

La correction troposphérique humide pour l'altimétrie

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La correction troposphérique humide

$$dh = 77,67 \cdot 10^{-5} \int_0^H \frac{p}{T} dz + 0,3744 \int_0^H \frac{e_v}{T^2} dz - 6 \cdot 10^{-6} \int_0^H \frac{e_v}{T} dz$$

- « dry » term ($\approx 2\text{m}$) provided by meteorological models with a good accuracy
- « wet » term, almost proportional to the integrated water vapor, highly variable in space and time, ranging from a few cm to about 50 cm, not provided with enough accuracy by meteorological models (actual resolution of 50km/6hours)

Radiométrie hyperfréquence sur les missions altimétriques

Les instruments

MISSIONS	GEOSAT	ERS1	TOPEX	ERS2	GFO	JASON1	JASON2	ENVISAT	AltiKa	Sentinel 3
Life in space	1985-19 90	1991-19 96	1992-20 05	1995-	1998-20 08	2001-	2008-	2002-	2010-	2012-
Altimeter freq. (GHz)	13.5	13.8	13.6 5.3	13.8	13.5	13.575 5.3	13.575 5.3	13.575 3.2	35.75	13.575 5.3
Radiometer channels (GHz)	/	23.8 36.5	18 21 37	23.8 36.5	22 37	18.7 23.8 34	18.7 23.8 34	23.8 36.5	23.8 37	23.8 36.5

Radiométrie hyperfréquence sur les missions altimétriques

Les contraintes

To provide the wet tropospheric correction :

- with a good accuracy (≈ 1 cm rms)
- with a good stability (≈ 1 mm/year)
- with no geographically correlated errors

Microwave radiometry chosen because:

- Compact and assessed technology (first radiometers launched at the beginning of the seventies)
- Humidity retrieval methods available, based on the use of 2 or more channels since SMMR

ERS1/MWR first microwave radiometer dedicated to the altimeter path correction

Radiométrie hyperfréquence sur les missions altimétriques

les points durs:

- 1 Étalonnage en vol :
 - Étalonnage absolu,
 - Stabilité court terme
 - Dérive long terme

- 2 Correction troposphérique:
 - Uniformité de l'erreur
 - Traitement à l'approche des côtes, banquises,...
 - Nouvelles questions

1 Etalonnage en vol:

Quelques problèmes rencontrés sur l'étalonnage et méthode de correction

Problems encountered:

- 10 dB gain drop for the ERS2/MWR : loss of an amplifier ?
- Satellite attitude impact with yaw mode effect on TBs for Topex/TMR and Jason1/JMR : thermal effects ?
- Long term drift for Topex/TMR and Envisat/MWR (components aging ?)
- Noise diode stability for Jason1/JMR: diode unstabilities ?

Corrections:

Empirical methods based on TBs time series and intercomparison of instruments

Jason2/AMR: Mise en œuvre de ARCS (processus de calibration automatique

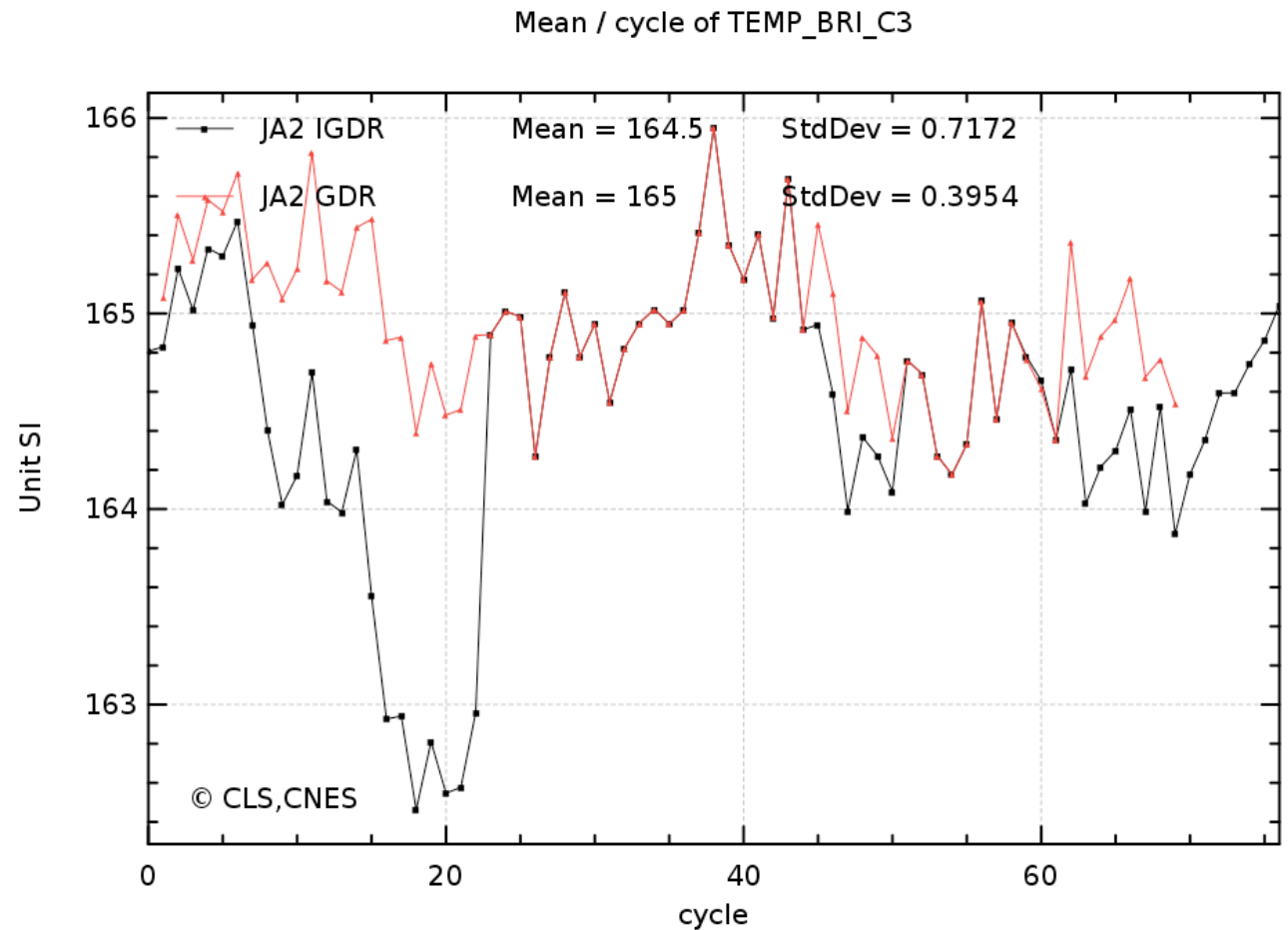


Illustration sur le suivi des TBs à 34 GHz

Le produit IGDR est le produit à 3 jours, le produit « brut » pour le radiomètre

Le produit GDR est le produit à 60 jours (délai rallongé à cause du radiomètre) après application de ARCS.

Non satisfaisant car:

- pénalise la distribution d'un produit temps réel de qualité
- sans doute pas mal de signaux géophysiques absorbés dans ces corrections de calibration a posteriori

1 Etalonnage en vol:

exemple de Altika

- Similar to the one used for ERS1, ERS2 and Envisat MWRs since the 1990s
 - Performed during the verification phase after thermal stabilization of the radiometer
 - Systematic comparison between measured TBs and simulated TBs by a radiative transfer model applied on coincident analyzed profiles (ECMWF).
 - Slight modification of some instrumental parameters to adjust the measured TBs on simulated TBs.
 - not an **absolute calibration** of the radiometer
 - **relative calibration** with respect to a reference, the one used to formulate the retrieval algorithm
 - Same tools (same radiative transfer model, same version of the ECMWF model) used for the in-flight calibration and for the formulation of the L2 algorithm
- => *Essential consistency between the measured TBs and retrieval algorithm is achieved*

(Obligis et al, 2006)

1 Etalonnage en vol: Intercomparaison d'instruments

TBs comparison on a selected area of the Amazon rain forest



Mean TB (K)

