EART60071 Measuring and Predicting 2

THE UNIVERSITY OF MANCHESTER · ENVIRONMENTAL SCIENCE · POSTGRADUATE

Full guide + ask Sia about EART60071

SIDE 1/2 METHODS · RULES · DECISIONS — OPEN-BOOK EXAM SHEET — S1 2026/27 · v2 · 2026-10-19

1 · Exam Map

COURSE.JSON · BRIEF

Summative online assessment 100% · Formative online

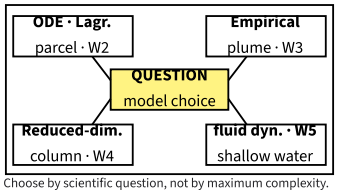
Final: timed two-hour online assessment on Canvas, under examination conditions, during the examination period; **10 questions**, same format as the formative assessment. Generative AI is prohibited.

OFFICIAL RULE *"The assessment is open book: you may bring and consult your own notes during the assessment." (EART60071 syllabus, 2026/27 1st semester)*

LIKELY TASK	ANSWER SPINE
Calculate	formula → SI units → substitution → unit + sense-check
Interpret output	changed input → plotted response → physical/numerical mechanism
Compare models	question → family/frame → explicit/omitted process → cost/limit

2 · Model Chooser

C1 TOPIC MAP



Choose by scientific question, not by maximum complexity.

FRAME	VARIABLES	MODULE USE
Lagrangian	move with parcel/path	adiabatic parcel
Eulerian	fixed grid; material moves	plume, column, shallow water

Controlled comparison: state control, change one input, hold all else fixed, compare the named output, explain mechanism. Complexity is useful only when its assumptions and detail fit the question.

PRACTICAL WORKFLOW

STAGE	ACTION + EVIDENCE TO RETAIN
connect	SSH to remote server; check `hostname` and `pwd`
obtain/edit	clone supplied code; change the labelled input only
run	compile where required; record settings and control run
retrieve	SFTP from remote to the directory shown by `↳pwd`; rename output descriptively
interpret	compare plots/numbers; identify mechanism, artefact and omission

SSH ≠ SFTP: SSH runs commands remotely; SFTP moves files between remote and local directories. A repeated remote filename can overwrite the prior run, so preserve each output under a meaningful local name.

3 · Forward Euler

C2

GENERIC STEP

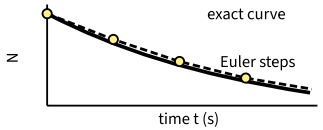
$y_{n+1} = y_n + \Delta t \cdot f(t_n, y_n)$

DECAY

$\frac{dN}{dt} = -\lambda N$; exact $N = N_0 e^{-\lambda t}$

$N_{n+1} = N_n(1-\lambda\Delta t)$

1. Write differential equation.
2. Replace derivative by forward difference.
3. Compute the one-step factor before iterating.
4. Reduce Δt and check ***convergence***.



Forward Euler samples the start gradient; smaller Δt reduces error.

SIGNATURE	DIAGNOSIS
Δt↓ → exact curve	convergence
$1-\lambda\Delta t<0$	unphysical sign flip
oscillator amplitude grows	method error; exact amplitude is constant
plot interval changes only	sampling, not numerical solution

OSCILLATOR UPDATE

$y_{n+1} = y_n + v_n\Delta t$

$v_{n+1} = v_n - \omega^2 y_n \Delta t$

amplitude factor/step = $\sqrt{(1+\omega^2\Delta t^2)} > 1$

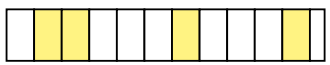
4 · Advection + CFL

C3

$\partial C/\partial t + u\partial C/\partial x = 0$

$C_i^{n+1} = C_i^n - \mathcal{C}(C_i^n - C_{i-1}^n)$

$\mathcal{C} = |u|\Delta t/\Delta x \le 1$



One upwind step from a four-unit spike: diffuse, exact shift, unstable.

