Radiance Assimilation

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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
  - Assimilating Radiances in the GSI
  - Monitoring.

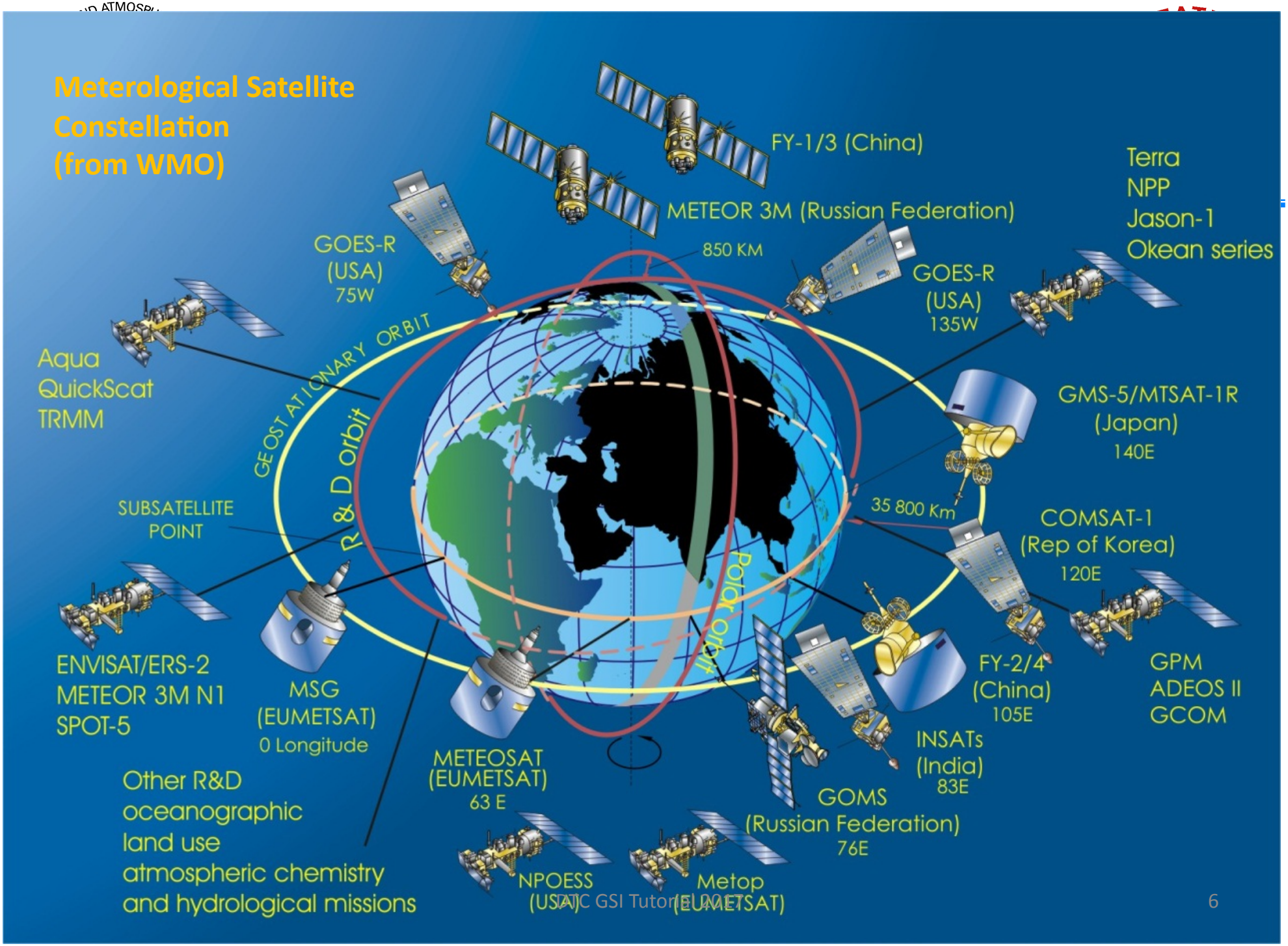
Introduction

- 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.

Introduction

- To effectively assimilate a data type it is important to understand the measurement system. This means:
  - The measurement needs to be accurately simulated from the model state.
  - Where the measurement cannot be simulated accurately, this needs to be understood so that we can:
    - Bias correct, if possible.
    - Remove data through quality control.
  - The full error budget of the system needs to be understood too, including:
    - Observation error
    - Forward model error
    - Representivity Error

Different Types of Satellite Data

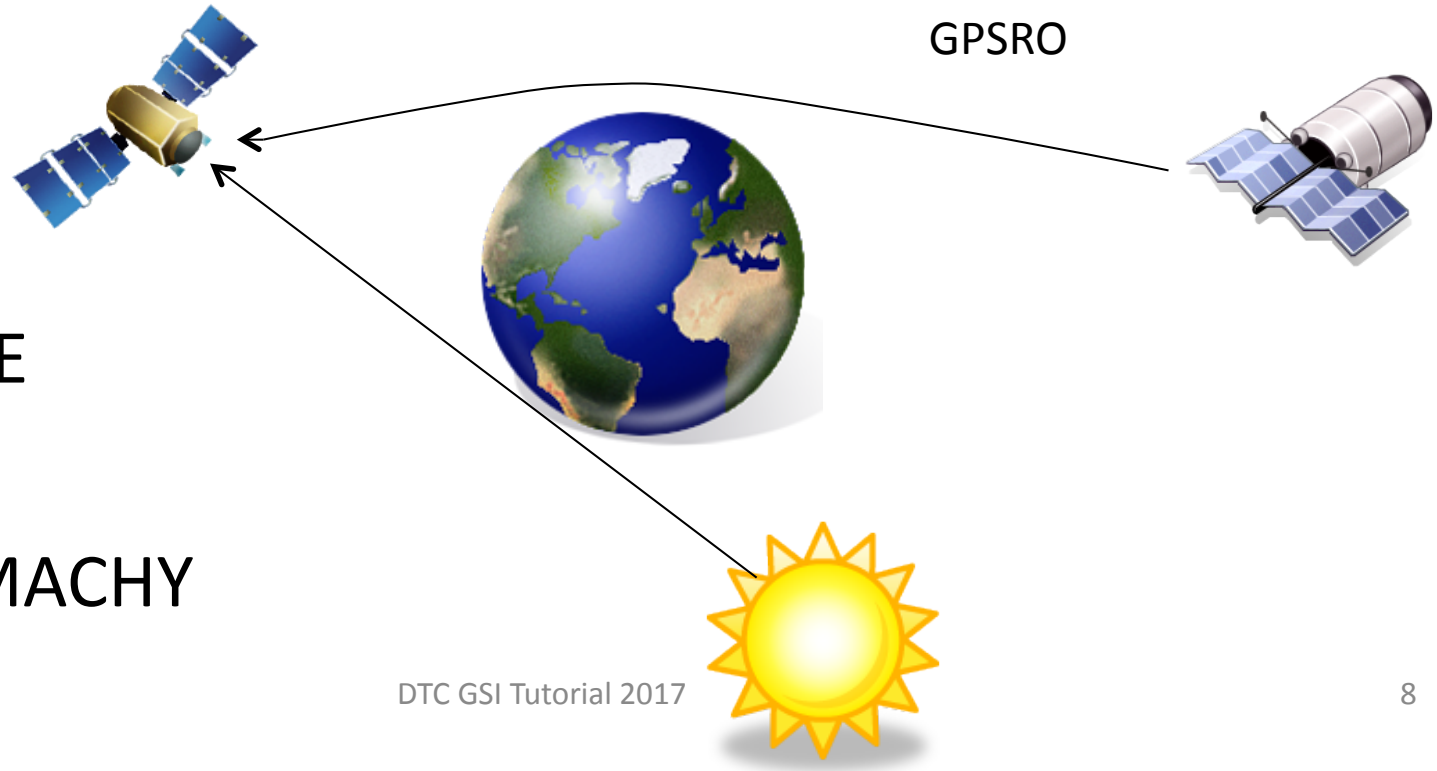

Meterological Satellite Constellation (from WMO)
FY-1/3 (China)
METEOR 3M (Russian Federation)
850 KM
Terra
NPP
Jason-1
Okean series
GOES-R (USA) 75W
GOES-R (USA) 135W
Aqua
QuickScat
TRMM
GEOSTATIONARY ORBIT
R & D orbit
Polar orbit
GMS-5/MTSAT-1R (Japan) 140E
35 800 Km
SUBSATELLITE POINT
COMSAT-1 (Rep of Korea) 120E
ENVISAT/ERS-2
METEOR 3M N1
SPOT-5
MSG (EUMETSAT) 0 Longitude
FY-2/4 (China) 105E
GPM
ADEOS II
GCOM
INSATs (India) 83E
METEOSAT (EUMETSAT) 63 E
GOMS (Russian Federation) 76E
Other R&D
oceanographic
land use
atmospheric chemistry
and hydrological missions
NPOESS (USA)
Metop (EUMETSAT)

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)



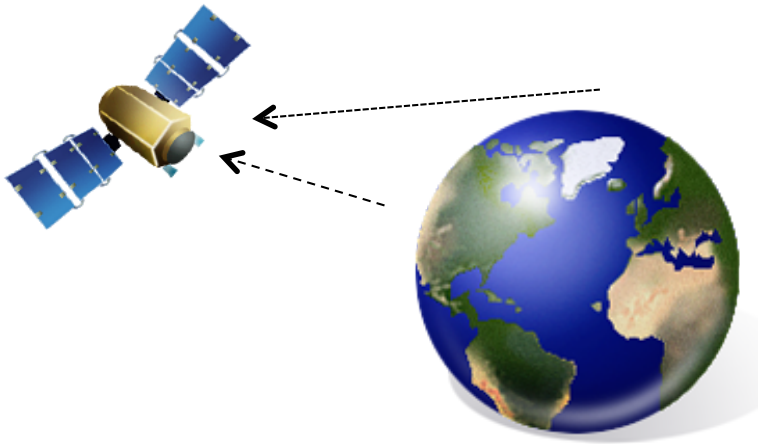
HALOE

SAGE

SCIAMACHY

Different Types of Satellite Data

- Passive (receiving radiative signal from source)



Visible instruments

IR instruments

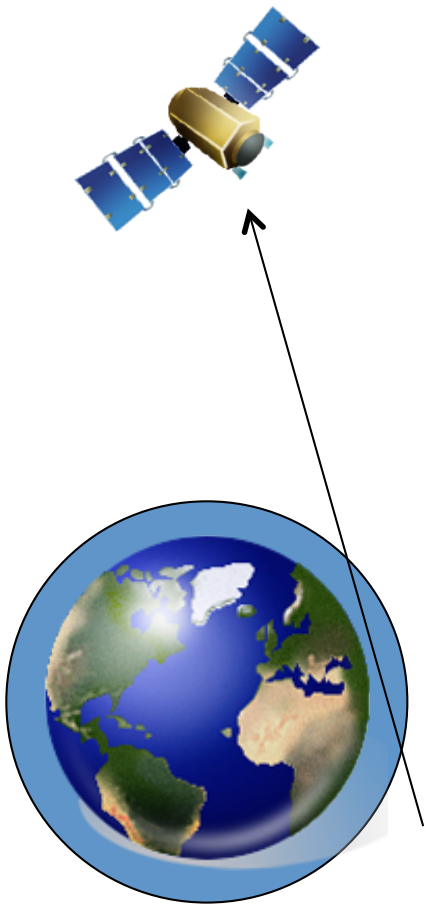
Microwave instruments

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

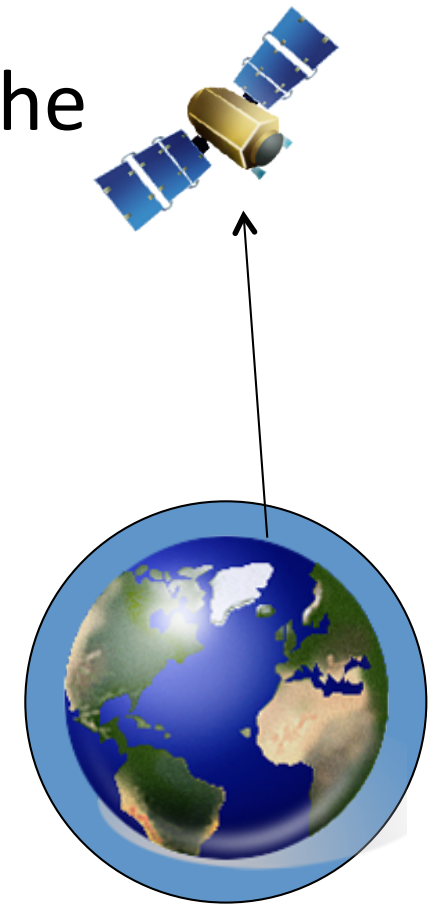
Geometry: Limb vs Nadir Sounding

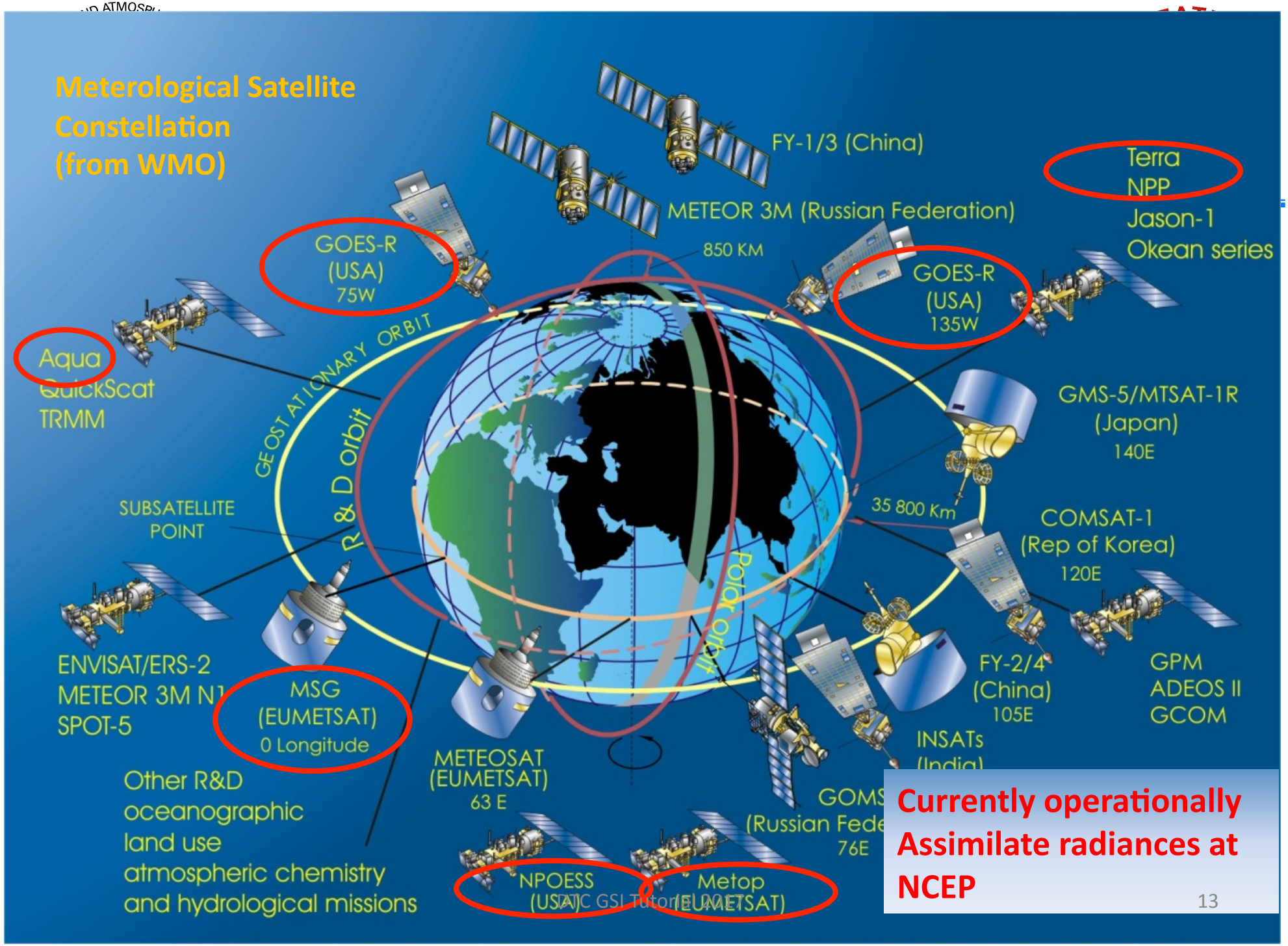
- Limb sounding: Viewing the Earth's atmosphere tangentially
  - Higher vertical resolution
  - Lower horizontal resolution
  - Most often used for observing the stratosphere and above.
  - Not often used in NWP



Geometry:
Limb vs Nadir Sounding

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

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NPOESS (USA)
Metop (EUMETSAT)
Currently operationally Assimilate radiances at NCEP

Theory of Assimilating Observations from Passive Nadir Sounders

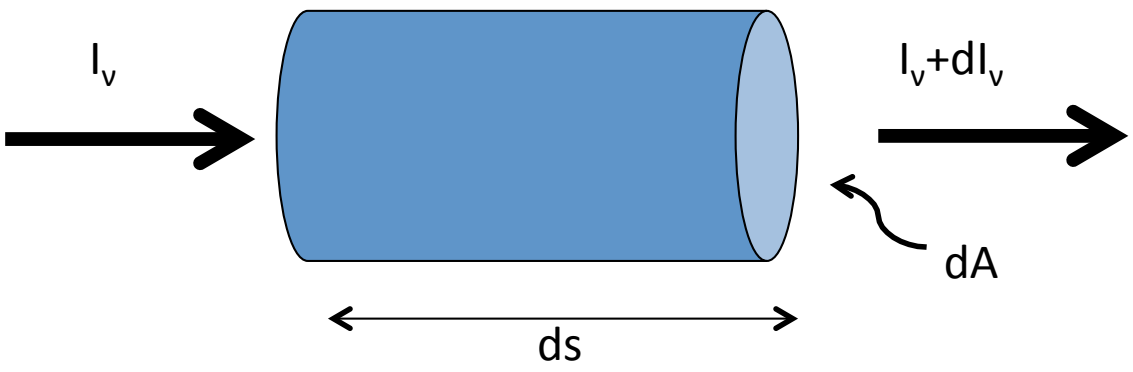
Radiative Transfer: Definitions

- *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 $Wm^{-2}sr^{-1}(cm^{-1})^{-1}$ 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 $Wm^{-2}(cm^{-1})^{-1}$.