Freq	18.0	18.7	21.0	23.8	31.4	34.0	36.5	37.0	#
AmsuA	-	-	-	285.8	282.7	-	-	-	641
TMR	278.6	-	278.1	-	-	-	-	277.6	2160
JMR	-	283.5	-	283.4	-	280.2	-	-	227
SSM/I	-	284.2	-	283.4	-	280.5	-	-	14564
ERS-2	-	-	-	285.7	-	-	291.9	-	3937

TMR too low
at each frequency

Very good agreement
at 23.8 GHz

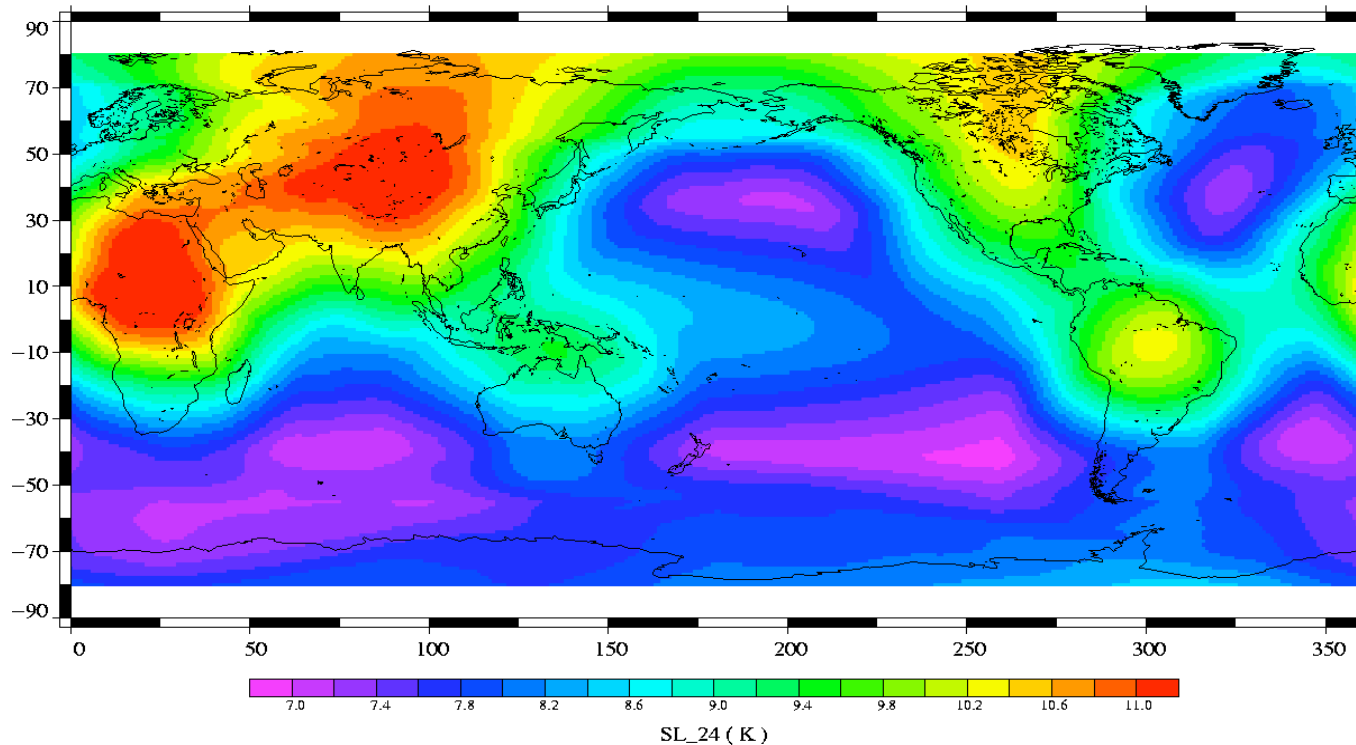
ERS2 too high
at 36.5 GHz

(Eymard et al, 2005)

1 Etalonnage en vol:

Les lobes secondaires

Dynamic correction of the side lobe contribution to take into account geographical and seasonal variations



- Useful part of the signal is in the main lobe of the antenna pattern
- Necessity to remove the contribution due to side lobe
- Dynamic correction to take into account the presence of land in the side lobe

(Obligis et al, 2007)

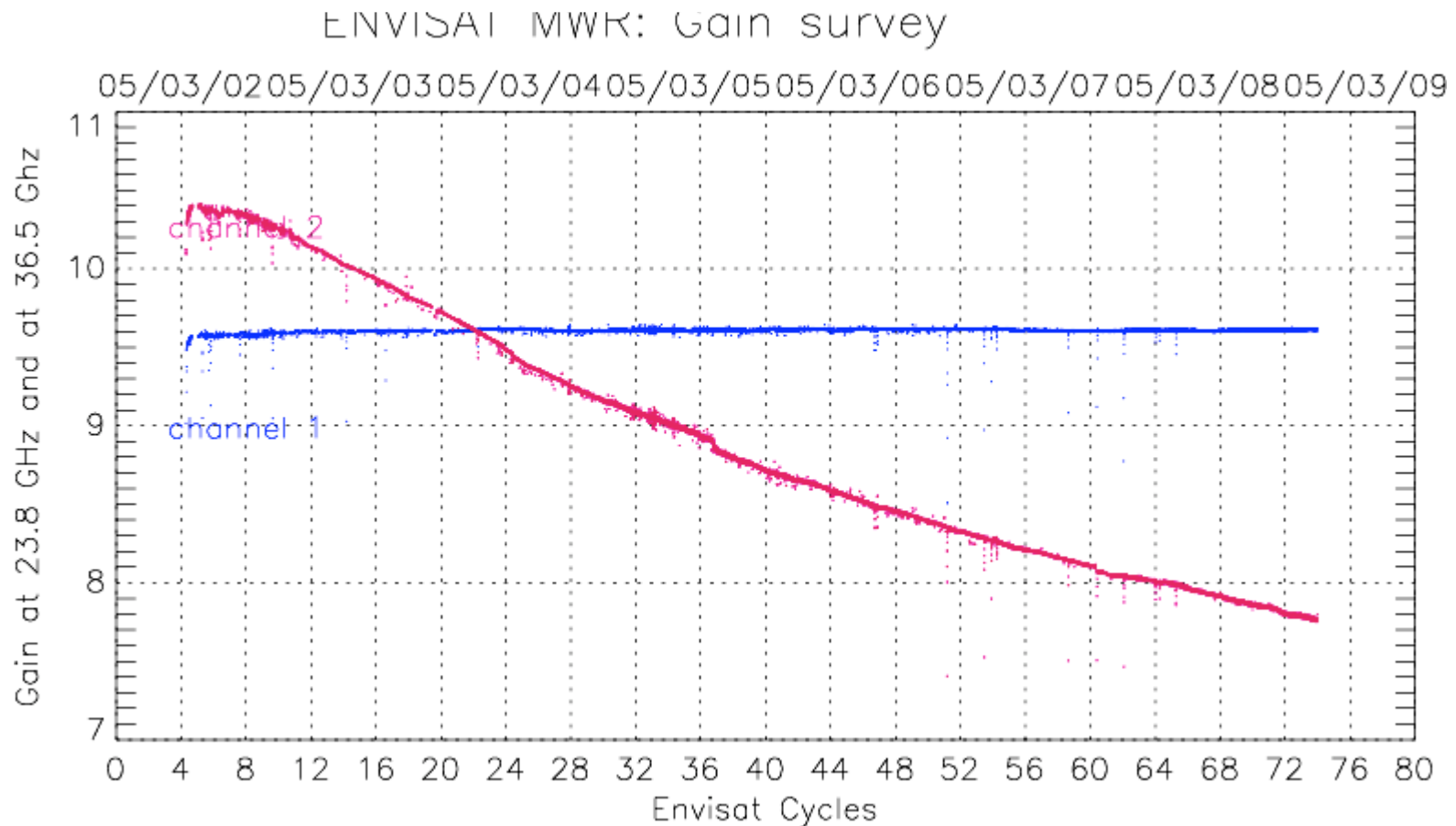
1 Etalonnage en vol:

Suivi long terme et stabilité des températures de brillance

- Microwave radiometers have been proved quite stable with time
- But requirements for altimetry missions are much more stringent (sea level rise)
- Proposition of dedicated methods to detect, quantify and correct possible drifts
 - ✓ Instrumental parameters survey
 - ✓ TBs long term survey over hot targets quite similar to a blackbody (Amazon rain forest, Eymard et al, 2005)
 - ✓ TBs long term survey over coldest ocean (Ruf et al 2001)

