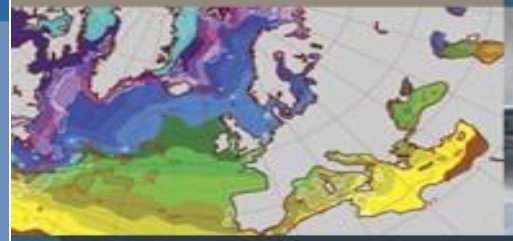
ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

GLOBAL PREDICTION | SEVERE WEATHER | ATMOSPHERIC COMPOSITION | CLIMATE MONITORING | SUPERCOMPUTER CENTRE





Satellites and Numerical Weather Prediction

Tony McNally

ECMWF approach to storms….

We seek operate the best global assimilation and forecasting system that we can…

We evaluate the system performance in all weather regimes including severe weather and storms…

But the forecasting of storms but does not drive our research and development plans.

Overview

- Introduction – what do satellites measure ?
- The major satellite observing systems – what do they provide ?
  - Infrared
  - Microwave
  - GPS-RO
  - Scatterometers
- Quantifying the benefit of satellites
- Future systems

Overview

- Introduction – what do satellites measure ?
- The major satellite observing systems – what do they provide ?
  - Infrared
  - Microwave
  - GPS-RO
  - Scatterometers
- Quantifying the benefit of satellites
- Future systems

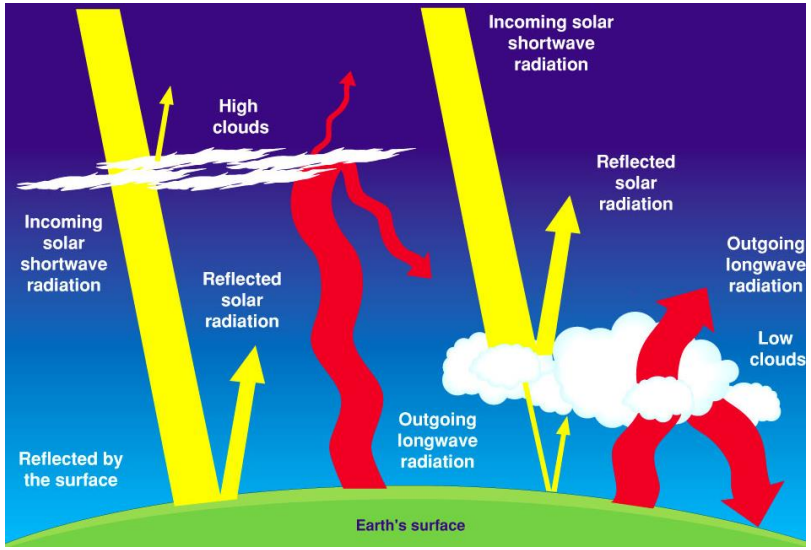
What do satellites actually measure ?

They **DO NOT** measure TEMPERATURE

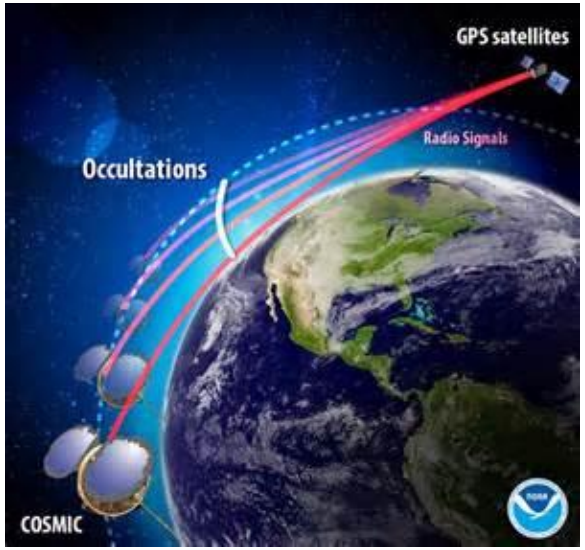
They **DO NOT** measure HUMIDITY or OZONE

They **DO NOT** measure WIND

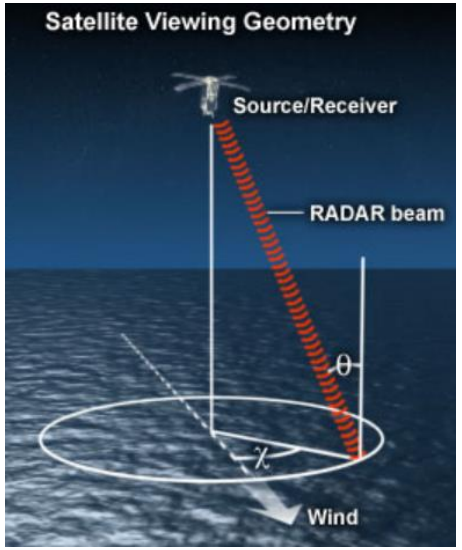
Measure natural thermal <u>radiation</u> at infrared and microwave wavelengths



Detect magnitude of <u>refraction</u> in GPS signals



<u>Modulation</u> of active radiation signals beamed at the surface



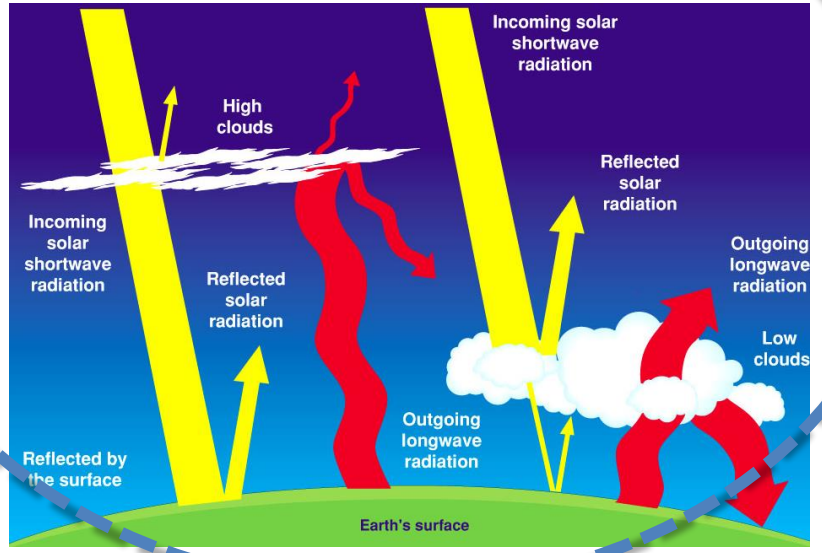
What do satellites actually measure ?

They **DO NOT** measure TEMPERATURE

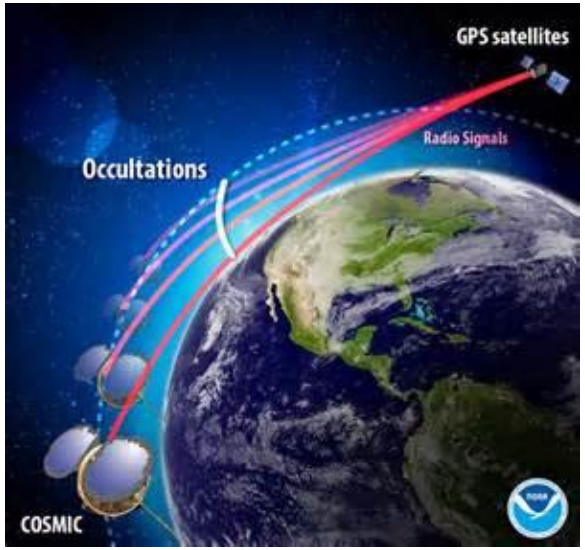
They **DO NOT** measure HUMIDITY or OZONE

They **DO NOT** measure WIND

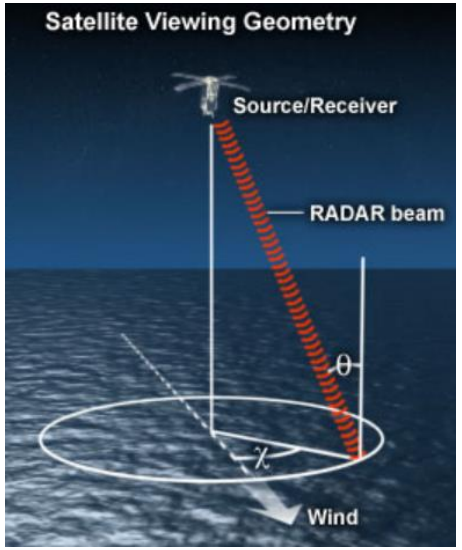
Measure natural thermal <u>radiation</u> at infrared and microwave wavelengths



Detect magnitude of <u>refraction</u> in GPS signals

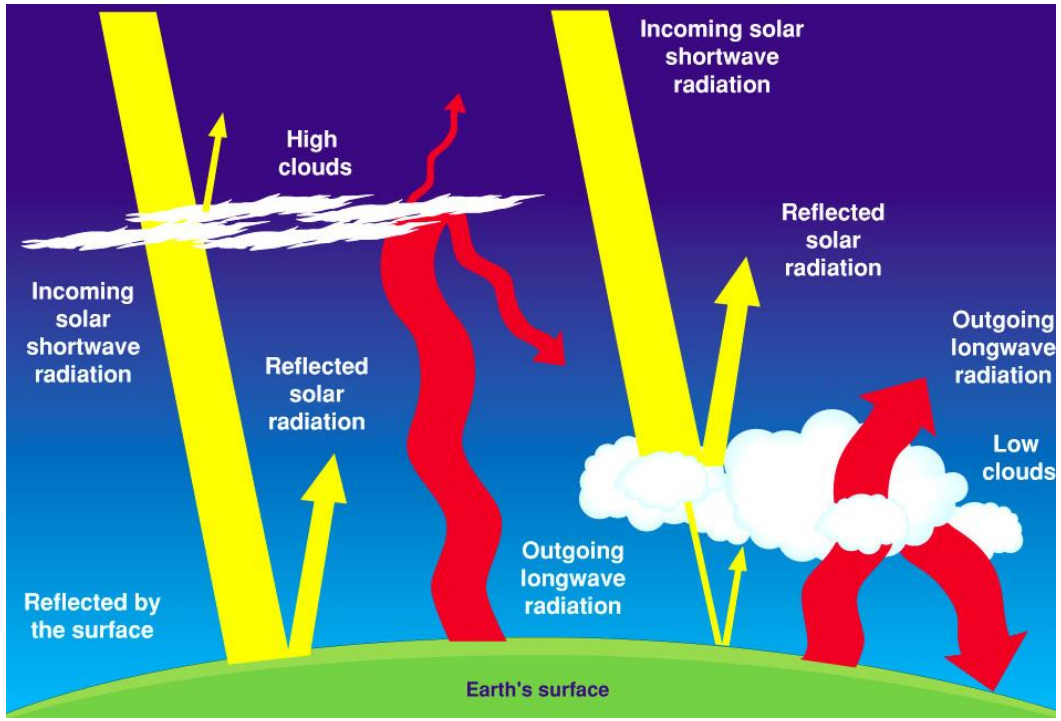


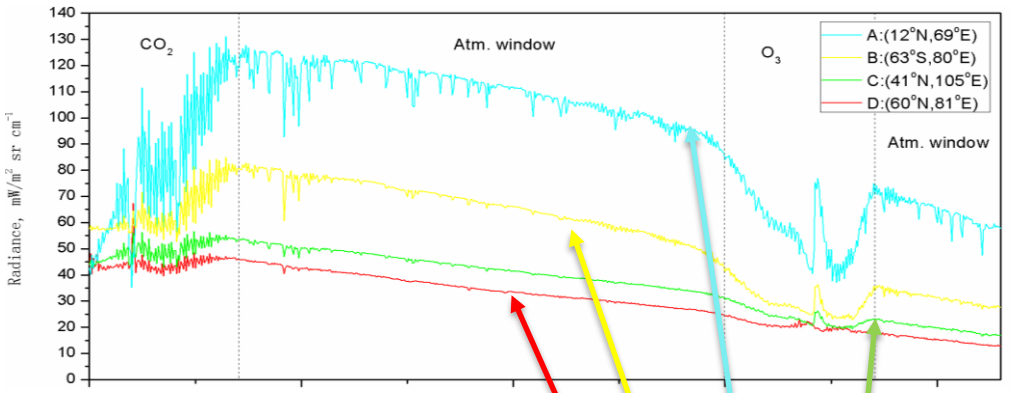
<u>Modulation</u> of active radiation signals beamed at the surface

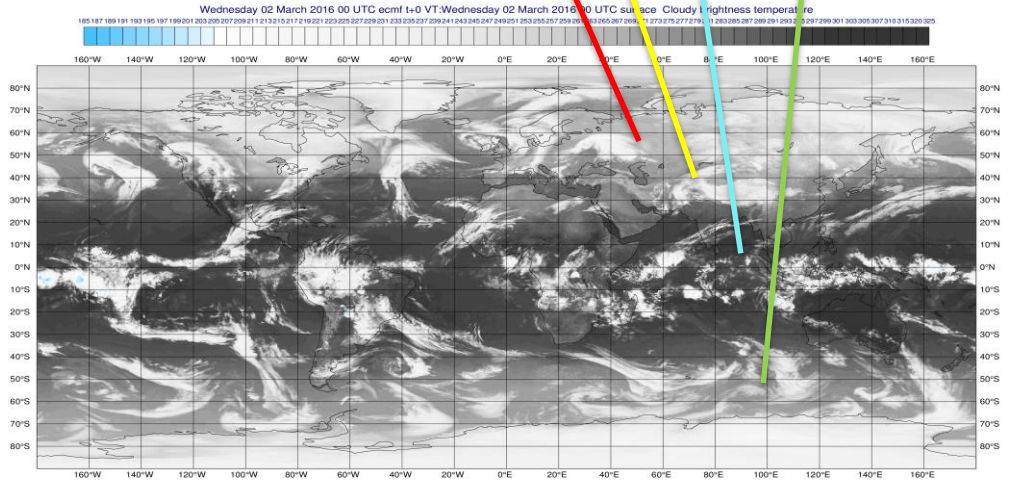


Satellite sounders (e.g. IASI, AMSU, ATMS, CrIS)

Measure natural thermal <u>radiation</u> at infrared and microwave wavelengths





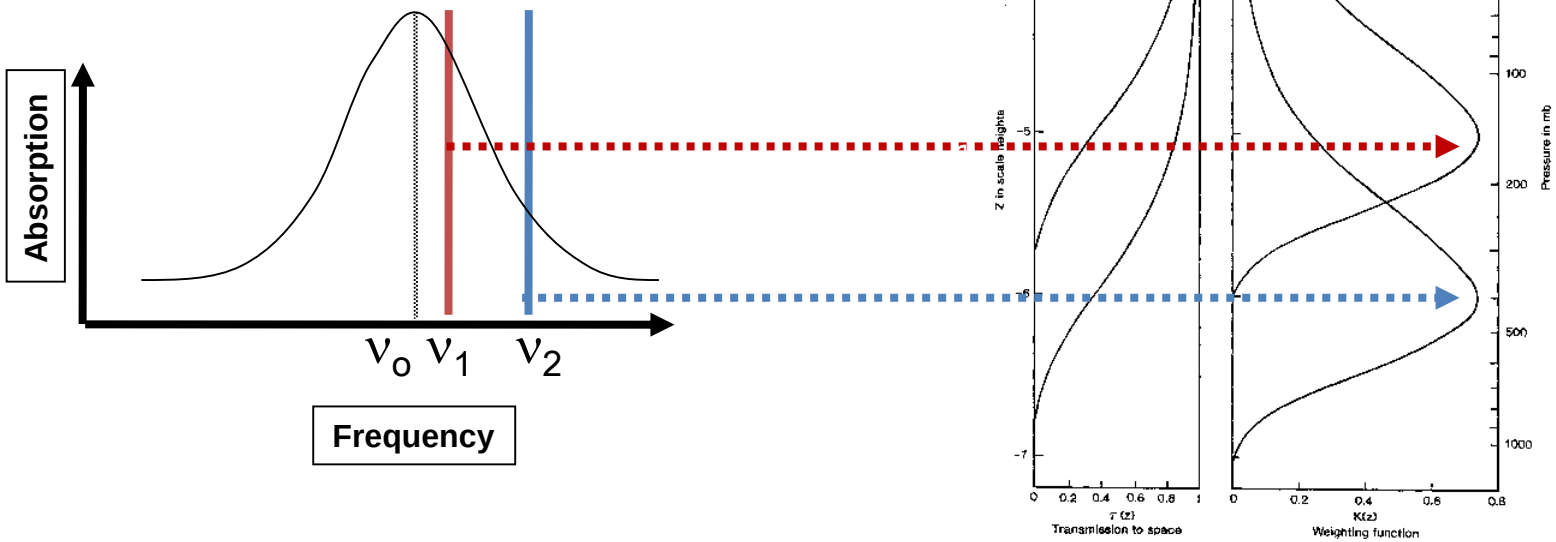


Downward looking radiation measurements provide vertically integrated information

radiance

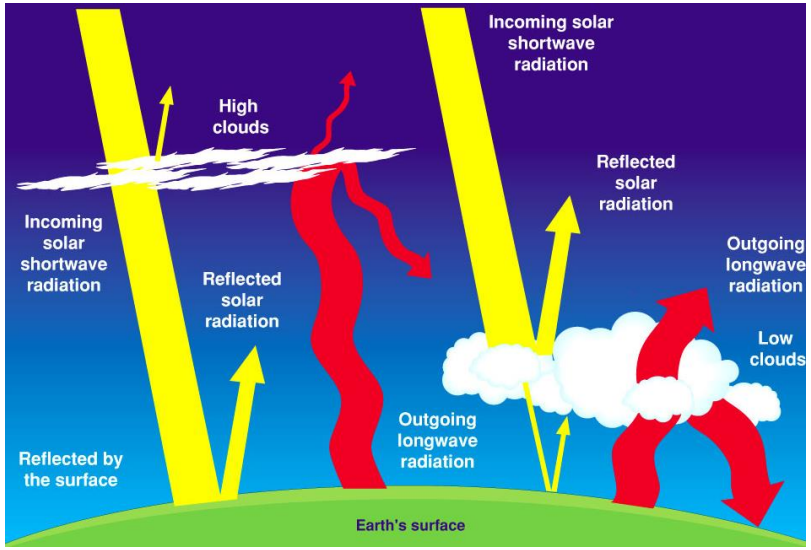
temperature

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

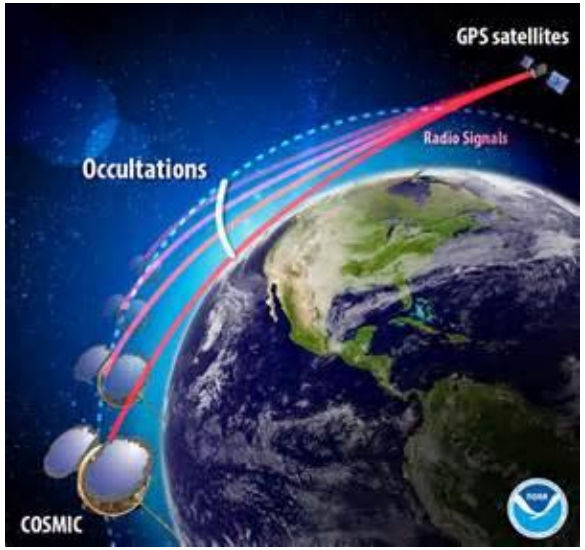


We need highly sophisticated assimilation algorithms to digest and combine these many sources of satellite observations

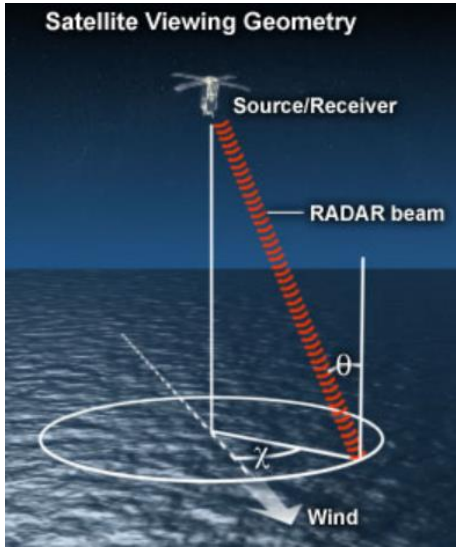
Measure natural thermal <u>radiation</u> at infrared and microwave wavelengths



<u>Detect</u> magnitude of <u>refraction</u> in GPS signals



<u>Modulation</u> of active radiation signals beamed at the surface



The 4D-Var Algorithm

It can be shown that given a prior estimate of the atmosphere ($\mathbf{X_b}$) with error covariance described by **B**, and a set of observations **Y** with error covariance described by **R**, the maximum probability solution is the trajectory state that minimizes a cost function J defined by:

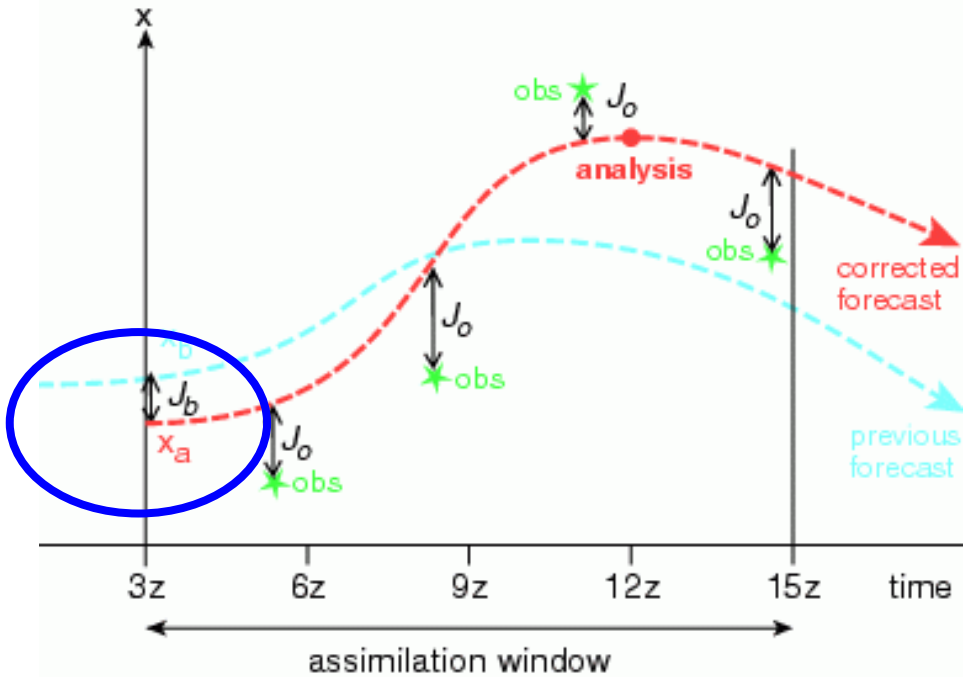
$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) +$$

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

Where **H** is an operator that maps the model state to the observation location, time and measured quantity.

