Atmospheric Data Assimilation

Thomas Navarro (LMD)
with F. Forget, E. Millour

and University of Maryland (S. Greybush[1], T. Miyoshi[2], E. Kalnay)

1 : Now at Penn State University
2 : Now at Riken Institute (Japan)

ACS Team Meeting, October 14th 2013

Assimilation of LMD Mars Global Climate Model (GCM)

- What is data assimilation ?
- Science goals and roadmap
- Assimilation of ACS meteorological data

What is data assimilation ?

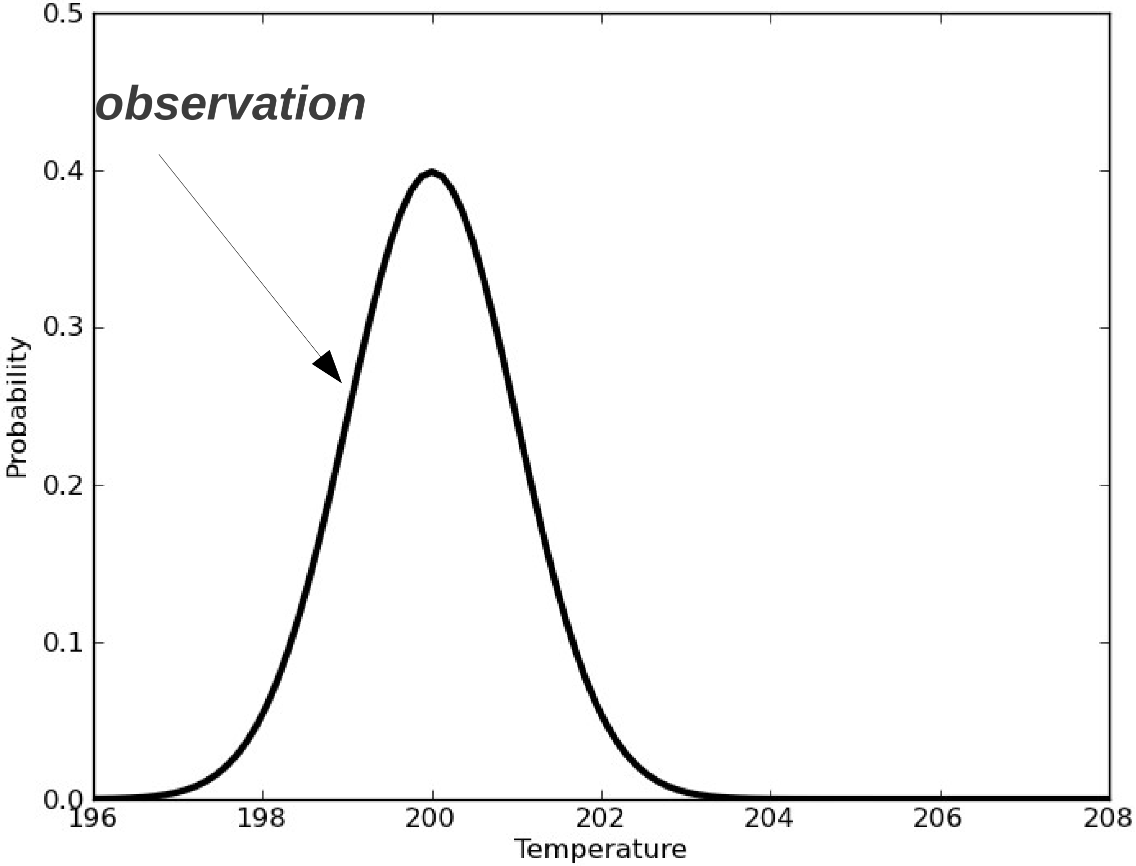
- *« Using **all the available information** to determine as accurately as possible the state of the **atmospheric flow.** »* (O.Talagrand)
- **Optimal interpolation** of observations, taking into account their **errors**, with the help of a **model.**

What is data assimilation ?

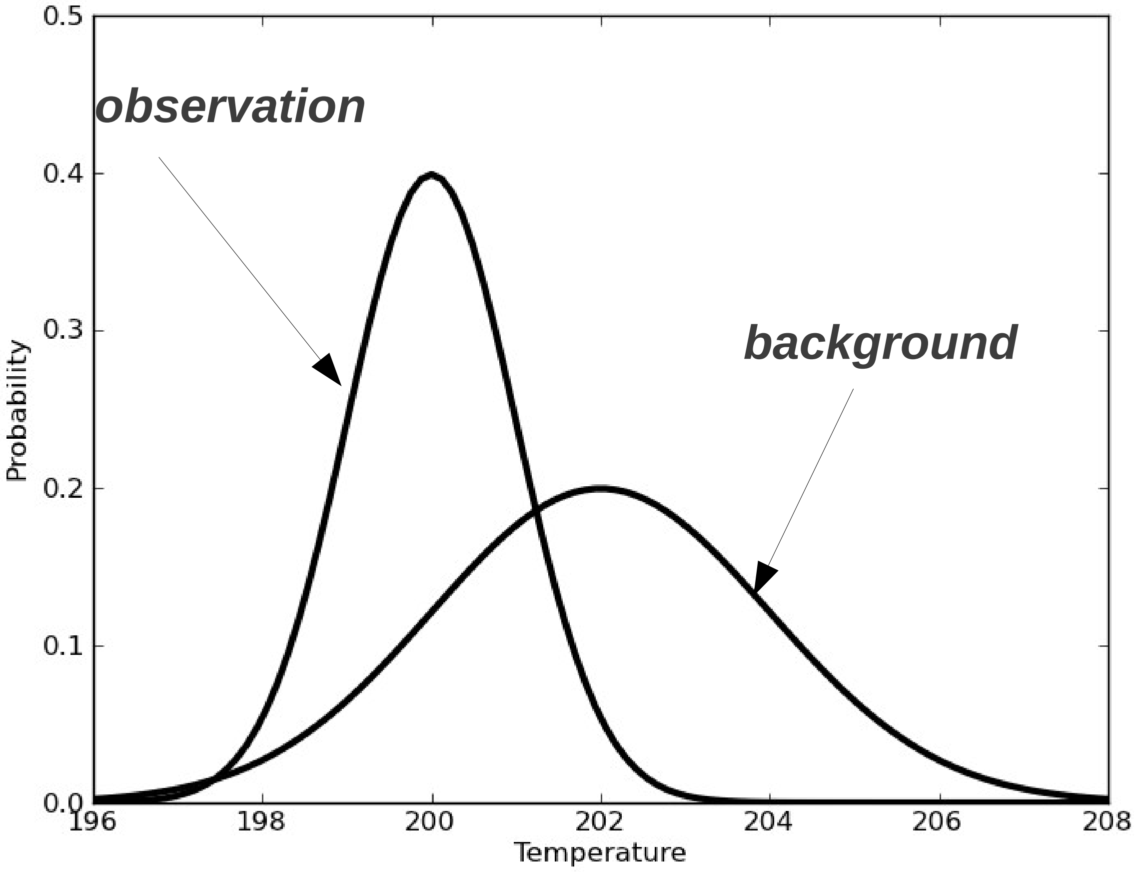
- *« Using **all the available information** to determine as accurately as possible the state of the **atmospheric flow.** »* (O.Talagrand)
- **Optimal interpolation** of observations, taking into account their **errors**, with the help of a **model.**

- Usually, **more confidence in observations** vs. **more data points in a model.**
- Two advanced techniques for chaotic systems: ensemble methods or variationnal methods

