10:00-14:00 T9/T10/T11 (with lunch break 12:00-13:00)

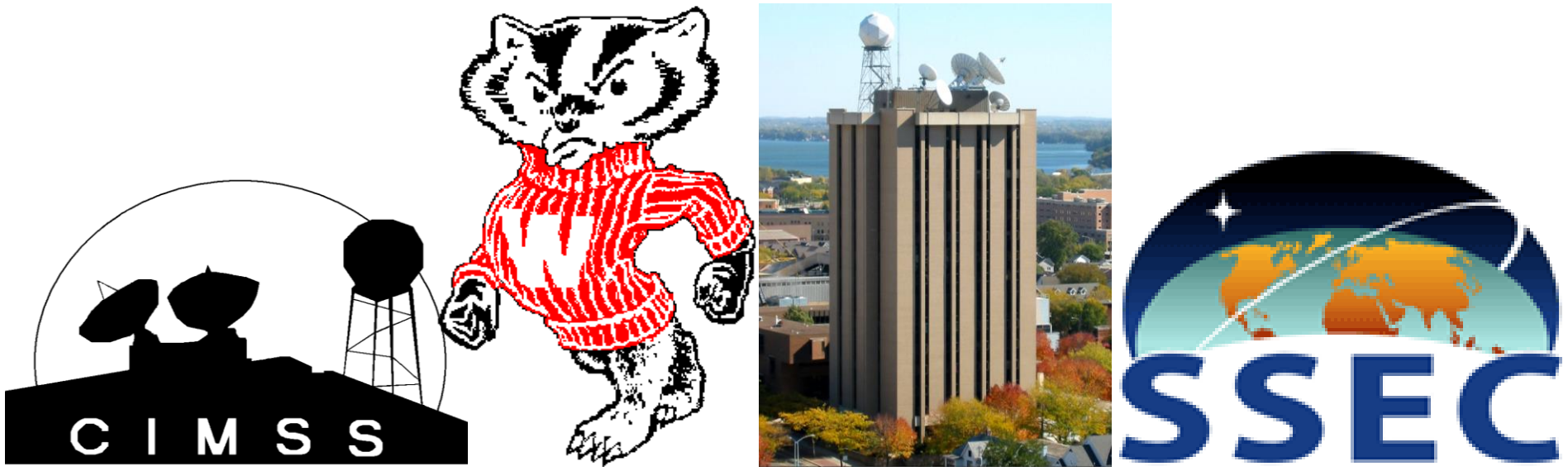
Quantitative Analysis and Applications of IR/VIS Imagery with Labs

1. **Meteorological Satellite Sounding Theory & Resources** by Allen Huang
2. **Why Sounding Data Can Help You** by Scott Lindstrom
3. **Geostationary vs Polar Orbit satellite data - Making the Case for Both** by Jessica Braun
4. **Microwave Satellite Retrievals and Applications** by Kathy Strabala

AOMSUC-13
Training Workshop
Jincheon, S. Korea
4 November, 2023

Meteorological Satellite Sounding Theory & Resources

Allen Huang
Distinguished Scientist Emeritus
Space Science & Engineering Center (SSEC)
University of Wisconsin-Madison, USA



AOMSUC-13
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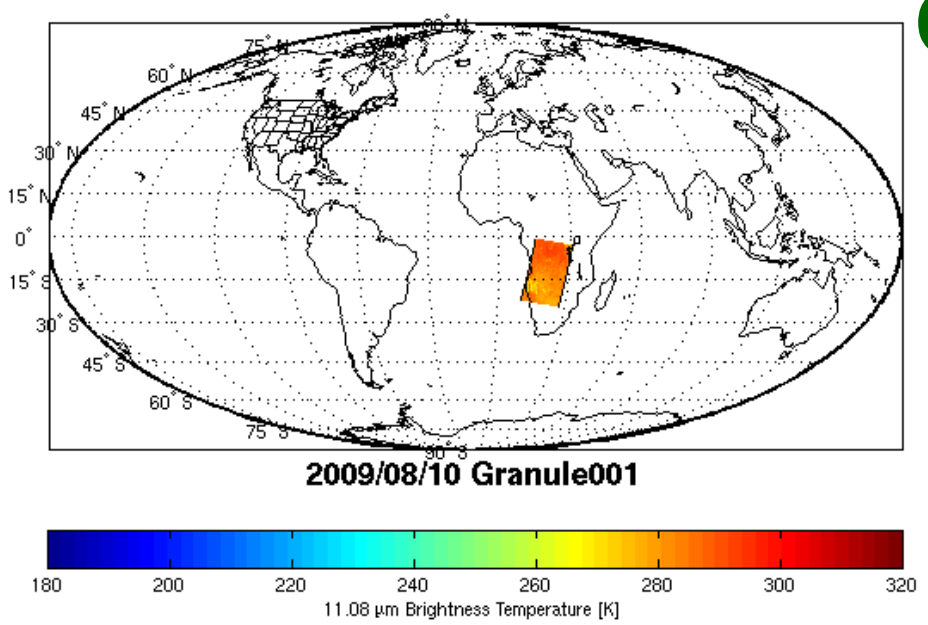
Two Types of Weather Satellite
Low-Earth Orbit (LEO) Vs. Geosynchronous (GEO)
Spatial/Temporal/Domain Illustration

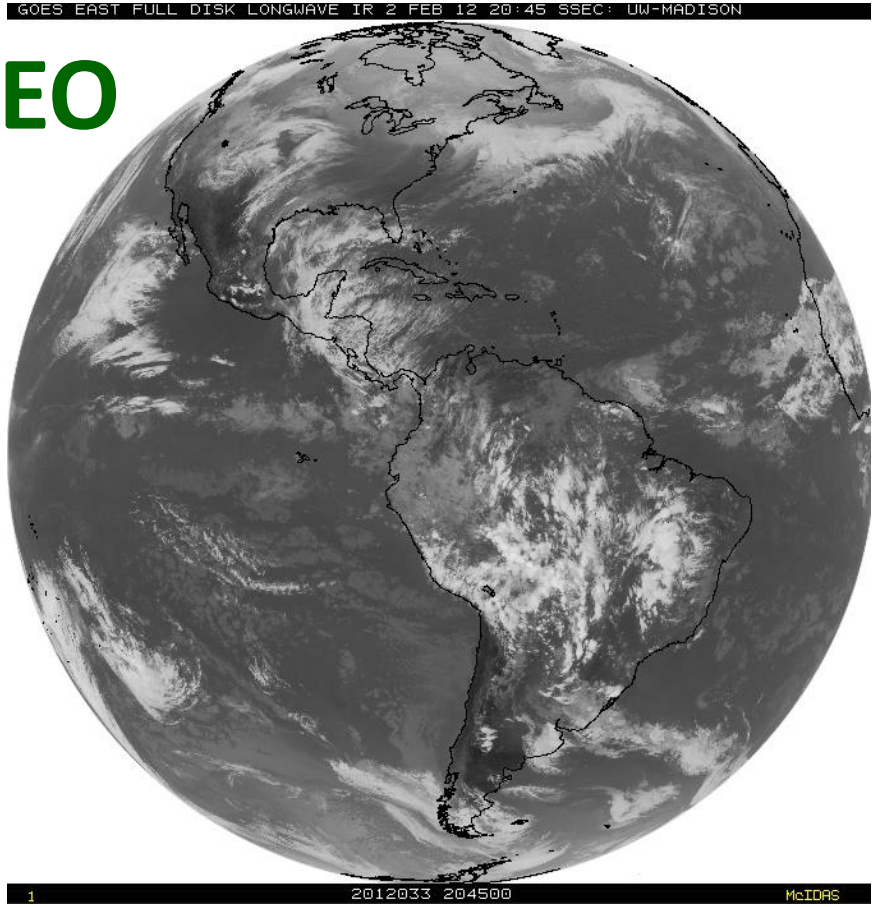
LEO



LEO: Regional; twice per day (every 12 hrs)

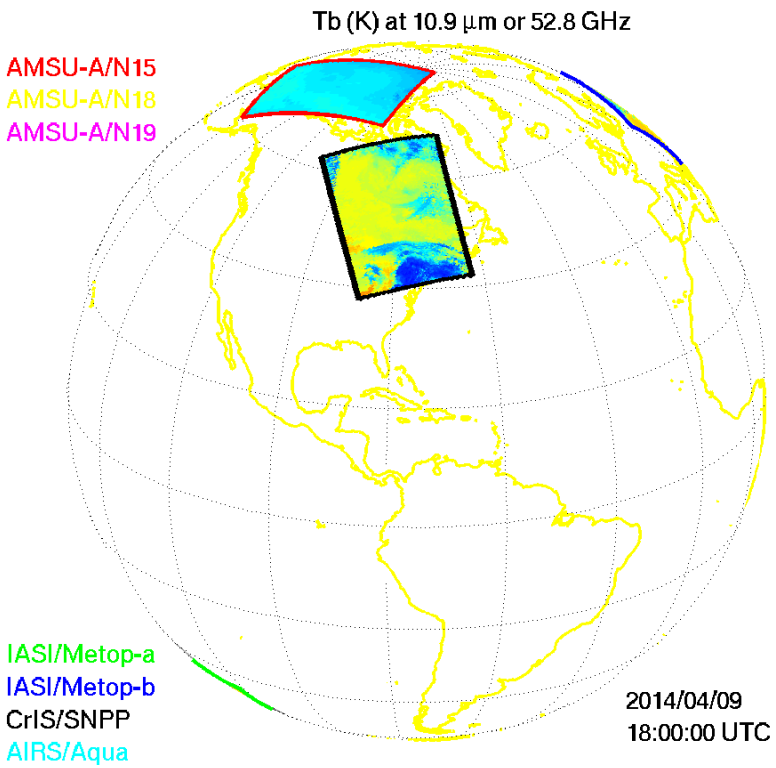
GEO: Full Disk; 24 per day (hourly)

