

TRAINING
COURSE

The assimilation of satellite radiance observations

Tony McNally

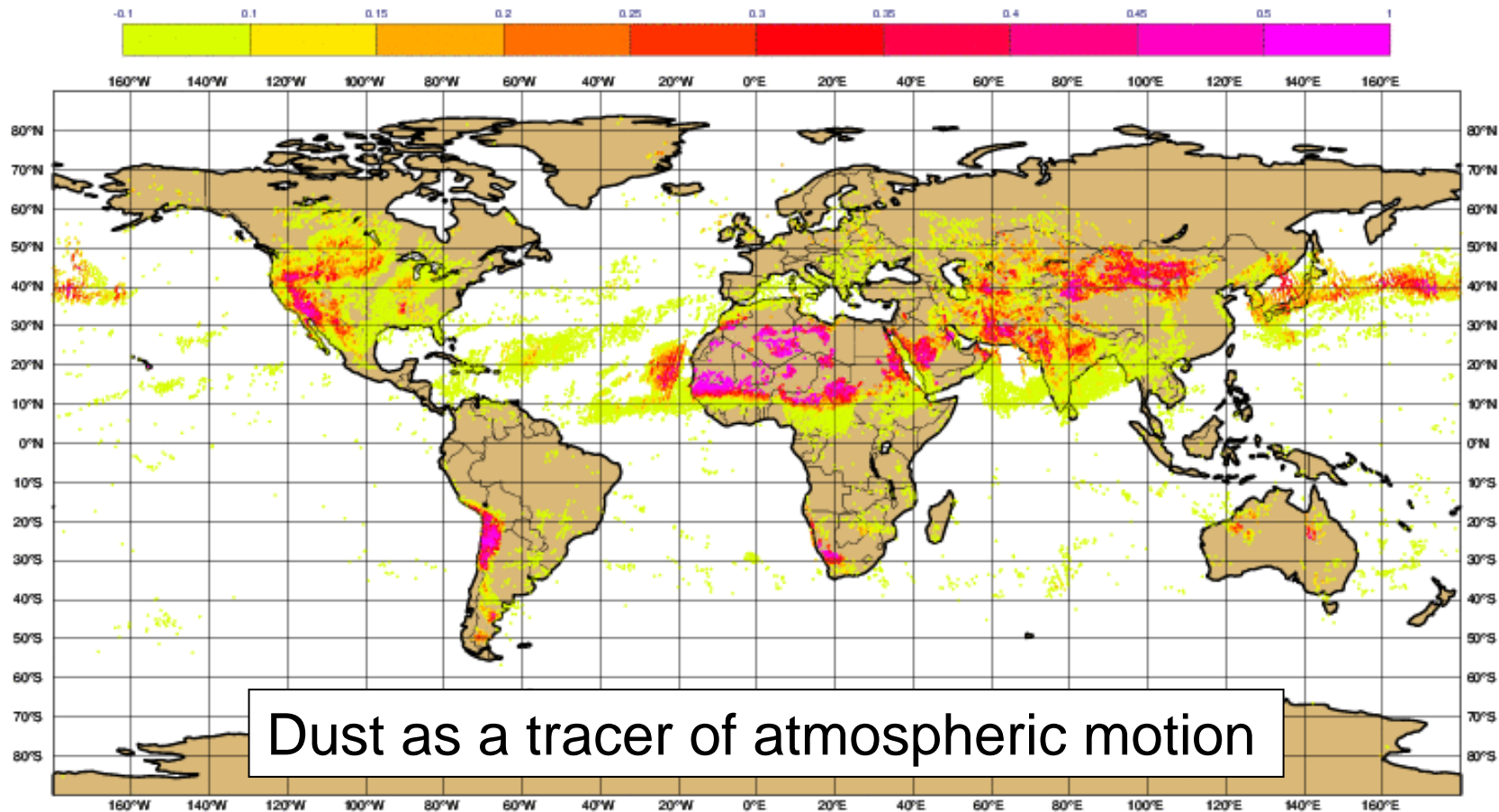


Overview:

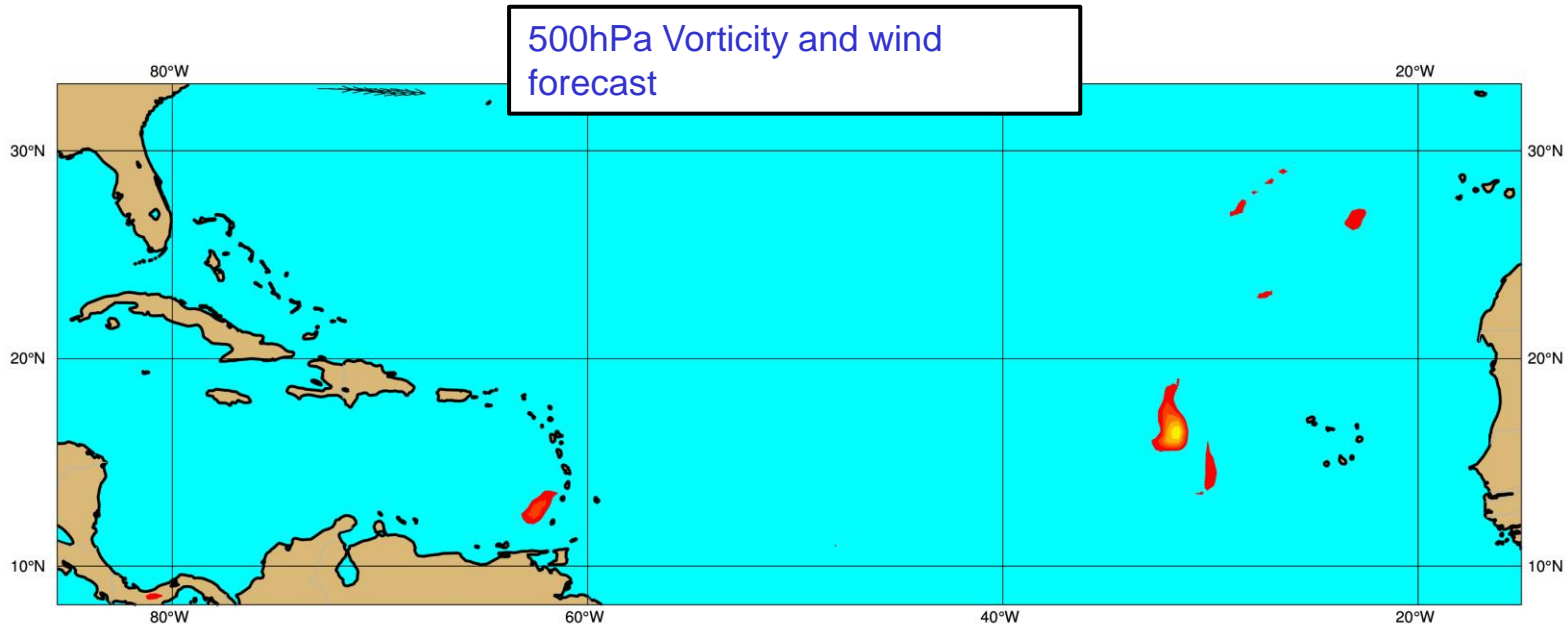
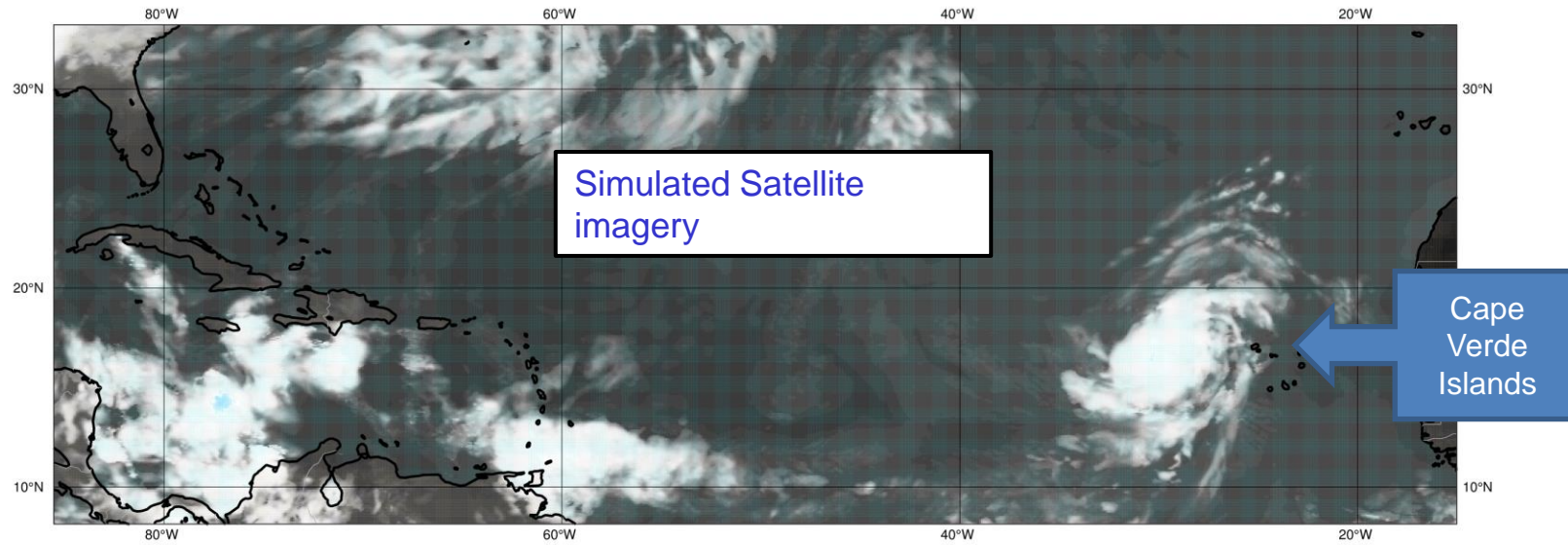
- **Why do we need satellites ?**
- **What do we have and which are most important ?**
- **What is actually measured ?**
- **Key elements of satellite data assimilation**

Why do we need satellites ?

To forecast many days in to the future we need a global picture of the current atmospheric state...

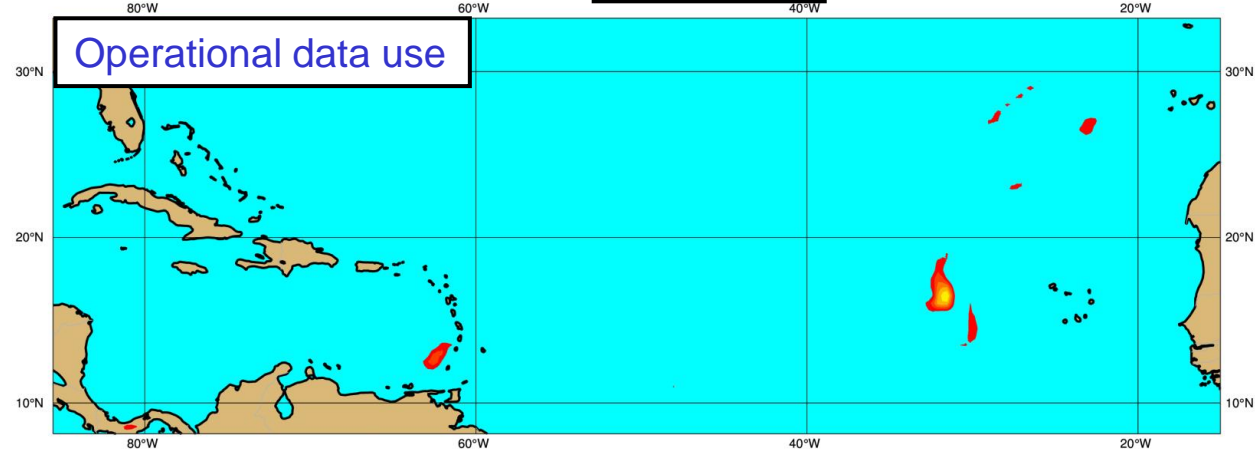


Wednesday 30 August 2017 12 UTC ecmf t+0 VT:Wednesday 30 August 2017 12 UTC surface Cloudy brightness temperature



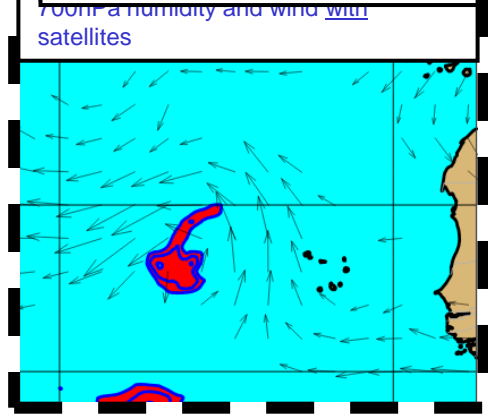
Thursday 31 August 2017 00 UTC ecmf 500 hPa Vorticity (relative)
Thursday 31 August 2017 00 UTC ecmf 500 hPa U component of wind/V component of wind

FORECAST



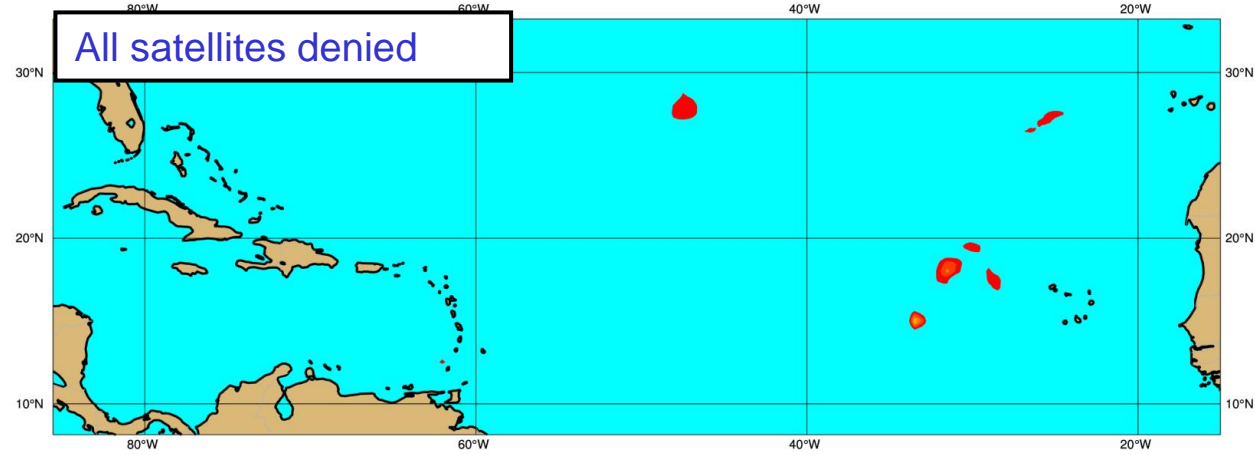
Thursday 31 August 2017 00 UTC ecmf 500 hPa Vorticity (relative)
Thursday 31 August 2017 00 UTC ecmf 500 hPa U component of wind/V component of wind
gt0v

INITIAL CONDITIONS 31/8
00z

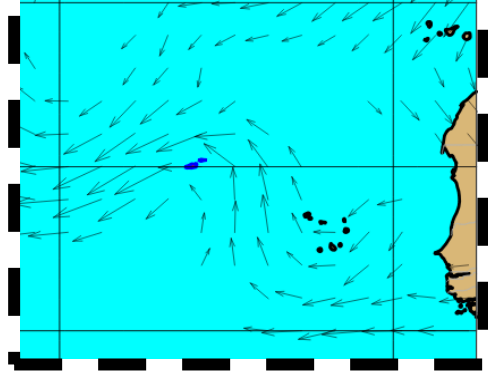


Red shading humidity > 95%

All satellites denied



700hPa humidity and wind without satellites



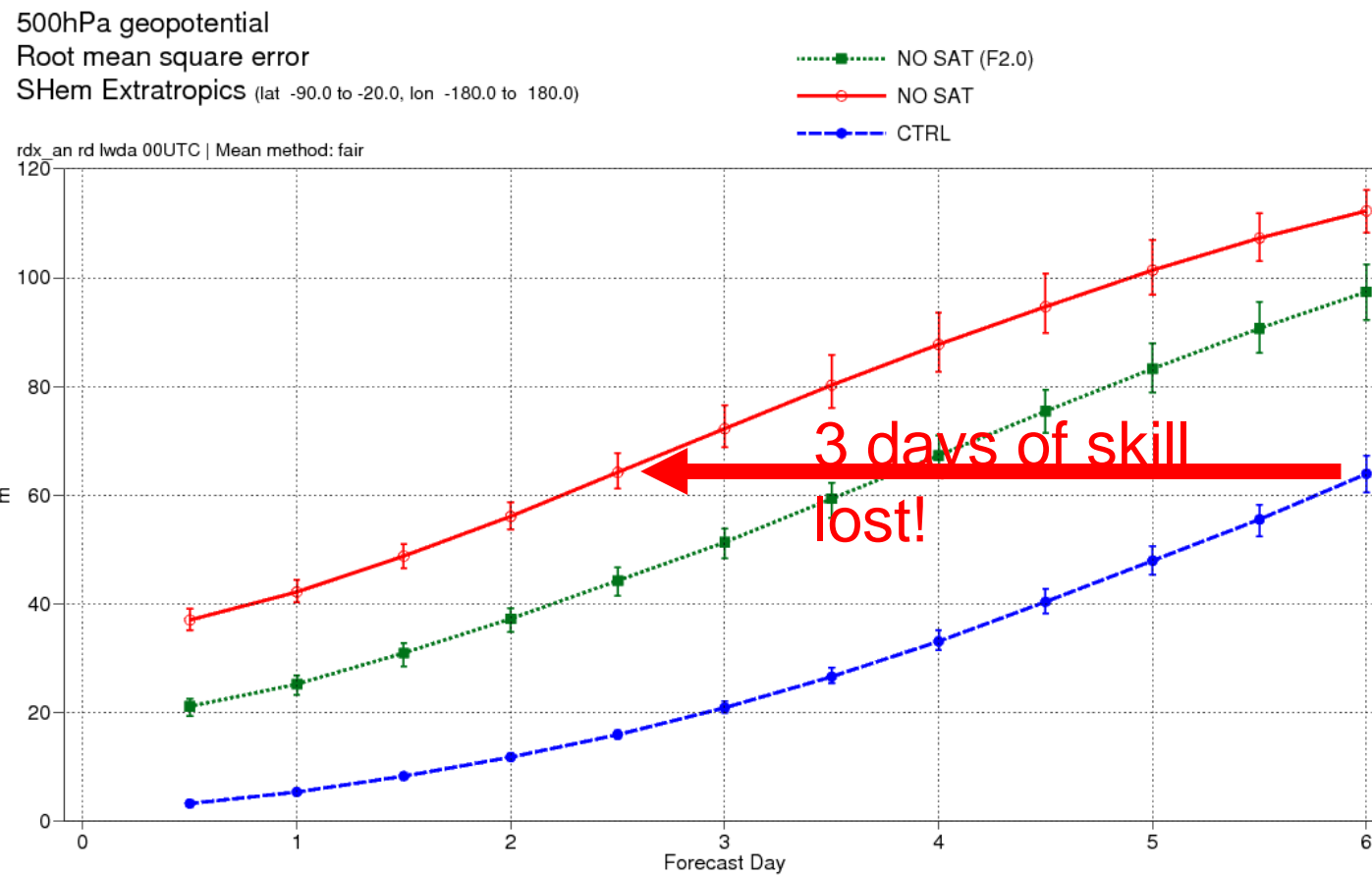
**Can we quantify how important
are satellites for NWP ?**

...denial experiments...

Can we quantify how important are satellites for NWP ?



Can we quantify how important are satellites are for NWP ?



Satellites used for NWP at ECMWF

OB TYPE	Satellite / sensors	EUROPE	USA	ASIA
Atmospheric Motion Vectors	METOP A,B,C,DUAL (AVHRR) METEOSAT 8,11 (SEVIRI) HIMAWARI 8 (AHI) NPP, NOAA 20 (VIIRS) NOAA 15,18,19 (AVHRR) GOES 15,16 (I/ABI) AQUA (MODIS)	METOP A,B,C + DUAL (AVHRR) METEOSAT 8,11 (SEVIRI)	NPP, NOAA 20 (VIIRS) NOAA 15,18,19 (AVHRR) AQUA (MODIS) GOES 15,16, 17, 18 (ABI)	HIMAWARI 8, 9 (AHI)
Atmospheric Sounding Radiances	METOP A,B,C (AMSU/MHS/IASI) NPP, NOAA 20 (ATMS/CrIS) NOAA 15,18,19 (AMSU/MHS) AQUA (AMSUA/AIRS) FY3-B,C,D (MWHS/MWHS2) METEOSAT 9,11 (SEVIRI) HIMAWARI 8 (AHI) GOES 15,16, 17,18 (I/ABI) GCOM-W (AMSR-2) GPM (GMI) DMSP 17,18 (SSM/IS)	METOP B,C (AMSU/MHS/IASI) METEOSAT 8,11 (SEVIRI)	NPP, NOAA 20 (ATMS/CrIS) NOAA 15,18,19 (AMSU/MHS) AQUA (AMSUA/AIRS) GOES 15,16, 17, 18 (I/ABI) DMSP 17,18 (SSM/IS)	FY3-C,D,E (MWHS/MWHS2/MWRI) HIMAWARI 8, 9 (AHI) GCOM-W (AMSR-2)
GNSS-RO	METOP B,C (GRAS) COSMIC2 Spire (2020) TERRASAR / TANDEM FY3 (GNOS) KOMPSAT5 (GNOS)	METOP A,B,C (GRAS) TERRASAR / TANDEM SPIRE (commercial)	COSMIC2	FY3 (GNOS) KOMPSAT5
SCAT / ALT	METOP B,C(ASCAT) / JASON3 / AltiKA / S3A/B / Cry2	METOP A,B,C (ASCAT) / JASON3 / JASON3 / AltiKA / S3A/B / CRY2		
Doppler Wind Lidar	Aeolus	Aeolus		

Plus many others used for COPERNICUS Atmospheric composition and climate services

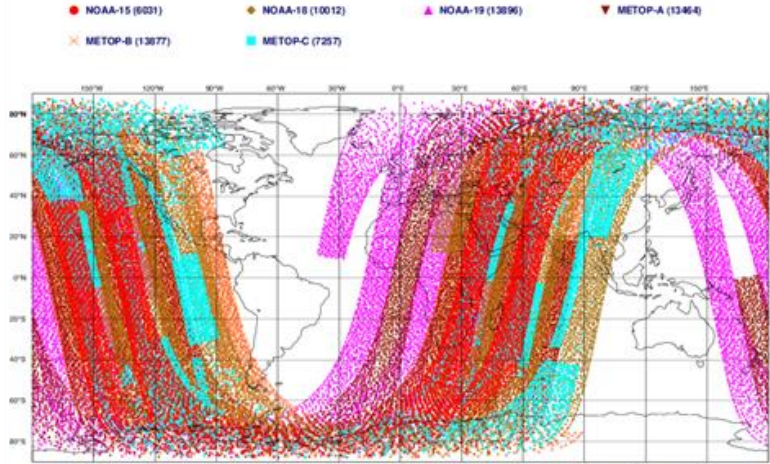
Split by sensor technology...

