Lecture 1 - 2012

Dynamic Meteorology
(Atmospheric Dynamics)

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Students (background & e-mail adress?):
What do you expect from this course?

Lecture notes and grade

Lecture notes
You can also download them from the following website.
http://www.phys.uu.nl/~nvdelden/dynmeteorology.htm

Grade
Exams (2x) in week 45 of 2012 (9/11/2012) and week 5 of 2013 (1/2/2013) (2x35%=70%)
Presentation of a case study/practical exercise (oral* and written) (30%)

*in January 2013
Schedule

**Lectures**
First period Friday 1100-1245 in weeks 37, 38, 39, 40, 41, 42, 44.
Second period Friday 1100-1245 in weeks 46, 47, 48, 49, 50, 2, 3, 4

**Practical sessions**
First period Friday 1330-1630 in weeks 37, 38, 39, 40, 41, 42, 44.
Second period Friday 1330-1630 in weeks 46, 47, 48, 49, 50, 2, 3, 4

**Exams**
First period week 45 (Friday, November 11 (09-11-12)) (retake in week 51)
Second period week 5 (Friday, February 1, 2013) (retake in week 11)

**No lectures on**
October 26 (week 43) (BBOS-days)

**Excursion KNMI**
November 23 (week 47) ??

Prior knowledge

I assume that the reader is familiar with the thermodynamic concepts of temperature and pressure of a fluid or gas, and with the conservation laws governing the fluid in a rotating frame of reference.

**What is pressure?**

**What mechanism causes pressure in a fluid or gas?**

**The core of the first part of course consists of sections 1.1-1.8 and 1.13-1.35.** If you have passed the bachelors course *Geophysical Fluid Dynamics*, you will be familiar with the subject matter of sections 1.1-1.8.

John Dutton has phrased it in the following way.

“The basic problems of atmospheric dynamics revolve around the question of why the observed responses are those that are chosen”

Atmosphere responds to forcing by *adjusting to some kind of balance of forces*. 
Groenekan, 12 sep. 2012, 17:15 LT, looking south east:
Cumulus clouds

Groenekan, 12 sep. 2012, 17:15 LT, looking north west:
cumulus clouds and higher layered clouds
Cold front

Weather map (surface) 14-09-2012 0000 UTC

Cyclone over Italy 14-09-2012
John Dutton has phrased it in the following way.

“The basic problems of atmospheric dynamics revolve around the question of why the observed responses are those that are chosen”

Atmosphere responds to forcing by adjusting to some kind of balance of forces.

Heating due to absorption of Solar radiation, absorption and emission of long-wave radiation, latent heat release
Cold: why? (problem 1.1)

Heating due to absorption of Solar radiation, absorption and emission of long-wave radiation, latent heat release
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insolation [W m\(^{-2}\)]

>500 W m\(^{-2}\)
Intertropical convergence zone (ITCZ) and “stormtracks”
“The basic problems of atmospheric dynamics revolve around the question of why the observed responses are those that are chosen”

What features do you observe???
Subtropical jet; polar night stratospheric jet; Trade winds; What else?

Why does the atmosphere respond to heating in this way?
General Circulation-1

The vertical and longitudinal flows in the idealized general circulation
Analysis of sea-level pressure in hPa shows a depression or cyclone.

Satellite Image

NOAA, channel 4 (infra-red). 12 feb 1996, 1313 UTC
Upper-air observations

850 hPa
9/14/12

500 hPa

100 hPa
Questions

Why does the air rotate anticlockwise?
Why does the wind direction change with height?
Why does the wind speed change with height?
What determines the cloud pattern?

What do we want to know about the atmosphere?

Density, $\rho$ (mass)
Speed, $\vec{v}$
Pressure, $p$
Temperature, $T$

Four unknowns
What do you know about fluid dynamics?

