NWP and Satellite data dependencies

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Part 1: General NWP Concepts

Part 2: Use of Satellite Data in NWP models

Part 3: Case Study, Satellite Data improving NWP Tropical Cyclone Forecast

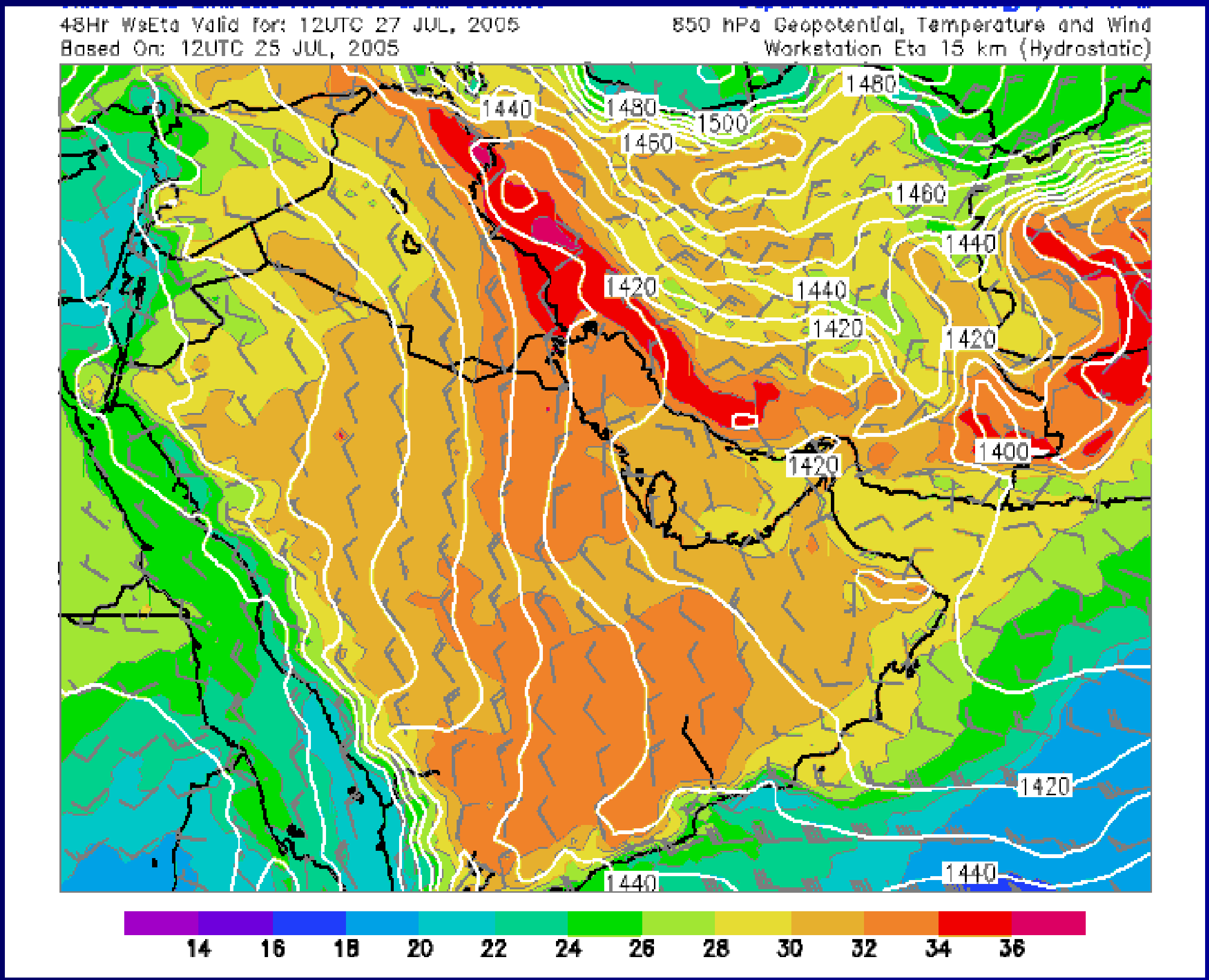
Part 4: Supporting tool for dust storm forecasting

Part1: General NWP Concepts

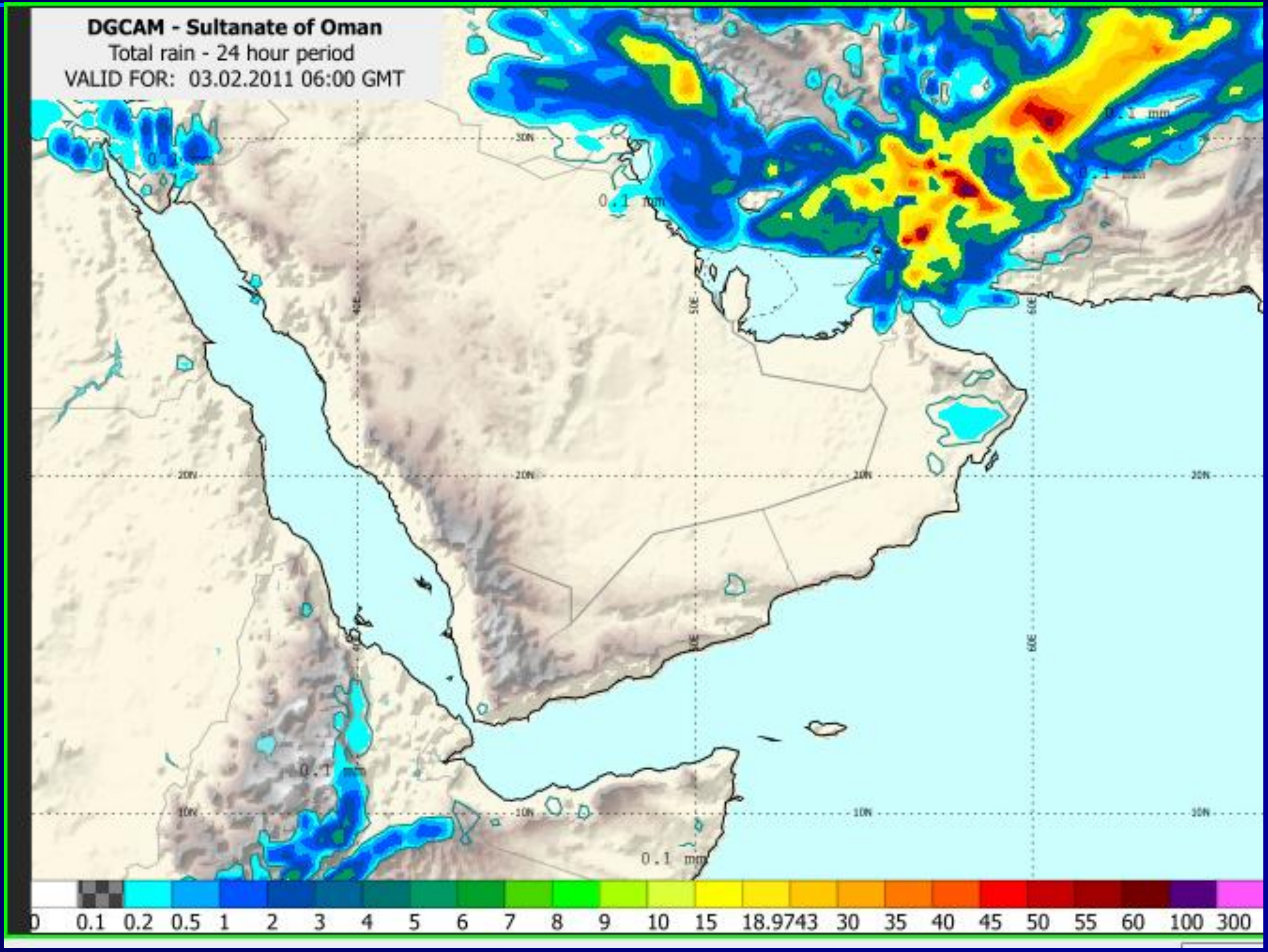
Objective

- What is NWP model?
- Why do we need NWP model?
- How to understand NWP model output?
- What do we need to run NWP model?
- Why NWP models are not perfect?

NWP model Products



NWP model Products



Model equations

Zonal wind u

$$\frac{\partial u}{\partial t}-(\varsigma+f)v+\dot{\eta}\frac{\partial u}{\partial \eta}=-\frac{1}{a\cos\varphi}\frac{\partial}{\partial\lambda}(\Phi+K)-\frac{RT_v}{a\cos\varphi}\frac{\partial}{\partial\lambda}(\ln p)+\left(\frac{\partial u}{\partial t}\right)_{sub}-K_4\nabla^4 u - \mu_{\mathrm{lbc}}(u-u_{lbc})$$

Meridional wind v

$$\frac{\partial v}{\partial t}+(\varsigma+f)u+\dot{\eta}\frac{\partial v}{\partial \eta}=-\frac{1}{a}\frac{\partial}{\partial\varphi}(\Phi+K)-\frac{RT_v}{a}\frac{\partial}{\partial\varphi}(\ln p)+\left(\frac{\partial v}{\partial t}\right)_{sub}-K_4\nabla^4 v-\mu_{lbc}(v-v_{lbc})$$

Temperature T

$$\frac{\partial T}{\partial t}+\frac{1}{a\cos\varphi}\left(u\frac{\partial T}{\partial\lambda}+v\cos\varphi\frac{\partial T}{\partial\varphi}\right)+\dot{\eta}\frac{\partial T}{\partial\eta}=\frac{\alpha\omega}{c_p}+\frac{L_v}{c_p}C_{vc}+\left(\frac{\partial T}{\partial t}\right)_{sub}-K_4\nabla^4\left(T-T_{ref}\right)-\mu_{\mathrm{lbc}}(\mathrm{T}-\mathrm{T}_{\mathrm{lbc}})$$

Surface pressure p_s

$$\frac{\partial p_s}{\partial t}=-\frac{1}{a\cos\varphi}\int_0^1\left\{\frac{\partial}{\partial\lambda}\left(u\frac{\partial p}{\partial\eta}\right)+\frac{\partial}{\partial\varphi}\left(v\cos\varphi\frac{\partial p}{\partial\eta}\right)\right\}d\eta-\mu_{\mathrm{lbc}}(p_s-p_{s,lbc})$$

Model source code

```
      INCLUDE "compar.h"
      INCLUDE "comhumid.h"

      zepclc = 1.E-7

      DO j3=ki3s,ki3e
        DO j2=ki2sc,ki2ec
          DO j1=ki1sc,ki1ec
!
!         layer mean pressure and p/ps
          zp    = pakf(j3) + pbkf(j3)*ps(j1,j2)
          zpdps=                  zp/ps(j1,j2)

!         calculate ice fraction
          zt_ice1 = T_melt-5.
          zt_ice2 = T_melt-25.
          zf_ice  = 1.-MIN(1.,MAX(0.,(pt (j1,j2,j3)-zt_ice2) /
     &                            (zt_ice1-zt_ice2)))
!
!         total water content (vapour + liquid (+ice))
          zqw = pqv(j1,j2,j3) + pqc(j1,j2,j3) + pqi(j1,j2,j3)
!
!         saturation humidity over water and ice
          zqvs_i  = sf_qsat (sf_psat_i (pt (j1,j2,j3) ), zp )
          zqvs_w  = sf_qsat (sf_psat_w (pt (j1,j2,j3) ), zp )
          pqvs(j1,j2,j3) = zqvs_w*(1.-zf_ice)+zqvs_i*zf_ice

!         critical relative humidity
          zrh_crit = 0.95-Rh_cr1*zpdps*(1.-zpdps)
     &                 *(1.+Rh_cr2*(zpdps-0.5))
!
!         cloud liquid water content (0.5% of saturation humidity for
!         non-convective, 1% for convective type clouds)
          zqci = 0.005*pqvs(j1,j2,j3)

          IF ( j3.GE.NINT(ptop_con(j1,j2)) .AND.
     &         j3.LT.NINT(pbas_con(j1,j2)) ) zqci = zqci * 2.0
          IF ( j3.GE.NINT(ptop_con(j1,j2)) .AND.
     &         j3.LT.NINT(pbas_con(j1,j2)) ) zqci = max(zqci,0.15E-03)

!         partial cloud cover as function of relative humidity
          zclc_rh = MAX(0.0,MIN(1.,
     &          (zqw/pqvs(j1,j2,j3)-zrh_crit)/(Rh_cr3-zrh_crit)))**2

!         combine convective cloud cover and rel.hum. cloud cover
          pclc (j1,j2,j3) = zclc_rh + pclc_con(j1,j2,j3)*(1.-zclc_rh)
          pqcwc(j1,j2,j3) = zqci*(1.-zf_ice)
          pqiwc(j1,j2,j3) = zqci*zf_ice
```

What is NWP Model?

- **Take the equations that describe atmospheric processes.**
- **Convert them to a form where they can be programmed into a large computer.**
- **Let the computer to solve them**
- **This is called a "model" of the atmosphere**

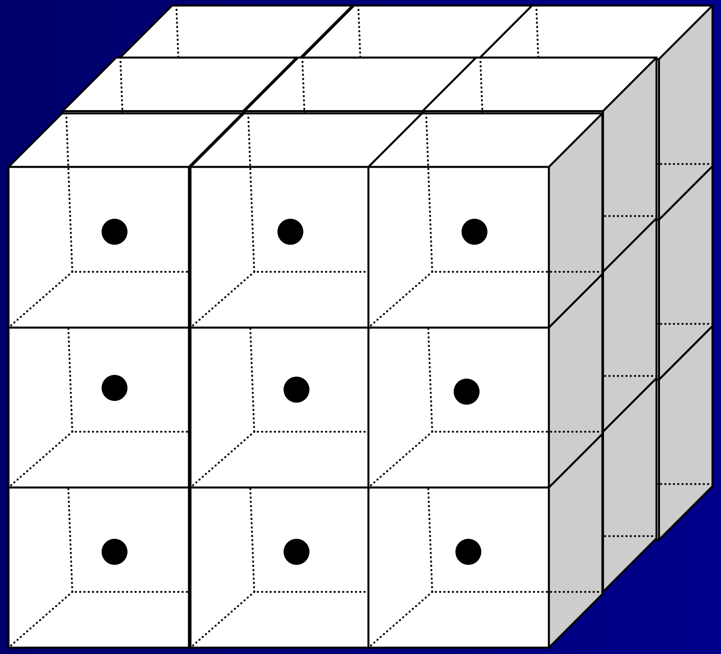
What do we mean by "solve the equations"

- **The equations describe how the atmosphere changes with time.**
- **For example, one equation would be**

$$\frac{T\ Change}{Time} = Solar + Condensation + Convection$$
$$+ Evaporation + Advection + \ldots\ldots$$

NWP Concept: General overview

- **NWP consists of:**
  - Subdividing a chosen geographic **3D area** in thousands (or millions) of little **cubes**.



3D cubes of the atmosphere used by NWP models

NWP Concept: General overview

- **NWP consists of :**
  - Subdividing a chosen geographic 3D area in thousands (or millions) of little cubes.
  - Gathering all current (and past) actual information about atmosphere and ocean : all types of observational data.
  - Affecting one value for the main meteorological parameters (Pressure, Temperature, Wind, Humidity) in each cube.
  - Calculating through complex equations (momentum, thermodynamics, water) the modifications affecting these meteorological parameters in time.
  - Presenting the predicted parameters values in a comprehensible standard format (charts, meteograms, soundings, …etc).

Model equations

Zonal wind u

$$\frac{\partial u}{\partial t} - (\varsigma + f)v + \dot{\eta}\frac{\partial u}{\partial \eta} = -\frac{1}{a\cos\varphi}\frac{\partial}{\partial \lambda}(\Phi + K) - \frac{RT_v}{a\cos\varphi}\frac{\partial}{\partial \lambda}(\ln p) + \left(\frac{\partial u}{\partial t}\right)_{sub} - K_4\nabla^4 u - \mu_{\mathrm{lbc}}(u - u_{lbc})$$

Meridional wind v

$$\frac{\partial v}{\partial t} + (\varsigma + f)u + \dot{\eta}\frac{\partial v}{\partial \eta} = -\frac{1}{a}\frac{\partial}{\partial \varphi}(\Phi + K) - \frac{RT_v}{a}\frac{\partial}{\partial \varphi}(\ln p) + \left(\frac{\partial v}{\partial t}\right)_{sub} - K_4\nabla^4 v - \mu_{lbc}(v - v_{lbc})$$

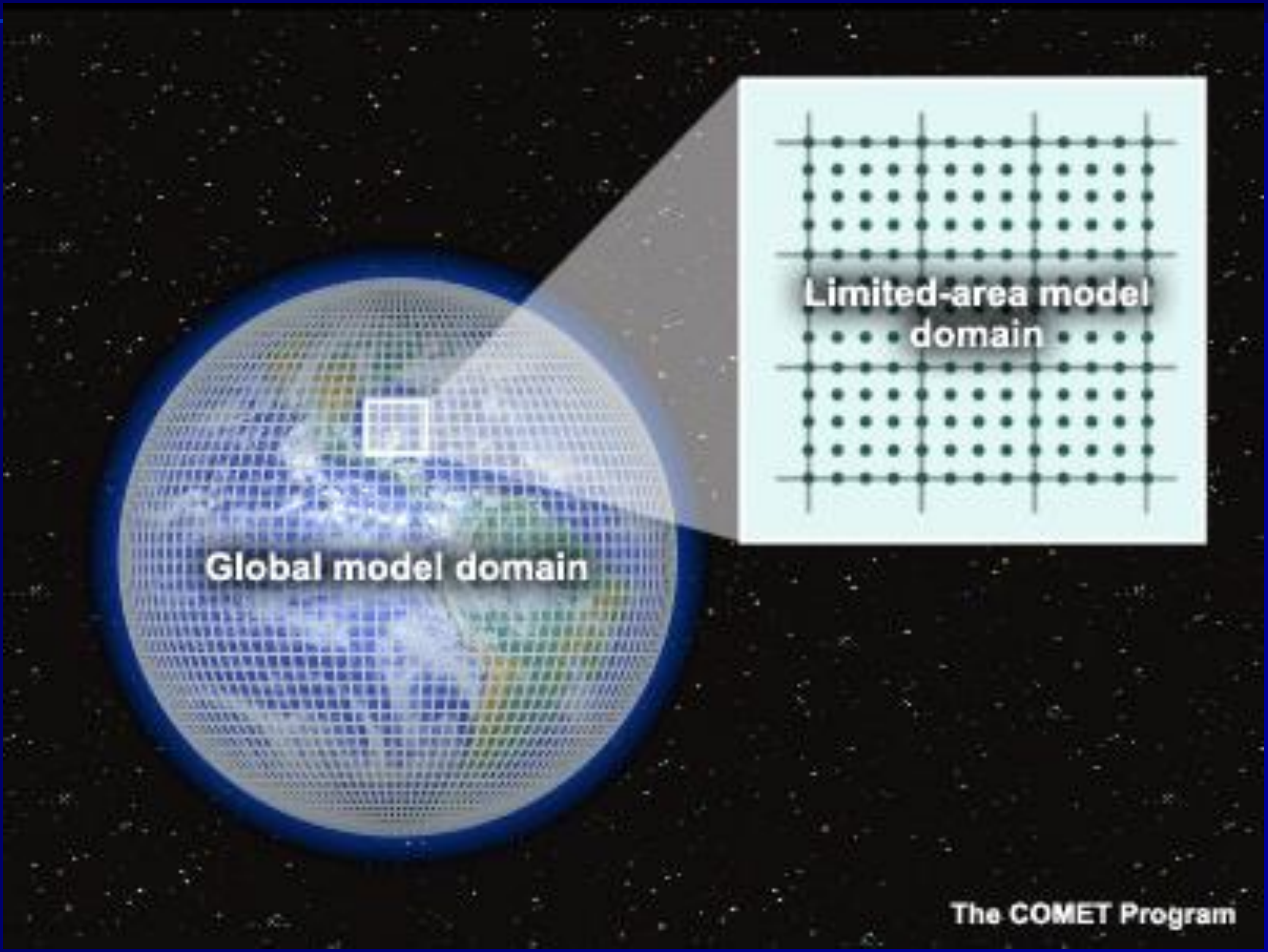
Temperature T

$$\frac{\partial T}{\partial t} + \frac{1}{a\cos\varphi}\left(u\frac{\partial T}{\partial \lambda} + v\cos\varphi\frac{\partial T}{\partial \varphi}\right) + \dot{\eta}\frac{\partial T}{\partial \eta} = \frac{\alpha\omega}{c_p} + \frac{L_v}{c_p}C_{vc} + \left(\frac{\partial T}{\partial t}\right)_{sub} - K_4\nabla^4(T - T_{ref}) - \mu_{\mathrm{lbc}}(\mathrm{T} - \mathrm{T}_{\mathrm{lbc}})$$

Surface pressure p_s

$$\frac{\partial p_s}{\partial t} = -\frac{1}{a\cos\varphi}\int_0^1 \left\{\frac{\partial}{\partial \lambda}\left(u\frac{\partial p}{\partial \eta}\right) + \frac{\partial}{\partial \varphi}\left(v\cos\varphi\frac{\partial p}{\partial \eta}\right)\right\} d\eta - \mu_{\mathrm{lbc}}(p_s - p_{s,lbc})$$

NWP concepts : Global & LAM models.



NWP concepts : Global models

- Global models resolve atmospheric equations on the whole glob.
- They can not use very fine resolution because of computers limitations.
- Because of their weak resolution, they can not detect small scale phenomena.
- The most popular global models are :
  - ECMWF/IFS (partially public and received on MDD) : http://www.ecmwf.int.
  - NCEP/GFS (completely public) : http://www.ncep.noaa.gov.
  - Météo-France/ARPEGE (not available on the net).
  - German DWD global model.
  - METOFFICE/UKMO Unified Model.
  - Japan Meteorological Agency JMA Global Model.
- They need powerful computers (CRAY, FUJITSU VPP, NEC SX, IBM, ...etc).
- Global models are used to forecast general synoptic circulation and to provide Initial and Lateral Boundary Data for Limited Area models.

NWP Concepts : Limited Area Models (LAM).

- They resolve the atmospheric equations on regional or local limited area domains.

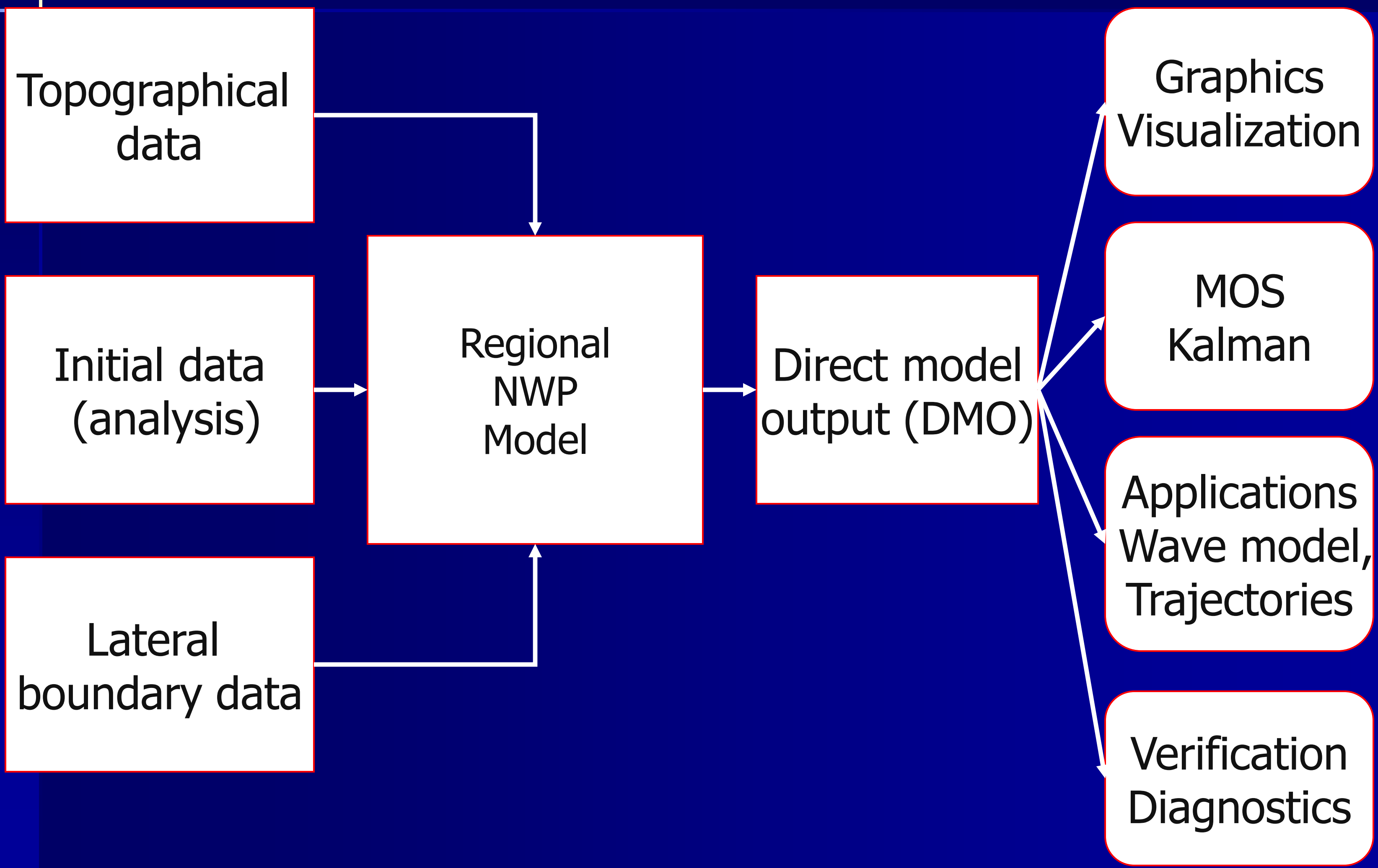
- They can use very high resolution (100m to 28km) and more vertical levels. They can catch very small phenomena.

- They can run on small to medium computers (normal PCs, workstations, Servers, Clusters)

NWP Concepts : Limited Area Models (LAM).

- They are obliged to get LBC and Initial data from global models (NCEP/WAFS, NCEP/GFS, ECMWF, UKMO, JMA ...etc).
- They are widely used by Weather Centers over the world.
- The most popular LAMs are:
  - HRM (used in more than 30 Centers and universities)
  - ETA (used in more than 50 Centers and Universities).
  - MM5 (AFWA and more than 20 centers over the world).
  - ALADIN (Private Consortium guided by Meteo-France : 15 European and north African countries)
  - COSMO / LM (COnsortium for Small scale MOdeling guided by DWD).
  - HIRLAM (Private Consortium : Scandinavian countries and Spain).
  - NMM / WRF (the next generation LAM model taking advantage from both ETA and MM5).
  - COAMPS, RAMS, RUC, ...etc.

General structure of a regional NWP system



NWP Concepts : Initial Data.

- The **actual situation** used by the model to start integrate equations.

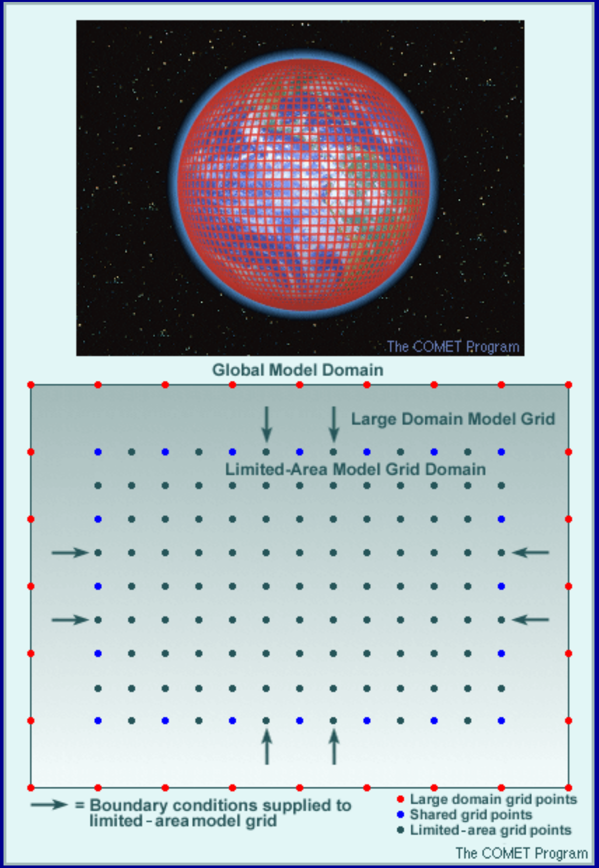
- It is created by techniques called **data assimilation**.
- The information used to create initial data are:

  – **GTS data** (Conventional observations) : **SYNOP, SHIP, BUOY, SYNOR, TEMP, PILOT, AIREP, AMDAR, ACAR, SATEM, SATOB**).
  – **Non Conventional Data** (Data not transmitted through GTS, and private in general) : RADAR, TOVS, SSMI, …etc
  – **Old forecast** valid at the time of this initial situation (used to compensate data in regions devoid of observations).

- The process of initial data creation (analysis and data assimilation) is more **complicate** than the forecast model itself, and more **consumer in term of CPU time**.

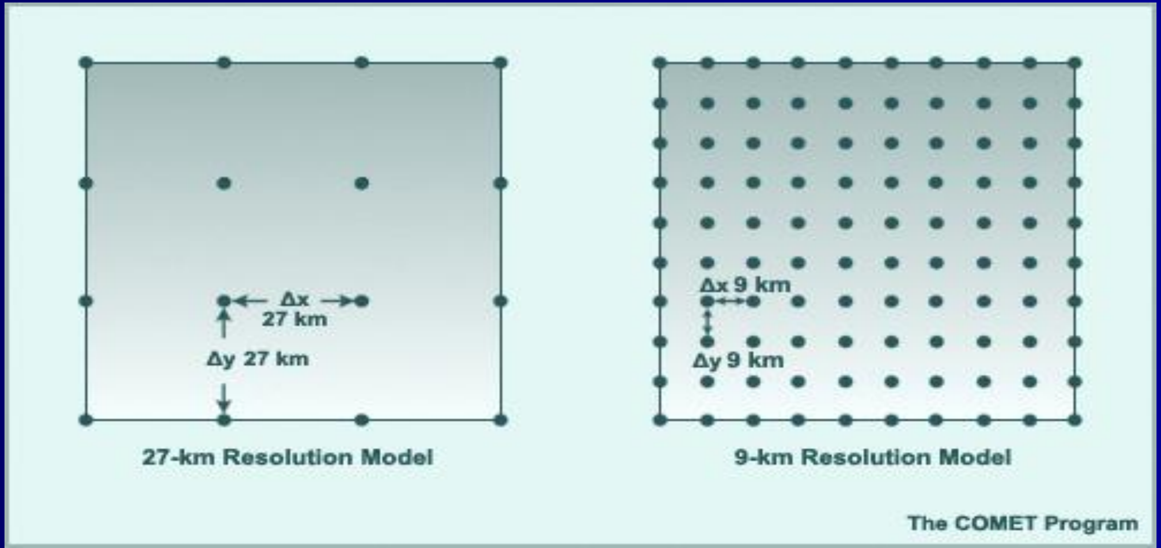
NWP Concepts : LBC data

- **Lateral Boundary Data** are used in the LAM models for the following reasons:
  - To be able to compute derivatives at the model borders.
  - To know what is likely to penetrate the domain of interest from outside.
  - To avoid noisy fields at the borders.
- LBC data come **from global or regional models** including the LAM domain.
- LBC data are downloaded from the **Internet**; they are generally very heavy (**large size**)

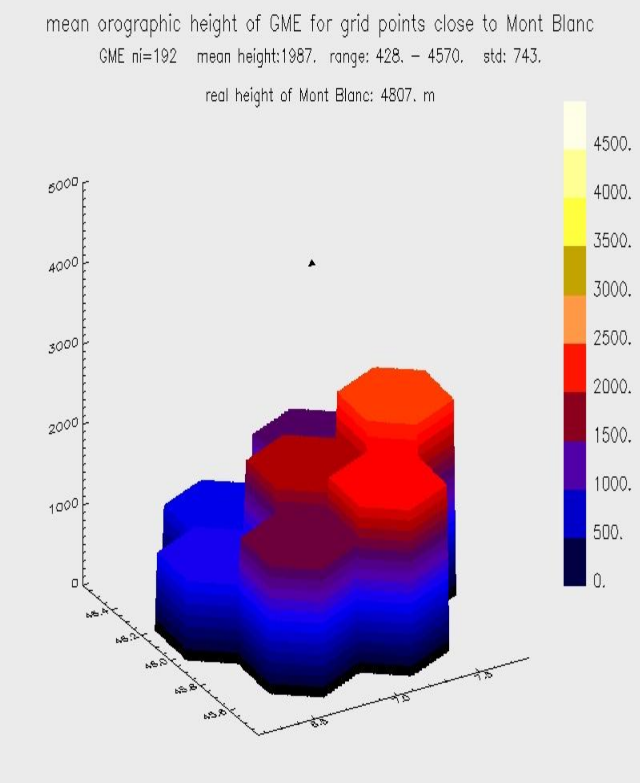


NWP Concepts : Grid Resolution

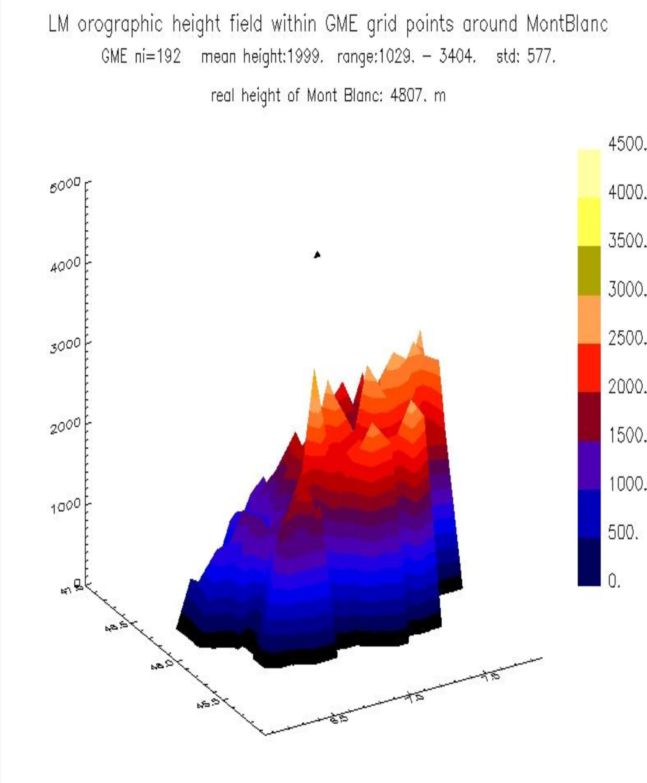
- **Horizontal resolution.**
  - When resolution is fine enough (< 10km), small scale phenomena (thunder storms, convective cells, sea breeze, local sand storms… etc) could be well depicted.
  - Otherwise, only large scale phenomena (systems movement, large scale precipitations, Jet Stream evolving, … etc) could be well simulated.