OB TYPE	Satellite / sensors
Atmospheric Motion Vectors	METOP A,B,C,DUAL (AVHRR) METEOSAT 8,11 (SEVIRI) HIMAWARI 8 (AHI) NPP, NOAA 20 (VIIRS) NOAA 15,18,19 (AVHRR) GOES 15,16 (IABI) AQUA (MODIS)
Atmospheric Sounding Radiances	METOP A,B,C (AMSU/MHS/IASI) NPP, NOAA 20 (ATMS/CrIS) NOAA 15,18,19 (AMSU/MHS) AQUA (AMSUA/AIRS) FY3-B,C,D (MWHS/MWHS2) METEOSAT 8,11 (SEVIRI) HIMAWARI 8 (AHI) GOES 15,16 (IABI) GCOM-W (AMSR-2) GPM (GMI) DMSP 17,18 (SSM/IS)
GNSS-RO	METOP A,B,C (GRAS) COSMIC2 Spire (2020) TERRASAR / TANDEM FY3 (GNOS) KOMPSAT5 (GNOS)
SCAT / ALT	METOPA,B,C(ASCAT) / Saral JASON3 / AltiKA / S3A/B / Cry2
Doppler Wind Lidar	Aeolus

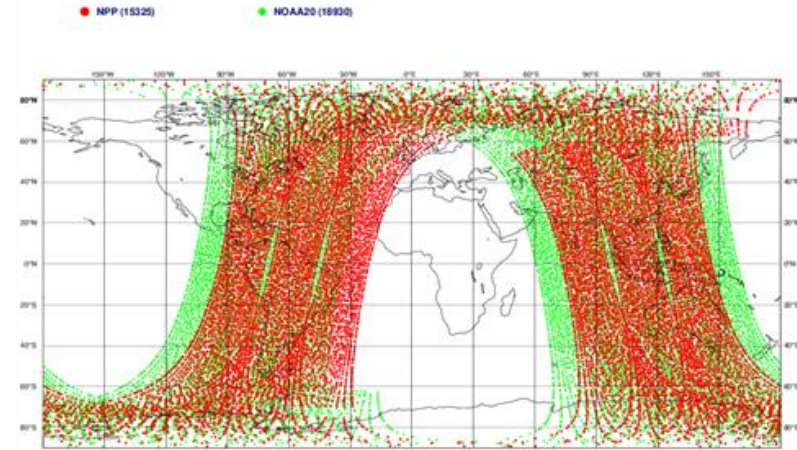
Sensor technology	Processing route
Passive microwave	L1 Radiances
Passive infrared	L1 Radiances / AMV
Radio occultation	Bending angles
SCAT / Altimeter	L2 wind / SLA / SWH
Doppler wind lidar	L2 LOS wind

Passive microwave (LEO)

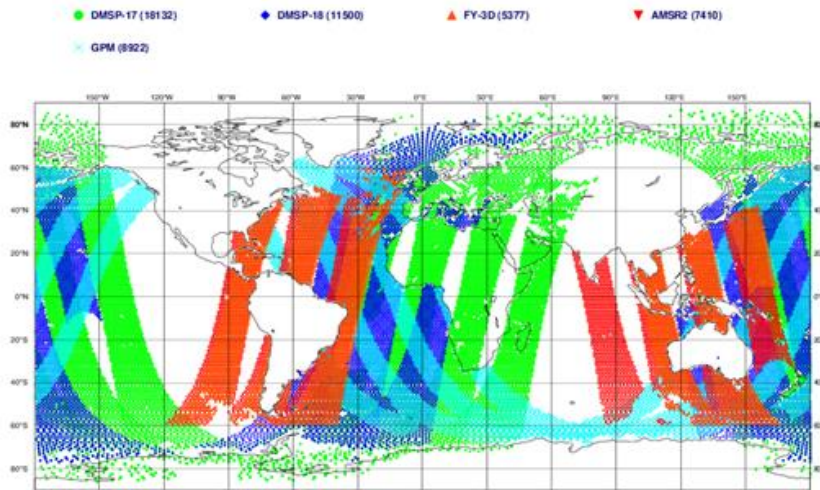
ECMWF data coverage (used observations) - AMSUA
 2021021703 to 2021021709
 Total number of obs = 64537



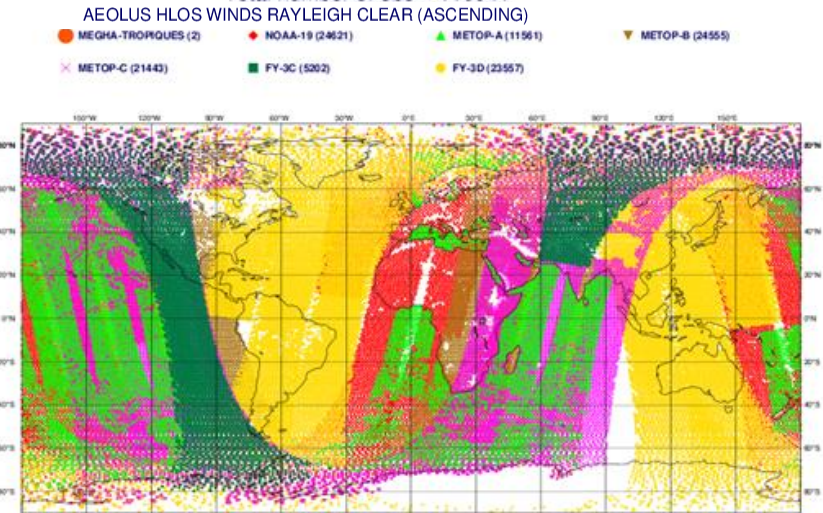
ECMWF data coverage (used observations) - ATMS
 2021021703 to 2021021709
 Total number of obs = 34255



ECMWF data coverage (used observations) - MICROWAVE HUMIDITY IMAGERS
 2021021703 to 2021021709
 Total number of obs = 51341

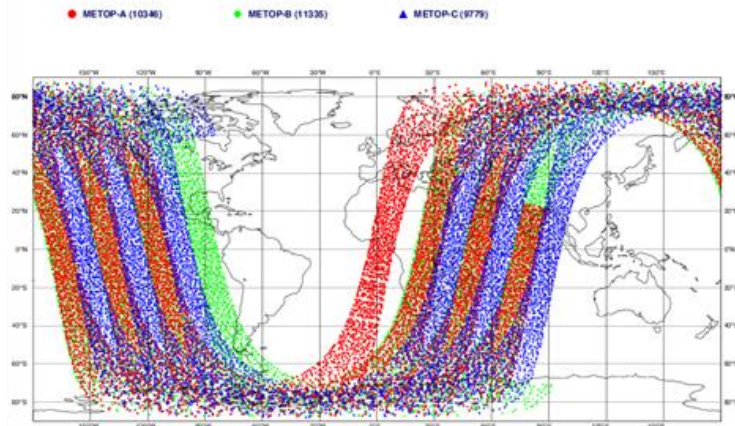


ECMWF data coverage (used observations) - MICROWAVE HUMIDITY SOUNDERS
 2021021703 to 2021021709
 Total number of obs = 110941

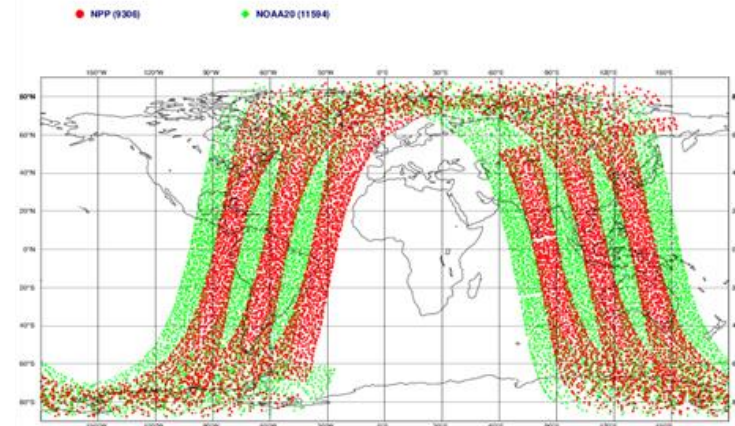


Passive infrared (LEO and GEO)

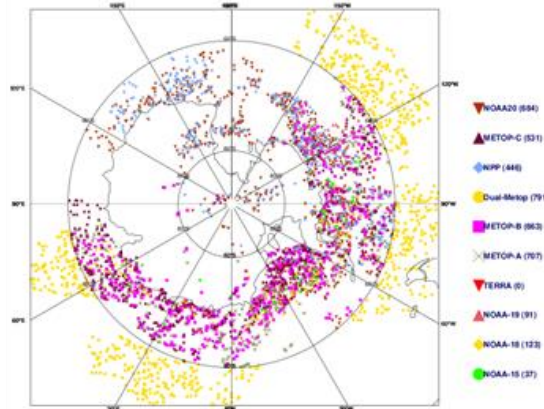
ECMWF data coverage (used observations) - IASI
2021021703 to 2021021709
Total number of obs = 31460



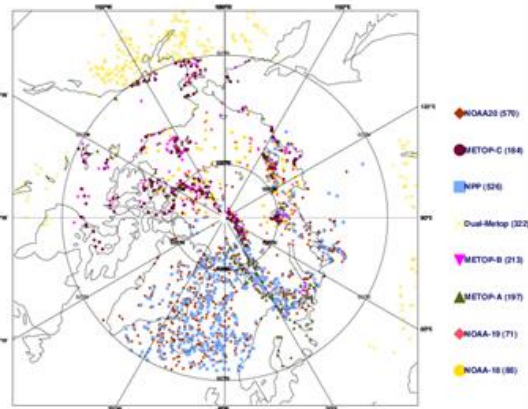
ECMWF data coverage (used observations) - CRIS
2021021703 to 2021021709
Total number of obs = 20900



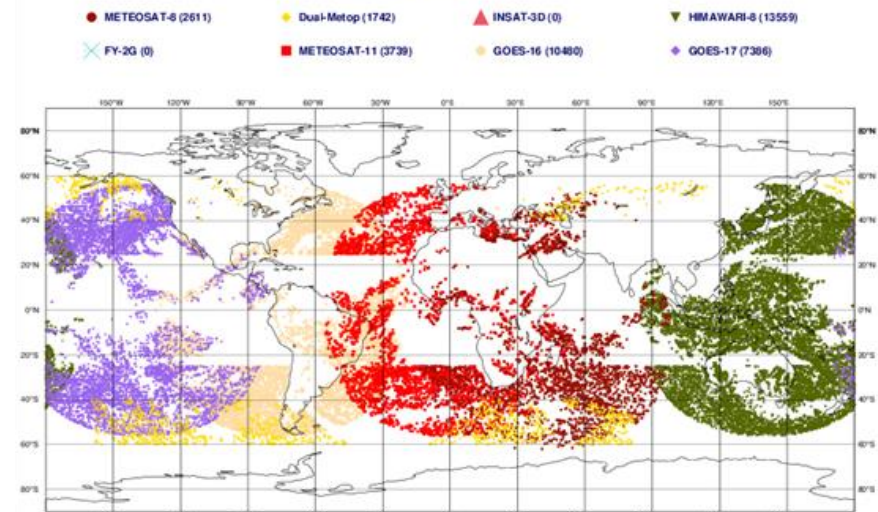
ECMWF data coverage (used observations) - AMV IR POLAR
2021021703 to 2021021709
Total number of obs = 4073



ECMWF data coverage (used observations) - AMV IR POLAR
2021021703 to 2021021709
Total number of obs = 2171

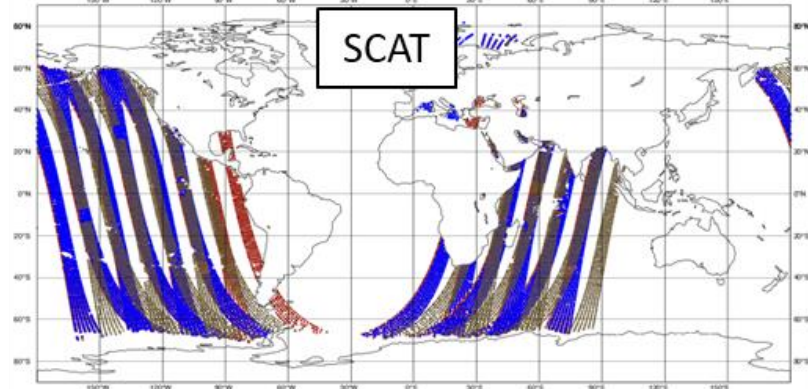


2021021703 to 2021021709
Total number of obs = 39517



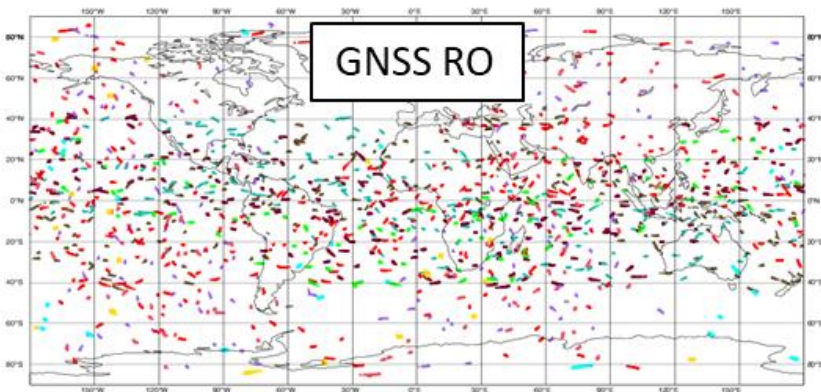
Active sensors

ECMWF data coverage (used observations) - SCATTEROMETER
 2021021703 to 2021021709
 Total number of obs = 24631

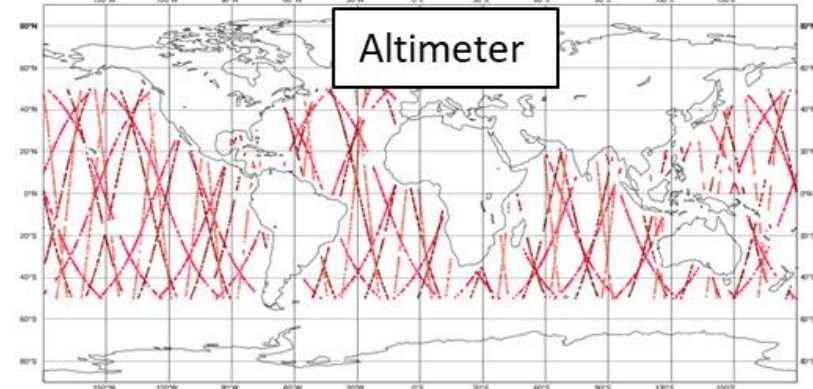


2021021703 to 2021021709
 Total number of obs = 25832

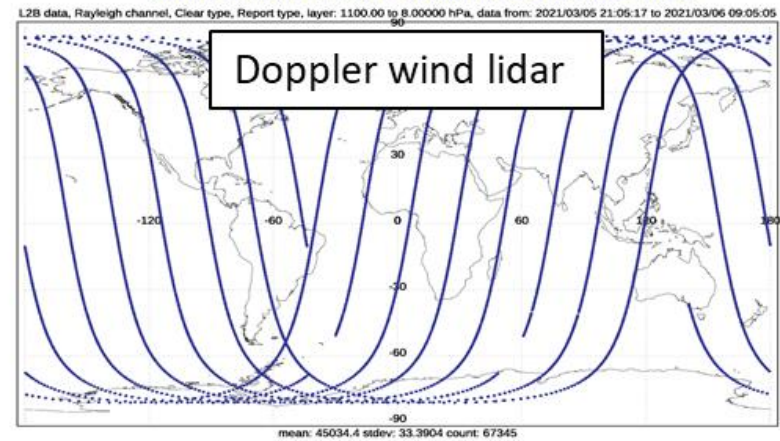
- METOP-A (2475)
- TerraSAR-X (463)
- ▲ METOP-B (2851)
- ▼ TanDEM-X (66)
- KOMPSAT-5 (419)
- METOP-C (2275)
- PAZ (0)
- COSMIC2-E1 (3906)
- ▲ COSMIC2-E2 (3924)
- ▼ COSMIC2-E3 (3747)
- COSMIC2-E5 (1680)
- COSMIC2-E6 (4026)



ECMWF data coverage (used observations) - SEA LEVEL ANOMALY
 20210215 00
 Total number of obs = 5376

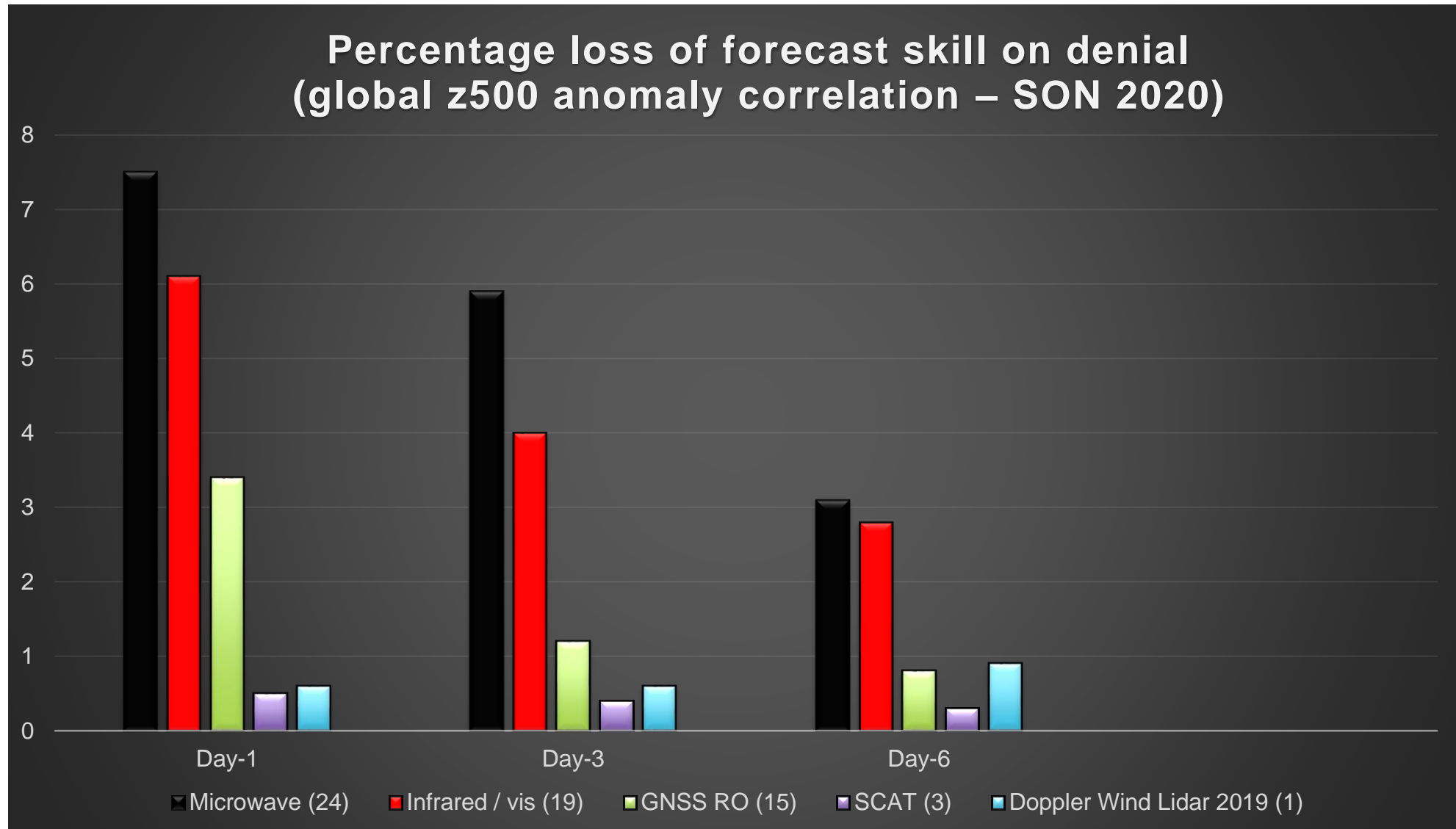


AEOLUS HLOS WINDS RAYLEIGH CLEAR (ASCENDING)



**Which satellite observations
are most important for NWP ?**

Impact of different sensor technologies



Which satellite observations are most important for NWP ?