1 Etalonnage en vol:

Suivi long terme et stabilité des températures de brillance

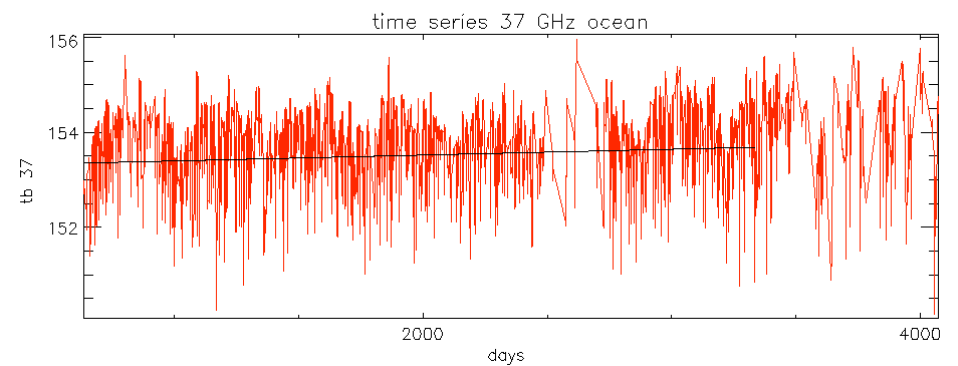
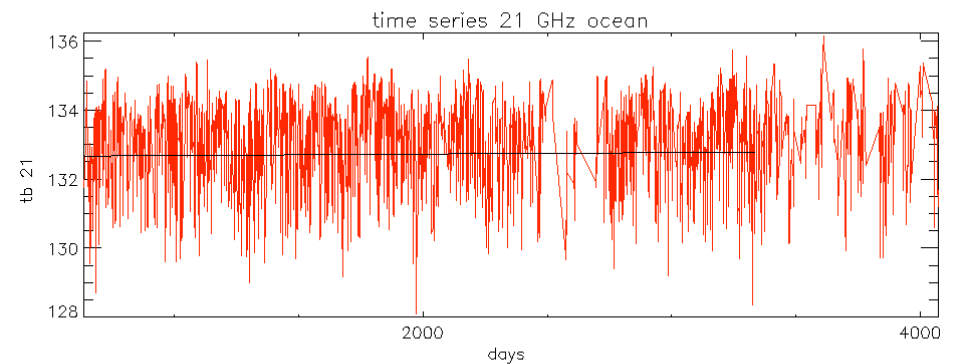
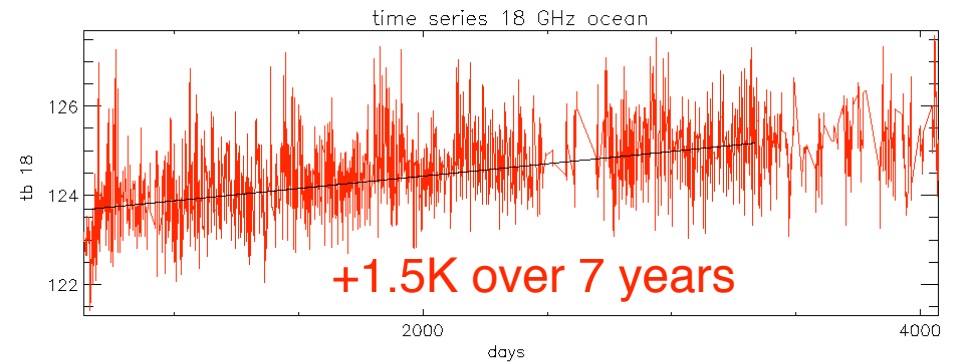


Impact sur TBs?

1 Etalonnage en vol: Suivi long terme et stabilité des températures de brillance

Statistical selection of the coldest OceanTBs:

- ✓ brightness temperatures histogram fitted with an analytical function, that is next used to find the minimum brightness temperature by extrapolation
- ✓ study of the time series of the selected lowest temperatures for the three channels



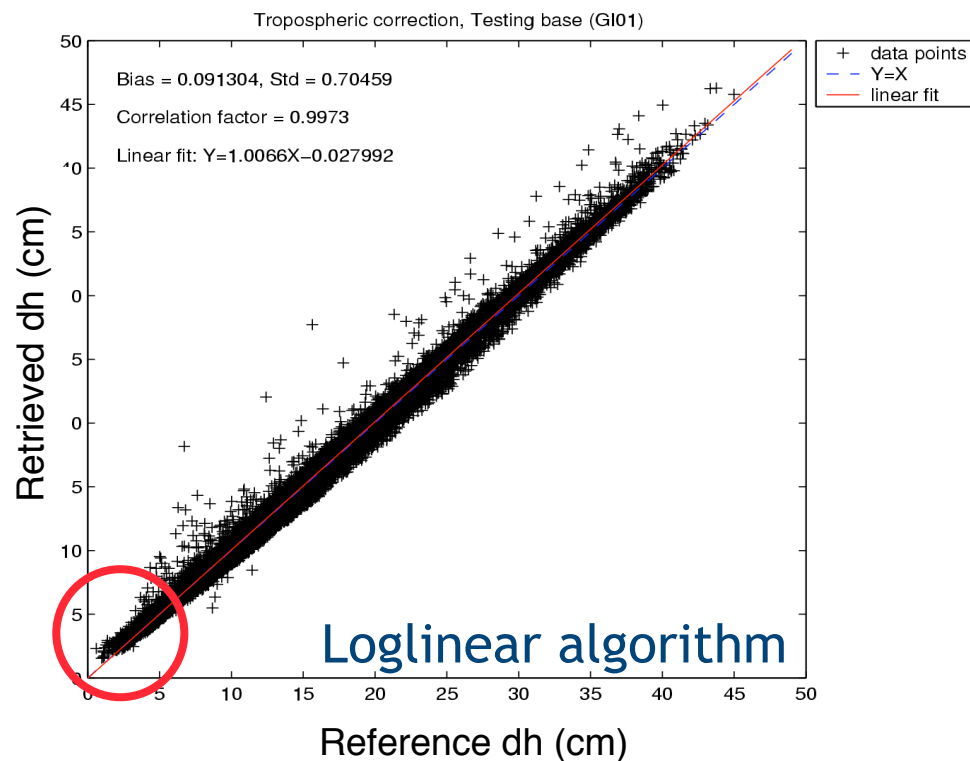
2 La correction troposphérique

Statistical methods (Obligis et al, 2006; Keihm et al, 1995)

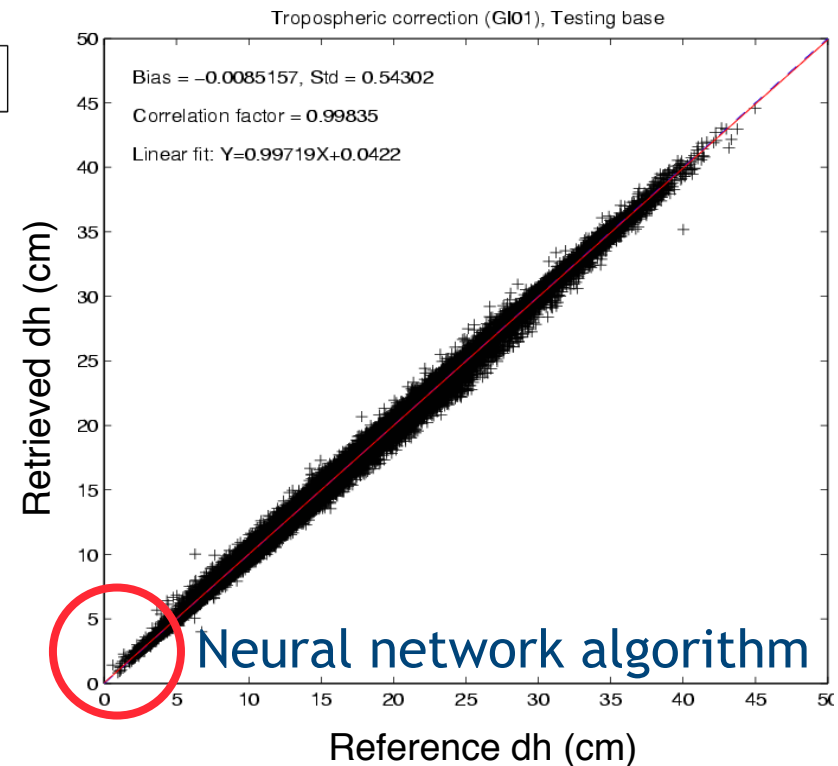
- synthetic data base built using radiative transfer modelling on atmospheric profiles (radiosoundings - TMR ; ECMWF - EMWR)
- TMR/JMR retrieval in two steps: « wind » estimate, then linear combination of the 3 channel Tbs, coefficients depending on the « wind » and « wet tropo » classes
- ERS1/2-MWR algorithm : loglinear combination of the 2 channel Tbs and the altimeter wind
- Envisat/MWR algorithm : neural network combination of the 2 channel Tbs and the altimeter backscattering coefficient in Ku band
- AltiKa: neural network combination of the 2 channel Tbs and the altimeter backscattering coefficient in Ka band