Closed system of four equations with four unknowns:

The equations expressing conservation of momentum, mass and energy

The equation of state

The coordinate system
*see geophysical fluid dynamics and sections 1.7 and 1.8 of lecture notes

The equations*

\[ \frac{dv}{dt} = -\alpha \rho \nabla p - g \hat{k} - 2\Omega \times \rho v + Fr \]

\[ \rho \equiv \frac{1}{\rho} \]

Pressure gradient (1.5) Gravity (1.4) Coriolis (1.6&1.7) Friction (1.3)

mass

\[ \frac{dp}{dt} = -\rho \nabla \cdot \vec{v} \]

energy

\[ Jdt = c_v dT + pd\alpha \]

state

\[ p\alpha = RT \]

Unknowns are: \( \vec{v}, \rho, T, p \)

Solution these equations

The analytical solution of these equations is very difficult

Why?
Motion in the atmosphere is Turbulent!

Windspeed in m s\(^{-1}\) on January 25, 1990 between 1430 and 2000 UTC (time runs from left to right) at Amersfoort (the Netherlands) during one of the most severe wind storms in the Netherlands in the twentieth century.

Fig 1.3

Meteorology as a branch of physics

**Feynman (physics Nobelpriize 1965) about meteorology in 1960:**

“The theory of meteorology has never been satisfactorily worked out by the physicist. "Well," you say, "there is nothing but air, and we know the equations of motions of air". Yes we do. "So, if we know the condition of air today, why can't we figure out the condition of the air tomorrow?". First, we do not really know what the condition is today, because the air is swirling and twisting everywhere. It turns out to be very sensitive, and even unstable. If you have ever seen water run smoothly over a dam, and turn into a large number of blobs and drops as it falls, you will understand what I mean by unstable. You know the condition of the water before it goes over the spillway; it is perfectly smooth; but the moment it begins to fall, where do the drops begin? What determines how big the lumps are going to be? That is not known, because the water is unstable. Even a smooth moving mass of air, in going over a mountain turns into complex whirlpools and eddies. In many fields we find this situation of turbulent flow that we cannot analyze today. Quickly we leave the subject of weather…"
Motion in the atmosphere is Turbulent!

Windspeed in m s\(^{-1}\) on January 25, 1990 between 1430 and 2000 UTC (time runs from left to right) at Amersfoort (the Netherlands) during one of the most severe wind storms in the Netherlands in the twentieth century.

Solution these equations

The analytical solution of these equations is very difficult (why?)

Because of:
1. Boundary conditions (initial value) not known exactly
2. Turbulence
3. Non-linearity
Solution these equations

Nevertheless, Every day these equations are solved *numerically* as an initial value problem (numerical weather prediction)

Here is an example...

Initial condition

Based on numerical solution of the equations that were introduced earlier:
Prediction 126 hours ahead

Based on numerical solution of the equations that were introduced earlier:

PRED

Analysis for the same time

Based on numerical solution of the equations that were introduced earlier:

ANA
Yesterday: uncertain prediction

A very uncertain prediction

Another example
Initial condition

Based on numerical solution of the equations that were introduced earlier:

INIT

Prediction 186 hours ahead

Based on numerical solution of the equations that were introduced earlier:

PRED

Tropical cyclone
Analysis for the same time

Based on numerical solution of the equations that were introduced earlier:

\[ \text{ANA} \]

\[ ? \]

*see geophysical fluid dynamics and sections 1.7 and 1.8 of lecture notes

The equations*

**momentum**

\[ \frac{d\vec{v}}{dt} = -\alpha \vec{\nabla} p - \hat{k} - 2\Omega \times \vec{v} + \vec{F_r} \]

Pressure gradient (1.5)  
Gravity (1.4)  
Coriolis (1.6&1.7)  
Friction (1.3)

**mass**

\[ \frac{dp}{dt} = -\rho \vec{\nabla} \cdot \vec{v} \]

**energy**

\[ Jdt = c_v dT + p d\alpha \]

**state**

\[ p\alpha = RT \]

Unknowns are: \( \vec{v}, \rho, T, p \)