Stable ≠ accurate. For $0<\mathcal{C}<1$, repeated cell blending lowers/widens peaks: ***numerical diffusion***. At $\mathcal{C}=1$, constant 1-D flow shifts one cell per step. At $\mathcal{C}>1$, growing ripples/negative values signal instability. Fix by reducing Δt or increasing Δx; refining Δx also requires a smaller Δt.

SPIKE [0,4,0,0]	AFTER ONE STEP	READ
$\mathcal{C}=.5$	[0,2,2,0]	conserved but smeared
$\mathcal{C}=1$	[0,0,4,0]	clean one-cell shift
$\mathcal{C}=1.2$	[0,−.8,4.8,0]	overshoot + negative

5 · State + Lapse Rates

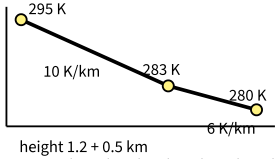
C4

IDEAL GAS

$PV = nR_{gas}T$; $R_{gas} = 8.314\ J\ mol^{-1}\ K^{-1}$

$\rho_a = P/(R_a T)$; $R_a \approx 287\ J\ kg^{-1}\ K^{-1}$

NEED	METHOD	TRAP
moles	n=PV/(R_{gas}T)	hPa→Pa
molecules	N=n·6.022×10²³	mol ≠ molecules
density	ρ=P/(R_aT)	T in K
parcel T	$T_2 = T_1 - \Gamma\Delta z$	km with K km⁻¹



Split at saturation: dry cooling, then slower latent-heated cooling.

Unsaturated parcel: ≈10 K km⁻¹ (9.8; rounded in exercises). **Saturated:** representative 6 K km⁻¹ because condensation releases ≈2.5×10⁶ J kg⁻¹. The ***environmental*** lapse rate is measured surroundings; the parcel rate belongs to the moving parcel.

6 · Humidity Chain

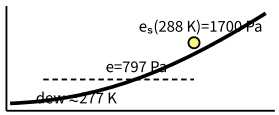
C4 NOTES

$e = \rho_v R_v T$; $R_v \approx 461\ J\ kg^{-1}\ K^{-1}$

$e_s = 610.7\ \exp[(L_v/R_v)(1/273.15 - 1/T)]$

$RH = e/e_s$

$r_v = 0.622e/(P-e) \approx 0.622e/P$



Cooling at fixed vapour content raises RH until e meets e_s.

1. Convert vapour density to kg m⁻³.
2. Find *e*, then e_s*(T)*.
3. RH<1 unsaturated; RH=1 saturated.
4. Use total pressure in Pa for mixing ratio.

Say precisely: saturation vapour pressure rises steeply with temperature; warm air does not "hold" a fixed reservoir of water.

QUICK NUMERIC ANCHORS

5 m³, 950 hPa, 285 K:
n=95000×5/(8.314×285)=**200.5 mol**
N=200.5×6.022×10²³=**1.21×10²⁶ molecules**
p=95000/(287×285)=**1.16 kg m⁻³**

At 500 hPa and 250 K, ρ=50000/(287×250)≈**0.70 kg m⁻³**: lower pressure dominates despite colder air. Cooling humid air without removing vapour leaves *e* tied to vapour density and temperature while e_s falls steeply; saturation occurs near the intersection.

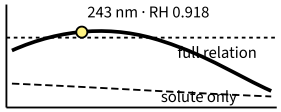
7 · Köhler Method

C5

$RH_{eq} = [n_w/(n_w + i\ n_s)] \cdot \exp[2\sigma_w M_w/(R\ T\ \rho_w\ r)]$

FACTOR	EFFECT	EXAM LANGUAGE
$n_w/(n_w+in_s)$	<1	solute lowers equilibrium RH
exp(curvature/r)	>1	small drops need higher RH
larger wet r	curvature weakens	activation becomes easier

1. Dry mass: $m_s = (\pi/6)\rho_s D_{dry}^3$.
2. Moles salt $n_s = m_s/M_s$; water n_w from stated ratio.
3. Water volume $n_w M_w/\rho_w$; add dry volume.
4. Wet $r = [3V/(4\pi)]^{1/3}$; evaluate both factors.



