ECMWF Training Course on Data Assimilation

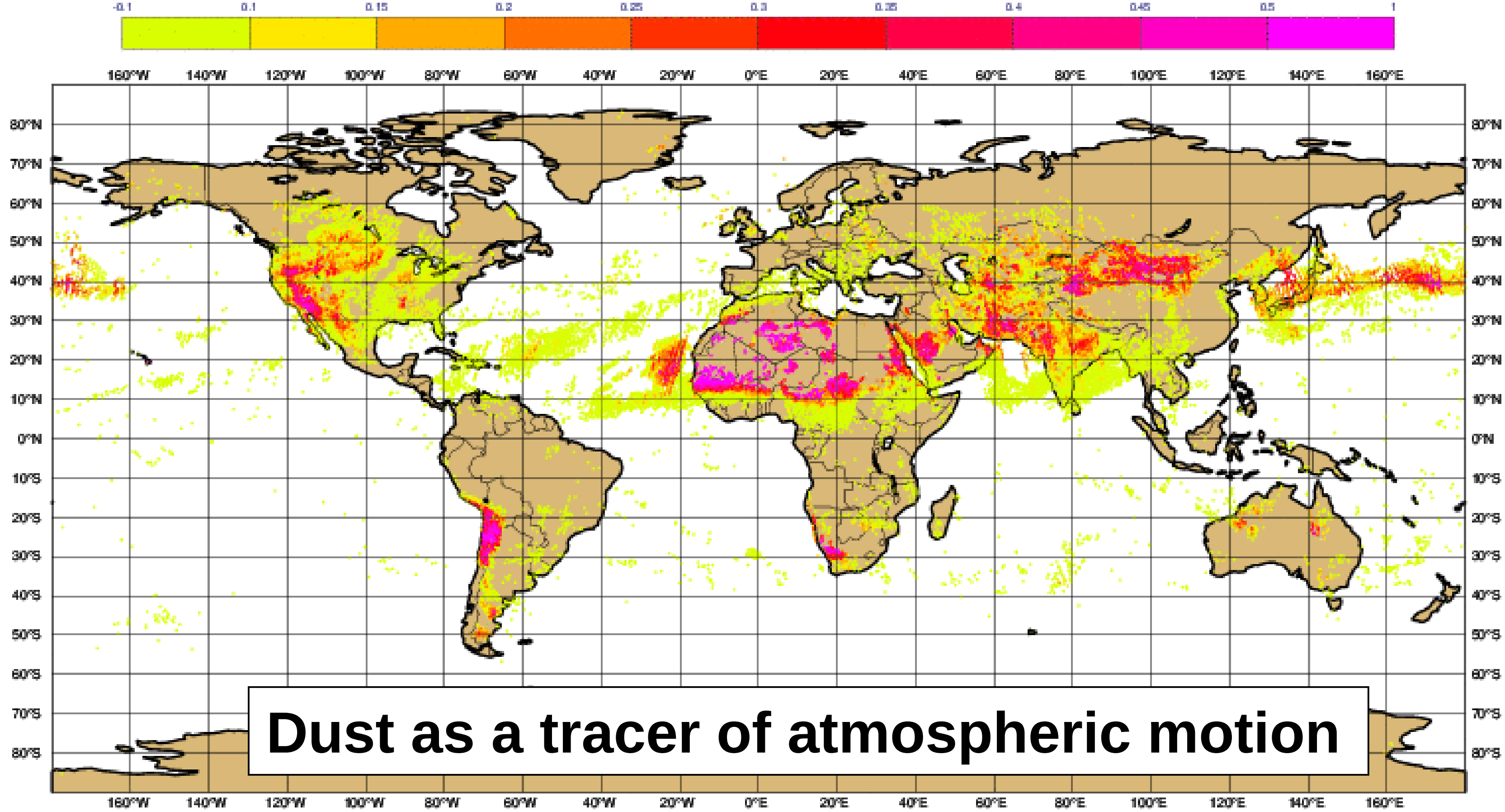
The Analysis of Satellite Radiance Observations

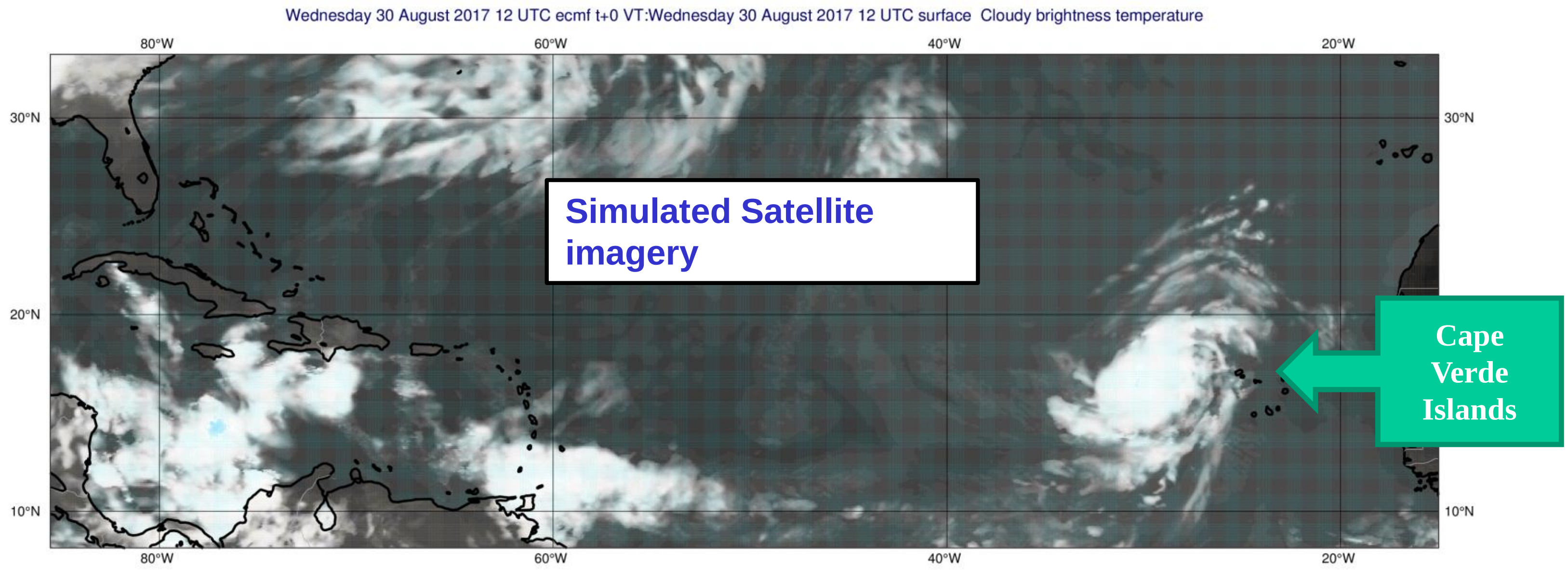
Tony McNally
12 March 2019

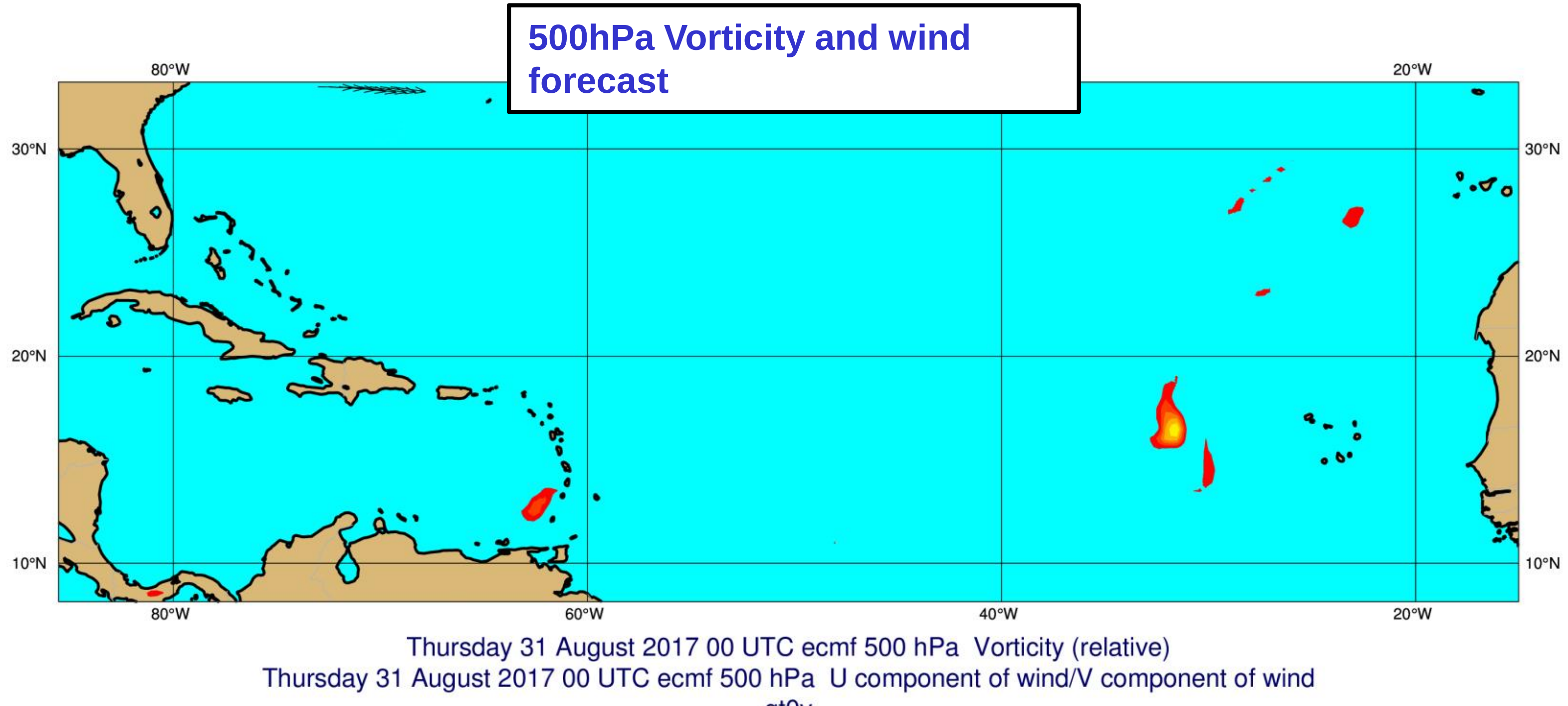
Why do we need satellites ?

Why do we need satellites ?

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

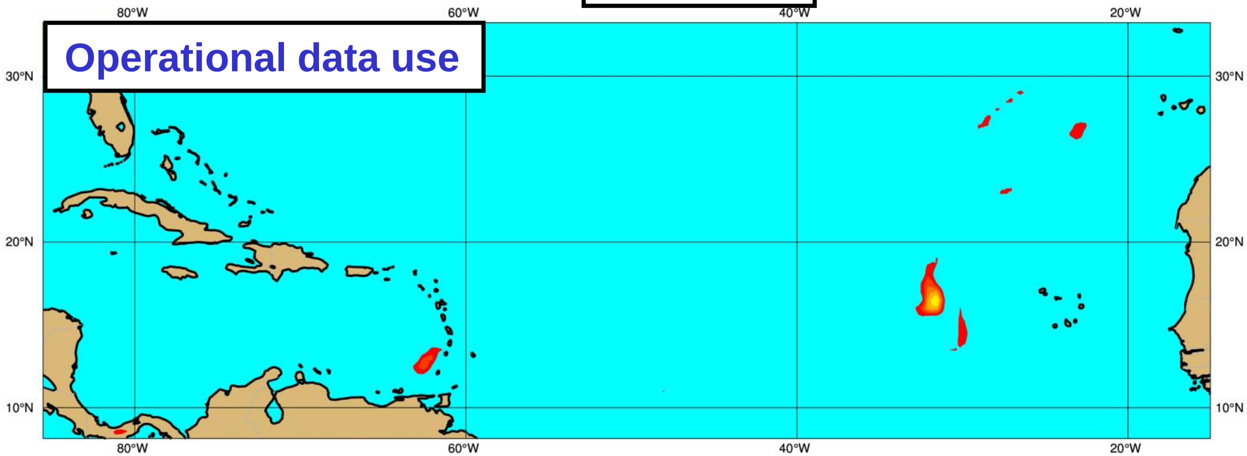



Wednesday 30 August 2017 12 UTC ecmf t+0 VT:Wednesday 30 August 2017 12 UTC surface Cloudy brightness temperature
Simulated Satellite imagery
Cape Verde Islands
80°W
60°W
40°W
20°W
30°N
20°N
10°N

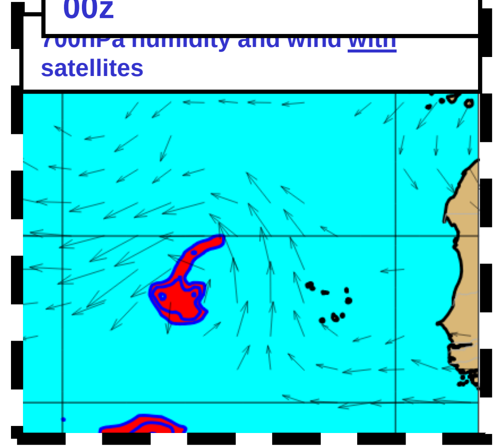

500hPa Vorticity and wind forecast
80°W
60°W
40°W
20°W
30°N
20°N
10°N
Thursday 31 August 2017 00 UTC ecmf 500 hPa Vorticity (relative)
Thursday 31 August 2017 00 UTC ecmf 500 hPa U component of wind/V component of wind

FORECAST

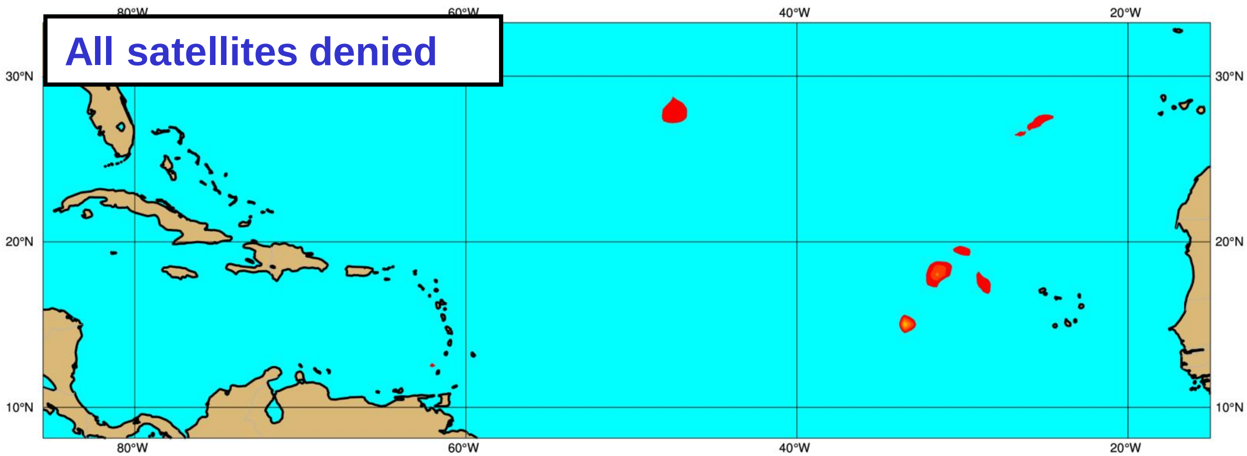
INITIAL CONDITIONS 31/8 00z

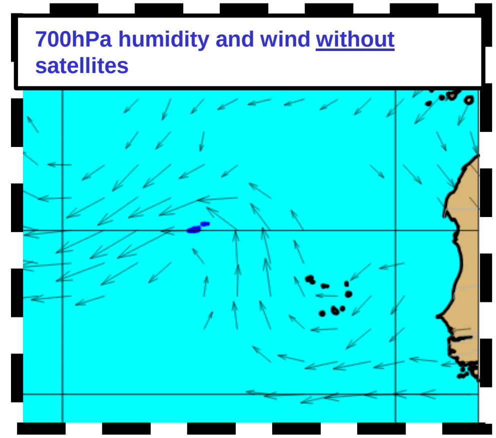


Thursday 31 August 2017 00 UTC ecmf 500 hPa Vorticity (relative)
Thursday 31 August 2017 00 UTC ecmf 500 hPa U component of wind/V component of wind
gt0v



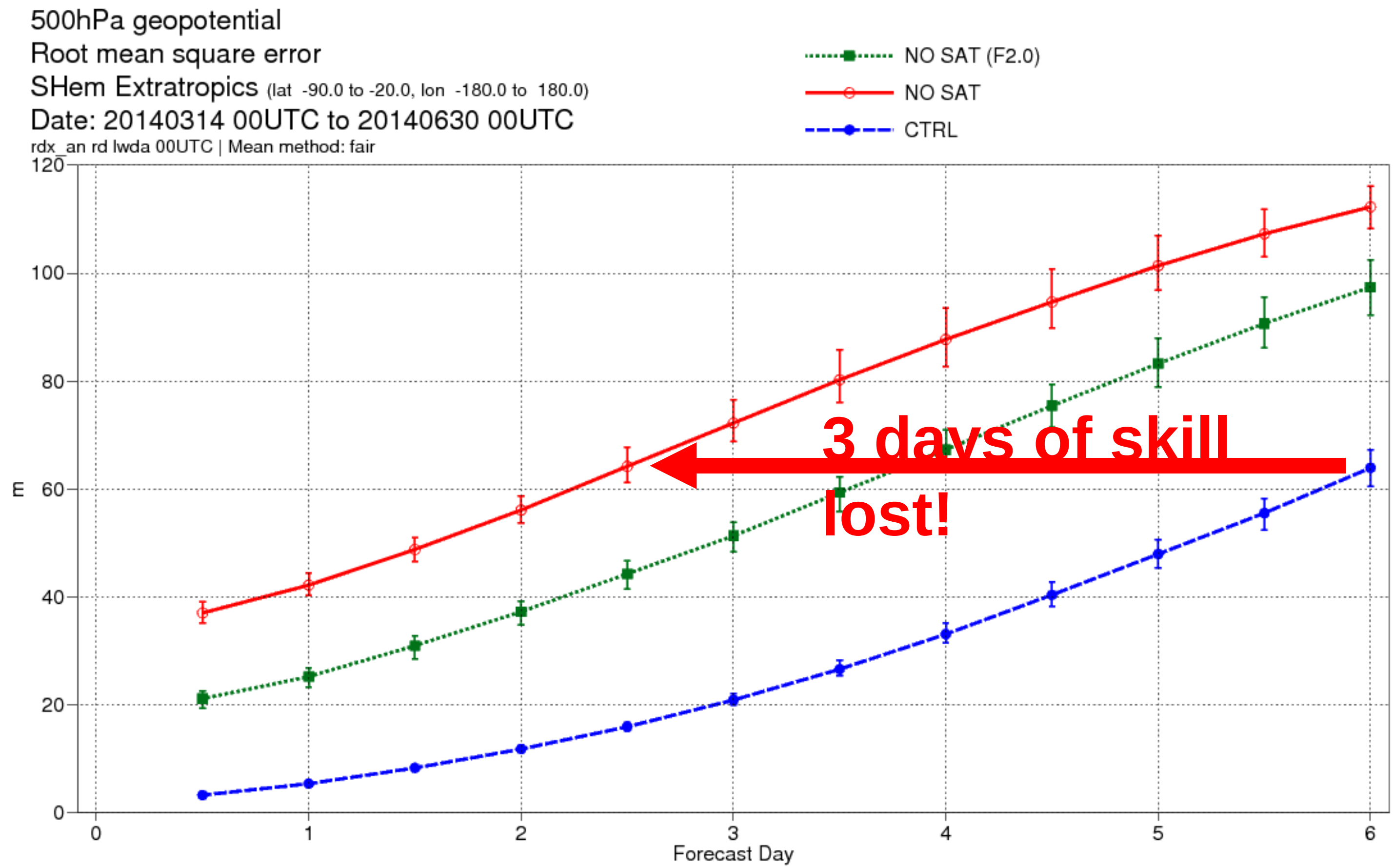
Red shading humidity > 95%





Can we quantify how important satellites radiance are ?

