Numerical Weather Predictions

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Numerical Modelling Section

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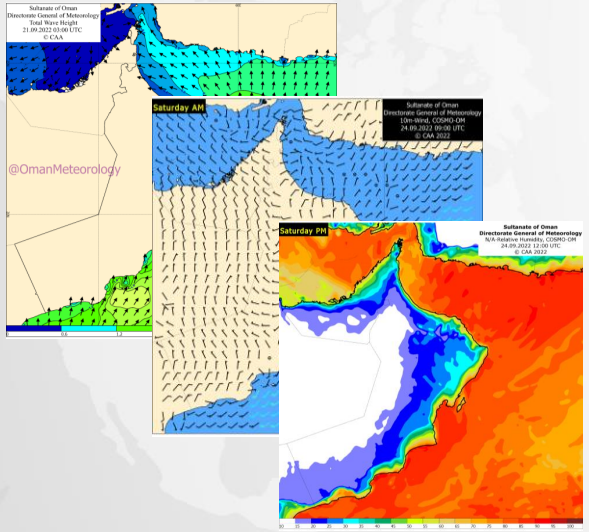
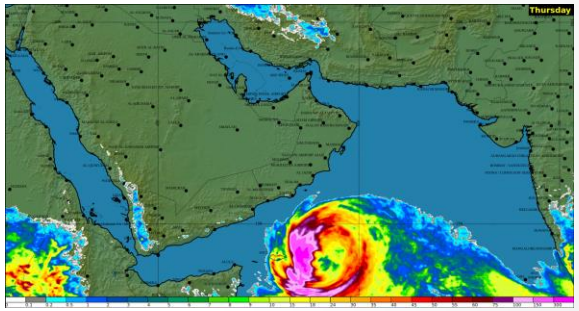
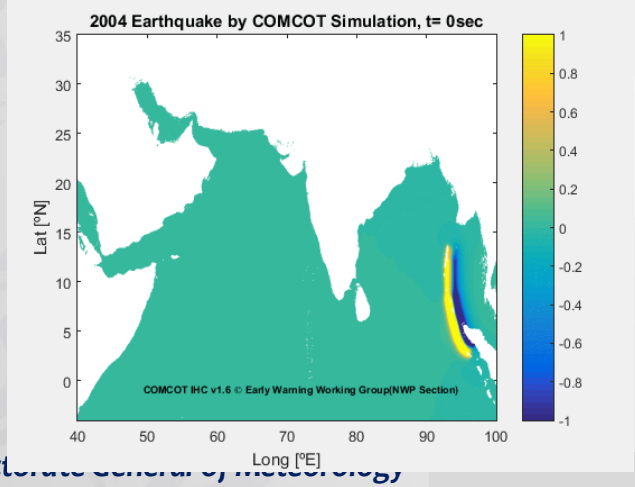
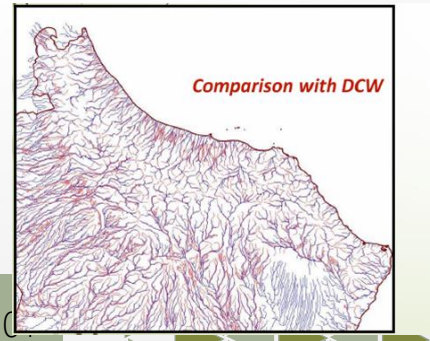
Numerical Weather Prediction

Numerical weather prediction (NWP) is a method of weather forecasting that employs a set of equations that describe the flow of fluids. These equations are translated into computer code and use governing equations, numerical methods, parameterizations of other physical processes and combined with initial and boundary conditions before being run over a domain (geographic area). The most important tool for weather forecasting around the world.









Numerical Weather Forecast Model (governing equations)

Momentum equations

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial x} + fv$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial \rho}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial y} - fu$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

Thermodynamic equation

$$\frac{\partial \theta}{\partial t} = -u\frac{\partial \theta}{\partial x} - v\frac{\partial \theta}{\partial y} - w\frac{\partial \theta}{\partial z} + \dot{Q}$$

Mass continuity equation

$$\frac{\partial \rho}{\partial t} = -u\frac{\partial \rho}{\partial x} - v\frac{\partial \rho}{\partial y} - w\frac{\partial \rho}{\partial z} - \rho\nabla\cdot\vec{V}$$

Moisture equation

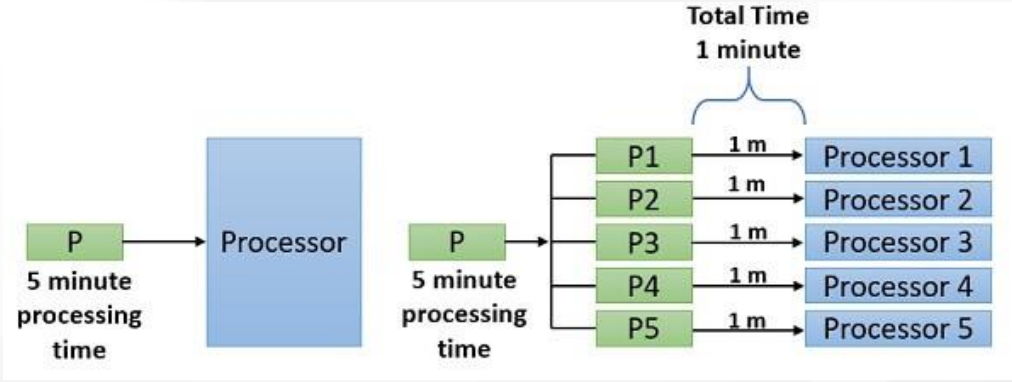
$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - w\frac{\partial q}{\partial z} + micro(q)$$

Ideal gas law

$$p = \rho RT$$

What is HPC?

- Definition: High-Performance Computing refers to the use of supercomputers and parallel processing techniques to solve complex computational problems.
- Key Points:
  - Enables solving complex problems faster.
- Used in various fields like weather forecasting, drug discovery, and engineering simulations.



Supercomputer Examples

- **Location:** Oak Ridge National Laboratory — Tennessee, U.S.
- **Performance:** 1,194 petaFLOPS (1.2 exaFLOPS) =
- **Components:** AMD EPYC 64-core CPUs and AMD Instinct MI250X GPUs
- **First online:** August 2022

1 petaFLOPS is equal to 1,000,000,000,000,000 FLOPS

Supercomputers can be one million times more processing power than the fastest laptop.

Your laptop might have one central processing unit (CPU) and one graphics processing unit (GPU), but one supercomputer may have thousands upon thousands of CPUs and GPUs