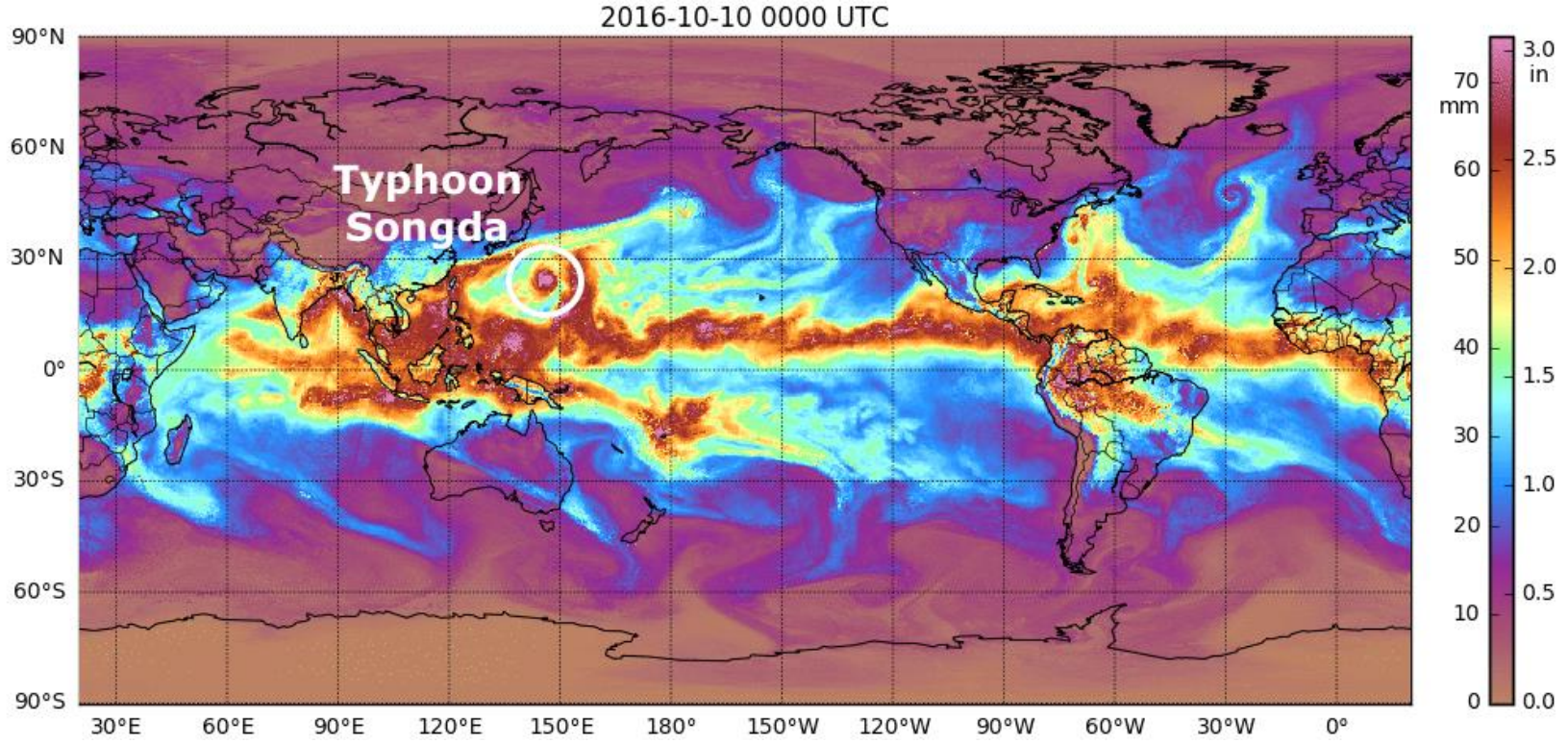
GEO



For 24 hours time period

Multiple LEOs Provide Timely/Global Coverage

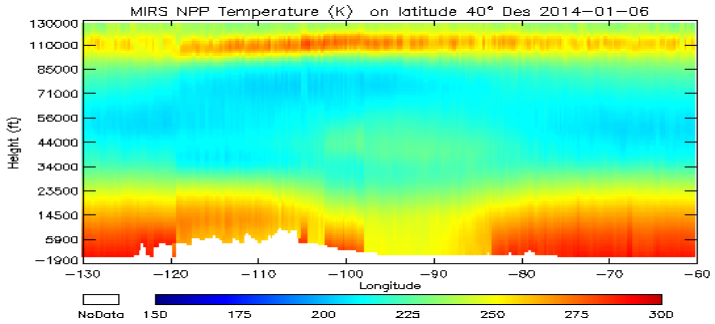




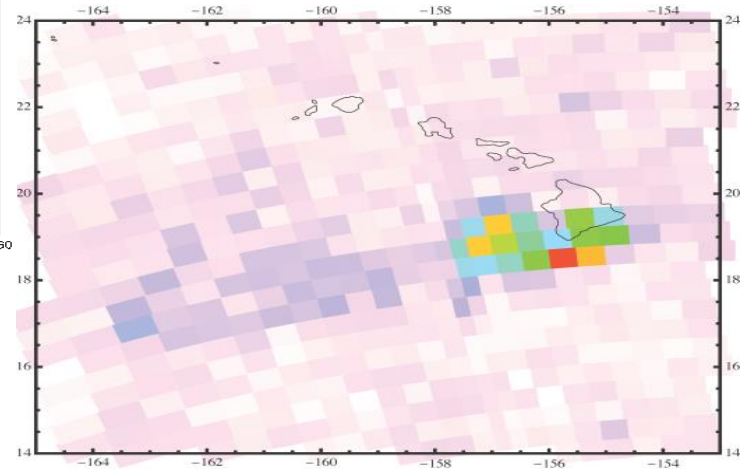
From Tony Wimmers - MIMIC TPW2

Worldwide LEO Meteorological Satellite provides a wide range of capabilities

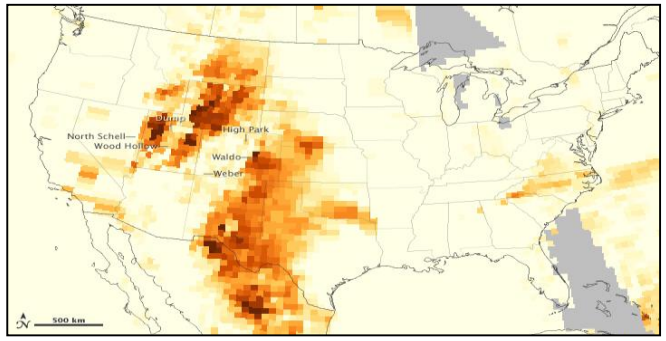
- **Microwave** – provides temperature and moisture soundings in cloudy conditions and rainfall rates, sea ice, snow, surface temperature - ATMS
- **Infrared** – provides high vertical resolution temperature and moisture soundings in clear and cloud corrected regions; atmospheric chemistry - CO, CH4, SO2, … and cloud products - CrIS
- **Visible (day & night)** and Infrared Imagery (including deep blue channels) – chlorophyll, cloud imagery, cloud products, SST, Active Fires, Smoke, Aerosols, land products, Snow, Ice, oil spills… at exceptional resolution/global coverage - VIIRS
- **UV** - ozone - Aerosols over bright surfaces, SO2 plumes, NOx (air quality)… - OMPS



Temperature X-Section Polar Vortex

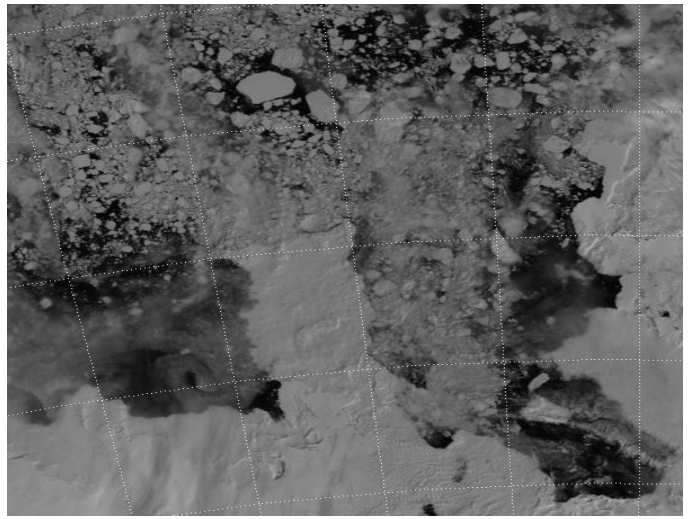

OMPS- Volcano SO2 degassing


Algae in Lake Erie



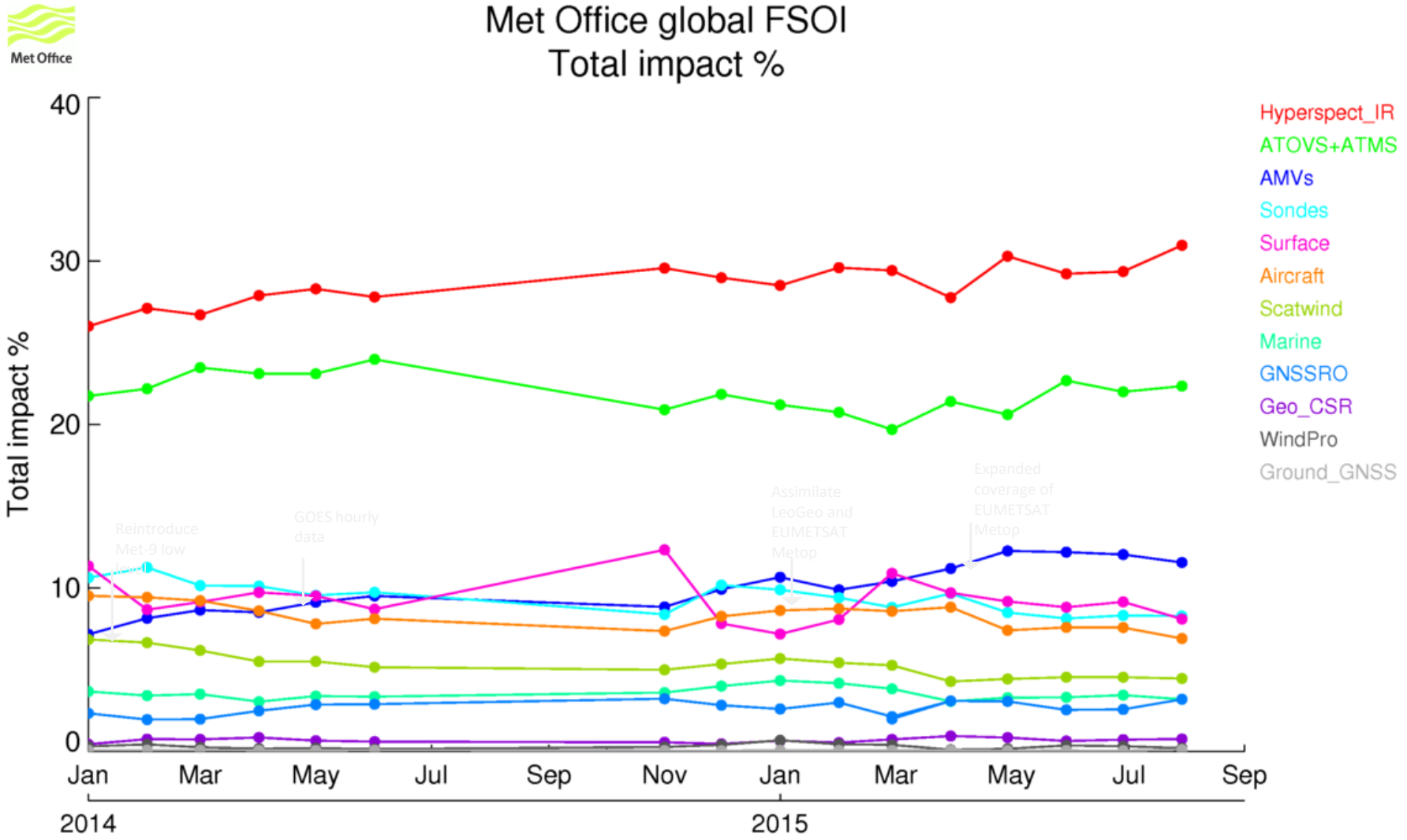
OMPS Aerosols from Fires

DNB Ice detection



Impact on 24h forecast error (FSOI)

UK Met Office



Contributions to the total observation impact on a moist 24-hour forecast-error energy-norm, surface-150 hPa (James Cotton)

Remote Sensing Science

- **Sounding & Imaging Infrared measurements**
- **Gases Absorption Signature**
- **Land/Ocean Surface Signature**
- **Atmospheric Signature**
- **Clouds, Aerosol/Dust Signature**

Radiance received by AIRS/CrIS/IASI/HIRAS/GIIRS

RTE (no scattering) in LTE

$$R_\nu = \tau_{s\nu} \cdot \varepsilon_{s\nu} \cdot B_\nu(T_S)$$

← Upwelling IR radiation from surface

$$+ \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu(p)$$

← Upwelling IR radiation from atm. layers

$$- \tau_{s\nu} \cdot r_{s\nu} \cdot \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu^*(p)$$

← Reflected downwelling IR radiation

$$+ R_\nu^{sun} \cdot \cos(\theta) \cdot \tau_{s\nu}^{sun}(p_s) \cdot r_\nu^{sun}$$

← Reflected solar radiation

R…radiance, υ…wavenumber, *s*…surface, *p*…pressure, *sun*…solar,

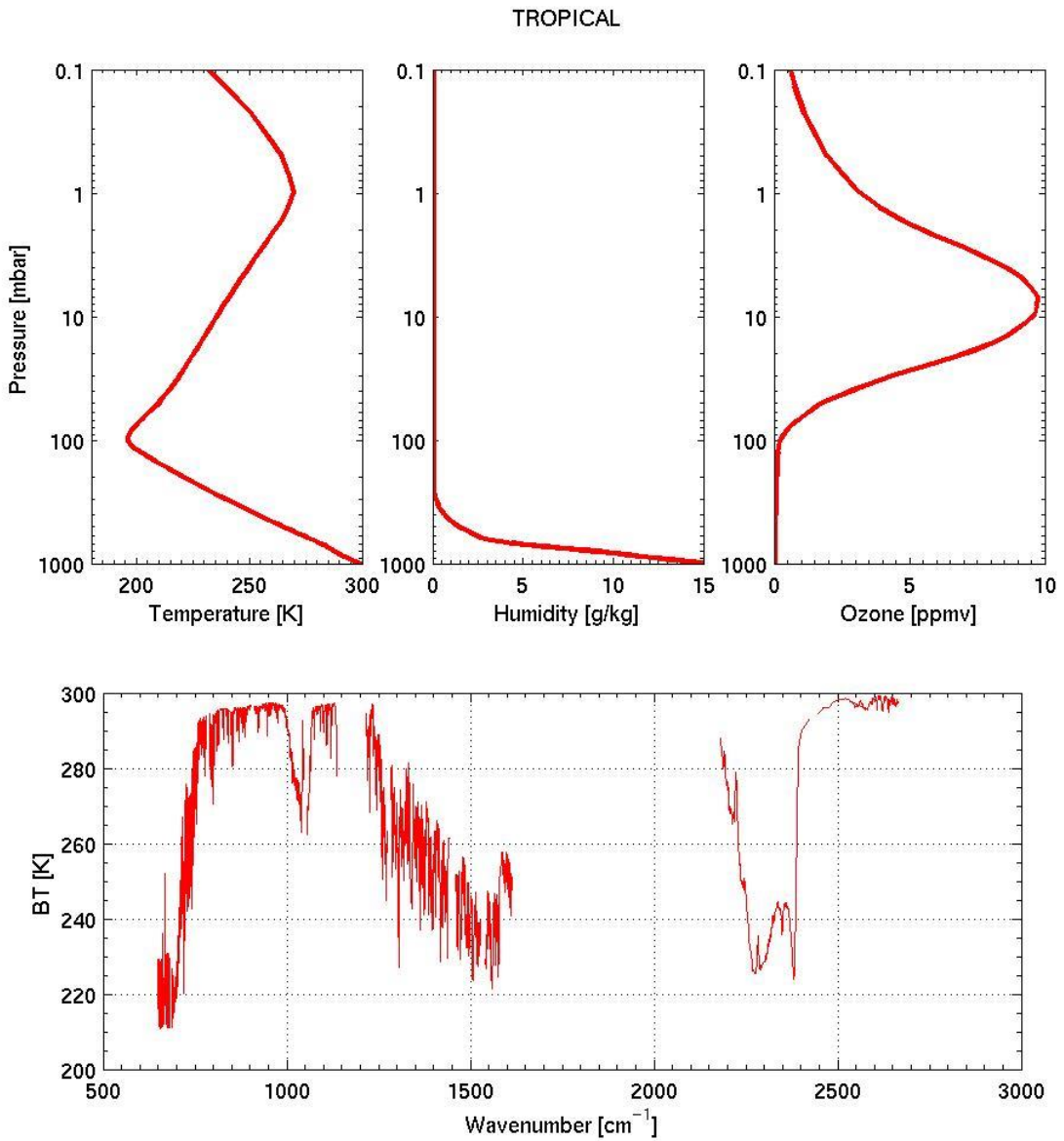
T…temperature, *B*…Planck function, ε …emissivity,

τ…level to space transmittance, θ...local solar zenith angle

r…reflectivity, with $r = (1- \varepsilon)/\pi$,

τ^*…level to surface (downwelling) transmittance [$\tau^* = \tau_\upsilon^2(p_s)/\ \tau_\upsilon(p)$]