The 4D-Var Algorithm J_b

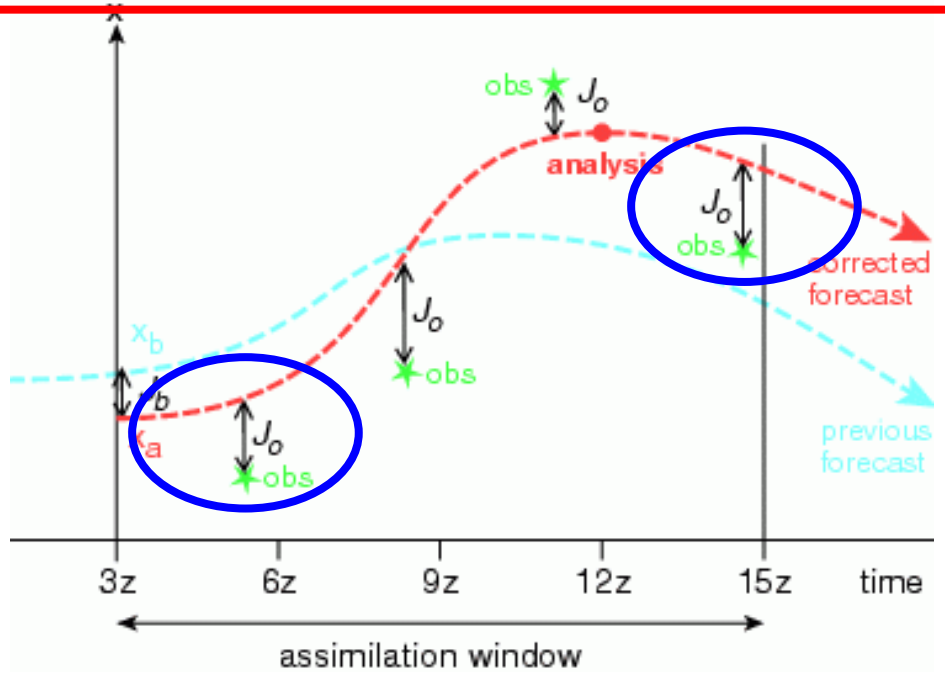
$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) + (y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$



The 4D-Var Algorithm J_o

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

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



Overview

- Introduction – what do satellites measure ?

- The major satellite observing systems – what do they provide ?
  - Infrared
  - Microwave
  - GPS-RO
  - Scatterometers

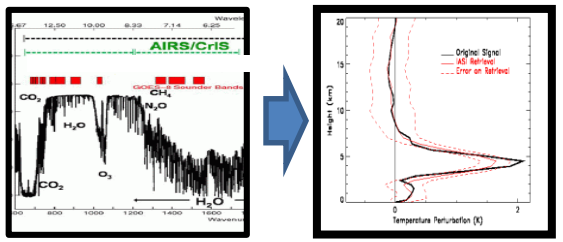
- Quantifying the benefit of satellites

- Future systems

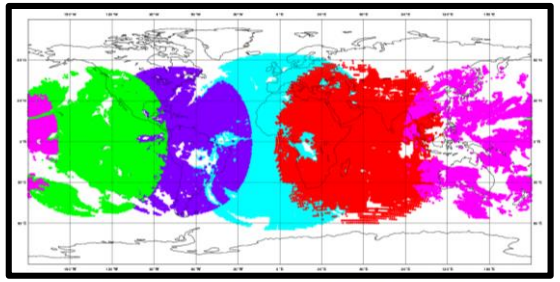
Infrared observations

What do infrared satellites provide ?

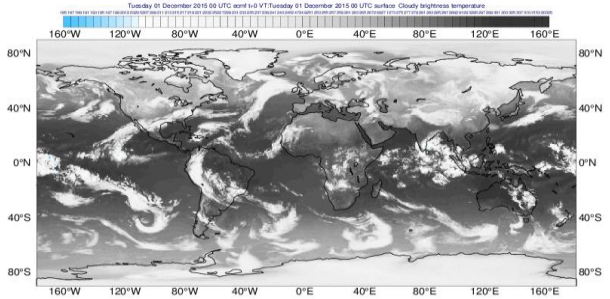
- Hyperspectral infrared observations provide significantly **enhanced vertical resolution** information on atmospheric temperature and humidity and ozone (c.f. microwave)



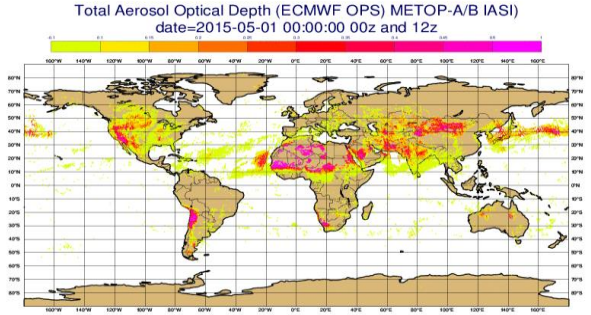
- High temporal resolution radiance observations from GEO provide **atmospheric wind information** (via 4D-tracing)



- Radiances measured in window regions of the spectrum provide information on **clouds and the surface**



- Distinct spectral fingerprints of individual molecules (and aerosols) provide **atmospheric composition** information

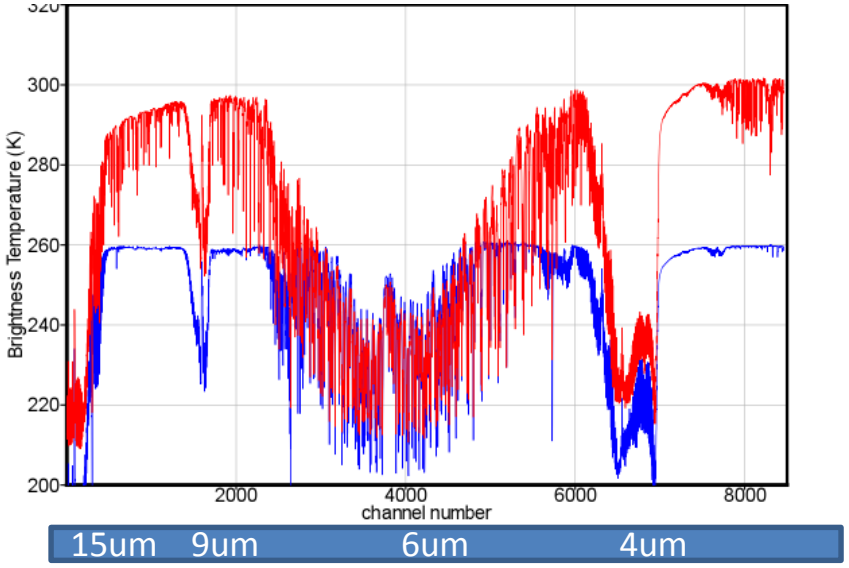


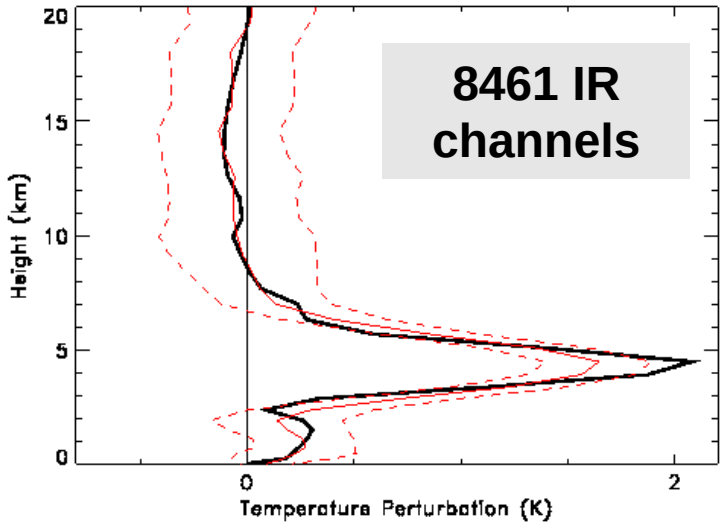
ECMWF

Infrared provides improved vertical resolution

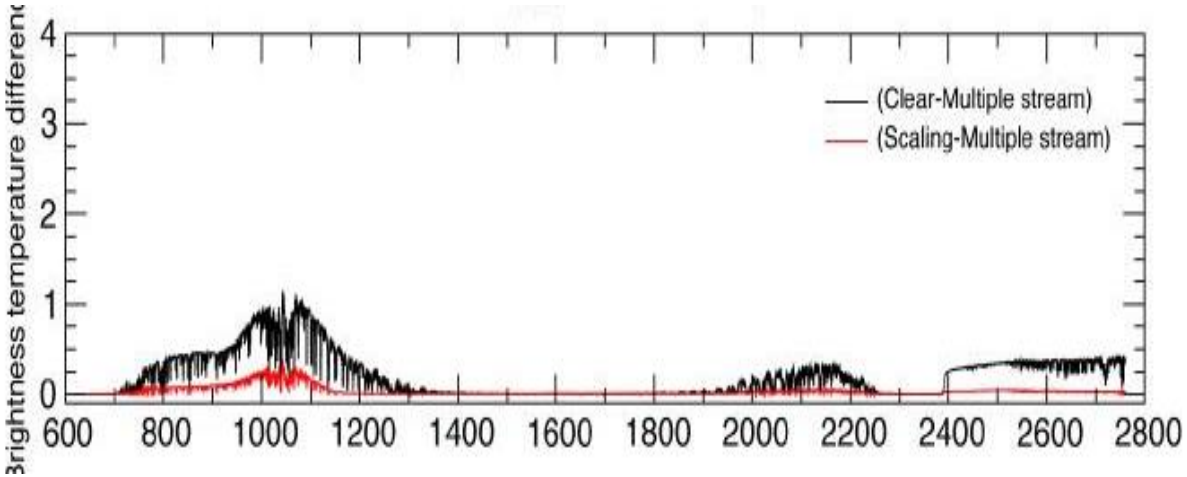
Each individual radiance measurement provides only **deep layer** information on e.g. temperature and humidity.

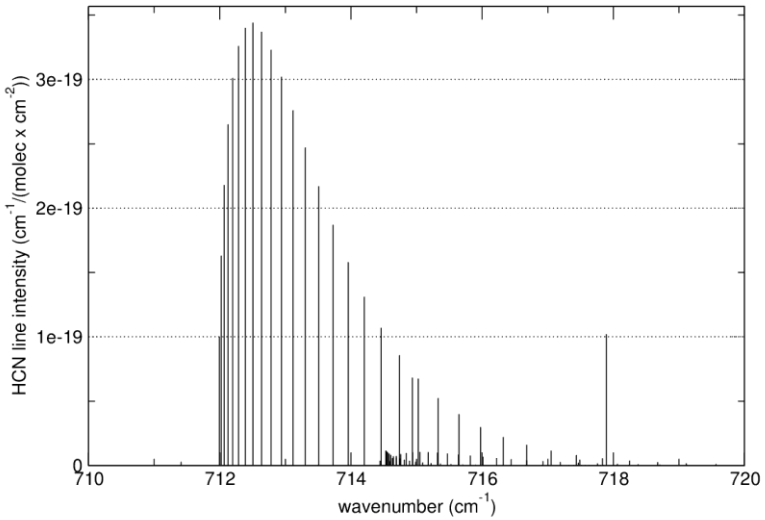
But by making **many thousands of radiation measurements** at different frequencies – each sensitive to a slightly different vertical layer – infrared instruments can provide good vertical resolution information.

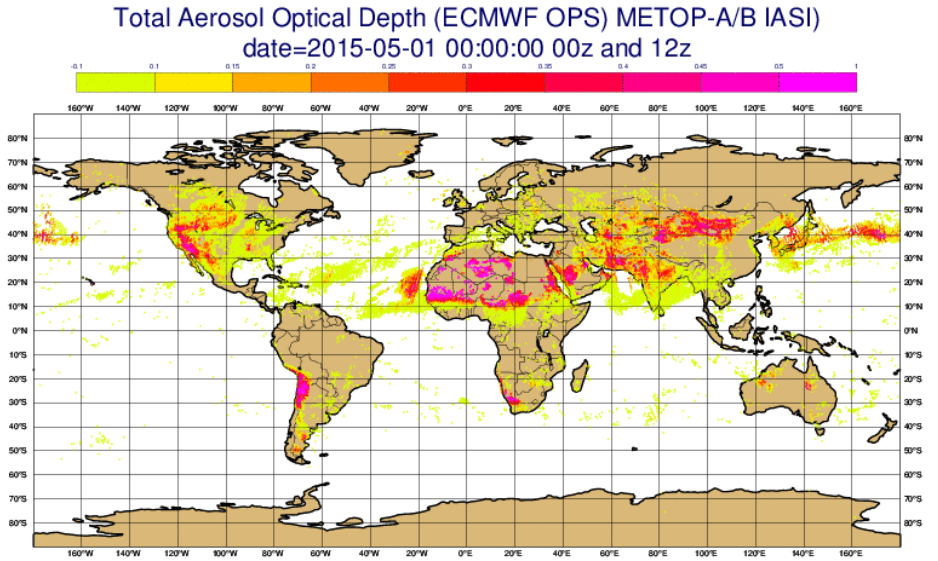


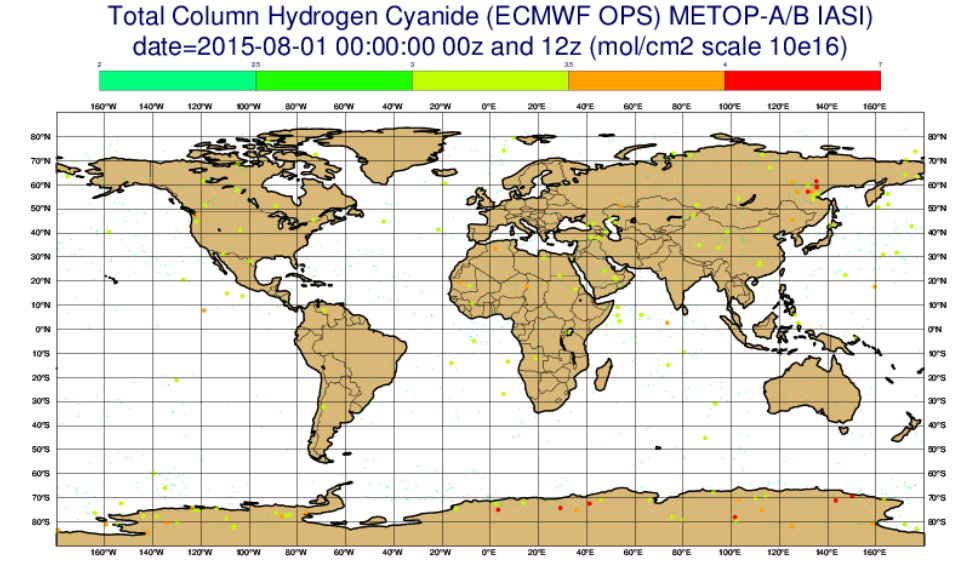


Infrared provides information on composition

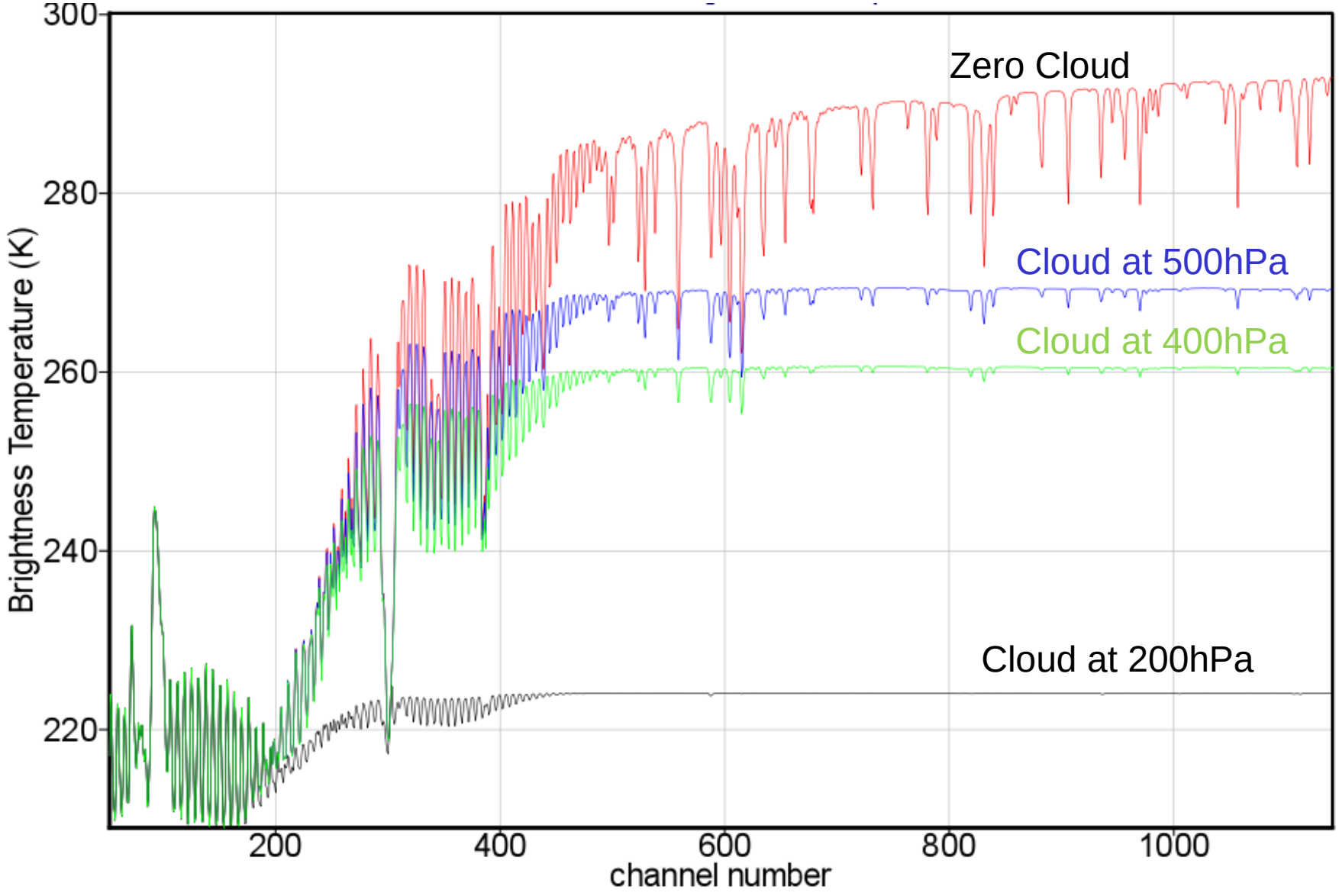




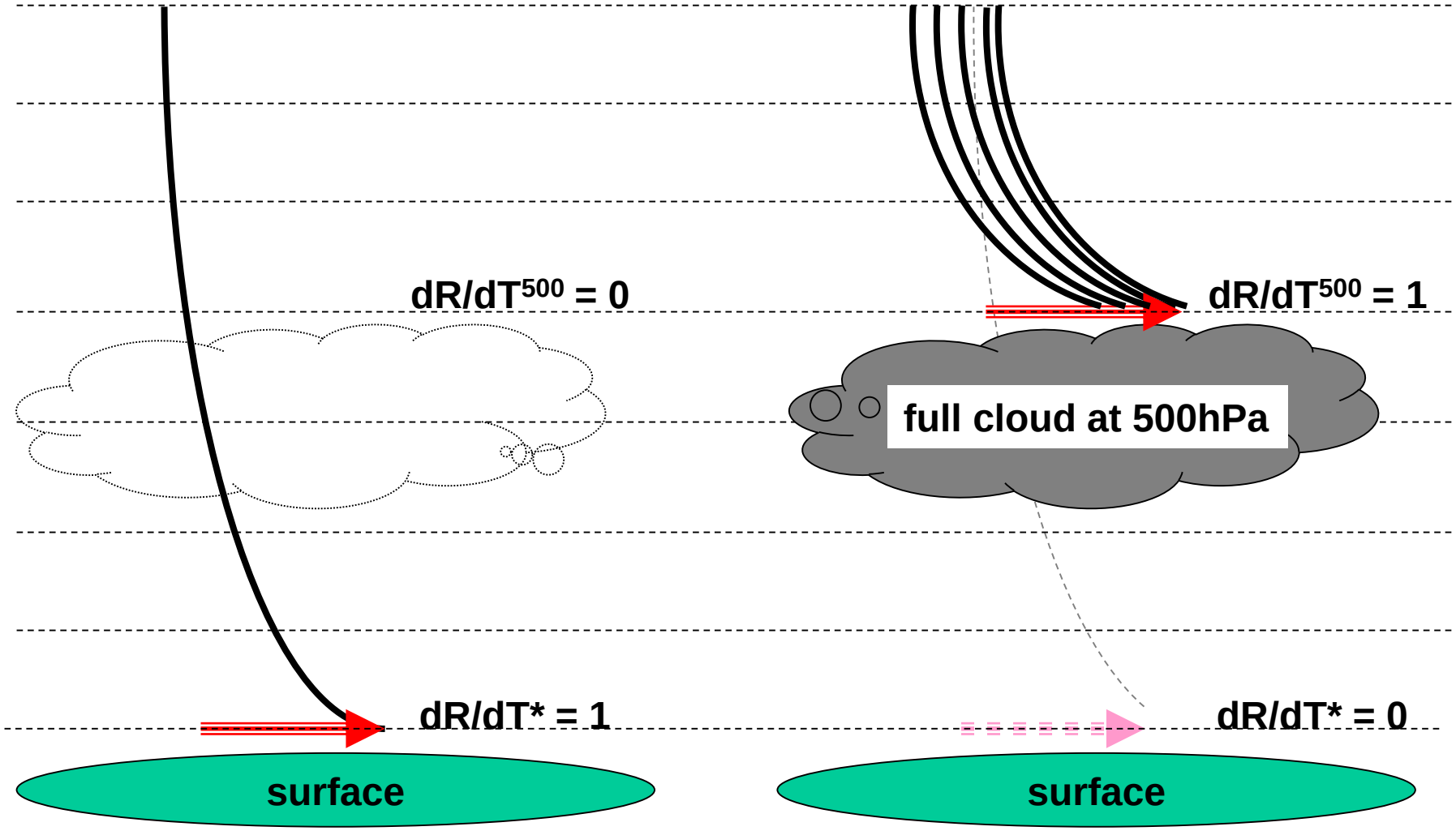




But IR spectra are dominated by clouds



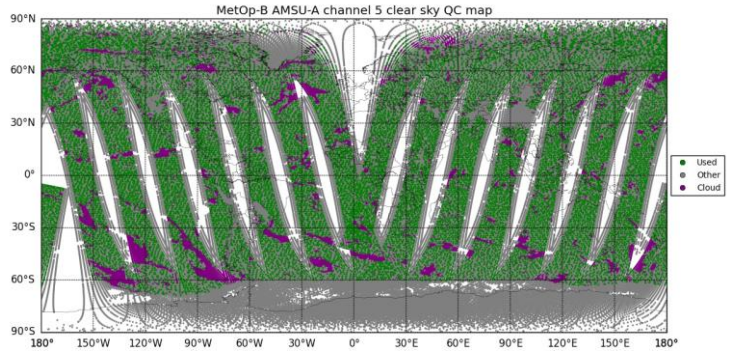
Providing no information below cloud top