Sensor technology	Processing route
Passive microwave	L1 Radiances
Passive infrared	L1 Radiances / AMV
Radio occultation	Bending angles
SCAT / Altimeter	L2 wind / SLA / SWH
Doppler wind lidar	L2 LOS wind

Note that sensors available for NWP are typically downward looking instruments (not limb viewing)

**What do passive microwave
and infrared satellite
instruments measure ...?**

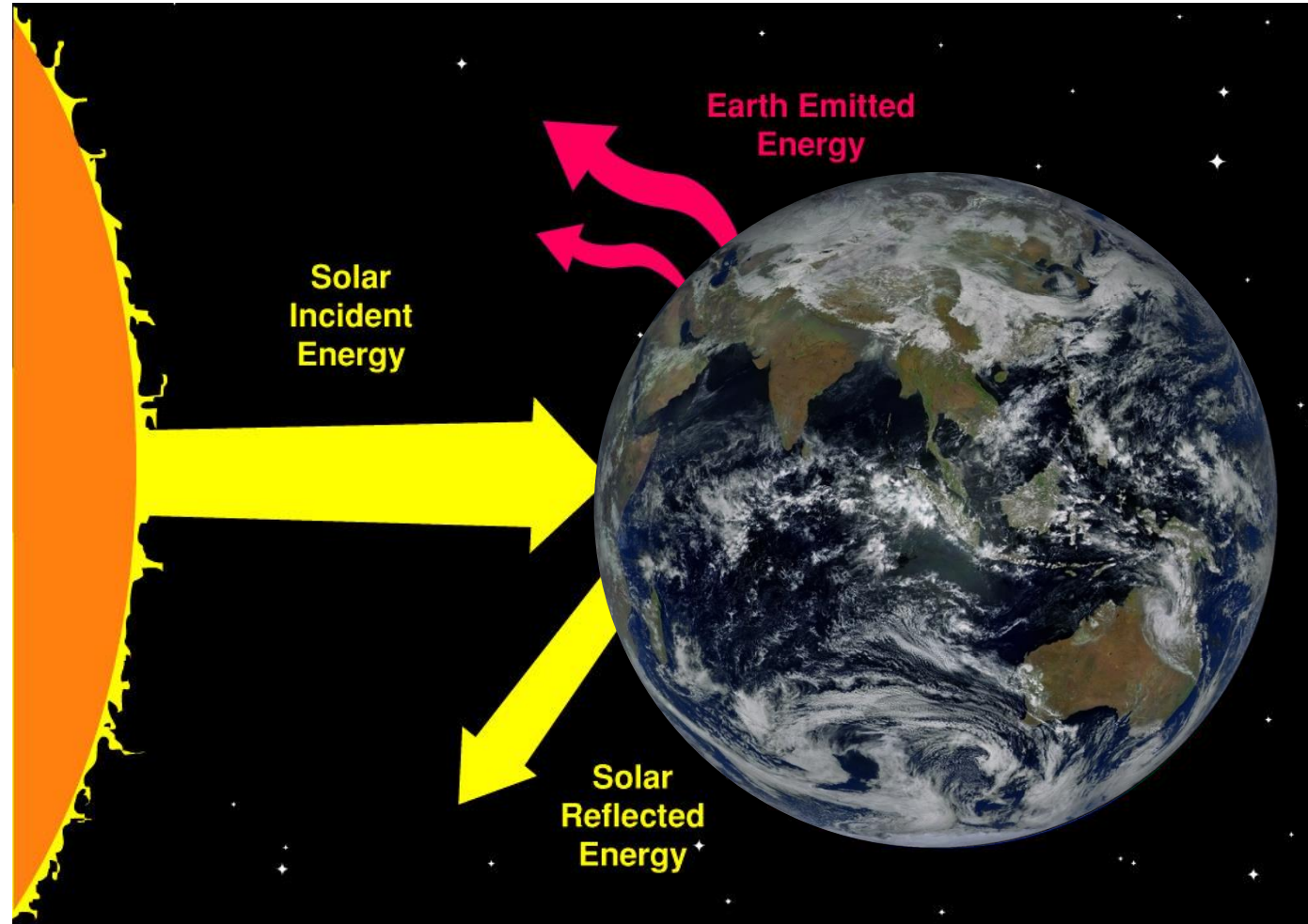
What do passive microwave and infrared satellite instruments measure ...?

They **DO NOT** measure TEMPERATURE

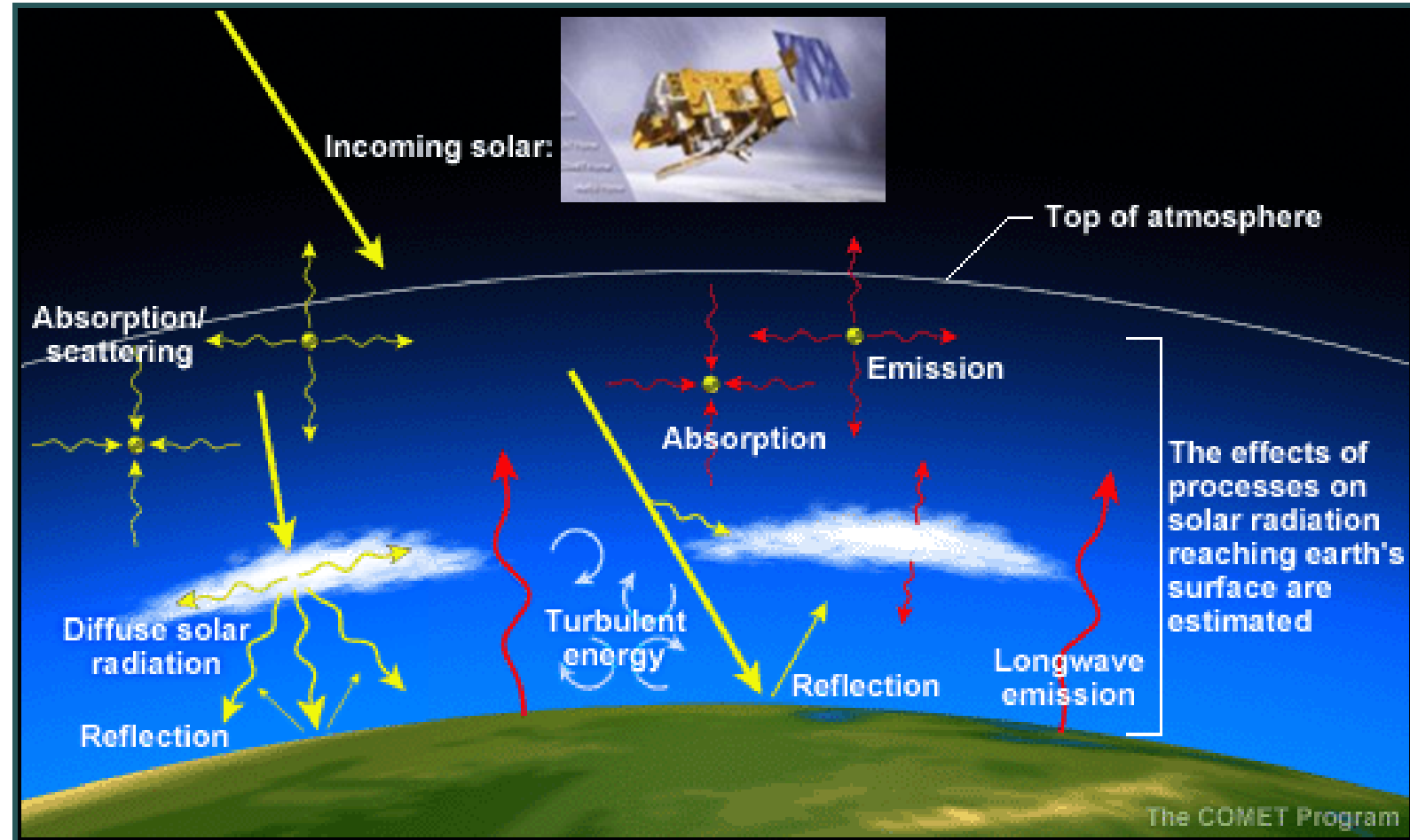
They **DO NOT** measure HUMIDITY or OZONE

They **DO NOT** measure WIND

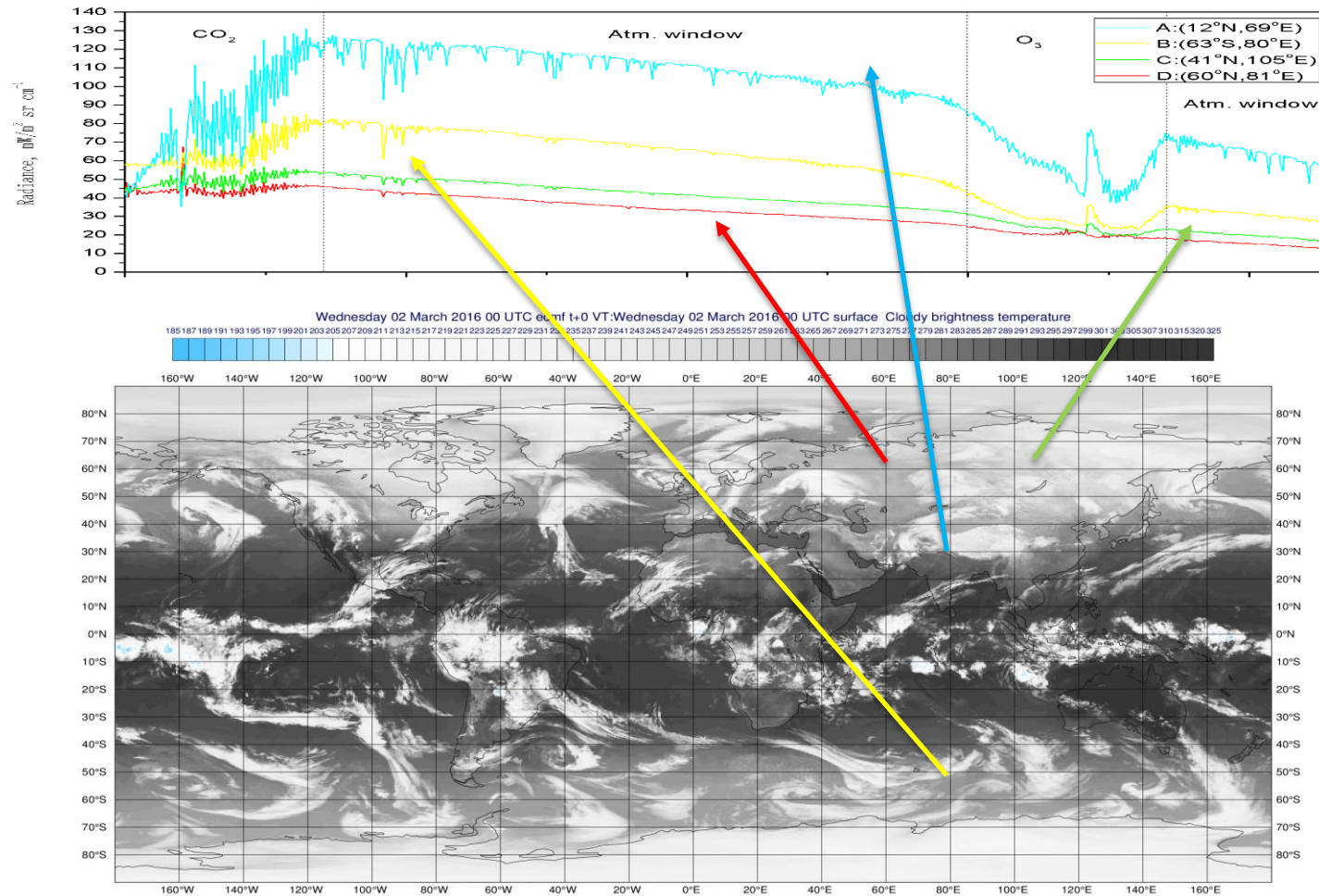
SATELLITES CAN ONLY MEASURE OUTGOING THERMAL RADIATION FROM THE ATMOSPHERE



SATELLITES CAN ONLY MEASURE OUTGOING THERMAL RADIATION FROM THE ATMOSPHERE



Every atmosphere has its own complex spectral radiance fingerprint ...



What do satellite instruments measure ?

Satellite instruments measure the **radiation** L that reaches the top of the atmosphere at given **frequency** ν .

The measured radiance is **related** to geophysical atmospheric variables (T, Q, O_3 , clouds etc...) by the

Radiative Transfer Equation

measured by the satellite

Our description of the atmosphere

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

Planck source term* depending on temperature $T(z)$ of the atmosphere

Transmittance / Absorption in the atmosphere

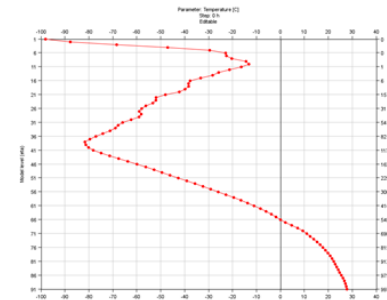
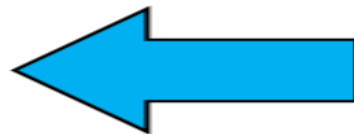
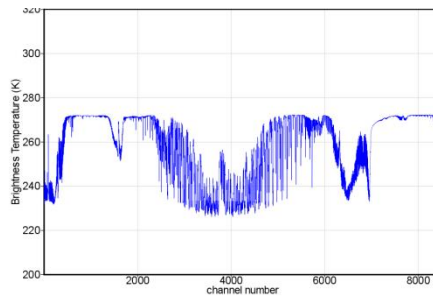
Other contributions to the measured radiances

The Radiative Transfer (RT) equation

measured by the
satellite

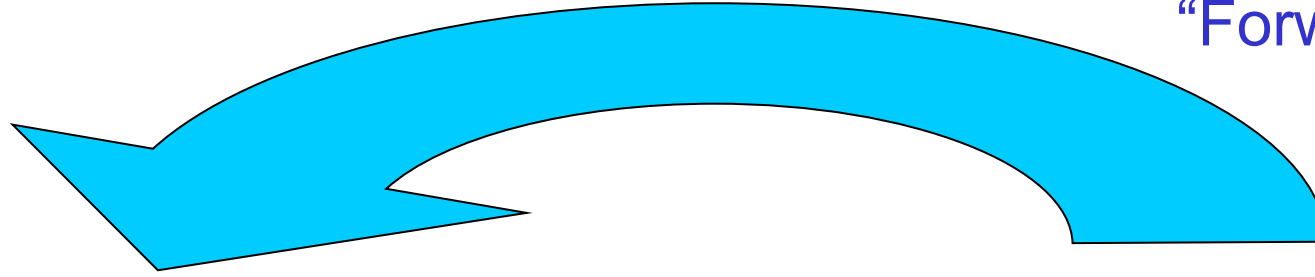
depends on the state of the atmosphere

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



The Radiative Transfer (RT) equation

“Forward problem”



measured by the
satellite

depends on the state of the atmosphere

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

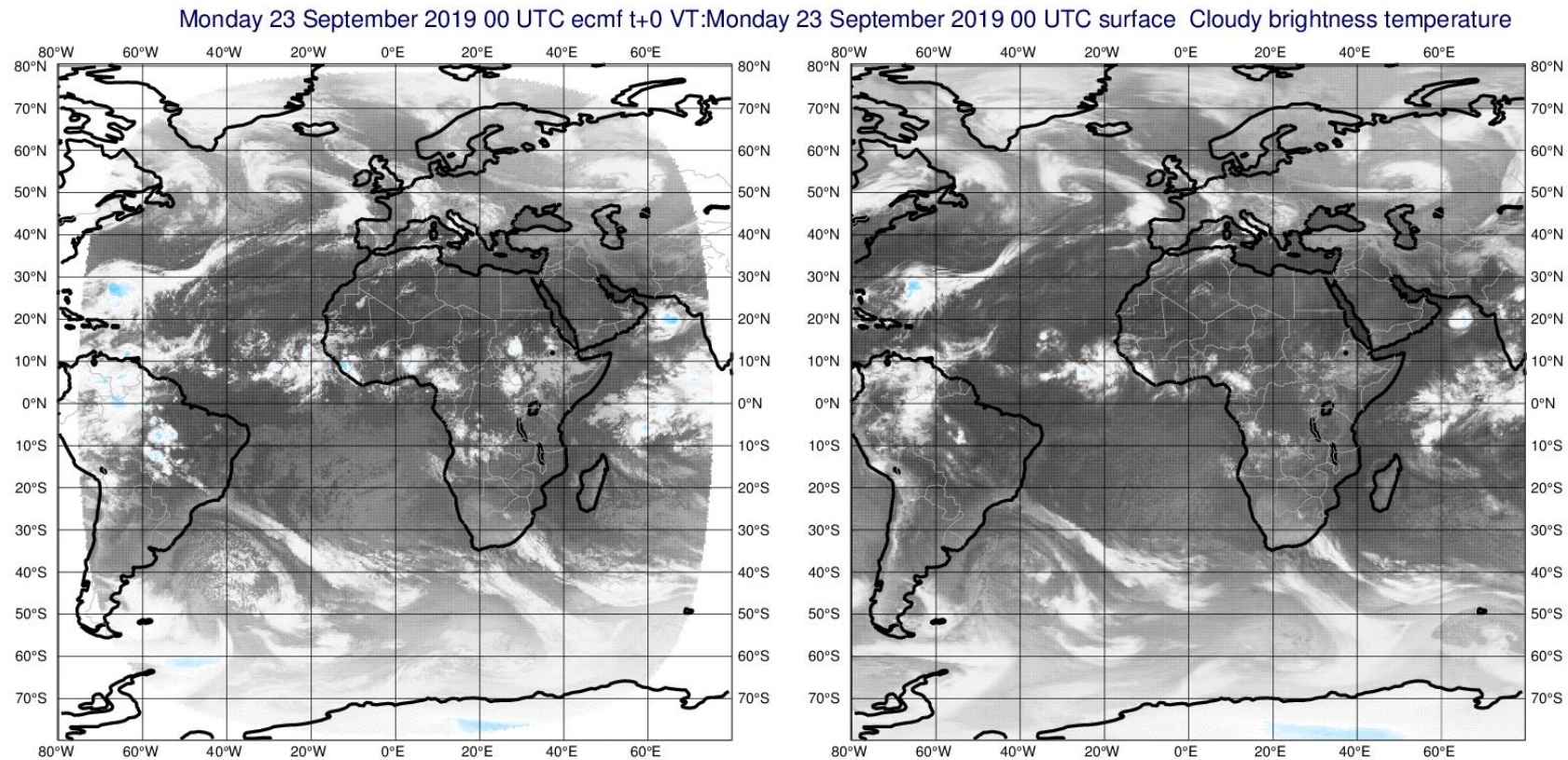
...given the state of the atmosphere, what is the radiance...?

*i.e. we can **simulate** what radiation would reach the satellite from a particular atmosphere...*

The Radiative Transfer (RT) equation

Observations from Meteosat-11

Simulated from the forecast model



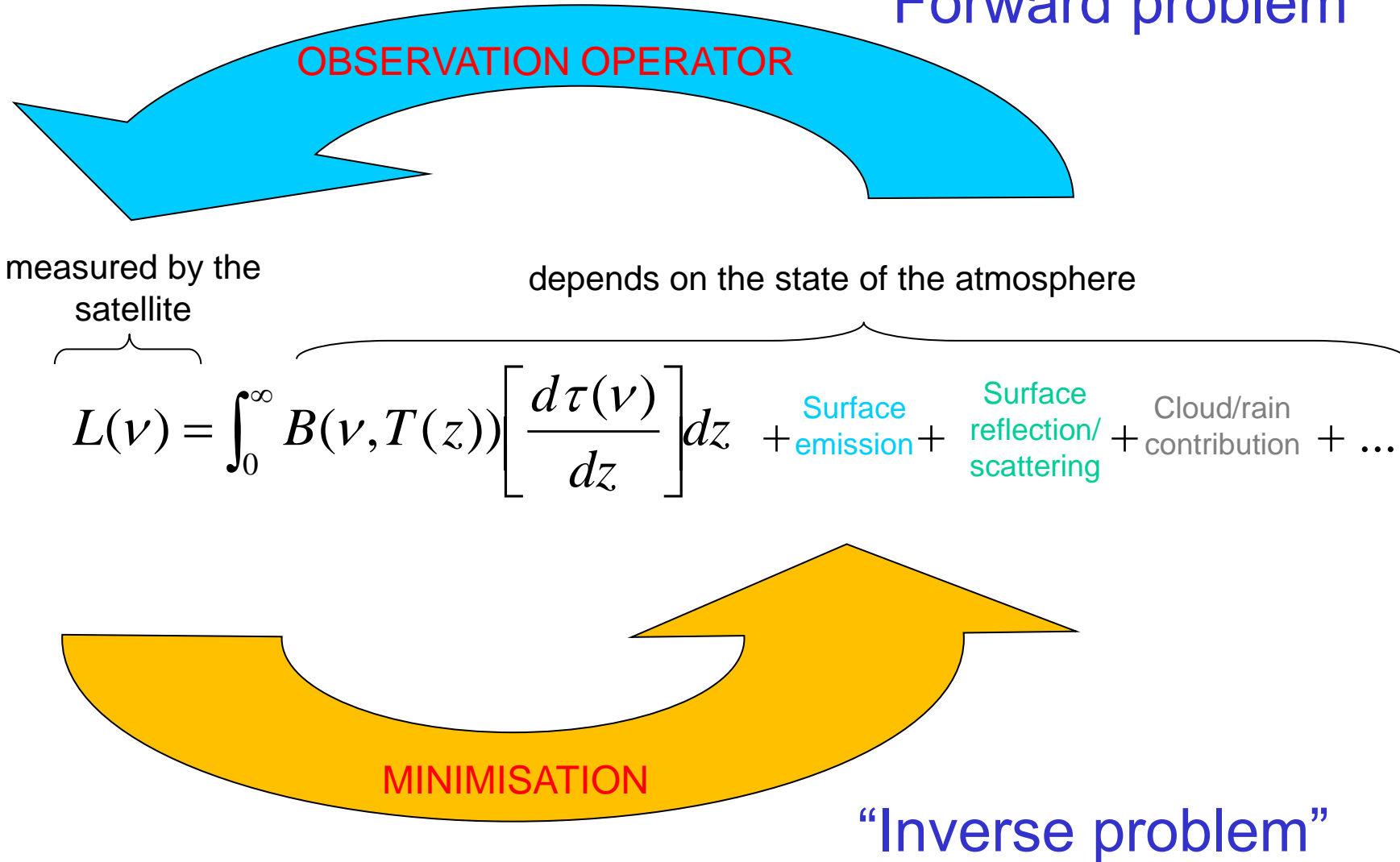
Modern radiative transfer can simulate atmospheric radiation very accurately ...so why do these two radiation images diverge ?

