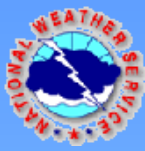


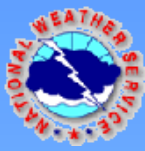
Radiance Data Assimilation

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NCEP/NWS/NOAA
With input from:
John Derber



Outline

- Introduction
- Different types of satellite data.
- Basic theory of satellite observations
 - Radiative Transfer
 - Spectroscopy
 - Basic concept of a retrieval
- Assimilating satellite radiances.
 - Data assimilation equation
 - Quality control.
 - Bias correction.
 - Observation errors.
 - Thinning
 - Monitoring.
 - Thinning
- Future of satellite data assimilation.



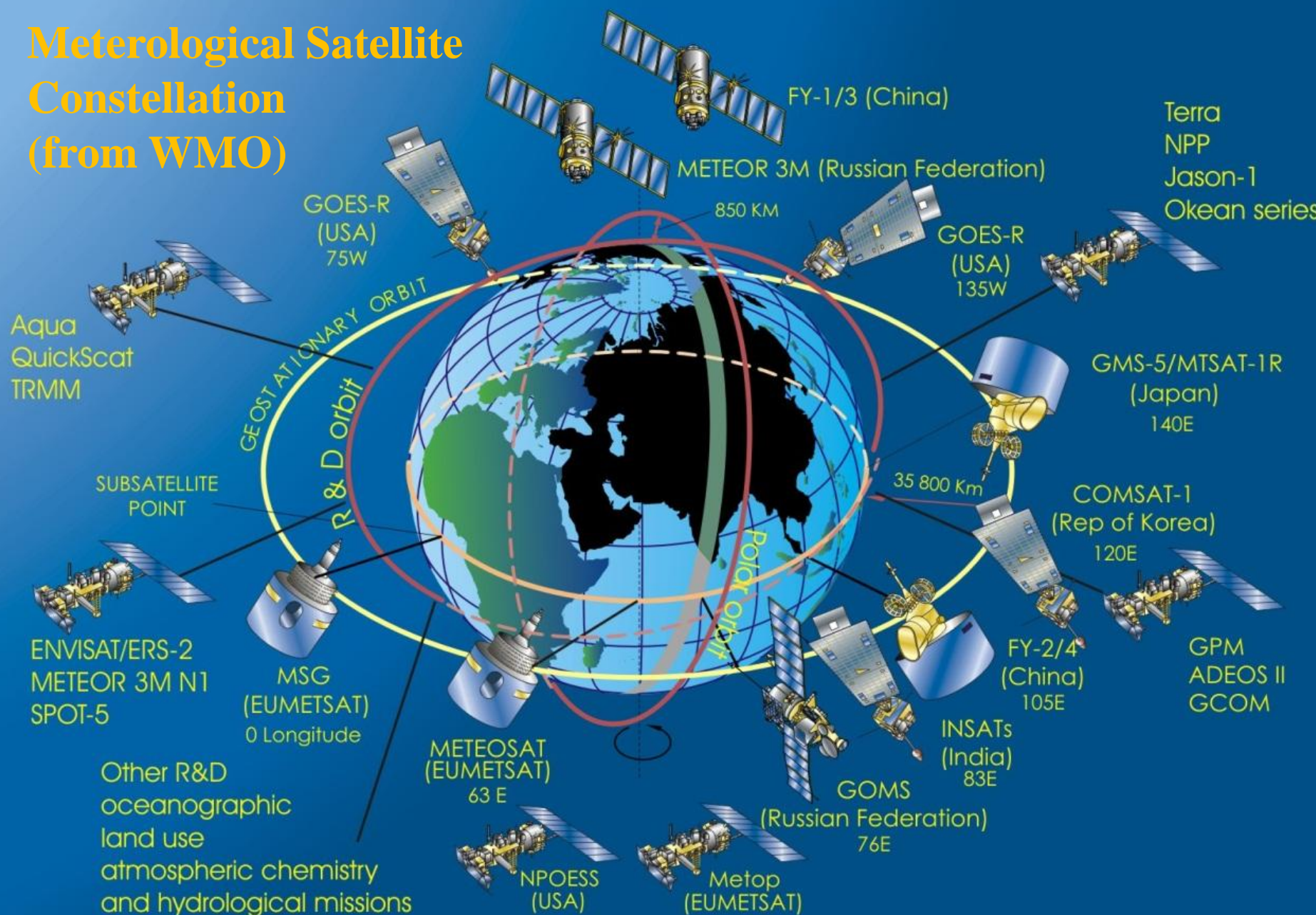
Introduction

- Satellites instruments do not directly measure the atmospheric state.
- Instead they measure radiation emitted by and/or transmitted by the atmosphere.
- This presentation describes the relationship between the atmospheric state and the observed radiation. And how the information contained therein is exploited through assimilation into the NWP model.



Different Types of Satellite Data

Meteorological Satellite Constellation (from WMO)





Different Types of Satellite Data

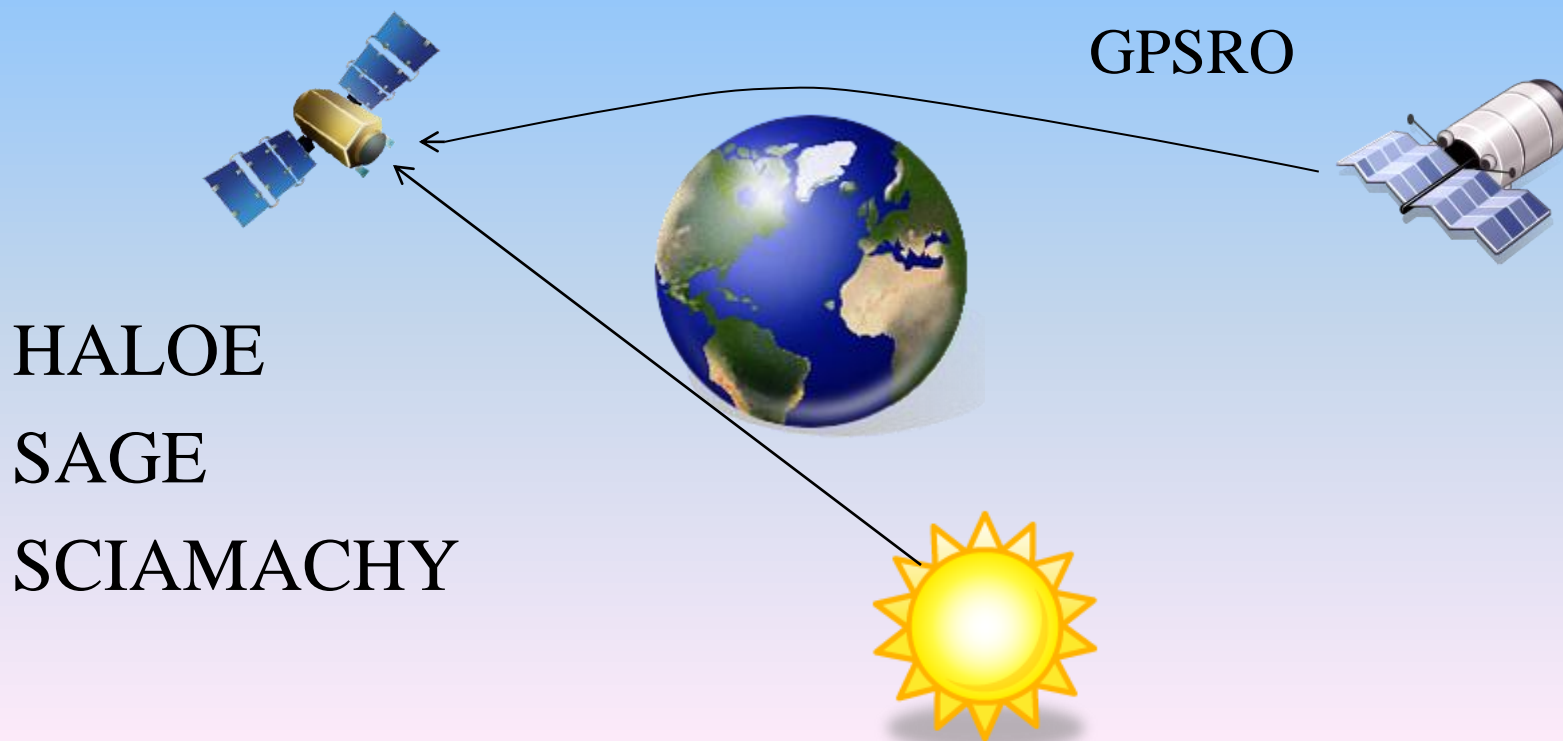
- Active (bouncing a signal off something)
 - Wind Lidar
 - SAR
 - Cloud radar
 - Scatterometry

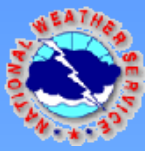




Different Types of Satellite Data

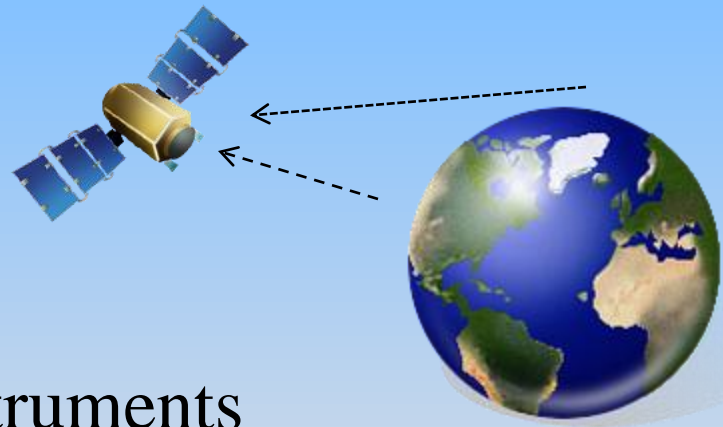
- Occultation (signal passing through atmosphere)





Different Types of Satellite Data

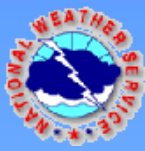
- Passive (receiving radiative signal from source)



Visible instruments

IR instruments

Microwave instruments



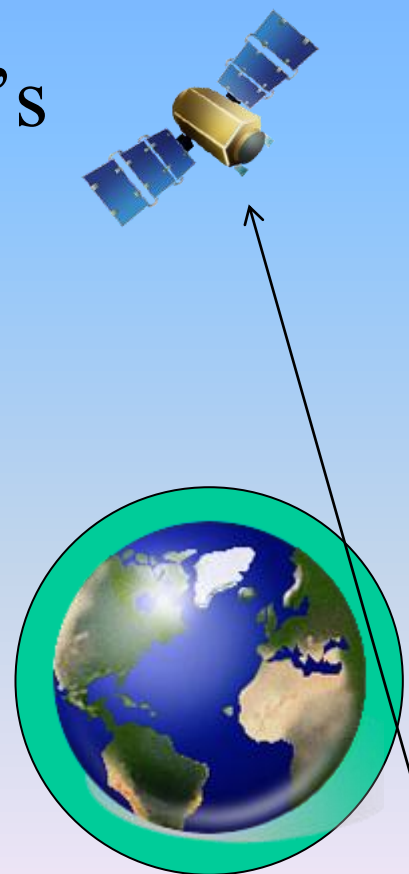
Passive Instruments

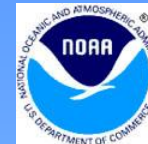
- This talk will focus on passive infrared and microwave instruments as they are the most common and biggest contributors to Numerical Weather Prediction



Geometry: Limb vs Nadir Sounding

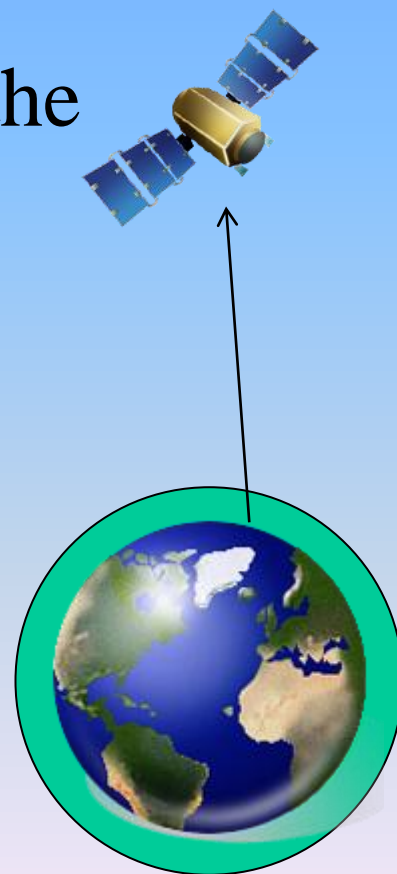
- Limb sounding: Viewing the Earth's atmosphere tangentially
 - Higher vertical resolution
 - Lower horizontal resolution
 - Most often used for observing the stratosphere and above.
 - Not often used in NWP



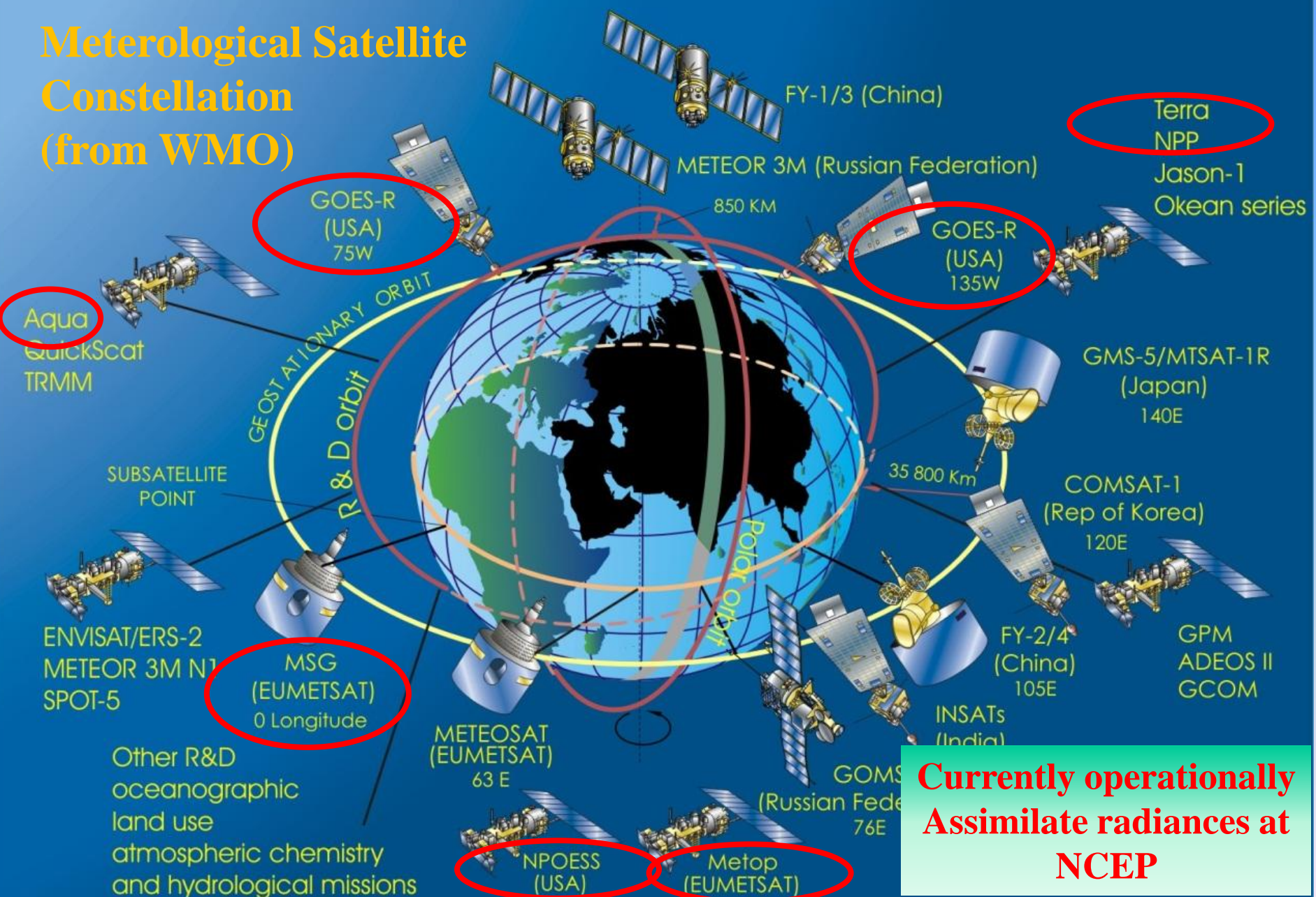


Geometry: Limb vs Nadir Sounding

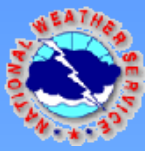
- Nadir sounding: Viewing towards the Earth's surface
 - Lower vertical resolution
 - Higher horizontal resolution
 - Most often used in NWP



Meteorological Satellite Constellation (from WMO)



**Currently operationally
Assimilate radiances at
NCEP**



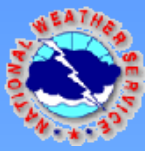
Basic theory of satellite observations

Radiative Transfer



Radiative Transfer : Definitions

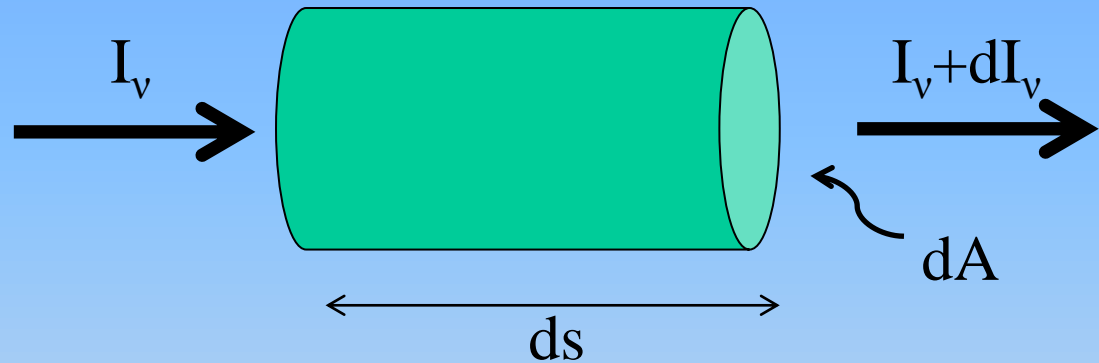
- *Radiance*, I_ν , is the radiant energy emitted per unit time, per unit frequency interval, per unit area, and per unit solid angle in a specified direction at a given frequency, ν .
 - The units for radiance are $\text{Wm}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1}$ or equivalent. Radiance is often expressed as the temperature that would produce the equivalent black-body radiance: the *Brightness Temperature*.
- This is not to be confused with *Irradiance* or *Flux Density* which is the total power per unit frequency interval, crossing perpendicular to a unit area which has units $\text{Wm}^{-2}(\text{cm}^{-1})^{-1}$.