Can we quantify how important satellites radiance are ?



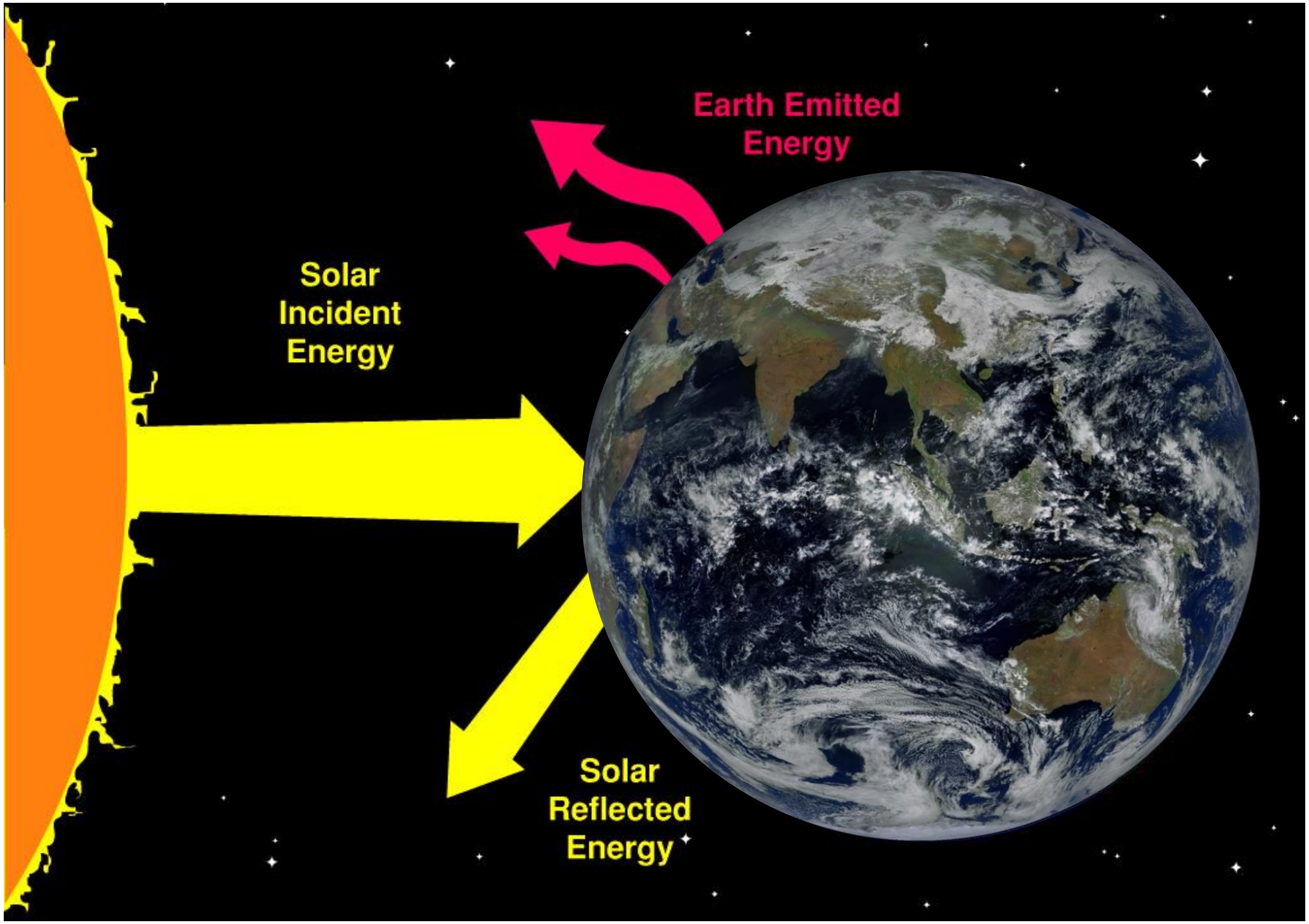
What do satellite instruments measure ?

They **DO NOT** measure TEMPERATURE

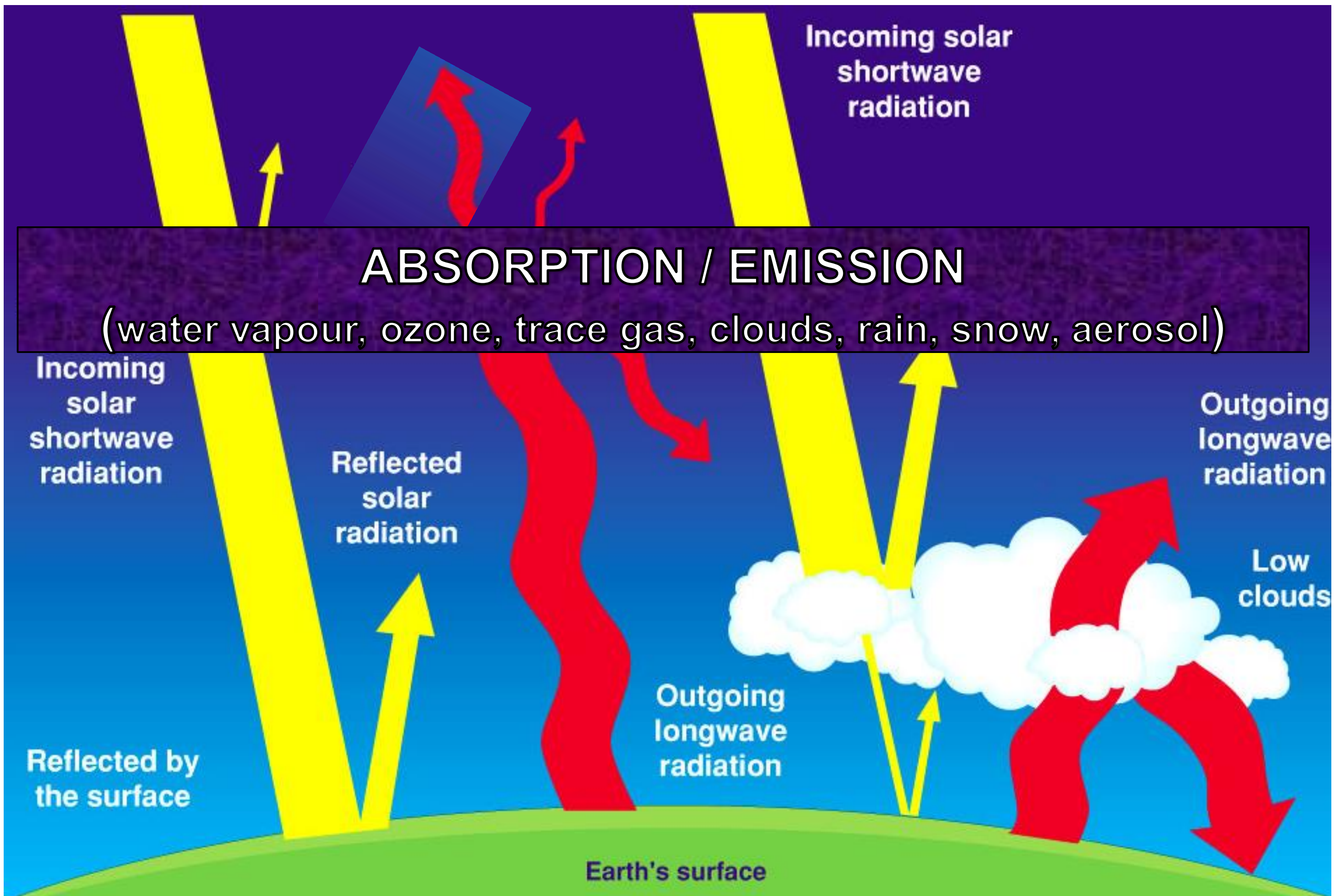
They **DO NOT** measure HUMIDITY or OZONE

They **DO NOT** measure WIND

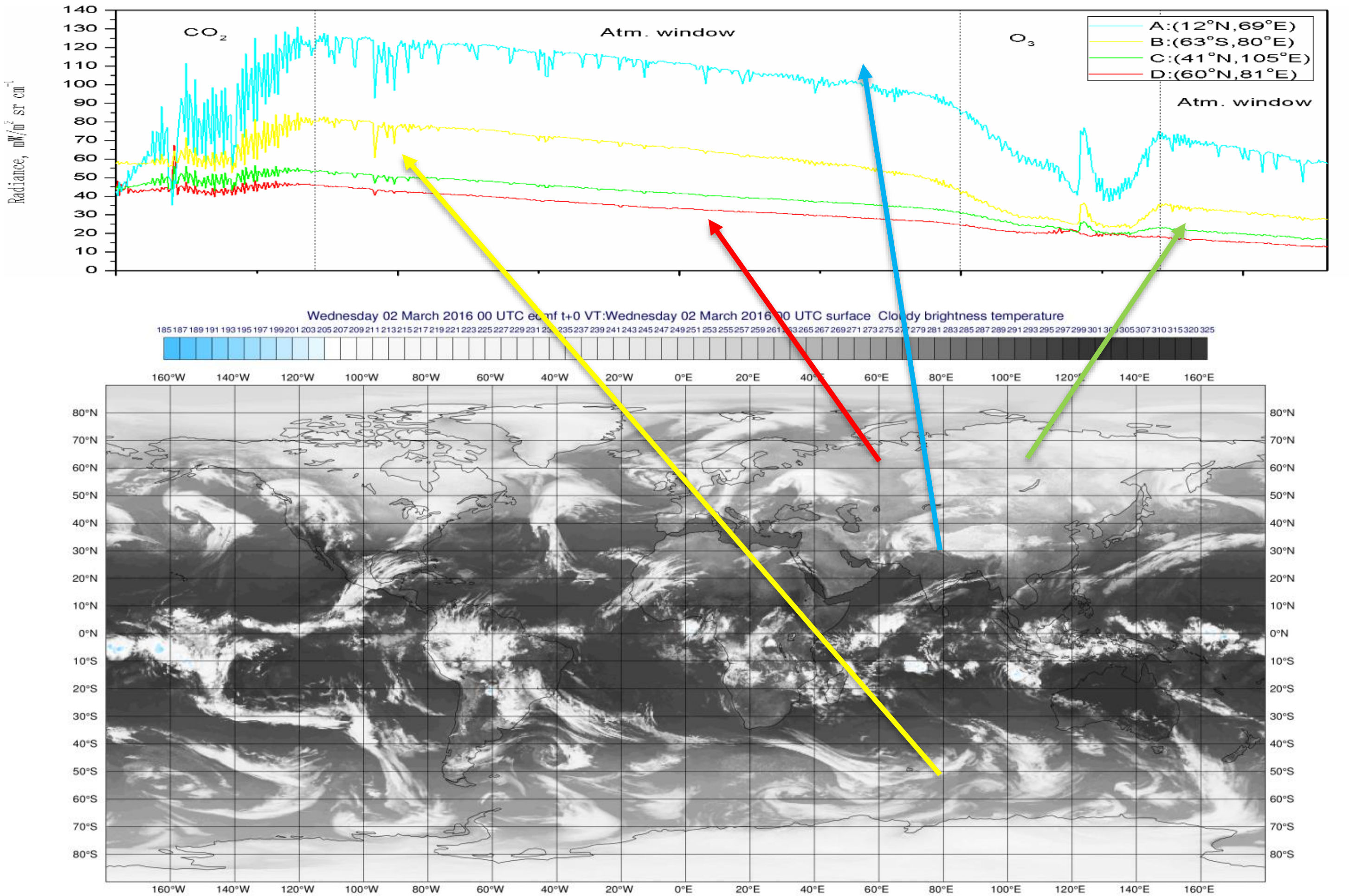
SATELLITES CAN <u>ONLY</u> MEASURE OUTGOING THERMAL RADIATION FROM THE ATMOSPHERE



SATELLITES CAN ONLY MEASURE OUTGOING THERMAL RADIATION FROM THE ATMOSPHERE



Every atmosphere has its own complex spectral fingerprint …



What do satellite instruments measure?

Satellite instruments measure the radiance 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

$$\overbrace{L(\nu)}^{\text{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu,T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz \;+\; \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots}^{\text{Our description of the atmosphere}}$$

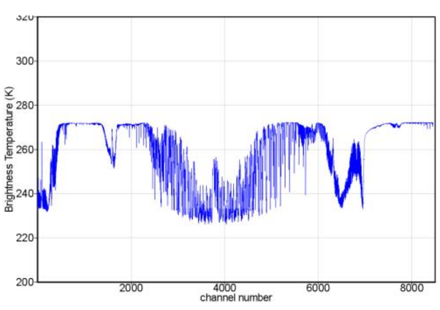
Planck source term* depending on temperature of the atmosphere

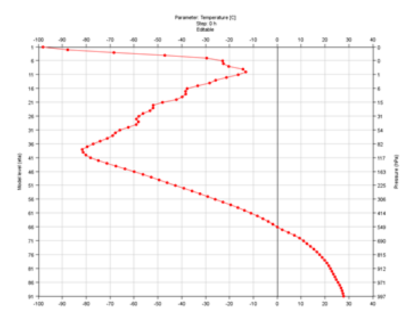
Absorption in the atmosphere

Other contributions to the measured radiances

The Radiative Transfer (RT) equation

$$\overbrace{L(\nu)}^{\textbf{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz \;+\; \textbf{Surface emission} \;+\; \textbf{Surface reflection/scattering} \;+\; \textbf{Cloud/rain contribution} \;+\; \ldots}^{\textbf{depends on the state of the atmosphere}}$$





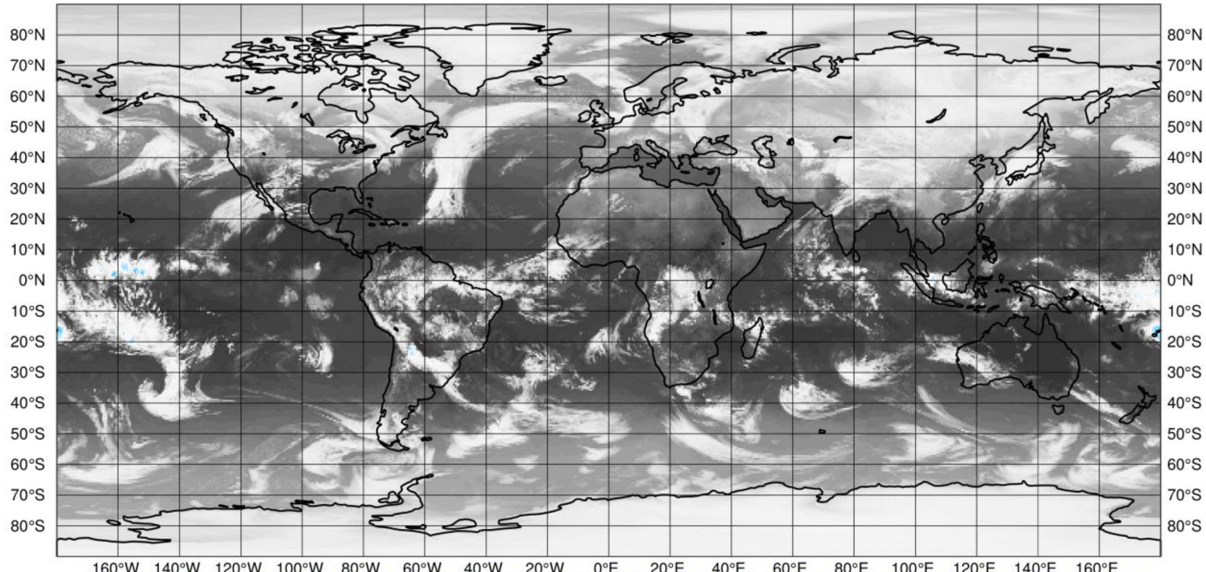
The Radiative Transfer (RT) equation

"Forward problem"

$$\overbrace{L(\nu)}^{\text{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu,T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots}^{\text{depends on the state of the atmosphere}}$$

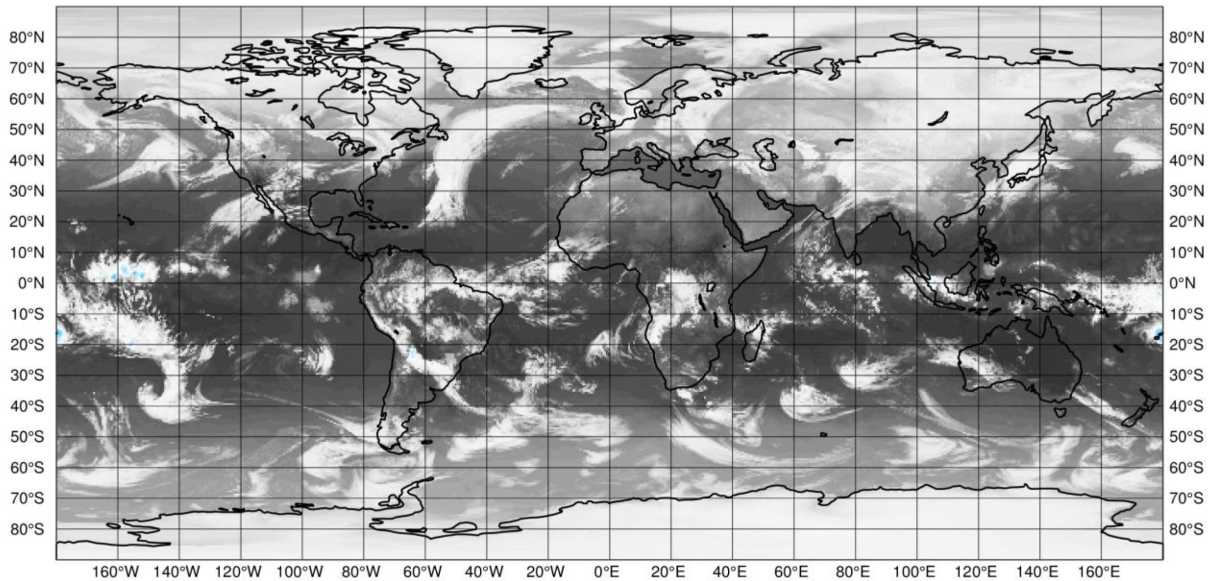
…given the state of the atmosphere, what is the radiance…?