So by comparing simulated radiation to real satellite observations we can tell if the assumed state of the atmosphere is right or wrong.....

.....this is the basis for satellite radiance data assimilation...

The Radiative Transfer (RT) equation

“Forward problem”



...but first we have to simplify things a bit...

“Channel selection” ...

...designing satellite instruments to measure atmospheric radiation at very specific frequencies (channels)

Measuring radiances in different frequencies (channels)

By deliberately **selecting** radiation at different frequencies or **CHANNELS** satellite instruments can provide information on specific geophysical variables for different regions of the atmosphere.

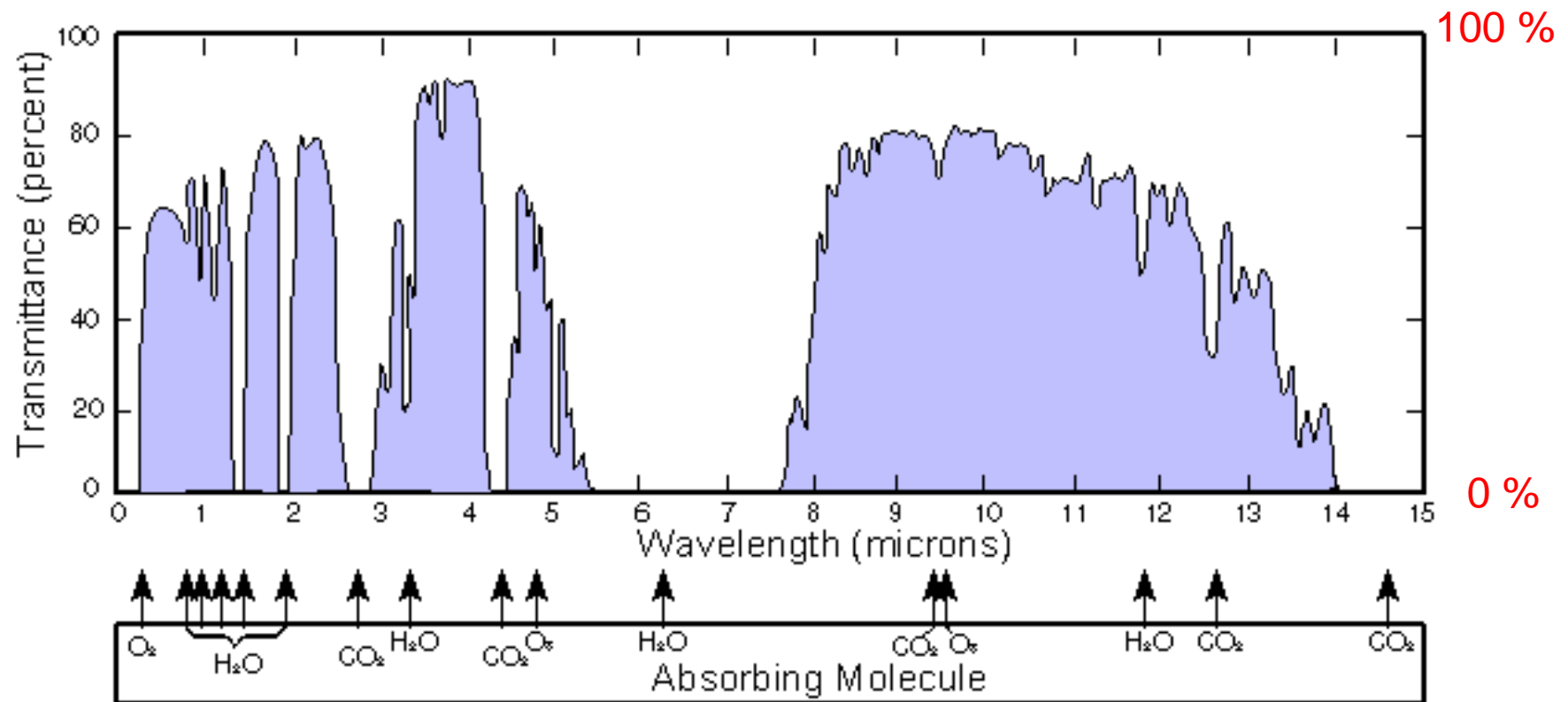
In general, the frequencies / channels used within NWP may be categorized as one of **2** different types ...

1. **atmospheric sounding** channels
2. **surface sensing** channels

Note:

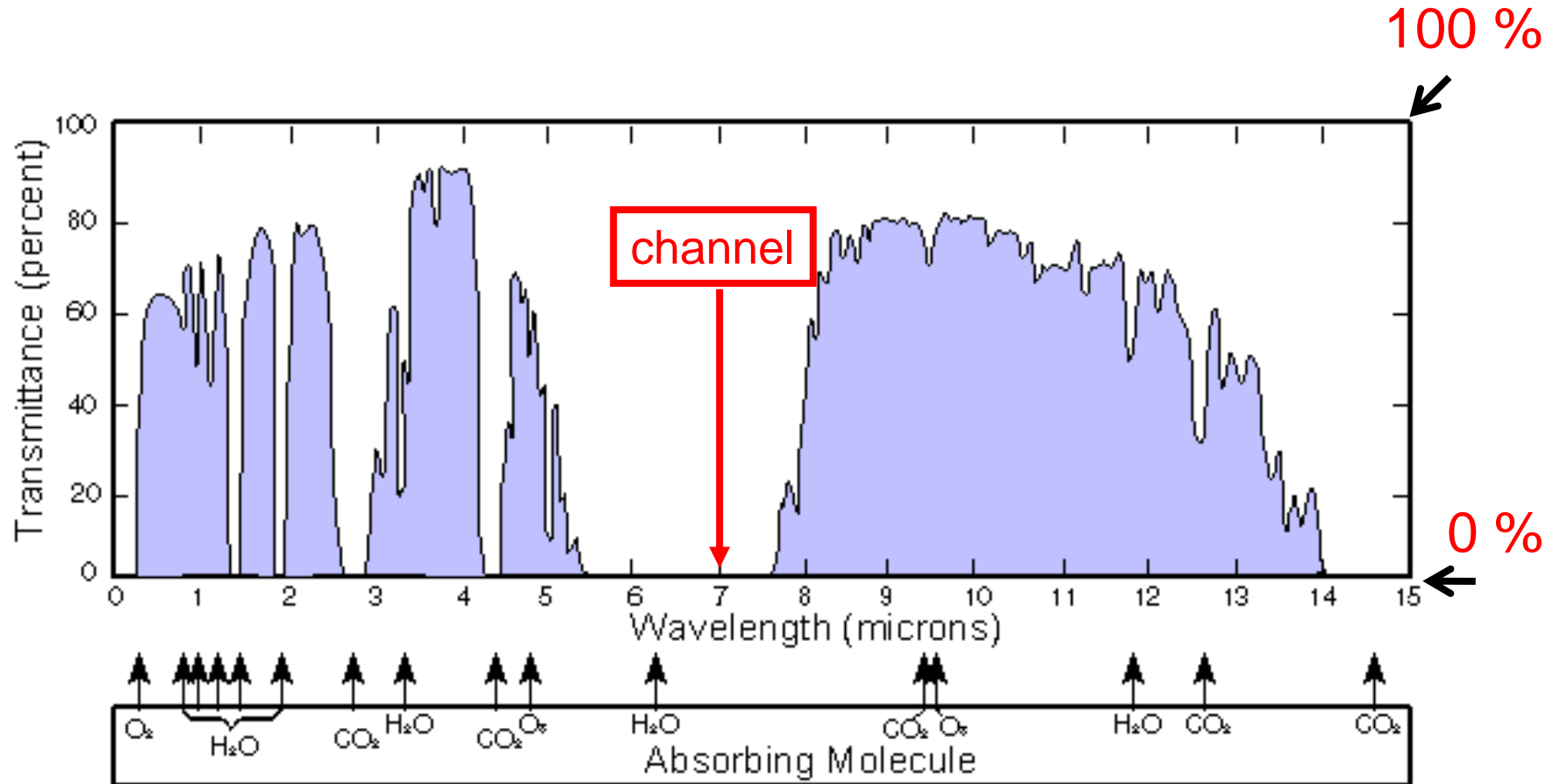
*In practice (and often despite their name!) real satellite instruments have channels which are a **combination** of atmospheric sounding and surface sensing channels*

Atmospheric transmission at different wavelengths

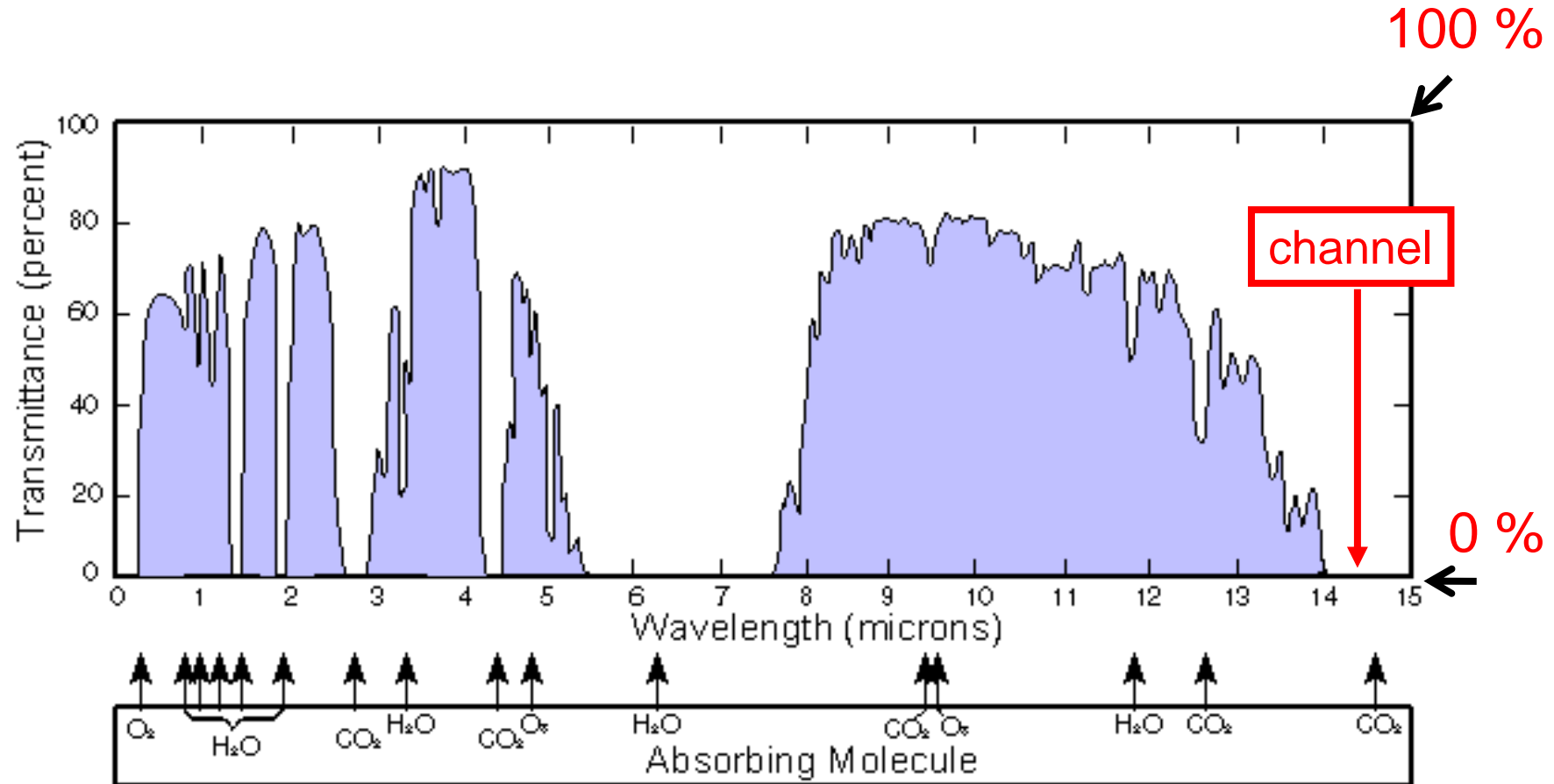


Atmospheric sounding channels...

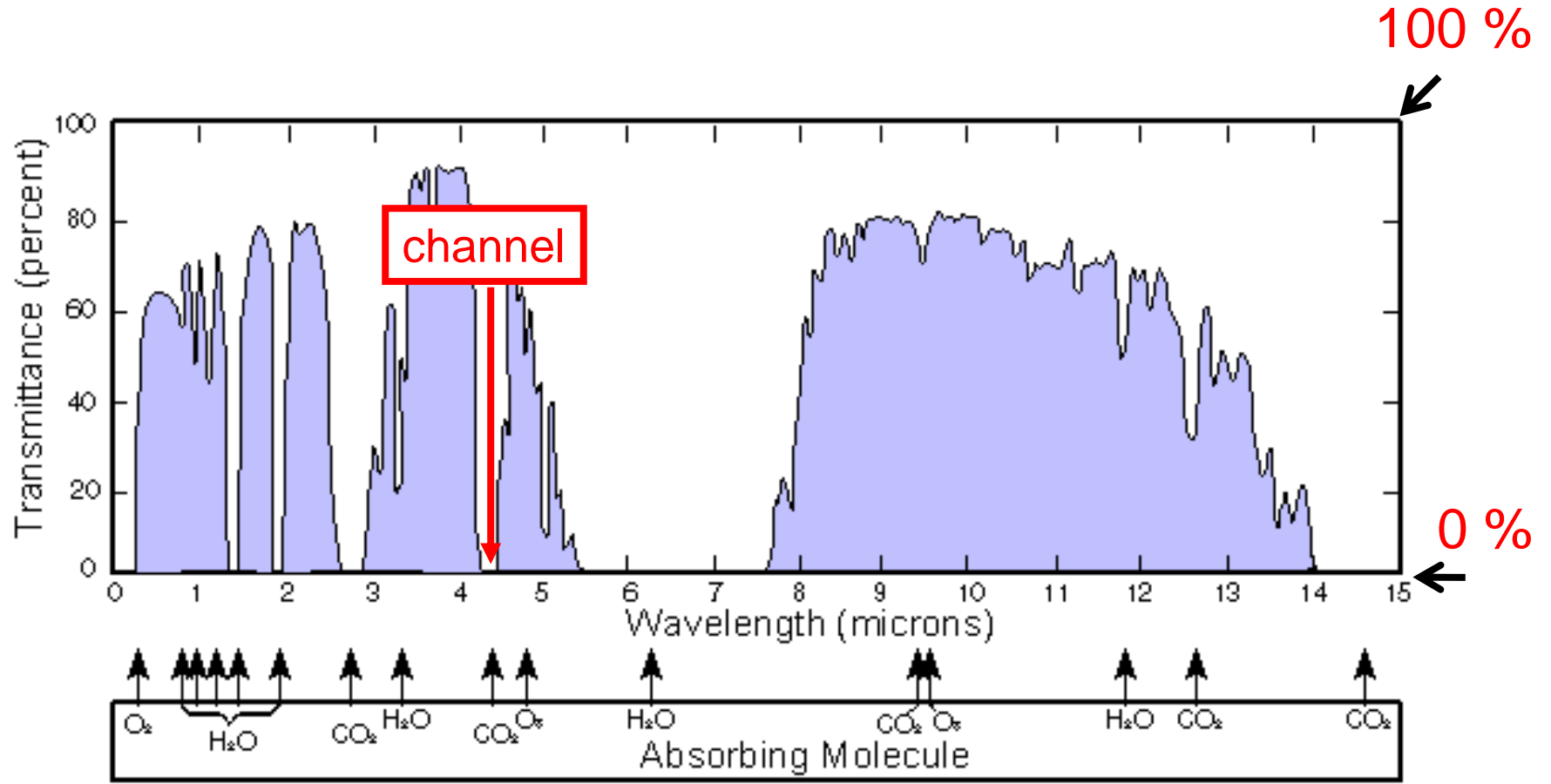
Atmospheric sounding channels...



Atmospheric sounding channels...



Atmospheric sounding channels...



Atmospheric sounding channels...

...selecting channels where there is **no** contribution from the **surface**....

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

Atmospheric sounding channels...

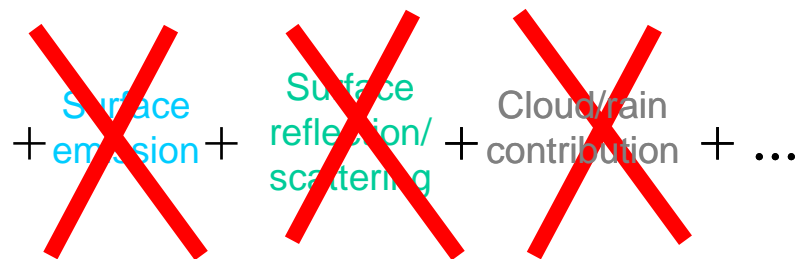
...selecting channels where there is **no** contribution from the **surface**....

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

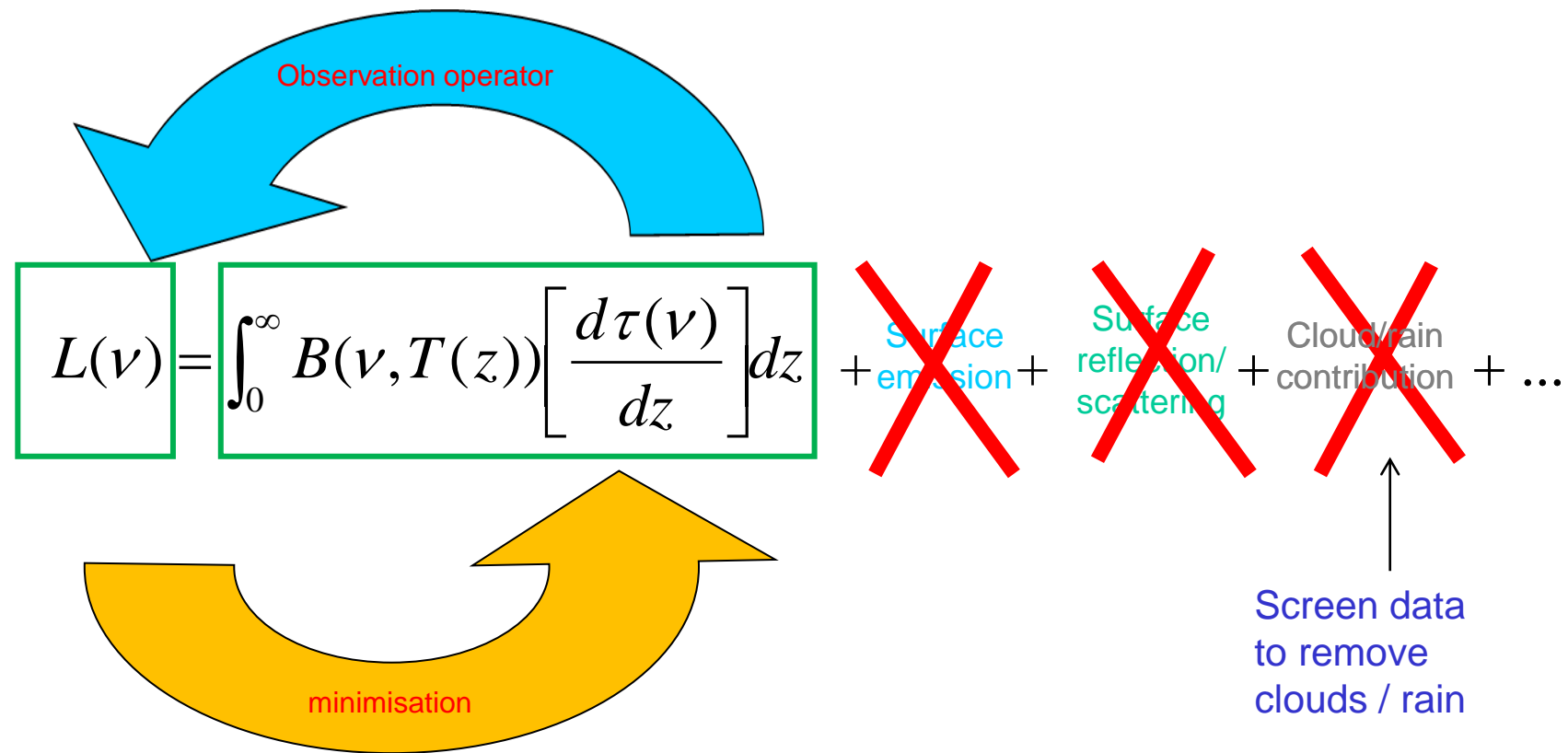
The terms "Surface emission" and "Surface reflection/scattering" are crossed out with large red X's.

Atmospheric sounding channels...

...if we additionally **screen observations** to remove measurements in cloudy or rain locations...

$$L(\nu) = \int_0^{\infty} B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \dots$$
The diagram shows the equation for radiance L(ν) as a function of frequency ν. The main term is an integral from 0 to infinity of B(ν, T(z)) times the derivative of optical depth dτ(ν)/dz with respect to altitude z, multiplied by dz. To the right of this integral are three terms: '+ Surface emission', '+ Surface reflection/scattering', and '+ Cloud/rain contribution', followed by an ellipsis. Each of these three terms is crossed out with a large red 'X', indicating that these contributions are being screened out of the observations.

We now have a much simpler forward ...and inverse problem for the DA



Atmospheric sounding channels...