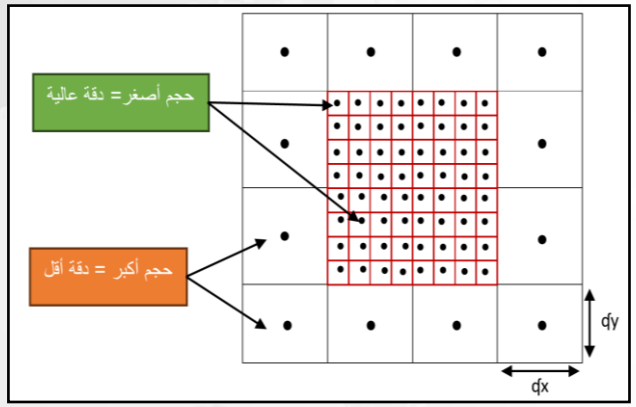
Supercomputer Examples

A PS3 supercomputer at UMass Dartmouth. Photo by Gaurav Khanna / UMass Dartmouth

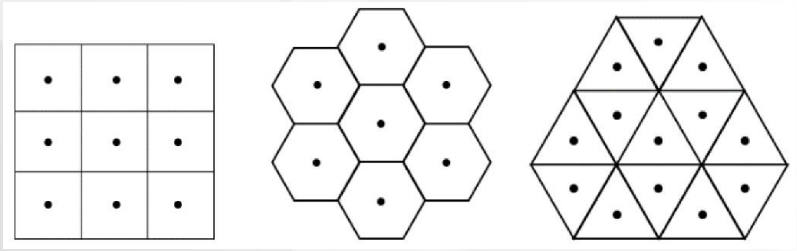
Basic Principals in NWP

مفاهيم أساسية في التنبؤات العددية

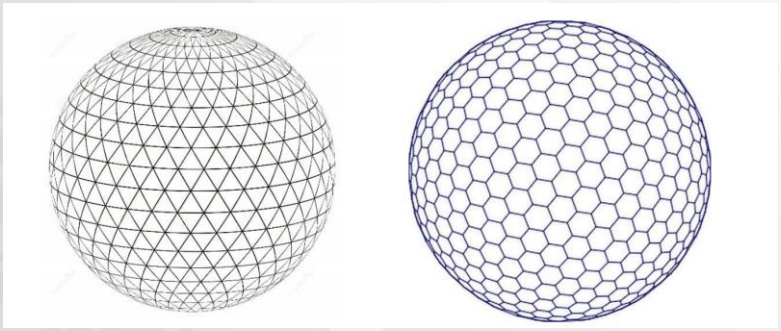
Grid point النقاط الشبكية



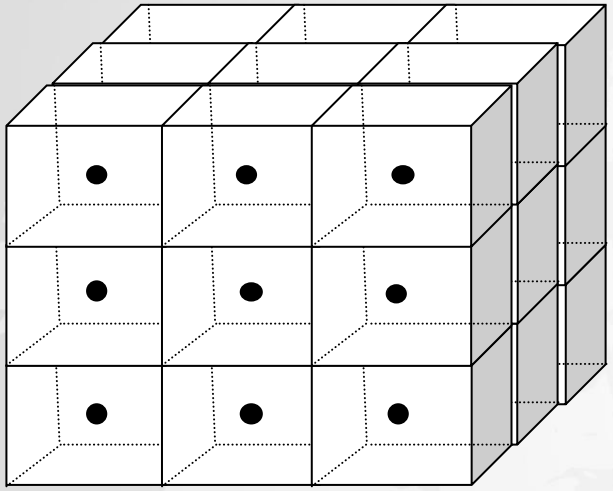
The models divide the area of interest into a set of grids, the importance of the number of discrete grid points in order for the model to best represent the atmospheric structures. There are different grid shapes used in numerical models; e.g., rectangular, triangular, and hexagonal



هي نقاط منفصلة وتمثل هيكل النموذج العددي لمنطقة معينة او لكل الكرة الأرضية، يتم فيها حل معادلات الطقس لتمثيل حالة الغلاف الجوي بالشكل الأفضل. عندما يكون النموذج العددي عالي الدقة فإنه يتطلب المزيد من النقاط الشبكية. أمثلة عليها: المستطيلة/ المربعة، والمثلثة، والسداسية.



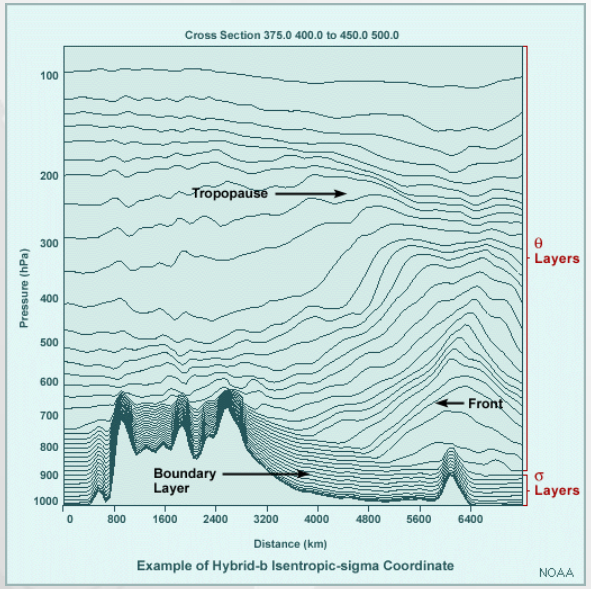
Spatial Resolution الدقة المكانية

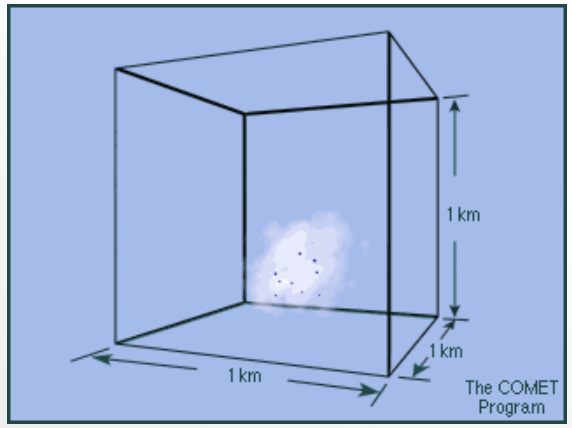


3D cubes of the atmosphere used by NWP models

A grid point model's resolution is defined as the average distance between adjacent grid points with the same variables.

يتم تقسيم الغلاف الجوي الى نقاط بشكل افقي و عامودي
المسافة بين النقاط هي التي تحدد مستوى الدقة في النماذج العددية
كل النقاط تحتوي على كل المعلومات اللازمة لتشغيل النماذج العدية

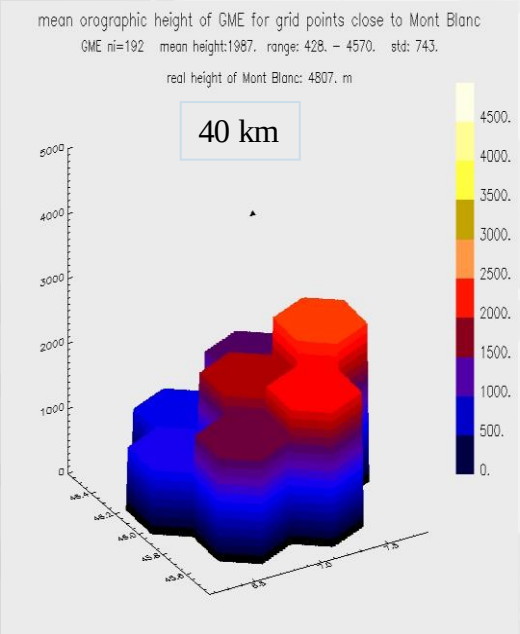


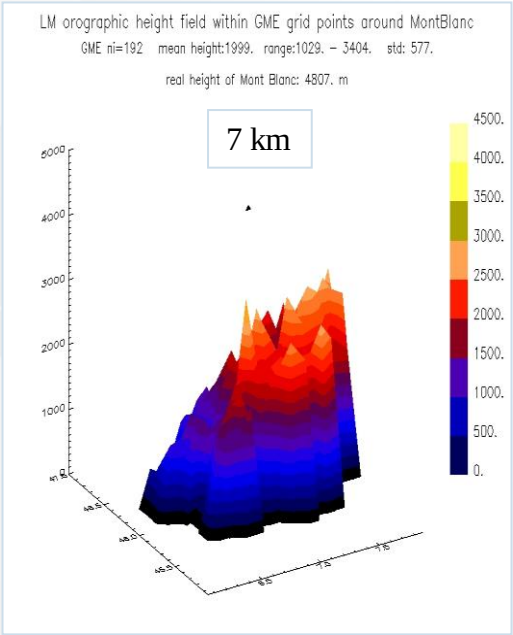


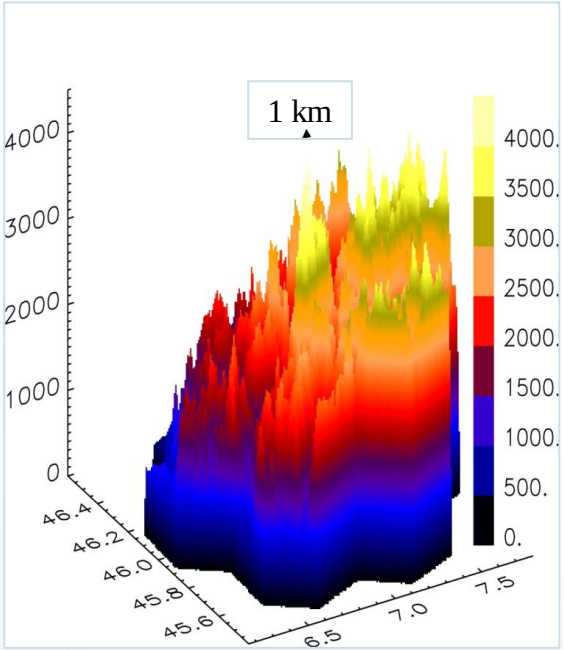
1. الدقة الأفقية **Horizontal Resolution**
2. الدقة الرأسية **Vertical Resolution**

Spatial Resolution الدقة المكانية

Orography



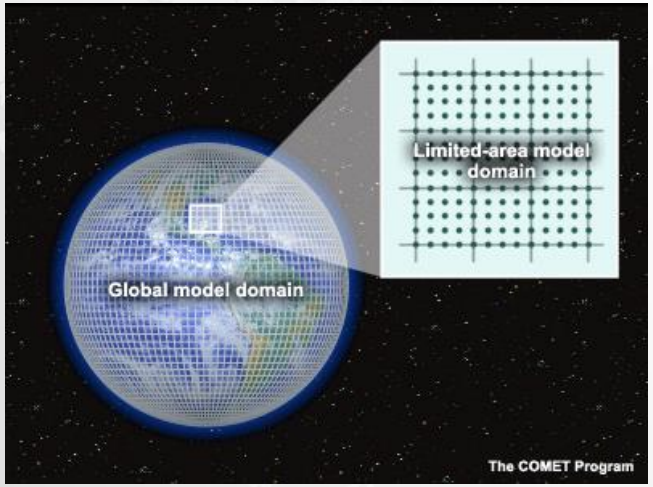




Constant Data

orography is a fundamental aspect of NWP that significantly influences weather patterns and forecasting accuracy, particularly in regions with complex terrain. Advances in model resolution, parameterizations, and Computational capabilities continue to improve the representation and impact of orography in weather prediction models.