2 La correction troposphérique: validation

Performances over simulated database during the learning phase



$$dh = c_0 + c_1 \ln(280-TB_{23.8}) + c_2 \ln(280-TB_{36.5}) + c_3 / \sigma_0^2$$



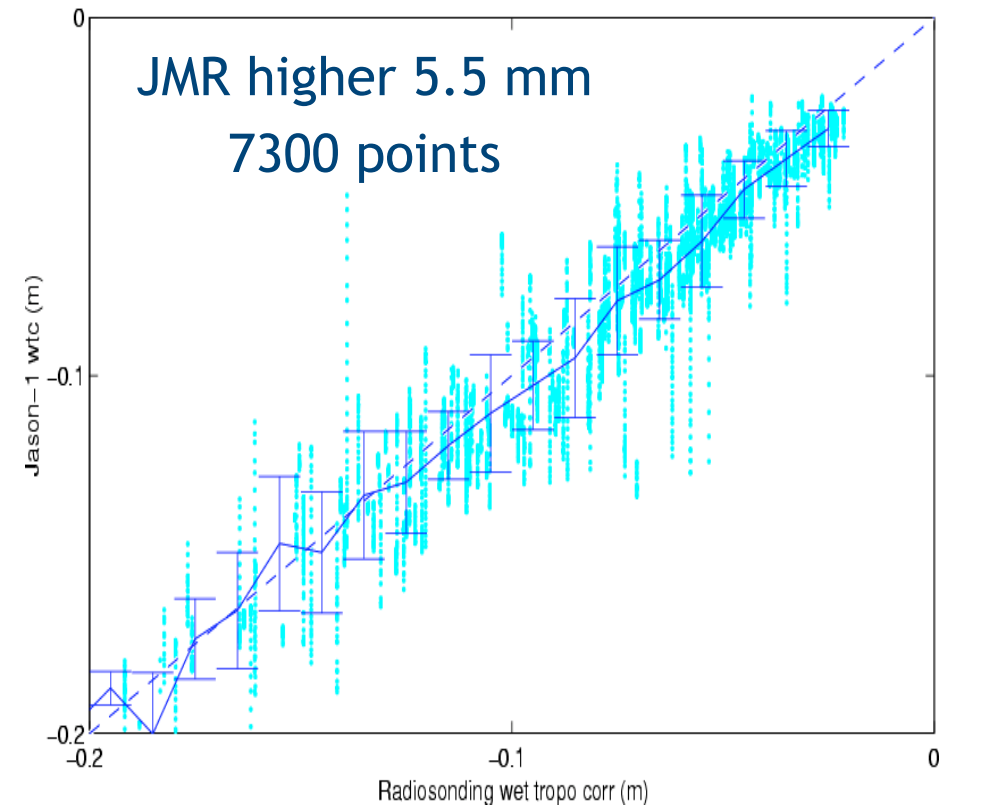
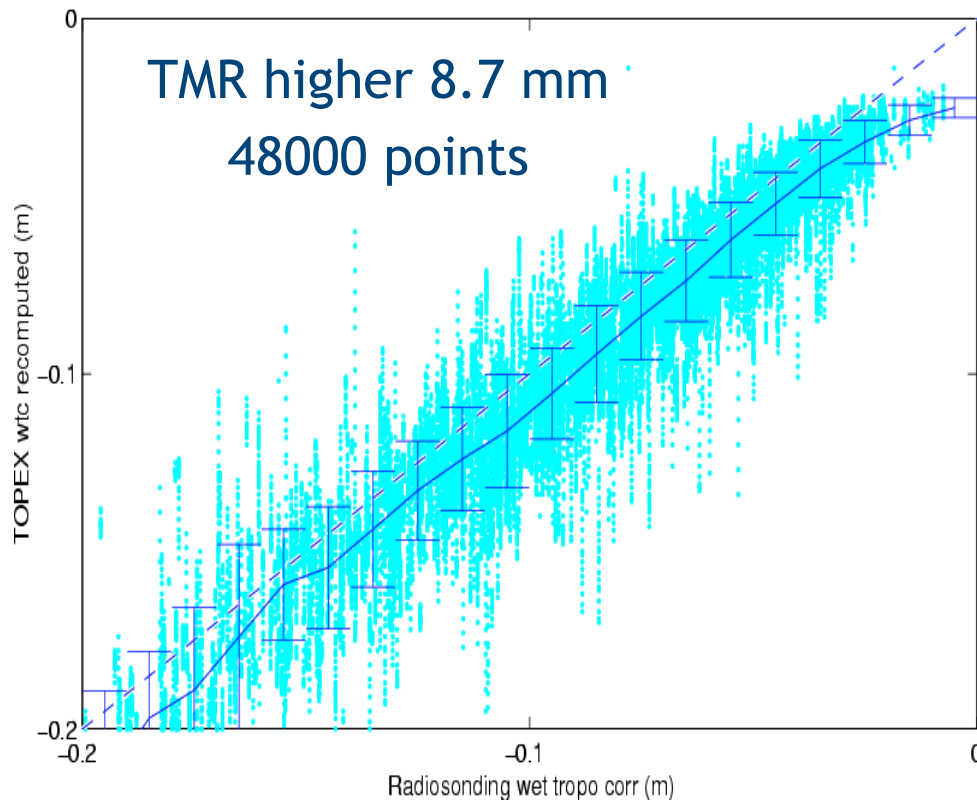
$$dh = NN(TB_{23.8}, TB_{36.5}, \sigma_0)$$

Réduction biais à faible valeur

(Obligis et al, 2006)

2 La correction troposphérique : Importance des données de validation (et ajustement)

Comparison avec radiosondages 1992->2003 (100km, 1h, plein océan)



20 cm

0 cm

20 cm

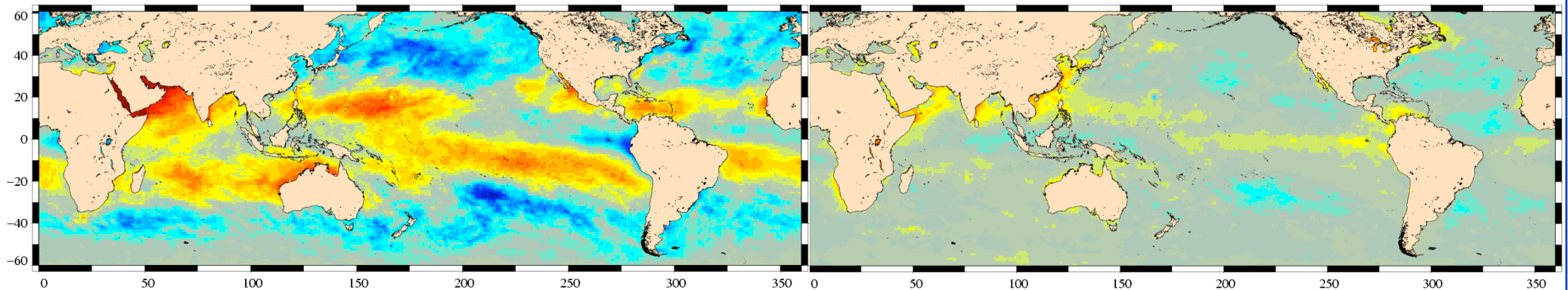
0 cm

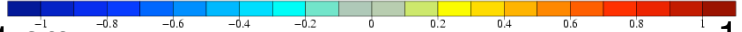
Algorithmes TMR et JMR ajustés / validés sur RS et radiomètres sur côtes et îles (50 km): cause de l'écart? (Obligis et al, 2004)