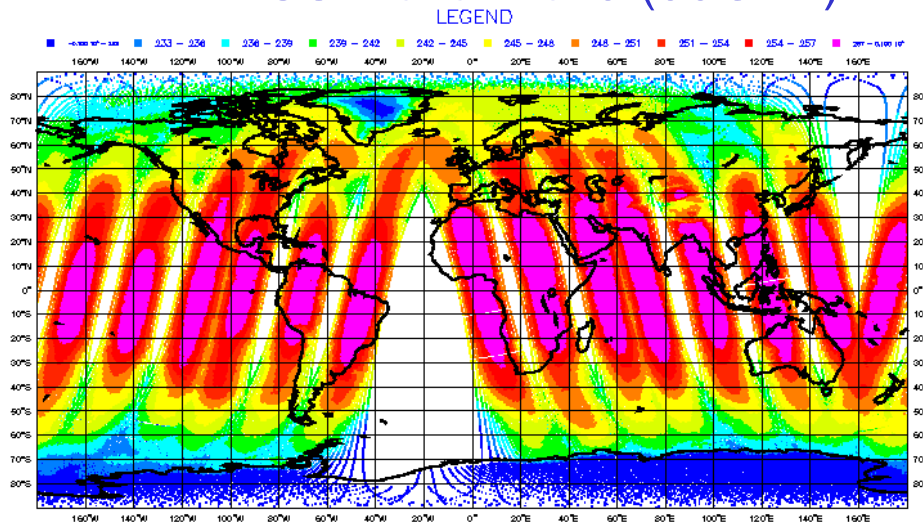
These channels are located in parts of the infra-red and microwave spectrum for which the main contribution to the measured radiance is from the atmosphere and can be written:

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

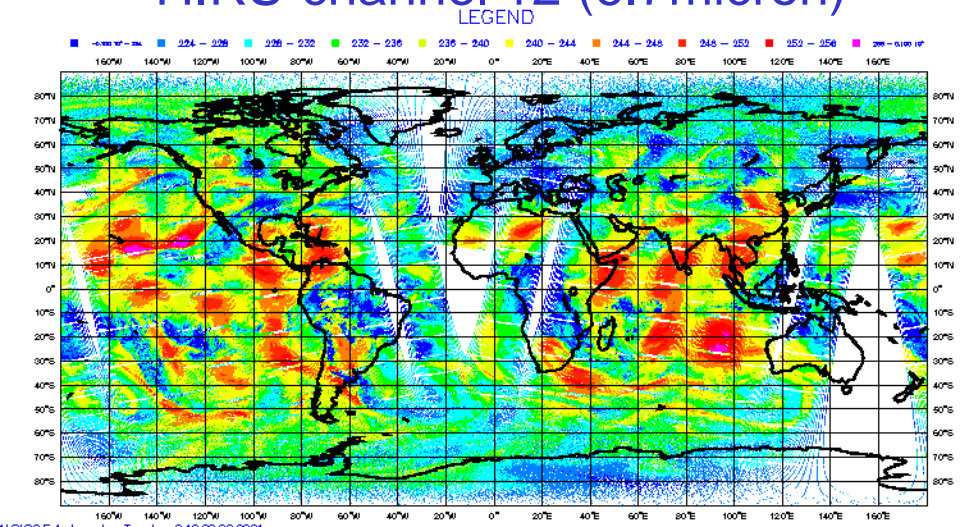
Where B = Planck function
 t = transmittance
 $T(z)$ is the temperature
 z is a height coordinate

That is they try to **avoid** frequencies for which **surface radiation** and cloud contributions are important. They are primarily used to obtain **information about atmospheric temperature and humidity** (or other constituents that influence the transmittance e.g. CO₂).

AMSUA-channel 5 (53GHz)

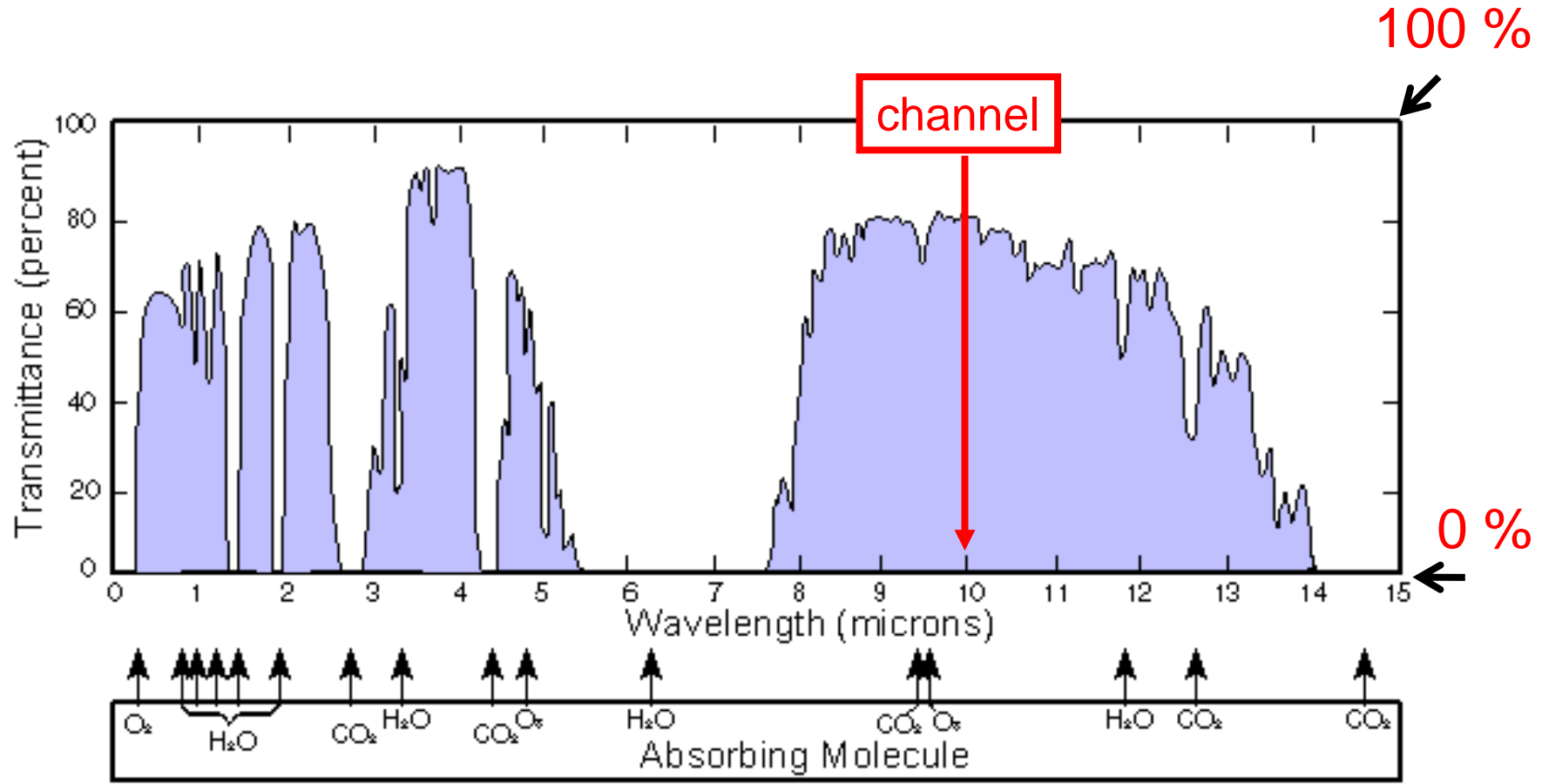


HIRS-channel 12 (6.7micron)

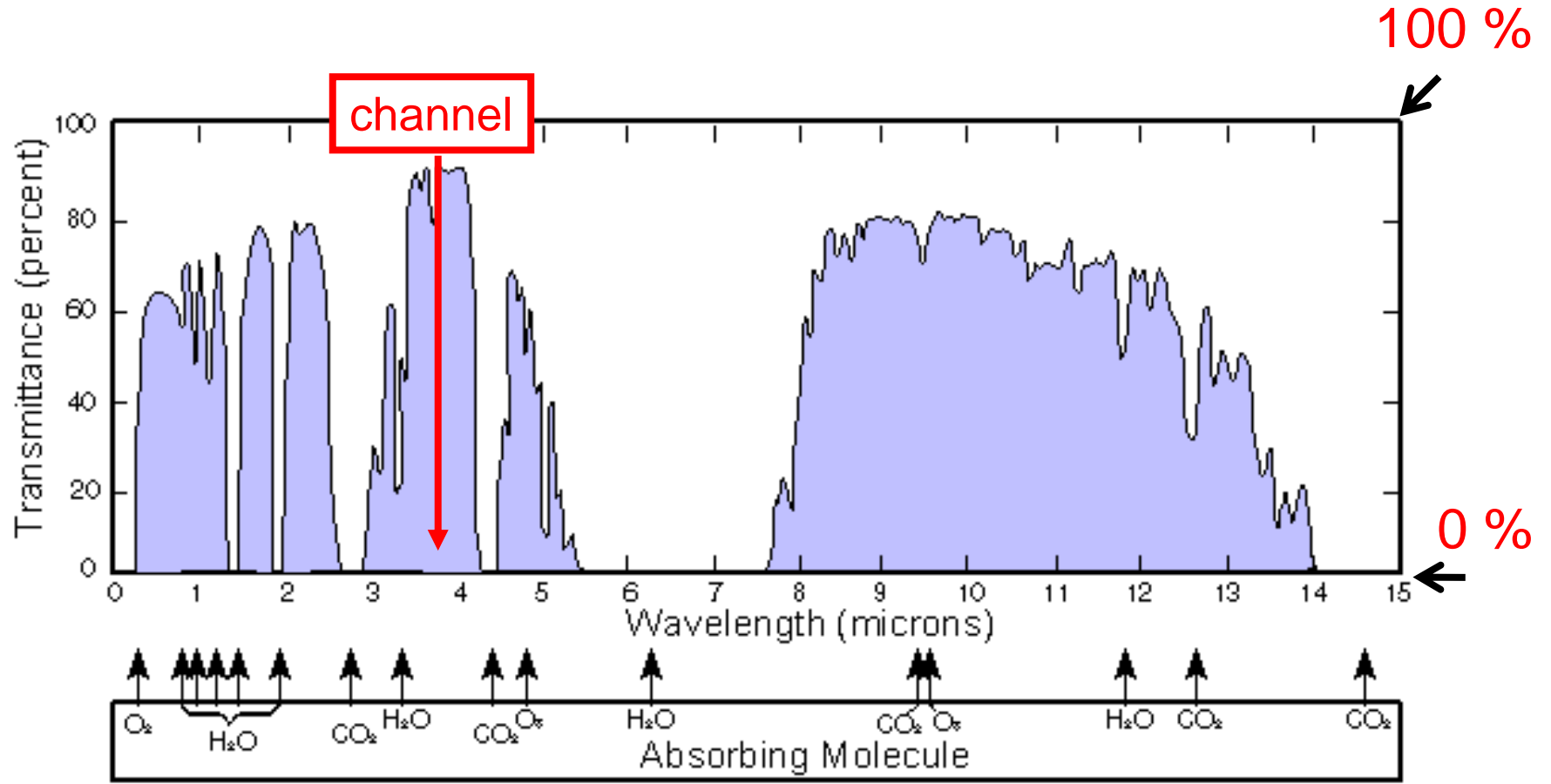


Surface sensing Channels...

Surface sensing Channels



Surface sensing Channels



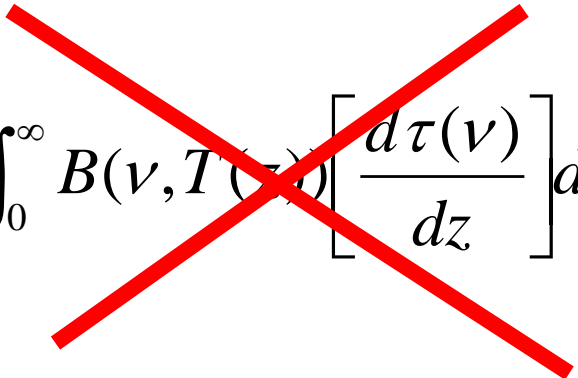
Surface sensing Channels

...selecting channels where there is **no** interaction in the **atmosphere**....

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

Surface sensing Channels

...selecting channels where there is **no** interaction in the atmosphere....

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


Surface sensing Channels

...selecting channels where there is **no** interaction in the atmosphere....

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

↑
IR ~ zero

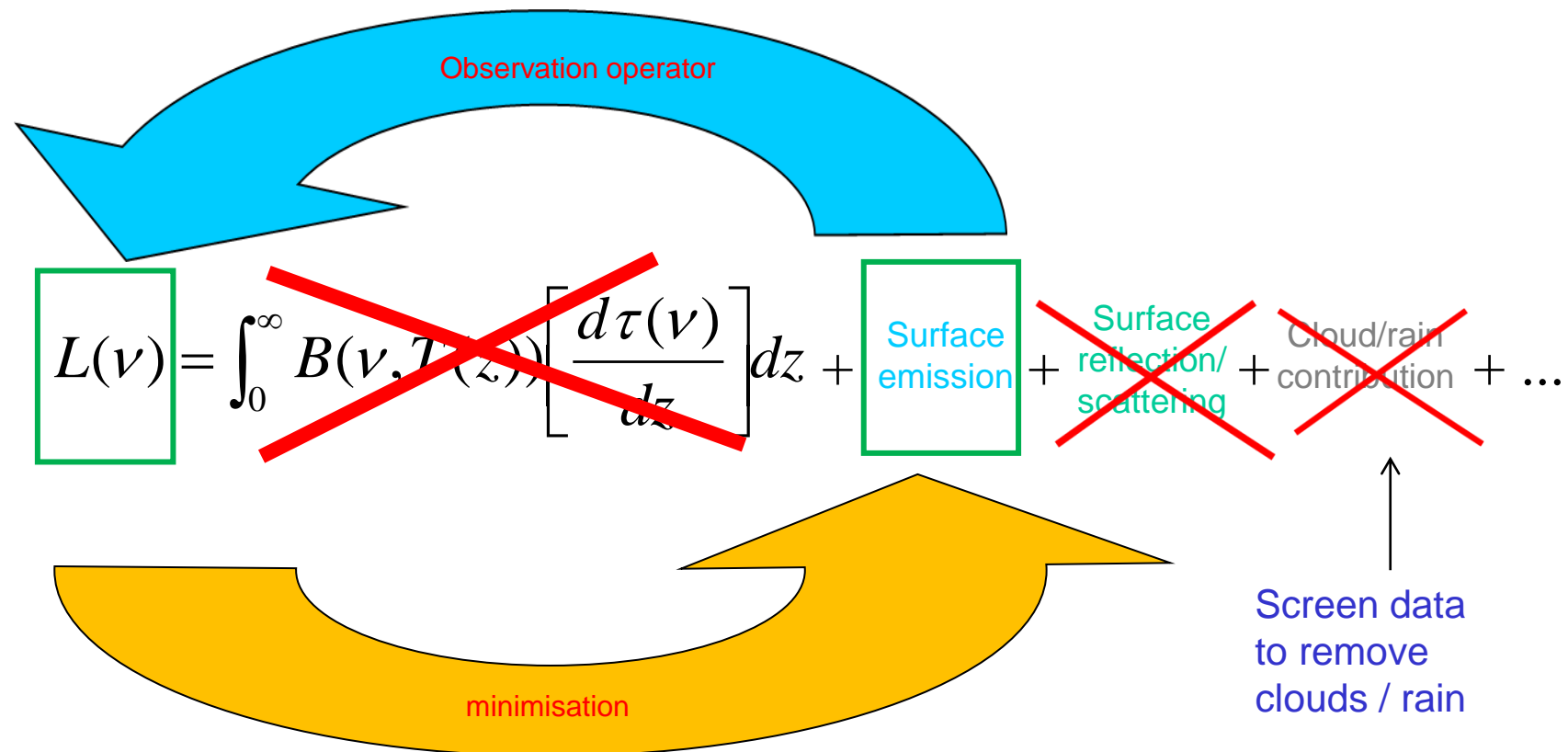
Surface sensing Channels

...selecting channels where there is **no** interaction in the atmosphere....

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

↑
Screen data to remove clouds / rain

We now have a much simpler forward ...and inverse problem for the DA



Surface sensing Channels

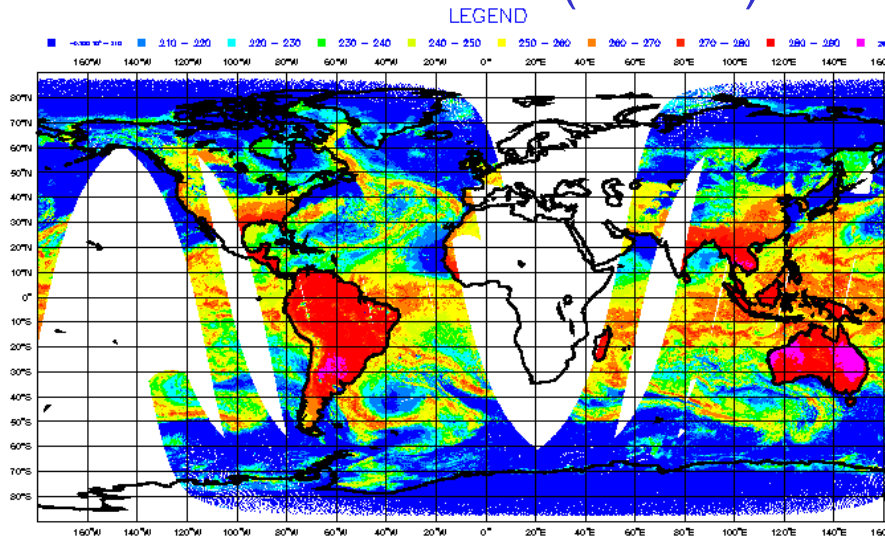
These are located in **window regions** of the infra-red and microwave spectrum at frequencies where there is very little interaction with the atmosphere and the primary contribution to the measured radiance is:

$$L(\nu) \approx B[\nu, T_{\text{surf}}] \epsilon(\mathbf{u}, \nu) \quad (\text{i.e. surface emission})$$

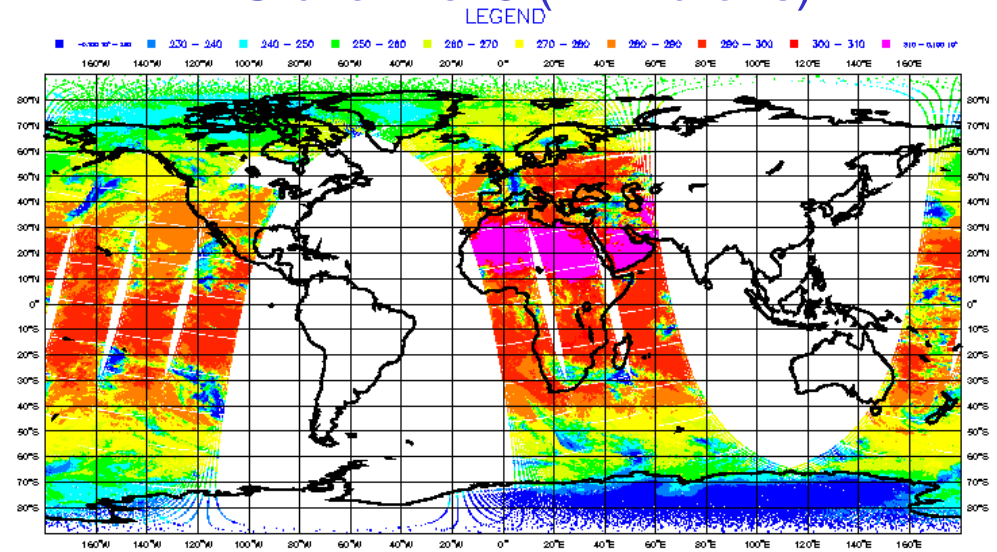
Where T_{surf} is the surface skin temperature and ϵ the surface emissivity

These are primarily used to obtain information on the **surface temperature** and quantities that influence the **surface emissivity** such as wind (ocean) and vegetation (land). They can also be used to obtain information on **clouds/rain** and cloud movements (to provide **wind** information)

SSM/I channel 7 (89GHz)



HIRS channel 8 (11microns)



What type of channels are most important for NWP ?

Atmospheric temperature sounding...