Solute lowers the curve; curvature raises the small-drop requirement.

Kelvin-only screen: $e_v/e_0 = \exp[2\sigma_w/(R_v T \rho_l r)]$. At 290 K the exponent is $1.12\times10^{-9}/r$ (r in m). Observed ratios rarely exceed ≈1.02, so very small particles rarely activate.

8 · Visibility + PM

C5

$\sigma_{ext} = Q_{ext}(\pi D^2/4)N_p$

$V_{vis} = K/\sigma_{ext}$

$C_{mass} = N_p(\pi/6)\rho_p D^3$

D: 2 → 3 µm
extinction ×2.25
V: 1512 → 672 m

Power check
optics ∝ D^2
mass ∝ D^3

Humidity can raise PM mass and extinction with no new particles.

CLASS	COUNT	BOUNDARY
PM10	sum mass of eligible populations	aerodynamic diameter ≤10 µm
PM2.5	subset of PM10	aerodynamic diameter ≤2.5 µm

Compute each size population separately, convert kg m⁻³ to µg m⁻³ (×10⁹), then classify and sum. Do not infer number concentration from mass without diameter and density.

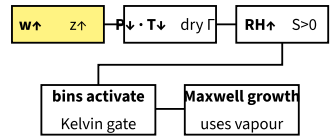
CLASSIFICATION DRILL

4 µm: $50\times10^6(\pi/6)1500(4\times10^{-6})^3$
$=2.51\times10^{-6}$ kg m⁻³ = **2513 µg m⁻³**
2 µm population = **1508 µg m⁻³**
PM10=4021; PM2.5=1508 µg m⁻³

9 · Parcel Model

C6

Frame/family: Lagrangian ODE model following one adiabatic parcel; supplied code integrates seven coupled quantities through the ascent. Assumes parcel properties match the atmosphere at the same height.



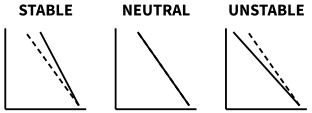
The coupled feedback: ascent builds supersaturation; drops remove it.

CONTROLLED CHANGE	PREDICTION + MECHANISM
w: 0.3→3.0 m s⁻¹	cooling outruns condensation; higher S activates smaller particles
initial RH ↑	saturation reached lower/earlier
sea salt added	large soluble particles activate readily
w: 0.3→0.03	condensation removes S; fewer activate

Kelvin filter: at 290 K, r=50 nm requires ≈2.3% supersaturation; r=0.5 µm requires ≈0.2%. At 1%, only the larger drop grows.

10 · Stability

C7



Dashed parcel Γ=10 K km⁻¹; compare temperatures at the same height.

LIFTED PARCEL	CLASS	PLUME
colder/denser; returns	stable	fanning; least mixing
same T	neutral	coning
warmer; rises	unstable	looping; fastest mixing

FORCE + BALANCE BRIDGE

$f = 2\Omega\sin\varphi$; $a_{PGF} = -(1/\rho)\nabla P$

$|u_g| \models |a_{PGF}|/|f|$; wind ∥ isobars

low: $v^2/R + fv - a_{PGF} = 0 \rightarrow v < u_g$

high: $v^2/R - fv + a_{PGF} = 0 \rightarrow$ near branch $v > u_g$

Pressure gradient points high→low. Coriolis turns motion right in the Northern Hemisphere and left in the Southern, is zero at the equator and does no work. For a high, a negative discriminant means no anticyclonic solution.

11 · Gaussian Plume

C7

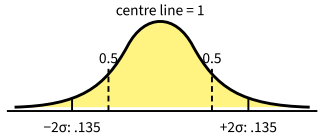
Empirical, Eulerian, analytical: evaluated on a 3-D fixed grid. Simplifications: no time dependence; transport only downwind; no along-wind mixing. Meandering/looping becomes a time average through wider Gaussian profiles.

CROSSWIND FACTOR

$C(y)/C(0) = \exp[-y^2/(2\sigma_y^2)]$

half peak: $|y| \models \sigma_y\sqrt{(2\ \ln 2)} = 1.177\sigma_y$

$|y| \models 2\sigma_y \rightarrow$ factor = $e^{-2} = 0.135$



Wider σy spreads concentration laterally and lowers the centre peak.