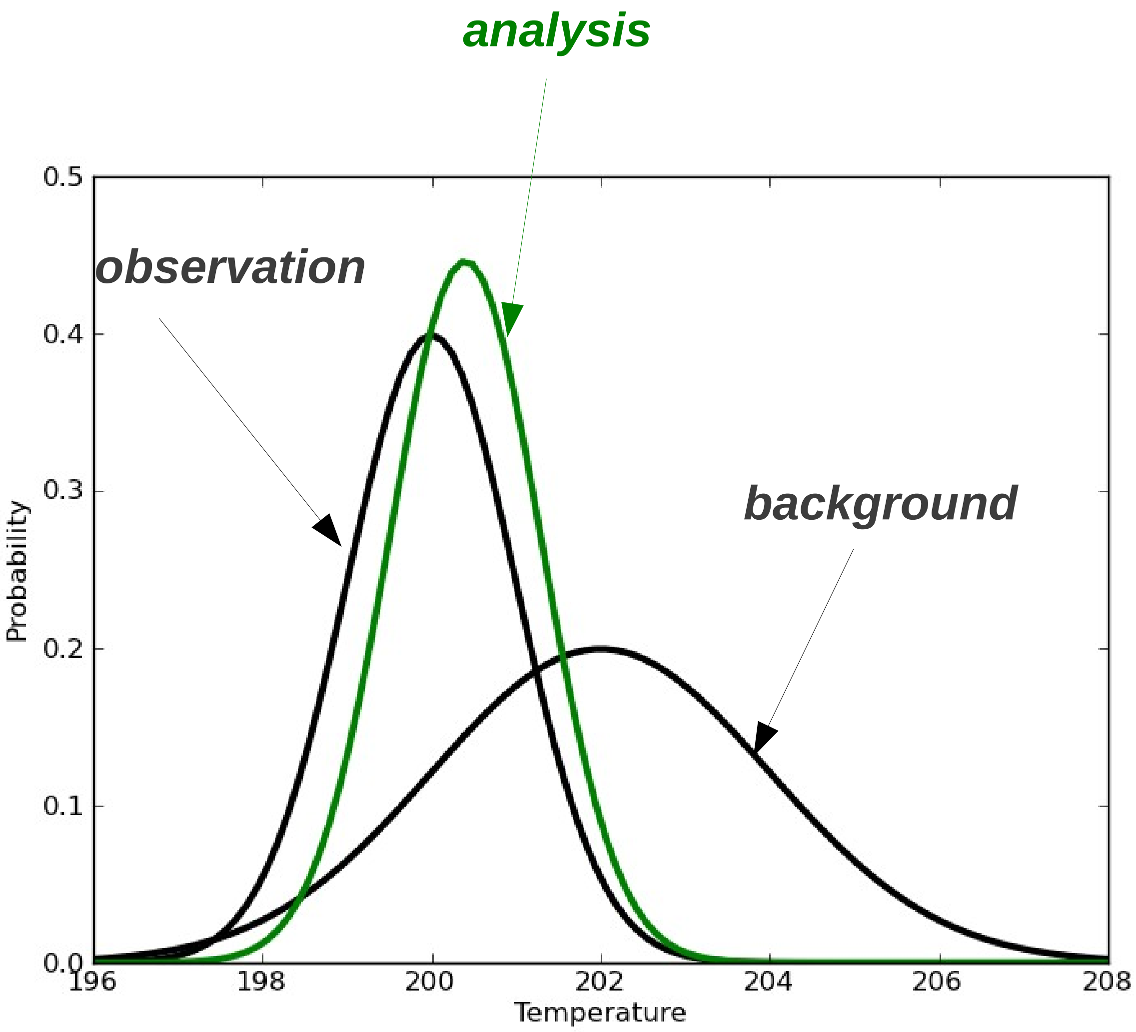
Simple exemple



Simple exemple



Simple exemple



$$T_a = T_b + k(T_o - T_b)$$

$$with\,k = \frac{\sigma_b^2}{\sigma_b^2 + \sigma_o^2}$$

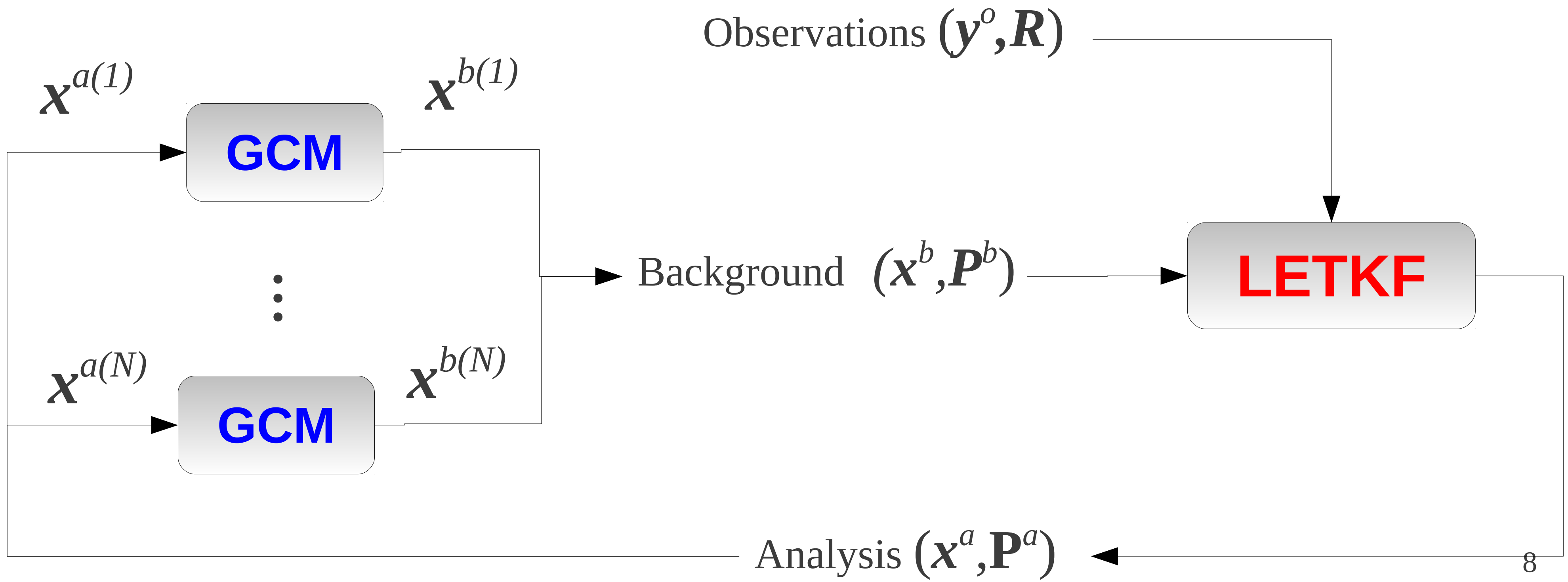
$$\frac{1}{\sigma_a^2} = \frac{1}{\sigma_b^2} + \frac{1}{\sigma_o^2}$$

Atmospheric assimilation

$\boldsymbol{x}$	atmospheric state vector
$\boldsymbol{y}^o$	vector of observations
$\boldsymbol{P}$	atmospheric covariance matrix
$\boldsymbol{R}$	error covariance matrix of observations

Typical numbers :

~ 20 members
State vector size : 10^5
Cycle length : 6 hours
Spin-up : ~ 5 days



What is LETKF ?

LETKF is developped at University of Maryland. It is used today with numerous geophysical models.

Local

Only observations within a certain distance are considered.

Ensemble

An *ensemble* of GCM forecasts is used to estimate the mean state and its covariance.

Transform

Square-root filter

Kalman Filter

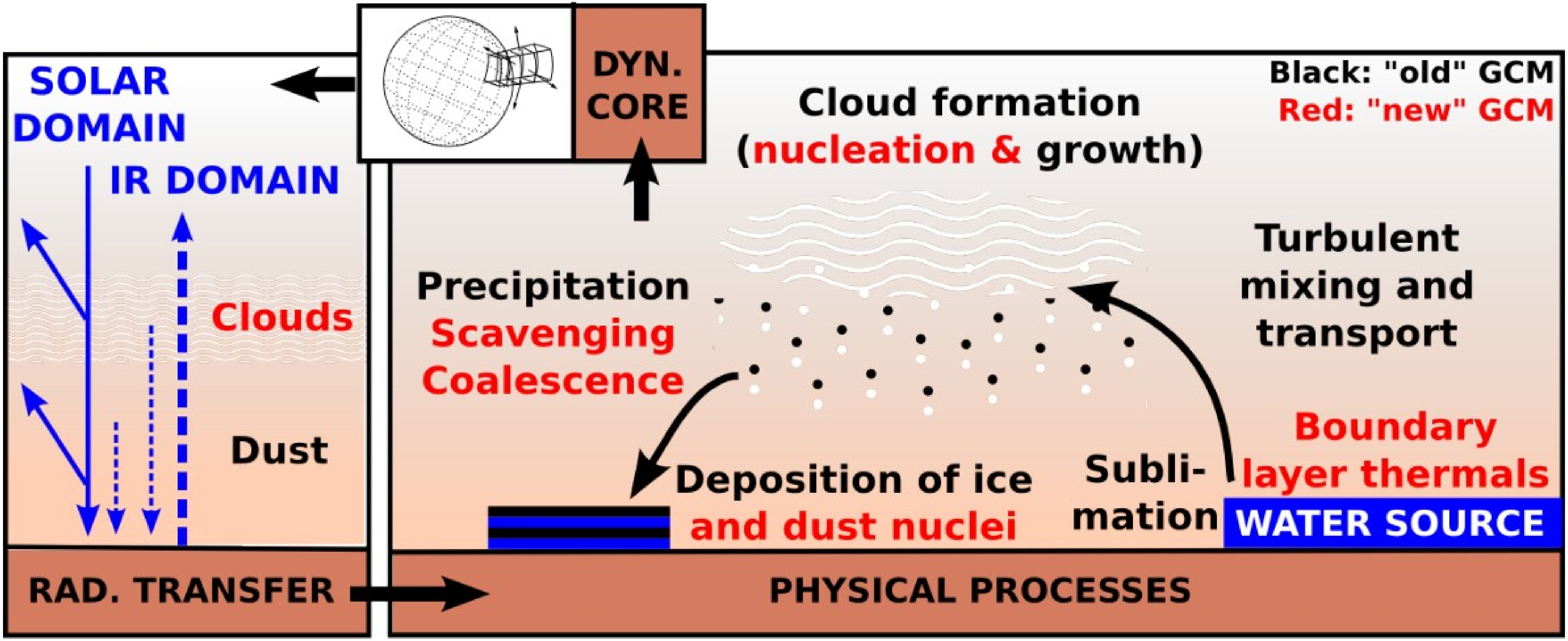
A filter uses past information to update the present state

A Kalman filter estimates both the state and its uncertainty (via its covariance)

LMD Mars Global Climate Model

A complete model including dust, water, clouds and CO2 cycle.