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:

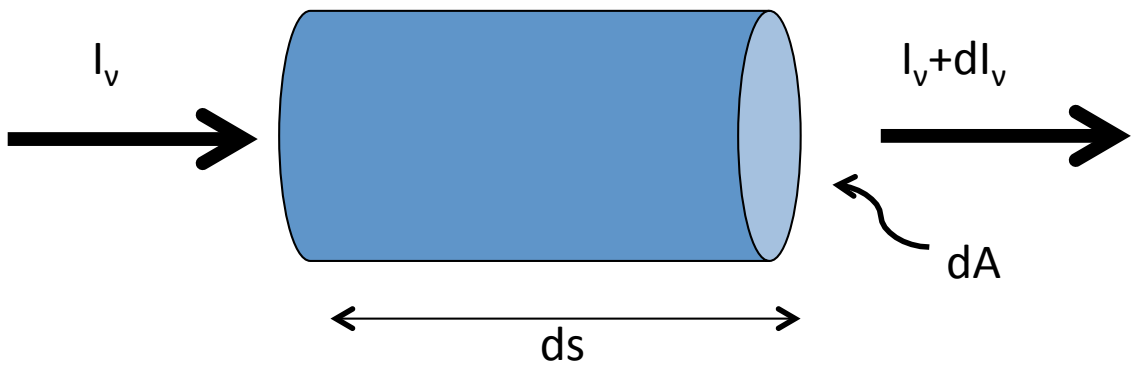
$$(I_\nu + dI_\nu)\, dA = -(n\, k_\nu\, ds)\, I_\nu\, dA$$

$(n\, k_\nu\, ds)$ 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:



$$(I_\nu + dI_\nu)\, dA = \varepsilon_\nu S_\nu\, dA$$

Where ε_ν is the emissivity of the volume and S_ν is 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:

Schwartzchild Equation

Combining the terms for emission and absorption gives

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

Kirchoff's Law states that the absorptivity and the emissivity are equal, so $(n\, k_\nu\, ds) = \varepsilon_\nu$

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

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

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

$$dI_\nu/d\tau_\nu = I_\nu - B_\nu(T)$$

Radiative Transfer

Schwarzchild Equation in a scattering atmosphere

$$\frac{dI_\nu}{d\tau_\nu^*} = I_\nu - (1-\omega_\nu)B_\nu(T) - \omega_\nu \int I_\nu(\Omega)P_\nu(\Omega)d\Omega$$

Extinction term (absorption+scattering)

Emission term

Radiation scattered from all directions, Ω, into the beam

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 σ_ν is the the scattering coefficient.

ω_ν is the single scattering albedo and is given by $\sigma_\nu/(k_\nu+\sigma_\nu)$.

$P(\Omega)$ is the phase function and describes the angular distribution of how incident radiance is scattered.

Radiative Transfer

Solution to Schwarzchild Equation

The general solution to the Schwartzchild equation is:

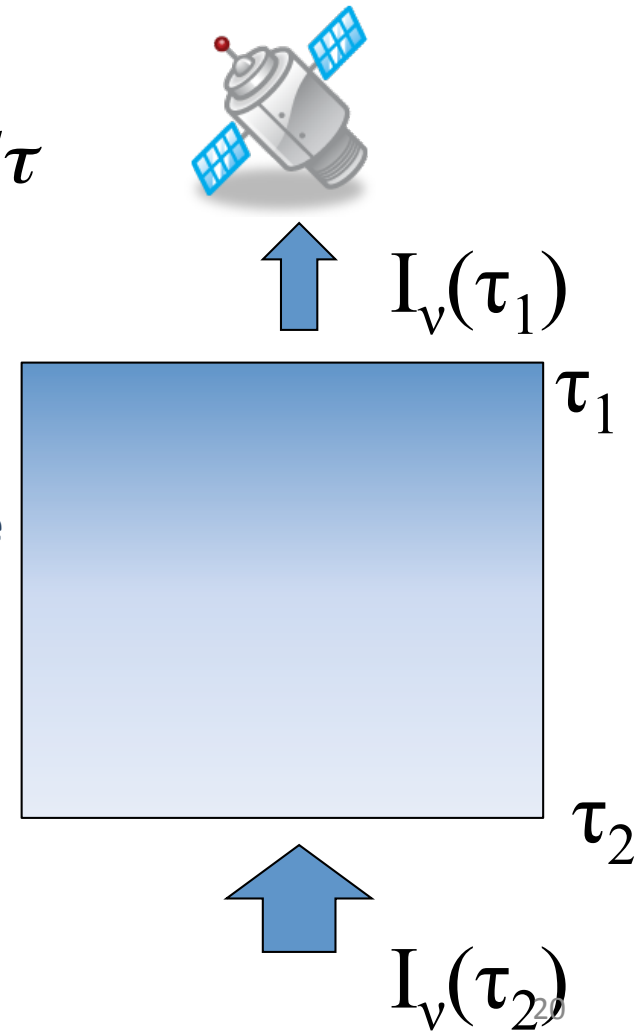
$$I_\nu(\tau_1) = I_\nu(\tau_2)e^{-(\tau_2-\tau_1)} + \int_{\tau_1}^{\tau_2} S(\tau)e^{-(\tau-\tau_1)}d\tau$$

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 Schwarzchild equation is:

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

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

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

Which we can transform into pressure, p, coordinates:

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

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

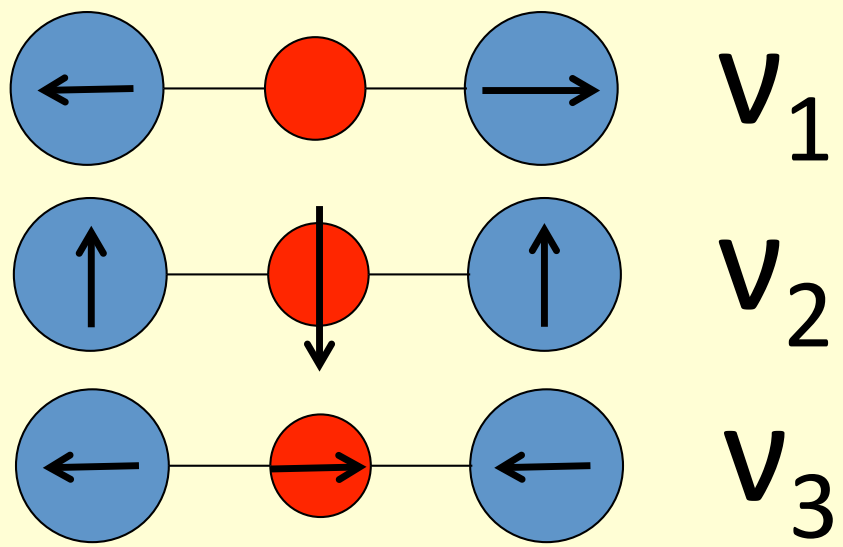
Weighting Functions and Jacobians

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 **y**) with respect to the *state vector* , **x**. This is the Jacobian matrix**, K**=d**y**(**x**)/d**x**

Here **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.

So where does atmospheric absorption come from?

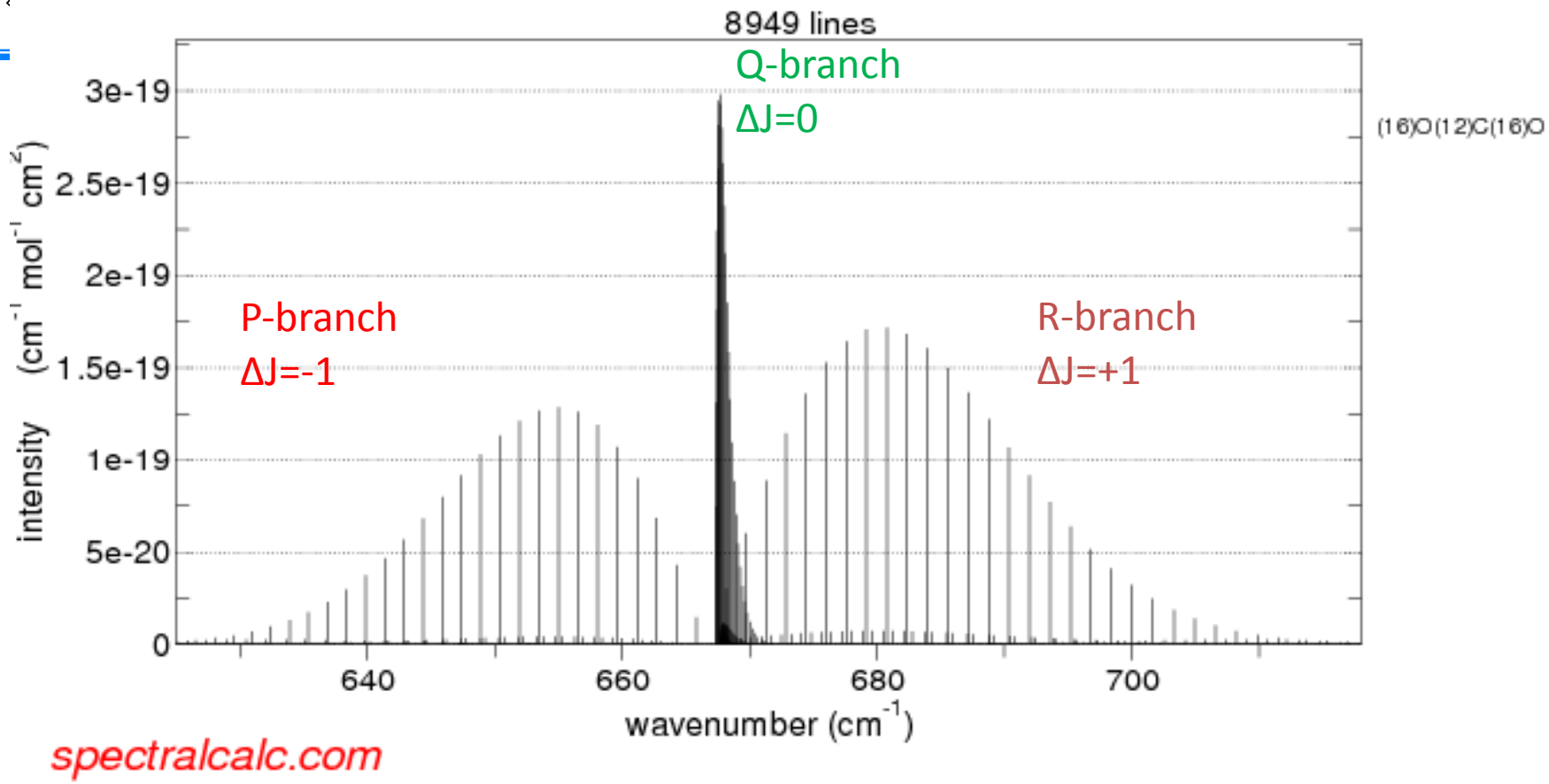
- Molecules in the atmosphere have energy stored as rotational, vibrational and electronic components
- The energy states are quantised and may be transformed through emission or absorption of electromagnetic radiation. This results in discrete spectral emission/absorption features in the spectrum.



Vibrational Modes for CO_2

- 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→ν_2 transition for CO_2



An example of a vibration-rotation band in the infrared CO_2 spectrum. 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

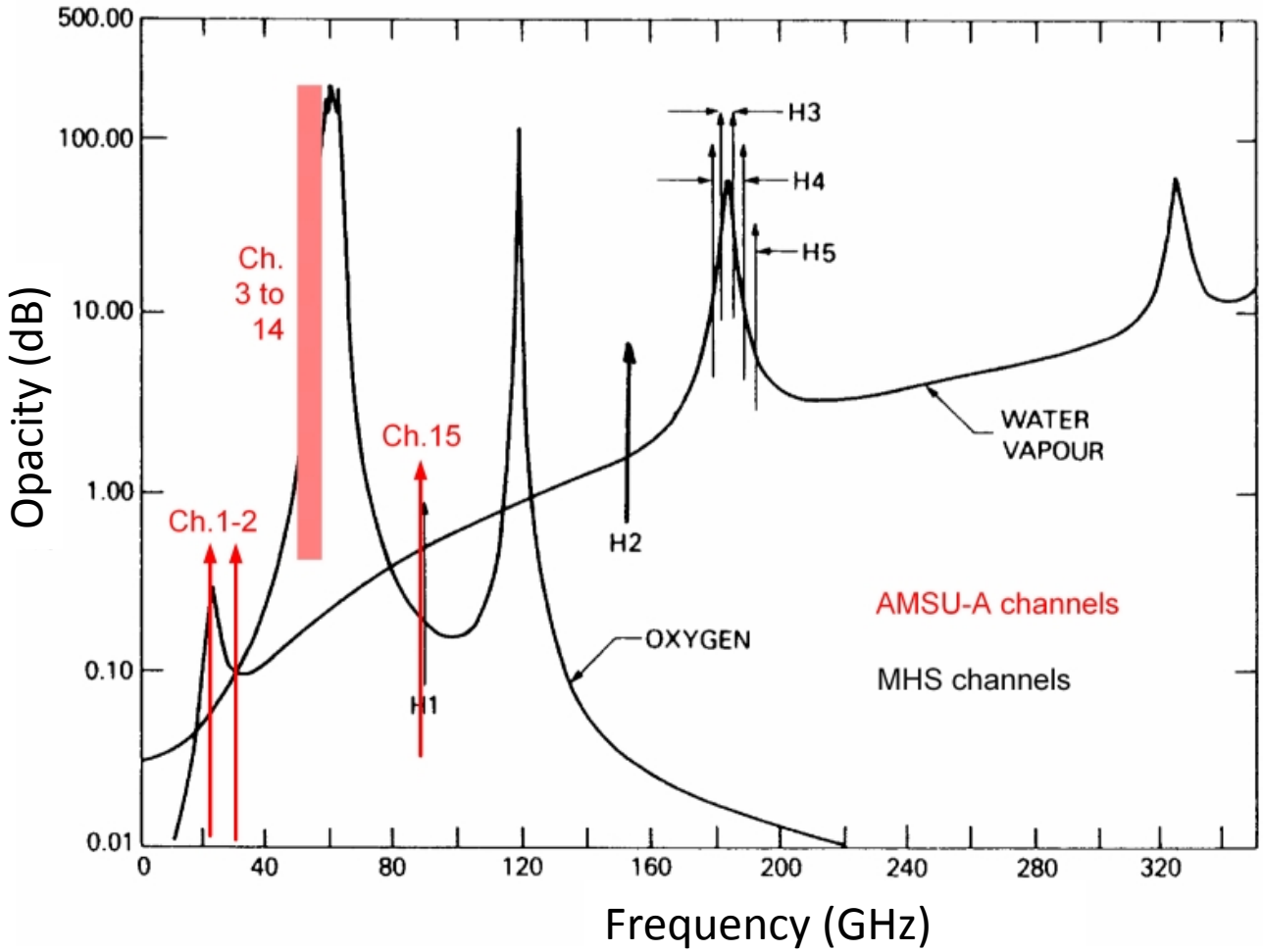
- Spectral lines will be broadened through one of the following three processes:
  - **Natural broadening**: The finite time of the quantum transition corresponds to an uncertainty in the energy through the uncertainty principle.
  - **Doppler broadening:** Thermal motion of the molecules along the line 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 8-12m 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.