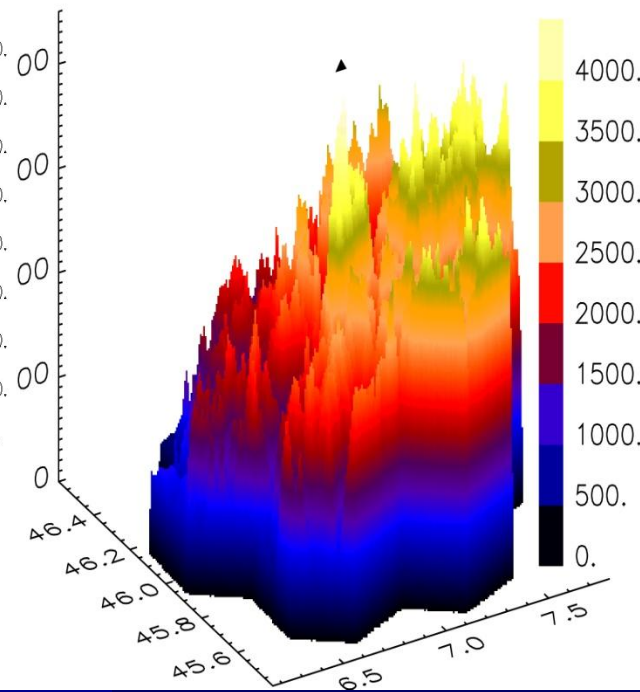
Orography (m) in the Alps (Mont Blanc region)



Aggregated to 40-km GME; grid element area: 1384 km^2

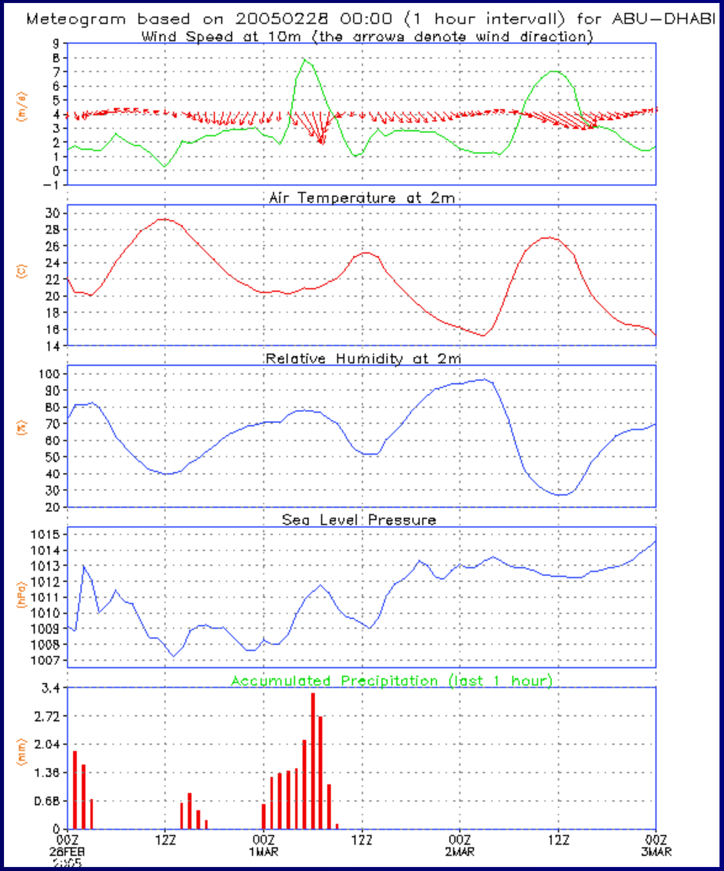


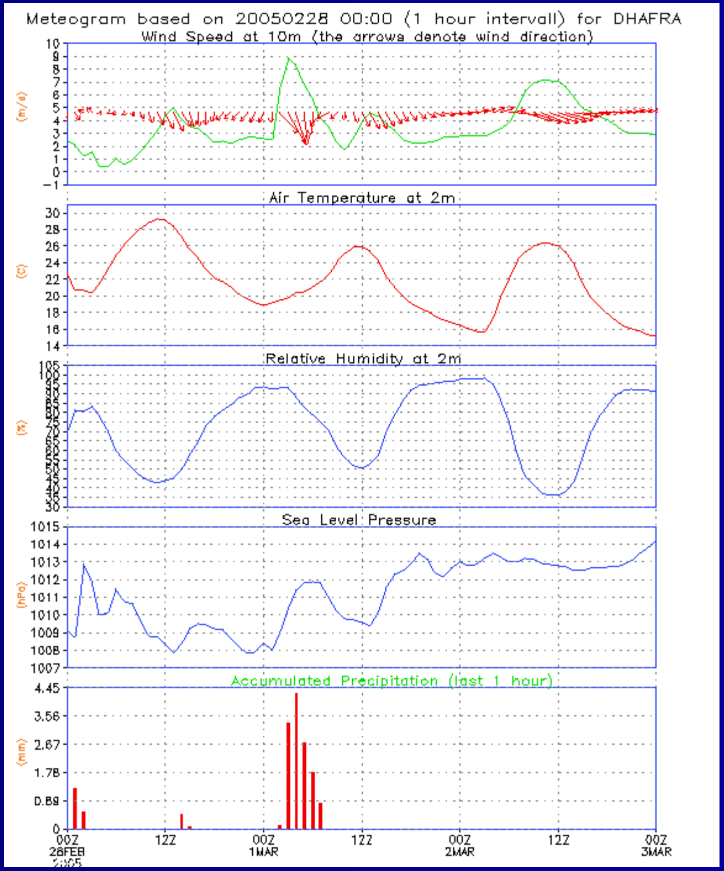
Aggregated to 7-km HRM; grid element area: 49 km^2



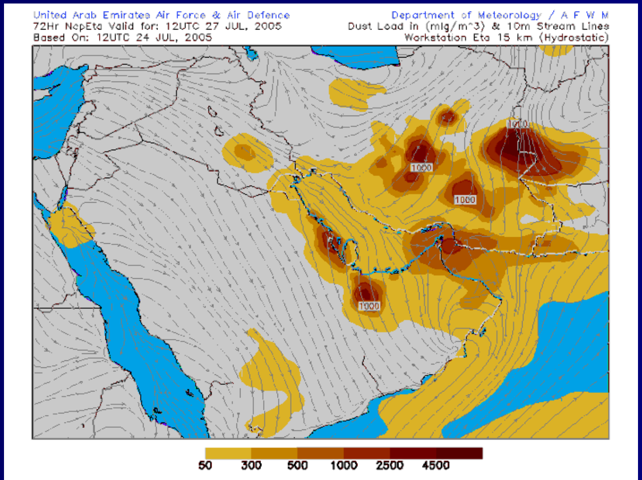
1 km x 1 km raw data

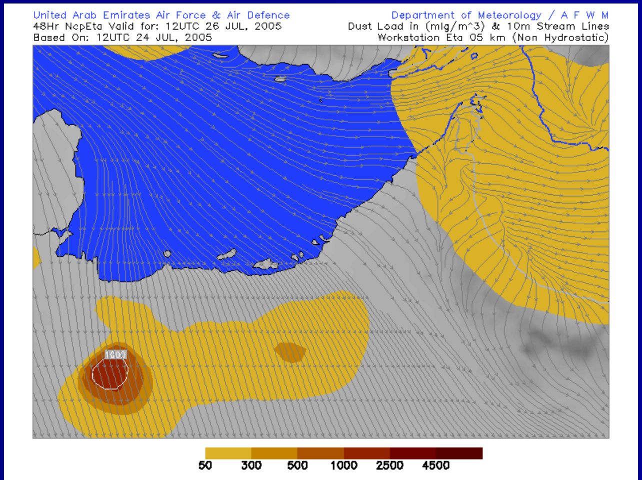
NWP Concepts : Meteograms

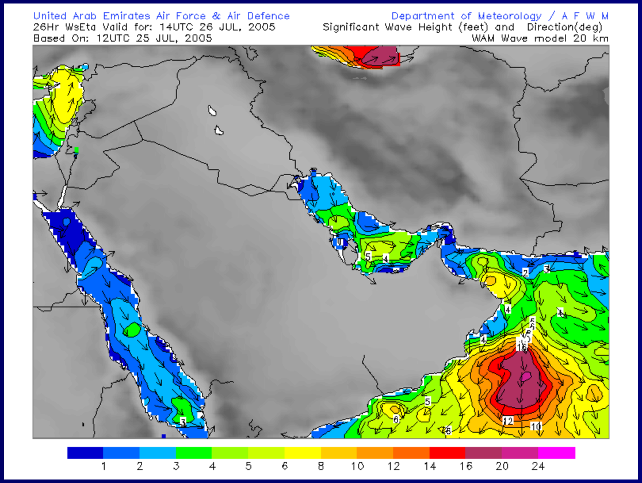


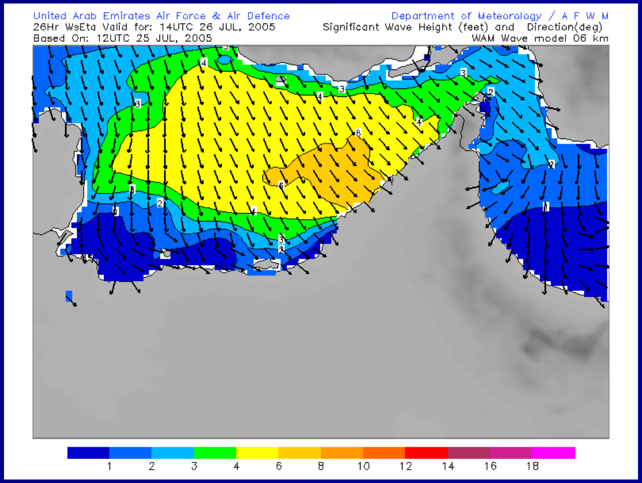


NWP Concepts: Off-line Driven Models.





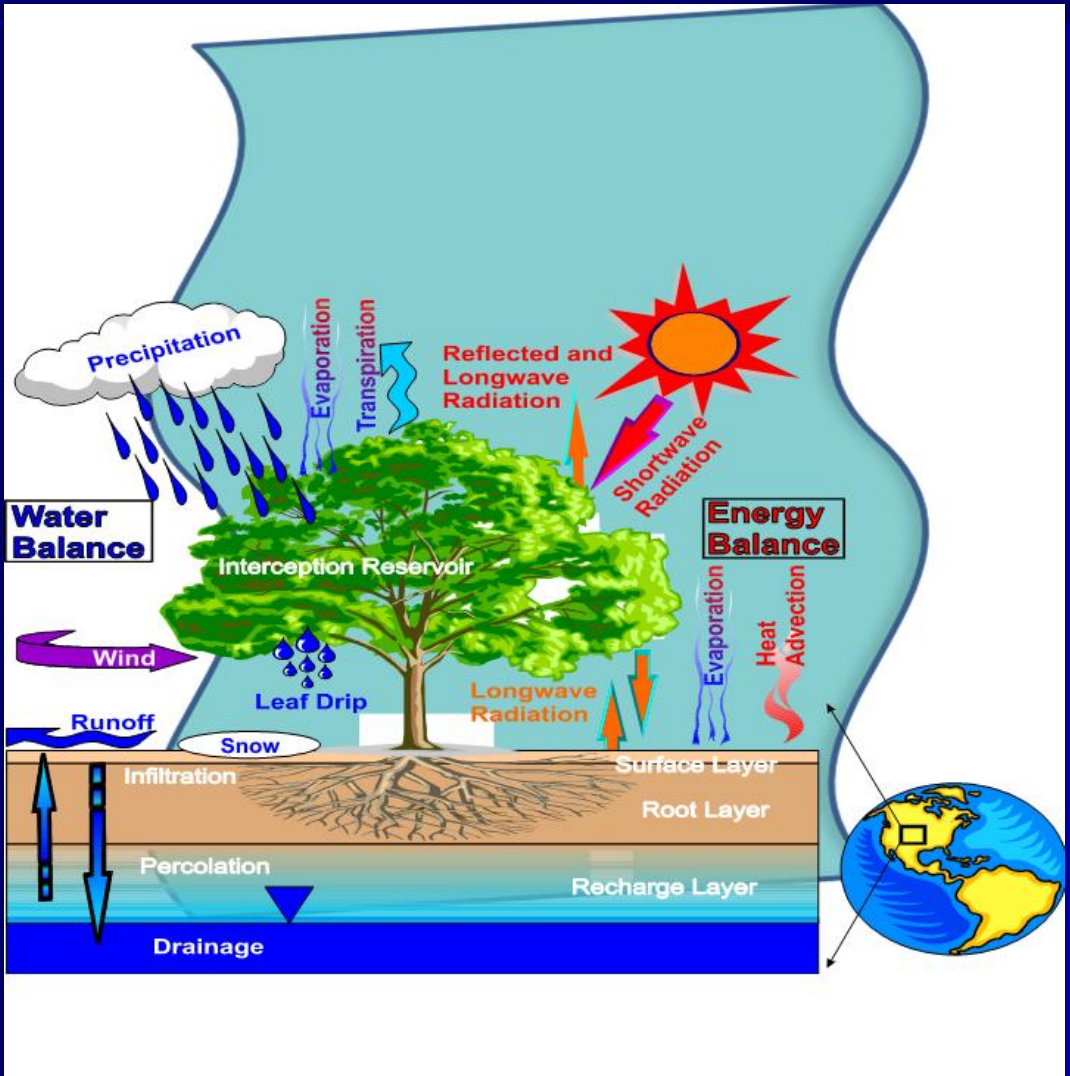




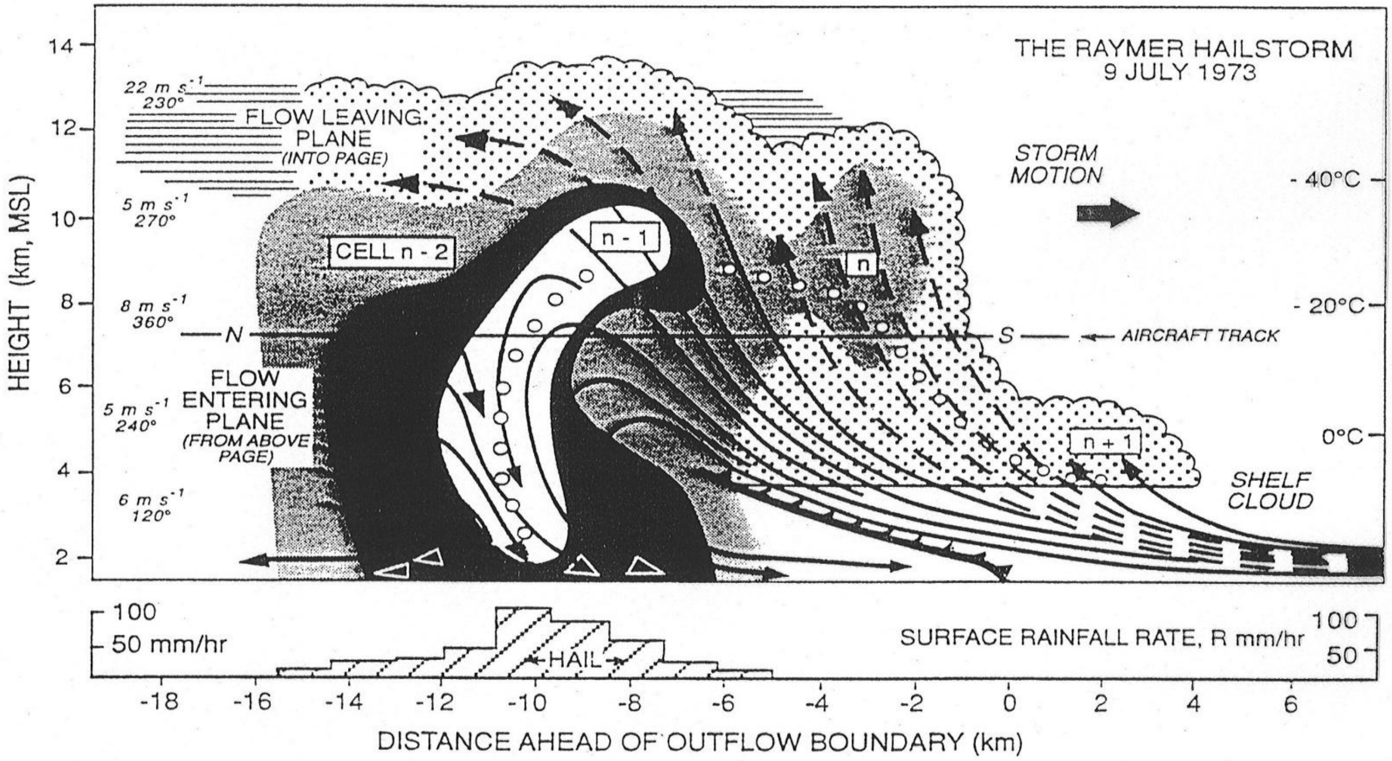
Errors of the short-range NWP

- Due to model formulation.
- Due to simplifications in parameterisation schemes.
- Due to uncertainty in the initial state.
- Due to errors in lateral boundary conditions.
- Due to uncertainties in soil fields (soil temperature and soil water content, …).

Physical Process at the Surface

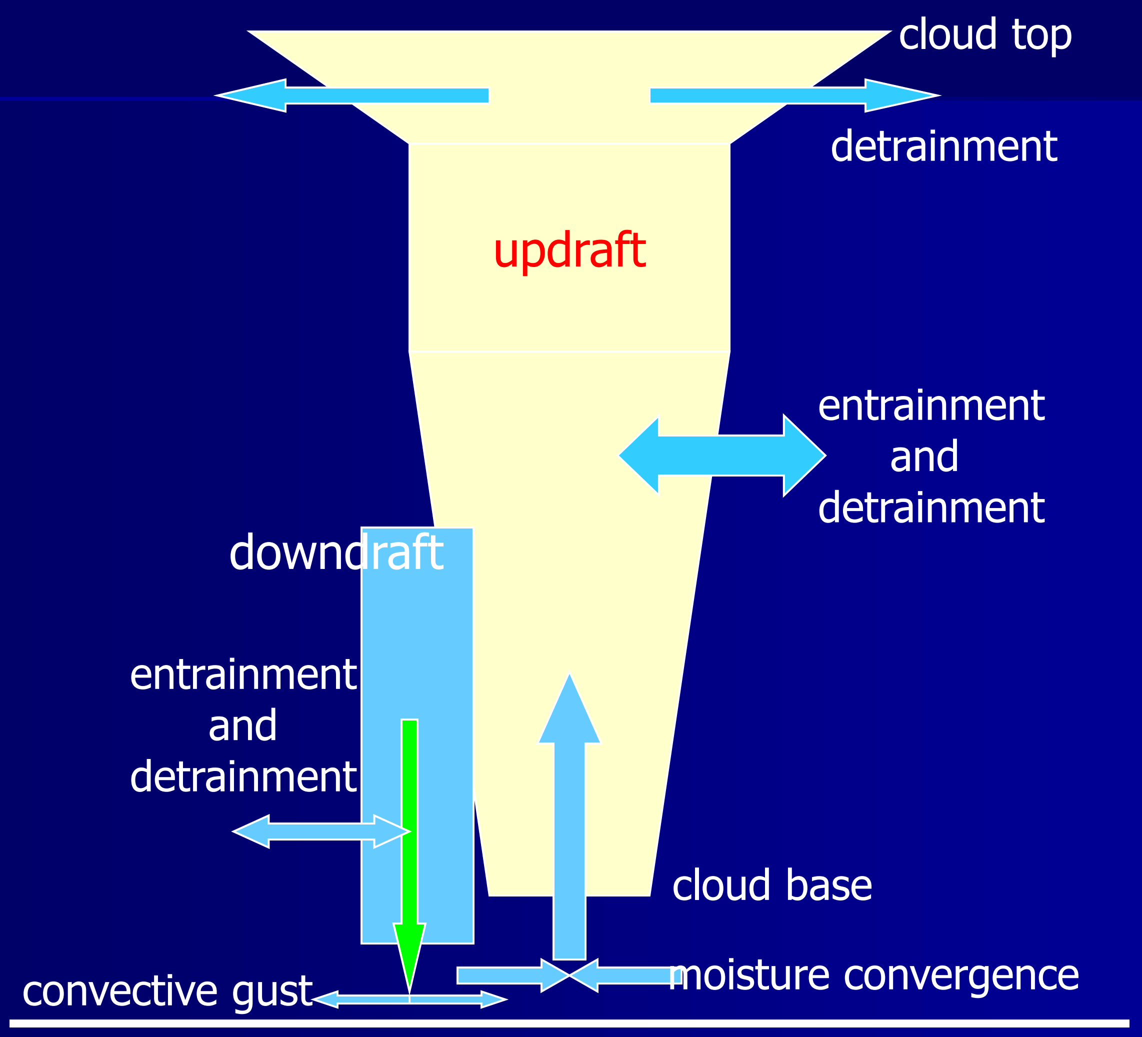


Vertical cross-section through a mesoscale convective complex



R. A. Houze, Jr.: Cloud Dynamics
International Geophysics Series, Vol. 53

Cloud model of the Tiedtke convection scheme



Part2: Use of Satellite Data in NWP models

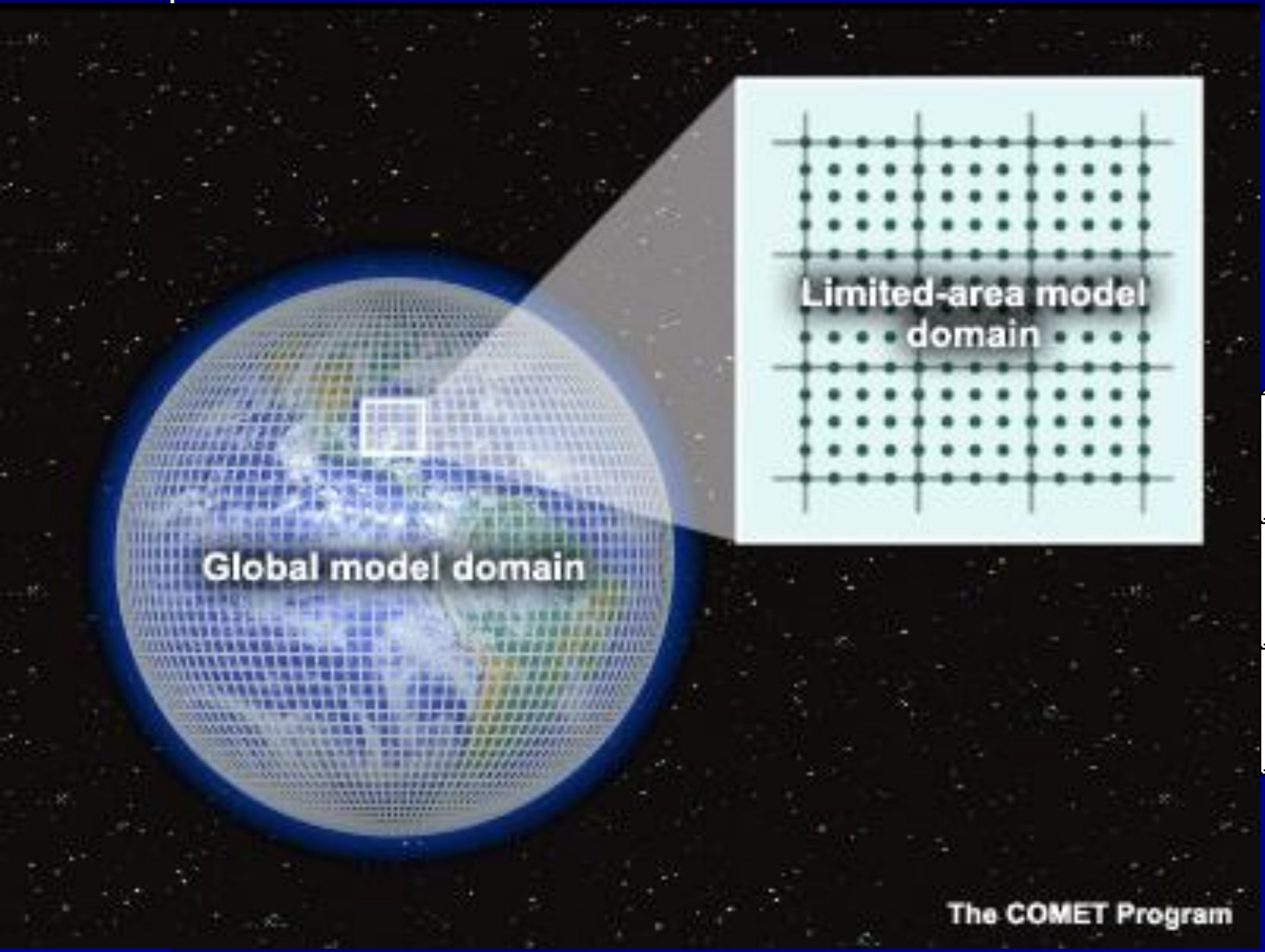
Objectives

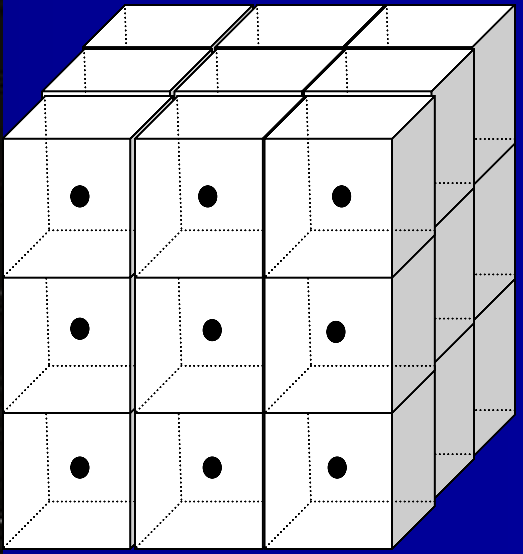
- Why NWP needs Observations (satellite)?
- What is data assimilation?
- What type of data (ex. satellite)can be used?
- How much improvement can satellite data
- Why all available data can’t be used?

Why do we need satellite data for NWP models???

- ✓ Creating model initial condition
- ✓ Model verification

Creating model initial condition



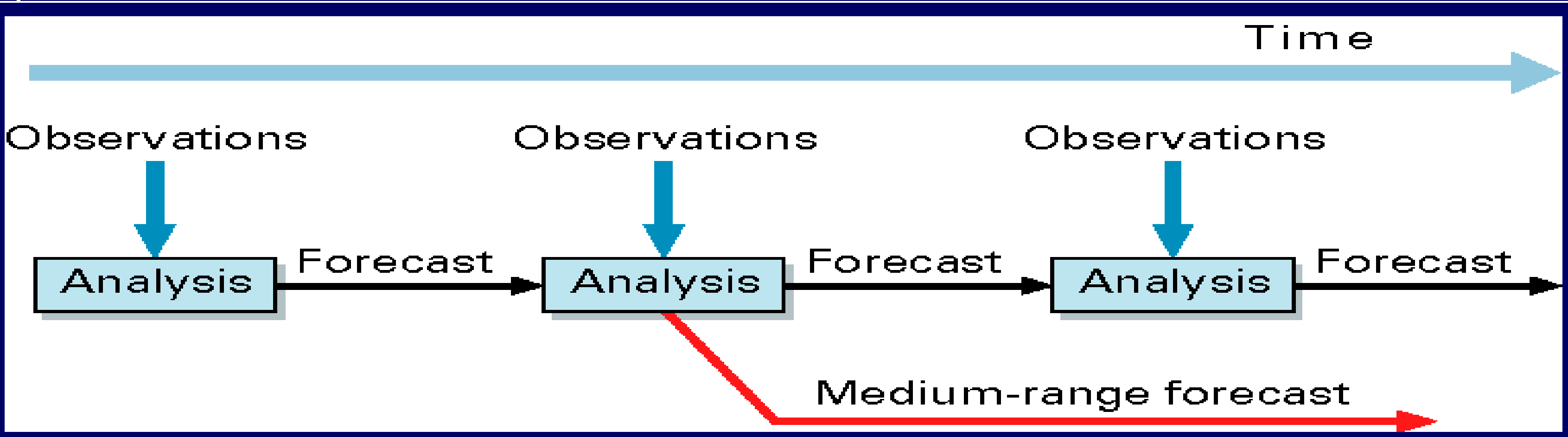


Data Assimilation

- Data assimilation proceeds by *analysis cycles*. In each analysis cycle, observations of the current (and possibly, past) state of a system are combined with the results from a mathematical model (the *forecast*) to produce an *analysis*, which is considered as 'the best' estimate of the current state of the system

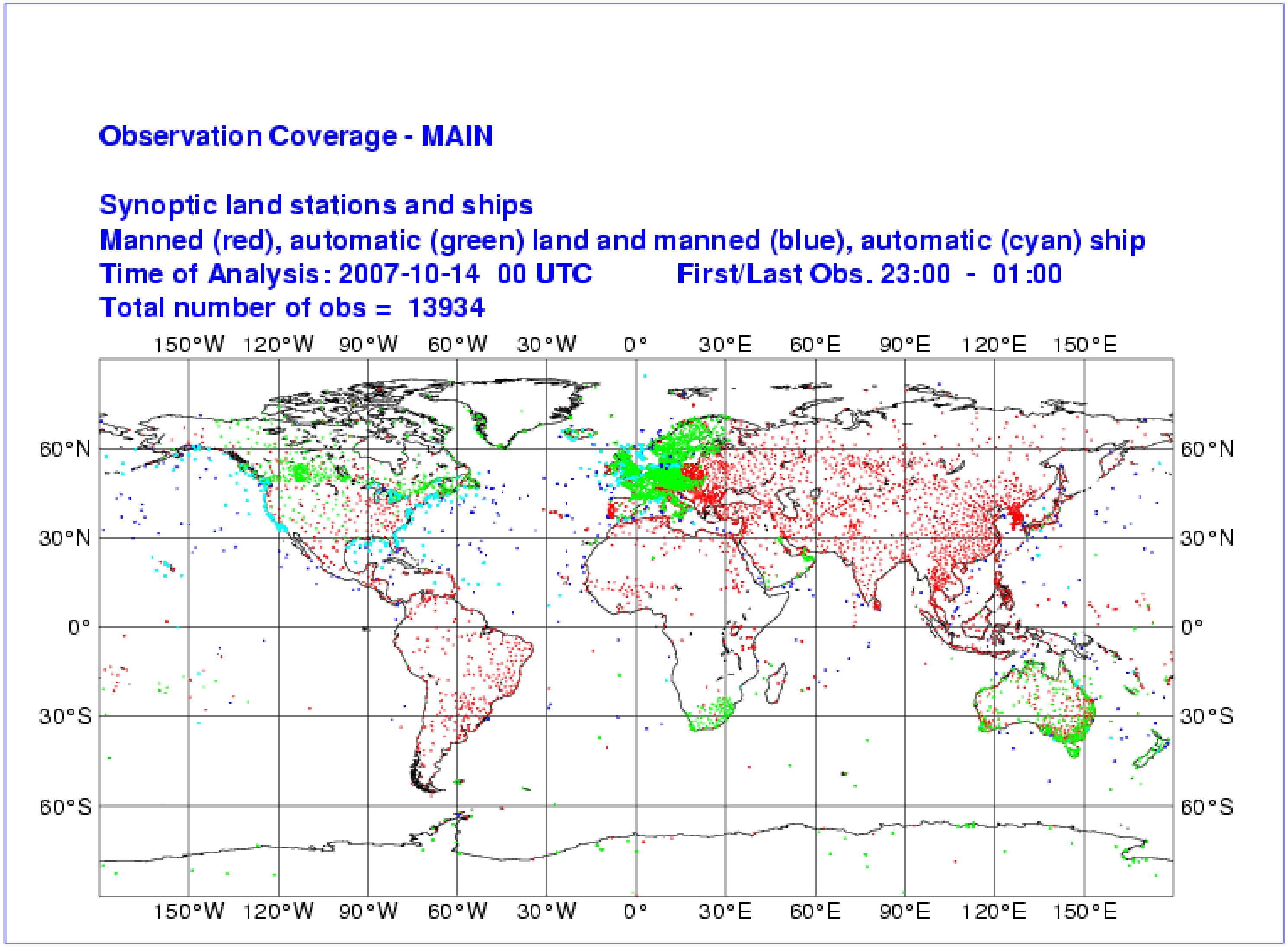
- Data assimilation is a concept encompassing any method for combining observations of variables like temperature, and atmospheric pressure into numerical models as the ones used to predict weather.