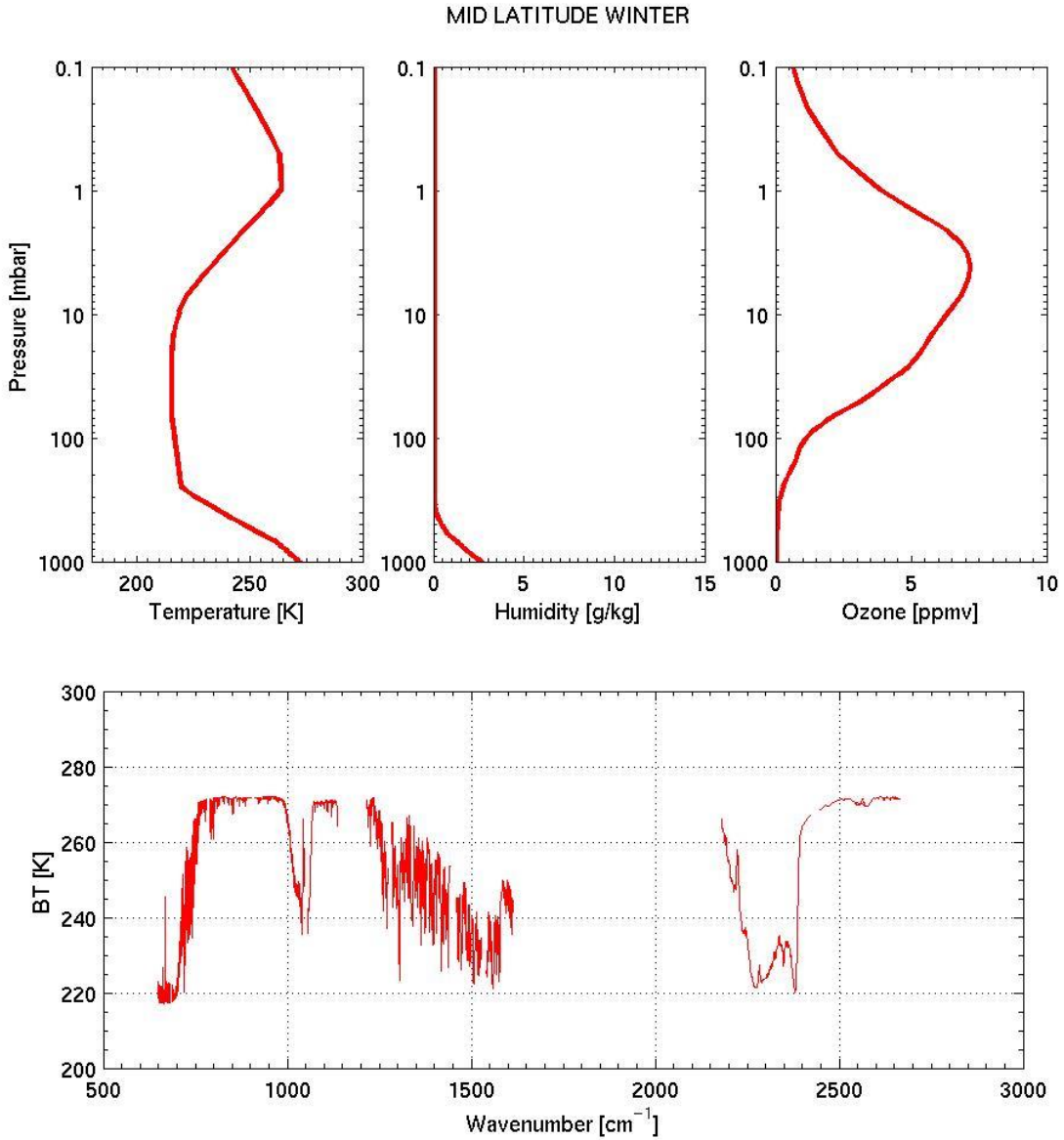
AIRS T,q, O3 profile and simulated spectrum - tropical



Tropical Profile:

- sharp tropopause at ~100 mbar
- high water vapor amount
- high T gradient in troposphere (~100 K) and stratosphere (~80 K)
- high skin temperatures

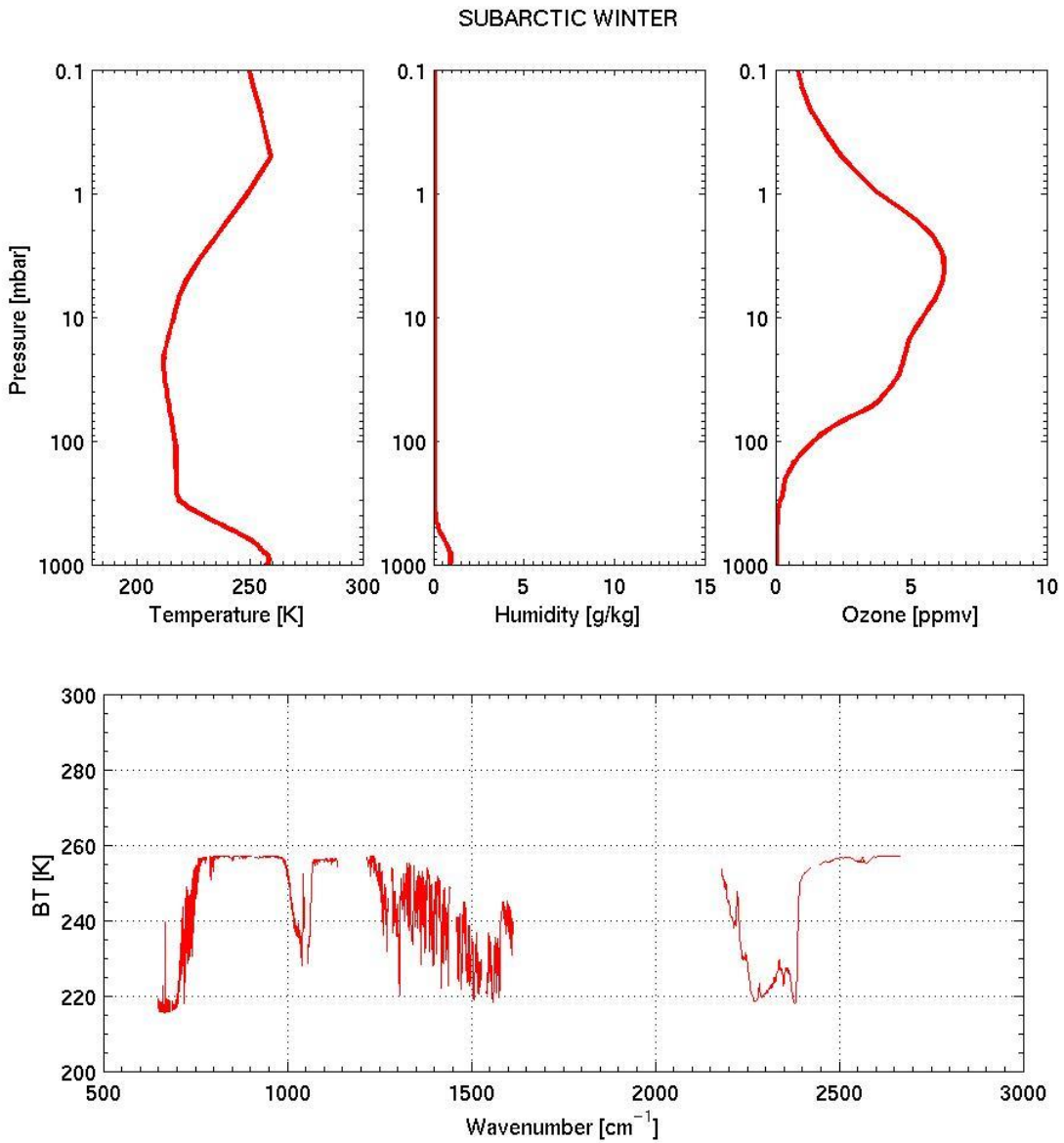
AIRS T,q, O3 profile and simulated spectrum – midlatitude winter



Midlatitude Summer Profile:

- T near surface ~ 260 K
- tropopause at < 100 mbar
- ~constant temperature above tropopause
- smaller T gradient in troposphere and stratosphere
- less moisture
- lower skin temperatures

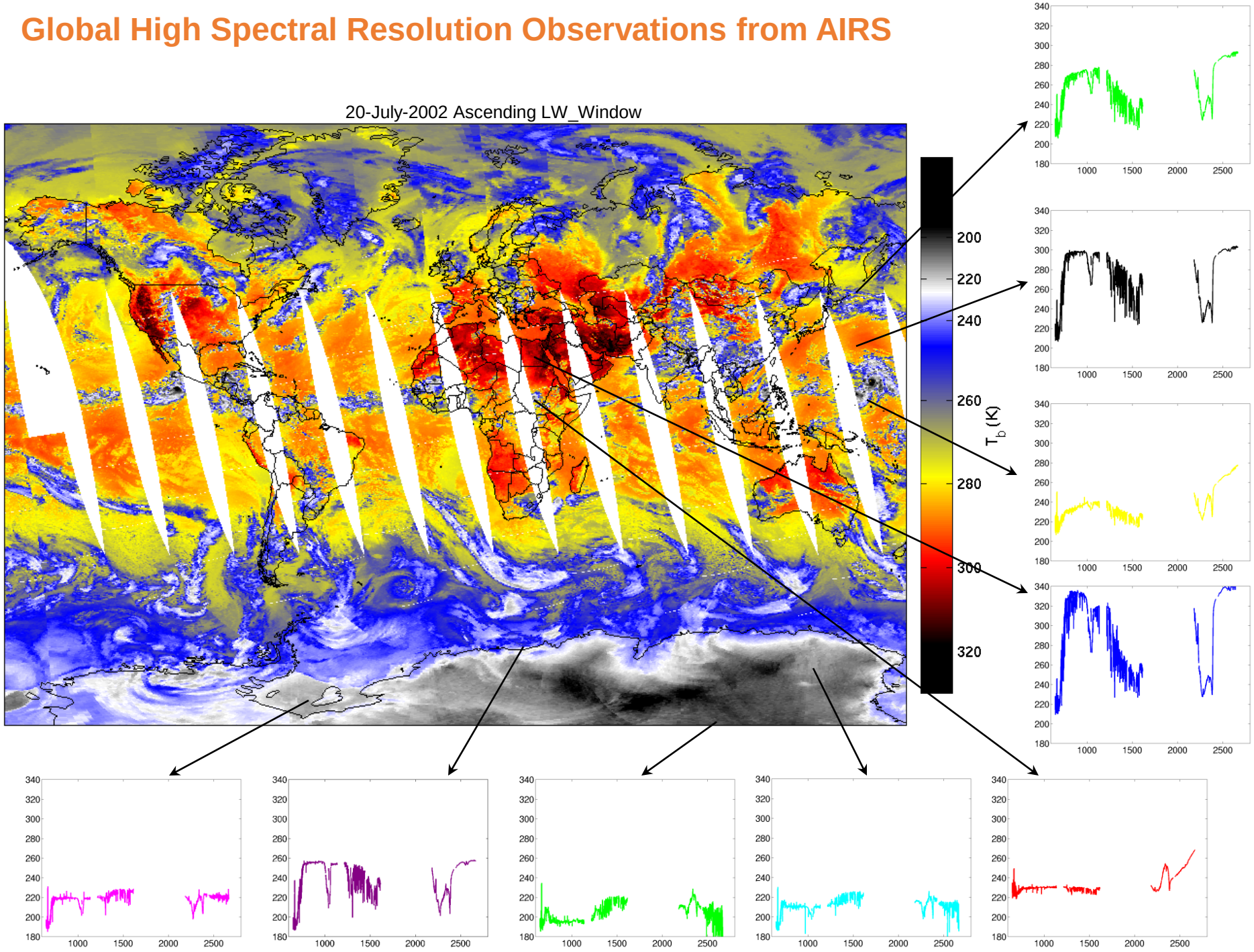
AIRS T,q, O3 profile and simulated spectrum – subarctic winter



Subarctic Winter Profile:

- T near surface < 260 K
- tropopause at < 100 mbar
- ~constant temperature above tropopause (20-200mbar)
- small T gradient in troposphere
- very dry
- low skin temperatures

Global High Spectral Resolution Observations from AIRS



Radiance received by CrIS/IASI/HIRAS/GIIRS

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← Upwelling IR radiation from surface

$$+ \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu(p)$$

← Upwelling IR radiation from atm. layers

$$- \tau_{s\nu} \cdot r_{s\nu} \cdot \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu^*(p)$$

← Reflected downwelling IR radiation

$$+ R_\nu^{sun} \cdot \cos(\theta) \cdot \tau_{s\nu}^{sun}(p_s) \cdot r_\nu^{sun}$$