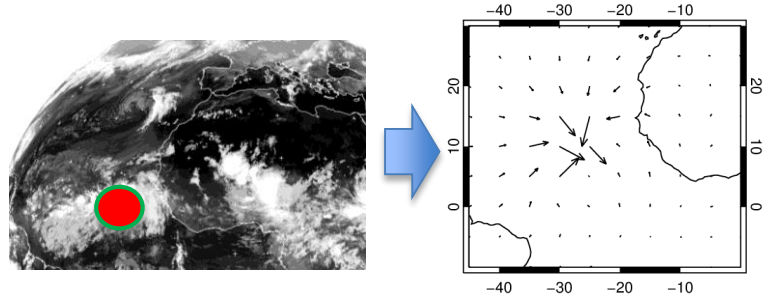
Microwave observations

What do microwave satellites provide ?

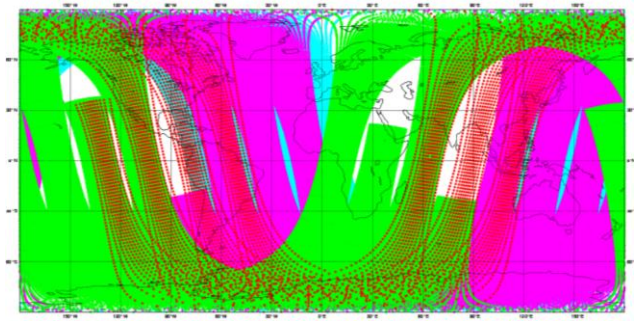
- The effect of clouds on microwave measurements is smaller (compared to infrared) and thus MW data typically provides **better data coverage**



- Cloud and precipitation signals can be used to infer liquid water and ice content for input to NWP models and **influence physics** (e.g. convection)

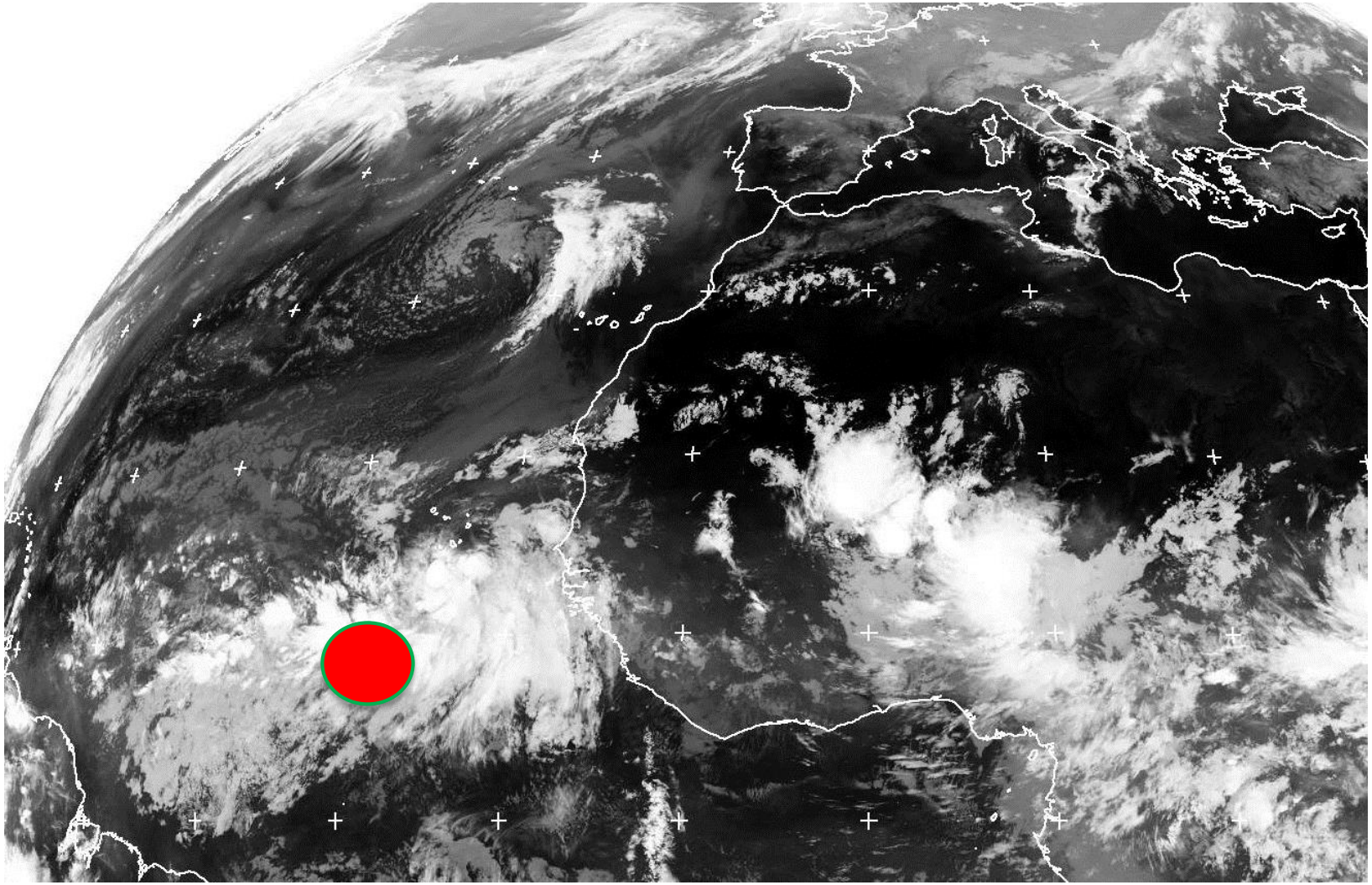


- Rather simple and inexpensive technology and thus numerous MW instruments carried on **many different spacecraft**.



ECMWF

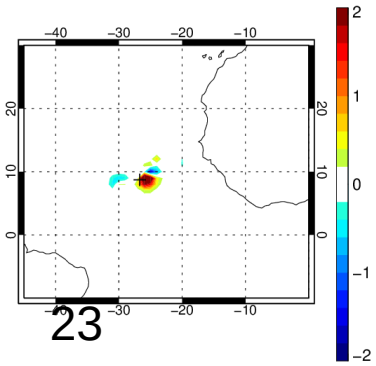
Microwave radiances giving convection information



ECMWF

	Column WV [kg/m^2]	Sfc. pressure [hPa]	Low-level winds (850 hPa)	Upper-level winds (100 hPa)	Column rain [kg/m^2]
21Z (analysis time)					N/A
00Z (obs time)					
09Z					

The microwave radiance measurement suggests that that the model is missing water vapour, cloud and rain at this location…how do we fit this observation ?



ECMWF

Column WV [kg/m^2]

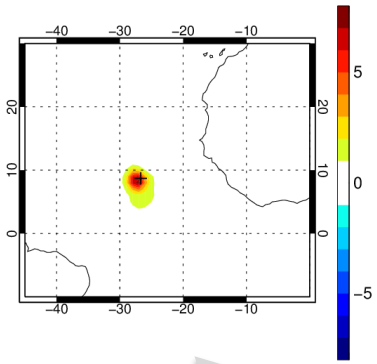
Sfc. pressure [hPa]

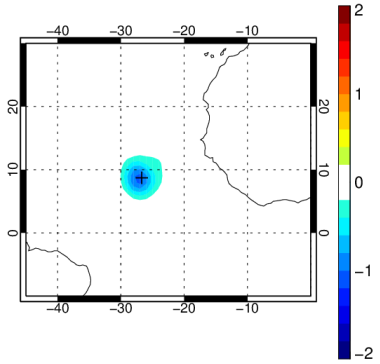
Low-level winds (850 hPa)

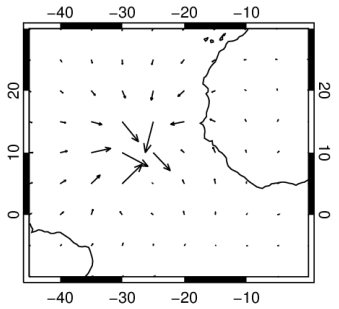
Upper-level winds (100 hPa)

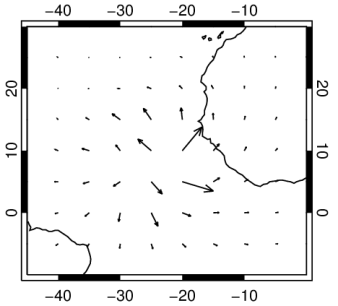
Column rain [kg/m^2]

21Z (analysis time)







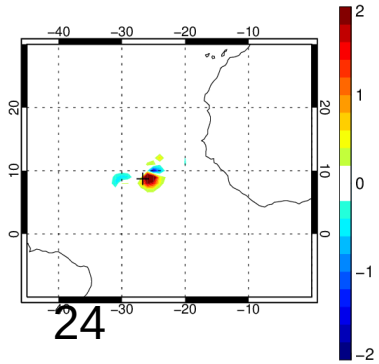


N/A

00Z (obs time)

…by adding water vapour at the start of the 4DVAR window …

09Z



ECMWF

Column WV [kg/m^2]

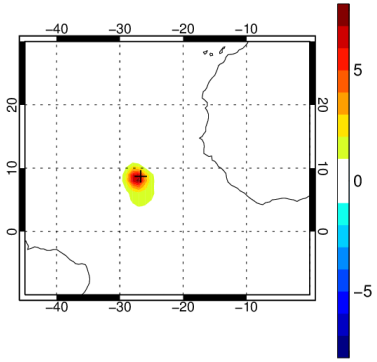
Sfc. pressure [hPa]

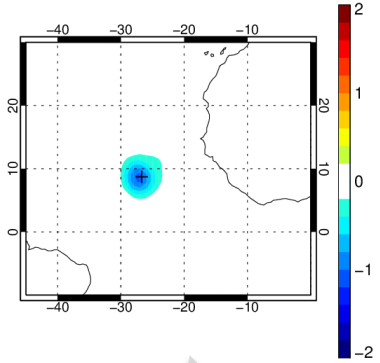
Low-level winds (850 hPa)

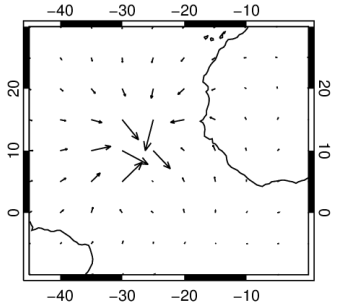
Upper-level winds (100 hPa)

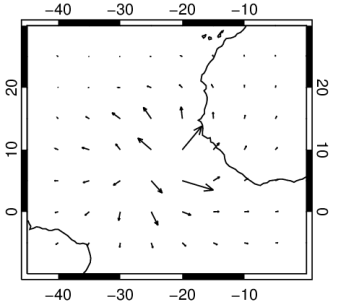
Column rain [kg/m^2]

21Z (analysis time)







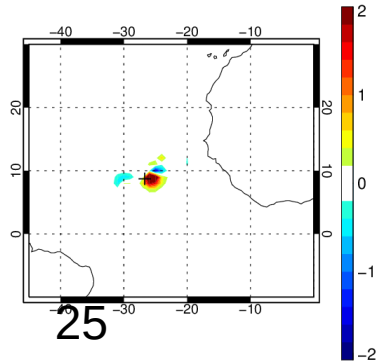


N/A

00Z (obs time)

…and initiating convection…

09Z



ECMWF

Column WV [kg/m^2]

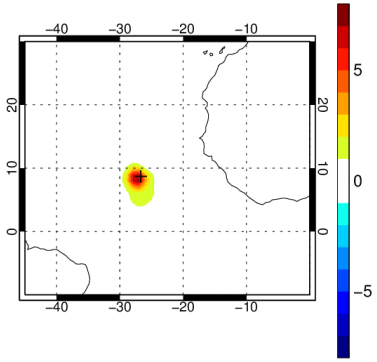
Sfc. pressure [hPa]

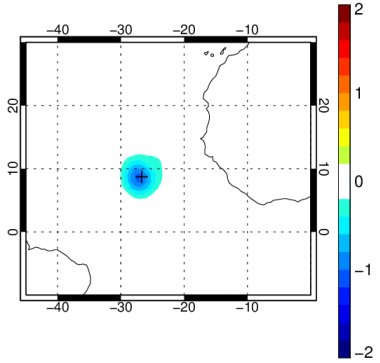
Low-level winds (850 hPa)

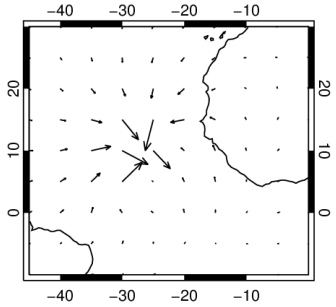
Upper-level winds (100 hPa)

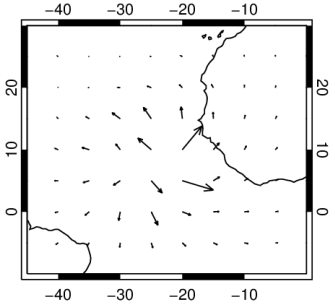
Column rain [kg/m^2]

21Z (analysis time)



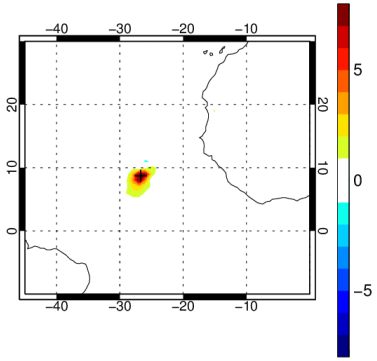


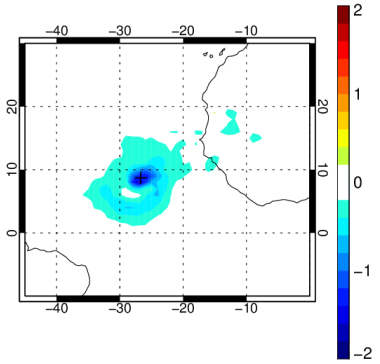


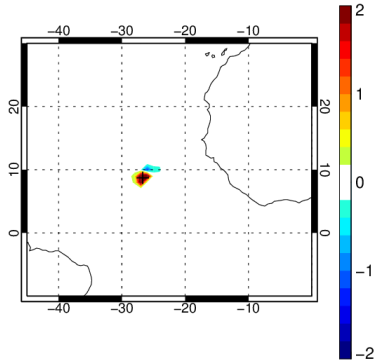


N/A

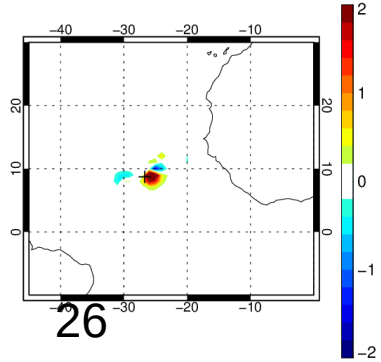
00Z (obs time)







09Z



Column WV [kg/m^2]

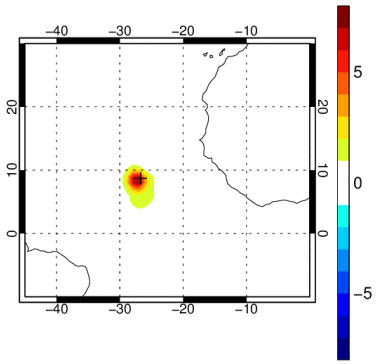
Sfc. pressure [hPa]

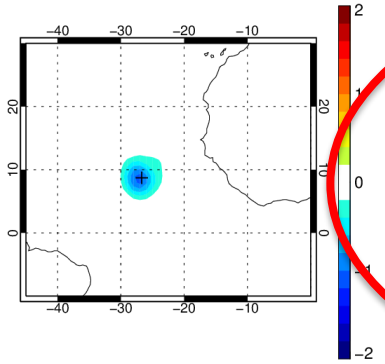
Low-level winds (850 hPa)

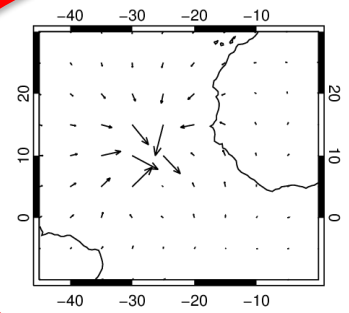
Upper-level winds (100 hPa)

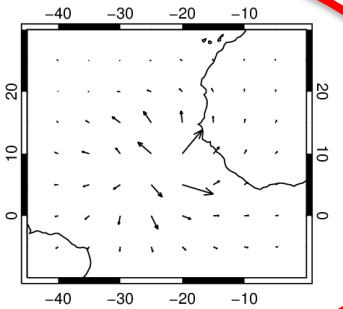
Column rain [kg/m^2]

21Z (analysis time)



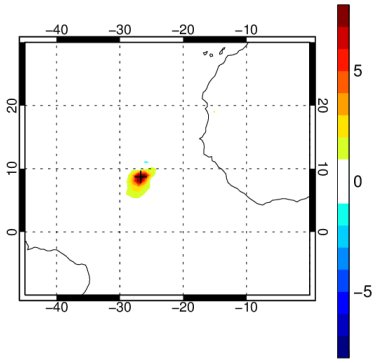


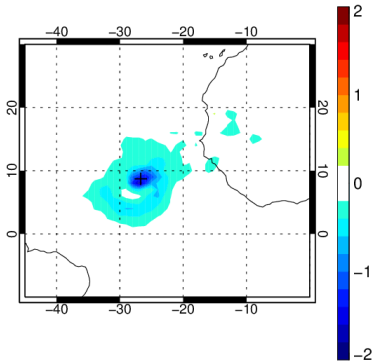


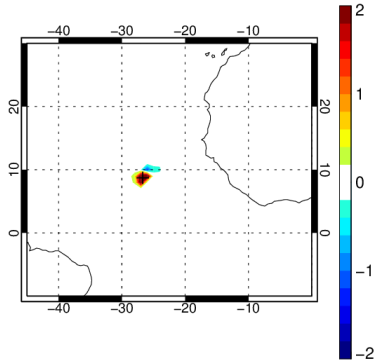


N/A

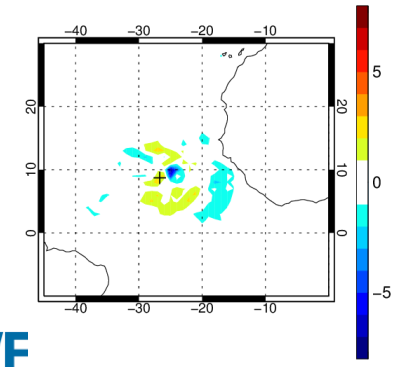
00Z (obs time)