Also : Photochemistry model, extension to the thermosphere



Courtesy of J.-B. Madeleine

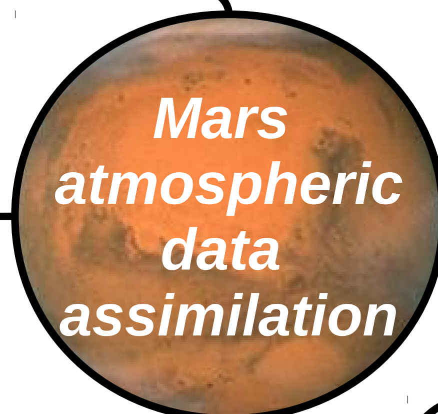
LMD Science goals

Climatology database

4D climatology with
temperature, winds, aerosols.

Backtracking of trace gases

Location of sources thanks
to the wind reconstruction.



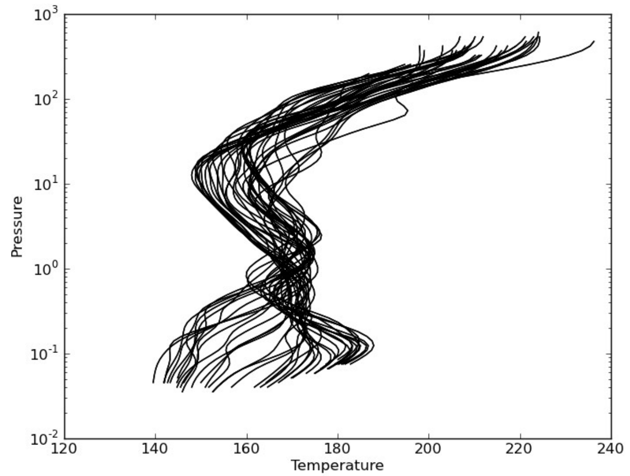
Support EDL

Meteorological forecast
before the Entry, Descent
and Landing of a probe.

Improve GCM

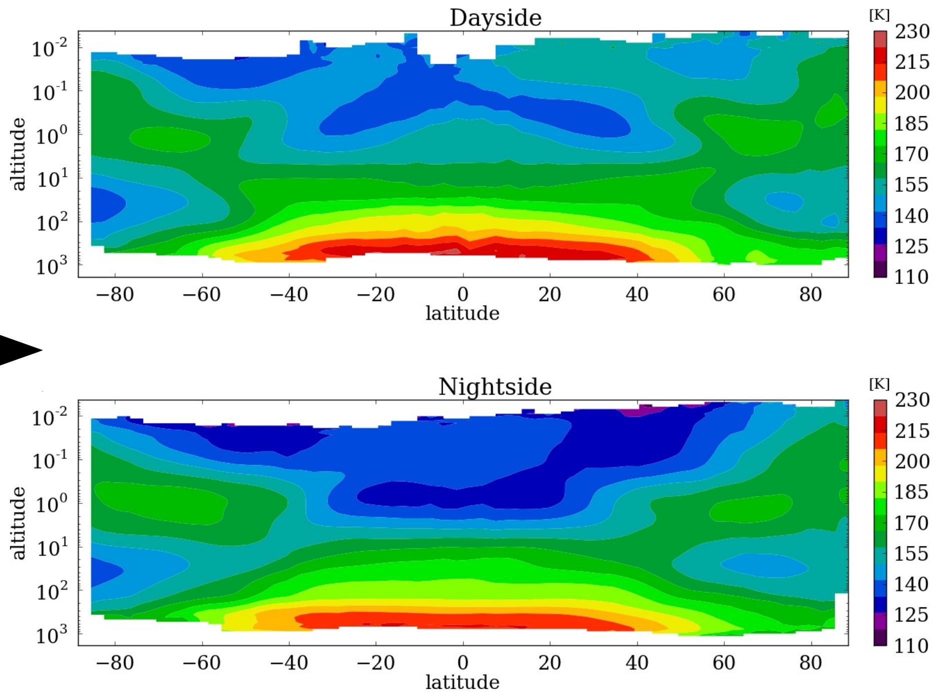
Estimate parameters with
poorly known values that
control the physics of the model.

Sun-synchronous orbit (MRO)