Data assimilation system

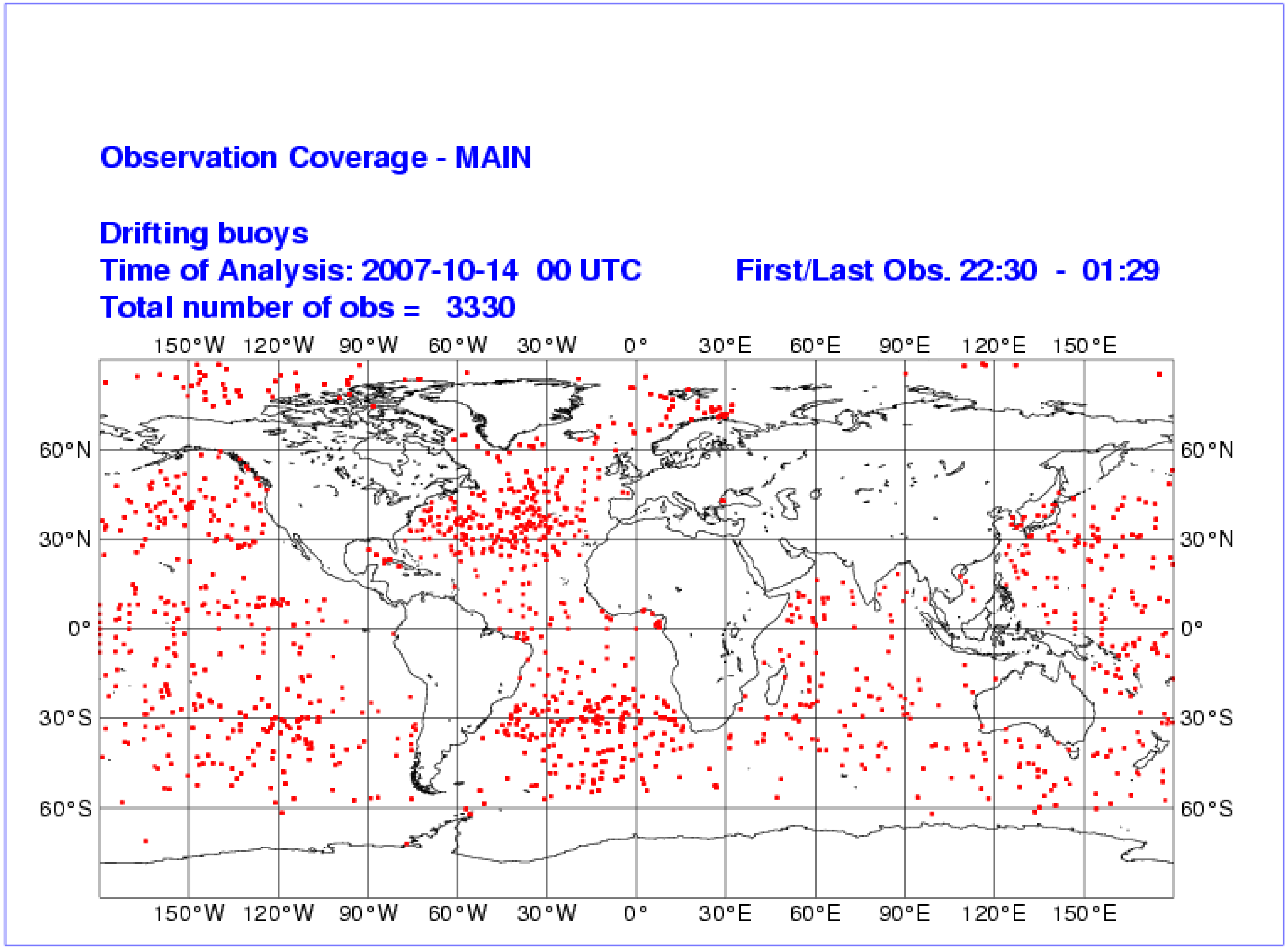


- The observations are used to correct errors in the short forecast from the previous analysis time.
- For global model (ECMWF) Every 12 hours, assimilate 7 – 9,000,000 observations to correct the 80,000,000 variables that define the model's virtual atmosphere.
- This is done by a careful (3D,4D) interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.
- you must never loose a forecast!

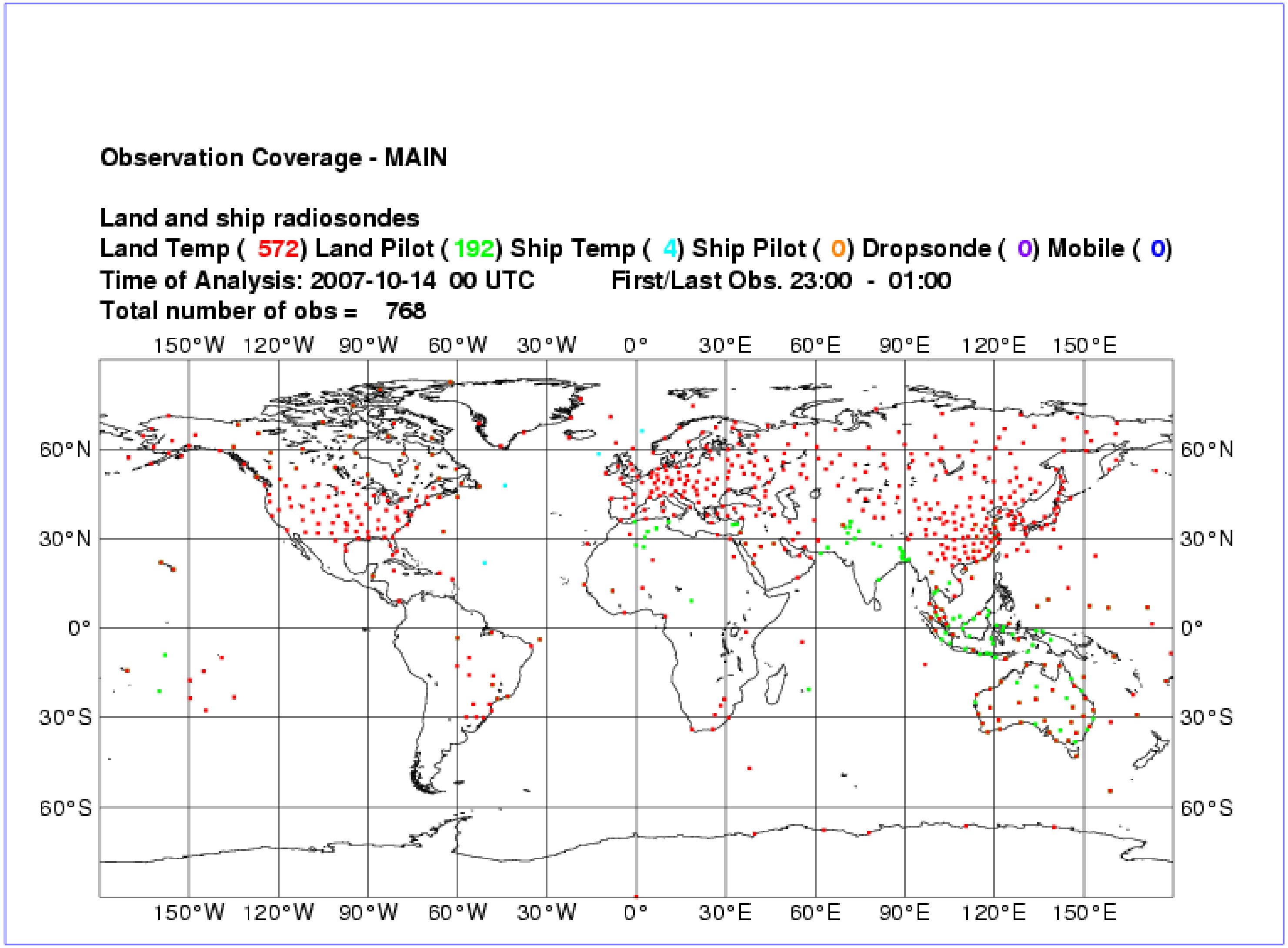
SYNOP stations and ships



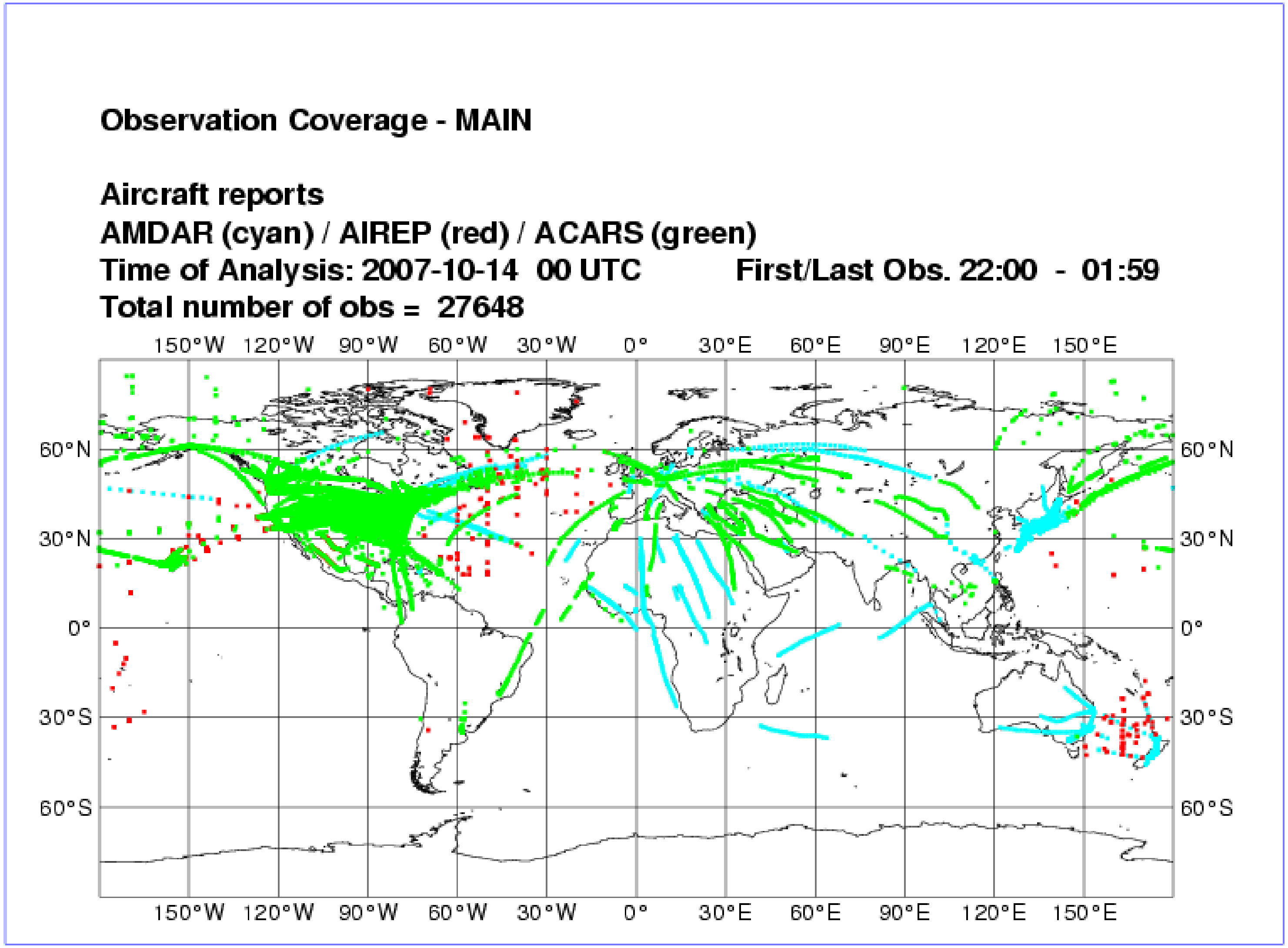
Buoys (moored and drifting)



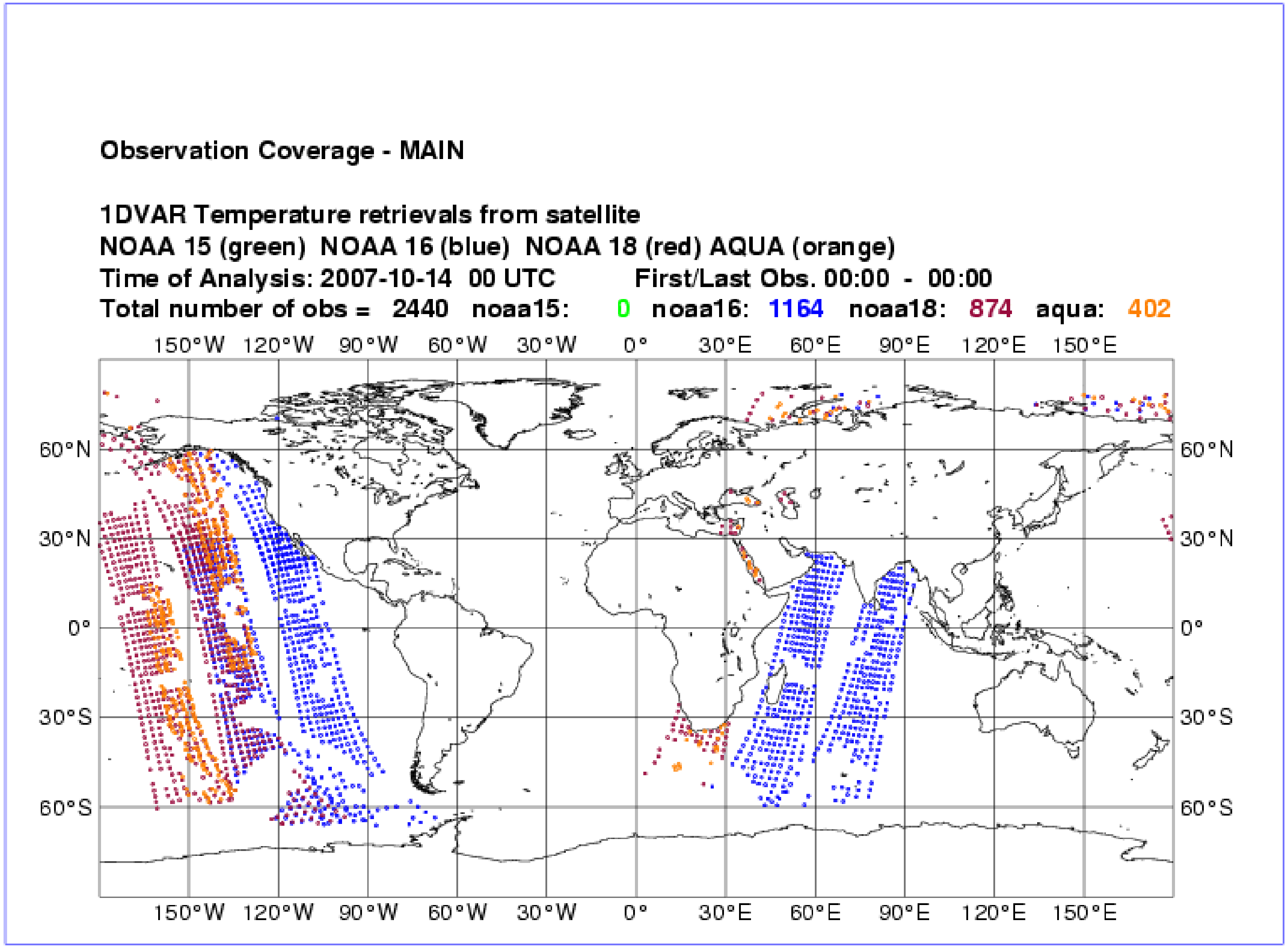
TEMP stations



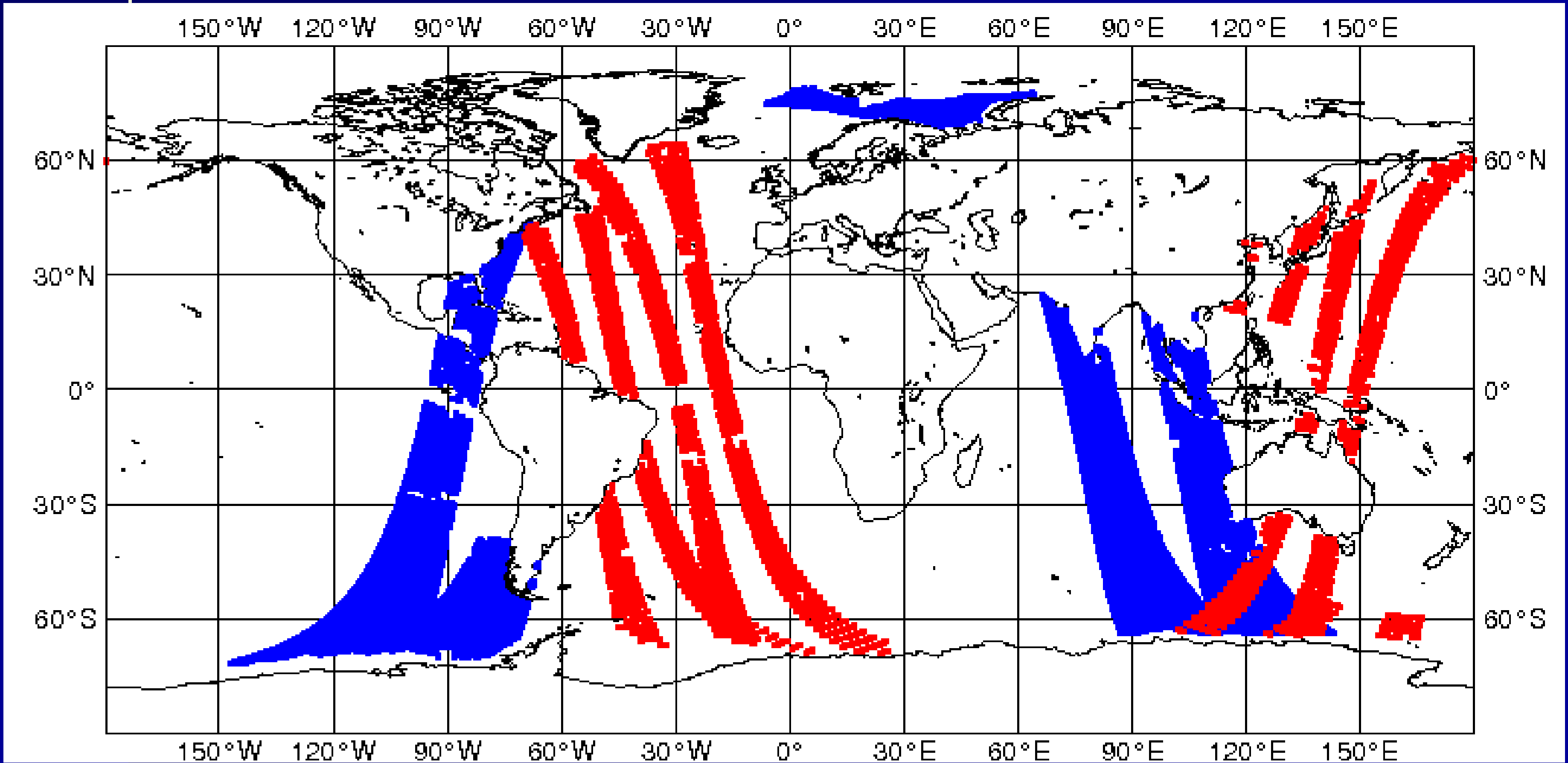
Aircraft measurements (AMDAR)



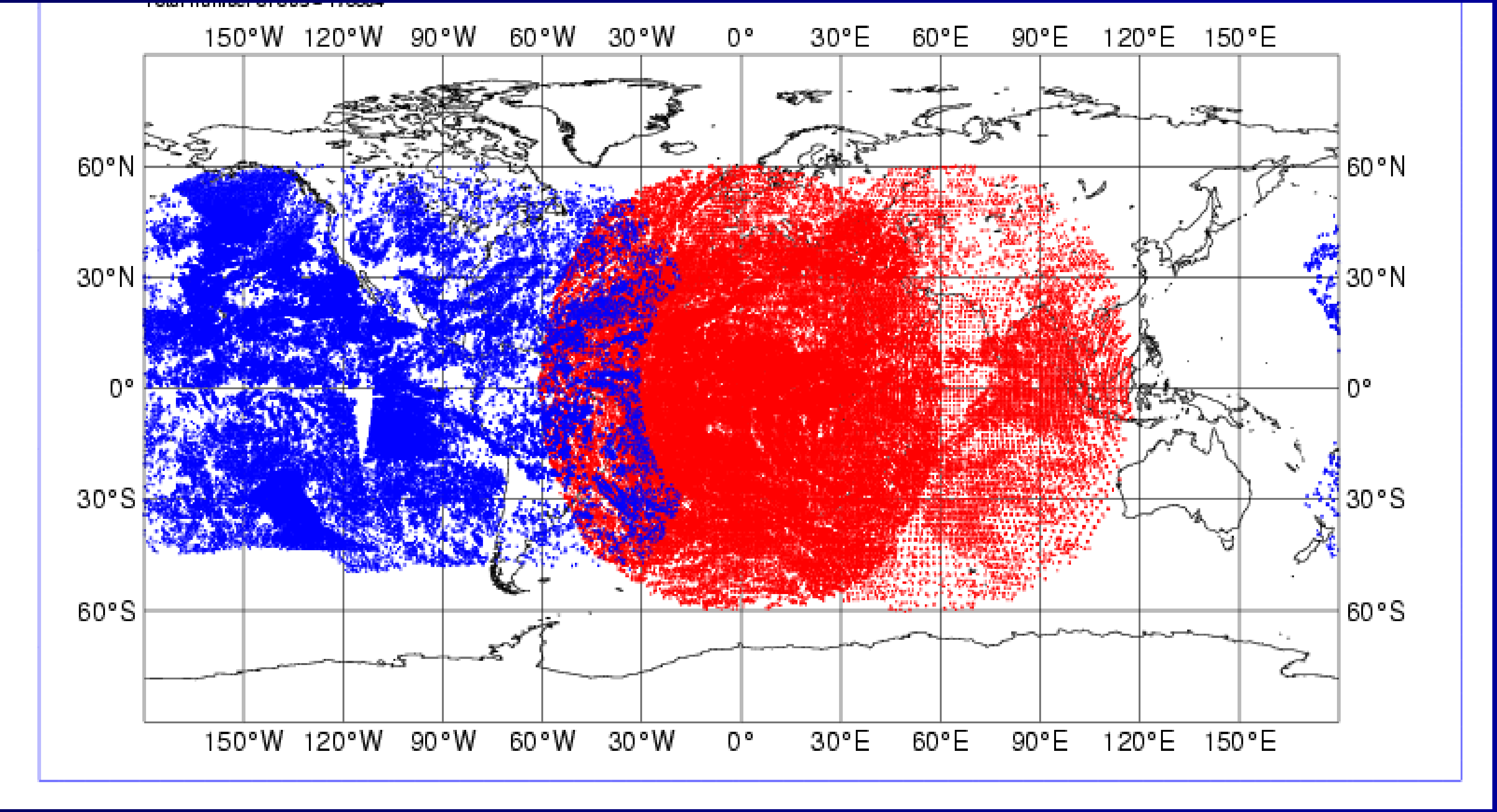
ATOVS from polar orbiting satellites

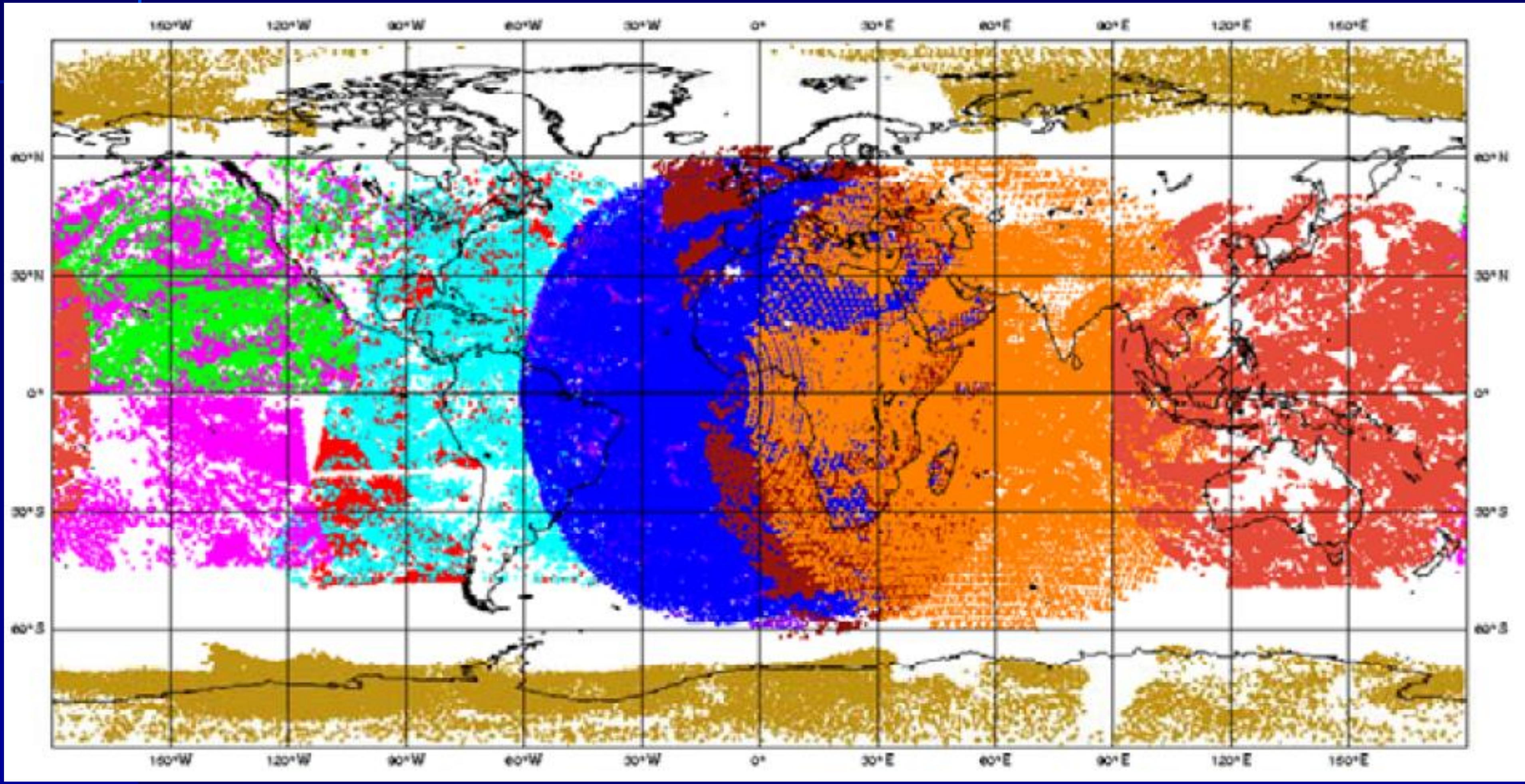


Scatterometer Data Coverage 2011022500 +/- 1.5 H ASCAT (red) QuikScat (blue)

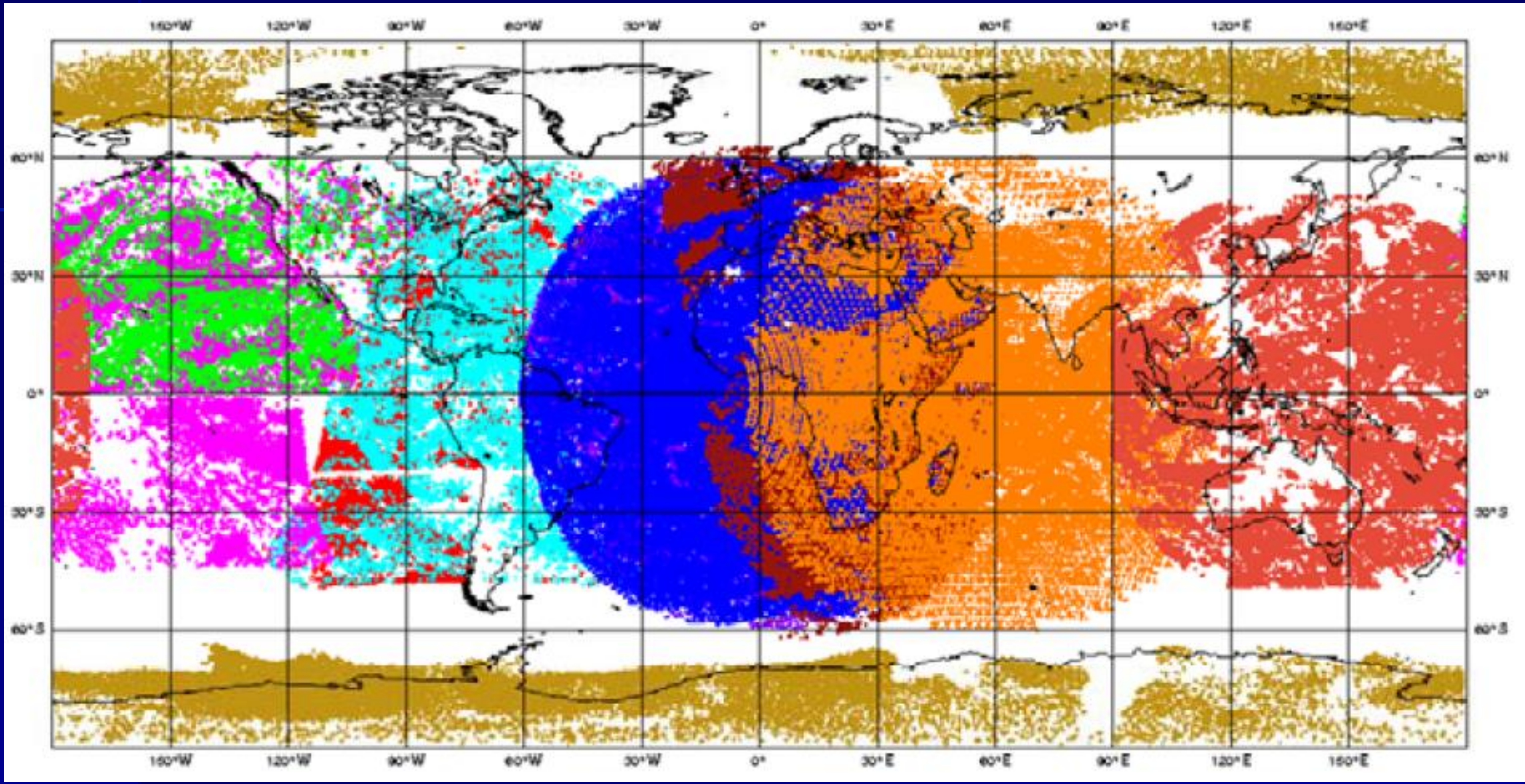


AMV winds from geostationary satellites





Example of AMV coverage at ECMWF (9th April 2011 06UTC cycle): 374104 OBS.



Example of AMV coverage at ECMWF (9th April 2011 06UTC cycle): 374104 OBS.

Pink , green: GOES11
Dark blue, brown-red Met-9
Dark orange MTSAT-1R.

red and light blue GOES12,
orange: Met-7 and
Gold: Polar orbiters Terra and Aqua.

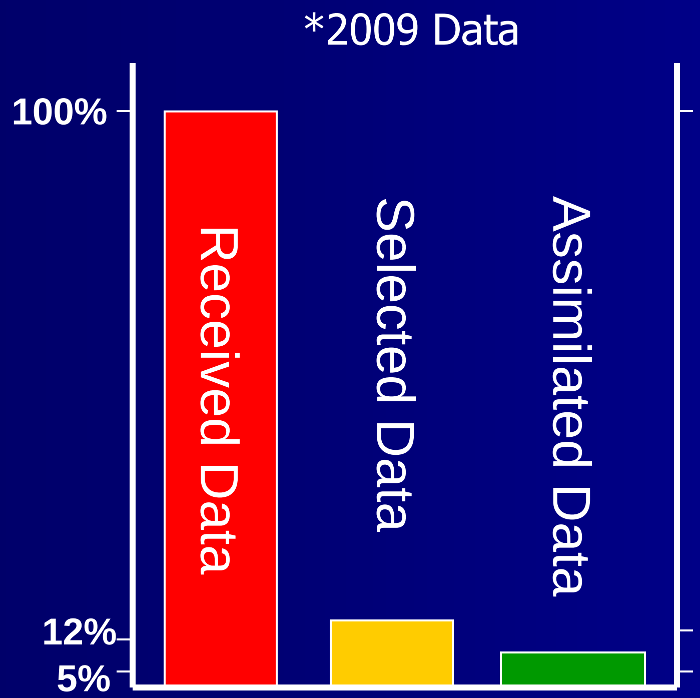
Can we use all sat. data?

We hope but we can't

- Bias correction
- Model variable matching

Satellite Data Utilization

Daily Percentage of Data Ingested into Models



Received = All observations received operationally from providers
Selected = Observations selected as suitable for use (cloud free, …)*
Assimilated = Observations actually assimilated into models

*Science, data resolution, computer issues,… need to be addressed

Bias correction

- Satellite provide measurement of the radiation emitted from the earth's surface and atmosphere. This radiances contain temperature and humidity information, but this information is not perfect and includes:
  - random errors: are reduced within a data assimilation by spatial and temporal averaging
  - systematic errors (biases): can vary with time, geographic location, air-mass or with scan position of the satellite instrument; we have to use sophisticated methods to bias correction.
- In order to directly assimilated information from satellite in NWP system, biases must be corrected.
- Any observation which is biased can systematically damage the quality of analysis and the forecasting system.