← Reflected solar radiation

R…radiance, υ…wavenumber, *s*…surface, *p*…pressure, *sun*…solar,

T…temperature, *B*…Planck function, ε …emissivity,

τ…level to space transmittance, θ...local solar zenith angle

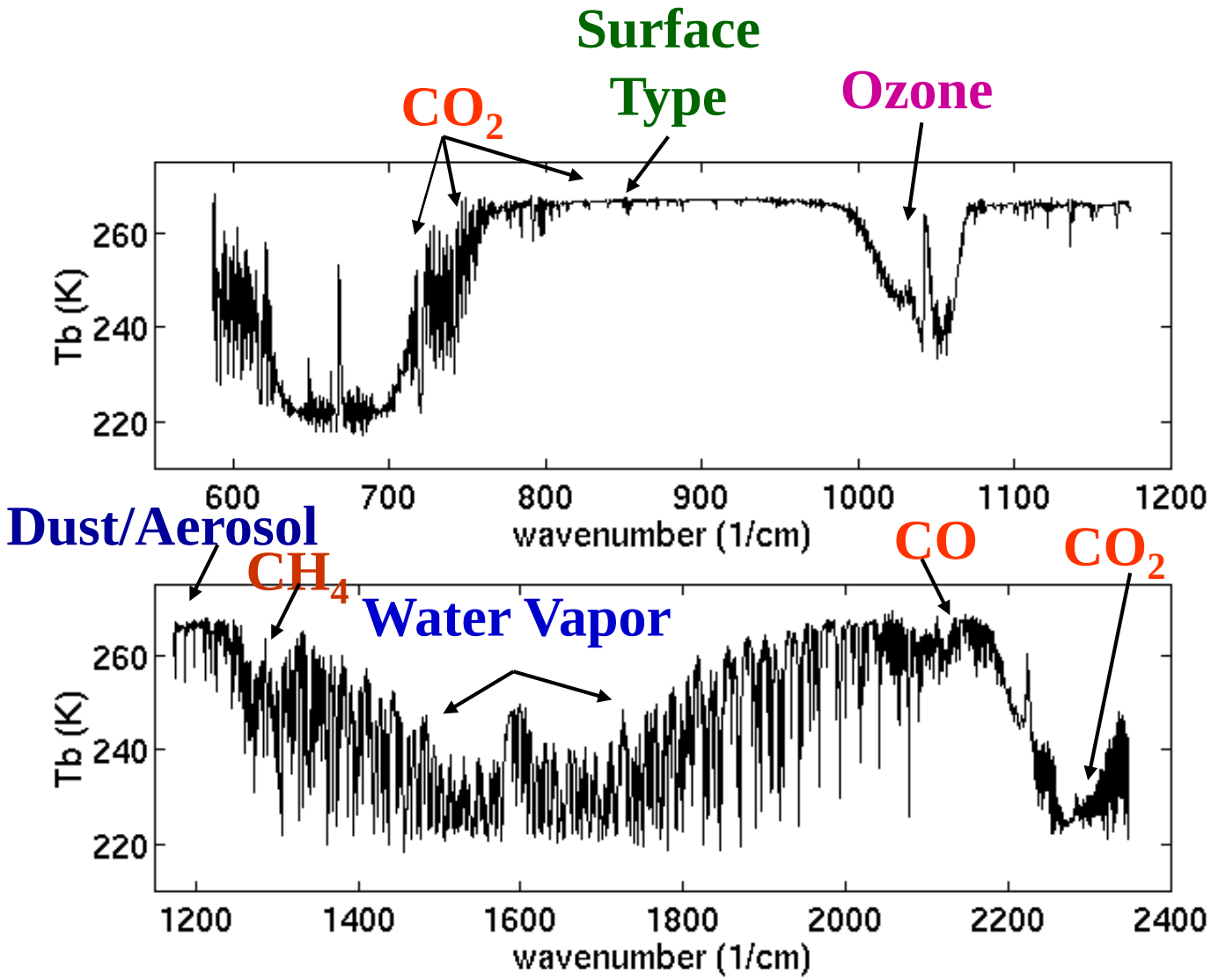
r…reflectivity, with $r = (1- \varepsilon)/\pi$,

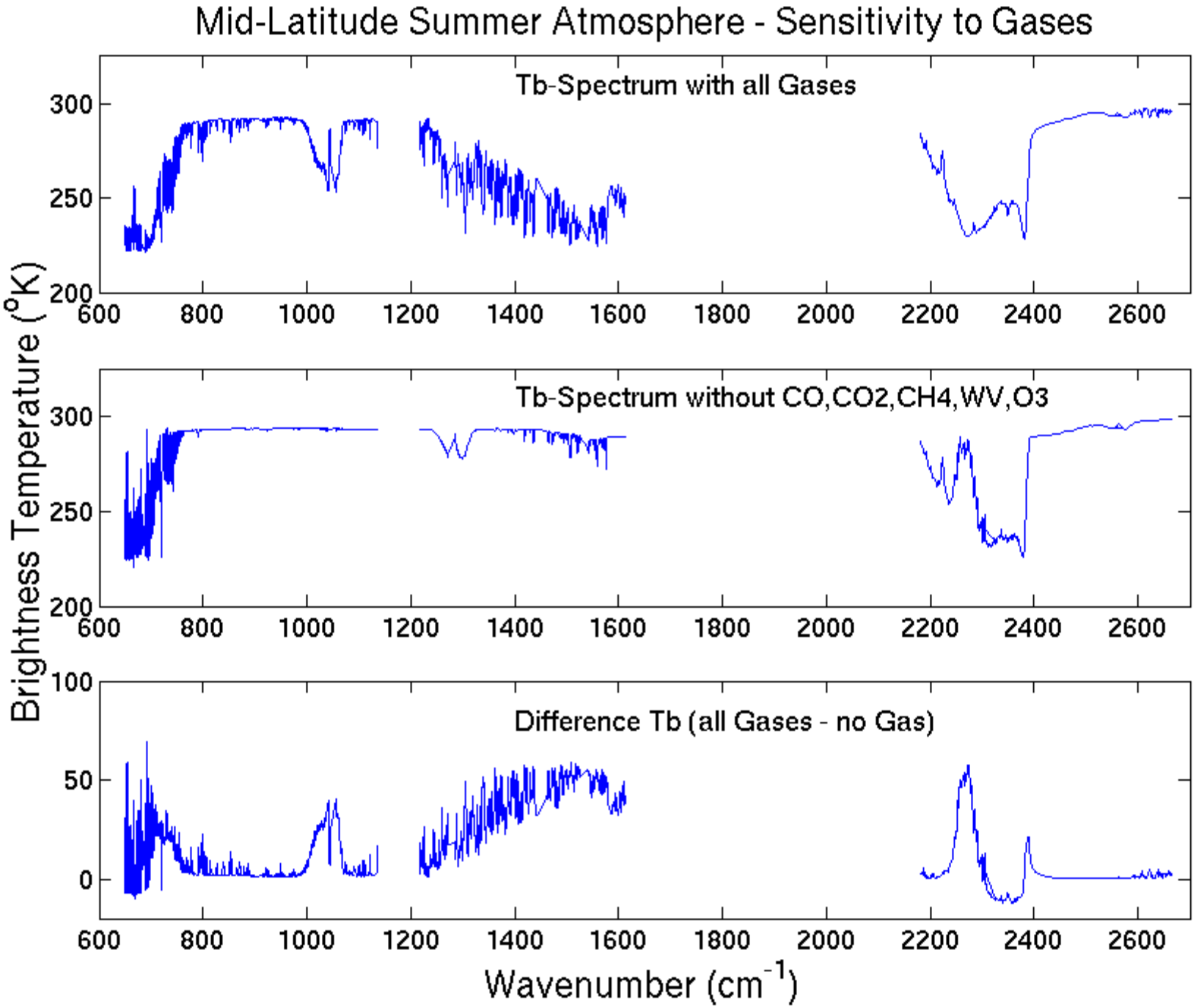
τ^*…level to surface (downwelling) transmittance [$\tau^* = \tau_\upsilon^2(p_s)/ \tau_\upsilon(p)$]

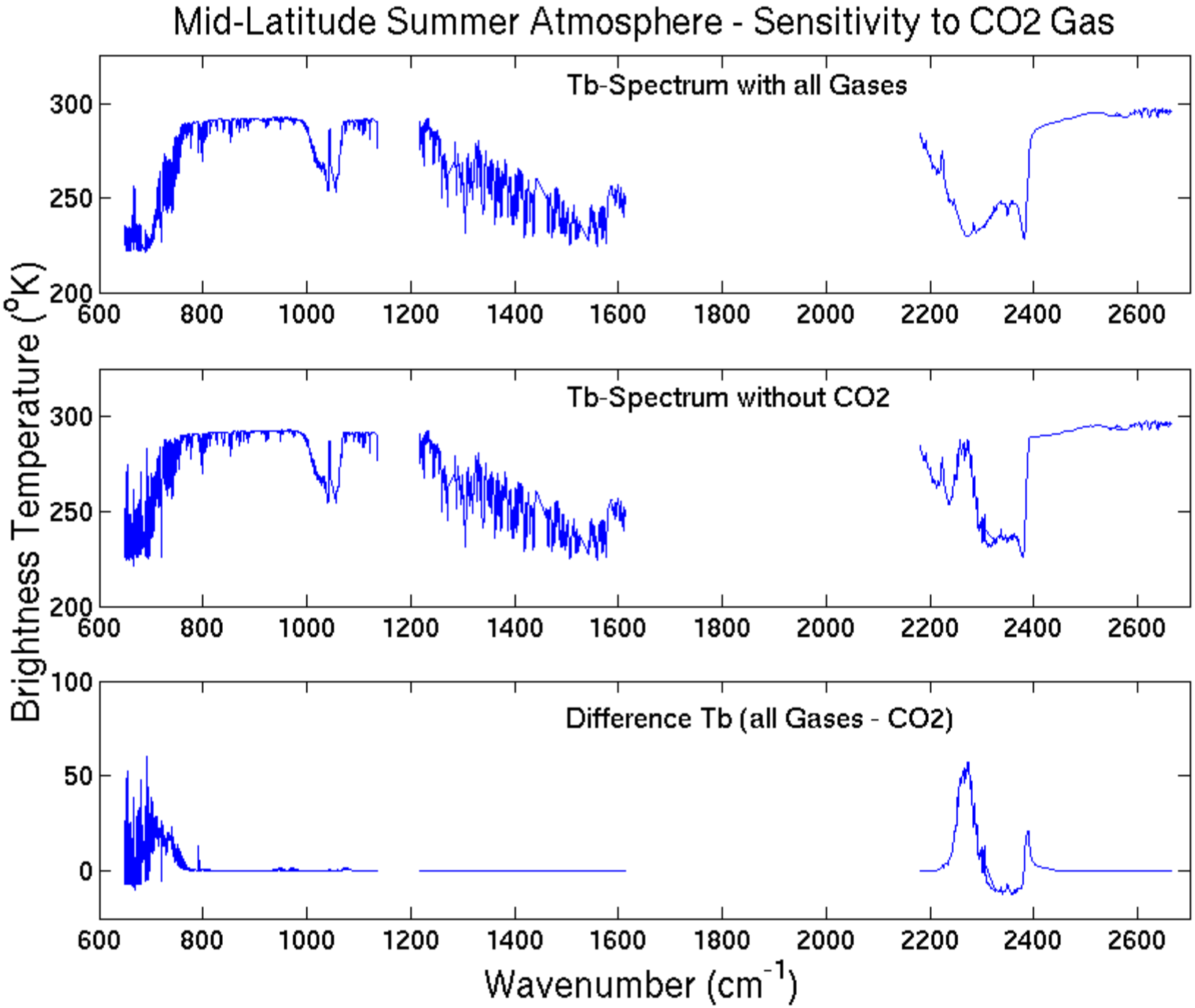
High spectral resolution Sounding & Multi-Spectral Imaging Infrared Remote Sensing

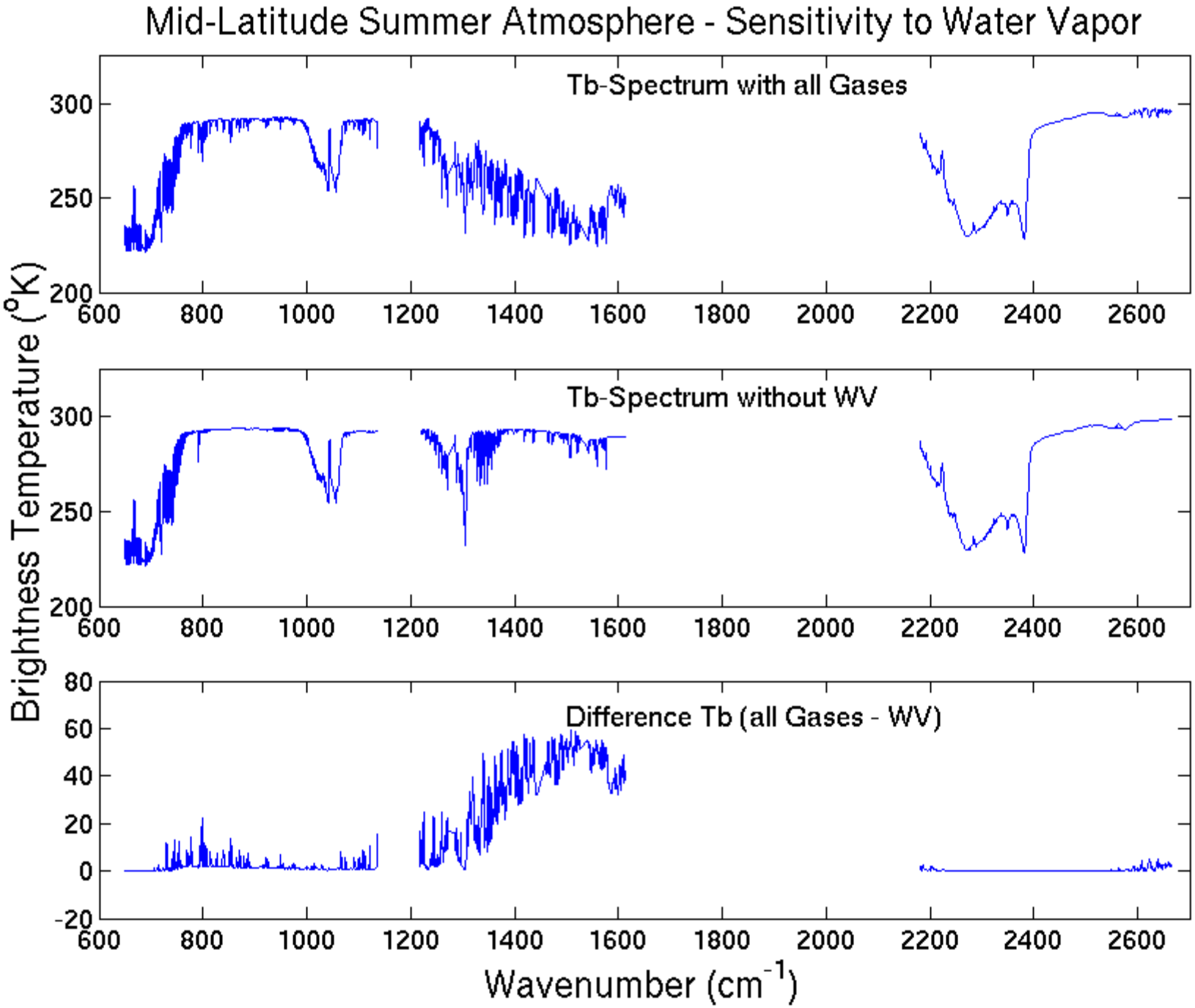
- **Sounding & Imaging Infrared measurements**
- **Gases Absorption Signature**
- **Land/Ocean Surface Signature**
- **Atmospheric Signature**
- **Clouds, Aerosol/Dust Signature**
- **GOES-10 Sounding**