Domain and Boundary Conditions النطاق والبيانات الحدودية



Domain and Boundary Conditions

Model domain refers to a model's area of coverage. Limited-area models have horizontal and vertical boundaries, whereas global models, which by nature cover the entire earth.
Boundary conditions are a function of surface physics parameterizations.

نطاق النموذج هو منطقة تغطية النموذج. النماذج ذات المساحة المحدودة LAMلها حدود، في حين أن النماذج العالمية Global Models فهي تغطي الأرض بأكملها.

Parameterization المعلمات

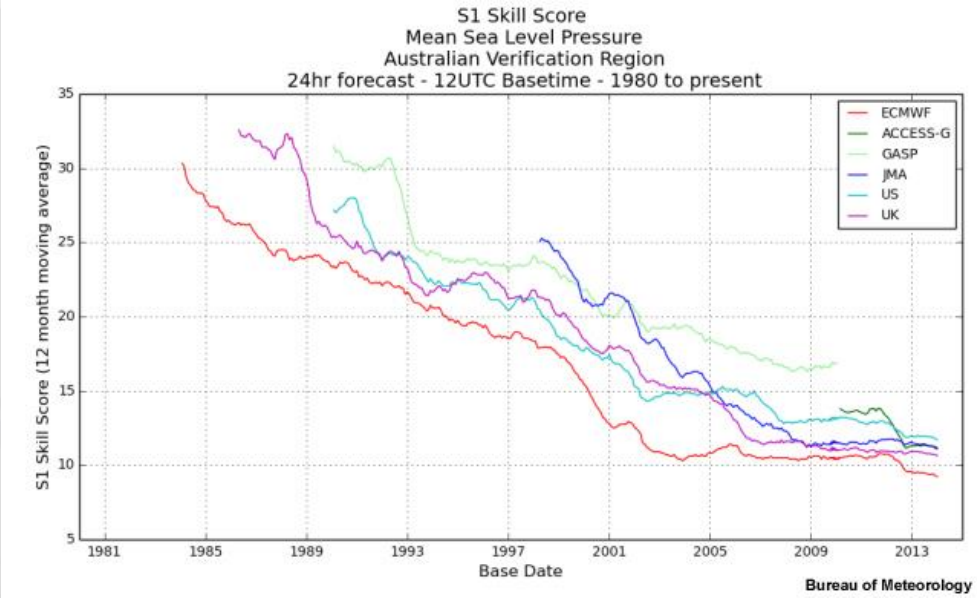
A model cannot resolve any of these local flows, swirls, or obstacles if they exist within a grid box. The method of accounting for such effects without directly forecasting them is called **parameterization**.

في هذا المثال يتضح التدفق المعقد حول المباني:

1. الاحتكاك أو القوة المقاومة الذي تسببه الأشجار العالية
2. دوامات هوائية تنشأ حول المباني
3. الاحتكاك أو القوة المقاومة السطحية

لذلك لا يمكن للنموذج حل أي من التدفقات المحلية أو الدوامات الهوائية المحلية أو العوائق إذا كانت موجودة داخل شبكة النموذج العددي. ومع ذلك، يجب أن يأخذ النموذج في الاعتبار التأثير الإجمالي باستخدام طريقة حساب هذه التأثيرات دون التنبؤ بها بشكل مباشر بالمعاملات.

Uncertainty عدم اليقين (نسبة الخطأ)



Smaller numbers indicate greater skill

كل ما قلت القيمة زادت دقة النموذج

NWP models are representations of the atmosphere. They are always wrong. The issue is not whether or not a model is 100% correct, but they have skill.

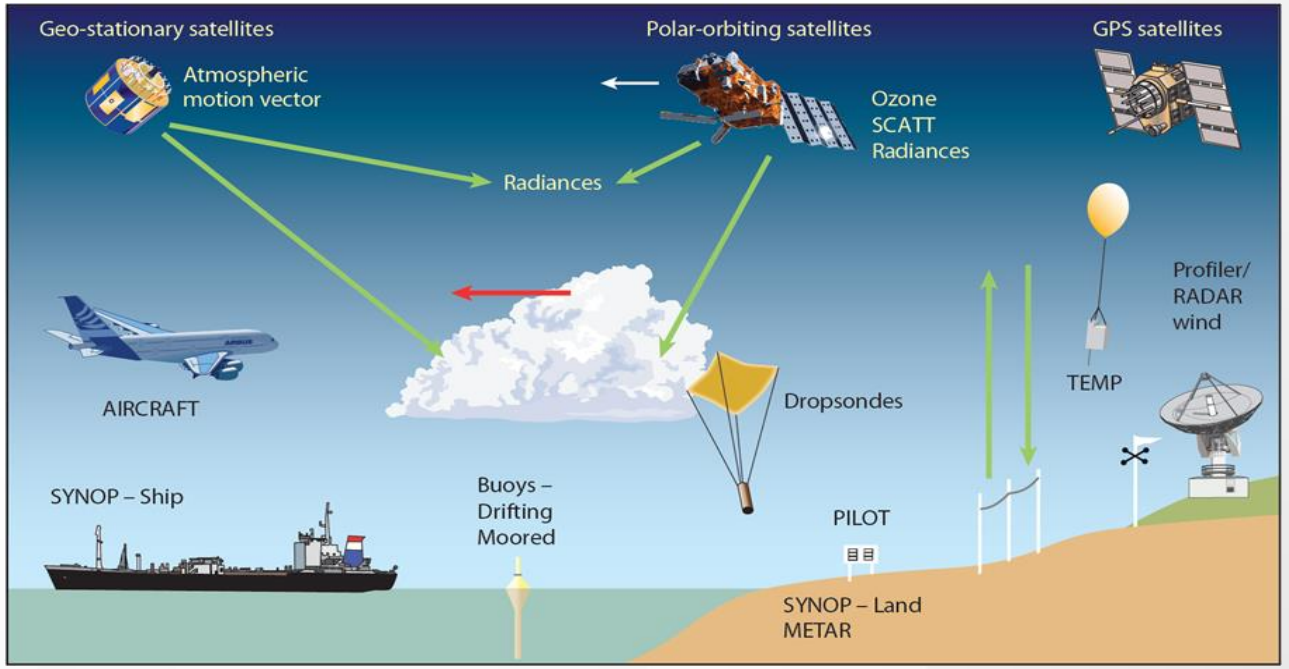
النماذج العددية تمثل الغلاف الجوي. لذلك لا يوجد نموذج صحيح بنسبة 100%
ولكن هناك نسبة خطأ يتم من خلالها معرفة النموذج الأقرب للواقع.

Initial Data البيانات الأولية

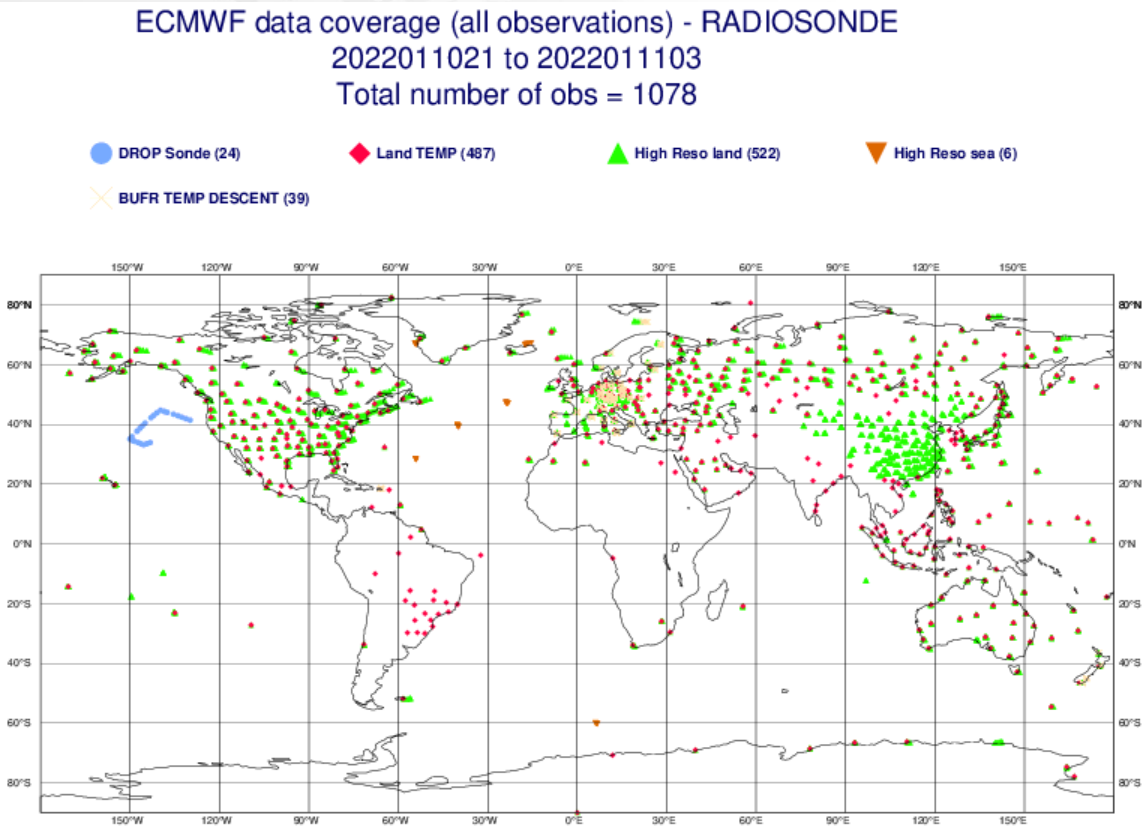
- The **actual situation** used by the model to start integrate equations.