Radiative Transfer

Absorption of radiance in a volume element

Consider monochromatic radiation of frequency ν passing through a volume element of length ds and cross-sectional area dA . It contains a gas with n molecules per unit volume, each with an absorption coefficient of k_ν .



If we ignore scattering, the change in radiance across the volume due to absorption is given by:

$$(I_\nu + dI_\nu)dA = -(n k_\nu ds) I_\nu dA$$

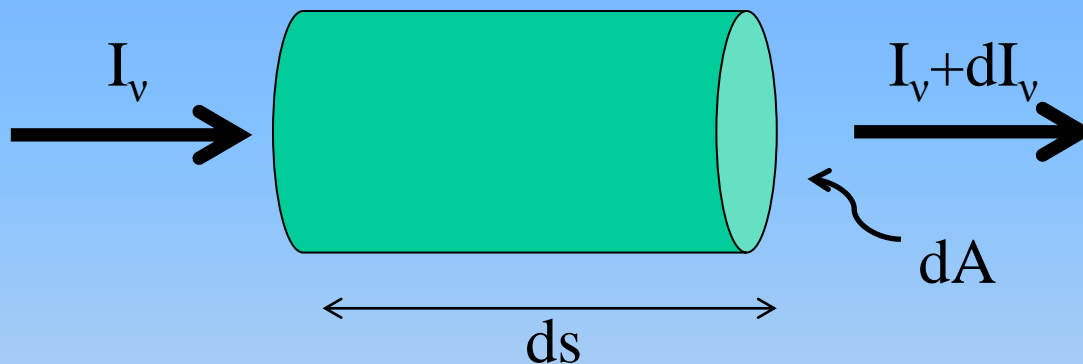
$(n k_\nu ds)$ is the *absorptivity* of the volume element.



Radiative Transfer

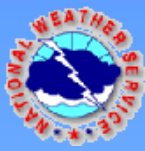
Emission of radiance in a volume element

If we continue to ignore scattering, the change in radiance across the volume due to emission from the same volume element is given by:



$$(I_v + dI_v)dA = \epsilon_v S_v dA$$

Where ϵ_v is the emissivity of the volume and is S_v the *Source Function*. In regions of local thermodynamic equilibrium (LTE) – as is usually the case in the troposphere and stratosphere – the Source Function is the Planck Function, $B(T)$, where T is the temperature.



Radiative Transfer

Schwarzchild Equation of Radiative Transfer

Combining the terms for emission and absorption gives

$$(I_\nu + dI_\nu)dA = -(n k_\nu ds) I_\nu dA + \epsilon_\nu S_\nu dA$$

Kirchoff's Law states that the absorptivity and the emissivity are the same, so $n k_\nu ds = \epsilon_\nu$.

If we now define the *optical depth, τ* , through $d\tau_\nu = -n k_\nu ds$, we obtain the *Schwarzchild Equation of Radiative Transfer*:

$$\frac{dI_\nu}{d\tau_\nu} = I_\nu - S_\nu$$

As stated above, for LTE, $S_\nu = B_\nu(T)$, so

$$\frac{dI_\nu}{d\tau_\nu} = I_\nu - B(T)_\nu$$



Radiative Transfer

Schwarzchild Equation in a scattering atmosphere

$$\frac{dI_{\nu}}{d\tau^*} = I_{\nu} - (1 - \omega_{\nu})B - \omega_{\nu} \int I_{\nu}(\Omega) p_{\nu}(\Omega) d\Omega$$

Extinction term

Emission term

Radiation scattered from all directions, Ω , into the beam

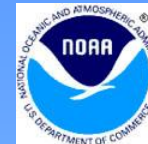
(absorption+scattering)

Now the optical depth, τ^*_{ν} , is an extinction optical depth and is defined via $d\tau^*_{\nu} = -n(k_{\nu} + \sigma_{\nu})ds$, where is σ_{ν} the scattering coefficient.

ω_{ν} is the single scattering albedo and is given by $\sigma_{\nu}/(k_{\nu} + \sigma_{\nu})$.

$p_{\nu}(\Omega)$ is the phase function and describes the angular distribution of how incident radiance is scattered.

We are not going to be considering scattering in this talk.



Radiative Transfer

Solution to Schwarzschild Equation

The general solution to the Schwarzschild equation is:

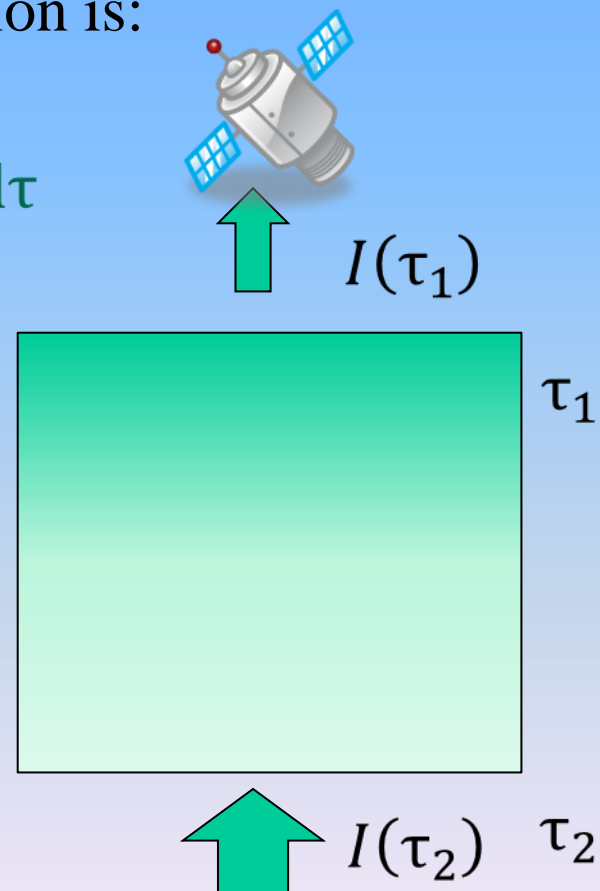
$$I(\tau_1) = I(\tau_2)e^{-(\tau_2-\tau_1)} + \int_{\tau_1}^{\tau_2} S(\tau) e^{-(\tau-\tau_1)} d\tau$$

**Radiation at
observer**

**Radiation at lower
Boundary (usually the
surface for terrestrial
planets) ...**

**... attenuated by the
intervening atmosphere**

**Emission of radiation from the
atmosphere itself including
reabsorption of this radiation**





Radiative Transfer

Transmission and Weighting Functions

The general solution to the Schwarzschild equation is:

$$I(\tau_1) = I(\tau_2)e^{-(\tau_2-\tau_1)} + \int_{\tau_1}^{\tau_2} S(\tau) e^{-(\tau-\tau_1)} d\tau$$

The *transmission*, between optical depths τ and τ_1 , $T(\tau, \tau_1)$ is $e^{-(\tau-\tau_1)}$ and $dT = -e^{-(\tau-\tau_1)} d\tau = -T(\tau, \tau_1) d\tau$. So now the solution is:

$$I(\tau_1) = I(\tau_2)T(\tau_2, \tau_1) + \int_{T_2}^{T_1} S(\tau) dT$$

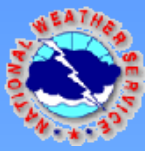
Which we can transform into pressure, p , coordinates:

$$I(\tau_1) = I(\tau_2)T(\tau_2, \tau_1) + \int_{p_2}^{p_1} S(\tau) K(p) dp$$

where

$$K(p) = \frac{\partial T(p, p_1)}{\partial p}$$

is the historical definition of the *weighting function* as it is the weight given to the source function at each level in the solution.



Radiative Transfer

Weighting Functions and Jacobians

This definition of the weighting function was used in many early retrieval schemes. But in modern data assimilation, the weighting often refers to (e.g., Rogers, 2000) the derivative of the observation (which we now designate \mathbf{y}) with respect to the *state vector*, \mathbf{x} . This is the Jacobian matrix, $\mathbf{K} = \nabla_{\mathbf{x}} \mathbf{y}(\mathbf{x})$.

Here \mathbf{x} is typically a vector of temperatures, molecular abundances (including major absorbers such as H_2O , CO_2 , O_3 , CH_4) for many layers throughout the atmosphere, surface properties and often cloud and aerosol properties.

Note that whereas the Planck emission is implicit in the calculation of the Jacobians, it is not included in the weighting function as the weighting function *is the weighting for the Planck emission at each level*.

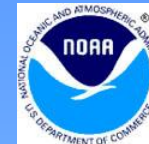
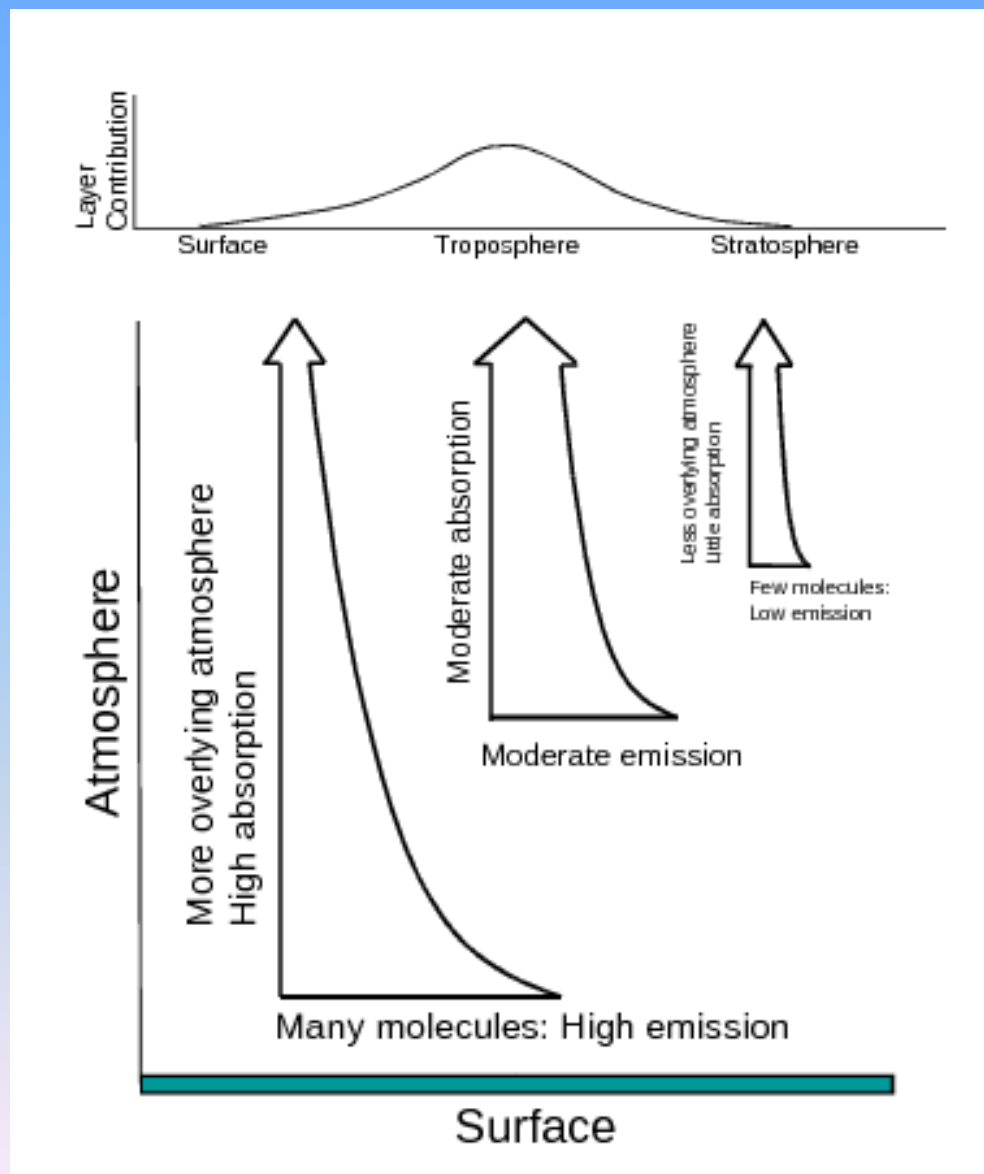
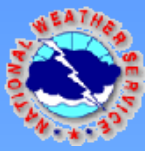


Illustration of Jacobian or Weighting Function

The form of the Jacobian or weighting function is highly frequency dependent as the atmospheric absorption properties vary with frequency and pressure in the atmosphere.

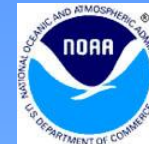
Weighting functions and Jacobians can peak at any level of the atmosphere including the surface.





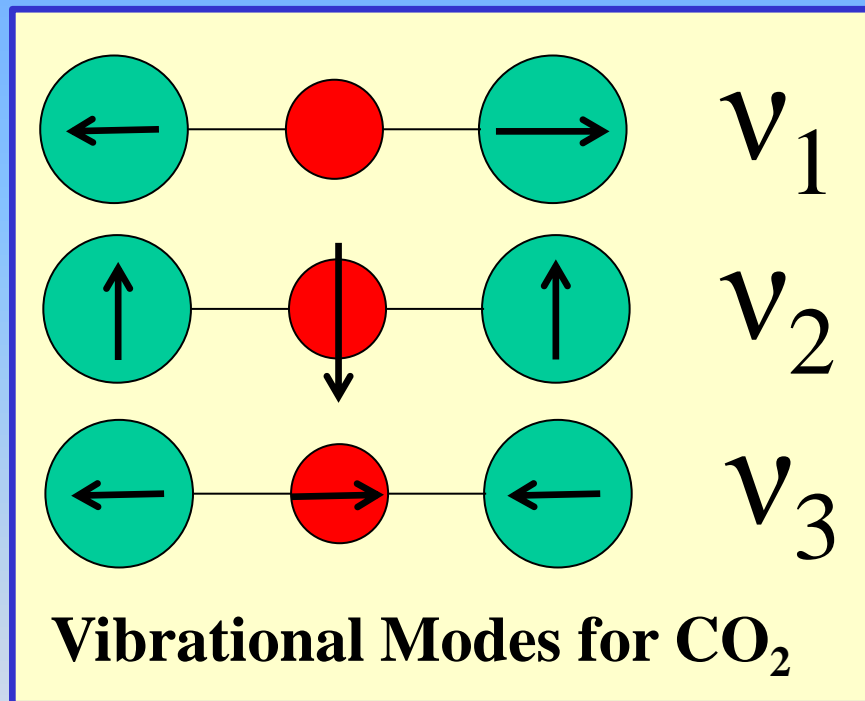
Basic theory of satellite observations

Spectroscopy

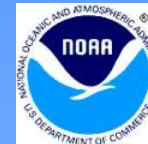


So where does atmospheric absorption come from?