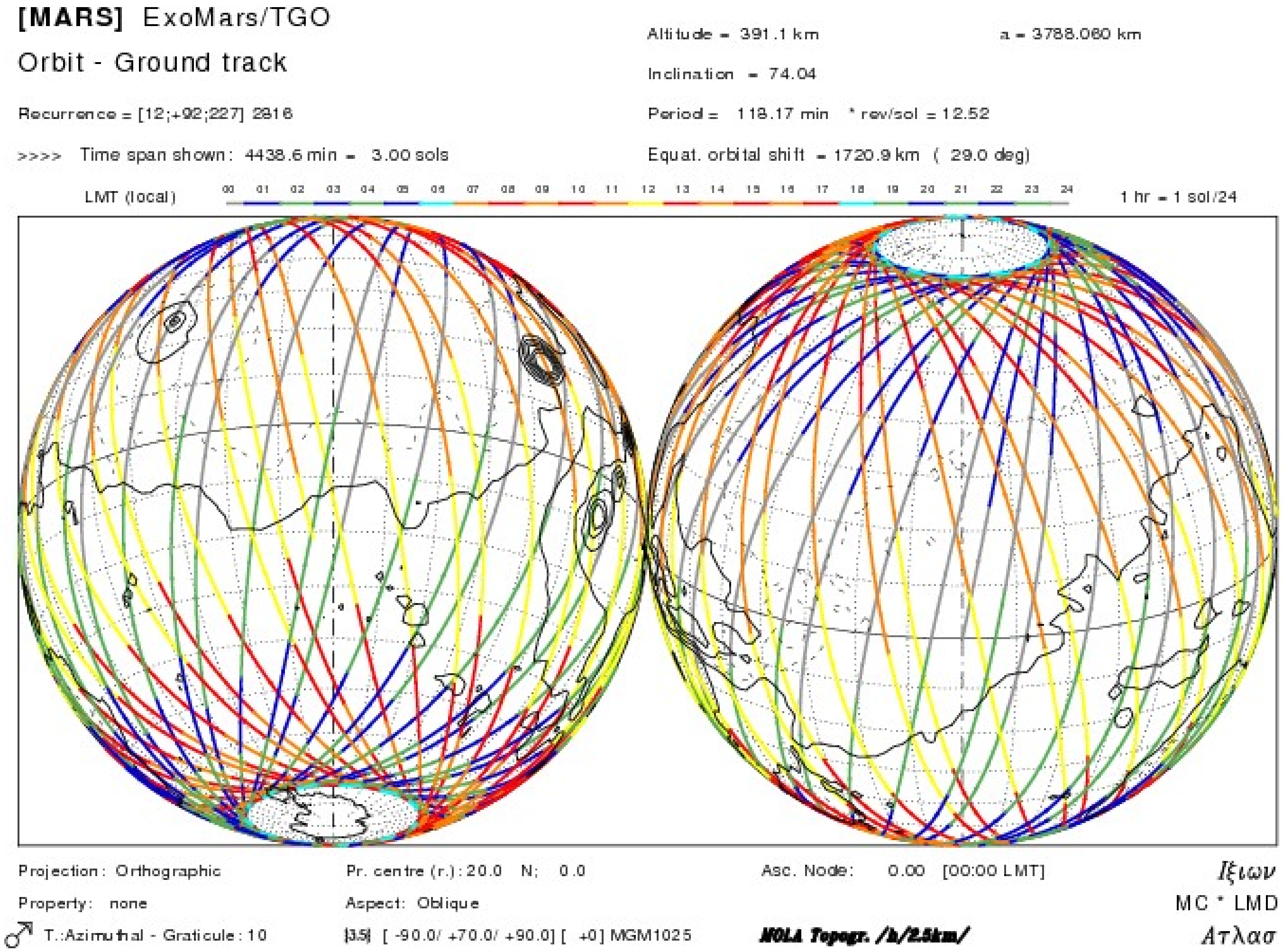
Vertical profiles

Straightforward



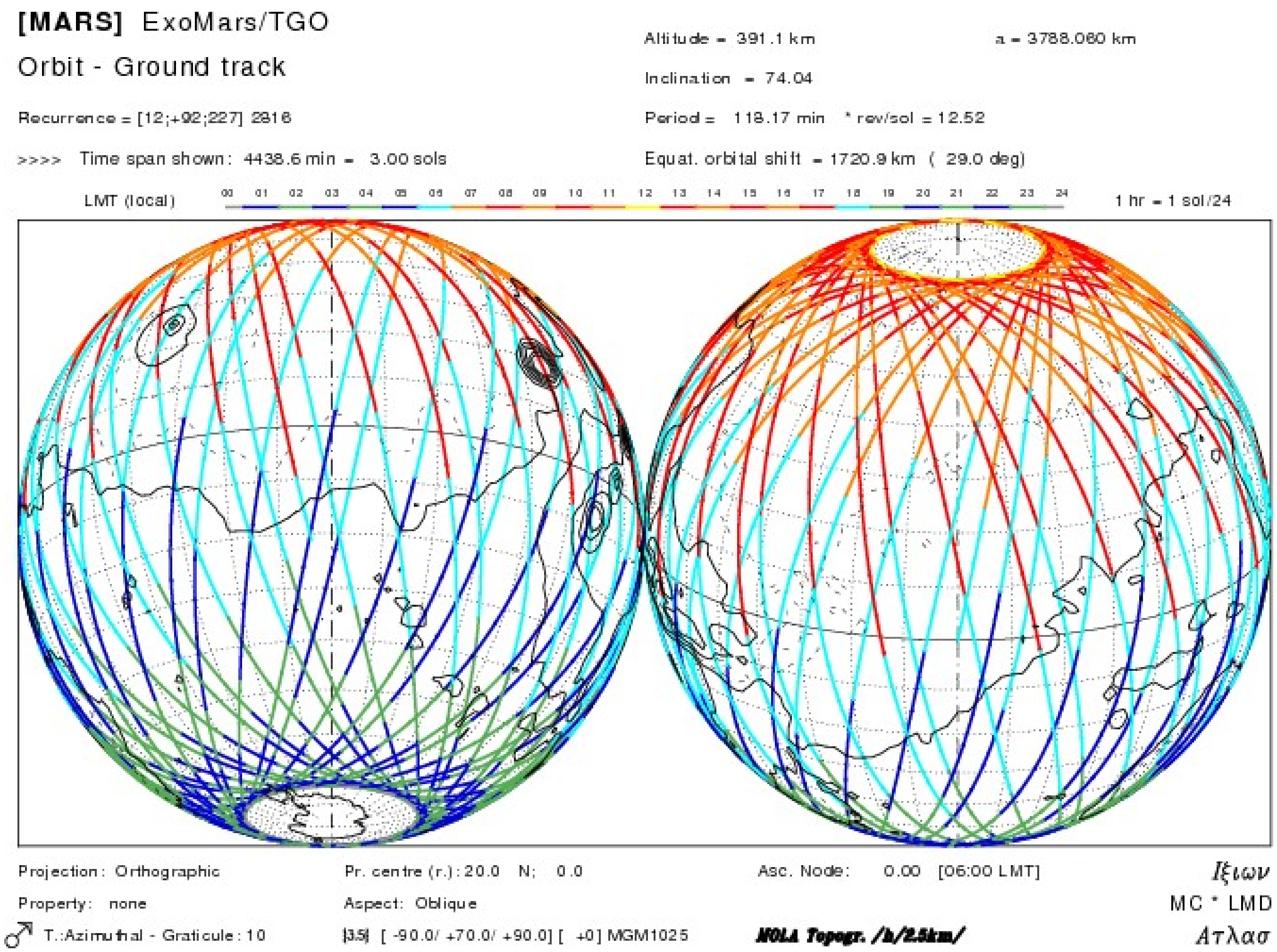
TWO LOCAL HOURS *Climatology*

TGO local time



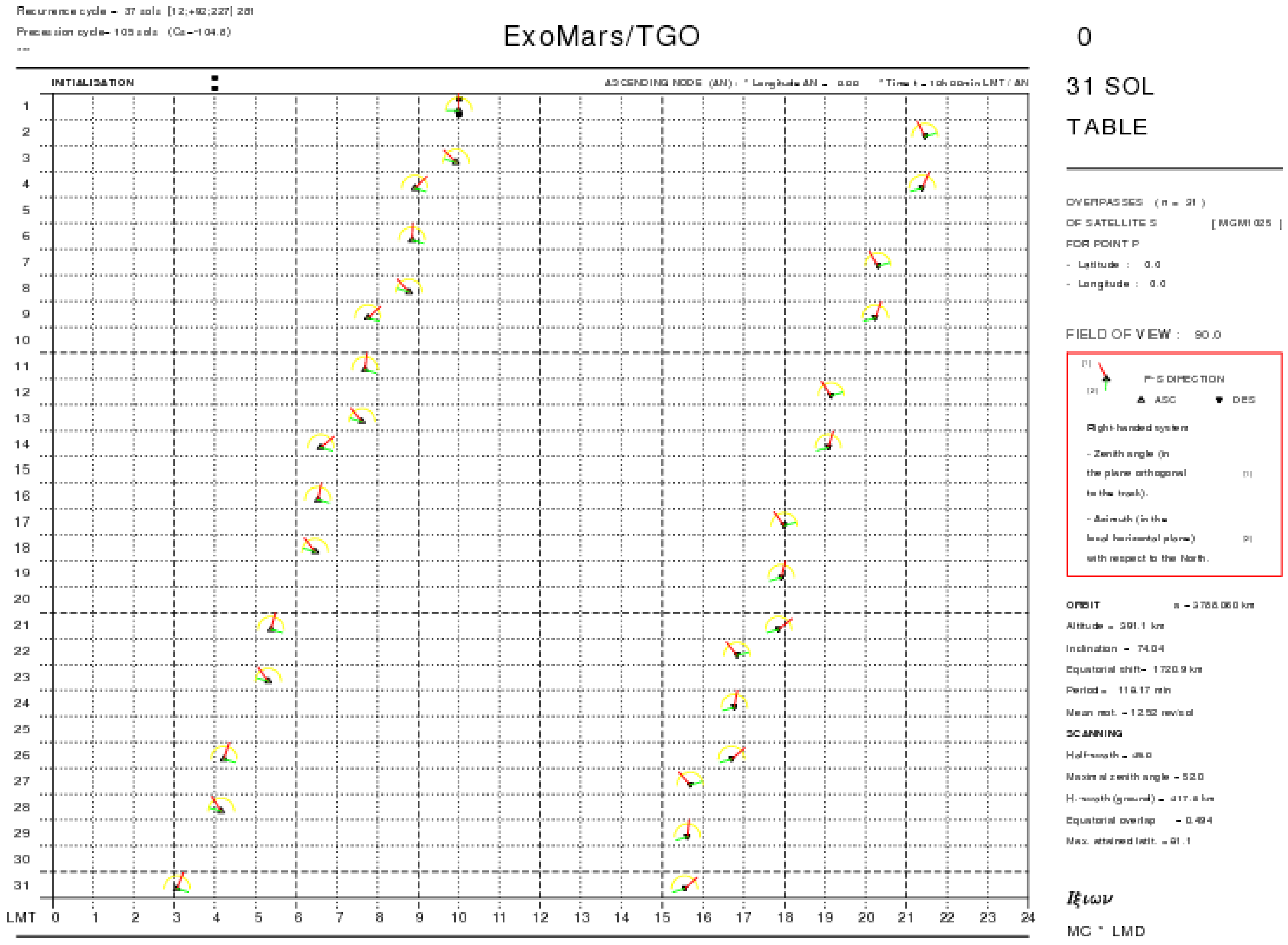
Ixion software:
http://climserv.ipsl.polytechnique.fr/ixion.html

TGO local time



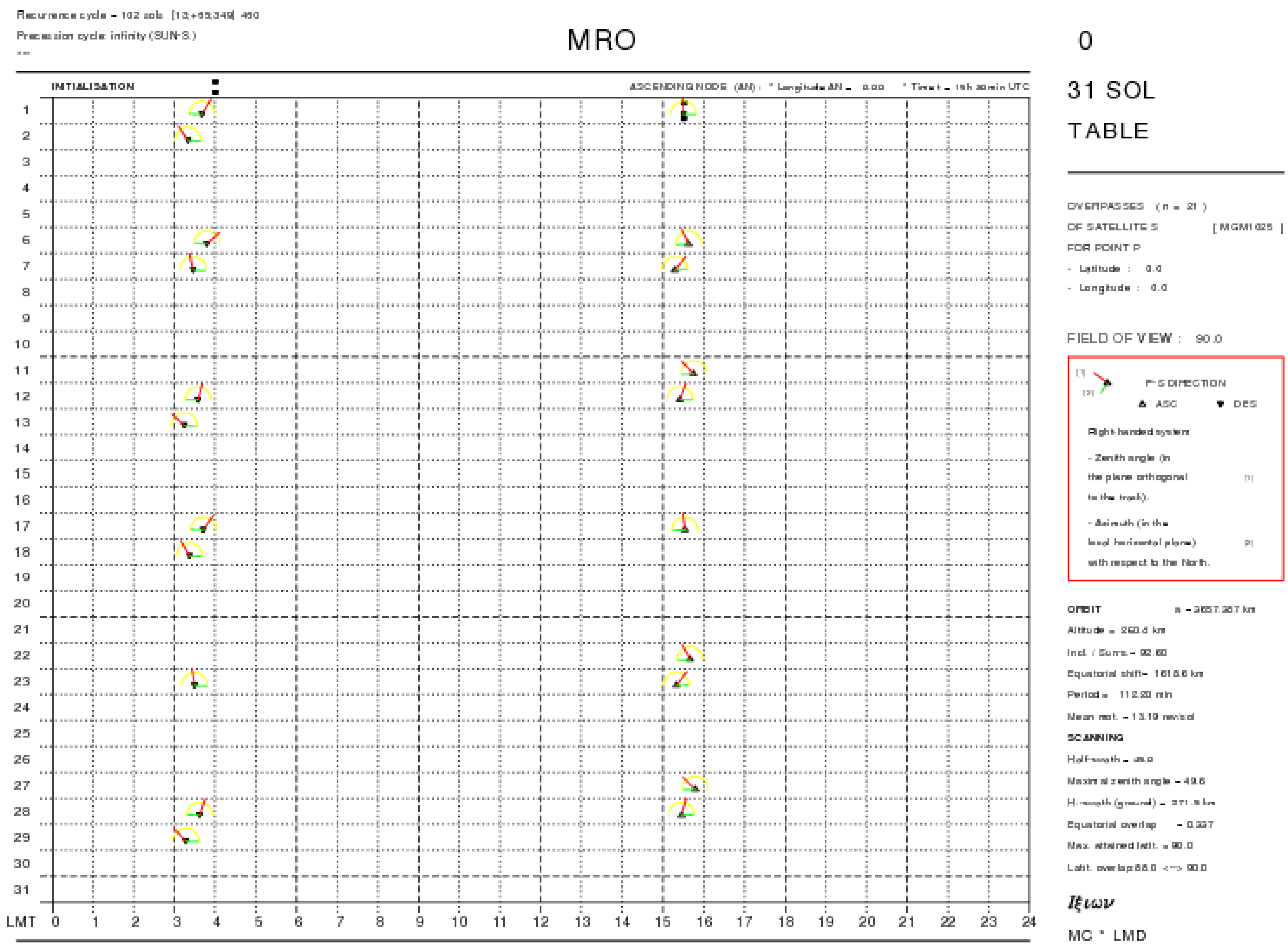
Ixion software:
http://climserv.ipsl.polytechnique.fr/ixion.html

