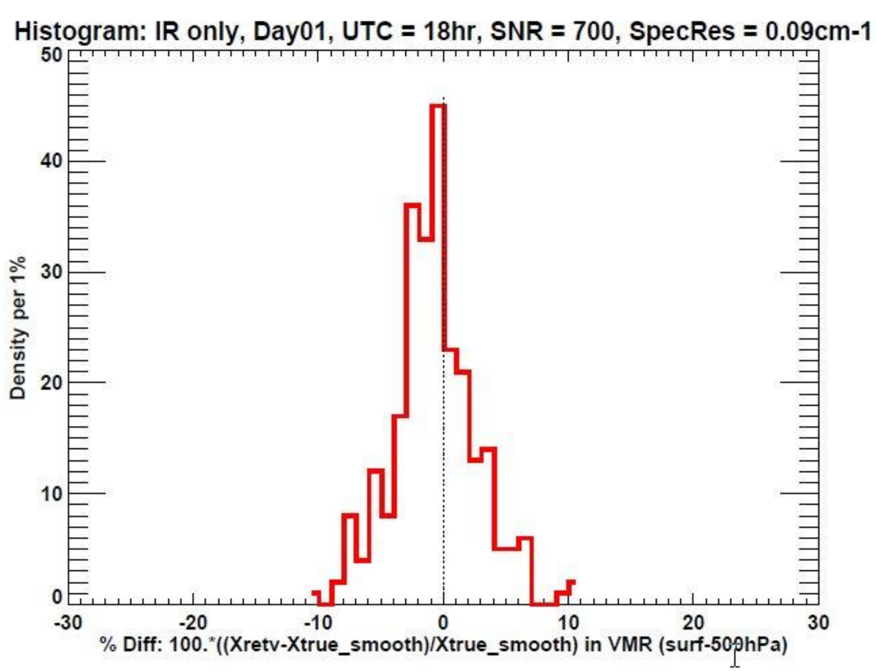
UV: 29000-37200 cm-1



Mean of 100.*((Xretv-Xtrue_smooth)/Xtrue_smooth) in VMR
Stddev of 100.*((Xretv-Xtrue_smooth)/Xtrue_smooth) in VMR
Mean of 100.*(err/Xtrue_smooth) in log(VMR)

GEOCAPE-OSSE





SOX

Technology Infusion

MLS – OSE/OSSE

Nathaniel Livesey (JPL)
Meemong Lee (JPL)
Michelle Santee (JPL)
Jessica Neu (JPL)
Kevin Bowman (JPL)