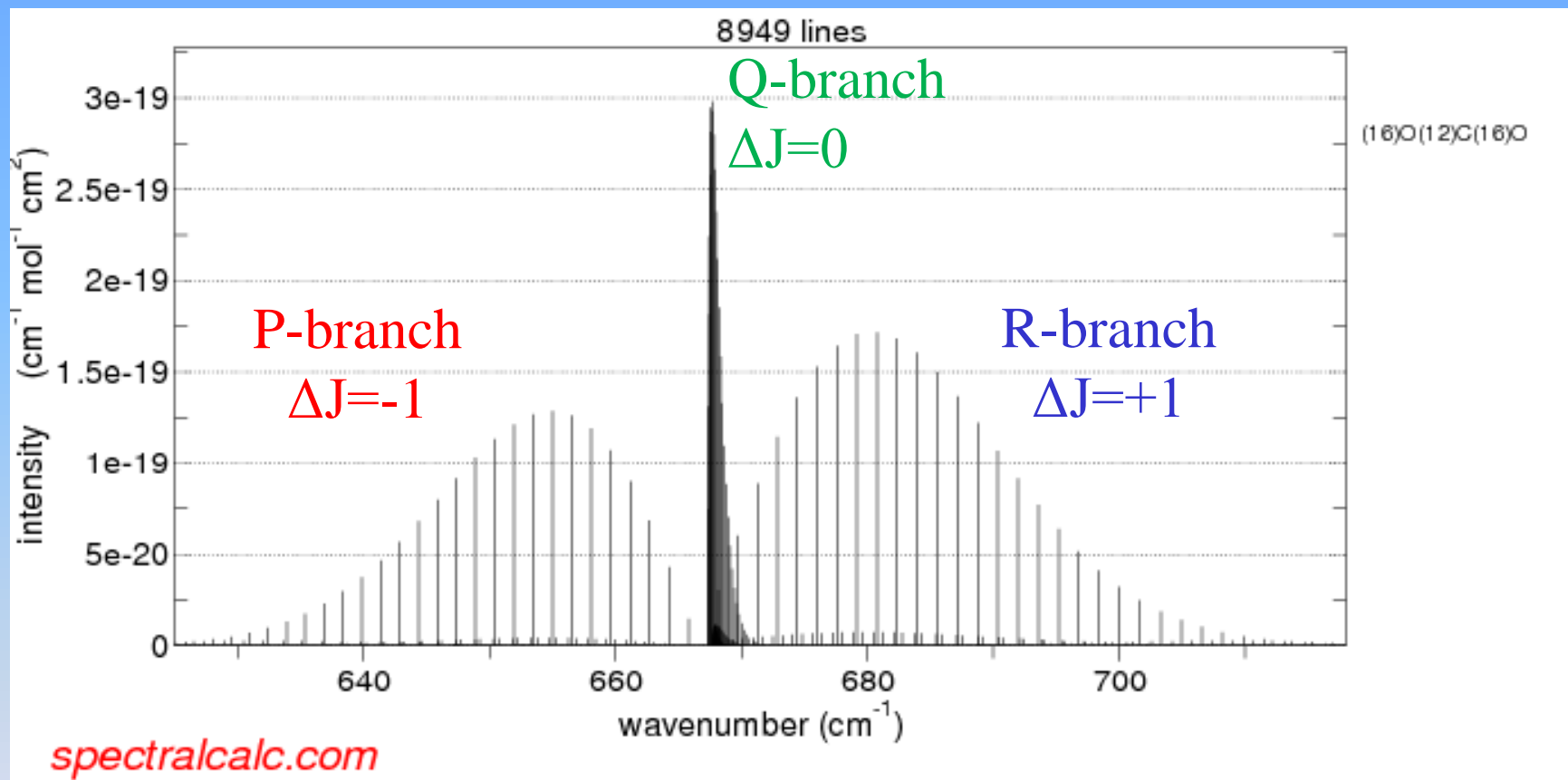
- Molecules in the atmosphere have energy stored as rotational, vibrational and electronic components
- The energy states are quantised and may be transformed through emission or absorption of electromagnetic radiation. This results in discrete spectral emission/absorption features in the spectrum.



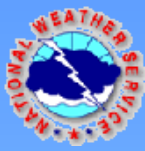
- In the microwave these are due to rotational transitions
- In the infrared these are rotational and vibrational transitions
- Electronic transitions manifest themselves in the visible and ultraviolet



Vibration-Rotation Spectrum Ground→v2 transition for CO₂

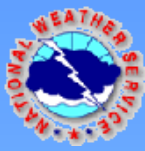


An example of a vibration-rotation band in the infrared CO₂ spectrum. Due to considerations of angular momentum, only changes in the rotational quantum number, J , of -1, 0 or 1 are optically active, producing the characteristic three branch structure to the band (some linear molecules have the Q-branch missing).



Line Broadening

- Spectral lines will be broadened through one of the following three processes:
 - **Natural broadening:** The finite time of the quantum transition corresponds to an uncertainty in the energy through the uncertainty principle.
 - **Doppler broadening:** Thermal motion of the molecules along the line of sight result in apparent uncertainty in the frequency through the Doppler effect.
 - **Collisional (or pressure) broadening:** Collisions between molecules during emission and absorption results in modification of energy levels and hence broadening of the spectral line.
- In the lower atmosphere, collisional broadening dominates, while Doppler broadening is more important in the upper atmosphere.



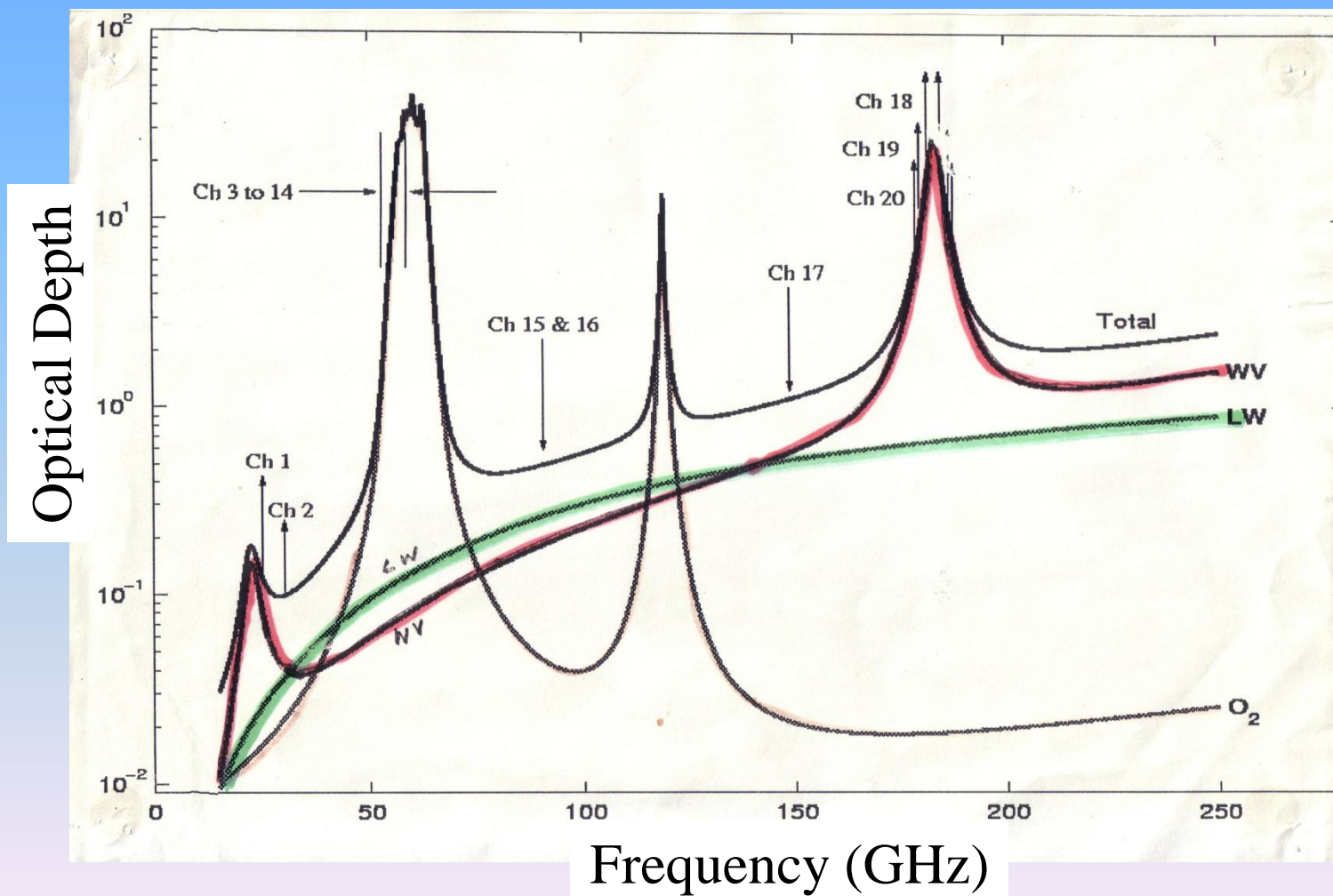
Other Sources of Atmospheric Opacity

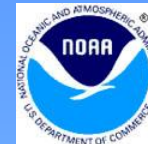
- Continuum absorption: Mostly the combined effect of the far wings of lines from collisional broadening or collisionally induced absorption bands (O_2 , N_2 , CO_2 on Venus!). Possible effect from dimers of H_2O . In the 8-12 μ m infrared window, the H_2O continuum is the dominant source of opacity (except for clouds).
- Absorption and scattering from cloud particles. Mie theory describes liquid water cloud RT well. Ice crystals are more complicated. Particle size distributions can be important to characterize.
- Absorption and scattering from aerosols. Similar problem to cloud with added complication of varying compositions.

All the above tend to have much broader spectral features than gaseous absorption.

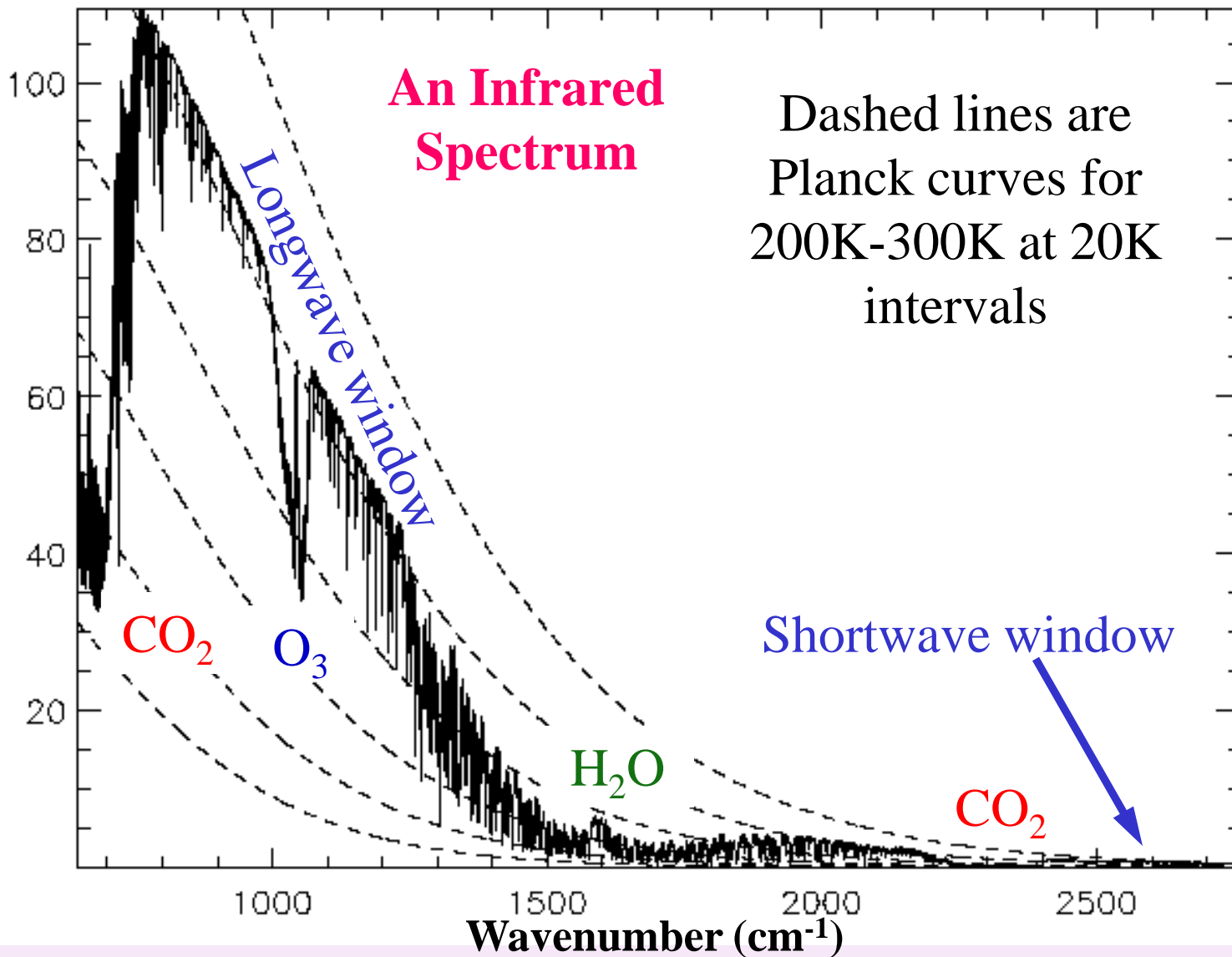


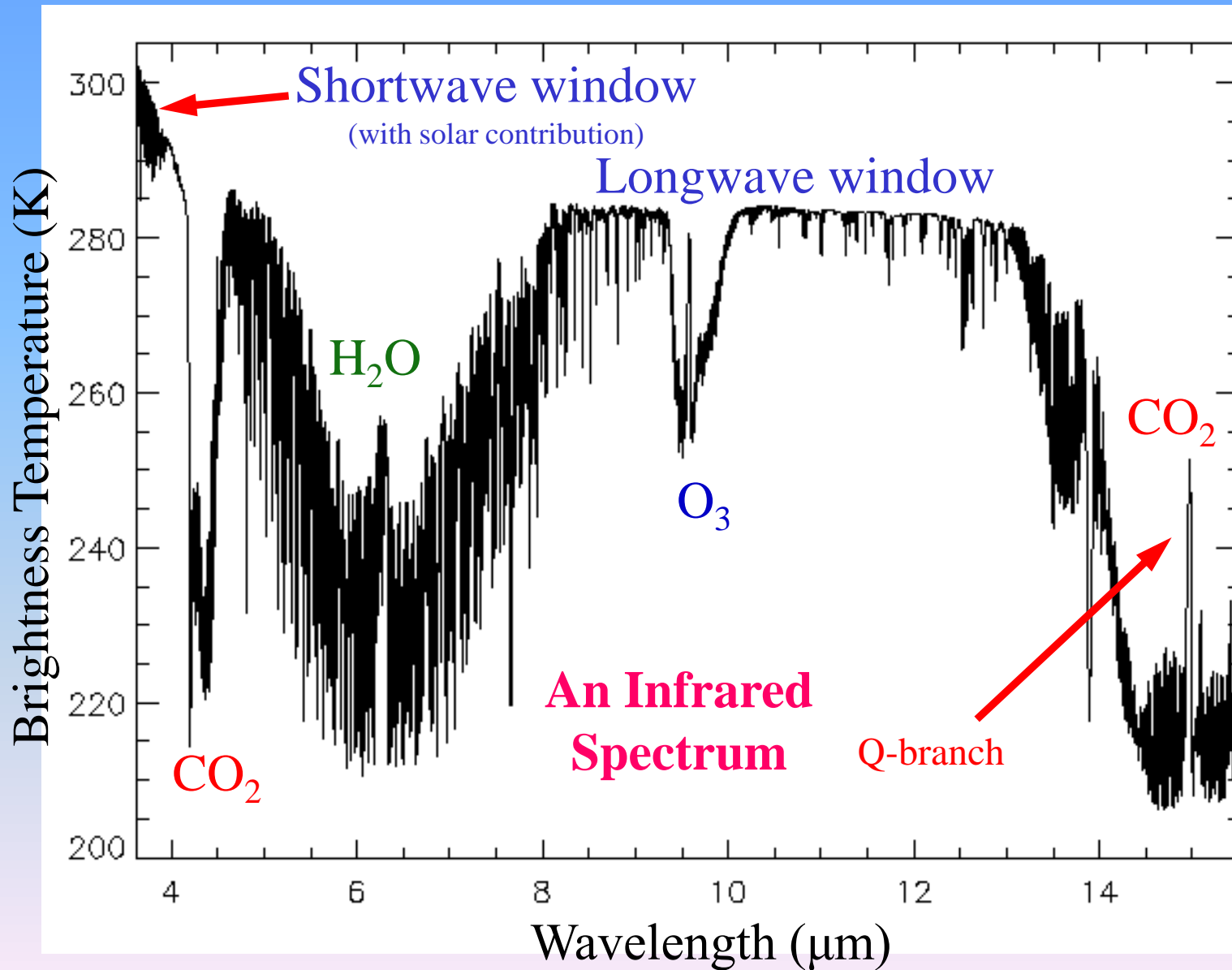
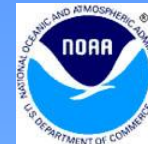
Microwave Spectrum