La correction troposphérique :

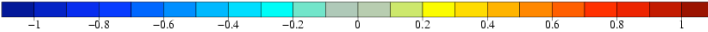
Biais géographiques: amélioration algorithmique

- Les approches statistiques de restitution négligent les particularités régionales
- Amélioration significative des algorithmes d'inversion si ajout d'une valeur a priori sur la SST et sur la distribution verticale de vapeur d'eau (Γ = taux de décroissance de la température avec l'altitude)

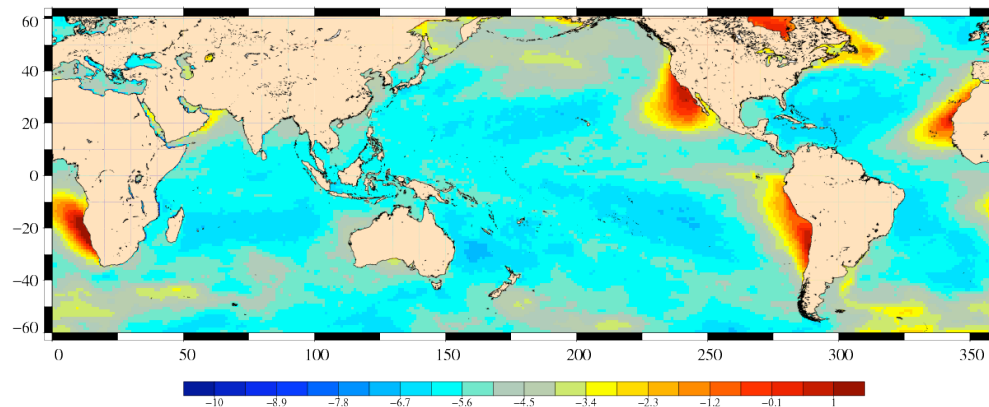


-1 cm  1 cm

$dh=NN(TB23.8, TB36.5, \sigma_0)$



$dh=NN(TB23.8, TB36.5, \sigma_0, SST, \Gamma)$



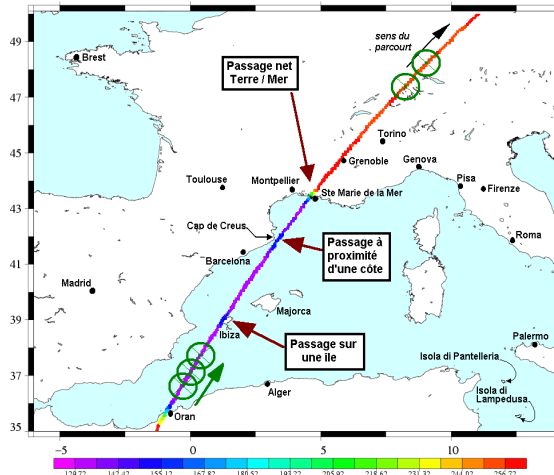
Carte climatologique
Gamma (K/km)

Obligis et al, 2009

La correction troposphérique :

Traitement près des côtes : méthode empirique

Nécessaire à l'exploitation des mesures altimétriques qui sont valides pratiquement jusqu'à la côte alors que la mesure radiométrique est contaminée dès 50 km



p = lissage par le lobe d'antenne d'un masque terre/mer à 0.01°

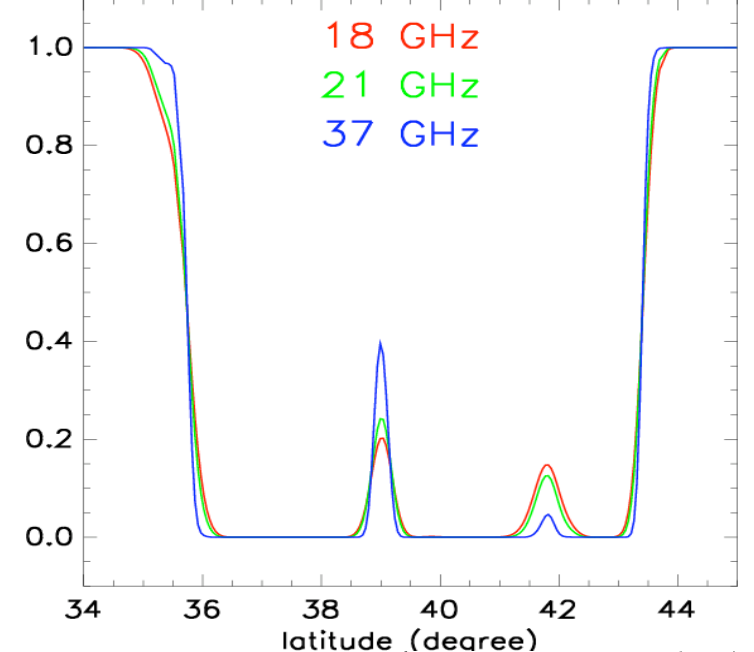
TB corrigée = TB mesurée – corr

$$\text{corr}(p, f) = [\text{TB}_{\text{terre}}(f) - \text{TB}_{\text{mer}}(f)] \times p(f)$$