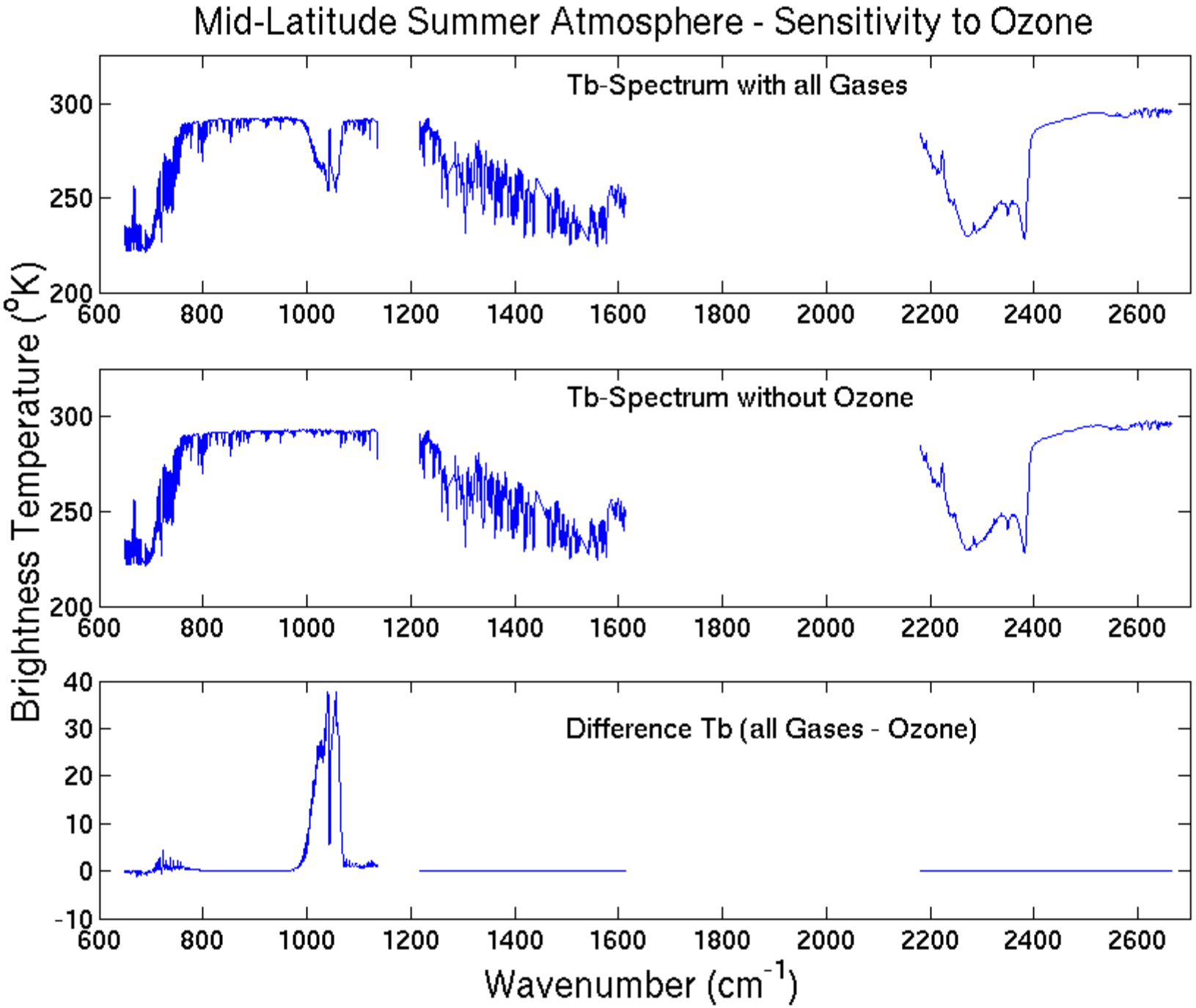
Major Infrared Gases' Absorption

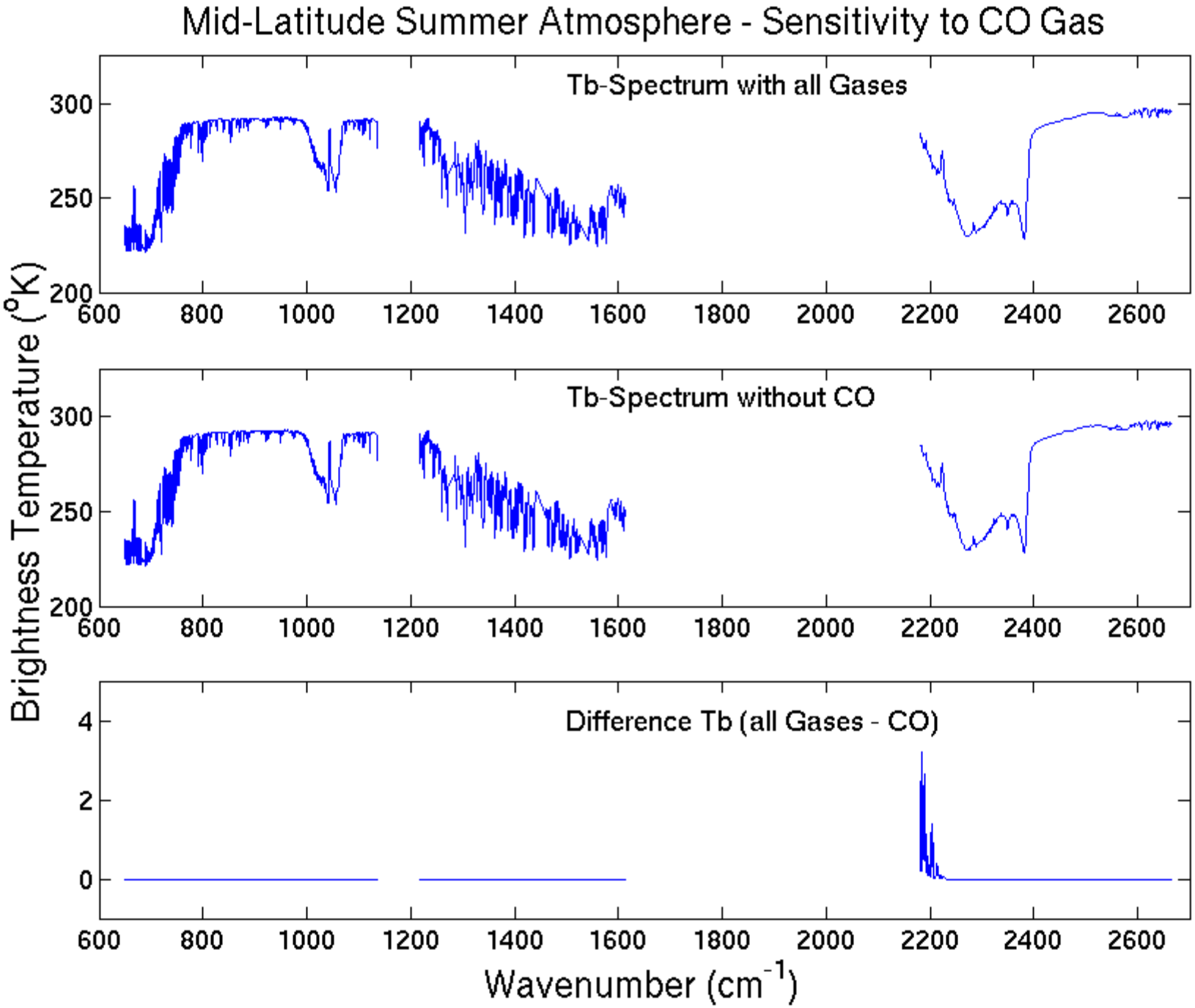


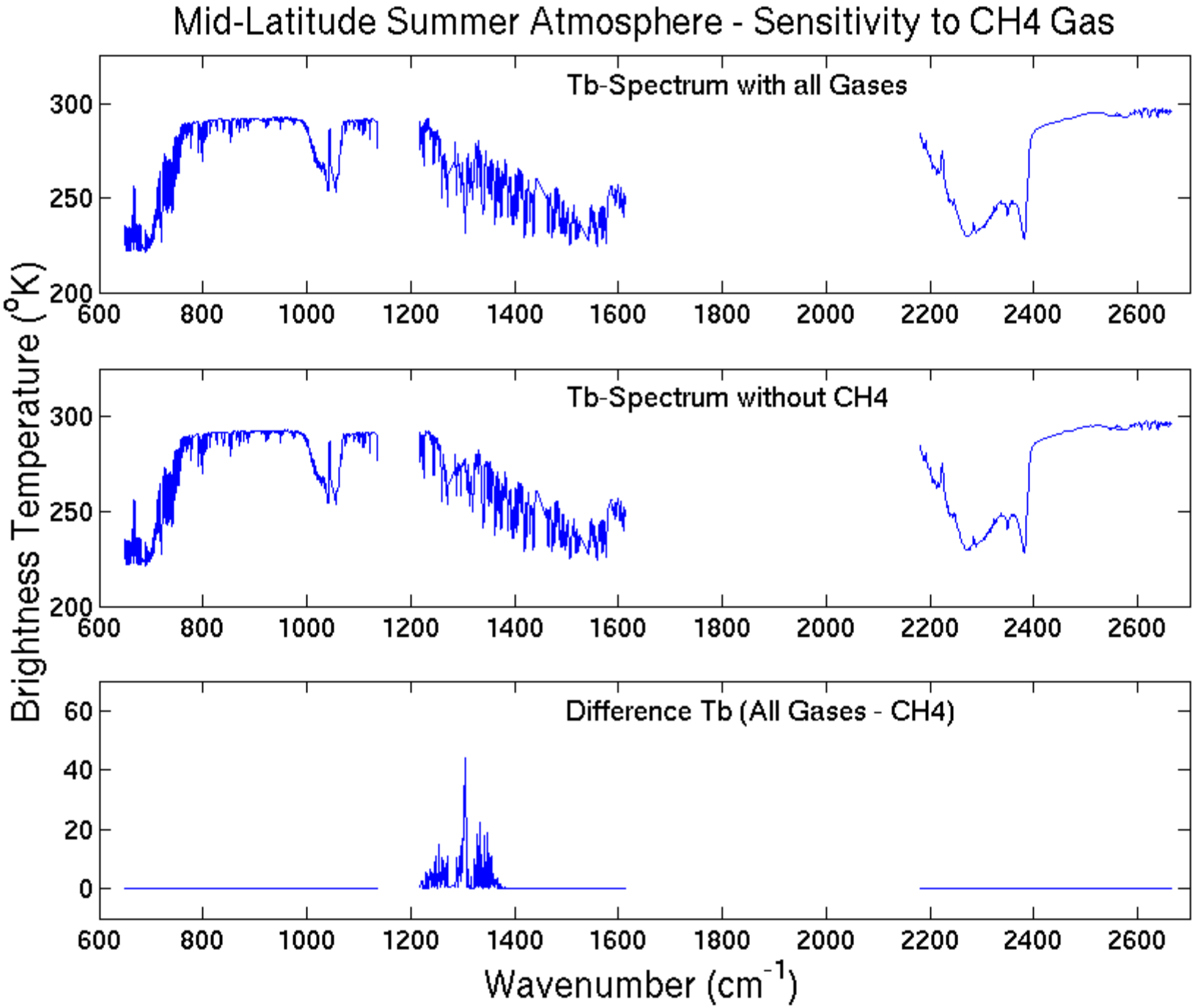

Mid-Latitude Summer Atmosphere - Sensitivity to Gases
Tb-Spectrum with all Gases
Tb-Spectrum without CO,CO2,CH4,WV,O3
Difference Tb (all Gases - no Gas)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
100
50
0
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600


Mid-Latitude Summer Atmosphere - Sensitivity to CO2 Gas
Tb-Spectrum with all Gases
Tb-Spectrum without CO2
Difference Tb (all Gases - CO2)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
100
50
0
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600


Mid-Latitude Summer Atmosphere - Sensitivity to Water Vapor
Tb-Spectrum with all Gases
Tb-Spectrum without WV
Difference Tb (all Gases - WV)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
80
60
40
20
0
-20
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600


Mid-Latitude Summer Atmosphere - Sensitivity to Ozone
Tb-Spectrum with all Gases
Tb-Spectrum without Ozone
Difference Tb (all Gases - Ozone)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
40
30
20
10
0
-10
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600


Mid-Latitude Summer Atmosphere - Sensitivity to CO Gas
Tb-Spectrum with all Gases
Tb-Spectrum without CO
Difference Tb (all Gases - CO)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
4
2
0
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600