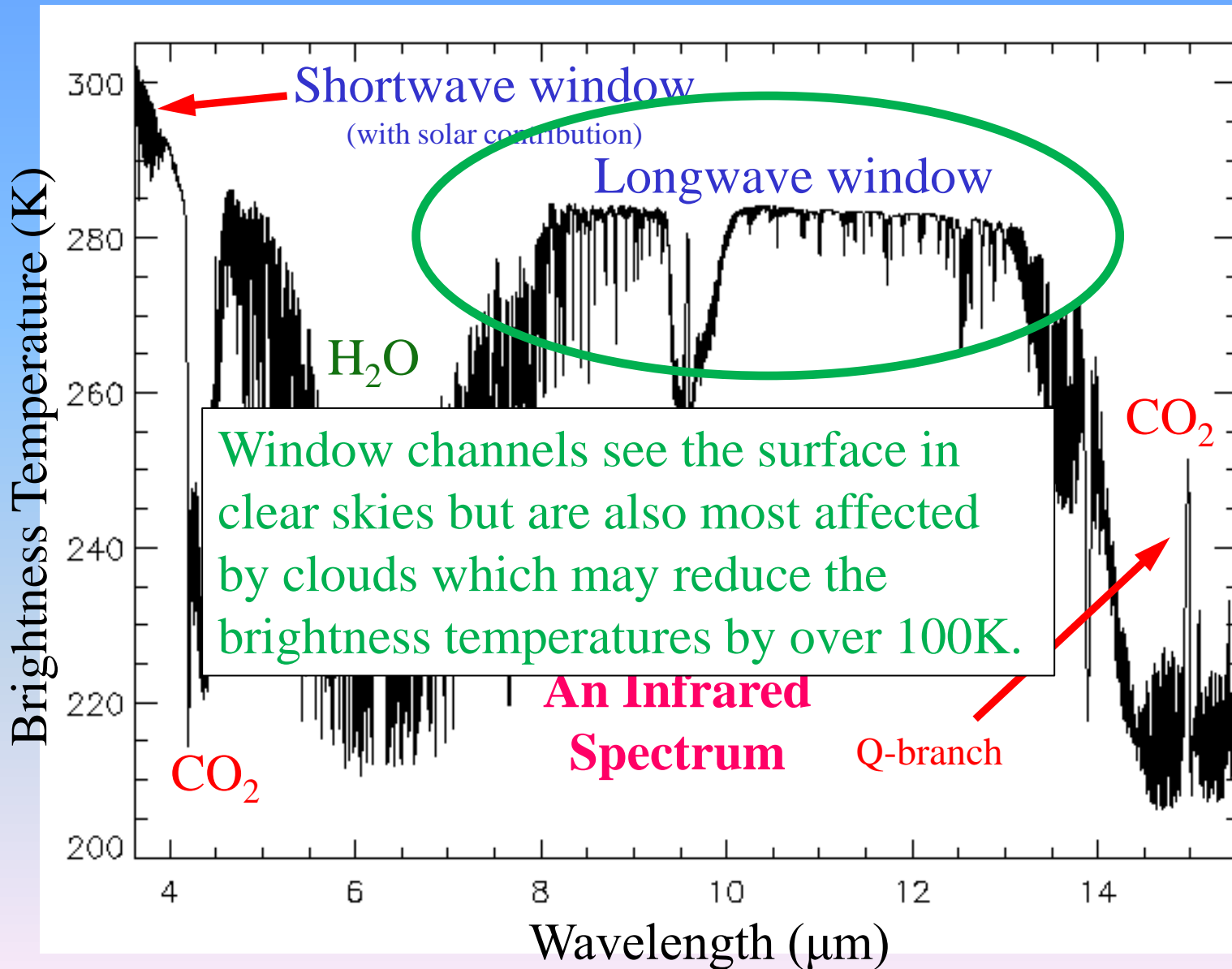
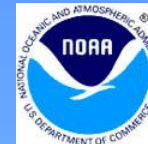


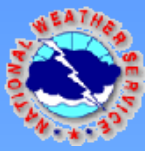


Radiance ($\text{mW}/\text{cm}^2/\text{sr}/\text{cm}^{-1}$)

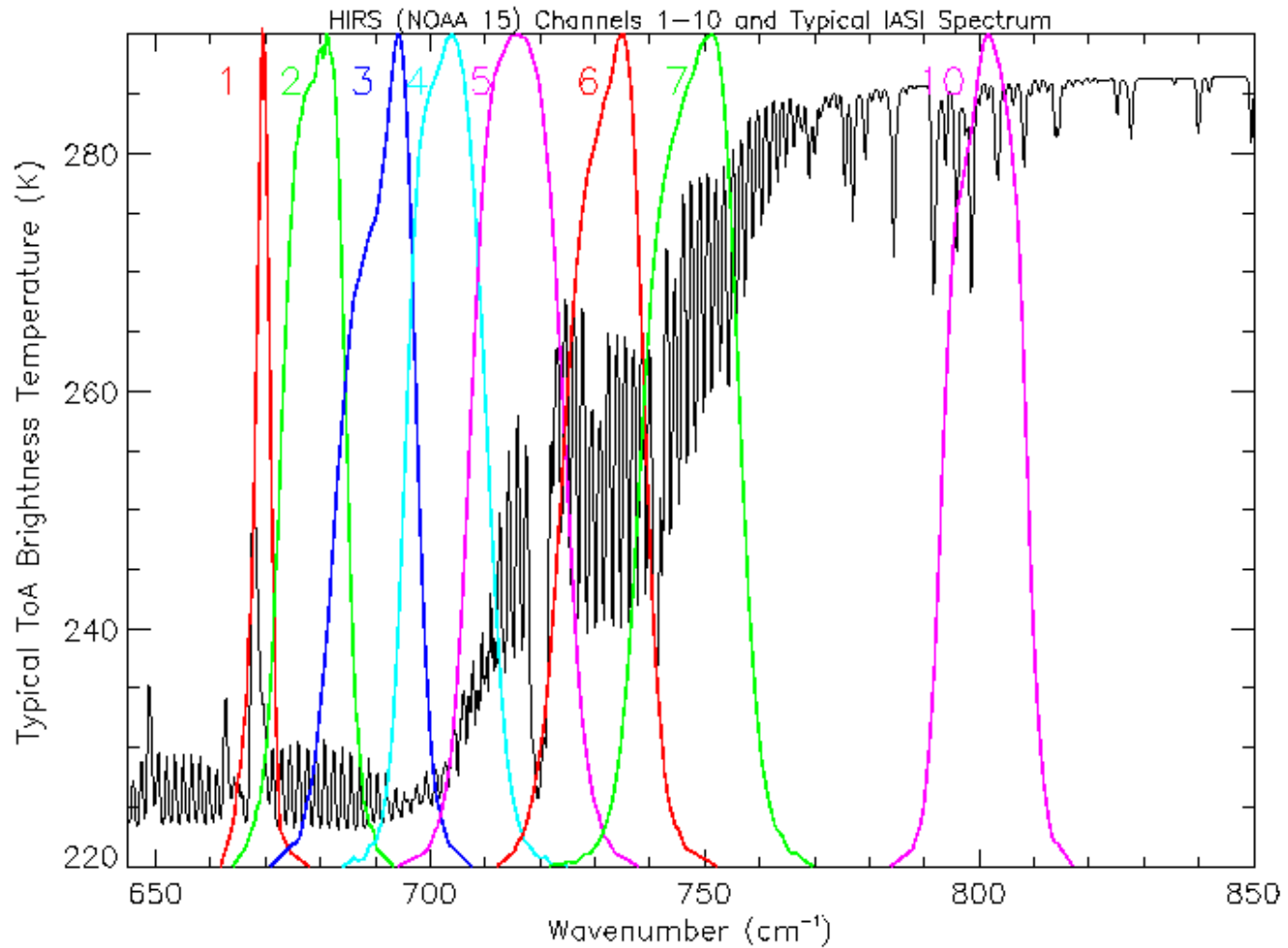


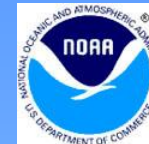






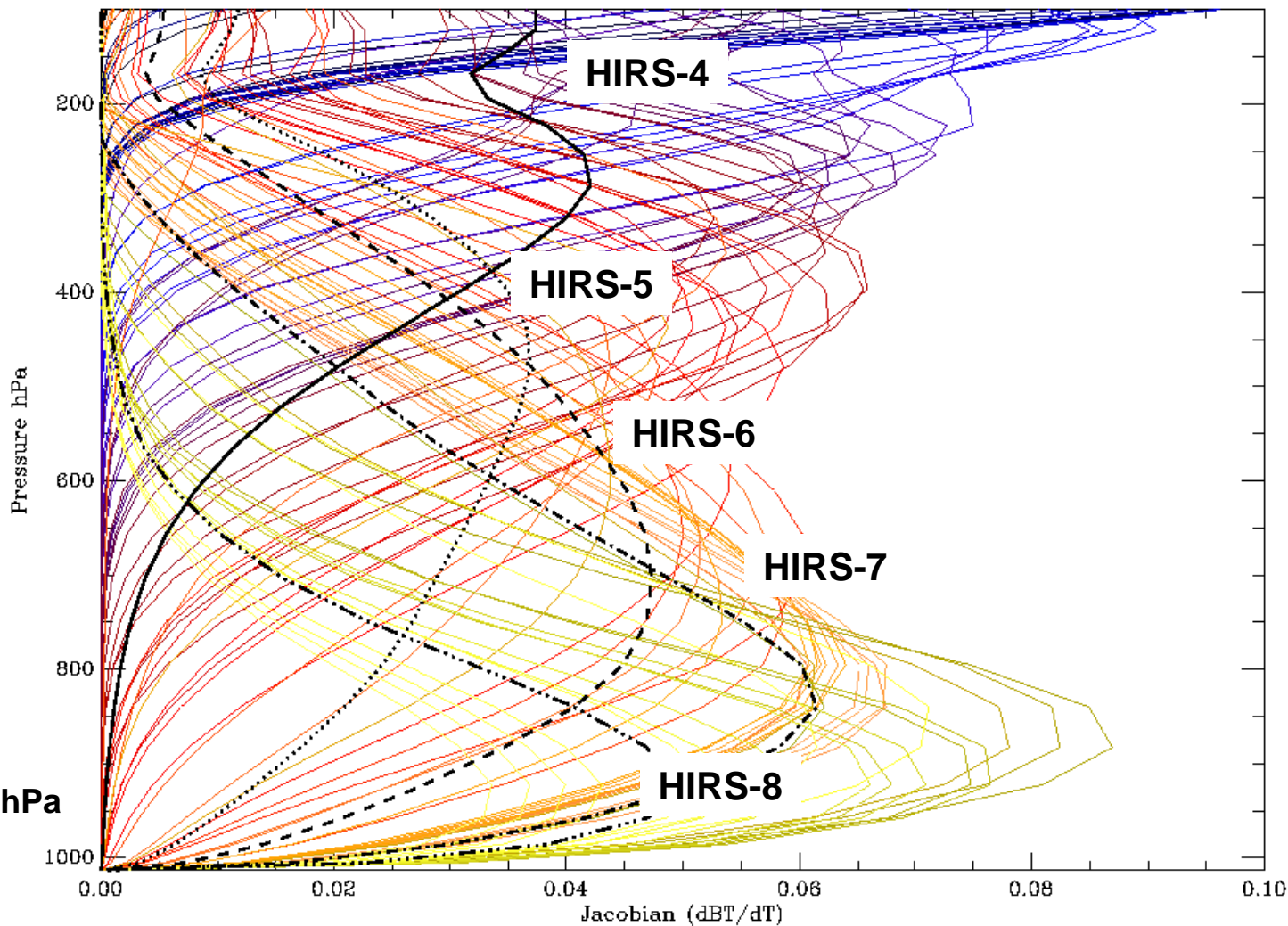
IASI vs HIRS: The Thermal InfraRed

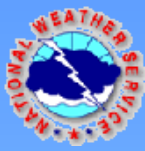




AIRS & HIRS Jacobians in the 15 μ m CO₂ band

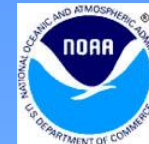
100 hPa





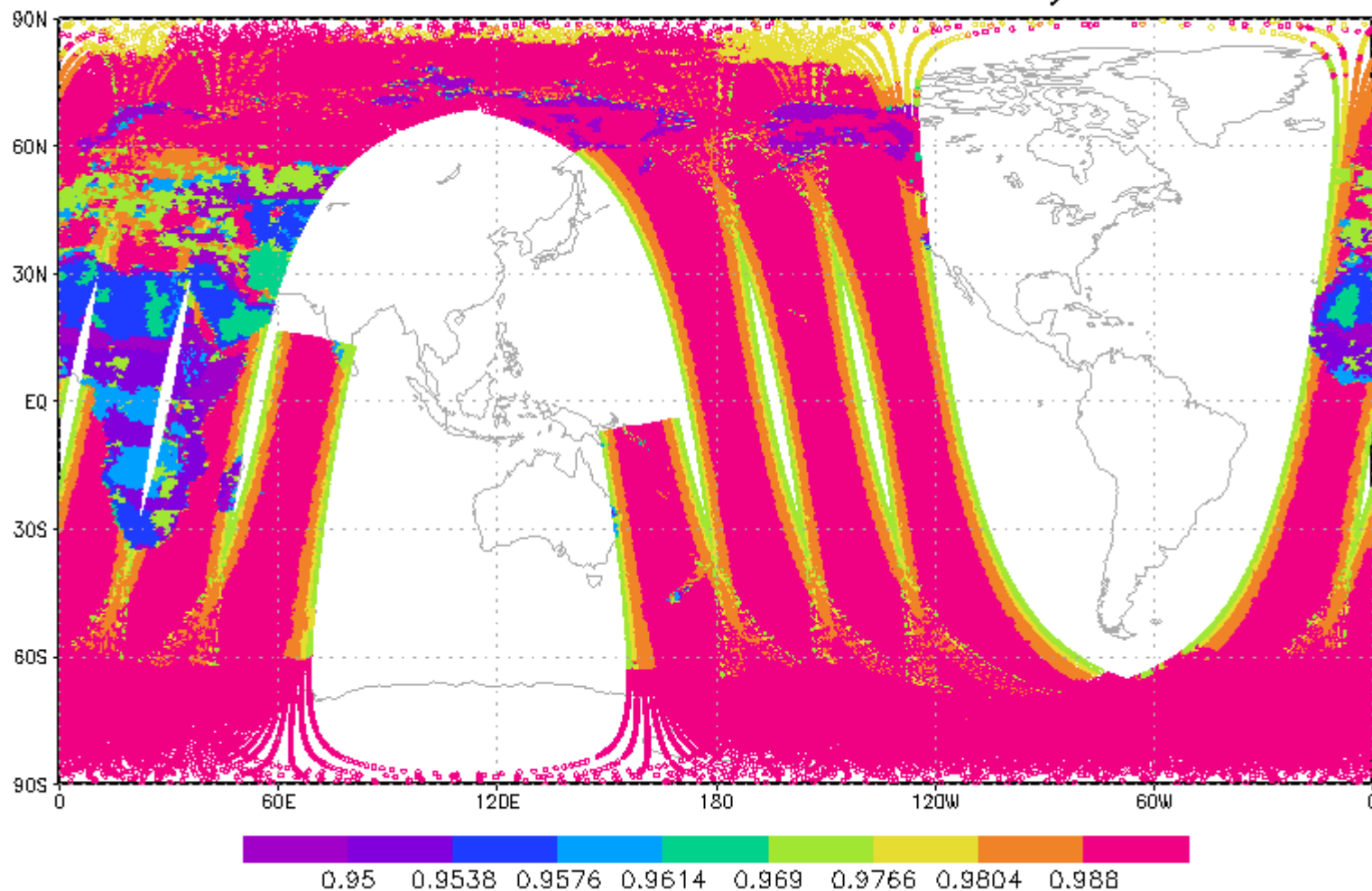
We also need to know the surface emissivity

- Over ocean we usually have models, e.g.:
 - ISEM (infrared)
 - FASTEM (microwave)
- Over land we often use atlases, either of the emissivities themselves or of the land type.
- Emissivities can also be retrieved from the observations themselves.