Saturday 20 February 2016 00 UTC ecmf t+0 VT:Saturday 20 February 2016 00 UTC surface Cloudy brightness temperature



Radiation simulated from forecast state

Saturday 20 February 2016 00 UTC ecmf t+0 VT:Saturday 20 February 2016 00 UTC surface Cloudy brightness temperature



Radiation simulated from analysis state

The Radiative Transfer (RT) equation

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

$$\overbrace{L(\nu)}^{\text{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu,T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz + \text{Surface emission} + \text{Surface reflection/ scattering} + \text{Cloud/rain contribution} + \ldots}^{\text{depends on the state of the atmosphere}}$$

"Inverse problem"

The Radiative Transfer (RT) equation

"Forward problem"

OBSERVATION OPERATOR

$$\overbrace{L(\nu)}^{\text{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu, T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots}^{\text{depends on the state of the atmosphere}}$$

MINIMISATION

"Inverse problem"

How can we simplify the forward and inverse problems

?

Channel selection

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.

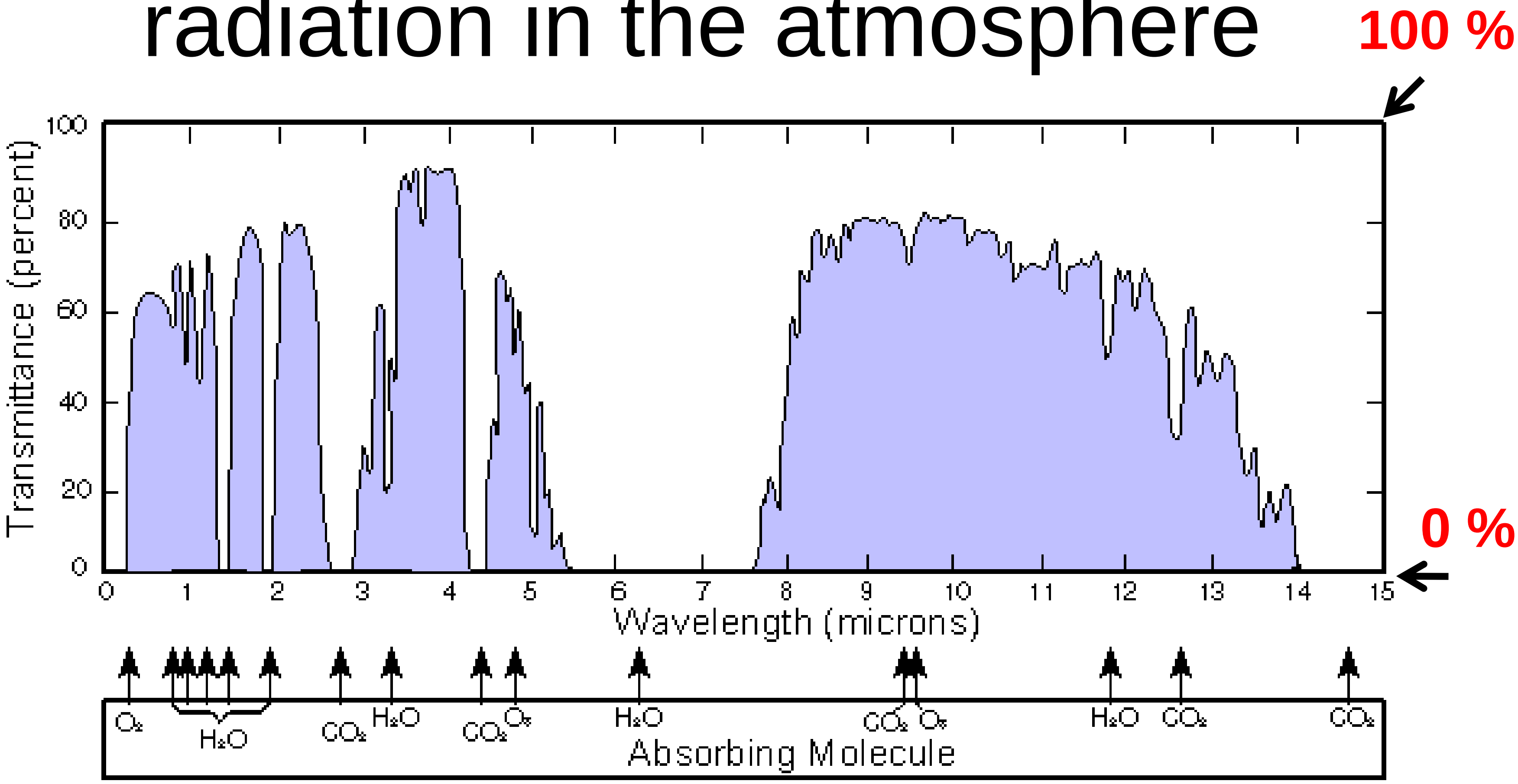
In general, the frequencies / channels used within NWP may be categorized as one of 3 different types …

1. **atmospheric sounding** channels (**passive** instruments)
2. **surface sensing** channels (**passive** instruments)
3. **surface sensing** channels (**active** instruments)

Note:

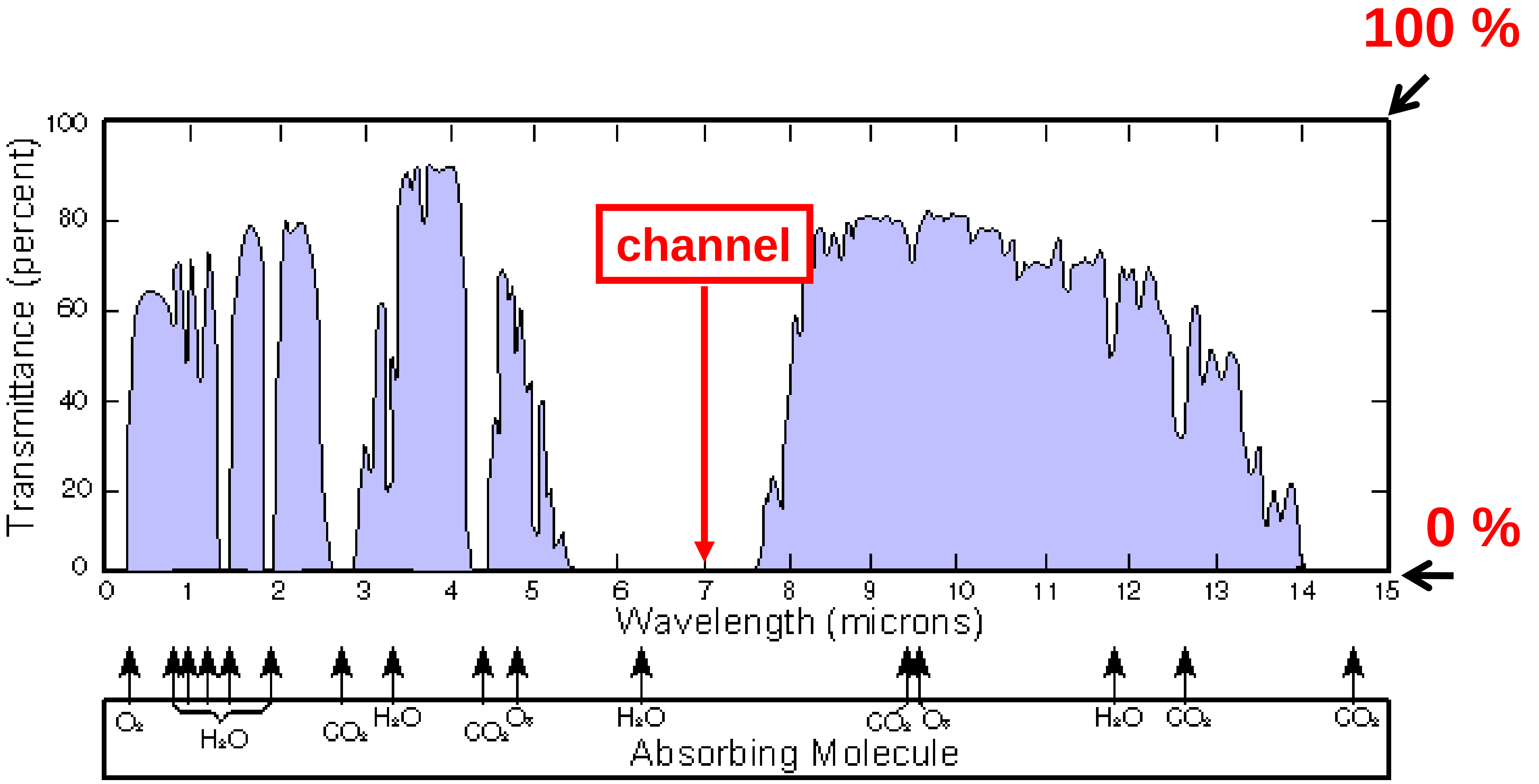
In practice (and often despite their name!) real satellite instruments have channels which are a **combination** *of atmospheric sounding and surface sensing channels*

Example:
absorption / emission of infrared radiation in the atmosphere

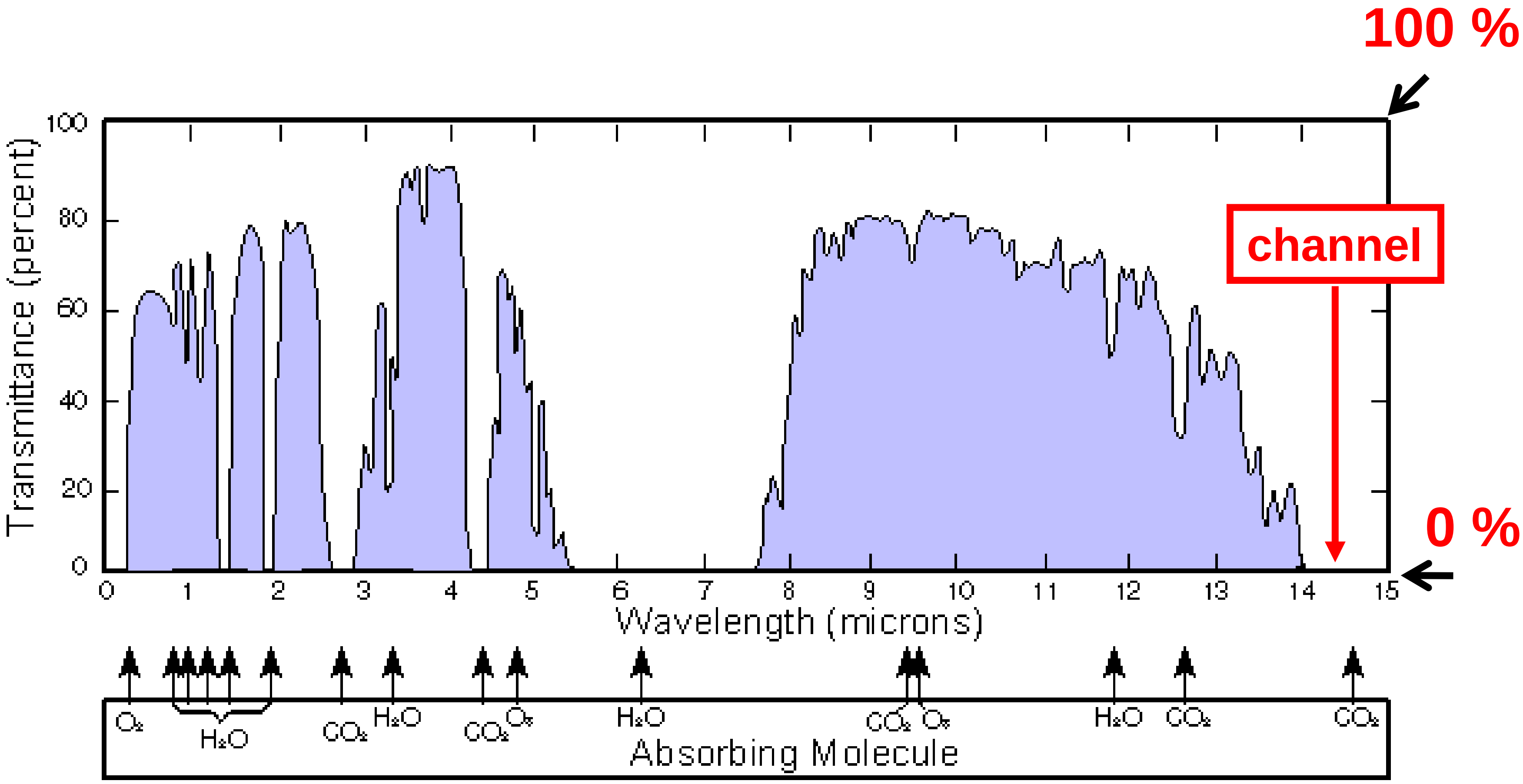


Atmospheric sounding channels

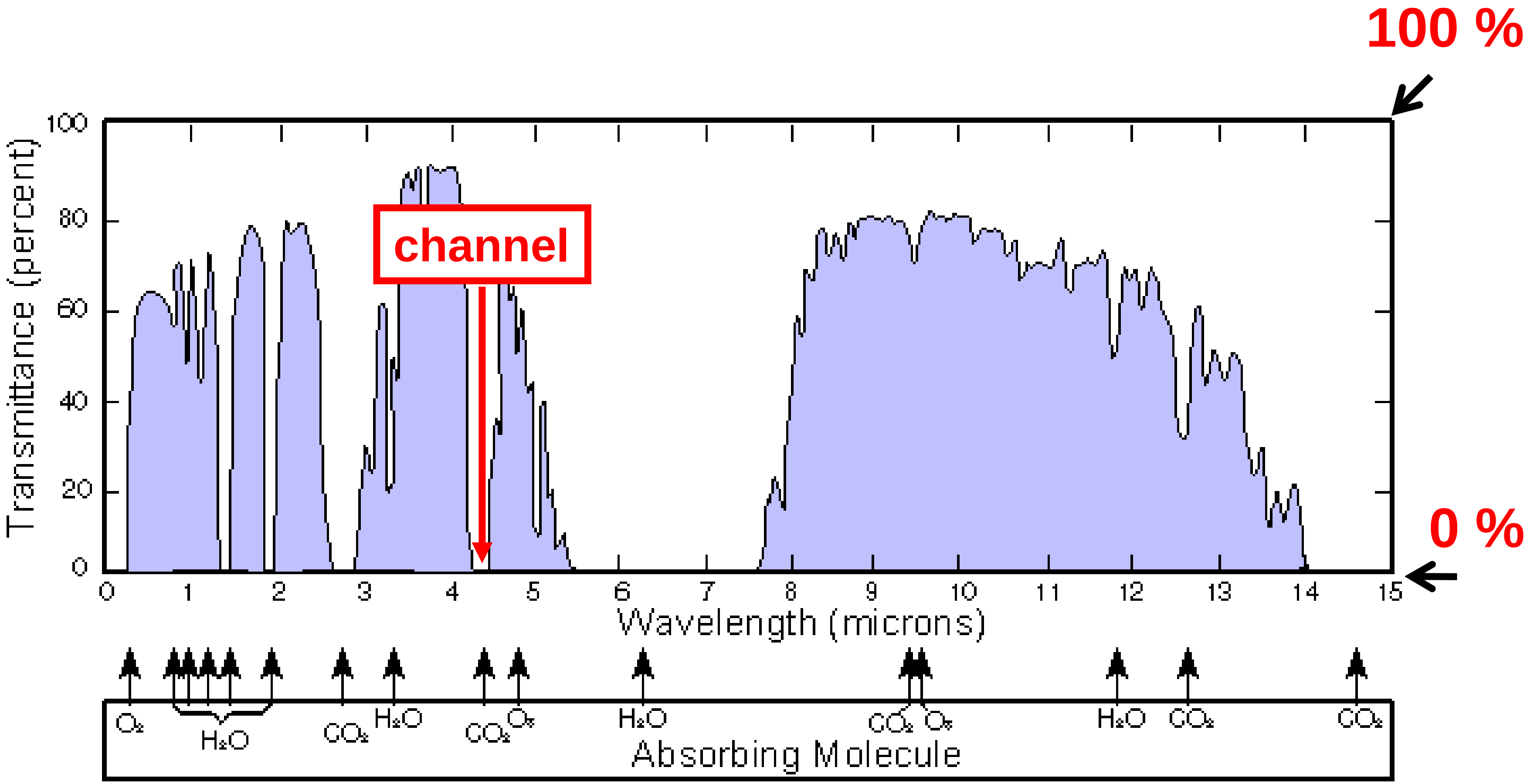
Atmospheric sounding channels



Atmospheric sounding channels



Atmospheric sounding channels



Atmospheric sounding channels

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

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

Atmospheric sounding channels

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

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Atmospheric sounding channels

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

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

\+ ~~Surface emission~~ + ~~Surface reflection/ scattering~~ + ~~Cloud/rain contribution~~ + …

Screen data to remove clouds / rain

ATMOSPHERIC SOUNDING CHANNELS

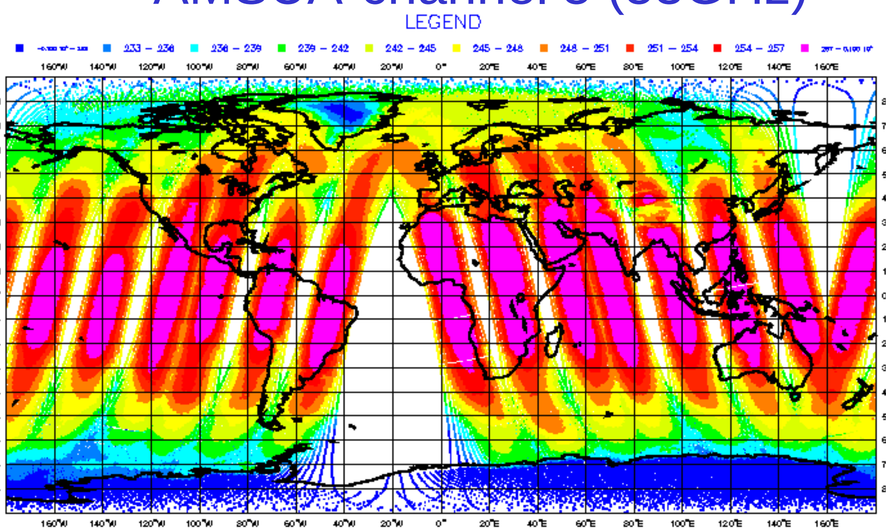
These channels are located in parts of the infra-red and microwave spectrum for which the main contribution to the measured radiance is from the **atmosphere** and can be written:

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

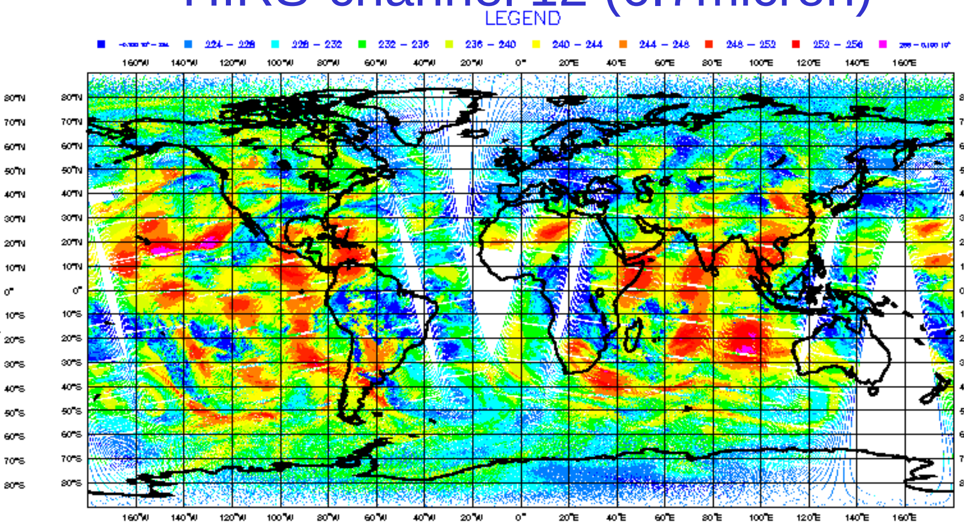
Where B=Planck function
t = transmittance
T(z) is the temperature
z is a height coordinate

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. CO_2).