Data extraction

- Check out duplicate reports
- Ship tracks check
- Hydrostatic check

Thinning

- Some data is not used to avoid over-sampling and correlated errors
- Departures and flags are still calculated for further assessment

Blacklisting

- Data skipped due to systematic bad performance or due to different considerations (e.g. data being assessed in passive mode)
- Departures and flags available for further assessment

Model/4D-Var dependent QC

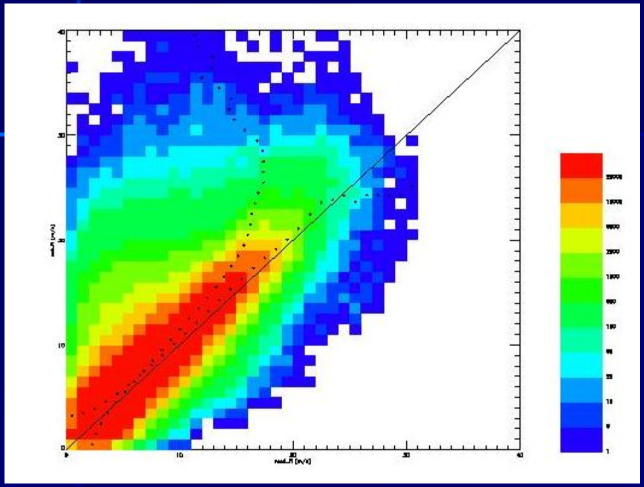
- First guess based rejections
- VarQC rejections

Used data → Increments

Analysis

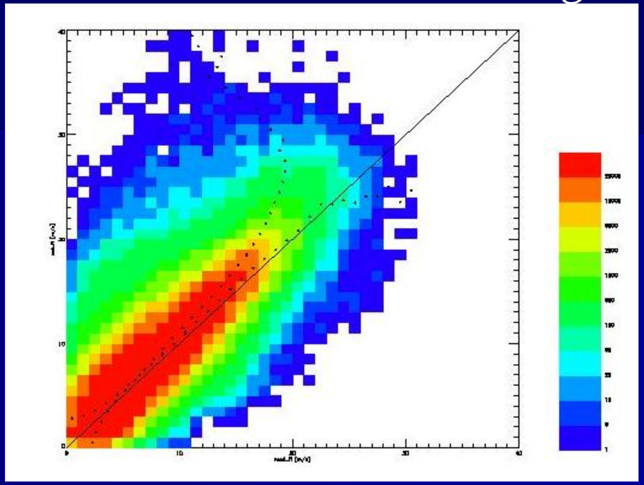
Scatterplots Obs vs. FG and bias correction

All Data



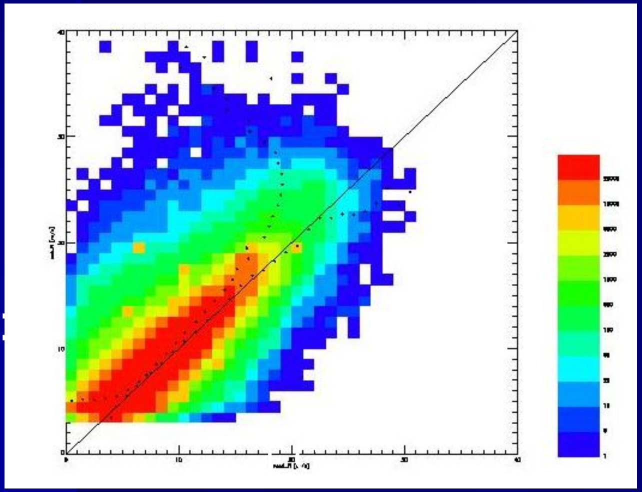
bias: 0.80
rms: 3.21
cor: 0.66

Data with KNMI Rain Flag 0



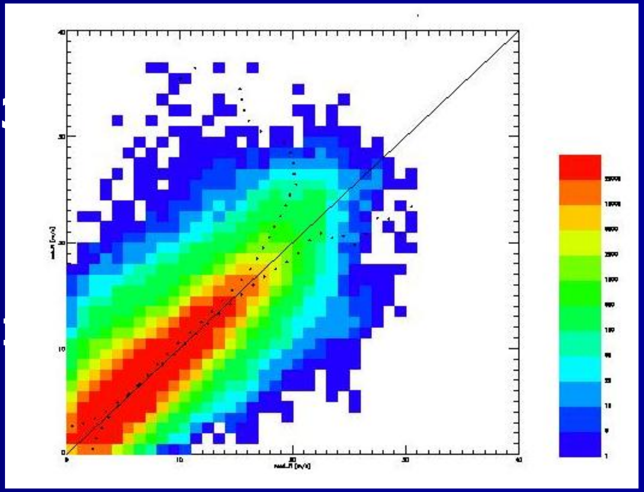
bias: 0.63
rms: 2.64
cor: 0.75

Data with KMNI Rain Flag 0
without outer zone and 4% reduction



bias: 0.50
rms: 2.33
cor: 0.76

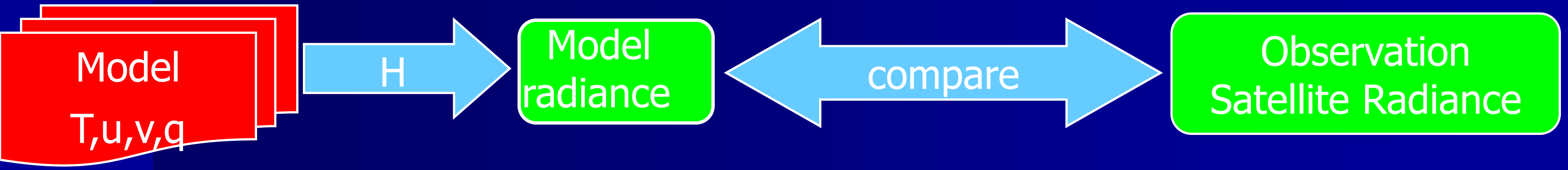
Data with KMNI Rain Flag 0
without outer zone and full bias correction



bias: 0.22
rms: 2.06
cor: 0.82

Model variable matching

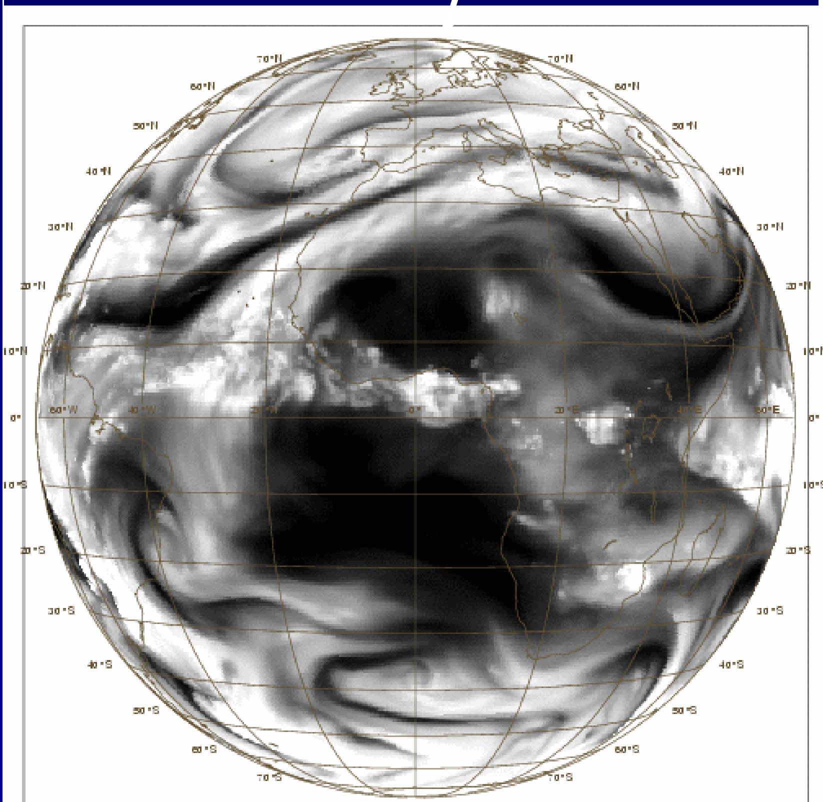
- ❑ Observations are not made at model grid points
- ❑ Satellites often measure radiances, NOT temperature and humidity
- ❑ We calculate a model radiance estimate of the observation to enable comparison.
- ❑This is done with the 'observation operator' H.
- ❑ H may be a simple interpolation from model grid to observation location
- ❑ H may possibly perform additional complex transformations of model variables to 'radiance space' for satellite data.

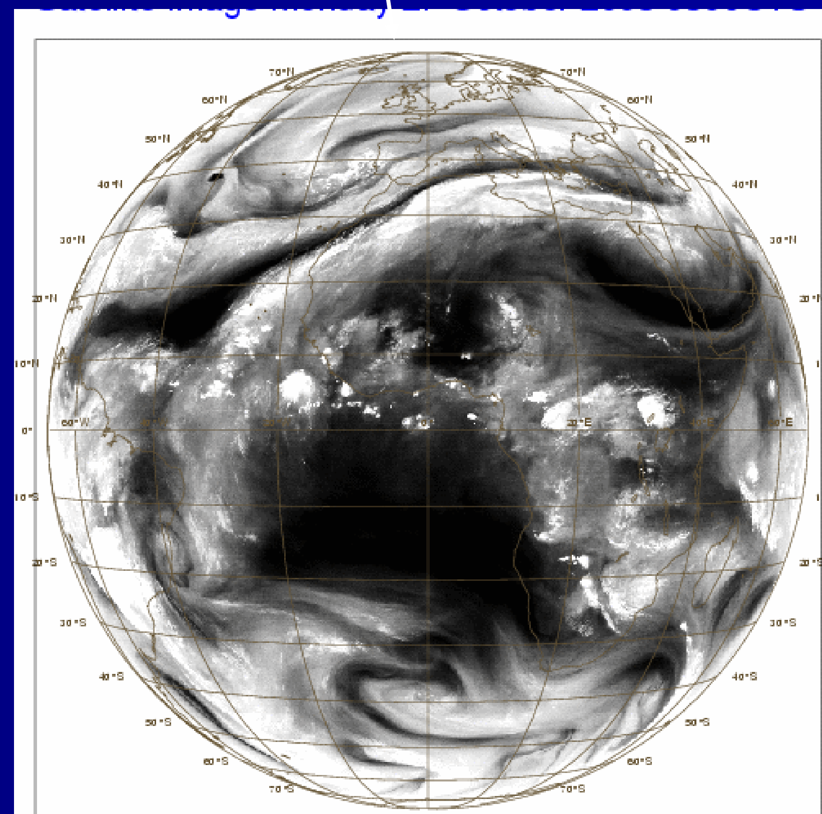


The variational method allows model radiances to be compared directly to observed radiances

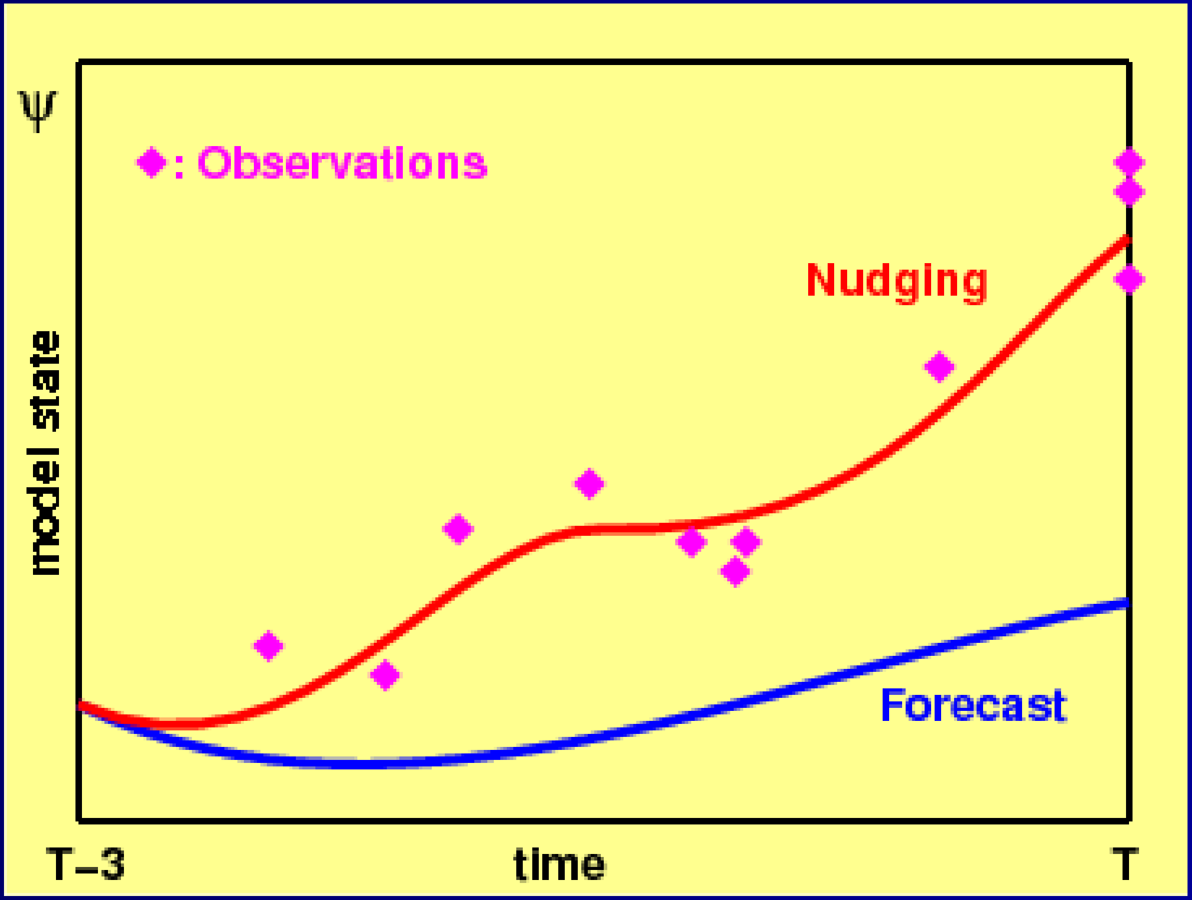
Enables use of advanced observation operators

Model T and q → H → Model Radiance ⟷ compare ⟷ Observation Satellite Radiance

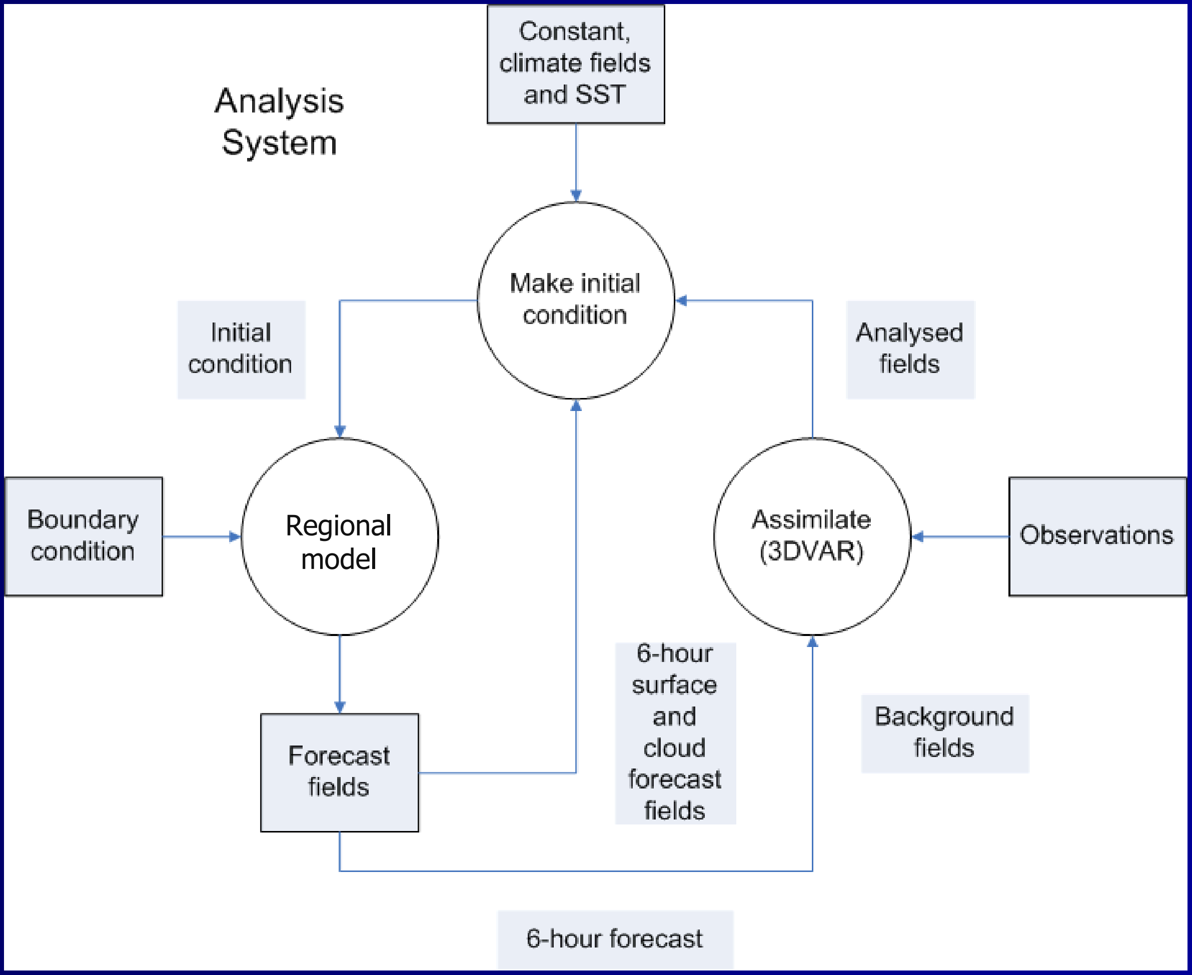




Observation Nudging

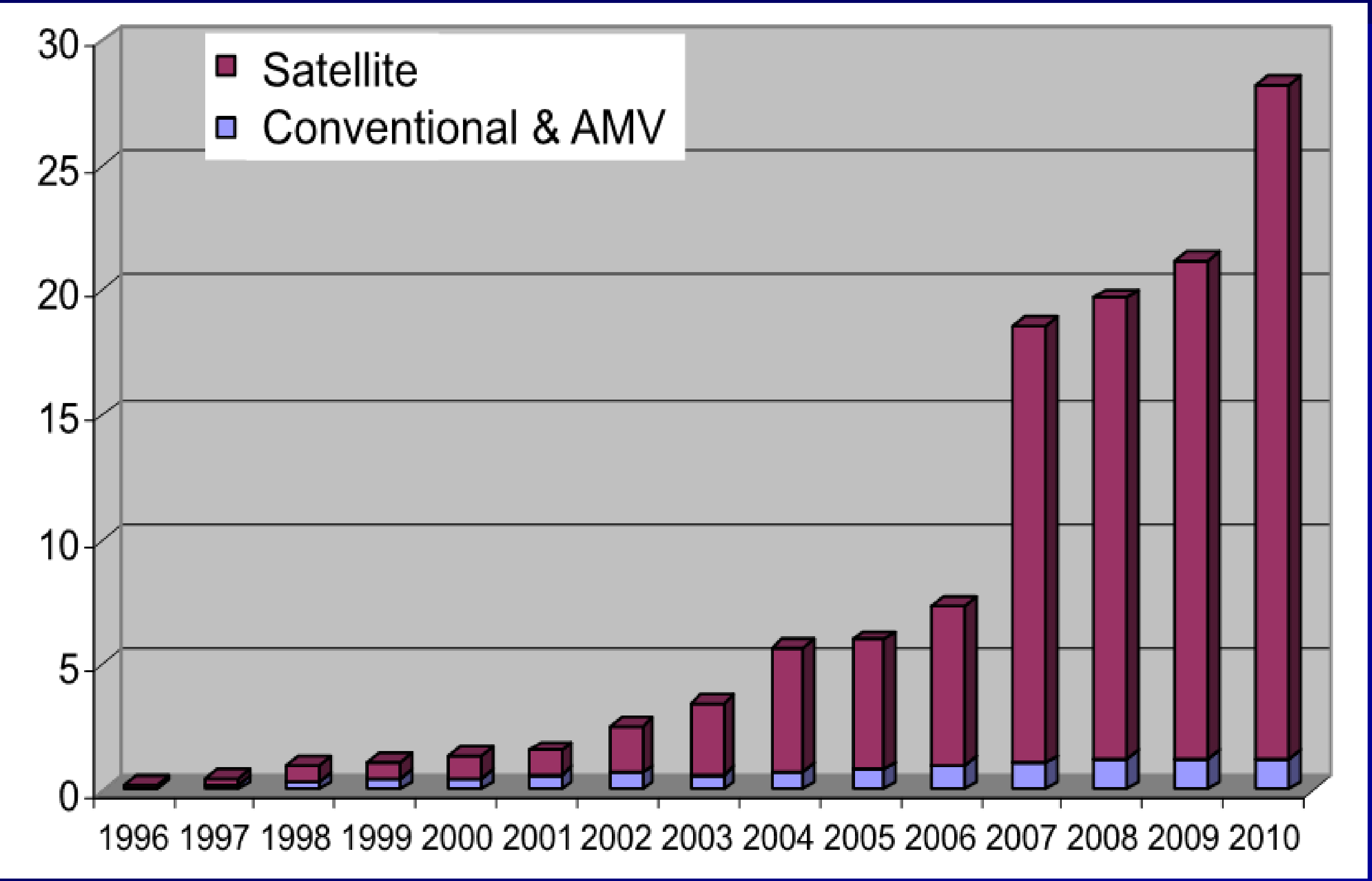


Regional model DA system



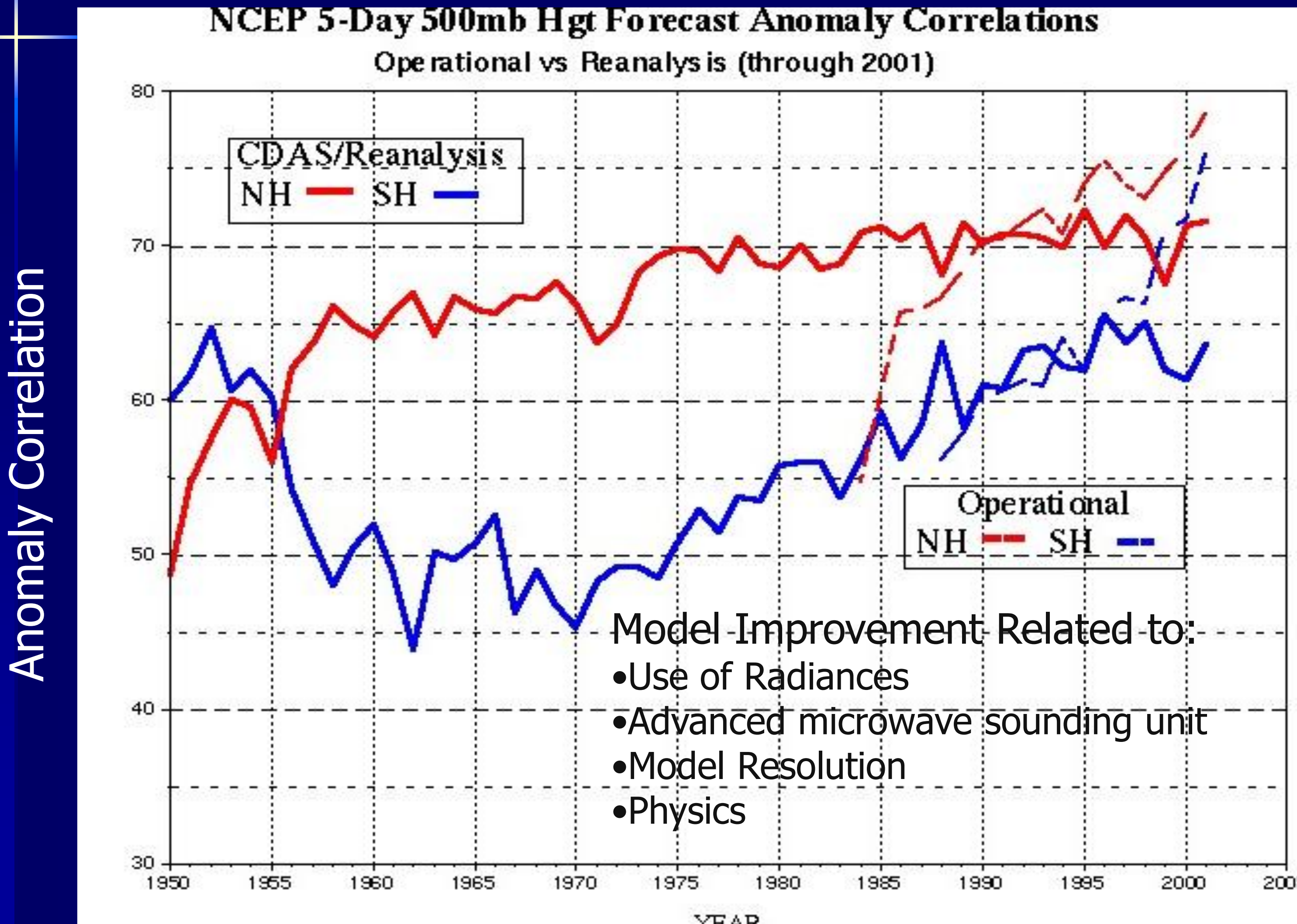
Significant increase in number of observations assimilated

Conventional and satellite data assimilated at ECMWF 1996-2010



Unit is millions of data values assimilated per 24 hour period

Impact of Satellite Data on Operational Forecasts

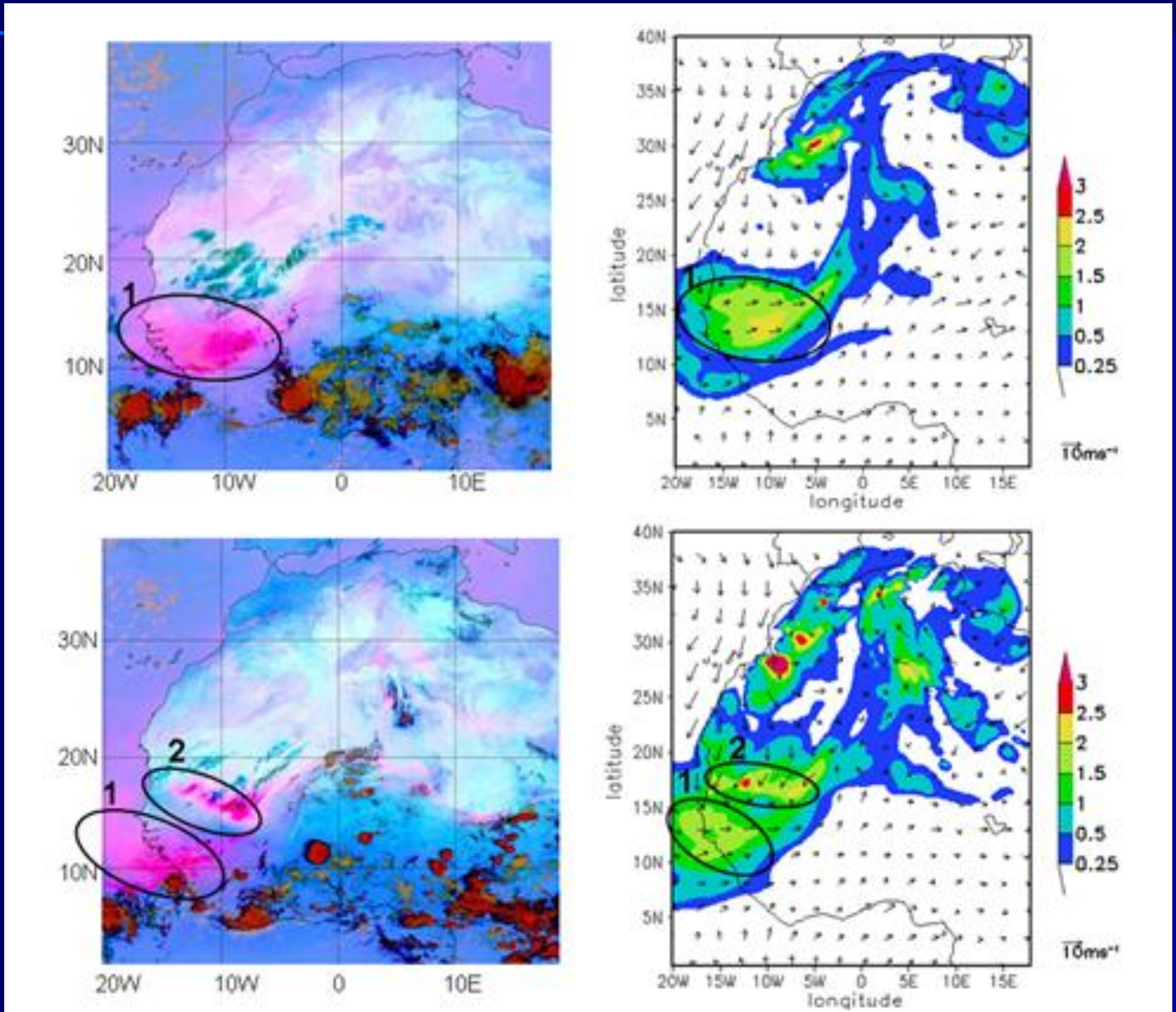


Model verification

Comparison with SEVERI Dust Product, June 21, 2007

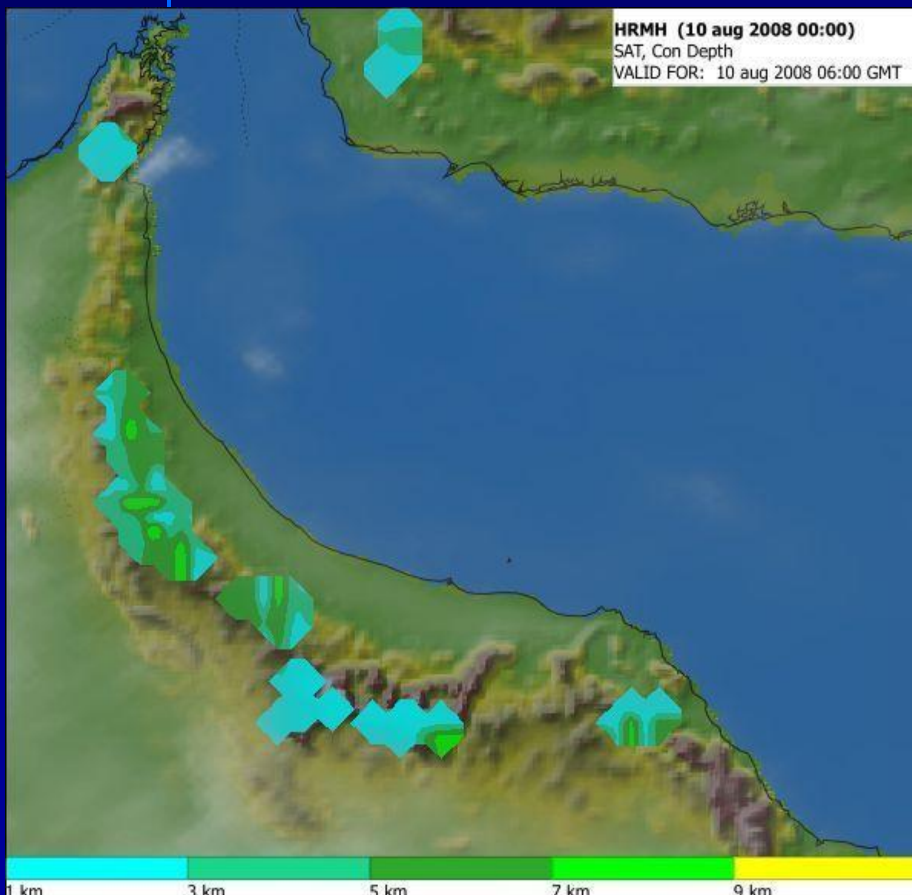
8 UTC

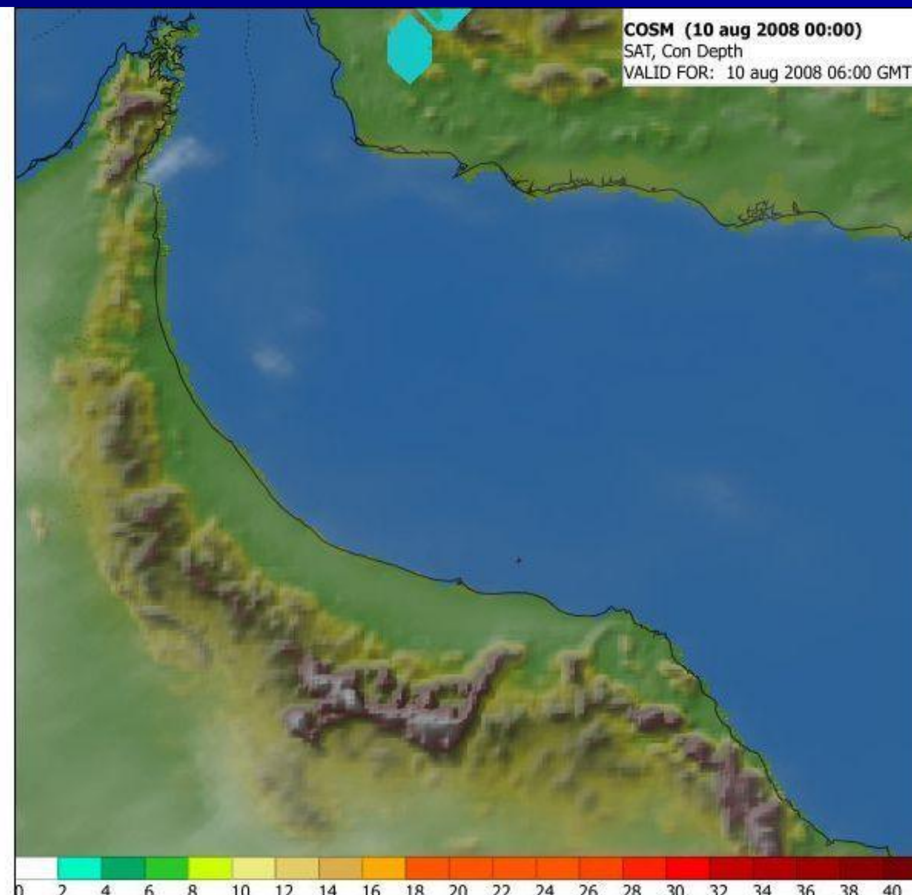
16 UTC



Con. Depth / Satellite(10/08/08)