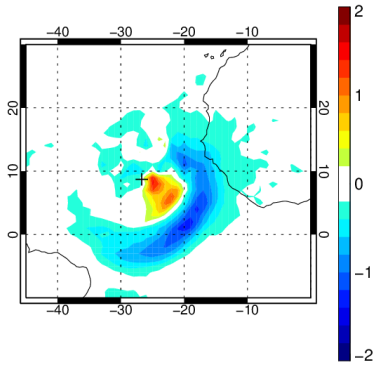


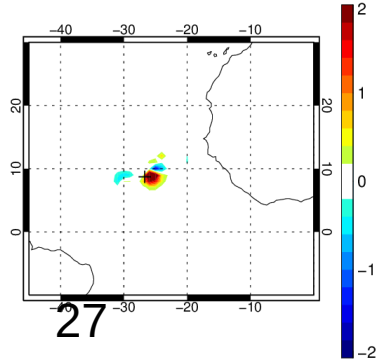




09Z

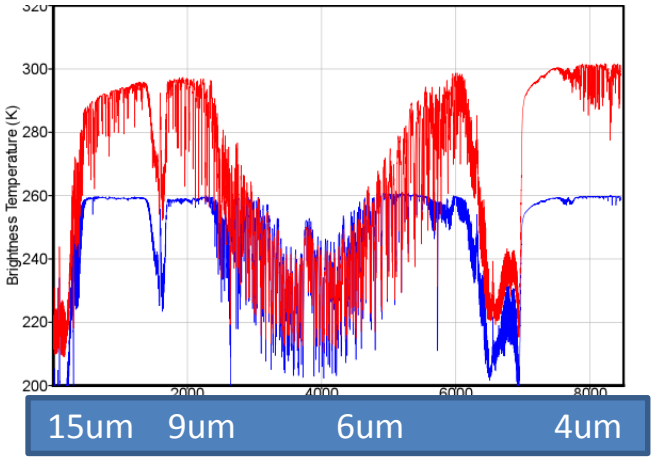


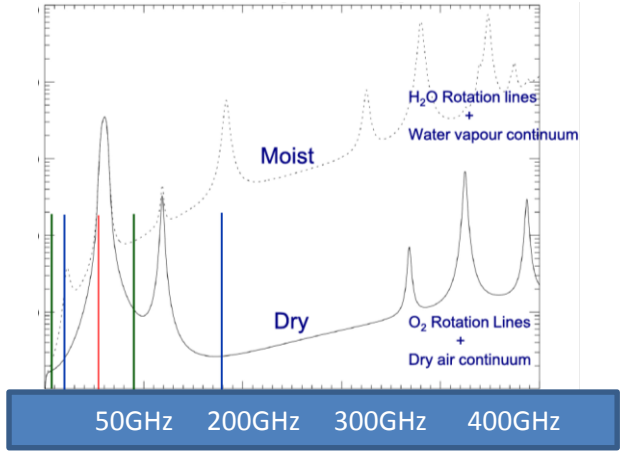


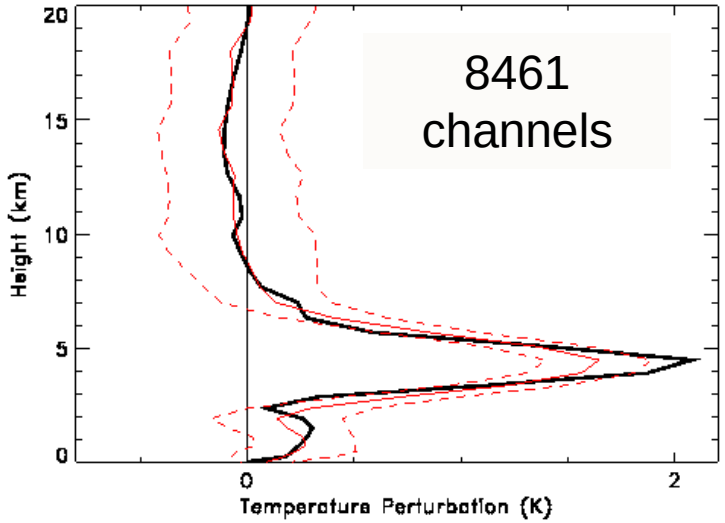


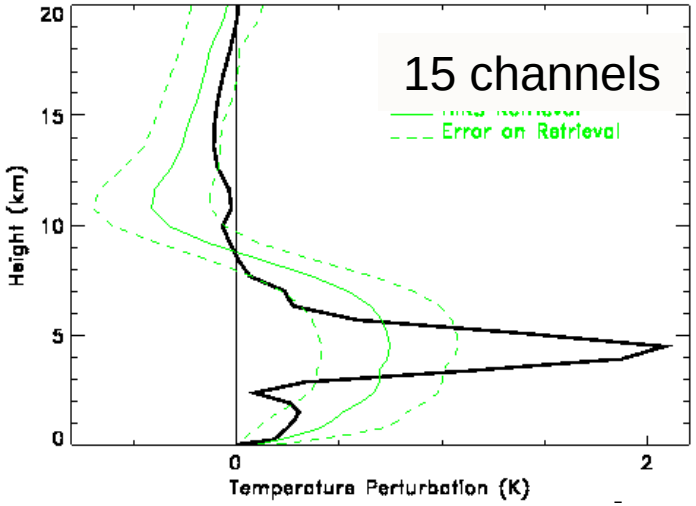
Wind information in convective situations from microwave sounding radiances

But microwave data have very poor vertical resolution

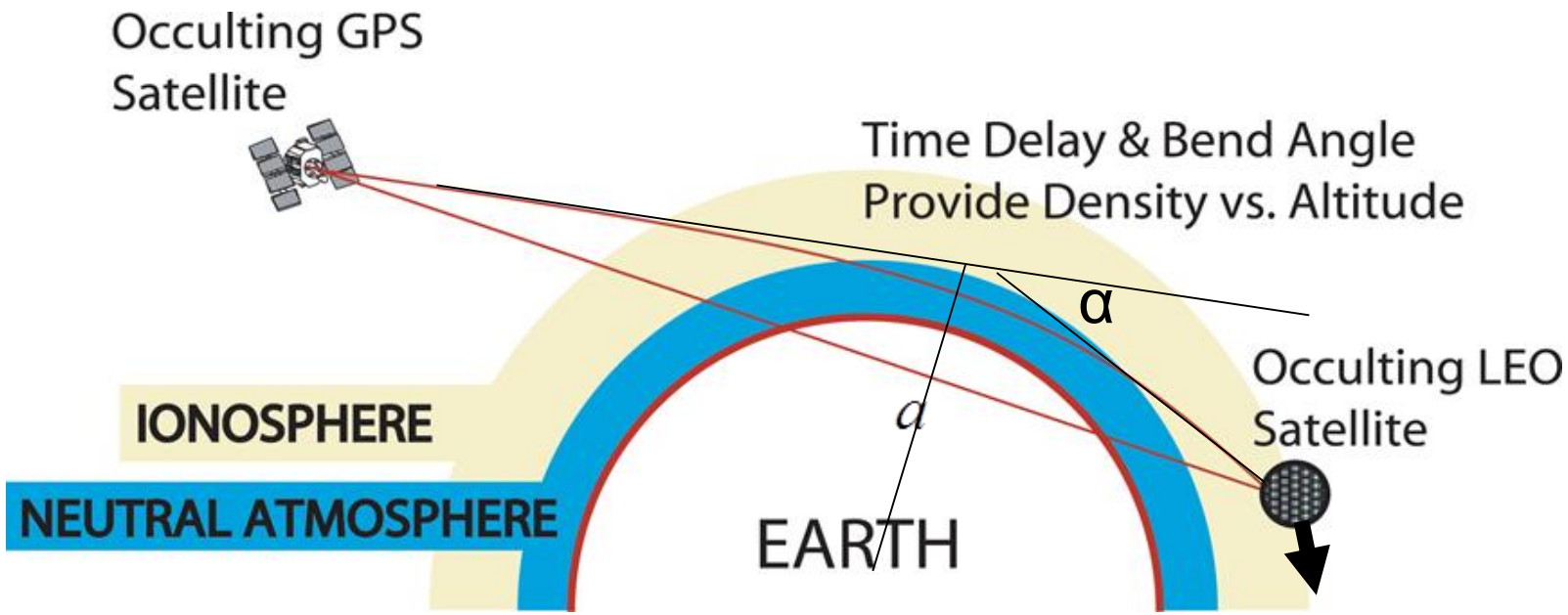








GPS-RO observations



We assimilate bending angle as a function of impact parameter (~height).

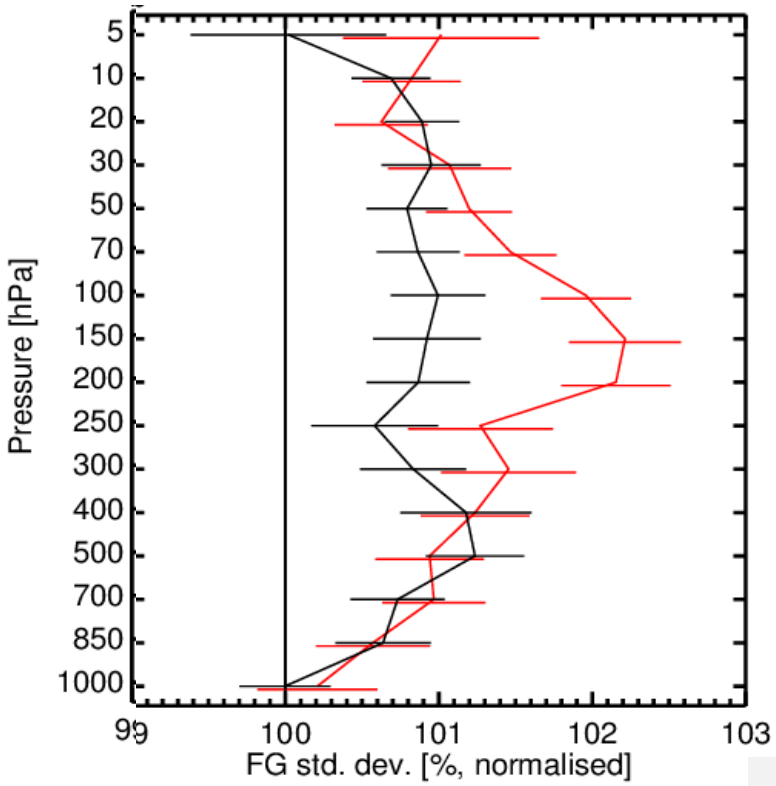
Key characteristics:

- Limb geometry provides good vertical resolution.
- Assimilation without bias correction to the model.

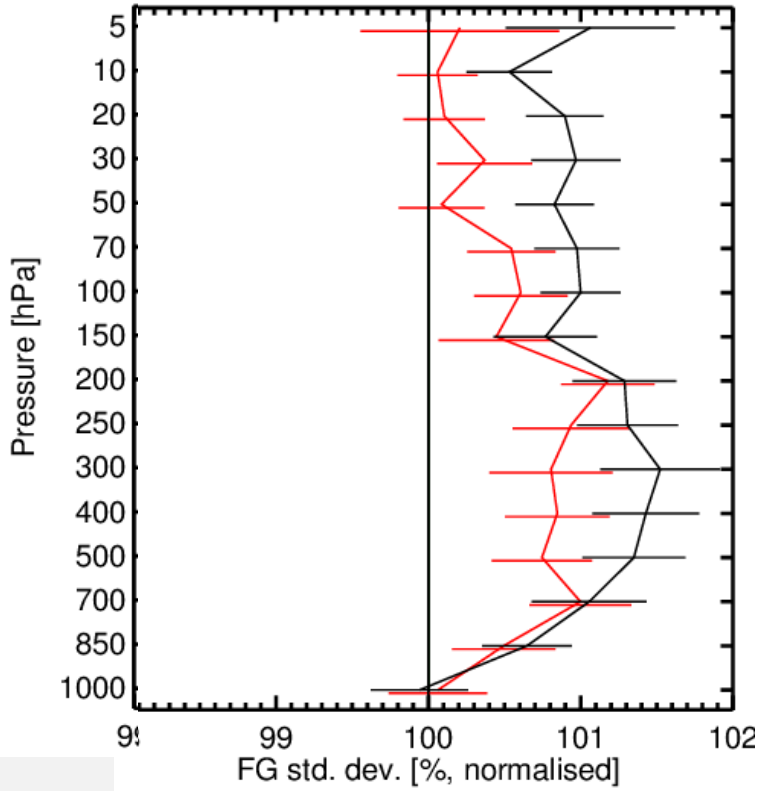
METOP v NPP (impact of GPS data from GRAS)

Verification against radiosonde temperatures clearly shows that GRAS provides a **significant proportion** of the METOP impact in the shorter forecast ranges, throughout the mid – upper troposphere and stratosphere!

METOP with GRAS v NPP



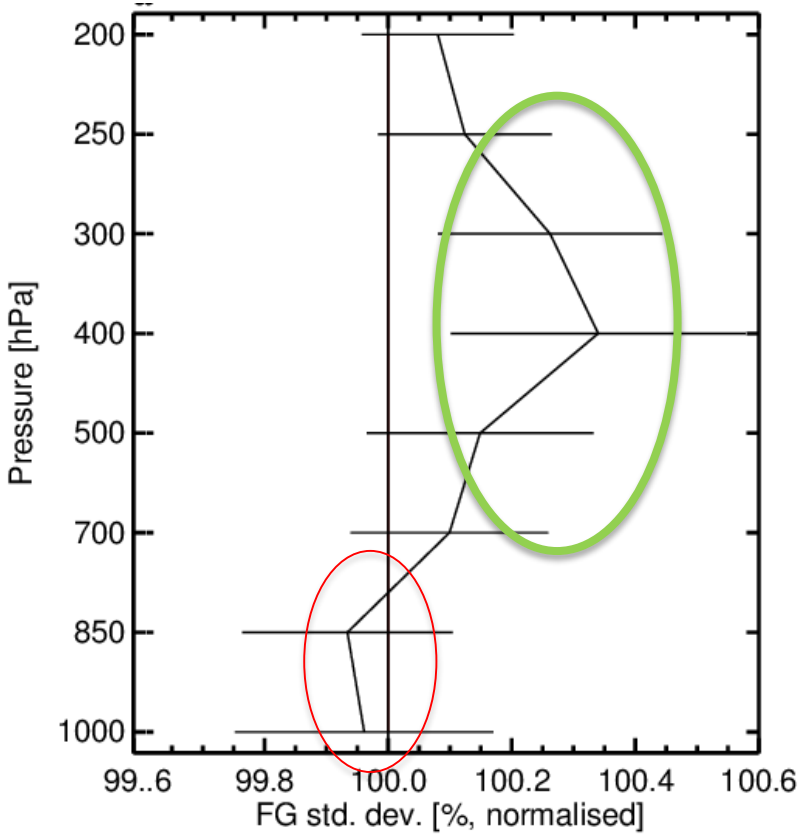
METOP without GRAS v NPP

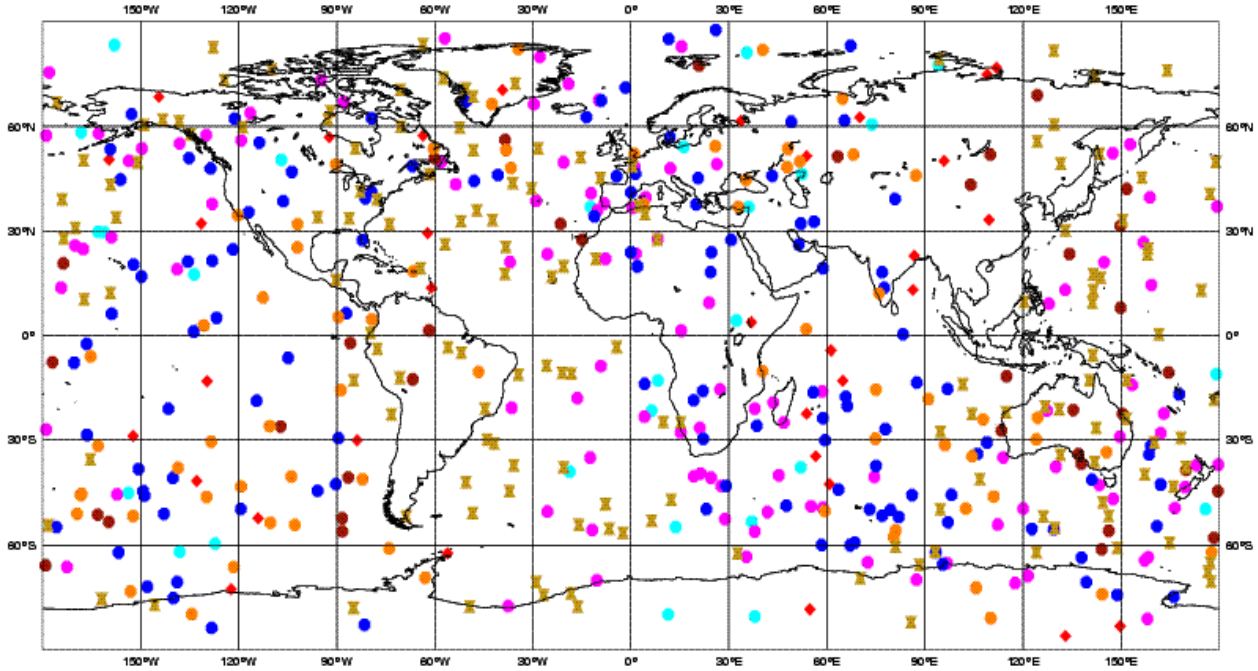


remove NPP
remove Metop-A

(EUMETSAT Study WP)

But GPS data are difficult to use in the lower troposphere and have poor spatial resolution



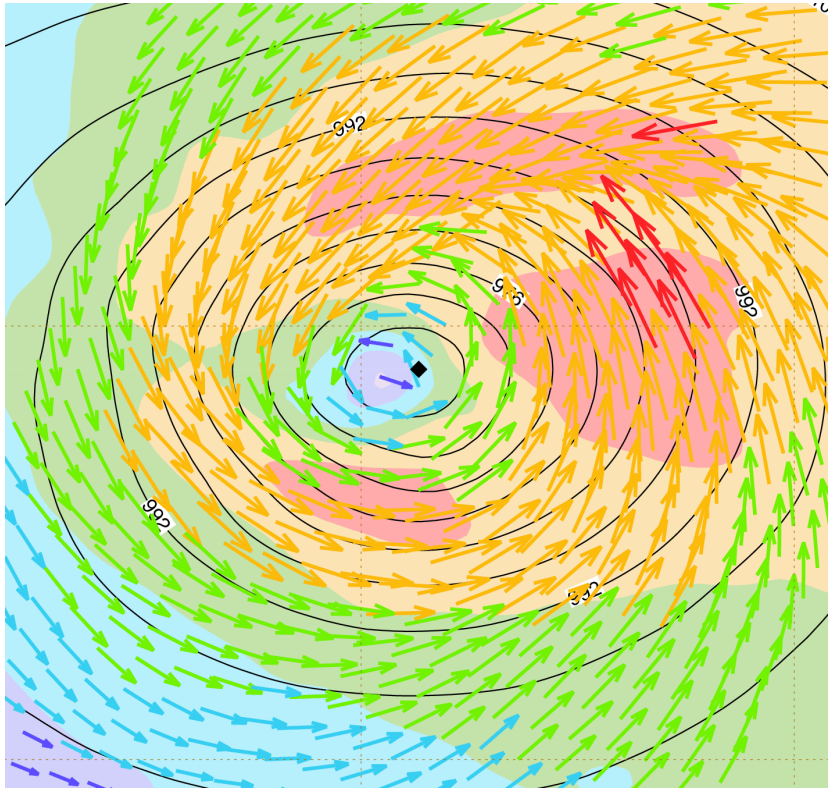


ECMWF

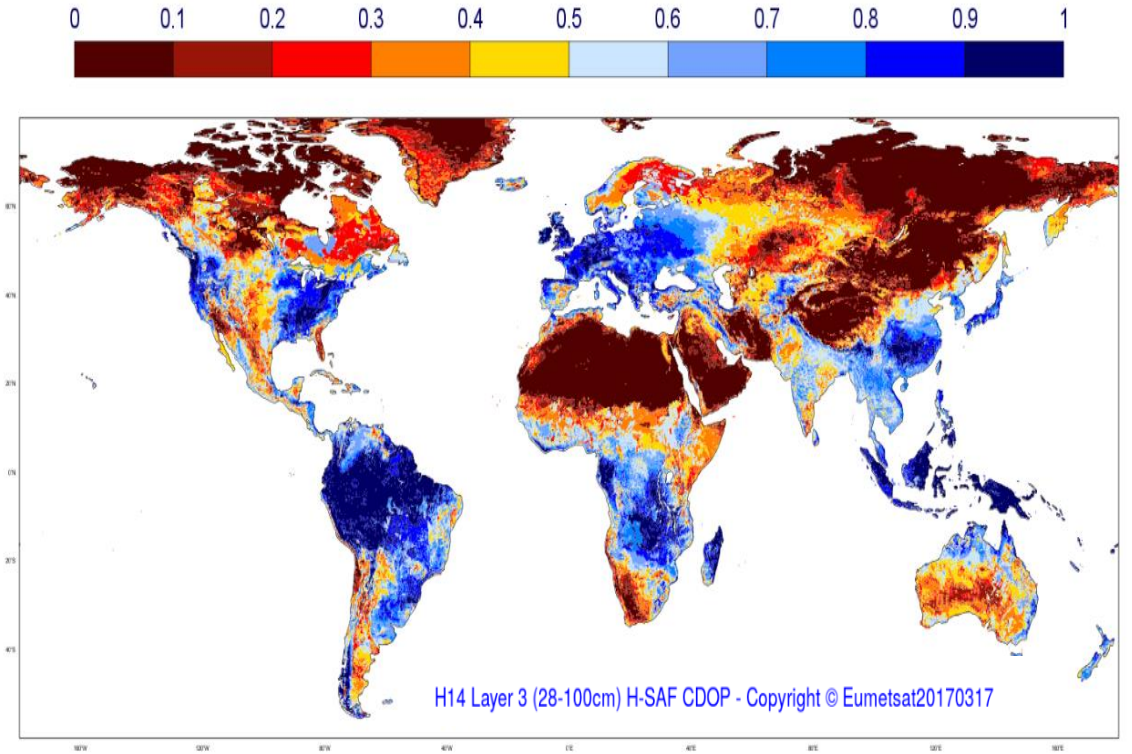
Scatterometer observations

What do Scatterometer satellites provide ?