AMSUA-channel 5 (53GHz)



HIRS-channel 12 (6.7micron)



Surface sensing Channels (passive)

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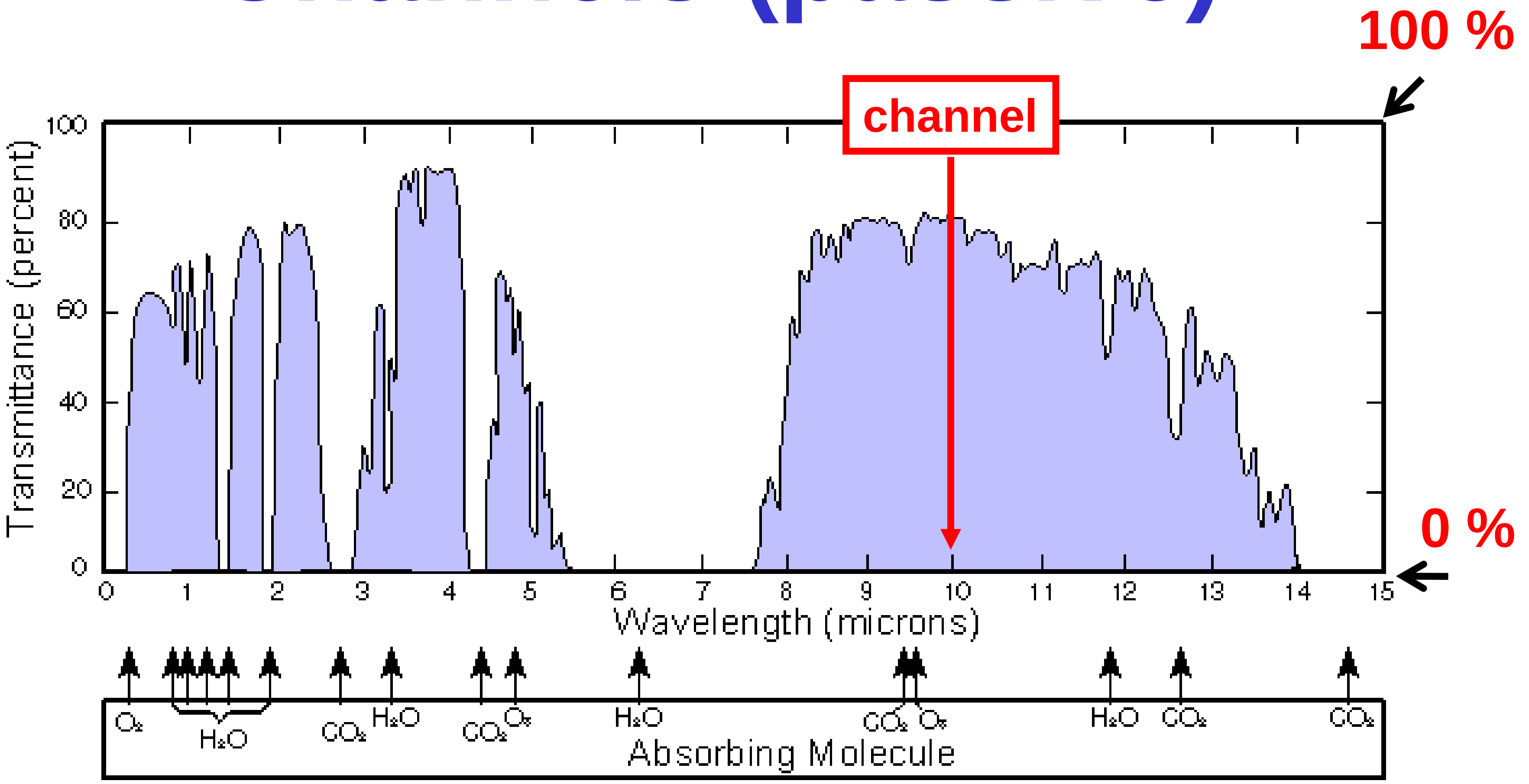
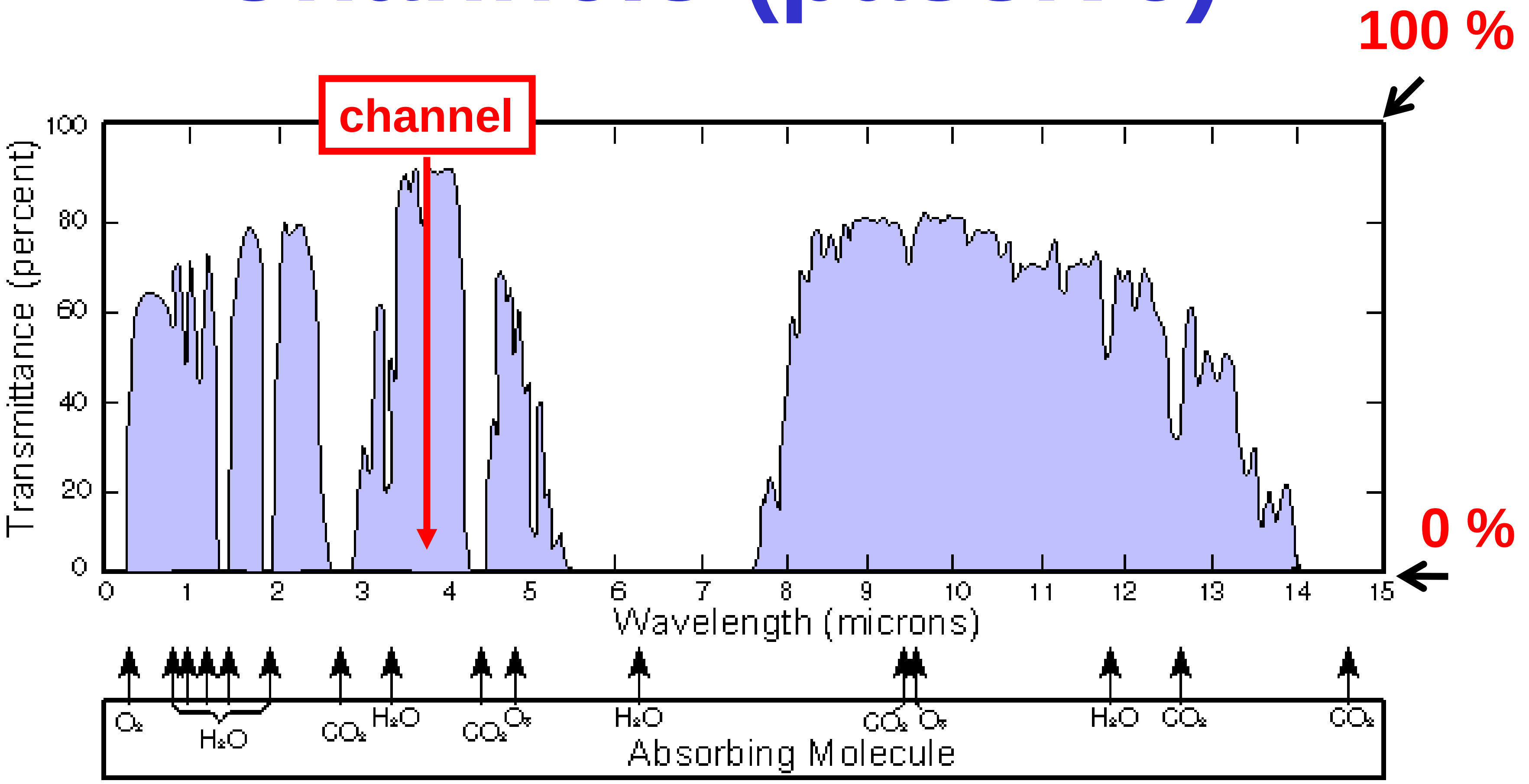


Surface sensing Channels (passive)



Surface sensing Channels (passive)

…selecting channels where there is no contribution from the atmosphere….

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

Surface sensing Channels (passive)

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

Surface sensing Channels (passive)

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

IR ~ zero

Surface sensing Channels (passive)

…selecting channels where there is no contribution from the atmosphere….

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

Screen data to remove clouds / rain

SURFACE SENSING CHANNELS (PASSIVE)

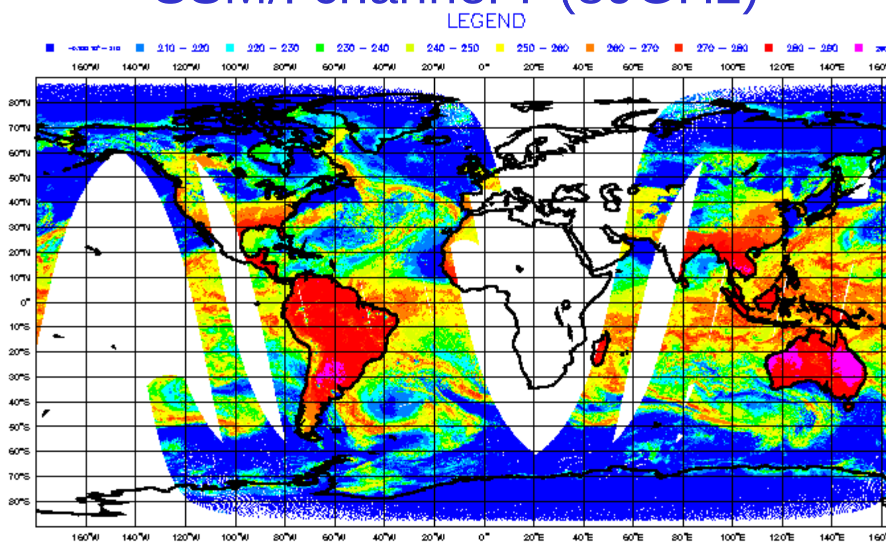
These are located in **window regions** of the infra-red and microwave spectrum at frequencies where there is very little interaction with the atmosphere and the primary contribution to the measured radiance is:

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

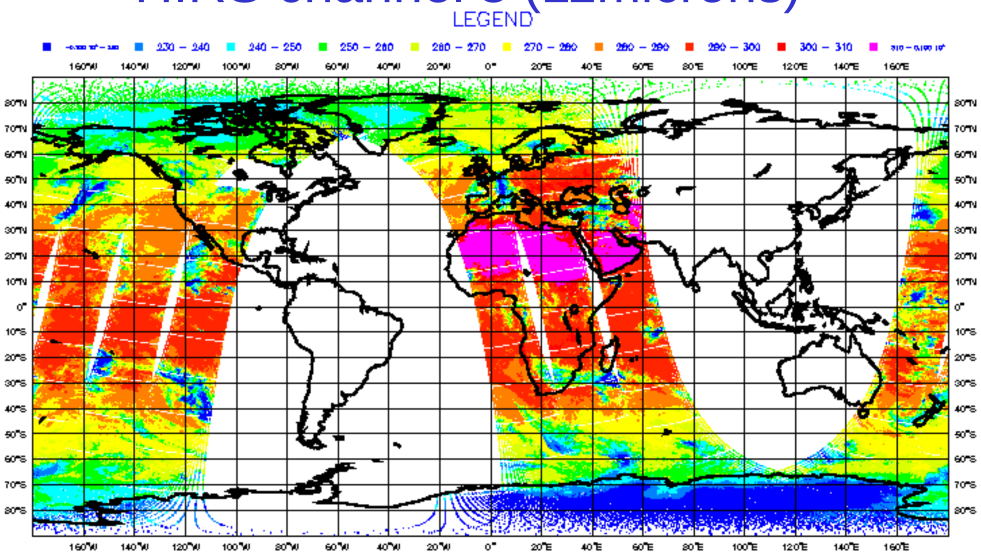
Where T_{surf} is the surface skin temperature and E the surface emissivity

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)

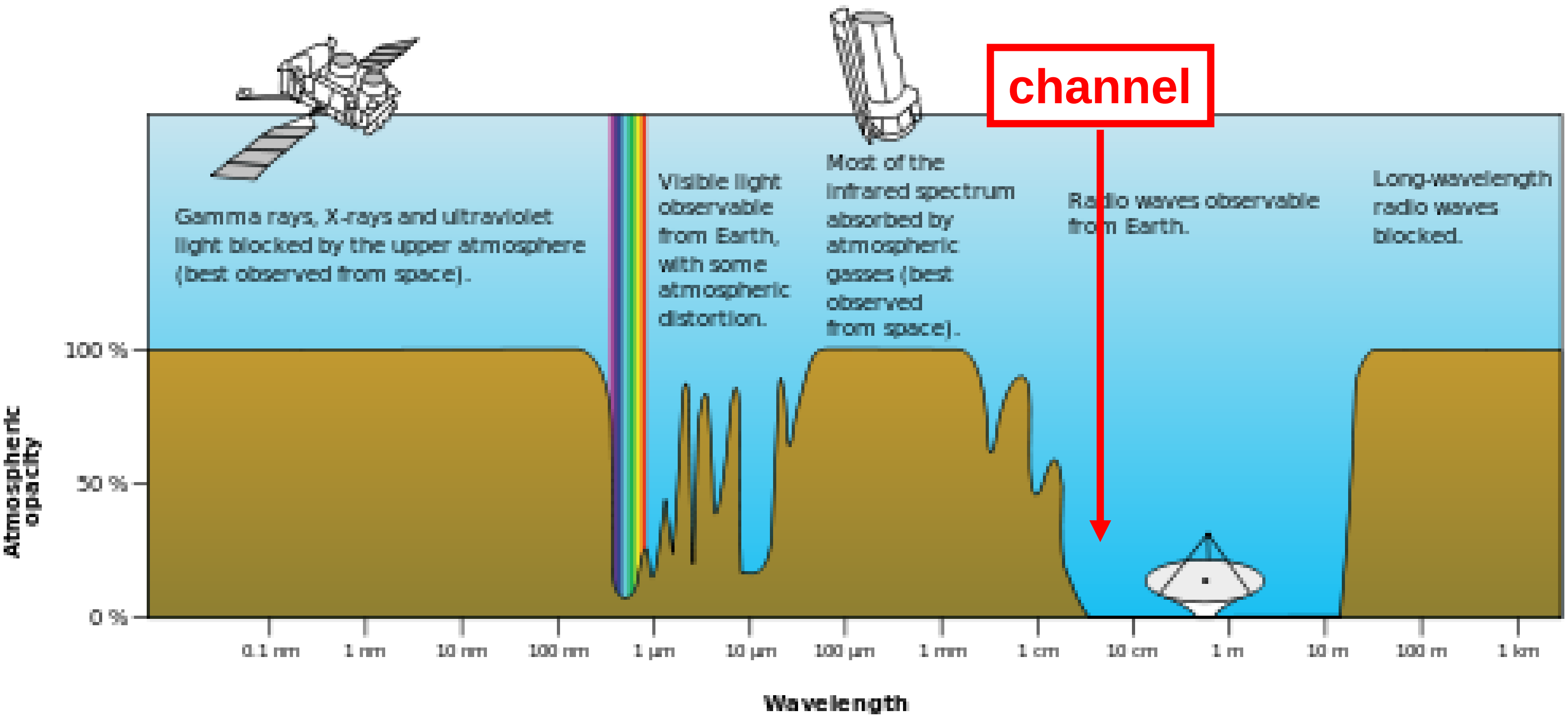


HIRS channel 8 (11microns)



Surface sensing Channels (active)

Surface sensing Channels (active)



SURFACE SENSING CHANNELS (ACTIVE)

…selecting channels where there is no contribution from the atmosphere or emission from the surface....

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

SURFACE SENSING CHANNELS (ACTIVE)

…selecting channels where there is no contribution from the atmosphere or emission from the surface....

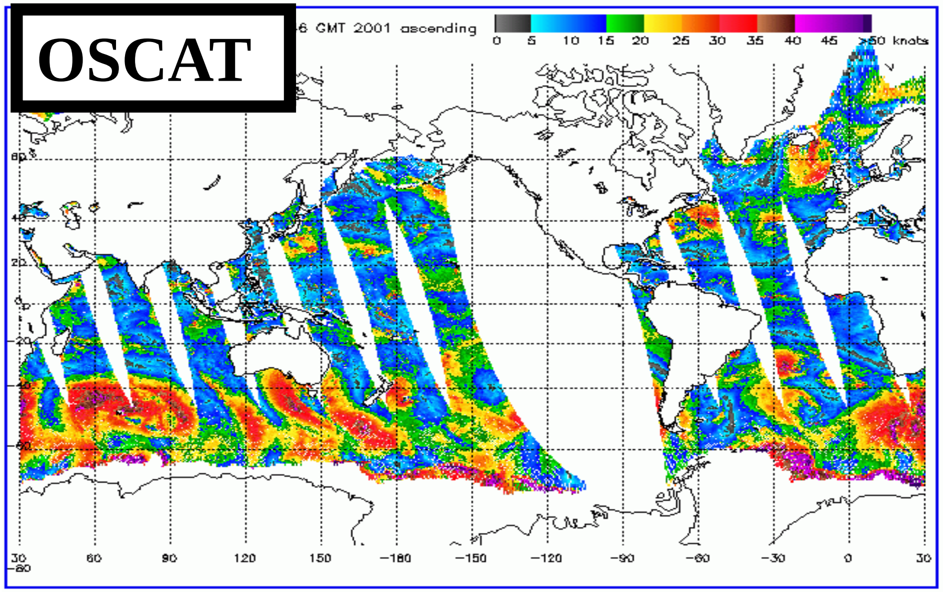
$$L(\nu) = \cancel{\int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz} + \cancel{\text{Surface emission}} + \text{Surface reflection/scattering} + \cancel{\text{Cloud/rain contribution}} + \ldots$$

SURFACE SENSING CHANNELS (ACTIVE)

These (e.g. scatterometers) **actively illuminate the surface** in window parts of the spectrum such that

$$L(\nu) = \text{ surface scattering } [\ \varepsilon(u,v)\ ]$$

These primarily provide information on **ocean winds** (via the relationship with sea-surface emissivity) **without** the strong surface temperature ambiguity .