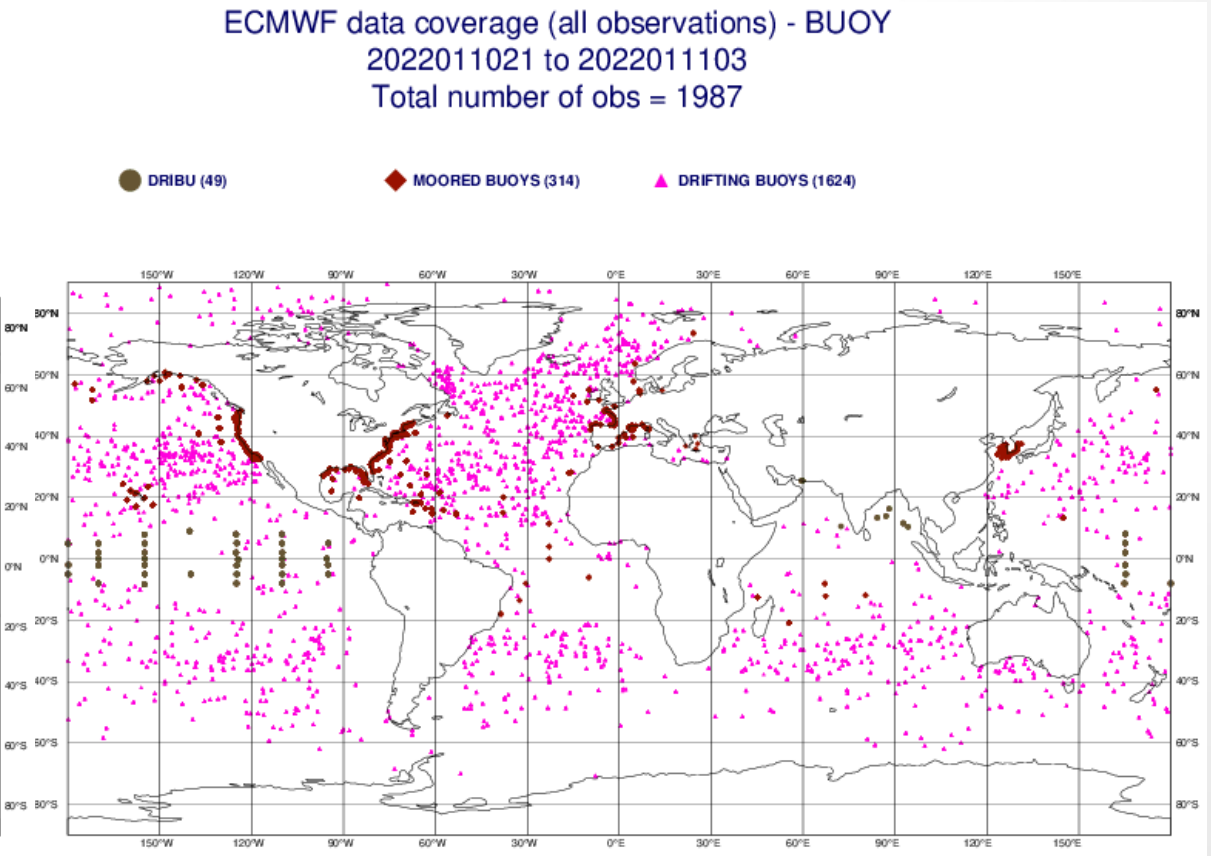
- It is created by techniques called **data assimilation**.
- The information used to create initial data are:
  - **GTS data** (Conventional observations) :

  SYNOP, SHIP, BUOY, TEMP, PILOT, AMDAR,…)
- 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**.