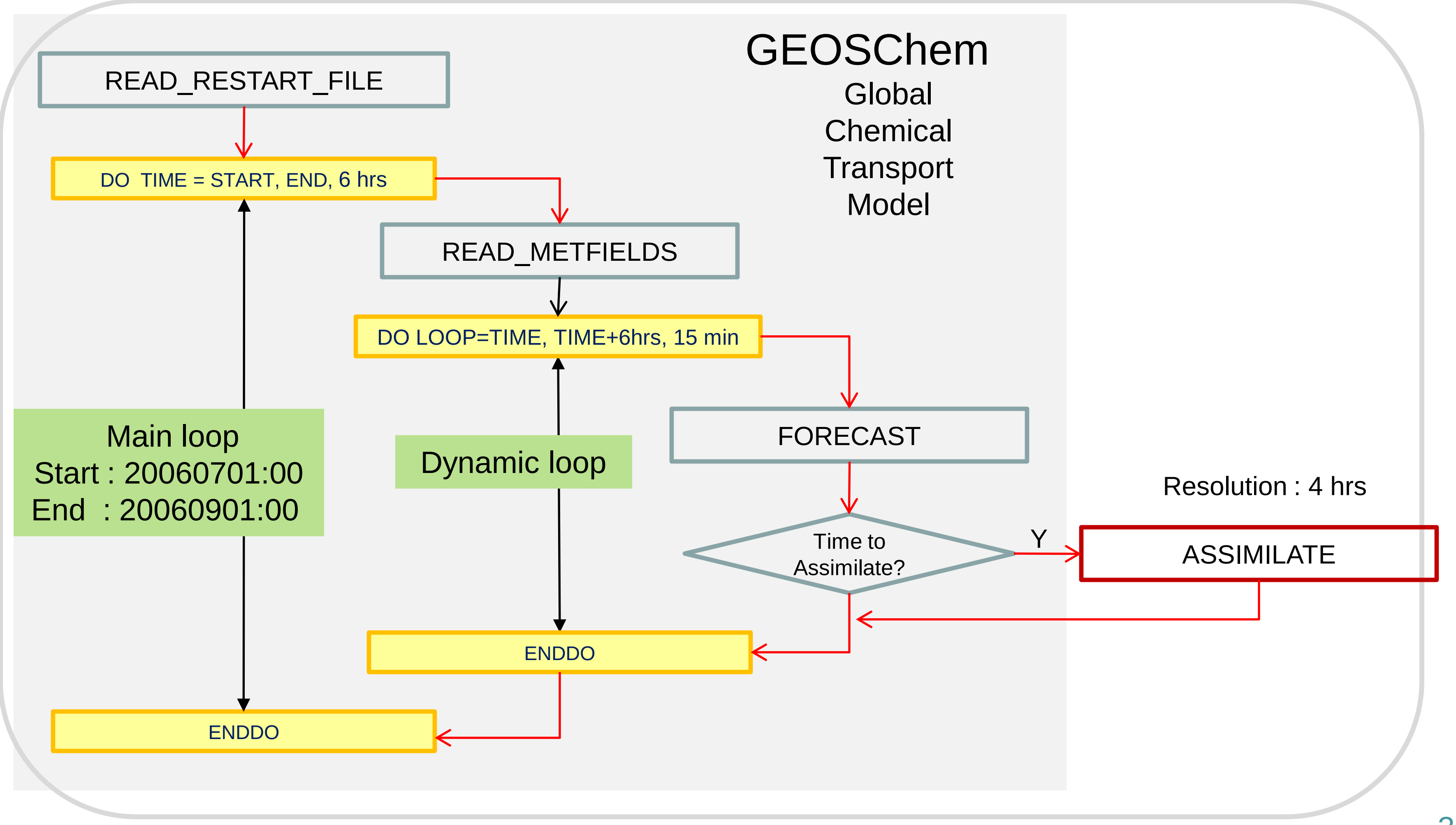
Technology Infusion

Microwave limb sounder (MLS) project led by Dr. Nathaniel Livesey utilized the SOX framework for assimilating MLS ozone observations (level 2 product) to evaluate the science impact of MLS observation in studying the process controlling the upper tropospheric composition.

Product name	Useful range	Significant averaging needed?	Quality threshold	Convergence threshold	Differences needed?
BrO	10 – 3.2 hPa	yes	1.2	1.5	yes
CH3CN[e]	Unclear	N/A	N/A	N/A	N/A
ClO	100 – 1.0 hPa	no	0.8	1.5	see text
CO	215 – 0.0046 hPa	no	0.2[f]	1.8	no
GPH[gh]	316 – 0.001 hPa	no	0.6	1.2	no
H2O[h]	316 – 0.002 hPa	no	0.9	N/A	no
HCl	100 – 0.15 hPa	no	1.0	1.5	no
HCN	10 – 0.1 hPa	no	0.2	2.0	no
HNO3	215 – 3.2 hPa	no	0.4	1.8	no
HO2	22 – 0.032 hPa	yes	N/A	1.1	yes
HOCl	10 – 2.2 hPa	yes	1.4	1.5	no
IWC[hi]	261 – 68 hPa	no	N/A	N/A	no
IWP[j]	N/A	no	N/A	N/A	no
N2O	100 – 1.0 hPa	no	0.5	1.55	no
O3[k]	215 – 0.022 hPa	no	0.4[f]	1.8	no
OH	32 – 0.0032 hPa	no	N/A	1.1	no
RHI[hl]	316 – 0.002 hPa	no	0.9	N/A	no
SO2[em]	215 – 10 hPa	no	0.4	1.8	no
Temperature[hn]	316 – 0.001 hPa	no	0.6	1.2	no