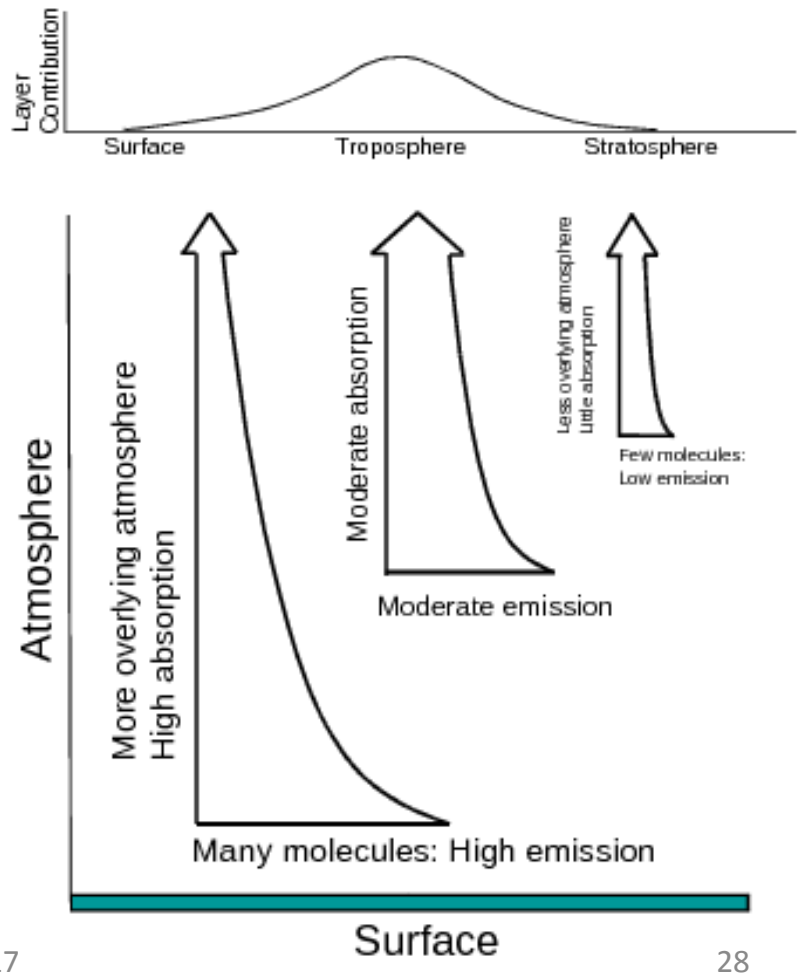
Atmospheric Opacity in the Microwave Spectrum

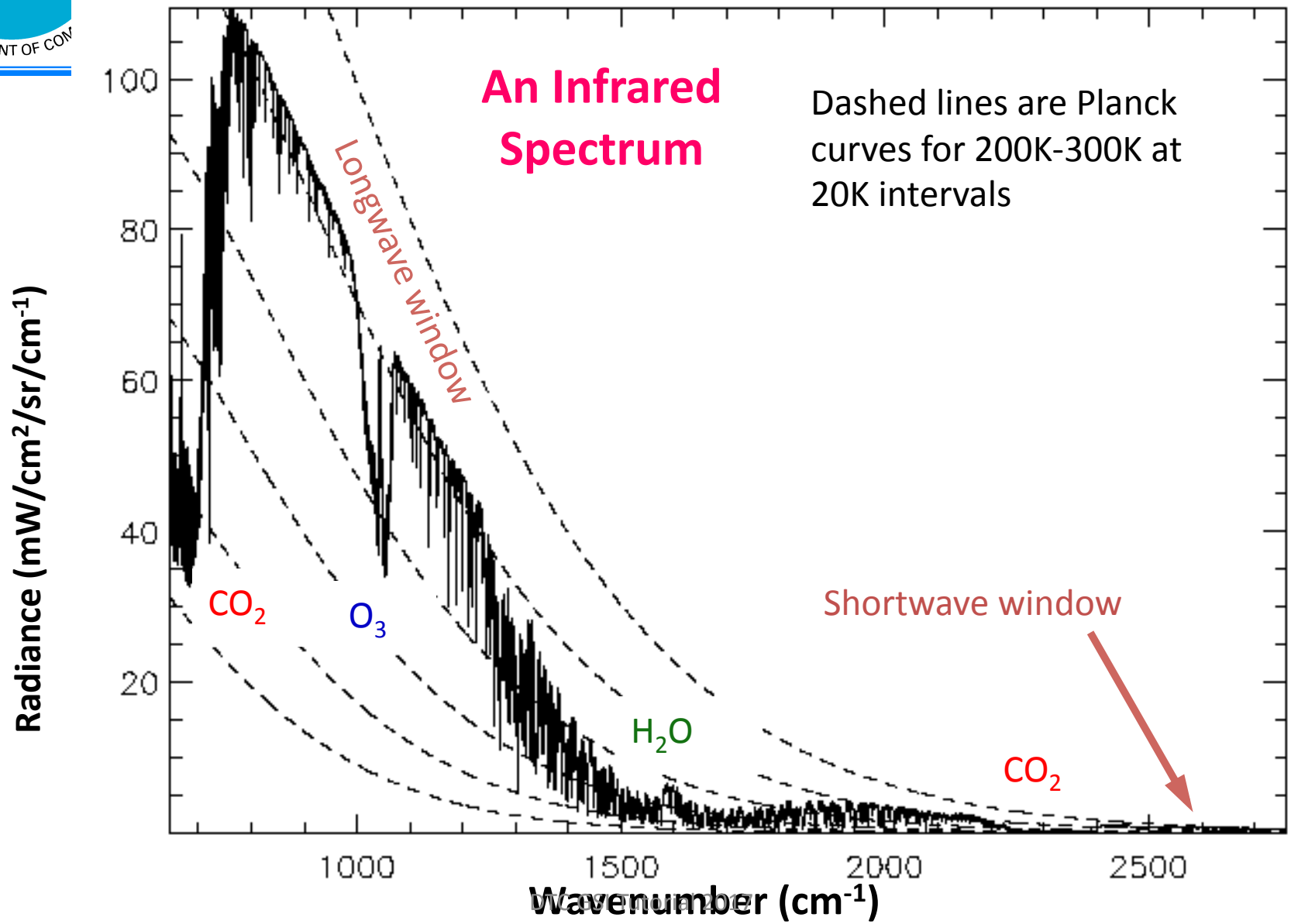


Sensitivity to cloud and/or precipitation increases as frequency increases

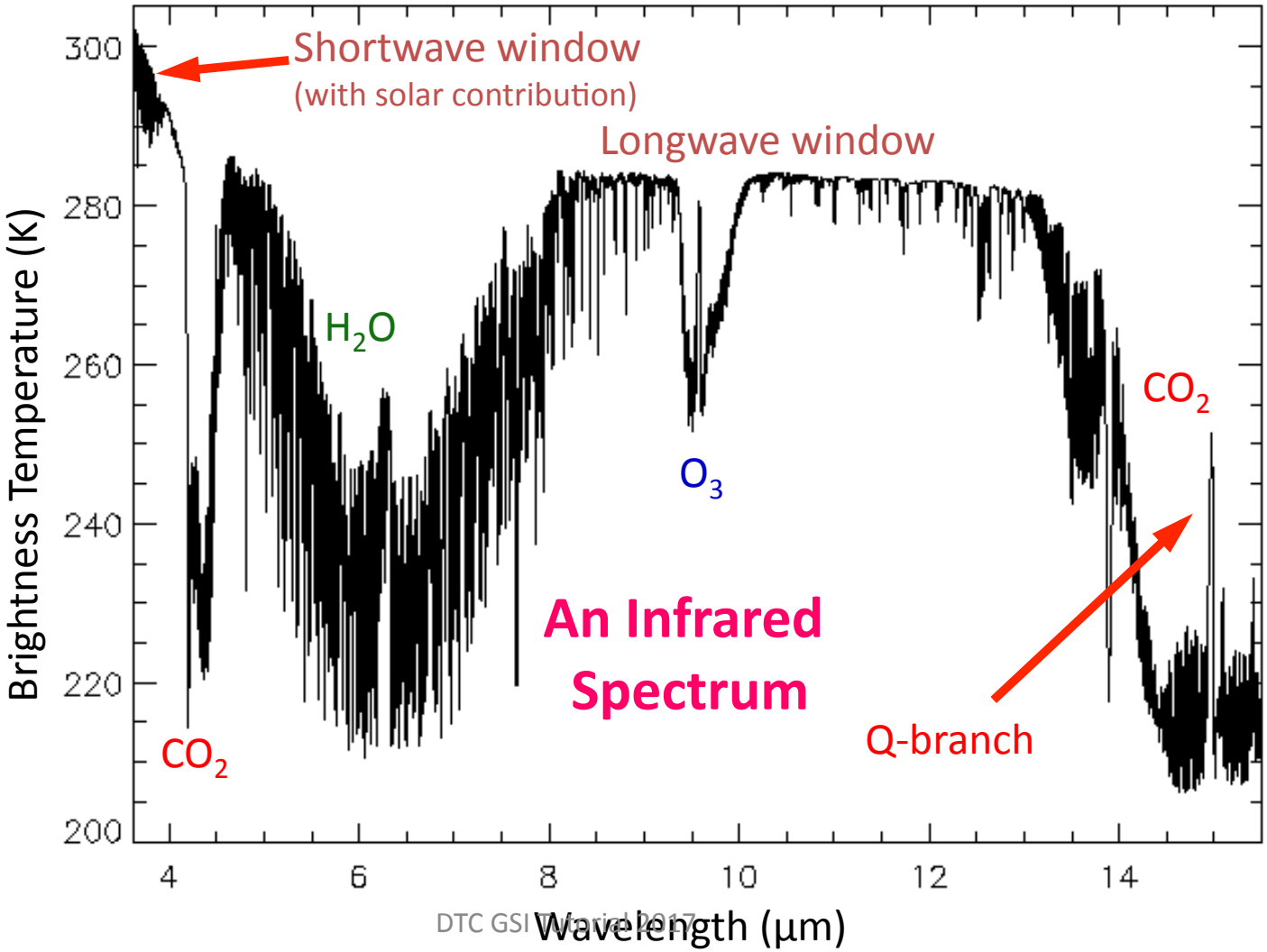
Illustration of Jacobian or Weighting Function

Radiation observed at the top of the atmosphere will originate predominantly from layers where the emission is high and is not obscured by overlying layers.

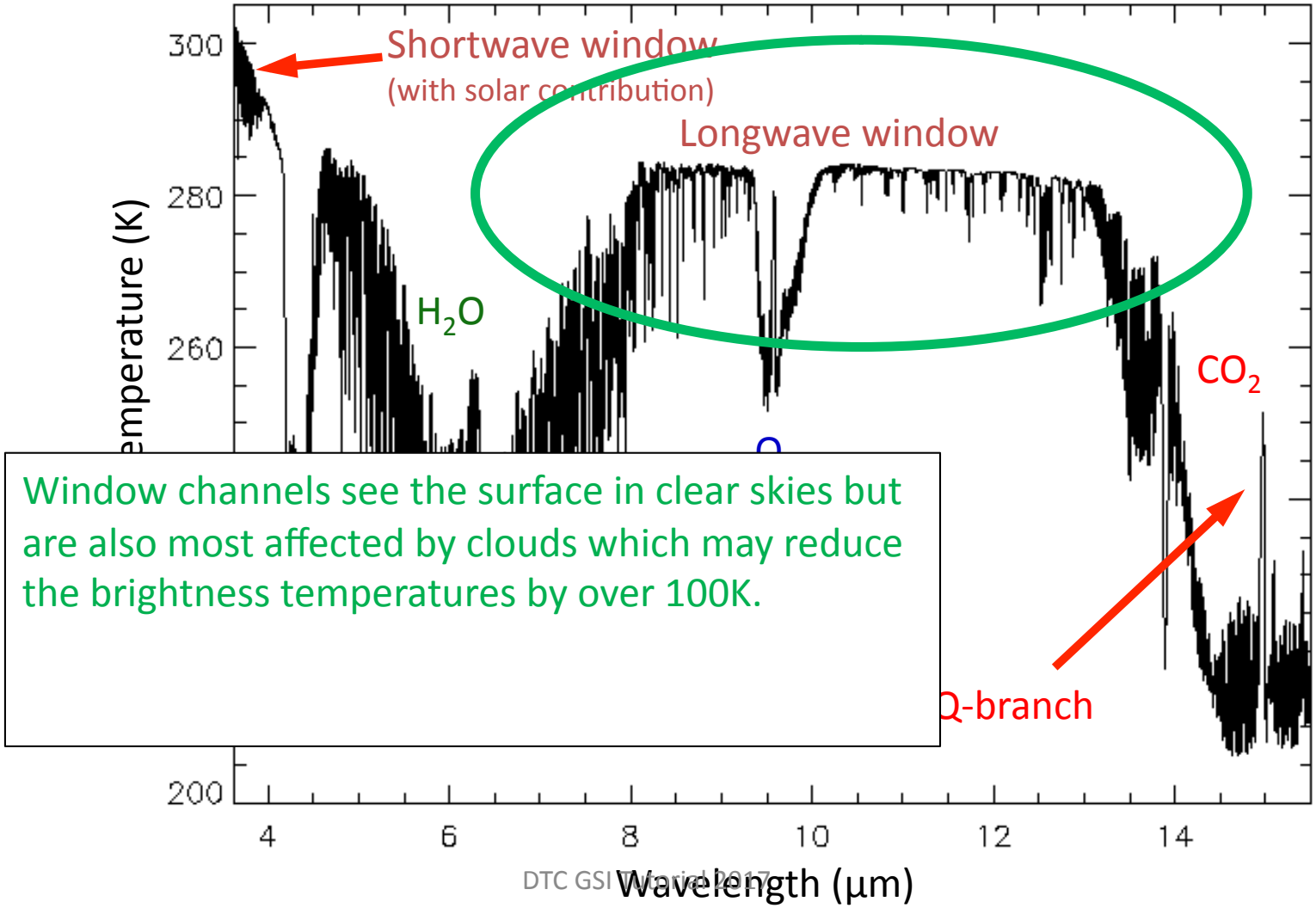



An Infrared Spectrum
Dashed lines are Planck curves for 200K-300K at 20K intervals
Longwave window
Shortwave window
CO_2
O_3
H_2O
CO_2
Radiance (mW/cm^2/sr/cm^{-1})
Wavenumber (cm^{-1})
100
80
60
40
20
1000
1500
2000
2500

An IASI Spectrum

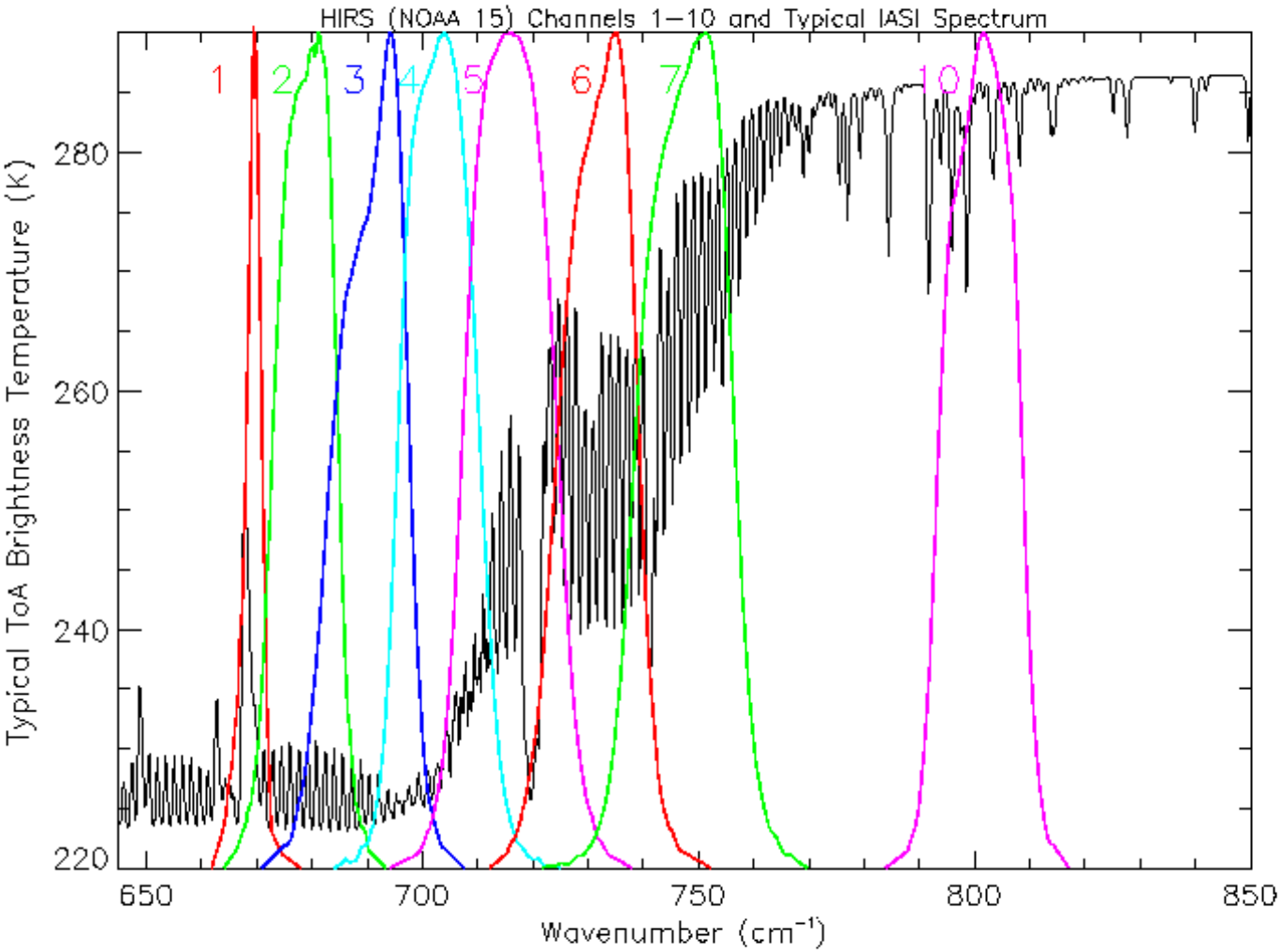


An IASI Spectrum

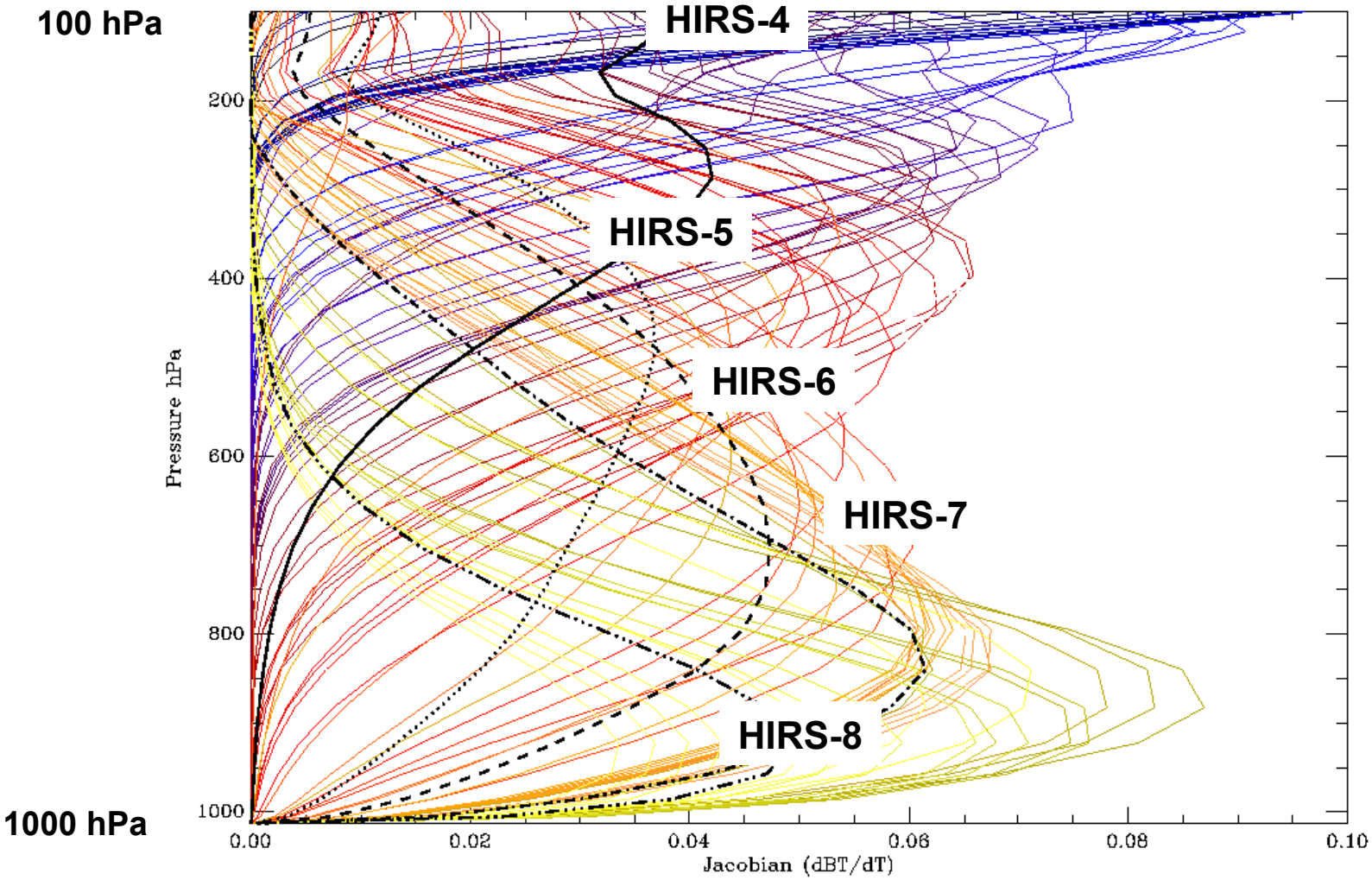


Window channels see the surface in clear skies but are also most affected by clouds which may reduce the brightness temperatures by over 100K.