Mid-Latitude Summer Atmosphere - Sensitivity to CH4 Gas
Tb-Spectrum with all Gases
Tb-Spectrum without CH4
Difference Tb (All Gases - CH4)
Brightness Temperature (°K)
Wavenumber (cm-1)
300
250
200
60
40
20
0
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600

Radiance received by CrIS/IASI/HIRAS/GIIRS

RTE (no scattering) in LTE

$$R_\nu = \tau_{s\nu} \cdot \varepsilon_{s\nu} \cdot B_\nu(T_S)$$

← Upwelling IR radiation from surface

$$+ \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu(p)$$

← Upwelling IR radiation from atm. layers

$$- \tau_{s\nu} \cdot r_{s\nu} \cdot \int_{p_s}^{0} B_\nu(T(p)) d\tau_\nu^*(p)$$

← Reflected downwelling IR radiation

$$+ R_\nu^{sun} \cdot \cos(\theta) \cdot \tau_{s\nu}^{sun}(p_s) \cdot r_\nu^{sun}$$

← Reflected solar radiation

R…radiance, υ…wavenumber, *s*…surface, *p*…pressure, *sun*…solar,

T…temperature, *B*…Planck function, ε …emissivity,

τ…level to space transmittance, θ...local solar zenith angle

r…reflectivity, with $r = (1- \varepsilon)/\pi$,

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Illustration of Hyperspectral Sounding Concept (1/10)

- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
- Radiance at band center is emitted from top of atmosphere; radiance in window region is emitted from surface; & radiances in-between are emitted from layers between surface & top of atmosphere which give atmospheric vertical structure of temperature (if radiances are measured from CO_2 bands) and water vapor (if radiances are measured from water vapor bands)

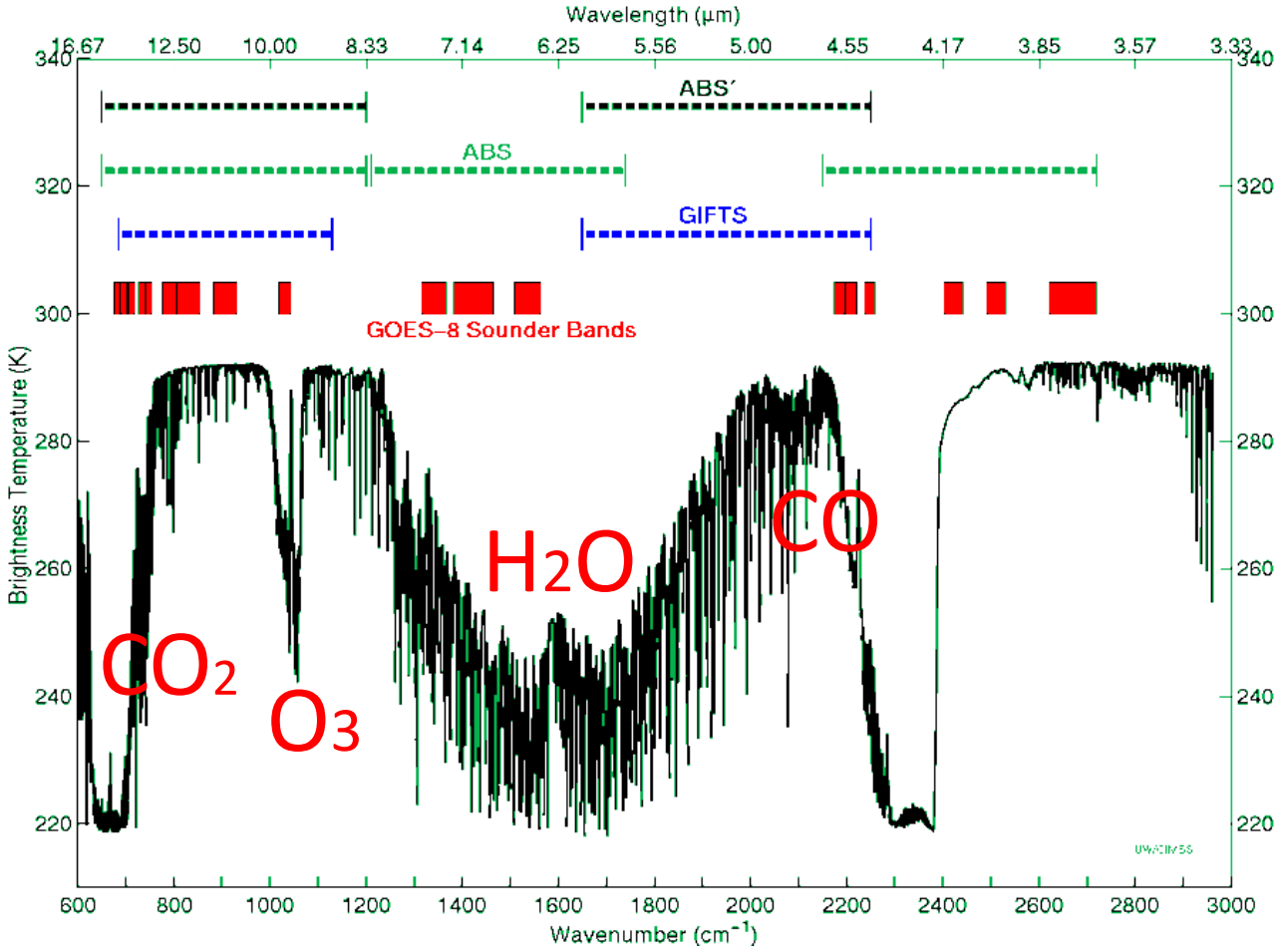

Illustration of Hyperspectral Sounding Concept (2/10)

- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
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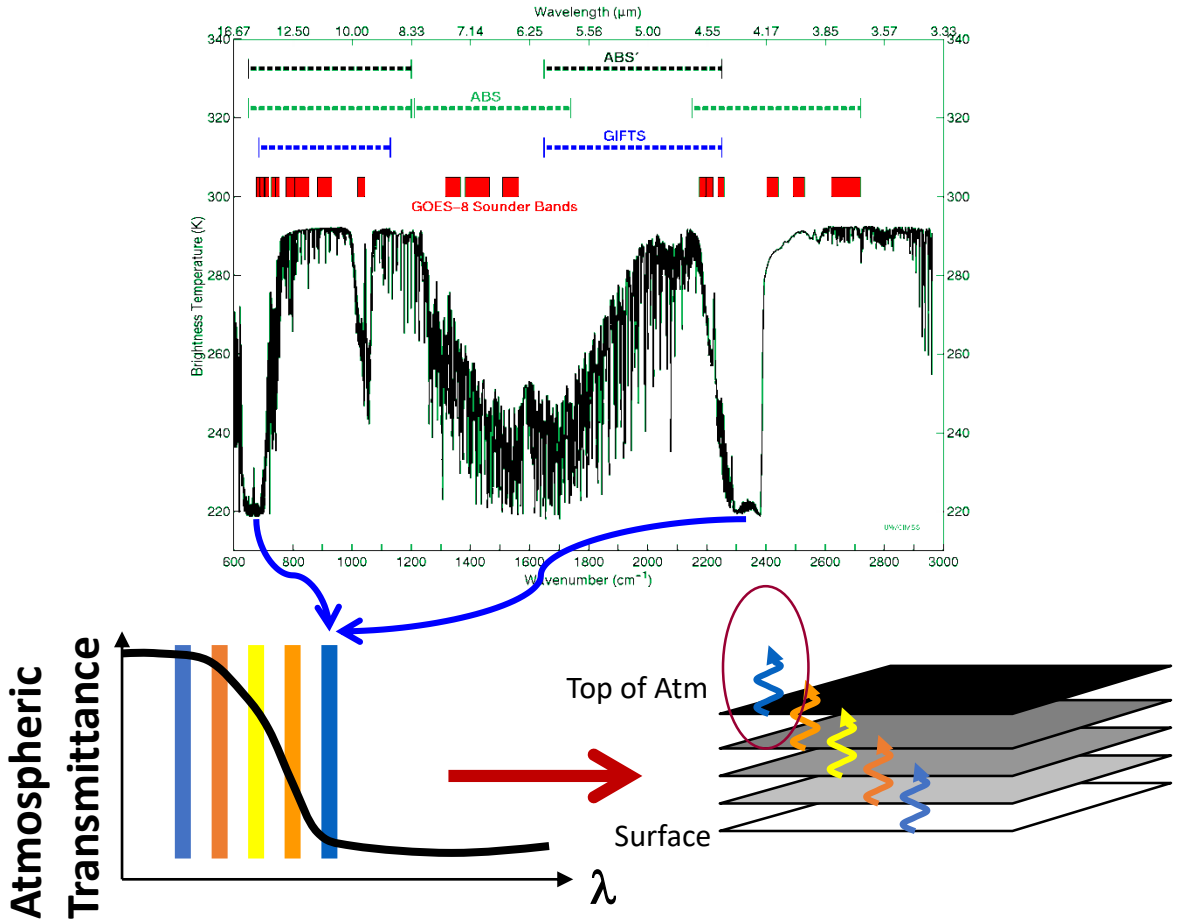

Illustration of Hyperspectral Sounding Concept (3/10)

- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
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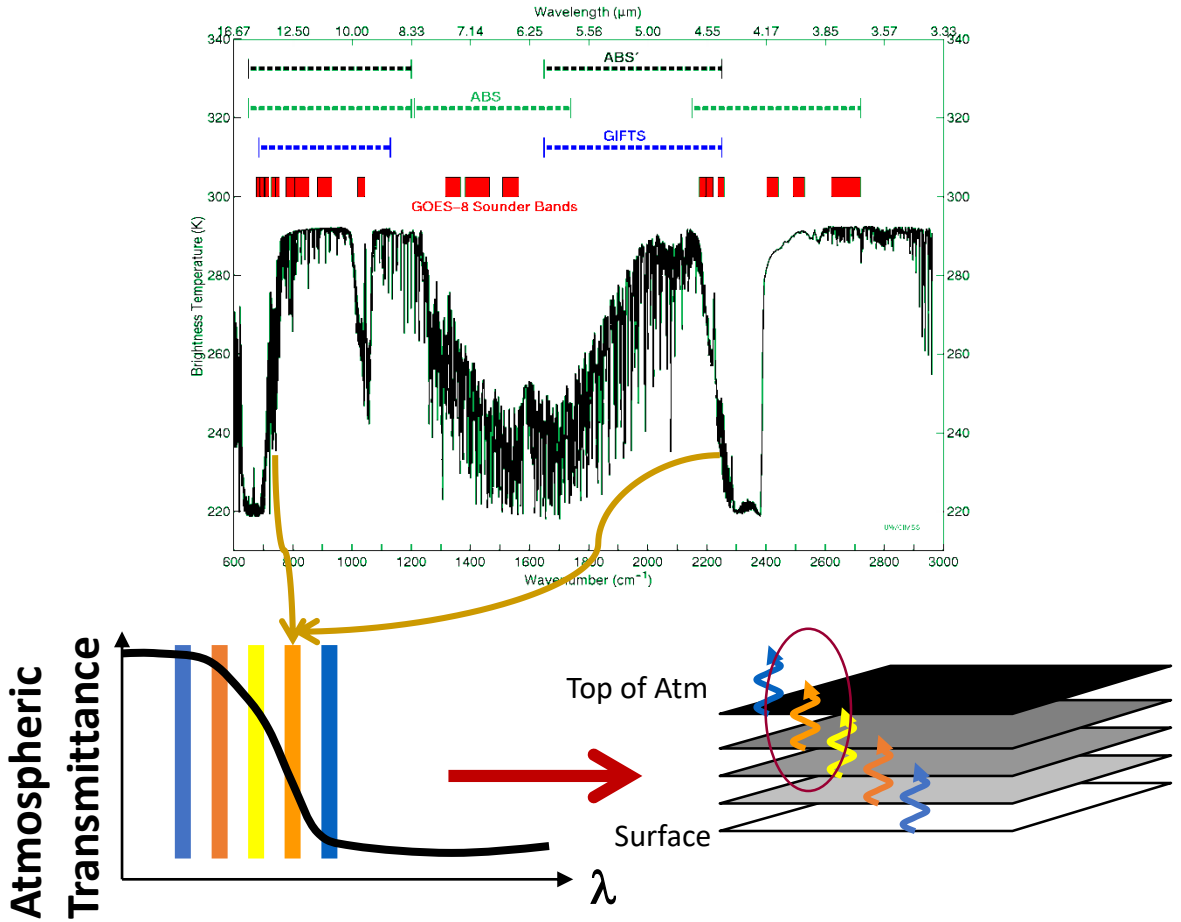

Illustration of Hyperspectral Sounding Concept (4/10)