SOX

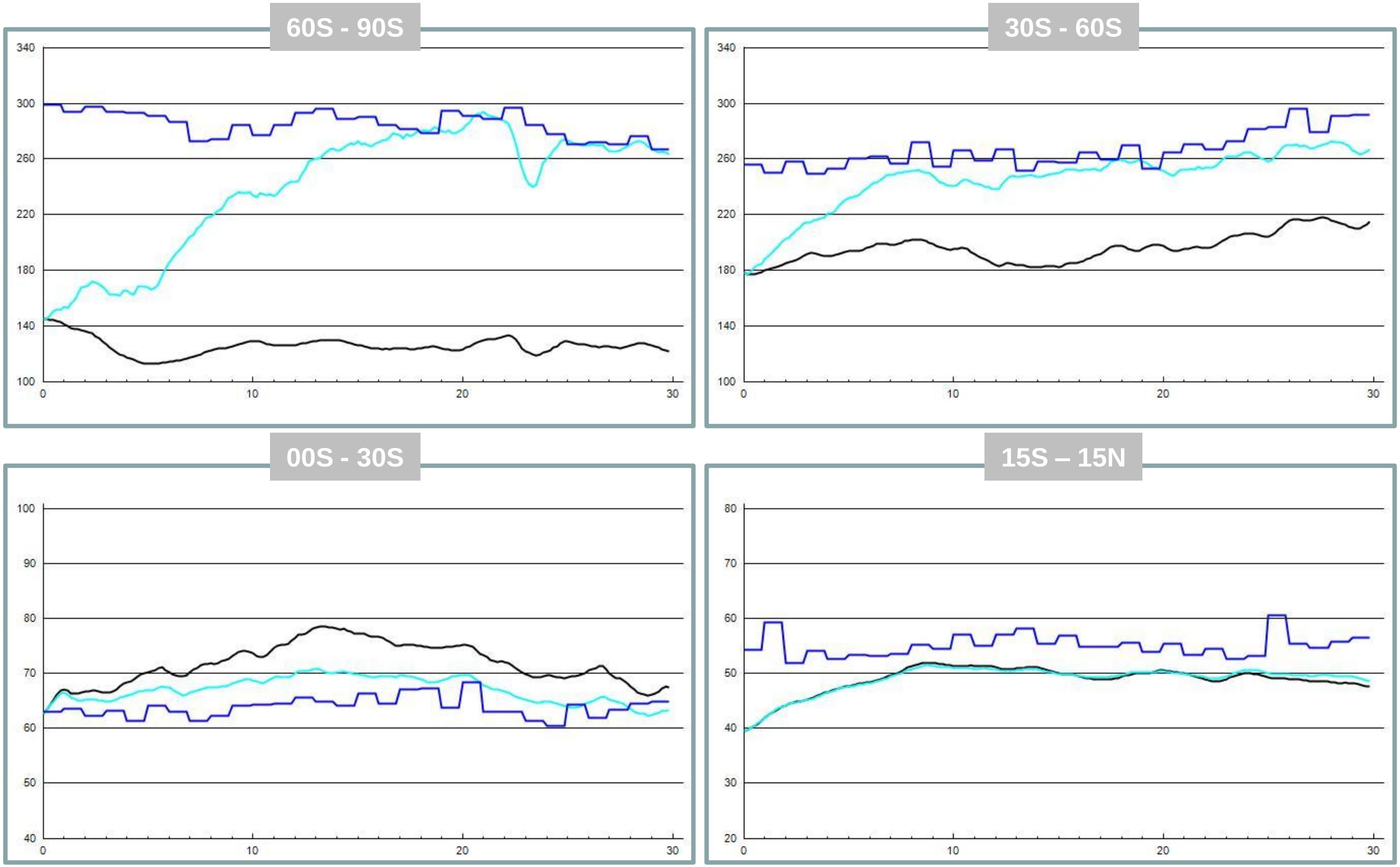
MLS-OSE/OSSE



SOX

GeosChem free run
MLS Ozone
MLS Ozone Assimilation

P=200 hPa

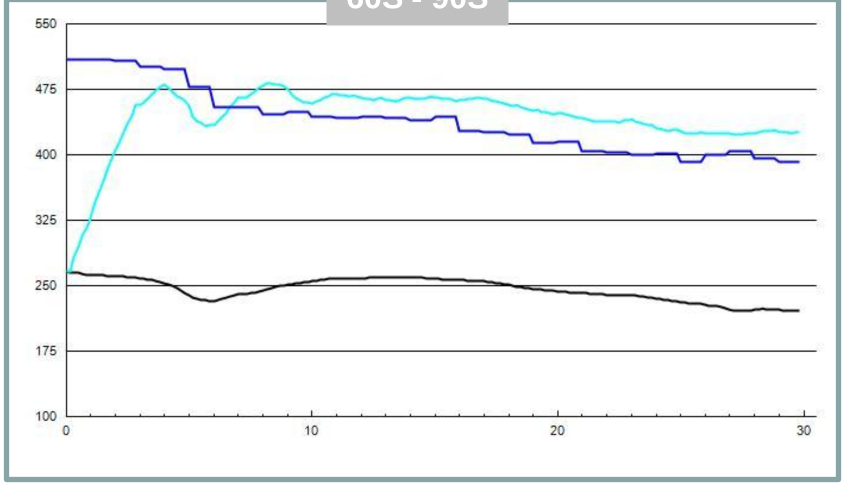


SOX

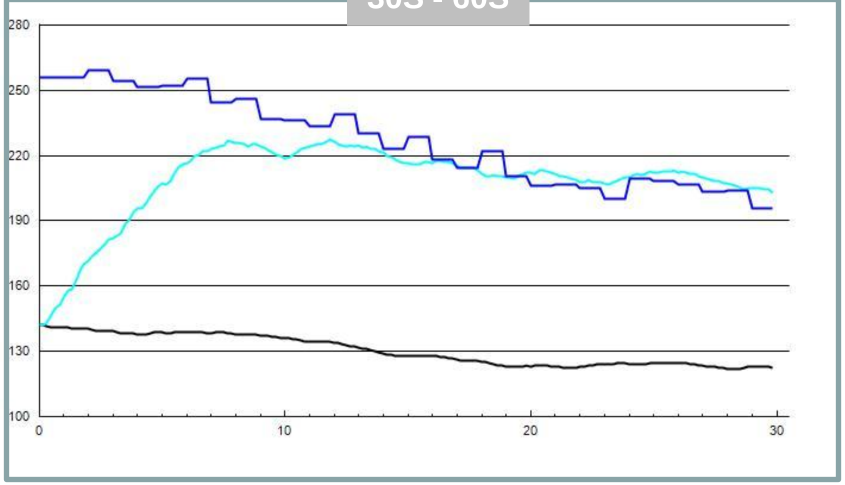
GeosChem free run
MLS Ozone
MLS Ozone Assimilation