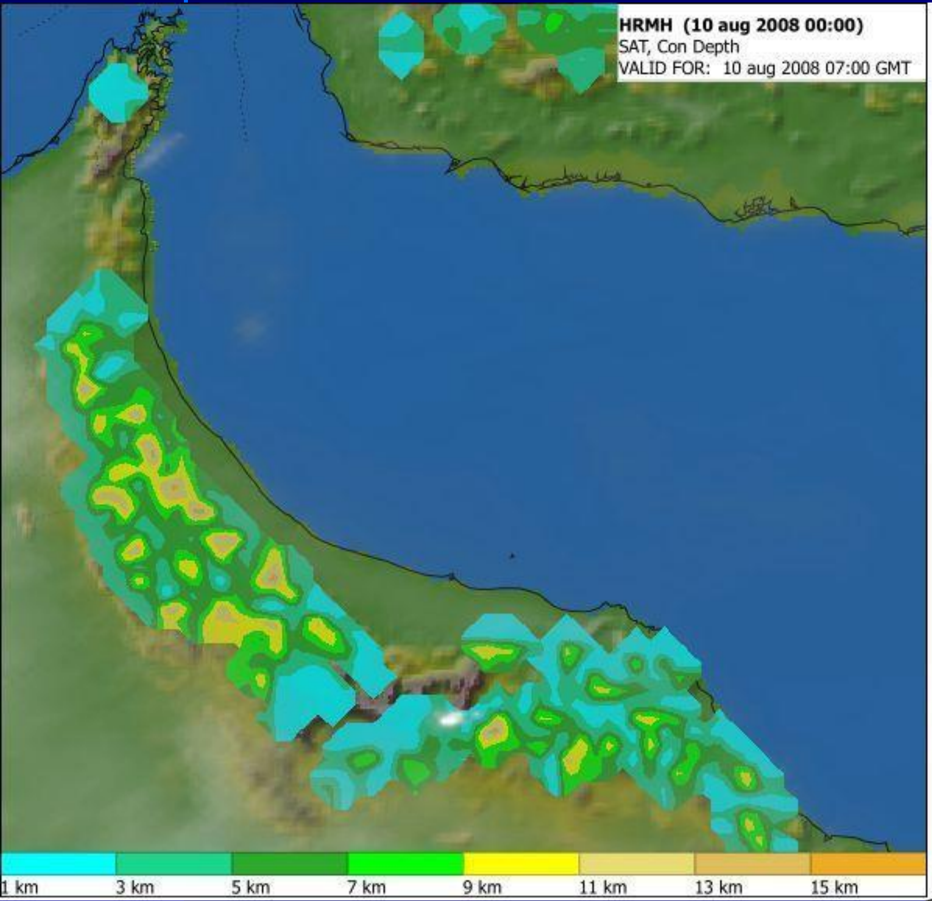
HRM (06 GMT) | COSMO (06 GMT)

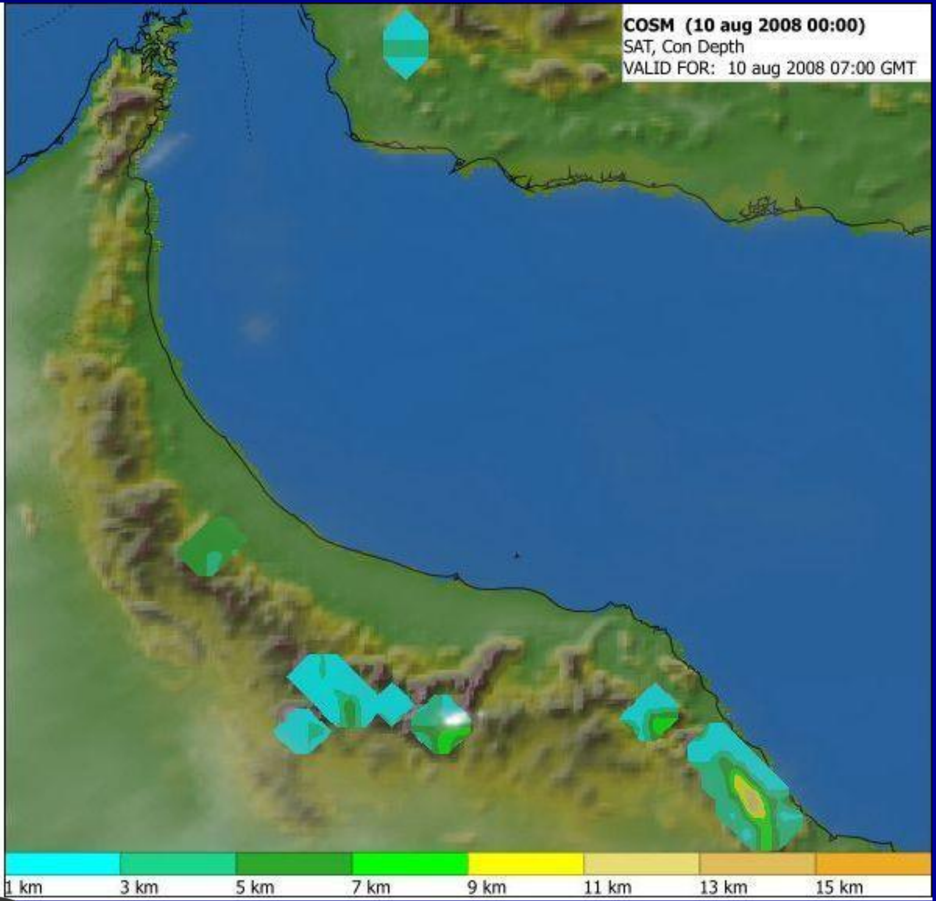




Con. Depth / Satellite(10/08/08)

HRM (07 GMT) | COSMO (07 GMT)

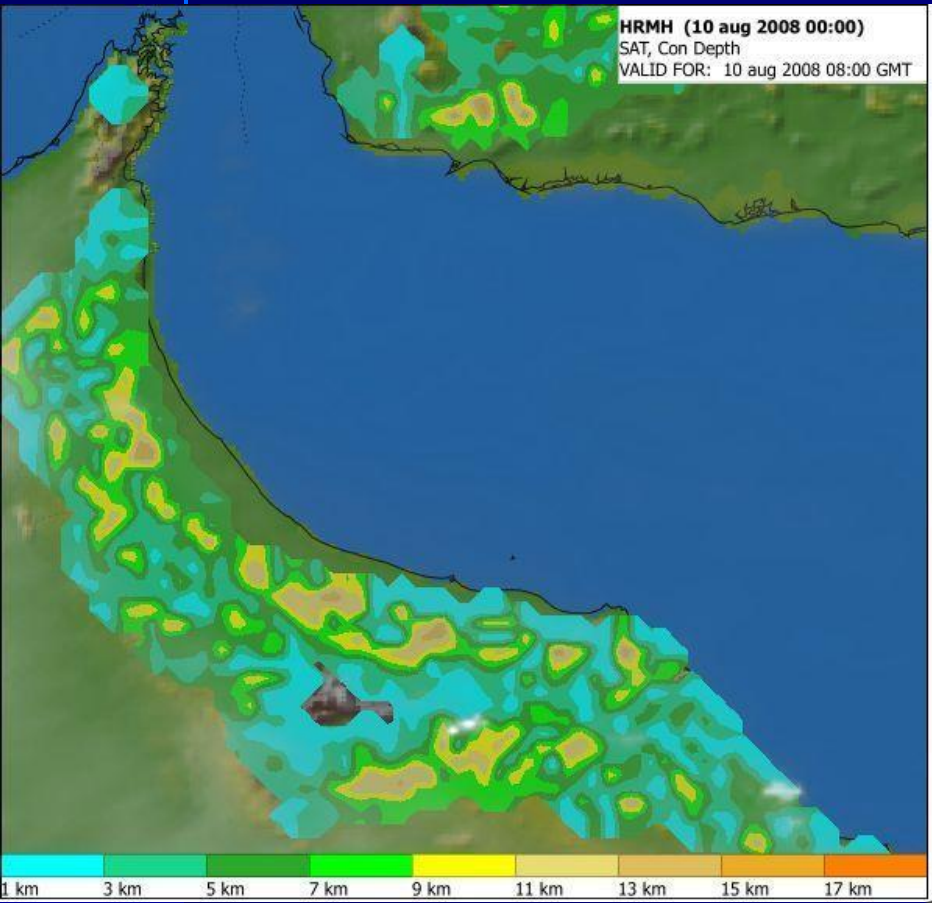


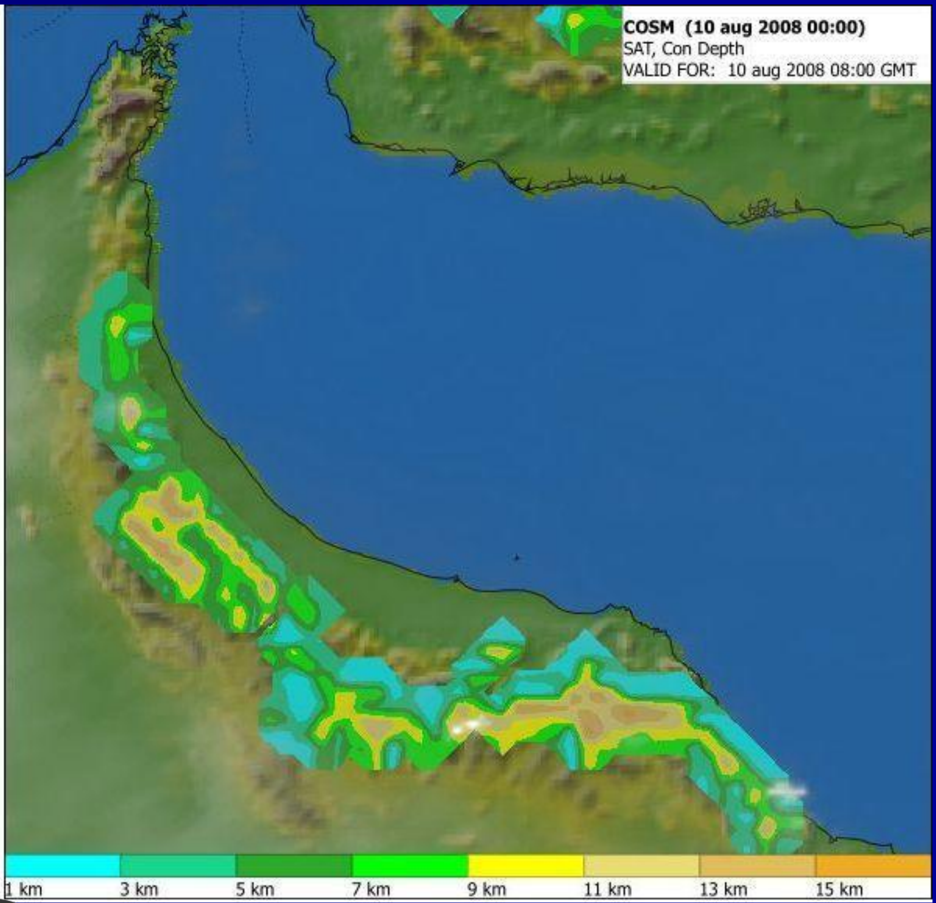


Con. Depth / Satellite(10/08/08)

HRM (08 GMT)

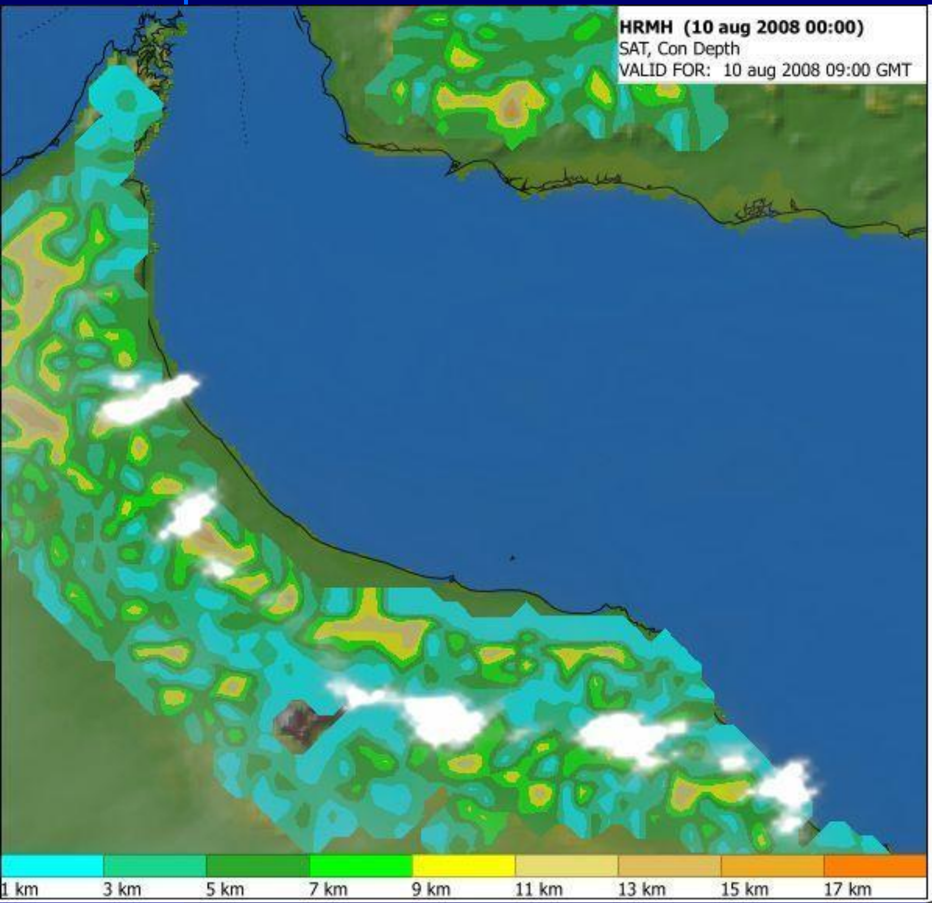
COSMO (08 GMT)

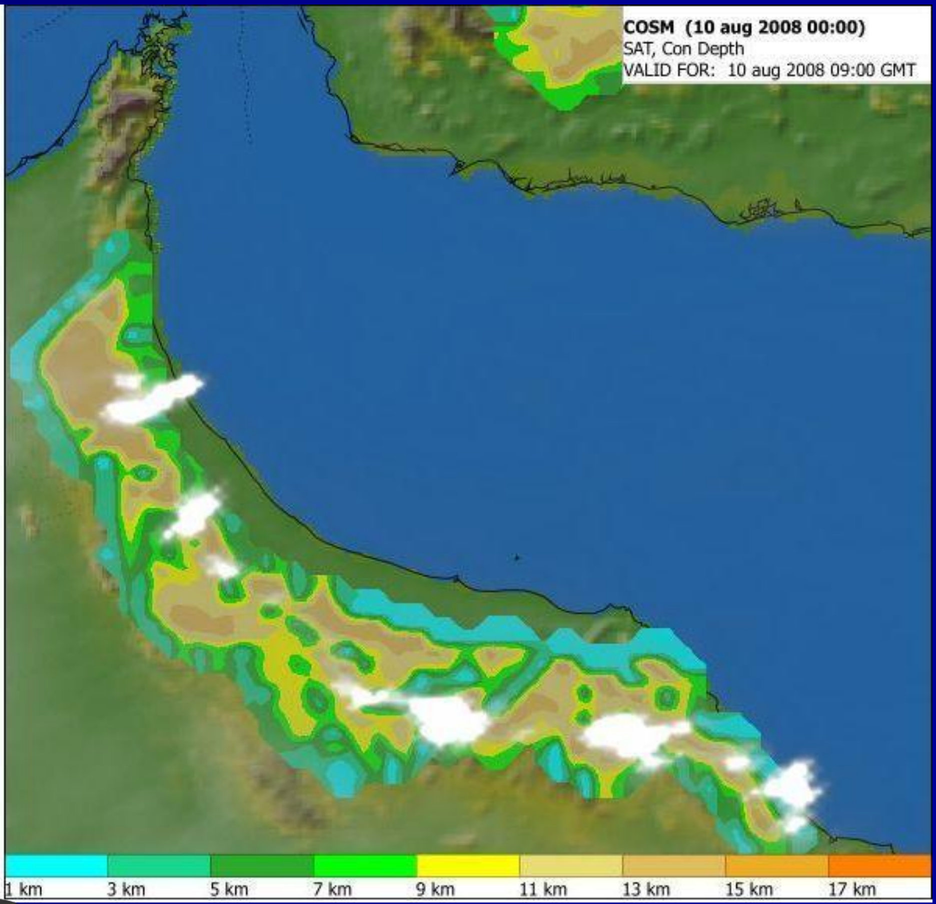




Con. Depth / Satellite(10/08/08)

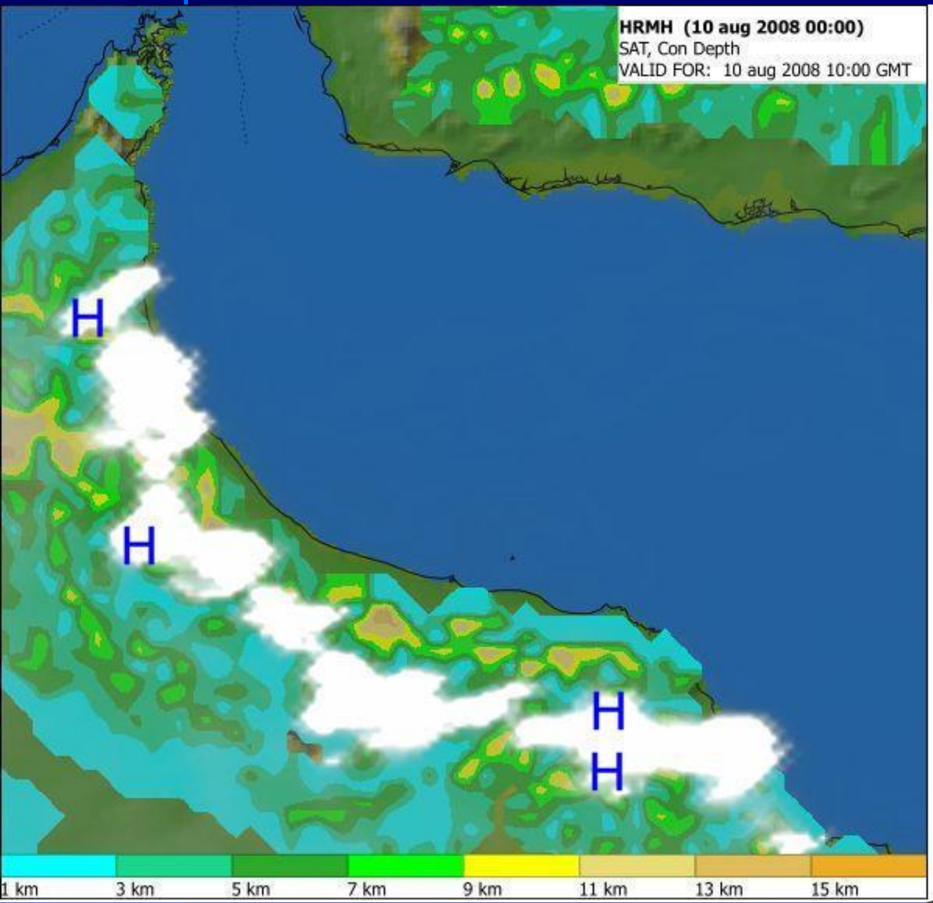
HRM (09 GMT)	COSMO (09 GMT)

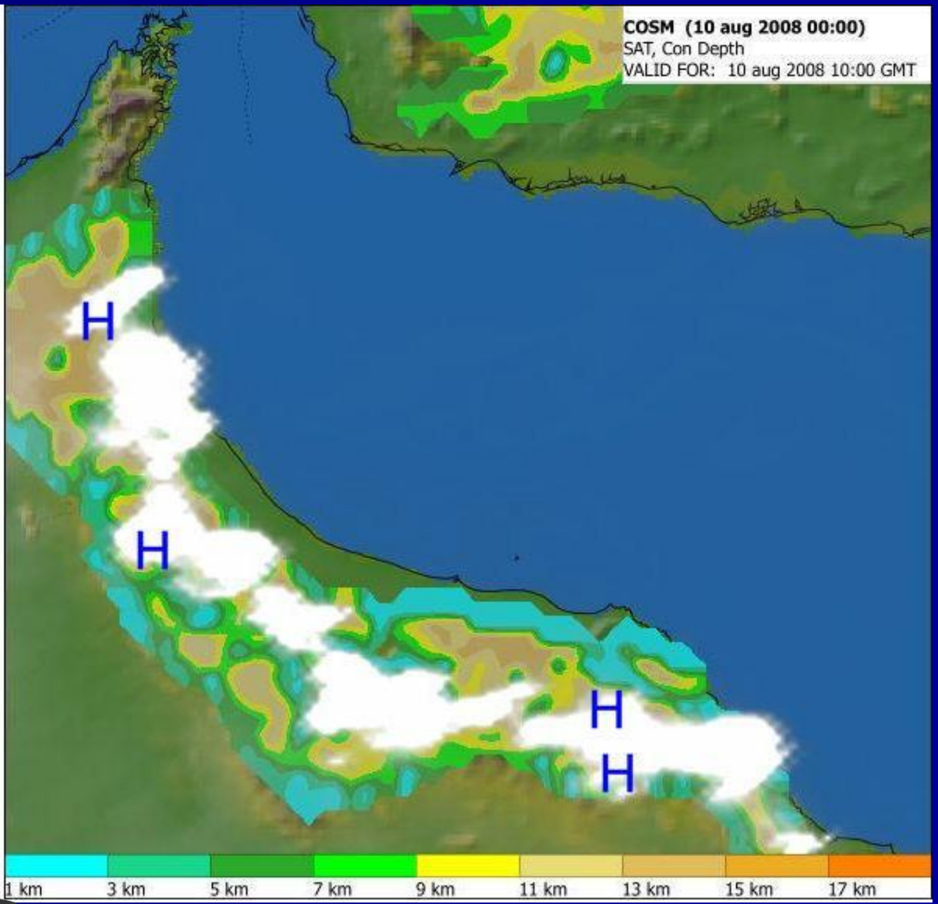




Con. Depth / Satellite(10/08/08)

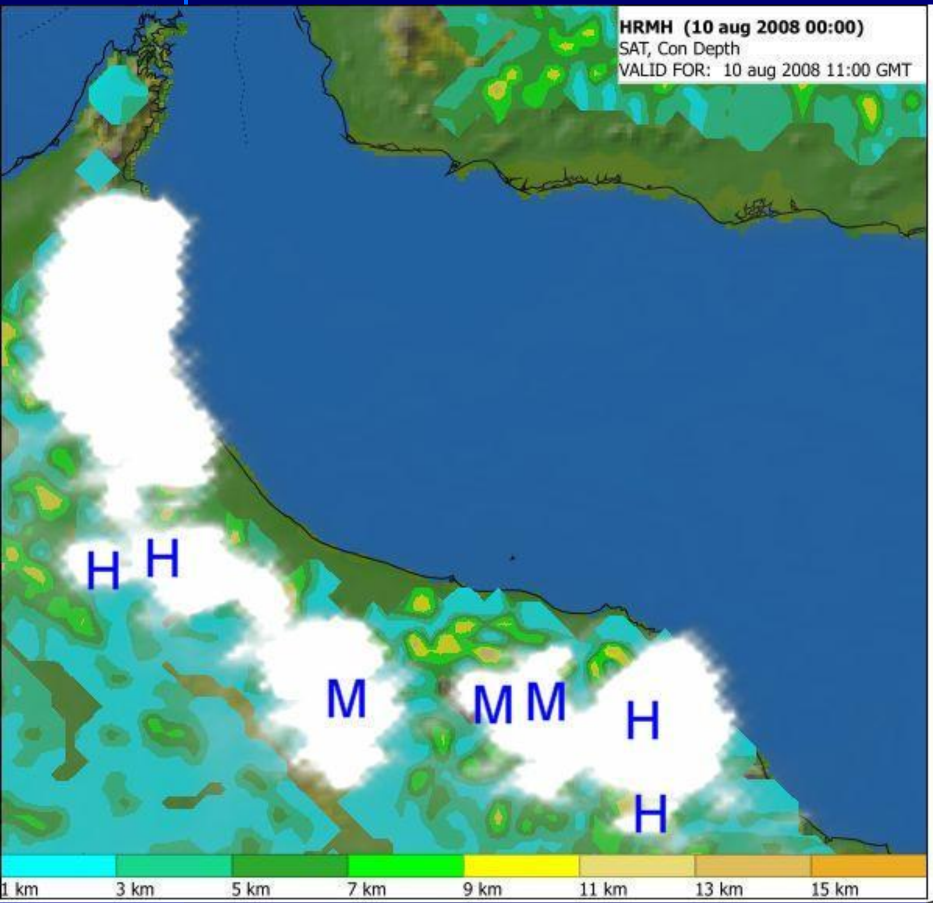
HRM (10 GMT) COSMO (10 GMT)

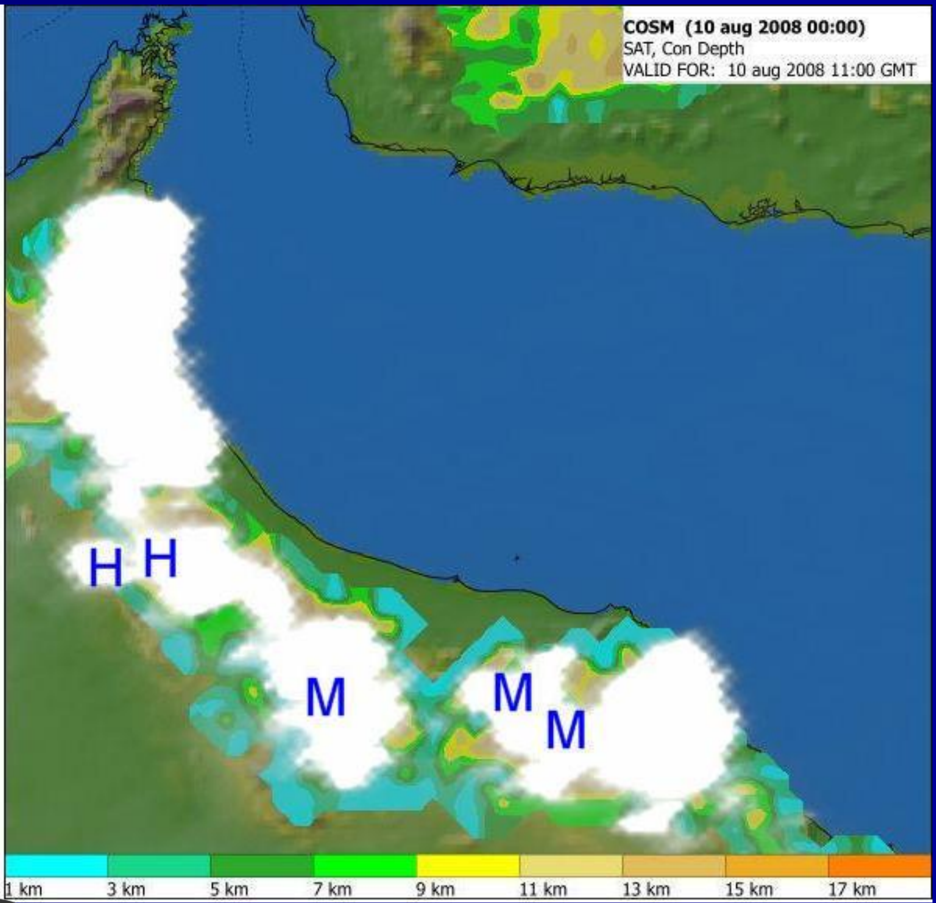




Con. Depth / Satellite(10/08/08)

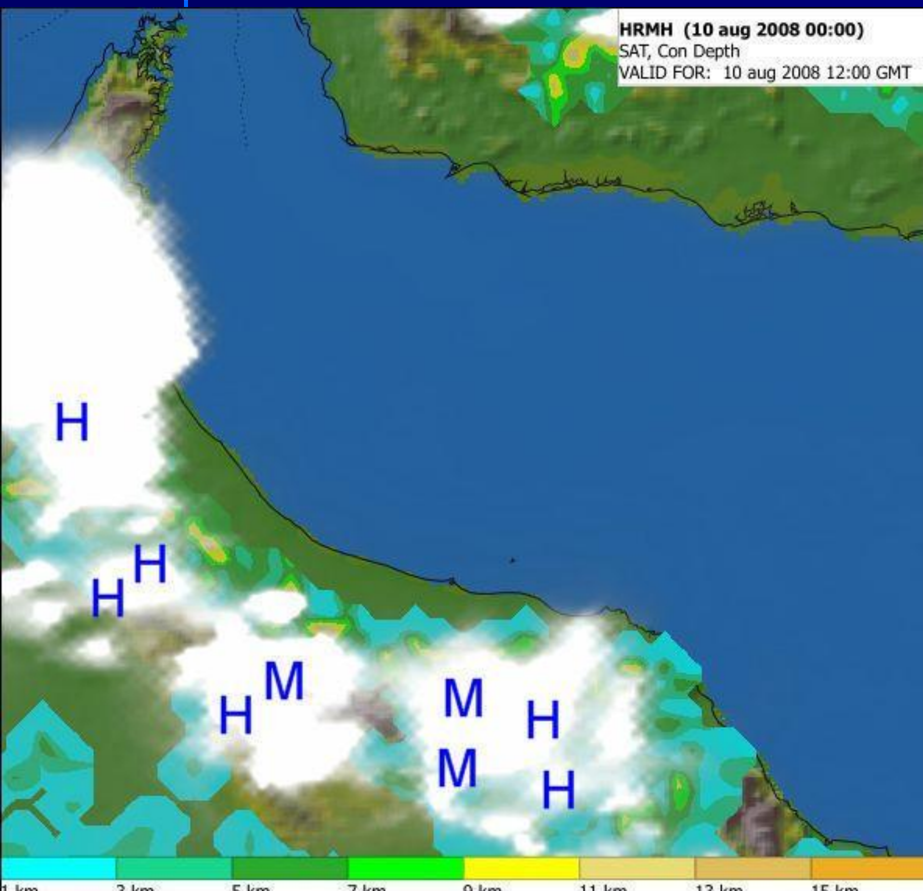
HRM (11GMT) COSMO (11GMT)

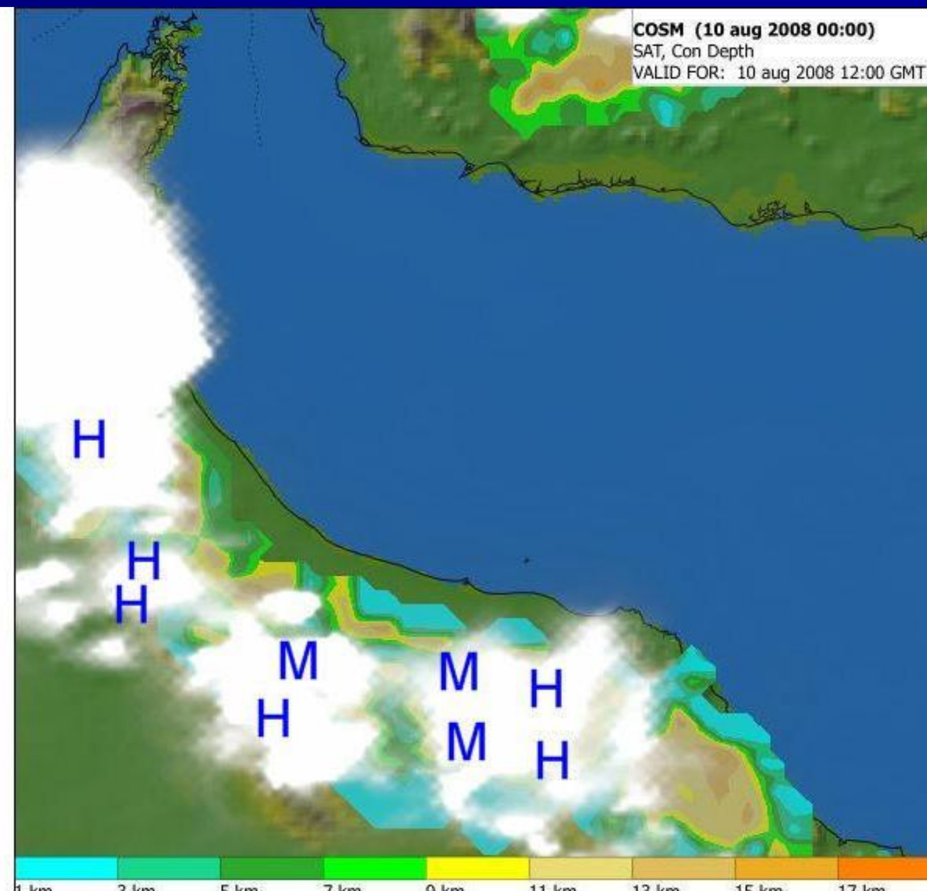




Con. Depth / Satellite(10/08/08)