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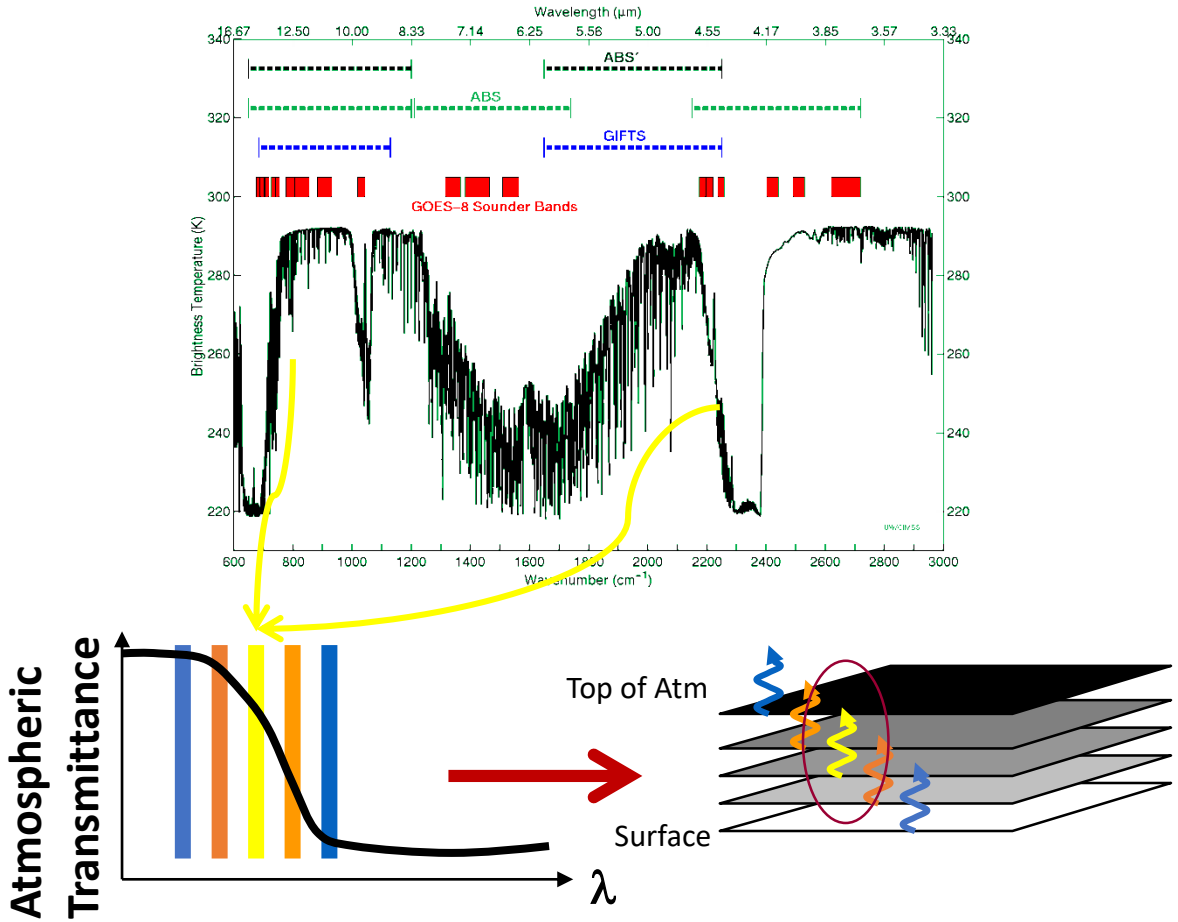

Illustration of Hyperspectral Sounding Concept (5/10)

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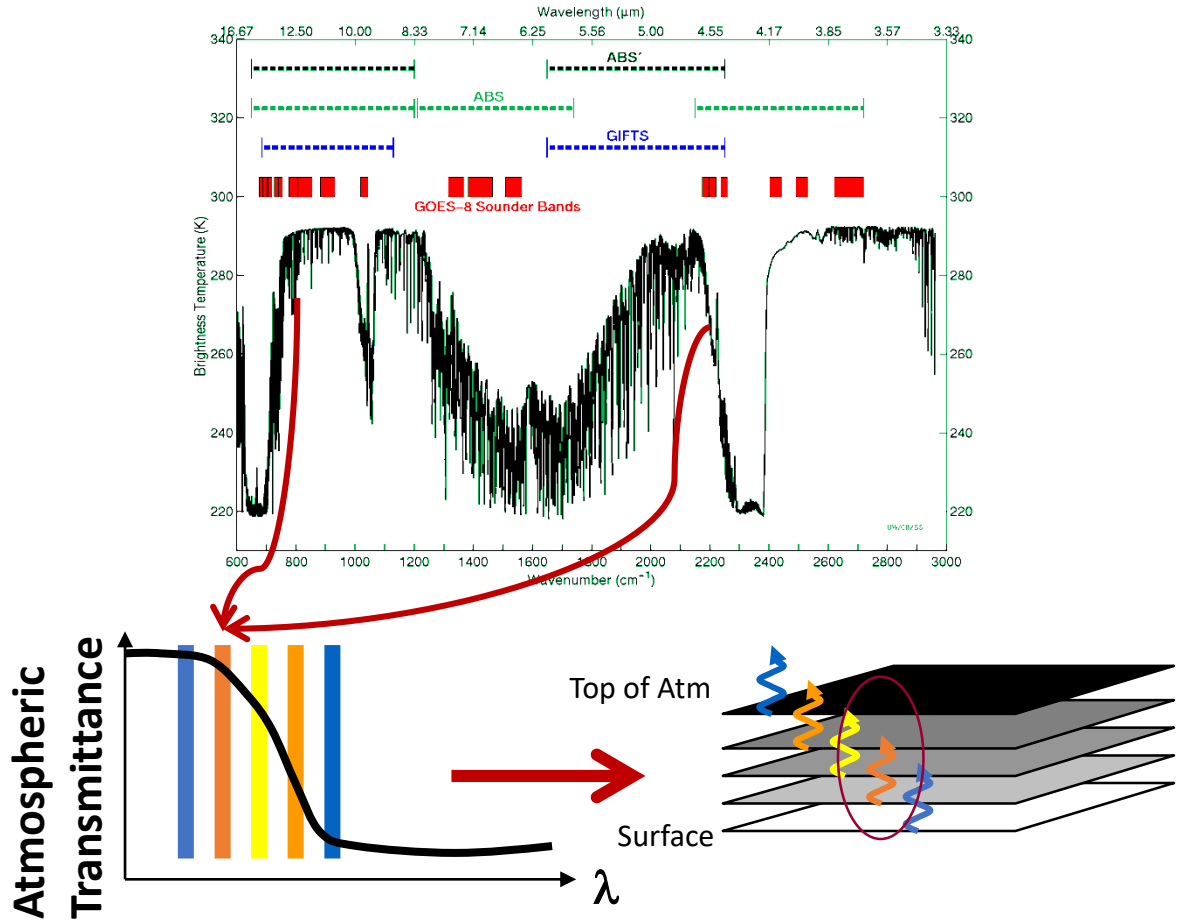

Illustration of Hyperspectral Sounding Concept (6/10)

- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
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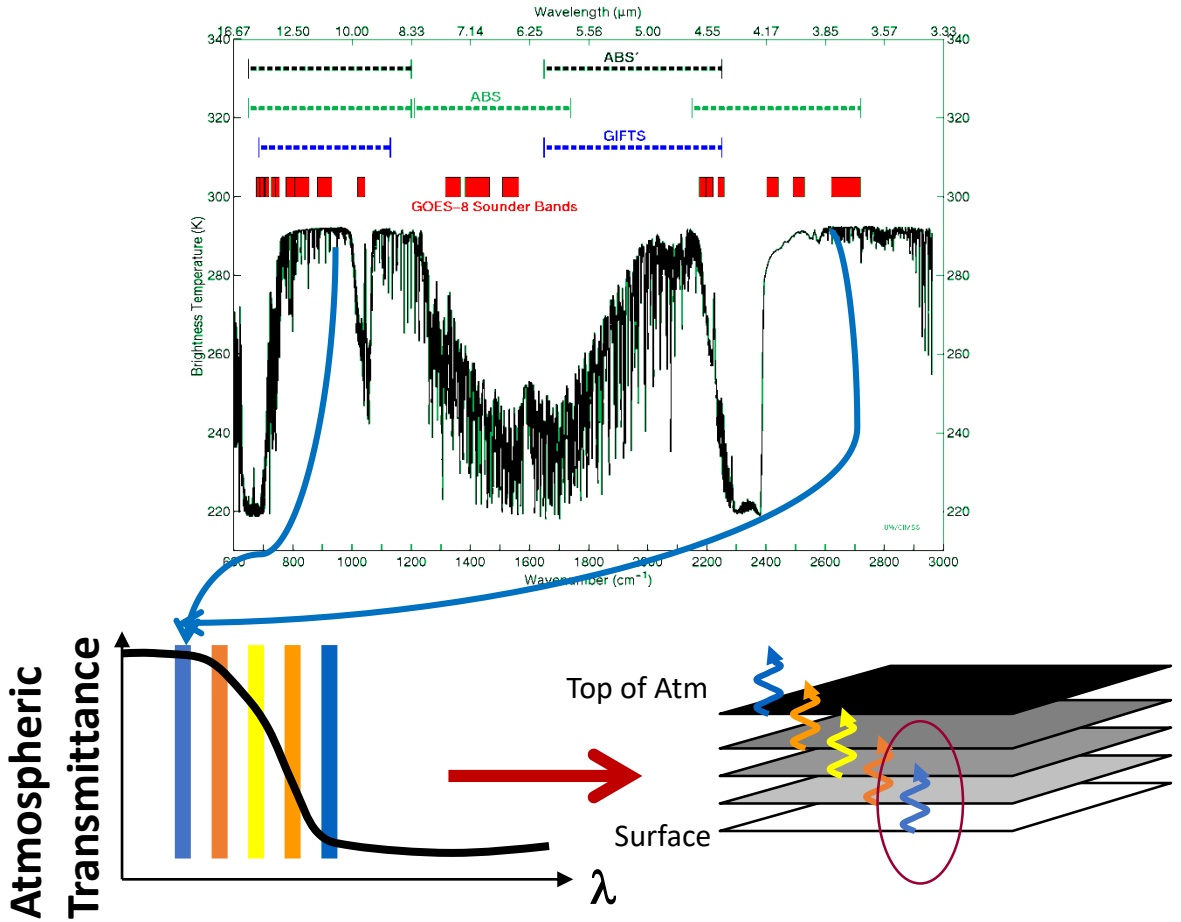

Illustration of Hyperspectral Sounding Concept (7/10)

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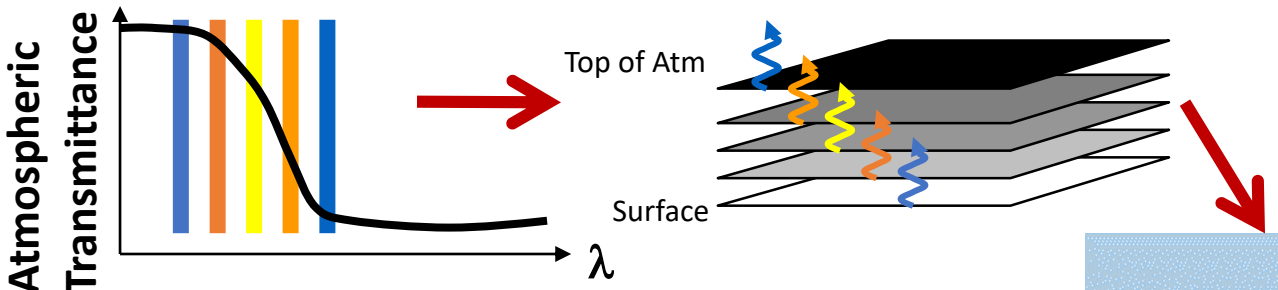
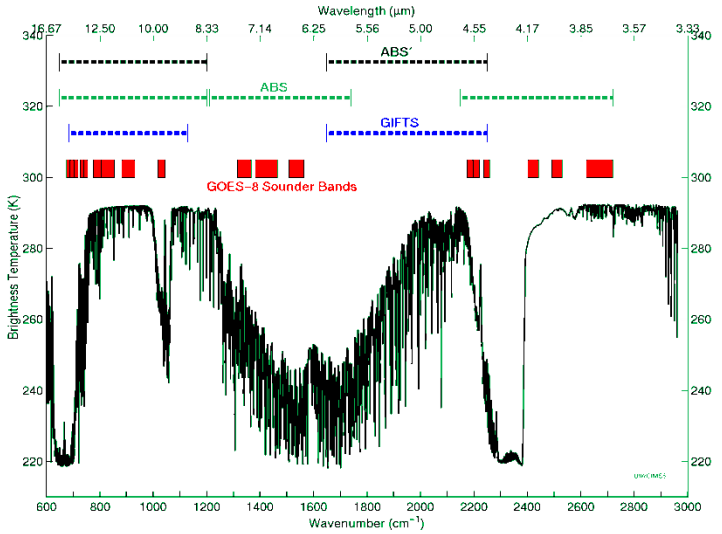
- Radiance at band center is emitted from top of atmosphere; radiance in window region is emitted from surface; & radiances in-between are emitted from layers between surface & top of atmosphere which give atmospheric vertical structure of temperature (if radiances are measured from CO_2 bands) and water vapor (if radiances are measured from water vapor bands)





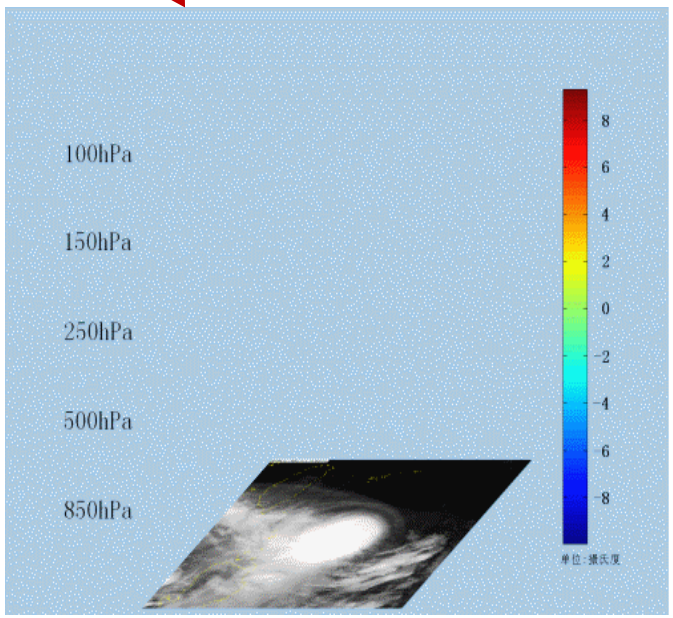


Illustration of Hyperspectral Sounding Concept (8/10)