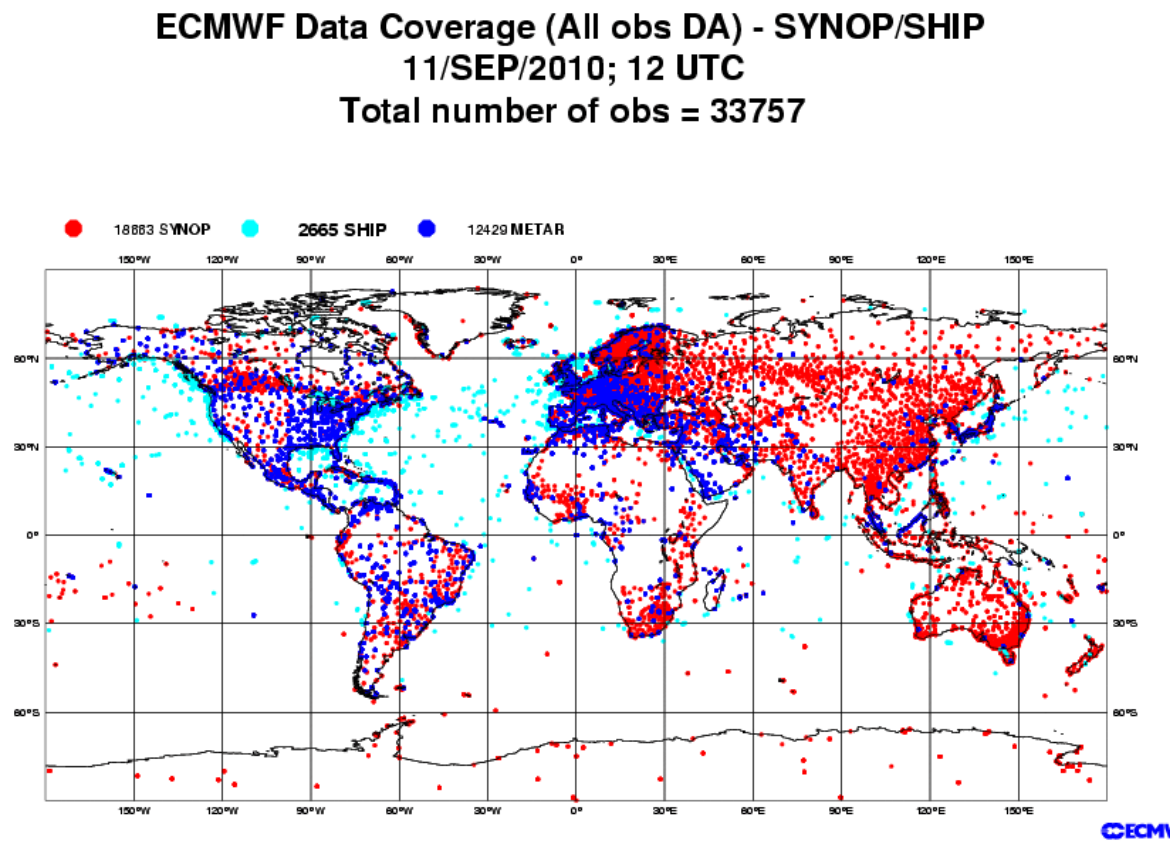


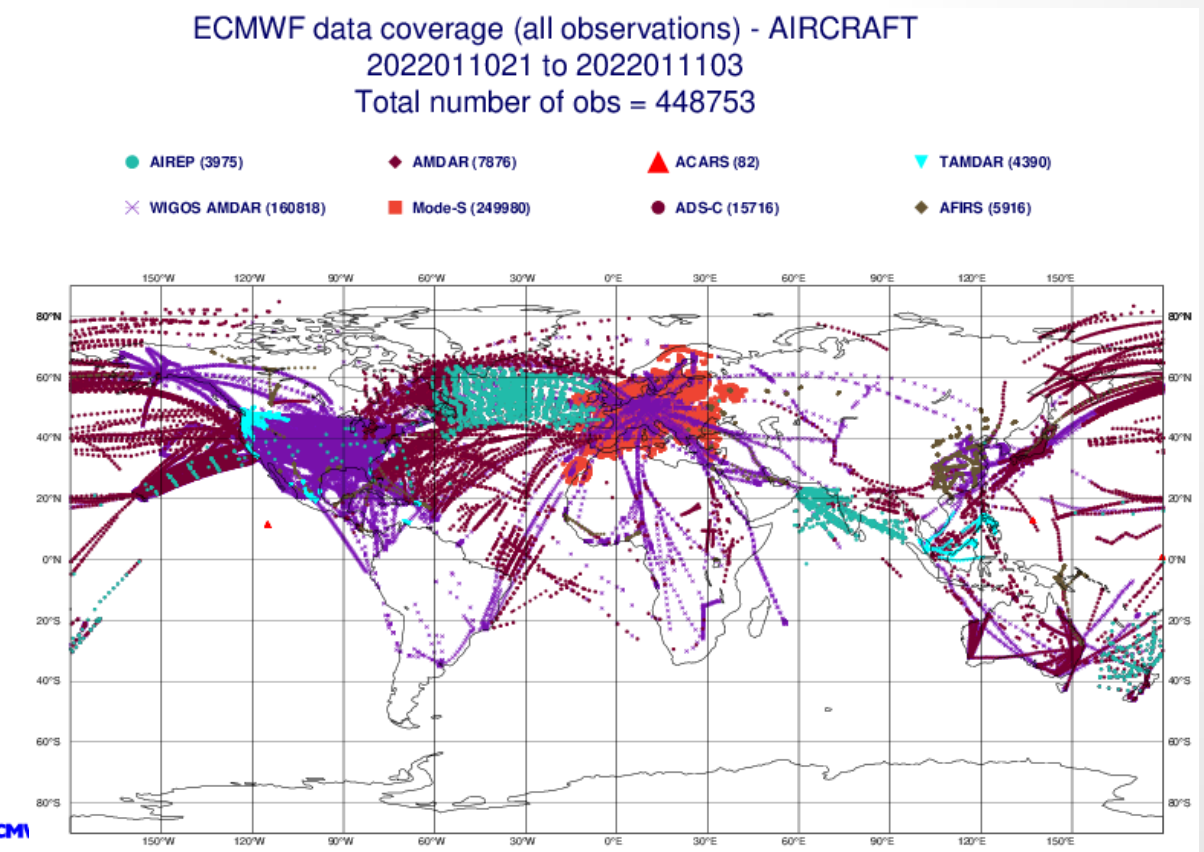
Initial Data البيانات الأولية





Initial Data البيانات الأولية





Sources of Model Error أهم مصادر الخطأ في النموذج

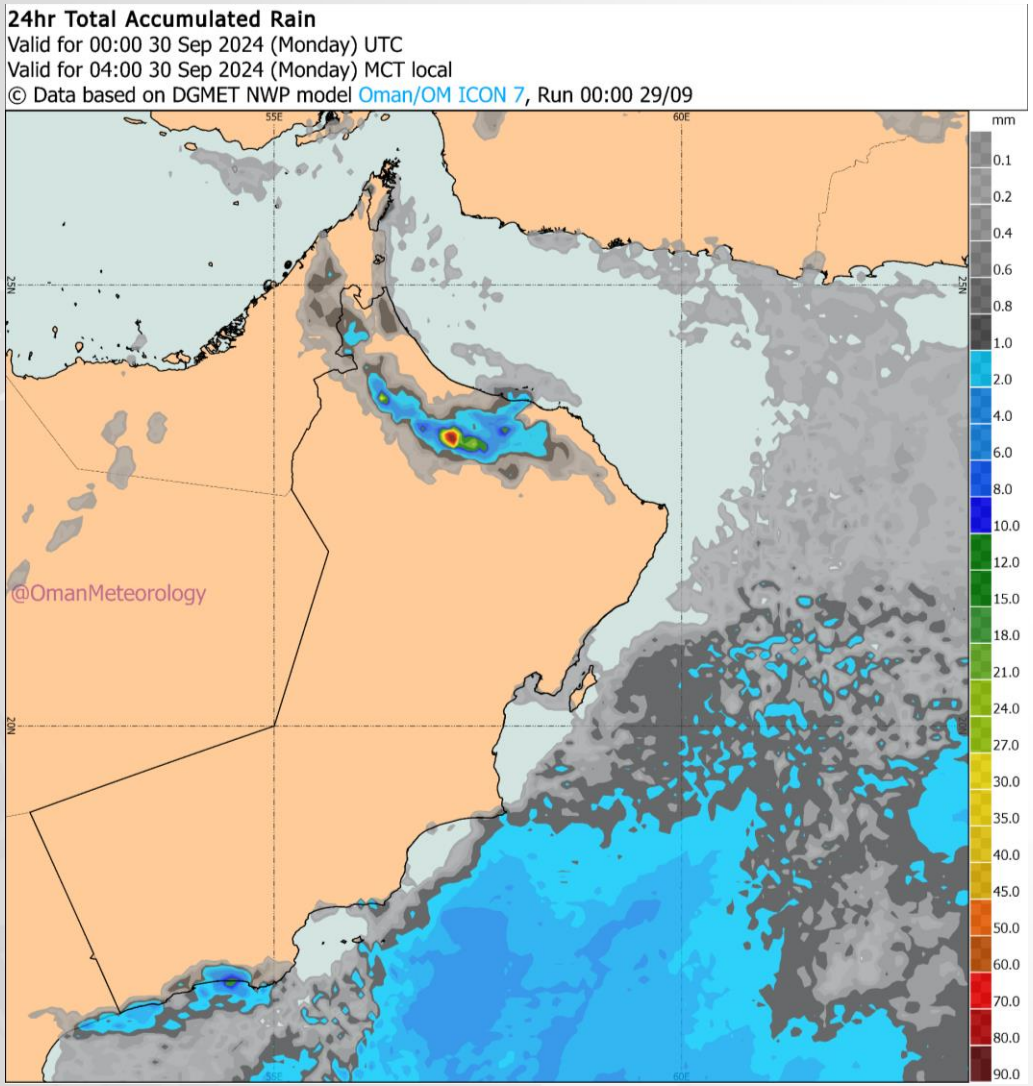
1. Errors in initial conditions
   - Inadequate spatial density
   - Instrument error/data transmission problems
   - Quality control errors

1. أخطاء في البيانات الأولية
   - توزيع وتغطية الرصدات غير كافي.
   - عدد الرصدات خلال اليوم غير كافي.
   - أخطاء فنية في الأجهزة / مشاكل في نقل البيانات.
   - أخطاء في ضبط الجودة.

2. Errors in the model
   - Boundary conditions
   - Inadequate terrain representation
   - Large-scale precipitation processes not well estimated
   - Shortcomings of convective parameterizations

2. أخطاء في النموذج العددي وتتضمن:
   - خطأ في البيانات الحدودية.
   - تمثيل التضاريس غير دقيق.
   - عمليات هطول الأمطار واسعة النطاق لم يتم تقديرها بشكل جيد.
   - أوجه القصور في المعلمات.

أساسيات الخرائط العددية
NWP Maps Basics



NWP Maps basics information:

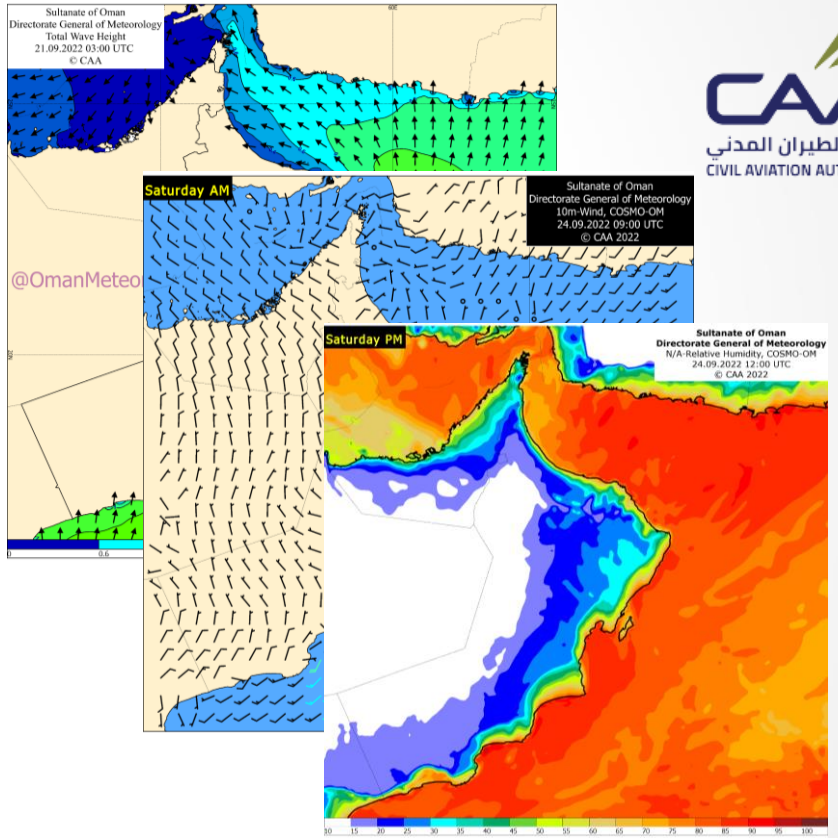
1. Parameter Name + unit
2. Layer Height
3. Run Time
4. Validity Time
5. Model Name and Resolution
6. Colour Scale (if applicable)