P=200 hPa

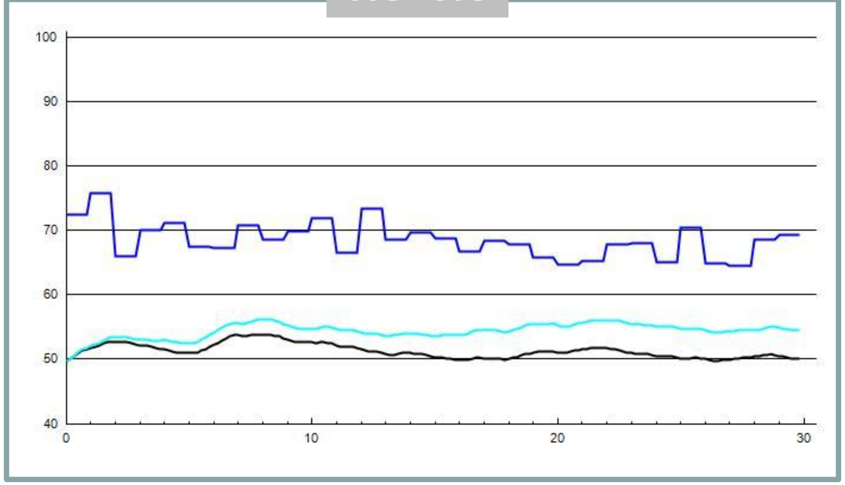
60S - 90S



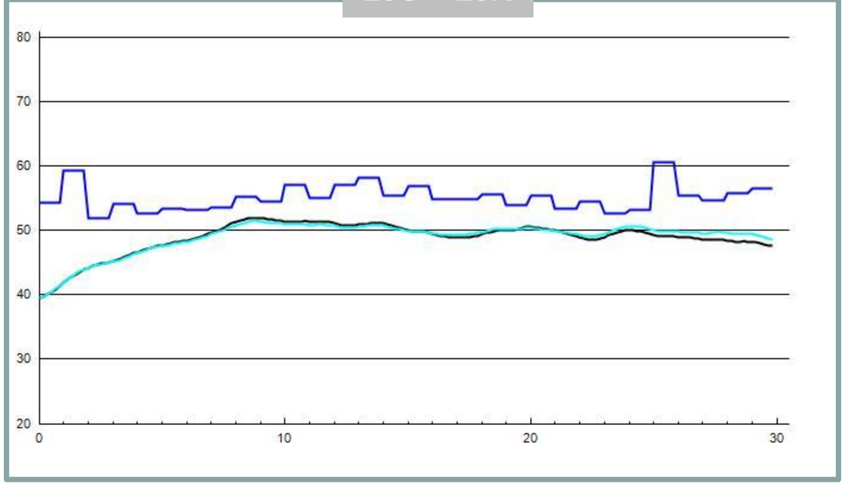
30S - 60S



00S - 30S



15S – 15N

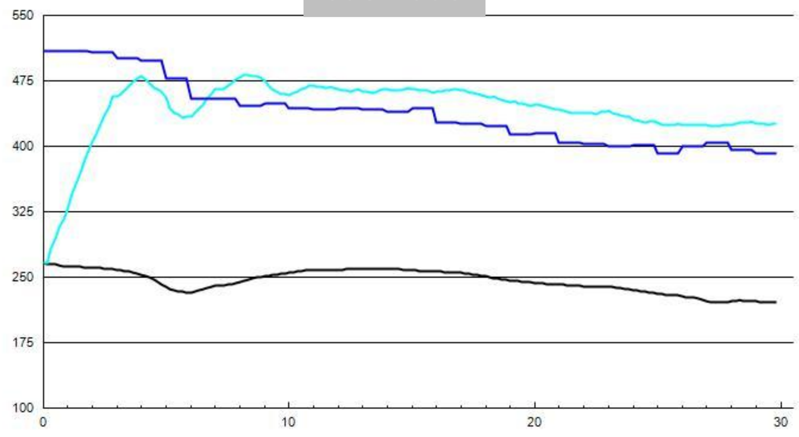


SOX

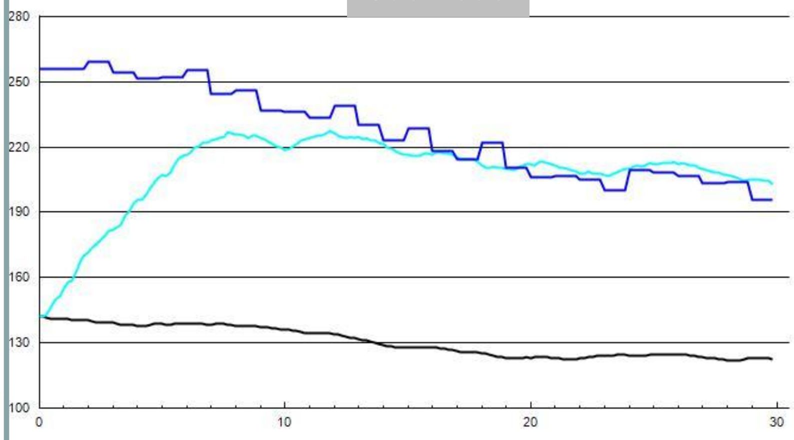
GeosChem free run
MLS Ozone
MLS Ozone Assimilation