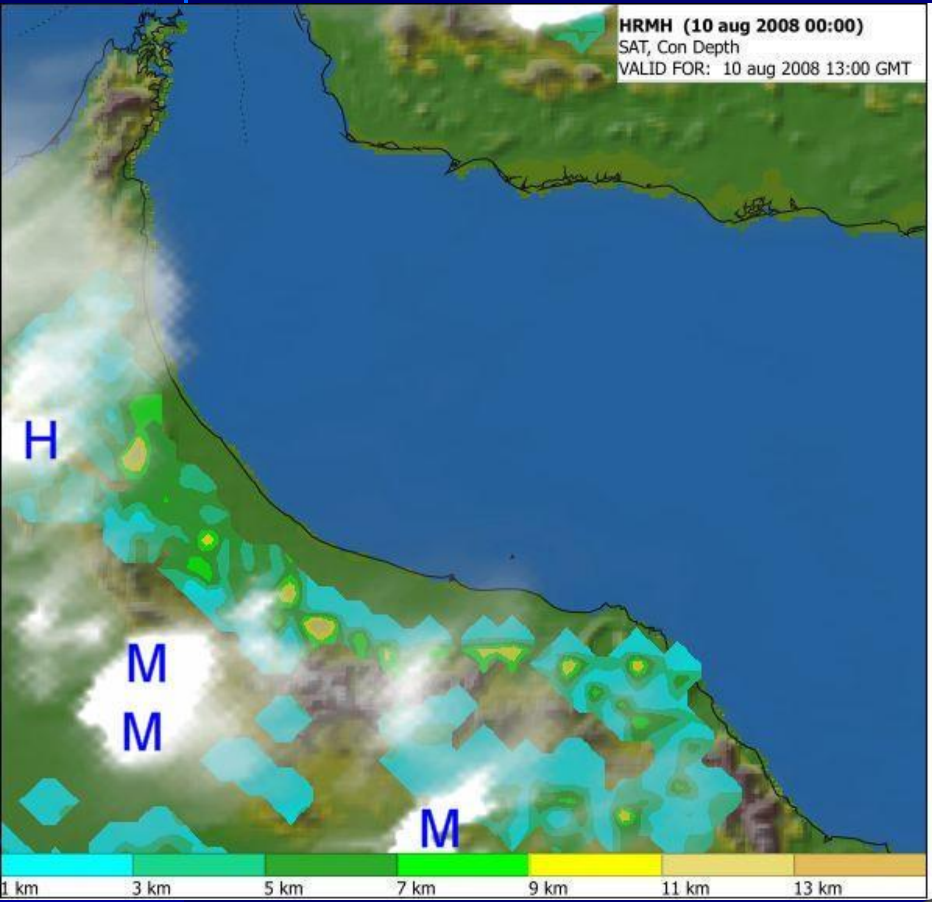
HRM (12GMT) COSMO (12GMT)

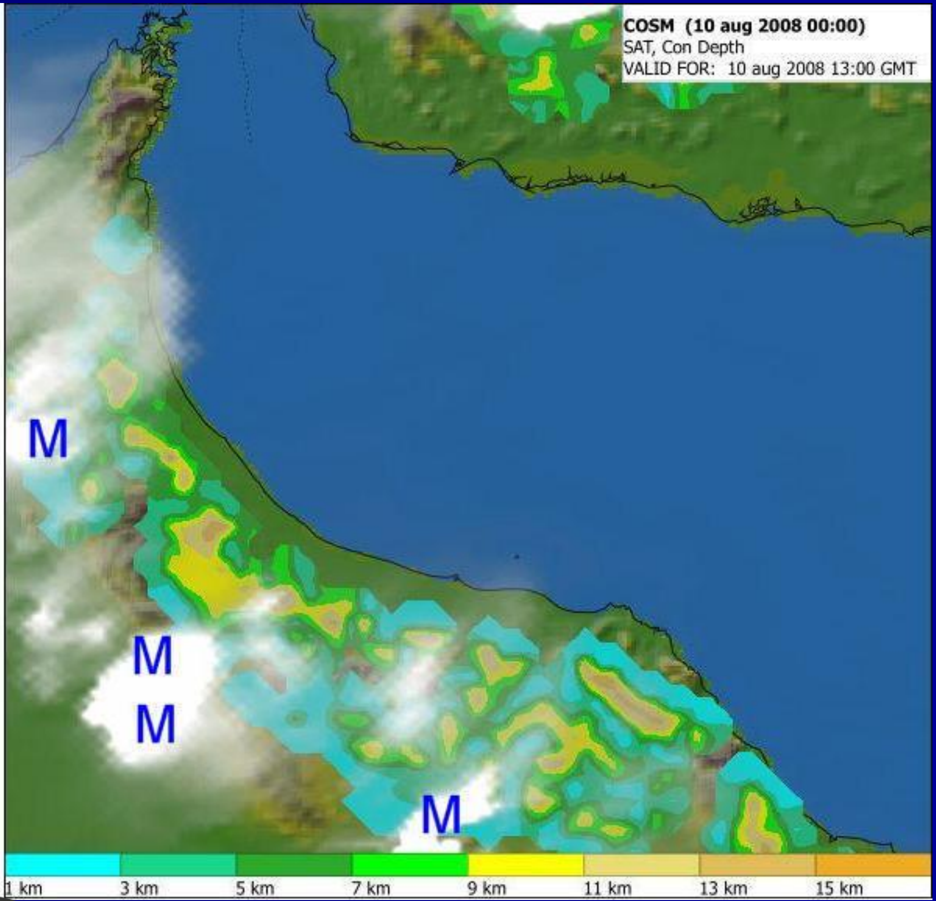




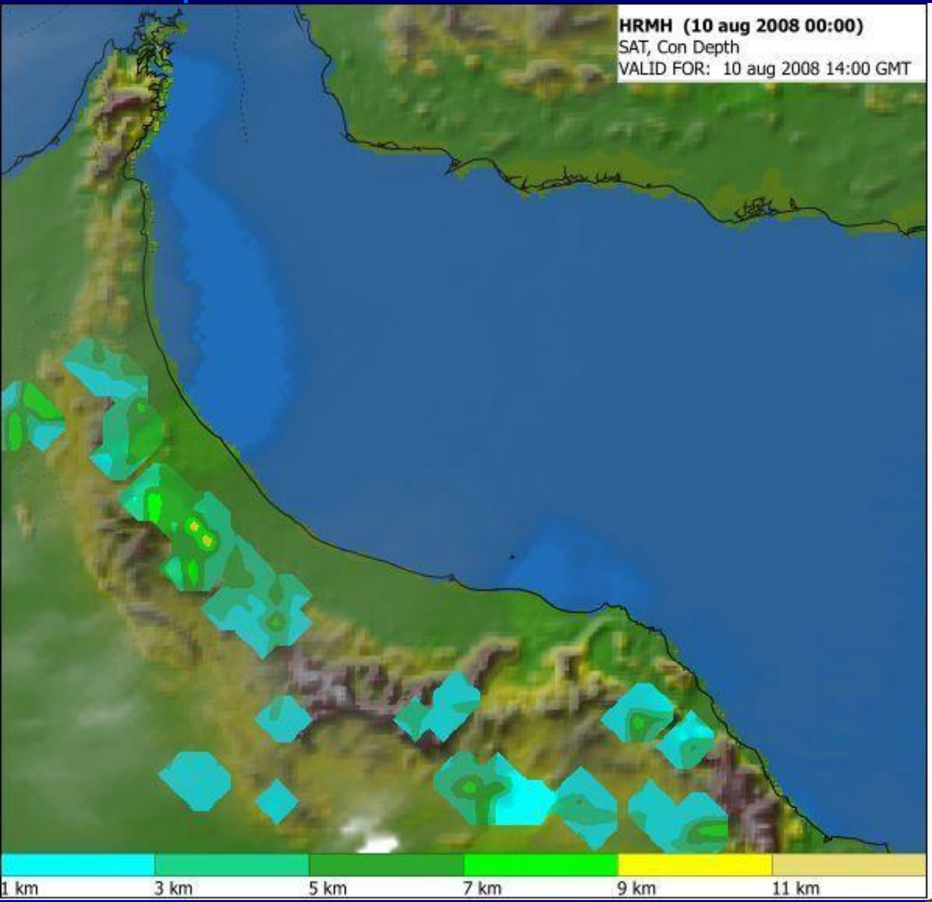
Con. Depth / Satellite(10/08/08)

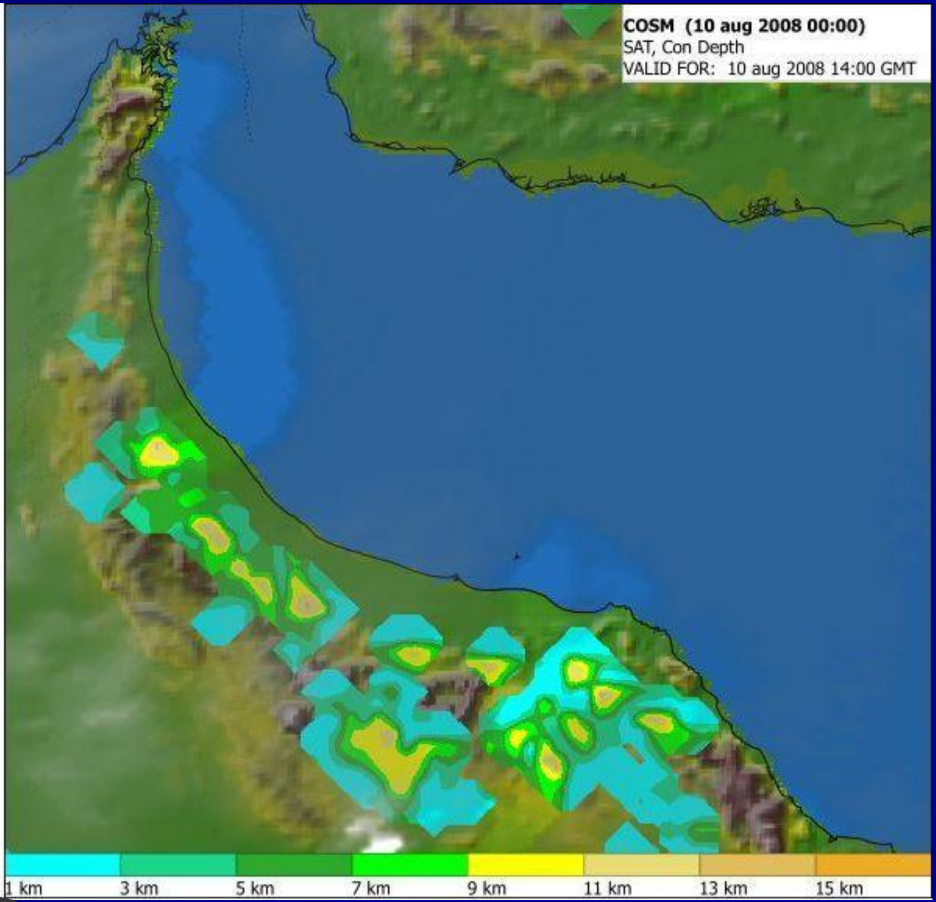
HRM (13GMT) COSMO (13GMT)





HRM (14GMT) COSMO (14GMT)





Part3: Case Study, Satellite Data improving NWP Tropical Cyclone Forecast

INTRODUCTION

- **Numerical weather prediction (NWP) is an Initial value problem**

- **In last two decades, there have been significant improvement in NWP models and is mainly attributed to**
  - the increase in model resolution
  - improvement in model physics
  - improvement in analysis and assimilation techniques

- **In recent years, the research focus is on**
  - Better Initial and boundary conditions
  - Better physical parameterization schemes

Major focus for improvement in NWP

1. Enhancement of observations over data sparse regions
2. Utilization of all available information in data assimilation
3. Improvement in parameterization of physical processes

One of the Major focus ……

Enhancement of Remote sensing observations

1. Enhancement of Satellite observations over data sparse regions (vertical soundings of wind, temperature and moisture)

2. Network of DWR

3. Aircraft observations

Next step ………….

- The main goal of collection of meteorological data is to produce an accurate image of the true state of the atmosphere at a given time with assimilation of all available, reasonably accurate observations.

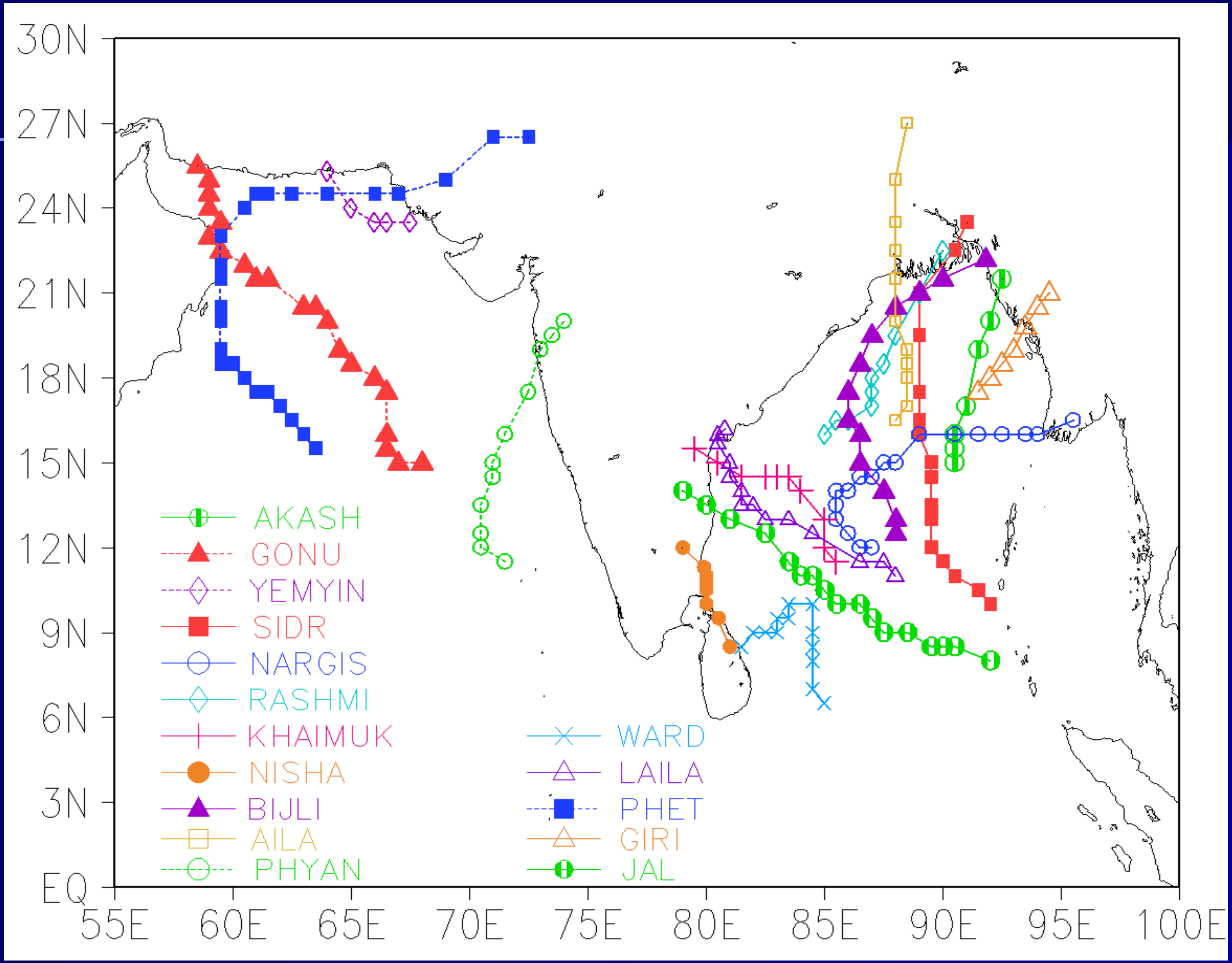
- Comprehensive quality control of all available observational information before assimilation

- Data Assimilation with sophisticated methods like 3Dvar and 4Dvar

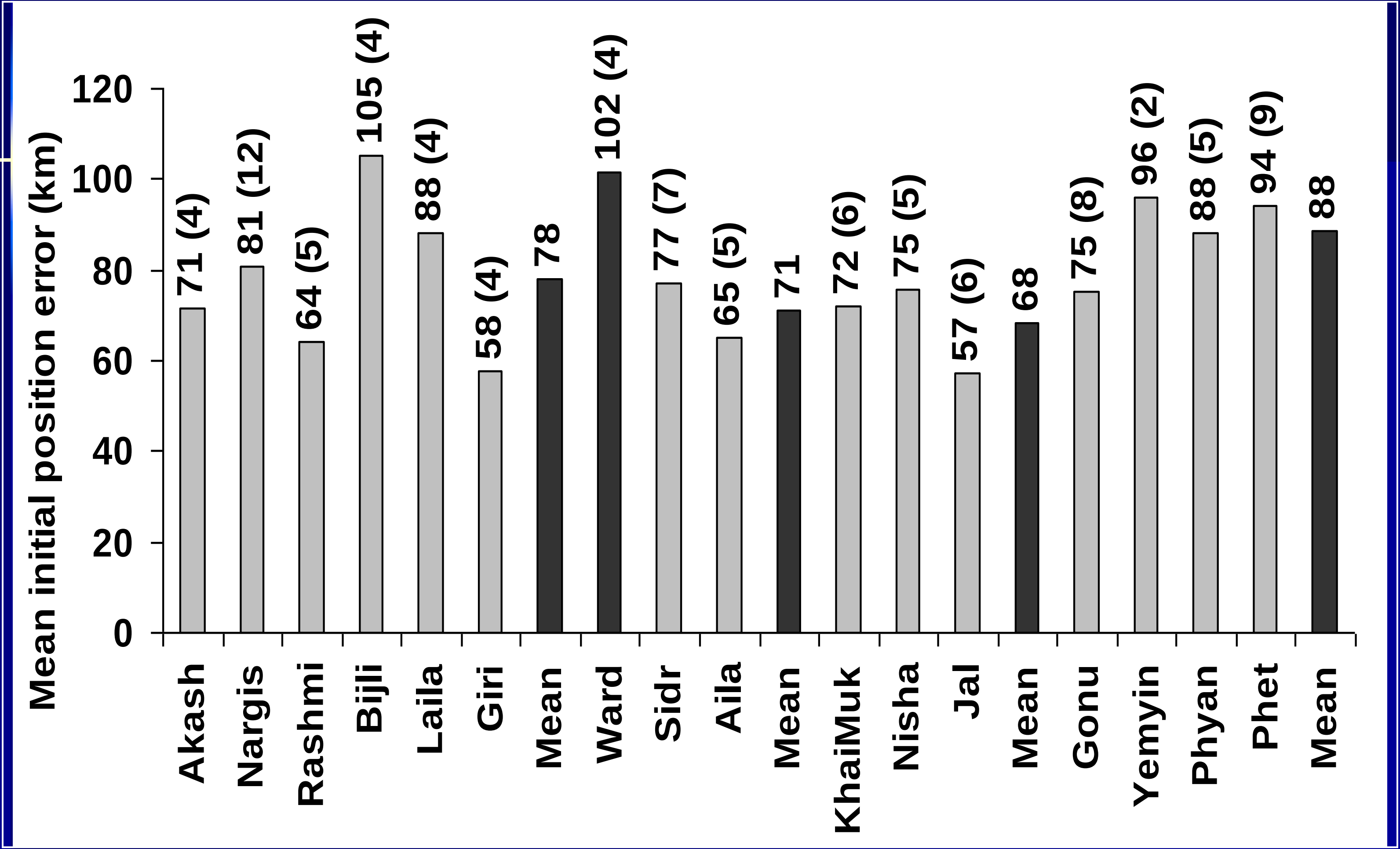
SCOPE OF THE STUDY

- Real time simulation of tropical cyclones over Arabian Sea and Bay of Bengal.
- High resolution meso-scale models WRF-ARW and WRF-NMM for the prediction of tropical cyclones over North Indian Ocean.
- Improvement in model initial condition with high resolution meso-scale satellite data assimilation system.

16 cyclones over Indian Ocean during 2007 – 10



Mean initial position error (km) of each TC

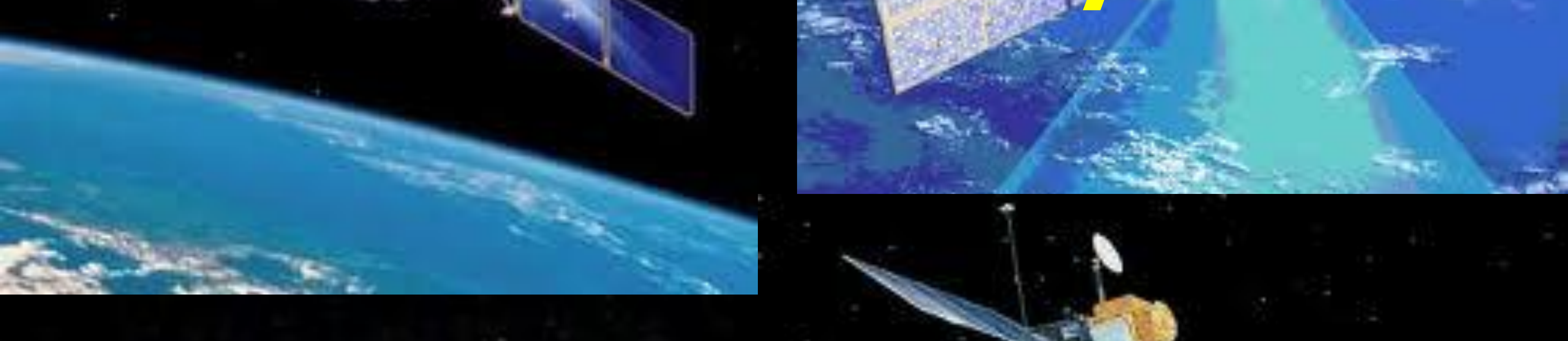


NIO cyclone - 80 Km

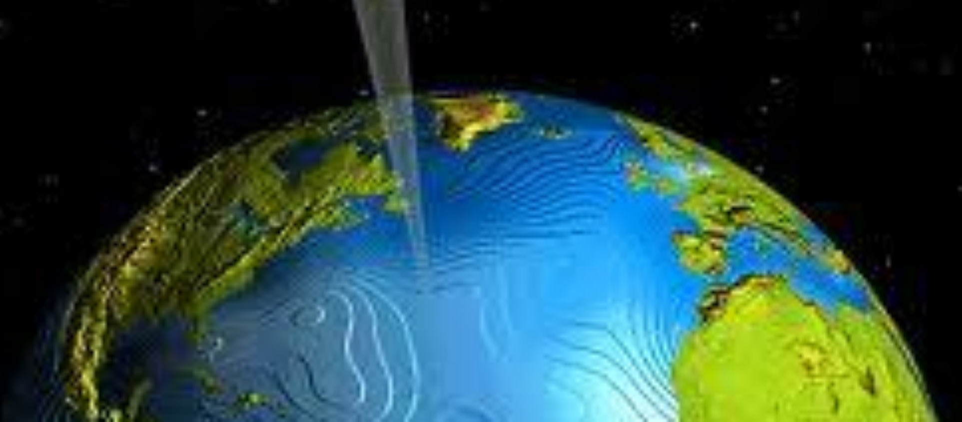
BoB cyclone - 76 Km

AS cyclone - 88 Km

Impact of Satellite derived winds Assimilation on Track and Intensity

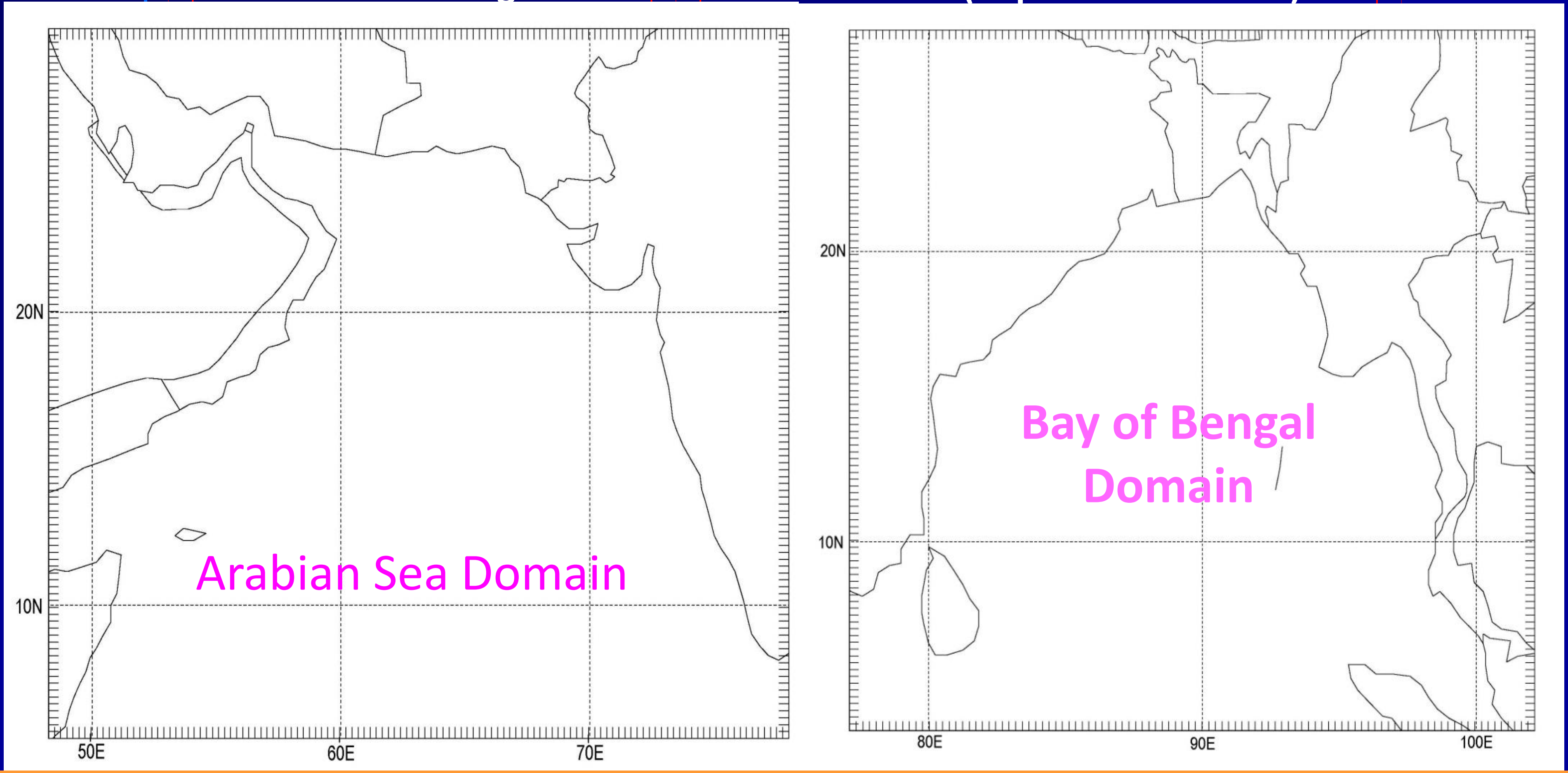


WRF-ARW modeling systems with 9km resolution



ARW Model Configuration

Model	WRF
Dynamics	Non-hydrostatic
Horizontal resolution	9 km
Forecast Length	72 – 96 hrs (depends on TCs life)

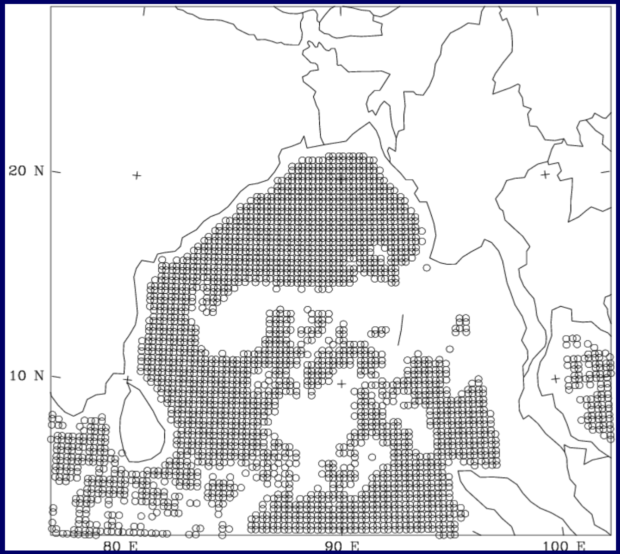


Data used in the Assimilation Derived winds of QSCAT (wind speed and direction) and SSM/I (wind speed)

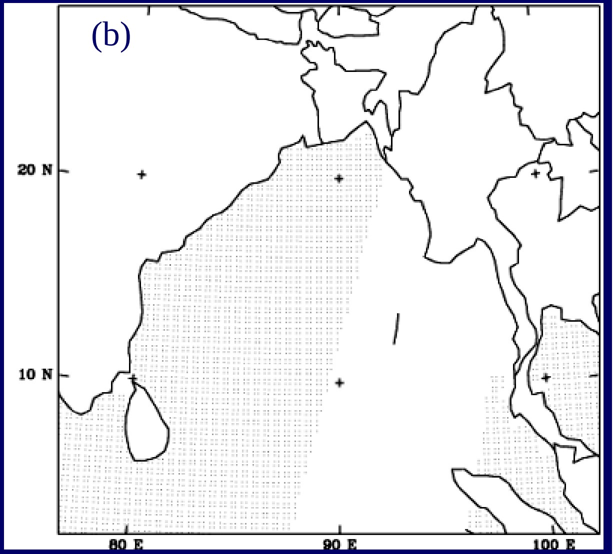
Cyclone	Location	Initial condition (FNL)
NARGIS (27 April – 3 May 2008) (5 Cases)	BOB	00UTC of 28 April 2008 12UTC of 28 April 2008 00UTC of 29 April 2008 12UTC of 29 April 2008 00UTC of 30 April 2008
GONU (2 – 7 June 2007) (4 Cases)	Arabian Sea	00UTC of 2 June 2007 12UTC of 2 June 2007 00UTC of 3 June 2007 12UTC of 3 June 2007

Satellite derived wind ingested into the model initial condition of TC NARGIS

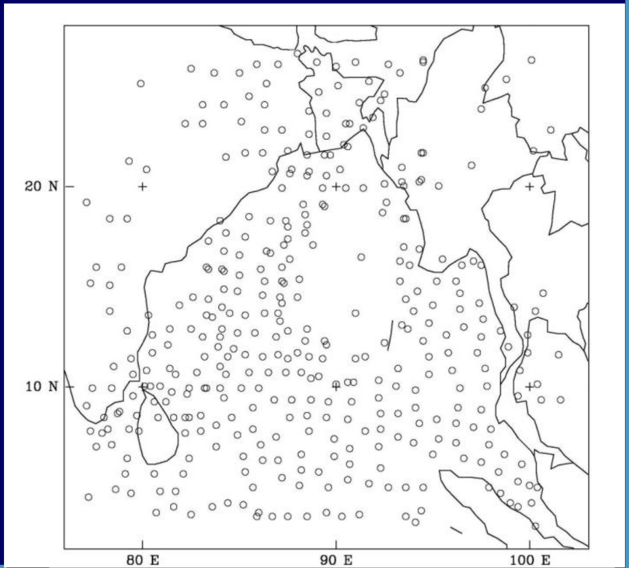
SSMI, QSCAT and Kalpana winds for 12 UTC of 28 April 2008



o 2851 SSMI 2008042812



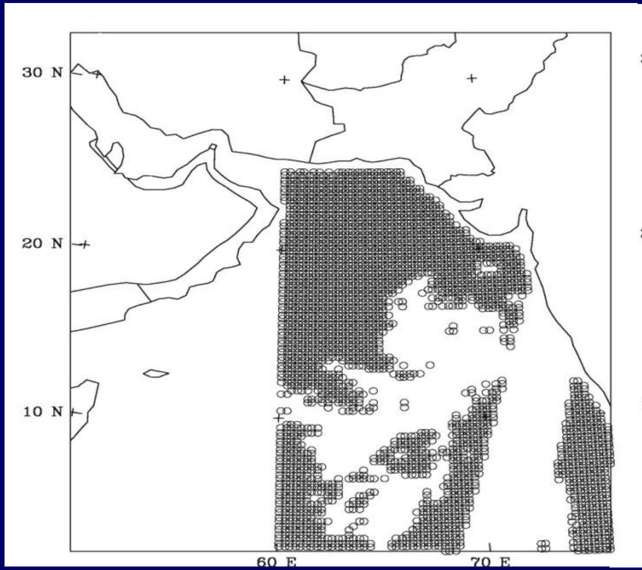
3374 QSCAT 2008042812

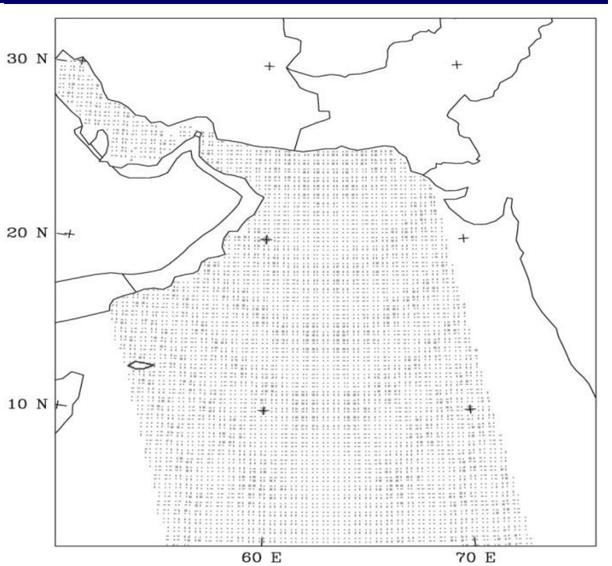


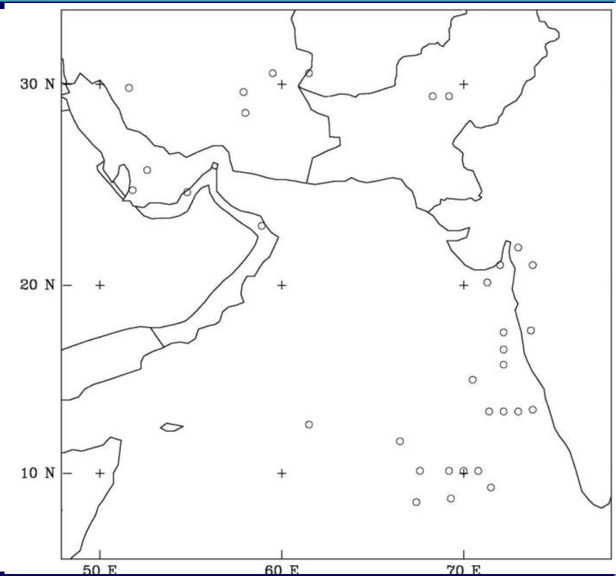
o 377 Kalpana CMV wind

Satellite derived wind ingested into the model initial condition of TC GONU

SSMI, QSCAT and Kalpana winds for 00UTC of 2 June 2007



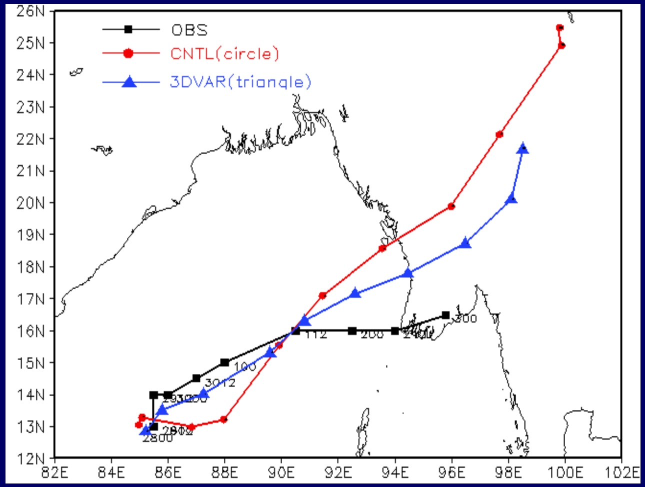




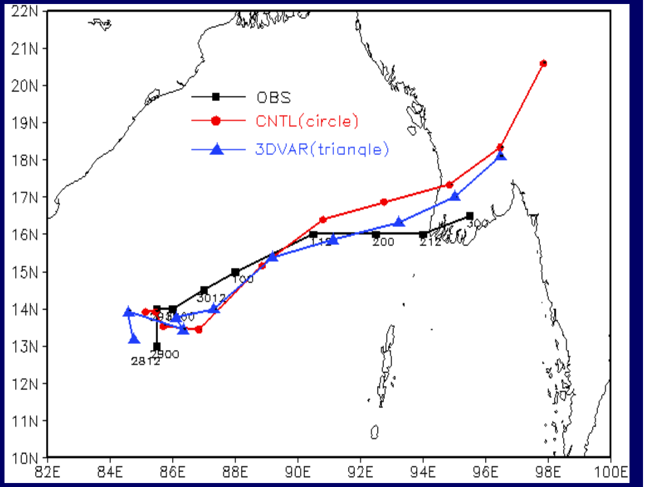
- o SSMI 2701 2007060200
- • QSCAT 5794 2007060200
- o Kalpana 33