Surface Emissivity Infrared

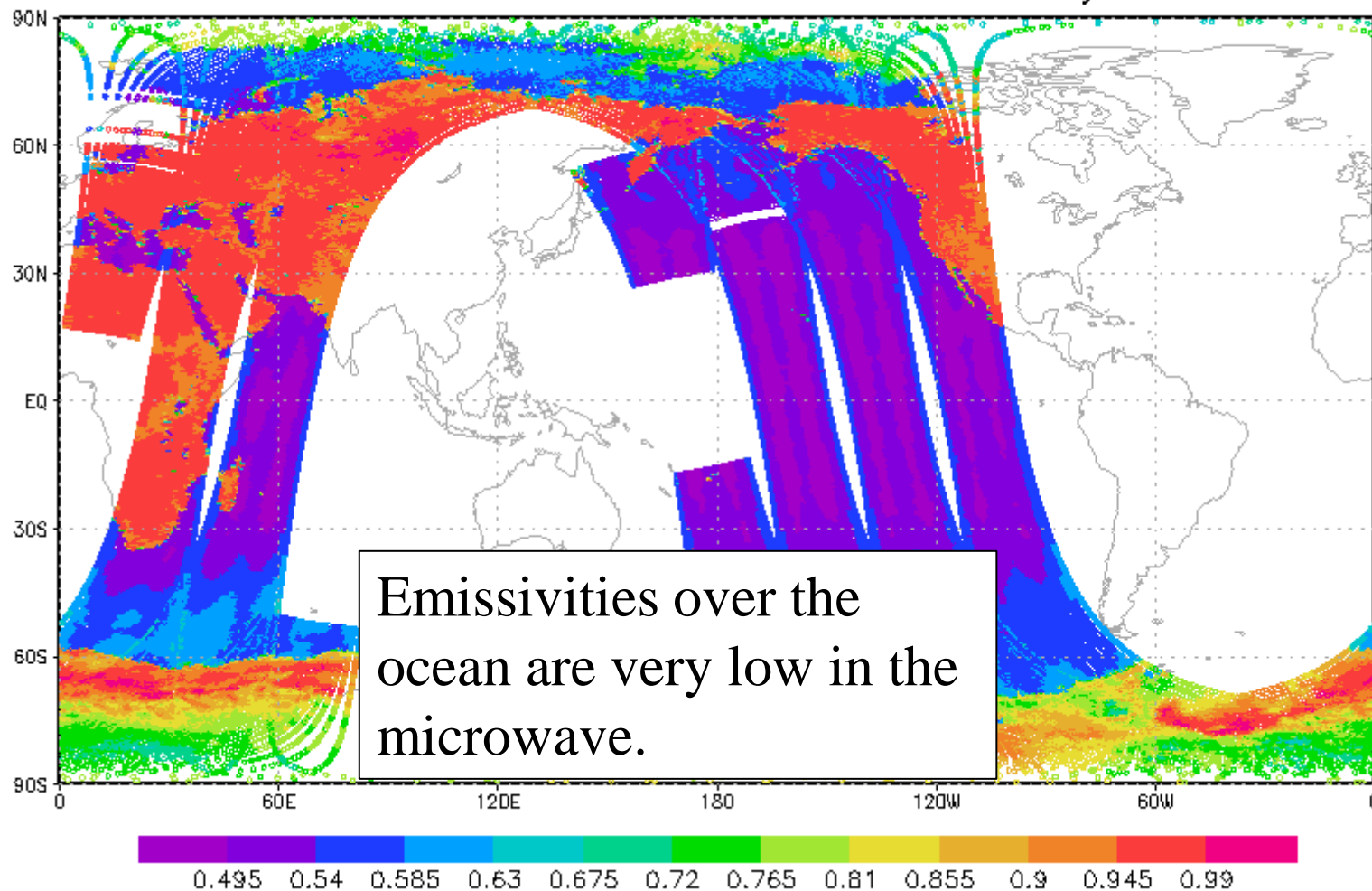
n19 ch. 8 hrs surface emissivity





Surface Emissivity Microwave

n18 ch. 5 amsua surface emissivity





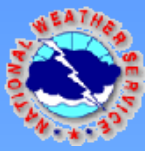
Forward models

- To exploit these radiances, it is important to have an accurate way of simulating them from the atmospheric state.
- Line-by-line (LBL) models use state-of-the-art spectroscopic databases to make these calculations at high spectral resolution.
- These monochromatic calculations are then combined using the instruments' spectral response functions (ISRFs) to simulate what the instrument observes.
- This can be **very slow**. Too slow for operational radiance assimilation.



Fast Forward models

- To allow radiances to be operationally assimilated, fast radiative transfer models, which use regression schemes to simulate the output from LBL models, have been produced.
- The two main fastmodels used operationally in NWP centers are RTTOV (developed by the EUMETSAT NWPSAF) and CRTM (JCSDA).
- The errors in the fastmodel are not usually a significant component of the total error budget.
- Most importantly, fastmodels allow the Jacobians (and the model adjoint) to be calculated efficiently.



Basic theory of satellite observations

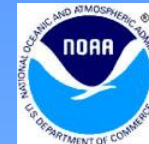
Basic Concept of a Retrieval



- So we have observations of the radiation emitted from the atmosphere at various frequencies corresponding to:
 - Emission and absorption at various levels
 - Emission and absorption by various gases/clouds/aerosols
- Now what?



- Unless we can infer the temperature profile we won't be able to do much else.
- To do this we need to choose frequencies where we know the absorption profiles already
- We choose gases with a constant distribution to do this.
- For the infrared we use CO_2
- For the microwave we use O_2
- These are hence known as *temperature sounding bands*.
- But **all bands are sensitive to temperature**, often – as in the case of H_2O – with sharper Jacobians.
- Once we have a good temperature profile we can use that to infer molecular abundances of variable species using appropriate frequencies.
 - This is actually performed simultaneously with the temperature estimation when we do data assimilation

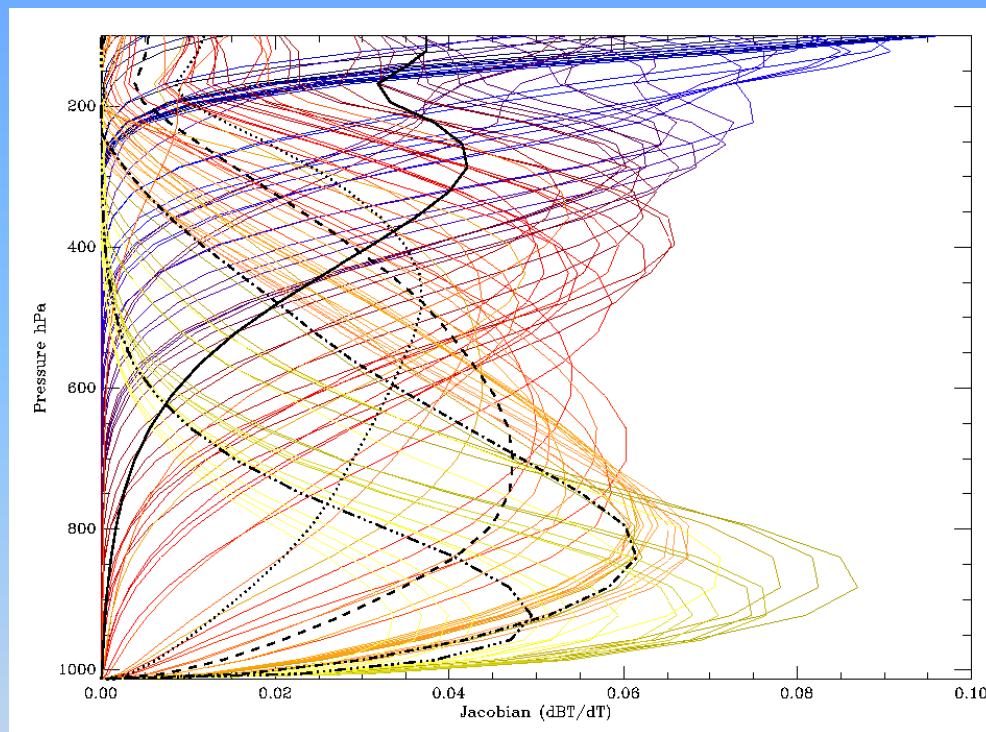


Obtaining vertical profiles

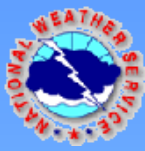
The Jacobians give the sensitivity to the vertical profiles of temperature/gases/clouds etc.

If we sum the contribution of each channel, we can get a very accurate estimate of the mean atmospheric temperature (with very low vertical) resolution.

If we take differences between each of the channels we can infer the profile with high vertical resolution, but the result will be very noisy.



When we assimilate the radiance observations we are effectively producing a minimum variance solution to the problem: which is a compromise between these two extremes



Assimilating satellite radiances

Data Assimilation Equation



Atmospheric Analysis Problem

$$\mathbf{J} = \mathbf{J}_b + \mathbf{J}_o + \mathbf{J}_c$$

$$\mathbf{J} = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}_x^{-1} (\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - \mathbf{K}(\mathbf{x}))^T (\mathbf{E} + \mathbf{F})^{-1} (\mathbf{y} - \mathbf{K}(\mathbf{x})) + \mathbf{J}_c$$

\mathbf{J} = Fit to background + Fit to observations + constraints

\mathbf{x} = Analysis

\mathbf{x}_b = Background

(usually a short-range forecast from the previous cycle)

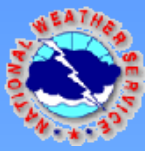
\mathbf{B}_x = Background error covariance

\mathbf{K} = Forward model (nonlinear)

\mathbf{O} = Observations

$\mathbf{E} + \mathbf{F} = \mathbf{R}$ = Instrument error + Representativeness error

\mathbf{J}_c = Constraint term



Atmospheric Analysis Problem

$$\mathbf{J} = \mathbf{J}_b + \mathbf{J}_o + \mathbf{J}_c$$

$$\mathbf{J} = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}_x^{-1} (\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - \mathbf{K}(\mathbf{x}))^T (\mathbf{E} + \mathbf{F})^{-1} (\mathbf{y} - \mathbf{K}(\mathbf{x})) + \mathbf{J}_c$$

$\mathbf{J} = \text{Fit}$ The difference between the observations **constraints**
and the background transformed into

\mathbf{x} = / model space, the first guess departure, is

\mathbf{x}_b = | an important measure. It is often the

\mathbf{B}_x = | basis of quality control procedures.

\mathbf{K} = |

\mathbf{O} = Observations

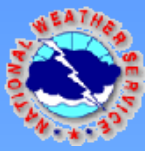
$\mathbf{E} + \mathbf{F} = \mathbf{R}$ = Instrument error + Representativeness error

\mathbf{J}_c = Constraint term



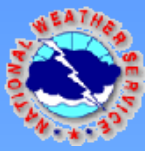
Assimilating satellite radiances

Quality Control



Quality Control Procedures

- The quality control step may be the most important aspect of satellite data assimilation.
- Data which has gross errors or which cannot be properly simulated by forward model must be removed.
- Most problems with satellite data come from 4 sources:
 - Instrument problems.
 - Clouds and precipitation simulation errors.
 - Surface emissivity simulation errors.
 - Processing errors (e.g., wrong height assignment, incorrect tracking, etc).

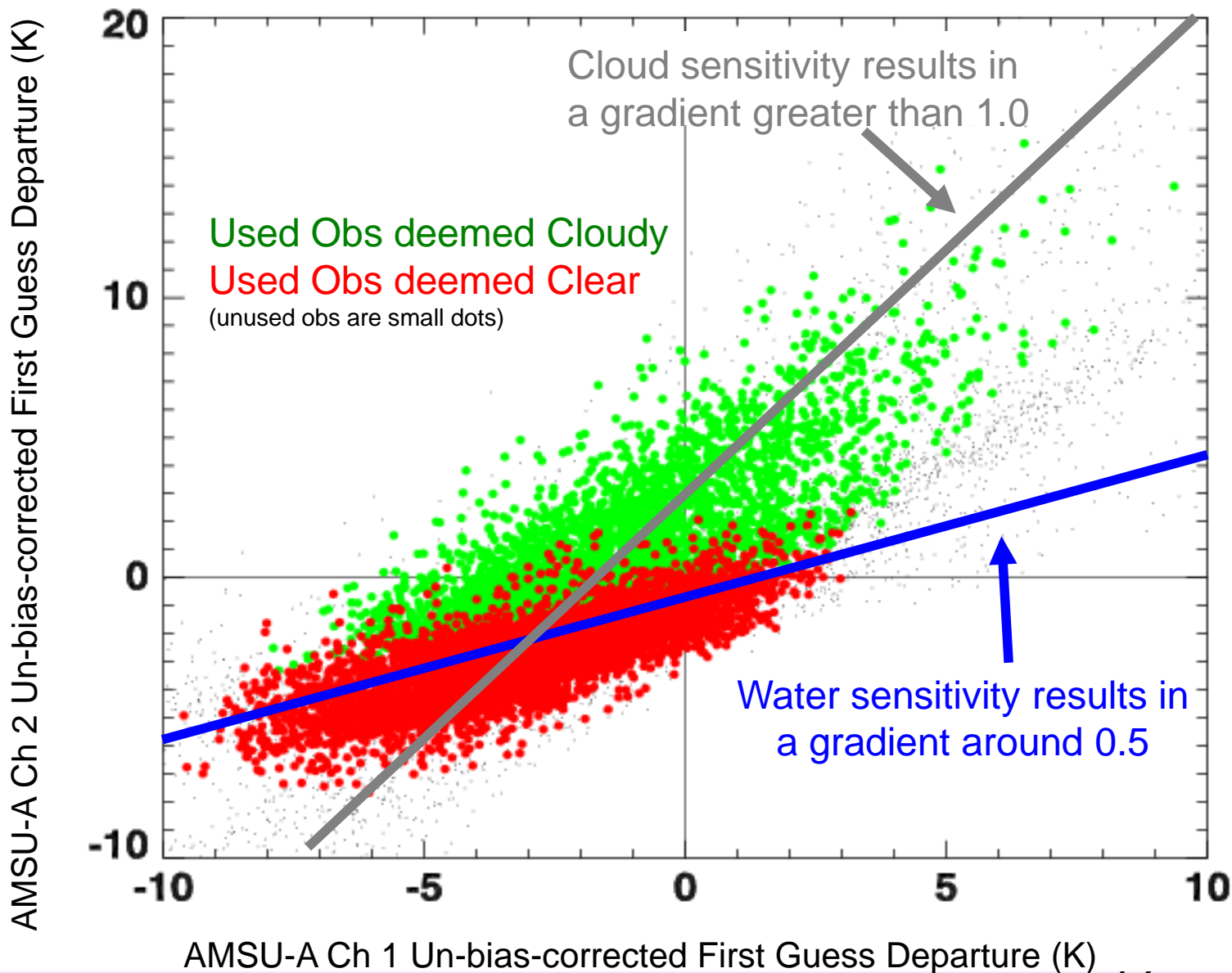
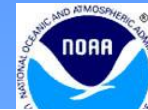


Quality Control Procedures

- IR cannot see through most clouds.
 - Cloud height difficult to determine – especially with mixed FOVs.
 - Since deep layers not many channels completely above clouds.
- Microwave impacted by clouds and precipitation but signal is smaller from thinner clouds.
- Surface emissivity and temperature characteristics not well known for land/snow/ice.
 - Also makes detection of clouds/precip. more difficult over these surfaces.
- Error distribution may be asymmetric due to clouds and processing errors.