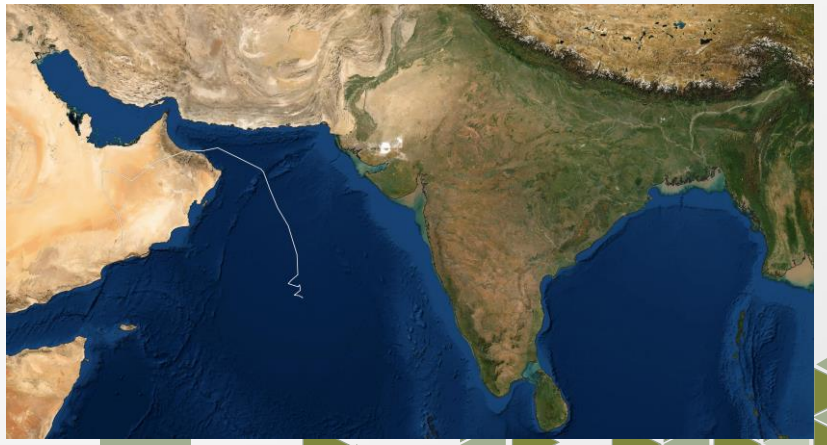
خرائط مُخرجات نماذج الطقس العددية تأتي بمعلومات والتي من دونها ستكون مبهمة للمُستخدم وأهمها:

1. اسم العُنصر ووحدة القياس.
2. ارتفاع الطبقة سواء كان بمستويات الضغط أم بالمتر.
3. تاريخ وساعة التشغيل.
4. وقت الصلاحية.
5. اسم النموذج والدقة المكانية.
6. دليل الألوان إن وُجِد تدرج.

Numerical Models

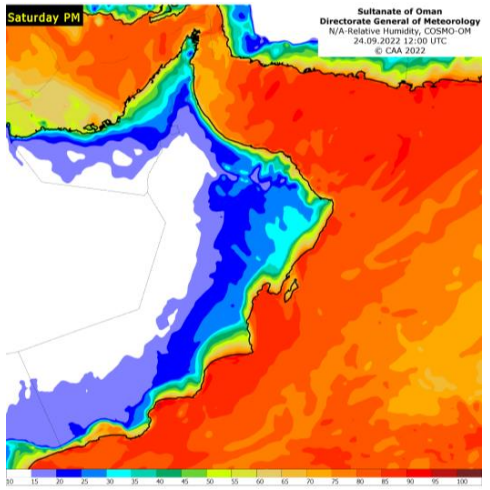
- Weather Models
- Wave Models
- Ocean Models
- Tsunami Models
- Flash Flood Models
- Search and Rescue Model
- Dispersion Models

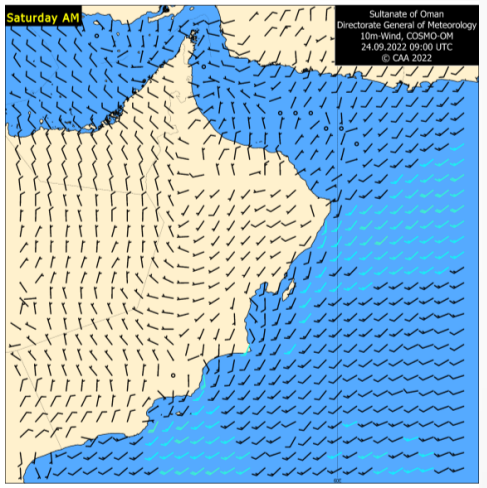




Weather Models

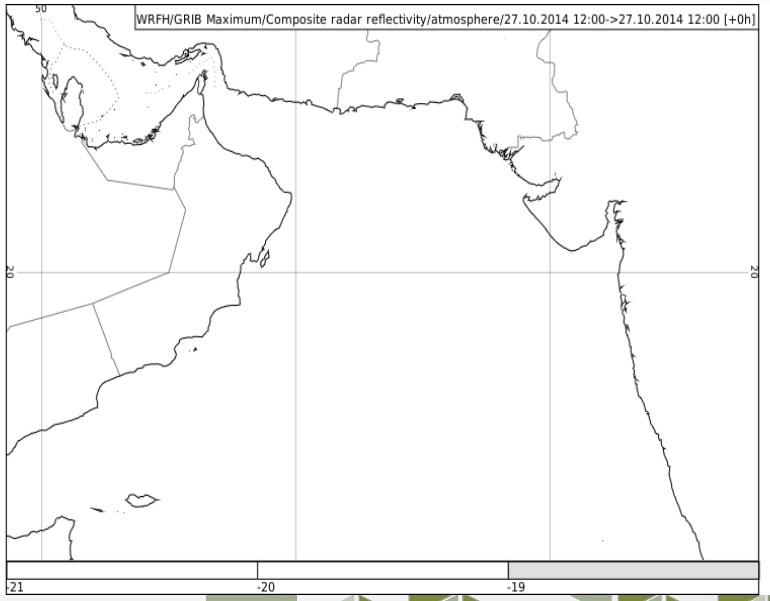
- Temperature
- Wind
- Precipitation
- Humidity





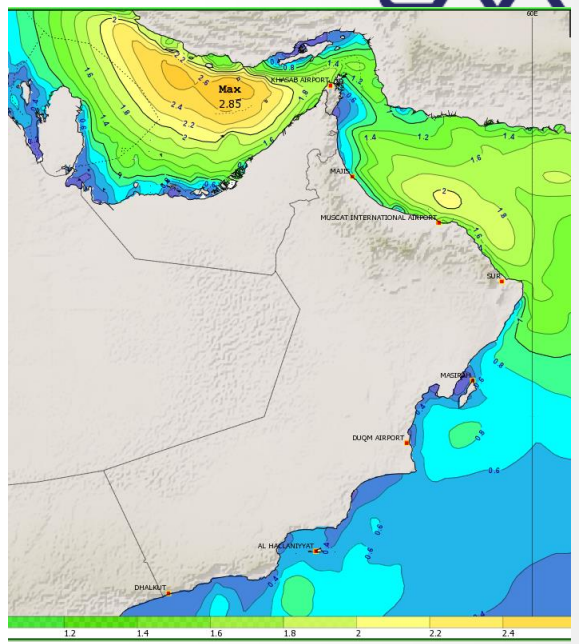
* Provide many outputs for Tropical Cyclone:

- Possible Tracks
- Tropical Cyclone strength
- Arrival time
- Rainfall amounts



Sea and Ocean Models

- Numerical models provide detailed predictions of sea conditions, such as: wave height, surface wind speed, and the time period between waves.
- It directly serves fishermen and maritime traffic, as well as all maritime activities such as competitions and others.