What type of channels are most important for NWP ?

Atmospheric temperature sounding

ATMOSPHERIC TEMPERATURE SOUNDING

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

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

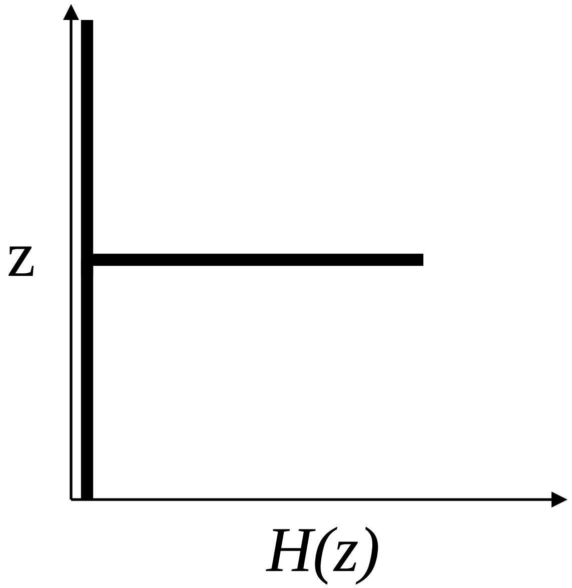
and we define a function $\mathbf{H(z)} = \left[\dfrac{d\tau}{dz} \right]$

When the primary absorber is a well mixed gas (e.g. oxygen or CO_2) with known concentration it can be seen that the **measured radiance** is essentially a **weighted average of the atmospheric temperature profile**, or

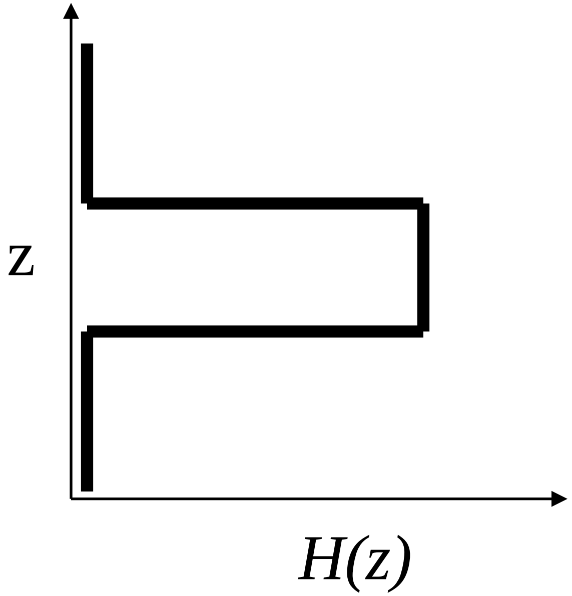
$$\boxed{L(\nu) = \int_0^\infty B(\nu, T(z))\ \mathbf{H(z)}\, dz}$$

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

IDEAL WEIGHTING FUNCTIONS

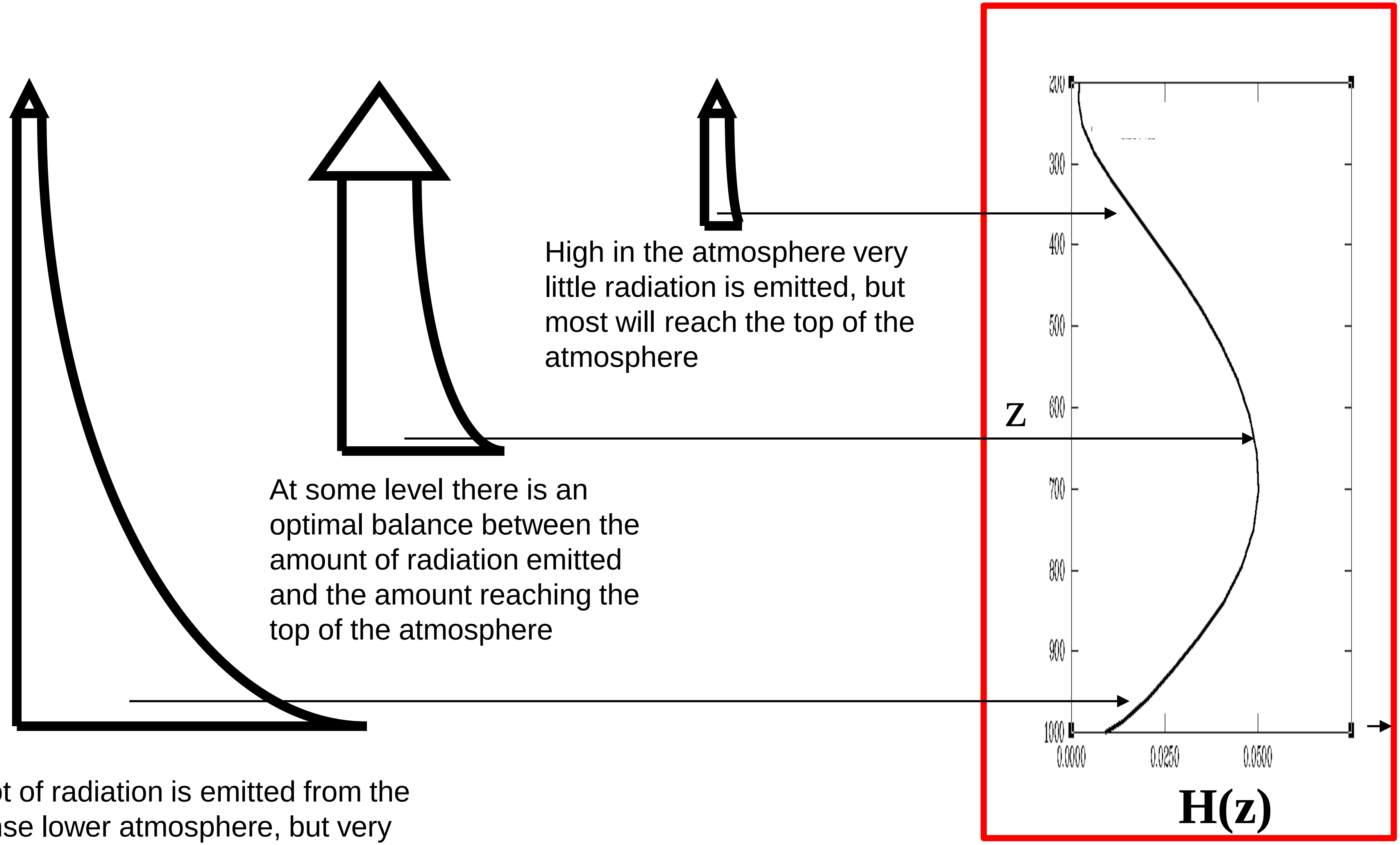


If the weighting function was a delta-function - this would mean that the measured radiance in a given channel is sensitive to the temperature at a single level in the atmosphere.



If the weighting function was a box-car function, this would mean that the measured radiance in a given channel was only sensitive to the temperature between two discrete atmospheric levels

REAL ATMOSPHERIC WEIGHTING FUNCTIONS



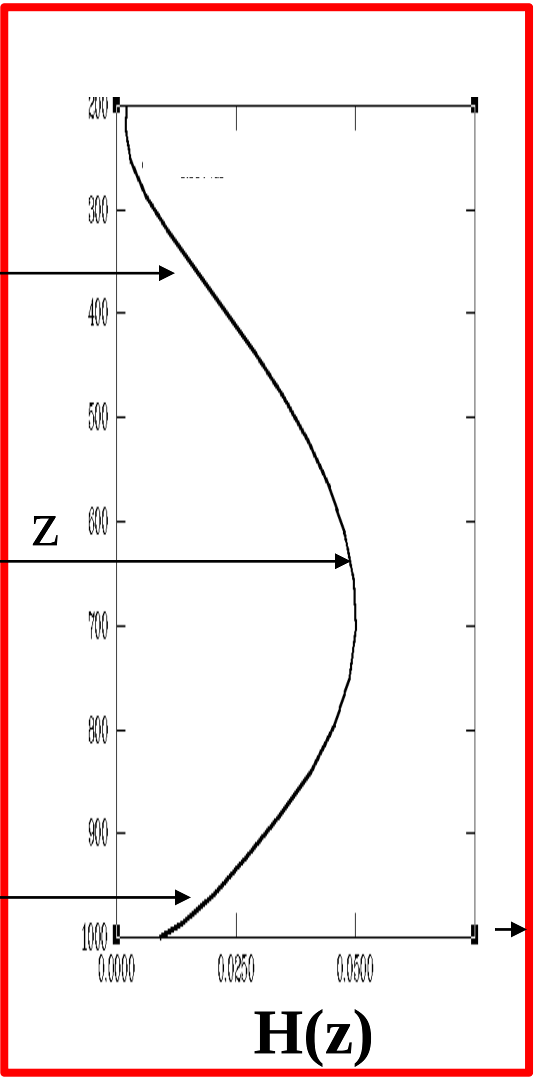
High in the atmosphere very little radiation is emitted, but most will reach the top of the atmosphere

At some level there is an optimal balance between the amount of radiation emitted and the amount reaching the top of the atmosphere

A lot of radiation is emitted from the dense lower atmosphere, but very little survives to the top of the atmosphere due to absorption.

REAL ATMOSPHERIC WEIGHTING FUNCTIONS

Satellite sounding radiances are broad vertical averages of the atmospheric temperature structure

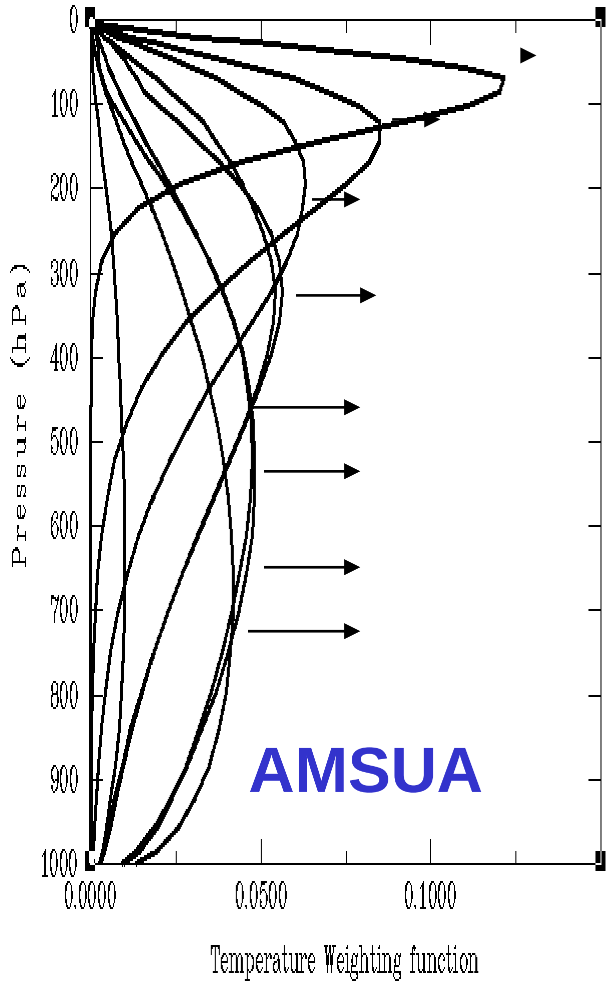


REAL WEIGHTING FUNCTIONS continued...

- The altitude at which the **peak** of the weighting function occurs depends on the **strength** of absorption for a given channel

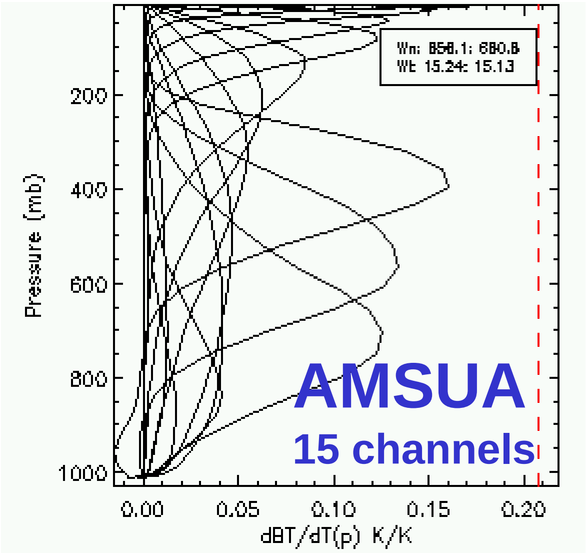
- Channels in parts of the spectrum where the absorption is **strong** (e.g. near the centre of CO2 or O2 lines) peak **high** in the atmosphere

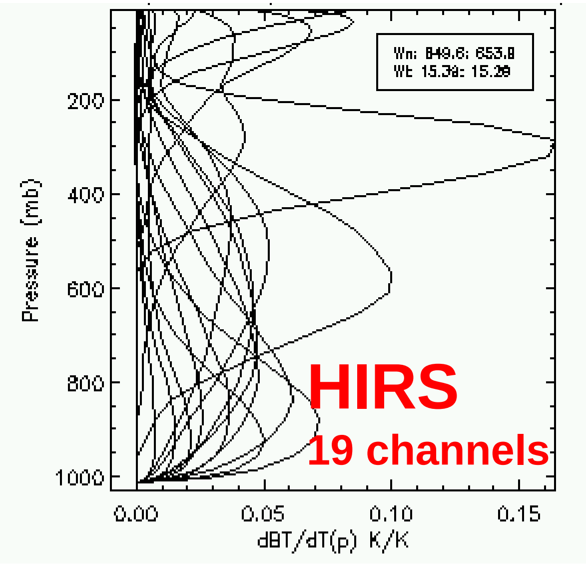
- Channels in parts of the spectrum where the absorption is **weak** (e.g. in the wings of CO_2 O_2 lines) peak **low** in the atmosphere

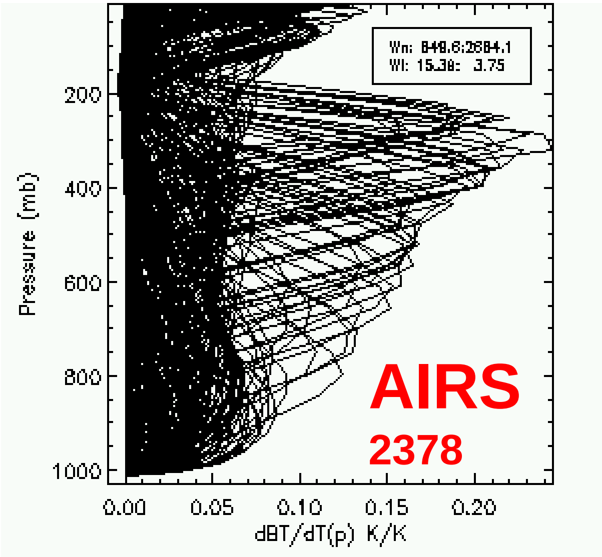


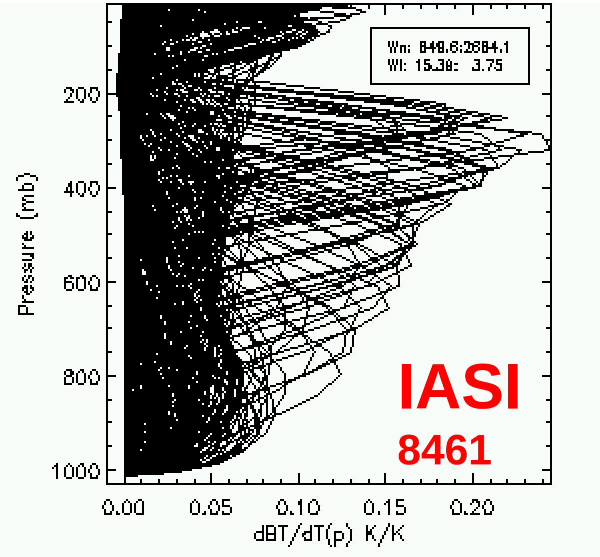
By selecting a **number of channels** with varying absorption strengths we **sample** the atmospheric temperature at **different altitudes**

MORE REAL WEIGHTING FUNCTIONS ...









How do we extract atmospheric information (e.g. temperature) from satellite radiances

?

…i.e. how do we solve the inverse problem….

The Radiative Transfer (RT) equation

"Forward problem"

OBSERVATION OPERATOR

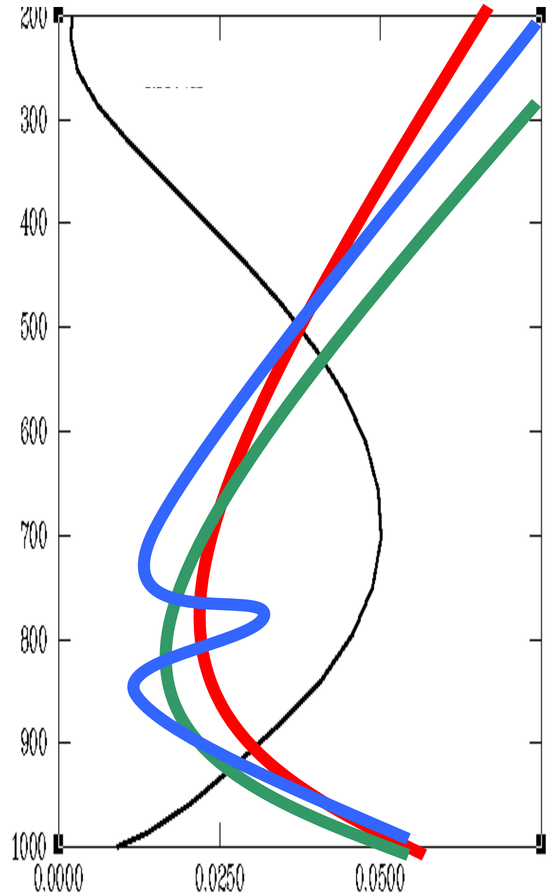
$$\overbrace{L(\nu)}^{\text{measured by the satellite}} = \overbrace{\int_0^\infty B(\nu, T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots}^{\text{depends on the state of the atmosphere}}$$

MINIMISATION

"Inverse problem"

The Inverse problem

As the weighting functions are broad, if we have a finite number of channels, the inverse problem is **formally ill-posed** because **an infinite number of different temperature profiles could give the same measured radiances !!!**



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

…so to solve the inverse problem we need to bring in additional information ….