IASI vs HIRS: The Thermal InfraRed



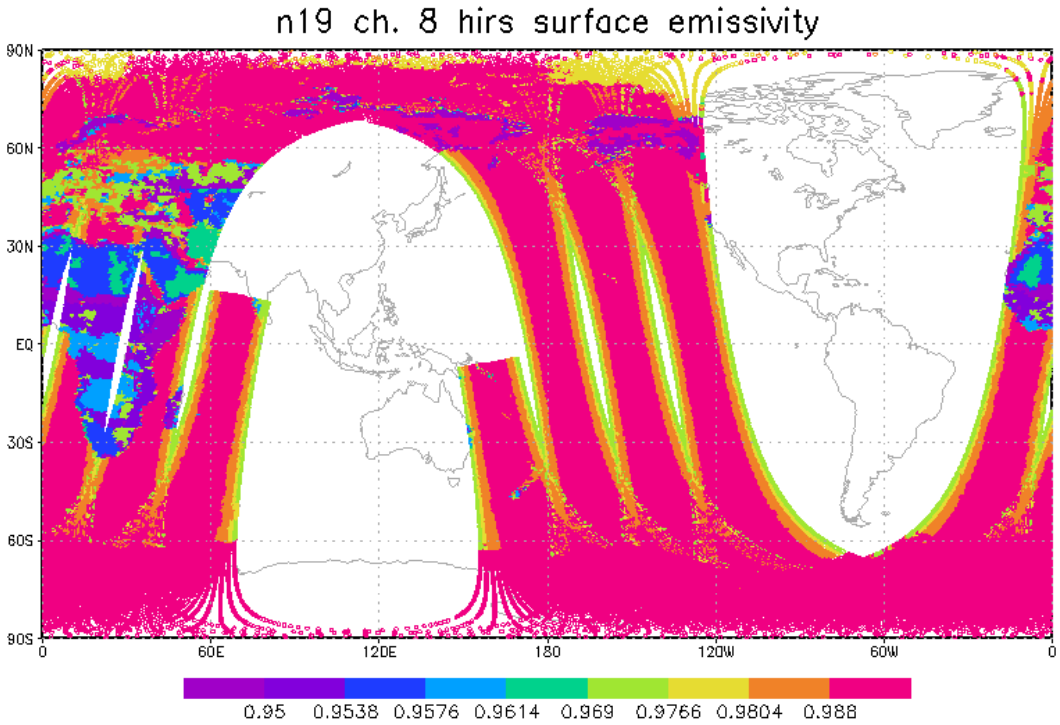
AIRS & HIRS Jacobians in the 15µm CO_2 band



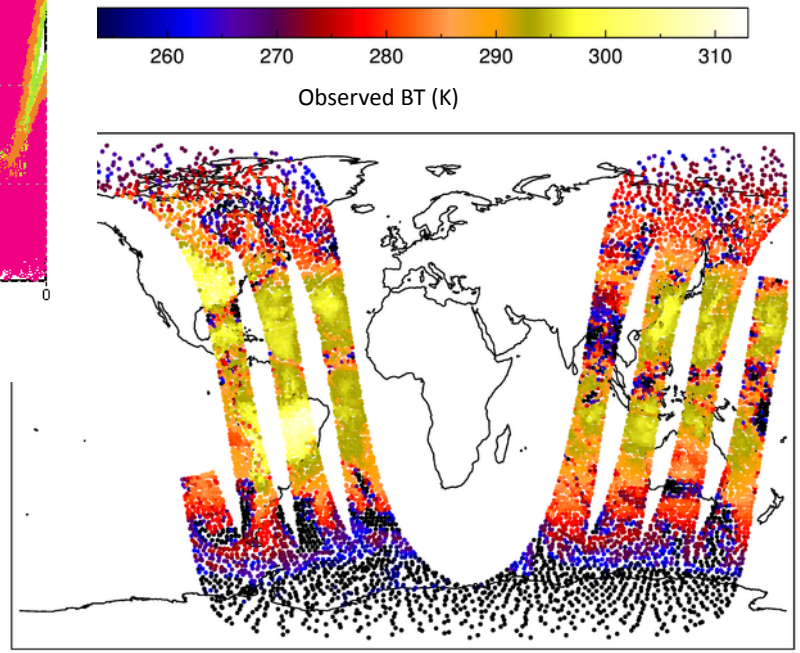
We also need to know the surface emissivity

- 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



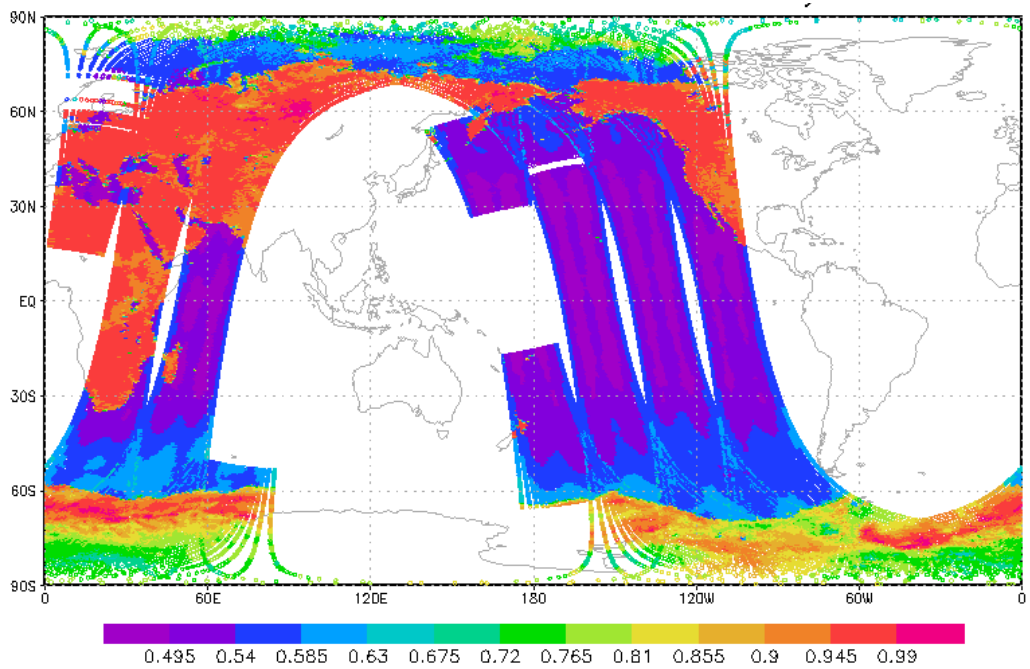
Surface emissivity is high, particularly for water surfaces



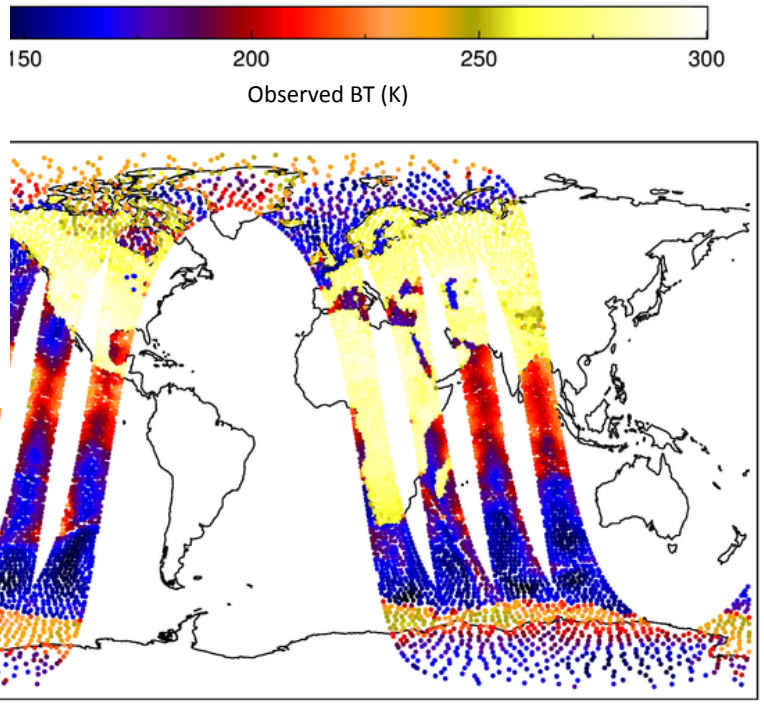
Clouds generally have lower brightness temperatures than the relatively warm surface

HIRS Ch 8

Surface Emissivity: Microwave



Surface emissivity is high for land and ice/snow, but very low for water surfaces



Clouds have higher brightness temperatures than the radiatively cold water surfaces.

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 calcuations 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

Retrievals

- 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?

Retrievals

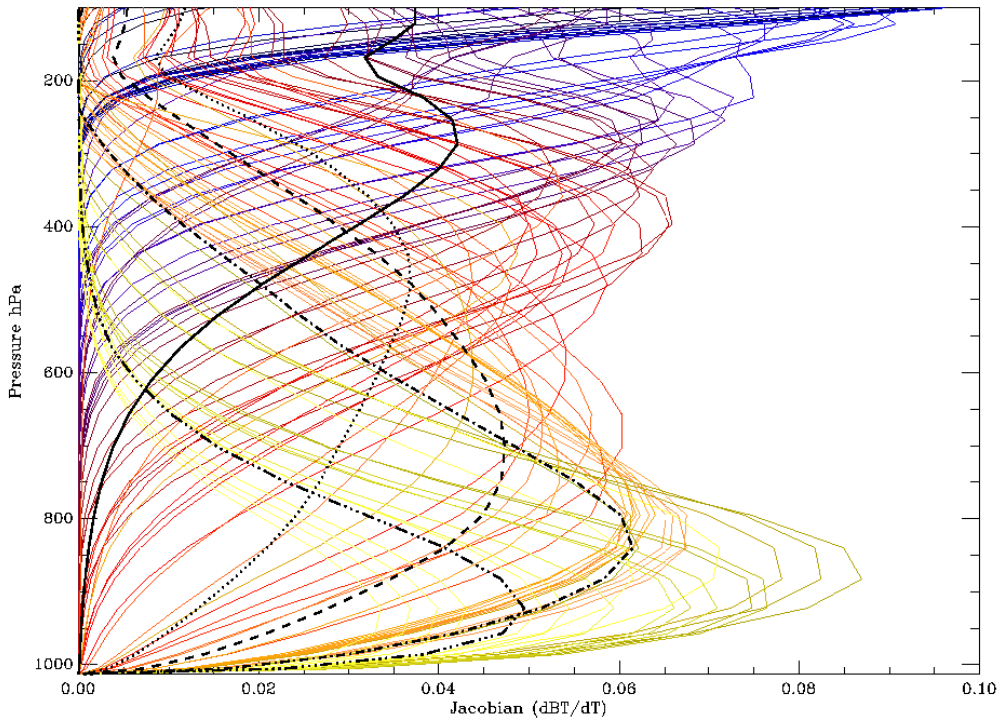
- Unless we can infer the temperature profile we won't be able to do much else.
- To do this we need to choose frequencies where we know the absorption profiles already
- We choose gases with a constant distribution to do this.
- For the infrared we use CO_2
- For the microwave we use O_2
- These are 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

$$J = J_b + J_o + J_c$$

$$J = (x-x_b)^T B_x^{-1}(x-x_b) + (y-K(x))^T(E+F)^{-1}(y-K(x)) + J_C$$

J = Fit to background + Fit to observations + constraints

x = Analysis
x_b = Background
(usually a short-range forecast from the previous cycle)
B_x = Background error covariance
K **= Forward model (nonlinear)**
O = Observations
E+F = R = Instrument error + Representativeness error
J_C = Constraint term

Atmospheric Analysis Problem

$J = J_b + J_o + J_c$

$$J = (x-x_b)^T B_x^{-1}(x-x_b) + (y-K(x))^T(E+F)^{-1}(y-K(x)) + J_C$$

J = Fit to background + Fit to observations + constraints

The difference between the observations and the background transformed into model space, the first guess departure, is an important measure. It is often the basis of quality control procedures.

x = A

x_b = B

B_x = B

K = F

O = C

E+F = R = Instrument error + Representativeness error

J_C = Constraint term

Assimilating satellite radiances

Quality Control

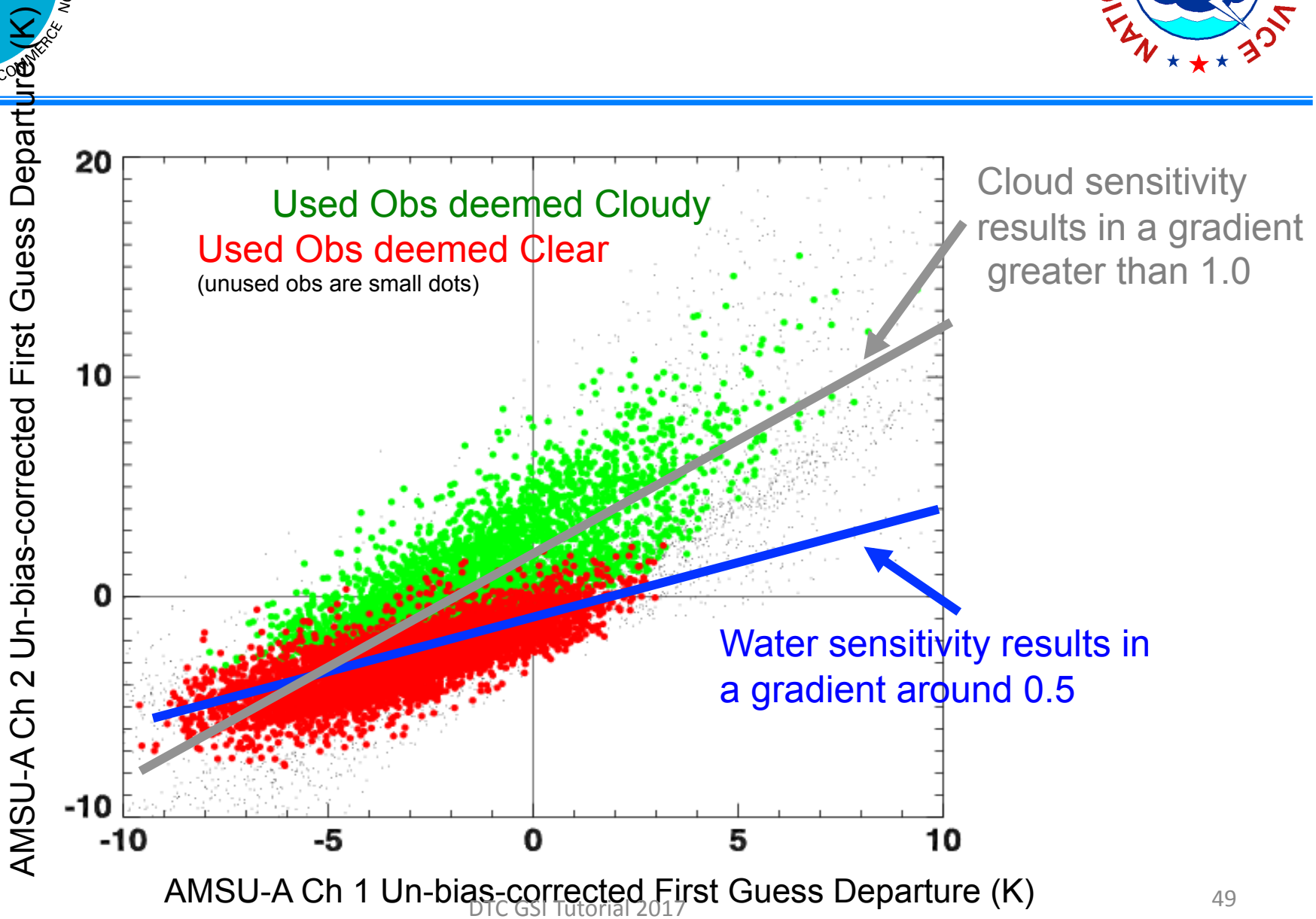
Quality Control Procedures

- 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.