Atmospheric temperature sounding – *weighting functions*

If radiation is selected in an **atmospheric sounding channel** for which

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

and we define a function $H(z) = \left[\frac{d\tau}{dz} \right]$

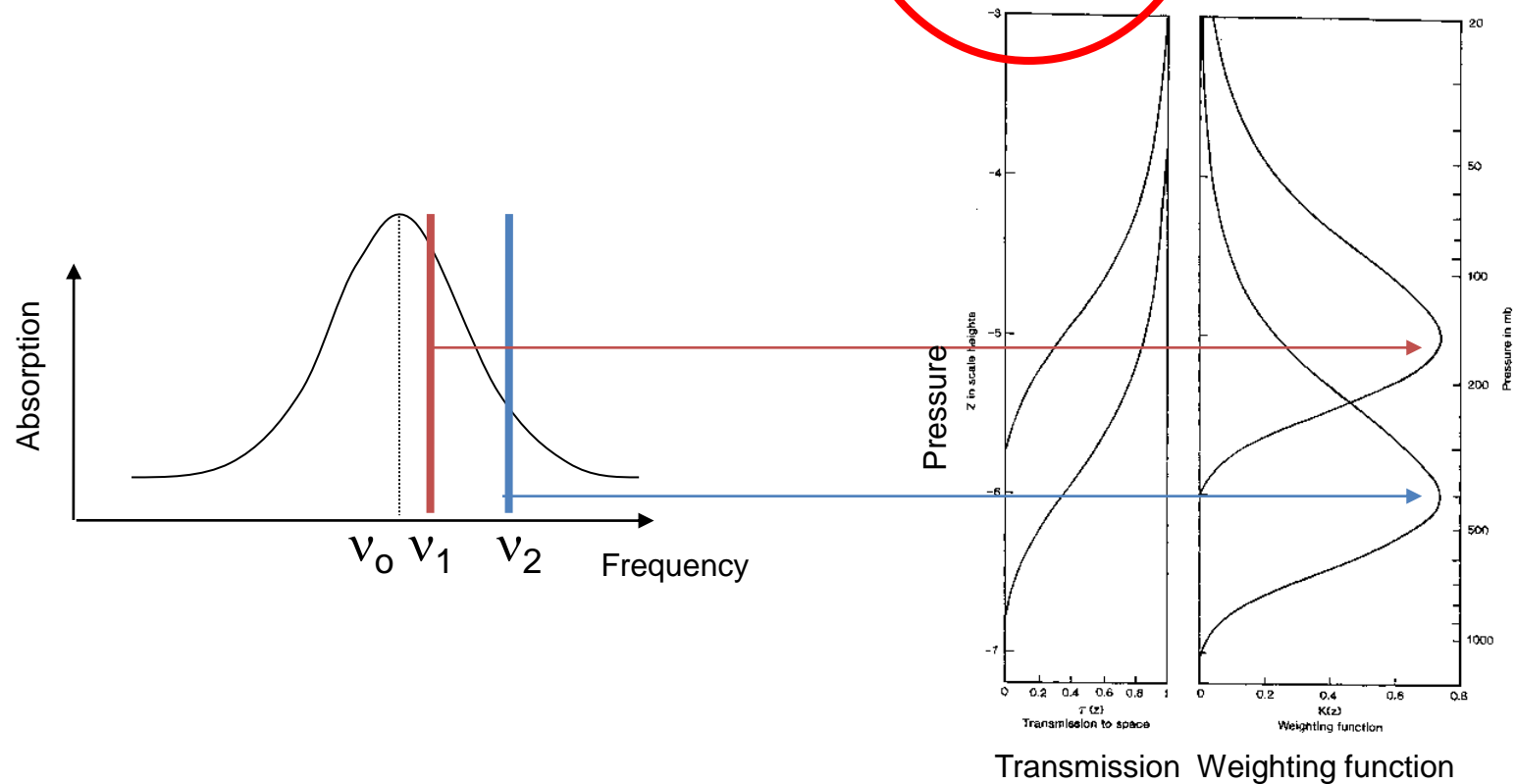
When the primary absorber is a well mixed gas (e.g. oxygen or CO₂) with known concentration it can be seen that the **measured radiance** is essentially a **weighted average of the atmospheric temperature profile**, or

$$L(\nu) = \int_0^{\infty} B(\nu, T(z)) H(z) dz$$

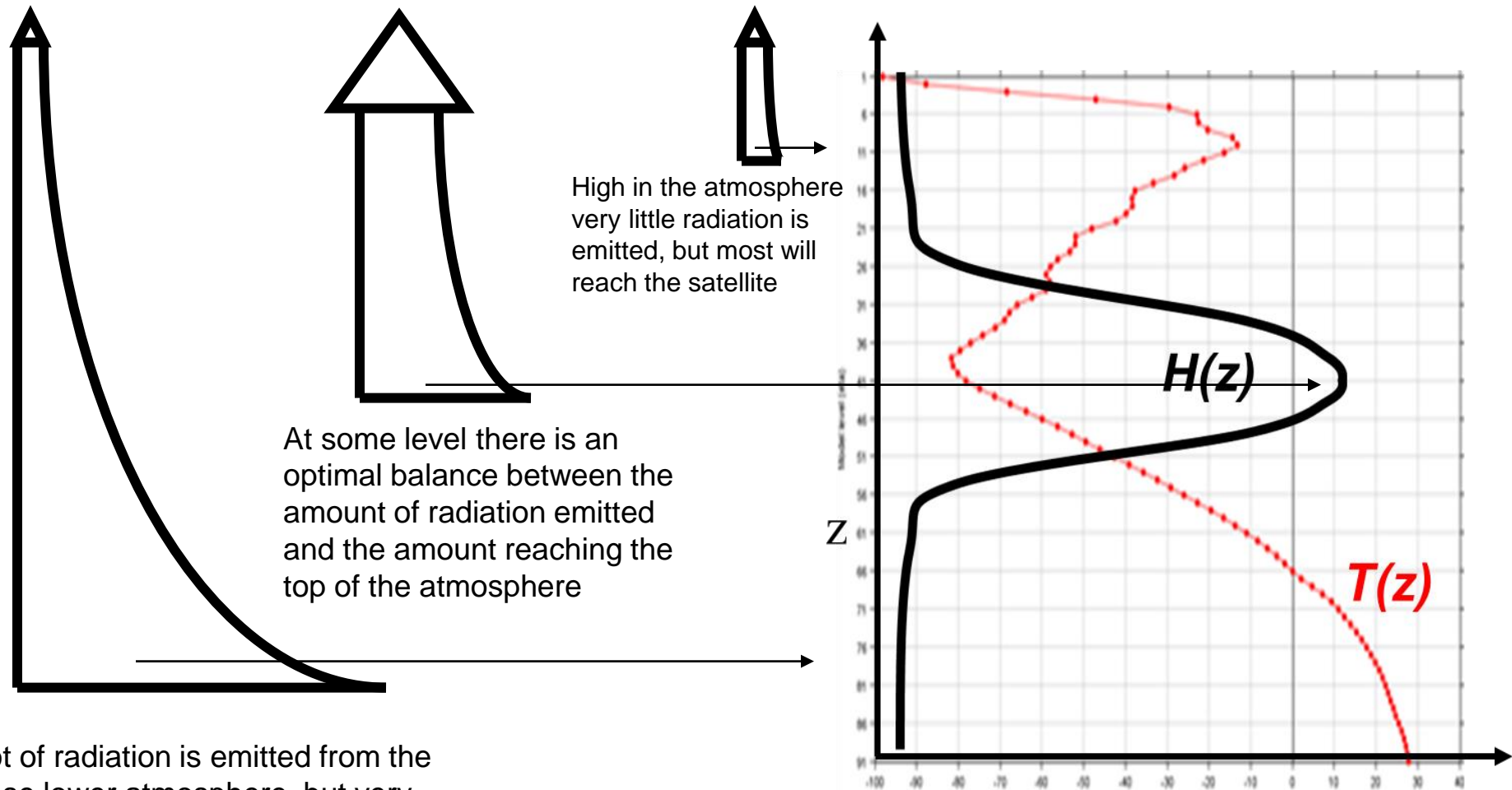
The function $H(z)$ that defines this vertical average is known as a **WEIGHTING FUNCTION**

What do weighting functions look like ?

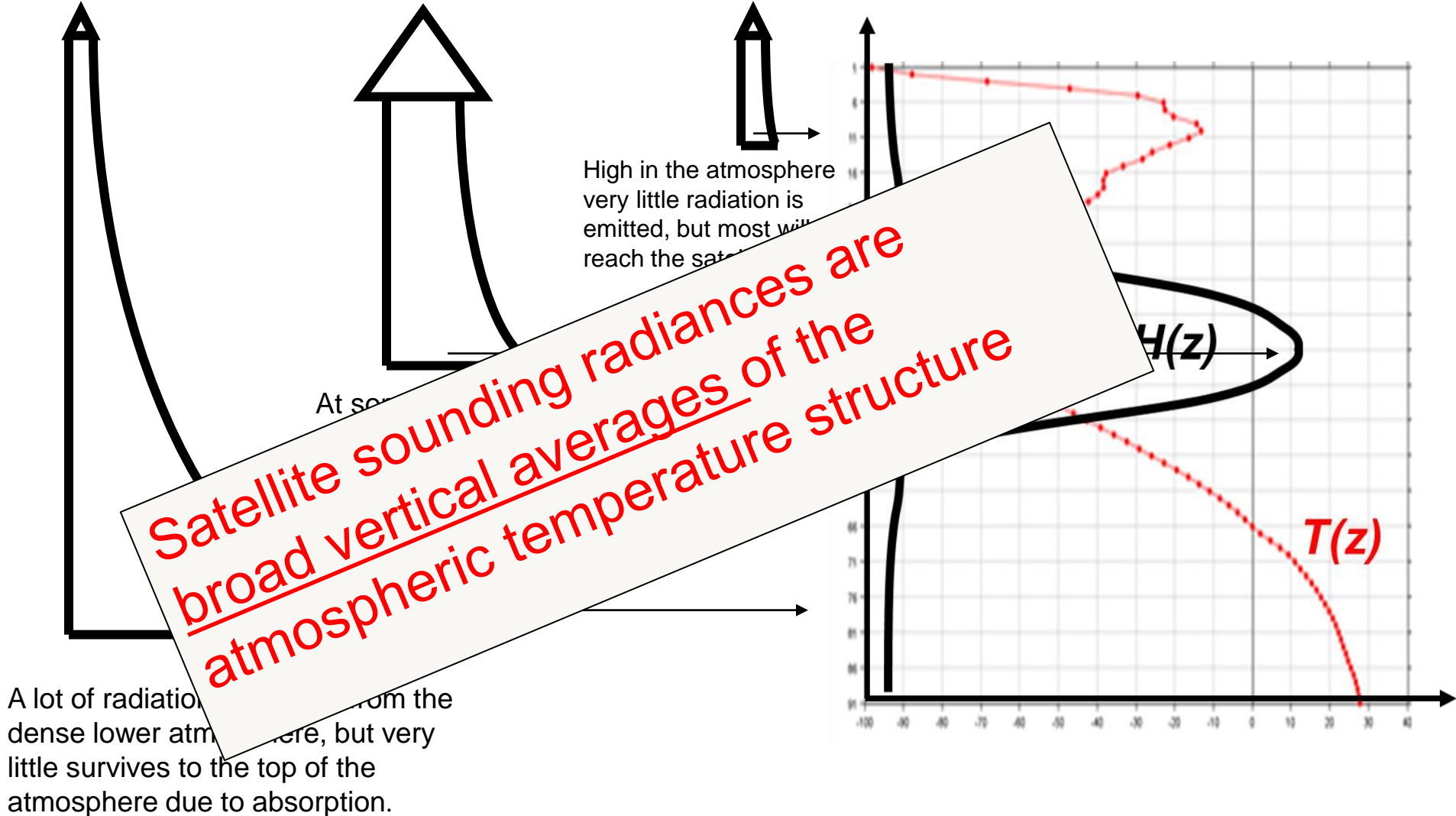
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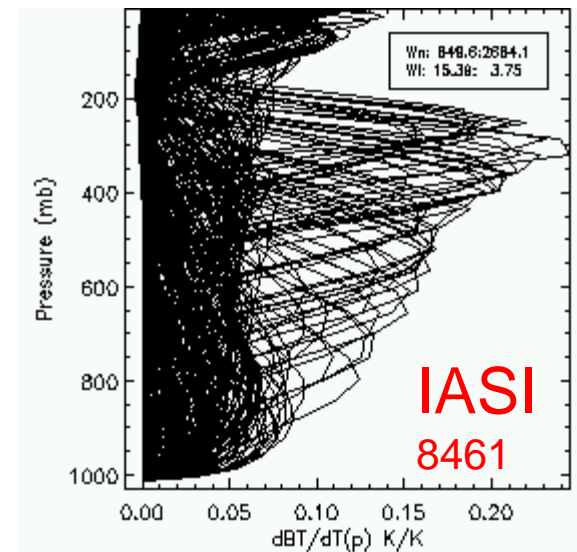
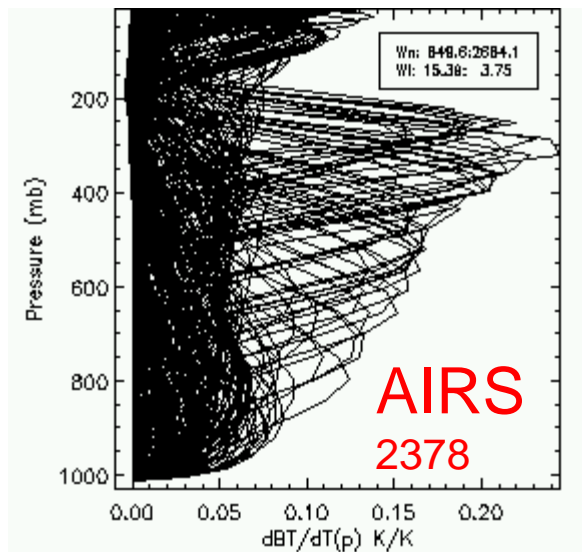
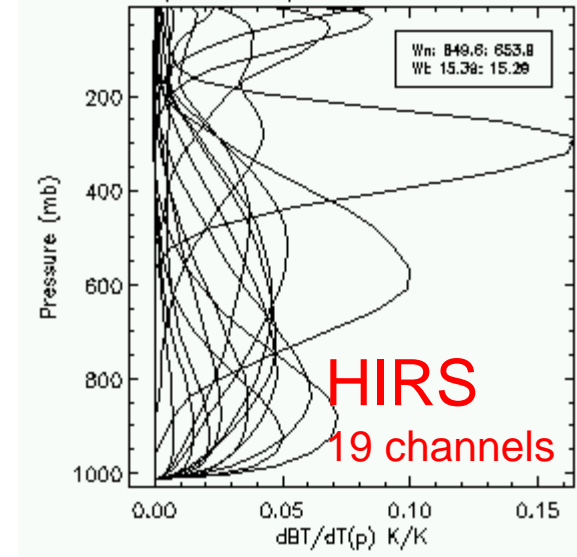
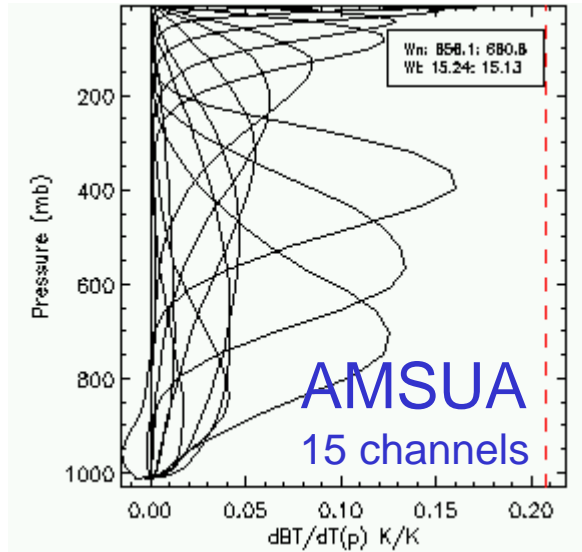
What do weighting functions look like ?

For any given channel the altitude at which the peak of the weighting function occurs depends on the strength of atmospheric absorption :

- Channels in parts of the spectrum where the absorption is **strong** (e.g. near the centre of CO₂ or O₂ lines) peak **high** in the atmosphere
- Channels in parts of the spectrum where the absorption is **weak** (e.g. in the wings of CO₂ O₂ lines) peak **low** in the atmosphere

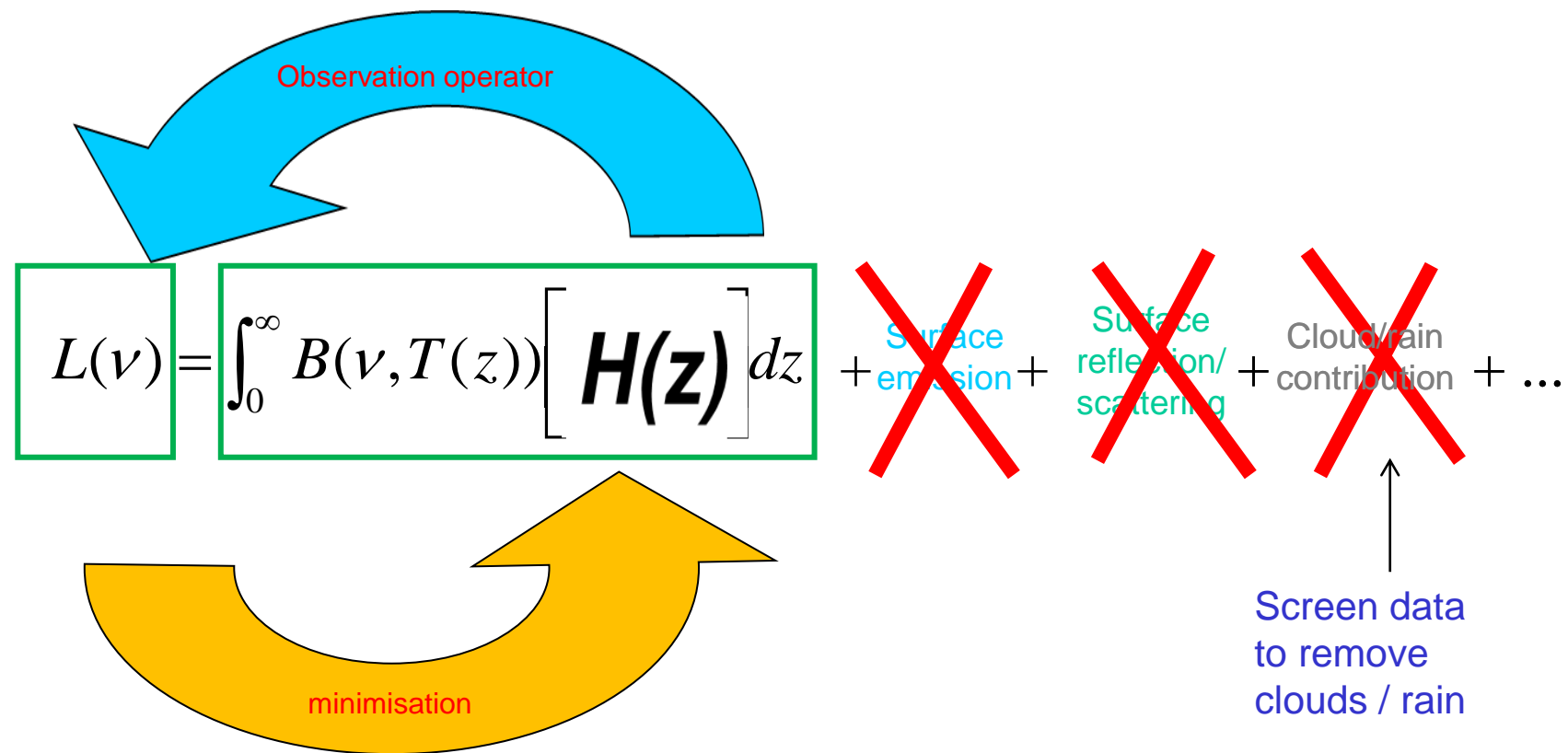
By building a satellite instrument that measures radiation in **many different channels**, all with varying absorption strengths we sample the atmospheric temperature profile at **different altitudes** (but of course not independently!)

What do real weighting functions look like ?

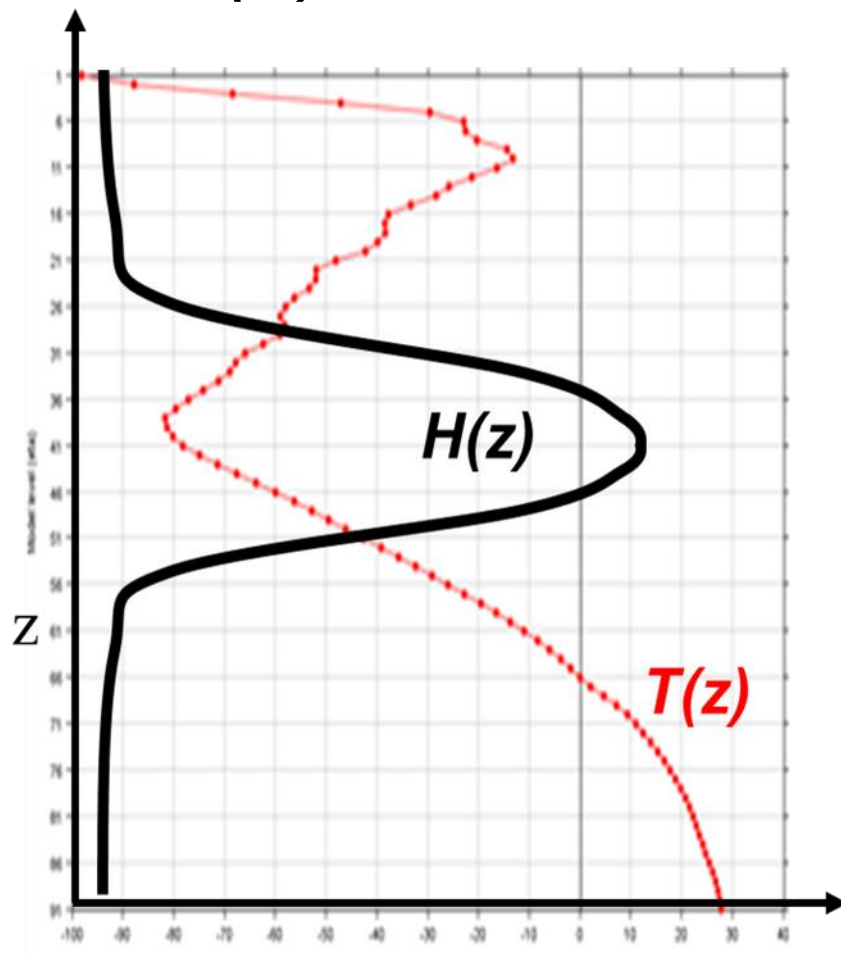


What are the implications of these broad weighting functions for Data Assimilation ?