…satellite data relies strongly on background information and Data Assimilation skill…

“Direct Radiance Assimilation”

The cost function J (X)

background error covariance

model state

$$J(x) = (x - x_b)^T \mathbf{B}^{-1}(x - x_b) +$$

$$(y - \mathrm{H}[x])^T \mathbf{R}^{-1}(y - \mathrm{H}[x])$$

observations

observation* error covariance

observation operator (maps the model state to the observation space)

The cost function components (J_b)

$$J(x) = \boxed{(x - x_b)^T \mathbf{B}^{-1} (x - x_b)} + (y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$

Fit of the solution to the background estimate of the atmospheric state weighted inversely by the background error covariance B

The cost function components (J_o)

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) +$$

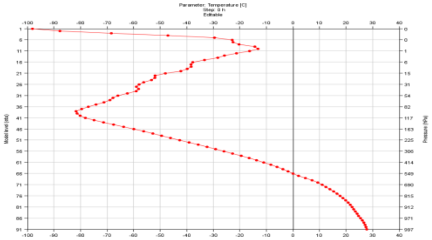
$$\boxed{(y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])}$$

Fit of the solution to the observations weighted inversely by the measurement error covariance R (observation error + error in observation operator H)

Various implementations of the assimilation algorithm

- 1D-Var
- 3D-Var
- 4D-Var

One dimensional variational analysis (1D-Var)



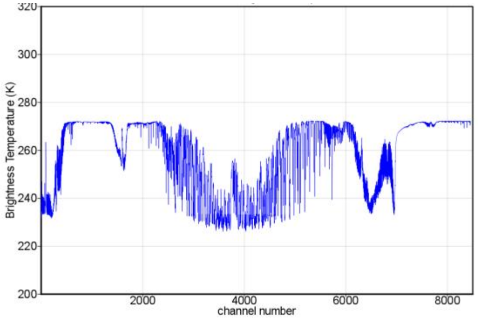
1D model state profile

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) +$$

$$(y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$

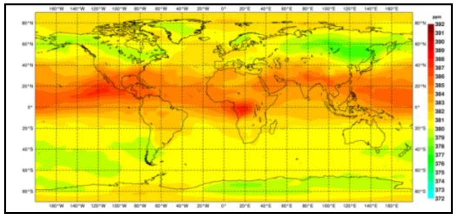
vector of measured radiances at one location

observation Operator
= radiative transfer model



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

Three dimensional variational analysis (3D-Var)

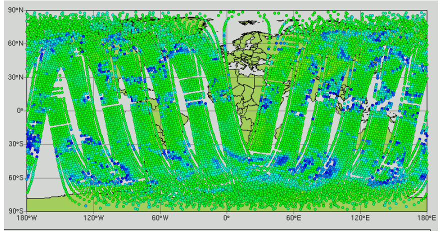


3D model state

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) +$$

$$(y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$

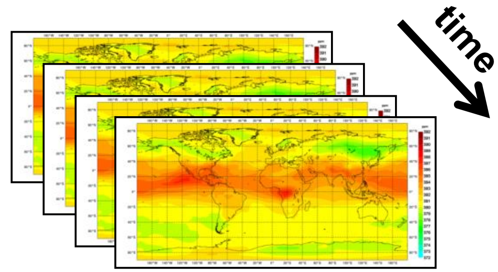
global vector of measured radiances



observation operator
= spatial interpolation +
radiative transfer model

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

Four dimensional variational analysis (4D-Var)

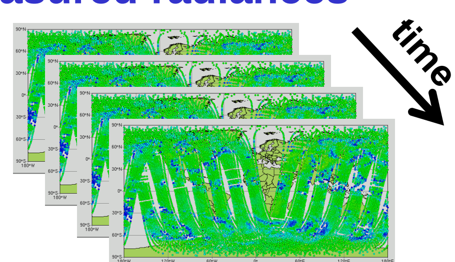


4D model state

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) +$$

$$(y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$

global time windows of
measured radiances



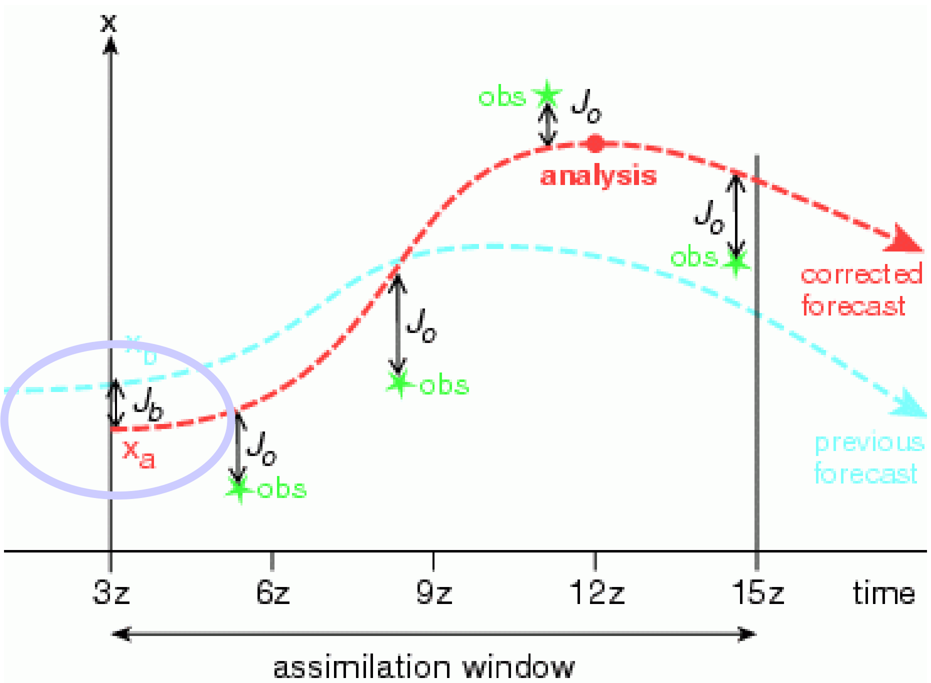
observation operator
= spatial interpolation + forecast model
radiative transfer model

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

$X_{t=0} \longrightarrow X_{t=t}$

The 4D-Var Algorithm J_b

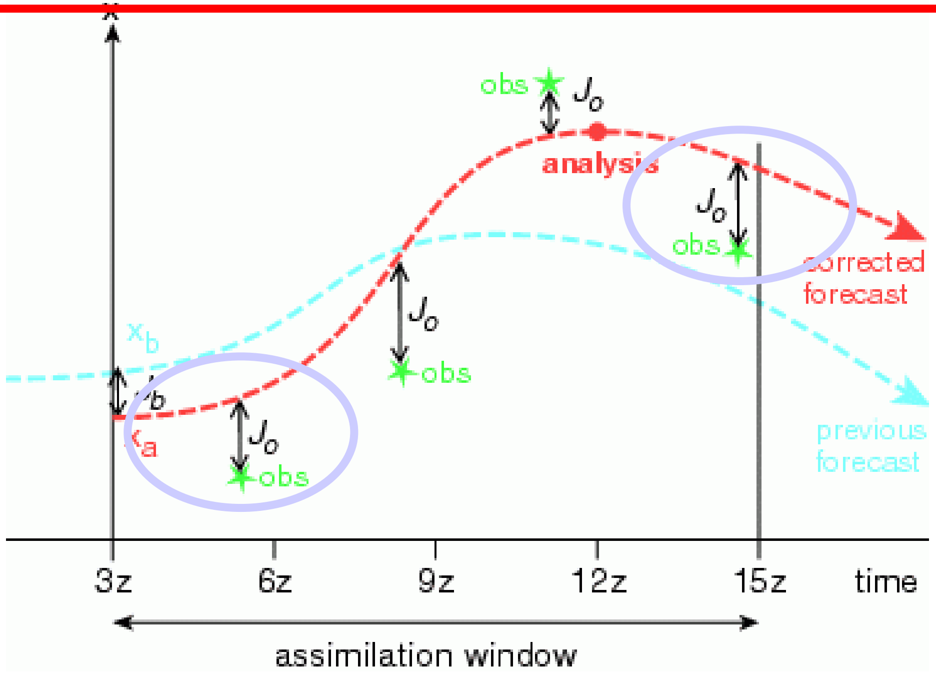
$$J(x) = \boxed{(x - x_b)^T \mathbf{B}^{-1} (x - x_b)} + (y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$



The 4D-Var Algorithm J_o

$$J(x) = (x - x_b)^T \mathbf{B}^{-1}(x - x_b) +$$

$$\boxed{(y - \mathrm{H}[x])^T \mathbf{R}^{-1}(y - \mathrm{H}[x])}$$



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**
- background errors
- observation errors
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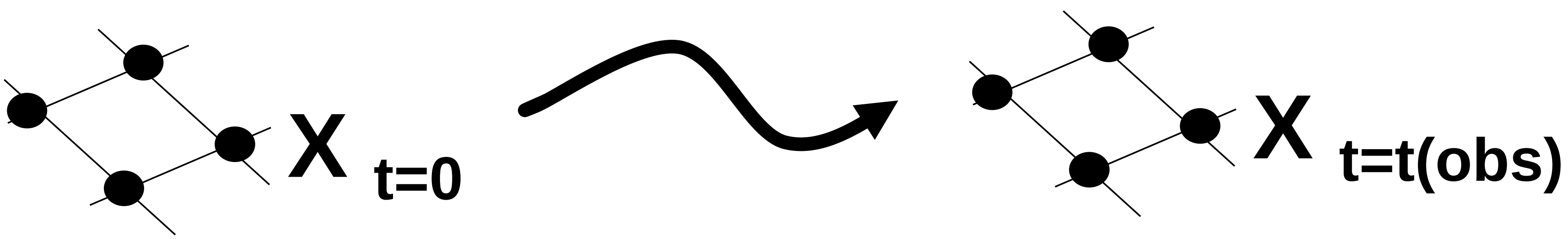
- data selection and quality control

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)

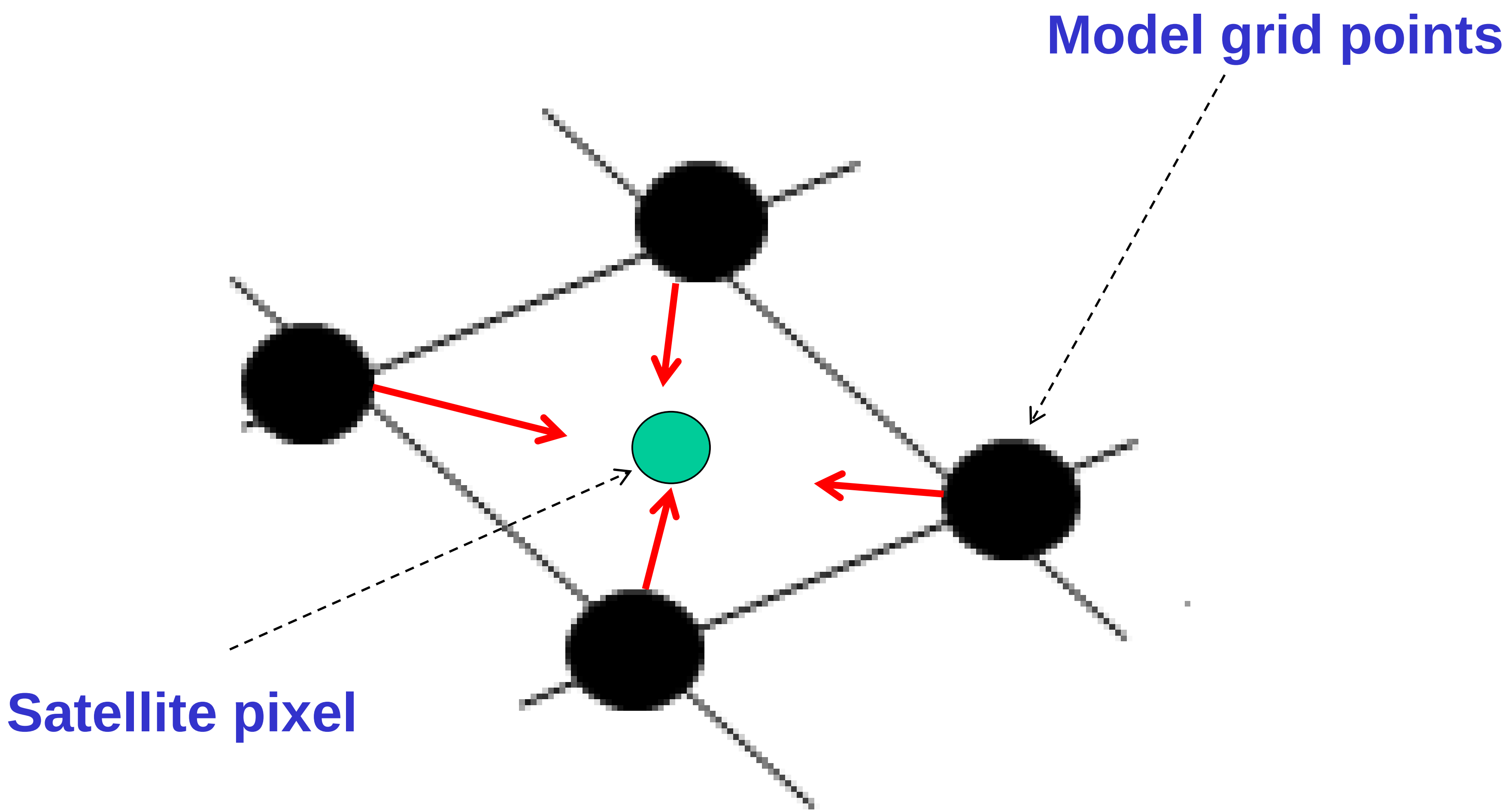
Observation operator

1) Time evolution of forecast model field to OBS time



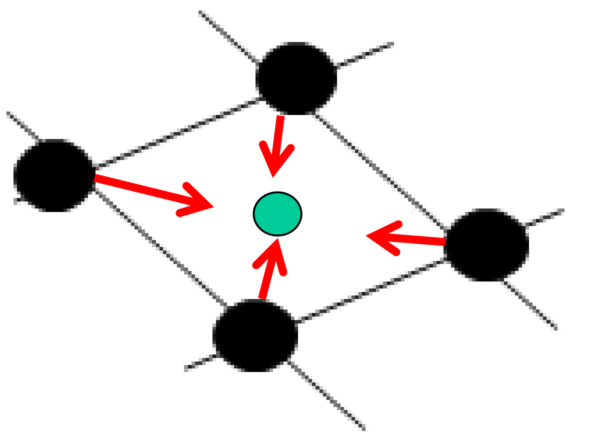
Observation operator

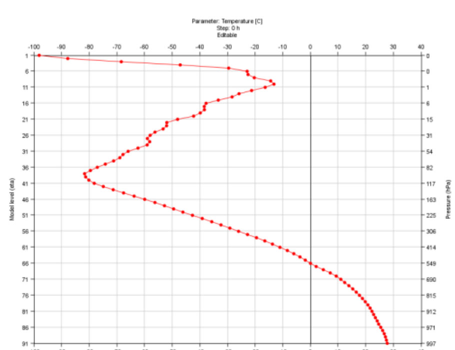
2) Spatial interpolation of model grid to OBS location



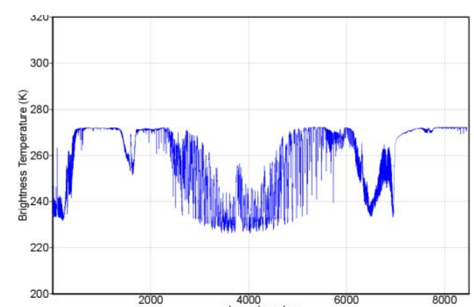
Observation operator

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





RTTOV



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

Key elements of a data assimilation system

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

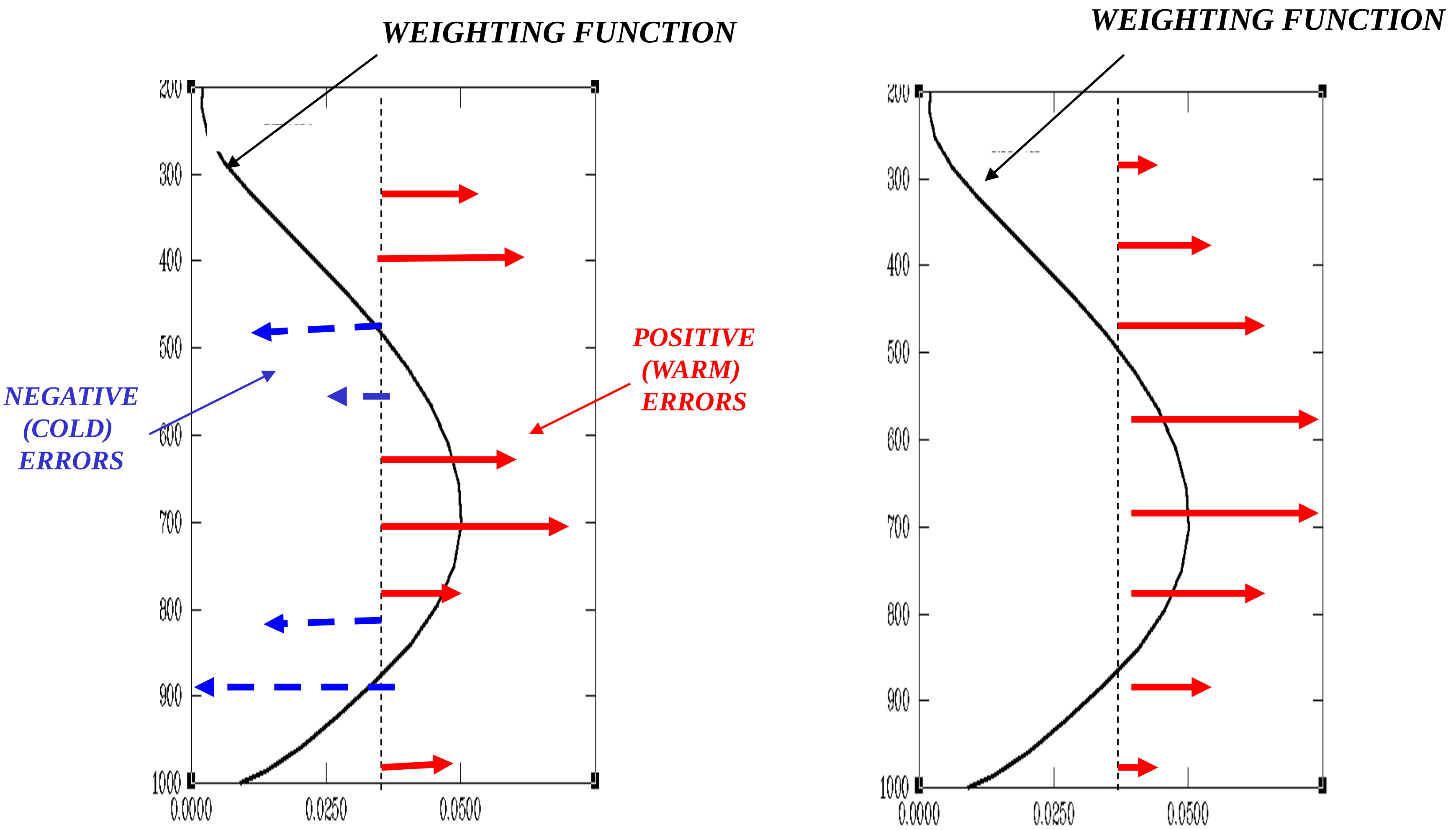
Background errors (and vertical resolution)