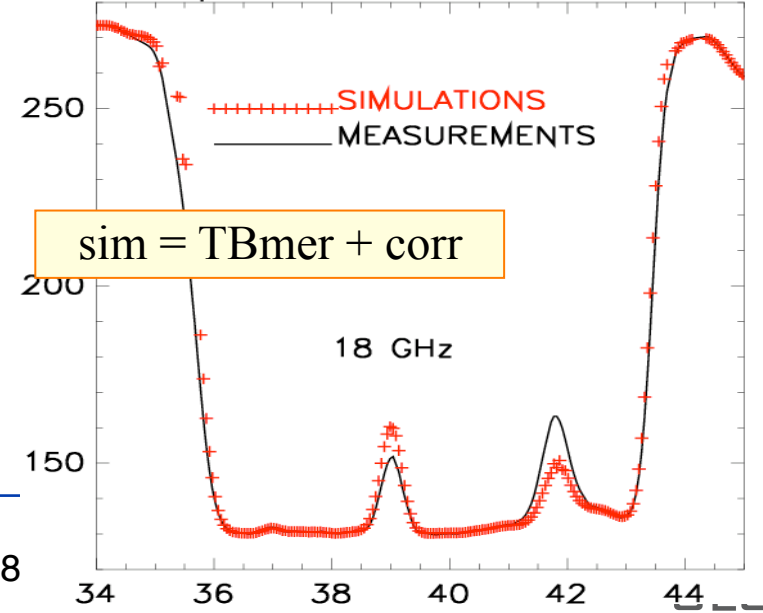
Où $p = 1$

Où $p = 0$

land proportion in pixel along track



TBs Topex and simulated, 031612



2 La correction troposphérique :

Traitement près des côtes : inversion variationnelle

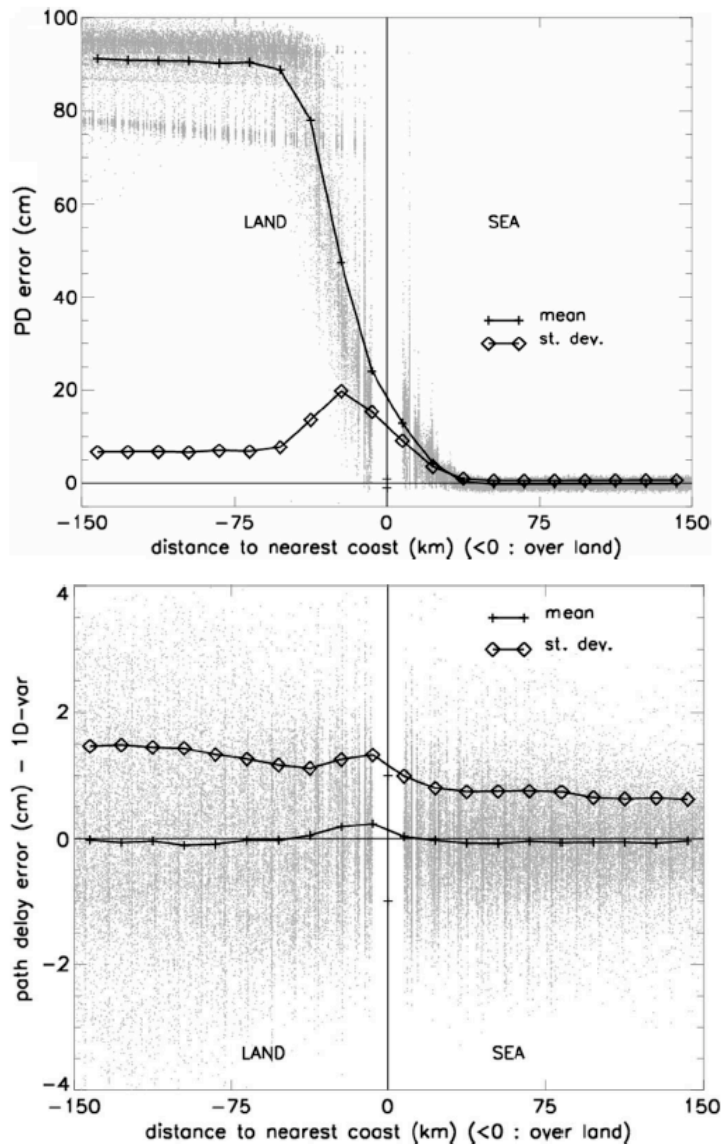


Fig. 5. Difference between the 1-D Var PD and ECMWF PD, as a function of the distance to the nearest coast, with mean and standard deviation (in centimeters).

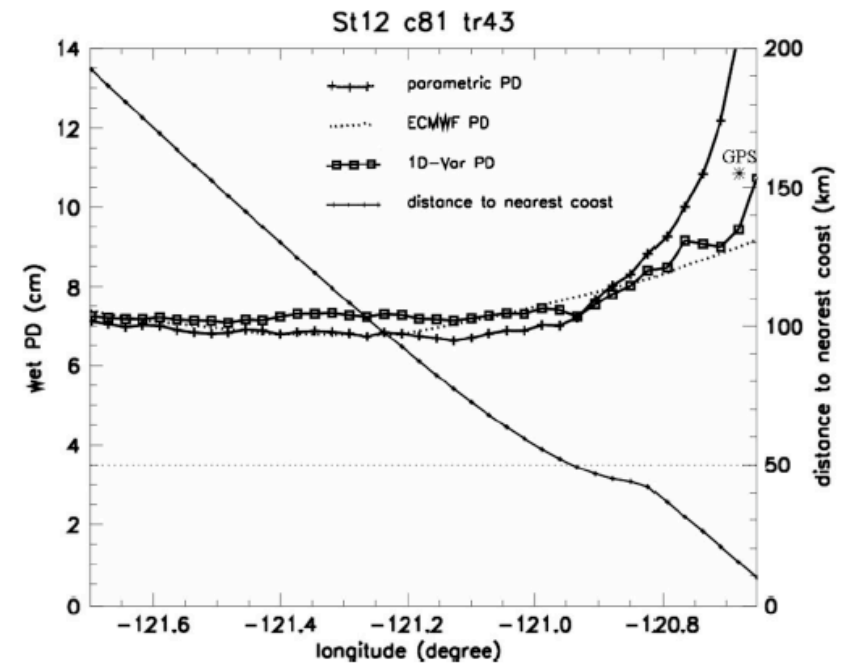


Fig. 8. Comparison between (+) the parametric PD, (squares) the 1-D Var PD, and (dotted line) the ECMWF PD from the Jason-1 product (in centimeters). (Ordinate at the right) The line going down gives the distance to the nearest coast.

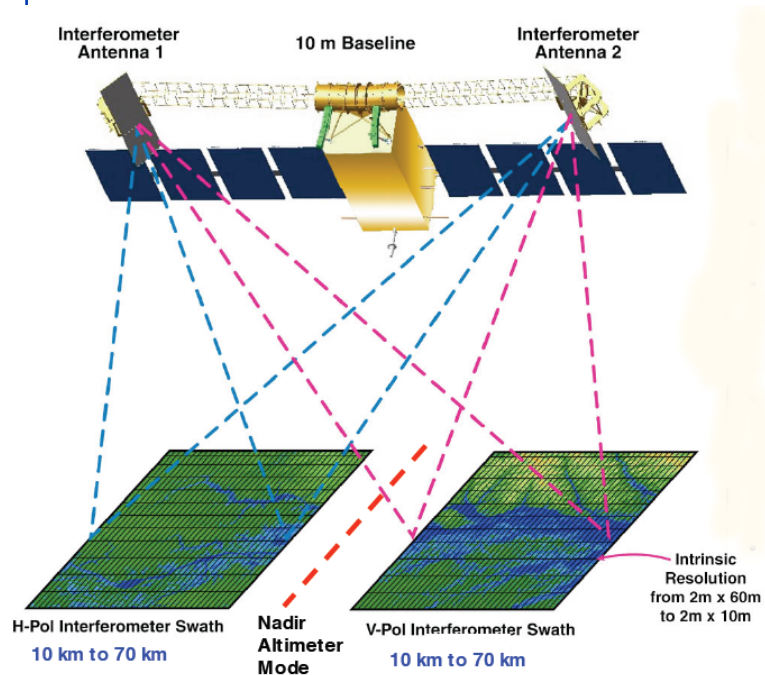
Limites:

- nuages et pluie
- trait de côte
- Connaissance de l'émissivité (terre et mer)

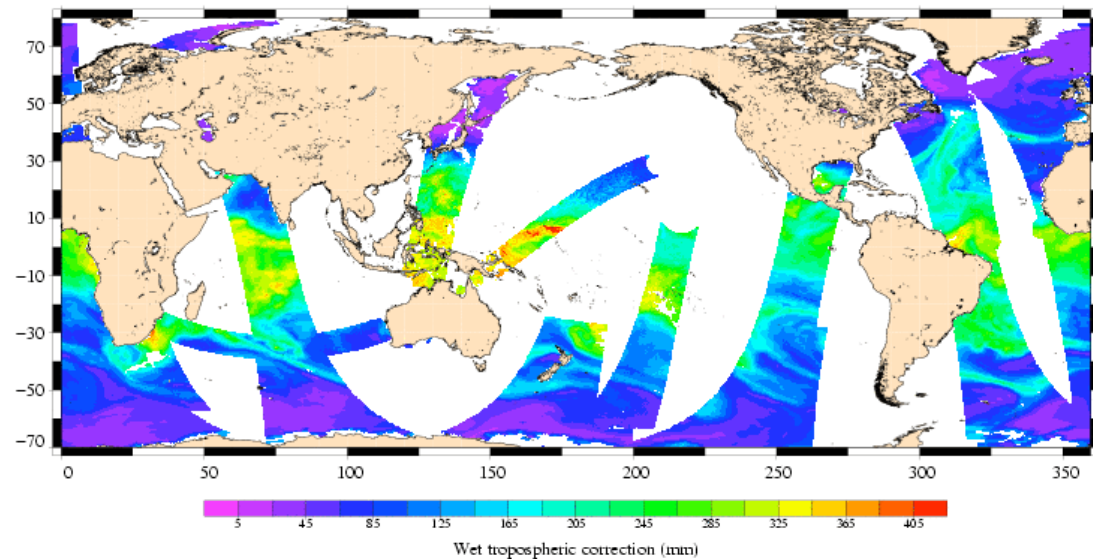
Desportes et al, 2010

3 Nouvelles questions?

Le cas de SWOT



AMSU15 + AMSU16 + AMSU17 + AMSU18 + AMSUMA + SSMI13 + AMSRE + TMITR
January 5th, 2008, from 16h to 17h GMT



Produits de vapeur d'eau sur une heure

Besoin d'une correction tropo dans la fauchée ? (Impact des variations d'humidité sur phase du signal?)