P=200 hPa

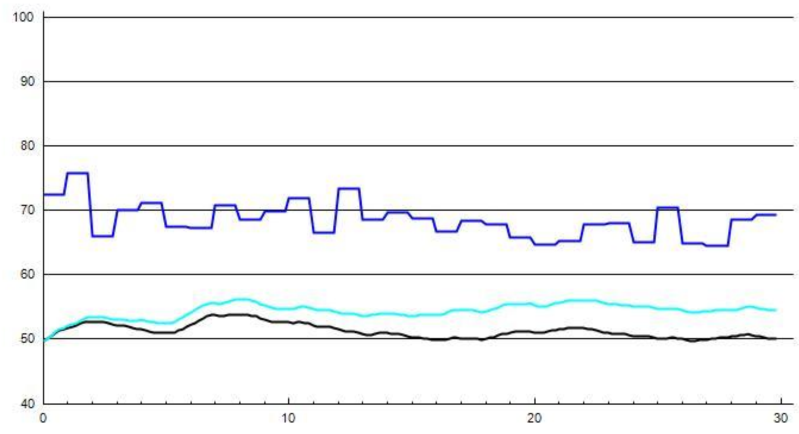
60S - 90S



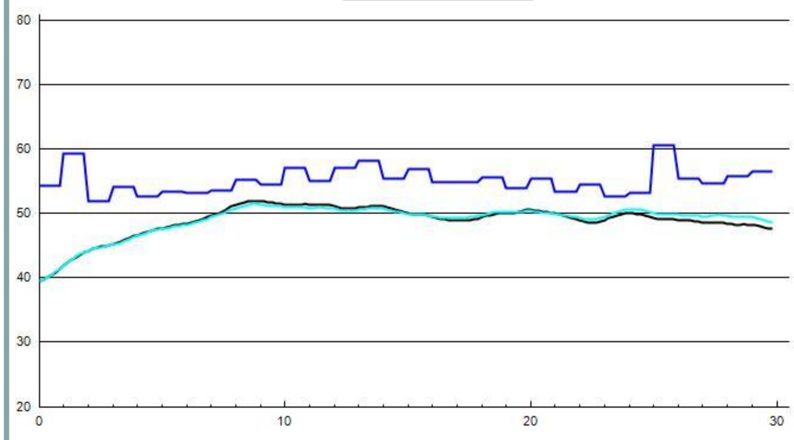
30S - 60S



00S - 30S

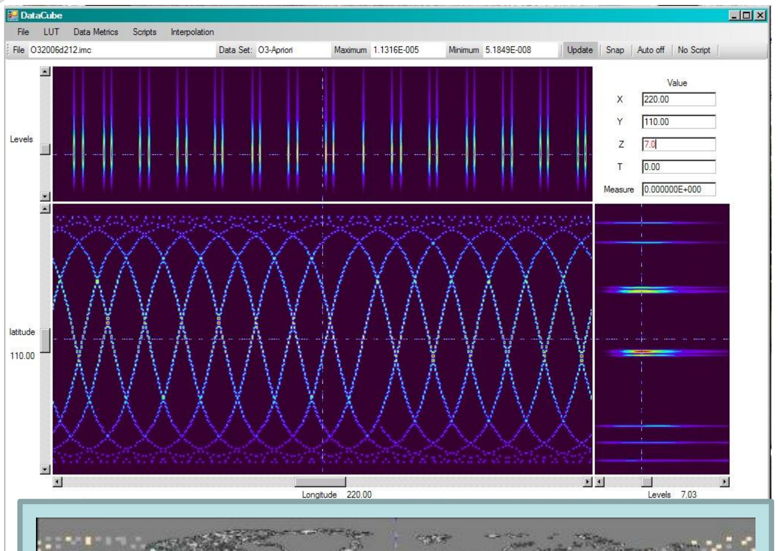


15S – 15N

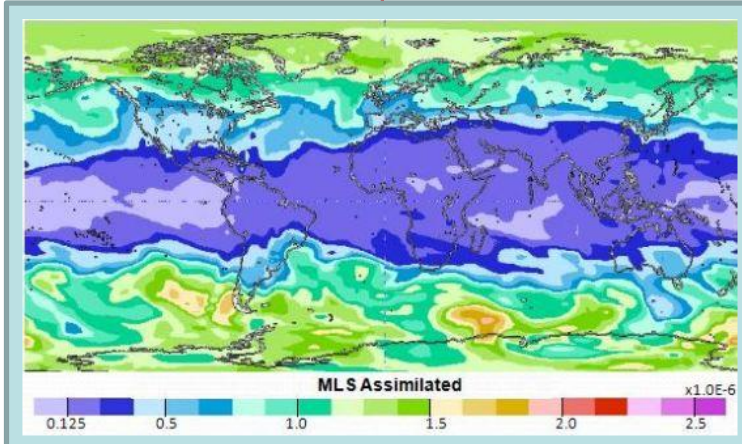


SOX

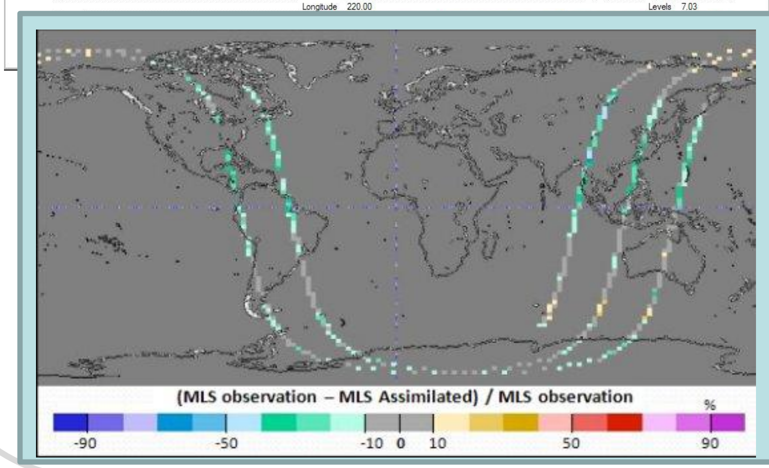
MLS-OSE/OSSE