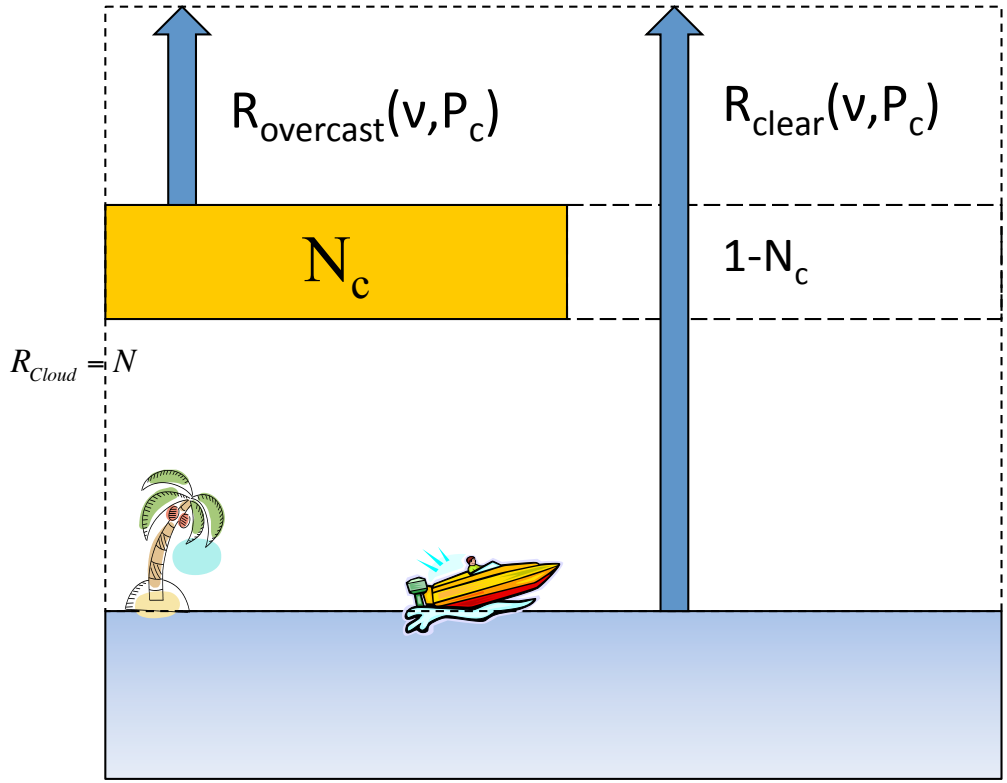
Cloud detection in the microwave



GSI Cloud Detection

(based on Eyre and Menzel, 1989)

- Assume the cloud is a single layer at pressure P_c and with unit emissivity and coverage within the FOV, N_c.
- $0 \le N_c \le 1$
- P_c is below the tropopause and above the ground
- Find P_c and N_c so that the RMS deviation, $J(N_c,P_c)$, of the calculated cloud from the model (over a number of channels) is minimized.
- Remove all channels that would be radiatively affected by this cloud.



Cloudy radiance, R_{cloud}, is calculated from:

$$R_{cloud}=N_cR_{overcast} + (1-N_C)R_{clear} = N_c(R_{overcast}-R_{clear}) + R_{clear}$$

GSI Cloud Detection (contd.)

The height and fraction of the cloud is found by minimizing the cost function:

$$J_C = \Sigma_i (R_{cloud,i} - R_{observed,i})^2/\sigma_i^2 =$$
$$\Sigma_i (N_C[R_{overcast,i} - R_{clear,i})] + (R_{clear,i} - R_{observed,}))^2/\sigma_i^2$$

i=channel index; σ_i= assigned observation error for channel

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 uses variational bias correction:

$$J(x,\beta) = \frac{1}{2}(x - x_b)^T B_x^{-1}(x - x_b) + \frac{1}{2}(\beta - \beta_b)^T B_\beta^{-1}(\beta - \beta_b)$$
$$+ \frac{1}{2}\left[y - \tilde{h}(x,\beta)\right]^T R^{-1}\left[y - \tilde{h}(x,\beta)\right]$$

B is the vector of bias-correction predictors

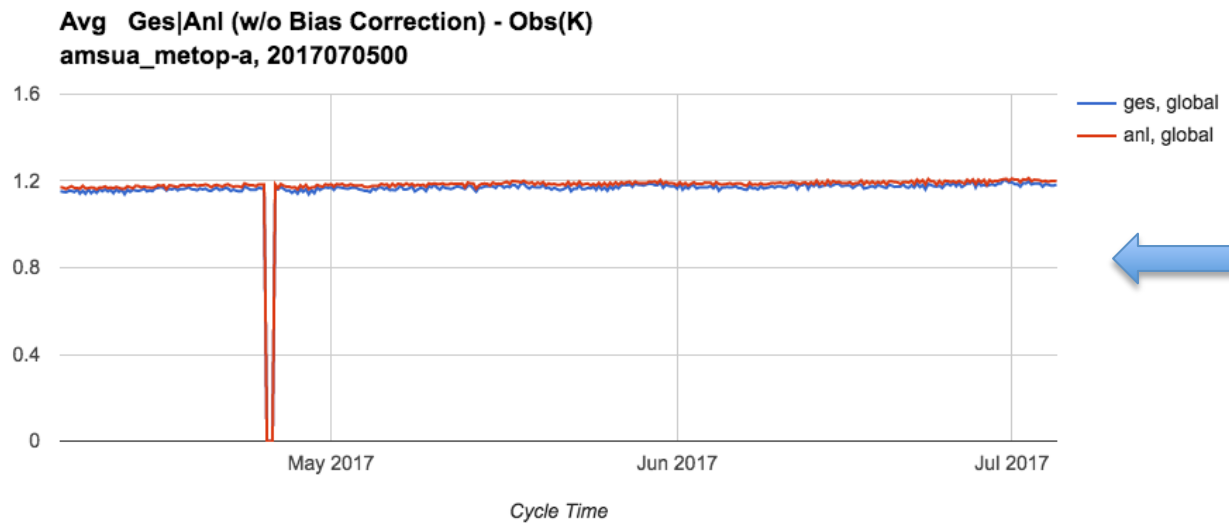
Satellite radiance observations bias correction

- Air mass prediction equation for bias – variational bias correction
  - Add to control vector (analysis variables x_{n+i})

    where total bias correction = $\sum_{i=1}^{np} x_{n+i} p_i$
  - Predictors (p_i) for each channel
    - mean
    - path length (local zenith angle determined)
    - integrated lapse rate
    - (integrated lapse rate) ^{2}
    - cloud liquid water
    - Surface emissivity sensitivity (0 over ocean, dTB/dε elsewhere)
    - Fourth-order polynomial of scan angle
    - Ascending/descending node * latitude (SSMIS only)

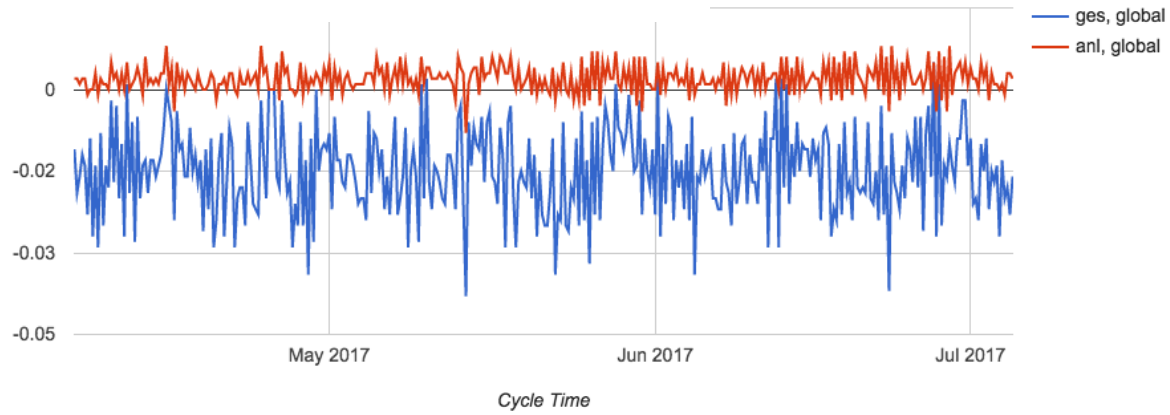
MetOp-A AMSU-A Ch 6 Mean Departures

Observed-Guess
Observed-Analysis

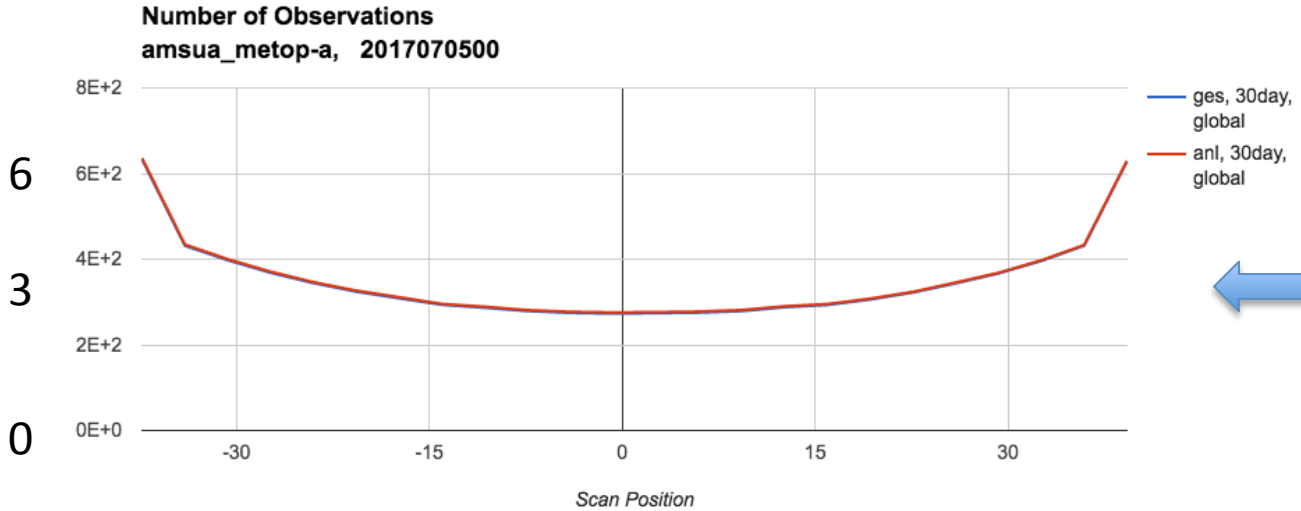


Before
Bias Correction

After
Bias Correction



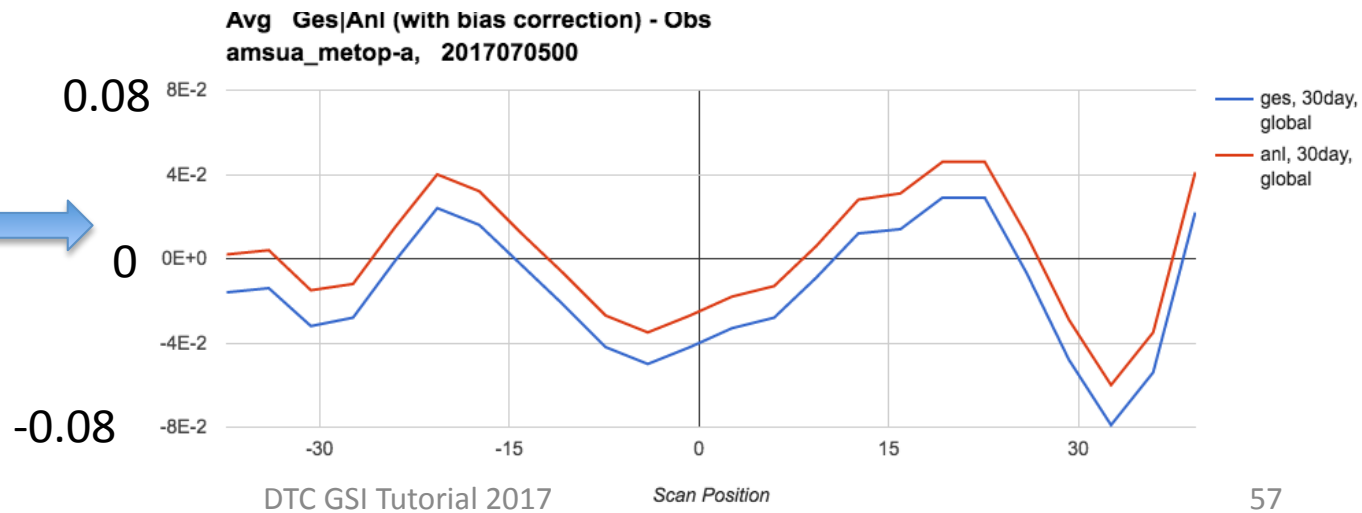
MetOp-A AMSU-A Ch 6
Mean of Departures vs Scan



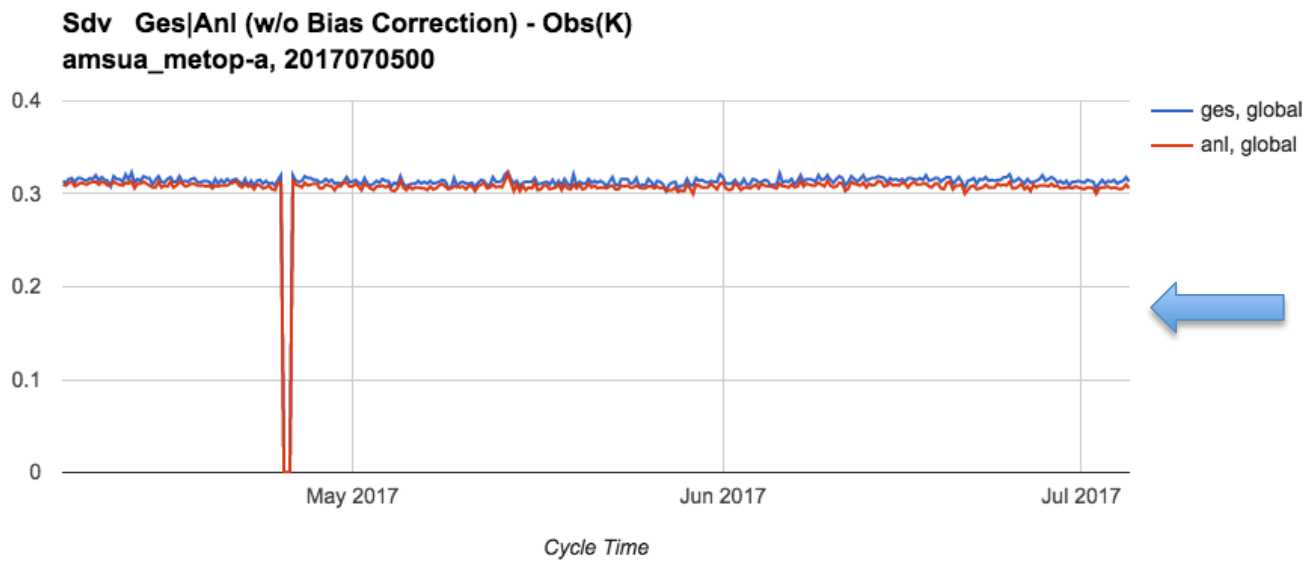
Observed-Guess
Observed-Analysis

Before
Bias Correction

After
Bias Correction



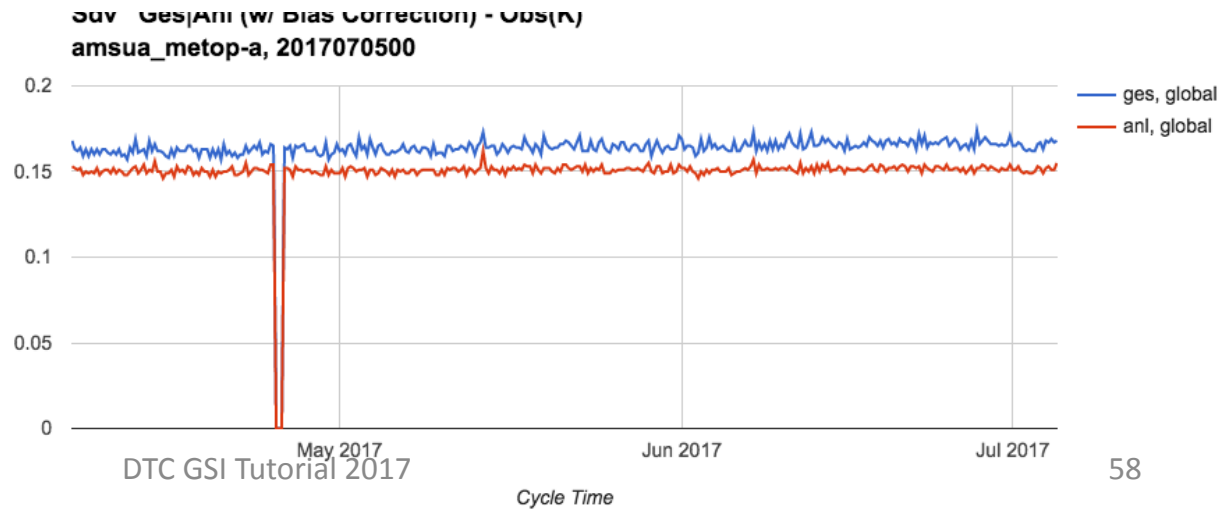
MetOp-A AMSU-A Ch 6 Std Dev of Departures