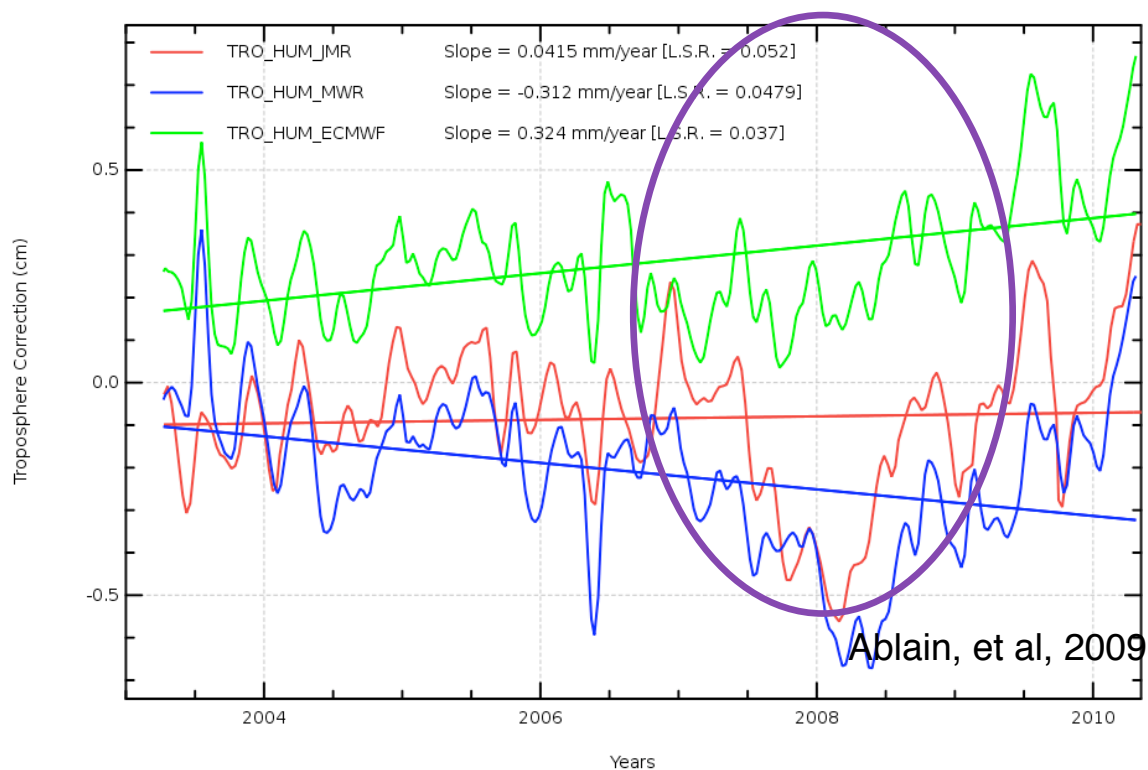
Impossibilité d'embarquer un instrument à balayage car contraintes drastiques de stabilité

Etudes menées ou en cours pour:

- évaluer la variabilité de la tropo accross-track et analyser le besoin d'un radiomètre à plusieurs visées
- évaluer la qualité d'une correction tropo fournie en combinant toutes les informations de vapeur d'eau disponibles

3 Nouvelles questions ?

Stabilité de la correction pour le suivi climatique du niveau de la mer



Tendance variable d'un instrument à l'autre
Critique pour le suivi du niveau moyen océanique
ECMWF néglige complètement l'assèchement Nina 2008

Conclusions

- Les MWR sont nécessaires (modèles météo: pbs de variations rapides de WV, biais dans les régions tropicales, changement de version)
- Les spécifications sont très exigeantes : étalonnage en vol et stabilité, homogénéité de la correction tropo et erreur minimale
- De nouveaux champs d'investigation s'ouvrent actuellement:
 - Le côtier (et polaire)
 - SWOT
 - Le suivi climatique du niveau de la mer
- De plus en plus, les approches et difficultés sont communes avec celles de la météorologie et du climat (assimilation/ inversion, analyse statistique des champs et séries de données, séparation des effets instrumentaux des variations naturelles,...)

6. Is the radiometer actually useful ? Model limitations (1/5)

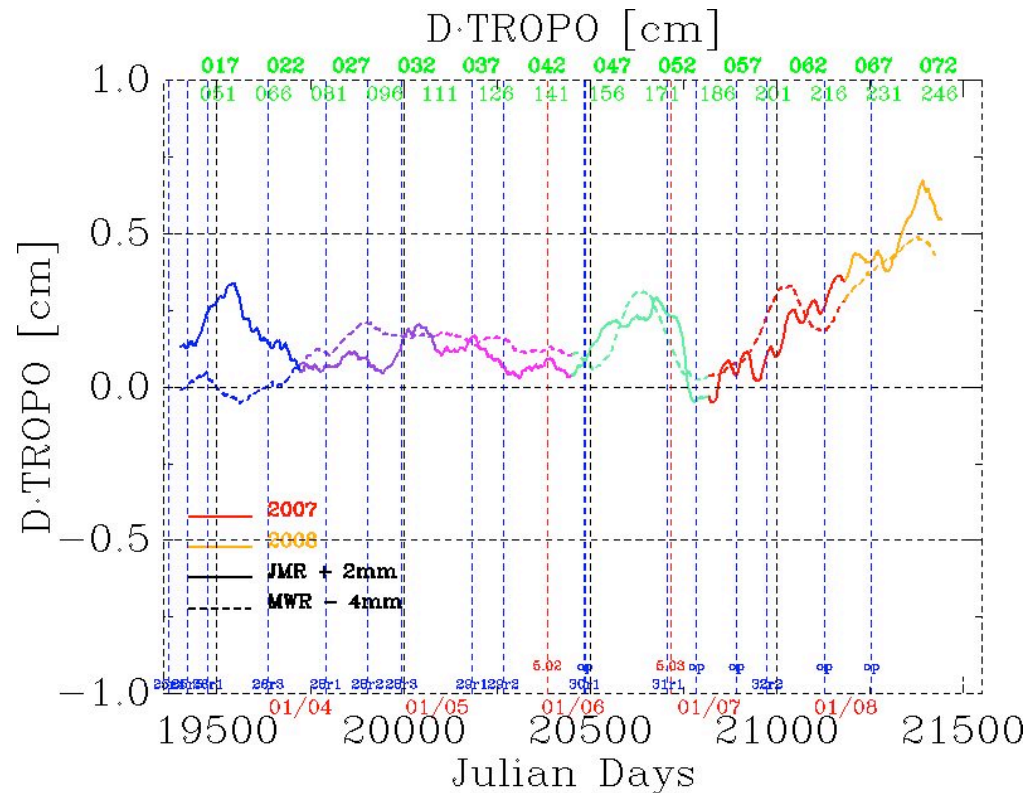
- Technical problems may occur, reducing the quality of measurements
- The wet tropospheric path uncertainty is difficult to reduce, due to the instrument, and due to limitations of the reference in situ data (radio-soundings)
- The footprint size is wide compared with the altimeter one => difficult to provide an accurate wet tropospheric correction for coastal altimetry
- ECMWF model (and others global models) assimilate in situ and satellite data over oceans (SSM/I...), so the ECMWF wet tropo is statistically equivalent to radiometer products
- Why to add a microwave radiometer???

6. Is the radiometer actually useful ? Model limitations (2/5)

- Water vapor analyses suffer from the model spin-up of the hydrological cycle, which reduces the impact of assimilated SSM/I data
- In tropical latitudes (high water vapor content), model estimations are biased and too low variance characterizes ECMWF fields, compared with radiometers
- Model version changes are generally accompanied by significant mean differences (January 2002, November 2007)=> difficult to get homogeneous long time SSH series
- Horizontal resolution is still worse than the radiometer one so abrupt changes are poorly depicted, temporal sampling (6h) is inadequate
- In coastal areas, model performances are not better than the radiometer one....
- Also large scale atmospheric signals seem not always well represented

5. Retrieval of the wet tropospheric correction and validation (4/4)

comparison with ECMWF estimation



- Good consistency between the different radiometers
- For the 2007-2008 period, geophysical signal observed with radiometers and missed by the ECMWF model ?