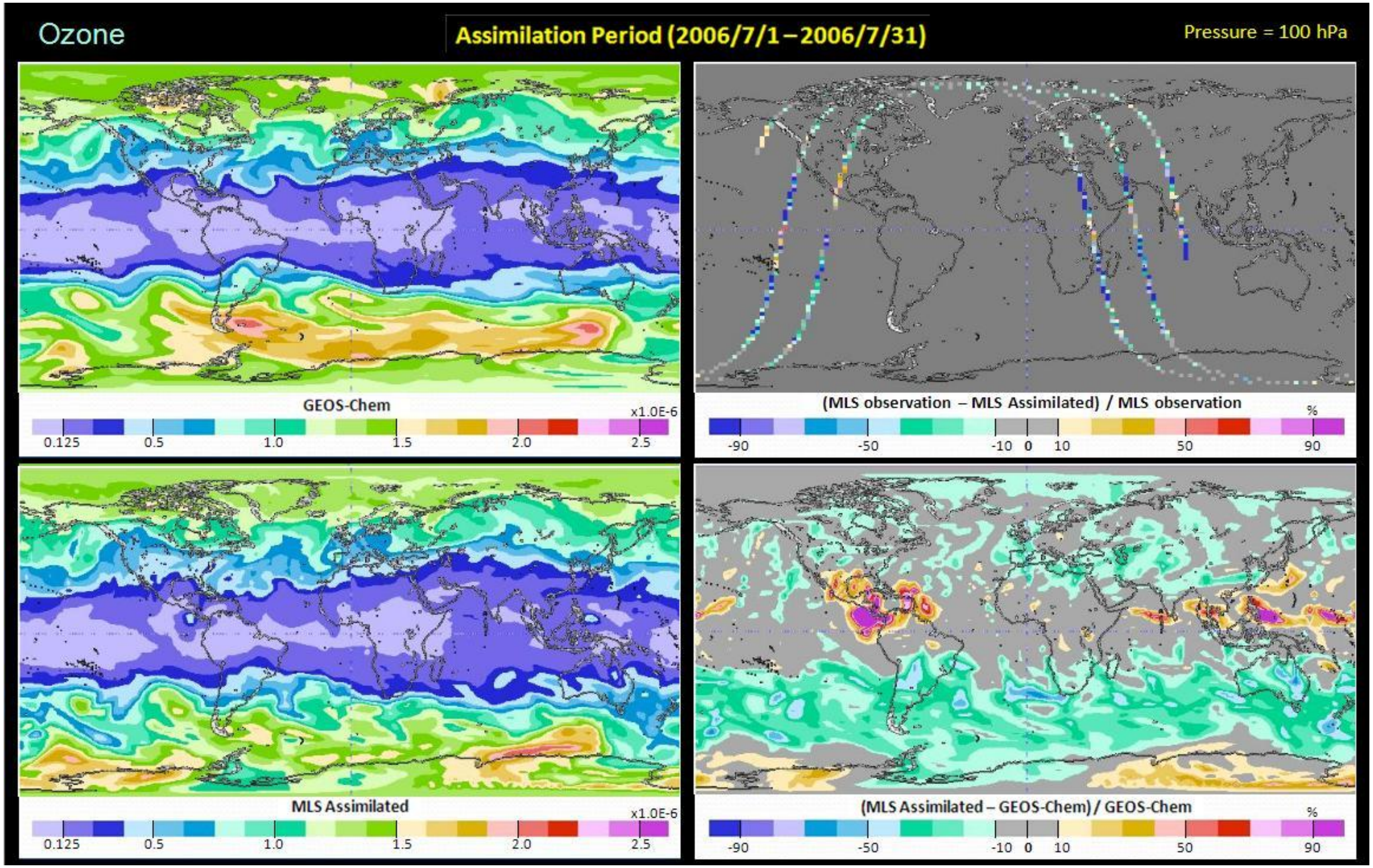
O3 observation assimilation



Observation - assimilated



MLS-OSE/OSSE


Ozone
Assimilation Period (2006/7/1–2006/7/31)
Pressure = 100 hPa
GEOS-Chem
x1.0E-6
0.125 0.5 1.0 1.5 2.0 2.5
(MLS observation – MLS Assimilated) / MLS observation
%