PLOT CHANGE	MECHANISM
wind direction changes	plume axis rotates
variable wind	time-mean footprint broadens
more sources	contributions superpose
less stable	σ_y, σ_z wider; more dispersion
RH ↑, PM mass ↑; shape same	hygroscopic D^3 mass; widths unchanged

12 · Column → Dynamics

C8–C10

1 PROCESS ODEs at each level
2 TRANSPORT between fixed levels

net speed = w − fall speed
advect potential temperature + species
repeat to end of run

Time splitting separates local microphysics from grid transport.

QUANTITY/METHOD	RULE
potential T	advected because conserved during pressure change; latent heating in process step
warm rain	collision/coalescence bridges condensation's tens-of-days timescale to ≈20 min
more aerosol	same water / more drops → smaller drops → slower collection → rain suppressed
ice	rare ice-nucleating particles (e.g. desert dust) open cold-rain pathway
shallow wave	$c = \sqrt{(gh)}$
vorticity	$\zeta = \partial v/\partial x - \partial u/\partial y$; absolute=ζ+f

Transport anchor: with w=1.5 m s⁻¹, vapour/cloud rise at 1.5, snow falls at 1 but still rises at 0.5, and rain falls at 6 so descends at 4.5 m s⁻¹. Use the largest |net speed| when checking $\mathcal{C}$.

EART60071 Measuring and Predicting 2

WORKED DRILLS · TRAPS · FAST RECALL

Full guide + ask Sia about EART60071

SIDE 2/2 WORKED STEPS · ERROR CLINIC · METHOD CHOOSER

OPEN-BOOK EXAM SHEET

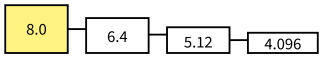
Use numbers to check method + direction

13 · Worked: Euler Decay

C2 EXAMPLE

Given: $N_0=8.0\times10^{18}$ atoms; $\lambda=1/500\ s^{-1}$; $\Delta t=100$ s; three steps.

```
factor=1-λΔt=1-100/500=0.8
8.0 → 6.4 → 5.12 → 4.096 ×10^18
exact=8.0×10^18 e^-0.6=4.390×10^18
% error=(4.096-4.390)/4.390=-6.7%
```



×0.8 each 100 s step

units: ×10¹⁸ atoms

Factor first: it predicts the sign and fractional loss of every step.

Explain underestimate: decay magnitude is largest at the start of each interval; Forward Euler applies that larger starting gradient across the whole 100 s.

LARGE-STEP CHECK	OUTCOME
$N_0=10^{20}$, $\lambda=1/2000$, $\Delta t=1000$	factor .5 → 5×10^{19}
same, $\Delta t=10{,}000$	factor −4 → negative: numerical failure

14 · Worked: CFL

C3 EXAMPLE

Given: $u=15\ m\ s^{-1}$; $\Delta x=300$ m; $\Delta t=12$ s.

```
𝒞=15×12/300=0.6 stable, diffusive
Δt_max=Δx/|u|=300/15=20 s
25 s → 𝒞=1.25 → unstable oscillations
10×12×15=1800 m=6 cells
```

Expected plot: exact triangle shifts 1800 m unchanged; upwind has correct position but wider base and peak ≈0.61. Name *numerical diffusion*, not physical mixing.

TRAP *"Stable" only rules out blow-up; it does not certify accuracy.*

14b · Oscillator + Spike

C2–C3 DRILLS

```
dy/dt=v; dv/dt=-ω²y
y_{n+1}=y_n+v_nΔt; v_{n+1}=v_n-ω²y_nΔt
amplitude multiplier=√(1+ω²Δt²)>1
```

The exact harmonic oscillator keeps constant amplitude; Forward Euler's outward spiral is numerical. Cutting Δt from 0.5 s to 0.05 s reduces, but does not reverse, the per-step growth. A denser plotting interval alone cannot change it.