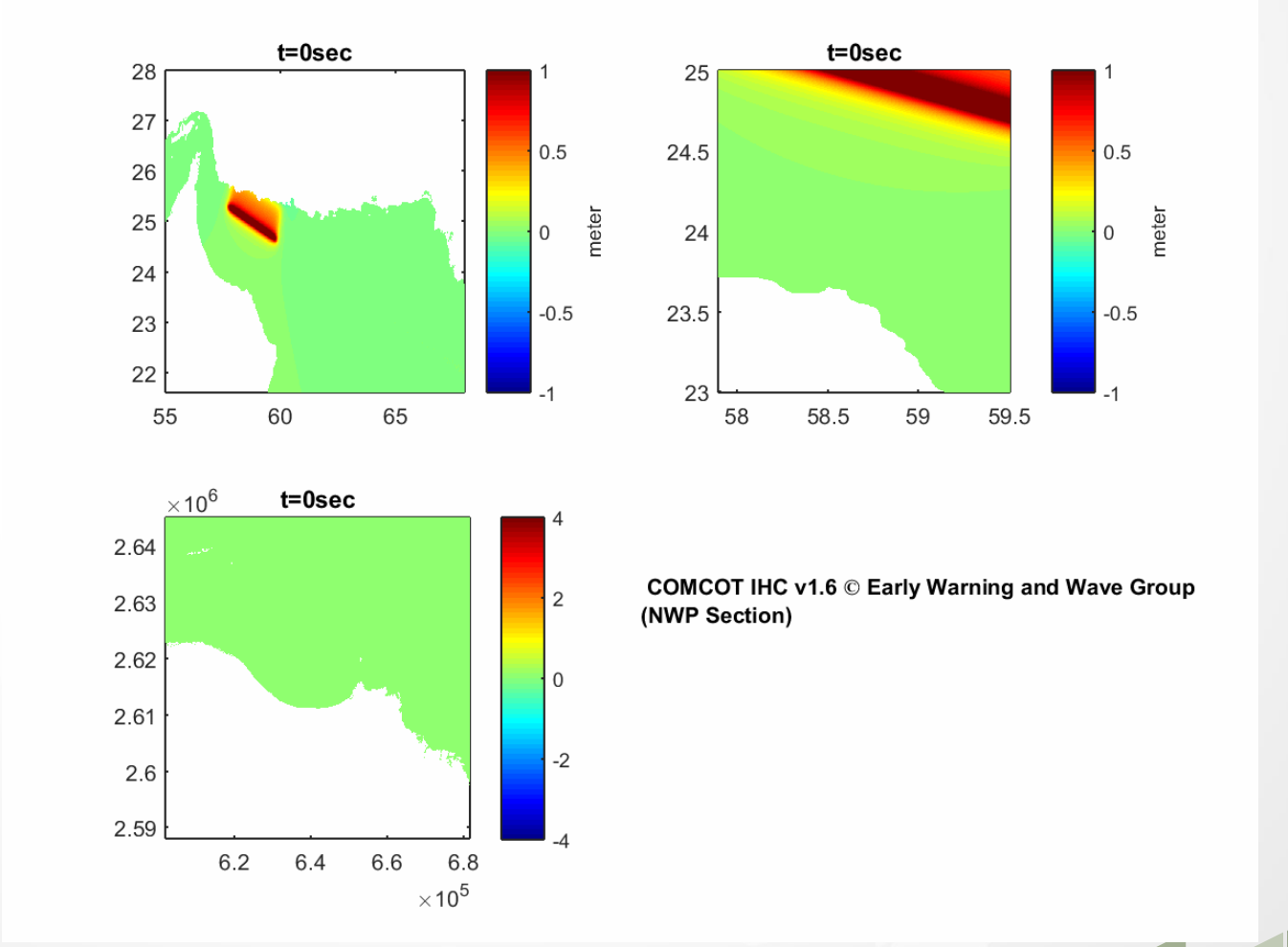
*Special models for Tropical Cyclone:

- Storm Surge
- Inundation

Tsunami Models

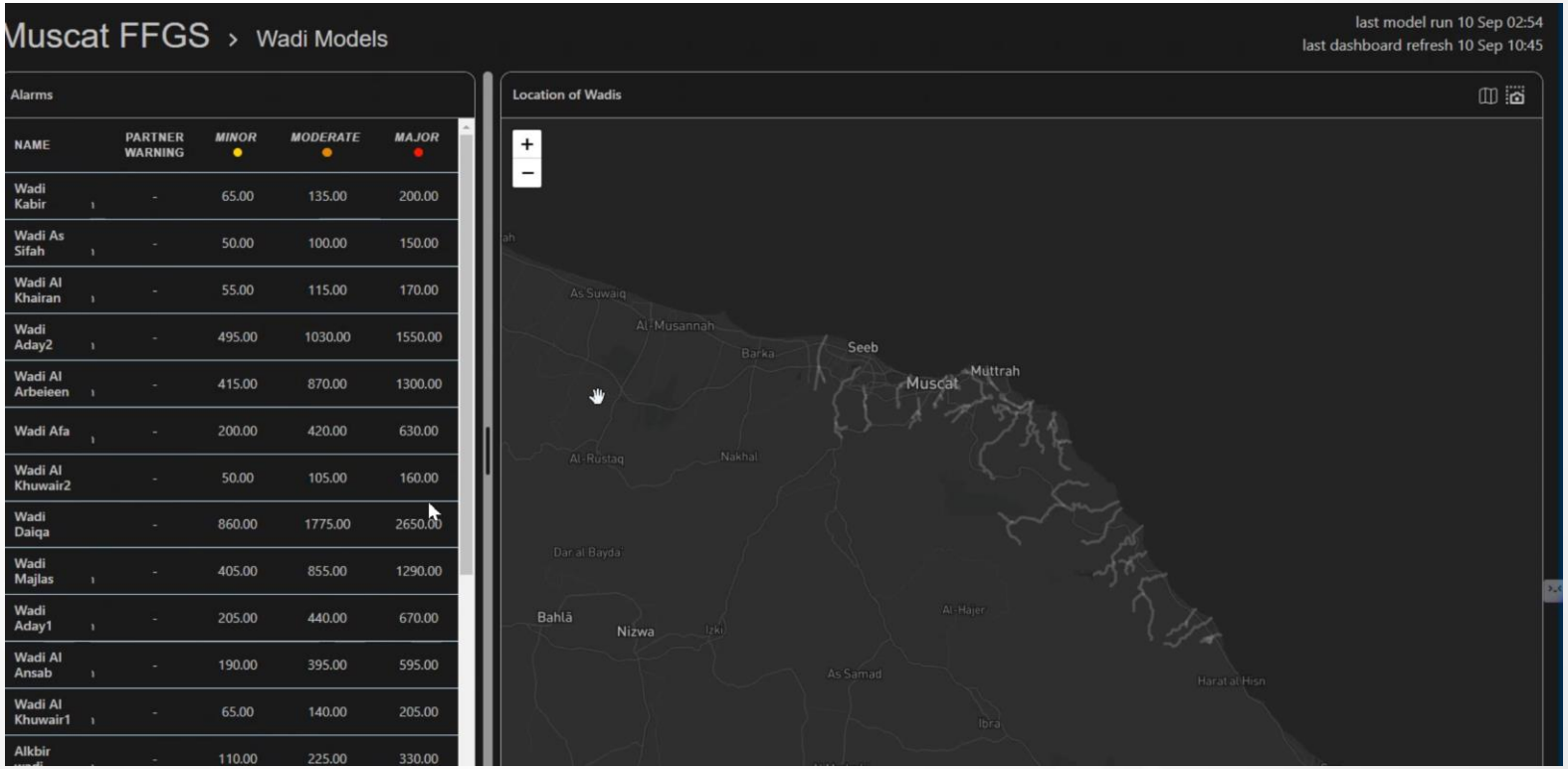
Numerical models of tsunamis simulate the wave from the deformation through propagation until it reaches the coasts. These models can calculate:

- Wave height at the coast
- Inundation Area/distance
- The arrival time of the wave