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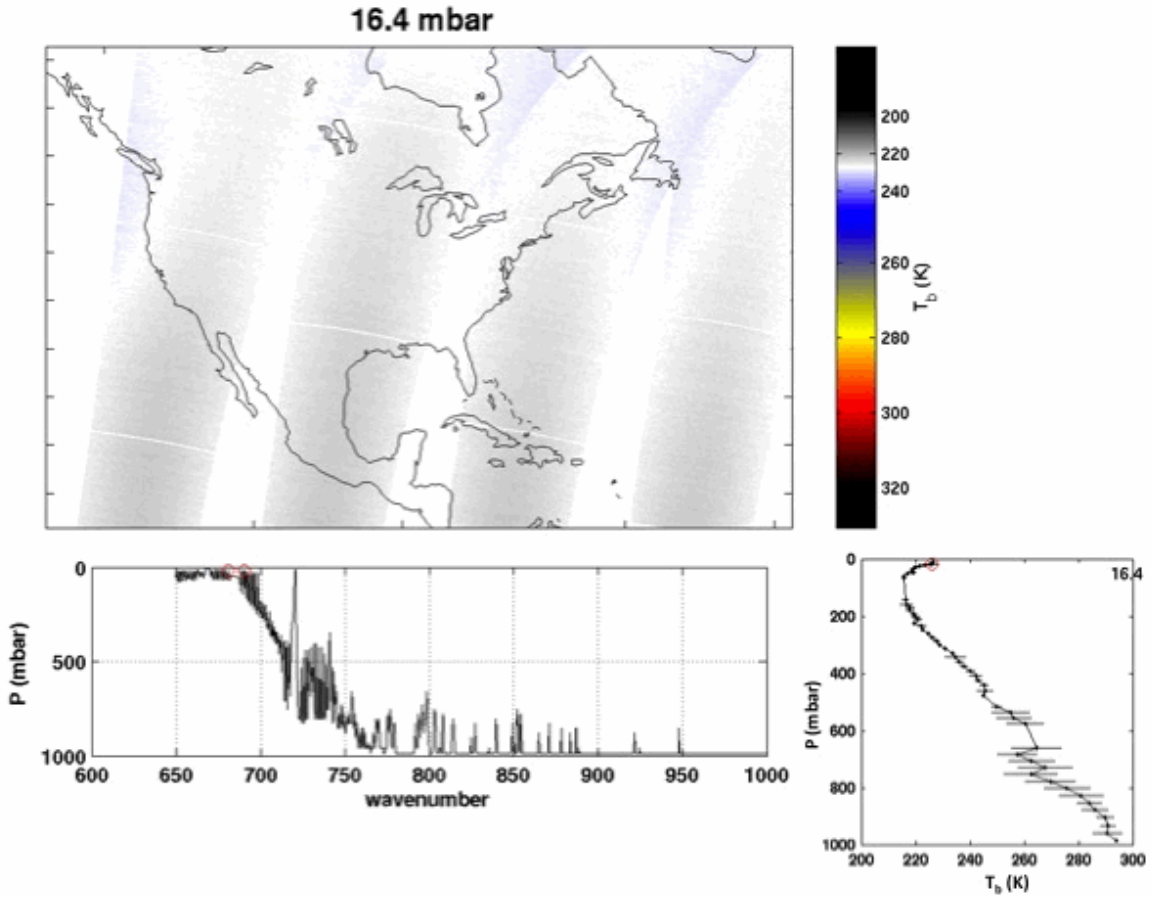
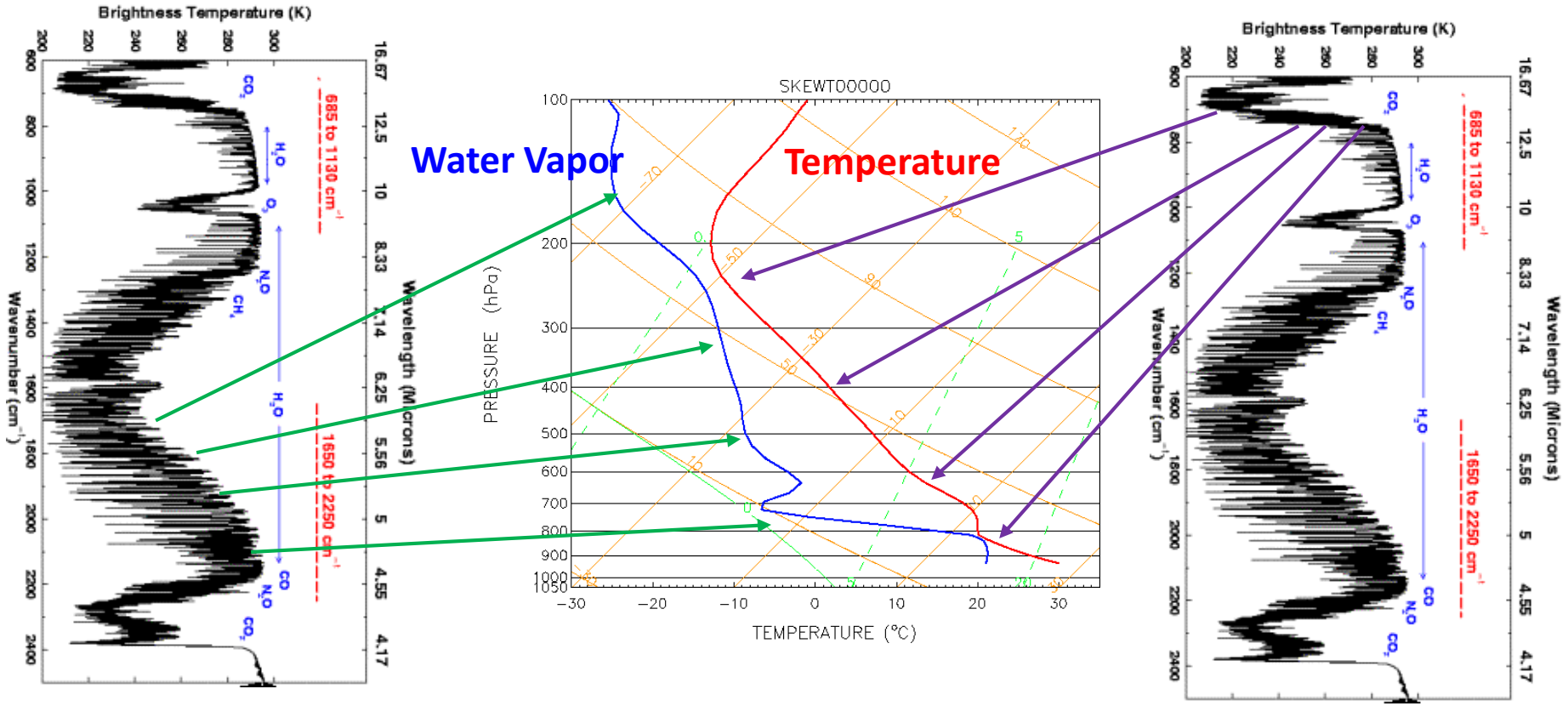


Mouse click or page down to start movie

Illustration of Hyperspectral Sounding Concept (9/10)

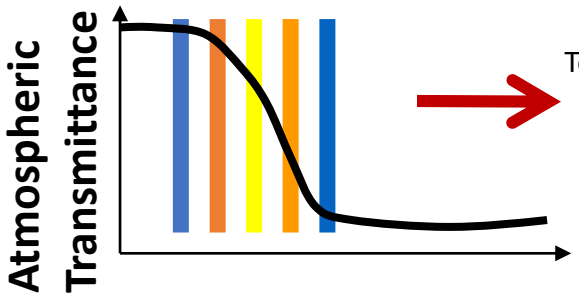
- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
- Radiance at band center is emitted from top of atmosphere; radiance in window region is emitted from surface; & radiances in-between are emitted from layers between surface & top of atmosphere which give atmospheric vertical structure of temperature (if radiances are measured from CO_2 bands) and water vapor (if radiances are measured from water vapor bands)

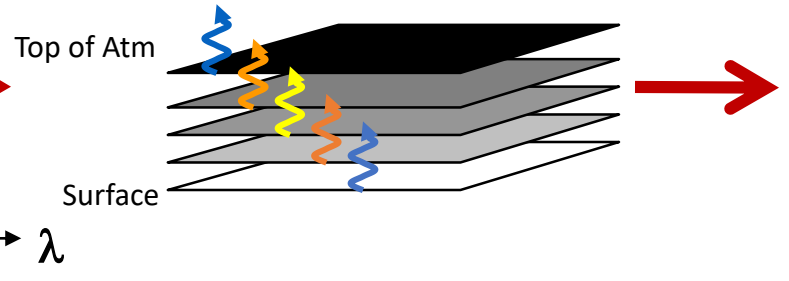


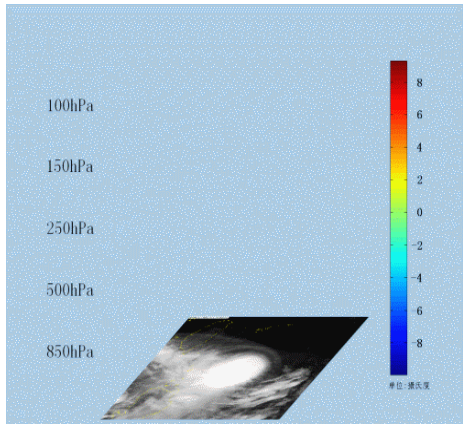
Single STORM IFOV (one spectrum = ~1800 channels)

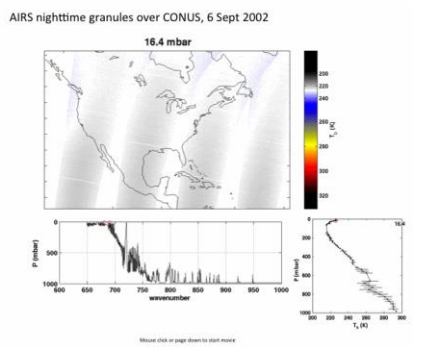
Illustration of Hyperspectral Sounding Concept (10/10)

- Hyperspectral sounder collect thousands of high spectral resolution measurements of atmospheric upwelling radiance along edge of molecular absorption (i.e. CO_2 & H_2O) spectral bands
- Radiance at band center is emitted from top of atmosphere; radiance in window region is emitted from surface; & radiances in-between are emitted from layers between surface & top of atmosphere which give atmospheric vertical structure of temperature (if radiances are measured from CO_2 bands) and water vapor (if radiances are measured from water vapor bands)

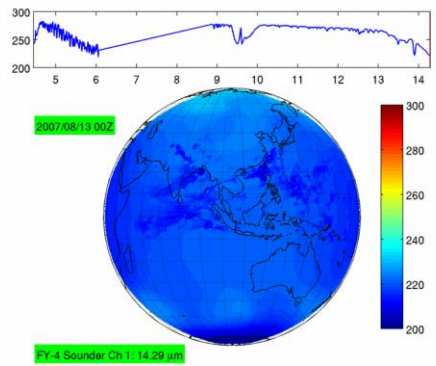




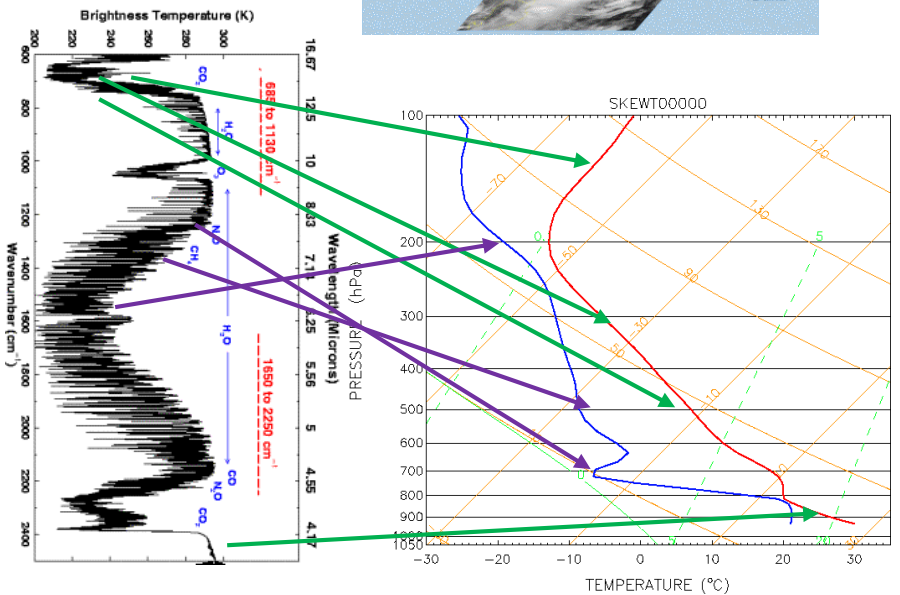




LEO Sounding



GEO Sounding



Useful Resources
ATBD and CSPP

STAR JPSS
Science Documents
NESDIS JPSS Technical Documents page

Algorithm Theoretical Basis Documents (ATBD)
Document List

https://www.star.nesdis.noaa.gov/jpss/Docs.php#S561421

NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm Theoretical Basis Document
https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_NUCAPS_v3.1.pdf

Community S/W ready to use
http://cimss.ssec.wisc.edu/cspp/

10:00-14:00 T9/T10/T11 (with lunch break 12:00-13:00)

Quantitative Analysis and Applications of IR/VIS Imagery with Labs

1. **Meteorological Satellite Sounding Theory & Resources** by Allen Huang
2. **Why Sounding Data Can Help You** by Scott Lindstrom
3. **Geostationary vs Polar Orbit satellite data - Making the Case for Both** by Jessica Braun
4. **Microwave Satellite Retrievals and Applications** by Kathy Strabala

AOMSUC-13
Training Workshop
Jincheon, S. Korea
4 November, 2023