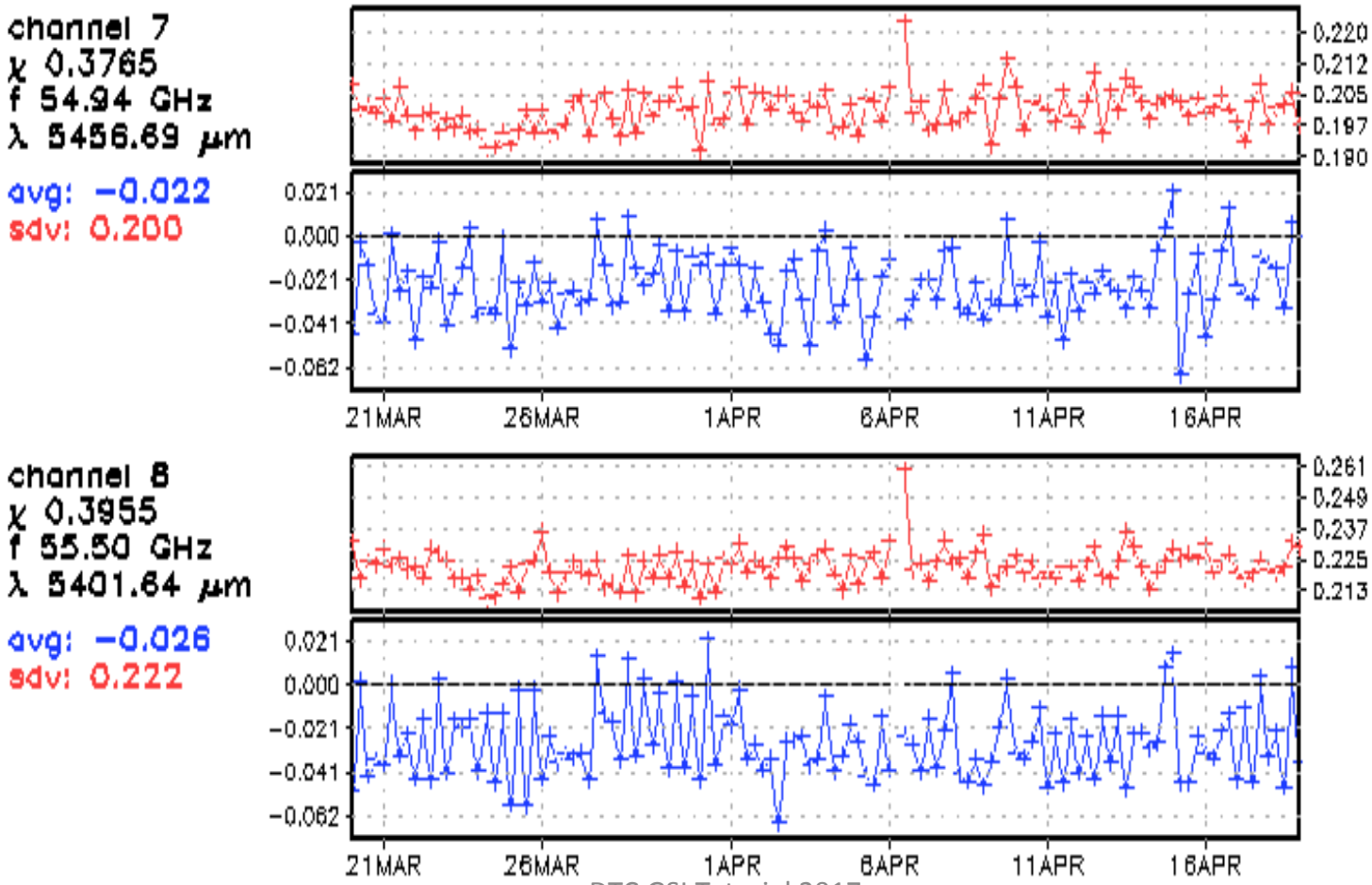
Observed-Guess
Observed-Analysis

Before
Bias Correction

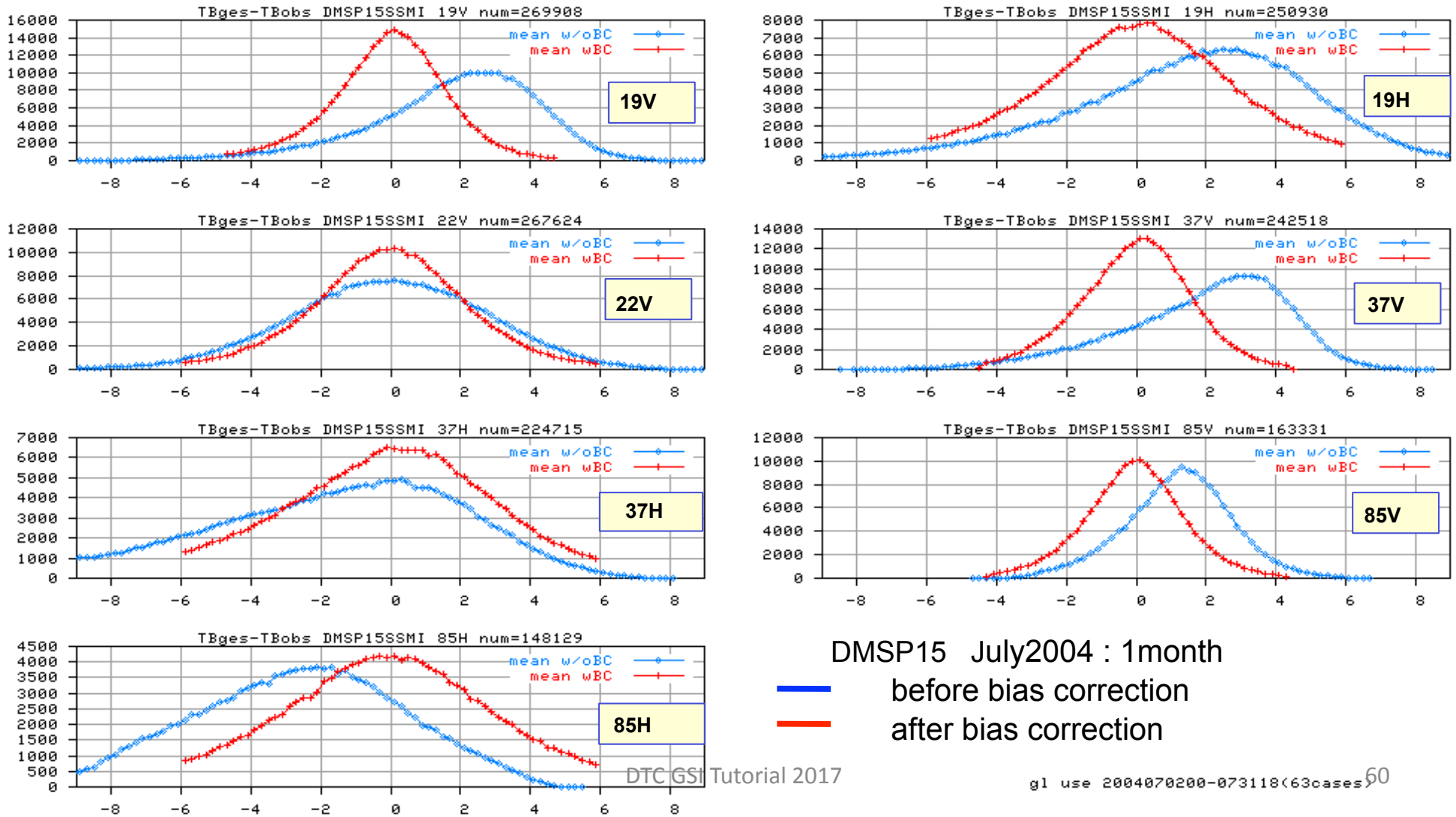
After
Bias Correction



NOAA 18 AMSU-A
Bias Corrected



Observation - Background Histogram



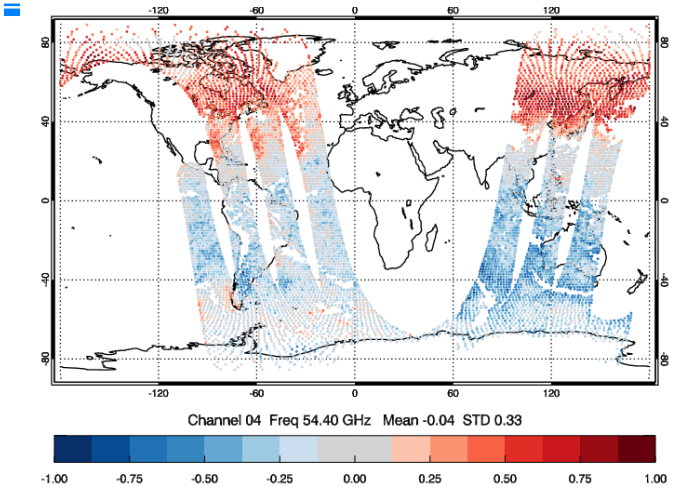
DMSP15 July2004 : 1month

before bias correction

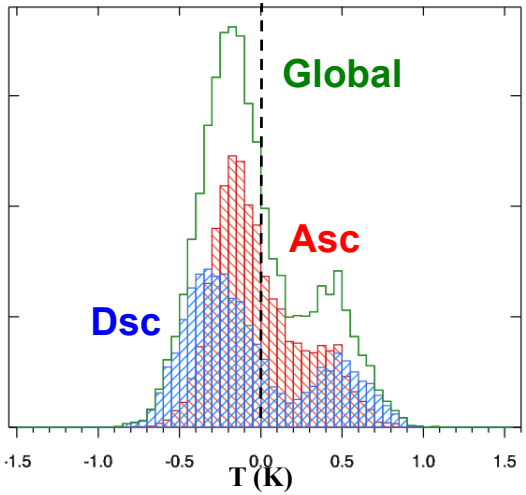
after bias correction

Application of NWP Bias Correction for SSMIS F18

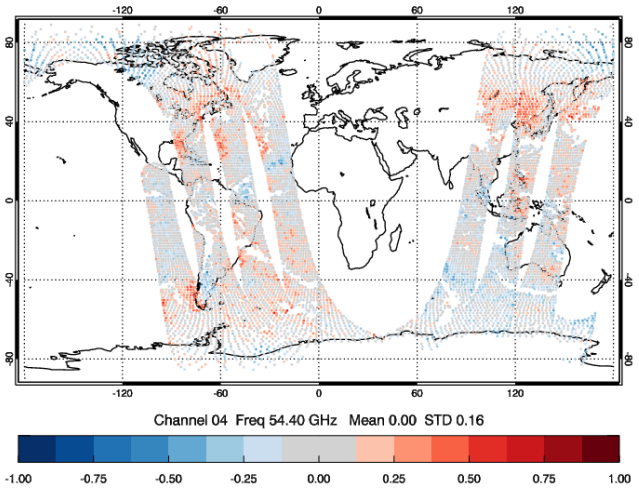
O-B Before Bias Correction



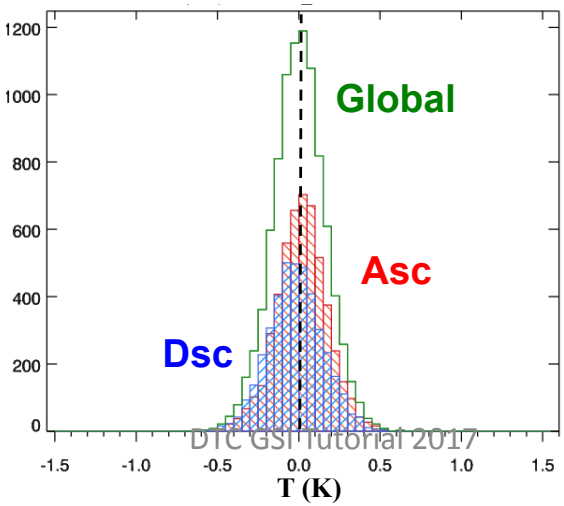
O-B Before Bias Correction



O-B After Bias Correction

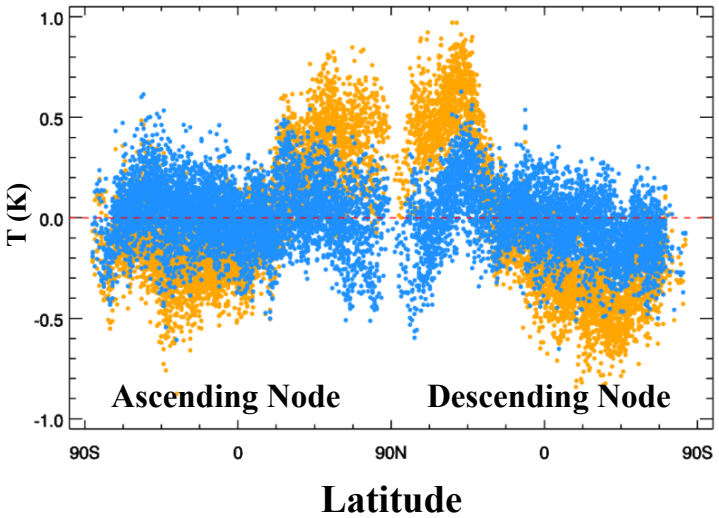


O-B After Bias Correction



Using Met Office SSMIS Bias Correction Predictors

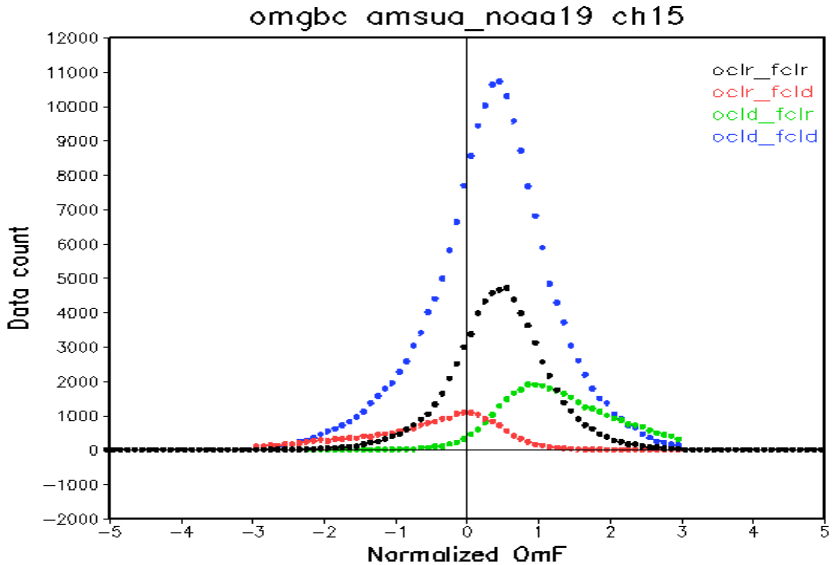
Unbias & Bias Corrected O-B



Observation Sampling in Bias Correction

- An important consideration in calculating bias correction coefficients is the data sample used.
  - A certain subset of the data may have model error that should not be bias corrected
- Strategies could include:
  - Only using observations close to uncorrected observations (radiosondes) that "anchor" the analysis
  - Only use infrared radiances that are considered clear based on sub-FOV imagery
  - Only use observations where the observation and the model agree on whether it is cloudy or not (next slide).

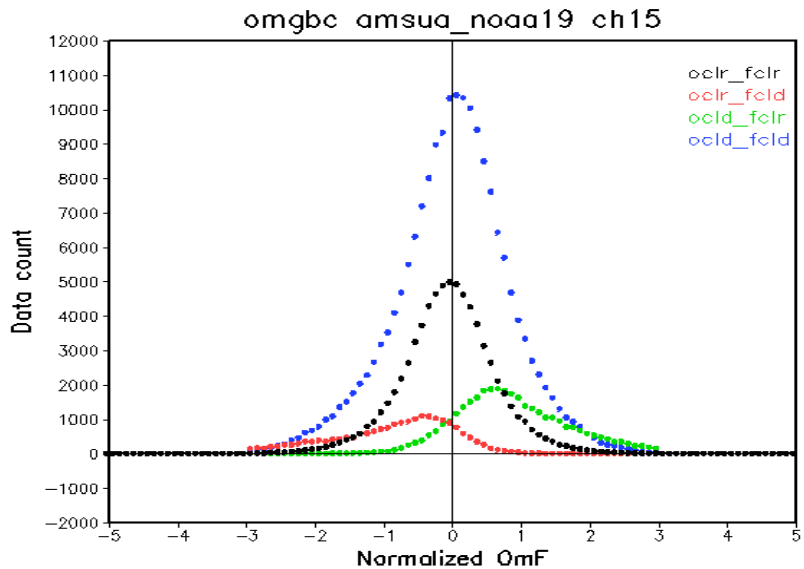
All-sky Radiance Bias Correction (Zhu et al. 2014)



Using all observations

Normalized OmF w/ BC

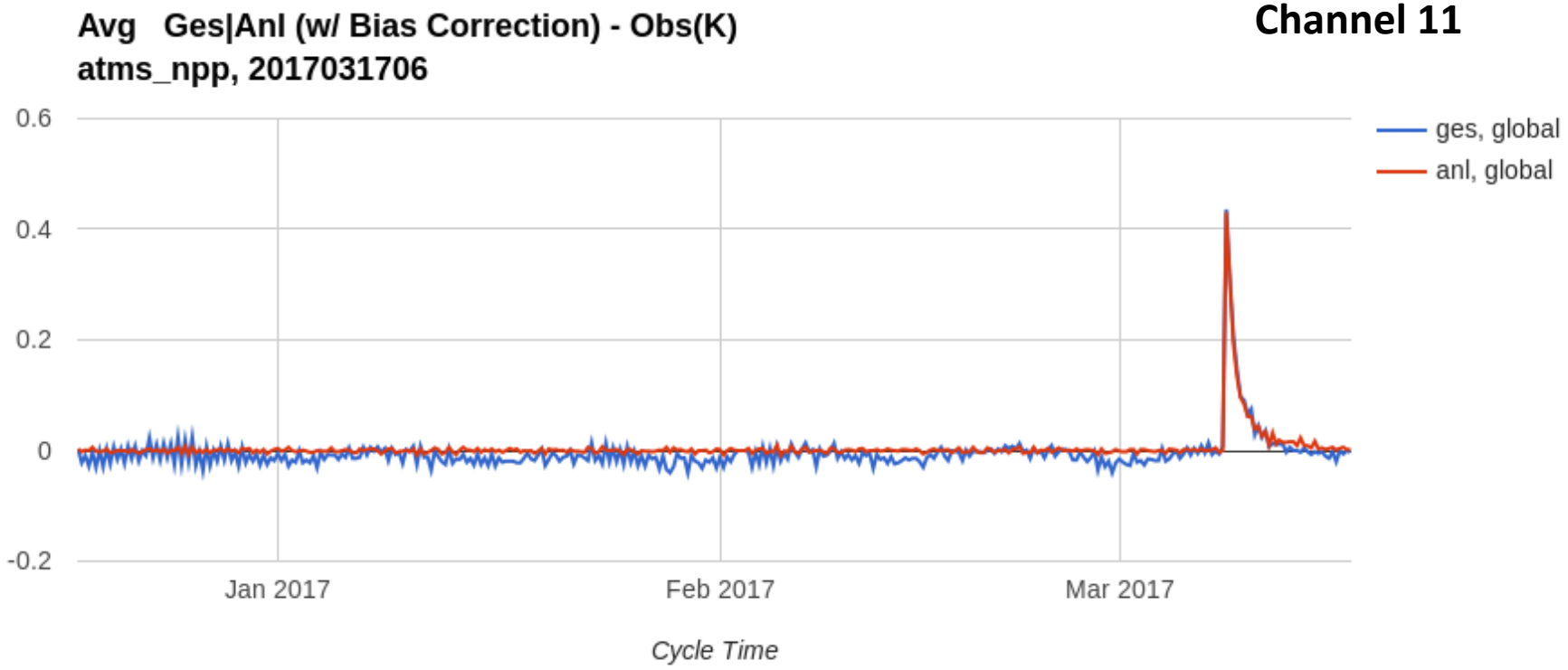
Using observations where cloudiness inferred from observations and model agree