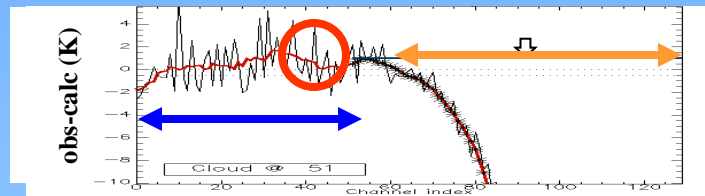


Cloud detection in the microwave



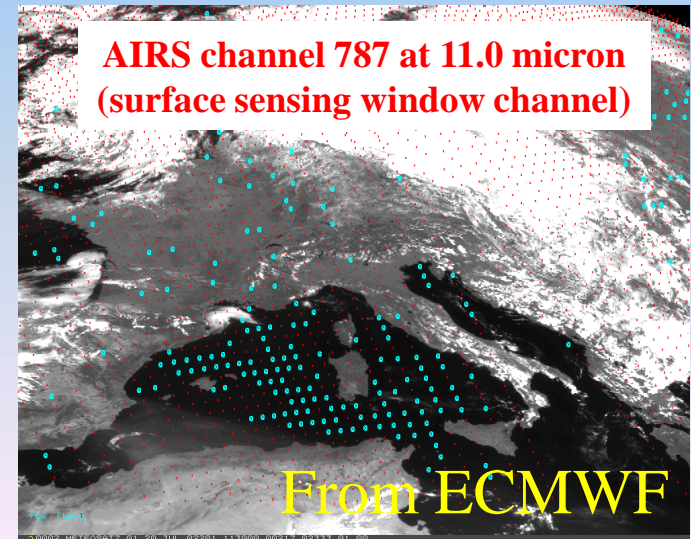
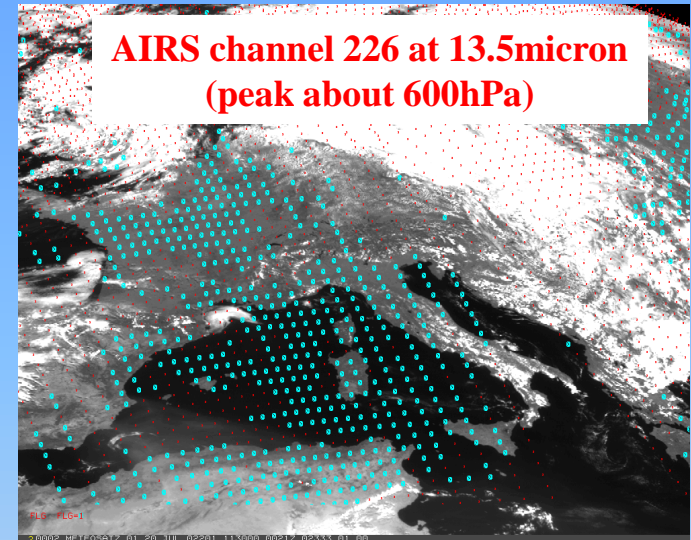
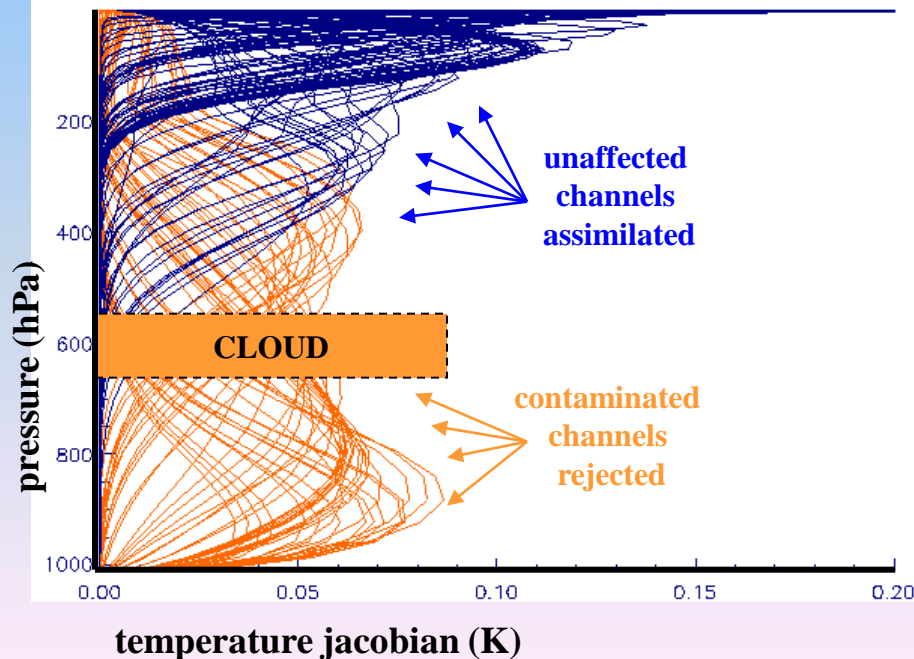
Cloud detection in the infrared

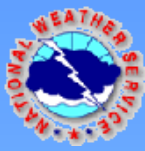
A non-linear pattern recognition algorithm is applied to departures of the observed radiance spectra from a computed clear-sky background spectra.



Vertically ranked channel index

This identifies the characteristic signal of cloud in the data and allows contaminated channels to be rejected





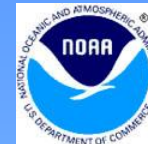
Assimilating satellite radiances

Bias Correction



Bias Correction

- The differences between simulated and observed observations can show significant biases.
- The source of the bias can come from:
 - Inadequacies in the characterization of the instruments.
 - Deficiencies in the forward models.
 - Errors in processing data.
 - Biases in the background.
- Except when the bias is due to the background, we would like to remove these biases.

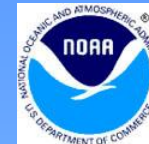


Bias Correction

- Currently bias correction only applied to a few data sets:
 - Radiances.
 - Radiosonde data (radiation correction and moisture).
 - Aircraft data.
- For radiances, biases can be much larger than signal. Essential to bias correct the data.
- NCEP currently uses a 2-step process for radiances (other centers are similar).
 - Angle correction (very slowly evolving – different correction for each scan position).
 - Air Mass correction (slowly evolving based on predictors).

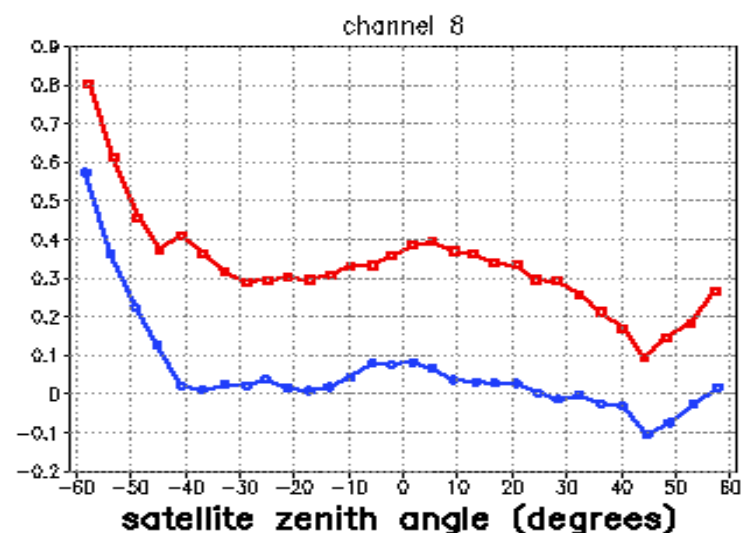
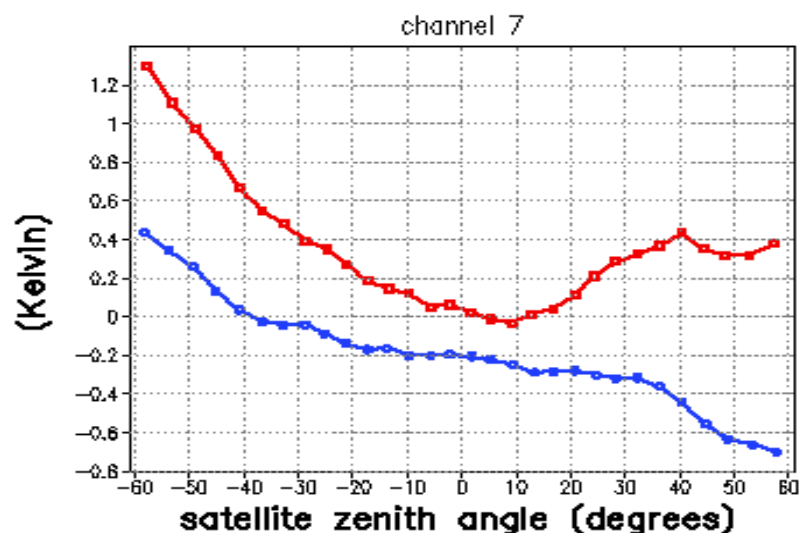
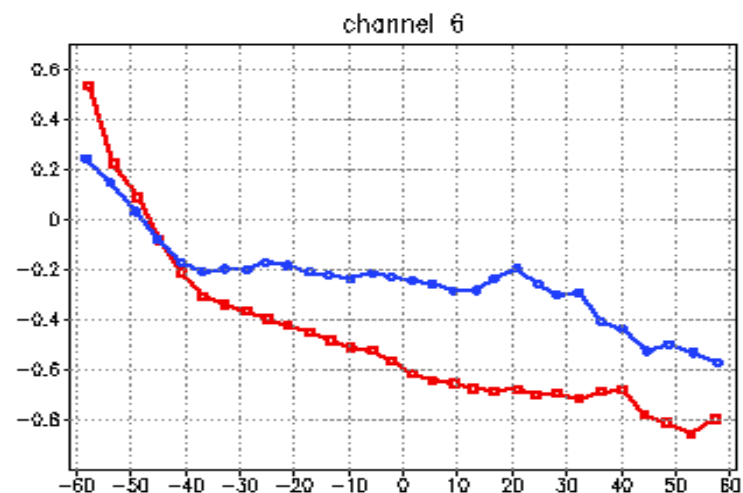
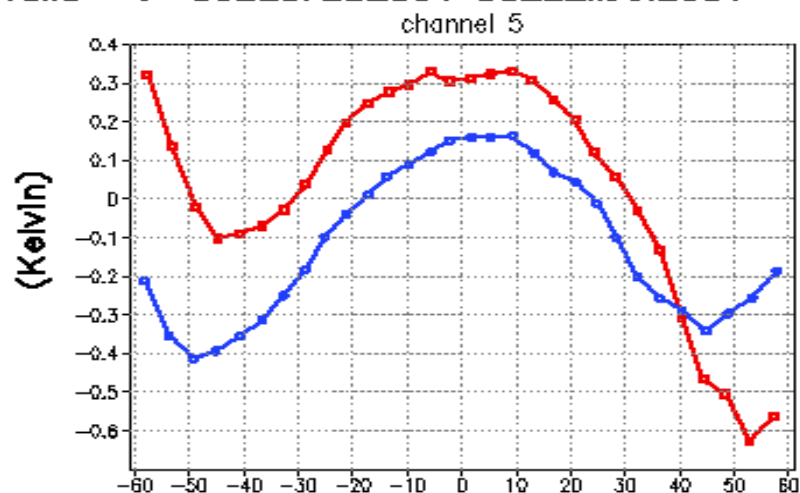


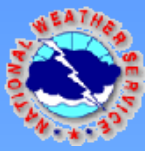
Scan dependent biases for AMSU



platform: amsua
region : global
variable: observed-simulated (without bias correction) (K)
valid : 00Z20FEB2001 00Z22MAR2001

NOAA-15 (red)
NOAA-16 (blue)





Satellite radiance observations

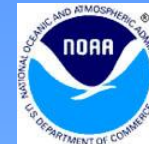
Bias correction

- Air mass prediction equation for bias – variational bias correction

- Add to control vector (analysis variables x_{n+i})

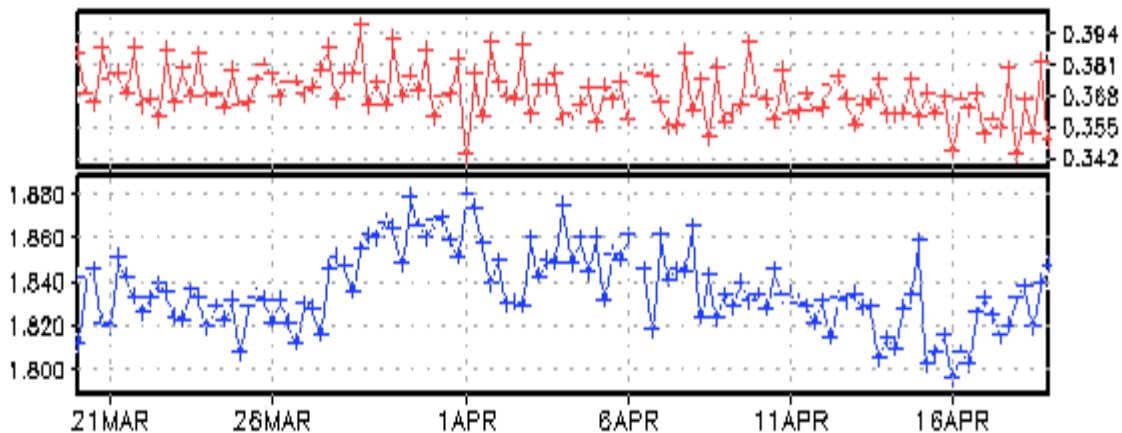
where total bias correction = $\sum_1^{n_p} x_n + ip_i$

- Predictors (p_i) for each channel
 - mean
 - path length (local zenith angle determined)
 - integrated lapse rate
 - (integrated lapse rate) ²
 - cloud liquid water

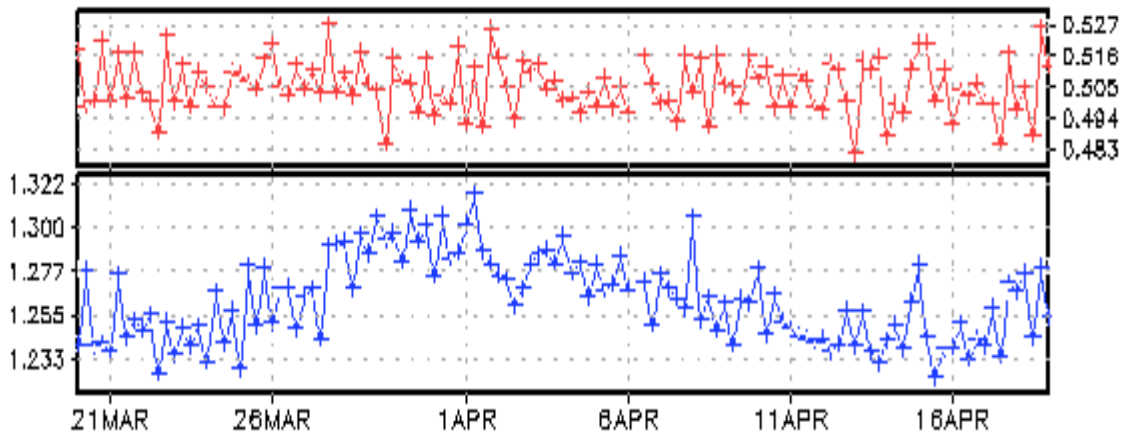


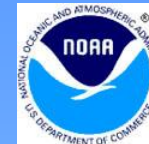
NOAA 18 AMSU-A No Bias Correction

channel 7
 χ 0.3765
f 54.94 GHz
 λ 5456.69 μm
avg: 1.837
sdv: 0.389



channel 8
 χ 0.3955
f 55.50 GHz
 λ 5401.64 μm
avg: 1.263
sdv: 0.505

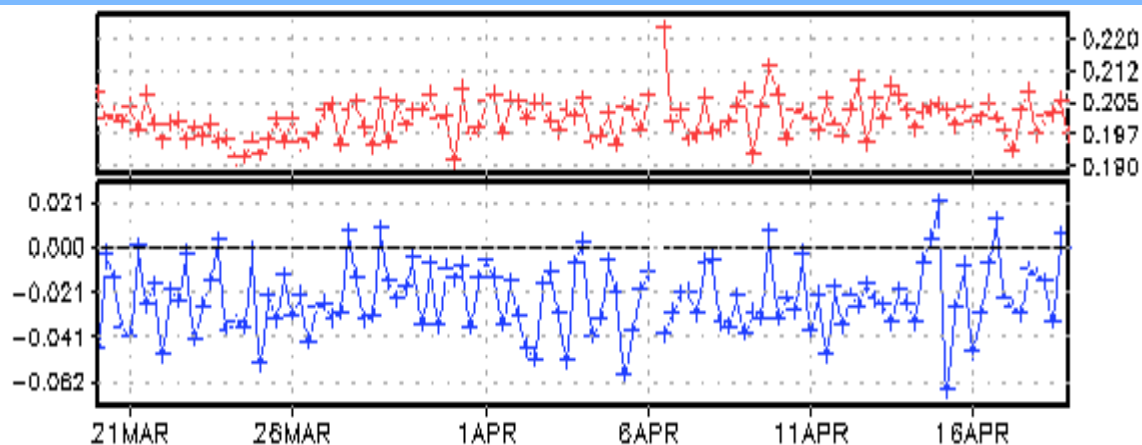




NOAA 18 AMSU-A Bias Corrected

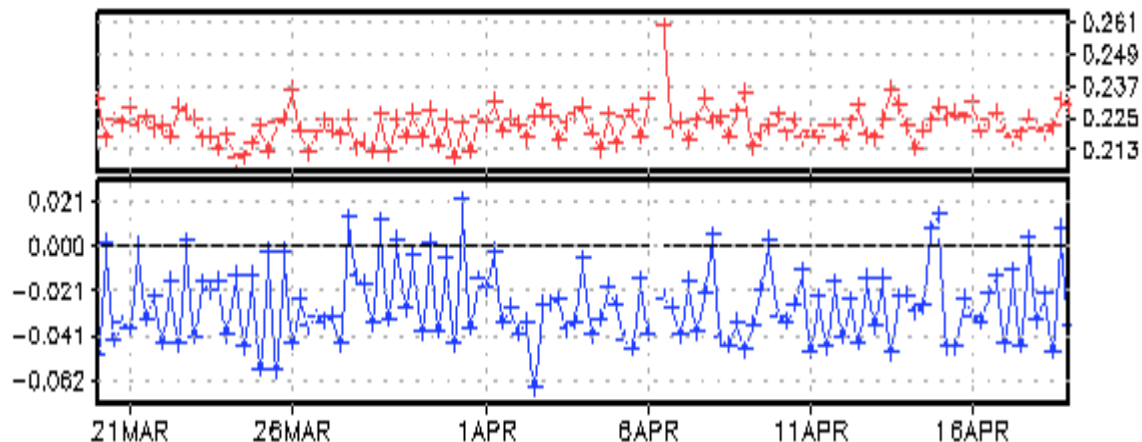
channel 7
 χ 0.3765
f 54.94 GHz
 λ 5456.69 μm