ONE UPWIND STEP FROM [0,4,0,0]	INTERPRETATION
$\mathcal{C}=.5$ → [0,2,2,0]	stable smoothing
$\mathcal{C}=1$ → [0,0,4,0]	exact one-cell transfer
$\mathcal{C}=1.2$ → [0,−.8,4.8,0]	negative + overshoot

Conservation check: every row still totals four. Conservation alone therefore cannot distinguish an accurate transport result from a diffusive or unstable one.

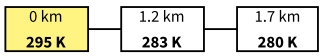
15 · Worked: Air + Humidity

C4 DRILLS

TWO-STAGE THERMAL

295 K rises 1.2 km dry, then 0.5 km saturated:

```
T_sat=295-10×1.2=283 K
T_top=283-6×0.5=280 K
```



latent heat slows cooling after saturation

Apply each lapse rate only across its own depth.

HUMIDITY CHAIN

At 288 K: $\rho_v=6\ g\ m^{-3}=0.006\ kg\ m^{-3}$; P=900 hPa=90,000 Pa.

```
e=.006×461×288=797 Pa
exponent=(2.5×10^6/461)
(1/273.15-1/288)=1.024
e_s=610.7e^1.024=1700 Pa
RH=797/1700=0.47
r_v=.622×797/(90000-797)=5.56 g kg^-1
```

SENSE-CHECK	PASS CONDITION
vapour pressure	$e<e_s$ if unsaturated
mixing ratio	small positive kg kg^{-1}
density at 500 hPa, 250 K	well below surface density

16 · Worked: Visibility

C5 EXAMPLE

$N=200\times10^6\ m^{-3}$, $Q_{ext}=2$, K=1.9.

```
D=2 μm: σ_ext=1.26×10^-3 m^-1
V=1.9/σ=1512 m
D=3 μm: σ ×(3/2)²=2.83×10^-3
V=672 m
```

No new particles: humid growth alone cuts range because extinction ∝ D^2.

16b · Gas-Law Drill

C4 EXAMPLE

A 5 m³ container at 950 hPa and 285 K:

```
P=95000 Pa
n=PV/(R_gas T)=95000×5/(8.314×285)=200.5 mol
N=nN_A=1.21×10^26 molecules
ρ=P/(R_a T)=1.16 kg m^-3
```

CONVERSION	MULTIPLIER
hPa → Pa	×100
g m^{-3} → kg m^{-3}	×10^{-3}
km → m	×10^3
nm / μm → m	×10^{-9} / ×10^{-6}
kg m^{-3} → μg m^{-3}	×10^9

16d · Thermodynamic Checks

C4 FAQ + DRILLS

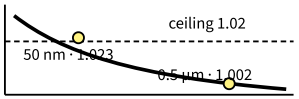
PROMPT	QUICK RESULT / EXPLANATION
500 hPa, 250 K density	50000/(287×250)=**0.70 kg m^{-3}**; low pressure dominates

17 · Worked: Köhler/Kelvin

C5–C6

Sea salt: $D_{dry}=100$ nm; $\rho_s=2160\ kg\ m^{-3}$; $M_s=0.05844\ kg\ mol^{-1}$; i=2; $n_w/n_s=20$; T=290 K.

```
m_s=(π/6)2160(10^-7)^3=1.13×10^-18 kg
n_s=1.94×10^-17 mol; n_w=3.87×10^-16 mol
wet D=243 nm; RH_eq=0.918
```



drop radius (log idea)

Kelvin curvature penalty collapses as radius grows.

At 1% supersaturation: 50 nm needs ≈2.3%, so does not grow; 0.5 μm needs ≈0.2%, so grows. Convert nm→m inside 1.12×10^{-9}/r.