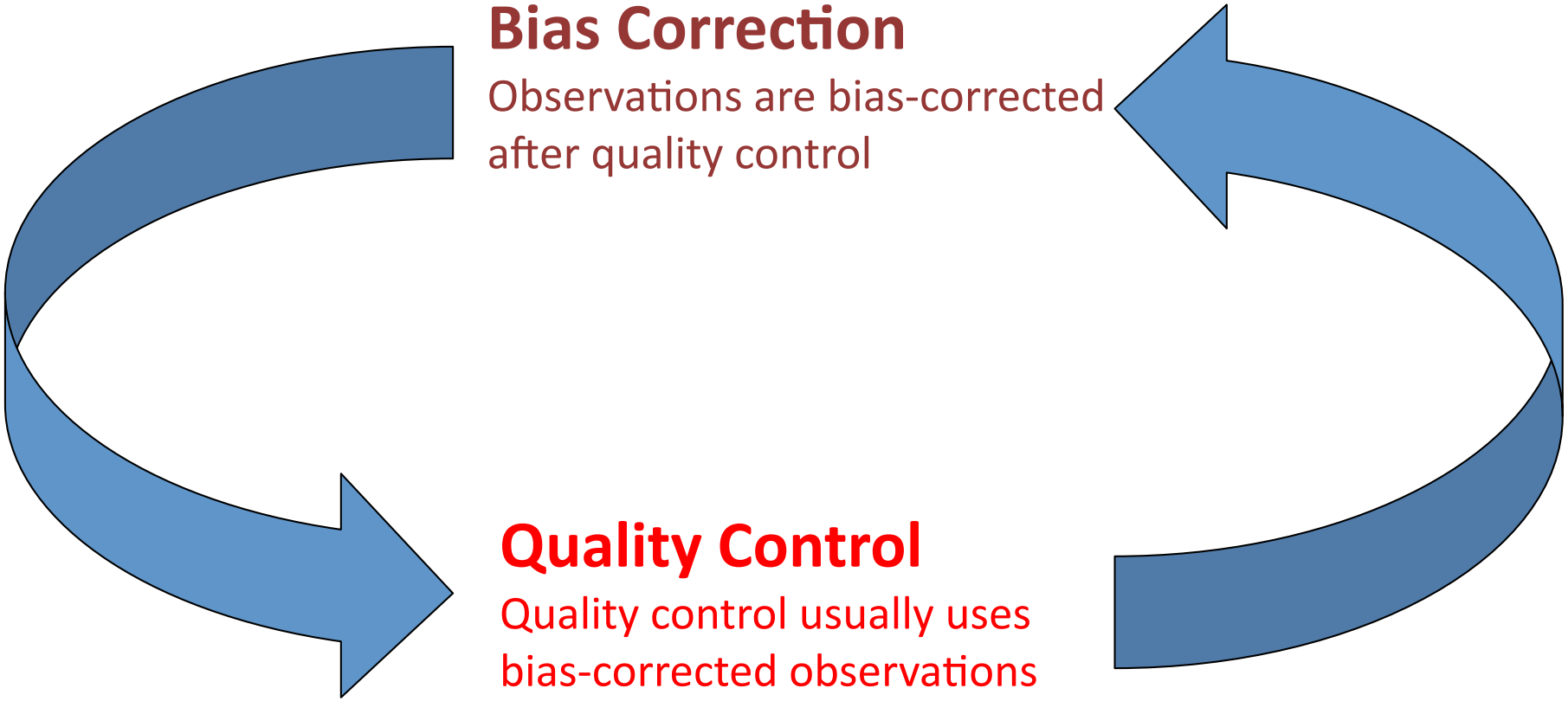
Normalized OmF w/ BC

Variational Bias Correction Adjusts to a Calibration Shift of ATMS

Channel 11



Bias Correction and QC Interact



Assimilating satellite radiances

Observation Errors

Observational Errors

- The observation error is made up of a number of components:
  - Instrument noise
  - Forward model error
    - Including the ability of the quality control to identify cases that the forward model cannot simulate (e.g., clouds)
  - Representivity error
  - Linearity error
- Very often the first guess departure is used as a rough estimate of the observation error
  - This includes model error – which strictly should not be part of the observation error.

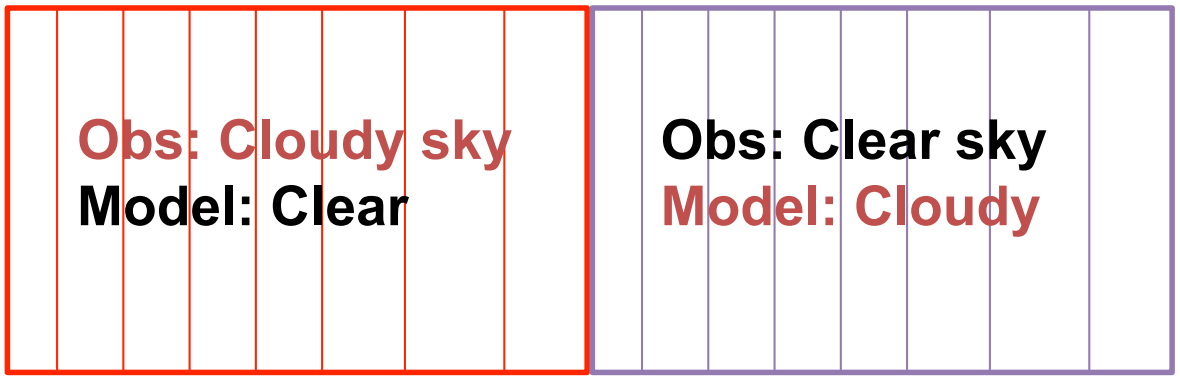
Situational Dependent Errors

- Observation errors are often adjusted within the GSI code to reflect situations where uncertainties are higher:
  - Surface emission over land is less well characterized than over sea
  - Characterization of cloudy scenes is less accurate than for clear sky.

Cloudy Observation Errors

Function of observed cloud or model cloud ?

Geer et al. (2010)



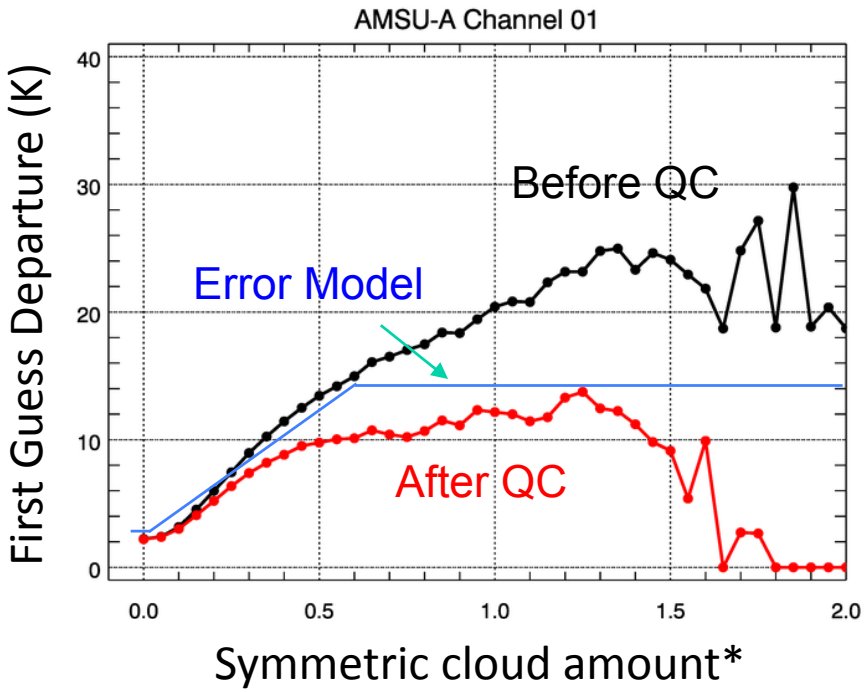
Obs error function of Obs cloud → Large obs errror (Small weight)

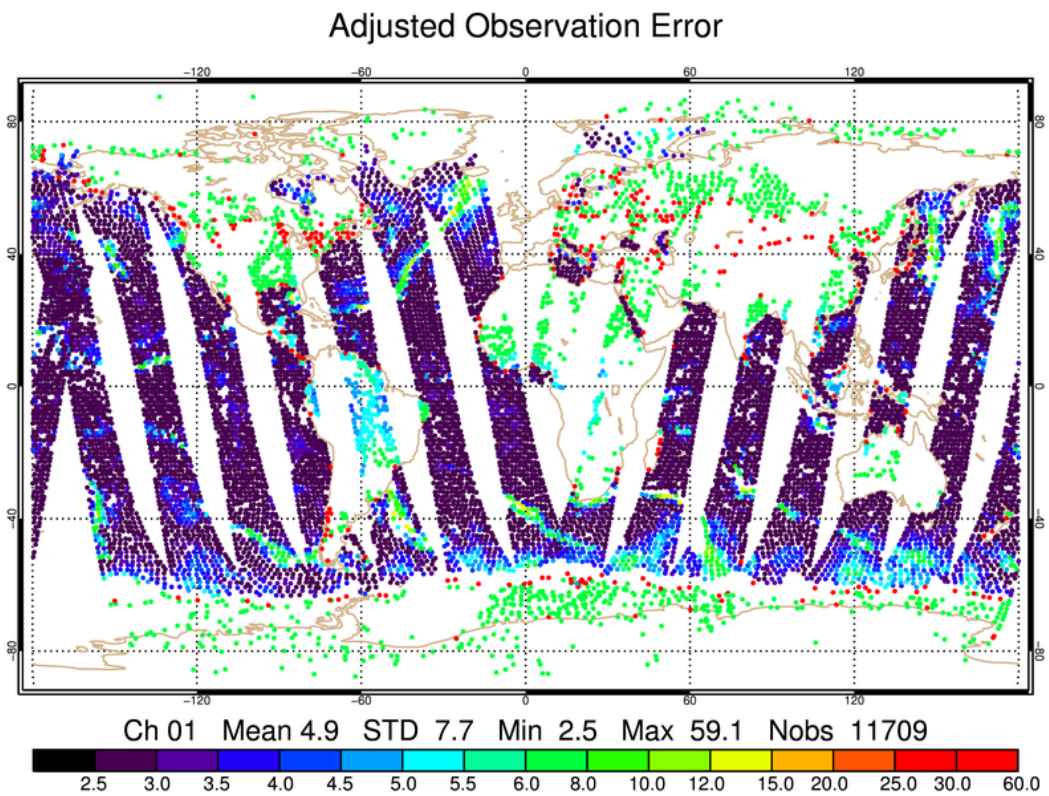
Small obs errror (Large weight) → Dry model atmosphere

Obs error function of Model cloud → Small obs errror (Large weight)

Large obs errror (Small weight) → Moisten model atmosphere

Symmetric Observation Error Assignment for AMSU-A under All-sky Condition





Obs. error used in the analysis

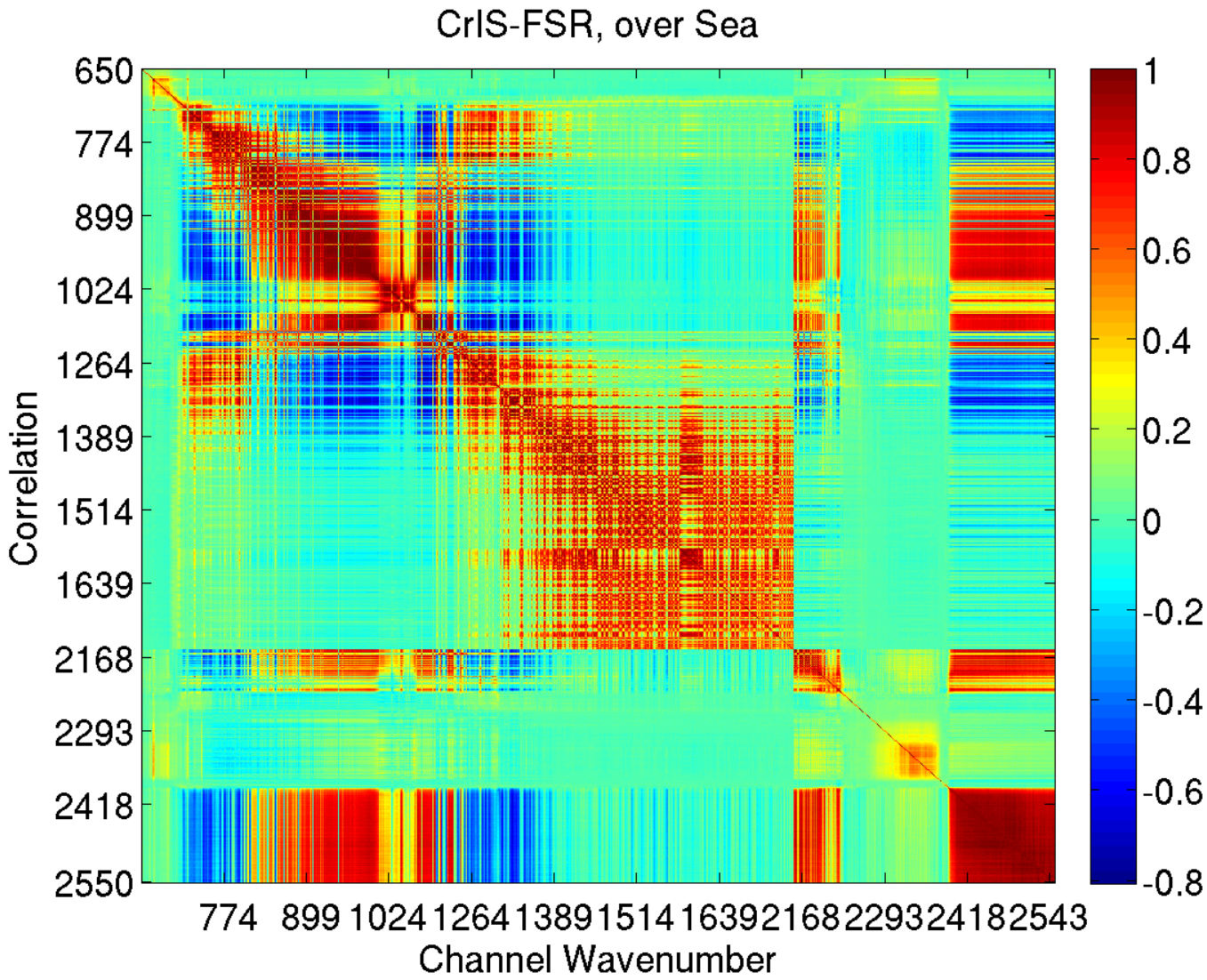
*Mean of cloud derived from model and cloud derived from observations

Correlated Errors

- Observation errors are in general correlated both spectrally and spatially.
- A number of techniques are currently used to empirically determine these errors. The most common are the Hollingsworth-Lönnberg and Desroziers techniques which are well-summarized in Bormann and Bauer (2010)*.
- In the GSI we now have the capability to use spectrally correlated errors.

*Bormann and Bauer (2010), Q.J.R.M.S., **136**: 1036–1050.

CrIS Observation Error Correlation Matrix



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.

Assimilating satellite radiances

Assimilating Radiances in the GSI

GSI Code Flow

Get user input parameters

(resolution, static/hybrid, 3d/4d, constraints, data type, data thinning, … etc)

Get resource files*

anainfo: bkg/anl vars
satinfo : sensor/channel + obs error
locinfo : localization length
…etc

Initialization

*GSI advanced user's guide

Read in and distribute:
Observations
Bkg fields, Bkg errors Radiance bias correction info
Radiance diag. files (opt)

Initialize CRTM observation operator (call int_crtm)

- Sensor/channel spectral information
- Sensor/channel transmittance coefficients for gases
- Spectral coefficients for surface emissivity, cloud and aerosol optical properties

Outer Loop Iteration (glbsoi.f90)
Call setup routines: (e.g., setuprad.f90 for radiance)

- Compute simulated observation and Jacobian with associated observation operator (call_crtm provide h and H for radiance data)
- Compute radiance bias correction predictors
- Compute Hessian of J from radiance bias correction
- Compute observation innovations $d = y_o - h(x) - bias$
- Quality control and adjust obs errors

Call **Inner Loop Iteration** (pcgsoi.f90)

- Compute gradient information $H^T R^{-1} (H\delta x - d)$
- Apply background error (B, L)
- Compute search direction and step size
- Update analysis increment
- Check convergence

Update guess fields
Estimate bias correction coefficients for passive channels

Write output files for analysis, radiance bias correction and obs diagnostic files

Important Input Files For Radiance Assimilation

USER PROVIDED FILES:

- OBS_INPUT namelist: Lists instruments, links to CRTM files, defines thinning etc.
- SATINFO*: Controls channel-by-channel data usage, observation errors quality control
- SCANINFO: Defines relation between scan position and scan angle plus usage at scan edges
- ANAVINFO: Defines state and control variables and their use within the CRTM.
- cloudy_radiance_info.txt*: Additional information of cloudy radiance observation error model.