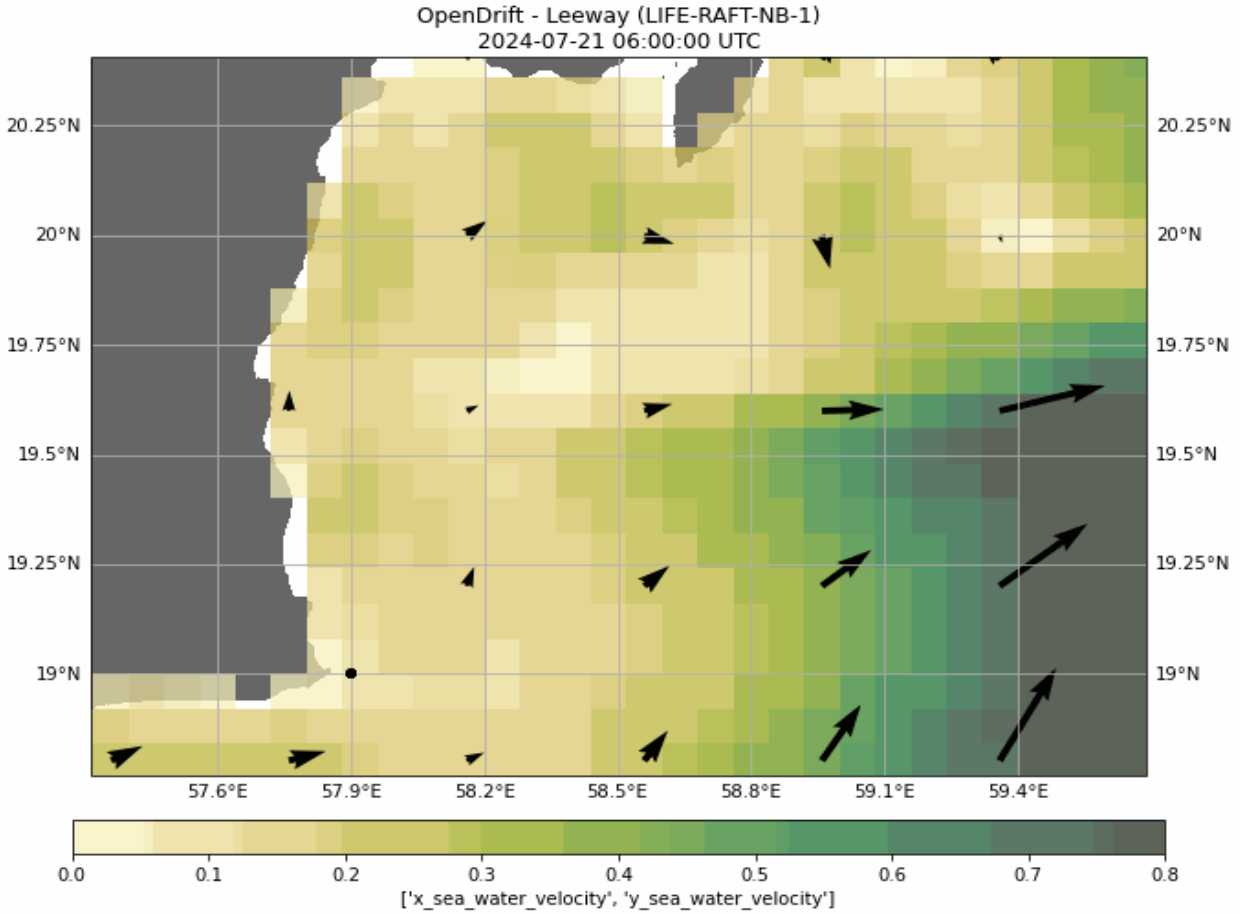
Flash Flood Models

The flash flood prediction system is an indicator of the possibility of a flood occurring in a specific area during the next 6 hours, by calculating the total volume of precipitation that is sufficient for a flood to occur.



Final submission by December, 2024

Search and Rescue



Gives Forward trajectory and Back trajectory for:

Missing ships

Drown people

Oil spills

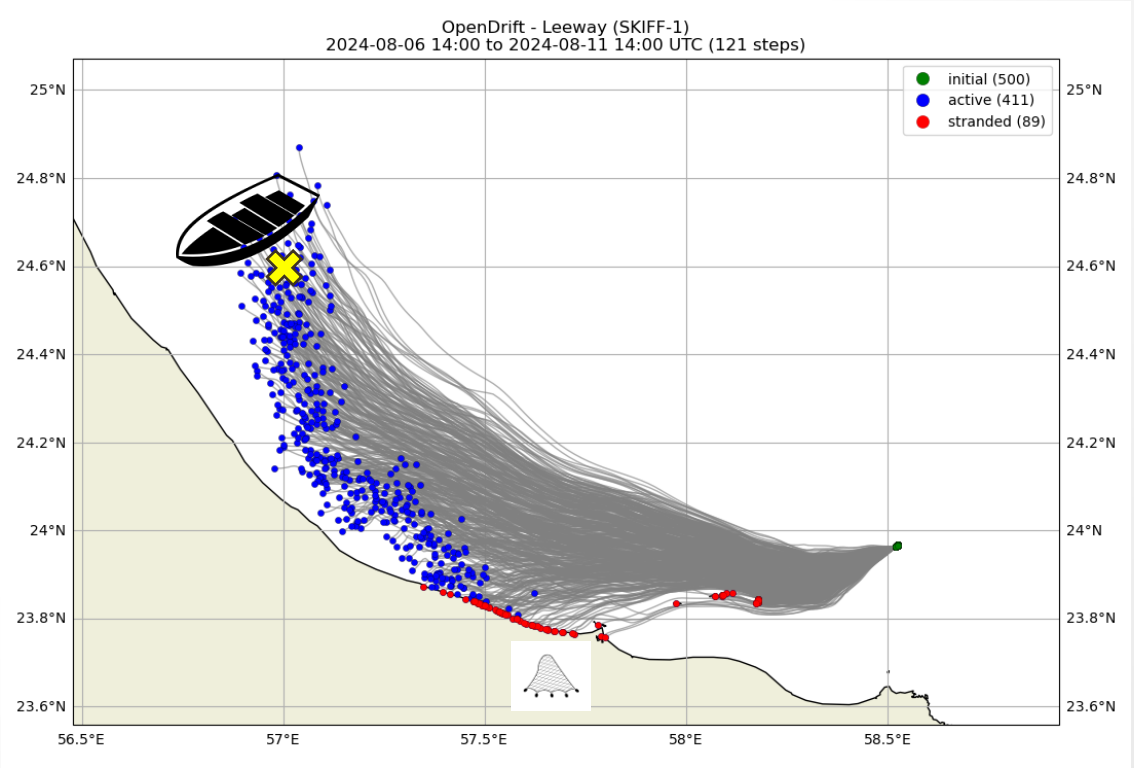
Is not operational yet

Search and Rescue

Output of the Opendrift model for missing boat with 2 fishermen onboard.

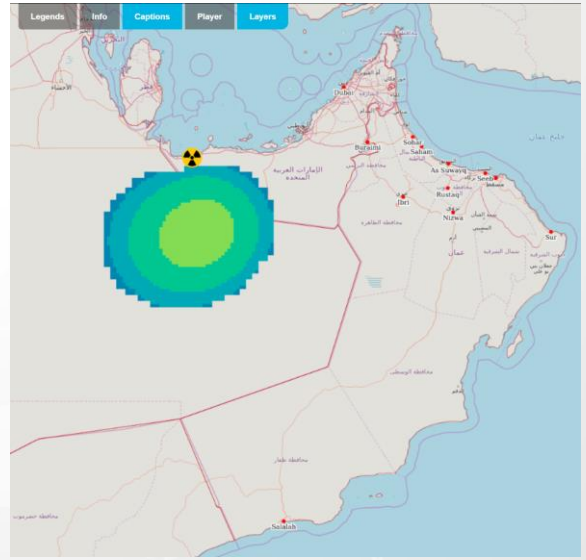
Date: 6-8-2024

Location: NE Qurum



Fire Plume and Dispersion Model

One of the important needs of air quality modeling is to develop further integrated modeling systems that can be used to understand the impacts from aerosols and gas-phase compounds emitted from urban sources at/on the regional and global climate.



NWP Models Available in DGMet

منظومة النماذج العددية

NWP Models Available in DGMet Model	Resolution	Forecast Days	Run Time	Start (Local)	Finish (Local)
COSMO Regional	7 km	7 days	00, 12	06:43 AM, PM	07:54 AM, PM
COSMO Local	2.8 km	3 days	00, 12	06:44 AM, PM	07:23 AM, PM
WAM-4 Regional	14 km	5 days	00, 12	07:44 AM, PM	07:46 AM, PM
WAM-4 Local			00, 12	07:49 AM, PM	07:50 AM, PM
ICON-OM Regional			00, 12	07:46 AM, PM	09:13 AM, PM
			06, 18	12:56 PM, AM	01:37 PM, AM
ICON-OM Local	2 km	3 days	00, 12	07:50 AM, PM	09:13 AM, PM
			06, 18	12:59 PM, AM	01:23 PM, AM
WAM-6 Regional	7 km	7 days	00, 12	09:24 AM, PM	09:48 AM, PM
		3 days	06, 18	01:44 PM, AM	01:55 PM, AM
WAM-6 Local	2 km	3 days	00, 12	09:20 AM, PM	09:32 AM, PM
			06, 18	02:35 PM, AM	02:50 PM, AM
UAE COSMO			00, 12	06:45 AM, PM	07:30 AM, PM
			06, 18	12:40 PM, AM	01:05 PM, AM
ECMWF (EU)	9 km	10 days	00, 12	09:40 AM, PM	12:06 PM, AM
		3 days	06, 18	05:30 PM, AM	07:30 PM, AM
UNIFIED (UK)		7 days	00, 12	08:35 AM, PM	08:55 AM, PM
		3 days	06, 18	02:30 PM, AM	02:40 PM, AM
ICON (GR)		6 days	00, 12	08:30 AM	9:30 AM
GFS (US)		10 days	00, 12	07:28 AM	08:34 AM
WATCHIII (US)		16 days	00	09:45 AM	10:15 AM
EGRR (UK)	35km	3 days	00	07:22 AM	08:56 AM
			12	07:21 PM	08:54 PM
NEMO Ocean	10 km	7 days	00	10:00 AM	03:00 PM

Oman Limited Area Model

نماذج عددية عُمانية محدودة النطاق

UAE Limited Area Model

Global Model

نماذج عالمية

Thank You