TGO local time



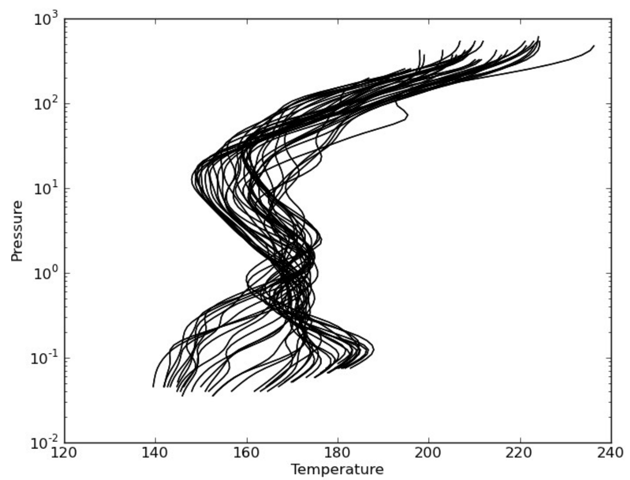
Ixion software:
http://climserv.ipsl.polytechnique.fr/ixion.html

MRO local time



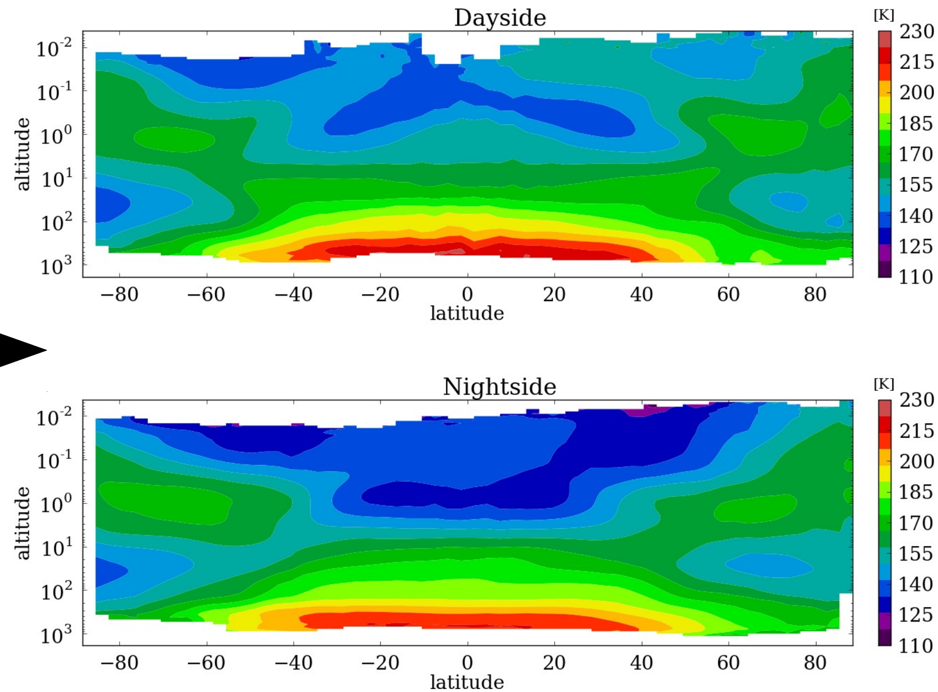
Ixion software:
http://climserv.ipsl.polytechnique.fr/ixion.html

Sun-synchronous orbit (MRO)



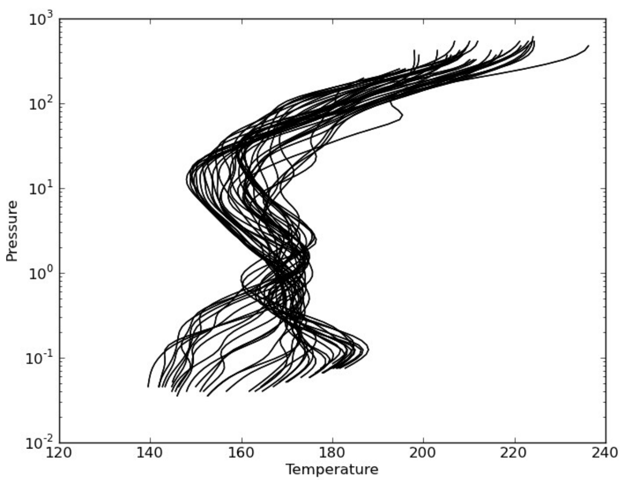
Vertical profiles

Straightforward



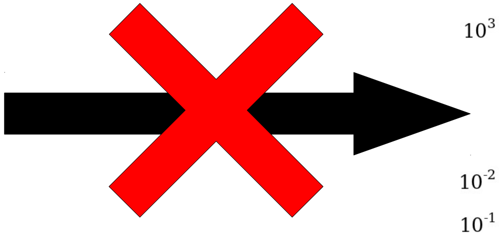
TWO LOCAL HOURS *Climatology*

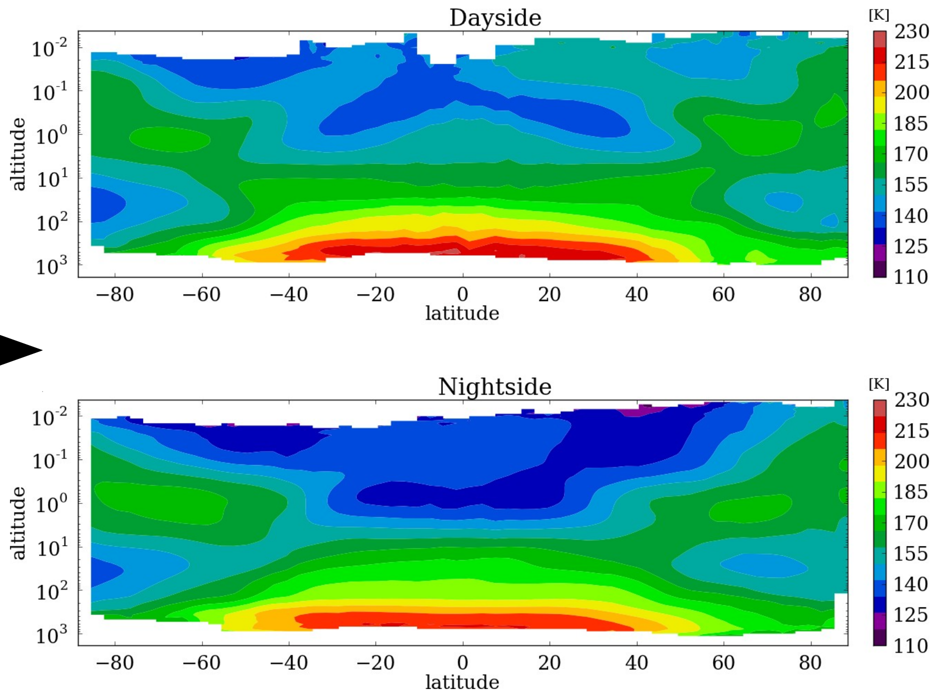
Not sun-synchronous (TGO)