FILES UPDATED BY THE GSI:

- SATBIAS: Contains bias-correction coefficients
- SATBIAS_PC: Preconditioning information for bias correction
- SATANGBIAS: Scan-dependent bias correction file if this is done offline (a depreciated feature in NCEP DA)

*There has been a restructuring of the way radiance assimilation is being done resulting in modifications to some files and addition of extra ones. The current release of the DTC GSI does not include these changes.

OBS_INPUT namelist

```
 &OBS_INPUT
   dmesh(1)=145.0,dmesh(2)=150.0,dmesh(3)=100.0,time_window_max=3.0,
   $OBSINPUT
 /
OBS_INPUT::
!  dfile          dtype       dplat       dsis                dval dthin dsfcalc
 ....
   hirs3bufr      hirs3       n17         hirs3_n17            0.0     1      0
   hirs4bufr      hirs4       metop-a     hirs4_metop-a        0.0     1      1
   gimgrbufr      goes_img    g11         imgr_g11             0.0     1      0
   airsbufr       airs        aqua        airs_aqua            0.0     1      1
   amsuabufr      amsua       n15         amsua_n15            0.0     1      1
   amsuabufr      amsua       n18         amsua_n18            0.0     1      1
   amsuabufr      amsua       metop-a     amsua_metop-a        0.0     1      1
   airsbufr       amsua       aqua        amsua_aqua           0.0     1      1
   amsubbufr      amsub       n17         amsub_n17            0.0     1      1
   mhsbufr        mhs         n18         mhs_n18              0.0     1      1
   mhsbufr        mhs         metop-a     mhs_metop-a          0.0     1      1
```

satinfo: old configuration

!sensor/instr/sat	chan	iuse	error	error_cld	ermax	var_b	var_pg	icld_det
amsua_n15	7	1	0.250	0.250	2.000	10.000	0.000	-2
amsua_n15	8	1	0.275	0.275	2.000	10.000	0.000	-2
amsua_n15	9	1	0.340	0.340	2.000	10.000	0.000	-2
amsua_n15	10	1	0.400	0.400	2.000	10.000	0.000	-2
amsua_n15	11	-1	0.600	0.600	2.500	10.000	0.000	-2
amsua_n15	12	1	1.000	1.000	3.500	10.000	0.000	-2
amsua_n15	13	1	1.500	1.500	4.500	10.000	0.000	-2
amsua_n15	14	-1	2.000	2.000	4.500	10.000	0.000	-2
amsua_n15	15	1	3.500	15.000	4.500	10.000	0.000	-2
hirs3_n17	1	-1	2.000	0.000	4.500	10.000	0.000	-1
hirs3_n17	2	-1	0.600	0.000	2.500	10.000	0.000	1
hirs3_n17	3	-1	0.530	0.000	2.500	10.000	0.000	1

satinfo: new configuration

!sensor/instr/sat	chan	iuse	error	error_cld	ermax	var_b	var_pg	icld_det	icloud	iaerosol
amsua_n15	7	1	0.250	0.250	2.000	10.000	0.000	-2	1	-1
amsua_n15	8	1	0.275	0.275	2.000	10.000	0.000	-2	1	-1
amsua_n15	9	1	0.340	0.340	2.000	10.000	0.000	-2	1	-1
amsua_n15	10	1	0.400	0.400	2.000	10.000	0.000	-2	1	-1
amsua_n15	11	-1	0.600	0.600	2.500	10.000	0.000	-2	1	-1
amsua_n15	12	1	1.000	1.000	3.500	10.000	0.000	-2	1	-1
amsua_n15	13	1	1.500	1.500	4.500	10.000	0.000	-2	1	-1
amsua_n15	14	-1	2.000	2.000	4.500	10.000	0.000	-2	1	-1
amsua_n15	15	1	3.500	15.000	4.500	10.000	0.000	-2	1	-1
hirs3_n17	1	-1	2.000	0.000	4.500	10.000	0.000	-1	-1	-1
hirs3_n17	2	-1	0.600	0.000	2.500	10.000	0.000	1	-1	-1
hirs3_n17	3	-1	0.530	0.000	2.500	10.000	0.000	1	-1	-1

-1: not use cloud/aerosol info;
0: include cloud/aerosol in forward obs operator;
1: cloud/aerosol analysis

All or some channels of a sensor can be activated for all-sky radiance assimilation

cloudy_radiance_info.txt (new)

```
radiance_mod_instr_input::
!obsname    obsloc    ex_obserr  ex_biascor  cld_effect
 amsua      sea       .true.     .true.      .true.
::

obs_amsua::
!  Parameters for the observation error model
!  cclr [kg/m2] & ccld [kg/m2]: range of cloud amounts
!  over which the main increase in error take place
!  ch   cclr   ccld
   1   0.050  0.600
   2   0.030  0.450
   3   0.030  0.400
   4   0.020  0.450
   5   0.000  1.000
   6   0.100  1.500
  15   0.030  0.200
::
```

Extra parameters used for the observation error model

Anavinfo

```
met_guess::
!var    level   crtm_use   desc              orig_name
 ps      1      -1         surface_pressure     ps
 z       1      -1         geopotential_height  phis
 u      64       2         zonal_wind           u
 v      64       2         meridional_wind      v
 div    64      -1         zonal_wind           div
 vor    64      -1         meridional_wind      vor
 tv     64       2         virtual_temperature  tv
 q      64       2         specific_humidity    sphu
 oz     64       2         ozone                ozone
 cw     64      10         cloud_condensate     cw
 ql     64      12         cloud_liquid         ql
 qi     64      12         cloud_ice            qi
::
```

```
control_vector::
!var    level  itracer as/tsfc_sdv  an_amp0   source  funcof
 sf      64     0      0.60        -1.0     state    u,v
 vp      64     0      0.60        -1.0     state    u,v
 ps       1     0      0.75        -1.0     state    prse
 t       64     0      0.75        -1.0     state    tv
 q       64     1      0.75        -1.0     state    q
 oz      64     1      0.75        -1.0     state    oz
 sst      1     0      1.00        -1.0     state    sst
 cw      64     1      1.00        -1.0     state    cw
 stl      1     0      3.00        -1.0     motley   sst
 sti      1     0      3.00        -1.0     motley   sst
::
```

crtm_use:

<0: general variable; not used in CRTM

0: general variable; use prescribed global mean data to affect CRTM

1: use gfs yearly global annual mean historical value

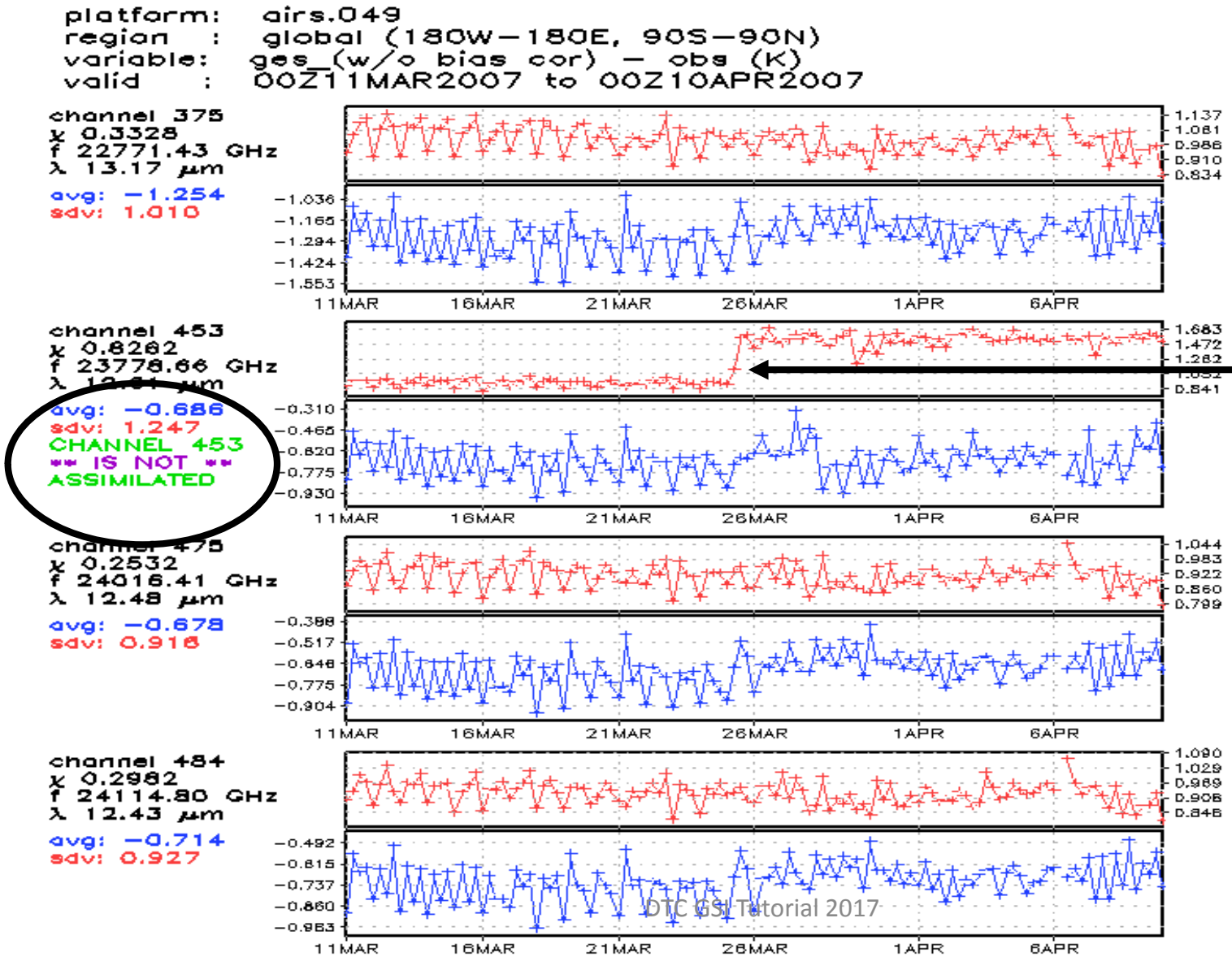
>1: use gfs 3d background field (in interval [10,20) indicates cloud)

Data Monitoring

- It is essential to have good data monitoring.
- Usually the NWP centres see problems with instruments prior to notification by provider.
- The data monitoring can also show problems with assimilation systems.
- Needs to be ongoing/real time.
- Monitoring reports from most major NWP centers at: https://nwpsaf.eu/site/monitoring/
- NCEP data monitoring is at: http://www.emc.ncep.noaa.gov/gmb/gdas/

Quality Monitoring of Satellite Data

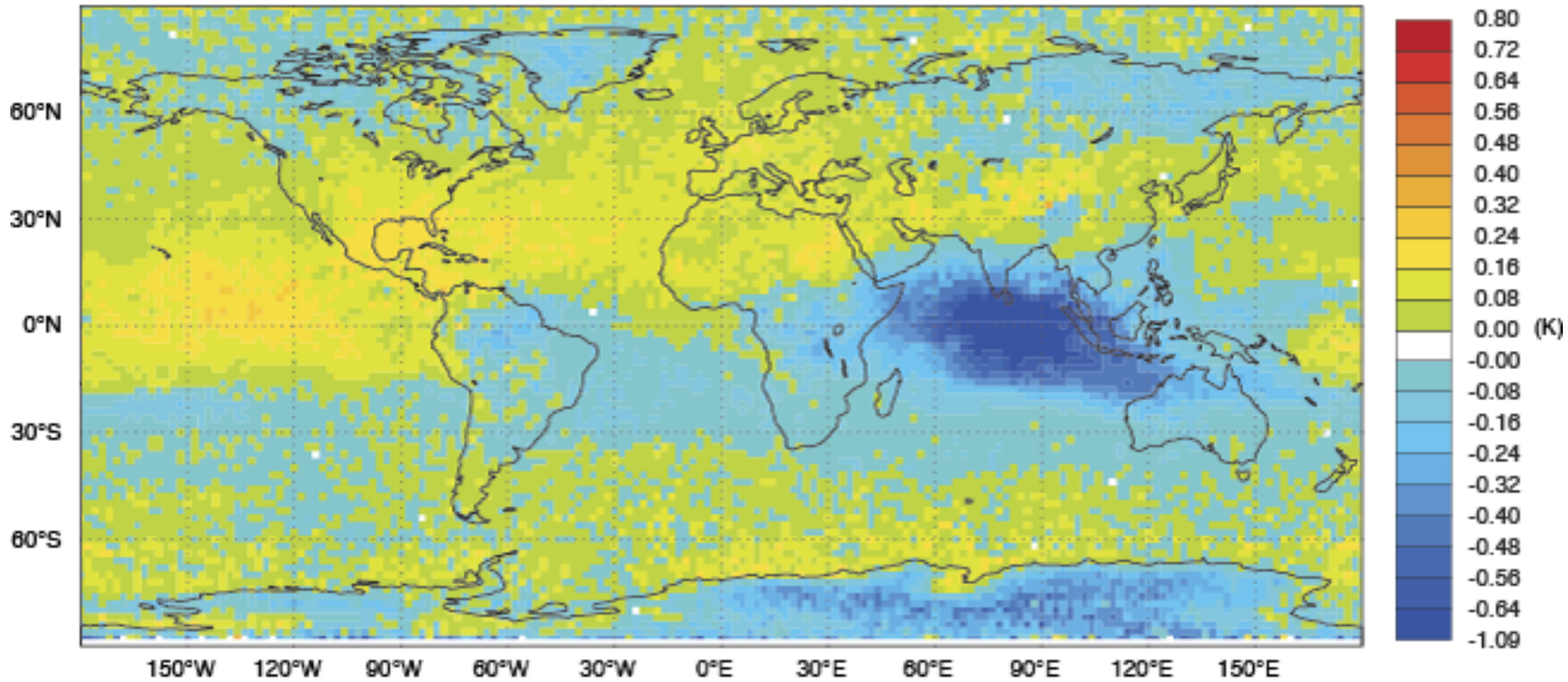
AIRS Channel 453 26 March 2007



Increase in SD Fits to Guess

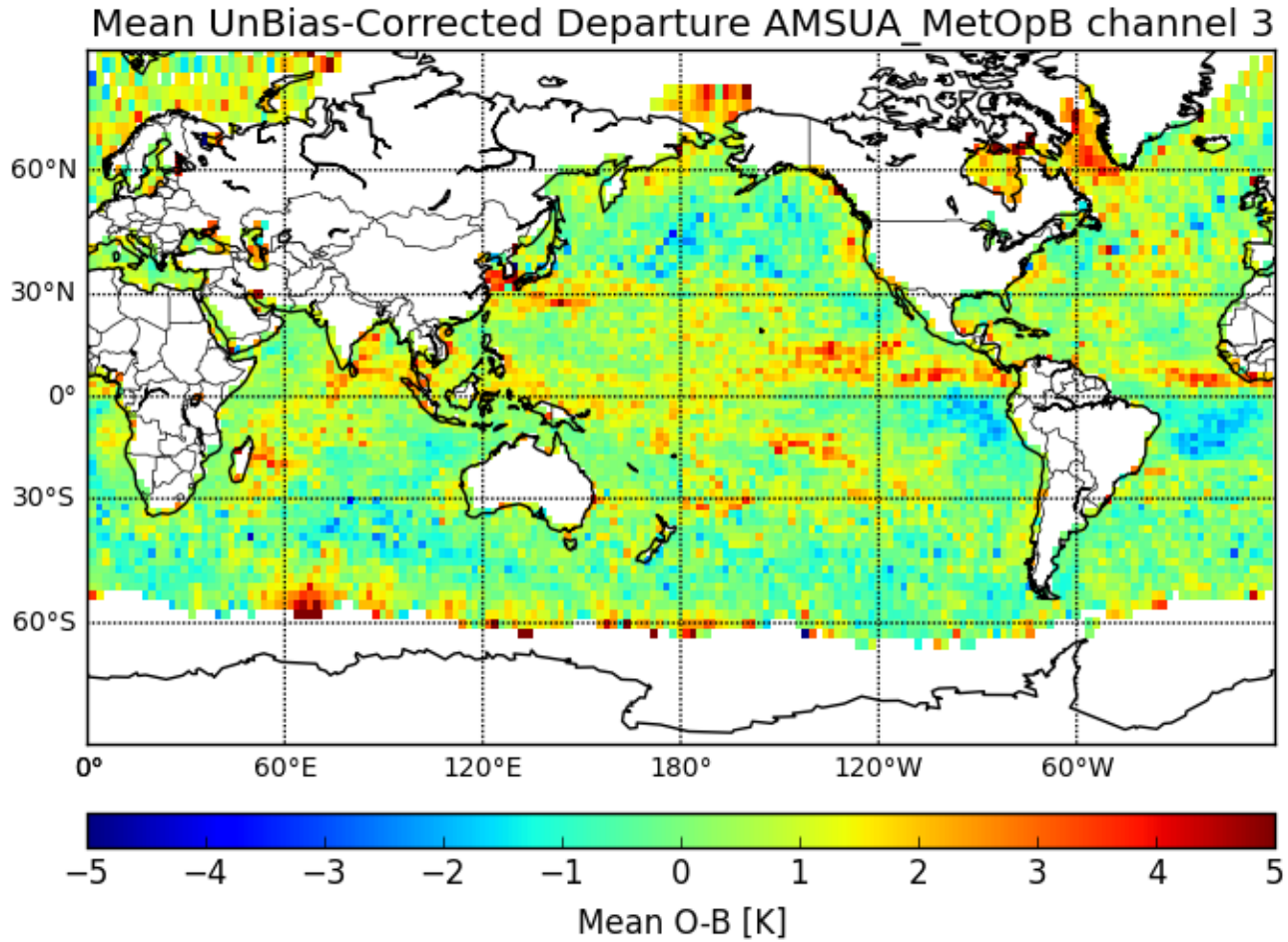
Unexpected HCN Signal

First guess departure at *713 cm*$^{-1}$



Maps of Mean First-Guess Departure …

… can help identify where the model or the radiative transfer are introducing biases.



Some Final 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?