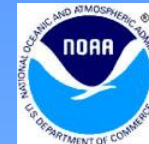
avg: -0.022
sdv: 0.200



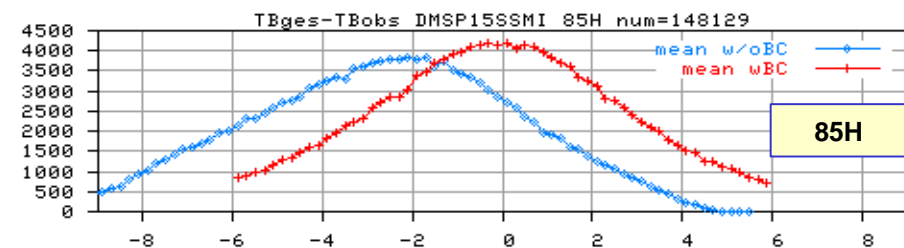
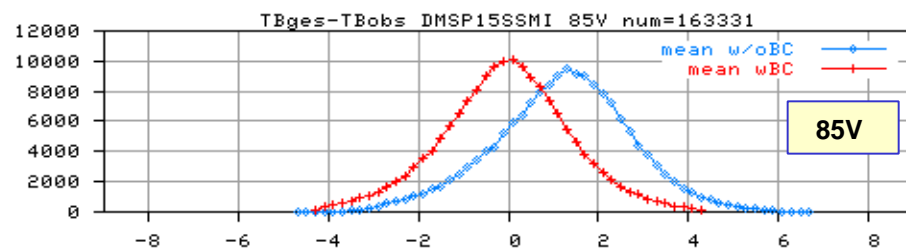
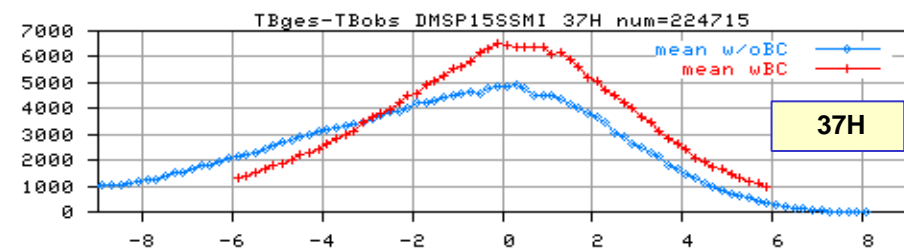
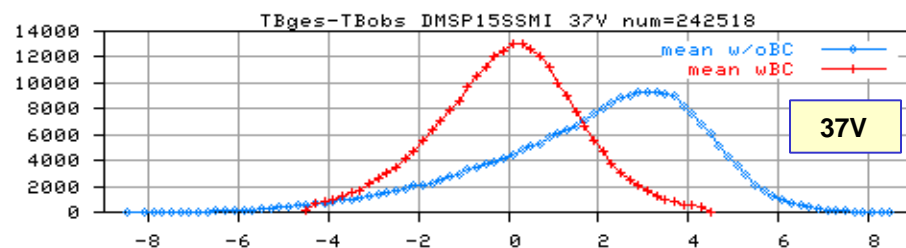
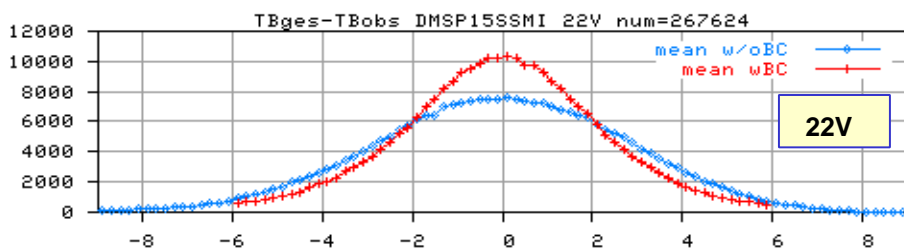
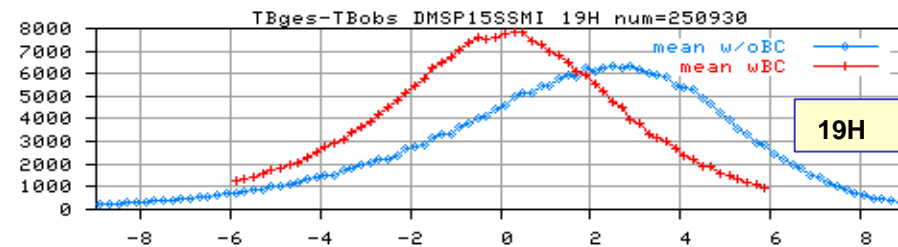
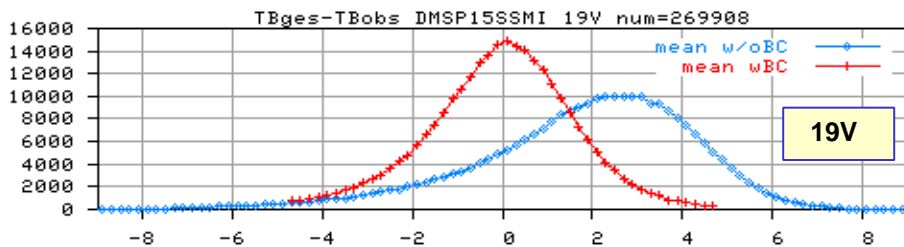
channel 8
 χ 0.3955
f 55.50 GHz
 λ 5401.64 μm

avg: -0.026
sdv: 0.222





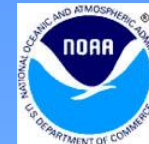
Observation - Background Histogram



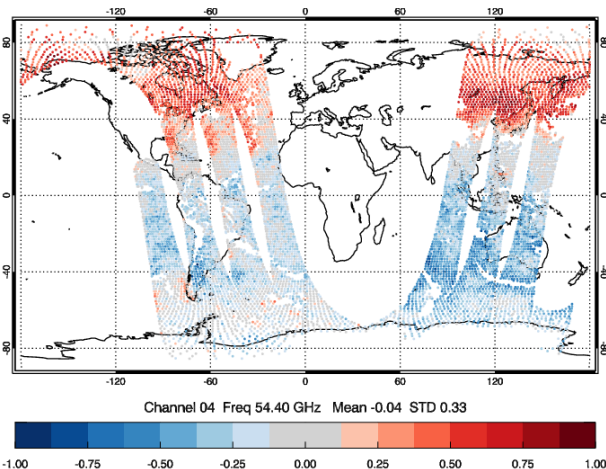
DMSP15 July2004 : 1month
— before bias correction
— after bias correction



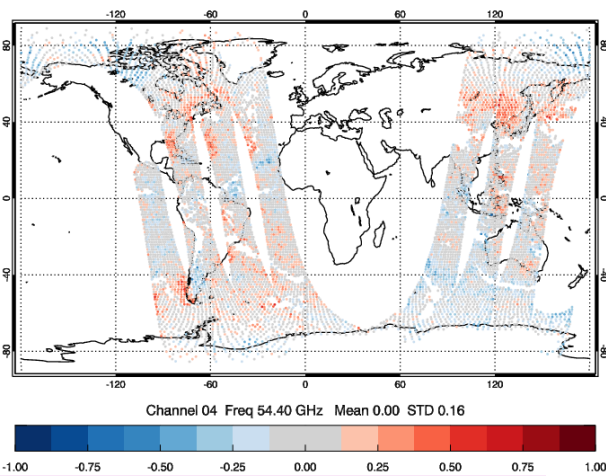
Application of NWP Bias Correction for SSMIS F18



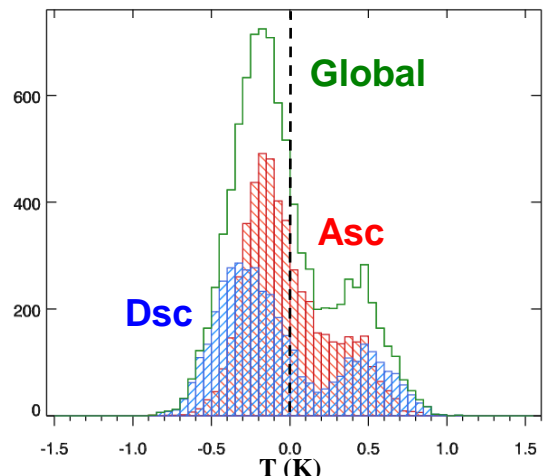
O-B Before Bias Correction



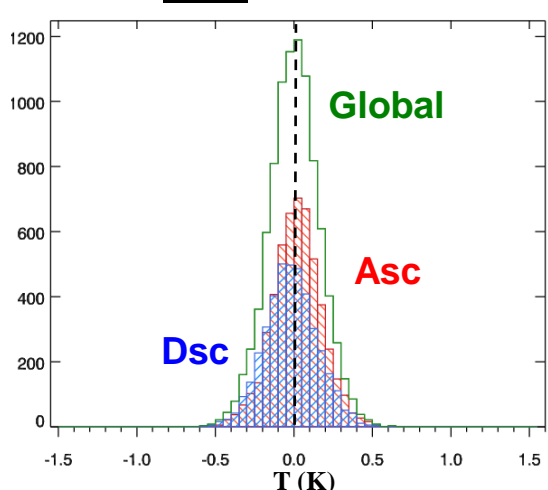
O-B After Bias Correction



O-B Before Bias Correction

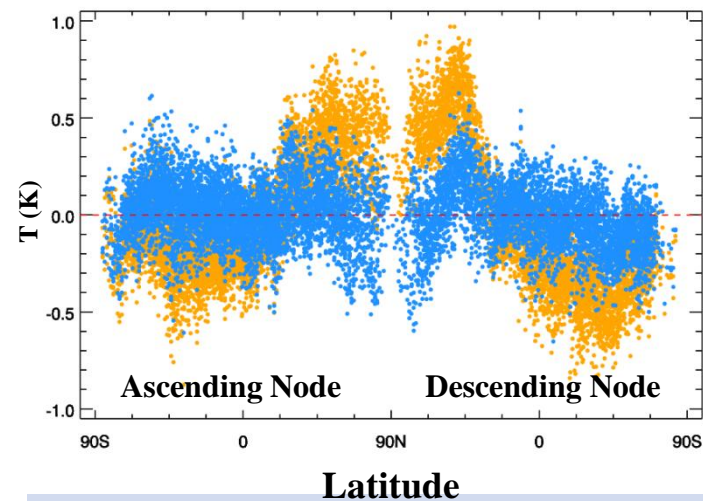


O-B After Bias Correction



Using Met Office SSMIS Bias Correction Predictors

● Unbias & ● Bias Corrected O-B





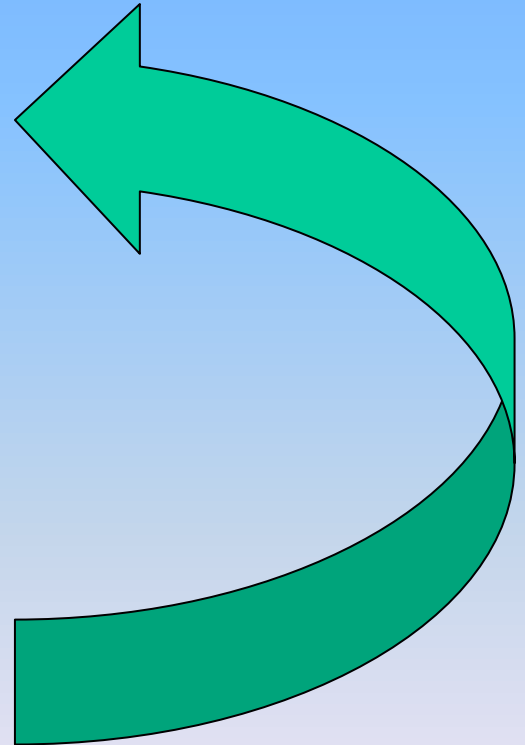
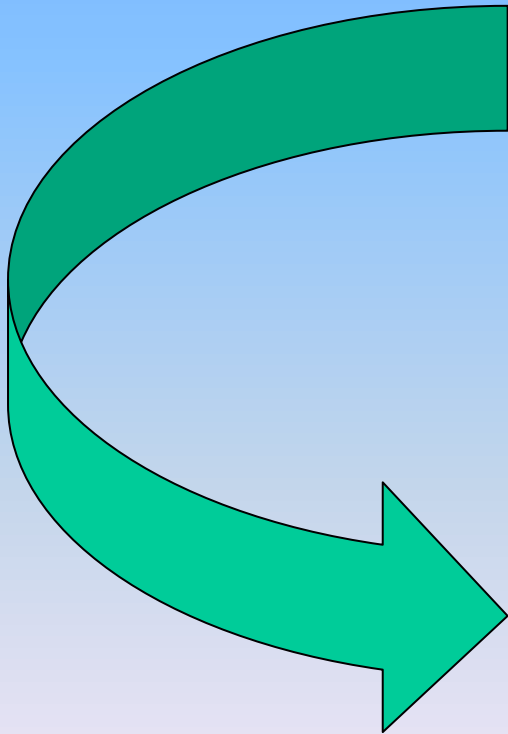
Bias Correction and QC Interact

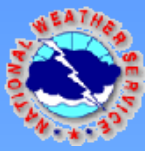
Bias Correction

Observations are bias-corrected
after quality control

Quality Control

Quality control usually uses
bias-corrected observations





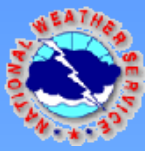
Assimilating satellite radiances

Observation Errors

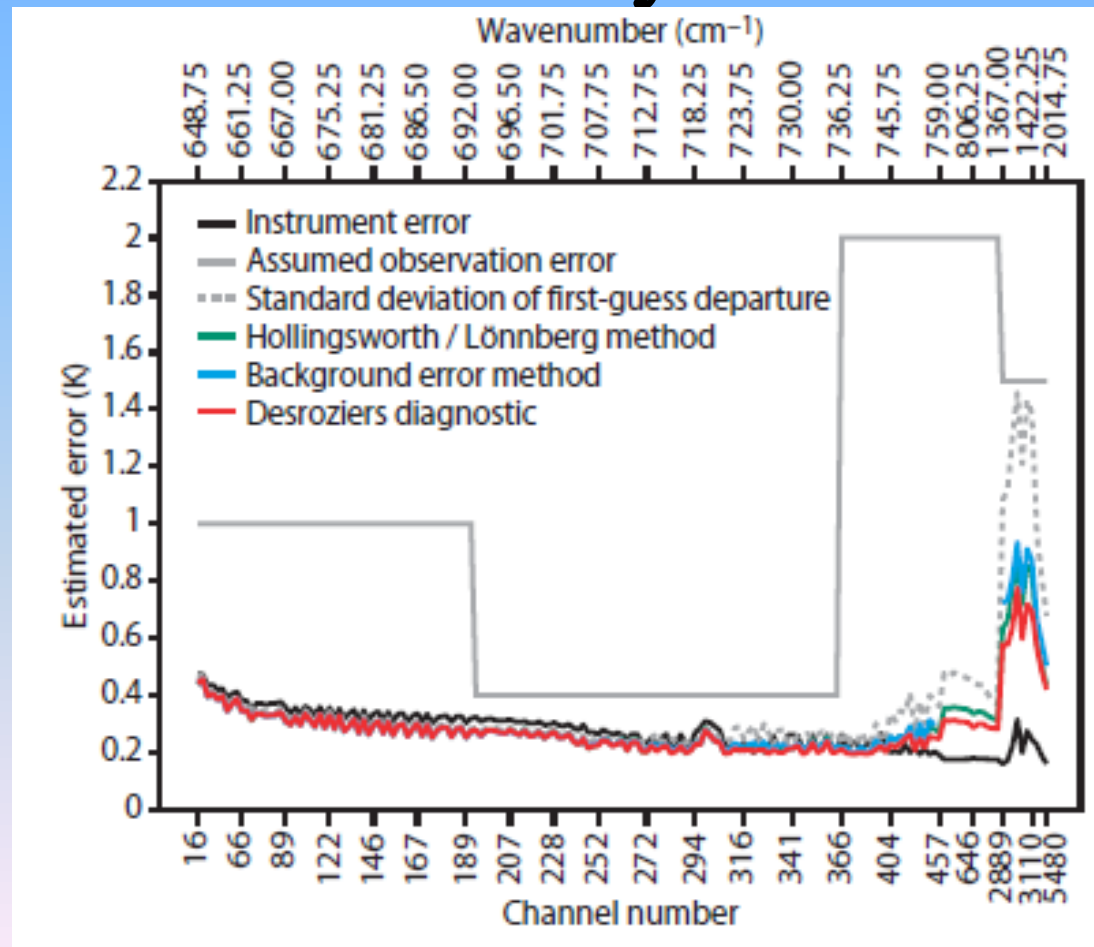


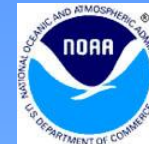
Observational Errors

- Observation errors specified based on instrument errors and statistics
- Generally for satellite data, variances are specified a bit large since the correlated errors (from RT and instrument errors) are not well known.
- Observation errors are also generally specified as being uncorrelated spectrally, but efforts are being made to determine the off-diagonal components of the observation error covariance matrix.