-90 -50 -10 0 10 50 90
MLS Assimilated
x1.0E-6
0.125 0.5 1.0 1.5 2.0 2.5
(MLS Assimilated – GEOS-Chem) / GEOS-Chem
%
-90 -50 -10 0 10 50 90

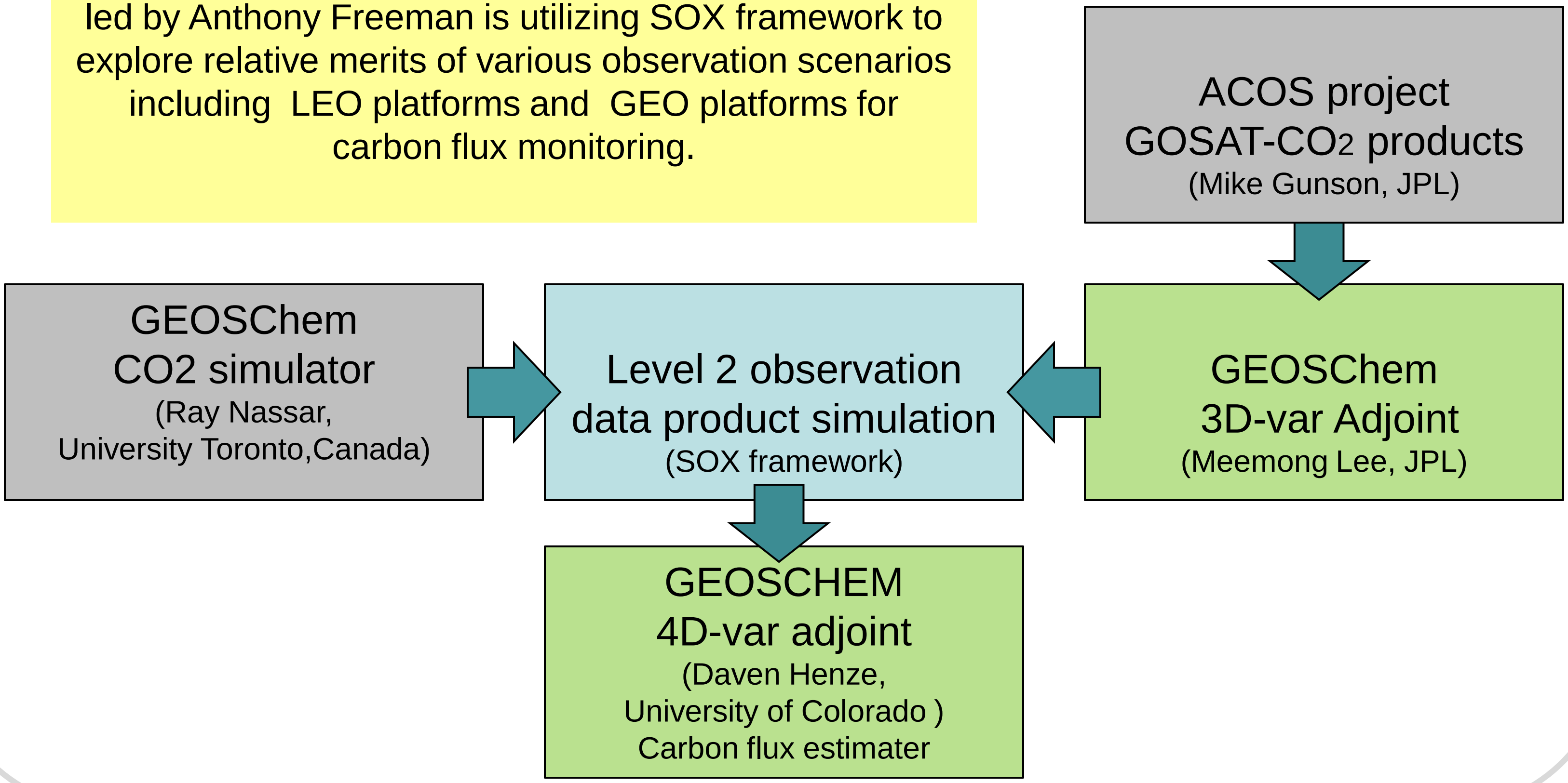
GHGIS - OSSE

Kevin Bowman (JPL)
Meemong Lee (JPL)
Richard Weidner (JPL)
John Worden (JPL)
Anthony Freeman (JPL)