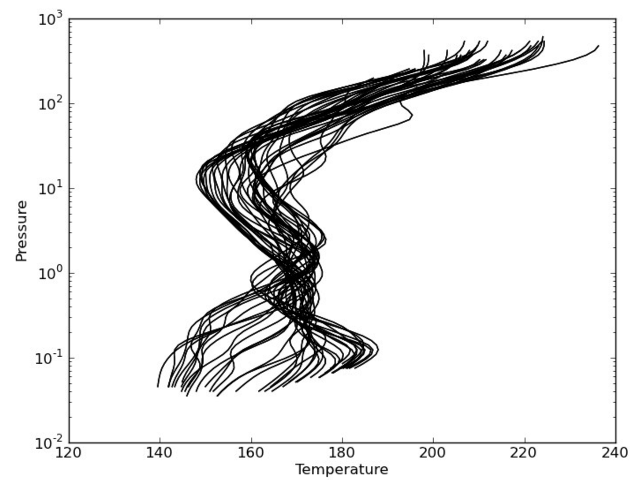
Vertical profiles

Not adapted



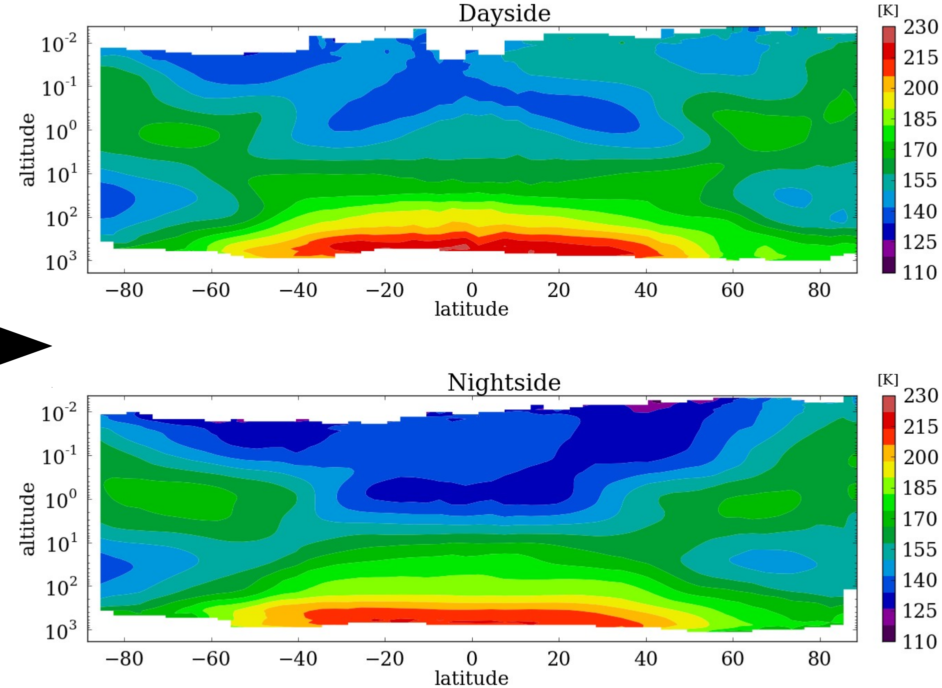


Not sun-synchronous (TGO)



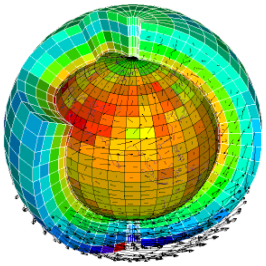
Vertical profiles

Not adapted



GLOBAL 4D *Climatology*

GCM



Data Assimilation

Near-Real Time « Analysis »

- Winds reconstruction for **retro-transport** of observed trace gases

- Profiles of temperature, density, dust, etc ... at night/day interface for **solar occultations**

Roadmap

- Coupling of LMD Mars GCM with University of Maryland's LETKF

- Assimilation of MCS and PFS temperatures

  → Validation by radio-occultations

- Assimilation of MCS dust and ice profiles

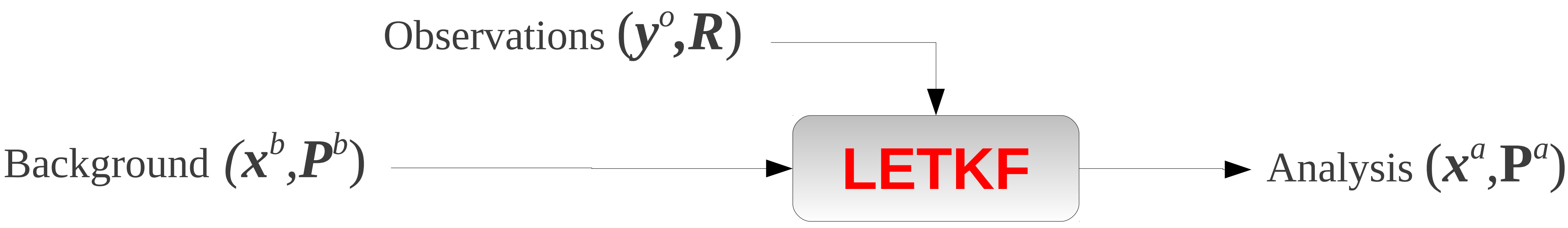
- Assimilation of MCS/PFS radiances ?

→ Preparation of near real-time assimilation of ACS data

→ temperature, dust, water ice from TIRVIM

→ water vapor, water ice (?), dust (??) from NIR

How can we use observations ?



- We need to compare the same quantities

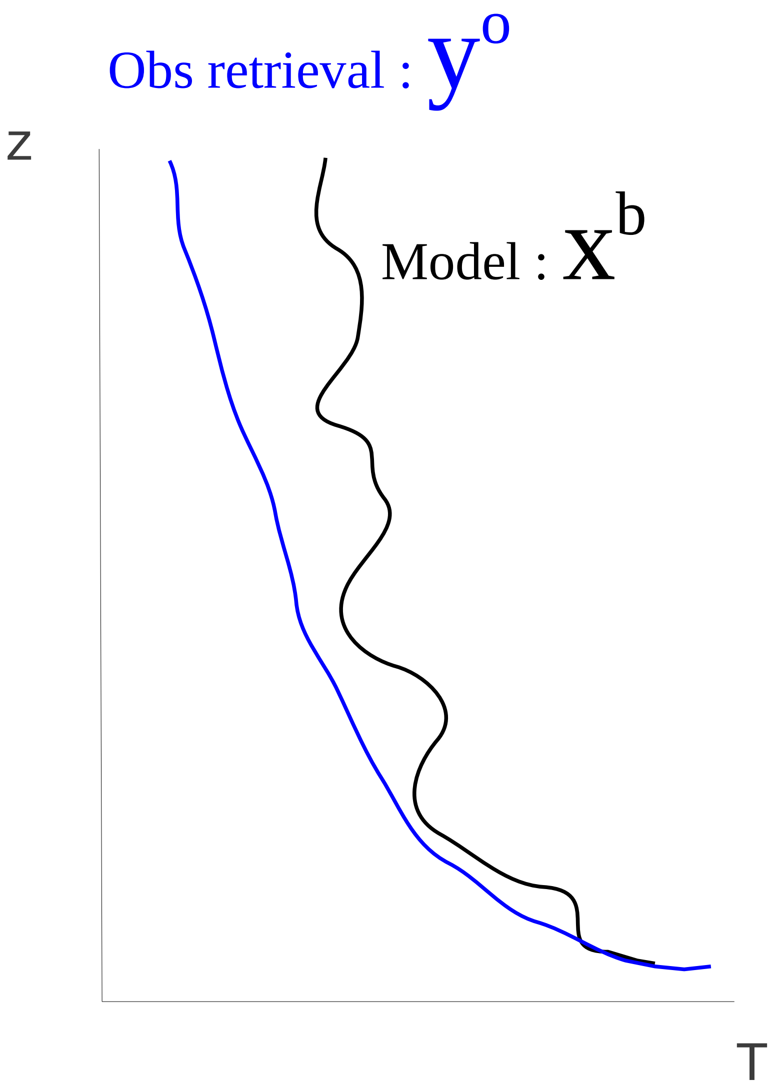
$$\boldsymbol{y}^b = H(\boldsymbol{x}^b)$$