The implications of broad weighting functions $H(z)$



The implications of broad weighting functions $H(z)$

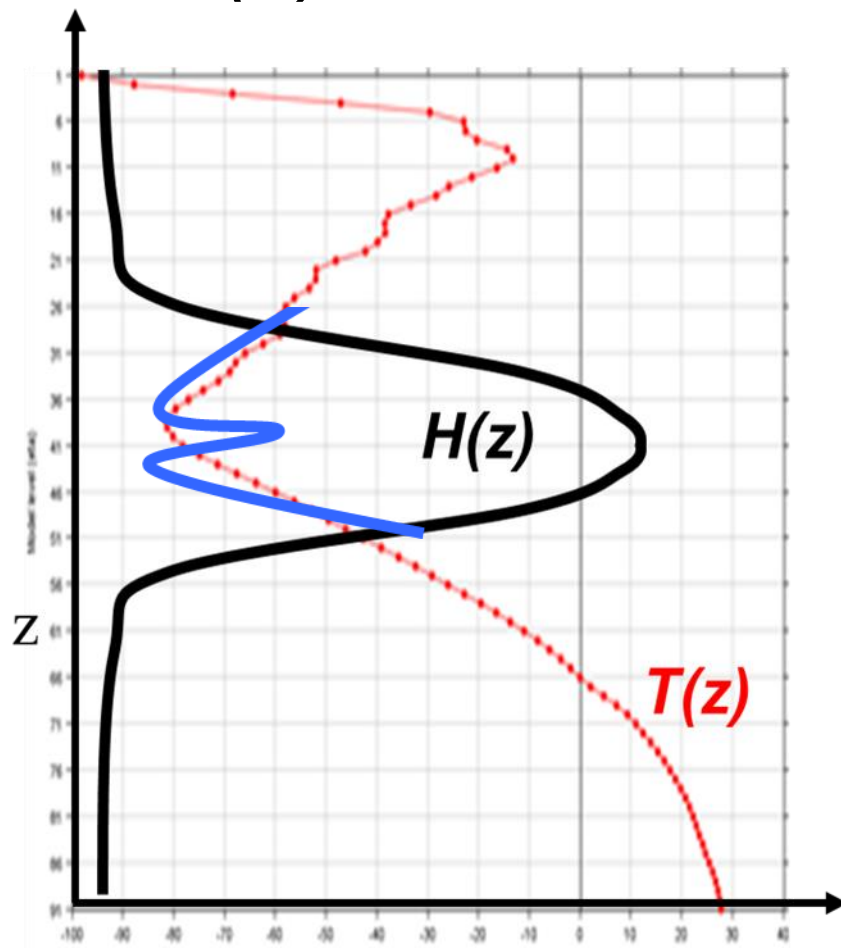


In principle for a single channel an **infinite** number of different temperature profiles could produce exactly the **same measured radiance**...

The extraction of temperature information within the data assimilation for these observations is mathematically **ill-posed**

See paper by Rodgers 1976 Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev. Geophys.Space. Phys. 14, 609-624

The implications of broad weighting functions $H(z)$

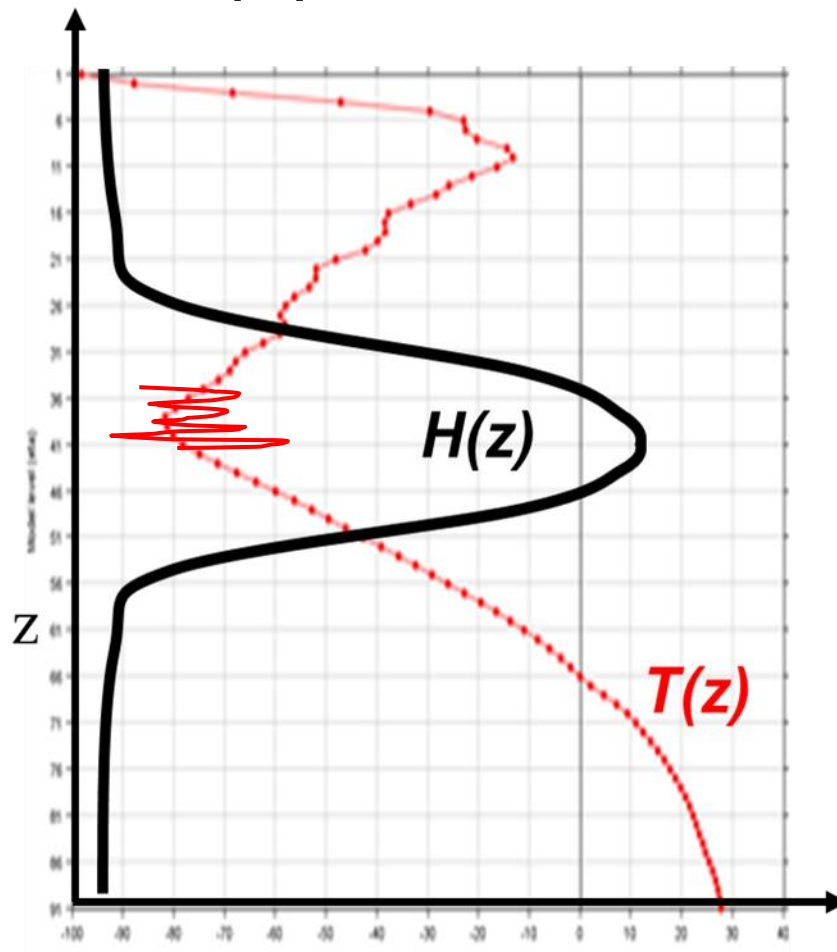


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The implications of broad weighting functions $H(z)$



In principle for a single channel an **infinite** number of different temperature profiles could produce exactly the **same measured radiance**...

The extraction of temperature information within the data assimilation for these observations is mathematically **ill-posed**

But having **lots of different channels** improves resolution...see later lecture

See paper by Rodgers 1976 Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev. Geophys.Space. Phys. 14, 609-624

What are the implications of these broad weighting functions for Data Assimilation ...?

...there are some vertical scales we cannot measure...

...the assimilation of satellite radiance data relies heavily on prior or background information ...

A QUICK REVIEW OF KEY CONCEPTS

- Satellite instruments measure radiance (not T,Q or wind)
- Downward looking satellite radiances are broad vertical averages of the temperature /humidity profile (defined by the weighting functions)
- The estimation of atmospheric temperature (or humidity) from the radiances is mathematically ill- posed and all L2 retrieval / DA algorithms rely heavily on background prior information

Questions ?

Planck's law

From Wikipedia, the free encyclopedia

(Redirected from [Planck's law of black body radiation](#))

For a general introduction, see [black body](#).

In physics, **Planck's law** describes the [spectral radiance](#) of [electromagnetic radiation](#) at all [wavelengths](#) from a [black body](#) at temperature T . As a function of [frequency](#) ν , Planck's law is written as:^[1]

$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}.$$

This function peaks for $h\nu = 2.82kT$.^[2]

As a function of wavelength λ it is written (for unit solid angle) as:^[3]

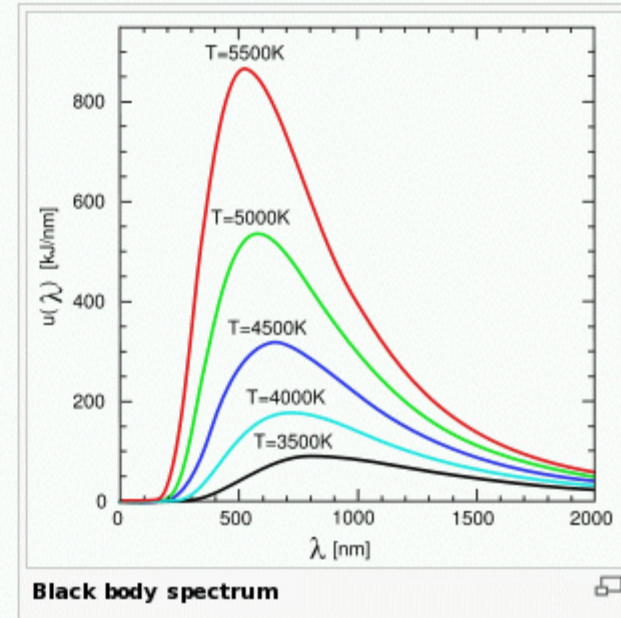
$$I(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.$$

Note also that the two functions have different units — the first is radiance per unit frequency interval while the second is radiance per unit wavelength interval. Hence, the quantities $I(\nu, T)$ and $I(\lambda, T)$ are not equivalent to each other. To derive one from the other, they cannot simply be set equal to each other (ie: the expression for λ in terms of ν cannot just be substituted into the first equation to get the second). However, the two equations are related through:

$$I(\nu, T) d\nu = -I(\lambda, T) d\lambda.$$

One can easily step from the first formula into the latter by using:

$$d\nu = d\left(\frac{c}{\lambda}\right) = c d\left(\frac{1}{\lambda}\right) = -\frac{c}{\lambda^2} d\lambda.$$



The key elements of a satellite data assimilation system

Key elements of a data assimilation system

- **observation operator**
- **background errors**
- **observation errors**
- **bias correction**
- **data selection and quality control**

Key elements of a data assimilation system

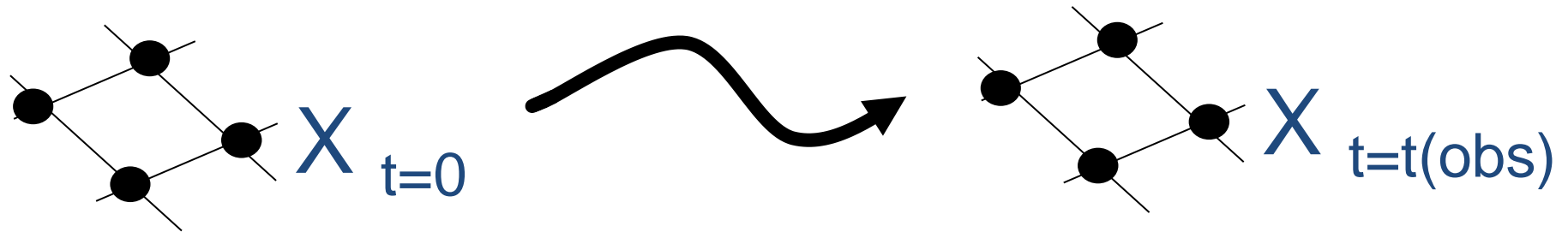
- **observation operator**
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Observation operator

- The observation operator must map the model state at beginning of the assimilation window ($t=0$) to the observation time and location.
- In the **direct assimilation of radiance observations**, the observation operator must incorporate an additional step to compute radiances from the model state variables (radiative transfer model RTTOV).
- This means that radiance observations are significantly more computationally expensive than conventional observations (e.g. radiosonde temperature data)

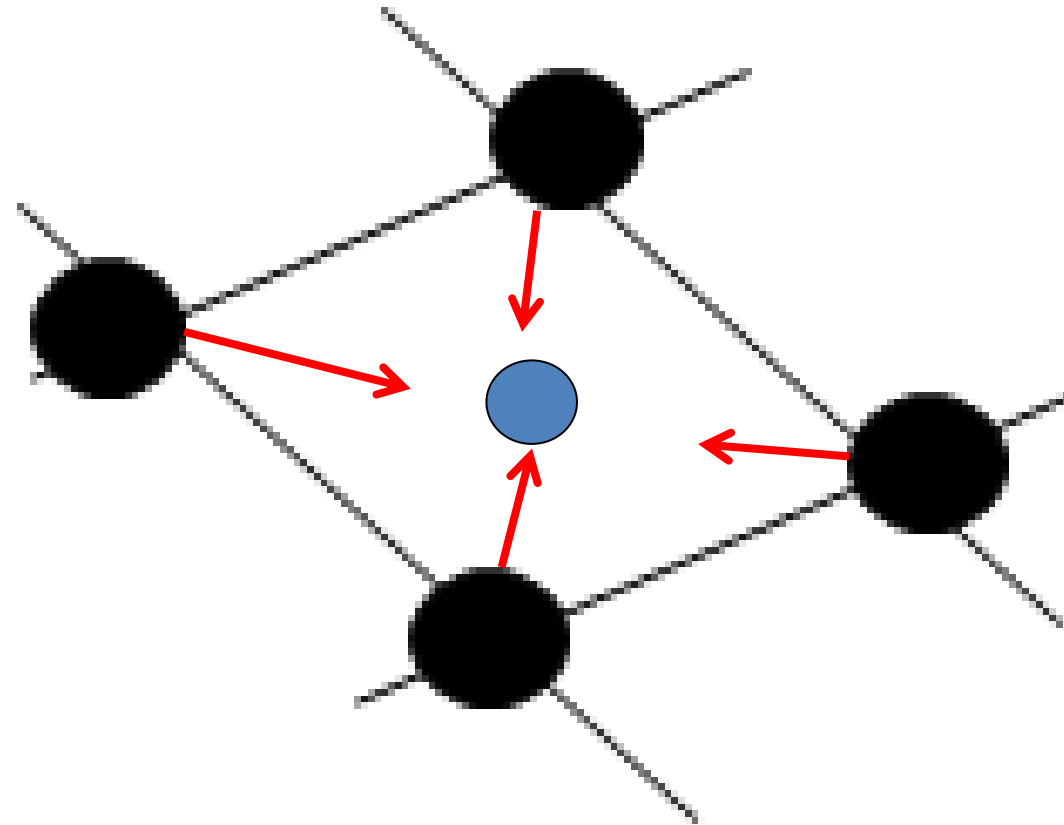
Observation operator

1) Time evolution of forecast model field to OBS time



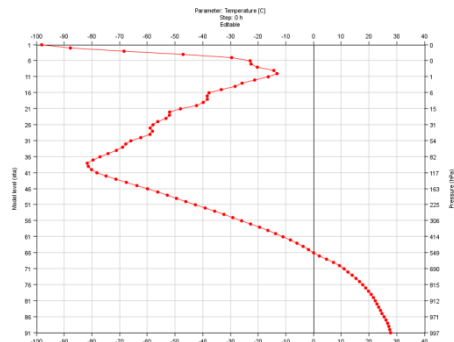
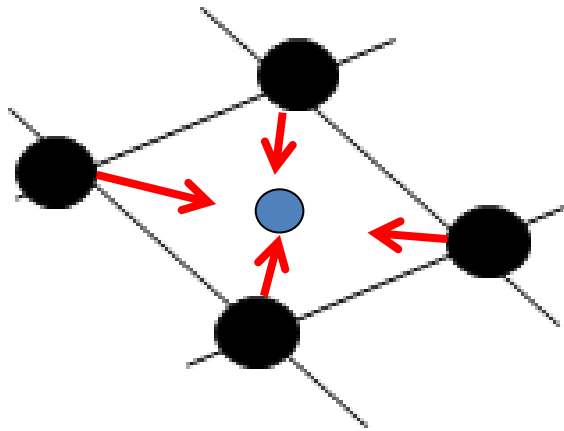
Observation operator

2) Spatial interpolation of model grid to OBS location

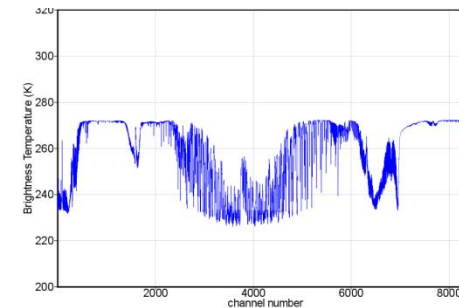
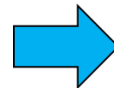


Observation operator

3) Radiative transfer calculation from model state at that location to radiances at that location



RTTOV



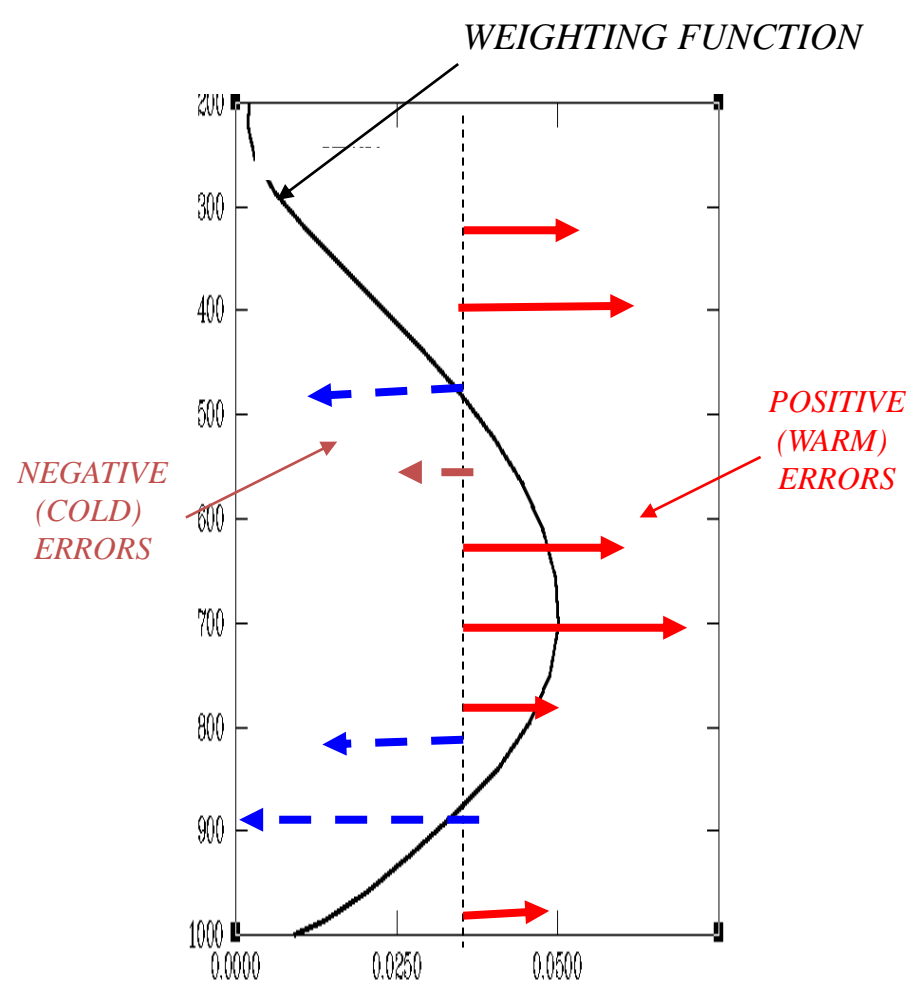
Key elements of a data assimilation system

- observation operator
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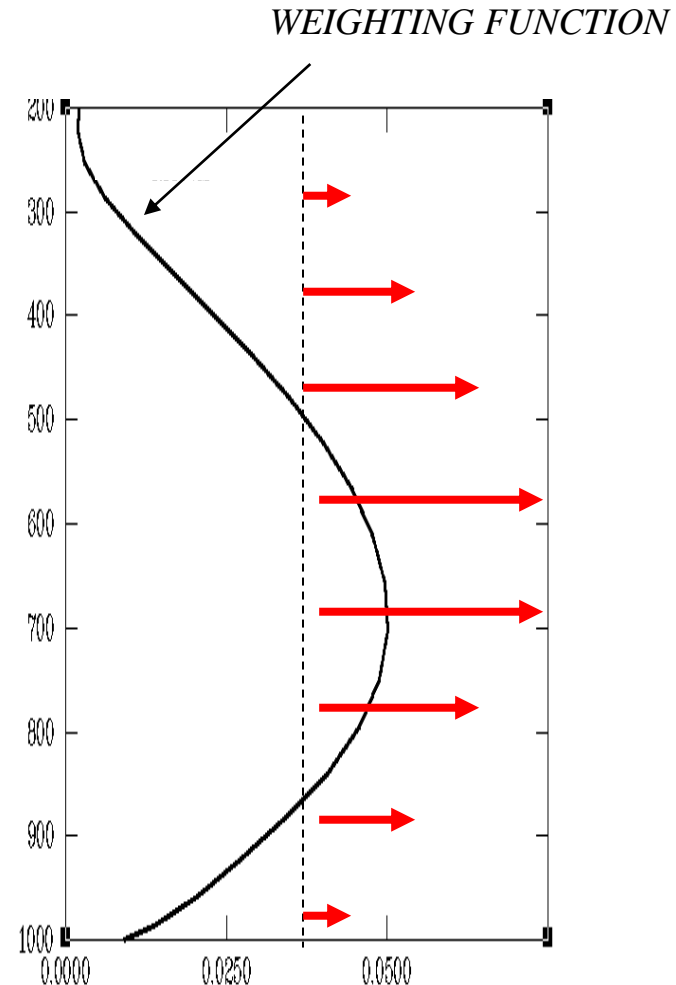
Background errors (and vertical resolution)

- The matrix B must accurately describe errors in the background estimate of the atmospheric state. It determines the weight given to the background information.
- A very important aspect for the assimilation of near-nadir viewing satellite radiances are the **vertical correlations** that describe how background errors are distributed in the vertical (sometimes called structure functions)
- These are important because satellite radiances have very **limited vertical resolution** (previous lecture)

Background errors (and vertical resolution)