SOX

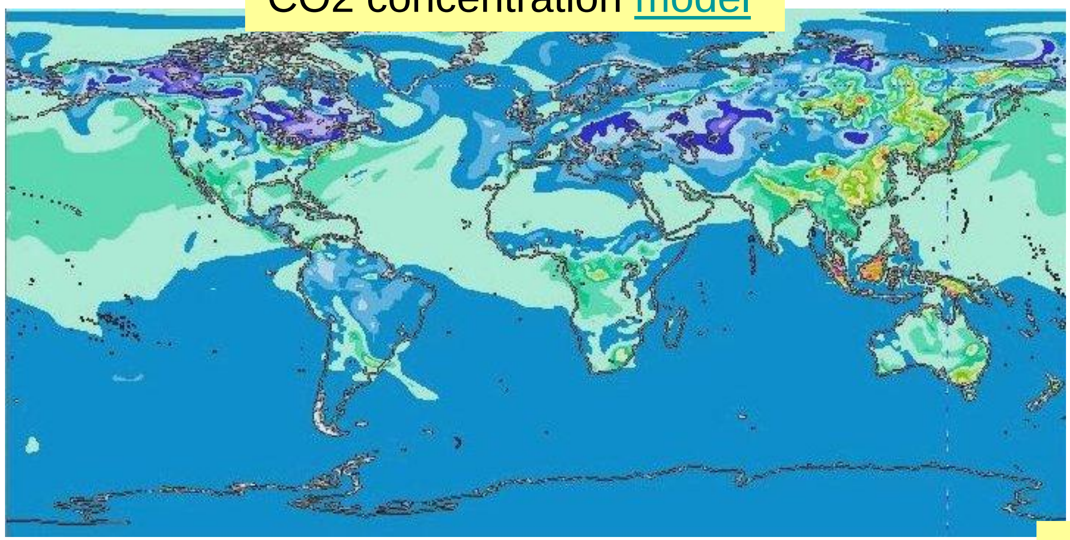
GHGIS-OSSE

Green house gas information system (GHGIS) project led by Anthony Freeman is utilizing SOX framework to explore relative merits of various observation scenarios including LEO platforms and GEO platforms for carbon flux monitoring.

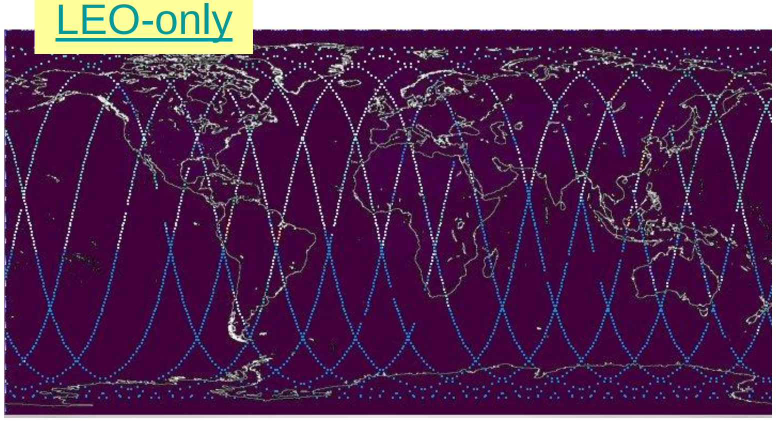


GHGIS-OSSE

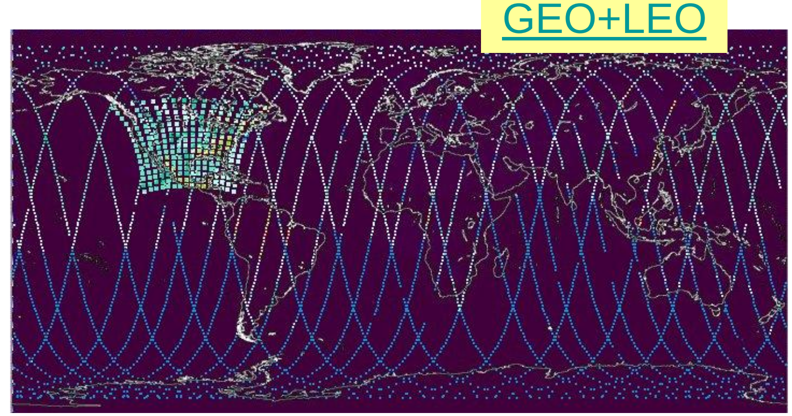
CO_2 concentration model



LEO-only



GEO+LEO



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