High spatial resolution instantaneous wind information over ocean surfaces

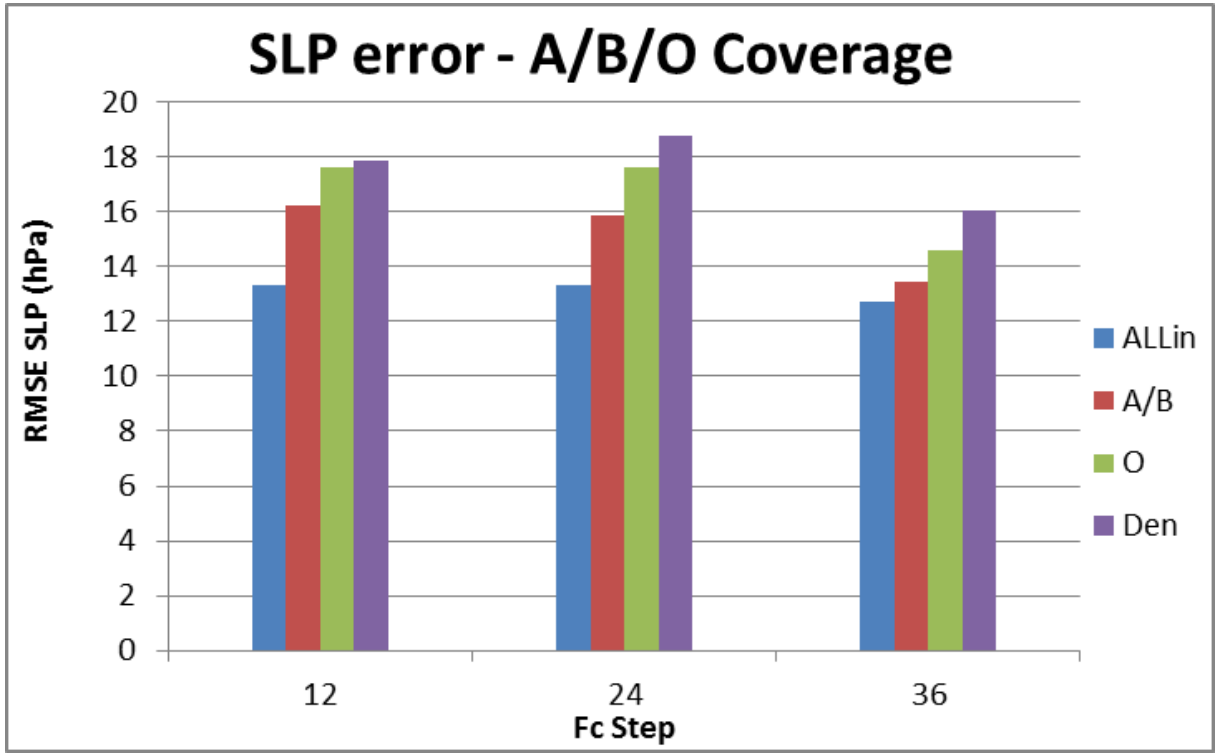


Soil moisture content information over land surfaces



Impact of scatterometer winds on Tropical Cyclone FC

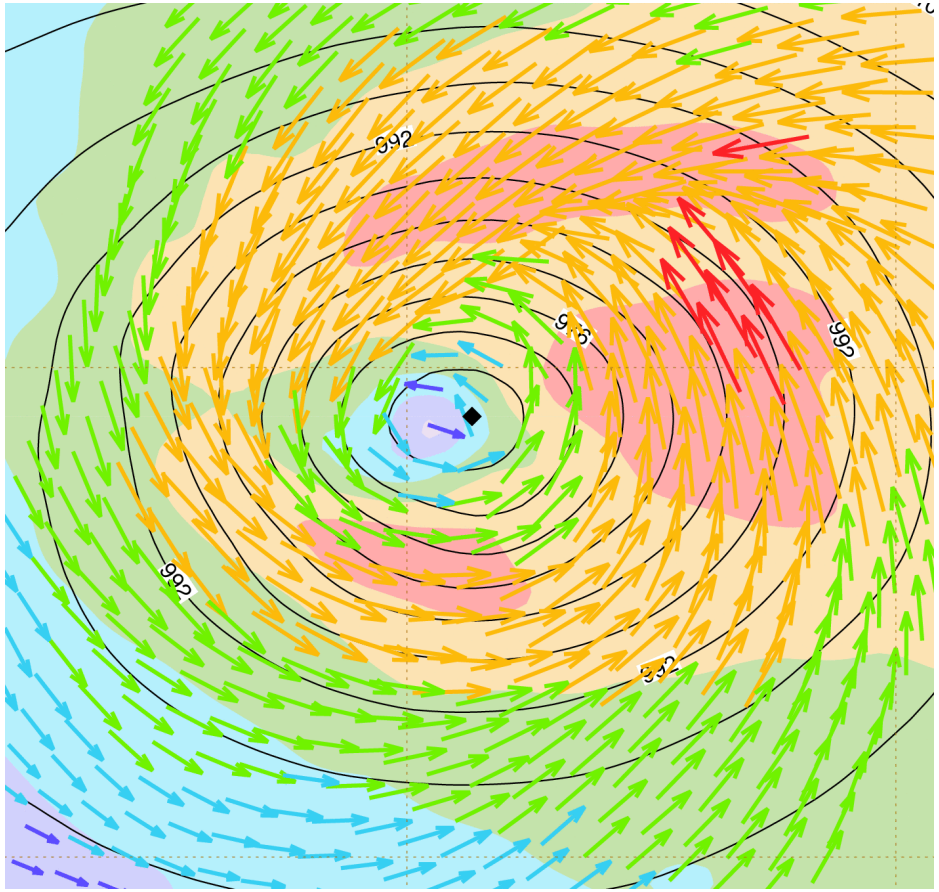
- ✓ For each storm the min SLP have been detected from the ECMWF model fields
- ✓ SLP have been compared to observation values (from NHC and JMA)



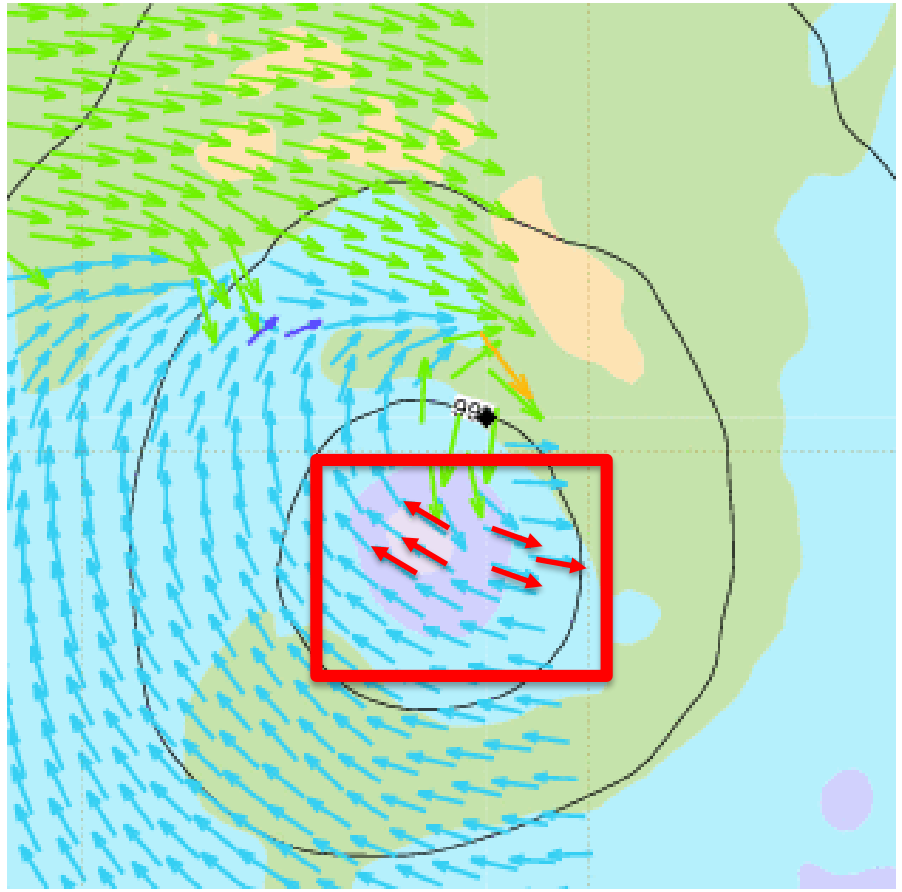
Statistics based only on cases where ASCAT-A, ASCAT-B and OSCAT passes were available
Dec 2012/ Feb 2013

But SCAT wind direction is a problem

The ASCAT wind direction ambiguity is removed by comparison to model during the assimilation process (below is a good example, TC *KILO*)



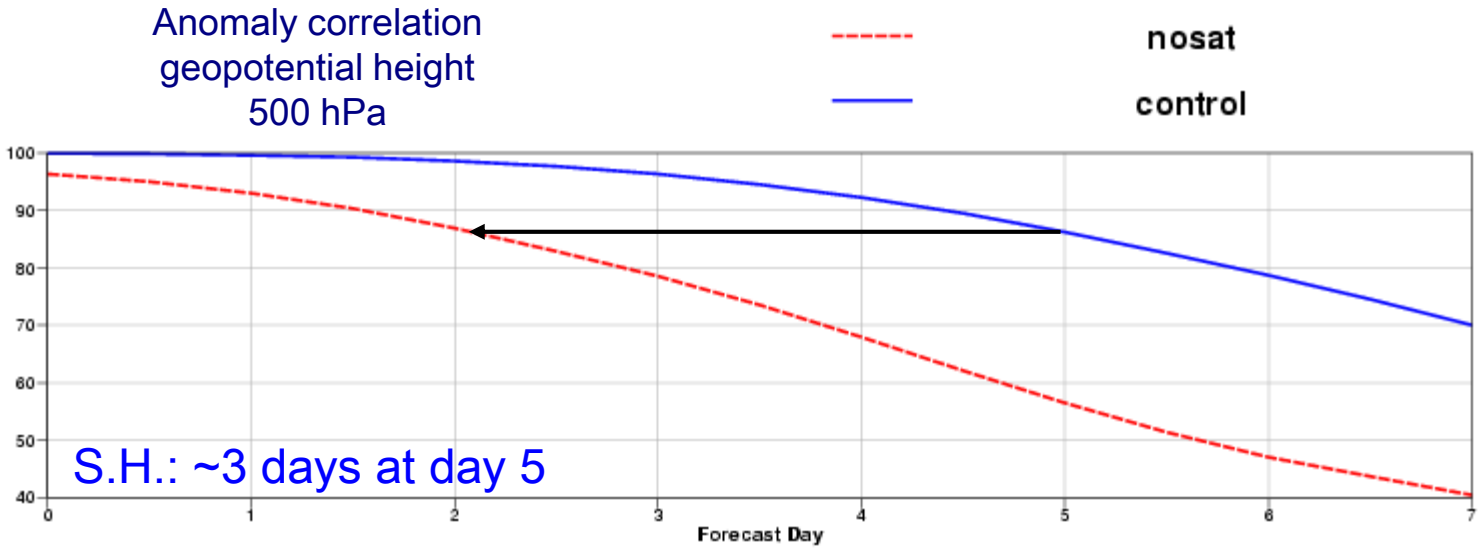
But if the model has a error in the cyclone position sometimes the **wrong ASCAT wind is selected** (below is a <u>bad</u> example, TC *PAM*)

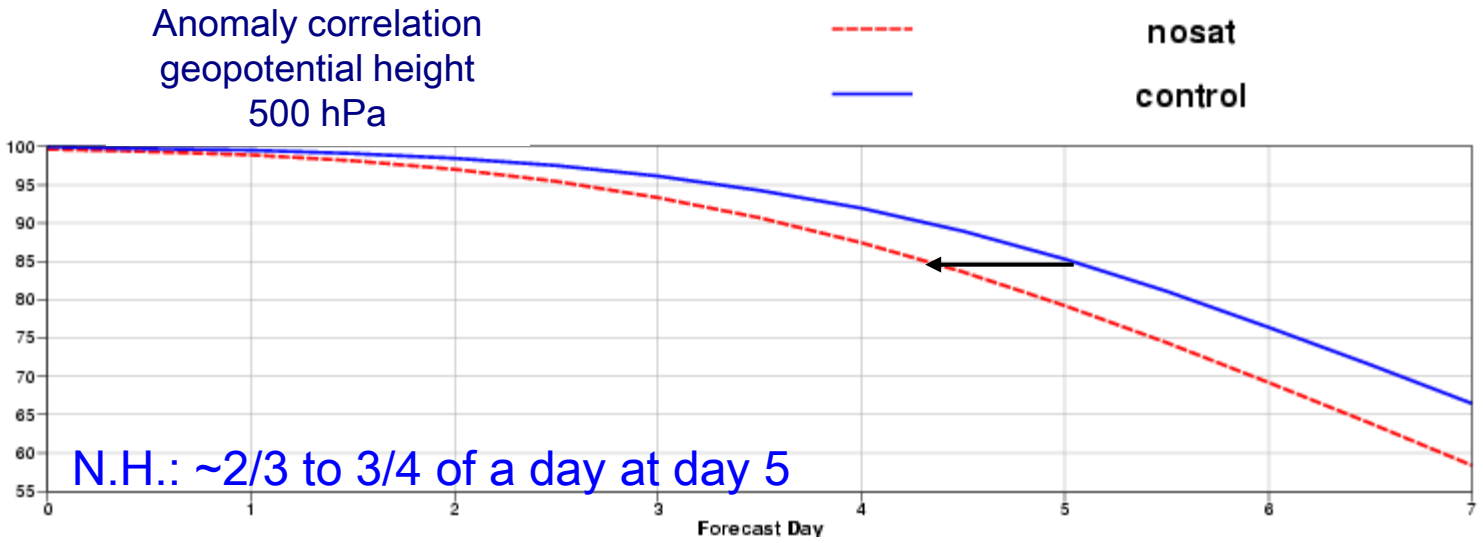


Overview

- Introduction – what do satellites measure ?
- The major satellite observing systems – what do they provide ?
  - Infrared
  - Microwave
  - GPS-RO
  - Scatterometers
- Quantifying the benefit of satellites
- Future systems

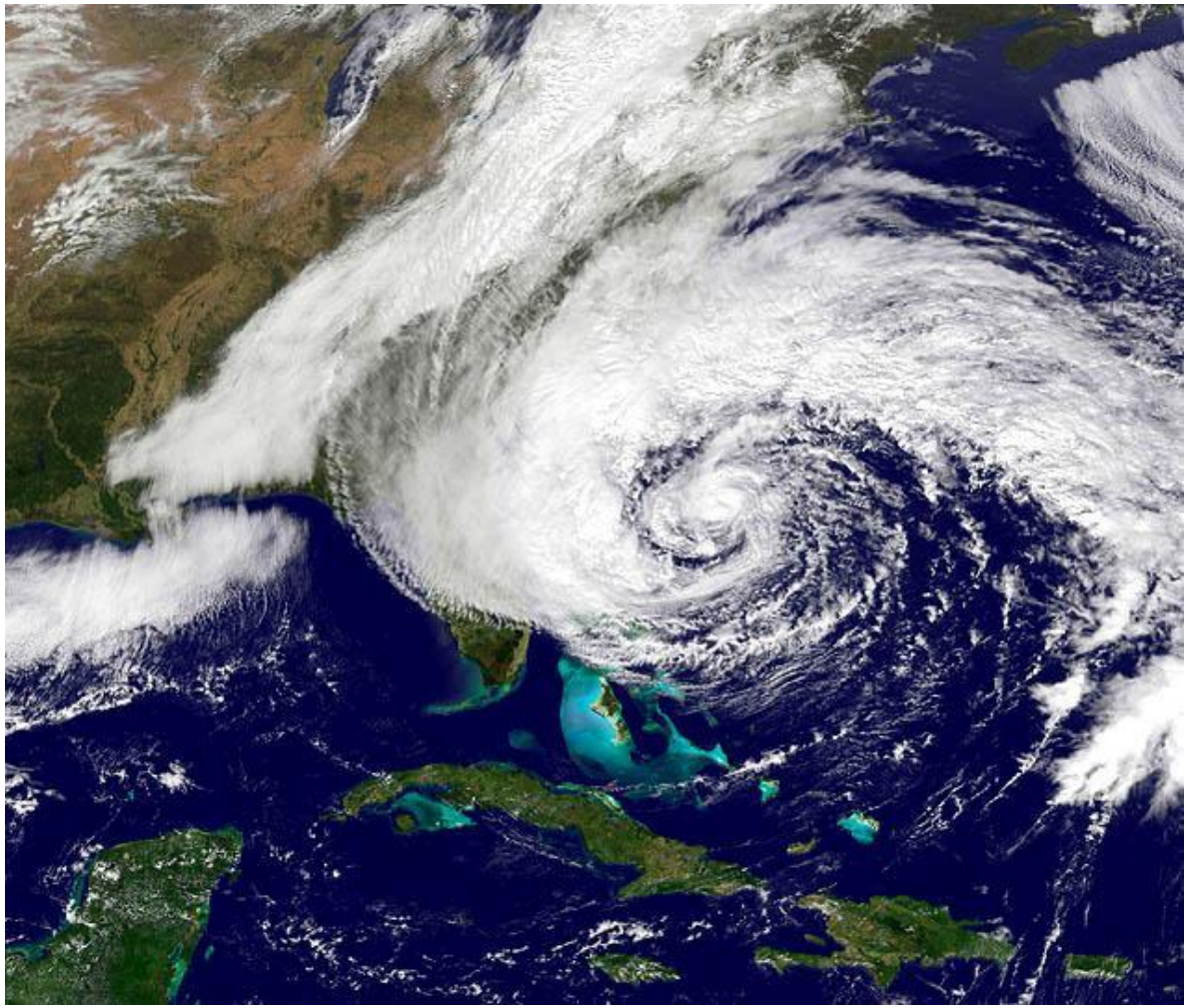
Forecast skill without satellites ?



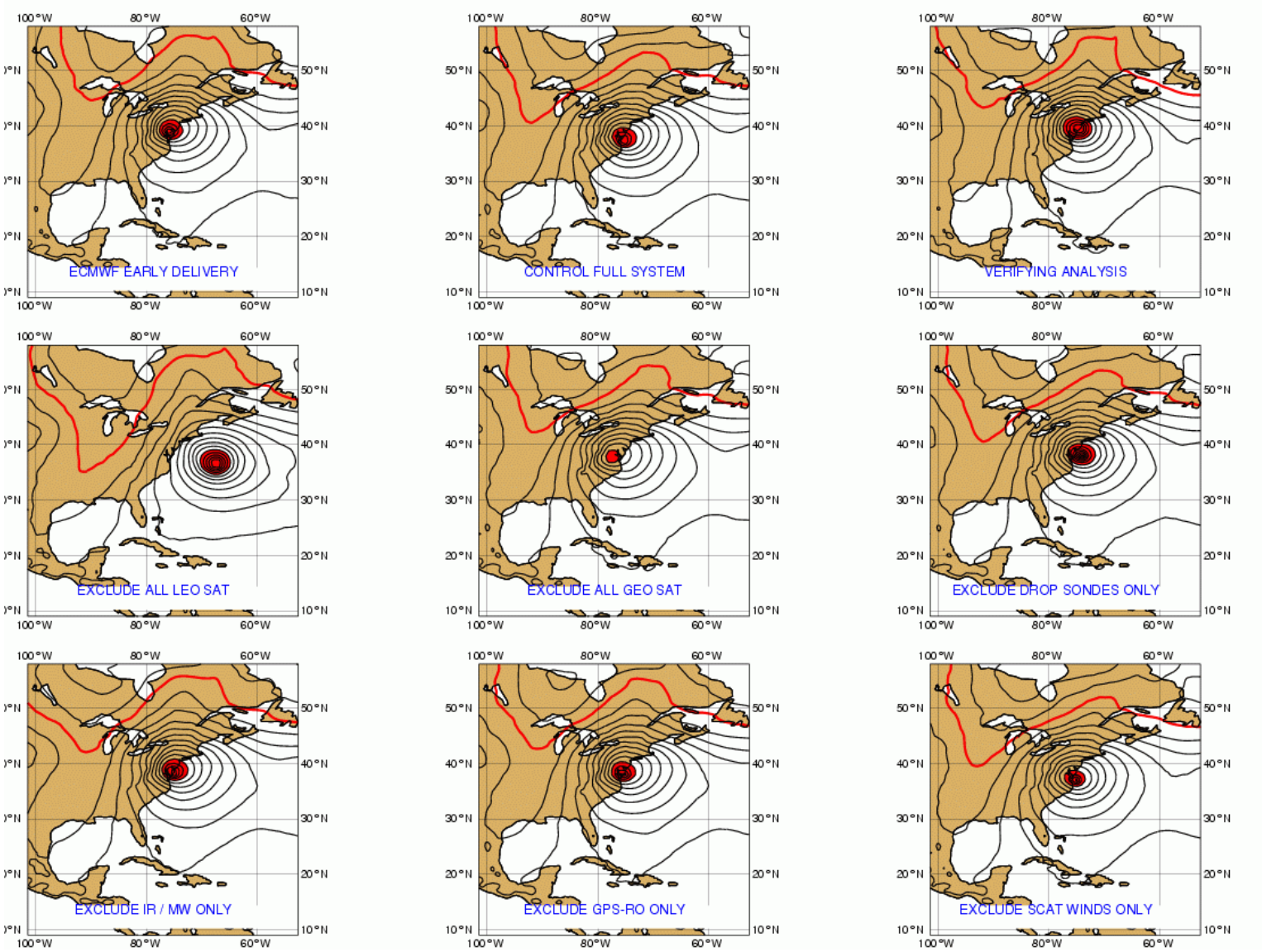


Storms without satellites ?