TC: NARGIS

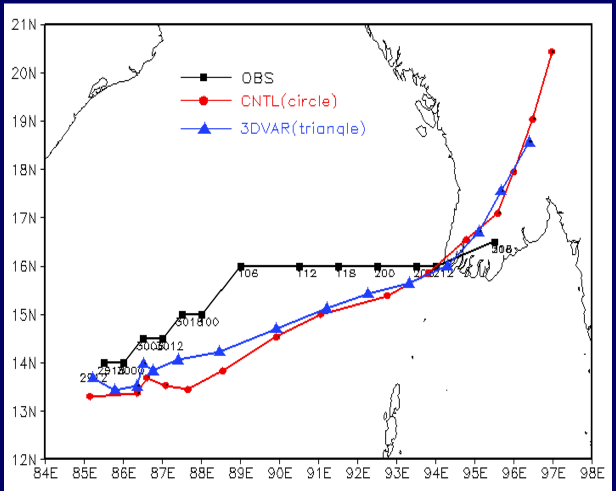
IC: 00UTC of 28 April 2008



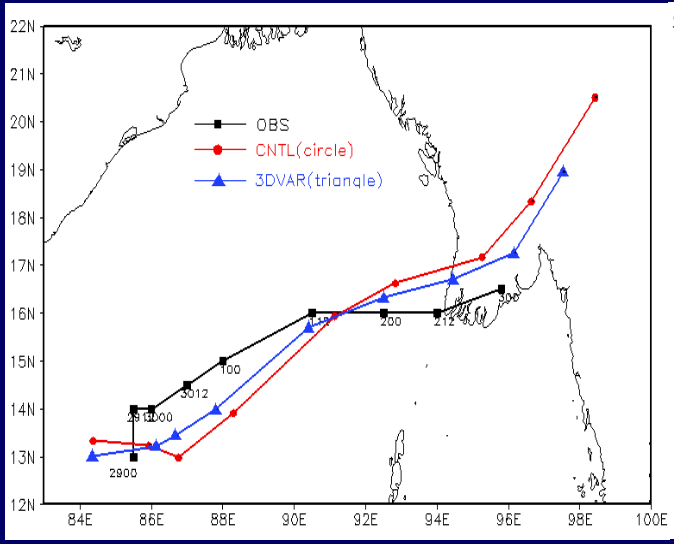
IC: 12UTC of 28 April 2008



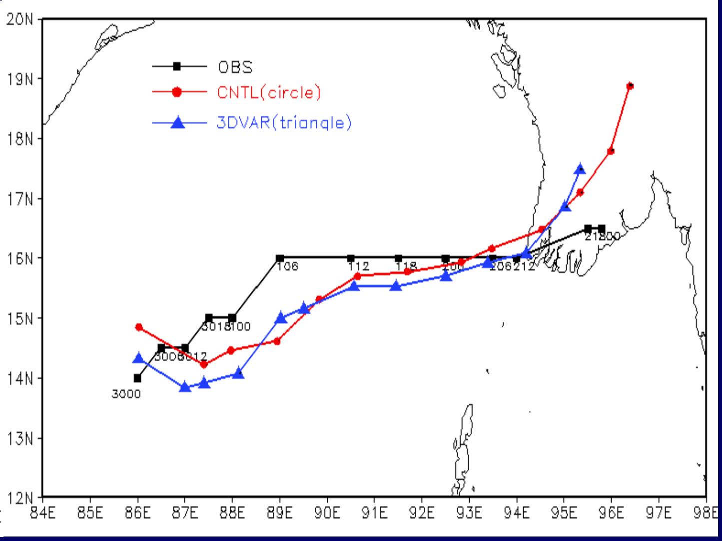
IC: 12UTC of 29 April 2008



IC: 00UTC of 29 April 2008

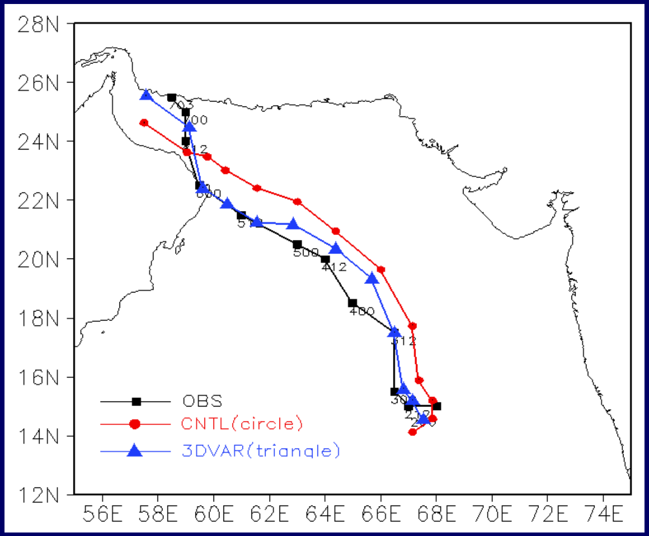


IC: 00UTC of 30 April 2008

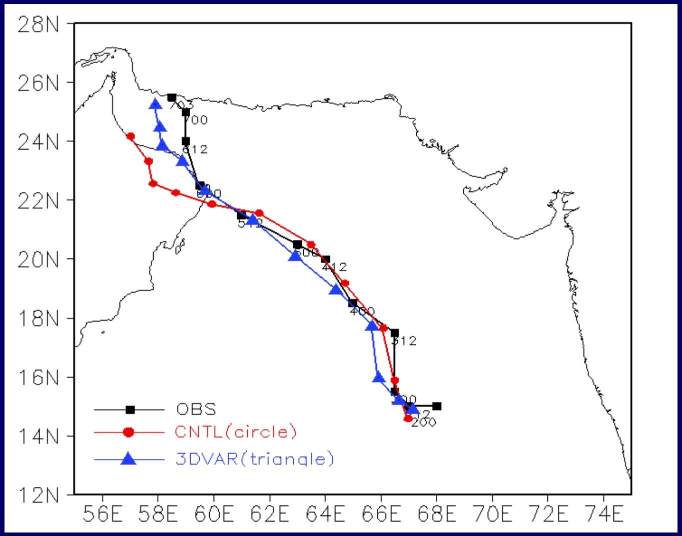


TC: GONU

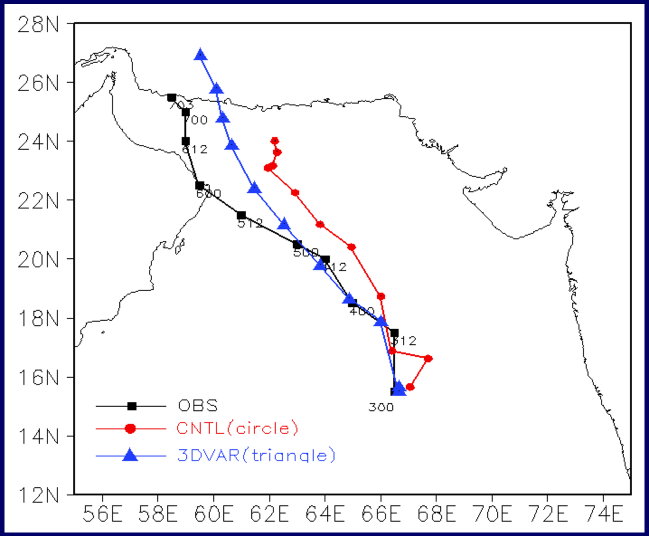
IC: 00UTC of 2 June 2007



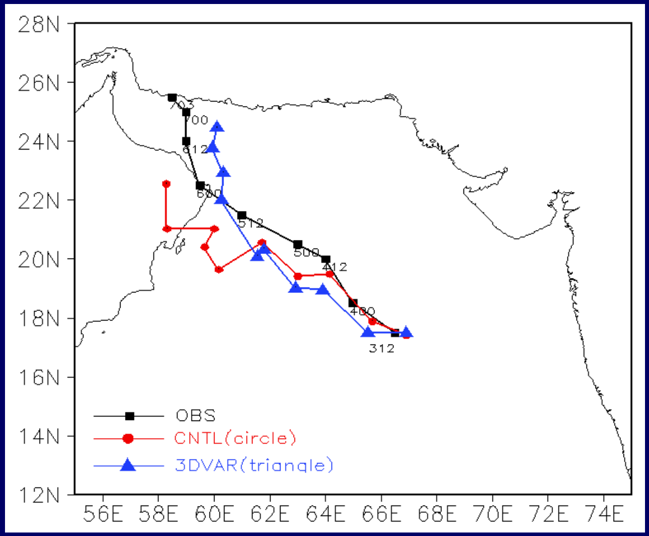
IC: 12UTC of 2 June 2007



IC: 00UTC of 3 June 2007

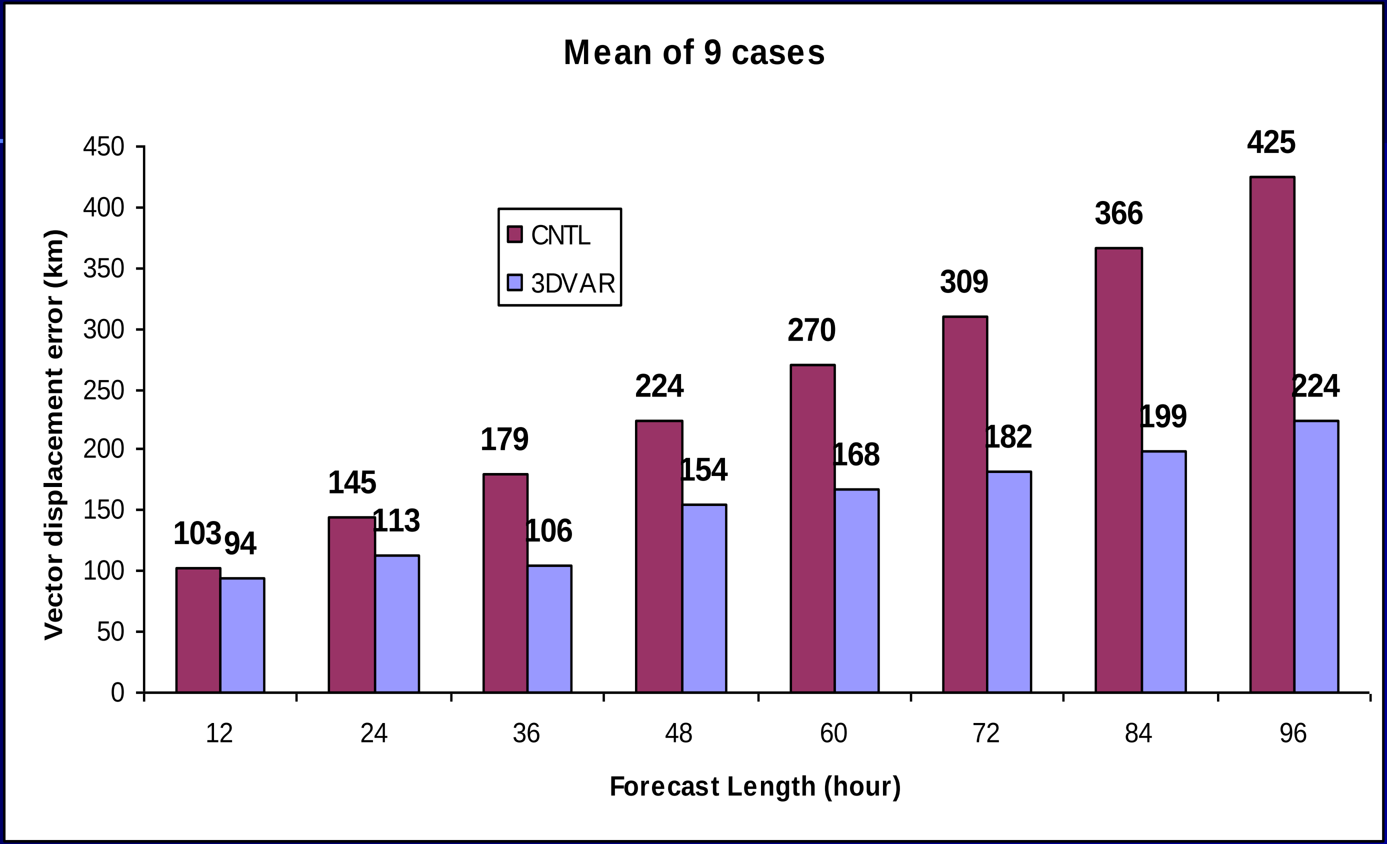


IC: 12UTC of 3 June 2007



Mean of 9 cases

(Nargis – 5 Cases and Gonu – 4 Cases)



Mean improvement:		
	24hr track error	22%
	48 hr track error	31%
	72 hr track error	41%
	96 hr track error	47%

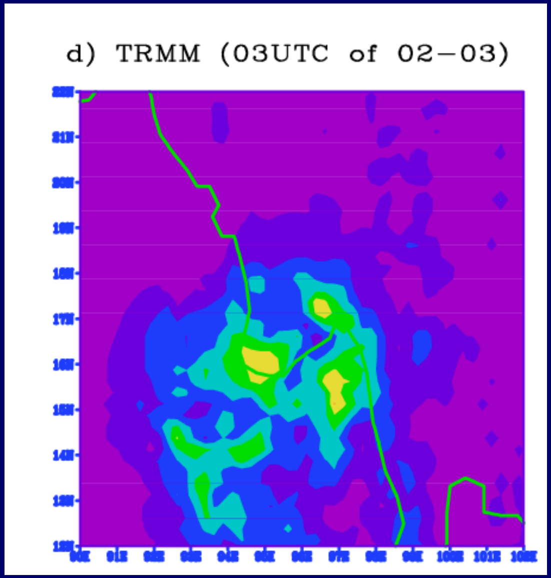
Landfall Errors (Nargis – 5 Cases & Gonu – 4 Cases)

TCs	Cases	Time Error (hour)	
		CNTL	3DVAR
Narigs: Landfall over Myanmar	1	33	24
	2	12	3
	3	15	12
	4	12	6
	5	6	0
Gonu: landfall over Oman	6	NL	2
	7	-4	2
	8	NL	NL
	9	30	NL

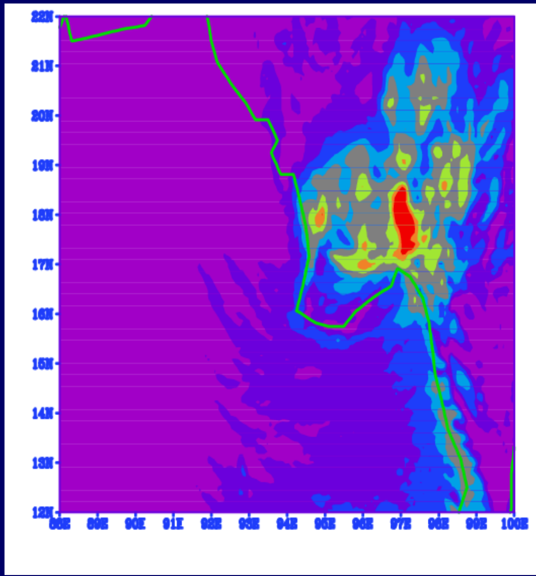
24-hr accumulated rainfall valid at landfall for **TC NARGIS**

From IC: 12UTC of 28 April

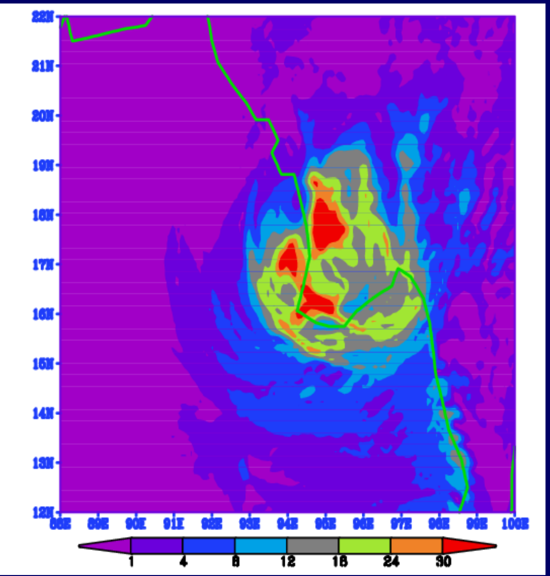
(a) TRMM



(b) CNTL



(c) 3DVAR



Part 4: Trajectory Calculation as Supporting tool for dust storm forecasting

Outline

- Introduction
- Dust forecasting
- Methodology
- Proposed system
- System validation
- Conclusions

Introduction

- **Dust storms affect human**
  - Health
  - Commercial
  - Transport
  - Military operations
- **Dust storm research topics**
  - Dust characteristic
  - Dust sources
  - Transport process
  - Dust forecasting

Dust Forecasting

- Wind plays a major role in the generation and transport of dust storm.
- Several dust forecasting models were developed
  - Aerosols models coupled with NWP models
- Proposal: Dust forecasting support tool using forward trajectory calculation is proposed.

Methodology

- Considering dust as a moving object in space and time
- Forward trajectory is used to determine the path it will follow

Trajectory Calculation

$$x_i(t+\Delta t) = x_i(t) + v_i(t)\,\Delta t$$

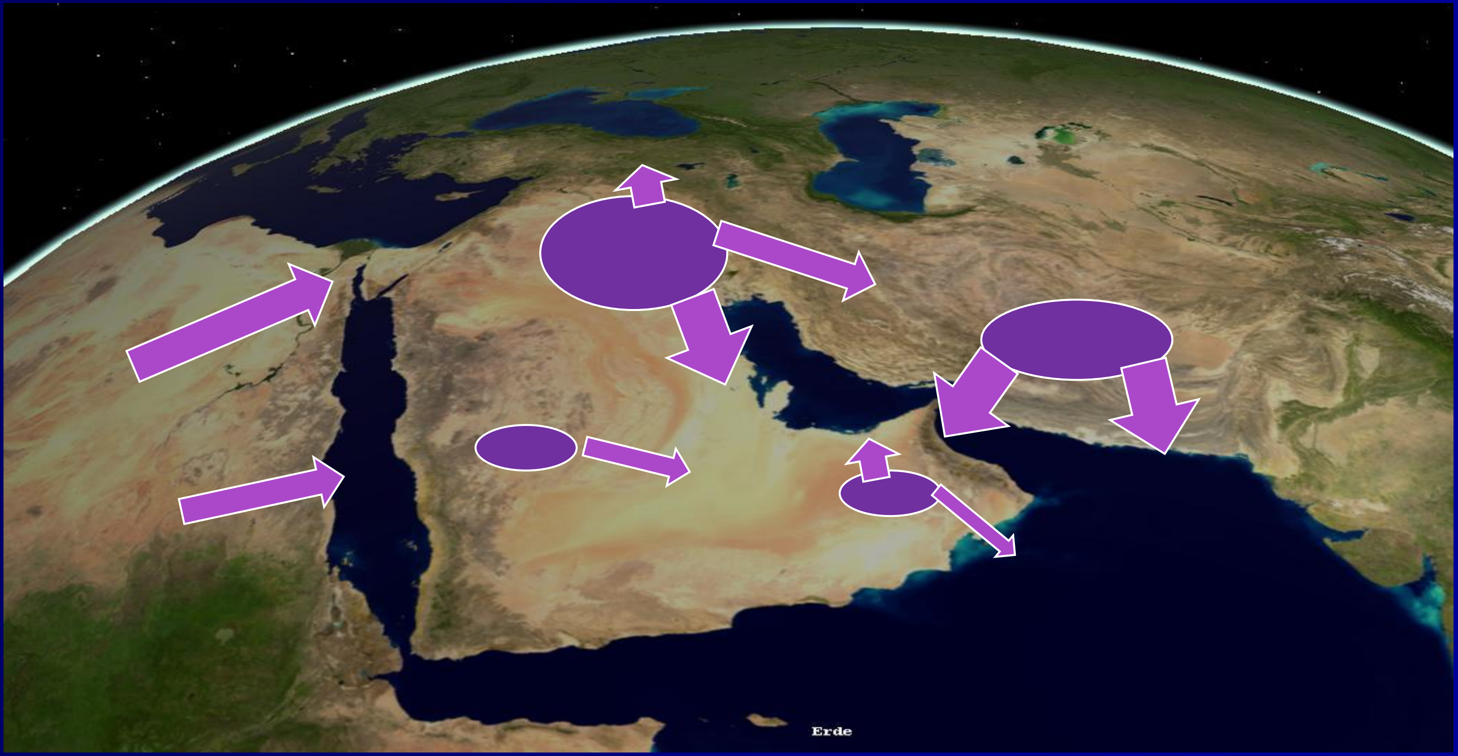
where i=1,2,3

$$x_i^{n+1}(t+\Delta t) \approx x_i(t) + 0.5\Delta t\left\{v_i(x_i(t),t) + v_i(x_i^n(t+\Delta t),t+\Delta t\right\}$$

Euler-Cauchy -Method with iteration, 2nd order accuracy

- hourly input of wind data
- cubic spatial interpolation
- linear temporal interpolation

Dust sources surrounding the area

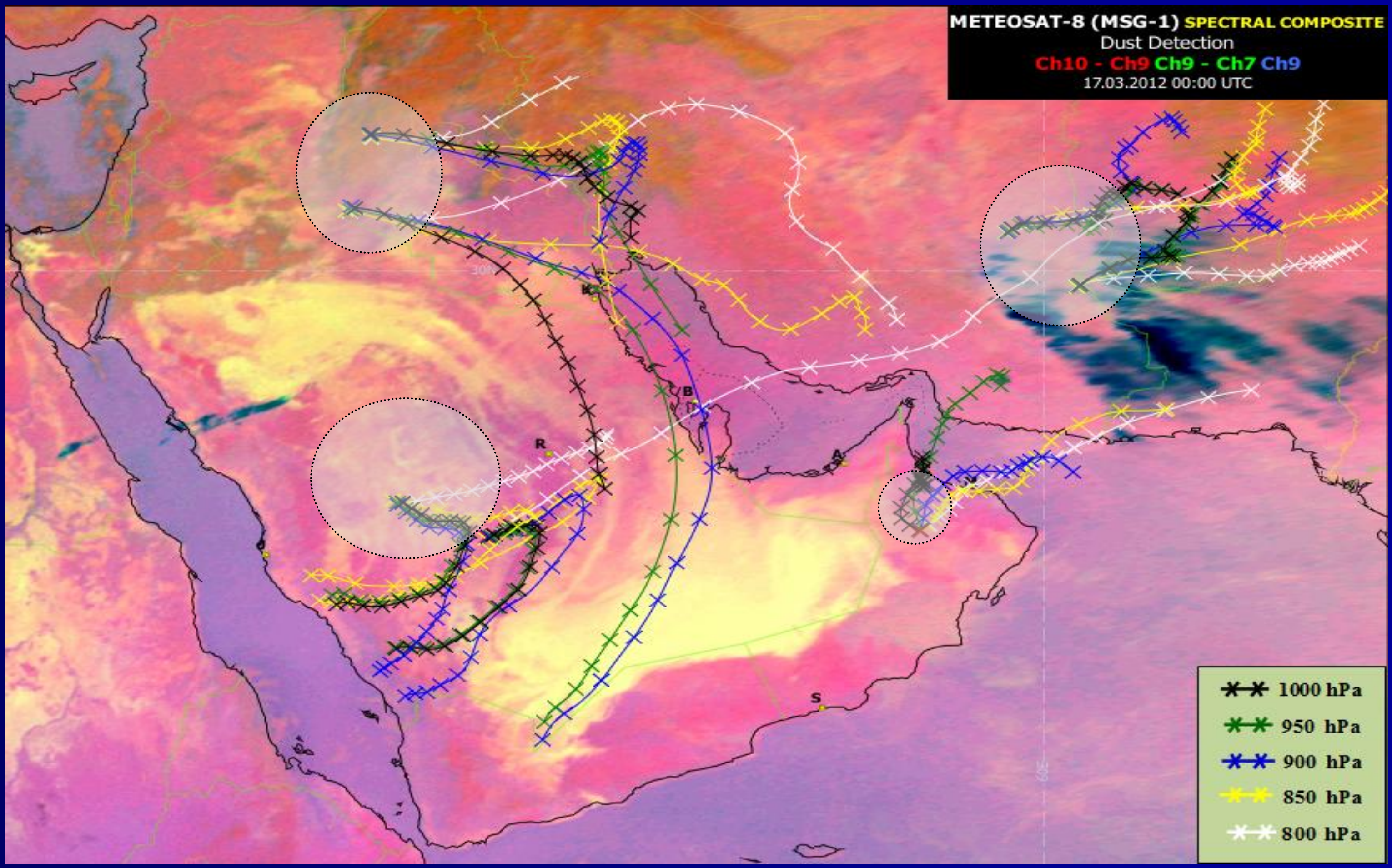


Dust sources surrounding the Arabian Peninsula [Al-Badi, 2006]

Proposed System

- “if Scenario” mode
  - Answer the question “what are the possible paths if a dust storm is generated from one of the sources?”
  - Trajectory is calculated for each dust source after each NWP model run and for different time
- “real time” mode
  - Used to adjust the first guise of the “if scenario” mode.
  - Trajectories are recalculated after dust detection with the correct location

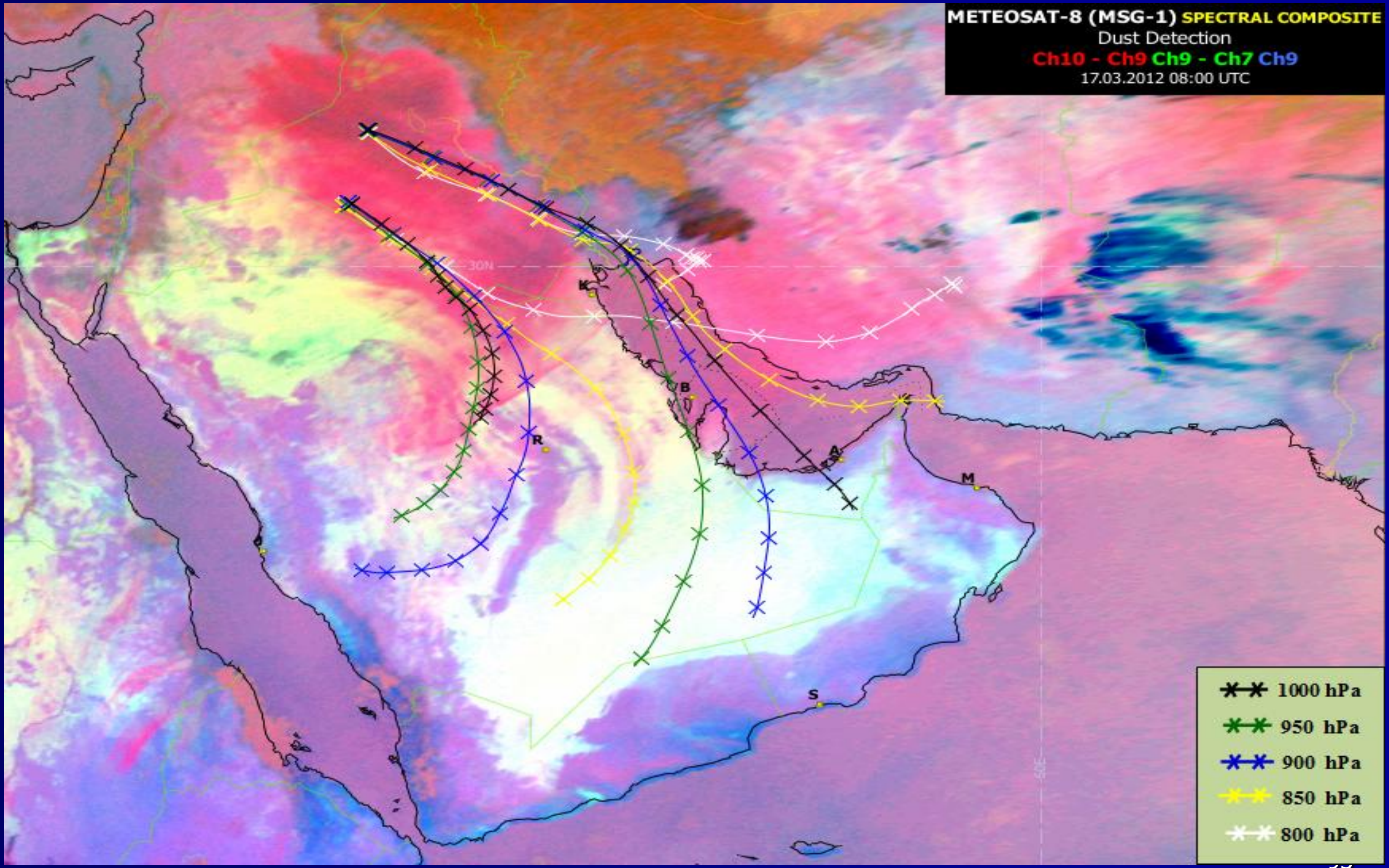
48h forecast "if scenario" for 17/3/2012 00 UTC