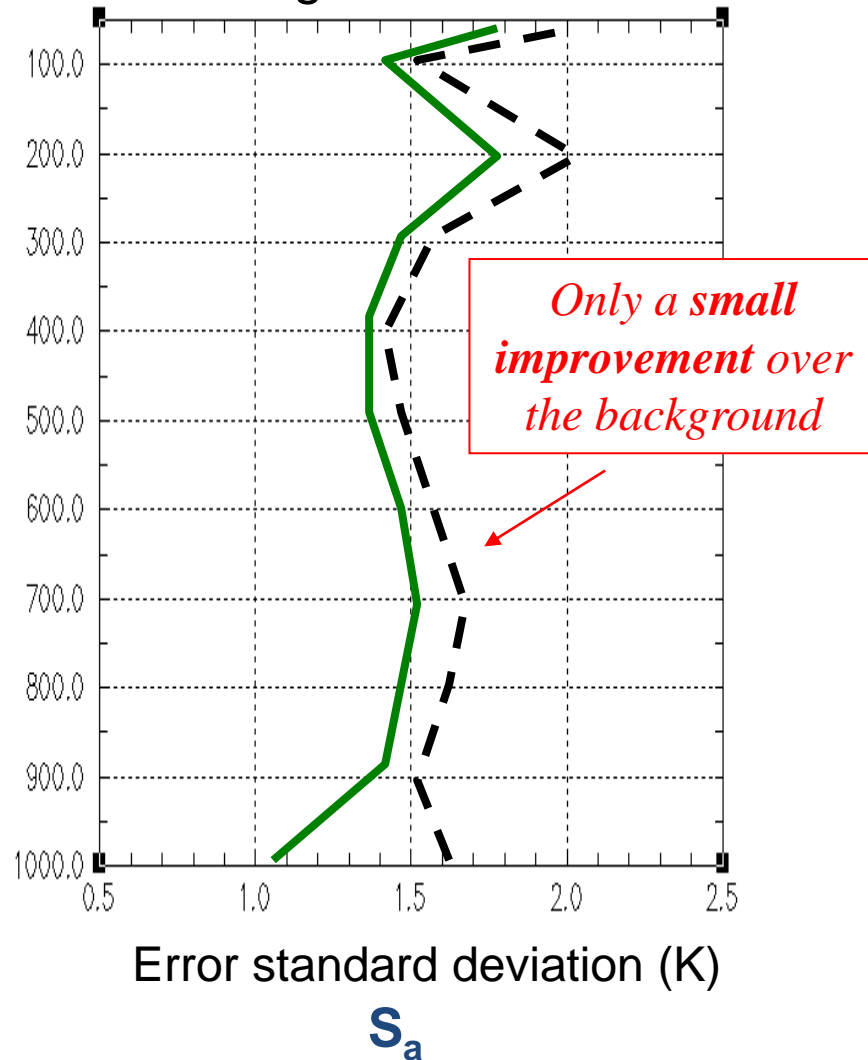
“Difficult” to correct



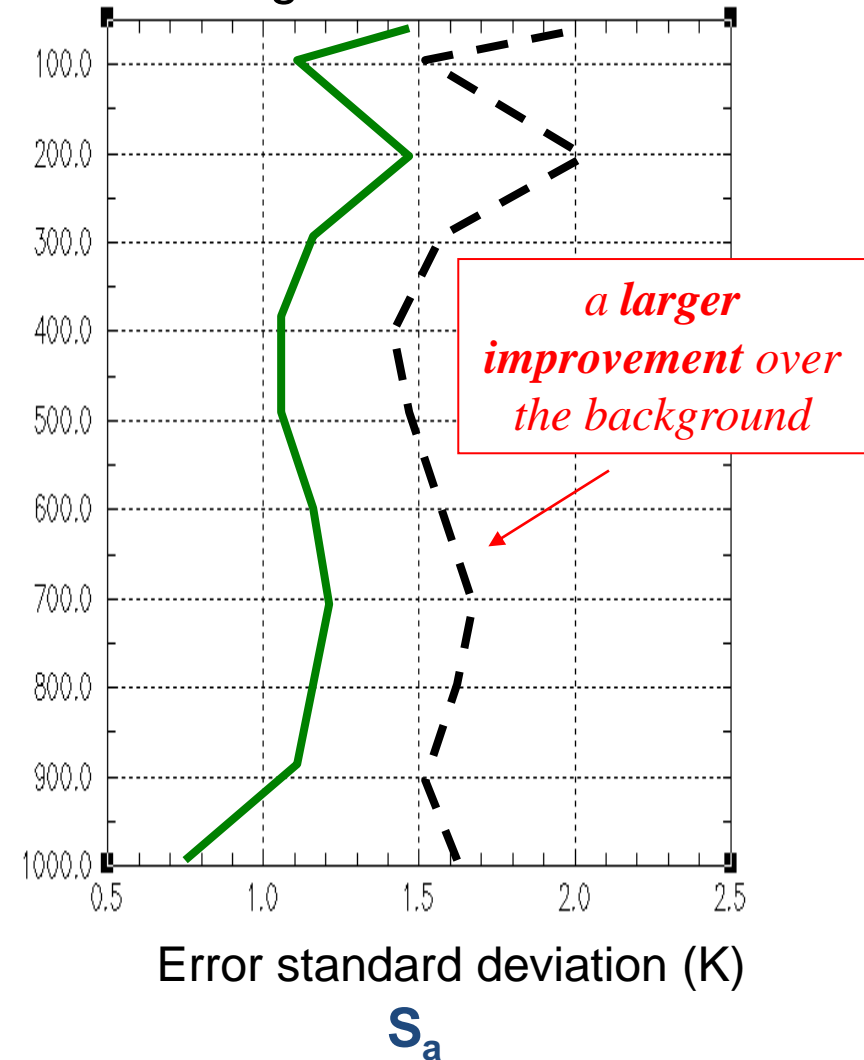
“Easy” to correct

Background errors (and vertical resolution)

Sharp / anti-correlated background errors



Broad / deep correlated background error

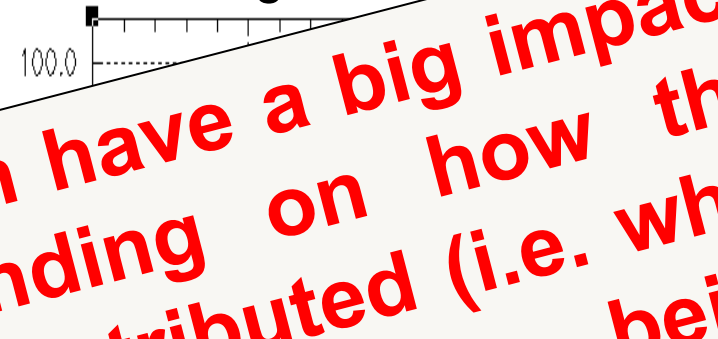


Background errors (and vertical resolution)

Sharp / anti-correlated background errors



Broad / deep correlated background errors



So the same satellite can have a big impact or small impact depending on how the background errors are distributed (i.e. what type of forecast errors are being "corrected")

Error standard deviation (K)

S_a

Error standard deviation (K)

S_a

Key elements of a data assimilation system

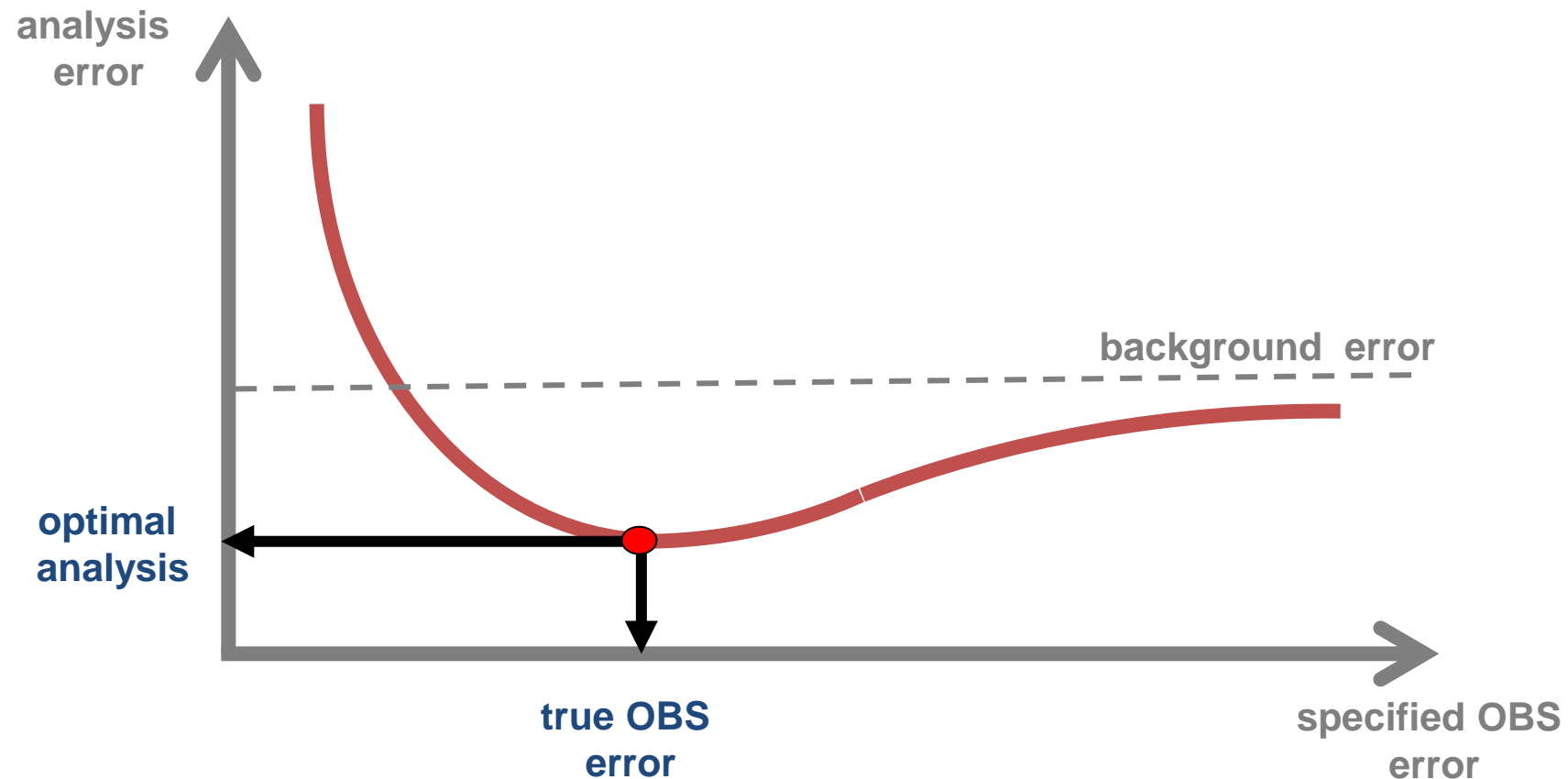
- observation operator
- background errors
- **observation errors**
- bias correction
- data selection and quality control

Observation errors:

- These determine the weight we give to the radiance observations. The observation error must account for **instrument noise**, random uncertainties in the **observation operator** (e.g. RT model), errors in data **screening** (e.g. residual clouds) and errors of representativeness (e.g. scale mismatch).
- It is important to model both the magnitude of errors (diagonals of R) and **any inter-channel correlations**
- Wrongly specified observation errors can lead to an analysis with **larger errors than the background!**

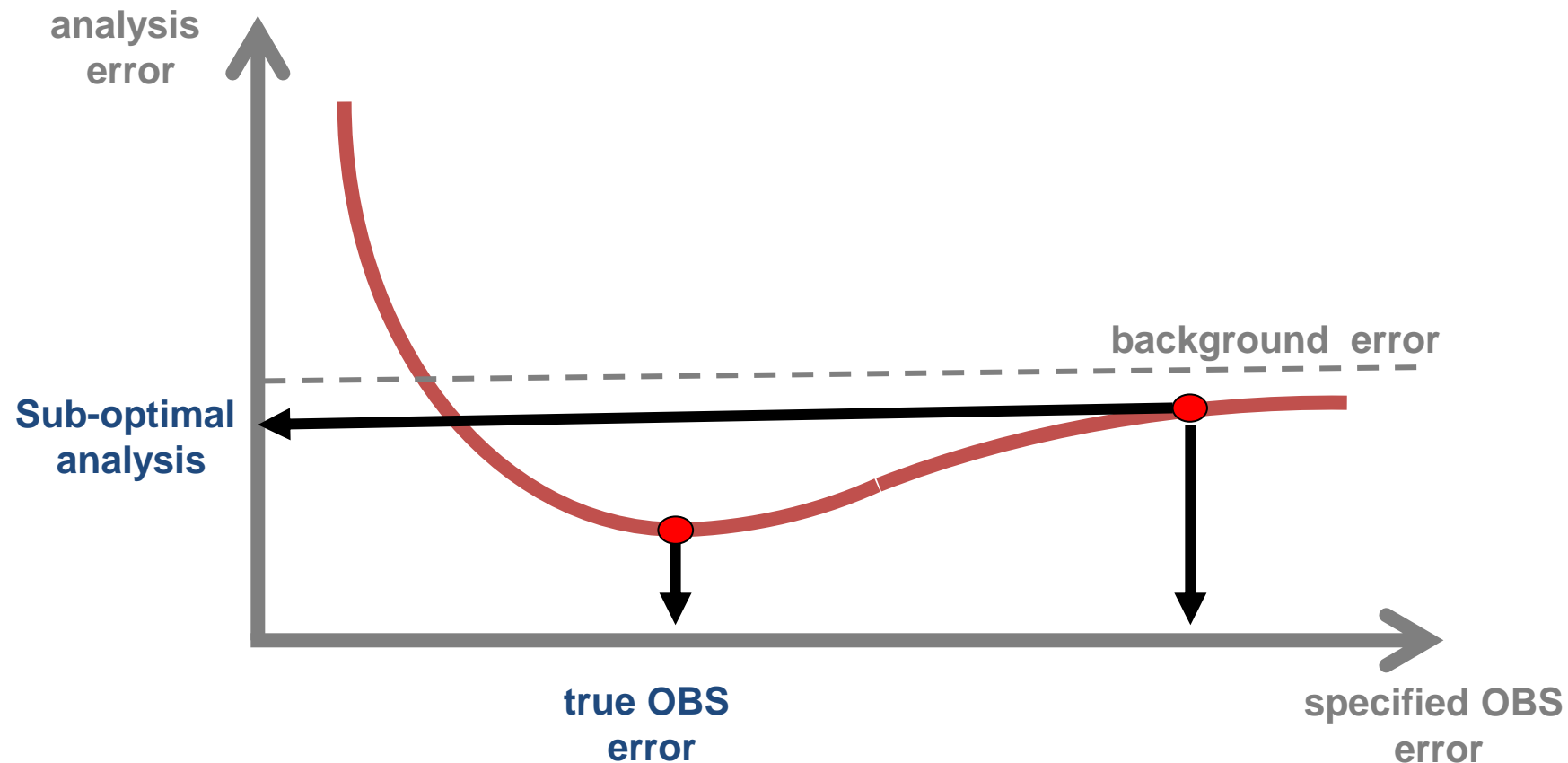
Observation errors:

- Specifying the correct observation error produces an optimal analysis with minimum error.



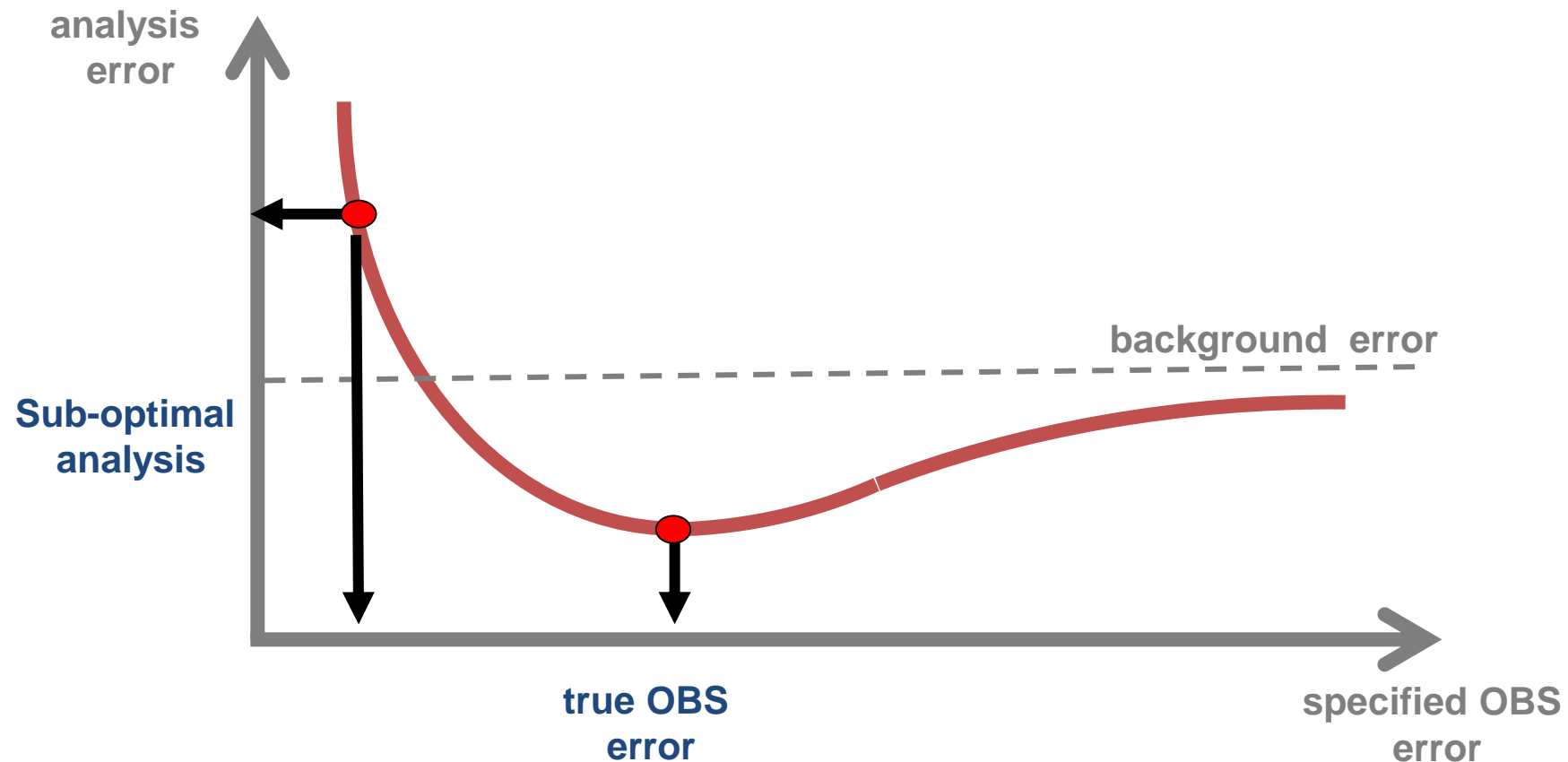
Observation errors:

- Over-estimating the OBS error degrades the analysis, but the result will not be worse than the background.



Observation errors:

- Under-estimating the OBS error degrades the analysis, and the result can be worse than the background!



Key elements of a data assimilation system

- observation operator
- background errors
- observation errors
- **bias correction**
- data selection and quality control

Bias correction:

Systematic errors must be removed otherwise biases will propagate in to the analysis (causing **global damage** in the case of satellites!). A bias in the radiances is defined as:

$$\textit{bias} = \textit{mean} [Y_{\text{obs}} - H(X_{\text{true}})]$$

Sources of systematic error in radiance assimilation include:

- instrument error (scanning or calibration)
- radiative transfer error (spectroscopy or RT model)
- cloud / rain / aerosol screening errors

Key elements of a data assimilation system

- observation operator
- background errors
- observation errors
- bias correction
- **data selection and quality control**

Data selection and quality control (QC):

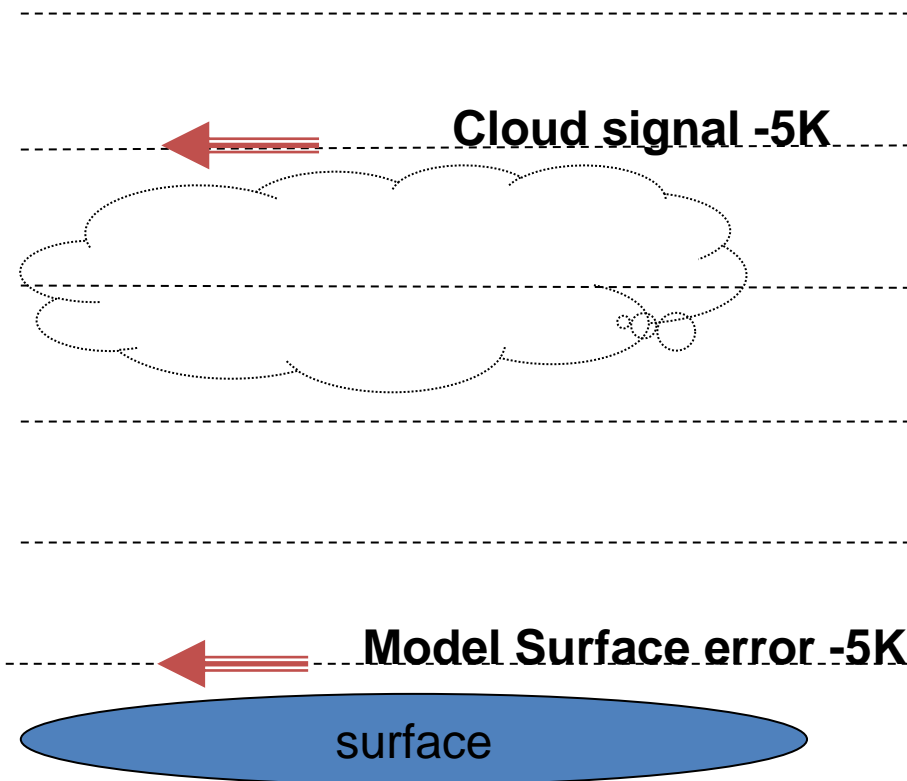
The primary purpose of this is to ensure that the observations entering the analysis are consistent with the assumptions in the observations error covariance (\mathbf{R}) and the observation operator (\mathbf{H}).

Primary examples include the following:

- Rejecting bad data with **gross error** (not described by \mathbf{R})
- Rejecting data affected by **clouds** if \mathbf{H} is a clear sky RT
- Thinning data if no **correlation** is assumed (in \mathbf{R})
- Always **blacklisting** data where we do not trust our QC!

Data selection and quality control:

- Missed rejection of a **bad** observation



The radiance are contaminated by cloud (**cold 5K**) compared to the clear sky value.

But our computation of the clear sky value from the background is also **cold by 5K** due to an error in the surface skin temperature.

Thus our checking (against the background) sees no reason to reject the observation and is it **passed!**

Summary

- **observation operator**
(complex and expensive for radiances)
- **background errors**
(important due to limited vertical resolution)
- **observation errors**
(a challenge to specify correctly)
- **bias correction**
(small, but global impact of bias)
- **data selection and quality control**
(primarily data selection, few bad observations)

Questions ?

Spare slides

TRAINING
COURSE

**EUMETSAT/
ECMWF
NWP-SAF
satellite data
assimilation**

4–7 May 2021



ECMWF/EUMETSAT NWP-SAF Satellite data assimilation Training Course

**Why do we need satellites
and what do they measure ?**

May 2021

Observation operator (RT component)

- The RT model should produce an accurate simulation of the satellite radiance from the model state, based upon the best knowledge of the instrument characteristics and up to date spectroscopic information.
- However, the model must be fast enough to process huge quantities of data in near real time (thus line-by-line models are not suitable)
- In addition, the adjoint and tangent linear versions of the RT model are required by the algorithm that minimises the cost function
- Ideally the same RT model should be used for all satellite sensors being assimilated