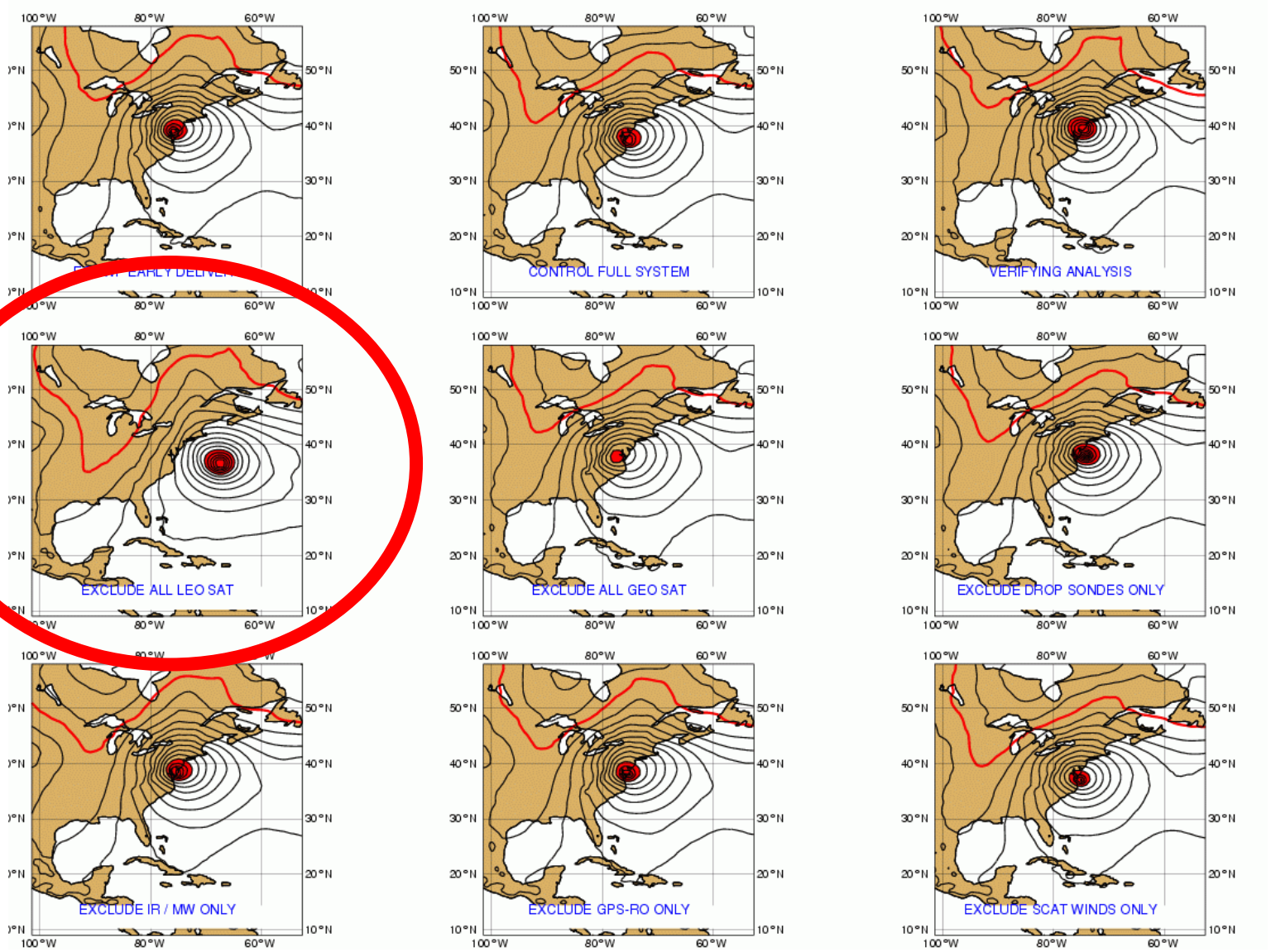
Hurricane Sandy



Storms without satellites …OSE experiments

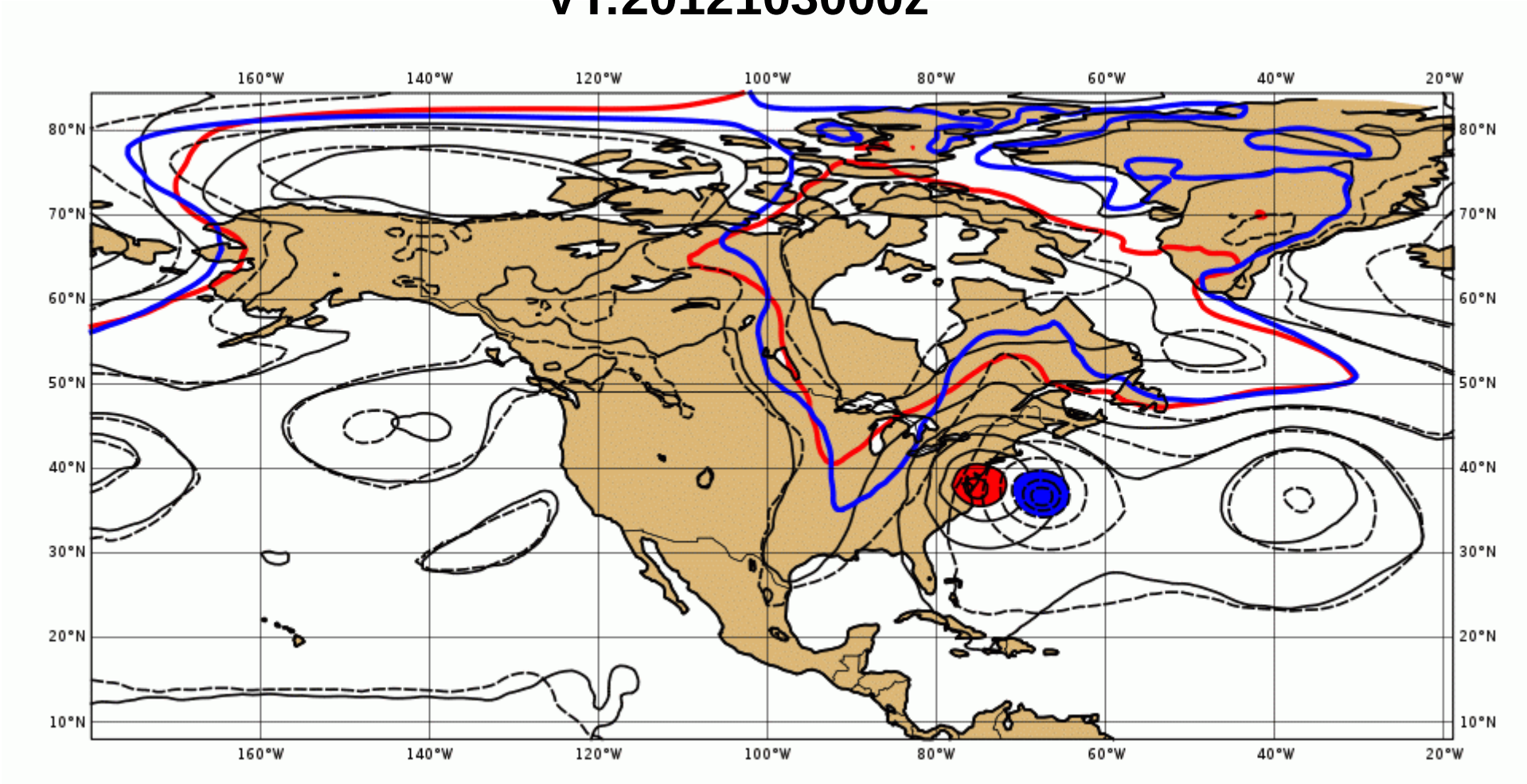


Without LEO satellites …forecast failure!

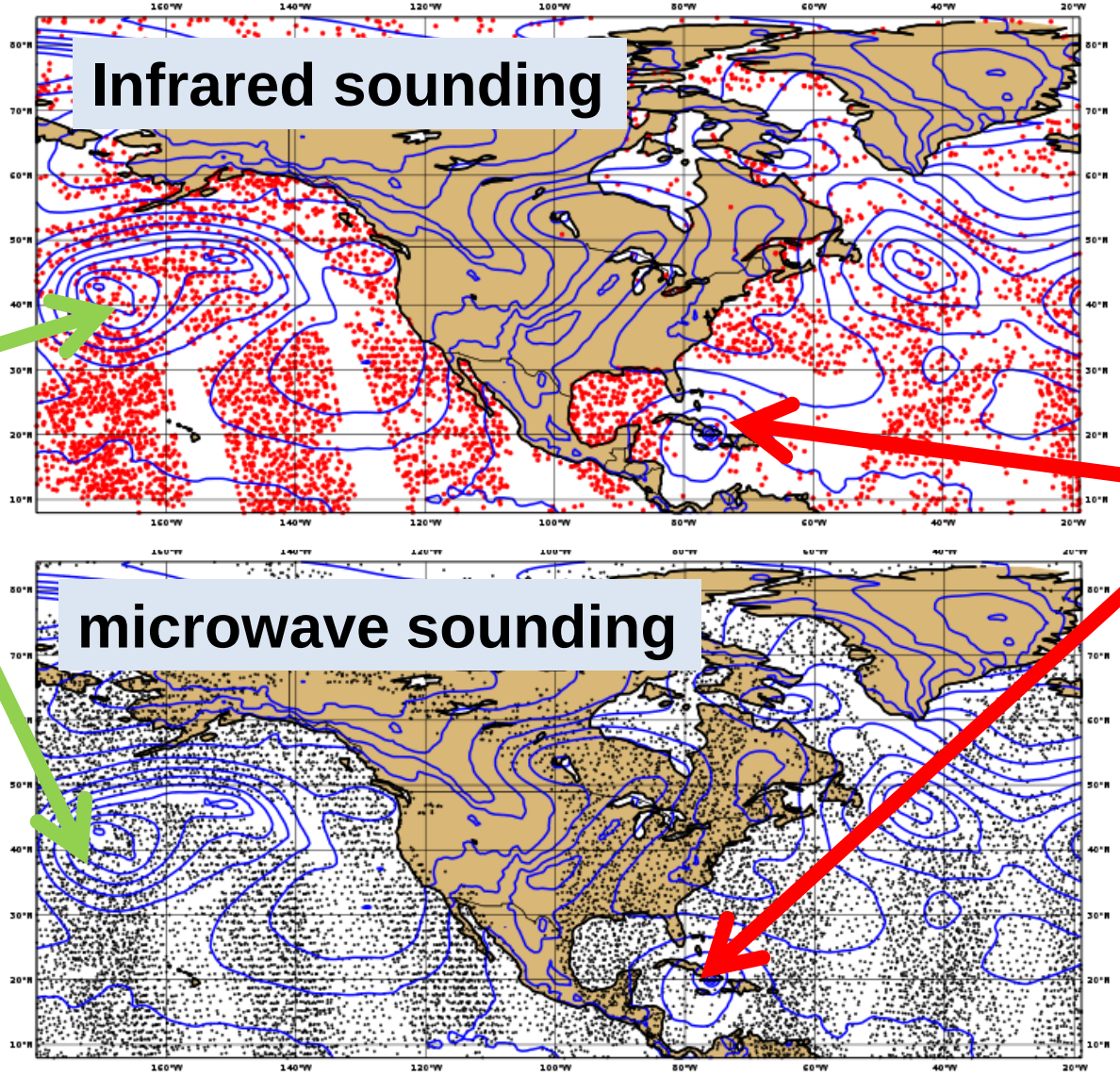


Without LEO satellites …forecast failure!

MSLP in Control (red and black solid)
NO-LEO SAT (blue and black dash)
VT:2012103000z



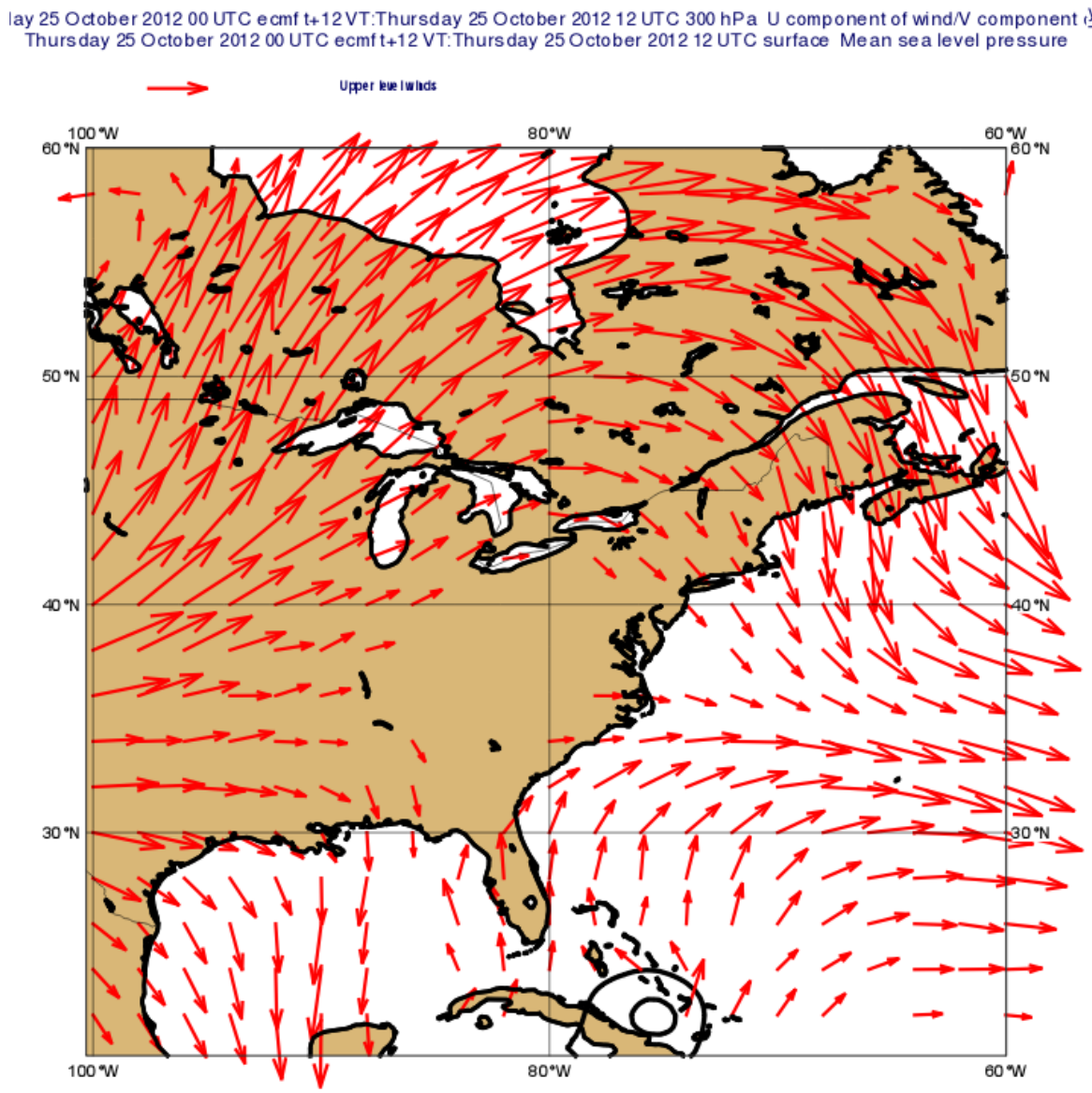
LEO satellites determined large scale environment

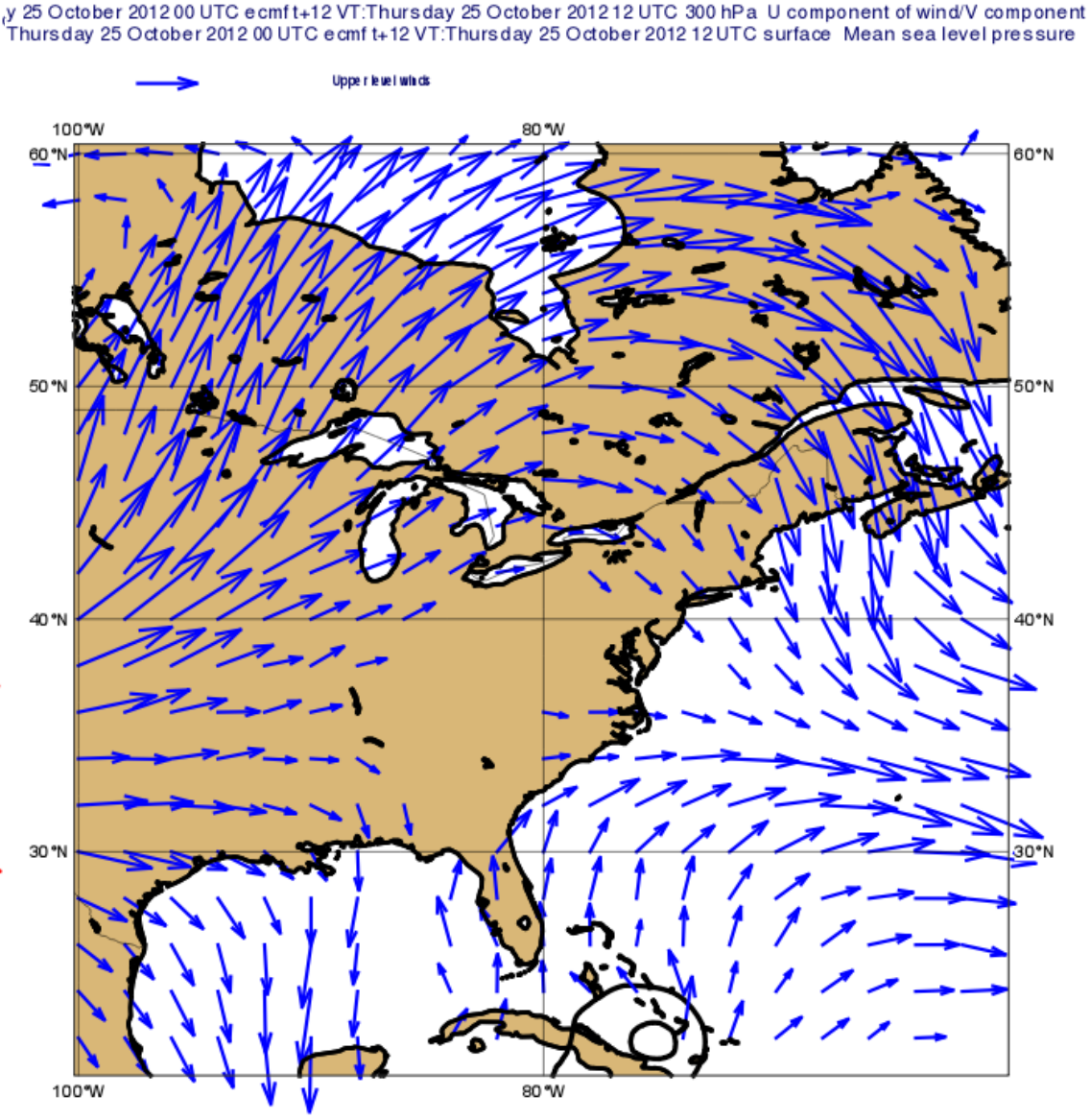


Good in the N.Pacific

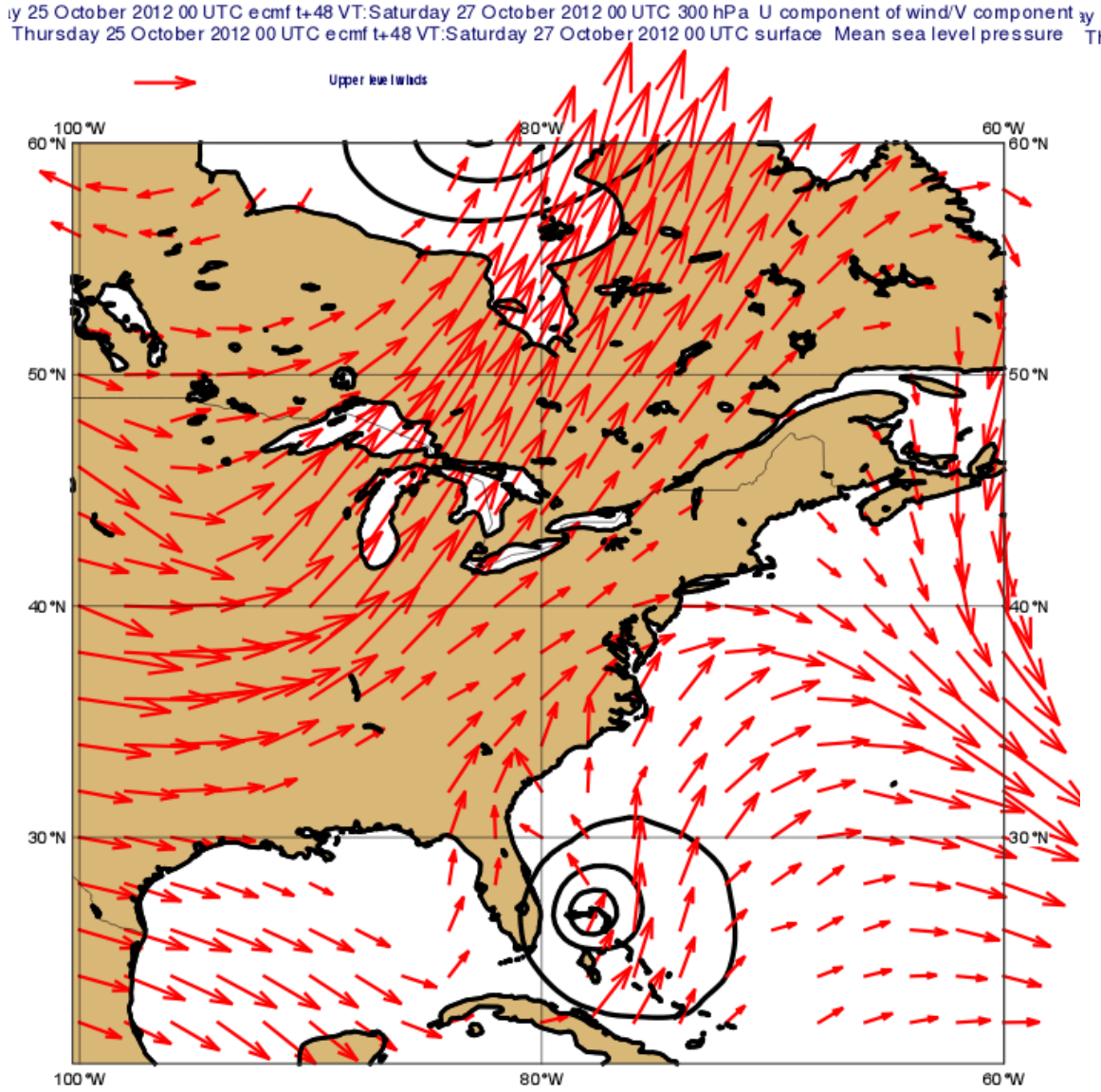
Very few data used in the immediate vicinity of the storm due to cloud and precipitation