- **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)

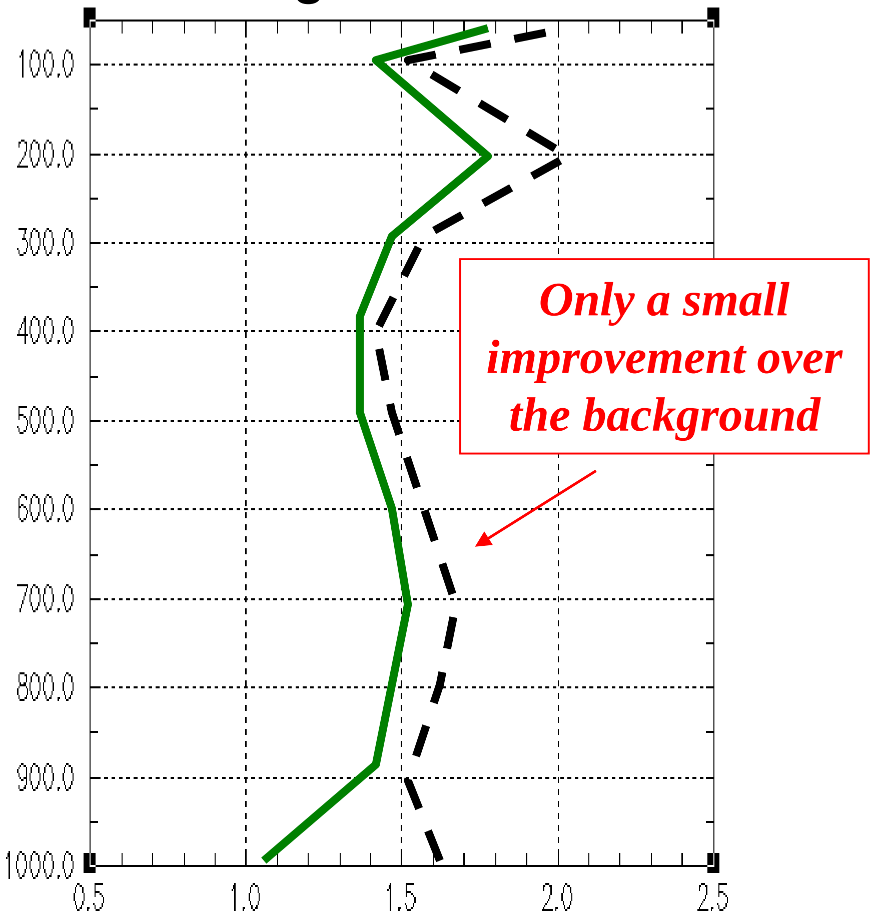
We can quantify the improvement of the analysis of the satellite radiances compared to the background (for a given sensor) for these two different regimes of background error:

$$\mathbf{S_a} = \mathbf{B} - \underbrace{[\mathbf{HB}]^T[\mathbf{HBH}^T + \mathbf{R}]^{-1}\,\mathbf{HB}}_{\text{improvement term}}$$

The improvement has been simulated for the assimilation of all 8461 channels of IASI.

Background errors (and vertical resolution)

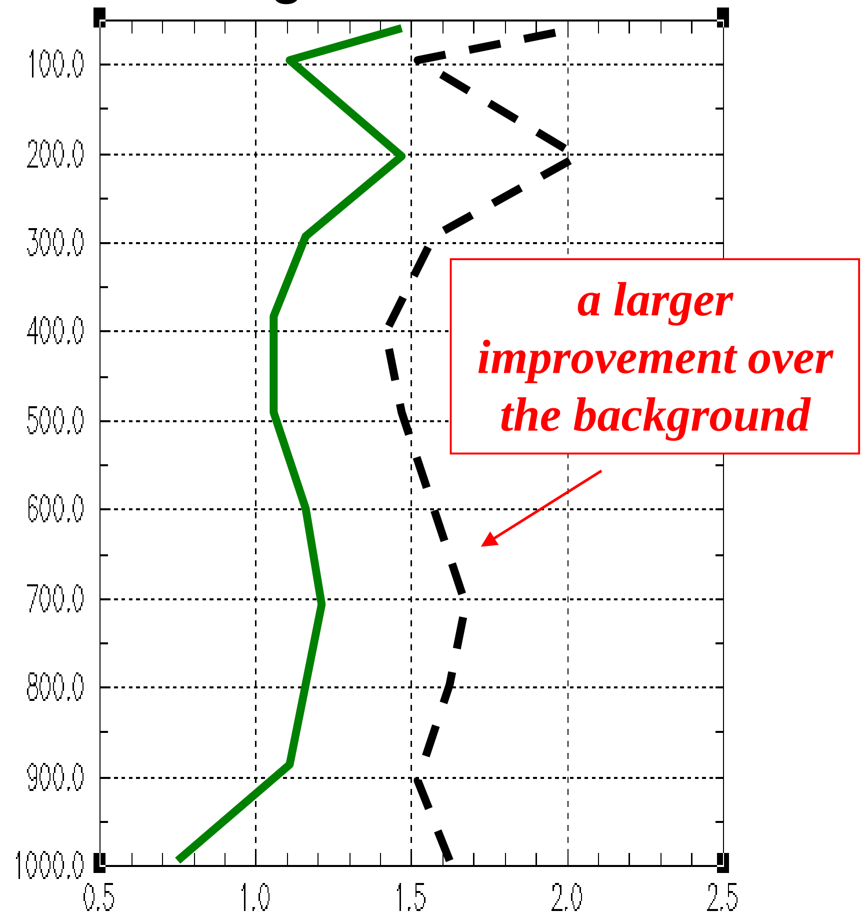
Sharp / anti-correlated background errors



Error standard deviation (K)

S_a

Broad / deep correlated background error

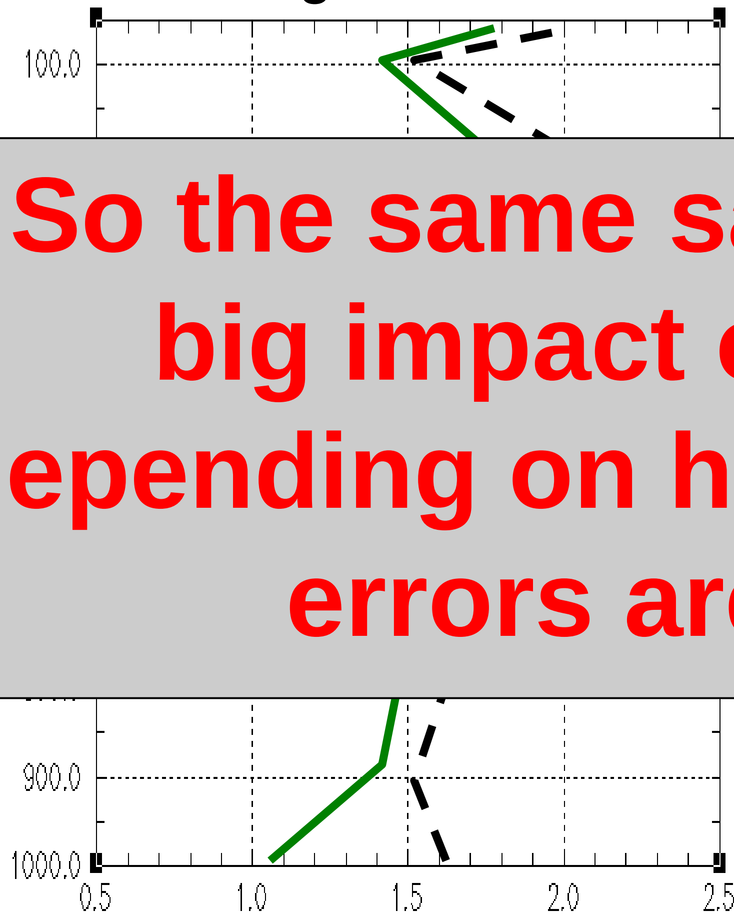


Error standard deviation (K)

S_a

Background errors (and vertical resolution)

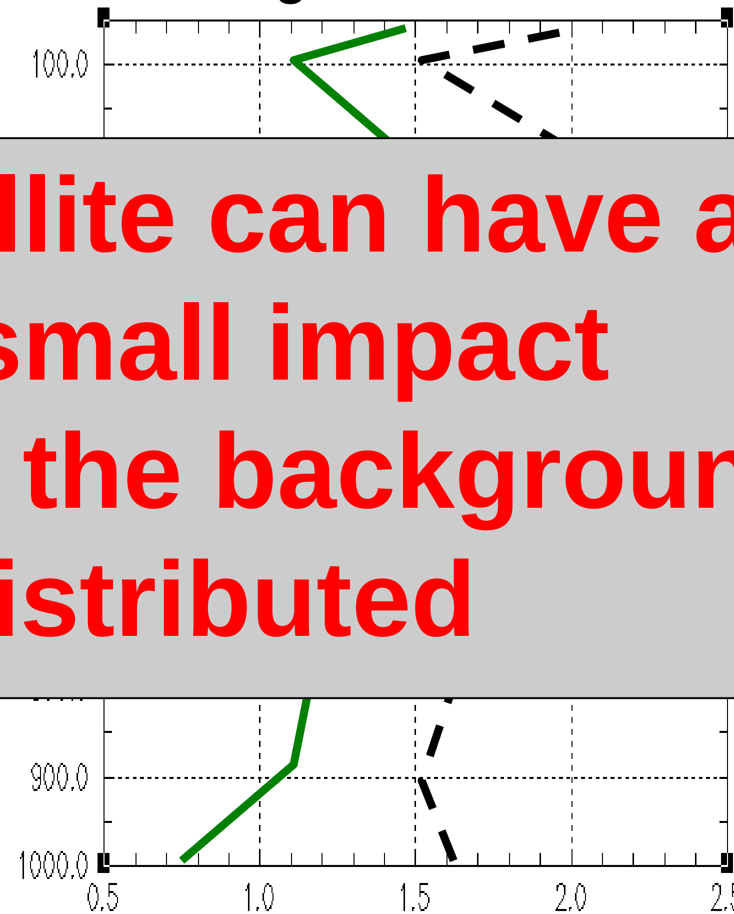
Sharp / anti-correlated background errors



Error standard deviation (K)

S_a

Broad / deep correlated background error



Error standard deviation (K)

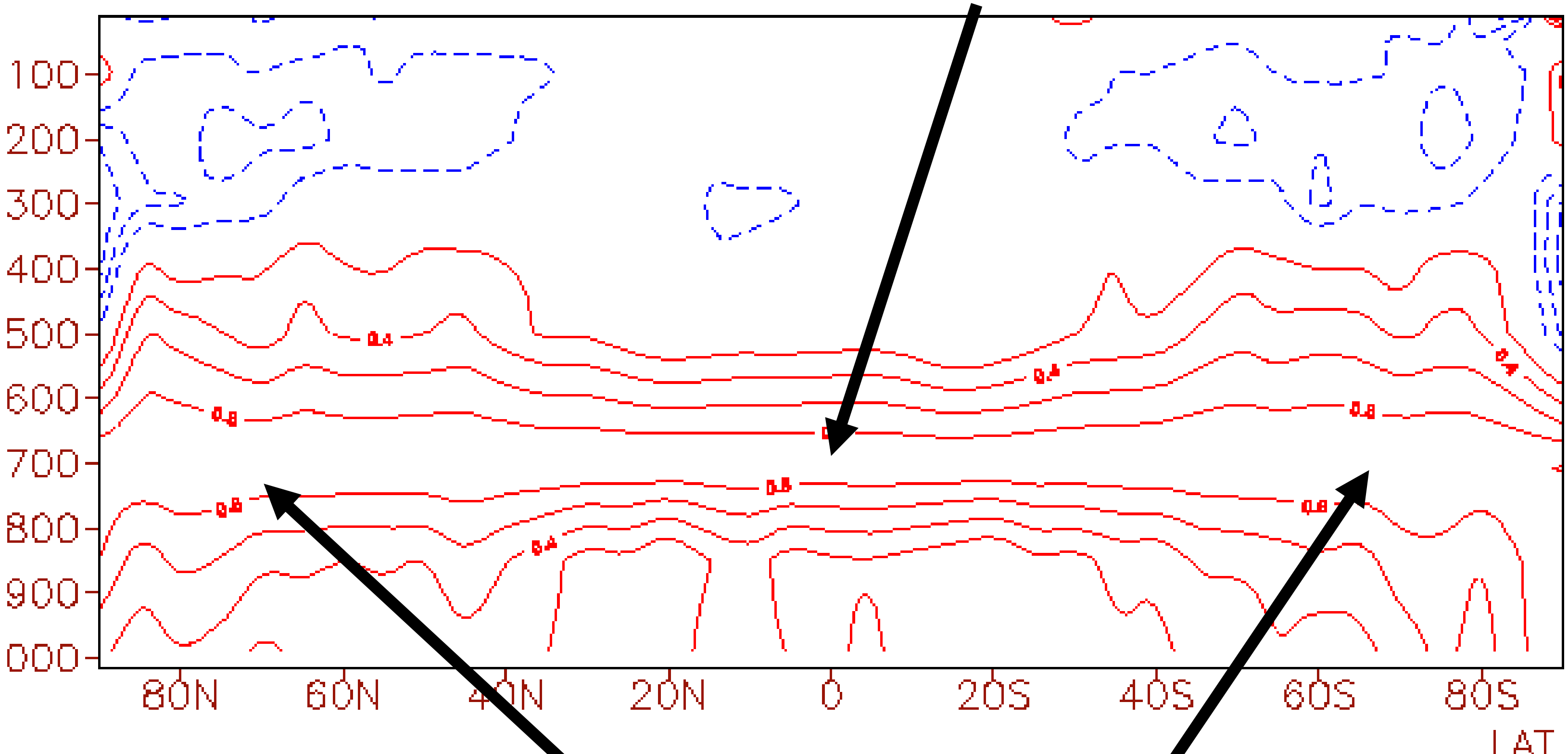
S_a

So the same satellite can have a big impact or small impact depending on how the background errors are distributed

Background errors (and vertical resolution)

700hPa T error

Sharper error correlations in the Tropics



Broader vertical correlations in the mid-latitudes

Key elements of a data assimilation system

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

Observation errors:

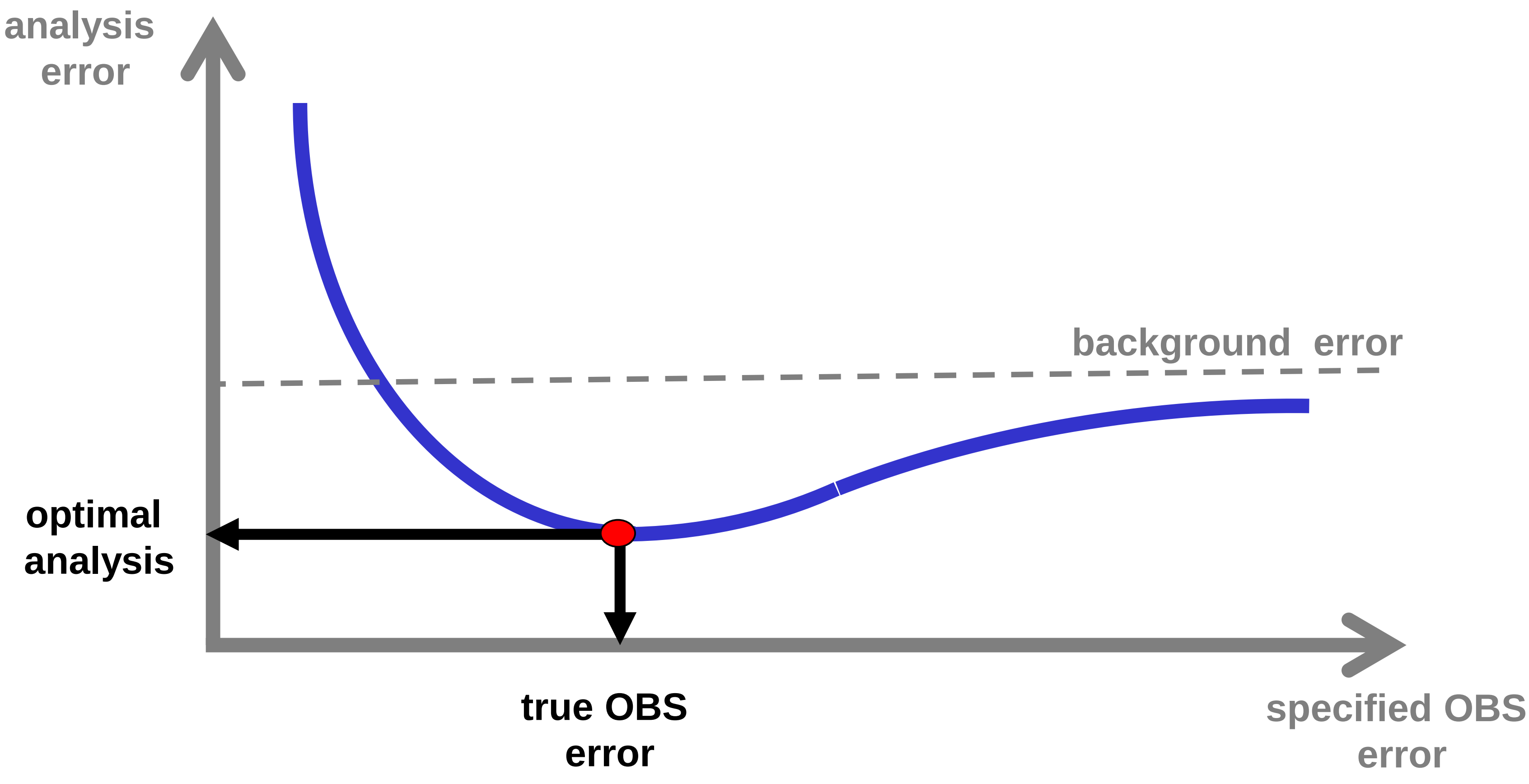
- **These determine the weight we give to the radiance observations. The observation error must account for random uncertainties in the observation operator (e.g. RT model), errors in data screening (e.g. residual clouds) and errors of representativeness (e.g. scale mismatch).**