- Two possibilities for vector of observations $\boldsymbol{y}^o$

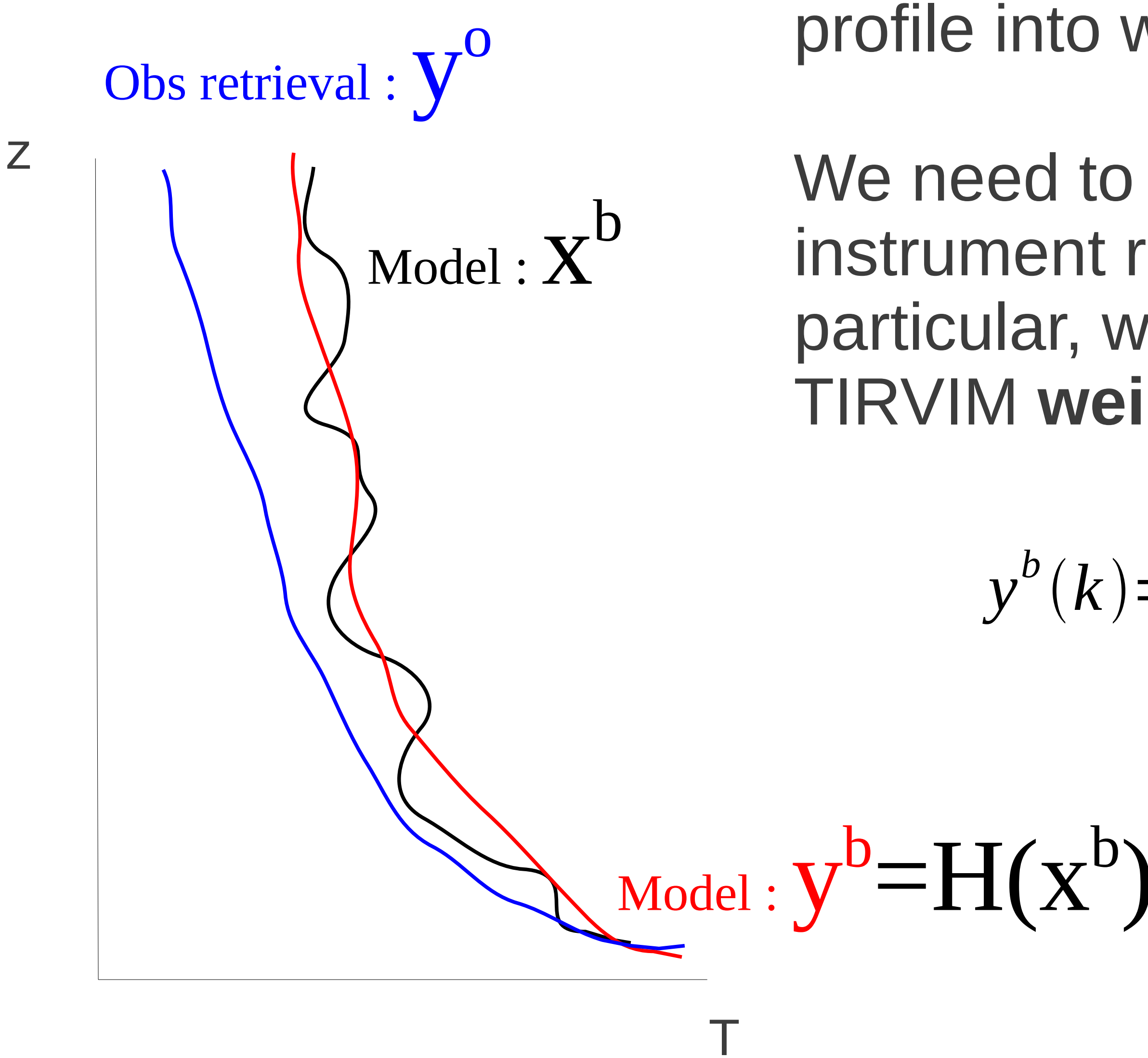
  1) Atmospheric retrievals

  2) Instrument radiances

1) Atmospheric retrievals



1) Atmospheric retrievals

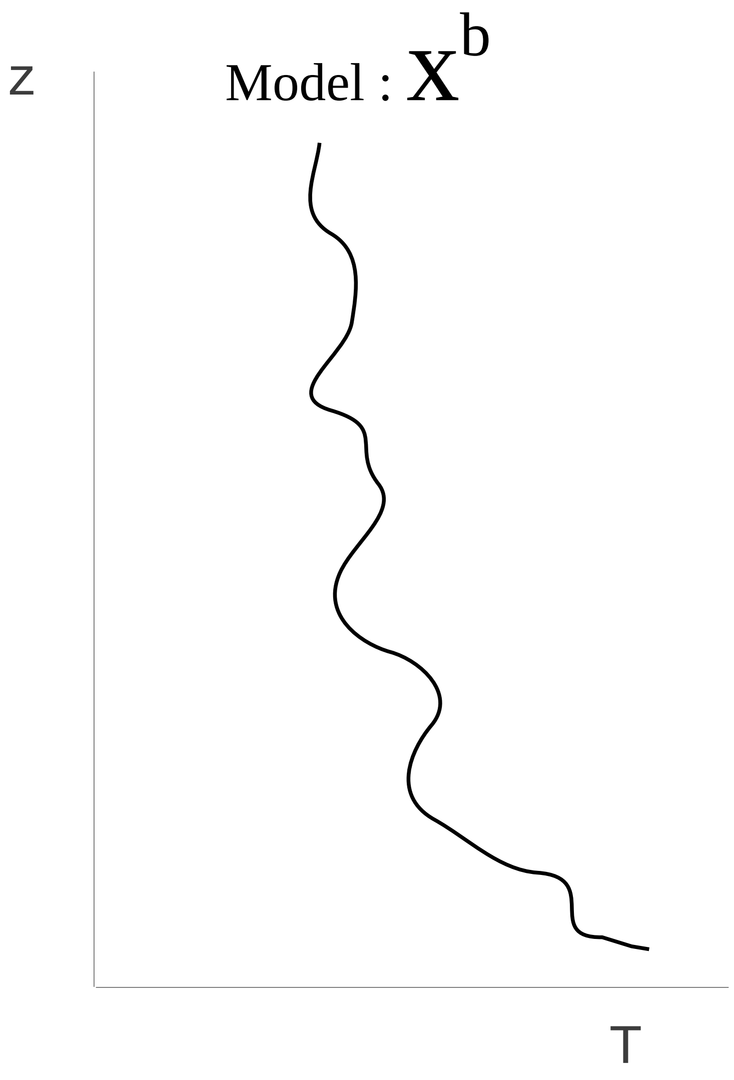


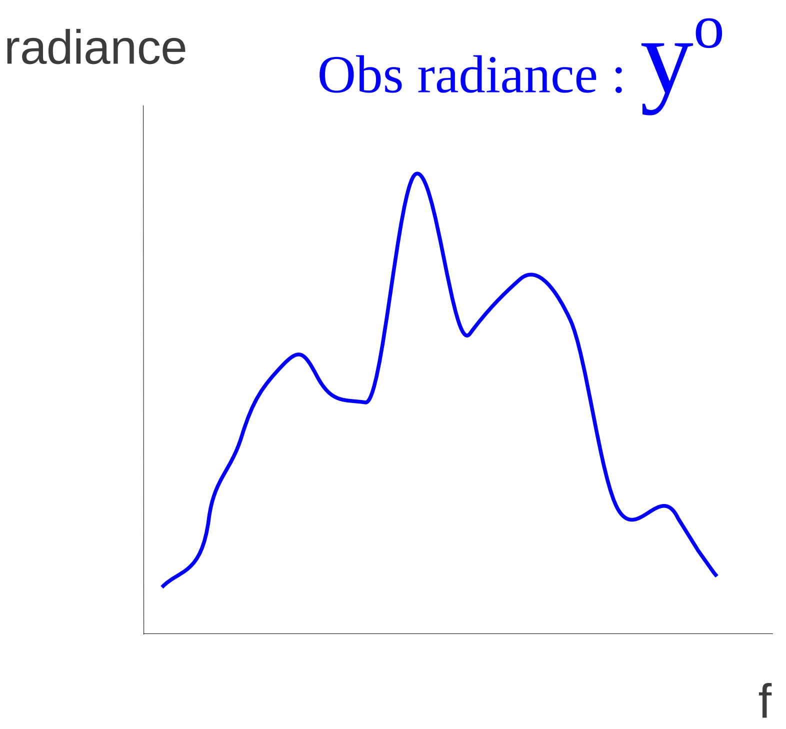
H transforms a GCM « real » profile into what ACS would see.

We need to simulate the instrument response, and in particular, we need to use the TIRVIM **weight functions** :