WRONG MOVE	CORRECTION
use dry radius as wet radius	add water volume, then cube-root
forget van't Hoff i	solute particles count i n_s
read full curve as solute only	full = solute × curvature
supersaturation 1.02%	ratio 1.02 = 2%

18 · Worked: Stability + Plume

C7 EXAMPLES

Surface 290 K; lift 0.5 km; parcel Γ=10 K km^{-1} → **285 K**. Environments:

Γ_E	T_{ENV}	PARCEL RELATION	RESULT
7	286.5 K	1.5 K colder	stable/fanning
10	285 K	equal	neutral/coning
13	283.5 K	1.5 K warmer	unstable/looping

```
σ_y=80 m: half at 1.177σ=94 m
y=160 m=2σ: factor=e^-2=0.135
```

TRAP *Larger environmental lapse rate favours instability. Always compare parcel and environment at the same height.*

18b · Parcel Experiment Decoder

C6 PRACTICAL

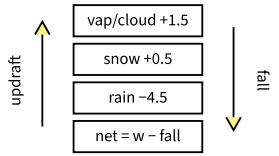
Default comparison: w=0.3 m s^{-1}, ascent to 1200 m, initial RH=0.65 and background aerosol. Below about 800 m, temperature follows the dry rate; the later kink marks condensation and latent heating.

CHANGE ONLY	PREDICTION TO JUSTIFY
w: 0.3→3.0	supersaturation builds faster; more small particles activate
w: 0.3→0.03	condensation removes vapour as S develops; fewer activate
initial RH ↑	saturation/latent-heating kink occurs lower
sea salt added	large soluble particles activate readily

19 · Worked: Column Transport

C8 EXAMPLE

Given: w=+1.5 m s^{-1}; snow fall speed=1; rain=6; Δz=50 m; Δt=8 s.



Positive rises, negative descends; use the largest |net speed| for CFL.

```
vapour/cloud: +1.5 m s^-1
snow: 1.5-1=+0.5 m s^-1
rain: 1.5-6=-4.5 m s^-1
𝒞_rain=4.5×8/50=0.72
1500/4.5=333 s ≈5.5 min
```

MICROPHYSICS PROMPT	MECHANISTIC ANSWER
Why not condensation-only rain?	growth would take tens of days; observed rain ≈20 min
Why collision accelerates?	larger drops fall faster and sweep up smaller drops
Why more aerosol suppresses rain?	more, smaller drops; slower fall/collection
Why mountains increase rain?	lift/cool/deepen cloud on windward side; more growth depth/time
Why potential T?	conserved during pressure-change transport

20 · Ice Pathway

C8

Below 0°C, rare ice-nucleating particles (not ordinary cloud condensation nuclei) form fewer crystals that grow/fall as snow and may melt into rain. Desert dust is an important example. Separate **warm rain** (collision/coalescence) from **cold rain** (ice → snow → melt).

PLOT ANSWER *Name phase/pathway, then describe how the changed aerosol or vertical motion alters size, fall speed and surface precipitation.*

20b · Warm/Cold-Rain Numbers

C8 EXAMPLES

Two clouds each contain 0.5 g m^{-3} liquid water. Clean: 100 drops cm^{-3}=10^8 m^{-3}; polluted: 400 cm^{-3}=4×10^8 m^{-3}.

```
r=[3(m/Nρ_w)/(4π)]^1/3
clean: m/drop=5×10^-12 kg → r=10.6 μm
polluted: 1.25×10^-12 kg → r=6.68 μm
```

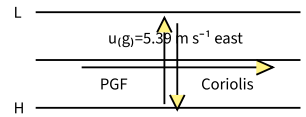
The clean cloud's larger drops fall and collect sooner, so it is more likely to produce warm rain. Same liquid water divided among four times as many drops reduces radius by $4^{-1/3}$.

21 · Worked: Balanced Flow

C9 EXAMPLE

Given: ϕ=45°N; ρ=1.2 kg m^{-3}; ΔP=800 Pa across 1200 km; R=1200 km.

```
f=2(7.292×10^-5)sin45°=1.031×10^-4 s^-1
a_PGF=800/(1.2×10^6×1.2)=5.56×10^-4 m s^-2
u_g=a/f=5.39 m s^-1
low: v²/R+fv-a=0 → 5.17 m s^-1
high, near branch → 5.64 m s^-1
```



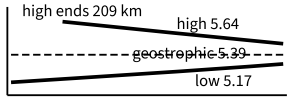
equal/opposite; wind ∥ isobars

At 45°N, eastward wind has southward Coriolis balancing northward PGF.