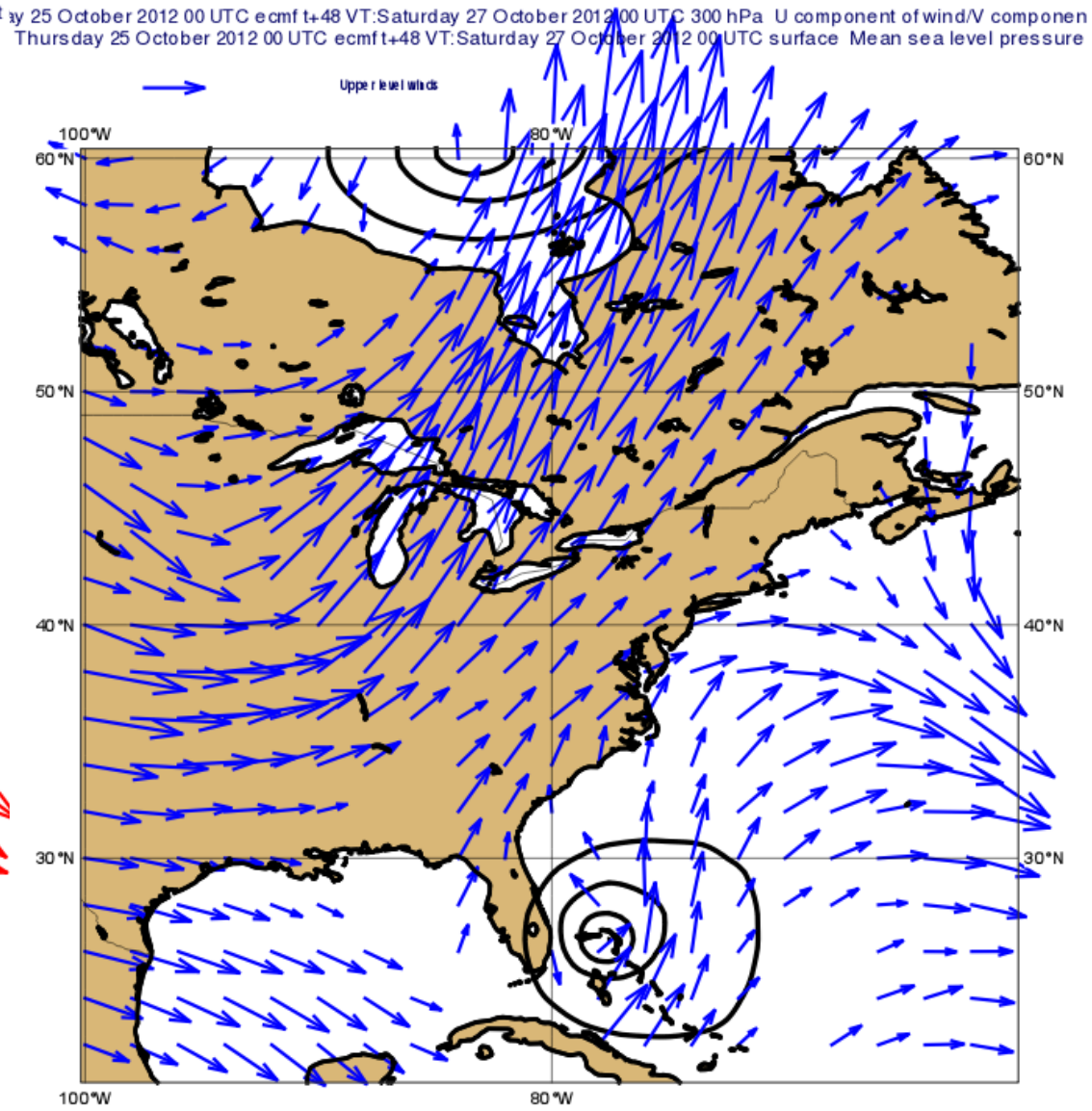
T+12


lay 25 October 2012 00 UTC ecmf t+12 VT:Thursday 25 October 2012 12 UTC 300 hPa U component of wind/V component
Thursday 25 October 2012 00 UTC ecmf t+12 VT:Thursday 25 October 2012 12 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N

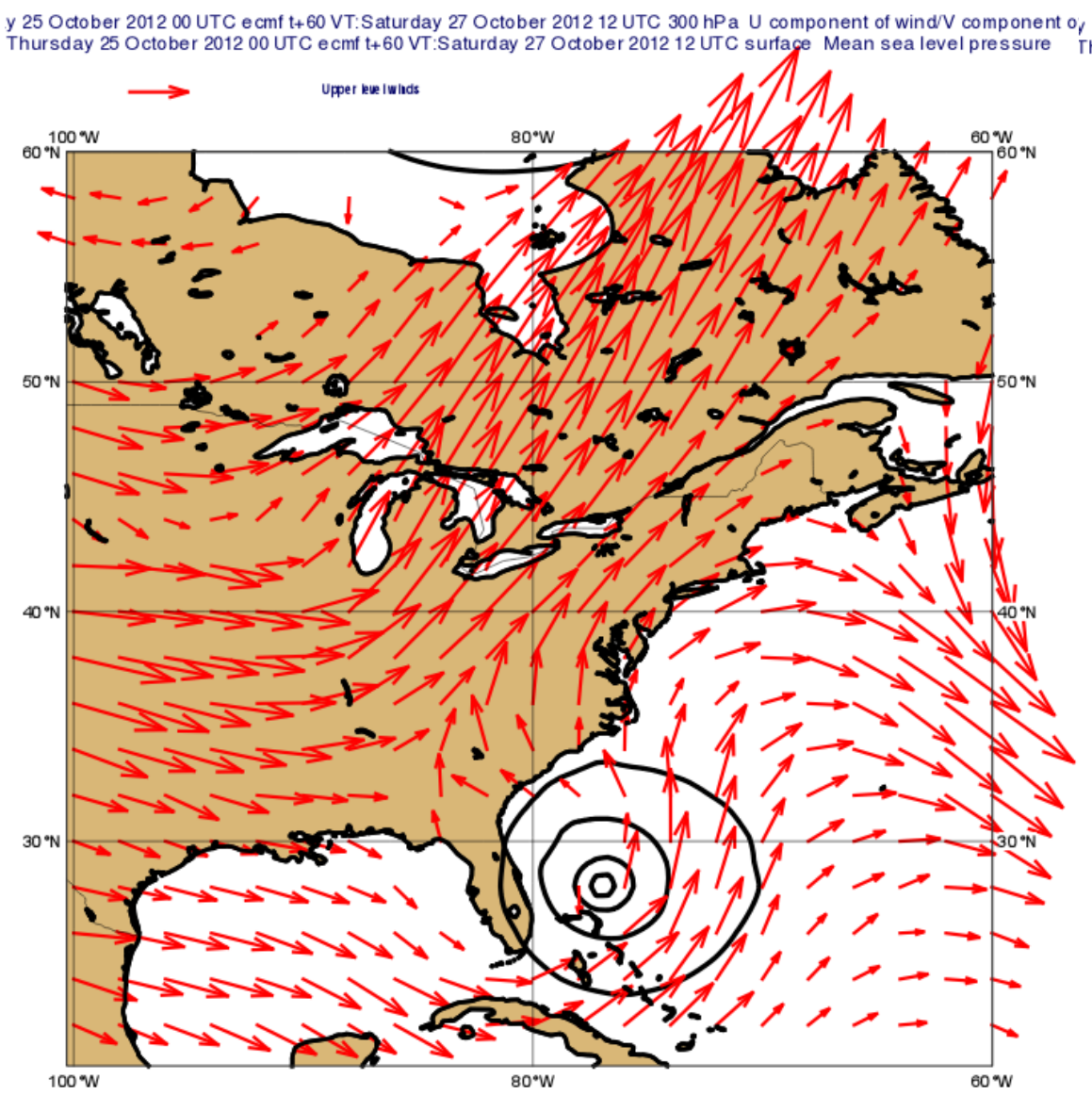

y 25 October 2012 00 UTC ecmf t+12 VT:Thursday 25 October 2012 12 UTC 300 hPa U component of wind/V component o
Thursday 25 October 2012 00 UTC ecmf t+12 VT:Thursday 25 October 2012 12 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

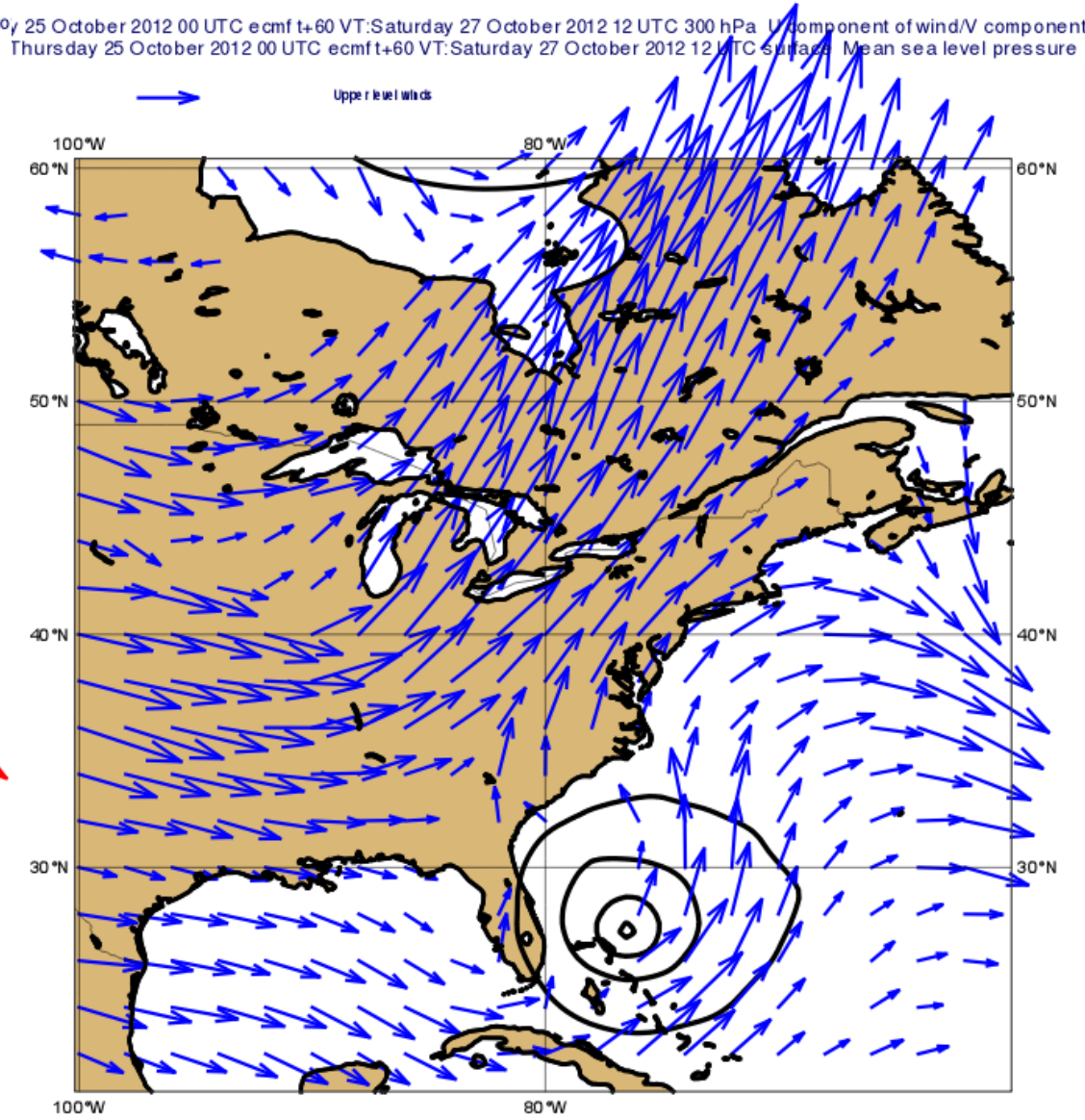
T+48


y 25 October 2012 00 UTC ecmf t+48 VT:Saturday 27 October 2012 00 UTC 300 hPa U component of wind/V component
Thursday 25 October 2012 00 UTC ecmf t+48 VT:Saturday 27 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N

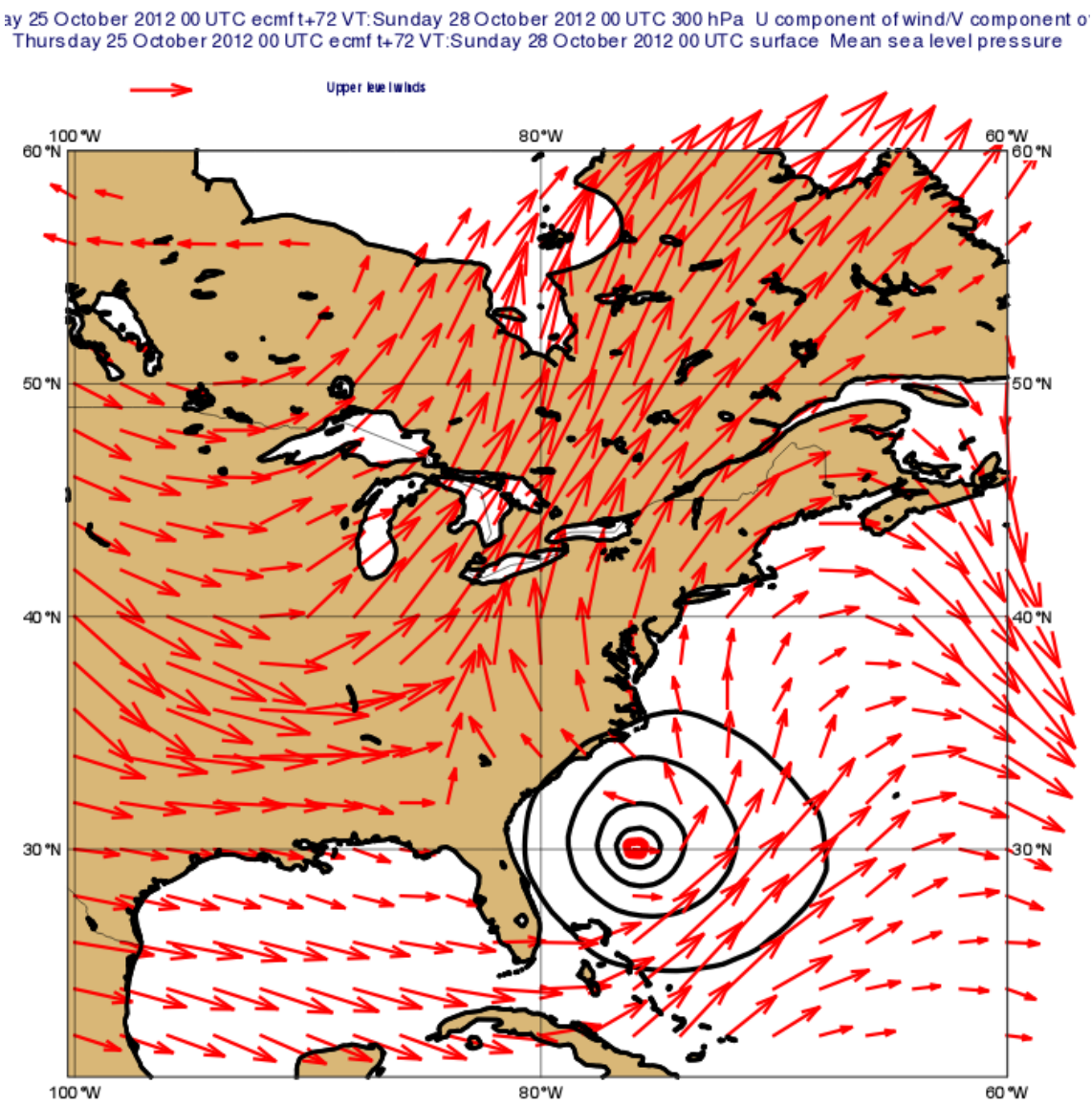

y 25 October 2012 00 UTC ecmf t+48 VT:Saturday 27 October 2012 00 UTC 300 hPa U component of wind/V componen
Thursday 25 October 2012 00 UTC ecmf t+48 VT:Saturday 27 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

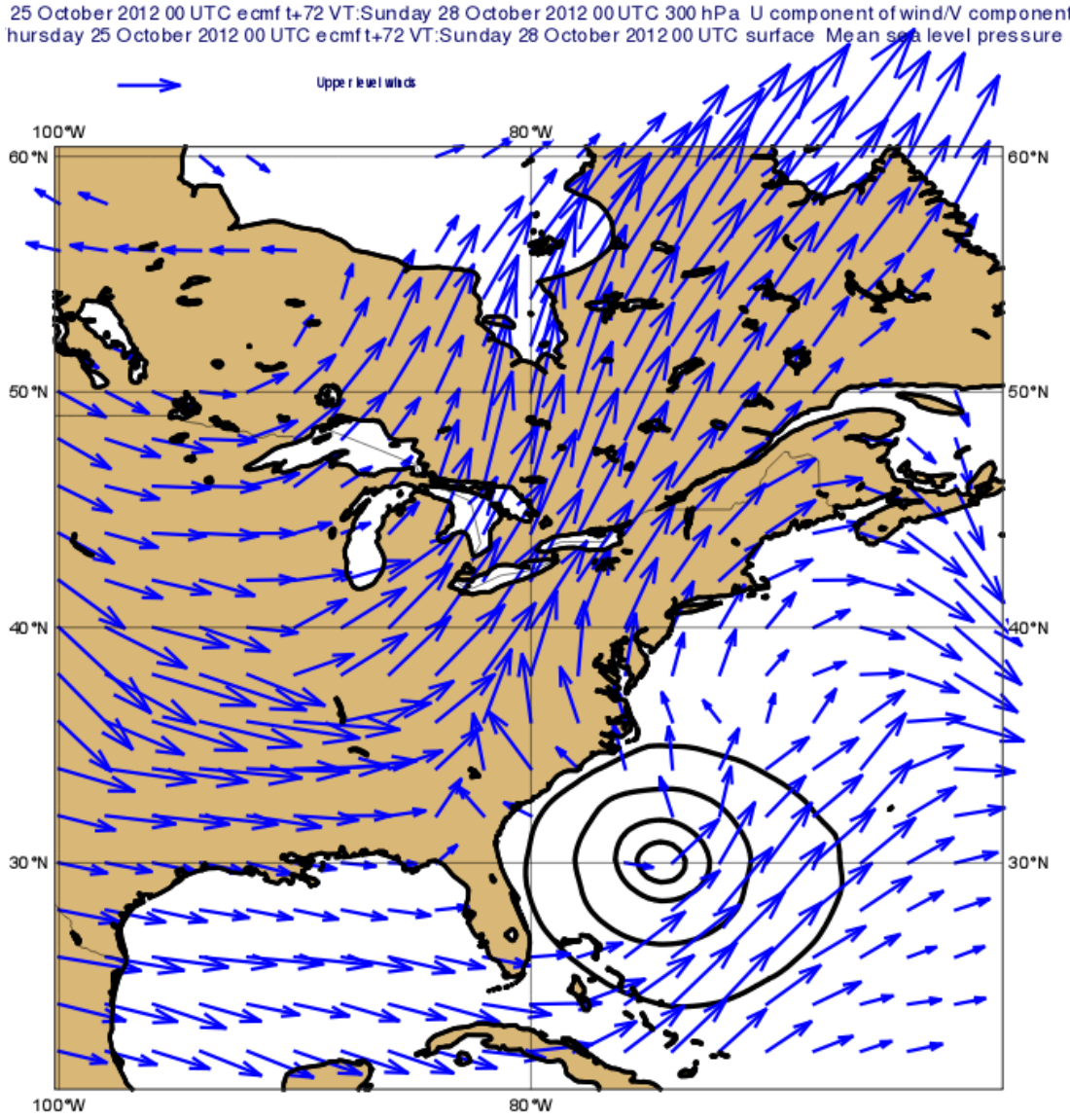
T+60


y 25 October 2012 00 UTC ecmf t+60 VT:Saturday 27 October 2012 12 UTC 300 hPa U component of wind/V component o
Thursday 25 October 2012 00 UTC ecmf t+60 VT:Saturday 27 October 2012 12 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N