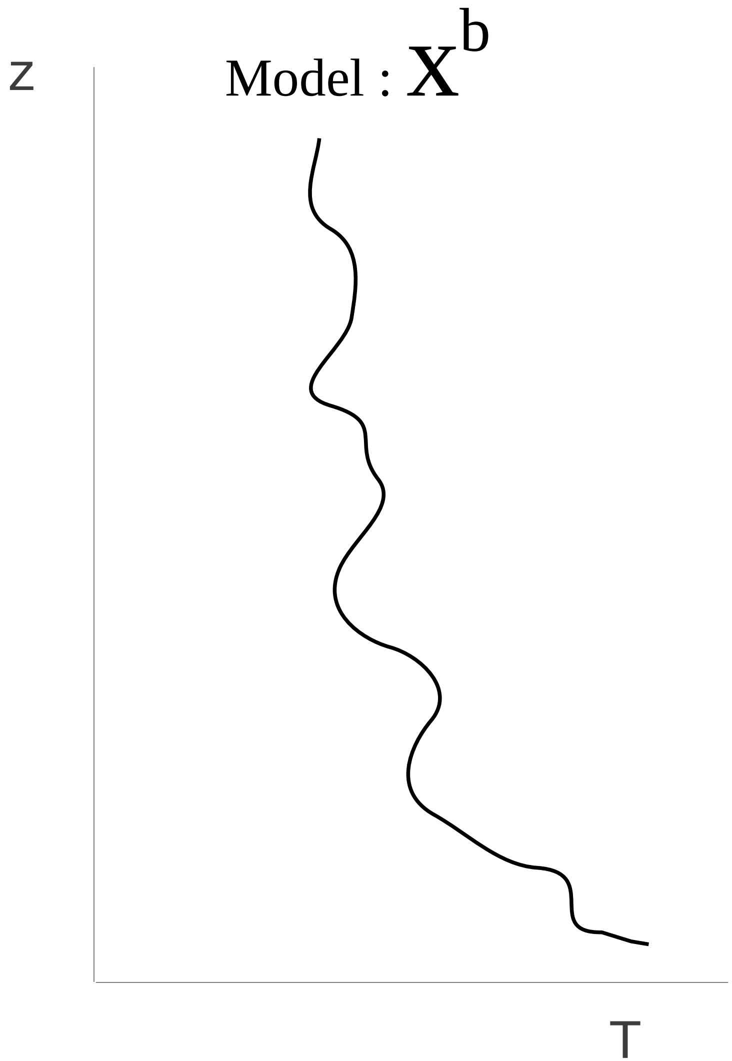
$$y^b(k) = \sum_i w_i(x^b)$$

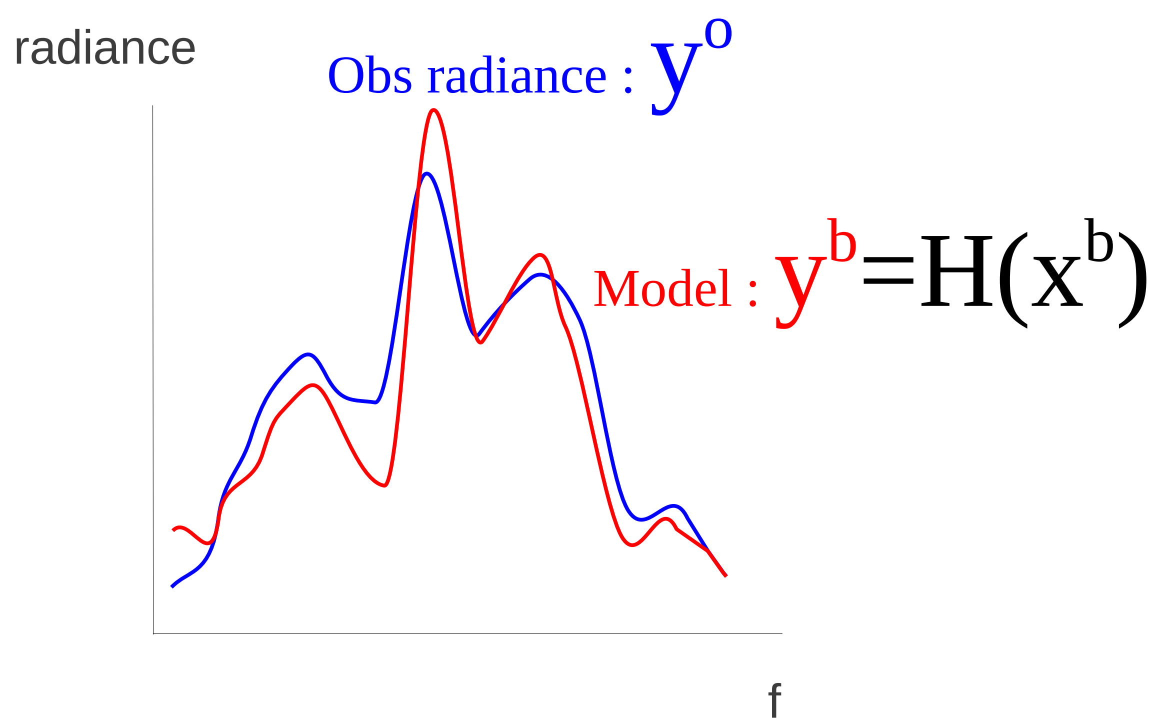
2) Instrument radiances





2) Instrument radiances





H transforms an atmospheric profile into a radiance.
It is a **forward model** of the Instrument ACS.

Radiance vs Retrievals assimilation

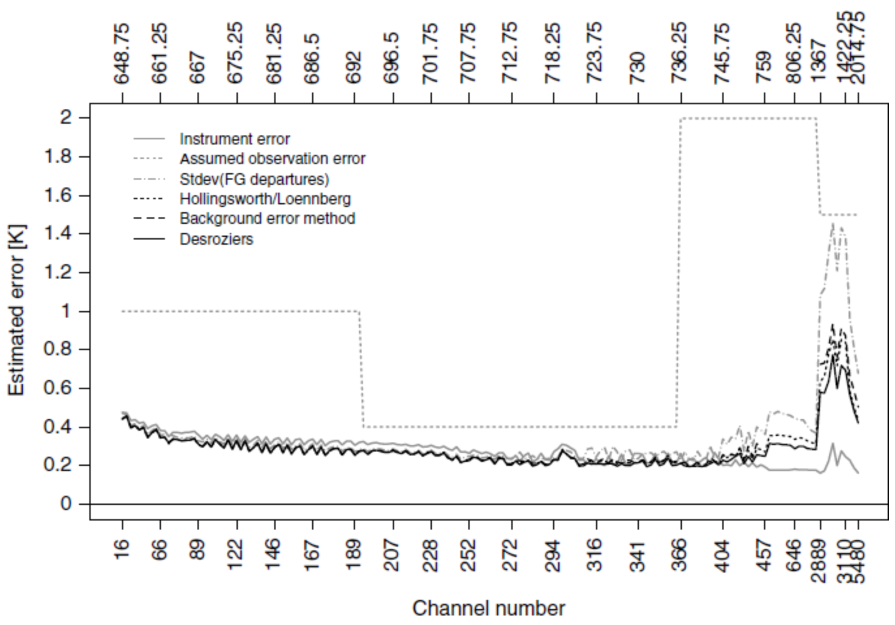
- **Retrievals**
  - Easier to implement, because the observationnal operator H **does not require a forward model**.

- **Radiance**
  - Better performance, because there is **no vertical correlation** and a **better error constraint**.

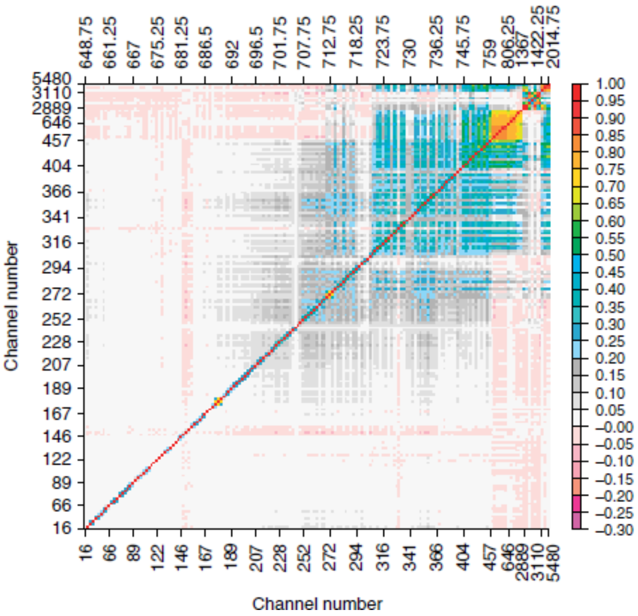
Experience for Earth shows that radiance assimilation greatly improve results. Experience on Mars shows it is very difficult [Lee et al, 2011].
We will do it for dust & ice first, then possibly temperature.

Observation errors

One can estimate **observations errors** and **correlations** using the statistics of the innovation vector (y^o-y^b)



Estimation of Observation error of IASI channels
Bormann et al, 2010



Estimation of IASI channel correlation matrix
Bormann et al, 2010

IASI is an Infrared Interferometer onboard METOP

Conclusion : for a successful data assimilation...

1 **A good model for the atmosphere**

- **Modeling of aerosols is critical** for temperature and global circulation!
  - Dust lifting and transport
  - Water ice clouds

Conclusion : for a successful data assimilation...

1 **A good model for the atmosphere**

- **Modeling of aerosols is critical** for temperature and global circulation!
  - Dust lifting and transport
  - Water ice clouds

2 **A good data assimilation technique**

- A team dedicated to LETKF, large community in data assimilation, long experience for the Earth ...
- ... but **Mars is not the Earth!**
  - Local analysis?
  - Mars atmospheric flow is less chaotic : not enough variability, but evolution of dust & ice induce a specific « Martian variability »

Conclusion : for a successful data assimilation...

1 **A good model for the atmosphere**

- **Modeling of aerosols is critical** for temperature and global circulation!
  - Dust lifting and transport
  - Water ice clouds

2 **A good data assimilation technique**

- A team dedicated to LETKF, large community in data assimilation, long experience for the Earth ...
- ... but **Mars is not the Earth!**
  - Local analysis?
  - Mars atmospheric flow is less chaotic : not enough variability, but evolution of dust & ice induce a specific « Martian variability »

3 **A good instrument with well specified observation errors**

- The orbit is awesome for assimilation
- Possibility to estimate errors
- **A forward model would improve the analysis**

→ We look forward to a close collaboration with the ACS instrument team