- **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 <u>larger errors than the background</u>!**

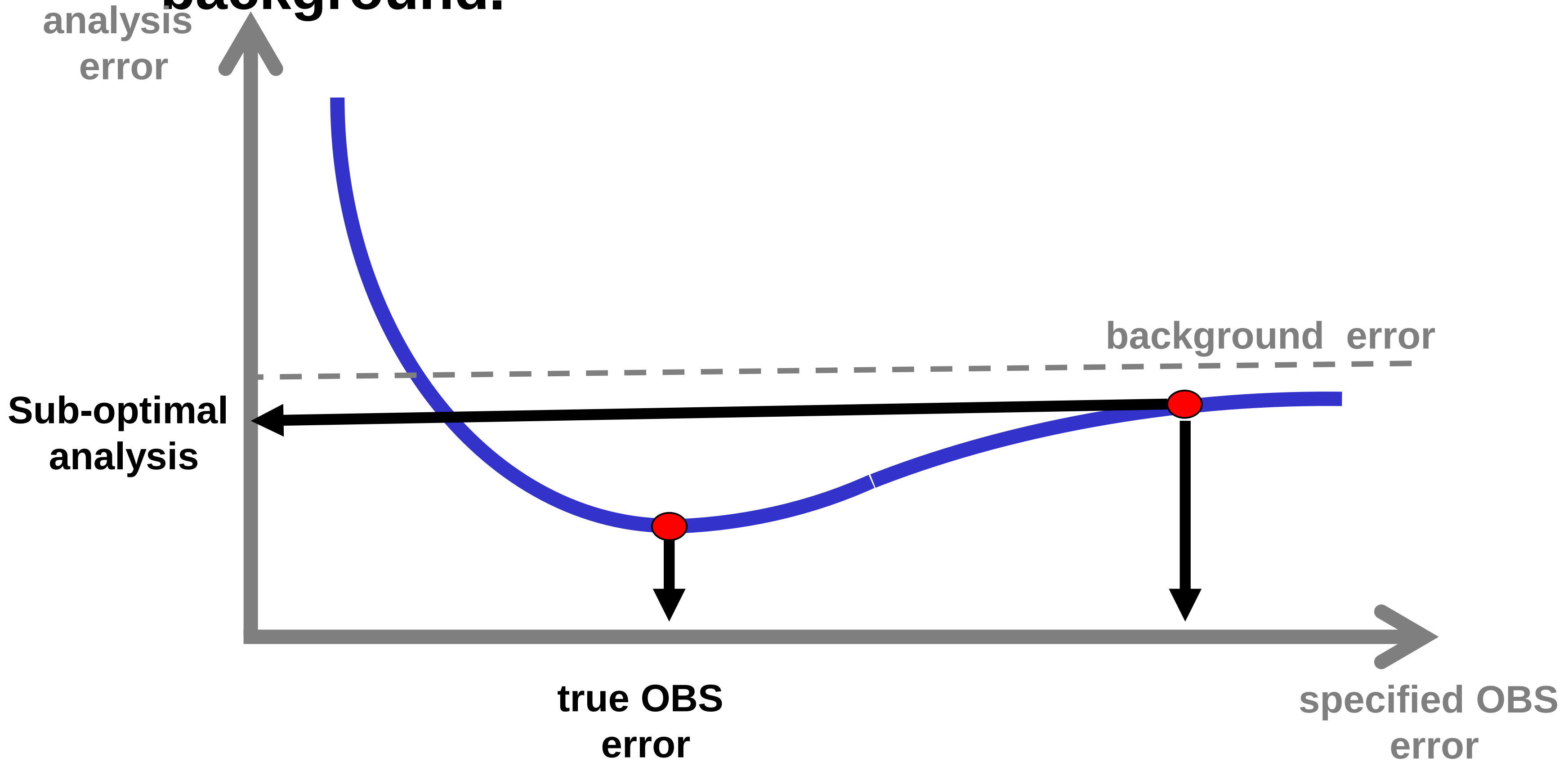
Observation errors:

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



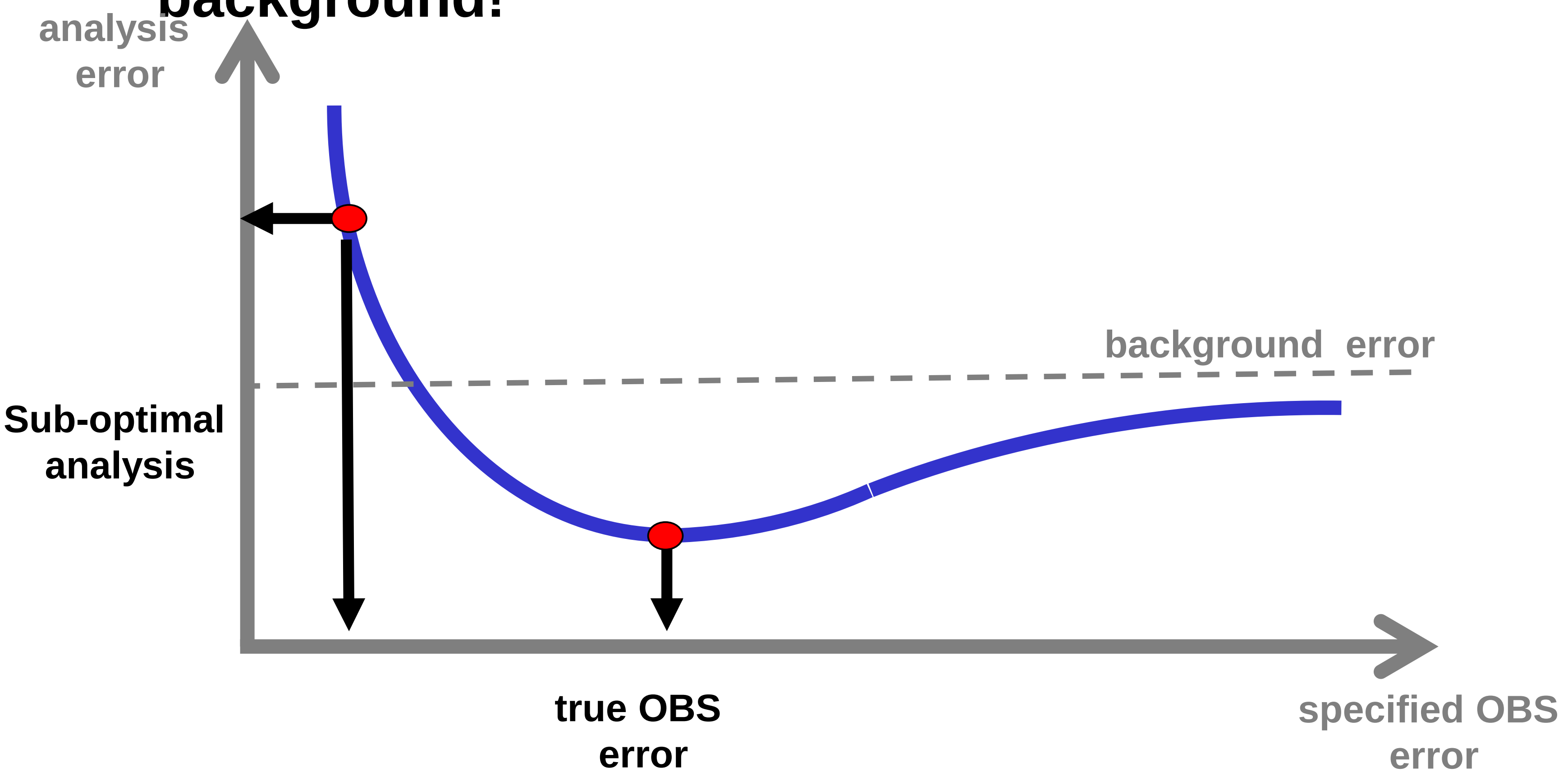
Observation errors:

- **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:

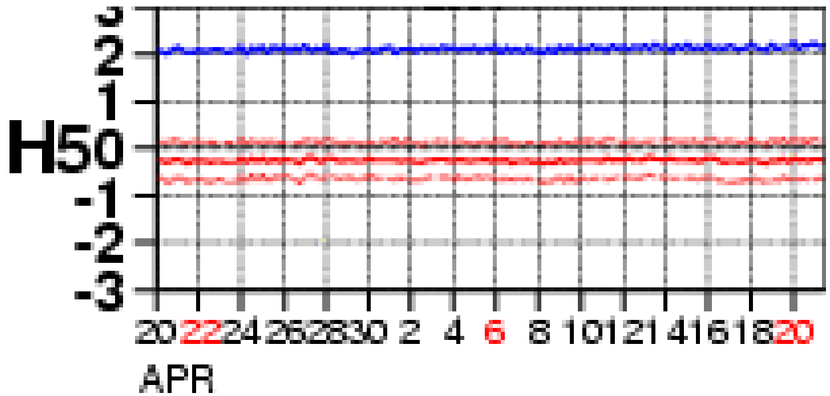
$$\mathbf{bias} = \mathbf{mean}\left[Y_{obs} - H(X_{true}) \right]$$

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

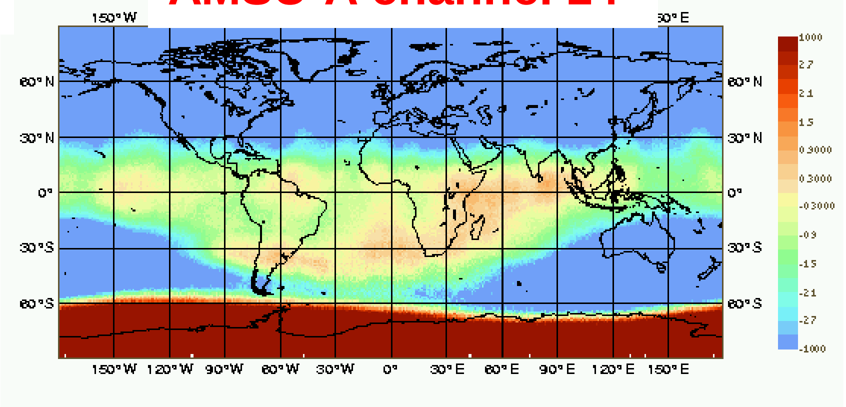
Bias correction:

HIRS channel 5



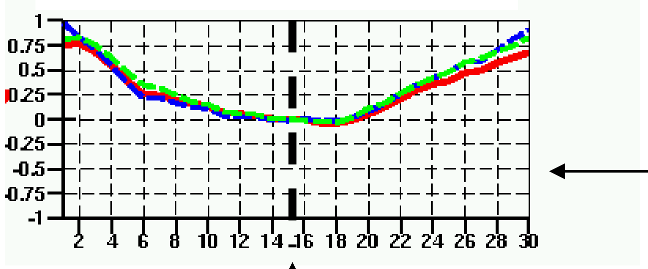
simple flat offset biases that are constant in time

AMSU-A channel 14



biases that vary depending on location or air-mass

AMSU-A channel 7



biases that vary depending on the Scan position of the satellite instrument

limb

nadir

limb

Bias correction:

But sometimes NWP systematic errors can make it difficult to diagnose and correct observation biases

What we would like to quantify is:

$$\text{Bias} = \text{mean}\left[\, Y_{obs} - H(X_{true}) \,\right]$$

But in practice all we can monitor is :

$$\text{Bias} = \text{mean}\left[\, Y_{obs} - H(X_{b/a}) \,\right]$$

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 (R) and the observation operator (H).

Primary examples include the following:

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

Data selection and quality control (QC):

Often checks are performed using the forecast background as a reference. That is an observations is rejected if the departure from the background exceeds a threshold T_{QC}:

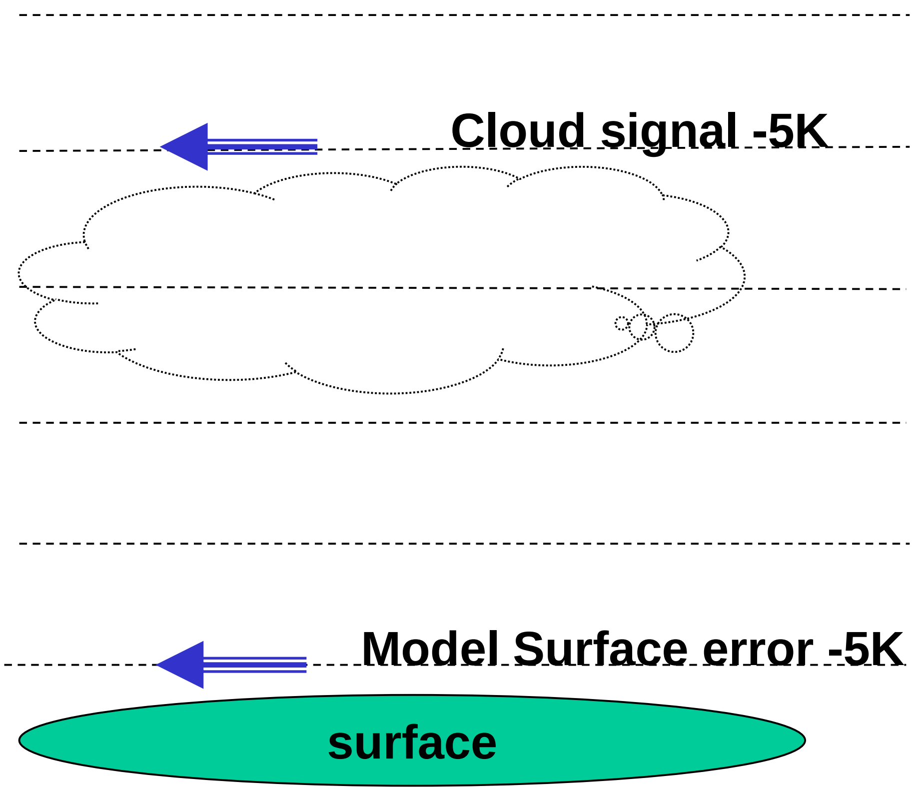
$$Y_{obs} - H(X_{true}) > T_{QC}$$

But sometimes large errors in the background can lead to:

- **False rejection of a good observation**
- **Missed rejection of a bad observation**

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!

A QUICK REVIEW OF KEY CONCEPTS

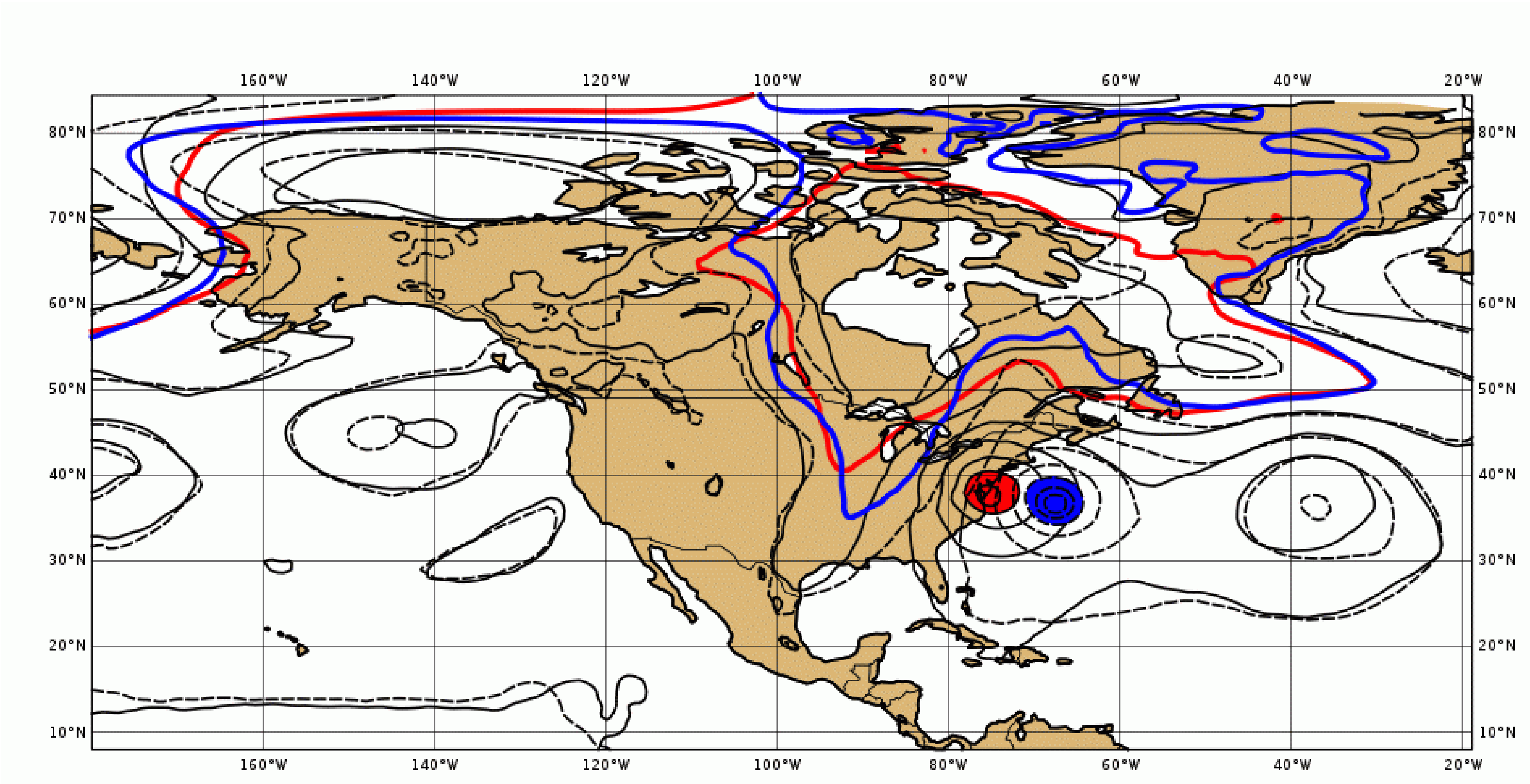
- Satellite instruments measure **radiance** (**not** T,Q or wind)

- Sounding radiances are **broad vertical averages** of the temperature profile (defined by the weighting functions)

- The estimation of atmospheric temperature from the radiances is **ill- posed** and all retrieval algorithms use some sort of **prior information**

- The correct specification of observation errors, background errors (vertical correlations) , bias corrections and QC **are all crucial!**

End


160°W
140°W
120°W
100°W
80°W
60°W
40°W
20°W
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