\( \alpha = \frac{1}{\rho} \)
Material derivative of a scalar

\[
\frac{d}{dt} + \vec{v} \cdot \nabla = \frac{\partial}{\partial t} + u \frac{\partial}{\partial x} + v \frac{\partial}{\partial y} + w \frac{\partial}{\partial z}
\]

Equation 1.6

Section 1.7

cloud advection & stationary gravity waves
Materials derivative of a vector

\[ \frac{d\vec{v}}{dt} = \left( \frac{du}{dt} - \frac{uv \tan \phi}{a} + \frac{uw}{a} \right) \hat{i} + \left( \frac{dv}{dt} + \frac{u^2 \tan \phi}{a} + \frac{vw}{a} \right) \hat{j} + \left( \frac{dw}{dt} - \frac{u^2 + v^2}{a} \right) \hat{k} \]

Additional terms due to curved coordinate system!!

These terms are frequently neglected in theoretical analysis

Section 1.7
Archimedes principle & buoyancy

An element or object immersed in a fluid at rest experiences an upward thrust which is equal to the weight of the fluid displaced. If $\rho_0$ is the density of the fluid and $V_1$ is the volume of the object, the upward thrust is therefore equal to $g\rho_0 V_1$. The net upward force, $F$ (the so-called buoyancy force), on the object is equal to $(g\rho_0 V_1 - g\rho_1 V_1)$, where $\rho_1$ is the density of the object. With the equation of state and some additional approximations we can derive that

$$F = mg \frac{T_0 - T_1}{T_0}$$

p. 16

Gravity is dynamically important if there are temperature differences

problem 1.2

Coriolis effect

$$\mathbf{\Omega} \times \mathbf{\hat{v}} = (w\Omega \cos \phi - v\Omega \sin \phi)\mathbf{i} + (u\Omega \sin \phi)\mathbf{j} - (u\Omega \cos \phi)\mathbf{k}$$

From “scale analysis”:* 

$$2\mathbf{\Omega} \times \mathbf{\hat{v}} = -(2\Omega v \sin \phi)\mathbf{i} + (2\Omega u \sin \phi)\mathbf{j} = -f\mathbf{\hat{i}} + fu\mathbf{\hat{j}}$$

$f$ is the Coriolis Parameter

* see Holton, chapter 2, e.g. $w << v$ and $w << u$
Potential temperature, $\theta$

$$\theta \equiv T \left( \frac{p_{\text{ref}}}{p} \right)^\kappa$$

eq. 1.54

$$\kappa \equiv R / c_p$$

$$p \alpha = RT$$

$$J dt = c_v dT + p \alpha$$

$\{ \}$

$$\frac{d\theta}{dt} = \frac{J}{\Pi}$$

eq. 1.55

$$\Pi \equiv c_p \left( \frac{p}{p_{\text{ref}}} \right)$$

Exner-function

If $J=0$ (adiabatic) $\theta$ is materially conserved!!

Equations in terms of potential temperature and Exner-function

$$\frac{d\theta}{dt} = \frac{J}{\Pi}$$

eq. 1.55

$$\frac{d\vec{v}}{dt} = -\theta \nabla \Pi - g \hat{k} - 2\hat{\Omega} \times \vec{v} + F_I$$

eq. 1.56

$$\frac{d\Pi}{dt} = \frac{R \Pi}{c_v} \nabla \cdot \vec{v} + \frac{R J}{c_v \theta}$$

eq. 1.58

problem 1.6

Three differential equations with three unknowns!
Steady State

A large portion of the material is grouped around the steady states (balance of forces), i.e. hydrostatic balance, geostrophic balance and thermal wind balance. For each of these steady states we analyse the stability to perturbations and the manner of adjustment.

This afternoon
- Problem 1.2 (p.25), Problem Box 1.2 (p.29)
- Problem 1.6 (p.32)

homework
- Study sections 1.1-1.8 & 1.13

Next week
- Sections 1.14-1.18
- Stability of hydrostatic balance
- Potential instability
- Equivalent potential temperature
- Convective available potential energy
- Thermodynamic diagram