6. Is the radiometer actually useful ? Model limitations (5/5)

Defficiencies of model estimation for mesoscale signals

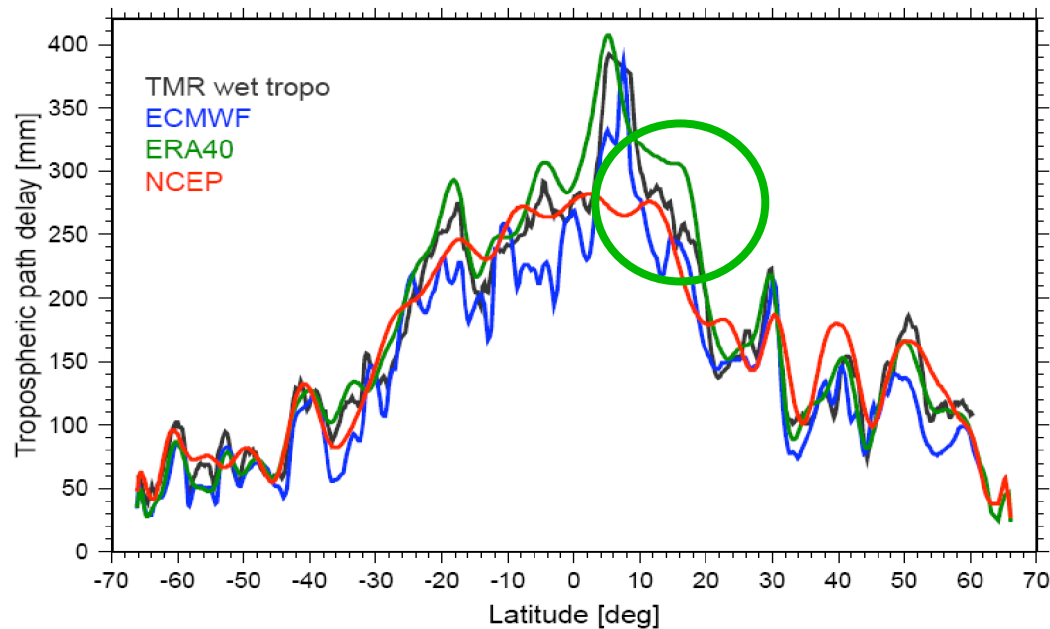
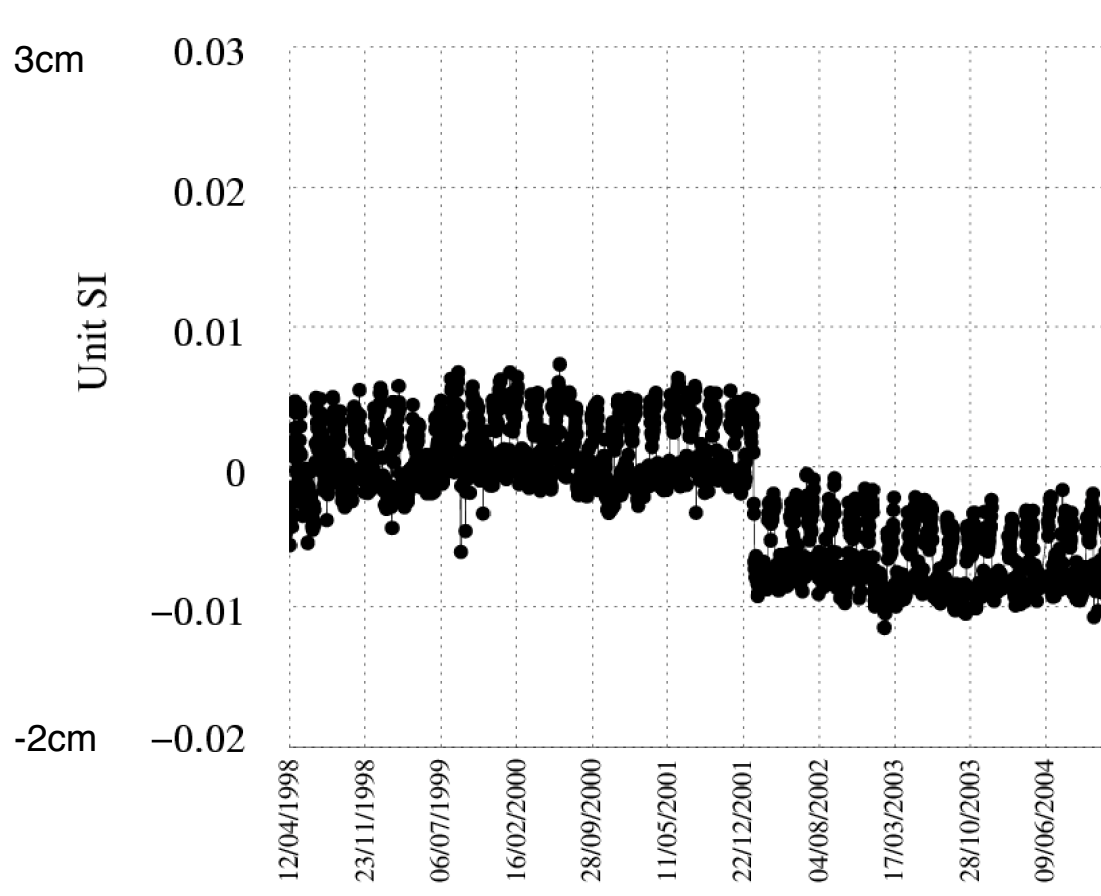


Figure 5. Comparison of the wet tropospheric path delay as measured by TMR (grey) with model results from the ECMWF operational analysis (ECMWF, blue), ECMWF 40-year re-analysis (ERA40, green) and the NCEP/NCAR re-analysis (NCEP, red).

(Scharroo, 2004)

6. Is the radiometer actually useful ? Model limitations (4/5)

Impact of model changes for mean sea level studies...

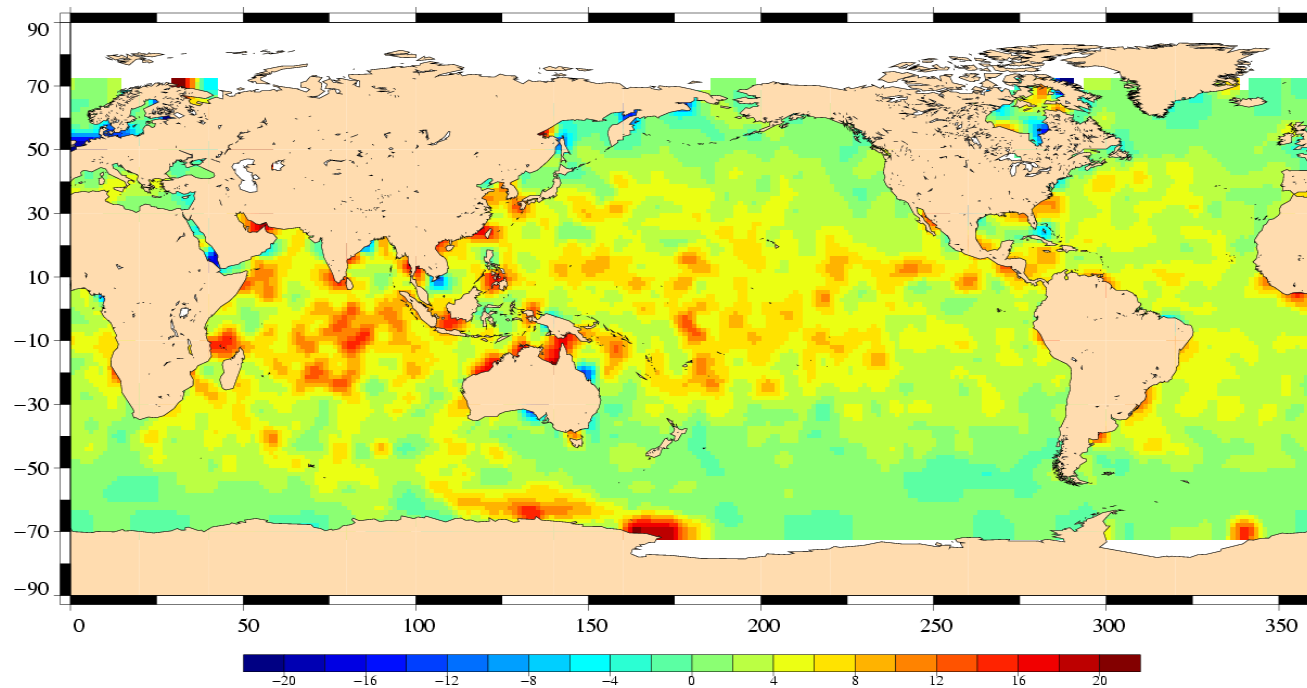


(Ablain et al, 2006)

6. Is the radiometer actually useful ? Model limitations (3/5)

Variance improvement by using TMR instead of ECMWF at cross-over points (104 cycles)

Cycles 340 to 444



(Ablain et al, 2006)