CHECK	REASON
calculator degrees	sin(latitude), not radians
Δx in metres	PGF units N m^{-3} or acceleration m s^{-2}
low v<u_g	PGF must exceed outward Coriolis to supply inward force
high v>u_g	Coriolis must exceed inward PGF
high discriminant <0	no anticyclonic solution

22 · Gradient Branches

C9 FIG. 2



radius of curvature R →

Curvature effect weakens as R grows; both branches approach geostrophic.

22b · Force-Direction Drill

C9 EXAMPLE

Pressure falls 1015→1003 hPa northward across 600 km: ΔP=1200 Pa, so $|\partial P/\partial y|=$**2.0×10^{-3} N m^{-3}**, directed north towards low pressure.

```
at 30°: |f|=2Ωsin30°=7.292×10^-5 s^-1
|F_C|/V=ρ|f|u=1.2×7.292×10^-5×12
=1.05×10^-3 N m^-3
```

12 M S^{-1} EASTWARD	CORIOLIS DIRECTION
30°N	right of motion → south
30°S	left of motion → north

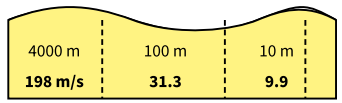
Magnitude first, direction second: use the sign of *f* and a sketch. Do not attach a direction to |f| until the hemisphere and velocity vector are known.

Quadratic routine: write coefficients with R in metres; evaluate the discriminant before roots; discard a negative low-pressure root and retain the smaller, near-geostrophic high-pressure root. Finally compare low<geostrophic<high.

23 · Worked: Waves + Vorticity

C10 EXAMPLES

```
c=√(gh), g=9.81 m s^-2
h=4000 m → 198 m s^-1
h=100 m → 31.3 m s^-1
h=10 m → 9.9 m s^-1
```



shoreward: depth ↓ → wave speed ↓

Long-wave condition: wavelength ≫ depth, so speed depends on depth.

1500 km crossing at 4000 m: t=1.5×10^6/198=7.6×10^3 s≈**2.1 h**, before coastal shoaling.

```
ζ=∂v/∂x-∂u/∂y; anticlockwise positive
(a) u=-2y,v=2x → ζ=2-(-2)=+4 s^-1
(b) u=3y,v=0 → ζ=0-3=-3 s^-1
(c) u=2x,v=-2y → ζ=0-0=0
```

PHENOMENON	CONSERVATION EXPLANATION
shear vorticity	paddle wheel turns even without circular path
absolute vorticity	ζ+f conserved in 2-D flow
stretch/squash	stretching spins column faster; squashing slower
orographic Rossby wave	compression/extension and latitude changes cause alternating turns + overshoot
barotropic instability	jet perturbations draw energy from horizontal shear

25 · Method Chooser

ALL TOPICS

PROMPT	METHOD → CHECK
step/transport	Euler factor or $\mathcal{C}$ → sign/stability/convergence
air/water	gas law or e→e_s→RH→r_v → SI units
aerosol	D^3 mass/Köhler; D^2 extinction → radius + units
parcel/plume	T comparison or Gaussian factor → same height/σ
column	w–fall speed → sign + fastest-species $\mathcal{C}$
rotating flow	f→a_{PGF}→balance → direction/root
wave/vorticity	$\sqrt{gh}$ or ∂v/∂x−∂u/∂y → metres/sign

26 · Error Clinic

FAQ + EXAMPLES

SYMPTOM	CORRECT DIAGNOSIS
smooth broadening	numerical diffusion; stable may still be inaccurate
ripples/negative values	$\mathcal{C}>1$ instability; reduce Δt
RH↑, same plume shape	D^3 mass growth; dispersion widths unchanged
lifted parcel colder	stable; denser parcel returns
balanced wind crosses isobars	wrong: geostrophic is parallel

Output stem: "Relative to control, changing *[input]* changes *[output/value]* because *[mechanism]*; the model assumes/omits *[limit]*."