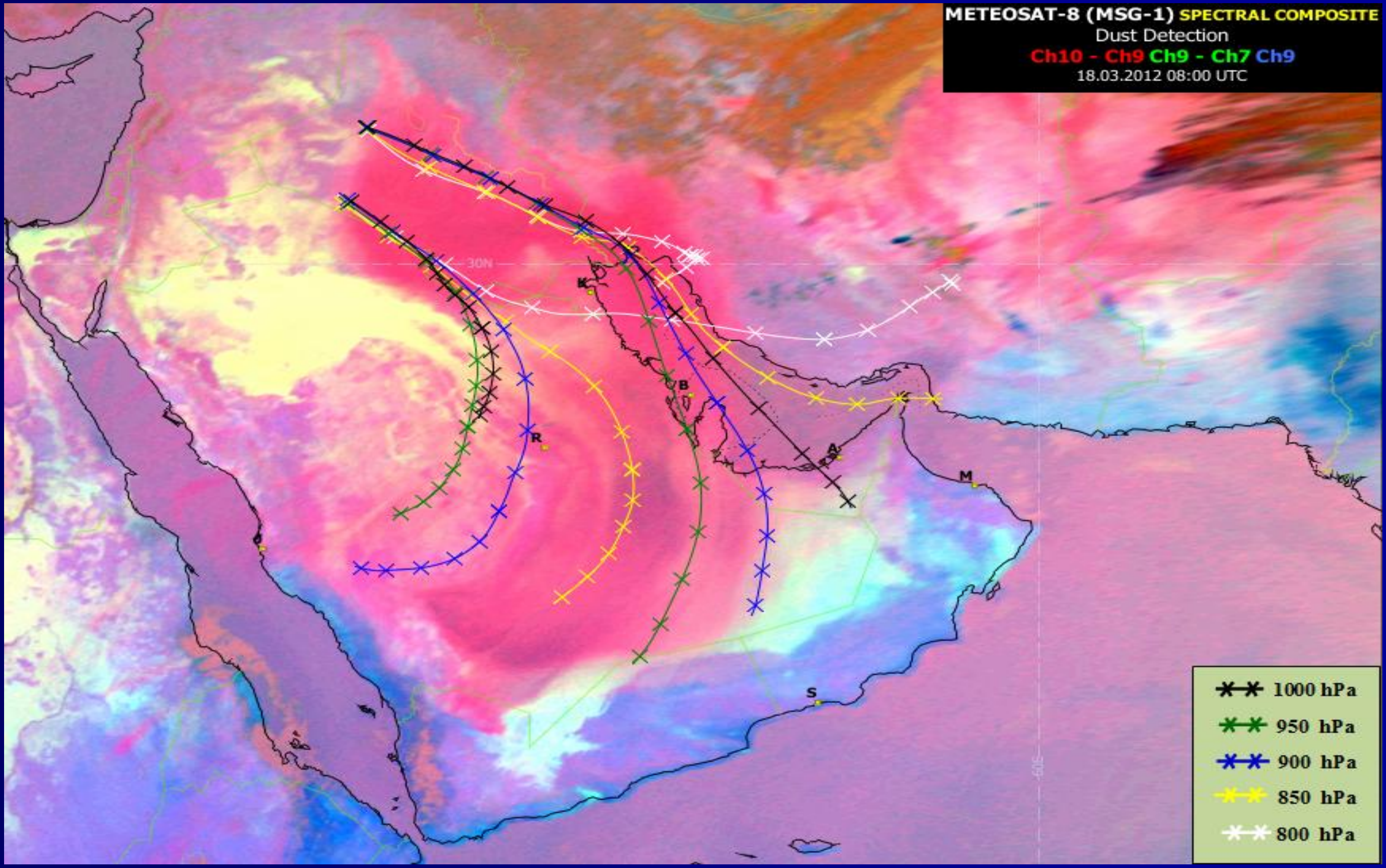
System Validation

Dust Storm 17-19 Mar 2012
Tigris and Euphrates rivers basin

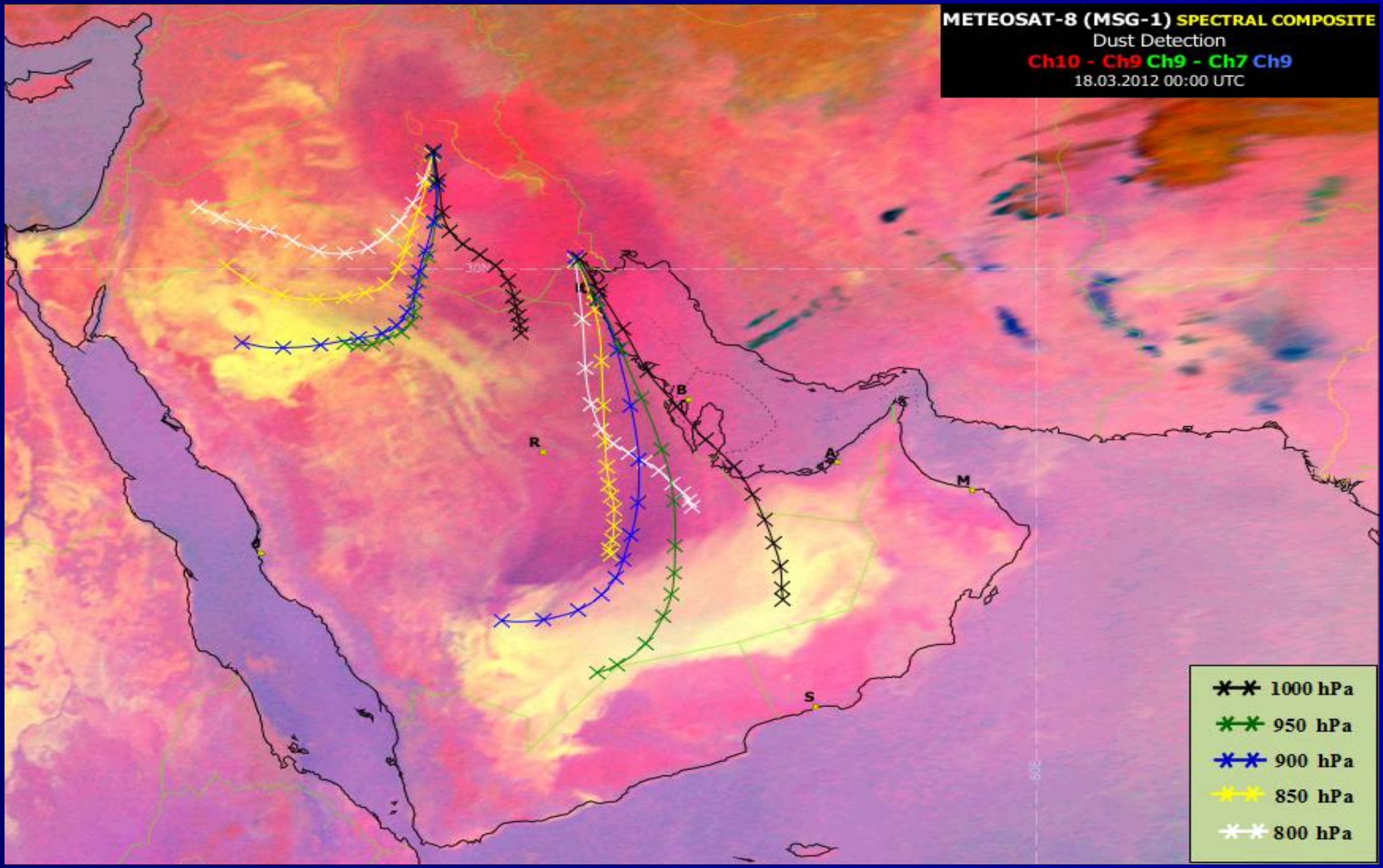
Sat: 17/3/2012 08UTC
Trajectory: 48h based on 17/3/2012 00UTC



Sat: 18/3/2012 08UTC
Trajectory: 48h based on 17/3/2012 00UTC



Sat: 18/3/2012 00UTC
Trajectory: 48h based on 18/3/2012 00UTC



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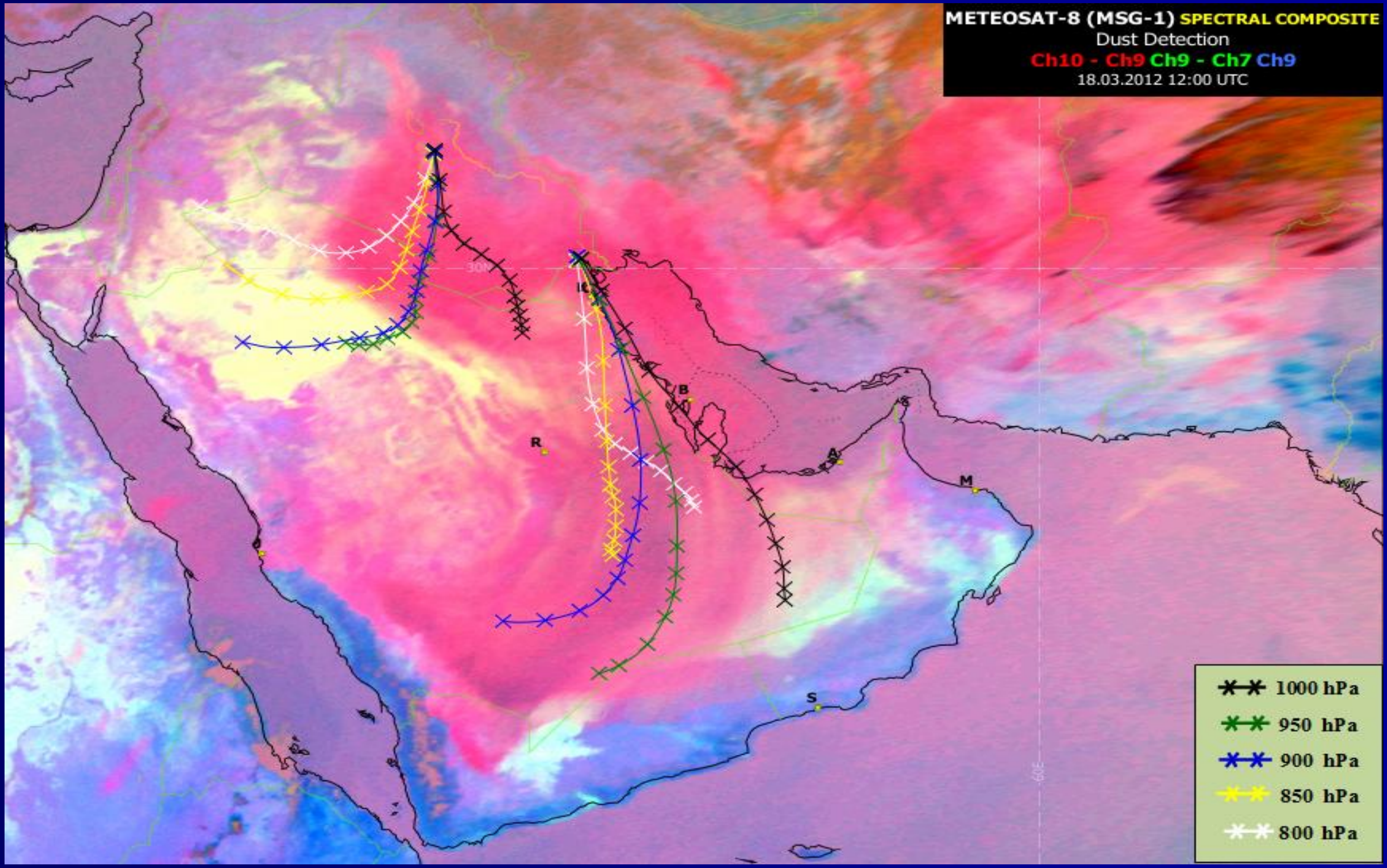
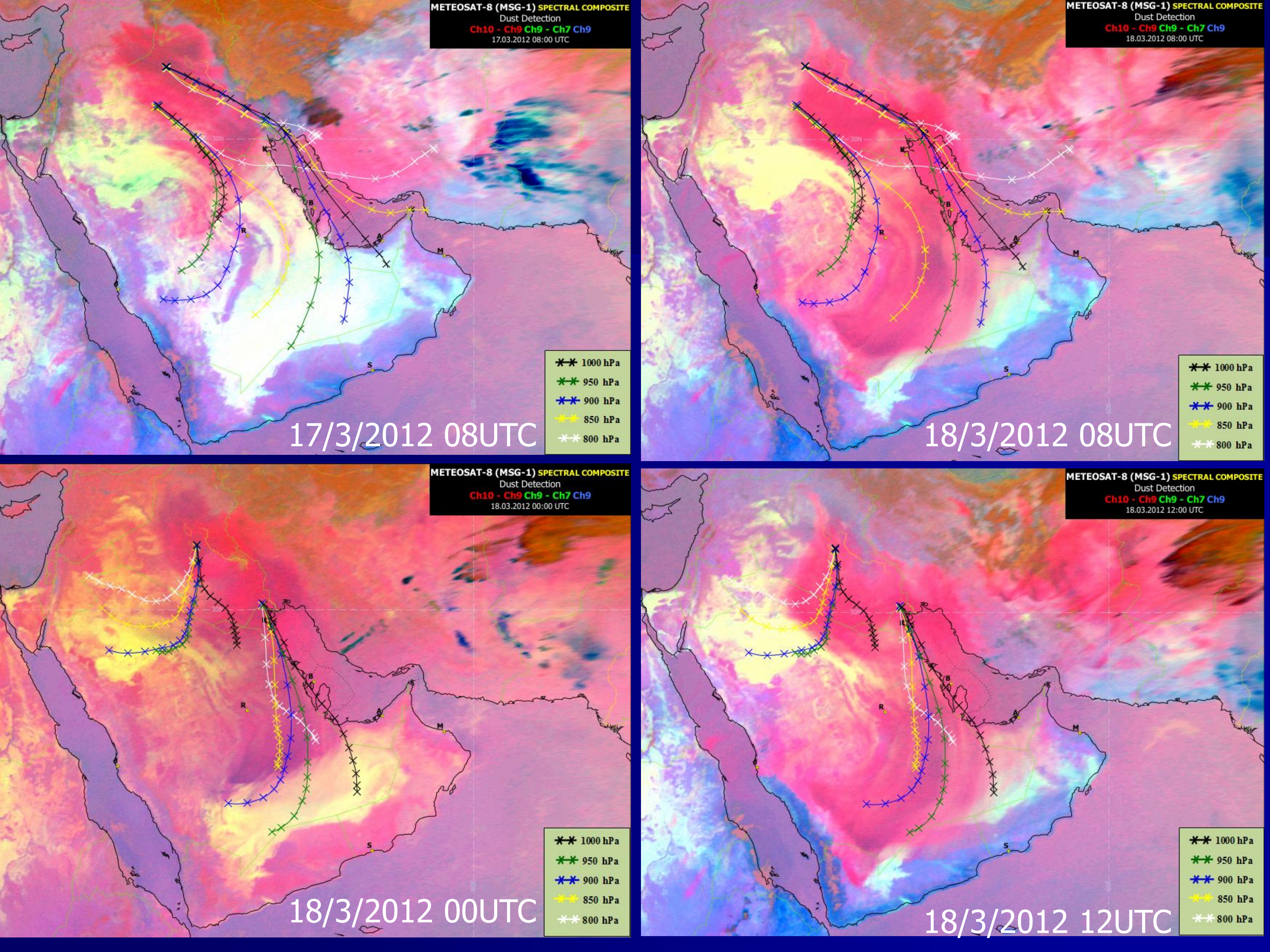
Trajectory: 48h based on 18/3/2012 00UTC

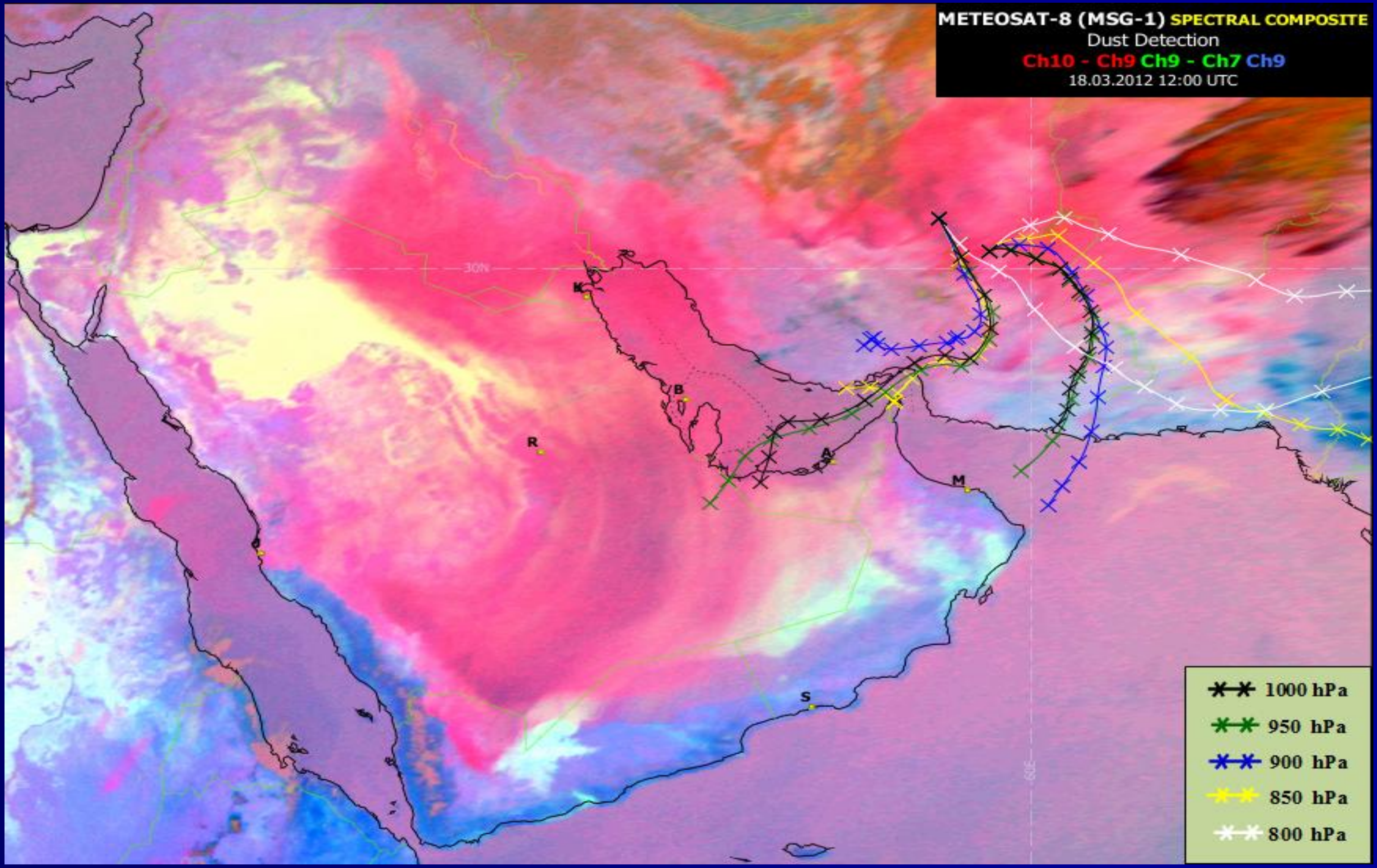



METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
17.03.2012 08:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
17/3/2012 08UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
18.03.2012 08:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
18/3/2012 08UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
18.03.2012 00:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
18/3/2012 00UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
18.03.2012 12:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
18/3/2012 12UTC

System Validation

Dust Storm 18-21 Mar 2012
Sistan and Baloushistan basin

Sat: 18/3/2012 12UTC
Trajectory: 48h based on 18/3/2012 00UTC



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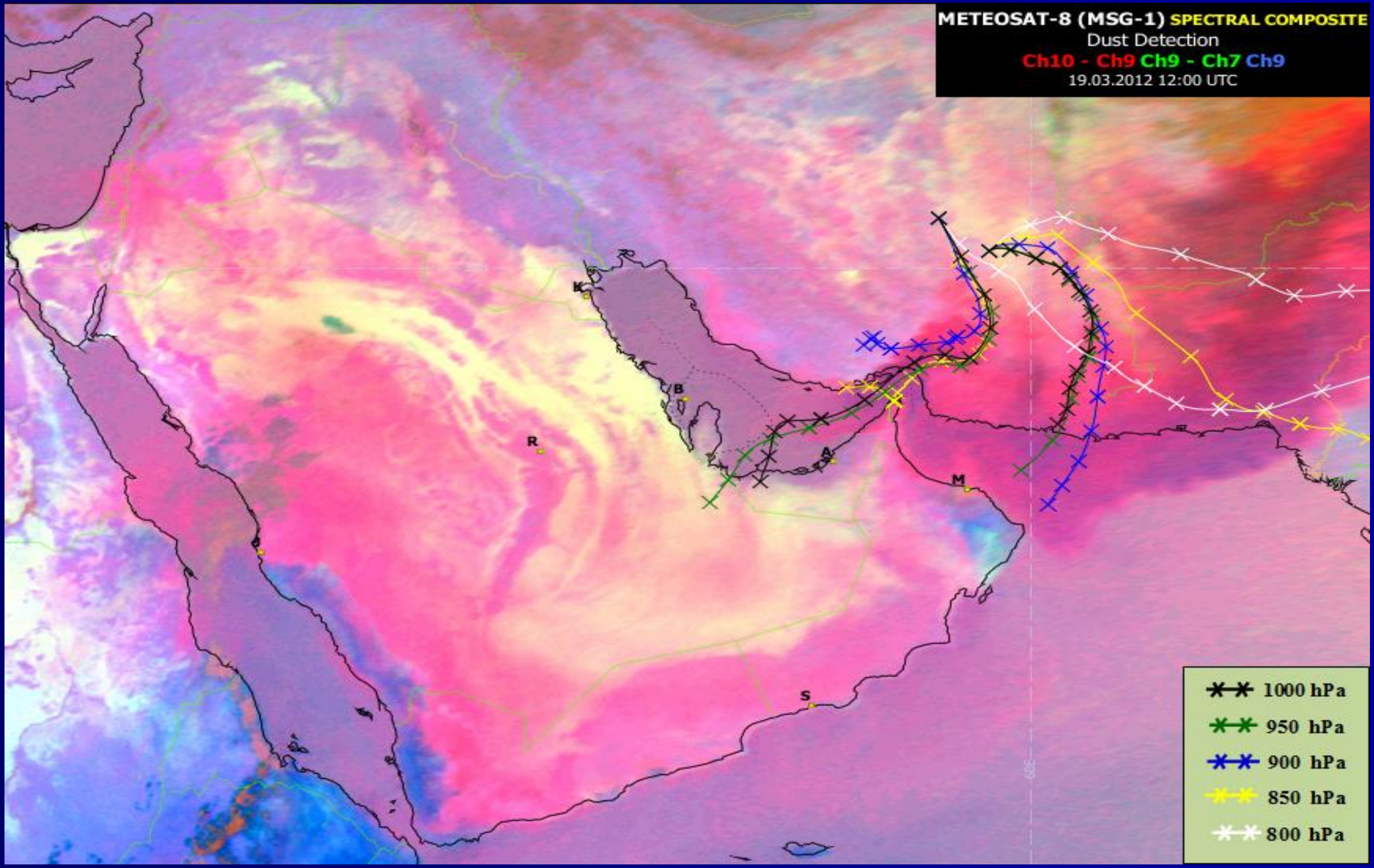
Trajectory: 48h based on 18/3/2012 00UTC



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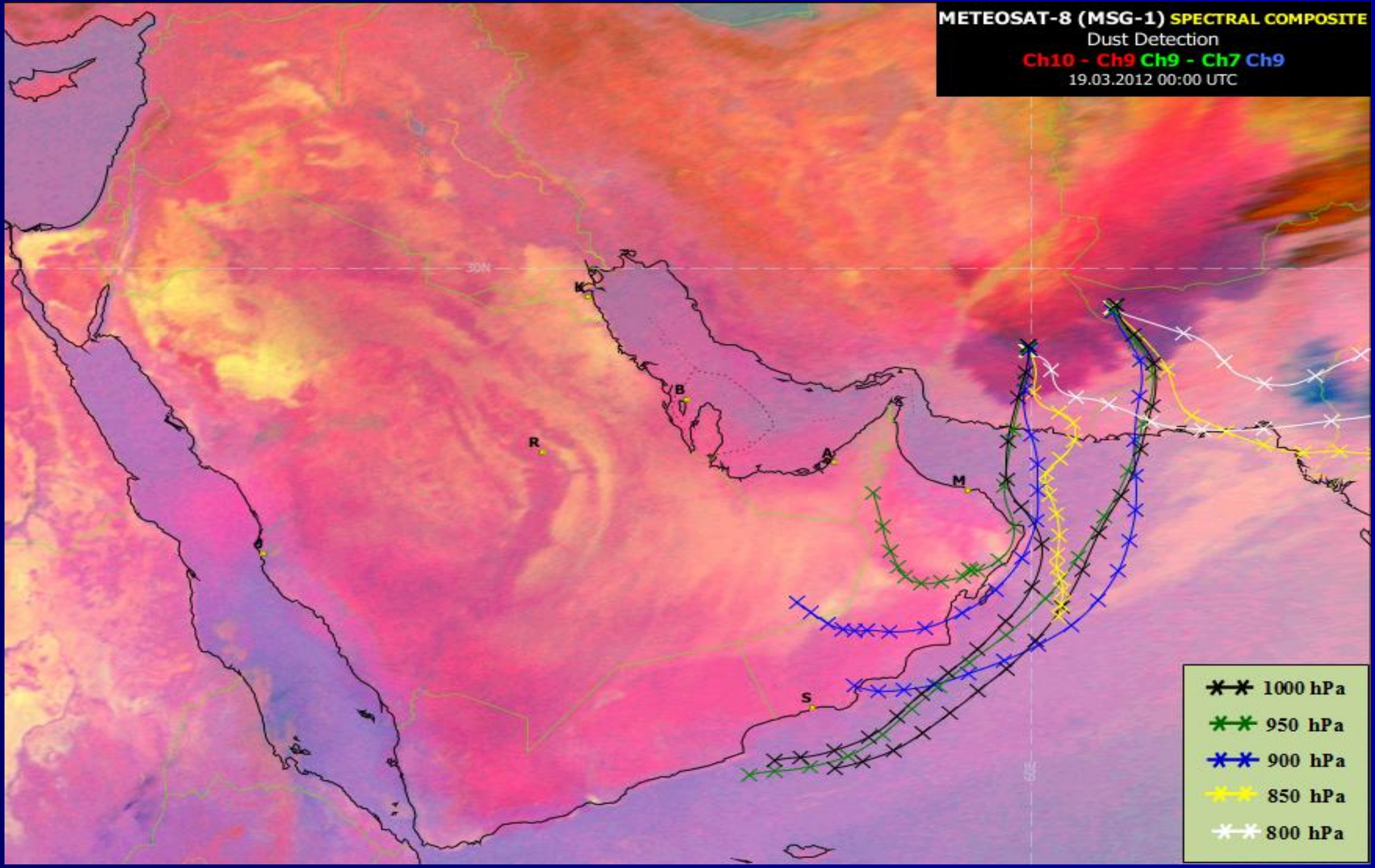

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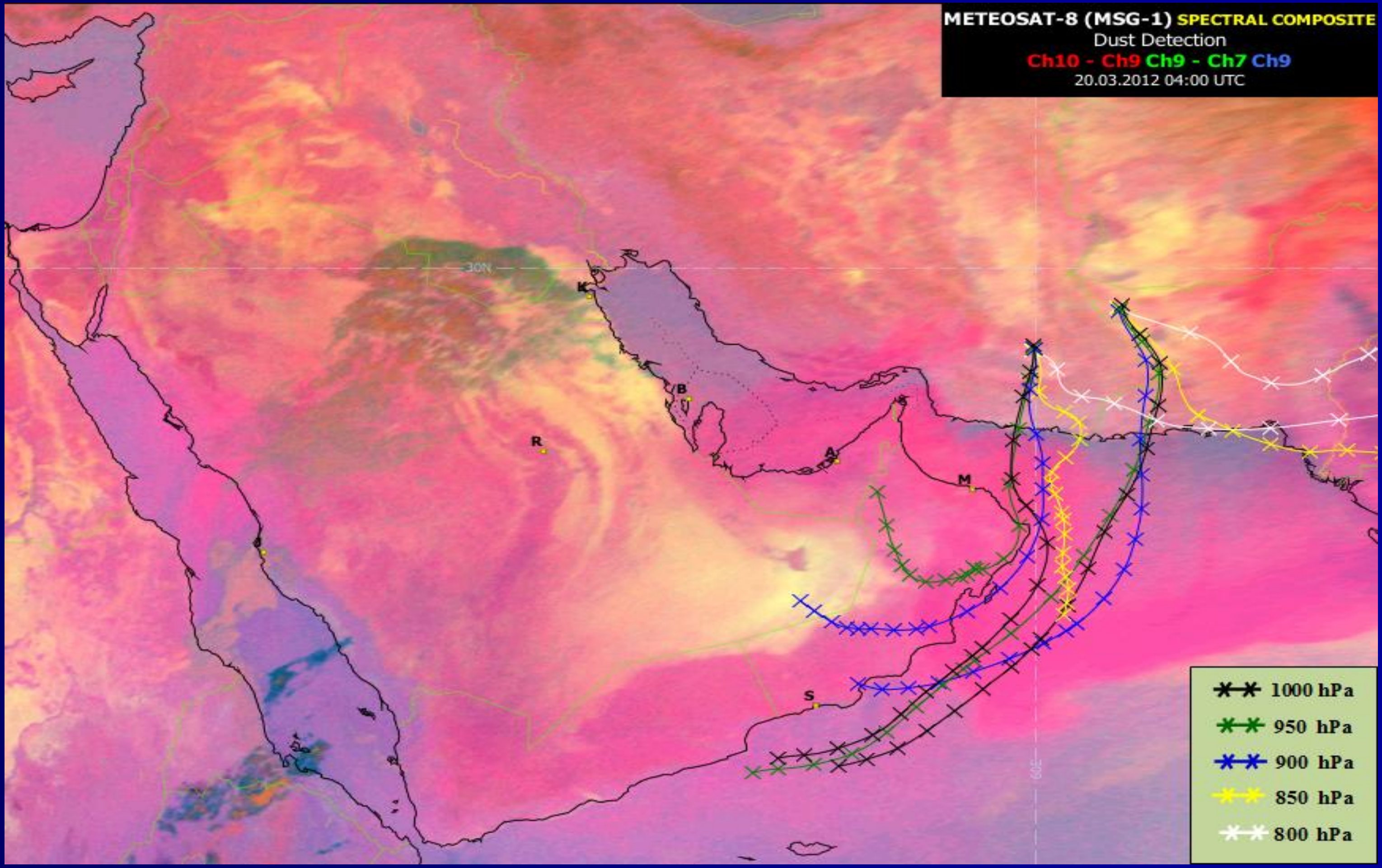

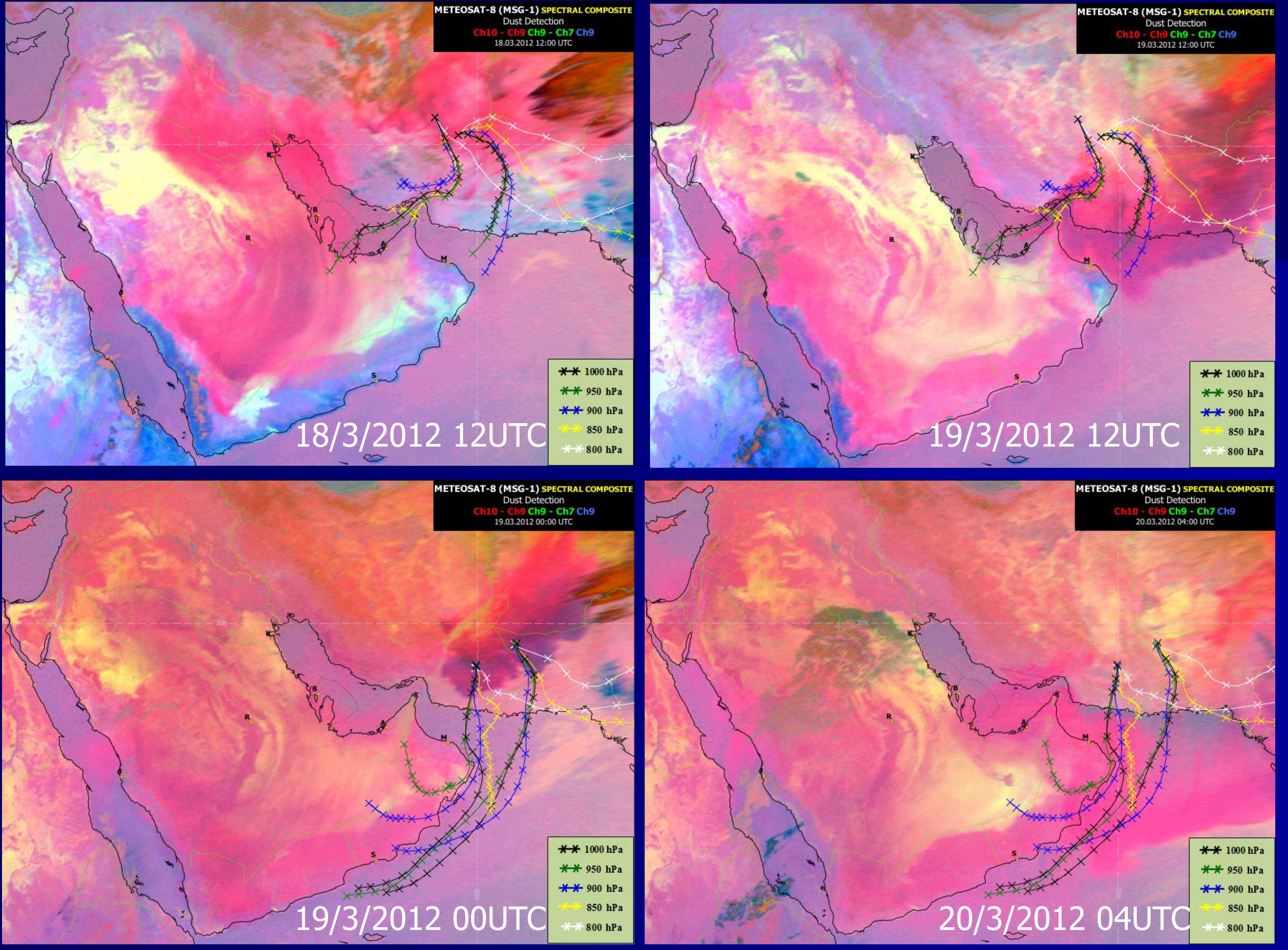
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
18.03.2012 12:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
18/3/2012 12UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
19.03.2012 12:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
19/3/2012 12UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
19.03.2012 00:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
19/3/2012 00UTC
METEOSAT-8 (MSG-1) SPECTRAL COMPOSITE
Dust Detection
Ch10 - Ch9 Ch9 - Ch7 Ch9
20.03.2012 04:00 UTC
1000 hPa
950 hPa
900 hPa
850 hPa
800 hPa
20/3/2012 04UTC

Conclusions

- Trajectory based forecast supporting system was proposed
- The system give a first guess guidance.
- First guess is improved once the dust storm is detected
- Validation results shows good agreement with observation
- The quality of the system is a function of the quality of the NWP model forecast

Thank you for your attention