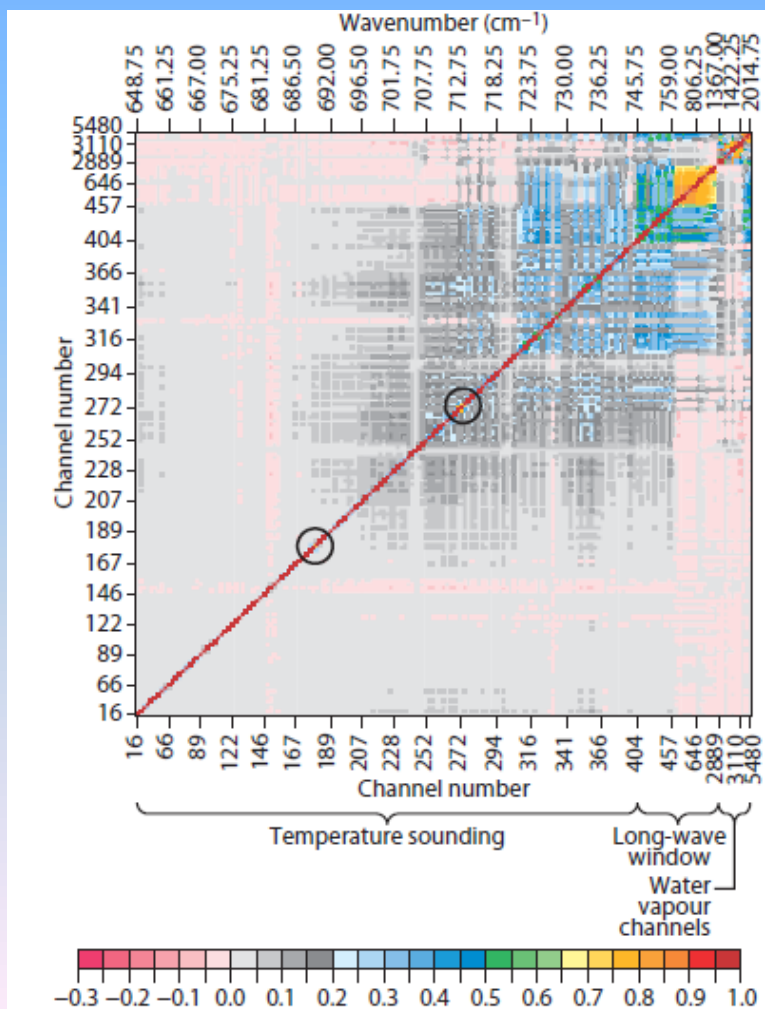


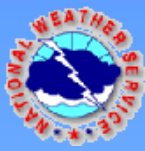
IASI Observation Errors in ECMWF System





IASI Inter-Channel Correlations





Specifying Errors in the GSI: Satinfo file

!sensor/instr/sat	chan	iuse	error	error_cld	ermax	var_b	var_pg
amsua_n15	1	1	3.000	9.100	4.500	10.000	0.000
amsua_n15	2	1	2.000	13.500	4.500	10.000	0.000
amsua_n15	3	1	2.000	7.100	4.500	10.000	0.000
amsua_n15	4	1	0.600	1.300	2.500	10.000	0.000
amsua_n15	5	1	0.300	0.550	2.000	10.000	0.000
amsua_n15	6	1	0.230	0.230	2.000	10.000	0.000
amsua_n15	7	1	0.250	0.195	2.000	10.000	0.000
amsua_n15	8	1	0.275	0.232	2.000	10.000	0.000
amsua_n15	9	1	0.340	0.235	2.000	10.000	0.000
amsua_n15	10	1	0.400	0.237	2.000	10.000	0.000
amsua_n15	11	-1	0.600	0.270	2.500	10.000	0.000
amsua_n15	12	1	1.000	0.385	3.500	10.000	0.000
amsua_n15	13	1	1.500	0.520	4.500	10.000	0.000
amsua_n15	14	-1	2.000	1.400	4.500	10.000	0.000
amsua_n15	15	1	3.000	10.000	4.500	10.000	0.000
hirs3_n17	1	-1	2.000	0.000	4.500	10.000	0.000
hirs3_n17	2	-1	0.600	0.000	2.500	10.000	0.000
hirs3_n17	3	-1	0.530	0.000	2.500	10.000	0.000
hirs3_n17	4	-1	0.400	0.000	2.000	10.000	0.000
hirs3_n17	5	-1	0.360	0.000	2.000	10.000	0.000

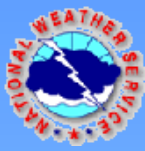
Is channel assimilated?
 -1=Passive, 1=Active
 (there are other options)

The assigned observation error (K)

See tomorrow's talk

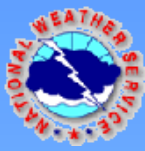
The maximum allowed departure
 to pass quality control (K)

Used in VarQC



Assimilating satellite radiances

Thinning



Thinning or Superobbing

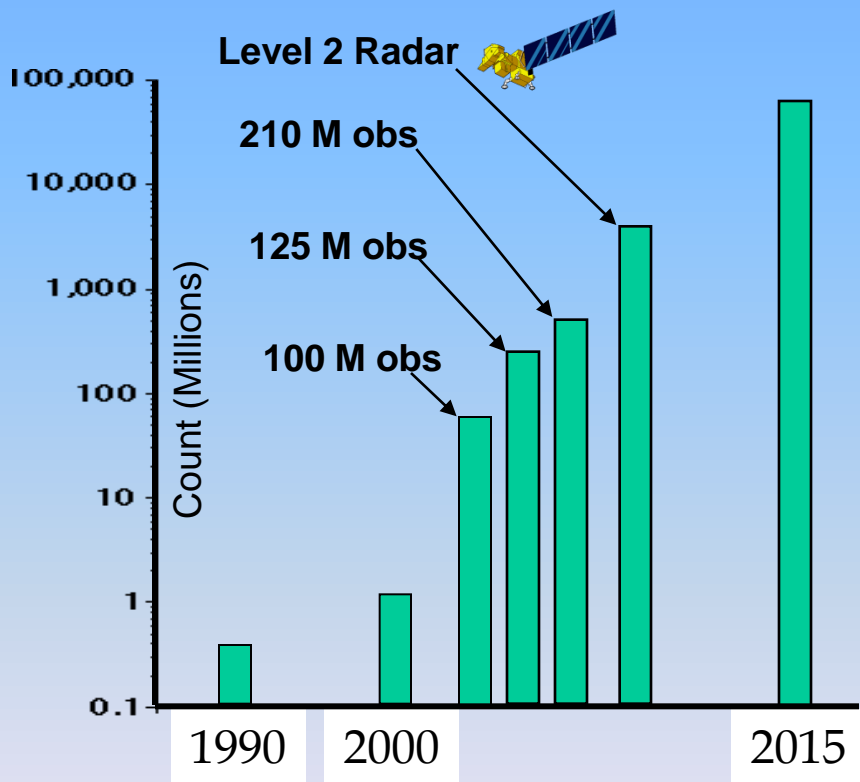
- Thinning
 - Reducing spatial or spectral resolution by selecting a reduced set of locations or channels.
 - Can include “intelligent thinning” to use better observation.
- Superobbing
 - Reducing spatial or spectral resolution by combining locations or channels.
 - Can reduce noise.
 - Includes reconstructed radiances.
 - Can include higher moments contained in data [Purser et al., 2010](#).
 - Can be done with obs or departures, but should be done after QC.
- Both can be used to address 3 problems:
 - Redundancy in data.
 - Reduce correlated error.
 - Reduce computational expense.



Satellite Data Ingest

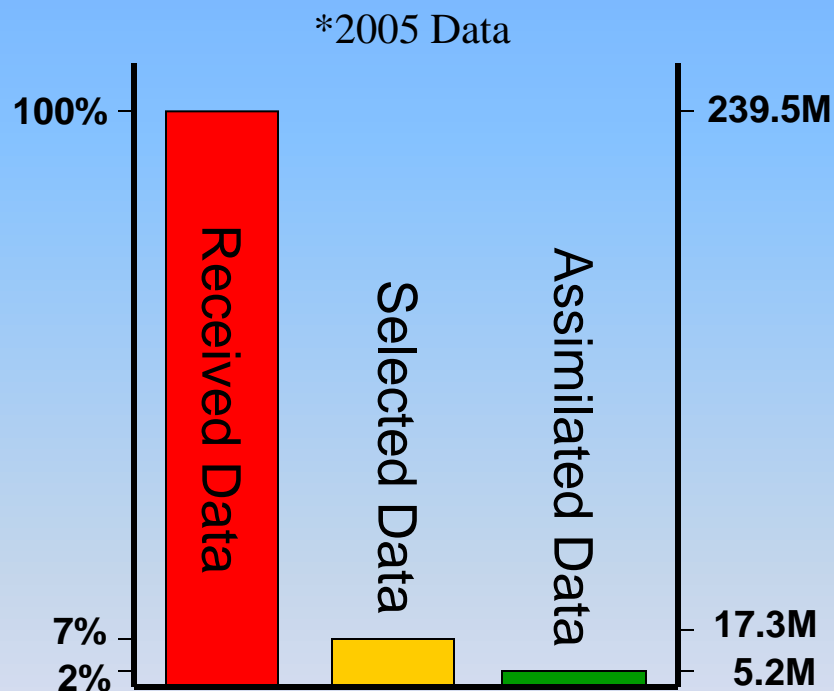


Daily Satellite & Radar Observation Count

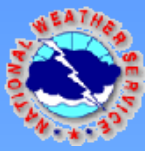


Five Order of Magnitude Increases in Satellite Data Over Fifteen Years (2000-2015)

Daily Percentage of Data Ingested into Models



Received = All observations received operationally from providers
 Selected = Observations selected as suitable for use
 Assimilated = Observations actually used by models



Assimilating satellite radiances

Data Monitoring



Data Monitoring

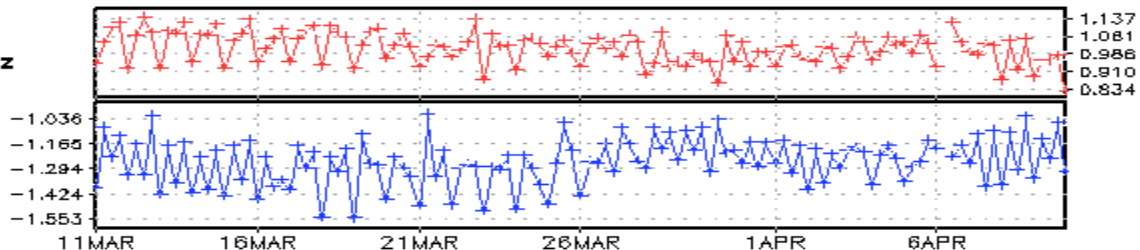
- It is essential to have good data monitoring.
- Usually the NWP centres see problems with instruments prior to notification by provider (Met Office especially).
- The data monitoring can also show problems with assimilation systems.
- Needs to be ongoing/real time.
- Monitoring reports from most major NWP centers at:
<http://research.metoffice.gov.uk/research/interproj/nwpsaf/monitoring.html>

Quality Monitoring of Satellite Data

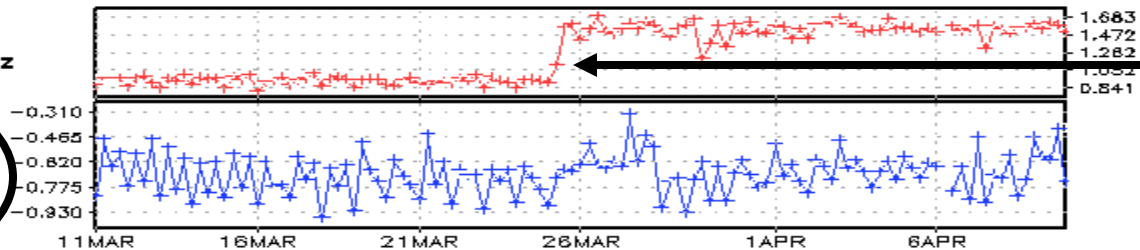
AIRS Channel 453 26 March 2007

platform: airs.049
region : global (180W-180E, 90S-90N)
variable: ges_(w/o bias cor) - obs (K)
valid : 00Z11MAR2007 to 00Z10APR2007

channel 375
 χ 0.3328
f 22771.43 GHz
 λ 13.17 μm
avg: -1.254
sdv: 1.010

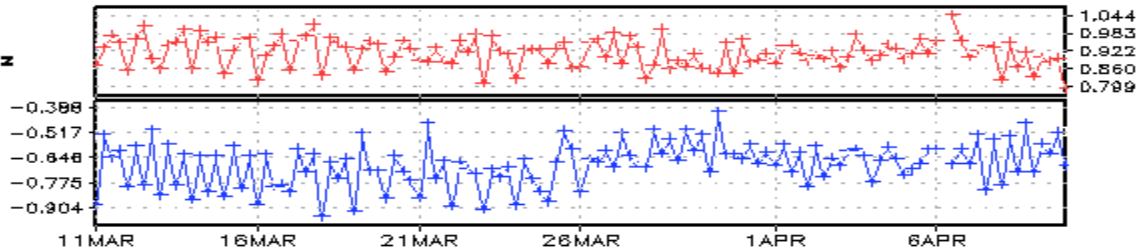


channel 453
 χ 0.8262
f 23778.66 GHz
 λ 12.81 μm
avg: -0.686
sdv: 1.247
CHANNEL 453
**** IS NOT ****
ASSIMILATED

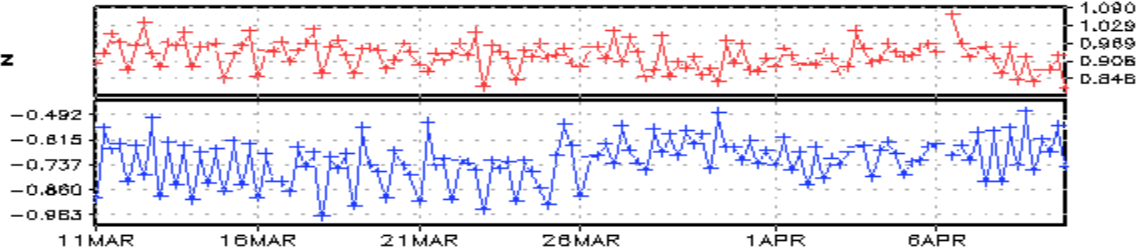


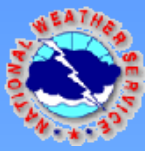
Increase in SD
Fits to Guess

channel 475
 χ 0.2532
f 24016.41 GHz
 λ 12.48 μm
avg: -0.678
sdv: 0.916



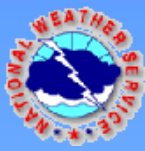
channel 484
 χ 0.2962
f 24114.80 GHz
 λ 12.43 μm
avg: -0.714
sdv: 0.927





Overall Comments

- Satellite data must be treated carefully.
- Important to be aware of instrument characteristics before attempting to use data.
- No current component of observing system is used “perfectly” or “as well as possible”.
- Computational expense plays important role in design of system.



Questions and/or Comments
Please



Useful References (1/2)

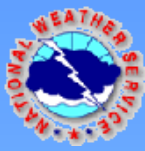
Auligne T.; McNally A. P.; Dee D. P., 2007: Adaptive bias correction for satellite data in a numerical weather prediction system, *QJRMS*, **133**, 631-642.

Bormann, N., A. Collard, and P. Bauer, Observation Errors and their error correlations for satellite radiances, *ECMWF Newsletter* No. 128, p17-22. available at

<http://www.ecmwf.int/publications/newsletters/pdf/128.pdf>.

Collard, A., F. Hilton, M. Forsythe and B. Candy (2011). From Observations to Forecasts – Part 8: The use of satellite observations in numerical weather prediction. *Weather*, **66**: 31–36.

CRTM ftp site: <ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/>



Useful References (2/2)

- Dee, D. P. , Uppala S., 2009: Variational Bias correction of satellite radiance data in the ERA-Interim reanalysis, QJRMS, **135**, 1830-1841.
- Derber, J. C. and W.-S. Wu, 1998: The use of TOVS cloud-cleared radiances in the NCEP SSI analysis system. Mon. Wea. Rev., **126**, 2287 - 2299.
- Desroziers, G., L. Berre, B. Chapnik & P. Poli, 2005: Diagnosis of observation background and analysis-error statistics in observation space. QJRMS., **131**, 3385–3396.
- McNally, A.P., J.C. Derber, W.-S. Wu and B.B. Katz, 2000: The use of TOVS level-1B radiances in the NCEP SSI analysis system. Q.J.R.M.S., **126**, 689-724.
- RTTOV
homepage.: <http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm/>
- Rizzi, R., and R.W. Saunders. Principles of remote sensing of atmospheric parameters from space. ECMWF Training Course.
http://www.ecmwf.int/newsevents/training/rcourse_notes/DATA_ASSIMILATION/REMOTE_SENSING
- Rodgers, C.D. (2000). Inverse Methods for Atmospheric Sounding: Theory and Practice. World Scientific Pub Co Inc.



Backup Slides