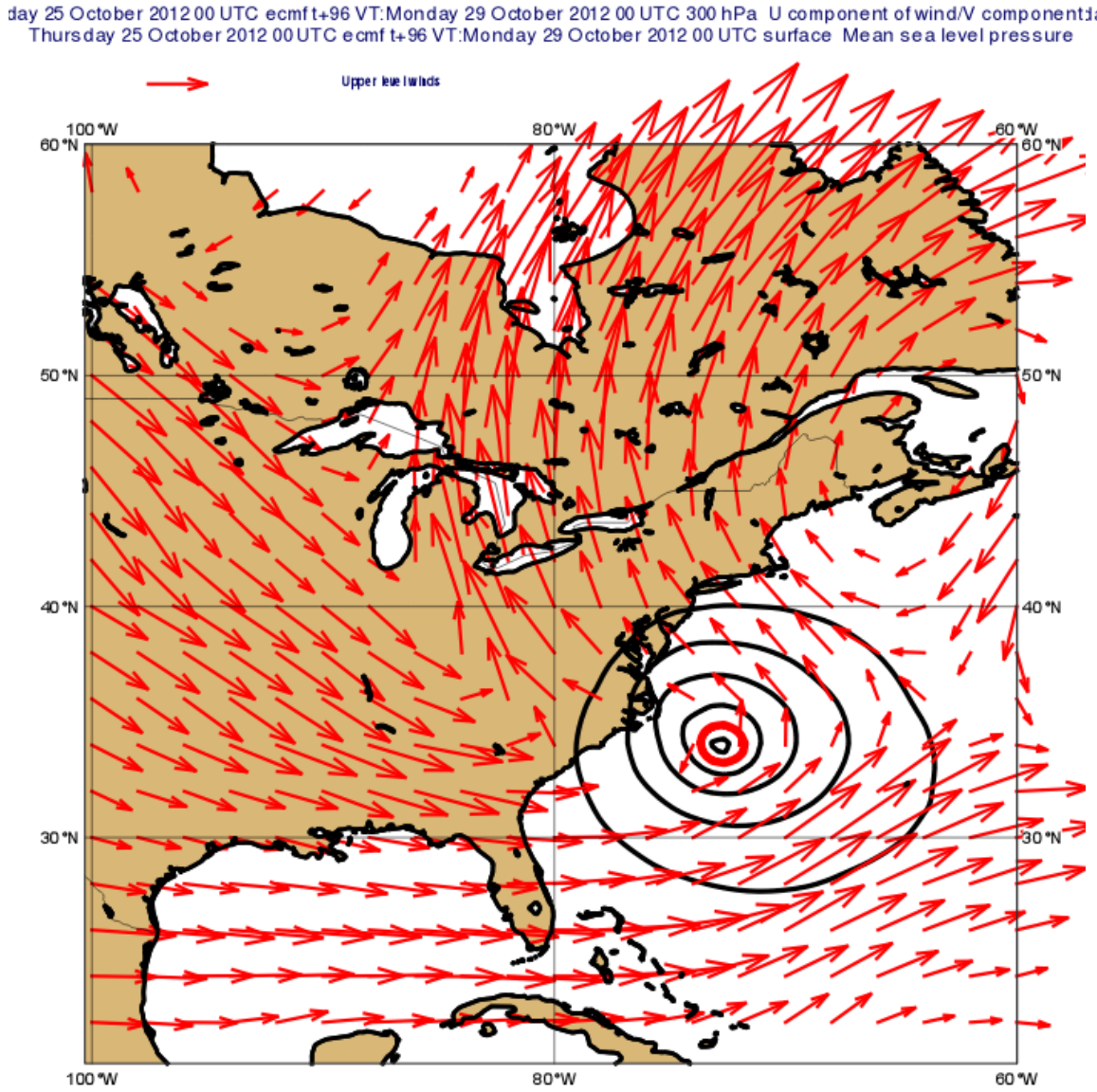

y 25 October 2012 00 UTC ecmf t+60 VT:Saturday 27 October 2012 12 UTC 300 hPa U component of wind/V component of
Thursday 25 October 2012 00 UTC ecmf t+60 VT:Saturday 27 October 2012 12 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

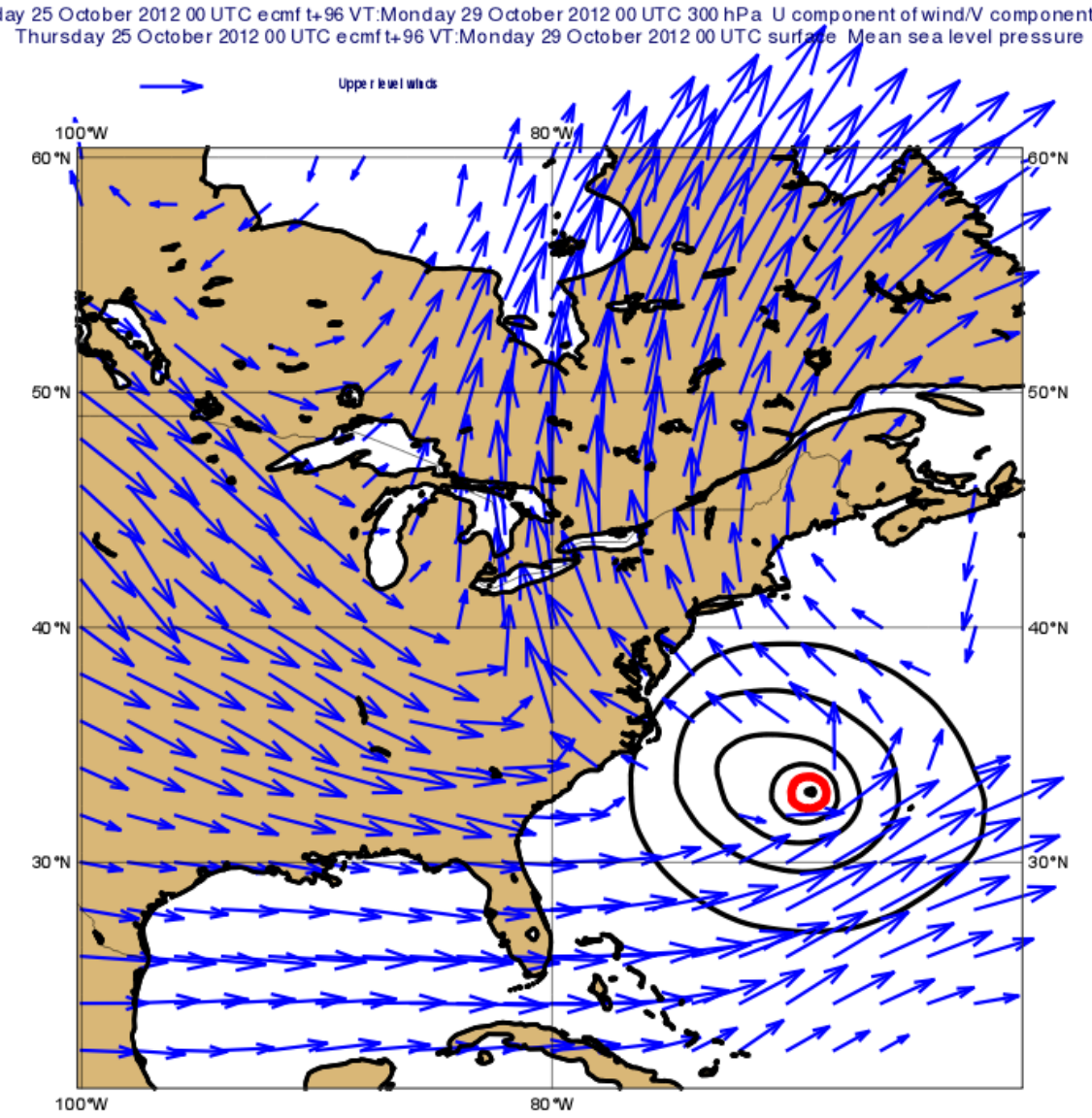
T+72


ay 25 October 2012 00 UTC ecmf t+72 VT:Sunday 28 October 2012 00 UTC 300 hPa U component of wind/V component o
Thursday 25 October 2012 00 UTC ecmf t+72 VT:Sunday 28 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N

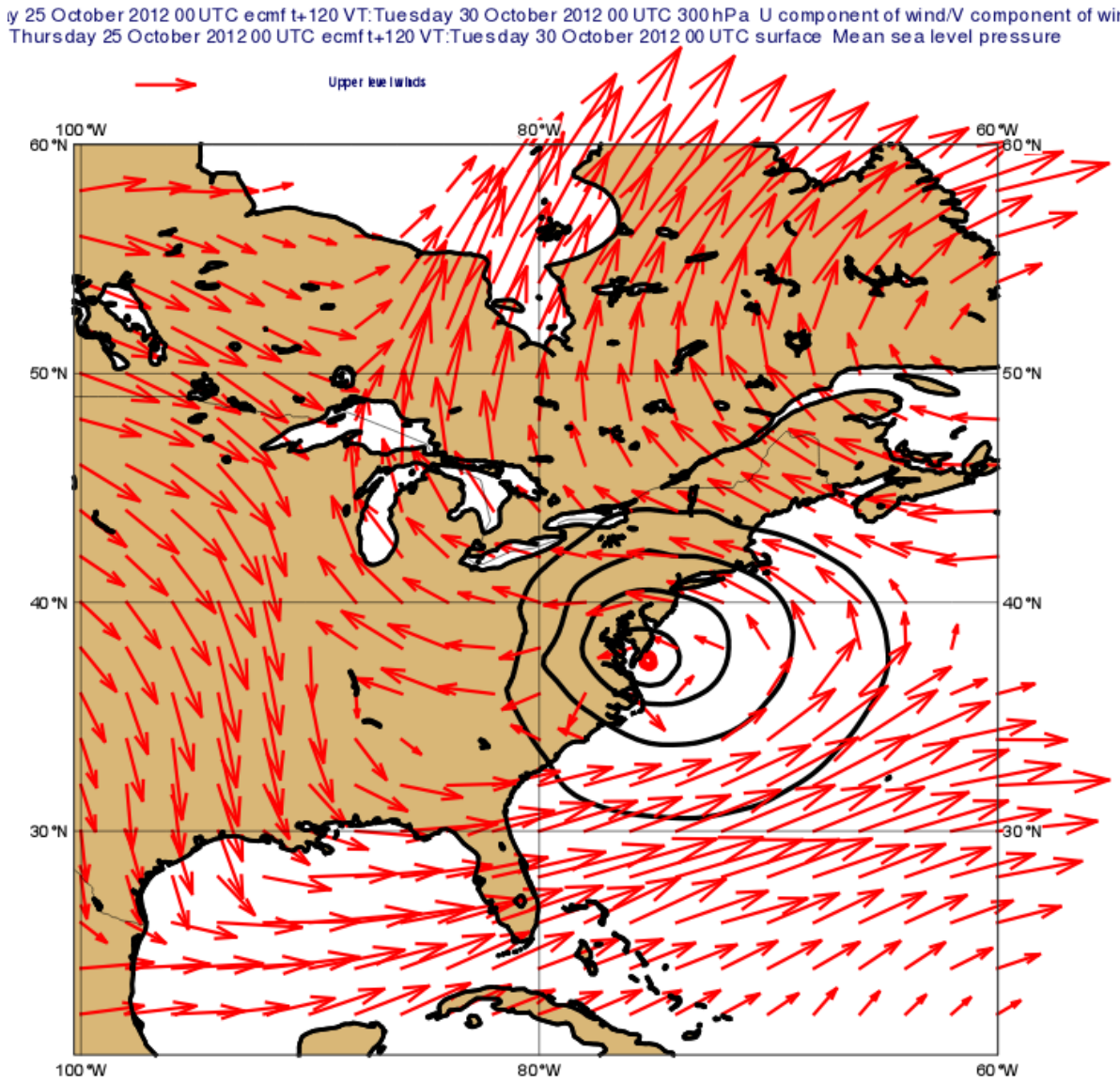

25 October 2012 00 UTC ecmf t+72 VT:Sunday 28 October 2012 00 UTC 300 hPa U component of wind/V component
hursday 25 October 2012 00 UTC ecmf t+72 VT:Sunday 28 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

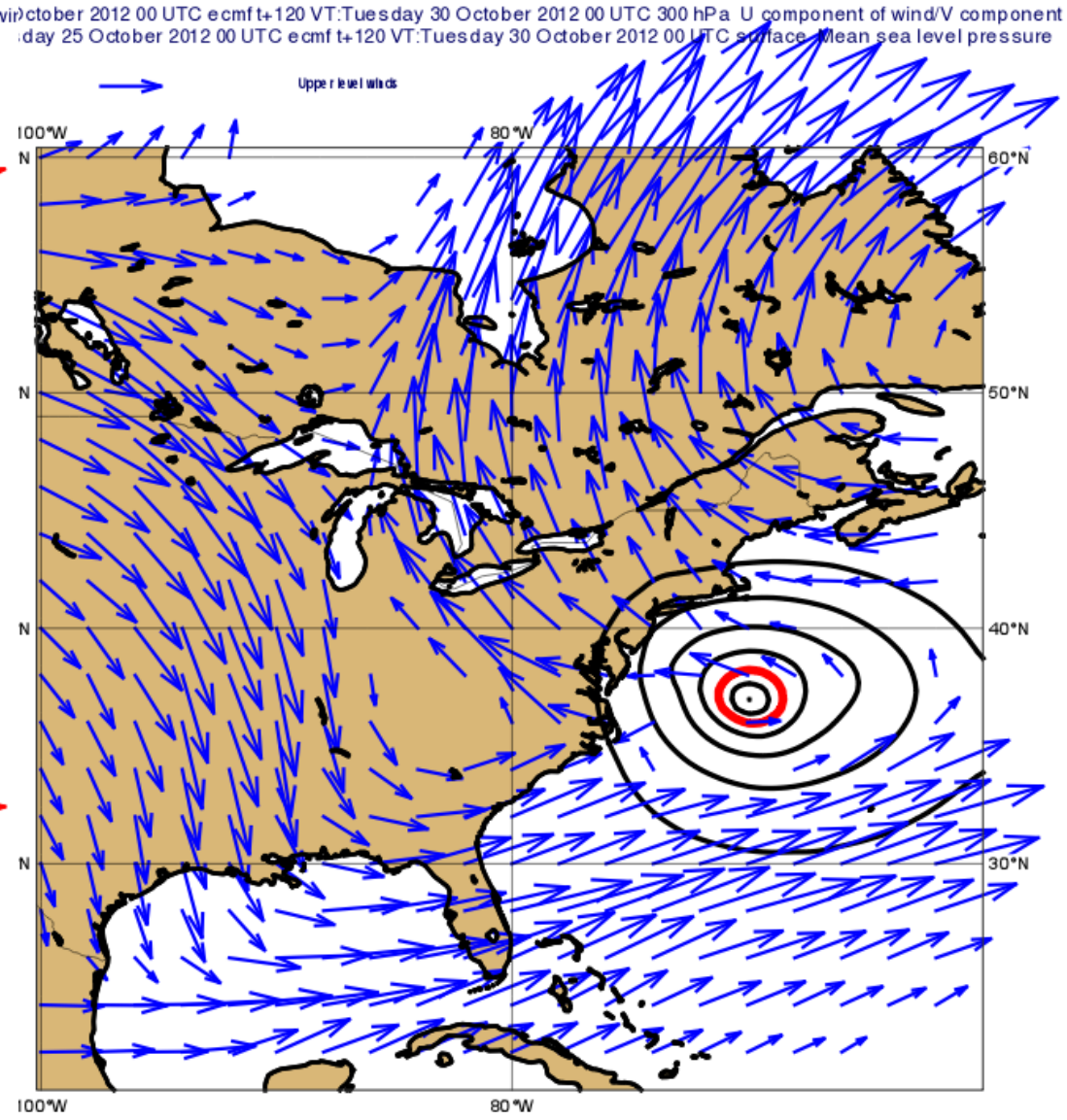
T+96


day 25 October 2012 00 UTC ecmf t+96 VT:Monday 29 October 2012 00 UTC 300 hPa U component of wind/V component
Thursday 25 October 2012 00 UTC ecmf t+96 VT:Monday 29 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N


day 25 October 2012 00 UTC ecmf t+96 VT:Monday 29 October 2012 00 UTC 300 hPa U component of wind/V component
Thursday 25 October 2012 00 UTC ecmf t+96 VT:Monday 29 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

T+120


y 25 October 2012 00 UTC ecmf t+120 VT:Tuesday 30 October 2012 00 UTC 300 hPa U component of wind/V component of wi
Thursday 25 October 2012 00 UTC ecmf t+120 VT:Tuesday 30 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°W
60°N
50°N
40°N
30°N

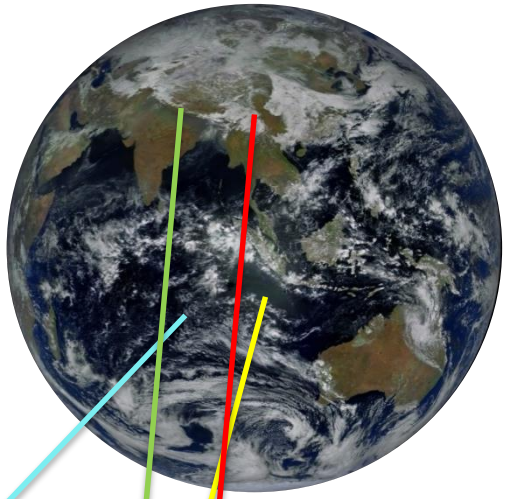

ctober 2012 00 UTC ecmf t+120 VT:Tuesday 30 October 2012 00 UTC 300 hPa U component of wind/V component o
day 25 October 2012 00 UTC ecmf t+120 VT:Tuesday 30 October 2012 00 UTC surface Mean sea level pressure
Upper level winds
100°W
80°W
60°N
50°N
40°N
30°N

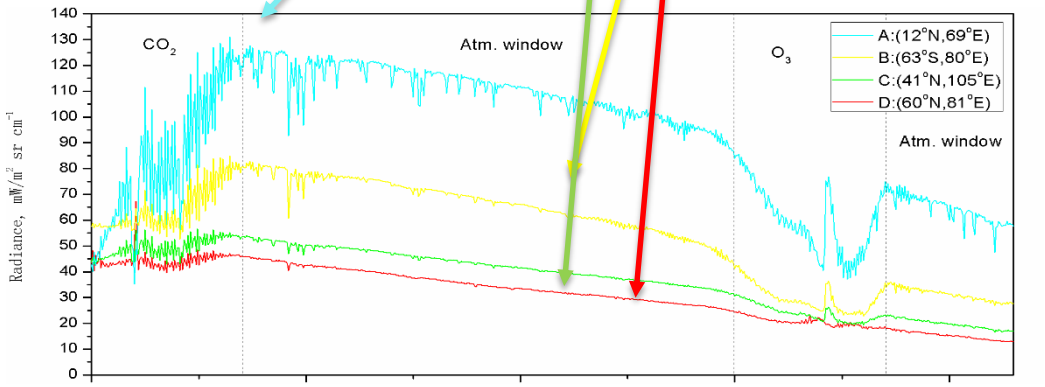
Overview

- Introduction – what do satellites measure ?
- The major satellite observing systems – what do they provide ?
  - Infrared
  - Microwave
  - GPS-RO
  - Scatterometers
- Quantifying the benefit of satellites
- Future systems

Preparing for hyperspectral GEO…MTG-IRS…FY-4A

The sample spectra published by CMA look qualitatively realistic…but we need to get the data !

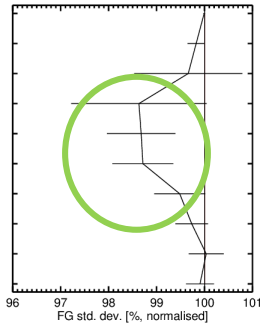




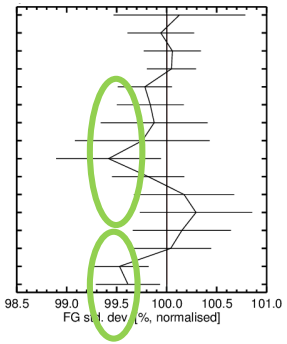
ECMWF

GEO radiances are currently a strong driver of humidity and <u>wind</u> (via 4D advection tracing) so a hyperspectral GEO could have major impact!

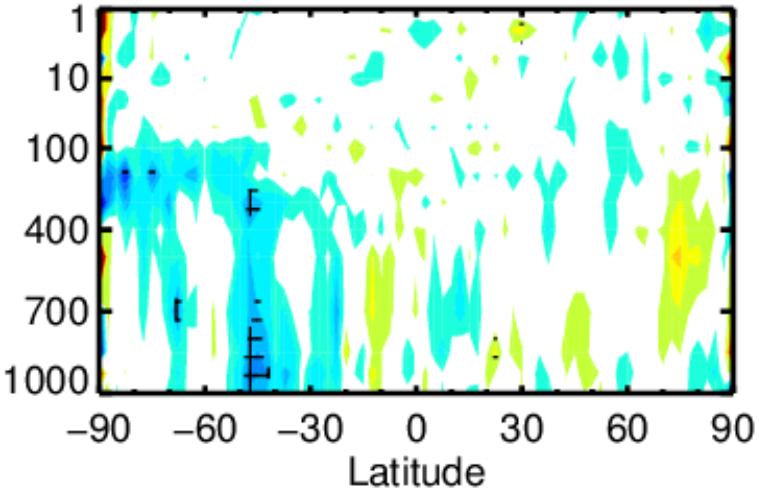
TEMP-Q



TEMP-VW



STD DEV T+72 VW FC ERROR



Summary

Summary

- Satellites are complicated observations **not** measuring meteorological parameters
- The major satellite observing systems all provide **complementary information**, but all have limitations
- The combined impact of satellites is enormous – they are the **most important observations for NWP**
- The future systems have huge potential to improve further!